AXIAL CRYOGENIC CURRENT COMPARATOR (CCC) FOR FAIR

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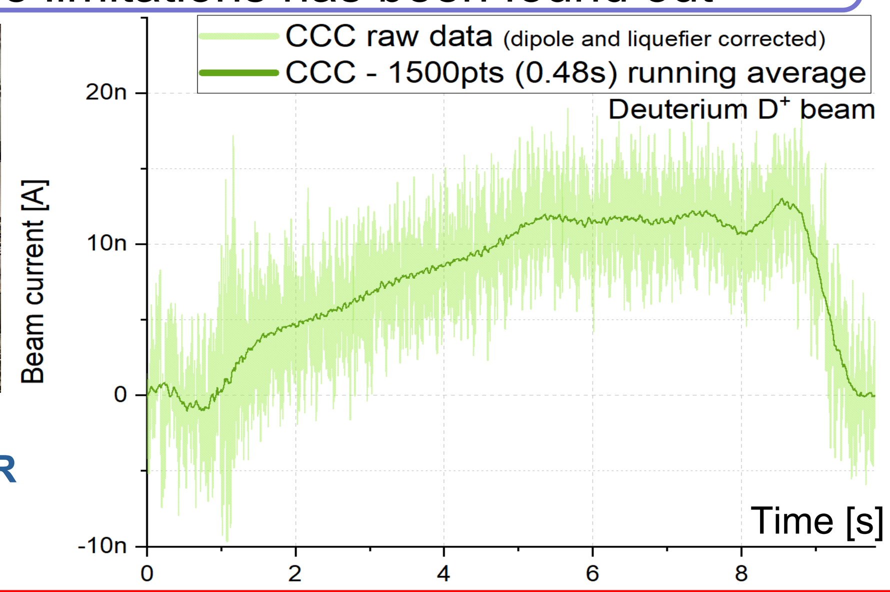
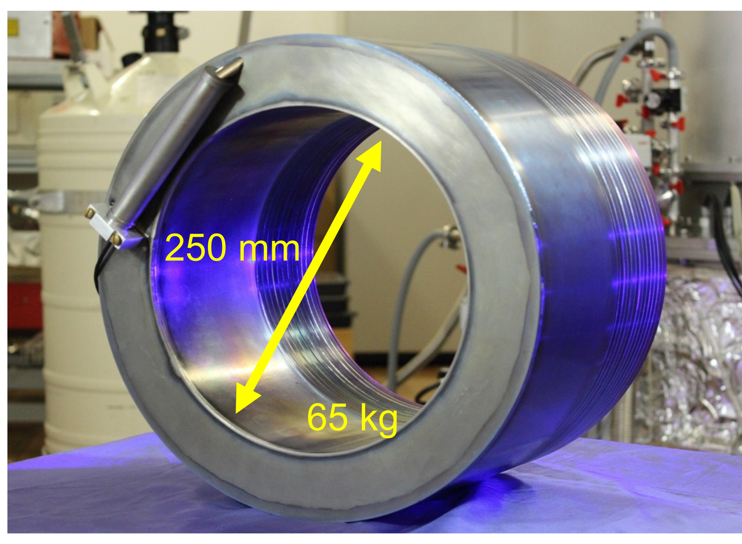
- The Cryogenic Current Comparator (CCC) provides a **calibrated non-destructive** measurement of beam current with a **resolution of 10 nA** or better.
- A first prototype of the detector, FAIR-Nb-CCC-xD with axial geometry, has been tested on the beamline at the storage ring CRYRING@ESR confirming its current resolution in the order of 10 nA, even if some limitations has been found out

