



Evaluation 2017 - 2022

NWO Institute and partnership Nikhef

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1. Foreword by the committee chair

Over the course of this review Nikhef has consistently presented itself as the preeminent Dutch institution in particle and astroparticle physics, with a coherent strategy and a clear vision for the future. The uniformity of this approach has been evident throughout the evaluation in a way which is rare for such a research endeavour.

This is no small feat, as the institute encompasses the activities of six major universities with sometimes conflicting scientific ambitions. These university aspirations are alive and well, yet Nikhef provides a common platform for scientific and social debate and a stronghold of technical support. This is all the more true with the recent reopening following the renovation of much of the building, which now provides a focal point, the vertex, a meeting place for the exchange of ideas and the identification of common interests.

The review committee appointed by the NWO met in November 2023 and weighed Nikhef's self-evaluation against the realities and demands of the future. We found in the review that Nikhef has taken rather a modest presentation of its potential. Nikhef will not only have to support the short-term strategy of particle and astroparticle physics, namely for the time 2023-2027. Nikhef is also the only institution capable of leading the next gravitational wave detector in the EMR region to approval. While Belgium and Germany will be partners in this endeavour, the Netherlands, and therefore Nikhef, is the natural place to make the proposal a success. Nikhef includes Maastricht University, where extensive experimental preparations and research are being carried out. On the political side, however, Nikhef must take the lead, with the support of NWO. Developments must be closely monitored: The preparatory activities of hosting the Einstein Telescope (ET) in the EMR-region will remain a separate activity of Nikhef, until the ET becomes an international organisation in its own right.

Not a small but fitting challenge for Nikhef.

Last but not least the committee wishes to thank the Nikhef management and meeting organisers, in particular Rosemarie Aben, for hosting this meeting in a very pleasant atmosphere. The committee is also grateful to Dr. Meg van Bogaert in preparing this report and to Dr. Maartje van Kempen, our contact to NWO-I.

Eckhard Elsen
Chair Review Committee

2. Executive Summary

The participating six universities and Nikhef have devised a strategy that perfectly serves the demands of the large international infrastructures and positions Nikhef at the forefront of experimental and technology development, backed by theoretical studies and advanced computing. Common underlying mechanical, electronics and computational challenges have been identified that can be applied consistently to various experimental environments. Such an approach minimises the required resources and maximises impact. The selection of the research topics has been made to correspond to the talents in the universities and has been extended by matching expert recruitment.

European research institutions, such as CERN in Geneva, have managed to attract the forces of participating member states in joint projects at the forefront of science that otherwise would not be feasible. The LHC is such an example where the accelerator infrastructure is financed through formally agreed member state contributions while the construction of the experiments is largely left to the participating universities or research infrastructure. With several thousand scientists engaged in an experiment, individual contributions risk to be overlooked and the efforts to be neglected. This is not the case for the laboratory Nikhef, the Dutch Institute for Subatomic Physics.

Nikhef has consistently made an effort to further the ground of common approaches while fostering excellence in the individual topics. Open and transparent communication and ample room for discussion create an environment that springs the best ideas and rapid realisation of projects. This spirit shows in the large number of leadership positions Nikhef has been awarded with. It also shows in the large number of excellent PhD theses that have been completed.

Staff draws considerable satisfaction from working at Nikhef, irrespective of whether employed by Nikhef or a university. Gender balance has considerably improved over the past years and a Diversity, Equity and Inclusion (DEI) plan is emergent.

The excellent research strategy has been formulated for the foreseeable period and is both demanding and sound. It will maintain Nikhef's prominent role. However, this prominent role will only be possible if the base funding can be maintained at a sufficient level. It would be naive to suppose that the distinction and excellence of the Nikhef infrastructure and the scientific exploitation of the long term projects can be accomplished with ad-hoc funding from projects of comparably short duration.

Nikhef also has significant weight in a role of science management and science policy. Nikhef has to take the Dutch lead both in the discussion of the long term strategy at CERN, which is well under way, and in the realisation of the next generation of gravitational wave detectors. While the former has recently begun in earnest the latter needs the backing at the highest political level to enable international discussion.

The committee very much commends the example set by Nikhef.

3. Procedure

3.1 Scope of the evaluation

This evaluation was carried out as part of the evaluation of the nine research institutes of the Dutch Research Council (NWO). NWO asked evaluation committees of external peers to perform an evaluation of its research institutes over the period 2017-2022. Quality assurance agency Academion acted as independent intermediary to safeguard the quality of assessment, providing secretaries for each of the site visits and helping the institutes and evaluation committees prepare and execute the site visits together with NWO-I, the institute organisation of NWO.

The evaluations were carried out according to the Strategy Evaluation Protocol 2021-2027 (SEP), the protocol for research evaluations in the Netherlands, agreed upon by NWO, the Royal Netherlands Academy of Arts and Sciences (KNAW) and the Universities of the Netherlands (UNL). The committees were requested to carry out the evaluations according to a list of questions derived from the main assessment criteria of SEP (see appendix 1). The assessment was to include a backward-looking and a forward-looking component. The committees were asked to judge the performance of the institute based on the list of SEP questions and to offer its written conclusions as well as recommendations based on considerations and arguments. The main assessment criteria are:

- Research Quality;
- Societal Relevance;
- Viability.

During the evaluation of these criteria, the committees were asked to incorporate four specific aspects relating to how the institute organises and actually performs its research, its composition in terms of leadership and personnel, and how the institute is run on a daily basis. These aspects are:

- Open Science;
- PhD Policy and Training;
- Academic Culture;
- Human Resources Policy.

For more information on the SEP questions, see Appendix 1.

3.2 Composition of the committee

The committee for the evaluation of Nikhef was appointed by the Board of NWO, and consisted of the following members:

- Dr. Eckhard Elsen, Frankfurt Institute for Advanced Studies, Germany;
- Dr. David Shoemaker, MIT, USA
- Dr. Jorgen D'Hondt, Vrije Universiteit Brussel, Belgium;
- Dr. Frank Schuurmans, ASML, the Netherlands;
- Dr. Marek Kowalski, DESY, Germany;
- Dr. Paula Collins, CERN, Switzerland;
- Dr. Rohini Godbole, Indian Institute of Science; India.

The committee was supported by Dr. Meg van Bogaert, who acted as secretary on behalf of Academion. Dr. Maartje van Kempen was present during the site visit to support the committee on behalf of NWO-I.

3.3 Independence

Before the site visit all members of the committee signed the NWO Code of Conduct, by means of which they declared that their assessment would be free of bias and without regard to personal interest, and that they had no personal, professional or managerial involvement with the institute or its research programmes. It was concluded that the committee had no conflicts of interest. The NWO-I coordinator present during the site visit did not take part in the evaluation, but provided the committee with background information and context on the position of the NWO institute upon request.

3.4 Data provided to the committee

The committee received the self-evaluation report from the institute, including all the information required by the SEP. The committee also received the Nikhef Strategy 2023-2028.

3.5 Procedures followed by the committee

The committee proceeded according to the SEP 2021-2027. The secretary instructed the committee chair on their role in the evaluation. In its first meeting on 24 October 2023, the committee was briefed by the secretary on research evaluations according to the SEP 2021-2027, and by the NWO-I coordinator on the Dutch research landscape and position of the NWO institute therein.

Prior to the site visit, all committee members independently formulated a preliminary evaluation based on the written information that was provided before the site visit. During its preparatory meeting on 20 November 2023, the committee discussed the preliminary evaluations and identified questions to be raised during the site visit. It agreed upon procedural matters and aspects of the evaluation. The site visit took place on 20 -22 November 2023 (see the schedule in Appendix 2). After the interviews the committee discussed its findings and comments in order to allow the chair to present the preliminary findings and to provide the secretary with argumentation to draft a first version of the evaluation report. The final evaluation is based on both the documentation provided by Nikhef and the information gathered during the interviews with representatives of the institute during the site visit.

The draft report by the committee was presented to Nikhef for factual corrections and comments. In close consultation with the chair and other committee members, the comments received were reviewed to draft the final report on March 4, 2024. The final report was approved by the Board of NWO and endorsed by the Nikhef board.

4. Evaluation of Nikhef 2017-2022

4.1 About Nikhef

Nikhef (National Institute for Subatomic Physics) coordinates and leads the Dutch experimental activities in the field of subatomic physics. 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. Six Dutch universities participate in the Nikhef partnership: Radboud University, Utrecht University, University of Amsterdam, VU University Amsterdam, University Groningen and Maastricht University. The Nikhef partnership (NWO institute and its university partners) is governed by the Nikhef Board. Since the addition of Maastricht University to the Nikhef partnership in the evaluation period, the Nikhef Board consists of eight members; six members assigned by the six university partners and two members assigned by NWO-I. The Scientific Advisory Board (SAC) is the external advisory board for the Nikhef Board and consists of (maximum) seven international experts in Nikhef's fields of research.

Daily management of the institute takes place in the Directorate Team (DT), consisting of the Nikhef director, institute manager and the head of the personnel department. Since March 2023 an additional member is part of the DT, the strategic advisor. Scientific policy is discussed in the scientific council (WAR), which serves as the internal advisory board for the Nikhef director. The committee is impressed with the way the current director leads the institute.

Research at Nikhef is organised into programmes, each led by a programme leader (PL) 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. At the time of this review, there were eleven programmes:

- LHC experiments: 1) ATLAS, 2) LHCb, and 3) ALICE
- Astroparticle physics experiments: 4) Neutrino physics (KM3NeT, DUNE), 5) Gravitational waves (Virgo/LIGO, ET, ETpathfinder), 6) Cosmic rays (Pierre Auger Observatory), 7) Dark Matter (XENONnT), and 8) eEDM (low-energy precision)
- Enabling programmes: 9) Theoretical Physics, 10) Detector R&D and 11) Physics Data Processing

In addition to the research programmes, technical expertise is organised in three groups: a) Computing Technology, b) Electronics Technology and c) Mechanical Technology.

4.2 Mission, vision and strategy

The mission of 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.

