Beschleuniger-Inbetriebnahme bei HITRAP - Strahldiagnose bei niedrigsten Intensitäten

Jochen Pfister

Institut für Angewandte Physik, Universität Frankfurt

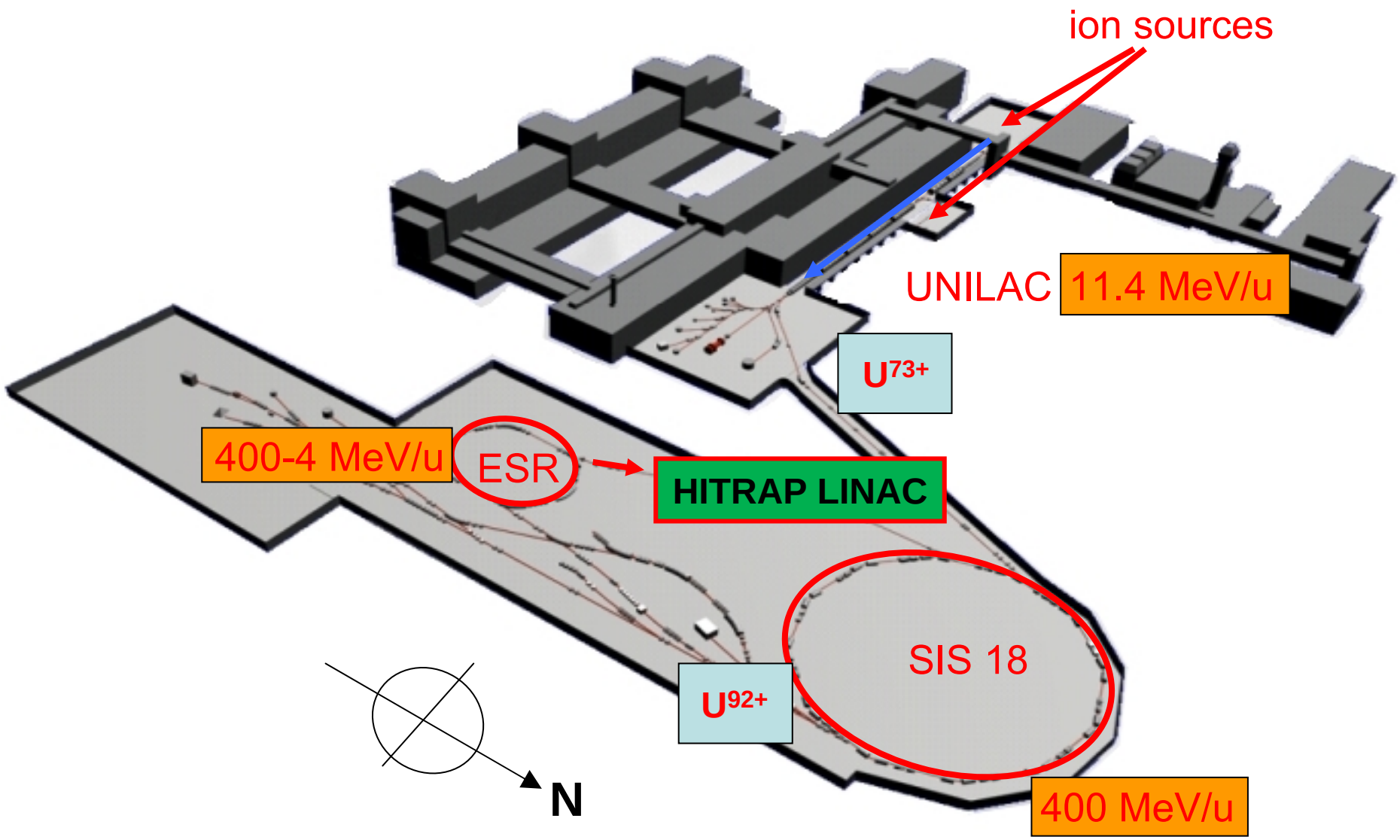
Seminar "Aktuelle Probleme der Beschleuniger- und Plasmaphysik"

IAP, Universität Frankfurt, 23. April 2010

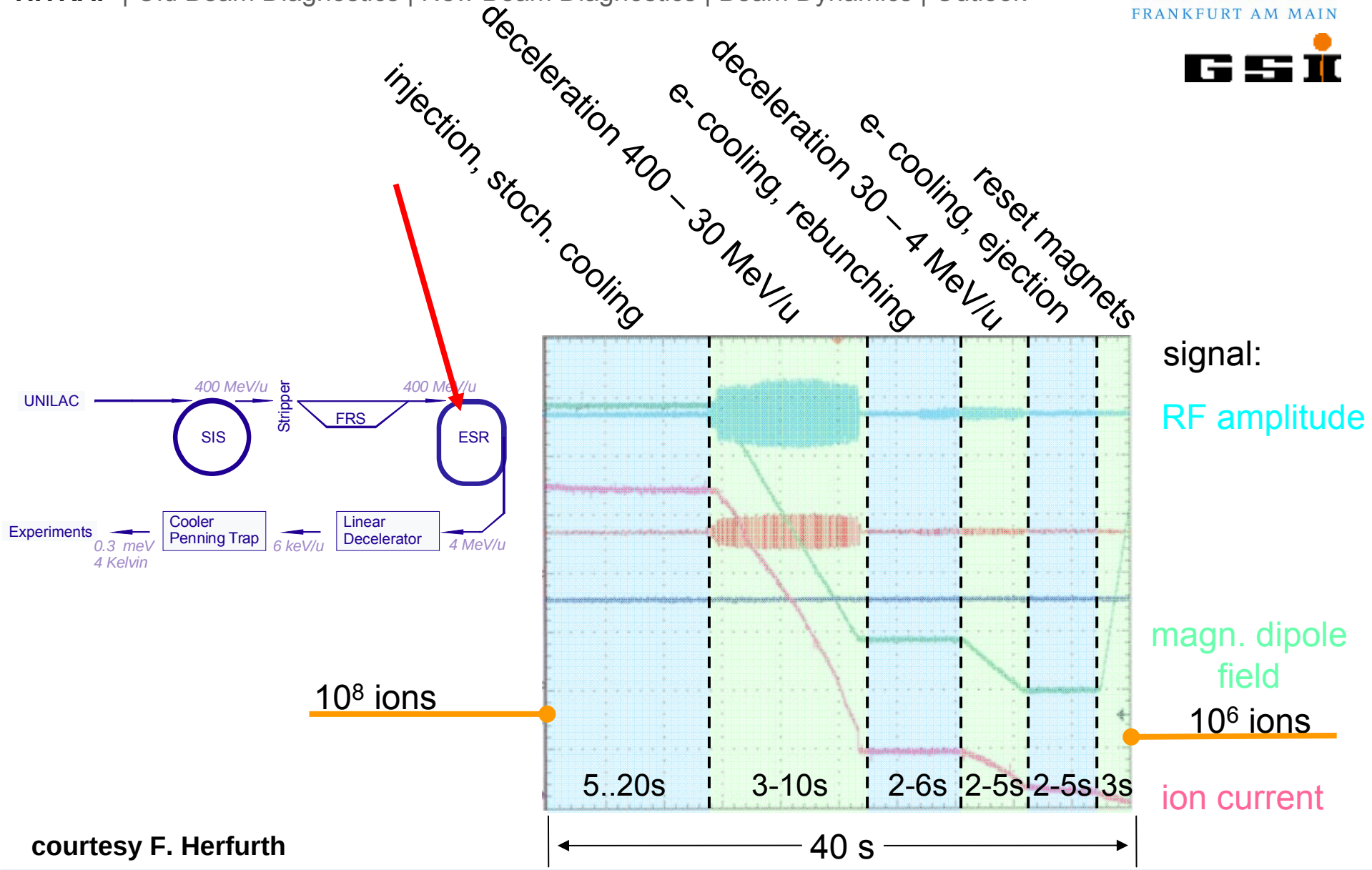
Agenda

- The HITRAP project at GSI
- "Old" beam diagnostics and results
- New beam diagnostic developments and first results
- Transverse beam dynamics studies
- Outlook

HITRAP @ ESR


ion sources
UNILAC
11.4 MeV/u
U73+
400-4 MeV/u
ESR
HITRAP LINAC
SIS 18
U92+
400 MeV/u
N

ESR – From 400 to 4 MeV/u



courtesy F. Herfurth

HITRAP Overview

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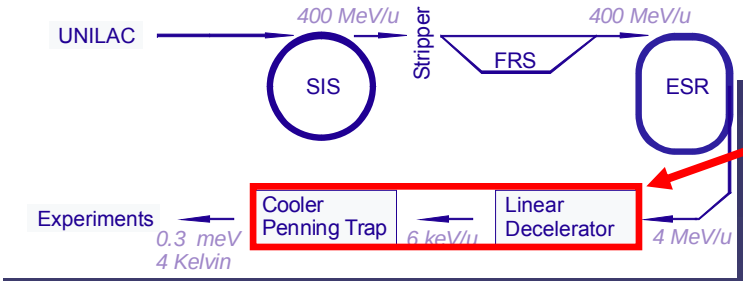
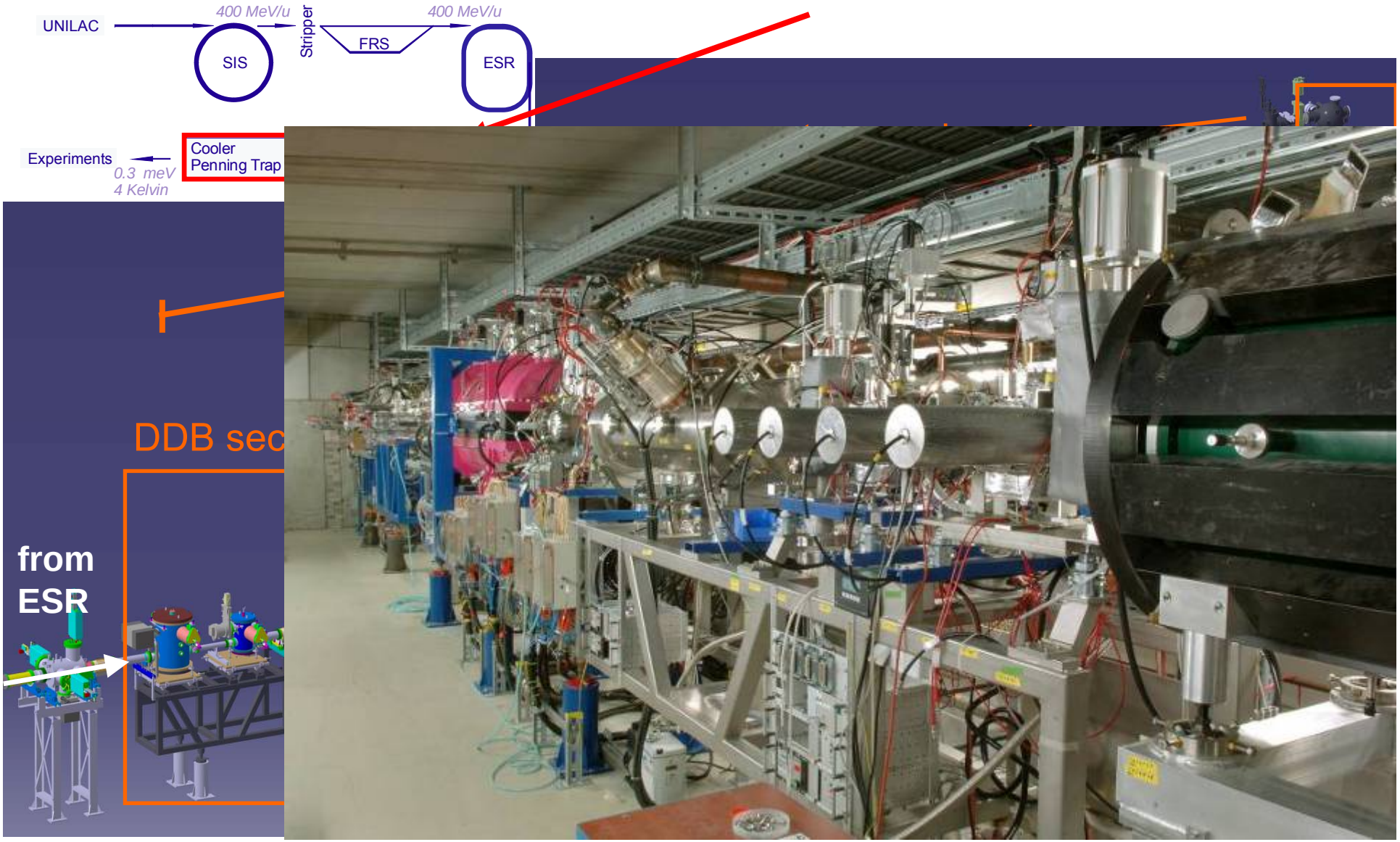


HITRAP Overview



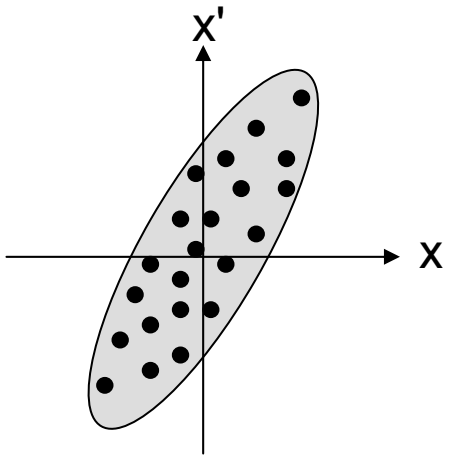
Experiments @ HITRAP

- Experiments based on Penning traps
  - Laser spectroscopy
  - g-factor measurements of the bound electron
  - Mass measurements of extreme accuracy
  - Polarization of radionuclides
  - Decay spectroscopy of highly-charged radionuclides

- Collision experiments:
  - Collisions at very low velocities
  - Surface studies and hollow-atom spectroscopy
  - X-ray spectroscopy

Emittance

- complete description of particles through 6-dim vector (position and momentum)
- phase space area of many particles in 1 of 3 dimensions



$$A_x = \iint dx \cdot dp_x$$

since transverse momentum is difficult to measure → normalize to longitudinal momentum → angle to beam axis!

$$A_{xx'} = \frac{1}{p_z} \iint dx \cdot dp_x = \frac{1}{\gamma \cdot m_0 \cdot \beta \cdot c} \iint dx \cdot dp_x$$

$$= \iint dx \cdot dx' \quad \text{mit} \quad x' = \frac{dx}{dz} = \tan\left(\frac{p_x}{p_z}\right) \approx \frac{p_x}{p_z}$$

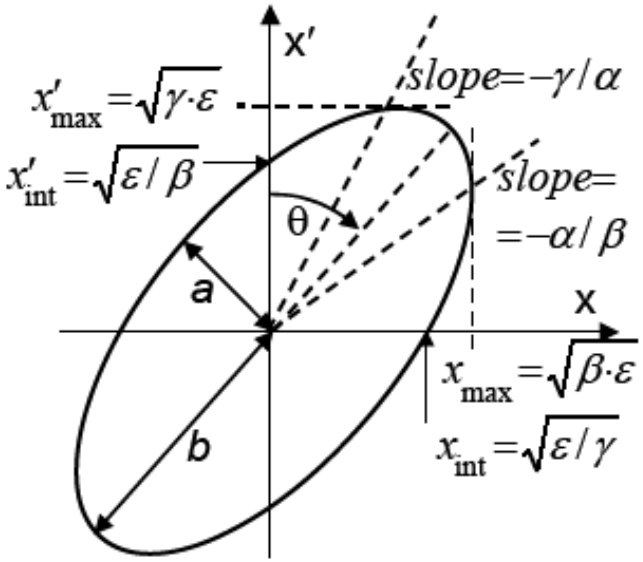
coordinates are decoupled → Liouville theorem → 2-dim phase space stays const. (also for $A_{xx'}$ if no acceleration ($\beta*\gamma$=const.))

