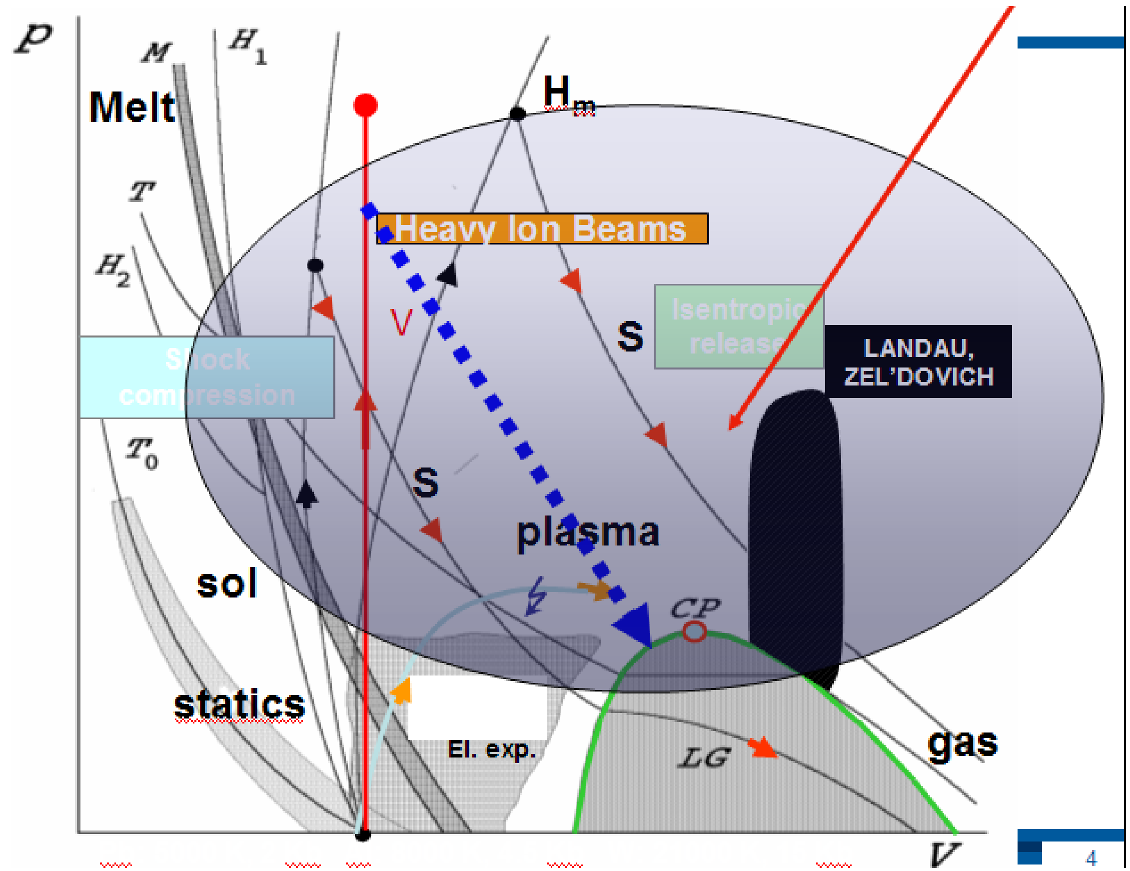
Fundamental properties of matter under extreme conditions

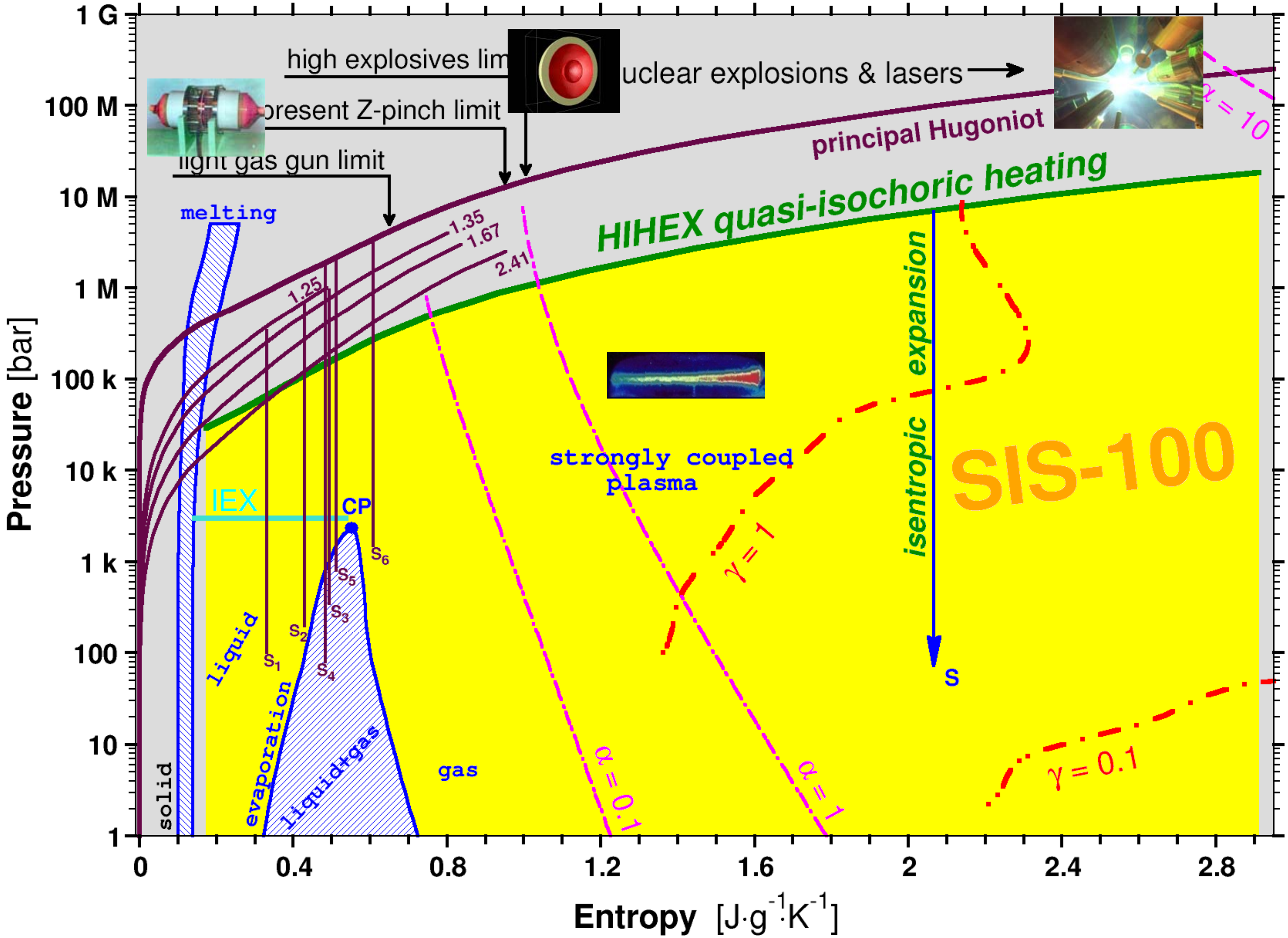
Intense heavy ion beams at FAIR provide unique capabilities for generation and study HED states in matter

- equation-of-state (EOS) of HED matter
- phase transitions and exotic states of matter
- transport and radiation properties of HED matter
- stopping properties of non-ideal plasma

Isentropic Expansion



"Terra Incognita" regions of the phase diagram accessible in **HEDgeHOB** experiments at FAIR



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

Critical Parameters of Some Metals

I.V. Lomonosov and V.E. Fortov

	T_c (K)	P_c(kbar)	r_c(g/cm3)
Aluminum	6390	4.45	0.86
Copper	7800	9.00	2.28
Gold	8500	6.14	6.10
Lead	5500	2.30	3.10
Niobium	19200	11.1	1.70
Tantalum	14550	7.95	3.85
Tungsten	13500	3.10	2.17
Beryllium	8600	2.00	0.40

ISOCHORIC HEATING TECHNIQUE

1. HIHEX [Heavy Ion Heating and Expansion]

.

This technique involves isochoric and uniform heating of matter by an intense ion beam and the heated material is allowed to expand isentropically.

