Nikhef

EVALUATION 2017 → 2022

National
Institute for
Subatomic Physics

\ NIKHEF EVALUATION
2017 → 2022

NIKHEF MISSION STATEMENT

The mission of the National Institute for Subatomic Physics Nikhef is to study the interactions and structure of all elementary particles and fields at the smallest distance scale and the highest attainable energy.
Two complementary approaches are followed:

1. Accelerator-based particle physics studying interactions in particle-collision processes at particle accelerators, in particular at CERN;
2. Astroparticle physics studying interactions of particles and radiation emanating from the universe.

Nikhef coordinates and leads the Dutch experimental activities in these fields. Research at Nikhef relies on the development of innovative technologies. The transfer of knowledge and technology to third parties, i.e. industry, society and the general public, is an integral part of Nikhef's mission.

Nikhef Jamboree 2023 at Felix Meritis, Amsterdam

\ EVALUATION AT A GLANCE

The period 2017-2022 was a memorable one for Nikhef, both scientifically and as an organisation. Nikhef welcomed University Maastricht as a new partner, bringing the total of university partners in the partnership to six. This partnership was able to fully execute its national strategic agenda for particle and astroparticle physics, as laid down in 2017.

A substantial fraction of the period we suffered from the Covid pandemic, making working together challenging. The pandemic was followed by an extensive three-year renovation of the institute's building in Amsterdam Science Park. This made the period in which the Nikhef community was challenged in meeting each other sufficiently quite long. Nevertheless, during these times the Nikhef partnership and its people have shown to be extraordinarily resilient.

The past years had some great scientific and technical highlights.

- → In an intensive collaboration between research programmes and the technical teams, detector parts have been designed and built for the upgrades of notably LHCb and ALICE. ALICE has designed, constructed and installed a completely new vertex detector. Nikhef took full responsibility for a number of ITS2 layers. In LHCb, Nikhef made major contributions: the design, construction and installation of 12 large Scintillator Fibre modules, the production of VELO modules and the corresponding RF box, and the GPU technology for a complete software-based trigger system were installed during the shutdown period.
- → KM3NeT reached a new level of maturity with more deployments and first analyses. Nikhef is one of the major construction sites for the Digital Optical Modules (DOMs) and Detector Unit (DU) integration, which have led to 18 DUs installed in ORCA France and 21 in ARCA Italy. The first data of KM3NeT look promising; the experiment will soon be world leading on a number of neutrino properties. Nikhef was also actively involved in the design of the seafloor network.
- → Together with the astronomy department of Radboud University, Nikhef is responsible for the (complete) radio antenna network at Pierre Auger. With its new SSD detectors, AugerPrime is all set for a new data-taking run to unravel the particle content of the ultrahigh-energy cosmic rays.
- → In Gran Sasso in Italy, the XENONnT experiment started with enhanced sensitivity to look for Dark Matter particles. Nikhef is heavily involved in the commissioning and DAQ of this upgraded detector.
- → As an in-house activity, the electron-EDM measurement with world-class accuracy is being prepared at Groningen University. The decelerator has been almost fully constructed and the sources and target zones have been tested; the instrument will be ready for first accurate measurements in the coming years.
- → The activities on gravitational waves have expanded, gaining a lot of attention over the past years. Nikhef contributed significantly to (1) the upgrade of the VIRGO interferometer in Italy; (2) the design and construction of the ETpathfinder at Maastricht University; and (3) the major effort towards a bid to host the Einstein Telescope in the Euregion Meuse-Rhine, the southern part of Limburg.

Financially, Nikhef has met all its funding targets. Multiple grants were obtained for research and infrastructure programmes, some in larger interdisciplinary contexts and some to fund PhD candidates and postdocs. Large funds were obtained via the Einstein Telescope programme, both nationally and internationally through interregional funding, with the National Growth Fund grant as a particular highlight. Some of the proposals that were unsuccessful will be resubmitted again later. At the same time, the already tight basic funding level has not kept up with inflation in 2017-2022. On a positive note, income from the data centre at Amsterdam Science Park exceeded targets, and is being extended to allow further growth.

Finally, it is worth noting that in 2017-2022, Nikhef significantly improved gender balance in its work force. Notably in the scientific staff population, the share of women now exceeds 25%. A dedicated task force has been working on an agenda for further diversity and inclusion, so make sure this balance reaches all levels in the organisation.

CONTENTS

01 INTRODUCTION

In this report, we reflect on the results of the Nikhef partnership from 2017 to 2022. This is done according to the so-called Strategy Evaluation Protocol (SEP). As developed by KNAW, NWO and Universities of the Netherlands (formerly VSNU), this protocol provides guidelines for evaluating research and research policy. It is used for the assessment of all Dutch universities and research institutes. The three main assessment criteria in the SEP are research quality, societal relevance and viability. Additionally, SEP assessments pay special attention to open science, PhD policy and training, academic culture and human resources policy.

For Nikhef, the 2017-2022 evaluation period had some great highlights worth mentioning. In an intensive collaboration between research programmes and technical teams, detector parts were designed and built for the upgrades of notably LHCb and ALICE. KM3NeT reached a new level of maturity, the eEDM experiment in Groningen is about to start and the search for Dark Matter entered a new phase with XENONnT. Data analysis following from the discoveries of the Higgs boson and gravitational waves was developed, leading to a plethora of new physics results. The construction of the ETpathfinder research facility that will be used for the development of gravitational waves instrumentation in preparation for the Einstein Telescope, has started. On a more organisational note, a sixth university partner, Maastricht University, joined the Nikhef national partnership.

A substantial part of the period under study has also been the time of the Covid pandemic, making the work extra challenging, especially as an extensive three-year renovation of the institute's building in Amsterdam Science Park followed the tail end of the pandemic. Nevertheless, during these times, the Nikhef partnership and the people involved have shown to be extraordinarily resilient. Soon, the renovated building will fulfil its role as a hub for excellent research for many years ahead.

In this self-evaluation report, we'll first look back at the previous strategy and summarise the main results, both scientific and financial. Subsequently, organisation and personnel are discussed, followed by a more detailed overview of the achievements per research programme. Finally, attention is given to topics indirectly related to research and to Nikhef's connection to society. Throughout the document, several case studies highlight important themes.

02 LOOKING BACK: SUMMARY OF RESULTS IN 2017 - 2022

STRATEGY 2017-2022

The Nikhef strategy for 2017-2022 contained the pillars “proven approaches”, “new opportunities” and “beyond scientific goals”, which entailed the following:

Pillar I Proven approaches

- Construct the upgrades and exploit the physics of the LHC experiments ATLAS, LHCb and ALICE
- Build KM3NeT phase 2.0 and exploit neutrino (astro)physics
- Exploit the astroparticle physics experiments Advanced Virgo, XENON1T/nT and the Pierre Auger Observatory
- Fully utilise the theory, detector R&D and computing activities at Nikhef

Pillar II New opportunities

- Determine the electron electric dipole moment with world-class precision
- Prepare for a new era of high-energy accelerators
- Strengthen and exploit the thematic connections between individual scientific programmes
- Prepare a bid to host the Einstein Telescope in the Netherlands

Pillar III Beyond scientific goals

- Establish further links with industry in terms of transfer of knowledge generated at Nikhef
- Attract and train a new generation of scientists and engineers
- Modernise the Nikhef branding and building
- Inspire and nurture scientifically aware general audiences

MAIN RESULTS OF THE PHYSICS PROGRAMME

In Table 1 we summarise the main results of the physics programme for 2017-2022. More detailed results per individual group are described in Chapter 5.

TABLE 1 **Results in the scientific programmes**

Programme	Mission 2017-2022	Main results 2017-2022
ATLAS	To study the Higgs particle responsible for the generation of mass and to search for physics beyond the Standard Model, or unexpected phenomena.	• Precision measurements of the Higgs boson properties, with results on several rare Higgs decays and difficult Higgs processes. • A multitude of searches for BSM physics. • Installation and successful operation of newly developed FELIX system for trigger data acquisition.
LHCb	To search for new particles and interactions that affect the observed matter-antimatter asymmetry in the universe.	• Observation of rare B-meson decays and time varying CP violation. Subtle unexplained effects in the decay of B-mesons have been reported. • Major upgrade of the detector hardware (SciFi and Velo) and data readout. • Incident with the RF box in January 2023.
ALICE	To study the physics of strongly interacting matter at extreme energy densities, where the formation of a new phase of matter, the quark-gluon plasma, is expected.	• Observation of a near-perfect liquid of the quark-gluon plasma (QGP). • Emphasis on heavy quark transport through QGP and understanding of non-planar events. • Installation of silicon-based tracking detectors.
KM3NeT	To discover neutrino sources in the universe and to study the properties of neutrinos.	• Deployment of the first set of KM3NeT strings in ORCA and ARCA. • Accomplishment of the first oscillation parameter measurements. • Searches for point sources of neutrinos.
Virgo, LISA & ETpathfinder	To detect and study gravitational waves that are produced by violent events throughout the universe.	• Detection of gravitational waves by the LIGO-Virgo collaboration, including observations of black holes and neutron star coalescences. • Start of the construction of the ETpathfinder in Maastricht.

CONTINUE →

Programme	Mission 2017-2022	Main results 2017-2022
Pierre Auger Observatory	To investigate the origin and composition of ultra-high-energy cosmic rays.	• Mass composition studies in ultra-high-energy cosmic rays. • First deployment of radio detection of CR. • Completion of Auger-Prime.
XENON	To identify and study the particle responsible for dark matter in the universe.	• Construction and scientific exploitation of XENON1T with results on dark matter and other rare event searches. • Construction and start of scientific exploitation of XENONnT with the first WIMP data results.
Theory	To describe and explain the properties and interactions of subatomic particles.	• World-class results in perturbative field theory, B-physics, cosmology and gravity. • Development of a formalism for calculating inclusive processes.
Detector R&D	To develop state-of-the-art detector technologies to advance future particle and astroparticle physics experiments.	• Readout of new TimePix4 technologies. • Development of R&D toward 4d fast timing instrumentation. • Front wave detection for LISA and ET.
Physics Data Processing	To ensure that the physics reach of Nikhef experiments is never limited by computing.	• Establishment of a coordinated national e-Infrastructure led by the SURF foundation, FuSE, as continuation of BiG Grid. • Data processing capacity provided to our global collaborations and local users increased by ~ 60% over the 2017-2022 period, and on-line storage capacity by ~ 250%.
Electron Electric dipole moment	To perform the most sensitive measurement of the electric dipole moment of the electron.	• First beams slowed down in the decelerator and first measurements of eEDM in the target area. • High precision calculations on the sensitivity of the BaF molecule to CP- violating physics.

FINANCIAL RESULTS

In Table 2 we summarise the (project) funding targets for the previous strategy period (first three columns) followed by the actual acquired funding (final two columns).

TABLE 2 **Nikhef funding targets for 2017-2022**

(Research) activity	Year(s)	Funding target in 2017-2022 Strategy	Achieved	Annually
1 LHC physics, astroparticle physics	2018-2022	Obtain long-term (6 – 8 year) programme funding from NWO Science Domain for postdocs and PhD candidates, increasing to 2 M€ annually in 2022	16.26 M€	2.7 M€
2 Astroparticle physics	2018-2022	Obtain NWO Gravitation grant: ca. 20 M€ for 10 years to strengthen the Dutch astroparticle physics activities with tenure track positions, temporary scientific staff and moderate investments	-	-
3 All research activities	2018-2022	Obtain additional funding (from NWO, EU, etc.) for PhD candidates, postdocs and other personnel (working e.g. on engineering efforts) of 3 M€ annually	33.8 M€	5.6 M€
4 Data centre	2017-2022	Increase net income above 2 M€ annually	14.8 M€	2.7 M€
5 KM3NeT 2.0	2018	Obtain investment of 12.7 M€ (National Roadmap)	12.7 M€	
6 Auger radio detection	2018	Obtain investment of 3 M€ (NWO Large)	2.5 M€	
7 Gravitational Wave research	2018-2020	Obtain investment of 4 M€ for Virgo upgrade and ET instrumentation (NWO Large)	3.5 M€	
8 LHC experiments – Tier 1	2020	Obtain investment of 3 M€ for Tier-1 to run for another 5 years	6.0 M€	
9 Einstein Telescope	2020	Obtain investment, amount to be determined, depending on site selection		
10 Renovation of building	2017-2022	(National Roadmap?) Obtain funding for the renovation (total sum estimated at 20-25 M€); Combined with expansion of the data centre (estimated synergy saving: 1 M€).	26 M€	
11 (Not anticipated)	2017-2022	E-TEST, ETpathfinder, ET technologies National Growth Fund ET (Feasibility study)	11.2 M€ 42 M	

CONTINUE →

At the end of the current strategy period, we observe that most of these ambitions have been realised:

1. With regard to 'programme' funding, the target of 2 M€ has been reached: in 2018, two proposals were granted in the NWO Physics free programme round, one on gravitational waves (2.5 M€) and one on dark matter/neutrino detection (1.9 M€). In 2020, a programme on Higgs physics (with a focus on the ATLAS experiment) was scored in the successor call ('ENW Large', now called ENW-XL) (3 M€). And in 2022, the Nikhef partnership has been awarded another three ENW-XL proposals in the 2022 round with a total size of over 9 M€, in the programme lines Physics Data Processing and Detector R&D ('FASTER'), in the eEDM programme and in astroparticle physics (gravitational waves/heavy-ion physics).

2. We have not been able to obtain an NWO Gravitation grant. A proposal on the theme of multi-messenger astronomy unfortunately did not make it in 2020. A new Gravitation proposal with the theme of gravitational physics, submitted in 2021 was also not granted. Yet another proposal on gravitational physics has been submitted in January 2023.

3. In obtaining additional funding, mainly for PhD positions and postdocs (through the NWO Innovation Impulse Scheme, small and medium projects, eScience Center grants, Horizon 2020 funding, etc.), Nikhef has reached almost twice its target of 3 M€ per year.

4. The net income of the data centre has exceeded the target of 2 M€ in the past years. The facility has been extended –in conjunction with the building renovation– to allow a further growth in turnover.

5/6. Two projects were granted in the NWO Large Investments scheme 2018, providing investments in Auger radio detection (2.5 M€) and in gravitational waves instrumentation (3,52 M€).

7. In the 2018 Roadmap call for Large Research Infrastructures, 12.73 M€ was acquired for the realisation of KM3NeT 2.0 (2019-2028); the bulk of the investments were made in the period 2019-2022.

8. In the 2020 Roadmap round, the 'Fuse' proposal was granted, together with ASTRON. This project funds the computing infrastructure of three Research Infrastructures on the National Roadmap: the LHC experiments, KM3NeT and SKA. The amount awarded is 12 M€ for the period 2021-2025, for Nikhef and ASTRON together (the Nikhef share is 6 M€).

9. The original plan to have an NWO Roadmap proposal for Einstein Telescope in 2020 turned out to be a far too optimistic timeline. Instead, other funds have come available (see point 11).

10. For the renovation, the NWO Board made an allocation of 26 M€ in 2018, (1.3 M€ per year for the period 2019-2038); Nikhef is supplementing this with own funds from the base funding and from the data centre operation to reach the total required amount of 40 M€.

11. Not anticipated in 2017 were several large grants around Einstein Telescope, mostly European (Interreg) funding for ETpathfinder, ET technologies and some preparatory geological surveys. In 2022, Nikhef, together with the ministries of Education, Culture and Science, and Economics Affairs and Climate, the Province of Limburg and the regional development company of Limburg (LIOF) successfully submitted a National Growth Fund (NGF) grant of 42 M€ to fund the feasibility phase of hosting the Einstein Telescope in the Euregio Meuse-Rhine (EMR).

Beyond the current strategy period, but nevertheless relevant to note is that in in the first quarter of 2023 Nikhef has been granted two Investment proposals:

- → A Roadmap Large Research Infrastructures Roadmap grant for instrumentation of the LISA-project. SRON is lead contractor; the Nikhef share is 3 M€.
- → A grant from the NWO Large investment call for instrumentation of Advanced Virgo+ (2.7 M€).

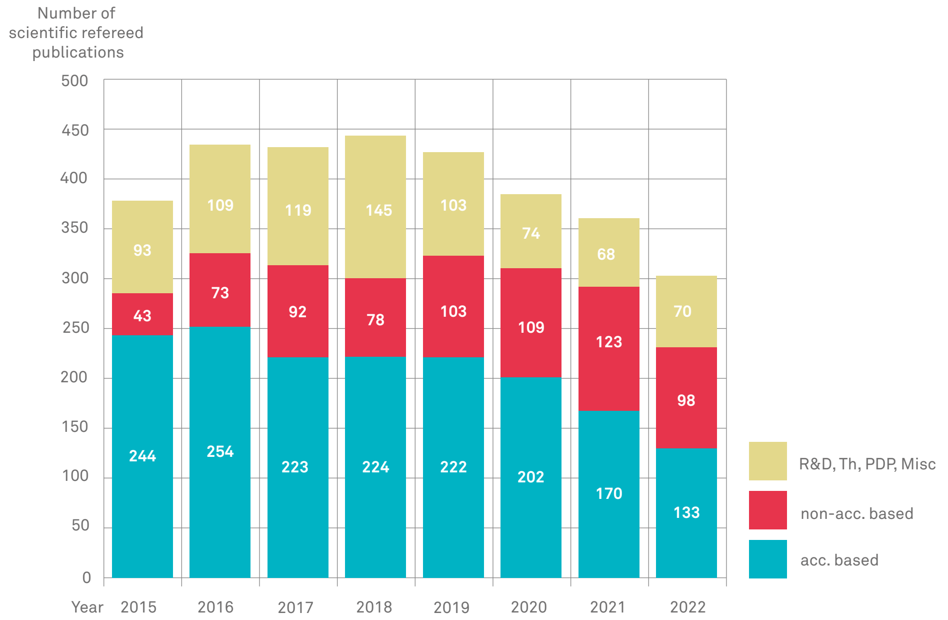
\ SCIENTIFIC OUTPUT

Scientific output is traditionally defined by peer-reviewed publications and corresponding number of citations. As Nikhef's playing field is characterised by large collaborations with many authors per publication and few competing research collaborations, Nikhef does not target optimising on this type of output. Achievements like the design and construction of detectors, development of new technologies, contributions to important data analyses and theory development are far more important, although more difficult to quantify. These and other achievements, briefly discussed in the previous section, are described in more detail in Chapter 5 (Evaluation of research programmes). In this section, some more traditional output indicators are shown.

In the 2017-2022 review period, Nikhef published 2356 refereed citable scientific articles in international journals, according to the SPIRES-HEP database. This number does not include about 90 papers by the LHC collaboration that have been delayed as a new form of institutional acknowledgment had to be developed in the light of Russia's invasion of Ukraine. With a new publishing policy recently adopted, a peak in publications is expected for 2023. Figure 1 traces the number of scientific refereed publications over the last eight years, distinguishing between publications on accelerator-based physics (LHC), non-accelerator-based physics (astroparticle physics and eEDM) and others (Detector R&D, Theory, Physics Data Processing and Miscellaneous). Typically, experiments in a building phase produce relatively few papers per year, mostly on design studies, hardware, electronics and beam tests. Running experiments produce a large number of papers per year, especially on physics results.

FIGURE 1 **Number of scientific refereed publications 2015-2022**

divided in: accelerator-based physics (LHC + eEDM)
non-accelerator-based physics (astroparticle physics)
other (Detector R&D, Theory, Physics Data Processing and Miscellaneous)



CWTS, the centre for science and technology studies, performed a bibliometric study of Nikhef's publications, using the Web of Science database and their own publication-level classification system for analysis. The main results can be found in Table 3. Note that there is a small difference in the total number of publications used by CWTS and by Nikhef.

TABLE 3 **Output and impact statistics calculated for the years 2017-2022 by CWTS.**

Indicator	Total number 2017-2022
N pubs: Number of publications	2318
P[full]: Number of N pubs included in the citation analysis (excluding e.g. 2022)	2061
PP[OA]: Proportion of P[full] that concerns open access publishing	0.98
PP[collab]: Proportion of P[full] involving collaboration	0.98
PP[int collab]: Proportion of P[full] involving international collaboration	0.95
PP[industry]: proportion of P[full] with co-authorship with industry	0.02
P[fract]: Number of P[full] fractionally counted. The fraction is based on the number of co-authoring organisations.	253
MNCS[full]: Mean normalised citation score of papers in P[full], showing the impact of these papers with respect to the world average in associated publication clusters (see below for an explanation).	1.85

The indicator MNCS[full] entails the mean normalised citation score of the papers represented in P[full]. Scores higher than 1 reflect a citation-based impact that is higher than the world average. The indicator shows that the worldwide impact of the papers Nikhef (co-)authored is 85% higher than the world average of the associated publication clusters.

Finally, Table 4 presents the numbers of PhD degrees awarded over the past six years.

TABLE 4 **Number of completed PhD theses per year.**

	2017	2018	2019	2020	2021	2022	Total
PhD theses	18	19	14	21	26	12	110

FOLLOW UP OF RECOMMENDATIONS BY THE 2017 EVALUATION PANEL

The previous NWO-I evaluation panel visited Nikhef in 2017 to assess the Nikhef partnership over the period 2011-2016. The panel formulated recommendations on the scientific programme as well as topics like viability, PhD programme and diversity. In Table 5, a follow-up on the panel's recommendations is presented.

TABLE 5 **Follow-up of recommendations by the 2017 evaluation panel.**

Theme	Recommendation	Follow-up
Research quality	The Committee encourages Nikhef to put in place mechanisms that enable vigorous pursuit of hosting ET in the Netherlands. It would be beneficial for Nikhef to join EGO/ Virgo as full members in view of hosting the ET in the Netherlands.	Nikhef has become the first external full member of EGO in 2021, next to INFN and CNRS, at an annual membership cost of 450 k€. Additional funding for upgrade projects at Virgo is contributed by Nikhef on 'best effort' basis. With the reward of the National Growth Fund grant and intense collaboration with Belgium and Germany, Nikhef is preparing a serious bid for hosting the ET in the EMR region.

CONTINUE →

Theme	Recommendation	Follow-up
Relevance to society	The Committee was pleased to see considerable and successful effort in this direction and encourages Nikhef to continue and further strengthen such efforts.	Nikhef has increased the outreach communication significantly through its website and e.g. by starting of the DIMENSIES magazine. Nikhef coordinates the ILO network and there are plenty of contacts with industry, in the Netherlands and via CERN.
Viability	The Committee notes that long-term projects, a norm at Nikhef, require allocation of long- term funding. NWO is encouraged to adapt its funding schemes to recognise this nature of Nikhef's work and also to include funding related to the recurring operating costs of experiments.	NWO did not adapt its funding scheme, but offers the possibility for a one-time Summit call in competition. Nikhef has submitted a Summit pre-proposal in June 2023.
	The Committee endorses Nikhef's plans for the renovation of its buildings to provide more space for performing high quality scientific research.	The renovation of the Nikhef institute in Amsterdam is taking shape and we expect to inaugurate the new building in late 2023.
PhD program-mes	The Committee urges Nikhef to continue its efforts to reduce the duration of the PhD research project to the nominal 4 years. A business training course adds excellent value to doctoral training and NWO should continue supporting it.	See Chapter 6, section on PhD supervision and mentorship.
Research integrity	Nikhef should raise more awareness, and further define procedures to follow, in case issues arise concerning research integrity.	See Chapter 6, section on research integrity.
Diversity	The Committee encourages Nikhef to look at possibilities of mobility post PhD, including within the Netherlands itself. The Committee was pleased to see an improvement of gender balance since the last assessment, and encourages efforts towards the continuation of this trend, also at more senior levels. Nikhef is encouraged to write a "Gender Equality Plan" and to use the relevant available tools, and targeted funding plans such as WISE, also at higher levels.	The gender balance has further improved over the last period, resulting in a gender balance among the younger generation of staff scientists at Nikhef. Focus has now shifted to Diversity & Inclusion, for which a dedicated task force has been formed that will formulate an agenda and stimulate further diversity and inclusion at Nikhef.

NARRATIVE – TEN YEARS OF HIGGS

By Martijn van Calmthout

Nikhef was heavily involved in the discovery of the Higgs boson in 2012, and has since been zooming in on the particle that is central to the Standard Model.

A new era in particle physics

The discovery of the Higgs boson in 2012 was certainly one of the finest hours in modern particle physics and physics in general. In the media, the event has since been celebrated as the closing moment of a long and hard search. The end of an era. In reality, the evidence for a Higgs field in the form of a 125 GeV mass boson was only a beginning of a new era in particle physics.

Nikhef was heavily involved in the search and the discovery of the Higgs particle, mainly though the ATLAS experiment at the Large Hadron Collider at CERN. After 2012, Nikhef-ATLAS physicists proceeded to study the properties of the newly found boson and the field it is associated with.

Open questions

Properties like spin, predicted to be 0, and mass remained to be determined experimentally. Interactions had to be measured, like the couplings to the other particles in the Standard model. Many questions remained open, even if the boson could be part of a whole family of Higgs-like particles. One central issue is the form of the Higgs potential giving rise to the interactions with the rest of the Standard model and even the interaction with the Higgs itself.

After a decade of intense further research, many of those issues have been studied and some even resolved. Nevertheless, the physics of the Higgs boson is still in its infancy and thus continues to be a central theme in the research programme at Nikhef. Particularly in the ATLAS group, Higgs physics is more important than ever. After the hunt for the particle, the hunt now is for the details. And if possible, for real surprises.

Central role of the Higgs mechanism

The Higgs particle properties have been further determined with substantial work from Nikhef PhD candidates and staff, with the Higgs life time as a recent example. Still, most work is focused on the predicted central role of the Higgs mechanism in particle physics.

The Higgs particle is the experimental manifestation of the so-called Higgs field. Proposed in the sixties by Peter Higgs and others this field is predicted to add mass to the massless elementary particles in the Standard Model. In theory, these masses arise through a coupling with the Higgs field, typical for each type of particle. Such couplings can be derived from accelerator experiments where Higgs is acting together with the other particle.

After the discovery of the boson, and thus the proof of the existence of a Higgs-like field, the question remained if the coupling with elementary particles was really proportional to their masses, as predicted.

Nikhef physicists at ATLAS have been heavily involved in experiments to measure and determine these couplings. Many theses have been written on specific measurements, and through the collaboration many Nikhef physicists were authors in ATLAS papers on Higgs results.

