Collaboration Building for a Future μIC

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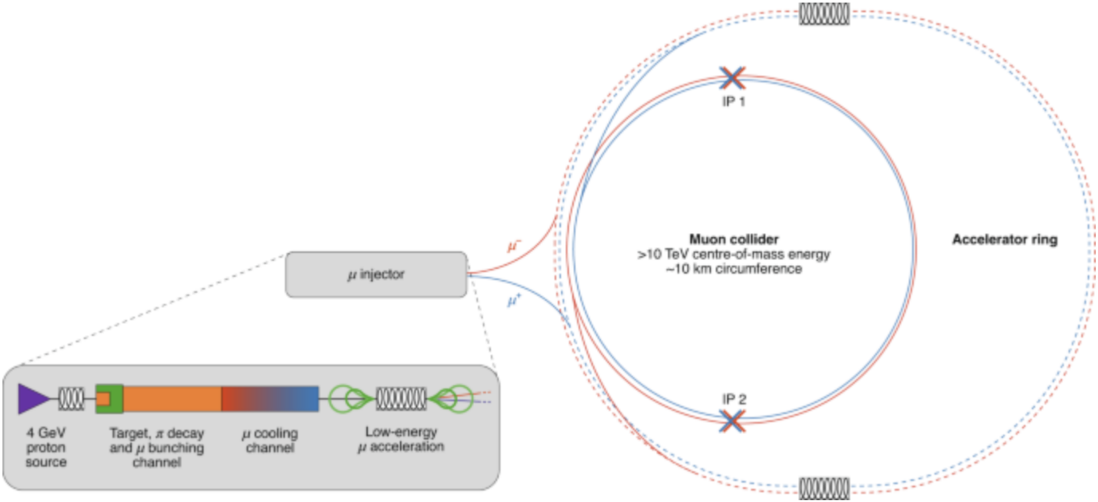
A Future Muon Collider



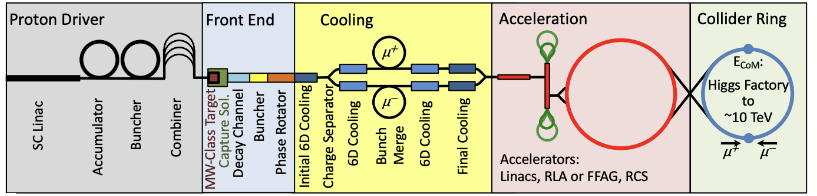
https://muoncollider.web.cern.ch/node/25

A Future Muon Collider

- A future muon collider has strong interest in the community
- Wide physics reach at $\sqrt{s} = 10$ TeV and beyond
- Several papers submitted as part of SNOWMASS process
- Significant R&D work necessary to prove feasibility
- MICE project at Rutherford lab demonstrated 6D cooling (Nature 578, p. 53–59 (2020))
- There is a rich physics program possible along the way to realizing a muon collider!

Muon Generation - Proton Driven

- Proton driven scheme - reference design for μC
  - Proton on high Z target, produce π's which decay to μ's
  - μ's have wide emittance, need to be cooled
  - Preferentially produce μ^+
  - Selecting polarized μ's reduces luminosity



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Muon Generation - Proton Driven

- Cooling is a non-trivial challenge!
  - From Forum Report arxiv:2209.01318 4 of 5 major challenges in realizing accelerator come from cooling!
    - “operation of RF cavities in high magnetic fields in the front end and cooling channel.”
    - “development of a 6D cooling lattice design...”
    - “a direct demonstration and measurement of the ionization-cooling process.”
    - “development of very-high-field solenoids to achieve the emittance goals of the Final Cooling system”
  - MICE at Rutherford lab has demonstrate low beam intensity cooling
  - From talk by K. Yonehara here, transmission efficiency through cooling channel is $\approx 20\%$
- It would be great to not need to cool the μ beams!
- However, proton driven scheme has seen the most study and seems to be the most widely accepted method of generating μ

Muon Generation - the EIC

What could be built at the EIC?

- Proton-driven scheme/LEMMA would require significant construction - difficult with ePIC running
- BACKGAMMON could be implemented with minimal interference and collaboration with other groups likely
- Alternatively, backscatter γs off e-beam for exclusive π production on nuclear target? BACKGAMMON-Factory?
  - Back-of-the-laptop calculation indicates if we want 300 MeV photons, we can use the BACKGAMMON method to get $\approx 6.5 \times 10^{13}$ γ/s
  - Likely destructive to EIC electron beam

LRP and EIC

RECOMMENDATION 1

The highest priority of the nuclear science community is to capitalize on the extraordinary opportunities for scientific discovery made possible by the substantial and sustained investments of the United States. We must draw on the talents of all in the nation to achieve this goal.

RECOMMENDATION 3

We recommend the expeditious completion of the EIC as the highest priority for facility construction.

RECOMMENDATION 4

We recommend capitalizing on the unique ways in which nuclear physics can advance discovery science and applications for society by investing in additional projects and new strategic opportunities.