Expanded Hot Liquid

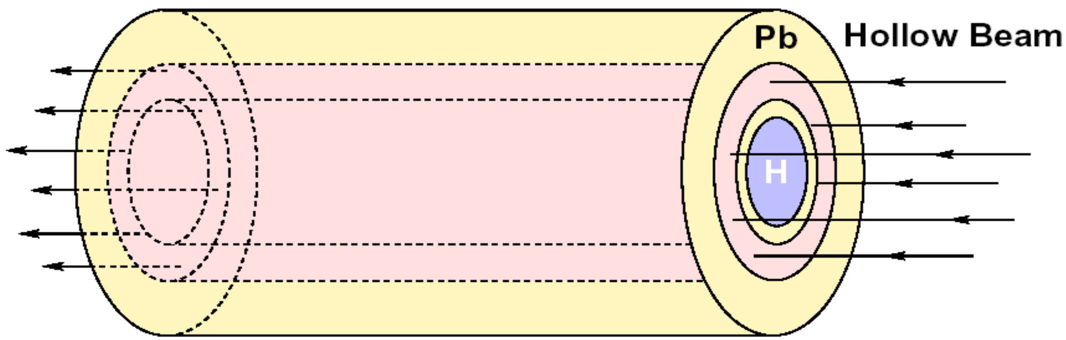
Two Phase Liquid-Gas Region

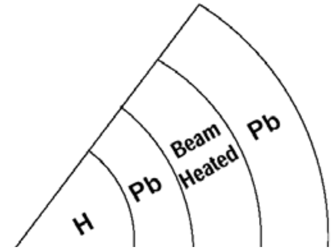
Critical Parameters

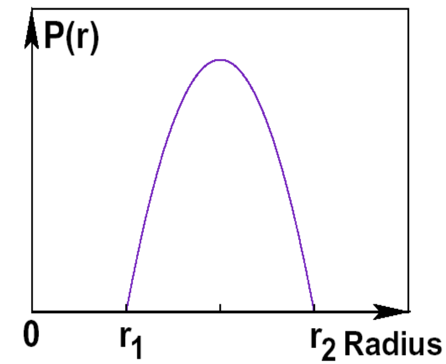
Strongly Coupled Plasma

N.A. Tahir et al., Phys. Rev. Lett. 95 (2005) 035001

Low entropy compression







Target Parameters

$r_d = 0.4$ mm

$r_1 = 0.6$ mm

$r_2 = 2.1$ mm

$r_0 = 3.5$ mm

Beam Parameters

2.7 GeV/u Uranium

$N = 0.2 - 1.5 \times 10^{12}$

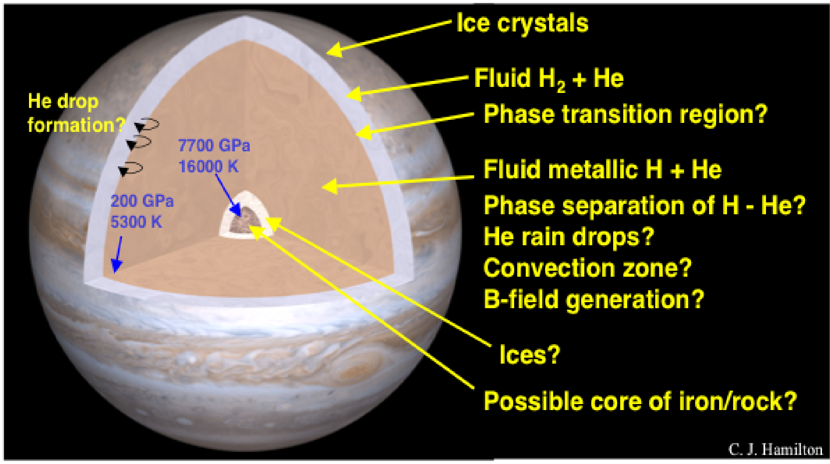
$\tau = 20$ ns

$E_b = 21 - 155$ kJ

$\rho = 1 - 2\ g/cm^3$

$P = 2 - 10$ Mbar

$T = 0.2 - 0.6$ eV

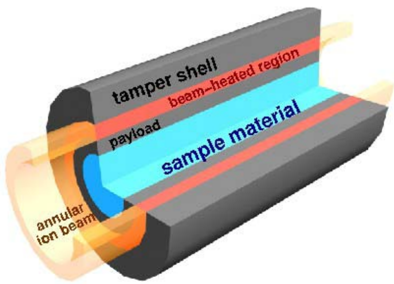


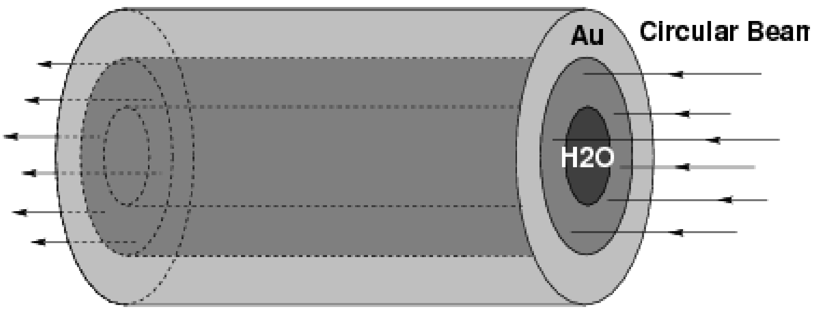
2. LAPLAS [LAboratory PLAnetary Sciences]

Experimental Scheme: Low entropy compression of a test material like H, D_2 or H_2O, in a multlayered cylindrical target

[Hydrogen Metallization , Planetary Interiors]

N.A. Tahir et al., PRE 64 (2001) 016202; High Energy Density Phsics 2 (2006) 21;
A.R. Piriz et al, PRE 66 (2002) 056403.





Hollow Beam

Au or Pb

Circular beam

Shock reverberates between the cylinder axis and the hydrogen-outer shell interface.

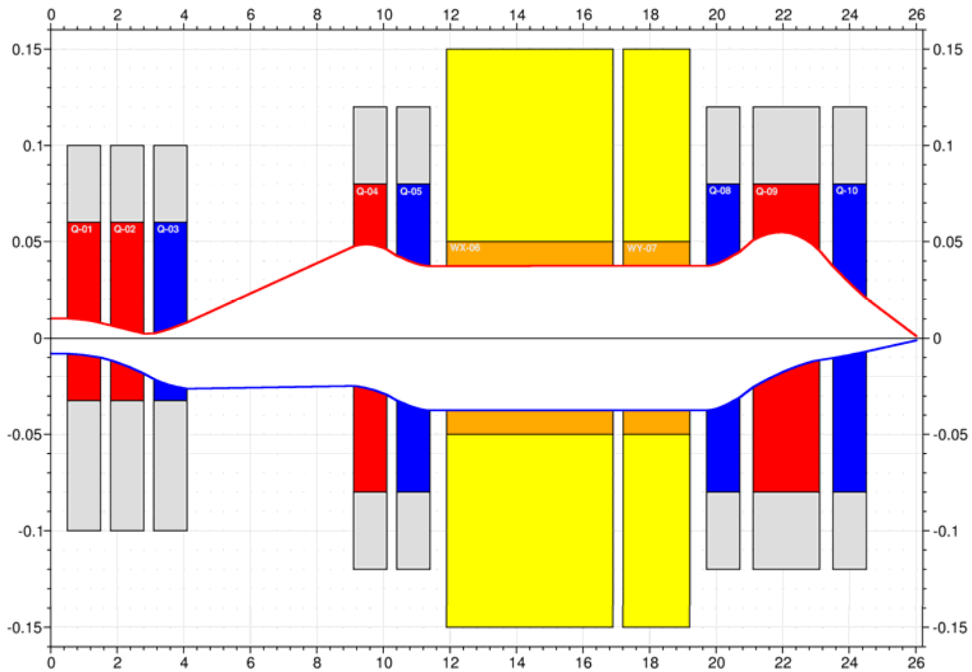
Very high densities, high pressure, higher temperature

Very high □ (23 g/cc), ultra high P (30Mbar) , low T (of the order of 10 kK).

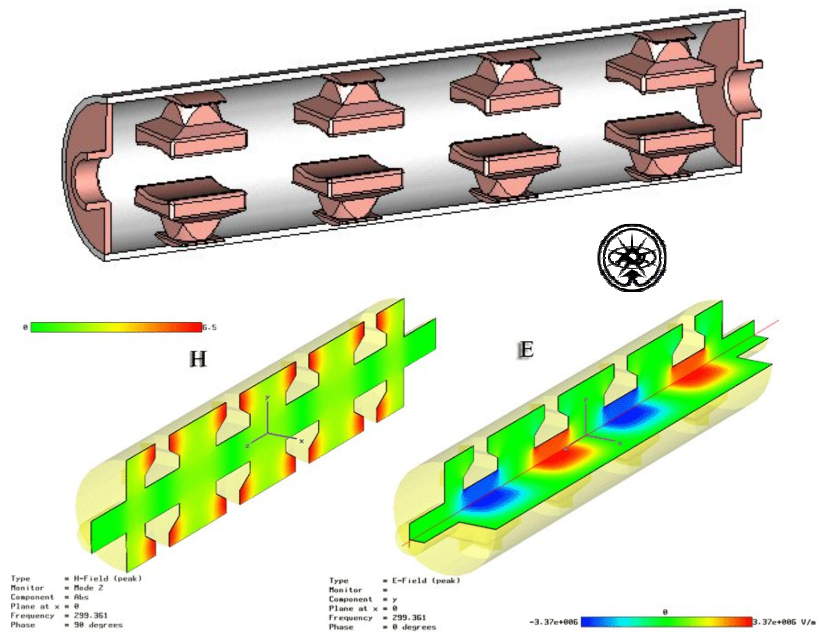
□ = 1.2 g/cc, P = 11 Mbar, T = 5 ev

P6.1&6.2: Ion optical design of the **LAPLAS** beam line: focusing and RF beam deflector (wobbler), ITEP design.

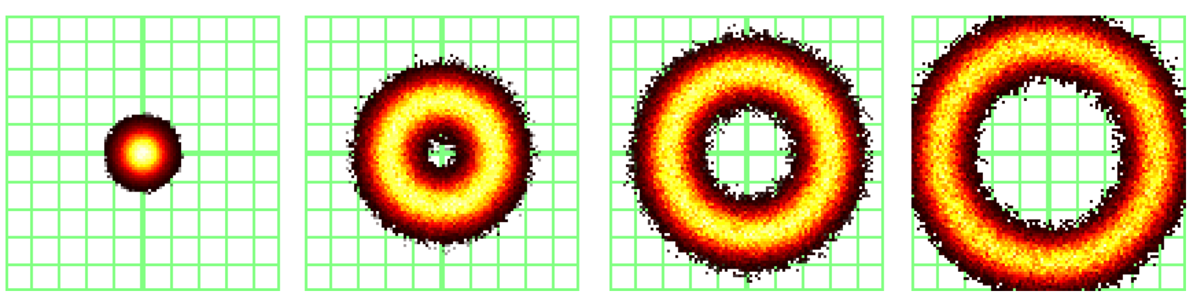
Layout of the **LAPLAS** beam line



Design of rf beam deflector (wobbler)

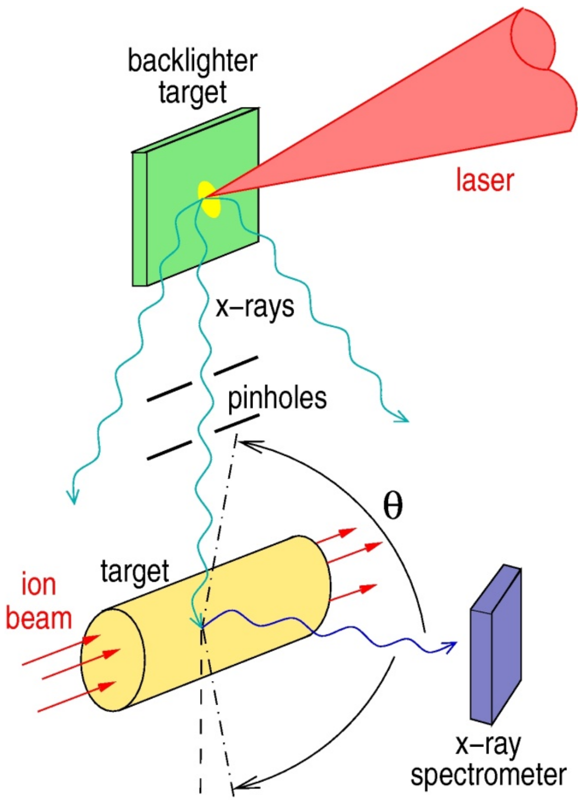


Transverse beam intensity distribution in the focal spot



WDM collaboration –
Atomic physics in dense environments

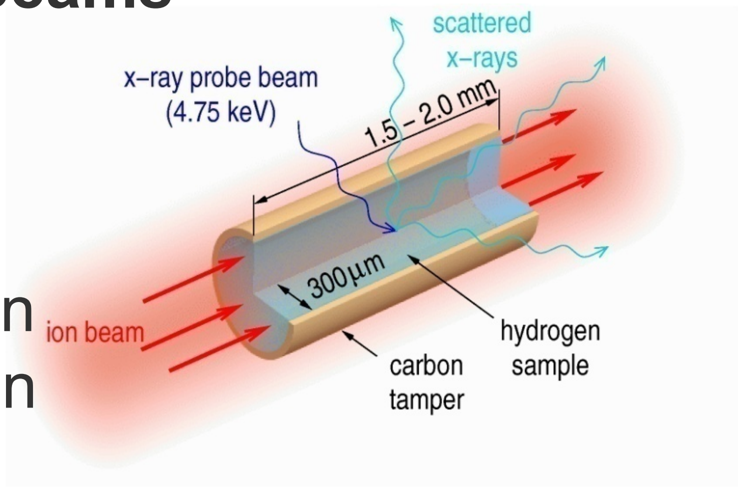
WDM produced by Intense Heavy Ion Beams and probed by Intense Laser Beams



