Current Status of High Energy Density Physics with Intense Ion- and laser Beams at GSI and FAIR in Darmstadt

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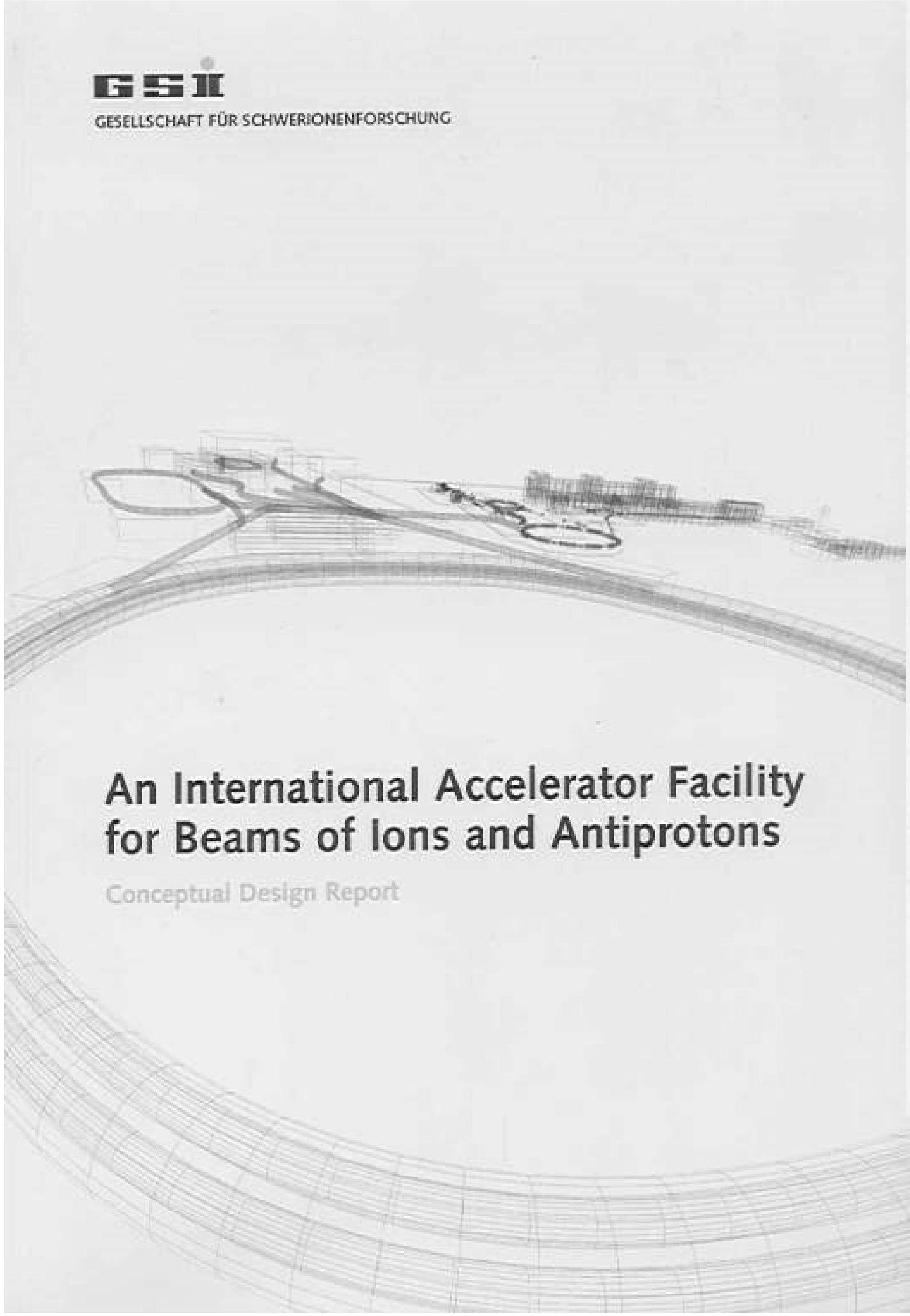
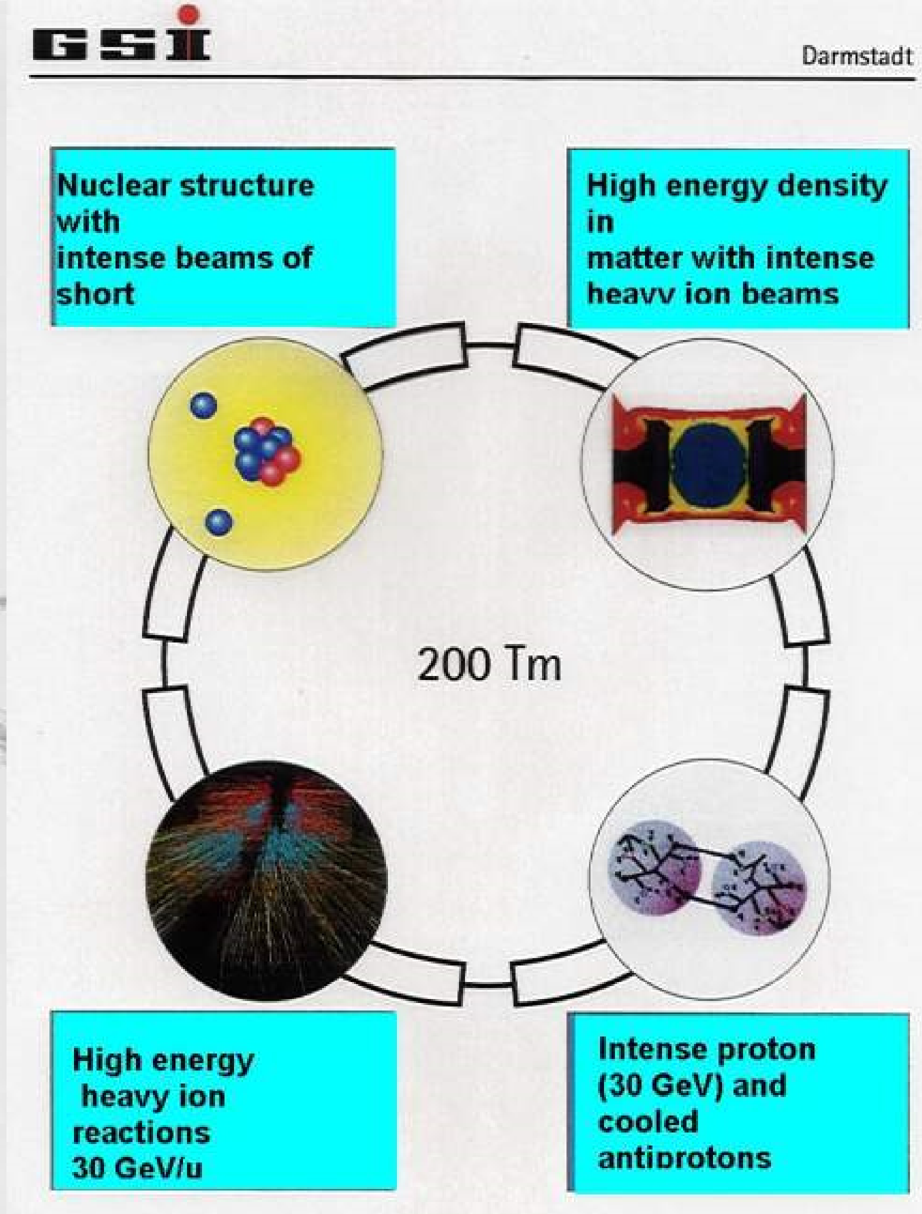
Technical University Darmstadt
HEDgeHOB Collaboration
Currently guest at : Chinese Acad. Science, IMP, Lanzhou





Status in 2003

Topics:

Remarks on Inertial Fusion

Properties of Heavy Ion Beams

Ion Beam Plasma Interaction

Generating WARM DENSE MATTER with Ion Beams

Diagnostics: Proton Microscopy

The HEDgeHOB collaboration:

Studies on high energy density matter with intense heavy ion and laser beams at FAIR

(officially inaugurated: June 2005)

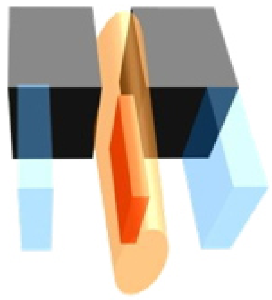
- >200 Scientists
- 44 Institutes
- 15 Countries

http://hedgehob.physik.tu-darmstadt.de

HEDgeHOB Experimental Program

HIHEX
Heavy Ion Heating and Expansion

U^{28+}, 2 GeV, $5 \cdot 10^{11}$, SC FFS

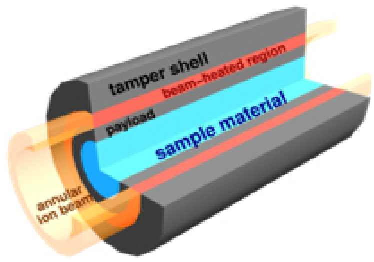


uniform quasi-isochoric heating of a large-volume dense target and isentropic expansion

numerous high-entropy HED states:
EOS and transport properties of non-ideal plasmas / WDM for various materials

LAPLAS
Laboratory Planetary Sciences

U^{28+}, 1 GeV, $5 \cdot 10^{11}$, Wobbler

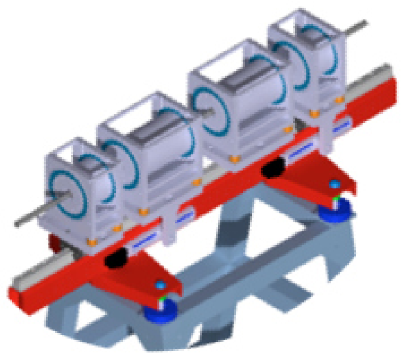


ring-shaped beam implodes a heavy tamper shell, low-entropy compression of hydrogen

Mbar pressures @ moderate temperatures:
hydrogen metallization, interior of Jupiter, Saturn or Earth

PRIOR
Proton Microscope for FAIR

p, 5–10 GeV, $2 \cdot 10^{12}$, PRIOR



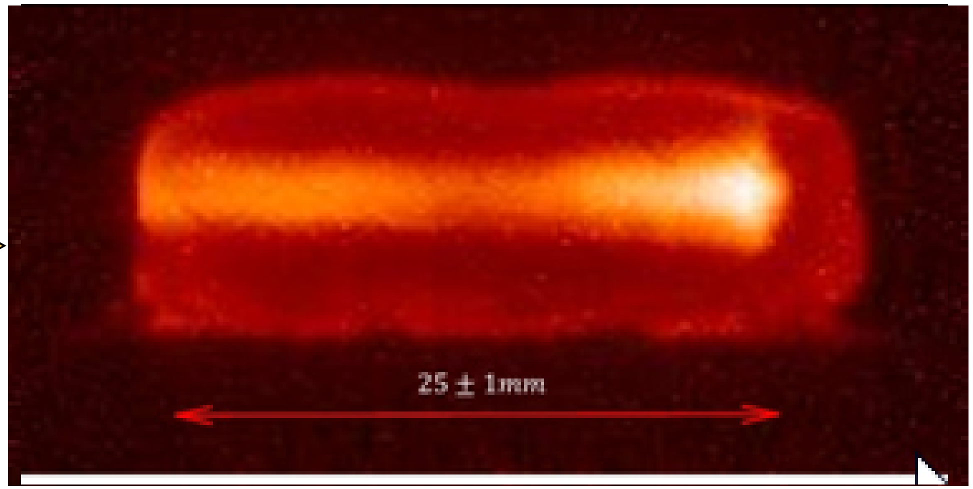
worldwide unique high-energy proton microscopy setup with SIS-100 proton beam

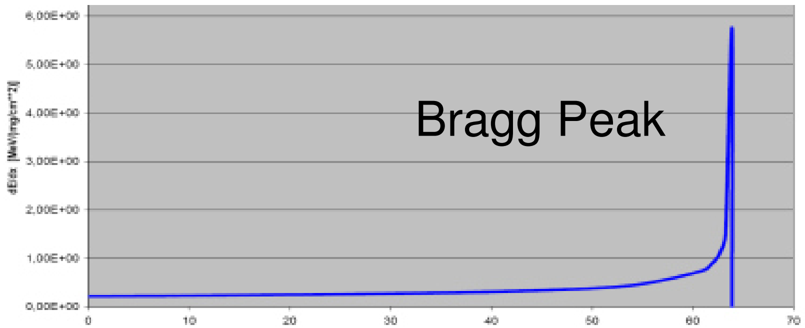
dynamic HEDP experiments and PaNTERA, jointly with BIOMAT collaboration:
unparalleled density distribution measurements and Proton Therapy and Radiography (PaNTERA) project

