LHC Mini Workshop
- Improving the accuracy of the BCT measurements -

Experience with the DCCTs at GSI

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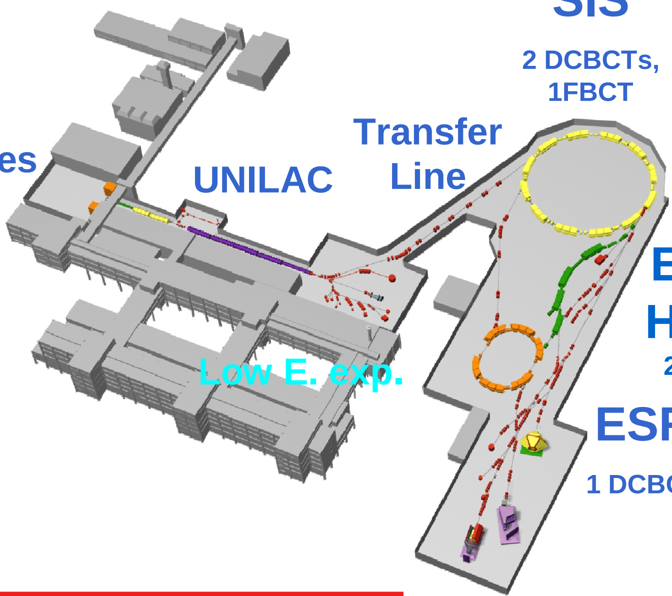
GSI

Overview

- GSI's accelerator facility
- GSI DCBCT System Layout
  - Block diagramm
  - Control Loop
  - Installations
- GSI DCBCT Main Parameters
- Effects observed during operation
  - related to hardware
  - related to software/machine control
- Improvements
- **C**ryogenic **C**urrent **C**omparator
- Addendum: FBCTs for SIS / HEBT

GSI Accelerators & Exp. Areas

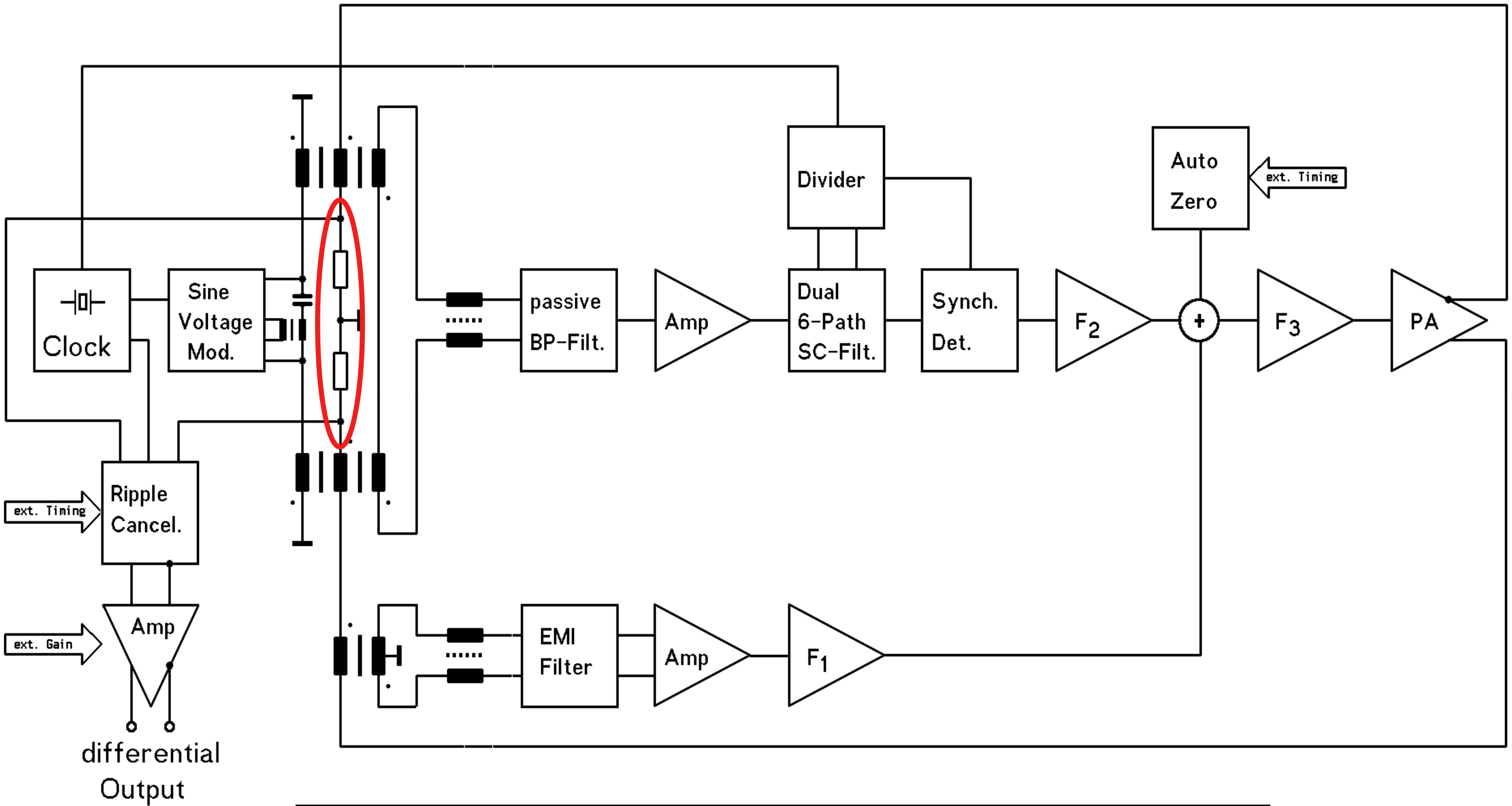


- Sources: CHORDIS, MUCIS, MEVVA, (ECR)
- max. A/z: 65
- injection energy: 2.2 keV/u
- RF: 36.1/108.4 MHz
- Energy: 1.4 … 18 MeV/u

- *U* : 50 … 1000 MeV/u
- *Ne*: 50 … 2000 MeV/u
- *p* : 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

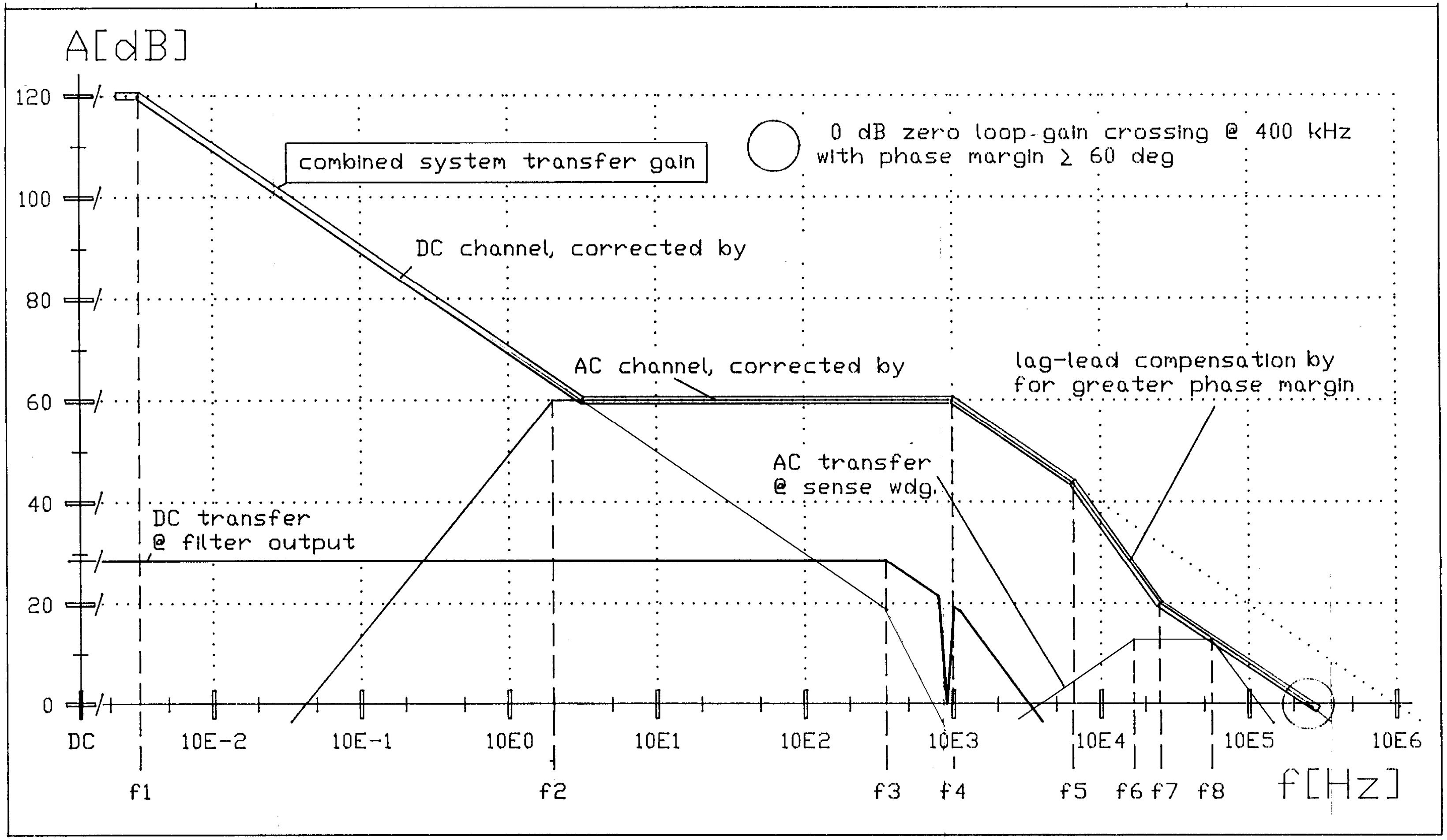
- *U* : 560 MeV/u
- *Ne*: 830 MeV/u
- mag. rigidity: max. 10 Tm
- RF: 0.8 – 5.6 MHz
- mag. Ramp rate: typ. 1 T/s
- orbit length: 108.1 m
- beam currents: single particle .. ~ 10 mA
- max. storage time: ~ min.

