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A conduction-cooled SRF cavity: Apparatus and first results

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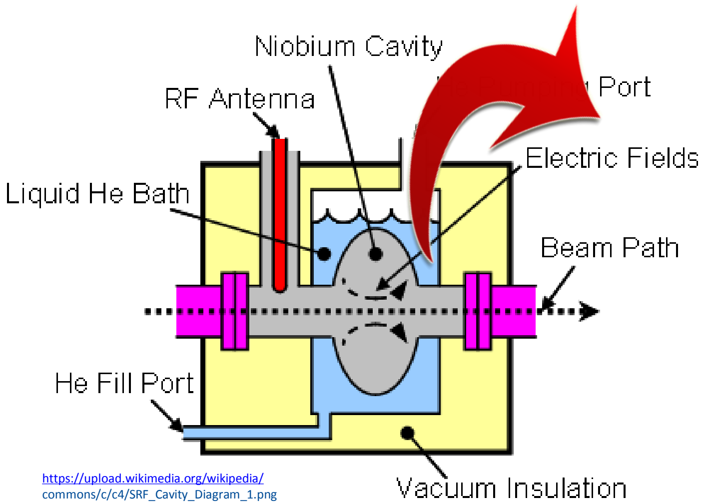
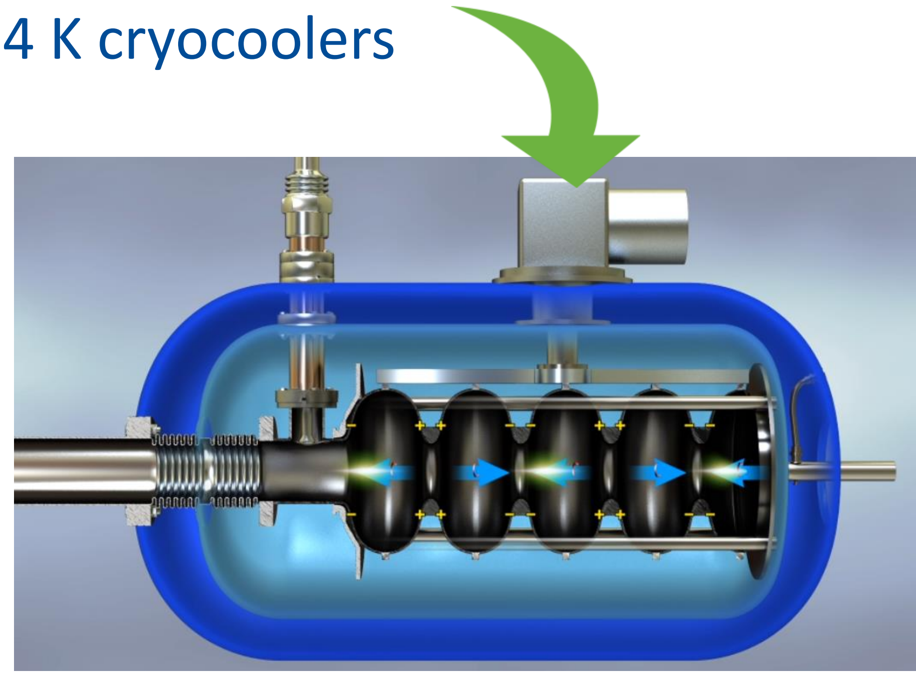
Goal: To demonstrate cryogen-free SRF cavity operation

Take out liquid helium (and its complexities)