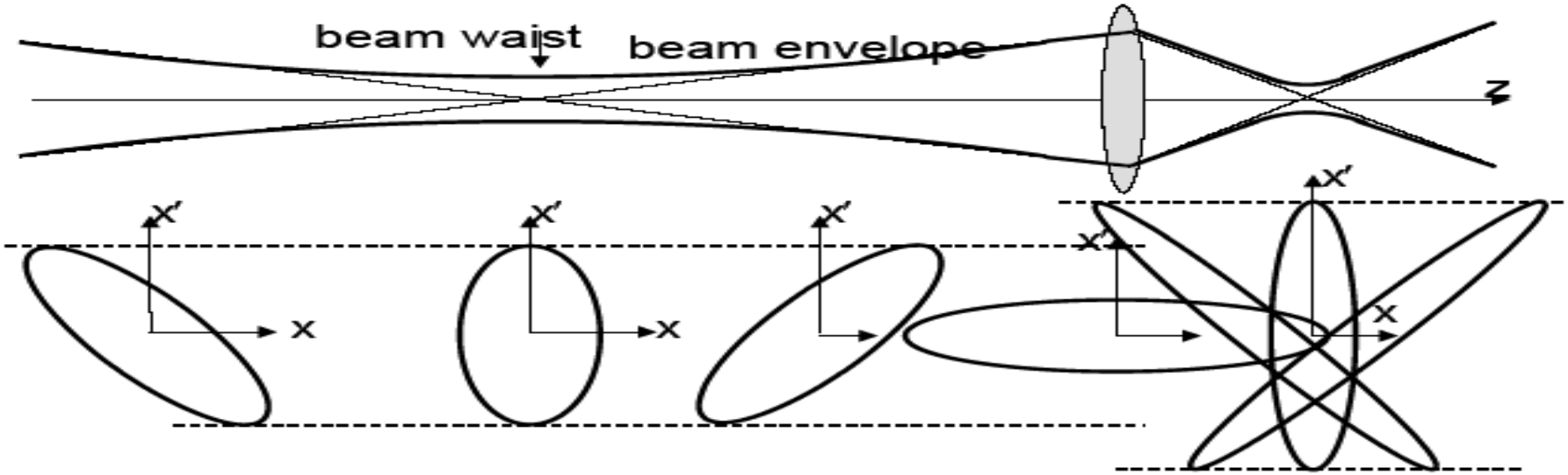
$$\varepsilon_{xx'} = \frac{A_{xx'}}{\pi} = \frac{1}{\pi} \iint dx \cdot dx' \text{ in [mm·mrad] and}$$

$$\varepsilon_{xx',norm} = \beta \cdot \gamma \cdot \varepsilon_{xx'}$$

Transformation of the Emittance Ellipse

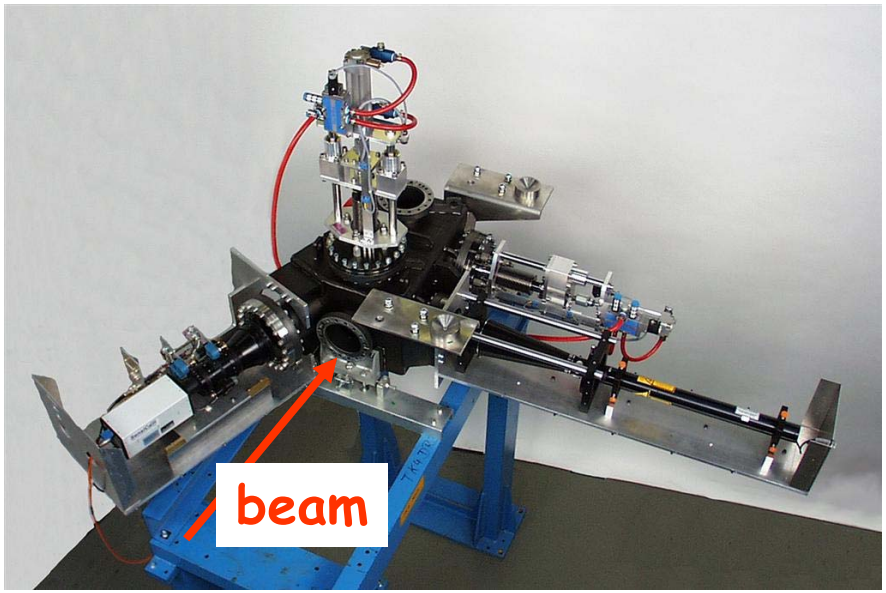
$$\varepsilon = \gamma \cdot x^2 + 2\alpha \cdot xx' + \beta \cdot x'^2$$

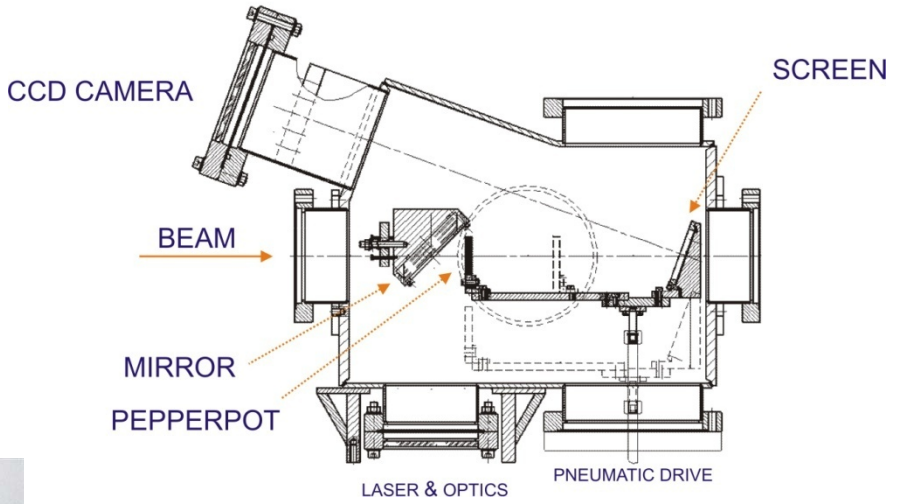


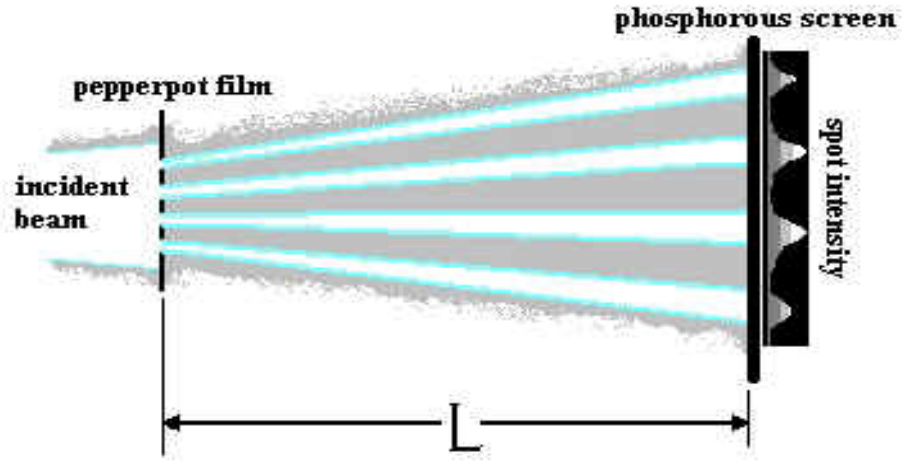


The GSI Pepperpot Emittance Meter

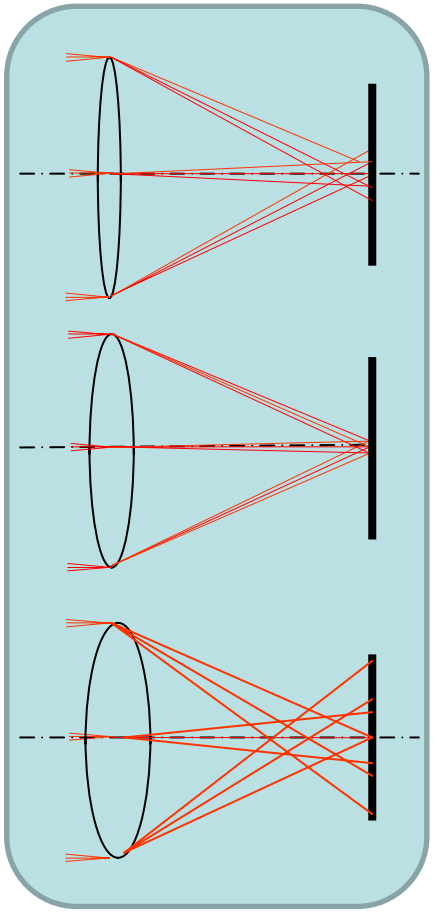
- matrix of 15x15 holes
- diameter 100µm
- spacing 1.6mm
- drift length 150mm
- 8-bit cooled CCD
- $\delta\phi$ 0.3mrad

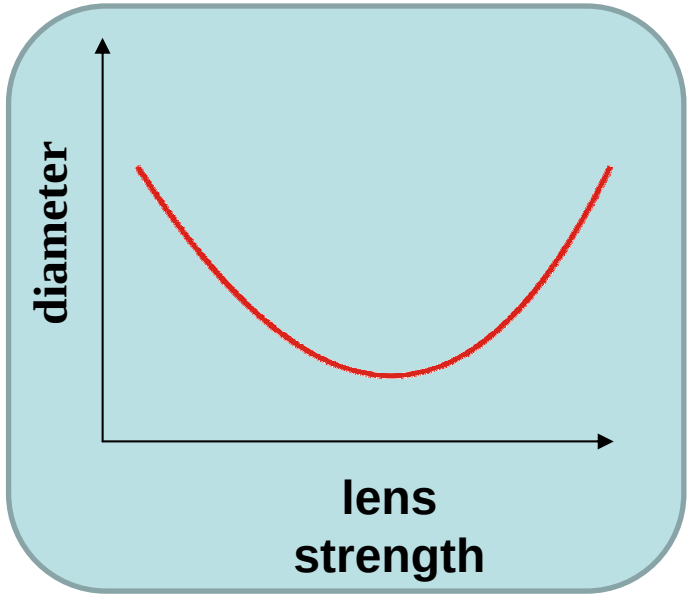






Gradient Scan Emittance Evaluation



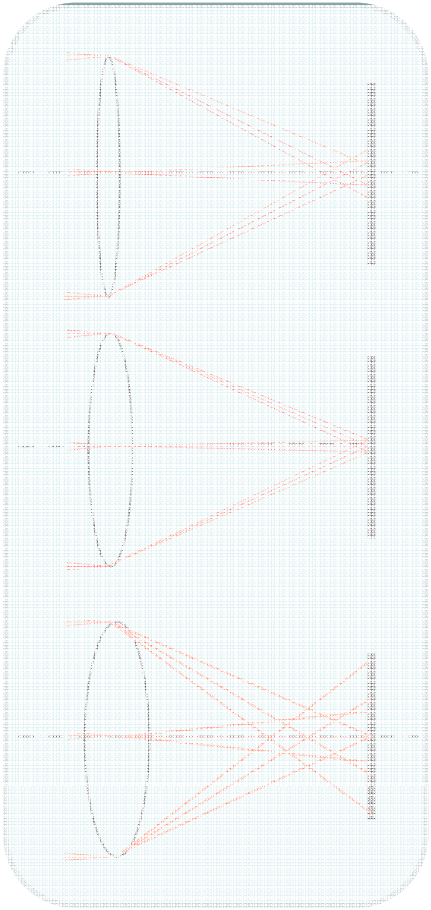


We get:
- beam spot diameter
- beam transport matrix

$$\begin{bmatrix} x \\ x' \end{bmatrix}_f = [R] \cdot \begin{bmatrix} x \\ x' \end{bmatrix}_i$$

$$\begin{bmatrix} A & -2\cdot B & C \\ -2\cdot B & 4\cdot C & -2\cdot D \\ C & -2\cdot D & E \end{bmatrix} \cdot \begin{bmatrix} \varepsilon\cdot\beta_I \\ \varepsilon\cdot\alpha_I \\ \varepsilon\cdot\gamma_I \end{bmatrix} = \begin{bmatrix} \sum_{k=1}^{N} {R_{11,k}}^2 \cdot {r_k}^2 \\ -2\cdot \sum_{k=1}^{N} R_{11,k}\cdot R_{12,k}\cdot {r_k}^2 \\ \sum_{k=1}^{N} {R_{12,k}}^2 \cdot {r_k}^2 \end{bmatrix}$$

