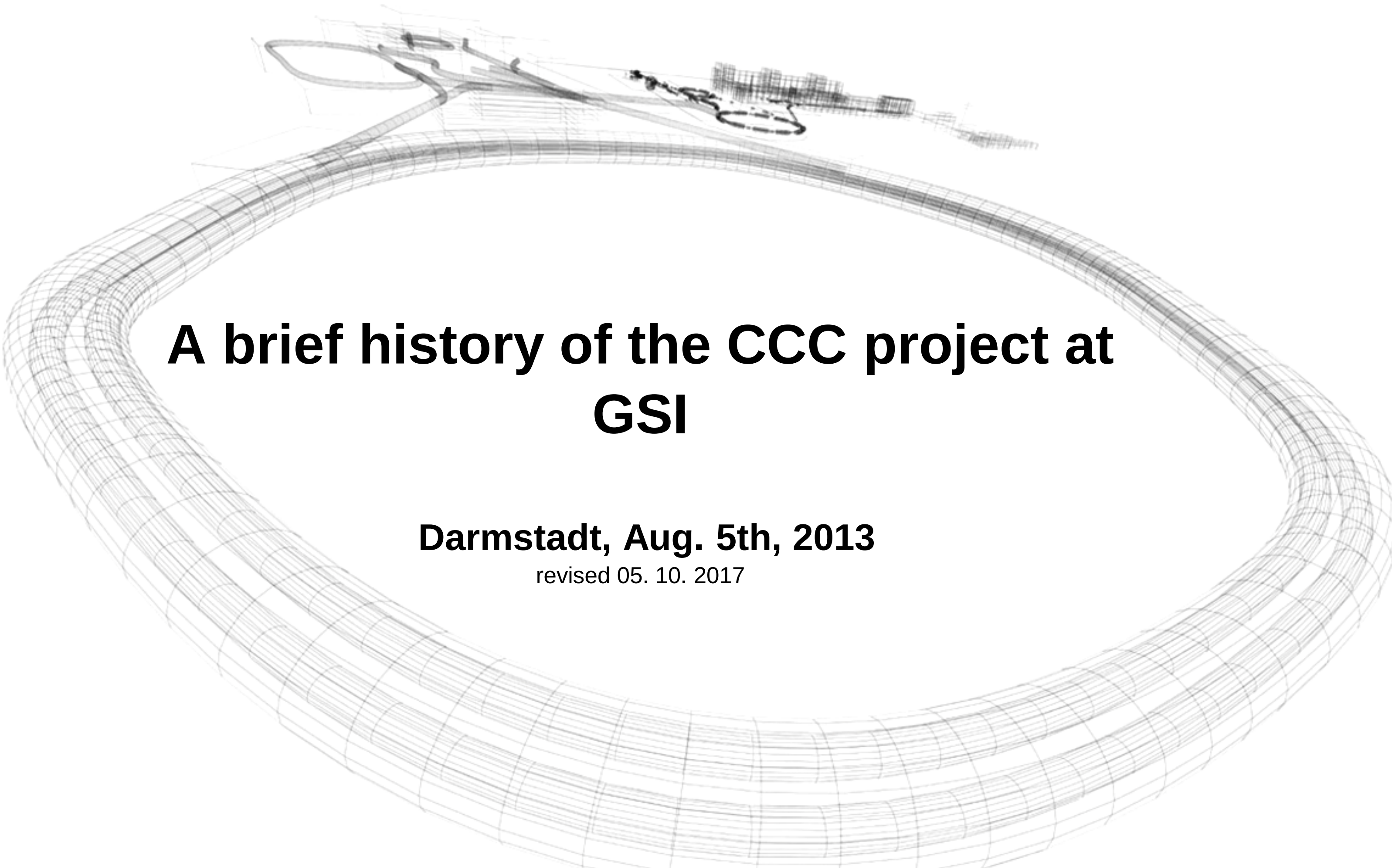
- Beam Current Monitors with LT-SQUIDs -



