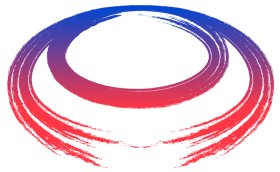


US P5 and EPP Synergies

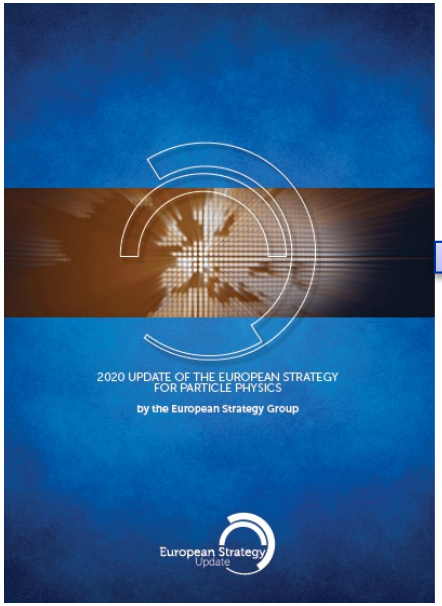
Mark Palmer
May 12, 2025

A Brief Historical Perspective

- 1969: Muon Collider Concept first described by G. I. Budker
  - G. I. Budker, — “Accelerators and colliding beams,” 7th International Conference on High-Energy Accelerators, Yerevan, USSR, 27 Aug - 2 Sep 1969, p. 33, extracts in AIP Conf. Proc. 352 (1996) 4.
  - Subsequent development by A. N. Skrinsky, —Intersecting storage rings at Novosibirsk,‖ International Seminar on Prospects of High-Energy Physics, Morges, Switzerland, Mar 1971, extracts in AIP Conf. Proc. 352 (1996) 6.
- 1996: US Snowmass – Discussion of feasibility
  - Muon Collider: Feasibility Study, Snowmass 1996, BNL-52503, Fermilab Conf. 96/092, LBNL-38946.
  - C. Ankenbrandt et al., “Status of Muon Collider Research and Development and Future Plans,” Phys. Rev. ST-AB 2 (1999) 081001.
  - Further discussion at Snowmass 2001, but primary focus on linear colliders to explore the Higgs
- 2000s: Neutrino Factory and Muon Collider development efforts synergistically pursued
  - MICE Experiment launched
- 2010: Muon Accelerator Program (MAP) proposed in US
  - US DOE approval in 2011 a Restructured effort based at Fermilab starting in 2012
- 2012: Higgs discovery!
- 2013: US Snowmass – major focus on options for a Higgs Factory and a US long baseline neutrino program
  - 2014 P5 recommends narrowed focus to achieve goals of field a ramp-down of MAP effort
  - 2014-2020 Key R&D results from MAP and MICE efforts
- 2018: Launch of the 2020 EPPSU
  - Renewed interest in MC for its high energy scaling (also an evaluation of LEMMA vs Proton-Driver concepts)

International MUON Collider Collaboration

2020 European Strategy Update



Re-establishes Muon Collider R&D

Accelerator R&D Roadmap arXiv:2201.07895

Lays out an R&D Roadmap to a Muon Collider

2021 Snowmass Report arxiv:2301.06581

FERMILAB-CONF-23-008
SLAC-PUB-17717
January 2023

Report of the 2021 U.S. Community Study on the Future of Particle Physics (Snowmass 2021)

Summary Chapter

2021 – 2022 Snowmass Steering Group:

Joel N. Butler[1], R. Sekhar Chivukula[2], André de Gouvêa[3], Tao Han[4], Young-Kee Kim[5], Priscilla Cushman[6] (APS Division of Particles and Fields), Glennys R. Farrar[7] (APS Division of Astrophysics), Yury G. Kolomensky[8] (APS Division of Nuclear Physics), Sergei Nagaitsev[1] (APS Division of Physics of Beams), Nicolás Yunes[9] (APS Division of Gravitational Physics)

Snowmass 2021 Frontier Conveners:

Stephen Gourlay[10], Tor Raubenheimer[11], Vladimir Shiltsev[1] (Accelerator), Kétévi A. Assamagan[12], Breese Quinn[13] (Community Engagement), V. Daniel Elvira[1], Steven Gottlieb[14], Benjamin Nachman[10] (Computational), Aaron S. Chou[1], Marcelle Soares-Santos[15], Tim M. P. Tait[16] (Cosmic), Meenakshi Narain[17], Laura Reina[18], Alessandro Tricoli[12] (Energy), Phillip S. Barbeau[19], Petra Merkel[1], Jinlong Zhang[20] (Instrumentation), Patrick Huber[21], Kate Scholberg[19], Elizabeth Worcester[12] (Neutrino), Marina Artuso[22], Robert H. Bernstein[1], Alexey A. Petrov[23] (Rare Processes), Nathaniel Craig[24], Csaba Csáki[25], Aida X. El-Khadra[3] (Theory), Laura Baudis[26], Jeter Hall[27], Kevin T. Lesko[28], John L. Orrell[29] (Underground Facilities), Julia Gonski[30], Fernanda Psihas[1], Sara M. Simon[1] (Early Career)

Editor: Michael E. Peskin[11]

Abstract

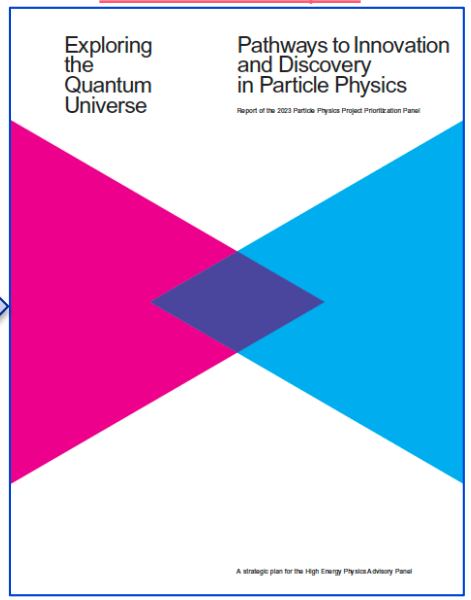
The 2021-22 High-Energy Physics Community Planning Exercise (a.k.a. "Snowmass 2021") was organized by the Division of Particles and Fields of the American Physical Society. Snowmass 2021 was a scientific study that provided an opportunity for the entire U.S. particle physics community, along with its international partners, to identify the most important scientific questions in High Energy Physics for the following decade, with an eye to the decade after that, and the experiments, facilities, infrastructure, and R&D needed to pursue them. This Snowmass summary report synthesizes the lessons learned and the main conclusions of the Community Planning Exercise as a whole and presents a community-informed synopsis of U.S. particle physics at the beginning of 2023. This document, along with the Snowmass reports from the various subfields, will provide input to the 2023 Particle Physics Project Prioritization Panel (P5) subpanel of the U.S. High-Energy Physics Advisory Panel (HEPAP), and will help to guide and inform the activity of the U.S. particle physics community during the next decade and beyond.

[1]deceased, Jan. 1, 2023.

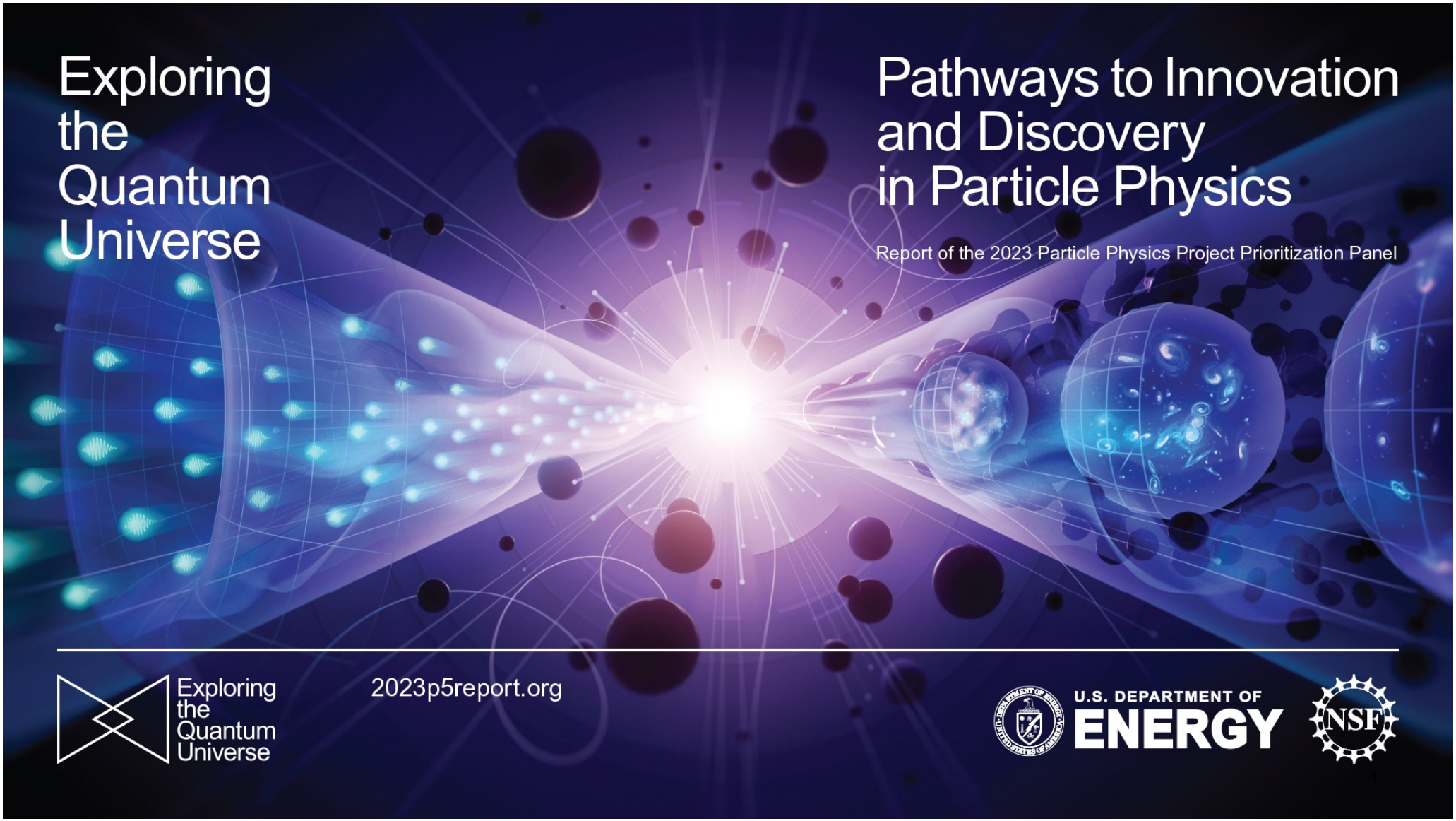
Focuses on the physics potential of a Muon Collider as a pathway to Energy Frontier physics

US Muon Collider Collaboration

2023 US P5 Report



Emphasizes the need to explore the 10 TeV pCM scale and the aspiration to host a US frontier machine – the *Muon Shot*


Exploring
the
Quantum
Universe
Pathways to Innovation
and Discovery
in Particle Physics
Report of the 2023 Particle Physics Project Prioritization Panel
Exploring
the
Quantum
Universe
2023p5report.org
U.S. DEPARTMENT OF
ENERGY
NSF

Exploring the Quantum Universe

2.3 The Path to a 10 TeV pCM

Realization of a future collider will require resources at a global scale and will be built through a world-wide collaborative effort where decisions will be taken collectively from the outset by the partners. This differs from current and past international projects in particle physics, where individual laboratories started projects that were later joined by other laboratories. The proposed program aligns with **the long-term ambition of hosting a major international collider facility in the US, leading the global effort** to understand the fundamental nature of the universe.

…

In particular, a muon collider presents an attractive option both for technological innovation and for bringing energy frontier colliders back to the US. The footprint of **a 10 TeV pCM muon collider is almost exactly the size of the Fermilab campus**. A muon collider would rely on a powerful multi-megawatt proton driver delivering very intense and short beam pulses to a target, resulting in the production of pions, which in turn decay into muons. This cloud of muons needs to be captured and cooled before the bulk of the muons have decayed. Once cooled into a beam, fast acceleration is required to further suppress decay losses.

…

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 Presentation to HEPAP Excerpt

Exploring the Quantum Universe

Recommendation 4

Not Rank-Ordered

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).
b. Enhance research in **theory** to propel innovation, maximize scientific impact of investments in experiments, and expand our understanding of the universe (section 6.1).
c. Expand the **General Accelerator R&D (GARD)** program within HEP, including stewardship (section 6.4).
d. Invest in R&D in **instrumentation** to develop innovative scientific tools (section 6.3).
e. Conduct **R&D** efforts to define and enable new projects in the next decade, including detectors for an e^+e^- Higgs factory and 10 TeV pCM collider, Spec-S5, DUNE FD4, Mu2e-II, Advanced Muon Facility, and line intensity mapping (sections 3.1, 3.2, 4.2, 5.1, 5.2, and 6.3).
f. Support key **cyberinfrastructure** components such as shared software tools and a sustained R&D effort in computing, to fully exploit emerging technologies for projects. Prioritize **computing and novel data analysis techniques** for maximizing science across the entire field (section 6.7).
g. Develop plans for improving the **Fermilab accelerator complex** that are consistent with the long-term vision of this report, including neutrinos, flavor, and a 10 TeV pCM collider (section 6.6).

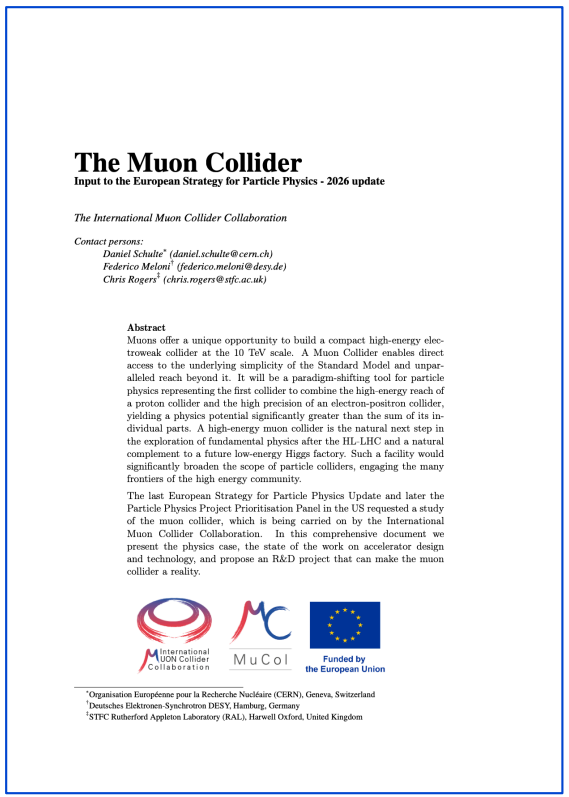
We recommend specific budget levels for enhanced support of these efforts and their justifications as **Area Recommendations** in section 6.

P5 Presentation to HEPAP Excerpt

2025 EPP Strategy Update

IMCC

US Muon Collider Collaboration



The Muon Collider
Input to the European Strategy for Particle Physics - 2026 update

The International Muon Collider Collaboration

Contact persons:
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Abstract
Muons offer a unique opportunity to build a compact high-energy electroweak collider at the 10 TeV scale. A Muon Collider enables direct access to the underlying simplicity of the Standard Model and unparalleled reach beyond it. It will be a paradigm-shifting tool for particle physics representing the first collider to combine the high-energy reach of a proton collider and the high precision of an electron-positron collider, yielding a physics potential significantly greater than the sum of its individual parts. A high-energy muon collider is the natural next step in the exploration of fundamental physics after the HL-LHC and a natural complement to a future low-energy Higgs factory. Such a facility would significantly broaden the scope of particle colliders, engaging the many frontiers of the high energy community.

The last European Strategy for Particle Physics Update and later the Particle Physics Project Prioritisation Panel in the US requested a study of the muon collider, which is being carried on by the International Muon Collider Collaboration. In this comprehensive document we present the physics case, the state of the work on accelerator design and technology, and propose an R&D project that can make the muon collider a reality.

Funded by the European Union

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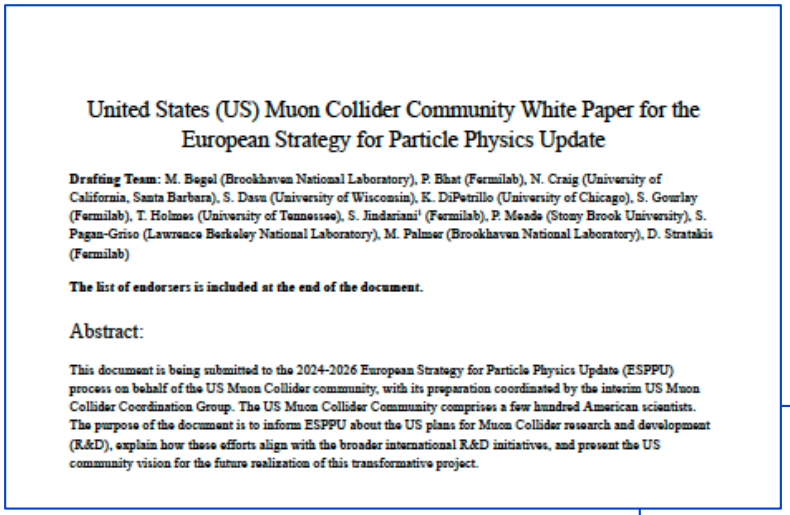
[†]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany
[‡]STFC Rutherford Appleton Laboratory (RAL), Harwell Oxford, United Kingdom



United States (US) Muon Collider Community White Paper for the European Strategy for Particle Physics Update

Drafting Team: M. Begel (Brookhaven National Laboratory), P. Bhat (Fermilab), N. Craig (University of California, Santa Barbara), S. Dasu (University of Wisconsin), K. DiPetrillo (University of Chicago), S. Gourlay (Fermilab), T. Holmes (University of Tennessee), S. Jindariani[1] (Fermilab), P. Meade (Stony Brook University), S. Pagan-Griso (Lawrence Berkeley National Laboratory), M. Palmer (Brookhaven National Laboratory), D. Stratakis (Fermilab)

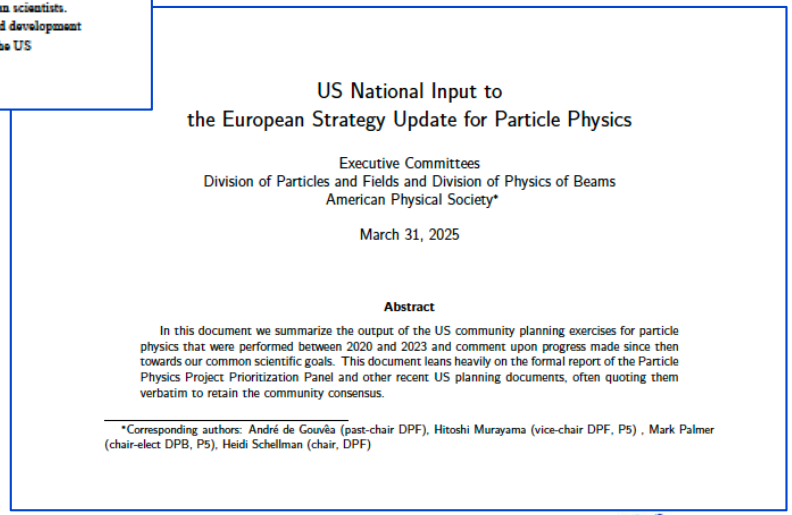
The list of endorsers is included at the end of the document.

Abstract:

This document is being submitted to the 2024-2026 European Strategy for Particle Physics Update (ESPPU) process on behalf of the US Muon Collider community, with its preparation coordinated by the interim US Muon Collider Coordination Group. The US Muon Collider Community comprises a few hundred American scientists. The purpose of the document is to inform ESPPU about the US plans for Muon Collider research and development (R&D), explain how these efforts align with the broader international R&D initiatives, and present the US community vision for the future realization of this transformative project.

US Muon Collider Community

US National Input Emphasizing the P5 Recommendations



US National Input to
the European Strategy Update for Particle Physics

Executive Committees
Division of Particles and Fields and Division of Physics of Beams
American Physical Society*

March 31, 2025

Abstract

In this document we summarize the output of the US community planning exercises for particle physics that were performed between 2020 and 2023 and comment upon progress made since then towards our common scientific goals. This document leans heavily on the formal report of the Particle Physics Project Prioritization Panel and other recent US planning documents, often quoting them verbatim to retain the community consensus.

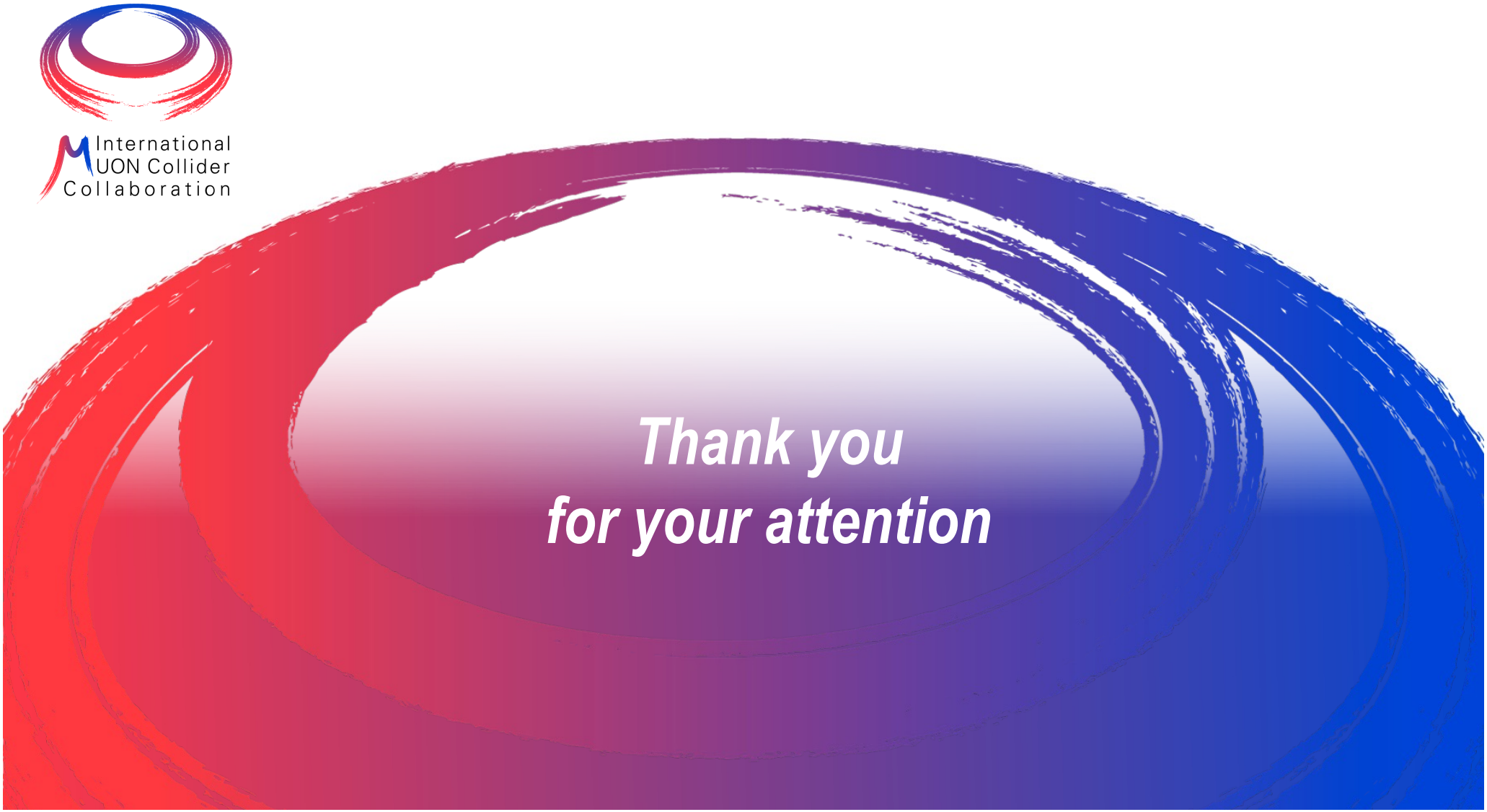
*Corresponding authors: André de Gouvêa (past-chair DPF), Hitoshi Murayama (vice-chair DPF, P5) , Mark Palmer (chair-elect DPB, P5), Heidi Schellman (chair, DPF)

What Are the Key Synergies Between These Inputs?

- Realizing a Muon Collider requires a ***global*** effort
  - Tremendous progress has been achieved since the inception of the IMCC
  - US efforts are actively forming after the 2021-22 Snowmass and the 2023 P5 Report
    - Budget constraints remain a challenge
- It is crucial to move effectively towards a full end-to-end design
  - Critical input for the next round of community decisions!
  - US "bridge" efforts can accelerate progress by the IMCC on the current design
  - The world-wide particle physics community needs a solid framework to be able to evaluate this option
- Continuing to develop the R&D roadmap and Demonstrator plans sets the stage for follow-on decisions
  - For example: intermediate US panel later this decade

Next Steps

- In the US, the USMCC (https://www.muoncollider.us) has just approved its charter
  - Will help drive US engagement with the global effort via the IMCC
  - Will provide the support to explore potential US siting options – Demonstrator and/or MC
  - Will work to maintain US agency focus on the P5 recommendations
- APS DPF/DPB has provide an overarching national input to the EPPSU
  - Hitoshi Murayama will present at the Community meeting
  - Also expect strong participation from the US Muon Collider community
- Looking forward:
  - Will need international engagement to help drive progress towards the next decision steps in the US later in the decade


International
MUON Collider
Collaboration
Thank you
for your attention