The Nikhef strategy for 2017-2022 included three topics: Proven Approaches, New Opportunities and Beyond Scientific Goals. The strategy of these three topics is very well thought through and paid dividends. The Nikhef strategy for 2023-2028 "Connecting the Large and the Small" sets a slightly different focus with four themes: Expanding Knowledge, Providing Technologies, Preparing the Future and Fostering Healthy Partnerships and is well matched to the coming challenges and positions Nikhef accordingly. According to the committee, the Nikhef mission statement is clear and positions Nikhef in the Dutch research landscape. The short term goals directly profit from the expertise at Nikhef and constitute a natural and important evolution of the past activities. Nikhef has an excellent focus on topical developments with impact and

assumes leadership in several of these international endeavours. The short and long term strategies are well-balanced, and leverage optimally the capacity and experience built up at Nikhef. The scientific questions addressed are at the core of the global scientific endeavour. Some of the scientific themes span across different research groups at the Nikhef institute enabling prolific cross-institute actions to address the questions. The strategy for technology R&D is such that the innovative technologies are key enablers for scientific exploration and at the same time envisage concrete societal applications.

The Nikhef strategy is based on the most fundamental and therefore very ambitious science drivers. With the engagement in three LHC experiments Nikhef is able to approach its physics from three different angles. The engagement in gravitational waves is exemplary and well thought out. This engagement finds its complement in the participation in the Auger experiment and emerging neutrino physics in DUNE. Apart from the LHC, new physics is explicitly addressed in the search for dark matter and the measurement of the electron electric dipole moment. The activities in the theory department embrace many of the experimental programmes. The group certainly fulfils the role of being an enabling programme for the Nikhef community and in addition is playing a central role in the development of particle phenomenology, not just in the Netherlands but worldwide.

One key pillar of the strategy for Nikhef relates to its unique position as a coordinator of the Dutch activities in the fields of accelerator based and astroparticle physics. The tight collaboration between Nikhef and the universities enables an impact which is greater than the sum of its parts, driven by the vision for the Nikhef strategy and the opportunities that can be provided by the central grouping of expertise and infrastructure. Other countries look to the Netherlands as setting an example in terms of what can be achieved with this model. In the evaluation period Nikhef has welcomed both the University of Groningen (2016) and Maastricht University (2019) as new partners. In recent years, due to the pandemic and renovations of the Nikhef building, it was not easy to stimulate and maintain the sense of community. The increased number of partners and the enlarged geographical collaboration – both Groningen and Maastricht being remote from Nikhef in Amsterdam – emphasises the need for Nikhef to pull its weight in the partnership. This is reinforced by the challenges in recent years to foster and maintain the community feeling. Remote work during Covid-19 was prolonged by the renovation of the Nikhef building. At the same time, the growth of Nikhef is again a confirmation of the validity of the quality of the science offered by the Nikhef strategy. The growth is testimony that universities are confident that the Nikhef model is the most impactful path to the future.

Nikhef is a powerful long-term national strategic resource, which enables the Netherlands to punch above its size on the international stage. One of the reasons that Nikhef has been able to demonstrate impressive impact and be internationally competitive is its ability to share common infrastructure (workshops, computing) and shared expertise (engineers, software experts) between its various programmes. The proven success of Nikhef, which is the envy of many countries in terms of research model, is the breadth and strength of its critical mass of expertise. This requires long term strategic funding to attract and retain the right people and to compete with industry. The Nikhef partnership model is a precious resource which has been built up over a long period of time and has repeatedly proved its worth. Nikhef has the responsibility to use its authority to continue to provide a strong voice in the international collaborations where it forms a part as well as within institutions such as CERN. The model should be fostered and protected, including with a funding strategy more matched to the long term structure.

4.3 Funding

The total annual Nikhef income has increased in the evaluation period (from 38.5 MEUR to 49.3 MEUR per year). Nearly all increase is attributable to the increase in contribution via the university groups who now contribute more than a third of the total effort. Whereas the total budget has increased, the NWO mission

budget has been static, taking into account inflation the mission budget even shows a shortfall of 2 MEUR. According to the committee, the mission budget of Nikhef should keep pace with the total budget, otherwise it could be destabilising to the partnership.

As mentioned above, Nikhef is a powerful long-term national strategic resource. The committee is of the opinion that it would be logical if the funding structure therefore should match long term vision and commitment, requiring long term strategic funding to attract and retain the right people and to compete with industry. This can in turn help in securing shorter grants, but relying on punctual short term competitive funding disrupts continuity, requires wasteful shut-down and start-up cycles, and is thus unsuited to provide the long term stability needed to deliver outstanding science. It must be recognised that grant acquisition must be embedded in a bigger picture and a stable institute that provides the knowledge and experience. In the past, this is how Nikhef has been able to punch above its size.

As the committee concluded from the programme evaluations, Nikhef has made scientific choices enabling it to build core components of experiments in international collaborations, e.g., those at CERN. For the sake of Nikhef and of getting the best science, these groups must be involved in the exploitation of these instruments. However, the current trend of increased focus on individual, short-term grants severely risks upsetting this proven successful model, as insufficient long-term strategic funding makes it impossible to properly acquire the required long-term resources, plan investments, and provide a perspective for the people on whose expertise this strategy builds. Hence the need to re-address the balance between long term strategic funding, and shorter-term competitive funding instruments.

4.4 SEP aspects

4.4.1. Diversity and Equity and Inclusion(DEI)

In the evaluation period, Nikhef particularly focused on improving the gender balance. This was achieved using actions like the development of procedures for inclusive recruitment, organising workshops on diversity and unconscious bias towards minority groups, and paying attention to inclusive communication. The efforts resulted in an improved gender diversity, in particular among the research staff. The percentage of female permanent scientific staff members increased from 12.3% to 27.4% and that of female PhD candidates to 32.4%. Although the committee commends this development, it also notices that the percentage of female postdocs decreased and the technical/engineering staff remains low with 7% females. The committee concludes that Nikhef managed to significantly improve the gender balance during the evaluation period and has demonstrated approaches that can work in the future. Nikhef is to be congratulated for taking such a lead in the field of international scientific research institutions, and should be encouraged to further improve gender balance.

In addition to improving gender parity numerically, Nikhef is shifting focus to creating a diverse and inclusive environment. The Diversity, Equity and Inclusion (DEI) task force, composed of seven Nikhef staff members, is just getting going. The DEI task force consists of a mixture of PhD candidates and (research) staff and at various levels of seniority. Some of the plans in development are a 'diversity day', and a focus on welcoming to non-Dutch community members. The task force is enabled to gather observations from the community and communicate observations, presumably anonymised, to the Directorate. It has a clear mandate from the Director, and support from the HR manager, to critique the Diversity & Inclusivity Plan the Director is currently drafting. The scope of the task force and its intentions are broad and the comfortable interaction with the PhD candidates and professionals at Nikhef will be invaluable in forming a functional optimised plan, to help execute it. The committee notes that the task force is not directly involved in hiring, although they could participate in the endeavour to create hiring plans which are more DEI-positive.

The committee is of the opinion that it is crucial to adopt a very broad scope for inclusivity. In addition to gender, religion, nationality and gender identity, neurodiversity, and vision, hearing, and in general physical infirmity are all important underrepresented minorities to be listened to, and included in plans to address shortcomings. One additional point of attention is that Nikhef should also focus on the “leaky pipeline”, the loss of diversity towards more senior positions. It is therefore important to talk to PhD candidates and young scientific staff to hear their experiences to understand how they may feel excluded or more successfully engaged. The committee observed during the site visit that the PhD council is verbal, and comes with observations from the PhD candidates, e.g., that neurodiversity is an issue for students. From this the DEI task force can ‘customise’ the programme to address the specific issues found at Nikhef. Although there is still a way to go, the committee is of the opinion that the Nikhef community is already wonderfully diverse, and can profit from having a voice in the form of the task force.

4.4.2. Academic culture

Nikhef aims at creating a climate in which people can find and meet each other, in order to have ideas and insights emerging from the interactions. This implies that people meet in a physically and psychologically safe environment. This also includes bringing together a diverse group of people who view challenges from a multitude of perspectives. The long duration of the renovation and lock-downs during the Covid pandemic unfortunately put a strain on the interaction, making personal contact virtually impossible. The Nikhef building has been renovated with the intent to stimulate interaction. The committee was impressed by the (completely renovated) Nikhef building and the facilities it offers; the ‘vertex’ seems an excellent place to be used as a meeting point and allow for the exchange of ideas.

Although the stated principles of openness and inclusivity are laudable, some metrics for other measures of diversity would be welcome. A safe environment for all is not discussed in any detail in the self-evaluation report, while mentioned as a value and goal. It would be good to also have some metrics for this aspect of the social environment and hear more specifics of how vulnerable persons are protected. From the interviews during the site visit, openness, safety and inclusivity come across as intrinsic goals of Nikhef’s management, and the organisation is fostering them proactively by training and dedicated activities. Efforts on gender balance have been successful among the cohort of junior researchers, and new efforts are planned to evolve this success in due time also to the level of senior researchers. Beyond the gender dimension, other important dimensions of diversity are being addressed, not only in numbers but also towards a full inclusivity in the organisation of the institute and in the life at the institute.

4.4.3. Sustainability

Although not a SEP-aspect, Nikhef wanted to inform the committee on its initiatives concerning sustainability. In the evaluation period, the Nikhef Sustainability Roadmap emerged, based on a CO₂-equivalent footprint analysis. Sustainable travel is a spearhead in the Roadmap, with a goal of reducing air travel. Nikhef is taking sustainability very seriously and is actively driving a change programme in the organisation to create more awareness and change the mindset. Especially with respect to travel, significant steps were and can be further made, for instance taking the train instead of the airplane. The committee applauds the approach and is really impressed by the attention to the topic. In addition to the very good initiatives so far, the committee would like to trigger an even more extensive approach, by including the footprint of the work that is being done at Nikhef. Performing science, especially the experiments and the computing, is energy intensive and including the sustainability considerations in the design of these activities will lead to further improvements.

