Beam Diagnostics for SIS100

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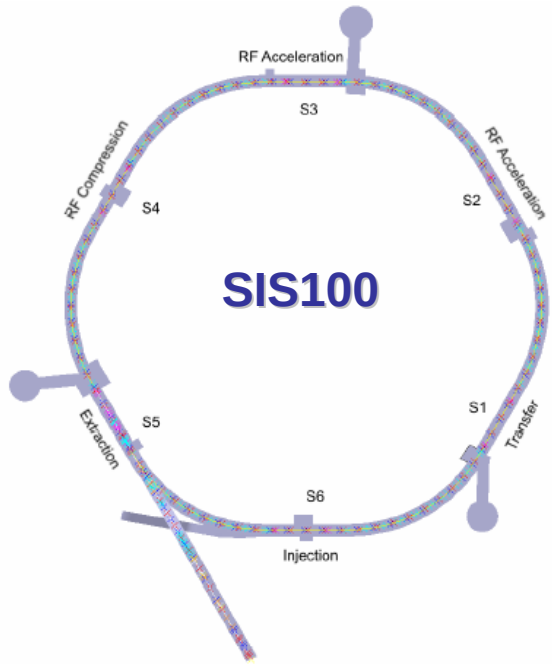
- SIS100 Features and General Concepts
- Overview of Diagnostic Installations
- Functions and Specs of Diagnostic Equipment & Ongoing RnD Projects
- EoI13i: Data Acquisition for Beam Diagnostics
- Summary

SIS100 Features

SIS100 Parameters

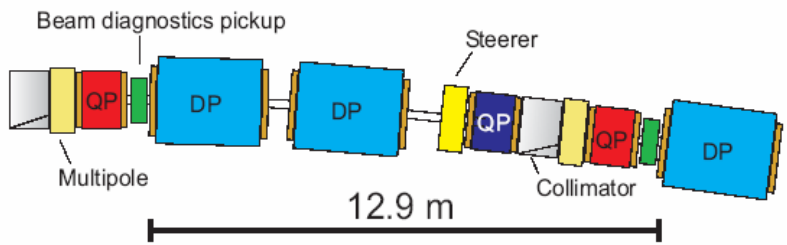
Circum-ference [m]	Beam rigidity [Tm]	Beam Energy [GeV/u]	Features
1083.6	100	2.7 for U^{28+} 29 for protons	fast pulsed superferric magnets max. B-field up to B=2 T, max. ramp rate dB/dt=4 T/s, bunch compression to ~60 ns of $5 \cdot 10^{11}$ U^{28+} ions, fast and slow extraction, $5 \cdot 10^{-12}$ mbar operating vacuum



Challenges for Beam Diagnostics

- wide range of beam intensities (up to $5 \cdot 10^{11}$ U^{28+}/pulse, $2.5 \cdot 10^{13}$ protons/pulse)
- short (25-100 ns) and long (8 µs) pulse length
- space charge effects
- RF 'gymnastics' (barrier bucket system, bunch compression system)
- XHV conditions, installation of BPMs in cryostats

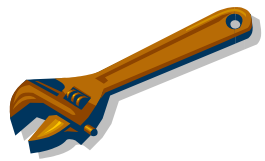
Standard Lattice Cell



General Layout Concepts

Layout Criteria for Beam Diagnostic Devices of FAIR:

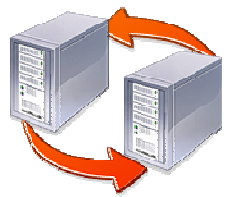
- application of **industrial standards** to maximum extent:
  Mechanics: flanges, valves, connectors etc.
  Electronics: form factors, bus systems, pinnings, network



- facility-wide standardization, i.e.wherever possible:
  common realizations of diagnostic devices for all machines!
  → reduces RnD work
  → improves maintainability (less administrative effort)
  → saves time + manpower (e.g. less training for service teams)
  → reduces spares inventory (ease of exchangeability)

- where applicable, e.g. for actuators, electronic parts:
  Use of **commercially available products** (COTS), with "second source"

- **comprehensive timing concept** in collaboration with GSI controls and equipment groups
- clear **separation of 'Data Acquisition'-layer** as common interface to control system
  → german Expression-of-Interest No. 13i



- full access to software **source code** (down to VHDL) is mandatory
- use of **open source** instead of proprietary software / operating systems
- decision for **FESA (Front-End Software Architecture, CERN)** as software standard for data acquisition

Beam Diagnostic Installations of SIS100

Diagnostic Device	Quantity	Measured Parameter	Application
DC Transformer	1	DC current	Stored current, beam lifetime
Novel DC Transformer	1	DC current	Stored current, beam lifetime
Pulse Current Transformer	1	Pulse-current	Injection efficiency
Cryogenic BPM	84	Beam centre-of-mass	Closed orbit, turn-by-turn variations, K-modulation, lattice functions, closed orbit feedback
Exciter+BPM	1	Beam centre-of-mass after excitation	Tune by BTF, tune by noise excitation, PPL tune tracking, tune by Q-kick
Schottky pickup	1	Momentum distribution, transverse Schottky	$\Delta p/p$ determination, tune, chromaticity
Fast Current Transformer	1	Broadband bunch structure	Longitudinal emittance
Ionization Profile Monitor	1	Beam profile	Transverse emittance, injection matching
Beam Loss Monitor	50	Beam loss	Mis-steering of magnets, Halo detection at scraper, Vacuum induced loss
Scintillation Screen	2	Beam profile	First turn diagnostics
SEM-Grid	6	Beam profile	First turn diagnostics