Couplings established

For the heaviest particles in the Standard Model, both the ATLAS and the competing CMS experiments across the LHC have succeeded in measuring the Higgs couplings to rather high precision. So far, the couplings of the top quark and the W and Z boson have been firmly established.

In more recent years, refined methods have been developed to probe the couplings to some of the lighter leptons and quarks in the Standard Model. These coupling are weaker and therefore harder to measure. They are also much harder to study as many more particle processes can produce similar patterns as a background in the detectors. For the tau-lepton, an electron-like particle, the coupling has been determined as well as for the bottom quark. First results have been reported also for the muon, an intermediate-mass electron-like particle. These are to be further refined. Together, these measured coupling give an astonishing clear view already on the Higgs mechanism. The coupling appears to be directly proportional to the known particle masses. The Higgs particle found in 2012 in many ways seems to be the simplest Higgs boson possible, performing just as needed to give the massless particle theory mass.

Recently the medium mass charm quark, mainly through pioneering work from Nikhef, has been added to the already convincing graphs from ATLAS. These were presented at the celebrations of 10 years of the Higgs particle discovery. Still with rather large error bars, but nevertheless spot on in the straight line presented, showing the Higgs mechanism in full force.

High-luminosity era

Nevertheless, not all coupling constants have yet been determined, with growing challenges as particle masses are smaller. For other reasons, one particular coupling, the self-coupling of the rather massive Higgs particle with its own field, is still an open issue of great theoretical importance. The shape of the Higgs field potential can turn out to be especially important in cosmological issues such as the processes just after the big bang, including the dominance of matter over antimatter.

In de upcoming decade the LHC accelerator at CERN in Geneva will be transformed to a high-luminosity proton machine, producing many more proton collisions and an expected tenfold data increase over the years in detectors like ATLAS. Nikhef is heavily involved in preparations for this high-luminosity era, with contributions to ATLAS upgrades, innovative electronics and sensor concepts, and extended data handling infrastructures. The tenfold increase in data is expected to allow for even more detailed studies of the particle world and its central inhabitant, the Higgs boson, gradually coming of age.

Work at the ATLAS detector at CERN, essential to the higgs boson discovery in 2012.

03 ORGANISATION AND PERSONNEL

ORGANISATION

The Nikhef organisational structure as sketched in this section pertains to the Nikhef partnership, so includes the NWO institute and the six partner universities.

Governance: boards and bodies

On 1 January 2017, a change in governance took place. NWO, including its FOM Foundation that was Nikhef's mother organisation for over seventy years, was reorganised. In its new shape, a new NWO institutes organisation, called NWO-I, has a total of nine institutes under its wings, including Nikhef. Note that this does not concern the partnership as a whole, for which the Nikhef Board is in place, see below. Refining the relatively new NWO governance is still ongoing and requires attention and thought, both from NWO-I and the institutes. The NWO-I Foundation Board and the Nikhef directorate meet at least twice a year. Moreover, several task forces are in place in which members of the Nikhef directorate and other institutes develop an intensified and more formal collaboration between NWO institutes on themes like operations and human resources.

The Nikhef partnership (the NWO institute and its university partners) is governed by the Nikhef Board. Since Maastricht University joined the partnership, this Nikhef Board consists of eight members: two members assigned by NWO-I, and six members assigned by the governing boards of the six university partners. This Board approves the joint scientific programme of Nikhef and the annual budgets, as provided by each partner. The Nikhef Board meets once a year.

The Scientific Advisory Committee (SAC), consisting of a maximum of seven international experts in Nikhef's fields of research, is the external advisory body for the Nikhef Board. The SAC visits the institute on average once a year and produces an advisory report on Nikhef's scientific activities. Members are appointed by the Nikhef board on a proposal by the Nikhef director. Current SAC members are: P. Hernandez (University of Valencia), M. Kowalski (Humboldt University Berlin, DESY), S. Mertens (Technical University Munich), J. D'Hondt (Vrije Universiteit Brussel, chair) and B. Erazmus (CNRS, Nantes).

Internal management, bodies and meetings

The Nikhef director is appointed by the NWO-I Foundation Board for a five-year term with an option of a second five-year term. The appointment always needs the approval of the Nikhef Board. During the period covered by this review Prof. Stan Bentvelsen has been the director.

Daily management of the institute takes place in the Directorate Team (DT), consisting of the director, institute manager (who also serves as deputy director) and head of the personnel department. Per March 2023 the DT is expanded with an extra position: the strategic advisor. The DT is supported by the head of the secretariat.

The institute works council (Nikhef Ondernemingsraad, NOR), a body required by Dutch law for organisations with 50 or more employees, represents Nikhef personnel and holds meetings with the director on average every two months to discuss developments within the institute. The NOR consists of Nikhef employees who are elected by all Nikhef personnel in bi-annual elections. The NOR is consulted by the director in cases prescribed by law, in particular on safety and working conditions.

Scientific policy is discussed in the scientific council (Wetenschappelijke Advies Raad, WAR), which serves as the internal advisory body for the Nikhef director. The WAR meets several times a year. The permanent scientific staff and technical group leaders also meet every four months for the staff meeting (Stafoverleg). The annual scientific meeting of Nikhef ("Jamboree") is held in Winter or Spring and sets the stage for each group to present their scientific highlights of the year. It also serves as a moment to have a full and detailed overview of Nikhef's scientific programme. In recent years, the jamboree also included discussions on general topics such as sustainability, career perspectives and diversity & inclusion.

Group structure

The research activities are organised into programmes, each led by a programme leader (PL) (and in case of large programmes also a deputy programme leader), appointed by the Nikhef director. The PLs are responsible for all activities and personnel in their research lines, including the share contributed by the university groups. Currently there are 11 programmes. Three of these are LHC experiments (ATLAS, LHCb, ALICE) and four are astroparticle physics experiments: neutrino physics (KM3NeT, DUNE), gravitational waves (Virgo/LIGO, ET, ETpathfinder), cosmic rays (Pierre Auger Observatory) and direct Dark Matter searches (XENONnT). Since 2016, a low-energy precision research activity has been added (eEDM: measuring the electron electric dipole moment). The remaining three programmes are: Theoretical Physics, Detector R&D and Physics Data Processing.

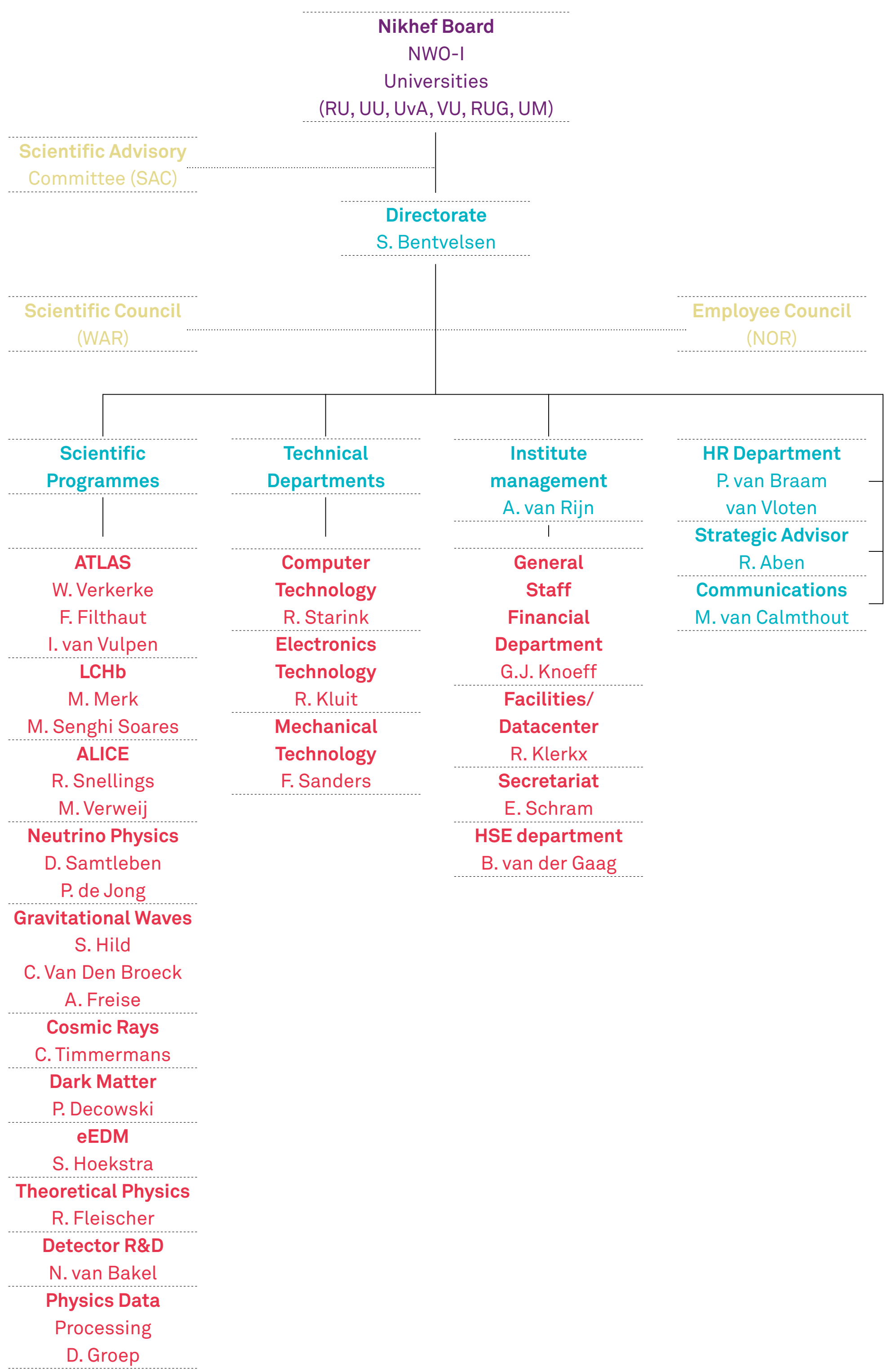
The technical expertise is organised in three groups, each led by a technical group leader (TGL): computing technology (CT), electronics technology (ET) and mechanical technology (MT). These groups do not include the technical staff at the university groups, which have a local embedding.

The support section (Beheersectie) led by the institute manager, consists of the departments for financial & control, facilities and data centre, occupational health and safety, secretariat & reception, library and staff including the industrial liaison officers. Two other staff departments, personnel affairs and science communication, report directly to the director.

Annual management cycle

The Nikhef Directorate Team (DT) follows an annual management cycle. In March the DT organises a two-day retreat (code name 'Bronkhorst'). In preparation, all groups are invited to share any input they wish (concerns, ideas, plans) with the DT. At 'Bronkhorst', the DT carries out a comprehensive analysis of the financial and personnel state of affairs. Usually a selection of themes (such as diversity and inclusion, internal communication) is also discussed. Furthermore, all input of the groups is addressed, as specifically as possible, for example the needed additional competences in the group due to personnel and scientific developments. In the months following 'Bronkhorst' (April - July), the DT has meetings with the leaders of the technical and scientific groups, with emphasis on the functioning of the group members. The 'Bronkhorst' feedback is always on the agenda as is the group's financial state of affairs. The resulting insights are used for the update of the Nikhef (NWO-I) budget, which is due in August. Generic actions are summarised in the annual plan for the next year.

FIGURE 2 **Nikhef organigram as of 2023.**



Project structure for scientific instrumentation

Nikhef uses a so-called 'project-matrix' structure for carrying out large scientific instrumentation projects. A project, which is usually part of a larger programme, is requested by the programme leader and assigned a project leader, who composes a project plan that contains –apart from technical and financial requirements– the estimated personnel requirements and a planning with milestones that are refined in discussions with the technical group leaders. If agreed, the personnel is assigned by the Nikhef director. The overall capacity planning is updated twice a year. Progress on projects is reported in the Project Plans Meeting (Overleg Projectplannen, OPP), which is held every two months. Personnel priorities between projects within a programme are decided by the programme leader; priorities between different programmes are decided by the director.

The project-matrix structure has worked quite well, although permanent attention is needed to deal with the inherent tension between the hierarchical line (technical group leaders) and the project line (project leaders). This requires clear rules, effective communication and adequate leadership. Key players (technical group leaders, project leaders, programme leaders and the directorate) are regularly updated on the rules of engagement for project management. In addition, junior project leaders are offered a project management course to learn how to use the project-matrix structure.

For several years, Nikhef has also engaged in the Agile methodology. Several projects participated in a pilot programme to adopt the Agile methodology for Nikhef instrumentation projects. Agile methodologies are designed to improve teamwork and collaboration with stakeholders, with the ultimate intent of producing excellent results by strong and happy teams. Especially in the mechanical technology department, Agile framework Scrum has been very successful and popular (for example, the ATLAS-ITk project). We believe this is due to the integral way in which Agile and Scrum are implemented at Nikhef: alongside the natural attention to producing high-quality instrumentation in each project, there is attention paid to the organisation/structure of the project, the professional development of each team member, and to the quality of the teamwork within and between projects. The number of Agile projects is increasing, being primarily limited by the availability of staff trained to assume Agile leadership roles, such as "Scrum master" or "Product owner". An Agile organisation requires some investments of people that take these roles. The benefits, integrated over result, personal and teamwork dimensions, exceed these costs by far.

PERSONNEL (HUMAN RESOURCE POLICY)

Nikhef tries – in every conceivable way – to create a climate in which people can find and meet each other, so that insights and ideas can emerge from their interactions. To that end, people must be able to meet in a physically and psychologically safe environment where ideas are welcomed and mistakes are valued as learning opportunities. In addition, it is necessary to bring together a varied group of people who view everyday challenges from a multitude of perspectives. For this reason, a lot of time and attention has been devoted to increasing diversity, and making it a safe and learning-rich academic environment.

Obviously, the Covid pandemic and the renovation of the Nikhef building in Amsterdam had a major impact on this agenda. The intended outcome of the renovation is built around the motto “the power of interaction”. Yet that very interaction suffers from the execution of the renovation itself. Add to this the many lockdowns during the Covid pandemic, during which personal collegial contact was virtually impossible, and the magnitude of the challenge becomes clear. Consequently, at Nikhef we are very much looking forward to the completion of the renovation.

In an organization made up of people, human things happen-even the saddest ones. The results presented by Nikhef in this review were co-created by Professor Els Koffeman. Els is still associated with our institute, even though we miss her daily presence. Also, during the evaluation period, Nikhef had to bid involuntary and sometimes unexpected farewell to four colleagues who were invaluable to our institute. We will all have to continue living and working in the missing of some outstanding colleagues. In particular, colleagues in the ALICE group, the ATLAS group, the Computer Technology group and the Mechanical Technology group still feel the loss daily.

In this section, we first provide a basic quantitative description of the Nikhef population. This is followed by a more qualitative description of measures and actions taken to contribute to the development and maintenance of the Nikhef culture.

Quantitative evaluation

The number of personnel, expressed in full–time equivalents (fte), at Nikhef has increased in the period 2017–2022 from about 307 to 350 fte (Table 6). The number of permanent scientific staff is now at a level of about 91 fte, an increase of about 15 fte compared to 2017. This growth has two origins: the addition of Maastricht University to the Nikhef partnership, and the funding of more university-employed Nikhef staff members from the ‘sector plans’ provided to Dutch universities by the Dutch government.

Nikhef typically hosts around 30 to 40 postdocs. This number is rather volatile, mostly because it depends on the availability of temporary funding (grants). For the same reason, the number of PhD candidates fluctuates around 100 to 110 fte.

After a dip in 2016, the number of engineers and technicians has increased to almost 80 in 2022. This number could have been higher, had the labour market not been so tight in recent years. The increased number of technicians is needed to realise the ambitions on the upgrades of existing experiments at the same time as realising the new ambitions in the astroparticle physics field.

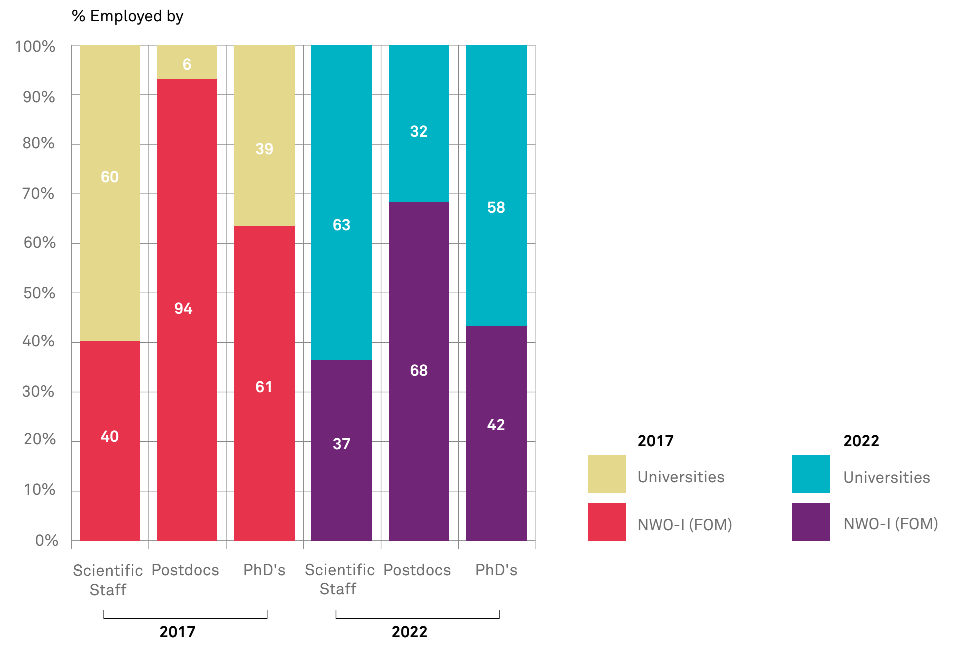
The *flexible shell* of personnel members with fixed-term contracts and temporary workers is still effective, and has proven to be an effective tool that allows managers to move with the qualitative and quantitative needs that science has in the technical field.

TABLE 6 **Development of staff 2017-2022 per category.**
Note that all Nikhef programme leaders have been counted as the equivalent of full professors.

Scientific staff	2017		2018		2019		2020		2021		2022	
	#	fte	#	fte	#	fte	#	fte	#	fte	#	fte
Assistant professor	23,0	20,5	20,0	18,3	22,0	21,0	31,0	29,3	37,0	35,5	35,0	34,3
Associate professor	27,0	25,9	28,0	28,0	30,0	28,1	27,0	26,5	26,0	25,5	24,0	22,7
Full professor	32,0	30,7	30,0	29,2	30,0	28,7	37,0	33,5	33,0	30,5	37,0	33,6
Postdocs	32,0	32,0	38,0	36,6	51,0	48,3	37,0	33,4	41,0	39,7	36,0	35,6
PhD candidates	97,0	97,0	95,0	95,0	108,0	107,5	100,0	99,5	122,0	121,1	111,0	111,0
Total scientific staff	**211,0**	**206,1**	**211,0**	**207,1**	**241,0**	**233,6**	**232,0**	**222,2**	**259,0**	**252,3**	**243,0**	**237,2**
Technical and Support staff	**2017**		**2018**		**2019**		**2020**		**2021**		**2022**	
	#	fte	#	fte	#	fte	#	fte	#	fte	#	fte
Technical Staff	74,0	71,6	73,0	71,4	76,0	74,6	79,0	77,9	83,0	79,9	80,0	78,5
Support staff	36,0	29,5	42,0	34,1	41,0	32,6	42,0	35,0	42,0	34,9	42,0	35,2
Total Technical and Support staff	**110,0**	**101,1**	**115,0**	**105,5**	**117,0**	**107,2**	**121,0**	**112,9**	**125,0**	**114,8**	**122,0**	**113,7**
Total all staff	**321,0**	**307,2**	**326,0**	**312,6**	**358,0**	**340,8**	**353,0**	**335,1**	**384,0**	**367,1**	**365,0**	**350,8**

Where in the previous evaluation it was stated that most Nikhef staff members are employed by NWO-I, this situation has now turned around. In 2022, 58% of all 243 scientific staff members were employed by a Nikhef partner university. In 2017, this was 39%. Although this is no problem for the Nikhef institute as such, it becomes increasingly difficult to service a growing group of Nikhef staff who are employed by seven different employers. As a result, some extra support staff members have been hired.

FIGURE 3 **Ratio of scientific staff employed by NWO-I and the universities.**
NWO-I
Universities



Diversity and inclusion

In Nikhef's working environment, almost all nationalities, religions and cultures are represented, as well as genders and gender identities. Although the commitment to being a diverse and inclusive institute leads to a broad agenda, over the past evaluation period, Nikhef focused specifically on the topic of gender equality. To add content to this ambition, a Gender Equality Plan has been drafted and implemented to create a better gender balance in the Nikhef scientific staff group. This resulted in actions, most of which have been or are being executed at this moment, such as developing and implementing procedures for inclusive recruitment and selection of staff, organising workshops and trainings on diversity and unconscious bias towards minority groups, offering additional support to employees belonging to minority groups, and paying attention to inclusive images in all Nikhef communications. The quantitative effects of this gender agenda can be found in the table below.

TABLE 7 **Gender balance of Nikhef personnel in 2017 and 2022.**

	2017				2022				Development 2017-2022	
	M (fte)	F (fte)	total fte	%F	M	F	total	%F	△	relative change
Permanent scientific staff	67,6	9,5	77,1	12,3%	65,8	24,8	90,6	27,4%	15,1%	122,3%
PhD candidates	69	28	97	28,9%	75,0	36,0	111,0	32,4%	3,6%	12,4%
postdocs	22	10	32	31,3%	26,0	9,6	35,6	27,0%	-4,3%	-13,7%
Technical/ engineering	67,9	3,6	71,5	5,0%	73,0	5,5	78,5	7%	2,0%	39,2%
Management & General support	23,2	9,3	32,5	28,6%	24,3	7,9	32,2	24,6%	-4,0%	-14,1%
Nikhef total	**249,7**	**60,4**	**310,1**	**19,5%**	**264,0**	**83,8**	**347,8**	**24%**	**4,6%**	**23,7%**

It is clearly visible that most of the attention has gone to the permanent scientific staff, with the gender balance shifting significantly, especially for the 30-39 age group (see Table 8).

TABLE 8 **Gender of permanent scientific staff per age category in 2022.**

Age	Total	M	F	%F
30-39	20	9	11	55%
40-49	36	27	9	25%
50-59	33	28	5	15%
60-67	7	6	1	14%
Total	**96**	**70**	**26**	**27%**

For the future, the focus will shift to retaining the newly welcomed colleagues, and supporting them in their career paths. The Nikhef directorate is highly committed to support women in their development to leadership positions. At the same time, more attention will also be paid to the gender balance in the technical groups.

Another societal development Nikhef embraced was the growing attention for gender identity-related diversity. Nikhef emphasises that it welcomes all people, regardless of their sexual orientation or gender identity. We expressed this, for example, by actively expressing support for the LHBTIQ+ community, and by promoting diversity events.

To further improve the inclusiveness and diversity of Nikhef, a Diversity and Inclusion (D&I) plan will developed, for which a D&I Taskforce was installed and meets regularly.

The Covid pandemic

Nikhef, as an international, diverse group of people, has had to face many major problems as a result of the pandemic. During lockdowns, we have made every effort to stay in touch with and help each other in every possible way. Nikhef personnel was quickly and generously provided home working facilities. We did everything in our power to provide a social safety net for people who were far from their families. Nikhef did not issue orders about working from home, but rather tried to use the available space for people who needed it most. Individual tailoring took precedence over generic policies. The utilisation rate at the institute during lockdowns fell well below 25%. Throughout this period, strict monitoring of possible occupational health and safety risks took place. The number of Covid infections that could be traced to physical encounters at Nikhef was negligible. And finally, with the highly valued help of the Covid fund created by NWO-I, we could offer contract extensions to many PhD candidates, which allowed them to make up for accumulated delays.

Education & personal development

Nikhef aims at a level playing field for all its employees in terms of compensation and benefits, education and personal development opportunities. For example, the highly valued 'soft skills courses' offered to PhD candidates employed by NWO-I, are also made available to university-employed PhD candidates. These courses do not only aim at scientific writing and presenting scientific work, but also focus on 'shaping your career', in which PhD candidates actively explore their future possibilities on the labour market. Whenever necessary or desired, additional coaching and support is offered.

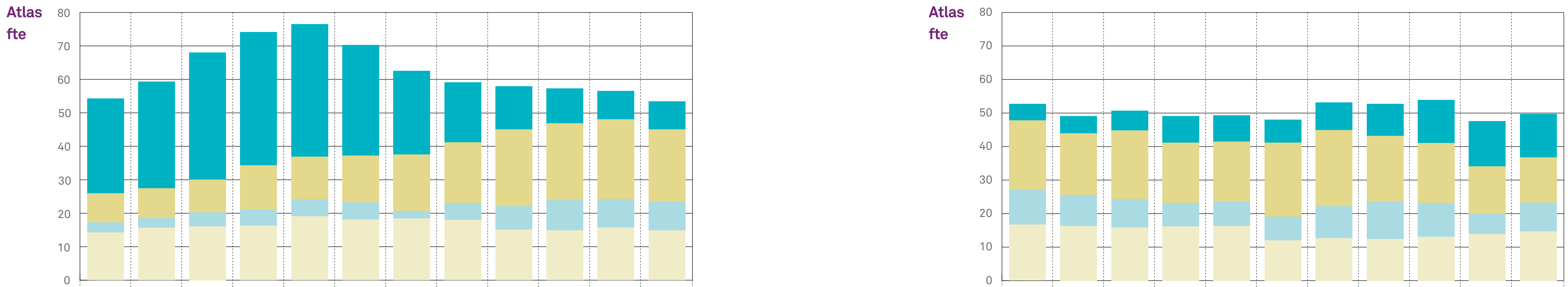
During the Covid pandemic, the first reflex was to postpone or cancel in-person training activities. Very rapidly, however, it became clear that alternative ways had to be found to continue the support in personal development of employees. Luckily, providers of training and workshops were innovative, and many online alternatives came on offer. Nikhef has gratefully taken advantage of these opportunities. At the same time, we have also gained a good understanding of the limitations of these modes of operation. We will benefit greatly from the newly acquired knowledge in the years to come.

Deployment of personnel

Figure 4 illustrates the lifecycle of long-term 'big science' experiments. In the years 2000-2008, Nikhef spent tremendous technical and engineering effort on designing and building its ATLAS instrumentation commitments (BOL muon chambers, SemiConductor Tracker, Trigger and Data Acquisition). When the experiment came online, the number of PhD candidates and postdocs increased, decreasing again as the funding provided by FOM/NWO-I winded down as of 2014. After 2018, technical and engineering staff numbers increased again for Phase 1 and in particular Phase 2 (Inner Tracker) commitments of Nikhef.

