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Developing conduction-cooled SRF cavities and first test results

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(with contributions from Fermilab AD/ME and APS-TD/SRF teams)

February 4, 2020
Work group 4, TTC 2020, CERN

This manuscript 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

Motivation: develop SRF accelerators for industrial applications

Electron beam radiation processing

- Requirements: high power electron beams 0.5-10 MeV, with very high beam power > 100 kW
- Applications:
  - Water/sludge decontamination
  - Flue gas cleanup
  - Environmental remediation
  - Medical waste sterilization

http://accelconf.web.cern.ch/AccelConf/napac2016/talks/thb3io02_talk.pdf

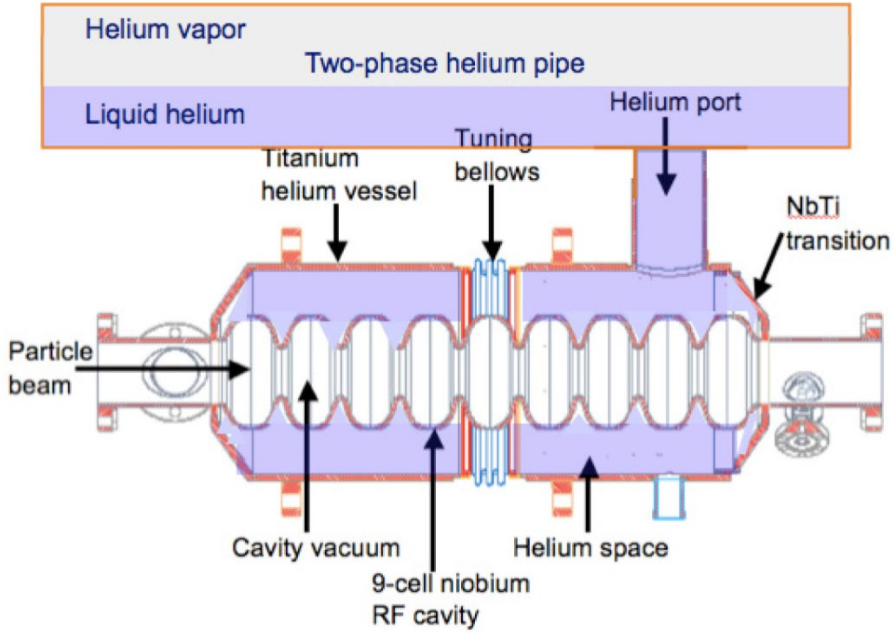
A meter long SRF linac

- E_{acc} 10 MV/m
- cw for high beam power

Industrial settings require:

- Low capital and operating cost
- Robust, reliable, turn-key operation

SRF accelerators rely on LHe, which makes them complex machines



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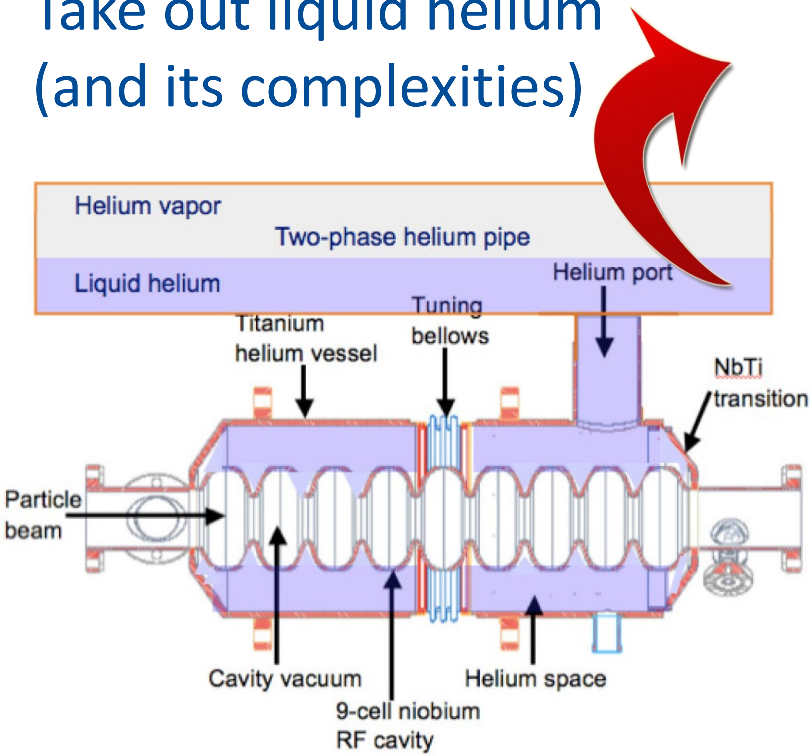
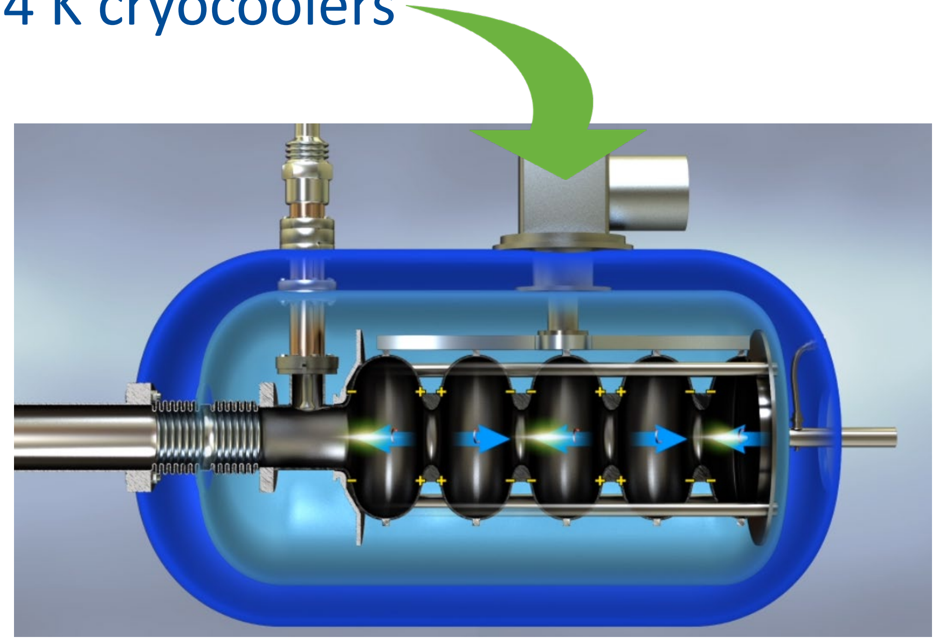
Need: simplify SRF accelerator cryogenics

Take out liquid helium (and its complexities)



Cool SRF cavities conductively with 4 K cryocoolers

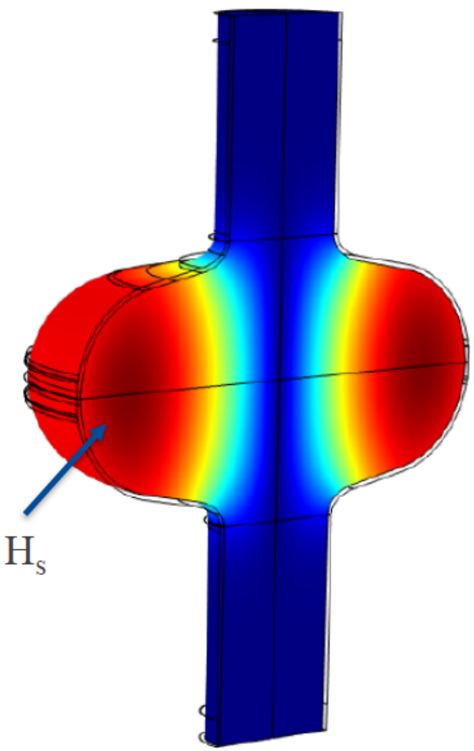


Goals:
- Practical design of a thermal conduction link
- Demonstration of 10 MV/m cw gradient

