RPF – AF synergies

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On behalf of the RP frontier

September 2021

Many thanks to R. Bernstein (FNAL) and P. Winter (ANL)

Quick summary of the LOIs submitted to RPF with overlap with AF

RF0 – Generic / multiple TG

FCC-ee, LHC-HL, **Low-energy muon facility LEμ**, muon antigravity expt, CBETA, Belle-II, accelerator (generic), new physics (generic)

RF3 – Fundamental Physics in Small Experiments

Proton srEDM, storage rings (generic)

RF5 – Charged Lepton flavor violation

Mu2e-II, **next generation muon facility - ENIGMA**

RF6 - Dark Sector Studies at High Intensities

LESA, **Proton beam dumps @FNAL**, LANSCE-PSR, SHiP, Faser, Forward facility at LHC, Mathusla

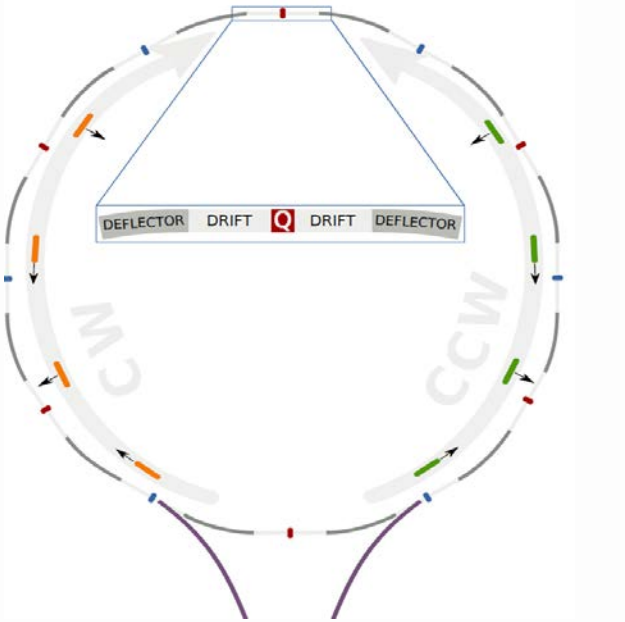
Most of these LOI contain generic considerations on accelerator facilities and/or reference to efforts extensively discussed in other frontiers

I will focus on a few efforts that could benefit from coordination between our two frontiers

Proton storage ring for EDM experiment (srEDM)

- Based on a hybrid scheme: radial E and magnetic field for focusing (instead of E field) – see arxiv:2007.10332.
- Allows for clockwise (CW) and counter clockwise (CCW) beams at the same time in the ring: radial B field systematic cancels (EDM same for CW and CCW). Eliminates the need to significantly shield the ring from external magnetic fields.
- Essentially based on existing technology, limited R&D needed
- Generic physics reach of $d_p \sim 10^{-29}$ e-cm. Sensitive to new physics mass scale of O(3000) TeV for O(1) couplings
- Radially polarized protons sensitive to dark matter (axion) and dark energy field (arxiv:2005.11867). This is much harder to do than EDM measurement, so perform later
- Advantageous to do the experiment at BNL (polarized protons available, synergies with EIC)

Proton storage ring for EDM experiment (srEDM)



Sensitivity timeline of EDM and DM/DE

Year	Lattice alignment specs per 10^3s storage time (quads, e-field plates)	EDM sensitivity target $\times 10^{-29}\ e \cdot \mathrm{cm}$	DM/DE sensitivity $\times 10^{-29}\ e \cdot \mathrm{cm}$ equiv.	Physics and main alignment methods
Year 1	100μm, 1mm	$<10^4$	N/A	EDM. Optical alignment
Years 2 & 3	100μm, 100μm	$<10^2$	N/A	EDM. Beam-based alignment and radial polarization
Years 4 & 5	10μm, 100μm	1	N/A	EDM. Beam-based alignment and radial polarization
Year 6	10μm, 10μm	1	$<10^6$	DM/DE and EDM. BPM and S-BPM
Years 7 - 9	1μm, 1μm → <0.1μm	1	$<10^4$ → 1	DM/DE and EDM. BPM and S-BPM
Years 10 - 14	TBD	1	1	Studying deuteron and ^{3}He nuclei EDM

