Optical probing of plasma dynamics generated by high intensity laser pulses on ultrathin foils

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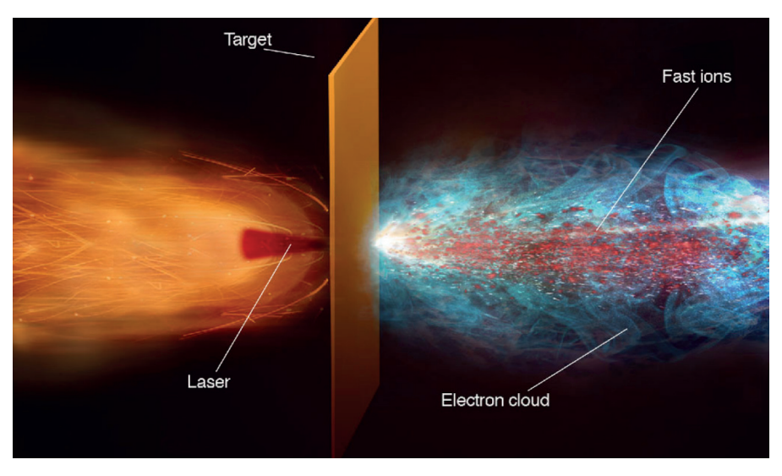
Introduction



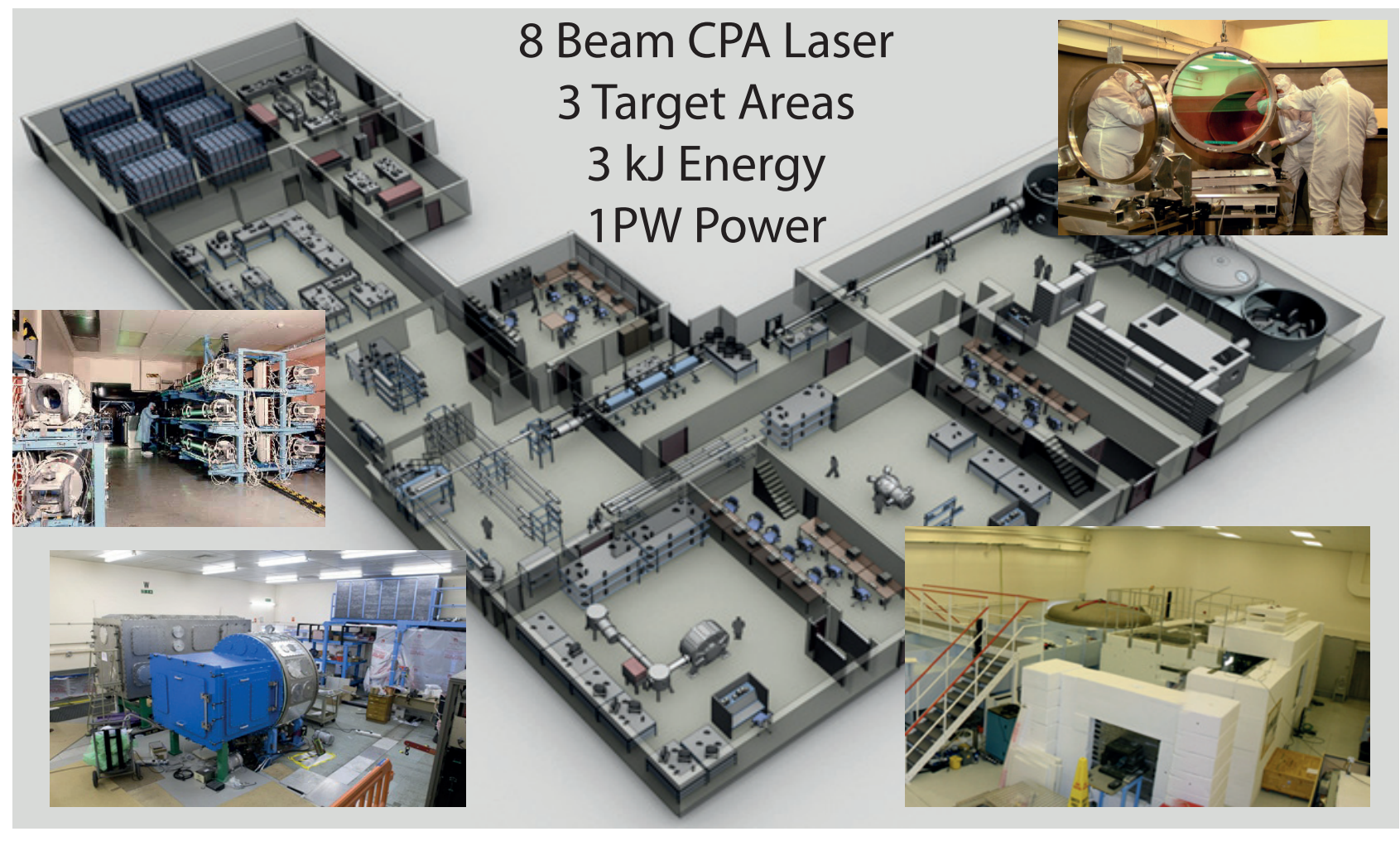
Extensive experimental and theoretical studies on the topic of high intensity laser- target interaction, investigating new efficient acceleration regimes and optimizing the electron and ion beam properties (brilliance, energy spectrum, duration, divergence) undergo large scientific interest. Here we report on recent experimental investigations of ion acceleration by sub-picosecond, high-intensity (3x10^{20} W/cm^2) laser pulses interacting with ultra-thin foil targets of different materials at the VULCAN Laser facility in Didcot (UK). In particular, we are presenting the temporal evolution of plasma expansion and the formation of plasma jets on the rear side detected by optical interferometry and shadowgraphy over time intervals of 0-150ps after the laser pulse irradiation.
The investigations of plasma expansion of the targets irradiated by high intensity laser can offer relevant information in order to characterize the ion acceleration regime (TNSA, RPA-HB or RPA-LS) [2,3].