4.4.4. Open Science

Open and collaborative science is a key value of Nikhef's strategy and an integral part of the way research at Nikhef is conducted. The majority of the data are managed collectively through international experiments. According to the committee, recognition at Nikhef of the importance of making data accessible and useful is clear in the description of activities over the evaluation period. Nikhef is one of the early subscribers to the Open Access policy and data management. The FAIR principles are at the core of their business model and Nikhef can be placed among the pioneers of open and FAIR data in the field. These concepts are embedded into projects from the initial design/definition stages. Almost all papers are published open access. The culture of Nikhef seems well matched to promote open and collaborative science, beyond just "ticking the boxes" and proactively including the concepts from an early stage.

In the self-evaluation report there is no explicit discussion of public access to Gravitational Wave (GW) data, which is currently held privately for up to two years after collection. This approach was seen as necessary to initially build up the Virgo and LIGO collaborations and to establish the field of GW science. Reconsideration of this policy may be timely. A roadmap from today's practice in data management to that of the Einstein Telescope epoch (2035-2040) would be valuable in planning and executing an adiabatic transition both in terms of the technical approach as well as managing the sociological shift. Evidently this is a matter of the experimental collaborations at large but Nikhef could provide its opinion.

4.5 Research quality

The research quality of the eleven Nikhef research programmes will be evaluated separately in chapter 5. In this chapter, the committee provides its evaluation on Nikhef wide aspects on research quality.

Nikhef has a strong and coherent organisation that allows the institute to take a visible place in the international landscape. The management of the institute can truly speak on behalf of the institute, and accordingly the management is well informed to engage with impact in the international organisations and committees. Nikhef's reputation is outstanding and Nikhef is welcomed in all European high-level committees for oversight and steering of the research. The institute is very visible on the international landscape, much more than the size may suggest. Nikhef has been on the vanguard of introducing new technologies and continues to do so by carefully selecting topics. The scientific impact is evident in the distinction of the academic staff.

Researchers associated with Nikhef are generally highly regarded and are accordingly invited or elected to leadership roles in international research collaborations. Nikhef has an outstanding reputation in the field. It is seen as a serious and leading institute with leadership being provided at all levels. At the senior level the impact exceeds expectations in terms of named leadership positions, and in high-profile European steering committees. This leadership is clearly something that is nurtured and fostered within the institute at an early stage. The leadership of Nikhef is automatically transferred into the highest levels of European and international leadership due to the high respect and again, outstanding reputation.

4.5.1. Facilities and Infrastructure

The real backbone of the success of Nikhef comes from the excellent mechanical, vacuum, and electronics labs, both in the teams and the technical capabilities. The committee was very impressed with the site tour, which showed the essence of Nikhef. The matrix approach for the utilisation of the workshop and the full vertical integration from shop to science results is unique and must be preserved. The mechanical workshop has gained reputation with the series production of the LHCb RF vacuum foil, and its engagement in the seismic isolation of the suspension of the mirrors of gravitational wave detectors. The electronic workshop excels in the production of ASICs and FPGAs for frontend electronics and triggering. The LHC detectors will

have to rely on timing to discern the individual vertices. An accuracy of some 10 ps is required. Nikhef has identified this topic as a common challenge for the future which will be a focus in the laboratory and is within reach of the very capable teams. The computing centre is also impressive and the number of networks hosted on the Nikhef premises is spectacular. There is a commercial benefit to Nikhef from the latter, and a social benefit to the greater community. Given its location in the Nikhef building, the PUE (Power Usage Effectiveness) of 1.3 is commendable but cannot compete with that of modern specifically designed computer centres.

Some of the Nikhef physicists indicated the concern that the continuity and complete vertical integration of the design-fabrication loop may be lost in a cost-cutting venture. The value of the integrated workshops and technical/engineering skill is central to Nikhef's abilities and stature in the field, and the ability to attract a certain kind of scientist who wants to work in this unique environment.

4.5.2. Wetenschappelijke Advies Raad (WAR)

Scientific policy is internally discussed in the scientific council (Wetenschappelijke Advies Raad, WAR), which serves as an internal advisory body for the Nikhef Director. From the meeting with the WAR during the site visit, the committee got the impression that the WAR has a broad list of activities organised to encourage interaction within the institute.

The committee had the impression that the WAR functioned outstandingly and that its discussions have an impact to shape Nikhef's future (e.g., the emergence of discussions on future colliders) and that the management is receptive to its input. It is a model that should be praised and fostered. It seems that the WAR has an explicit place in the organisation of Nikhef, but it is not clear if the WAR is formalised in Nikhef's constitution with mandate. If that is not the case, the committee recommends to Nikhef to reflect and act in this direction.

4.6 Societal Relevance Nikhef

With the focus on fundamental research the primary goal of Nikhef on societal relevance is in educational and cultural terms. The direct application of results from this research to society at Nikhef is very limited. However, to enable application, science technologies are being developed that can, and will have impact on society, for example the MediPix efforts with Nikhef being a major partner. Nikhef has always been very inventive in making sure that the experimental tools also find their way into society, often in a surprising way. The self-evaluation report has several appealing statements demonstrating how work on knowledge and technology are shared and to maximise this impact.

4.6.1. Communication and outreach

Nikhef's science lends itself very well to entice interest with the greater public in science and technology, and stimulates young people to start a career in science/physics, which undoubtedly has a positive impact on the innovation potential of society. The public is usually very interested in topics of particle physics and astrophysics, and accordingly, the research performed at Nikhef has the potential to trigger fascination and interest among many age groups. It can motivate the youngest to study physics, a useful education with broad applications in industry. The interaction the committee had with the 'communication and outreach group' was also fruitful. The Nikhef staff, including PhD candidates, is involved in a number of interesting outreach activities, helped by the communication and outreach group. Extending it to the local environments of the partner Universities is envisaged and will leverage the advantage of the Nikhef model.

4.6.2. Knowledge impact

Spinoff and valorisation are supported from a bottom-up approach with which the committee agrees and some very impressive examples have been shown. Attention is paid not to create an imbalance in the Nikhef

core portfolio: when an idea can be transferred to a commercial endeavour in a way which strengthens Nikhef, support and encouragement are available. There is a proactive effort with industrial contacts to approach industry, and close coordination among the network of institutes. Education is also a priority. In the case study presented, cooperation is close but has sufficient formality, and offers return to Nikhef in the form of in-kind contributions and sharing in profits and management in the firm.

Nikhef's industry liaison office is well organised and connected to help develop spin-offs activities. With a view to further stimulate Nikhef researchers in the direction of knowledge transfer and developing applications, establishing a dialogue between current Nikhef researchers and Nikhef alumni successful in the corporate world would have an impact.

Nikhef has an organic process in which solutions for research needs lead to contacts with industry, enabling the industrialisation of a scientific tool, and then to either a collaboration or potentially the start of a new firm. PhD candidates learn a great deal in their research at Nikhef which is useful in transferring to industry after their PhD. It may be of value to keep track of students who move to industry to build a more complete story for the impact and to help new candidates find contacts; organising a day or evening meeting periodically of graduates together with current students could be a powerful tool for networking. Arranging for visits back to Nikhef can be mutually advantageous.

4.7 Viability of Nikhef

The institute has a convincing institute-wide strategy with clear ambitions and a strong organisational structure with an increasing number of partners. Nikhef is able to approach a broad range of subatomic physics from different angles, making the different research programmes complementary to each other. The committee is very impressed by the scientific results in all physics experiments and research programmes and there is no doubt on the viability of the institute

For two decades the LHC endeavours are the main driver of particle physics research in Europe and the place where Nikhef's strategy enabled the Netherlands to achieve significant impact. This was and remains a prolific basis to foster a variety of connected but complementary research programmes that have attracted numerous external and competitive funding grants. Also the engagement in gravitational waves is exemplary, with Nikhef playing an important role in the early approach phase with a well thought-out plan, as is discussed later on. Additional compliments can be given on the engagement in neutrino physics, specifically in the DUNE activities. In addition, Nikhef addresses some aspects of new physics, in dark matter and eEDM programmes. Together with the workshops and technical staff that constitute the backbone of Nikhef, the institute can and does compete on the international stage. The matrix approach that is implemented proves very useful, with unique vertical integration from the shop to the science that Nikhef should preserve.

With the occupancy of the renovated building ('Vertex') in November 2023 the years of limited physical interactions due to Covid-19 and temporary housing will be left behind. The building will be put to use and stimulate interactions (formal and informal) between Nikhef staff. The committee hopes and expects the Vertex to become a respected meeting point to exchange ideas to also attract researchers from the more distant university partners.

PhD candidates and postdocs appear to be content and engaged. The self-organisation of the PhD-candidates is very successful and gives them a sense of ownership. In the four years of their PhD, this group is really developing into mature scientists. The committee is propagating to also include the mentorship for postdocs. This group is beyond direct training, but not yet at the level of seniority to work independently.

With the expansion of Nikhef, it is more difficult to have a cohesive cohort of PhD candidates. Now, after Covid-19, this might require some increased attention.

Regarding diversity, Nikhef made big strides towards achieving gender balance. The committee admires the progress made that shows that it is possible to make a difference. The committee encourages the institute to continue paying attention to broader diversity and inclusion. The DEI task force and Diversity and Inclusion plan will be tested via its implementation.

In conclusion, the committee is impressed with the many strengths it encountered during the site visit and in the self-evaluation report, that jointly provide a solid and outstanding basis for the future of Nikhef. There are some challenges and future plans that require attention and on which the committee has more extensive input. These are the Nikhef roles in CERN, the Einstein Telescope, and ensuring long term strategic funding.

4.7.1. CERN

Nikhef has carved out a good and consistent scientific programme. However, a vision of the far future in accelerator science has not been presented and needs attention. Approximately 50 MEUR goes to CERN annually, so Nikhef could and should speak up in CERN Council and help shape the CERN science programme in a way that fits the Dutch interests. Nikhef also should engage in the exploration and decision process, as it is important to engage in a comprehensive discussion. The committee did notice that initial steps are taken with the future collider discussion task force. There are more aspects where Nikhef could influence the present and future CERN programme that could be put into action. The Netherlands has a voice in the council and could look for strategic partners to set the agenda. Reporting the Nikhef opinion is important, which should be the message from the Netherlands.

