Cryogenic Current Comparator (CCC)

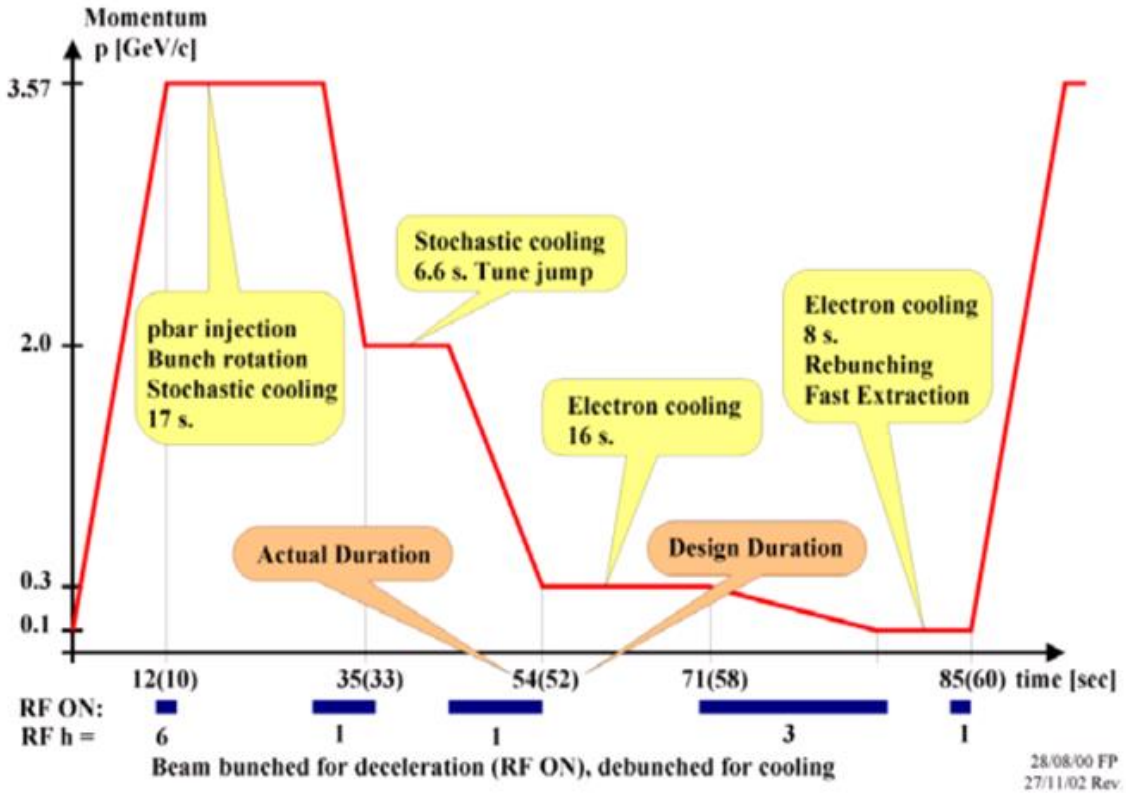
Beam intensity monitor for the Antiproton Decelerator

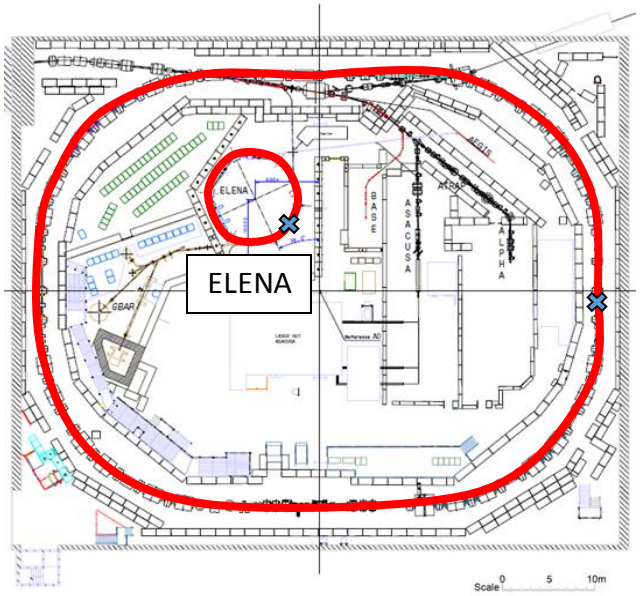
Miguel Fernandes

Presentation outline

1. Motivation and specifications for new intensity monitor
2. CCC functioning overview and design considerations
3. First beam measurements
4. Current limitations (monitor + cryogenics)
5. Summary

Antiproton Decelerator at CERN





AD beam parameters	
Beta	0.97 … 0.11
Cycle	~85 s
N particles	(5 … 1) x 10^7
Current	**(12 … 0.1) µA**

Motivation for new monitor in AD

DCCT:

Insufficient resolution (1μA) for the low current regime (low β,N)

Fast BCTs:

Limited to bunched phases

Schottky monitor:

Un-bunched:

- time resolution of $\sim 1s$
- accuracy error > 10%

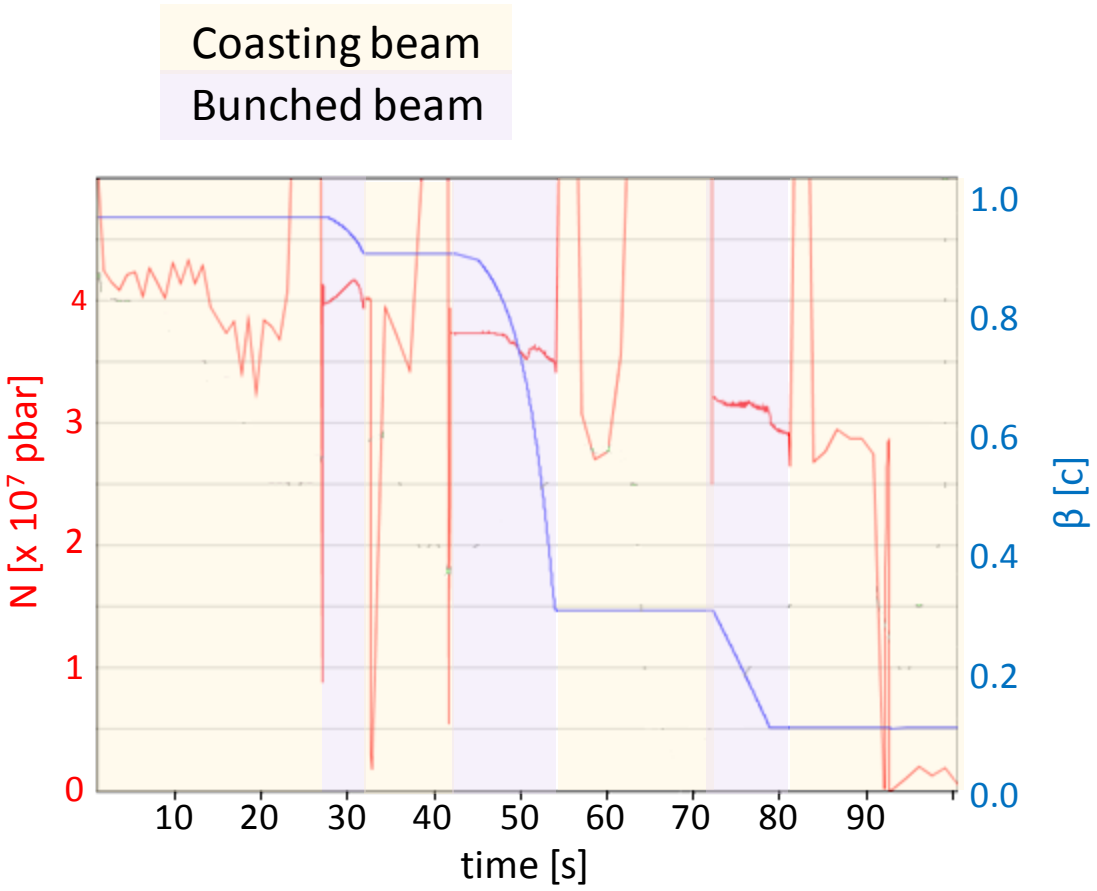
Bunched:

- time resolution of $20\ ms$
- accuracy error of <10%

Bunch length dependency

Complex calibration process

Schottky Intensity Measurement



Specifications for new intensity monitor

Requirements for a new current/intensity monitor:

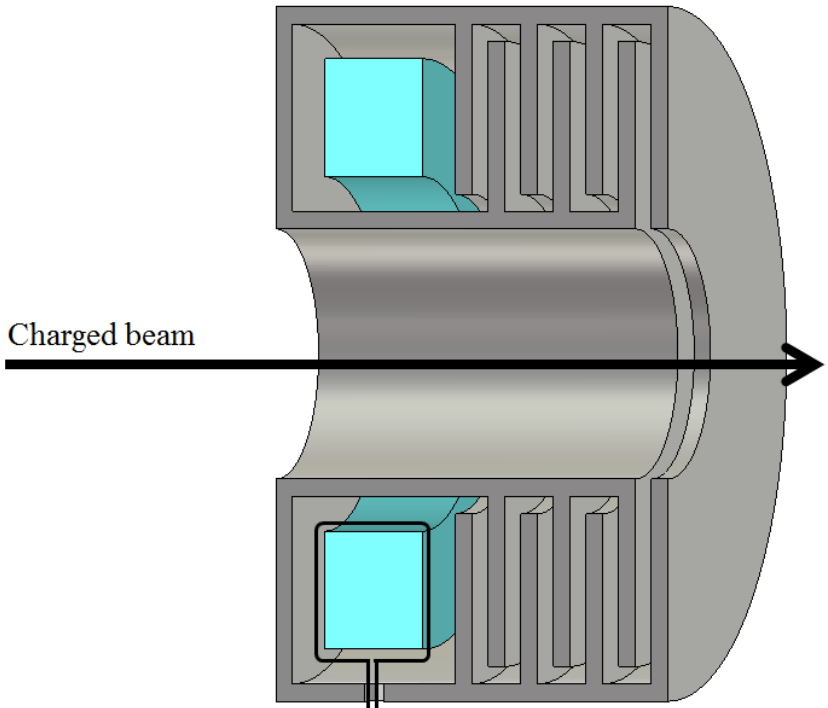
- Current resolution: 10 nA
- Intensity resolution: 5 x 10^5 charges
- Bandwidth: DC - 1 kHz

Requirements for the cryostat

- "Zero-boil off" using a pulse tube cryocooler as He reliquefier unit
- Long term operation

Collaboration partners:

CCC functioning overview



Magnetic shield:

- Suppresses all field components except azimuthal beam component

Pickup coil:

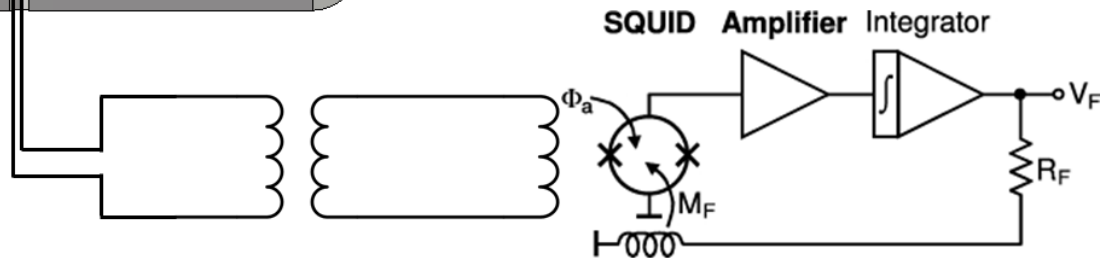
- Soft ferromagnetic material with high-permeability concentrates flux

Flux transformer:

- Couples magnetic flux (down to DC) to SQUID

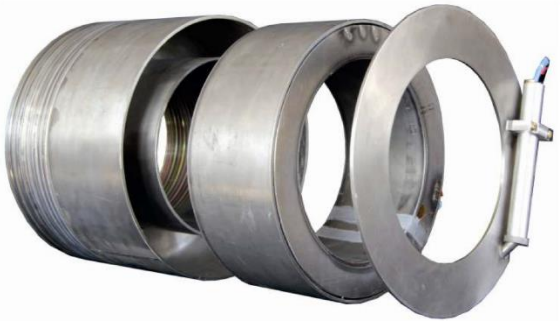
SQUID + Electronic readout:

- Superconducting QUantum Interference Devices
- Measures the magnetic field induced in the SQUID's input coil



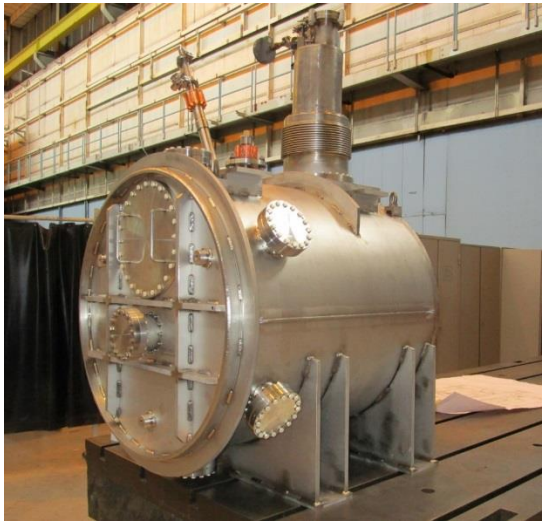
Monitor and cryogenic system

- CCC magnetic shield and ferromagnetic core fabricated by collaboration partners



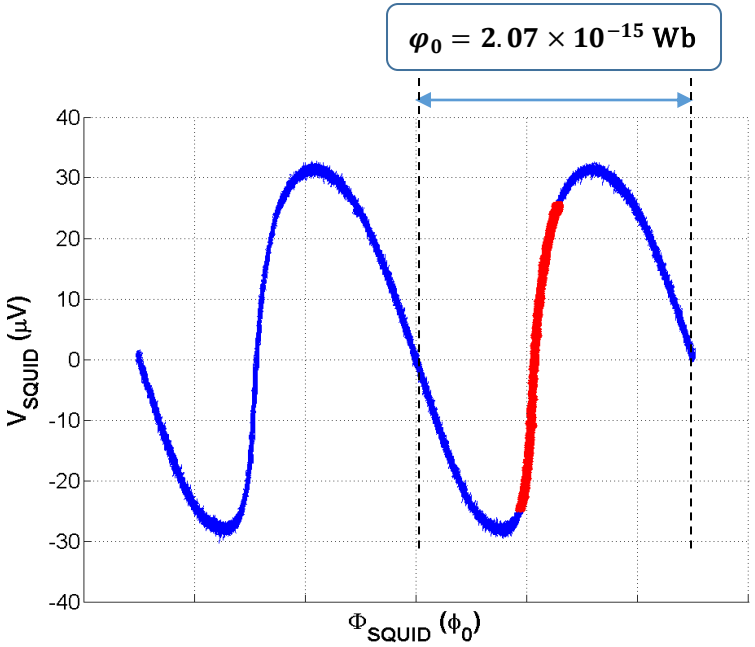
- New coupling circuit was designed using commercially available SQUID system

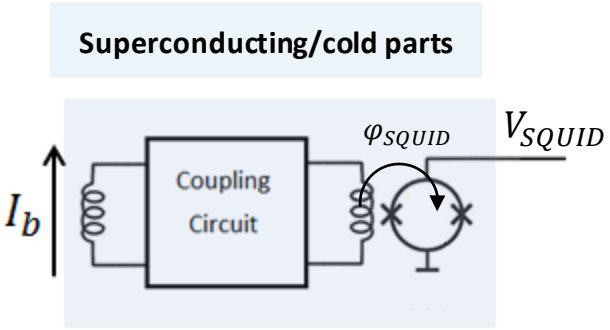
- New cryostat was designed and fabricated
  - Low-level of mechanical vibration
  - Low heat in leak
  - Capacity for 50 liters liquid Helium
  - Diameter of ~ 0.8m



SQUID devices

- SQUID's are very sensitive magnetometers
- But periodic transfer function limits its dynamic range





