Summary of the Workshop
“The future of Non-Collider Particle Physics“
+
First proposal for the German input to the ESPPU2026

Heiko Lacker (HU Berlin)

German strategy workshop in preparation of the ESPP update
Bad Honnef, 20.01.2025

Purpose of this talk

* Summarize Non-Collider workshop, in particular its summary document

* Propose version 0 for section 4 in the German ESPPU2026 KET input
  → To be discussed and iterated (after this talk and the talk on KAT recommandations)

* KAT will provide inputs on direct DM searches and non-accelerator neutrino physics
  → KET input will refer to KAT input in those cases, which are relevant for particle physics related experiments

* General goal: aim for coherence in the input documents of KET and KAT/KHuK

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* After non-collider workshop: Contacted by a brand-new initiative, called „DMInfraNet“
  → Added a few slides and a possible proposal for a possible ESPPU2026 input

Workshop Program Committee

Frank Ellinghaus (former KET, co-chair)
Heiko Lacker (KET ex-officio, co-chair)
Lutz Feld (KET chair)
Felix Kahlhöfer
Matthias Schott
Manfred Lindner (for KAT)
Michael Wurm (for KAT)
Achim Denig (for KHuK)

Challenge:
Cover in one workshop the topics that were covered for the ESPPU2020 input
by two workshops (Neutrino Physics (2017), Non-Collider Particle Physics (2017))

→ Many thanks to the committee members for their efficient and constructive work!

Questions sent to the speakers to be addressed in the talks (Many thanks for your work!)

Questions for speakers (2), 3), and 4) mainly relevant for talks on experimental projects):

1) What are the important / primary scientific questions of the field?
   Which experimental options exist to answer them (completely, partially,?) and when?
   For proposed projects: Are scientifically important results guaranteed, likely or possible?
   Which secondary topics are covered by the project and what are its chances for success?

2) Estimate of the time scales, costs (invest) and structures (collaboration size and international composition).
   Which risks exist? Which competing projects exist world-wide for the physics question, taking also realistic schedules and progress into account?
   An example for what is meant here:
   a) Neutrinoless double beta decay can be pursued in different ways.
      Which one is best or most promising for discovery?
      Projects should be justified by their potential for discoveries/major progress and not by history, personal taste or other secondary aspects.
   b) There are different options to determine the mass hierarchy and among them are JUNO, PINGU/ORCA and DUNE.
      But global fits, cosmology or a galactic supernova may provide an answer or partial answer earlier.
      The question is therefore how many sigmas are necessary or how to justify extra effort.

3) Where is the specific German interest? Do special strengths of German groups play a role?
   Are there enough interested groups/people for a meaningful contribution?
   Will the participation create synergies and international visibility?
   How does the required funding fit to the German funding structures (which funding line, volume)?

4) Where could the project be realized? Funding agencies of other countries look much more after attracting some projects to their countries.
   This has different advantages including positive economic effects for the region, better contributions due to ease of access (it is much easier to contribute and make an impact close-by compared to far away) to visibility and prestige for the country in general and via awards/prizes.

5) Are there special opportunities which should be realized since others have so far paid little or no attention to emerging topics?

All speakers should try to answer these questions either in their talks or in a brief tabular summary at the end of the talk.

Workshop Programme

15:59 → 16:00 Start of "The Future of Non-Collider Particle Physics" worksh

16:00 → 18:20 **Theory I: Non-Collider Workshop**
Conveners: Frank Ellinghaus (Bergische Universität Wuppertal), Heiko Lacker (Z_ATLAS (Experiment ATLAS

16:00 **Introduction**
Speaker: Prof. Lutz Feld (RWTH Aachen)
Intro Non-collider ...

16:10 **Particle-like Dark Matter**
Speakers: Alejandro Ibarra (Technical University of Munich), Alejandro Ibarra (TUM)
Ibarra.pdf

16:45 **Axions and wave-like Dark Matter**
Speaker: Andreas Ringwald (T (Cosmology))
strategy_meeting_...

17:15 **Feebly Interacting Particles + Kaon Physics**
Speakers: Felix Kahlhoefer (RWTH Aachen University), Felix Kahlhofer (Karlsruhe Institute of T
FIPs (and some ka...

18:00 **Discussions: Theory Part I**

18:20 → 19:40 Dinner

19:40 → 21:10 **Theory II: Non-Collider Workshop**
Conveners: Frank Ellinghaus (Bergische Universität Wuppertal), Heiko Lacker (Z_ATLAS (Experiment ATLAS

19:40 **Gravitational Waves → Cosmology, Particle Physics: Theory**
Speaker: Pedro Schwaller (University of Mainz)
KET_future_beyond...