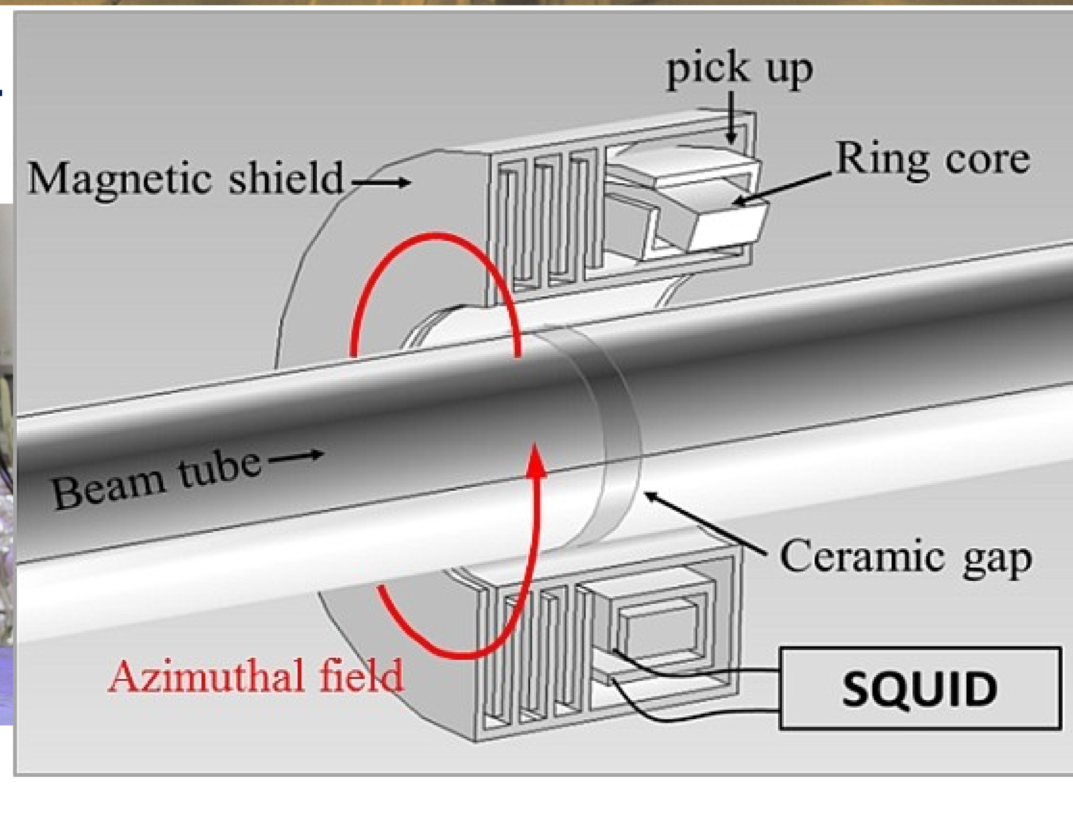

CCC installation on CRYRING@ESR beamline



The FAIR prototype CCC-eXtended-Dimensions (GSI-CCC-xD)

