Welcome Remarks

Muon Collider Physics & Detector Workshop

Dec. 17-18, 2022

Pushpa Bhat

Fermi National Accelerator Laboratory

Welcome!

- Welcome to you all, on behalf of the Fermilab directorate, and the Fermilab Future Colliders Group.

- Snowmass2021 was a marathon of two years! It afforded the US/global HEP community a tremendous opportunity to take stock and look to the future of the Energy Frontier!

- The Muon Collider has been resurrected, and once again, it has sparked great interest and a lot of a excitement within the community, across frontiers.

- The International Muon Collider Collaboration hosted by CERN and the US Snowmass Muon Collider Forum were instrumental in the progress made during Snowmass.

Highlights of Snowmass Summary

- The Energy Frontier community would like to
  - Realize an e+e- Higgs Factory as soon as possible
  - Work towards an energy frontier collider to access the ~10 TeV scale
  - (The favorite machine for the 10 TeV scale is a Muon Collider)
- The Accelerator Frontier recommended the proposed national R&D program.
- The Muon Collider has synergies and support across frontiers beyond EF and AF.
- There is greatly renewed interest and ambition in bringing back energy frontier collider physics to the US while maintaining international partnerships at facilities abroad.

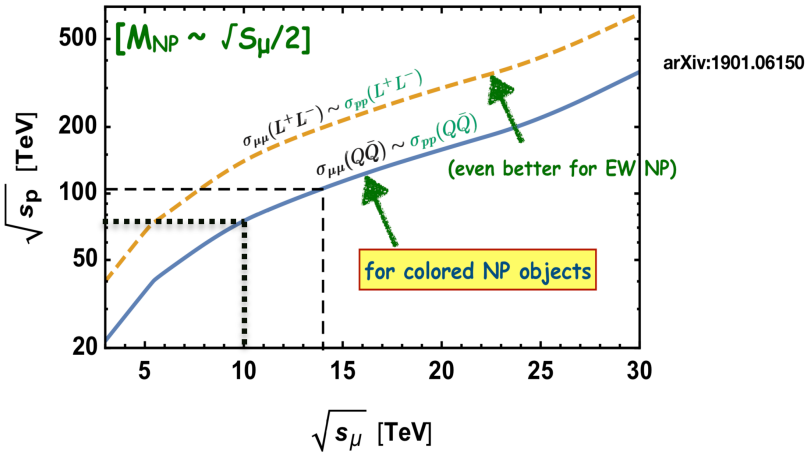
The most surprising thing that emerged from Snowmass was an overwhelming sentiment to engage in hosting a future collider in the US

Highlights and Messages from the Snowmass Summer Study.
Prisca Cushman

The Lure of the Muon Collider

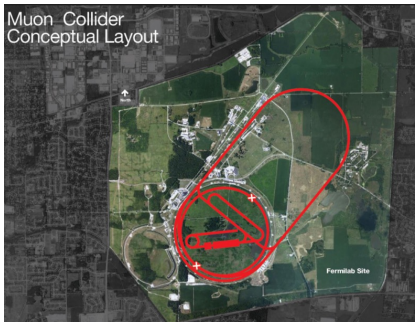
- A precision and discovery machine!
  - Excellent precision for Higgs coupling measurements
  - Great direct reach for new physics
    - 10 TeV $\mu^+\mu^-$ ≅ 70 TeV pp
    - 10 TeV $\mu^+\mu^-$ ≅ 150 TeV pp for EW
- A Compact collider for multi-TeV scale
- Cost-efficient, power-efficient
- Can be built in stages
  - Demo facility, Sub-TeV, 3 TeV, 10 TeV, ..
  - Physics potential at each stage
- Technologically challenging, exciting, unique opportunities for innovation
- Synergies with other HEP interests
  - An Advanced Muon Facility, neutrinos, …

