Status of High Energy Density Physics Research at GSI

ion beam - target interaction

Dmitry Varentsov

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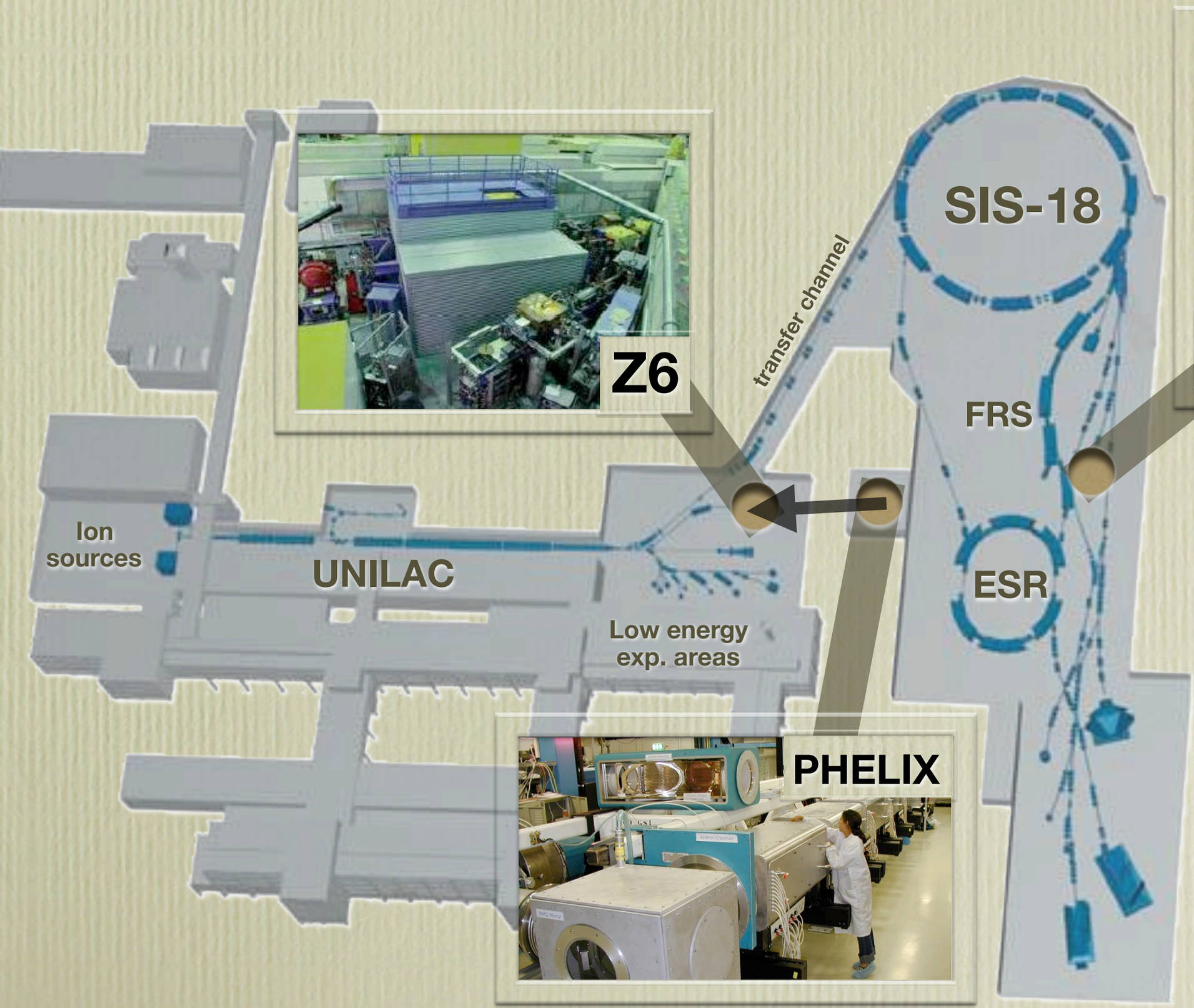
Darmstadt, Germany

Научно-координационная сессия “Исследования неидеальной плазмы”
30 ноября 2009 г. *Президиум РАН, Москва*

