FCC-ee and FCC-hh

R&D related projects in the Cryolab

T. Koettig, P. Borges de Sousa, R. van Weelderen, J. Bremer

16th May 2024

CERN

Contents

R&D projects in the Cryolab related to:

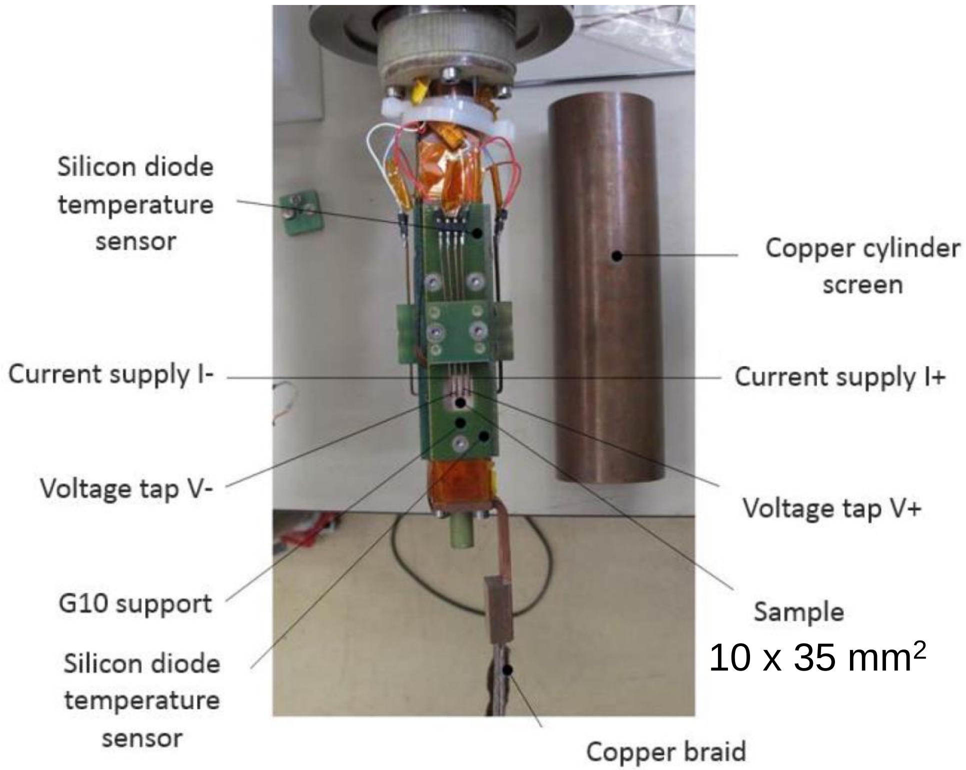
- FCC-ee non-baseline R&D
- FCC-hh baseline R&D
- Summary

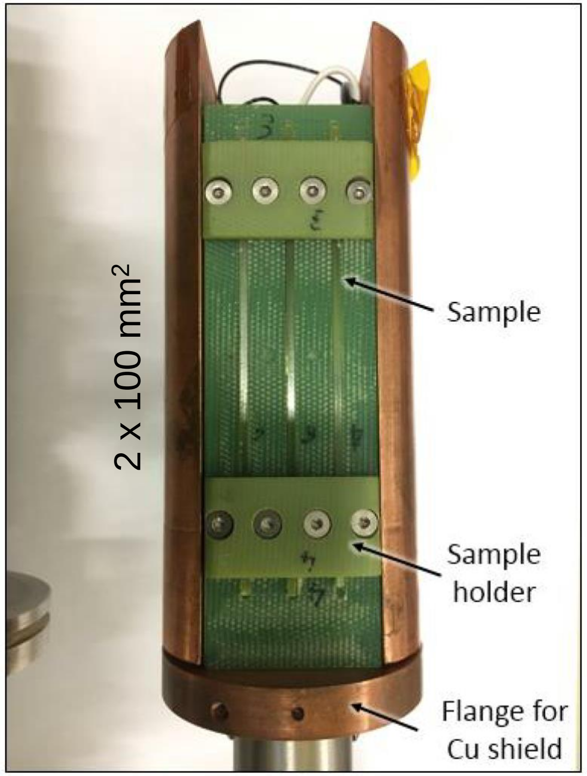
FCC related R&D projects in the Cryolab

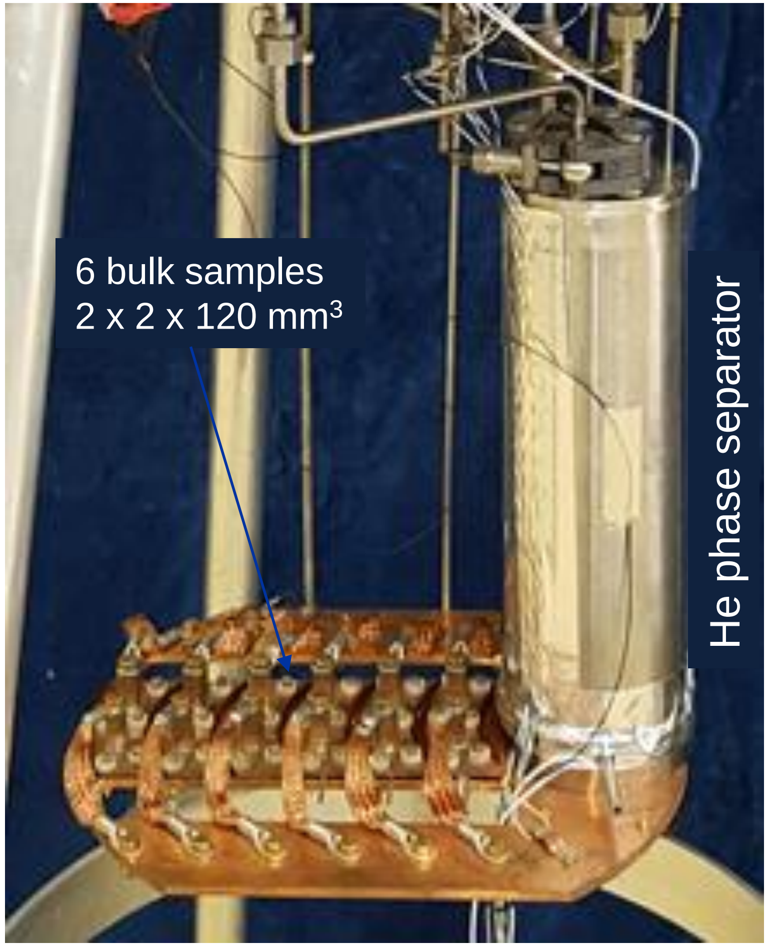
- RRR & Thin film T_c (e.g. thermal properties 3D printed parts, cavity material and coatings) VSC and SRF