4.7.2. Einstein telescope (ET)

Nikhef is clearly positioning itself as the initiator of the ET and rightfully so. The approval of the ETpathfinder project sets out the road for the development of a gravitational wave programme focused on the Einstein telescope. The ETpathfinder will probe and verify the technical solutions for the eventual telescope and establish its viability. Nikhef plays a vital role in the initial founding process of ET and is superbly positioned to lead on the path to its ultimate realisation.

In an important new initiative, funds were obtained (42 M€) to pursue the siting of ET near Maastricht. This also involved establishing partnerships with multiple regions in the Netherlands and with Germany and Belgium. This activity is a strong indicator of imagination and success in conception and execution of a vision. In the case the ET indeed will be built in the Belgian/German/Dutch area, the impact on Nikhef is going to be profound.

Nikhef has a clear vision for the future in the domain of gravitational-wave science, with significant activities in the instrument realisation via the creation of ETpathfinder and the activities of the groups pursuing technologies and the development of the observational science exploitation. Synergy with other efforts in nuclear physics and multi-messenger astrophysics is strong, and is taking advantage of Nikhef's organisation. As in other domains, the stability of the funding (mission vs. narrow-scope smaller grants) is somewhat of a concern to the scientists working in this field. Maintaining an optimal balance with the present Virgo detector development and operation is critical to the long-term health of the field in Europe.

The committee supports the approach that Nikhef is taking to start laying out the organisation and governance structure in an early phase - likely with ET ultimately being a separate organisational entity next to Nikhef. It appears to the committee that the best near-term approach is for the ET to be maintained as a

Nikhef project, taking advantage of the formidable management, scientific, and technical skills of the Institute. While it will require some strategy and discipline to ensure that the ET Project does not imbalance Nikhef's portfolio, a project of this scale requires what Nikhef can offer in proceeding through the initial phases of site selection, funding approaches, and establishment of the definitive observational science goals and the technical infrastructure to deliver them. Once ET is launched, it is likely that the new ET Organisation can take on much of this scope, and Nikhef can then take a perspective more like that with CERN or other large multi-institution projects.

It is evident that success with the Virgo instrument is a prerequisite for a credible path to ET, and Nikhef both needs to ensure its programme supports this fact, and can in its leadership role help the ET community broadly appreciate this imperative.

4.7.3. Long term strategic funding

The Nikhef model of collaboration with the universities gives a much increased visibility to the universities and the Dutch research programme as a whole. However, the Nikhef base funding is insufficient and jeopardises the scientific successful exploitation of the investments made. The current funding model, in which Nikhef has to operate, is not commensurate with the long-term objectives of its scientific instruments (big science). The proportion of base funding is decreasing and does not allow proper utilisation of the infrastructure for science purposes and returns on the investments for the infrastructure. The burden on the scientific staff to prepare proposals with a probability of success of 20% compounds the difficulty with the present situation. This general European tendency to compete for research funding is not unique to Nikhef, but the Netherlands, through Nikhef and the six-year cycle SEP review, has a unique opportunity to establish a pioneering view on commitments to long-term research programmes like those at CERN.

The self-evaluation report and the strategy highlight the funding challenges which lie ahead with the tension between the institute planning, which can be more closely tied to long term strategy and international influence, and short term national funding competition. This can create gaps with destructive effect on the best use of physical and human resources, and Nikhef not being able to exploit its own investments. Judging from the evaluation Nikhef has been an exemplary model of collaboration between institutes and universities, which rests on long term strategic planning and passing on of knowledge and the scientific expertise built up in the groups with sufficient postdocs and PhD students.

4.8 PhD Policy and Training

Supervision of students is a core responsibility of Nikhef and a key element of the collaboration with academic partners. In partnership with the universities Nikhef plays a crucial role in ensuring that the young graduating men and women go out into the international research environment with the highest reputation and the strongest training and foundation. The attractiveness of Nikhef to PhD candidates is intimately connected to the entire research strategy in the sense of the strength of the Nikhef offering. This can include access to cross disciplinary expertise in hardware or computing, opportunities for interactions between the national student cohort, training for scientific collaboration in a supportive environment, support on the PhD publication, style and impact. All of this can and will weigh crucially when PhD candidates move on with their research careers. It is a critical future investment for Nikhef in terms of the leadership of the future and the international reputation, both for the institute and nationally.

PhD candidates 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 provide education, mentorship and training (scientific and in soft skills), supporting them along the trajectory of obtaining a PhD. The Nikhef Education Committee (OWC) is coordinating the PhD training and education,

including providing Topical Lectures (four times per year), The Belgium-Netherlands-Germany international graduate school and Computing at Nikhef. Although some supervisors (and sometimes as a result PhD candidates) might not be pleased with PhD candidates spending time on soft skill training and content courses that are outside the scope of their research project, the committee is commending Nikhef for providing a broad training to its PhD candidates.

In addition to their (co) supervisors, PhD candidates are assigned a C3-mentor. This is a Nikhef staff member from a different programme with sufficient experience in PhD supervision who meets regularly with the PhD candidate. The C3-mentor is supporting the PhD candidate at various stages in the process, ensures that appropriate steps are followed, and is the first contact to raise issues related to (for example) conflicts with the supervisor or other colleagues. The C3-mentorship scheme results in a safe environment by having an independent mentor who is regularly meeting with the PhD candidate without (co)supervisors. PhD candidates are positive about the C3-mentorship programme and the committee is of the opinion that extending it to the postdocs would be valuable.

The geographical span of Nikhef has grown, and the best approach to maintaining cohesiveness of the PhD candidates across the network will profit from a fresh look. The Nikhef broad challenge over the past years to realise in-person meetings is also observed in the PhD and Postdoc cohorts. The committee understood that in particular in the group of PhD candidates that have to travel a long distance there is a lack of enthusiasm for going to Amsterdam. Some have to stay in a hotel (and pay themselves) to be on time for meetings and courses. This issue requires attention.

Although mental health has the attention of the OWC and institute management, the committee recommends making it a central and embedded part of the programme. It is also important to pay attention to the diversity and inclusion in the context of women as well as international PhD candidates and other minorities. The PhD and postdoc representatives stated that the institute can gain something by inclusion. It is desirable that Nikhef set up some special programmes which will work towards keeping women in a science career after a PhD. Traditionally the number of women decreases after completion of each stage: from master to PhD to post-doctoral programme and finally to a career in Physics. Some of the efforts for retention might be integrated within the education and training of PhD candidates.

The committee perceived that the group of postdocs feels not connected as a community and most do not feel strongly connected to Nikhef. The challenge to include the postdoc-community is not unique to Nikhef or the Netherlands. Postdocs often stay only for a short period, making it difficult to be fully integrated. Nevertheless, the committee is of the opinion that action can be taken. As mentioned above, the postdocs could benefit from the mentoring that PhDs are receiving, including career monitoring. The committee furthermore suggests the introduction of an InterVision scheme to help postdocs meet each other and discuss their issues and challenges (that are often similar to that of their colleagues).

The conversations with PhD candidates and postdocs showed a cohort of junior research staff that was clearly content and engaged. Nikhef has recognised the changes in the attitude of young researchers and their expectations and is well responding. The mentoring programme for the PhD candidates and their self-organisation have been very successful and give a sense of ownership to the candidates for their experience. One of the initiatives that was appreciated, in particular by the international PhD candidates, is the buddy system.

The goal of the duration for a PhD trajectory is four years. Should PhD candidates take longer, the contract is usually extended. The median duration is 54 months, which is acceptable taking into consideration a delay

of several months between finishing the thesis and the defence. However, approximately 30% of the PhD candidates require more than five years. Although Nikhef is partly dependent on the policies and efforts of the various partner universities in this regard, the committee encourages keeping this group as small as possible.

The current practices for education and training of PhD candidates are quite praiseworthy. The programmes of topical lectures, BND graduate school and the C3 mentor are useful and serve their purpose. Equally important is the training of the soft skills which can also be very useful for retooling oneself for a new career after the PhD programme, if need be. In conclusion, Nikhef's organisation enables the Nikhef management to be very well and timely informed about potential concerns by its cohort of early-career researchers. For each PhD project a specific trajectory and a dedicated guiding team is put in place. The guidance is proactive and the researchers involved have in general been trained to successfully take up this important role. Taking into account suggestions and experiences, the system has evolved over the years and is now a cornerstone of the institute. Efforts should continue to match the effective PhD duration with the expected duration of 4 years.

5. Research Programmes

In the self-evaluation report, Nikhef provides the scientific highlights in the review period for each of the eleven scientific programmes. In this section of the report, the committee provides its findings on each programme.

5.1. LHC programmes

Nikhef has clearly made remarkable contributions to the flagship programmes of fundamental particle physics. The Institute has carved out a position for itself as a leading and trusted authority and voice in the international community.

The hardware contributions to the LHC experiments have been positioned at the “technological jewels” of the experiments with ambitious new techniques included for the upgraded Inner Tracker device of ATLAS, the vertex detector of LHCb, the ITS2 layers of ALICE, the spectacular lightweight scintillating fibre modules of the LHCb tracker, the RF box which forms the interface between the LHCb experiment and the LHC, and in the area of GPU trigger related technology. These contributions have been enabled through a long term investment and strategic vision of the institute. Each of these topics relates to a specific Nikhef expertise, which has been built up over time. An example is the way in which Nikhef has and continues to be a worldwide innovator in the topic of cooling, for instance the original “invention” of CO₂ cooling for particle physics experiments (and AMS) which has had such a huge impact, through to the construction of innovative lightweight cooling structures which have underpinned the construction of the ALICE and LHCb modules and will be important for the future ATLAS tracker upgrade. Similarly the LHCb RF box construction required investment in the milling machine which makes most sense when done centrally within the country, but then spins off into providing national access to the machines. Nikhef has taken on several major upgrades of the ATLAS detector, embarking on the new FELIX system for trigger and data acquisition, a complex and very ambitious project which has successfully been established at the core of the upgraded DAQ system and is being progressively rolled out, and the Nikhef mechanical expertise has again been in high profile with the assembly of the end-cap carbon fibre frames. On a more managerial level, Nikhef faculty also hold important leadership positions in the structure of CERN and CERN experiments.

