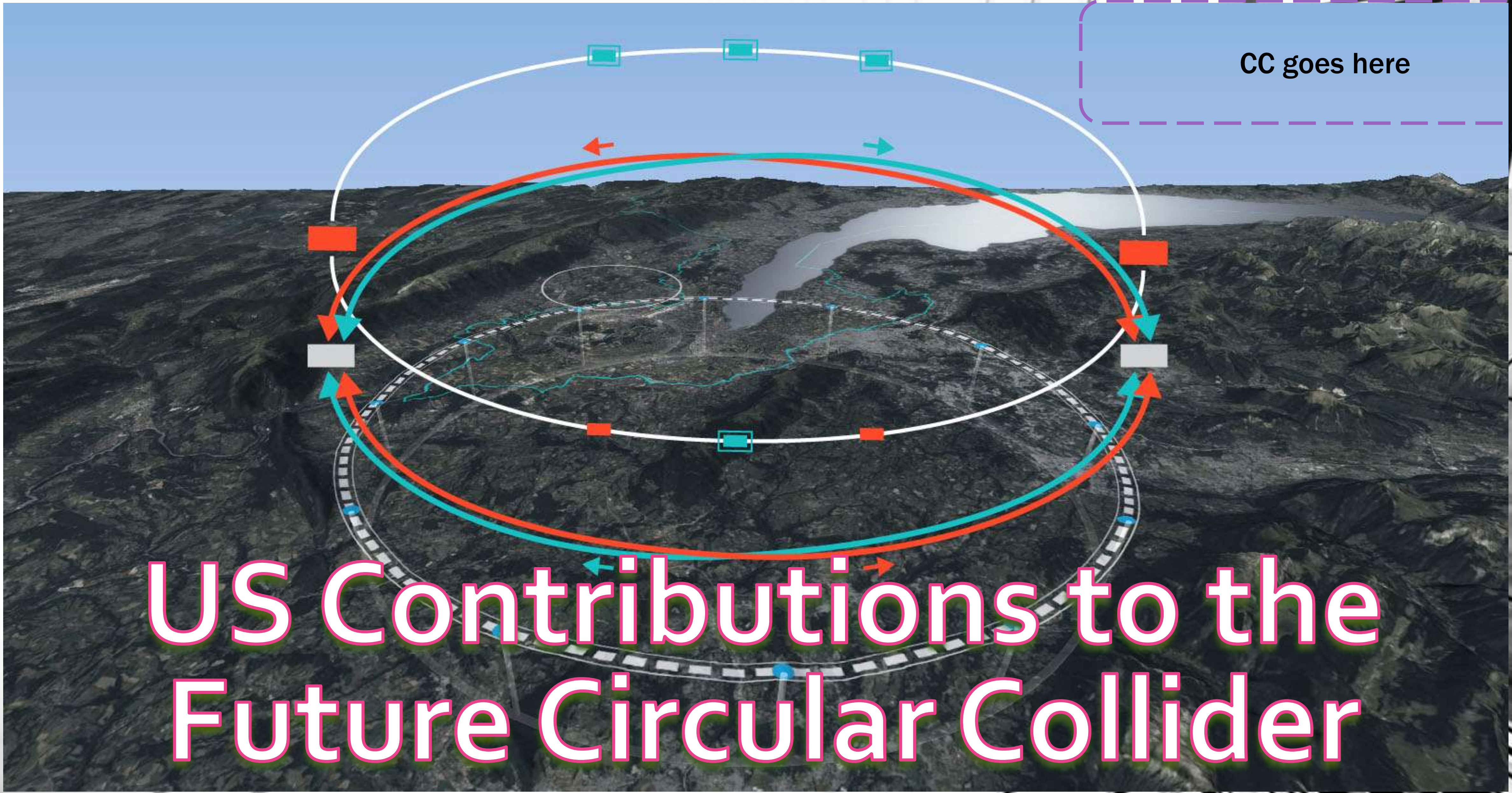

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US Contributions to the Future Circular Collider

