Use of nuSTORM as a Demonstrator for Muon Collider

Science & Technology Facilities Council
ISIS Neutron and Muon Source

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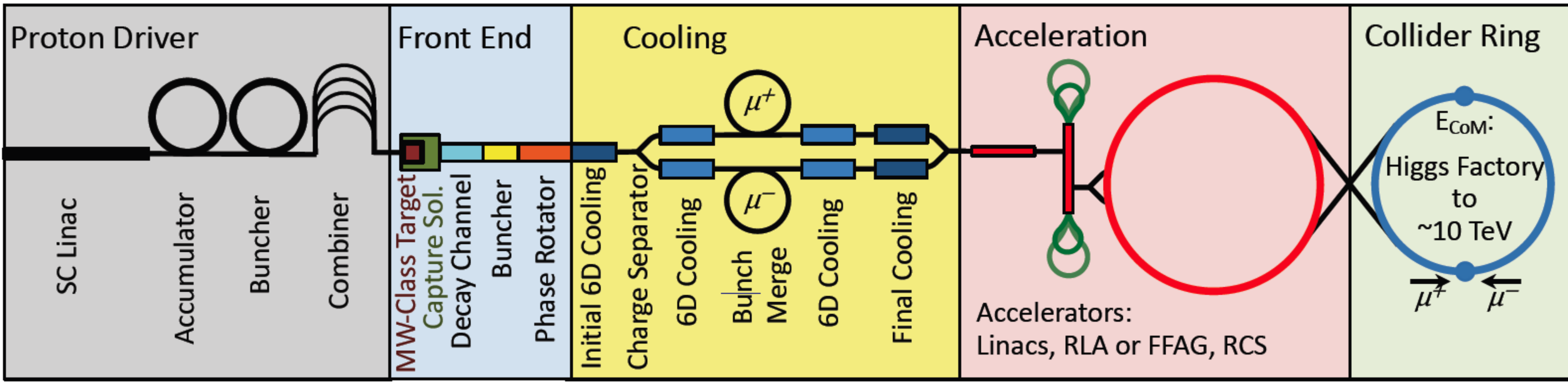
Muon Collider

- **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 issues
- Aim to incite discussion

Muon Collider Facility



- Reminder – proton based Muon Collider (MC) facilility
  - Protons on target → pions, muons et al.
    - 2 ns bunches
    - 2-4 MW protons
  - Transverse and longitudinal cooling
  - Acceleration
  - Collider ring

Muon Collider Facility

Parameter	Unit	3 TeV	10 TeV	14 TeV
L	10^{34} $cm^{-2}s^{-1}$	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14
<B>	T	7	10.5	10.5
ε_L	MeV m	7.5	7.5	7.5
σ_E / E	%	0.1	0.1	0.1
σ_z	mm	5	1.5	1.07
β	mm	5	1.5	1.07
ε	μm	25	25	25
$\sigma_{x,y}$	μm	3.0	0.9	0.63

