Muon accelerators for particle physics

Presented by *D. Newbold*
STFC, RAL

K. Long, 11 September, 2019

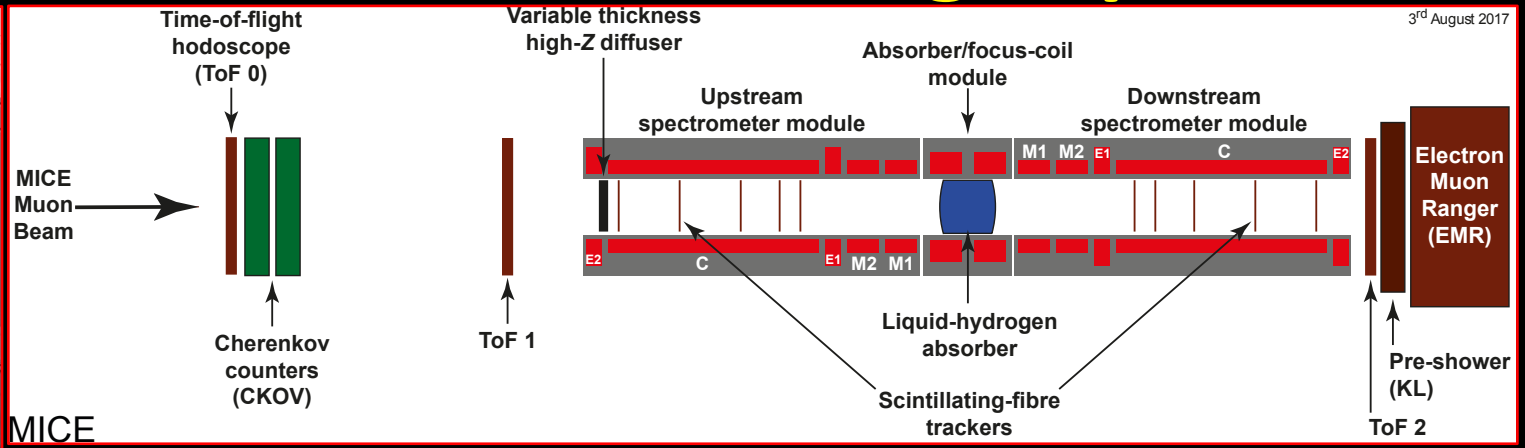
Energy frontier beyond HL-LHC

- Clear priority for field
- ILC/CLIC/circular e^+e^-
  - Uncertain
  - May require initiative from Asia
    - Long timescale in any case
  - LC limited to one experiment?
- FCC-hh
  - Clear, but general, case
  - Very long timescale
  - Risks:
    - Financial, technical, schedule, …
  - Way points:
    - e^+e^-:
      - Z?, H
    - eh:
      - A winner if $\langle lq \rangle$

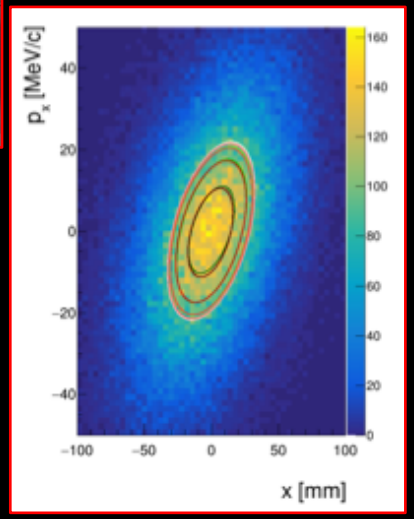
    Still very long timescale
- Motivates accelerator R&D portfolio