DCBCT block diagram, GSI 1986-88



=> U_{diff} ~I_{beam}, 16.66 V/A, dynamic range ≥100 dB

DCBCT open control loop, Bode diagram



DCBCTs: (usual 3-core scheme)

- Dimensions of toroids: 264 x 284 x 10 mm
- Magnetic ribbons: VAC V6025F, transverse-field anneal.
- Windings: N_{comp}=12, N_{DC}=16, N_{AC}=96, N_{mod} =16
- Main control loop: Current output, burden resistor 200 Ω
- Control sub-loops: Peak modulation current & Auto-Zero
- Modulator characteristics: Sine voltage, avalanche capacitor
- Modulator frequency: 987.5 Hz
- Peak modulation field: ~ 20 A/m
- Crossover frequency DC/AC channel: ~ 6 Hz
- Open loop gain @ DC: > 120 dB
- Open-loop 0dB crossing frequency: ~ 1.2 MHz (0.4 Mhz before modification)
- Signal transmission, toroid set to front end: differential, twisted pair lines
- Cable length, toroids to front end: 2.5 m, limited by cable capacitance
- Shunt impedance, min., @ DC: 2 kΩ

DCBCT Specifications

• 8 Ranges:	± 300 µA …1 A DC f. s., (…1...3...10)
• Winding scheme:	crossed-differential, unchanged by range
• Overrange margin @ DC:	~ 20 % f.s.
• Gain error:	≤ 0,1 % (for I <20 mA)
• Linearity error:	≤ 0,1 % (for I <20 mA)
• 1/f corner frequency:	~ 2 Hz
• Temperature coefficient:	~ 5 uA/°C, both SIS and ESR
• Zero error, SIS type:	~ 3.5 μA_{pp}, repetitive Auto-Zero / T, B_{ext} =const.
• Zero error, ESR type:	~ 2 μA_{pp} / T, B_{ext} =const.
• Ripple cancellation, SIS:	AD-MEM-DA chain, reduction ~32 dB
• Ripple cancellation, ESR:	2f - synchroneous sampling at zero-crossing
• Resolution, SIS type:	~ 10 uA_{pp} @ 20 kHz bandwidth
• Resolution, ESR type:	~ 4 uA_{pp} @ 2 kHz bandwidth
• Output bandwidth:	DC - 20 kHz (small signal, 1st order LP)

DCBCT in Heavy Ion Synchrotron (SIS), 1988

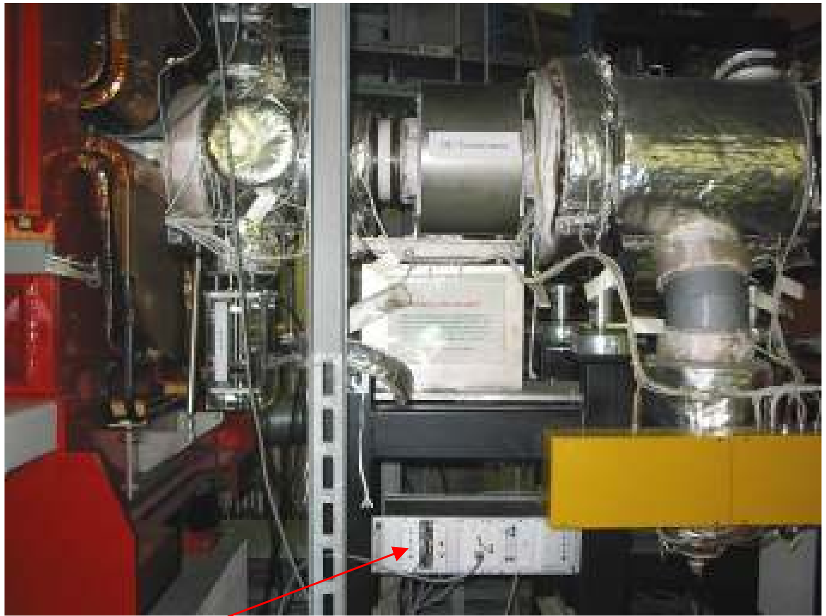
- Aperture: DN200CF, bakeable
- Length: 600mm
- Al_2O_3 gap w. resistive SiO-Cr coating on inner surface
- Mumetal ® magnetic shield, double-layer
- Toroids separated by µMetal shielding rings, reduces cross-talk from mod. field
- 4th toroid added for medium fast transformer

- Instrument entirely designed / constructed at GSI BD lab
- Locally mounted front end electronics
- Remote control / DAQ electronics placed outside tunnel
- upgraded with two V/f-converters:

  fixed range 1 MHz / 60 mA / switched range, 1 MHz f. s.
- Error from dipole stray field corrected by DAQ SW

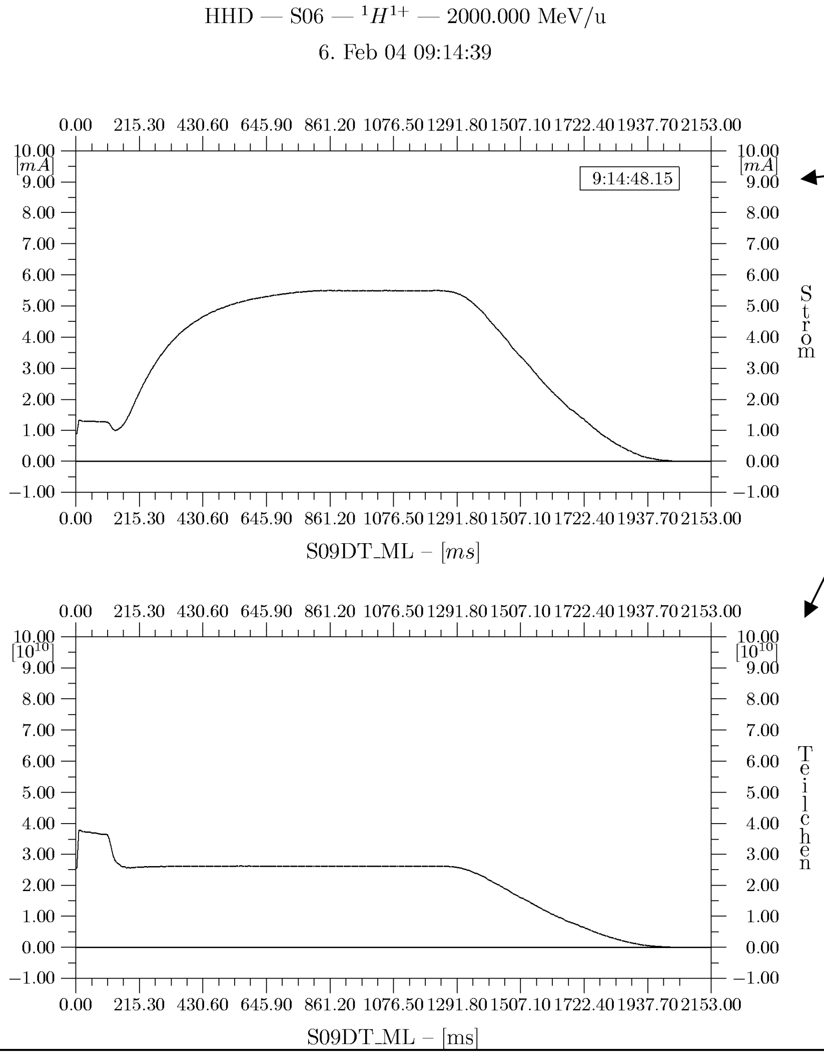
DCBCT in Experimental Storage Ring ESR, 1991

- Modication of SIS type
- Aperture DN200CF, bakeable
- Length: 600mm
- Ceramic gap w. resistive SiO-Cr coating on inner surface
- Mumetal ® magnetic shield, double-layer
- Toroids separated by Mumetal shielding rings reduces cross-talk



- Locally mounted front end electronics
- Remote control / DAQ electronics placed outside accelerator hall
- upgraded with V/f-converter, fixed range 1 MHz / 20 mA
- Error due to Quad's stray field corrected by Hall probe signal fed into BCT‘s feedback amp

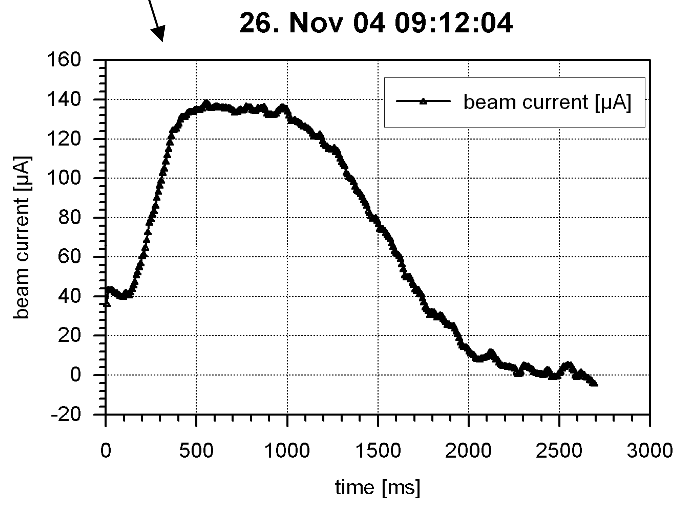
SIS DCBCT, operation at low/medium currents



