Overview of Warm-Dense-Matter experiments at GSI-Darmstad

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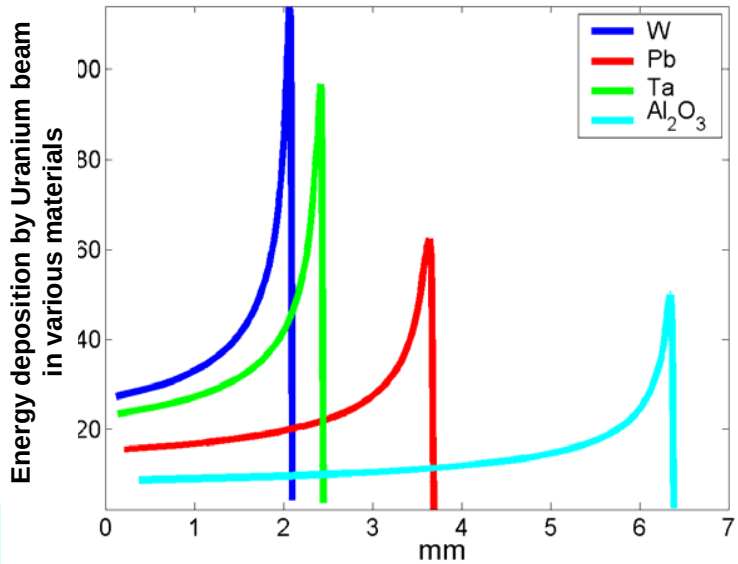
Physics motivation: fundamental properties of matter in WDM regime

Warm **D**ense **M**atter: **T** ~ 2,000 – 200,000 K, ρ ~ solid density, **P** ~ kbar, Mbar

Intense heavy ion beam is an excellent tool to genera large-volume WDM samples:

- large volume of sample (mm^3)
- fairly uniform physical conditions
- high entropy @ high densities
- high rep. rate and reproducibility
- any target material (incl. mineral, liquids oxides, etc.)



Give possibilities to studies of:

Equation-of-state of HED mater
basic thermodynamic properties of matter in unexplored regions of the phase diagram (two-phase regions, critical points, non-ideal plasmas)

Phase transitions and exotic states of matter
metal-to-insulator or plasma phase transition, hydrogen metallization problem, etc.

Transport and radiation properties of HED matter
electrical and thermal conductivity, opacity, etc.

Stopping properties of non-ideal plasma
anomalous temperature and density dependence heavy ion stopping and charge-exchange cross sections

