Optimization of the Cryogenic Current Comparator for slow extracted Beams

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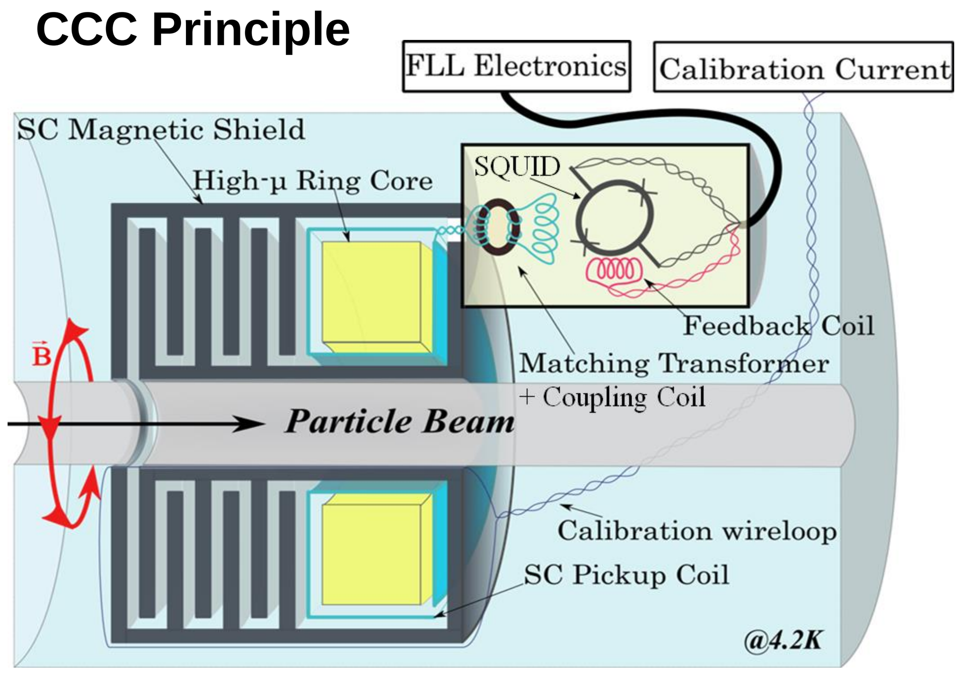
Abstract: The Cryogenic Current Comparator (CCC) is a superconducting device for measurement of low beam intensities with magnetic fields in the range of fT. It uses a Superconducting Quantum Interference Device (SQUID) as an ultrasensitive magnetometer and an elaborated superconducting shield for its protection from external magnetic fields. The system is operated in a helium bath cryostat, which has to fulfil many requirements, such as being non-magnetic, pressure/temperature stable (mK), vibration dampening, UHV fit, bakeable, compact and accessible for maintenance and repair.

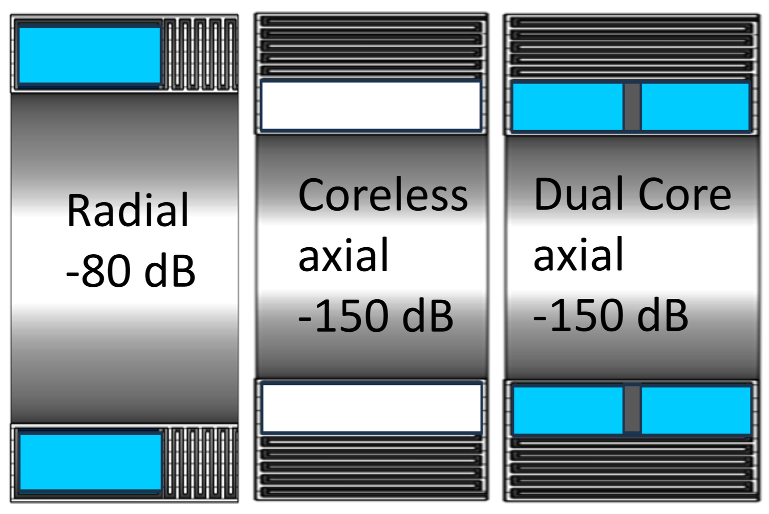
First operation of a CCC as beam current monitor was achieved in the 90s at GSI. The idea has been updated for measurement of slow extracted beams and exotic ions at FAIR, since 2014 there has been steady optimization by an international collaboration of expert institutes. Looking at noise figures and current resolution as well as practical applicability and costs, a Dual-Core CCC (DCCC) has turned out as best candidate for FAIR.

