HED@FAIR collaboration: Overview of the current experimental activities and upcoming projects with laser and particle beams at GSI.

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on behalf of HED@FAIR collaboration

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Plasma Physics Group, IAP, GU-Frankfurt
New international research laboratory to explore the nature and evolution of matter in the Universe

High energy density matter generated with heavy ion beams

**Heavy Ion Heating and Expansion**
- Uniform quasi-isochoric heating, isentropic expansion
- EOS and transport properties
- $T = 1-10$ eV; solid density

**HIHEX**
- $U^{28+}$, 2 GeV/u, $5 \times 10^{11}$/bunch

**LAPLAS**
- Mbar, low temperatures
- Metallic hydrogen, interior of planets
- $U^{28+}$, 1 GeV/u, $5 \times 10^{11}$/bunch

**PRIOR**
- Proton Microscope for FAIR
- Diagnose high-density samples
- (Shock physics, biophysics (PaNTERA), etc.)

- Protons, 5-10 GeV, $2.5 \times 10^{13}$/bunch
• **Phase-0 (2019-2025?)**
  – FAIR experiments using beams from upgraded SIS18 and CRYRING, complemented by external experiments with FAIR equipment.
  – **beam-time : total 3 months/year**

• **Phase-1** (experiments with first SIS100 parameters >2025)
  – FAIR experimental programme with SIS100 and secondary beams for early exploitation with Start Setups before full MSV operation (first two to three years of operation).

• **Phase-2** ( >20....?)
  – FAIR experimental programme at the full potential of the MSV.

• **Phase-3**
  – Beyond Modula Start Version operation.
Theta-pinching coil changed from spherical to cylindrical

Cylindrical coil:
increased magnetic field homogenity due to spiral cylindrical coil
enhanced stripping effect expected (higher plasma temperature and density)

**Problem:** low transmission

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**Table:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_{\text{coil}}$:</td>
<td>4.7 $\mu$H</td>
</tr>
<tr>
<td>Volume:</td>
<td>about 12000 ml</td>
</tr>
<tr>
<td>Capacity:</td>
<td>60 $\mu$F</td>
</tr>
<tr>
<td>Current:</td>
<td>up to 100 kA</td>
</tr>
<tr>
<td>Voltage:</td>
<td>up to 30 kV</td>
</tr>
<tr>
<td>Magnetic Density:</td>
<td>about 2 T</td>
</tr>
<tr>
<td>Gas:</td>
<td>$H_2$</td>
</tr>
<tr>
<td>Pressure:</td>
<td>20 Pa up to 120 Pa</td>
</tr>
<tr>
<td>Transfered Energy:</td>
<td>up to 30 kJ</td>
</tr>
<tr>
<td>Expected $n_e$:</td>
<td>up to $5 \times 10^{17}$ cm$^{-3}$</td>
</tr>
<tr>
<td>Target density:</td>
<td>over 30 $\mu$g/cm$^{-2}$</td>
</tr>
</tbody>
</table>
Charge state distribution of a 3.6MeV/u Au$^{26+}$ Ion beam after crossing a hydrogen plasma in comparison to a cold gas.

**Ion:** Au$^{26+}$  
**Energy:** 3.6 MeV/u  
**Contact:** K. Cistakov

Image with charge distribution of ion beam after passing the plasma stripper device (on scintillator with an ICCD camera). Up with a beam transmission through cold gas, down through the plasma pinch.
**X-Ray Conversion to Optical Radiation and Transport**

**XCOT**: 2D x-ray poly/monochromatic imaging of the ion beam-target interaction region, conversion into optical light and transport to the detector over long distance.

1. Spatial resolution – better than 100 \(\mu\text{m}\), imaging with magnification, high resolution optical camera
2. Effective conversion of the x-ray signal into optical one, keeping SR CsI:Tl 100\(\mu\text{m}\) thin scintillator
3. Signal transport over large distances to the optical camera, optical fibers or lengths
4. Signal amplification will allow for short exposition times at SIS18, MCP (up to 10\(^6\))

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O. Rosmej et al. in collaboration with ITEP, FSU-Jena
Monochromatographic X-ray image of the copper grid with Si 444 crystal

two toroidally bent crystals for monochromatic imaging of Cu Kα and Au L shell emission at 13.5 keV

<table>
<thead>
<tr>
<th>Photon energy / keV</th>
<th>Crystal reflection</th>
<th>Bragg angle</th>
<th>Horizontal radius</th>
<th>Vertical radius</th>
<th>Magnification factor</th>
<th>Distance source-crystal</th>
<th>Distance crystal-detector</th>
<th>Spectral window Δλ/λ</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.028</td>
<td>Si 444</td>
<td>80,09469</td>
<td>200</td>
<td>193</td>
<td>6</td>
<td>114,9</td>
<td>689,5</td>
<td>0,00748</td>
<td>2,2E-5</td>
</tr>
<tr>
<td>13.53</td>
<td>GaAs 12 0 0</td>
<td>76,33078</td>
<td>200</td>
<td>189,6</td>
<td>6</td>
<td>113,4</td>
<td>680,2</td>
<td>0,01042</td>
<td>8,1E-7</td>
</tr>
</tbody>
</table>

M 4:1

150er mesh, 100min exposures under action of Au-beam spatial resolution:
Vertical bars: 20 μm
Horizontal bars: 30 μm

M 4:1

400er mesh (bars 8 μm), 70 min exposures

Cu Ka 8 KeV

30° viewing angle
Polychromatic X-ray image of the copper grid with XCOT-system

**Experiment 2019, GSI UNILAC**

**Experiment**

**Simulation**

4 Folded X-ray images

Difference in spatial resolution:
- blurring effects in a real detector (CsI).
- vibration of target during the accumulation.