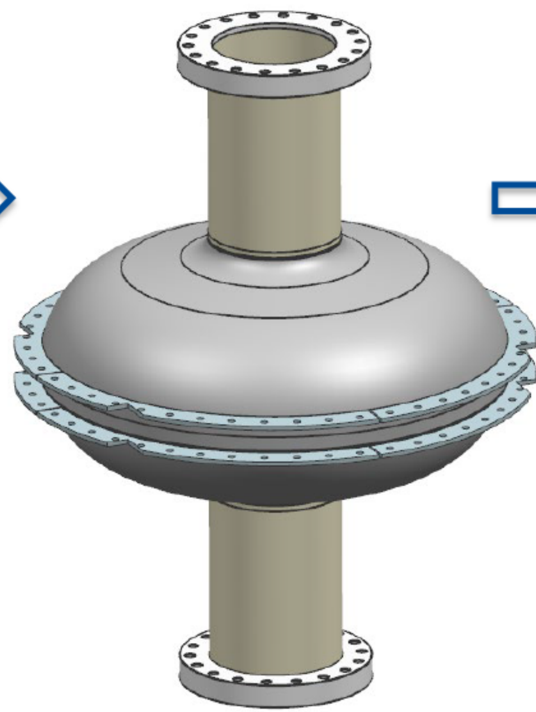
Conduction cooling for SRF cavities: Design approach

Dissipation is prominent near the equator

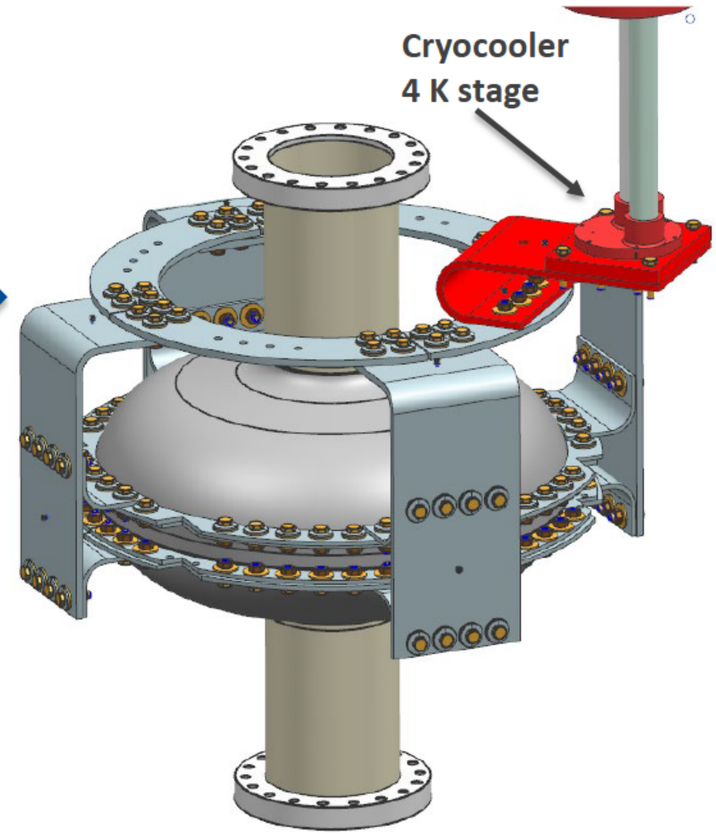
$$P_{diss} = \frac{1}{2} R_s \oiint |H_s|^2 ds$$



