UK Muon Beams - Introduction

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UK Background

- UK has a world-leading background in muon accelerator R&D
- Leader in neutrino factory International Design Study
  - Developed proton driver optics
  - Optimised target, muon selection and cooling schemes
  - Acceleration via non-scaling FFA
  - Decay rings for muon decays to neutrinos
- Strong collaboration with CERN on nuStorm project
- World-leading hardware R&D programme
  - Constructed EMMA world-first non-scaling FFA
  - Hosted Muon Ionisation Cooling Experiment (MICE)
  - Developed target test stand for high power targetry
- 20 years of experience on muon accelerator R&D

European strategy Update (2020)

Strategy document

3 | High-priority future initiatives

A. An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

- ***the particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors;***

- ***Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.***

The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

B. Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. ***The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.***

Deliberation Document

…n chamber (TPC) technique that …ved the development of very large cryostats, suitable for the multi-kiloton scale of the envisaged DUNE detector. Other developments at the Neutrino Platform have included the refurbishment of ICARUS for use in the Fermilab short-baseline programme, as well as a magnetic spectrometer (BabyMIND) and the upgrade of the near detector ND280 for the T2K experiment in Japan. The community is very keen for the Neutrino Platform to continue operation at CERN for the benefit of the worldwide neutrino community.

To extract the most physics from DUNE and Hyper-Kamiokande, a complementary programme of experimentation to determine neutrino cross-sections and fluxes is required. Several experiments aimed at determining neutrino fluxes exist worldwide. The possible implementation and impact of a facility to measure neutrino cross-sections at the percent level should continue to be studied. Other important complementary experiments are in preparation using reactor and atmospheric neutrinos. They have the potential to discover the mass ordering and to perform other precision oscillation measurements. The study of the neutrino absolute mass and nature (either Dirac or Majorana) is the other priority for the field, covered by both laboratory and cosmology measurements. The design studies for next-generation long-baseline neutrino facilities should continue.

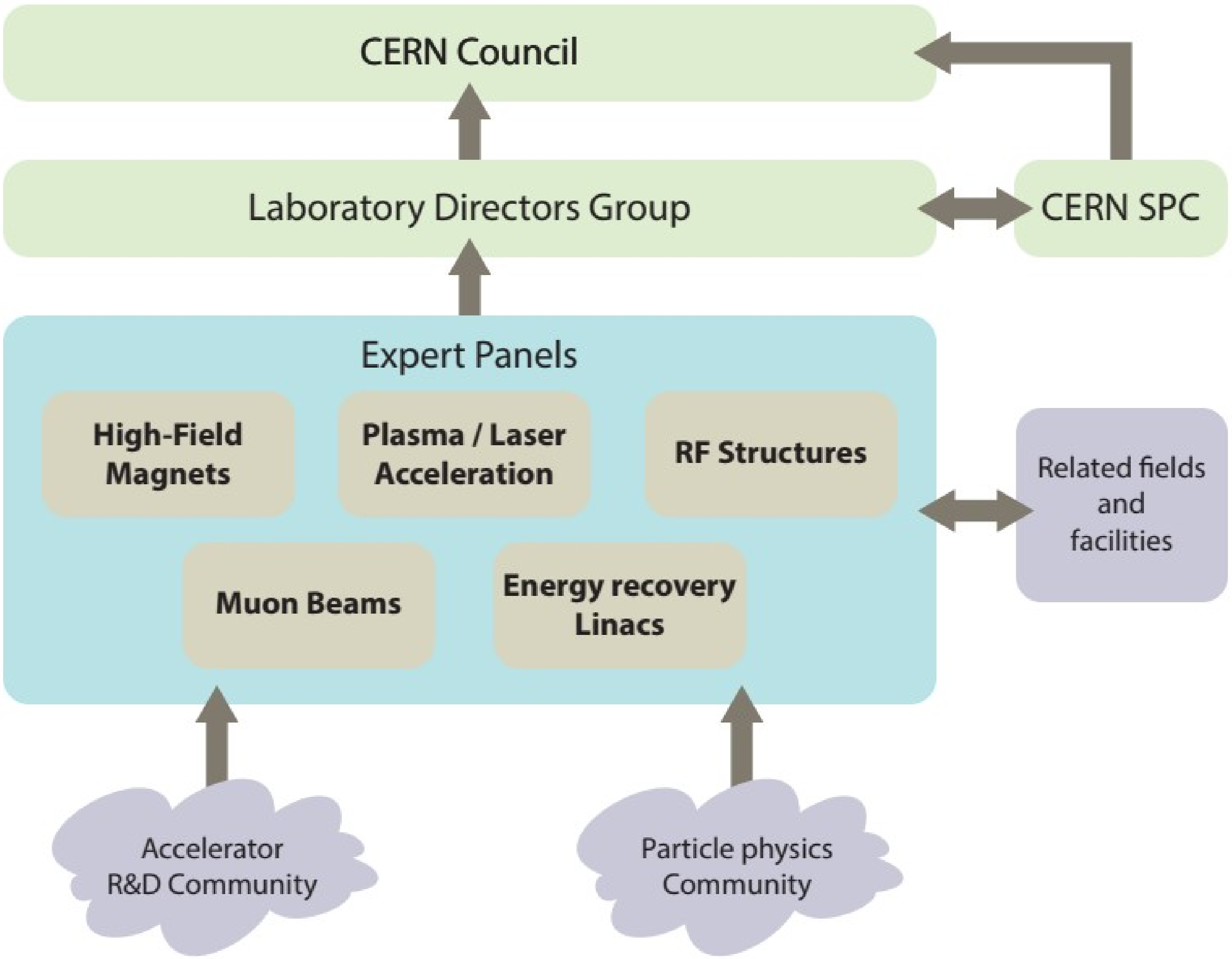
Balanced European support for this worldwide effort will make it possible to secure the determination of the neutrino masses, oscillation parameters, including the CP violation phase, and to test for possible deviations from the three-neutrino framework.