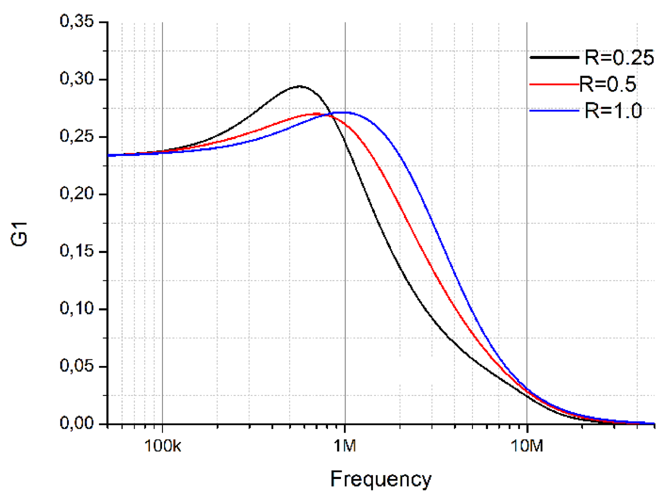


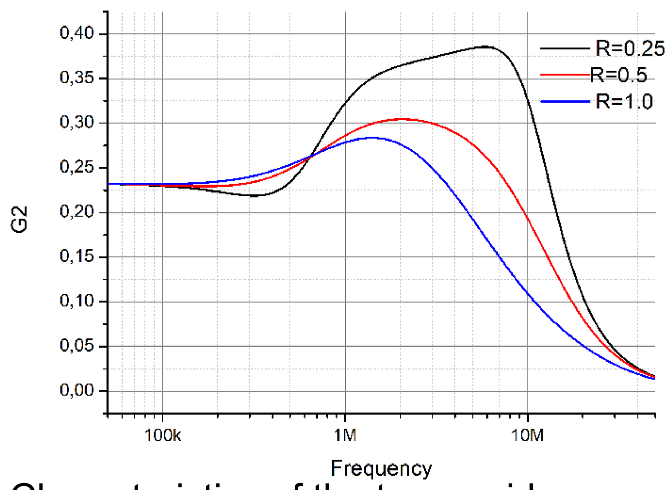
Deuterium beam in CRYRING@ESR



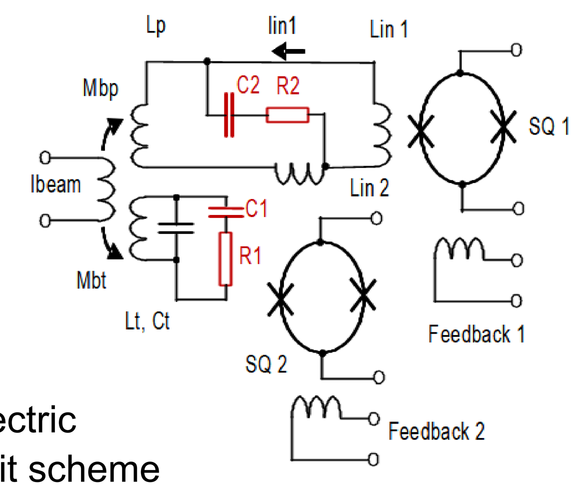
Axial Lead Coreless CCC

- A new CCC version is under development in collaboration with IPHT Jena to solve the issues found out with the FAIR-Nb-CCC-xD, in particular the low slew rate and the low magnetic shielding
- The new CCC will have an axial geometry and it will lack the high magnetic permeability core
- This CCC will be equipped with a two parallel squid system, to increase the bandwidth and the resolution
- One of the squid will be more sensible but with lower bandwidth, the other one will have a lower sensitivity but higher bandwidth
- The new CCC will reach a 10 MHz bandwidth, allowing to reach an higher slew rate without decreasing the detector resolution
- The lack of the core will reduce the low frequency noise due to magnetic field trapped in the core
- The axial shielding allows to strongly increase the shielding, up to an estimate theoretical value of **200 dB**

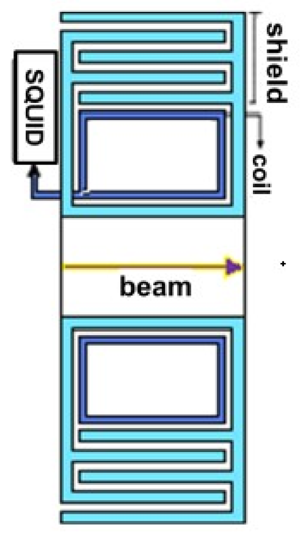


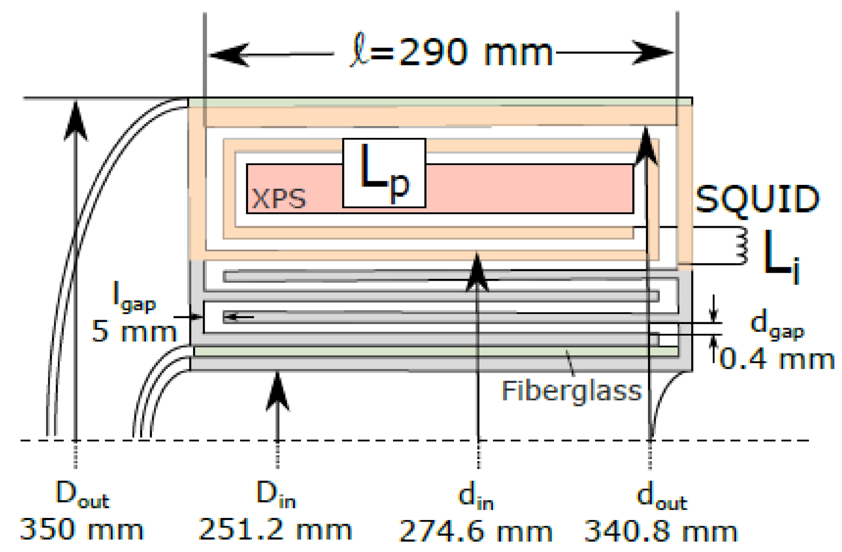


Characteristics of the two squids.
High: Squid CN4, higher sensitivity
Low: Squid CN2, lower sensitivity