Heating Matter with Intense Ion Beams

Ne^{10+} beam at E_0 =300MeV/u penetrating into a Kr crystal

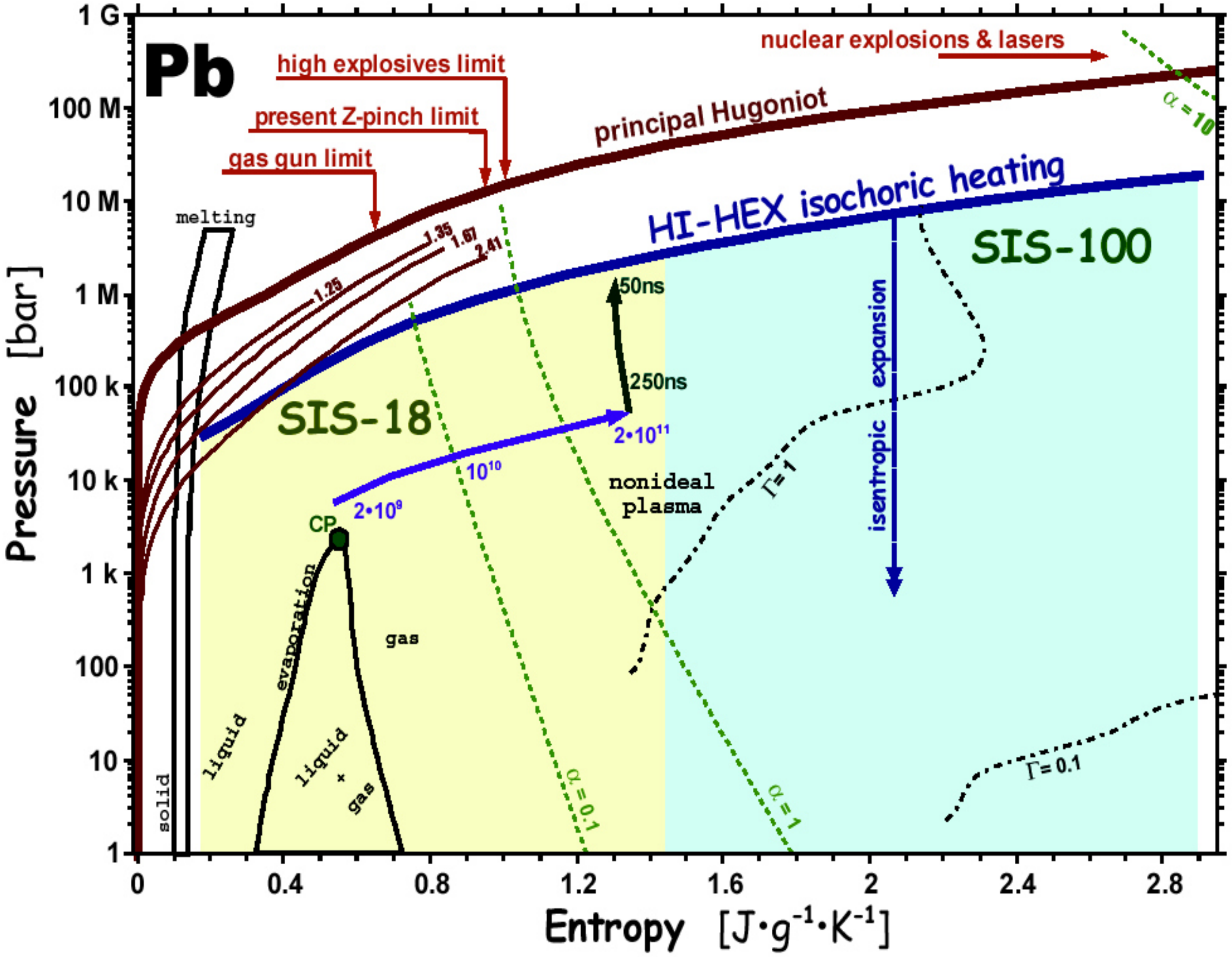
Intense Pulse
of Heavy Ions





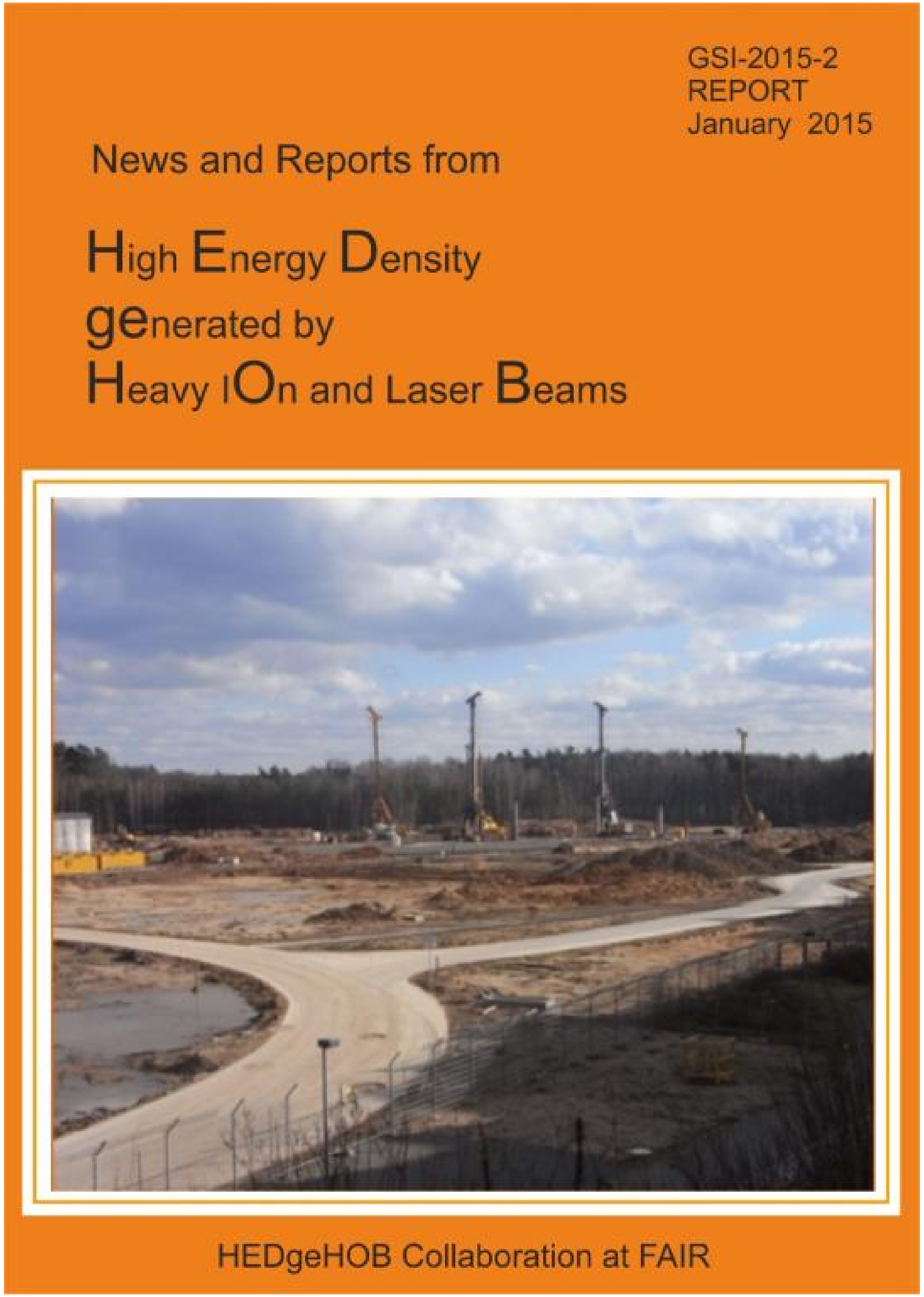
What are the most interesting problems for the next 10 years ?

What type of experiments can be done at new international facilities



D.H.H. Hoffmann, V.E. Fortov et al. Phys. Plasmas 9 (2002) 3651.

HED regions of the phase diagram accessible by intense heavy ion beams



FAIR Construction Site

View also:

https://indico.gsi.de/conferenceDisplay.py?confId=3206

Ion Beam Facilities for HEDP (Past)

