Fermilab U.S. DEPARTMENT OF ENERGY | Office of Science

Status of Snowmass EF LoIs

and

Introduction to the

PPD Future Colliders Group

Pushpa Bhat, Anadi Canepa, Patrick Fox, Sergo Jindariani, Sergei Nagaitsev

SAC Energy Frontier Group Conveners

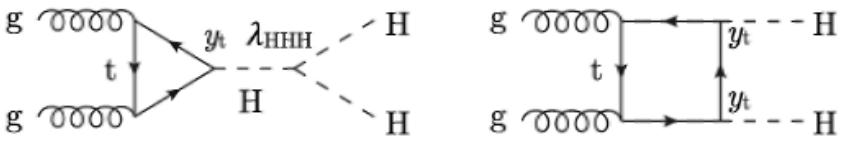
FERMILAB ENERGY FRONTIER LOI FOR SNOWMASS

- A significant body of work was produced in preparation for the European Strategy Planning Update
  - Summary of presentations at https://indico.cern.ch/event/808335/timetable/?view=standard
- The objective of the the Fermilab scientists is to carry out selected study of sensitivity with updated machine parameters and/or in a parametric fashion for the FCC-hh and ILC, to initiate a systematic evaluation of the muon collider physics case, and to explore future collider options
  - All activities are carried out within the Snowmass Working Groups and within the Muon Collider Forum created by the Snowmass Energy Frontier Working Group itself (and hosted by the LHC Physics Center at the lab)
- Fermilab scientists submitted 10 LOIs
  1. Vector Boson Scattering
  2. Higgs Self-couplings
  3. Probing extended scalar sectors in multi-Higgs channels
  4. Supersymmetry Searches
  5. Dark Matter Searches
  6. Dijet Resonances at pp Colliders
  7. Muon Collider: Solidifying the physics case
  8. Muon Collider: A Window to New Physics
  9. Muon Collider: Higgs and Electroweak Physics
  10. Future Collider options for the US

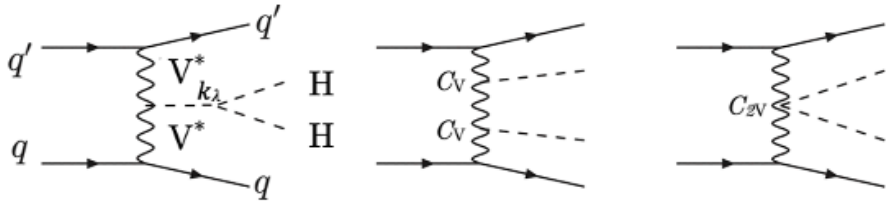
THE HIGGS BOSON AS A TOOL FOR DISCOVERY

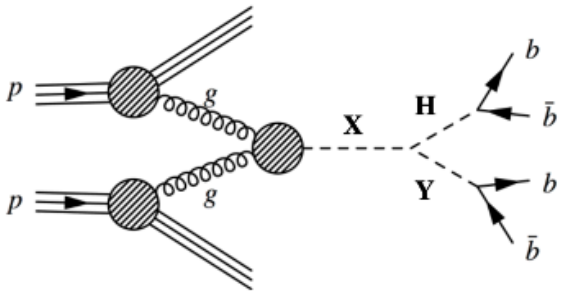
- **Higgs Self Couplings: Measurements at Future proton-proton Colliders**
  - *P. C. Bhat, A. Canepa, M. Carena, C. Gao , P. Merkel, F. Ravera*
  - The measurement of the Higgs trilinear and quartic self-couplings provide invaluable information on the electroweak symmetry breaking and the electroweak phase transition.
  - Plan to explore the HH vector boson fusion production process via the hhVV quartic coupling at various pp colliders using Deep Neural Networks to maximize sensitivity
- **Probing extended scalar sectors in multi-Higgs channels: Prospects at Future proton-proton Colliders**
  - *P. C. Bhat, A. Canepa, M. Carena, C. Gao , P. Merkel, F. Ravera (EF2_EF0-198)*
  - Many BSM theories (e.g. NMSSM) predict the existence of extended Higgs sector
  - Sensitivity of future pp colliders under study

High cross section ggHH production



High sensitivity VBF HH production

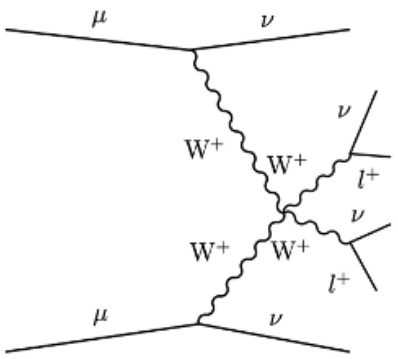


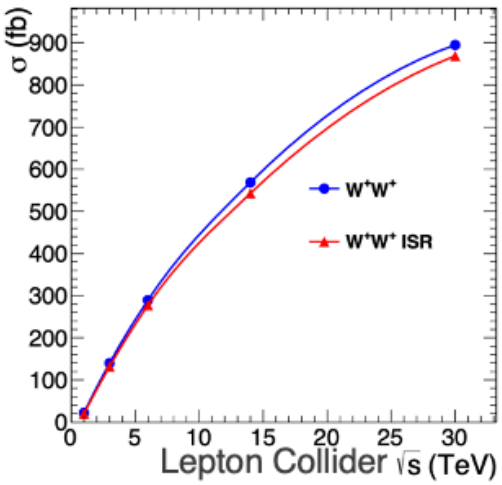


Current activity: Generation of samples

SEARCHES IN EWK SECTOR

- **The Prospects of Vector boson scattering at future colliders**
  - *A. Apyan, J. Berryhill (EF4_EF0)*
  - VBS processes provide key insights into the quartic gauge couplings as well as the Higgs sector.
  - Plan a comparative study of sensitivity at future high-energy hadron colliders as well as circular multi-TeV $\mu^+\mu^-$ and linear e^+e^- machines





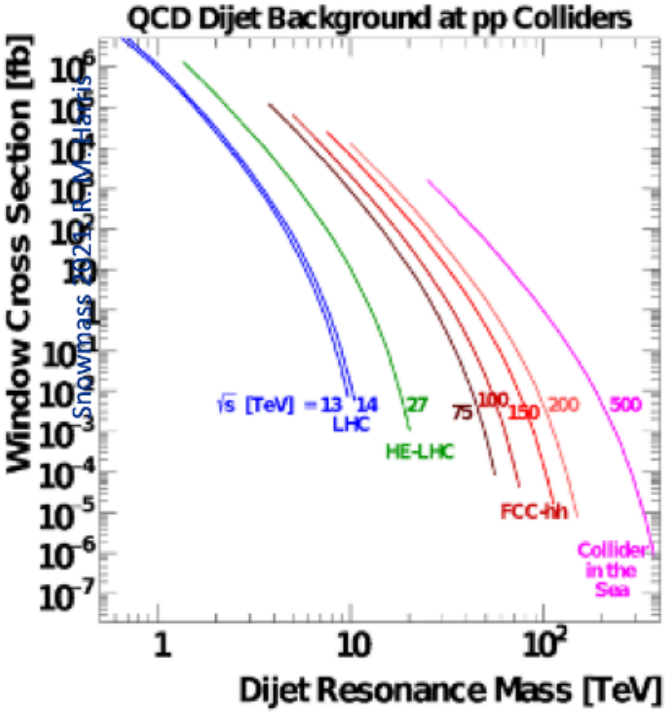
Current activity: Development of MuC simulation

- **Using pMSSM scans to elucidate SUSY sensitivity and complementarity of future colliders**
  - *J. Dickinson, Jim Hirschauer*
  - Use the 19-parameter phenomenological minimal supersymmetric standard model to quantify individual sensitivity to SUSY from a variety of current and future experiments
    - Markov chain Monte Carlo (McMC) "grand scan" populating all relevant regions of parameter space
    - Likelihood including measurements from external packages to steer scan towards un-excluded regions.

Central McMC code development nearly completed

DIRECT SEARCHES FOR BSM

- **Sensitivity to Dijet Resonances at Proton-Proton Colliders**
  - *R. Harris (EF9_EF8)*
  - Sensitivity to a dijet resonance X is a classic benchmark for discovery at a proton-proton collider
    - X(jj) predicted by a variety of BSM models (including excited quarks, axigluons/colorons, scalar diquarks, Z', W', gravitons)
  - Assessing sensitivity for 27 (HE-LHC), 75, 100 and 150 TeV (FCC-hh) and 500 TeV (Collider in the sea!)