A brief history of the CCC project at GSI

Darmstadt, Aug. 5th, 2013

revised 05. 10. 2017

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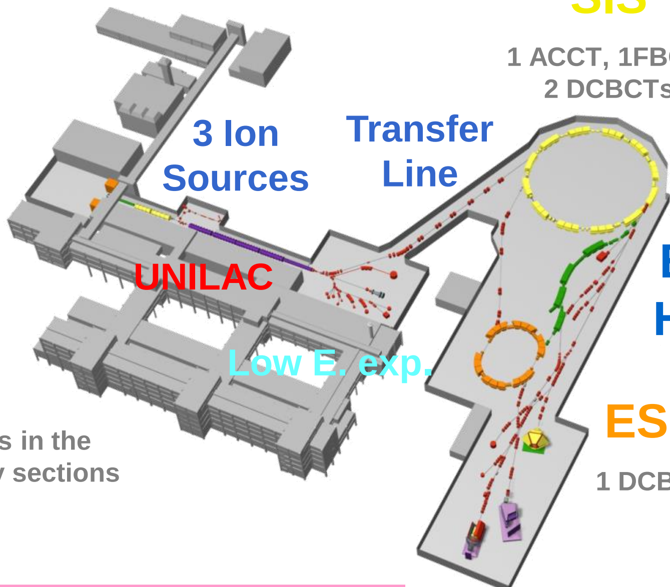
GSI Acc. Facilities and Intensity Monitors

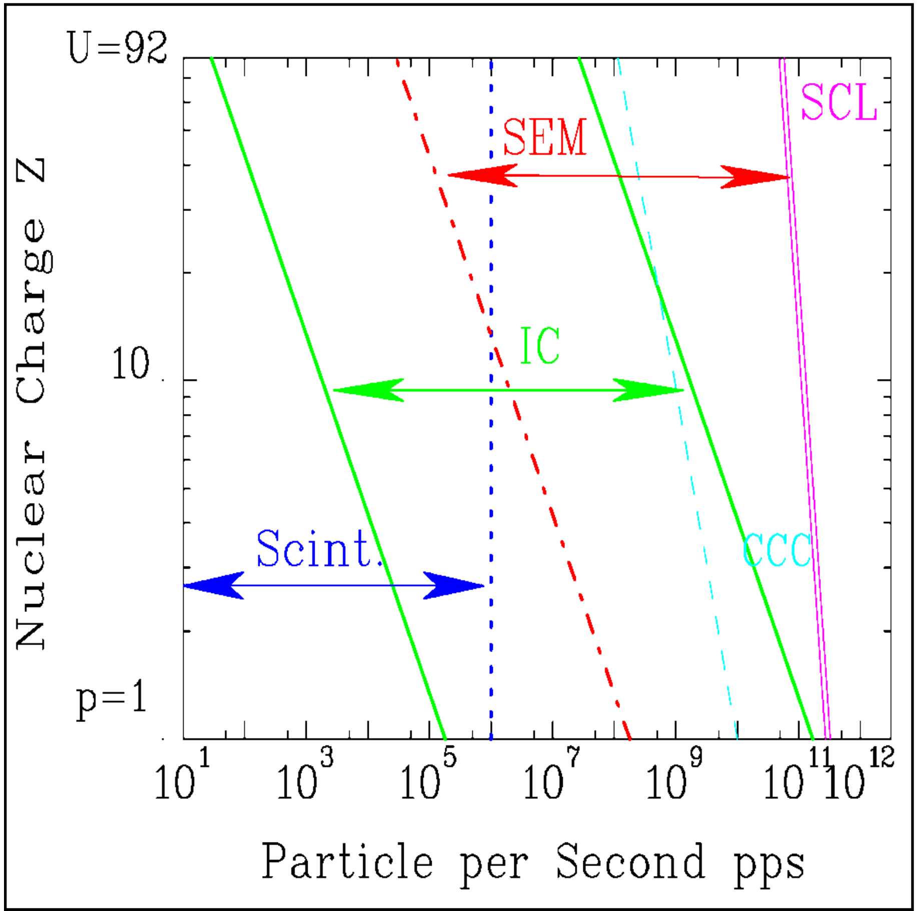


- *Uranium* : 50 … 1000 MeV/u
- *Neon*: 50 … 2000 MeV/u
- *Protons* : 4,5 GeV
- mag. rigidity: max. 18 Tm
- RF: 0.8 – 5.6 MHz
- mag. ramp rate: typ. 1.3 T/s
- orbit length: 216.72 m
- beam currents: nA … ~120 mA
- multiturn injection: typ. 25 turns
- resonant / KO extraction: ~ .1 … 10 s
- kick extraction: single bunch .. whole turn
- cycle duration: 0.2 … 16 s

- Sources: Penning, ECR, CHORDIS, MUCIS, MEVVA,
- max. A/z: 65
- injection energy: 2.2 keV/u
- RF: 36.1/108.4 MHz
- Energy: 1.4 … 18 MeV/u

- *Uranium* : 560 MeV/u
- *Neon*: 830 MeV/u
- mag. rigidity: max. 10 Tm
- RF: 0.8 – 5.6 MHz
- mag. ramp rate: typ. 1 T/s
- orbit length: 108.1 m
- beam currents: single particle .. ~ 10 mA
- max. storage time: ~ min.

