# Beam Diagnostic Developments for FAIR*

M. Schwickert, P. Forck, P. Kowina, T. Giacomini H. Reeg, A. Schlörit

GSI Beam Diagnostics Department

- GSI and the FAIR Project
- Challenges for Diagnostics
- Current Measurement (Beam Current Transformer)
- Position Measurement (Beam Position Monitor)
- Profile Measurement (Ionization Profile Monitor)
- Summary

* work partly funded by EU-FP6 DIRAC Secondary Beams

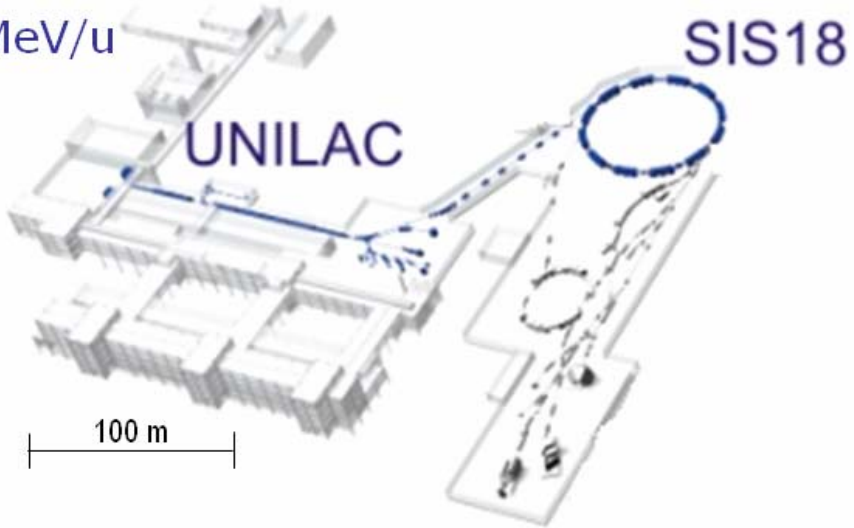
# GSI and the FAIR Project

Existing GSI facility:
**UNILAC** & **SIS18** as injectors

**UNILAC:**

Length: 120 m

Energy: 11 MeV/u




**SIS18:**

Circumference: 216 m

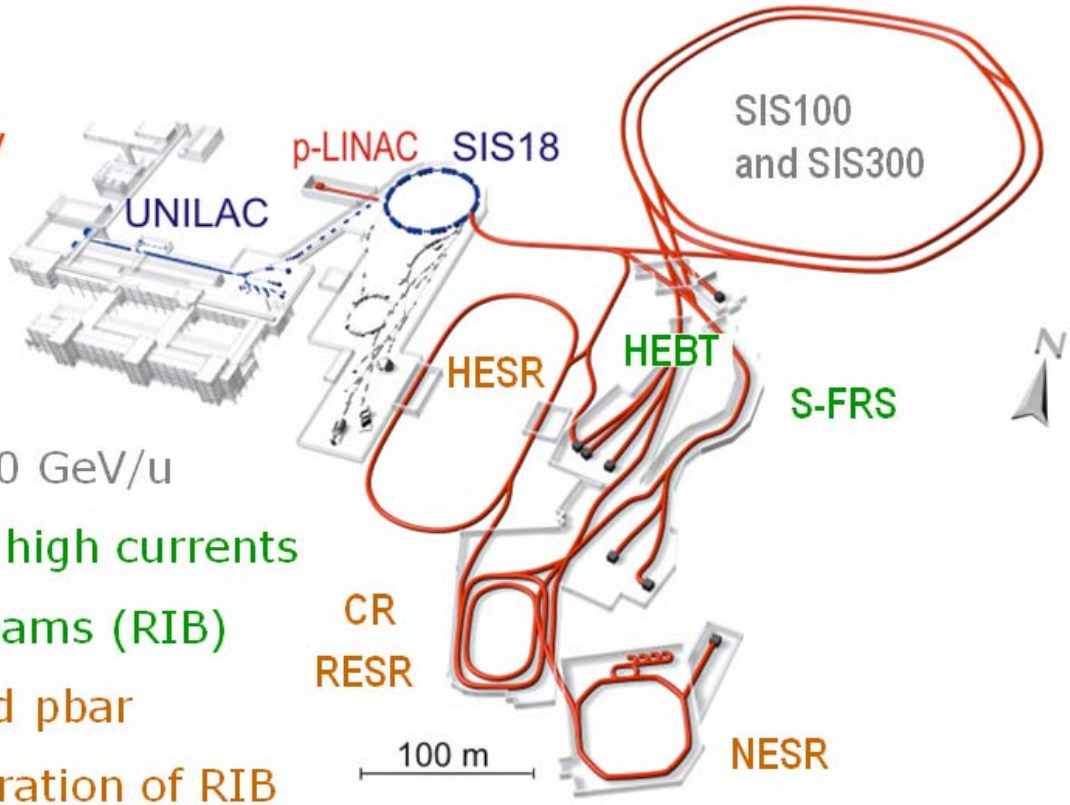
Energy up to 2 GeV/u

**acceleration of all ion species (protons to uranium)**

# GSI and the FAIR Project

Existing GSI facility:
**UNILAC** & **SIS18** as injectors

## FAIR: Facility for Antiproton and Ion Research




**p-LINAC:** high current 70 mA, 70 MeV

**SIS100:** Superconducting, 100 Tm, 1-29 GeV/u, **high current operation p to U**
p: 2.5 $10^{13}$, $U^{28+}$: 5 $10^{11}$ /pulse