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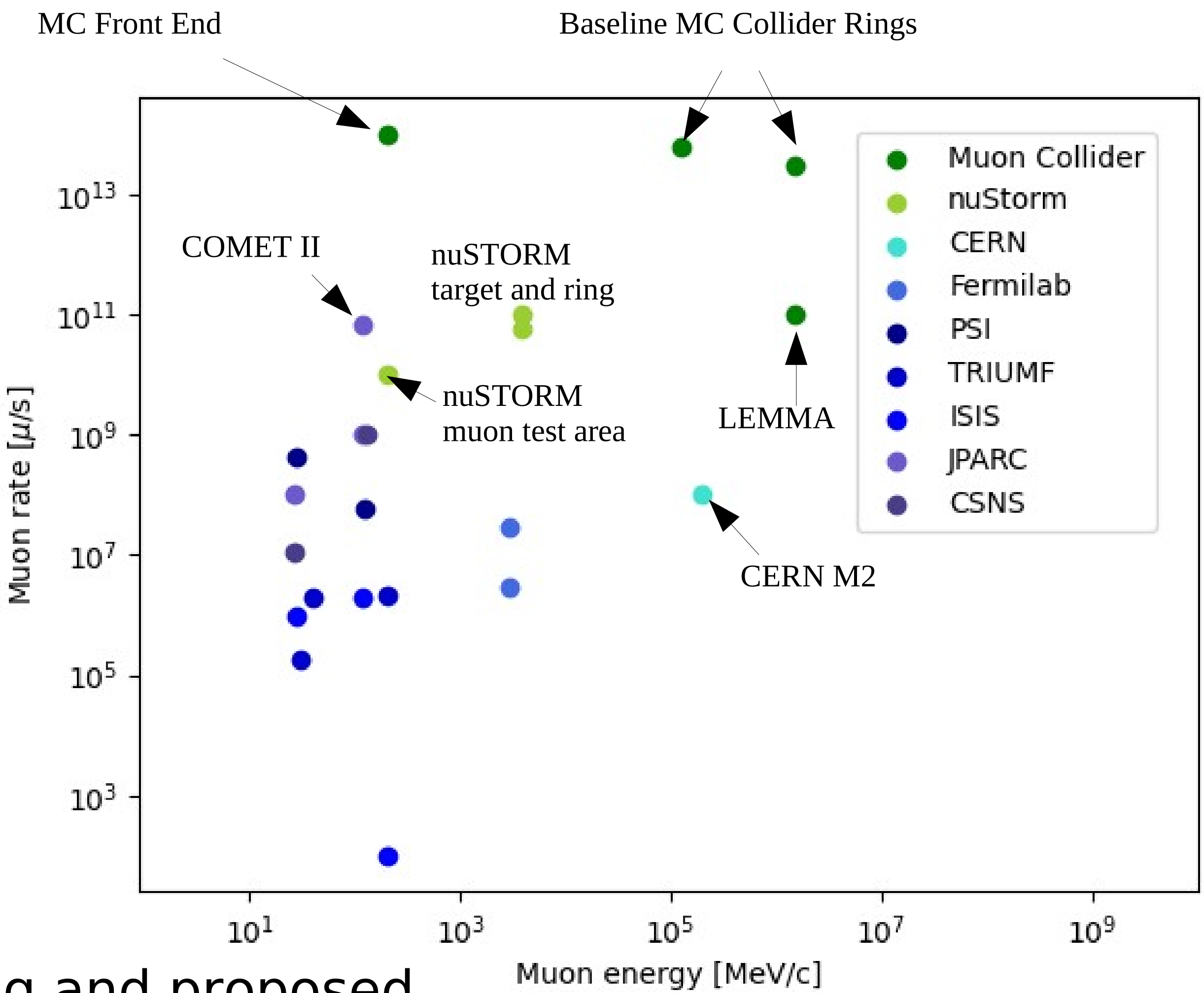
Survey of Muon Beamlines