Equivalent reach in pp after rescaling for pdf's



125 GeV to 8 TeV (10 TeV?)
Muon collider can fit on Fermilab site

Fermilab and the Muon Collider



- Fermilab has been enamoured with the possibility of a muon collider for a very long time!
- Fermilab/US had been the drivers for Muon Collider activities since its proposal in the 1980s.
  - Initial Proposal by Skrisnsky & Parkomchuk; David Neuffer (1983)
  - Several conferences held during the 1990s in the US
  - Feasibility Study Report produced for Snowmass 1996
  - Many pioneers:
    - R. Palmer, A. Sessler, D. Cline; At Fermilab: D. Neuffer, A.Tollestrup, R.Raja, N. Mokhov, Y. Alexahin, A. Bross, S. Geer, M. Palmer, E. Eichten, C. Hill, C. Quigg, …
  - A Muon Collider Task Force launched in 2006
- The US Muon Accelerator Program initiated at Fermilab in 2010 (2011-2014)
  - https://map.fnal.gov/ (Director: Mark Palmer)
  - A lot of progress made, cooling R&D and other important design aspects.

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The first in a series of *FermiNews* articles about possible future accelerators at Fermilab

Reaching for the Muon

Is a Fermilab group exploring the collider of the future—or only chasing muonbeams?

by Judy Jackson, Office of Public Affairs

Like tomorrow, the goal of particle physics never arrives; it's always a day—or an accelerator—away.

The field of high-energy physics has its collective gaze ever fixed on the future, on the spot just over the horizon, where the next step forward in technology will make possible the next generation of experiments to explore the next new theoretical territory. Particle physics advances by the complex synergy of theory, experiment, and technology, all moving forward together, by lurches and leaps and discoveries and missteps, beyond the horizon into the unknown.

The work of accelerator physicists is never done; there is always the next accelerator to build, and the next after that. Currently, physicists worldwide are putting their minds to the challenge of how to explore the realm of physics beyond the Standard Model. One aim of Fermilab's coming reorganization is to allow the Fermilab scientific community more time and flexibility to work on ideas and plans for an accelerator at Fermilab to follow the Large Hadron Collider now planned at CERN, the European Particle Physics Laboratory. They seek an accelerator design to take particle physics deep into unexplored territory.

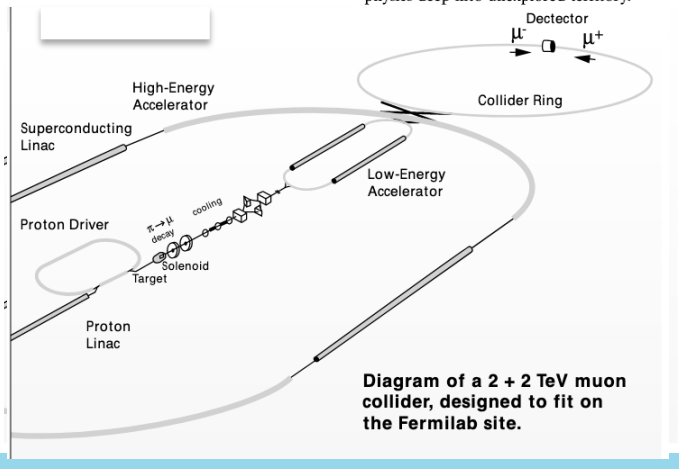

Diagram of a 2 + 2 TeV muon collider, designed to fit on the Fermilab site.

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New Support for Muon Collider R&D

by Sharon Butler, Office of Public Affairs

Just last February, as part of efforts to "position the U.S. for a long-term leading role at the energy frontier," the Gilman Subpanel on Planning for the Future of U.S. High Energy Physics recommended expanding research and development on a possible future muon collider.

And already rolling is the muon collider collaboration of which Fermilab is a part—thanks to more than $1 million in new funding from the U.S. Department of Energy.

"Spiritual Leader"
for the Muon Collider

Future Colliders Initiative at Fermilab

- Fermilab Future Colliders Group (FCG) formed in early 2021
  - Develop Fermilab's **engagement plans in future collider projects**, across aspects of accelerators, technology, particle physics and detectors
    - FCC, IMCC, ILC ; be a key partner in developing next generation colliders
  - Provide a forum to **synergize efforts** on future colliders/accelerators **across frontiers**
  - **Develop a roadmap** for further (design) studies and R&D for future colliders
    - Develop compact, cost-effective options for hosting future colliders in the U.S.
  - Work with US universities and other US national labs, and with international collaborators on pertinent issues and proposals
- The initial focus was to produce robust input for Snowmass