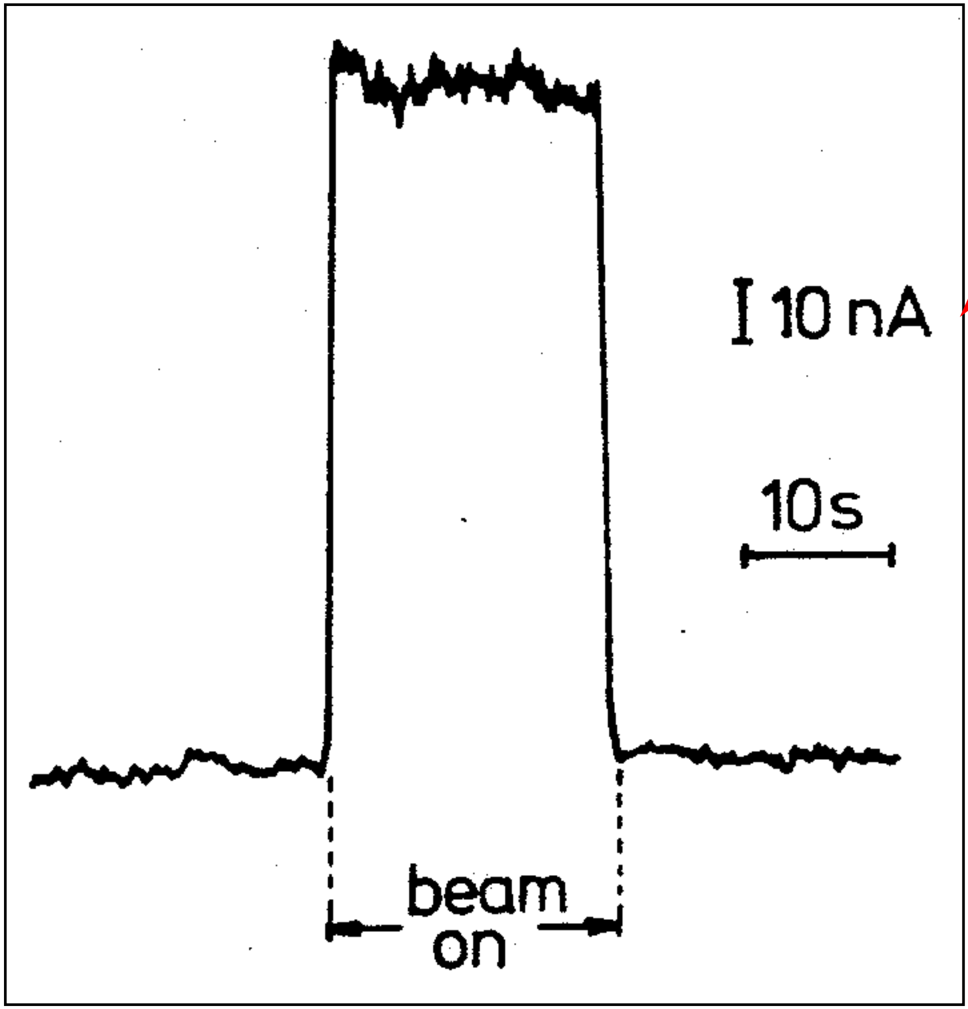
Motivation



operating ranges of spill-intensity monitors (©P. Heeg/P. Forck)

- non-destructive „online“ intensity monitor
- signal bandwidth sufficient to resolve spill fluctuations
- possibly usable as a sensor for a spill servo controller
- as an absolutely-calibrated device usable to re-calibrate SEMs and ICs

The 1st kick-off (1989, or early in 1990)



That's it ! We have to explore if we can copy it.

Ref.:

K. Grohmann, D. Hechtfischer, J. Jakschik, H. Lübbig

"A cryodevice for induction monitoring of dc electron or ion beams with nano-ampere resolution"

in: "Superconducting quantum interference devices and their applications",

Walter de Gruyter & Co., p. 311, 1977

The 2nd kick-off

Kooperationsangebote aus der DDR

Bemerkenswert war das starke DDR-Interesse an deutsch-deutscher Kooperation in Forschung und Fertigung. Es nahmen Vertreter fast aller im Bereich der Sensorik/Aktorik tätigen Betriebe und Einrichtungen der DDR am Kongreß teil. Einige Angebote zur intensiven Zusammenarbeit:

- TH Ilmenau: Bau eines linearen Zwei-Koordinaten-Gleichstromantriebs mit getriebeloser Krafterzeugung;
- Institut für Halbleiterphysik Frankfurt/O.: Entwicklung von CCD- und Quanten-Hall-Sensoren, Fotolithografie, SOI-Substrate;
- die TU Chemnitz stellte ein Inter Disziplinäres Analyse System – IDAS – für die Leistungselektronik und elektrischen Antriebe vor;
- Kombinat Mikroelektronik: Zusammenarbeit bei Mikroelektronik-Techniken und bei der Fertigung verschiedenster Sensoren (Optoelektronik, Temperatur, Druck, Beschleunigung u. a.);
- Universität Jena: Supraleitender Quanten-Interferenzdetektor (SQUID) für magnetische Felder mit extremer Empfindlichkeit von 10 Femtotesla;
- Robotron-Elektronik Dresden: Sensorentwicklung, ASIC-Entwurf, CAD/CAM-Software und Mikroelektronik-Technologien.

Vom Zustandekommen enger Kooperationsbeziehungen zu bundesdeutschen Partnern hängt für viele DDR-Betriebe und -Einrichtungen wesentlich die Überlebensfähigkeit in der Marktwirtschaft ab.

Auf einigen technischen Gebieten sind auch gute Ansatzpunkte für eine enge deutsch-deutsche Zusammenarbeit vorhanden.

The iron curtain already was open, but …

1957–1990

… so, wait for reunification.

Ref.:

Elektronik Journal 17/1990
Hüthig Verlag, Heidelberg

Project CCC* starts

October 3rd, 1990:

1957–1990

Nach 1990

In 1991:

- a He-liquification and recycling system for the FOPI exp. is installed
- CCC project leader Andreas Peters, physicist
- knowledge and expertise by Dr. Claus Riedel (thermal and mechanical calculations) and Dr. Dieter Schüll (cryogenics) now available
- investigations on commercial SQUIDs on the market (fall-back?)
- cost estimations, funding
- first contacts with Friedrich-Schiller-University by mail, fon and FAX
- looking for students to support the project by diploma theses

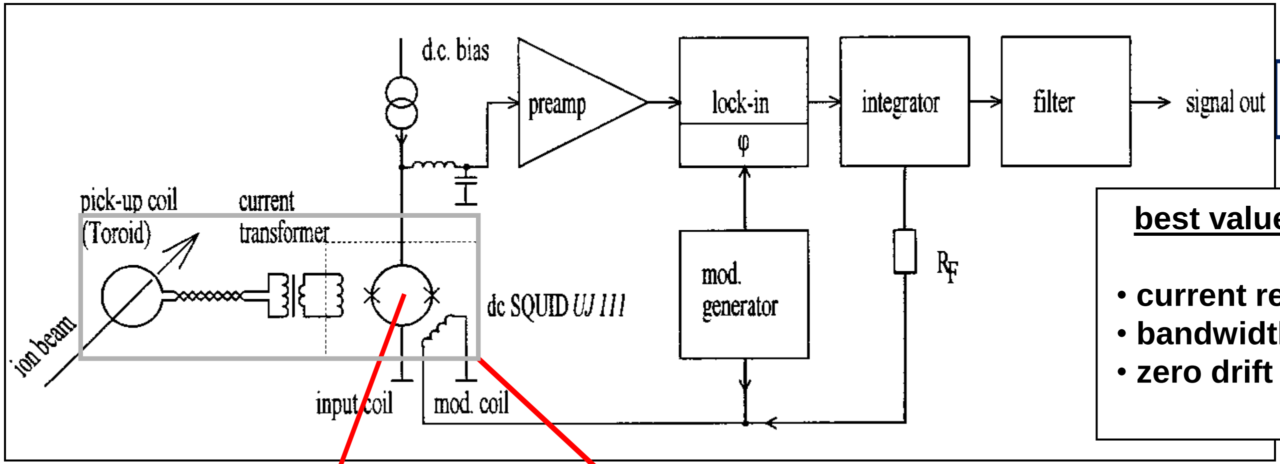
In 1992:

- Claus H. Schroeder – student; design and mfg. of cryostat
- Volker Dürr – student; design and mfg. of sensor/shield assembly
- collaboration contract made with FSU -> SQUID and controller will be provided
- Dr. Wolfgang Vodel, Dr. Helmar Koch, Holger Mühlig and Ralf Neubert are now consultants, co-designers, helpers and friends
- a cage in the experimental hall near the GHe-recycling line was claimed

Design Goals (A. Peters)

