A SQUID-BASED BEAM CURRENT MONITOR FOR FAIR / CRYRING

HELMHOLTZ
GEMEINSCHAFT
Helmholtz-Institut Jena
GSI
FAIR

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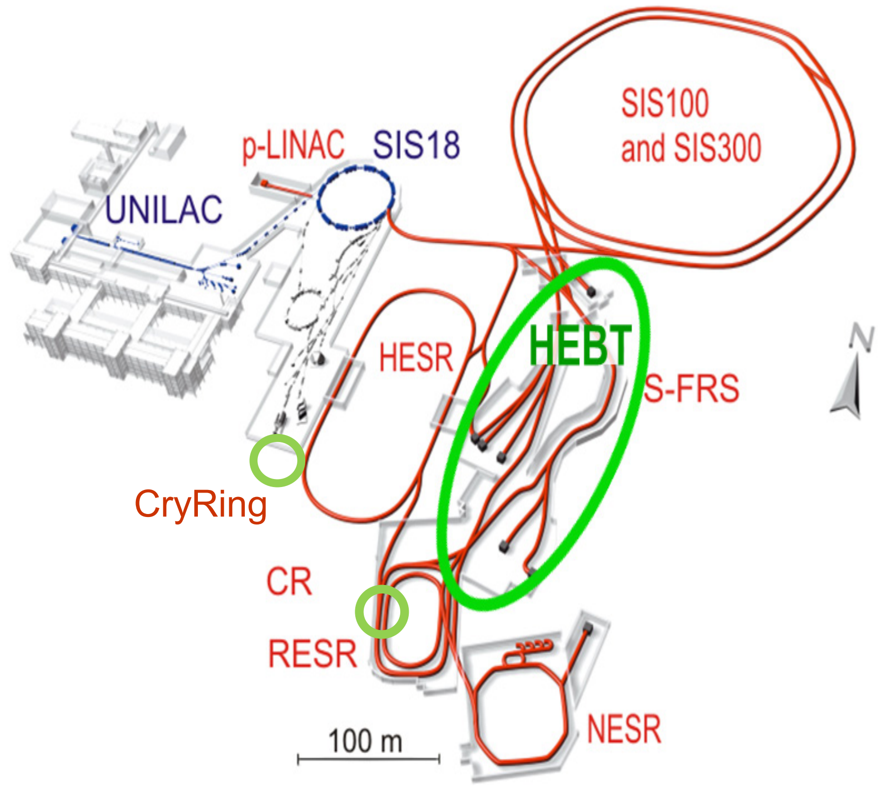
OUTLINE

- Future Installations at FAIR
- Challenges
- **C**ryogenic **C**urrent **C**omparator (CCC) principle
- Experimental results for improved sensitivity
- Conclusions and Outlook

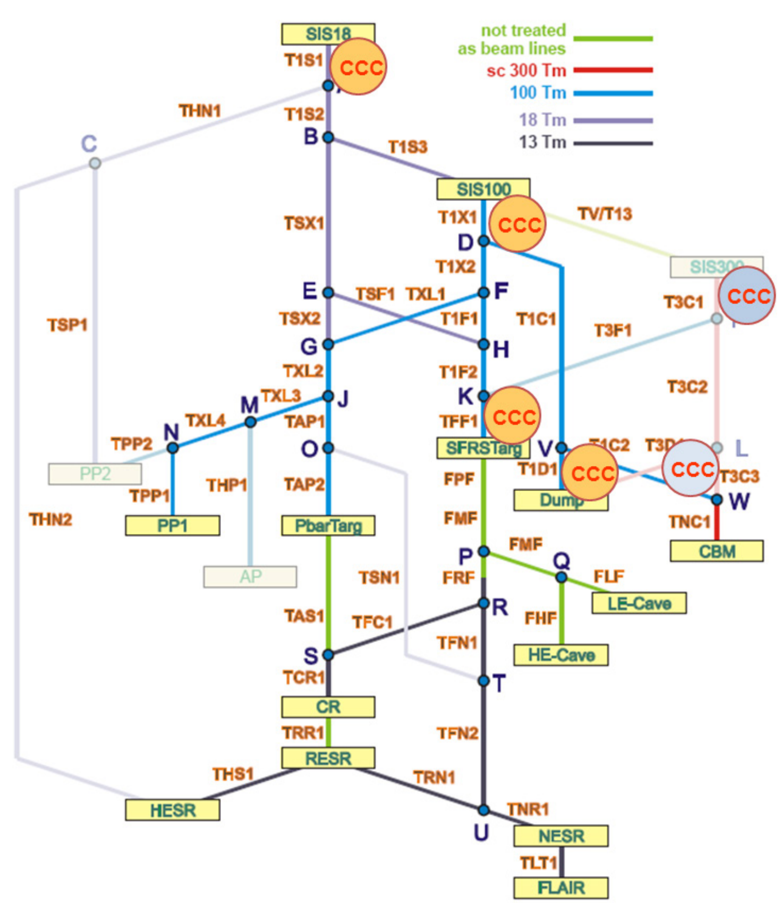
CCC for FAIR

- Facility of Antiproton and Ion Research (FAIR)
- Beam current measurement in
  - High-Energy Beam Transport (HEBT)-section,
  - Collector Ring (CR)
  - CryRing



CCC for FAIR

Beamline	Location	Extraction type	Particle species	Stage
T1S1	SIS18-SIS100	slow, fast	ions, protons	FAIR Startversion (Modules 0-3)
T1X1	SIS100 extraction	slow, fast	ions,protons	
T1D1	SIS100 → dump	slow	ions, protons	
TFF1	SFRS-Target	slow	ions	
T3C1	SIS300 extraction	slow	ions, protons	Phase B
T3D1	SIS300 → dump	slow	ions, protons	

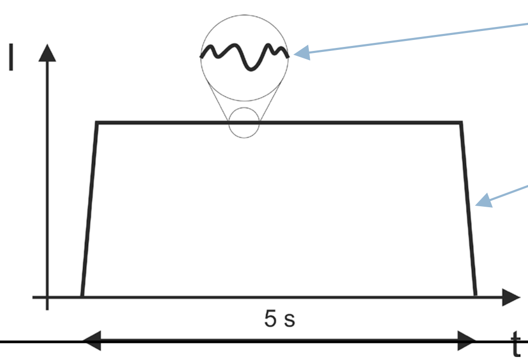


For all 6 beam lines above:
minimal Intensity: 10^4 pps
maximal intensity: 10^{12} pps