20:10 **Neutrinos: Theory/Pheno**
Speaker: Thomas Schwetz-Mangold (KIT)
KET-EPPSU-Neutrin...

20:55 **Discussion: Theory II**

Saturday 23 November

08:30 → 10:55 **Non-Collder Workshop: WIMPs and Axions**
Convener: Matthias Schott (Uni Mainz)

08:30 **WIMP experiments: DARWIN, DarkSide, Helium, electron scattering, ...** 30m
Speaker: Federica Petricca (Max-Planck-Institut für Physik)
WIMP_Experiments...

09:25 **Axion experiments** 30m
Speaker: Döbrich Babette
BadHonnefBabette...

10:20 **FASER(nu), SND @ LHC → AdvSND, Forward Physics Facility** 25m
Speaker: Felix Kling (T (Cosmology))
24-11-24-Neutrino...

10:55 → 11:25 Coffee 30m

11:25 → 12:50 **Non-Collider Workshop: Neutrinos: (Accelerator, Non-Accelerator, Astro-physical)**
Convener: Michael Wurm (Universität Mainz)

11:35 **Long-baseline neutrinos** 25m
Speaker: Prof. Alfons Weber (Johannes Gutenberg-Universität, Mainz & Fermilab, Batavia)
KET_AccNu_2024.... KET_AccNu_2024-...

12:10 **Non-accelerator Neutrinos** 30m
Speaker: Susanne Mertens (Max Planck Institute for Physics)
Mertens_KET_nona...

Workshop Programme

14:00 → 16:55 **Non-Collider Workshop: FIPs et al.: SHiP, MESA, Mu3e, LUXE, Possible Future Collider infrastructures**
Convener: Felix Kahlhofer (Karlsruhe Institute of Technology)

- 14:00 **Astrophysical Neutrinos**
  Speaker: Marek Kowalski (Z_NA (Neutrinoastronomie / Kosmologie))
  2024_KET_Neutrin...
- 14:30 **SHiP**
  Speaker: Marc Schumann (Univertity of Freiburg)
  SHiP_KET.pdf
- 15:10 **LUXE**
  Speaker: Ruth Magdalena Jacobs (FHR (Bereichsreferent FH))
  LUXE.pdf
- 15:35 **Opportunities at future (Collider) infrastructures (e.g. beam-dumps)**
  Speaker: Ivo Schulthess (FTX (FTX Fachgruppe SLB))
  202411_KETPBC_s...
- 16:00 **MESA + Mu3e + Lohengrin**
  Speaker: Niklaus Berger (Universität Heidelberg)
  MESAMu3eLoheng...
- 16:40 **Kaon experiments**
  Speakers: Rainer Wanke (University of Mainz), Rainer Wanke
  KaonFuture_KET_N...

16:55 → 17:20 **Coffee**

17:20 → 18:30 **Closed session:: Drafting session for a first attempt of a prioritization**

18:30 → 19:50 **Dinner**

19:50 → 21:50 **Discussion: Presentation and discussion of the first draft**
Conveners: Frank Ellinghaus (Bergische Universität Wuppertal), Prof. Lutz Feld (RWTH Aachen)

SUNDAY 24 NOVEMBER

08:30 → 10:00 **Experiments continued: EDMs, Gravitational Waves, Quantum sensors**
Convener: Prof. Manfred Lindner (Max-Planck-Institut für Kernphysik)

- 08:30 **Electric Dipole Measurements at Storage Rings** — 20m
  Speakers: Joerg Pretz (Forschungszentrum Juelich/RWTH Aachen), Jorg Pretz (Forschungszentrum Juelich/RWTH Aachen)
  jpretz_non_collider...
- 09:00 **Gravitational Waves projects: connections with particle physics and cosmology** — 20m
  Speaker: Krisztian Peters (ATLAS (ATLAS Beyond Standard Model))
  KET_meeting_GW....
- 09:30 **Quantum Sensors for Particle Physics** — 20m
  Speaker: Loredana Gastaldo (Kirchhoff-Institut für Physik, Universität Heidelberg)
  Quantum_Sensors....

10:00 → 10:30 **Coffee** — 30m

10:30 → 13:00 **Final Discussion: First draft of the summary**

Many thanks to:

* all the speakers for their work

* the participants for the fruitful discussion

Workshop Participation

Registered:	120
Present at the Physikzentrum:	75
Zoom participation:	45

The Summary Document

* The participants did not prioritize specific research areas over others!