Gradient Scan Emittance Evaluation



with

$$A = \sum_{k=1}^{N} {R_{11,k}}^4$$

$$B = \sum_{k=1}^{N} {R_{11,k}}^3 \cdot R_{12,k}$$

$$C = \sum_{k=1}^{N} {R_{11,k}}^2 \cdot {R_{12,k}}^2$$

$$D = \sum_{k=1}^{N} R_{11,k} \cdot {R_{12,k}}^3$$

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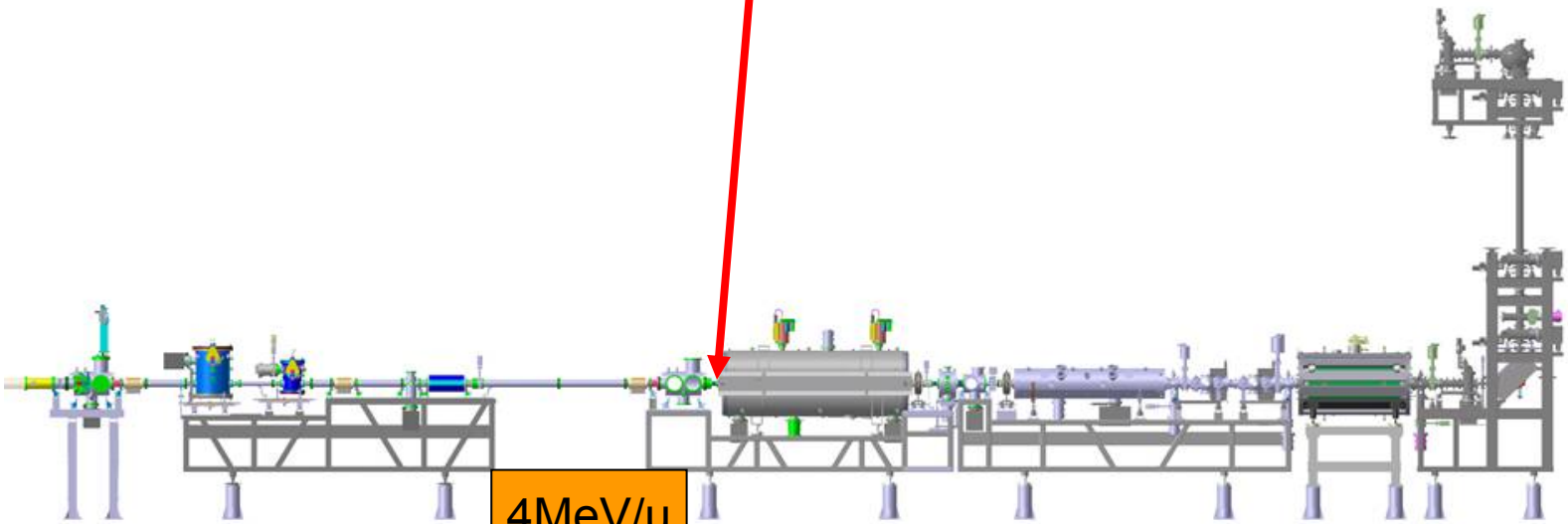
Transverse Emittance of 4MeV/u Beam

design value: $\varepsilon_{90\%}$ = 2.2 mm·mrad

GSI pepperpot emittance meter in front of IH



Emittance for IH Injection

	Pepperpot x	gradient method x	Pepperpot y	gradient method y
Ni^{28+} (2007)	2.1(2)	1.9(2)	2.3(1)	3.8(2)
Ne^{10+} (2007) uncooled!!!	6.4(6)	3.4(1)	6.3(5)	5.4(32)

* all emittances in mm·mrad

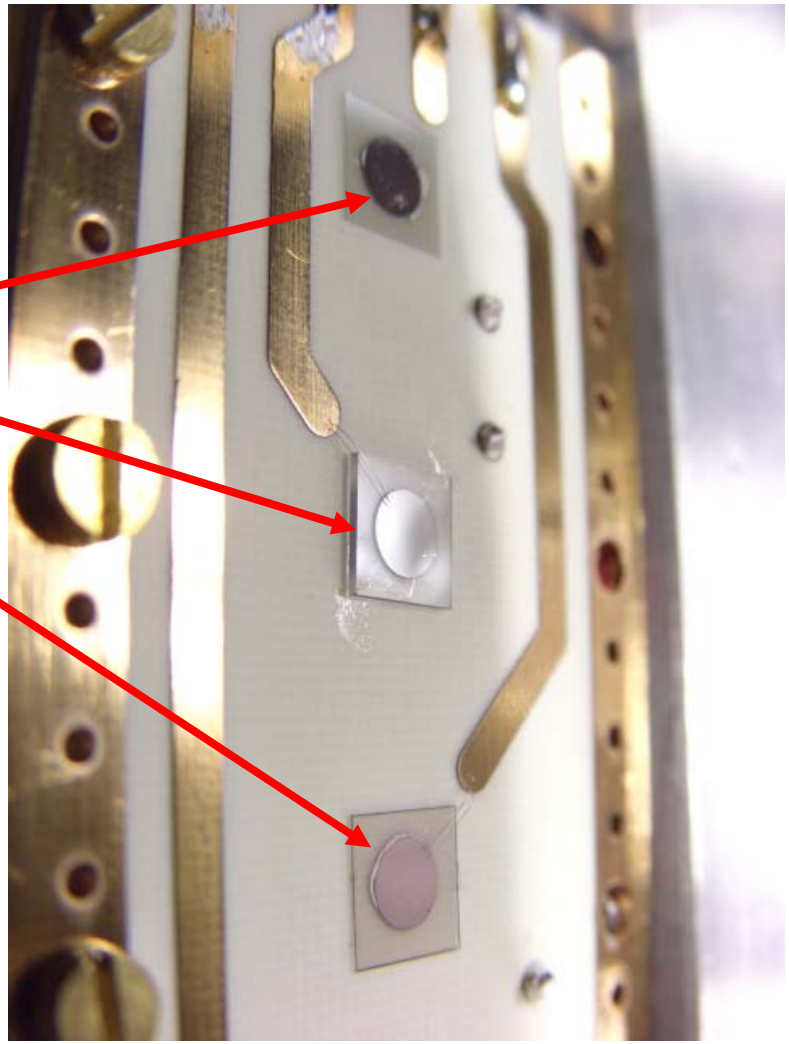
Diamond Detector

4 different separate diamond layers:

- poly-crystal CVD 10µm
- single-crystal CVD 480/380µm
- poly-crystal CVD 15µm
- poly-crystal CVD 600µm

(diameter: 3mm each)

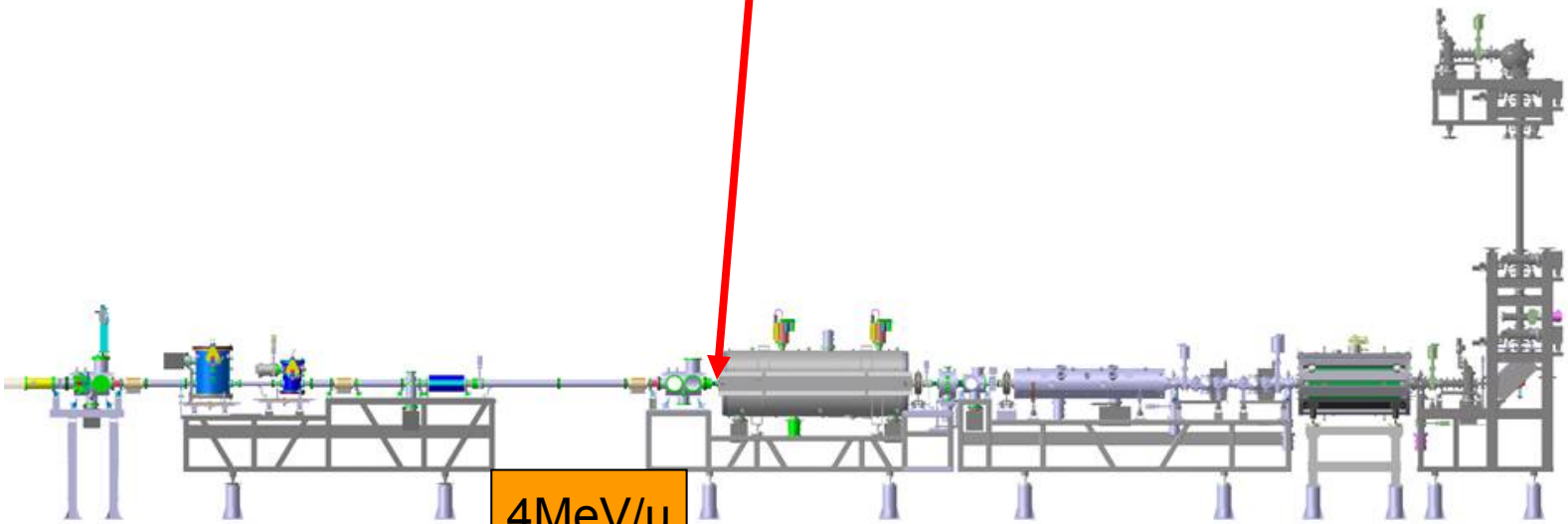
single-crystal: energy measurement
poly-crystal: time structure measurement



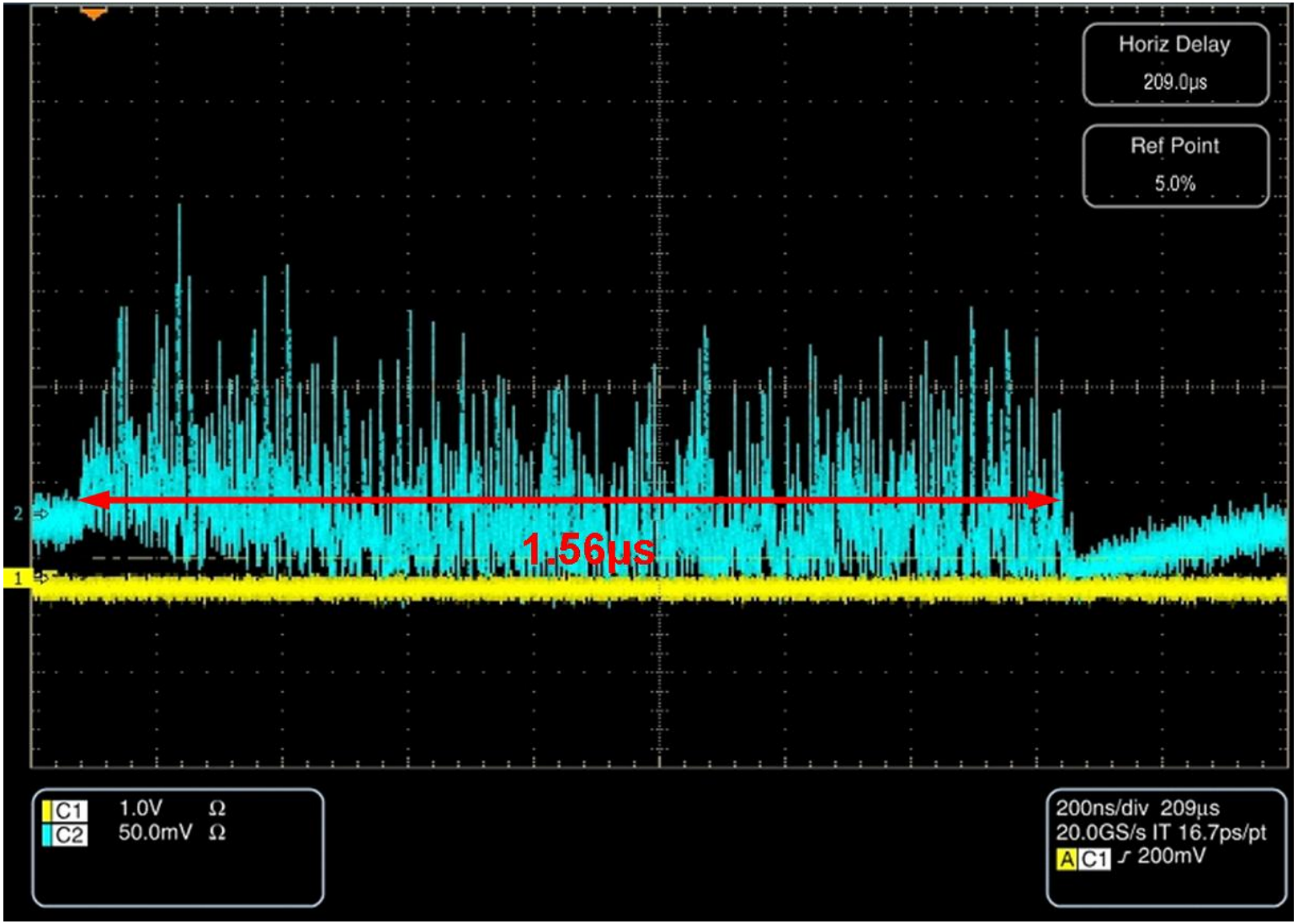
Bunch shape measurement

macro bunch: 1-3μs from ESR **or**
micro-structured: 108MHz bunched for acceptance of IH

