US-FCC: next steps

Sarah Eno
U. Maryland
(talk in my US-FCC role, not my HFSC role)

US participation in the FCC

Began as a grassroots effort by a US community eager to support US participation in its exciting physics program. First, we worked with our international partners to provide the needed physics case information for the Snowmass process.

arxiv.org/abs/2203.06520

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Cornell University

We gratefully acknowl

arXiv > hep-ex > arXiv:2203.06520

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High Energy Physics - Experiment

[Submitted on 12 Mar 2022 (v1), last revised 19 Dec 2022 (this version, v3)]

The Future Circular Collider: a Summary for the US 2021 Snowmass Process

G. Bernardi, E. Brost, D. Denisov, G. Landsberg, M. Aleksa, D. d'Enterria, P. Janot, M.L. Mangano, M. Selvaggi, F. Zimmermann, J. Alcaraz Maestre, C. Grojea R.M. Harris, A. Pich, M. Vos, S. Heinemeyer, P. Giacomelli, P. Azzi, F. Bedeschi, M. Klute, A. Blondel, C. Paus, F. Simon, M. Dam, E. Barberis, L. Skinnari, T. Raubenheimer, S. Antusch, W. Altmannshofer, L.-T. Wang, J. de Blas, S. Eno, Yihui Lai, S. Willocq, J. Qian, J. Zhu, R. Novotny, S. Seidel, M.D. Hildreth, E.J. Thomson, R. Demina, J. Gluza, G. Isidori, R. Gonzalez Suarez

In this white paper for the 2021 Snowmass process, we give a description of the proposed Future Circular Collider (FCC) project and its physics program. The paper summarizes and updates the discussion submitted to the European Strategy on Particle Physics. After construction of an approximately 90 km tunnel, an electron-positron collider based on established technologies allows world-record instantaneous luminosities at center-of-mass energies from the Z resonance up to tt thresholds, enabling a rich set of fundamental measurements including Higgs couplings determinations at the sub percent level, precision tests of the weak and strong forces, and searches for new particles, including dark matter, both directly and via virtual corrections or mixing. Among other possibilities, the FCC-ee will be able to (i) indirectly discover new particles coupling to the Higgs and/or electroweak bosons up to scales around 7 and 50 TeV, respectively; (ii) perform competitive SUSY tests at the loop level in regions not accessible at the LHC; (iii) study heavy-flavor and tau physics in ultra-rare decays beyond the LHC reach, and (iv) achieve the best potential in direct collider searches for dark matter, sterile neutrinos, and axion-like particles with masses up to around 90 GeV. The tunnel can then be reused for a proton-proton collider, establishing record center-of-mass collision energy, allowing unprecedented reach for direct searches for new particles up to the around 50 TeV scale, and a diverse program of measurements of the Standard Model and Higgs boson, including a precision measurement of the Higgs self-coupling, and conclusively testing weakly-interacting massive particle scenarios of thermal relic dark matter.

Comments: 84 pages
Subjects: **High Energy Physics - Experiment (hep-ex)**
MSC classes: for Snowmass 2021
Cite as: arXiv:2203.06520 **[hep-ex]**
(or arXiv:2203.06520v3 **[hep-ex]** for this version)
https://doi.org/10.48550/arXiv.2203.06520

Documented the strong support

Appendices

Supporters of U.S. involvement in a future FCC program

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Along with another document on the information of the level of effort needed to make an impact

Working with our pro-ILC colleagues

arxiv.org/abs/2306.13567

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We gratefully acknowledge support from the S institutions.

arXiv > hep-ex > arXiv:2306.13567

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High Energy Physics - Experiment

[Submitted on 23 Jun 2023 (v1), last revised 26 Jun 2023 (this version, v2)]

Detector R&D needs for the next generation e^+e^- collider

A. Apresyan, M. Artuso, J. Brau, H. Chen, M. Demarteau, Z. Demiragli, S. Eno, J. Gonski, P. Grannis, H. Gray, O. Gutsche, C. Haber, M. Hohlmann, J. Hirschauer, G. Iakovidis, K. Jakobs, A.J. Lankford, C. Pena, S. Rajagopalan, J. Strube, C. Tully, C. Vernieri, A. White, G.W. Wilson, S. Xie, Z. Ye, J. Zhang, B. Zhou

