WG3 Summary: Accelerator

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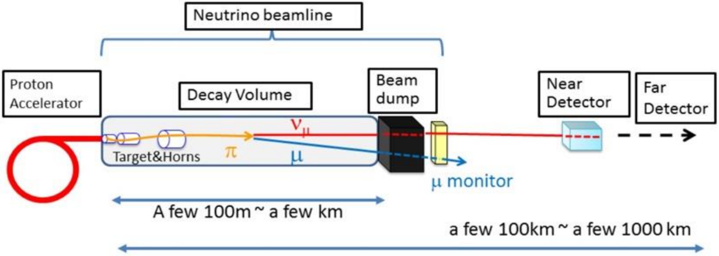
Statistics

Monday	Tuesday	Wednesday	Thursday
Parallel 1 **3 talks**	Parallel 2 **3 talks**	Plenary session **4 talks**	Parallel WG 1X3 **4 talks**
Poster 16:05 session **1 poster**	Parallel WG 3X4 **3 talks**		

Accelerator for Neutrino Experiments



Conventional and upcoming world-class neutrino beams require:

- **High-intensity proton beam**
  - Effective manipulation of high-power beams
  - Stable operation through commissioning
- **Radiation-hard equipment**
  - Durable targetry and monitoring systems
- **Comprehensive beamline modeling**
  - In-depth understanding of beamline dynamics
- **Synergies between neutrino and muon beamlines**

Key Topics to be Addressed

•**Exploring New Target Technologies**
- Can fluidized powder or granular targets revolutionize our approach?

•**Advancing Accelerator Capabilities**
- What is the roadmap for 2MW and beyond?

•**Shaping the Future of Neutrino Research**
- Where do we go after DUNE, T2K, and ESSnuSB?

•**Leveraging Synergies in Physics**
- How can collider, neutrino, and muon research intersect?

Key Topics Addressed

Robert Zwaska

Fermilab

- **Exploring New Target Technologies**

- Can fluidized powder or granular targets revolutionize our approach?

ACE-MIRT plan motivated by faster delivery of DUNE science

For instance, allows to achieve 5 σ mass ordering sensitivity for 100% of δ_{cp} values in 3.5 years instead of 5 years

ACE-MIRT scope to enable >2MW

This component of ACE plan aims to develop the Fermilab accelerator complex capabilities beyond PIP-II, *without new accelerator construction.*

Proposed components offer independent (*) and incremental benefits

Overall efficiency and reliability of operations

- Implement improvements aiming to reduce losses, radioactive activation

Task 1) Improve MI reliability by replacing quadrupole magnets with robust design

Machine capability: Maximum proton flux produced by the accelerator

Task 2) Upgrade MI ramp power system to enable faster cycle time (1.2→0.6s)

Task 3) Upgrade MI RF acceleration system to allow for more beam flux

Ability of target station to convert protons to neutrinos

Task 4) Upgrade LBNF Target and Horns to reliable 2+ MW capability (*)

Strategy for ACE-MIRT

- Main Injector
  - Power supplies ~$100M (DOE O413.3b project), needs alternatives analysis
  - RF ~$140M (DOE O413.3b project), needs alternatives analysis
  - Abort line upgrade Accelerator Improvement Project (AIP)
  - Provide power supplies for LBNF beamline which need different specifications for fast cycle time
- Targetry
  - Target materials R&D
  - Staged target development for higher beam power
  - Horn analysis and design modification
- Reliability
  - Complete instrumentation AIPs for 20-Hz operations
  - MI magnet testing at faster cycle time, produce spare quadrupoles to install as needed
  - Increment in ops funding eg $5M/y for modernization, $0.5M/y for SPS

Key Topics Addressed

[Abe Burleigh](#)

Fermilab

•Exploring New Target Technologies

- Can fluidized powder or granular targets revolutionize our approach?

