CRYOGENIC CURRENT COMPARATOR FOR LOW-INTENSITY BEAM CURRENT MEASUREMENT

IN THE CERN ANTIPROTON DECELERATORS

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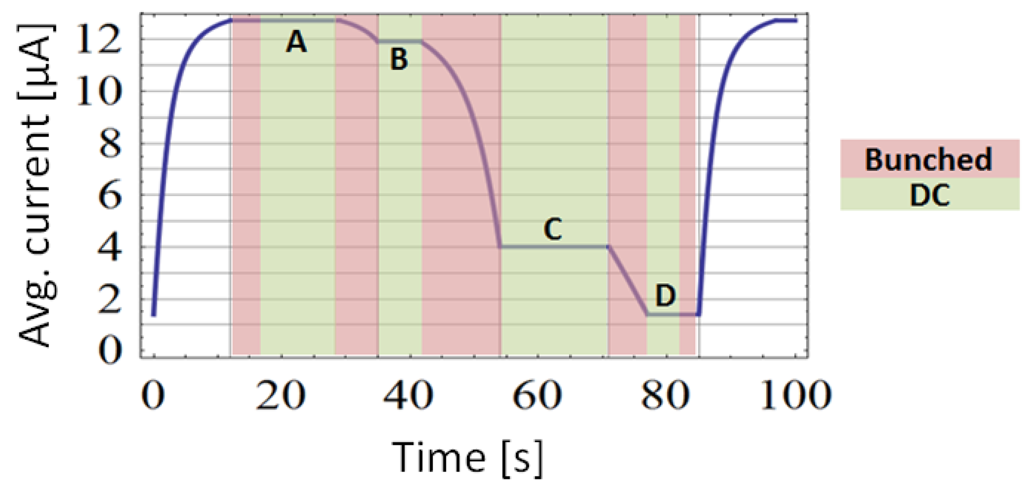
Low-energy antiproton decelerator at CERN

- The Anti-proton Decelerator (AD) is a low-energy $\bar{p}$ ring at CERN.

	A	B	C	D
β	0.97	0.91	0.30	0.11
E_K [MeV]	2753	1271	46.8	5.3
f_{rev} [MHz]	1.6	1.5	0.50	0.17
I_{mean} [μA]	12	11	4	1.3 - 0.3
σ_{bunch} [ns]	172	136	104	>110

- Low beam current challenges traditional beam current monitors.
- Precise beam intensity measurement is important to monitor the efficiency of the different deceleration and beam cooling phases.



Existing DC current monitors in the AD

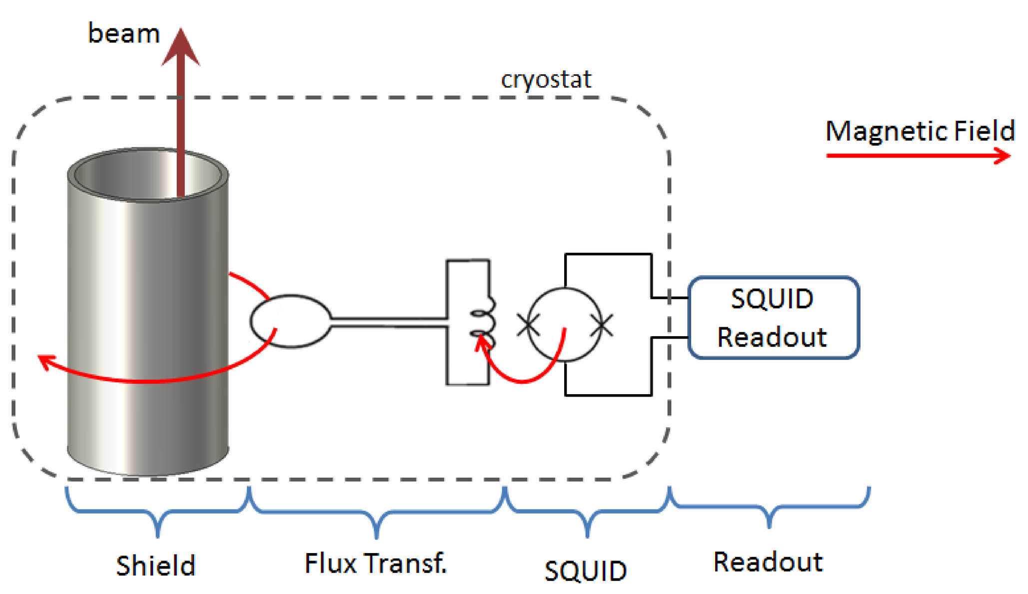
- DC Current Transformers (DCCTs) resolution is limited to $\sim 1\,\mu$A, normally achieved after integration period of ~ 1 s [1].
- On-line analysis of longitudinal Schottky (L-Schottky) noise:
  - Absolute accuracy error: $\geq 10\%$
  - Time resolution: 200 ms
  - Complex calibration procedure
- Despite its limitations, the L-Schottky monitor has enabled routine operation of the machine over many years.