Background calculations complete

Good progress on signals (6 models calculated: q*, Z', W', Graviton, Coloron, Diquark)

Signal shape simulations begun

PHYSICS STUDIES AT MUON COLLIDER

- 3 LoIs:
  - *Performance Studies, Higgs/SM Physics, and BSM*
  - *A. Apresyan, D. Berry, A. Canepa, M. Cremonesi, K. Di Petrillo, Z. Gecse, A. Hall, C. Herwig, J. Hirschauer, B. Jayatilaka, S. Jindariani, R. Lipton. N. Mokhov, K. Pedro, H.Weber*
- Significant progress with the framework:
  - Tracking performance shown to be excellent
  - Fermilab scientists have done assisting studies, such as measuring the occupancies in the tracker from backgrounds to inform the decision on the size and time resolution of the active readout devices (pixels).
- So far, the focus has been on tracking, (b-) jets and muons. Recently started looking into the reconstruction of electrons.
- Discussed strategy for MDI studies at high energies
- First meeting of the Cross-Frontier Muon Collider Forum (S. Jindariani and D.Stratakis are co-leaders)
- The informal LPC working group that had formed last summer decided to slow down activities (but not halt). Hold regular meetings on a monthly instead of biweekly schedule.

PPD Future Colliders Group

Outline

- Introduction
- Future Colliders Group composition
- Planning and activities
- Brief Status of major global projects
- Summary

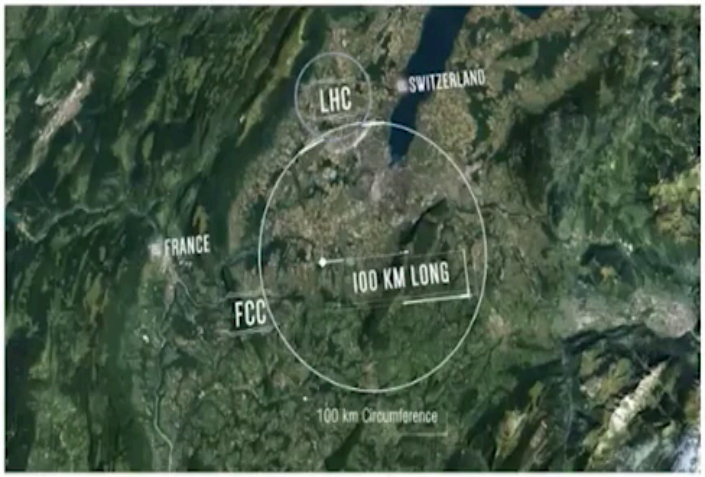
Introduction

- Physics at the Energy Frontier is of paramount importance! Fermilab's leadership role at the Energy Frontier must continue!
- The **Future Colliders** group was proposed to facilitate engagement in future collider projects abroad as well as the full exploitation of the Fermilab accelerator complex.
- The questions we would like to answer :
  - What kind of future is the Lab aspiring to create for itself in particle physics and accelerator physics in order to maintain its leadership in these areas?
  - Which international projects would Fermilab engage in to advance the energy frontier program and how will that engagement evolve and be managed?
  - What kind of large-scale project(s) can the Lab envision undertaking that makes it unique?
  - What steps must be taken from now through the next twenty years so that the Lab is well placed to realize that vision?

PPD Future Colliders Group

From
Director's All Hands
Meeting 03/24/2021

- Mission
  - Develop Fermilab's **engagement plans in future collider projects**, such as ILC and FCC, and in int'l collaboration on muon collider, across aspects of accelerators, technology, particle physics and detectors
    - ILC pre-Lab (Japan) could launch next year
    - DOE-CERN agreement on collaboration on FCC
    - CERN launched study on Muon collider
  - Provide **forum to synergize** efforts on future colliders/accelerators of interest to Fermilab
  - **Develop roadmap** for further (design) studies; R&D for future colliders
- Work with US universities and other national labs
- Near-term focus: robust proposals as input to Snowmass
- Members: Pushpa Bhat (Lead), Sergo Jindariani (Deputy), liaisons from divisions



Photos related to the FCC study, reflecting the different aspects of the project and the ongoing R&D activities to advance new technologies that can guarantee a reliable and sustainable operation. (Image credit: CERN)

PPD Future Colliders Group

Composition:

- Pushpa Bhat (PPD, Lead) *
- Sergo Jindariani (PPD, Deputy) *
- Alan Bross (ND)
- Anadi Canepa (PPD) *
- Daniel Elvira (SCD)
- Giorgio Apollinari (APSTD)
- Mike Syphers (AD/NIU)
- Patrick J. Fox (Theory) *
- Petra Merkel (PPD, detectors)
- Sergei Nagaitsev (AD/DO) *
- Sergey Belomestnykh (APSTD)
- Sam Posen (APSTD)
- Tanaji Sen (AD)
- Vladimir Shiltsev (AD)
- Zoltan Gecse (PPD, IPPM)

* SAC Energy Frontier Conveners

- Some discussions on division liaisons still ongoing.

Activities planned

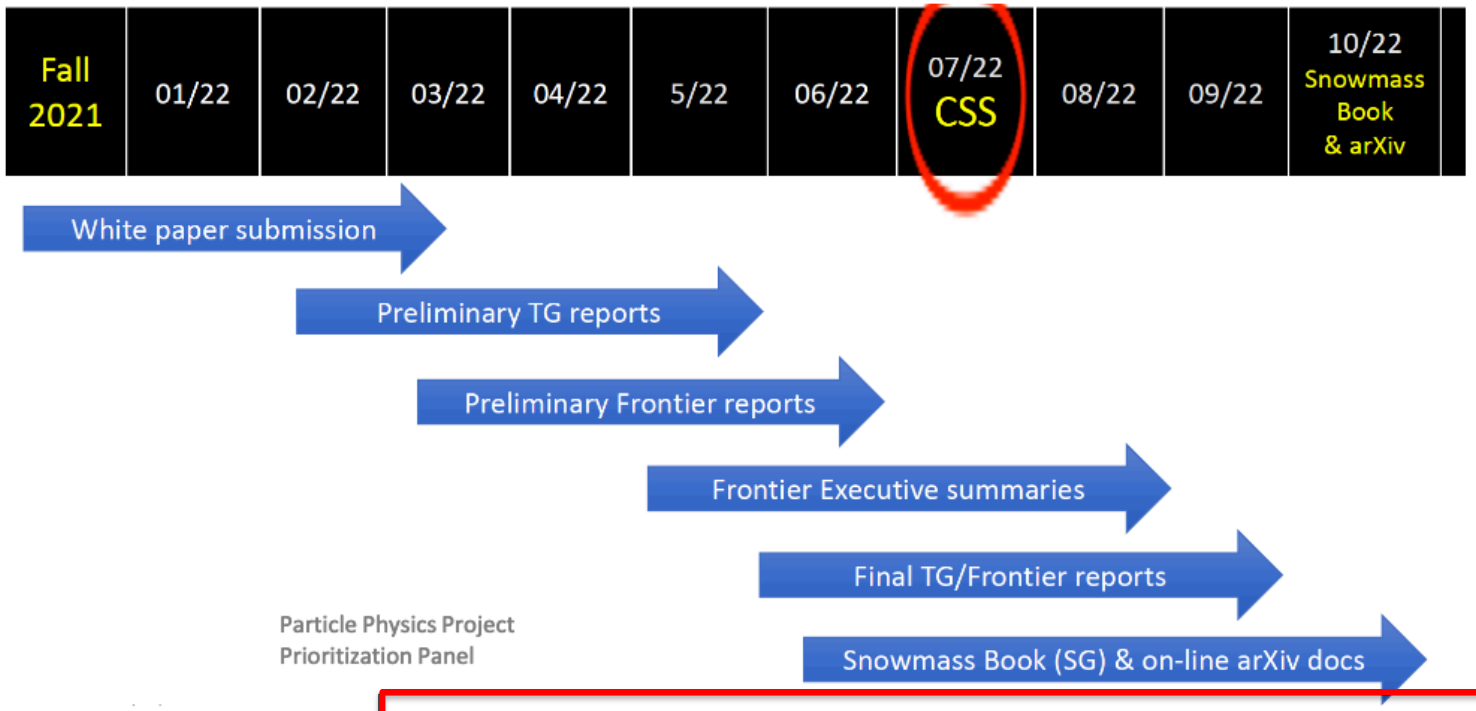
- Launch task forces and create forums for discussion among experts and enthusiasts in key areas such as engagements in ILC, FCC, muon collider study, ...
- The core group meets frequently to discuss and will have open forums with brief reports periodically.
- Mailing lists will be created for key areas that you can self-subscribe
- A website will be created to provide information on activities planned and events.
- Group members will give/arrange seminars to keep Lab scientists informed of progress
- Communicate through Fermi News articles
- Planning to organize a workshop this fall.
- Your input and participation is encouraged!

Strategic Planning – U.S. Particle Physics

Formulating the Long Range Plan for ~ 2025 – 2035.