Setup and Main Diagnostics

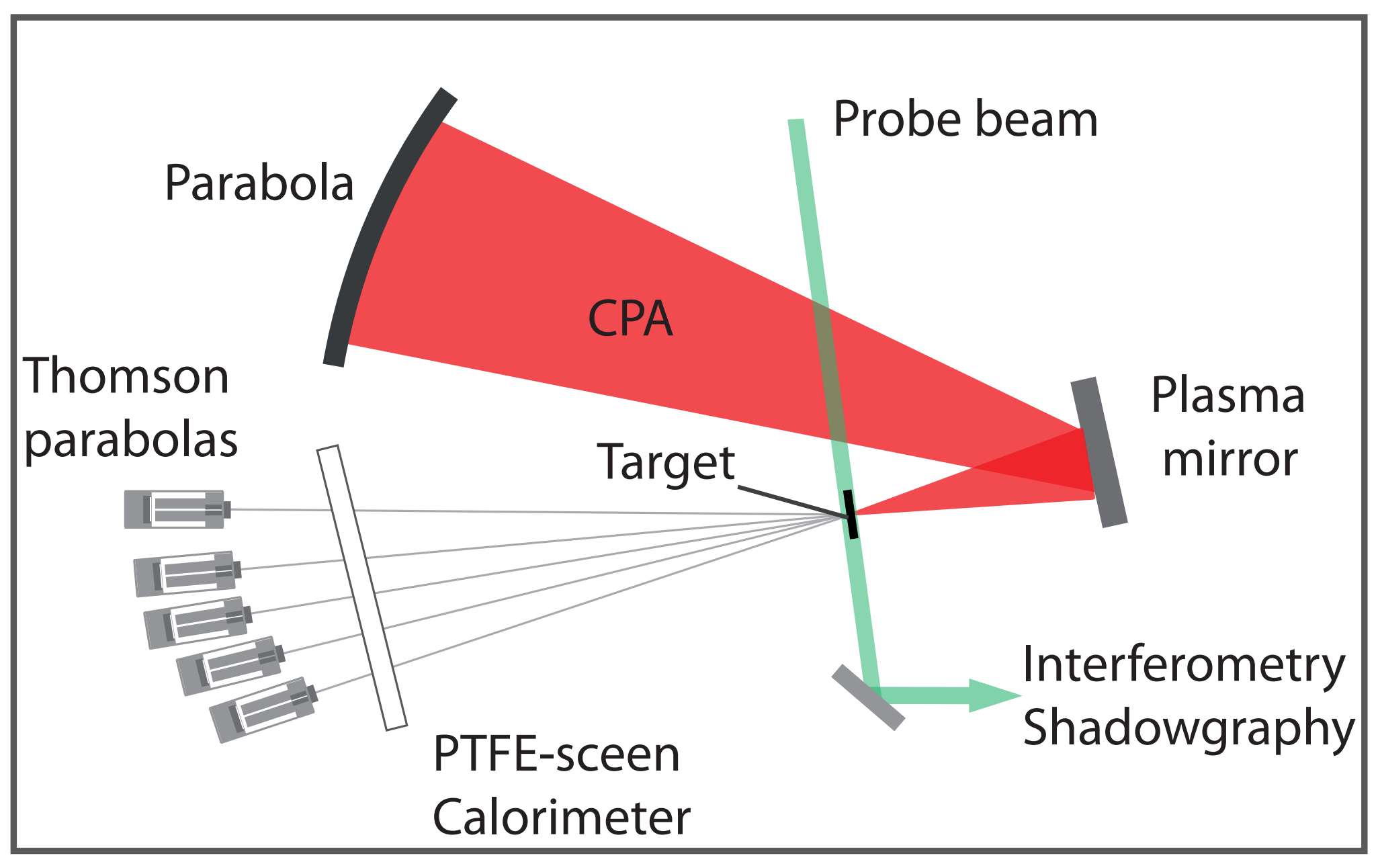
Experimental conditions

- 1056 nm laser beam
- with intensities up to 3x10^{20} W/cm^2
- Plasma mirror to enhance the contrast to 10^9 between main pulse and ns-long amplified spontaneous emission
- 700fs - 5ps pulse duration
- focused down to 7µm spot
- on Au, Cu, Ag foils with thicknesses between 10nm - 100nm