Specifications for a More Precise Current Monitor

- Measurement of bunched and DC absolute beam current.
- Easy and accurate calibration procedure.
- Independence of beam shape, trajectory and energy.
- Current resolution: **3 nA** (1% accuracy at lowest current level)
- Bandwidth: [DC – 1 kHz]
- Minimum aperture: 100 mm

Cryogenic Current Comparator (CCC) Overview

- Measures the magnetic field generated by the circulating beam.
- Superconductor shield suppresses components not linked to the beam current.
- Superconductor QUantum Interference Device (SQUID), in Flux-Locked Mode (FLL) configuration, is normally chosen to measure the magnetic field.

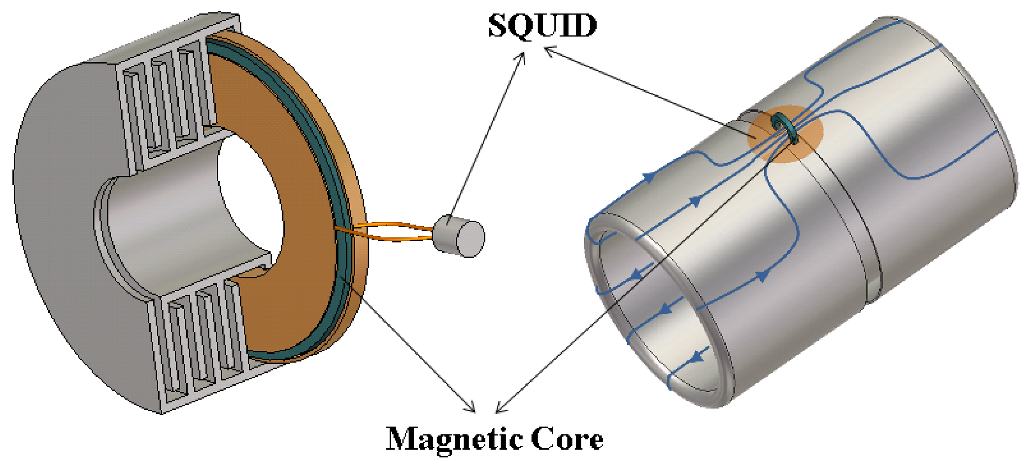


- Rapidly increasing magnetic field of bunched beam in AD may be above slew-rate of SQUID electronics.
- Minimum magnetic field induced at minimum pickup coil radius: $\sim$ **0.75 pT**.

References

[1] P. Odier, "DCCT technology review," C04-12-01.1, Proceedings of CARE-HHH-ABI.
[2] A. Peters, *et al.*, Journal of Physics: Conference Series 43 (2006) 1215.
[3] T. Watanabe, *et al.*, "Improvement of beam current monitor with high Tc current sensor and SQUID at the RIBF," TUPC105, Proceedings of IPAC2011.
[4] R. Geithner, *et al.* "An improved Cryogenic Current Comparator for FAIR," MOPPR020, Proceedings of IPAC2012.
[5] British Geological Survey, http://www.geomag.bgs.ac.uk