Plasma physics experimental areas at GSI

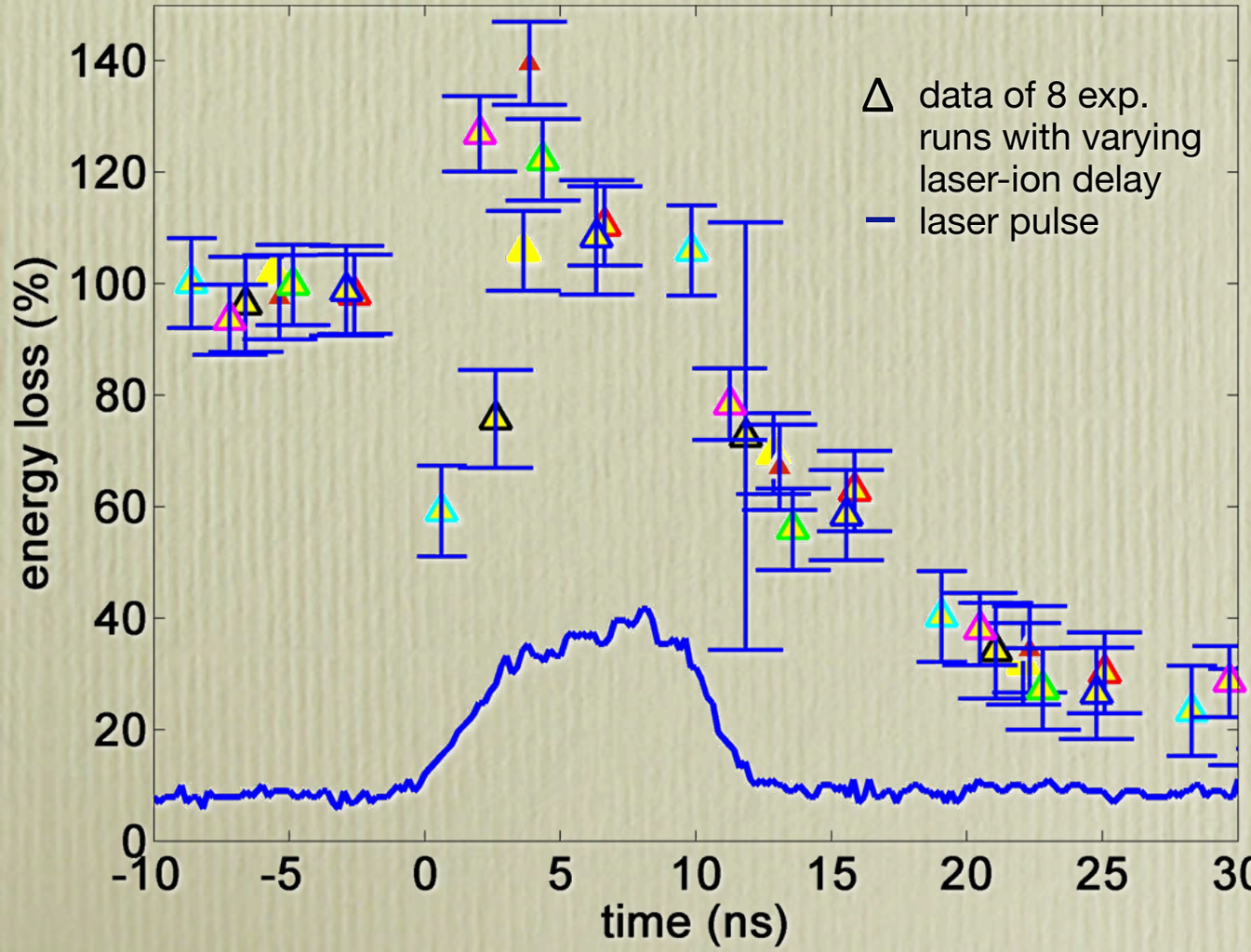


1000 shots of PHELIX delivered for experiments

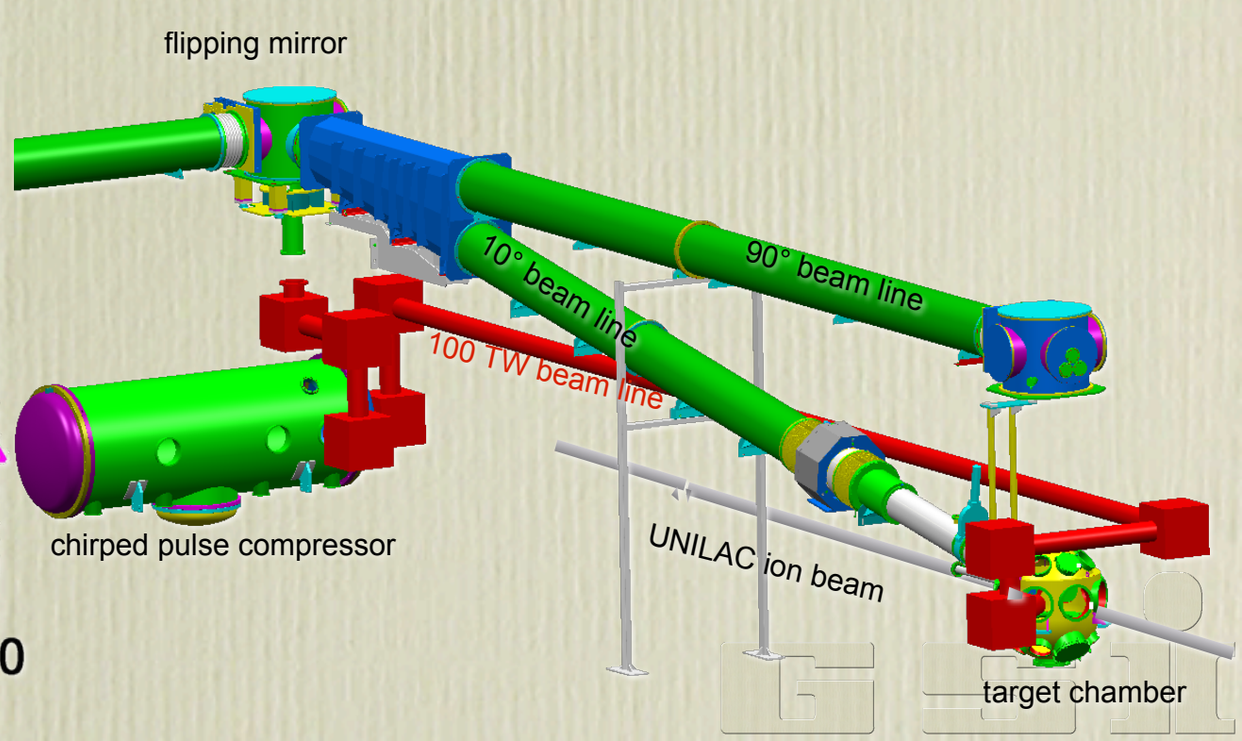
Total of 16 experimental campaigns with PHELIX:

- 5 x Ion stopping @ Z6 (GER, RUS)
- 3 x Proton acceleration (GER, GB)
- 3 x Kα – x-ray production (GER, FRA, RUS)
- 3 x X-ray lasers (GER, FRA)
- 2 x Relativistic electron transport (GER, GB)

Energy loss of 3.6 MeV/u S in carbon plasma (100 µg/cm²)



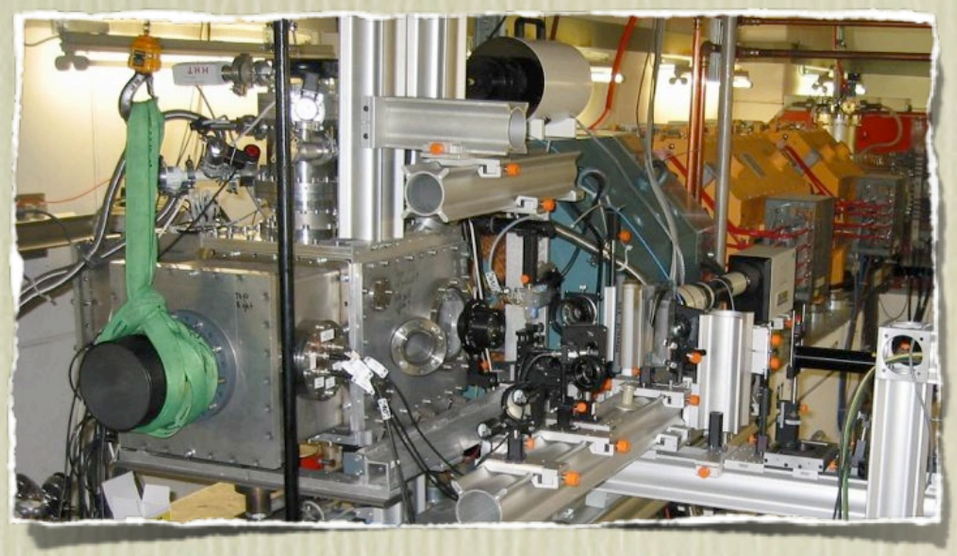
- UNILAC ion beam:
  3 < Z < 92, E < 11 AMeV
  108/36 MHz, Δt_{ion} = 3 ns
- nhelix laser beam:
  100 J @ 6-14 ns (heating)
  5 J @ 0.5 ns (Thomson scattering)
  <1 mJ @ 0.5ns (interferometry)
- PHELIX laser beam:
  1 kJ @ 1-10 ns **+2ω (10º)**
  50 J @ 0.5 ps =>**100 TW**
  (compressed 12 cm beam)
  150 J @ 700 ps
  (chirped short puls)



HHT is unique experimental area at GSI designed for HED physics experiments with intense heavy ion beams

HHT: High energy **H**igh **T**emperature:

	SIS-18 (now)	SIS-18 (upgrade)	
Ion species	from protons to uranium		
Ion energy	up to ~ 230 GeV U; 4.5 GeV p		
Beam intensity	$5 \cdot 10^9$ (U^{73+})	$2 \cdot 10^{10}$ (U^{73+})	$1 \cdot 10^{11}$ (U^{28+})
Bunch length	0.1 – 1 µs	0.07 – 1 µs	
Focal spot	0.2 mm – 2 mm		2.5 mm



Solid metallic targets:

- specific energy: 1 – 5 kJ/g
- temperature: up to 2 eV
- pressure: in multi-kbar range

in 2009:

- beam diagnostics, spectroscopy
- defocused, 1 µs flat-top beam -> uniform, isobaric heating
- W and Ta around melting and in hot liquid states
- reflectivity + multi-channel pyrometry + el. conductivity

=> presentation of **Dmitry Nikolaev**, today

Helmholtz-Russia Joint Research Group

HELMHOLTZ GEMEINSCHAFT

РФФИ

Helmholtz-Russia Joint Research Group

Experimental Study on Warm Dense Matter by Intense Heavy Ion Beams

GSI – JIHT – IPCP – ITEP – TUD *Research Statement*

Summary

We aim to study fundamental properties of high energy density (HED) matter generated by intense heavy ion beams. Experimental investigations on the thermodynamic, transport and optical properties of various materials in HED states will be carried out at HHT area of GSI, using intense beams delivered by SIS-18 heavy ion synchrotron. The experiments will allow us to access unexplored domains of the phase diagram such as high-temperature solid, hot expanded liquid or liquid–gas two-phase and the critical point regions. The work of HRJRG will secure the essential basis for the future HED physics experiments at FAIR.

HRJRG will improve, develop, commission and apply complex diagnostic methods for measuring the basic physical parameters of warm dense matter (WDM) under the specific conditions of ion-beam heating. This includes the following:

- spectroscopic methods for determination of the target temperature with high temporal and spatial resolution, such as fast radiation pyrometry with emissivity measurements;
- interferometric techniques for precision measurement of target velocity, volume and pressure using displacement interferometers and VISARs;
- instruments and methods for measuring opacity of thin WDM layers in visible and UV;
- characterization of the hydrodynamic response of ion-beam heated matter by optical methods: backlighting and schlieren using different photon sources;
- techniques to measure electrical conductivity with high temporal resolution;
- instruments and methods for laser-assisted measurements of the sound velocity;
- methods for transverse diagnostics of intense strongly focused heavy ion beams;
- techniques to determine specific energy deposition in the target volume.

In order to establish and optimize the accuracy of the measurements, these diagnostic instruments and methods will be tested by HRJRG in dedicated experiments at HHT within the time frame of the project: 2009 – 2012.

