Beam Diagnostics Challenges and Innovations for FAIR

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Facility for Anti-Proton and Ion Research

Outline of the talk:

- ***Demands and boundaries for beam diagnostics***
- ***Examples of recent development***
- ***Conclusion***

UNILAC & SIS as injector after upgrade

p-LINAC: high current 70 mA, 70 MeV

SIS100: Supercond. 100 Tm, 1-10 GeV/u
high current operation p to U
design: p:4*10^{13}, U^{28+}: 5*10^{11}

SIS300: 300 Tm, stretcher or accel.
up to 30 GeV/u

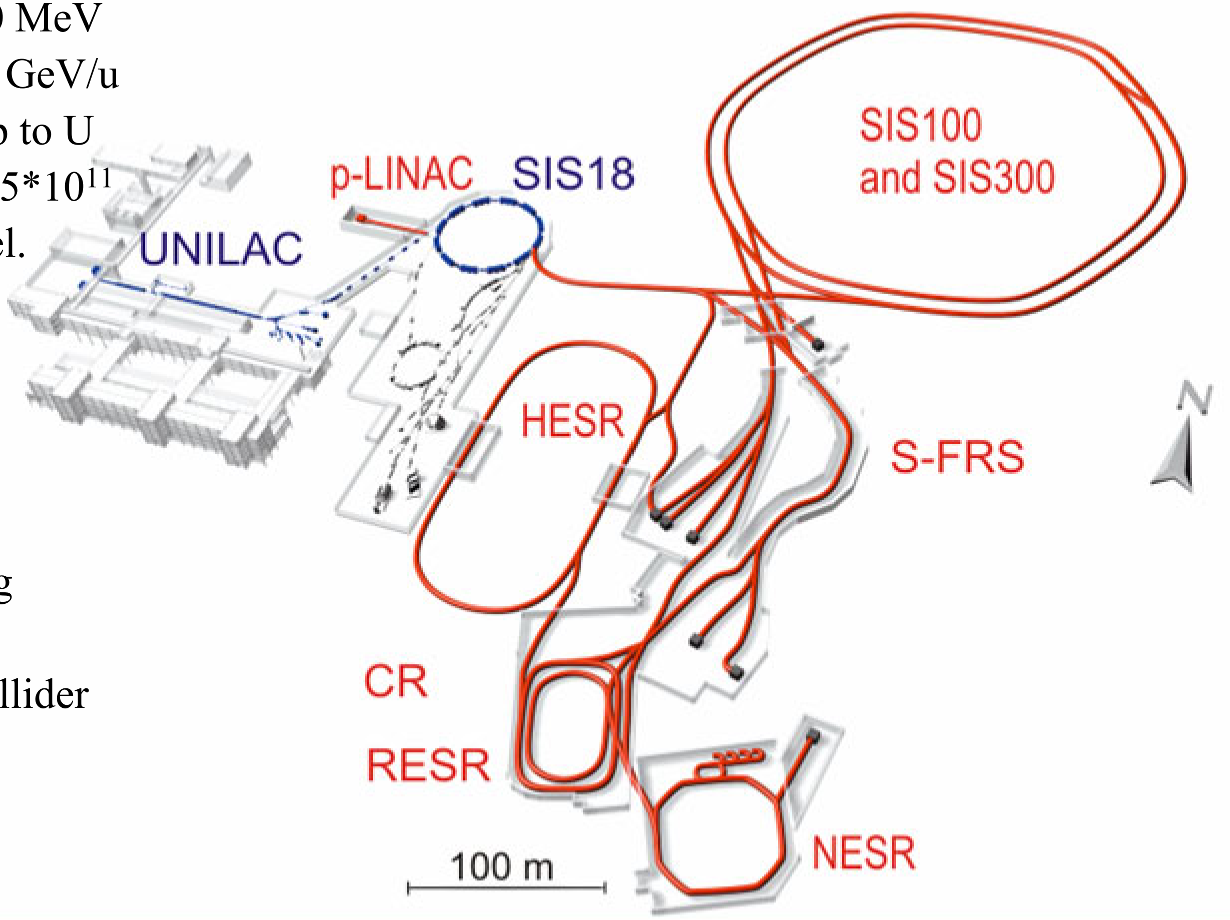
CR: stochastic cooling
of RIB and pbar

RESR: accumulation
of pbar, decel. of RIB

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

HESR: storage and acc.
of pbar to 14 GeV/u

HEBT: for fast & slow extraction
and low & high currents.



Demand and Boundaries for Diagnostics

- ***Common realization:*** Same design for all synchrotrons and storage rings
  $\Rightarrow$ saves man-power and cost, required for maintenance
- ***Exceptional large dynamic range:***
  High currents up to 10^{13} and down to single particles for RIBs
- ***Precise beam alignment:*** Small acceptance in synchrotrons and HEBT,
  large space charge
  $\Rightarrow$ feedback (closed orbit, tune chromaticity etc.) and ABS required
- ***Beam loss:*** Due super-conducting magnets low loss budget $\Rightarrow$ feedback&ABS
- ***High radiation:*** Charge changing losses and slow extraction
  $\Rightarrow$ radiation hard electronics and shielding
- ***Compactness and UHV:*** low insertion space, materials for $5*10^{-12}$ mbar
  $\Rightarrow$ dedicated mechanical designs
- ***Interface to control system:***
  Modern and versatile, capable to accept various front-end systems
- ***Parallel operation:*** Complex operation scheme
  $\Rightarrow$ flexible and reliable data acquisition and analysis.

