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# US Contributions to the Future Circular Collider

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# US-FCCee Planning Panel

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First Annual U.S.

**Future Circular Collider (FCC) Workshop 2023**

# US - FCC Contributions

## Past Contributions (2015-now)

**SRF:** 800 MHz 5-cell cavity prototype

JLAB

**Magnets/MDI:** IR magnets, MDI, Nb<sub>3</sub>Sn&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 cont'y no esc'n) and the timeline:

- 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  $Q_0 = 3e10$  at 25 MV/m for Booster up to Higgs operation
- b. **R&D on cavities** with  $Q_0 = 6e10$  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):

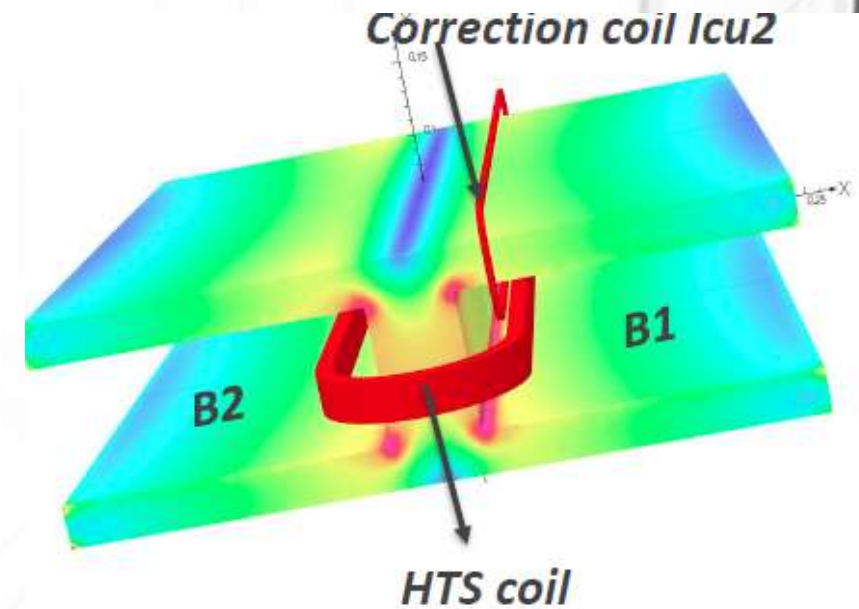
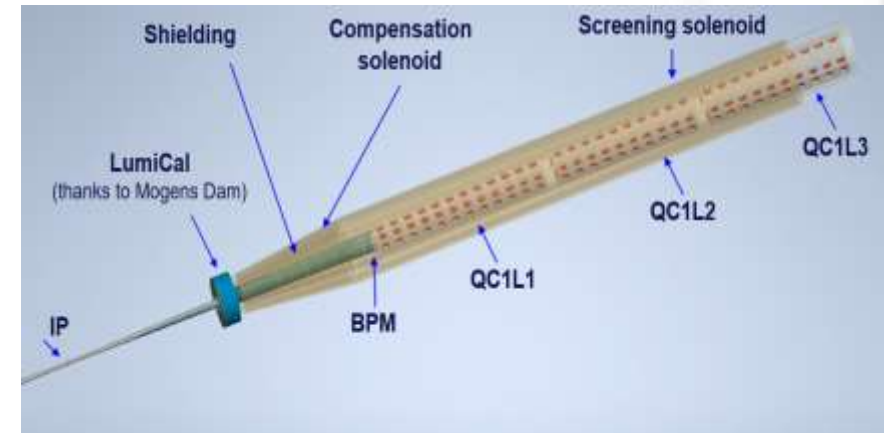
- R&D: comparative analysis of technical options
- Design/Prototype of HTS cable-based solution
- Design/Prototype of PM dipole
- **Decision on construction - tbd**