The 2021 Snowmass Energy Frontier panel wrote in its final report "The realization of a Higgs factory will require an immediate, vigorous and targeted detector R&D program". Both linear and circular e^+e^- collider efforts have developed a conceptual design for their detectors and are aggressively pursuing a path to formalize these detector concepts. The U.S. has world-class expertise in particle detectors, and is eager to play a leading role in the next generation e^+e^- collider, currently slated to become operational in the 2040s. It is urgent that the U.S. organize its efforts to provide leadership and make significant contributions in detector R&D. These investments are necessary to build and retain the U.S. expertise in detector R&D and future projects, enable significant contributions during the construction phase and maintain its leadership in the Energy Frontier regardless of the choice of the collider project. In this document, we discuss areas where the U.S. can and must play a leading role in the conceptual design and R&D for detectors for e^+e^- colliders.

Comments: 63 pages, 6 figures, submitted to P5
Subjects: **High Energy Physics - Experiment (hep-ex)**; Instrumentation and Detectors (physics.ins-det)
Cite as: arXiv:2306.13567 **[hep-ex]**
(or arXiv:2306.13567v2 **[hep-ex]** for this version)
https://doi.org/10.48550/arXiv.2306.13567

Submission history

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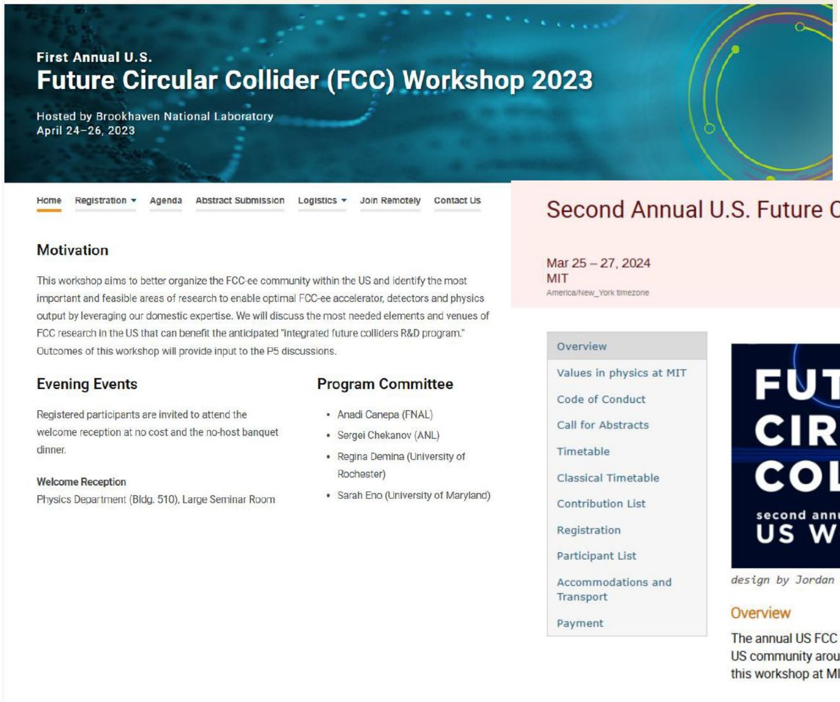
c. An offshore Higgs factory, realized in collaboration with international partners, in order to reveal the secrets of the Higgs boson. The current designs of FCC-ee and ILC meet our scientific requirements. The US should actively engage in feasibility and design studies. Once a specific project is deemed feasible and well-defined (see also Recommendation 6), the US should aim for a contribution at funding levels com- mensurate to that of the US involvement in the LHC and HL-LHC, while maintaining a healthy US onshore program in particle physics (section 3.2).

Area Recommendation 10: To enable targeted R&D before specific collider projects are established in the US, an investment in collider detector R&D funding at the level of $20M per year and collider accelerator R&D at the level of $35M per year in 2023 dollars is warranted.

Area Recommendation 10: To enable targeted R&D before specific collider projects are established in the US, an investment in collider detector R&D funding at the level of $20M per year and collider accelerator R&D at the level of $35M per year in 2023 dollars is warranted.

These funding levels are not of course yet endorsed by the funding agencies.

Workshops to organize and strengthen the US community



First Annual U.S.

Future Circular Collider (FCC) Workshop 2023

Hosted by Brookhaven National Laboratory
April 24–26, 2023

Home | Registration | Agenda | Abstract Submission | Logistics | Join Remotely | Contact Us

Motivation

This workshop aims to better organize the FCC-ee community within the US and identify the most important and feasible areas of research to enable optimal FCC-ee accelerator, detectors and physics output by leveraging our domestic expertise. We will discuss the most needed elements and venues of FCC research in the US that can benefit the anticipated "integrated future colliders R&D program." Outcomes of this workshop will provide input to the P5 discussions.