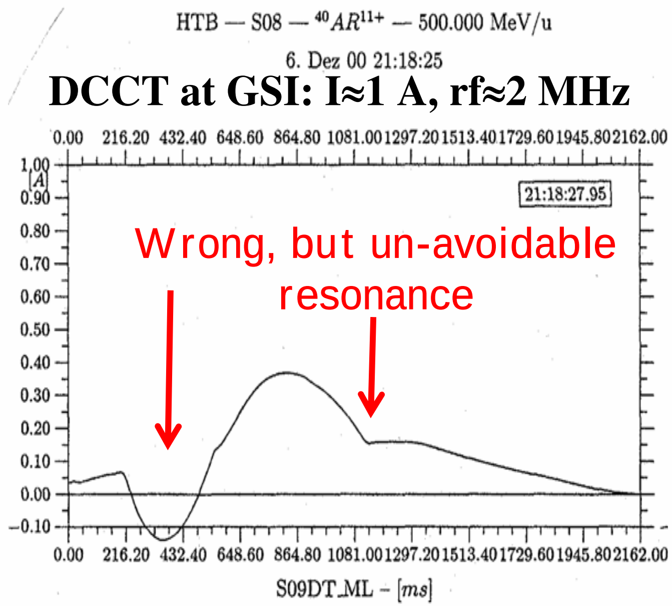
The Synchrotron and Storage Ring Diagnostics

Device	Measurement	Application	Remark & Status
DCCT	dc-current	Stored current, 1μA < I < 1A	Commercial (Bergoz)
GMR-DCCT	dc-current	Stored current, I > 100 mA	**Novel principle**
CCC	dc-current	Stored current, 10 nA<I<1μA	**R&D phase**
ACCT	Pulsed current	Injection efficiency, interlock	GSI-design
FCT or WCM	Bunch structure	Maching, bunch gymnastics	Commercial (?)
BPM	Beam center	Closed orbit & feedback Turn-by-turn, lattice functions	**Careful investigations** **Novel baseband proc.**
Exciter+BPM	Beam center	BTF, PLL tune tracking	Design not started
Quad-BPM	Quad.-moment	Quadrupolar-BTF, maching	Design not started
Schottky	Longi.+transv.	Δp/p, cooling, tune, chroma.	Adoption of GSI design
IPM	Beam profile	Emittance, cooling, matching	**Novel design, complex**
BLM	Beam loss	Matching, halo, interlock	Versatile use, not started
Gird/Screen	Beam profile	First-turn	Standard

Current Measurement: GMR as Magnetic Sensor

'Known bug': high current
+ low frequency bunches
⇒ Disturbance of DCCT-feedback:

DCCT at GSI: I≈1 A, rf≈2 MHz



Possible solution: New DCCT from Bergoz
→ Test in winter 2006.

Possible solution: Magnetic sensor based on **G**iant **M**agnetic **R**esistance (used e.g. in hard-drives)

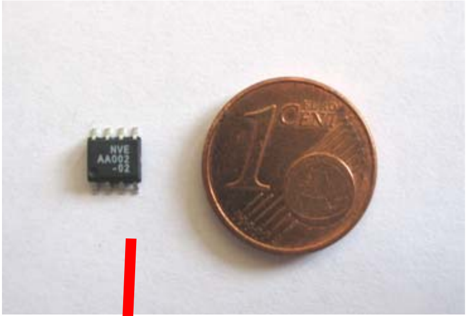
Saturation field: 10 mT

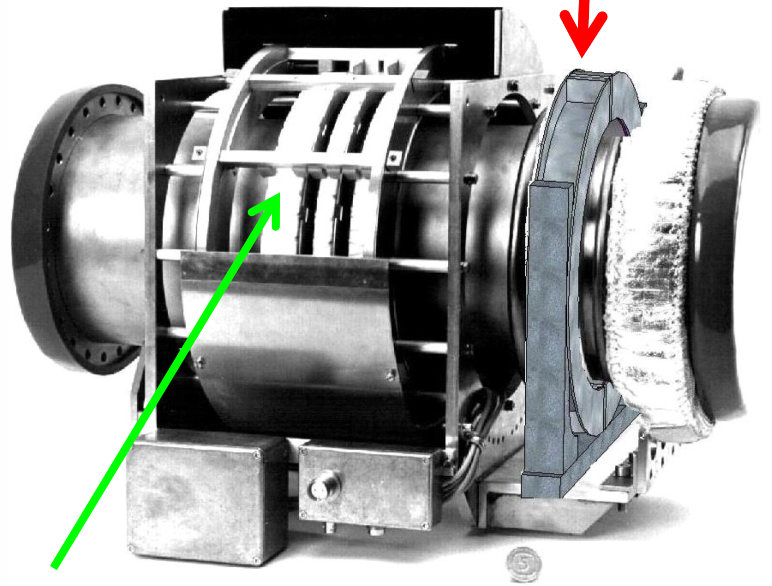
Linear range: 0 to ±7 mT

Field-concentrator:
Vitrovac© torus with 2 gaps

Status: Test in 2007

R&D: GSI, Uni-Kassel.





SIS DCCT/ACCT with 270 mm diameter

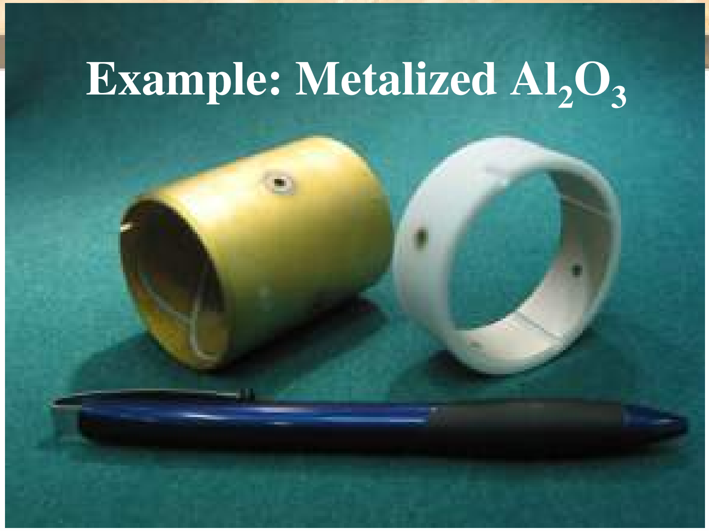
BPM Layout for Cryogenic Installation

Foreseen design for SIS100/300:

- Elliptical shape for beam impedance
- Metalized ceramics

  expected mechanical stability of ≈50 µm after many cryo-cycles

⇒ **material considerations.**



Specification:

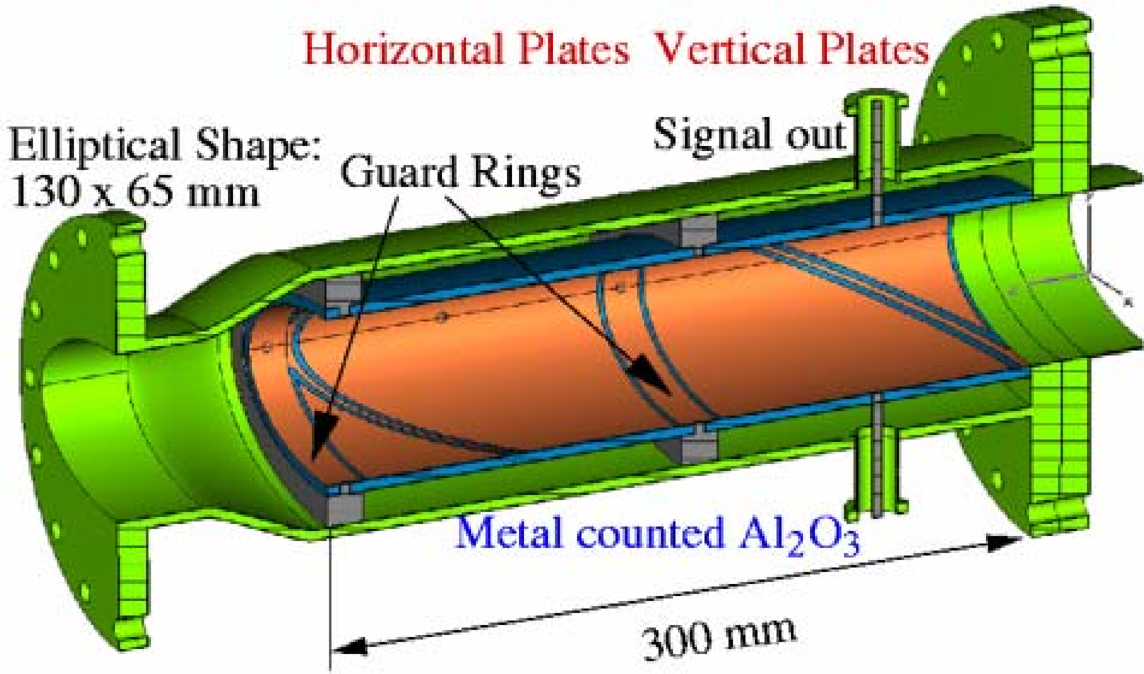
- ***Accuracy:*** 100 µm on turn-by-turn

  ≈10 µm @ 10 kHz

  (via 'k-modulation')
- ***Sensitivity:*** as high as possible,

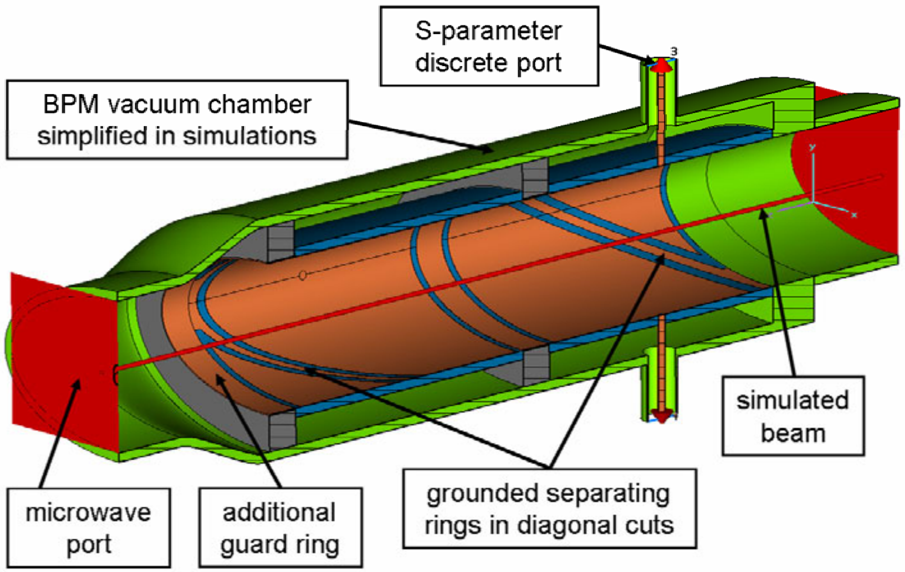
  pre-amp: 120 dB dynamics
- ***Bandwidth***: 0.1 to 100 MHz