Beam Current Measurement (DC current)

1 DC-Transformer

Role

- precise determination of stored and accelerated beam current
- beam lifetime determination and coarse beam loss measurement

Requirements

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

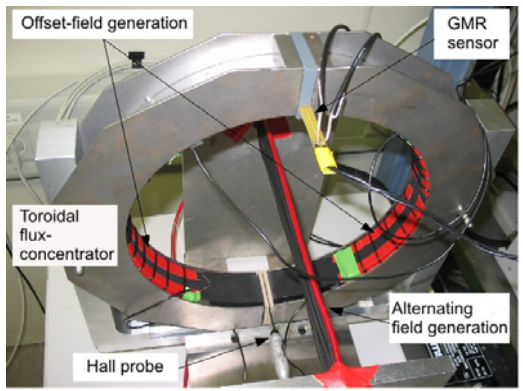
Technical Design

- commercially available system, e.g. New-PCT

www.bergoz.com/products/NPCT/NPCT.html

1 Novel DCCT (GMR DC-Transformer)

- dc beam current measurement
- especially for high current bunched beams with MHz repetition rate
- new development necessary, signal of standard DCT disturbed at MHz repetition rate

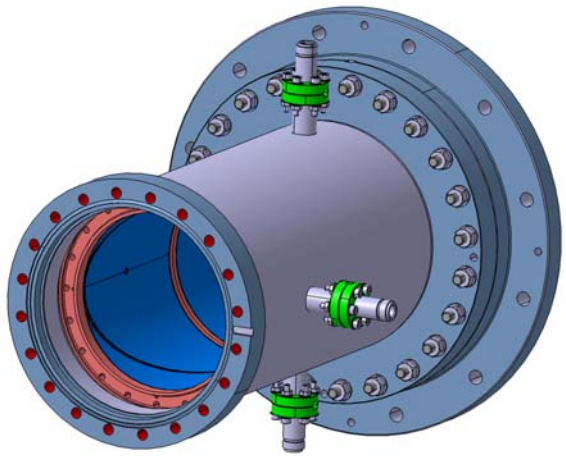


Ongoing R&D:

- Sensitive GMR magnetic field sensor
- soft-magnetic flux concentrator (amorphous VITROVAC® or CMD® ferrite) with 5mm gap

Beam Position Measurement 1/3

84 Cryogenic Beam Position Monitors

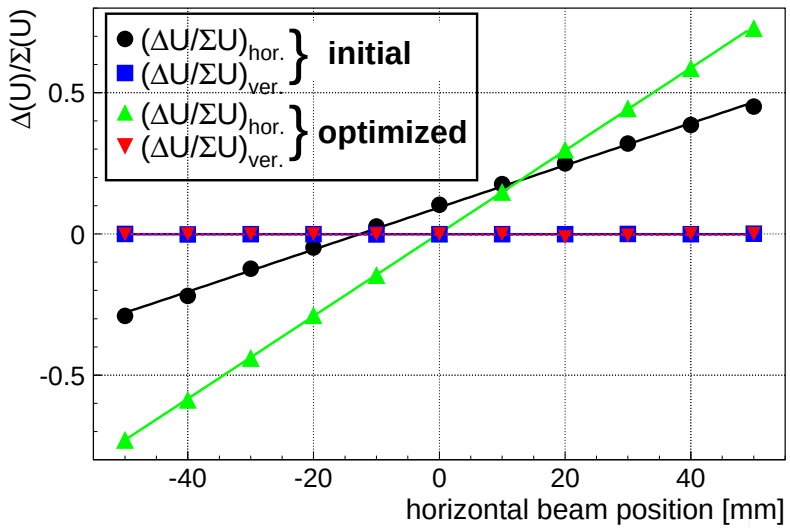


Role

- precise beam position measurement
- closed orbit control during rf manipulations (bunch compression, acceleration) and different extraction schemes
- use of position data for closed orbit feedback
- mechanical mis-alignment minimized with k-modulation

Requirements

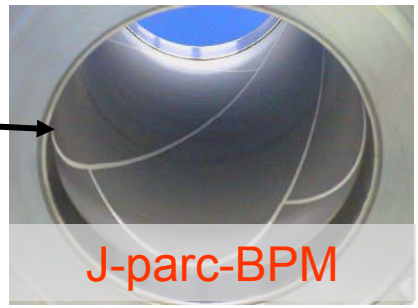
- all BPMs installed in cryogenic regions (quadrupole cryostats)
- large dynamic range (1 µV< U_{plate}<1.8 kV, mainly due to variation in bunch length)
- linear cut type BPM is preferred, because:
  - bunch length >> BPM length
  - rel. low bunch frequency: 0.5-2.7 MHz
  - good linearity even for transversally large beams
- mech. stability of ~50 µm required for 0.1 mm accuracy
- good response in frequency range 0.1-100 MHz
- all components suitable for XHV conditions (< 10^{-11} mbar)

