

## LWFA low-energy electron beams

M. Šmíd, K. Boháček, U. Chaulagain, Y. Gu, M. Krůs, M. Kozlová and K. Falk

*Institute of Physics, ELI-Beamlines project, Academy of Sciences CR, Prague, Czech Republic*

The diagnostics for Warm Dense Matter is a very challenging topic. In this work we aim to develop an ultrafast electron beam with sufficient brightness to be used as a diagnostic back-lighter capable of providing single-shot diffraction measurement. We are aiming to generate low energy electrons produced by Laser Wake Field Acceleration (LWFA). The required energy for these applications needs to be around 1 MeV in order to keep the influence caused by the probed matter significant relative to the electrons initial energy. Too low energy, on the other hand, could cause strong temporal dispersion of the beam.

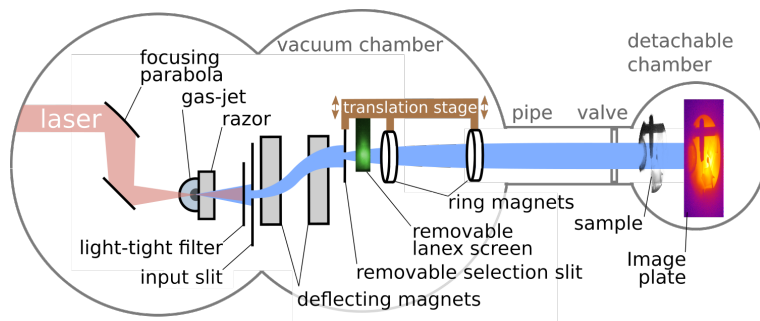


Figure 1: *Experimental setup*

In the latest experiment, we have used the downramp gradient LWFA scheme which produced a beam of 77 pC ( $4 \times 10^8$  electrons) centred at 1.9 MeV. The relatively huge initial divergence which is a common drawback of low-energy acceleration ( $\sim 10^\circ$ )

was improved by focusing ring magnets which keep the beam close to parallel for a distance of 2.67 m. A spectrometer setup was used to allow for simultaneous monitoring of electron spectra and using the beam for radiographic imaging.

### Experimental setup

The Ti:Sapphire laser beam in the PALS laboratory delivered 600 mJ in 50 fs into a 10  $\mu$ m focal spot. The target consists of a 3 mm diameter Laval type supersonic gas-jet, whose rear side was covered by a steel razor blade which created a sharp density gradient. Fig. 2 shows the measured interferogram and the reconstructed on-axis density profile (blue). The golden line represents a Gaussian profile with FWHM 600  $\mu$ m. Using the online interferometric diagnostics, the laser was focused to the downramp gradient region.

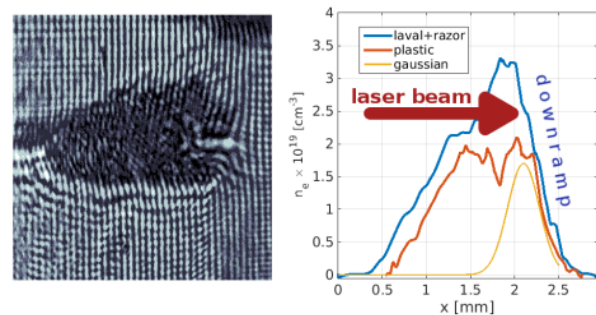


Figure 2: *Measured interferogram, reconstructed profile and expected profile.*

The electron spectrometer consists of two 20 mm thick magnets with maximum field of 270 mT. It offsets the electron trajectories by an amount depending on their energies, but it keeps their direction parallel to the experimental axis. This feature enables adjustment and utilization of the beam downstream. Behind the magnets, there was a removable 5 mm wide slit and removable Lanex screen. When inserting the screen and removing Lanex, the reference spectra can be observed, while when inserting the slit and removing the screen we could use the beam further downstream. Eventually, the screen could be partly inserted to monitor the top part of the beam while letting most of it through.

