Imperial College London

Science & Technology Facilities Council

Introduction and goals

K. Long, 28 June, 2021

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UPDATE SINCE OUR LAST MEETING ON 17MAY21

Developing framework for work with CERN

Synergies between ENUBET and nuSTORM
Proposal for Joint R&D Studies and Implementation

Introduction

The ENUBET (Enhanced NeUtrino BEams from kaon Tagging; NP06) collaboration [1] proposes a dedicated facility to measure ν_μ and ν_e cross sections precisely. ENUBET proposes to do this with a combination of monitored, narrow-band neutrino beams at the GeV energy scale, instrumenting the meson-decay tunnel with a segmented calorimeter. The ENUBET approach is based on monitoring the production of large-angle positrons from $K^+ \to \pi^0\, e^+\, \nu_e$ (K^+_{e3}) decays in the decay tunnel. In addition, ENUBET will monitor muons produced in from kaon and pion decays, thus providing a solid measurement of the ν_μ flux. Thanks to the optimisation of the focusing-and-transport system of the momentum-selected narrow-band beam of the parent mesons, the K^+_{e3} decay represents the main source of electron neutrinos. Furthermore, the positron rate may be used to measure the ν_e flux directly. Consequently, the monitored ν_e beam will lower the uncertainties on the neutrino flux and flavour for a conventional beam from the current level of about O(7% – 10%) to ~1%. Similar precision is expected on the ν_μ flux, with the bonus that the neutrino energy will be determined with a precision ≈10% at the single neutrino level by the "narrow-band off-axis technique", i.e. using only the position of the interaction vertex.

The nuSTORM collaboration [2] proposes a new facility capable of delivering a neutrino beam for which the flavour composition is precisely known and for which the neutrino flux is determined at the 1%-level or better from the storage-ring instrumentation. The large-acceptance storage ring delivers a large ν_μ and ν_e flux which will allow cross-section measurements to be made with unprecedentedly large samples of events. nuSTORM relies on a new concept whereby the neutrinos are produced in a storage ring through the decay of muons. Besides measuring the neutrino-nucleus cross-sections useful for DUNE and Hyper-Kamiokande precisely, the nuSTORM facility can also be used to search for sterile neutrinos with a sensitivity beyond the capabilities of the Fermilab Short Baseline Neutrino (SBN) experiments. nuSTORM can also serve as the test facility for the development of a neutrino factory and muon accelerators to serve in a multi-TeV lepton-antilepton collider.

The operation of ENUBET and/or nuSTORM by 2027 would maximise the impact of the measurements outlined above for the world neutrino programme. Both ENUBET and nuSTORM are to a large extent site-independent concepts, studies and R&D; however, both consider a possible implementation at CERN. For nuSTORM, under the auspices of the PBC, an initial study of implementation at CERN was carried out, and no showstoppers were identified. For ENUBET, the option of using the SPS as the proton driver has been considered in greater detail, with a possible site in the North Area and the ProtoDUNEs as neutrino detectors.

ENUBET and nuSTORM - Synergies and Common R&D and Implementation Studies

NP06/ENUBET has already submitted to PBC a proposal for a dedicated study of:

- The engineering aspects of the transfer line, with emphasis on accessibility to the instrumentation and an assessment of the cost in collaboration with CERN-SY and CERN-BE. If technically possible, the CERN implementation of the transfer line should

be compatible with the option of serving NP02/ProtoDUNE-SP, NP04/ProtoDUNE-DP, and dedicated detectors of relevance for high-precision neutrino cross-section measurements. This is the most important resource request of ENUBET to PBC and the Collaboration is in the process of further strengthening the SY section with ENUBET personnel to reach such a key milestone;

- The study of the implementation aspects of the target station with special emphasis on synergies with NuSTORM concerning secondary capture in the 3—8.5 GeV/c momentum region, the target infrastructure, and proton extraction from the SPS. These items are further detailed in this document; and
- The use of an upgraded Gigatracker as a particle time tagger, functionally replacing the BCT with the bonus of high precision time tagging.

Both ENUBET and nuSTORM require the capture and transport of meson beams from a target. This is a key technical synergy between the two projects and with the development needed for the pion collection required at a proton-driven muon collider. Further, the nuSTORM storage ring, instrumentation, and exploitation have the potential to serve as technology demonstators for the muon collider and an ENUBET/nuSTORM complex has the potential to provide the beam for the 6D ionization cooling demonstration experiment that is an essential part of the muon-collider development programme.

There are many opportunities for a common implementation of ENUBET and nuSTORM. nuSTORM can be seen (simplistically) as an "ENUBET without a hadron dump", where pions and muons are channeled into a ring (see Figure 1).

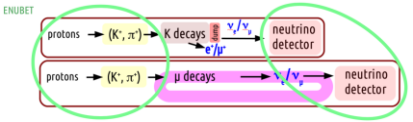

Figure 1: Generalised concept of ENUBET and nuSTORM.

