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Towards the first high-Q treatments for 800 MHz 5-cell elliptical cavities

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Abstract

High-efficiency, high-velocity, sub-GHz elliptical superconducting RF cavities are a critical enabling technology for multiple upcoming accelerator development projects such as for the Powerful Energy Recovery Linac for Experiments (PERLE), and for the Future Circular Collider's (FCC) Booster, and future realizations of its Collider ring. The ambitious quality factor and gradient requirements of these applications require strong SRF R&D programs aimed at developing and optimizing advanced surface processing techniques for 800 MHz cavities. We report the initiation of the 800 MHz R&D program at Fermilab, with the aim of developing high-performance cavities compatible with PERLE and FCC applications.

Motivation

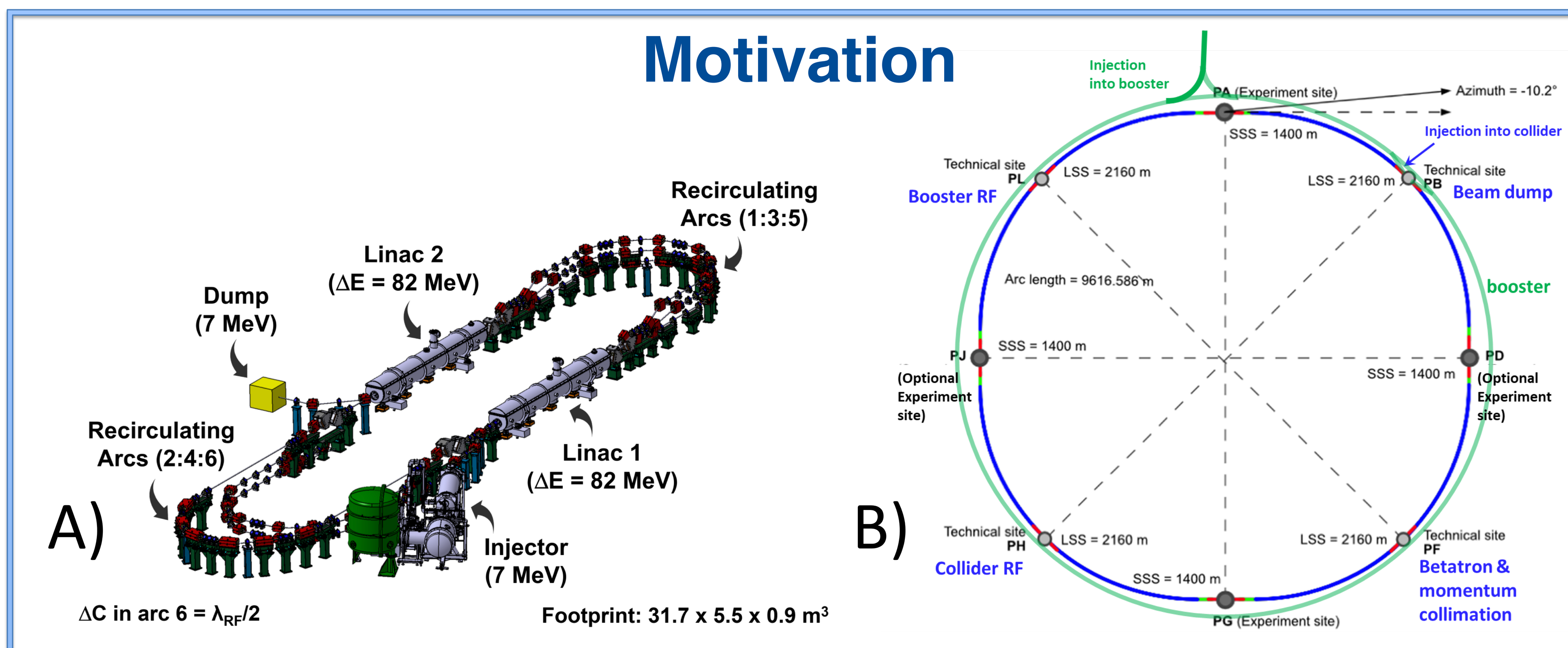


Figure 1: A) PERLE layout, showing the two linac segments that shall employ 802 MHz SRF cavities. B) Final 90.7 km layout chosen, showing 4 interaction regions and 8 surface sites configured for FCC-ee [1,2].