https://upload.wikimedia.org/wikipedia/commons/c/c4/SRF_Cavity_Diagram_1.png

Cool SRF cavities conductively with 4 K cryocoolers



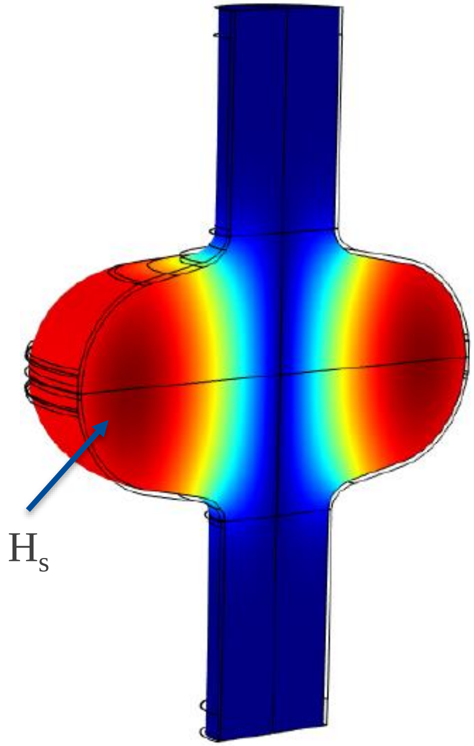
Key thermal design criterion

- SRF cavities dissipate heat during operation (dynamic heat load)
- Cryocoolers have limited 4 K cooling capacity
- Need a high thermal conductance link to extract this dynamic load and transport to the cryocooler.

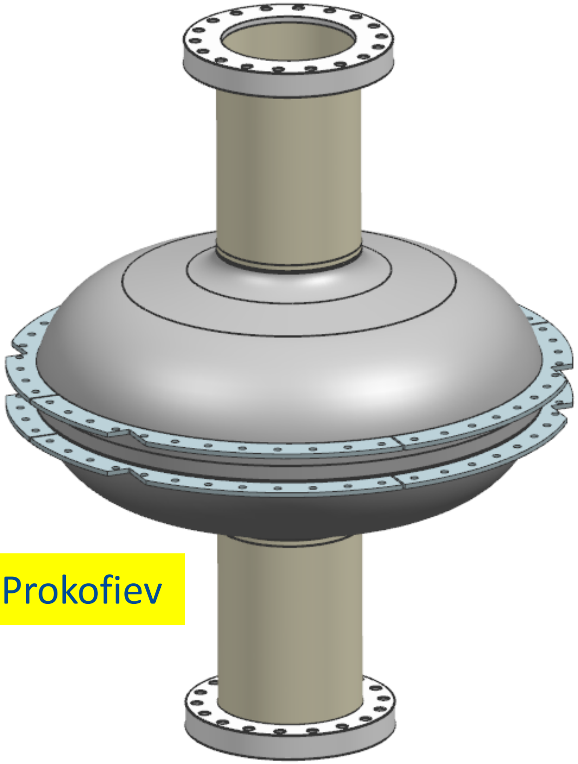
Cavity-cooler thermal link: Our design approach

Surface magnetic fields dissipate most heat near the equator

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



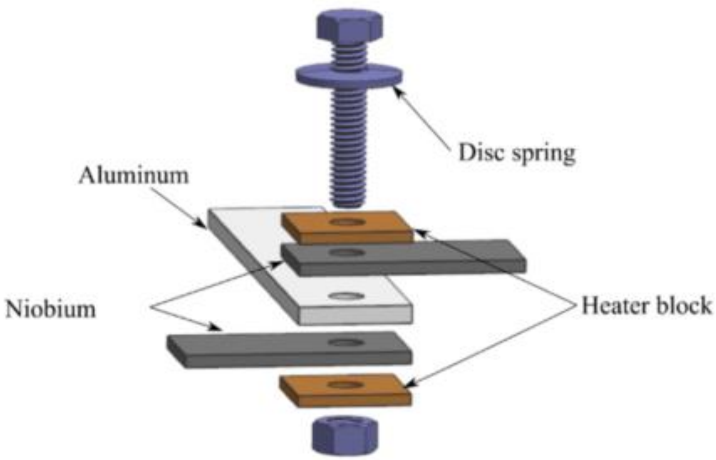
E-beam weld niobium rings around the equator to attach a thermal link