In parallel to detector development the cryostat has been investigated and improved. It has recently achieved stand-alone operation >6 months, which is a main requirement for operation in the FAIR tunnels.

CCC Principle

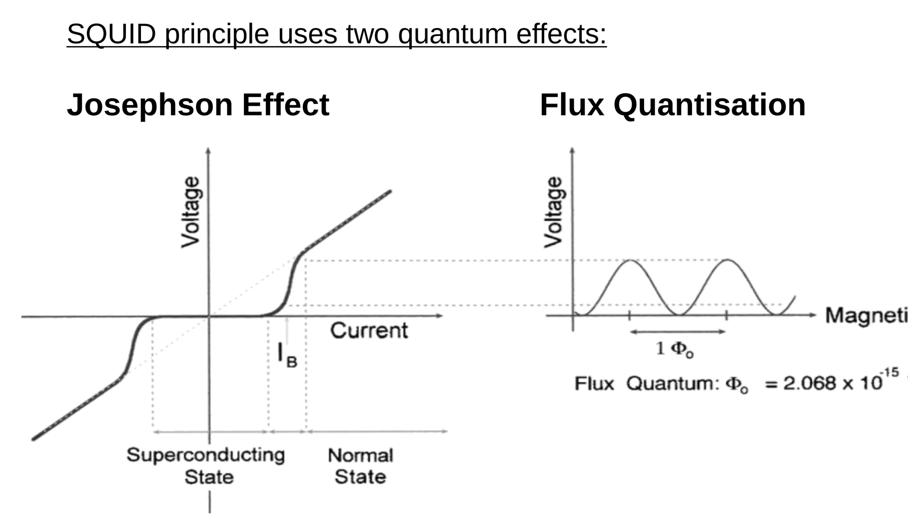


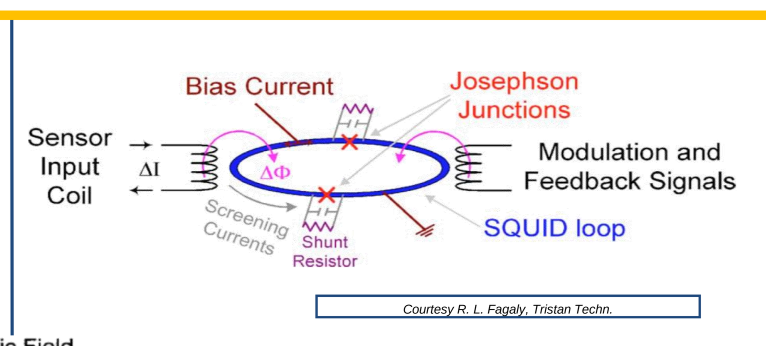
CCC shielding types and external field attenuation