**SIS300:** 300 Tm, acceleration up to 30 GeV/u

**HEBT:** fast & slow extraction, low & high currents

**S-FRS:** production of rare-isotope beams (RIB)

**CR:** stochastic **cooling** of RIB and pbar

**RESR:** accumulation of pbar, deceleration of RIB

**NESR:** versatile experimental ring for stable ions, RIB, pbar cooling, gas-target, e-A collider

**HESR:** storage and acceleration of pbar to 15 GeV/u

# Challenges for Beam Diagnostics

## Current

### SIS100

- bunch length: 25 ns - 8 µs
- beam current: $5 \times 10^{11}$ $U^{28+}$/pulse, $2.5 \times 10^{13}$ p/pulse

→ up to 10 A bunch current

- bunch frequency: 0.5 - 2.7 MHz

→ critical for DC Current Transformer

### HEBT

- **low** and high intensities ($10^4$-$10^{13}$ /pulse)
- **slow** and fast extraction (µs – s)

→ high resolution required

## Position

### SIS100

- bunch length: 25 ns - 8 µs

→ high dynamics, amplification / attenuation

- RF 'gymnastics' (barrier bucket, bunch compression system)

→ sophisticated data acquisition as feedback source

## Profile

### SIS100

- bunch frequency: 0.5 - 2.7 MHz
- acceptance = 3 × beam width σ

→ turn-by-turn profile detection on µs timescale

- beam current: $5 \times 10^{11}$ $U^{28+}$/pulse, $2.5 \times 10^{13}$ p/pulse
- space charge effects

→ online emittance control, injection matching

# Current Measurement at SIS100

## Role

- **Precise current determination** of stored and accelerated beam
- **Beam lifetime** determination and coarse **beam loss** measurement

## Requirements

- dynamic range of 10 µA – 20 A for typical beam parameters
- bandwidth of 10 kHz to measure beam lifetime
- beam loss: acquisition on ms timescale

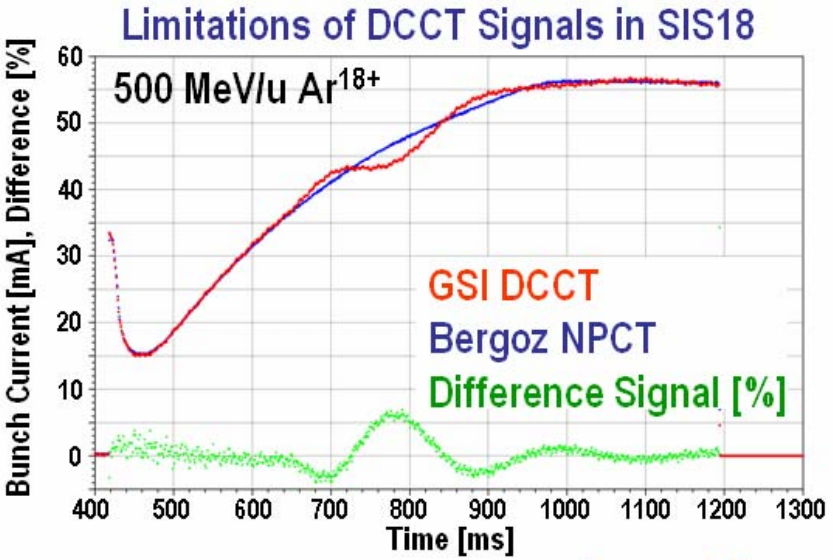
Feasible with GSI standard DCCT

## Critical

- SIS100: High current bunched beams with MHz repetition rate

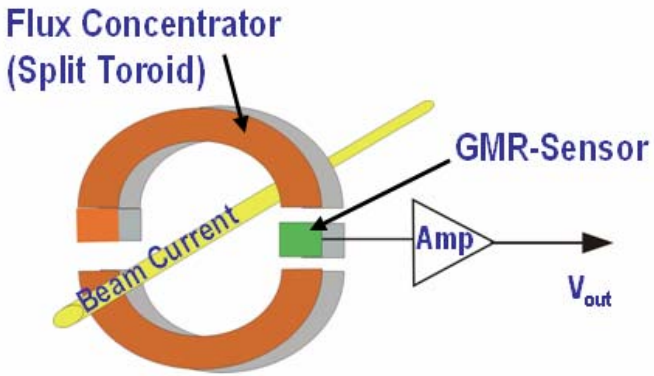
**signal of standard DCCT disturbed due to internal resonance**