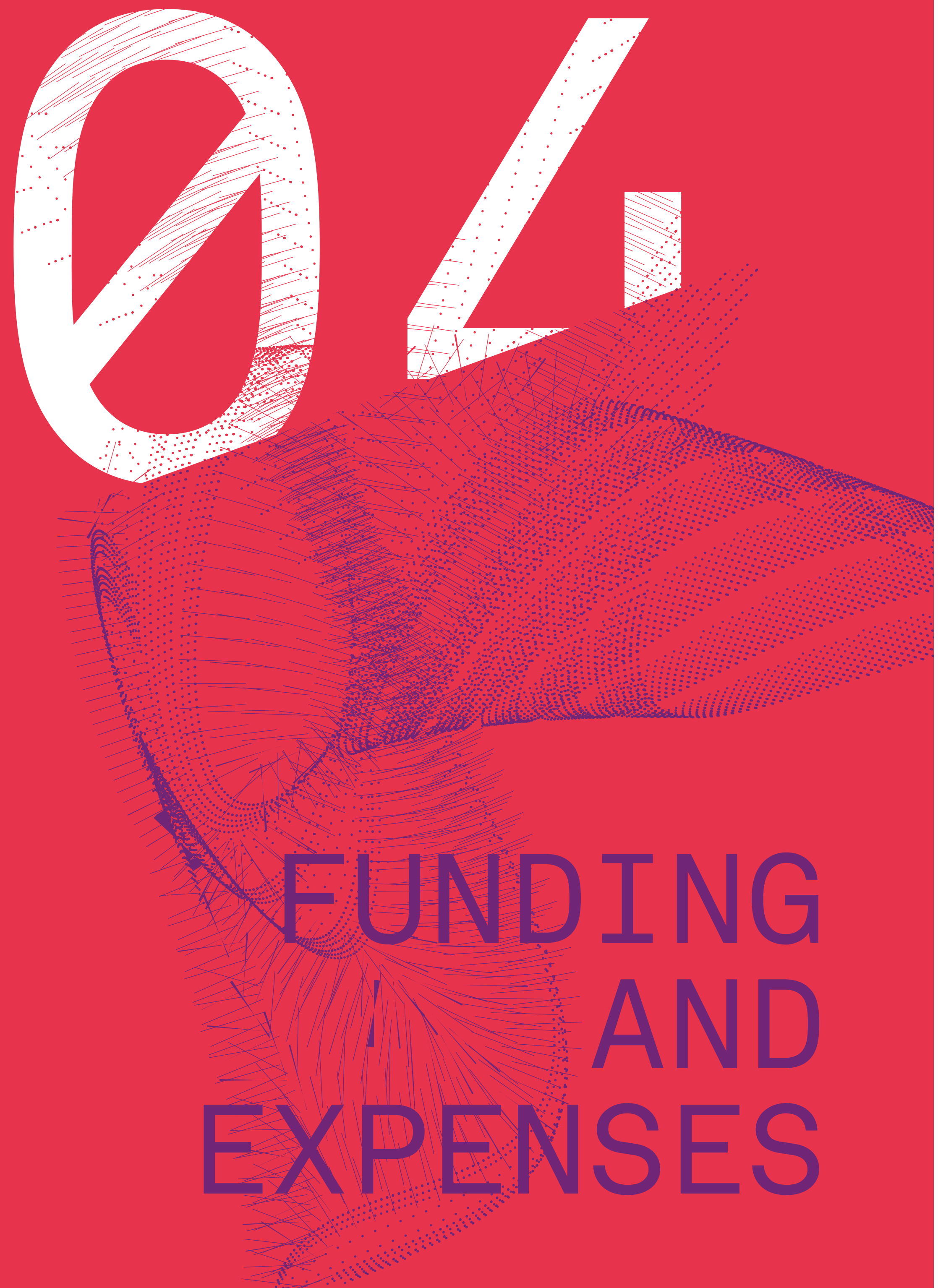
Preparing sensor elements for the ALICE detector upgrade.

FIGURE 4 **Personnel distribution in the ATLAS programme (2000-2022).**



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Technical staff	28,4	31,8	38,0	39,9	39,6	33,1	25,1	17,9	12,9	10,4	8,4	8,4
PhD students	8,6	9,0	9,8	13,2	12,8	13,9	16,8	18,1	22,9	23,0	23,9	21,6
Postdocs	3,1	2,9	4,1	4,8	5,0	5,2	2,3	5,1	7,0	9,0	8,5	8,5
Staff	14,2	15,6	16,1	16,3	19,1	18,1	18,4	18,0	15,1	14,9	15,7	14,9
Total	54,3	59,3	68	74,2	76,5	70,3	62,6	59,1	57,9	57,3	56,5	53,4

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Technical staff	4,9	5,1	5,9	8,0	7,9	6,9	8,3	9,5	12,9	13,5	13,0
PhD students	20,7	18,5	20,5	18,0	17,9	22,0	22,7	19,5	17,9	14,3	13,5
Postdocs	10,4	9,2	8,4	6,9	7,2	7,1	9,5	11,2	10,0	5,8	8,5
Staff	16,7	16,3	15,9	16,2	16,3	12,0	12,7	12,5	13,1	14,0	14,7
Total	52,7	49,1	50,7	49,1	49,3	48	53,2	52,7	53,9	47,6	49,7



04 FUNDING AND EXPENSES

The Nikhef income has increased over the course of 2017 to 2022 (from 38.5 M€ to 49.3 M€). Inflation in this period (CBS index) has been a little over 21%, implying that about 3 M€ has been 'real' growth. Almost all of this (absolute) increase is attributable to the increase in the contribution via the university groups. The university groups now contribute more than a third of the total effort.

TABLE 9 **Funding for Nikhef 2017-2022 (source: Nikhef partnership budgets).**

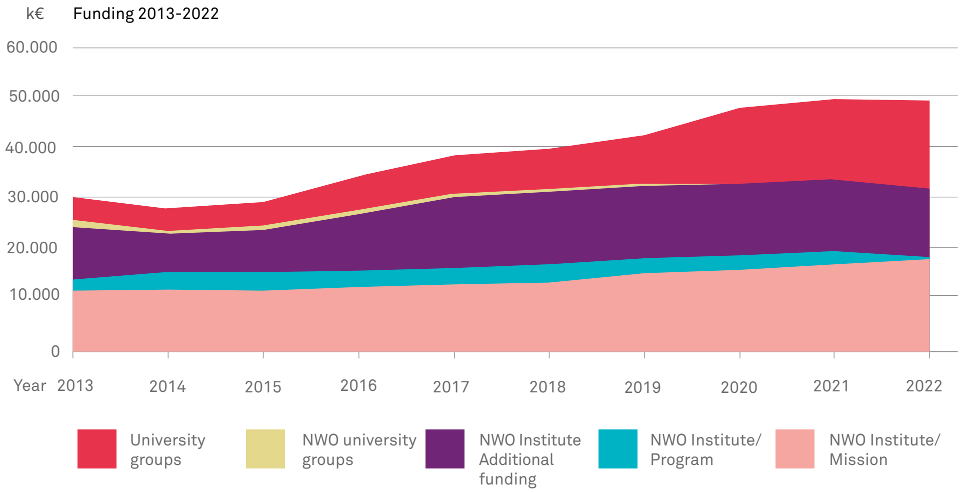
Funding (M€)	2017	2018	2019	2020	2021	2022
NWO institute - mission (of which earmarked for renovation)	12.805	13.368	15.106 (1.300)	15.666 (1.300)	16.773 (1.300)	17.802 (1.300)
NWO institute - programmes	3.326	3.453	3.107	2.957	2.818	436
NWO institute - additional funding	14.668	15.154	14.658	13.891	14.123	13.462
NWO-I university groups	843	687	280			
Universities	7.707	7.852	9.627	15.297	16.059	17.623
Total	**38.506**	**39.827**	**42.498**	**47.811**	**49.773**	**49.323**

The remainder of this chapter explains the Nikhef funding situation in more detail. We consider a 10-year time frame (2013 - 2022) to understand the trends in funding and expenses that affect the current evaluation period.

Funding 2013-2022

The tables and graphs shown below illustrate how over the past decade, the Nikhef research programme has been funded from five separate sources. The first source is the 'base' funding for the (formerly FOM, now NWO-I). The second source is the programme funding line stemming from the former FOM-era. This funding line has ended in 2022. The third source represents any form of other funding administrated by the NWO institute: project funding from third parties (such as the EU, NWO, the Ministry of Economic Affairs), contract research and other activities. The fourth source was the (FOM/NWO-I) programme funding for the university groups. This source has now been stopped. The fifth source is (the equivalent in money of) the personnel and material budgets of the university groups.

FIGURE 5 **Nikhef funding 2013-2022.**



Base funding: mission budget and programme funding

Until and including 2016 one could consider the base funding to be the sum of the programme budget and the mission budget, where the programme budget was primarily intended for funding PhD graduates and postdocs and associated running costs. In 2016, this sum was 15.6 M€. At the transition from FOM to NWO-I (per 2017), it was decided to label about half of the programme budget as base funding and the other half as programme funding, which would gradually end from 2017 to 2022.

The increases shown in the mission budget are due to compensation for salary and price compensation and -per 2019 - a contribution of 1.3 M€ annually (for 20 years) to cover the costs of the Nikhef renovation. Evidently these renovation funds cannot be used for research activities. If we compare the 2016 base funding (15.6 M€) with the 2022 base funding corrected for the renovation funding (17.8 - 1.3 = 16.5 M€), one must conclude that Nikhef's base funding has unfortunately not kept up with inflation (~21% over the period 2016-2022). Corrected for inflation, a consistent base funding would have amounted to (15.6 * 1.21 =) 18.9 M€ in 2022, indicating a shortfall by about 2 M€, largely due to the year 2022, which had an enormous inflation level.

If we start the comparison not in 2016 but in 2017, after the system change to NWO-I, and we use the core of the base funding (i.e. the part that is not dependent on incidental granting nor is earmarked for the renovation), this core base funding grows from 13.9 M€ in 2017 to 16.0 M€ in 2022. The core base funding received in 2017, corrected for inflation, would have been 16.7 M€ in 2022, implying a loss of spending power of about 0.7 M€, again mostly due to the year 2022.

Additional funding

The Nikhef partnership has been increasingly successful in acquiring support from external funds (see Table 'Grants 2017-2022' in Appendix C and also the section 'Financial results 2017-2022' in Chapter 2 of this document). Figure 5 above shows the funds that are administered via the NWO institute, which over the course of 2017 – 2022 remained relatively stable. However, an increasing fraction of the total additional funding of the partnership is administered through the university partners (see Fig. 5 and below).

NWO-I (FOM) funding university groups

This funding stream, the remnant of the programme funding of FOM to the university groups, has stopped and replaced by other forms of 'additional funding'.

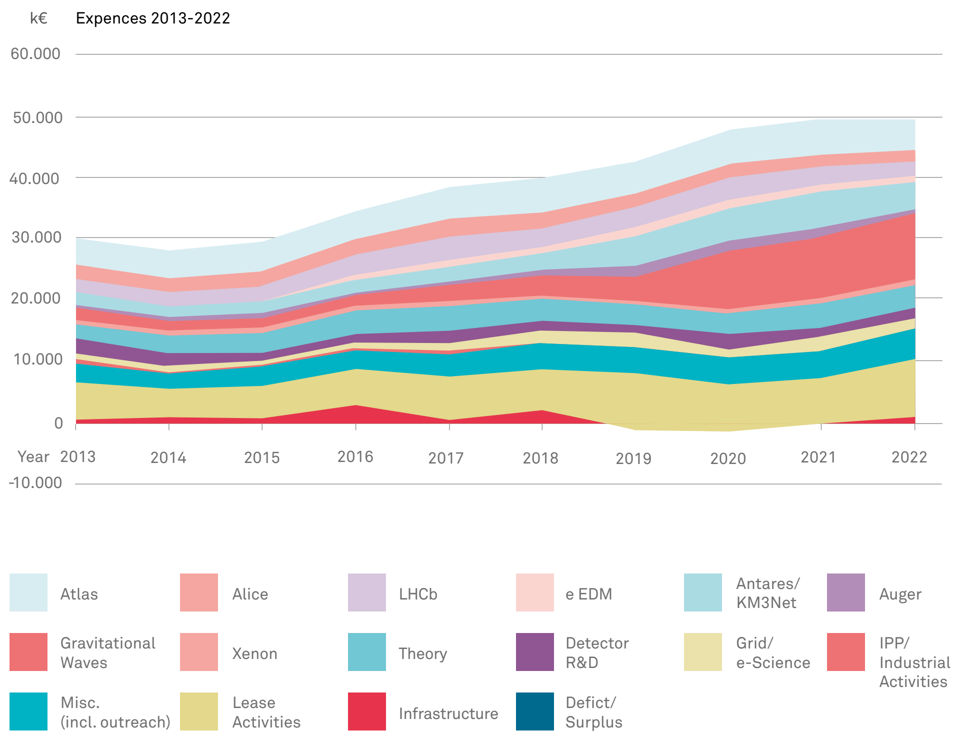
University funding

The strong increase in university funding is due to new partners joining (the University of Groningen in 2016 and of the University of Maastricht in 2019) and because an increasing amount of project funding (additional funding) is administered by the university partners, estimated to be a third of their financial contribution. The universities -more so than the NWO-institute- have also been able to profit from extra governmental funds to strengthen physics research ('sectorplannen'). Many university partners have opted to join the gravitational waves physics activities at Nikhef.

Expenses

Figure 6 shows the distribution of costs over the joint research activities during the evaluation period. Expenses have by and large matched funding, with (slightly positive and negative) exceptions in various years. In this figure, most expenses are directly attributable costs; all other costs (which are by definition not directly attributable) are defined as 'infrastructure' costs. These indirect costs are at a relative stable level of around 20%.

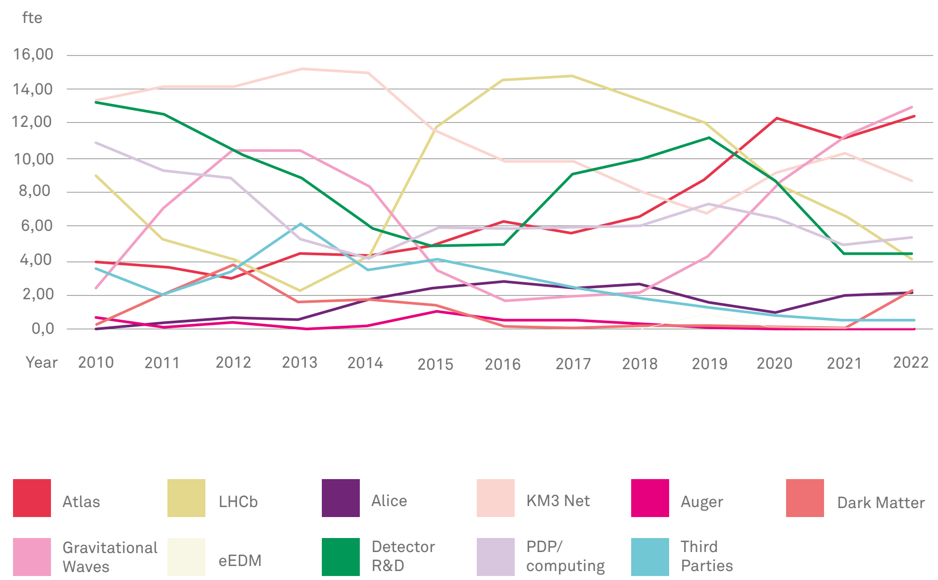
FIGURE 6 **Nikhef expenses 2013-2022.**



In this 10-year period, Nikhef's research programme lines have not changed with the exception of the eEDM activity, which evidently only started in 2016 with Groningen entering the Nikhef partnership. The growth of the Gravitational Waves activity in recent years can be clearly seen, however is a bit exaggerated due to the 2020-2022 investment activities in the ETpathfinder facility at Maastricht University.

The total (financial) expenses in a research line are evidently also heavily influenced by the technical and engineering effort. Figure 7 illustrates the use of technical and engineering effort over the past 13 years in Nikhef's experimental activities. The total effort ranged from 70 to 80 fte, which illustrates the flexibility Nikhef has to exert in planning and realising its instrumentation projects. The figure shows a.o. the enormous effort in the early years (2010 – 2016) for the engineering of the KM3NeT telescope. The

FIGURE 7 **Technical and engineering effort in fte of the Technical Groups at Nikhef.**



first curve for Gravitational Waves represents the effort for Virgo, the second for Advanced Virgo and ETpathfinder. The efforts for ATLAS are steadily increasing due to Nikhef's commitments in the Inner Tracker. The construction activities for LHCb and ALICE had their peak in the period 2015-2019.

Finally, the costs of the data centre are categorised in Fig. 6 under 'Lease activities'. As part of the renovation, the data centre has been expanded. The 9 M€ investment cost for this expansion has been funded from the data centre turnover and will be earned back in about 7 years. For reference: in the years 1997-2022, the total data centre turnover was ~60 M€ and the operating and investment cost 38 M€, leaving a net result of more than 20 M€. More on the data centre finances can be found in Chapter 4 (Financial ambitions 2023 – 2028) in the Strategy 2023-2028.

NARRATIVE - HOSTING A NEW WINDOW ON THE UNIVERSE

By Gieljan de Vries

Gravitational waves are the dynamic expression of the extreme strong gravity, the fourth fundamental force of nature, and have allowed a view into the hearts of dying stars, showing what no ordinary telescope can see. The next observatory in this new field of research might sit under the Dutch border. That's exciting for physicists, but why is local government also interested in the Einstein Telescope?

New research group

The floor-to-ceiling blackboard in the coffee corner is covered in physics. Particle interactions, schematics for gravitational wave detectors: it's all still a bit new, here at the traditionally liberal-arts Maastricht University in the south of the Netherlands. With their new research group, Nikhef and the university want to prepare the border region to host the world's most advanced observatory for gravitational waves. This Einstein Telescope represents a quantum leap forward in the field. But first let's take a step back. Why gravitational waves?

It's been eight years since the LIGO observatories in the United States detected its first gravitational waves in 2015. Ages ago, two black holes collided in deep space, shaking the fabric of the universe. Those waves travelled out at the speed of light, causing tiny expansions and contractions in distances between objects as they pass.

Einstein famously predicted the phenomenon in 1915, but thought it could never be seen experimentally. He wasn't being pessimistic — gravitational waves are smaller than the nucleus of the smallest atoms and take fantastic precision and noise control to detect. Still, spotting the elusive ripples has slowly become routine: the discovery has become a tool.

At the time of writing, astrophysicists have observed the gravitational waves of 90 colliding black holes and neutron stars. In one instance, the shape of the waves even gave enough detection to work out that the collision between two neutron stars had created hundreds Earth masses worth of gold and platinum, shedding light on how heavier elements are formed throughout the universe. If the Einstein Telescope community has its way, that's just the start.

Striking gold

To peer deep into the sky, go underground. Europe wants its Einstein Telescope to go beyond what surface-detectors like LIGO (USA) and Virgo (Italy) can detect, and that means shielding the delicate equipment from surface noise. Three hundred metres below the surface, the facility will be able to reach ten times the sensitivity of its predecessors and detect a thousand times more gravitational waves.

That improved performance doesn't just result in more snapshots of colliding black holes. The Einstein Telescope will be sensitive enough to detect humps on spinning neutron stars and hear the rumblings of the early universe, before light started to shine through. It will also hear softer and lower-frequency signals, letting the Einstein Telescope detect inspiralling black holes a day before they collide. Current detectors can only observe the relatively loud last few seconds before that crash. World-class science, agrees the ESFRI (European Strategy Forum on Research Infrastructures), putting the Einstein Telescope on its roadmap in 2021.

Impression of the underground Einstein Telescope facilities.

Underground prize

The Einstein Telescope will be a true new window on the universe. And a prize for whichever countries get to host the world-class facility. This 'miniature CERN' will likely attract world-class researchers to the host region, and inspire high-tech companies to deliver the necessary technological innovations.

Nikhef realises early on that North-Western Europe has both the knowledge infrastructure and the unique geology required to make the Einstein Telescope a success. Here, the soft top soil will dampen surface noise from human activity to let the underground facility observe undisturbed. In 2018, Nikhef starts mobilising allies in the Netherlands, Belgium and Germany in a network of nineteen knowledge institutes that work together to bring the top facility to their border region.

Science is not the only field interested in the Einstein Telescope. Hans Priem, manager

Science & Technology at the Dutch high-tech VDL Group: "The Einstein Telescope offers us a unique opportunity. Not only does this infrastructure allow us to take a global leadership position in a pioneering field of science, it will also generate orders and collaboration opportunities for companies, which in turn results in spin-off and strengthens the high-tech and knowledge ecosystem in the region. At VDL, we get very excited by the possibilities this offers."
Recognition also comes from regional, then national politics. The province of Dutch Limburg quickly sees the potential of the Einstein Telescope to lift up the border region, increase employment and inspire innovation. This will make the host region more attractive for young talent, local and otherwise. Studies in 2018 show that the Einstein Telescope could generate 500 direct and 1150 indirect full-time jobs. If the region is really suitable as a candidate site, that is. Time to dig deep and find out.

Undiscovered country

Supported by the Einstein Telescope's inclusion on the ESFRI roadmap, Nikhef proposes the facility as a key element of the Dutch National Science Agenda (NWA) and the Dutch investment fund Nationaal Groeifonds to finance the necessary research. Both entries are awarded, allowing the quick growth of a network of a diverse network of research activities. The Netherlands even reserve a sum of 870 million euro for the construction phase of the Einstein Telescope - if the border region is awarded the site by European politicians somewhere after 2025.
At Maastricht University, a diverse project group of geophysicists, spatial planners and experts on international collaboration join the Nikhef physicists to delve into the details of a possible Einstein Telescope. Dutch, Flemish and Walloon colleagues start delving into the many aspects that make up Einstein Telescope. It is in many ways an undiscovered country.
The region may boast a soft top layer that dampens surface noise before it can reach the deeper hard rock where the Einstein Telescope could sit, but what does the deeper underground look like? Any unknown fault lines or underground streams will influence how easy or hard it is to drill the facility's triangle of perfectly straight ten-kilometre tunnels. Initial campaigns are set up in the Netherlands and Belgium, drilling boreholes at Dutch Terziet and Cottesen, and performing seismological experiments to map the subsurface. Meanwhile, above-ground, planning experts investigate what legal frameworks are necessary to ease planning of the cross-border facility.
If all lights show green, that will make it easier to convince the Belgian and German governments to join the Netherlands in a joint bid to host the Einstein Telescope. Already, the three countries have decided to form a

Preparations for the new ETpathfinder at Maastricht University.

joint governmental task force to pool information from their authorities and work together towards a strong, joint bid for the observatory.

Test lab

While a lot of activity goes into determining whether the border region of the three countries is suitable to host the Einstein Telescope, other research is designed to be useful even if another candidate site is awarded the facility. At Maastricht University, the international R&D lab ETpathfinder headed by Nikhef staff member Stefan Hild opens in 2021 to pioneer technologies like cryogenic vibration-dampened mirrors that will end up in the actual gravitational wave detector.
"Here we'll develop technology that doesn't yet exist anywhere in the world", says Hild at the opening of the new lab space. Even before the siting decision, the Einstein Telescope is already inspiring top science at its possible home.

05 EVALUATION OF RESEARCH PROGRAMMES

The Nikhef research portfolio consists of eleven research programmes. In this section we provide per programme a short description of the main research goals during the evaluation period under study and the highlights and achievements from this period.

THEORETICAL PHYSICS

Goals 2017-2022

1. Test the Standard Model with higher and higher precision
2. Confront theory with experimental data
3. Constrain and explore effects of New Physics
4. Perform analyses within the Standard Model Effective Field Theory (SMEFT) framework
5. Develop new theoretical methods and experimental observables
6. Perform studies in astroparticle physics and cosmology.

Results

Major new results were obtained on the following topics:

→ Pushing perturbation theory to new frontiers: five-loop beta function and renormalisation of QCD; hadronic Higgs decay rates and R-ratio at five loops in QCD; progress with QCD splitting functions at N4LO (and beyond); new methodology for IR divergences in QCD and computing renormalisation constants.

→ Next-to-leading order corrections to single top-quark production including SMEFT at ATLAS; leading-log resummation for Higgs production, Drell-Yan and direct photon production; development of Flow-Oriented Perturbation Theory, a coordinate-space dual of Time-Ordered Perturbation Theory.

→ Development of a formalism for calculating electroweak logarithms in inclusive processes; predictions for a range of jet substructure; proposal of a new method to constrain the three-dimensional structure of the proton using recoil-free jets.

→ Evidence for intrinsic charm quarks in the proton; studies of parton distribution functions; precise predictions for neutrino scattering from GeV to EeV energies; investigation of the gluon structure in the nucleon.

→ Global analysis of beyond-the-Standard Model physics with SMEFT; combination of data of high- and low-energy experiments; development of effective field theory frameworks for lepton-number-violating processes with a focus on neutrinoless double beta decay, and frameworks to analyse the physics of sterile neutrinos; phenomenology of axion-like particles at colliders.

- Proposed Bs0 → e+e– as a new probe for New Physics, leading to a first search by LHCb; analyses of puzzling patterns in data for non-leptonic B decays; comprehensive tests of lepton flavour universality in (semi)-leptonic modes of charged and neutral B mesons; constraints of New Physics effects in the mixing of neutral B mesons, with state-of-the-art control of hadronic uncertainties; theoretical frameworks for determinations of CKM matrix elements were developed.
- Various studies of dark matter, showing the importance of non-perturbative effects, in particular the existence and formation of bound states, in dark matter models with long-range interactions.
- Studies of the UV dependence of Higgs inflation; new insights into electroweak baryogenesis, with important consequences for the testability and validity of this scenario for the generation of the matter-antimatter asymmetry of the universe.
- Research on cosmology in the supersymmetric context, quantum field theory in accelerated frames, and on the gravity of light.

Members of the theory group are also actively developing computer codes. The historic key example is FORM for perturbative calculations at highest orders, which was further developed within the corresponding projects. Examples of more recent software tools include a Monte Carlo event generator to evaluate the impact of matter effects in the propagation of high energy neutrinos (NuPropEarth), parton distribution functions of protons and nuclei from global analyses of hard-scattering data (NNPDF), and a toolbox for global interpretations of particle physics data within SMEFT (SMEFiT).