Vladimir Shiltsev (Fermilab) for the US-FCC-ee Planning Panel

P5 Town Hall Meeting, May 3, 2023, SLAC

US-FCCee Planning Panel

Kathleen Amm (BNL)
John Byrd (ANL)
Steve Gourlay (FNAL)
Matthias Liepe (Cornell)
Sergei Nagaitsev (JLab)
Tor Raubenheimer (SLAC)
Sergey Belomestnykh (FNAL)
Yunhai Cai (SLAC)
Mark Kemp (SLAC)
Michiko Minty (BNL)
Soren Prestemon (LBNL)
Vladimir Shiltsev (FNAL)

With contributions from: Michael Benedikt, Helen Durand, Eliana Gianfelice-Wendt, Georg Hoffstaetter, Vladimir Kashikhin, Andy Lankford, Emilio Nanni, Mark Palmer, Vittorio Parma, Franck Peauger, Srini Rajagopalan, David Sagan, Frank Zimmermann, Silvia Zorzetti

US - FCC Contributions

Past Contributions (2015-now)

SRF: 800 MHz 5-cell cavity prototype JLAB

Magnets/MDI: IR magnets, MDI, Nb3Sn&HTS magnets BNL, FNAL, LBNL, NHFML

Design: optics, instabilities, ERL collider, polarization SLAC, FNAL, BNL, Cornell, UNM

Infrastructure: tunnel safety, surface bld design FNAL

Future Work (2024-2045) – to be recommended by P5 and supported by DOE, projectized and aligned with international FCC efforts

CERN Timeline*: approved **2028**, start civil **2032**, install'n **2041**, beam **2045**

US Timeline**: CD0 ~**2029**, CD1 **2030/31**, CD2 **2033/34**, CD4 **2046/47**

US-FCCee plan - Key questions:

- What does the FCC-ee project need? [NB: cost, power efficiency, schedule]
- What expertise and capabilities can the U.S. provide to address those needs while benefiting the US programs?

* discussed by F.Gianotti @ BNL TH
** example used in this exercise

Elements of Planning

First, we identified the **areas** (SRF, magnets, design) and **topics**.

Then for each topic we defined the **phases** and **deliverables** :

- Technology R&D
- Preliminary design and component prototyping
- System design and system prototyping
- Preproduction models
- Fabrication

Then we estimated the **cost** (FY23$, loaded no esc'n) and the **timeline**: no cont'y

- With the year-by-year granularity till ~2033, And ~5 years periods beyond 2034
- **Below we present ONLY 2024-2033 R&D/pre-CD-2 estimates**

Finally, we identify where the expertise can potentially be drawn from

1. RF Systems

1) 800 MHz SRF for Booster and Collider:

a. **R&D on cavities** with Q0 = 3e10 at 25 MV/m for Booster up to Higgs operation
b. **R&D on cavities** with Q0 = 6e10 at 25 MV/m for Booster and Main Ring for *ttbar* operation
c. **CM(cryomodule) design** optimization for 800 MHz cavities, possibly with integrated focusing
d. **Fabrication of 2.1 GV of 800 MHz SRF cavities, CMs, and power sources for Booster**
   - **28 RF cryomodules** are needed for the Higgs
e. **Fabrication of additional 18.4 GV of 800 MHz SRF for Collider** *ttbar* **– 244 CMs**

2) 800 MHz RF power sources:

a. R&D on high efficiency **power sources** for 800 MHz with h > 80%
b. Development of **high efficiency modulators** for 800 MHz RF source
c. **Engineering design** of 800 MHz RF power sources and modulators

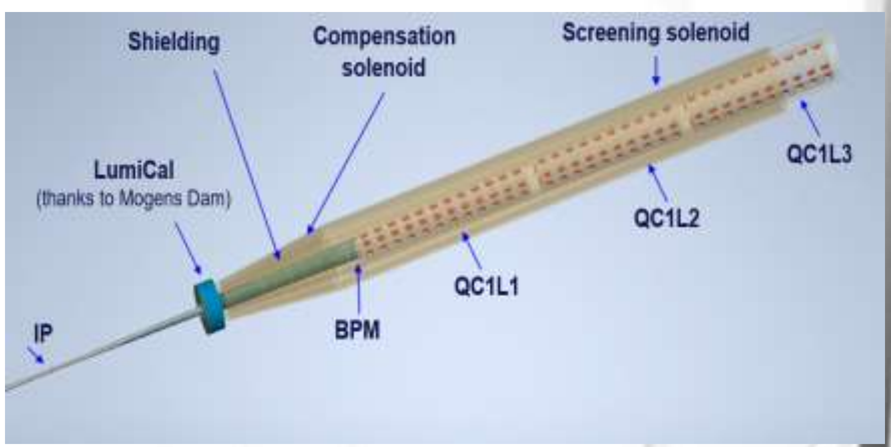
3) RF for 6-20 GeV e+/e- injector linac:

a. R&D on high gradient 70 MV/m 150 MOhm/m **cool copper RF** for injector
b. **Engineering and prototype** of high gradient 70 MV/m 150 MOhm/m cool copper RF for injector
c. **Fabrication of selected RF for 6-20 GeV injector linac**

2. Magnets and MDI

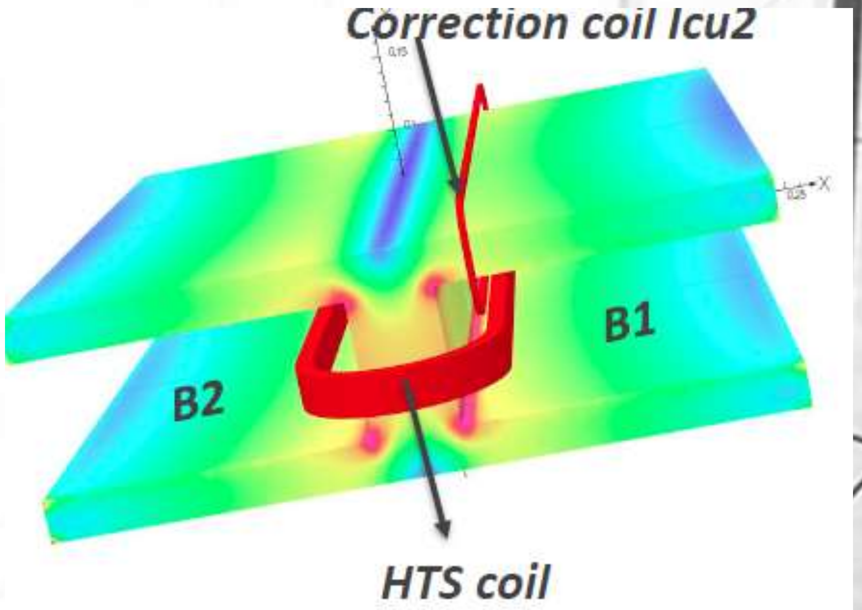
1) IR magnets and cryostats

- R&D: Comparative analysis of technical options
- Design/Prototyping of two most critical magnets
- IR Magnets engineering design
- **Construction of IR magnets for 4 IRs**



2) Collider ring magnets (low field):

- R&D: comparative analysis of technical options
- Design/Prototype of HTS cable-based solution
- Design/Prototype of PM dipole
- **Decision on construction - tbd**



3) Booster ring magnets - tbd

4) FCC-hh collider ring magnets:

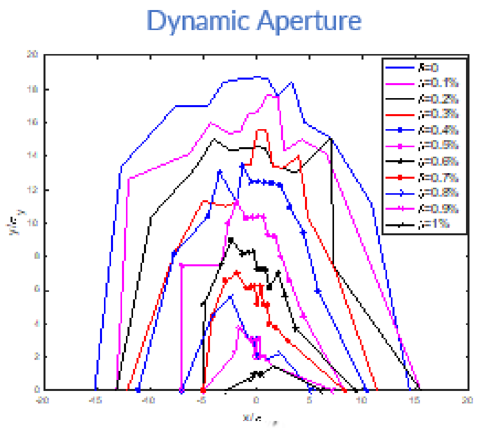
- R&D/prototyping: 14-20T dipoles (part of MDP*, not part of these estimates)