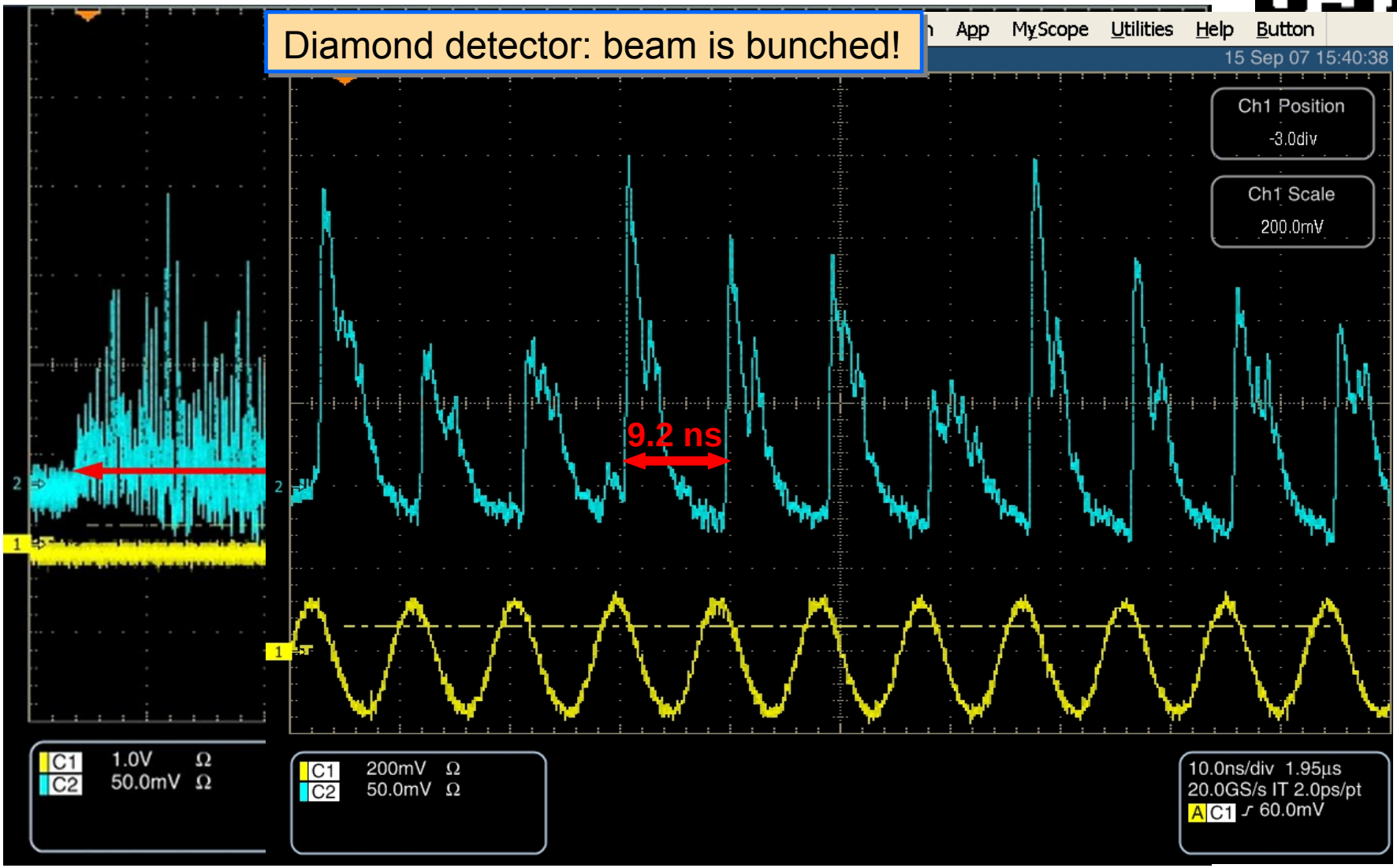
diamond detector in front of IH



Diamond Detector

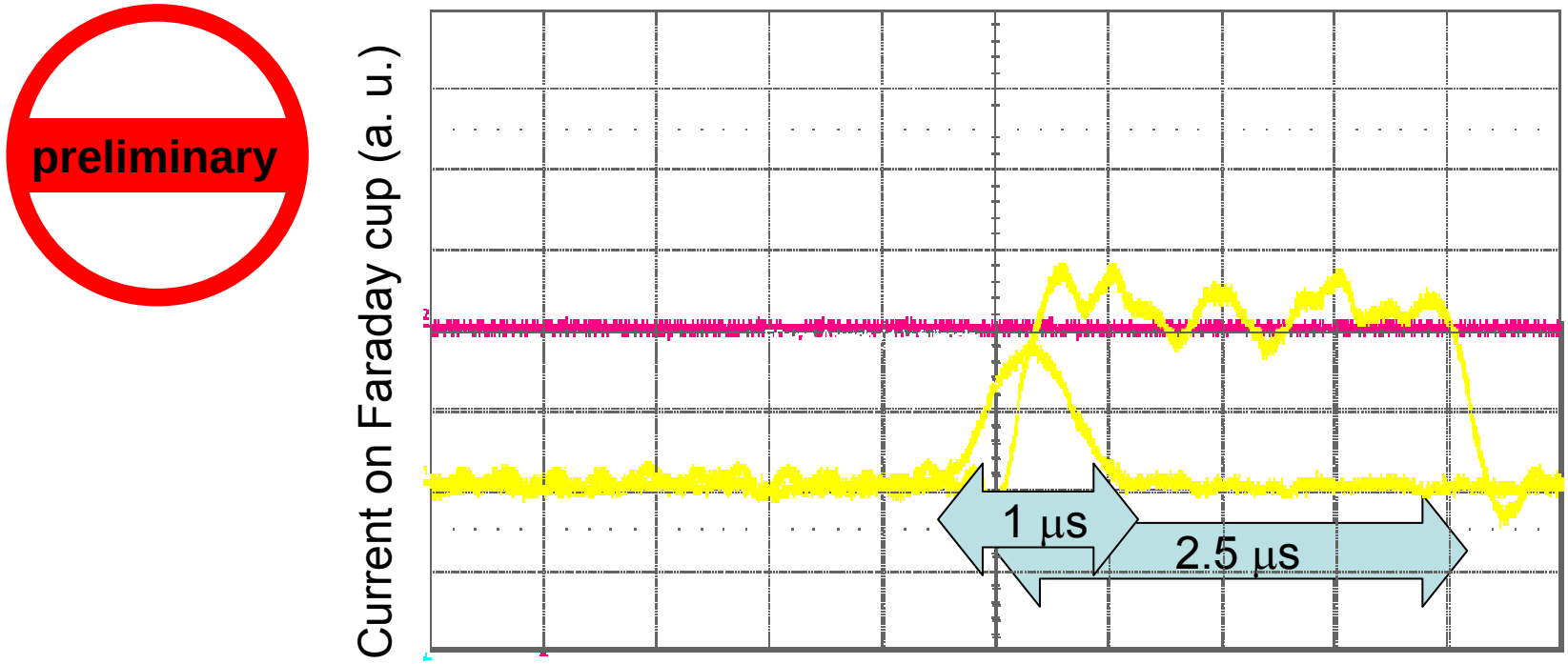


Diamond Detector



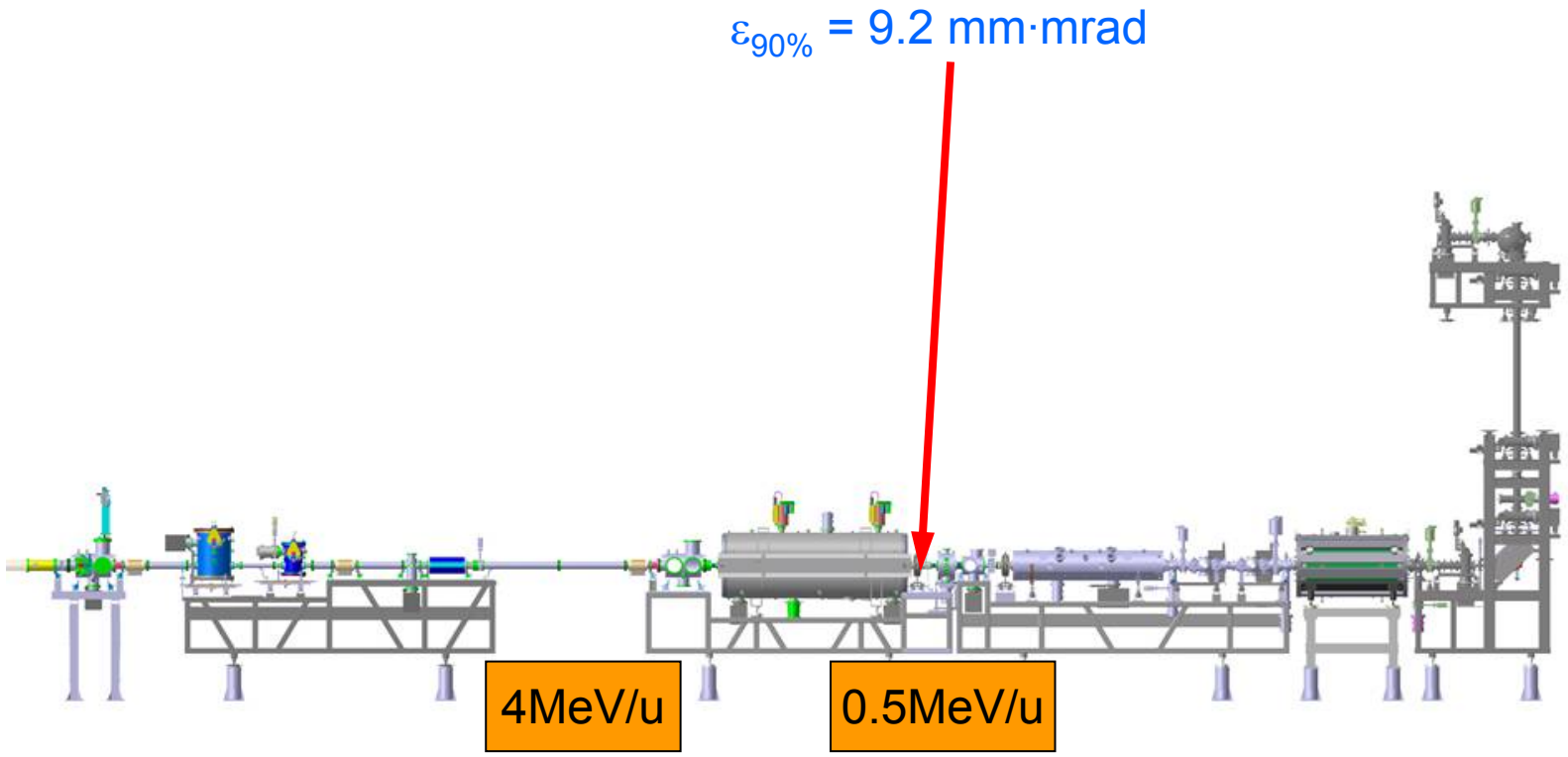
ESR bunching

Bunched beam from ESR extracted to HITRAP for the first time: April 2010



courtesy F. Herfurth

IH Commissioning in 2008/2009

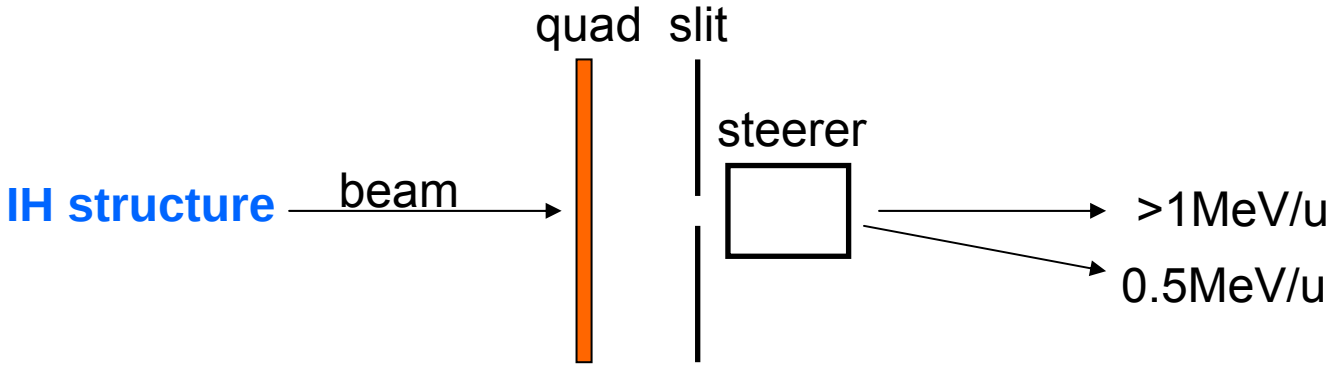


IH Commissioning in 2008/2009

no signal of low energy beam on YAG scintillator or P-43

~~conventional 3-gradient method or pepperpot measurement~~

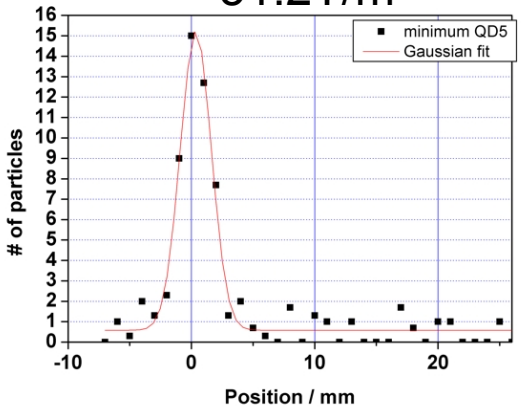
→ 3-gradient method via profile measurements using diamond detector (vertical direction only!)



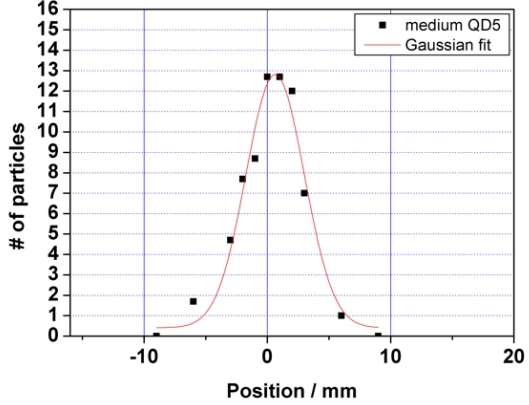
$$\begin{bmatrix} x \\ x' \end{bmatrix}_f = [R] \cdot \begin{bmatrix} x \\ x' \end{bmatrix}_i$$

varying gradient of quadrupole doublett behind IH structure

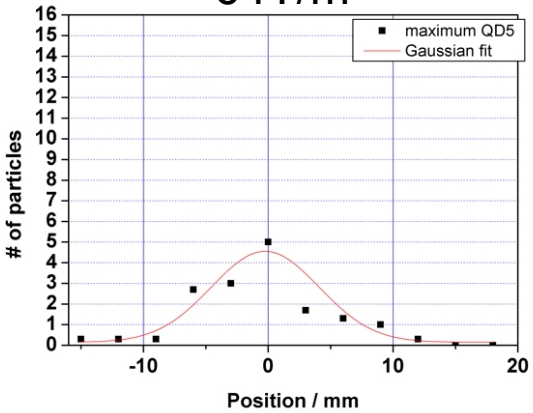
51.2T/m



57.6T/m



64T/m



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with

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$$C=\sum_{k=1}^{N} {R_{11,k}}^2\cdot {R_{12,k}}^2$$