FUTURE COLLIDERS GROUP
(P. BHAT, HEAD)
(S. JINDARIANI, DEPUTY HEAD)

(G. APOLLINARI, APSTD)
(A. BROSS, ND)
(S. BELOMESTNYKH, APSTD)
(J. BUTLER)
(A. CANEPA)
(D. ELVIRA, SCD)
(P. FOX, THEORY)
(Z. GECSE)
(P. MERKEL)
(S. NAGAITSEV, DO)
(S. POSEN , APSTD)
(V. SHILTSEV, AD)
(T. SEN, AD)
(M. SYPHERS, AD, JA/NIU)

Activities:

- Organized a series of "Snowmass Agora" events on Future Colliders in partnership with Snowmass Energy and accelerator Frontier conveners
- Facilitated Fermilab's Energy Frontier contributions to Snowmass; organized mini-workshops
- Produced a comprehensive summary of "Future Collider Options for the U.S." https://arxiv.org/abs/2203.08088/
- Proposed "U.S. National Accelerator R&D Program on Future Colliders" https://arxiv.org/abs/2207.06213

Snowmass Agora on Future Colliders

- The Fermilab Future Colliders Group organized a series of Snowmass "Agora" on Future Colliders, in conjunction with Snowmass Accelerator and Energy Frontier conveners.
  - Org. Committee:
    - P. Bhat, J. Butler, M. Narain, L. Reina, A. Tricoli, S. Gourlay, T. Raubenheimer, V. Shiltsev
- Five Agora events held from Dec. 2021 to April 2022, once a month, on Wednesdays. Each 2.5 hrs; 4-5 talks, ~1 hr moderated Q&A, 30 min. informal post-Agora chat.

1.	**Linear e+e- colliders**	**Dec. 15, 2021**
2.	**Circular e+e- colliders**	**Jan. 19, 2022**
3.	**Muon colliders**	**Feb. 16, 2022**
4.	**Circular pp and ep**	**Mar. 16, 2022**
5.	**Advanced colliders**	**Apr. 13, 2022**

Aspects covered:

Physics reach
Challenges and R&D required
Synergy of project with global context
Synergy of project with local resources
Time frame (short-term R&D, long-term construction)
Costs projections: both R&D and construction costs

- Comparative physics potential of various machines
- Intense focus on proposed machines in various categories!
  - Technical readiness or maturity status, what specifications have been achieved, remaining challenges, timelines, cost, …
- Slides, videos, google doc with Q&A, summary from moderators available on the indico pages. https://indico.fnal.gov/e/snowmass-agora-n/ (n=1,..5)

Future Collider Options for Fermilab Site

- A comprehensive whitepaper outlines several options for e+e-, μ+ μ- and pp colliders at Fermilab.