- Prototype for R&D has to work “offline” in our lab cage and will be later integrated into our group’s test beam line HTP
- Thus accelerator vacuum can serve as isolation vacuum → “warm hole” in LHe-container necessary
- Possibility of unlimited access and total and “easy” dismantling of the cryostat and all components installed therein
- Low L-He consumption aspired (5 – 7 l / d) → thermal shield (Cu) cooled by refrigerator (down to 40 – 50 K)
- additional superinsulation wrapped around shield (20 – 30 layers) → ~ 3 days of experiments should be possible with one fill of 100 l LHe (cooling-down and storage)
- One experimental period should have a “cycle time” (cooling down, experiments / repairs / enhancements, refilling, warming up) of 8 – 10 days only
- **And last but not least: measure beam currents in the nA region !**

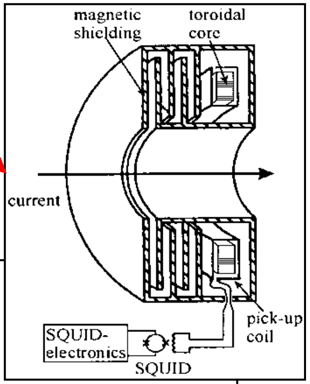
*CCC - a cryogenic DC flux transformer

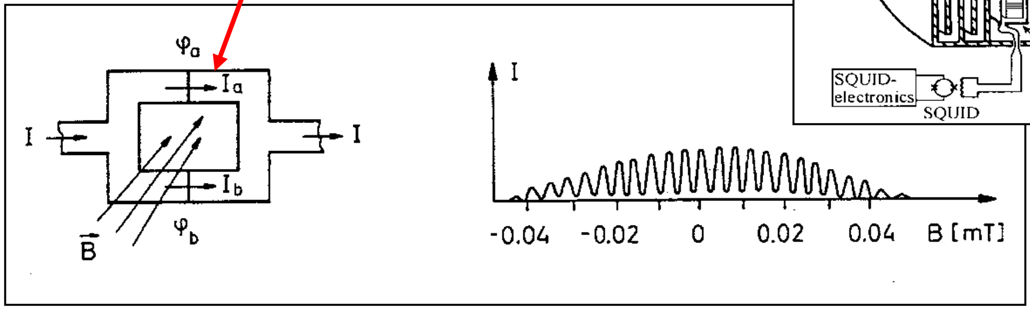


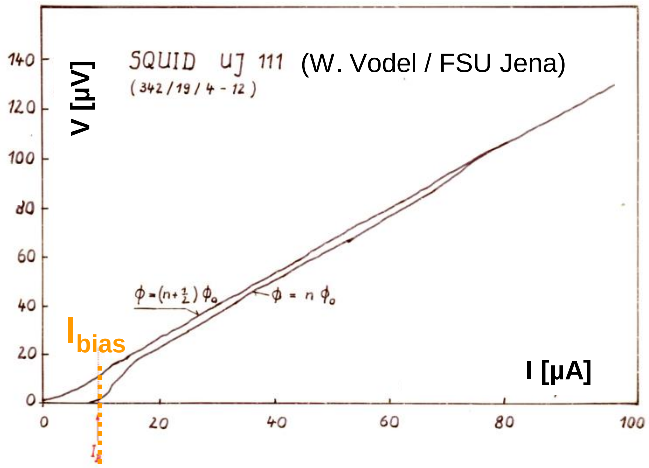
~ 14 mV / nA

best values reached so far:

- **current resolution < 250 pA/sqrt(Hz)**
- **bandwidth > 50 kHz**
- **zero drift < 4 pA/s**