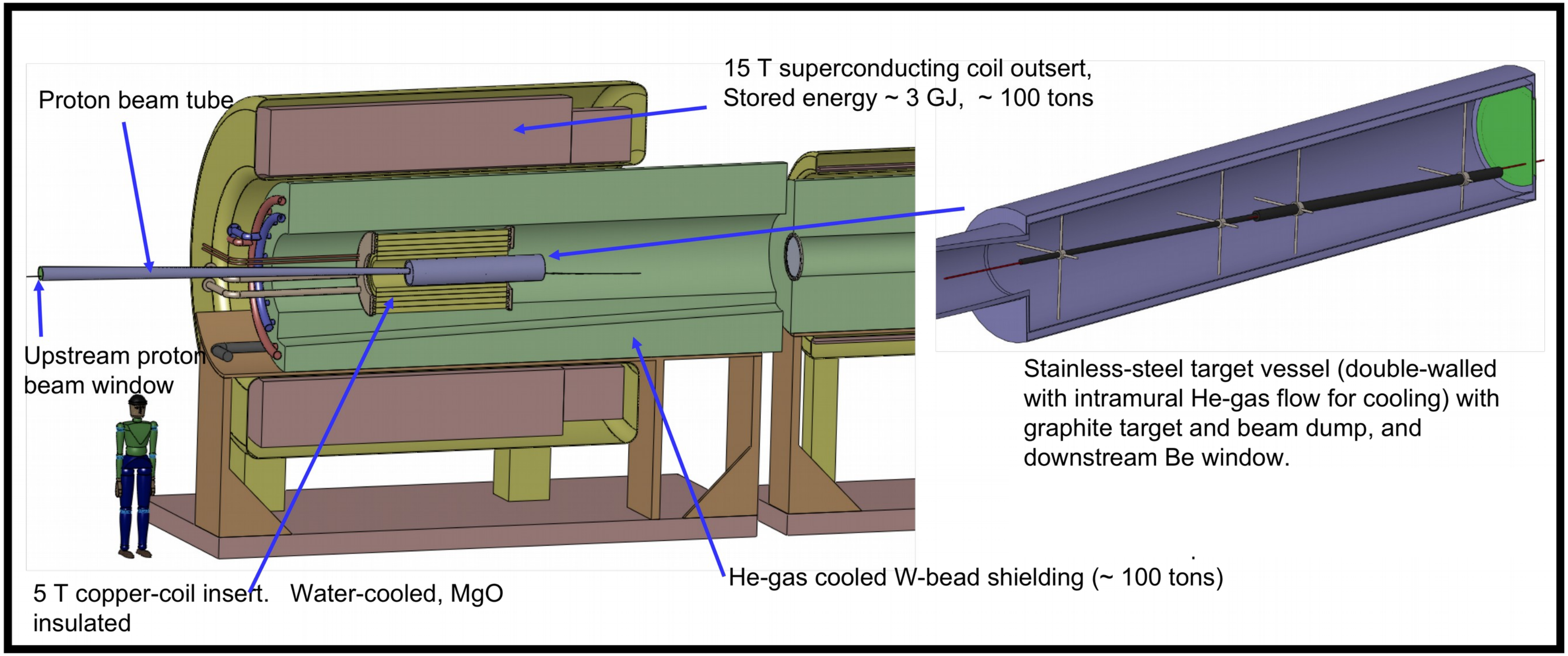
- Existing and proposed
- nuSTORM is based on JINST paper (i.e. Fermilab)

Potential Issues

- Collaboration is developing an overview of the potential issues
  - Solenoidal focussing target for capturing both muon signs
    - Radiation load on SC magnet must be managed okay
    - Short proton bunches → high instantaneous power deposition on the target
  - Ionisation cooling
    - Longitudinal cooling and low emittance (tight focussing)
    - Collective effects
      - Conventional collective effects e.g. space charge etc
      - Novel collective effects e.g. plasma loading of cavities
  - Acceleration and collider
    - Muon decay → Power deposition on magnets
    - Neutrino radiation