Spokesman: Dr. Alexander Fertman (ITEP) alexander.fertman@itep.ru
Co-Spokesman: Dr. Dmitry Varentsov (GSI) d.varentsov@gsi.de

GSI IPCP RAS TECHNISCHE UNIVERSITÄT DARMSTADT

- for HED physics experiments with intense heavy ion beams at HHT July 2009 – June 2012
- GSI, JIHT, IPCP, ITEP, TUD
- jointly funded by Helmholtz Association and RFBR

- thermodynamic, transport and optical properties of ion-beam generated HED states in matter
- R&D and commissioning of essential diagnostics for FAIR:
  - spectroscopy, pyrometry
  - interferometry
  - opacity in UV, VIS, NIR
  - backlighting and schlieren
  - electrical conductivity
  - sound velocity
  - beam diagnostics

Four new experimental proposals by HRJRG in 2009

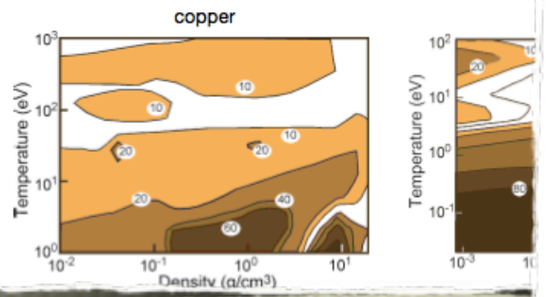
Study of Near-Critical States of Refractory Materials by Intense Heavy Ion Beams

experimental proposal

V. Ternovoi[1], E. Brambrink[2], A. Fertman[3], A. Golubev[3], D.H.H. Hoffmann[4], A. Hug[4,5], B. Ionita[4,5], A. Kantsyrev[3], K. Khishchenko[6], A. Khudomyasov[3], M. Kulish[1], J. Ling[4], N. Markov[3], V. Mintsev[1], D. Nikolaev[1], A. Pyalling[1], N. Shilkin[1], V. Turtikov[3], S. Udrea[4], D. Varentsov[5], D. Yuriev[4]

[1]Institute of Problems of Chemical Physics, Chernogolovka, Russia
[2]LULI, Ecole Polytechnique, Palaiseau, France,
[3]Institute for Theoretical and Experimental Physics, Moscow, Russia,
[4]Technische Universität Darmstadt, Darmstadt, Germany,
[5]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany,
[6]Joint Institute for High Temperatures, Moscow, Russia

Spokesperson: Vladimir Ternovoi (ternovoi@ficp.ac.ru)
GSI contact: Dmitry Varentsov (d.varentsov@gsi.de)



Diagnostics for Intense Focused Heavy Ion Beams

experimental proposal

A. Ulrich[1], A. Fertman[2], D. Varentsov[3], V. Turtikov[2], A. Fedenev[3,4], A. Golubev[2], D.H.H. Hoffmann[6], A. Hug[3,6], B. Ionita[3,6], A. Kantsyrev[2], K. Khishchenko[7], A. Khudomyasov[2], M. Kulish[5], J. Ling[6], N. Markov[2], V. Mintsev[5], D. Nikolaev[5], N. Shilkin[5], V. Ternovoi[5], S. Udrea[6], J. Wieser[8], D. Yuriev[5]

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[6]Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany
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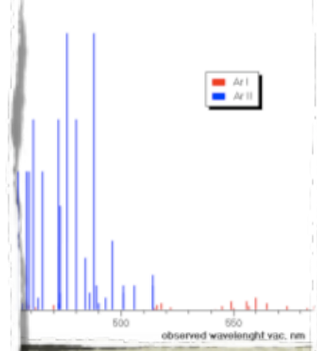
Spokesperson: Andreas Ulrich (andreas.ulrich@ph.tum.de)
GSI contact: Dmitry Varentsov (d.varentsov@gsi.de),



Heavy-Ion and Laser Beam Driven Planar Isentropic Compression

experimental proposal

E. Brambrink[1], V. Bagnoud[2], A. Benuzzi[1], A. Blazevic[2], A. Fertman[3], D. Gericke[4], A. Golubev[3], A. Grinenko[4], D.H.H. Hoffmann[5], M. Koenig[1], V. Mintsev[6], D. Nikolaev[6], M. Roth[5], V. Ternovoi[6], V. Turtikov[3], S. Udrea[5], D. Varentsov[2]

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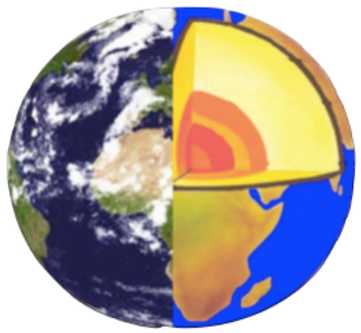
Spokesperson: Erik Brambrink (erik.brambrink@polytechnique.edu)
GSI contact: Dmitry Varentsov (d.varentsov@gsi.de),
Abel Blazevic (a.blazevic@gsi.de)



interior of the earth

Electrical Conductivity of Heavy Ion Driven WDM States in Metals

Experimental proposal

S. Udrea[1], A. Fertman[5], A. Golubev[5], D.H.H. Hoffmann[1], A. Hug[3], B. Ionita[1,3], A. Kantsyrev[5], K. Khishchenko[4], A. Khudomyasov[5], M. Kulish[2], J. Ling[1], N. Markov[5], V. Mintsev[2], D. Nikolaev[2], N. Shilkin[2], V. Turtikov[5], D. Varentsov[3], D. Yuriev[2]

[1]Technische Universität Darmstadt, Darmstadt, Germany
[2]Institute of Problems of Chemical Physics, Chernogolovka, Russia
[3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
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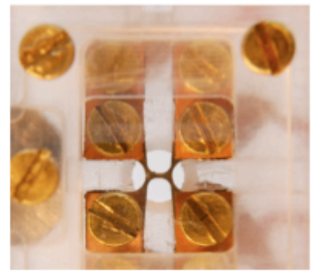
[5]Institute for Theoretical and Experimental Physics, Moscow, Russia

Spokesperson: Serban Udrea (serban.udrea@skmail.ikp.physik.tu-darmstadt.de)
GSI contact: Dmitry Varentsov (D.Varentsov@gsi.de)



H-shaped target for conductivity measurements

High Energy Proton Microscopy

1st Workshop on

High Energy Proton Microscopy

HEPM-2009

August 24 – 25, 2009
GSI, Darmstadt, Germany

Scope

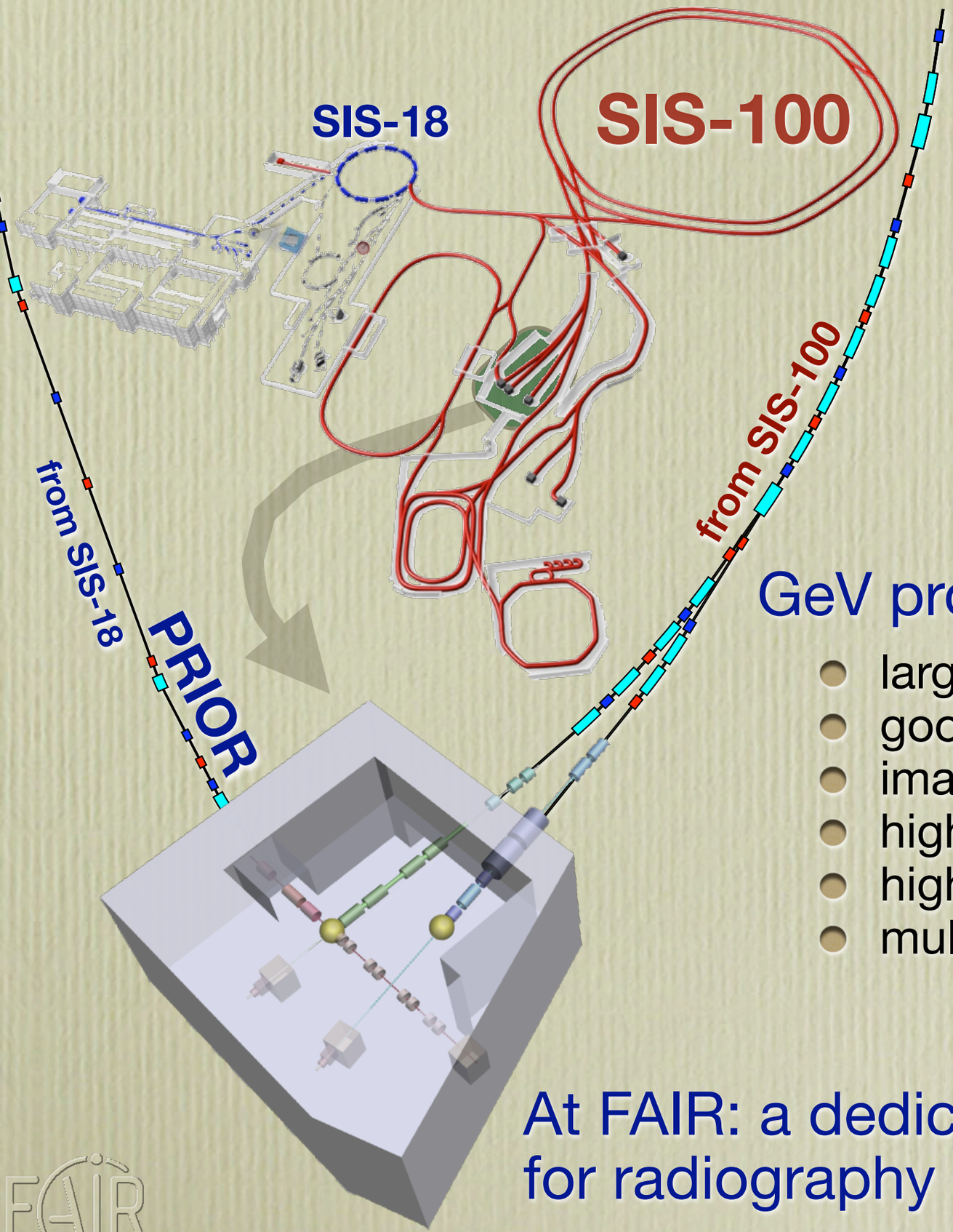
- present and future applications of high spatial and temporal resolution proton microscopy for materials research, plasma physics, biophysics, HEDP / WDM studies and other fields
- existing and planned accelerator proton microscopy facilities at FAIR, GSI, ITEP, LANSCE, MaRIE.

