Experiments on a conduction cooled SRF cavity with field emission cathode

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NAPAC 2022

8 Aug 2022

In partnership with:

Northern Illinois Center for Accelerator and Detector Development

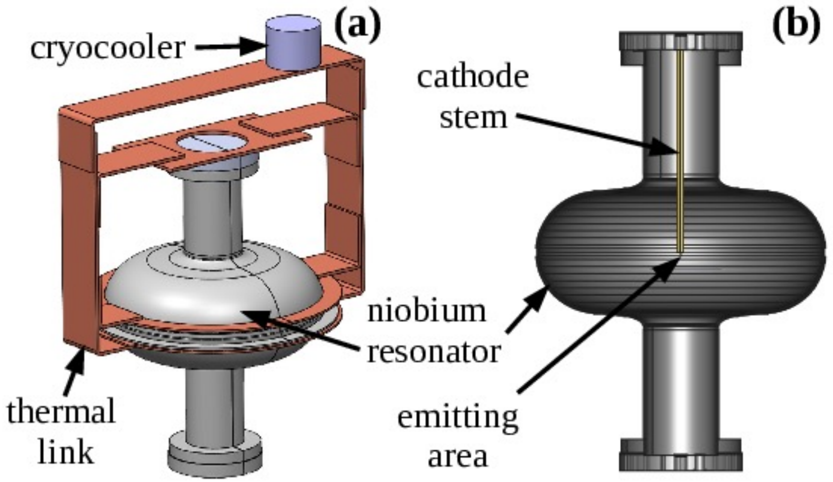
The Need for High Repetition Rate High Current Electron Source

- The goal of present work
  - Design and build an SRF cavity with a field emission cathode
  - Do preliminary experiment of the accelerating gradient and the quality factor

- Emerging industrial application of high-power E-beam accelerators
  - Medical device sterilization
  - Wastewater treatment
  - See WEZE3 talk for more applications

- Industrial settings requires small footprint, high power, high reliability.
  - High power can be achieved using high current sources; for example, high repetition rate field emission cathode
  - Field emission cathode housed in a SRF cavity can be operated in the CW mode to obtain high average current
  - The SRF cavity can be conduction cooled using 4K cryocoolers to make the accelerator compacted and reliable

Field Emission Array Inside a SRF Cavity Forms a High Current Cathode



- Utilizing the strong RF field inside SRF cavity to generate electron with field emission array
  - High current cathode
  - Simple design
  - Repetition rate at RF frequency
  - Reduce footprint

- Study the cavity performance with the emission array support rod
  - Determine if we can generate strong enough EM field

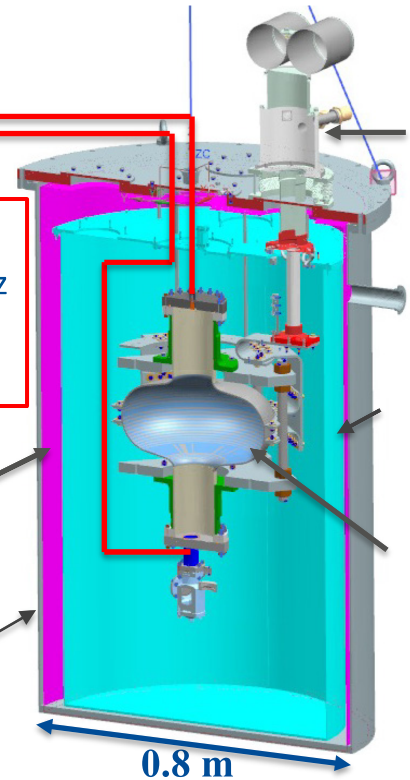
- Field emission array is not installed
  - Only studying the Cavity performance

The Conduction Cooled SRF Cavity Set-up

R.C. Dhuley *et al.*, ***IOP Conf. Ser.: Mat. Sci. Eng.***, 2020. https://doi.org/10.1088/1757-899X/755/1/012136

Euclid Techlabs

RF system
- 10 W cw @ 650 MHz, 1.3 GHz
- Resonance locking
- P_f, P_r, P_t, τ_L measurements