Ion	Maximum Beam Current [slow extraction, 1 s]
p	160 nA
U^{28+}	4.5 μA

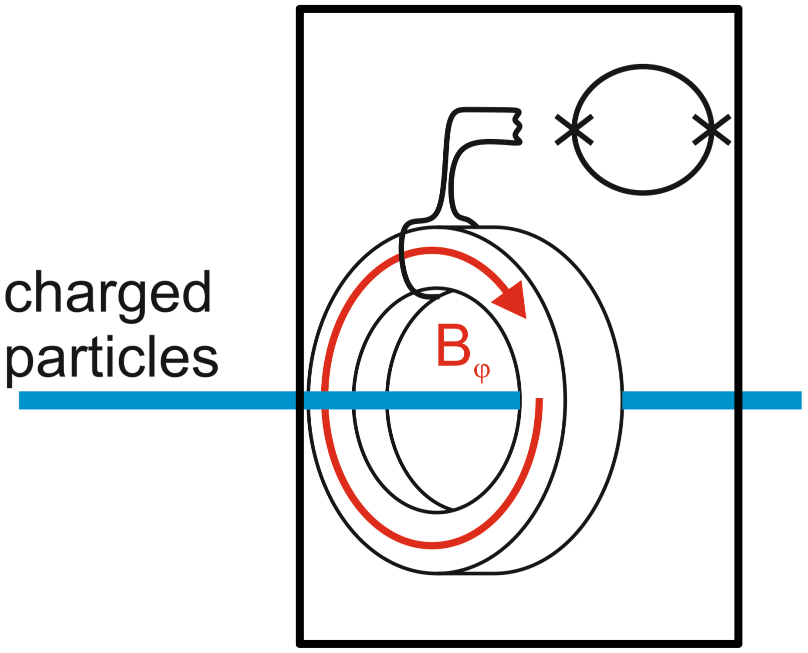
Challenge

Beam current measurement	Detector requirements
Transport section, Storage rings	On-line, non-destructive, absolute measurements easy, linear calibration
Maximum beam current: 160 nA for (anti-)protons 4.5 µA for uranium ions U^{28+}	goal: Current resolution < 1nA
Current pulses with DC-part	High bandwidth incl.DC High slew rate