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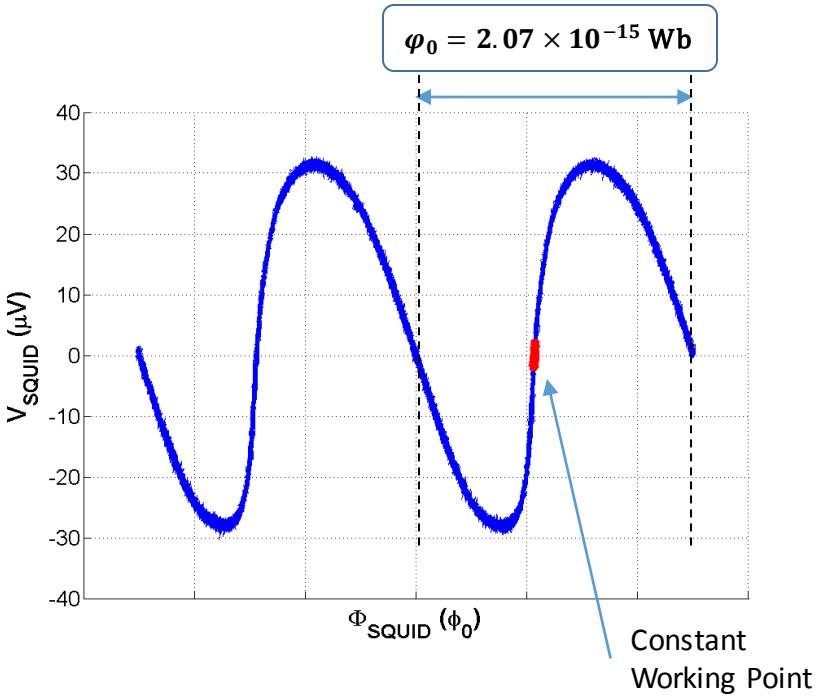
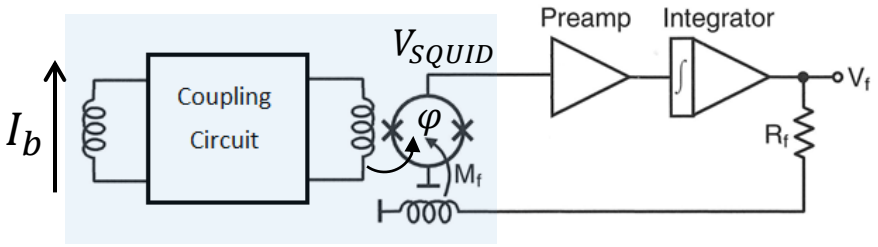
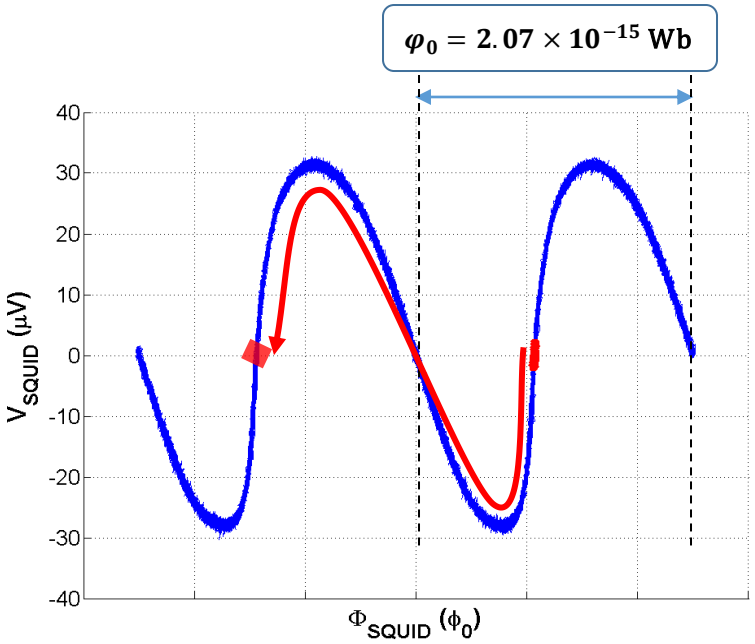


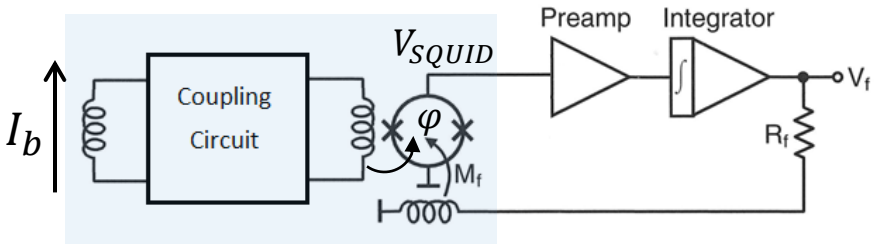


SQUID devices

- SQUID's are very sensitive magnetometers
- But periodic transfer function limits its dynamic range
- Necessary to limit slew-rate of coupled signal to avoid flux-jumps

$$\frac{d\phi_s}{dt} \leq 5\, M\varphi_0/s$$





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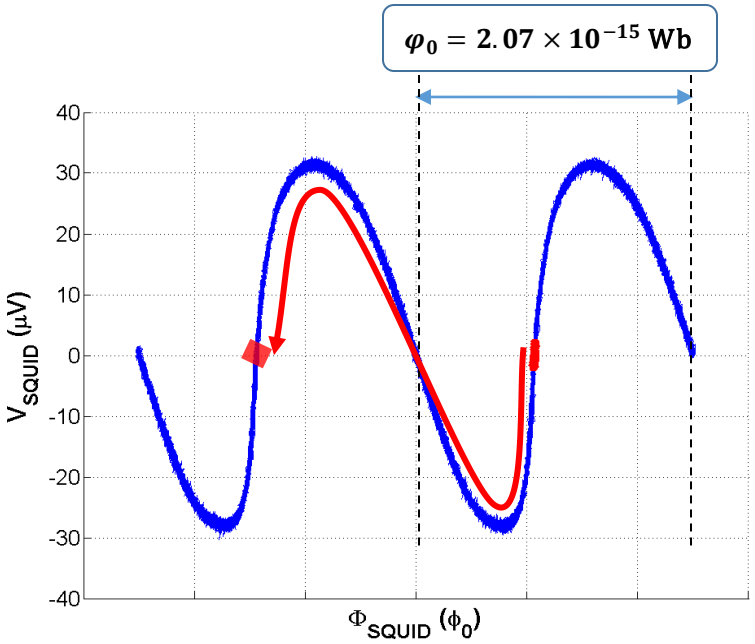
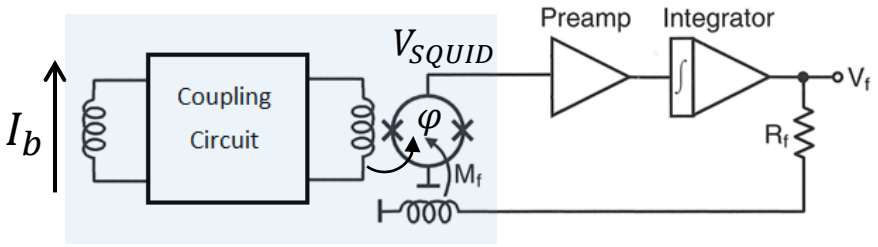
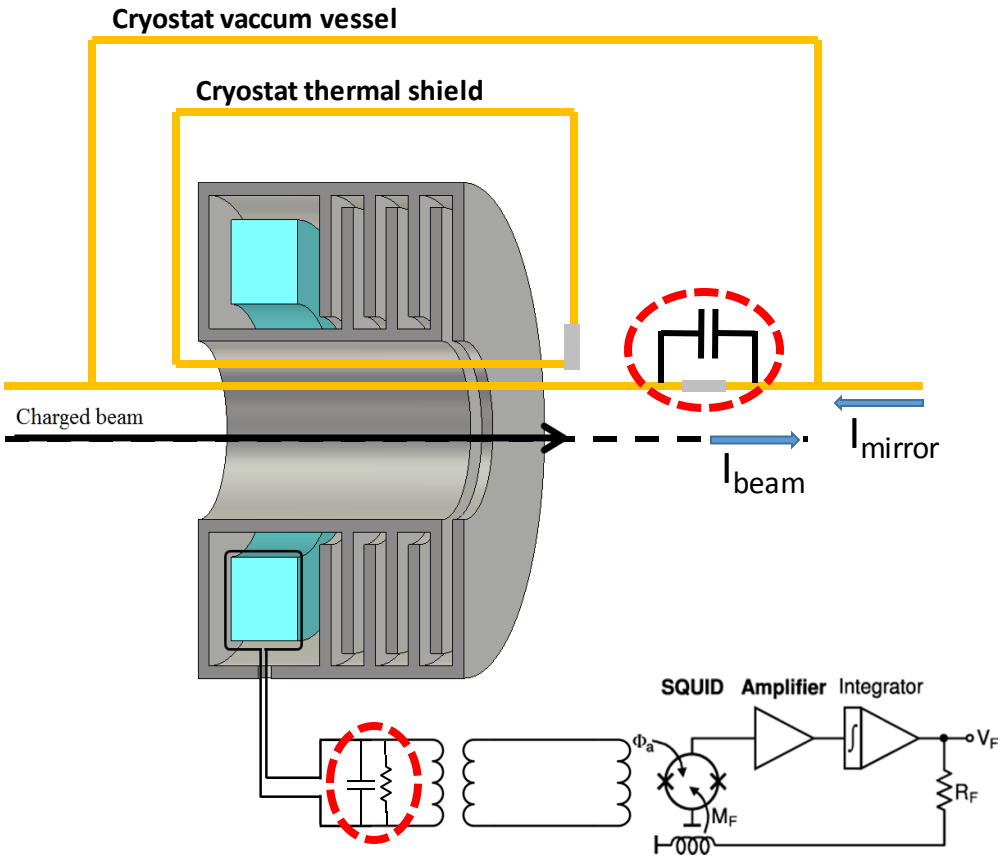


$$\frac{d\phi_s}{dt} \leq 5\, M\varphi_0/s$$

AD injection: $\frac{d\phi_s}{dt} \approx 400\, M\varphi_0/s$!!



