CERN

# CERN Cryolab Service and R&D

Torsten Koettig on behalf of the Cryolab team

*CERN TE/CRG-CL*

# Outline

- Mandate
- R&D highlights directions
- Particle Detectors R&D
- SC cavity material testing and novel cooling strategies
- High Field Magnets (HFM) cryogenics
- Summary

# Mandate

- Consultancy ……… Cryogenic design, instrumentation & safety.
- Infrastructure …… Provide test facility at the Cryolab.
- Cryogenic System … Design, build-up & commissioning
- Complete Projects ... as above + performing measurements => reporting

# Cryolab projects in 2021-2022

## Technology development

- RF cavity diagnostics
- BCCCA upgrade
- RRR thin films, strips and bulk samples
- Thermal conductivity test stand
- Thermal dilatation test stand
- Helios refill
- CAST
- Compass DR support
- Gas permeability
- LHe level gauge calibration
- PT for low-temperature validation

Updated Cryolab capabilities doc:
https://edms.cern.ch/document/2384399/1

## Project driven

- HL-LHC inner triplet current feeders
- Thermal cycling of 11 T coil samples
- Heat transport in $Nb_3Sn$ cable geometries
- He II cooling simulations of $Nb_3Sn$ coils
- LAr calorimeters high-density feedthroughs
- BPM thermal link
- Tc of SC thin film on substrate
- DarkSide
- HTS Small coil test
- LKr purity monitor NA62
- Fresca 2 seal test
- LHC pressure safety assembly validation
- PUMA sphere support thermal conductivity
- Rades 2 K - cavity validation
- RF surface impedance
- Flux lens - SRF
- MadMax
- Babylaxo
- SWELL cavity heat transfer

## Generic R&D

- Thermal mapping of SRF cavities
- Remote cooling study
- Dry Cavity cooling
- Sub-Kelvin cryogenic cooling study

## Training and Outreach

- Cryogenic Safety courses:
  - Fundamentals
  - LHe transfer
  - Fire Brigade
- (Visits/Demonstration $LN_2$)

34 projects in 2021 -2022 short and long term projects

# Cryolab R&D branches

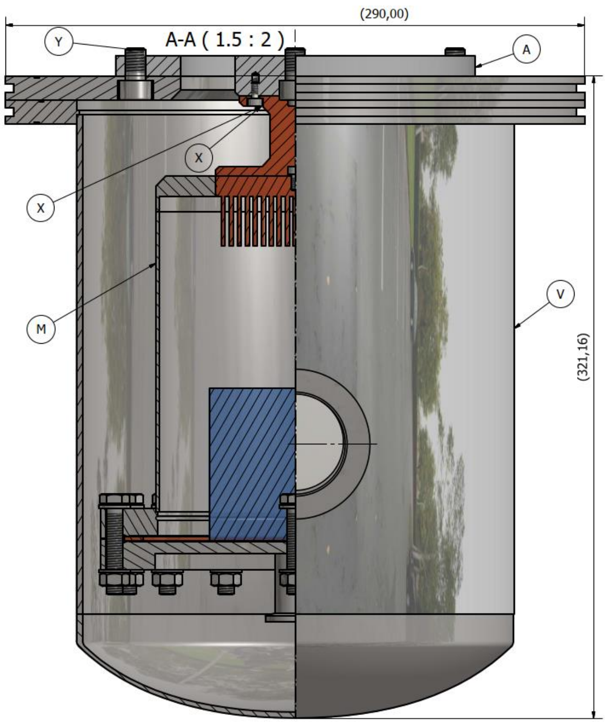
| Cryogenics for detectors | High Field Magnet cryogenics | SC cavity cooling |
|---|---|---|
| LAr proximity cryogenics | Material properties, thermal conductivity T>1.8 K | Material properties, bulk, thin films, substrates |
| LKr purity monitor | Thermal performance of magnet coil samples | Thermodynamics of interfaces at low temperature |
| COMPASS large scale DR 11 mW @ 100 mK | Numerical simulation of $Nb_3Sn$ coils cooling performance | Quench localization in He I and He II |
| Antimatter factory Beam current monitor ZBO SQUID cryostat | Novel cooling schemes: higher temperatures => reduced He content | |
| MadMax, Rades | | |

# R&D highlights

# NA62 - Liquid Krypton Purity Monitor

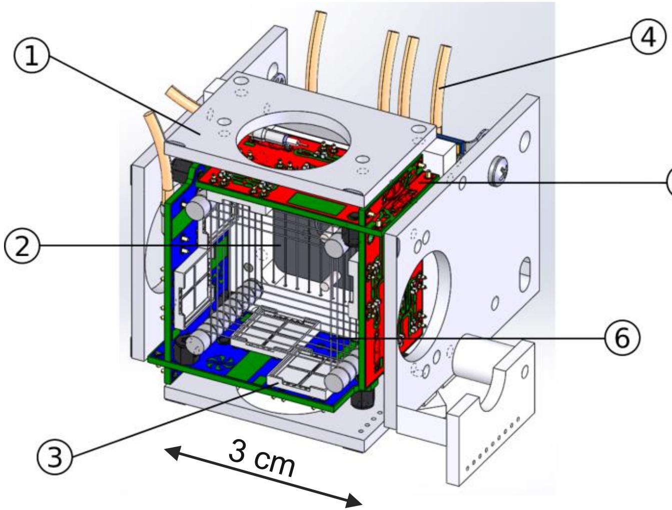
=> Krypton refill of the calorimeter after 26 years of operation

# LKr purity monitor – Krypton vessel and TPC




TPC from NA62 Triumf/University Vancouver:

