nuSTORM: entry-level bright stored-muon beam

- Extraction from SPS through existing tunnel
- Siting of storage ring:
  - Allows measurements to be made ‘on or off axis’
  - Preserves sterile-neutrino search option
  - Technology demonstrator for muon collider; part of study
Abstract

The neutrinos from SuperNovae, muSTORM, facility has been designed to deliver a definitive neutrino-nucleus scattering program using beams of $\frac{1}{2}$ and $\frac{1}{2}$ from the decay of muons confined within a storage ring. The facility is unique, it will be capable of steering a $\frac{1}{2}$ beam with a central momentum of between 1 GeV/n and a momentum spread of 1/4%. This specification will allow neutrino-scattering measurements to be made over the kinematic range of interest to the DUNE and Hyper-K collaborations. At muSTORM, the favour composition of the beam and the neutrino-energy spectrum are both precisely known. The storage-ring instrumentation will allow the neutrino flux to be determined to a precision of 1% or better. By exploiting sophisticated neutrino-detector techniques such as those being developed for the near detectors of DUNE and Hyper-K, the muSTORM facility will:

- Serve the future long- and short-baseline neutrino-oscillation programs by providing definitive measurements of $\frac{1}{2}$ and $\frac{1}{2}$ scattering cross-sections with present-level precisions;
- Provide a probe that is 100% polarized and sensitive to allow in situ studies of nuclear dynamics and collective effects in nuclei;
- Deliver the capability to search for light sterile neutrinos beyond the sensitivities that will be provided by the final Short Baseline Neutrino (SBN) program; and
- Create an essential test facility for the development of muon accelerators to serve as the basis of a multi-TeV lepton-antilepton collider.

To maximise its impact, muSTORM should be implemented such that data-taking begins by 2027/28 when the DUNE and Hyper-K collaborations will each be accumulating data sets capable of determining oscillation probabilities with present-level precision.

With its existing proton-beam infrastructure, CERN is uniquely well-placed to implement muSTORM. The feasibility of implementing muSTORM at CERN has been studied by a CERN Physics Beyond Colliders study group. The mu storage ring has been optimised for the neutrino-scattering programme to store muon beams with momenta in the range 1 GeV to 6 GeV. The implementation of muSTORM exploits the existing fast extraction from the SPS that delivers beam to the LHC and to HiRbDet. A summary of the proposed implementation of muSTORM at CERN is presented below. An indicative cost estimate and a preliminary discussion of a possible time-line for the implementation of muSTORM are presented in the addendum.
• nuSTORM unique facility:
  – %-level *electron* and muon neutrino cross-sections
  – Exquisitely sensitive sterile neutrino searches
  – Serve 6D cooling experiment & muon accelerator test bed

• Feasibility of executing nuSTORM at CERN:
  – Established through Physics Beyond Colliders study
  – Previous/alternative sites:
    • FNAL (2013); ESS studied by ESSnuSB group

• nuSTORM: a step towards the muon collider:
  – nuSTORM as a technology demonstrator and test bed:
    • Proof-of-principle and test bed for stored muons for particle physics
  – Serve 6D ionization-cooling programme to follow MICE:
    • Required in *p*-driven neutrino factory and muon collider
EU strategy document (19 June 2020):

“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”.
### Exploit synergies:
**Articulate the need**

### Key issue/opportunity:
**Neutrino detector**

<table>
<thead>
<tr>
<th>Decay region</th>
<th>Hadron dump</th>
<th>Proton extraction</th>
<th>Neutrino detector</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ENUBET</strong></td>
<td>~40 m. Instrumented.</td>
<td>Slow, 400 GeV (flexible)</td>
<td>Yes, similar</td>
</tr>
<tr>
<td><strong>nuSTORM</strong></td>
<td>Replaced by straight section of the ring (180 m).</td>
<td>Fast, 100 GeV</td>
<td>Yes, similar</td>
</tr>
</tbody>
</table>

- Different concepts, budget, geometry.
- Main synergy: target facility, 1st stage of meson focusing, proton dump.
nuSTORM as part of the muon collider programme

• Development of muon collider requires:
  – Technology demonstrator(s) and R&D test bed(s)

• nuSTORM:
  – Is the first in the required series of demonstrators; and
  – Delivers important *physics* measurements too