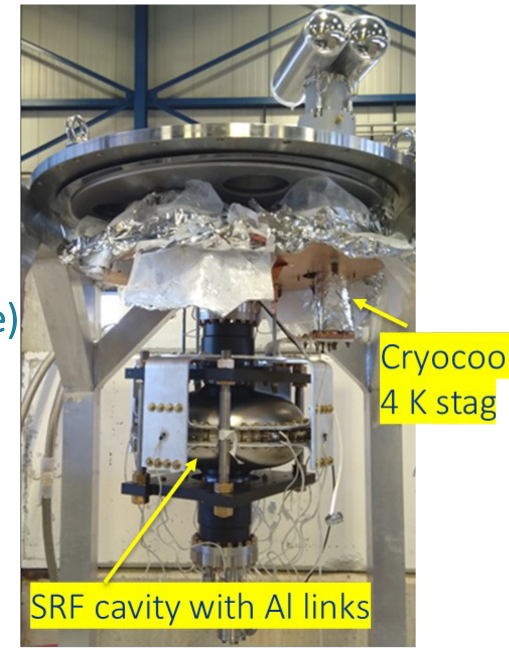
Two-stage cryocooler
- 55 W @ 45 K
- 2 W @ 4.2 K

Thermal shield
(cooled by the 45 K stage)

Magnetic shield
(~15 mG)

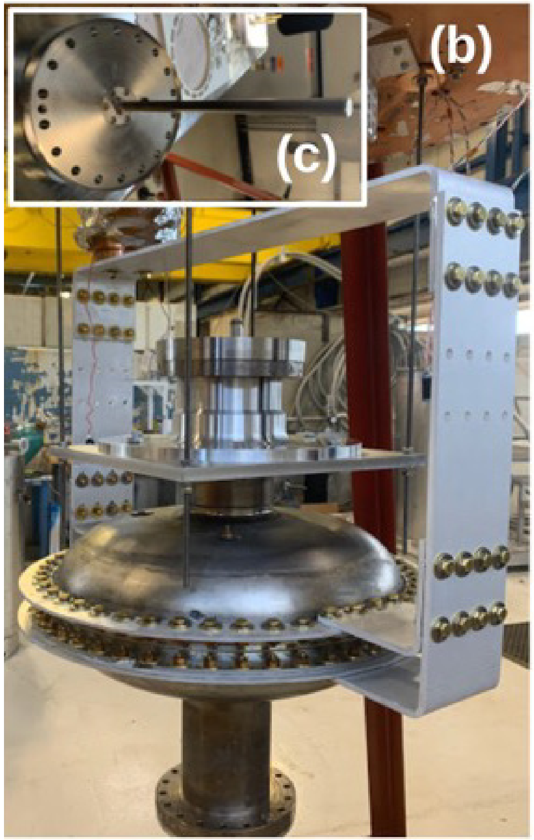
SRF cavity with Al link
(cooled by the 4 K stage)