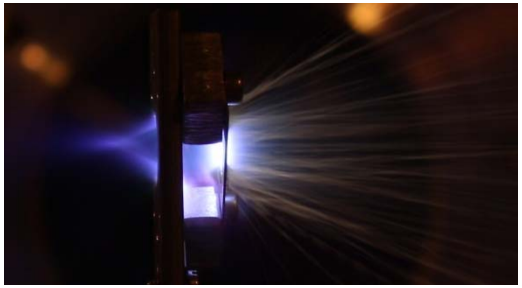
Unique combination of intense heavy ion beam driven experiments

+

Laser driven diagnostics

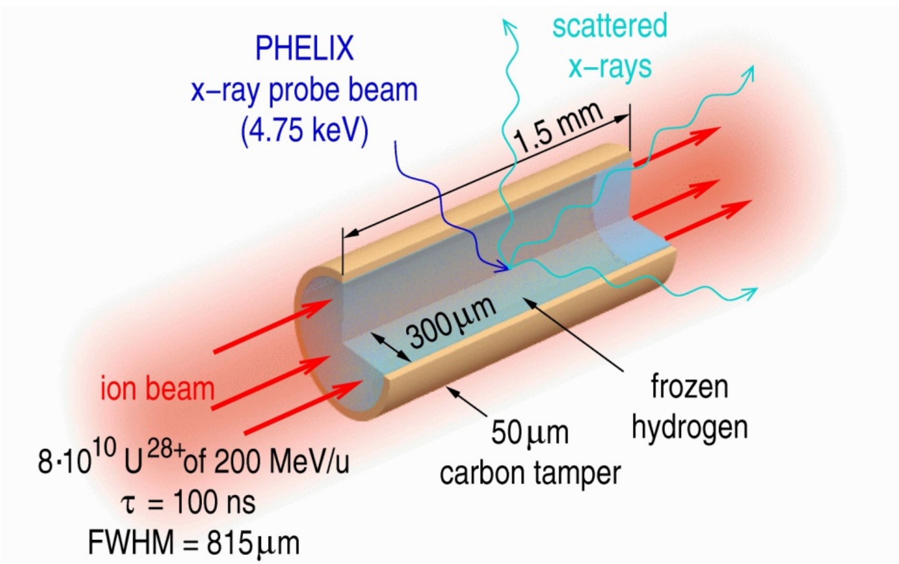


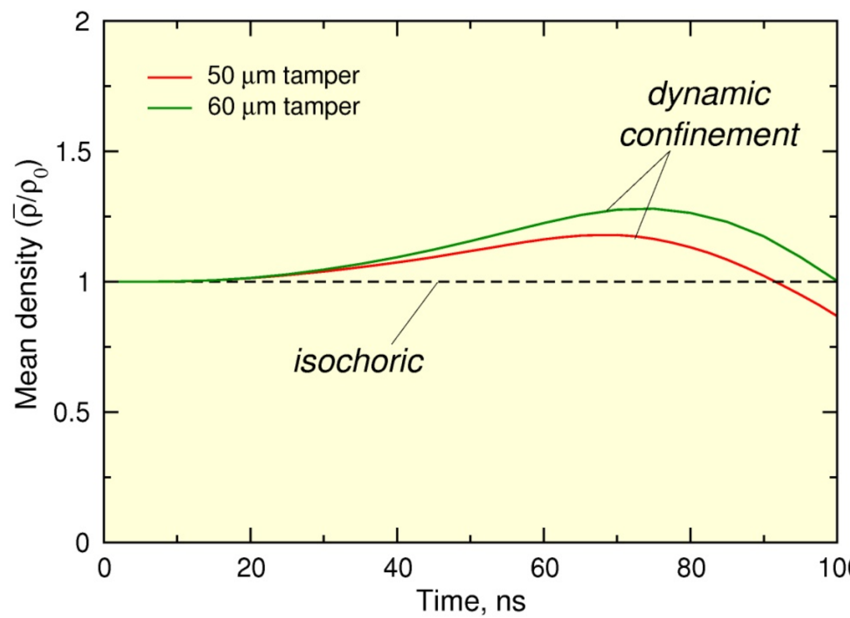
High Power Laser PHELIX



Dynamic confinement of targets heated quasi-isochorically with heavy ion beams

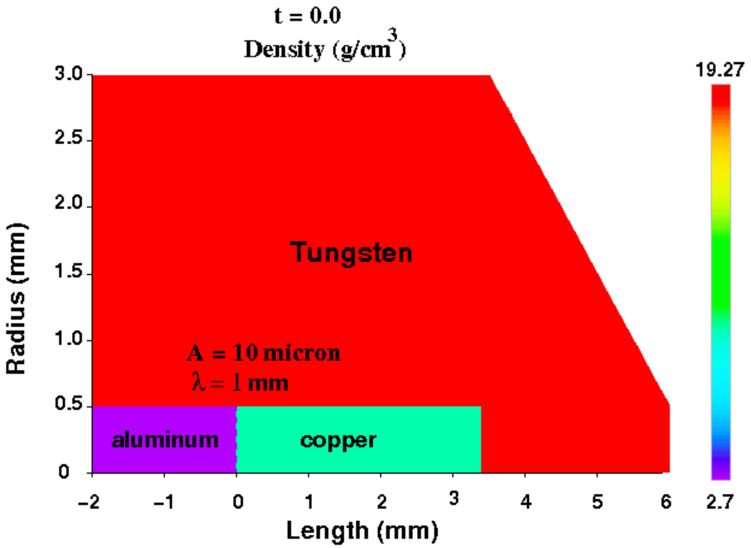
A. Kozyreva[1], M. Basko[2], F. Rosmej[3], T. Schlegel[1],
A. Tauschwitz[3] and D.H.H. Hoffmann[1,3]

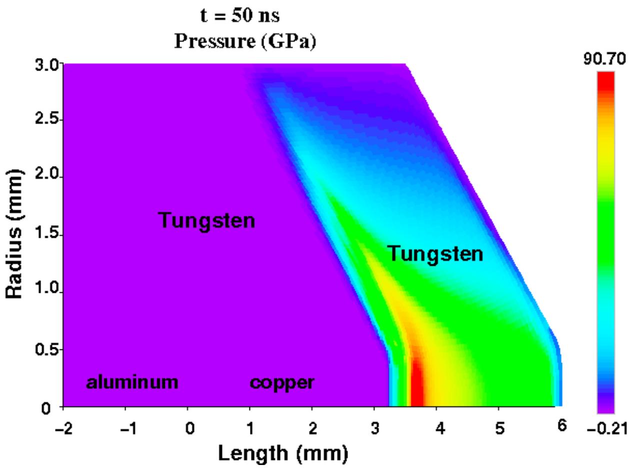




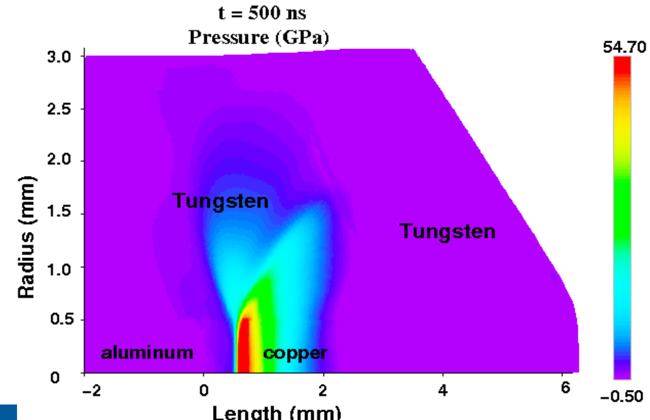
Target: Solid (cryogenic) hydrogen
For isochoric heating in at ε = 130 kJ/g → T = 0.64 eV (Warm Dense Matter regime)

Ion Beam Generated Plane Shock Waves
Using a Mach Type Reflection Scheme
N.A. Tahir et al., Phys. Plasmas 18 (2011), 032704.