GSI, Darmstadt

ИТЭФ, Москва

HIFS-VNL, Berkeley

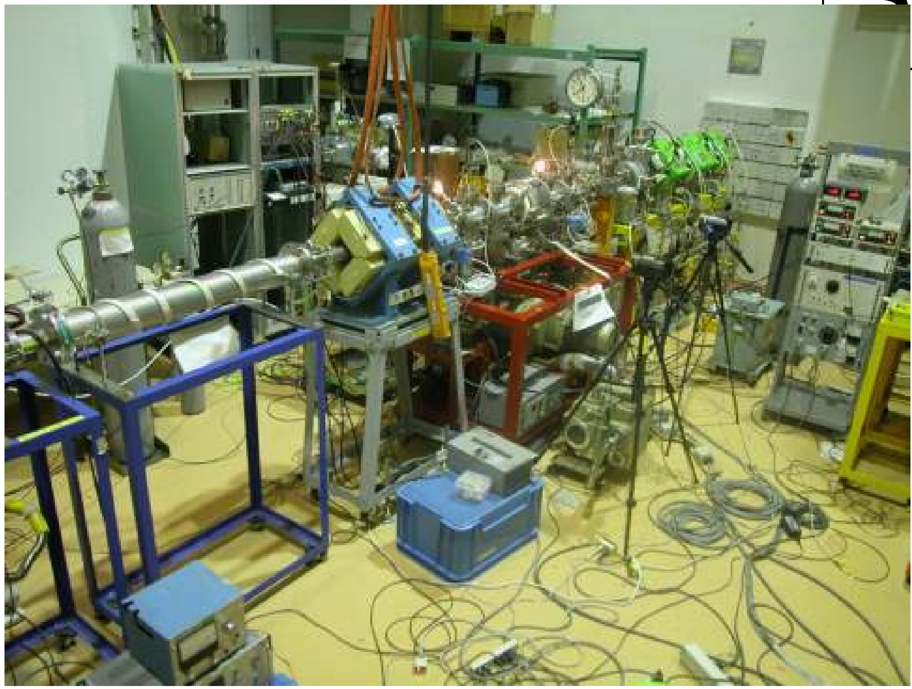
IMP, Lanzhou

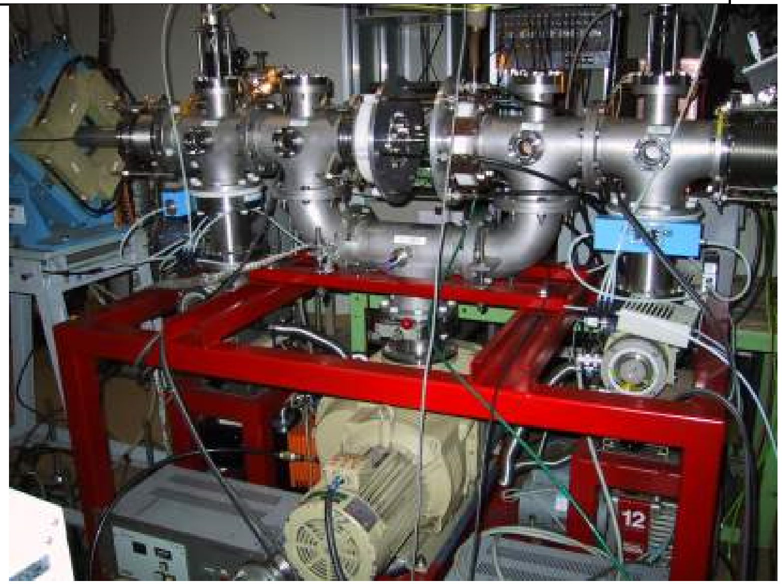
Rare Isotope Science Project

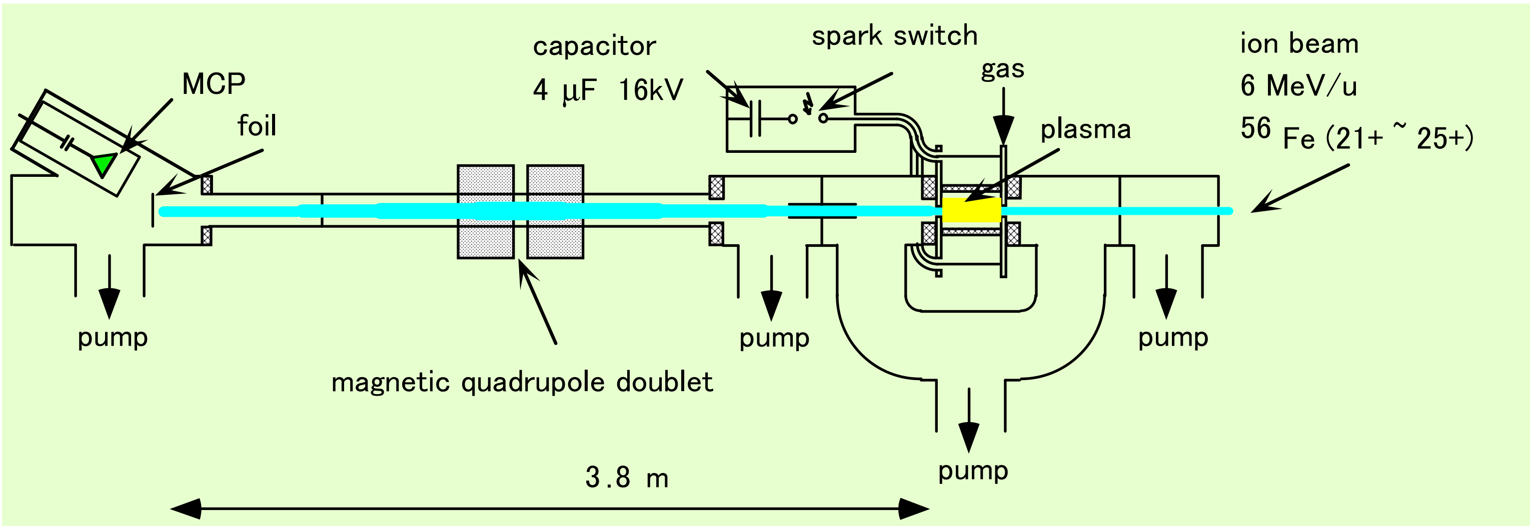
M. Chung

Korea

Setup at HIMAC, Japan

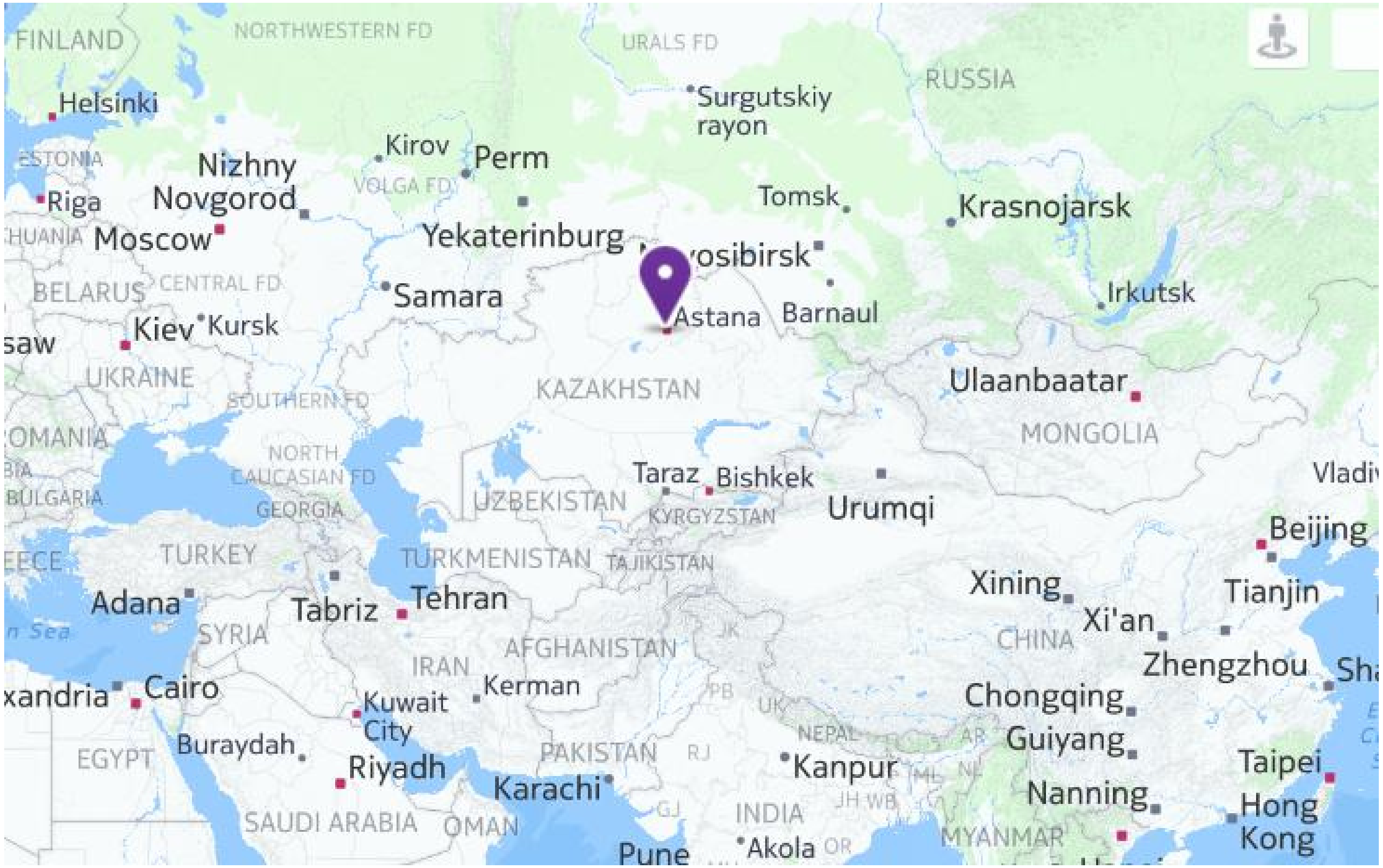




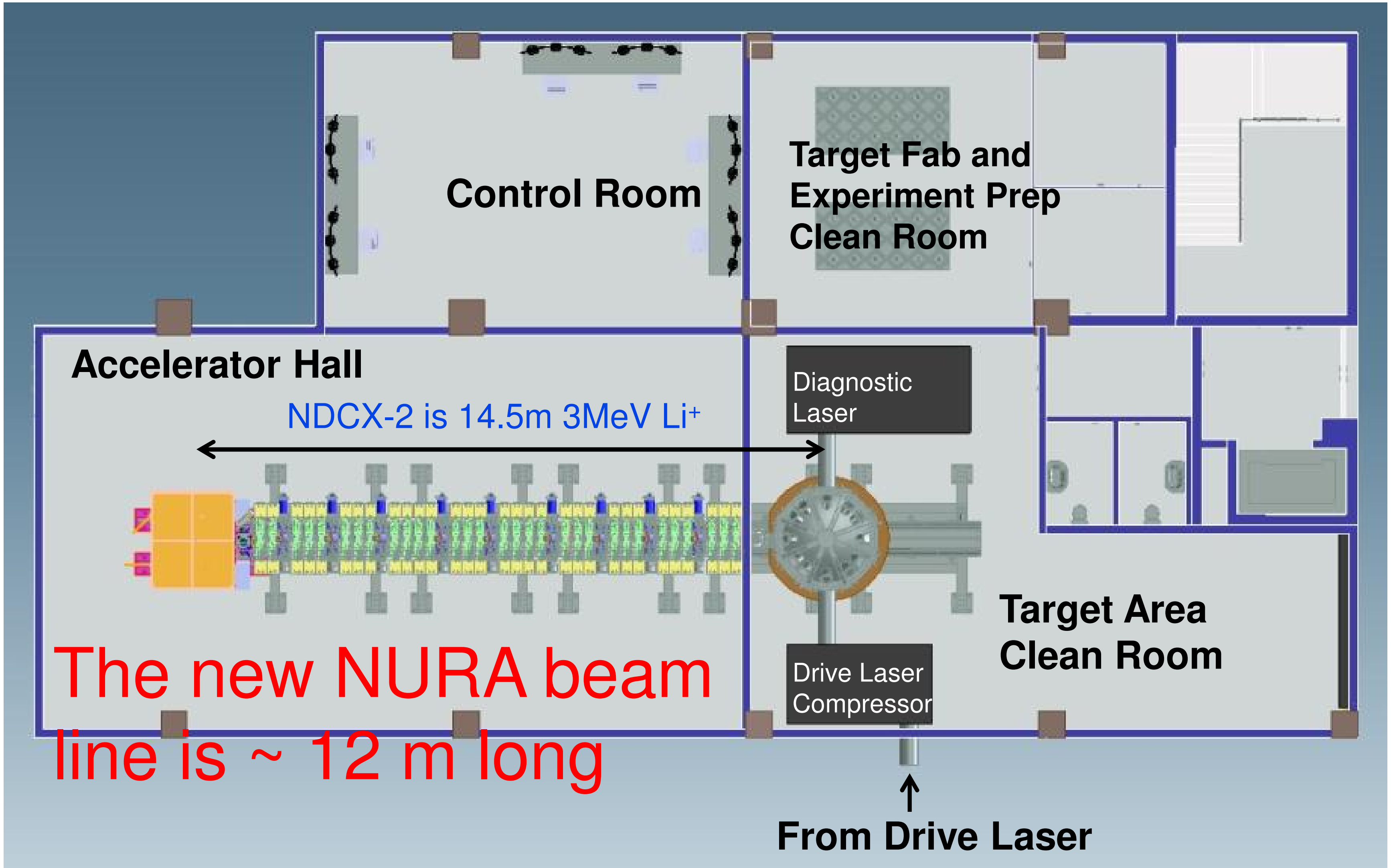


M. Ogawa 2003

Nazarbayev University at Astana, Kazakhstan is building a facility for HIF/HEDP research

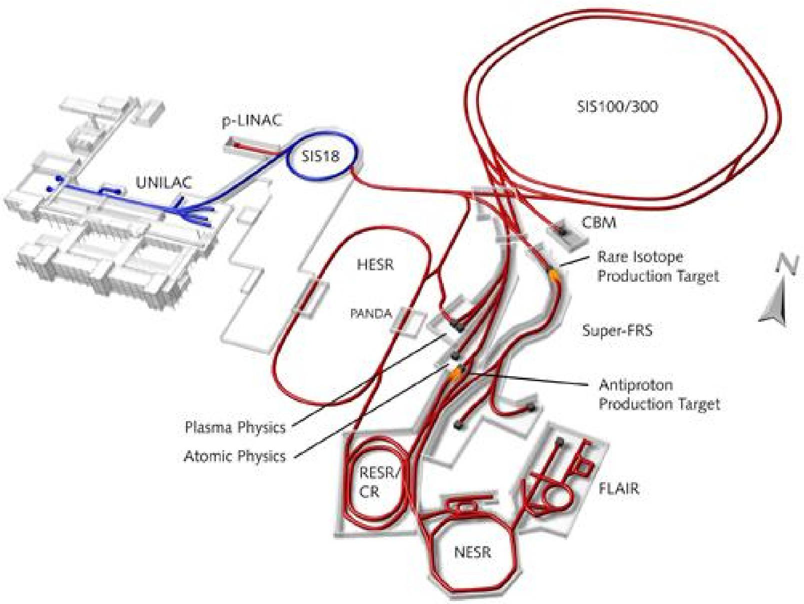


The NURA Facility for HIF and HEDP Research

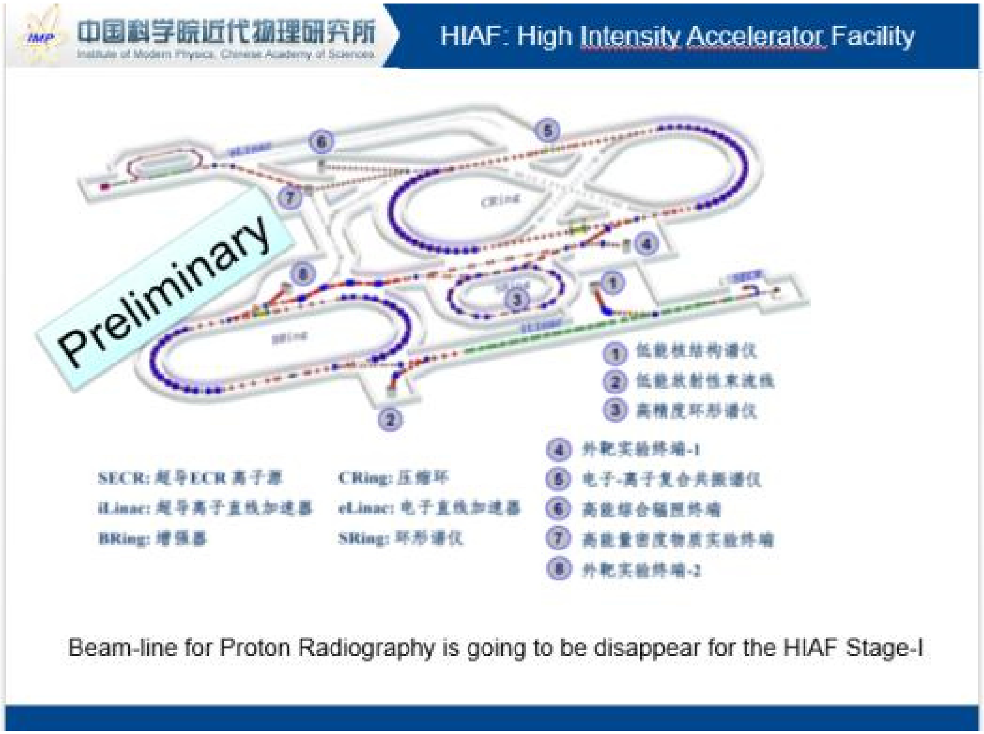


Ion Beam Facilities for HEDP (Future)

FAIR, Darmstadt



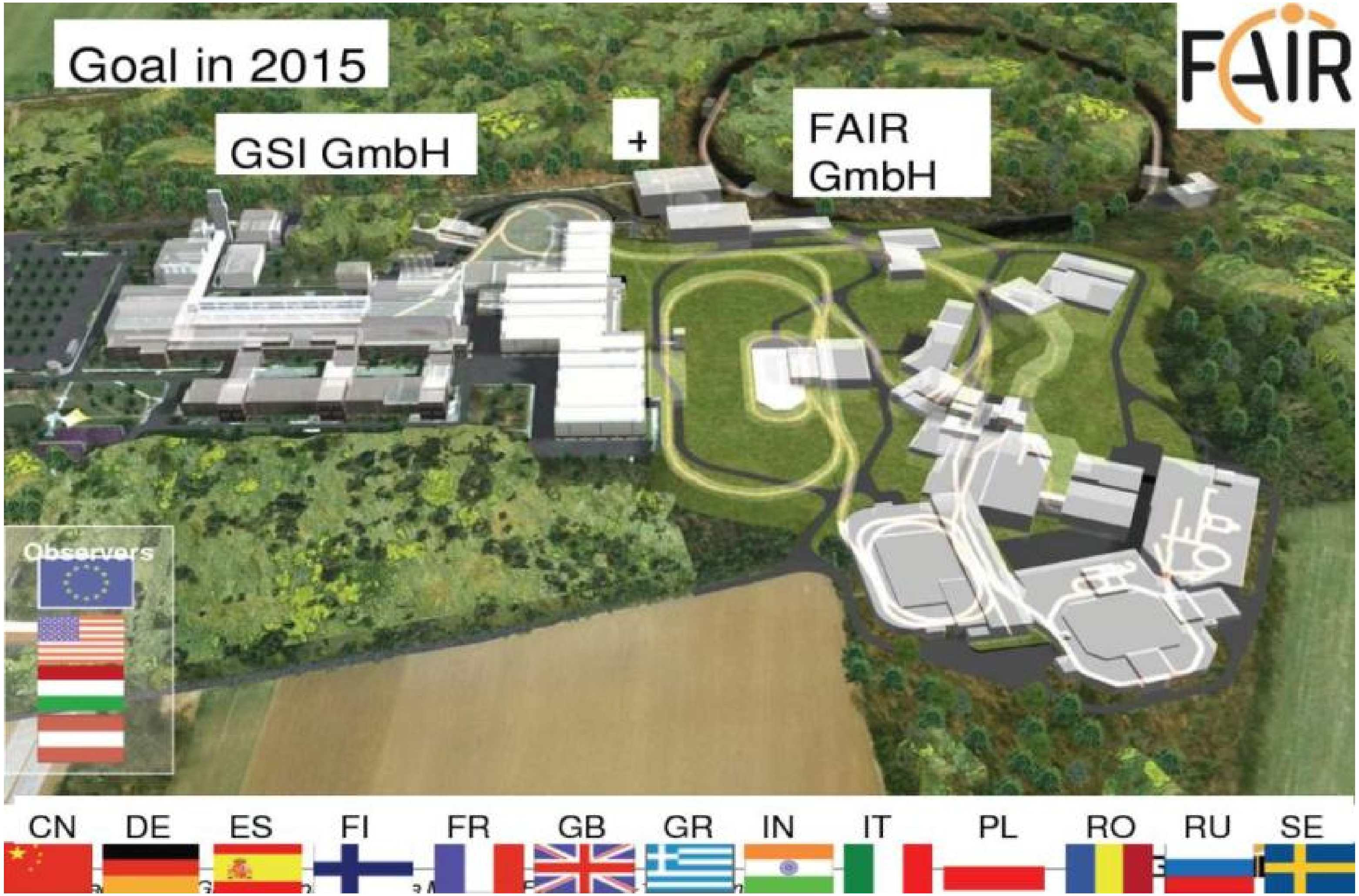
HIAF, China (Lanzhou)