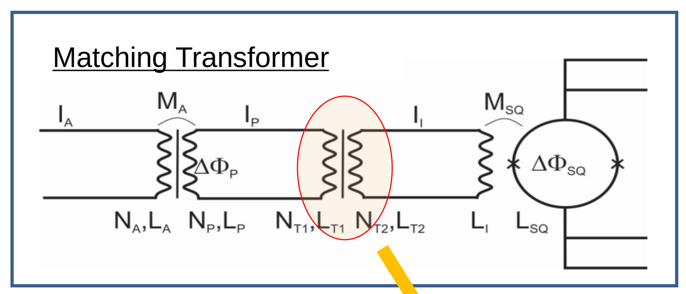
CCC provides …

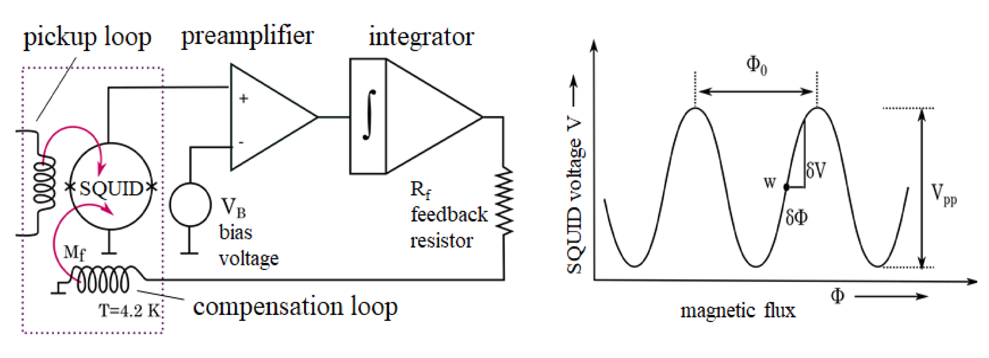
- non-destructive online measurement of beam intensity down to nA range
- high bandwidth compared to standard techniques (Ionization Chambers, Secondary Electron Monitor etc...)
- absolute measurement of beam current → calibration of other, indirect measurement techniques (eg. Secondary Electron Monitor)
- measurement independent of particle energy, position and species



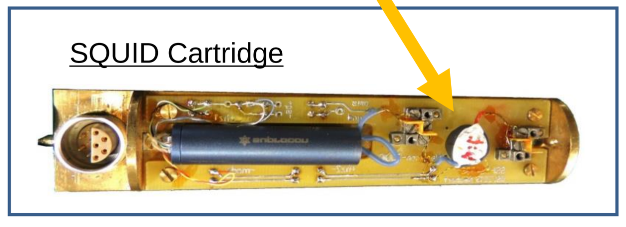


SQUID operation





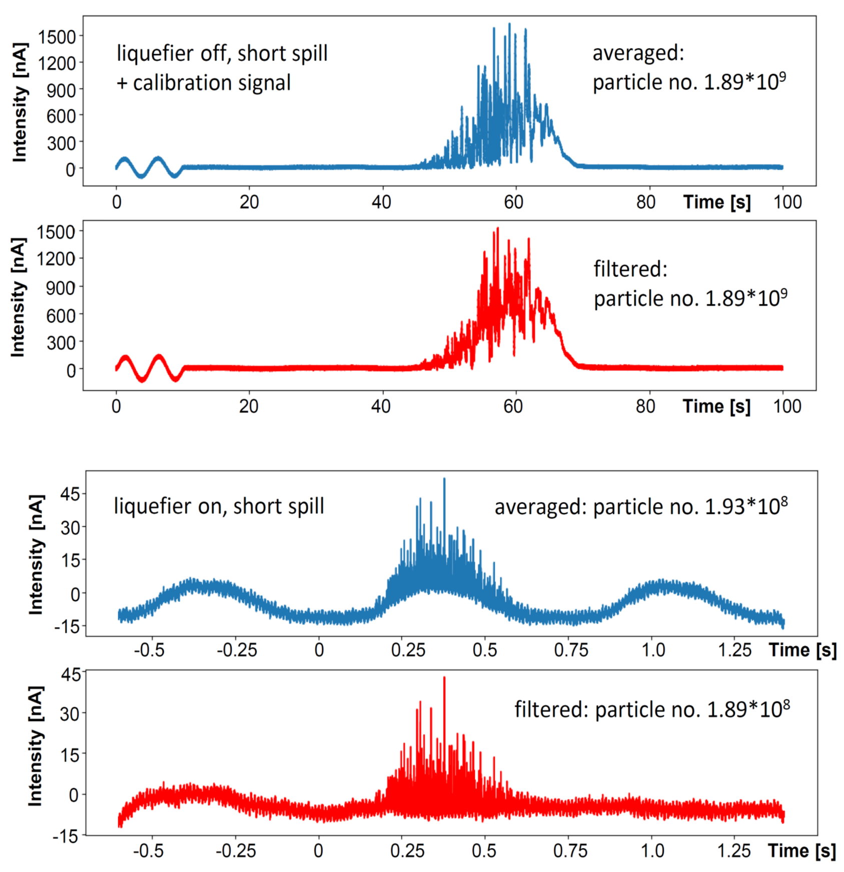
Schematic of the FLL /SQUID electronics, W = working point