$$D=\sum_{k=1}^{N} R_{11,k}\cdot {R_{12,k}}^3$$

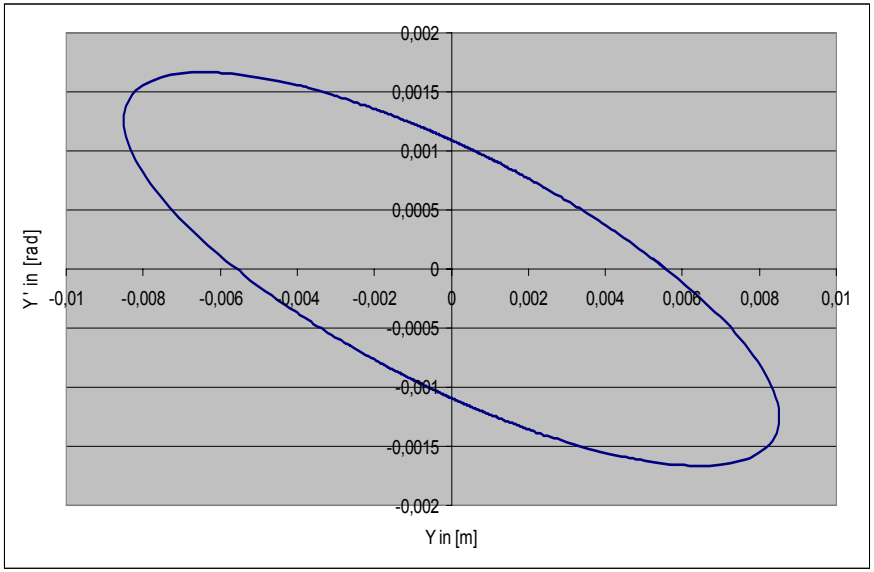
$$E=\sum_{k=1}^{N} {R_{12,k}}^4$$

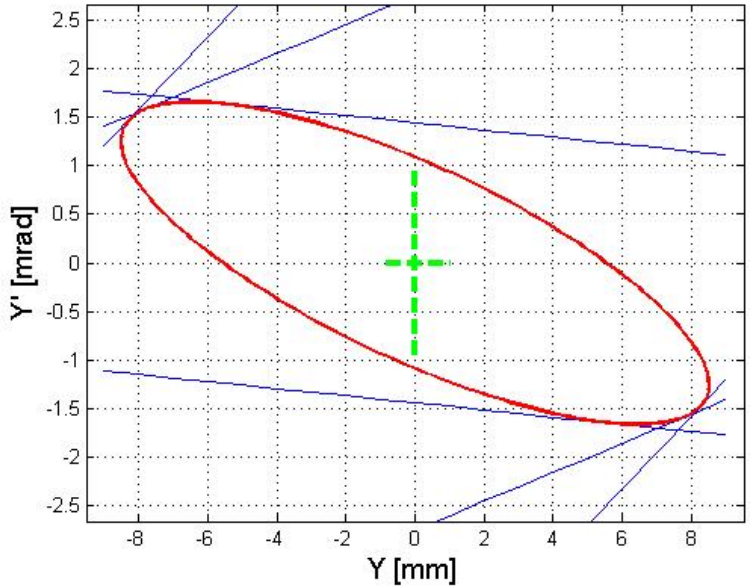
0.5MeV/u Emittance

independent evaluation of data in EXCEL and MATLAB show same result

design value at this point: 9.2 mm·mrad

$\varepsilon_{y,90\%}$	= 9.3 mm·mrad
α	= 1.15
β	= 7.80 mm/mrad
γ	= 0.30 mrad/mm

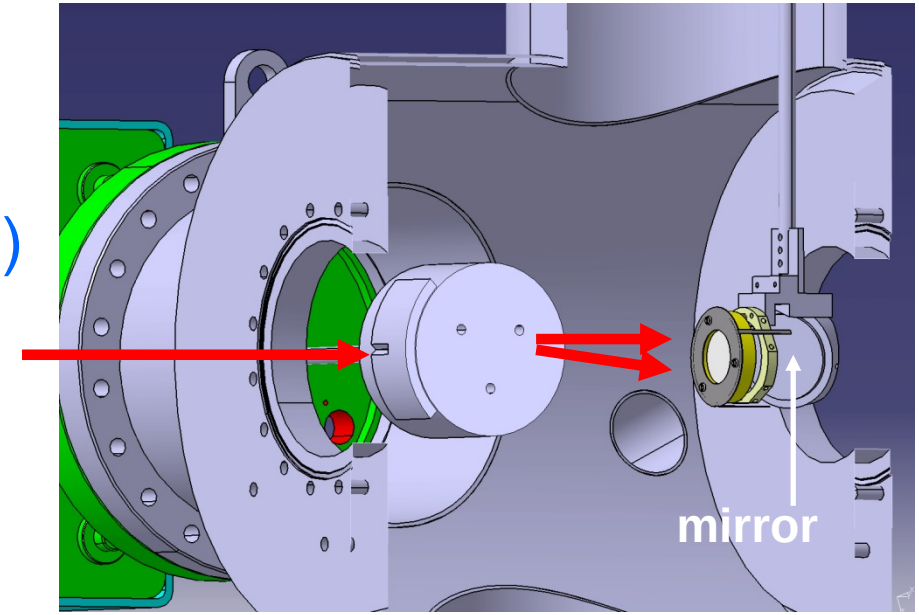


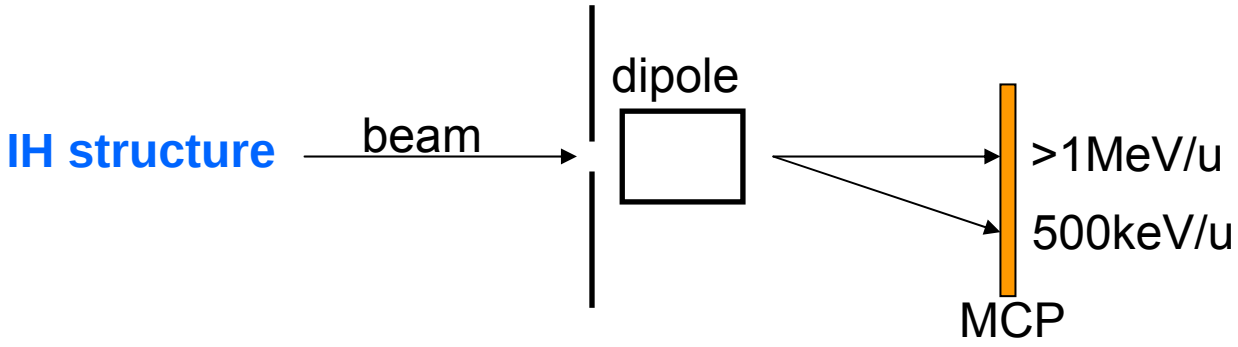


We cannot distinguish between 4MeV/u (transmitted) and 0.5MeV/u (decelerated) with RFQ set up in position

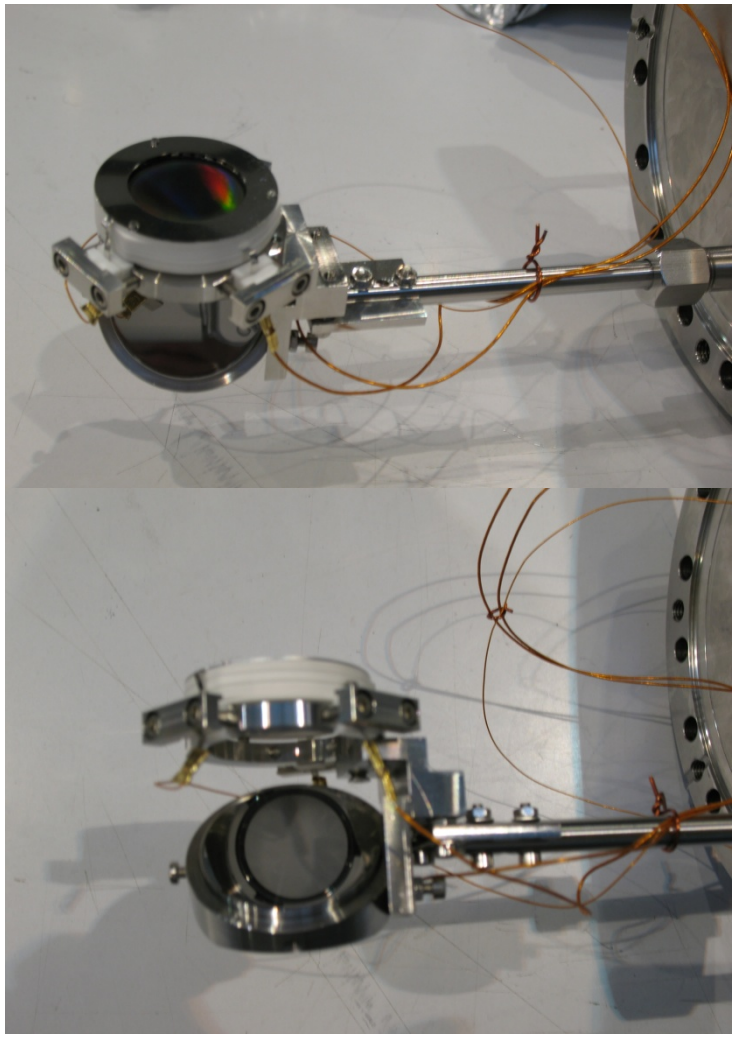
New Energy Analyzer

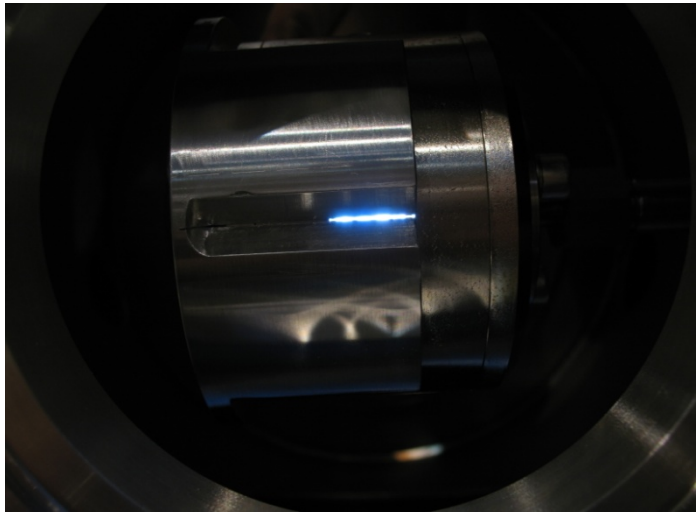
- 0.1mm slit
- 0.5T permanent magnet
- MCP (chevron type, 10^6-10^7)
- SONY CCD camera
  - 1034x779px
  - 4.65x4.65µm pixel size

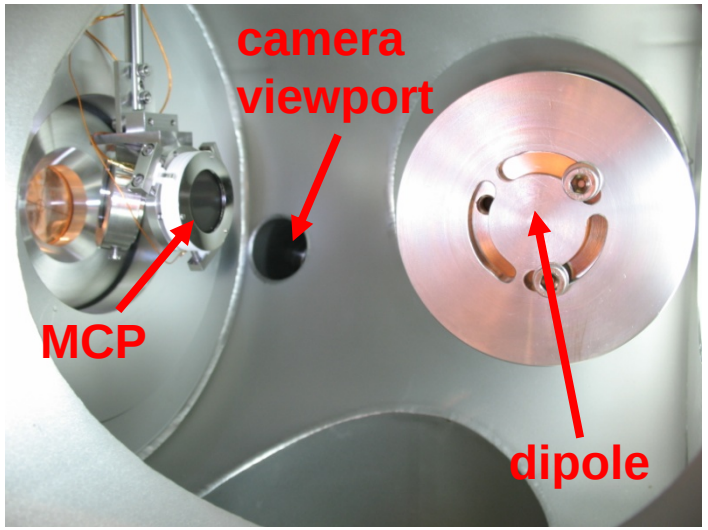




New Energy Analyzer





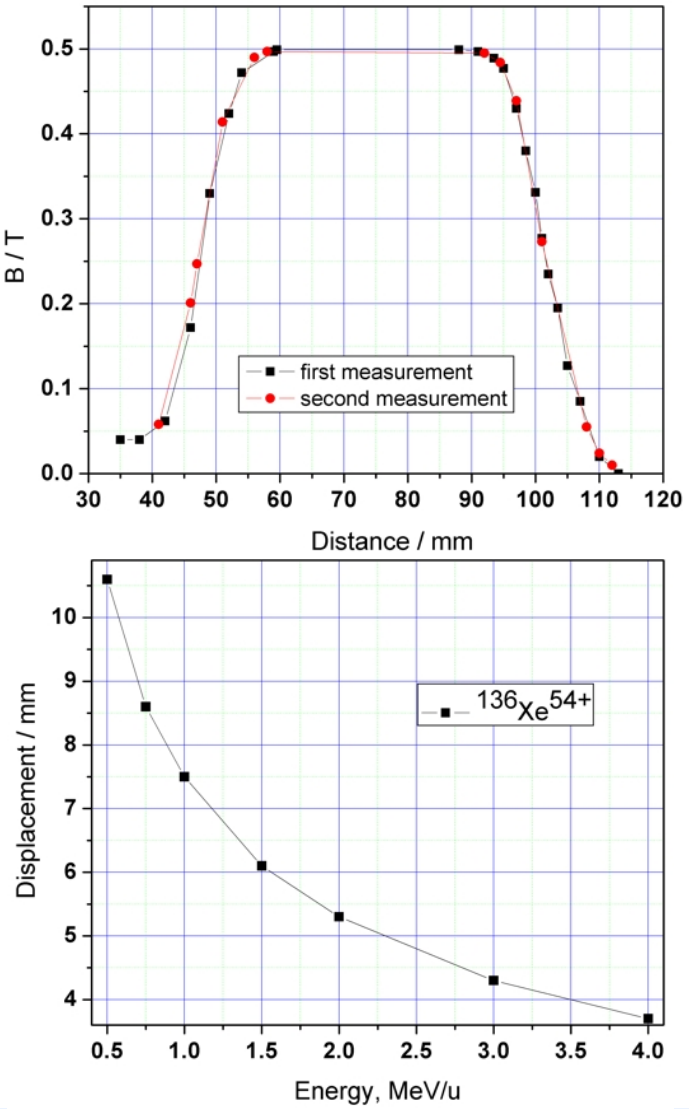


New Energy Analyzer

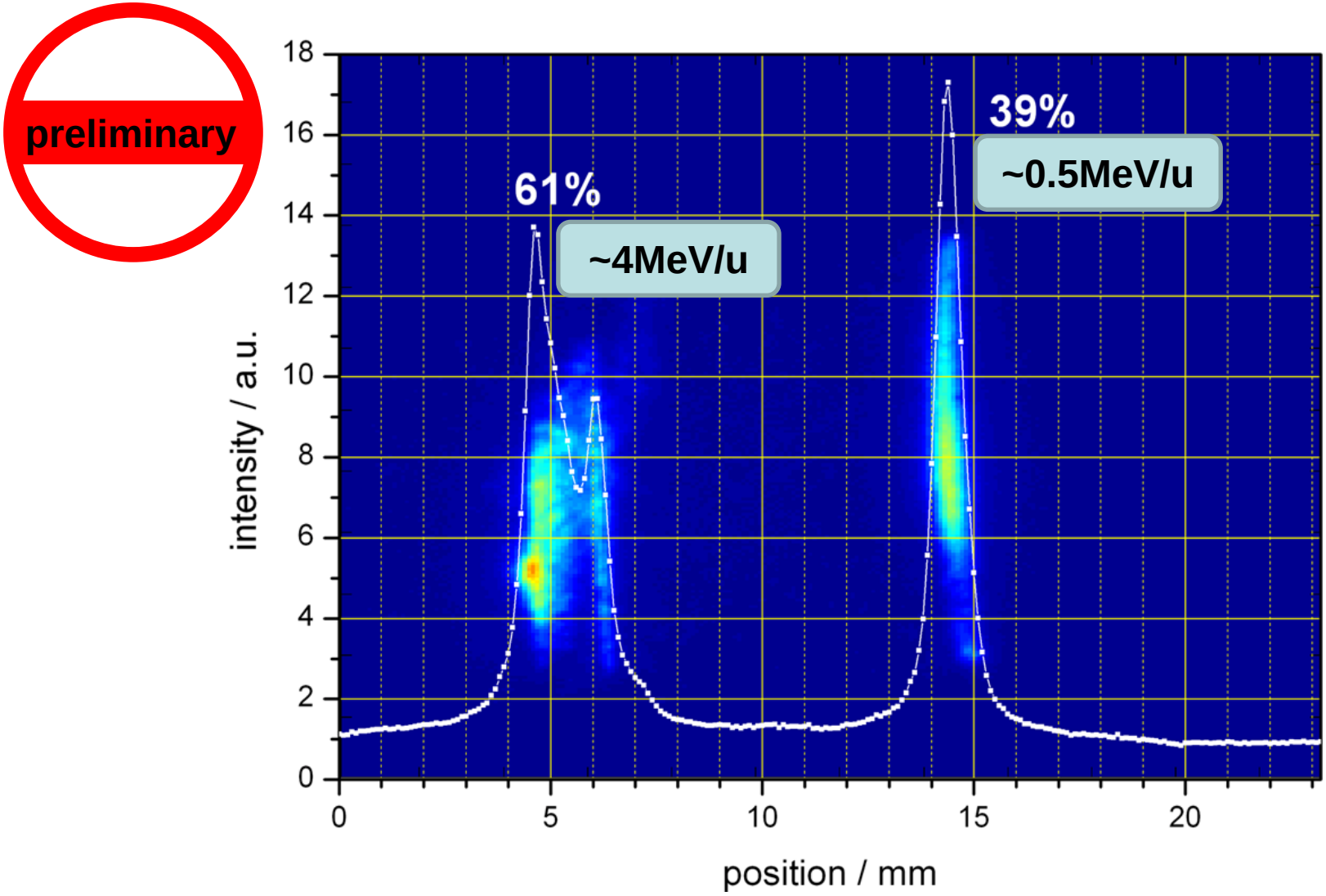
Homogeneous field on magnet axis measured with hall probe