Limiting slew-rate of input signal

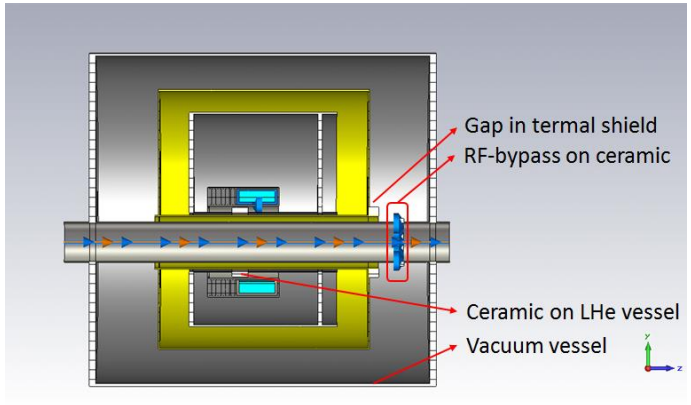


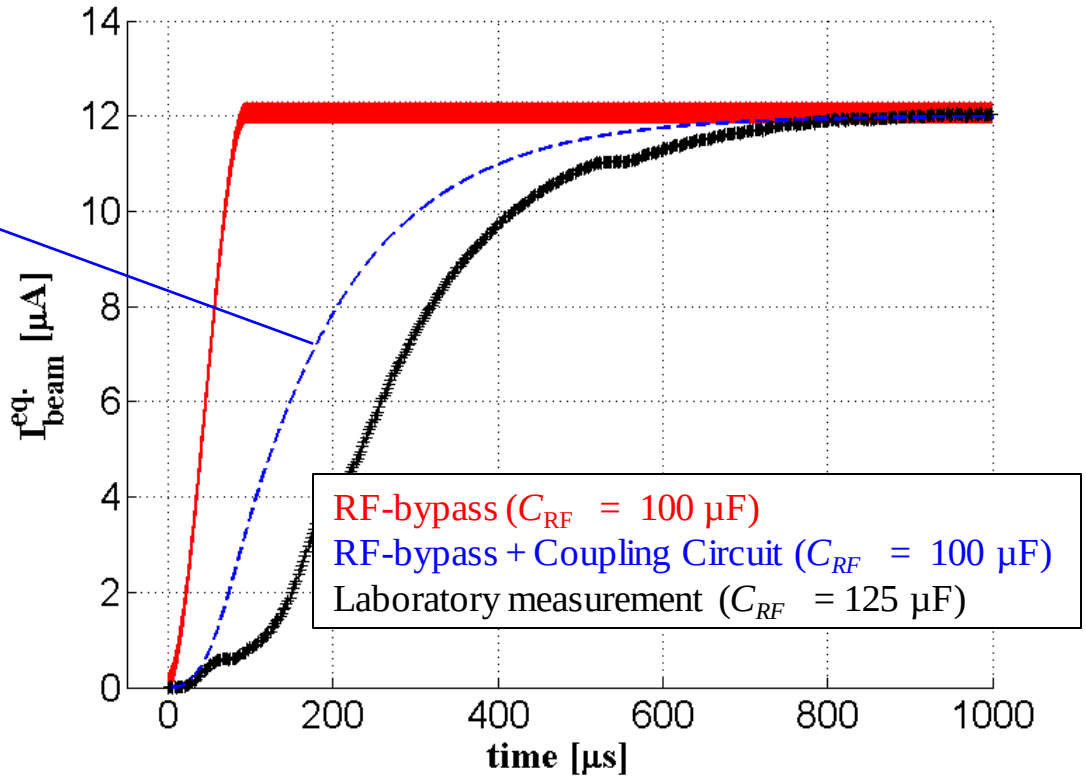
- Implement signal filtering to decrease slew-rate
- RC filter in coupling circuit
- RF-bypass in ceramic at beam pipe

Laboratory measurement

- Time response to a current signal identical to AD beam injection
- Simulated signal using CST Wakefield simulation and linear system treatment
- Laboratory measurement of wire carrying current through beam pipe

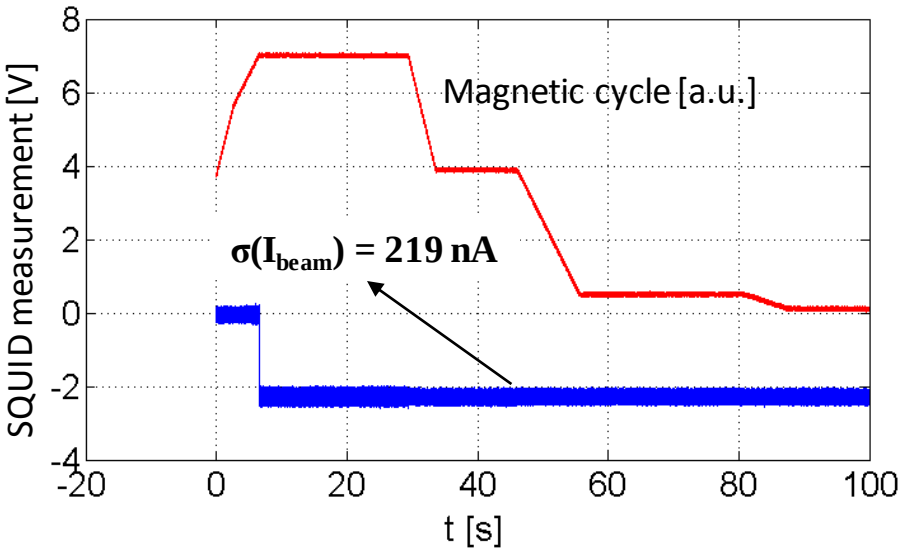
$$\frac{d\phi_s}{dt} \leq 2\,M\varphi_0/s$$



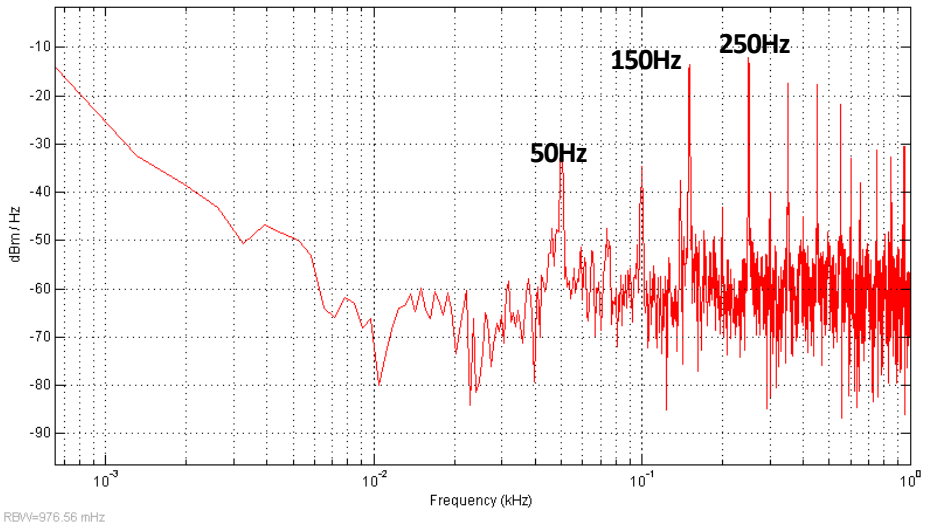


Measurements with no beam

Time-domain signals



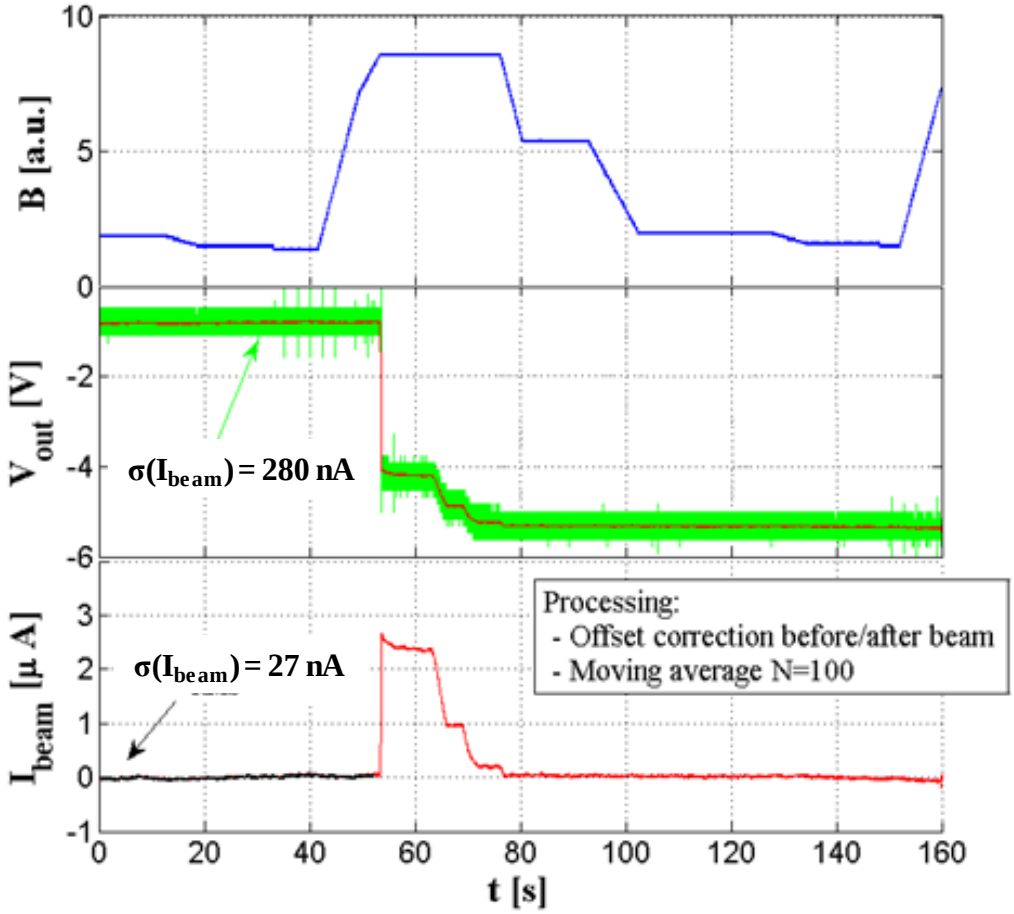
Frequency-domain



- Current resolution is mainly limited by noise/perturbations at 50Hz + harmonics
- Offset jump around moment of injection due to discharge of bunch rotation cavities