Panels

- European Committee for Future Accelerators panel (ECFA)
  - European strategy for detector R&D
- Laboratory Directors' Group panels (LDG)
  - European strategy for accelerator R&D
- Particle Physics Advisory Panel (PPAP)
  - What physics goals/experiments should UK pursue
- Particle Physics Technology Advisory Panel (PPTAP)
  - What technologies should UK develop

- Muon Collider Collaboration
  - Memorandum of Collaboration and statement of interest
  - EU funding bid to be prepared

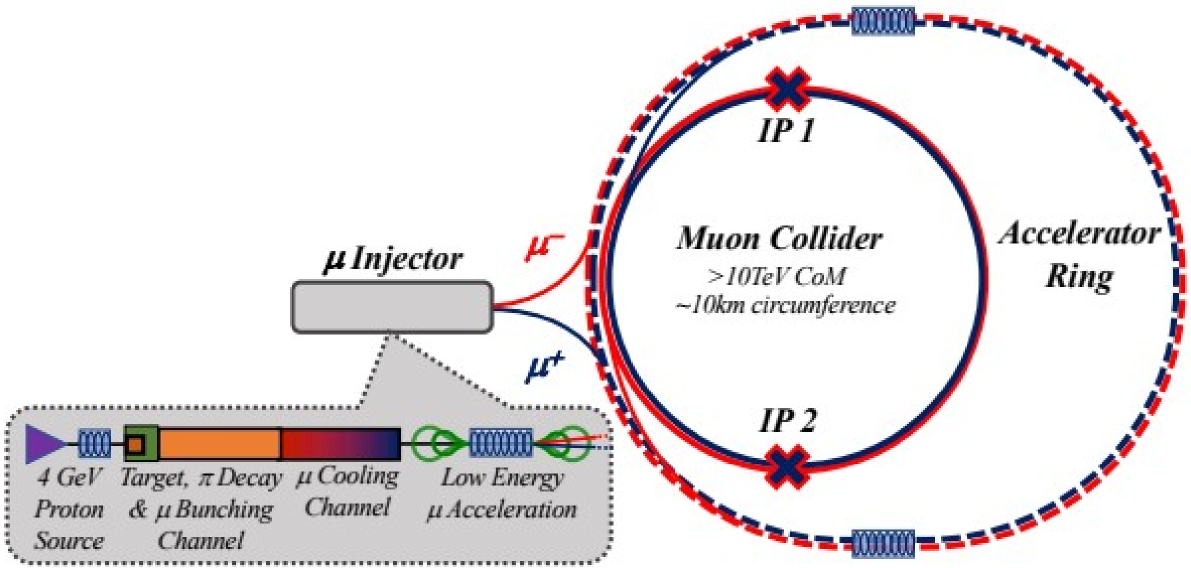
LDG Panel


CERN Council
Laboratory Directors Group
CERN SPC
Expert Panels
High-Field Magnets
Plasma / Laser Acceleration
RF Structures
Muon Beams
Energy recovery Linacs
Related fields and facilities
Accelerator R&D Community
Particle physics Community

LDG Panel

European Strategy Update
2020
Nov: Definition of process
Jan: Appointment of expert panels
Jan – Jun: Community consultation
Jul: Public reports (EPS-HEP 2021)
Sep – Nov: Planning discussions
Dec: Approval of final roadmap
Stage 1: Roadmap Definition
2021
Stage 2: Roadmap Implementation
European Strategy Update
~2026

LDG Panels Interim Report (1)