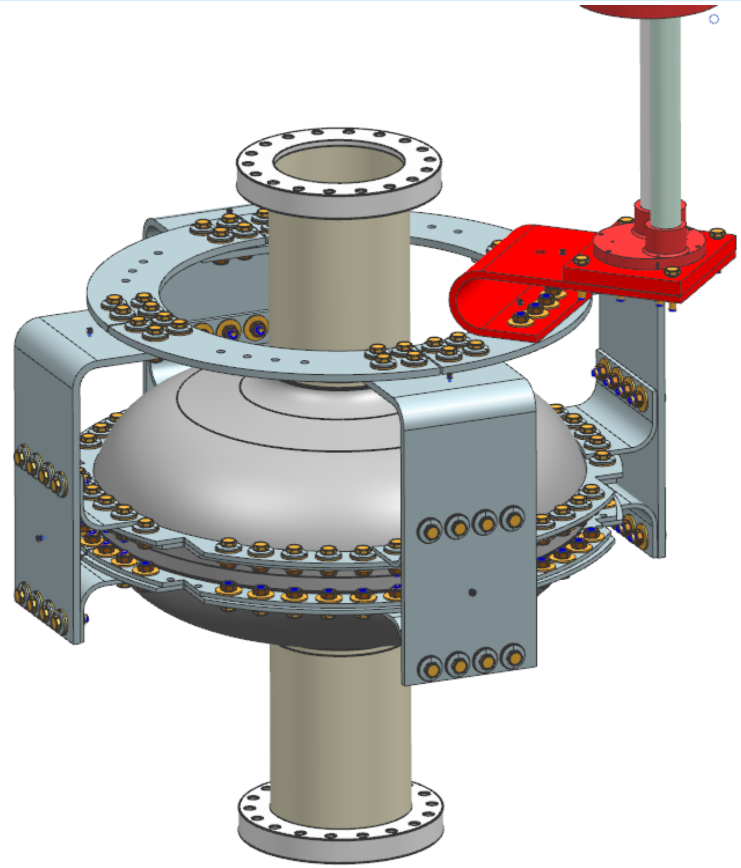
Cavity-cooler thermal link: Our design approach

Use high purity (5N) aluminum as the thermal link material

Measure and design low thermal resistance pressed niobium-aluminum contacts



R. C. Dhuley et al., *Cryogenics* 93, 86-93, 2018



Construct a thermal link for distributed cooling around the cavity equator

R. C. Dhuley et al., *IEEE TAS* 29(5), 0500205, 2019

Conduction cooled cavity test setup

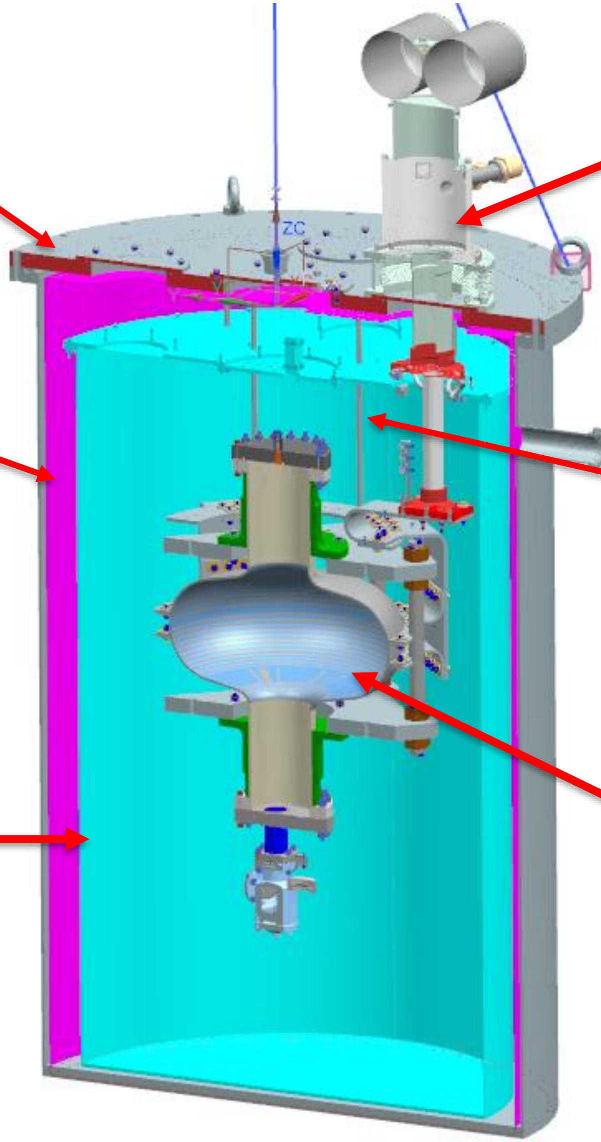
Vacuum vessel
- SS304
- 5 feet tall

M. Alvarez

Magnetic shield
- MuMetal
- Room temperature
- <10 mG total field at the cavity location

