Commissioning of the High Current ERL Injector at Cornell

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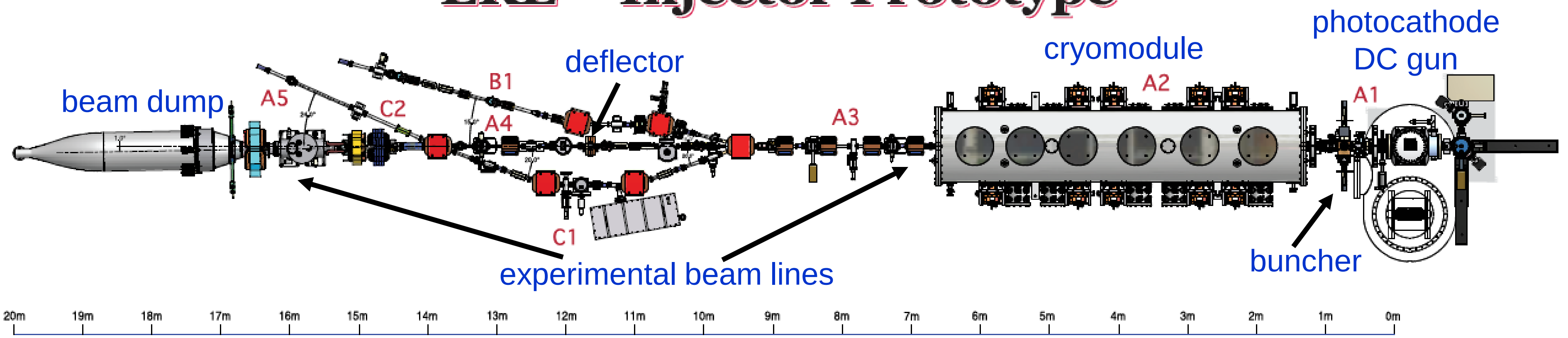
for the Cornell ERL team

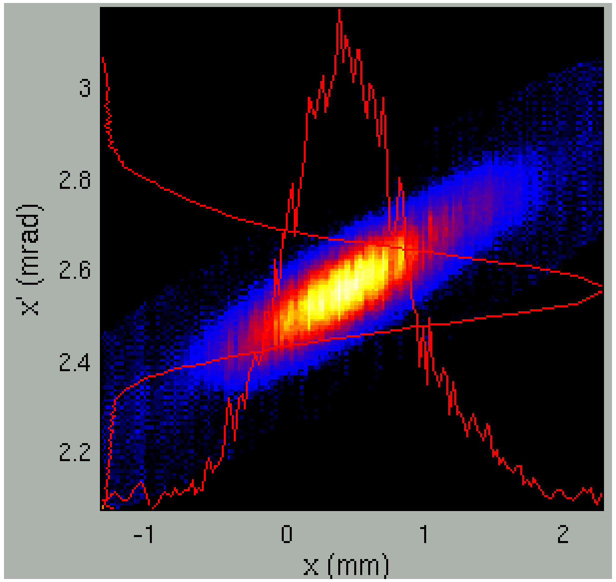
ERL – Injector Prototype



Design parameter:

Nominal bunch charge	77 pC
Bunch repetition rate	1.3 GHz
Beam power	up to 550 kW
Nominal gun voltage	500 kV
SC linac beam energy gain	5 to 15 MeV
Beam current	100 mA at 5 MeV
	33 mA at 15 MeV
Bunch length	0.6 mm (rms)
Transverse emittance	< 1 mm-mrad

Initial thermal emittance measurements



Measured normalized beam emittance at ~fC bunch charge (5 MeV):

0.2 to 0.4 mm mrad
(in both planes)

Good agreement with predictions from thermal limit at cathode and utilized laser spot size.

→Next step: optimizing injector for 77 pC operation

- Implemented fast (~5 s), "single button" measurement
- Will be used for parametric optimization of the injector

Comparison of beam measurements with simulations

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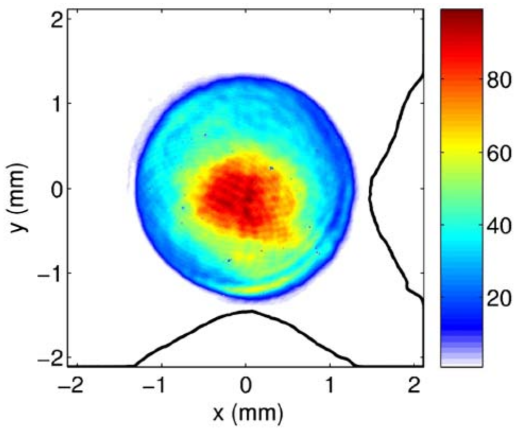
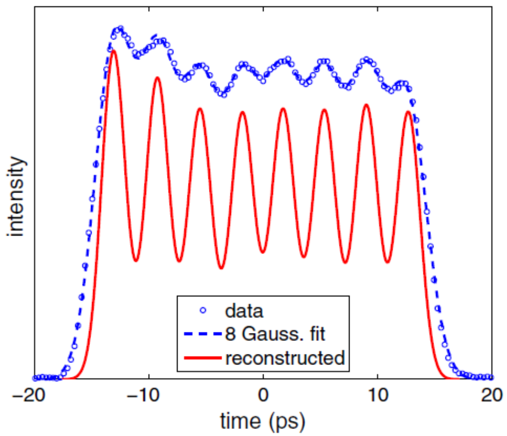
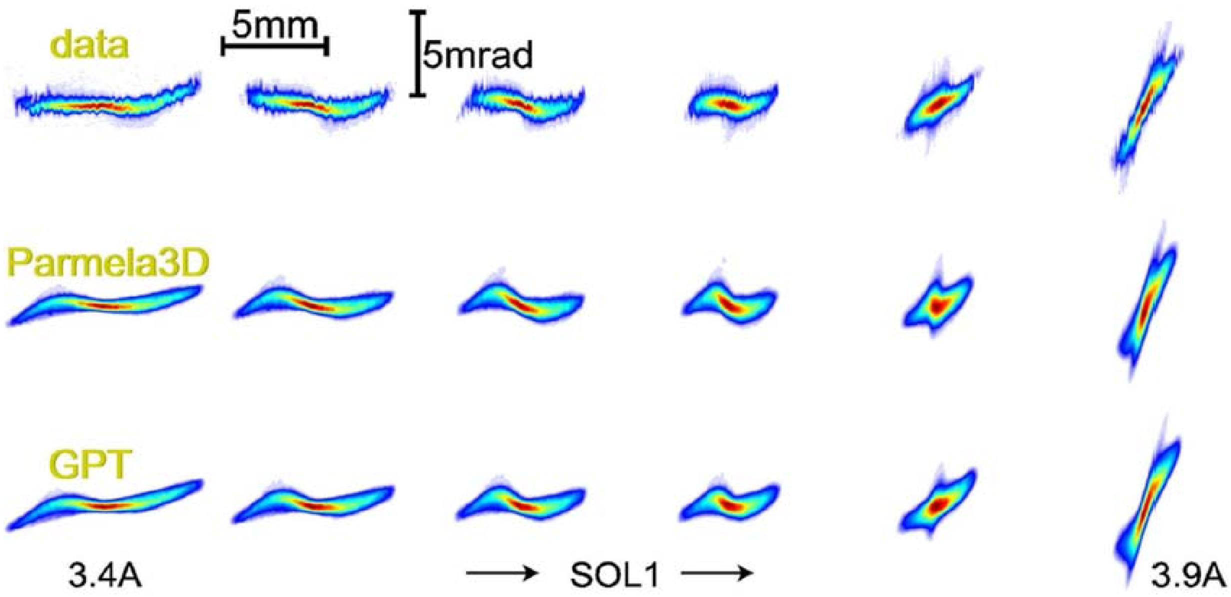
Beam properties at the cathode





Fixed slits phase space measurements

- Corrector coils for beam scanning
- 10 to 20 micron precision slits
- 1 kW beam power handling



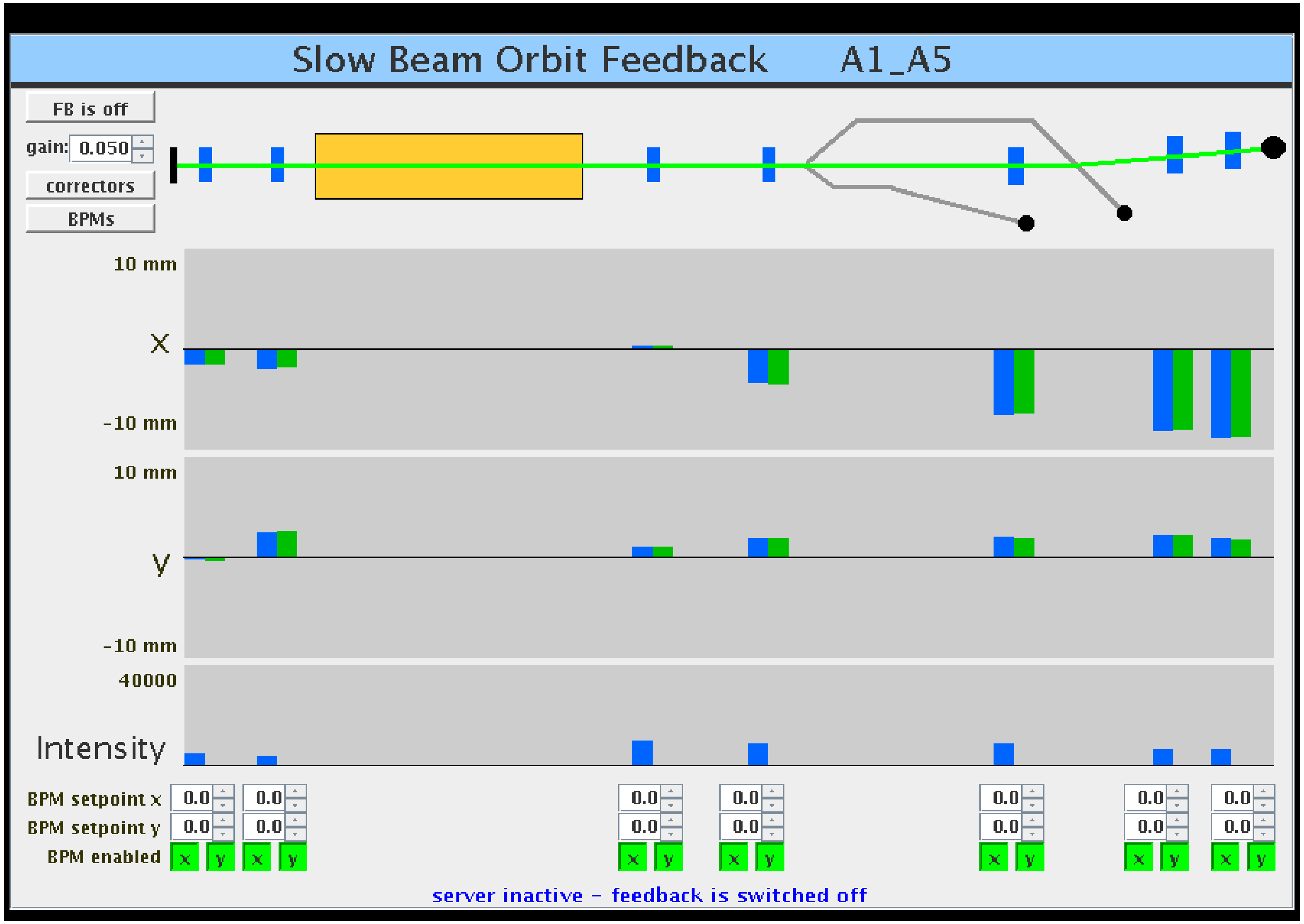
From Phys. Rev. ST-AB 11, 100703 (2008)