Low- vs High-Temperature supercondutors CCC



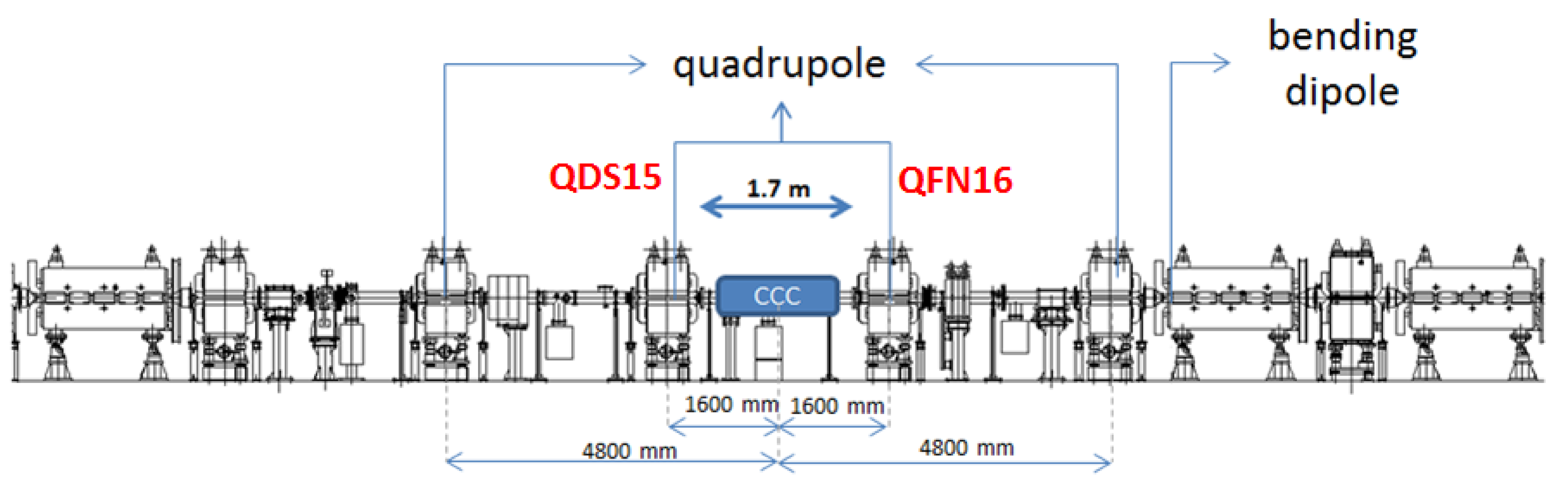
LTS CCC

- Meander-shaped geometry also shields against noisy background magnetic field.
- High-permeability core and single-turn coil couple magnetic field to the SQUID.
- Current resolution: **8 nA** (**250 pA/$\sqrt{\textbf{Hz}}$** at 1 kHz) [2].