Future Collider Options for the US

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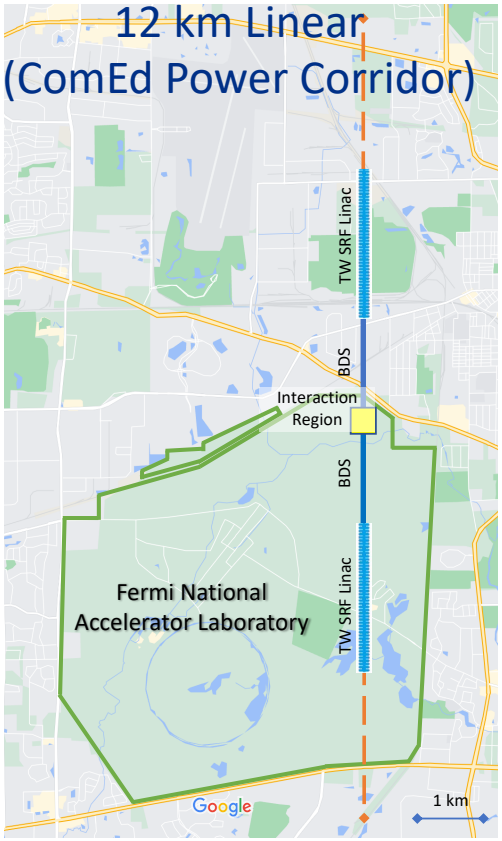
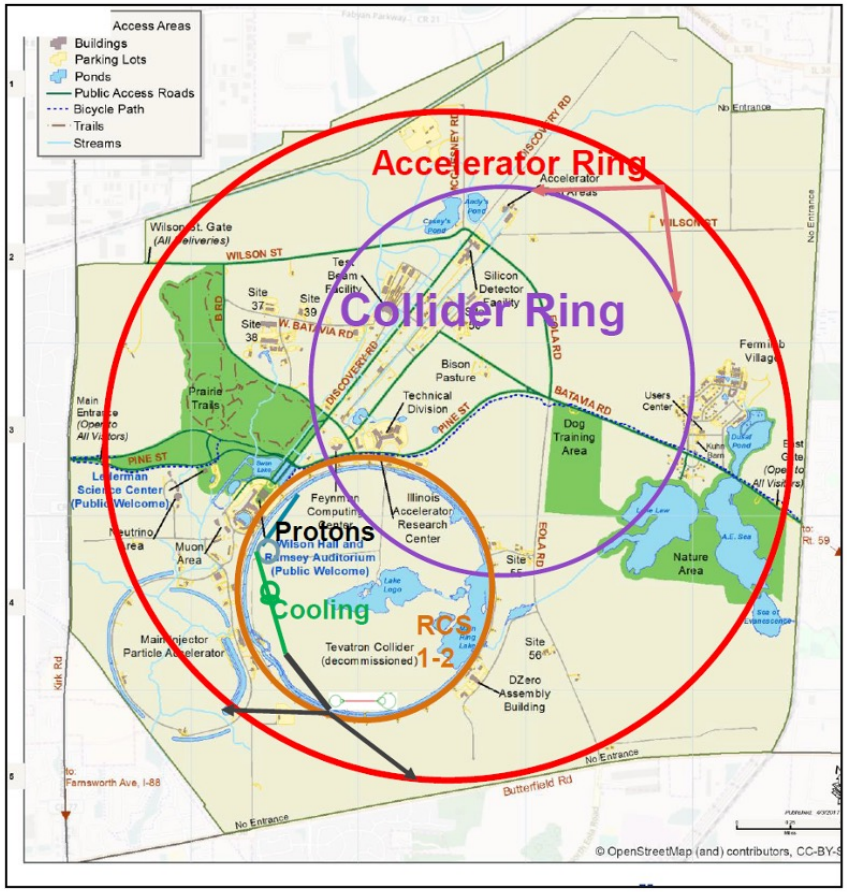
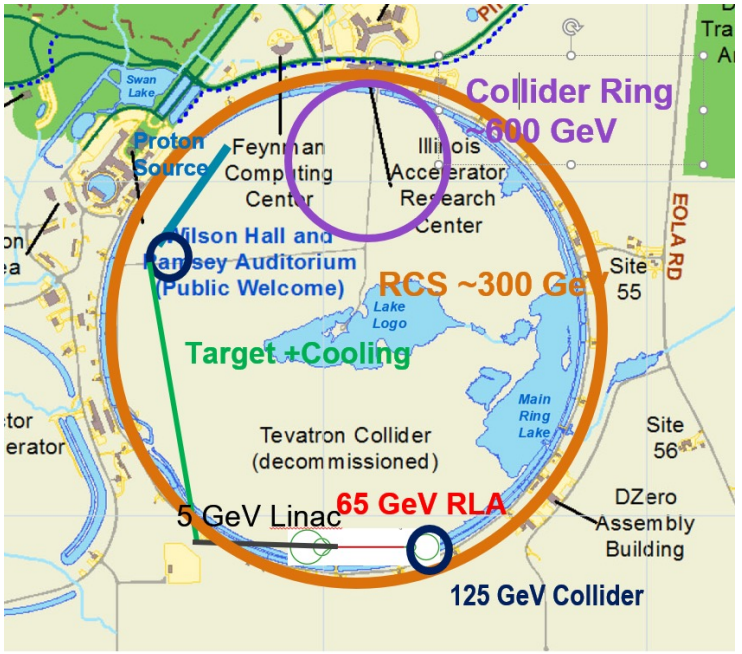