Vulcan Laser Facility



Chamber setup

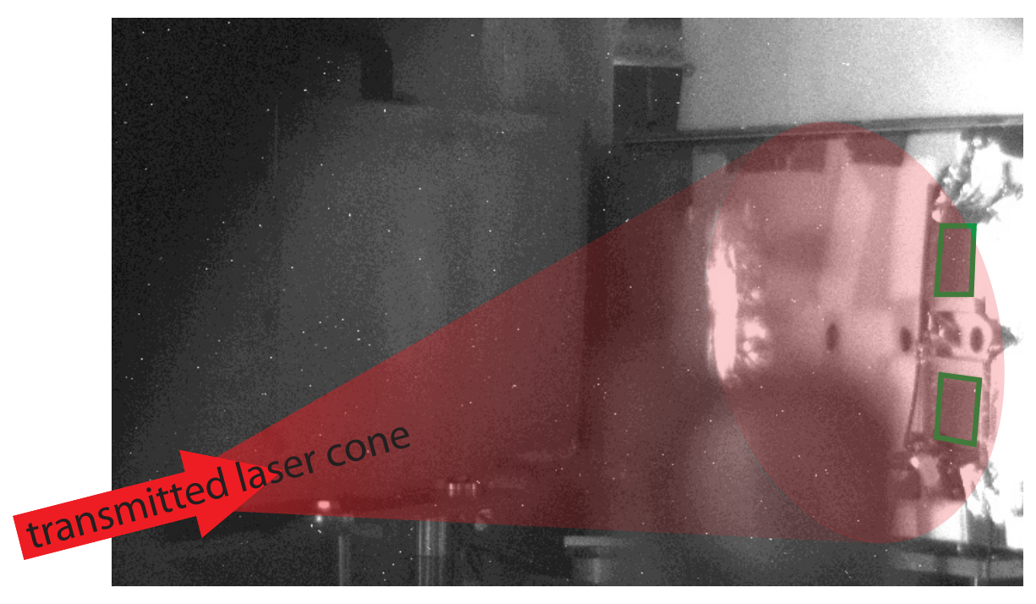


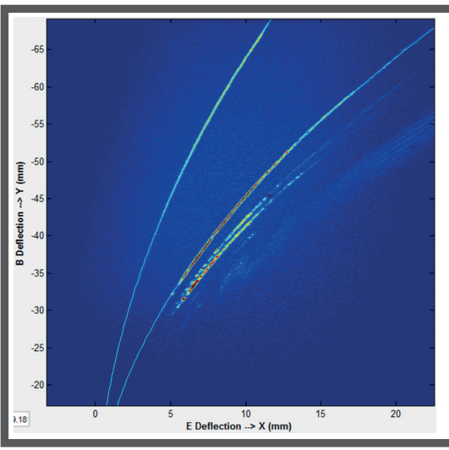
Optical probe

- frequency doubled (527nm) fraction of the interaction beam
- delay controlled by double pass timing slide

Laser energy coupling of thin foils

- transmitted energy measurement in a certain distance behind the target with calorimeter
- Analysis of laser energy absorption

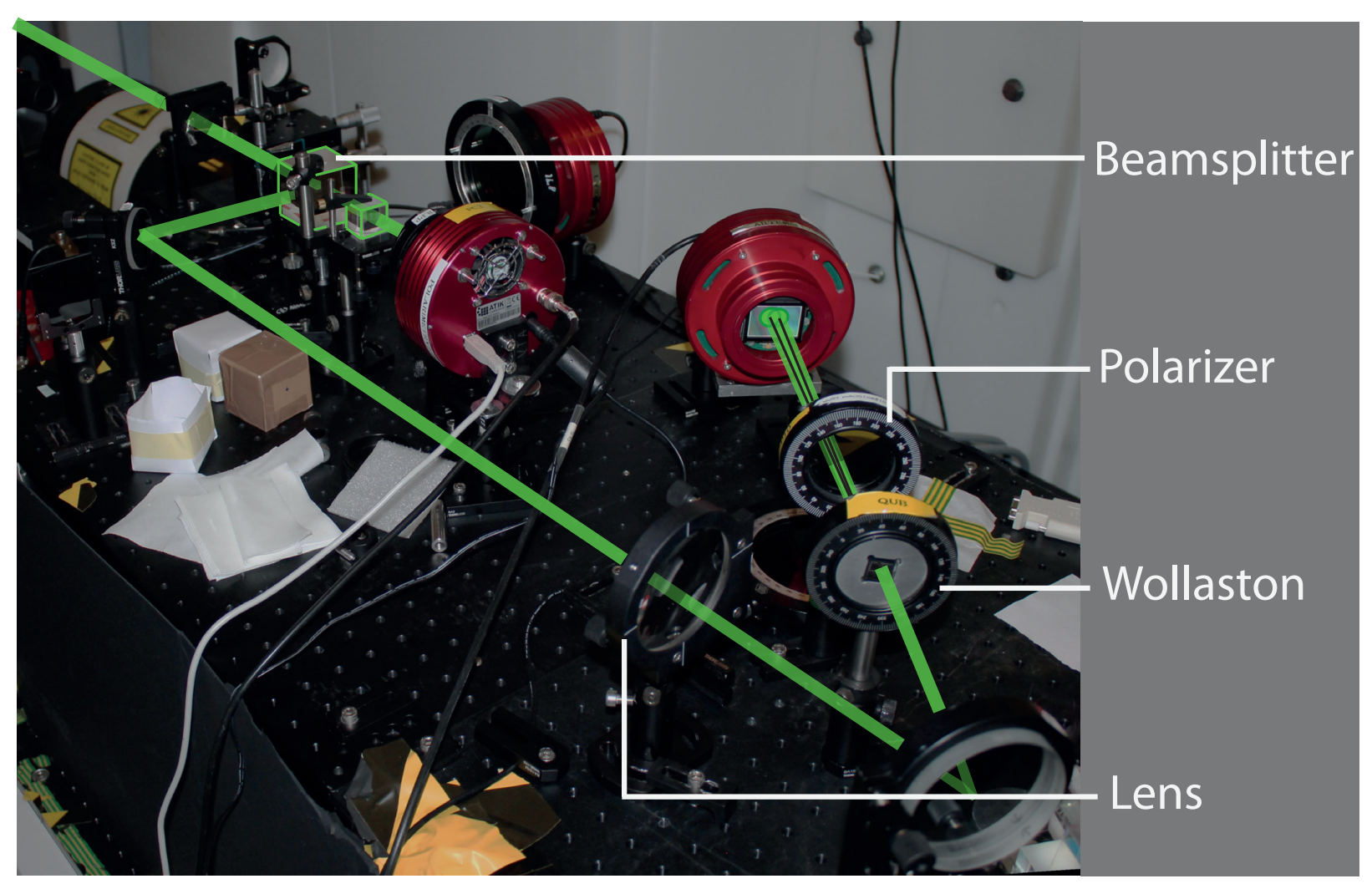




Ion spectra diagnostics

- 5 Thomson parabolas at -6.5°, 0°, 4.5°, 9.5° and 24° to target normal
- Image plates for detection and recording