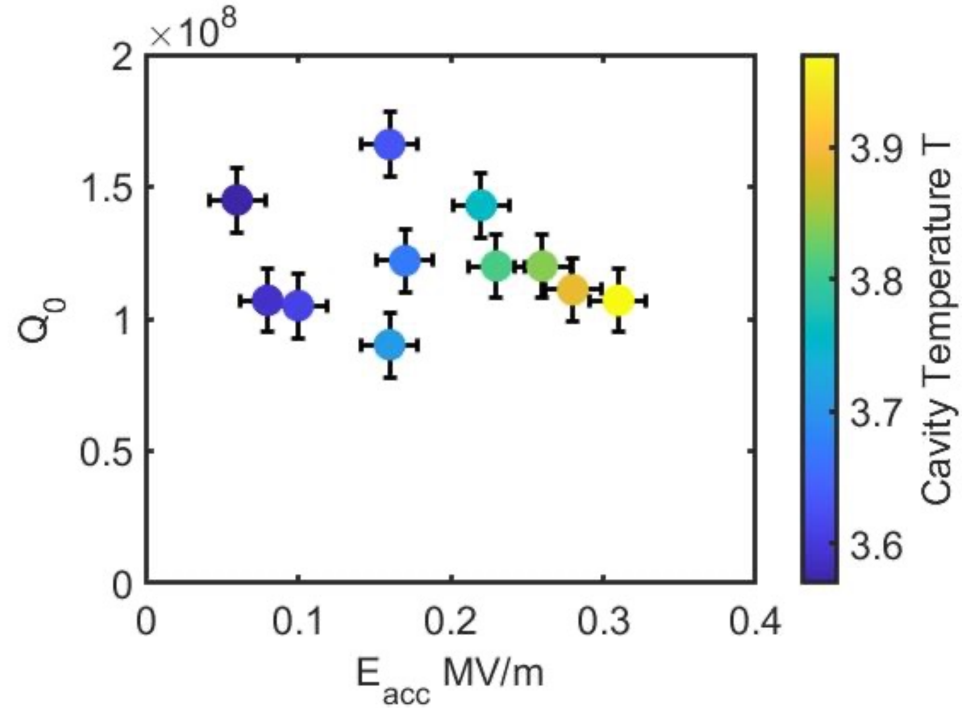
Vacuum vessel



- With out the cathode, the Cavity achieved 10 MV/m at Q_0= 2× 10^{10}
- This experimental set-up is used to measure the cavity with cathode

The SRF Cavity with Emitter Rod, Design Goal and preliminary Measurement





- Emission Rod made of Niobium
- Tip of the rod located at peak field
- The Rod is 22cm long

Design Goal

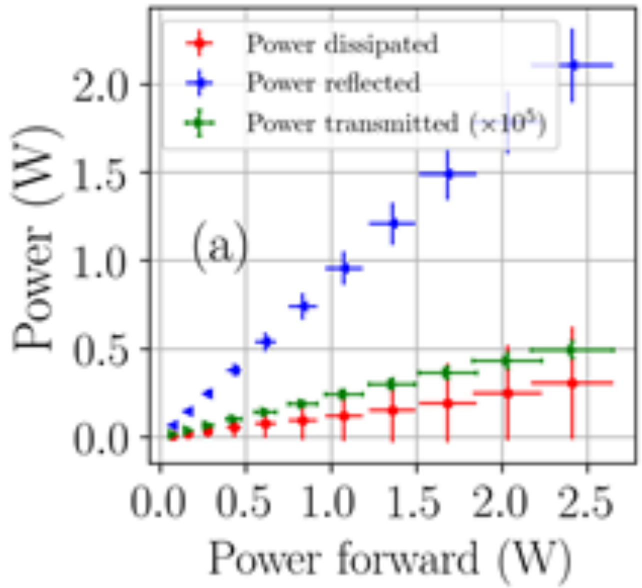
- $Q_0 \sim 10^8$
- $E_{acc} \sim 1\ MV/m$
- $peak\ E_{acc} \sim 8\ MV/m$

Experiment measurement

- $Q_0 = 1.4 \times 10^8$
- $E_{acc} \approx\ 0.32\ MV/m$
- $peak\ E_{acc} \approx 2.56 MV/m$

Fermilab

How Is The Performance Limited?



- Low coupling caused low power dissipation and low energy stored.

$$U = \frac{4\beta P_f}{(\beta+1)^2}\frac{Q_{cav}}{\omega} \quad with\ \beta = \frac{Q_{coupler}}{Q_{cav}}$$

Stored energy maximized at $\beta = 1$, $\beta \approx 0.03$ measured

- The emitter rod is not fully cleaned and not coated, thus limiting the Q-factor of the rod and flange

- Ideal coupling could improve cavity performance to 0.6 MV/m
- Coating the emission Rod with Nb_3Sn could also increase the cavity performance by 40%

Summary and Future Plans

- SRF cavity with field emission cathode shows promise
- The Q-factor and accelerating gradient of SRF Cavity with field emission support rod under conduction cooling was measured.
  - $Q_0=1.4\times10^8$
  - $E_{acc}=0.32$ MV/m
- Future Plans
  - Potential increase antenna surface to improve coupling.
    - Ideal coupling could improve to 0.6 MV/m .
  - Coat the rod and flange with Nb3Sn could improve performance by another 40%.

Collaborators

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Acknowledgement

This presentation has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics. Research funded by an Accelerator Stewardship grant to Fermilab by U.S. Department of Energy, Office of Science, Office of High Energy Physics. This work was supported by the US Department of Energy (DOE) under contract DE-SC0018367 with Northern Illinois University.