⇒ **FEM calculations.**

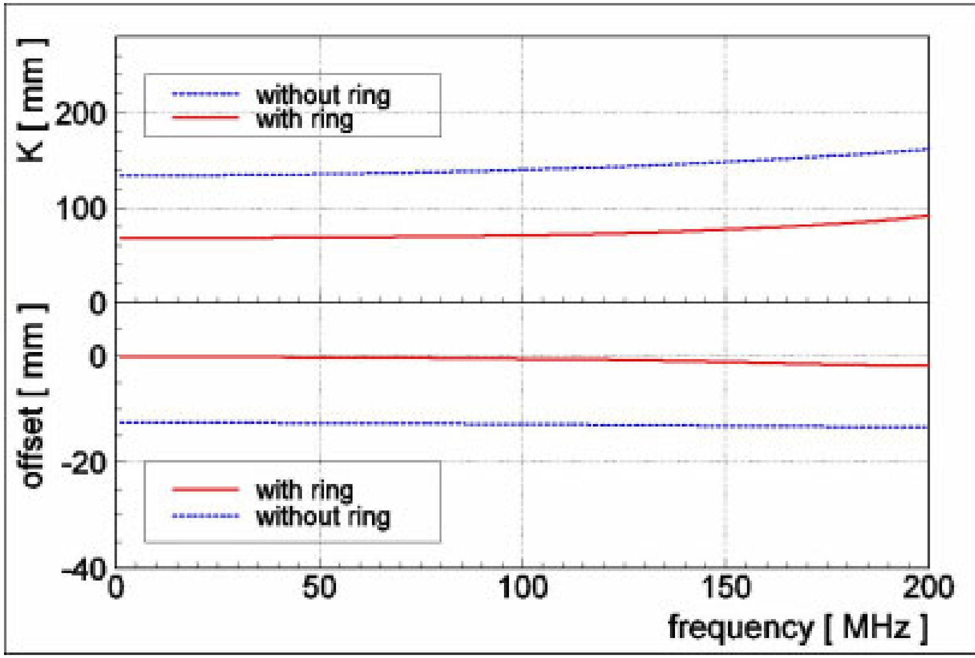


BPM Layout: Detailed Finite Element Calculation

Model of BPM for
S-parameter CST-Studio® calculations:



Position x(f) =K(f) * ΔU/ΣU + offset(f)



Results:

- Optimized separation rings (thickness 1.5mm) double the sensitivity
- Optimized guard rings between planes suppress the offset
- Flat frequency response.

Novel Approach: BPM Baseband Digitalization

Peculiarity: Bunch formation,
varying rf 0.5 to 5 MHz
Tunnel: ampl./att. 120 dB dynamics

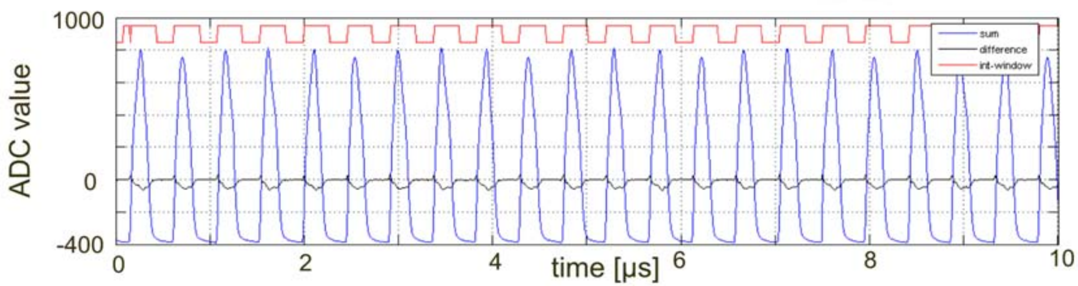
Digital baseband processing:

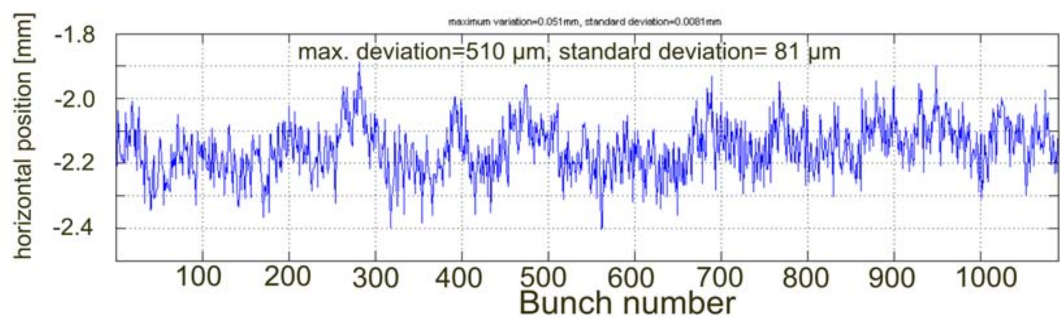
- Digitalization: 125MSa/s, 14bit
  e.g. by Libera from I-Tech
- Sample-synchronous processing with Xilinx FPGA
- 256MB RAM, 1.25Gbit interface
- Algorithm design for FPGA
  → noise reduction
  → integration-gate, no-Gaussian
  → baseline reconstruction
- Planned for closed orbit feedback

Results at SIS18:

≈100 µm for bunch-by-bunch

EU-FP6 Collaboration: GSI, CERN, FZ-Jülich, Uni-Darmstadt, I-Tech.





1200 bunches = 300 turns

Transverse Profile by Ionization Profile Monitor

IPM: **High performance device for turn-by-turn readout *and* 0.1 mm resolution**
required for high current studies at SIS18/100/300, cooling studies at storage rings.

e^- or ions detection:

- E-field (E≈±50 V/mm, 1% in-homogeneity)
- B-field for guidance (B≈30 mT, 1% in-homo)
- MCP (100x40 mm^2)