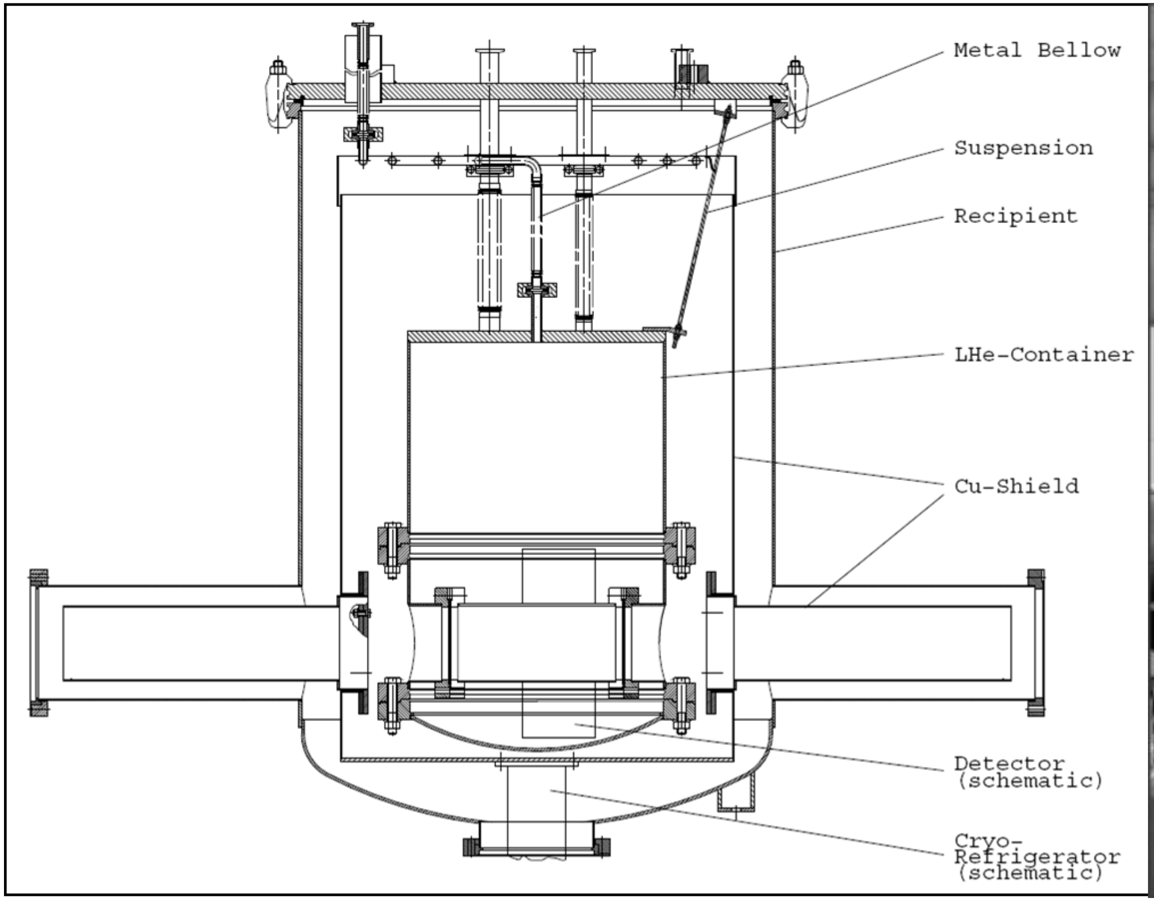






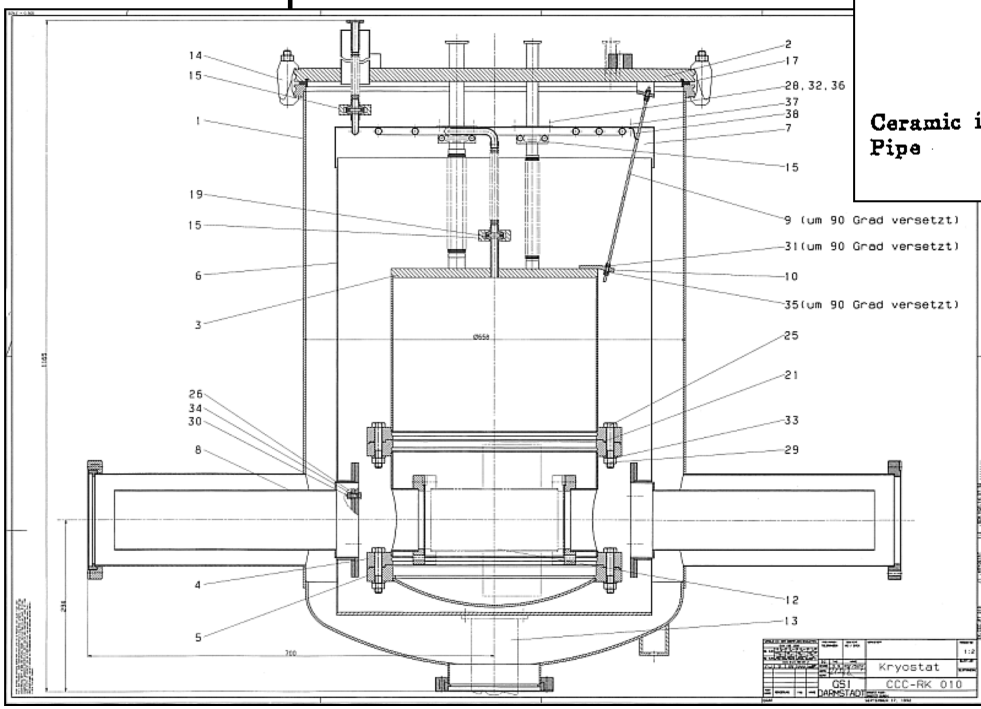
all figures: © FSU Jena / W. Vodel

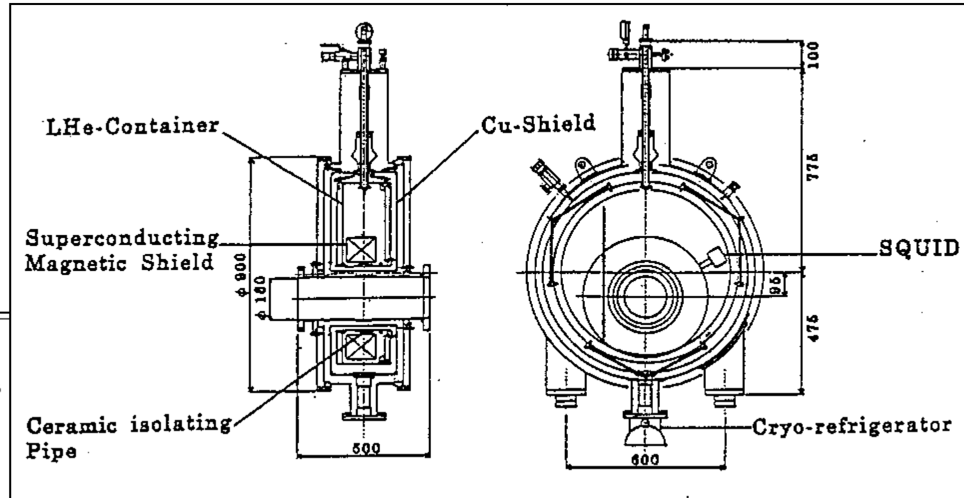
CCC in HTTP beamline, 1993



Main parameters of CCC cryostats:

- Aperture: 100 mm
- Height: ~ 1.1 m
- Lenght: ~ 1.4 m
- Thermal loss: ~ 170 mW
- L-He content: ~ 20 l
- L-He consumption: ~ 5 l/day