Evening Events

Registered participants are invited to attend the welcome reception at no cost and the no-host banquet dinner.

Welcome Reception
Physics Department (Bldg. 510), Large Seminar Room

Program Committee

- Anadi Canepa (FNAL)
- Sergei Chekanov (ANL)
- Regina Demina (University of Rochester)
- Sarah Eno (University of Maryland)

Second Annual U.S. Future Circular Collider (FCC) Workshop 2024

Mar 25 – 27, 2024
MIT
America/New_York timezone

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- Call for Abstracts
- Timetable
- Classical Timetable
- Contribution List
- Registration
- Participant List
- Accommodations and Transport
- Payment

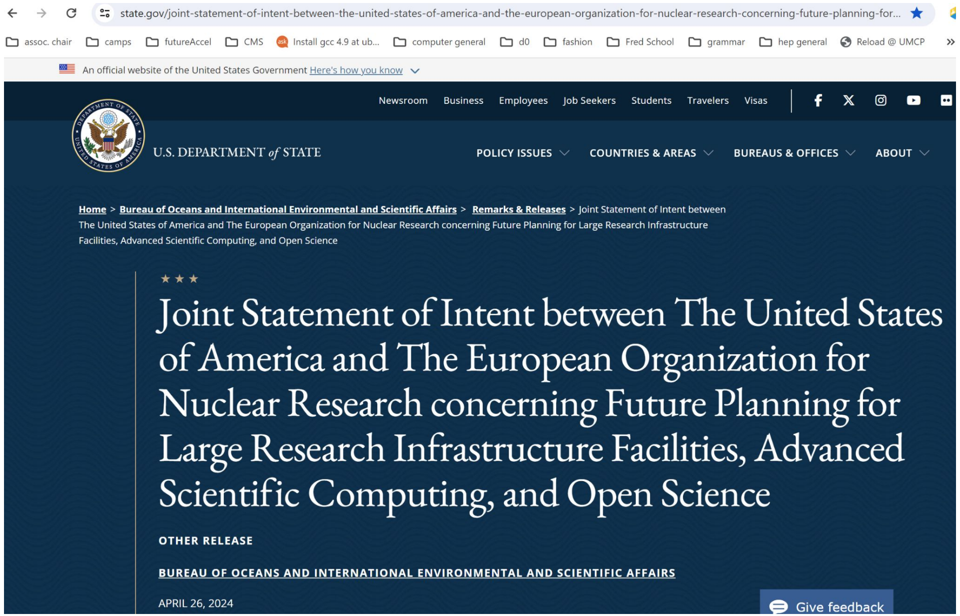
design by Jordan Lang

Overview

The annual US FCC workshop series started in 2023 at BNL with the idea of building and fostering the US community around the FCC and in particular the FCC-ee project. We will have the second instance of this workshop at MIT in Cambridge, MA.

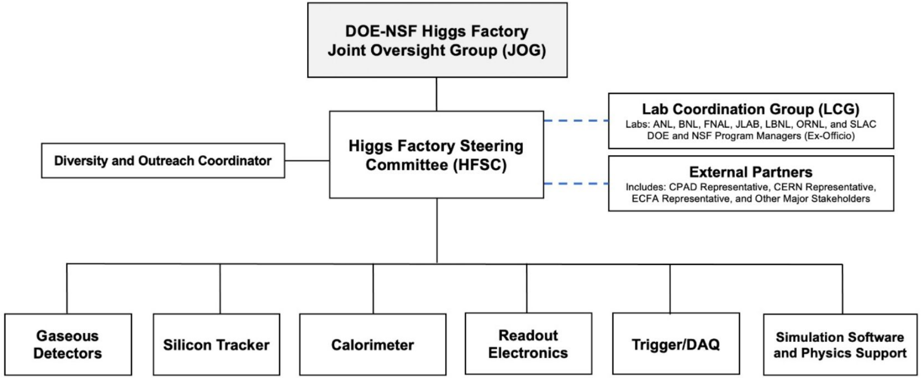
With strong international participation to strengthen our ties