Phase space measured after the beam was transported through the accelerator.

Good agreement with theory gives confidence that the very small simulated emittances can be achieved.

Beam Orbit Control

Implemented global beam position feedback which uses all BPMs, corrector, and dipole magnets.



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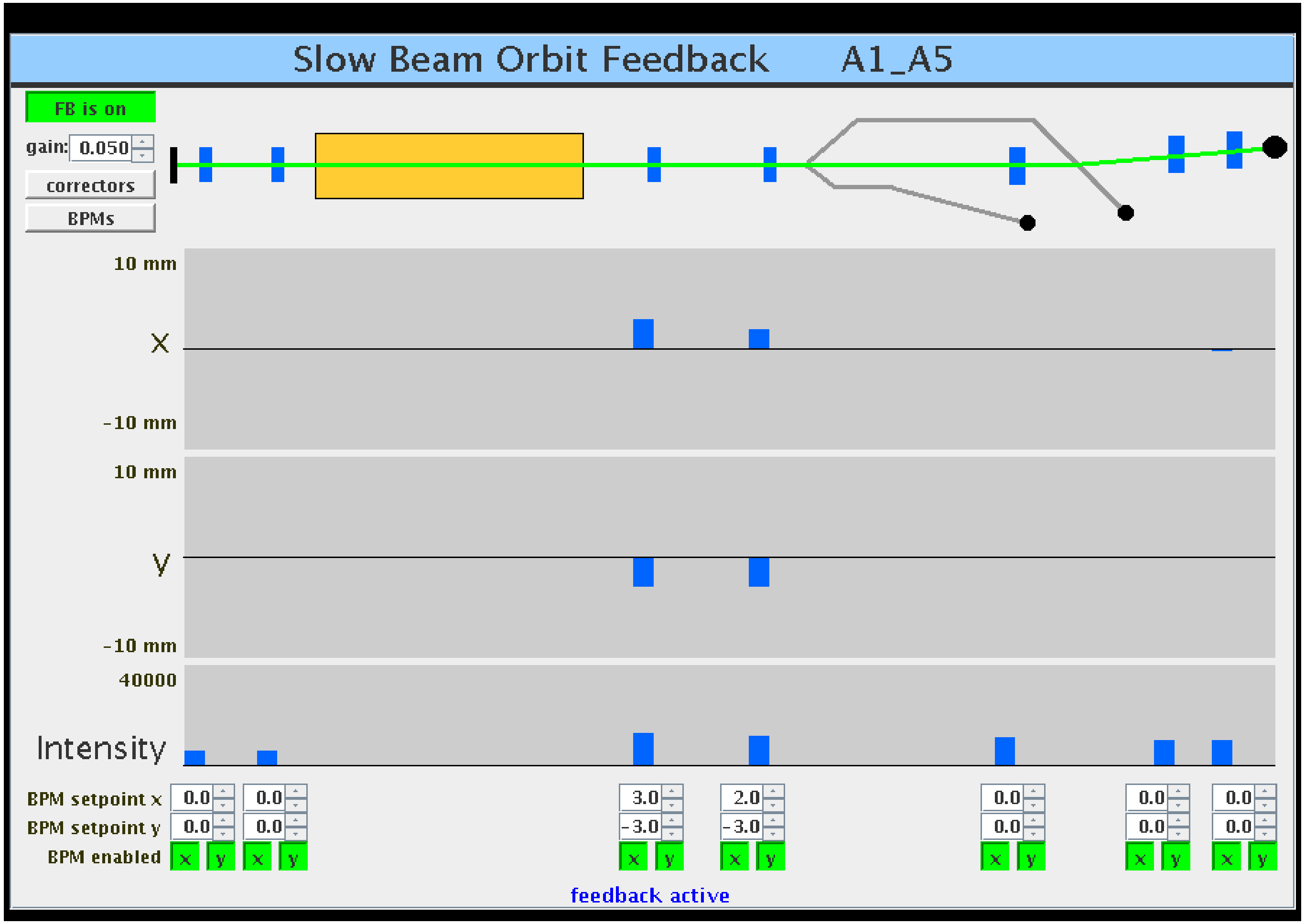
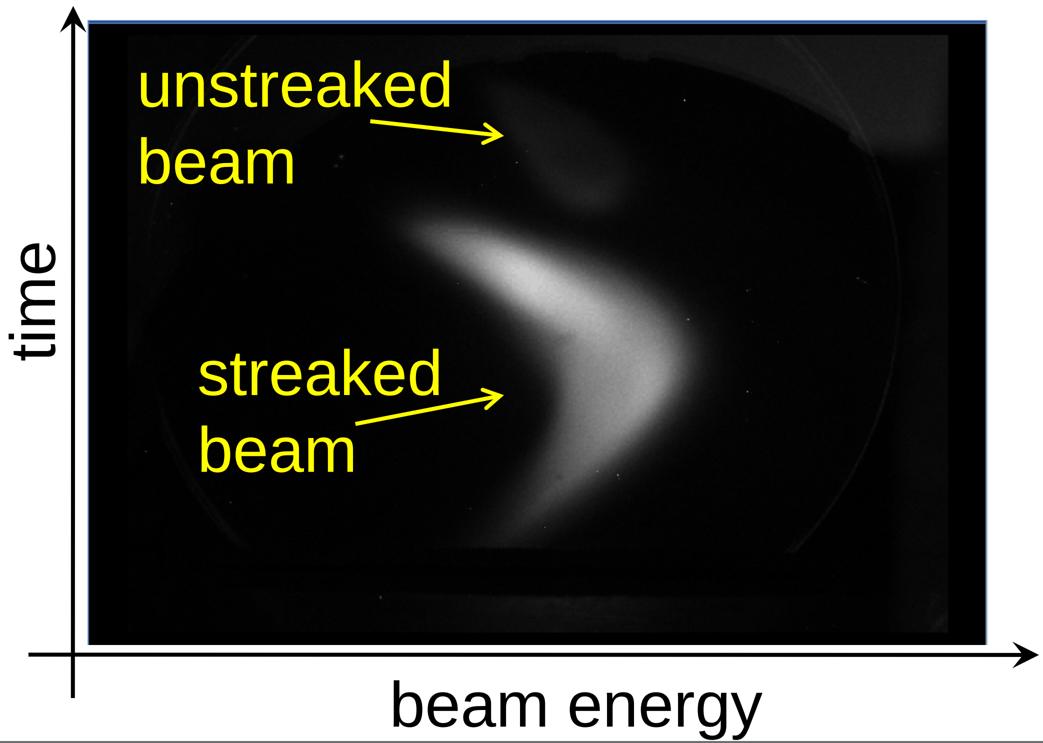
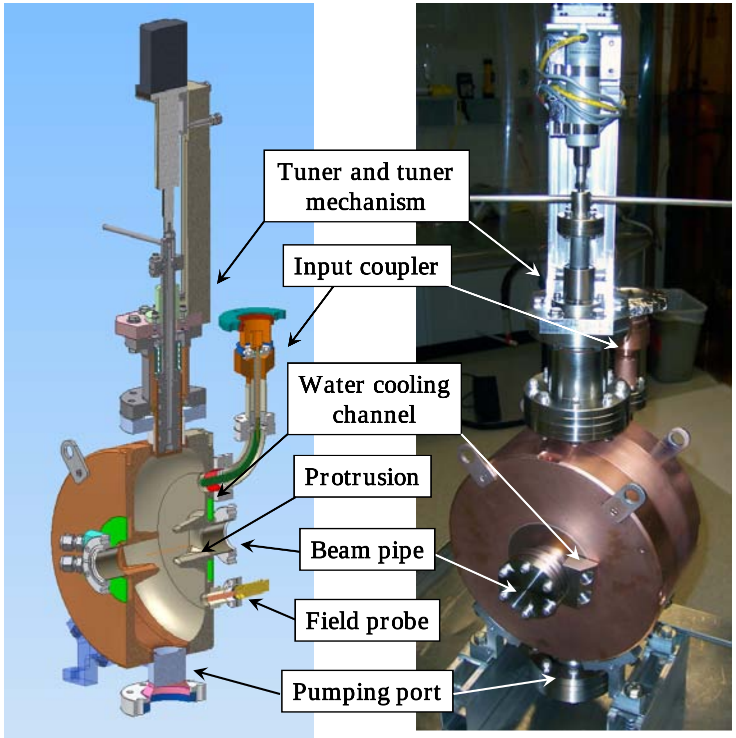