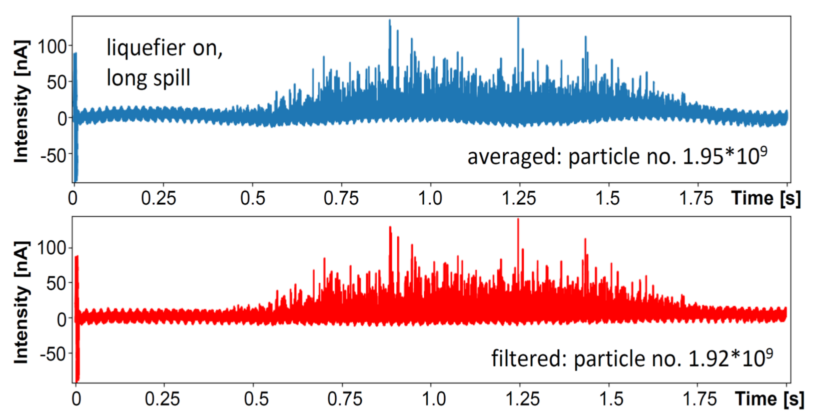


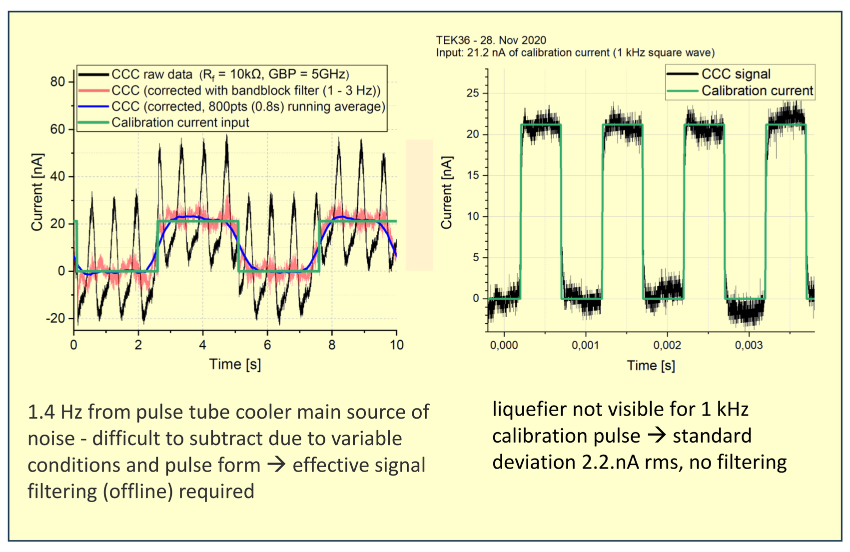
Matching transformer provides not only impedance matching but also provides resonance damoing and allows for implementation of filtering