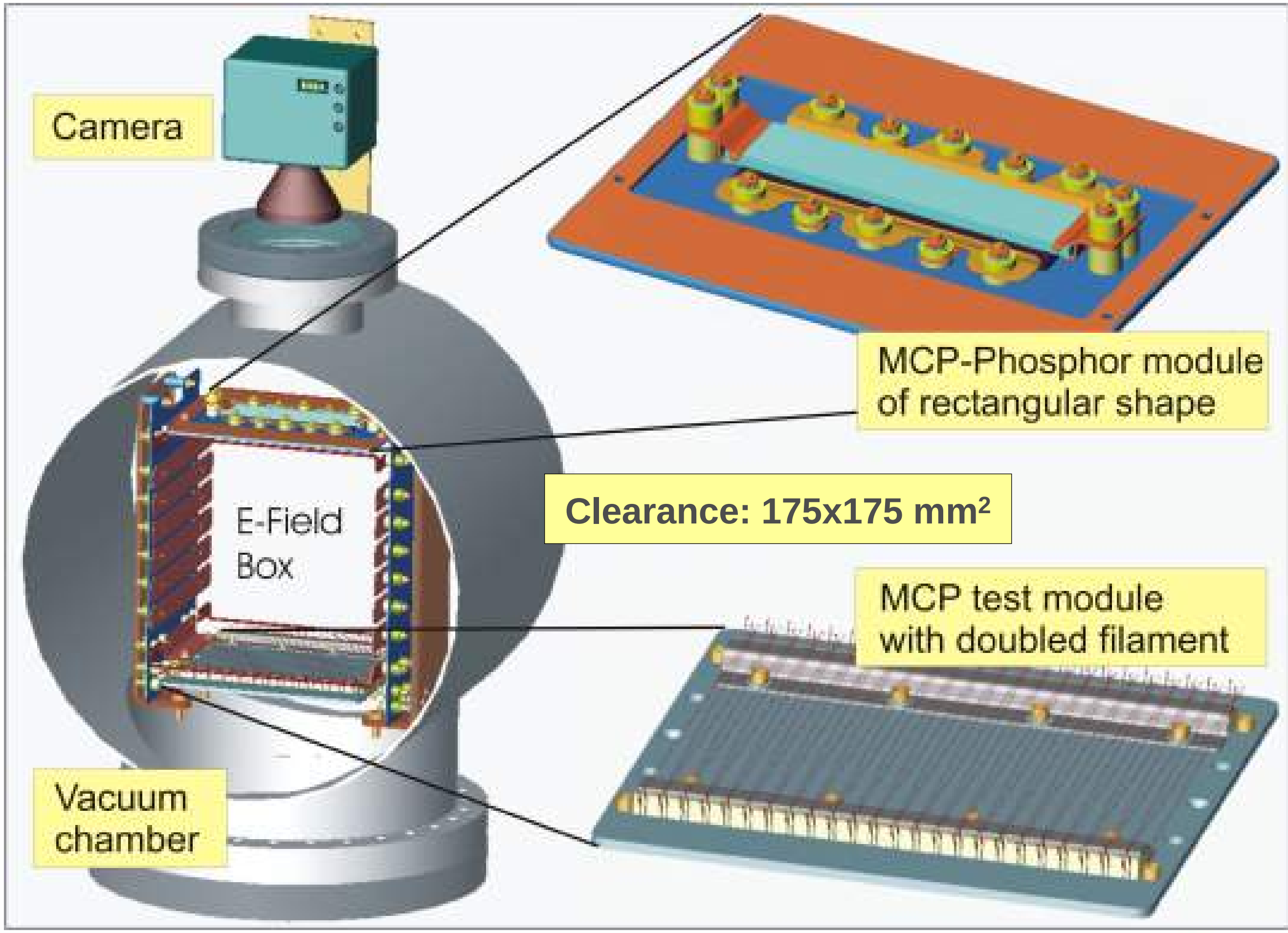
High resolution mode with 100 μm:

- CCD readout

Turn-by-turn mode with 1 μs time resolution:

- 100 photo-detectors

R&D: GSI, FZ-Jülich, MSL-Stockholm, ITEP, NPI-Uni-Moscow under INTAS&EU-FP6.



Status: Test winter 2006 at COSY (without magnet).

Novel Photo-Detectors for IPM: Si-Photomultiplier

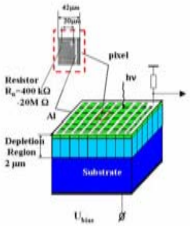
Turn-by-turn readout → injection matching

→ fast emittance changes

Specification: One turn ≈1 μs, 1 mm resolution.

Novel photo-detectors: Silicon-Photomultiplier

(developed by B. Dolgoshein et al., Moscow).

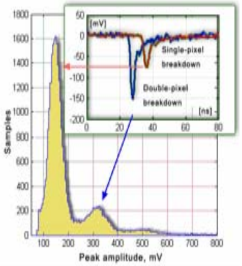


Test-device:

576 avalanche photo-diodes on 1mm^2 biased above break-down

Result: Single-photo amplification,

but acting as analogue detector.



R&D: ITEP-Moscow (incl. electronics)

Large aperture magnets for IPM

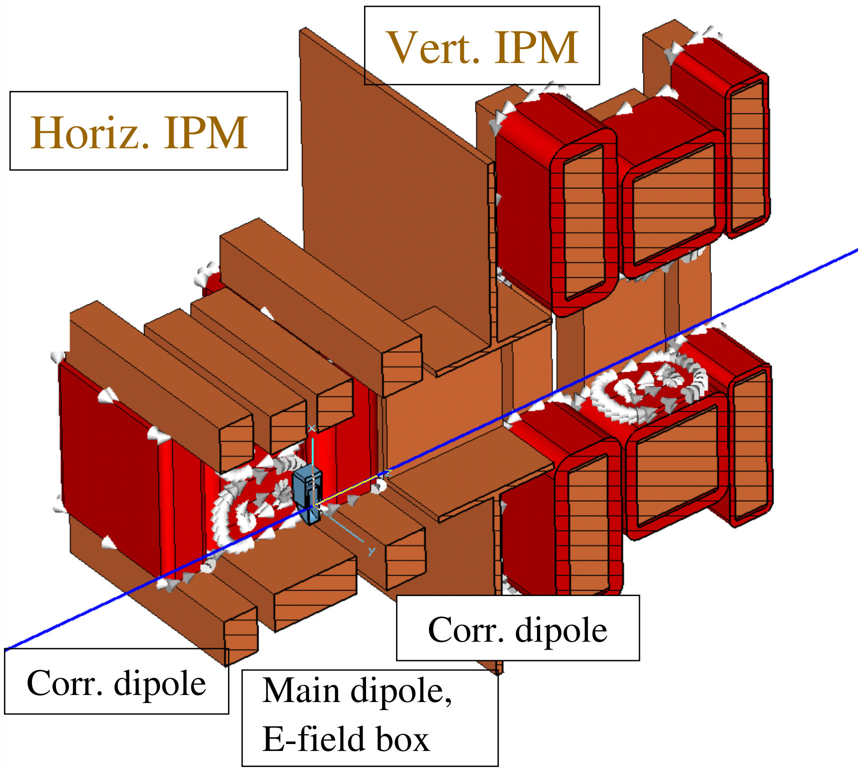
Space charge of bunches influences e⁻ trajectory:

⇒ guidance of e⁻ to MCP: B=30 mT, $\Delta B/B<1\%$

⇒ Magnet design with large 480x480 mm^2 aperture, correctors and ≈ 2 m ***total*** insertion.