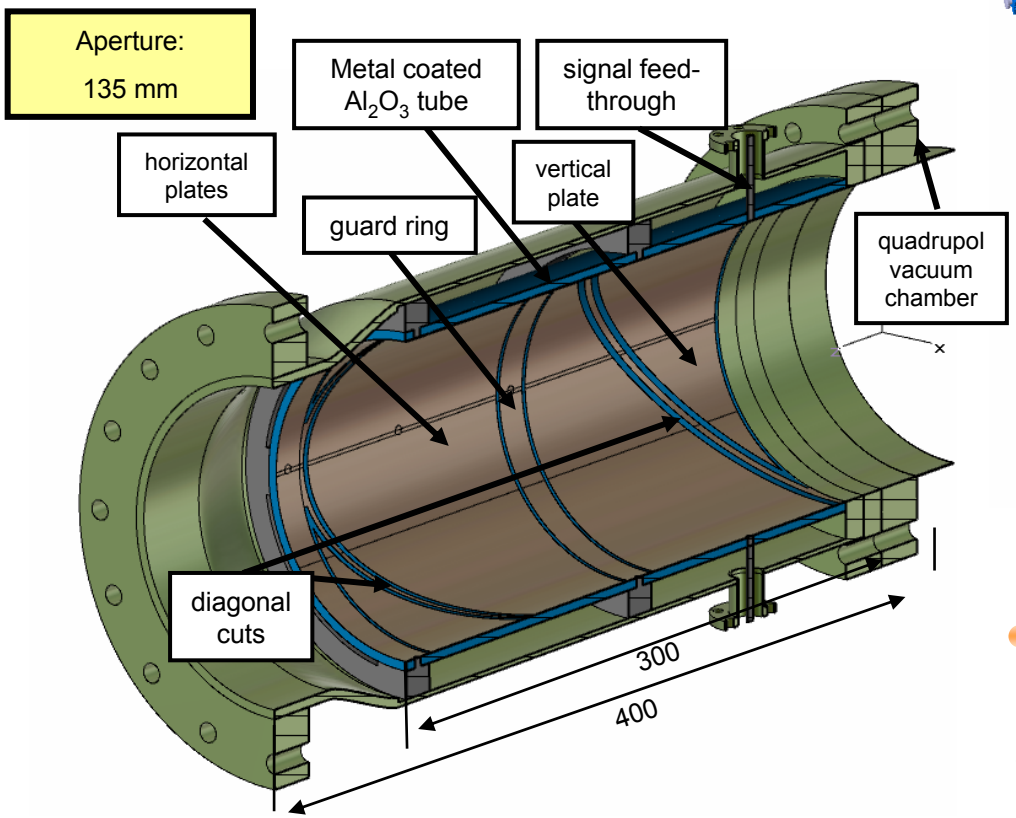


Beam Position Measurement 2/3

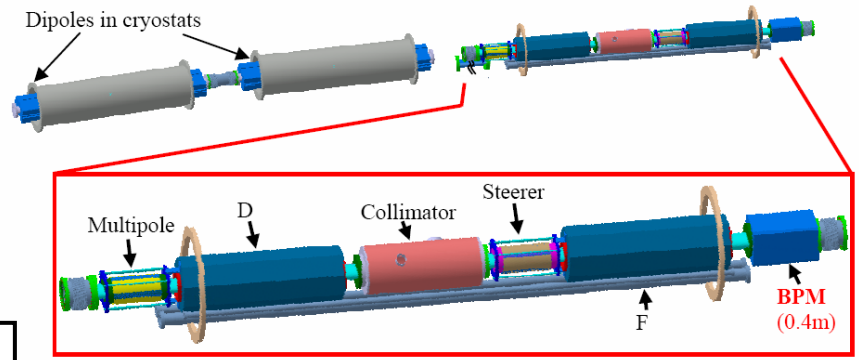
Technical Design

- metal coated Al_2O_3
- matching transformer inside cryostat

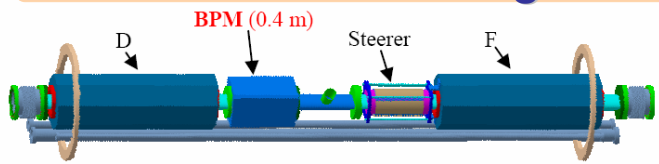




BPM Location in SIS100 Arcs



BPM Location in Straight Sections



Ongoing R&D:

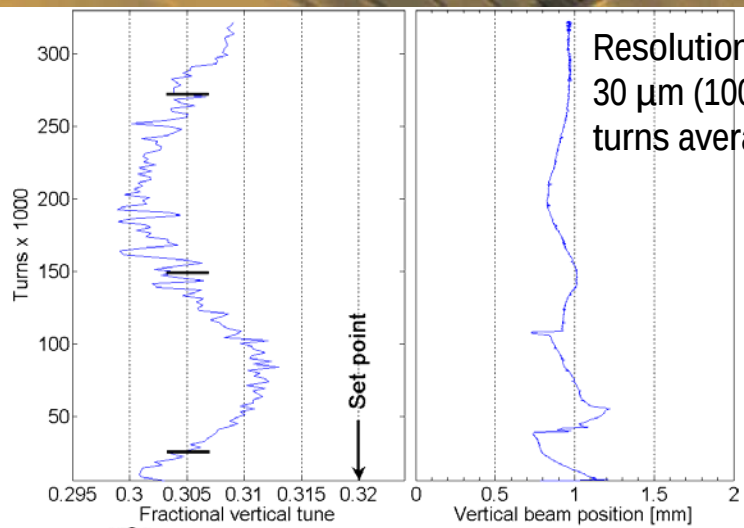
pick-up design, cryo test of components (feedthroughs, matching transformers), FEM-Simulations