- Muon collider:
  - Alternative route to energy frontier
  - Arguably possible to:
    - Advance timescale
    - Reduce investment cost
    - Reduce running cost (lower power at high energy)
    - Multiple experiments
  - Way points:
    - nuSTORM:
      - Science and muon-collider test bed
    - Neutrino factory?
  - For UK:
    - Still a community that's interested and expertise
    - Legacy from large, historic, investment
      - MICE cooling demo submitted to Nature (under review)
    - Opportunity for leadership
  - For CERN:
    - New techniques for particle physics:
      - Neutrinos:
        - » 'Still' pulsed extraction and van de Meer horn
      - Energy frontier:
        - » 'Still' synchrotron; implies limit on energy with e^+e^-

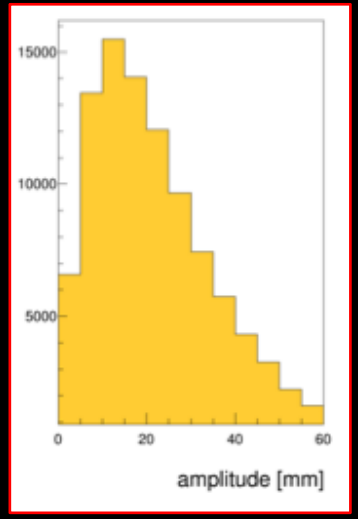
Muon Ionization Cooling Experiment



Absorbers:
65 mm LiH disk
350 mm LH_2

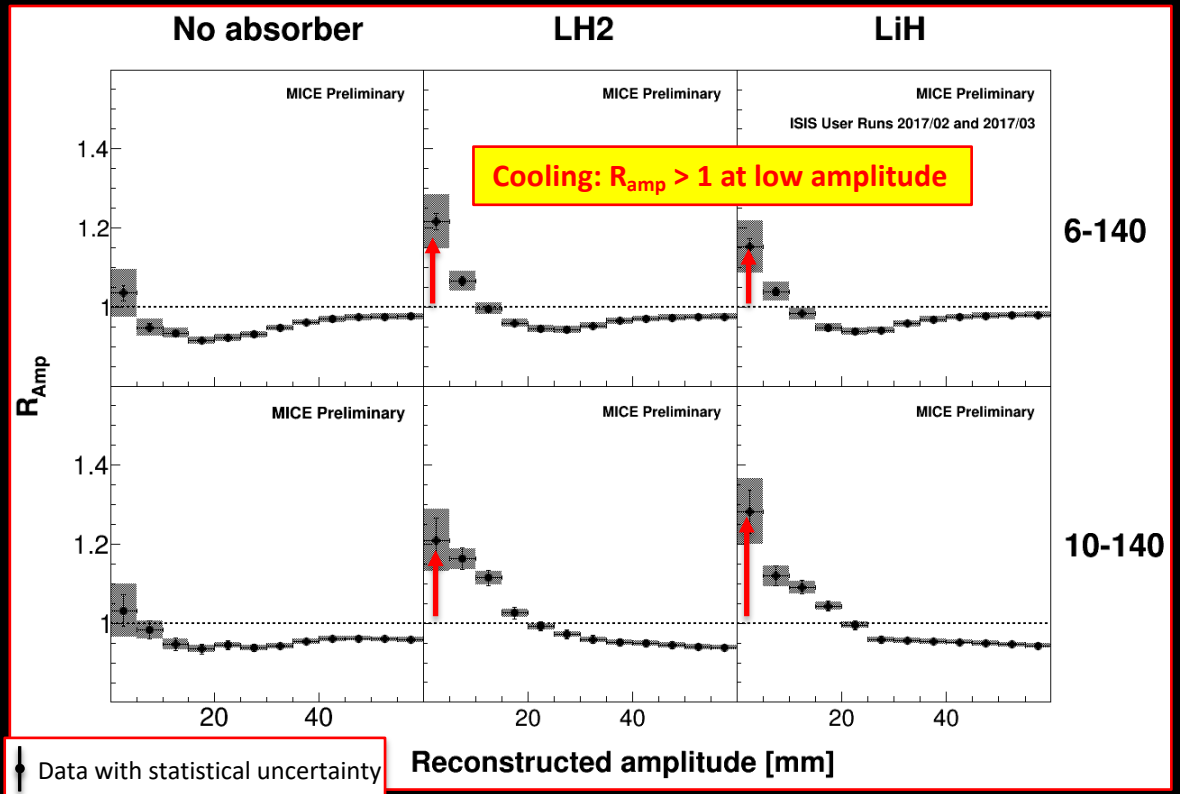


- Ionization cooling:
  - Due to energy loss in absorber
- Observe by comparing:
  - Beam d/s of absorber to that u/s
- Emittance (ε):
  - From RMS beam ellipse
- Amplitude:
  - Distance from beam core
- Mean amplitude ~ ε