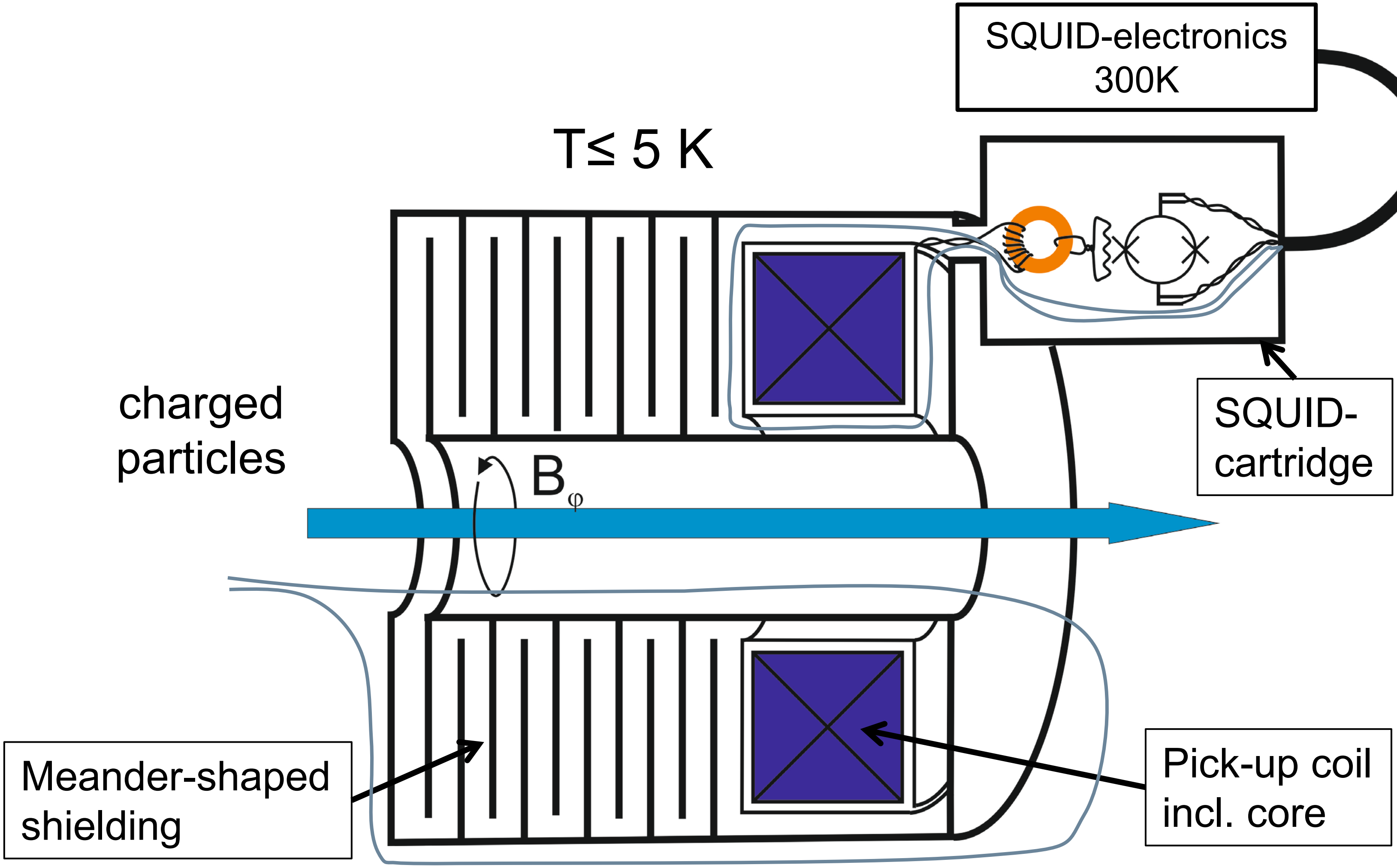


CCC-principle

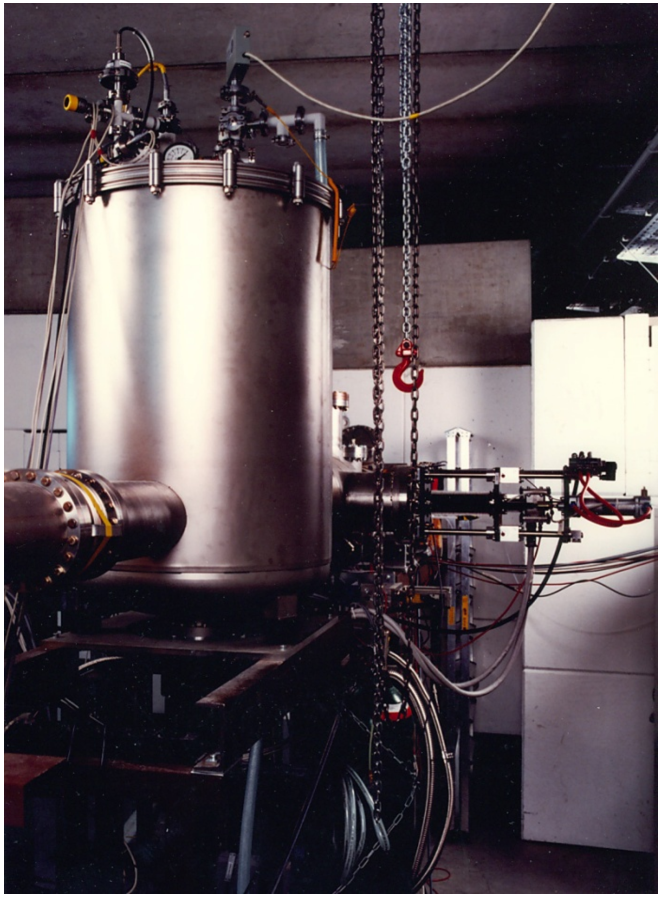
- Detection of the beam's azimuthal magnetic field
- Superconducting Pick-up coils
  - DC-magnetic field measurements due to flux conservation in closed sc loops
  - Lower noise, because of no hysteresis losses
- DC-Superconducting QUantum Interference Device, (DC-SQUID) acting as current sensor
  - Highly sensitive, low intrinsic noise contribution
- Superconducting Shielding
  - Attenuation of all non-azimuthal magnetic field components

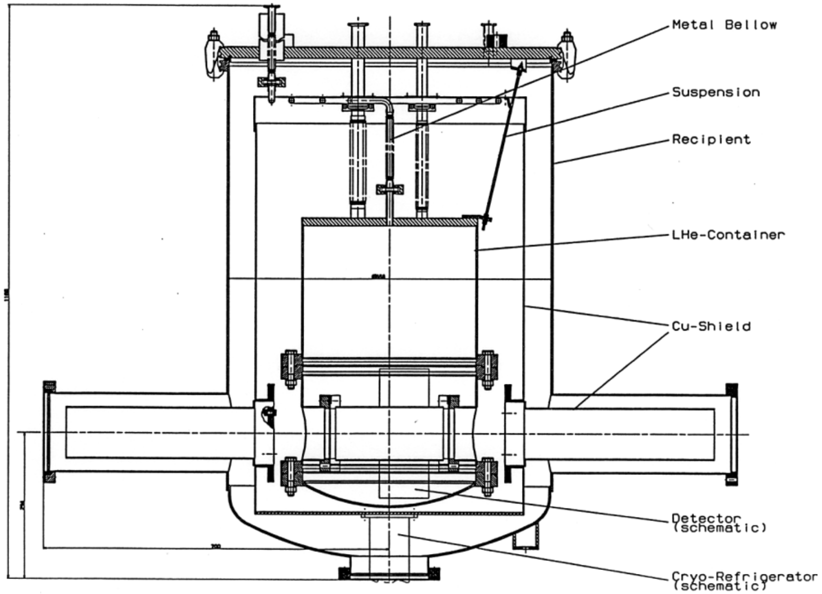


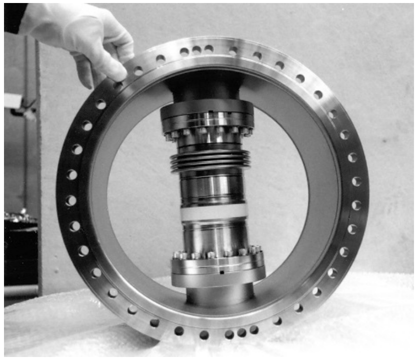
CCC-principle



The CCC at GSI Darmstadt



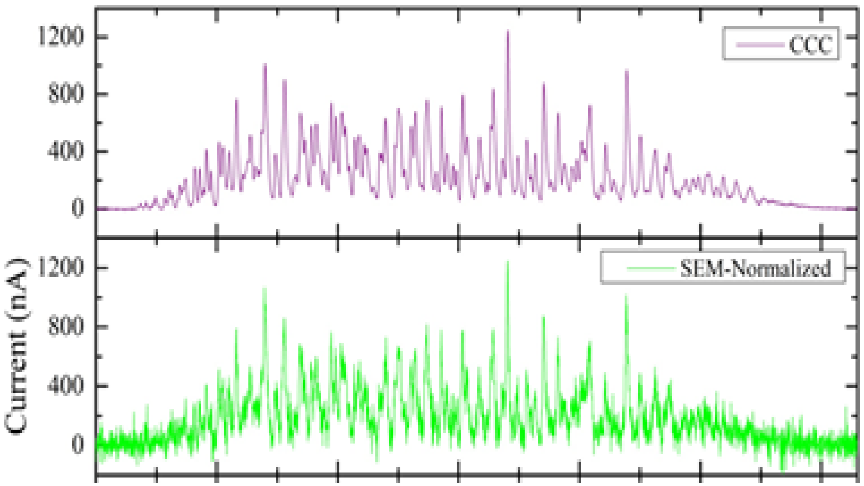




Photography of the CCC assembled in the beam line and some technical details.

