

Beam Instrumentation for FAIR – An Overview

Report to FC2WG – M. Schwickert
for the Beam Instrumentation Team

Outline

- Mission of BI Department and General Concepts
- Infrastructure Systems and In-Kind Situation
- Overview of diagnostic systems for FAIR,
Focus on HEBT and SIS100
 - **Beam Intensity (Details on Current Transformers, Particle Counters, related Aquisition Systems...)**
 - Beam Profile
 - Position (incl. closed orbit feedback and tune measurement)
- Summary

The BI-Mission

- ***Supply operations team with all necessary beam parameters for routine operation and first-level troubleshooting***
 - machine commissioning treated as **separate project phase**
 - quite a few '**expert systems**', presently for specialists only....
- New BI tasks / responsibilities at FAIR (taken from CSCO):
 - Front-end controllers (FEC) for beam instrumentation
 - related FEC software
 - ALL BI-related electronics at beamlines
 - fieldbus for diagnostics, i.e. PROFINET
- Former BI tasks given to CSCO:
 - interlock system
 - stepper motor control

General Concepts

- 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 In-Kind Contribution EoI 13i**
- **full access to software source code** (down to VHDL) is mandatory
- use of **open source/open hardware** instead of proprietary software / operating systems

LOBI – Organizational Chart

Department Head: M. Schwickert, Deputy: A. Reiter (48,3 FTE)

7 LOBI - Work Package Leader

SIS100
P. Kowina

CR
O. Chorniy

IPM
T. Giacomini

HEBT
B. Walasek-Höhne

SFRS
M. Schwickert

p-Target
A. Reiter

p-Linac
P. Forck

6 LOBI - Groups

MI 8,7 FTE

Mechanics & Infrastructure

Leader: R. Fischer
Dpty: C. Dorn

R. Boywitt
S. Fiedler
M. Glück
M. Hartung^{SP}
R. Mahr
S. Schuhmacher
K. Steiner^{SP}
J. Wohlers

ED 11 FTE

Electronics Development

Leader: H. Reeg
Dpty: W. Kaufmann^{SP}

R. Johänntges
C. Krüger
K. Lang
C. Müller
H. Rödl^{DO,SP}
C. Schmidt^{DO,SP}
J. Wiessmann^{DO,SP}
M. Witthaus
F. Kurian*

DS 6,2 FTE

Data Acquisition & Software

Leader: T. Hoffmann
Dpty: R. Haseitl

H. Bräuning
R. Lonsing^{SP}
P. Miedzik
T. Milosic
M. Beck^{*}

HI 4,2 FTE

HEBT Instruments
Leader:

B. Walasek-Höhne
Dpty: C. Andre

P. Boutachkov
H. Graf
{A. LeFevre -> RBDL}
V. Lavrik*

RI 7,2 FTE

Ring Instruments

Leader: P. Kowina
Dpty: T. Giacomini

P. Burkhard
O. Chorniy
M. Müller
C. Wetzel^{DO,SP}
T. Reichert*
J. Latzko*

RD 9 FTE

Research & Development

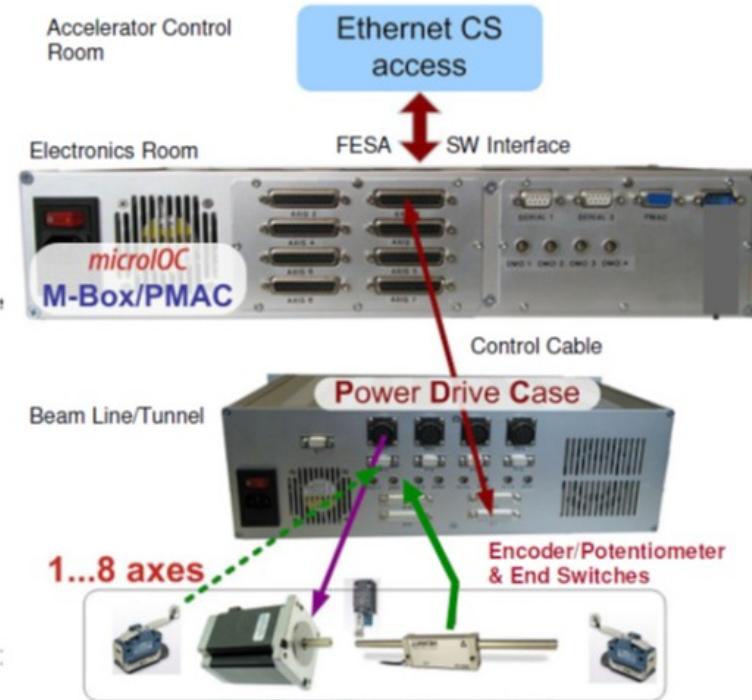
Leader: P. Forck
Dpty: T. Sieber

R. Singh
S. Udrea^{EC}
M. Almaliki*
S. Lederer*
A. Lieberwirth*
Y. Shutko*
B. Zwicker*

*student, *phd student, ^{DO} delegated operator, ^{SP} shift participant, ^{EC} external contract

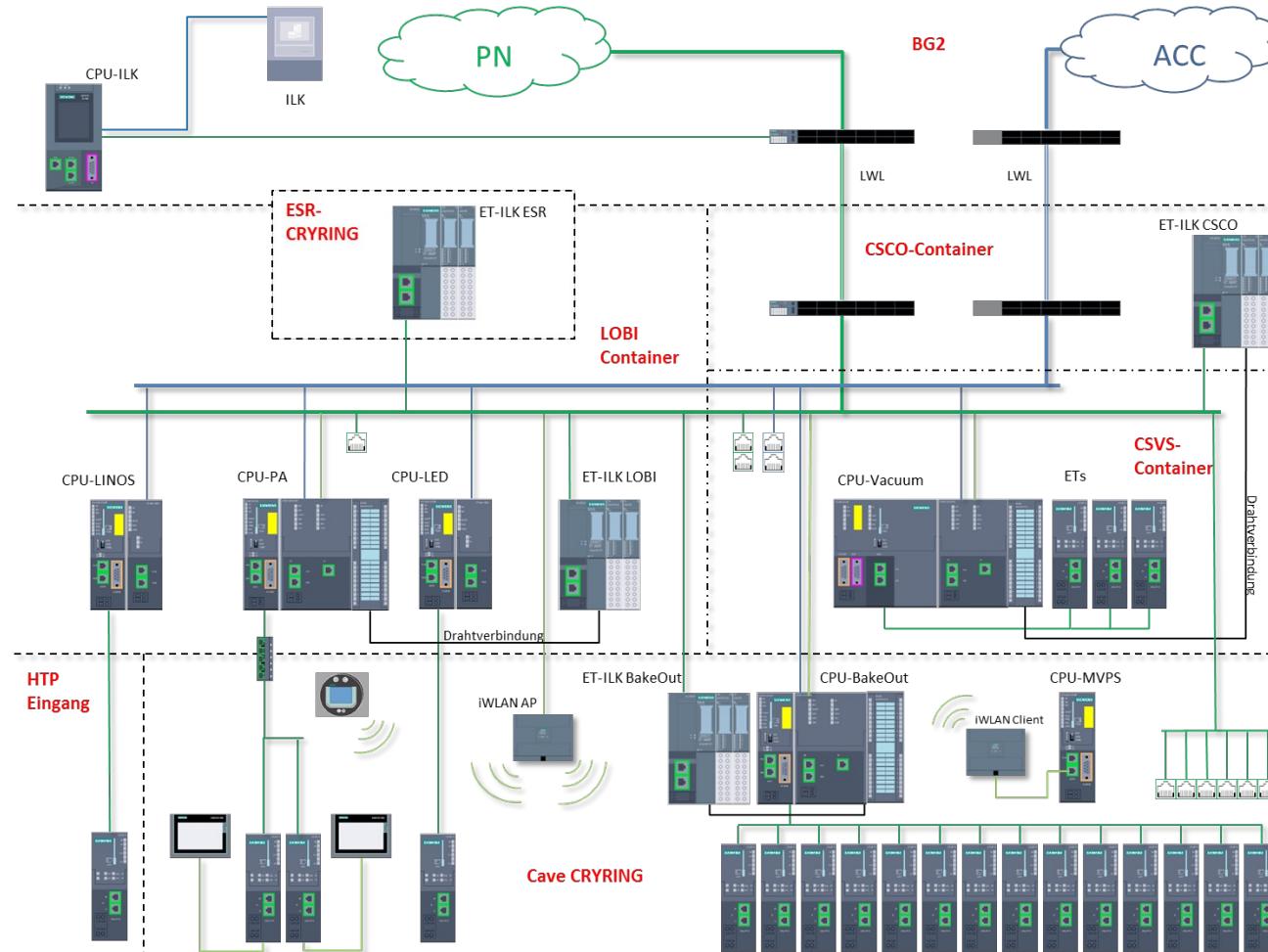
General Concepts Infrastructure I / II

- In agreement with other equipment groups (CSCO, CSVS, LORF, LOEP etc.) clear decisions for:
 - **FESA** as common software interface
 - **CENTOS7** as FEC operating system
 - **White Rabbit** and **BuTiS** as timing sources
 - **PROFINET** as common fieldbus
 - **Siemens PLC** as standard
 - supported form factors:
VME, uTCA/xTCA, PCIe/IPC
 - **MBox** (Cosylab) for stepper motor control



General Concepts Infrastructure II / II

PROFINET and PLC based devices



Example: PROFINET layout for Cryring as testbed for FAIR

BI-Applications:

- pressurized air control
- iris control (BIF, CUPID)
- gas flow control?
- ... more?

Applications integrated for CS:

- vacuum control
- bake-out
- interlock
- mobile vacuum pumping system
- industrial WLAN
- HMI / manual ctrl

Courtesy of A. Petit

REMoTe Beam instRumentation And Network Diagnosis Tool

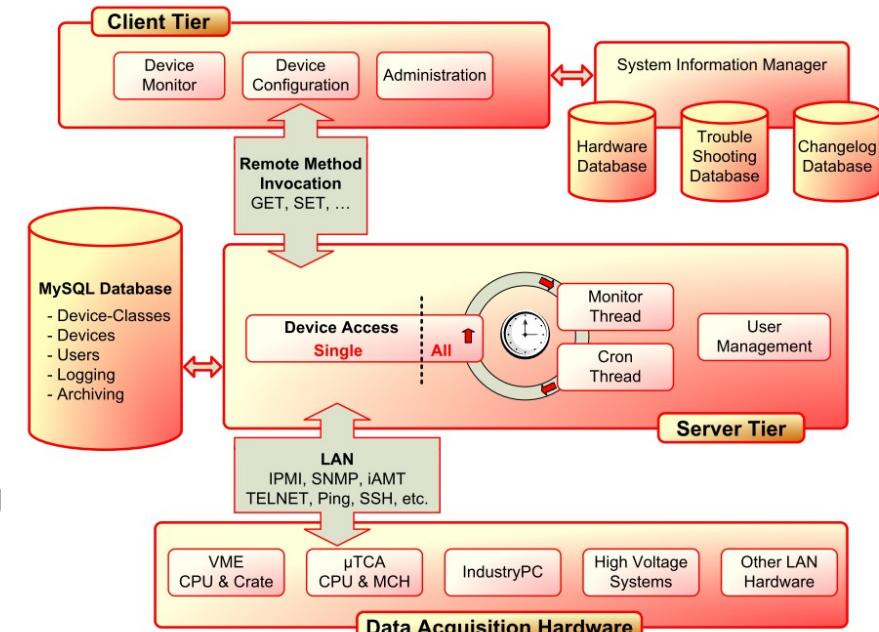
□ Java Framework to allow authorized user to monitor and control remote systems while hiding the underlying protocols, IP-addresses, user-ids, passwords etc.

- **Problem:** In FAIR beam instrumentation devices and data acquisition components will be distributed over large area, partially inaccessible
- **Mandatory:** control supporting LAN-based components like VME/μTCA crates, front-end controllers, middleware servers etc.
- Many **commercial systems** provide remote control via various standardized protocols

REMBRANDT features:

- Client-server architecture, fully implemented in Java
- Application available for Linux/X-Term, MS Windows
- REMBRANDT server monitors devices typ. every 10 seconds, logs changes, sends e-mail notifications...
- Several user clients available: control and monitoring tool, system information management, database and user administration
- REMBRANDT currently supports:
 - SNMP, iAMT, IPMI, Ping, RDA
 - direct device access via telnet, ssh or iAMT SOL

REMBRANDT Software Architecture



Courtesy of
T. Hoffmann

FAIR-BI: In-kind-Partner, we're not alone...

In-Kinds by Slovenia (~9.5 M€)

Work Package	Content	FAIR Section
D1	BPM pre-amplifiers	SIS100, HEBT, HESR
D2	BPM Data Acquisition (circular machines)	SIS100, CR, HESR
D3	Closed Orbit Feedback System	SIS100
D4	BPM Data Acquisition (Single Pass)	p-Linac, HEBT
D5	Pressurized Air Drives and Control	SIS100, HEBT, CR, p-Linac
D6	<i>Low-Level RF (responsible: GSI-RF Team)</i>	<i>p-Linac</i>
D7	Beam-Loss Monitor (without Detector)	SIS100, HEBT, CR, HESR
D8	Transformer Data Acquisition	SIS100, HEBT, CR, HESR

In-Kinds by India (~0,9 M€)

HEBT Diagnostic Vacuum Chambers

(psp-codes 2.3.6.3.1.2, 2.3.6.5.1.2, 2.3.6.5.2.2, 2.3.6.5.3.2)

In-Kinds by Russia

CR	ITEP
2.5.6.3.1	Tune / BTF Exciter
2.5.6.3.2	Schottky Pick Up
SIS100	
2.8.6.3.1	Tune / BTF Exciter
2.8.6.3.2	Schottky Pick Up

+ CR Diagnostics by BINP

(various components)

In-Kinds by France (~0.5 M€)

p-Linac: Parts of LEBT diagnostics

p-Linac BPMs (Pick-ups, psp-code 2.7.6.5.1)

GSI In-Kinds (~20 M€)

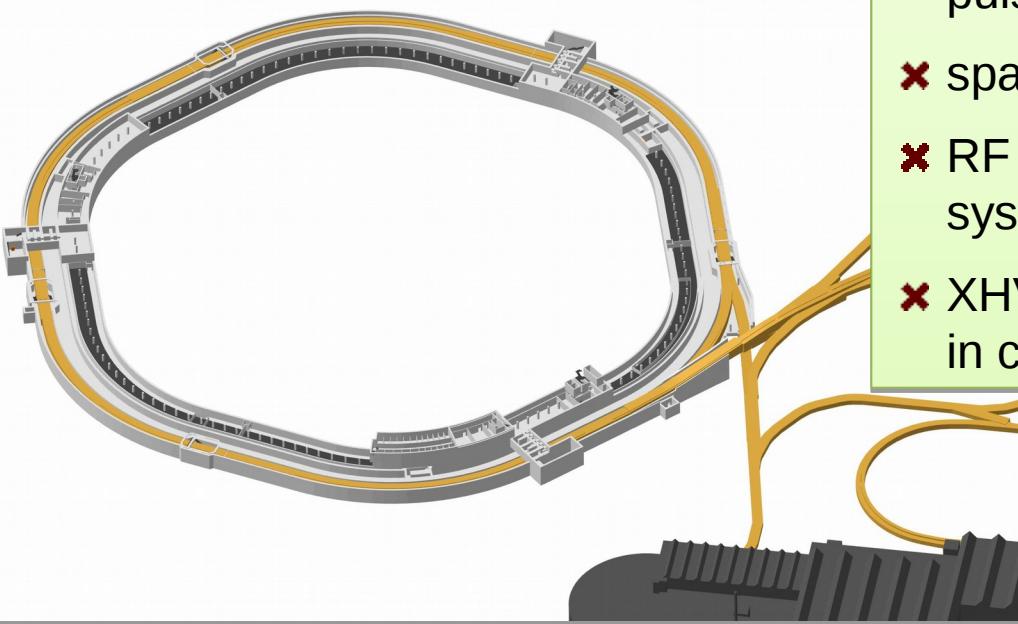
- Data Acquisition for all machines:**
HEBT PSP: 2.3.6.x.y.6
S-FRS PSP: 2.4.6.3.1
CR PSP: 2.5.6.x.y.6
SIS100 PSP: 2.8.6.x.y.6
pBar-Target PSP: 2.9.6.x.y.6
- SIS100: Beam Position Monitors**
(PSP 2.8.6.2)
- p-Linac: All diagnostic components**
except for french and slovene contributions
- p-Bar Target (PSP 2.9.6): all diagnostic components**
- All Cryogenic Current Comparators**
HEBT PSP: 2.3.6.2 CR PSP: 2.5.6.1.3
- All Residual Gas Profile Monitors**
CR PSP: 2.5.6.4 SIS100 PSP: 2.8.6.4
- Multiwire-Proportional Chambers (MWPC), Particle Detector Combinations (PDC) of HEBT (MWPC)**
PSP: 2.3.6.5.3 PDC PSP: 2.3.6.3)

- Overview SIS100
and HEBT

SIS100 - Challenges

Challenges for the Design of Beam Instrumentation:

- ✖ wide range of beam intensities
(up to $5 \cdot 10^{11}$ U²⁸⁺/pulse,
 10^{13} protons/pulse)
- ✖ short (30-100 ns) and long (8 μ s)
pulse length
- ✖ space charge effects
- ✖ RF 'gymnastics' (barrier bucket
system, bunch compression system)
- ✖ XHV conditions, installation of BPMs
in cryostats



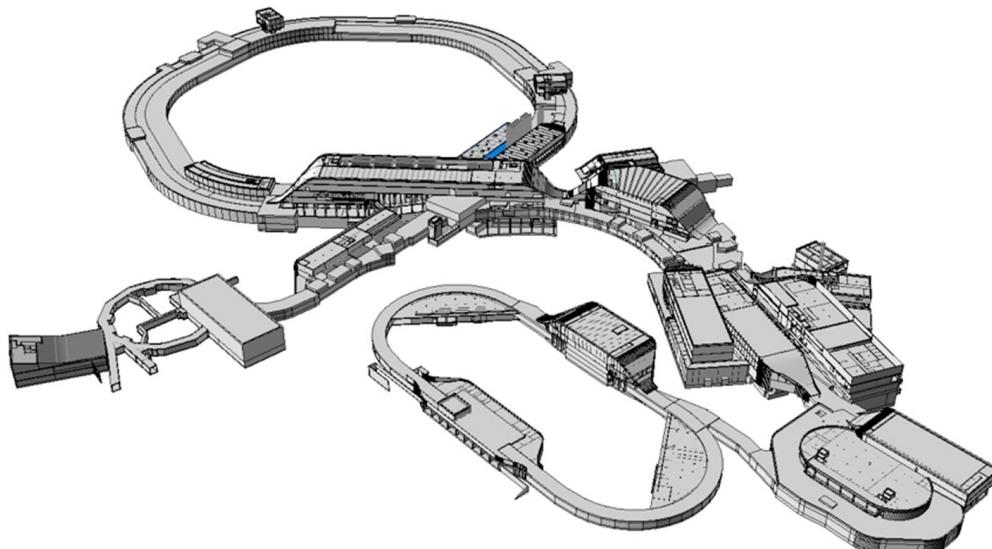
SIS100 Diagnostic Instruments

Diagnostic Device	Quantity	Insertion length [mm]	Measured Parameter	Application
DC Transformer	1	600	DC current	Stored current, beam lifetime
Novel DC Transformer	1	600	DC current	Stored current, beam lifetime
Fast Current Transformer #1	1	(common with DCT)	Pulse-current	Injection efficiency
Cryogenic BPM	83	400	Beam centre-of-mass	Closed orbit, turn-by-turn variations, lattice functions, closed orbit feedback
BTF exciter	1	1800	Beam centre-of-mass after excitation	Tune by BTF, tune by noise excitation, PPL tune tracking, tune by Q-kick
Schottky pickup	1	1600	Momentum distribution, transverse Schottky	$\Delta p/p$ determination, tune, chromaticity
Fast Current Transformer #2	1	450	Broadband bunch structure	Longitudinal emittance
Ionization Profile Monitor	1	2500	Beam profile	Transverse emittance, injection matching
Beam Loss Monitor	200	x	Beam loss	Mis-steering of magnets, Halo detection at scraper, Vacuum induced loss
Scintillation Screen	2	350	Beam profile	First turn diagnostics
SEM-Grid	6	450	Beam profile	First turn diagnostics
Beam Stopper	6	350	Relat. Current	First turn diagnostics
Q-BPM	1	950	Quadrupol oscillations	injection matching, determination of incoherent tune spread

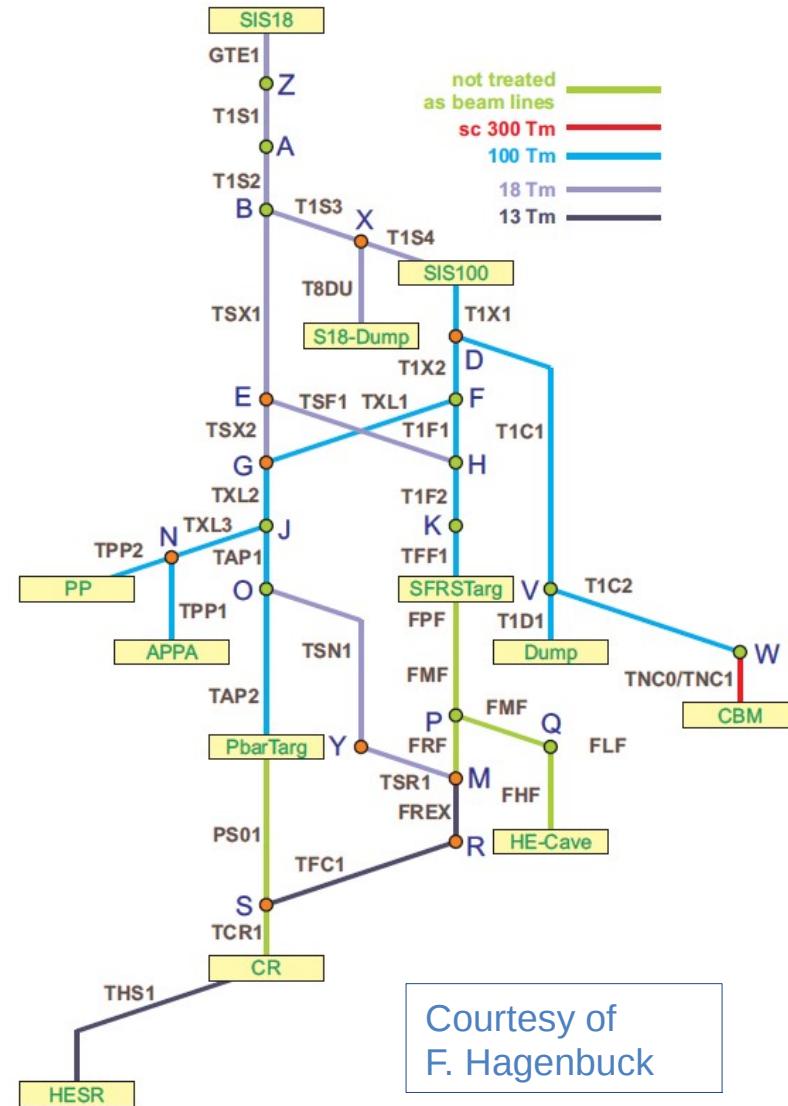
FAIR-High Energy Beam Transport (HEBT)

General requirements for beam diagnostic devices to measure....

... both, **low and high beam intensities**
... both, **slow and fast extracted beams**



$\frac{z}{x}$



Courtesy of
F. Hagenbuck

HEBT Diagnostic Instruments

Diagnostic Device	Quantity (MSV)	Extraction Type	Measured Parameter	Remark
Resonant Transformer	24	Fast	Beam current	
Fast Current Transformer	11	Fast	Bunch charge / time structure	
Particle Detector Combination	16	Slow	Particle number	Measurement of low intensities
Cryogenic Current Comparator	4	Slow	Beam current	Measurement of high intensities
Beam Position Monitor	38	Fast	Centre-of-mass	
SEM-Grid	49	Fast	Transverse profile	Profile & position
Scintillating Screen	16	Fast&Slow	Transverse profile	Profile & position
Multi-Wire Proportional Chamber	34	Slow	Transverse profile	Profile & position
Beam Ind. Fluoresc. / Ionization Profile Monitor	15	Fast&Slow	Transverse profile	Profile & position, high intensities
Beam Loss Monitor	30	Fast&Slow	Beam loss	

Common Acquisition Systems for FAIR

Acquisition System	Measured Parameter	Machines	Detectors
LASSIE	Beam Intensity, Loss, any time dependent signal	SIS18, HEST, SIS100, HEBT, p-Bar Separator, S-FRS, CR, HESR	Scintillator, Ionization Chamber, Secondary Electron Monitor, I/F-, U/F-device
CUPID	Beam Profile	SIS18, HEST, SIS100, HEBT, p-Bar Separator, S-FRS, CR, HESR	Scintillating Screen
POLAND	Beam Profile	SIS100, HEBT, p-Bar Separator, S-FRS, CR, HESR	SEM-Grid, Multi-Wire Proportional Chamber
TOPOS	Beam Position	SIS18, SIS100, CR, HESR	Shoe-Box BPM



BEAM INTENSITY

Intensity Measurement - Overview

SIS100

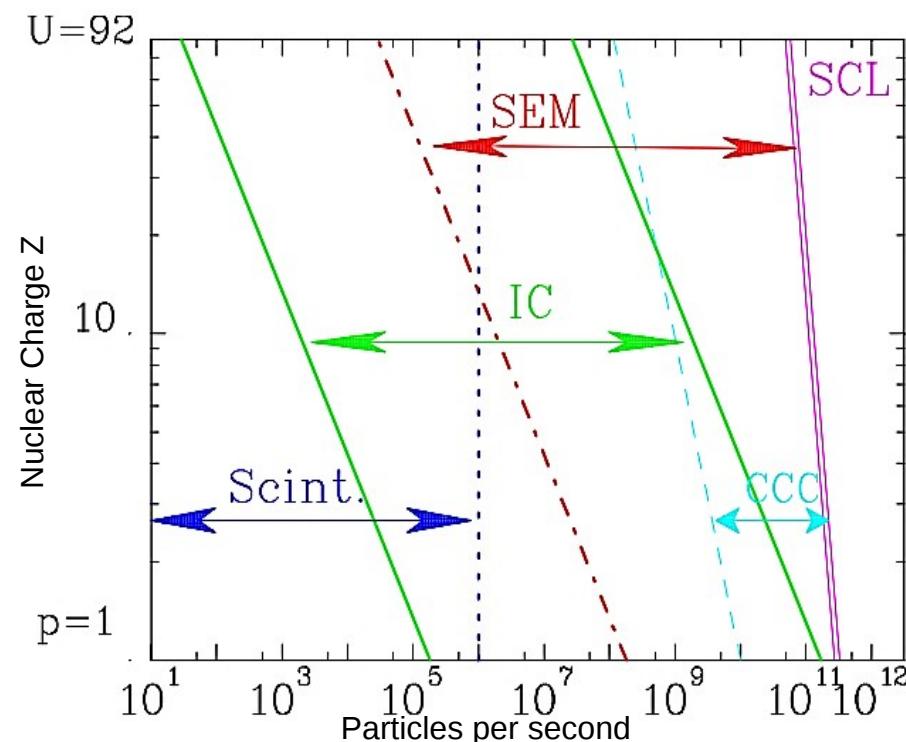
System		No. of pcs.	Task
DCT	DC Current Transformer	1	Precise determination of stored and accelerated dc beam current, mid-range to high dc beam intensity, 10 kHz bandwidth, drawback: interference artefacts at certain revolution frequencies
N-DCCT	Novel DC Current Transformer	1	measurement of mid-range to high beam intensities inside SIS100 with high input bandwidth from dc to several kHz current signal.
FCT	Fast Current Transformer	2	#1: intensity measurement, not 'optimized' for large bandwidth #2: bunch shape, tomography, large bandwidth (9 kHz - 650 MHz)
Stopper	Beam Stopper	6	Beam stoppers will be equipped with SEM detector for relative intensity measurements
BLM	Beam Loss Monitor	200	CERN-type BLMIs, ionization chambers

HEBT

System		No. of pcs.	Task
RT	Resonant Transformer	24	Low intensities of fast extracted beams
FCT	Fast Current Transformer	11	Mid to high intensities of fast extracted beams
CCC	Cryogenic Current Comparator	4	High intensities of slow extracted beams
PDC	Particle Detector Combination	16	Scintillator: Low intensities of slow extracted beams Secondary Electron Emission Monitor: high intensities of slow extr. beams
IC	Ionization Chamber	34	Mid to high intensities of slow extracted beams
BLM	Beam Loss Monitor	30	Scintillating counters

Comparison Current Measurement

- Standard Beam current measurement techniques
 - Current Transformers
 - Measurement of beam's magnetic field
 - Not dependent on energy
 - Detection threshold $\sim 1\mu\text{A}$
 - Faraday cups
 - Measurement of beams electric charges
 - Destructive techniques
 - For low energy only
 - Current down to 10 pA with low bandwidth
 - Particle detectors (Scintillators, IC, SEM)
 - Detection of particles energy loss in matter
 - Used for lower currents at higher energies



Working ranges of the spill-intensity monitors
used for slow extraction at GSI
(SCL: space charge limit)

Courtesy of
F. Kurian

DC Current Transformer (DCT)

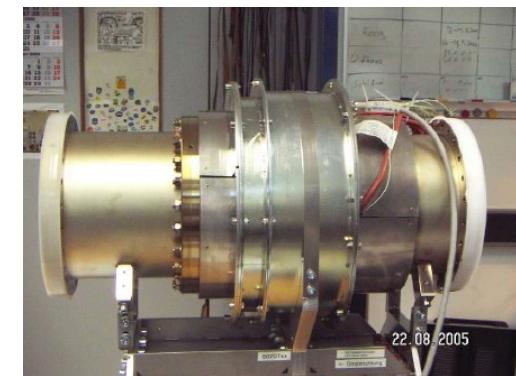
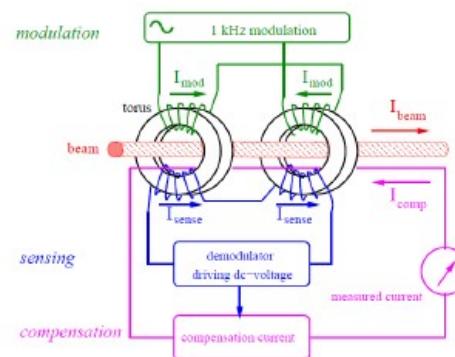
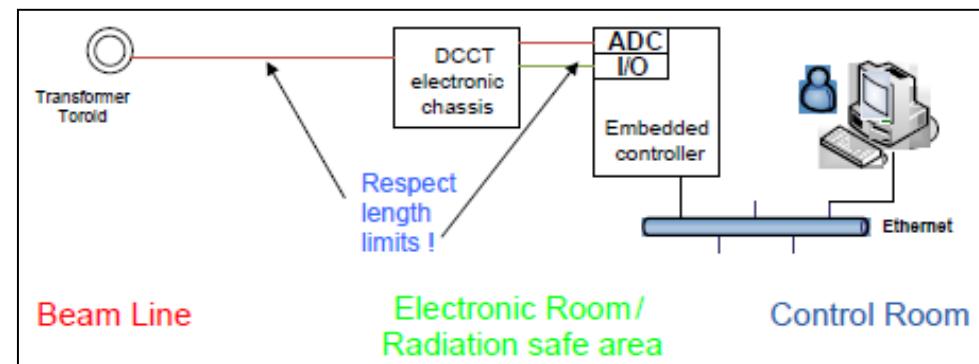
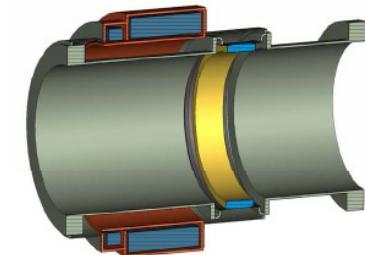
Goal:

- determination of dc beam current
- typical meas. range: **10 μ A – 20 A**

Specifications

Full scale ranges	$\pm 20\text{mA}$, $\pm 200\text{ mA}$, $\pm 2\text{A}$, $\pm 20\text{A}$
Range control	2 TTL lines on rear panel DB9
Output	$\pm 10\text{ V}$
Output over range	up to $\pm 12\text{V}$
Output bandwidth (-3dB)	8 kHz in 20-mA Range 10 kHz in other ranges
Response time (@ 90%)	< 50 μs
Resolution	< 5 $\mu\text{A}/\sqrt{\text{Hz}}$
Standard model	< 1 $\mu\text{A}/\sqrt{\text{Hz}}$
High Resolution model	< 0.5 $\mu\text{A}/\sqrt{\text{Hz}}$
Very High Resolution model	$\pm 0.1\%$ \pm zero-offset \pm magnetic field sensitivity \pm temperature drift
Output accuracy	< 0.1%
Linearity error	< 0.5 $\mu\text{A}/\text{K}$ typ.
Temperature coefficient	-40...80°C
Operating temperature	100 Ω
Output impedance	10mA max, source or sink
Output current	Isolated BNC on rear panel and front panel
Output connectors	Injects +100mA in sensor TTL line on rear panel (DB9) 10-turn floating calibration winding on sensor from external source (2A max, Z > 100 Ω)
Test function	Isolated BNC on rear panel and front panel
Test control	(2A max, Z > 100 Ω)
Calibration winding	
Calibration current	
Calibration connectors	

Commercial 'New Parametric' Current Transformer
(Bergoz Instrumentation)



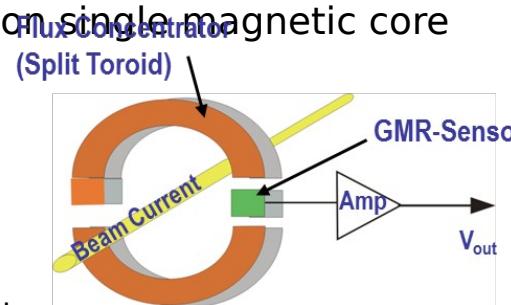
Novel DC Current Transformer (NDCCT)

Goals:

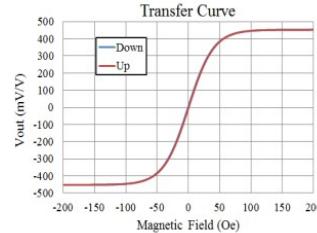
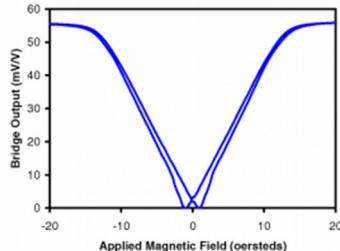
- precise online measurement of accelerated and stored beams with large dynamic range of beam intensities and bunch frequencies (eg. MHz \square standard DCCT)
- desired meas. range: **100 μ A - 150 A**
- desired input bandwidth: dc - several kHz
- combination of 2 different transformers on single magnetic core

Basic Principle:

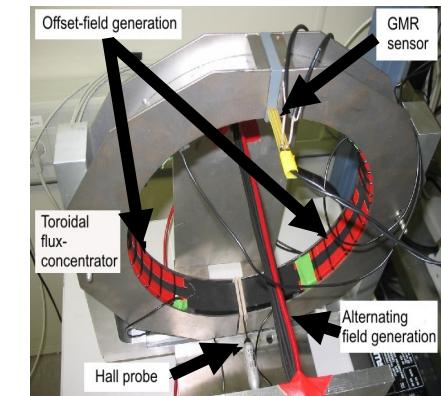
- clip-on Ampere-meter design
- split toroid to allow dismounting before bake-out
- soft-magnetic flux concentrator (amorph. VITROVAC®)
- gap with induction of 80 μ T @ 1 A beam current
- sensitive GMR magnetic field sensor (resolution: 10^{-9} T/ $\sqrt{\text{Hz}}$) or TMR sensor (resolution down to 10^{-11} T/ $\sqrt{\text{Hz}}$)



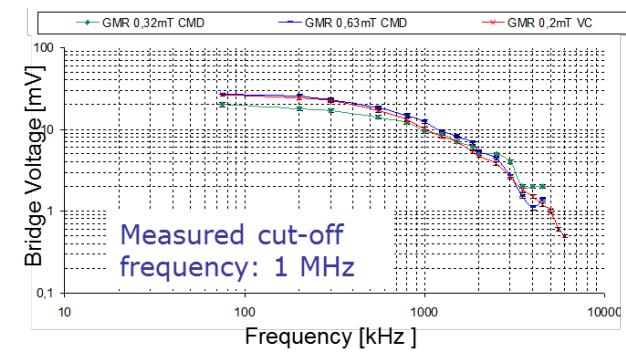
Giant Magn. Res. vs. Tunneling Magn. Resist.:



N-DCCT Test Setup



Frequency Response (GMR + Pre-Amp)

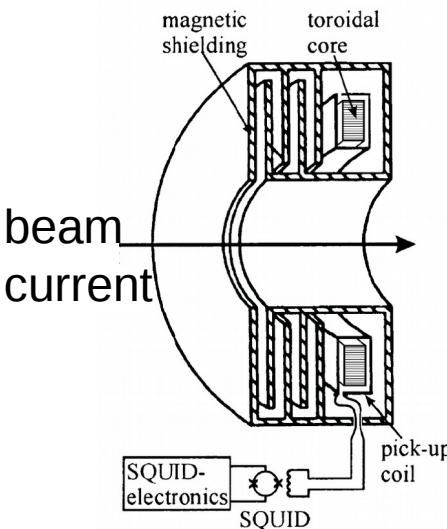


Cryogenic Current Comparator CCC (HEBT)

Role in HEBT Section

- online current monitoring for **slow extracted beams**
- beam current **below threshold of regular transformers**
- **desired meas. range: 0.5 nA - 100 µA**

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, HI Jena, MPI-K Heidelberg, HIT Heidelberg, GSI
- resolution improvement by optimal **selection of core material**

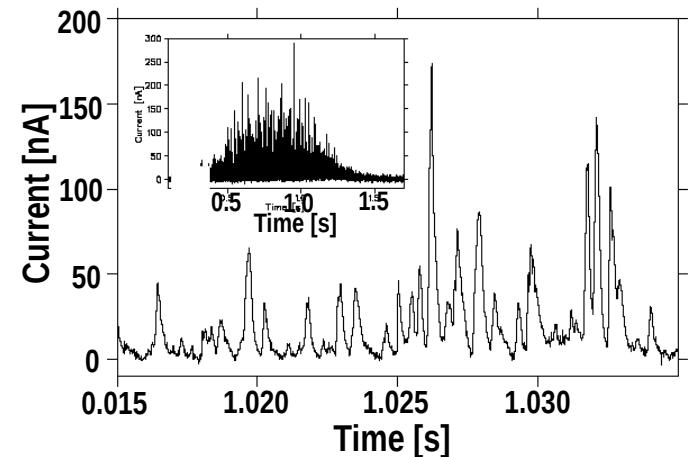
- ▲ GSI prototype resolution:

8 nA (1 kHz readout) → 2×10⁹ U²⁸⁺/s

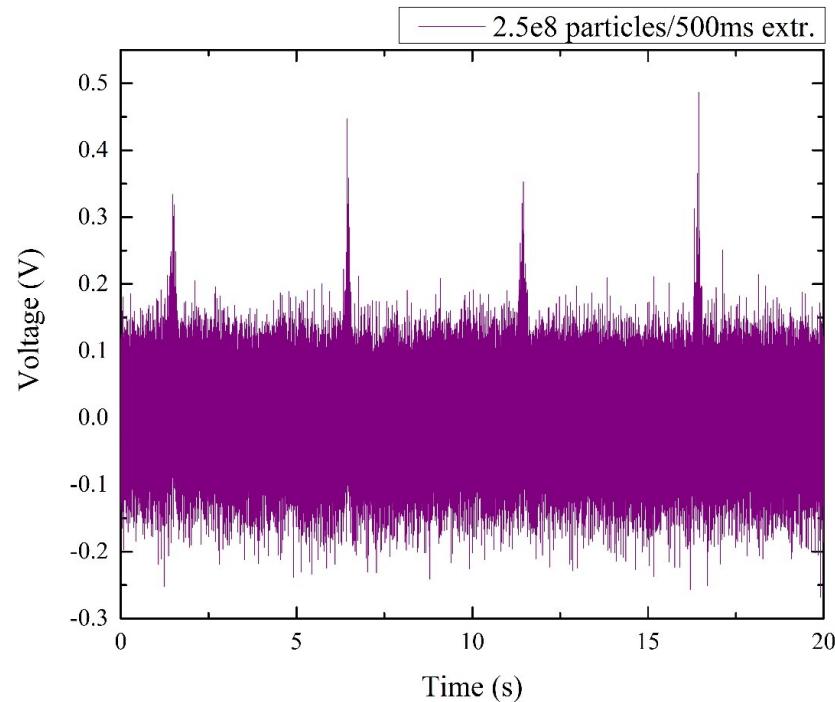
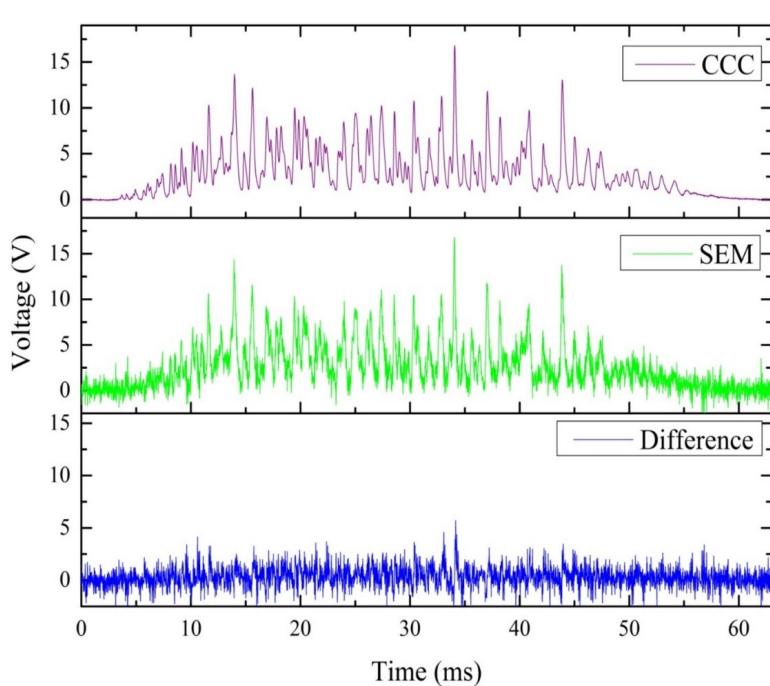
GSI prototype in 1997:



7×10^9 Ar¹¹⁺ at 300 MeV/u within 1.2 s, readout 20 µs:



Comparison CCC / SEM, Spill Structure



- Comparison of the spill structure measured by CCC and SEM for the 600 MeV particles of Ni^{26+} extracted over 64 ms.
- Both the SEM and CCC signals are filtered by low pass filter of 10 kHz
- Spill structure with cut-off frequency of 10 KHz (given by the Anti-Alias filter)
- Spill duration 350 ms, average current 2 nA signal to noise ratio SNR = 1.73 (4.78 dB)

Courtesy of
F. Kurian

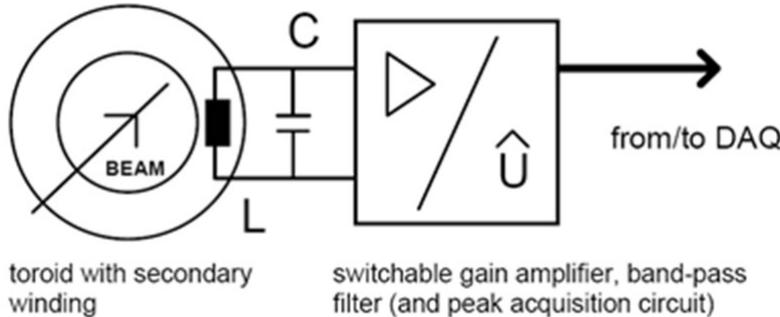
Resonant Transformer – RT

Goal:

- determination of total electric charge of a bunched particle beam
- built-in calibration using precision pulser
- typical meas. range: **10 pC – 10 µC**
($6\text{E}7$ – $6\text{E}13$ protons)

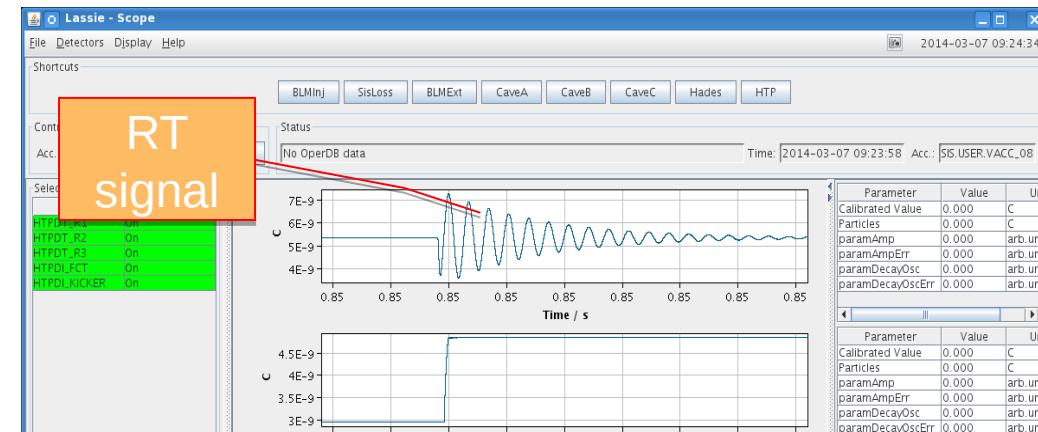
Technical Specs:

Number of elements	36	
Overall length	mm	400
Horizontal aperture	mm	220
Vertical aperture	mm	220
Acceptable peak current	A	≤ 150
Full scale	nC	1...10000
Charge resolution		$\leq 1\%$ full scale
Built-in calibration		required



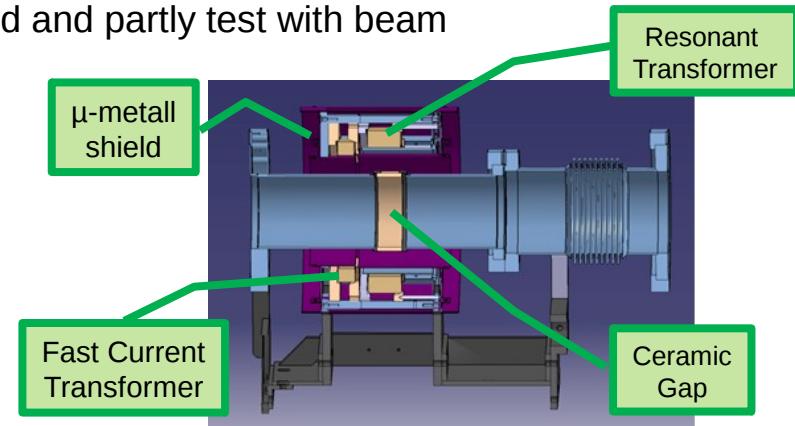
Contract situation:

DAQ: Slovenian InKind (signed)



Prototype:

Mechanics, Electronics, detector, DAQ were designed, build and partly test with beam

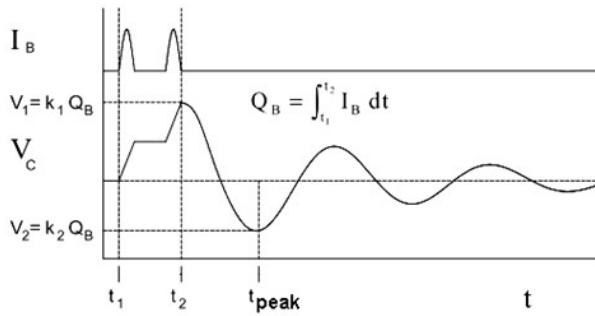


RT Improvement by Post-Processing

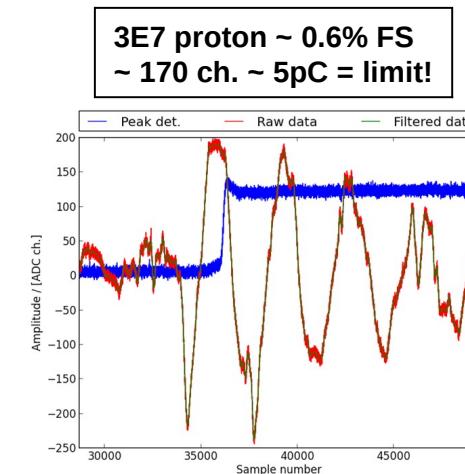
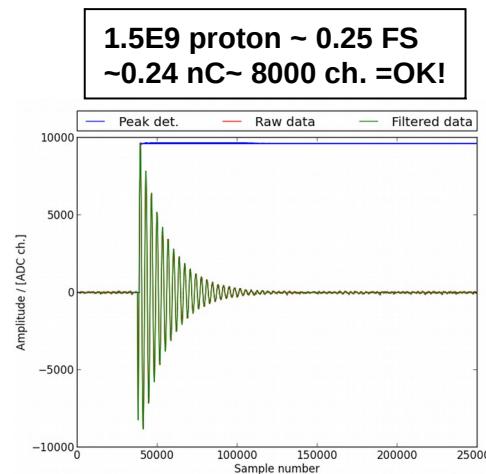
Basic Principle:

- bunch of charged particles excites damped oscillation in electronic circuit of the RT
 - oscillation amplitude is proportional to total charge of particle bunch
 - existing GSI RT: signal fed to peak detector
 - prone to noise at maximum position
 - large dynamic range: ~ 120 dB.
 - typical resolution: ~ 10 pC_{RMS} (6×10^7 protons)
 - for high current operation resolution drops to 100 nC (6×10^{11} protons)
- insufficient e.g. for transmission control

Bunch Charge determination:



[from: "A High Stability Intensity Monitoring System", M. A. Clarke-Gayther, RAL, Didcot (UK), presented on EPAC, Sitges (E) 1996]



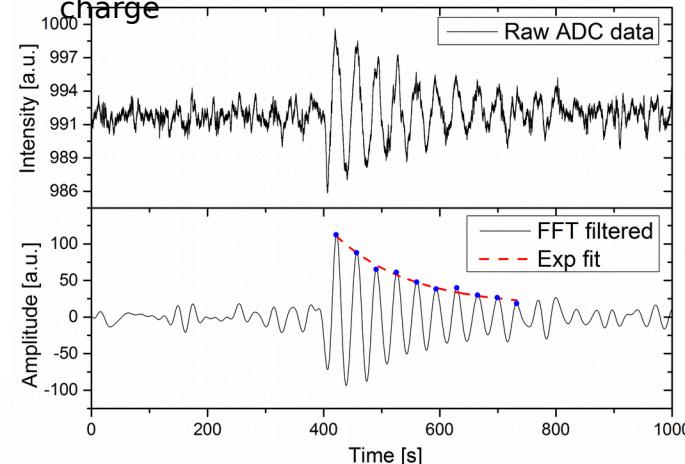
Courtesy of A. Reiter

Post-Processing of RT Oscillation Data:

- idea: resonant frequency ω_0 and decay time constant λ , are fixed by hardware
- omission of inexact peak detector
- **improved RT resolution by digitization of oscillation data, FFT filtering and envelope fit**

Algorithm for bunch charge determination:

- FFT filtering and offset correction
- identification of maxima and minima until pre-set S/N value crossed
- robust estimator of exponential decay curve
- evaluation of amplitude \propto total pulse charge



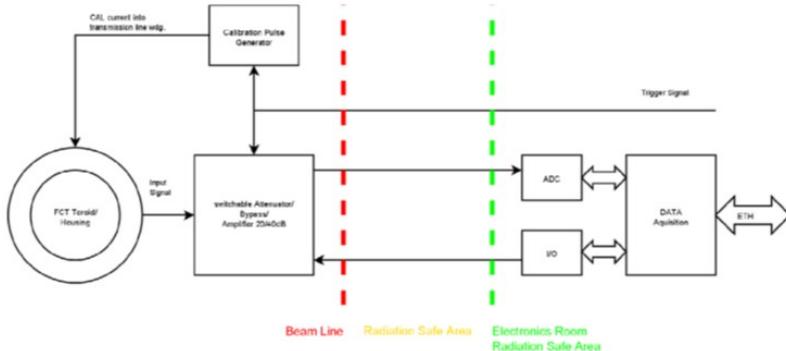
Fast Current Transformer – FCT

Goal:

- pulse current measurement
- typical meas. range: **30 μ A – 150 A**
- determination of the longitudinal bunch structure for fast extracted beams
- built-in calibration using precision pulser

Technical Specs:

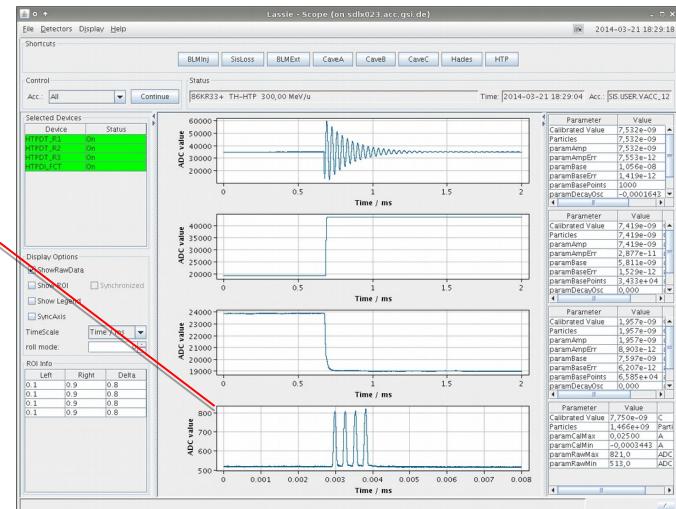
Number of elements		16 (module 0-6)
Overall length	mm	tbd (together with RT)
Horizontal aperture	mm	150
Vertical aperture	mm	150
Acceptable peak current	A	< 150
Turns ratio of toroids	-	1:10 ... 1:100
Resolution, full bandwidth	μ A _{pp}	~ 100
Bandwidth (-3dB)	kHz	3 – 650000
Number of gain ranges		6
Full scale current	mA	1 ... 150000
Current resolution		< 3% full scale
Max. bake out temperature	°C	300
Built-in calibration source		needed



Contract situation:

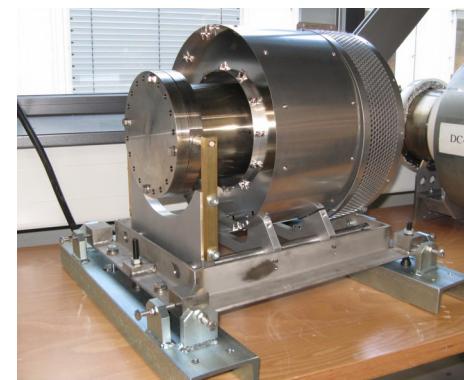
DAQ: Slovenian InKind (signed)

FCT
signal



Prototype:

Mechanics, Electronics, detector, DAQ were designed, build and partly test with beam



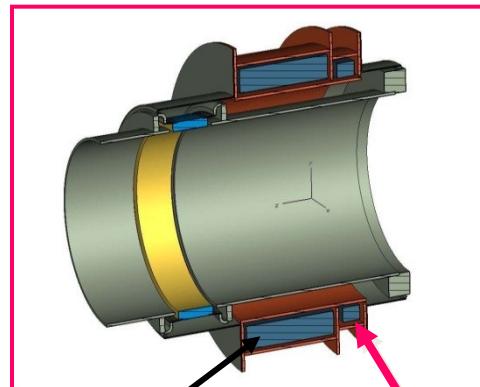
Ring FCT: Longitudinal Bunch Diagnostics

Commercial Fast Current Transformer
(Bergoz Instrumentation)



**Exemplary realization at
GSI**

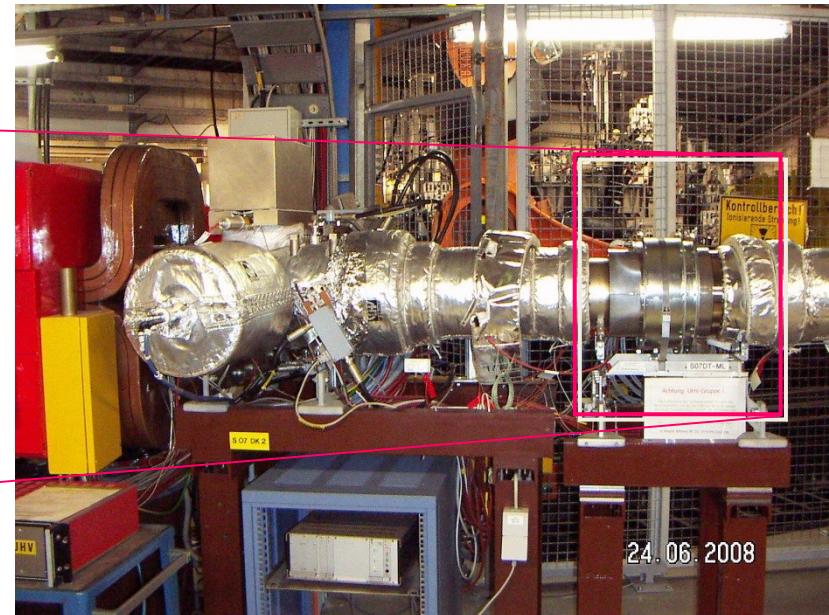
DCCT



**FCT installed in same
shield as DCCT**

Fast Current Transformer (FCT) has extremely wide bandwidth

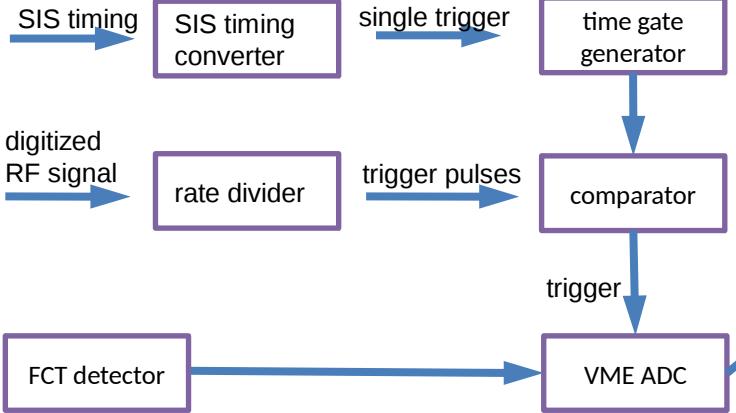
- $9 \text{ kHz} < f < 650 \text{ MHz}$
- 50 Windings
- resolution 1V/A in 50 Ohm
- $\sim 30 \mu\text{A}$ for FCT with 500 MHz bandwidth
- upper pulse current limit 1000 A
- max. rms current 25 A



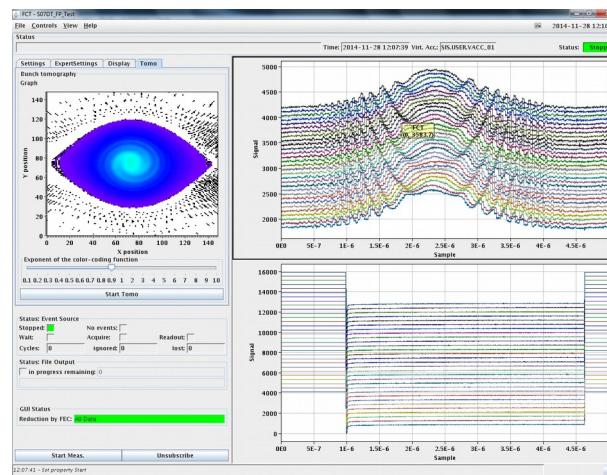
FCT signal was amplified by 20 dB (miteq AM-1422) and digitized a 500 Ms/s ADC via $\sim 100\text{m}$ HQ coax cable

Ring FCT: DAQ Developments

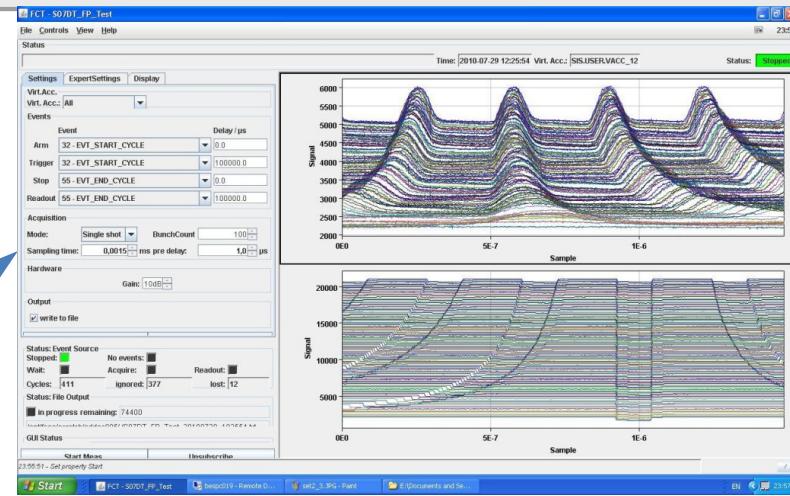
Scheme for FCT DAQ



Development of online tomography
and tests with beam in SIS18

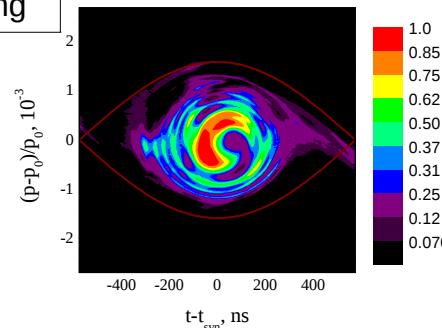


Courtesy of:
O. Chorniy,
H. Bräuning

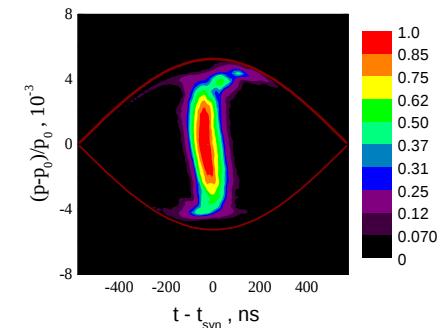


Measurement of 4 bunch acceleration in SIS 18

Main FCT application: **bunch dynamics during RF manipulations**. Example: SIS18 beam measurements using 8 bit LeCroy oscilloscope



RF capture at top energy



Fast compression at top energy

Particle Detector Combination – PDC

combination of plastic scintillator & secondary electron emission monitor

Goal:

- beam intensities and transmission measurements for slow extracted beams
- typical measurement ranges:

scintillator: **100 – 1E6 particles/s**
 SEM: **1E5 – 1E11 particles/s**

Prototype:

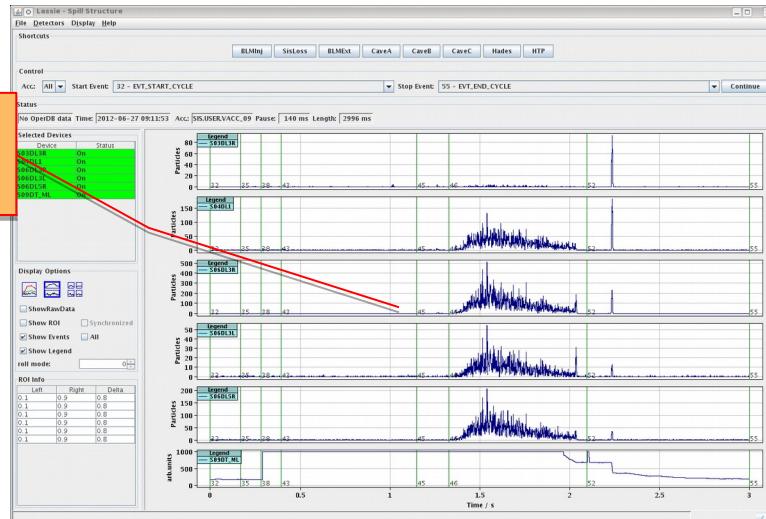
Mechanics, Electronics, detector, DAQ are currently to be finalized, build and partly tested with beam



Contract situation:

DAQ: Slovenian InKind (signed)

scintillator signal

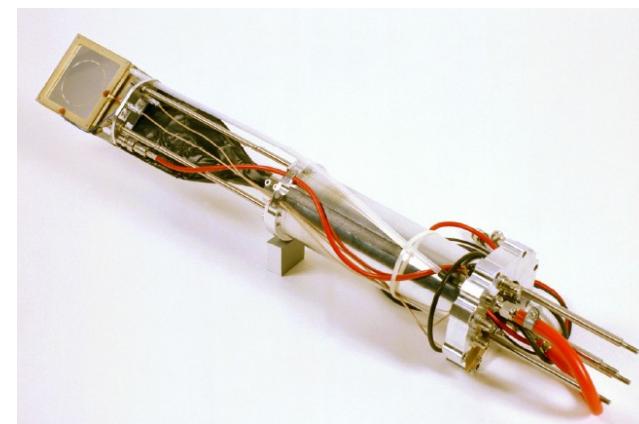
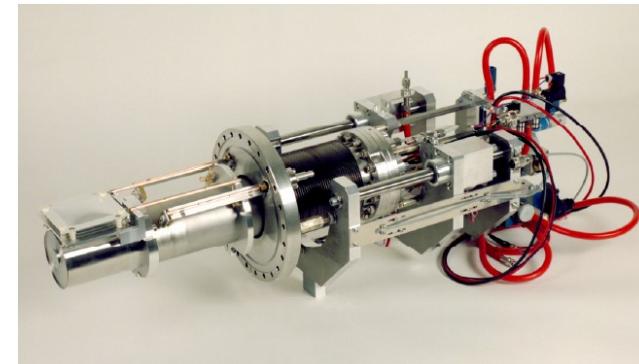


Contract situation:

Detector, Mechanics, DAQ, HV, Long Cables, Detector Gas: GSI InKind (signed)
 Pneumatic Drive and Control: Slovenian InKind (signed)
 Vacuum Chambers: India InKind (in preparation)

PDC – Technical Specs

PDC: Number of elements in HEBT		Total: 21 Module 0-3: 16
Overall length	mm	460 – 790*
Horizontal aperture	mm	150
Vertical aperture	mm	150
Scintillator – 2 types (ions / protons)		
Scintillator material		BC400, diamond tool finish, sensitive for alpha, beta and gamma rays
Scintillator thickness (ions)	mm	1 – 3
Scintillator thickness (protons)	mm	5
Detection area	mm ²	100 – x
High voltage	kV	- 2.5
Max number of particles	pps	10 ⁶
SEM		
Detection width ø	mm	100 – x
Gap size	mm	5
High voltage	kV	+ 0.3
Min. number of particles	pps	10 ⁵ (U), 10 ⁸ (p)
Min. secondary current	pA	10
Number of electronic ranges		3
PDC DAQ		
time resolution	MHz	max. 1
time slice	µs	min. 1
cycle length	s	0.25 - 30
resolvable time structure	ms	<1



- * Length of diagnostic chamber depends on number of BD components in chamber at defined position
- Standard detector sensitive area 100 – x mm (depend on beam size at defined position)

Ionization Chamber (MWPC/IC)

IC: Ionization chamber

Beam intensity

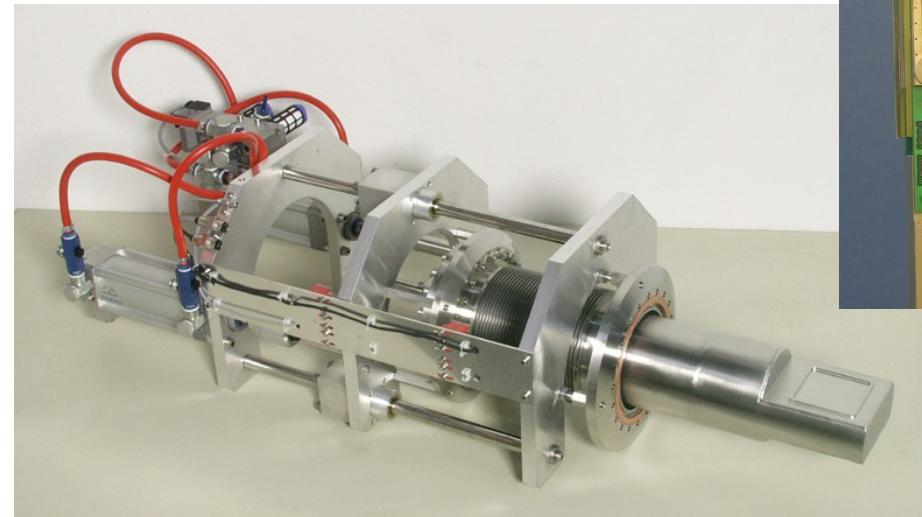


Goal for Ionization Chamber:

- beam intensities and transmission measurement for slow extracted beams
- typical measurement range:

1E4 – 1E9 particles/s

Pneumatic drive with cylindrical housing
for gas detectors
(foil window: 50µm stainless steel)



designed and manufactured by GSI Detector Lab (RBDL)

MWPC: Multi-wire proportional chamber

Beam profile



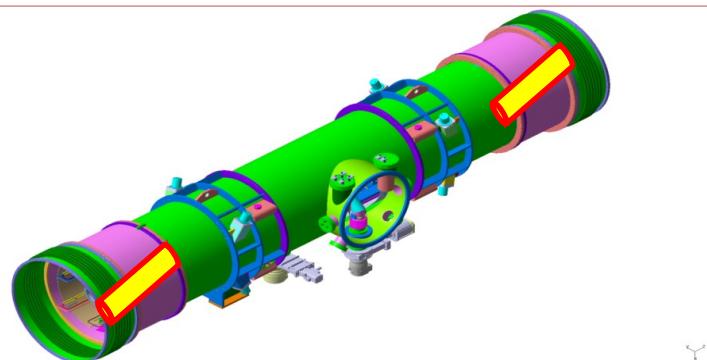
SIS100 Beam Loss Monitors (BLM)

Purchase of 200 pcs. CERN-type BLMs, ie. cylindrical ionization chambers (steel vessel, N₂ gas, 61 parallel plate Al electrodes)

Goal:

- detection of particle shower due to beam loss in SIS100

**BLM are at the moment
not foreseen for machine
protection !!!**

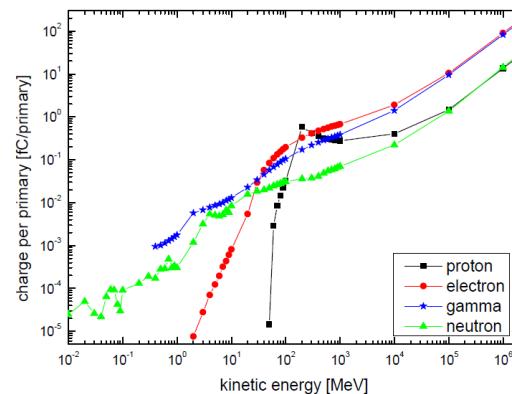


2 BLMI per Quadrupole Doublet: $2 \times 84 = 168$
+ 32 for special locations like Injection, Extraction, etc.
(200 in total).

FLUKA Simulation:

BLMI response on
longitudinal impact of
p, e⁻, γ, n at 10 keV-1 TeV

Courtesy of
P. Kowina, V. Lavrik



At LHC: 6 BLMs per Straight Short Section

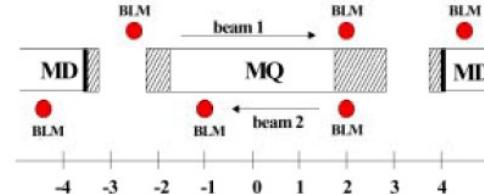
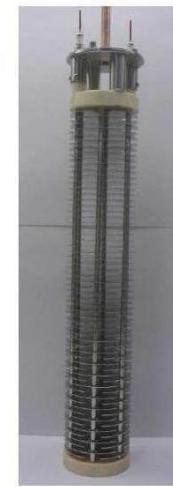
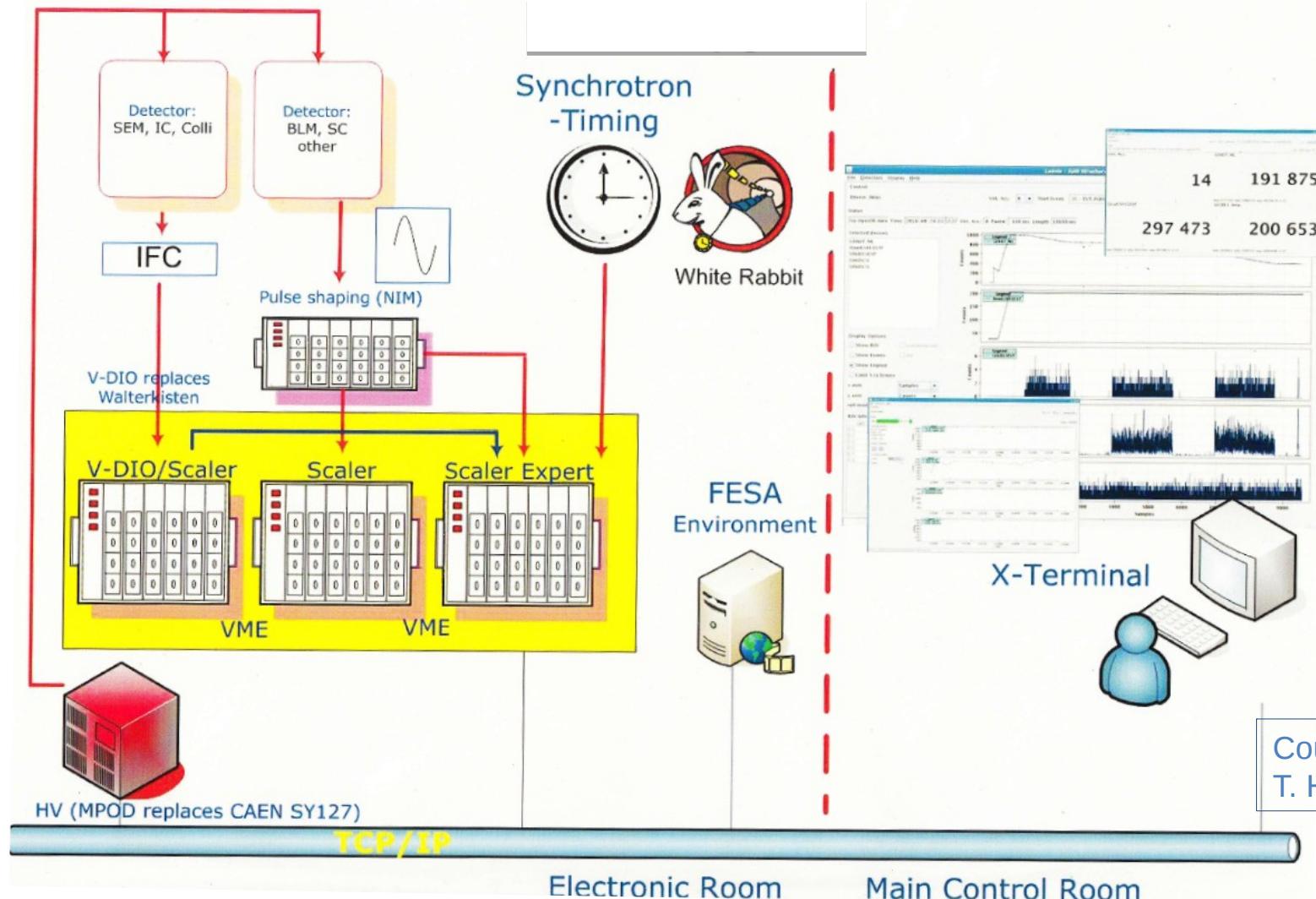


FIGURE 3. Location of the beam loss detectors near to the quadrupole magnets MQ.



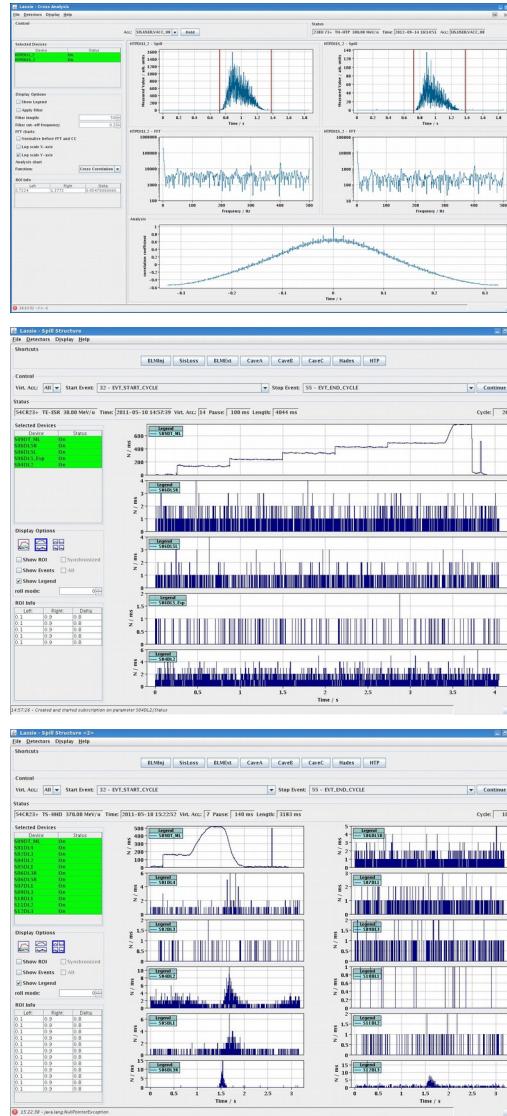
LASSIE

Large Analogue Signal and Scaling Information Environment



Courtesy of
T. Hoffmann

LASSIE Features



- Precursor: ABLASS, i.e. **conversion of analoge signals to frequencies** counted in modular VME systems
- LASSIE designed as **distributed system**, used at all FAIR accelerators in **uTCA** form factor
- not restricted to BI systems, eg. rf signals, magnet ramps etc. using **I/f- and U/f-conversion**
- acquisition, analysis and presentation of time correlated signals
- standard: **sampling at 1 kHz**, high resolution up to 1 MHz
- LASSIE is fully **FESA based**, Java for analysis and display data acquired over 1 accelerator cycle
- **LASA FESA class** designed to handle 200+ channels
 - data **storage of full acc cycles**, min. 15 s with selectable sampling freq.
 - conversion to physical units (particles per second)
 - each scaler presented as separate **device**, integrated spill data over full acc cycle, or between 2 events

Courtesy of
T. Hoffmann



BEAM PROFILE

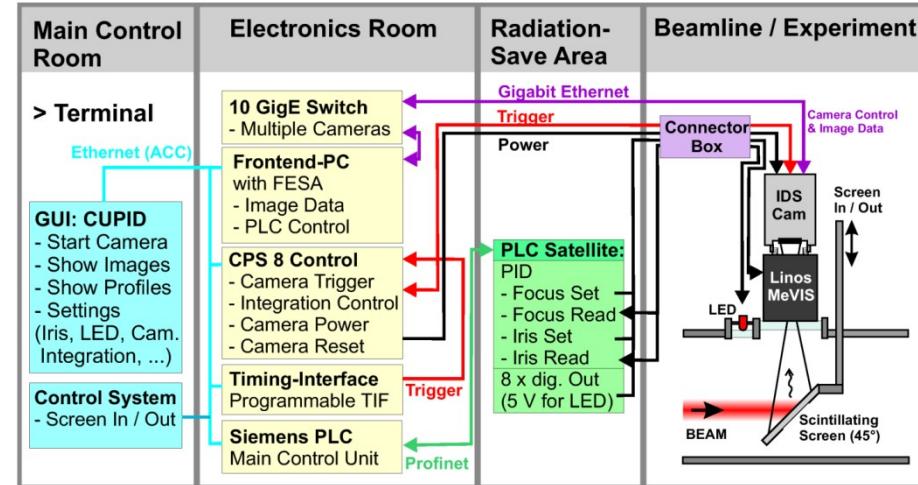
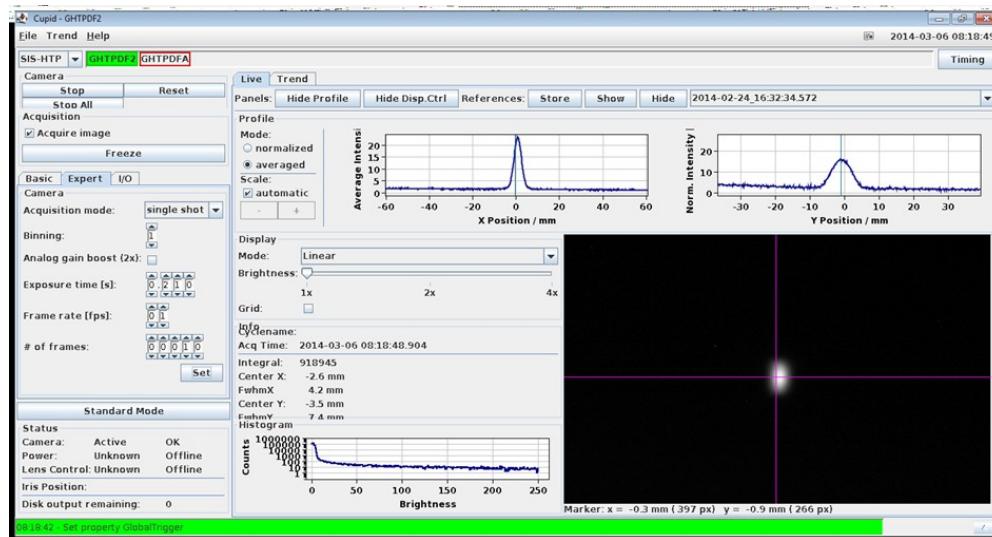
CUPID: Control Unit for Profile and Image Data

Courtesy of B. Walasek-Höhne

- Fully FAIR-conformal System (FESA, IEPLC..)
- Testbed: diagnostic upgrade of HTA (ESR-Cave A)
- Radhard CID cam ('Megarad', Thermo Fisher)
- Framegrabber function available for analog cams

Features:

- digital image acquisition (CMOS GigE camera)
- pre-processing of optical data (rotation, stretching, projections, intensity histogram)
- performance: 15 fps (one client connected)
- two network adapters (ACC, local GigE-network)
- raw image data can be saved for offline analysis
- PLC for control of lens focus, iris settings, LED for calibration



CUPID consists of 2 parts:

I) Data Acquis. and Control using FESA

- Front-end PC
- Processing of image data
- Slow-control using PLC

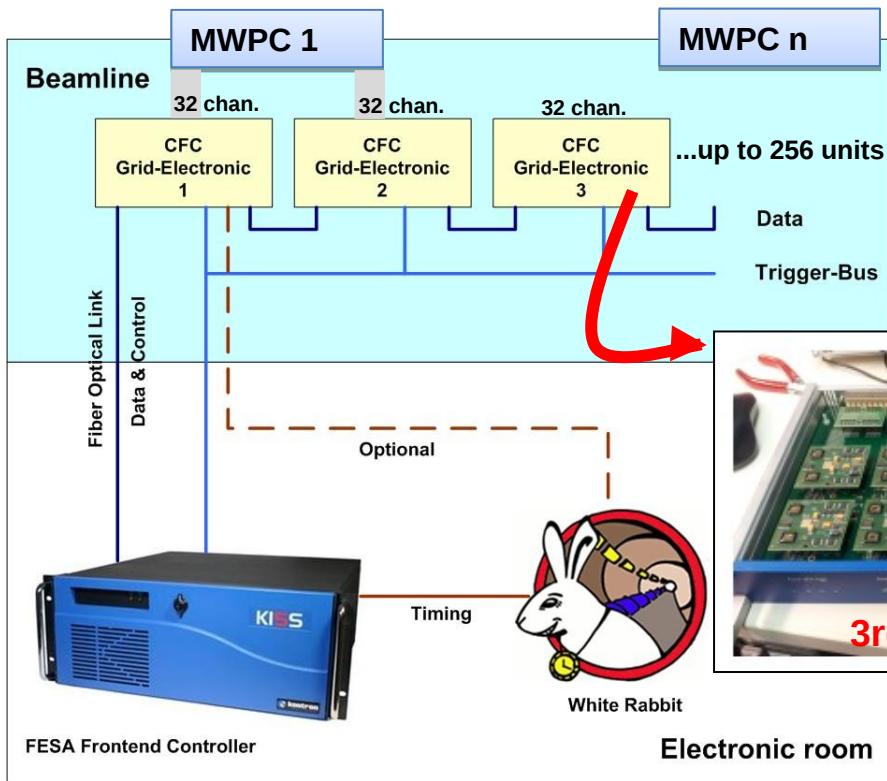
II) Java-based Graphical User Interface

- select and start cameras
- free-run or triggered mode
- adjust camera and iris settings
- display of processed image, hor. and vert. profile, Intensity histogram

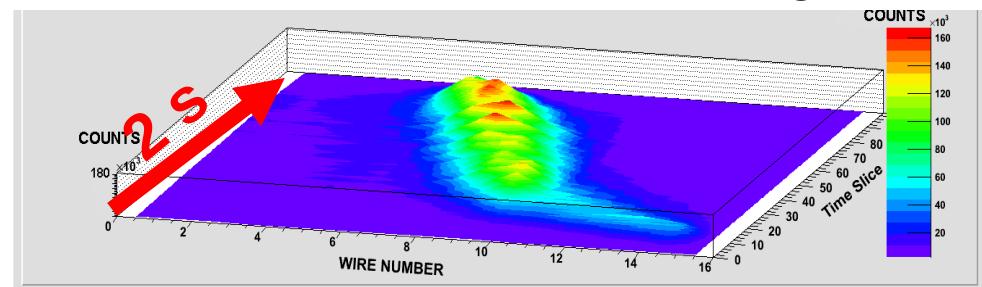
POLAND: PrOfiLe AcquisitioN Digitizer

CFC-Module (H. Flemming, Dep. CSEE)

- 32 input channels, units in daisy chain
- ASIC with two ranges (0.24 / 2.4 pC/Pulse)
- large dynamic range (300 fA – 180 µA)
- output frequency up to 40 MHz
- fully digital interface, FESA drivers available

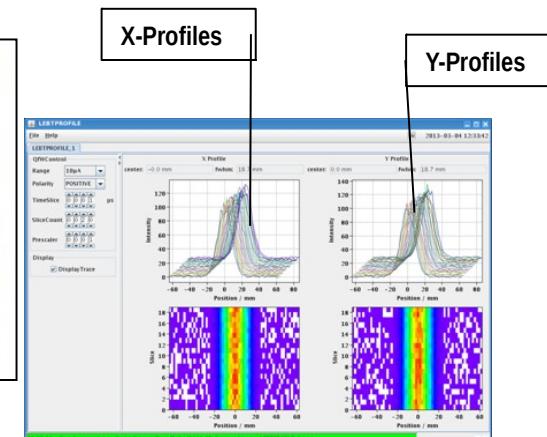


Measurement of slow extraction using MWPC



- $^{40}\text{Ar}^{18+}$ ion beam at 300 MeV/u
- time-dependent beam profiles for 16 wires
- spill duration: 1.8 s, time slices of 20 ms
- for this measurement: beam mismatched on purpose

FESA-Graphical User Interface



Ionization Profile Monitor (IPM) I/III

Magnetic field for electron guidance:

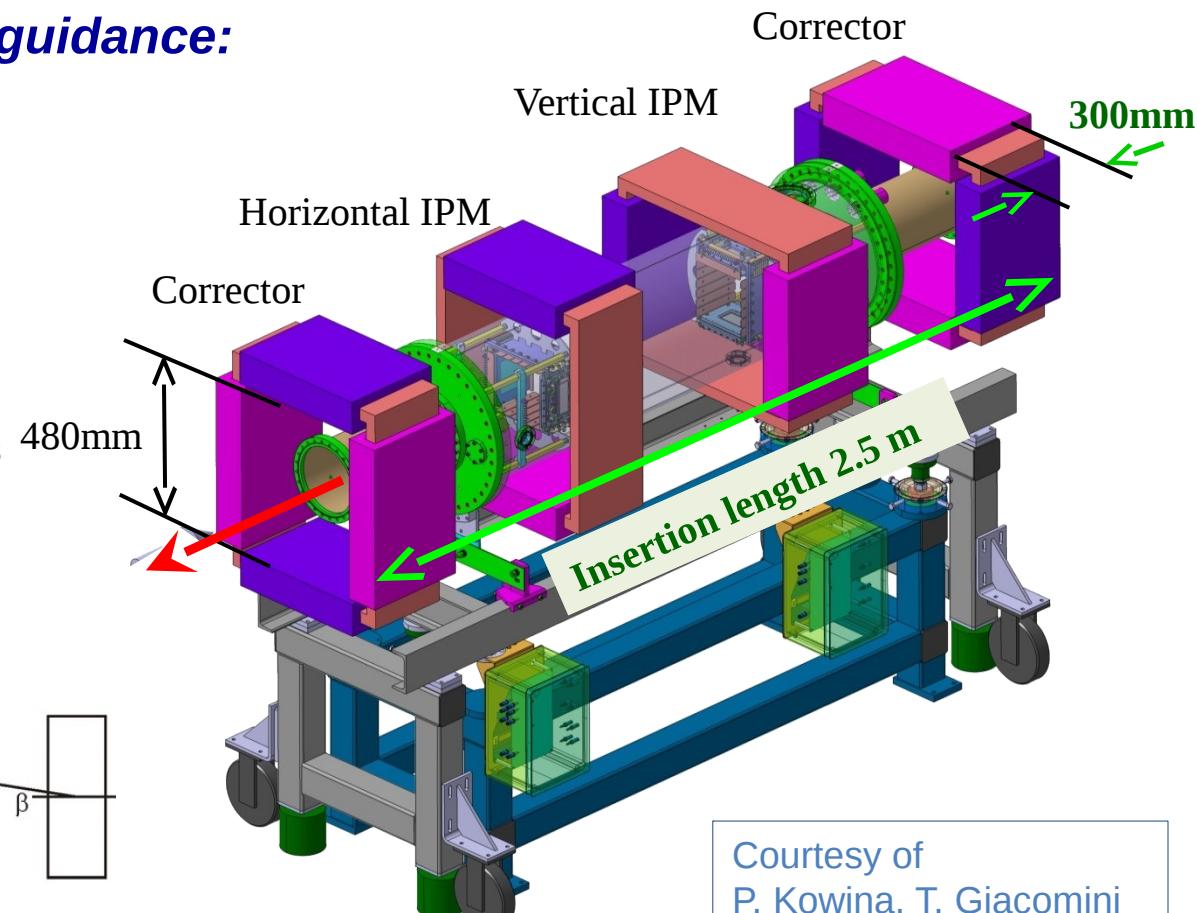
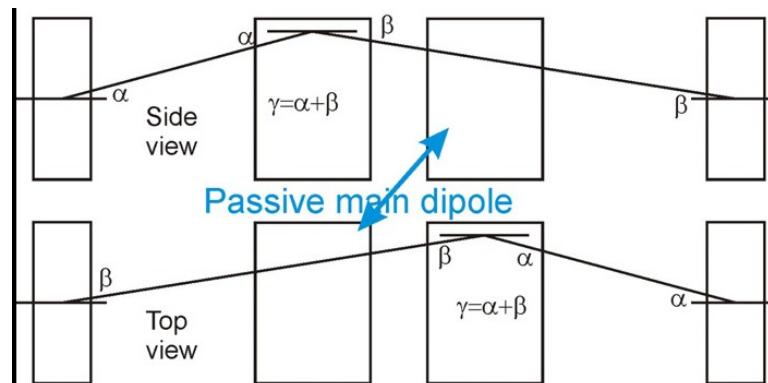
Maximum image distortion:

$$5\% \text{ of beam width} \Rightarrow \Delta B/B < 1\%$$

Challenges:

- High B-field homogeneity of 1%
- Clearance up to 500 mm
- Correctors required to compensate beam steering
- Insertion length 2.5 m incl. correctors
- read-out on $\approx 1 \mu\text{s}$ turn-by-turn scale by multi-anode photo-multiplier

Compensation scheme:



Courtesy of
P. Kowina, T. Giacomini

Design by
G. de Villiers (iThemba Lab), T. Giacomini (GSI)

IPM Prototype at SIS18

Goal:

IPM with high resolution comparable to ESR installation

Hardware:

Phosphor & CCD readout

Insertion length 2.5 m in period S03
installation of magnets foreseen

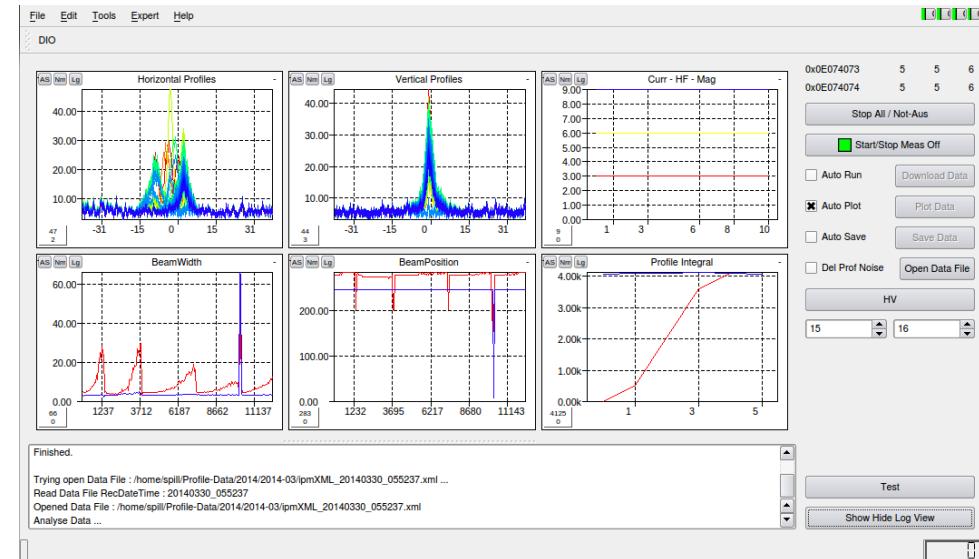
Results: First commissioning at SIS18 done

Specs for SIS18: Approved

SIS100:

Will be almost 1:1 copy
of SIS18-IPM

Courtesy of
P. Kowina, T. Giacomini



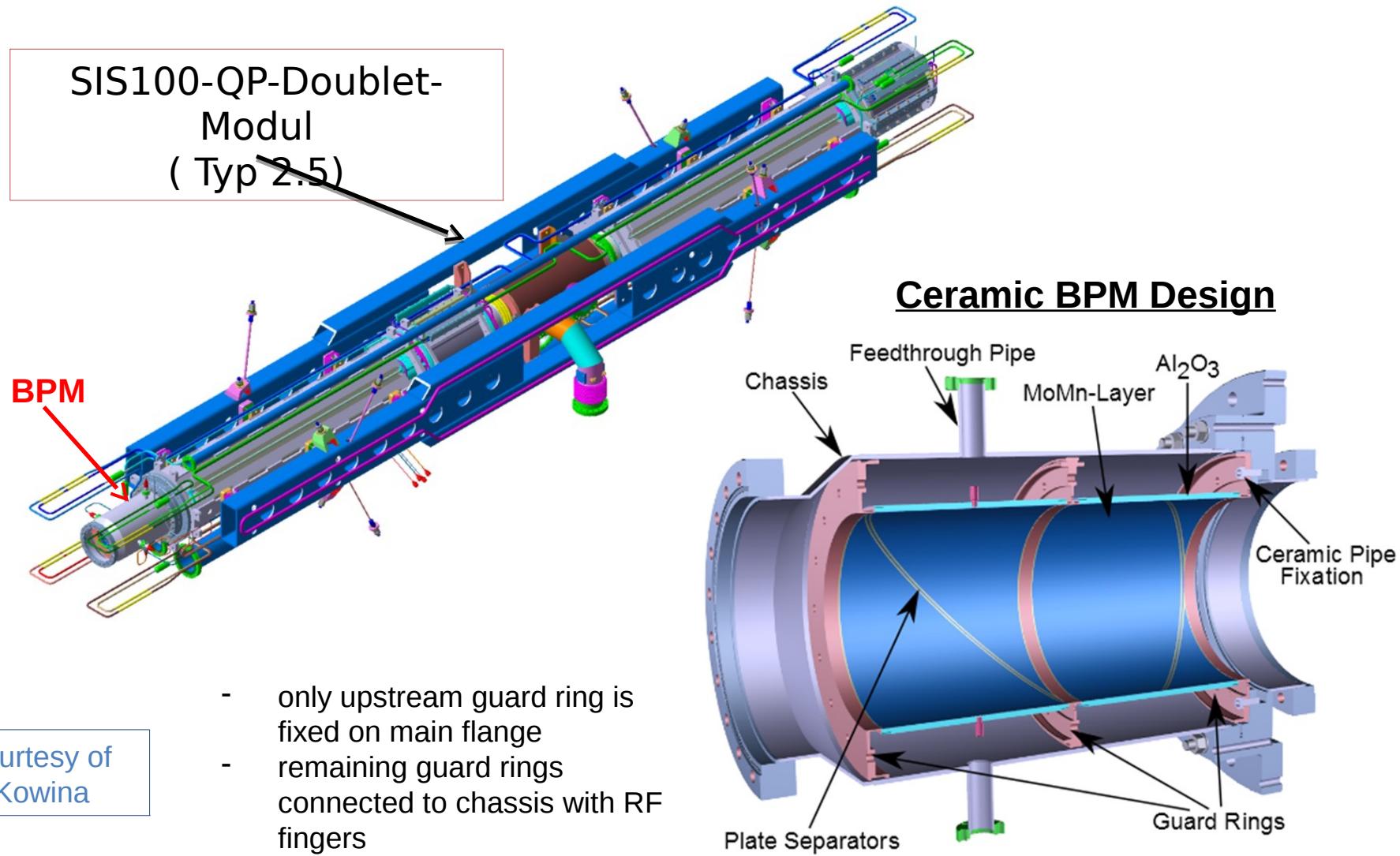
IPM Profile Software

Profiles H & V
Beam Current
Beamwidth
Beamposition
BeamprofileIntegral
Images H & V



BEAM POSITION

SIS100: Cryo Beam Position Monitor (BPM)



Courtesy of
P. Kowina

SIS100 BPM – Technical Specs

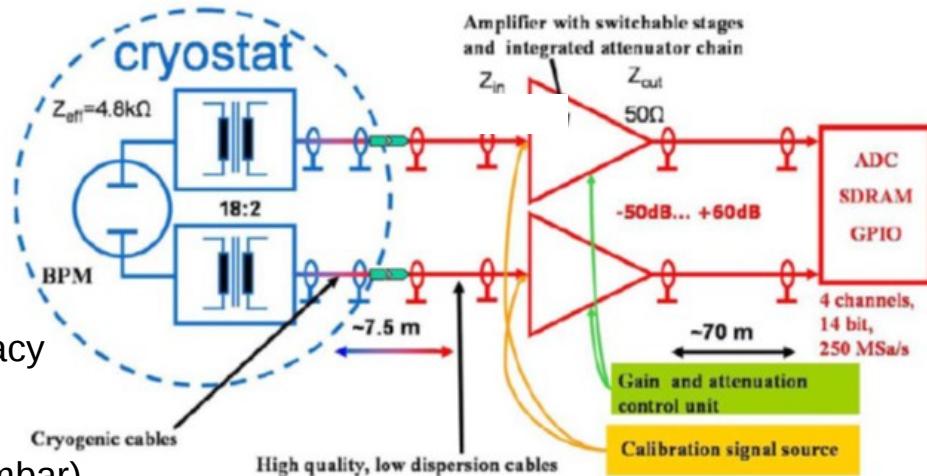
Goal:

- precise beam position measurement
- closed orbit control over whole cycle, also during rf manipulations (bunch compression, acceleration) and different extraction schemes
- use of position data for closed orbit feedback
- open: k-modulation possible?

Requirements

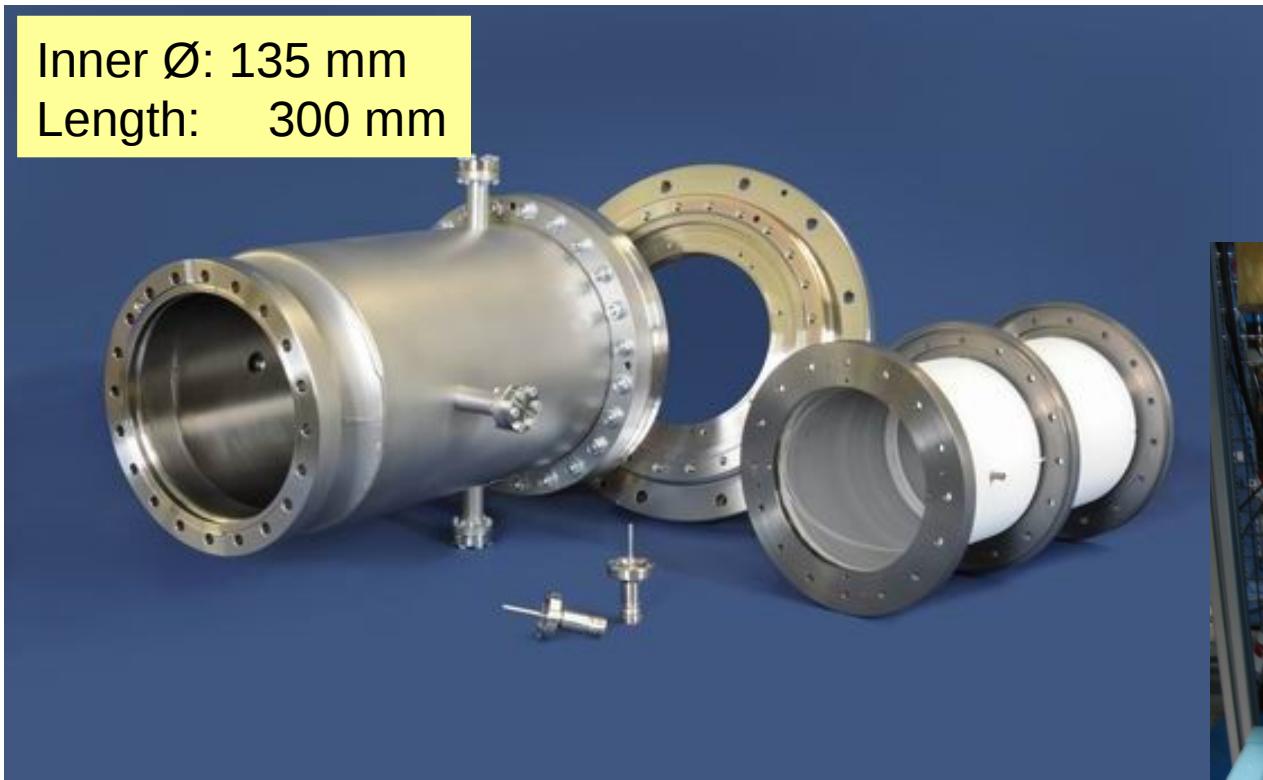
- all BPMs installed in cryo regions (quadrupole cryostats)
- large dynamic range ($1 \mu\text{V} < U_{\text{plate}} < 1 \text{ kV}$, mainly due to variation in bunch length)
- linear cut type BPM is preferred, because:
 - good linearity even for transversally large beams, or inhomogeneous charge distributions, eg. hollow beams
 - bunch length $>>$ BPM length
 - rel. low bunch frequency: 0.5-2.7 MHz
- mech. stability of $\sim 50 \mu\text{m}$ required for 0.5 mm accuracy
- good response in frequency range 0.1-100 MHz
- all components suitable for XHV conditions ($< 10^{-11} \text{ mbar}$)

Number of elements		83
Overall length	mm	400
Horizontal aperture	mm	135
Vertical aperture	mm	135
Pick-up bandwidth	MHz	0.5-100
Resolution (single bunch)	mm	0.5
Min. bunch current for given resolution	μA_{rms}	20
Max. bunched beam current	A	100
Output rate for closed-orbit feedback	kHz	1



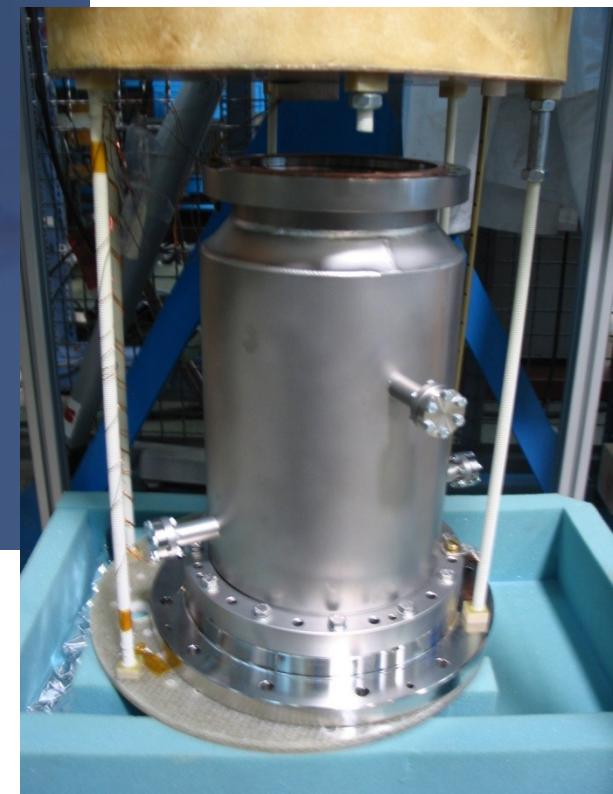
BPM Prototype / Cryo Tests

Inner Ø: 135 mm
Length: 300 mm



Courtesy of
P. Kowina

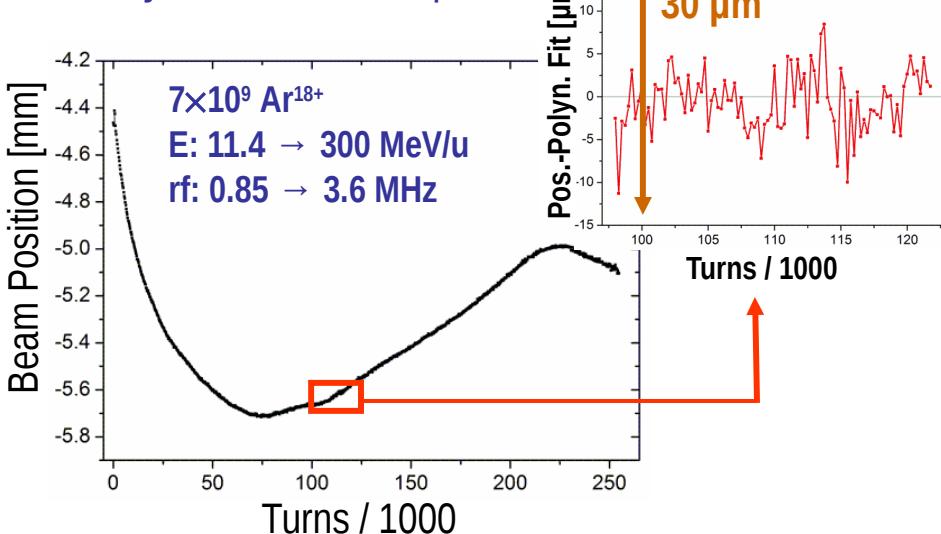
Preparation of cryo
tests inside IHe dewar



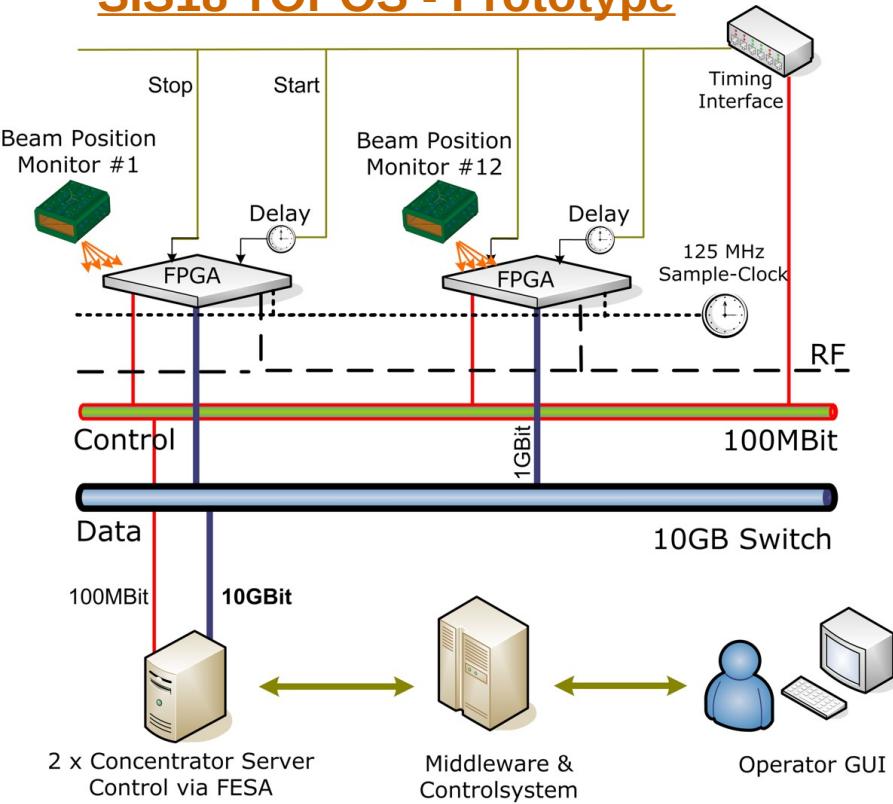
SIS18-Prototype: Tune, Orbit and POSITION: TOPOS

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 TOPOS - Prototype



- ▲ 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)

SIS100 BPM: DAQ Design

Hardware Layout:

- 24 LIBERA Hadron Platform B stations (Instrumentation Technologies)
- 84 BPM modules
- 0.04 – 55 MHz RF front end bandwidth
- 250 MSa/s sampling frequency
- 16 bit ADC, 12 effective bits

4 Principal Modes of Operation:

1. Bunch-by-bunch mode

- closed orbit, X,Y vs. BPM
- Trending X,Y vs. time/bunch
- Trending mean over n BPMs
- Sum of amplitudes vs. time/bunch
- Tune: FFT of BbB data

2. Raw ADC data mode

- subset of 14 BPMs vs. time/samples

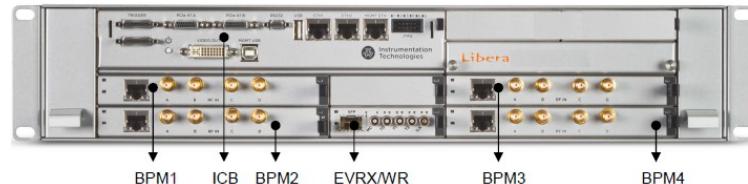
3. Zero ADC calibration mode

- R-,L-,U-,D-offsets for all BPMs

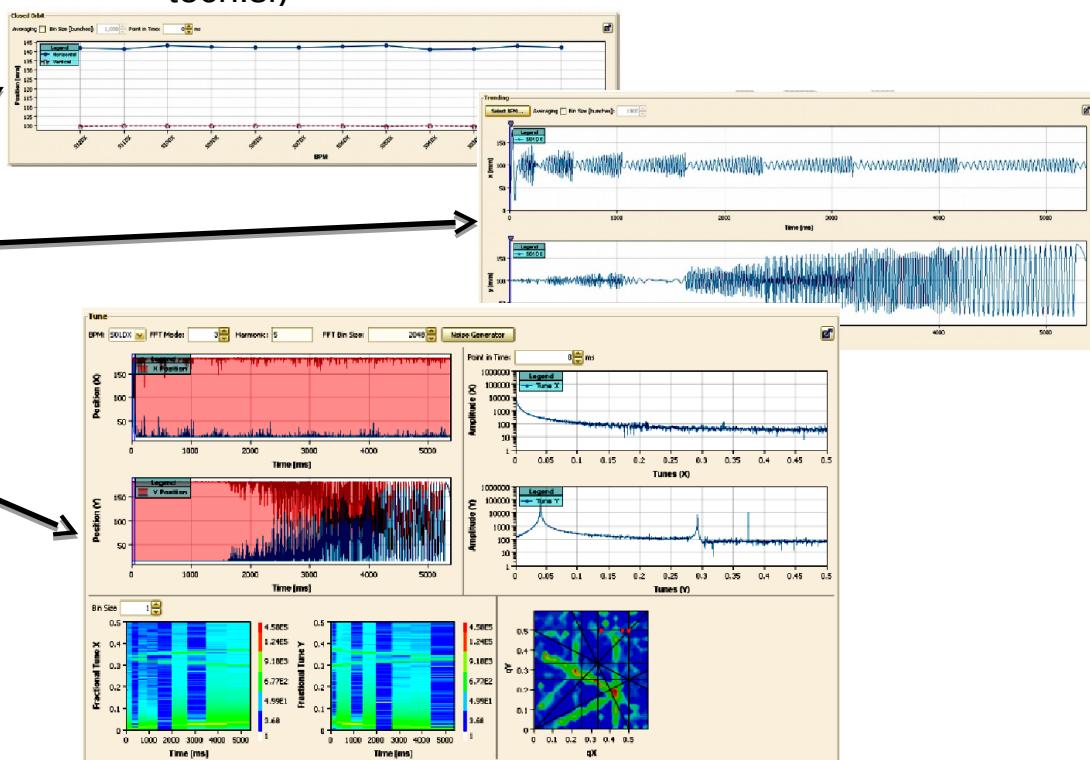
4. Position calibration mode

- X_{off} , Y_{off} for all BPMs

Libera Hadron Platform B



(courtesy Instrumentation Technologies, www.i-tech.si)



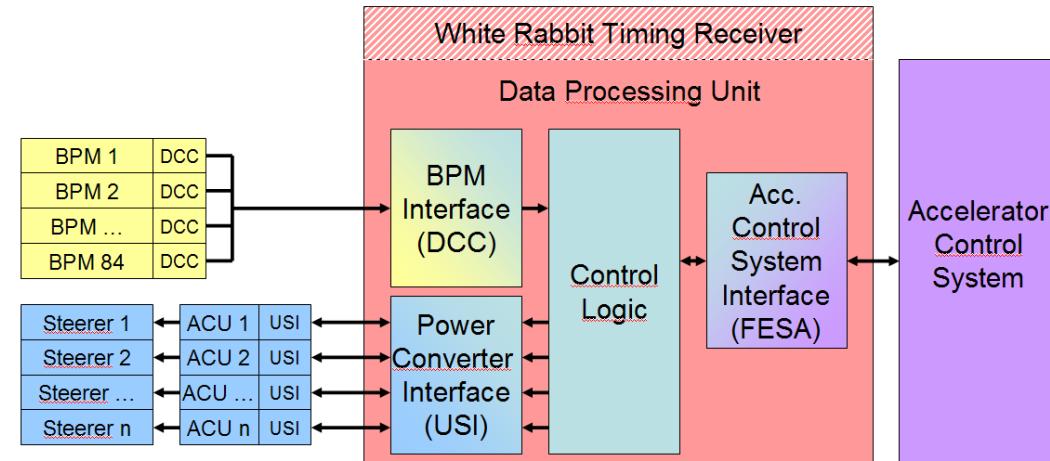
SIS100 Closed Orbit Feedback

Concept:

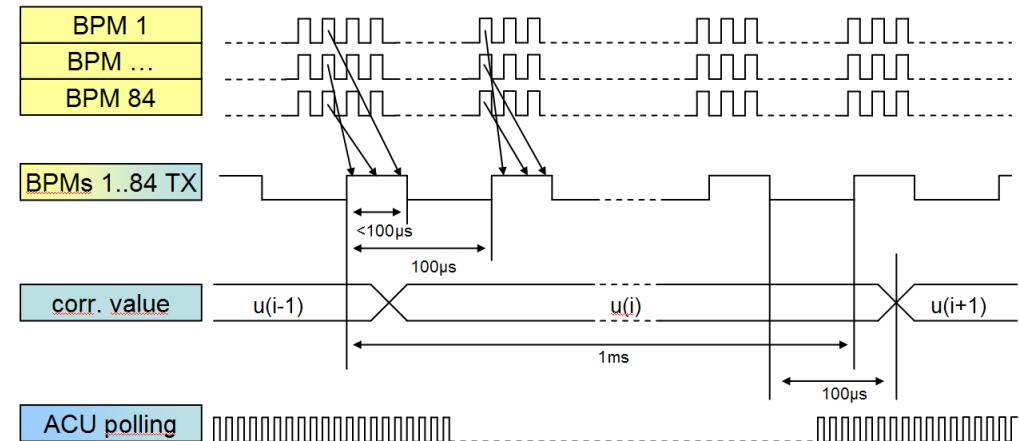
- Libera Hadron measure beam position
- export in real-time at a **fixed rate 10 kHz**
- Position data concentrator collects data from all BPMs and builds the actual orbit
- Interconnection of Libera stations by **GDX module with Libera Grouping protocol**
- Control logic/Data Processing Unit (DPU) calculates magnet correction signal based on desired and actual orbit, algorithm resides in the GDX modules
- **Power converter interface** sends correction signal to the steerer magnets (USI protocol, RS-485).

Device	Parameter	Value	Unit
<i>SIS100 Features</i>			
Bunch frequency	0.2 .. 2.7	MHz	
<i>Related Hardware</i>			
Number of steerer magnets	84		
Number of BPMs	84		
<i>DPU Parameters</i>			
Position data rate	10	kHz / BPM	
Correction data rate	100	Hz / corrector	
Latency for correction value	max. 1	ms	
<i>Network Communication (e.g. DCC)</i>			
Latency	< 100	µs	
<i>Power Converter Communication (USI)</i>			
Polling time	6	µs	

System Schematic

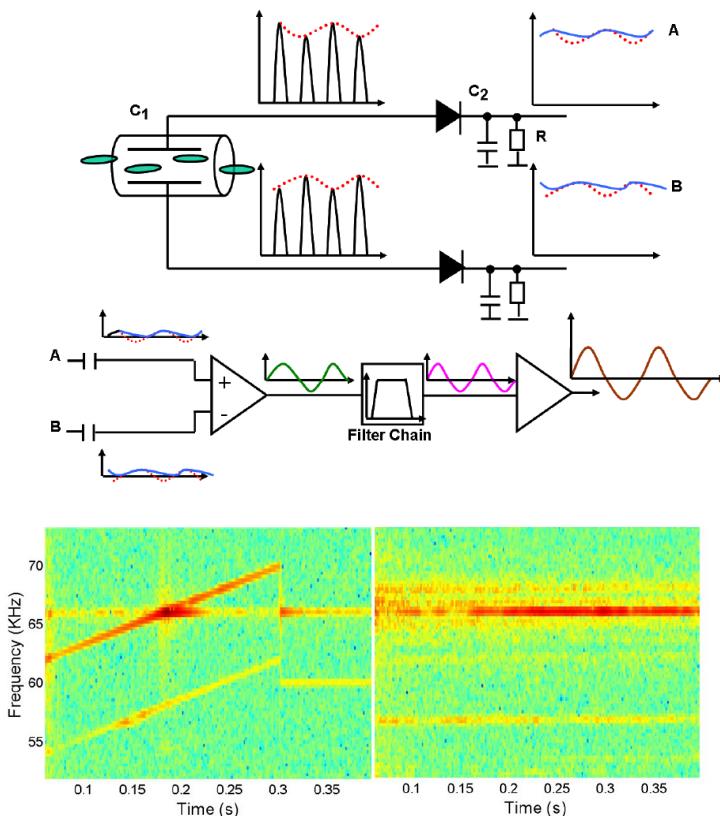


Timing Diagram



Tune Measurement: BBQ & TOPOS

BBQ: Base-Band Tune Measurement



Courtesy of
R. Singh

Tune Measurement with TOPOS

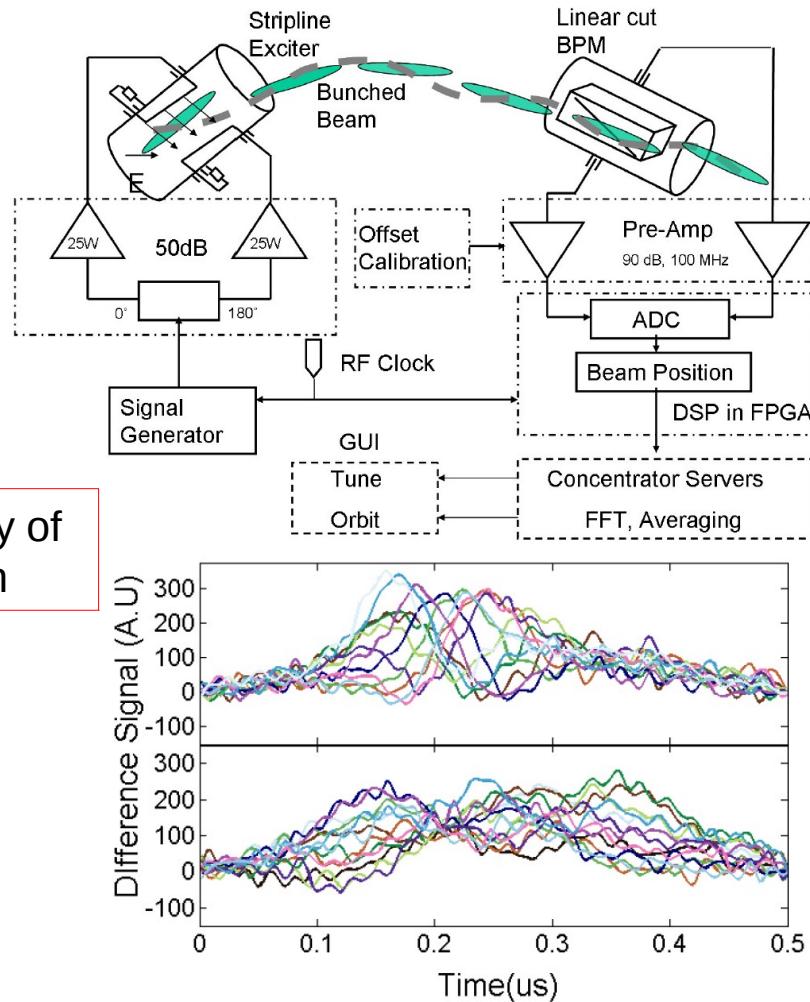


Figure 3: Output of the BBQ system in horizontal plane for frequency sweep (left) vs. band limited noise excitation (right) at $5 \cdot 10^8$ U⁷³⁺ ions. Tune is set to 65.6 KHz (0.315).

Summary

- BI-Mission to provide all relevant beam parameters...
...up to FEC level
- Infrastructure: FESA, PROFINET, Siemens PLC, MBox, REMBRANDT...
- In-Kind Contributions by Slovenia, Russia, India, France
- Integrated BI systems:
 - LASSIE (all particle counters & more),
 - CUPID (scintillating screens),
 - POLAND (SEM-grids, multi-wire proportional chambers),
 - TOPOS (beam position monitors, tune measurement)
- Beam Intensity Measurement
(DC Current Transformer, Novel DC Current Transformer, Fast Current Transformer, Resonant Transformer, Cryogenic Current Comparator, Scintillating Counter, Secondary Electron Monitor, Ionization Chamber)
- Beam Profile Measurement
(Scintillating Screen, Multi-Wire Proportional Chamber)
- Position Measurement (Beam Position Monitors, Closed-Orbit Feedback)
- Tune Measurement by noise excitation and Base-Band Tune System (BBQ)

Thank you!

Special thanks to the fantastic BI-team !!



**Thank you for your
attention!**

Open Questions BI

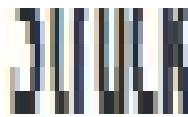
- BI Detectors, Devices, Infrastructure and FEC SW are clearly defined, ready for production and to great deal ready for tests (eg. Cryring), superordinate/integrated systems (eg. Transmission Monitoring, Machine Protection...) are NOT !
- No clear procedure for development of integrated systems yet! (who?, what?, how?)
- User requirements are missing to large extent! (For the moment we try to supply maximum set of parameters to be prepared.)
- Larger discussion / agreement on infrastructure topics (PROFINET, database, safety issues) is required.
- Open issues:
 - Definition, technical layout, manufacturing plan for interlock system (many ILKs from BI devices)
 - Definition Definition, technical layout, manufacturing plan for machine protection system (many BI devices are sources/drains for machine protection, eg. BLMs, Stopper....)
 - Commissioning Concept for each machine (general strategy, required measurements....)

■ Spare Slides

Fast ADC Board (FCT...)

100 2/4/8 CHANNEL 0.2.5/1.25 GS/s 10-BIT VME DIGITIZER

Example for
commercially
available ADC board:



Features/Properties:

- Single width 6U VME card
- 2/4/8 channels
- 5 GS/s/2.5 GS/s/1.25 GS/s per channel
- 512/256/128 MSamples/channel memory
- 2 GHz bandwidth
- Internal/External clock
- readout in parallel to acquisition
- Multi event mode
- Sparsification
- Pre/Post trigger capability
- Trigger or output (4 individual thresholds)
- A32/D32/BLT32/MBLT64/2eVME/SST
- 1/2/4 GBit/s optical link option
- In field JTAG and VME firmware upgrade capabil

Slow ADC (DCT, N-DCCT, CCC,....)

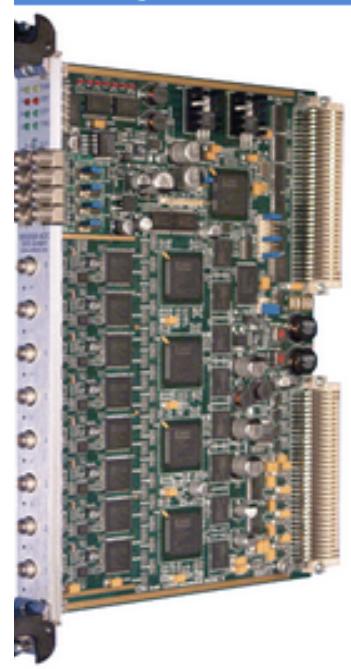
Example for commercially available ADC board:



302 8 CHANNEL 100 MS/S 16-BIT ADC

SIS3302 is the 16-bit extension to our 100 MS/s digitizer family. It is the 2nd D
or based digitizer unit in the SIS33xx family. The board is used for the readout
resolution detectors, accelerator controls and other applications.

ograph
out ADC coolers and
al cover)



Features/Properties:

- Single width 6U VME card
- 8 channels
- 100 MS/s per channel (1 - 100 MHz external clock, external random clock, 1/10/25/50/100 MHz internal clock)
- 16-bit resolution
- > 13 effective bits
- 32 MSamples memory/channel
- 16-bit offset DACs
- 50 MHz bandwidth
- Internal/External clock
- Multi event mode
- Readout in parallel to acquisition
- Pre/Post trigger capability
- Trigger OR output (8 individual thresholds)
- A32/D32/BLT32/MBLT64/2eVME
- 1-wire Id. serial PROM
- In field JTAG and JTAG over VME firmware upgrade

Multi-Channel Scaler Module

Example for commercially available scaler module
(uTCA variant now available):

S2U MULTI PURPOSE SCALER

COUNTER

MULTISCALER (MCS)

SHING SCALER

SET SCALER

PROGRAMMING SCALER

S3820 is the next step in Struck Innovatives continuing effort to develop state of the art scaler/counter boards and associated firmware for a variety of applications. It combines the functionality of standard counters and multiscalers without compromising performance. The use of standard commodity market memory solutions in combination with recent FPGA technology results in unprecedented functionality.

S3820 scaler is a single width 6U VME card, no non standard voltages are required. It comes with a 20 pin header connector for the control section and two 34 pin headers for the counters (ECL and flat cable TTL version) or via 8 LEMO connectors for the control section and 32 LEMOs for the counter section (NIM and LEMO TTL version).

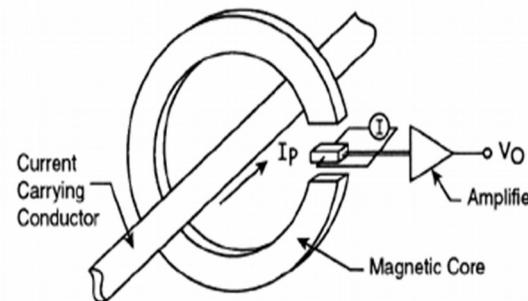
/RS485 is available as input option. The front panel design is compatible with the



- A24/A32 D16/D32/BLT32/MBLT64/2eVME/...
- interrupt capabilities
- broadcast features
- channels (+32 channel option via P2)
- control inputs and 4 control outputs
- Byte default (512 MByte optional) memory
- memory emulation mode
- 2-bit channel depth
- 4MHz (ECL inputs)/50 MHz on rear inputs
- TTL/LVDS or NIM inputs
- table/LEMO mixed input configurations
- anal/VME time slice advance
- num dwell time 220ns (for 8 channels)
- synchronous clock shadow register
- on the fly accuracy to lowest bit
- front panel user bits (in 24-bit mode)
- in progress output
- reset for arbitrary channel of 16ch group
- upgradeable firmware
- 4x connectors, can be used in standard or
- 4x side shielding
- access/user LED
- e +5 V supply

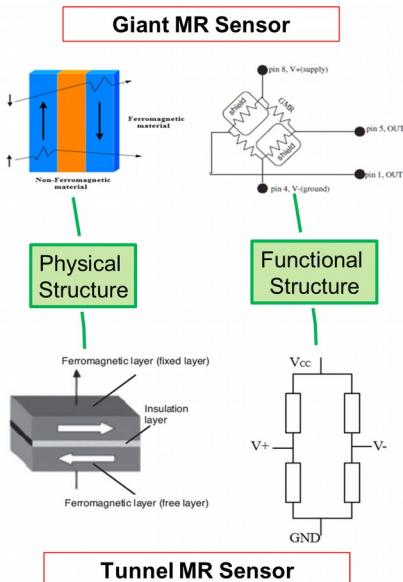
Design Concept:

- The NDCCT consists of a high permittivity slotted flux concentrator
- A magnetic field sensor is placed inside the air gap of the flux concentrator
- The magnetic sensor output voltage is proportional to the magnetic field inside the air gap ' B_{gap} '
- The sensitivity of the NDCCT is inversely proportional to the air gap width 'd'
- An amplifier is implemented on the sensor PCB to amplify the output signal to increase sensitivity.
- Different types of magneto-resistance (MR) sensors integrated circuits are available as magnetic field sensors



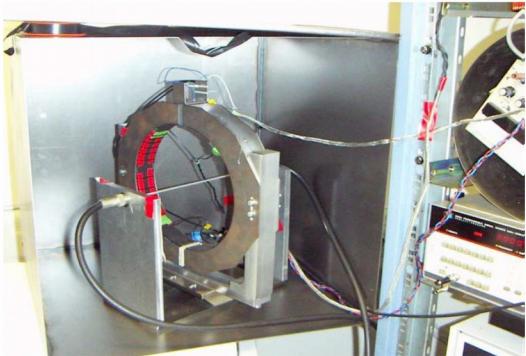
$$B_{gap} = \mu_0 \frac{I}{d}$$

Magneto-resistance Sensors

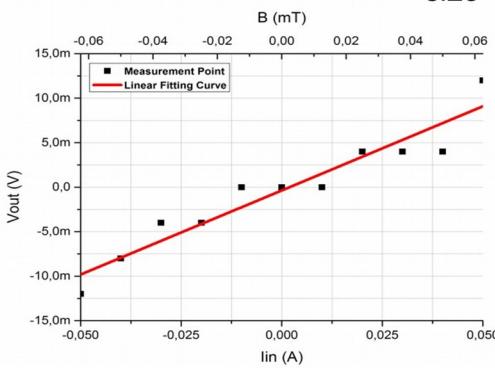


- MR sensors are based on a quantum mechanical magneto-resistance effect
- The MR effect refers to the change of the material's electrical resistivity in response to a change of an external magnetic field
- The change in the material's resistance could be enhanced significantly in thin film multilayer structures of alternating ferromagnetic/non-magnetic materials
- Two main types of MR sensors Giant Magneto-Resistance (GMR) and Tunnel Magneto-Resistance (TMR) sensors
- The functional structure is identical for all MR sensors. Four thin film resistors form a Wheatstone bridge.
- If an external magnetic field is applied the resistor's value changes and consequently the voltage of the bridge changes as well
- GMR has two shielded resistors in the bridge and this causes unipolar output voltage in contrast to the bipolar output voltage of the TMR.

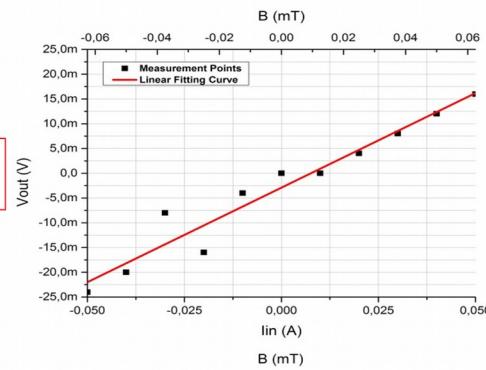
N-DCCT Test Setup



- A ring core flux concentrator from Vitrovac Company '6025F' is used
- The width of the air gap is 10 mm for MMLP57FP and MMLH45F sensors
- A μ -metal box for shielding covers the whole NDCCT test setup
- two types of the TMR sensors in SOP8 package were used MMLH45F and MMLP57FP
- The sensitivity of the NDCCT is given by the slope of the curves
- MMLP57FD is a TMR sensor in a DFN8 package → smaller size → smaller air gap width → higher sensitivity

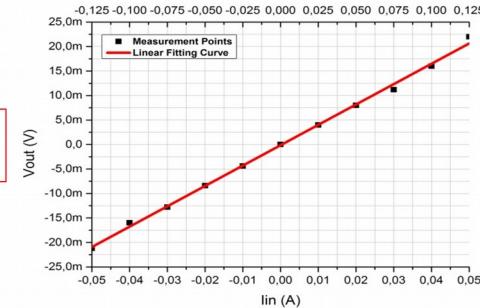
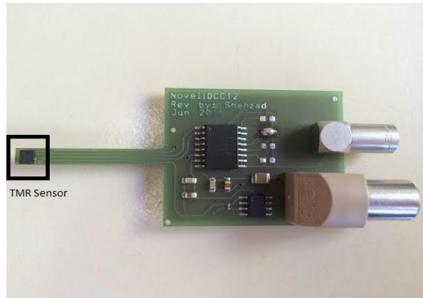


**TMR
MMLH45F**

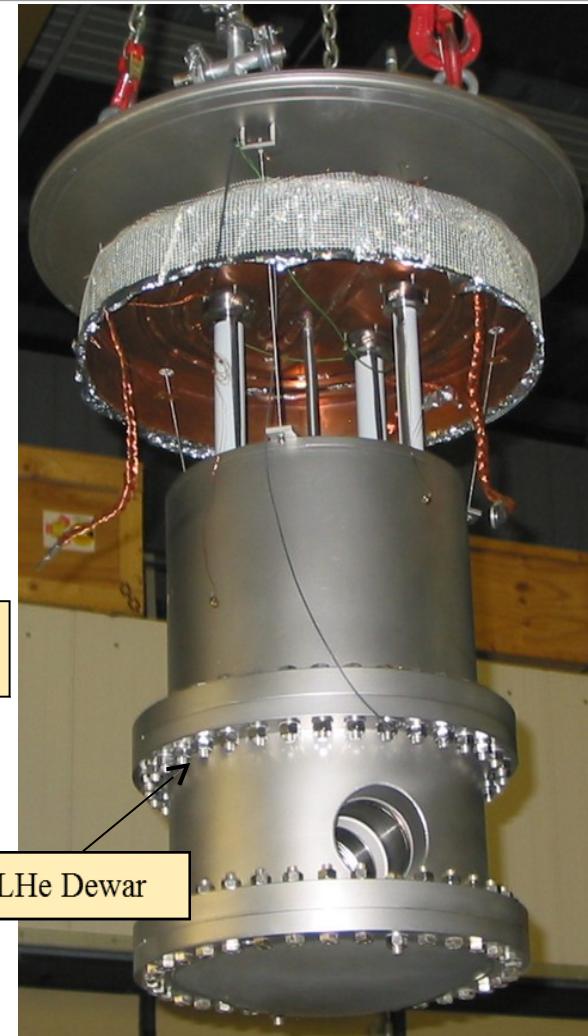
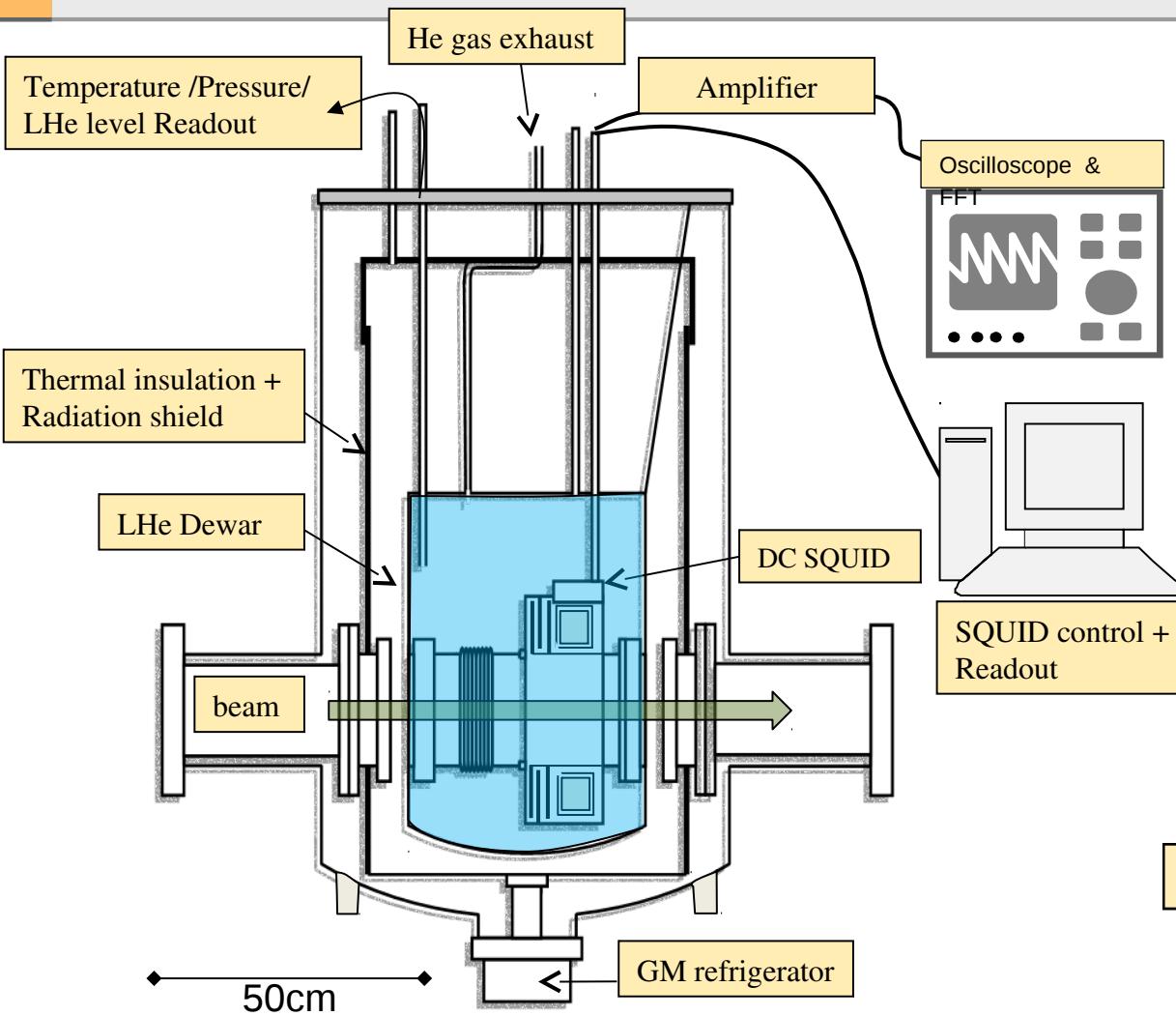


**TMR
MMLP57FD**

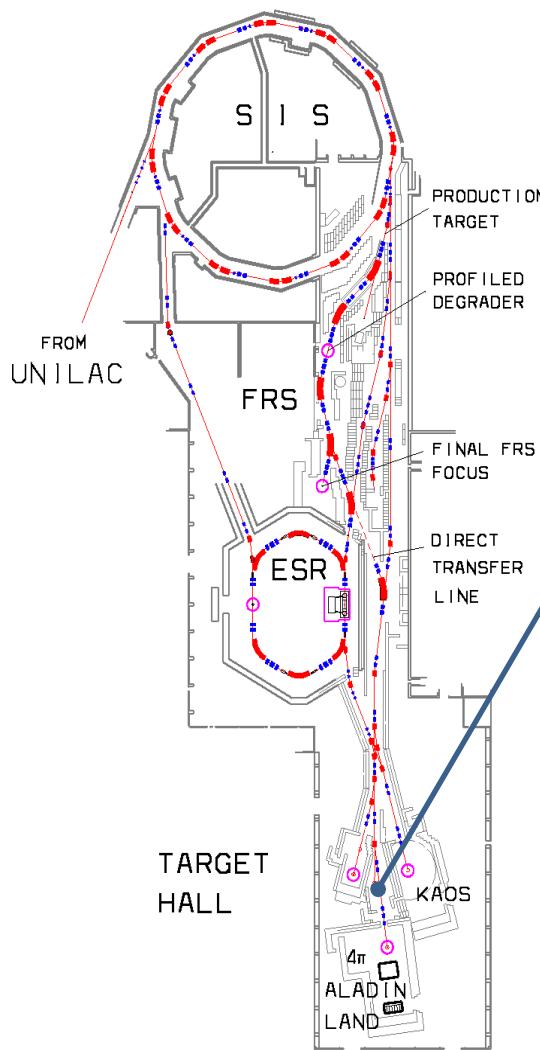
**MMLP57FD
PCB**



Cryogenic Current Comparator (CCC)



CCC Prototype Tests at HTP



CCC test setup at HTP



CRYRING@ESR: Beam Instrumentation



Planning

Hardware & DAQ layout fixed

Infrastructure in preparation (cable lists, container, racks, ProfiNet)

Integration into ACS to be discussed soon (GSI & FAIR timing, LSA, Interlock)

MSL Hardware Tests

All HW was tested,

no damage on critical components!

IPMs: OK, final test with alpha source and new
FESA DAQ in preparation

PCT: all HW OK, "cross talk" due to sextupole magnet
measured

BPMs: New pre-amplifier design developed and tested

Hardware development

Pickups (Linac): GSI HW available

SCR: SPS satellite & Timing unit CPS8 ready and tested

Power supplies for IPM, ICT ready

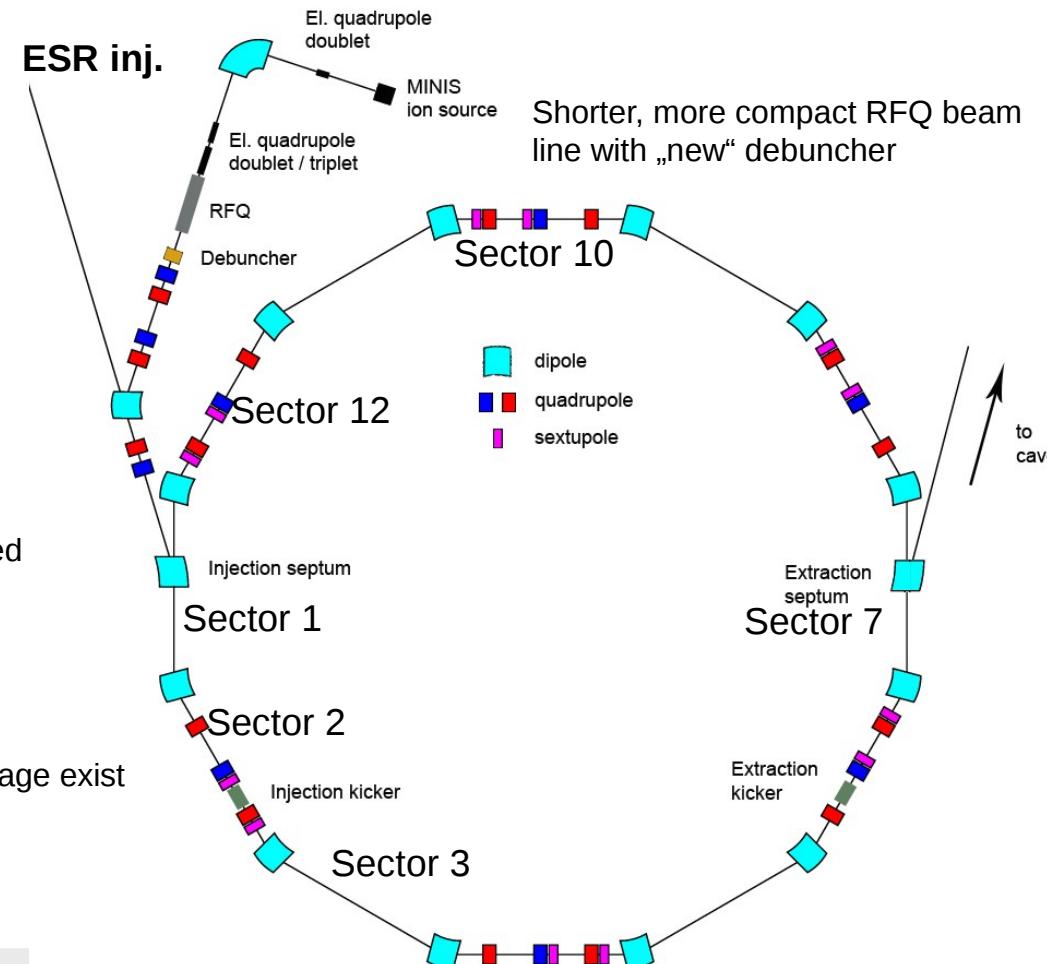
FC: Connector box under construction

SW development

FESA classes for FC, SCR, Switching Matrix, High Voltage exist

Basic FESA class for IPM exists

Infrastructure monitoring project Rembrandt



DS Beam Transmission Monitor System

3. Technical Specifications

3.1. The Devices

The Beam Transmission Monitor System (BTM) has to handle a lot of different beam diagnostic devices with different physical characteristics and therefore different representations (different properties). These devices offer a variety of data, e.g. current, counts or charges. For further details of beam diagnostic data acquisition see [7].

For the calculation of the particle count often additional parameters are needed, like energy, pulse-length or even calibration factors given by an experimenter.

Devices influence the beam in different ways. Non-beam-destructive devices can measure all the time, disruptive devices only temporarily (as long as they are in the beam).

Not all devices are suitable for all beam parameters, e.g. counters make only sense with slow beam extraction.

3.2. Beam Transmission Monitor

Depending on the actual beam chains and beam parameters the Beam Transmission Monitor System generates device lists. Whenever beam parameters change, or devices enter or leave the beam, these lists change.

8

Document Title: Detailed Specification Beam Transmission Monitor System

The BTM gathers data online for all beam chains and all devices, calculates the particle count and stores this data in the database. In addition it informs the Interlock System about the transmission quality.

Information about not properly working devices (e.g. offline, values out of range) must be stored too, but the data must be marked as invalid respectively unusable.