- 65 participants from China, Germany, Italy, Russia, Spain, USA
- 21 presentations
- open discussions

- focus: PRIOR project - proton radiography at GSI and FAIR

http://www-aix.gsi.de/conferences/HEPM2009

PRIOR – Proton Microscope for FAIR



Challenging requirements for **density measurements** in dynamic HEDP experiments:

- up to ~20 g/cm^2 (Fe, Pb, Au, etc.)
- ≤10 µm spatial resolution
- 10 ns time resolution (multi-frame)
- sub-percent density resolution

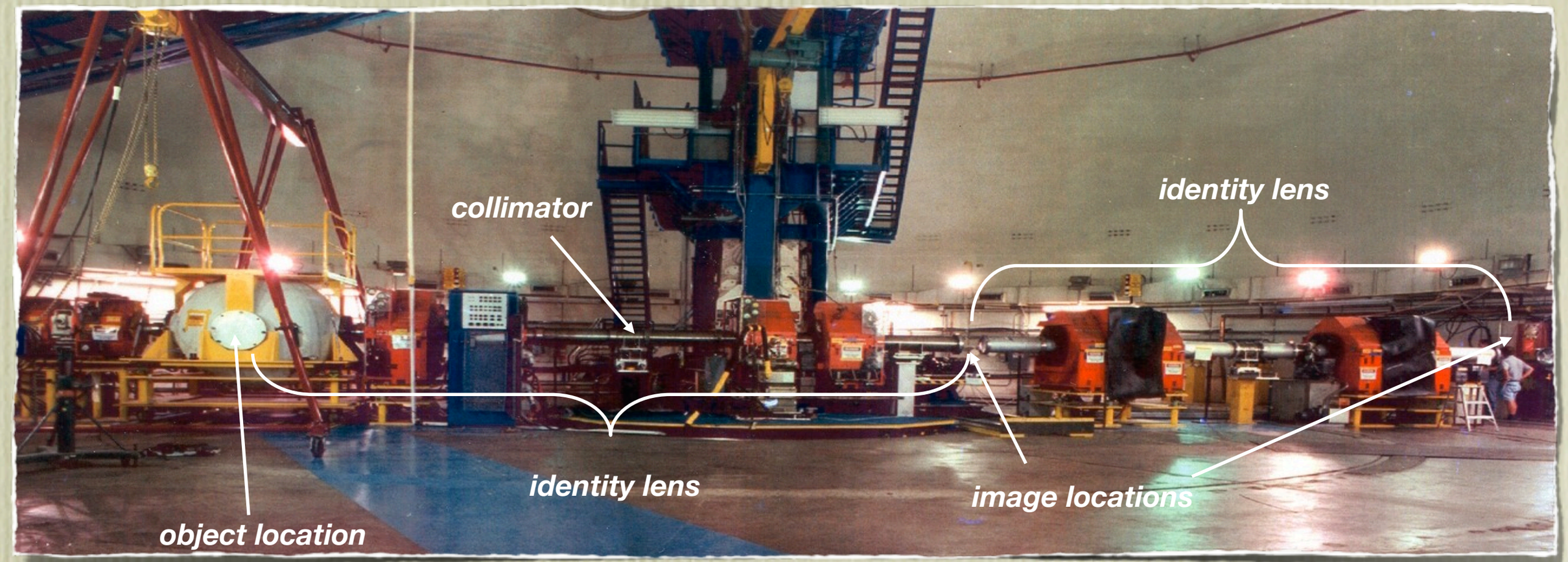
GeV protons:

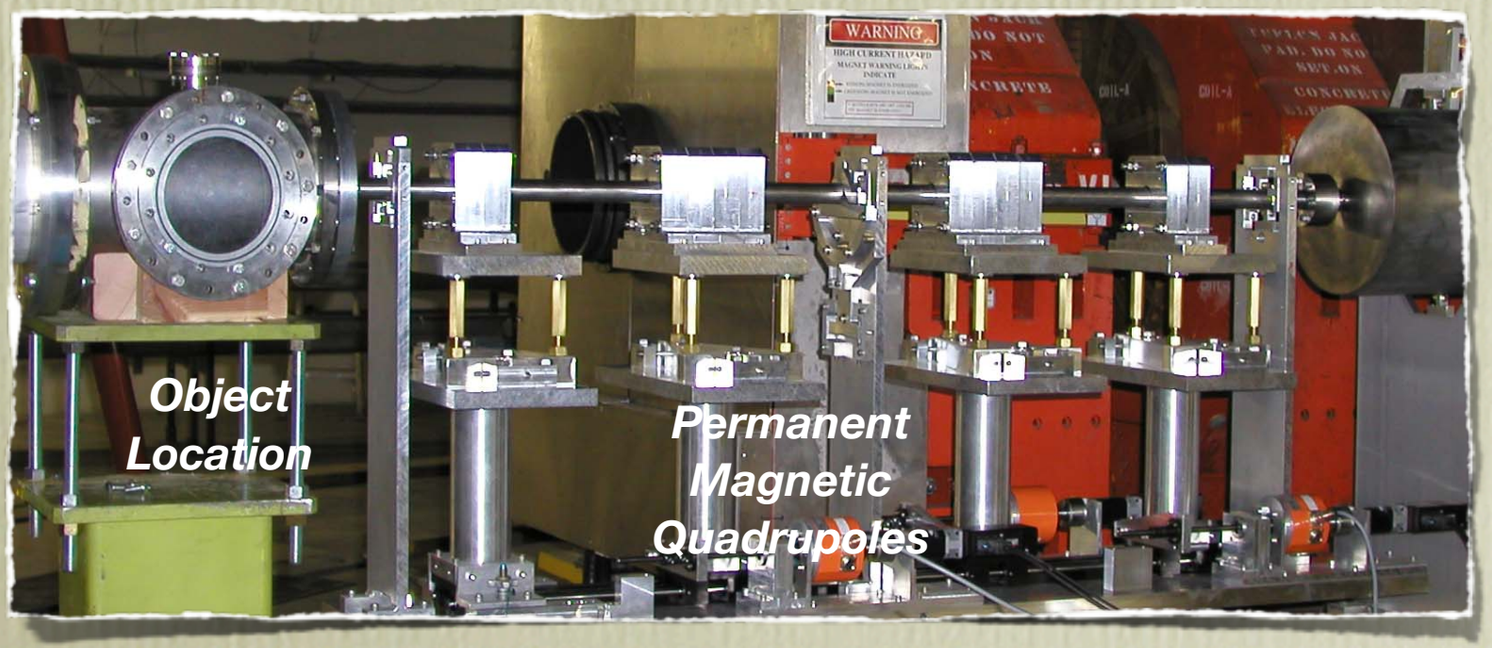
- large penetrating depth (high ρx)
- good detection efficiency (S/N)
- imaging, aberrations correction by magnets
- high spatial resolution (microscopy)
- high density resolution and dynamic range
- multi-frame capability for fast dynamic events