Beam measurement
$^{28}Ni^{26+}$ at 600 MeV/u

- Replacement of
  - SQUID-sensor
  - SQUID-electronics
- Secondary Electron Emission Monitor (SEM) for comparison
- Perfect agreement between two independent spill monitors (CCC vs. SEM)



Ni^{26+} at 600 MeV/u extracted from SIS18

10 CCC for FAIR

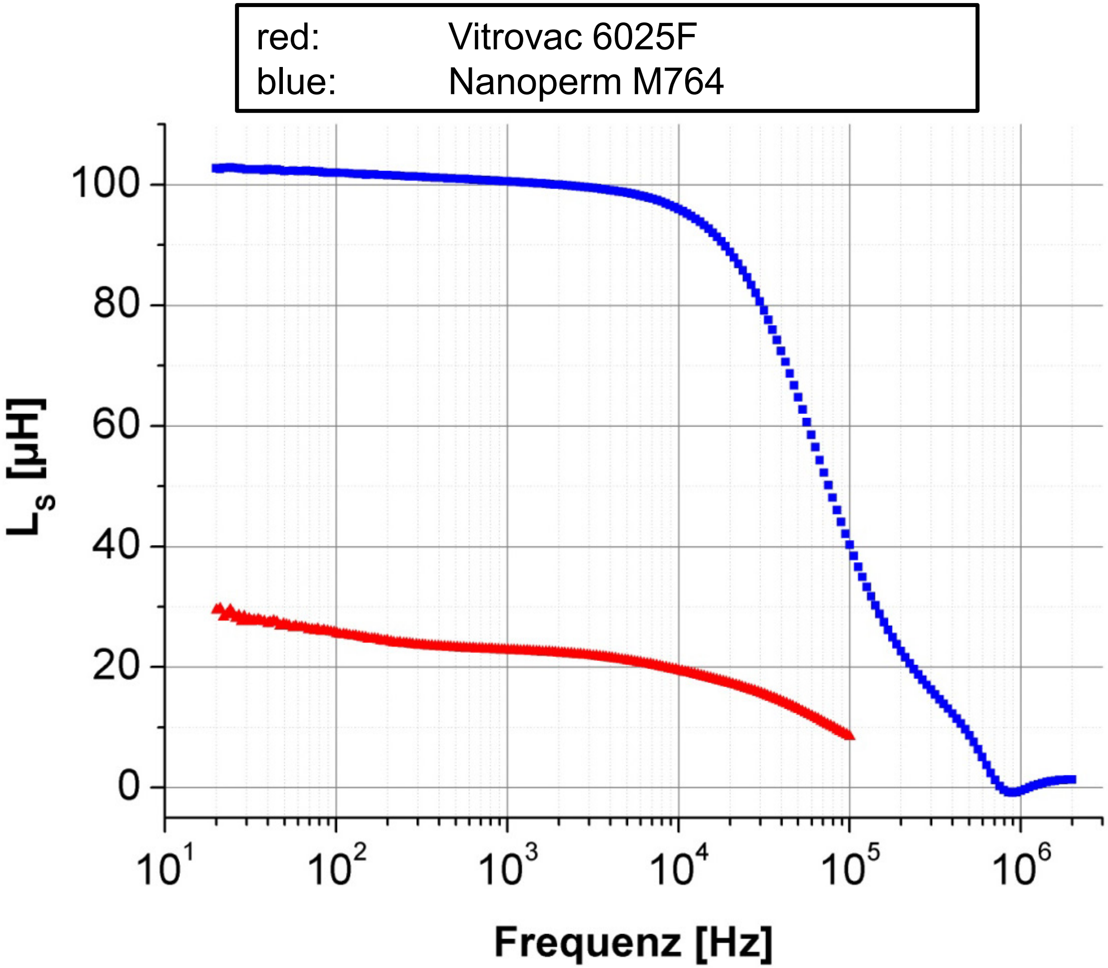
Improvements using new core materials and concepts

Improved pick-up coil

$$\langle I^2 \rangle = 4k_B T \int \frac{R_S(\upsilon)}{(2\pi\upsilon L_S(\upsilon))^2 + (R_S(\upsilon))^2} d\upsilon$$

Requirements to core materials:

- frequency independent high real part of the permeability (L_S).
- low imaginary part over a wide frequency range which corresponds to a low losses in the material (R_S).



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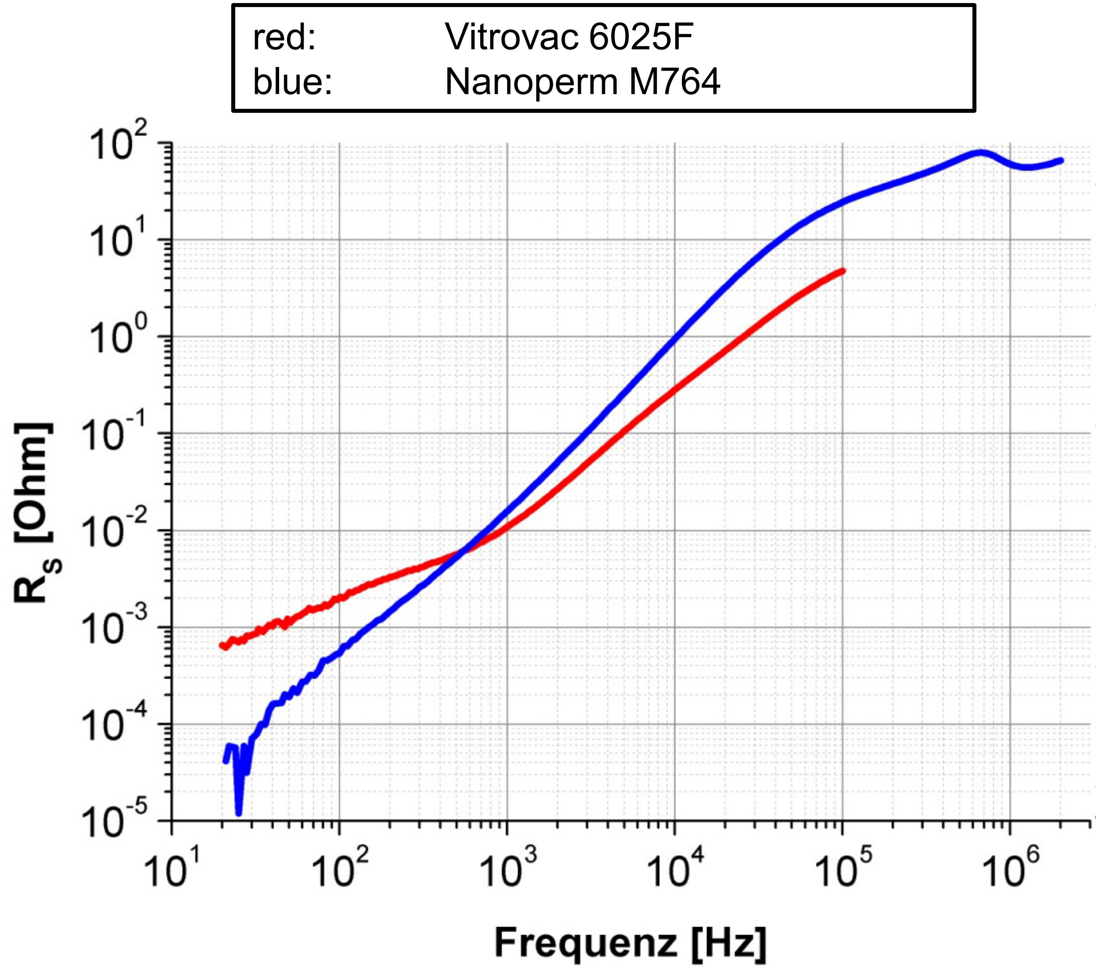
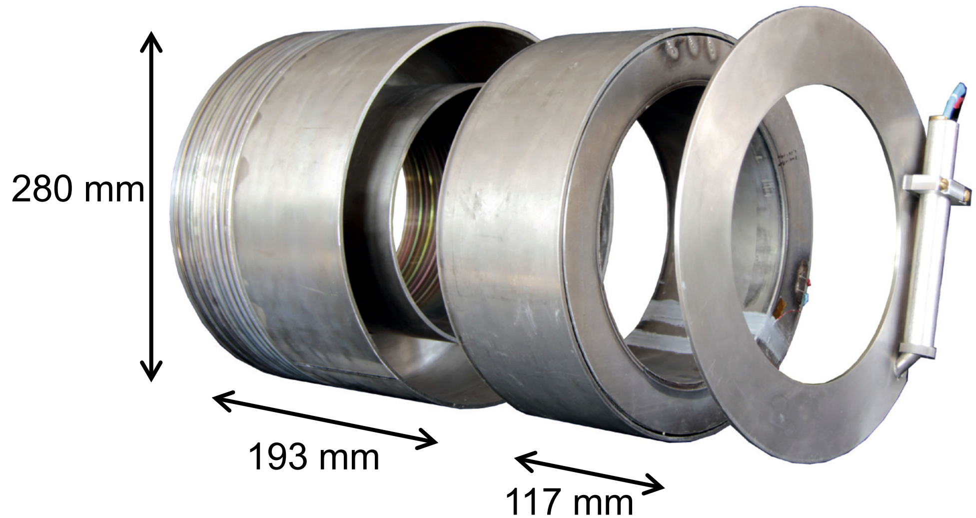