The MTF (modulation transfer function) is about 20% both for experiment and simulation.

A. Skobliakov, A. Kantzyrev, MEPhI, ITEP
Generation of well directed relativistic laser accelerated electron beam and its application for gamma and neutron production

N. Andreev, O. Rosmej, M. Günther in collaboration with GU-Frankfurt, JIHT, ITEP
Results P176, September 2091

other participants:
P. Neumayer, A. Kantzyrev, V. Panyskkin, A. Skobliakov, A. Bogdanov (ITEP, Moscow), F. Consoli, M. Salvadori, M. Sciscio (ENEA, Italy) and the PHELIX-team (GSI).
Target chamber for phase 0 (HHT) and phase 1 (APPA-cave)

- **Vacuum chamber:**
  - design finished
  - out for offers

- **Target exchange system:**
  - detailing design
  - software development

- **Commissioning at HHT:** mid-end 2020

**Diagram highlights:**
- Cryo target supply
- Turbo pump
- Protection hood
- Access holes for set-up
- Beam dump
- Target positioning
- Breadboard
- Target reservoir
- Target supply robot
A target table confines the exploding target, reduces the contamination of the chamber and protects the positioning system. The protection hood is lifted for the exchange of the targets. It has customized openings for diagnostics. The table has no connection to the breadbord.

A breadboard is used for the set-up of diagnostics. It is isolated from the vacuum chamber to remain stable during pump-down. The actuators of the target exchange and positioning systems are connected to this breadboard.
PHELIX-laser at HHT: 2021

PHELIX: 200 J @ 1 – 10 ns, $2\omega$
- focal spot size in ns-pulse: 0.1 mm/0.5 mm/1 mm (with phase plate)
- max. intensity: $10^{16}$ W/cm$^2$ (long-pulse mode)
- 30 J @ 0.3 – 2 ps (100 TW)

PHELIX:
- Laser bay: 0.5 PW, 200 J @ 400 fs
  - focal spot size: 3 µm
  - maximum intensity: $5 \times 10^{20}$ W/cm$^2$ (short-pulse mode)
  - $> 10^{11}$ temporal contrast

HHT (new, 2021):
- PHELIX: 200 J @ 1 – 10 ns, $2\omega$
  - 15 cm beam diameter
  - maximum intensity: $\sim 10^{16}$ W/cm$^2$
HHT
high energy, high temperature experimental cave

FRS
fragment separator

ESR hall

HITRAP
deceleration facility

PHELIX

Laser-beam parameters in HHT:
- 200 J
- 527 nm
- 0.33-1 ns, up to ~10 ns
- 15 cm beam diameter

~ 65 m

Project leader Dr. S. Major
Combination of 200J ns laser pulse and U-beam SiS 18

2W, 200J, 0.3-10 ns
Potential of PHELIX- laser at HHT

Long (ns) laser pulses at $\sim 10^{14\ldots16}$ W/cm$^2$

- Multi-Megabar ablation pressure
  - Shock compression + heating
  - Flyer-acceleration
  - High strain-rate material strength testing

High-power „driver“ for dynamic events to be diagnosed with proton microscope PRIOR

- Radiography
  - low-Z targets: (isentropic) expansion/compression, ablation/fracture/spallation/explosion
  - high-Z targets: expansion into low-Z tamper

- X-ray diffraction
  - lattice constant + strength, structural phase transitions (e.g. diamond-graphite), melting

- X-ray scattering
  - liquid structure (ion-ion distance, coupling strength, ion temperature, compressibility)

- Absorption spectroscopy
  - XANES (electron temperature), VUV-opacity (e.g. Bi, Pb), continuum lowering
Demonstration of application examples using x-ray diagnostics driven with PHELIX laser pulses

- **X-Ray Near Edge Absorption Spectroscopy (XANES)**
- **Radiography (Heα)**
- **Diffraction**

Resolution obtained:
- <2 eV spectral
- 200 μm spatial

Results P. Neumayer et al
Upcoming projects of HED@FAIR collaboration 2020-2021

- **Proton beam-time**: May-June 2020
- **HIHEX-proposal** for HHT February 2020 (proposals from collaboration are required)
- **HIHEX beam-time** (new HHT target chamber, with /without laser) 2021

<table>
<thead>
<tr>
<th>E, GeV/u</th>
<th>Z+</th>
<th>2σ, mm</th>
<th>N_{ion}/100ns</th>
<th>E_s, kJ/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4 - 1.</td>
<td>+73</td>
<td>0.9</td>
<td>0.5 - 1 (10^{10})</td>
<td>1-2(Pb) 1.5-3 (Al)</td>
</tr>
</tbody>
</table>

Laser driven X-ray radiography /PHELIX:

Proton radiography / SIS18

Laserpulse: E=30J, t=700 fs, FWHM=15 μm
Target: 10 μm Au-foil, P176 Sept. 2019