  The guideline for prioritization of specific projects was:
  „... we summarize ongoing non-collider experiments with a significant German contribution and prioritize the next major projects, for which a sustained funding is vital to guarantee the already existing strong German participation also in the future. The document is structured along different research questions with dedicated sections on common detector technology as well as theory developments.“

* 1st email sent on 11.12.24 to the registered particpants asking for feedback on the 1st version of the summary document proposed by the program committee (Deadline for feedback: 17.12.24, 23:59)
  Feedback from 12 registered participants

* 2nd email sent on 03.01.25 to check whether feedback was correctly implemented/the answers to the feedbacks were satisfactory (Deadline for feedback: 07.01.25, 23:59)
  Feedback from 3 registered participants

* Final version of summary document distributed to the registered persons of the Non-Collider workshop and KET Concluding workshop (for information): 09.01.25

Summary of the Summary Document

Summary of the workshop
“The Future of Non-Collider Particle Physics”
in preparation of the ESPP update
22-24 November 2024, Bad Honnef

This document reflects the final discussion of the workshop which was attended by 120 registered participants. The workshop was organized by a committee of representatives of all involved communities and open to everyone interested in the field. The agenda is available here: https://indico.desy.de/event/45358/.

Introduction

Particle physics in the 21st century is driven by finding answers to a manifold of fundamental questions, such as:
What is the nature of dark matter?
What are the properties of neutrinos and their interactions?
What is the nature of the neutrino mass?
What is the origin of the matter-antimatter asymmetry in the Universe?
How can the strong CP problem be solved?
Are there measurable charged-lepton-flavor violating processes?
To what precision is the standard model (SM) of particle physics valid?
…

→ This should be part of section 2 of the German KET input document to ESPPU2026

Promoting a diverse experimental landscape of non-collider experiments with a high physics potential

***** essential for advancing our understanding of the fundamental questions
* complementary to collider experiments
* explore phenomena that are challenging or impossible to access in colliders, e.g.
  studying neutrino properties, searching for axions, dark matter, feebly interacting particles (FIPs)

* operate on distinct timescales compared to large-scale collider projects
  → temporal flexibility ensures a continuous flow of scientific results and technological advancements, even between major collider upgrades

* German community:
  - deeply involved in a diverse array of non-collider experiments
  - strength heavily based on long-term engagement in highly-sophisticated detector technologies as well in the fixed-target programme at CERN
  - heavily profits from dedicated national facilities: KATRIN & Tritium Lab at KIT, Axion Platform at DESY, MAMI/MESA in Mainz, ELSA in Bonn

* Support by CERN and DESY as the national laboratory for particle physics with respect to technology, infrastructure, coordination is vital

* provide an excellent platform for training next generation of researchers, which is essential to retain and develop expertise
  in forefront detector technologies and experimental techniques

* Typically, the size and complexity of many non-collider experiments makes it easier for early career researchers to take part in all stages of an
  experiment, from the detector design, the detector construction and operation, until the data analysis and the publication of the physics results.

To address the fundamental questions of particle physics,
the community considers a diverse experimental landscape of non-collider experiments with a high physics potential being essential.

→ A strong general support statement should go into the German ESPPU2026 input, together with the arguments

Particle Physics and Dark Matter
* Rich set of theoretical ideas regarding the nature of DM, some of which address known deficits of the Standard Model (SM) of particle physics.
* Candidates: WIMPs, Axions (related to the so-called strong CP problem)/ALPs, keV sterile neutrinos (related to the neutrino mass problem)

Searches for WIMPs
* motivation: many SM extensions predict new physics around EW scale; WIMP miracle
* Search signals: - annihilation signals from cosmos,
  - missing energy/momentum or scattering signatures, at collider/non-collider experiments
  - direct detection

* Direct WIMP detection exps → big detector made of special target materials with extremely low natural radioactivity.

→ excellent German expertise in low background physics →essential role in world-wide leading efforts

→ XENON: major German involvement (XENON10, XENON100, XENON1T and now XENONnT)
German XENON groups also pursued crucial R&D for the next generation DARWIN project.
XENON, DARWIN and the US-led LZ project joined into future project XLZD

→ CRESST and future upgrade CRESST-III: complementary and very promising detection method → better suited for lighter WIMPs

→ DELight: German-led, upcoming experiment → novel approach to probe thus far uncharted low-mass WIMP DM parameter space.

→ Combined programme covers expected WIMP parameter space and puts German groups in strong position.

The German community therefore recommends to prioritize the XLZD, the CRESST-III as well as the DELight experiment in the future, which all cover different WIMP mass ranges.