Snowmass Community Planning Process timeline

COVID caused a pause in Snowmass process,
with delay of 1 year for the Community Summer Study (CSS)



P5 will convene after Snowmass and report in early 2024.

In-person meetings!?

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:

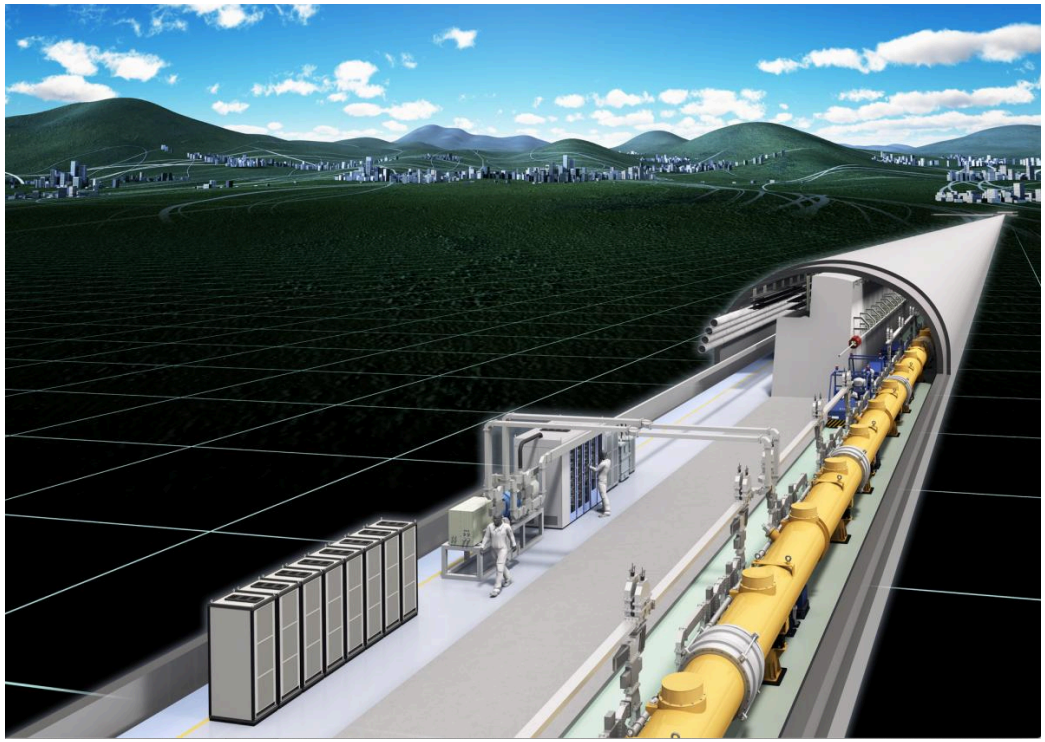
- Recommendation 11: Motivated by the strong scientific importance of the ILC and the recent initiative in Japan to host it, the U.S. should engage in modest and appropriate levels of ILC accelerator and detector design in areas where the U.S. can contribute critical expertise. Consider higher levels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

Status of Major projects

The International Linear Collider

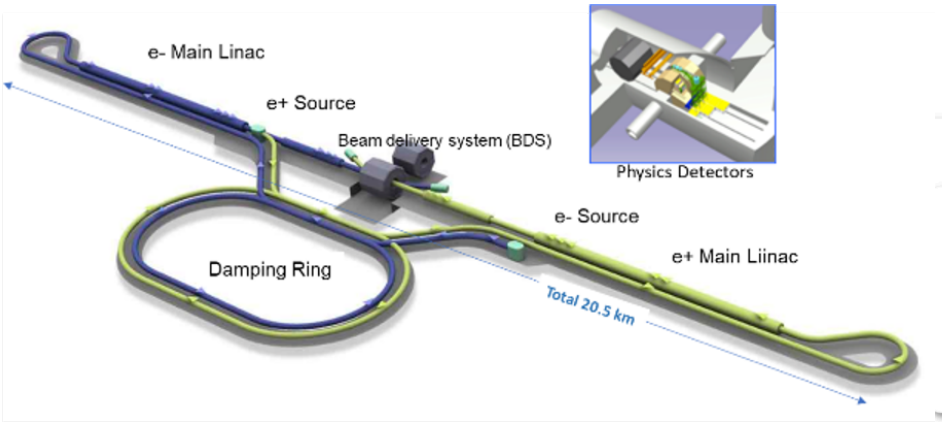


The International Linear Collider (ILC)

- The International Linear Collider maybe the next (post-LHC) collider to be realized, if decision to host is made by the Japanese Government.
  - Construction could start within this decade.
- "It is the one proposal (of a future collider) that is on the table now."
  -- Michael Peskin at LCWS2021.
- Strong support from the US community and a strong endorsement from P5 could help funding for US participation in the ILC.
- **Japan's Ministry for Science & Technology (MEXT) is aggressively advocating for the ILC. ICFA is encouraging international negotiations.**
- The United States will have a pivotal role to play in the preparation and construction of the ILC.
- **ICFA has recently created the ILC International Development Team to help launch the ILC pre-Lab once the decision to go ahead is made.**
- **The ILC pre-Lab will be set up as an international collaboration of national, intergovernmental and university laboratories governed through Memorandum of Understanding (MoUs).**

The International Linear Collider

The International Linear Collider in Japan (**ILC250**), if approved, could start construction in this decade and start operations by 2035.



International Development Team (IDT)

ICFA

ILC International Development Team

Executive Board

Americas Liaison	Andrew Lankford (UC Irvine)
Working Group 2 Chair	Shinichiro Michizono (KEK)
Working Group 3 Chair	Hitoshi Murayama (UC Berkeley/U. Tokyo)
Executive Board Chair and Working Group 1 Chair	Tatsuya Nakada (EPFL)
KEK Liaison	Yasuhiro Okada (KEK)
Europe Liaison	Steinar Stapnes (CERN)
Asia-Pacific Liaison	Geoffrey Taylor (U. Melbourne)

Working Group 1 Pre-Lab Setup | **Working Group 2** Accelerator | **Working Group 3** Physics & Detectors

Timeline

ICFA launched the ILC-IDT in Feb. 2020

America in the International Development Team

IDT Executive Board

Andy Lankford (UCI) – Americas rep
Hitoshi Murayama (UCB/Tokyo) – WG3 chair

IDT WG1 – Pre-lab organization (includes EB)

Bruce Dunham (SLAC)
Reiner Krueken (TRIUMF)
Stuart Henderson (TJNAF)
Joe Lykken (FNAL) *

IDT WG2 – Accelerator

SRF

Sergey Belomestnykh (FNAL) *
Rongli Geng (ORNL)
Bob Laxdal (TRIUMF)
Matthias Liepe (Cornell)
Sam Posen (FNAL) *
Bob Rimmer (TJNAF)
Marc Ross (SLAC)

DR/BDS/Dump

Tom Markiewicz (SLAC)
Brett Parker (BNL)
David Rubin (Cornell)
Nikolai Solyak (FNAL) *
Glen White (SLAC)

Sources

Joe Grames (TJNAF)

IDT WG3 – Physics & Detector

Hitoshi Murayama (UCB/Tokyo) – WG3 chair

Steering Group

Jim Brau (Oregon)
Dmitri Denisov (BNL)
Patty McBride (FNAL) *
Tim Nelson (SLAC)
Andy White (UT Arlington)

Speakers Bureau

Alain Bellerive (Carleton)

Detector & Technology R&D conveners

Petra Merkel (FNAL) *
David Miller (Chicago)