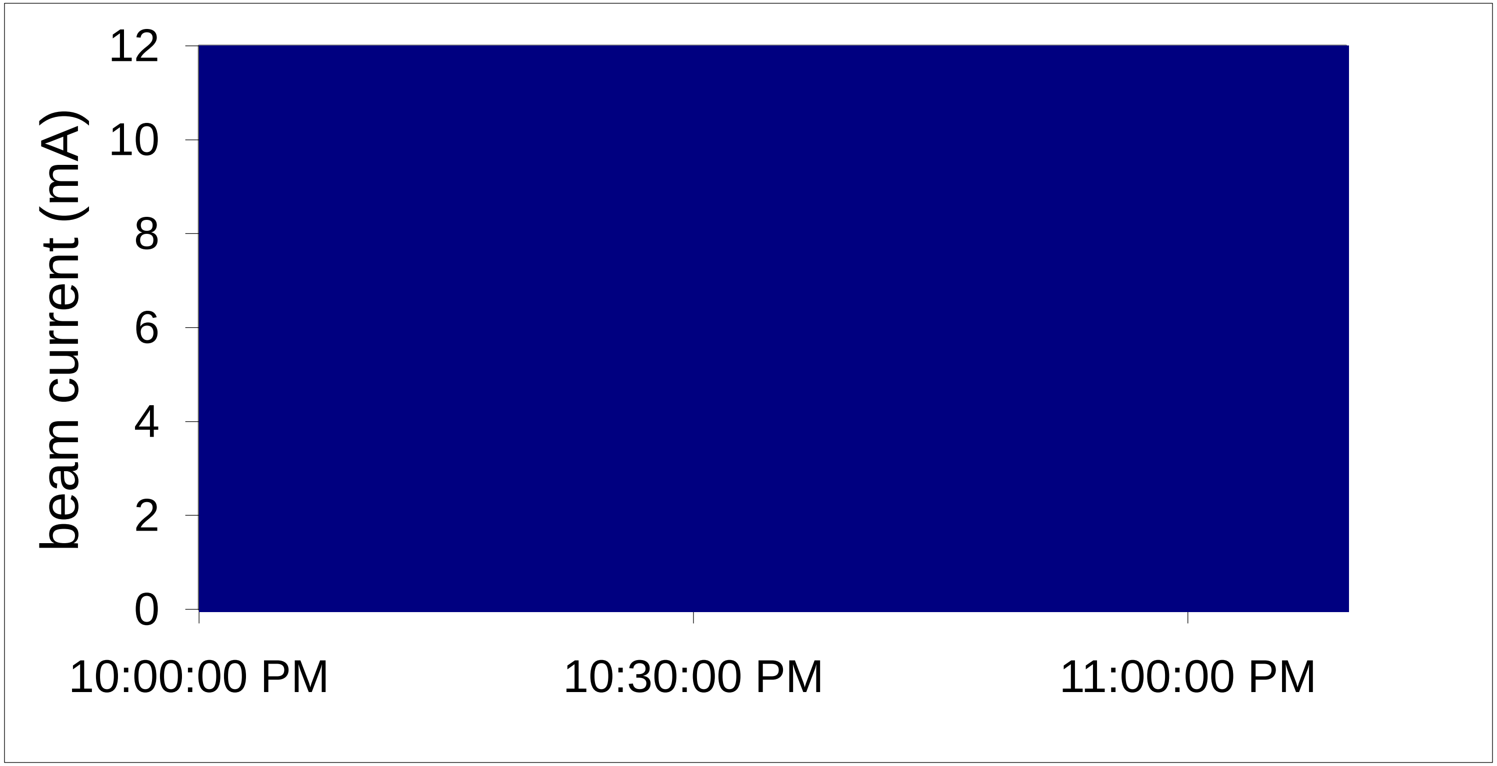
Transverse Deflecting Cavity

- Number of cavities 1
- Max transverse kick voltage 200 kV
- Max RF power 3.8 kW
- Average power 200 W
- Pulse duration 60 μs
- Max rep. rate 1 kHz





Initial high current run

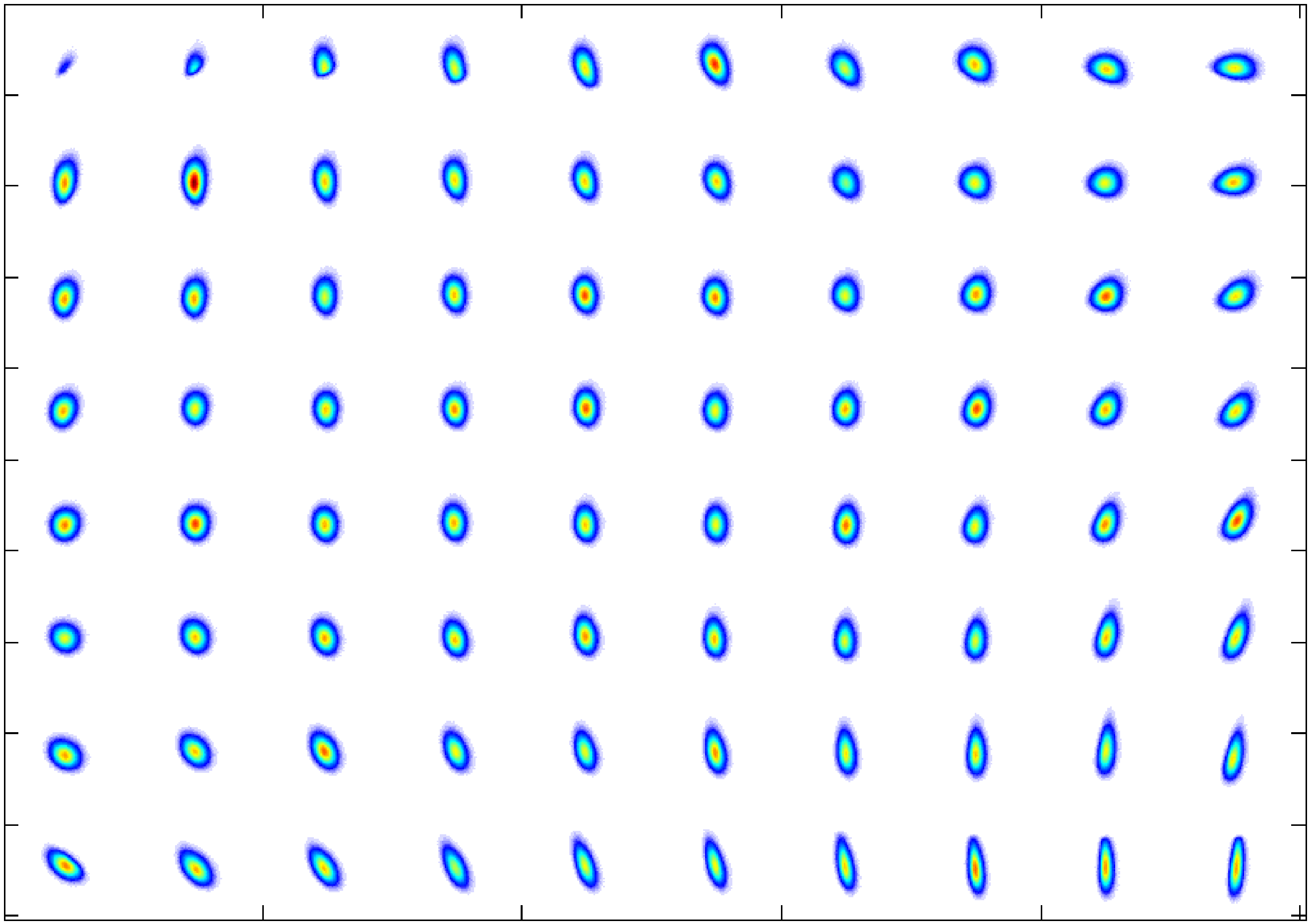


- Achieved maximum current is about 9 mA
- Main limitations: - Gun high voltage instabilities
  - Laser amplitude / position instabilities