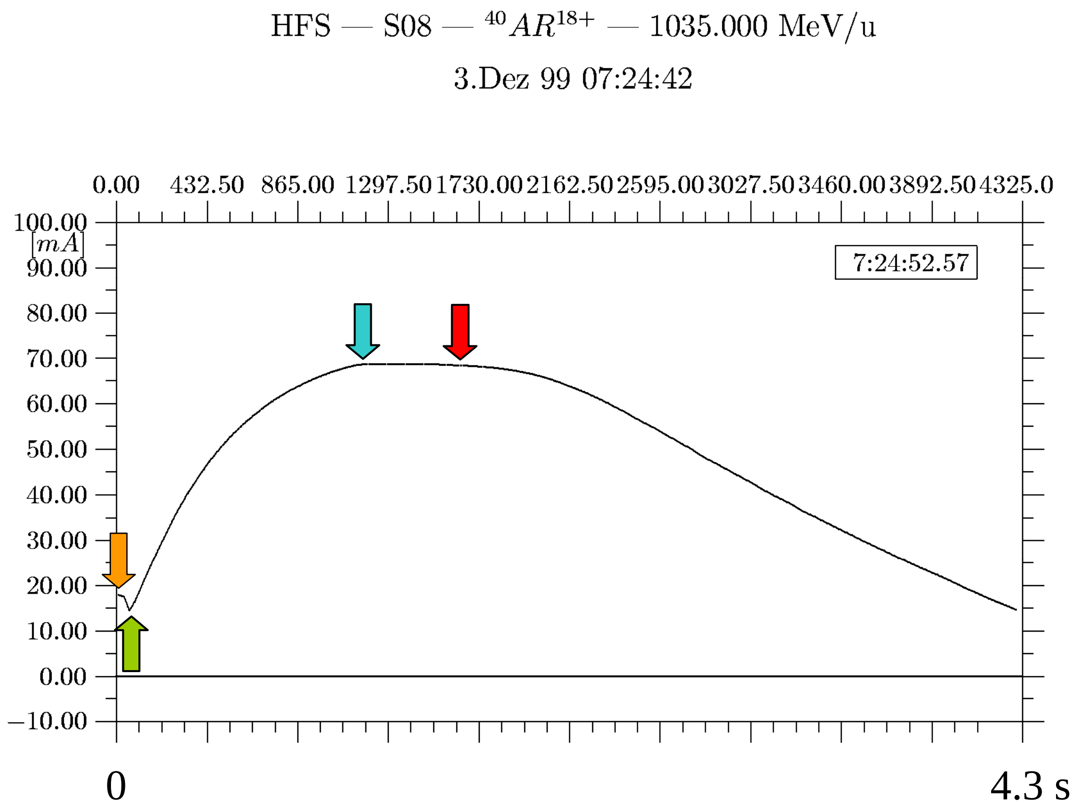
beam current during machine cycle (~ 2 s, resonant extraction)

particles, calculated from RF table

low intensity cycle (~2.5 s), for tumor treatment campaign, $^{12}C^{6+}$, 240 MeV/u; typical (Barkhausen) noise is visible



SIS DCBCT, operation at higher beam intensity

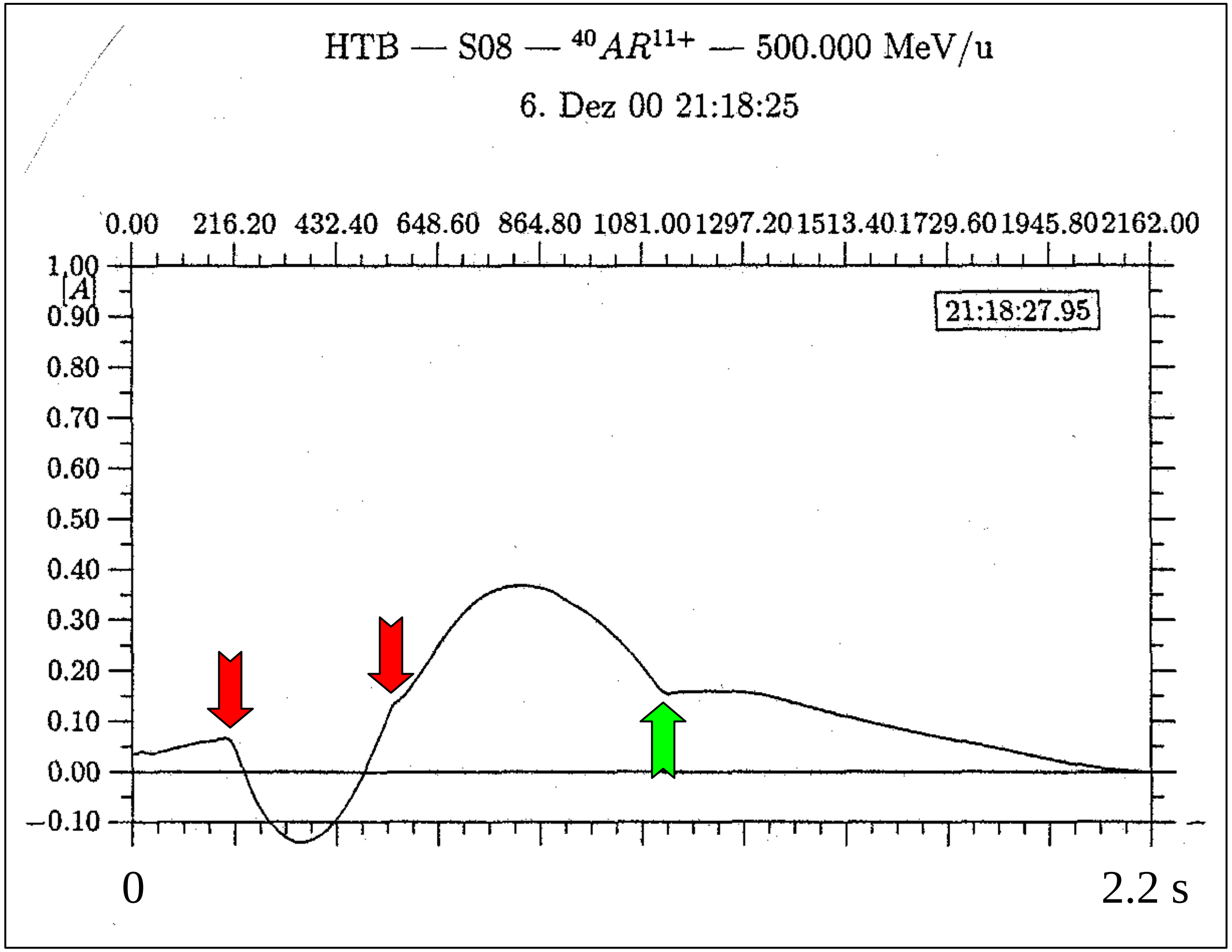


⇩ beam current is measured and no. of particles calculated at 4 (or more) dedicated points; β - normalization done using RF master frequency table

⬇ value at start of extraction is logged gapless, for each shift period (8 h)

... this looks very smooth ...

Carbon copy from the operator‘s logbook:



... ouch !

BCT‘s feedback loop loses contol at certain energy / intensity levels, here ~1.2 MHz / 70 mA. Possible sources:

- common-mode RF voltages on input stages
- max. slew rates inside loop exceeded
- crosstalk of beam current signal harmonics into demodulator / N-path filter ?
- ...?