Interferometry and Shadowgraphy



Nomarski-Interferometry

- Wollaston prism divides the beam in two separated beams of perpendicular polarization
- Polarizor 45° to both beam to let them interfere
- 2 partially overlapped images of region of interest

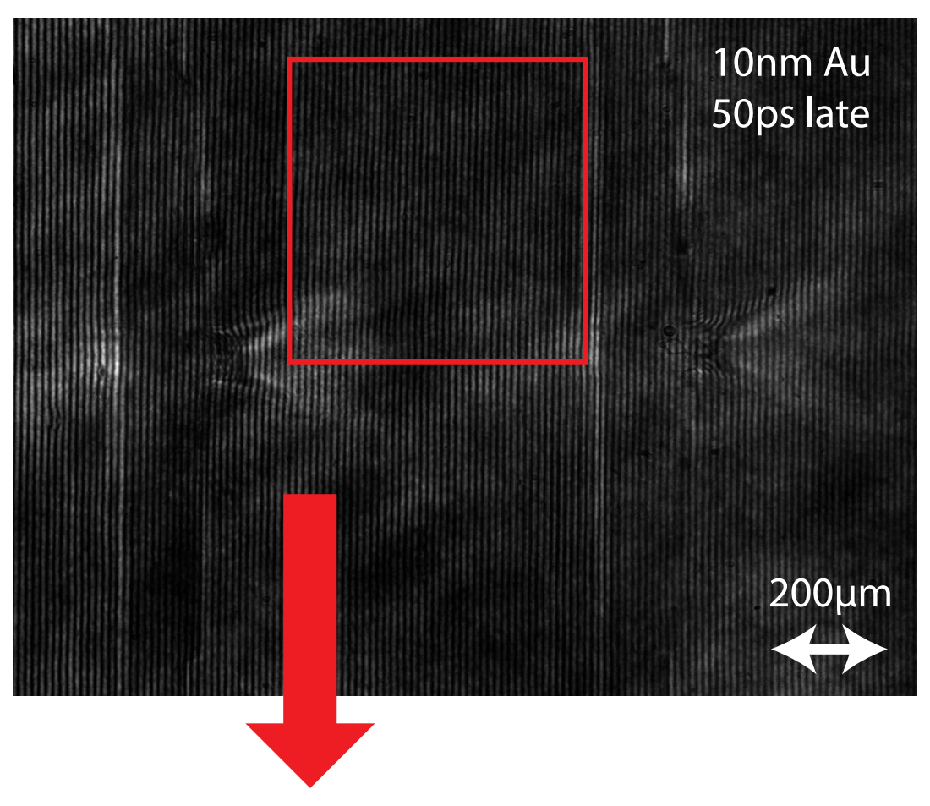
Shadowgraphy

- Beamsplitter devides probe beam for use of both diagnostics at the same time

Images taken between 15-130ps after main beam arrives at the target

Examples of raw data and analysis

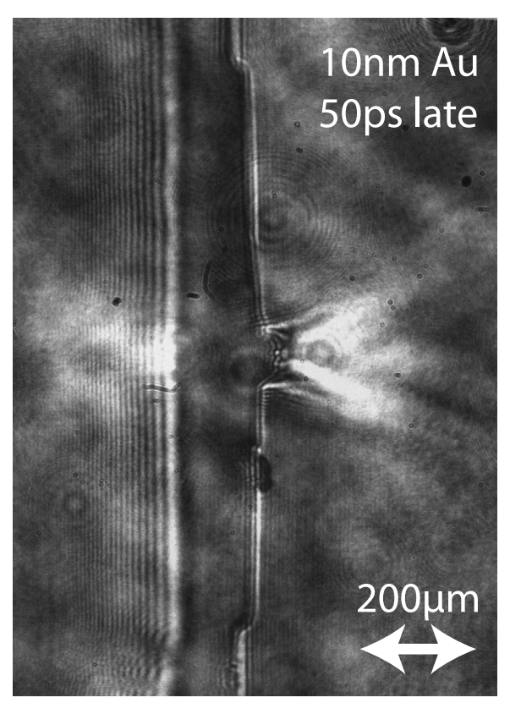
Interferometry



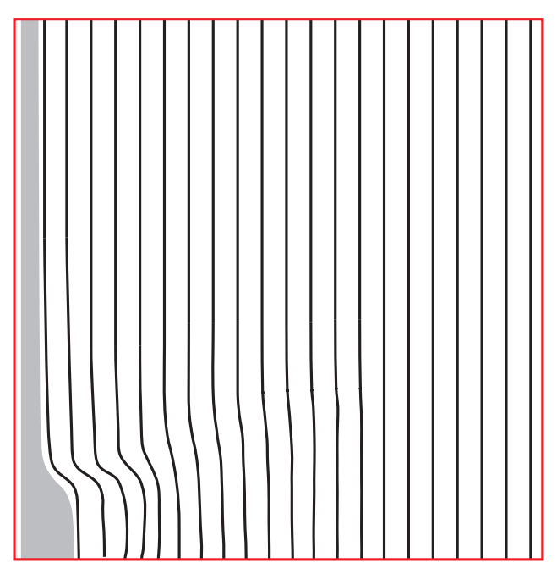
Data selection

- just half of the expansion due to cylindrical symmetry
- left image due to fringeshift in the direction of the expansion