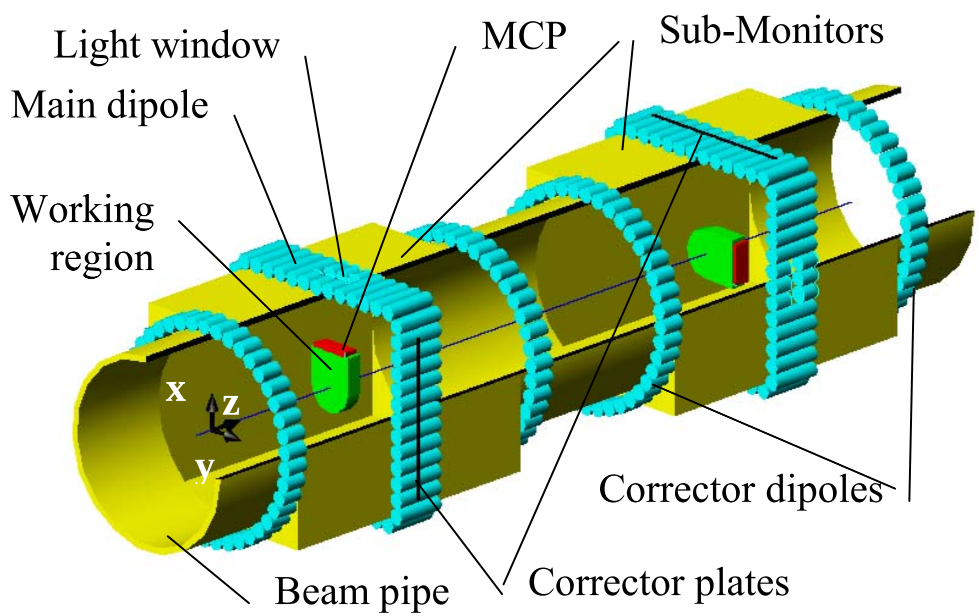
Electro-magnet design:

Length: 2.04 m, max. trans. size: 1.7 m



Permanent-magnet design:

Length 2.03 m, main dipole 132 mm, corrector 57 mm, gap 370 mm, trans. 520 mm



Both types fulfill the requirements, ***but*** PM is more compact.

R&D: ITEP&MSU-Moscow,
see Poster P.44 by V. Skachkov.

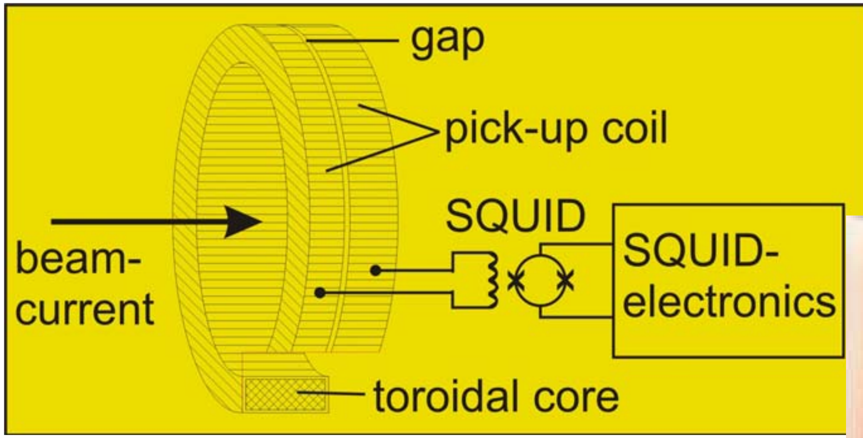
The Transport-Line Diagnostics

Device	Measurement	Extr.	Application	Remark &Status
Reso. Trans.	Pulsed-current	Fast	Transmission, interlock	GSI-design
CCC	dc-current	Slow	Transmission, interlock → For high current	**Novel principle**
Particle Det.	dc-current	Slow	Transmission, → For low current	GSI-design
FCT	Pulsed- current	Fast	Bunch structure	Commercial (?)
BPM	Beam center	Fast	Position, ABS	Like for rings, baseband processing
SEM-Grid	Profile	Fast	Profile → low current	Adoption of GSI-design
MWPC	Profile	Slow	Profile	Adoption of GSI-design
Screen	Profile	F&S	Profile → low current	Material investigations
IPM or BIF	Profile	F&S	Profile → high current	**R&D started**
BLM	Beam loss	F&S	Matching, interlock	Like for Rings

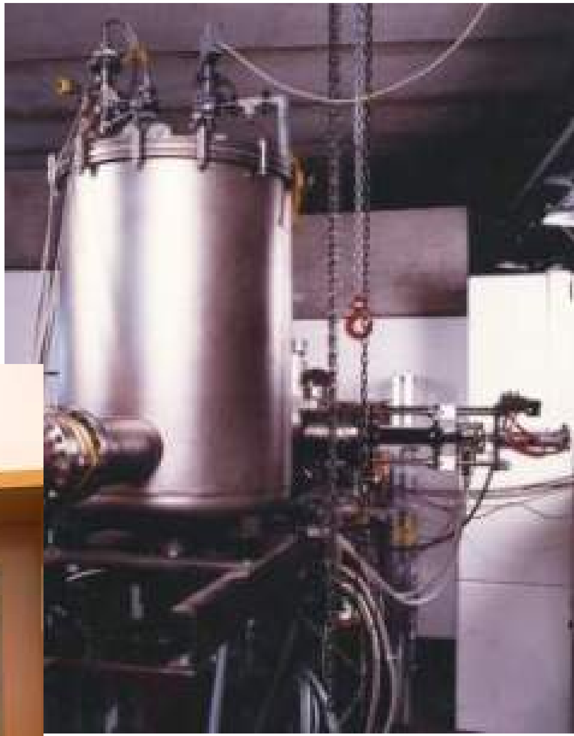
Current Determination with nA Resolution

- **HEBT:** slow extraction → online transmission control
- **Rings:** low stored current e.g. RIB.