- BUT: accuracy of few percent needed for beam current measurement



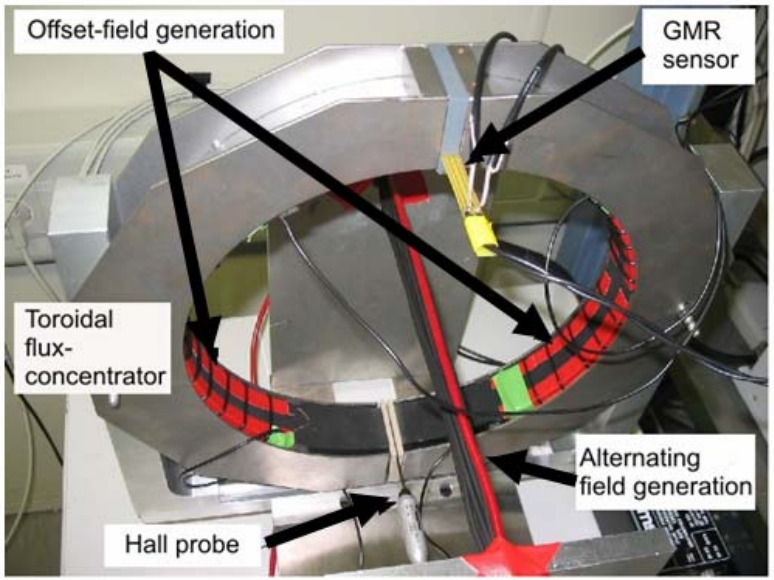
# Beam Current Measurement – Novel DCCT

## Measurement Principle

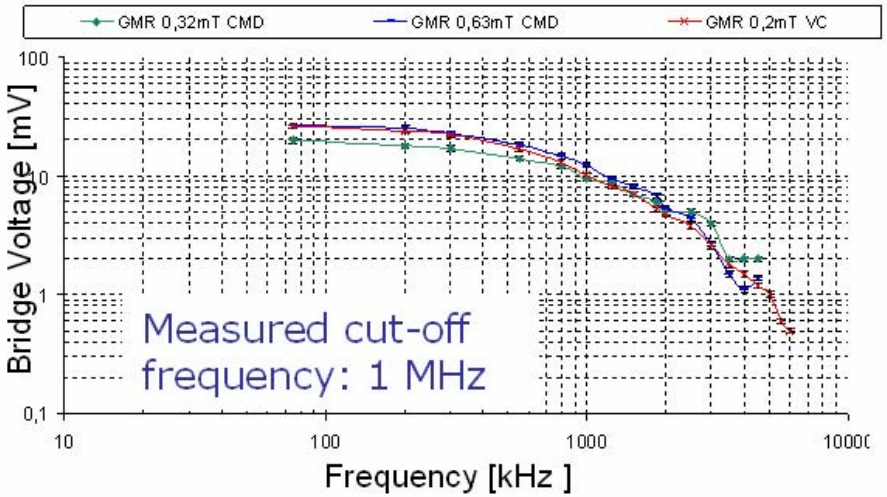



- idea: **clip-on Amperemeter** design
- **split toroid** to allow **dismounting** before bake-out
- soft-magnetic **flux concentrator** (amorph. VITROVAC®)
- **gap** with induction of 80 µT @ 1 A beam current
- **sensitive GMR** (Giant Magneto Resistance) magnetic field sensor (resolution: $10^{-9}$ T/√Hz) → used for harddisks

## Test Setup




## Frequency Response (GMR+Pre-amp)

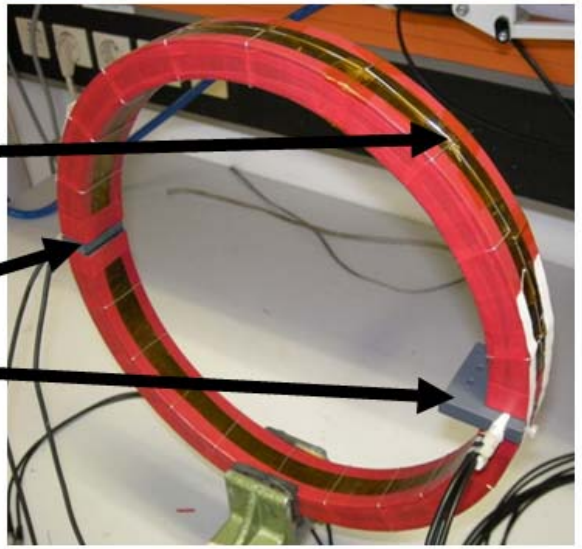



- Reasons: induced voltages in sensor material, eddy currents in NiFe-layer

# 2nd Iteration: Combined ACT-DCCT-System

## NDCCT Version 2.0

- add single ACT-winding to core
- add high-pass filtered ACT-branch to electronics
- use 2 GMR sensors (1 sensor per gap)



**New:** dc and ac measurement on single core!

## Pulse Response (Combined System)


## Improvements

- For S/N=2: 88 nV/√Hz
- calculated resolution threshold: **220 µA**
- Bandwidth: $\frac{0.35}{t_{rise}} = f_{CO} \approx 13\ MHz$

## Ongoing R&D

- design & layout of readout electronics
- investigation of NDCCT rf- characteristics

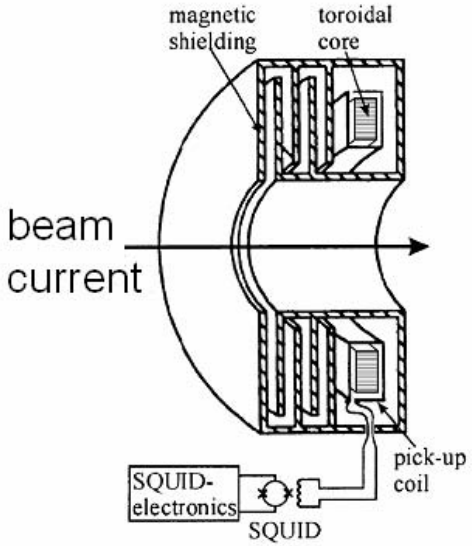
# Cryogenic Current Comparator CCC (HEBT)

## Role in HEBT Section

- online current monitoring for **slow extracted beams**
- beam current **below threshold of regular transformers**

→ **WEOA02 by T. Sieber, MPI-K**

## Measurement Principle



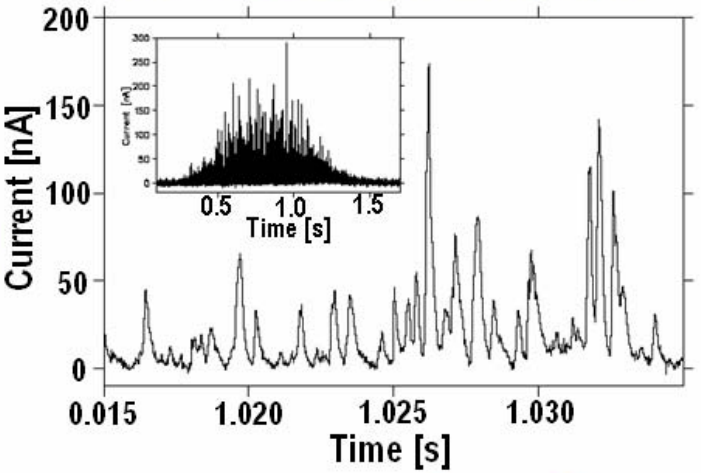

- high-resolution detection of the **beam's magnetic field**
- **superconducting pick-up coil** with ferromagnetic core
- **SQUID** for sensitive detection of coil magnetic field
- collaboration: Univ. Jena, MPI-K Heidelberg, HIT Heidelberg, GSI
- resolution improvement by optimal **selection of core material**