Updates / Actions taken, 2001

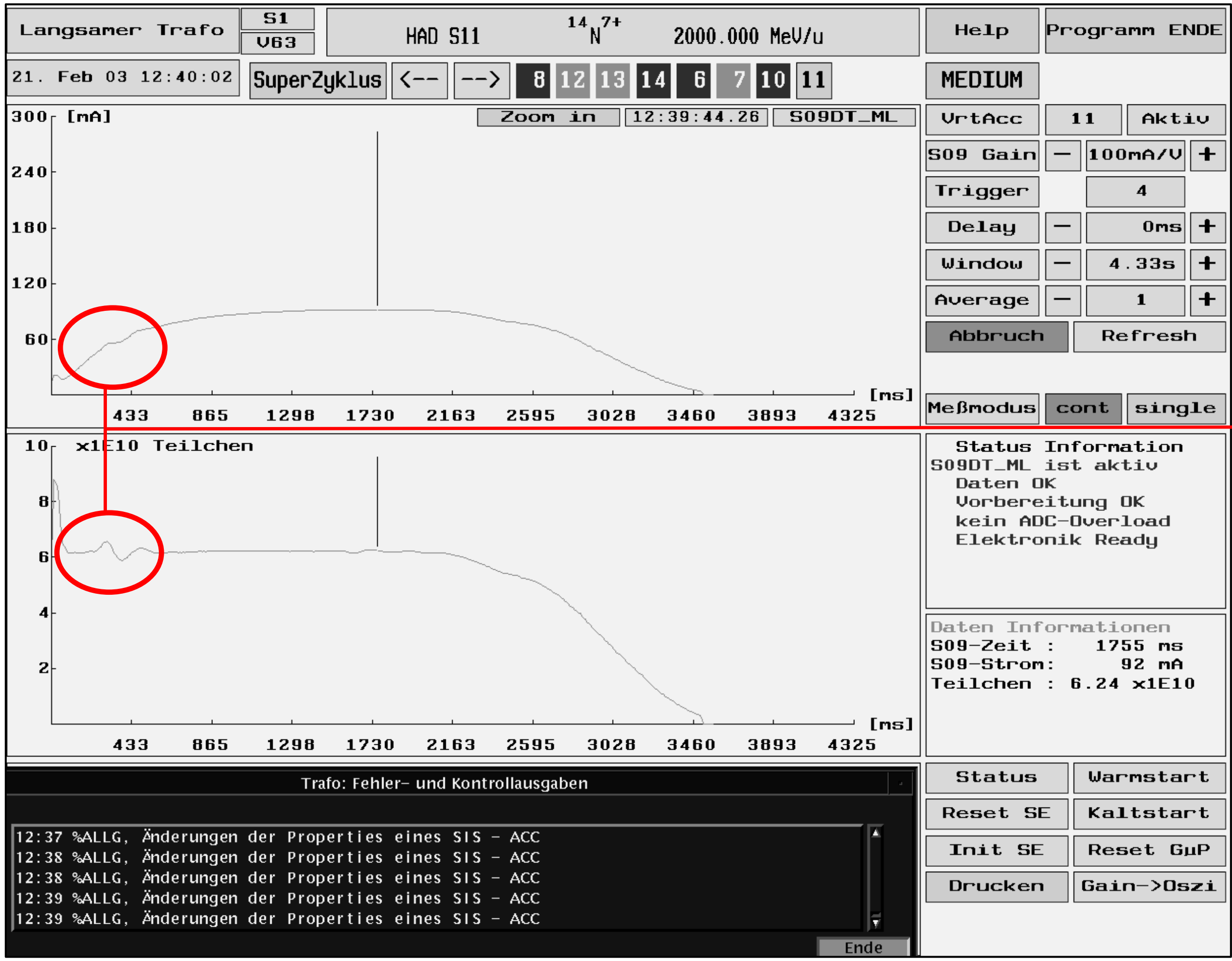
- EMI suppression on sense inputs by RF chokes / transformers, RF filters
- Updated feedback loop amplifier

  - OpAmps and current driver stage with enhanced GBW and slew rate in feedback amp
  - Reworked lag-lead compensation around the loop‘s zero-crossing; 0dB gain crossing point is now ≥ 1 MHz

- Installed local RF bypass loop around entire DCBCT core stack

<u>The installation of a capacitive gap bypass was almost ineffective.</u>

Result still inadequate



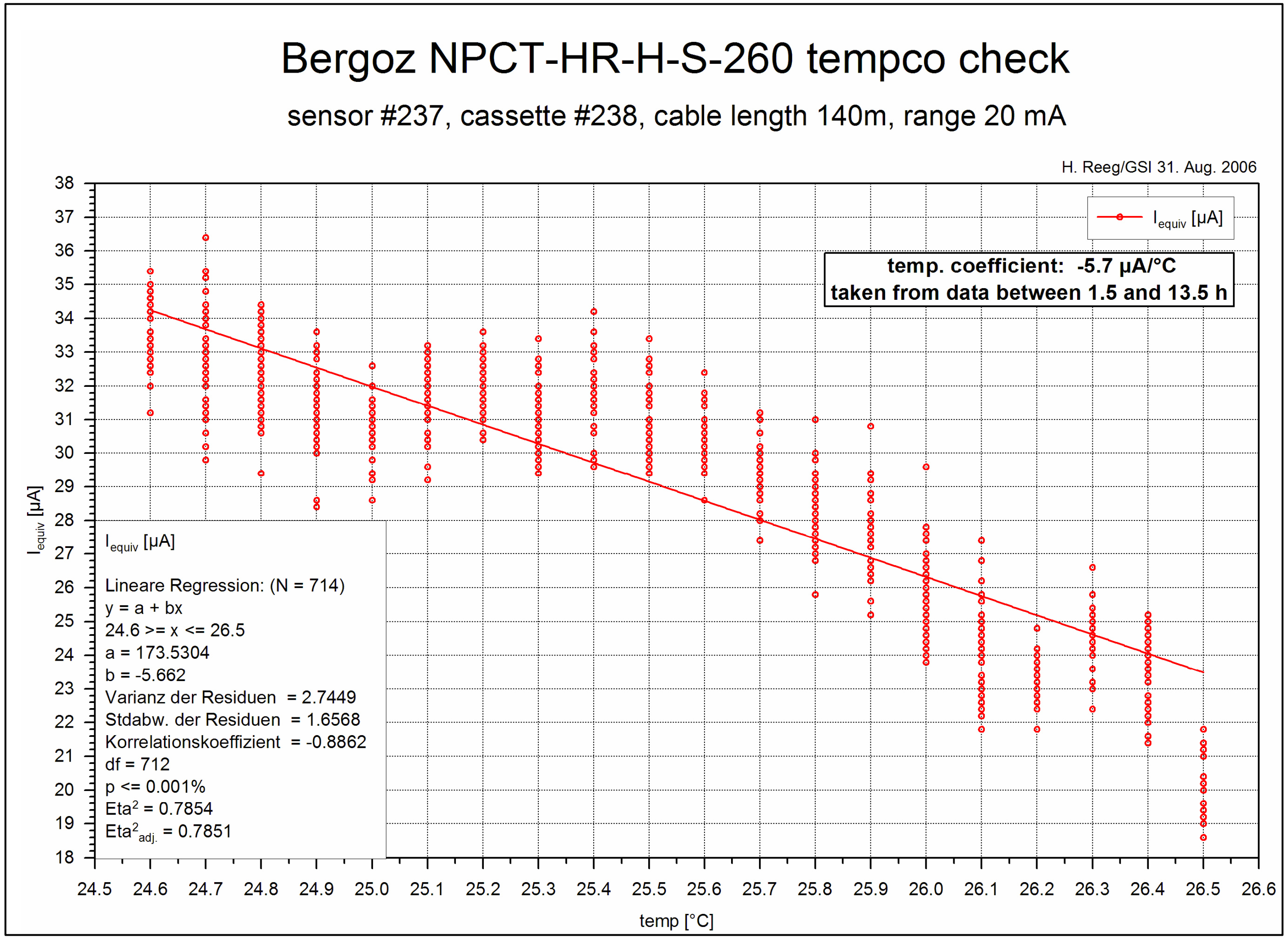
Fortunately data during the ramp are not logged …

„High Intensity“ DCBCT, added in SIS 2006

- Toroid: Bergoz NPCT-260 (I_{max} = 20A)
- Aperture: DN200CF, bakeable
- Length: 600mm
- Front end electronics now placed outside tunnel, as well as remote control / DAQ electronics

- Ceramic gap w. Ti coating on inner surface, improved wall gap and RF bypass design
- Armco ® soft iron magnetic shield

NPCT, offset temperature coefficient



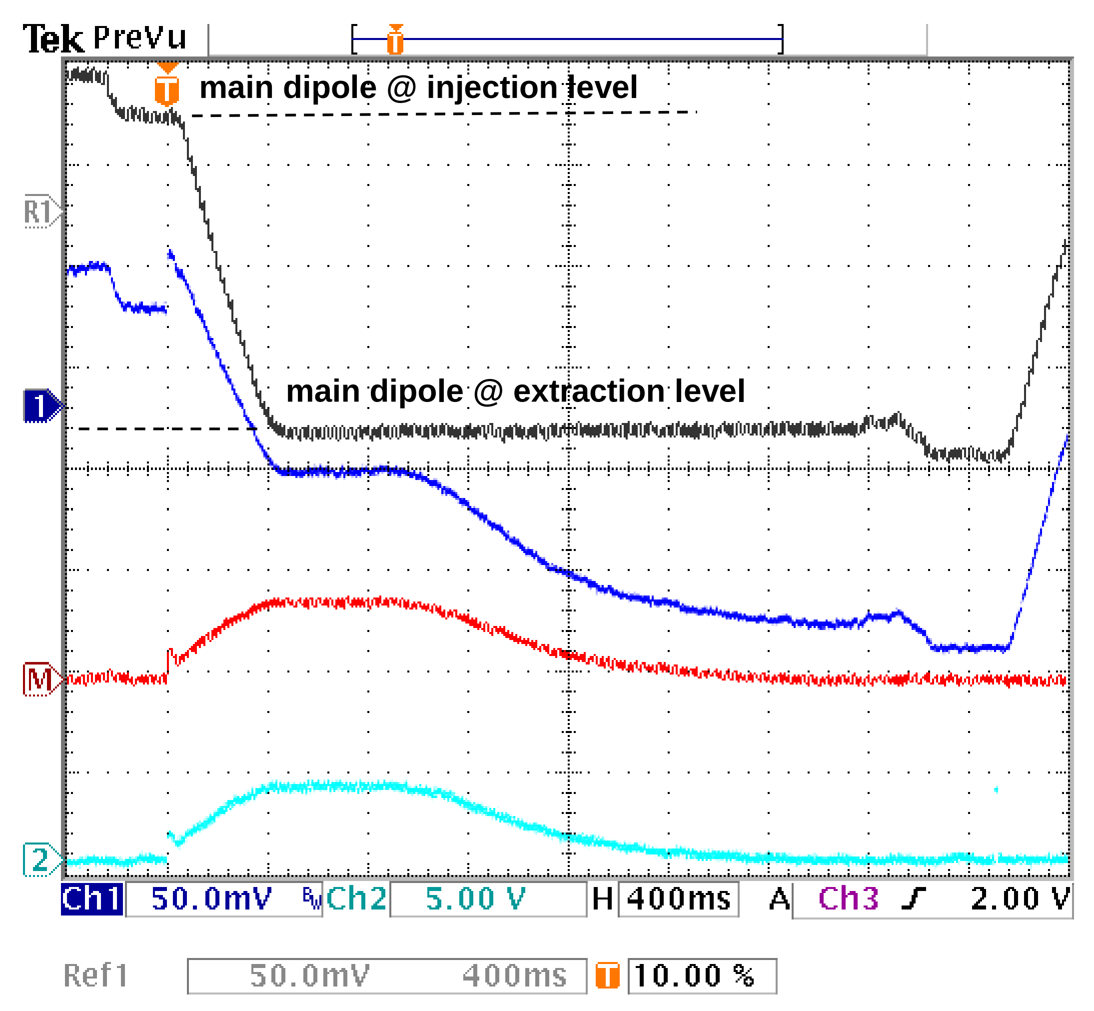
Info:

thermometer resolution was 0.1℃, hence offset voltages at each temp. were averaged, then fit line was calculated

Notable:

coefficient is well below catalogue value !

NPCT, influence of main dipole's stray field



I_{max} ~ 100 µA, $^{12}C^{6+}$, 350 MeV/u

T: injection into SIS @ 11.4 Mev/u

Ref1: NPCT (in period 7), w/o beam; the inverse dipole ramp is clearly visible

Ch1: NPCT (Period 7), with beam in SIS

Mem: (CH1 – Ref1) = true beam current

Ch2: GSI DCBCT (Period 9), DAQ input signal

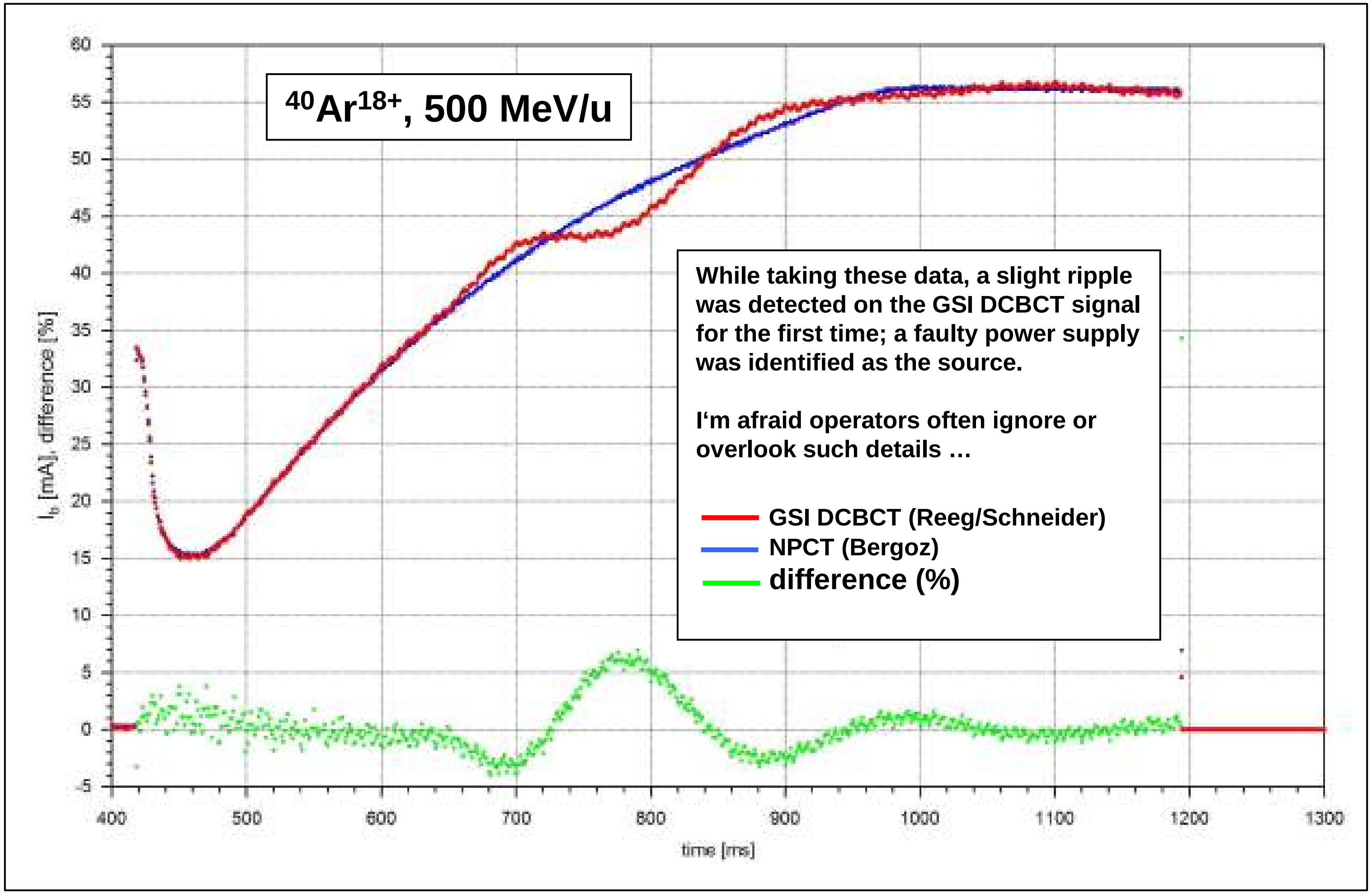
Conclusion:

the dipole field has a (nearly) linear influence, roughly 250 µA/Tesla, so it follows:

- install NPCT far off ramping magnets
- provide excellent mag. Shielding
- for best data correction a 3rd order polynome must be used at least

Remark: GSI DCBCT shows only ~5 µA/T

Comparison of SIS DCBCT signals

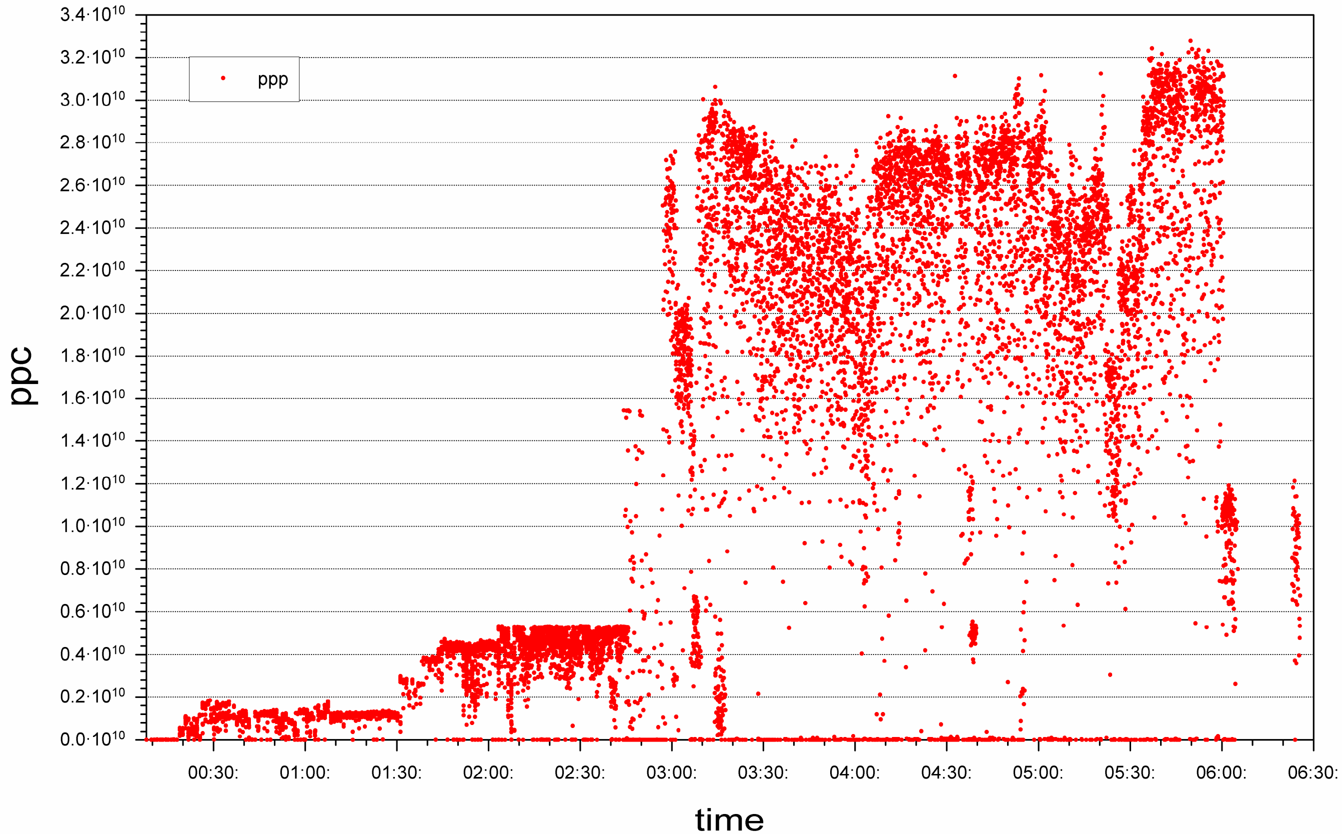


Ongoing: Logfiles reveal HW- and SW errors

SIS $^{238}U^{28+}$, different end energies

no. of particles / cycle just before extraktion to exp.

