Information document on Nikhef strategy process

Many of the experiments that currently define Nikhef's research landscape are expected to reach the end of their lifetime around 2040. This creates both a challenge and an opportunity: to ensure continuity of scientific excellence, the institute needs a shared, forward-looking strategy with broad support accross the entire Nikhef community. The process of obtaining this strategy must be inclusive and iterative. Furthermore, the Nikhef strategy will be based on the European strategies for particle physics and astroparticle physics, building on them without repeating the European discussions.
To develop such a strategy, the Nikhef Strategy Group (NSG) was established in February 2026. Its first task is to collect and structure input from across the institute, mapping current research activities as well as future ambitions. Furthermore, clusters that require a strategy have to be identified. The strategy group has gathered informal input from the various groups across Nikhef, and used its own expertise, to answer the four guiding questions elaborated upon below. Using the answers to these questions, we have identified four clusters that require a dedicated strategy. The information presented in this document represents a synthesis of this initial consultation phase and serve as a basis for further discussion within the community.

1. **What are the physics questions that drive us?**
   Nikhef's scientific mission is driven by a broad set of fundamental questions, spanning from particle physics, astroparticle physics, gravitational waves to cosmology. Key open questions include whether Standard Model particles are elementary or composite, whether additional particles or forces exist, and whether deeper symmetries underlie the observed structure of the Standard Model. This includes unresolved aspects of flavour physics, such as the origin of fermion generations, flavour hierarchies, and potential new sources of CP violation. The Higgs sector remains another central focus. While the Higgs boson has been discovered, its full role is still unknown. Does the Higgs field interact with itself as predicted? Is the Higgs sector minimal, or part of an extended structure? Precision measurements of its properties remain crucial for uncovering new physics. Neutrinos represent another promising probe of (beyond the) Standard Model physics. Outstanding questions include the neutrino mass hierarchy and absolute mass scale, the Majorana or Dirac nature of neutrinos, and the presence of additional CP violation in the lepton sector. These properties may be directly related to the origin of the matter–antimatter asymmetry. The nature of dark matter (and dark energy) remains unknown and constitutes a major scientific priority. Additional key questions include the origin of the matter–antimatter asymmetry, mechanisms of baryogenesis, the properties of dense matter, and the physics of the early universe, including possible connections to Planck-scale phenomena. Ultra-high-energy cosmic messengers open a window onto extreme astrophysical environments. What are the sources and nature of ultra-high-energy cosmic rays? What fundamental laws govern their interactions, and what can they tell us about both particle physics and astrophysical accelerators? Gravitational wave physics opens a fundamentally new observational window on the universe and provides access to regimes that are inaccessible through conventional particle physics experiments. Is general relativity the correct description of gravity in the

strong-field and highly dynamical regime, or are there deviations that point to new fundamental physics? What is the true nature of black holes and other compact objects, and can their properties reveal physics beyond our current understanding? Gravitational waves may also provide unique access to the early universe: are there primordial gravitational-wave backgrounds or signals from cosmological phase transitions, cosmic strings, or other new phenomena? Finally, precision observations across a broad range of frequencies may shed light on the nature of dark matter and dark energy and on the fundamental structure of gravity itself.

2. **What is the current expertise at Nikhef?**
   To make strategic decisions, it is important to also identify the expertise and capacity that is currently present at Nikhef. Currently, there is a broad and integrated portfolio of expertise spanning theoretical physics, experimental physics, instrumentation, and computational methods.

   Theory and Phenomenology
   Core competencies include parton distribution functions, resummation techniques, Monte Carlo event generators, effective field theories (including SCET and SMEFT), Higgs physics, flavour physics, neutrino phenomenology, heavy-ion physics and aspects of cosmology and inflation.

   Software, Data Processing, and Data Analysis
   Expertise includes large-scale (high-performance) data acquisition systems, computing and networking (Tier 1), event reconstruction, simulation frameworks, statistical inference methods, and domain-specific analysis software for neutrino, cosmic ray, interferometer simulation software, and collider experiments.

   Detector and Instrumentation Technology
   Nikhef possesses extensive expertise in mechanical design, thermal and multiphysics simulation, materials science under extreme conditions, precision manufacturing, and detector system integration.