At FAIR: a dedicated beam line from SIS-18 for radiography

4.5 GeV, $5 \cdot 10^{12}$ protons

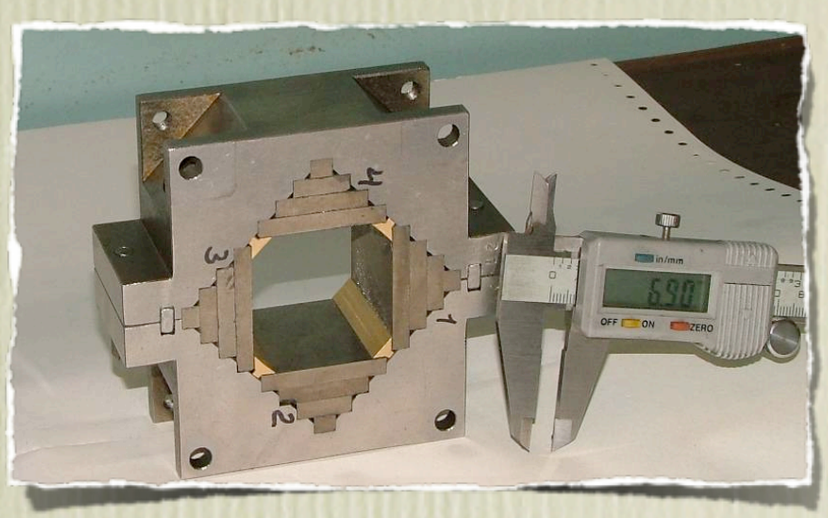
“pRad” facility at LANSCE linac (LANL)





Protons: 800 MeV (linac)
Density range: ~1 – 70 g/cm^2 (Fe)
Spatial resolution:
X1a: 178 μm @ 120 mm FOV
X1b: 280 μm @ 120 mm FOV
X3: 65 μm @ 44 mm FOV
X7: 30 μm @ 17 mm FOV
up to ~40 frames (~50 ns, 10^9 each)

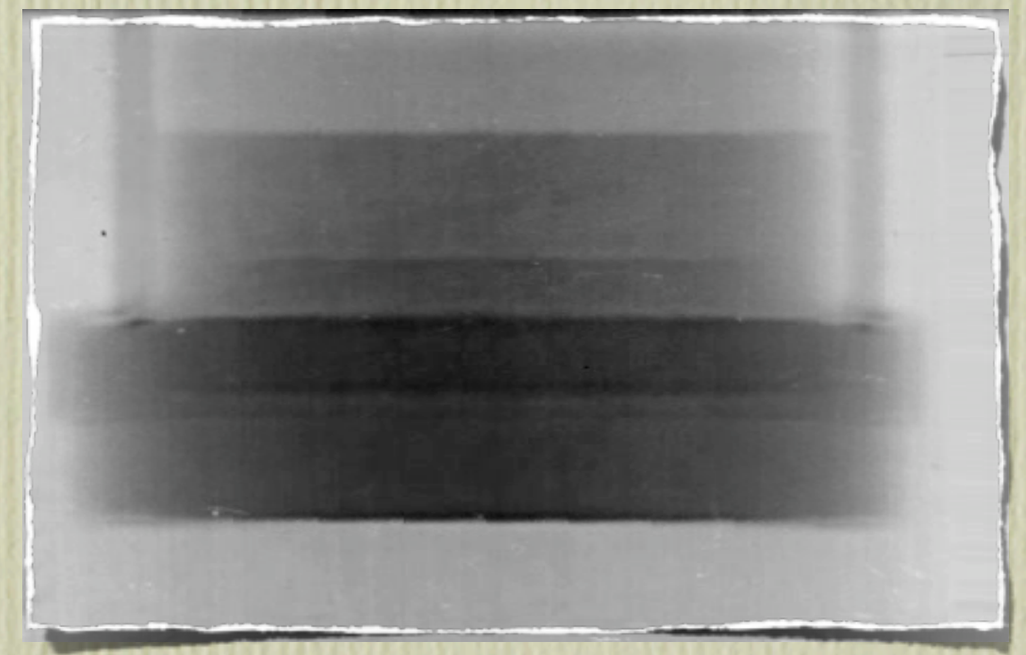
Proton radiography at TWAC synchrotron (ITEP)

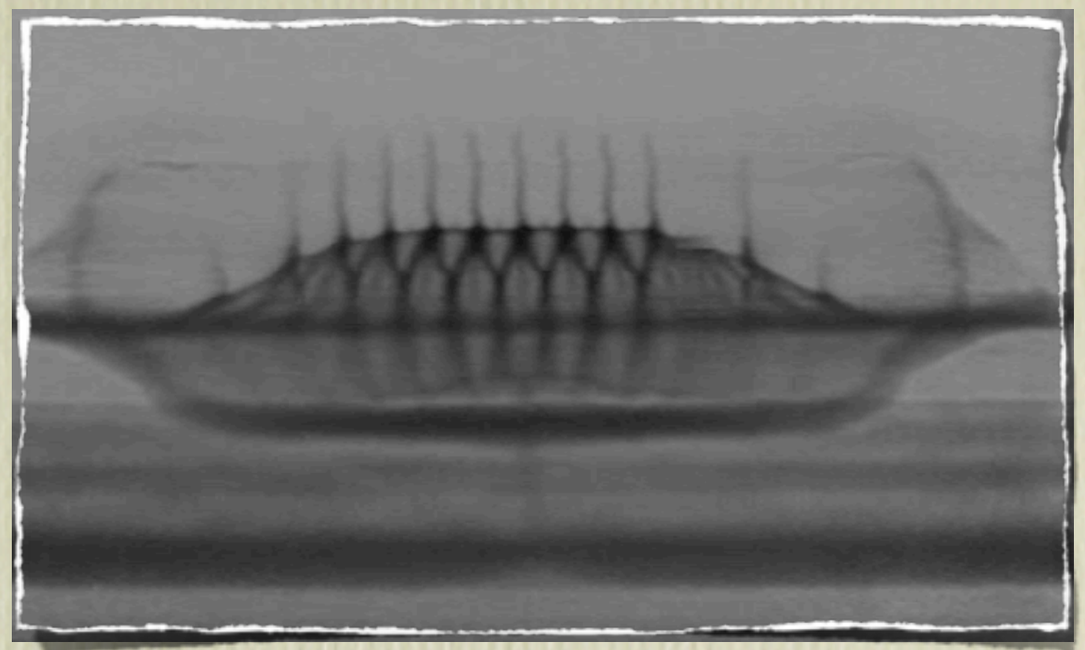


- protons from a synchrotron
- collaboration: ITEP – IPCP – GSI
- prototyping and R&D for FAIR

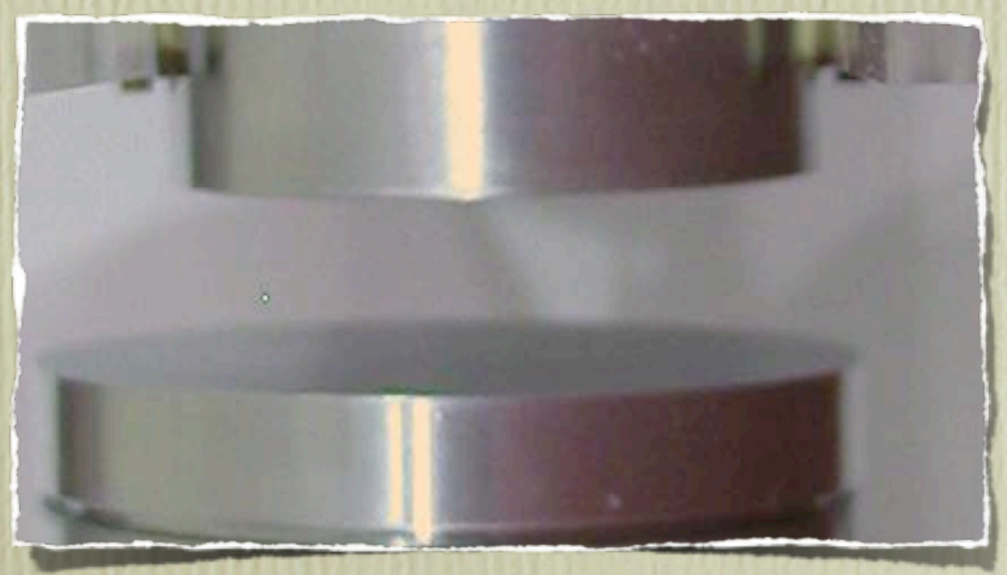
Protons: 800 MeV (synchrotron)
Density range: ~1 – 60 g/cm^2
Spatial resolution:
X1: 270 μm @ 40 mm FOV
X4: 60 μm @ 22 mm FOV
X8: 50 μm @ 10 mm FOV
up to 4 frames (10^{10} – $5 \cdot 10^{11}$ in 1 μs)