→ Agreed with KAT chairs: KET input refers to KAT

Axions and axion-like sub-eV-mass particles

* Axions: motivated by strong CP problem in QCD

* ALPs: DM candidate; could explain transparency of the Universe to high-energy photons or cooling rates of stars
→ increasing theoretical and experimental attention during past decade
→ led to development of a dedicated experimental infrastructure for axion-related experiments at DESY
→ ALPS II: taking data since 2023.
→ ALPS II, IAXO, MADMAX, BRASS, CASPER, RADES, SUPAX, and WISPLC approaches pursued in Germany are complementary, with many of them being internationally leading in the field of axion phenomenology.

The community prioritizes the two complementary concepts of MADMAX and IAXO together with its precursor experiment BabyIAXO as large-scale experiments on an international level.

Both experiments will make use of the available unique large-scale infrastructure at DESY and will have a science case beyond axion-related physics. Given the huge relevant parameter space, it is important to complement the future large international projects BabyIAXO and MADMAX, with dedicated and coordinated efforts to develop and operate complementary experiments on national or bi-national level.
Moreover, the community encourages the further development of physics cases from purely axion-like particle searches towards other models, such as high-frequency gravitational waves.

→ **A strong support statement for MADMAX and IAXO should go into the German ESPPU2026 input**

→ **The importance of smaller-scale exps with a complementary physics case should be high-lighted as well; strategic coordination!**

Feebly Interacting particles

* FIPs: → masses well below EW scale and very weak couplings to SM particles
  → arise generically in many models of particle DM, neutrino mass generation, and BAU
  → may be linked to other open questions of SM, e.g. hierarchy problem/strong CP problem.
* tiny production Xsections and long lifetimes
  → collider exps not designed for long-lived FIPs, but can be targeted in high-intensity beam-dump or scattering exps operating at lower energies
* In past years: impressive results from NA62 and NA64
* new insights expected from MESA (start of operation: 2025)
  → MAGIX: improved sensitivity in visible and invisible decays of a dark photon
  → DarkMESA: direct search for light dark matter exploiting the large number of dumped beam electrons

A clear priority of the community for the future is the SHiP (Search for Hidden Particles) experiment, hosted in a new beam dump facility (BDF) at the ECN3 experimental hall at CERN.

In March 2024, CERN took the strategic decision to realize SHiP at a dedicated BDF in ECN3 as the flagship project in CERN's non-collider diversity programme. SHiP will achieve world-leading sensitivity for many types of FIP searches, which will establish CERN as the world-leading laboratory in this research field. The experimental programme is complemented by searches for sub-GeV dark matter through scattering signatures and a portfolio of neutrino measurements exploiting the huge neutrino flux from BDF. Thanks to their vital contributions to key detector subsystems, the participating German institutes are in an ideal position to play an essential role in SHiP.

→ A strong support statement should go into the German ESPPU2026 input

Plasma-wakefield accelerator facilities like AWAKE at CERN can serve as energy boosters for electron beams in the future and have the potential to significantly increase the FIP search sensitivity of existing fixed-target experiments.
We encourage including facilities for FIP searches in the planning of future collider infrastructures like FCCee or any linear collider.

→ Expect that AWAKE will be mentioned in the accelerator section
→ FIP searches with dedicated facilities at future colliders could be mentioned in the collider section ?

Precision experiments

* play a critical role in testing the SM and probing BSM physics → German community: leading/strong involvement

* P2(@MESA): high-precision determination of the weak mixing angle at low energies in parity-violating electron-proton scattering

* Mu3e: searches for charged-lepton flavor-violating decays → observation would be a direct BSM physics signal

* NA62: extremely rare kaon decays → window into rare processes that could reveal the influence of new particles or interactions.

* Ongoing and future measurements of electric dipole moments (EDMs) of neutral and charged particles
  → important tools for probing fundamental symmetries and potential extensions of the Standard Model.
  These developments will be followed with great interest by the German particle physics community.

* Future priorities identified by the German particle physics community include the LUXE experiment and the Phase 2 upgrade of Mu3e.
  → LUXE will delve into strong-field Quantum Electrodynamics (QED) by studying the interactions of intense laser light with high-energy electrons, probing the transition between the perturbative and non-perturbative regimes of QED.
  → The Phase 2 upgrade of Mu3e aims to enhance its sensitivity by several orders of magnitude, pushing the boundaries of (charged-)lepton-flavor-violation searches and allowing even deeper exploration of new physics scenarios.

→ German input should highlight in general the fixed-target program at CERN and in particular non-collider experiments hosted at national labs, emphasizing the importance of European and German infrastructure at national labs.