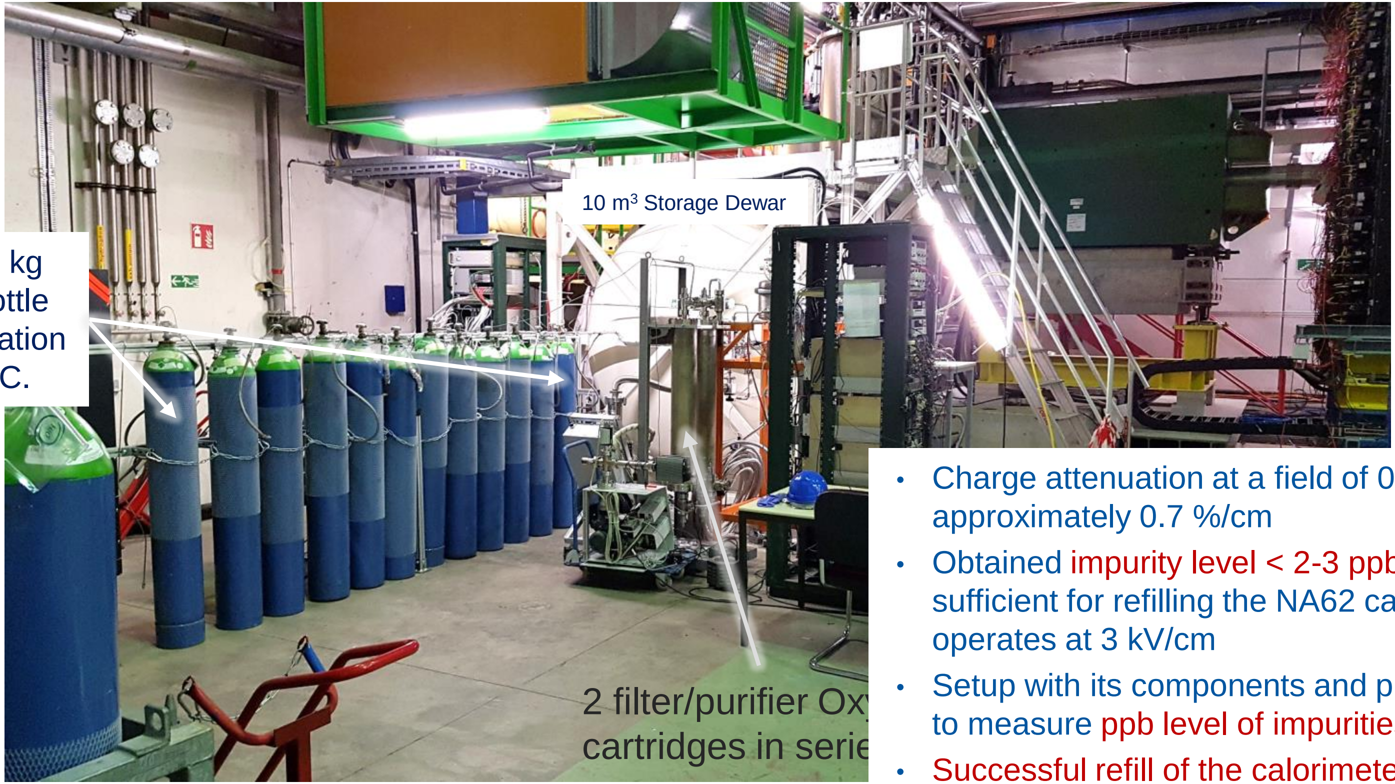
- 3 x 3 x 3.6 $cm^3$ active volume
- $^{22}Na$ positron source providing 511 keV photons
- Electrons drift due to 3-4 kV potential difference
- Two thin-walled windows to TPC => limit the PS to 0.5 barg




1. Macor® panel
2. Anode "A2" and grid
3. Hamamatsu VUV4 SiPM
4. Coaxial signal and power cables
5. Support PCB for the SiPMs
6. Field cage wires

# LKr purity monitor setup in ECN3 at CERN

Sampling of 0.5 kg Kr from each bottle during condensation (10 h) in the TPC.




Calorimeter

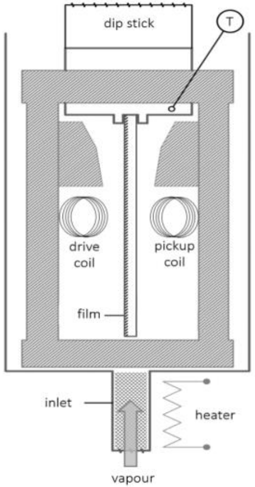
- Charge attenuation at a field of 0.77 kV/cm was approximately 0.7 %/cm
- Obtained impurity level < 2-3 ppb $O_2$ equivalent sufficient for refilling the NA62 calorimeter that operates at 3 kV/cm
- Setup with its components and procedure allows to measure ppb level of impurities in LKr
- Successful refill of the calorimeter by 250 l LKr