There is significant scope for innovative proposals of joint R&D to match the requirements of the two experiments. Some common points, shared between ENUBET and nuSTORM (see Figure 2), are the:

- Proton extraction line;
- Target station;
- The first stage of meson focusing;
- The proton dump; and, possibly,
- The neutrino detector.

	Decay region	Hadron dump	Proton extraction, energy, focusing	Target, sec. transfer line, p-dump	Neutrino detector
ENUBET	~40 m. Instrumented.	Yes. Dumps μ in addition → preventing a (small) ν_e pollution to K_{e3}-ν_e	Slow extraction (≈ quad triplets) "slow" in bursts (≈1sec) 400 GeV	similar	Similar but at ~100 m (some flexibility)
nuSTORM	Replaced by straight section of the ring (180 m).	No. μ kept: the most interesting flux parents.	Fast extraction (≈1sec) 100 GeV	similar	Similar but at > 100 m from target (ring straight section)

Figure 2: Common points between ENUBET and nuSTORM.

Various options for the implementation of the ENUBET and nuSTORM facilities should be explored. A first option is a configuration based on independent operation with optimised secondary beams and with the beam split upstream of each facility (Option 1; see Figure 3). This would require the splitting of the proton beamlines plus two targets. This scheme would not be the most cost effective but would have a higher number of degrees of freedom and opportunities for parallelisation. The use of a single detector might also be possible.

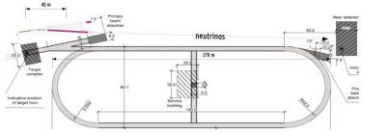

Figure 3: Option 1 of implementation configuration of ENUBET and nuSTORM.

Secondly, the use the same lay-out, but with a staged / mixed configuration, should be considered (Option 2; see Figure 4). The scheme would have the same or similar transfer-lines for the two facilities and cold be operated sequentially between ENUBET and nuSTORM. This scheme would be cost effective and also result in a stronger interdependence of the two facilities.

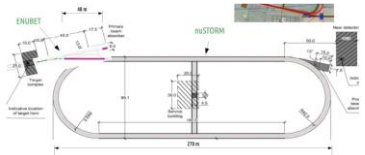

Figure 4: Option 2 of implementation configuration of ENUBET and nuSTORM.

Conclusions

ENUBET and nuSTORM could f
properties (such as neutrino
experiments (DUNE and Hyper-K
solutions. Studies within the fram
two projects take a step forward
the costs in the different scenari

References

[1] A. Longhin *et al.* [ENUBET C
Generation of Short-baseline Exp
Strategy (2020).

[2] K. Long, *nuSTORM at CERN: Ex*
Physics Strategy (2020) and C. A
(2020).

- **Will circulate for comment after the meeting:**
  - **Deadline: 17:00 BST on Friday 02Jul21**
    - **Then transmit to G. Arduini and D. Shulte**

Meeting schedule established

- Next meetings:
  - 28Jun21
  - 09Aug21
  - 20Sep21

- Have outlined next steps in nuSIM development
  - See PK

- Next meeting; need to:
  - Review nuSIM progress
  - Continue discussion of target synergies w\ ENUBET and demo
  - Begin discussion of SPS, muon, and neutrino timing issues
  - Begin discussion of neutrino detection

nuSTORM -- general meeting

Monday 28 Jun 2021, 14:00 → 18:00 Europe/London

Kenneth Richard Long (Imperial College (GB))

Description Meeting to discuss developments in the simulation of nuSTORM and the next steps in its development.

The agenda is being developed. Please feel free to volunteer a talk to K.Long@imperial.ac.uk.

The meeting will be by ZOOM at the URL: https://cern.zoom.us/j/63026973484?pwd=cHg3VW5hMjBmMGhwa0lRb085RCtUdz09

14:00 → 14:10 **Introduction** 10m
Speaker: Kenneth Richard Long (Imperial College (GB))

14:10 → 14:25 **Towards a detector simulation** 15m
Speaker: Anna Holin (STFC/RAL)

14:25 → 14:40 **nuSTORM accelerator modelling** 15m
Speaker: Jaroslaw Pasternak (Imperial College, London)

14:40 → 14:55 **nuSIM** 15m
Speaker: Paul Kyberd (Brunel University (GB))
210628CollM.pdf

14:55 → 15:10 **Timing from target to injection** 15m
Speaker: Marvin pfaff

15:10 → 15:25 **Muon decays beyond the production straight** 15m
Speaker: Omar Ibna Nazim

15:25 → 15:40 **Tea/coffee** 15m

15:40 → 15:55 **Pion-production target considerations** 15m
Speaker: Nikolaos Vassilopoulos (Institute of High Energy Physics, CAS)
Nustorm-2021June...

15:55 → 16:10 **ENUBET update** 15m
Speaker: Francesco Terranova (Universita & INFN, Milano-Bicocca (IT))

16:10 → 16:25 **Muon cooling update** 15m
Speaker: Chris Rogers (STFC)

16:25 → 16:40 **Possible synergies with US high-intensity muon programme** 15m
Speaker: Bertrand Echenard (California Institute of Technology)