Snowmass plans

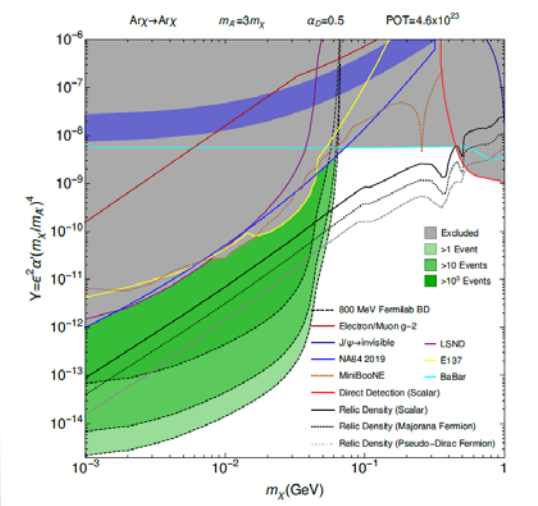
- Study systematic errors and produce white paper
- Hope for a strong endorsement of the physics and community support for CD-0 approval.

Proton beam dumps at FNAL

RF/SNOWMASS21-RF6_RF0-NF3_NF0-AF5_AF0-084.pdf

New Booster-sized, permanent magnet or DC-powered storage ring for PIP-II

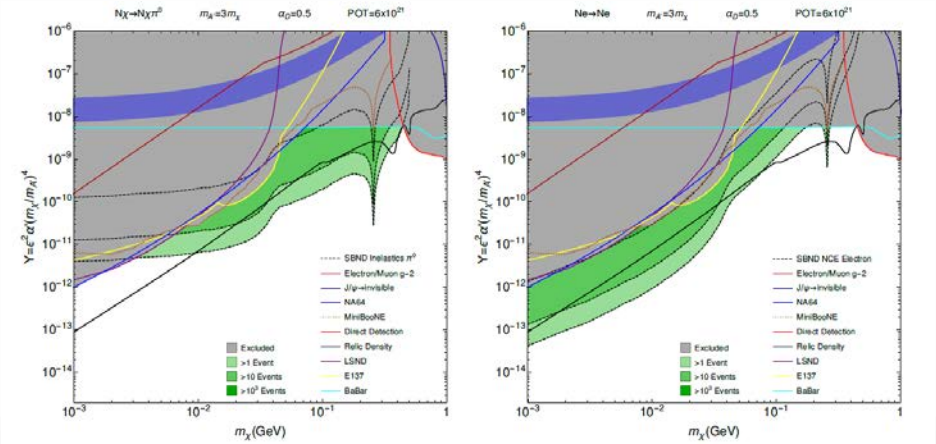
- Compressed PIP-II beam into pulses suitable for a proton beam dump facility
- Designed to operate at 800 MeV, with an upgrade path in the GeV range.
- Related science: dark matter, CEvNS, sterile neutrinos,…
- Existing technology, limited R&D



RF/SNOWMASS21-RF6_RF0-NF2_NF3-AF2_AF5_099.pdf

A new dedicated beam dump target station at the BNB

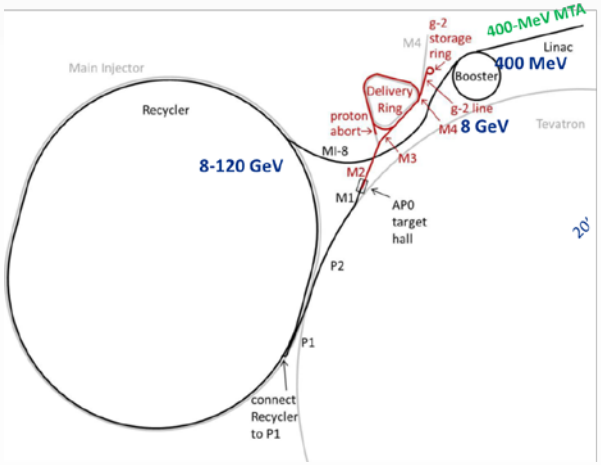
- Near SBND detector
- Improve the sensitivity to DM by an order of magnitude compared to current bounds
- Existing technology and modest investment

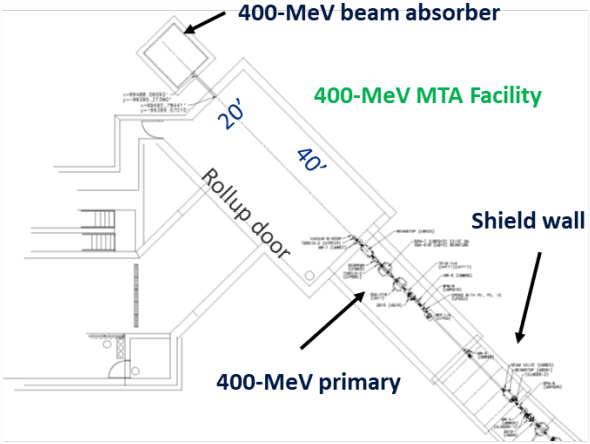


Low-energy muon facility at FNAL

- High intensity surface muon beam using PIP-II (energy well matched to maximize low-energy pion production)
- New facility at MTA (MuCool Test Area) or new greenfield site at FNAL

