NuSTORM accelerator: Challenges and opportunities

C. T. Rogers
NuSTORM accelerator challenges

- nuSTORM facility is a unique facility for
  - High muon rate
  - Well-characterised neutrino beam
- Several applications
  - Measurement neutrino scattering cross sections
  - Search for sterile neutrinos and other BSM physics
  - Provide a technology test-bed for the muon collider
- What is the nuSTORM facility?
- What is the physics reach?
- How can it provide a test-bed for the muon collider?
What is the nuSTORM facility?

Main features

- ~250 kW target station
- Pion transport line
- Stochastic muon capture into storage ring
- Option for conventional FODO ring or high aperture FFA ring
Target and Pion Transport Line

- Conventional 250 kW target horn
- Pion transport line
  - Proton beam dump
  - Momentum selection
  - Active handling
Stochastic Muon Capture

- Pions injected into the decay ring
- Capture muons that decay backwards in pion CoM frame
- Undecayed pions and forwards muons diverted into muon test area
  - Extraction line at end of first decay straight
Storage Ring

- Storage ring technologies:
  - Conventional FoDo ring
  - High acceptance FFA ring

Neutrinos momentum range up to 4 GeV
- Tunable ring energy under investigation
  - Optimisation so far has focused on 3.8 GeV $\mu$
  - Higher energy would give more reach to cross section measurements
- Optimisation of storage ring to give improved neutrino flux
  - Hybrid FoDo straights with high acceptance FFA bends

Lagrange et al, Racetrack FFAG muon decay ring for nuSTORM with triplet focusing, J. Inst 13 (2018)
DUNE and T2K $\nu$ energy spans QE and DIS
Major contributor to systematic uncertainty
See talk this afternoon!
- NuSTORM has excellent sensitivity to CCQE
- Studies of optimal detector geometries ongoing
- Studies of other cross-section sensitivities ongoing
- See talk this afternoon!
Sterile Neutrino Sensitivity

- Sterile neutrino sensitivity
  - Assumes 1.3 kt magnetized iron
  - $1.8 \times 10^{18}$ useful muon decays
  - Flux known to 0.5 % level
- See talk this afternoon!

D. Adey et al, Light sterile neutrino sensitivity at the nuSTORM facility, PRD 89 (2014)
Challenges

- High current radioactive beam passing active components
  - Normal conducting transport line near target
  - Superconducting combined function dipoles in muon ring
- Containment of tertiary beam (i.e. muons)
  - Large momentum spread and transverse size
Muon Collider

- Why – and how - is nuSTORM related to muon collider?
- **Muon beam physics** highlighted as **high priority initiative** by European strategy update
  - ~10 TeV Muon Collider has **physics reach comparable to FCC-hh**
  - **Footprint** is considerably **smaller**
- CERN-led Muon Collider Collaboration formed in June
- Some discussion of making a “demonstrator”
  - Demonstrate some of the beam physics concepts
  - Address some of the technical issues
Muon Collider Facility

- Proton based Muon Collider (MC) facility
  - Protons on target → pions, muons et al.
  - Transverse and longitudinal capture and cooling
  - Acceleration
  - Collider ring

- Challenges
  - High current radioactive beam passing active components
  - Containment of tertiary beam (i.e. muons)
Technologies

- High power dual-sign ($\mu^+\mu^-$) target
- Capture and ionisation cooling
- Acceleration and storage
  - Either conventional FODO-based Rapid Cycling Synchrotron
  - Or novel FFA

X. Ding et al, Carbon and Mercury target system for muon colliders and neutrino factories, IPAC16
Absorber

- Beam loses energy in absorbing material
  - Absorber removes momentum in all directions
  - RF cavity replaces momentum only in longitudinal direction
  - End up with beam that is more straight

- Multiple Coulomb scattering from nucleus ruins the effect
  - Mitigate with tight focussing
  - Mitigate with low-Z materials
  - Equilibrium emittance where MCS completely cancels the cooling
Muon Cooling

4D Final cooling

Phase rotation

6D cooling
- Muon ionisation cooling has been demonstrated by MICE
  - Muons @ ~140 MeV/c
  - Talk earlier today
- But
  - Transverse cooling only
  - No re-acceleration
  - No intensity effects
  - Larger emittance beams
Survey of Muon Beamlines

- **NuSTORM** would make an excellent facility
  - One of the highest current high energy muon beams
- Target/irradiation test area
- Muon beam physics tests
Summary

- nuSTORM facility ideal facility for a number of aims
  - Measure neutrino scattering cross sections
  - Search for sterile neutrinos and other BSM physics
  - Provide a technology test-bed for the muon collider
- Unique facility to yield
  - High muon rate
  - Well-characterised beam
- Potential to be the highest current high energy muon beam