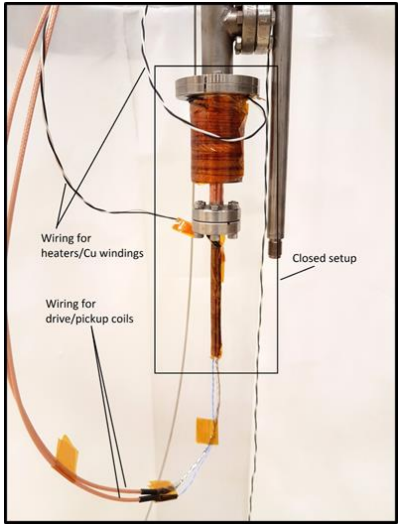
# SRF cavity R&D cryogenics

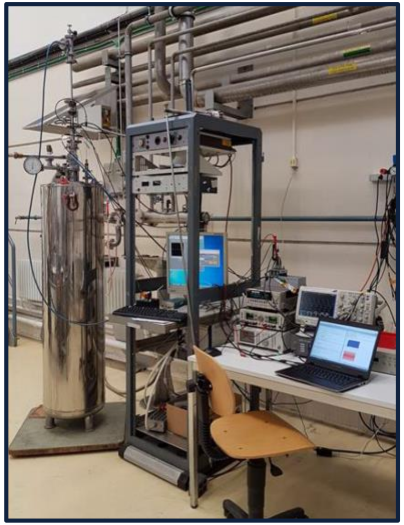
=> from thin films, to disks to cavities

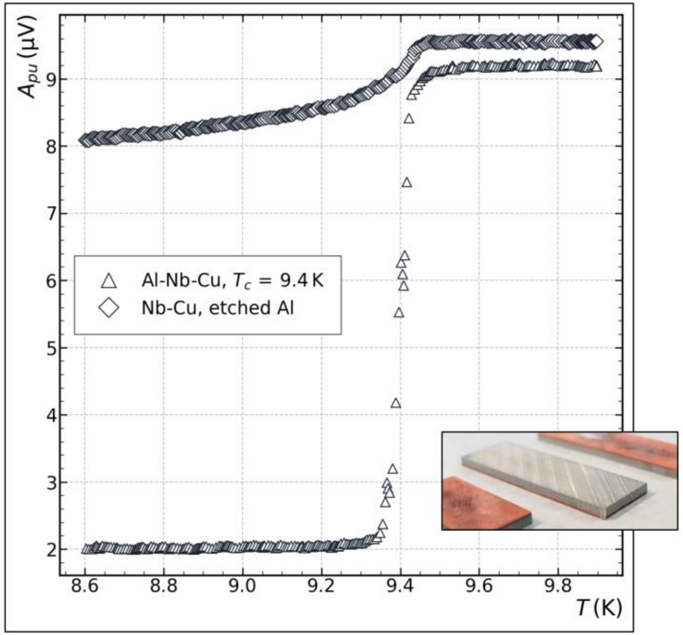
# $T_c$ thin film test stand Nb or novel A15 compounds on Cu (TE/VSC)

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



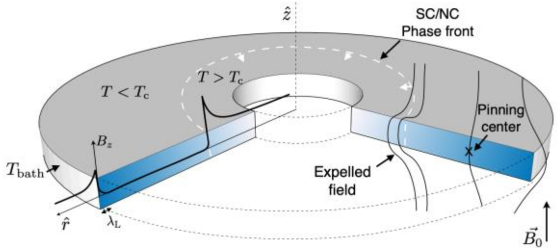


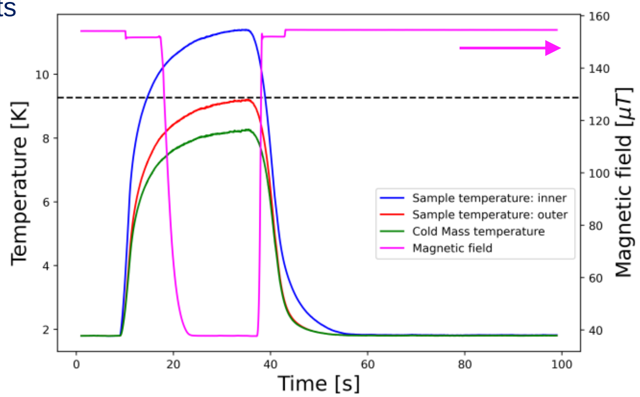

Supported R&D studies of TE/VSC:

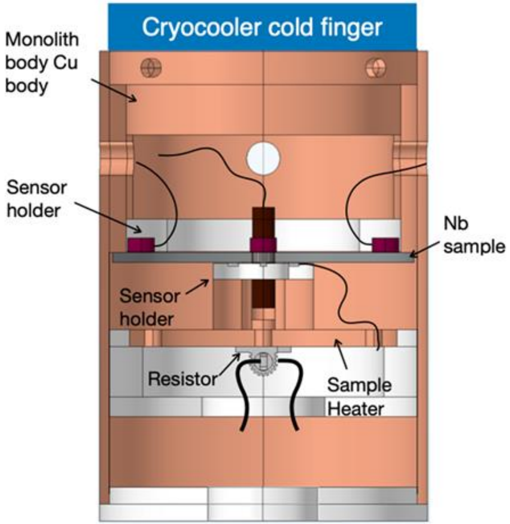
- ✓ film density for HiPIMS Nb/Cu coatings at grazing incidence angles (WOW cavities)
- ✓ reverse coating technique to produce electro-formed copper cavities with integrated superconducting layer (graph)
- ✓ quality of HiPIMS $Nb_3Sn$/Cu coatings => novel coatings => quality insurance: film, material,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

# Flux Expulsion Lens with SY/RF-SRF

- Flux Expulsion Lens: measurement of flux trapping in superconducting samples
- Concept : Application of heat pulses to inner radius of a “donut” geometry
- Expelled flux is pushed toward donut hole giving clear measure of $B_{SC}/B_{NC}$ => magnitude estimates flux trapping effectiveness
- Measurement setup to qualify materials => ongoing measurement campaign for bulk niobium:
  - High RRR Nb sheet from High Gradient programme
  - High RRR Nb sheet from CRAB cavity project
  - 3-D printed Nb sheet (both raw & heat treated)
- Clear set of results already achieved
  - Relates flux expulsion to spatial thermal gradients
  - Excellent reproducibility: over 4000 expulsions processed