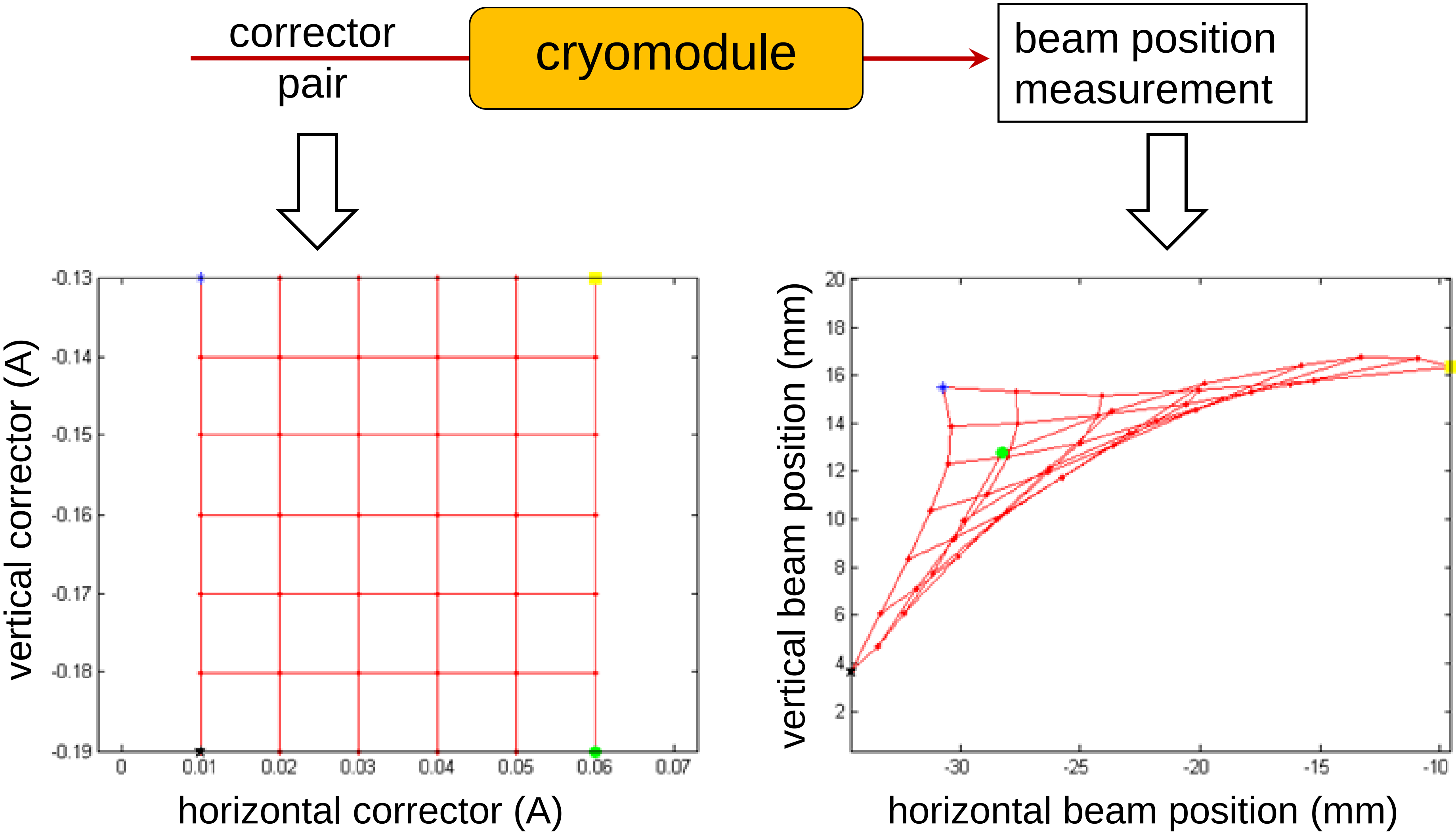
→ Work on solving the stability issues is in progress

Strange beam response of 250 kV beam

Steering the beam differently through the cryomodules changed the beam shape (no RF field in cavities)



Strange beam response



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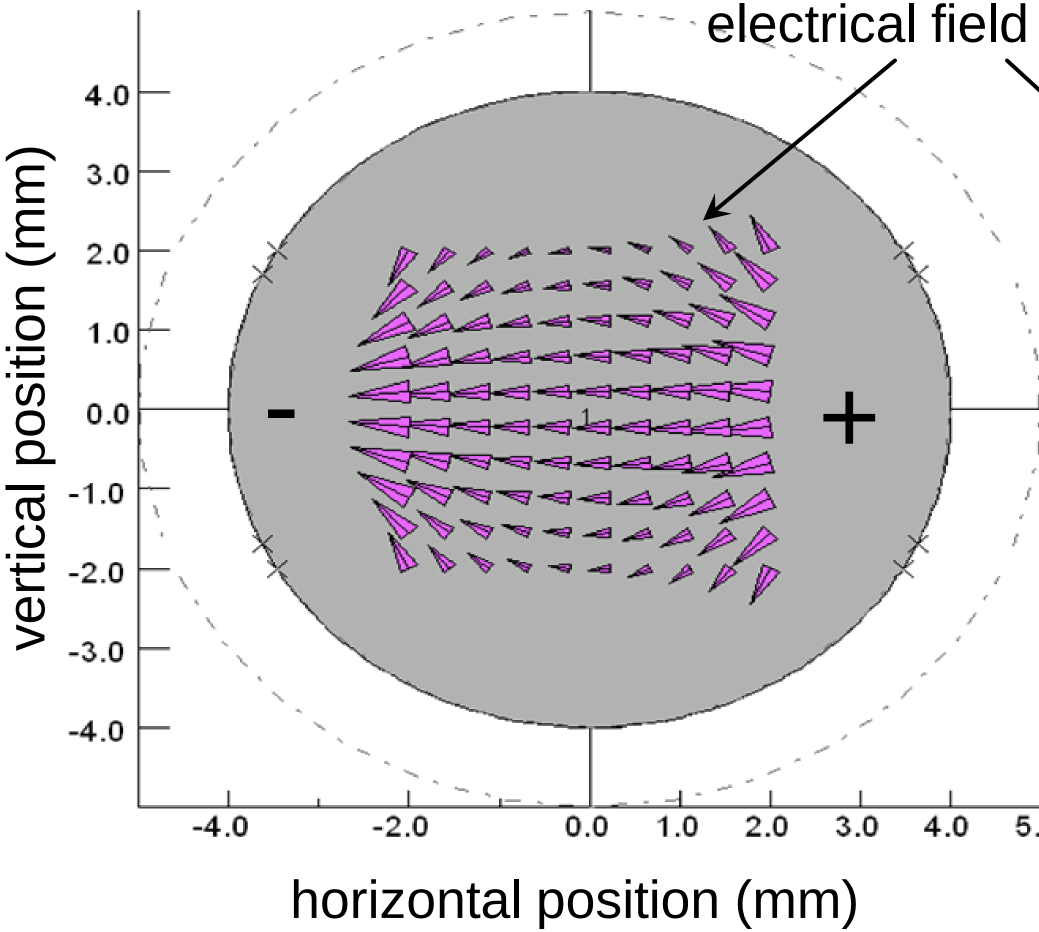
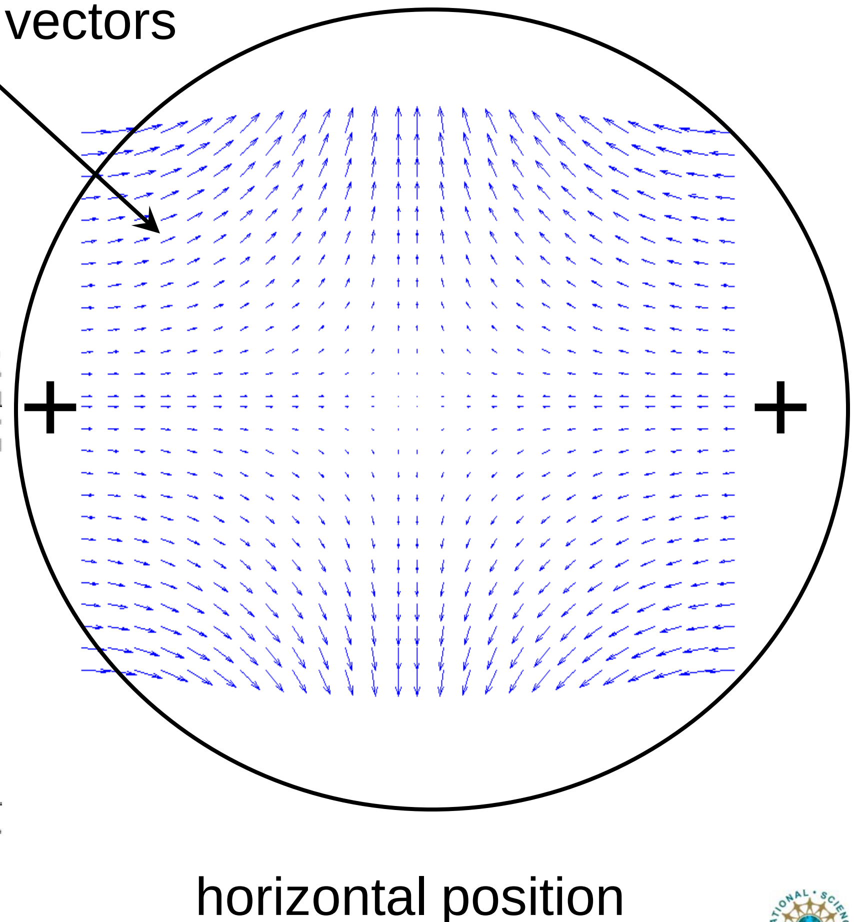
Localizing stray fields in the cryomodule with DC coupler-kicks