Beam current measurements

- First measurement during beam setup
- After signal filtering it's possible to obtain resolution ~30 nA
- Good example of how this measurement can speed up setup of AD beam (currently takes ~3 weeks)

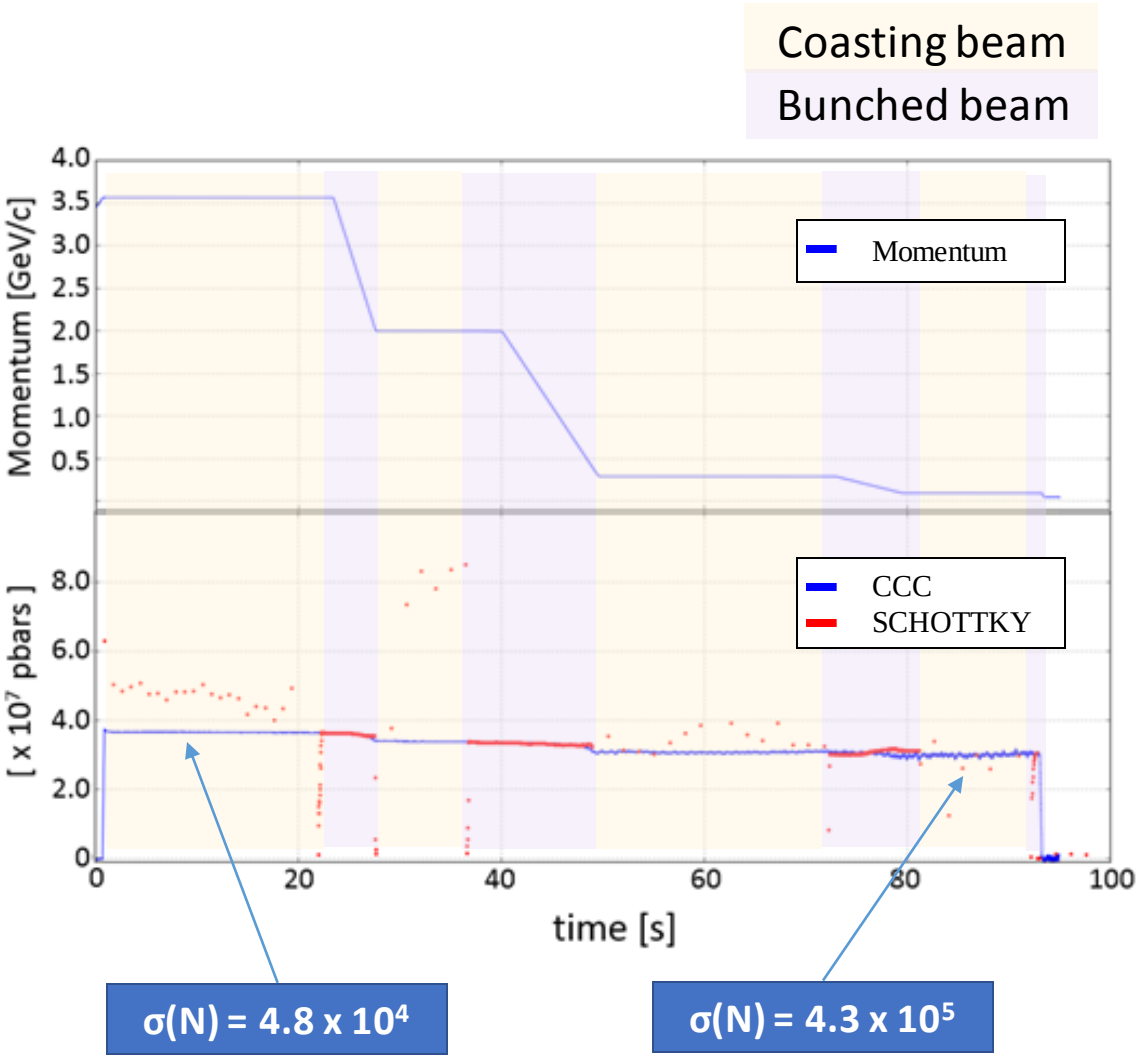


Beam intensity measurements

- Intensity obtained by normalizing beam current with velocity
- Noise of current measurement is amplified for low-β.

Nominal injection:

$N_{inj} = 3.7 \times 10^7$

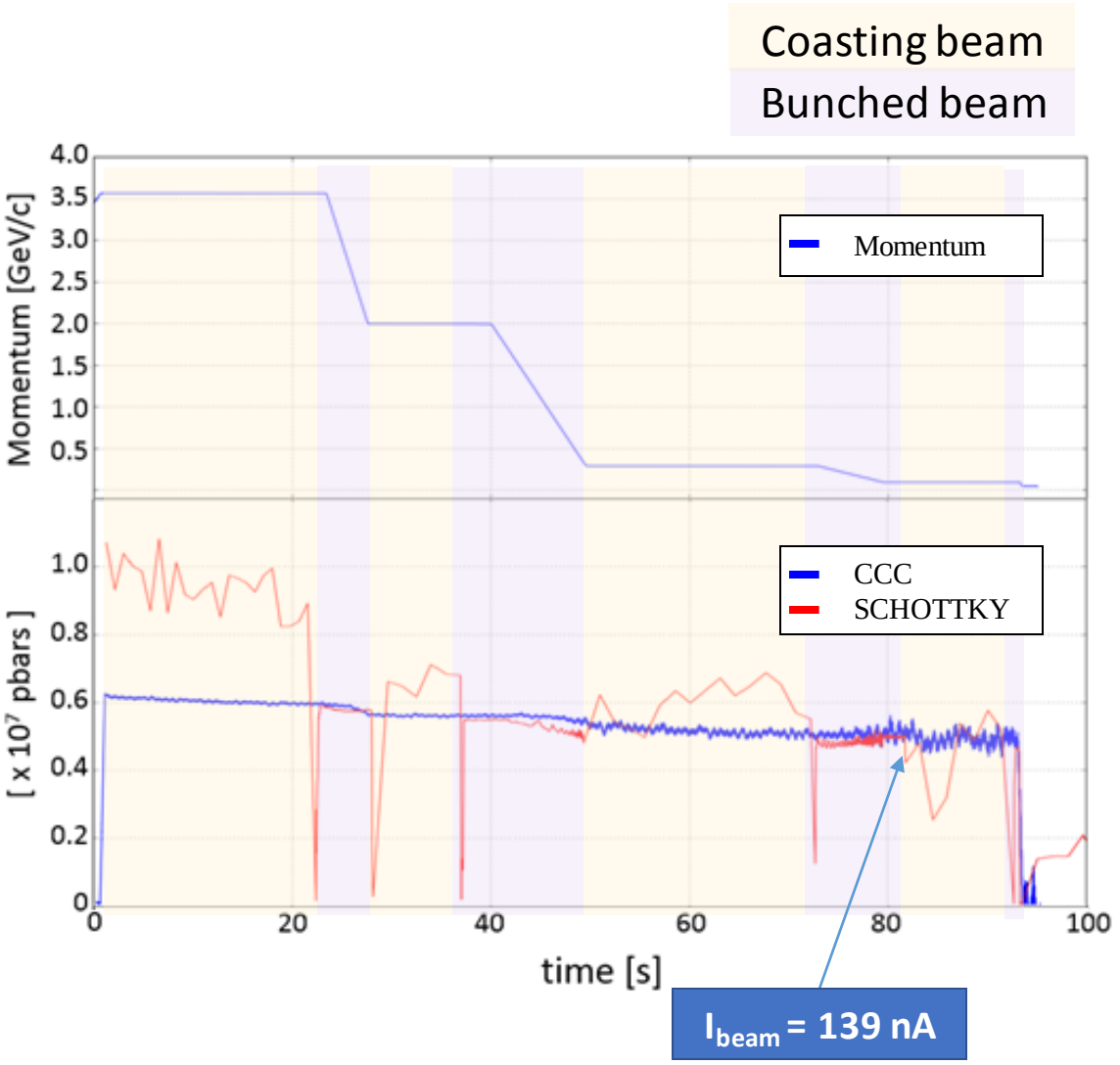


Beam intensity measurements

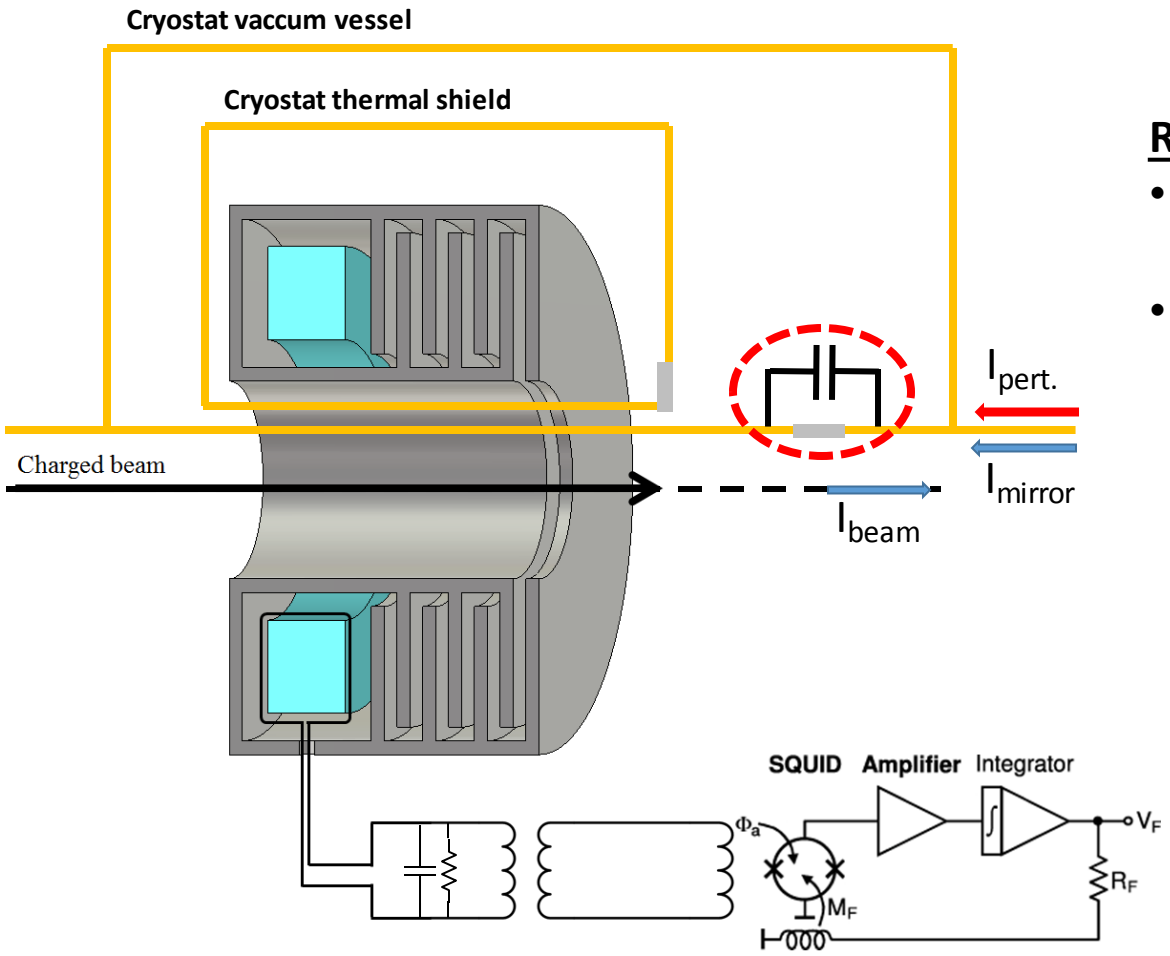
- Intensity obtained by normalizing beam current with velocity
- Noise of current measurement is amplified for low-β.

Low intensity injection:

$N_{inj} = 0.61 \times 10^7$



Performance limitations



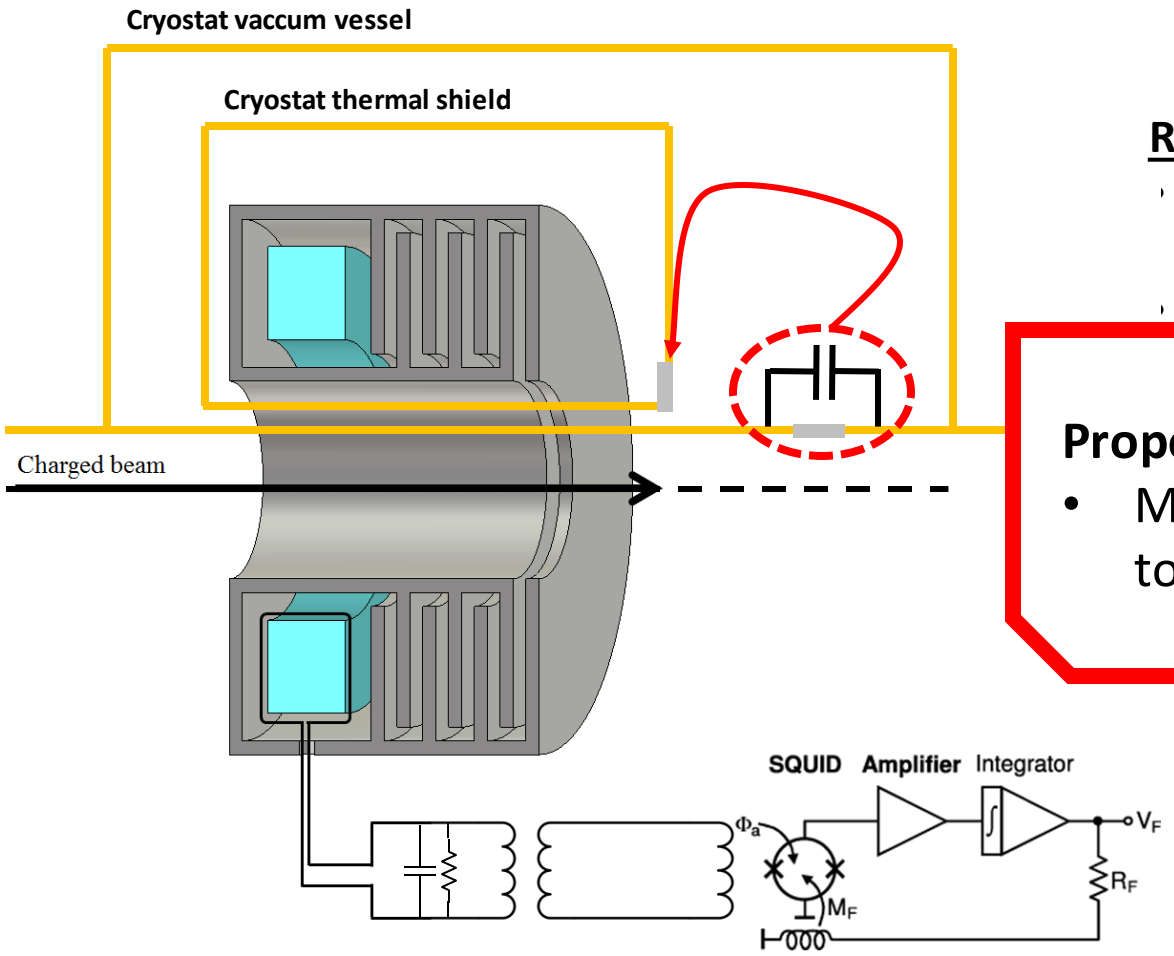
RF-bypass

- Needed for reducing signal slew-rate
- opens path for perturbation currents flowing in beam pipe

Could be responsible for:

- Noise at 50Hz+harmonics
- Offset jump due to discharge of rotation cavities

Intensity measurement limitations



RF-bypass

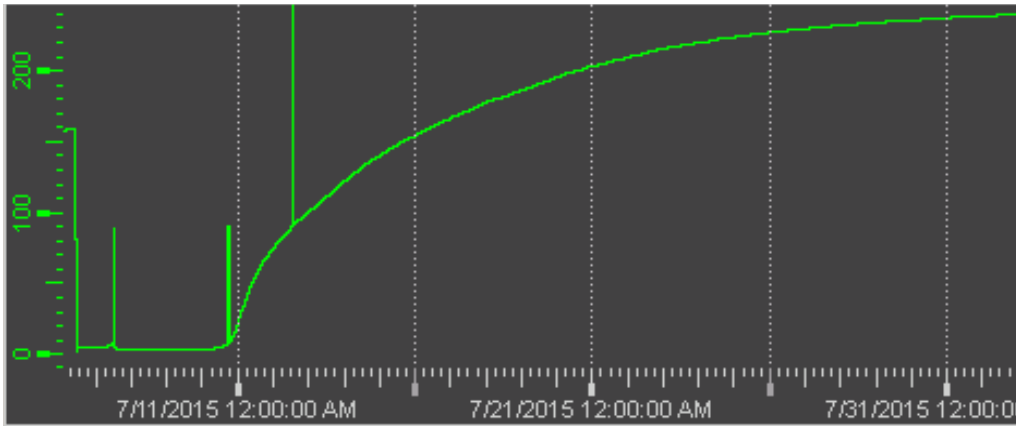
- Needed for reducing signal slew-rate
- opens path for perturbation

Proposed solution:

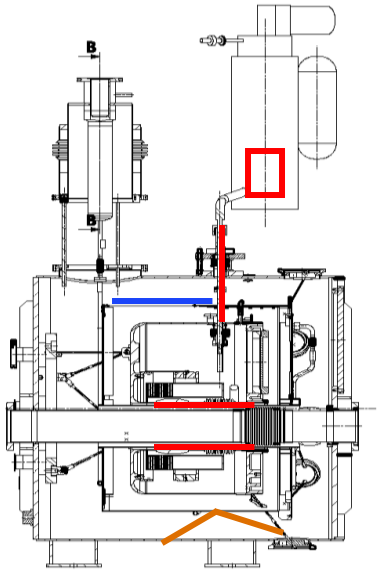
- Move RF-bypass from ceramic gap to gap in thermal shield

- Noise at 50Hz+harmonics
- Offset jump due to discharge of rotation cavities

Cryogenic performance limitations



- Cryogenic system is not able to keep a constant level of liquid Helium
- Current investigations indicate this is due to excessive heat-load in thermal shield of: 12.1 W (while design value is 7 W)



Summary

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5. Cryostat needs to be periodically refilled due to excessive heat-load in thermal radiation shield
6. Corrective measures for these limitations are to be implemented during next year end technical shutdown

Acknowledgements

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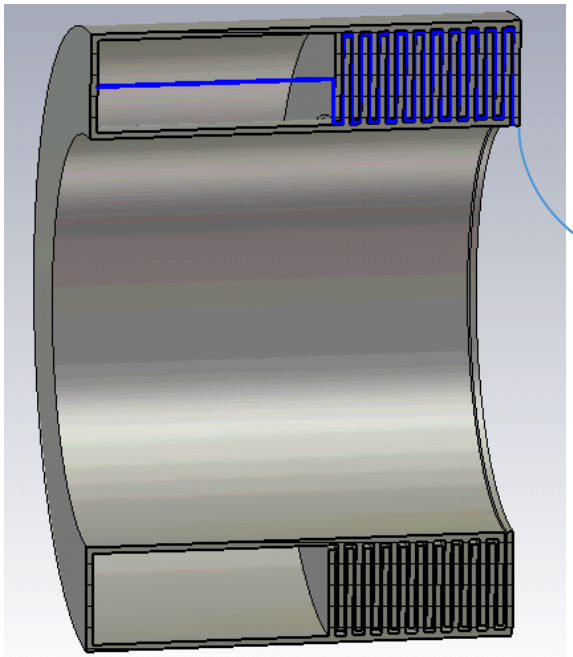
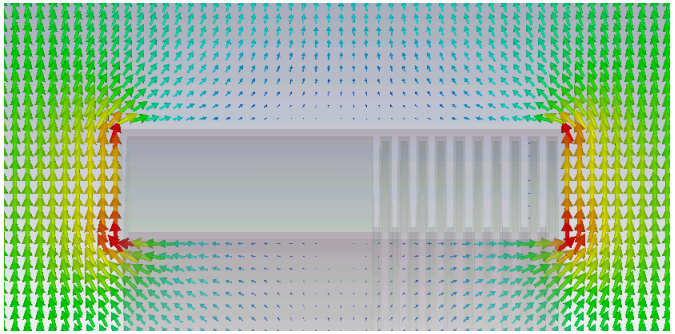
R. Geithner; R. Neubert

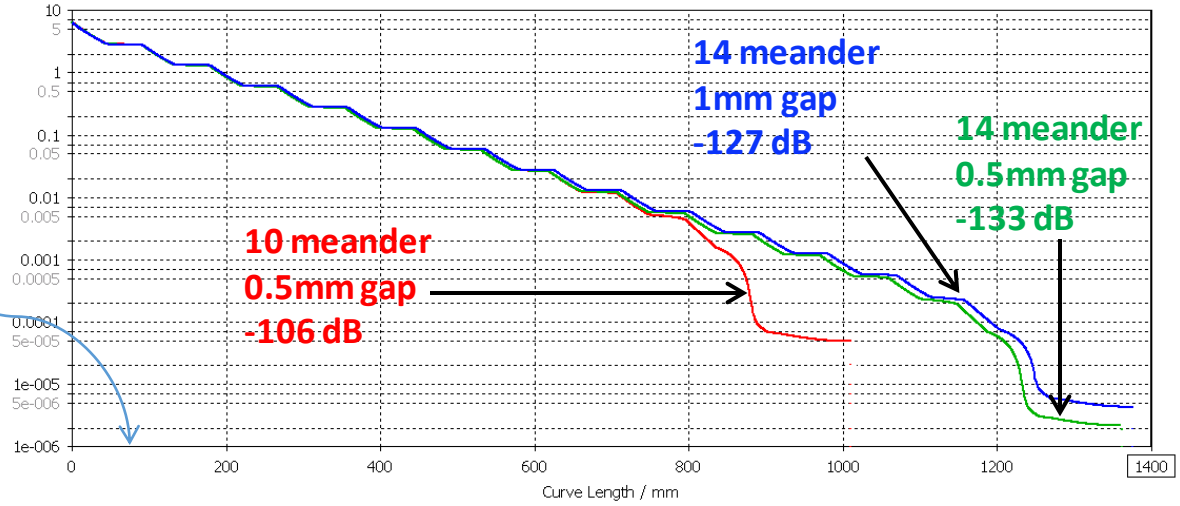
Thank you !

EXTRA SLIDES

Magnetic shielding



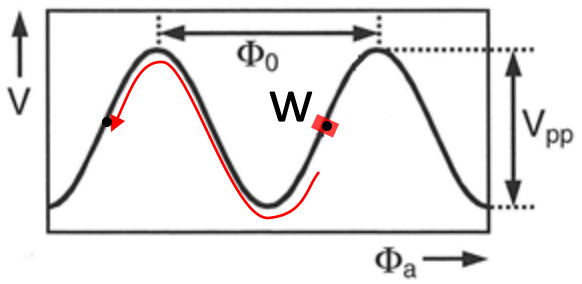


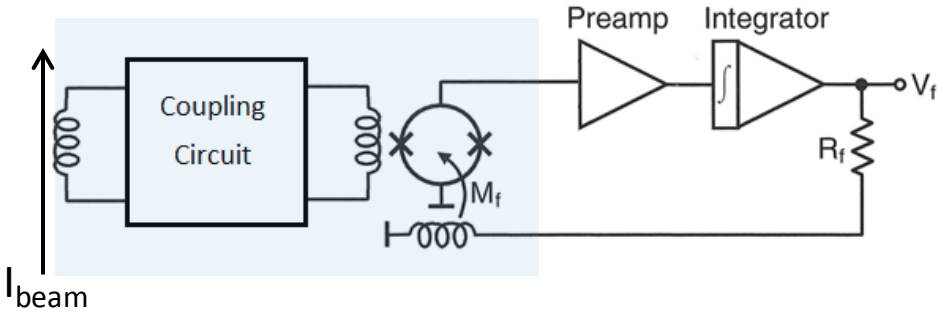


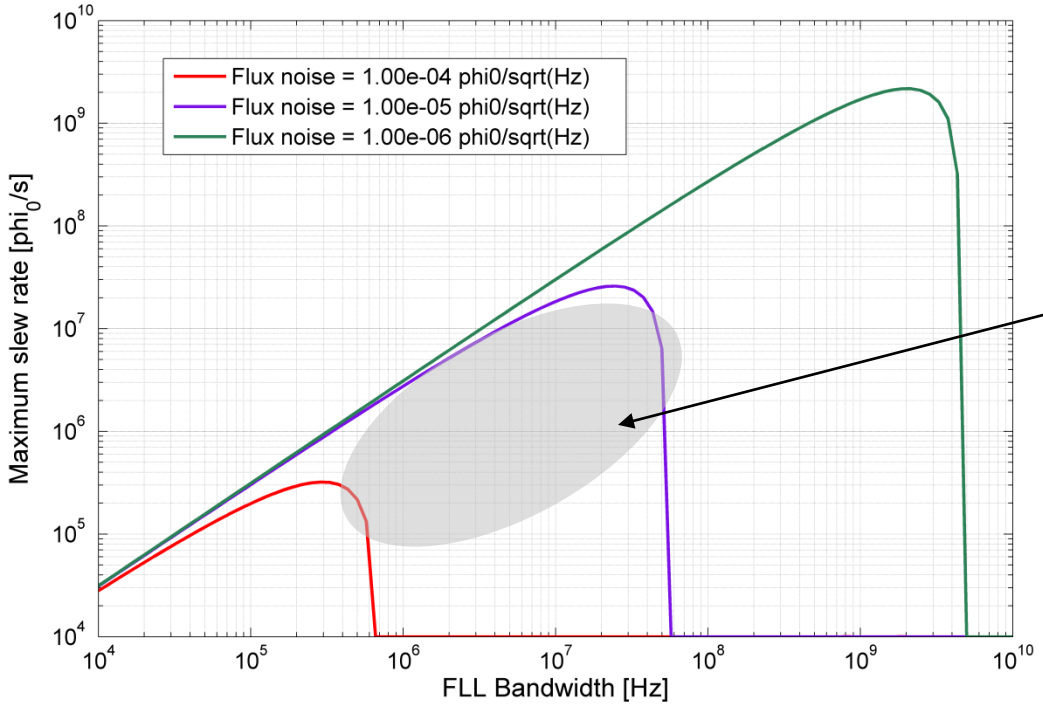
- Number of meanders is the dominant factor to total attenuation
- Magnetic field:
  - Earth: 50 μT;
  - Signal: $\sim pT$