Shadowgraphy

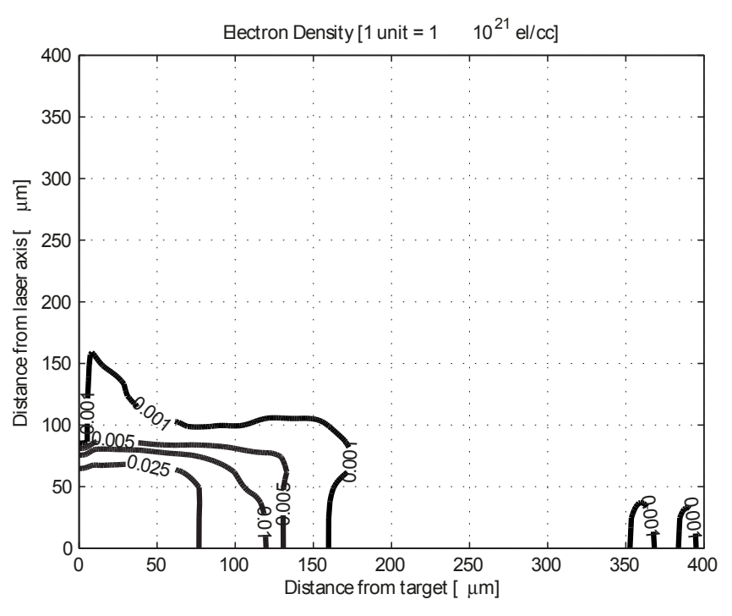


Shadow of the target and the overdense plasma.



The phase map is reconstructed by using fast Fourier transformation of the traced fringe pattern.
Solving the Abel inversion gives the final density map [5]

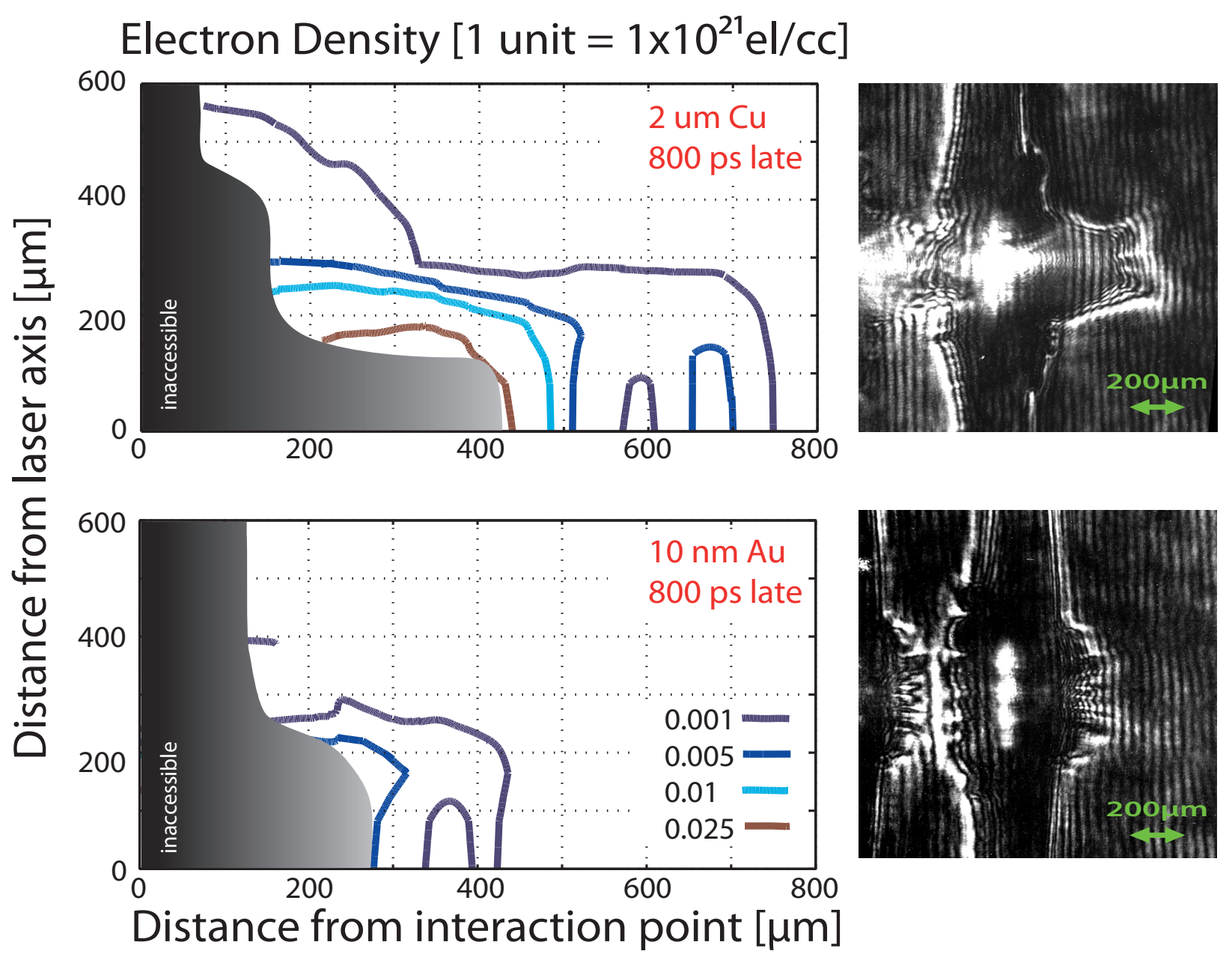
$$n_e(\rho,z) = -\frac{\lambda n_c}{\pi^2}\int_{\rho}^{\rho_0}\frac{\partial[\Delta\phi(x,z)]}{\partial x}\frac{dx}{\sqrt{x^2-\rho^2}}$$



Experimental Outcome and Evaluation

Correlation between target parameters, jet generation and the dominant acceleration process