Generation of electrical DC fields in the coupler regions of the SRF cavities

dipole-like field | **quadrupole-like field**

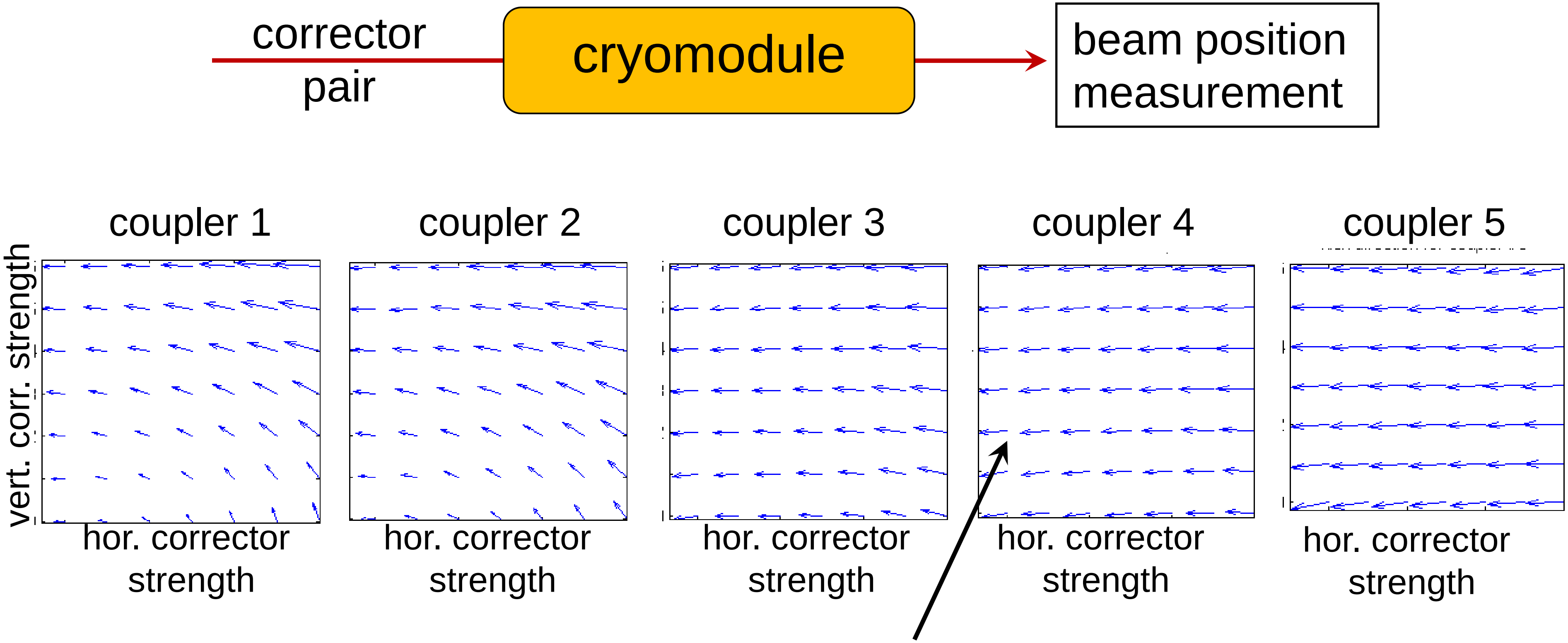
electrical field vectors





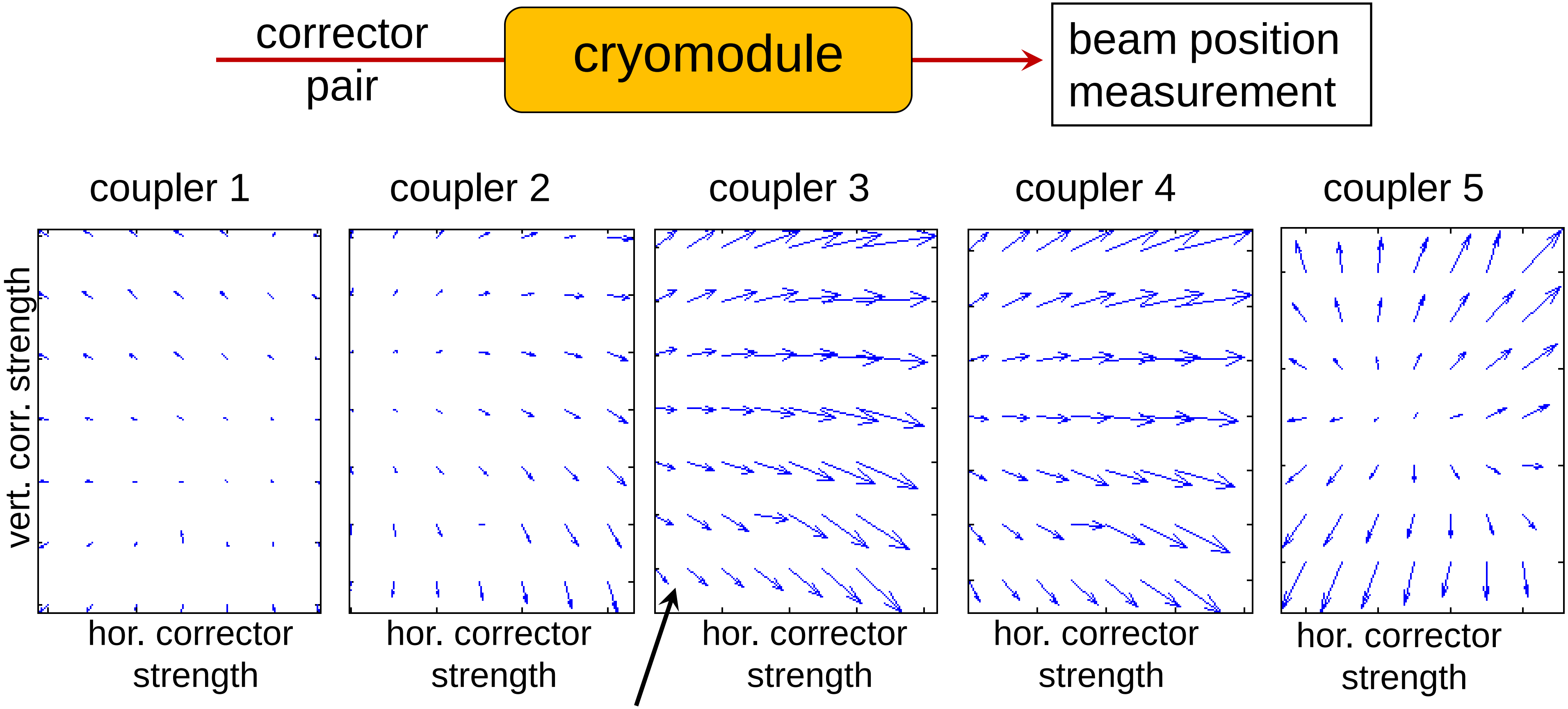
Localizing stray fields in the cryomodule with DC coupler-kicks

dipole-like coupler kick



deflection of the beam after the cryomodule
due to the coupler field

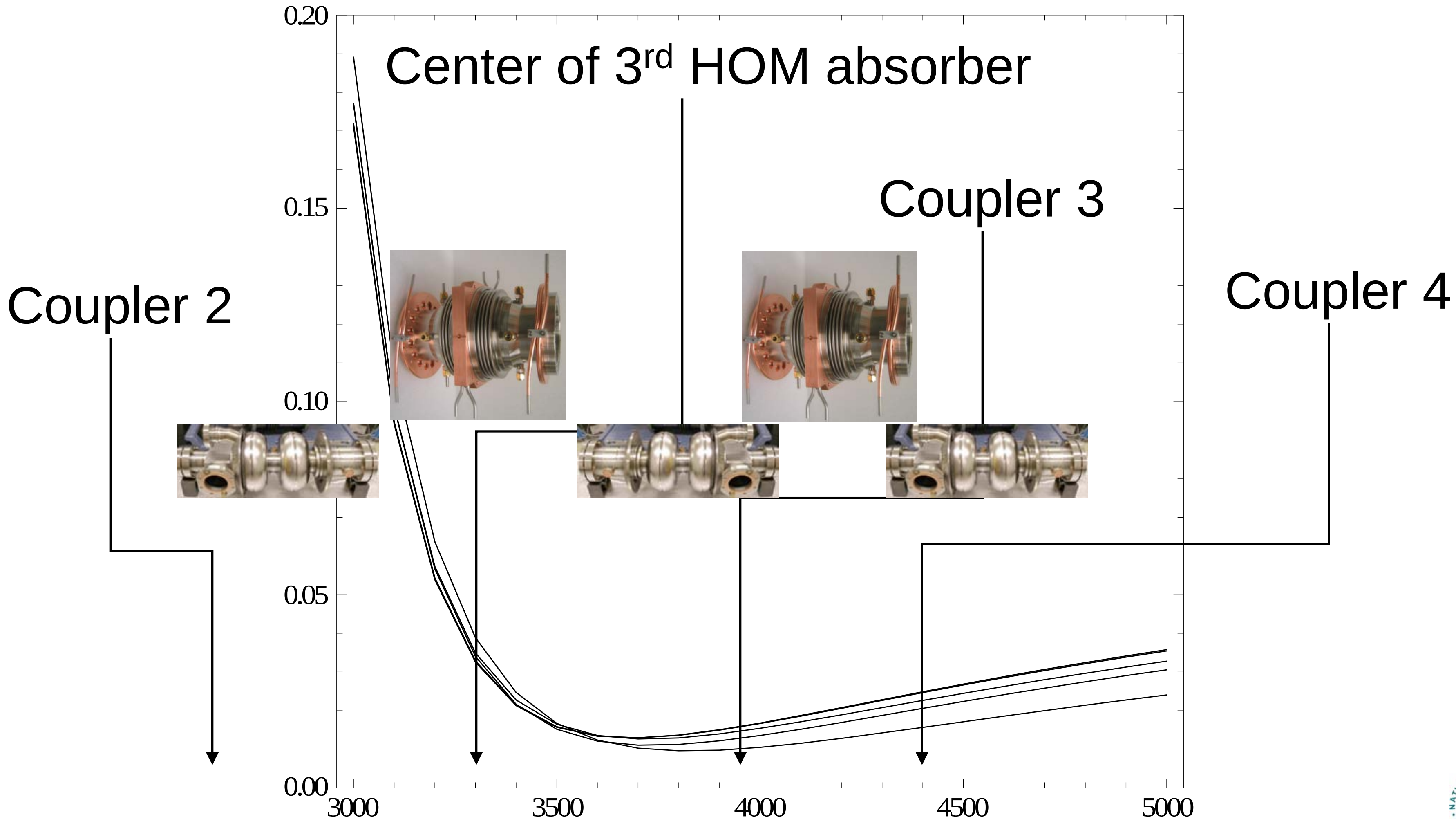
quadrupole-like coupler kick



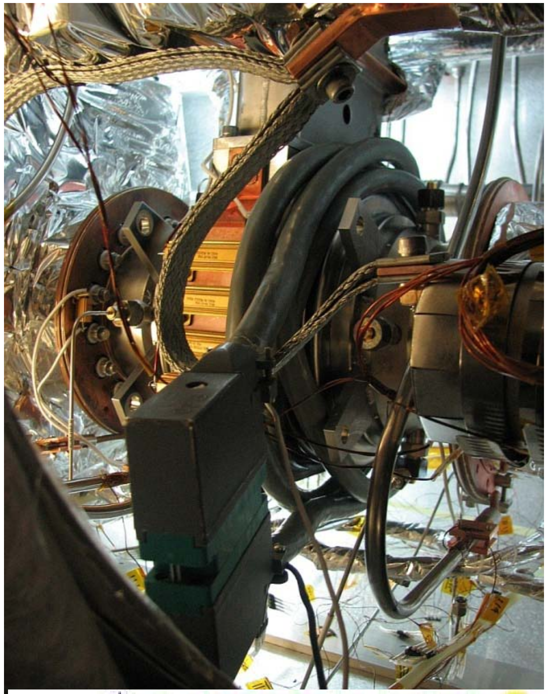
deflection of the beam after the cryomodule due to the coupler field