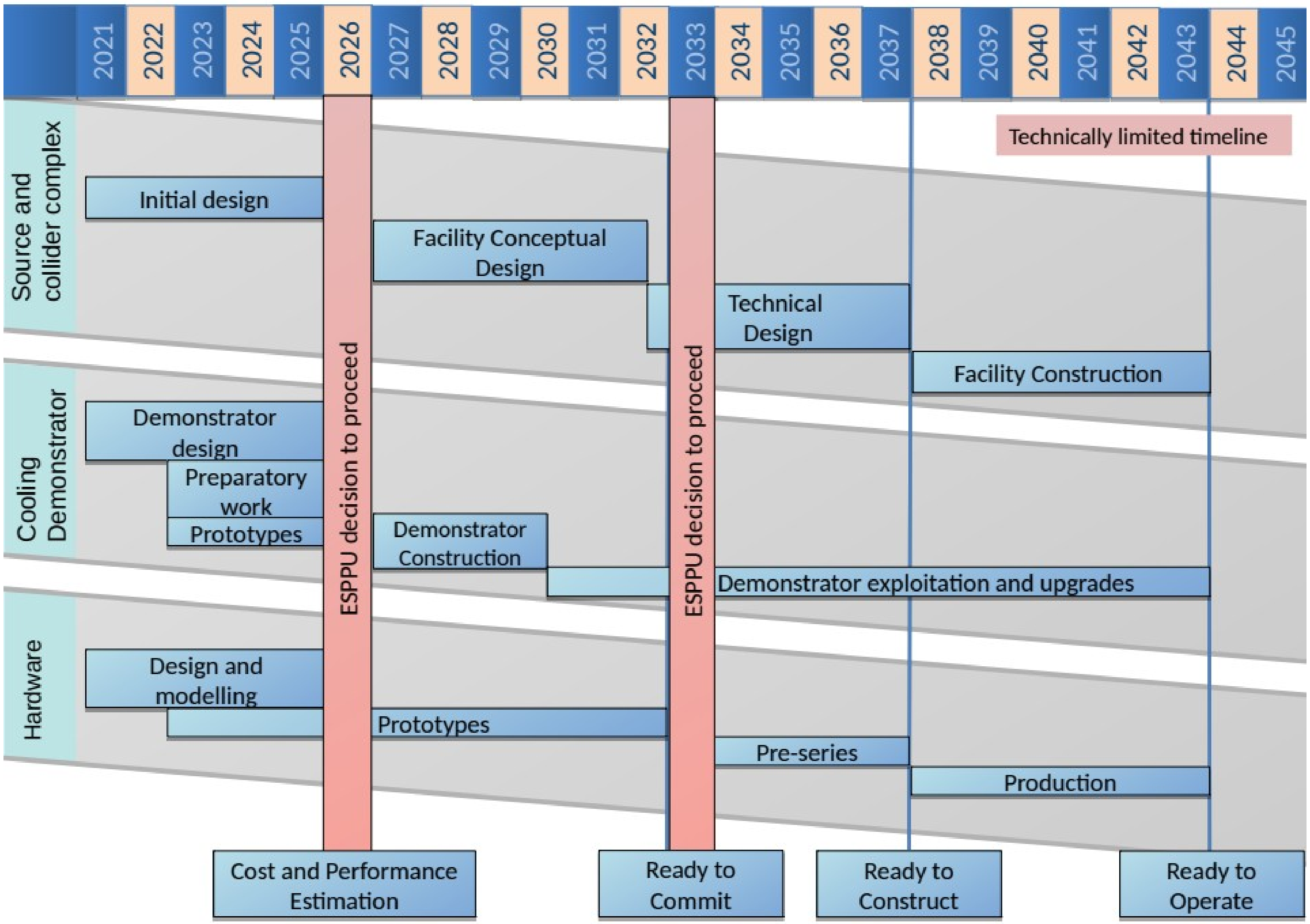


- Protons → pions/muons → cooling → acceleration and collision
- The only route to leptons with energy > 3 TeV
- Potential for