First observation of ionization cooling

10.18429/JACoW-IPAC2018-FRXGBE3
arXiv:1907.08562



Core-density:

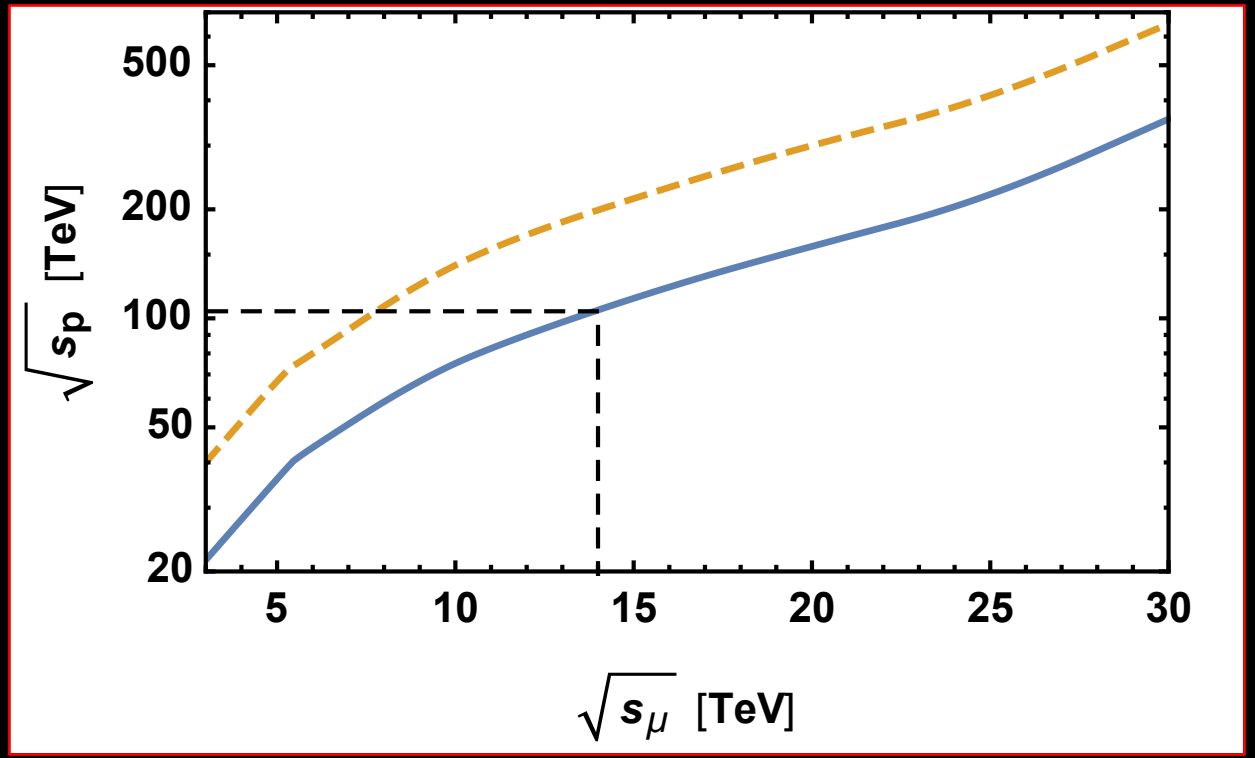
- *Increases* with LiH and LH2 absorbers
- *Consistent with 'no change'* for no absorber