- GSI prototype resolution:

**8 nA (1 kHz readout) → $2\times10^9$ $U^{28+}$/s**

GSI prototype in 1997:

$7\times10^9$ $Ar^{11+}$ at 300 MeV/u within 1.2 s, readout 20 µs:



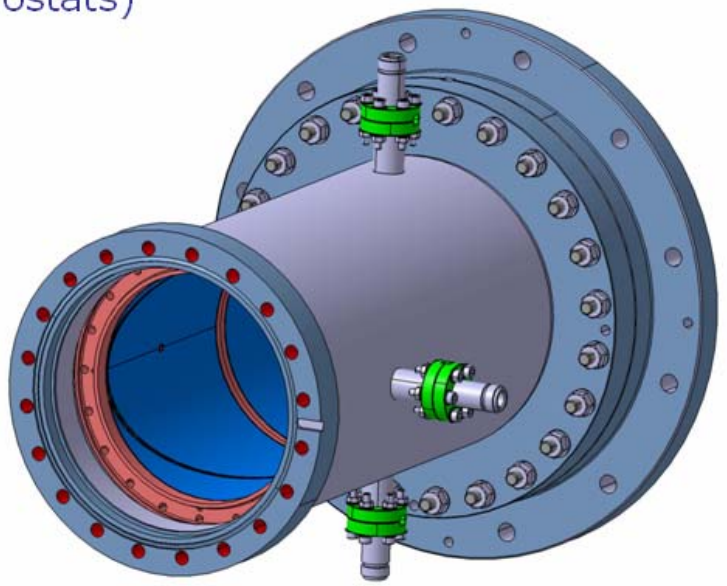
# Beam Position Monitors (BPM) for SIS100

## Role

- **precise beam position measurement** in SIS 100
- closed orbit control during **RF manipulations** (bunch compression, acceleration)
- use of position data for **closed orbit feedback**

## Requirements

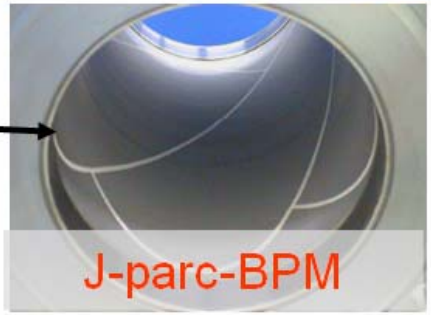
- all BPMs installed in **cryogenic regions** (quadrupole cryostats)
- **large dynamic range** (**1 µV < $U_{plate}$ < 1.8 kV**)
- **linear-cut type BPM** preferred, because:
  - bunch length >> BPM length
  - relatively low bunch frequency: **0.5-2.7 MHz**
  - linear response even for transversally large beams
- **mechanical reproducibility** of **~50 µm**
  required for 0.1 mm accuracy
- flat response in **frequency range 0.1-100 MHz**
- all components suitable for **XHV conditions** (< $10^{-11}$ mbar)