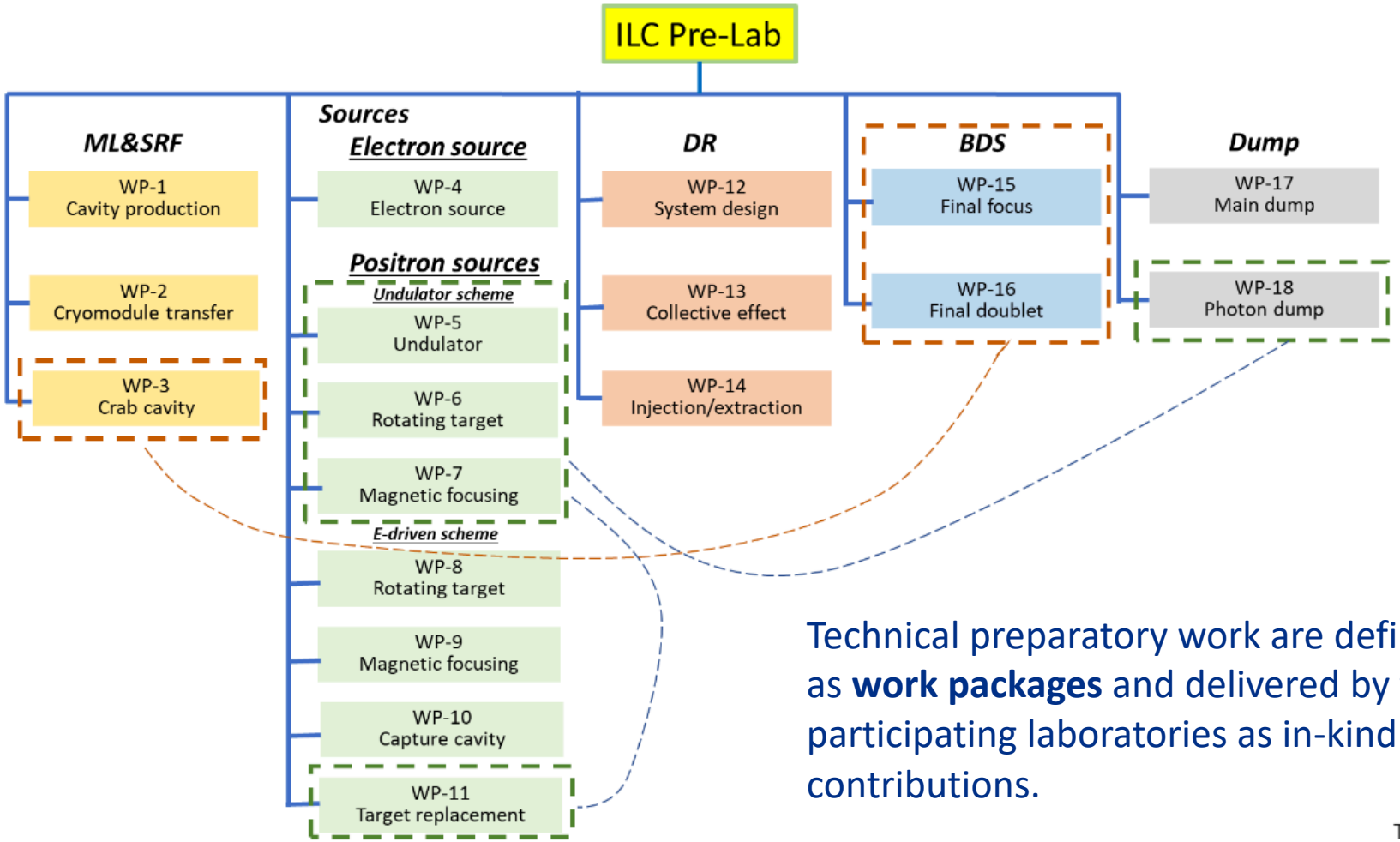
Software & Computing conveners

Jan Strube (Oregon)

Physics Potential & Opportunities conveners

Michael Peskin (SLAC)

Pre-lab machine work packages



Technical preparatory work are defined as **work packages** and delivered by the participating laboratories as in-kind contributions.

T. Nakada,

See talks at LCWS2021 for more info on ILC status
https://indico.cern.ch/event/995633/

SRF Work Packages for the ILC Main Linac

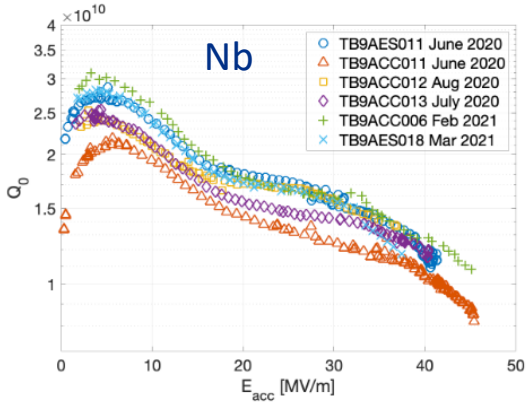
Sergey Belomestnykh

- ILC 250 will have 10 km SRF main linacs (MLs) with 900 cryomodules with 8 cavities in each; 9-cell cavities operating at 31.5 MV/m; SRF crab cavities for Beam Delivery system
- During the ILC pre-Lab, three work packages in SRF R&D are planned.
- **WP-1**: Cavity Industrial-Production Readiness (Prepare for mass production)
  - US-Japan collaborative work to improve cavity performance and for cost-reduction ongoing since 2017
  - 120 cavities to be produced (40 x 3 regions) using cost-effective methods while maintaining performance higher than baseline
- **WP-2**: Cryomodule (CM) Global Transfer and Performance Assurance
  - Demonstrate cryomodule transport from abroad to Japan by sea with no performance degradation after transport
  - CM must satisfy high-pressure-gas safety regulations
  - The CM design to be re-evaluated and the design fixed before production
- **WP-3**: Crab Cavity (CC) for BDS
  - Produce and test a prototype two-cavity cryomodule (pCM)

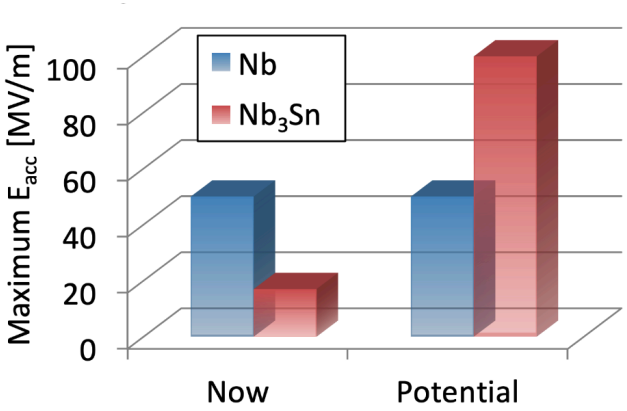
SRF R&D for ILC++

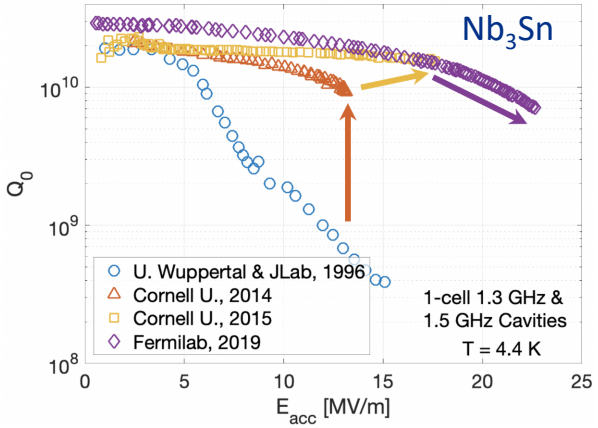
Sam Posen

- Significant progress in SRF technology since ILC-TDR with new innovative cavity treatments
  - The ILC TDR design spec 31.5 MV/m.
  - Aiming for 38 MV/m, Q>10^{10} ; stretch goal ~ 40 MV/m
  - Nb cavities have reached ~ 48-50 MV/m
- Higher gradients ➔ Cost reduction and upgrades



- Nb_3Sn cavities could potentially provide much higher gradients (>100 MV/m) in the future
- Possible use in ILC energy upgrades.





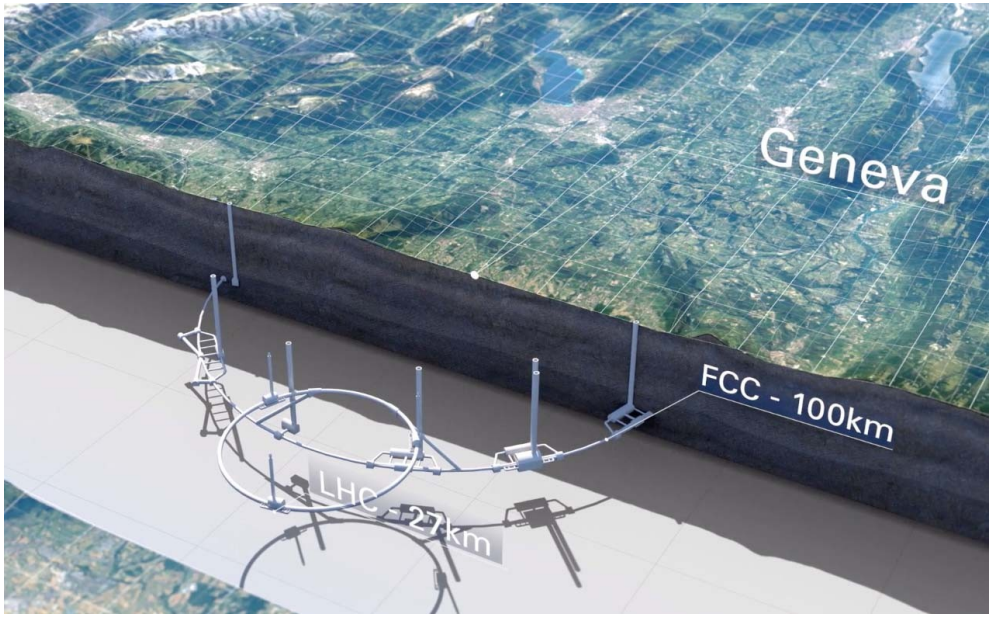
Physics and Detectors

- Fermilab EF scientists primarily engaged in physics and detectors at hadron colliders so far
- ILC physics is of great interest even at 250 GeV
  - A lot of interest in the US community
  - A small ILC physics group foreseeable for ILC physics
- Great potential for engagement with detector R&D
  - Precision tracking, High granularity calorimeters, timing detectors
  - Two detector systems – SiD, ILD
  - Experiment LoIs to be requested once pre-Lab is set up
  - A workshop on ILC experiments (ILCX) this fall in Tsukuba
  - Detector R&D in the context of ILC or EIC could be beneficial for other future collider experiments