Challenges in High-Power Targetry:

Radiation damage & thermal shock limit accelerator efficiency

Current materials like graphite & titanium face embrittlement, swelling, and reduced thermal conductivity

Research Focus:

RaDIATE collaboration tests advanced materials for better radiation & thermal shock resilience

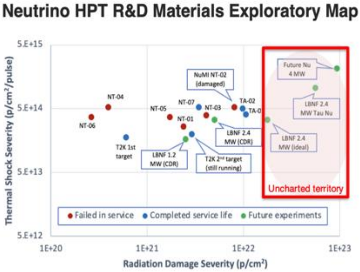
Focus on nanofibers, high-entropy alloys, and granular materials

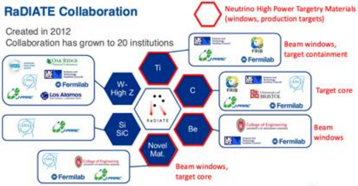
Nanofiber & Granular Approaches:

Zirconia & tungsten nanofibers absorb stress, showing high radiation resistance

Nanofibers & high-entropy alloys show promise for future high-power targets

Ongoing simulations & fabrication





Key Topics Addressed

Michel Hedges
Fermilab

•Exploring New Target Technologies

- Can fluidized powder or granular targets revolutionize our approach?

Material Performance:

•Graphite: Lower DPA (~1 DPA/year), more resilient

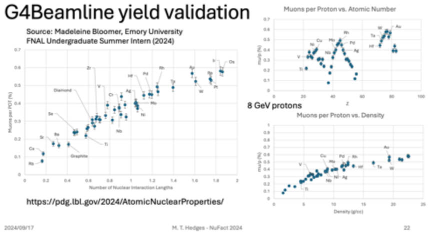
•Tungsten: Higher DPA (~100 DPA/year), rapid degradation

•Inconel: Used in muon/antiproton targets but prone to melting

Takeaways

- Increasing target density worsens peak radiation damage faster than muon production increases
- Good news! Lower density targets also absorb less energy, and (usually) run less hot
- Fewer beam studies done with mid-density targets (e.g. TZM)
- Fun fact: Inconel was the material for FNAL antiproton source!

2024/09/17 M. T. Hedges - NuFact 2024



Athula Wickremasinghe

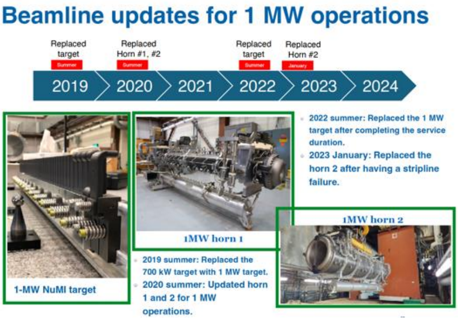
Fermilab

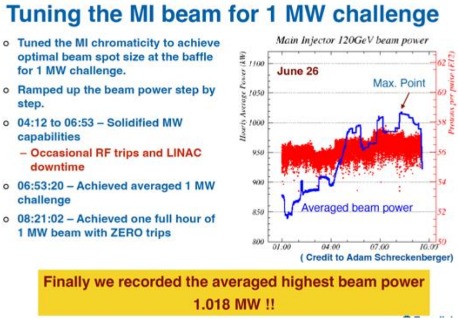
Key Topics Addressed

•Advancing Accelerator Capabilities

•Tuning MI beam for 1 MW beam on target provided valuable lessons learnt

•**Future Upgrades**: Testing new graphite materials for improved thermal conductivity and preparing spare horns for future operations





Key Topics Addressed

Robert Zwaska

Fermilab

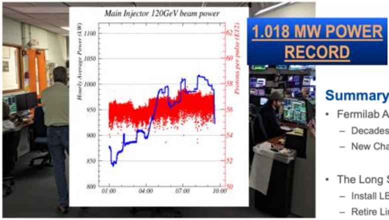
•Advancing Accelerator Capabilities

•At Fermilab, PIP-II upgrades to reach 1.2 MW, followed by ACE-MIRT improvements to achieve 2+ MW, focusing on enhancing Main Injector reliability and target system upgrades