The LHC programmes at Nikhef have been prolific in acquiring major individual grants to hire PhD candidates and postdocs. While this was the backbone for Nikhef’s success during the previous LHC Run-2, at this stage the level of funding through similar grants is not available to establish an equally impactful cohort of PhD candidates and postdocs for the current LHC Run-3. This comes exactly at the moment where Nikhef has the opportunity to leverage its major and successful investment and leadership. The groups are actively writing grant proposals, with several presently underway. In this respect, the demographics of the teams are crucial to success. The current funding continues until the end of 2025, and further resource loading and therefore enabling the long-term research programmes will depend on funding applications with a typical success rate of only 20%. The main threat all three LHC programmes identify, is the absence of a source of base funding to support the exploitation of the infrastructure. There is a clear gap in the systematic funding, for each new project a new, complex and burdensome process has to be started. This results in a lack of continuity, for PhD candidates and postdocs positions the programme relies on personal grants and NWO-XL. However, the NWO-XL favours broad consortia, making it a poor fit for this group.

In collaboration across its LHC groups and with a view to experiments at future colliders, Nikhef identified for its future detector R&D engagement the wide theme of timing detectors and 4D tracking particle detector technologies. The committee strongly values this vision and encourages Nikhef to establish a leading role in the related Detector R&D Collaborations emerging under the auspices of CERN. An exploration with the

corporate world in the Netherlands and Europe would have to be part of this programme to foster Nikhef as a major laboratory for these enabling technologies

The concerted and centralised capacity of Nikhef is a key enabler of the "full-chain" involvement in experimental particle and astroparticle physics projects with which Nikhef established great achievements, leadership and recognition for example at the LHC experiments. Initial and generic blue-sky R&D is performed at Nikhef with results integrated as novel enabling technologies into concrete detector and experiment designs that on their turn allow empirical observations with the capability to enter into new territories with dedicated physics analyses. This synergetic strategy between technology drivers and physics quests is to be fostered with the most talented researchers and research teams, supported with adequate long-term visions for funding and sustained technology platforms. Nikhef successfully demonstrated this strategy with its initial engagement in three major LHC experiments at CERN, and needs timely support to further implement this strategy for the next phases of the LHC.

5.1.1. ATLAS

At the energy frontier of particle colliders, Nikhef has made several high-impact contributions to the study of the Higgs boson, top quarks and searches for new physics with data collected by the ATLAS experiment and assumed high-level leadership in this broad international community. Theoretical interpretations in the so-called EFT frameworks have been pioneered. These contributions are unique and achieved via developments of innovative methods by talented Nikhef researchers. The new FELIX system for trigger and data acquisition developed by Nikhef is now the central backbone in the DAQ system of the upgraded ATLAS experiment towards the HL-LHC phase of the experiment, as well as in several other high-energy physics experiments the FELIX system enables optimal data taking. Nikhef has made a huge contribution at the cutting edge of ATLAS physics, focusing on some of the most important physics measurements including a wide portfolio of Higgs measurements, combined with new reconstruction techniques pioneered by Nikhef measurements, and combined interpretation techniques which have resulted in high profile publications.

Nikhef has been successful with its long-term strategic engagement in the ATLAS-experiment, embracing the importance of a *full-chain* involvement, for example from tracking detector expertise enabling advanced developments of tracking and heavy-flavour tagging (bottom and charm quarks) which – on their turn enable the high-end Higgs physics analyses with flavour tagging as an essential ingredient (e.g., Higgs boson decays to bottom-quarks) – an impactful model to plan as well future research projects in ATLAS.

Leveraging Nikhef's research environment, concrete and impactful projects between ATLAS experimentalists and the Nikhef theory group have been established in support of the interpretation of the experimental results. Frequent meetings between experimental and theoretical researchers at Nikhef are the trigger for discussions and seeds to unlock innovations especially in the interpretation of experimental data. The international ATLAS tracker upgrade is on a tight schedule with not much contingency, but already at this early stage Nikhef is exploring the option to increase its (technical) capacity in the project to accelerate the assembly. The machine learning methods are more and more intertwined with the research in ATLAS, and the ATLAS group at Nikhef initiated opportunities for PhD candidates with a Machine Learning master's degree to further deepen this cross-disciplinary opportunity. This opens the path to explore collaborations with computing science groups at universities in the Nikhef partnership.

5.1.2. LHCb

Nikhef is a stronghold in the LHCb experiment with participation and leadership in multiple high-impact analyses, including developments of novel ideas and innovative methods. By focusing on the key areas of CP violation and quantum loops, Nikhef has been able to produce results which are worldwide highlights in the

realm of flavour physics. Similarly on the hardware side, Nikhef has formed clear targets in the topics of tracking, triggering and DAQ, and hence has been able to draw on its core areas of expertise to make leading contributions to the most advanced components of the upgraded LHCb experiment. These include the spectacular 6 m long scintillating fibre (SciFi) modules of the tracker and the complex hybrid pixel modules of the 40 MHz readout Vertex Locator (VELO). For both of these construction projects Nikhef has led the complete cycle from design to construction, which in addition to the scientific impact, has also given significant ownership of these projects to Nikhef colleagues at all levels of seniority. Nikhef has designed substantial components of the high speed VELO readout ASIC, as well as the readout and evaluation system, and led the project. This effort grew as a natural continuation of Nikhef's longstanding involvement in the MediPix programme. Nikhef has designed, constructed and installed the cold boxes and readout system of the SciFi photomultipliers. In addition, Nikhef has opened up a new discipline with the addition of GPU technology expertise, enabling the design and commissioning of the new LHCb first level software trigger and the multi-threaded CPU-based second level trigger. These contributions rely on the infrastructure and traditional strengths available at Nikhef. For example, the VELO module design and construction, relies on expertise in precision machining, metrology, wire bonding, CO₂ cooling, system readout architecture, and control systems. In parallel to the hardware contributions Nikhef has also positioned itself at the exploitation interface for detector commissioning and has achieved impressive results in a broad range of high impact physics publications.

After the LHC vacuum incident Nikhef was able to mobilise resources to plan and implement a replacement strategy at CERN during the 2023-2024 winter shutdown, in addition to producing two completely new boxes at Nikhef to act as spares. This was a major and highly publicised endeavour which demonstrated the commitment of Nikhef to the success of the LHCb collaboration and the strength of its leadership and resources. Nikhef staff have held many positions of responsibility within the collaboration, including the prestigious elected position of physics coordinator.

Nikhef has already identified major opportunities for the LHCb Upgrade-2 detector which well matches the strengths of the institute. These focus on the development of 4 dimensional tracking devices, with close synergy with the Nikhef R&D activities. Nikhef will develop sensors with timing capabilities of the order of tens of picoseconds and high radiation tolerance, along with the infrastructure to be able to evaluate these devices and bring their individual performances to bear at system level. To this end, Nikhef has already developed a high speed Timepix4 telescope as well as lab based laser setups. The development of novel reconstruction algorithms will be crucial for the future of high speed triggering and reconstruction in complex high density environments. Nikhef plans to build on the expertise used for track finding and track fitting algorithms for the LHCb trigger system and extend this to the development of novel reconstruction algorithms using a heterogeneous computing model.

5.1.3. ALICE

The Nikhef ALICE group, of which the members are located mostly at Utrecht University, aims to understand the properties of quantum chromodynamics and its emergent structures of matter (or phases). The group members frequently spend time at Nikhef, including the two Utrecht technicians. The Nikhef group has participated in the ALICE experiment at CERN since 1994. ALICE-NL has a broad physics programme that contributed to the design and construction of the ITS2 upgrade and strong involvement in detector R&D for future upgrades. In a joint venture with the Gravitational Waves programme, ALICE enabled a successful funding application on the synergetic topic of the Equation of State of matter in both systems.

The Nikhef contributions to ALICE physics programme have been very impressive, with the development of a precision tool for anisotropic flow observations, as well as the observation of similar anisotropies in small

systems, and the resulting analyses which have attracted much attention. In the judgement of the committee, ALICE at Nikhef is a stronghold with an outstanding track record and bright future. Nikhef showed leadership in the organisation of the ALICE experiment and contributed strongly to various physics analyses in the context of the quark-gluon plasma. Nikhef has successfully delivered in the context of the experiment's upgrade, especially the ITS2 tracker devices, and now evolves to studies for a potential upcoming upgrade. This detector R&D is well synchronised with the overall 4D tracking developments at Nikhef.

5.2. Detector R&D

Two well-defined R&D paths have emerged at Nikhef, both aiming for a global and broad impact in the field of particle, astroparticle and gravitational wave physics. The R&D path on 4D tracking devices is a crucial component of the plan to enable full exploitation of the high luminosity upgrade of the LHC. This concerted project is therefore a binding force at Nikhef in which Nikhef excels and achieved major results. The ultimate goal to reach 10 ps timing in pixel chips is an ambition that matches the capacity, strength, scale and organisation of Nikhef. A timely commitment to new DRD international collaborations is important. In its strategy (since 2017) Detector R&D not only aims at expanding towards new research topics, it also aims at applying focus and stopping certain activities. For example, the X-ray imaging activities were terminated in 2021. The impact of pioneering activities at Nikhef in detector R&D is all pervading. The CO₂ cooling technology or ASIC development are but two fine examples.