- **Related science**
  - Precision muon and muonium experiments
  - Muonium gravity & spectroscopy experiments
  - μSR (Muon Spin Resonance) for materials science, chemistry, & biology
  - muon-catalyzed fusion





Low-energy muon facility at FNAL

- Current Muon facilities are for μSR (< 30 meV) and limited by the target thickness to minimize beam divergence
  - CW intensity limited to ~1 surface muon / 10 μs
  - Need a timing signal only present in pulsed beams

- Pion production favors heavy target
  - Tantalum has a factor of 3 (8) π^+ (π^-) increase over graphite

- "Estimated" Muon Production @MTA with Tantalum target
  - >1000 μ^+ or μ^-/s; cm^2 spot size; 4–100 MeV

Snowmass plan

- Study secondary production beamline design, production target geometry and material studies, capture optimization into secondary beamline,…
- Write contributed paper

ENIGMA - new facility for a next generation of muon experiments based on the PIP-II accelerator with a

Surface muon beam for muon decay experiments

- Similar to what is done at PSI (1.4MW target, well known technology)
- Dedicated beam with higher intensity – **up to 10^{12} μ/s with PIP II**
- Potentially improve sensitivity by a factor x100 w.r.t MEG-II

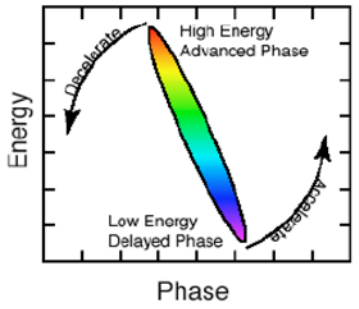
New beam for muon conversion experiments

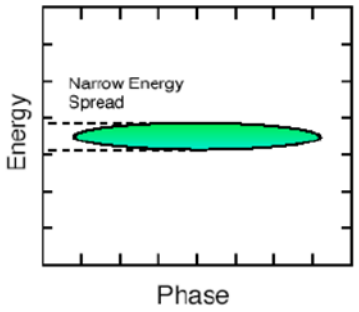
- **Probe $R_{\mu e}$ sensitivity down to 10^{-19}, with the ultimate objective to reach 10^{-20}** and probe O(10^4 - 10^5) TeV effective mass scale
- Probe high-Z target (e.g. Au) to explore underlying new physics if CLFV is observed
- Based on the PRISM concept to provide a low momentum, quasi-mono-energetic muons beam with extremely low pion contamination

New beam for conversion experiment, based on the PRISM (Phase Rotated Intense Slow Muon beam) concept proposed by Y. Kuno and Y. Mori

PRISM concept:

- High intensity (MW) proton beam with very short pulse duration hit target in a capture solenoid, producing $\pi \rightarrow \mu$
- Inject muons into a fixed-field alternating gradient (FFA) ring
- Phase rotates to reduce the beam energy spread (slow down leading edge, accelerate trailing edge)
- Pion contamination is reduced to negligible level during phase rotation (O(μs)) – this is a major advance in such experiments!
- Extract purified muon beam to detector



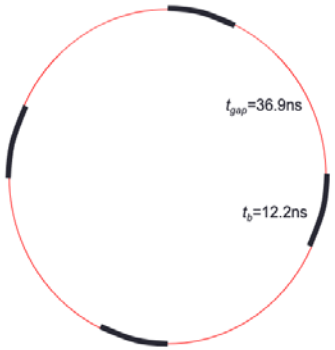


Requires a compressed proton bunch and high power beam to achieve high μ rate
$\rightarrow$ PIP II with a compressor ring (bunch size limit is much too small for the FFA)

RF/SNOWMASS21-RF5_RF0-AF5_AF0_Robert_Bernstein-027.pdf
AF/SNOWMASS21-AF5_AF0-RF5_RF0_Prebys-071.pdf