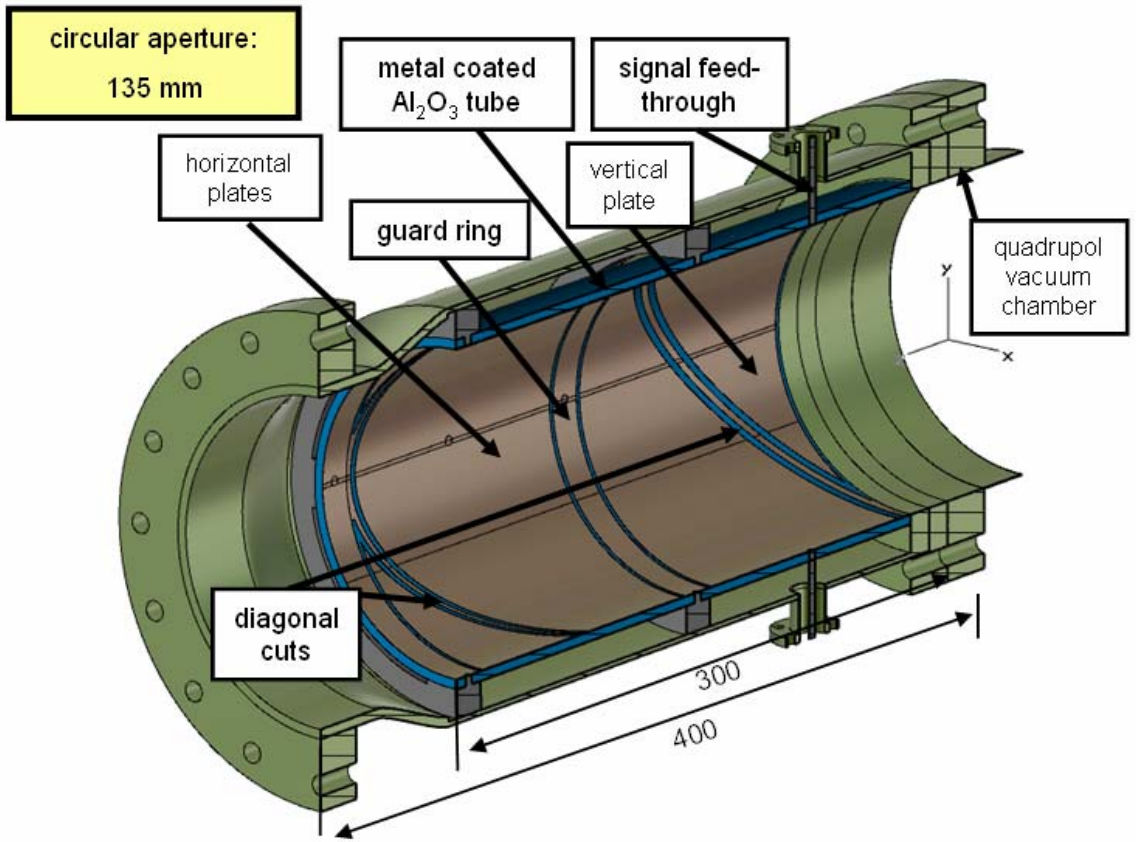


# BPM Mechanical Design

## Technical Design

- pick-up material: metal-coated $Al_2O_3$
- cylindrical ceramics structure



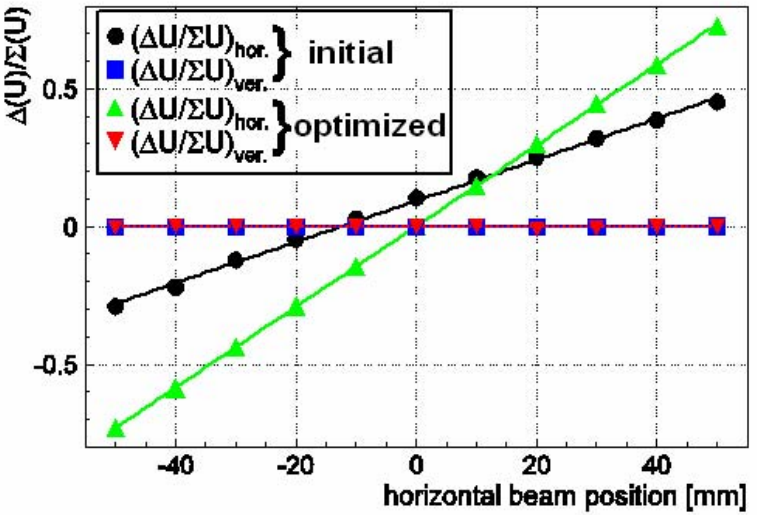




## FEM-Simulations:

- increase sensitivity
- reduce plate-to-plate crosstalk
- reduce offsets
- suppress fringe fields

→ MOOC03 by P. Kowina, GSI

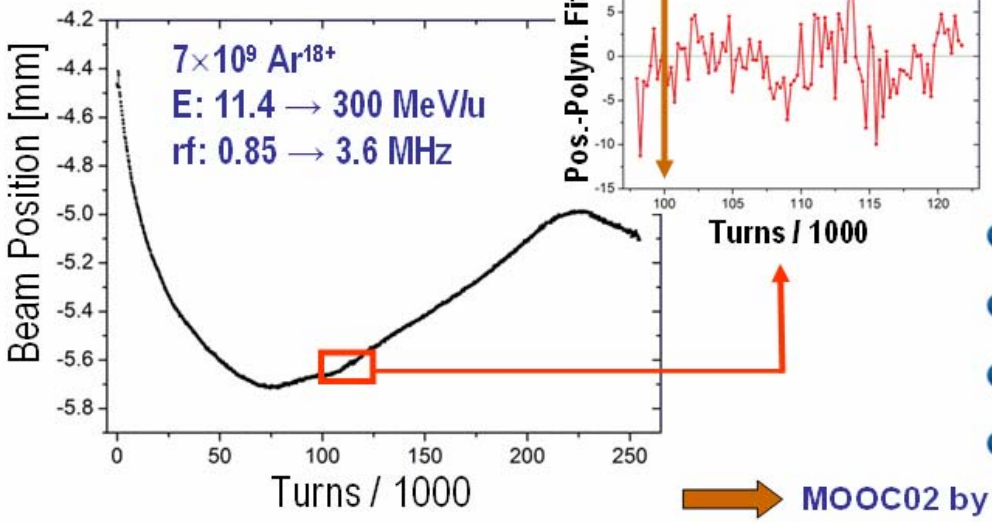
## Simulation Results:



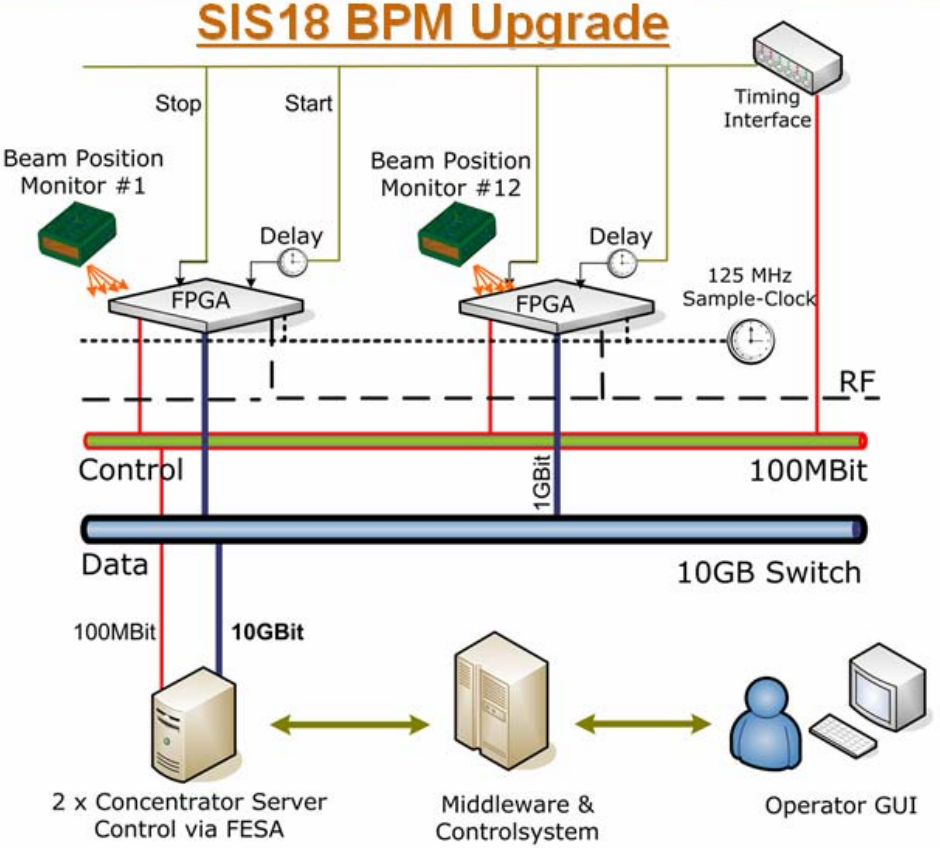
# BPM Data Acquisition

## Direct Baseband Digitization

- digitization: 4 ADCs, **125 MSa/s**, 14 bit using LIBERA Hadron (I-Tech), 256 MB RAM, 1 Gbit interface
- **sample-synchronous** processing in FPGA
- development of **FPGA algorithm** for noise reduction, integration-gate, baseline reconstruction
- **bunch-by-bunch position measurement** on synchrotron ramp:




## SIS18 BPM Upgrade




- 12 BPMs, 12 LIBERAs, 2 concentrator servers
- 10 GBit Network, high data rate: 720 MB/s
- DAQ software: FESA classes (Cosylab)
- online tune evaluation (FFT)

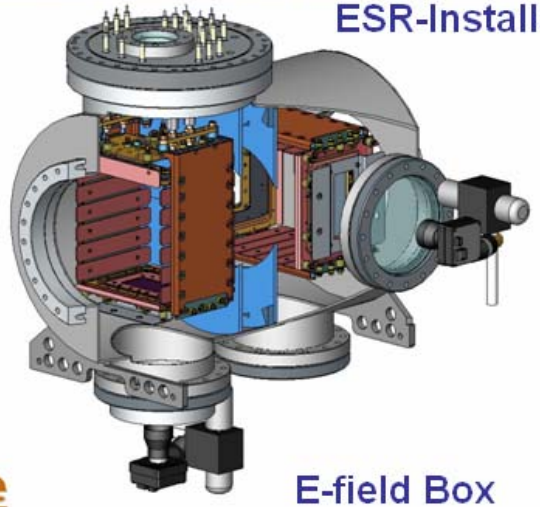
→ **MOOC02 by J. Belleman, CERN**

# Ionization Profile Monitor (IPM) for SIS100

## Role

- measurement of **transverse beam profile**
- emittance determination, evolution and changes due to **RF manipulations**
- detection of emittance growth
- monitoring of **fast profile changes** in turn-by-turn mode

ESR-Installation



## Requirements

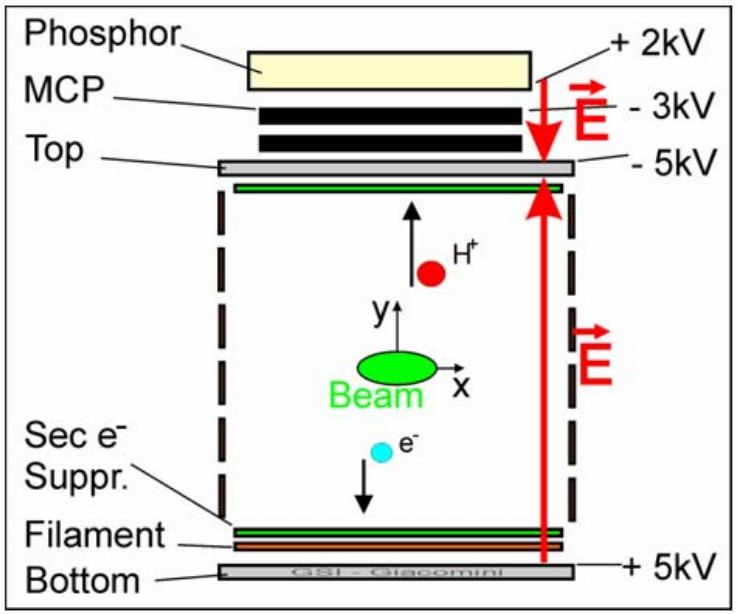
**Electrons or ions detection:**

- E-field (extraction) (E≈±50 V/mm, 1% inhomog.)
- B-field (guidance) (B≈30 mT, 1% inhomog.)

**Two photo-detector types:**

- **High spatial-resolution mode:** CCD readout (100 µm resol.)
- **Turn-by-turn mode:** array of photo-multiplier tubes (~1 µs time resolution)