Radial CCC - pertubation filtering / ‚tune wobbling' test

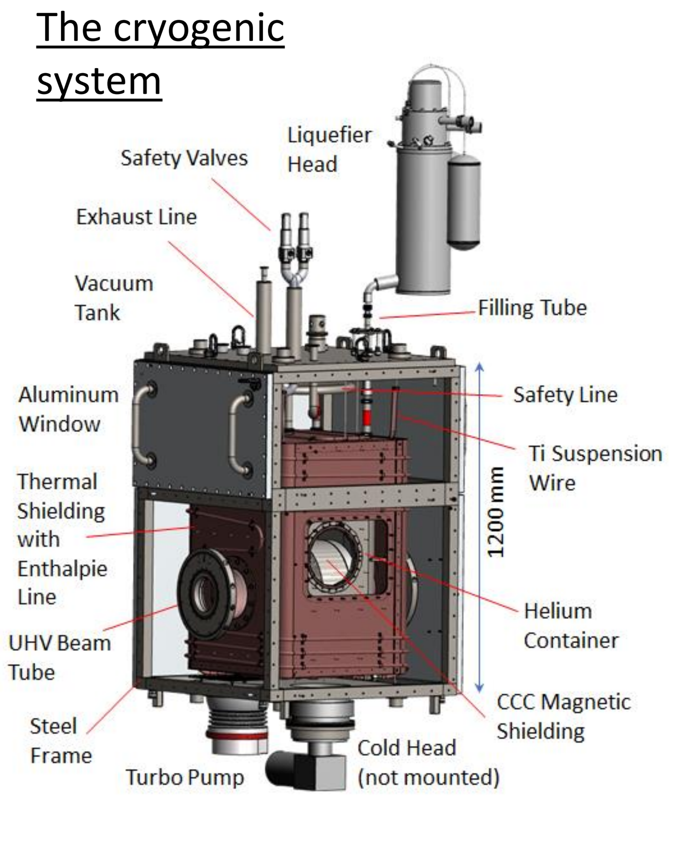
Beam: U^{73+}, $3*10^9$ pps, 200 MeV/u, t_{extr} 50 ms – 1 s. Goals: eliminating pertubations, investigation of bandpass (1.4 Hz, 2.8 Hz and 4.2 Hz) offline filtering effects on particle numbers + spill shape ⇔ single shot / averaging only to derive particle no.