Weld niobium rings around the equator to extract dissipation



Connect cavity to cryocooler with a thermal conduction link

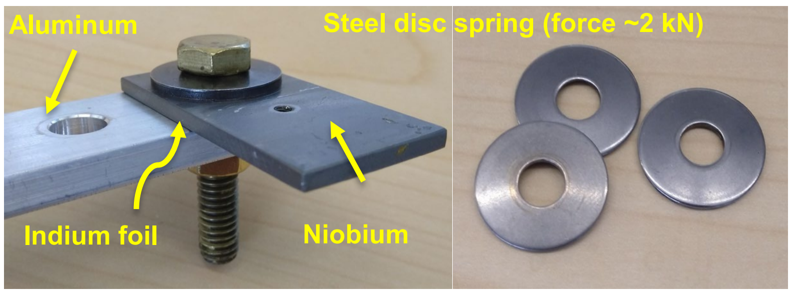


Design of thermal link

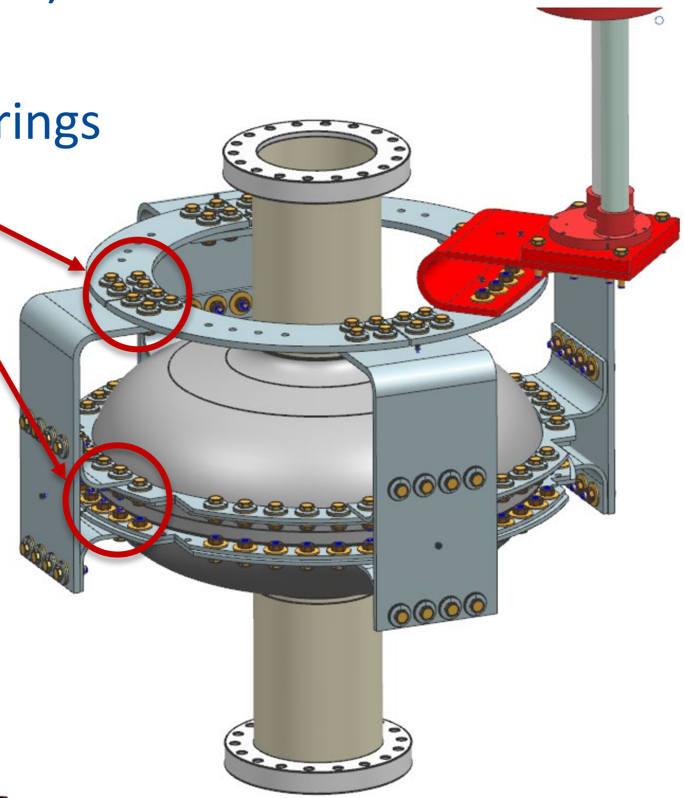
Material: High purity aluminum (5N or 99.999% pure)

Connection method: bolting, pressed using disc springs

Thermal design of pressed contacts established via contact resistance measurements on small samples