I. Terechkine

MLI wrapped thermal shield
- Cooled by cryocooler stage-1
- Copper 101 top plate
- Aluminum 1100 shell

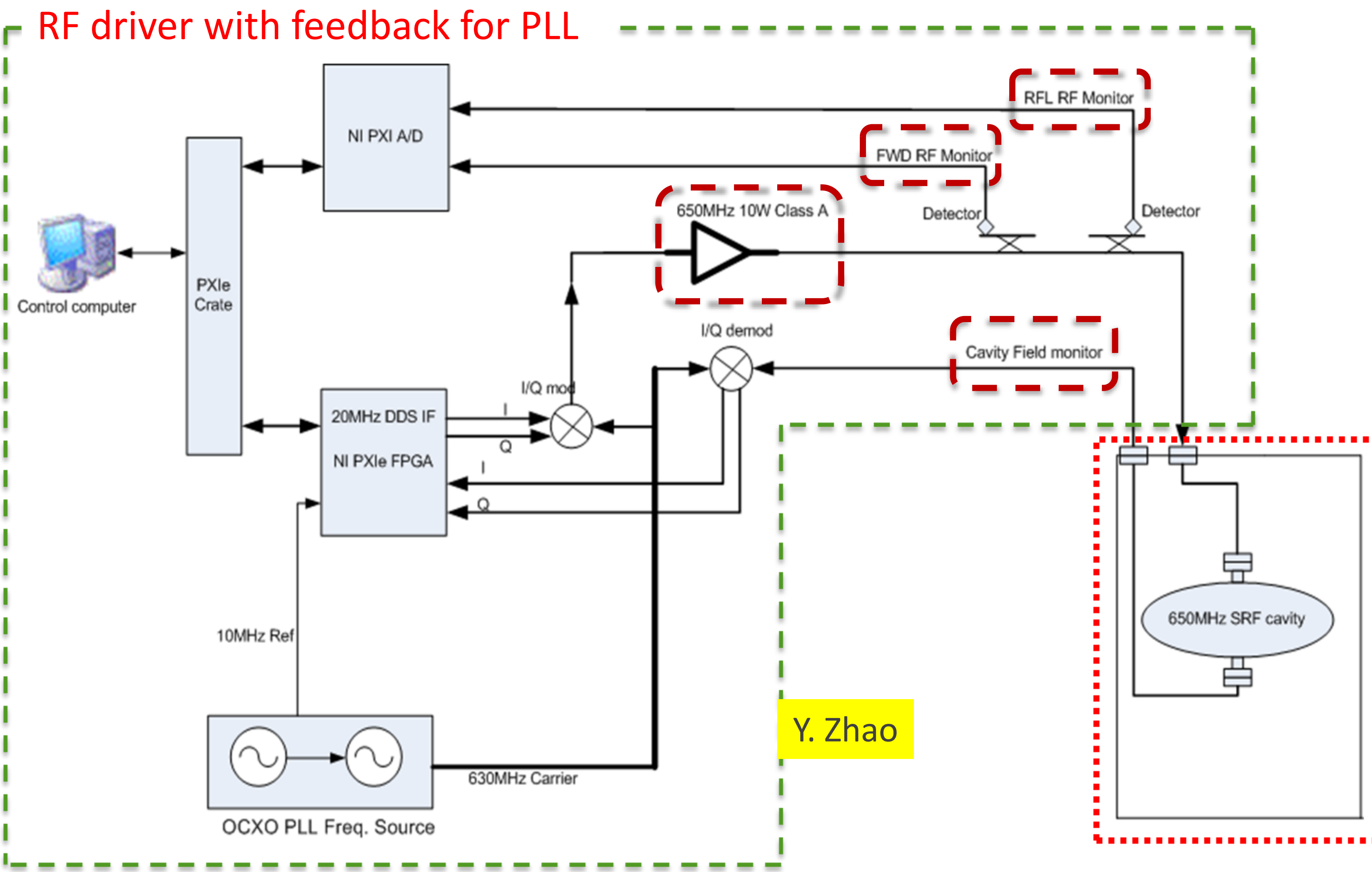


Cryocooler
- Cryomech PT420 (2 W @ 4.2 K with 55 W @ 45 K)