Beam Parameters

	SIS-18	FAIR(Ph-I)	HIAF (V1)
E_0	0.4 GeV/u	1 GeV/u	1.1 GeV/u
N	4×10^{9}	4×10^{11}	1×10^{12}
E_{total}	0.06 kJ	15 kJ	40 kJ
S_f	~1 mm	~1 mm	1mm - 0.5 mm
τ	130 ns	50 ns	130ns - 33 ns
E_s	~1 kJ/g	120 kJ/g	300 kJ/g-1.2MJ/g
E_p	2×10^{10} J/m^3	2.4×10^{12} J/m^3	6×10^{12}J/m^3 -2.4×10^{13} J/m^3

FAIR


Goal in 2015
GSI GmbH
+
FAIR
GmbH
FAIR
Observers
CN
DE
ES
FI
FR
GB
GR
IN
IT
PL
RO
RU
SE

Bird’s View

FAIR Construction Site

Beam-intensity limited by desorption

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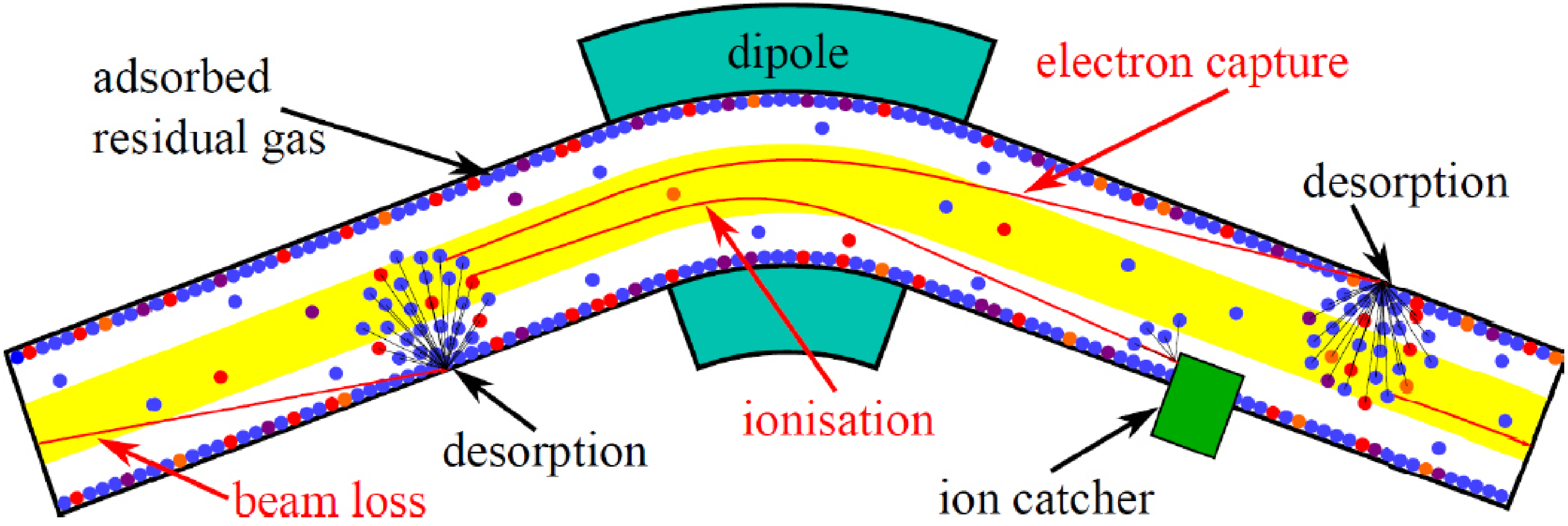


Lars Bozyk, Peter Spiller

Desorption yield scaling

- Room temperature: desorption yield η scales with beams electronic energy loss at the target's surface.
- New scaling at cryogenic temperatures.
- Possible explanation: dependance of η on heat capacity and thermal conductivity.
- Experimental investigation necessary.

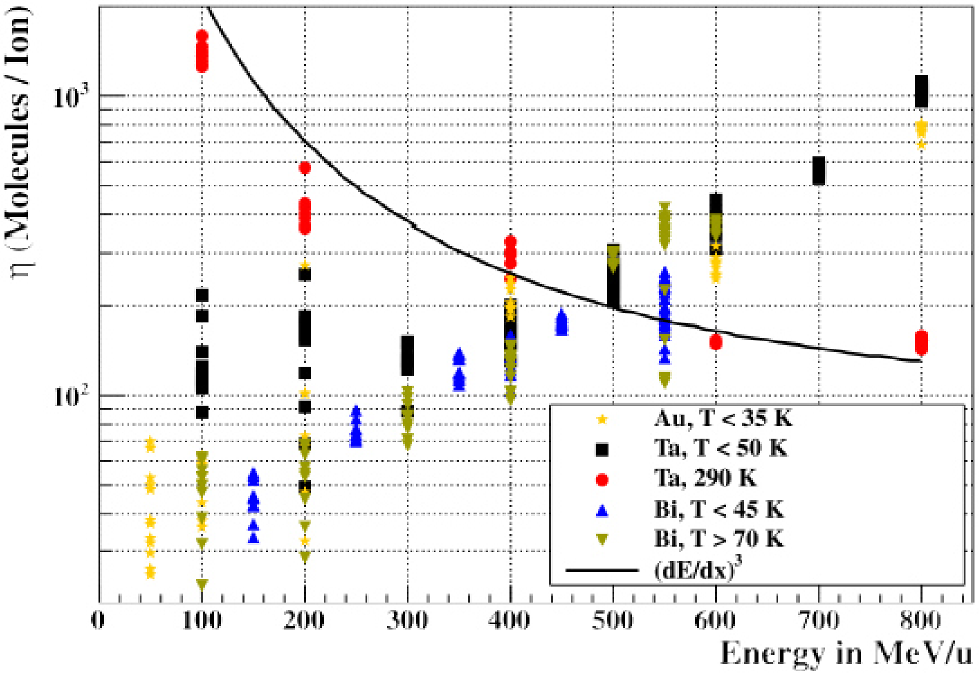
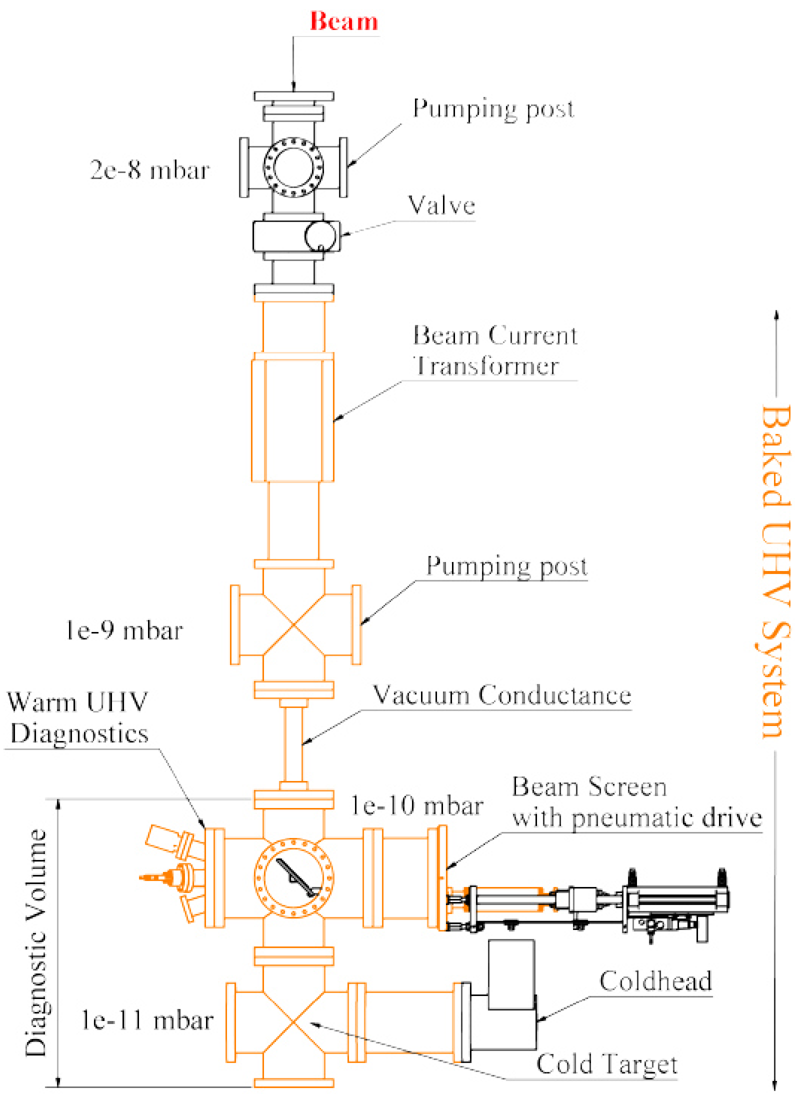
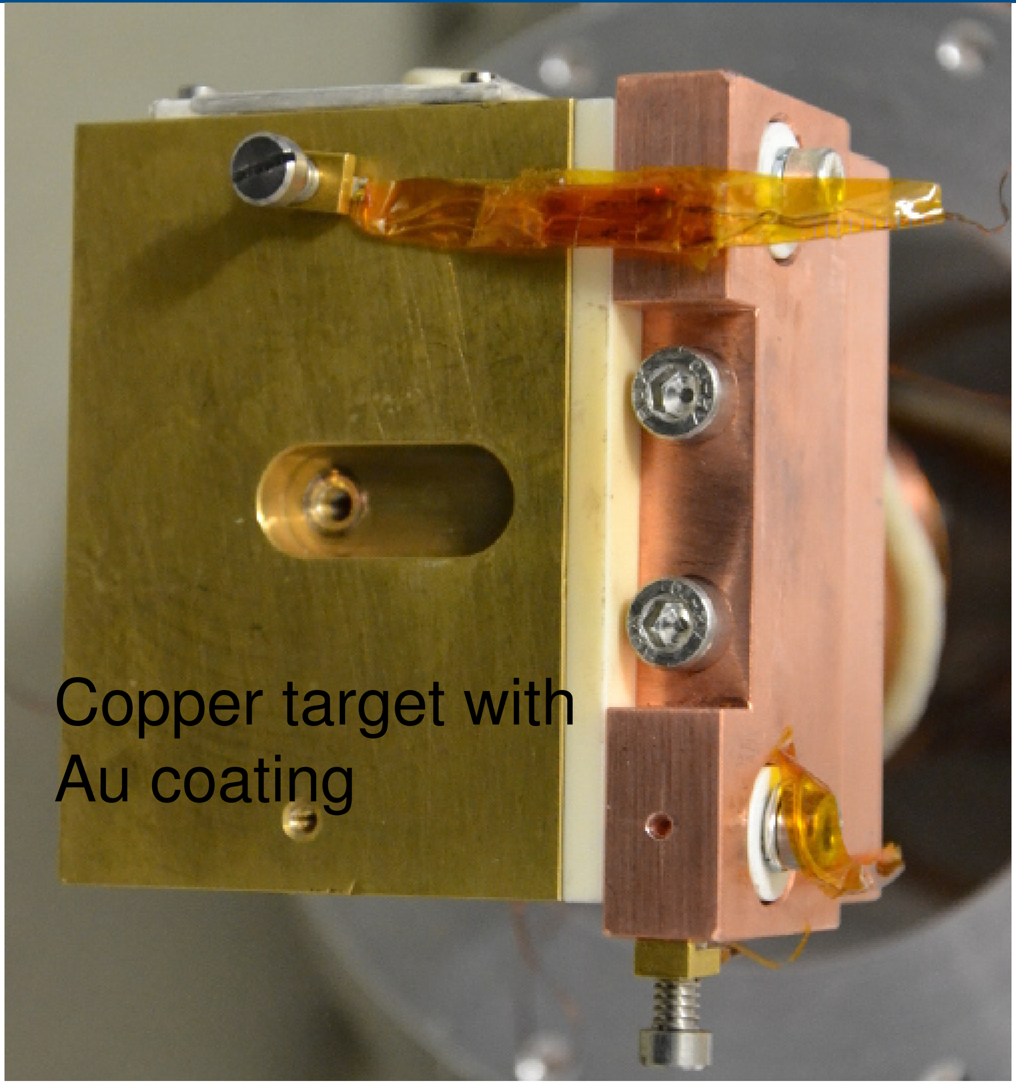


Image source: Phd-thesis L. Bozyk

Desorption yield scaling



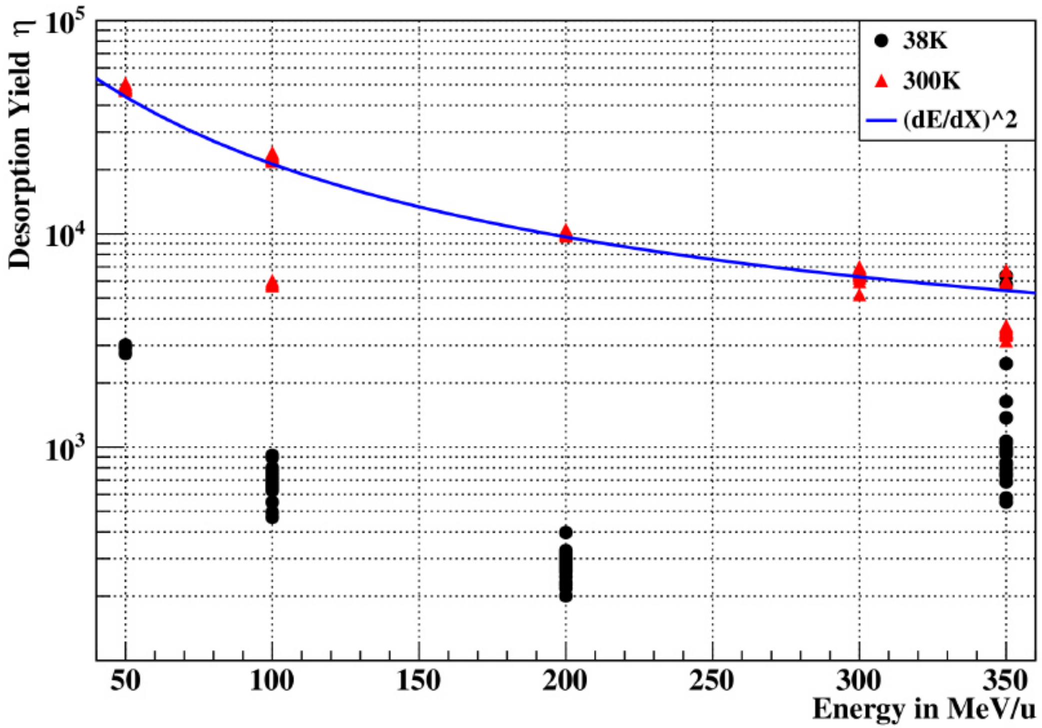


C. Maurer, L. Bozyk, P. Spiller

Desorption yield scaling

- Room temperature scaling and cryogenic scaling could be reproduced.
- Experience with new setup gained.
  - cooling provided by coldhead instead of liquid gas.
  - analysis of data measured on a temperature ramp instead of equilibrium.