## Detection Principle

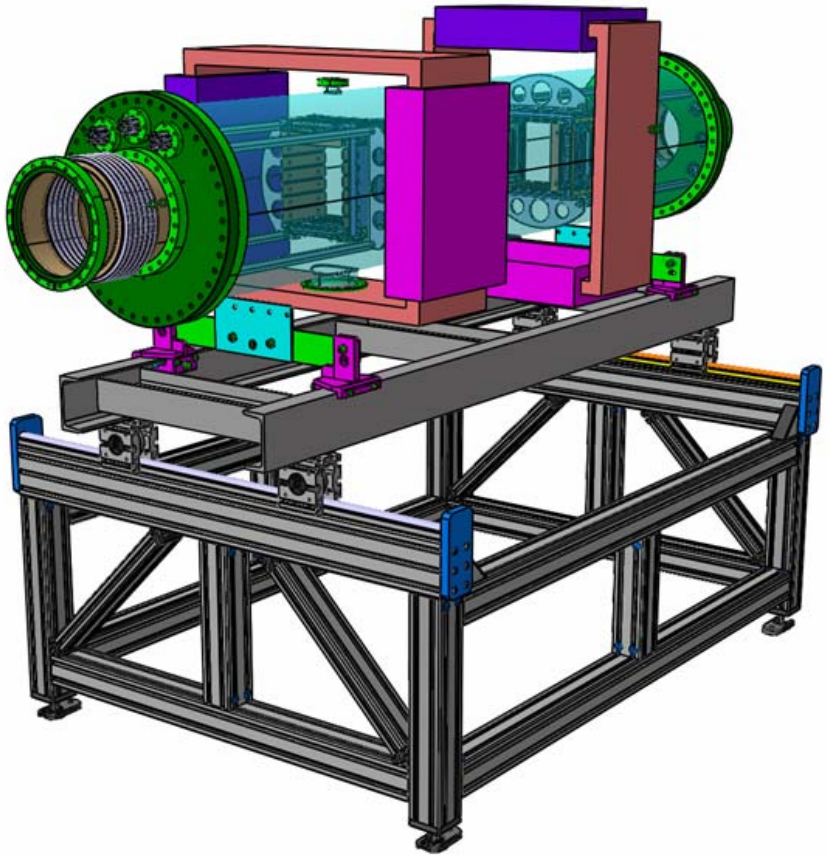



E-field Box

# Advanced IPM (Turn-by-Turn Measurements)

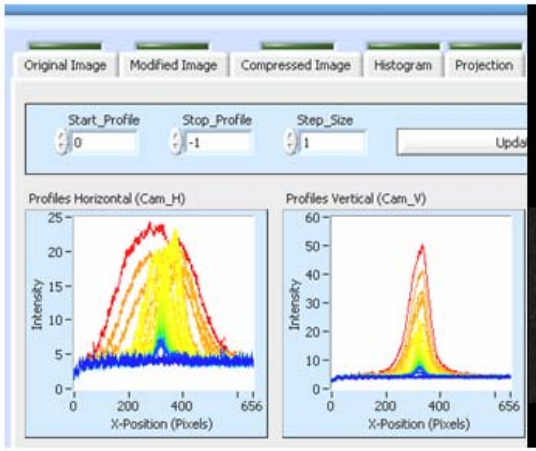
## Mechanical Construction

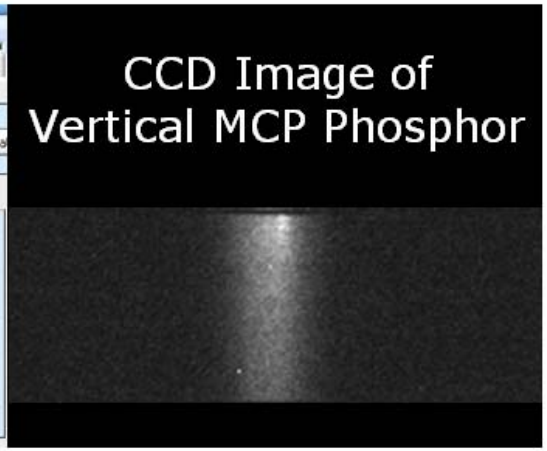
SIS18 Design



## Ongoing R&D

- detector tests with beam at COSY (FZ Jülich)

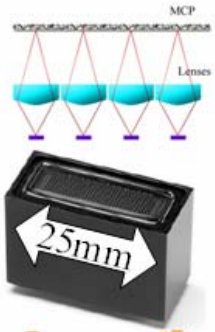



→ **TUPB12 by V. Kamerdzhiev, FZ Jülich**

- **fast readout for turn-by-turn mode**:
  - development of digitizer board for PMT array (ITEP, Moscow)
  - FPGA, DSP electronics for high time resolution:
    **1 profile each 100 ns**