- Intensity regime predicts transition between TNSA and RPA
- Ion spectra of thin foils (e.g. 10nm Au) show RPA feature, whereas thick foils (e.g. 2µm Cu) show typical TNSA spectra



Relevant parameters [6]

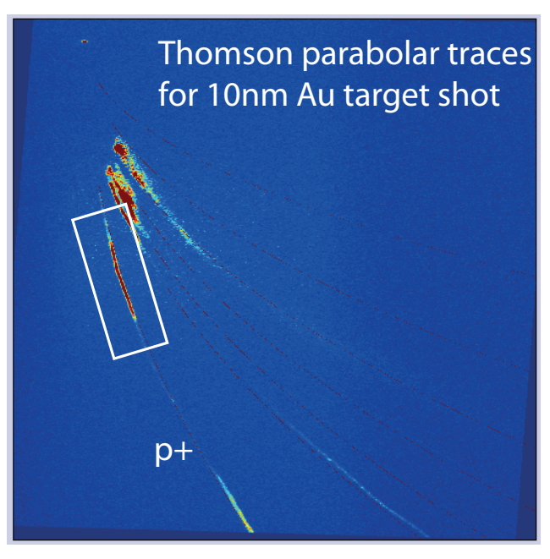
$$t_{HB} = \frac{l_{Target}}{v_{HB}} = \frac{l_{Target}}{c}\sqrt{\frac{\rho_{Target}c^3}{l_{Target}}}$$ „hole boring" time

$\tau_{Laser} = 3ps$ FWHM pulse duration

Classification for different acceleration regimes

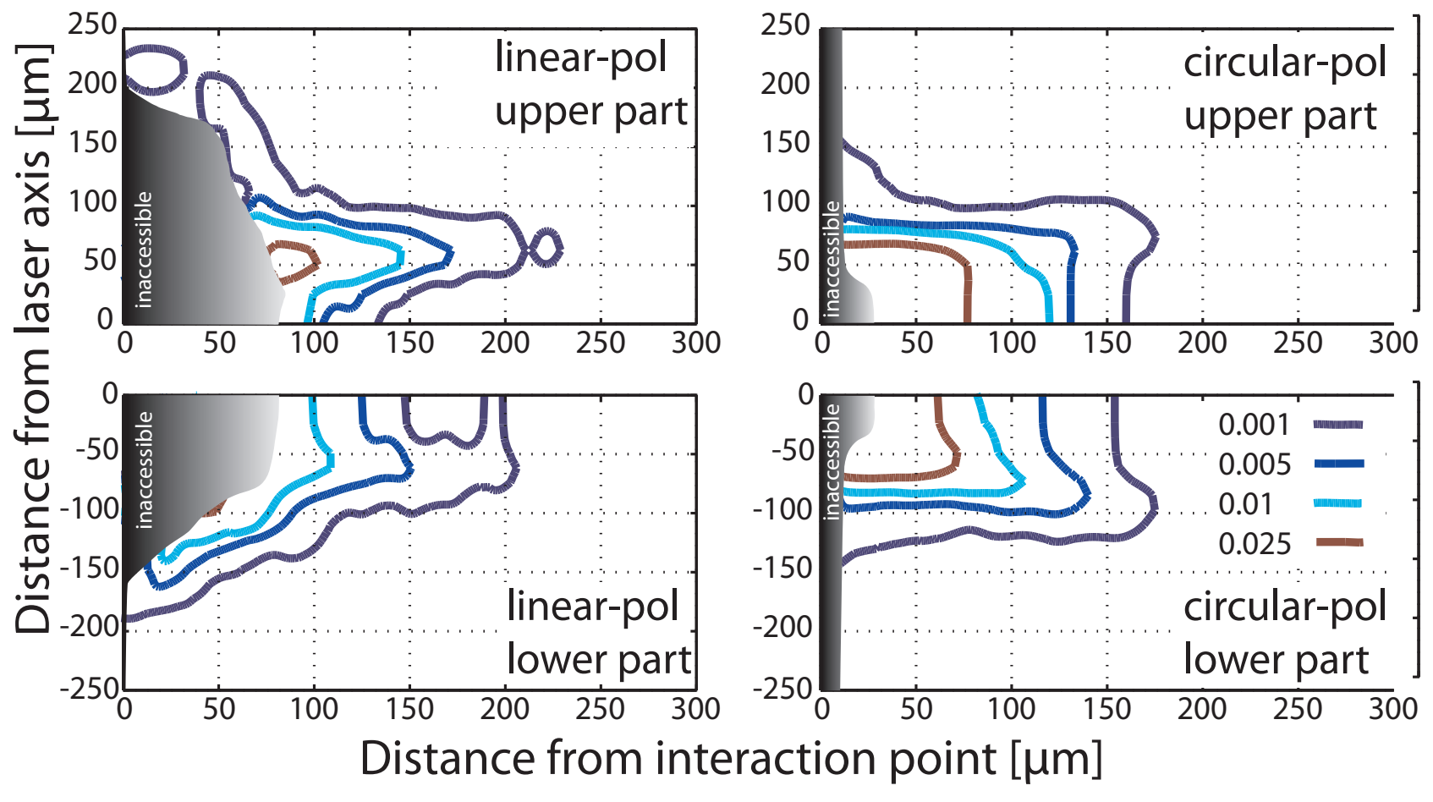
$t_{HB}^{2\mu mCu} = 2ps \approx \tau_{Laser}$ ⟶ HB not yet or just finished by the end of the laser pulse
- collimated electron jet

$t_{HB}^{10nmAu} = 0.014ps \ll \tau_{Laser}$ → HB finished before the end of the laser pulse
- no jet generation
- explosion or transition to LS instead