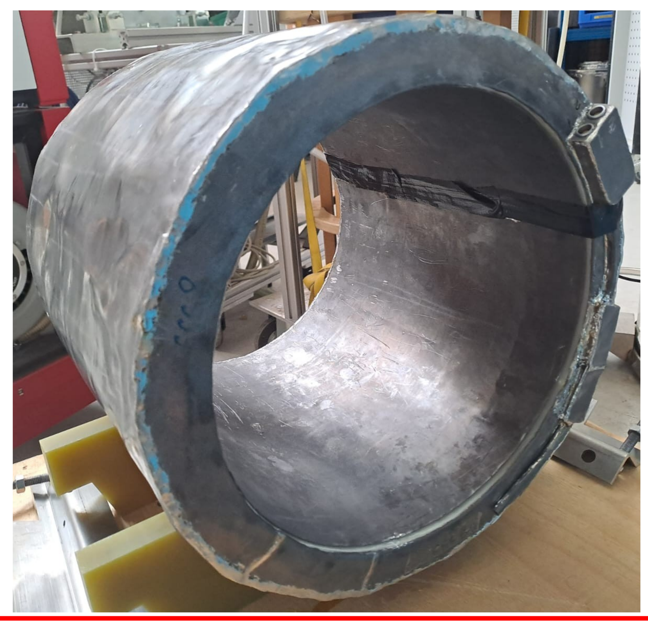


Electric circuit scheme



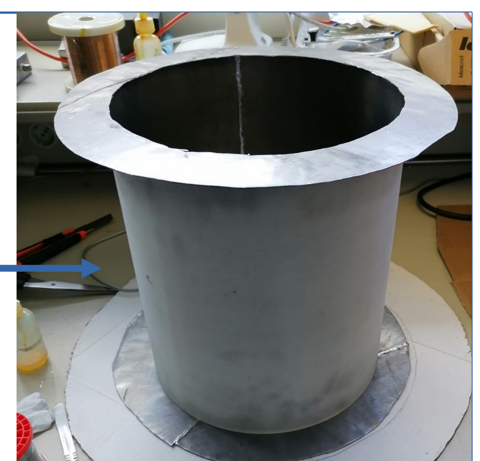


Axial CCC:
Up left : Schematic
Up right: Side view and dimensions
Right: Axial CCC front view



First Axial CCC Prototype Construction

- First prototype built in collaboration with IPHT Jena
- First step: Magnetic shielding, meanders structure, 10 layers
  - First layer: 1 mm thick Pb sheet, placed inside a fiberglass cylinder (250 mm inner radius) that provide structural integrity, wielded to upper and lower cap, carved out of 1.5 mm thick Pb sheet
  - 9 inner layers: made out of 0.25 mm thick Pb-SI sheet, interlaced by a layer of thin electric-insulation
- Pick-up Coil: 2 coils of 0.25 mm thick Pb-SI sheet are winded around a structure of XPS foam
  - The XPS foam is not magnetic and is used to fill up the volume of the pick-up coil and provide structural integrity
- Squid Box: The squid are connected with small PB strip to the pick-up coil
  - The squid are enclosed in a Pb box that shields them from external magnetic field
- Outer layer: The CCC is then completed by a 320 mm inner radius fiberglass cylinder, to provide integrity and avoid deformation during handling, enclosed by a last layer of 1mm thick Pb sheet that connect the upper and the lower cap.
- The wielding is performed with Pb-Sn material (ensure junction superconductivity) and the insulation is held in place by cryoglue



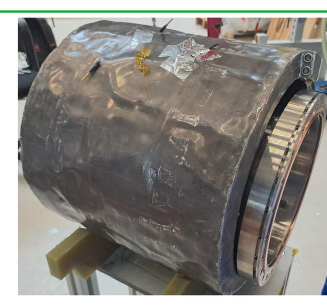

First inner meander layer, the insulation will be added on the outside of the lead sheet