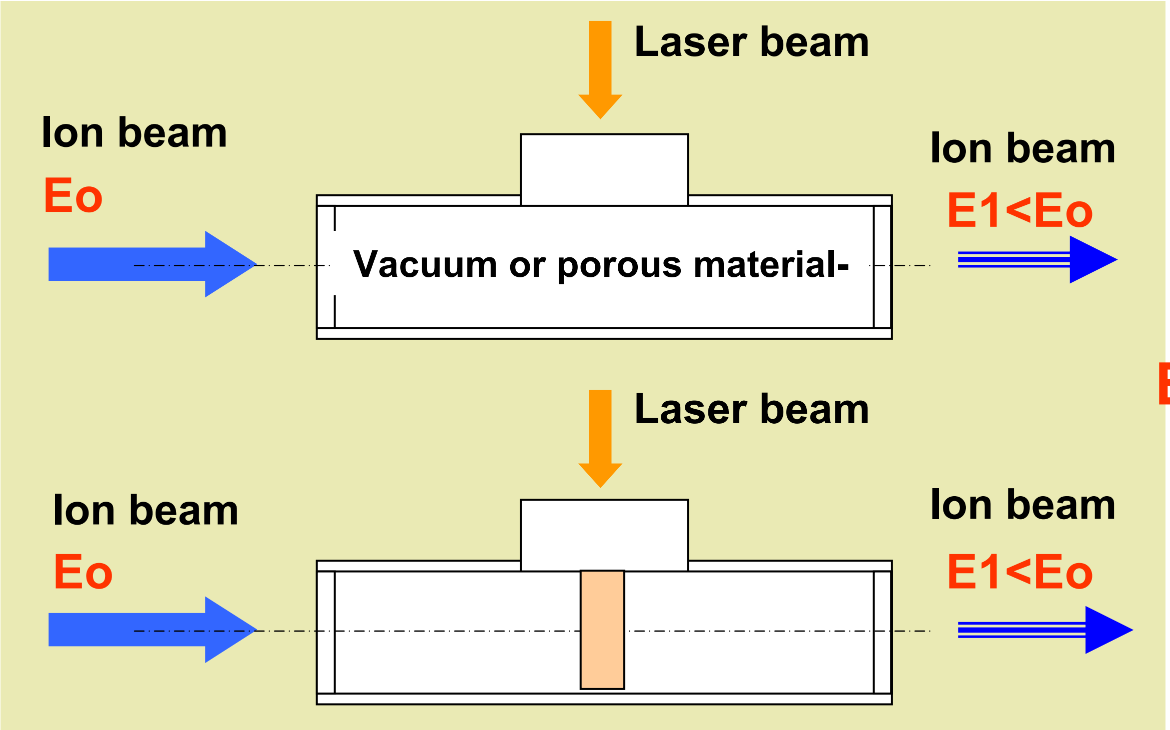


U ions 400 MeV/u
N = 5x10E10
FWHM = 2 mm



Indirect target design for investigation of ion stopping in plasma targets (V. Vatulin, VNIIEF,1999)

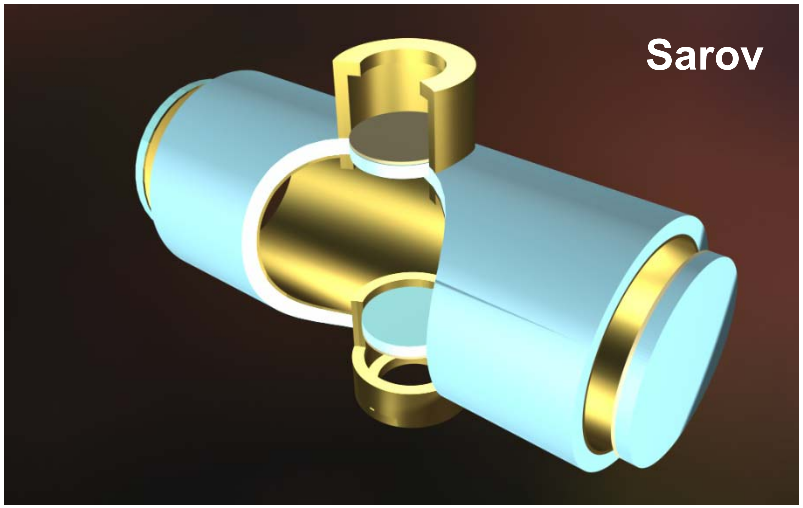
In order to get clear experimental evidence of temperature effect on ion stopping in dense plasma, it is desirable that the target density is uniform and *ρ·l target* conserved going from cold to plasma target. It is also very important to determine plasma parameters accurately.

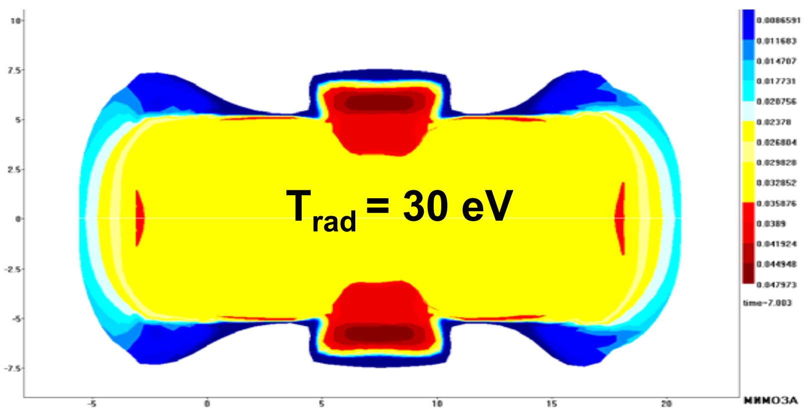


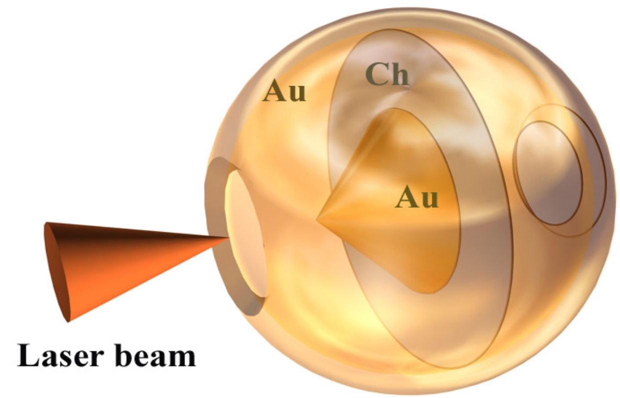
E1/Eo=?

X-rays generated by Phelix laser heat the main volume of the target.

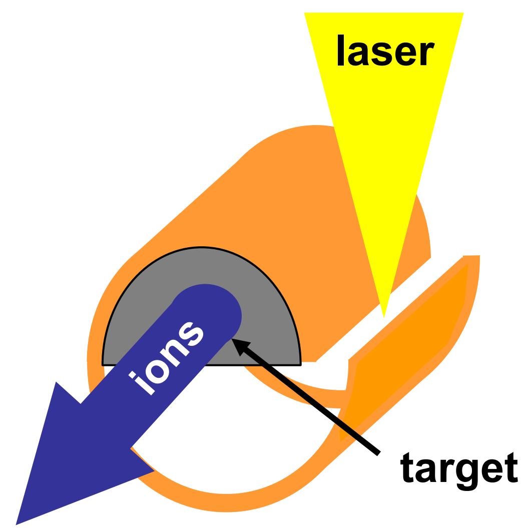
Various design of Hohlraum targets







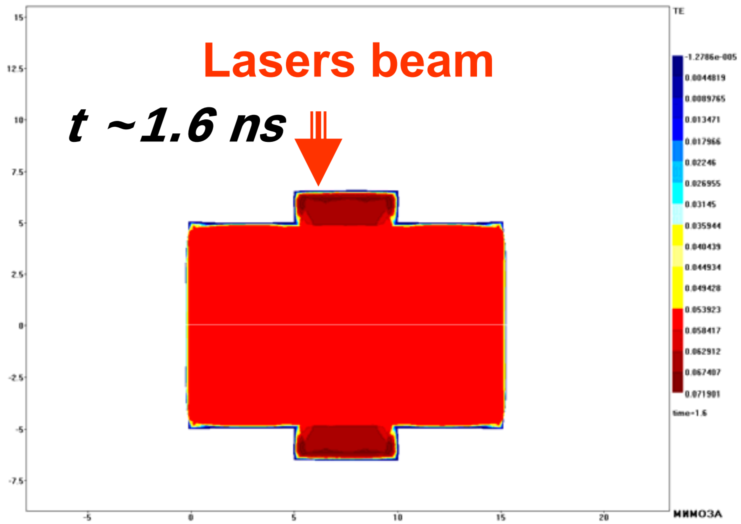
Type of Asterix target as x-ray source for Hohlraum target (GSI proposal)

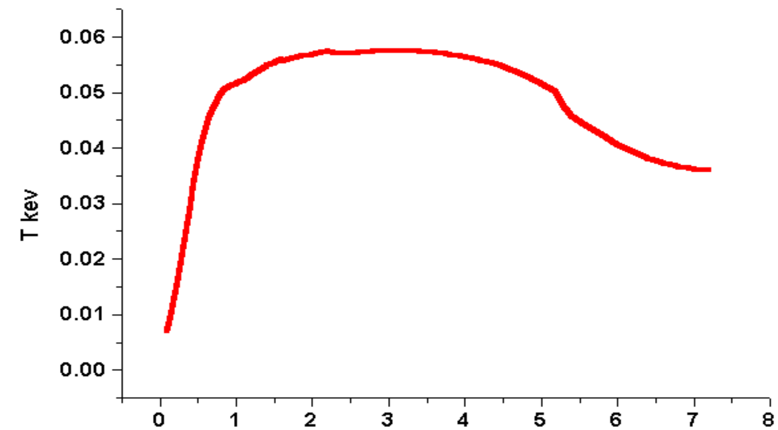


Basko

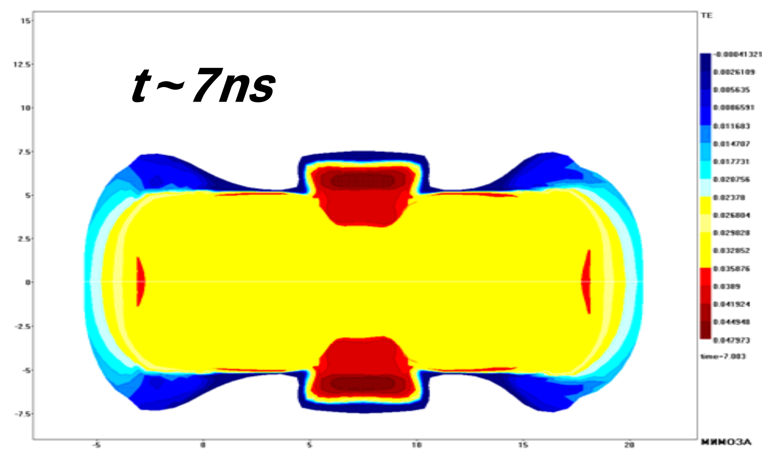
Numerical simulations: Y.Belyakov et al., Sarov
Maruhn, Frankfurt
Basko, Moscow