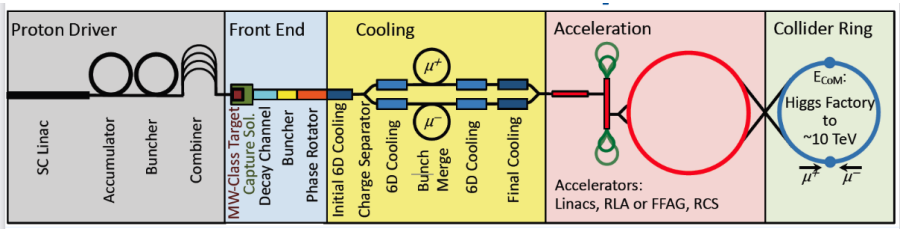
Muon Collider at Fermilab

Site Filler (10 TeV collider)



125 GeV and 600 GeV staging options





Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

July 14, 2022

U.S. National Accelerator R&D Program on Future Colliders

P.C. Bhat[1,†], S. Belomestnykh[1,5], A. Bross[1], S. Dasu[6], D. Denisov[4], S. Gourlay[7], S. Jindariani[1], A.J. Lankford[8,†], S. Nagaitsev[1,2,†], E.A. Nanni[3], M.A. Palmer[4], T. Raubenheimer[3], V. Shiltsev[1], A. Valishev[1], C. Vernieri[3], F. Zimmermann[9]

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[2]University of Chicago
[3]SLAC National Accelerator Laboratory
[4]Brookhaven National Laboratory
[5]Stony Brook University
[6] University of Wisconsin, Madison
[7]Lawrence Berkeley National Laboratory, Retired
[8] University of California, Irvine
[9]CERN

[†] Lead Contacts; Email: pushpa@fnal.gov, andrew.lankford@uci.edu, nsergei@fnal.gov

Scope, Organization and Coordination are discussed in the whitepaper.