   Electronics and Readout Systems
   Capabilities include digital and analog electronics design, FPGA-based data acquisition systems, ASIC design (analog, digital, and mixed-signal), high-speed high-throughput data transmission, and precision timing systems. These technologies are applied across major experimental domains, including collider physics, neutrino experiments, gravitational wave detectors, and dark matter searches.

   Detector Research and Development
   Nikhef is active in the development of advanced detector technologies, including fast-timing silicon detectors, radiation-hard sensors, cryogenic systems, and precision optical instrumentation (SiPM, PMT). Additional expertise includes gravitational wave sensor development, vibration isolation systems, and quantum-limited measurement techniques.

3. **What are future experimental opportunities beyond ET and FCC?**
   The future experimental and technological programme of Nikhef will be shaped by a combination of major international facilities and complementary smaller-scale or novel experiments. Regarding large-scale facilities, key experiments include high-energy collider programmes (in particular the FCC), gravitational waves observatories (in particular the ET), neutrino experiments (Dune and Hyper-Kamiokande), dark-matter detection experiments (e.g. XLZD, but also axion searches such as ADMX), and cosmic microwave background and gravitational wave space missions. Future observatories such as SWGO, GRAND, and HERON aim to study cosmic rays, gamma rays, and neutrinos at ultra-high energies using hybrid detection techniques combining optical, radio, and particle-based methods. On smaller-scales, programmes include muon g−2, electric dipole moment measurements or neutrinoless double beta decay searches. There is also a question on whether Nikhef wants to be host for a smaller local facility.

4. **What are enabling technologies for the future?**
   Future experimental programmes will depend critically on advances in both hardware and software technologies.

   Hardware and Instrumentation
   Priority areas include advanced semiconductor technologies, low-power high-performance electronics, fast timing systems, novel materials, and scalable detector architectures. Emerging areas such as quantum sensors, interferometric techniques, cold atom sources, and advanced cryogenic systems are expected to play an increasing role. Hybrid detection approaches for cosmic messengers, such as hydrophones and radio-based techniques are worth considering.

   Data Processing and Software
   Artificial intelligence and machine learning methods are expected to become integral to simulation, reconstruction, and data-analysis workflows. These methods offer potential improvements in computational efficiency, multi-detector data fusion, and model-based inference.
   In addition, high-performance computing architectures, including GPUs, FPGAs, and other accelerators, will play a central role in future data-intensive experiments.

   New technologies
   Quantum computing and quantum sensing are identified as areas requiring further exploration. While not yet mature for large-scale deployment, these technologies may offer transformative capabilities in precision measurement and fundamental physics experiments.

From themes to clusters
Based on the synthesis of physics drivers, existing expertise, and future experimental opportunities, four strategic research clusters are identified, which each require an in-depth strategy analysis. These analyses will be carried out by dedicated working groups (WGs). Here

an overview of these four clusters are given, more in-depth information can be found in the dedicated documents.

Cluster 1: Collider Physics
This cluster encompasses theoretical and experimental activities related to future collider programmes. The cluster has a strong focus on the FCC and our contributions to its potential future experiments. One practical aspect of this cluster is preparing an LSRI roadmap application related to FCC experiments. Possible participation in the EIC will also be explored within this cluster.

Cluster 2: Cosmic messengers
This cluster focuses on the various cosmic messengers - gravitational waves, astrophysical neutrinos, ultra-high-energy cosmic rays and potentially gamma rays - to address fundamental questions about (dense) matter, gravity, astrophysical sources and the early universe. Additionally, it focuses on how to leverage our efforts within this field strategically within the realm of multimessenger astronomy. Developments around the Einstein Telescope will also form part of this cluster.

Cluster 3: Weakly Interacting Particles
This cluster covers future weakly and feebly interacting particle research at Nikhef. It is about studying neutrino properties, searches for Dark Matter, Axion-like particles (ALP) and sterile neutrino's/long-lived particles (LLP) beyond primary collider physics experiments. As such, it covers our involvement in a potential successor/upgrade of *KM3NeT*, long-baseline neutrino experiments like *DUNE*, our future involvement in XENONnT successors (*XLZD and beyond*), as well as the continuation of forward facilities (SND@LHC/FASER → *FPF*) or beam-dump facilities (*SHiP@SPS*).