Nikhef has designed a new programme to develop intelligent pixel tracking with built in timing capability, building on deep expertise acquired at Nikhef. Nikhef has designed major components of the Timepix4 and Velopix chips, two of the most complex 65 nm ASICs available in particle physics, incorporating features such as 60 picosecond time resolution and 10 Gbps output serializers, and has developed dedicated readout systems, with the latest incarnation, SPIDR4 reaching speeds of 160 Gbps. Nikhef has demonstrated expertise in the characterisation of sensor technologies with timing, including LGAD and monolithic sensors and has produced and commissioned the Timepix4 telescope, a tool capable of characterising timing sensors in particle beams with exquisite precision and ultra-high speeds. The programme will now be expanded to continue this research, to incorporate traditional and blue sky sensor technologies, and to address system level aspects of timing performance. Nikhef is one of very few institutes able to bring such a breadth of experience and capability to this complex topic, and its development as a design and evaluation hub for a variety of devices and readout systems will find wide application in future experiments.

Nikhef has the ambition to help shape the new ECFA-established "Detector R&D" (DRD) Collaborations currently being formed by CERN, but it foresees more internal discussion to determine how best to engage concretely in this international context. Nikhef could indeed take a more prominent role in the Detector R&D collaborations. Obtaining Roadmap funding in the Netherlands would be a major enabling factor. When Roadmap funding would be obtained, it is worth considering how to embed the long-term 4D timing project/programme in Nikhef's structure connecting all internal partners and establishing a clear spokesperson to communicate with external partners (including the above mentioned DRD collaborations). The committee strongly values Nikhef's vision to develop 4D tracking particle detector devices with ample applications in particle physics experiments. The committee recommends Nikhef to establish a prominent role in the relevant Detector R&D Collaboration and to actively build the capacity to become a European reference laboratory for the development of these emerging technologies with stepping stone opportunities for concrete applications inside and outside fundamental particle physics research

5.3. Gravitational Waves

In the domain of gravitational waves, Nikhef is robustly positioned to follow through with its 4-point plan of expanding knowledge (exploitation of the GW data from Virgo and LIGO), providing technologies (development of the ETpathfinder as well as near-term Virgo hardware), preparing the future (evaluating a local site for ET), and fostering healthy partnerships (seeking partners for the ET site bid, and working in the LIGO-Virgo-KAGRA consortium of collaborations).

Nikhef researchers have been active in the exploitation of the GW data to date, and have taken on responsibilities in organising the research and directing it. Specifically, leadership in the tests of General Relativity has been key. On the hardware side Nikhef's professionalism and excellent engineering capabilities have been vital to the implementation of Virgo+, helping Virgo to move from an experiment to an observatory. ETpathfinder is just reaching completion and has not yet made contributions to the science of GW detectors but has unique and significant promise.

Nikhef in the field of GWs is highly regarded, as a stand-alone entity and in its partnerships in the Netherlands. The election of a Nikhef scientist to serve as the Spokesperson of the Virgo Collaboration is an evident confirmation of this position in the domain. Contributions in the observational science of GWs, conception and production of components for Virgo, and contributions to the Cascina site activities have been very significant with commissioning leadership given to several Nikhef staff in the past years.

As noted elsewhere, the vision in Nikhef for the field of gravitational waves is well developed and currently in motion. Near-term activities to support Virgo are a major focus, and crucial to realising success in the longer-term plan. The work on Virgo informs the design of Einstein Telescope, trains early-career scientists and engineers in the domain, and provides data for observational science. Success with Virgo in the near term, which is challenging, will be necessary to demonstrate to all that the ET programme has a high probability of success. The rapid development of the GW field and the timely development of next-generation observatories is in some tension with near-term development of Virgo. There are a finite number of real experts in the development of these instruments – with a significant number of them at Nikhef – and it is crucial to balance the effort between the near-term and long-term plans. Nikhef can play a significant role here in providing a model that ‘works’, given its broad strengths and high visibility in the field.

The plans for ET take Nikhef into the 2030's and beyond. The ETpathfinder, which is nearing completion of its infrastructure and first experiments, is a beautiful example of the ‘vertical integration’ that is Nikhef's signature. The installation will offer a unique environment for development and testing of detailed engineering designs for ET, and will be a magnet for the ET detector designers looking to prove practical approaches for the challenging mechanical, optical, and control elements; it will also be powerful teaching locus for students in the Nikhef collaboration and thus launching point for careers in the field. The bid for an ET site in the vicinity of Maastricht is well thought out and persuasive. The design of ET is undergoing consideration in light of evolution in observational science goals as more sources are observed by Virgo and LIGO, and in a better understanding of technology opportunities and limitations. In addition, there is also a very good alternative site in Sardinia. It is important to maintain flexible planning to adapt to the outcome of the significant decisions yet to be made (and, of course, to continue to be key in informing and influencing those decisions).

Nikhef's growth in observational science from traditional particle physics, to interpretation of the GW signals, and extending into multi-messenger astrophysics, feels appropriate and well-connected to instrument science and technology. The core observational science scope will naturally be limited to that which

connects best with topics which are related to Nikhef's traditional vision, but with substantial collaborative ties to the broader possibilities of interpretation of the GW data.

There is also a good role for Nikhef in the space gravitational-wave mission LISA in producing the quadrant photodiodes in collaboration with SRON, and there is also planned participation in the data analysis and observational science. Synergies in the latter exist with the development of 'global fits' for the multiple overlapping signals anticipated in both LISA and ET.

5.4. Dark Matter

The nature of dark matter remains one of the biggest scientific questions. Nikhef thereby has played a crucial role in the leading dark matter experiments of our time, XENON1T and XENONnT. It made essential contributions to the Xenon detectors, both in hardware (designing and building the cryostat) as well as in software/electronics and in analysis. The limits on dark matter obtained by the Xenon collaboration are routinely the most stringent worldwide and are cited thousands of times. Dark Matter is not just generating fascination among physicists and astronomers, but also within the general public. Accordingly, it was very encouraging to see the Nikhef group's exceptionally well developed outreach activities.

The XENON dark matter community has converged on one, large next generation detector, DARWIN/XLZD. It is a natural continuation of the Nikhef dark matter programme and will allow probing dark matter down to the natural "neutrino fog" limit, as well as perform a competitive search for neutrinoless double-beta decay. There is a good chance that DARWIN/XLZD will be realised in Europe, making the prospects even more exciting. The Nikhef group is well positioned to play a major role (leading design and construction) in the DARWIN/XLZD project with essential contributions to the next generation project that will build on the engineering strength of Nikhef. The Nikhef dark matter group has been growing and we recommend that Nikhef embraces the emerging opportunities provided by DARWIN/XLZD to lead the global search for dark matter. Furthermore, there are significant synergies with the DUNE activities at Nikhef.

It would be good to see an increase in the theory contribution to the important topic of Dark Matter physics in the context of collider studies as well as its direct/indirect detection in laboratory/astrophysical context. Some of the new members of the Nikhef theory group have the required expertise. Combining the expertise in higher order calculation and/or discrete symmetry breaking with the DM physics is one unique direction in which the Nikhef group could make invaluable contributions.

5.5. Neutrino Physics

Neutrinos are starting to show their unique potential as messengers of the high-energy Universe. Nikhef is playing an outsized role in the development and construction of KM3NeT, the leading effort to implement a neutrino telescope in the open water. KM3NeT is being deployed in two detector configurations: ARCA, located off the coast of Italy, focuses of higher energies most relevant for neutrino astronomy and ORCA, located off the coast of France, focusing on lower energies, thus enabling it to measure atmospheric neutrino mixing. Nikhef takes a very clear and impactful leadership in the KM3NeT neutrino observatory, especially with the developments and production of the detector modules, as well as with the assembly of deployable detection units. Nikhef's DOM design has had an impact on the neutrino community beyond KM3NeT, the idea to utilise several smaller PMTs instead of one large PMT is being copied in essentially all other projects under construction / development.

Nikhef was also involved in the KM3NeT predecessor ANTARES, the first functional neutrino detector operated in the open sea. The detector has now been decommissioned, and the analysis of the ANTARES data showing initial hints of cosmic neutrinos. The deployed ARCA and ORCA modules provide for more

sensitivity, compared to ANTARES, and accordingly, the attention has shifted to the new detector. First data from KM3NeT has been analysed, e.g. resulting in the observation of a clear signal of atmospheric neutrino oscillations. The performance of the existing detector components is outstanding. With a continuously growing detector, the time to harvest the science from the initial investments made is starting essentially now (requiring adequate funding of personnel).

Unfortunately, the completion of KM3NeT, consisting of full ORCA and ARCA detectors, has been delayed due to external factors and correspondingly some of the goals from the previous review period have not yet been reached. But since they remain essential, they should be renewed. In particular the ORCA science case is time critical, with the competing IceCube Upgrade scheduled for deployment in the winter of 2025/26. The committee encourages that the stakeholders at Nikhef and NWO discuss with their colleagues in France to secure the funding to swiftly complete KM3NeT-ORCA.

The Nikhef neutrino group has already made several contributions to ProtoDUNE at CERN that are important contributions to DUNE that build on synergistic activities at Nikhef. The Nikhef FELIX system is being integrated in the readout of ProtoDUNE which leverages Nikhef's developments made in the context of the LHC experiments.

In summary, Nikhef is on track to meet the set goals 2017-2022 with the delays mentioned. A most interesting data set is emerging from KM3NeT, awaiting full scientific exploitation. The KM3NeT group at Nikhef has accumulated an exceptionally good reputation from its detector development work, and the strategy to diversify by joining the DUNE effort is sound.

5.6. Cosmic Rays

For the last 15 years, AUGER has been the leading observatory for cosmic rays at the highest energies. It has measured cosmic ray spectra and composition with unprecedented precision, finding for the first time anisotropies in the arrival directions of the highest-energy cosmic rays and thereby strongly constraining their origin. The Nikhef group has made essential contributions to these measurements, and in addition has been key in establishing the radio signature of cosmic rays interacting with the atmosphere. The next phase of the project will be starting with the completion of the construction of AUGER prime (scheduled for 2024). AUGER Prime represents a technological upgrade, employing scintillators and radio antennas that will over the next few years significantly improve the composition and anisotropy studies. The AUGER Prime detector upgrade is largely enabled through Nikhef's initiative and expertise.