Petra Merkel, Artur Apresyan

Status of Major projects

Future Circular Colliders



Future Circular Colliders @CERN

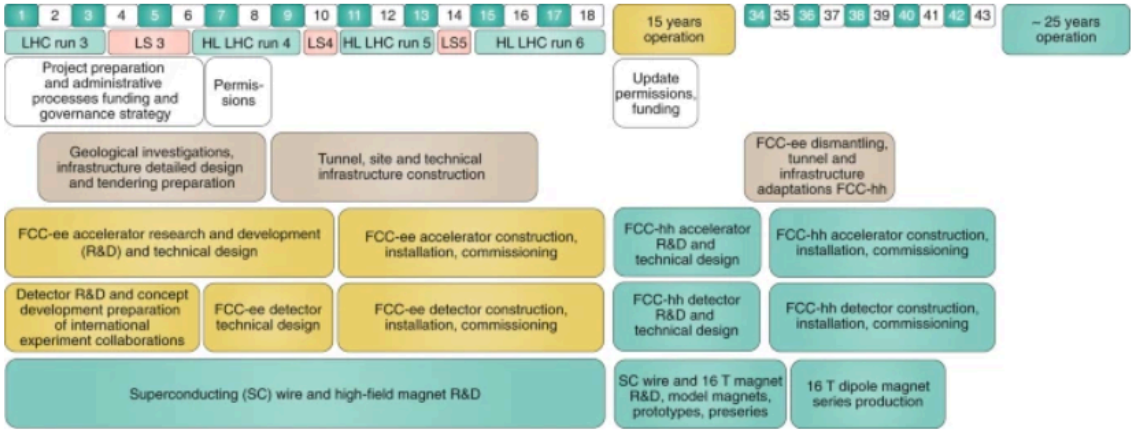
- As per the 2020 European Strategy update, the FCC Study is now focused on investigating the technical and financial feasibility of a ~100 TeV pp collider at CERN in a 100 km ring, with an e+e- Higgs and electroweak factory as a first stage
  - FCC(ee) followed by FCC(hh)
- Highest priority studies:

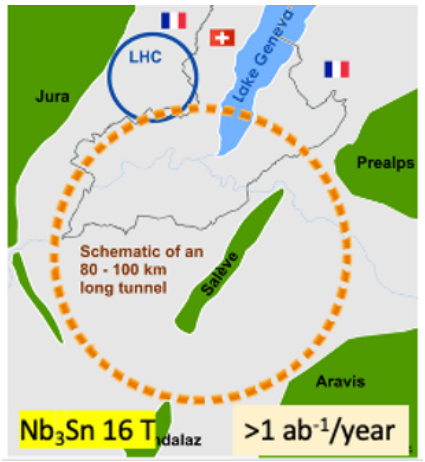
❑ tunnel: high-risk zones, surface areas, administrative processes, environment

❑ machines: R&D (e.g. superconducting RF for FCC-ee; magnets for FCC-hh); design

→ Goal is CDR++ with results of feasibility studies by ~ 2026.

Fig. 1: Technical schedule of the FCC integrated project. ~ 70 years timeframe



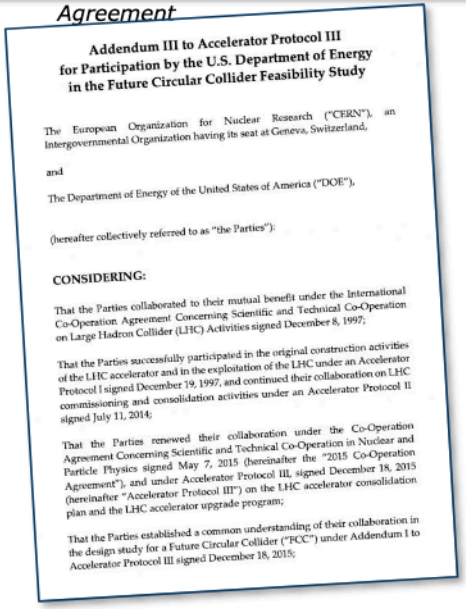


Future Circular Colliders (FCC)

DOE-CERN Future Circular Collider Cooperation

- **DOE coordinating with CERN to update the 2015 DOE-CERN FCC agreement to continue future R&D topics**
  - — Framework to advance the next stage of FCC feasibility studies as emphasized in the 2020 update of the European Strategy for Particle Physics
- **Cooperative activities include**
  - — Overall FCC concept optimization, including civil engineering and technical infrastructure designs
  - — Beam physics studies
  - — Accelerator R&D and key technology developments in view of either the FCC-ee and FCC-hh collider
  - — Longer-term activities towards the development of concepts of time- and cost-effective FCC tunneling techniques
- **Framework continues to allow DOE national labs to undertake topic-specific activities with CERN that are to be identified through subsequent MOUs**
  - — For additional guidance, interested DOE labs may contact Abid Patwa and L.K. Len at abid.patwa@science.doe.gov and lk.len@science.doe.gov
- **DOE and CERN aiming to sign the new FCC agreement by end of calendar year 2020**

2020: *Proposed DOE-CERN FCC Agreement*



Addendum III to Accelerator Protocol III for Participation by the U.S. Department of Energy in the Future Circular Collider Feasibility Study

The European Organization for Nuclear Research ("CERN"), an intergovernmental Organization having its seat at Geneva, Switzerland,

and

The Department of Energy of the United States of America ("DOE"),

(hereafter collectively referred to as "the Parties"):

CONSIDERING:

That the Parties collaborated to their mutual benefit under the International Co-Operation Agreement Concerning Scientific and Technical Co-Operation on Large Hadron Collider (LHC) Activities signed December 8, 1997;

That the Parties successfully participated in the original construction activities of the LHC accelerator and in the exploitation of the LHC under an Accelerator Protocol I signed December 19, 1997, and continued their collaboration on LHC commissioning and consolidation activities under an Accelerator Protocol II signed July 11, 2014;

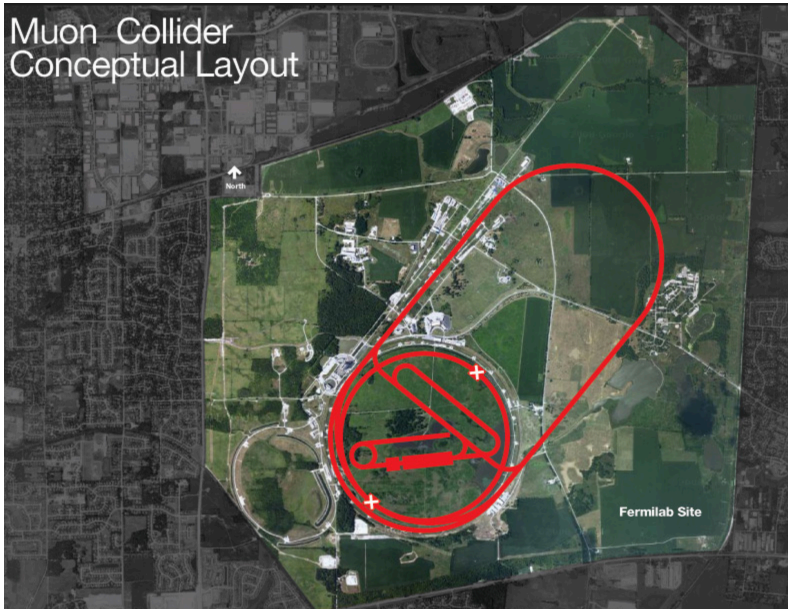
That the Parties renewed their collaboration under the Co-Operation Agreement Concerning Scientific and Technical Co-Operation in Nuclear and Particle Physics signed May 7, 2015 (hereinafter the "2015 Co-Operation Agreement"), and under Accelerator Protocol III, signed December 18, 2015 (hereinafter "Accelerator Protocol III") on the LHC accelerator consolidation plan and the LHC accelerator upgrade program;