Drift distance between magnetic field edge and MCP: 95mm

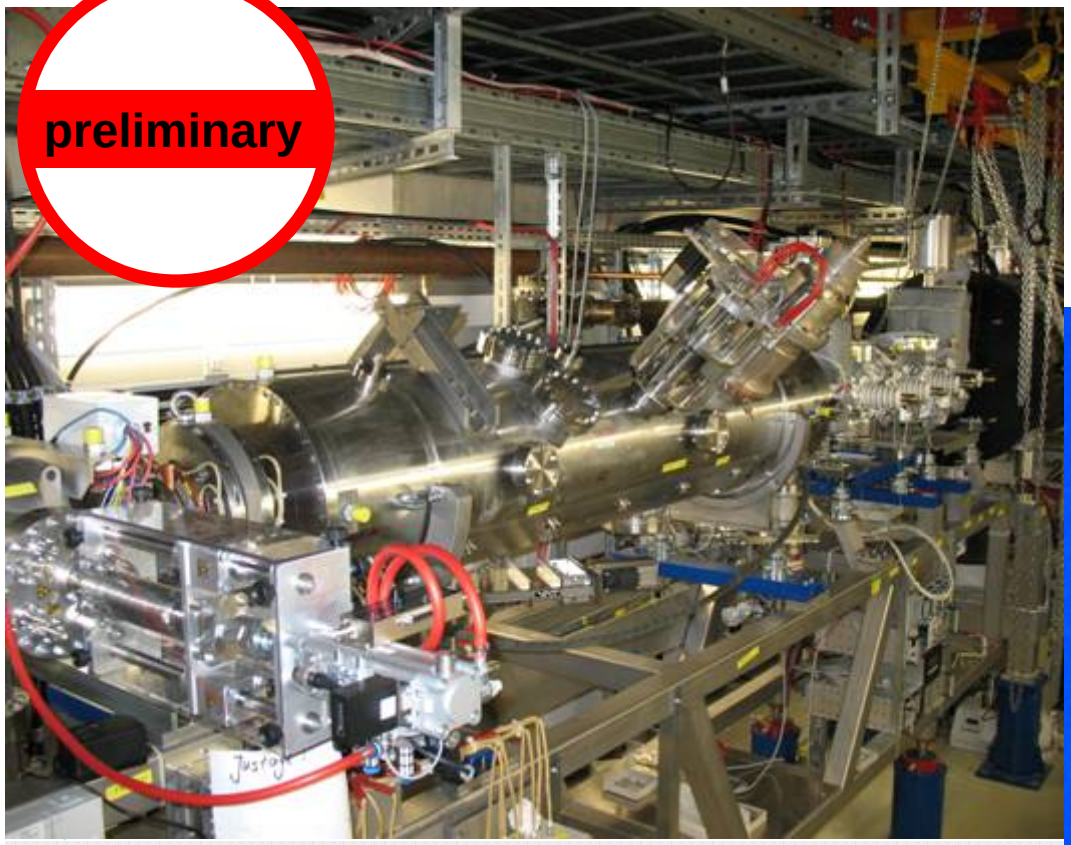
Residual field on axis if magnet out: <1 gauss



Energy Spectrum behind IH

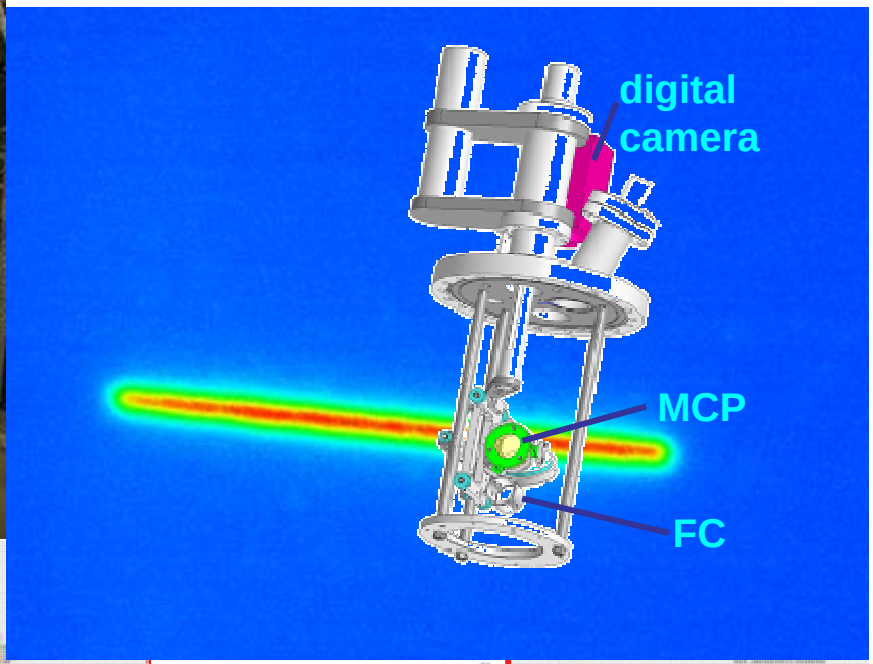


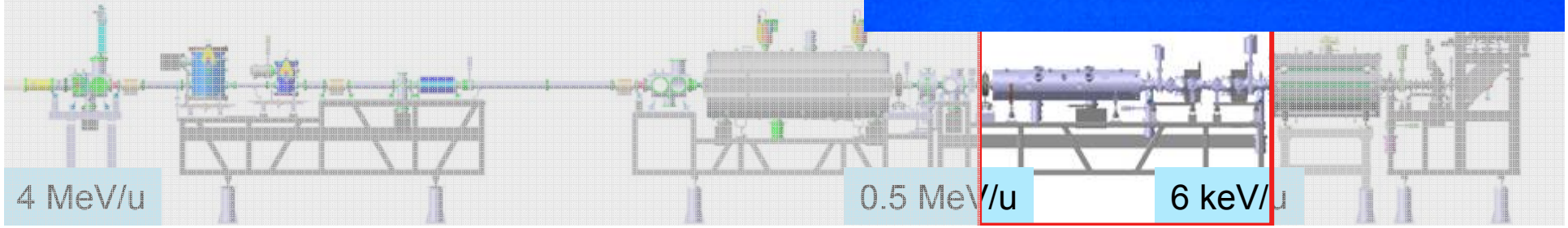
First Beam through RFQ



courtesy F. Herfurth

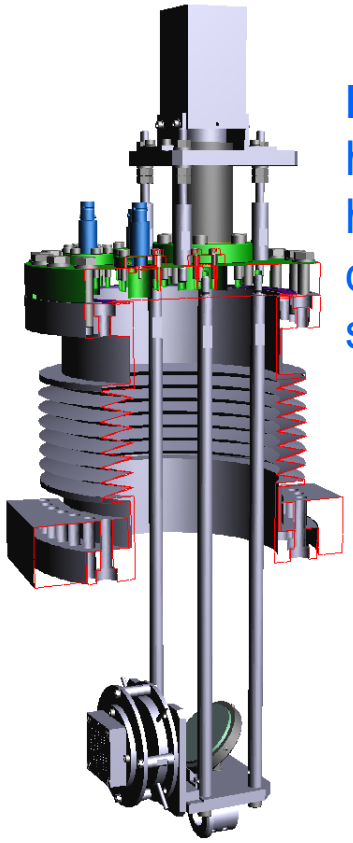
- deceleration from 0.5 MeV/u to 6 keV/u
- Installed, first beam through

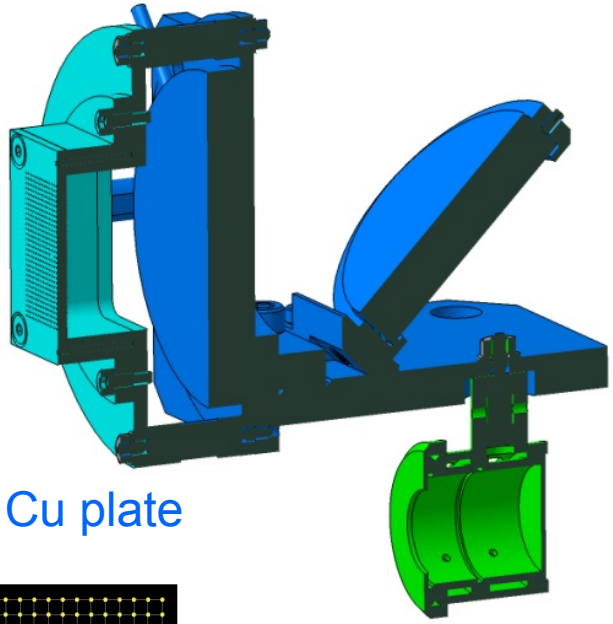




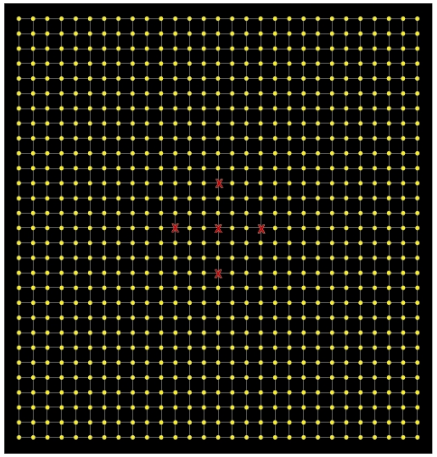
Low Energy/Intensity Pepperpot Device

- stand-alone device
- multi diagnostic

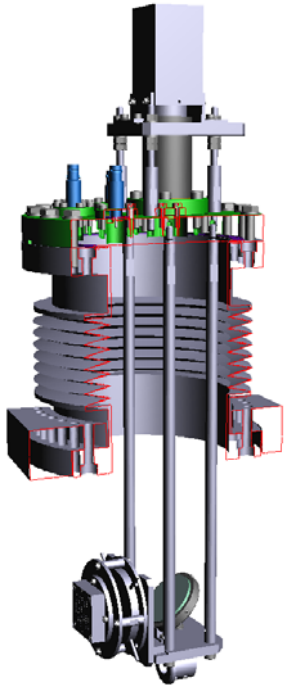


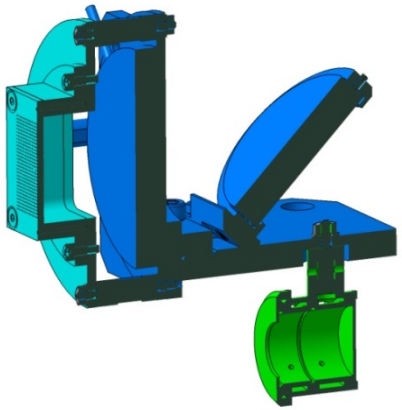


Pepperpot data:
hole diameter: 0.1mm (0.1mm W foil)
hole spacing: 1mm
drift distance: 31.8mm
sandwiched between Al frame and 2mm Cu plate



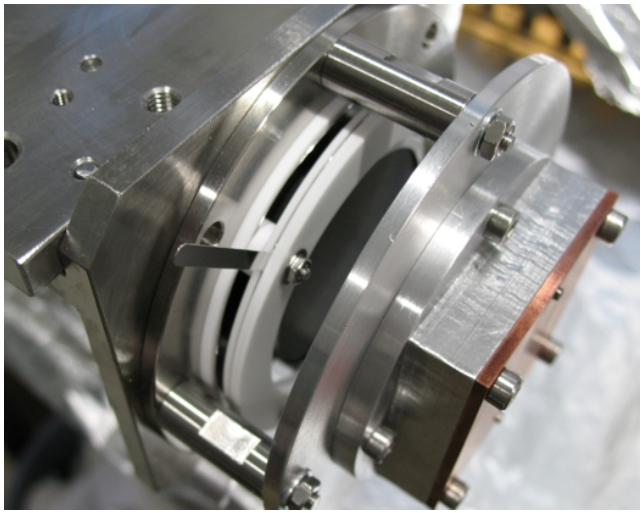
Low Energy/Intensity Pepperpot Device





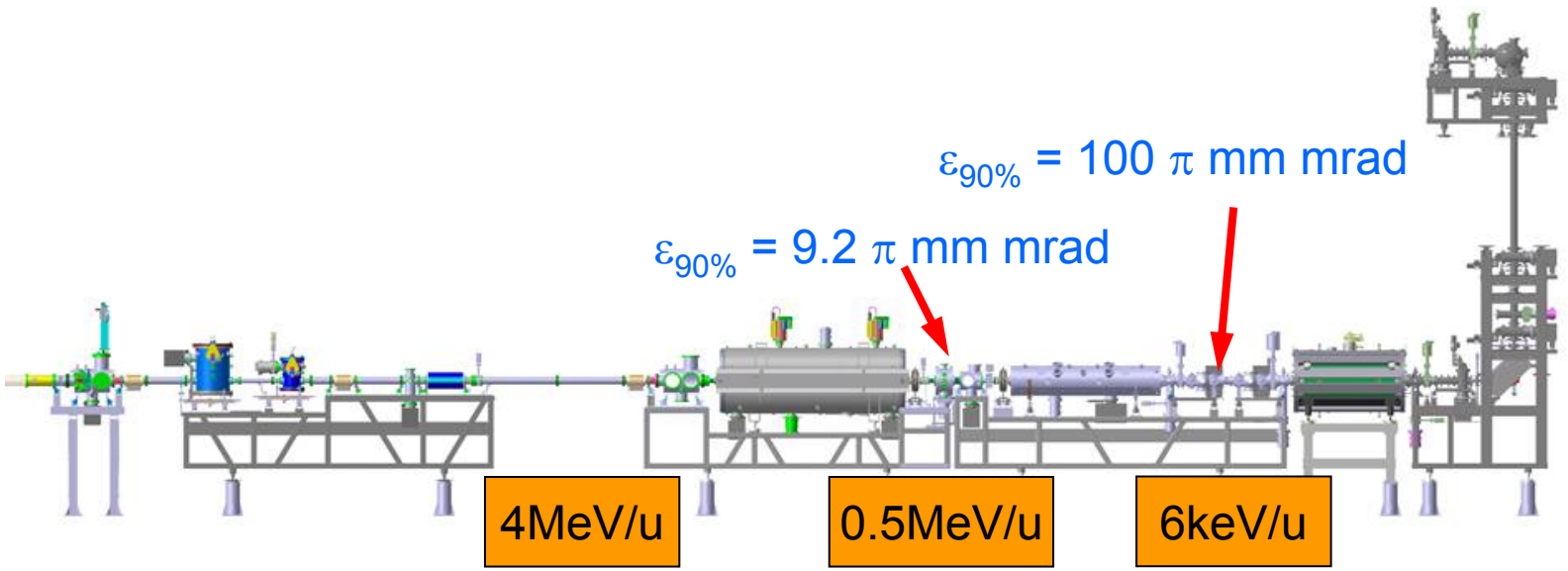
MCP data:
diameter: 40mm
channel diameter: 12µm
gain: 10^4
scintillator: P-43 (λ_{max}=545nm)
afterglow (10%): 1ms

camera: resolution: 1392x1040pixels
→ ~40µm spatial resolution
lens: fixed focus f=50mm, high quality with narrow band pass filter with λ_{max}@ 545nm