Setup FAIR-CCC

- Nanocrystralline Nanoperm M764 as core material
- Electron beam welded niobium parts
- Commercial SQUID-sensor Supracon CP2 blue.
- Commercial SQUID elctronics
  Magnicon XXF-1



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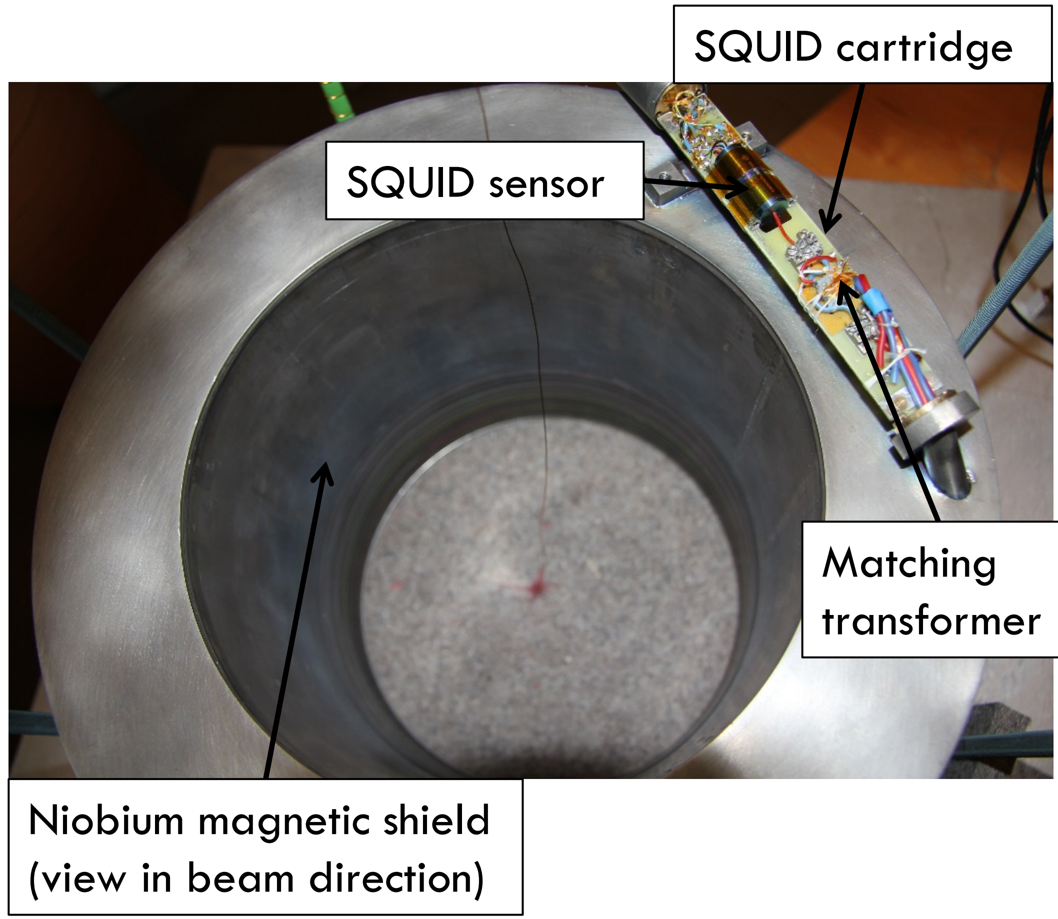
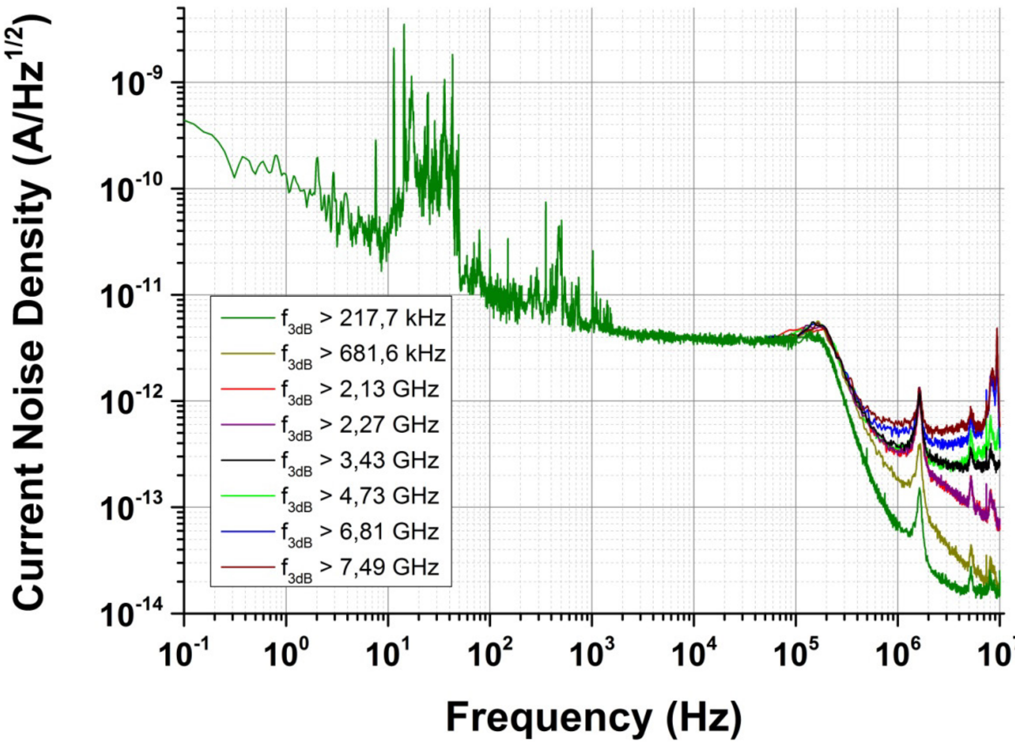