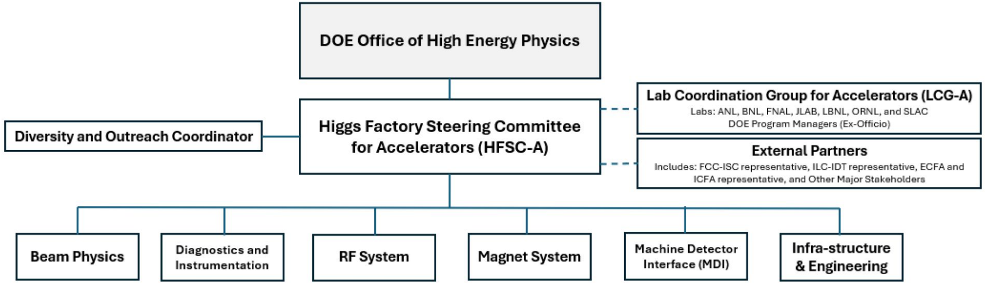
Signing of the joint statement of intent



DOE and NSF Higgs factory organization

(organizations will evolve to follow the needs of the community)





Charge

1. Physics and technical feasibility studies, including any associated design and R&D efforts, to advance various experiment detector concepts at a future Higgs factory;
2. Prioritization and stewardship of the national R&D efforts should funds be identified by DOE and/or NSF;
3. Development of the pre-project detector R&D scope that will be required prior to DOE and/or NSF initiating any detector project at a future e+e- collider;
4. Conceptualization of the software and computing framework that will be needed to advance physics studies and R&D efforts; and to collect, store, and analyze the large volumes of physics data at future collider experiments;
5. In consultation with DOE and NSF program managers, develop various funding models that will be required to support the R&D efforts described in items (3) and (4) above; and
6. Ensure collaborations by the U.S. with our partners are cost-effectively carried out to advance the future Higgs factory initiatives. (CPAD, ECFA, DRD, others).

- Prepare the groundwork to respond to the P5 Recommendation 6: "[Convene a targeted panel to review] 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"

5

Grateful

To the P5 committee for including an offshore Higgs factor as a high level recommendation

To DOE and NSF for signing the agreement and for the formation of the Higgs factory committee

For the support of our international colleagues who have helped us get here

To our ILC colleagues who are working with us where our goals are in common. Such collegiality means our resources go much further.

At this workshop: many US talks!

Practical information about the conference - Julia Gonski
NSF: Opening Remarks and Perspectives on US Engagement in FCC - Jim Shanks
DOE: Opening Remarks and Perspectives on US Engagement in FCC - Regina Rameika
Key Note - Joanne Hewett
The Physics at FCC-ee - Zoltan Ligeti
Detectors requirements and benchmarks - Junjie Zhu
US Plans FCC-PED - Srini Rajagopalan
US Plans FCC-Accelerators - Tor Raubenheimer
Higgs physics and SMEFT at FCC - Francis Petriello
BSM searches with FCC-ee - Christopher Verhaaren
FCC-ee sensitivity to SUSY through precision Z-boson measurements - Kevin Langhoff
Synergies of FCC-ee with ILC and EIC - Michiko Mint
Conceptual Design of HTS Accelerator Magnets for Future Lepton Colliders - Vladimir Kashikhin (FNAL)
Advantages of C3 technology for the injector linacs - Emilio Nanni
LCC Optics - Pantaleo Raimondi
The IOTA Research Program and Possible Studies Relevant for the FCC - Giulio Stancari
BSM at FCC-ee - Zeynep Demiragli
EW/QCD measurements using ee->hadrons - Marina Nogueira
Jet tagging as a tool for measuring Higgs couplings at O(0.1%) precision and H->ssbar - Loukas Gouskos
Higgs properties + Top at FCC-ee - Ang Li
Gaseous tracking review - George Iakovidis
Fast timing possibilities at FCC-ee - Matthew Gignac
Opportunities for low mass mechanics/cooling for FCC-ee - Eric Anderssen