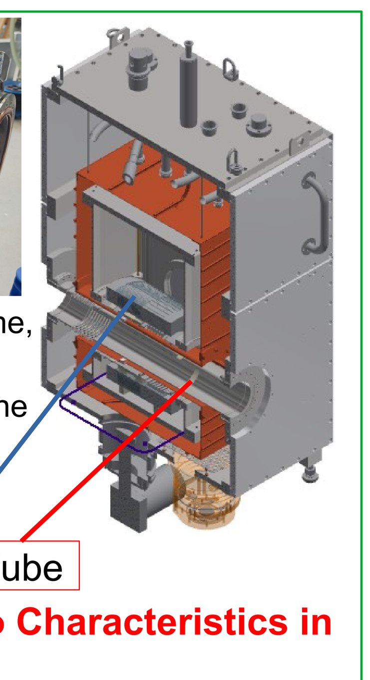

XPS foam structure during costruction, the foam piece are held together with cryoglue

Test in GSI beam-line cryostat

The test in GSI has shown huge issues of the Axial Coreless CCC:

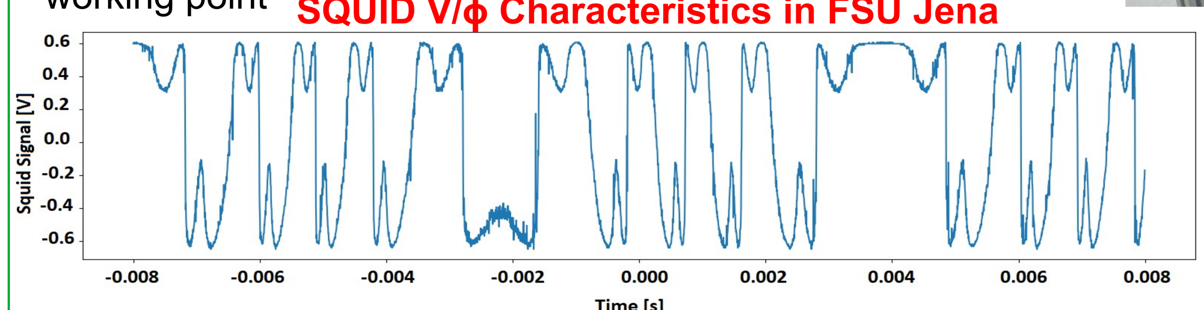
- The noise is too high, the squid can not be set in a proper working point

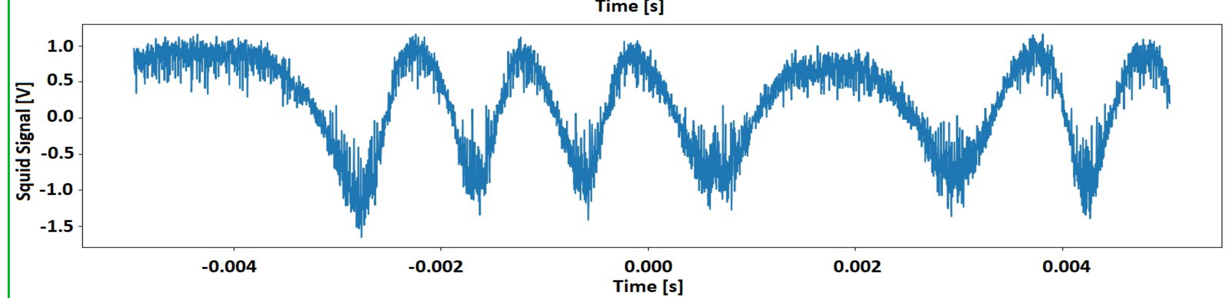




Cryostat scheme, The CCC is Installed over the beam tube

SQUID V/ϕ Characteristics in FSU Jena





SQUID V/ϕ Characteristics in GSI is noisy, the squid working point is not stable, it will not be possible to use it for the data acquisition