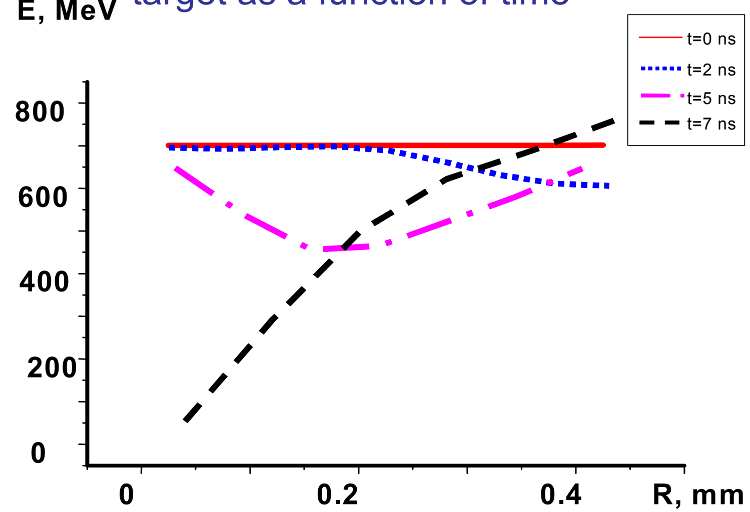
Results of 2D calculations (O. Vinokurov) for Phelix conditions (E_{laser}~1 kJ, dt~ 1 ns, ρ_{CH}~0.02 g/cm^3)





Plasma temperature inside the target as a function of time

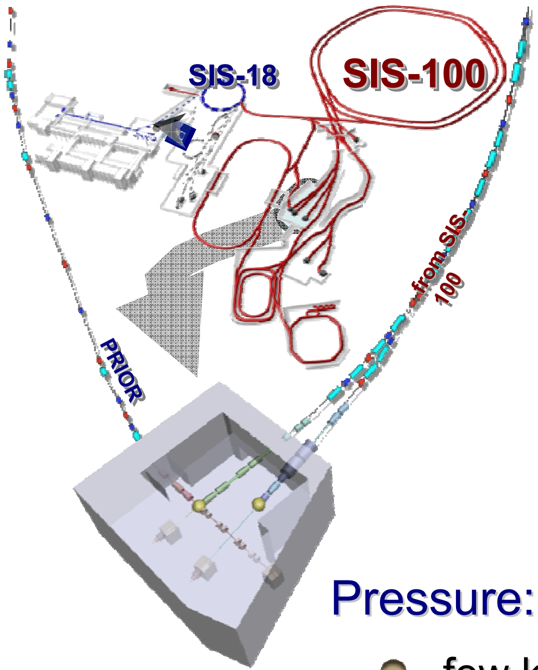




Temperature distribution inside the target

Ion energy behind the target as a function of the target radius for different moments

Challenging requirements for beam and target diagnostics in HED Physics experiments:



Density distribution:

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

Temperature:

- 0.2 – 20 eV
- 10 – 20 µm spatial resolution
- 1 – 5 ns time resolution (continuos)

Fast multi-channel pyrometers

Pressure:

- few kbar – few Mbar
- spatial distribution
- 0.5 – 5 ns time resolution

Line-imaging VISARs and displacement interferometers

Intense focused ion beam:

- intensity distribution in the focal spot
- 10 µm spatial resolution
- 1 – 5 ns time resolution

Residual gas fluorescence, etc.

Spatial resolution scalings with proton energy:

- object scattering

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

- chromatic aberrations

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

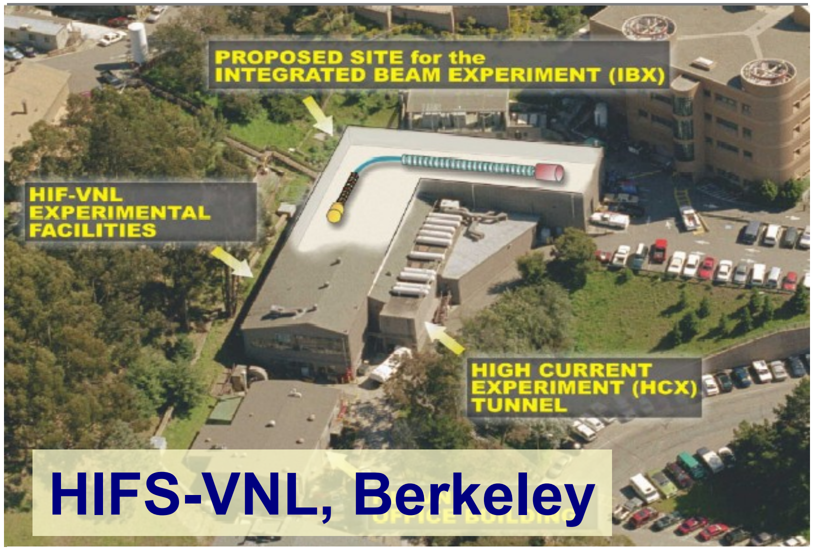
- detector blur

$$\sigma_d \propto \frac{\ell_s \ell_t^{\frac{1}{2}}}{p}$$

PRIOR technical specifications (for FAIR experiments):

- 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: 10 – 15 mm
- stand-off distance: 1 – 1.5 mproton illumination spot size: 3 – 15 mm
- total length after object plane: less than 15 m
- using permanent magnets and existing electromagnets

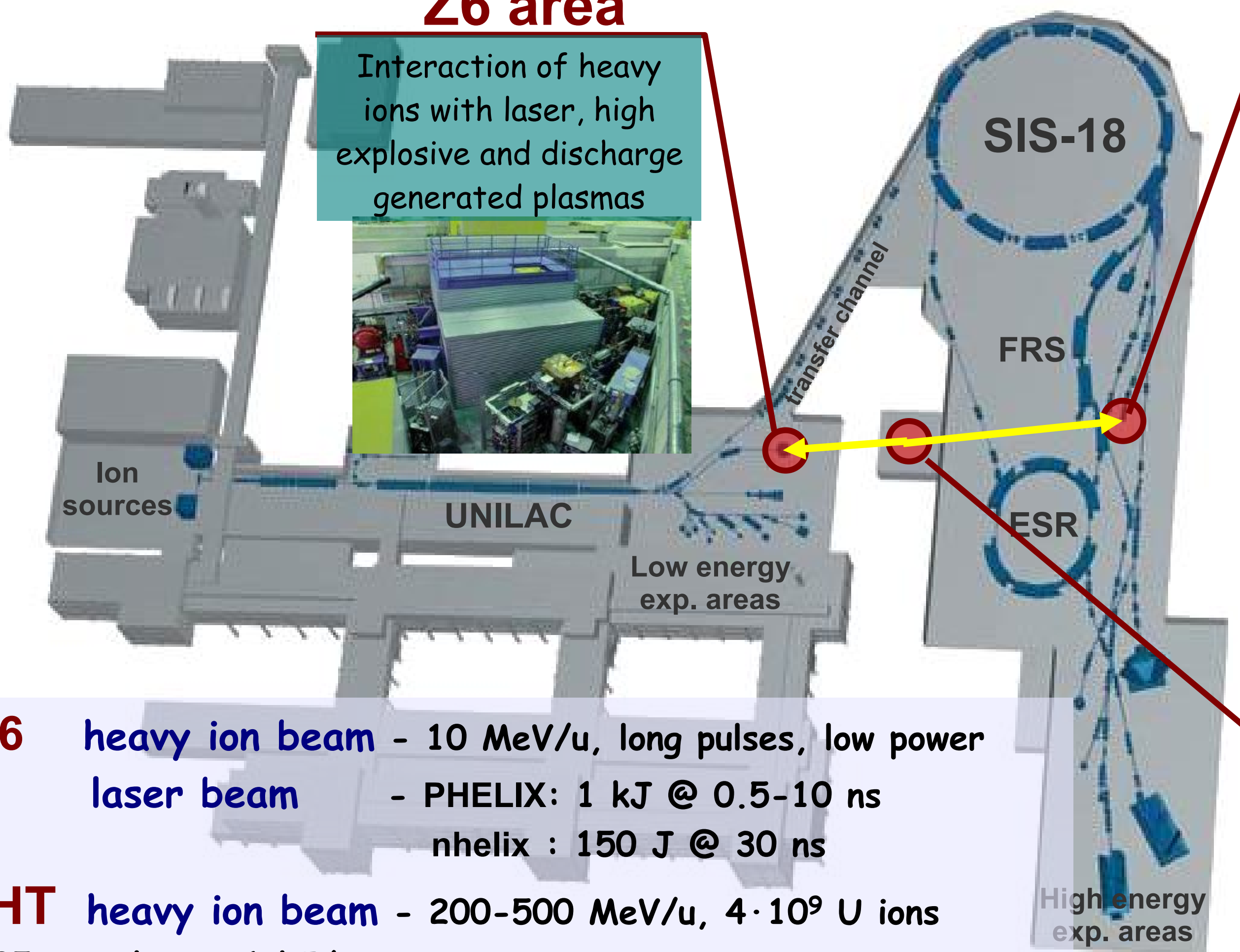
Accelerator centers for IFE related HED research with intense HIB



Present Plasma Physics experimental areas at GSI- Darmstad, Germany

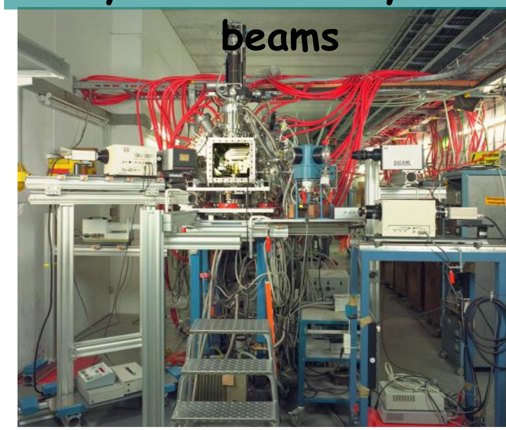
Z6 area

Interaction of heavy ions with laser, high explosive and discharge generated plasmas