A National Accelerator R&D Initiative on Future Colliders

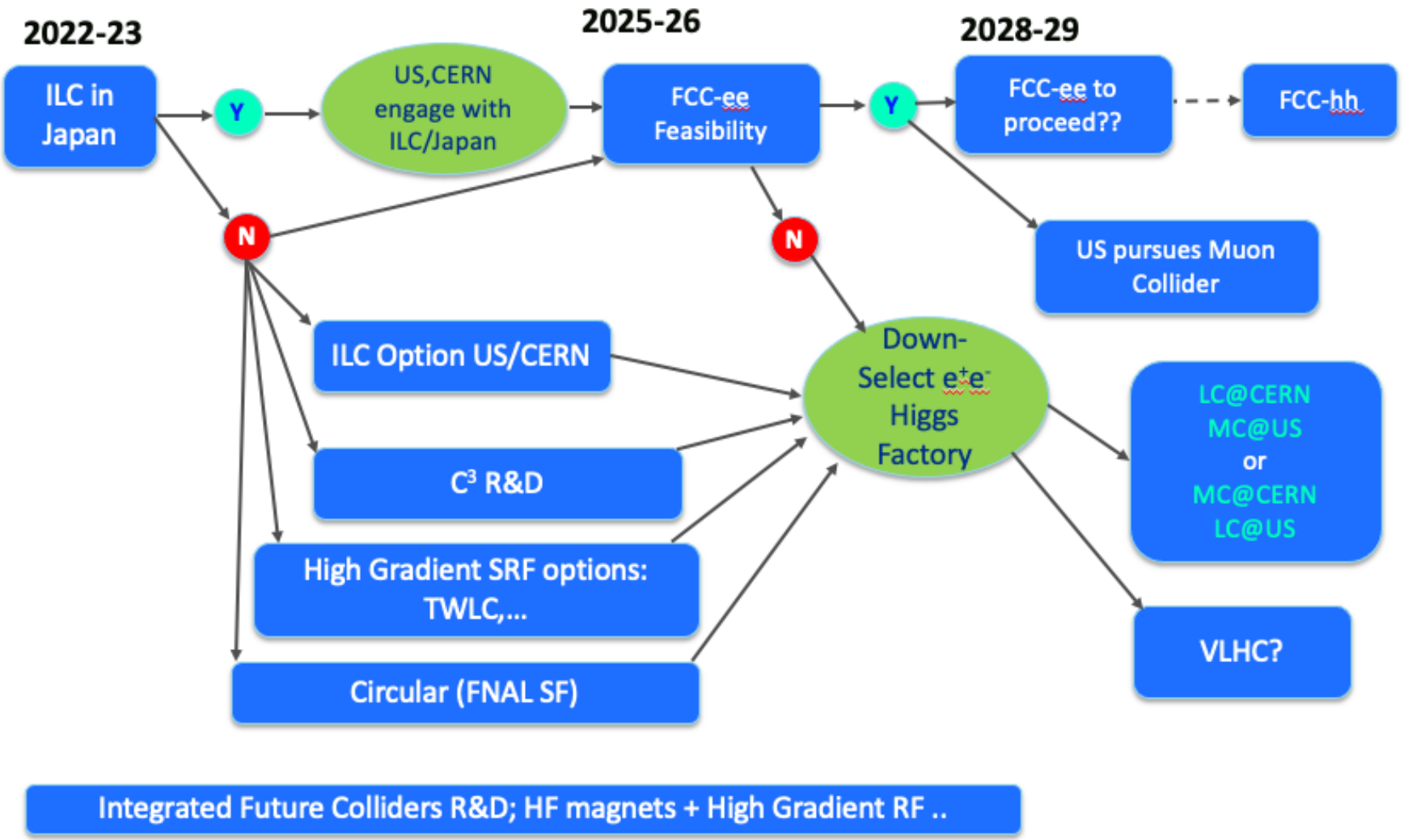
- An integrated U.S. national accelerator R&D program on future colliders has been proposed (arxiv:2207.06213), which has received broad support.
- **The overarching objective: Address in an integrated fashion the technical challenges of promising future collider concepts, particularly those aspects of accelerator design, technology, and beam physics that are not covered by the existing General Accelerator R&D (GARD) program.**
- The goal is to inform decisions in down-selecting among the collider concepts by the next European strategy update and the next US community planning cycle
  - **help move towards realization of the next collider as soon as possible (e+e- Higgs Factory)**
  - **help to subsequently advance towards a collider at a higher energy scale (to probe Multi-TeV scale)**

- The US community is already engaged and working with IMCC
- If the proposed National Collider R&D program is recommended by P5, and launched by DOE, it would enable formal and significant US engagement with IMCC.
- The R&D program would enable participation of US experts and facilitate activities of US researchers on the Muon Collider
  - Machine scenarios and design, beam induced background, neutrino radiation, demonstrator facility, detector/physics studies
- We could consider the formation of a US Muon Collider Collaboration with Fermilab as the host.
- Fermilab proton complex upgrade towards a multi-MW beam power for LBNF-DUNE is compatible with development of Muon Collider R&D and demonstrator facility. The evolution of the complex will also prepare Fermilab to be able to host the Muon Collider.

Let us have a fruitful workshop!

Extra Slides

A Roadmap for the Decade



Scope of the Proposed Program

- Scope:
  - Sharply focused on future colliders
    - Address challenges for next colliders (e.g., Higgs factories) and for collider concepts for ~10 TeV-scale machines
  - Spans accelerator design, technology and full concept development
  - Complements the existing HEP GARD program
  - Multifaceted but selective, and synergistic
    - Support multiple approaches but be selective among R&D topics in a way that leads to converging on viable option(s)
    - Cost-effective, opportunity for technical benefits, innovation
  - Integrates all critical R&D for a concept
    - Enable full development of collider concepts
  - Priorities guided by P5

Organization and Coordination

- Organization:
  - Coherent national program
    - Key: Advance developments and preparedness for future colliders
    - Program's portfolio of activities centrally selected, coordinated
    - Guided by P5 and an Advisory Committee/Board
  - Collaborative effort of U.S. national labs and universities
    - Funding allocations through proposals/review process
- Coordination:
  - Centrally coordinated and funded
    - Management hosted at a national lab
  - Coordinated with global design studies and R&D
    - Avoid duplication of efforts, engage in complementary R&D
  - Periodic assessment
    - Of coherence of activities, specifications