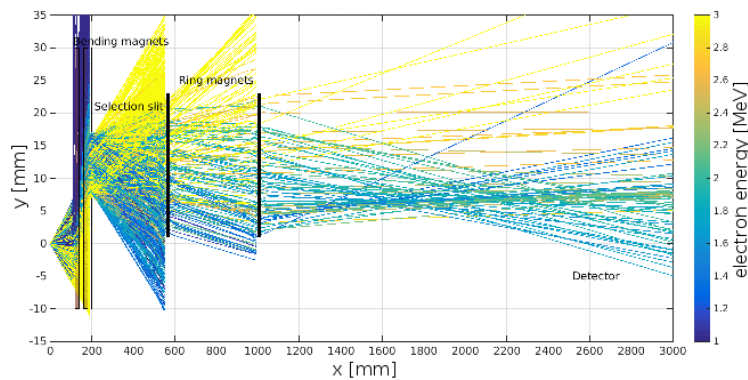


Figure 3: *Electron trajectories calculated by the raytracing code*

While the 1.5 MeV electrons (blue) are focused much before the detector, the 2.1 MeV electrons (green) are focused on the detector and the 2.6 MeV ones (orange) form a parallel beam.

The detector was positioned 267 cm away from the electron source. First, the Lanex screen imaged by a CCD was used in order to obtain online information. This was used to optimize the beamline by changing its lateral offset, which selects the range of electrons let in. After this optimization, the Image Plate (IP) was used in order to get a brighter and calibrated image. A set of various steel and aluminum objects was placed ~5 cm before the detector. The radiography image with 10 shots accumulated on IP is shown in Fig. 4. Its calibration by using data provided in [1] revealed average charge of 77 pC / shot. The figure shows a strong edge enhancement effect on thin foils. The profile of edge marked by black box in Fig. 4 is shown in Fig. 5 by red color. The enhancement is caused by weak scattering of electrons penetrating through the thin foil. This effect was simulated by the Penelope Monte-Carlo code [2] (2 MeV electrons penetrating through 25  $\mu\text{m}$  Al foil) and

The beam-path consists of two permanent ring magnets working as magnetic lenses. These were setup to form a parallel electron beam. The function of these magnets was modelled by a ray-tracing code, its result is shown in Fig. 3. It is seen how the focal length changes with electron energy: While the 1.5 MeV electrons (blue) are focused much before the detector, the 2.1 MeV electrons (green) are focused on the detector and the 2.6 MeV ones (orange) form a parallel beam.

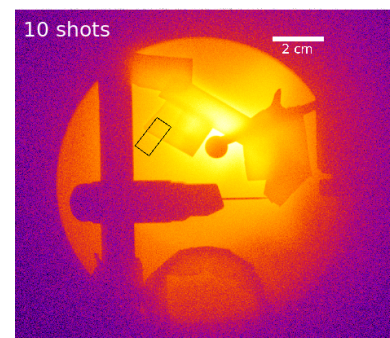


Figure 4: *Radiograph*

provided a great agreement to the observed data, independently confirming the mean electron energy.

## Simulation

The electron acceleration was modeled by a 2D PIC simulation code Epoch [3]. It used the same laser parameters as in the experiment impinging on a 600  $\mu\text{m}$  FWHM Gaussian gas density profile. The electron phase space diagram from the simulation is shown in Fig. 6. The white markers in the bottom of the image represent the centers of each wake emphasizing their lengthening. This happens due to the decreasing plasma density, indicated by its profile in the top part of the figure. Since the phase velocity is also decreasing with the decreasing density, the wakes are slowing down and the electrons can easily enter them from their rear side.

This causes the relatively high charge of the accelerated electrons. Second effect of the decreased wake velocity is that the dephasing length is very short and thus the electrons cannot be accelerated to high energies. In fact once they are accelerated to  $\sim 1$  MeV, they can penetrate through several wakes forward, being gradually accelerated and decelerated which stabilizes their energy.