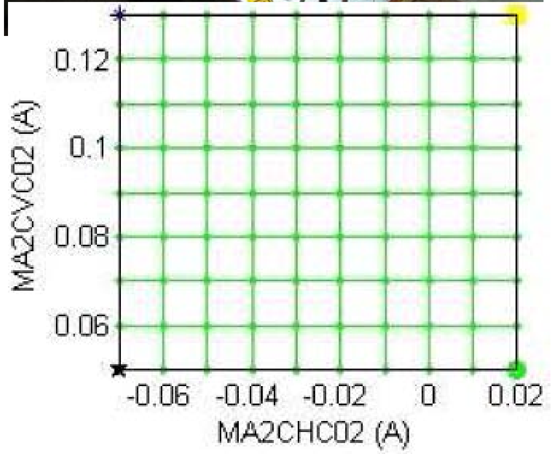
Localizing stray fields in the cryomodule with DC coupler-kicks

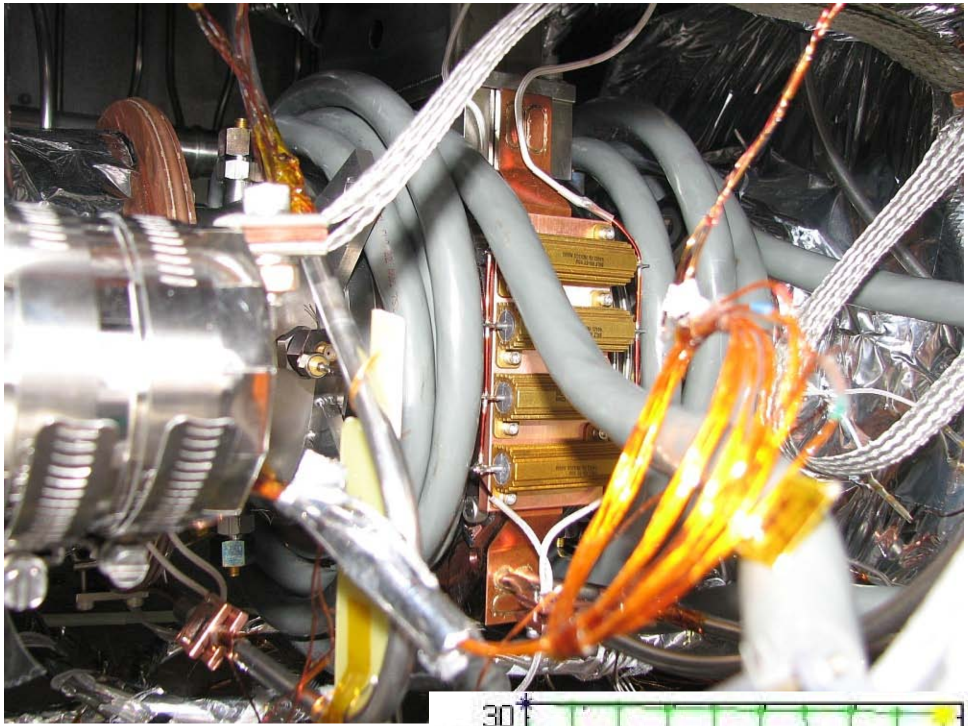
Determined the origin of the stray fields:



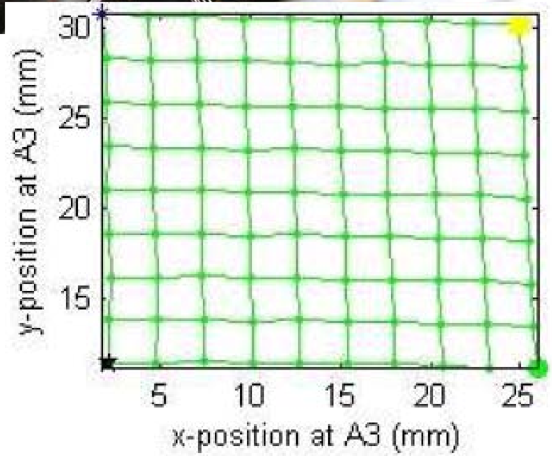
In-situ demagnetization







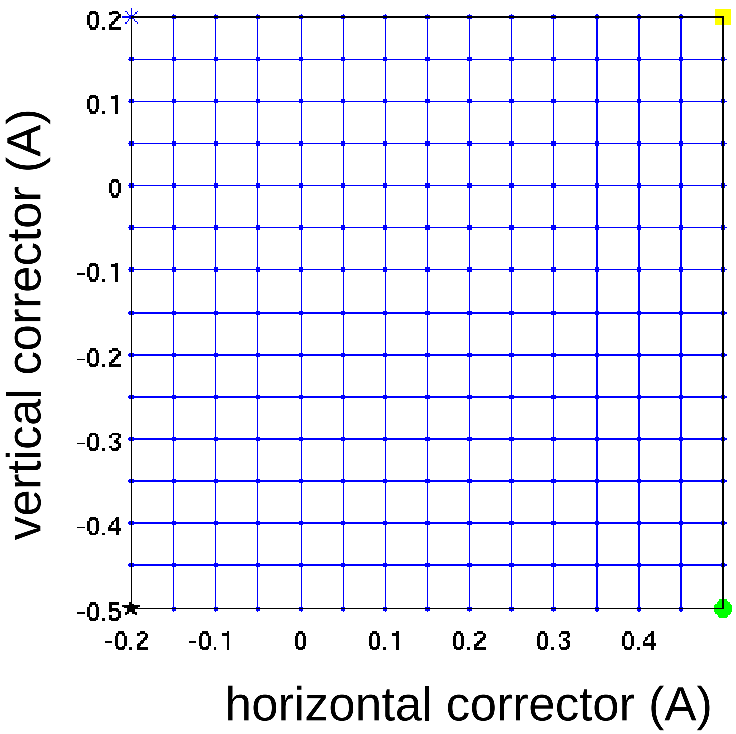
Warm up and in-situ demagnetization removed stray fields

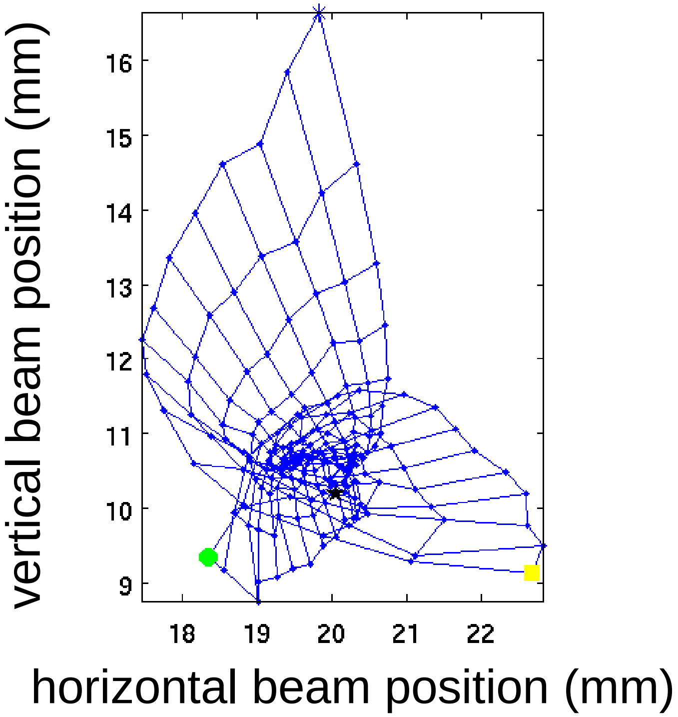


Stray fields

- Stray fields reappeared after a beam loss in the cryomodule
- Coupler conditioning changed the stray fields

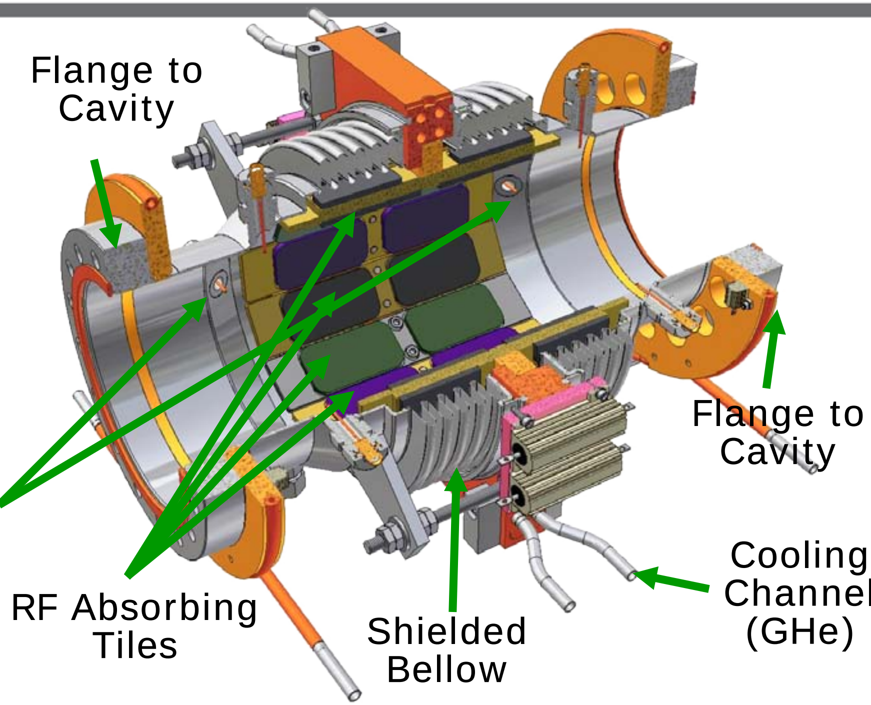
→ Charging up of HOM absorbers!