Neutrino Physics

Neutrino oscillations → origin and absolute scale of the neutrino masses and their smallness
→ Dirac or Majorana ?
→ Role of the leptonic CP violating phase(s) wrt matter-antimatter asymmetry,
→ influence of neutrinos on the evolution of early the Universe
→ unexpected large mixings and many connections to BSM physics

The German community plays a pivotal role in neutrino research for several decades, having leading contributions to several running or soon-to-be operational experiments.
The German-based KATRIN experiment is currently world-leading in the laboratory determination of the absolute neutrino mass scale with the TRISTAN upgrade for searching keV sterile neutrinos soon to start, while LEGEND200 is at the forefront of sensitivity for neutrinoless double beta decay searches.

Hence, the German community prioritizes next-generation experiments in both fields aiming to reach beyond the neutrino mass range indicated by the inverted mass ordering. KATRIN++, Project-8 as well as ECHo aim on different time scales with different technologies at the absolute neutrino mass. LEGEND 1000 aims at double beta decays which violate lepton number, which relates to neutrino masses if they are Majorana particles.

→ **Agreed with KAT chairs: KET input refers to KAT**

The community considers the long baseline accelerator neutrino oscillation experiments DUNE and Hyper-Kamiokande but also long-term studies like ESSnuSB important for the measurement of neutrino properties, in particular the CP violating phase of the PMNS matrix.
Besides a currently targeted participation in DUNE, the community is actively watching developments in this field.

→**Compared to ESPPU2020 input, current German involvement does not allow to make a strong statement about LBNF/DUNE.**

→**However, due to CERN’s investment into the neutrino platform (until end of ‘25?), not mentioning accelerator-based neutrino physics in the German ESPPU2026 input at all might look strange, given the size of the German CERN contribution.**

Neutrino Physics continued

Neutrino oscillations are also investigated in the neutrino telescopes IceCube-Upgrade, KM3NeT (ORCA) and the reactor neutrino experiment JUNO that follow complementary experimental approaches to discover the neutrino mass ordering.
The future extension IceCube-Gen2 is seen as a priority primarily regarding the investigation of astrophysical sources but also for potential results on neutrino oscillations and neutrino properties.

→ **Agreed with KAT chairs: KET input refers to KAT input**

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) was first observed using neutrinos from pion decays at rest and XENONnT recently detected CEvNS with solar neutrinos. The german reactor anti-neutrino experiment CONUS starts seeing the signal in the fully coherent regime. **The German community considers support for the small-scale experiments CONUS and NUCLEUS important, since CEvNS experiments will open with higher statistics within a few years a new direction with significant physics potential.**

→ **Agreed with KAT chairs: KET input refers to KAT input**

The first observation of collider neutrinos in 2023 at the FASER and SND@LHC experiments, opened a new experimental window for TeV neutrino physics. The community considers the collider neutrino physics program as highly relevant, in particular in the context of astrophysical questions, and encourages the maximization of the physics reach of the running experiments in the future.

→**Strictly speaking, this is in the area of collider physics.**

→**(Highly) visible German contributions to the running exps FASER and SND@LHC**

No or insignificant German contributions expected for HL-LHC upgrade of SND@LHC: AdvSND → groups will focus on SHiP

Compared to the size of the project: German interest in the proposed Forward Physics Facility not strong

→ **More than a general statement of the importance of full exploitation of the HL-LHC (in the collider section) difficult to make**

Theory

A broad theoretical exploration of the topics of this workshop is essential for the physical interpretation of the experimental data, which includes precision calculations as well as the development and maintenance of state-of-the-art simulation tools.
Theory establishes the cross-connections between these and other topics and identifies opportunities for a diversity of future experiments at an early stage.
More generally, it bridges the different fields of particle physics, nuclear physics, astro(particle) physics, and cosmology

The German community recommends guaranteeing robust support for theoretical work, which is critical for the optimal interpretation of data, for strategic decisions and for the success of the scientific program.

→ **This should be combined/merged with statement on the relevance of theory for both collider and non-collider physics**

→ **Not further considered here**

Gravitational Waves in the context of Particle Physics

GW detectors offer exciting scientific opportunities to probe early universe cosmology or late universe sources,
both of which require BSM physics to produce an observable GW signal.

For instance, signals from first-order phase transitions at very different scales could be detected and a measurement of the frequency spectrum could provide hints of new physics complementary to other experiments, e.g. at colliders and DM searches.
Low frequency signals (PTA, LISA) are sensitive to QCD and EWK BSM phase transitions, while high frequency signals beyond the LIGO/Einstein Telescope band provide opportunities to explore BSM phenomena and scales well beyond the reach of colliders.

In addition to possible contributions to particle physics science questions,
there are technological synergies between GW experiments and particle physics.
→ In the high frequency band, GW detection can be combined with axion search experiments.
→ In areas like vacuum technology and civil engineering, GW experiments can profit from the experience built up in particle physics and ongoing activities in this direction should be continued.