HHT area

HED matter generated by intense heavy-ion beams



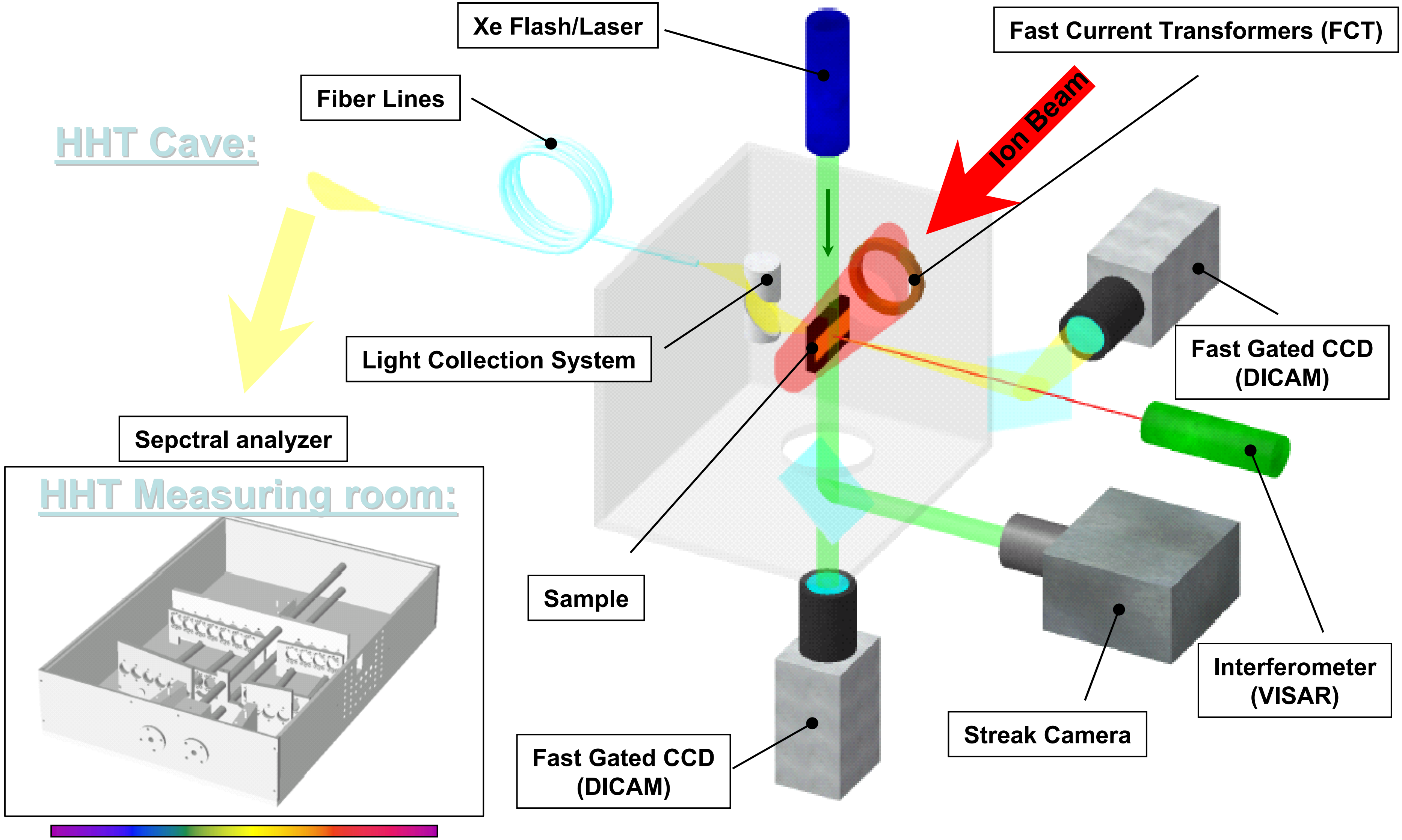
PHELIX

Petawatt High-Energy Laser for Ion-Beam Experiments

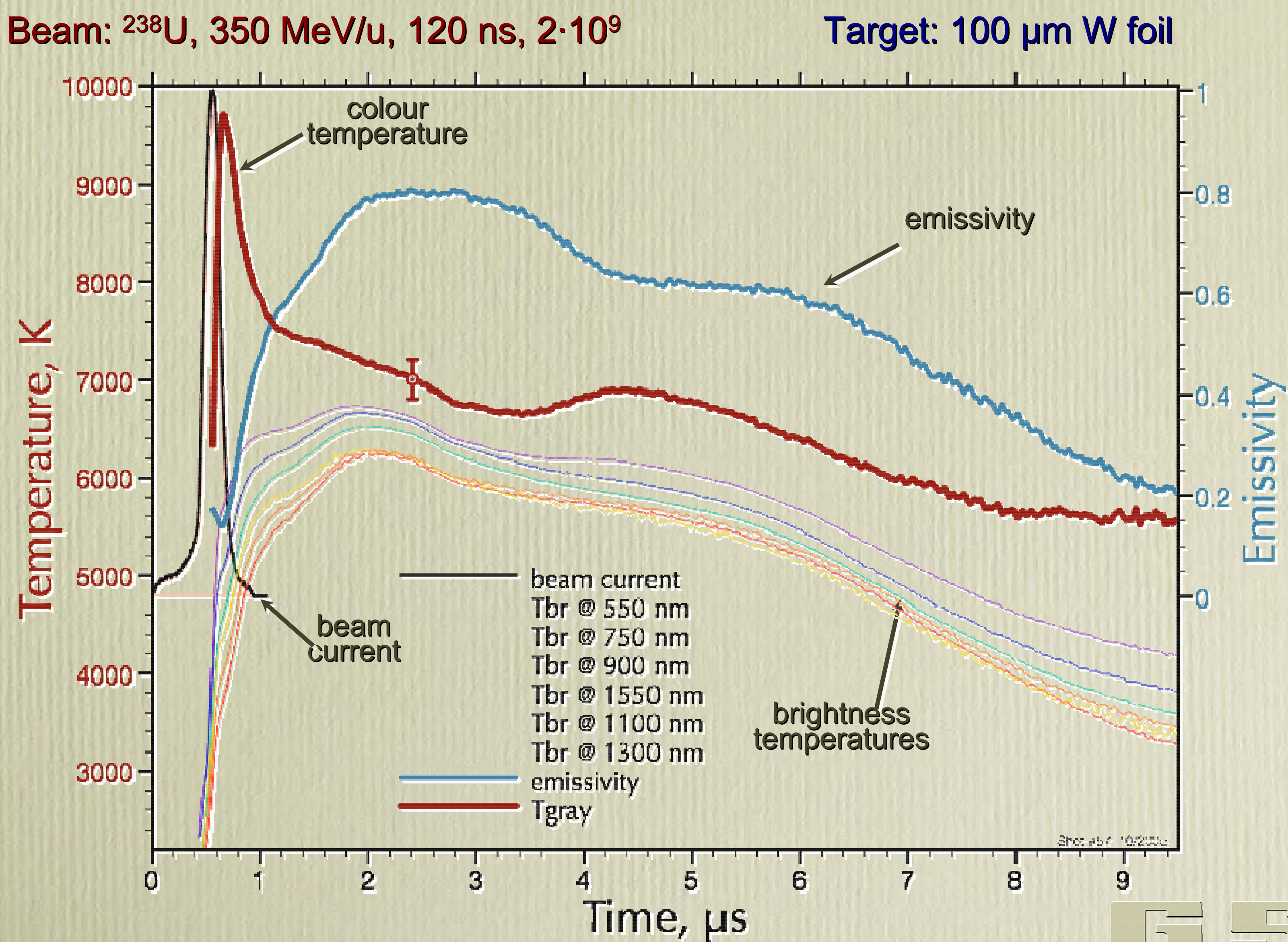
Z6 heavy ion beam - 10 MeV/u, long pulses, low power
laser beam - PHELIX: 1 kJ @ 0.5-10 ns
nhelix : 150 J @ 30 ns

HHT heavy ion beam - 200-500 MeV/u, $4 \cdot 10^9$ U ions in 125 ns pulse, ~ 1 kJ/g
laser beam - PHELIX: 0.5 kJ @ 0.5 ps (PW)
1-5 kJ @ 10 ns

HHT Experimental Setup

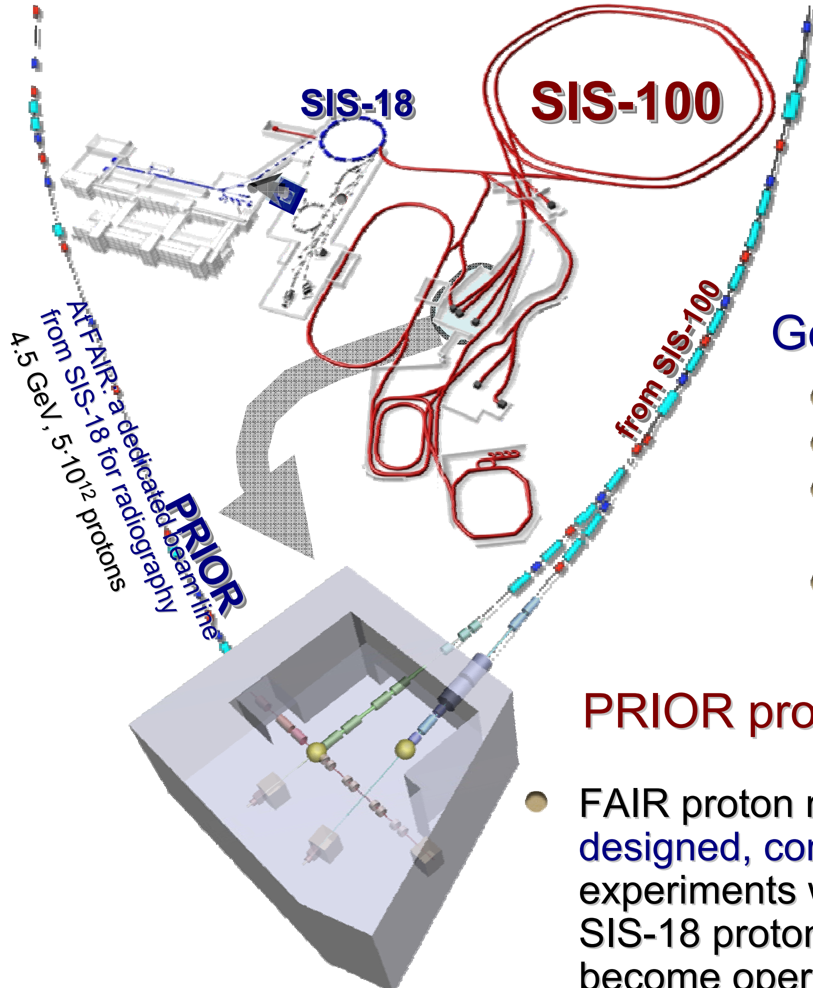


Temperature measurements in WDM experiments: tungsten foil heated up to 10,000 K and expanding



PRIOR – Proton Radiography at FAIR with 4.5 GeV proton beam

Collaboration GSI - LANL – ITEP (Moscow)



- 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:

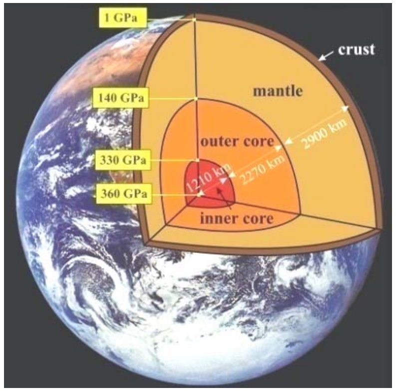
- large penetrating depth (high ρx)
- good detection efficiency (S/N)
- imaging, aberrations correction by magnetshigh spatial resolution (microscopy)
- high density resolution and dynamic rangemulti-frame capability for fast dynamic events

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 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

BIOMAT Full Program at SIS 100 - Module 1

Materials research



- **Exposure of matter to relativistic ions and high pressure:** **phase transitions in mineralogy and geophysics**
- **Ion-matter interaction at FAIR Energies:** **energy-deposition and short-time processes at relativistic projectile velocities**
- **Radiation hardness of materials:** **requirements for accelerator and spacecraft-components**

Biophysics

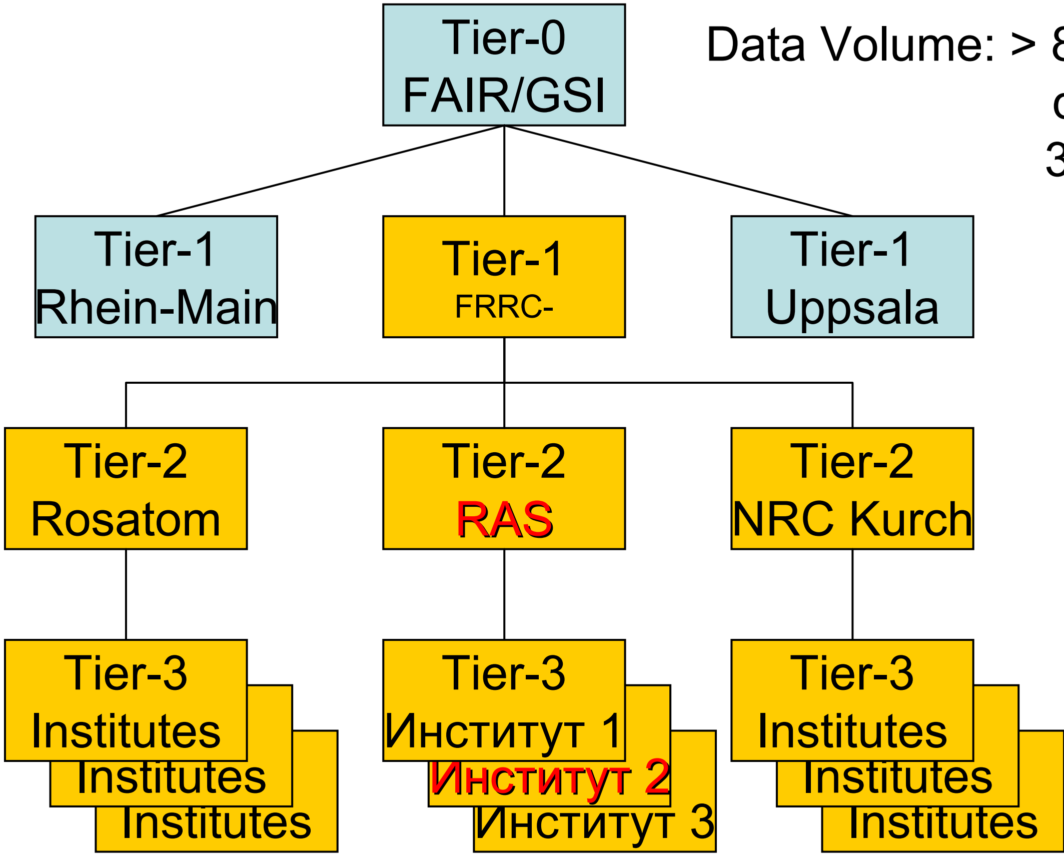
- **Cosmic radiation:** **the main hindrance toward manned space exploration**
- **Widely unknown biological effects of heavy ions**
- **A large experimental campaign in space radiation biophysic was started**

General MoU with CERN

signed on 18 November 2010

Rolf Heuer *Boris Sharkov*

FAIR Computing



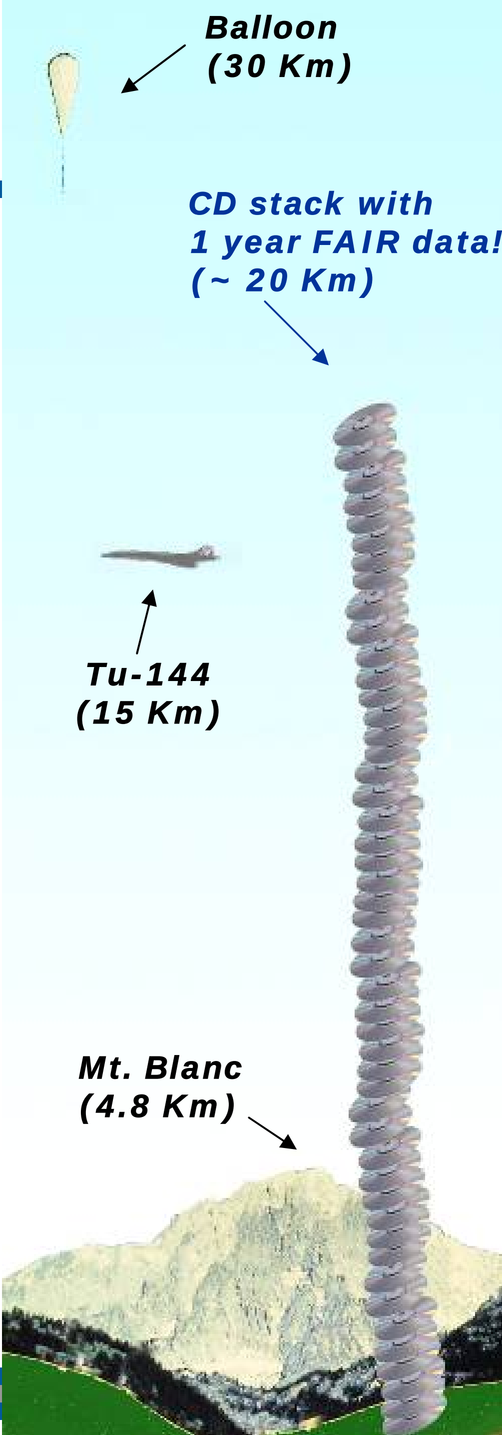
Data Volume: > 80 TB/day
dc load
330days/year

National/
transnational

Regional

Local

Tier-1 & Tier-2 совместно с БАК (LHC GRID)



Summary

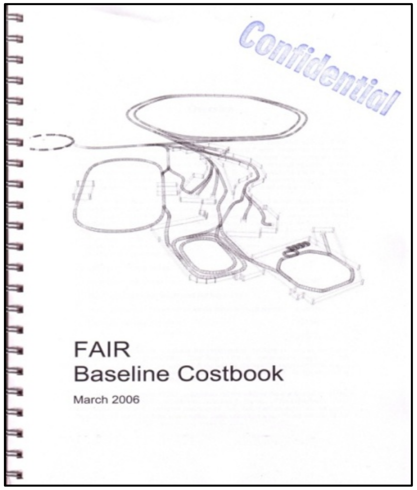
Construction Period, Cost, Users

- Construction until 2018
- Total cost 1.027 B€ (2005 prices)
- Scientific users: 2500 - 3000 per year

Financing

- up to 65 % Federal Government of Germany
- 10 % State of Hessen
- 25 % Partner Countries

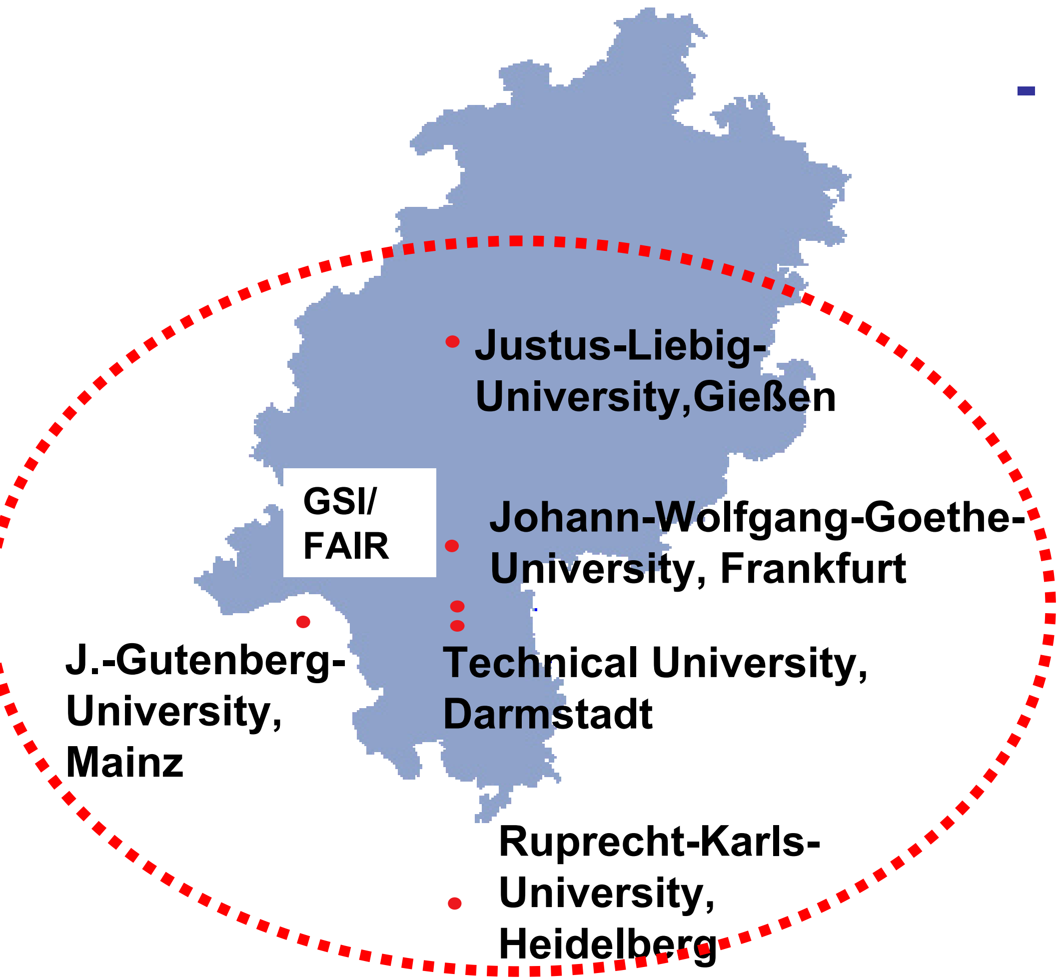
⇨ **FAIR GmbH with International Shareholders**



Operation cost will be negotiated in 3 years after FAIR GmbH will be established

FAIR

Concept of GSI / FAIR – Associated Universities



- with 'founding univ.' DA, F, GI, HD, and Mz ...