Cryogenic Current Comparators:



GSI prototype in 1997:



- Prototype tested at GSI in the 90ies
- Improvement:

  Nb instead Pb for the flux transducer

  less temperature drift
- reached 0.25 nA/$\sqrt{\text{Hz}}$ ⇒ **8 nA @ 1 kHz**
- ***R&D:*** GSI, DESY and Uni-Jena.

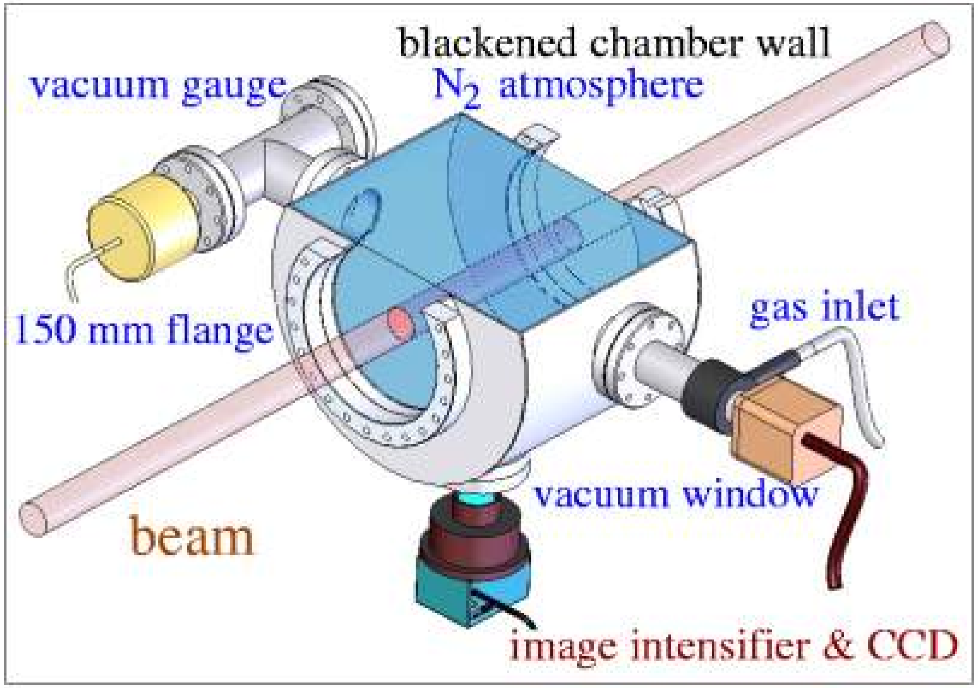
Beam Induced Fluorescence for intense Profiles

At RIB plasma-physics targets beam intensity melts intercepting material:

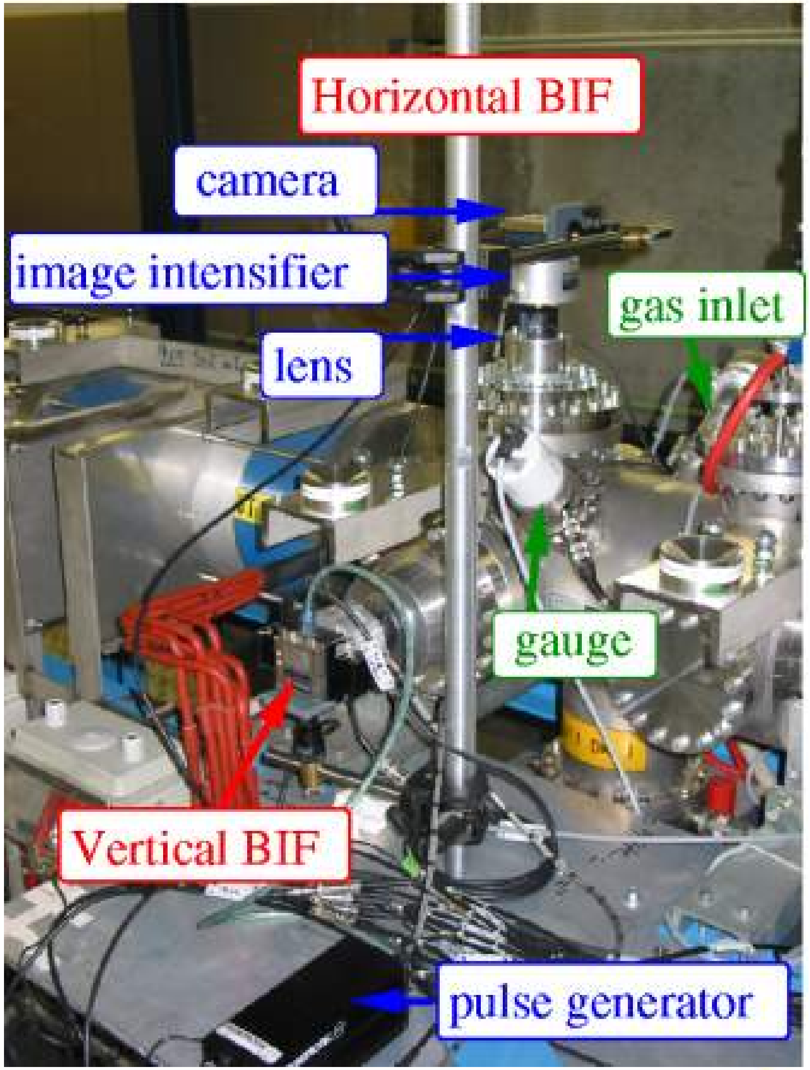
⇒ non-intercepting method required

⇒ compact installation in front of target.