These physics contributions and technological synergies are already being explored and should be used to strengthen the European particle physics program.

→ **Position of the GW text in the summary document after „Theory“ considered by some people not justified:**
3rd-gen GW exps have many links to particle physics and high-frequency GW exps are purely motivated by particle physics

We might consider moving the GW section upwards in the summary document (a-posteriori), if there are no strong objections

→ **People being active in GW particle physics propose the following recommandation:**
„The community encourages identifying fundamental particle physics questions that can be advanced through gravitational wave research.
Additionally, it recognizes the importance of supporting smaller-scale high-frequency gravitational wave experiments and fostering technological synergies with particle physics research.“

Comment: Some statements on „Axions/ALPs“ and „Enabling Technologies“ partially overlap with this.

Enabling technologies

Strategic R&D is necessary to enable the projects mentioned above. The ECFA detector R&D roadmap provides an internationally coordinated framework for the required development work within the DRD collaborations. Quantum sensors and large volume detection technologies are of particular importance to many projects considered above. For certain technologies developed for small-scale experiments, there is a strong potential to be later used in large-scale non-collider and collider experiments with the additional advantage to develop, attract and retain expertise for detector developments. As a result, sustained funding for university groups on emerging technologies is an important investment for the future of the field.

The expertise of CERN in the field of designing, constructing, commissioning and operating large-size magnets as well as electromagnetic cavities is also indispensable for the realization of some of the future non-collider experiments, for example axion experiments. CERN should strengthen the support towards those experimental efforts.

→ **A strong support statement should go into the German ESPPU2026 input**

→ **General recommandations on non-collider and collider aspects should be covered in the same section on „Enabling technologies ...“**

→ **The comment on magnets wrt non-collider, for example axion experiments, might (also?) go into section 4 of the input document**

→ **One of the feedbacks to the summary document was to make a recommandation how to further develop the DRDs.**

This was not really discussed at the non-collider workshop.

Should be brought up in the discussion on the detector R&D presentation.

I was asked by KET to propose possible recommandations
<u>open for discussion and your feedback</u>

Guiding principles:

* German community input to the ESPPU2020
  & KET strategy workshop 2022 to prepare for BMBF funding period 24-27
  → Guarantee continuity where continuity obviously makes sense

* Summary of the 2024 Non-Collider Workshop
  → What is in particular highlighted?
  → What has changed wrt ESPPU2020 input?

* Length of text limited (estimate: at most 2 pages out of 10 pages)

For everything what follows/is missing:
You can put (almost) all the blame on me, but we have to start with something

National Input on non-collider projects and other fields

Remit to ESG also specifies:

“The Strategy update should also indicate areas of priority for exploration complementary to colliders and for other experiments to be considered at CERN and at other laboratories in Europe, as well as for participation in projects outside Europe.”

It would thus be most useful if the national inputs explicitly included the preferred prioritisation for non-collider projects. Specific questions to address:

a) **What other areas of physics should be pursued, and with what relative priority?**

b) **What are the most important elements in the response to (a)? (The set of considerations as for the “next collider” should be used).**

c) **To what extent should CERN participate in nuclear physics, astroparticle physics or other areas of science, while keeping in mind and adhering to the CERN Convention? Please use the current level and form of activity as the baseline for comparisons.**

A reminder: German community input to ESPPU2020
(based on two workshops on non-collider and on neutrino physics)

Experiments searching for WIMPs and axion-like particles, and experiments searching for light very weakly interacting particles at a high-intensity proton beam-dump are strongly recommended.
Experiments using natural particle sources or performed at accelerators in fixed-target or beam-dump setups are able to address fundamental questions that are complementary to collider experiments. Various SM problems are addressed by BSM theories predicting very weakly interacting particles (neutral leptons, dark photons/scalars, ALPs, WIMPs, but also light dark matter). The German particle physics community is particularly interested in the experiments IAXO at DESY, SHiP at CERN's SPS and DARWIN.

A visible European participation in long-baseline neutrino experiments, in particular at LBNF/DUNE, is strongly recommended.
Neutrino physics is a dynamic field with strong discovery potential providing a unique window to physics beyond the SM. The major scientific questions include the mass ordering and absolute scale of neutrino masses as well as their particle-antiparticle properties. The measurements of mass ordering, oscillation parameters and leptonic CP violation require complementary experiments using neutrinos from reactors and accelerators as well as atmospheric neutrinos. For the long-term future, a precise measurement of leptonic CP violation is a key scientific objective in particle physics.