The ambitious programme as proposed in 2017 was realised, with a successful Nikhef role in AUGER observational science and its leading role in the upgrades. The committee expects a very interesting time ahead from the incoming AUGER Prime data. Beyond these measurements, the Nikhef Cosmic Ray group is a central player in the development of GRAND and GCOS, two next generation cosmic ray observatory concepts. The Nikhef group is recognised as the leader in the effort to establish the radio signature as a viable and efficient tool to study energy and composition of cosmic rays. Overall, it is encouraging to see that the Nikhef model of collaboration works so well, also in light of the dominance of Radboud University in the programme.

The AUGER data is unique and very valuable for the community. The committee hence welcomes the ambitions to release more of the AUGER data and encourage the Nikhef stakeholders to work with their international partners to further increase the percentage of data released (the goal should be to release all of its data, eventually).

5.7. Theory

The activity of the theory group at Nikhef has covered a very broad canvas and involved all the frontline areas in the theoretical investigations in particle and astroparticle physics. Important contributions have been made towards all the goals listed for the period 2017-2022. In particular, Nikhef has been the world leader in the subject of development of theoretical techniques and tools in the subject of precision calculation required for the precision measurements at the LHC(HL-LHC) as well as at the high intensity facilities. These are essential for the exploitation of the full LHC(HL-LHC) data to its complete potential and at the current/future high intensity facilities. The QCD studies have also involved explorations of the parton structure of the proton, again an essential ingredient to a reliable analysis of the wealth of the data from hadronic colliders: current and future LHC as well as the upcoming Electron Ion Collider.

The group members have made very significant contributions not just to the formalism of computing higher order QCD and QCD/EW corrections but also to the understanding of conceptual issues in the study of jets at colliders. All this, in the end, also allows more accurate and effective methods for using the data to study beyond standard model (BSM) physics at the LHC as well as at the future particle physics facilities such as the EIC in planning and those under consideration such as the FCC.

The contribution to studying the BSM physics is not just restricted to this aspect. Group members have developed methods for a global analysis of BSM physics using the entire gamut of low and high energy data. Phenomenology of sterile neutrinos, axion like particles as well lepton number violating processes, electroweak baryogenesis and DM physics are examples of BSM fields studied by the members. Very important contributions have been made to pursuing BSM in flavour physics (mainly in B physics) and some have been implemented in actual experimental searches by the experimental groups, most often in collaboration with the Nikhef theorists.

Over the years, the programme FORM, developed at Nikhef has become an indispensable ingredient of all the theoretical computations in theoretical particle physics. In the past five years the Nikhef group has continued the brilliant legacy of the development of important software tools: these are various Monte Carlo event generators (NNPDF, relevant both for collider and cosmic ray experiments and NuPropEarth, relevant in the context of neutrino astronomy and cosmic ray studies) and analysis toolkits (SMEFIT, for explorations of BSM). These are very significant contributions to the worldwide exercise of using the precision data from upcoming experiments to glean answers to various questions which are of great interest to the entire theoretical particle and /or astroparticle physics community today.

In recent years the theory group members have expanded their earlier collaborative activities with the LHC experimental groups ATLAS and LHCb, to include members of the AUGER and ALICE experiments in the Nikhef family. They are also involved in physics studies for the Electron Ion Collider (EIC), at present the only future collider physics project to be fully funded and which is expected to come on line in near future. The group has strength for extending its influence on the analysis of upcoming LHC data through their work on higher order corrections, parton densities in protons/nuclei and parton shower development. Theoretical activity in the context of cosmology and its impact on signals in multi messenger astronomy is also an area fertile for collaborative activity with the Nikhef theorists within the entire Nikhef family. The strong interaction of the Nikhef theory group with the electron-EDM experimental group is also very welcome. One looks forward to continued involvement from Nikhef staff in the intersectional area of exploring aspects of violation of discrete symmetries in the context of collider physics, DM physics, astroparticle as well as the high intensity atomic physics experiments.

The theory group has also got involved in setting up a group to take stock of physics possibilities of future colliders. Given the prime position that Nikhef has enjoyed in the entire chain of activities required for research in particle physics, from the detector development to theoretical computations to experimental analyses using the unique features of detectors developed at Nikhef to heavy computing needs, this is very welcome indeed. This should certainly be taken forward.

Another important initiative of the Nikhef theory group is the organisation of the activity ‘Theory meets experiment’. One would like to see this continued further, leading to even more collaboration between the theorists at Nikhef and the participants from Nikhef in various big experiments. This collaboration along with the periodic meetings of the Dutch particle theory community held by the group, has led to the development of Nikhef theory group as a hub for particle phenomenology in the Netherlands. For continuance of this unique position, hiring of younger Nikhef staff in theory group is necessary in view of the superannuation of a few key members during the review period.

5.8. eEDM

The Electric Dipole Moment (EDM) of a point like elementary particle vanishes; any non-zero moment is an indicator of violation of CP or T. The Standard Model is breaking CP; however, the observable effects on the EDM are predicted to be extremely small and still beyond experimental reach. New physics could yield much higher EDMs that may thus be measured essentially free of SM background. Various species have been suggested for measurements of the EDM; the electron EDM probes scales of 106 TeV.

Sensitivity for EDM measurements has quite recently been boosted by several orders of magnitude by using polar molecules as amplifiers; a beam of BaF molecules, in particular, can be dealt with by Stark deceleration and laser cooling. Such a setup is amenable to a university environment. The Nikhef eEDM activity is really impressive and substantial progress has already been made towards the goals mentioned in the self-evaluation report for the period 2017-2022.

Two cryogenic sources are now available, one at the Vrije Universiteit Amsterdam and the other at University of Groningen. In a stepwise approach, Stark deceleration for heavy molecules has been demonstrated for SrF molecules, the necessary laser system has been commissioned and a scheme has been implemented to perform eEDM-sensitive measurements while simultaneously accumulating data to monitor systematic effects. The first dataset of eEDM measurements with the completed set up should be available shortly.

The higher sensitivity of a molecular beam comes at a price: the measured molecular EDMs have to be translated into the EDM of an electron. Precise molecular structure calculations are warranted; indeed the calculations need to be carried out at the level of particle-hadron molecular theory. Light-matter interactions lead to further complications. Indeed, an effective field theory framework that bridges particle-molecular scales and connects to more common many-body molecular calculations is required to extract meaningful results on CP violating physics.

This is where Nikhef comes in with its combined expertise on experimental techniques and theoretical precision calculations. Theoretical calculations are as important as refined experimental measurement techniques and in fact guide the control of the systematic uncertainty of the result. The observed close interaction of theoretical and experimental work, both in Amsterdam and Groningen within the electron-EDM consortium, is very welcome to explore BSM physics in these experiments. It needs to be cherished and developed even further. One hopes that the general strong interest in the violation of discrete symmetries will naturally propel this interaction further.

5.9. Physics Data Processing

The physics data processing programme embraces essentially all scientific activities at Nikhef. It is driven by the need for advanced algorithm development in heterogeneous computing environments for CPUs, GPUs and eventually quantum processors. Such tools are needed to cope with the deluge of data from experiments, from networking to access remote storage and to enable collaboration that is adequate for the environment of open science in the Dutch and European environment.

Indeed, there is a long tradition in advanced computing provided by SURF, the Dutch cooperative for education and research. The efforts are solidly founded in contributions to the Worldwide LHC Computing Grid (WLCG) and following implementations for the experiments on gravitational waves and neutrinos. The efforts for the European Open Science Cloud (EOSC) represent just the latest example. The expertise is immediately visible in the Amsterdam Internet Exchange AMS-IX, housed at Nikhef, which is operated in parallel with the Tier-1 WLCG centre using the most advanced links e.g. for exchange of data with Geneva.

The amount of data will not only increase by more experiments or continued operation of detectors. In fact, the larger sophistication of experiments will have an additional effect. As an example, Nikhef is already preparing for processing 4D-detector data of the LHC that include timing information in addition to the spatial coordinates. Efficient processing of such data is key and requires new hardware.

Given the diversity of science topics at Nikhef the data processing group is ideally placed to respond to the future needs of computing in the European environment to support the use of and to increase the share of FAIR data.

Physics data processing is an enabling field that allows to venture ambitious physics applications and requires a high-level of expertise. Such experts are difficult to find given the salary limitations in public service. Yet, Nikhef offers such an attractive environment to develop new ideas and spring new solutions that is hardly found in a profit oriented company. Nonetheless a solid base funding is necessary and cannot just be skimmed off from the project funding.

6. Conclusion and recommendations

During the on-site meeting the committee found its positive impressions from the study of the strategy and self-evaluation documents fully and pleasantly confirmed. Nikhef represents a unique institution in the Dutch research landscape in support of leading universities that adds value to the scientific work that is unparalleled.

Nikhef's role and its implementation seem almost ideal and are exemplary at the national level: it attracts the freshest ideas from the participating universities and complements them with the solid knowledge and technical capabilities of a larger institution. In that spirit Nikhef is the Dutch large-scale workshop in subatomic physics that renders research ideas a reality. The approach is complete and includes theoretical guidance and support, advanced experimental expertise and technological impact.

In that spirit, Nikhef leads some of the most ambitious projects in the large CERN collaboration ATLAS, it is one of the world renowned leaders in Heavy Flavour physics and a science driver for the next generation tools in gravitational science. It excels in confronting experimental results with precision calculations that are possible e.g. with the Dutch developed tools. Theoretical physicists continue the Dutch tradition of excellence that has gained them worldwide renown. The experimental focus on detector technologies enables the universities to significantly contribute as leading institutions. The computing initiatives are exemplary, both for algorithms and for technology choice and evaluation.

Such a success only flourishes in an open environment where the appropriate academic culture meets transparency in the projects, open feedback and support in training and education. The newly established gathering place, the vertex, stands as an example of how this spirit is nurtured. Discussion prevails everywhere and while challenging at times is always constructive. PhD students praise an open atmosphere and access to expert knowledge. Accomplished principal investigators find the support that is needed. Early career researchers are placed in an exciting environment and no question the best will profit from this constructively. However, there is no direct mentoring programme for this peer group at this time.