## 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



# 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:

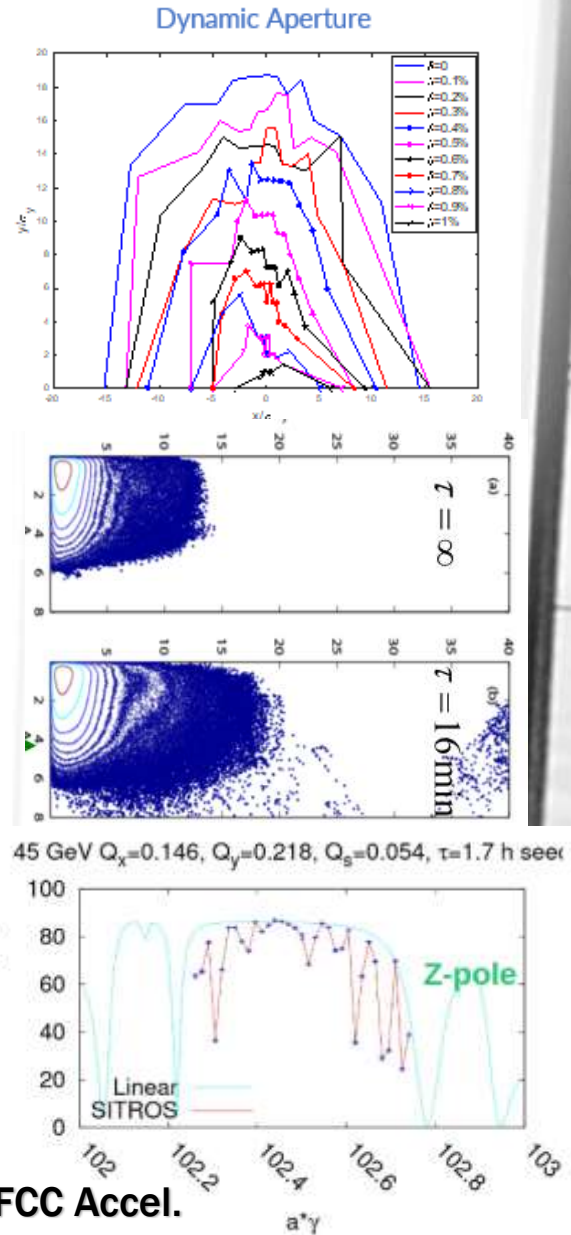
- Modeling/simul: halo formation, background in detectors, instability
- Design: efficient collimation systems (elens/NLO/CS), detector background masking
- **Possible fabrication: collimation system (IRs and Rings)**