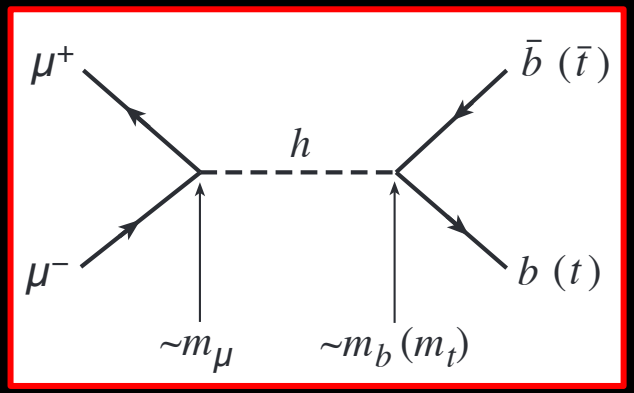
Ionization-cooling signal

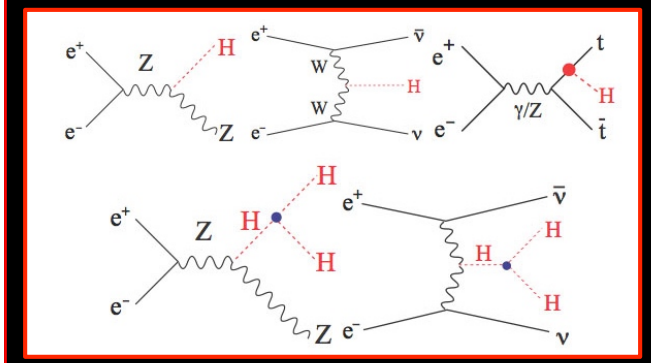
Publication in preparation

R_{amp} = ratio of cumulative density downstream to upstream

Benefit of muon beams







- Energy frontier: big advantage over pp because fundamental fermion
- Future study of the Higgs:
  - Line width; establish single resonance (?) in s-channel with $\mu^+\mu^-$
  - Couplings; requires > 1 TeV for complete, precise study

Muon collider

Rifkin, Granada, May 2019

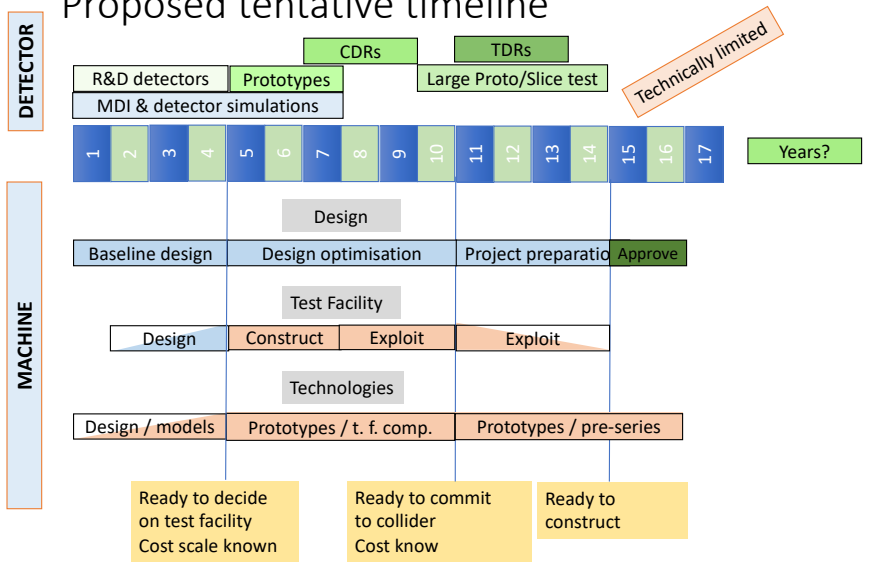
Answers to the Key Questions

- **Can muon colliders at this moment be considered for the next project?**
  - Enormous progress in the proton driven scheme and new ideas emerged on positron one
  - But at this moment not mature enough for a CDR, need a careful design study done with a coordinate international effort