→ **Very minimalistic.**
Input to EPPU2026: Can become a more detailed, however, still within limited space (target: At most 2 pages)

Proposal for input to the ESPPU 2026

Part on physics motivation in 4.1 might be already covered in section 2

4. Future projects complementary to colliders

4.1 Promoting a diverse experimental landscape of non-collider experiments with a high physics potential

To address the fundamental questions of particle physics, the German community considers a diverse experimental landscape of non-collider experiments with a high physics potential being essential.

Non-collider physics experiments provide complementary approaches to collider experiments and explore phenomena that are challenging or impossible to access in colliders:

There is a rich set of theoretical ideas regarding the nature of dark matter (DM), some of which address known deficits of the Standard Model (SM) of particle physics. Candidates are Weakly Interacting Massive Particles (WIMPs, which can be searched for e.g. by looking for annihilation signals from the cosmos, missing energy/momentum or scattering signatures at collider or non-collider experiments, and at direct detection experiments), axions (related to the so-called strong CP problem) and axion-like partices (ALPs), keV sterile neutrinos (related to the neutrino mass problem).

Various SM problems are addressed by beyond-the-SM (BSM) theories predicting feebly interacting particles (FIPs, e.g. neutral leptons, dark photons/scalars, ALPs, WIMPs, but also light dark matter). Dedicated beam-dump or scattering experiments at lower energies with extremely high beam intensities can achieve unprecedented sensitivities in this area.

Precision particle physics measurements play a critical role in testing the SM and are a tool to probe BSM physics.

Neutrino physics is a dynamic field with strong discovery potential providing a unique window to BSM physics. The major scientific questions include the ordering and absolute scale of neutrino masses as well as their particle-antiparticle properties. The measurements of mass ordering, oscillation parameters and leptonic CP violation require complementary experiments using neutrinos from reactors and accelerators as well as atmospheric neutrinos.

Gravitational wave (GW) detectors offer opportunities to probe early universe cosmology or late universe sources, both of which require BSM physics to produce an observable GW signal. Low frequency signals (PTA, LISA) are sensitive to QCD and EWK BSM phase transitions, while high-frequency signals beyond the LIGO/Einstein Telescope band provide opportunities to explore BSM phenomena and scales well beyond the reach of colliders.

Proposal for input to the ESPPU 2026

4.1 could continue then with the secondary strategy arguments

Besides their complementarity, non-collider particle physics experiments operate on distinct timescales compared to large-scale collider projects and therfore ensure a continuous flow of scientific results and technological advancements, even between major collider upgrades.

They provide an excellent platform for training the next generation of researchers, which is essential to retain and develop expertise in forefront detector technologies and experimental techniques.

They also have a size and complexity that makes it easier for early-career researchers to take part in all stages of an experiment, from the detector design, the detector construction and operation, until the data analysis and the publication of the physics results.

They heavily rely on the support by CERN and DESY as the national laboratory for particle physics with respect to technology and coordination, and profit especially from infrastructure and dedicated facilities at CERN (e.g. the fixed-target program) as well as at the European and national level (in Germany in particular: the KATRIN and Tritium Laboratory at KIT, the Axion Platform at DESY, MAMI/MESA in Mainz, ELSA in Bonn).

Proposal for input to the ESPPU 2026

4.2 Priorities

The following priorities do not cover direct WIMP searches and non-accelerator based neutrino physics, which are addressed by the input from the German astroparticle physics community.

(→ This sentence implies that we agree that the KAT and KET inputs are coherent. → See KAT input)

Given the priority of the HL-LHC and a future flagship collider project at CERN on one hand and the importance of a diverse physics programme on the other hand, CERN should m*aintain (?)* its non-collider programme at the current *fraction/level (?)*. Support of the fixed-target programme and strengthening the support of magnet development for non-collider experiments, for example axion search experiments, are considered of particular importance.

(Possible sentence on the future of the neutrino platform? → See KAT input)

The national infrastructures, in particular at DESY, should receive the necessary funding to guarantee a competitive non-collider particle physics research program in the future.

In the area of searches for feebly interacting particles, the German community prioritizes the SHiP experiment, hosted in a new beam-dump facility, fully exploiting the investment into CERN's north area consolidation.

In the area of axion(-like) particles searches, the German community prioritizes the two complementary concepts of MADMAX and IAXO together with its precursor experiment BabyIAXO as large-scale experiments on an international level.

Dedicated high-intensity/precision experiments at national labs with a unique selling point, such as Mu3e, LUXE, …, are important to support.

The community considers the long-baseline accelerator neutrino oscillation experiments DUNE and Hyper-Kamiokande but also long-term studies like ESSnuSB important. Besides a currently targeted participation in DUNE, the German community is actively watching developments in this field.