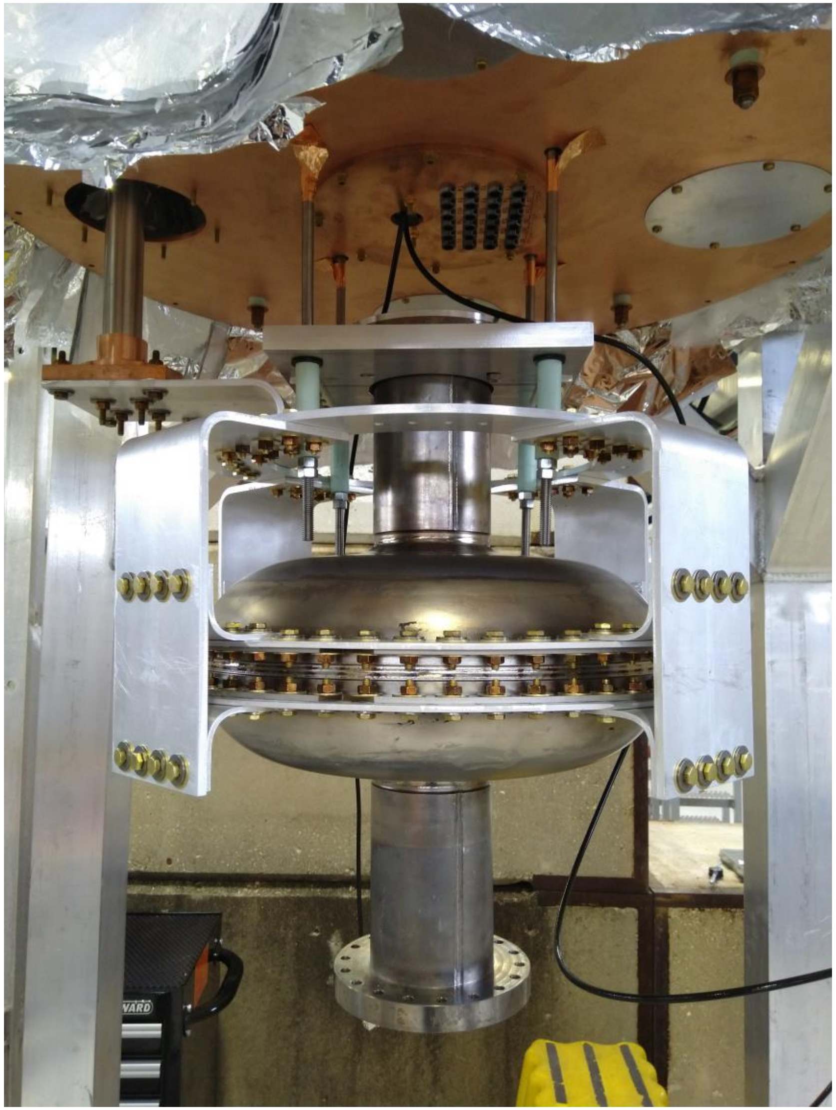
Cavity and shield supports
- Ti64 rods

SRF cavity
- Cooled by cryocooler stage-2
- Elliptical single cell, 650 MHz
- Niobium or Nb_3Sn coated