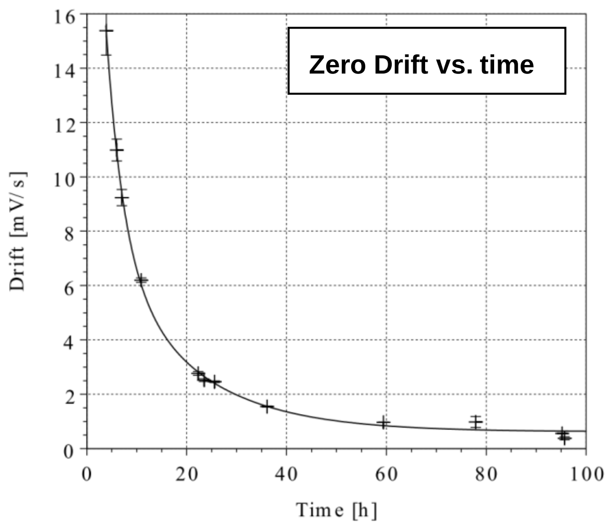


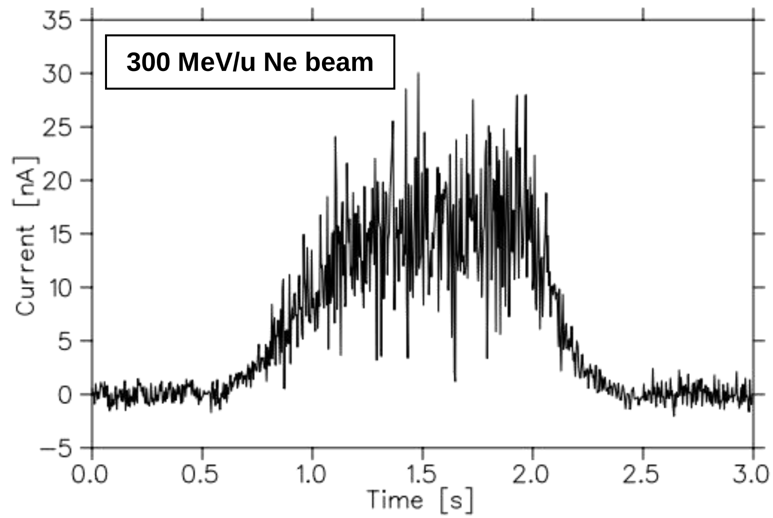


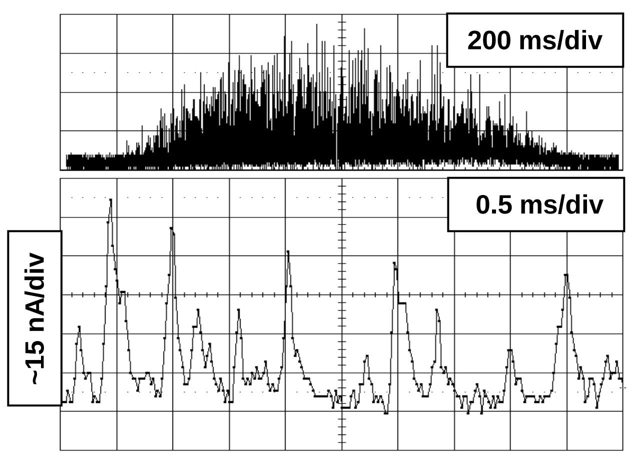
- Aperture: 100 mm
- Height: ~ 1.3 m
- Lenght: ~ 0.5 m
- Thermal loss: ~ 290 mW
- L-He content: ~ 15 l
- L-He consuption: ~ 9 l/day

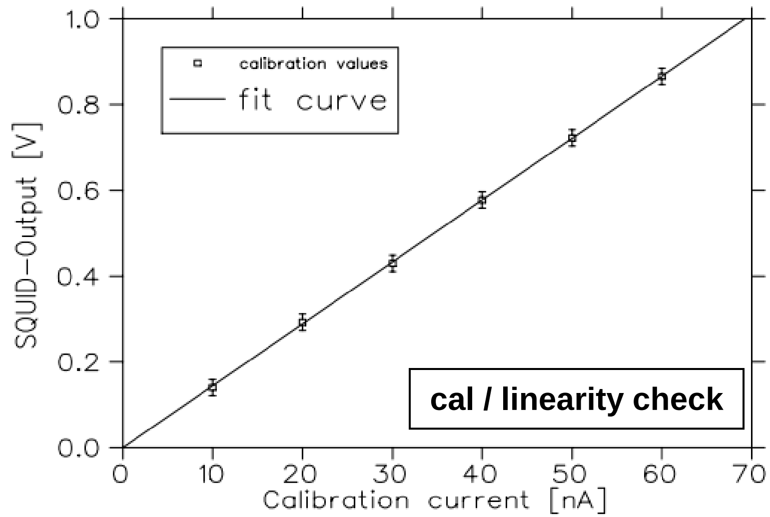
left: **GSI CCC** - right: **TARNII CCC (J)**

Results from the GSI CCC:









Next Steps, 1994-98(?)

Julien Bergoz, Bergoz Instrumentation,
presenting the Faraday Cup Award to Andreas Peters
with Bob Hettel of SLAC looking on.

- replacing the old SQUID4 and front end amp controller by SQUID 5 (R. Neubert) with higher bandwidth and stability, entirely manufactured from modern (Western) components
- fixing short circuit on Nb wiring inside Pb shield
- solving different EMC problems -> differential signal transmission/ADC, optical isolation amp etc.
- comparative measurements against SEMs and ICs (sorry, no data available)
- searching sources for zero drift (no result)
- accelerometer measurements to isolate sources of low frequency noise (?)
- ..
- ..
- temporary shut-down; Faraday Cup Award given to A. Peters

Re-activation since 2010

- the FAIR beamlines and the Collector Ring have to be equipped with (6-7) CCCs, now 150mm inner diameter
- a Ph. D. student (Febin Kurian) hired for the new project, re-calculated the s.c. magnetic shield and learned a lot about cryogenics
- collaborations arranged, again with the FSU Jena, and MPI-K Heidelberg (CSR)
- calculations of noise-limited current resolution by Alexander Steppke (FSU)
- s.c. magnets in the FAIR-HEBT lines abandoned, so all CCCs must have their own LHe-plant
- comprehensive investigations on ferromagnetic materials for the sensor toroid by René Geithner (FSU Jena)
- material selected, toroids produced, Nb meander shield assembly finished
- the old GSI-CCC is now refurbished as a test bench for FAIR developments
- in the meantime, a CCC is also requested for the modified LSR-CRYRING (to be commisioned soon), while MPI-K stopped the collaboration due to internal problems (-> stand-by observer)
- FSU Jena does not provide SQUID UJ111 anymore, as well as the SQUID 5 controller, so commercial products are foreseen -> a SQUID from Supracon AG (Jena) and a controller from Magnicon GmbH (Hamburg) have been purchased
- for increased signal bandwidth, the lock-in principle is abandoned in the new controller