The community encourages identifying fundamental particle physics questions that can be advanced through gravitational wave research. Additionally, it recognizes the importance of supporting smaller-scale high-frequency gravitational wave experiments and fostering technological synergies with particle physics research.

Enabling smaller-scale experiments, which complement the physics case of larger-scale experiments, is important. Strategic coordination and exploring the extension of the physics case of such experiments is necessary for optimal use of technological and human resources.

DMInfraNet *

There is a wide variety of existing and planned dark matter search experiments.
Their size typically exceeds the abilities of single institutions – collaboration is becoming increasingly necessary.

DMInfraNet intends to provide a platform for the exchange on organisation, technology choices, technical expertise, infrastructures, construction, integration, exploitation for these experiments.
With all these topics in mind, DMInfraNet will become a forum for strategy discussions among the involved institutions.
DMInfraNet can become THE place where infrastructure requirements of experiments in the sector of dark matter and feebly interacting particles are discussed.

DMInfraNet aims to fill the gap between the basic detector technology development, as addressed by the DRDs, and the exploitation of experimental data and analyses, as intended to be addressed by iDMEu.
It is in this respect orthogonal and complementary to these existing exchange and collaboration mechanisms.

The installation of DMInfraNet and its recognition by the European strategy update will give the topics treated by the network the needed visibility and political weight.

*: slide material provided by Thomas Schörner

(Concrete) Goals and Steps

Concretely DMInfraNet will address the following topics

- organise an improved flow of information on existing expertise, on available infrastructures and facilities, and on their planning;
- set up the necessary communication structures and collaborative tools;
- provide explicit support in the field of the network members' expertise;
- provide easier access to the infrastructures and facilities;
- provide a common framework for solutions to common questions such as a software eco-system;
- implement a common approach to computing and data handling issues, also in view of increasing open and FAIR data requirements.
- provide scientific scrutiny for new ideas in the field
- organise joint funding applications
- contribute to the shaping of the respective strategy(ies)

As first steps, after the approval, DMInfraNet will work towards a roadmap for infrastructures in the field of dark matter and feebly interacting particle experiments in Europe, taking existing roadmaps and strategy / discussion processes into account.

Institutions and Persons Contributing to Discussions So Far

Drivers so far

- Jochen Schieck, Director HEPHY Vienna
- Dirk Zerwas, Director DMLab / IN2P3
- Florian Reindl, Assistant Professor TU Vienna
- Thomas Schörner, DESY

Institutions with people involved in discussions

- Boulby
- CERN
- DESY
- DMLab
- Harvard
- HEPHY Vienna
- IFIC Valencia
- IJCLab
- KIT
- LPSC
- LPTHE
- LSM
- INFN (LNL, MIB, Roma)
- Max Planck Munich
- NCAC Poland
- NIKHEF
- ORNL
- TU Munich
- U Amsterdam
- U Bonn
- U Lund
- U Muenster
- U Napoli
- U Oxford
- U Zaragossa

DMInfraNet proposal for input to ESPPU2026:

We propose a “Dark Matter Infrastructures Network” (DMInfraNet) as a platform for the exchange on organisation, technology choices, technical expertise, infrastructures, construction, integration, exploitation for dark matter and feebly interacting particle search experiments.
It is foreseen that DMInfraNet will become a forum for strategy discussions among the involved institutions.
DMInfraNet can become THE place where infrastructure requirements of experiments in the sector of dark matter and feebly interacting particles are discussed.

DMInfraNet aims to fill the gap between the basic detector technology development, as addressed by the DRDs, and the exploitation of experimental data and analyses, as intended to be addressed by iDMEu. It is in this respect orthogonal and complementary to these existing exchange and collaboration mechanisms. The installation of DMInfraNet and its recognition by the European strategy update will give the topics treated by the network the needed visibility and political weight.
As a first step, DMInfraNet will work towards a roadmap for infrastructures in the field of dark matter and feably interacting particle experiments in Europe, taking existing roadmaps and strategy / discussion processes into account.

→ Initiative brand new: neither discussed at non-nollider workshop nor within KAT yet; details are still in the making
→ One might take out the specific network name and have an input that supports the usefulness of such a network
→ If supported: some re-phrasing needed, since the German community does not propose DMInfraNet, for example:

„Setting up a network that provides a platform for the exchange of information on organisation, technology choices, technical expertise, infrastructures, construction, integration, exploitation for dark matter and feebly interacting particle search experiments, and that provides among the involved institutions a forum for discussions on strategy as well as on infrastructure requirements of experiments, should be considered.“

→ Mainly in KAT or in KET input and then corresponding cross-reference? (depends on focus)