High Q0 800 MHz cavity R&D for FCC - Kellen McGee
Review of the Silicon and SiPM-Scintillator Calorimeters - Jeremy Mans
Review of Crystal and Fibre Dual-Readout Calorimetry - Sarah Eno
Noble Liquid Endcap EM Calorimeter: Geometry and Simulation - Erich Varnes
Recent Progress of Inorganic Scintillators for Future HEP Calorimetry - Renyuan Zhu
Potential of A15 materials for FCC SRF - Matthias Liepe
EIC 591 MHz SRF cavity progress - Jiquan Guo
First Nb3Sn coated CEBAF style quarter cryomodule? - Anne-Marie Valente-Feliciano
Flavor Tagging - Andrea Sciandra
EIC Dynamic aperture optimization & implications for FCC - Yunhai Cai
Beam-based alignment simulations - Xiaobiao Huang
Experience with FCC software - Scott Snyder
Python analyses tools from LHC - David Lange
GeoModel Toolkit for FCC simulation - Vakho Tsulaia
Optimization of the FCC-ee IR beam pipe elements for minimum of the wake field energy loss responsible for the heat load. - Alexander Novokhatski
IR magnet system - John Seeman
LCLS-II Commissioning - Dan Gonnella
EIC - detector - Zhenyu Ye
Neutrino complex/upgrades - Jeffrey Eldred
New simulation tools for beam-beam collisions at the interaction point - Arianna Formenti
Bmad for the FCC, and a future Bmad Julia for Machine Learning - Georg Hoffstaetter de Torquat

Introduction to requirements for BSM program - Louise Skinnari
Measuring Electrons & Photons with high precision - Chris Tully
Hadronic calorimeter: hermeticity and resolution - Daniel Elvira
High field magnet efforts at NHMFL, BNL & industry - Kathleen Amm
A new framework for synchrotron radiation studies in the EIC experiment - Andrii Natochii
AIML mini workshop: Introduction - Ben Nachman
AIML mini workshop: Accelerator Design/Control - Remi Lehe
AIML mini workshop: Detector design - Karthik Suresh
Polarized positron production - Joseph Grames
The EIC polarimeter, and lessons for the FCC - Dave Gaskell
AIML mini workshop: Fast inference - Elham E Khoda
AIML mini workshop: Data Analysis - Dennis Noll
Beamstrahlung monitor - Dmitri Liventsev
US Magnet Development Program and synergies with FCC-hh - Soren Prestemon
Conductor challenges for FCC-hh - Lance Cooley
Polarized electrons at the EIC, and lessons for the FCC - Georg Hoffstaetter de Torquat
Lessons from LEP, and final steps towards the Final Report of the Feasibility Study - Eric Torrence
The Silicon Vertex Tracker of the ePIC Detector at the Electron-Ion Collider - Nicole Apadula
Development of precision tracking detectors at Fermilab - Artur Apresyan
A Straw Tracker for the FCC-ee - Junjie Zhu
Accelerator R&D including RF - Tor Raubenheimer
FCC-hh & HFM - Soren Prestemon
Summaries: Physics - Christoph Paus
Summaries: Early Career - Matthew Daniel Citron

And posters

Investigation of low gain avalanche detectors exposed to proton fluences beyond 1015neq/cm2 and gamma dose up to 2.2 MGy - Josef Sorenson
Using Generative AI to Explore the Limits of Jet Tagging - Nishank Nilesh Gite
High radiation resistance LGAD designs - Simone Michele Mazza
The GeoModel Toolkit for FCC simulation - Vakho Tsulaia
Integrated Carbon Fiber Composite Structures for Future HEP Detectors - Sushrut Rajendra Karmarkar
Recent results on dual readout crystal EM calorimetry - Sara Nabili
Operational Considerations for Laser Control of the FCC Bunch Intensity - Spencer Gessner
FCC-relevant capabilities and compentencies available from ANL - Philippe Piot

Physics

Results @365 GeV [hot-off-the-press]

E_{CM} = 365 GeV [2.3 ab^{-1}, 4 IP]

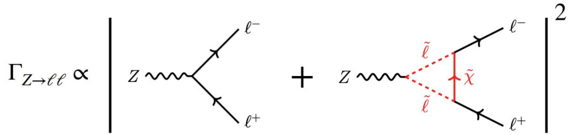
Decay mode	Z(→LL)H(→jj) [%]	Z(→νν)H(→jj) [%]	Z(→jj)H(→jj) [%]	Combination
H→bb	1.23	0.68	0.52	0.39
H→cc	8.20	3.95	4.68	2.83
H→ss	1153	214	664	201
H→gg	4.24	2.51	4.15	1.92

- Modest increase in sensitivity O(10%)
  - but: Jet tagger has never seen this regime [poor performance]
- Expect significant improvement

Loukas Gouskos FCC Week 2024

How might SUSY show up in EWPTs?

Let $\tilde{\chi} = (\tilde{W}, \tilde{B})$ and $\tilde{\ell} = (\tilde{L}, \tilde{e})$.