MC Target

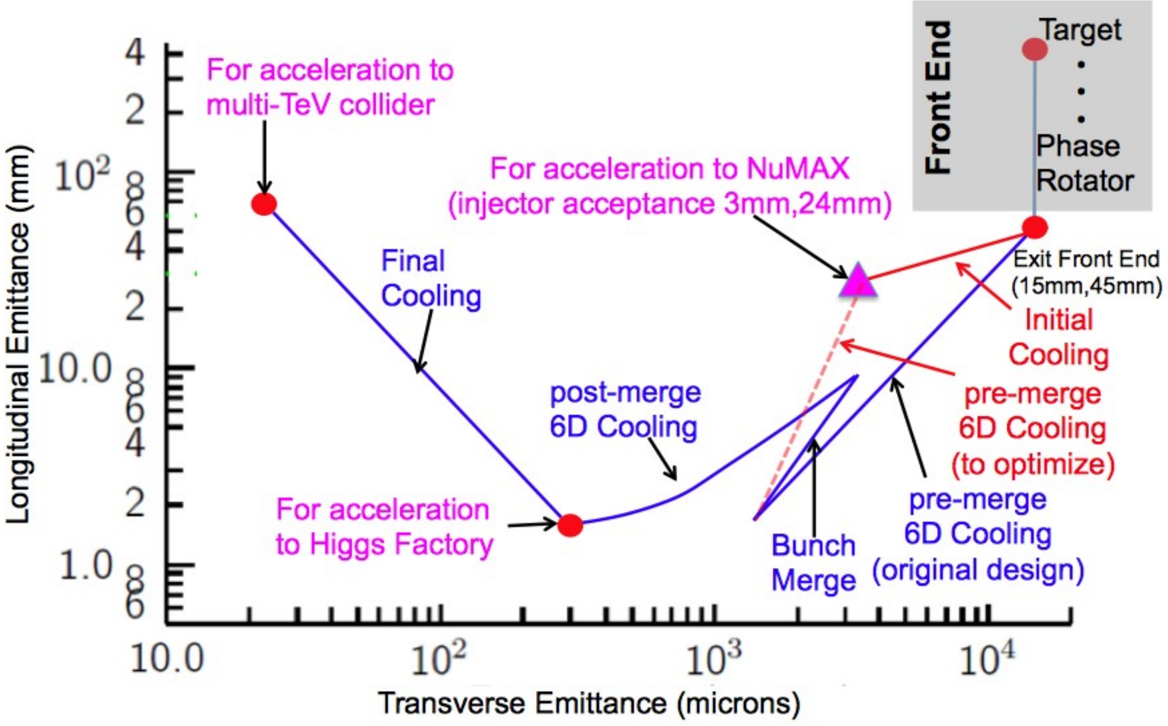
X. Ding et al, Carbon and Mercury target system for muon colliders and neutrino factories, IPAC16



Target - Questions

- Target considerations
  - Is there a benefit to using nuSTORM for target tests in horn configuration? Are higher power facilities better (e.g. T2K, DUNE)?
  - Can nuSTORM approach the MC instantaneous proton power?
  - Is there a benefit to considering nuSTORM in a solenoidal capture configuration?
    - Operational experience for Muon Collider
    - Relatively high power test of e.g. energy deposition on SC magnets etc
    - Both sign capture simultaneously
  - Is there a burden to nuSTORM to a solenoidal capture target
    - Cost, schedule, risk

Muon Cooling Issues



Muon Cooling Issues

- Longitudinal cooling
- Cooling in regime of tight focussing
- Integration of very high field solenoids with RF and beam
- “Conventional” intensity effects
- Absorber heating
- Plasma loading of cavities
- Day-to day operation
- ...

Cooling - Beam Tests

- Single-pass (linac) prototype
  - Measurement of cooling challenging
- Ring prototype
  - Multi-turns → bigger cooling signal
  - May be more expensive
- Muons
  - Difficult to get to high intensities
- Protons
  - High intensities available
  - Energy loss regime is quite different → thin absorbers
  - Nuclear effects may also contribute
- Don’t consider electrons - energy loss is primarily through Bremsstrahlung
- **Phased approach** may be productive
  - Build a ring segment for protons; add more segments for muons

Cooling - Questions

- Cooling considerations
  - Benefits of high intensity muons
    - Can we design an "affordable" lattice with strong enough cooling signal that conventional diagnostics are convincing
    - Or do we need to do single particle experiment like MICE
  - Is it easy to get a high intensity source of protons at nuSTORM?
    - Can we interleave proton/muon tests?
      - Excite collective effects with protons and test with muons?
      - Pump probe
    - What proton momentum is desired for physics tests?

Acceleration/Storage - Beam Tests

- Muon decay → Power deposition on magnets
  - Heat load on nuSTORM SC magnets
    - ~50 W and 480 m ring
    - Maybe more heat load at end of decay straights
  - Heat load on MC SC magnets
    - 5 MW primary beam and 4.5 km ring
  - Can we measure heat load on nuSTORM SC magnets?
  - Direct dump of nuSTORM onto a single magnet would roughly match power deposited per unit length
    - Note penetration depth different – O(TeV) vs O(GeV)
    - Instantaneous power vs average power
    - Electron or positron beam may be better for this sort of test
- Neutrino radiation
  - Calculation likely best method
  - Don't believe beam test is needed

Final Thought

νSTORM

- NuSTORM would be the highest energy, highest current stored muon beam ever produced
  - Opportunity to demonstrate step-up in capability
- Opportunity to build a community