The theory group actively connects with the experimental Nikhef communities, which is reflected by joint projects and papers as well as by the mini-workshop series "Theory Meets Experiment" which serves as a platform for theory/experiment exchange. Specific topics thus far addressed include axions, long-lived particles, high-energetic neutrino scattering processes and interactions of cosmic rays, SMEFT for Higgs and top, and the new measurement of the W mass by the CDF collaboration.

ATLAS

Goals 2017-2022

1. Measure couplings and CP properties of the Higgs particle, study Higgs production in exotic regimes, develop unified interpretation of Higgs measurements
2. Search for beyond-the-Standard-Model (BSM) physics: supersymmetry and lepton flavour violation
3. Study interaction of the top quark
4. Upgrade DAQ system with Felix in LS2, construct and ITk strip-detector end-cap to be ready for installation in LS3

Results

In the domain of **Higgs boson studies**, a rich programme of new detailed studies has been realised using the abundant data produced in LHC Run-2, organised in three focus areas. First, the study of Higgs boson signatures has been expanded into a new programme of precision measurements. There are new detailed characterisation studies of Higgs production and decay, including differential studies and simplified unfolded distributions ('STXS'), with major contributions to new measurements of HZZ, VHbb, HWW, Hττ and ttHbb. Second, the range of experimentally accessible Higgs signatures was expanded with first results on several rare or difficult Higgs processes, notably VHcc, Hμμ, HZγ and HHττbb, where the first two are important to understand the Higgs mechanism as origin of fermion masses, and the fourth crucial for exploring Higgs self-couplings and probing the Higgs potential. New reconstruction techniques were introduced, as were specific new measurements of Higgs production in extreme kinematic regimes (boosted VHbb), which are especially sensitive to effects of new physics. Finally, the development unified Higgs measurement interpretation frameworks has been significantly evolved, from the Run-1 method of only interpreting inclusive cross-sections to new methods that can exploit differential information ('STXS') with subsequent physics interpretations to a theoretically more robust framework (SM Effective Field theory). Notable combined interpretations published include the Higgs self-coupling interpretation of single and double Higgs production, the new combined interpretations of all Run-2 Higgs data (*Nature* paper), and their EFT interpretations.

In the search for direct Beyond-the-Standard-Model physics signatures, new results on searches for *supersymmetry* in a wide range of signatures were performed (0-leptons, 3-leptons and EW-compressed), significantly expanding the sensitivity w.r.t LHC Run-1 results. Furthermore, multiple searches for signs of *Lepton Flavour violation* were published, focusing on decays of Z and Higgs bosons including at least one tau lepton. These searches for specific signatures have been complemented with two broad 'general' searches that look for deviations in a range of final states that is chosen as wide as was practically feasible. Finally, searches for *heavy Higgs partners*, which occur in several BSM theories, were published using the abundant WW and ZZ final states, as well as the Zh final state.

The study of **top-quark interactions** has focused mostly on the polarised production of single top quarks, enabling the precision study of CP-violating properties of top-quark interactions to which this final state is uniquely sensitive. The latest interpretations of these results are now also available in the SM Effective Field Theory framework. A new research line was added in the measurement of four-top production, an extremely rare process with large sensitivity to BSM physics, resulting in a first observation of this process in 2022.

During the Long Shutdown 2 of the LHC (LS2, 2019-2021), several major **upgrades of the ATLAS detector** were installed. The newly developed FELIX system for trigger data acquisition was successfully installed and commissioned for the new Muon New Small Wheel detector and the Liquid Argon Calorimeter trigger. Development of FELIX components for the other detectors, often with higher data rate requirements, is continuing for a complete roll-out in LS3 (2026-2028). An additional responsibility was assumed for the FELIX DAQ system of the High-Granularity Timing Detector, a new detector to be installed in LS3. For the newly installed BIS muon chambers in LS2 a new version of the RASNIK alignment was developed and installed. With the technical design of the Inner Tracker strip end-cap detector finalised in 2017 and the production readiness review of the support structures clearing late 2019, the assembly of the carbon-fibre frames of both end-cap structures was started at Nikhef in 2020. One end-cap structure has currently been completed, and the second is under construction, along with the assembly of cooling manifolds. The complete detector assembly, including all services and sensors, is scheduled for completion in LS3.

\ LHCB

The overall focus of the group is on experimental physics with charged particles, including construction and commissioning of particle tracking detectors, developing algorithms for reconstruction of particle trajectories in the detector, and finally a focus on physics involving B-particle decays to charged particle final states.

Goals 2017-2022

1. Exploit LHCb data acquired during LHC Run-1 (2010-2013) and Run-2 (2015-2018) in terms of physics analysis of CP violation, and measure branching ratios of open charm decays and very rare decays,
2. Produce, install and commission new tracking detectors and a Real-Time Analysis system for the LHCb-Upgrade-1 detector,
3. Perform R&D on detectors and computing for the LHCb-Upgrade2 detector, to be installed in the future high-luminosity runs of the LHC.

Results

1. The exploitation of Run-1 and Run-2 data resulted in measurements on:

- → **Open charm B-decays.** The transition frequency of particles (Bs mesons) into antiparticles (anti-Bs mesons) was measured using decays of the type Bs→Ds, resulting in the world's most precise measurement of 2.828 +/- 0.001 THz. Subsequently, building on the efficiency and resolution results obtained with Bs→Ds decays, the phenomenon of decay time-dependent CP violation was measured in more rare decays of the type Bs→Ds K, leading to a measurement of the CP violation parameter . Moreover, measurements of branching fractions of decays of the type B→D+hadron were performed to measure the value of the CKM parameter Vub as well as to test the concept of factorisation in calculations involving the strong interaction.
- → **Decays of B to Charmonium.** The CP-violating parameter involving effects from Bs-anti Bs oscillations, , is measured with decays of the type Bs→. The work required a combined decay and angular dependent analysis of the particles produced and resulted in the world's best value.
- → **Very rare decays.** The very rare decay mode of Bs mesons, Bs→+- , has been observed and its branching fraction has been measured. In addition, a first measurement of the effective lifetime of this decay, which is very sensitive to effects of physics beyond the standard model, has been performed. In addition, a limit for forbidden Lepton Flavour violation in decays of the type B0→ e (< 1.3 x 10-9) and Bs→ e (< 6.3 x 10-3) were set.

2 The production, installation and commissioning of subsystems of the Upgrade-1 LHCb detectors. These included both hardware and software systems:

- → The production and installation of a thin aluminium vacuum encapsulation of the detector in the form of two detector half-boxes that function as a separation between beam and detector vacuum, as well as electronic isolation from the passing beam (RF-signal guide),
- → The design and production of high-precision Velo Silicon pixel detector modules integrating sensors, electronics and cooling structures into high-precision units,
- → The construction of 5m long Scintillating Fibre (SciFi) modules for the large SciFi tracking detector,
- → The construction and installation of cooling of cold-boxes housing the Si photomultipliers of the Scintillating Fibre detectors as well as their readout electronics, including a system to time-align all the detector elements,
- → The development of the framework for the GPU based High-Level-Trigger-1 (HLT1) and CPU-based multi-threaded High-Level-Trigger-2 (HLT2) systems,
- → The developments and implementation of track finding and track fitting algorithms used in the Real-Time Analysis system exploited in HLT1 and HLT2.

3 The R&D research for the future LHCb Upgrade-2 detector, which will operate in the high-luminosity mode of the LHC with a factor 10 increased particle densities. The Dutch contribution will focus on the concept of space-time (“4-dim”) tracking, which requires the development of new state-of-the-art fast timing sensors with a temporal resolution of better then ~50 fs and high irradiation resistance, as well as the development of novel reconstruction algorithms exploiting a heterogeneous computing model. Results so far include:

- → Development of a beam telescope and read-out for TimePix4 detectors,
- → Temporal and spatial resolution tests of TimePix4 based detector elements using a laser set-up as well as particle beam tests.
- → “Blue sky R&D” on quantum computing algorithms for trackfinding and b-jet tagging use during the LHC run-6.

RF box incident

In January 2023, an overpressure incident occurred with the vacuum system of the LHCb vertex detector (Velo). As a result of the incident the so-called Velo RF boxes, which separate the detector volume from the beam vacuum, were seriously deformed such that the particle sensors can no longer be positioned in the optimal position for physics data taking.

The 250 micron thick, 1 metre long aluminium boxes were designed and produced at Nikhef. In the LHC winter shutdown of 2023-2024, the damaged boxes will be replaced by a team of engineers from Nikhef, CERN and the University of Liverpool. In the meantime, Nikhef technicians have started the production of the new boxes.

\ ALICE

The Nikhef ALICE group aims to understand the properties of quantum chromodynamics (QCD) and its emergent structures of matter (or phases). For this we participate in the ALICE experiment at CERN which is optimised for the study of high-density strongly interacting phase of matter, also known as the quark-gluon plasma. Nikhef has been an ALICE member institute since 1994.

Goals 2017-2022

1 Determine the properties of the quark-gluon plasma

2 Install the upgrade of the inner-tracking system (ITS2) at CERN, commission it and take first data

3 Perform R&D for 4D tracking technology for ITS3 and ALICE3

Results

This field of research has matured in the period 2017-2022, with many new discoveries. For some subtopics, the field is now entering the domain of precision measurements, while, at the same time, there are many open questions which are just starting to be investigated in detail. To name just two examples where Nikhef members have significantly contributed: the observable of anisotropic flow has been developed into a precision tool, following the important discovery of the very low shear viscosity in the matter produced in heavy-ion collisions, while later, the observation of similar anisotropies in small systems has prompted lively discussions about the possibility of equilibration in these systems, and the interpretation of this is still not settled; after the original observation of parton energy loss as a probe of the colour charge density, many detailed measurements have been performed, most notably about the energy loss of charm quarks, but the studies of e.g. jet substructure and the energy loss of beauty quarks has only recently been started on a serious level.

The Nikhef ALICE group has (had) many important positions in this international collaboration, in fact significantly more than expected from the sheer number of collaborating scientists. Leading roles taken by members of the group in the review period are Physics Working Group (PWG) convenors of 4 of the 8 existing PWGs, Upgrade coordinator, Physics coordinator, Editorial Board members and Conference Committee members. PWG convenors oversee and coordinate all the physics analysis performed within the collaboration; that members of our group have played these roles in four PWGs is proof and peer acknowledgment of the significant breadth of our scientific expertise. The other positions demonstrate scientific leadership on a higher level in the collaboration structure.

The group is very strong in scientific output as corroborated by the number of publications and the citation level. The bulk of the scientific publications is naturally generated as ALICE publications. Among these many publications, the group has played very significant roles (as members of the paper committees and PWG convenors) in several topics simultaneously. In particular, jet production and substructure, direct photon production, the study of correlations and fluctuations, related to anisotropic collective flow and to the so-called chiral magnetic effect (CME), and the production and suppression of heavy flavour (charm and beauty) hadrons, both for inclusive and jet-related production.

The ALICE collaboration has embraced Open Science, and as such all the publications of the group in the context of ALICE are open-access. ALICE is also committed to making the experimental data accessible to the public. In addition to ALICE publications, which have long author lists, several members of the group work on phenomenological research, such as the interpretation of anisotropic flow measurements or on new methods for jet studies in heavy-ion collisions, resulting in several few-author papers.

Besides the research activities in data analysis and phenomenology, we provide a strong contribution to the ALICE detector in instrumentation. Since the first installations of ALICE, Nikhef has played a significant role in the silicon-based tracking detectors. In the review period, the main activities have been the contribution to the outer layers of the newly installed ALICE silicon tracker (ITS2), based on Monolithic Active Pixel Sensor (MAPS) technology, and the preparation for the future upgrade of the ALICE vertex tracker (ITS3).

Nikhef focused for ITS2 on sensor design and tracker modules (stave) assembly at the Silicon Alley. After the termination of the production phase in 2020, the groups have been largely involved in on-site detector qualification and calibration at CERN both in the surface experimental area and in the ALICE experimental cavern underground. In addition, in the last two years, the group has joined with a significant contribution to the research and development studies for the realisation of the ITS3. The group is involved in sensor design with the realisation, among others, of a 10.28 Gb/s serializer, in mechanics studies, test beams and sensor qualification.

\ ELECTRON-EDM

Goals 2017-2022

1. Design, build and commission a cryogenic buffer gas source for molecules. Demonstrate an intense and slow (200 m/s) beam of BaF molecules.
2. Demonstrate Stark deceleration of heavy molecules (atomic mass > 100 amu) down to 30 m/s.
3. Set up the laser system for BaF laser spectroscopy, and use this to perform state preparation and transverse laser cooling.
4. Design, construct and commission a magnetically shielded interaction zone suitable to measure the electron's electric dipole moment (eEDM) with a sensitivity of 10-30 e.cm.
5. Perform theory in direct connection with these experiments, both on the impact of eEDM measurements in relation to high-energy particle physics experiments, and on the molecular structure of eEDM-sensitive molecules.

Results

1) We now have two cryogenic sources operational. One cryogenic source is operated in our lab at the Vrije University Amsterdam. This is the development source, which we use to investigate and optimise molecular beam production, specifically of BaF molecules. The second source is operated in our main labs at the Van Swinderen Institute of the University of Groningen. This is our day-to-day operational source, connected to the Stark decelerator to produce even slower molecular beams. Both sources deliver their design flux.

2) We have demonstrated the deceleration to standstill of SrF molecules, the heaviest molecule to be decelerated (107 amu) to date. This was a key result for us, as it demonstrated the viability of our approach to combine the cryogenic source with a travelling-wave Stark decelerator to create slow molecular beams, and even demonstrate trapping. This work was published in *Physical Review Letters* in 2021. Currently we are working to extend this result to BaF molecules, for which an upgrade of the decelerator electronics is required.

3) We have completed the commissioning of a versatile laser system, including frequency stabilisation, that allows us to probe and manipulate BaF molecules. It covers the electronic, vibrational, rotational and hyperfine structure of the molecule, and we have demonstrated this on a supersonic beam of BaF molecules by measuring the lifetime of the electronically excited state. Furthermore, it allows us to perform coherent manipulation of the eEDM state, which was crucial to obtain the results related to the interaction zone. The first laser cooling results have recently been obtained.

4) The magnetically shielded interaction zone is complete, and we have recently demonstrated its working by performing Ramsey two-pulse interference measurements on a fast (600 m/s) beam of BaF molecules. We have implemented a novel scheme to perform eEDM-sensitive measurements while simultaneously accumulating data to monitor systematic effects. A publication of this work is currently under review. The first eEDM measurement datasets are being taken with the completed setup in the summer of 2023.

5) We have performed calculations that confirm with high precision the sensitivity of the BaF molecule to CP-violating physics. In addition, we have benchmarked the theoretical methods against directly measured molecular properties. We have also investigated transition rates and branching fractions for optimal laser cooling of BaF molecules, and investigated novel interesting species, such as BaOH, for future improved eEDM measurements.

\ NEUTRINO PHYSICS

Goals 2017-2022

ANTARES/KM3NeT (ANTARES dismantled in spring 2022):

1 Complete the KM3NeT - 2.0 detector
2 Measure the neutrino mass ordering and neutrino oscillation parameters
3 Detect PeV neutrinos and search for point sources

DUNE

Physics ambitions are the study of long-baseline neutrino oscillations and the measurement of CP-violation in neutrinos, and studies of beyond-the-standard-model physics in neutrino interactions:

4 Contribute to ProtoDUNE DAQ
5 Developments for data analysis (reconstruction and particle identification)
6 Contribute to computing resources

Results

ANTARES/KM3NeT

1) Nikhef plays a major role in various areas of the KM3NeT construction. The electronics (base) for the PMT operation including a custom ASIC was developed at Nikhef. Several mechanical parts (PMT support structure: 3D print and injection moulding) were designed at Nikhef. It is the largest KM3NeT DOM (Digital Optical Module) integration site with so far 470 DOMs (=26 strings) produced. At the same time, it serves as a string integration site. The still ongoing mass production including associated logistics and quality management has been newly set up in the Pimu hall with the capacity to continuously build 10 DOMs/week.
Delays arose due to funding in national batches with respective national tender procedures, component shortage and the impact of Covid restrictions. So far, 10% of the phase 2 strings have been deployed, funding for 50% of the 2.0 detector has been secured and construction is ongoing. Data are taken continuously and routinely processed and analysed, including corresponding simulations. PMT, time and position calibration procedures were developed at Nikhef allowing also for a time-dependent orientation and position reconstruction. The measurement of the Sun/Moon cosmic ray shadow by now demonstrated the excellent performance of the detector, calibrations and event reconstructions.

2) With 12 months of data and 6 (of 115 planned) strings in KM3NeT/ORCA the first oscillation parameter measurement could be accomplished (PhD thesis at Nikhef) with uncertainties not too far from other ongoing experiments, further refinements with the full data set (more years, strings) are underway. First competitive limits on Beyond-the-Standard-Model (BSM) scenarios were set from first data.

3) Point source searches with the full 16-year data set of the ANTARES detector (disconnected February 2022) are being finalised, already showing first indications of galactic emission and potential cosmic neutrino source candidates to be further explored with KM3NeT. The KM3NeT framework for point source searches has been developed at Nikhef. Substantial improvements in the event reconstruction and analysis for KM3NeT from Nikhef allowed to improve the expected point source search sensitivity for KM3NeT by 30%. KM3NeT is already active in public follow-ups of high-energy neutrino alerts and other public alerts, contributing also to Supernova triggers within SNEWS.

DUNE

The initial contribution of Nikhef to DUNE was to ProtoDUNE (Single Phase), a prototype liquid argon TPC, similar to but smaller than the designed DUNE first far detector modules. ProtoDUNE took beam data at CERN in 2018, and cosmics data in 2019.

4) In collaboration with CERN and BNL, readout of a part of ProtoDUNE was achieved with a modified FELIX system, as designed for ATLAS at the LHC.

5) Nikhef also participated in operating ProtoDUNE and analysis of the data, with emphasis on neutral pion reconstruction and electron-pion separation. Further deepening studies of electron- and photon shower reconstruction is ongoing.

6) Nikhef is also part of the DUNE computing consortium and has committed on best-effort basis to some 10% of DUNE grid computing.

Other

We contribute to studies of the detection of UV liquid argon scintillation light, wavelength shifters and light reflection/fluorescence from detector materials in cooperation with the dark matter group.

\ DARK MATTER

Goals 2017 – 2022

1 Search for dark matter signals in the science runs of XENON1T
2 Upgrade XENON1T to XENONnT and start the science run
3 Investigate the use of XENONnT for the search for neutrinoless double beta decay
4 Prepare for the ultimate direct-detection dark matter experiment DARWIN

Results

1) The XENON1T experiment used 3.5 tons of liquid xenon (LXe) to detect low-energy interactions expected from dark matter particles or other rare processes. The experiment operated between 2016 and 2019 in the underground LNGS laboratory in Italy. The Nikhef group was responsible for designing the cryostat vessels, designing and building the detector support and levelling structure and the data acquisition system. Computing resources were provided through SURF and Nikhef's PDP group. The experiment generated about 25 publications and many thousands of citations, with world-leading results on dark matter and other rare event searches.

2) XENONnT is an upgrade of the XENON1T experiment, with 8.5 tons of LXe, more PMTs and lower overall radioactive backgrounds. Most of the XENON1T infrastructure was reused, but also included several new subsystems like the novel LXe purification and radon distillation systems. The Nikhef group redesigned the DAQ for 'triggerless' operation, upgraded the detector support and levelling system and initiated the development of a new analysis reconstruction framework. One of the Nikhef members was the Technical Coordinator of the experiment. The XENONnT detector was completed just before the Covid lockdowns started in 2020, slowing down the commissioning. Nevertheless, the collaboration managed to commission the detector over the subsequent year and start a first 100-day science run in July 2021. Nikhef played a key role in the analysis of the first low-energy electronic recoil signal and the first WIMP data results from XENONnT.

3) About 8.9% of natural xenon is the double-beta-decaying Xe-136 isotope. This allows the search for neutrinoless double beta decay (0n2b), a lepton-number-violating process that would prove that the neutrino is

Majorana. Nikhef participated in several studies to investigate this signal in XENON. These demonstrate that as LXe dark matter experiments become more sizable, they will become competitive experiments to search for 0n2b.

4) The Nikhef group plans to participate in the future 60-ton liquid xenon DARWIN experiment. The group participated in a white-paper study demonstrating that the ultra-low background and high sensitivity of such an experiment would allow for a general rare-event observatory, covering science from dark matter to neutrinos and other rare signals. A major development is that the still currently competing US-based LZ experiment joined DARWIN and XENON to form the XLZD consortium. DARWIN/ XLZD is now used on a variety of national Roadmaps, such as the Dutch, German and Swiss Roadmaps, and in the US SNOWMASS/P5 process. The experiment will have world-leading sensitivities in the search for dark matter particles and the neutrinoless double-beta decay process.

\ COSMIC RAYS

Goals 2017-2022

1 Harvest Physics from the Auger Engineering Radio Array (AERA)
2 Better understand the particle content of air showers
3 Create AugerPrime SSD units (135) and mounting frames (1300+400)
4 Develop next-generation multi-messenger detector (GRAND)

Results

1,2) Auger published 47 full author-list papers between 2017 and 2022. The Dutch groups were the main driving force behind the papers on the detection of cosmic rays through the induced radio-signal. We contributed to the understanding of the signals in the water-Cherenkov detectors that led to a paper on composition of cosmic rays using only this surface detector. We also investigated the difference in signals for electrons and muons in the water-Cherenkov detector and the new scintillation detector. This study improves the separation of the different elements in the cosmic ray beam using AugerPrime. We advocated opening Auger data to the public, and now 10% of the data is freely available. This dataset can be used for outreach and analyses purposes and was used at the topical lecture on cosmic rays. Note that this open data contains more events than the second largest cosmic-ray experiment has produced so far.

3) Nikhef is the largest partner in the upgrade of the Auger observatory. We have been involved in the final design of the scintillator detector (SSD) that is added to the Auger water-Cherenkov tanks, as well as the design of the mounting brackets that hold these units as well as the radio antennas. The radio detector is a complete Dutch design and 1700 detectors have been created. Nikhef also produced 180 SSDs and 1300 mounting frames. These have (almost) all been installed in Argentina. A description of the detectors has been published by the collaboration. First results, obtained with a fraction of the detector upgraded already indicate the richness of the signal with signals of the water-Cherenkov tanks, the SSD, the radio detectors as well as the Argentine built underground muon detector that covers a small part of the array.

4) The next-generation air shower detector is designed as a multi-messenger detector and will have the sensitivity to measure charged cosmic rays, EeV neutrinos and photons. It will probe fundamental physics beyond the reach of current accelerators and use neutral messengers to help pinpoint the most violent astronomical objects. Nikhef has designed, and is responsible for, the complete DAQ. This includes electronics and software. In addition, the mechanical design of a single detector unit is Dutch. Covid, as well as international relations, have put a strain on the collaboration with Chinese institutes and the deployment in China. The risk is mitigated by the decision to develop two sites simultaneous, one in the southern hemisphere (Argentina). For the Argentine site, an MoU has been signed between the GRAND collaboration and the Auger collaboration. First antennas have been deployed both in China and Argentina. The latter allowing to cross calibrate with a known particle detector. All data from both sites are available in the Lyon data centre.

Despite (sometimes) difficult times we have achieved and surpassed all goals set out in 2017. Going beyond the original goals was possible due to the ERC-Advanced and NWO-XL grants that the Dutch groups were able to obtain. The nearly fully installed radio upgrade of Auger will lead to a better understanding of cosmic ray physics that will help shape the next generation of detectors, the design of which we are driving.

\ GRAVITATIONAL WAVES

Goals 2017-2022

1 Commission Advanced Virgo, run jointly with LIGO, and participate in the mid-term upgrade
2 Study gravitational waves from binary black-hole mergers and test black hole physics
3 Discover gravitational waves from neutron star coalescences and measure the neutron star equation of state
4 Investigate the possibility of hosting the Einstein Telescope in the Netherlands

Results

1,2,3) *Results Advanced Virgo*

→ Significant hardware contribution to Advanced Virgo+ upgrade focused on frequency-dependent squeezed light. This was designed, constructed, installed and is now operational.

→ The binary neutron star signal GW170817
- Various predictions for the neutron star equation of state were eliminated by the joint observation of gravitational waves and the electromagnetic afterglow of the merger. This afterglow was found thanks to the presence of Virgo in the detector network.
- In terms of fundamental physics, having a three-detector network enabled precision tests of the polarisation content of the signal, allowing us to put bounds on non-tensorial polarisations predicted by alternative theories of gravity. The associated gamma ray burst allowed us to demonstrate that the speed of light equals the speed of gravity down to one part in 10^{15}.

→ Observation Run 3 catalogs
- We actively participated in the detection effort.
- We played a seminal role in testing general relativity with binary black holes by studying the inspiral-merger-ringdown dynamics and the propagation of gravitational waves over large distances, and by probing the black hole nature of the remnant objects.
- We played a leading role in the search for gravitational lensing of gravitational waves.

→ Sub-solar mass black holes
- We put stringent upper bounds on the prevalence of sub-solar mass black holes, which, if they exist, would have to be of primordial origin.

→ Intermediate-mass black holes
- We helped detect GW190521, a binary black hole with 85 and 66 solar masses merging into a 142 solar mass object, which lies in the intermediate-mass black hole range. This was an indicator of hierarchical growth of black holes, as the progenitors must themselves have been the result of an earlier merger.

1,2,3) *Advanced Virgo's delayed start of Observation Run 4:*

While all Nikhef's hardware contributions to the Advanced Virgo+ upgrade (Phase 1) have been installed and commissioned successfully, it emerged in late 2021 and throughout 2022 that the commissioning of the new interferometer configuration with "Resonant Sideband Extraction (RSE)" has been more challenging to operate than expected. This led to significant delays in obtaining stable operation of the detector, leaving very little time for noise hunting, and together with the discovery of defects in two of the main mirrors in early 2023 this led to the decision for Virgo to delay the entry into the Observation Run 4 to the second half of 2023.

One of the expected key reasons for the difficulty to operate Virgo with RSE was traced down to the choice for marginally stable recycling cavities (adopted in 2011 at the approval stage of the initial Advanced Virgo project). Efforts are underway (with significant effort and leadership of Nikhef team members) to establish the feasibility of changing Virgo's recycling cavities from the current design to a more robust solution (so-called 'stable recycling cavities') for Observation Run 5.