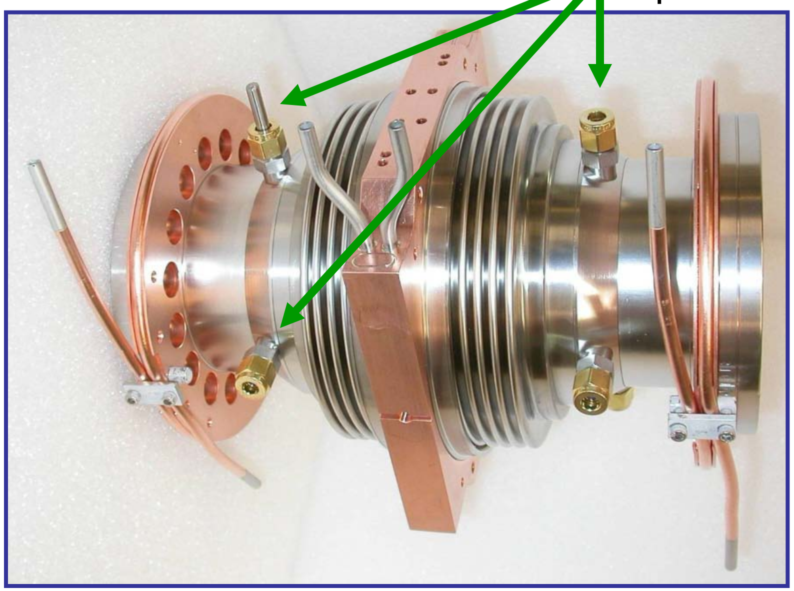


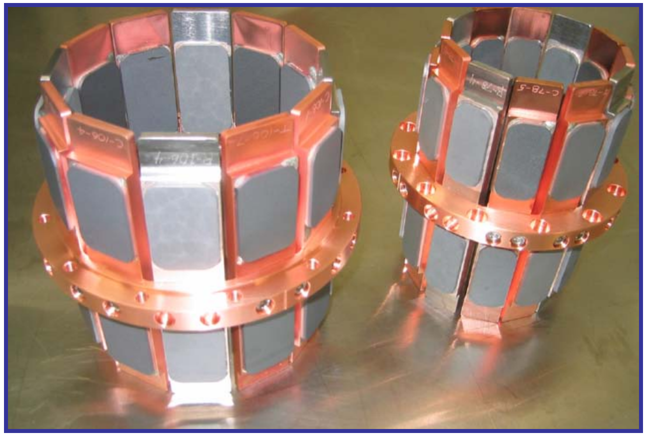


HOM absorbers

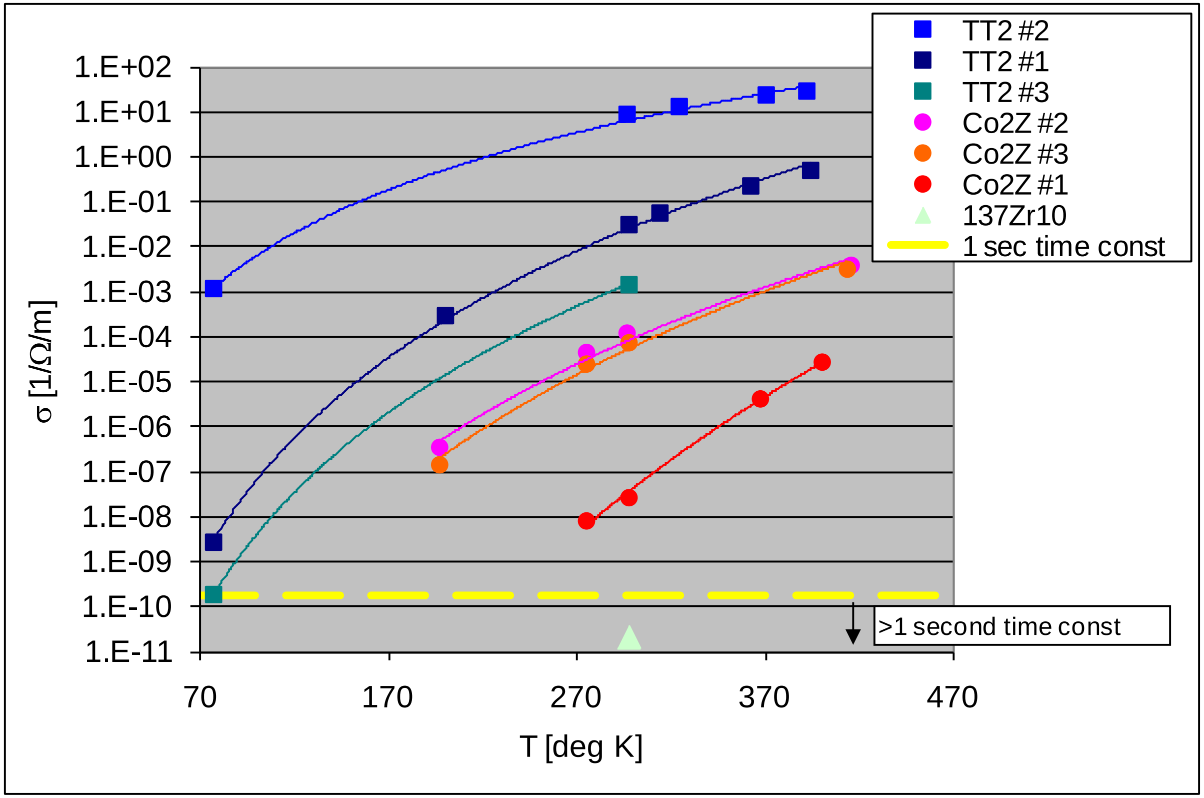
Total # loads	3 @ 78mm + 3 @ 106mm
Power per load	26 W (200 W max)
HOM frequency range	1.4 – 100 GHz
Operating temperature	80 K
Coolant	He Gas
RF absorbing tiles	TT2, Co2Z, Ceralloy

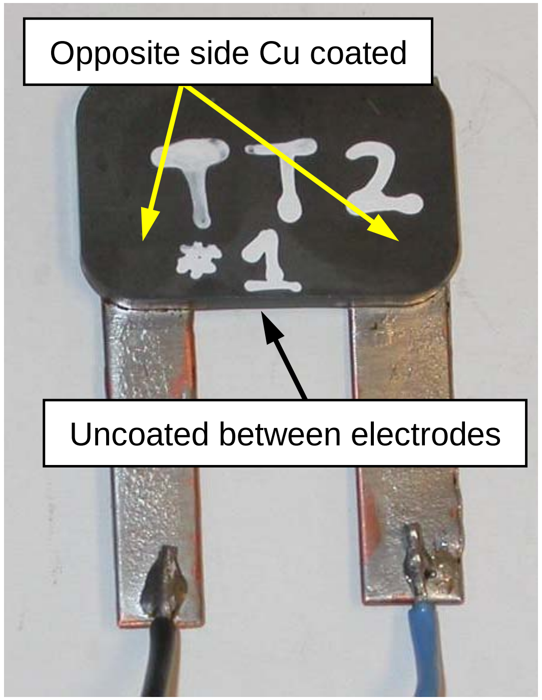






Charging up of HOM absorbers





Low conductivity of HOM absorber tiles: Can hold charge for many days / weeks!

Worst offender: **Ceramic 137Zr10**, followed by ferrite Co2Z and TT2

Small beam loss charged up absorber tiles -> kV **electric** fields at beam position!

Removing inner tiles

Consequence of low resistivities of absorber materials:

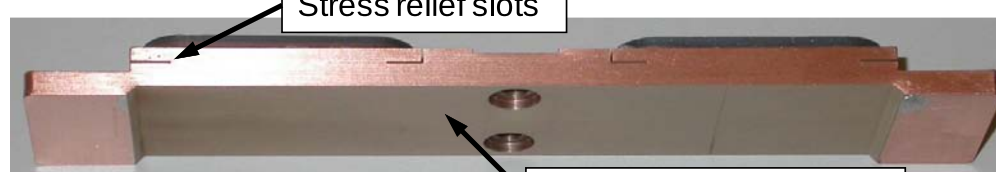
- Completely removed ceramic 137Zr10
- Tried gold coating of TTE absorbers but coating may fall off