Current noise density
Bandwidth estimation

- White noise 3.5 $pA/Hz^{1/2}$
- 3 nA total noise
- SQUID system bandwidth f_{3dB} adjusted by electronics settings
- Decrease at 200 kHz estimated as CCC bandwidth



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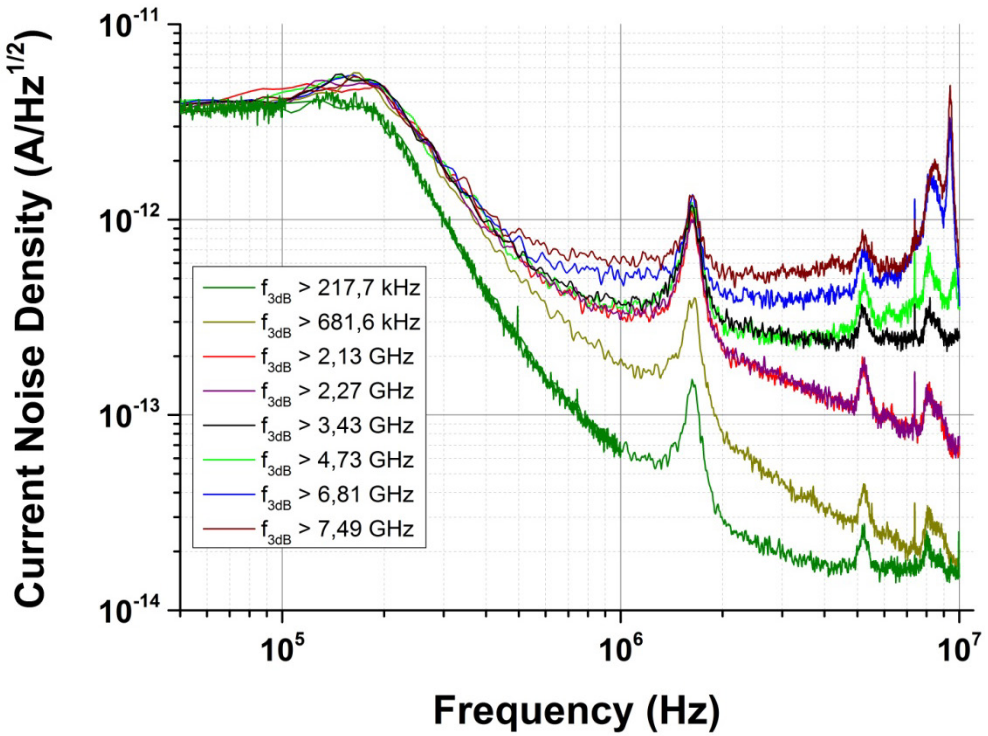
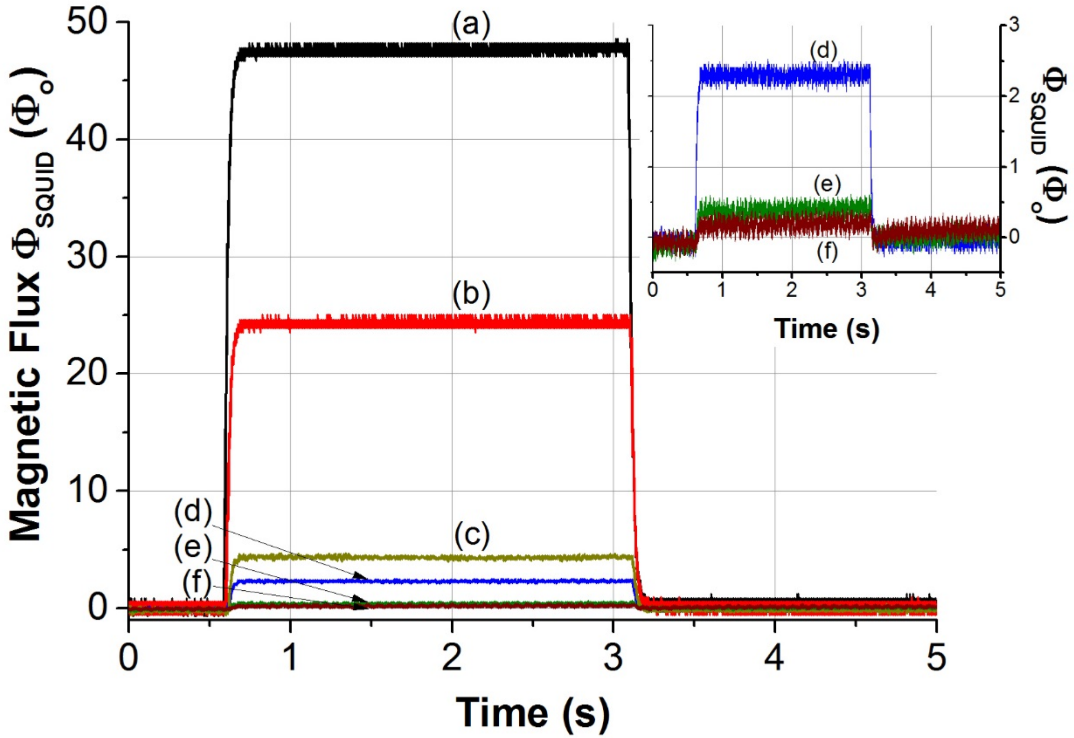
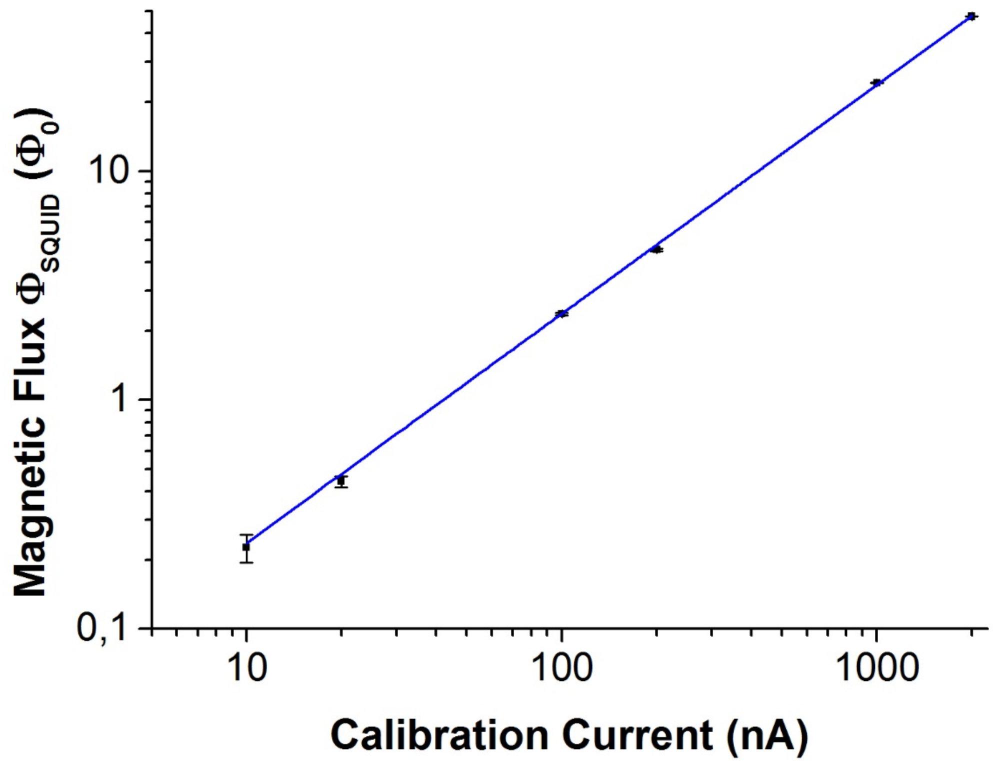