4) *Results Einstein Telescope*

→ We co-led together with INFN in Italy the submission of a proposal to add ET to the ESFRI roadmap. Nikhef took a leading role in shaping the proposal, which set the framework for major changes in the organisation of ET during the preparation phase, see below. Our proposal was successful, and ET was included in the ESFRI roadmap in 2021.

→ We remain a strong partner in the ET Collaboration, which for many years has been growing organically and was formalised in 2022.

→ The ESFRI status allowed us to bid for support the Infra-dev call from the Horizon programme of the EU. The successful bid for the 'ET-PP' project was led by IFAE in Spain. The total value of the grant is 12 M€ and Nikhef participates with 3 M€. We are involved in the whole programme and are leading the work packages that we found essential at this stage: WP2 on ET Organisation, Governance and Legal Aspects, and WP4 on Site Preparation.

- Nikhef and INFN have together initiated a new organisation to structure and manage the realisation of ET as the project: the ET Organisation (ETO). This organisation has gained traction very quickly. We have successfully set up an active Board of Governmental Representatives with delegates from ministries in involved countries and the equivalent Board of Scientific Representatives.
- We successfully secured funding from the National Growth Fund, including 42 M€ for the preparation of a bid to host ET in the EMR region near Maastricht and 870 M€ reserved for construction cost in case ET is indeed hosted (in part) in the Netherlands. The project itself involved several partners, two ministries, the region Limburg, Nikhef and LIOF. We are further expanding to the wider EMR context: a cross-border task force between government representatives from Germany, Belgium and the Netherlands has been setup. A partnership with local institutes and institutions in all three countries has been established and formalised with MOUs. These activities have as a focal point the new project office which was established in Maastricht under the guidance from Nikhef.
- ETpathfinder is a unique R&D facility providing a low-noise test-bed for ET related key technologies and interferometer concepts (such as cryogenic silicon mirrors etc). Construction started at the beginning of 2020 and the facility was officially opened by the outgoing Dutch science minister in November 2021. Her successor visited ETpathfinder in May 2022. To date, the ETpathfinder collaboration has grown to more than 20 research institutions from seven countries.

DETECTOR R&D

Goals 2017-2022

1. Develop smart & fast pixels. The DR&D group, the three Nikhef LHC experiments and the Electronics department have focused on fast sensors for 4D tracking in LHC detector upgrades. Next to the ongoing research on fast hybrid detectors, we started working on monolithic active pixel sensors (MAPS). The ultimate goal is to reach order ten picosecond timing (rms) in pixel chips.
2. Develop instrumentation for GW interferometers. This involves various sensor developments for gravitational wave research together with the Nikhef gravitational waves group.

Results

1) *Results for smart & fast pixels:*

- The Timepix4 chip arrived in 2019, and the first version of the chip worked almost right away! The remaining issues have been resolved in the improved "Timepix4v2" chip, which can be considered the final version of this readout chip. This new pixel chip with 80 picosecond time resolution (rms) makes faster timing possible in tracking detectors and enables high-rate X-ray imaging.
- The SPIDR4 readout system has been developed, which can readout the Timepix4 up to 160 Gb/s. This system played a crucial role in testing Timepix4.
- We performed sub-nanosecond timing and efficiency measurements with two monolithic technologies, where sensor and readout electronics are (integrated) in the same silicon wafer. The goal of this promising technology is to provide excellent spatial and time resolution while using less material and power.
- We performed the first gain measurement of trench-isolated Low-Gain Avalanche Detectors (LGADs). The LGADs can reach a tens of picoseconds time resolution when sufficient gain is achieved within the sensor layer.

2) *Results for instrumentation for GW interferometers:*

- We produced and performed a detailed characterisation of quadrant photodiodes for the Laser Interferometer Space Antenna (LISA), a detector in space to accurately measure gravitational waves. These custom InGaAs quadrant photodiodes are selected as baseline sensors for the LISA experiment.
- We developed a phase camera for Advanced Virgo, where an increased input power causes thermal expansion of the mirrors. This camera senses the wavefront that serves as input to correct the thermal effects.
- We built various quadrant photodiode systems for the angular alignment and frequency-dependent squeezer of Advanced Virgo.
- A next-generation miniaturised accelerometer, a sensor measuring acceleration, is under development, aiming at a challenging 1 ng sensitivity. This patented sensor is fabricated in micro-electro-mechanical systems (MEMS) technology and currently integrated with a custom readout chip.

Infrastructure upgrades:

- We realised an optical lab for photodetector research and interferometric techniques in a new cleanroom in Silicon Alley.
- We opened the FlexRay lab with CWI; X-ray detector research for industrial and medical applications
- We installed and commissioned the two-photon absorption (TPA) setup, allowing us to study the charge-collection properties of semiconductor sensors in great detail by liberating charge in a voxel instead of along a line.
- We upgraded our X-ray setup to perform colour microcomputed tomography (CT) scans to improve image resolution and material decomposition.
- We recorded and reconstructed the first tracks with the Nikhef Timepix4 beam-telescope at the CERN SPS beamline. The detector layers in the beam telescope are read out with Nikhef's SPIDR4 readout system.

Other achievements:

- We achieved secondary electron yield of 5.5 (MEMBrane), and stacked nano-membranes for a new type of photon detector.
- We developed a muon tomography system in collaboration with the TU Delft Faculty of Aerospace Engineering for asteroid muography (using muons to characterise the interior of near-earth asteroids via a detector on board a small satellite).
- We performed the first measurement of frequency-dependent squeezing below 100 Hz in the Japanese TAMA prototype, a former GW detector currently used to develop new technologies.
- We developed the QUAD detector: a gaseous pixel detector for the ILC time projection chamber. The first Gridpix is quad functional. We characterised a Gridpix Quad module for a future linear collider TPC.
- We developed and realised many parts of the frequency-dependent squeezer for Advanced Virgo, together with the Nikhef Gravitational Wave group.
- We performed a CERN test beam with fast sensors on Timepix3.
- X-ray images of small defects in steel sheets were made for Tata Steel, to help them verify their quality control equipment.
- We closely collaborated with our two spin-off companies on x-ray, ion and electron detectors and readout with ASI, and on the development of the MEMS accelerometer with Innoseis.

DR&D successes are based on long-term commitments from Nikhef to invest in instrumentation research, hardware expertise and enabling technologies.

\ PHYSICS DATA PROCESSING

Goals 2017-2022

1. Contribute to *Research Infrastructures* used by local users, collaborations and a diverse group of 'national users' of high-throughput computing;
2. Contribute to *Advanced Computing Technologies*, driving the innovation and R&D for the next generation research infrastructure systems and networks;
3. Contribute to *Applied Advanced Computing* to extend the 'physics reach' through new algorithms, systems and software infrastructure, and their validation in real-life environments; and
4. Contribute to *Scalable Multi-Domain Security* architectures and policies for global collaborative research.

Results

The data processing capacity we provide to our global collaborations and local users alike, has increased by about 60% over the 2017-2022 period, and on-line storage capacity by about 250%, reflecting the increased emphasis on 'high-throughput' processing by our experiments. Since budgets do not increase, we prioritised R&D for improved computational efficiency but also new methods for cost-effective procurement. We exploit the synergies that exist between these, since our advanced computing technologies R&D provides not only better systems co-design for our own users, but is also valuable to engineering teams of vendors. By engaging with vendors in their product engineering stage, we benefit from early access to next-generation systems, can encourage the development of systems (also) suitable for our use cases, and create favourable market conditions for acquisition. A consistent multi-vendor open collaboration approach ensures we engage with the then-most-innovative suppliers, and prevent single-vendor lock-in. By joining efforts with SURF and the national HPC procurements, we also take advantage of competitive larger-scale procurements than would be possible for Nikhef alone. Thus, we were the first site in Europe to deploy data throughput-focussed processor designs by AMD in 2019, we for example co-designed network and systems equipment with vendors and integrators.

To drive continuation of the infrastructure, we joined forces with the Square Kilometre Array (SKA) and the radio-astronomy institute ASTRON in a joint Fundamental Sciences E-infrastructure (FuSE, 27 M€ over 5 years, of which 12 M€ is 'new' and 10.5 M€ 'BiG Grid' GWI continuation funding). An integral part of the Dutch National e-Infrastructure coordinated by SURF (the national research and education ICT cooperative), FuSE supports Roadmap infrastructures of both Nikhef and ASTRON: the LHC, KM3NeT and SKA. It combines hardware provisioning and software development to increase the effectiveness of the infrastructure and to reduce the amount of hardware required for processing in the future, especially towards KM3NeT and the SKA. As part of this DNI, our computing infrastructure also supports a range of scientific and societal applications beyond (astro)particle physics, including WeNMR (protein docking in structural biochemistry), MinE (the genetic basis of Amyotrophic Lateral Sclerosis (ALS)) and seismic studies.

Significant improvements were obtained through ubiquitous deployment of GPU accelerators for on-line event-filter data processing. Here we specifically targeted LHCb, where - using the Allen framework - the HLT1 now is a completely software-based trigger, and we are working on the next step of improving the parallel inference with ONNX and Tensor machine learning libraries. The PDP group in this *Applied Advanced Computing* area has been strengthened with a permanent staff member, and in addition with a dedicated post-doc (2022-2025) through a collaboration with the Netherlands eScience Center (NLeSC). Also, the FASTER project (2022), an institute-wide investment in high-resolution timing and data processing, addresses both mid-term GPU-based acceleration and includes longer-term research on quantum computing algorithms and their application to particle tracking – where it strengthens the joint Nikhef-QuSoft-UvA-CWI-SURF collaboration started in 2020 on future quantum computing algorithms for (amongst others) LHCb and gravitational waves analysis.

The collaborative trust and identity activities were intentionally diversified, building on our contributions to the AARC project, and now also encompass the GEANT Project "Enabling Communities" activity and cybersecurity for both eduGAIN and the European Open Science Cloud. This reduced dependencies on a limited number of funding sources, and at the same time strengthened the link between federated identity and access management ("FIM") and our physics research programmes that are increasingly moving to FIM and 'token-based' access. Building on our site-access-control expertise, we designed and implemented key bridging technologies that enable the transition (such as RCauth.eu, the GEANT Trusted Certificate Service 'eScience' profiles, and the identity assurance work between IGTF and REFEDS).

The PDP group also coordinates, in collaboration with the computer technology group and the OSAF Research School, the Nikhef Computing Course. The course programme has been revised in 2022 to strengthen the intended learning outcomes on efficient large-scale computing, accelerators and GPUs, containerisation of workflows, research data management, reproducibility, research integrity, information security and identity management, and knowledge safety. Combining lectures with hands-on exercises, the teaching and learning activities show an effect beyond the immediate audience of PhD candidates and postdocs, since the attendees disseminate their new knowledge within their respective groups.

NARRATIVE - NIKHEF WORKSHOPS: OUR TREASURE

By Martijn van Calmthout

Zooming in on the large international experiments in high-energy physics, one will find the characteristic red Nikhef logo on many parts and subsystems. Electronics parts, mechanical constructions and ICT systems are prominent features of the institute, developed and often built by skilled in-house engineers and technicians.
In total over 75 technical staff mainly based in Amsterdam provide a prominent international visibility of Dutch subatomic physics research. The team travel the world to discuss plans of collaborations or install and test parts on-site.

Mechanical Technology (MT)
Most prominent are the large mechanical workshops in the institute building at Amsterdam Science Park, recently renovated and extended. In several halls, large milling machines are lined up, some computer-guided for ultimate precision and speed, others fit for specialist craftmanship. A large cleanroom, also upgraded, houses construction work on large parts for detector experiments to be installed on-site later. In the modern glass walled engineering department staff is working on large workstations, featuring computer models of new or existing constructions.
In all, about 25 engineers and technicians make up the MT department, moving from project to project in the large Nikhef research programme. This professional and dedicated workforce, says the new group leader, engineer Freek Sanders, is the main asset a national institute like Nikhef can offer in international projects. “Most university partners in the world mainly use PhD candidates or scientific staff to design and produce systems or components. This is not just a quality control issue. Also, stepping up or ad-hoc troubleshooting is hard to do. At Nikhef, that all comes quite naturally. And internationally, people know this.”
Sanders: “Actually, we are currently investing in a more prominent role as lead engineers internationally. In that way you get to pick the more interesting parts of a job early on. Making a mark.”
A recent example of Nikhef flexibility is the project to produce two so-called RF Boxes, roughly 0.5 mm metal vacuum screening foils located deep inside the upgraded LHCb detector at CERN. These are meant to replace, as soon as possible, recently damaged boxes also designed and built by Nikhef. Speed is necessary, but quality is crucial. It will take months to mill to specs from solid aluminium blocks.
Like in LHCb, Nikhef mechanical engineering is at the heart of many prominent particle physics experiments in the world. In recent years, a large super-lightweight sturdy carbon fibre carrier was designed and constructed for

Details of the aluminum VELO foil, precision milled at Nikhef.

ITk, the first half of the future Inner Tracker near the particle collisions in the ATLAS detector. A second half will be built next and also fully fitted with sensors and cooling infrastructure.
Nikhef engineers are also deeply involved in the designs of both the ETpathfinder facility at Maastricht University, and the proposed Einstein Telescope. In a brand-new Maastricht cleanroom, crews have already constructed the towering Pathfinder hardware in the past year. And finally, Nikhef mirror suspensions with mechanical damping are crucial to nearly all gravitational wave experiments in Europe.

Electronics Technology (ET)
In Amsterdam, a large production line is routinely constructing and testing sensor domes for the KM3NeT neutrino telescope in the deep Mediterranean Sea. Similarly, in earlier years, Nikhef technicians in Amsterdam have built unique parts for the recent upgrade of the ALICE detector and of LHCb, working closely together with scientists from the experiments.
Scientific engineering, says group leader Ruud Kluit of the Electronics Technology section at Nikhef, “is about building parts that do not

exist yet." His group of some 25 electronics engineers and designers is creating and testing the electronics needed in many ground-breaking physics experiments, from analog to fully programmable digital. Chip programming is an increasingly important inhouse skill. At the same time, hardware issues are often studied together with the Detector R&D group at Nikhef.

Often the designs have to be extra radiation hard, durable, extra sensitive, extra fast or broad-banded to accommodate scientific requirements. This can be accomplished in application-specific integrated circuits, ASICs for short.

Again, the work by the Nikhef team is not going unnoticed. For example, the FELIX readout hardware developed at Nikhef is finding its way into prominent experiments like ATLAS at CERN and elsewhere. Another special expertise had been developed with the White Rabbit timing system, based on LAN protocols, that can robustly synchronise elements hundreds of kilometres apart within picoseconds. At CERN, but also in other experiments like the KM3Net neutrino telescope in the Mediterranean, and even the LOFAR distributed radio telescope network. Testing is done on a desktop, with optic fibres thousands of miles long wound on compact coils.

Nikhef ET, says Kluit, is a real playground for ambitious electronical engineers. "In industry, things are far more straightforward, but also far less interesting to some." He can often spot the right mentality quite early in the interns the group welcomes.

Computer Technology (CT)

The same mentality permeates the nearly 30 computer engineers of the Computer Technology (CT) department and its Physics Data Processing (PDP) group at Nikhef. PDP programme leader David Groep: "For many of our experts, computer science and technology is a life style, not just a nine-to-five job."

The CT department provides Nikhef with optimal hard- and software. The department is fully engaged in the R&D on computing and data handling for Nikhef scientists and experiments. That starts with embedded systems, data acquisition, readout and control very close to the detectors, and then 'going all the way up the stack', with a prominent role in reliable trust and identity protocols, safe data storage and handling.

It also means designing systems that allow the science algorithms to exploit all hardware capabilities, reducing time to results and efficient computing to lower energy use. The data centre activities then boost international networking: Nikhef is a so-called Tier-1 node in the worldwide LHC Computing Grid, and embedded in the international particle-physics networks.

New networking possibilities are constantly being explored, with for instance the fastest data link to the LHC data at 400 Gbit/second, and doubling that speed to 800 Gbit/second on the R&D networks.

In house, the group runs the dedicated analysis facility called Stoomboot, making the data centre an even hotter and louder place due to all computer power and cooling fans used, and where Nikhef runs regular and experimental computing jobs. Bringing together technical possibilities and scientific demands all the time. One new development explored recently is the use of graphical processor units (GPUs) in readout software, which has found its way to experiments like LHCb already. To prepare for the long-term future, also quantum computing is being explored for new possibilities and opportunities.

Even in industry Nikhef CT definitely has a name, says Groep. "Suppliers think our extreme demands are an excellent testing ground for the latest technologies. That's a mutual interest. They offer us their best, we get to explore new roads in science."

Timepix sensor chips wire bonded to a circuit board at Nikhef.

06

EVALUATION OF TECHNICAL DEPART MENTS

MECHANICAL TECHNOLOGY

The Mechanical Technology (MT) department within Nikhef encompasses a team of 27 full-time equivalents (FTEs), consisting of engineers and technicians. This diverse team enables it to internally fully develop prototypes and small production runs. MT's in-house production capabilities include CNC mills, lathes, 3D printing and welding. To ensure the quality and accuracy of our products, a state-of-the-art coordinate measuring machine (CMM) is employed, whose data also plays a crucial role in aligning detectors.

Internally, MT has a vacuum lab that accommodates two residual gas analysers (RGAs) for measuring the quality of manufactured parts. This lab also facilitates the rapid development of vacuum setups. MT also has a cooling lab, which is presently focused on bi-phase CO2 cooling.

The facilities also encompass multiple cleanrooms, each with its own specialised purpose. A large cleanroom is dedicated to constructing ultrahigh-vacuum components and parts with a high temperature dependency. Another cleanroom is specifically designated for wire bonding and extends its services to industry partners in need of wire bonding solutions.

Highlighted below are the key contributions by MT to notable projects:

- → **Pierre Auger:** Engaged in the structural design of the detector and the establishment of the production line.
- → **LHCb Scintillating Fiber Tracker:** Involved in the design, tooling, cooling, construction and installation of 6-metre-long scintillating fibre modules at CERN.
- → **LHCb Vertex Locator:** Responsible for the design of detector modules, and the validation of modules under varying temperatures (-30°C to +20°C). Developed tooling and established a production line for detector construction. Assisted in the installation at CERN, ensuring meticulous transport and project planning.
- → **KM3NeT:** Conducted material research, evaluated water absorption, and enhanced the production line, sharing knowledge with other sites. Collaborated with Windesheim University of Applied Sciences to develop

injection moulding techniques as an alternative to 3D-printed structures. Provided mechanical coordination throughout the project.

- **Alice Inner Tracker System:** Designed tooling for detector construction, emphasising ultra-lightweight, high stiffness and precise alignment.
- **Einstein Telescope Pathfinder:** Oversaw the design, construction, and validation of a 170m³ ultra-high vacuum system. Implemented vibration damping measures and meticulously planned the project.
- **Advanced Virgo:** Provided support for the detector, focusing on high stiffness, space-grade suitability, thermal and mechanical stability, electromagnetic compatibility and precision alignment.
- **ATLAS Inner Tracker:** Developed a CO2 cooling machine and designed, built and validated an 8m³ carbon fibre detector support structure capable of operating at different temperatures (-30°C to +20°C). Executed the delicate transport of the structure.

COMPUTING TECHNOLOGY

The Computing Technology (CT) group operates on the boundary between systems engineering, control system design, trust and security infrastructure, and physics research support engineering. And while the range of topics is quite diverse, the structure of the CT – being a cross-programme capability group – allows seamless sharing of expertise and (human) resources between the different teams as the Nikhef programme evolves.

Closest to the detector design and data acquisition is the 'project support' team of control system engineers, who designed the operational systems that keep the sub-detectors for which Nikhef is responsible in good shape. In this way, CT provided 'physicist-proof' LHCb SciFi controls based on 'recipes' without the possibility to mess up with the sub-detector, but also the control system for VELO module production. Addressing the next phase in processing, the FELIX acquisition system (which will be the common solution for all of the ATLAS sub-detectors in the HL-HLC phase) is based on CT engineering expertise – but the expertise here is subsequently used also for other read-out systems such as TimePix4's SPIDR4 system. Close collaboration with the Electronics Technology group creates synergies in the control and DAQ systems area that allows Nikhef to optimally exploit the respective sub-detectors. A similar close link between physics and computing engineering is also employed for White Rabbit – incidentally also resulting in collaboration with the global Internet precision timing community through Nikhef Housing[1].

The CT group also provides the engineering expertise for simulation and analysis workflows, on the interface between the experimental programmes (specifically gravitational waves) and the Physics Data Processing programme. The latter highly depends on CT engineering and innovation expertise, both for the data processing design patterns (workflow management, data placement, resource planning and forecasting) and for the global trust and identity activities, including security operations.

Similarly, the data processing systems engineering and 'local user' systems management are also closely connected, with frequent exchange of expertise. As such, the Nikhef institutional IT infrastructure follows an 'open core' design approach, where large data flows can reach the local research clusters and even desktop users at maximum speed. With the core network prepared for the upgrade to 400 Gbps by the end of 2022, end-points can utilise this high-speed network for interactive analysis. Diversity in storage qualities of service (from highly resilient project and personal storage to ephemeral high-speed scratch space) provides an integrated path 'from analysis to thesis'. The CT-PDP 'DevOps' team combines the responsibility of operating local analysis facilities with its role of WLCG Tier-1 provider and international scientific computing facility (together with SURF, the Dutch e-Infra cooperative), with that of the R&D team for high-throughput computing and storage evolution. In support of all these activities, the CT also hosted international systems engineering conferences (such as HEPiX in 2019), and partakes in the key working groups of the Worldwide LHC Computing Grid (WLCG), EGI, GEANT and European Open Science Cloud.

The CT systems engineering and helpdesk teams, by construction, maintain close ties to the innovation engineers to ensure effective (and efficient) use of resources across the institute and the partner universities.

Increasingly, within Nikhef the CT group also takes a role in the privacy and security compliance context – with the specific aim to ensure the Nikhef research programme is not unduly encumbered by externally imposed mechanisms that are increasingly oriented towards 'enterprise'-oriented closed-system approaches. By developing its own capabilities and expertise, the CT group provides contextualised capabilities, aligned with WLCG and global standards, rather than be subjected to such bespoke enterprise

[1] Connectivity data centre, one of the largest internet hubs in Europe and home to more than 200 parties. AMS-IX certified, reliable, neutral and environmentally friendly.

controls. The CT is also itself continuously aware of the need to reduce 'red tape', and works actively with the Nikhef support departments to ensure that computing for Nikhef users remains as seamless as possible.

In the period 2017-2022, the CT group developed, or contributed to a significant extent to, the following activities:

- LIGO-Virgo-KAGRA (LVK) processing pipeline design and deployment on the 'European-model' Ganymede HTCondor cluster at Nikhef
- LVK resource planning and forecasting
- Co-design and validation of the Snellius SURF Dutch National Supercomputer
- System and network co-design with equipment vendor engineering teams to improve systems throughput and applicability to the Nikhef science use cases
- Reconfiguration and preparation of the Nikhef network and systems for the 400-gigabit era, required for the HL-LHC data processing
- LHCb SciFi front-end electronics and configuration controls
- LHCb VELO module production controls
- ATLAS Monitored Drift Tube alignment and detector control system
- Joint ATLAS+ FELIX data read-out system: data acquisition, control, and monitoring software
- Read-out and control for SPIDR4 (TimePix4 pixel chips), KM3NeT (Central Logic boards), and wave downconverters (Ptolemy)
- Finesse3 simulation program for interferometers
- WLCG and EGI Software Vulnerability Assessment and triage
- EGI and WLCG Security Service Challenges and traceability verification
- Design, building and operation of the Nikhef Security Operations Centre and event monitoring (SOC/SIEM) and the contribution of this single-collector model to the WLCG SOC working group
- EGI-CSIRT Security Operations, where Nikhef CT staff provides the European-wide Security Officer to the operational security and forensics team
- Red-teaming in the cybersecurity defence exercises for the Dutch government and national critical infrastructure (since the bandwidth and packet rate of our science data is on par with a typical denial-of-service attack)
- AARC Authentication and Authorization for Research Collaboration architecture design, federated collaboration management (OpenID Connect Federation and AARC Blueprint Architecture proxy integration) and RCauth.eu – the Pan-European Identity provisioning based on an anycasted certification authority, with GRNET (Athens) and RAL (STFC-UKRI, Oxford)
- Organisation of HEPiX Amsterdam (2019), bringing the forum of worldwide Information Technology staff, from the high-energy and nuclear physics institutes to Amsterdam

\ ELECTRONIC TECHNOLOGY

The Electronics Technology (ET) department develops electronics instrumentation for the experiments in which the Nikhef scientific groups do research. For a large part, this is for LHC experiments. Other areas are cosmic rays like KM3NeT, and more recently for gravitational wave detection experiments like Virgo and ETpathfinder.

The LHC contributions are for ATLAS (Muon detector readout), LHCb (SciFi and VELO) and ALICE (Inner tracker). For example, for ATLAS, the development of a new Data Acquisition (DAQ) is ongoing. Phase 1 (for LS2, 2020) has been delivered and is commissioned; phase 2 for installation in LS3 (2026-2027) is ongoing with higher data-throughput capability. The DAQ system comprises a state-of-the-art FPGA board and the Nikhef contribution is firmware development and coordination, and partly schematic design of the board.

In KM3NeT, the White-Rabbit technology was implemented for accurate time measurement over the complete detector. Continuous R&D on this topic led to improved specifications, and generic designs to be used in other experiments. It requires dedicated knowledge of accurate clocks/oscillators, jitter and phase noise reduction techniques and low-noise power supplies. For these characteristics, Nikhef invested in special test equipment.

In general, electronics technology is progressing continuously. Commercial off-the-shelf (COTS) electronic components are not only getting smaller (packages), but are regularly replaced by new parts with more functionality or improved specifications. Smaller sizes and increases in clock speed (e.g. ethernet 1>10>100Gbps, faster FPGAs and memory, wider data-busses) require more capabilities of the Printed Circuit Boards (PCBs) on which the parts are soldered. Solder techniques become more advanced because of the higher density, and PCBs contain more connection layers and special interconnect options. Therefore, the complete design chain is continuously under development with annual upgrades of our design tools.

The engineers and technicians follow these developments, by learning, training, doing and prototyping.