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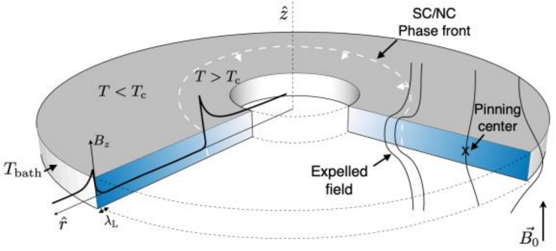
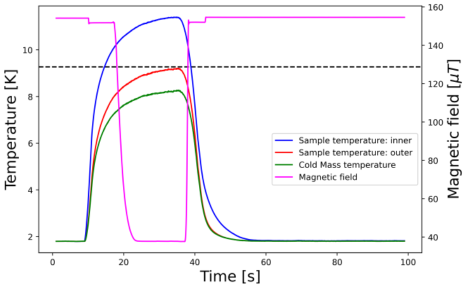
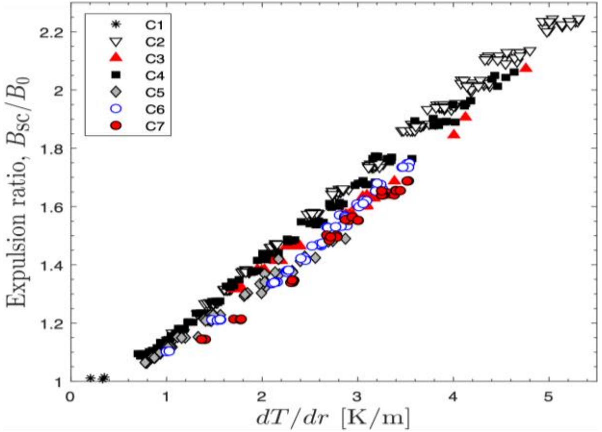


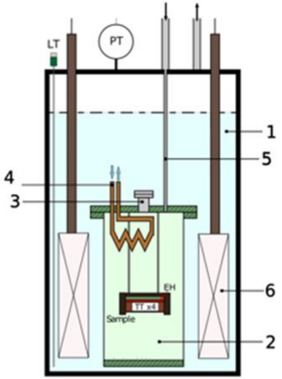
# SC magnet cooling –

# R&D activities in the HFM project

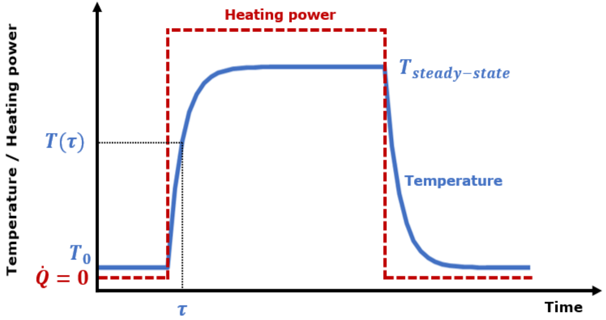
# MQXF thermal performance tests

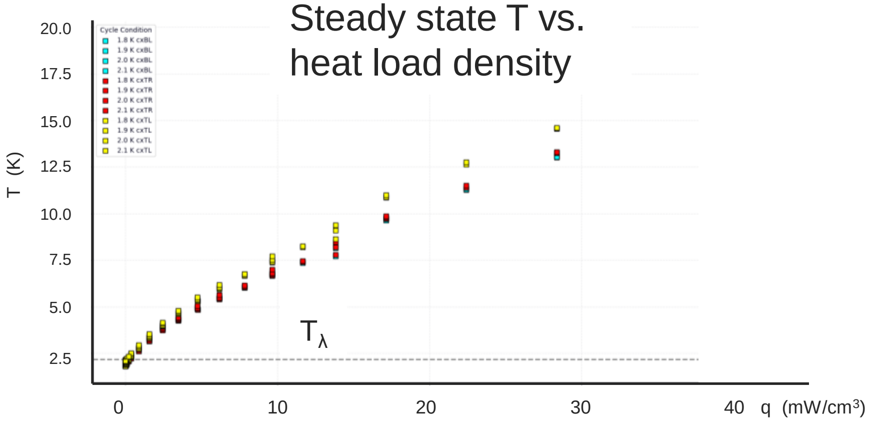
MQXF sample cut from coil P06, which was tested in MQXFAP1b

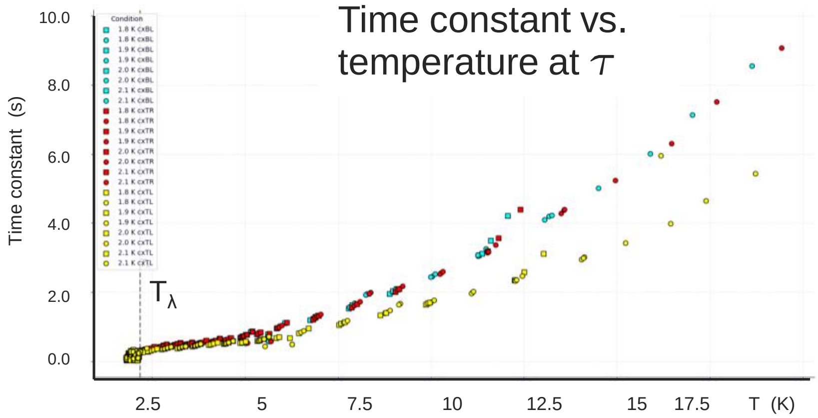
It is made of the final conductor (RRP108/127)