Nikhef is aware of its privileged position in the Dutch science landscape: fundamental research does not immediately return its research results into products for society. Nikhef emphasises its impact on advanced science education and training. The advanced research nonetheless leads to spin-offs that efficiently propagate to society.

Given its special and pivotal role in the Dutch science landscape Nikhef relies on predictable and continuous funding: a first class workshop must be maintained outside the cycle of project funding. The sophisticated detectors and tools are operated for years on end and require expert assistance. Such cycles of invention, conception, construction and operation fall outside the canonical project funding. The committee noticed a worrying trend of reduction of support in the exploitation of instruments, e.g. at the CERN experiments. The balance between institutional funding and project funding does require adjustment.

As to future projects Nikhef is the best and natural institution to lead and guide the Dutch effort for the next generation gravitational wave detector. The need for higher sensitivity measurements, i.e. full coverage mapping of the universe is undisputed. While the financial volume will probably exceed the capability of a single country it should not fall victim to endless and costly debates on siting and governance. In fact, the proposal of a site in the Maastricht region with Belgium, Germany and the Netherlands as partners has gained considerable traction largely due to the initiative of the Dutch community under the specific leadership of Nikhef. – The committee applauds the progress so far, including the ETpathfinder project, and

fully supports the role of Nikhef. However, the initiative should proceed with the full backing of the ministry and, aiming for success, also commence to develop plans for governance structures for the Einstein telescope itself once the project gains traction. This governance, and even the Dutch share, will exceed the current capability of Nikhef and needs to be resource loaded outside the regular budget.

The overall recommendation from the committee is to encourage Nikhef and its management to continue its successful path. Nikhef is a shining example of how to conceive an institution that embraces the scientific efforts of several universities and provides added value. The management is to be full heartedly congratulated and while the term of the current director continues until the end of 2024 the committee suggests to pay attention to the selection of a new director who must be familiar both with the aspirations of universities and the inner workings of Nikhef itself.

Nonetheless, the committee did not refrain from putting together some observations that deserve attention. They are directed towards the Nikhef management but also towards NWO-I and even the ministry.

List of recommendations

1. Maintain and enhance the collaborative spirit that prevails at Nikhef. After COVID and building renovation, cherish the tradition of in-person presence at Nikhef as often as possible. Many good steps have been made to this end.
2. Nikhef has made big strides in improving gender balance with very encouraging figures. Yet, these improvements have to permeate the full hierarchy and be instituted. The improvement of diversity, equity and inclusion has only begun to be addressed in a systematic fashion. Nikhef is encouraged to continue on this path.
3. Consider to conceive a programme of stewardship even for early career researchers at Nikhef so as to help them to decide for a career in academia or industry.
4. Nikhef is deeply involved in three LHC experiments and shines as a leader in various topics both on hardware and computing, as well as analysis. The activities reach well beyond the current evaluation cycle and include the HL-LHC. Yet, CERN as the European laboratory with significant funding from the Netherlands, is preparing the decision for a next big project which will only come to bear in the middle of the century. Nikhef should prepare an informed opinion on such projects and participate both on the scientific and political level. The committee saw a first discussion group being formed. However, it is felt that these discussions could be enhanced.
5. The composition of Nikhef funding has shifted from institutional funding towards more project oriented funding. Such a trend is counterproductive for the instruments that are developed and operated by Nikhef; more importantly, it can prevent Nikhef from maintaining its precious synergy of science and technology; and the synergy of scientists and dedicated technical staff. A larger share of institutional funding is needed to maintain the excellence of the workshops and to allow long term exploitation of the accomplished instruments.
6. Nikhef is the natural institution to propel the Dutch engagement in the next generation Einstein Telescope. It should endeavour to obtain the official charge to develop and negotiate the Dutch participation and prepare the case for international approval. This effort should be funded on top of the budget and in direct contact with the ministry as is appropriate for an infrastructure of this size and national importance.
7. The current director of Nikhef is also directing the important efforts for the Einstein Telescope. While the scientific and technological developments fall well within his remit, the political developments may be better placed in the hands of someone who reports directly to the ministry as the project matures and actually takes shape.

Appendices

Appendix 1: SEP Questions Evaluation NWO institutes

The 3 main criteria:

1. Research quality:

- How does the assessment committee assess the scientific quality of the institute, in light of its own aims and strategy? Central in this assessment are the contributions to the body of scientific knowledge. The assessment committee is asked to reflect on the quality and scientific relevance of the research. Finally, the academic reputation and leadership within the field is assessed. Looking ahead into the future, which recommendations can the committee give to the institute regarding their research quality?
- How does the committee assess the institute's place in the national and/or international research landscape? Is the institute a frontrunner or a follower in its field? Does the committee see untapped opportunities?

2. Societal relevance:

- How does the committee assess the societal relevance in terms of impact, public engagement and uptake of the institute's research in economic, social, cultural, educational or any other terms that may be relevant? The assessment committee is asked to reflect on societal relevance by assessing an institute's accomplishments in light of its own aims and strategy. Looking ahead into the future, which recommendations does the committee have for the institute regarding its societal relevance?

3. Viability:

- How does the committee assess the extent to which the goals for the coming six-year period remain scientifically and societally relevant? It is also asked to assess whether its aims and strategy as well as the foresight of its leadership and its overall management are optimal to attain these goals. Finally, the assessment committee is asked to assess whether the plans and resources are adequate to implement their strategic plan. The assessment committee is also asked to reflect on the viability of the institute in relation to the expected developments in the field and societal developments as well as on the wider institutional context of the institute.
- How does the committee assess the way the institute fulfils their national role and does the committee have any recommendations regarding this?¹
- How does the committee assess the way the institute contributes to the vision on 'Dutch research in 2030' as is written down in the NWO Strategy 2023-2027 and does the committee have any recommendations?

¹ With respect to the reports from the PCNI, the portfolio committee and (where relevant) the exploration reports.

In addition there are also 4 important aspects contributing to the success of the institute:

4.1 Open Science

The assessment committee is asked to consider to which extent the institute opens up its work to other researchers and societal stakeholders in the context of its strategy and policy. Furthermore, the committee is asked to consider whether the institute reuses data where possible; how it stores the research data according to the FAIR principles; how it makes its research data, methods and materials available; and when publications are available through open access. The committee is specifically asked to give the institute and NWO-I recommendations on their Open Access and FAIR data and software policy. The assessment committee is asked to reflect on the current policies, and the practices with regards to the open availability of the publications, research data and methods and assess them in light of NWO's high ambitions (e.g. is the institute a frontrunner in its field with regard to Open Access and FAIR data and software?).

4.2 PhD policy and Training

- The assessment committee is asked to consider the supervision and instruction of PhD candidates. Furthermore, the committee is asked to consider whether the quality assurance system is functioning properly. The committee is asked for recommendations on how to enhance the supervision and education of PhDs (together with the universities), also in light of the three main criteria.

4.3 Academic Culture

- *Openness, (social) safety and diversity & inclusivity:* The assessment committee is asked to consider the openness, (social) safety and diversity & inclusivity of the research environment. The assessment committee is also asked to evaluate the actions and plans for the future of the institute with regards to (social) safety, diversity & inclusivity.
- *Research integrity:* The assessment committee is asked to consider the institute's policy on research integrity as well as the way the institute facilitates the relevant actions and requirements formulated in the Netherlands Code of Conduct for Research Integrity. For both themes: Looking ahead into the future, which recommendations does the committee have for the institute regarding their academic culture, also in light of the three main criteria?

4.4 Human Resources policy

- *Talent Management:* The assessment committee is asked to consider the institute's policies on talent selection and development in relation to its aims and strategy. More specifically, it is asked to evaluate the institute's recruitment policies, opportunities for training and development, coaching and mentoring, as well as career perspectives for researchers and research support staff in different phases of their career. An important aspect of this is the (inter)national cultural change regarding recognition and reward in academia that NWO-I is implementing. What are the institute's plans to further the desired cultural change and which recommendations does the committee have for the institute and NWO-I?

Appendix 2: Programme of the site visit

Monday 20 November

17.00 - 19.00	Welcome - opening session
19.00	Dinner and evening session committee

Tuesday 21 November

08.30 - 09.00	Preparation session committee
09.00 - 10.00	ATLAS, LHCb and ALICE
10.00 - 10.30	Detector R&D and 4D Fast timing
10.30 - 10.50	Coffee break
10.50 - 12.45	Tour and discussion electronics and mechanical departments
12.45 - 14.00	Lunch with scientific staff
14.00 - 14.30	Human resources vision
14.30 - 15.00	Gravitational waves physics + instrumentation
15.00 - 15.30	Cross-boundary initiatives and ambitions
15.30 - 16.00	Coffee break
16.00 - 16.15	OSAF research school (presentation)
16.15 - 16.30	PhD council (presentation)
16.30 - 17.30	Roundtable discussions with PhD candidates and postdocs
18.00 - 19.00	Debriefing day 1

Wednesday 22 November

08.30 - 09.00	Preparation session committee
09.00 - 09.20	Dark Matter
09.20 - 09.40	Neutrino physics
09.40 - 10.00	Cosmic rays
10.00 - 10.30	Tour PiMu Hall
10.30 - 11.00	Coffee break
11.00 - 11.20	Theory
11.20 - 11.40	eEDM
11.40 - 12.10	Einstein Telescope and scenarios for the future
12.10 - 13.30	Lunch and discussion with management
13.30 - 14.30	Presentation + roundtable discussion physics data processing and computer technology
14.30 - 15.00	Tour data centre
15.00 - 16.30	Writing session committee
16.30 - 17.15	Roundtable discussions on societal impact & knowledge transfer, and outreach & communication
17.15 - 18.00	Debriefing committee
18.30 - 18.50	Initial feedback committee with management team

Appendix 3: Quantitative data

Quantitative data on the institute's composition and funding, as described in SEP Appendix E, Tables E2, E3 and E4:

Overview staff:

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

Funding:

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

PhD candidates:

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%