Cryolab test stands for material properties

RRR for films, foils and bulk samples



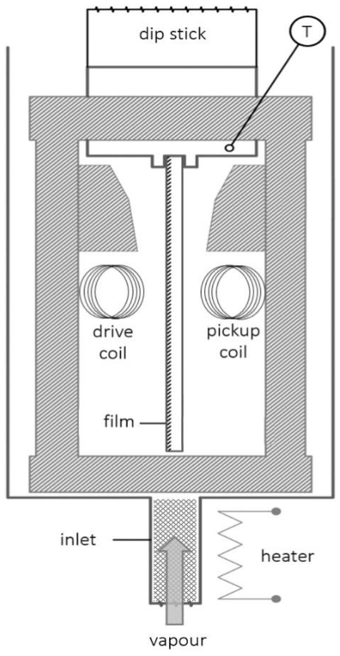


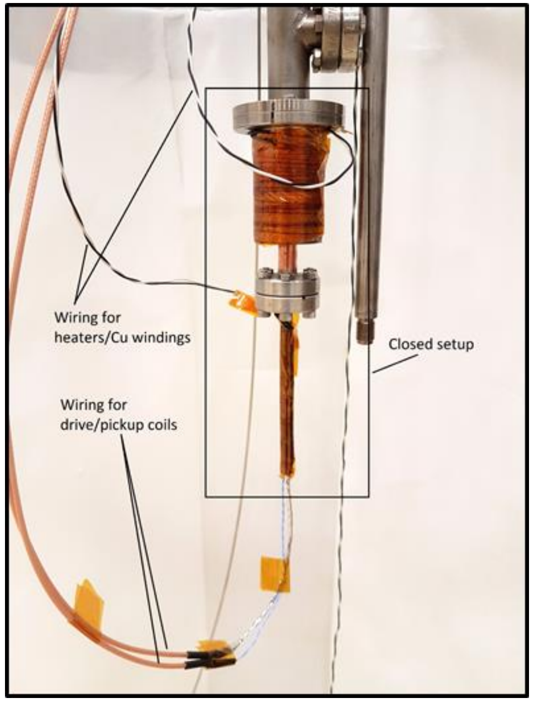


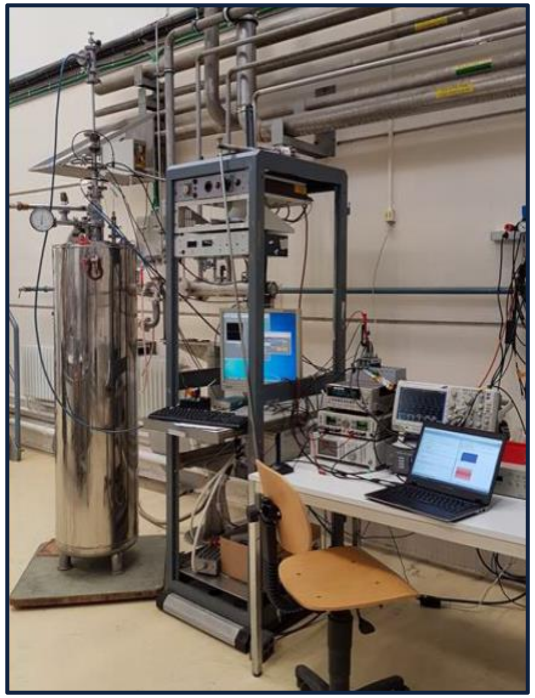
Cavity materials, beam screen, etc.

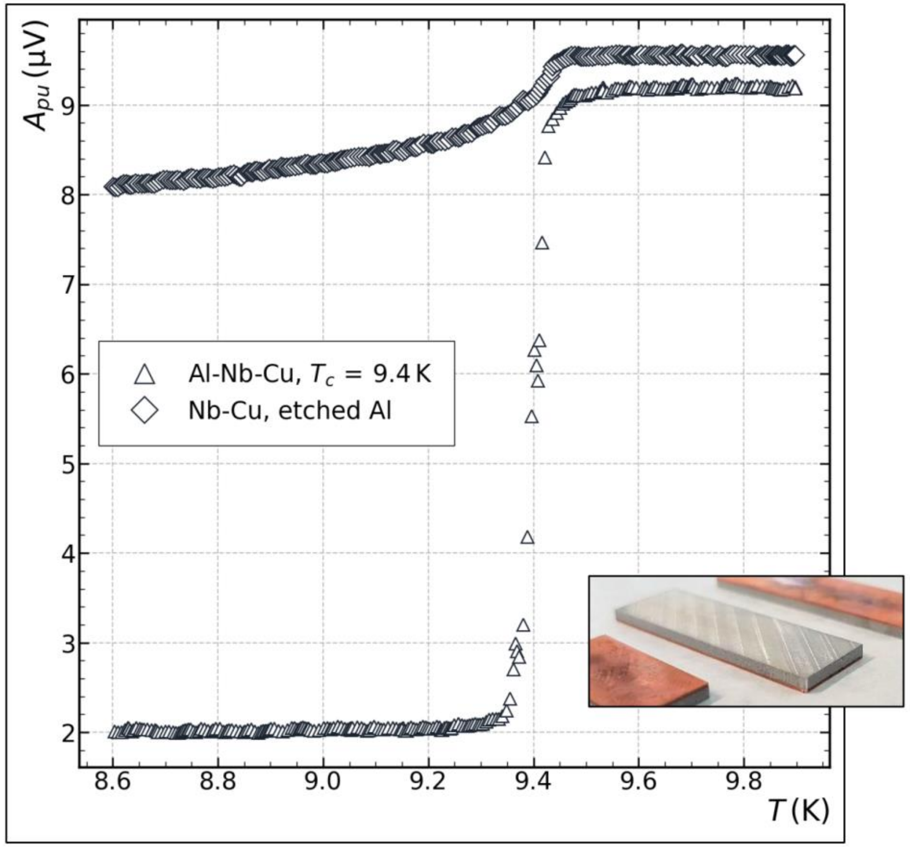
T_c thin film test stand Nb or novel A15 compounds on Cu (TE/VSC)

Contactless, inductive measurement of the critical temperature of superconducting thin films deposited on copper.









Supported R&D studies of TE/VSC:

- ✓ film density for HiPIMS Nb/Cu coatings
- ✓ reverse coating technique to produce electro-formed copper cavities with integrated superconducting layer (graph)
- ✓ quality of HiPIMS Nb_3Sn/Cu coatings => novel coatings => quality insurance: film, material, procedure etc.

FCC related R&D projects in the Cryolab

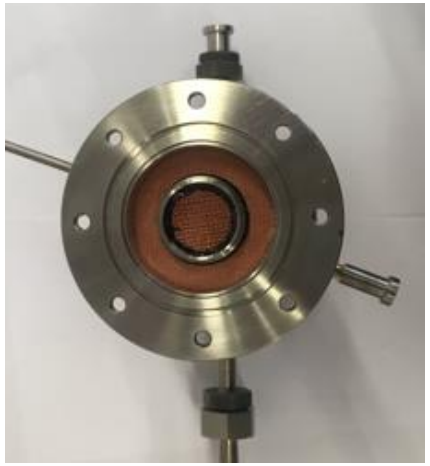
- RRR & Thin film T_c (e.g. thermal properties 3D printed parts, cavity material and coatings) VSC and SRF
- 2 K CFHEX, study for a more compact high-performance precooling HEX for SRF CMs at 2.0 K up to 10 g/s

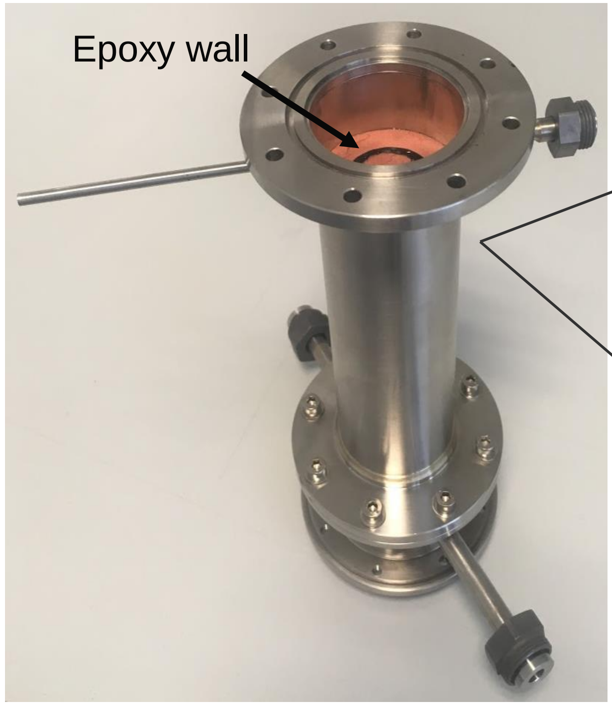
Towards a compact 2 K Pre-cooling HEX

- FCC-ee cryomodules (2 K) may need a local compact high-effectiveness CFHEX
- Inhouse design of such HEXs is tested down to 3.5 K already
- Study: extend application range to 2 K @ p ≤ 31 mbara VLP conditions