  - Next beamtime: mid october



More vacuum issues: J. Ren on Thursday

BIF Monitor: Principle

Graduate School of Energy Science and Engineering
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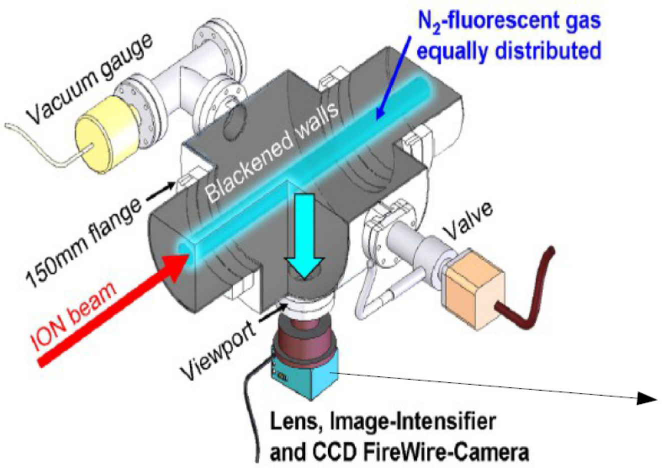
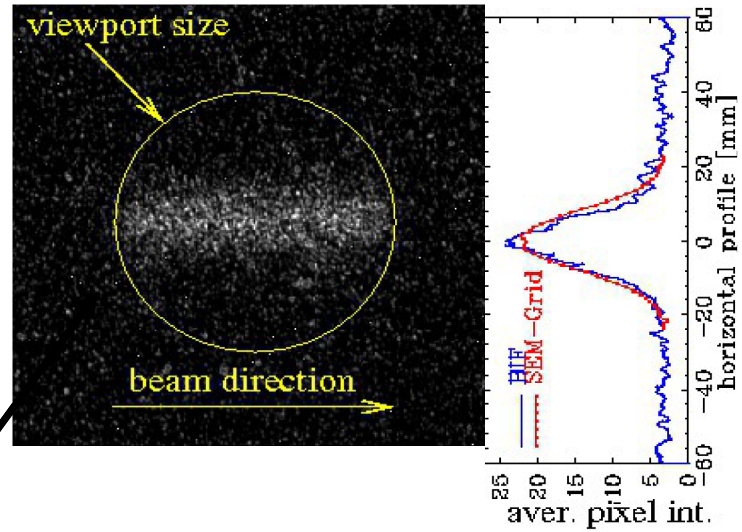
Detecting ***photons*** from residual gas molecules,
e.g. Nitrogen in spectral wavelength range
390 nm< λ< 470 nm emitted into solid angle Ω to camera





Yulia Shutko, S. Udrea, P. Forck

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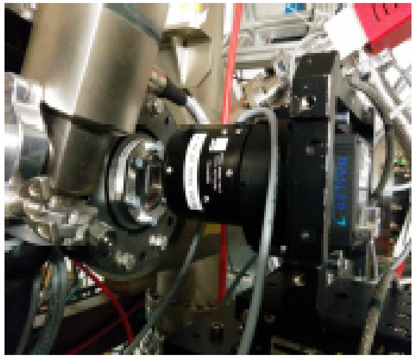
Graduate School of Energy Science and Engineering

Goals of the work

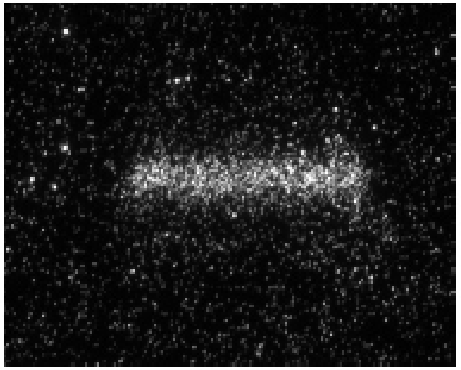
- Beam profile investigation with different gases (Nitrogen, Argon, Xenon) under different pressures with ICCD camera Proxitronic/Basler to compare profiles.
- Spectroscopy investigation with different gases (Nitrogen, Argon, Xenon) under different pressures (ICCD camera) for better physics understanding. Result: possibility to use more suitable gas and working pressure for high energy beam.
- Hardware development: Tests with new type of Electron-Multiplied CCD (EMCCD) camera ProEM+: 512B. Comparison with "standard" ICCD camera.
- Development of a gas control system, which allows to switch between gases in remote mode during experiments
- Development of data evaluation methods for all three types of experiments

Present status after the first GSI Beam Time block (02-05.2014):

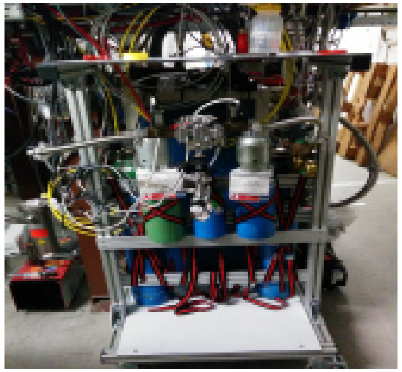
- Gas control system has been successfully developed
- Experimental set-up for beam profile investigations with ICCD camera have been successfully commissioned. Serial measurements (different pressures, gases, beam energies) have been done



BIF-monitor installation with ICCD camera Proxitronic/Basler



Example of a beam profile obtained with ICCD camera



Gas control system

Yulia Shutko, S. Udrea, P. Forck

Present status after the first GSI Beam Time block (02-05.2014):

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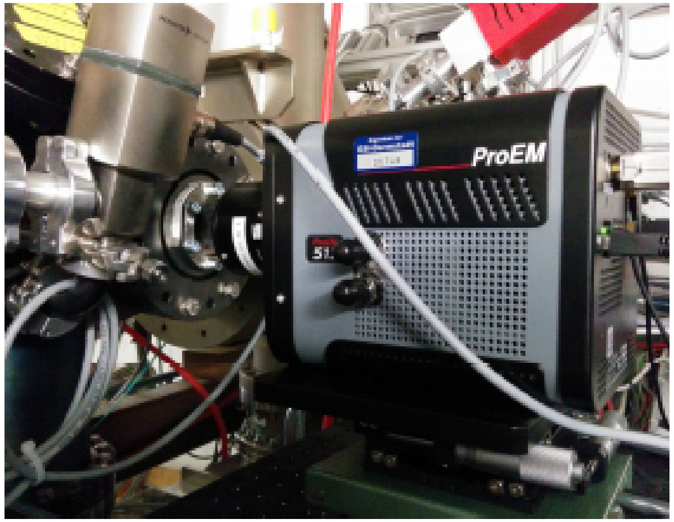
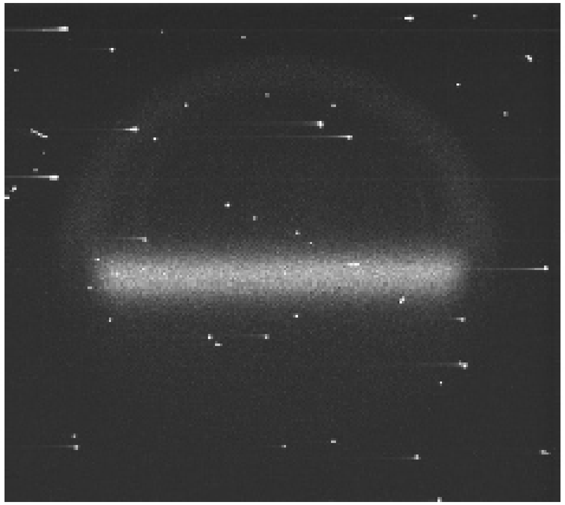
Graduate School of Energy Science and Engineering

- Experimental set-up for beam profile investigations with EMCCD camera have been commissioned on the beam line. First serial measurements with Nitrogen under different pressures have been done. Further functional tests with beam are necessary to obtain optimal camera setting for our applications



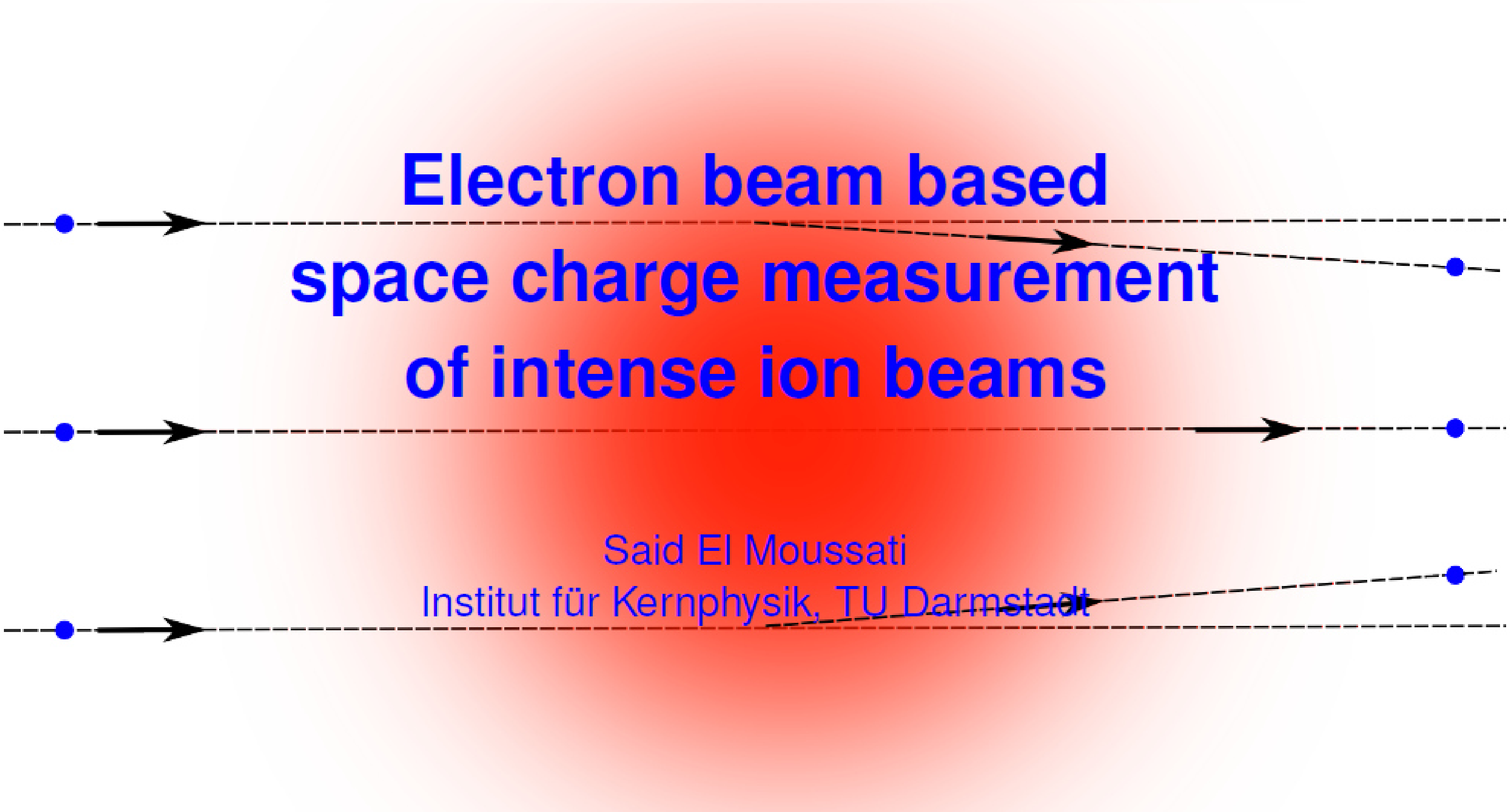
BIF-monitor installation with EMCCD camera ProEM+:512B



Beam profile obtained with EMCCD camera

Yulia Shutko, S. Udrea, P. Forck

Intense Beam Diagnostics



Motivation

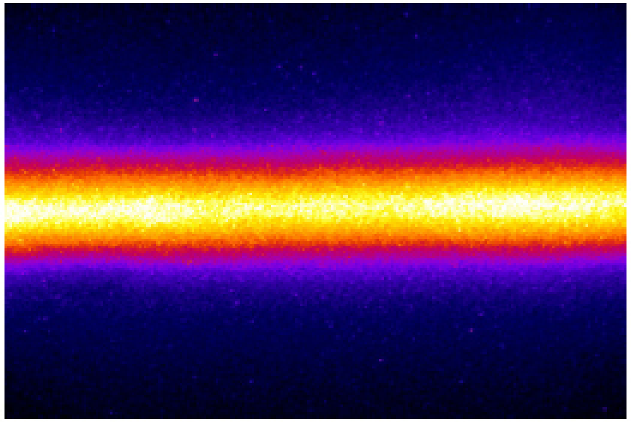
Properties of ion beams used at the HHT area of GSI for WDM/HEDM experiments