That the Parties established a common understanding of their collaboration in the design study for a Future Circular Collider ("FCC") under Addendum I to Accelerator Protocol III signed December 18, 2015;

Jim Siegrist
at HEPAP mtg.
Dec. 2020

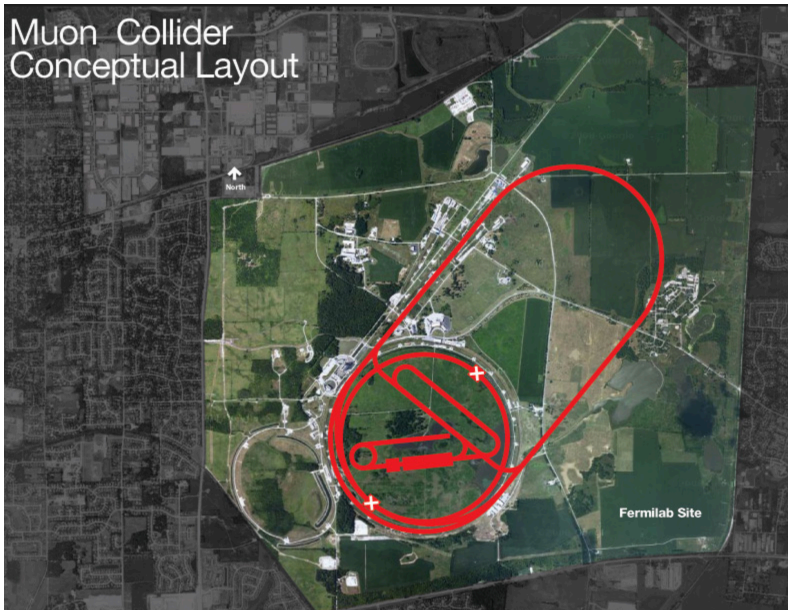
Status of Major Projects

Renewed Enthusiasm for Muon Colliders



Status of Major Projects

Renewed Enthusiasm for Muon Colliders



An explosion of interest!

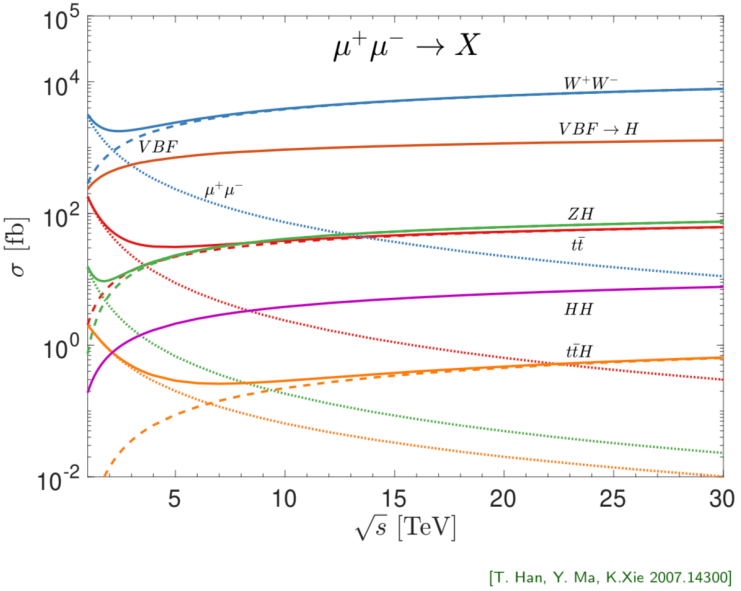
Touted as a precision and discovery machine

Technologically challenging and hence exciting

Unique opportunities for innovation

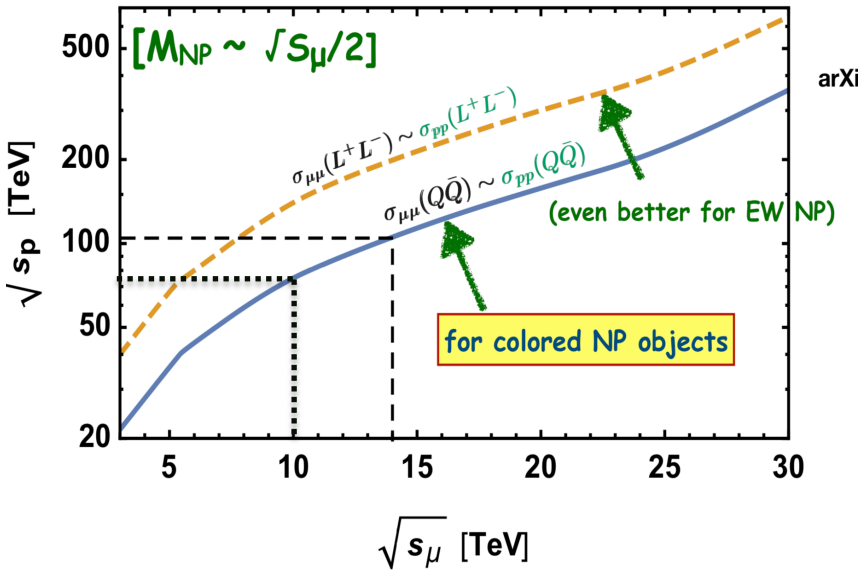
Physics at the Muon Collider

Precision and Discovery Machine



[T. Han, Y. Ma, K.Xie 2007.14300]

Equivalent reach in pp after rescaling for pdf's



arXiv:1901.06150

- A high energy Muon Collider (~10 TeV) can give excellent precision for Higgs couplings measurements and allow to probe trilinear Higgs coupling (also quartic coupling at higher energies)
- Direct New Physics Reach: for colored particles 10 TeV $\mu\mu$ ~ 70 TeV pp. For colorless particles 10 TeV $\mu\mu$ ~ 150 TeV pp

Also see recently released "**The Muon Smasher's Guide**" https://arxiv.org/abs/2103.14043

CERN/European Muon (Collider) Initiatives

- International Muon Collider Collaboration

Alan Bross

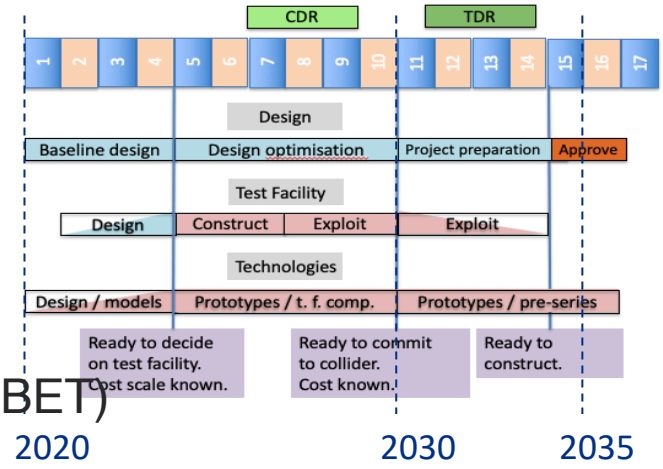
  - The 2020 European Strategy Update recommended integration of an international design study for a muon collider within the European Roadmap for accelerator R&D.

    (The ESPPU document actually says “bright muon beams”)
  - In response, the Laboratory Directors Group (comprising directors of major particle physics laboratories in Europe) has initiated an International Muon Collider Collaboration hosted at CERN to study the concept.

- NeUtrinos from STOred Muons (nuSTORM)
  - Part of Beyond Collider Physics study @ CERN
    - ~250 kW target station
    - Pion transport line
    - Stochastic muon capture into storage ring
    - Conventional FODO or high aperture FFA ring
- Enhanced NeUtrino BEams from kaon Tagging (ENUBET)
  - Part of Beyond Collider Physics study @ CERN
    - Design a narrow band neutrino beam at the GeV scale

    whose flux can be determined at the 1% level (Kaon tagging).
- Integration of nuSTORM and ENUBET with iMC
  - Neutrino science; cross section and BSM
  - Muon collider demonstrator and test bed

Fabiola, ICFA spring 2020



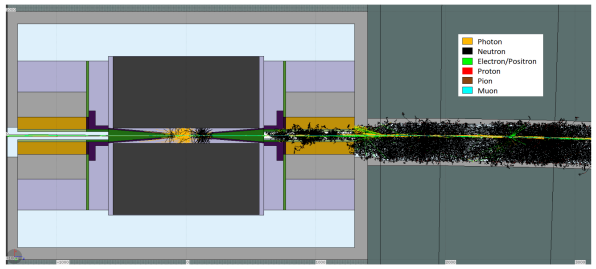
Establish whether the investment into a full CDR and a demonstrator is scientifically justified in time for the next European Strategy Update (~5 years)