- **Is it worthwhile to do muon collider R&D?**
  - Yes, it promises the potential to go to very high energy
  - It may be the best option for very high lepton collider energies, beyond 3 TeV
  - It has strong synergies with other projects, e.g. magnet and RF development
  - Has synergies with other physics experiments
  - **Should not miss this opportunity?**

- **What needs to be done?**
  - Muon production and cooling is key => A new test facility is required.
    - Seek/exploit synergy with physics exploitation of test facility (e.g. nuSTORM)
  - A conceptual design of the collider has to be made
  - Many components need R&D, e.g. fast ramping magnets, background in the detector
  - Site-dependent studies to understand if existing infrastructure can be used
    - limitations of existing tunnels, e.g. radiation issues
    - optimum use of existing accelerators, e.g. as proton source
  - **R&D in a strongly coordinated global effort**

Proposed tentative timeline

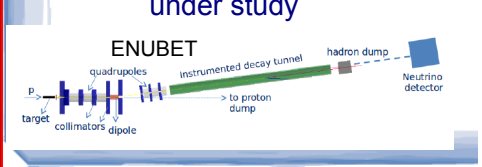


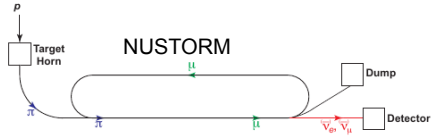
Neutrinos

Zito, Granada, May 2019

Precision program in Europe

- Squeezing every bit of information out of the future experiments requires a complementary program (special rôle for Europe) to
  - Measure hadroproduction for the neutrino flux prediction (NA61)
  - Understand the neutrino-nucleus cross-section at the % level, both theoretically and with new facilities (Enubet, Nustorm)
  - Collaboration to be developed with nuclear physicists
- Next-to-next generation facilities (ESSnuSB, …) are also under study





Neutrino Physics
(accelerator and non-accelerator)
summary of the session

Conveners: Stan Bentvelsen, Marco Zito

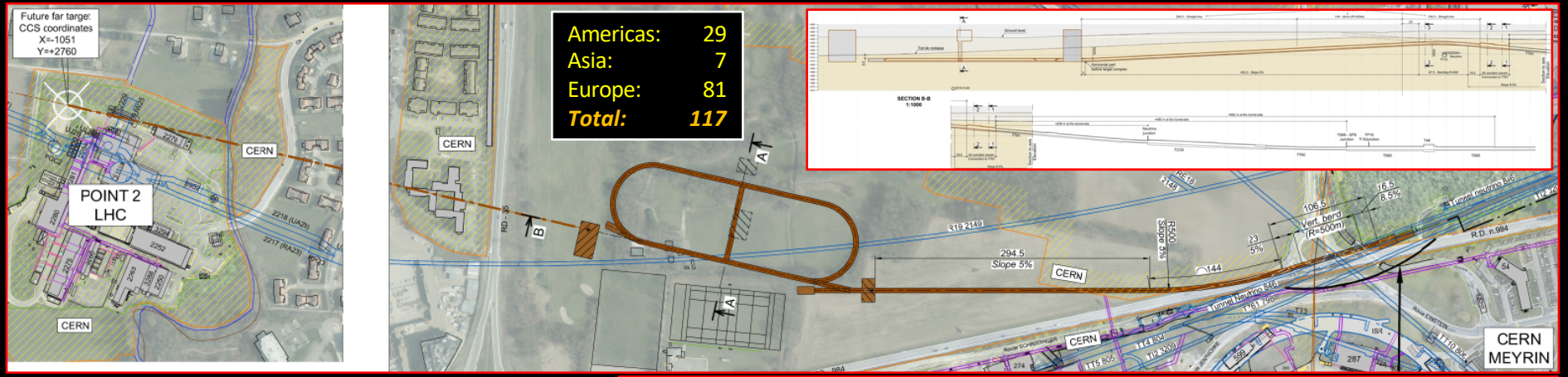
ESPPU Open Symposium Granada
May 16, 2019