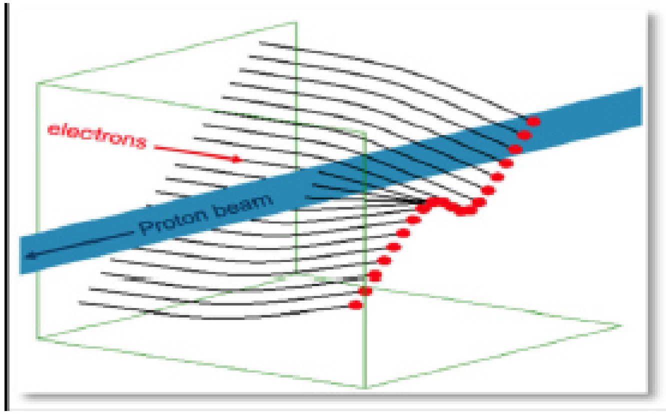
- $^{238}U^{73+}$
- energy up to 500 AMeV
- intensity up to $5 \cdot 10^9$ ions/pulse
- duration 100 – 1000 ns FWHM
- diameter $\approx$ 1 mm FWHM

Advantages of e-beam based profile measurement

- non-invasive
- good detection resolution (goal 10 μm)
- absence of secondary electron emission

Ion beam in gas





W. Bokland et al, Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA, 1438 (2011)

Theory

Analytical Considerations

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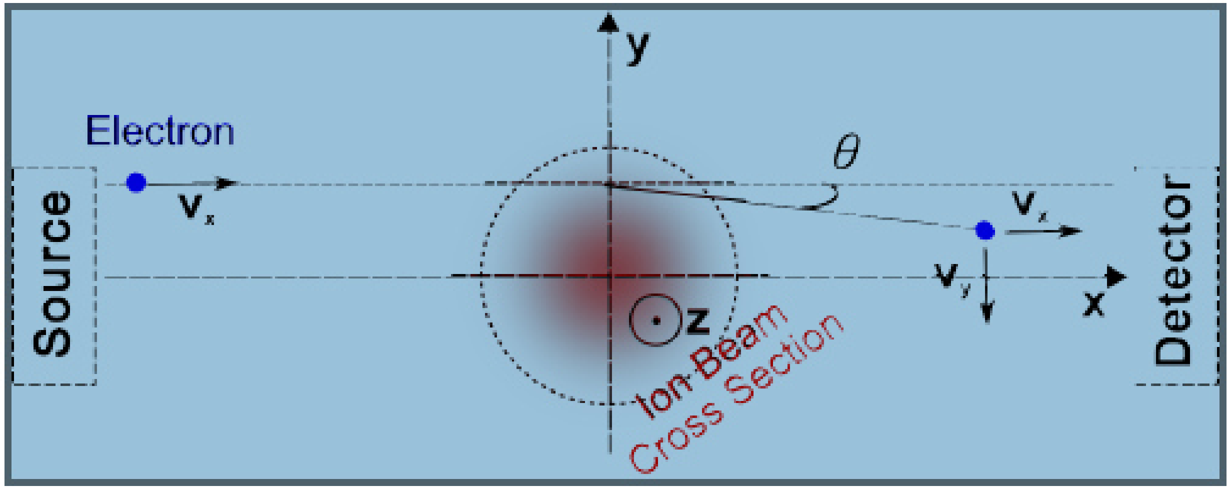
- Assumption: the ion beam is very long and cylinder symmetric ($E = E(r)$)
- The influence of the magnetic field is very small compared to the electric field



$$\frac{dv_{x,y}}{dt} = -\frac{e}{m_e} \cdot E_{x,y} \quad \xrightarrow[\theta = v_y / v_x]{} \quad \theta = -\frac{e}{m_e v_x} \int \frac{E_y}{v_x} dx$$

$$v_x = \sqrt{\frac{2E_0}{m_e}} \cdot \sqrt{\left(1 + \frac{E_p}{E_0}\right)} \quad \xrightarrow[E_0 \gg E_p]{} \quad \theta = -\frac{e}{2E_0} \int E_y dx$$

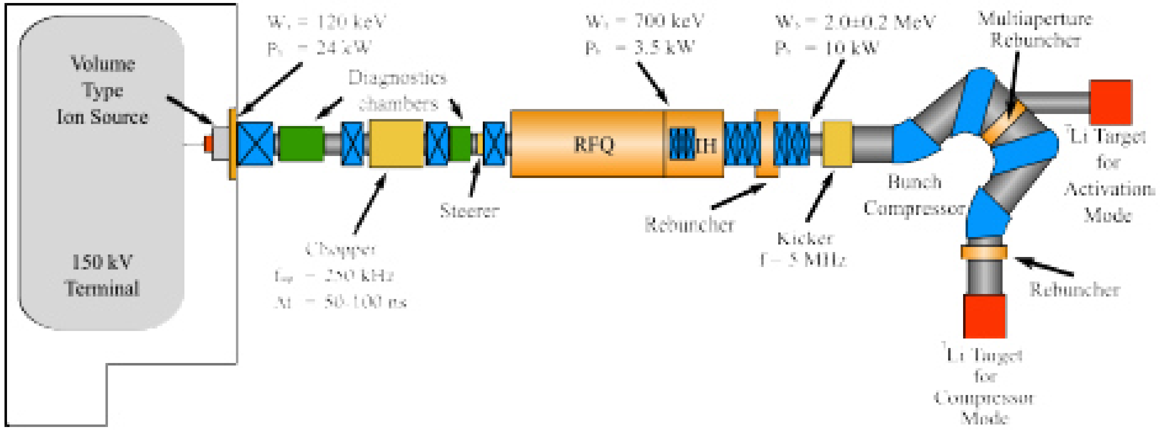
E_0 is the kinetic energy of the electron ; E_p is the potential energy of the electron in the field of ion beam

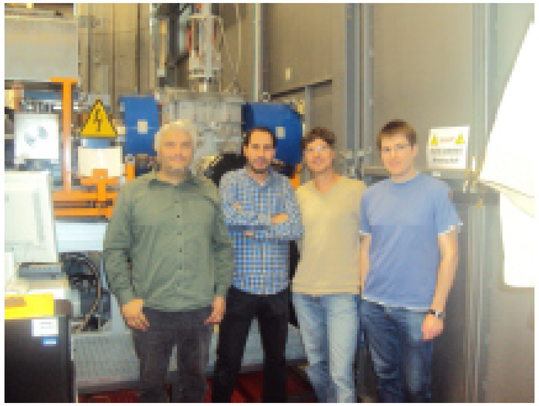
Prabir K. Roy et al, Review of Scientific Instruments, **76**, 023301 (2005)

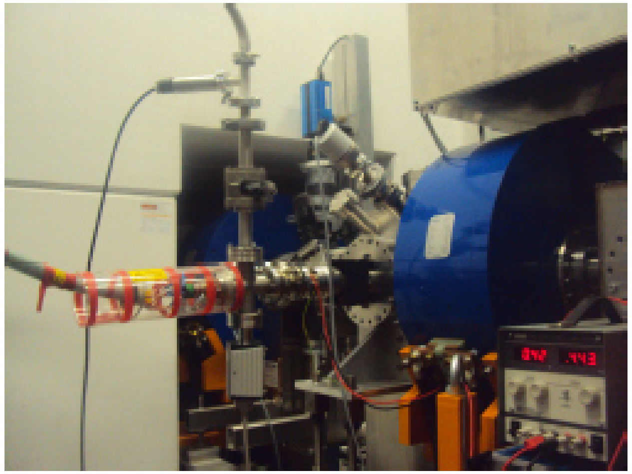
Experiment

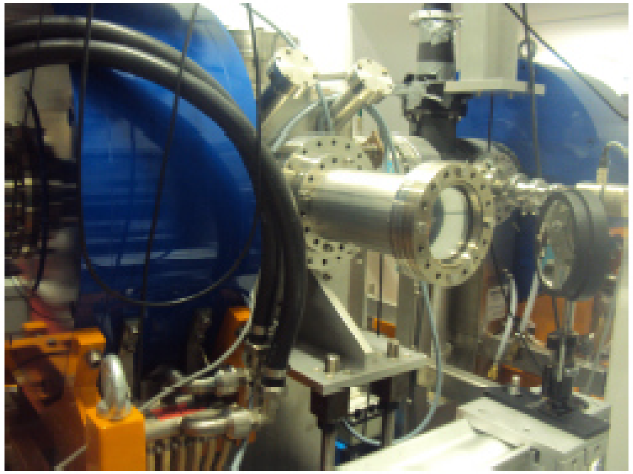
Experimental Setup

FRANZ-Accelerator at the Uni-Frankfurt









Experiment

Experimental Parameters

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electron beam

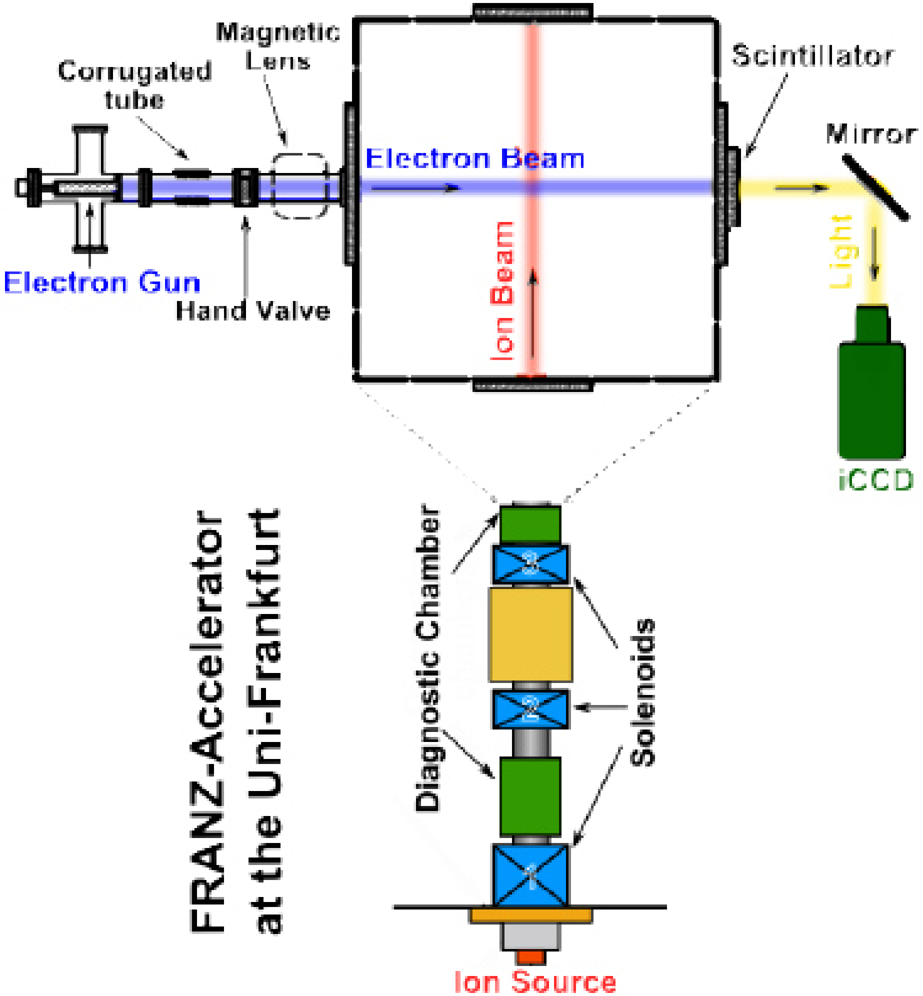
- energy up to 15 keV
- current up to 100 μA

ion beam

- cw $^4He^+$
- energy = 13.5 keV
- current $\approx$ 1 mA
- line charge density $\approx 1.25 \cdot 10^{-9}$ C/m