Today's investments enable tomorrow's discoveries, with corresponding benefits to society. We underscore the importance of innovative projects and emerging technologies to extend discovery science, which plays a unique role in supporting national needs.

NSAC LRP 2023 The foundations of R&D for a μIC?

P5 and μC

- 1960s: Muon Colliders mentioned in literature
- 1990s: Initial design studies
- 2011: MAP approved
- 2020s: EU R&D roadmap + US Snowmass show significant interest in muon colliders

> **Recommendation 25: Reassess the Muon Accelerator Program (MAP). Incorporate into the GARD program the MAP activities that are of general importance to accelerator R&D, and consult with international partners on the early termination of MICE.**

P5 2014 The end of MAP

*Disclaimer: Not involved with LRP or P5 processes beyond contributing to Town Halls and White Papers

P5 and μC

Recommendation 4: Support a comprehensive effort to develop the resources—theoretical, computational, and technological—essential to our 20-year vision for the field. This includes an aggressive R&D program that, while technologically challenging, could yield revolutionary accelerator designs that chart a realistic path to a 10 TeV pCM collider.

Investing in the future of the field to fulfill this vision requires the following:

a. Support vigorous R&D toward a cost-effective 10 TeV pCM collider based on proton, muon, or possible wakefield technologies, including an evaluation of options for US siting of such a machine, with a goal of being ready to build major test facilities and demonstrator facilities within the next 10 years (sections 3.2, 5.1, 6.5, and Recommendation 6).

P5 2023 The foundations of R&D for a μIC?

How does a μIC Extend the EIC?

“Staging”

- Hadron beam benefits from higher energy – beam-beam, space charge, intrabeam scattering, …
- Replacing the 275 GeV EIC hadron storage ring with a 1 TeV ring would result in higher luminosity
- Instead of colliding with one hadron bunch out of 1200 at a time, increase total number of bunches by factor 7, and collide with 7 bunches at a time
- This would increase the luminosity by factor 7, to $5{*}10^{32} cm^{-2} sec^{-1}$
- Note that total number of muons would be unchanged from original proposal - $20 * 10^{11}$

Slide from C. Montag, MUIC2023-Montag

Coordination with μC

- Spoke briefly with μC folks
- Potentially some interest in performing some simulations in coordination with μIC people
  - Must first develop a realistic machine-detector interface
  - Too many open questions without a baseline
  - Beam-induced background needs to be studied - some work from Rice group
- Need to determine what the μIC is
  - Extension of μC efforts?
  - Or independent project?

Fermilab? Or BNL?

2.3

The Path to 10 TeV pCM

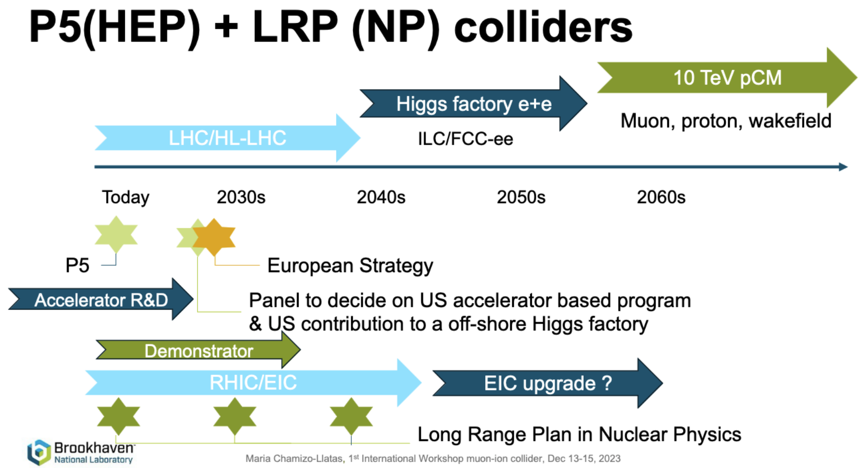
With a 10 TeV pCM muon collider at Fermilab as the long-term vision, a clear path for the evolution of the current proton accelerator complex at Fermilab emerges naturally: a booster replacement with a suitable accumulator/buncher ring would pave the way to a muon collider demonstration facility (Recommendation 4g, 6). The upgraded facility would also generate bright and well-characterized neutrino beams bringing natural synergies with studies of neutrinos beyond DUNE. It would also support beam dump and fixed target experiments for direct searches of new physics. Another synergy is in charged lepton flavor violation. The current round of searches at Mu2e can reveal quantum imprints of new physics at the 100 TeV energy scale, beyond the reach of direct searches at collider facilities in the foreseeable future. An intense muon facility may push this search even further.

Although we do not know if a muon collider is ultimately feasible, the road toward it leads from current Fermilab strengths and capabilities to a series of proton beam improvements and neutrino beam facilities, each producing world-class science while performing critical R&D towards a muon collider. At the end of the path is an unparalleled global facility on US soil. This is our Muon Shot.