→ Removed all tiles from the inside of the HOM absorber

Found one loose tile during cryomodule disassembly

- Thermal stress tests confirmed this problem

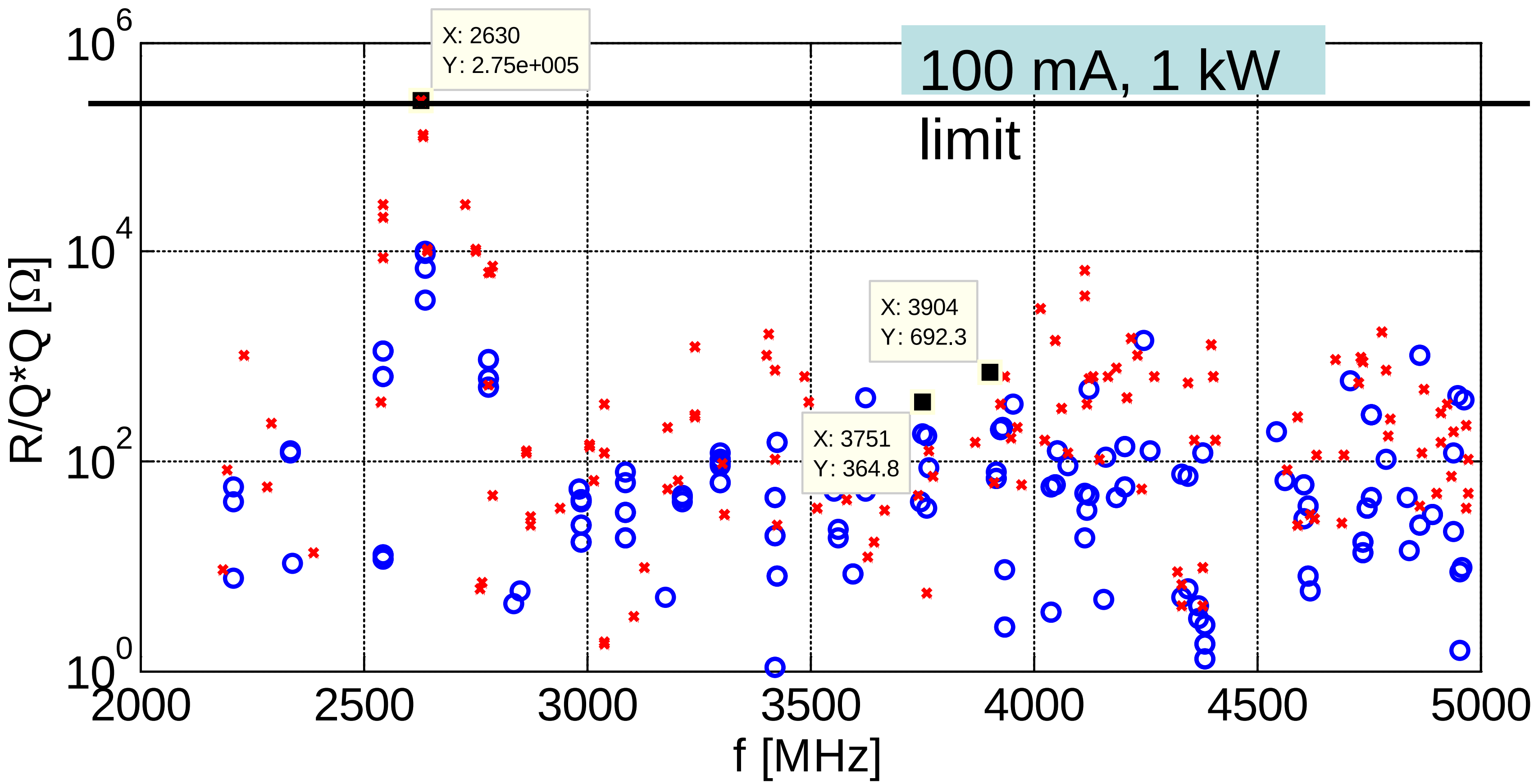
→ Solved by cutting stress relief slots in the tiles



Power limitations with modified HOM absorbers

Blue: inside and outside ferrites

Red: outside ferrites only

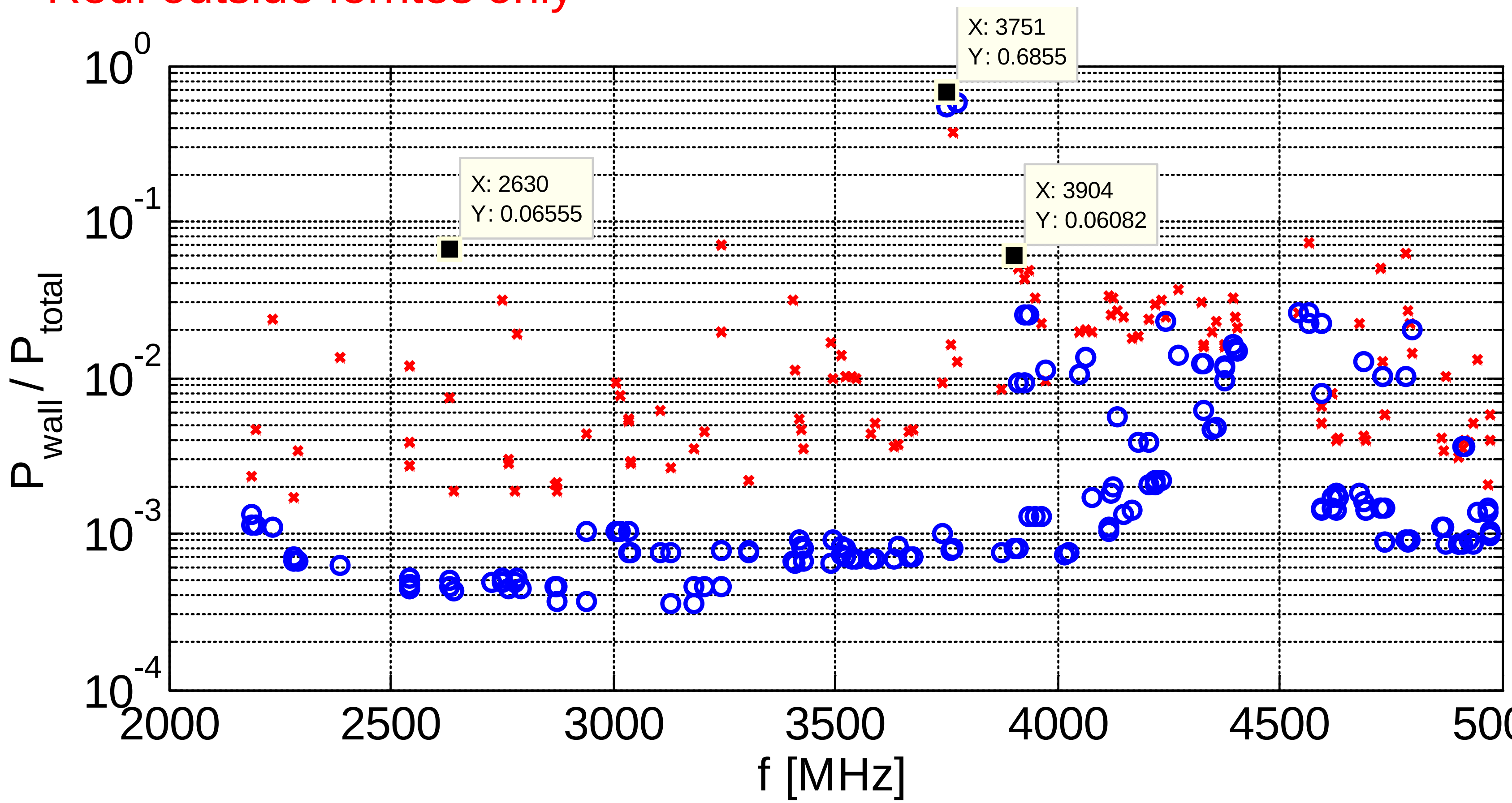


Power limitations with modified HOM absorbers

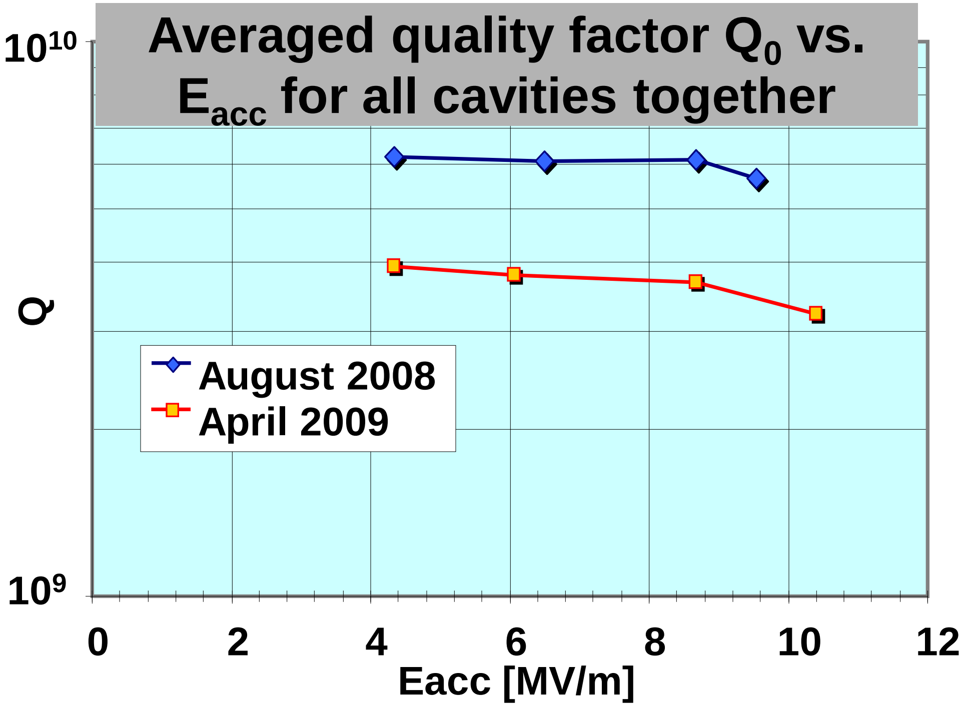
Power loss in the metal walls

Blue: inside and outside ferrites

Red: outside ferrites only



Cavity Quality Factors



Had difficulties with low cavity quality factors

- Q factors degraded over time
→ Q disease?

During the rebuild, all cavities were high pressure rinsed
→ Q restored to 1.6 x 10^{10} at 1.8 K
→ no Q disease
→ cavities were possibly contaminated with particles?

Current status of the injector cryomodule

- Cryomodule is rebuilt and back in the injector
- Cooled down to 4 K
- 2 K cool-down planned for next Monday

→ Ready to see beam in the next weeks!

Conclusion and Outlook

Charging up of the HOM absorbers caused difficulties during the first commissioning

→ Rebuild cryomodule during the last 6 months and removed problematic absorbers

Still, many critical systems could be successfully commissioned and prepared.

- Measured thermal beam emittance as expected
- Could increase beam current to 9 mA for short times (limitations understood and being worked on)

First beam operation after cryomodule rebuilt expected end of March

- Emittance optimization at 77 pC
- Work on high current beam operation