Conduction cooled cavity test setup



Conduction cooled cavity test setup



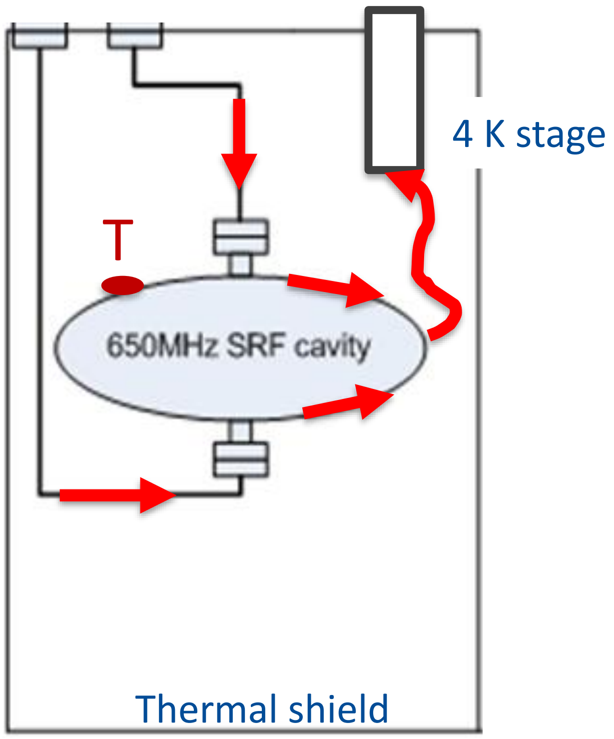
Cool down characteristics

The cryostat cooled to its base temperature within 24 hours

- Cryocooler stage I < 30 K, thermal shield top plate ≈ 32 K
- Cryocooler stage II ≈ 2.95 K
- Cavity cell ≈ 5 - 5.8 K (measured at multiple locations)

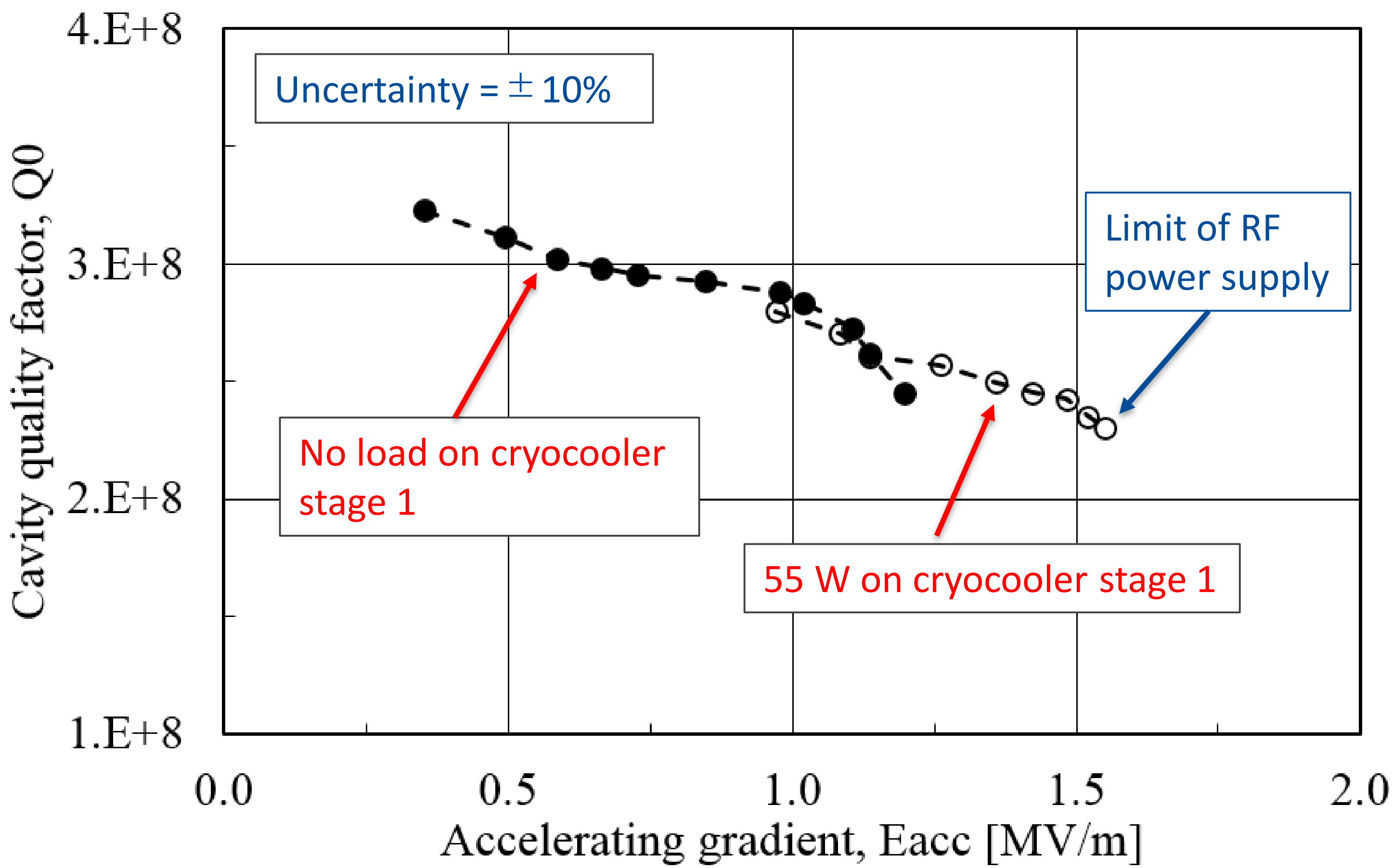
A possible reason for the significant cryocooler-cavity ΔT