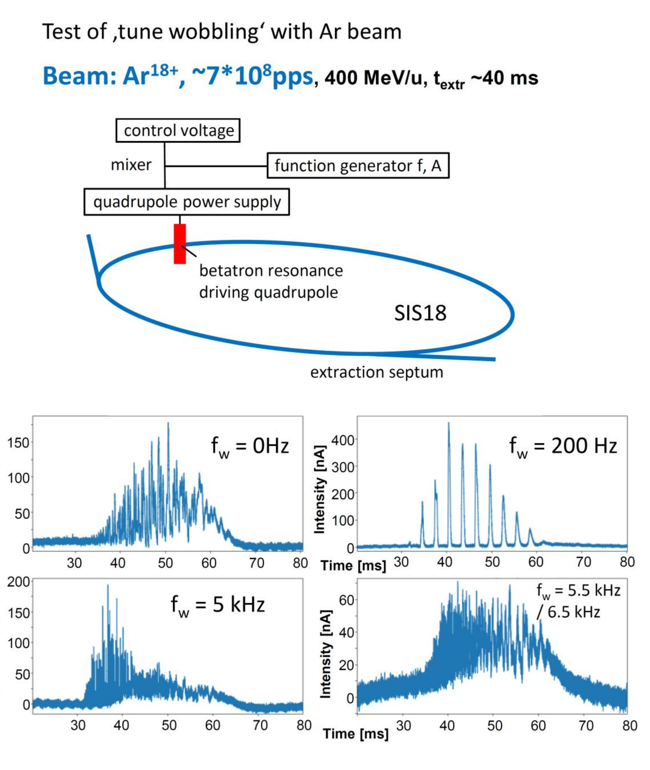




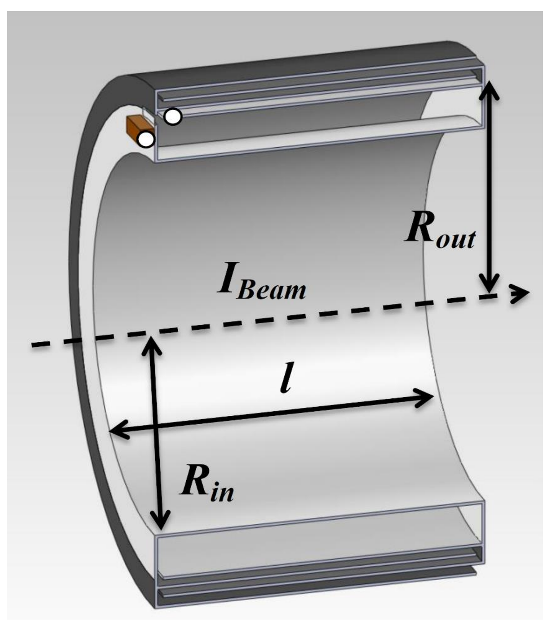


The cryogenic system

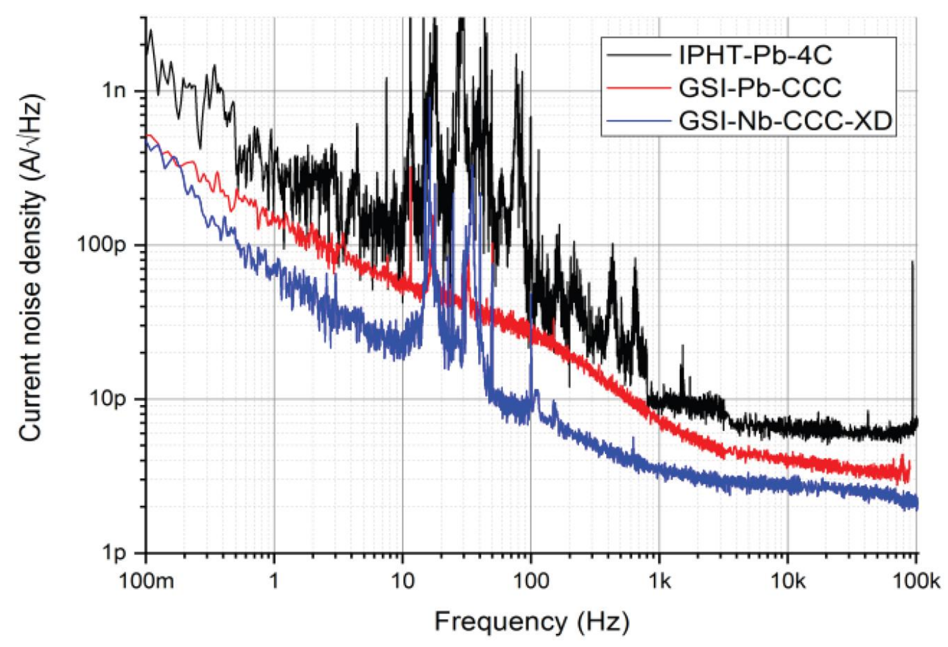




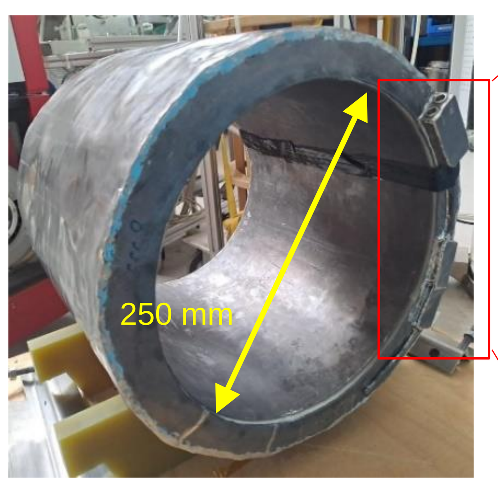
Dual Core CCC (DCCC) - test with slow extracted beams