P5 2023

Interest in other Sites: Semi-Random Sample

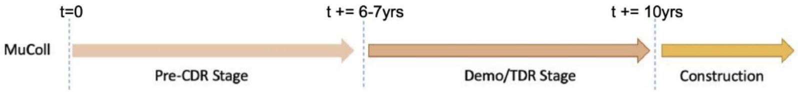
- Also some interest in μp collider at Fermilab
  - J. Yu, arXiv:9806033, 1998
  - D. Neuffer, μIC2023, 2023
  - B. Dagli, *et al.*, arxiv:2402.10952, 2024
- At the FCC
  - A. Caliskan, *et al.*, arxiv:1701.03426, 2017
  - Y. C. Acar, *et al.*, arxiv:1703.04030, 2017
  - G. Aydin, *et al.*, arxiv:2105.09686, 2021



Slide from M. Chamizo-Llatas muIC2023

Snowmass Muon Collider Timeline

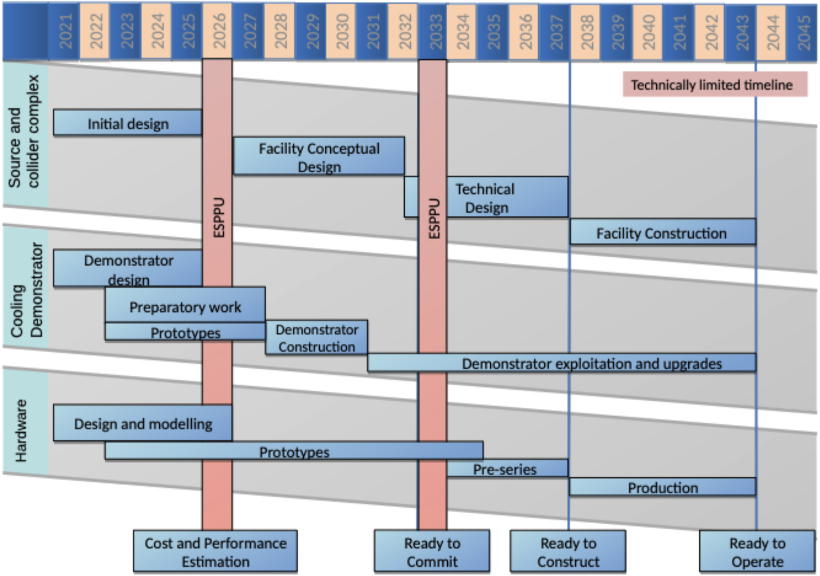
R&D program and an accelerator-demonstration facility in the shorter term



- **Caution:** this is a **Technically Limited, highly optimistic timeline**
- The actual construction start time is subject to:
  - Successful outcome of **the proposed extensive R&D program**
  - Availability of funding + resources, host laboratory, and international agreements
- Development will take a long time – **need to start now!**

Slide from S. Jindariani muIC2023

Timelines



European Strategy for Particle Physics – Accelerator R&D Roadmap arxiv:2201.07895

This Decade!

Recommendation 6: Convene a targeted panel with broad membership across particle physics later this decade that makes decisions on the US accelerator-based program at the time when major decisions concerning an off-shore Higgs factory are expected, and/or significant adjustments within the acceleratorbased R&D portfolio are likely to be needed. A plan for the Fermilab accelerator complex consistent with the long-term vision in this report should also be reviewed.

The panel would consider the following:

a. The level and nature of US contribution in a specific Higgs factory including an evaluation of the associated schedule, budget, and risks once crucial information becomes available.

b. Mid- and large-scale test and demonstrator facilities in the accelerator and collider R&D portfolios.

c. A plan for the evolution of the Fermilab accelerator complex consistent with the long-term vision in this report, which may commence construction in the event of a more favorable budget situation.

Area Recommendation 12: Form a dedicated task force, to be led by Fermilab with broad community membership. This task force is to be charged with defining a roadmap for upgrade efforts and delivering a strategic 20-year plan for the Fermilab accelerator complex within the next five years for consideration (Recommendation 6). Direct task force funding of up to $10M should be provided.

P5 2024

Personal Thoughts

- Collaborations aren't built in a day
- Small group of people interested now, should actively recruit and get broader interest
- Some level of organization needed, monthly meeting?
- Rice has mailing list, Stony Brook can provide dedicated indico (Slack workspace similar to SCHEMA?)
- Computing infrastructure, piggy-back off of μC efforts, central GitHub repo?
- Overview of scope and goals of μIC effort should be written down

Summary

- Muon collider collaborations have clearly demonstrated need for future collider
- R&D on a high-energy, high-intensity source of muons is desirable
- Design should reflect muon source characteristics useful for future μC, not just μIC
- Synergy between nuclear and particle physics community at the site of the future EIC
- Seize the chance to build a strong community involvement now!

Mailing list: https://mailman.rice.edu/mailman/listinfo/muic
Indico site: https://indico.cfnssbu.physics.sunysb.edu/category/6/

Thank you!

Any Questions?