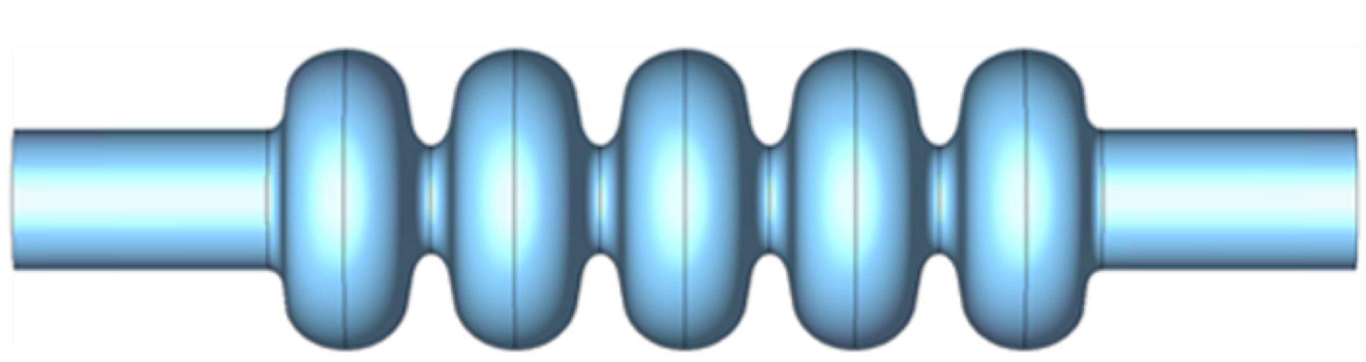
The Powerful Energy Recovery Linac for Experiments (PERLE) aims to generate high-current electron beams in continuous-wave mode. The design has a racetrack-style layout using four four-cavity cryomodules as the primary accelerating structures. From both cost optimization studies, and in order to be compatible with LHC, 801.58 MHz was chosen as the operating frequency [1].

Stage 1 of the FCC is an electron collider (FCC-ee), with phased approaches to Z, W, H, and $t\bar{t}$ physics operation points, to serve first as a Higgs factory, then as an electroweak probe and top factory at the highest planned luminosities. High-Q 800 MHz cavities and cryomodules will comprise a significant fraction of the machine in its final realization [2].

800 MHz Cavities for Booster and $t\bar{t}$ collider

A combination of 400 and 800 MHz RF cavities will function as the primary accelerating structures. While niobium-on-copper (Nb/Cu) is under development for the 400 MHz resonators, the high quality-factor and gradient needs at 800 MHz require boundary-pushing performance from superconducting bulk niobium.

Figure 2: 5-cell elliptical 800 MHz cavity design for FCC. 24, 56, 112, and 600 cavities are needed for Booster at Z, W, H, and $t\bar{t}$ physics operation points respectively, with an additional 488 for the $t\bar{t}$ collider.



- **Desired performance:**
  - **E_{acc} = 20 MV/m, Q0 = 3.0x10^{10} in operation**
  - **E_{acc} = 24.5 MV/m, Q0 = 3.8x10^{10} in vertical test**

800 MHz cavity R&D

A 5-cell prototype fabricated at Jlab has been successfully baseline electropolished [2]. It is currently being prepared for mid-T baking and vertical testing at FNAL [3]. 1-cell cavity design and drawings have also been produced by FNAL for fabrication at CERN, and will be used to explore and refine mid-T baking, N-doping, and Nb3Sn advanced high-Q RF surface processing recipes.