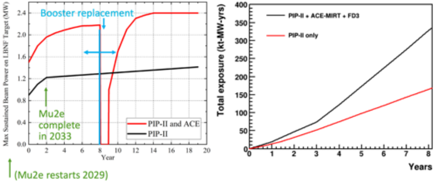
•Shaping the Future of Neutrino Research

•After DUNE, focus shifts to LBNF/DUNE Phase II, aiming for precise CP violation measurements and exploring next-generation experiments powered by a robust 2.4 MW accelerator complex

1.018 MW



DUNE power with a Booster Replacement



Summary

- Fermilab Accelerators have run for decades and are now at a turning point
  - Decades-long plans are being put into action
  - New Challenges and opportunities emerge on an almost daily basis
- The Long Shutdown is approaching in ~ 2027
  - Install LBNF & PIP-II
  - Retire Linac & NuMI
  - Integrate improvements to the complex: ACE-MIRT, AIPs, UIP, ACORN
- Until 2027:
  - Continue to deliver to present and new experiments
    - NOvA, SBND, ICARUS, 2x2, ANNIE, Mu2e, Spinquest, MTA/ITA, FTBF, …

Tetsuro Sekiguchi

Key Topics Addressed

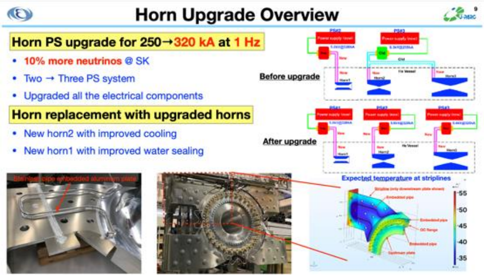
•Advancing Accelerator Capabilities

Increased Neutrino Beam Power: Horn upgrades enabled stable operation at 320 kA, supporting beam power up to 800 kW, with a target of reaching 1.3 MW for future experiments

Enhanced Neutrino Focus: Upgraded horns improve focusing of pions, intensifying neutrino beam by a factor of 15

Improved Cooling & Reliability: New horn designs feature improved water sealing and enhanced cooling, allowing better thermal management during high-power operations

Long-Term Operation: Upgrades ensure reliable, long-term operation of the neutrino beamline for high-precision experiments like T2K and Hyper-K



Key Topics Addressed

Tetsuro Sekiguchi

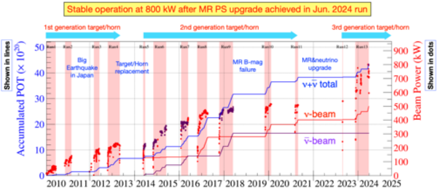
•Advancing Accelerator Capabilities

•Upgrades ongoing toward 1.3 MW operation by FY2028

•Second major upgrade scheduled for FY2026, with improvements to cooling, power supplies, and beamline systems

•Shaping the Future of Neutrino Research

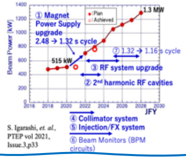
•J-PARC accelerators aim for full 1.3 MW operation by FY2028, supporting future high-intensity experiments

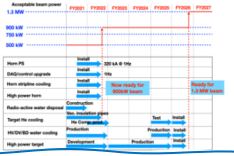


Total accumulated POT for T2K : 4.35 x 10^{21} POT (as of Jun. 2024) → 1.0x10^{22} POT (T2K goal)
c.f., 2.7x10^{22} POT (HK 10-years)

- J-PARC neutrino beam for CP violation search in lepton sector
- J-PARC accelerator and neutrino beamline upgrade toward 1.3 MW ongoing
  - MR upgrade toward 1.3 MW by 2028
  - 1st stage major upgrade completed in FY2021-2022
  - 2nd stage major upgrade in FY2026
- All the upgraded systems are working very well at 800 kW operation
- Woking on countermeasures for aging of old equipments