  - Lower cost
  - Lower power consumption
  - Shorter timescale
  - To be confirmed!

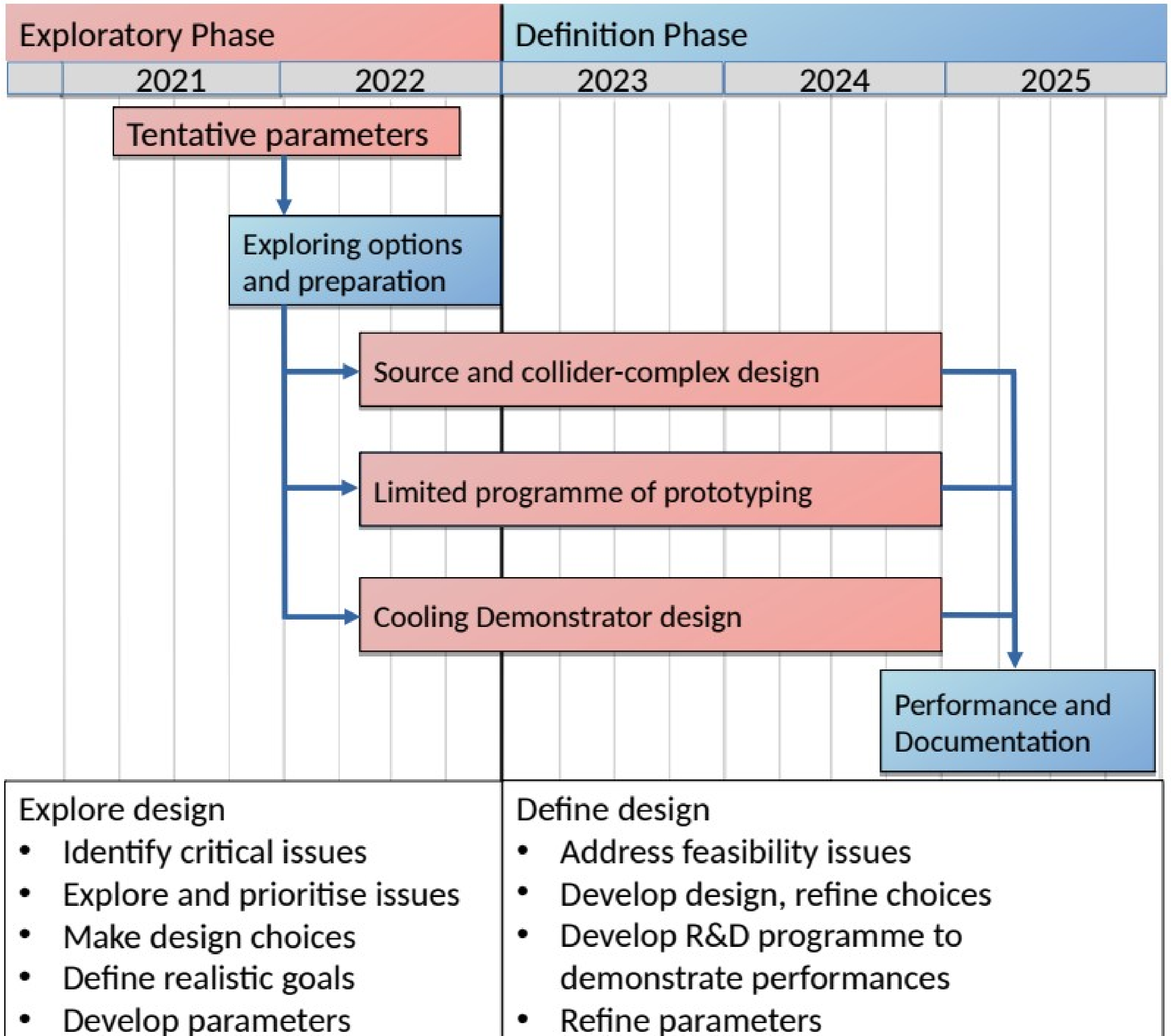
LDG Panels Interim Report (2)