In the session we also covered astroparticle physics

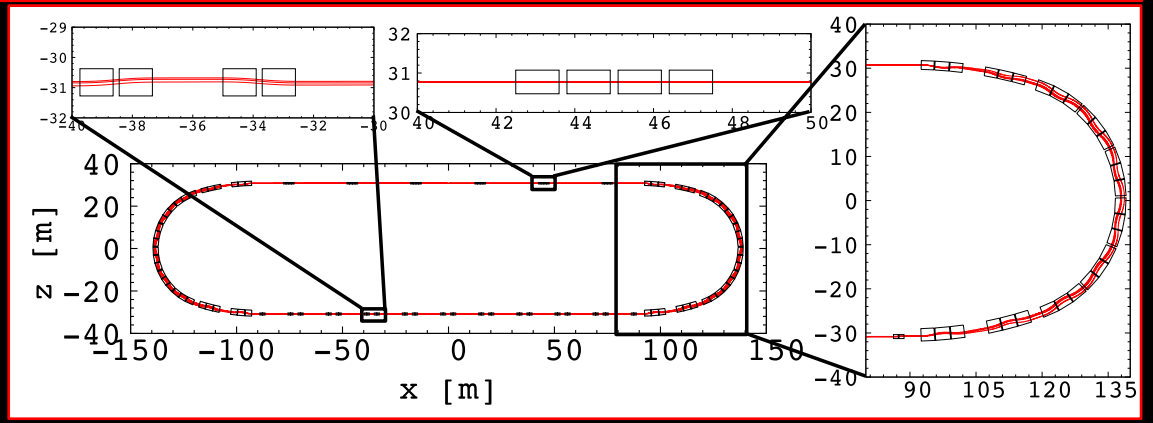
Neutrino oscillations

- Vibrant program (DUNE, Hyper-Kamiokande, JUNO, ORCA) to fully measure the PMNS mixing matrix and especially the Mass Ordering and the CP violation phase delta, with strong European contribution. Perceived by the community as a priority.
- Neutrino experiments need cutting-edge detectors and % precision on the flux and cross-sections: leading rôle for Europe (NA61, Neutrino Platform). New facilities currently under study.
- Long term future for high precision LBL measurements with new techniques. Time to prepare for it !