Novel transparent-wall CFHEX during assembly

Top view

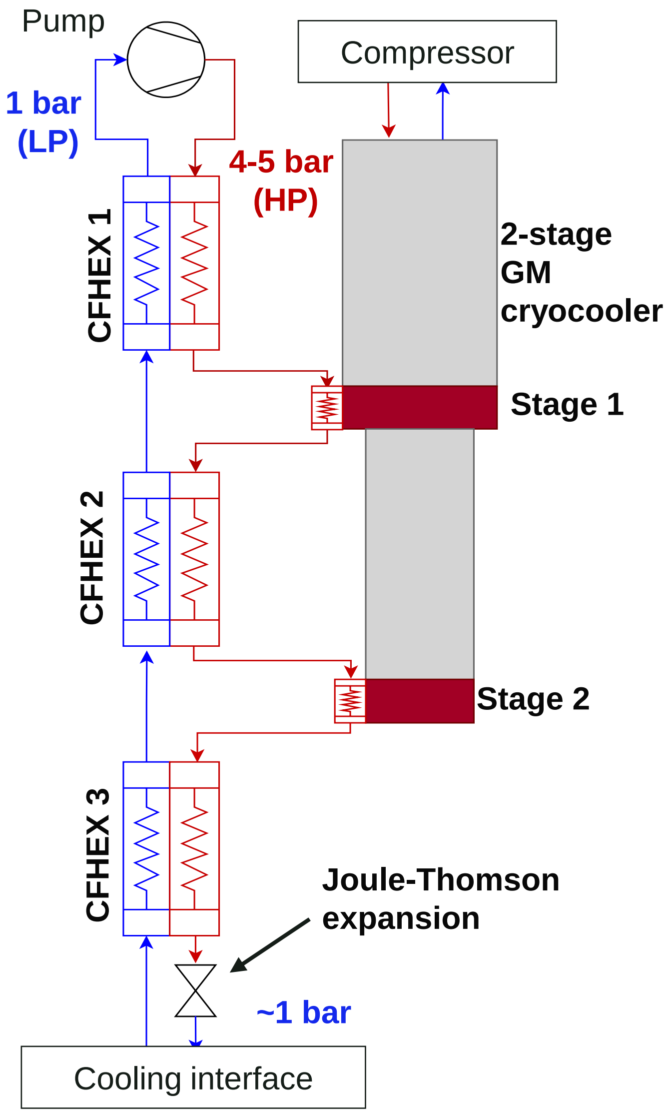




NTU=18.6
($\epsilon = 94.9\ \%$)

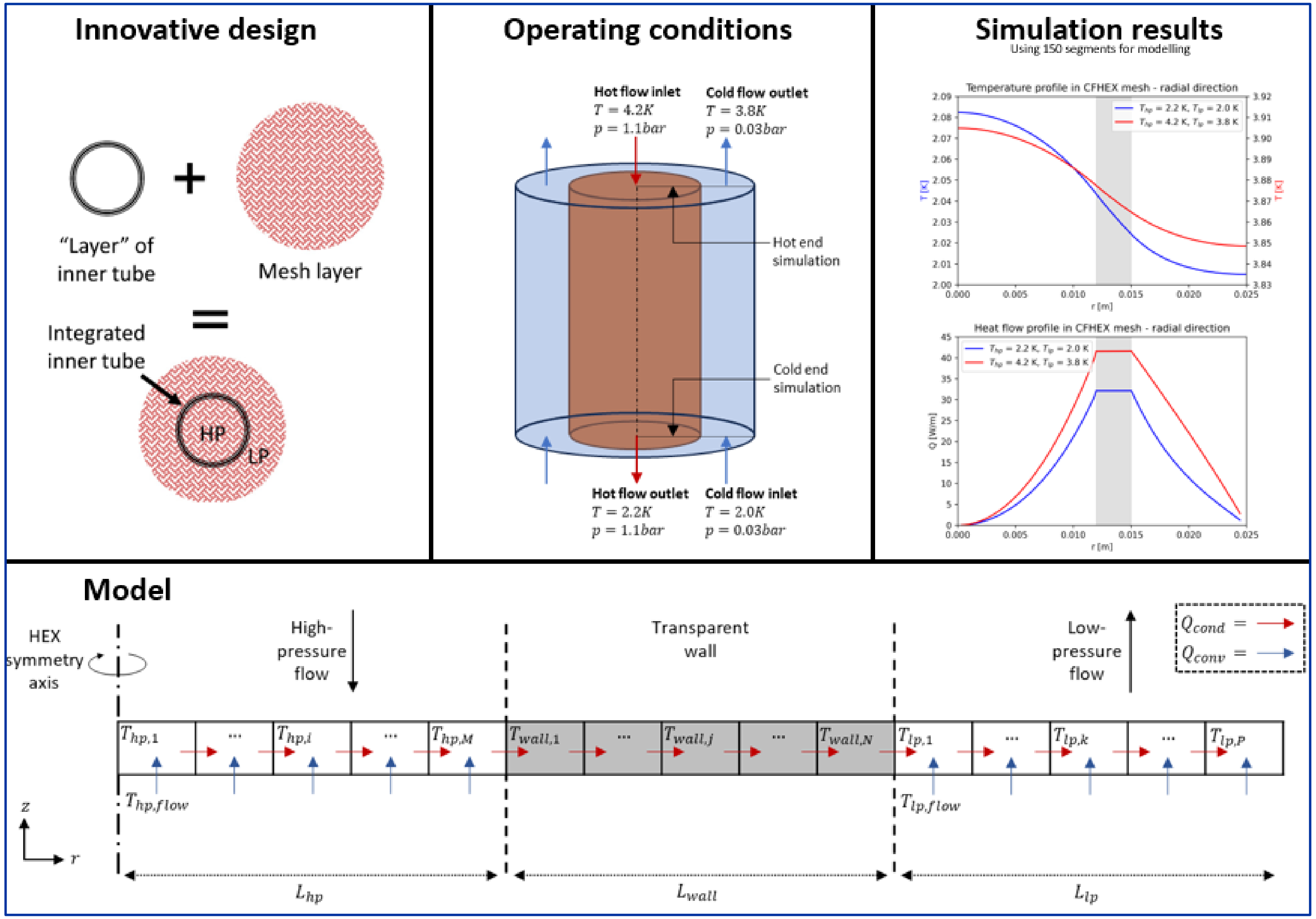
NTU = 55
($\epsilon = 98.2\ \%$)