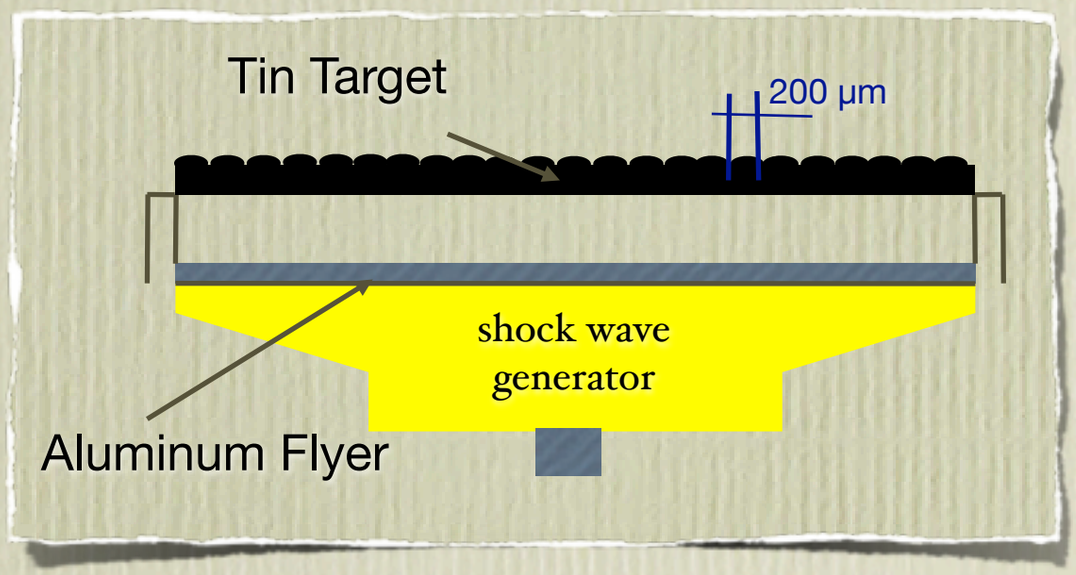
Physics applications example: EOS and hydrodynamic flows





Density: $\rho = 3.09 \pm 0.024$ g/cm^3



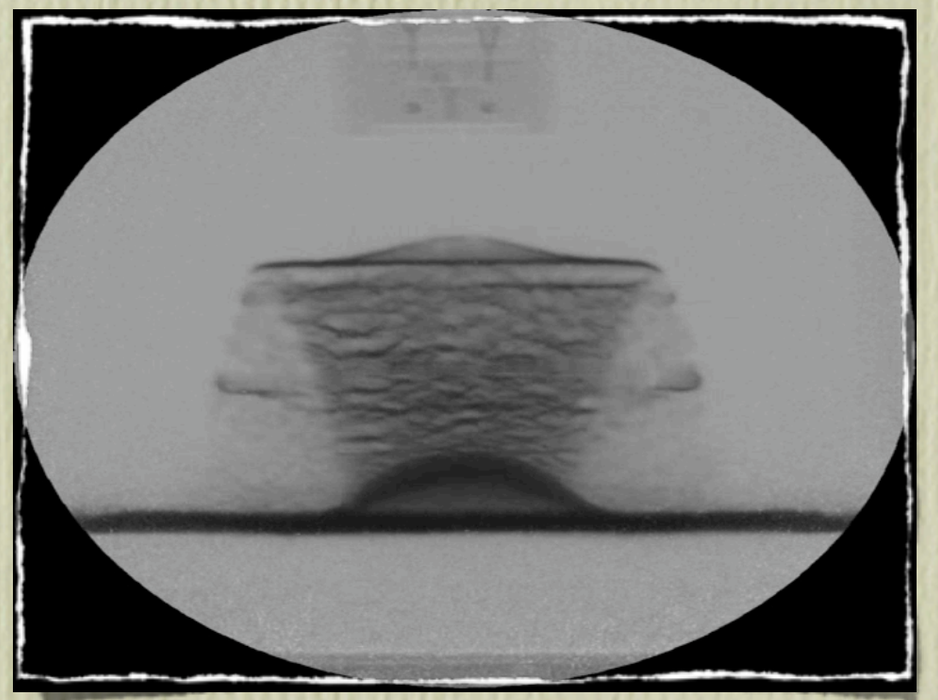


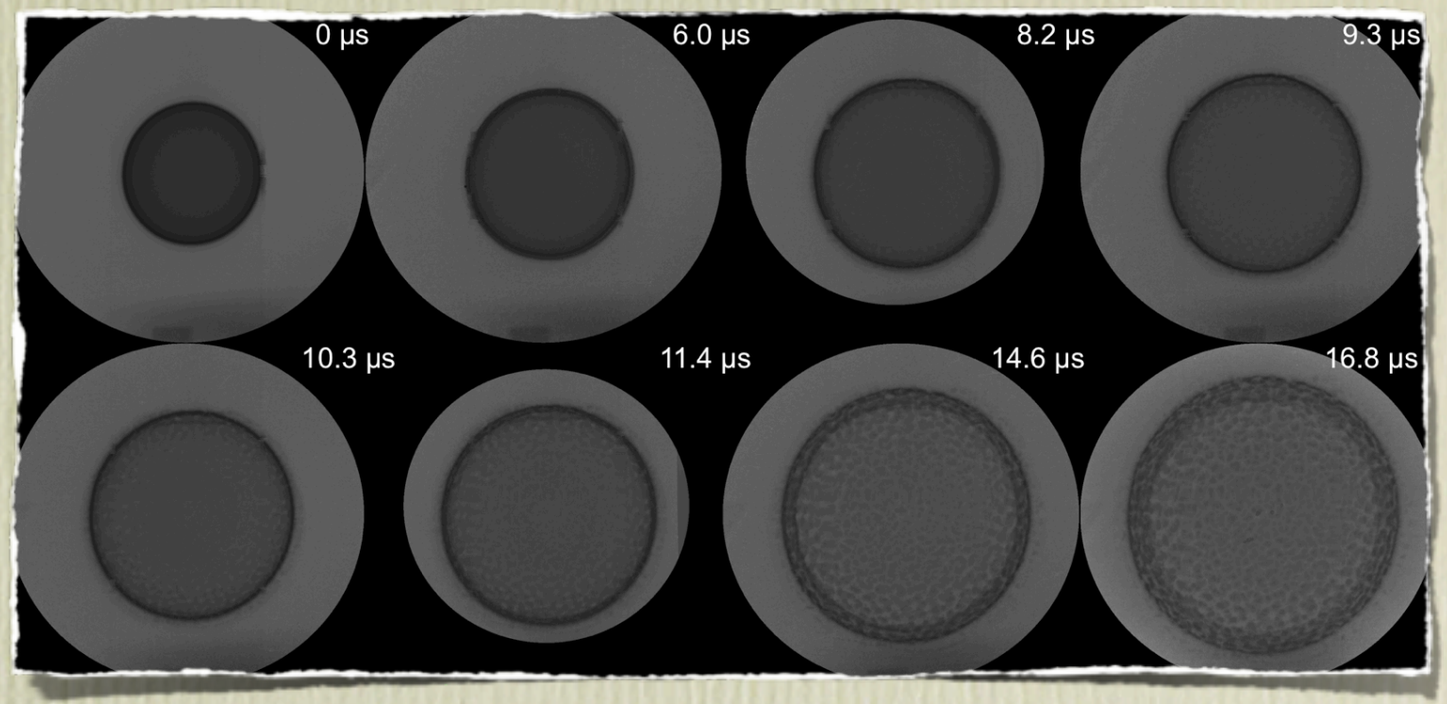
Two independent ways to determine Al EOS in one shock wave experiment by proton radiography only