Thomson parabolar traces for 10nm Au target shot

Electron Density [1 unit = 1x10^{21}el/cc] of 30nm Au target

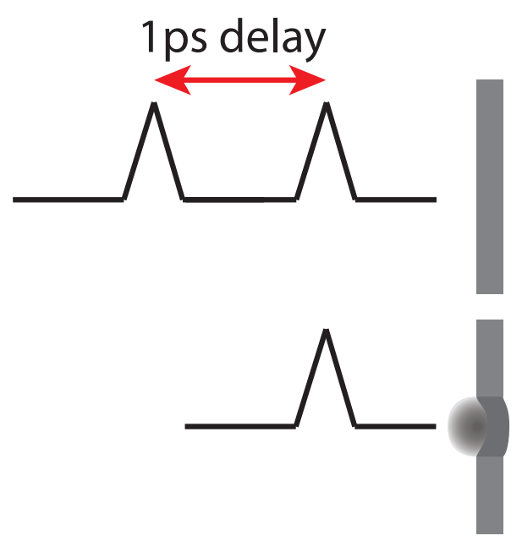


Impact of circular polarized pulses on the expansion

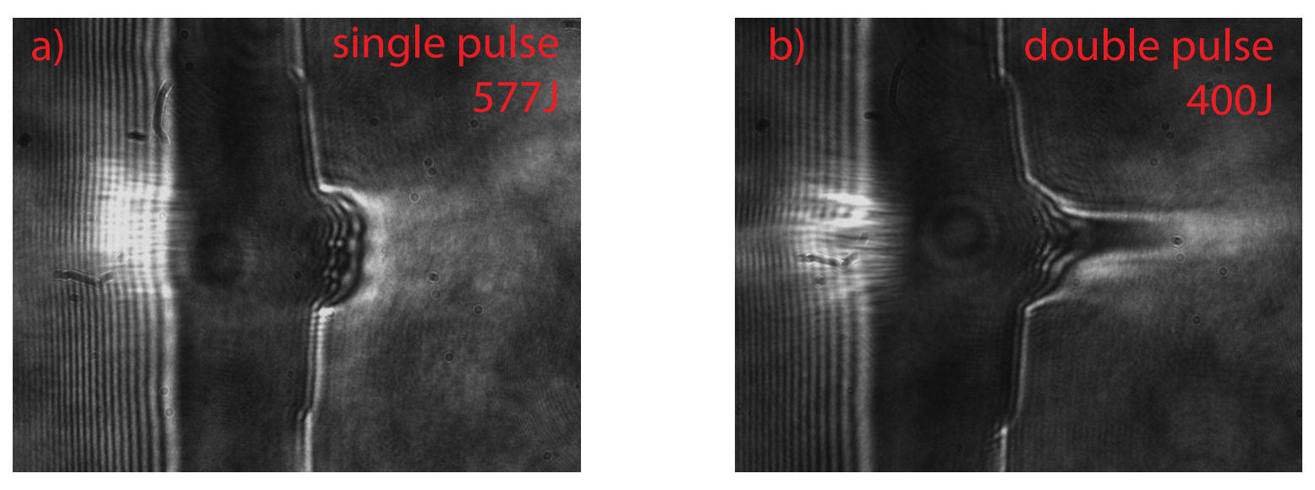
Absence of jxB heating leads to

- slower but more uniform expansion at the front surface
- less expansion of the bulk plasma (inaccessible area)
- lower proton cut of energy

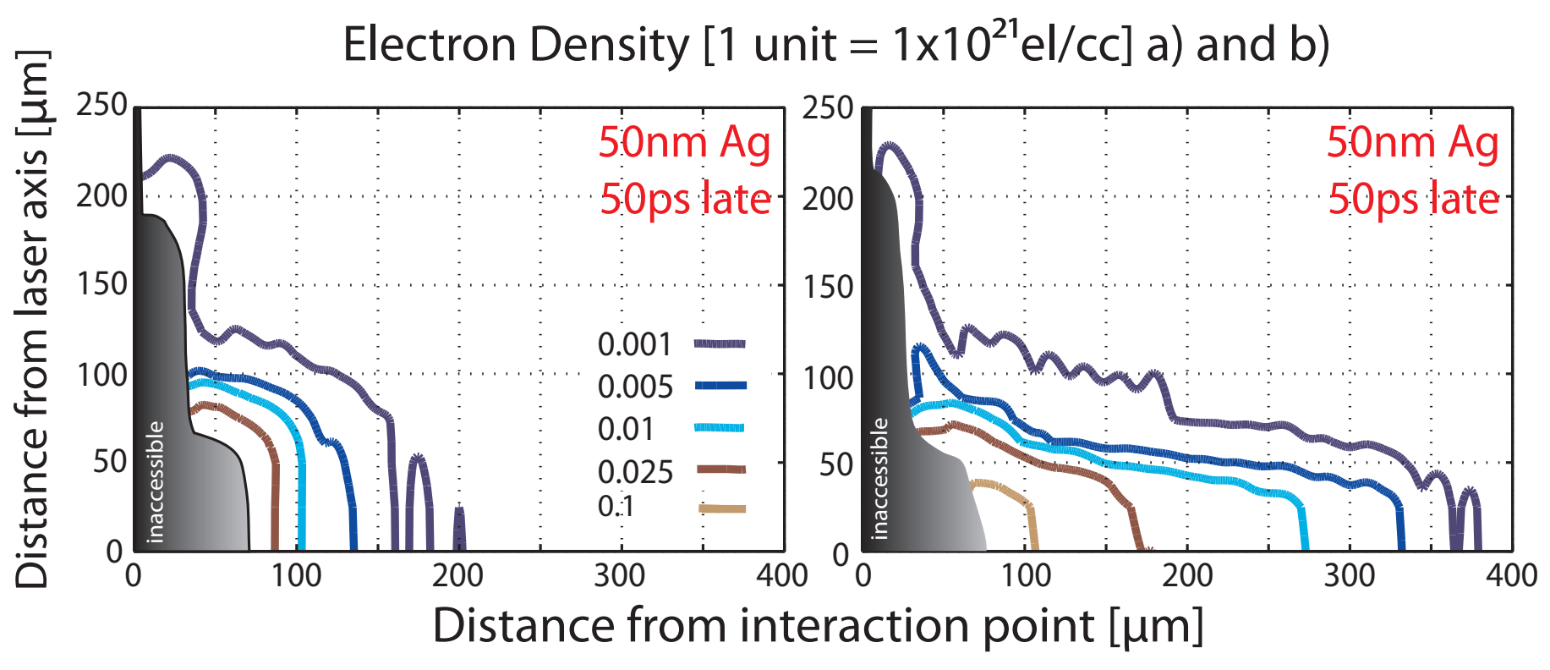
Double pulse configuration to increase the acceleration path