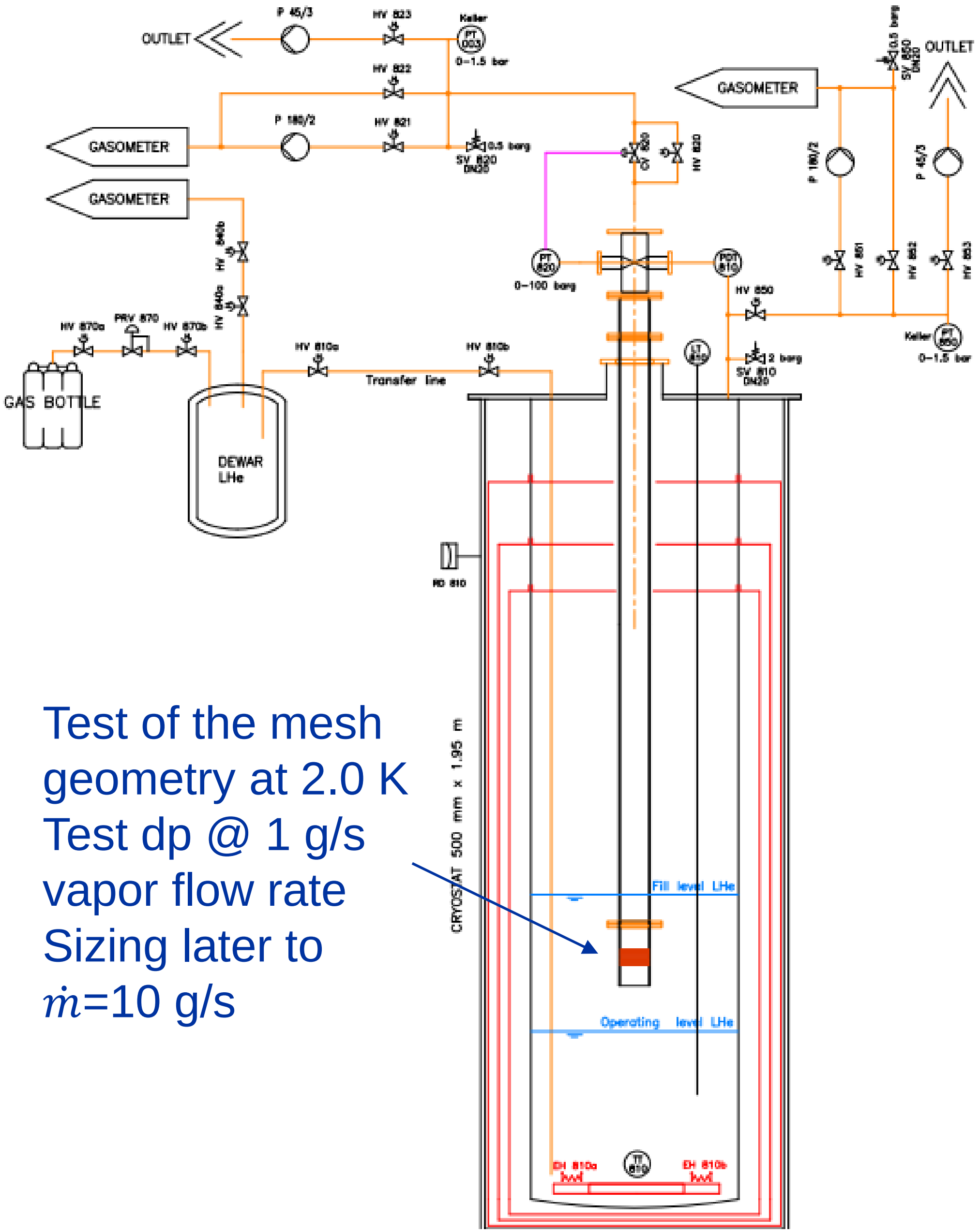
NTU >124
($\epsilon = 99.2\ \%$)



CFHEX as 2 K pre-cooling HEX

Simulation code of the radial performance 4.5 K ⟷ 2 K



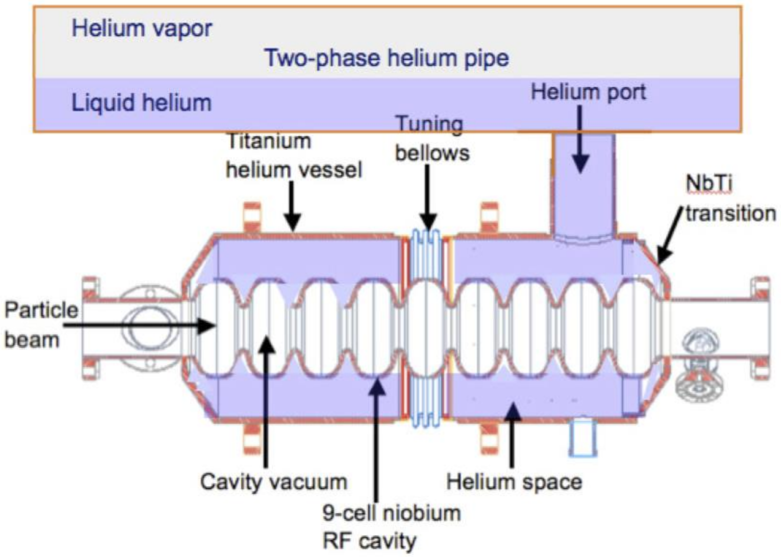


- Test of the mesh geometry at 2.0 K
- Test dp @ 1 g/s vapor flow rate
- Sizing later to $\dot{m}$=10 g/s

FCC related R&D projects in the Cryolab

- RRR & Thin film T_c (e.g. thermal properties 3D printed parts, cavity material and coatings) VSC and SRF
- 2 K CFHEX, study for a more compact high-performance precooling HEX for SRF CMs at 2.0 K up to 10 g/s
- Dry Cavity cooling (for a possible case of elliptical Nb_3Sn coated Cu cavities) SY/RF-SRF

Dry SRF cavity cooling



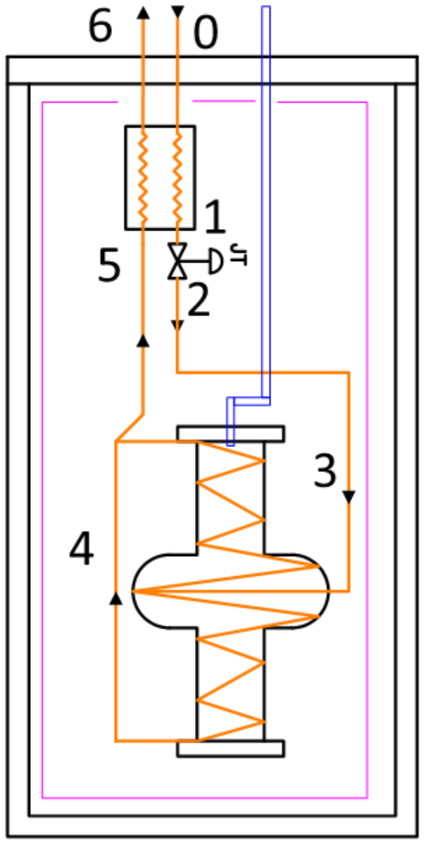
Courtesy: Tom Peterson, FERMILAB-TM-2620-TD, TESLA/ILC design

Pros vs. Cons.

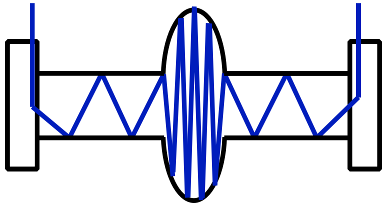
+ Reduced LHe content, incl. the ODH topic in a tunnel
+ Drastically reduced size of SV/RD
+ Higher operating He pressure possible, forced flow
-+ Cooling performance (forced flow vs. free convection)
+ No LHe vessel => simpler mechanical tuners at cold,
+ Material transitions, stainless steel, Ti, Nb, Cu
- Temperature profile along the cavity T> 6 K with A15
+ T_c transition front => trapped flux, cooldown speed
-+ Microphonics => compare with 4.5 K He I bath
- Quench thermodynamics? RF stopping the powering?

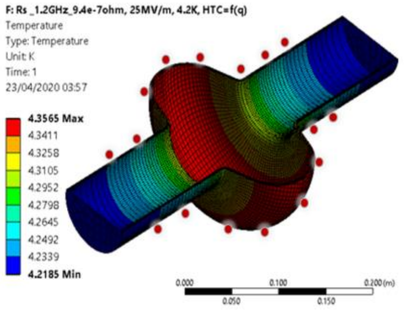
(Cavity stored energy is in the range of 100 J)