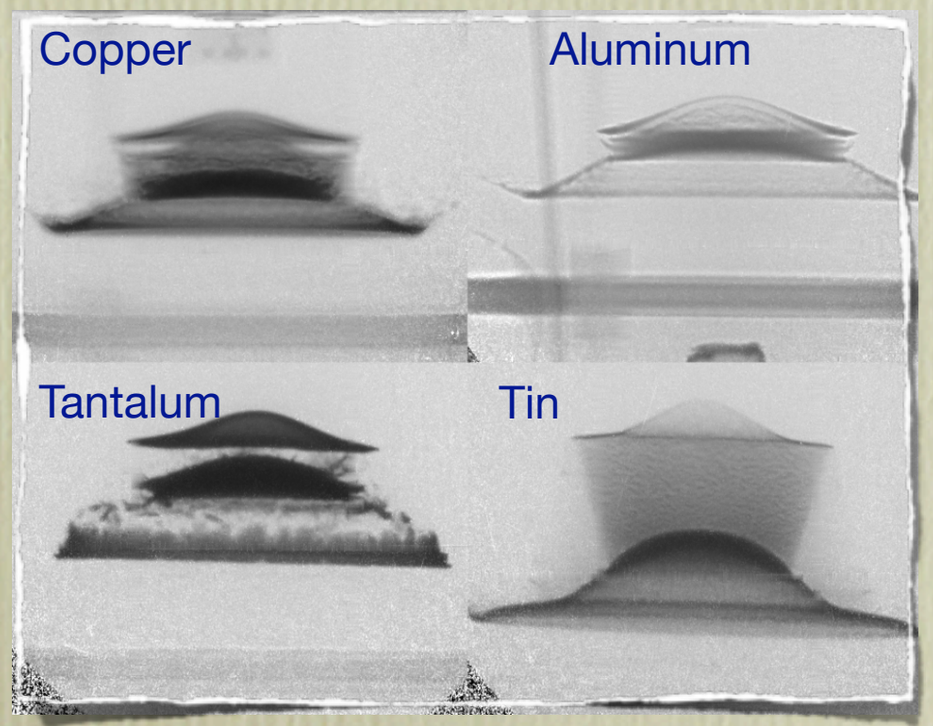
Non-linear growth of Richtmyer-Meshkov instability in shock-wave driven tin

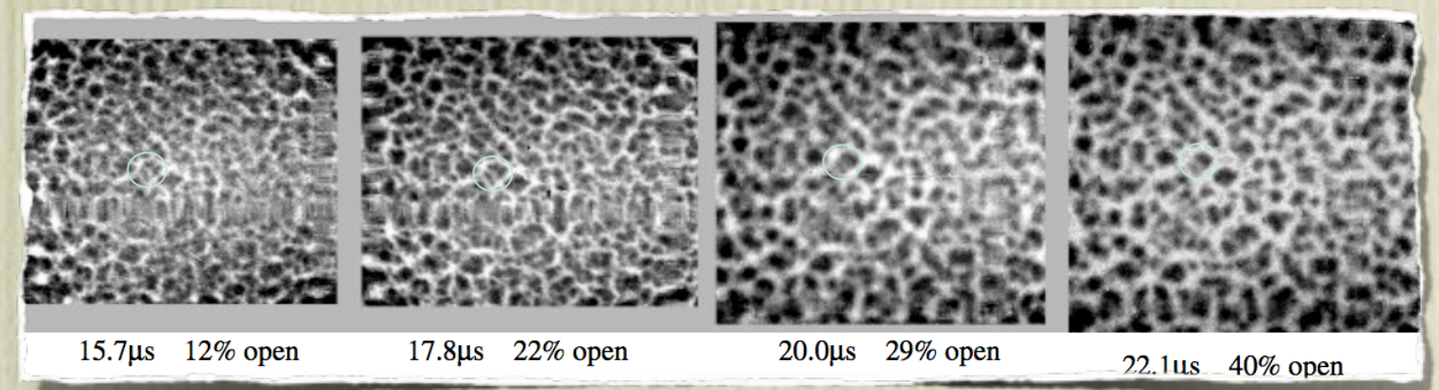
courtesy of Frank Merrill, LANL

pRad example: dynamic material strength / failure quantitative studies of spall, fragmentation – at μm level









courtesy of Frank Merrill, LANL

PRIOR project will accomplish two main tasks:

- FAIR proton radiography system which a core FAIR installation will be designed, constructed and commissioned in full-scale dynamic experiments with 4.5 GeV proton beam from SIS-18
- prior to FAIR using the same SIS-18 proton beam, a worldwide unique radiographic facility may become operational at GSI that would provide a capability for unparalleled high-precision experiments with great discovery potential at the leading edges of plasma physics, high energy density physics, biophysics, and materials research

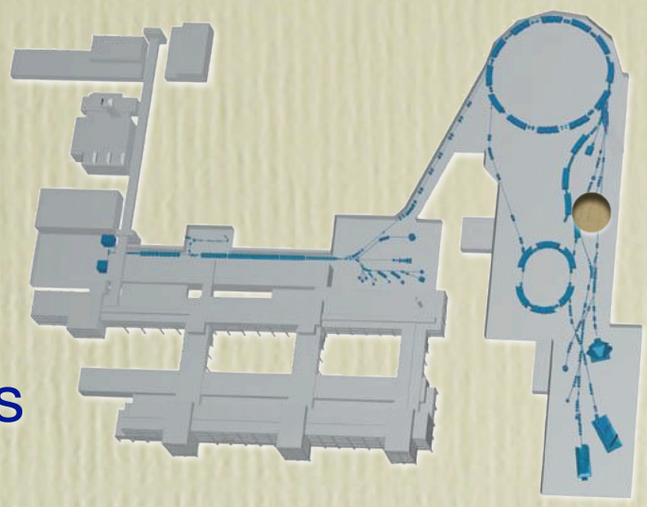
Spatial resolution scalings with proton energy:

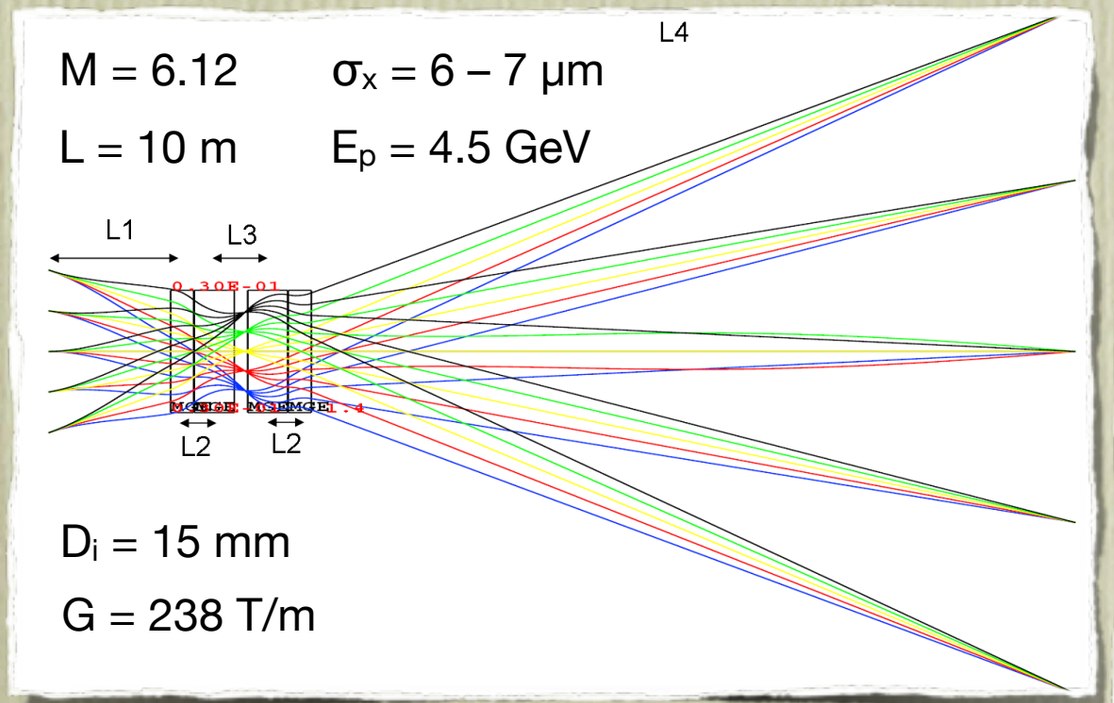
- object scattering $\sigma_o \propto \frac{\ell_t^{\frac{3}{2}}}{p}$
- chromatic aberrations $\sigma_c \propto \frac{\ell_t^{\frac{1}{2}}}{p^{\frac{3}{2}}}$
- detector blur $\sigma_d \propto \frac{\ell_s \ell_t^{\frac{1}{2}}}{p}$