Beam Position Measurement 3/3

Data Acquisition

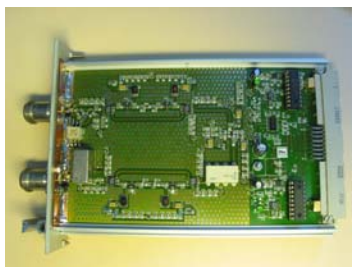
Digital baseband processing:

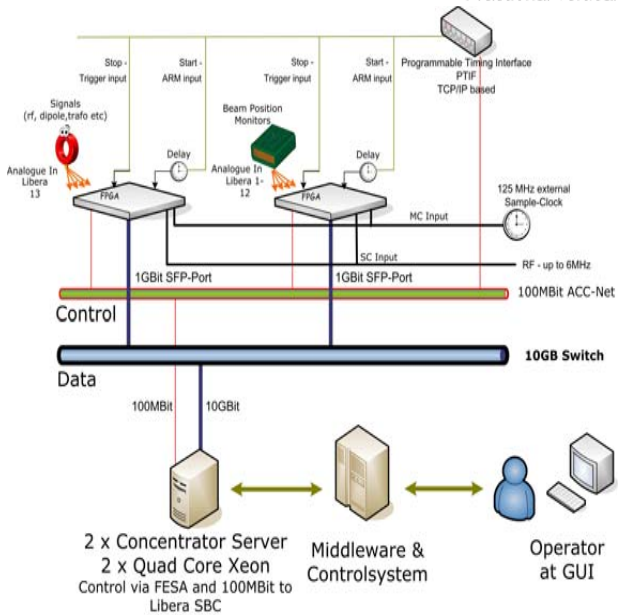
- Digitization: 4 ADCs, 125 MSa/s, 14 bit e.g. by Libera (Instrumentation Technologies)
- Sample-synchronous processing with Xilinx FPGA
- 256 MB RAM, 1.25 Gbit interface
- Algorithm design for FPGA (noise reduction, integration-gate, baseline reconstruction)



Ongoing R&D

- **closed orbit feedback** integration (FZ Jülich, DELTA Dortmund)
- **pre-amp development**
  RF amplifier bandwidth: 0.1-100MHz
  ampl./att. 120 dB dynamics





Libera test: SIS18 BPM upgrade

- 12 BPMs
- 2 concentrator servers
- 10 GBit switch
- DAQ software: FESA implementation

Longitudinal Diagnostics

1 Fast Current Transformer

Role

- control of longitudinal matching of space charge limited beams
- investigation of long bunches at injection and barrier bucket formation
- investigation of short bunches during bunch rotation
- tomographic reconstruction of longitudinal phase space evolution
- sensor for phase stabilization of accelerating rf → interface to rf system

Requirements

- bandwidth of 5 kHz up to 600 MHz

Technical Design

- commercially available product (Bergoz Instrumentation)

Ongoing R&D

- prototype purchased for tests
- tests with beam at SIS18 in 2009
- FESA test project with 500 MSa/s ADC

www.bergoz.com/products/FCT/d-fct.html

Schottky- / BTF- / Tune-Diagnostics

Role

Schottky

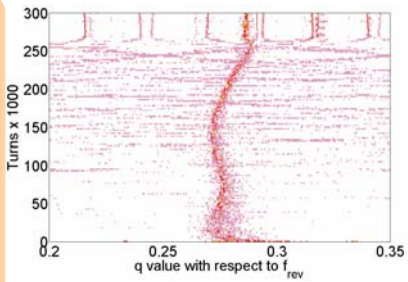
- long. Schottky to measure **momentum distribution** without affecting the beam
- study **dynamic effects**, e.g. rf capture process
- transv. Schottky to determine **tune** value and **incoherent tune spread**

BTF / Tune

- tune determination: measurement of the beam transfer function (BTF) using **weak beam excitation**
- dynamic tune determination during acceleration ramp: RF-exciter for **broadband noise excitation** (same hardware as for the BTF)
- sensitive tune measurement by **direct digitization**

Requirements

- no excitation needed
- MHz-Schottky PU (standard)
- GHz-Schottky PU for impedance measurements, space charge effects



- monitoring of tune, chromaticity, lattice functions, coupling coefficients by coherent beam excitation with fast kicker
- measurement of single kicked bunch: BPM read out on a bunch-by-bunch basis
- study space charge effects

Technical Design

- two pairs of **capacitive pickup electrodes**
- broadband (200 MHz) pre-amplifier
- digital **real-time spectrum analyzer** (min. 5 GSa/s)

- measurements with broadband noise excitation and fast kicker excitation: special mode of **BPM digitization system**
- BTF: **network analyzer**

Ongoing R&D:

- **novel Schottky pick-up** design (TU Darmstadt)
- study on **tune and chromaticity feedback** systems (TU Darmstadt)

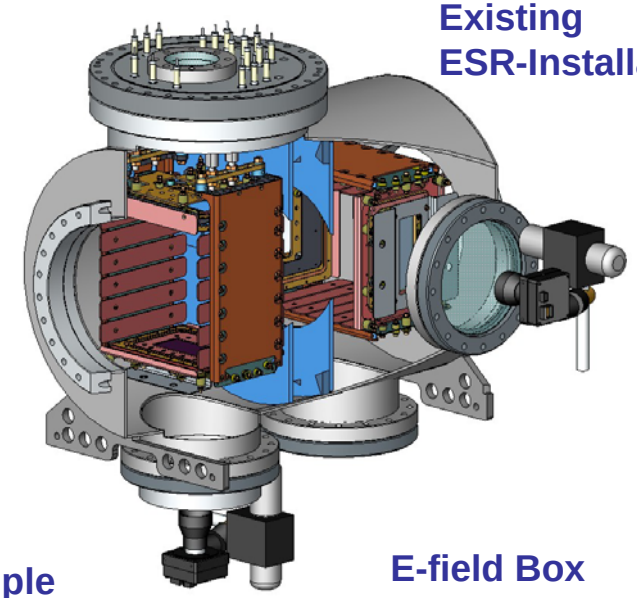
Beam Profile Measurement 1/3

1 Ionization Profile Monitor

Role

- measurement of transverse beam profile
- emittance determination, evolution, changes due to rf manipulations
- detection of emittance growth
- injection matching and fast profile changes measured in turn-by-turn mode

Existing ESR-Installation



Requirements

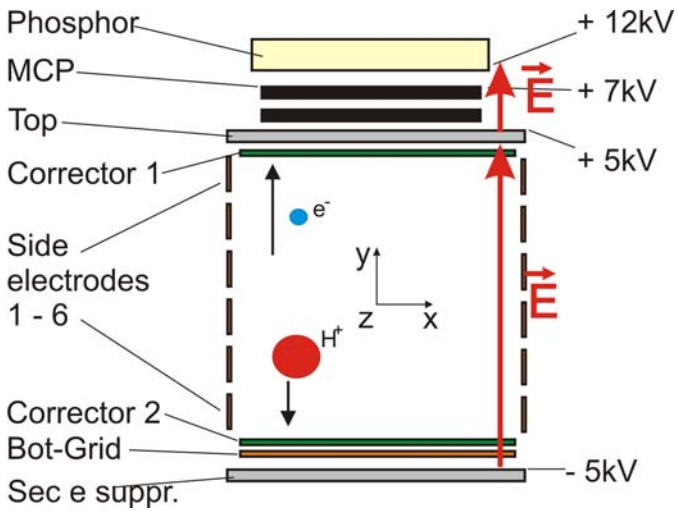
Electrons or ions detection:

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

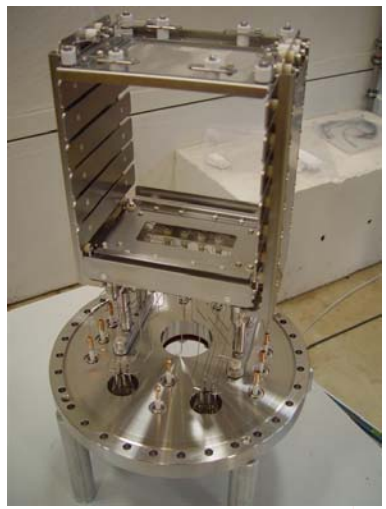
Two photo-detector types:

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

Detection Principle



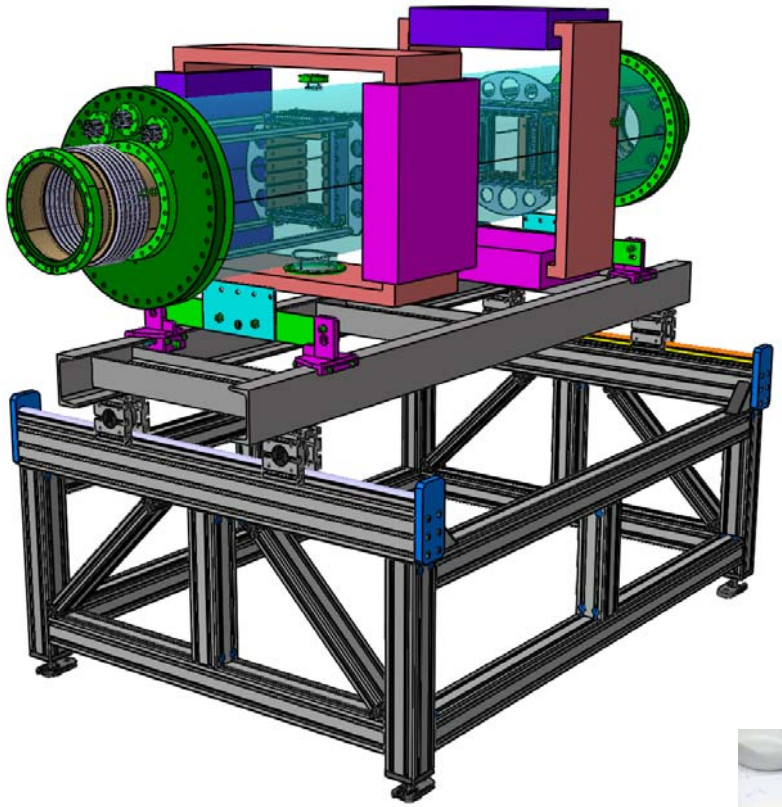
E-field Box



Beam Profile Measurement 2/3

Technical Design

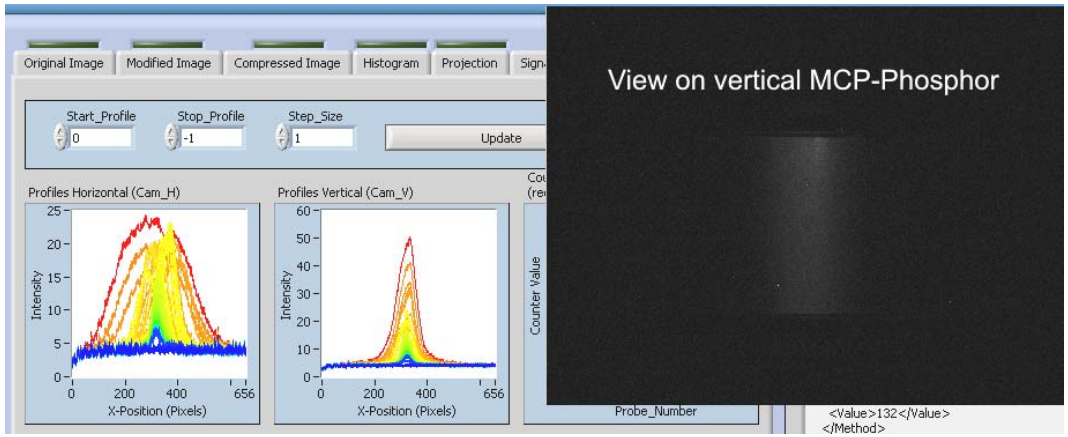
SIS18 Design



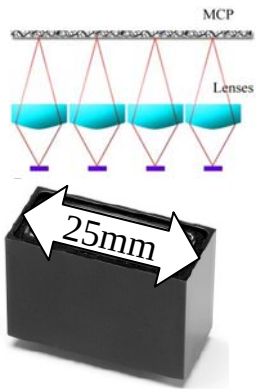
- studies on possible **permanent magnet layout** for guiding B-field (U Moscow)

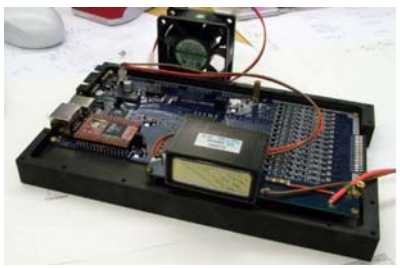
Ongoing R&D

- **detector tests** with beam at COSY (FZ Jülich)



- **fast readout for turn-by-turn mode**:
  - development of digitizer board for PMT array (ITEP, Moscow)





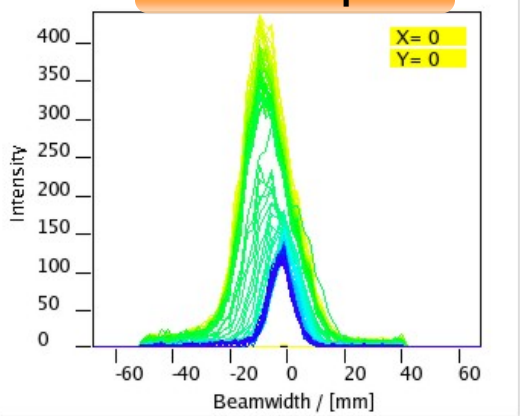
- FPGA, DSP electronics for high time resolution:
  1 profile each 100 ns

Beam Profile Measurement 3/3

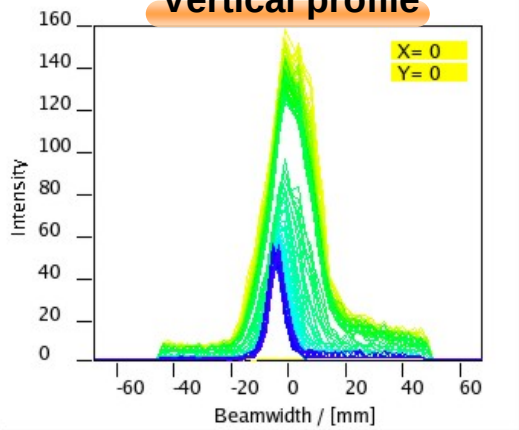
Measurement example using the existing SIS18 residual gas monitor

Ar18+, 350MeV/u @ flat top, losses after injection & accel. (t=0,9s), beam shift @ accel. start