Compressor ring and FFA accelerator complex + detector

E. Prebys



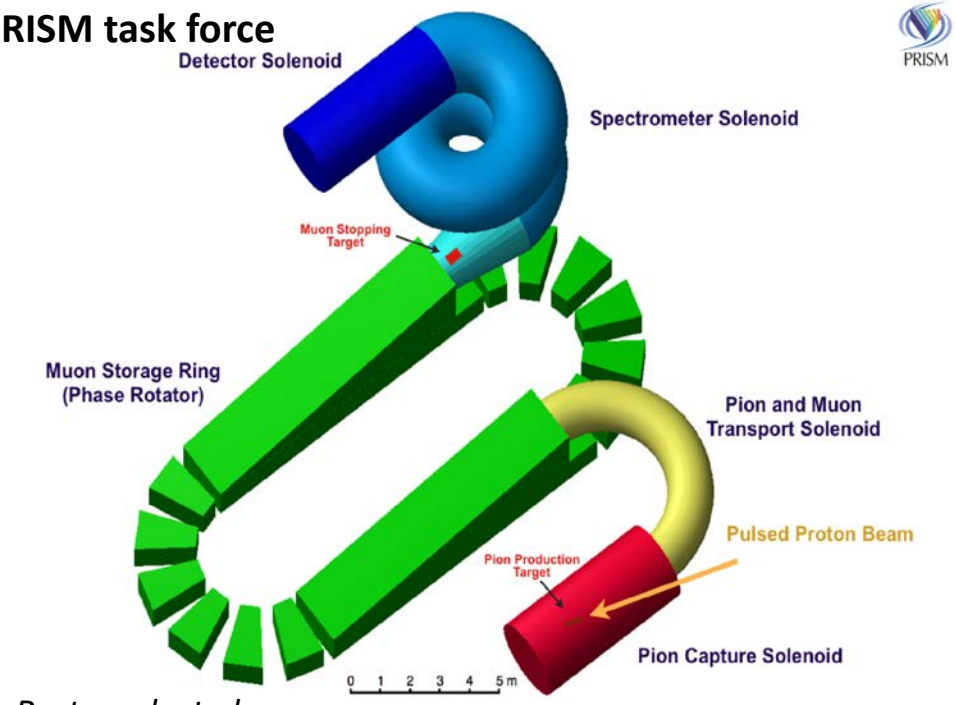
Circumference: $C = 49.7$ m
RF Frequency: $f_{RF} = 40.62$ or 20.31 MHz
harmonic: $h = 8$ or 4
Protons/bunch: $n_b = 1\times10^{12}$
Bunch length: $t_b = 12.2$ ns
Fill time: $t_{fill} = 1.3$ ms

https://www.snowmass21.org/docs/files/summaries/AF/SNOWMASS21-AF5_AF0-RF5_RF0_Prebys-071.pdf

Parameter	Value	Comment
Bunches	4	Assumed
Protons per Bunch	10^{12}	Target
Fill Time [ms]	1.3	$6667 \times \tau$
Extraction Rate [Hz]	100	Assumed
Average Power [kW]	12.8	

This is too low! Need R&D to push repetition rate or bunch size!

PRISM task force



J. Pasternak et al.
https://indico.phys.vt.edu/event/34/contributions/685/attachments/529/625/PRISM_nufact18.pdf

MUSIC - proof of PRISM FFA concept at Osaka with a 10 cell DFD ring

Many synergistic activities with muon collider and neutrino factory R&D

FFA ring design

- in full synergy with the Neutrino Factory and a Muon Collider

Target and capture system

- **MW class target in a solenoid (hard)**
- in full synergy with the Neutrino Factory and a Muon Collider

Design of the muon beam transport from the solenoidal capture to the FFA ring

- very different beam dynamics conditions
- very large beam emittances and the momentum spread

Muon beam injection/extraction into/from the FFA ring

- very large beam emittances and the momentum spread

Compressor ring

- fast kicker to transfer beam from compressor ring at 1kHz

ENIGMA is in a position to be a major step of the muon program, providing ground-breaking measurements and key R&D

Need to coordinate R&D efforts between ENIGMA / Muon collider / Neutrino factories

Summary

There are several projects of interest to both RPF and AF that might benefit from joint efforts: proton EDM ring, low-energy muon facility and a next generation high-intensity muon facility

Proton EDM and low-energy muon facility are mostly based on existing technologies and only require little R&D.

Next generation high-intensity muon facility requires significant R&D. This effort has **many synergies with the muon collider and neutrino factory** – notably the development of a MW class target in a solenoid

In the context of Snowmass, it would be desirable to **set up a framework to explore synergies and mesh R&D efforts between high-intensity muon facility, muon collider and neutrino factory.**

Thank you for your attention