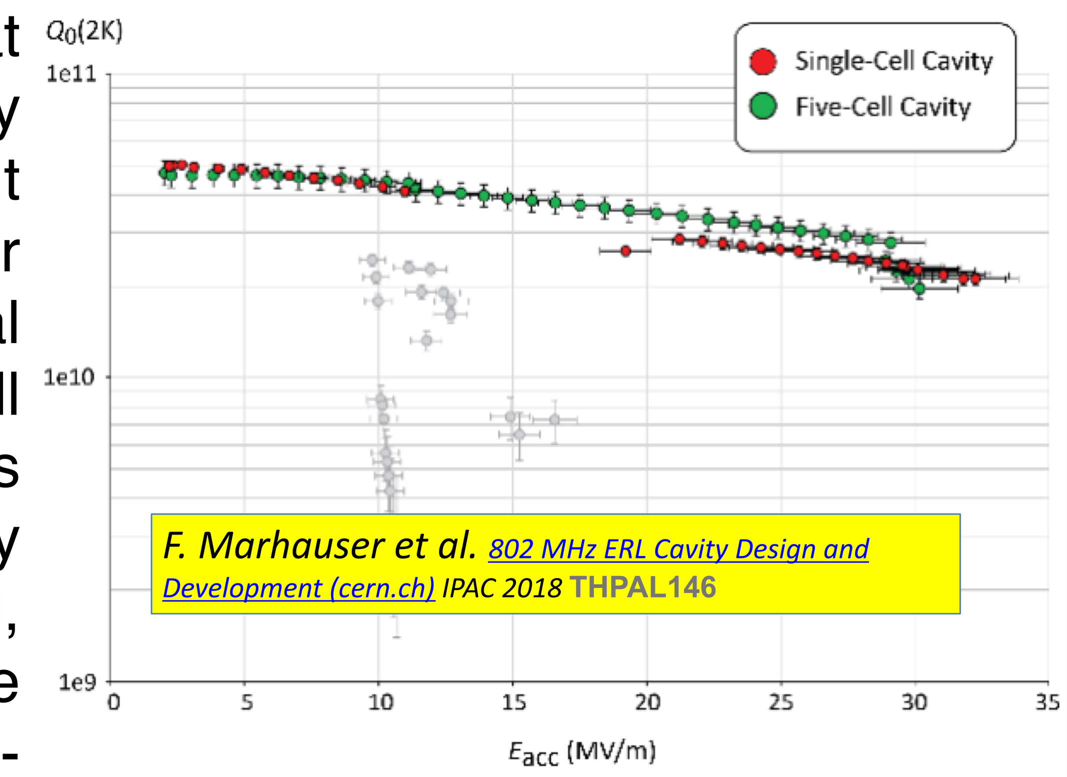


Figure 3: Combined vertical test results for the 5-cell and 1-cell cavities after electropolishing (EP), measured at 2 K.