Irradiation at best focus is followed by second suitably delayed pulse a Rayleigh range or fraction beyond the focus of the first pulse.

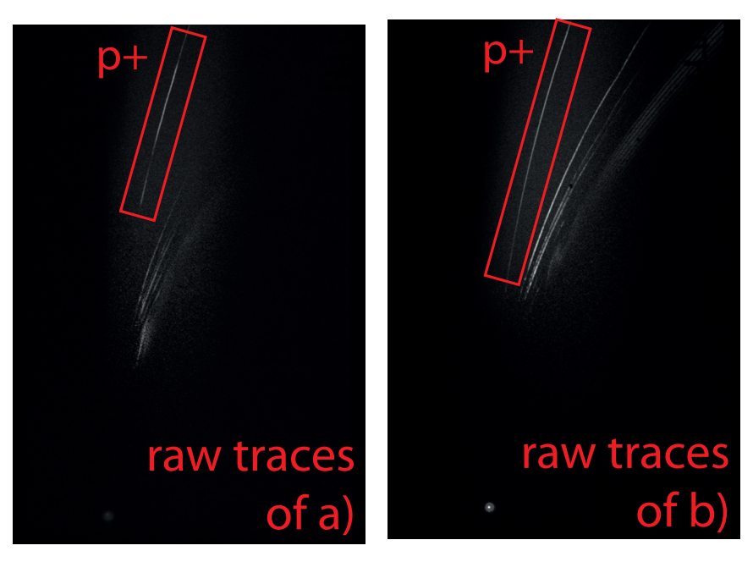


Electron Density [1 unit = 1x10^{21}el/cc] a) and b)



50:50 split of energy, focal displacement ~20µm

Aim
Second pulse continues to drive the compressed foil as soon as first pulse decreases, in order to enhance the interaction length

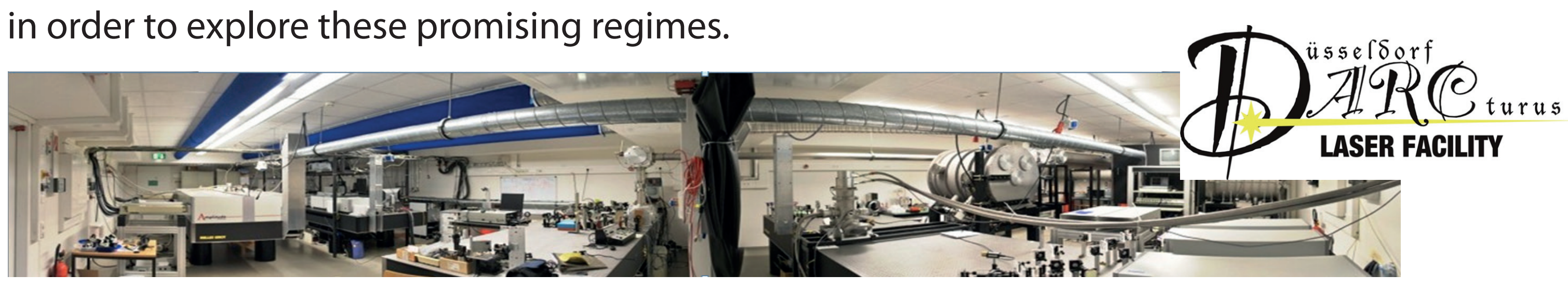


- stronger expansion in form of a collimated jet with steep density gradient in the periphery
- symmetric geometry indicates spacial overlap of both pulses
- higher proton cut of energy despite lower laser input energy
- low single pulse energy affects reflectivity of Plasma mirror and contrast of the pulses which has an impact on the heating process

Conclusions and further Work

The experimental outcome of the investigation gives more information to further characterize, optimize and control electron and ion beams to make them suitable for potential application in many different fields e.g. in particular therapy of cancer.
Irradiation of thin foils by double pulse, with a controlled temporal delay leads to new interaction regimes which could affect the acceleration mechanism (e.g. better energy coupling of the second beam onto expanded preplasma generated by the first pulse, lower density target by decompression realized by the first pulse, etc.). Further investigation on the experimental data are planed to identify the dynamics of the acceleration process on the double pulse configuration. The generation of a collimated plasma expansion with steep density gradients strongly depends on the target thickness and the duration of the laser pulse. The evolution of the plasma expansion offers indications regarding the dominant ion acceleration regime.

Follow up campains will concentrate on exploring the potential offered by double pulse geometry on controlling parameters like: the acceleration length, the density profile of the target by the arrival of the second peak pulse, pulse duration which are relevant for RPA or BOA regimes. The new upgraded ARCTURUS laser system at HHUD, with two ultrashort (30fs), high contrast (XPW module and 2 PM) beams of 200TW power and a probe beam, offers the opportunity of large flexibility on the selection of the proper interaction conditions in order to explore these promising regimes.



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