1. Outer He II volume
2. G11 pot with sample, inner He II volume
3. Rupture disk
4. Heat exchanger
5. Filling/pressurisation capillary
6. External NbTi magnet for AC loss heat generation method (not used)



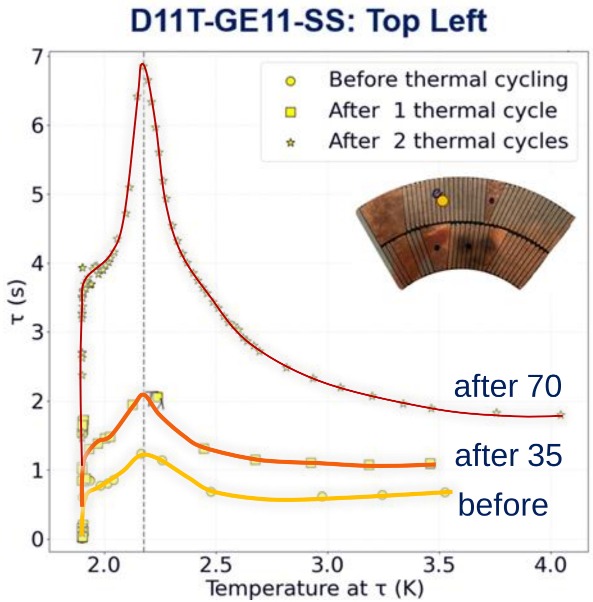



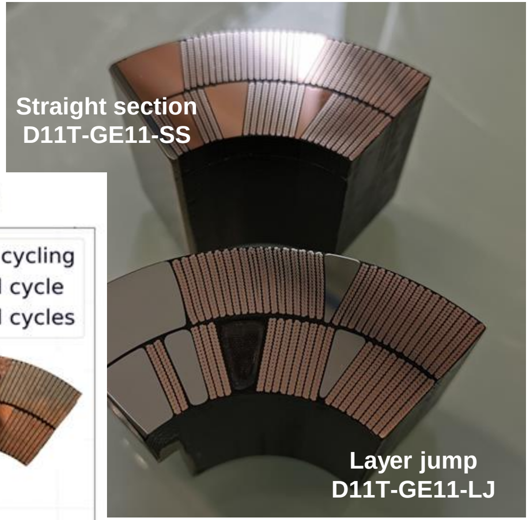



# Follow up on 11 T task force demand – τ/He diagnostics tool

Testing D11T-GE11 coil samples for time constant (He content development):

- Scan of thermal performance of He II cooled samples (similar to slide before),
- 35 thermal cycles from 1.9 K to ~25 K as a step function
- Scan of thermal performance to 3.5 K
- 35 thermal cycles from 1.9 K to ~25 K # 36-70
- Scan of thermal performance to 3.5 K




Main results in report:

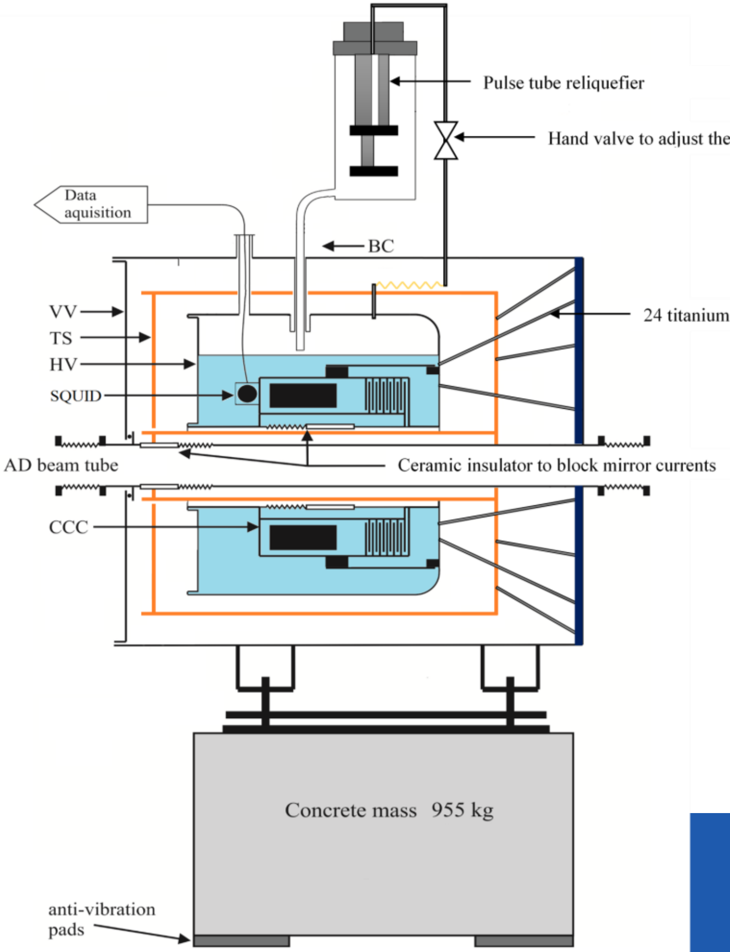
- Observed change in time constant (respective He content) depending on location and initial He content.
- Straight Section (SS) shows a different behavior than the Layer Jump (LJ) sample
- Samples are 2 x optically inspected by EN/MME