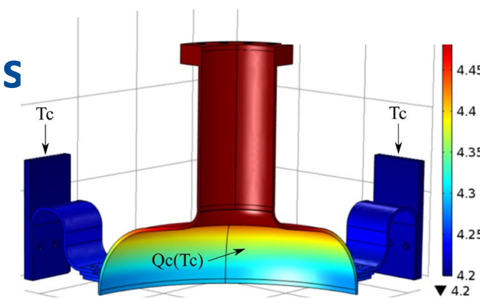


R.C. Dhuley, M.I. Geelhoed, J.C.T. Thangaraj, *Cryogenics* 93, 86-93, 2018

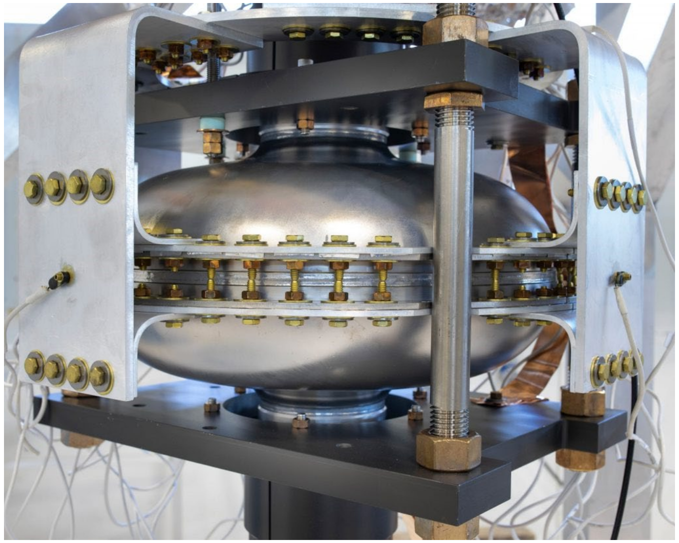


Physical design via thermal simulations

R. Dhuley, R. Kostin, S. Posen *et al.*, *IEEE TAS* 29(5), 0500205, 2019



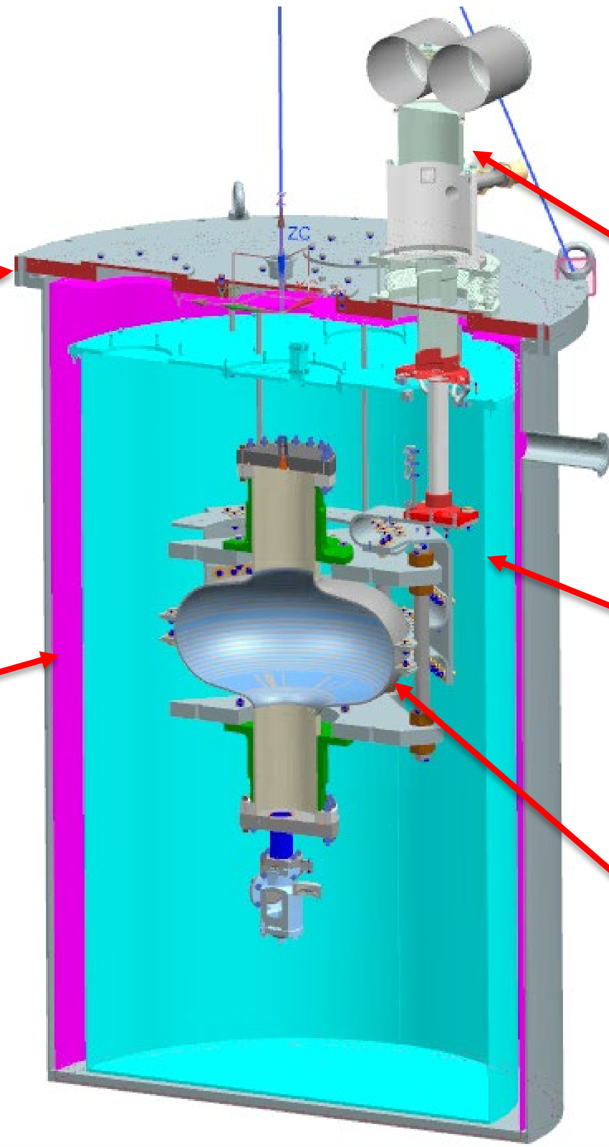
New test cryostat



Cavity bolted with thermal conduction links

Test setup

New test cryostat



Vacuum vessel

- 5 feet tall

Magnetic shield

- <10 mG total field at the cavity location

Cryocooler

- Cryomech PT420 (2 W @ 4.2 K with 55 W @ 45 K)