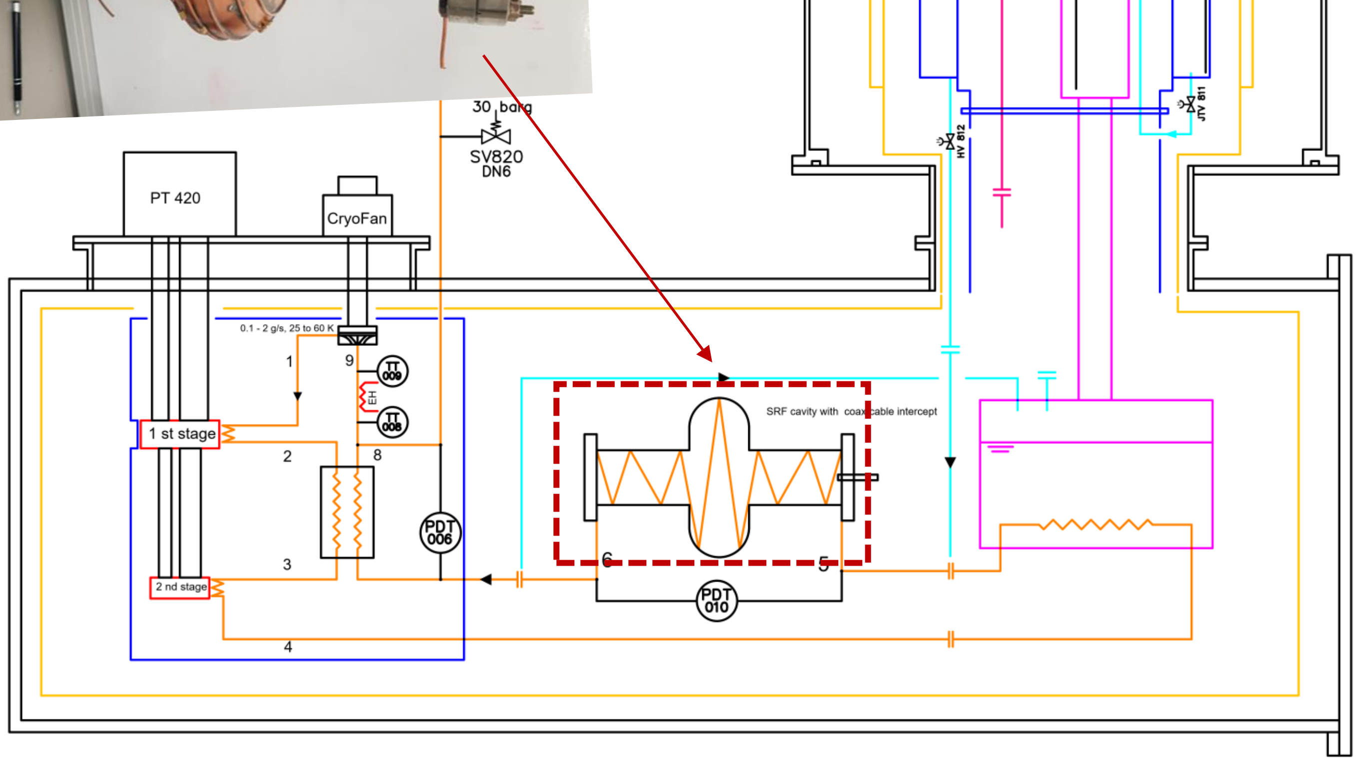
1-1.3 bar 3-4 bar



Dry SRF cavity cooling







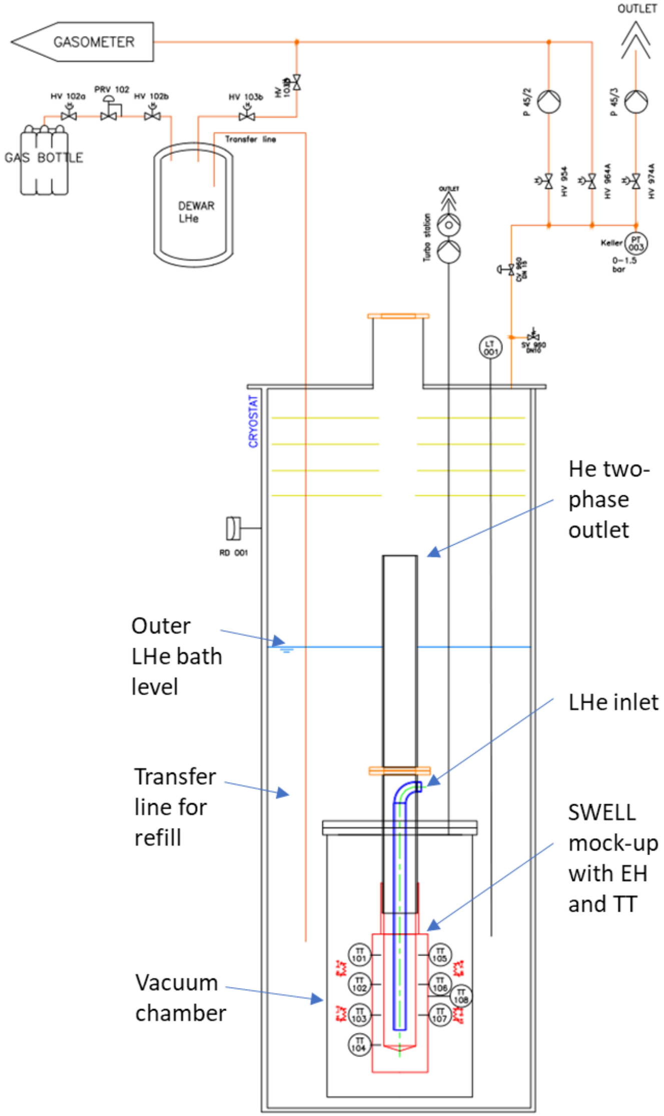
Test setup to study dry colling:

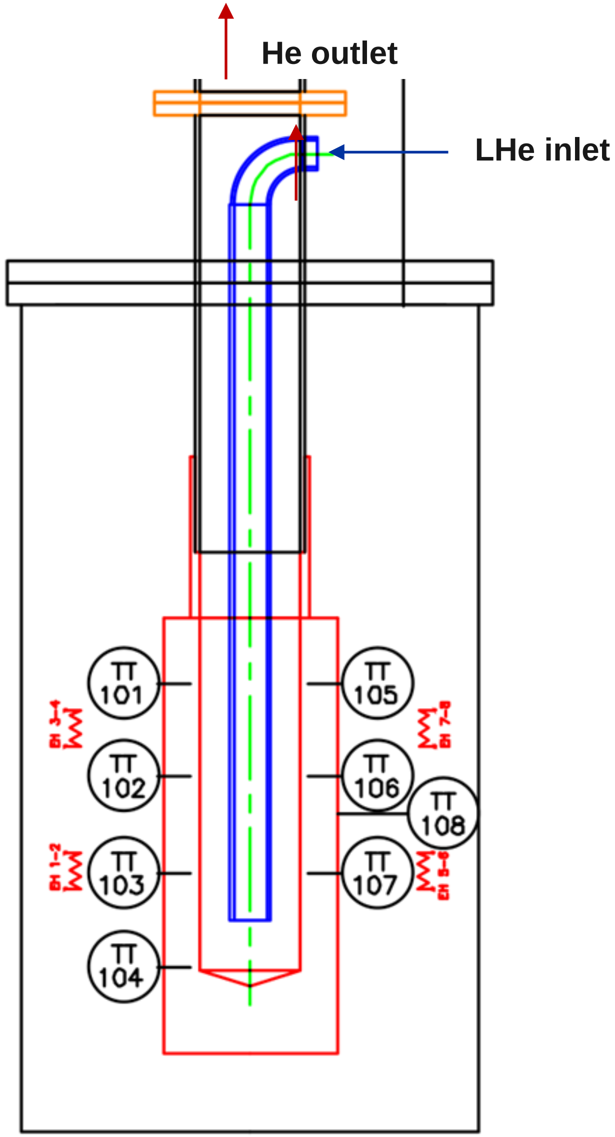
- system performance,
- flow conditions in the capillary,
- vibrations

FCC related R&D projects in the Cryolab

- RRR & Thin film T_c (e.g. thermal properties 3D printed parts, cavity material and coatings) VSC and SRF
- 2 K CFHEX, study for a more compact high-performance precooling HEX for SRF CMs at 2.0 K up to 10 g/s
- Dry Cavity cooling (for a possible case of elliptical Nb_3Sn coated Cu cavities) SY/RF-SRF
- Application to SWELL cavities (in case of and if its 400 MHz, Nb_3Sn coated on Cu) SY/RF-SRF