First Test of MCP-Pepperpot @ HITRAP in 2009

- Measurement behind RFQ (LEBT)
- Energy mixture: 4MeV/u > E > 6keV/u



First Test of MCP-Pepperpot @ HITRAP in 2009

- Measurement behind RFQ (LEBT)
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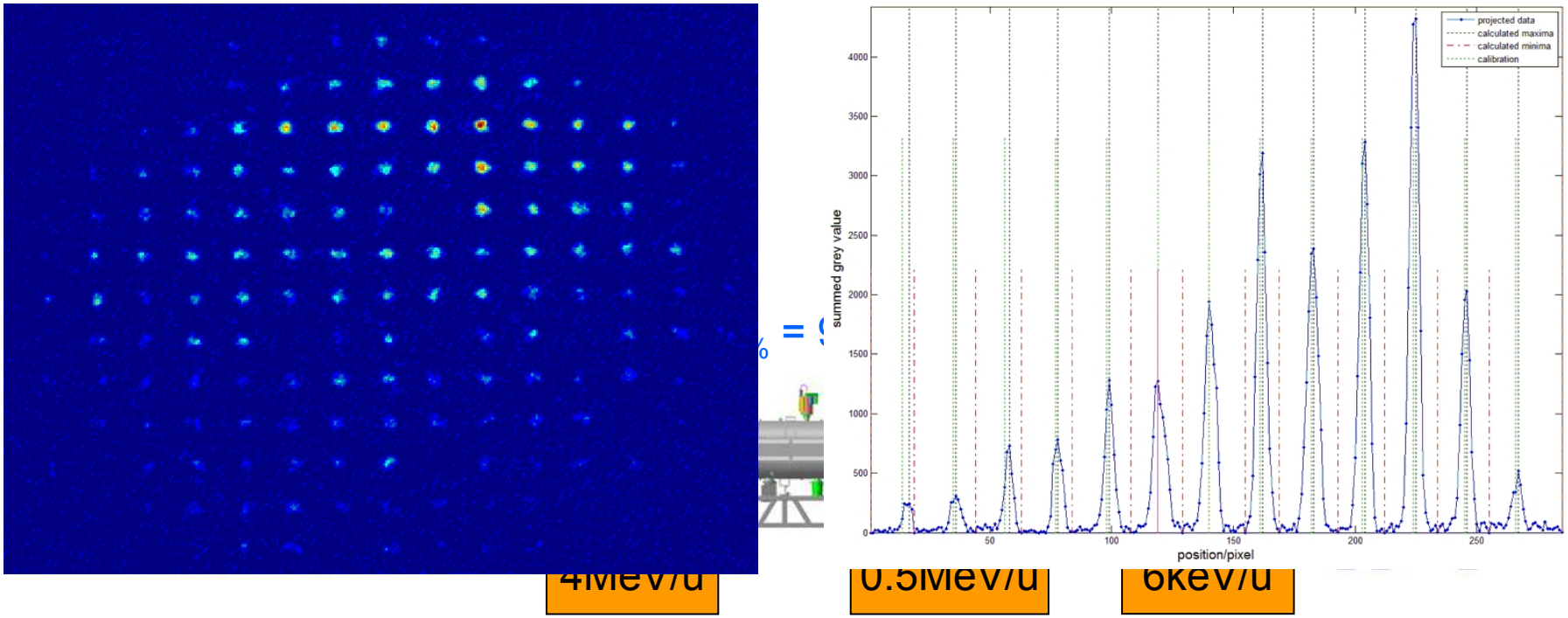

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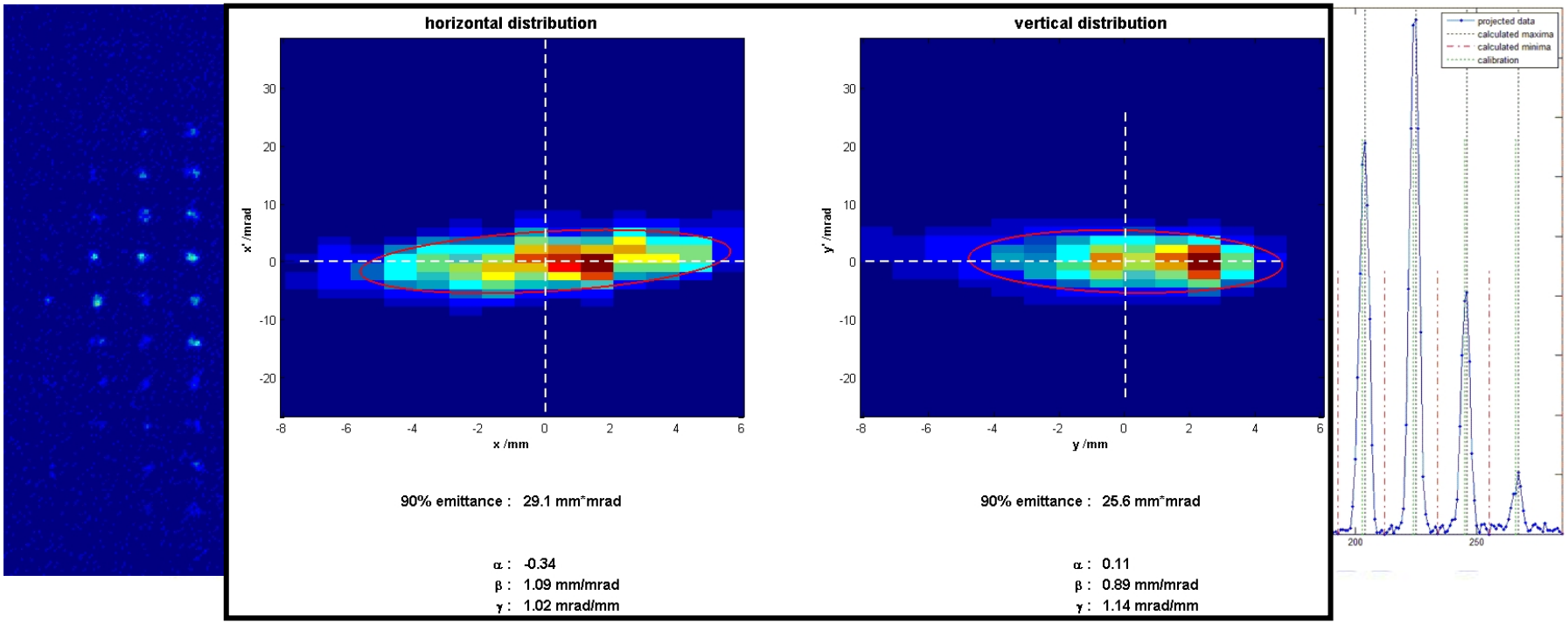
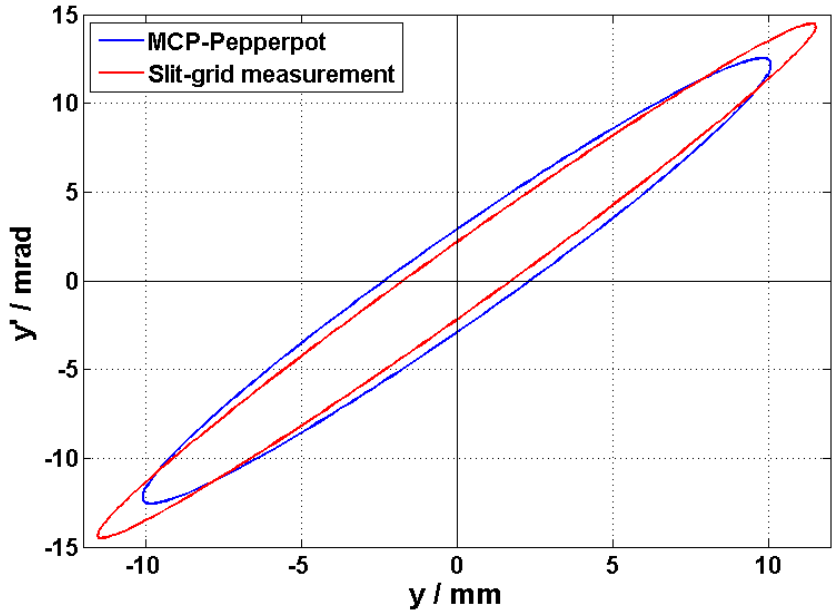
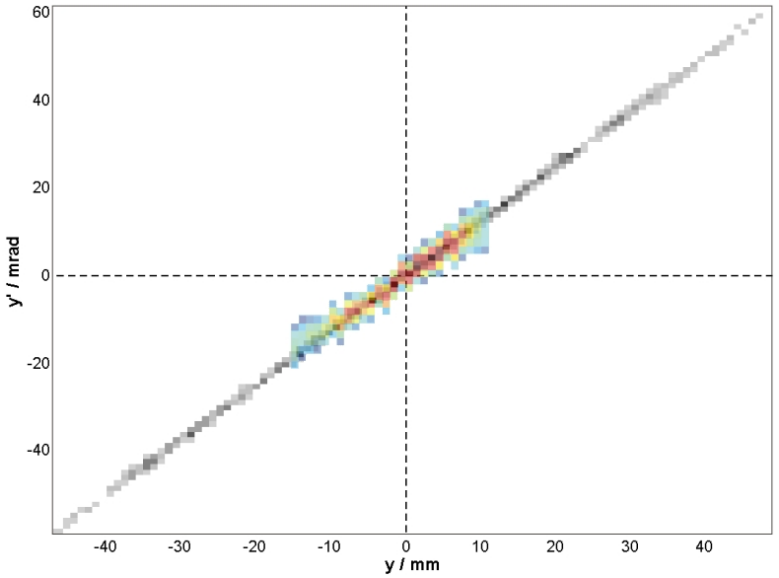


MCP-Pepperpot vs. Slit-Grid Measurement

- 6keV, 400nA, Ar^+-beam

Slit scan measurement	Single-shot pepper-pot measurement
$\varepsilon_{y,\,90\%}$=25.4 mm·mrad	$\varepsilon_{y,\,90\%}$=29.6 mm·mrad