- **Both hardware upgrade and beam operation are important**
  - Beamline should be ready to take beam for more than 4 months/year for T2K operation
- **Second major upgrade planned in FY2026**
  - 8 months shutdown required for the remaining upgrades
- **Beamline will be ready for 1.3 MW after FY2026 ⇒ J-PARC accelerators aim to achieve 1.3 MW by FY2028**





[Leon Halić](#)

Key Topics Addressed

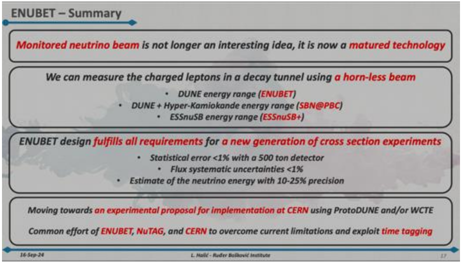
•Advancing Accelerator Capabilities

•ENUBET offers technology to produce monitored neutrino beam

•Uses a **hornless static focusing system** to enhance neutrino flux precision with slow extraction

•Employs **normal conducting magnets and quadrupoles** for narrow-band neutrino beams

•**Beam tests and GEANT4 simulations** confirm system's ability to achieve <1% flux uncertainty


ENUBET – Summary

Monitored neutrino beam is not longer an interesting idea, it is now a matured technology

We can measure the charged leptons in a decay tunnel using a horn-less beam

- *DUNE energy range (ENUBET)*
- *DUNE + Hyper-Kamiokande energy range (SBN@PBC)*
- *ESSnuSB energy range (ESSnuSB+)*

ENUBET design fulfills all requirements for a new generation of cross section experiments

- *Statistical error <1% with a 500 ton detector*
- *Flux systematic uncertainties <1%*
- *Estimate of the neutrino energy with 10-25% precision*

Moving towards an experimental proposal for implementation at CERN using ProtoDUNE and/or WCTE

Common effort of ENUBET, NuTAG, and CERN to overcome current limitations and exploit time tagging

16-Sep-24 L. Halić - Ruđer Bošković Institute 17

•Shaping the Future of Neutrino Research

•**Monitored neutrino beams** offer precision crucial for long-baseline experiments like **DUNE**

•**Kaon tagging** improves neutrino flux determination from decay modes

•Optimized design sets the stage for next-gen **cross-section experiments** with enhanced energy resolution and minimal systematic errors

[George Fanourakis]

Key Topics Addressed

ESS NEUTRINO SUPER BEAM

Co-funded by the European Union

•Advancing Accelerator Capabilities

•**ESSvSB** proposed next generation long baseline experiment

•**5 MW Proton Beam** for high-intensity neutrino production

•**Upgrades**: H- source, accumulator ring, and target station

•**Granular Targets** cooled by helium for enhanced reliability

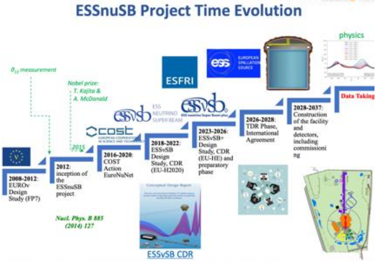
•Shaping the Future of Neutrino Research

•**CP Violation**: Precision at second oscillation maximum

•**Far Detector**: 538 kt Water Cherenkov at 360 km

•**Extended Physics**: Atmospheric neutrinos, proton decay, supernova neutrinos

•**ESSvSB+** proposes new physics opportunities with enhancements like Low Energy nuSTORM and far detectors enriched with gadolinium