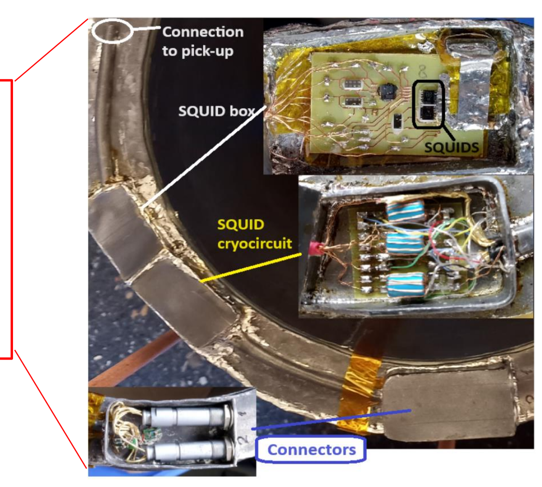
1st develoment step: coreless CCC



Noise spectra corless (black) radial (blue) 90s prototype (red) CCCs

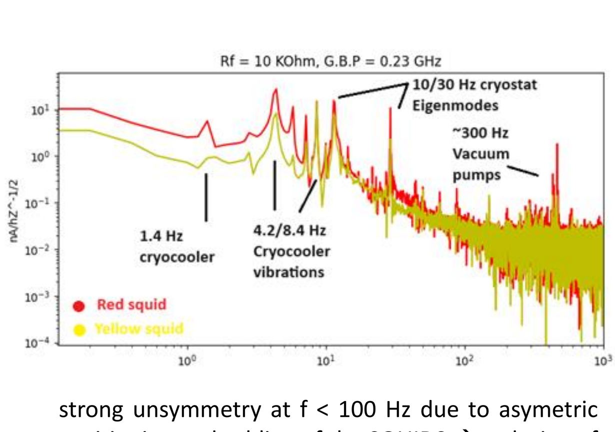


Dual Core CCC prototype



SQUID connections and SQUID circuit

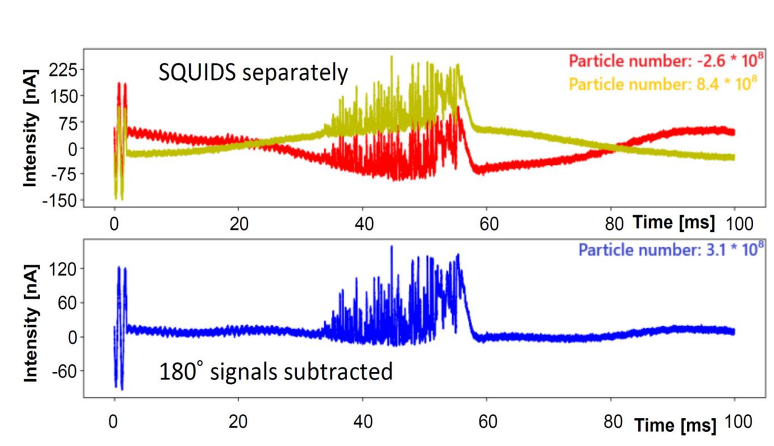
Periodic noise sources



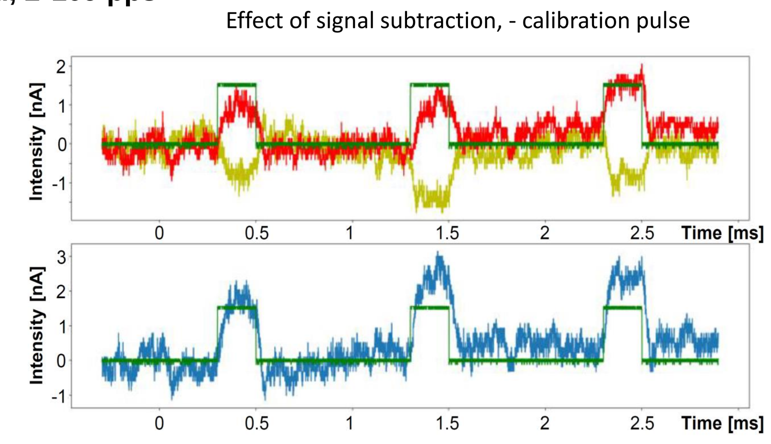
strong unsymmetry at f < 100 Hz due to asymetric positioning and cabling of the SQUIDS → redesign of SQUID circuit ongoing

DCCC Beam experiments / test of noise suppression by signal subtraction and filtering

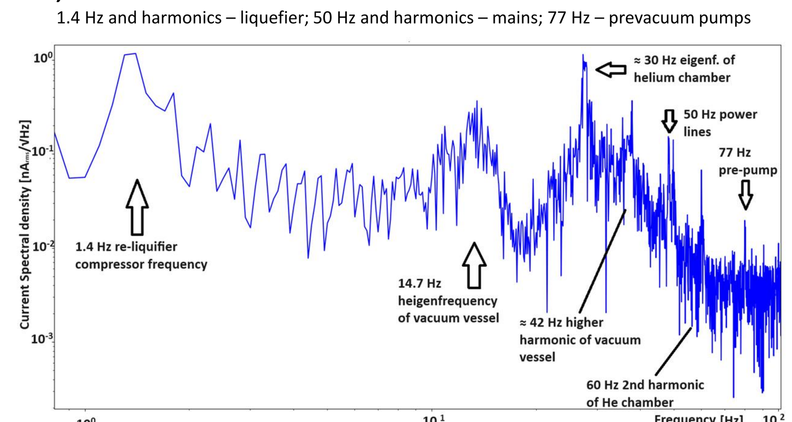
Beams: Er 57+ @ 400 Mev/u, 5+10^8 pps and Ar 18+ @ 400 MeV/u, 2*109 pps



Effect of signal subtraction, - calibration pulse



‚reliable' noise sources 1 Hz – 100 Hz:
1.4 Hz and harmonics – liquefier; 50 Hz and harmonics – mains; 77 Hz – prevacuum pumps



Filtering will be implemented in control GUI
→ FESA class currently under development

Filtering approaches
- **Summation:** signals cancel out → noise remains → subtract
- **Correlation Analysis:** frequency selective approach
- **Adaptive Filtering:** Ch1 noise reference → model noise in Ch2
- **Phase-based filtering approaches:** preserve signals with $\Delta\varphi = 180°$

Summary and Outlook

A CCC system has been designed and tested at GSI, which provides nA intensity measurement in storage rings as well as in extraction lines for spill analysis. Because of its superior magnetic shielding and very good and upgradable noise behavior the DCCC is chosen as detector for FAIR. As an additional advantage the lead construction reduces the costs for the device significantly (~1/5 of the detector costs). Work is ongoing to improve the balance between the dual SQUIDs (-> noise suppression) and for filtering of periodic noise (liquefier, pumps, mech. eigenmodes). A simple approach with notch filters shows already good results, more sophisticated filtering will be implemented in the CCC FESA class. Our cryostat in connection with a Cryomech HeRL25 liquefier has recently achieved 6 months of continuous operation, keeping the DCCC permanently available for measurements. Currently tests are performed to find the reason for (even though small) He losses, also contamination of the cold head with N or H_2O might play a role.

Contracts have been signed fo a second CCC cryostat for the FAIR 'Early Science' scenario as well as for a compact CCC version in CRYRING. An important task remaining is the integration of the cryostat into the GSI/FAIR cryogenic control system.

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