- The estimated heat leak to cryocooler 4 K stage is ≈ 450 mW, mostly coming *via* the RF cables
- This heat flows through the cavity body (4 mm thick niobium), then through the thermal link, and into the cryocooler



First results: Accelerating gradient > 1.5 MV/m

- First measurements used a single cell, 650 MHz, niobium cavity
- Cryocooler had available ~1.55 W @ 4.2 K after accounting for the static leaks



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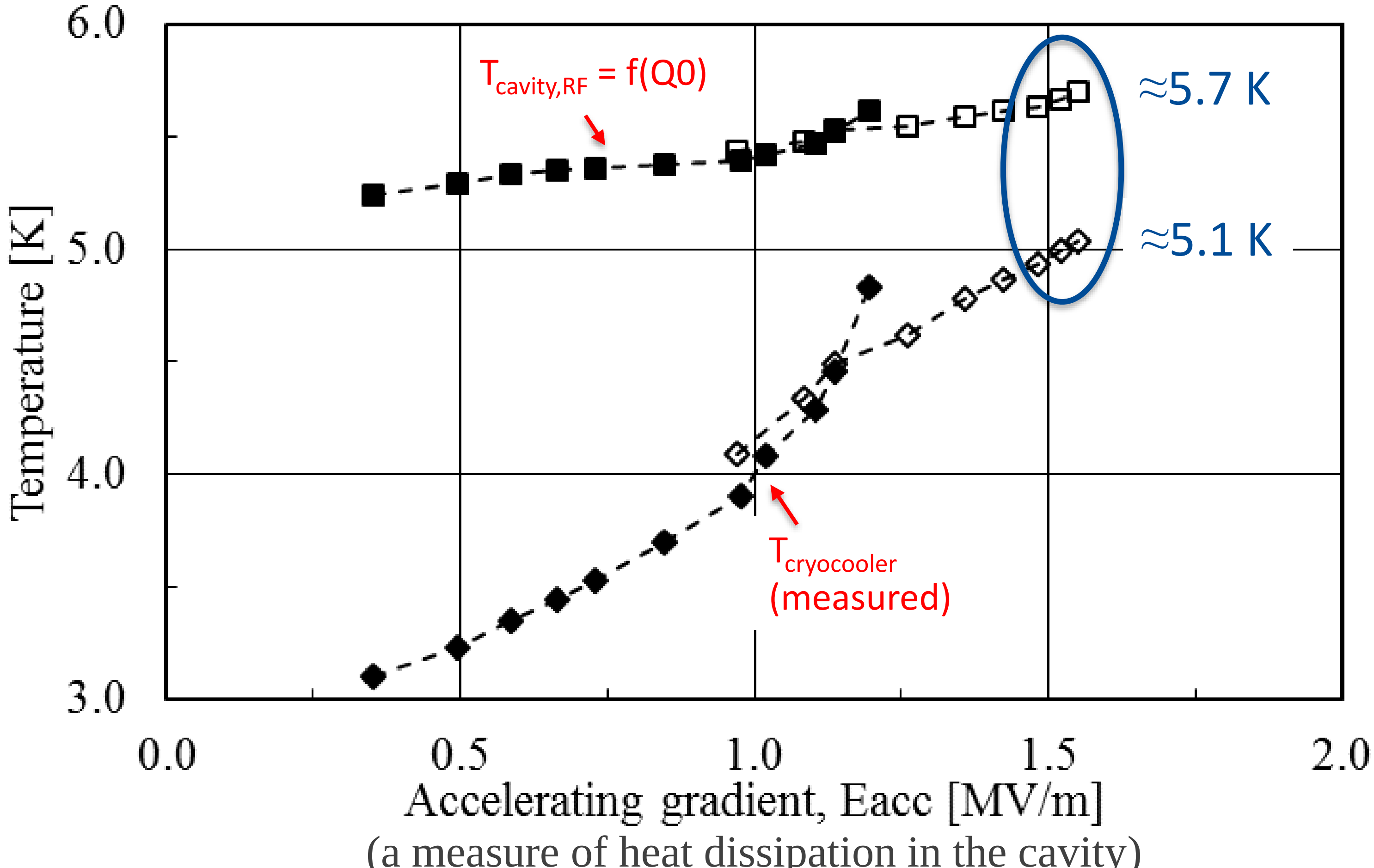
Projections for a Nb_3Sn coated cavity with the existing link