Thermal shield

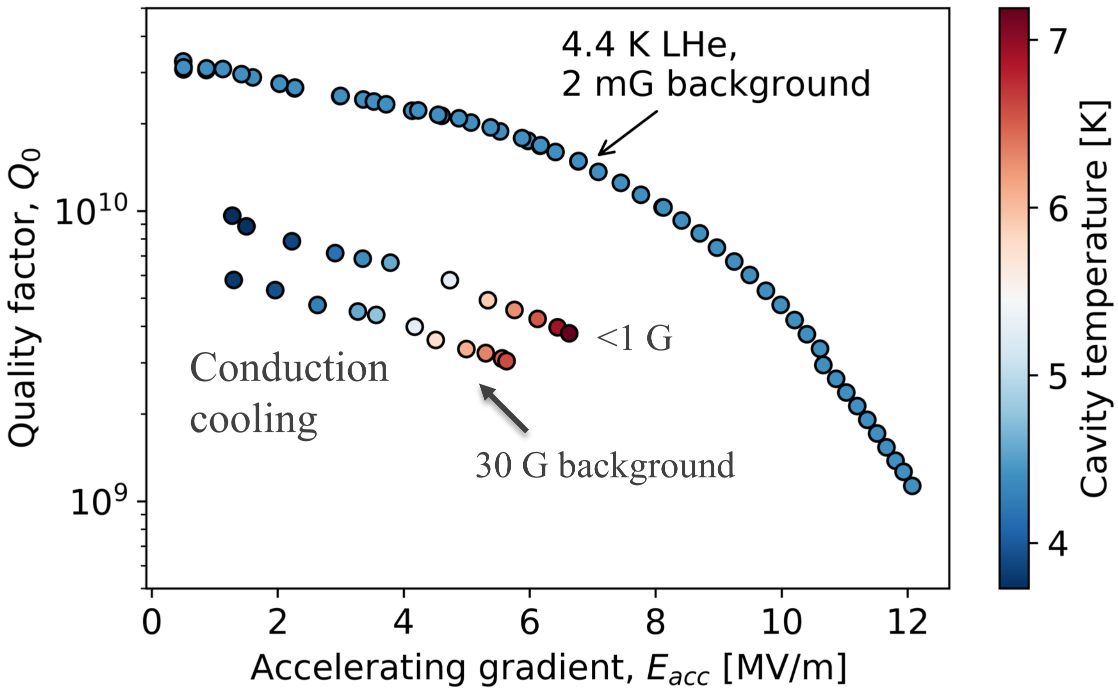
- Cooled by cryocooler stage-1

SRF cavity

- Cooled by cryocooler stage-2
- 650 MHz, Nb_3Sn

First results

Q_0 *vs.* E_{acc} for 650 MHz Nb_3Sn cavity

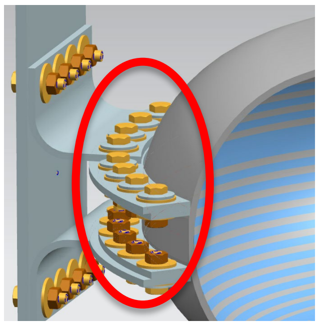


VTS baseline

- Q_0 $3x10^{10}$ at E_{acc} 1 MV/m
- E_{acc} 12 MV/m (power limit)

Conduction cooling

- Q_0 $5x10^9$ at E_{acc} 1 MV/m
- E_{acc} 5.5 MV/m (power limit)