* see Soren Prestemon talk on Thursday

3. Modeling & Design / Collimation / Polarization /Instrumentation

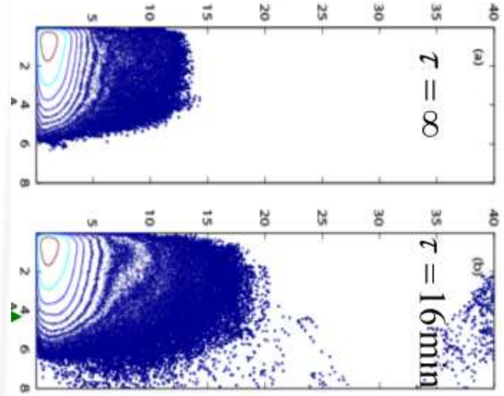
1) Interaction region design, and integrated machine design:

- Modeling/simulations: crab waist and beam-beam/beamstrahlung
- Modeling: DA, chromatic compensation and optics correction schemes
- Design: as needed for the “US-FCC-ee magnets” hardware



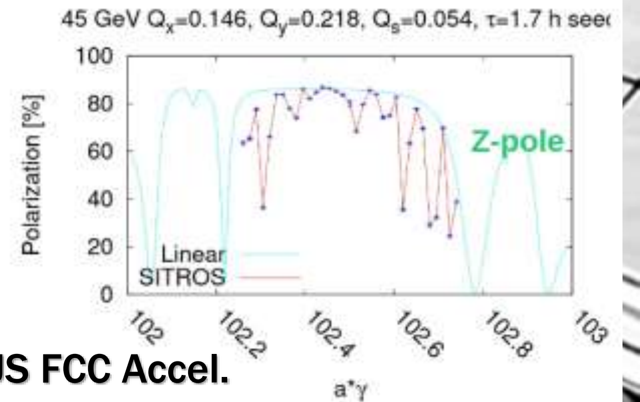
2) Losses, collimation and background:

- Modeling/simul: halo formation, background in detectors, instability
- Design: efficient collimation systems (elens/NLO/CS), detector background masking
- **Possible fabrication: collimation system (IRs and Rings)**



3) Polarization:

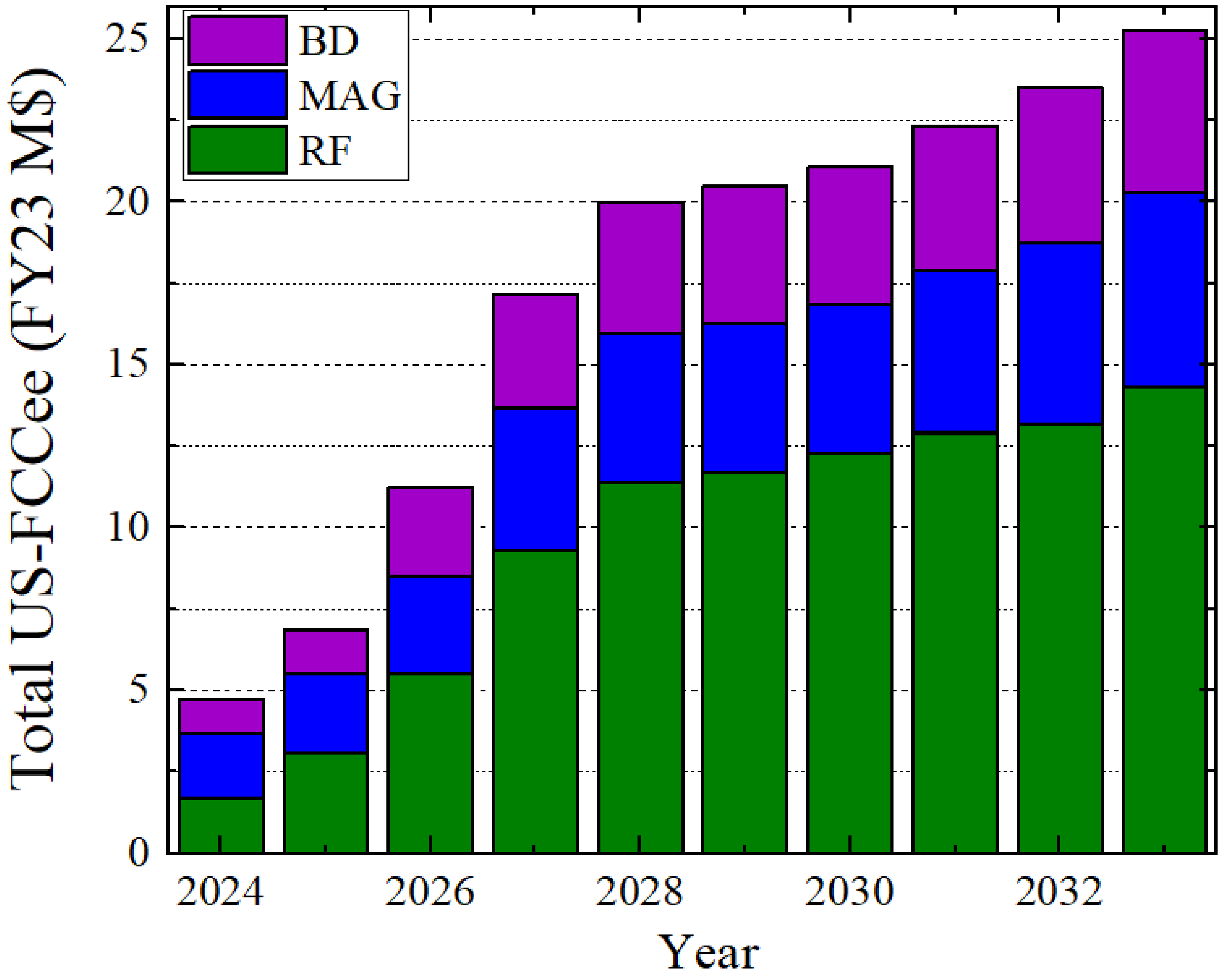
- Modeling/simulations: 45-80 GeV energy calibration, error analysis
- Design: wigglers, polarimeters, polarized sources
- **Fabrication: wigglers for 45 GeV ops and 2 polarimeters, polarized sources**