  Report: https://edms.cern.ch/document/2649442/1

# Remote cooling circuit solutions

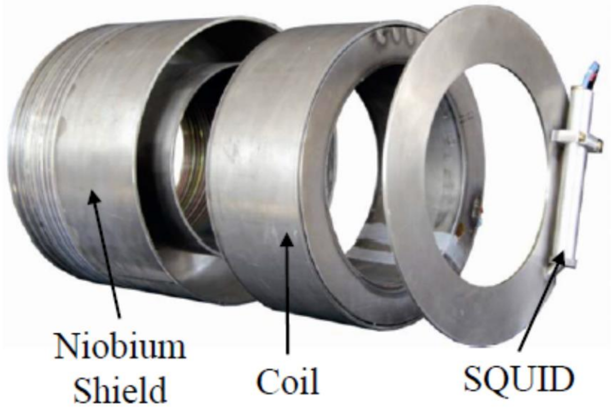
=> the path towards reduced He content / conduction cooling

# LHe zero boil off cryostat for the Antimatter Factory (BCCCA)




- Stand alone cryo system "ZBO"
- Complex design with ceramic breaks
- Q<1.2 W available cooling power
- Fully operational for 5 months

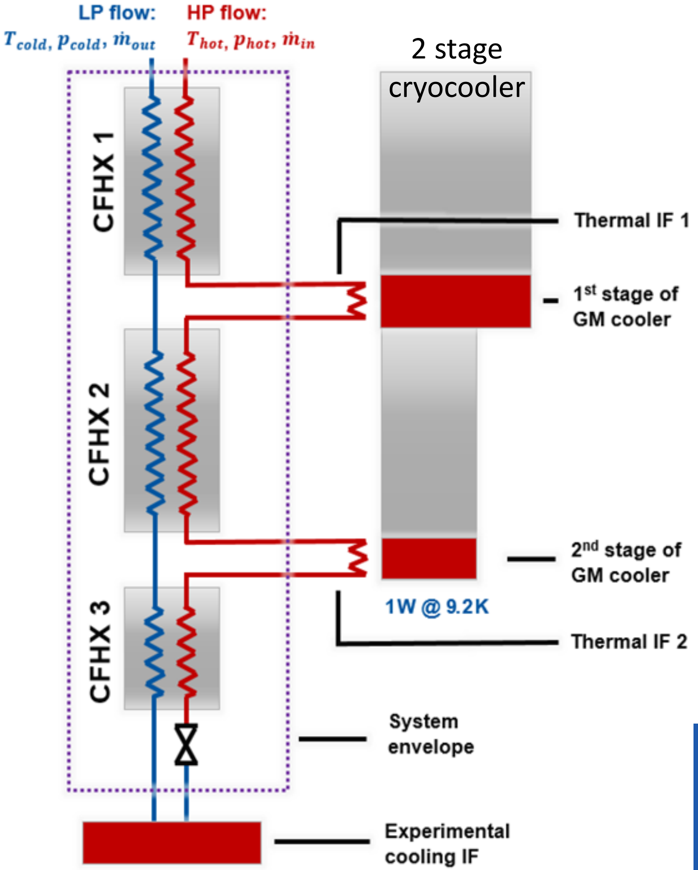
Warm bore cryostat for Antiproton beam pipe



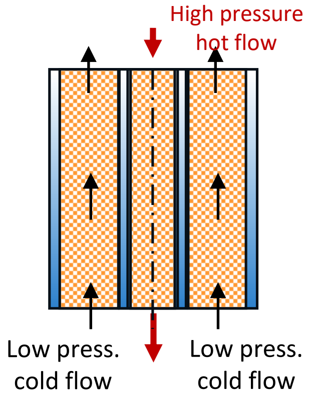

Low values of vibration, dT and magnetic field variations are crucial => paved the way to remote cooling circuit R&D

# Helium remote cooling circuit R&D

Research goal: Separate the cryocooler from harsh environment (radiation/mag. field) or protect the experiment from cryocooler influences (vibration/mag. disturbance).

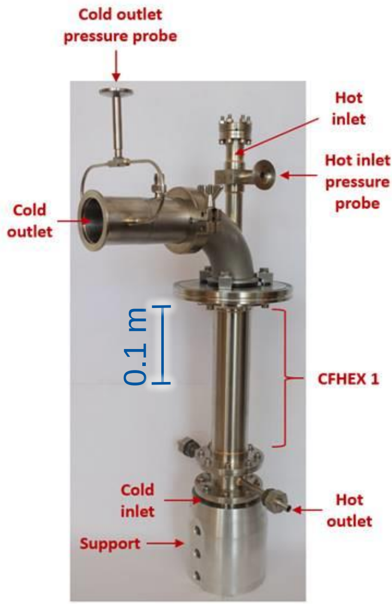



- Novel HEX design: highly compact enhanced tube-in-tube geometry
- High effectiveness of the HEXs is key for system performance
- Design code + scalable to various applications




Results:

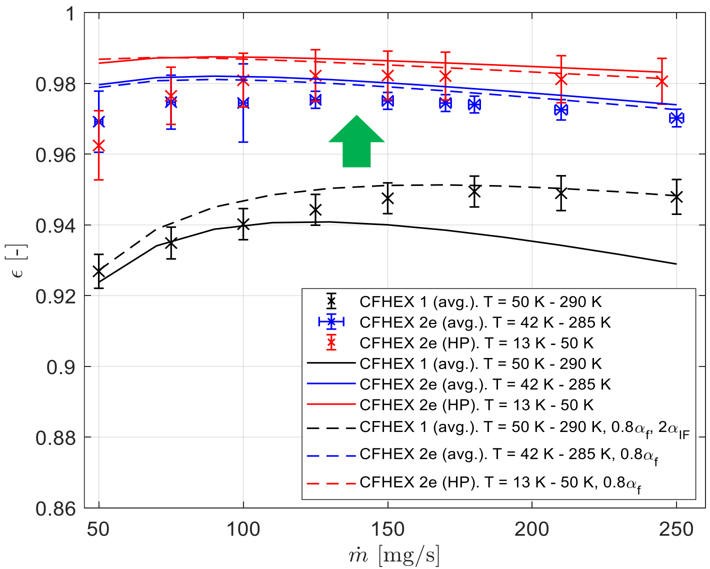
- Performance is tested in 293 K - 50 K range
- CFHEX 1 achieved 94.6 % effectiveness → enables an increased cooling performance of the circulation loop vs cryocooler alone