Oct. 18./19., 2010



- **1:40 .. 2:50**

  graph cropped due do faulty BCT amplifier (discrete range only)

- **2:50 .. 6:00**

  SIS-operator set to higher energy / β and BCT range down 1 step – but particle calculation uses the old β value:

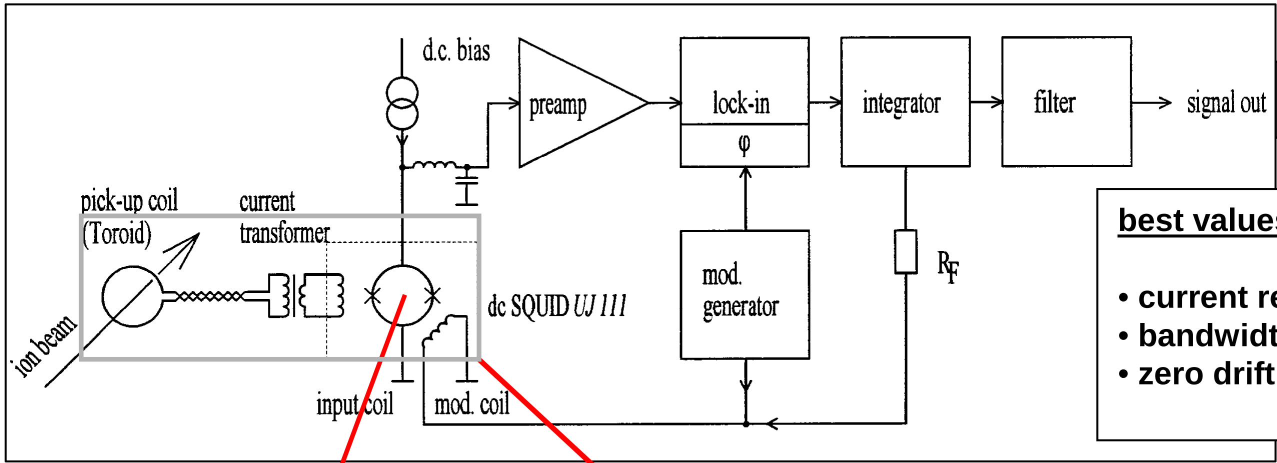
World Record for $^{238}U^{28+}$ intensity ?

- **6:00 ..**

  Machine control software synchronizes data / devices at begin of new shift – now no. of particles is correct due to rectified β setting:

World Record lost !

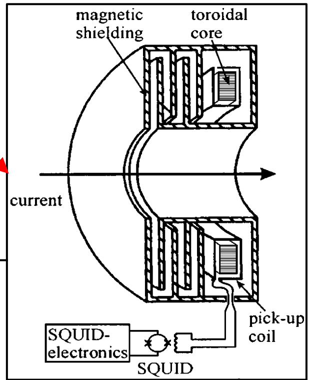
CCC - a cryogenic DC beam current transformer

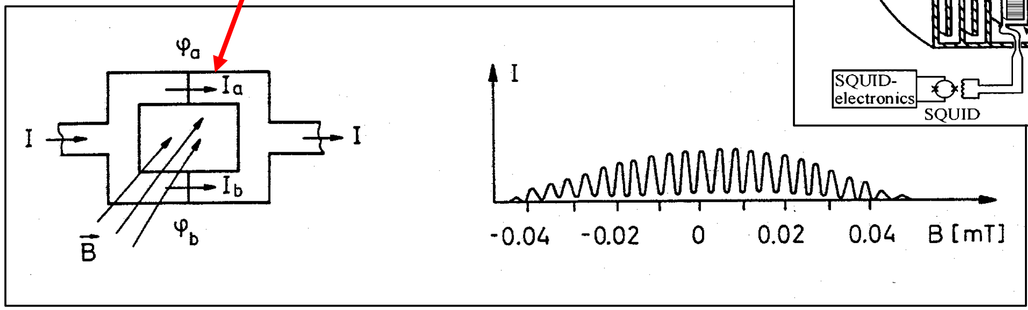


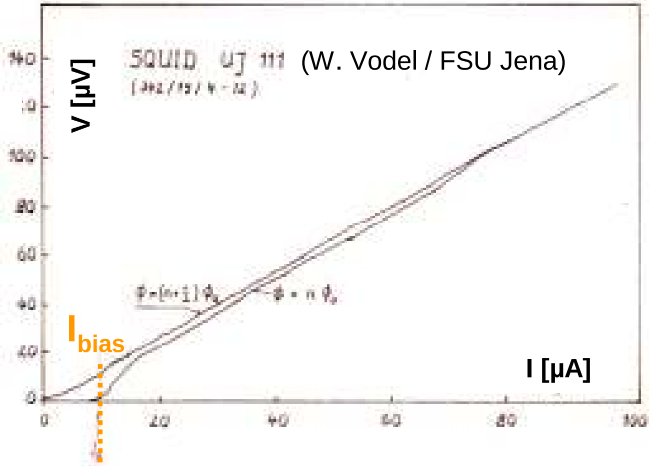
~ 14 mV / nA

best values reached so far (DESY CCC):

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

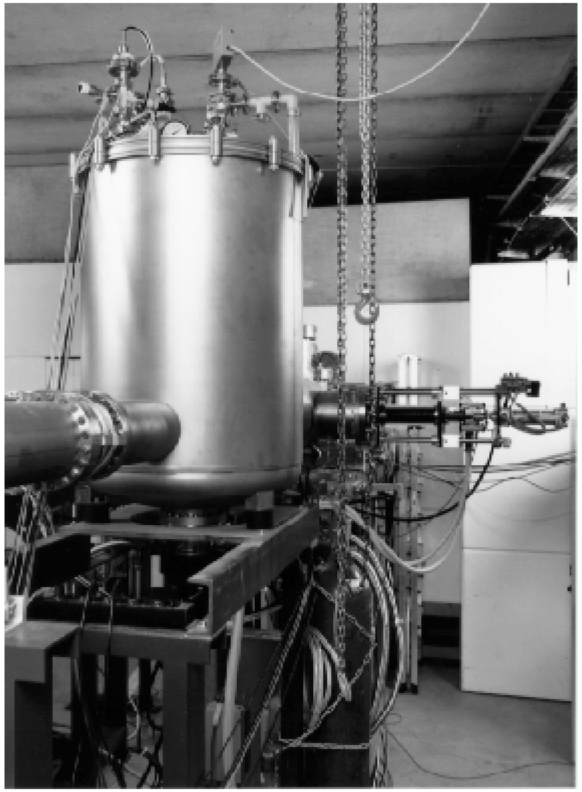






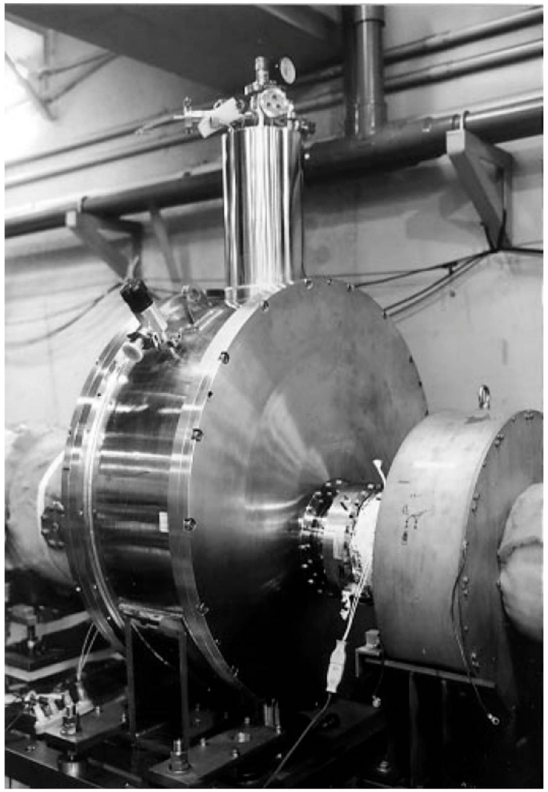
CCCs in Accelerators:

GSI (D)