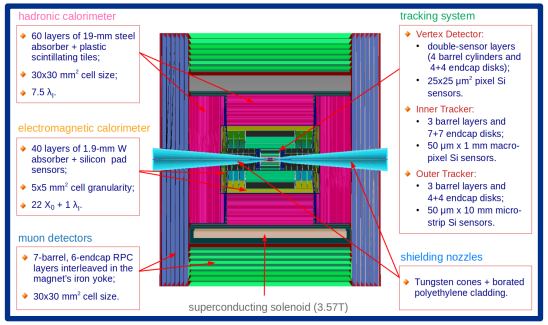
Muon Collider in Snowmass'21

- Clear resurgence of interest in Muon Colliders within Snowmass
  - Many LOIs and ongoing studies and White Papers expected. AF, EF and TF have recently established a cross-frontier forum dedicated specifically to Muon Collider
  - A three-day workshop organized by University of Pittsburgh. Covered recent developments in the areas of physics, accelerator and detectors (link)
  - An informal event organized jointly by USATLAS and USCMS collaboration members to provide more information to the LHC community (link)
  - LHC Physics Center (LPC) bi-weekly discussions. Mainly focused on detector and reconstruction.
  - Upcoming Muon Collider mini-symposium during the APS April Meeting
- Contact info
  - LPC muon collider physics/detectors
    - Subscribe to muoncolliderphysics@listserv.fnal.gov
  - Snowmass forum
    - Snowmass-muon-collider-forum@listserv.fnal.gov
  - International Collaboration
    - https://muoncollider.web.cern.ch/
    - (For NuStorm, see https://www.nustorm.org/trac/wiki/WikiStart)

Detectors at the Muon Collider

- Three main challenges identified: beam background, high power targets and neutrino radiation
  - At 1.5 TeV $\lambda = 9.3\times10^{6}$m, with $2\times10^{12}\mu$/bunch $\Rightarrow 2\times10^{5}$decays per meter of lattice.
- Cutting-edge detector technologies to mitigate effects of the Beam Induced Background
  - Smart trackers with high granularity and timing capabilities
  - PF Calorimetry with good timing capabilities
  - Innovative event reconstruction strategies exploiting time correlations between different subdetectors
- Simulation Framework exists, need design studies, optimization, and new ideas





Contributions and Synergies

- A group of Fermilab scientists are already involved in Muon Collider studies in the context of Snowmass
  - Physics Studies
  - Detector simulation and event reconstruction
  - BIB Simulations and MDI optimization
- Unique expertise at Fermilab in many other key areas:
  - Overall system design
  - RF and high field magnets
  - Ionization cooling
  - Targets
  - Advanced detector design
  - Neutrino radiation issues and mitigation
- Exploring synergies with Intensity and Precision Frontiers. The goal is to understand what other physics can be done with intense muons beams.
- Work within Snowmass and in collaboration with CERN to understand the evolving interest within the US community, identify key R&D needs and outline path forward
- Sergo Jindariani and Diktys Stratakis are among 6 coordinators for the Snowmass Muon Collider Forum; Sergo is coordinating LPC Forum with Kevin Black (Wisonsin).

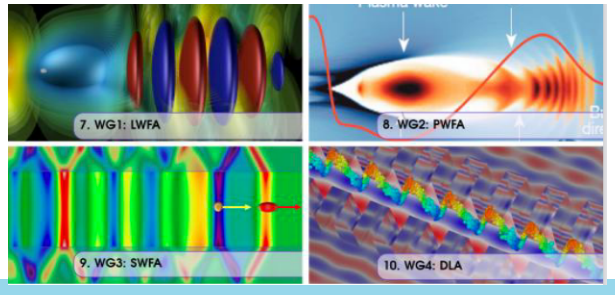
Future Colliders at Fermilab??

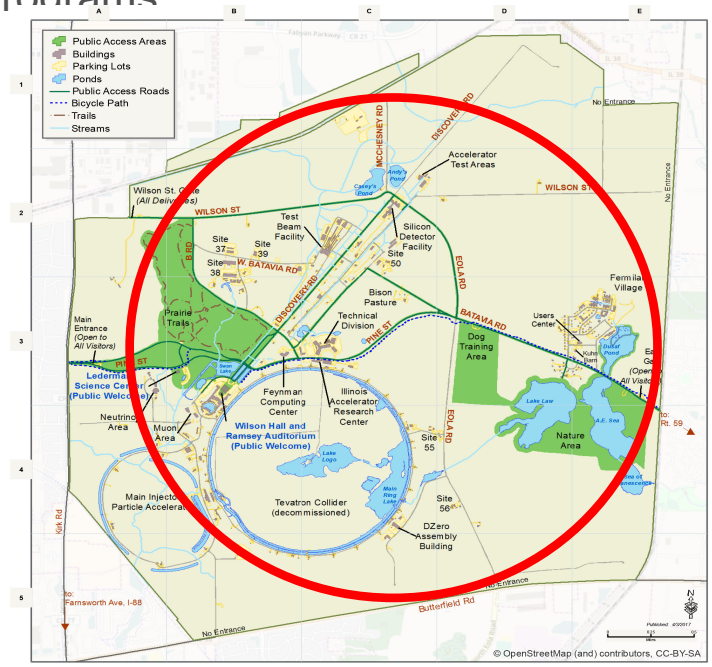
"Nothing happens unless first a dream!"

--Carl Sandburg

Future Collider Options

- Given the planned development of the accelerator complex for LBNF/DUNE program, Fermilab will have a robust infrastructure for a future muon collider or a hadron collider
  - Multi-MW proton beam with PIP-II linac and Booster replacement
  - A lot of expertise in all relevant areas
- A Site Filler for a Muon Collider or a Compact Hadron Collider?
- Muon accelerator complex at Fermilab
  - Muon Collider R&D facility with muon and neutrino programs
  - Multi-TeV (5 -10 TeV) Muon Collider (Neuffer, et al.)
- A Compact Hadron Collider at Fermilab
  - Site Filler (16 km, 24-28 TeV)
  - > 20 T LTS/HTS magnets
  - IBS magnet research promising for >20T but early days
- An Advanced Linear Collider (ALC?) > 10TeV





Summary

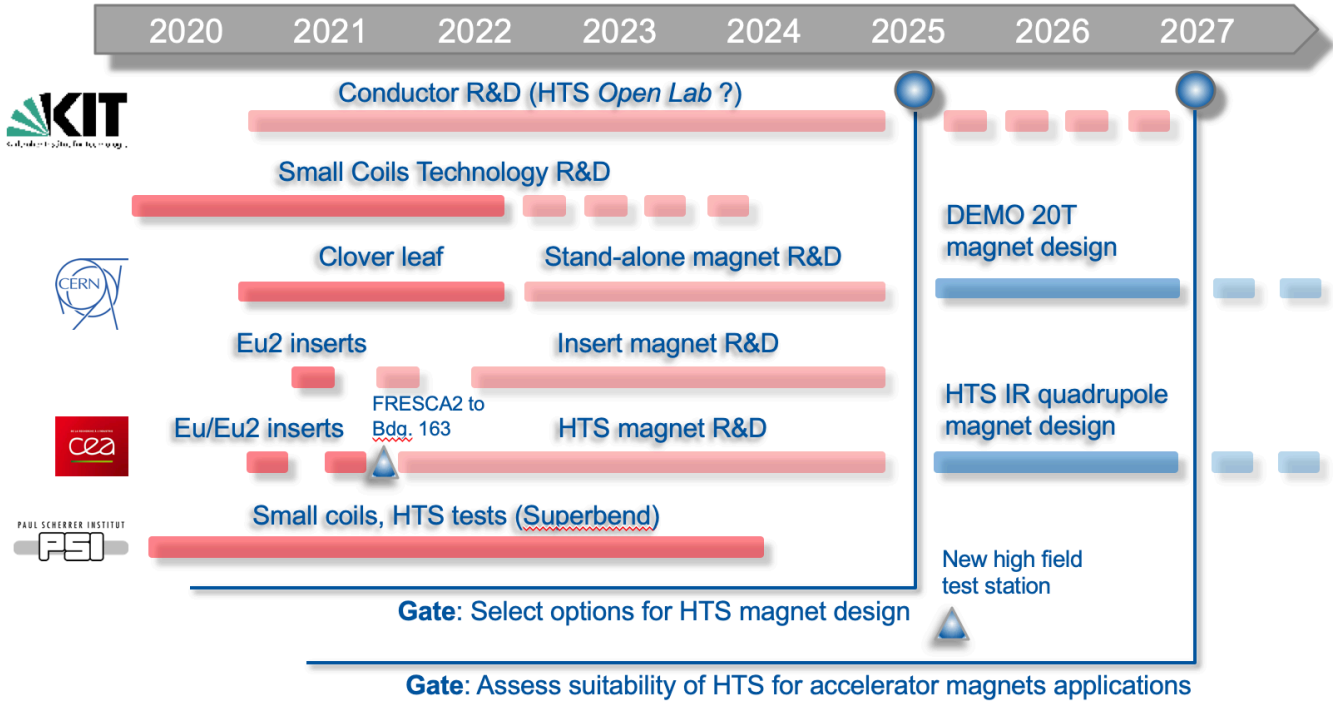
- The PPD **Future Colliders** group with representatives drawn from across the Lab has been formed.
- We plan to engage in cross-divisional collaboration as well as explore synergies with intensity and precision frontier plans.
- In the near term, we will continue to work with the US university and other national labs and the international community within the context of Snowmass.
- The ongoing and planned development of the Fermilab accelerator complex for LBNF/DUNE provides a great impetus and infrastructure for longer-range planning of future facilities.