Key Topics Addressed

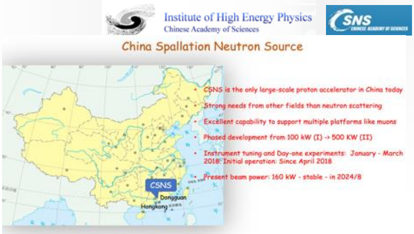
Shaping the future & synergies

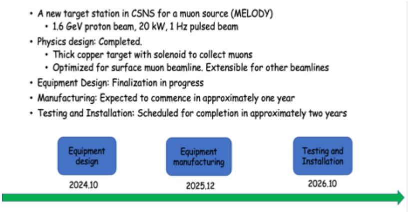
Key Topics Addressed

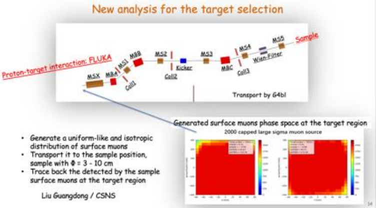
[Nikolaos Vassilopoulos](#)

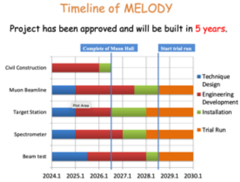
Muons

•**MELODY Project**: A new target station at CSNS to produce surface, negative, and decay muons for scientific research by 2028
•**Muon Applications**: Supports diverse fields, including superconductivity, magnetism, particle physics, and muon detector development
•**High Muon Yield**: Optimized copper target design and AI-enhanced solenoid focusing for high-efficiency muon production









Key Topics Addressed

Diktys Stratakis

Fermilab

Muon Collider

Advancing Accelerator Capabilities:

•**Multi-MW Proton Drivers**: R&D needed to adapt for Muon Collider requirements

•**Muon Cooling**: Muon ionization cooling demonstrated; significant R&D ongoing for 6D cooling

•**TeV Acceleration**: Conceptual designs up to 10 TeV using rapid cycling synchrotrons in place

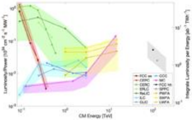
Shaping the Future:

•**Neutrino Radiation**: Innovative mitigation system developed to reduce radiation exposure from muons

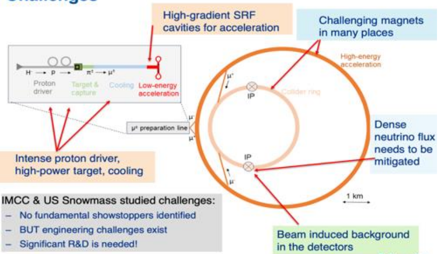
•**US Leadership**: Plans to build a Muon Collider at Fermilab by 2040 with global collaboration

Motivation

- **Muons** as compared to **protons**
  - Are leptons & use all energy in a collision
  - Need less collision energy for same physics
- **Muons** as compared **electrons**
  - Muons emit little synchrotron radiation
  - Acceleration in rings possible to many TeV
- A Muon Collider (MuC) can serve as **energy reach** and **precision** machine at the **same** time
- In a MuC, **luminosity** to power ratio improves substantially with energy



Challenges



IMCC & US Snowmass studied challenges:
- No fundamental showstoppers identified
- BUT engineering challenges exist
- Significant R&D is needed!

[Rohan Kamath](#)

Key Topics Addressed

Muon Cooling

Advancing Accelerator Capabilities:

nuSTORM: Creates high-precision neutrino flux from stored muons, acting as a testbed for future accelerator technologies

nuSTORM shares targetry and beam instrumentation technologies, supporting R&D for muon collider development

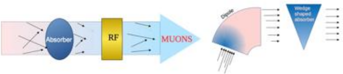
Muon Collider Synergy: 6D cooling demonstrates crucial technology for future muon colliders

Ionization Cooling: Uses absorbers and RF cavities to reduce emittance in all 6 dimensions

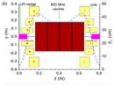
Engineering Innovations: RF cavities and magnet integration under development for effective cooling

- **Proton Driver Flexibility**: Demonstrator can be sited at CERN or Fermilab, offering versatility for future experiments

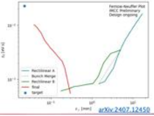
- Ionisation Cooling involves passing the beam through an absorber.
- The beam loses momentum in all direction as it ionises the absorber.
- An RF cavity restores momentum in a single direction.
- Multiple coulomb scattering from the nucleus is mitigated using low-Z materials and having tight focussing using solenoids.
- Having a dipole and a wedge-shaped absorber allows us to cool in all 6 dimensions.