European Strategy for Particle Physics Update

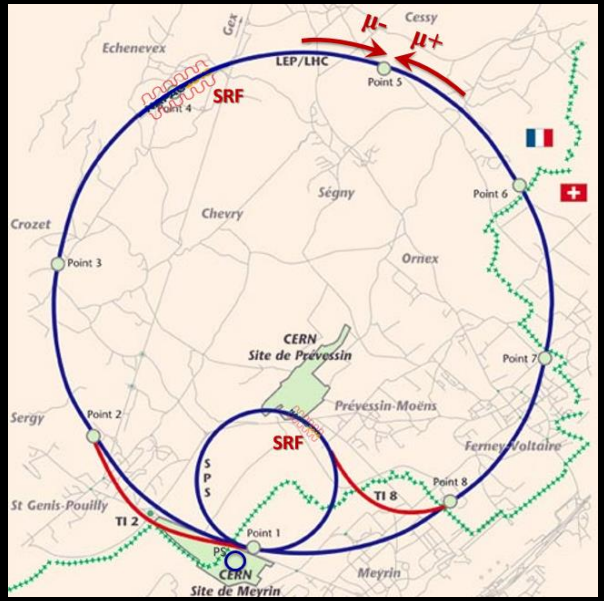


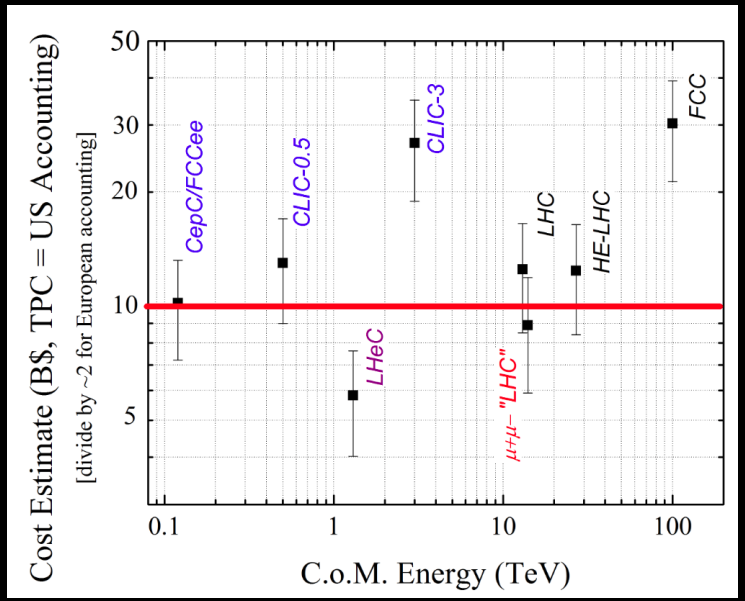
- **Scientific objectives:**
  1. %-level ($\nu_e N$) cross sections
     - Double differential
  2. Sterile neutrino search
     - Beyond Fermilab SBN
  3. Muon-accelerator R&D
     - FFA optics; cooling …



DMN Addendum: Muons in LHC Tunnel?

- arxiv:1811.10694, “On The Feasibility of a Pulsed 14 TeV c.m.e. Muon Collider in the LHC Tunnel”





Conclusions

- Muon collider:
  - Well motivated as energy-frontier l^+l^- machine
  - R&D programme:
    - Valuable in itself; and
    - Essential part of 'energy-frontier' risk-mitigation

- Strategic development of muon collider:
  - Must include (near)medium-term particle physics
    - nuSTORM excellent candidate
  - Must include balanced 'RD' programme
    - With decision points

- nuSTORM as a first step:
  - νN cross sections, sterile neutrinos, muon-collider test bed
    - Articulated in international (IDS-NF) and US (MASS) studies

Now at CERN (no travel funds…)

Muon Collider Workshop

https://indico.cern.ch/event/845054/

ber 2019
timezone

Search...

- Overview
- Timetable
- Participant List

The Coseners House

The Workshop will be held at the ~~Rutherford Appleton Laboratory~~ from Wednesday 9th October to Friday 11th October 2019 inclusive.

During the closing phase of the Update of the European Strategy for Particle Physics we would like to reconvene and try to better coordinate the renewed efforts on future studies for a muon collider facility.

In the contest described by the freshly published Briefing Book we would like to address past and new ideas on the main areas where work is in progress: physics, detector and machine.

The meeting aims to get experts and anybody who is interested to discuss the physics benchmarks, the detector simulation, the machine design and the technology issues towards a feasible R&D plan.

We aim to form a proto-collaboration group to address the most challenging and crucial items of the field.

nuSTORM, the next steps

21 Oct 2019, 13:30 → 22 Oct 2019, 15:00 Europ

774/R-013 (CERN)

Kenneth Richard Long (Imperial College (GB))

https://indico.cern.ch/event/837890/

Description An initial study of the feasibility of siting nuSTORM at CERN was carried out under the auspices of the Physics Beyond Colliders study group. The result of this initial feasibility study is now being prepared for publication as a Yellow report that will be submitted as part of the briefing material for the European Strategy Group as they prepare the update of the European Strategy for Particle Physics.

The report on the initial siting study is due to be completed at the end of August 2019. This, a proto-nuSTORM-collaboration is being organised to discuss nuSTORM and its potential as a neutrino-beam facility and as a test-bed for the development of the high-brightness muon beams required in a future muon collider.

The meeting will take place in the CERN BE auditorium (Prevessin 774/R-013) at CERN and will start at 13:30 on the 21Oct19 and finish by 15:00 on 22Oct19.