- Interim Report:
  - Four main areas of concern/risk
    - Small amount of off-site radiation from neutrinos must be minimised
    - Machine Detector interface & detector backgrounds
    - High energy complex design
      - Acceleration/collider at 3 TeV Centre of Mass energy needs work
      - Acceleration/collider at 10 TeV Centre of Mass energy unexplored
    - Muon production and cooling
      - Target area very challenging
      - Muon cooling needs work → drives performance
  - Also note
    - Proton complex also needs to be considered
    - Synergies
      - nuSTORM and ENUBET
      - Lepton flavour violation
      - Surface muon production
- Aim to establish the need for a complete programme (CDR) by 2026

LDG Panels Interim Report (3)



LDG Panels Interim Report (4)



PPAP

- Particle Physics Advisory Panel
- Report in final drafting
- Outcome reflects closely muon community inputs…

4.2.3 Muon Collider

Muon colliders could reach centre-of-mass energies of tens of TeV and high luminosity in smaller accelerator tunnels. A muon collider would allow accurate tests of the Standard Model to extremely high energy and searches for new physics. By exploiting the copious rate for VBF and vector boson scattering processes, it provides the opportunity to probe details of the EW symmetry breaking mechanism. Nonetheless, the technology is not mature enough to envisage such a facility in the medium term. The interest at the moment is focussed nuSTORM. This facility, possibly to be hosted at CERN, could deliver a precisely known (1%) level neutrino beam that are produced in a storage ring by the decay of muons. This could be considered as a technology demonstration platform for the construction of a muon collider. Such a facility would be an ideal tool for high-precision neutrino interaction cross-section measurements and to search for sterile neutrinos.

The CERN-led muon collider collaboration was formed in 2020 following publication of the ESPPU. The collaboration has entered a two year planning phase that will be followed by a three year study phase leading to a design report on a timescale consistent with the next strategy update. Nineteen UK institutes have expressed interest in nuSTORM, with that interest coming from both the neutrino and accelerator community. The UK has established leadership position in this area and should maintain it, in case the Muon Collider would become a future direction.