FPGAs (digital logic design) are also continuously growing in speed feature options and in the number of integrated functions (Ethernet, USB, ADC, DAC, memory, DSPs, CPUs, etc). One team of engineers can work for years on one design in one FPGA. Design tools offer more capabilities to design in a collaborative manner (also multi-site), and design automation and re-use is increasing.

For the design and verification of complex high-frequency PCBs, the ET has invested in state-of-the-art simulation software and training to use it. This requires continuous learning.

The Integrated Circuit (IC) designers in the group migrate about every six years to a more advanced technology. This means smaller feature sizes, more interconnect layers for higher density and faster ICs. New design concepts need to be learned in every transition, for design, verification and use of the design tools. Also for this designers are continuously learning and being trained.

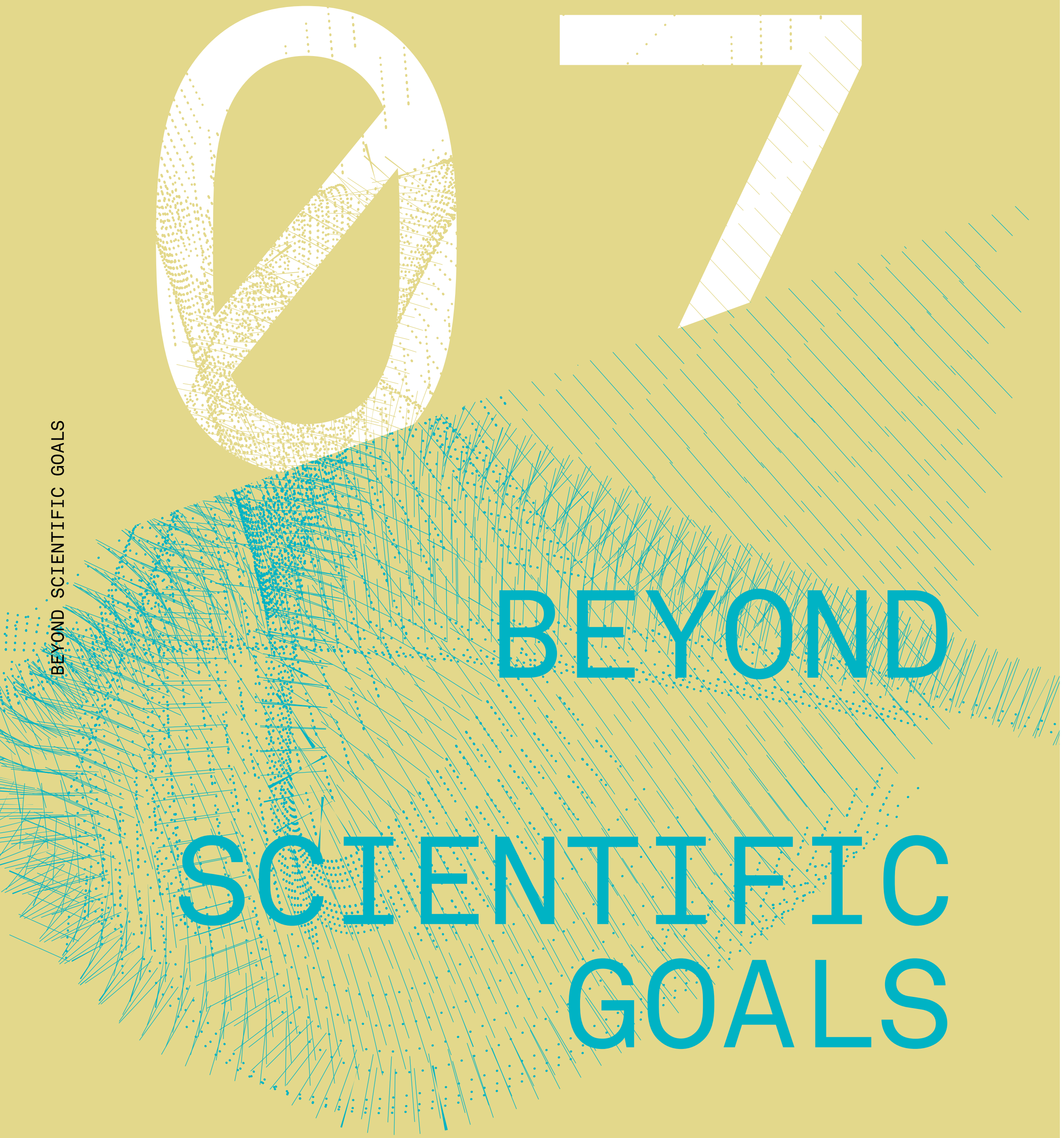
In order to follow the progress in test and verification of the designs, regular upgrades and renewal of the Test & Measurement equipment constitute an ongoing activity.

In most projects, the engineers work in international collaborations on one design. So, the design tools and the skills of the engineers are also adapted to enable this collaborative way of working.

In the table below, all the projects and associated deliverables of the period under evaluation are listed.

Year	Experiment/ programme	Projects and deliverables
2017-2022	KM3NeT	• Optical network design, procurement and commissioning • Design optical network KM3NeT Phase 2: more White Rabbit • Many procedures and manuals for instruction of other production & assembly sites for DOMs & DU integration. • ORCA DC/DC convertor (400/12V) for DOMs • PMT Base PCB production and test (>15000) • Central Logic Board firmware (White-Rabbit timing system) • Production of DOMs and DU Integration • Component pressure tests & test programmes • Design and qualification of GlenAir backplane (WR in DU base)
2020-2022	ALICE Inner Tracker system 3	Prototype ASICs; serialiser, digital PLL, bandgap voltage reference, Low-Dropout supply regulator (one regular & one special with very Low-Power Supply Rejection Ratio for accurate clocks)
2018-2019	ITS upgrade	Assembly of sensor modules on staves; special solder work
2017-2019	LHBb VELO	Contribution to VELOPix ASIC; 10Gbps serial readout with data formatter, clock cleaning PLL and output driver.
2017-2021	LHCb SciFi	• Front-End box electronics >800 control boards • Front-end box test system • Cabling with dedicated cable chain
2017-2022	DR&D ASICs	• Development of TimePix4 chip in collaboration with CERN; fast readout serialise + driver, timing, logic for readout. • Testing of the chip with the Nikhef contributions. • Documentation
2017-2022	DR&D Readout	• SPIDR3 Readout system for Medipix3 and TimePix3, collaboration with Amsterdam Scientific Instruments (ASI) • SPIDR3 adapted to readout VeloPix • SPIDR4 new readout system for TimePix4 with 8x 10Gbps readout speed and 100Gbps ethernet.
2018-2020	EMPIR Write	• White-Rabbit R&D calibration: Design and test of several boards with special power supplies, oscillators and controls for very (!) stable and low phase noise applications like Gravitational Wave instrumentation. • 2x best paper award at 2 ISPCS conferences (2018 & 2019)
2020-2022	White-Rabbit	General R&D for ET projects (Virgo, ATLAS, ETpathfinder): Design of BabyWhite-Rabbit module for generic WR implementations.
2018-2020	Virgo	• Upgrade new analog frontends & controls for photodiodes • LVDT amplifiers and drivers. • Prototype timing distribution upgrade system for very stable and low phase noise clock distribution over long cables. • High-resolution Phase camera for Virgo detector • Universal Microcontroller board in Collaboration with CT for software development kit (NEP: Nikhef Embedded Platform)
2020-2022	ETpathfinder	• Cable design for ETpathfinder experiment • acLVDT for new LVDT design to be used in vacuum • White-Rabbit Timing system for clock distribution • Photo diode front ends
2017-2022	ATLAS	• FELIX firmware & coordination for FELIX DAQ system Phase 1 and from 2021 on Phase 2 • Also for New Small Wheels; new ATLAS subdetector in 2020 • And prototyping in Proto-DUNE in 2018
2017-2022	Senseis	3x ASIC design + test boards + testing in collaboration with Innoseis: R&D on very high sensitivity seismic sensor
2020-2022	Ptolemy	Design of new electronics for very small RF-signal (26GHz) particle detection and dedicated data acquisition for RF signal digitisation.
2017-2022	Nikhef Laboratories	Technical support on Nikhef lab R&D set-ups and prototype systems. LabVIEW support.

CONTINUE →



07 BEYOND SCIENTIFIC GOALS

In this chapter we discuss themes that are directly or indirectly important for excellent research.

RESEARCH INTEGRITY

Aspects of "Research integrity" can be grouped into (1) ethical considerations such as fairness, honesty and responsible use of professional authority, and (2) objective considerations such as transparency about the research process, honesty concerning presentation of results, and openness of the data and software involved in reaching those results. Both groups received quite a bit of attention in 2017-2022. As Nikhef is both a NWO institute and a partnership of universities, we first surveyed ongoing activities in the rest of the ecosystem, before designing Nikhef-specific policies and awareness training. Assessing the courses and training offered by the universities, NWO-I and the large international collaborations our researchers operate in, we decided that additional training in the area of data integrity and analysis preservation would be of added value, especially related to the data and software issues common to high-energy and gravitational wave physics, which are quite specific to our fields and unlikely to be covered in a generic integrity training. To address this area, Nikhef has expanded (since 2022) the existing internal Computing Course with a one-day component covering Scientific Data Integrity issues along with the practical aspects of making research data and software open and reusable. This component is compulsory for all Nikhef PhD candidates.

EDUCATION, TRAINING AND POLICY FOR PHD CANDIDATES

PhD candidates carrying out research within the Nikhef partnership are enrolled in the Research School for Subatomic Physics (OSAF) or the Dutch Research School of Theoretical Physics (DRSTP). Both research schools are recognised as official graduate schools by the Nikhef partner universities granting their PhD degrees. OSAF and DRSTP provide education, mentorship and training (both scientific and in soft skills) for the Nikhef PhD candidates, supporting them along their trajectory towards successful PhD completion.

Scientific training

PhD training and education at Nikhef are coordinated by the Nikhef Education Committee (OWC). The main PhD scientific training activities organised by the OWC are:

- *Topical Lectures* (TLs), three-day-long specialised courses taking place 4 times per year. They are taught by experts in the field and aimed at PhD candidates across the Nikhef community. Accessibility and relevance for a broad PhD population are key factors in deciding the topics of the TLs. OSAF PhD candidates have attended (at least) 6 TLs by the time they graduate.
- *The Belgium-Netherlands-Germany (BND) international graduate school*, a two-week-long school covering scientific topics relevant for the Nikhef research portfolio by means of specialised lectures and hands-on tutorials. Following the Covid period, BND2022 took place in The Netherlands in September 2022 and BND2023 will take place in Wuppertal.
- *Computing at Nikhef* and C++ courses are organised yearly to provide our PhD candidates with IT skills required for their research.

In addition to the BND school, Nikhef PhD candidates often attend other international graduate schools such as MCnet and the CERN/FermiLab schools. The PhD mentor (C3 mentor, see below) ensures that the choices proposed by PhD candidates comply with the OSAF requirements.

Soft skills and career training

Complementing their scientific education, Nikhef PhD candidates receive extensive training in soft skills to prepare them for their post-PhD career both within and outside academia. Courses that they follow include *Taking charge of your PhD, Scientific Integrity* (offered to all NWO-I staff), *Research data management and integrity* (part of the Computing at Nikhef course) and *The art of scientific communication*. The candidates often follow soft-skills courses at the partner universities as well, whenever these form part of specific graduation requirements.

PhD supervision and mentorship

In addition to their PhD (co)-supervisors, PhD candidates are assigned a so-called C3 mentor. This is a Nikhef staff member from a different programme (to facilitate independence), with sufficient experience in PhD supervision, who meets regularly with the PhD candidate. **C3 mentors** support PhD candidates at the various stages of the PhD process and ensure that the appropriate steps are being followed, from registering a complete PhD plan and monitoring progress to planning the PhD write up. The C3 mentor also acts as the first contact point to raise issues related to e.g. conflicts with the supervisor or with other colleagues, and can also point the PhD candidate to external resources (confidential councillor, HR, mental health support) whenever needed. Recently, the pool of available C3 mentors has increased thanks to new hires. In particular the female/male balance among C3 members has improved over this evaluation period. The support of the C3 mentors is also required for any PhD contract extension and to validate training choices such as a different graduate school than the BND.

To improve the quality, quantity and consistency of feedback that supervisors provide to their PhD candidates, Nikhef also offers dedicated **training on PhD supervision** to their staff.

Internal quality monitoring

The input from Nikhef PhD candidates is instrumental to improve the quality of our training and education activities. PhD Council representatives participate in the monthly OWC-core group meetings and provide feedback in all proposed training activities. PhD candidates also provide feedback after each topical lecture and graduate school which is used to further improve their quality. We strive for a low-threshold communication with the PhD Council via a dedicated Slack workspace. All regulations and guidelines from OWC/OSAF are publicly available via documents open for feedback from both the PhD candidates and the staff, removing any possible ambiguity and preventing a possible expectation mismatch.

PhD duration

As indicated by the table below, around 22 PhD candidates start every year with their PhD trajectory at Nikhef, with a 30/70 female/male ratio. PhD candidates starting in 2016 or later were affected by the Covid pandemic, which resulted in many cases in delays in PhD finalisation. Nevertheless, the median duration is with 54 months reasonable. However, figure 8 shows a rather long tail towards longer durations. In the current evaluation period, only 4% of PhDs who started in 2019 or earlier dropped from the programme. Figure 9 shows the median duration for each year, for all defences in that year. Despite the covid pandemic, the PhD duration has not significantly increased. The C3 mentors play a key role to monitor progress during the PhD trajectory and carefully evaluate any request for extension, which is only accepted provided a realistic action plan towards completion is put together.

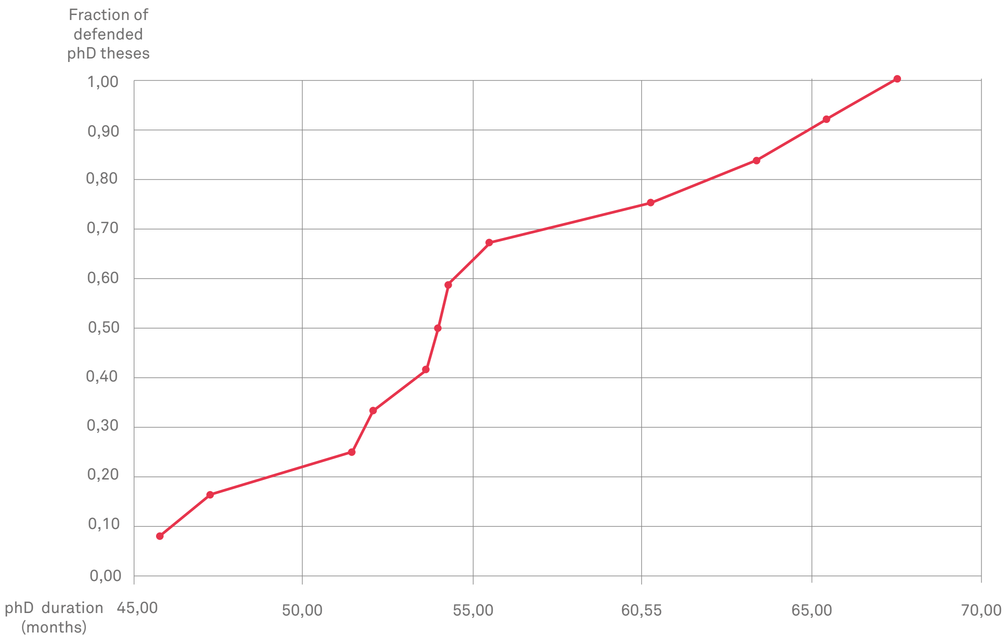
TABLE 10 **Duration of the PhD trajectory.***

Starting Year	Male	Female	Total (M+F)	Completed Y4	Completed Y5
2015	9	5	14	7,1%	28,6%
2016	22	8	30	10,0%	36,7%
2017	17	7	24	4,2%	33,3%
2018	12	7	19	5,3%	21,2%
2019	13	7	20	0,0%	0,0%
Total	**73**	**34**	**07**	**5,6%**	**25,2%**

Starting Year	Completed Y6	Completed Y7	Not yet finished	Discontinued
2015	50,0%	7,1%	0,0%	7,1%
2016	33,3%	3,3%	10,0%	6,7%
2017	16,7%	0,0%	45,8%	0,0%
2018	-	0,0%	68,4%	5,3%
2019	-	0,0%	100,0%	0,0%
Total	**19,6%**	**1,9%**	**43,9%**	**3,7%**

FIGURE 8 **The PhD duration from start till the PhD defence in 2022**

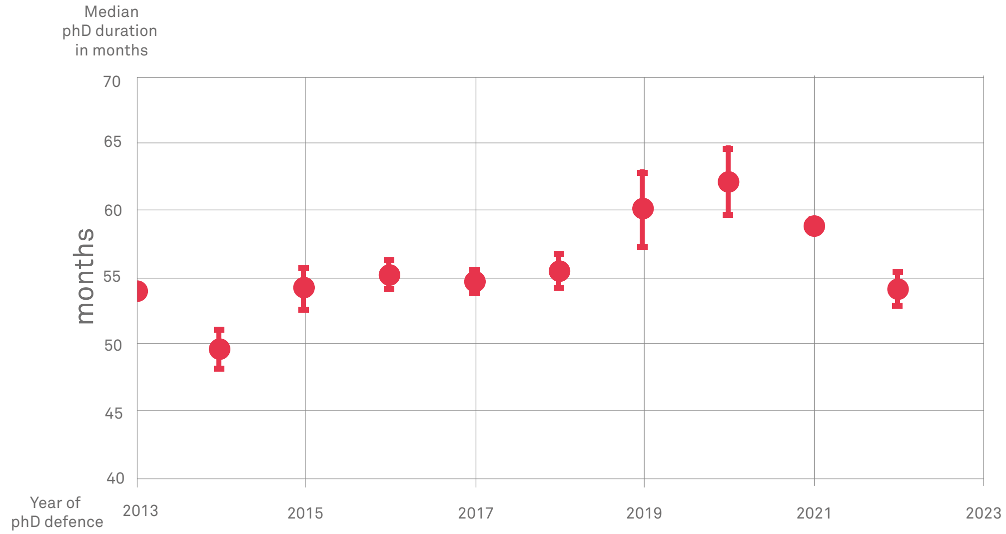
It has a median of 54.1 months. On the horizontal axis the duration in months, on the vertical axis the fraction of defended PhD theses. The used subset are all PhD defences in the year 2022. Note that there usually is a 3-4 months' delay between finishing the thesis and the thesis defence.



* Note that the data in this table concern the date of the official PhD ceremony, which is at least 3 months (in most cases rather longer) after the actual date of PhD finalisation (submitting the manuscript to the PhD committee).

FIGURE 9 **Median of PhD duration in months from start till PhD defence.**

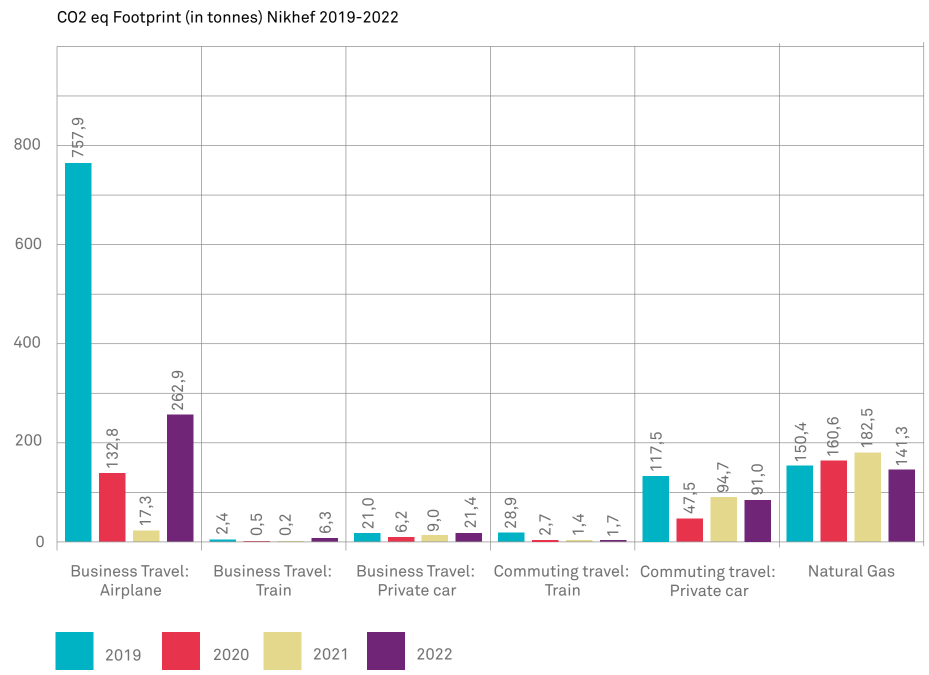
The error bars represent the median absolute deviation (MAD)/√(n-1). Note that there usually is a 3-4 months' delay between finishing the thesis and the thesis defence.



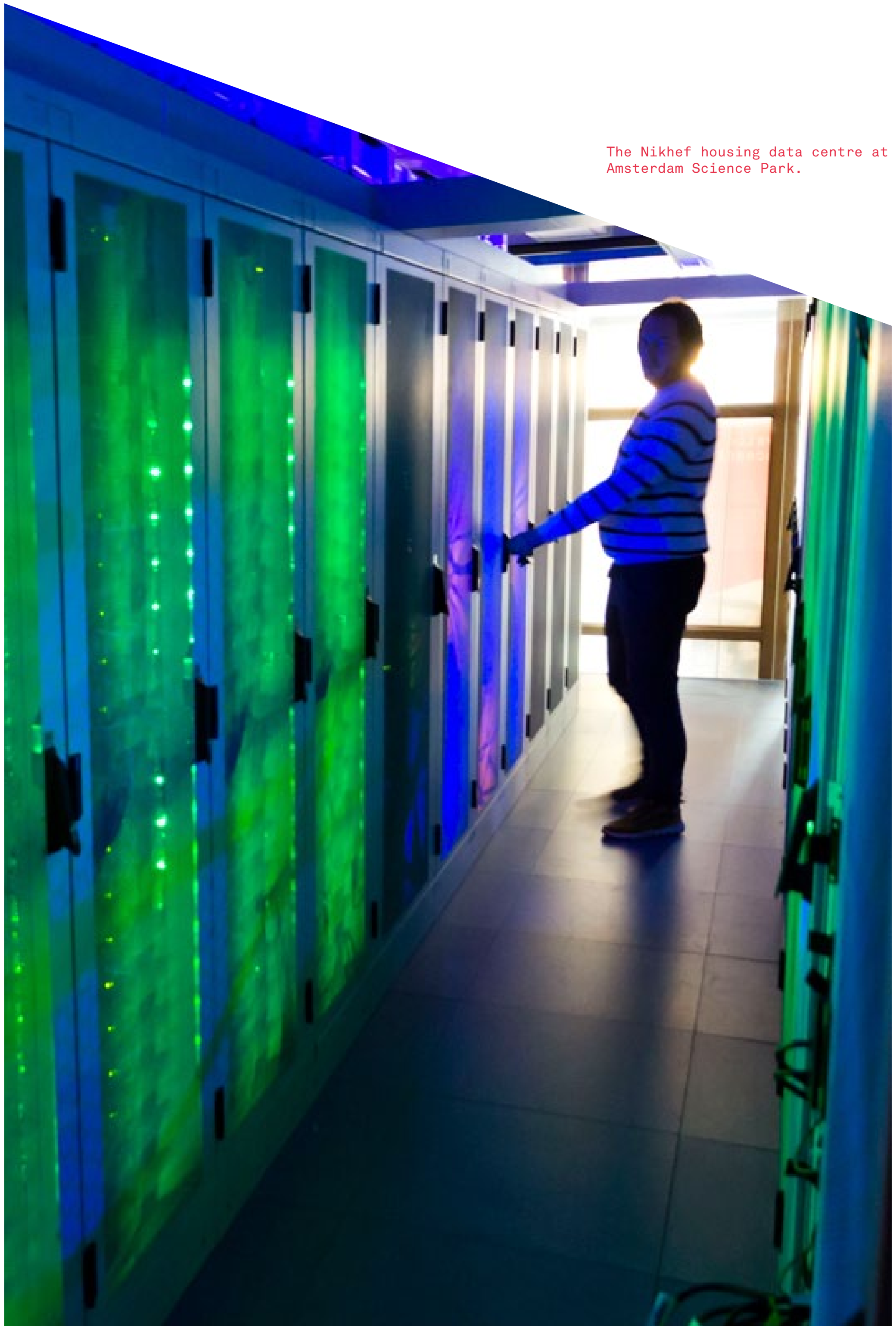
SUSTAINABILITY

The past strategy period (2017-2022) has seen the emergence of Nikhef's Sustainability Roadmap. The Roadmap is based on a CO_2-eq footprint analysis, which is the calculation of the greenhouse gas emissions (carbon dioxide, methane, nitrous oxide, hydrochlorofluorocarbons, hydrofluorocarbons and ozone) by an organisation due to daily activities, mobility, transport, construction and air travel. Every year since 2019, Arcadis performs a footprint analysis, fed with Nikhef's data. Figure 10 shows the results from 2019 to 2022.

FIGURE 10 **CO2-equivalent footprint (in tonnes) of Nikhef for the years 2019-2022.**



The figure shows that in 2019, business travel —in particular air travel— was the dominating factor, accounting for two thirds of the CO2-eq emission. The remainder of the footprint is attributable to the use of natural gas for heating the building, and commuter traffic. This led Nikhef management to make sustainable travel a spearhead in the Roadmap, as further described in our Strategy 2023-2028. In 2020 and 2021, Nikhef's total CO2-eq emissions dropped as a result of the Covid pandemic that reduced business and commute travel to an absolute minimum. In 2022, the footprint increased again, mainly due to air travel being resumed, but still only a third of the 2019 figure. The question remains whether this decrease will continue in the coming years, as air travel still remains the main source of CO2 emissions for Nikhef.



The Nikhef housing data centre at Amsterdam Science Park.

08 CONNECTION TO SOCIETY

The connections of Nikhef to society are plentiful. For example, through outreach to the broader public, and education, ranging from primary school children to teachers themselves. These connections also concern cooperating with industry and making our research results freely accessible to the public. In the next sections we describe these different types of connections.