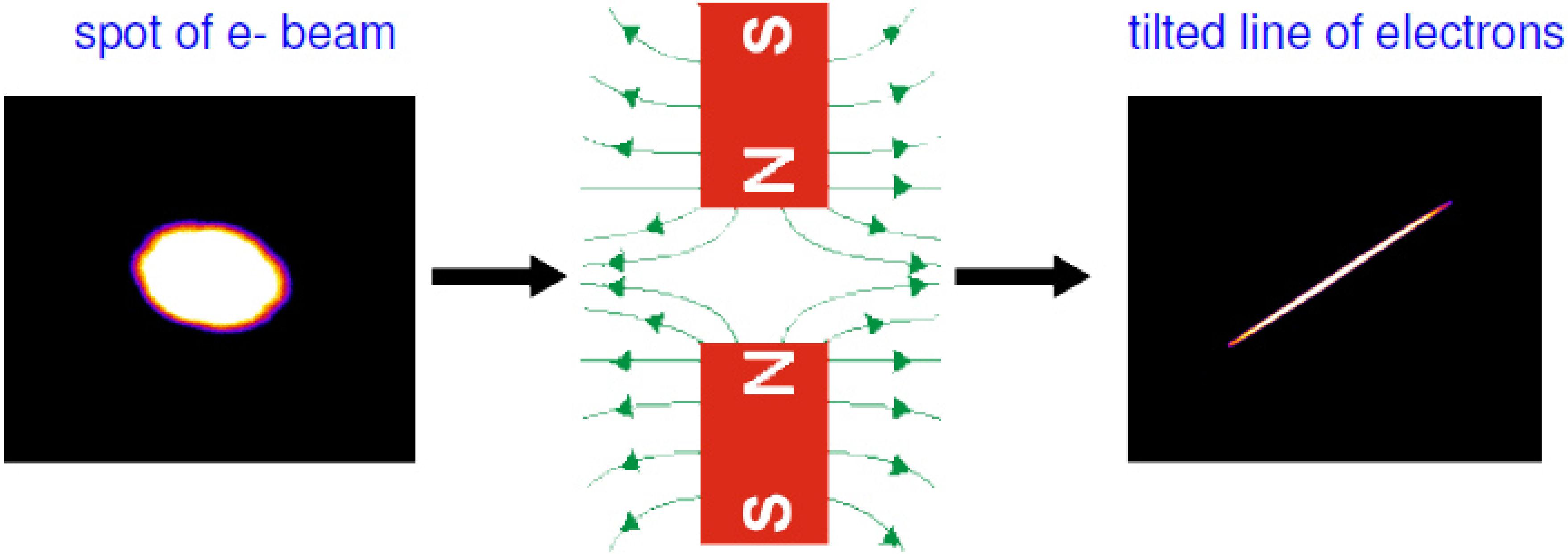
scintillator

- plastic (EJ–212)
- thickness 0.5 mm
- decay time of about 3 ns



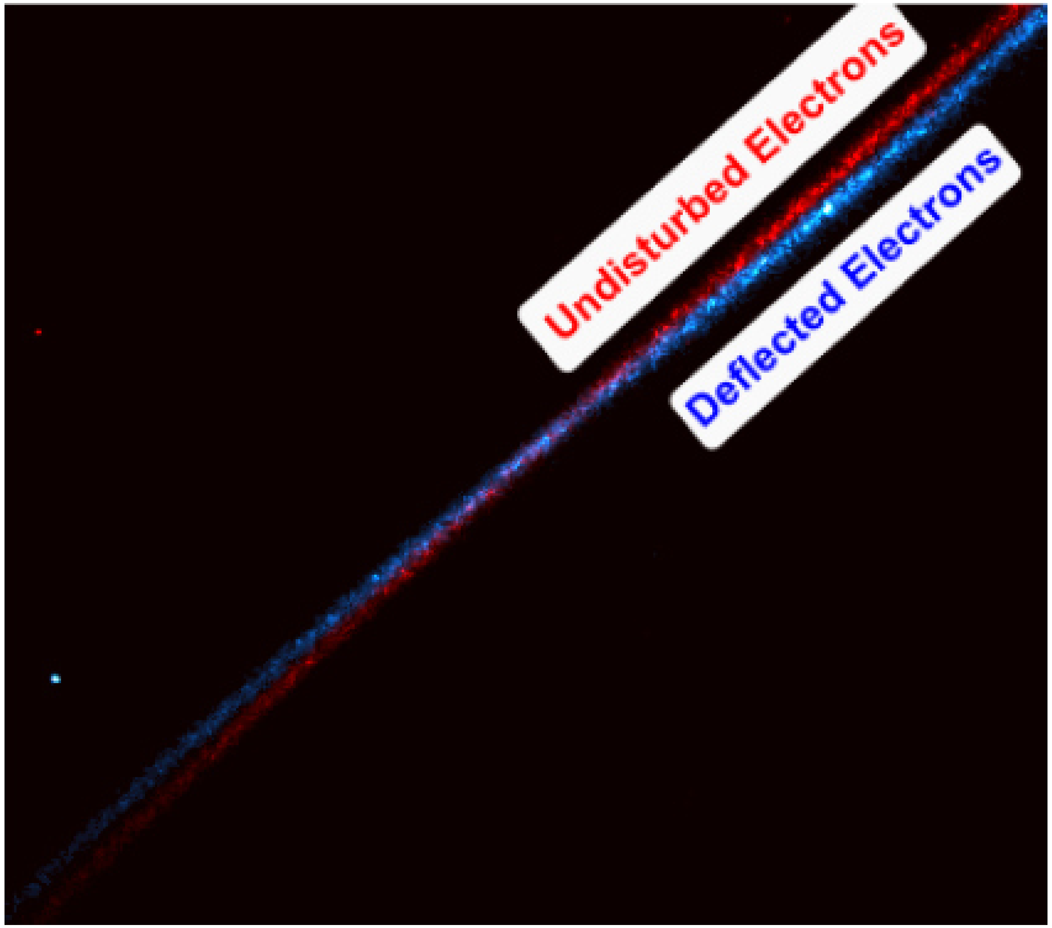
Experiment

Generation of a Tilted Line of Electrons



Experiment

Experimental Results



Experiment

Analysing of the Results

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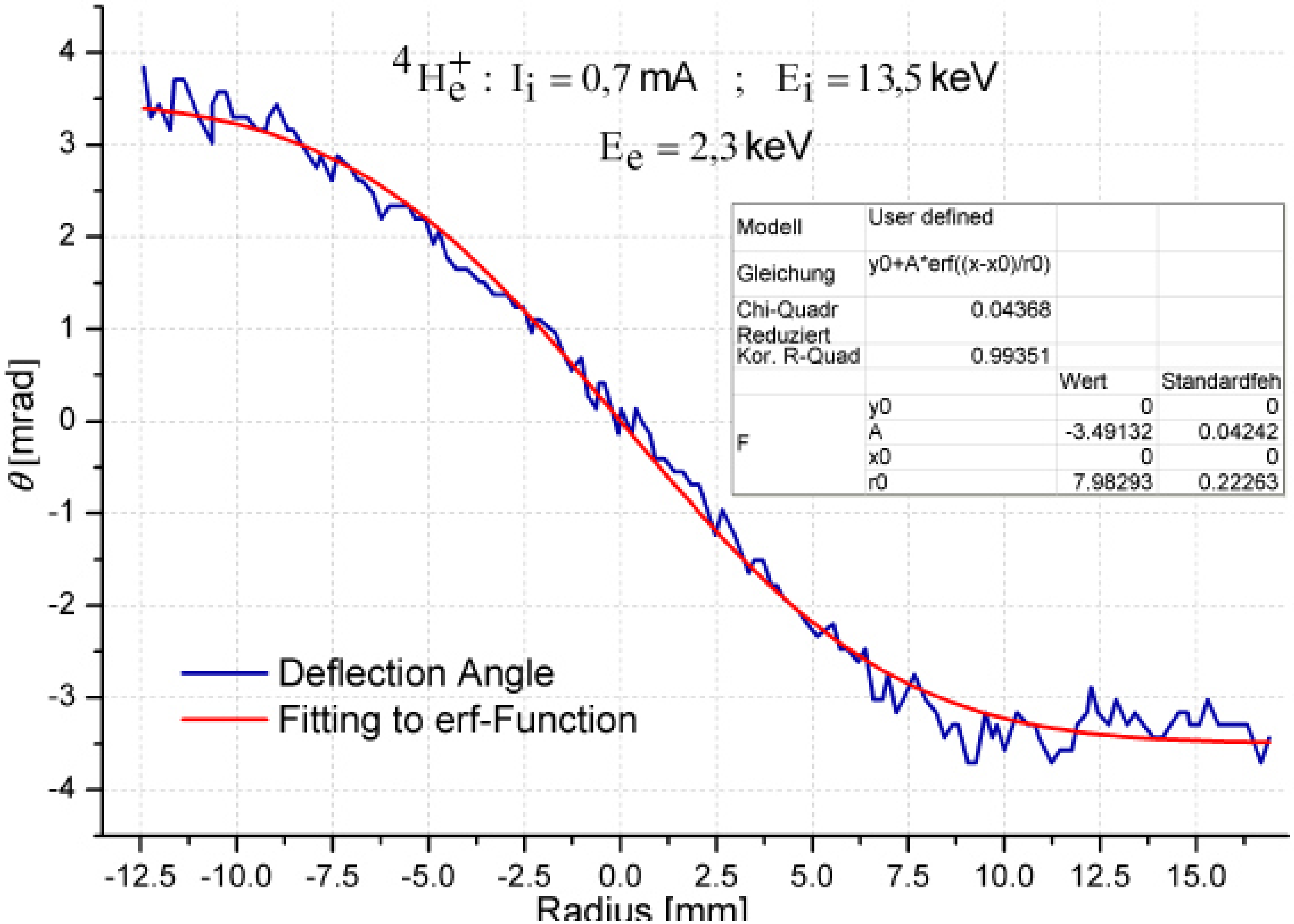
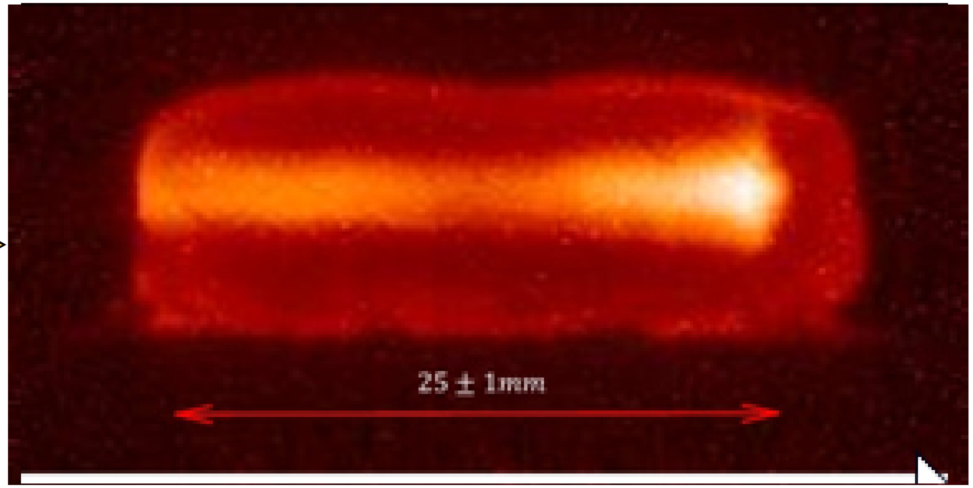
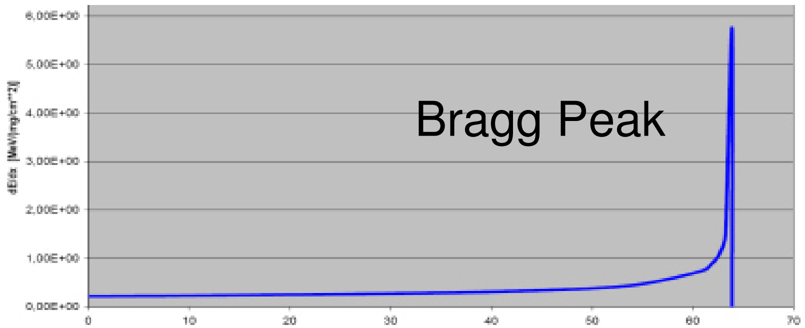


Heating Matter with Intense Ion Beams

Ne^{10+} beam at E_0 =300MeV/u penetrating into a Kr crystal

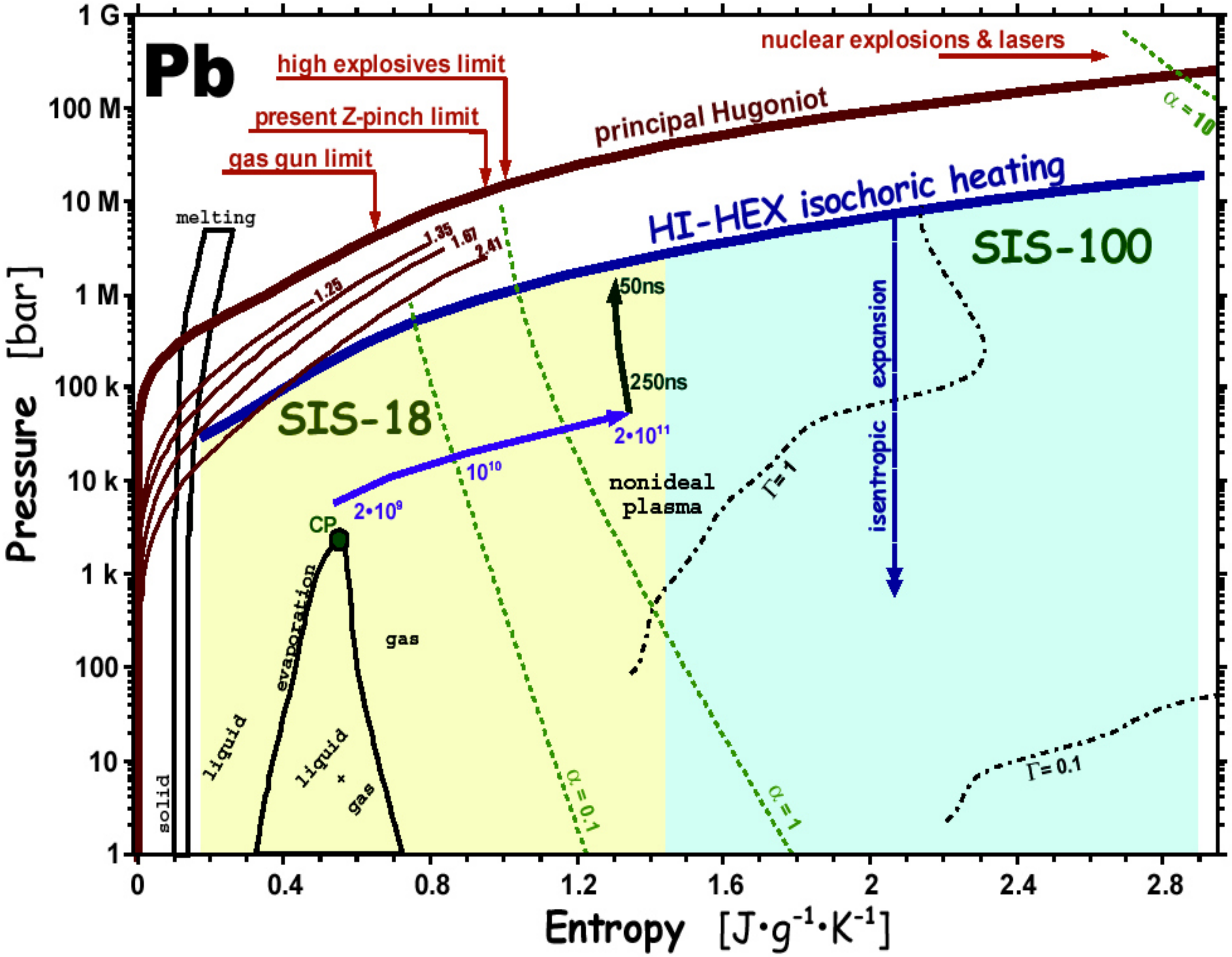
Intense Pulse
of Heavy Ions





What are the most interesting problems for the next 10 years ?