Step function response CCC



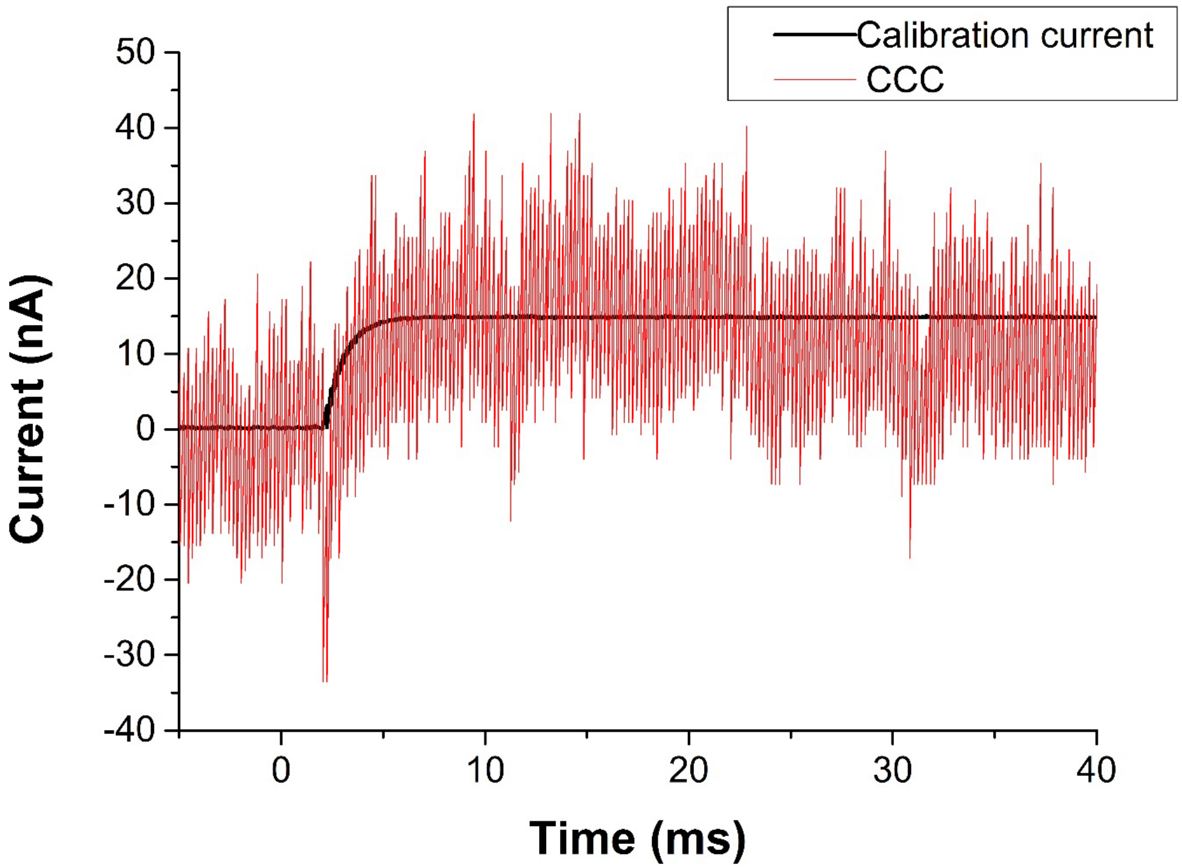
Tests with battery powered current source
(a) 2 µA, (b) 1µA, (c) 200 nA, (d) 100 nA, (e) 20 nA, (f) 10 nA