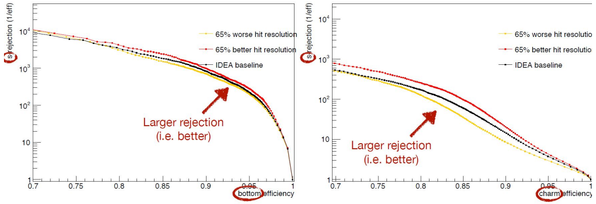


(Just one of several diagrams)

$$\frac{\Gamma_{Z\to\ell\ell} - \Gamma^{(SM)}_{Z\to\ell\ell}}{\Gamma^{(SM)}_{Z\to\ell\ell}} \propto \frac{g^2}{16\pi^2}\left(\frac{m_Z}{M_{\text{SUSY}}}\right)^2 \longrightarrow M^{\text{probed}}_{SUSY} \sim 1\ \text{TeV} \times \left(\frac{\delta\Gamma/\Gamma}{10^{-5}}\right)^{-1/2}$$

Berkeley BERKELEY LAB Kevin Langhoff - SUSY at Tera-Z 11

Bottom/Charm Tagging & Single-Point Resolution

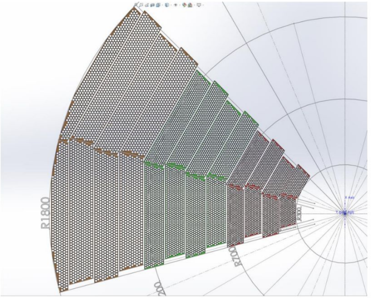


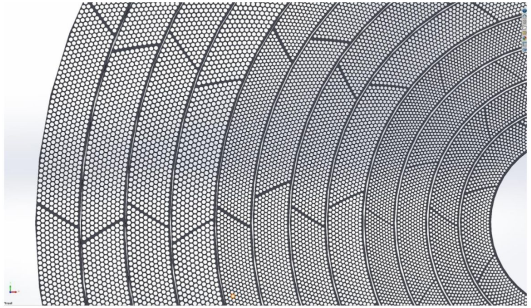
- Visible effects on *b*-tagging
- More significant effects on *c*-tagging
  - Fairly symmetric impact on rejection of all other flavors (see more in backup)
  - **Crucial role of single-point resolution** (nominal: 3µm with 25x25µm² inner barrel pitch) in rejection of major background for charm

[A. Sciandra | ParticleNet & Vertex Detector | FCC Week 2024 | June 12, 2024] 8

Detectors

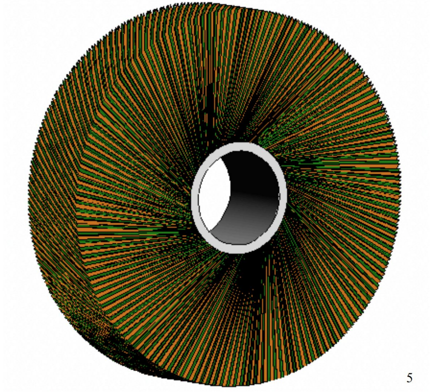
Possible detector layouts

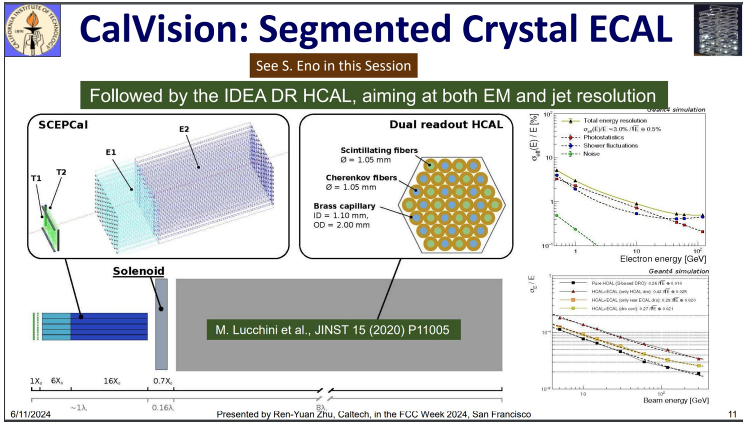




Straws with different diameters (1-1.5 cm) considered for different regions, the actual diameters needed to be determined from the simulation and physics studies
~60k straws (it will depend on the straw radius used for the final detector)

- Inner radius portion with the full set of absorbers and electrodes:





The machine

Surface Civil Engineering

Antoine Mayoux (SCE-PPM) presented ongoing work relating to the surface civil engineering for the FCC

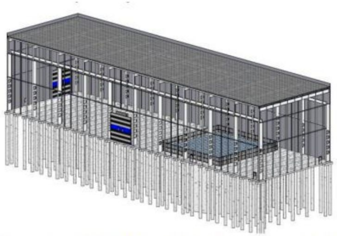
The results of the collaboration with Fermilab were shown.