Test of Beam Induced Fluorescence with N_2:

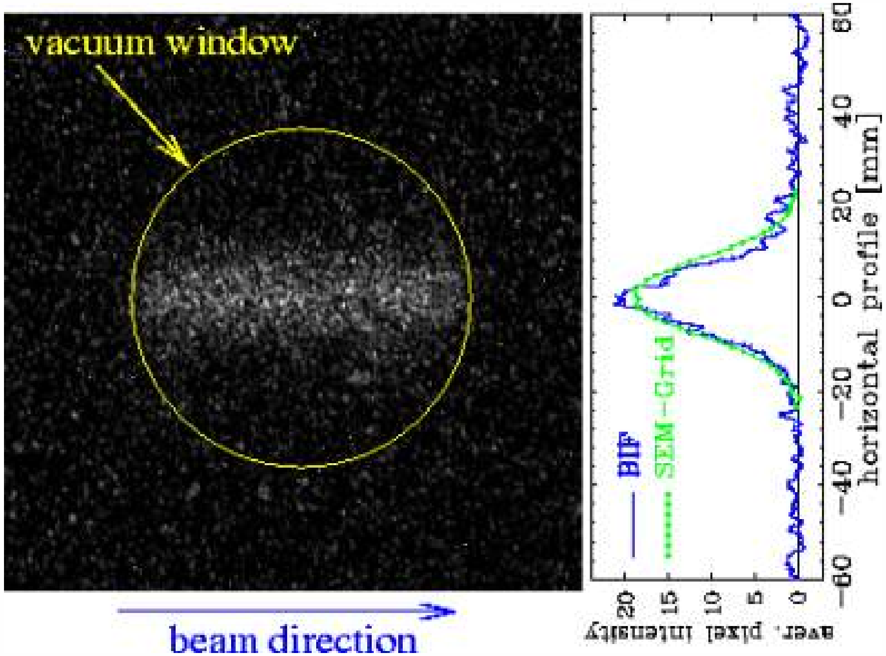


Installation of hor&vert. BIF Monitor:



Results of Beam Induced Fluorescence

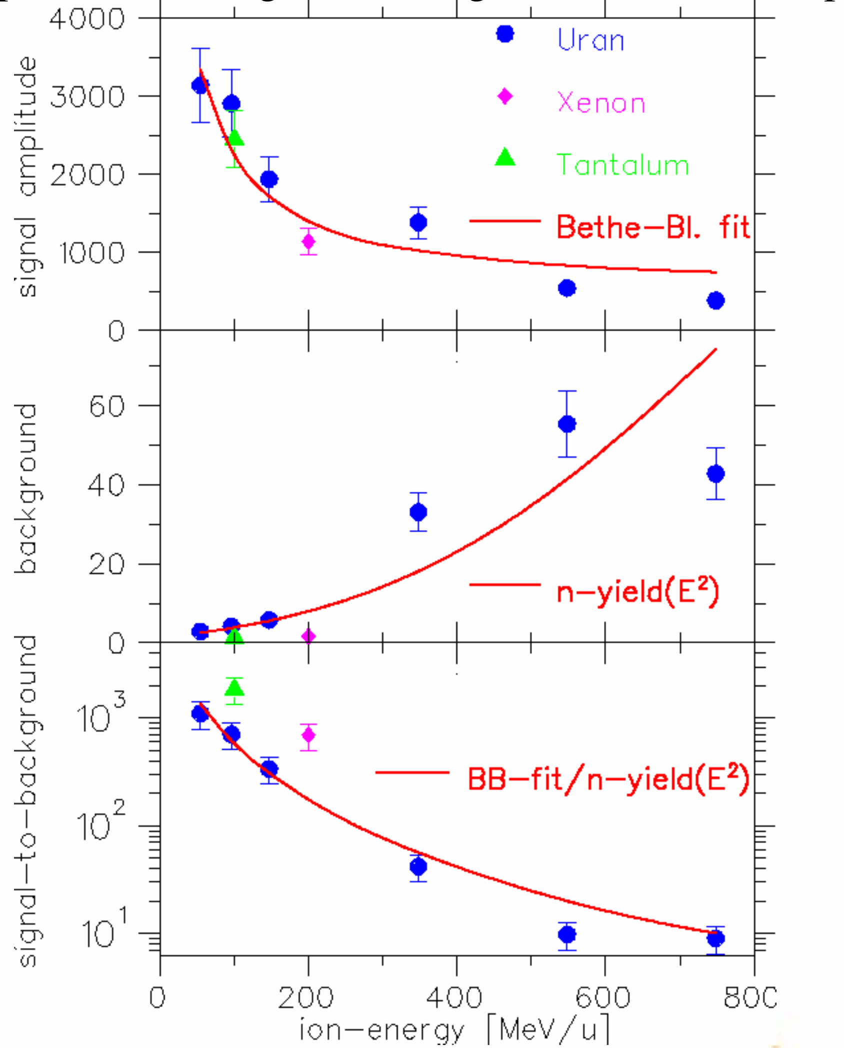
Image from $2x10^9$ Xe @ 200 MeV/u
$p= 10^{-3}$ mbar, 20 shot average,
mounted ≈2 m behind-beam dump:



'Single photo detection' @ 390 nm < λ < 470 nm

- Signal proportional energy loss
- Background prop. $E^2 \Rightarrow$ shielding required
- Suited for FAIR with $>10^{11}$ ions per pulse.

E_{kin} dependence for signal & background at beam-dump:



Conclusion

The new FAIR facility requires significant R&D for diagnostics:

- Common layout for large dynamic range: Form single particles to 10^{13} per pulse
- High current operation: Precise beam alignment with low beam losses,
  novel non-destructive devices required
- Interface to control system: Versatile architecture at distributed locations,
  suited for parallel operation
- Production and installation: Modern & cost-efficient solutions required.

Thanks to the collaborators from: CERN, DESY, FZ-Jülich, I-Tech (Slovenia), ITEP-Moscow, MSL-Stockholm, Universities Darmstadt, Jena, Kassel and Moscow.

Thanks for funding by: CARE-HIPPI, CARE-HHH, EU-FP6 DIRAC-PHASE 1,
EU-FP6 DIRAC Secondary Beams, INTAS.