  $A_{tt} \geq \sim 120\ dB$
- Coupling strength to magnetic core of magnetic field from beam is much higher than for other modes

Stability limits





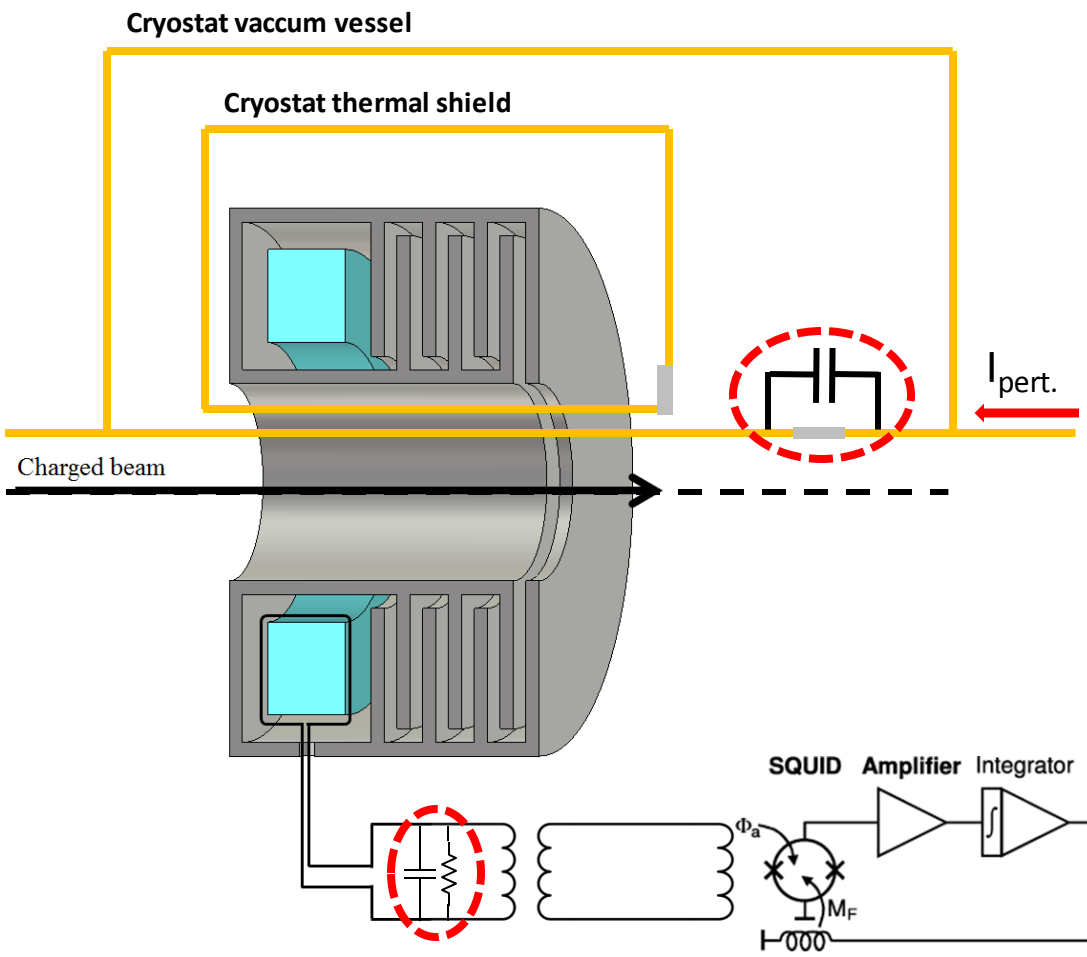


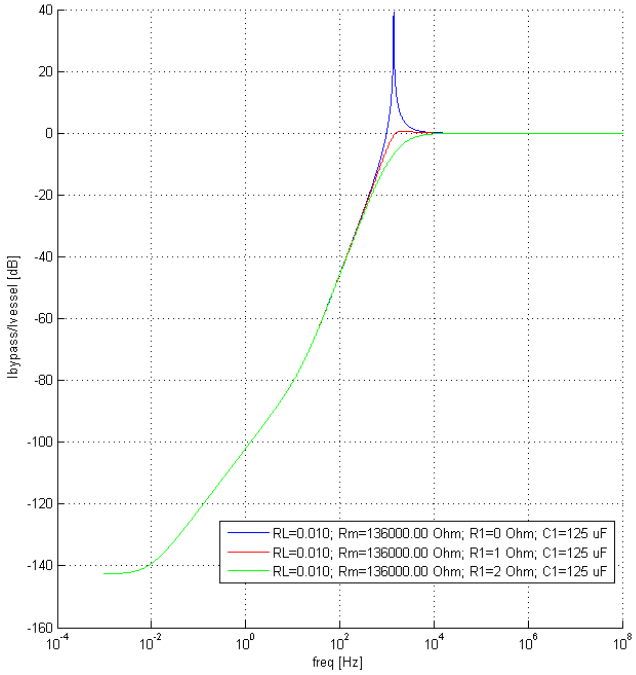
Working region for our system

Allowed flux jump rate: <1/hour

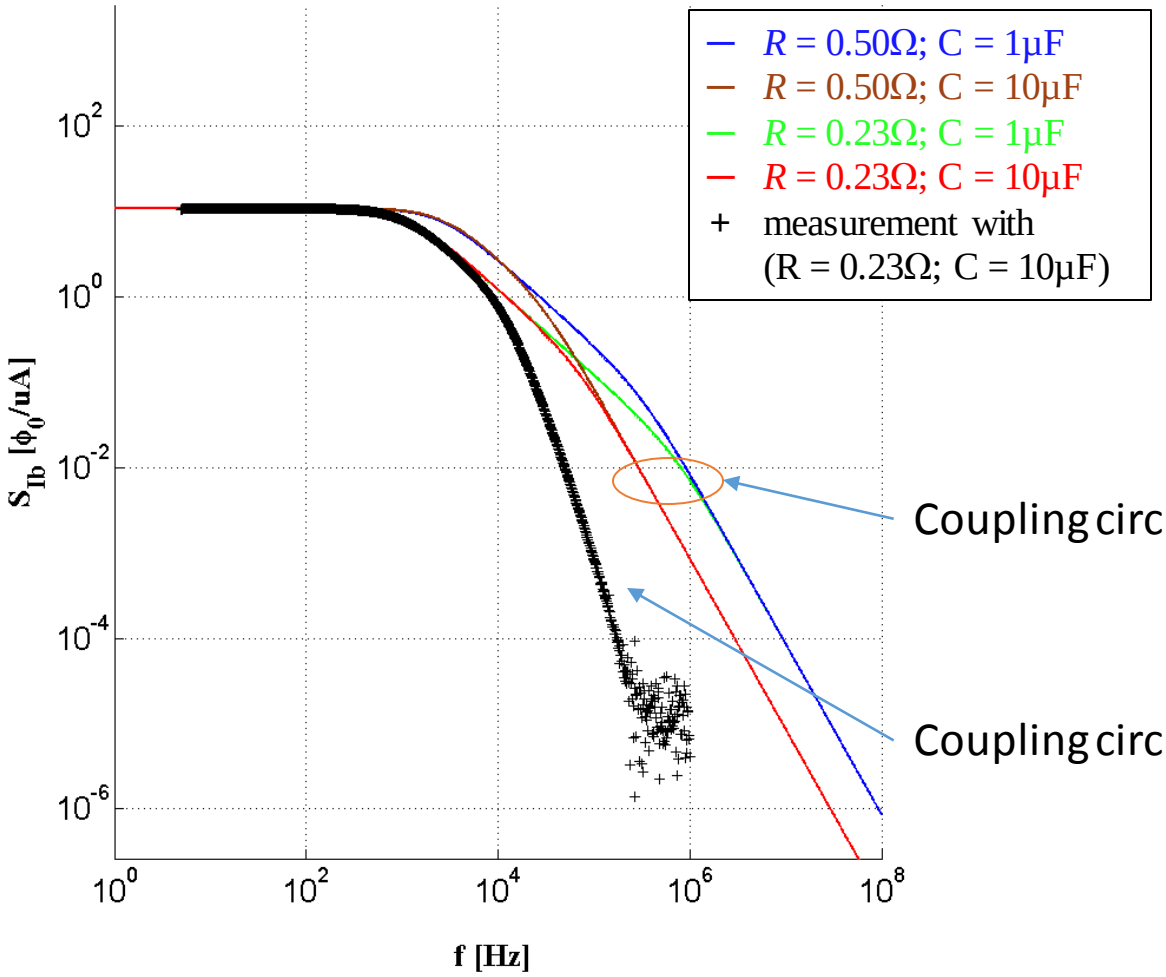
FLL – Flux-Locked Loop

BCCCA functioning overview





Frequency response



Coupling circuit theoretical response

Coupling circuit + cryostat measurement

Calibration