What type of experiments can be done at new international facilities



D.H.H. Hoffmann, V.E. Fortov et al. Phys. Plasmas 9 (2002) 3651.

HED regions of the phase diagram accessible by intense heavy ion beams

Topics not covered in this presentation

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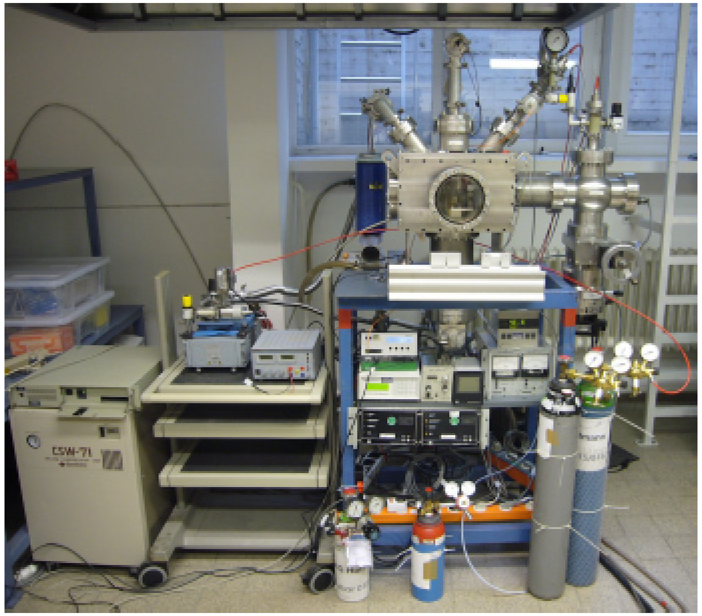
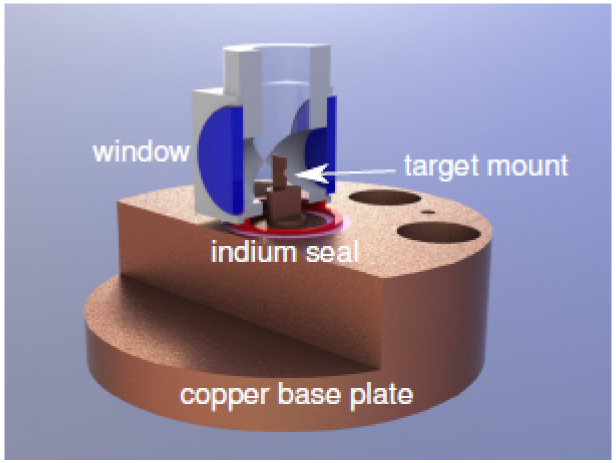
Cryogenic Hydrogen Targets: Stefan Bedacht



Cryogenic test rig at TU Darmstadt.



Technical Design of PRIOR

Philipp-M. Lang

PRIOR -
Proton Microscopy for FAIR

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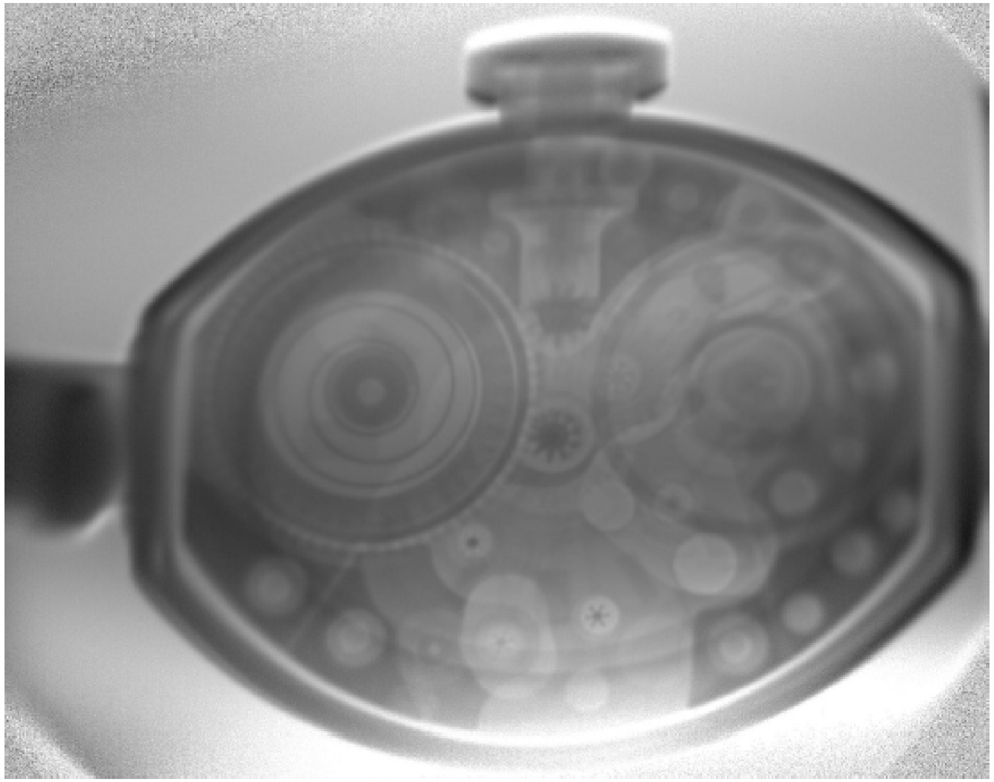
First images by high energy proton microscopy have been obtained at GSI


(proton radiography of a mechanical watch, July 2014)

- 4.5 GeV proton beam
- $>10^{10}$ particles/pulse
- Spatial resolution ≈25µm (improve to 10µm)
- First dynamic experiments with wire explosions in progress

P. Lang, M. Endres, D. Varentsov, S. Udrea Frank Merrill

Specifications and Resolution

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Spatial resolution scalings with proton energy

- object scattering

$$\sigma_o \propto \frac{\ell_t^{\frac{3}{2}}}{p}$$

- chromatic aberrations

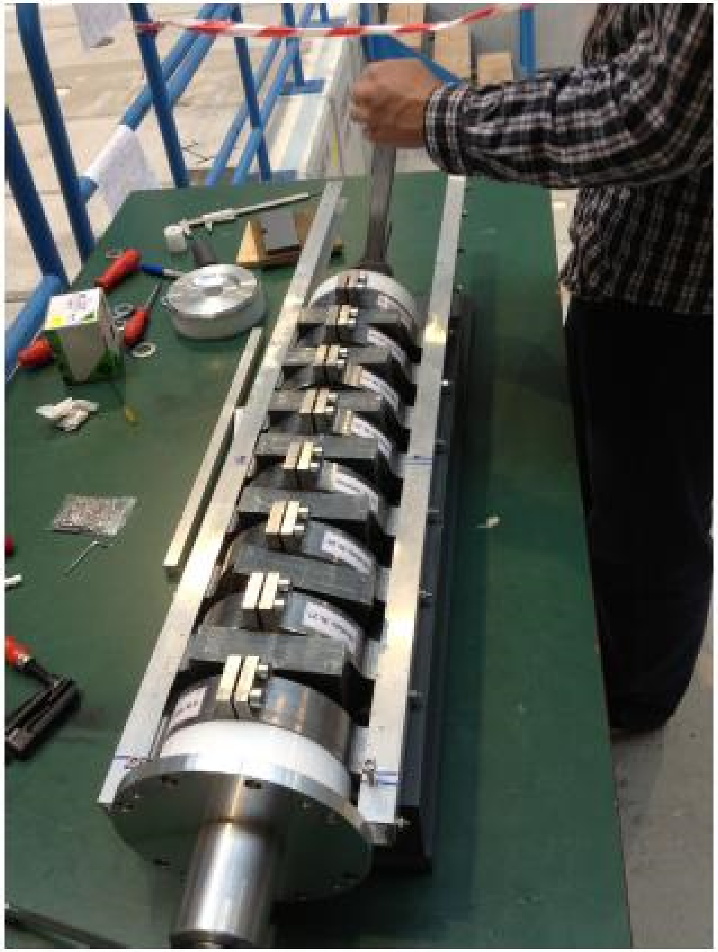
$$\sigma_c \propto \frac{\ell_t^{\frac{1}{2}}}{p^{\frac{3}{2}}}$$

- detector blur

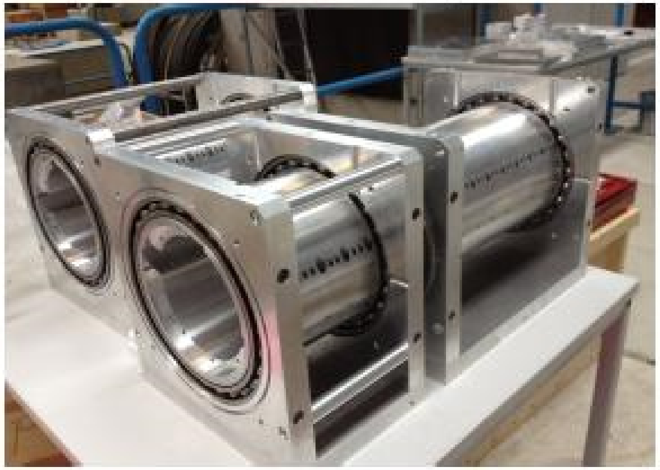
$$\sigma_d \propto \frac{\ell_s}{p}$$

	pRad (LANL), Puma (ITEP)	PRIOR (GSI)
proton energy	0.8 GeV	4.5 GeV
spatial resolution	50 – 150 µm	10 µm
time resolution	~ 50 ns	10 ns
magnification	3 - 5	~ 4.5
field of view	Ø 4 cm	Ø 1.5 cm

PMQs for the Microscope



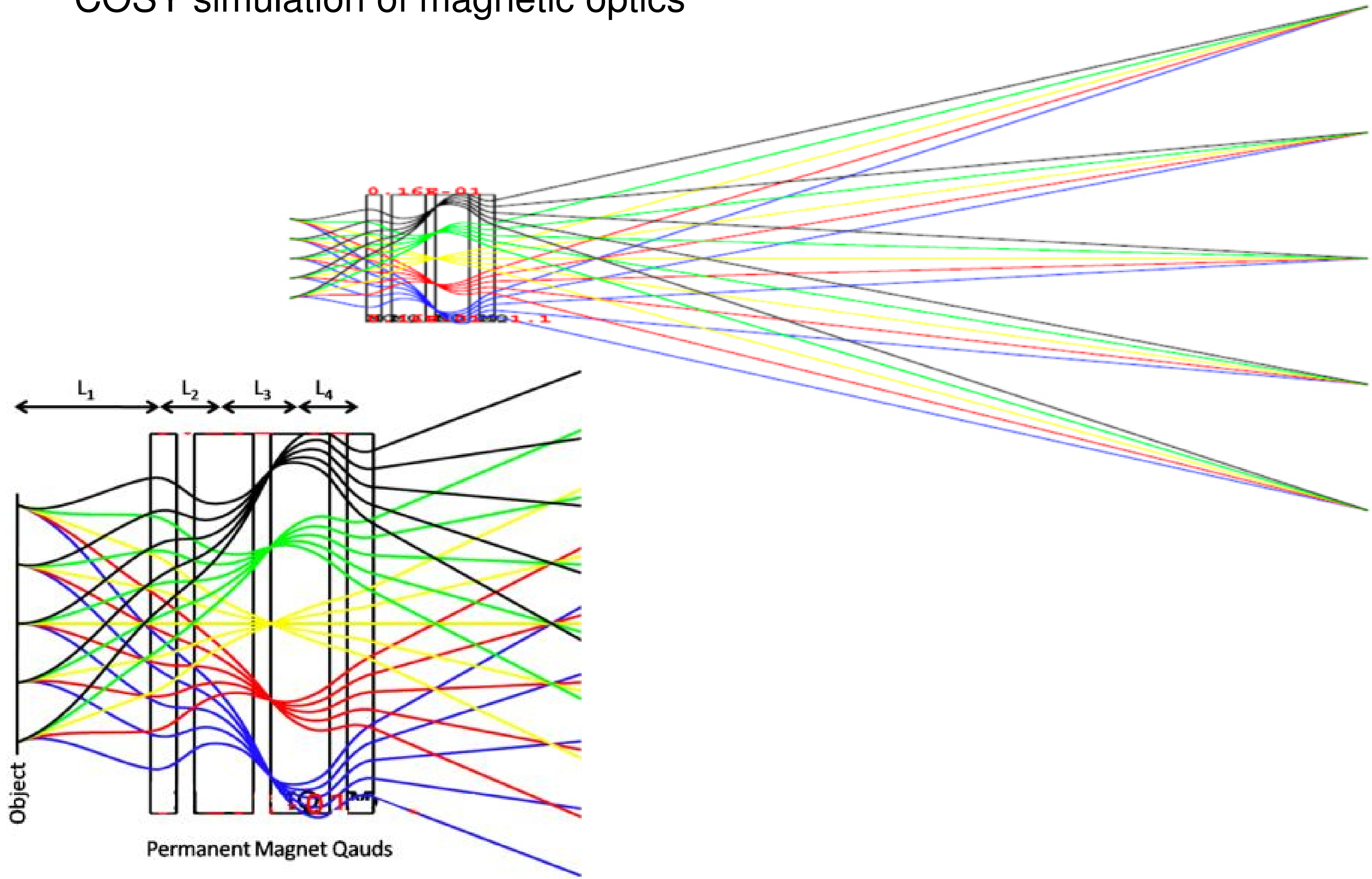
- **Pole tip field:**
  1.8 T
- **Non-linearity:**
  <0.75%



- **Material:**
  NeFeB

PRIOR: **Pr**oton M**i**crosc**o**pe at FAI**R**

COSY simulation of magnetic optics



The HEDgeHOB collaboration:

Studies on high energy density matter with intense heavy ion and laser beams at FAIR

(officially inaugurated: June 2005)

- >200 Scientists
- 44 Institutes
- 15 Countries

http://hedgehob.physik.tu-darmstadt.de