Plasma Mirror Reflectivity Measurements and Guiding on Gemini in a Staged LPWA Set-Up

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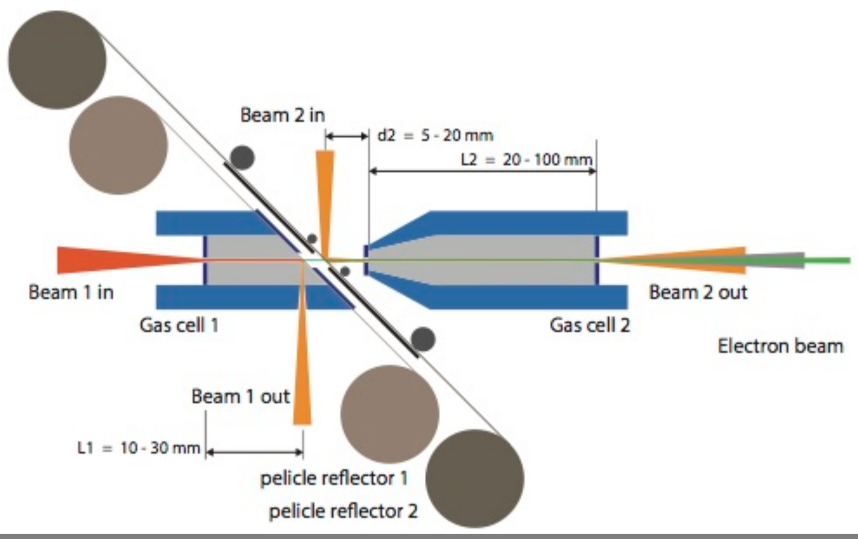
Staging Laser Plasma Wakefield Accelerators

The acceleration of electrons with ultra-short, high-intensity laser pulses is a successful method. Although, the maximum accelerated electron energy is limited mostly due to de-phasing of the electrons with the driving laser pulse and the depletion of the laser pulse energy. Staging two laser wakefield accelerators with two laser beams can overcome these limitations (1). Using the first plasma cell for electron-trapping and acceleration, and a secondary plasma cell for further acceleration. The space-constraints and the high intensity of the laser pulse does not allow conventional reflective optics. One way to reflect such intense laser beams are plasma mirrors. In this case composed of ultra-thin foil, Kapton 125 µm, it can inject the second laser pulse into the second gas cell, minimally disturbing an electron beam as it passes through. The reflectivity and subsequent focus spot in such a compact two stage set-up has been measured and is presented as well as it guiding characteristic in a 18 mm plasma cell.

Fig. left and right: From the theoretical set-up on the left to the machined set-up of a Laser Plasma-Wakefield staging experiment on the right. A second laser pulse is injected into a second gas cell by a plasma mirror between two cells



Reflecting the Gemini High Intensity Laser Pulse on Kapton Foil

This experiment requires the highest possible intensity thus reflectivity on the plasma mirror. Literature mentions reflectance measurements of >70 % (2) to up to 96 % using a more complex set-up (3). However, this set-up was limited by:

- Spatial constraints, gas cells distance has to be minimized due electron beam divergence
- Technical limitations, the size of the vacuum chamber and the available laser beam is fixed

The practical variables to tune the reflectivity in this experiment are:

- Polarisation – s-polarisation does reduce Brunel absorption and increases reflection
- Energy – measuring the normalised vector potential will determine if relativistic intensities are reached, which then would decrease the reflectivity (4).

Fig. right: Reflectivity measurements depending on the input Energy red (circle, cross: different days).

Higher intensity = higher/stable reflectance -> non-relativistic intensities

The energy *within the FWHM* can be seen in the same figure in blue. The initial 70% reflectivity drops to 10-20%.

