Experimental Investigation of the Sub-Picosecond Laser Interaction with Low Density Foams on the PHELIX Laser System

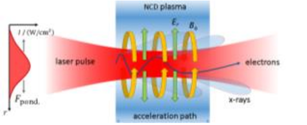
J. Cikhardt[1,2], M. Gyrdymov[3], N. Bukharskii[4], N. Borisenko[5], P. Tavana[3], S. Zähter[2], M. Günther[2], J. Jacoby[3], N. Andreev[6], O. Rosmej[2,3]

[1]Czech Technical University in Prague, [2]GSI Helmholtz Centre for Heavy Ion Research, Darmstadt, [3]Goethe University Frankfurt, [4]National Research Nuclear University MEPhI, [5]Lebedev Physical Institute RAS, Moscow, [6]Joint Institute for High Temperatures RAS, Moscow

42nd International Workshop on High-Energy-Density Physics with laser and Ion beams 2022

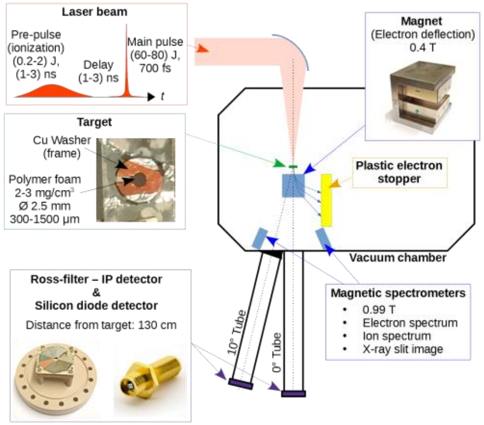
Introduction

- During the interaction of a petawatt-class laser beam with a near-critical density, plasma electrons are efficiently accelerated to energies that exceed ponderomotive potential by more than one order of magnitude. Due to the ponderomotive force, which expels background plasma electrons from the laser channel, the generation of a quasi-static radial E-field that has a pinching polarity for electrons, takes place. A current of accelerated electrons produces a strong (up to 100 MG) azimuthal magnetic field that traps the electrons in the plasma channel. Under these conditions, relativistic electrons oscillate with the betatron frequency and emit x-rays (betatron radiation). 3D particle-in-cell simulations considering conditions in the experiments on the PHELIX facility (10^{19} W/cm^2, 20 J, <1ps) predict a high yield of the betatron photons in the energy range (1–30) keV. This presentation is focused on the experimental characterization of the keV photon radiation and evaluation of the contribution of the betatron mechanism to the overall keV x-rays.
- The micrometer-scale source of ultrashort and bright x-ray pulses is promising for high-tech applications such as flash high-resolution x-ray radiography and phase contrast imaging in biology and medicine and in investigations of ultrafast processes in shock waves or implosions.



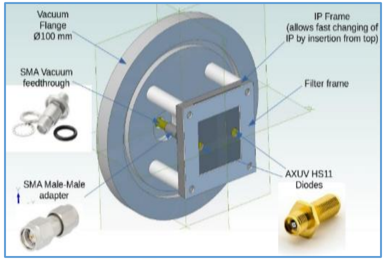
Experimental setup

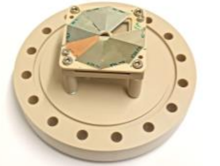
- The laser beam is focused to the focal spot with a diameter of (12 – 18) µm (FWHM of intensity).
- In the beginning, the foam is irradiated by laser pre-pulse with a length of (1 – 2) ns and energy of (0.2 – 2) J. After a delay of (1-3) ns during which the near-critical density plasma is created by super-sonic ionization, the target is irradiated by the main laser pulse with an energy of (60 – 80) J and a length of 0.7 ps.
- Electrons that escape the target are deflected by a
- C-shaped magnet with an inductance of 0.4 T.
- X-rays including betatron radiation are detected by the Image-Plate Ross-filter detector and solid-state diode placed at the distance of 130 cm from the target at the angles of 0° and 10°.

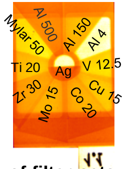


X-ray/betatron-ray diagnostics

- IP detector 40 x 40 mm with a set of Ross-filters or copper and aluminum filters with various thicknesses ("thick filters")
- Solid-state diode sensitive to photons (100 eV-50 keV) and ions (indicates occurrence of protons if enter the detector and gives information about their energy by time-of-flight method)

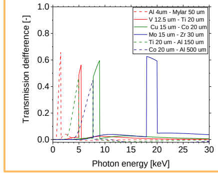




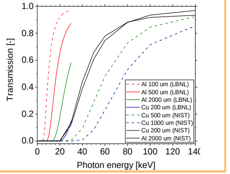


Transmission characteristics of filter sets

Ross filters ("Thin filters")



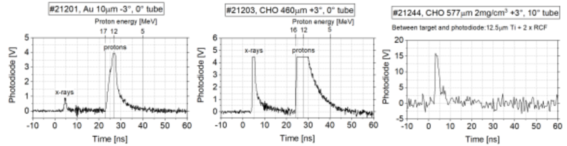
Al and Cu "Thick filters"



Results from October/November 2021

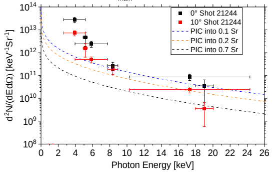
Solid-state diode signals

Reference (Gold foil) — Insufficient ion shielding — Well set shielding



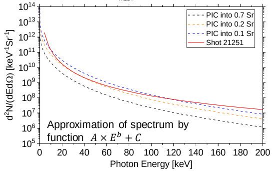
Ross filter spectrum

Shot no. 59 (ID 21244)
CHO Foam 577 µm, +3°
Main pulse energy: 65.9 J
Pre-pulse: 0.3% E_{main} ,length: 3ns, delay: 3ns

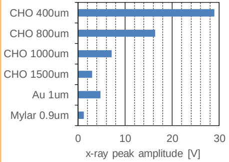


Spectrum by thick filters

Shot B1 (ID 21251)
CHO Foam 472 µm, -10°
Main pulse energy: 75.5 J
Pre-pulse: 0.3% E_{main} ,length: 3ns, delay: 3ns

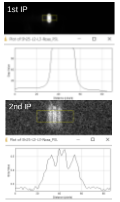


Results from diode



Slit x-ray image

No.25 (2168)-10°



GEANT 4 Simulation of Bremsstrahlung