## Conclusions and acknowledgments

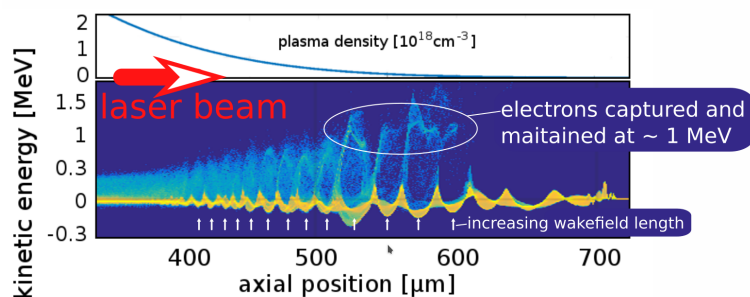


Figure 6: *Electron phase-space diagram from the PIC simulation. Negative kinetic energy represents particles heading against the laser beam.*

ity to provide a single-shot diffraction images which could be utilized to study the structure of WDM.

When assessing the usability of the source, the quantity of charge per unit energy has a big

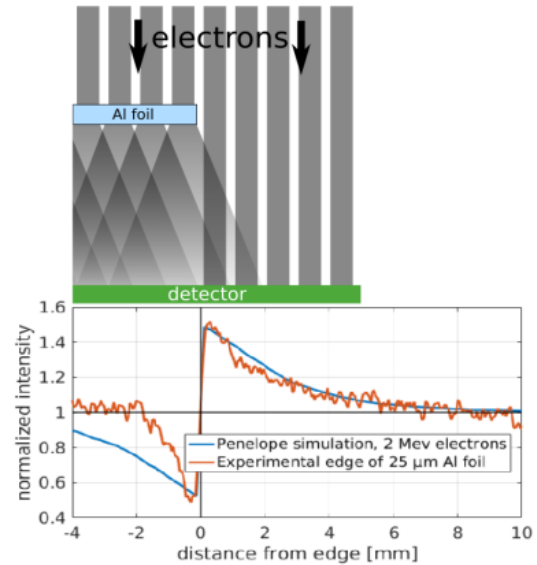


Figure 5: *Profile of the enhanced edge on the radiographic image.*

In conclusions, electron beam with mean energy of 1.9 MeV and charge 77 pC / shot was generated and collimated by using a two ring-magnet beam-path. Its sample utilization for electron radiography was demonstrated. This projects expects to be continued to further improve the beam qual-

significance. The divergence of the beam or energy range of produced spectra are quantities which might be improved in the beam-path. A survey of various reported laser based sources is shown in Fig. 7. Only very few works have been found which aim at this topic with LWFA (filled circles), many papers reported generation of electrons by various mechanisms based on laser interaction with solid materials (empty circles). For the sake of WDM studies, the LWFA is more favourable compared to solid interaction due to easier target replacement and lower debris production.

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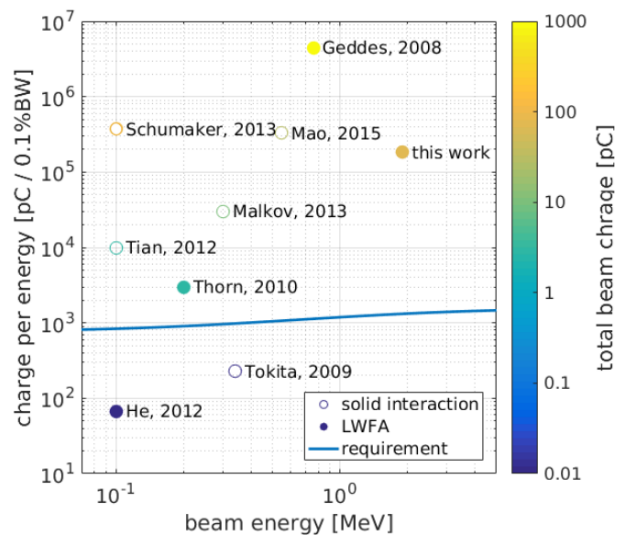


Figure 7: Comparison with other sources