A number of schematic layouts for some of the Eight surface sites were presented.

The strong coordination with the Implementation team and Integration team was highlighted.

Layouts for all sites to be completed in July for handove to external consultants to undertake cost estimates as input for final feasibility study cost report.

From the Environmental Initial State Analysis, in collaboration with Placement team and ecologists, integrate environmental constraints and opportunities.

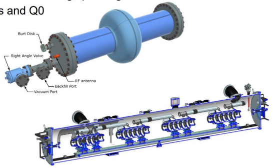


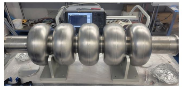
Example of 3D BIM Model: FCC-ee assembly hall

Example: Superconducting RF

SLAC

Fermilab, Cornell, and Jlab have expertise in high-Q bulk Nb SRF and cryomodule design. Goal: develop 800 MHz SRF for Booster and Main Rings pushing gradients and Q0





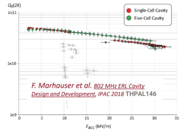


Figure 4: Combined VTA results for the five-cell and single-cell cavity as measured at 2 Kelvin.

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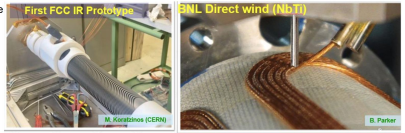
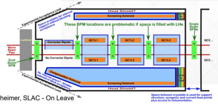
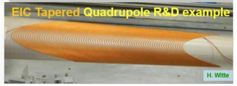
Example: Machine-Detector Interface and IR Magnets

SLAC

Fermilab and BNL have superconducting magnet expertise relevant for the IR quadrupoles and IR correction magnets







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Advantages of C^3 Technology for the Injector Linacs

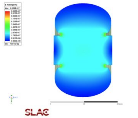
Presented by Emilio Nanni, SLAC

Possible Synergies with FCC-ee

FCC-ee High Energy Linac

- Injector linac operates with closely spaced bunches – up to 5.5 nC
- Initial study with a/wl = 0.125 (conservative, average for HE linac concept is 0.12)
- Gradient 22.5 MeV/m
- **Baseline: 6 MW/m, 3 microsecond**

Linac Properties	
Charge (nC)	0-5.5 nC
Number Bunches	1-4
Bunch Spacing	25 ns spacing
Initial Energy	6 GeV
Final Energy	20 GeV



Shunt impedance 300 K (77 K): 58.5 MΩ/m (146-158 MΩ/m)
a/wl = 0.125
Emax/Ea = 4.35
Sc max = 242mW/um^2
Period: 53.5 mm
Aperture: 13.4 mm
Nose Cone Gap: 41.1 mm
Height: 42.9 mm
R/Q: 3.04
Q: 19250 (300 K)
Power Dissipated @ 21.9MeV/m = 440 kW

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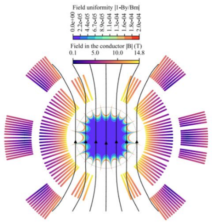
FCC — Raubenheimer / Burnet / Karpov / Mazzoni /Morrone

US MDP and collaboration with HFM

- MDP focused on “general” high field magnet development
  - “Stress-management” concepts
  - “Hybrid” LTS/HTS magnets
  - REBCO and Bi2212 HTS magnet technology



Complementarity of approaches mitigates risk factors:

- Bi-2212 as well as CORC/Star ReBCO wires in US-MDP,
- ReBCO anisotropic cables and IBS in HFM,
- High-risk high-reward topics (no-protection, hydrogen) covered in US-MDP.