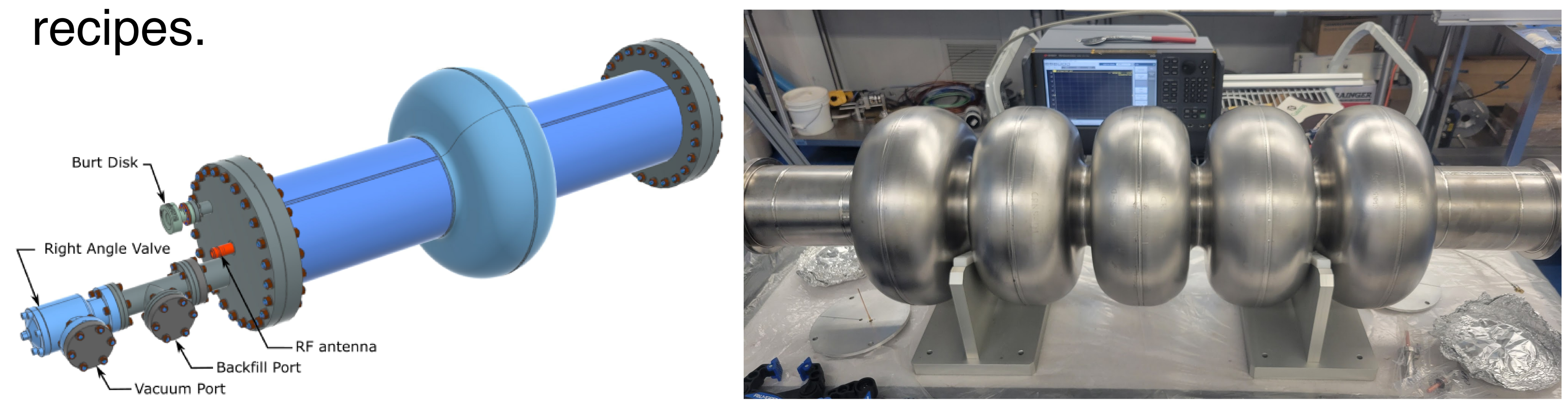


Figure 4: (Left) FNAL1-cell cavity design, prepared for fabrication in-house at CERN. (Right) Jlab fabricated 5-cell 800 MHz prototype cavity, under preparation for mid-T baking and vertical testing at FNAL.

Ongoing 800 MHz cryomodule development

Through collaborative efforts with CERN, FNAL has developed a CM design that aligns with the overarching requirements for both transverse and longitudinal dimensional envelopes, as well as for the main cryogenics and vacuum interfaces, to facilitate the transportation and installation processes within the tunnel infrastructure. Drawing on PIP-II design, four 800 MHz SRF cavities are bottom-supported on a room temperature strongback. In addition to considerable design experience, FNAL has world-leading expertise in cleanroom and cryomodule assembly, including robot-assisted cleanroom processes, cryomodule transportation, and cold testing.

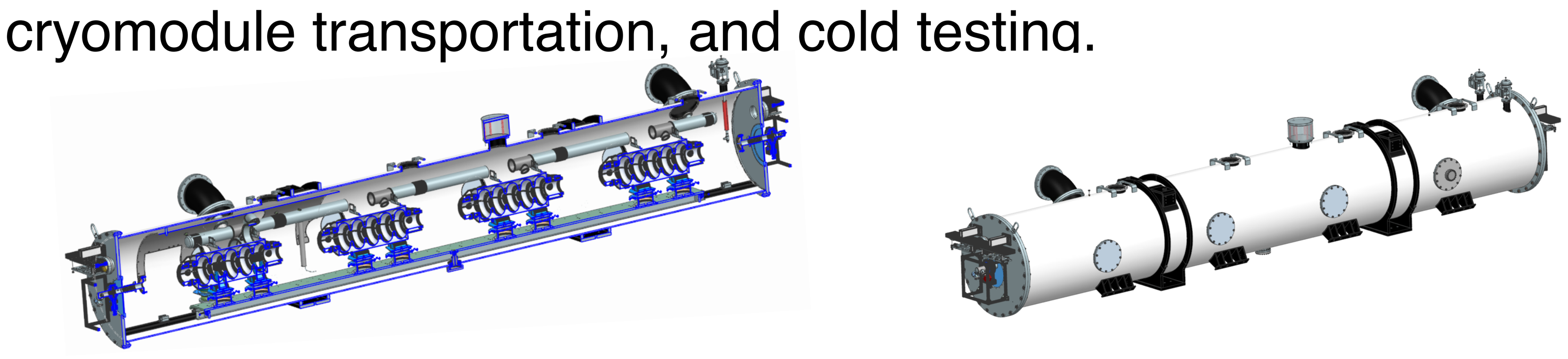


Figure 6: External (top) and internal (bottom) views of the segmented FCC 800 MHz cryomodule design.

Conclusions

Upcoming projects such as PERLE and FCC-ee drive the need for high-efficiency 800 MHz cavities, motivating a R&D program aimed at optimizing advanced, high-Q surface processing techniques. Prototype cavities have been fabricated and have initiated preliminary studies, which will progress rapidly after the completion of the 1-cell R&D cavities. In parallel, 800-MHz CM designs have been explored.

References

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Acknowledgements

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