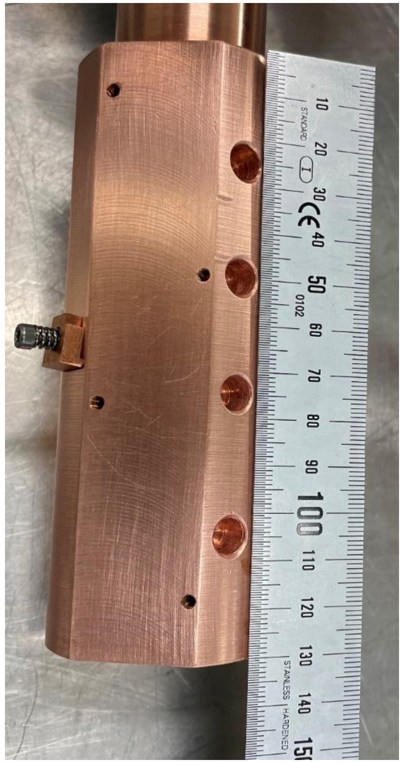
SWELL cooling tube heat transfer for SM18



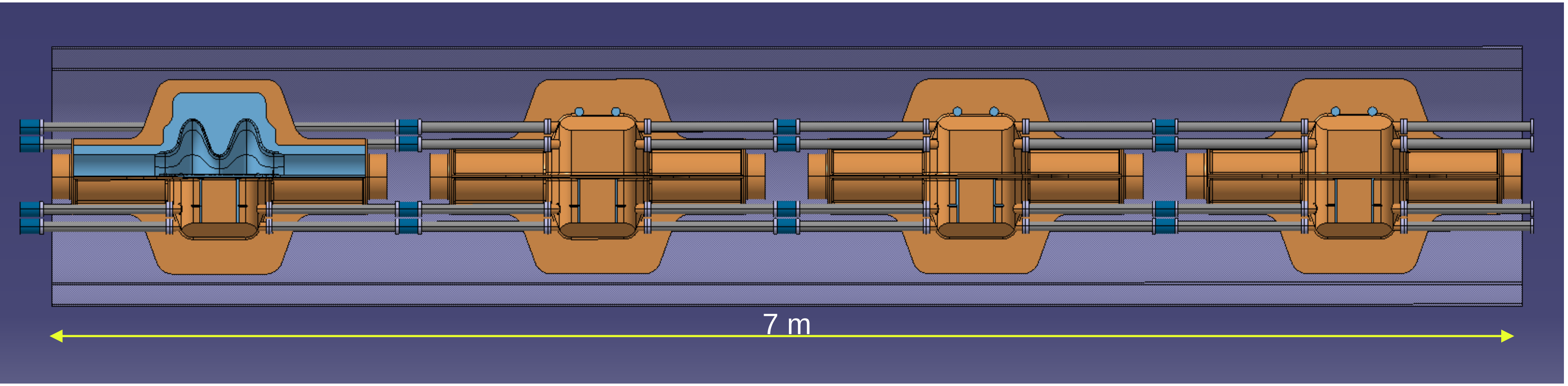


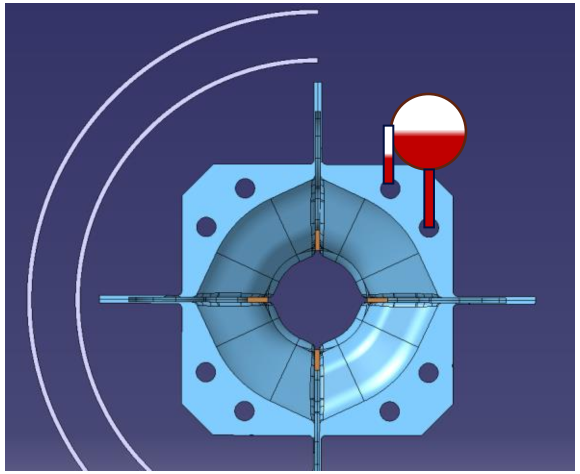
Vacuum chamber with surrounding He I bath

Mock-up



Cooling options for SWELL CM, cryogenics point of view



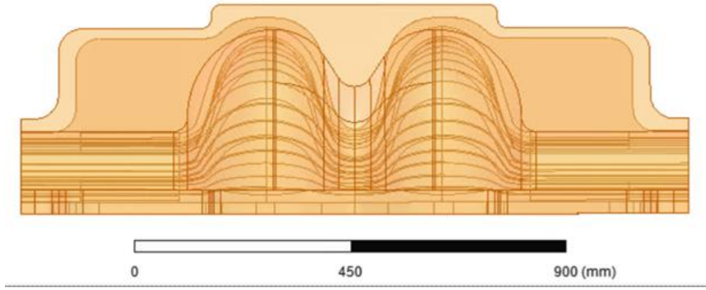


Thermosiphon @ 4.5 K

Cooling options (which I would suggest):

- ~~2.0 K He II saturated condition, excluded by boiling instabilities~~ due to high heat flux
- 2.0 K He II pressurized cooling tubes with heat exchanger (LHC magnet like),
  => need to be tested for the high heat flux of the SWELL quadrants?
- 4.5 K saturated liquid He with thermo-syphon to a two-phase tube (4 times) and using the small inclination angle of the tunnel plus cooling tube inclination,
- Our preferred option: supercritical 3 bara @ 4.5 K He I cooling flow in the tubes

Courtesy: F. Peauger (SRF) possible double SWELL 400 MHz design with cooling channels in a quadrat



FCC related R&D projects in the Cryolab

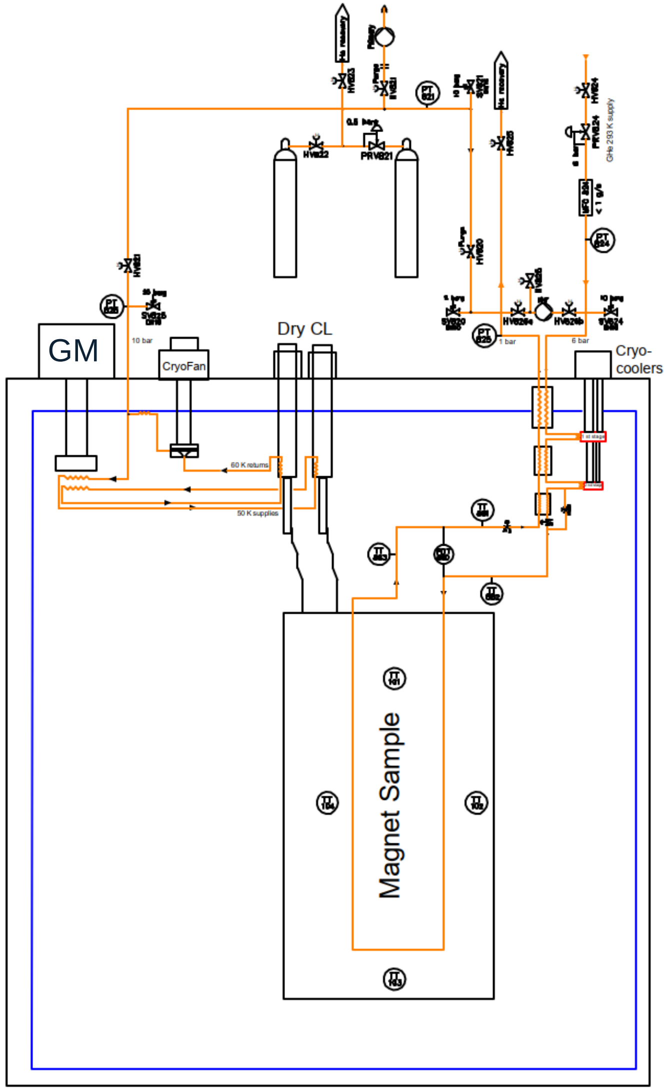
- RRR & Thin film T_c (e.g. thermal properties 3D printed parts, cavity material and coatings) VSC and SRF
- 2 K CFHEX, study for a more compact high-performance precooling HEX for SRF CMs at 2.0 K up to 10 g/s
- Dry Cavity cooling (for a possible case of elliptical Nb_3Sn coated Cu cavities) SY/RF-SRF
- Application to SWELL cavities (in case of and if its 400 MHz, Nb_3Sn coated on Cu) SY/RF-SRF