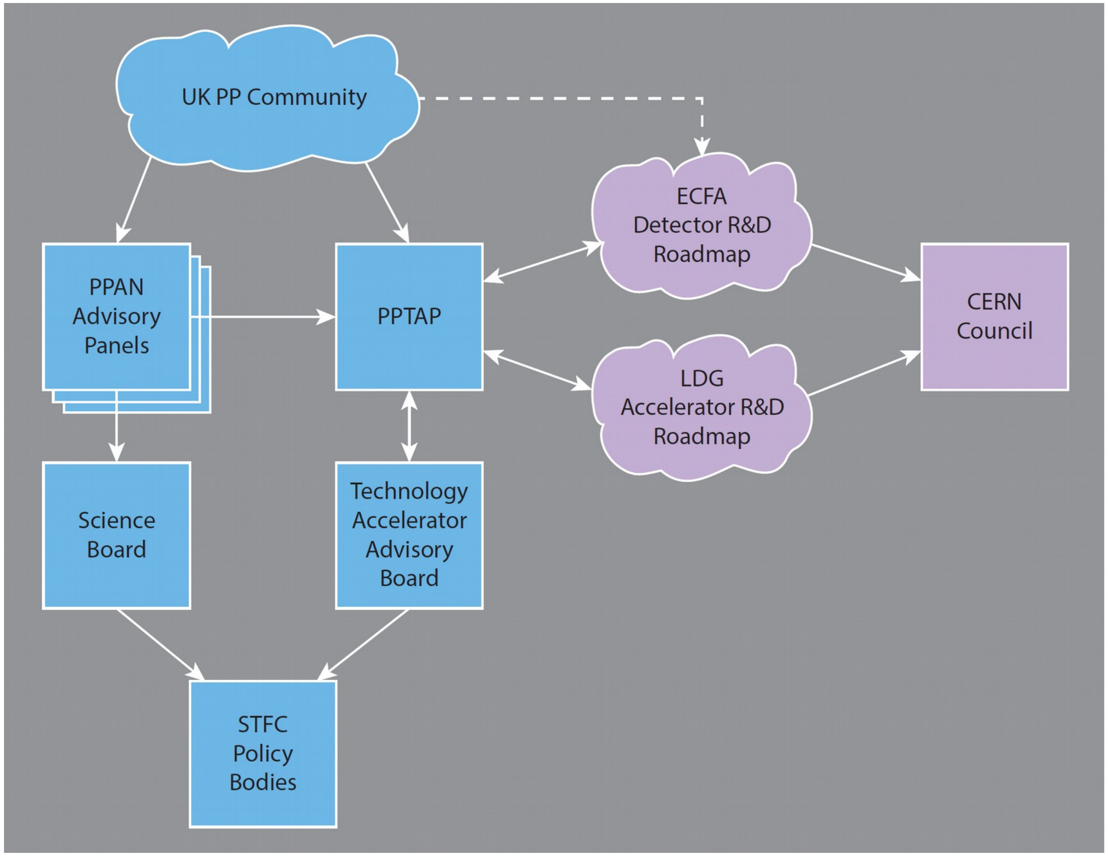
Recommendation 4.6: The UK should maintain its leadership in Muon Collider studies concentrating on medium-term projects focused on feasibility demonstration exploring synergies with neutrino physics such as nuSTORM.

Finally, we note that new initiatives are arising to study the interactions of high-energy neutrinos produced at a collider. The ForwArd Search ExpeRiment (FASER) experiment at CERN, designed to extend GPDs and LHCb searches for light and weakly-interacting particles at the LHC in the far-forward region, has been recently complemented with FASERν, an emulsion detector sensitive to neutrinos in the GeV-TeV energy range. A similar proposal, Scattering and Neutrino Detector at the LHC (SND), has been approved by CERN to exploit another underground tunnel connecting the LHC to the Super Proton Synchrotron, and it will start recording data in 2022 like FASER. Both Faserν and SND allow for detailed studies of ν_e and ν_τ at the highest energies yet explored and ν_μ neutrinos in a currently unexplored energy range between experimental data available from accelerator neutrino experiments and astrophysical neutrino observatories such as IceCube. Both experiments foresee a possible upgrade for the HL-LHC. The UK has some involvement in these initiatives, and should ensure that opportunities in this area are exploited further in the next decade.

Recommendation 6.1: The UK should maintain its leading role in long-baseline neutrino oscillation experiments. Exploitation of the currently running experiments should be supported. In the next 10-20 years the main priority will be on measuring the CP-violating phase of the mixing matrix and the neutrino mass ordering with the long-baseline programmes in Japan and USA. The UK should continue to engage with both programmes. In particular, it should maintain its leading involvements in LBNF and DUNE.

Recommendation 6.2: To extract the most physics out of the long-baseline neutrino experiments the UK should build on its existing expertise to pursue a complementary programme of precision measurements of neutrino interaction cross-sections and neutrino fluxes. In addition, recently emerged opportunities of detecting collider neutrinos, that allow measuring neutrino cross sections at energies where they are currently unconstrained, should be pursued.