A. Peters e. a., 1993 - 96

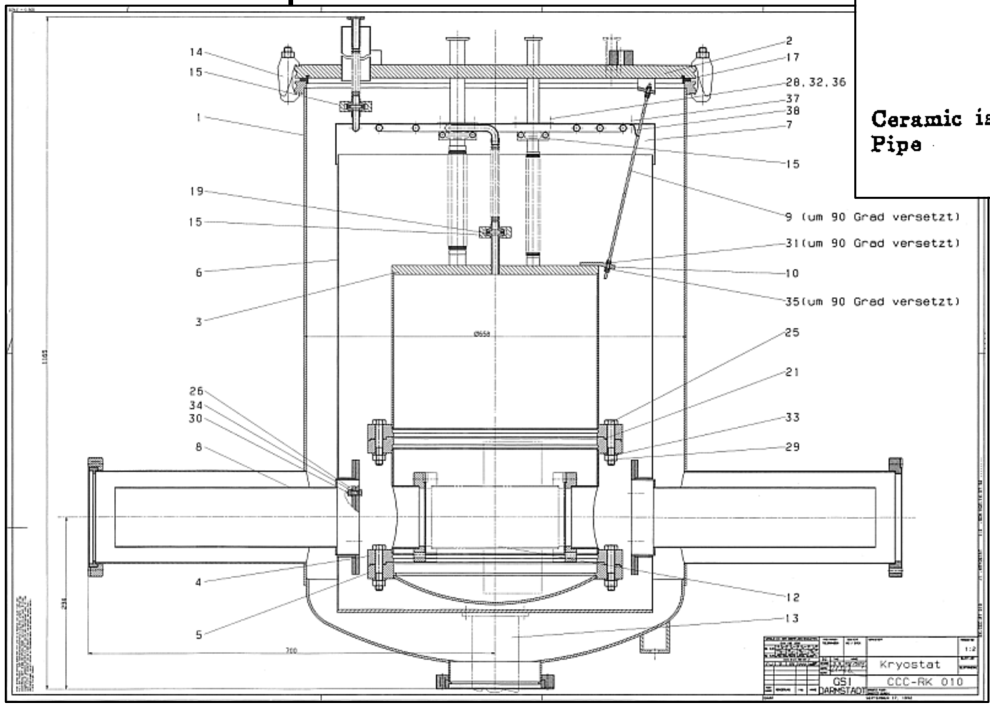
TARN2 (J)

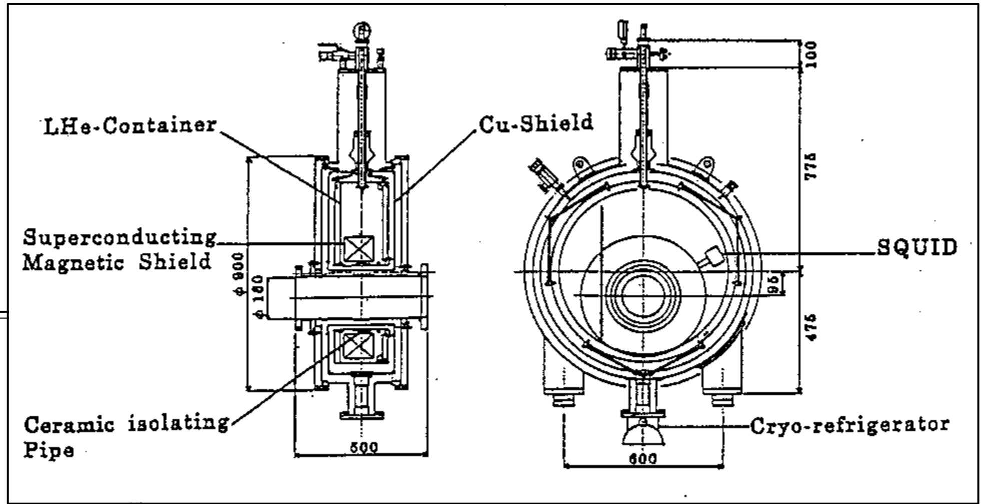


T. Tanabe e. a., 1996 - 98?

Important parameters of CCCs:

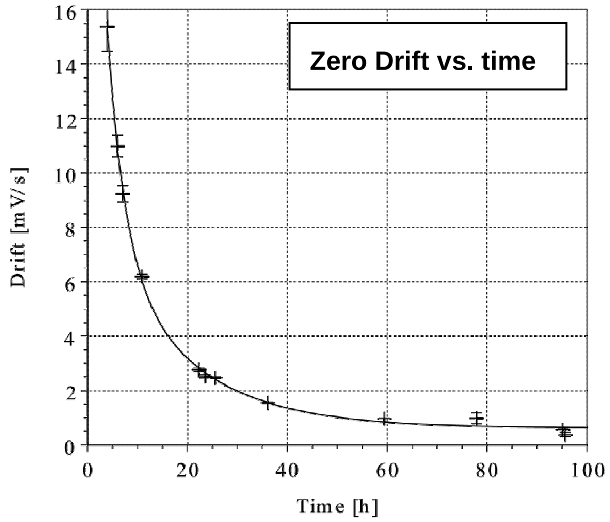
- Aperture: 100 mm
- Height: ~ 1.1 m
- Lenght: ~ 1.4 m
- Thermal loss: ~ 170 mW
- L-He content: ~ 20 l
- L-He consumption: ~ 5 l/day

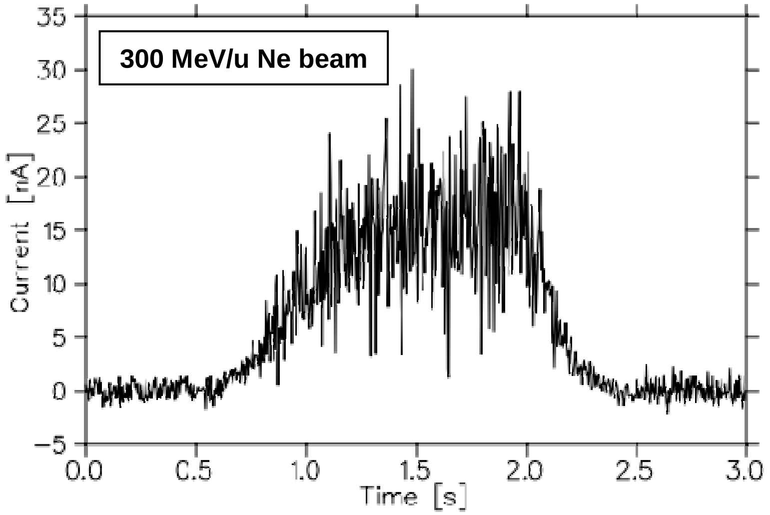


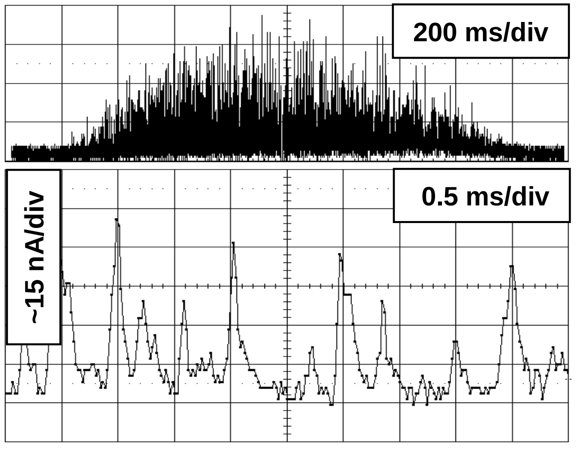


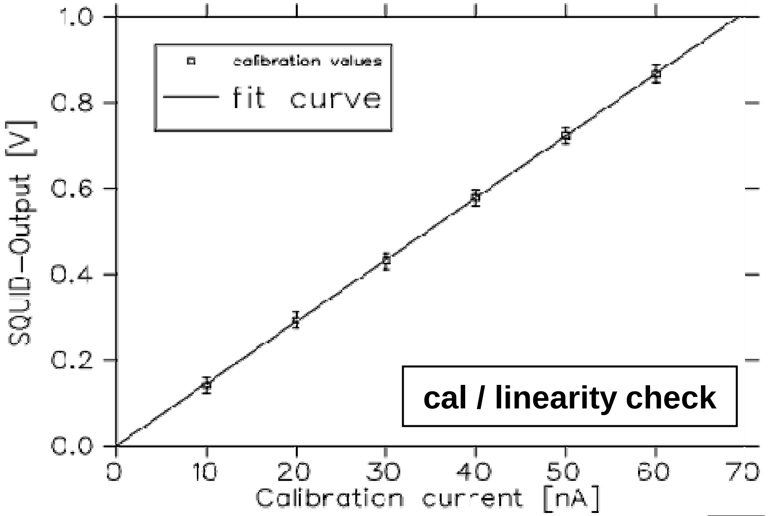
- Aperture: 100 mm
- Height: ~ 1.3 m
- Lenght: ~ 0.5 m
- Thermal loss: ~ 290 mW
- L-He content: ~ 15 l
- L-He consuption: ~ 9 l/day

Results from the GSI CCC:



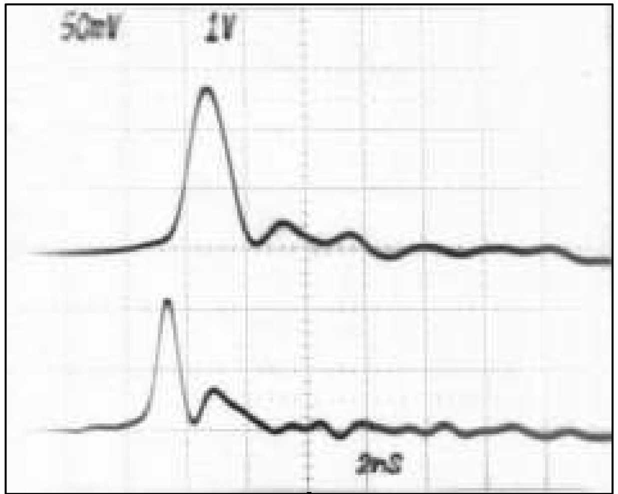






- Break -

Addendum: FBCTs at GSI

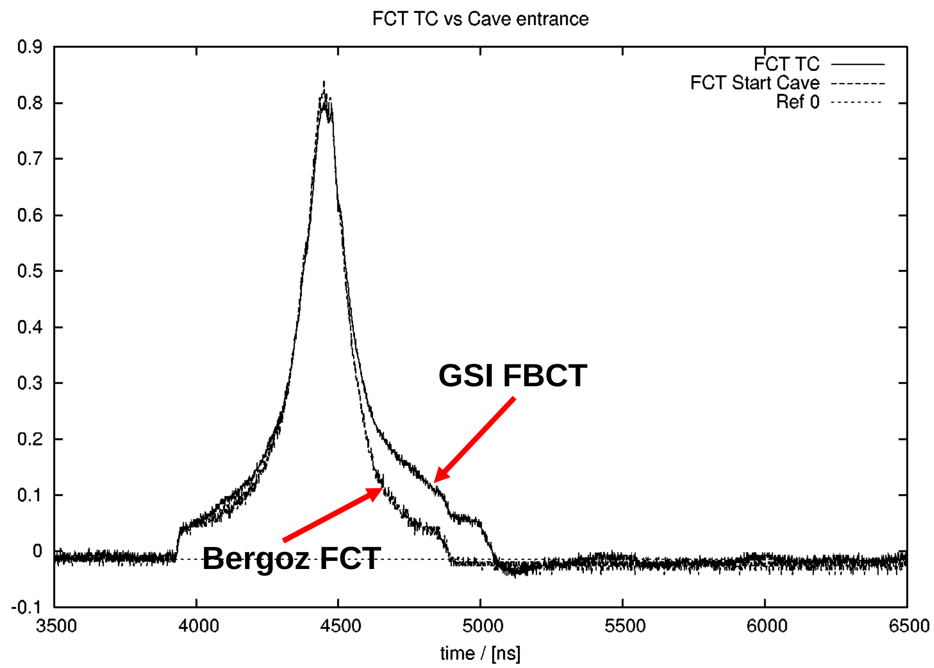


Pulse response of GSI FBCT toroid, used in the SIS extraction line and experiment caves; (V6025F core with 10 - turn transmission line winding)

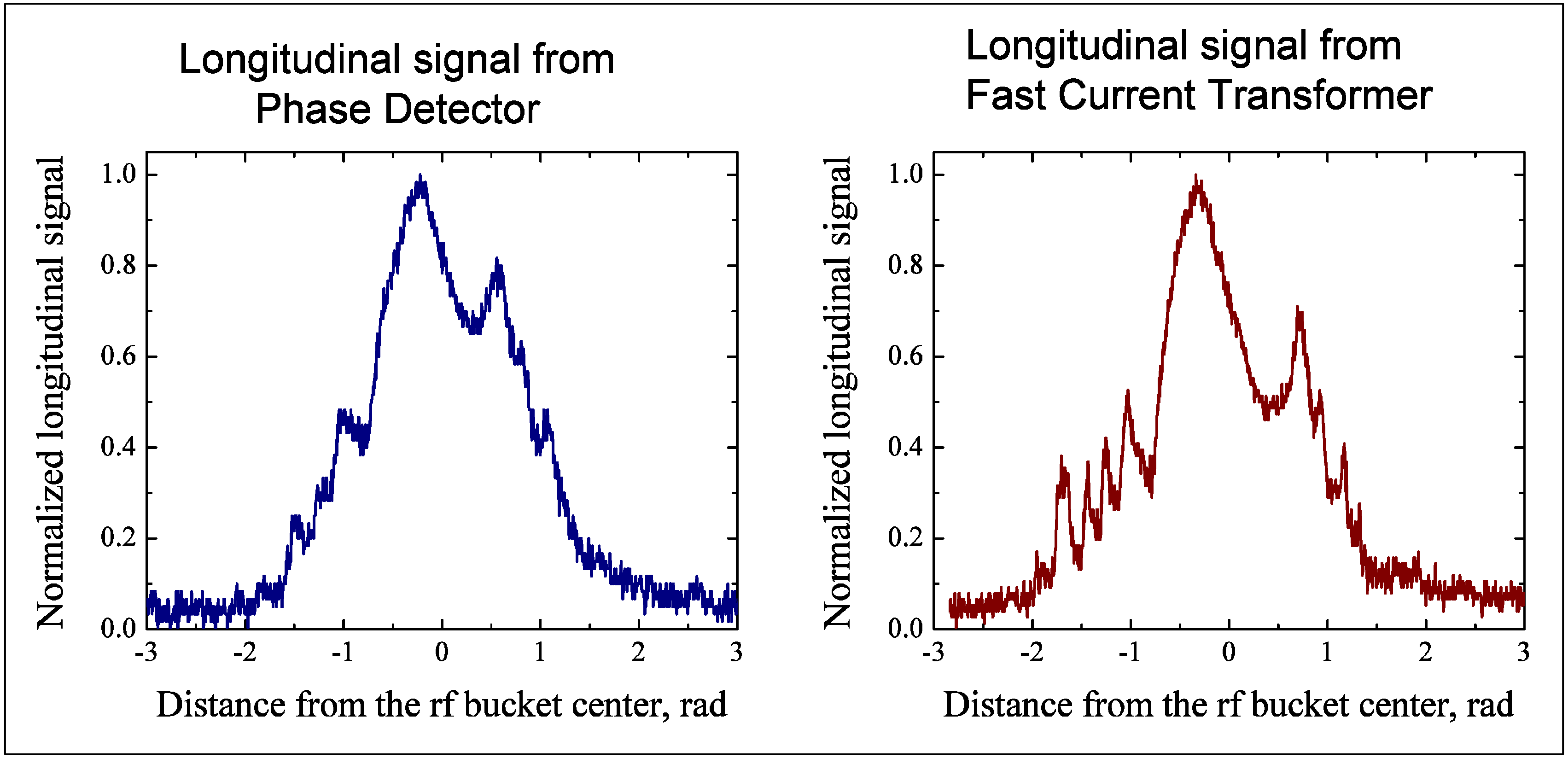
- Bottom trace: input
- Top trace: output

Sensitivity: 4.2 mV/mA into 50 Ω

Comparison of GSI and Bergoz FBCT signals; data from Alexander Hug, Plasma Physics Exp. (HHT)



SIS: Raw data from the Bergoz FBCT

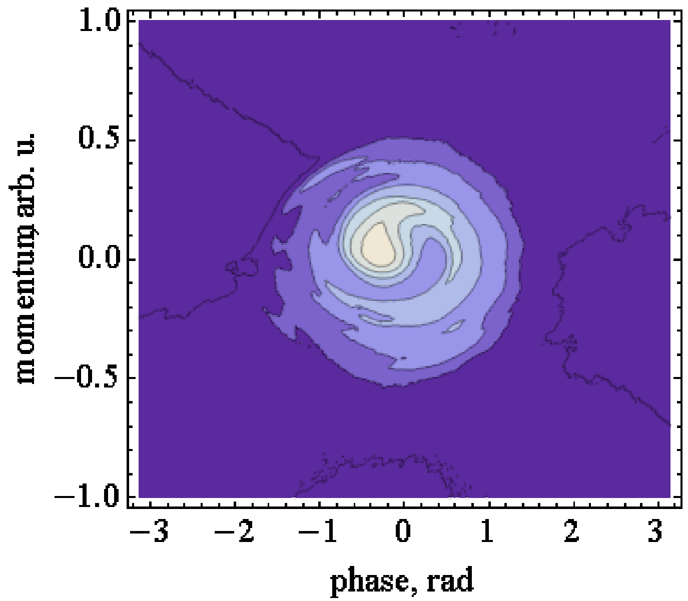


FBCT signal was amplified by 20 dB (miteq AM-1422) and digitized a 500 Ms/s ADC via ~100m HQ coax cable
No further signal processing is foreseen, but signal fidelity will be improved by optical fiber transmission.

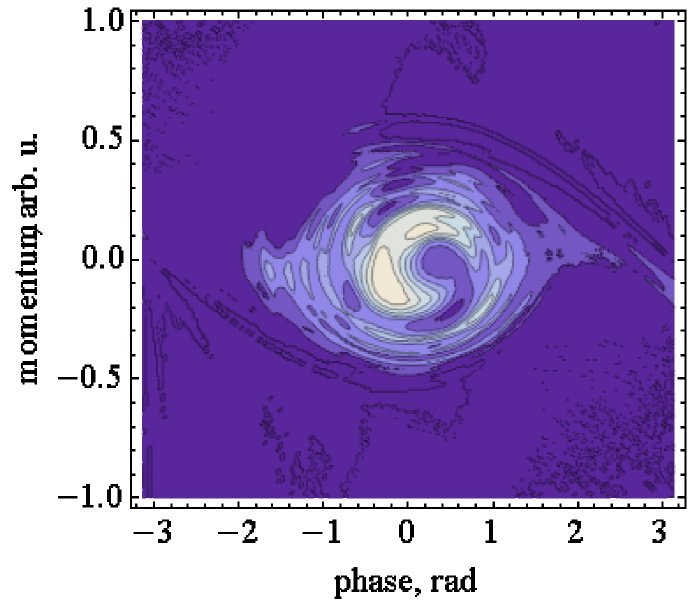
Ref.: **Chorniy, O. - RF Manipulations in SIS18 and SIS100 - , GSI 2010**

SIS: Bunch tomography with FBCT

Using longitudinal signal from Phase Detector



Using longitudinal signal from Fast Current Transformer



! Improved phase space density resolution.
More exact value of the rms emittance

Ref.: Chorniy, O. - RF Manipulations in SIS18 and SIS100 - , GSI 2010