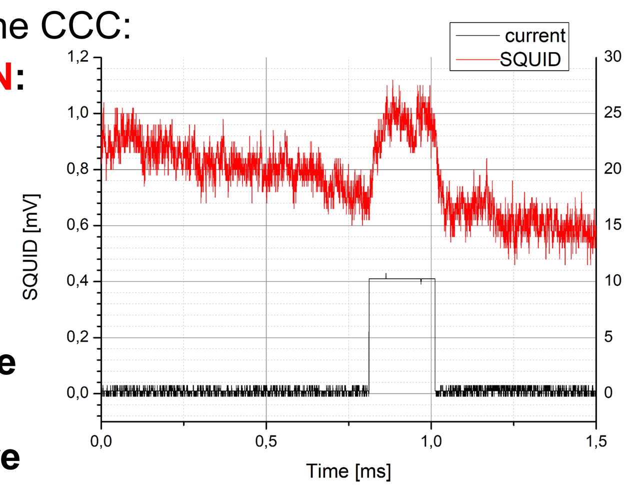
- The noise floor in GSI cryostat (≈ **1 μA**) is much higher than in FSU lab, and around 50-100 times higher than the noise floor of FAIR-Nb-CCC-xD
- The Axial coreless CCC can not be used in GSI cryostat, the noise is too high and the squid will never be able to work
- But the shield efficiency has been confirmed and the cascade squid system has strongly increased the slew rate, so the axial geometry is effectively a strong improve.

Test in FSU Jena Laboratory

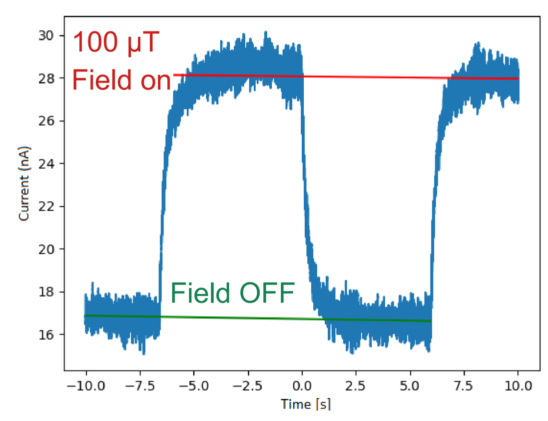
FSU Wide Neck cryostat, CCC during installation

The axial coreless CCC has been tested in Jena FSU laboratory. In this controlled environment we were able to test mainly three features of the CCC:

CURRENT RESOLUTION:
Minimum 10 nA
Lower than the one of the FAIR-Nb-CCC-xD, due to the lack of the core, especially because:
-Lower coupling with the beam field
-Higher noise floor (More than 10 times higher than the FAIR-Nb-CCC-xD)



Example of external field effect on FAIR-Nb-CCC-xD



-MAGNETIC SCREENING FACTOR:
FAIR-Nb-CCC-xD Screening factor 75 dB: 100 μT → 10 nA squid signal
AXIAL CORELESS CCC (Estimated 200 dB) 1 mT → <0.1 nA squid signal (too low to see it, much lower than noise floor)
-SLEW RATE: Axial Coreless CCC: Slew Rate **4 μA/μs** → FAIR-Nb-CCC-xD: Slew Rate **0.16 μA/μs**

The results found out for the magnetic screening factor and the slew rate are very positive, with strong improves for both. The main issues of the device seems the noise floor, that is much higher than the one of the FAIR-Nb-CCC-xD. What is left to do is to test the CCC in the GSI beamline cryostat

NEXT STEPS

- At the end of 2023 the FAIR-nB-CCC-xD will be definitively tested in the transfer lines at GSI, to perform the last test of the radial prototype in exactly the same condition in which it will be used in FAIR
- Even if the test in GSI has shown that the axial coreless CCC will not work in the accelerator environment it has confirmed the validity of the axial geometry for the magnetic shielding and of the cascade squid system to improve the slew-rate of the system
- This has suggested a new version of the CCC detector with axial geometry, based on the CCC Sm (Smart & Small) series[1], a double core axial CCC
- This new version will be tested in the GSI cryostat in the first months of 2024
- This test will be followed by a beam-line test at the end of the first half of 2024, as a final test of axial CCCs in the accelerator environment

[1]V. Tympel, et al., Creation of the first high-inductance sensor of the CCC-Sm series. IBIC'22, Krakow, Poland, Sept. 2022, doi:10.18429/JACoW-IBIC2022-WEP30

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