4) Beam Instrumentation.:

- **Design and prototyping:** BPMs, Lumi, instability feedback, emittance, halo monitors
- **Fabrication: Instability feedback, halo monitors, LLRF (other, eg BPMs - tbd)**

Possible US-FCC-ee pre-CD2 Contributions



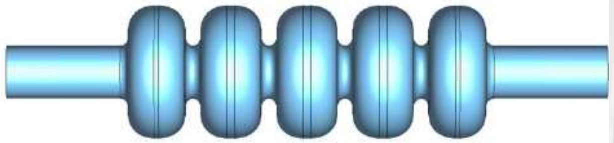
Total 2024-33: 184M$
Incl. Labor: 333 FTEs

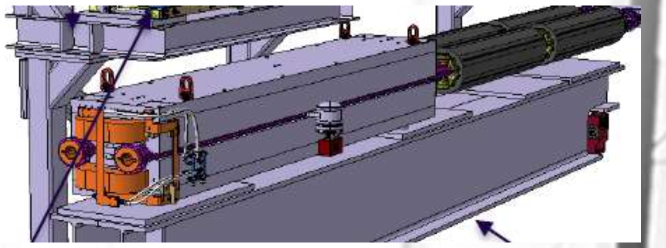
Area	Total M$	Incl. FTEs
RF systems	95	127
Magnets/MDI	53	116
Design/Dynamics	36	90

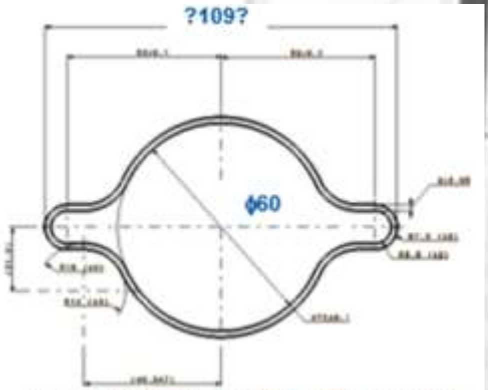
NB: cost of the post CD-2 (2033) fabrication phase is much higher and depends on the scope/elements (TBD)

Possible Fabrication Elements - for Consideration (the US contribution TBD)