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Next steps: US-FCC

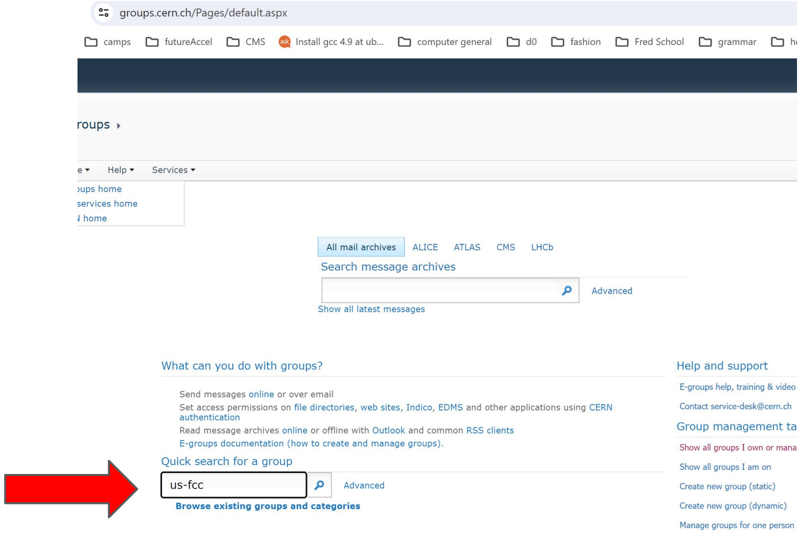
As mentioned in the questions in the Monday morning plenary, there is a danger of a “chicken and the egg” scenario.

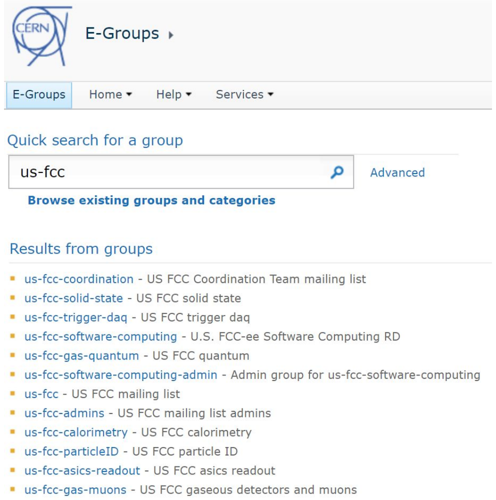
We have a special role in preventing this, **as a CERN observer state**. It can be broken by working with the funding agencies to show an enthusiastic community strongly supporting the creation of this machine, why an international machine is the right choice, and how the US benefits from an that will pay for a very long time.

Especially as an observer state, we cannot afford to just stand by as watchers, waiting to see how it will fall out. We need to do our part.

Next steps

First step is to join the us-fcc mailing list.





And if your institution has not yet done it, let me and Gregorio Bernardi know who your representative to the International Forum of National Contacts will be.

Next steps

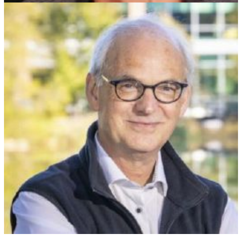
And, if you haven’t already done so, fill out an EOI regarding your particular interests of your institution. (let us know that you did so via an email so that we don’t miss it)

https://docs.google.com/presentation/d/1DEtHFjK2DYOQghM0kcWd1YRUzVpeOWLwzNBYrzP1c4w/edit?usp=sharing

Next steps: Higgs factory steering committee

- A small seed funding based on the snowmass processes expressions will be distributed soon to allow a small effort to start now.
- Contact with the labs has begun to form the membership of the lab advisory committee.
- Call for nominations for level-2 positions will come out shortly. We expect to work with the funding agencies and the lab advisory committee to finalize these on the time scale of a month
- We will work with the level 2s to coordinate and undertake R&D as funding allows. Through this organization, we hope to increase effectiveness, especially on initial hardware and simulation efforts.
- The level 2s will also work with the DRDs so the US can participate effectively in their work towards these detectors



Next steps: US-FCC

- We expect to have hour-long virtual US FCC meetings about every month to help keep US physicists informed on progress with FCC in a time efficient way.
- We intend to form a small committee of about 5 people committed to FCC to aid in organizing the annual US FCC in-person meeting, giving aid to the FCC speakers committee, and organizing US input to the European strategy (due March 2025). Expect news about this in our first monthly US FCC meeting.
- This will be followed by a call to host the next USFCC meeting

Please make sure you are subscribed to us-fcc@cern.ch to be informed.

Conclusions

- US-FCC is strong, committed, and engaged
- This wonderful workshop is another step in our path to a machine that will be worth the investment, paying back with a broad long-range physics program