KNOWLEDGE AND TECHNOLOGY TRANSFER

Over the last decade, attention within Nikhef for collaboration with industry has grown. Certain Nikhef activities are enabling spin-off companies, which until now has resulted in the establishment of two promising companies: Amsterdam Scientific Instruments (2011) and Innoseis (2013). Various activities in relation with industry and knowledge transfer have been initiated or coordinated by Nikhef's industrial liaison officers (ILOs), one of them (Jan Visser) dedicated to opportunities for CERN-related technologies, and the other (Rob van der Meer) more focussed on industrial opportunities for the Einstein Telescope. Visser also coordinates the Dutch ILO network.

CERN

The knowledge transfer group at CERN aims to find applications for the technologies developed at CERN through the CERN Business Incubator Center (BIC). Since 2014, Nikhef coordinates the Dutch instantiation of the CERN BIC. One of the Dutch business incubators linked to CERN through Nikhef, HighTechXL, established on the Eindhoven High Tech Campus, has started a number of companies inspired by CERN technologies. Examples include: **Inphocal** has a commercial licence for the structured laser beam invented at CERN. They apply it in various laser-marking applications where the ink of standard lasers is less suitable or more polluting. **Incooling**, which has worked with Nikhef on chip cooling, has closed a 3.5 M€ pre-series A investment round with the Germany-based Pierburg Pump Technology (part of the Sensors and Actuators Division of Rheinmetall AG), and is now an established company. **Aircision** develops Free Space Optics systems as a wireless alternative for backhaul communication. **Dynaxion**, inspired by a compact accelerator structure, is working towards a system to scan packages with neutrons for applications at e.g. airports.

HighTechXL regularly reaches out to Nikhef for support with other start-ups that could benefit from our knowledge or facilities.

In the development of new detector systems for the LHC collaborations, Nikhef engineers challenged companies with parts requiring innovative approaches in the production: **Airborne** was involved in building composite parts for the new ATLAS inner tracker; **Capable** provided complex cabling solutions; **Oceanz** provided precision 3D-printed parts for the scintillating fibre tracker of LHCb.

Gravitational wave research

Within the INTERREG projects for the ETpathfinder, the R&D facility for the future Einstein Telescope, specific attention has been given to present the technological challenges in a clear and concise manner to encourage companies to be involved from an early stage in co-development projects, in order to innovate together with us and be well positioned for future tenders. One particular concept implemented was to provide vouchers for companies working together on these challenges across borders in the Euregion Meuse-Rhine. Nikhef also continued to collaborate closely with its spin-off Innoseis Sensor Technologies on the development of MEMS-based seismometers, both fundamental for the Einstein Telescope and creating future market opportunities for Innoseis.

KM3NeT

To build a functional detector system over a large volume in the Mediterranean Sea, various components and systems were developed in collaboration with industry or with impact in industry. The oil-filled cable, necessary to have functioning optical fibres at 3 km depth, was developed together with the company MCAP. To synchronise the clocks at the individual detector units, which are separated by large distances, a White-Rabbit IEEE timing protocol was developed in a collaboration initiated by CERN and Nikhef. This protocol has already found its way into various industrial products.

Detector Research & Development

Next to the efforts on MEMS devices and optical systems for gravitational wave research, Nikhef's Detector R&D group is a fundamental partner in the CERN-based Medipix collaborations. The Nikhef group is the only partner to contribute significantly to the design of the Timepix family of ASICs, which has led to many industrial applications of which some are exploited by the Nikhef spin-off Amsterdam Scientific Instruments (ASI). SPIDR4, the latest read-out system for Timepix4 was developed in close collaboration with ASI to ensure a smooth transition to a marketable product. The historical connection with PANalytical, dating back to the early 2000s, is ongoing in that they are still using Nikhef staff and facilities for part of their detector supply chain and are collaborating to verify the potential of the Timepix4 chip for their application domain.

Together with our sister institute CWI, a research facility Flexray has been started to investigate the advantages of the Medipix3 chip in spectral X-ray computed tomography imaging. For example, together with the University of Utrecht, work is ongoing to study whether regular X-ray images taken with this device could provide an early indication whether a person suffers from osteoporosis.

Data science and ICT infrastructure

The strategic ICT innovation programme, run in close collaboration with the national research and education cooperative SURF and – also supported by the FuSE project – with our sister institute ASTRON, works closely with major industrial systems partners, Dutch national governmental agencies and internet telecom leaders. Since the infrastructure that Nikhef needs for its next-generation network infrastructure is relevant for what the public sector and industry consider their key scalability and cybersecurity challenges, we closely collaborate in national cybersecurity resilience exercises for the Dutch critical infrastructure in multi-annual arrangements, and – with network technology vendors including Nokia, Juniper, and NVidia-Mellanox – in high-bandwidth-high-rate experiments that address both HL-LHC, SKA (ASTRON) and public and commercial telecom requirements. This also exploits the synergies that our Housing (data centre) activities offer, since these operators are without exception already present on our Nikhef Housing data floor. As part of our systems co-design innovation, we work with hardware systems vendors such as AMD, Dell, Fujitsu, IBM, Intel, NetApp, Seagate and Western Digital. These connections at times result in capabilities being added specifically “for us” (with us being forerunners for future commercial requests), which cannot be underestimated in the results we have been able to obtain. At the same time, industry partners regularly benefitted from these additional features in other domains. Through a consistent open and neutral approach, we ensure we engage with, and stimulate research-infrastructure-relevant development in, the most innovative vendors.

In some cases, our technology transfer activities are part of educational activities:

ATTRACT

The ATTRACT initiative, started among others by CERN, stimulates researchers to come up with disruptive improvements in the domain of imaging. The Nikhef Detector R&D group successfully submitted a proposal in the first phase, allowing the initiative of a student of the Delft University of Technology to be made into a yearly Design Thinking summer school based on ATTRACT. This ATTRACT-funded school currently provides a unique opportunity for students from Delft, the University of Amsterdam and the Rotterdam School of Management. Via the ATTRACT funding there is also a connection with the Laurea University of Applied Science in Helsinki, the Esade business school in Barcelona and the Design Factories in Aalto and Leeuwarden.

Demolab

The ATTRACT summer school created another link between Nikhef and the UvA in the Bachelor course "Science & Innovation" and the Demolabs at the UvA and VU University of Amsterdam, both members of the Nikhef partnership. We are regularly present at their meetings and open to support initiatives that could profit from our support in connecting to others in our network or from the use of our facilities.

KM3NeT

Together with the Vocational Educational School Windesheim in Zwolle, a project was done to convert the 3D-printing of parts to injection moulding. Considering the large number of components, this was a successful cost-saving effort.

Patents

Nikhef does not actively pursues building up a patent portfolio. When opportunities arise, a patent is considered, but actually no new patents have been filed in the 2017 – 2022 period. Nikhef currently (co-)owns nine patents, of which only two are licensed, both to our spin-off Innoseis Sensor Technologies.

\ OPEN SCIENCE AND OPEN DATA

Nikhef considers open and collaborative science as a key value of its strategy and an integral part of the way research is conducted. This is broader than 'just' making data used in its publications and final results findable and accessible, and also includes software, infrastructure and the way data is managed during the acquisition and processing phase. The majority of the data at Nikhef (both in terms of volume and diversity) is managed collectively through our international experiments. As such we fully endorse and promote the open science strategy for our CERN experiments, and drive adoption of FAIR practices in those experiments where re-use of data was not yet common practice. We contributed our expertise in open data processing and collaboration policies, as well as GDPR and software licensing expertise, to the Digital Competence Centres (DCCs) that were established in knowledge institutions across the Netherlands from 2020 onwards. We also were a driving force in the definition of the Thematic Digital Competence Centre (TDCC) for the domain Natural and Engineering Sciences (NES). This TDCC NES launched in 2022, stimulating further adoption of interoperable standards, open research software and collaborative improvement of FAIR practices across the domain.

We take an expert-consultancy approach to data management in our projects and experiments, with each project receiving targeted briefings and continuous improvement by research data management and open science experts both in project preparation phase as well as in the writing of their data management plans. The concrete re-usability of data is the determining factor in the choice of repository used for final deposition to ensure findability and interoperability in a research context that is most appropriate for the data. Through this strategy we aim to maximise *actual* re-use, independent of semantic search engines and cross-indexing services that are today still limited in their functionality. Thus, researchers and societal stakeholders will be able to find the data in their 'usual' place, and in an open, discipline-relevant format: e.g., seismic data goes to designated seismic repositories, computational results are submitted alongside the code in HEPforge, and for projects linked to international collaborations data is deposited with the relevant experiment. Due to the nature of our research, there is limited re-use of existing data, but we are aware of the value of the data we generate and make those openly accessible as soon as practical. Data for which there is no discipline-native repository are submitted to Zenodo, pre-prints are commonly submitted to arXiv, and we are a contributing member of the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP3) since 2014.

With the increasing amount of detector R&D and institutional data sources, we decided in 2022 to also invest in an institutional data repository to support a new 'continuous data deposition and release' model during the research execution phase. Following a survey of candidate tools, in 2023 we partnered with 4TU.RD and TU Delft to deploy and contribute to their Open Source *Djehuty* RDM software. We attach important value to reusability of code, and software that is written is shared (and reviewed) in our global collaborations and follows their open science approach, whereas all institutionally developed software is Open Source by default and uses OSI-approved licences (predominantly Apache 2.0 and MIT).

\ OUTREACH AND COMMUNICATION

In 2017-2022, Nikhef has been actively working on a strong media presence with news items and events, as well as opening its doors to schools, student groups and the general public. Covid and the renovation of the buildings, however, severely limited the possibilities for live events in 2020-2022.

On average, Nikhef as an institute was featured at least once a month on radio and television, in newspapers and magazines, and more recently in podcasts. The communications team is constantly and actively promoting news and Nikhef-related information. This is mainly done through the website www.nikhef.nl, social media and the Nikhef paper magazine *DIMENSIES*. Nikhef PhD defences were featured on the website with brief video presentations, called *Paperclips*.

Dutch media continue to be the main channel for Nikhef news. The communications team has developed excellent direct relations with the Dutch and Belgian media, partly due to a press trip to CERN, Geneva, in 2019. Some Nikhef staff are regular guests in some media.

Nikhef communications is actively taking part in EPPCN, the European Particle Physics Communication Network, with regular visits to meetings and a co-chair since 2021.

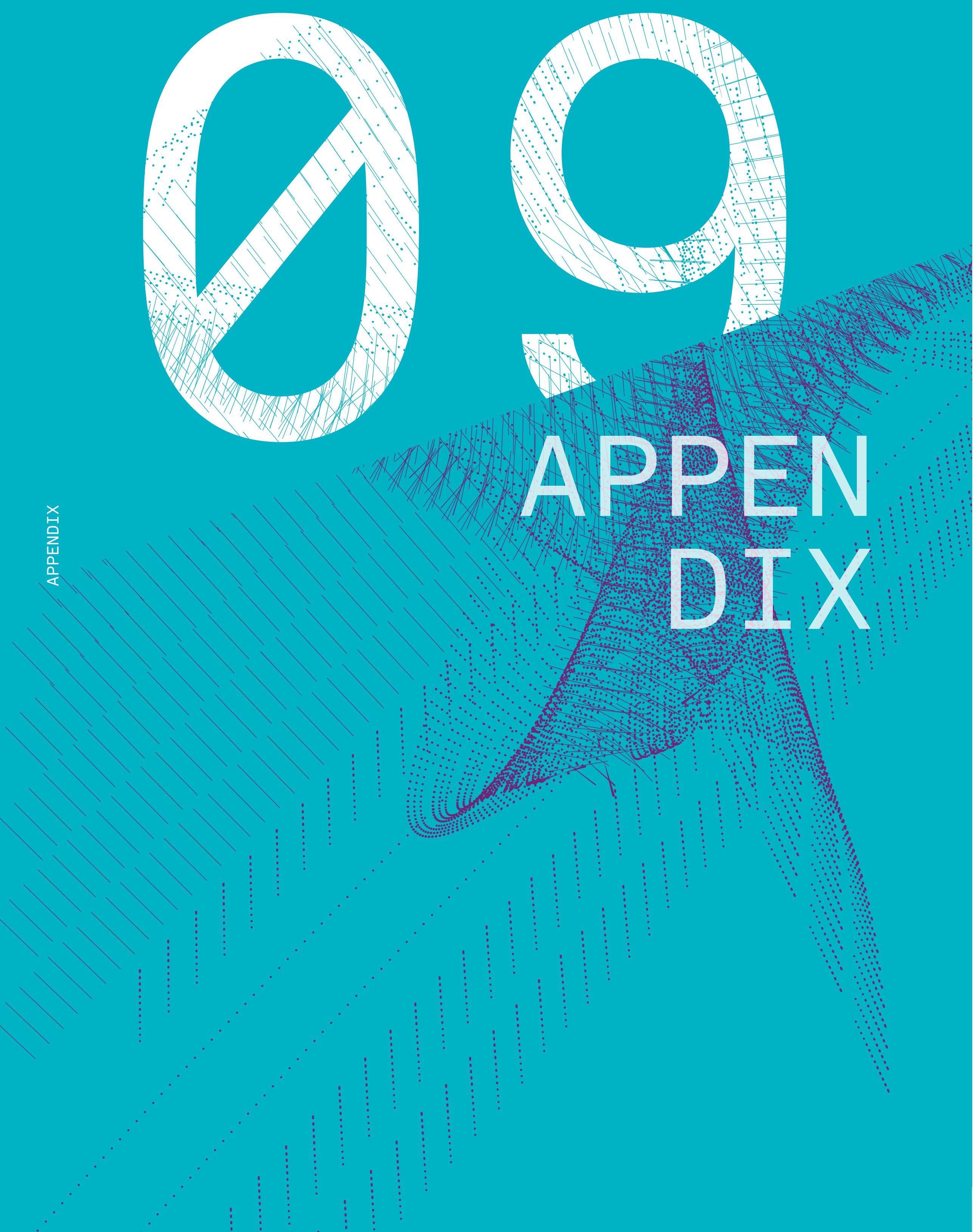
Three highlights can be mentioned, related to events of national or international importance. First was the detection of the first multimessenger event by LIGO-Virgo and others that attracted the attention of all national newspapers, radio and tv news bulletins and even the (then most important) prime-time talk show *De Wereld Draait Door*.

In 2022, the National Growth Fund subsidy for the kick-off of the Einstein Telescope project was national news, with many invitations to talk shows and news programmes, and massive interest from newspapers, ranging from international to regional (Zuid-Limburg).

In July 2022, the tenth anniversary of the Higgs discovery generated a lot of public and media attention, both in online and print media. Nikhef designed and featured a spectacular Higgs@10 laser show on one of the highest buildings at Amsterdam Science Park. A well-visited live public talk show with Nikhef specialists was organised in downtown Amsterdam. In the same period, CERN launched a media campaign for the restart of the LHC accelerator which Nikhef promoted in the Netherlands.

Due to Covid restrictions, many activities like open days and planned or regular visits to the institute as well as programmes for schools like masterclasses and hands-on projects had to be cancelled, scaled down or moved online in the years 2020-2022. Normally, dozens of groups from high schools and institutions are welcomed at Nikhef every year, for introductory talks, tours of labs and workshops, or educational activities. Furthermore, Nikhef annually organises the Dutch CERN teacher programme. After Covid, all these activities were gradually resumed.

09 APPENDIX



A. MEMBERSHIPS OF NATIONAL AND INTERNATIONAL COMMUNITIES AND BOARD

17th International Conference on Strangeness in Quark Matter, A. Mischke (conference chair) Stefan Meyer Institut, OAW, Vienna K. Jungmann (Scientific Advisory Board) ,2017
22nd symposium for astroparticle physics, C. Timmermans (organizer), 2018
7th International Conference on Trapped Charged Particles and Fundamental Physics (TCP 2018), MSU, East Lansing, USA, K. Jungmann (member International Advisory Committee), 2018
Academia Europaea, R. Loll, A. Mischke, S. de Jong, 2017-2018
Academia Europaea, R. Loll, S.J. de Jong, R. Snellings, 2019-
Advances in High Energy Physics – Editorial Board, F. Filthaut, 2017
ApPEC General Assembly, S. Bentvelsen, 2017-
ApPEC – Particle Astrophysics and Cosmology Theory (PACT), J. van Holten (board member) ,2017-2021
ApPEC SAC, S. de Jong (chair), M. de Jong, 2021-
ASTERICS (Astronomy ESFRI Research Infrastructure Cluster) External Advisory Board, F. Linde, 2017-2020
ASTERICS (Astronomy ESFRI Research Infrastructure Cluster), R. van der Meer (project manager), 2021-
Astroparticle Physics European Coordination (ApPEC), S. Bentvelsen, J. van den Brand, F. Linde (chair), 2017-2020
Astroparticle Physics International Forum (APIF), S. Bentvelsen, 2017-
Award of the Lorentz Medal 2018 of the KNAW, R. Loll (jury), 2018
Canada Foundation for Innovation (CFI), K. Jungmann (chair expert committee), 2019-
CC-IN2P3 Evaluation and Survey Committee, J. Templon, 2017-2
CERN Council, E. Laenen (Scientific delegate for the Netherlands) ,2017-
CERN Council, S. de Jong (president) ,2017-2018
CERN Physics Beyond Colliders Working Group, K. Jungmann, 2018-2021
CERN Scientific Computing Forum, J. Templon, 2018-
CERN Theory Department External Review Committee, E. Laenen, 2018-
Cold and Controlled Molecules and Ions conference Scientific Committee, A. Borschevsky ,2017-
Combinatorics, Physics and Their Interactions, Annales de Henri Poincaré l'Institut D (AIHPD), R. Loll (editor), 2017-
Committee for Astroparticle Physics in the Netherlands (CAN) D. Samtleben (chair), C. van den Broeck, A. Freise, S. Hild, J.R. Hörandel, C. Timmermans –2022-
Committee for Astroparticle Physics in the Netherlands (CAN), J. van den Brand, C. van den Broeck (co-chair), M. P. Decowski, J.R. Hörandel (chair), D. Samtleben (Leiden), C. Timmermans, 2017-2020
Committee for Astroparticle Physics in the Netherlands (CAN), S. de Jong (chair), C. van den Broeck, A. Freise, S. Hild, J.R. Hörandel, D. Samtleben (Leiden), C. Timmermans, 2021
Computer Algebra Nederland – Board, J. Vermaseren, 2017-
Council for Natural Sciences and Engineering (RNTW), KNAW, R. Loll ,2017-
DESY Evaluation panel, Helmholtz Gesellschaft, S.J. de Jong, 2018-2019
DESY Physics Research Committee, J. Templon, 2020-
Deutsche Forschungsgemeinschaft, Intl. Review ECHO Expt., K. Jungmann, 2017
Dutch Physics Committee, M.P. Decowski, 2020
Dutch Physics Council, M.P. Decowski, 2021-
Dutch Research School Theoretical Physics (Nikhef members only), R. Fleischer, J. Rojo (Governing Board), S. Bentvelsen, N. de Groot, E. Laenen, M. Postma, van Leeuwen, M. Merk, F. Saueressig (Educational Board), 2020-
Dutch Research School Theoretical Physics (Nikhef members only), W. Beenakker (Governing Board), R. Fleischer (Governing Board), J.-W. van Holten (Educational Board), P. Mulders (Educational Board), F. Saueressig (Educational Board), 2017-2019
ECFA Detector Training panel, N. van Bakel –2022-
ECFA PG1 – steering group, S. Caron (ATLAS representative for SUSY and Exotics), 2017-

ECFA (plenary), S.Bentvelsen, E.Laenen, M. van Leeuwen, S.Caron, N.Tuning –2022-
ECFA (plenary), S. Bentvelsen, N. de Groot, M. Merk, Th. Peitzmann ,2018-2019
ECFA (plenary), S. Bentvelsen , N. de Groot, S. de Jong, M. Merk, Th. Peitzmann, 2017
ECFA (restricted), S. Bentvelsen 2017-2022, F. Linde (ex off.) 2017-2019
EGI, advanced computing for research Federation, D.L. Groep (Dutch delegate to the Council), 2021-
EGO (European Gravitational Observatory) External Computing Committee, J. Templon, 2018-2021
e-Infrastructure Reflection Group (e-IRG), A. van Rijn (Dutch delegate), 2017-
Energy Frontier University Comparative Review, DOE (2020), C. Nellist, 2020
EUROCOSMICS, B. van Eijk (chair), 2017-
European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) – Scientific Board, P. Mulders (chair), 2017
European Committee for Evaluation panel, Helmholtz Gesellschaft, S.J. de Jong, 2020-
European Particle Physics Communication Network (EPPCN), V. Mexner, 2017-2020
European Particle Physics Communication Network (EPPCN), V. Mexner (co-chair), M. van Calmthout, 2021-
European Physical Society, E. de Wolf **(Executive Committee, Physics Education Board),** C. van den Broeck (HEP Board), 2021-
European Physical Society, E. de Wolf **(Executive Committee, Physics Education Board),** S. Bentvelsen (HEP Board) ,2017-2020
European Physics Journal C, S. de Jong (associate editor), 2017-
European Policy Management Authority for Grid Authentication in e-Science (EUGridPMA), D. Groep (chair), 2017-
EU-T0 Executive Board, J. Templon, 2018-2020
EXA 2017 International Conference on Exotic Atoms, K. Jungmann (International Advisory Committee), 2017
EXA2020, International Conference on Exotic Atoms (Vienna), IAC K. Jungmann, 2019-2021
Excellentieprogramma Radboud Pre-University of Science, S.J. de Jong (projectleader), 2017-
Fonds Wetenschappelijk Onderzoek, Vlaanderen – Expertpanel Physics, E. de Wolf, 2017-
Fonds Wetenschappelijk Onderzoek, Vlaanderen – Expertpanel W&T2, O. Igonkina, 2017
Funding Agencies for Large Colliders, S. de Jong (member), 2017-2018
GEANT Community Committee, D.L. Groep (member), 2021-
GEANT Trusted Certificate Service Policy Management Authority, D. Groep (member), 2017-
General Relativity and Gravitation (Springer), C. van den Broeck (associate editor), 2021-
General Relativity and Gravitation (Springer), R. Loll (associate editor), 2017-
Genootschap ter bevordering van de Natuur-, Genees- en Heelkunde, E. Koffeman (board member), 2017-2021
Gesellschaft für Schwerionenforschung, Darmstadt – Review Committee silicon tracking detector system for the Compressed Baryonic Matter experiment, G. Nooren, 2017-2021
Gravitational Wave International Committee, J. van den Brand (member), 2019-
Grid Community Forum, M. Sallé (Project Management Committee), 2018-
GSI Helmholtz Centre for Heavy-IonResearch, A. Mischke (Member, General Programme Advisory Committee), 2017-2018
Helmholtz Alliance for Astroparticle Physics, Germany (HAP), E. de Wolf (Advisory Board), 2017-
Higgs Tools ITN network, E. Laenen (Supervisory Board), 2017-2018
HOVO commissie Universteit Leiden, J.W. van Holten –2022-
HQL2018 conference (Yamagata), P. Koppenburg (convener), 2017-2018
Hyperfine Interactions, K. Jungmann (Editorial Board), 2017-
ICRC2021 International Program Committee, D. Samtleben, 2021
IEEE eScience Conference 2018, J. Templon, D. Samtleben (programme committee), 2018
INFN, F. Linde (Scientific Technical Council), 2017-
INFN-Laboratori Nazionali di Frascati Scientific Committee, M.P. Decowski, 2017-
Institute of Research in Mathematics and Physics (IR MP) – Université Catholique de Louvain, E. Laenen (Scient. Adv. Comm.), 2017-2018
Instituto Nazionale di Fisica Nucleare (INFN), F. Linde (member Technical Scientific Committee), 2017-
Instruments – Editorial Board –, N van Bakel –2022-
Interactions, M. van Calmthout, 2021-
Interactions, V. Mexner, 2017-2020
International Advisory Board for IdeaSquare, S.J. de Jong, 2019-
International Conference on Acoustic and Radio EeV Neutrino Detection Activities (ARENA), S. de Jong (programme committee), 2017
International Conference on B Physics at Frontier Machines (BEAUTY), R. Fleischer (Co-chair Int. Adv. Comm.), 2018-
International Conference on Computing in High Energy and Nuclear Physics (CHEP), D. Groep (Int. Adv. Comm.), 2017-
International Conference on Computing in High Energy and Nuclear Physics (CHEP), D. Groep, J. Templon (Int. Adv. Comm.), 2018
International Conference on Technology and Instrumentation in Particle Physics (TIPP) – Steering Committee & International Program Committee, N van Bakel –2022-
International Conference On Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter), M. van Leeuwen (Int. Adv. Comm.), 2017-2018
International Conference On Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter), M. van Leeuwen, R. Snellings (Int. Adv. Comm.), –2022-
International Conference On Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter), M. van Leeuwen, R. Snellings, M. Verweij (Int. Adv. Comm.), 2019-2021
International Conference On Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter), Th. Peitzmann (Int. Adv. Comm.), 2017-2018
International Particle Physics Outreach Group (IPPOG), C. Timmermans, 2017-
International Review Committee for ADV+, S.J. de Jong, 2019-
International Spin Physics Committee (ISPC), P. Mulders, 2021-
International Symposium on Grids and Clouds, D. Groep (programme committee), 2017-
International Union for Pure and Applied Physics – Commission on Astroparticle Physics, J. Hörandel, 2017-
International Workshop on Heavy Quark Production in Heavy-Ion Collisions, P. Kuijer, 2017-2018
Interoperable Global Trust Federation (IGTF), D. Groep (chair), 2017-
Int. Workshop high school cosmic ray experiments, C. Timmermans (organizer), 2017-2018
Int. Workshop Quantum Spacetime and the Renormalization Group, F. Saueressig (scientific organizer), 2017-
JPARC Muon Science Advisory Committee, K. Jungmann (MuSAC/MAC), 2017-2018
Kamioka Gravitational Wave Detector (KAGRA), J. van den Brand (Program Advisory Board), 2017-
KIT Advisory Board Matter, S.J. de Jong (chair), 2019-
Laboratory Directors Group (LDG), S. Bentvelsen, 2017-
Landelijk coördinatorenoverleg HiSPARC, B. van Eijk (chair), J. van Holten, 2017-
Land Hessen, LOEWE Begutachtung, Darmstadt, March-April 2018, K. Jungmann, 2018
Large Hadron Collider Physics Conference, N.Tuning (Programme Committee) –2022-
Lepton Moments 6, Symposium, Cape Cod, K. Jungmann (Advisory Committee), 2019-
LHCb Implications Workshop Geneva, member organisation committee, 2017
LHCP – 2017 Annual Conference on Hadron Collider Physics, P. Koppenburg (Programme Committee), 2017
LHCP – 2019 Annual Conference on Hadron Collider Physics, P. Koppenburg, Marco van Leeuwen (Programme Committee), 2018-2019
Living Reviews in Relativity – Editorial Board, R. Loll (member and subject editor for Quantum Gravity), 2017-
Lorentz Center – Physics Advisory Board, W. Beenakker, 2017-
Management Committee of the European Union COST action "Connecting insights in fundamental physics" (CA15108), W. Beenakker (Dutch representative), 2017-
Nationale Wetenschaps Agenda (NWA) Trekker route 'Bouwstenen', S. Bentvelsen, 2017-
Nederlandse Natuurkundige Vereniging (NNV) – Advisory Board, M. Vreeswijk, 2021-
Nederlandse Natuurkundige Vereniging (NNV) – Advisory Board, M. Vreeswijk, A. Mischke, 2017-2020
Nederlandse Natuurkundige Vereniging (NNV), E. de Wolf (vice chair), 2017-2020
Nederlandse Natuurkundige Vereniging (NNV) – Sectie Atomaire, Moleculaire en Optische Fysica (AMO), A. Borschevsky, S. Hoekstra (board), 2017-
Nederlandse Natuurkundige Vereniging (NNV)