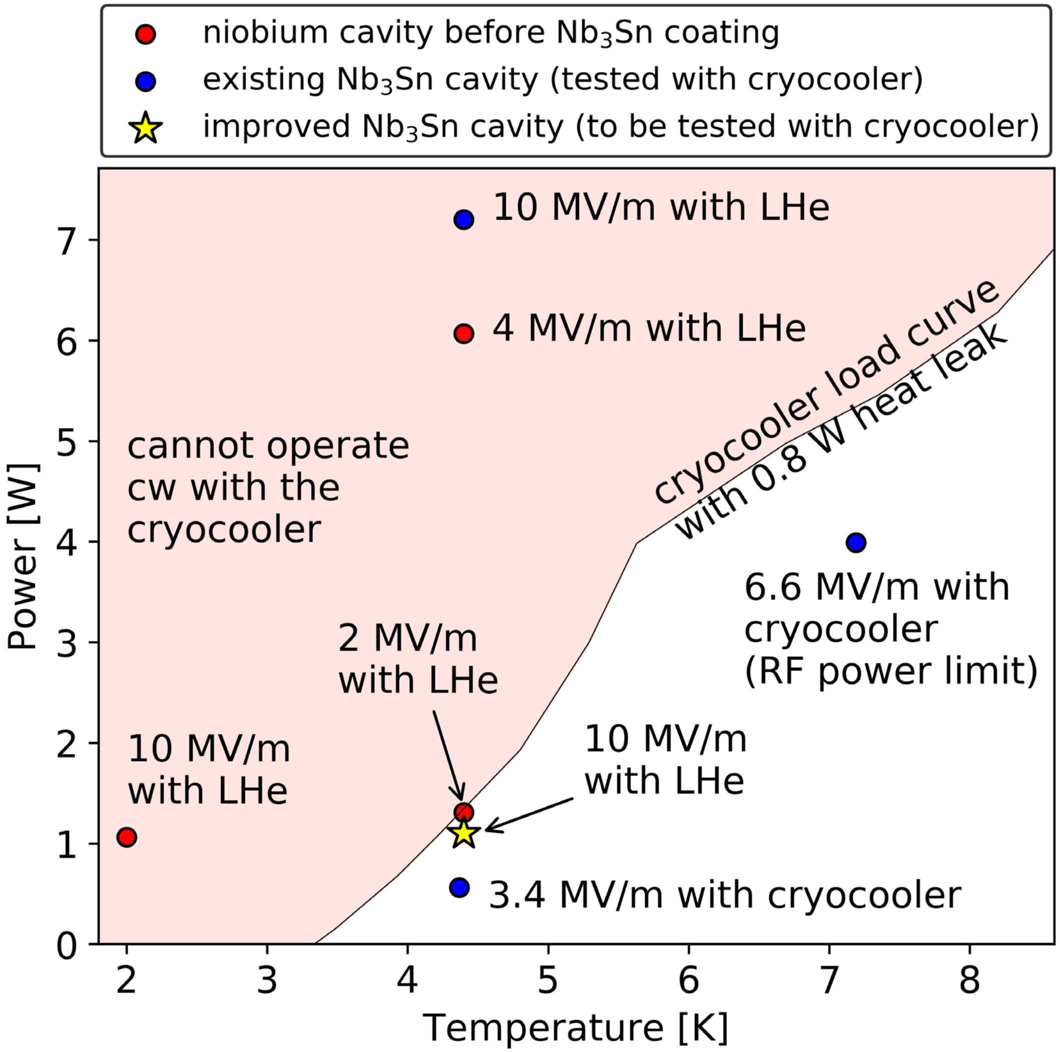


disc springs
~30 G

with <1 G disc springs

- Q_0 $1x10^{10}$ at E_{acc} 1 MV/m
- E_{acc} 6.6 MV/m (power limit)

Progress, lessons so far…



Niobium cavity

- limited in performance with 4 K cryocoolers

Nb_3Sn cavity

- Performance not limited by cryocooler capacity at 4.2 K. E_{acc} can be pushed up by letting the cryocooler operate warmer than 4.2 K.
- Better coating and magnetic hygiene is needed to reach 10 MV/m cw.

Improved Nb_3Sn coating

- New coating has produced 10 MV/m in VTS with dissipation manageable with the cryocooler at 4.4 K.

Summary and future work

Development of conduction cooling for SRF

- Practical thermal link design
- Experimental setup ready
- First results are promising
    - 6.6 MV/m cw recorded on a single cell 650 MHz Nb_3Sn cavity

Activities: ongoing and planned

- Improve magnetic hygiene of our cryostat
- Test with improved Nb_3Sn coating
- Identity and mitigate potential microphonics due to cryocooler vibrations

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.

Conduction cooled SRF demonstration
- Fermilab LDRD
- Accelerator Stewardship award from US DOE/SC/HEP

Infrastructure for Nb_3Sn coating at Fermilab
- Fermilab LDRD
- DOE Early Career Award (S. Posen)

Thank you

Extra slide - Test setup: RF driver and control system