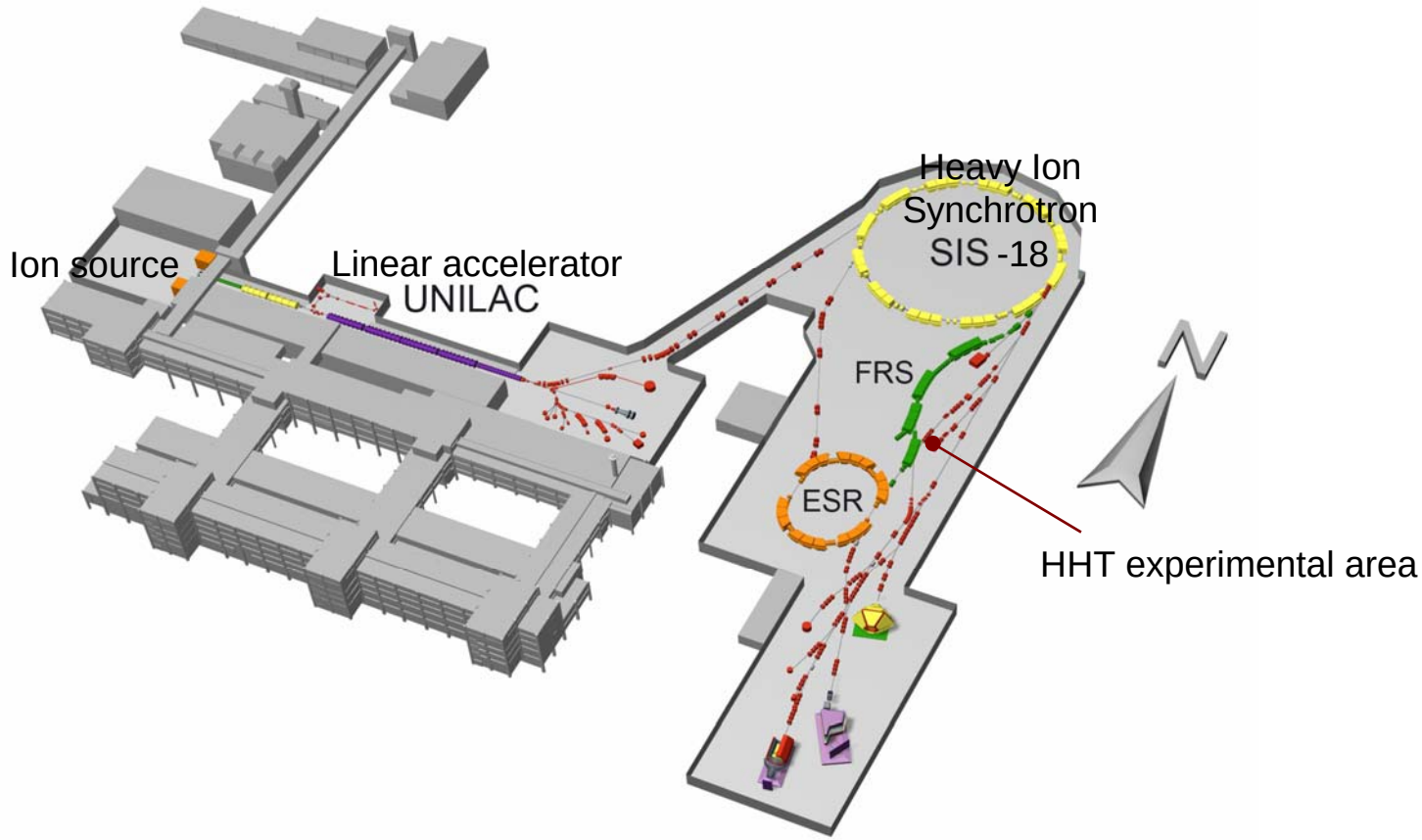
Experimental area at GSI


GSI, Darmstadt, Hessen, Germany


HHT control room


HHT cave

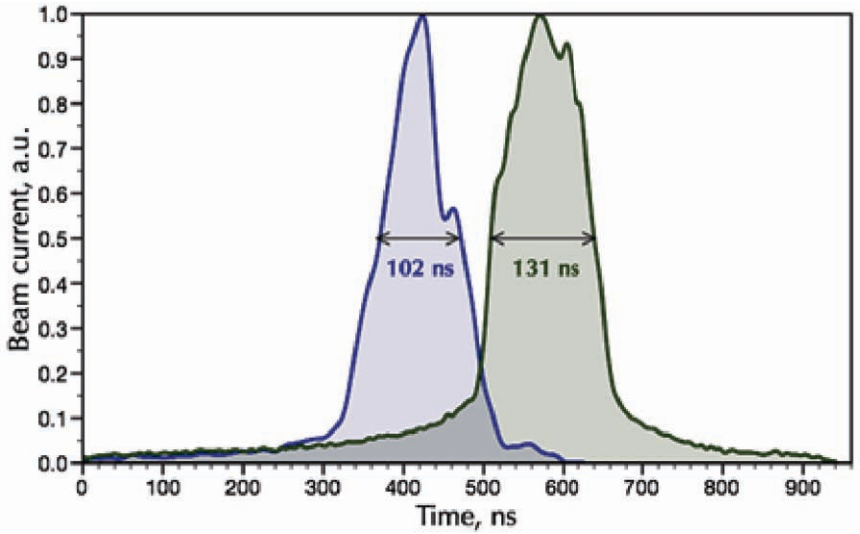

HHT beam line



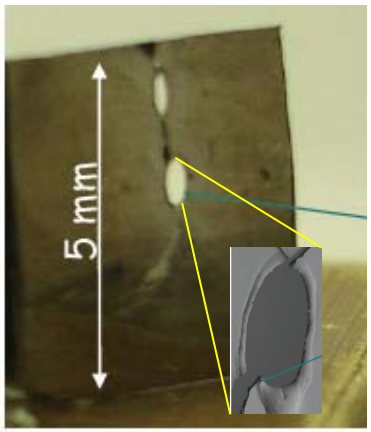
Heating beam parameters

Heavy Ion Beam used for WDM experiments at GSI:

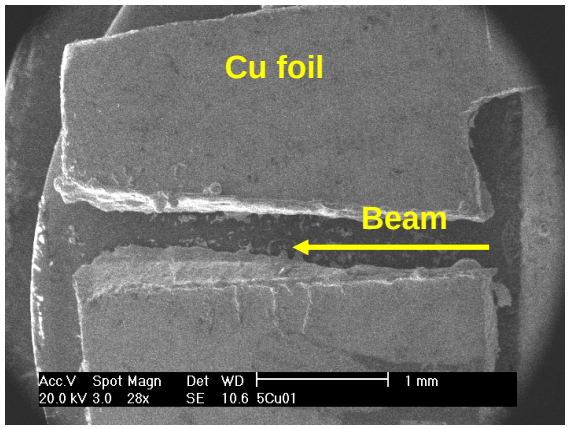
- ☑ Beam: Uranium (+74) e-cooled, compressed
- ☑ Intensity: (1 - 4.2)x10^9
- ☑ Energy: 350 MeV/nucleon
- ☑ Focal spot (ellepcitcal shape): 0.150 mm - 1.5 mm
- ☑ Duration (FWHM): 120 ns - 1000 ns



Hole punched in tungsten:



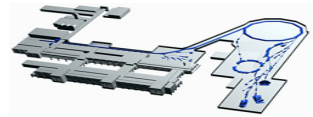
Copper foil after beam irradiation:



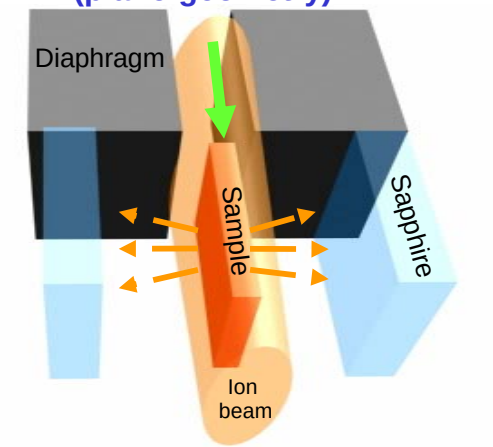
Allow generation of WDM samples:

- •temperatures up to 2 eV (above 16000 K)
- •kbar pressure range
- •@ solid state density

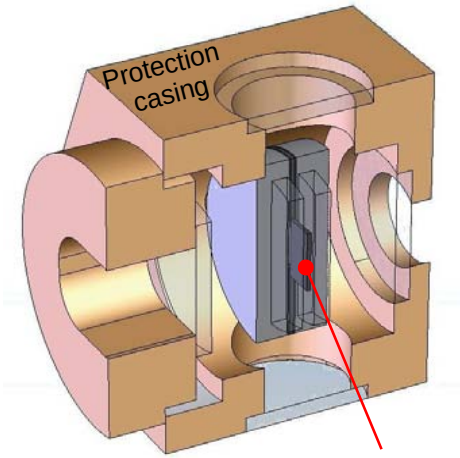
Target design



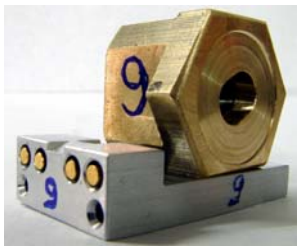
Target concept (plane-geometry) :

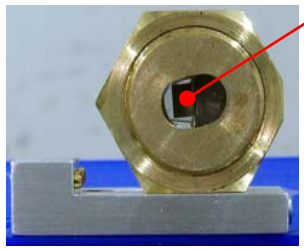


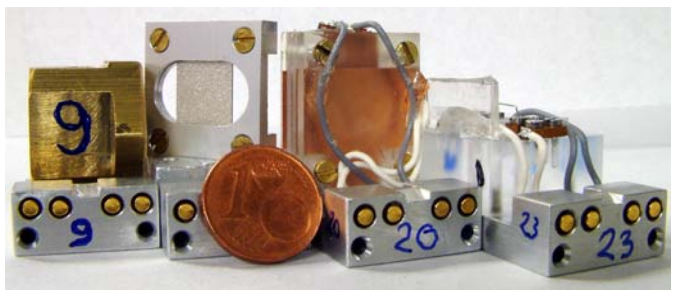
Target design:



Target Implementation:





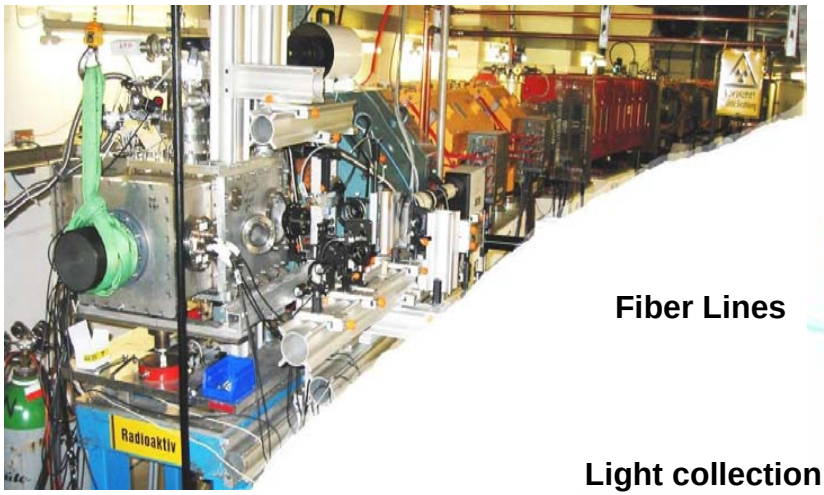


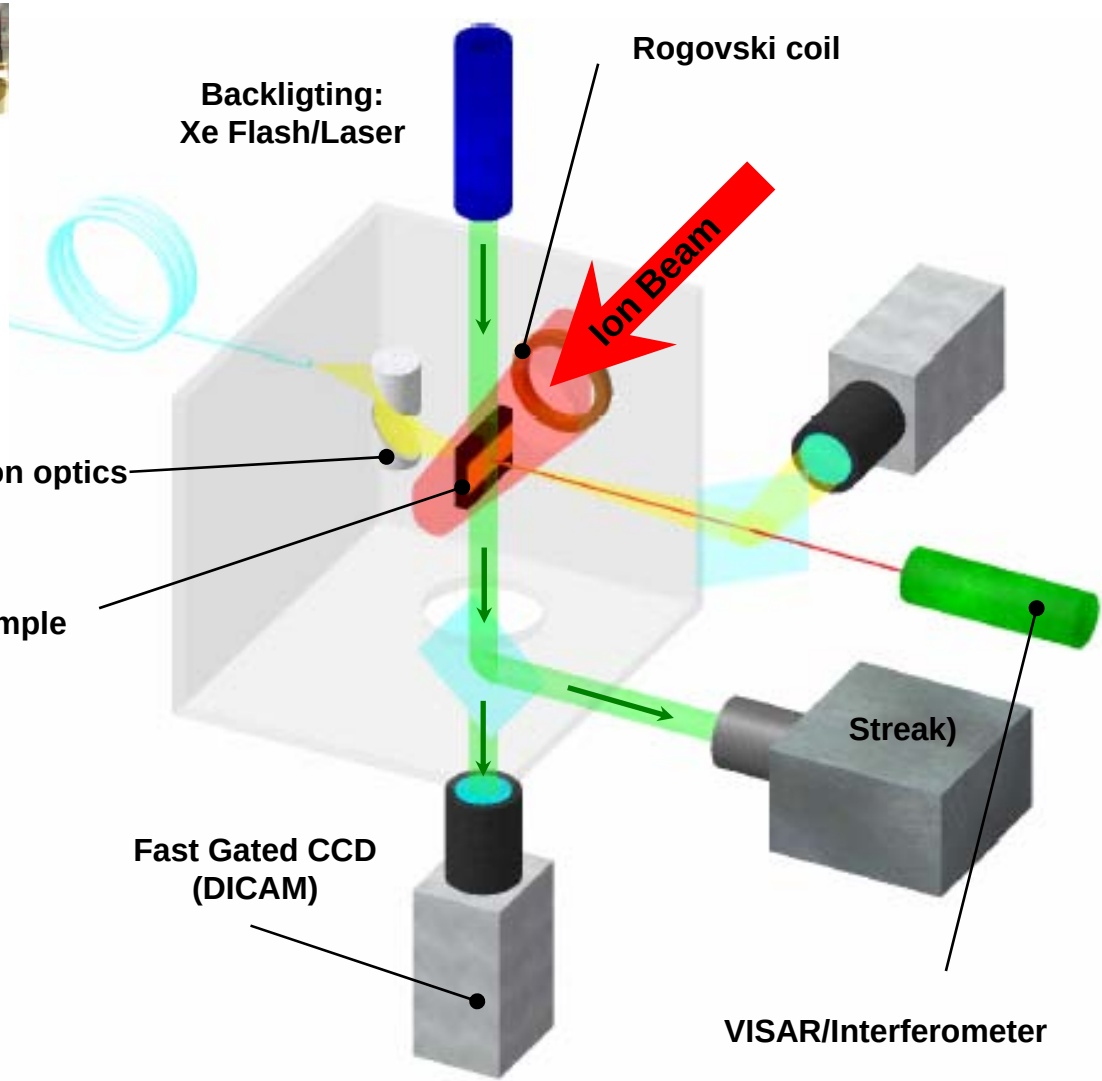
Target postioning (in vacuum) with micrometer precision:

Sample foils:

- 0.05 - 0.25 mm thick
- Pb, Fe, Sn, W, Ta, Cu, UO_2, Al, Al_2O_3
- Porous Au and Cu (LBNL)

Schematic layout of WDM experiments at GSI



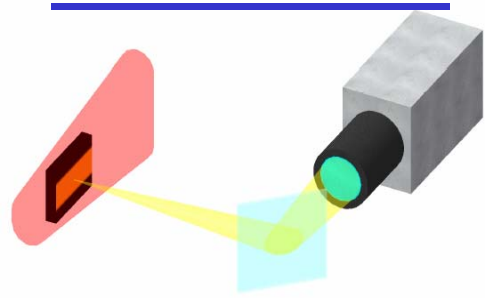


Diagnostic used:

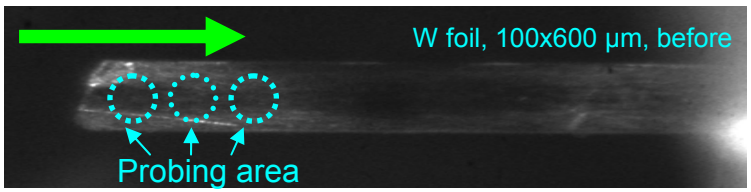
- ☑ Multi-channel pyrometer
- ☑ Gated CCDs
- ☑ Streak cameras
- ☑ VISAR
- ☑ Michelson Interferometer
- ☑ Rogovski coil
- ☑ Backlighting/shadography
- ☑ Electrical conductivity
- ☑ Schlieren imaging
- ☑ Capacitive pick up

Camera diagnostics

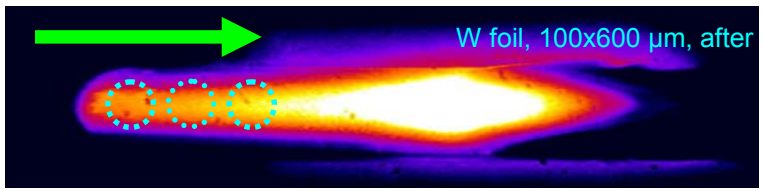
Side camera:



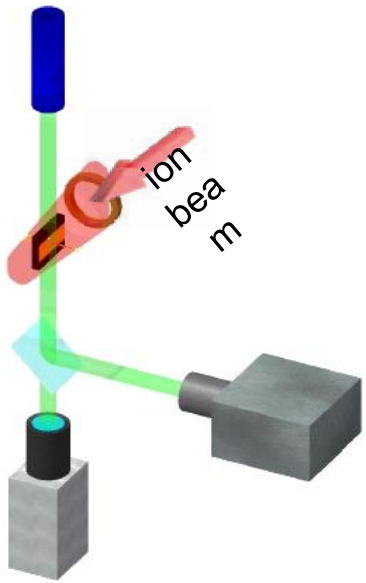
Precise beam-target positioning:

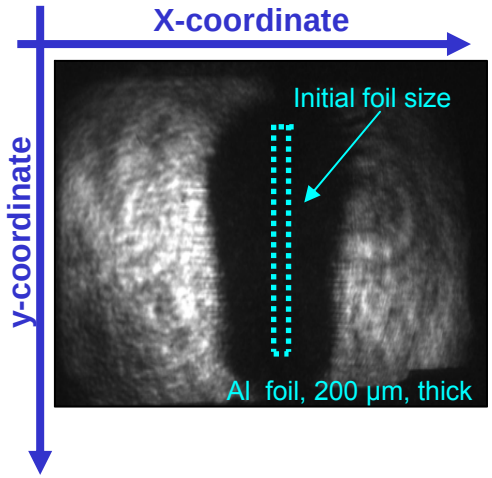


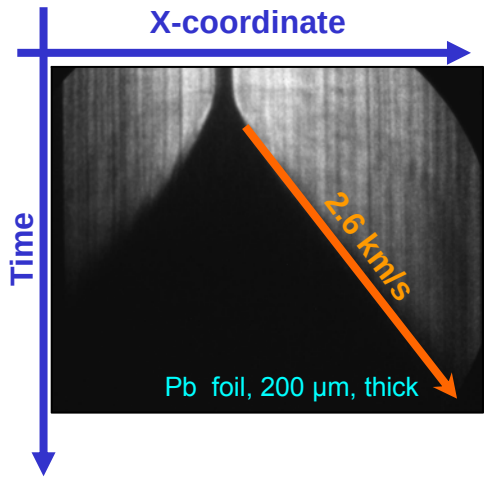
Images of self emission:



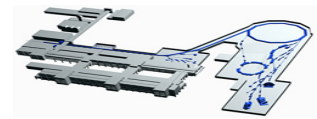
Vertical cameras:



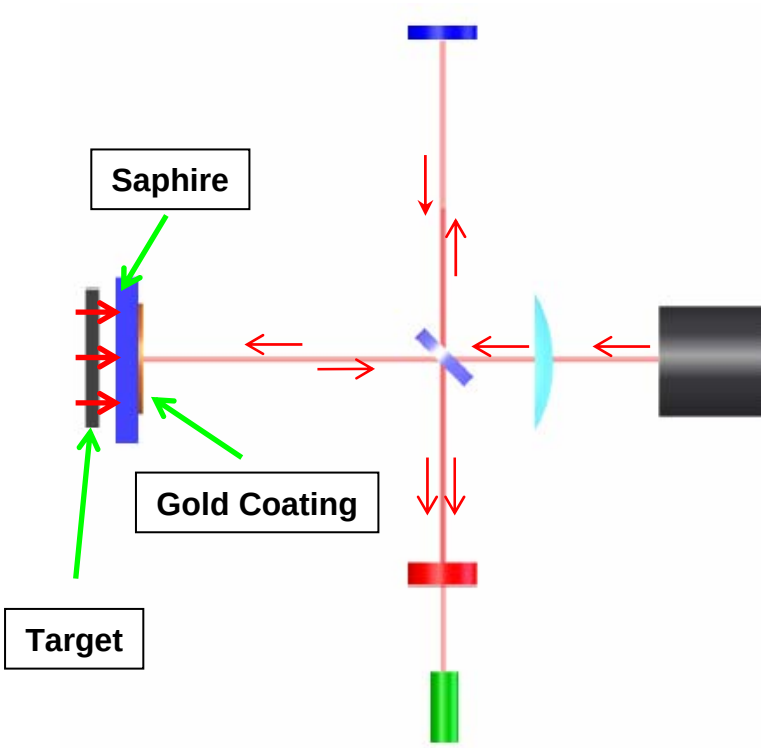




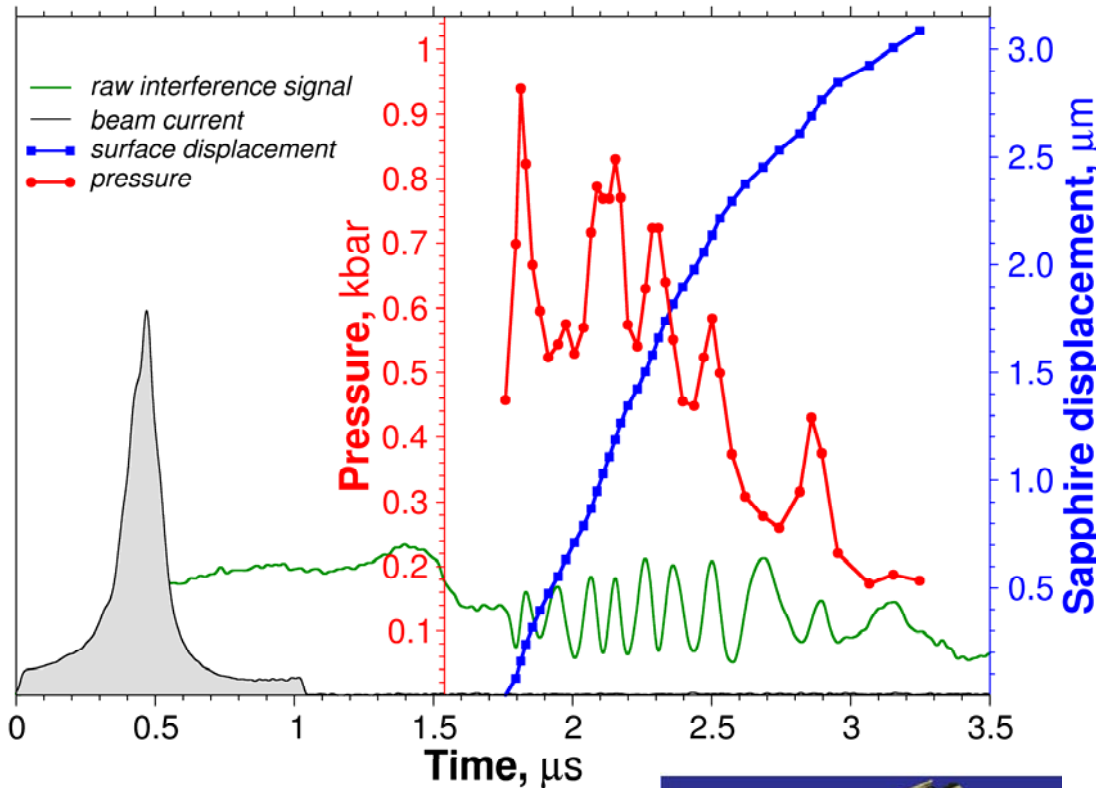
Michelson displacement interferometer



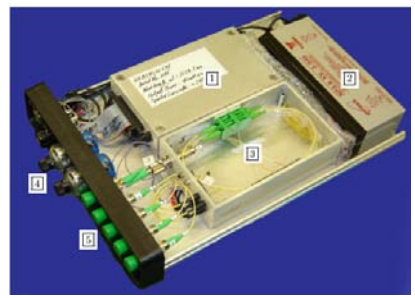
Michelson displacement interferometer



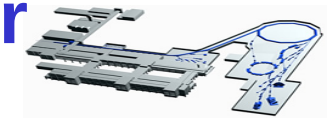
Shot 20(lead)



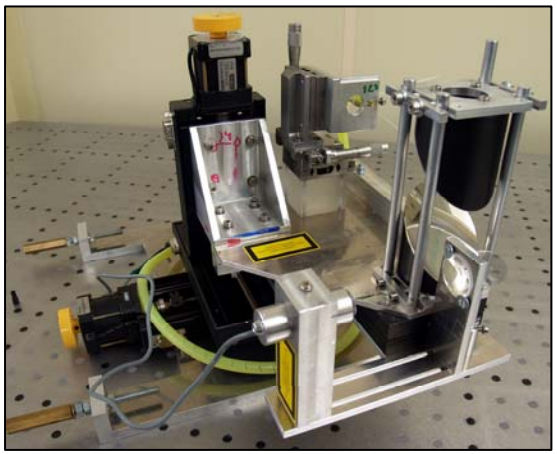
-All-fiber laser-Doppler interferometer (VISAR) is being incorporated



Fast multi-channel optical pyrometer

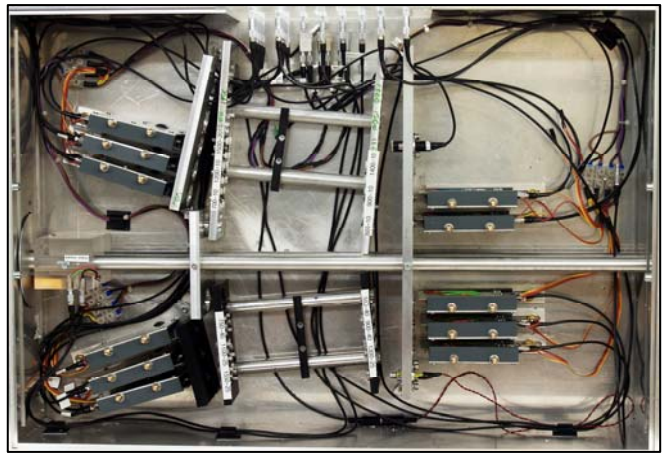


Ligh collection optics:



- high efficiency: f/2
- 1:1 imaging
- no chromatic aberrations
- high resolution (20-400 mm)
- motorized 0.01 mm

Spectral analyzer:

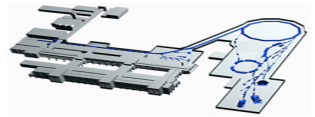


- Flexible/ modular design
- Interference filters as filters and mirrors
- 12 channels (550- 1550 nm)
- 5 ns temporal resolution
- Absolutely calibrated
- High efficiency, T ≤ 1000 K is detectable
- High dynamic range (from 1000 K up 6000 K)
- Gray and linear models of emissivity