FCC related R&D projects in the Cryolab

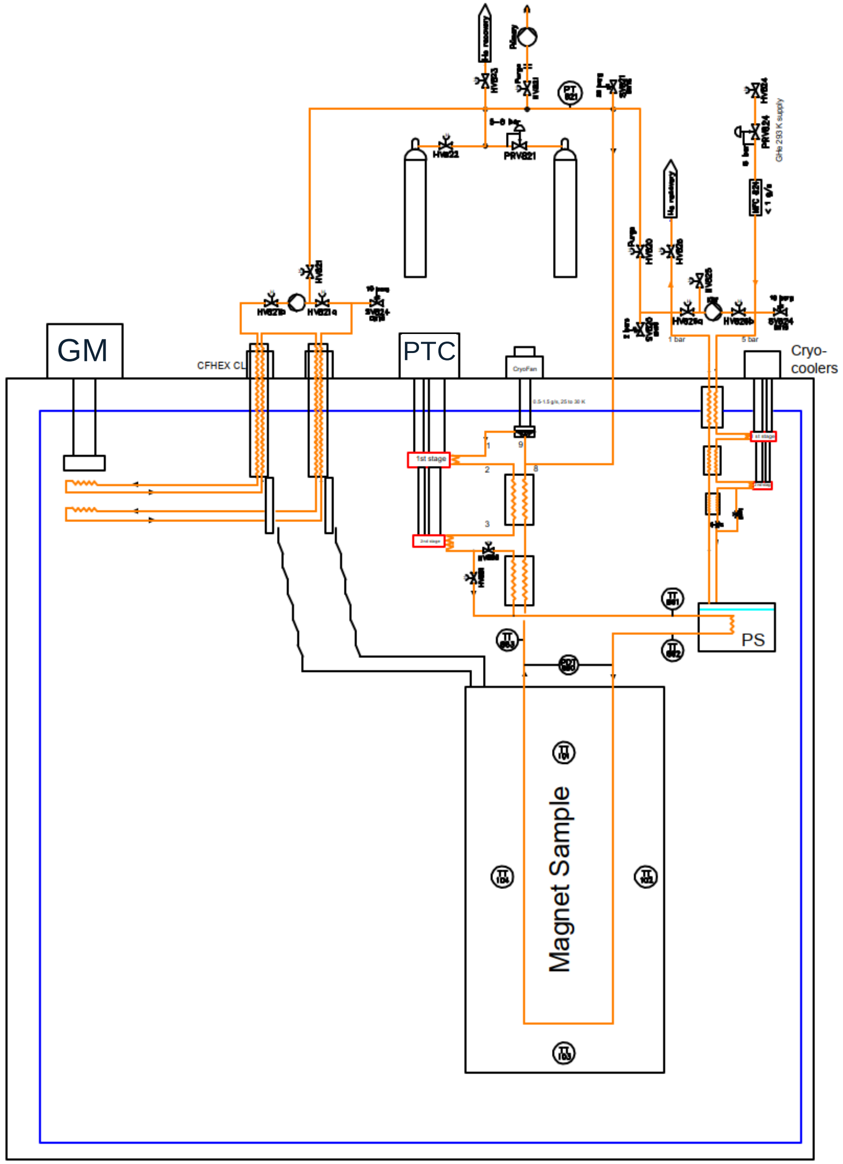
- RRR & Thin film T_c (e.g. thermal properties 3D printed parts, cavity material and coatings) VSC and SRF
- 2 K CFHEX, study for a more compact high-performance precooling HEX for SRF CMs at 2.0 K up to 10 g/s
- Dry Cavity cooling (for a possible case of elliptical Nb_3Sn coated Cu cavities) SY/RF-SRF
- Application to SWELL cavities (in case of and if its 400 MHz, Nb_3Sn coated on Cu) SY/RF-SRF
- Cryolab tests stands for:
  - HFM cooling test stations
  - Fast Reactive Tuner thermal commissioning (HL-LHC and FCC both options) SY-RF-SRF
  - Beam screen RF impedance VSC
  - Detector development support (e.g. transparent cryostats, feedthroughs) EP

Planned dry cooling test stations at the Cryolab (HFM)