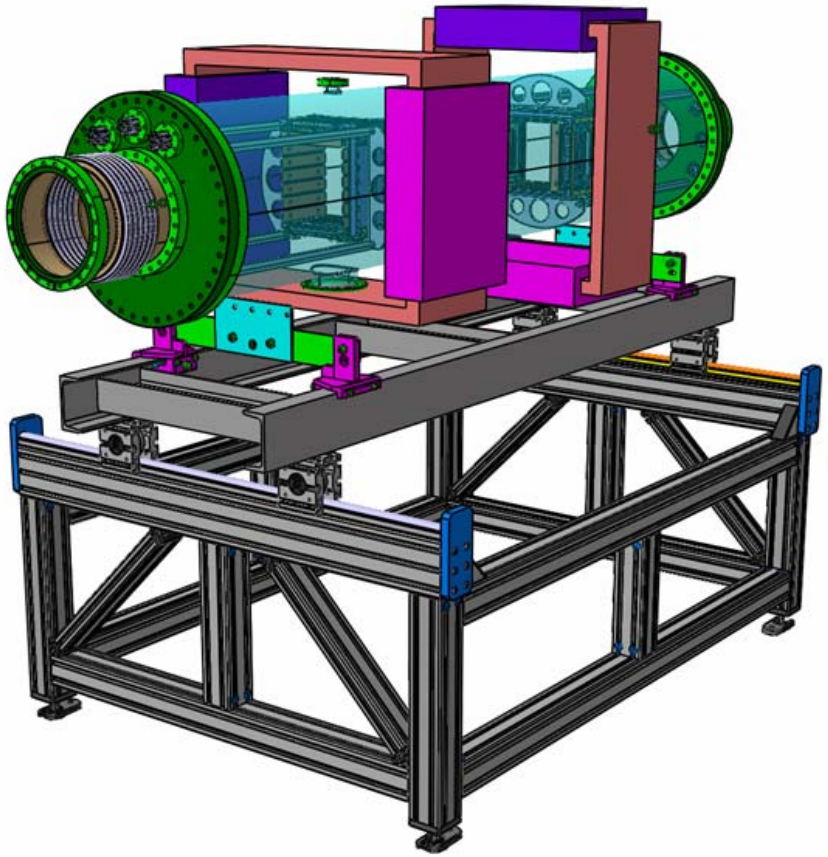
- **PMT array:**



# Advanced IPM (Turn-by-Turn Measurements)

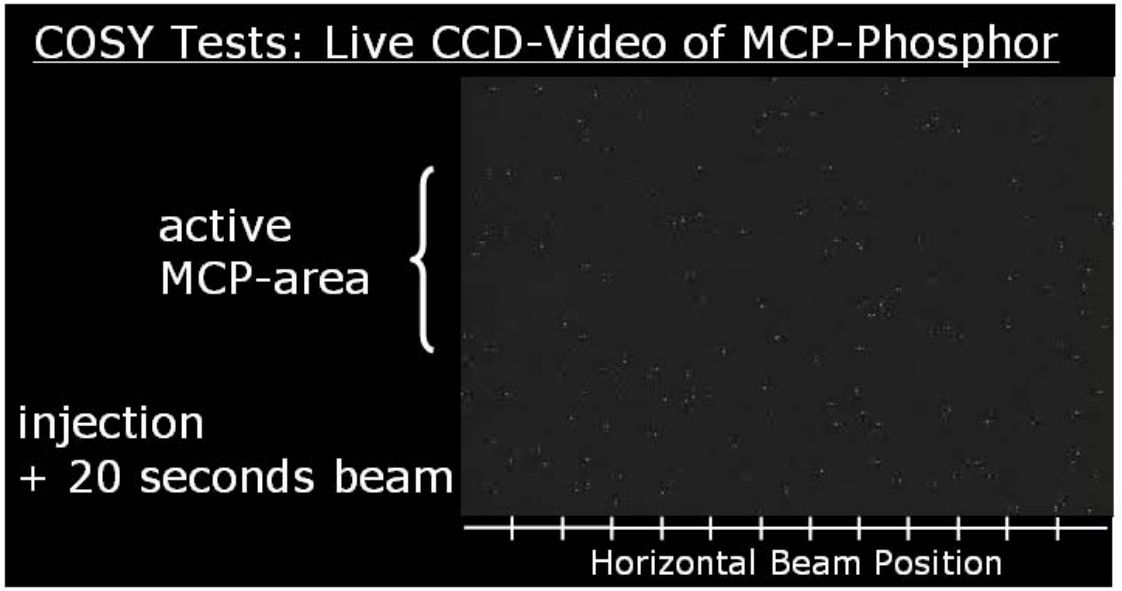
## Mechanical Construction

SIS18 Design



## Ongoing R&D

COSY Tests: Live CCD-Video of MCP-Phosphor

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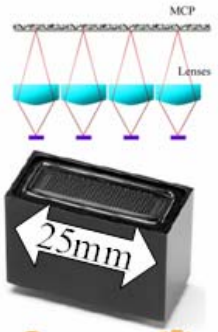
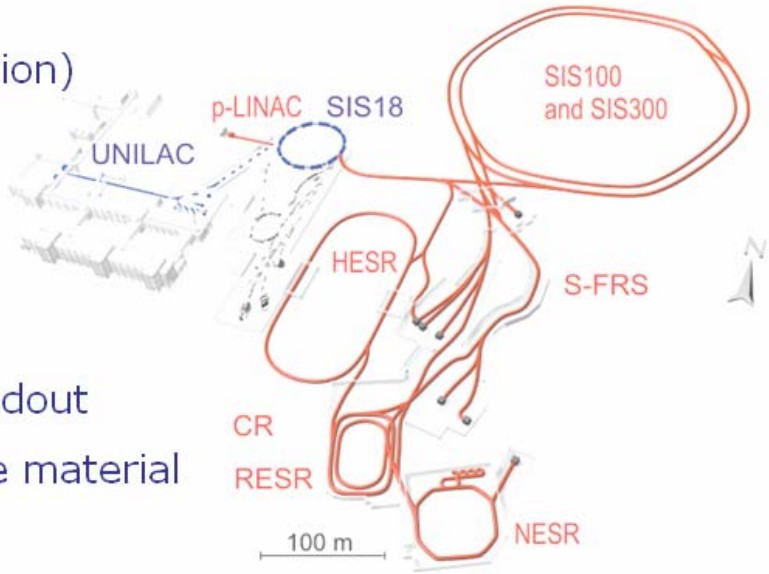


# Summary

- **FAIR**
  - versatile accelerator facility (SIS100, SIS300, CR, RESR, NESR...)
  - challenging requirements for BD (low&high currents, slow&fast extraction)
- **Novel DCCT**
  - bandwidth of combined system 13 MHz
  - calculated resolution 220 µA
- **Cryogenic Current Comparator**
  - resolution of GSI prototype: 8 nA@1kHz readout
  - susceptibility studies for optimization of core material
- **Beam Position Monitor**
  - simulations for optimized cryogenic shoe-box pick-up design
  - prototype: SIS18 BPM upgrade using LIBERA-HW and FESA-SW
- **Ionization Profile Monitor**
  - successful tests of high spatial resolution mode at COSY / FZ Jülich
  - fast readout electronics for turn-by-turn mode



# Acknowledgements

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- **Cryogenic Current Comparator**
  - W. Vodel, R. Geithner, Friedrich-Schiller-University Jena
  - T. Sieber, MPI-Kernphysik, Heidelberg
  - A. Peters, HIT, Heidelberg
- **Beam Position Monitor**
  - U. Raich, J. Belleman, CERN [EU-FP6, DIRAC Secondary Beams-Design]
  - D. Liakin, ITEP, Moscow
  - F. Wolfheimer, Technical University Darmstadt / CST
  - I-Tech, Slovenia [EU-FP6, DIRAC Secondary Beams-Design]
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- **Ionization Profile Monitor**
  - J. Dietrich, V. Kamerdzhiev, FZ Jülich [EU-FP6, DIRAC Secondary Beams-Construction]
  - D. Liakin, ITEP, Moscow [EU-FP6, DIRAC Secondary Beams-Construction]

Thank you for your attention!