# Helium remote cooling circuit R&D

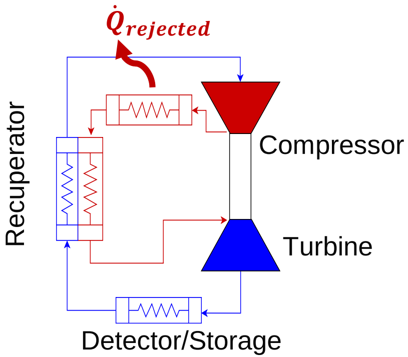
### Comparison of hard- vs transparent-wall CFHEX

- CFHEX 2e: 98.2 % (NTU = 54 @ T = 10 K – 50 K)
- CFHEX 2e: 97.5 % (NTU = 39 @ T = 42 K – 285 K)
- CFHEX 1: 94.9 % (NTU = 18.6 @ T = 50 K – 290 K)



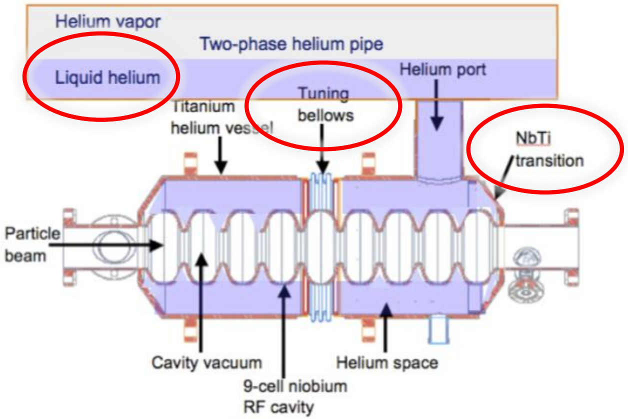

### Results

- Increased CFHEX effectiveness → even higher cooling performance of the circulation loop
- Technology opens the door to new applications:
  - Cooling Gravitation wave detector components
  - Space Reverse Turbo-Brayton for Earth Observation missions
  - Liquefying oxygen for interplanetary (e.g. Mars) space missions



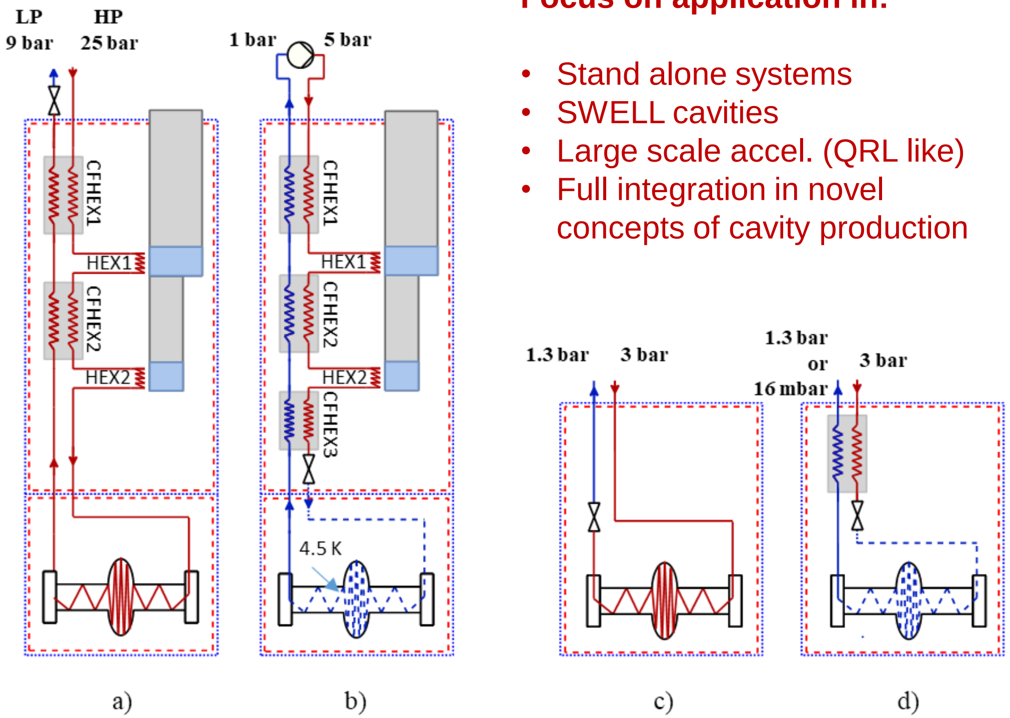
# Standard cryomodule vs. “dry” cavity cooling

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




**Pros vs. cons**

- LHe content, pressure safety at 0.5 barg
- Mechanical tuners at cold, material transitions
- Dilatation of up to 16 m long CMs
- $T_c$ transition front => trapped flux => orientation depend.
- Temperature profile, cooling performance