Need to know the cavity RF surface and cryocooler temperatures

- $T_{cavity,RF}$ is estimated from Q_0, $T_{cryocooler}$ is measured



Projections for a Nb_3Sn coated cavity with the existing link

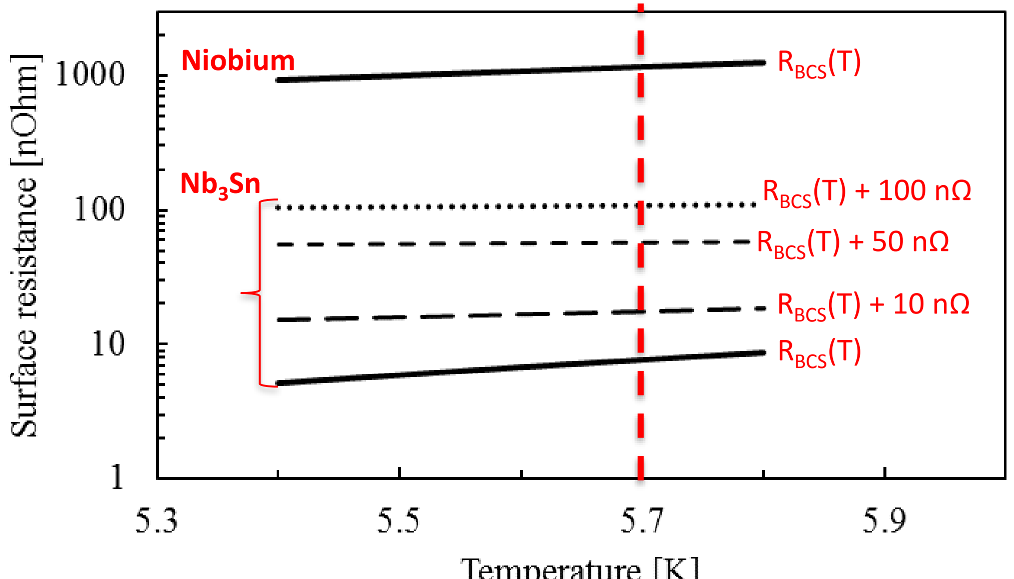
Assume no changes to the link

- $T_{cavity,RF}$ = 5.7 K
- $T_{cryocooler}$ = 5.1 K

$$E_{acc} \propto \frac{1}{\sqrt{R_{BCS}(T) + R_{residual}}}$$

Nb_3Sn << Niobium (see plot)

Nb_3Sn has demonstrated as low as 10 nΩ



R_{BCS}(T) computed using https://www.classe.cornell.edu/~liepe/webpage/researchsrimp.html

Projected E_{acc} for Nb_3Sn with different residuals

Surface resistance in Nb_3Sn [nΩ]	E_{acc} [MV/m] with the existing conduction-cooling link
20 (residual = 10)	11.5
60 (residual = 50)	6.5
110 (residual = 100)	5.0

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Summary and outlook

First ever demonstration of accelerating gradients on a cryogen-free, cryocooler conduction-cooled SRF cavity

- Niobium cavity produced >1.5 MV/m with a 2 W @ 4.2 K cryocooler
- There is considerable scope for improving the thermal management in our setup
  - Ongoing: mitigation of static heat leak
- An Nb_3Sn coated cavity is projected to yield >10 MV/m accelerating gradients on our existing setup
  - Tests are planned for the near future

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Thank you.