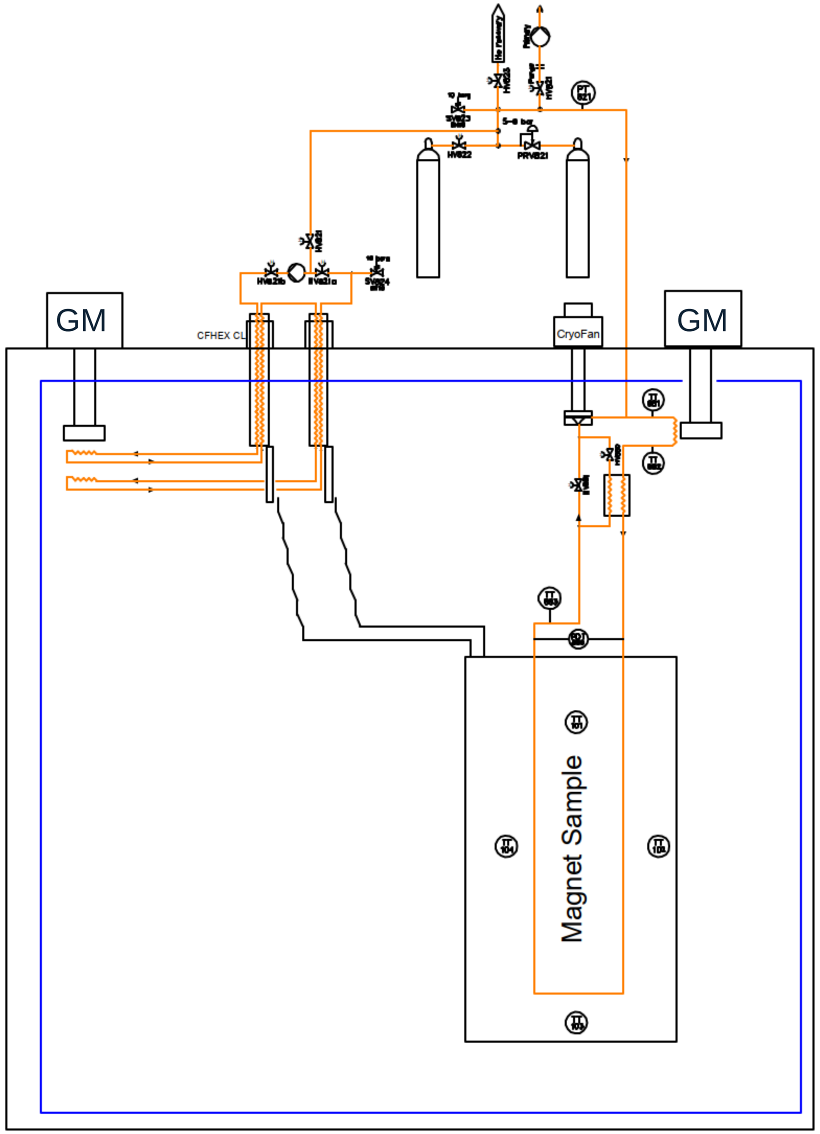
4.25 K two-phase flow
or SC m< 1 g/s



4.5 K<T<10 K, SC m< 1.5 g/s



18 K<T<25 K, SC m< 5 g/s



See details in P. Borges de Sousa's presentation

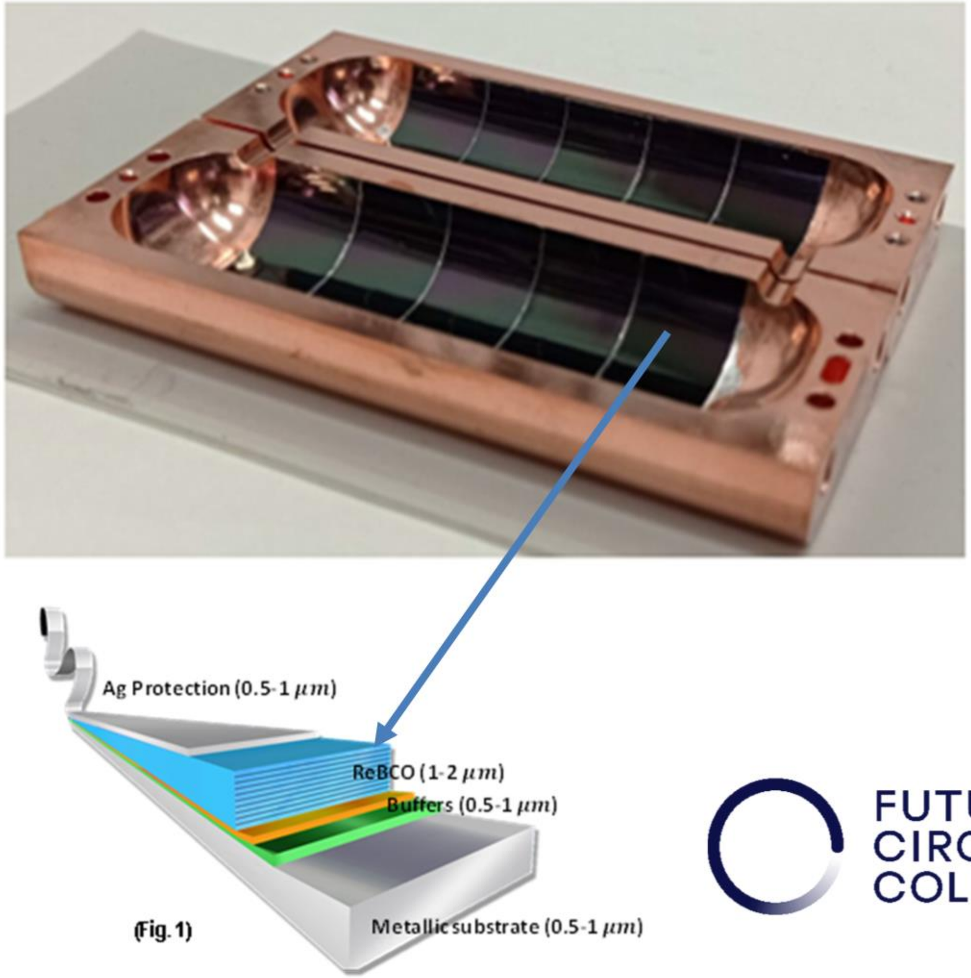
FCC related R&D projects in the Cryolab

- RRR & Thin film T_c (e.g. thermal properties 3D printed parts, cavity material and coatings) VSC and SRF
- 2 K CFHEX, study for a more compact high-performance precooling HEX for SRF CMs at 2.0 K up to 10 g/s
- Dry Cavity cooling (for a possible case of elliptical Nb_3Sn coated Cu cavities) SY/RF-SRF
- Application to SWELL cavities (in case of and if its 400 MHz, Nb_3Sn coated on Cu) SY/RF-SRF
- Cryolab tests stands for:
  - HFM cooling test stations
  - Fast Reactive Tuner thermal commissioning (HL-LHC and FCC both options) SY-RF-SRF
  - Beam screen RF impedance VSC
  - Detector development support (e.g. transparent cryostats, feedthroughs) EP

- HTS tape beam screen coating (stripped tape thermal conductivity for FCC-hh) VSC

Soldered and delaminated HTS tape as beam screen coating

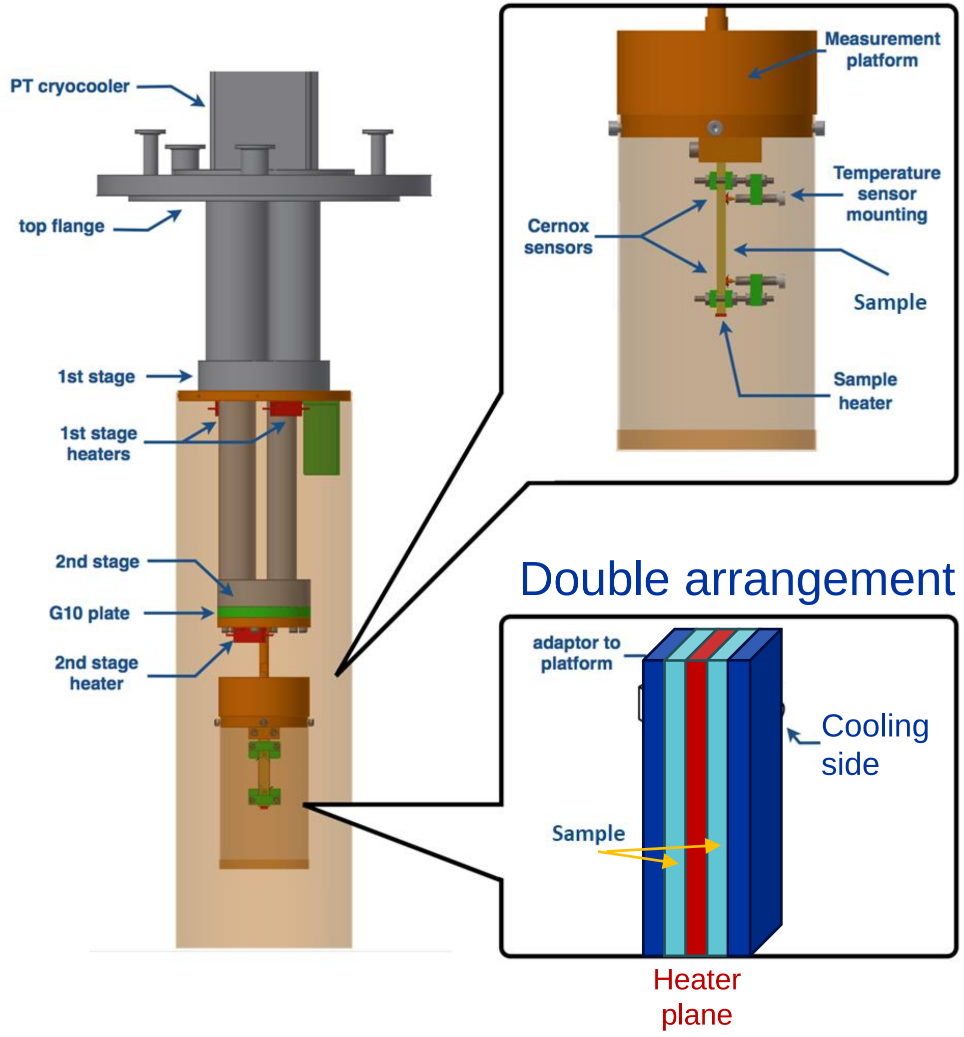
Soldered HTS tape, delaminated to expose the REBCO surface



From: S. Calatroni, REBCO Coatings for High-Gradient RF Applications

FUTURE CIRCULAR COLLIDER

Modifying our thermal conductivity test stand to measure the delaminated tape ⊥ thermal contact.



Summary

R&D projects (non-baseline FCC-ee)

- Support the thermodynamic design of the IR CRAB sextupole stand alone SC magnets
- Test stations for R&D on materials for cavities
- Study dry cavity cooling options
- Cryolab test stations for material properties, component development

R&D projects (baseline related FCC-hh)

- Magnet cooling study via HFM
- Beam screen thermal contact of delaminated HTS tape

Thank you for your attention!