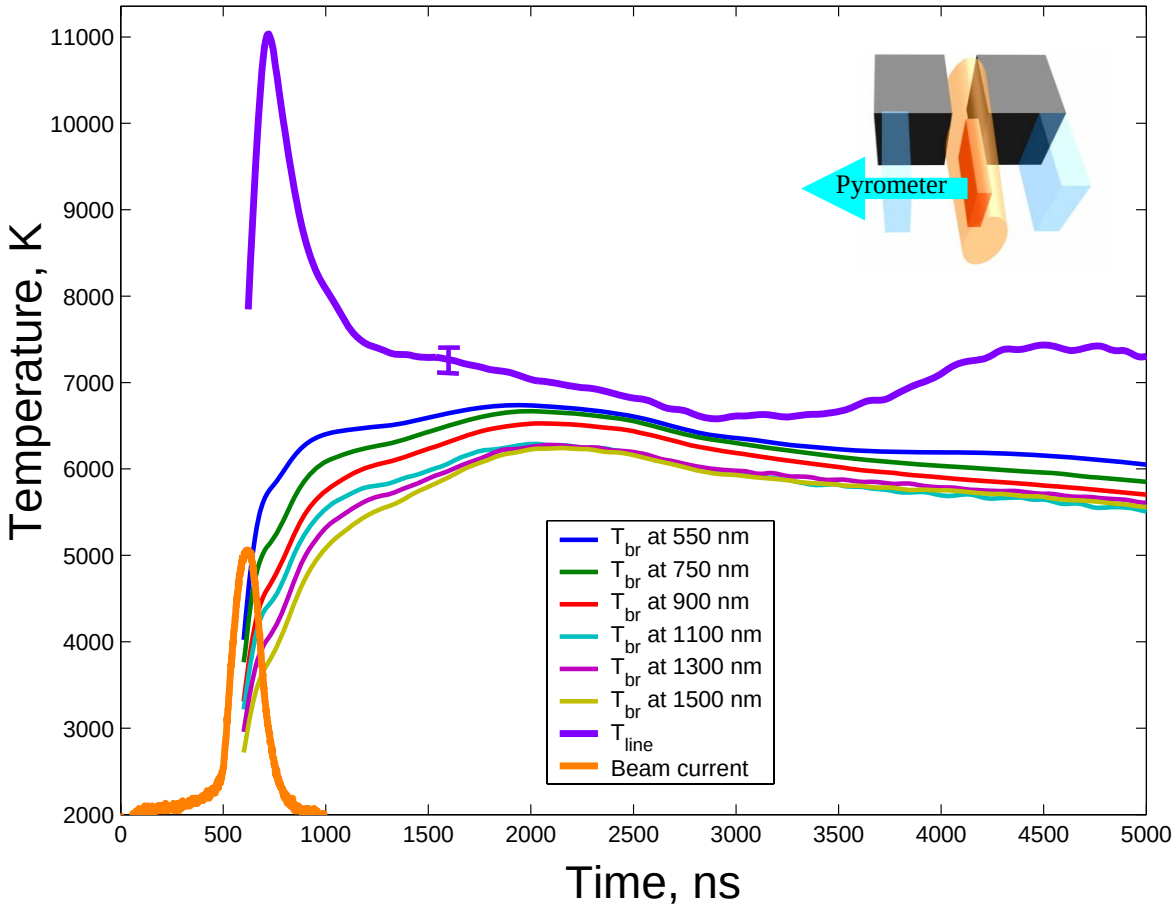
Data acquisition:

- 24 channels,
- 8 bit, 1 GHz bandwidth
- Controlled by LabView

Temperature measurement of tungsten foil

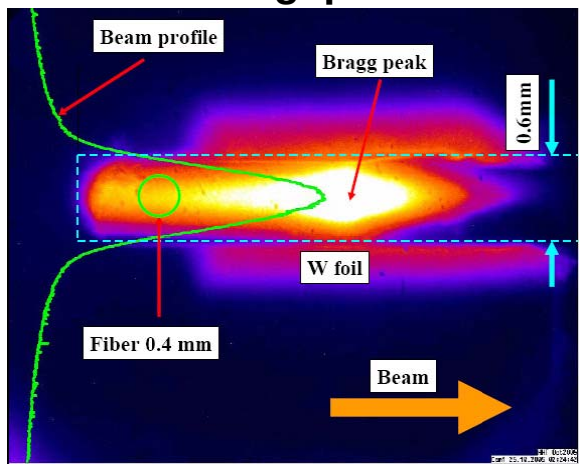


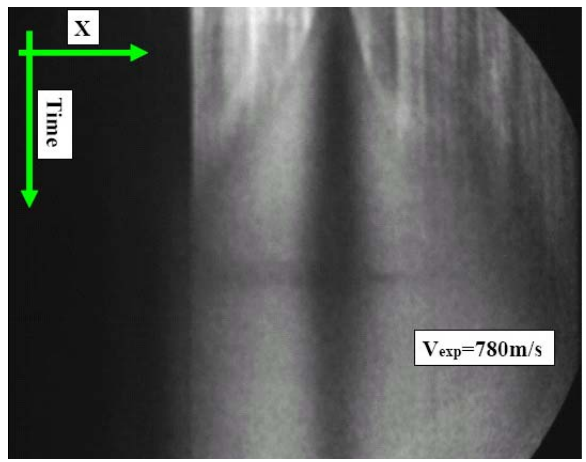
T_{melt}=3700 K,
T_{boil}=5800 K



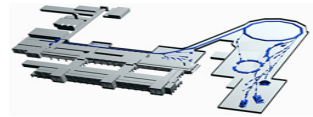
Beam: ^{238}U, 350 AMeV, 120 ns, 2·10^9

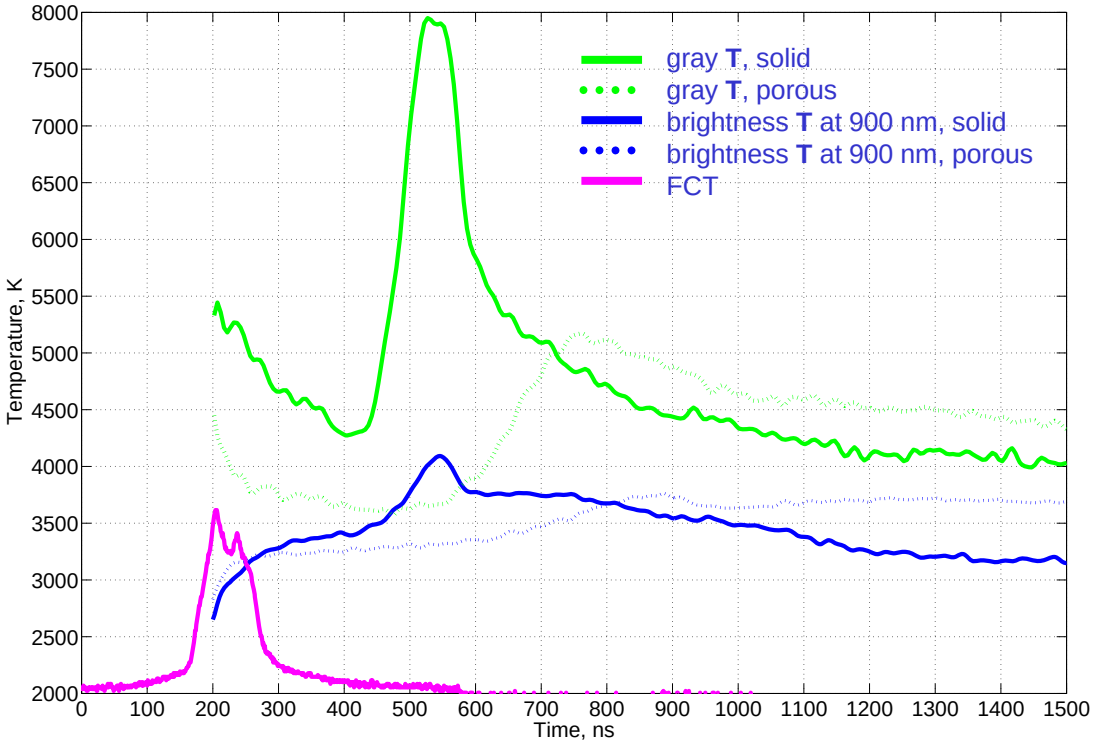
Target: W foil, 100 µm thickness, 3 mm gap



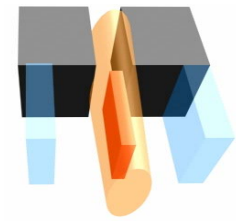


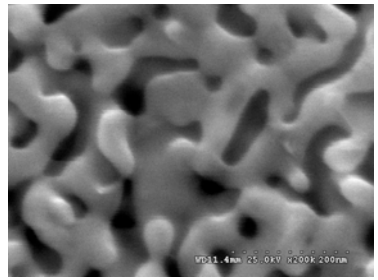
Joint GSI-LBNL experiments



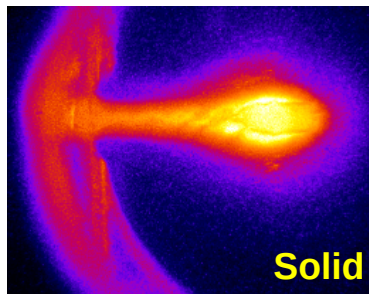


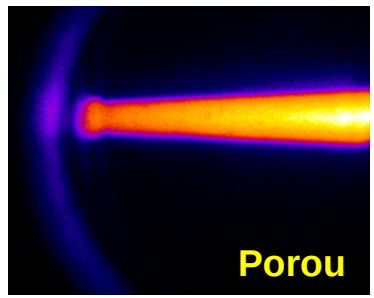
Porous gold target, 35% solid density 50-nm pore size:



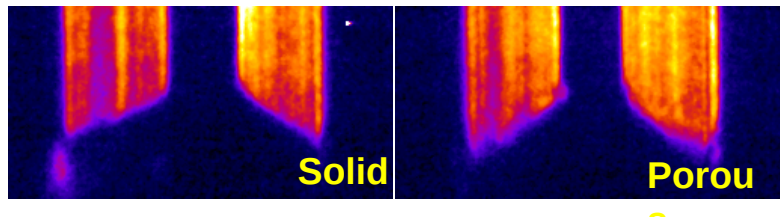


CCD cameras:

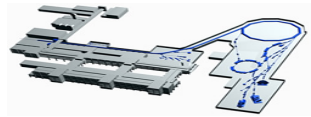




Streak (v=1.4 km/sec):



Summary



-Commissioned recently developed diagnostic instruments, methods and testing of different beam-target configurations for studies of thermo-physical of WDM

-It was shown that using intense heavy ion beam that is presently available at GSI and employing the HIHEX beam-target design concept, it is possible to investigate basic thermodynamic and transport propertiesb of HED metal states near boiling curve, in the two-phase liquid-gas region and near the critical point