Current sensitivity
Linearity



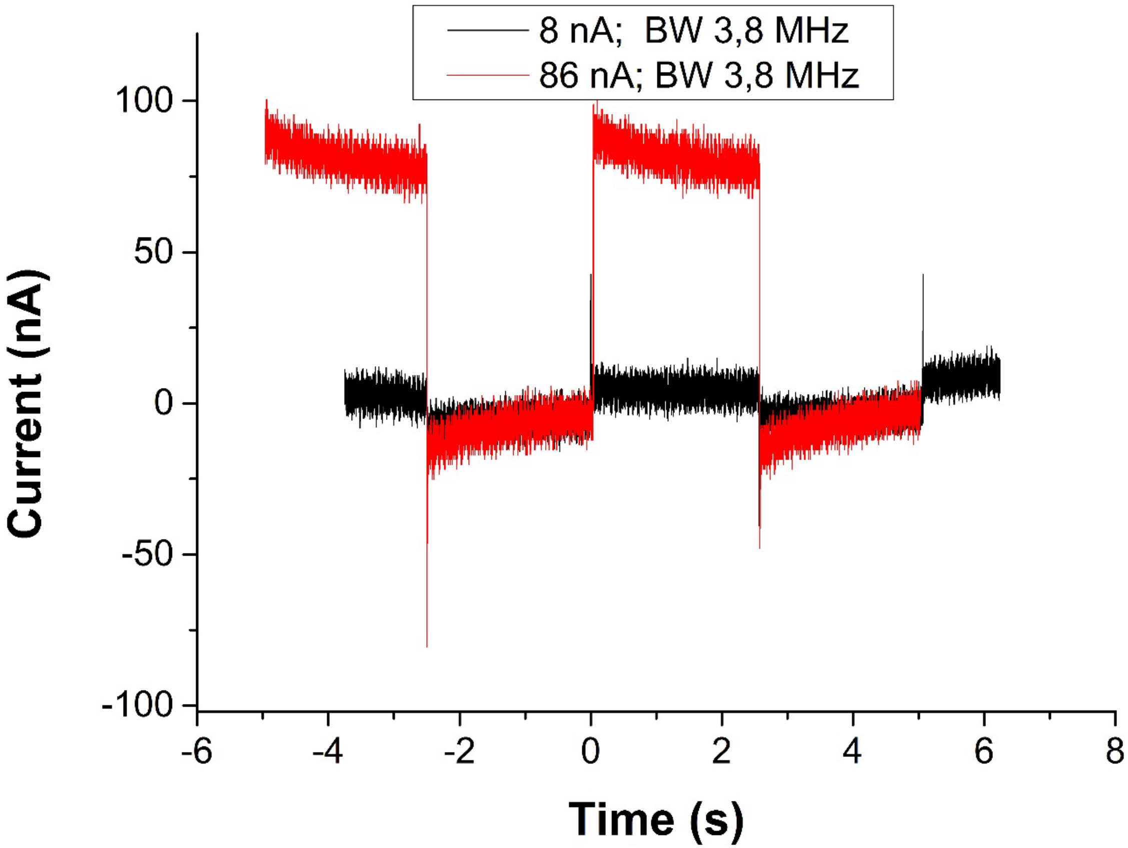
Current sensitivity $= 42.0 \pm 0.3\ \mathrm{nA}/\Phi_0$

Slew rate limitation



(black) 14 nA test signal with low signal slew rate
(red) CCC response

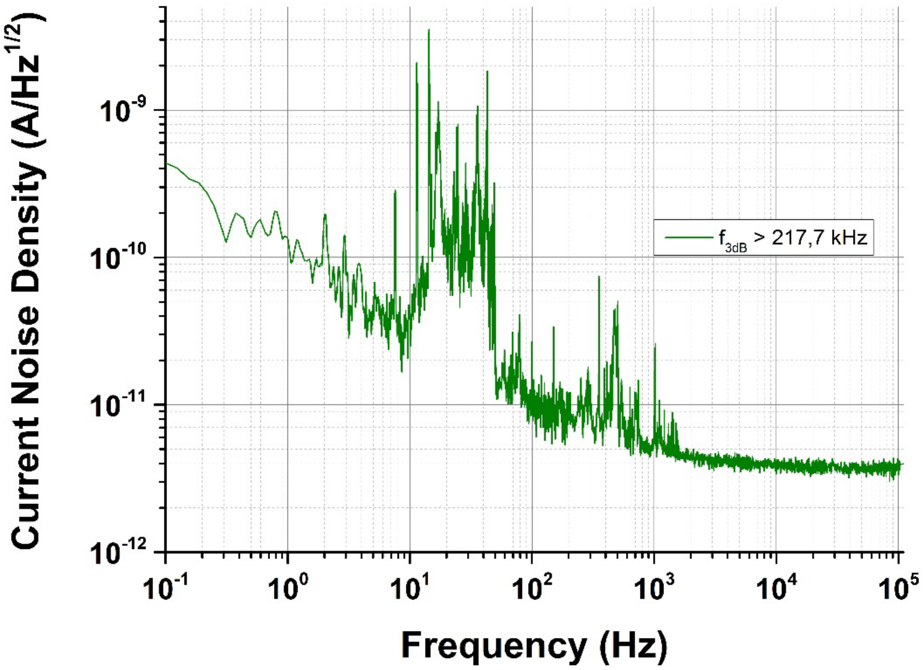
Slew rate limitation



CCC response on a 8 nA (black) and 86 nA (red) test signal with high signal slew rate

Future Investigations

- Investigations on microphonic effects
- Development of cryostat with local liquid helium supply
  - Reducing microphonic effects by damping of mechanical vibrations, pressure and temperature stabilization



Advantages of a SQUID based CCC

- Non-destructive measurement method
- Measurement of the absolute values of the current
- Exact absolute calibration using an additional wire loop
- Independency of charged particle trajectories and particle energies
- Demonstration of the suitability at GSI and HoBiCat
- High resolution (< 100 pA/√Hz), 3.5 pA/√Hz white noise
- High bandwidth of 200 kHz estimated
- High linearity

Acknowledgement

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THANK YOU FOR YOUR ATTENTION!