– Sectie Onderwijs en Communicatie, S. de Jong (vice chair), 2017
Nederlandse Natuurkundige Vereniging (NNV) – Sectie Subatomaire Fysica, F. Filthaut (secretary), J. Even (treasurer), H.Snoek (chair), D. Samtleben, 2019-2020
Nederlandse Natuurkundige Vereniging (NNV) – Sectie Subatomaire Fysica, F. Filthaut (secretary), J. Messchendorp (treasurer), A. Mischke (chair), H.Snoek, D. Sambtleben, 2017-2018
Nederlandse Natuurkundige Vereniging (NNV) – Sectie Subatomaire Fysica, J. Even (treasurer), G. Koekoek, M. van Leeuwen (secretary), H.Snoek (chair), M. Wu, 2021-
Nederlands Tijdschrift voor Natuurkunde, Redactie M. van Leeuwen, 2017-2018
Nederlands Tijdschrift voor Natuurkunde, Redactie M. van Leeuwen, E. de Wolf, 2021-
Nederlands Tijdschrift voor Natuurkunde, Redactie M. van Leeuwen, R. Muller, E. de Wolf, 2019-2020
Netherlands eScience Center, J. Templon (eScience Integrator), 2017-2018
New and Enhanced Photosensor Technologies for Underground/underwater Neutrino Experiments (NEPTUNE) workshop, D. Samtleben (Scientific Advisory Committee), 2018-2021
Nijmeegs NLT Cluster, S. de Jong (projectleader), 2017-
Nijmegen Centre for Advanced Spectroscopy – Supervisory Board, F. Linde (chair), 2017-
Nuclear Physics A, P. Mulders (associate editor), 2018
Nuclear Physics A, P. Mulders (associate editor),2 019-
Nuclear Physics European Collaboration Committee (NuPECC), R. Snellings, 2017-
NWA – ORC, Beoordelingscommissie 2019/20, K. Jungmann, 2019-2021
NWO Centrale Klachtadviescommissie (CKAC), L. Wiggers (member), 2017-2020
NWO Klachtencommissie, L. Wiggers (member), 2021-
NWO network Theoretical High Energy Physics, E. Laenen (chair), R. Loll, W. Beenakker, R. Kleiss, 2017-
NWO – PC-GWI (permanente Commissie Grootschalige Wetenschappelijke Infrastructuur), F. Linde, 2017-
NWO Research Community – Particle and Astroparticle Physics, S. Bentvelsen, D. Boer, S. Caudill, M.P. Decowski (chair), S. Hild, R. Loll, T. Peitzmann, H.G. Raven, H.L. Snoek –2022-
NWO Research Community – Particle and Astroparticle Physics, S. Bentvelsen, E.A. Bergshoeff, S. Caudill, M.P. Decowski (chair), S. Hild, S. Hoekstra, E. Laenen, R. Loll, T. Peitzmann, H.G. Raven, H.L. Snoek, 2021
NWO Research Community – Particle and Astroparticle Physics, S. Bentvelsen, E.A. Bergshoeff, S. Caudill, M.P. Decowski (chair), S. Hoekstra, E. Laenen, R. Loll, T. Peitzmann, H.G. Raven, H.L. Snoek, 2019-2020
NWO Research Community – Physics for Technology and Instrumentation, N. van Bakel, 2019-
NWO Round Table Physics M.P. Decowski, E. Pallante, 2022-
NWO-Shell CSER (Computing Science Energy Research), J. van den Brand (Board), 2017-
NWO – Vidi Committee, O. Igonkina, P. Mulders (chair), 2017
Open Grid Forum CA – OPS working group, D. Groep (co-chair), 2017-2020
Particle Data Group, P. de Jong, 2017-
Particle Physics Inside Products (P2IP BV), A. van Rijn (board member), 2017-2018
Particle Physics Inside Products (P2IP BV), A. van Rijn (director), 2019-
PDF4LHC (Parton Density Functions for the LHC) workshop series – Organising committee, M. Botje, 2017-
Permanente Commissie Grootschalige Wetenschappelijke Infrastructuur, F. Linde, 2017-
Platform Academische Natuurkunde (PAN), N. van Bakel, N. de Groot, P. de Jong, 2019-
Platform Bèta Techniek – Ambassador, F. Linde, E. de Wolf, 2017-
Platform Universitaire Natuurkunde (PUN), N. de Groot, P. de Jong, 2017-2018
PSI2019 Conference, Villigen, Switzerland Program Advisory Committee 2019, K. Jungmann, 2019
PSI Villigen, Switzerland Program Advisory Committee 2019, K. Jungmann, 2018
PyHEP Workshop 2018 — Co-Chair, J. Templon, 2018
Quark Matter 2017 — International conference on ultrarelativistic heavy-ion collisions, International Advisory Committee, M. van Leeuwen, R. Snellings, 2017-2018
Radboud University, Nijmegen – Committee Academic Integrity, R. Loll, 2017-
Radboud University, Nijmegen – Faculty Commission for Gender Equality, R. Loll, 2017-

Radboud University, Nijmegen – Opleidingscommissie natuur- en sterrenkunde, W. Beenakker, 2017-
Radboud University, Nijmegen – PR-commissie WiNSt, F. Filthaut, 2017-2021
Rencontres de Blois – Scientific Program Committee, D. Samtleben, 2017-
RIKEN-RAL , K. Jungmann (Muon Facility International Advisory Committee), 2017-2018
Scientific Advisory Committee OzGrav, S.Hild, 2021-
Scientific and Technical Advisory Committee European Gravitational Observatory, F. Linde, 2017-
Sectorplan committee for Physics and Chemistry (Commissie Breimer), B. de Wit, 2017-
Severo Ochoa and Maria de Maeztu evaluation panel 2017, S. de Jong (chair), 2017
SPS and PS Experiments Committee (CERN), D. Boer, 2019-
SPS and PS Experiments Committee (CERN), M. van Leeuwen (2016/2017), D. Boer (2017), 2017-2018
Stichting Conferenties en Zomerscholen over de Kernfysica (StCZK), S. de Jong (secretary), P. Mulders (treasurer), 2017-
Stichting EGI.eu, A. van Rijn (Chair EGI Council and EGI Executive Board), 2019-
Stichting EGI.eu, A. van Rijn (Dutch delegate in EGI Council), 2017-2018
Stichting Hoge-Energie Fysica, J. van den Brand,, S. Bentvelsen (chair), Th. Peitzmann, A. van Rijn (treasurer), 2017-
Stichting Industriële Toepassing van Supergeleiding, B. van Eijk, 2017-
Stichting Natuurkunde.nl, F. Linde (chair), A. van Rijn (treasurer), M. Vreeswijk (editorial board), 2017-
Stichting Natuurkunde Olympiade Nederland, E. de Wolf (board member), 2017-2020
Stichting Natuurkunde Olympiade Nederland, S.Hoekstra (chair) E. de Wolf (board member), 2021-
Stichting Physica, E. Koffeman, P. Mulders (treasurer), 2017-2019
Stichting Physica, H. Snoek, P. Mulders (treasurer), 2020-
Topsector High Tech Systems & Materials (HTSM) – Advanced Instrumentation / Precision Mechanics Board, J. van den Brand, 2017-
Topsector High Tech Systems & Materials (HTSM) – Scientific Committee and Roadmap
Circuits & Components Committee, N. van Bakel, 2017-
Universe – ,J.W. van Holten (member advisory board), 2022-2021
Universiteit Leiden – Exam Committee Physics, D. Samtleben –2022-
Universiteit van Amsterdam – Director Graduate School of Sciences, A.-P. Colijn, 2019-
Universiteit van Amsterdam – Director Institute of Physics, E. Laenen –2022-
Universiteit van Amsterdam – Director Institute of Physics, P. de Jong, 2019-2021
Universiteit van Amsterdam – Exam Committee Physics and Astronomy, R. Bruijn, 2019-
Universiteit van Amsterdam – GRAPPA Master Track coordinator, M.P. Decowski, 2019-2021
Universiteit van Amsterdam – GRAPPA Spokesperson, G. Bertone, S. Nissanke, 2019-2021
Universiteit van Amsterdam – GRAPPA Spokesperson, S. Nissanke –2022-
Universiteit van Amsterdam – Onderwijsdirecteur College of Sciences, M. Vreeswijk, 2020-
Universiteit van Amsterdam – Opleidingscommissie Bachelor Natuur- en Sterrenkunde, H. Snoek, 2019-
Universiteit van Amsterdam – Opleidingsdirecteur Bachelor Natuur- en Sterrenkunde, M. Vreeswijk, 2019
University of Edinburgh – Higgs Centre, E. Laenen (associate member), 2017
University of Edinburgh – Higgs Centre, E. Laenen (associate member), 2018-
University of Hamburg, Cluster of Excellence Quantum Universe, J. van den Brand (member), 2019-
Utrecht University – BKO/SKO Commissie (Teaching Qualifications Committee), T. Peitzmann (chair), 2017-
Utrecht University – Commissie Kwaliteit WP (Scientific Staff Quality Committee), T. Peitzmann (chair), 2017-
Utrecht University – Director Master Experimental Physics, R. Snellings, 2019-
Utrecht University – Scientific Director Institute of Subatomic Physics, R. Snellings, 2019-
Very Large Volume Neutrino Telescopes (VLVNT) workshop 2018, D. Samtleben (International Advisory Committee), 2018
Virgo STAC, Scientific & Technical Advisory

Committee (EGO), F. Linde, 2017-
VLVNT2021, Scientific Advisory Committee, M. de Jong, D. Samtleben, 2021
VUB Brussel , N. de Groot (Curriculum advisory board), 2017-
WISE Information Security for Collaborating E-infrastructures, D. Groep (Steering Committee), 2021-
Workshop Quantum Spacetime and the Renormalization Group, F. Saueressig (scientific organizer), 2017-2020
Workshop Quantum Spacetime and the Renormalization Group, F. Saueressig (scientific organizer), –2021-
Worldwide LHC Computing Grid, J. Templon (overview board), 2017-
KM3NeT Resource Review Board: S. Bentvelsen (chairs since 2020), 2017-
Auger Finance Board: S. Bentvelsen (chair since 2021), 2017-
EGO council member: S. Bentvelsen, J. de Kleuver, 2021-
ESFRI coordinator Einstein Telescope, S. Bentvelsen, 2020-
Advisory board Max Planck Munich, S Bentvelsen, 2020-
National Growth Fund Einstein Telescope, S. Bentvelsen, 2021-
Belle II physics advisory committee, W. Hulsbergen (2017-)
Editorial board member for Scientific Reports, Wouter Waalewijn, 2016-
Institutional board representative for EIC user group, Wouter Waalewijn, 2020-
Finance Committee CERN, E. Laenen, 2017-
KNAW CERN Contact Committee, E. Laenen (chair), 2017-
CERN Task Force to review Associate Membership of India, E. Laenen, 2022
Strategy Group for European Strategy Group for Particle Physics Update, E. Laenen, 2018-2020
Nikhef Advisory Committee for eEDM experiment, E. Laenen (chair), 2018-
Basis Kwalificatie Onderwijs Toetsingscommissie FNWI, M. Vreeswijk (chair), 2022-
Young Academy of Europe, J. Rojo, 2022-
Member of the Coordination Panel of the Forward Physics Facility at CERN, J. Rojo, 2022-
Chair of the National Research School on Subatomic Physics (OSAF), J. Rojo, 2022-
Board of PERIIA - Pan European Research Infrastructure ILO Association, J. Visser, 2022-
CERN ILO forum, J. Visser (chair), 2022-
BigScience.NL network of Industrial Liaison Officers, J. Visser, 2021-

Teaching masterclasses in particle physics to high school students at Nikhef.

B. WORKSHOPS AND CONFERENCES ORGANISED BY NIKHEF

Name	year	place
CERN-BIC Business Incubation Centres	2017	Amsterdam
ISOTDAQ, international school of trigger and data acquisition	2017	Amsterdam
ATTRACT.NL Symposium: Trends, Wishes and Dreams in Detection and Imaging Technologies	2017	Amsterdam
4th WISE Information Security for E-infrastructures workshop	2017	Amsterdam
Standard Model at the LHC conference	2017	Amsterdam
Interactions Collaboration Meeting	2017	Amsterdam
HEP analysis ecosystem workshop	2017	Amsterdam
XII Workshop on Particle Correlations and Femtoscopy	2017	Amsterdam
Physics and Astrophysics at the eXtreme workshop	2017	Amsterdam
BND graduate school	2017	Callantsoog
ATLAS ITk workshop	2017	Amsterdam
Monte-Carlo description of VBS at the LHC	2017	Amsterdam
AARC2 project All Hands meeting	2017	Amsterdam
LISA Consortium Meeting	2017	Amsterdam
Alice Physics Week	2017	Amsterdam
ATTRACT.NL Symposium: Trends, Wishes and Dreams in Detection and Imaging Technologies	2018	Amsterdam
Fourth Annual Meeting of the Future Circular Collider Study	2018	Amsterdam
7th Belgian-Dutch Gravitational Waves Meeting	2018	Groningen
DAWN IV meeting, global strategies for gravitational wave astronomy	2018	Amsterdam
The 15th international workshop on tau lepton physics	2018	Amsterdam
Fourth workshop of the LHC Long-Lived Particle (LLP) Community	2018	Amsterdam
Next-to-leading power corrections in Particle Physics	2018	Amsterdam
European Strategy for Particle Physics Update - Input from the Netherlands workshop	2018	Amsterdam
15th annual workshop on Soft-Collinear Effective Theory	2018	Amsterdam
LIGO Virgo Collaboration meeting	2018	Maastricht
IEEE eScience 14 workshop “the eScience Infrastructure Ecosystem”	2018	Amsterdam
FYSICA 2019, the annual conference of the Netherlands’ Physical Society	2019	Amsterdam

CONTINUE →

Name	year	place
LHCb upgrade II workshop	2019	Amsterdam
Summerschool on search for new physics with low-energy precision tests	2019	Ameland
HEPiX Autumn 2019 workshop	2019	Amsterdam
EUGridPMA+ 47 and AARC NA3 Policy workshop Utrecht meeting	2019	Utrecht
WLCG Security Operations Center WG Workshop/Hackathon	2019	Amsterdam
EUGridPMA+ 50 joint Amsterdam meeting	2020	Amsterdam
Deep Inelastic Scattering Workshop	2021	Amsterdam
25th Symposium on Astroparticle Physics in the Netherlands	2021	virtual
9th Belgian-Dutch Gravitational Waves Meeting	2021	virtual
Fundamental Sciences E-infrastructure User collaboration meeting	2021	Amersfoort
Quantum computing for HEP and GW – Joint Nikhef QuSoft workshop	2021	Amsterdam
Quantum computing for physics use cases - Joint SURF-Nikhef-UM-CWI-aQa workshop	2022	Utrecht
Quantum computing for HEP and GW – Joint Nikhef QuSoft SURF workshop	2022	Utrecht
ATLAS Exotics Workshop	2022	Amsterdam
Neutriverse Universe of neutrinos workshop	2022	Amsterdam
26th Symposium on Astroparticle Physics in the Netherlands	2022	Soesterberg
The 27th European Cosmic Ray Symposium (ECRS 2022)	2022	Nijmegen
Cern VM Users Workshop	2022	Amsterdam
NNV najaarsvergadering	yearly	Lunteren
ATLAS flavor tagging workshop	2022	Amsterdam
ATLAS High Granularity Timing Detector week	2022	Nijmegen
International Gravitational Waves Network F2F Meeting	2022	Amsterdam
ARC and HTCondor Computing Element Token Hackathon	2022	Amsterdam
PTOLEMY Collaboration Meeting	2022	Zandvoort

\ C. AWARDED GRANTS

leader	title	source	period	Budget (k€)
Rojo	Nuclear Parton Distributions from LHC Data	NWO/Pr	2017-2021	420
Van der Kolk	NWO N/V: Shower modelling in imaging calorimeters.	NWO	2017-2020	257
Gauld	VENI: Precision physics with heavy quarks: from colliders to the cosmos	NWO	2018-2021	250
Van der Schee	VENI: Black hole horizons and the quark-gluon plasma	NWO	2018-2021	250
Herzog	VIDI: Decoding Singularities of Feynman Graphs	NWO	2018-2023	800
Heijboer	VICI: Cosmic Neutrinos: a new tool for physics and astronomy	NWO	2018-2023	1.500
Hulsbergen	VICI: Discovering Dark Matter at the LHC	NWO	2017-2022	1.500
Tuning	VICI: Antimatter matters: probing the differences to the bottom	NWO	2017-2022	1.500
Bentvelsen	NWA Route 2 Startimpuls	NWO	2018-2021	738
Benson	Transformations with Neutrals and Turbo analyses	EU	2017-2019	166
Dietrich	Gravitational Waves and Electromagnetic Counterparts from Generic Binary Neutron Star Systems	EU	2018-2020	166
Nocera	Parton Dynamics in QCD Hadron Structure: collinear FFs and unpolarized TMDs	EU	2018-2020	166
Groep	EOSC Hub	EU	2018-2020	477
Van Den Broeck	VICI: Black holes and gravitational waves: A new route to cosmology and fundamental physics	NWO	2019-2023	1.500
Ferrari/ Van Eijk	Determining the Higgs Trilinear coupling with the ATLAS detector at the LHC	NWO	2019-2023	435
Waalewijn	New methods for precise predictions at the LHC	NWO	2019-2023	432
Fransen	Take-off: Holografische emitter	NWO	2018-2019	40
Bentvelsen	Roadmap: KM3NeT 2.0: Neutrino Science in the Deep Sea	NWO	2019-2028	12.730
Linde	NWO/G: Gravitational waves: The new cosmic messengers	NWO	2018-2023	3.520
S. de Jong	NWO/G: Searching for Ultra-High-Energy Cosmic-Ray Sources using a new Detector Concept in the Pierre Auger Observatory	NWO	2018-2023	2.500

APPENDICES

leader	title	source	period	Budget (k€)
Linde	Gravitational waves: a new road to fundamental physics, astrophysics, and cosmology	NWO	2019-2025	2.514
P. de Jong	The Hidden Universe of Weakly Interacting Particles	NWO	2019-2025	1.879
Basegmez	NWO/f: Dark Matter Detection in the Deep Sea	NWO	2019-2021	251
Jansweijer	EMPIR/WRITE: White Rabbit Industrial Timing Enhancement	EU	2018-2021	108
Bentvelsen	Einstein Telescope: ondersteuning taskforce	EZK	2019-2022	200
Van Leeuwen	VICI: Microscopy of the Quark Gluon Plasma using high-energy probes	NWO	2019-2024	1.500
Caudill	VIDI: A New Spin: The Next Generation of Gravitational-wave Searches for Merging Black Holes	NWO	2020-2025	800
Dubla	VENI: A charming witness of the strongest magnetic field in the universe	NWO	2020-2023	250
Van Beuzekom	Take-off: InCooling	NWO	2019-2020	40
Caudill	NWA: Cortex: the Center for Optimal, Real-Time Machine Studies of the Explosive Universe	NWO	2019-2023	399
Caudill	WISE: Women in Science Excel	NWO-I	2020-2022	320
Groep	GEANT Project GN4-3	EU	2019-2022	244
Heijboer	ESCAPE: European Science Cluster of Astronomy & Particle physics ESFRI research infrastructures'	EU	2019-2022	319
Van Leeuwen	STRONG2020: The strong interaction at the frontier of knowledge: fundamental research and applications	EU	2019-2023	99
Caudill	AHEAD2020: Integrated Activities for the High Energy Astrophysics Domain	EU	2019-2023	149
Van Bakel	ATTRACT: SIMS: Seismic Imaging and Monitoring Systems	EU	2019-2020	100
Van der Graaf	ATTRACT: HighQE: MEMS-made Photocathodes with High Quantum Efficiency	EU	2019-2020	100
Linde	R&D field lab ETpathfinder	EU/Interreg	2019-2022	7.650
Laenen/ Waalewijn	Perturbative QCD for Precision Physics at the LHC	Gov. India	2019-2021	100
Verkerke et al	At the heart of the Higgs	NWO-ENW-G	2021-2026	2.964

CONTINUE →

leader	title	source	period	Budget (k€)
Rojo/Verkerke	Fingerprinting the Higgs Sector with Effective Theories	NWO-ENW-K	2020-2025	700
Colijn/Postma	Searching for dark matter in the XENON waste	NWO-ENW-K	2021-2025	580
Colijn et al	One second after the Big Bang	NWO-NWA-ORC	2021-2026	1.171
Linde et al	The Dutch Black Hole Consortium (DBHC)	NWO-NWA-ORC	2021-2026	1.032
Bentvelsen	Fuse: FUndamental e-infrastructure for SciencE	NWO-Roadmap	2021-2025	5.955
Arnold	The Higgs boson's beauty and charm	NWO-VENI	2021-2024	250
Mohammadi	Searching for the primordial hot QCD matter in small collision systems	NWO-VENI	2021-2024	250
Klaver	Uncovering the lepton generation gap: what's the difference in their relationships?	NWO-VENI	2021-2024	250
Correia Zanoli	A charming witness of a little bang	NWO-VENI	2021-2024	250
Klaver	TOFU: Testing leptOn Flavour Universality in excited strange mesons	EU	2020-2022	176
Linde et al	E-TEST: Einstein Telescope EMR Site & Technology	EU/ Interreg	2020-2022	1.587
Groep	EGI-ACE: Advanced Computing for the EOSC	EU	2021-2023	130
Groep	EOSC-Future	EU	2021-2023	400
Van den Brand	PROBES: Probes of new physics and technological advancements from particle and gravitational wave physics experiments. A cooperative Europe - United States - Asia effort.	EU	2021-2024	46
Bentvelsen	NWA Support Route	NWO/NWA	2021	50
Green	Smoothing the Optical Bumps in the Road for Future Gravitational-Wave Detectors	NWO-VENI	2022-2025	280
Usachov	Search for spectacular signatures of light dark matter at LHCb	NWO-VENI	2022-2025	280
De Vries	The unbearable lightness of B-decaying	NWO-VENI	2022-2025	280
Van de Vis	Signs of the asymmetry between matter and antimatter	NWO-VENI	2022-2025	280
Van Bakel	Photoreceivers for the Laser Interferometer Space Antenna	NWO-M	2022-2026	500
Dias	On the trail of new particles	NWO-VIDI	2022-2027	800
De Vries	The Little Neutral Particle that Could	NWO-VIDI	2022-2027	800

leader	title	source	period	Budget (k€)
J. Steinlechner	Quiet mirrors to discover our Universe	NWO-VIDI	2022-2027	800
Aaij	High-throughput GPU computing for New Physics searches with electrons in LHCb	NLeSC	2021-2025	252
Rojo	Unravelling Proton Structure with Hyperoptimised Machine Learning	NLeSC	2021-2025	490
Hild	Speedmeter: Quantum back-action noise-free interferometry for improving the science capabilities of future gravitational wave observatories	EU/ERC AdG	2021-2026	2.176
Van Beuzekom	AIDAInova	EU	2021-2024	75
Raven	SmartHEP	EU	2022-2025	266
Linde et al	ET Technologies	EU React	2021-2024	2.000
Van Den Broeck et al	Finding the invisible: Localizing merging black holes through gravitational lensing	NWO-ENW-M2	2022-2027	700
Bonga	Observing resonating black holes with gravitational waves	NWO-ENW-M		350
Borschevsky/ Hoekstra	Probing Particle Physics with Polyatomic molecules	NWO-ENW-M2		700
Snoek at al	Fast sensors and Algorithms for Space-time Tracking and Event Reconstruction (FASTER)	NWO-ENW-XL	2023-2027	3.100
Watts et al	Probing the phase diagram of quantum chromodynamics.	NWO-ENW-XL	2023-2027	3.103
Hoekstra et al	Using cold molecules to find a gap in fundamental symmetries.	NWO-ENW-XL	2023-2027	2.700
Hoekstra	Searching for missing antimatter with trapped molecules.	NWO-VICI	2023-2028	1.500
Bouwhuis	A database-integrated KM3NeT solution for automated processing (DIKSAP)	NLeSC	2023-2025	213
J. Steinlechner	Revolutionizing Mirror Technology to Discover the Dark Universe	EU/ERC StG		2.500
Freise et al	Einstein Telescope Preparatory Phase	EU	2022-2026	729
Bouwhuis et al	KM3NeT-INFRADEV-2	EU	2023-2026	225
Groep et al	SURF: GEANT Project GN5-1	EU	2023-2024	79
P. de Jong	SENSE: Search for new physics and technological advancements from neutrino experiments at the high intensity frontier.	EU	2023-2026	92
J. Visser	Versterking ILOnet	EZK	2022-2026	870
Bentvelsen et al	Einstein Telescope - Nationaal Groeifonds	OCW-NGF	2023-2028	PM

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COLOPHON

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This document was prepared based on discussions with the Nikhef scientific and supporting staff. Descriptions and evaluation of the scientific programmes were reported by the programme leaders.

This self-evaluation report forms, together with the strategy report, input for the six-yearly evaluation of the institute. Both documents may be viewed online:
Digital version Evaluation:
www.nikhef.nl/evaluation2017-2022
Digital version Strategy:
www.nikhef.nl/strategy2023-2028

Organisation: