Fermilab **BENERGY** Office of Science



EF Vision Building Lessons from Snowmass Future Colliders Agora

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Snowmass Energy Frontier Workshop, Brown University March 28 – April 1, 2022

Introduction

- The Snowmass Agora events organized by Accelerator and Energy Frontiers and hosted by the Fermilab Future Colliders Initiative.
 - M. Narain, L. Reina, A. Tricoli, S. Gourlay, T. Raubenheimer, V. Shiltsev, P. Bhat, J. Butler
- Four Agora events held so far; the final one will be on April 13
 - Linear e+e- colliders Dec. 15, 2021
 - Moderators: Dmitri Denisov, Sergey Belomestnykh
 - Speakers: Tao Han, Hasan Padmasee, Steinar Stapnes, Emilio Nanni
 - Circular e+e- colliders Jan. 19, 2022
 - Moderators: John Seeman, Sarah Eno
 - Speakers: A. Blondel, F. Zimmermann, J. Gao, E. Gianfelice (T. Sen), V. Litvinenko
 - Muon colliders

Feb. 16, 2022

- Moderators: Sergo Jindariani, Jim Strait
- Speakers: N. Craig, D. Schulte, D. Stratakis, D. Lucchesi
- Circular pp and ep Mar. 16, 2022
 - Moderators: Oliver Bruning, Nausheen Shah
 - Speakers: M. Selvaggi, F. Zimmermann, B. Holzer, J. Tang, P. Bhat (T. Sen)
- Advanced colliders
 Apr. 13, 2022
 - Moderators: Andrei Seryi, Patrick Meade; Speakers: TBD
- Slides, videos, google doc with Q&A, summary from moderators available on the indico pages. <u>https://indico.fnal.gov/e/snowmass-agora/</u>

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Agora Program

- Program: A physics motivation talk + several machine talks in each agora, moderated Q&A + informal post-agora chat.
- Each Agora was two hours long + ~30 min. of post-agora chat.
- Aspects covered:
 - physics reach
 - challenges and R&D required
 - synergy of project with global context (comparative dis/advantages)
 - synergy of project with local resources
 - time frame (short-term R&D, long-term construction)
 - Costs projections: both R&D and construction costs



Broad Lessons

- The audience had the opportunity to ask experts a lot of indepth questions and get detailed answers.
- Comparative physics potential of various machines; which physics questions are important to answer, why and how, etc.
- Intense focus on proposed machines in various categories!
 - Technical readiness or maturity status, what specifications have been achieved, remaining challenges, timelines, cost, …
- e.g., e+e- colliders:
 - positron source, beam polarization, beam size (nano beams), beambased alignment, high bunch current, vacuum issues, beam collimation, machine protection, beam dumps, targetry, ..
 - Prototype/operating facilities e.g., XFEL (SRF), SwissFEL (NCRF), SuperKEKB (for circular-ee), test facilities (ATF2, CTF), demo facilities
 - A lot of work (for ILC, CLIC) has been done! A lot has been achieved!

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Session Agenda (Today)

- Opening PB
- Introductory remarks
- Theory Perspective
- Linear e+e- colliders
- Circular e+e- colliders
- Muon Colliders

Joel Butler

Patrick Meade

Sergey Belomestnykh

John Seeman

Mark Palmer

- ITF Evaluation of projects Thomas Roser
- EF Vision Building Discussion PB, JB, everyone



EF Vision Building Strategy for Future Colliders

What do we want from this Snowmass, P5? What are the most optimal paths forward?



Higgs Factory Options

- ILC: "shovel ready", but no takers so far
 - Can be operational by ~2035
 - The goal post keeps getting moved for ILC in Japan
- CLIC: on the backburner
- FCC-ee: front-runner at CERN; feasibility studies underway
 - If yes, then operations by ~2050
- CepC: Projected for ~2035; Funding uncertain/unknown
- C3: new, promising, need viability demo
 - Possible by ~2040
- High Gradient SRF machines: need aggressive R&D
 - Maybe possible in 2040s
- Muon Collider HF: More challenging than higher energies; 2040s – 50s
- FNAL-SF-ee: Very preliminary studies; many constraints Fermilab

Colliders for the 10-TeV scale

- FCC-hh: Prime candidate; very distant, beyond 2070
- SppC: to follow CepC, distant
- HE-LHC: on the backburner
- FNAL-SF-pp: need aggressive magnet R&D (>25T)
- ? VLHC: 40 TeV with 2T transmission magnets
- Muon Collider (8-10 TeV and beyond)
 - Unique, challenging, need aggressive R&D and more demo
 - A great tool for both precision and energy-scale
 - Could be feasible in 2040s-50s with intense efforts



LC Siting Options





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Fermilab FESS studying proposed siting

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ILC Site options in the US



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8-10 TeV Muon Collider at Fermilab





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A Roadmap for the Decade



Strategizing contd..

- Better to build a linear collider for the Higgs program so it is decoupled from the pp (no sequencing ee-hh)
- We can later decide to choose either pp or muon collider for the study of the multi-TeV scale.
- pp can be FCC or VLHC.
- Muon Collider can be planned to be in stages from sub-TeV to multi-tens of TeV.
- And, then there will be advanced colliders!

"How are we prisoners of conventional thinking, and how can we break out?"
- Chris Quigg, "Dream Machines" arXiv:1808.06036v2

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The US Energy Frontier community needs support

- to continue strong participation/leadership in the LHC/HL-LHC program
- And strong support for a new and bold "integrated national future Colliders R&D program"
- to engage with global projects: ILC, FCC, IMCC
- to develop options for colliders in the US: design studies, component R&D, demonstration facilities, preparation of concrete proposals with CDR/TDR on the timescale of next Snowmass/P5

Extra Slides



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Engagement in Global Projects

The International Linear Collider

- Fermilab scientists engaged in efforts of the ILC-IDT (ILC International Development Team)
 - SRF R&D for ILC main linacs and ILC++
 - Polarized Positron Source and Damping Ring
 - Physics, detectors are of great interest

Future Circular Colliders (FCC-ee/hh)

- CERN conducting Technical and financial feasibility studies; results and CDR++ by ~2026
- CERN/DOE agreement signed in Dec. 2020
 - Opportunities for engineering design studies, beam physics studies, High Q₀ SRF R&D, magnet R&D,...
 - Physics studies for Snowmass; EF work on detector, FastML technologies relevant

Muon Collider Collaboration

- Intense work in progress in the International Muon collider Collaboration, Snowmass Muon Collider Forum
 - Machine scenarios, beam induced background, neutrino radiation, demonstrator facility, detector/physics studies







Future Circular Colliders @CERN

- As per the 2020 European Strategy update, the FCC Study is now focused on investigating the technical and financial feasibility of a ~100 TeV pp collider at CERN in a 100 km ring, with an e+e- Higgs and electroweak factory as a first stage
 - FCC(ee) followed by FCC(hh)
- Highest priority studies:
- □ tunnel: high-risk zones, surface areas, administrative processes, environment
- □ machines: R&D (e.g. superconducting RF for FCC-ee; magnets for FCC-hh); design
 - \rightarrow Goal is CDR++ with results of feasibility studies by ~ 2026.

Fig. 1: Technical schedule of the FCC integrated project.

~ 70 years timeframe

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P5 (2013) Recommendations

 Recommendation 1: Pursue the most important opportunities wherever they are, and host unique, world-class facilities that engage the global scientific community.

ILC:

 Recommendation 11: Motivated by the strong scientific importance of the ILC and the recent initiative in Japan to host it, the U.S. should engage in modest and appropriate levels of ILC accelerator and detector design in areas where the U.S. can contribute critical expertise. Consider higher levels of collaboration if ILC proceeds.

FCC:

 Recommendation 24: Participate in global conceptual design studies and critical path R&D for future very high-energy proton-proton colliders. Continue to play a leadership role in superconducting magnet technology focused on the dual goals of increasing performance and decreasing costs.