- We look forward to your active participation!

Extra Slides

High Field Magnet R&D for pp Collider

CERN plan:



Muon Collider Parameter Table

(* as developed by the US MAP)

RAST, Vol 10, No. 01, pp. 189-214 (2019)

Table 3. Main parameters of the various phases of an MC as developed by the MAP effort.

Parameter	Units	Higgs	Top-high resolution	Top-high luminosity	Multi-TeV		
CoM energy	TeV	0.126	0.35	0.35	1.5	3.0	6.0*
Avg. luminosity	$10^{34}\,\mathrm{cm}^{-2}s^{-1}$	0.008	0.07	0.6	1.25	4.4	12
Beam energy spread	%	0.004	0.01	0.1	0.1	0.1	0.1
Higgs production/10^7 sec		13,500	7000	60,000	37,500	200,000	820,000
Circumference	km	0.3	0.7	0.7	2.5	4.5	6
Ring depth [1]	m	135	135	135	135	135	540
No. of IPs		1	1	1	2	2	2
Repetition rate	Hz	15	15	15	15	12	6
$\beta^*_{x,y}$	cm	1.7	1.5	0.5	1 (0.5–2)	0.5 (0.3–3)	0.25
No. muons/bunch	10^{12}	4	4	3	2	2	2
Norm. trans. emittance, ε_T	π mm-rad	0.2	0.2	0.05	0.025	0.025	0.025
Norm. long. emittance, ε_L	π mm-rad	1.5	1.5	10	70	70	70
Bunch length, σ_s	cm	6.3	0.9	0.5	1	0.5	0.2
Proton driver power	MW	4	4	4	4	4	1.6
Wall plug power	MW	200	203	203	216	230	270

*Accounts for off-site neutrino radiation

Yet Another Parameter Table

(* under consideration by the CERN-led *Muon Collider Collaboration* - 2020)

Target integrated luminosities

$\sqrt{s}$	$\int \mathcal{L} dt$
3 TeV	$1\ \mathrm{ab}^{-1}$
10 TeV	$10\ \mathrm{ab}^{-1}$
14 TeV	$20\ \mathrm{ab}^{-1}$

Reasonably conservative

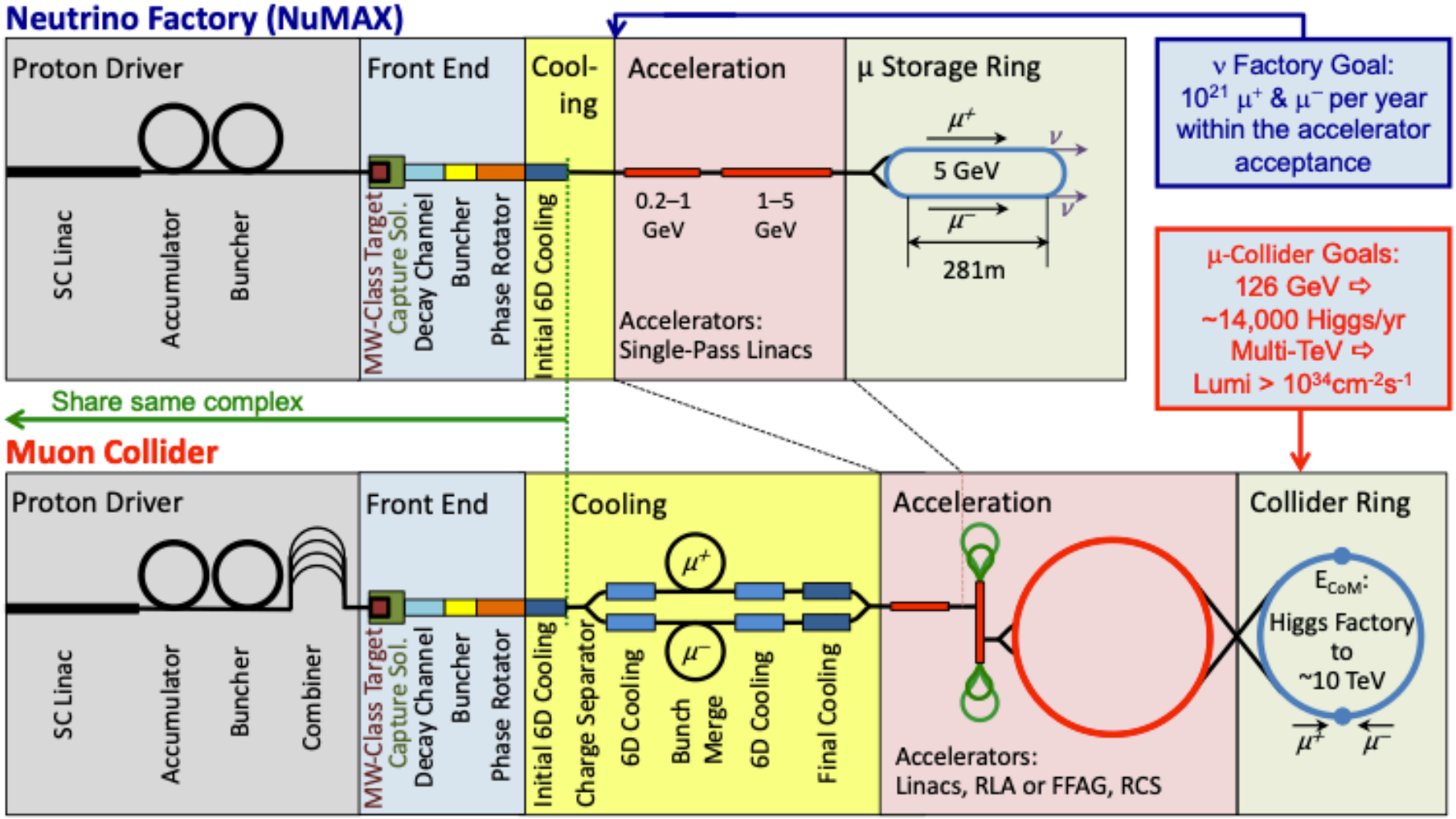
- each point in 5 years with tentative target parameters
- FCC-hh to operate for 25 years
- Aim to have two detectors
- But might need some operational margins

Note: focus on 3 and 10 TeV
Have to define staging strategy

Tentative target parameters, scaled from MAP parameters

Parameter	Unit	3 TeV	10 TeV	14 TeV
L	10^{34} cm^{-2}s^{-1}	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14
<B>	T	7	10.5	10.5
ε_L	MeV m	7.5	7.5	7.5
σ_E / E	%	0.1	0.1	0.1
σ_z	mm	5	1.5	1.07
β	mm	5	1.5	1.07
ε	µm	25	25	25
$\sigma_{x,y}$	µm	3.0	0.9	0.63

Snowmass process to give feedback on this


Neutrino Factory (NuMAX)
Proton Driver
SC Linac
Accumulator
Buncher
Front End
MW-Class Target
Capture Sol.
Decay Channel
Buncher
Phase Rotator
Cool-ing
Initial 6D Cooling
Acceleration
0.2–1 GeV
1–5 GeV
Accelerators:
Single-Pass Linacs
μ Storage Ring
5 GeV
281m
ν Factory Goal:
10^21 μ+ & μ− per year
within the accelerator
acceptance
μ-Collider Goals:
126 GeV ⇨
~14,000 Higgs/yr
Multi-TeV ⇨
Lumi > 10^34cm^-2s^-1
Share same complex
Muon Collider
Proton Driver
SC Linac
Accumulator
Buncher
Combiner
Front End
MW-Class Target
Capture Sol.
Decay Channel
Buncher
Phase Rotator
Cooling
Initial 6D Cooling
Charge Separator
6D Cooling
Bunch Merge
6D Cooling
Final Cooling
Acceleration
Accelerators:
Linacs, RLA or FFAG, RCS
Collider Ring
E_CoM:
Higgs Factory
to
~10 TeV