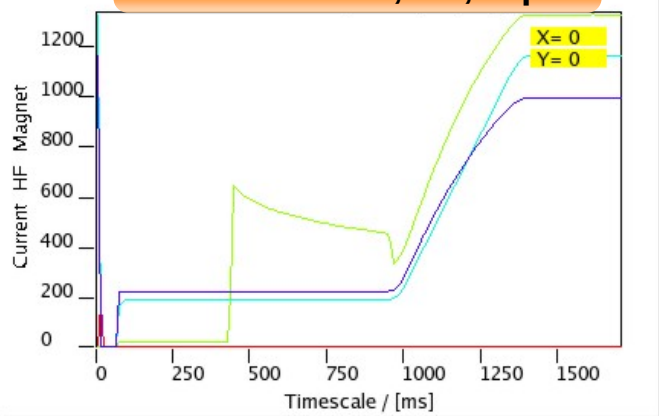
Horizontal profile



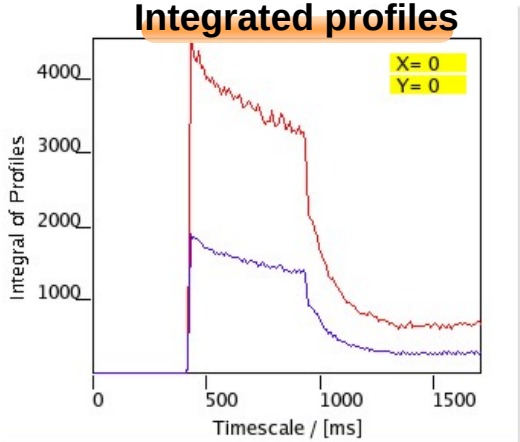
Vertical profile



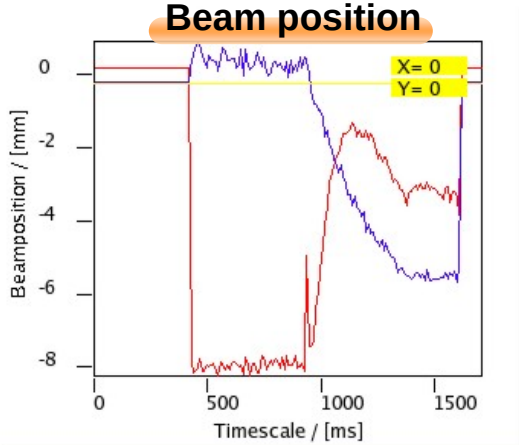
Additional: DCT, RF, Dipole



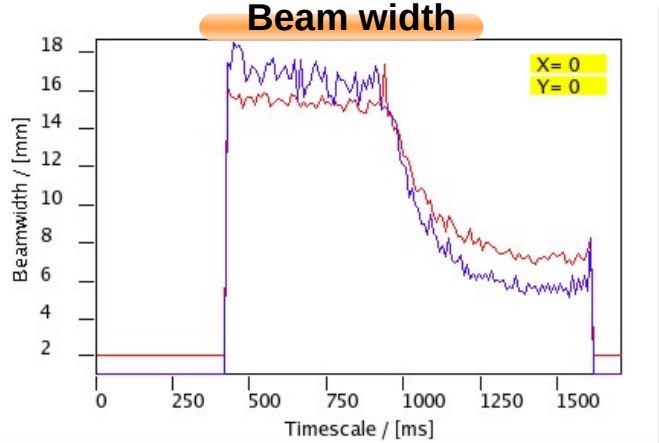
Integrated profiles



Beam position



Beam width



Beam Loss Monitor

50 Beam Loss Monitors

Role

- localize beam losses during adjustments and machine tuning
- optional: interlock generation / machine protection
- mounted at critical locations, e.g scrapers, collimators, septa...

Requirements

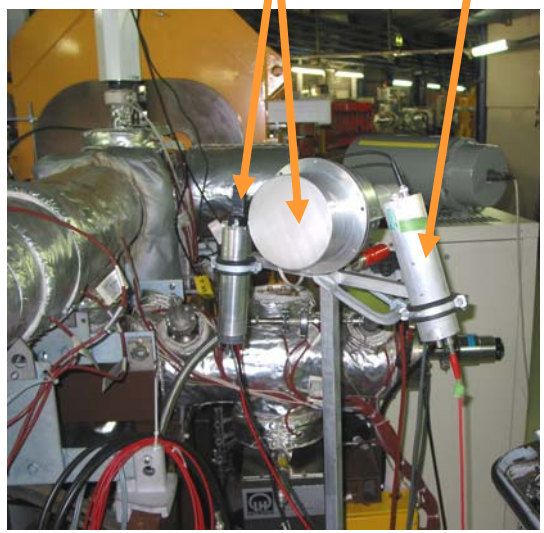
- scintillators: large sensitivity and precise timing properties, but **only relative measurement**, for slow extraction
- ionization chambers for **absolute dose** determination at fast extraction

Technical Design

- tripod outside vacuum
- active volume 20x20x50 mm^3
- ionization chamber:
  length 800 mm, diam. 100 mm

Ongoing R&D

- tests at SIS18
  with CERN-LHC BLMs



First Turn Diagnostics (intercepting)