1) 2.1 GV 800 MHz SRF for Higgs, 28 CMs *O*(0.2B$)
2) 18.4 GV of 800 MHz SRF for *ttbar*, 244 CMs *O*(1.7B$)
3) 6-20 GeV S-band C^3 type linac *O*(0.25B$)
4) IR magnets for 4 IPs *O*(0.6B$)
5) Magnets for the collider and booster rings *O*(1B$)
6) 270 km of vacuum beam pipes (collider, booster) *O*(0.3B$)
7) Several km RF bypass beamline (switch btw tt and ZH) - TBD
8) Beam instrumentation/polarization *O*(0.15B$)
   - Collimation, halo monitors | Polarization wigglers, meters, sources | TMCI feedback
9) Technical Infrastructure contributions - TBD
   - Alignment | Radiation protection | Safety systems | Power converters







Vacuum chamber prototype cross-section

Relevant US Expertise

	ANL	BNL	FNAL	LANL	LBNL	JLab	SLAC	Universities
SRF cavities/CMs			■			■	■	Cornell, ODU ...
RF sources/modul.	■						■	IIT, Stanford
Copper RF linac	■			■			■	NIU, IIT
IR magnets		■	■		■			FSU, MIT, TAMU
Booster/MR magnets	■	■	■		■			
Beam Optics	■	■	■	■	■	■	■	Cornell, ...
Collimation		■	■				■	
Polarization		■	■			■		Cornell, UNM, ...
Instrumentation	■	■	■		■	■	■	many
Infrastructure	■	■	■	■	■	■	■	

- the US has the expertise and interest to execute this broad program of R&D and to fabricate such a set of deliverables

Moving Forward

- Assuming CERN approval of FCC-ee in ~2028, we can **expect DOE CD-0 (mission need) in ~2029**, launching a US FCC-ee accelerator project.
  - CD-0 and likely CD-1 are within the 10-year window of consideration of this P5 subpanel.
- While a formal US FCC-ee accelerator project will only start following CD-0, it is critical that **the U.S. start now to develop a strategic and coherent US R&D program.**
  - The formation of a national FCC-ee accelerator R&D program now can define the scope and priorities of US R&D efforts with a focus on the R&D needs of the global FCC-ee project and with an eye to eventual US deliverables to FCC-ee construction.
  - While the U.S. has been involved from the outset in the international FCC planning efforts, it is time now to ramp up US involvement in order to:
    - Maximize the impact of US expertise and capabilities to the benefit of FCC-ee design and
    - Enable the U.S. to take leading roles in the development and realization of FCC-ee.
- Funding for targeted accelerator R&D of **~5M$/yr in early years, increasing to ~20M$/yr before CD-2**, is essential to meeting these objectives.
  - Such a level of funding is consistent with the scale of targeted R&D funds of the past US LARP program, which transitioned into the HL-LHC Accelerator Upgrade Project.
- Early engagement and investments in accelerator/detector R&D is crucial to ensure that the U.S. is a leader in the next generation of scientific discovery at FCC-ee, and is essential to enable the U.S. to be a leading stakeholder in other future global initiatives, whether hosted in the U.S. or abroad.

Summary

- A Higgs Factory is slated to be the **next high-priority energy frontier collider**, operating following the completion of the HL-LHC program.
- **FCC-ee** is one of the **most feasible** Higgs factory options:
  - Technology development is well advanced.
  - A thorough Feasibility Study is being carried out, supported by substantial resources from the CERN budget.
  - A host (CERN) has been identified.
- With its exceptional luminosity and energy span, FCC-ee will operate also **on the intensity frontier** in exploring electroweak phenomena and top quark properties.
- We are developing **a plan for impactful US accelerator R&D** that can lead to responsibility for fabrication of several critical deliverables to the FCC-ee.
  - This plan will establish the US as a leading partner in the successful realization of this high-priority international project.
  - Strong interest from US national labs and universities to collaborate on this R&D and in an FCC-ee project.
- We believe that, motivated by the strong scientific importance of FCC-ee as a Higgs factory and discovery machine, and by the initiative of CERN to host and to establish feasibility, **the U.S. should**:
  - Promptly engage in FCC-ee accelerator and detector R&D and design, and
  - Prepare the groundwork for a U.S. FCC-ee Project in anticipation of FCC approval in ~2028.