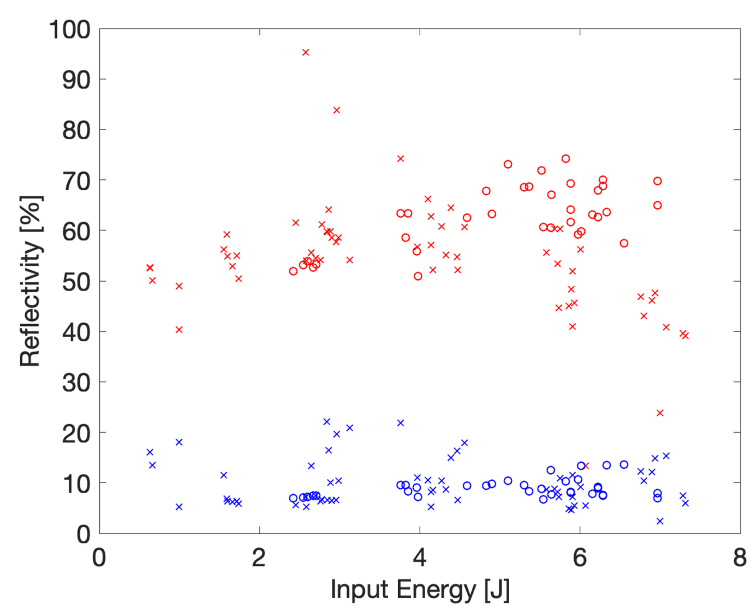


Fig. below: The normalised vector potential (the drop and fluctuations at the high energy end is due to degrading of mirrors upstream and more energy in the wings.

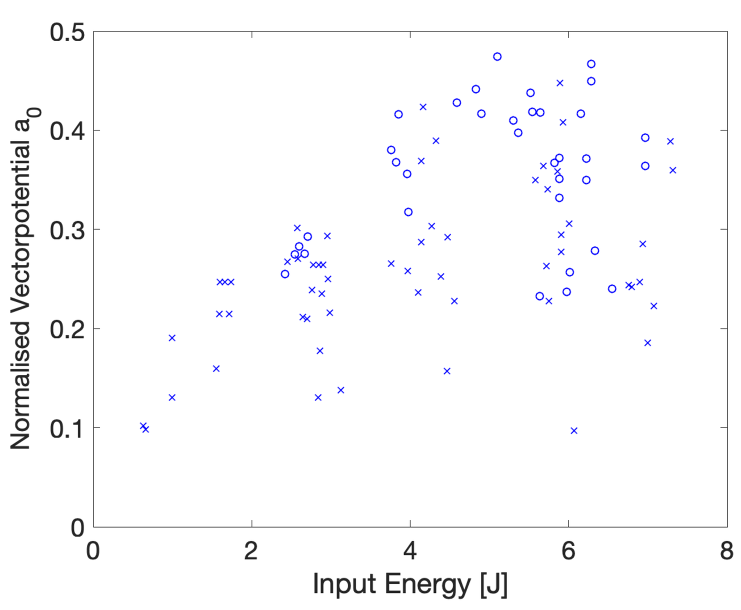


Fig. below: Exemplary 70 % reflected intensity profile. Red the ellipsoidal FWHM contour. White line outs of the short and long axis. This yield to an intensity of 4×10^{17}W/cm² (a_0 = 0.44) and beam size FWHM 47 µm in the short axis.