PRIOR – Proton Microscope for FAIR

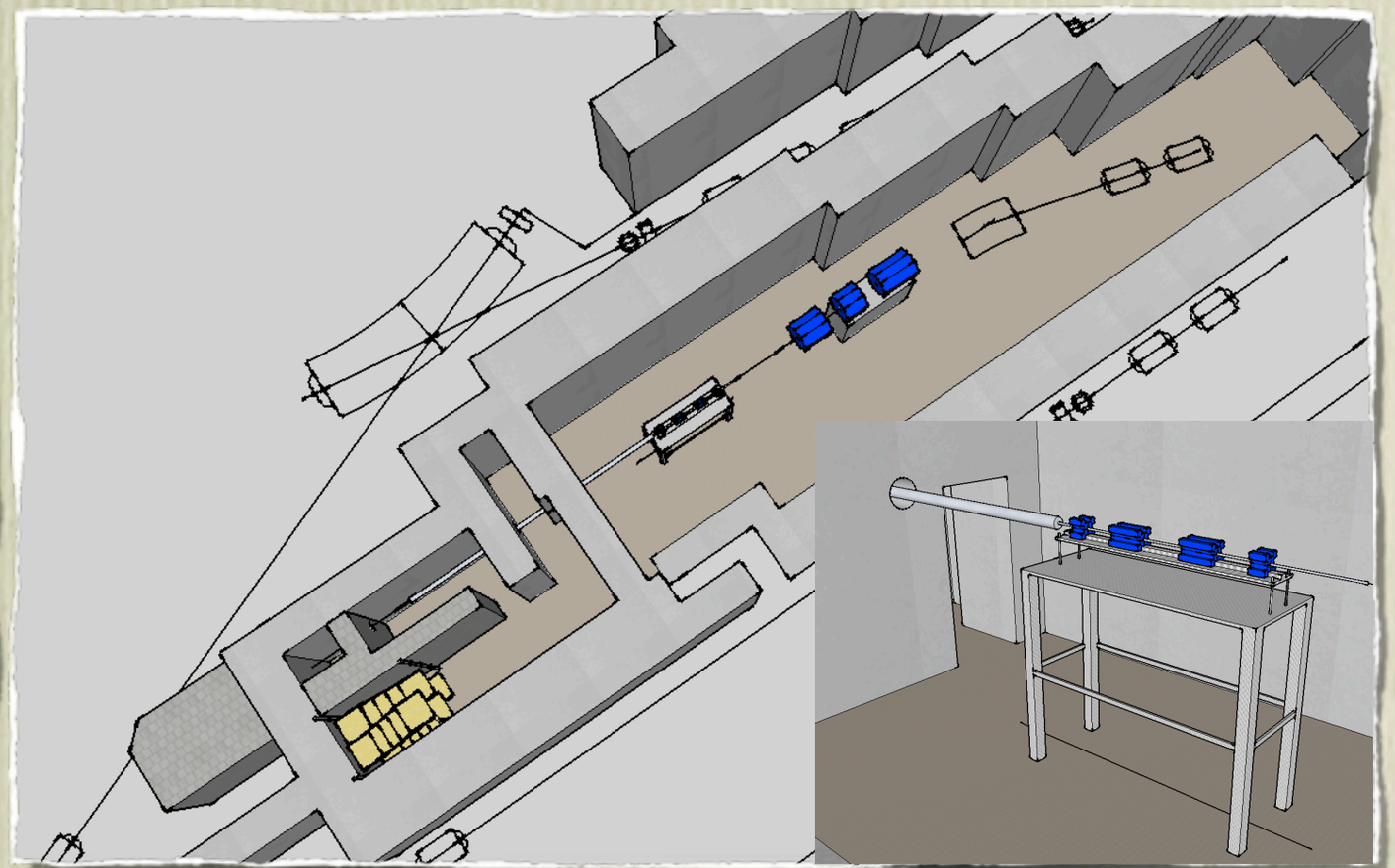
PRIOR technical specifications

- proton energy: **4.5 GeV**
- spatial resolution: ≤10 μm
- temporal resolution: 10 ns
- multi-framing capability: 1 – 4 frames within 1 μs
- target characteristics: up to 20 g/cm^2
- areal density reconstruction: sub-percent level
- field of view: 3 – 15 mm
- stand-off distance: 1 – 1.5 m
- total length after object plane: less than 15 m

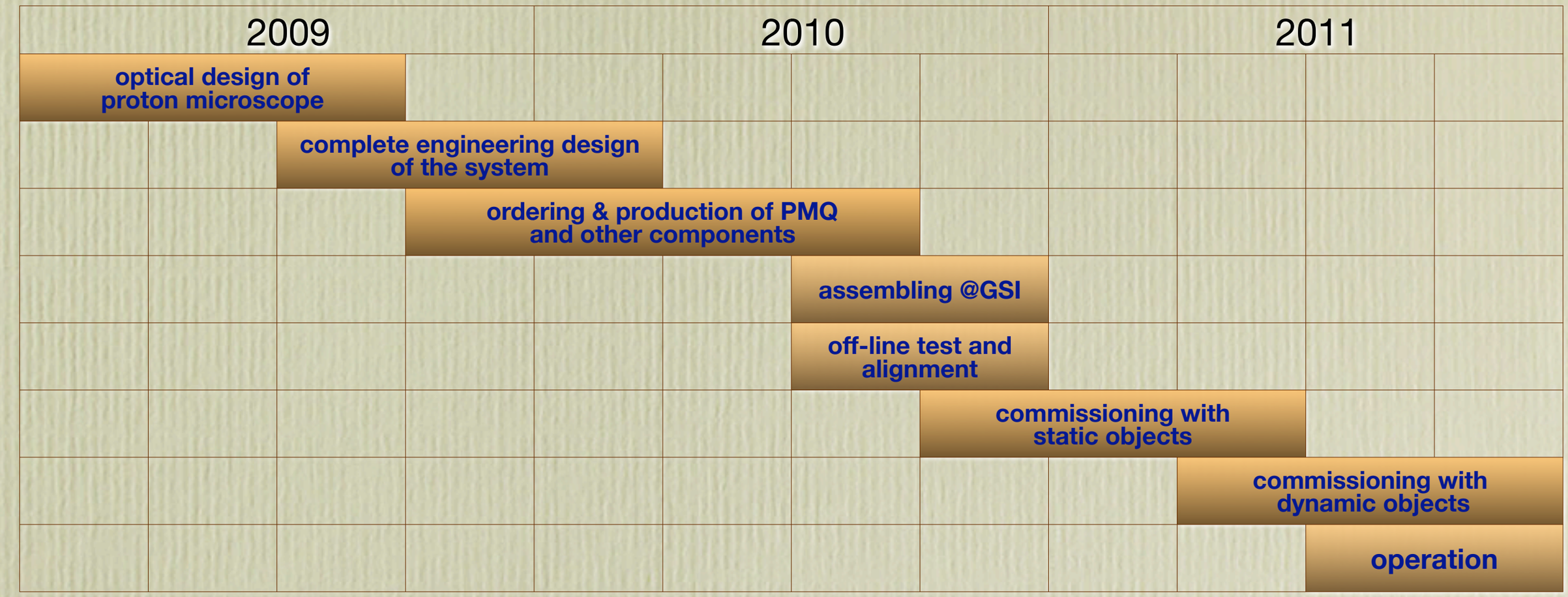




– a compact system but long drift is needed for the microscope



Time schedule and milestones for PRIOR project



- international scientific workshop at GSI Q3 2009
- approval of the project by GSI management Q4 2009
- ordering production of main components Q4 2009
- submitting first beam time applications Q2 2010
- assembling and off-line measurements Q4 2010
- commissioning with static objects Q1 2011
- commissioning with dynamic objects Q2 2011

Summary

- intense heavy ion, proton and laser beams available at GSI bring up unique capabilities for high energy density physics

- **at GSI:**
  - 1000 PHELIX shots delivered for 16 experimental campaigns (stopping power of laser plasmas, laser acceleration of protons, x-ray generation and lasers, etc.)
  - at HHT – developing essential beam and target diagnostic tools for FAIR, continuing experiments on thermophysical properties of refractory materials near melting, boiling and the critical point
  - new Helmholtz-Russia Joint Research Group for HEDP experiments with intense heavy ion beams at GSI
  - 1st Workshop on High Energy Proton Microscopy; PRIOR – radiography with 4.5 GeV proton beam @GSI

30th International Workshop on Physics of High Energy Density in Matter: 31.01 – 5.02.2010, Hirschegg, Austria

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http://www.gsi.de/forschung/pp/dates/hirschegg/index.html

December 20, 2009 (~ 90 have already registered!)