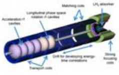
- In the muon collider, first 6D (rectilinear) cooling is done to reduce emittance in all directions.
- This is followed by 4D (final) cooling, which involves cooling only in the transverse direction at the cost of longitudinal emittance.



An example of a rectilinear cooling cell



arXiv:2407.12450



An example of a final cooling cell

Key Topics Addressed

Rohan Kamath

IMPERIAL

John Adams Institute for Accelerator Science

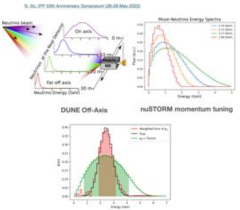
UKRI Science and Technology Facilities Council

Synergies with Neutrinos

Simulation and design of neutrinos from STORed Muons (nuSTORM) experiment

•**nuSTORM**: Creates neutrinos from stored muons with %-level precision for high-precision cross-section measurements

Shaping the Future:
•**BSM Physics**: nuSTORM offers sensitivity to rare processes and sterile neutrino searches
•**Synthetic Beams**: Uses linear combinations of fluxes to create quasi-monoenergetic neutrino beams for precision studies

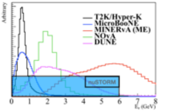


Scientific Program

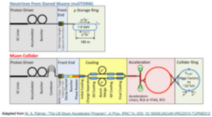
Cross Section Measurements
- One of the sources of error in LBL neutrino experiments is the constraint on flux and x-sec models.
- With a %-level precision on the neutrino flux, nuSTORM can constrain these cross section models
- With a tuneable muon storage ring, the neutrino flux can also be tuned to the energy spectrum of current (and future) long baseline neutrino experiments.

Beyond Standard Model Physics
- Combining the well constrained flux with high statistics, many exotic and rare scatterings can be studied.
- nuSTORM can also probe short baseline oscillations and sterile neutrinos, with a 2014 study showing a 10σ sensitivity to the LSND and MiniBOONE anomalies.

Muon Collider Demonstrator
- As a muon storage ring, nuSTORM exhibits synergies with muon collider research, serving as a test bed for technologies for magnets and beam instrumentation.
- Hence, a Muon Collider Demonstrator complex has been envisioned at CERN, allowing for shared targetry and capture between nuSTORM, the 6D cooling test facility.



Original plot: Katori T. YETI2019, IPPP, Durham, UK, Jan. 7, 2019



Key Topics Addressed

Jonathan Williams
Fermilab

Fermilab Facility for Dark Matter Discovery (F2D2)

Advancing Accelerator Capabilities:

- **F2D2 Beam Stop**: Designed for dark sector searches using excess beam from PIP-II

- **High Power Targetry**: F2D2 can serve as a testbed for future high-power targets, including muon collider facilities

- **Thermal Management**: Advanced cooling systems to handle 2.5 MW

F2D2 Site Layout – Integrated with Future Fixed Target Campus

Shaping the Future

Synergy with PIP-II: Leveraging unused beam power for smaller, focused dark matter experiments

Muon Collider Readiness: F2D2 shares target and cooling technologies with future muon collider developments

R&D for Next-Gen Facilities: Contributes to both neutrino and dark matter experiments while advancing muon collider capabilities

Summary

- We reviewed current accelerator operations, upcoming plans, and explored novel ideas crucial for next-generation neutrino experiments

- Synergies between neutrino, muon, and collider research will drive future breakthroughs

We had many interesting talks and discussions

Thank you!