6 SEM-Grids

2 Scintillation Screens

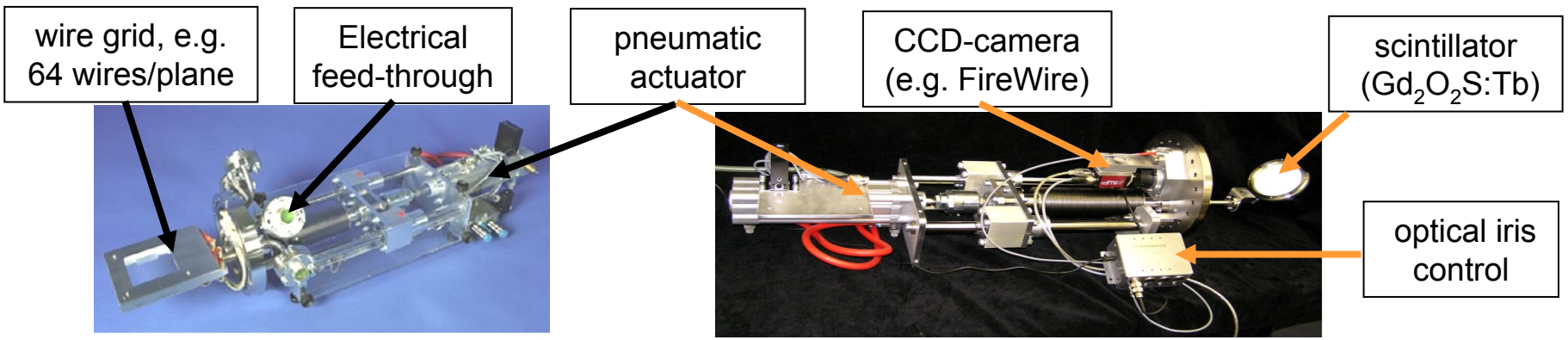
Role

- Monitor beam position and profile at each sector (+ beam stopper)
- Beam position and profile at ½ turn and first turn positions
- commissioning and troubleshooting

Requirements

- low detection threshold
- XHV conformity / thermal stability
- adequate screen material, e.g. YAG, Gadox
- large active area / small optical decay time
- image acquisition in triggered mode

Technical Design

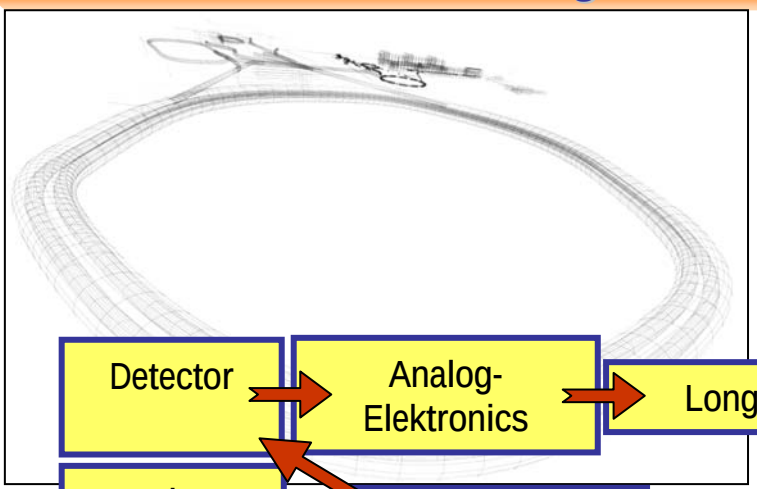


Ongoing R&D:

- development of new read out electronics
- studies on scintillating materials
- tests of ccd systems and iris control

EoI 13i: Data Acquisition for BD

Schematic for Beam Diagnostic Device



Detector

Drive

Mechanics

Analog-Elektronics

Subsystems: HV / Gases / Compressed Air Step. motor ctrl.

Long Cables

Accelerator Tunnel

Common Realization: GSI Contribution

Data Acquisition → EoI 13i

- ADC
- Scaler/Counter
- Digitizer
- I/O-board
- Controller
- Data concentrator/DSP
- DAQ software (FESA)

Analog-Electronics

Digitization

Embedded Controller

Network

Accelerator Control System

FAIR-BD Project Team

Electronics room

- **NO common scheme valid FOR ALL** ~30 different beam diagnostic systems

Ongoing R&D:

- FESA test installation at GSI
- collaboration with CERN-CO / -BI
- 2 FESA test projects: (SIS18-BPM upgrade, Fast Current Transformer)

Summary / Outlook

- Overview of concepts and beam diagnostic devices for SIS100
- **Specifications**, special **requirements** and **technical solutions** for beam diagnostic devices
- Many diagnostic devices subject of **ongoing RnD projects**, examples:
  - novel GMR sensor (UAS Wiesbaden)
  - cryogenic pick-up design / feedback systems (TU Darmstadt, FZ Jülich, DELTA Dortmund)
  - ionization profile monitor: mechanical prototype (EU FP6, FZ Jülich)
    layout of fast readout electronics (ITEP Moscow)
- EoI #13i: **Data acquisition for FAIR beam diagnostics** as common interface
- **FAIR-BD project team** now in operation
- **Outlook:**

Targets

+ start of interdisciplinary working groups, e.g. 'operational scenarios'
+ project-wide sustainable solution for missing manpower (e.g. 'project associates')
+ build-up of GSI infrastructure (procurement, human resources...)

Risks

- low coverage of beam diagnostic components by EoIs (in total 2)
- missing mandate for Expressions-of-Interest (GSI, other partners)
- obscurity of funding schemes

Thank you for your attention.