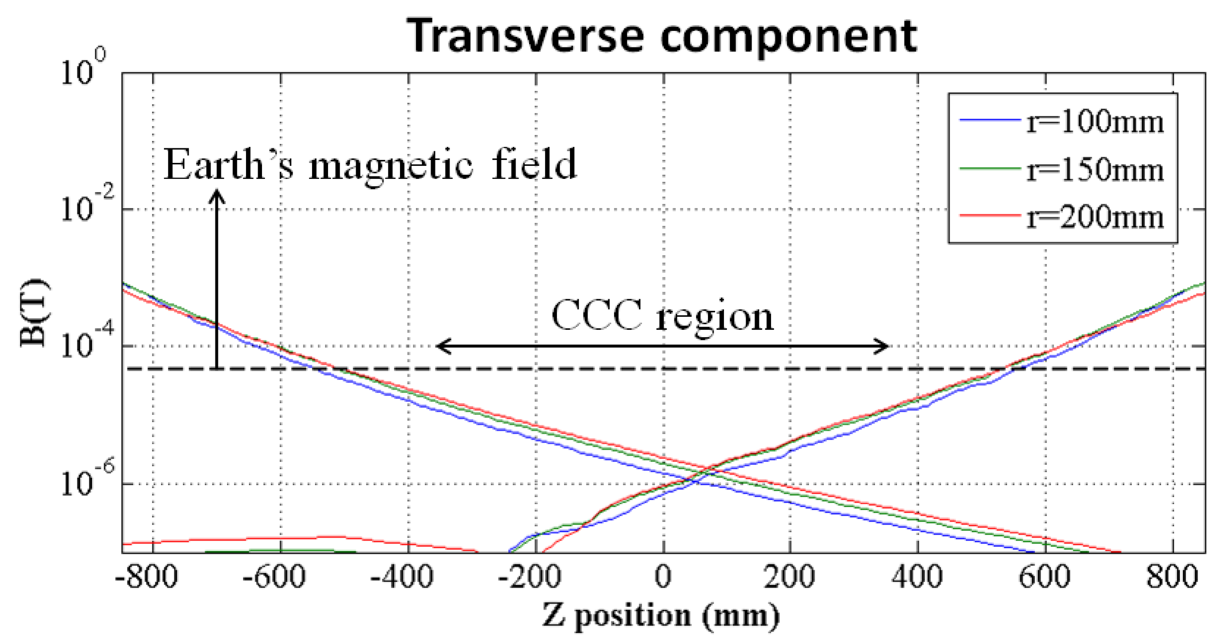
HTS CCC

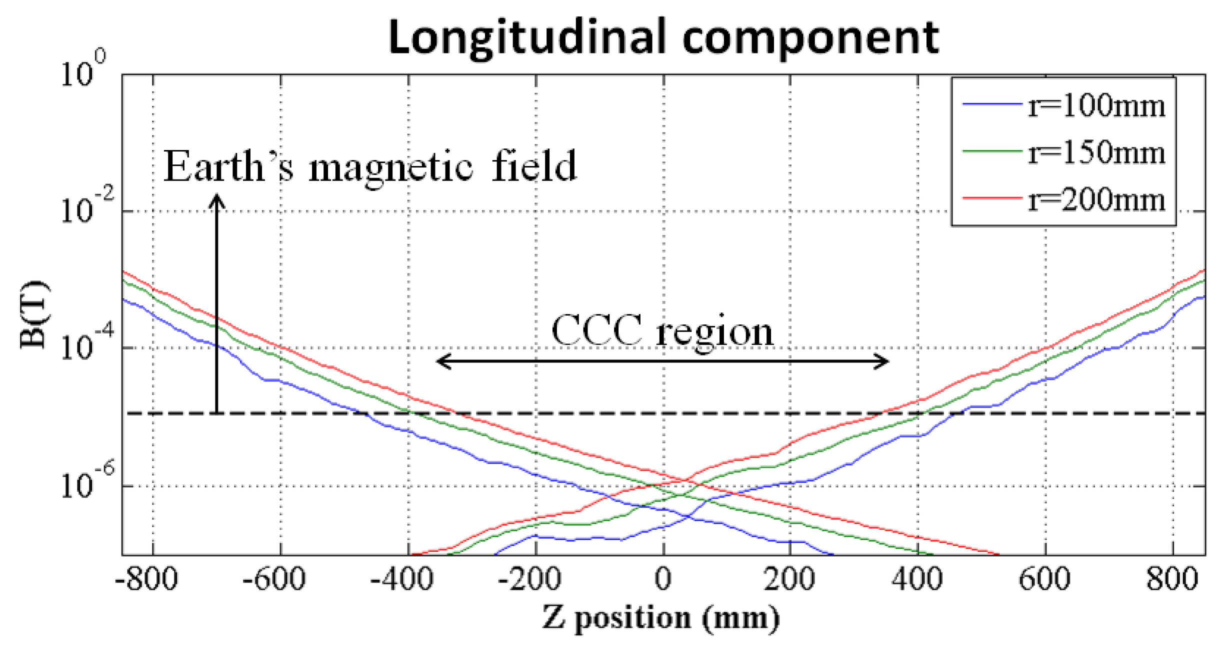
- A straight superconductor cylinder is used for shielding unwanted components.
- SQUID sensor is located directly on top of the cylinder.
- Bridge pattern is used to concentrate the total mirror current under the SQUID pickup coil.
- Small ferromagnetic core can be used to increase magnetic flux density.
- Current resolution: **100 nA** [3].

Magnetic Environment in AD



- Earth's magnetic field: **47 μT** [5] $\longrightarrow$ Required attenuation $\lesssim$ 200 dB
- Measurements of magnetic field inside AD hall: $<$ **10 μT**.
- Simulation of stray fields from nearby quadrupole magnets (using CST EM Studio): QDS15 and QFN16 at maximum field level.





Challenges and future R&D Topics

- Profit from work developed by other groups [4] on the optimization of the: shielding geometry, magnetic core and SQUID system for the (**LTS CCC**).
- Design specifications for cryostat.
- Find solution to prevent de-tuning of SQUID in FLL mode because of rapidly changing magnetic field.
- Characterize overall system in test setup.
- Analyse impact of background magnetic field, mechanical vibrations and temperature on resolution. Develop techniques to mitigate such effects.
- Study and understand zero-current drift effect.

MARIE CURIE ACTIONS PEOPLE
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