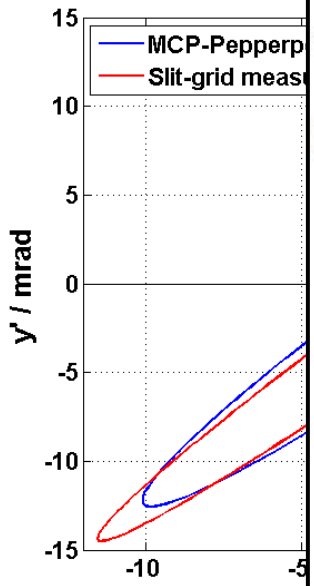


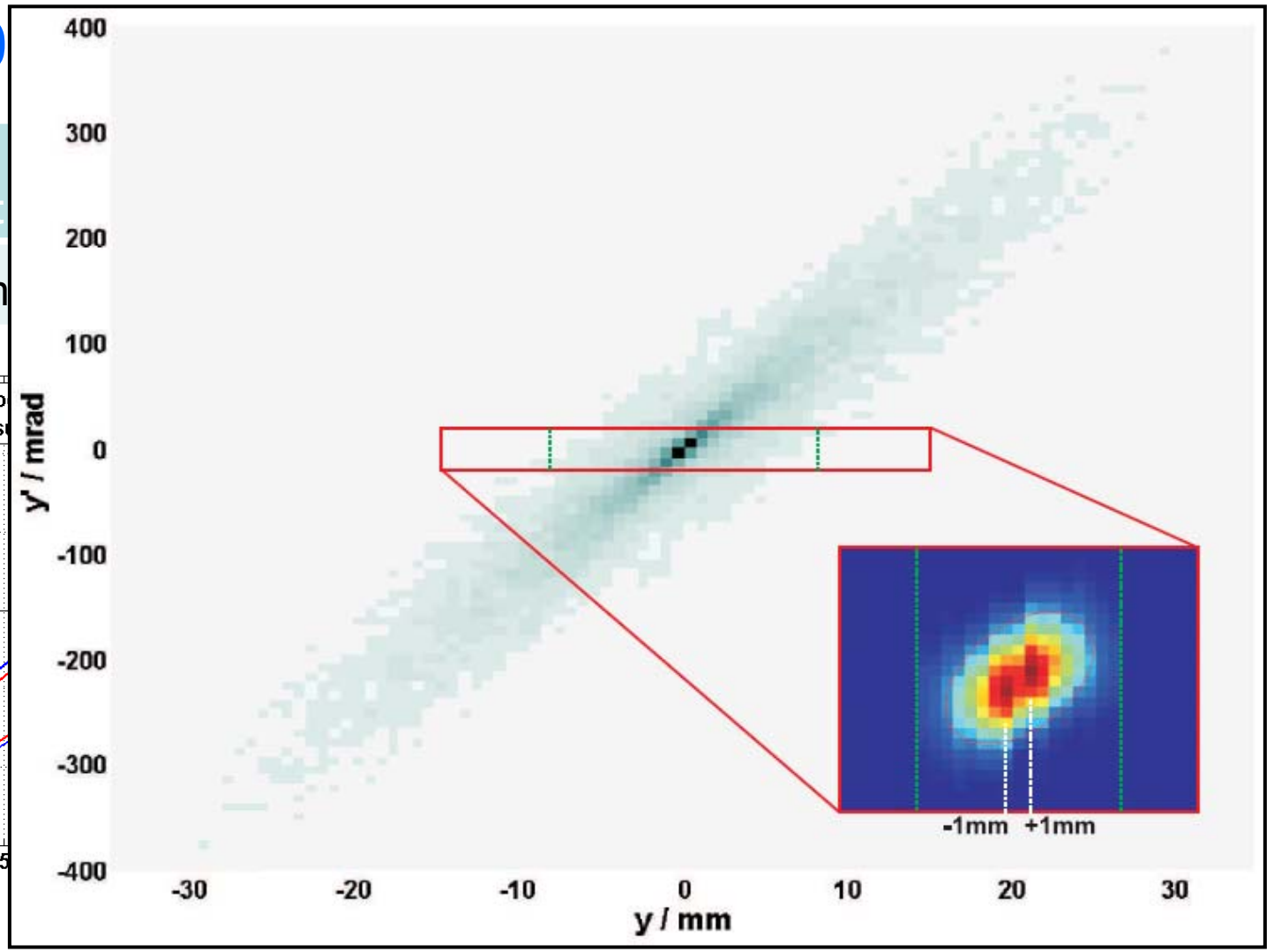
MCP-Pepperpot vs. Slit-Grid Measurement

- 6keV, 40

Slit scan measurement

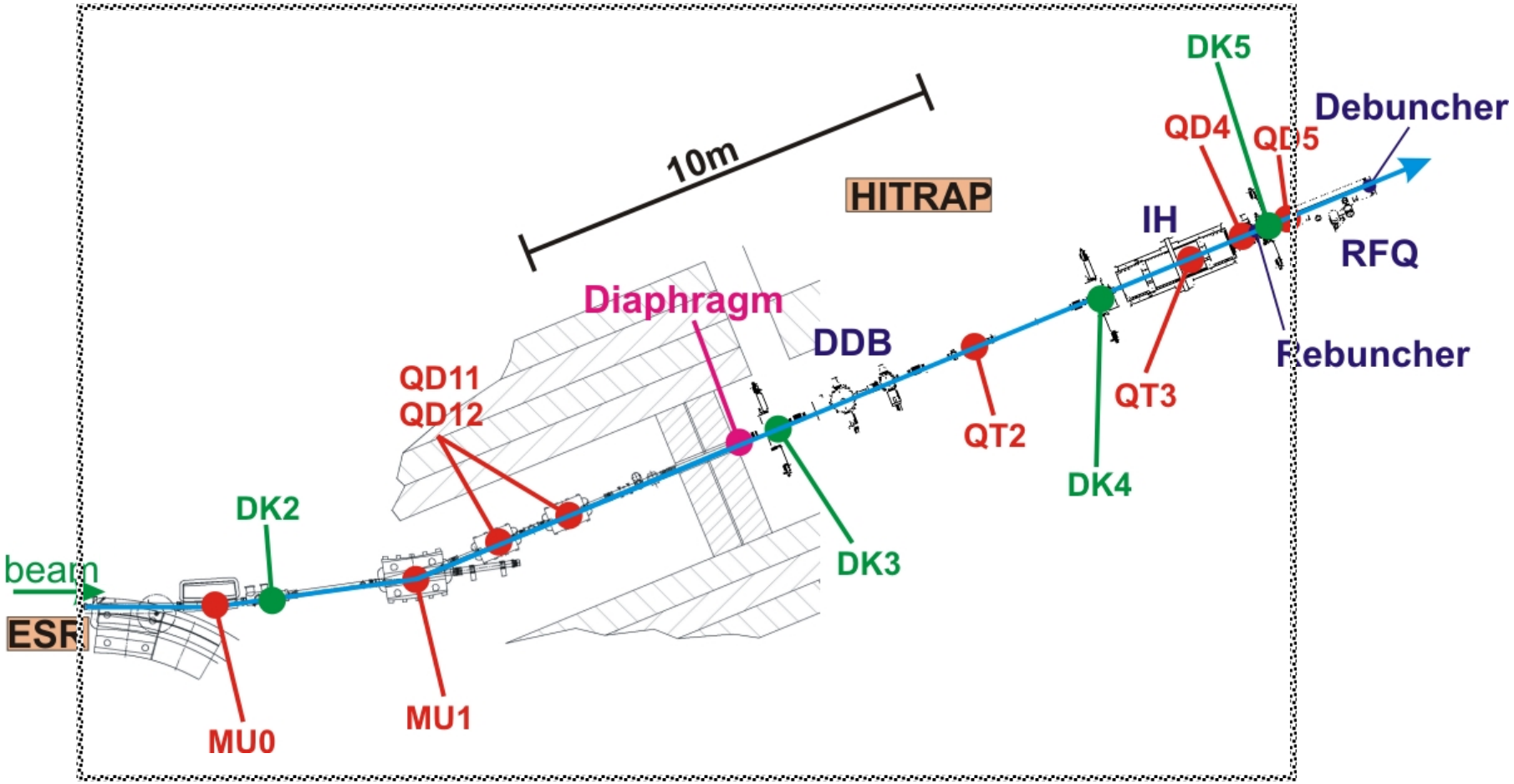
$\varepsilon_{y,\ 90\%}$=25.4 mm·m



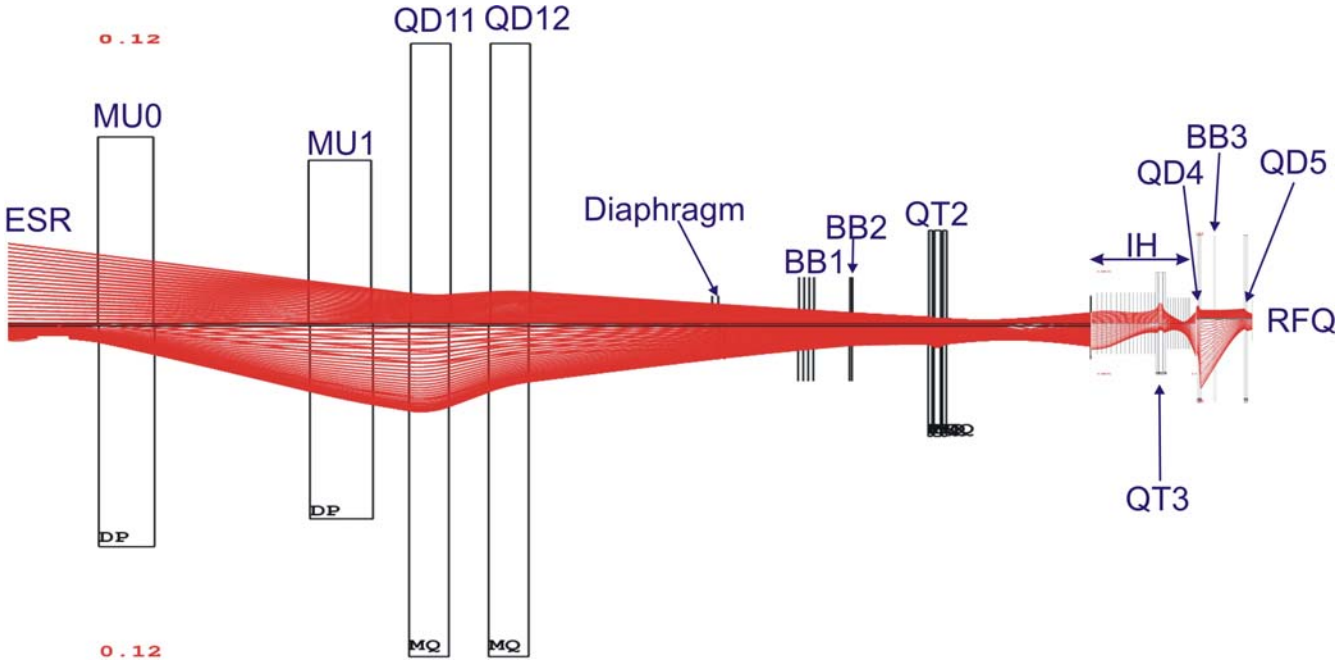


Transverse Beam Dynamics Studies

treated in studies



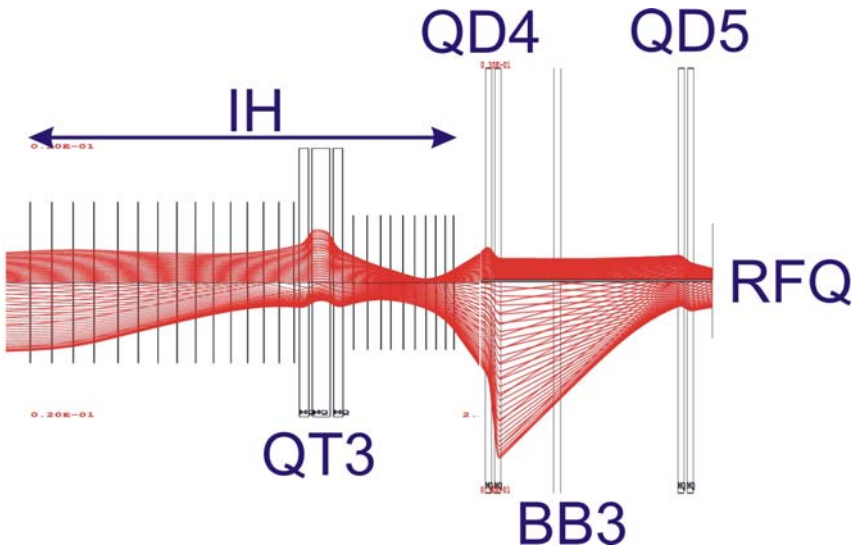
Transverse Beam Dynamics Studies vs. Exp.

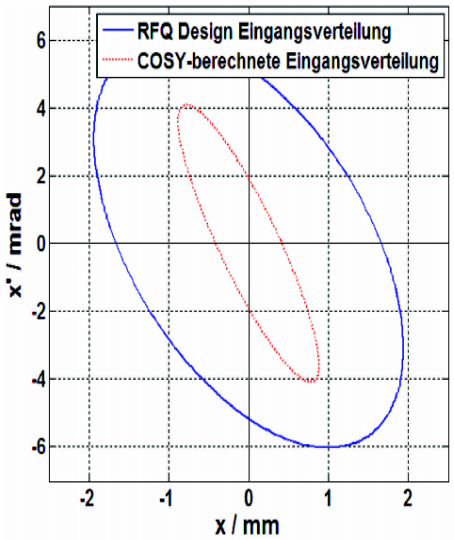


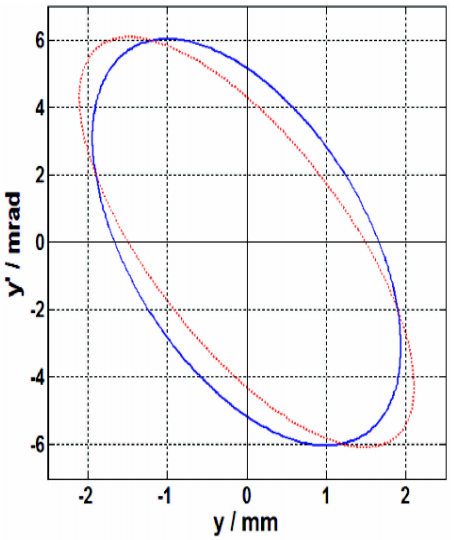
- beam size @ ESR: hor: ~40mm, vert: ~5mm (as expected, but different phase space distribution)
- emittance larger in y than x (measured)
- >98% transmission to IH, but
- “bad” focusing into IH due to diaphragm

Transverse Beam Dynamics Studies

- setup of QD4/5 cannot focus present beam transversally into RFQ (<50%)
- Pulsing QD4/5 higher could theoretically inject >95% of ions into transversal RFQ acceptance

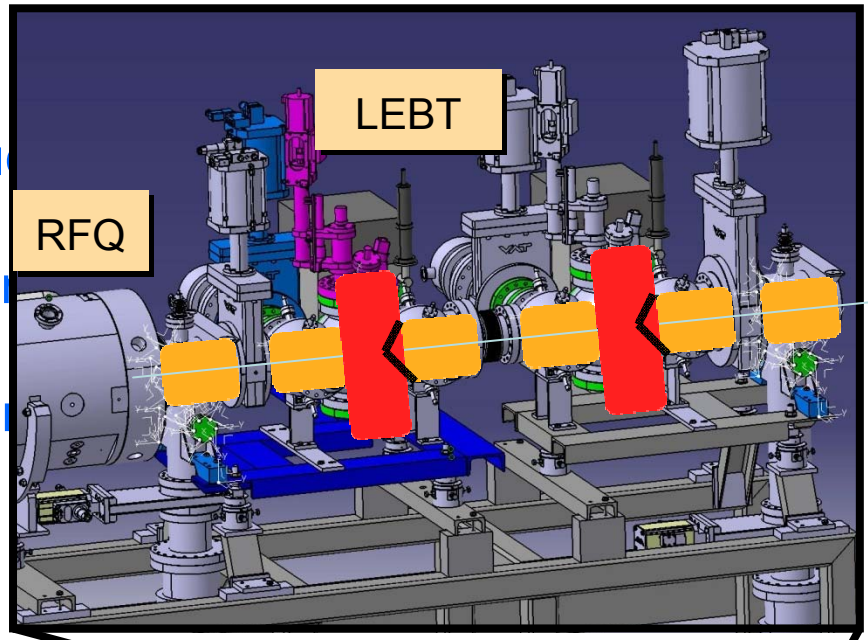






RFQ commissioning

- further fine tuning of IH-stru
- further diagnostics improver
  - energy analysis (2)
  - low energy emittance



HITRAP Collaborators

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

HITRAP facility:
GSI: AP Division and Accelerator division
University Frankfurt: B. Hofmann*, J. Pfister, U. Ratzinger, A. Sauer* and A. Schempp
KVI Groningen: R. Hoekstra

Experiments:
R. Hoekstra (KVI Groningen)
J. Ullrich, K. Blaum and A. Wolf (MPI-K Heidelberg)
A. Warczak (Kraków)
W. Nörtershäuser, J. Walz and G. Werth (University Mainz)
R. Schuch (Stockholm)
R. Thompson, D. Segal, M. Vogel (Imperial College London)
J. Burgdörfer (TU Wien)
C. Weinheimer (University Münster)
G. Birkl (TU Darmstadt)
M. Weidemüller (University Freiburg)