## 3) Polarization:

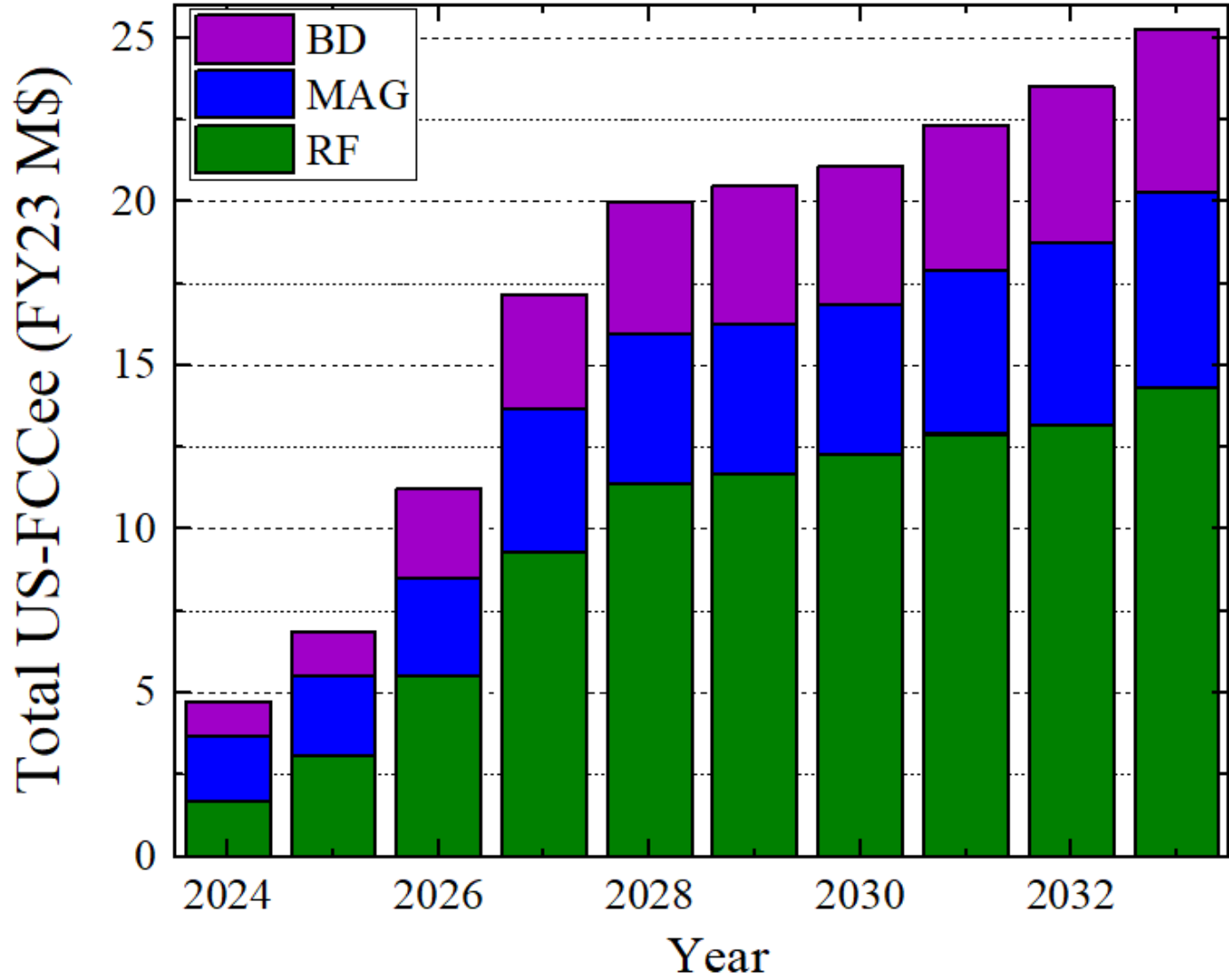
- Modeling/simulations: 45-80 GeV energy calibration, error analysis
- Design: wigglers, polarimeters, polarized sources
- **Fabrication: wigglers for 45 GeV ops and 2 polarimeters, polarized sources**

## 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**

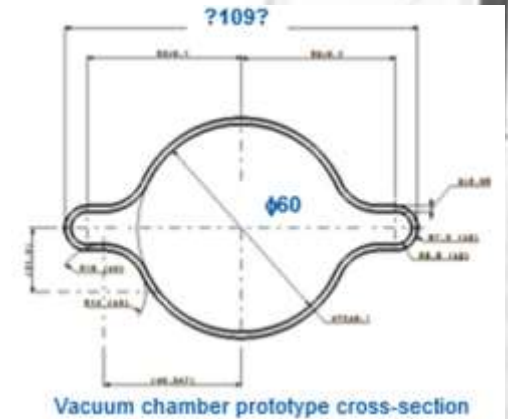
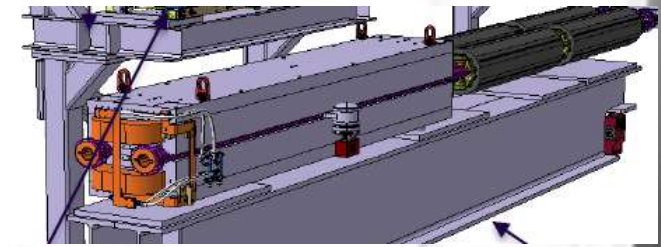
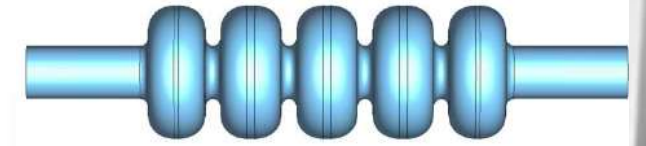
Area	Total M\$	Incl. FTEs
RF systems	95	127
Magnets/MDI	53	116
Design/Dynamics	36	90

**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  $t\bar{t}$ , 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  $t\bar{t}$  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/ <u>modul.</u>	■						■	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.