- Joint research & development projects related to GSI / FAIR
- Joint initiatives for graduate education at the universities

Expansion of this concept to further universities envisaged!

HIC4FAIR, HGS FAIR, EMMI ….

FAIR – Russia Research Center @ ITEP-Moscow

Strategic goal:

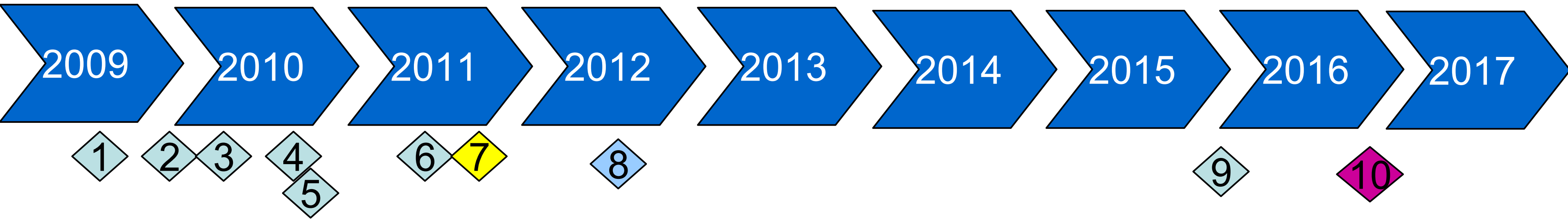
- Technical support of the Russian FAIR research activities and work packages
- Communication and cross-fertilization between the different Russian FAIR research communities
- Support for FAIR- related projects of masters, PhD students and post-docs in various fields of FAIR related fundamental and applied sciences

Seminar of FRRC Fellows 2009

Main results:

- **15 workshops, technical meetings and seminars on FAIR related issues**
- **23 in 2009 and 30 Fellows in 2010 representing 10 Russian Institutes and Universities and all FAIR collaborations**
- **2 regular lecture curses**
- **Basic analysis for White paper of Russian participation in FAIR project**

Road Map FAIR Site & Buildings



1. Handing in of preplanning documents to hbm
2. Clarification of user requirements Modularized Start Version (MSV)
3. Start revised preplanning for MSV
4. Expected approval of revised planning for MSV
5. Preparation of documents for building permit
6. Expected approval for (partial) building permit
7. Start site preparation (clearing trees)
8. Award contracts on civil construction work lot 1 … 4
9. Completion of civil construction work lot 1 … 4
10. Start installation of accelerators and detectors

Cost Estimate Modules 0-3 (Price Basis 2005)

Total accelerator and personnel Modules 0 - 3	**502**
Total civil construction Modules 0 - 3	**400**
Experiment funding	**78**
FAIR GmbH personnel and running costs	**47**
Grand Total Modules 0 - 3	**1027**

all values in M€

Firm Commitments for the FAIR Project

Contracting Party	Contribution [M€]
Finland	5.00
French Republic	27.00
Federal Republic of Germany	705.00
Republic of India	36.00
Republic of Poland	23.74
Romania	11.87
Russian Federation	178.05
Republic of Slovenia	12.00
Kingdom of Sweden	10.00
Total	**1.008,66**

Spain expected to join soon (11.87 M€)

China and UK want to contribute to experiments (6.6 M€)

Project costs (1027 M€)

Росатом(Rosatom)

РАН(RAS)

Научно-координационный Совет

Н/Т секретариат

Центр Исследований Экстремальных Энергетических Процессов Росатом –РАН

ВНИИЭВ

ВНИИТФ

ФЭИ

ИТЭФ

ИХПФ РАН

ИТЭС РАН

ТРИНИТИ

Raising New Funds

- New international Partners
  - Saudi Arabia
  - Brasilia
  - Turkey
  - Hungary
  - Norway . . .
- Increasing contributions to FAIR
  - China
  - Spain
  - India
  - Italy . . .
- EU Programme + National funding organizations…
- Costs optimisation, raising efficiency
  - Accelerator , CC , Experiments
    → implementation of MAC recommendations

Summary

1. An intense heavy ion beam is a very efficient tool to induce HED states in matter; large sample size, week gradients, long life times.

2. Construction of the FAIR facility at Darmstadt will enable to carry out novel and unique experiments in the filed of HED.

3. Theoretical studies (simulations + analytic modeling) has shown that an intense heavy ion beam can be employed using very different schemes to study HED physics.
   Work is in progress to investigate more experiment designs.

4. Currenet experiments are well in progress aiming at development of new experimental techniques required for FAIR experimental campaign.

5. FAIR is open for wide international collaborations on HED and HI IFE – Darmstadt – a crossroads of international activities.

(associated partnership possible)

International Workshop
“Shock wave data base: International Project”

FAIR / GSI *Darmstadt, Oct. 31- Nov.2 , 2011*

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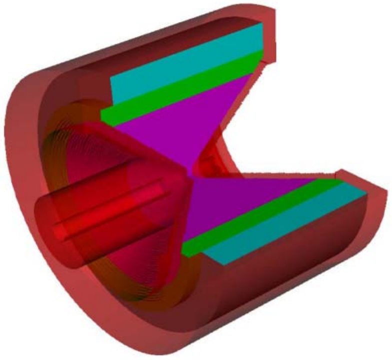

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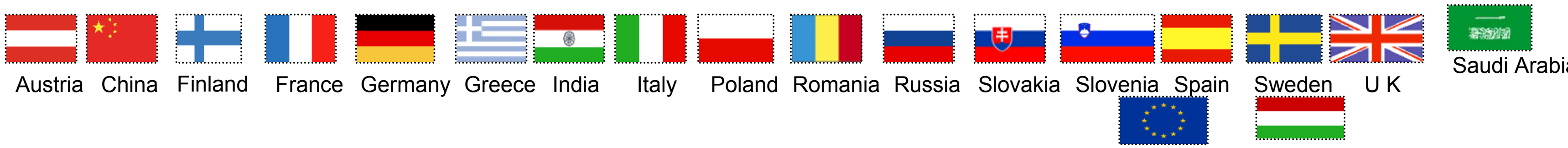

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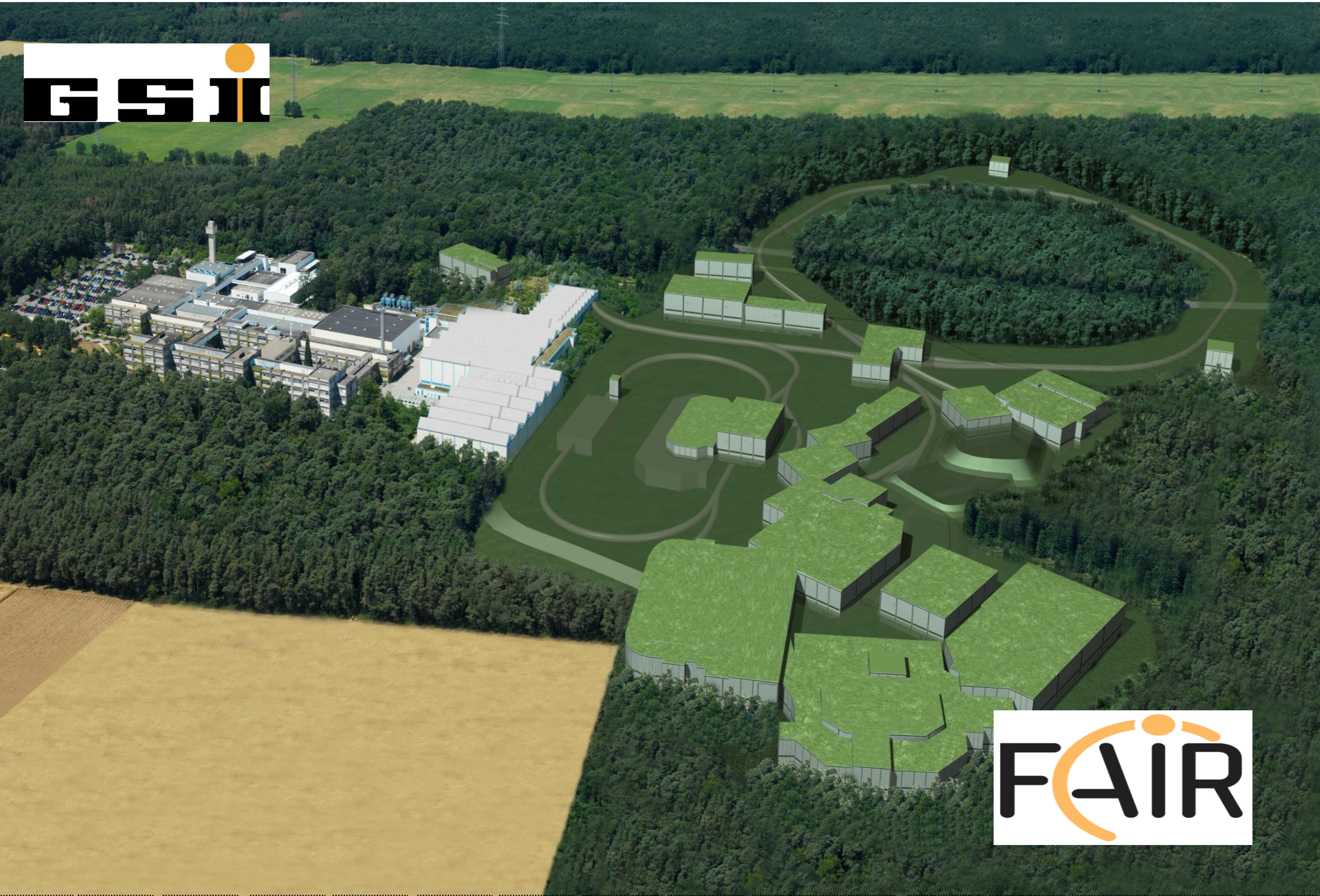

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