Cluster 4: Nikhef in-house experiment
The aim of this cluster is to identify one or more options for a globally impactful in-house experimental facility that will strengthen and broaden Nikhef's mission. An integral part of this process is assessing the added value in terms of physics potential, as well as organisational aspects such as the required technological capacity. Subsequently, we will examine in greater detail whether we wish to, and are able to, establish such a facility as an institute and partnership.

The long timescale of the transition toward 2040 requires adaptability. New experimental opportunities may arise, and existing ones may evolve or disappear. Bandwidth must remain to adapt to such an uncertain landscape.

The steps of the strategy process

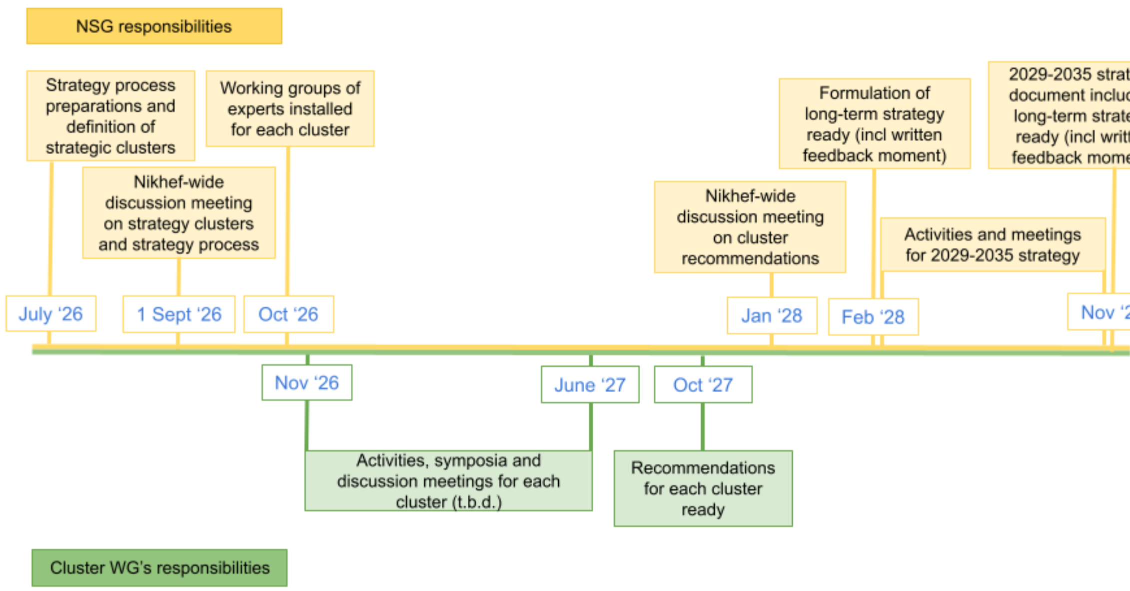

Figure 1 depicts the timeline of the strategy development process. We are currently at its initial stage, in which the NSG has identified clusters that require dedicated strategic plans. In September 2026, the contents and goals of these clusters will be discussed and finetuned with the Nikhef-wide community. This will also provide an opportunity for interested individuals to become involved; those wishing to participate in one of the WGs are encouraged to express their interest.

The dedicated cluster WGs are expected to be established in the beginning of October 2026. They will then have approximately one year to organise activities that enable both the groups themselves and the broader Nikhef community to develop an informed perspective on the cluster's topics. Each WG will produce a document containing its strategic recommendations. These recommendations will be discussed with the Nikhef community and subsequently compiled and reviewed by the NSG and will serve as the basis for formulating a long-term strategy.

It is important that the strategy results in a coherent portfolio of programmes with a clear rationale for their placement within one institute/partnership. Therefore, the NSG will consider the strategic recommendations in detail and assess the complementarity of the physics and the synergies between the required technologies, accross the portfolio, and discuss this with the Nikhef community whenever needed. The phase of integrating the separate cluster recommendations into a unified strategy is expected to begin in early 2028. A further year will then be devoted to gathering additional information where necessary and refining the resulting strategy document, which will also include the shorter-term strategy.