**Focus on application in:**

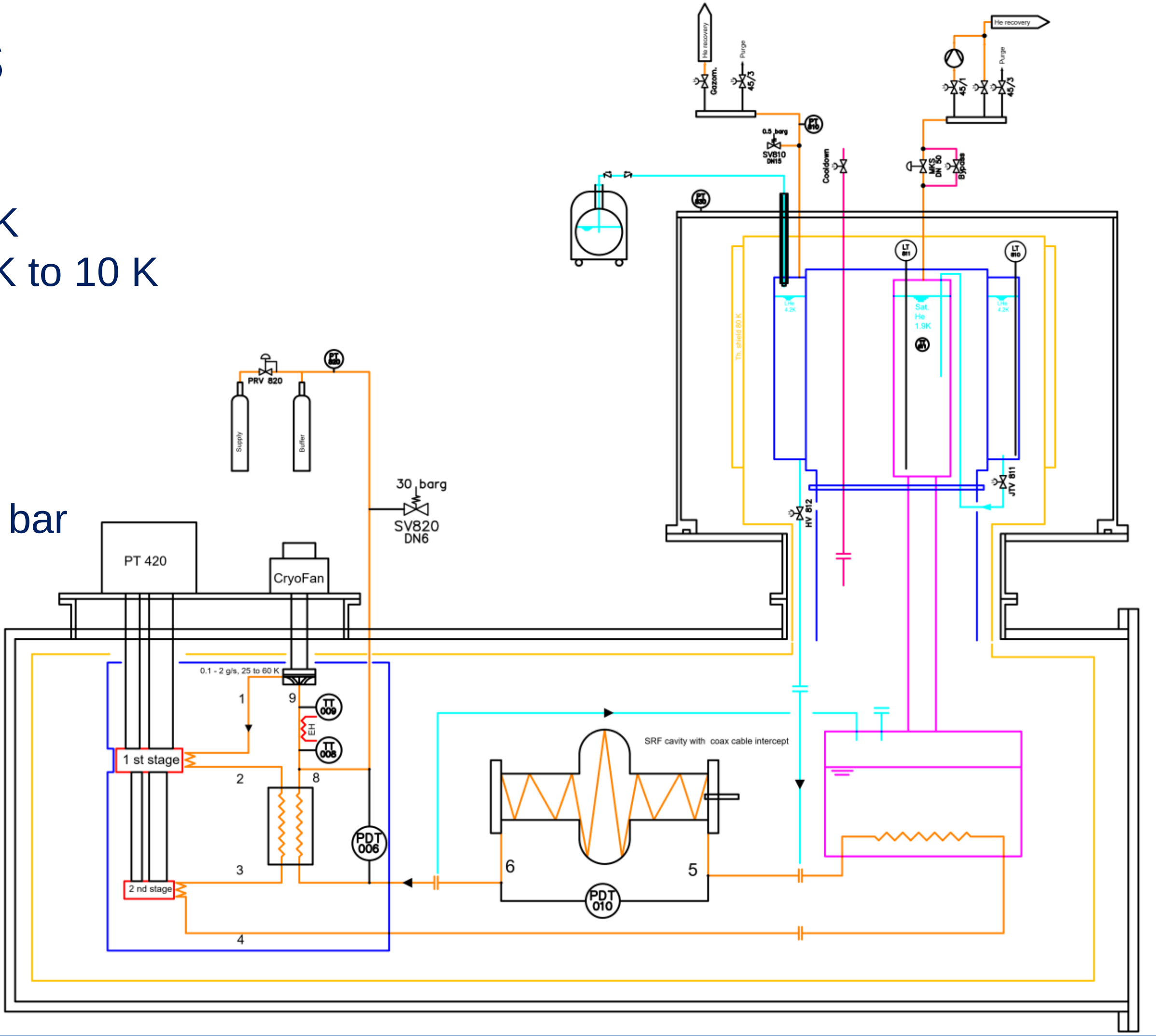
- Stand alone systems
- SWELL cavities
- Large scale accel. (QRL like)
- Full integration in novel concepts of cavity production

# Project objectives

- Pressure 1 bar – 25 bar
- Fluid 2-phase flow @ 4.2 K
  single phase @ 4.2 K to 10 K

- PTR < 1.8 W
- $LHe_{boosted}$ < 10 W (15 W)
- He II 1.9 K => 3 W
- Distributed J-T cooling 4 to 1.2 bar

- Cavity integration TE/VSC
- A15 SC coatings
- RF testing incl. stability



# Remote cooling circuit solutions

- **Sub-Kelvin solutions based on cryocoolers, Quantum computer** require vibration-free pre-cooling of dilution refrigerators => boosting cooling performance and further decoupling of the cryocooler(s) from **DR**
- **Radiation exposure tests** at low-temperature => e.g. CHARM (BLM, Diodes, Epoxies)
- Dark Matter search: **BabyIAXO/Rades** - coated cavities => remote cooling circuit
- **Mars mission:** effective $O_2$ liquefaction with Space Reverse Turbo-Brayton incl. HEX
- Cooling a **SC gantry** with cryocooler based solution

# Cryogenic - Magnet technology related R&D focal point

*"Road to <u>lower helium content cold-masses</u>, functioning at <u>higher temperatures</u>"*

- Functional cooling of High(er) Temperature Magnets
- Conduction cooled coil geometries and materials
- Thermal optimization of materials and constructs
- Remote cooling loops
- Heat transfer in and from HF magnets

# Summary

- CERN Cryolab capabilities
- Diverse program of cryogenic R&D
- Novel cooling options for accelerator and detector components

Cryolab capabilities document: https://edms.cern.ch/document/2384399/1
Cryolab website: https://te-dep-crg-ci.web.cern.ch/

Thank you for your attention