Particle Physics Technology Advisory Panel



- Report writing stage

International Muon Collider Collaboration

- International muon collider collaboration
  - Focus has been gathering input to LDG report
- Community meeting 6-8 October
  - LDG report status
  - Memorandum of Collaboration including statement of interest
  - Setup of collaboration structures
  - EU funding application due March 2022

International
MUON Collider
Collaboration

MoC

Memorandum on Cooperation
for the Muon Collider (MC) Study

THE INSTITUTES, LABORATORIES, UNIVERSITIES AND FUNDING AGENCIES AND OTHER SIGNATORIES OF THIS MEMORANDUM ON COOPERATION AND CERN AS THE HOST ORGANIZATION (“the Participants”)

Whereas

At a dedicated session of the CERN Council held on 19 June 2020, the Council updated the European Strategy for Particle Physics which included *inter alia* the following statement:

“...Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.”

The underlying Deliberation Document of the 2020 Update of the European Strategy for Particle Physics stipulates that, in addition to high field magnets, the accelerator R&D roadmap should contain:

“...an international design study for a muon collider, as it represents a unique opportunity to achieve a multi-TeV energy domain beyond the reach of e+e– colliders, and potentially within a more compact circular tunnel than for a hadron collider. The biggest challenge remains to produce an intense beam of cooled muons, but novel ideas are being explored”;

9. Duration

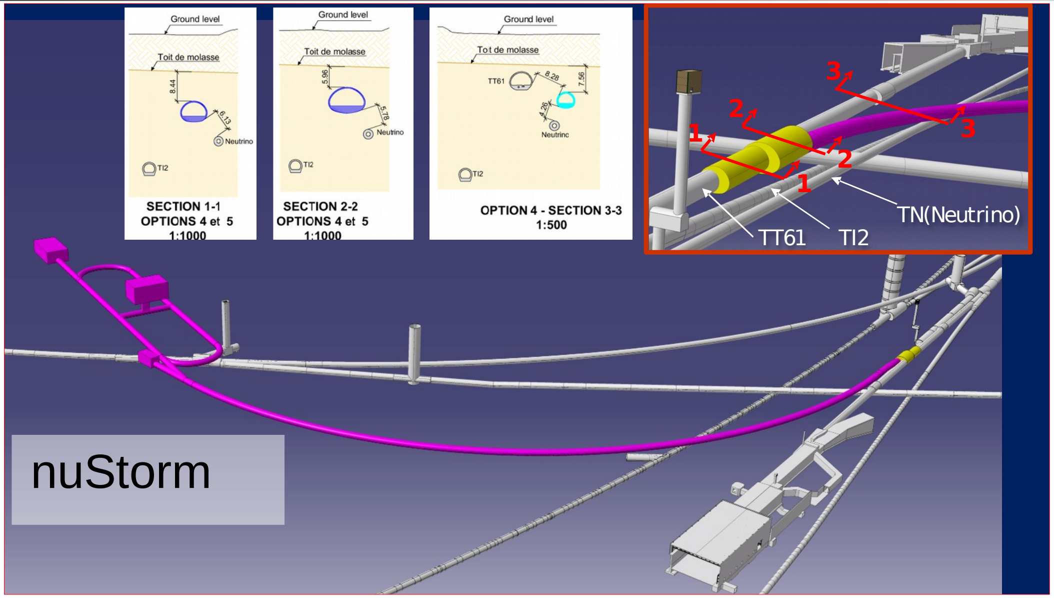
9.1. In recognition of the fact that this Memorandum does not imply any commitment of resources, a Participant may withdraw from this Memorandum by giving a minimum of three months written notice to CERN as the host organization.

9.2. This Memorandum shall remain in force for as long as required to give effect to its provisions.

Signed by the authorized representatives of:

For the European Organization for Nuclear Research (CERN) as the Host Organization	**For the “{Name of Participant Institute}” ({Short name})**
Daniel Schulte MC Study Leader	{First Name, Last Name} {Function}
Date:	Date:

nuStorm

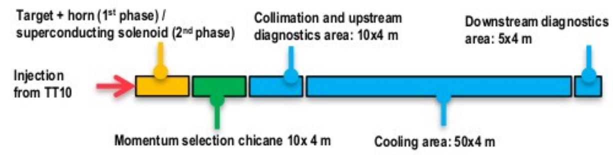


- nuStorm has good synergies with muon collider
  - FFA optics could enable high acceptance muon storage ring
  - Effects of pion and muon decay on active accelerator components
  - Relatively high current secondary pion/muon beam available for cooling studies
  - Synergy with Enubet
- It would be the highest current high-energy muon facility

nuSTORM/Demonstrator layout

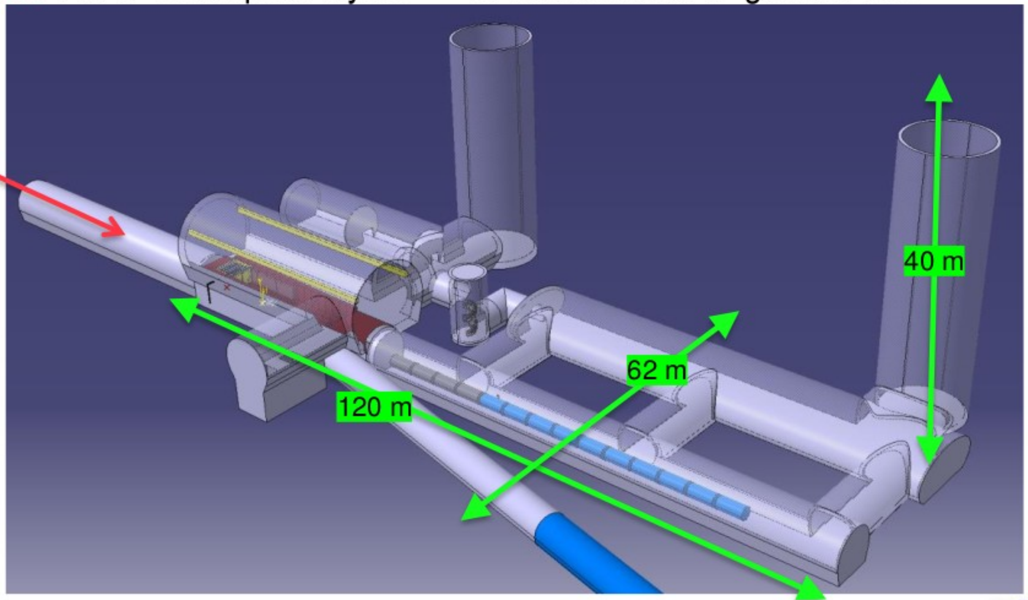
International MUON Collider Collaboration

Conceptual layout



MUC Demonstrator VERY Conceptual layout → To be taken with a "grain of salt"

CERN TT10 branch



Indicative dimensions. Model is very flexible at this stage

Today

- Update the status of muon studies in the UK?
- What should we seek to deliver over the coming few years?
- How should we go about gathering resource to do this?

Timetable

Mon 27/09

Print | PDF | Full screen | Detailed view | Filter

13:00	**Introduction**	*Chris Rogers*	13:00 - 13:20
	Muon collider detector	*Alessandro Cerri*	13:20 - 13:40
	Potential for physics at nuSTORM/eNUBET	*Matheus Hostert*	13:40 - 14:00
14:00	**nuSTORM detector**	*Paul Kyberd*	14:00 - 14:20
	NuSTORM and muon collider muon production target	*Chris Densham et al.*	14:20 - 14:40
	Demonstrator for 6D ionisation cooling	*Chris Rogers*	14:40 - 15:00
15:00	**Break**		15:00 - 15:15
	RF cavity R&D	*Adrian Cross et al.*	15:15 - 15:35
	nuSTORM accelerator facility	*Jaroslaw Pasternak*	15:35 - 15:55
16:00	**Development of BDSIM for muon simulations**	*Dr Laurie Nevay et al.*	15:55 - 16:15
	FFAs in the muon collider High Energy Complex and Proton Driver	*Jean-Baptiste Lagrange*	16:15 - 16:35
	Discussion to include: what interests should be expressed in the MoC; how would we like to contribute to the demonstrator/nuSTORM; how do we discuss with STFC		16:35 - 17:10
17:00	**Next steps**		17:10 - 17:20