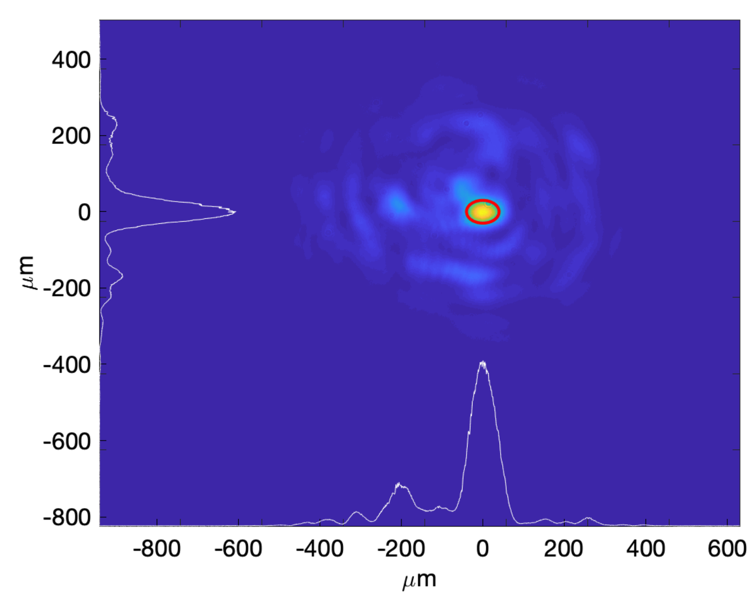
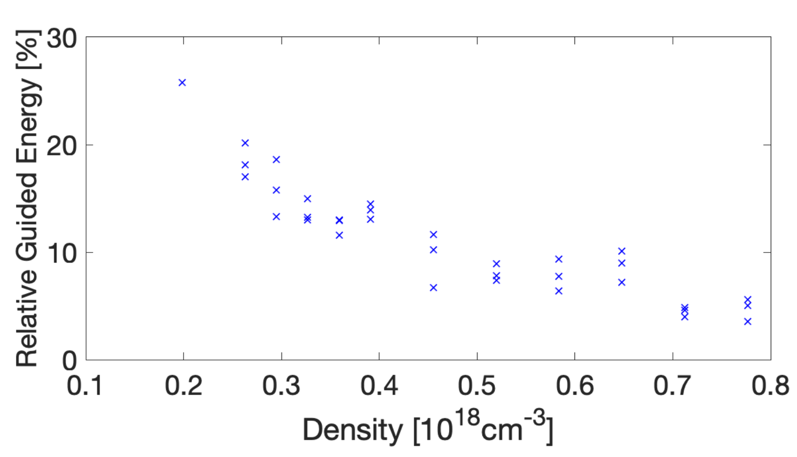


Fig. right: The total guided energy relative to the total input energy through a 18 mm long gas cell depending on the density.

Guiding density for 47 µm FWHM is around 0.3×10^{18} /cm³ thus the increase in guided energy (graph limited by technical capabilities.)



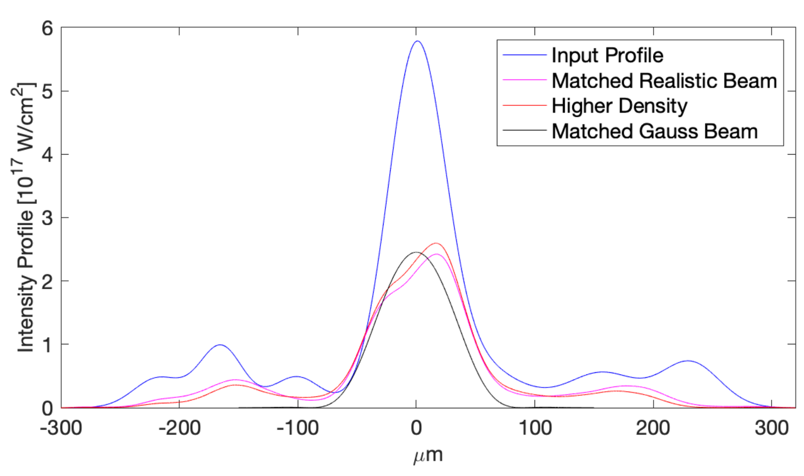
2D EPOCH Simulation on Guiding Realistic Focus Spots

With the beam profile on the right, 2D EPOCH simulation were performed. A total of 3 simulations consisted of

1. 7-mode Gaussian replicating the realistic beam profile and matched density using the centred spot size and $w_0 = \lambda_p = 2\pi c/\sqrt{e^2 n/\epsilon_0 m_e}$ (onwards called *matched density*)
2. 7-mode Gaussian beam with twice as high density
3. Single-mode Gaussian beam with matched density

Fig. below left: Transverse intensity profile. Initial profile of 1. is in blue and then the three cases from above after propagating 9 mm through the plasma (1. margin **2. red** **3. black**).

The depletion of the peak intensity seem equal to all cases. However the FWHM for the single-mode Gaussian remains lower than the other cases.



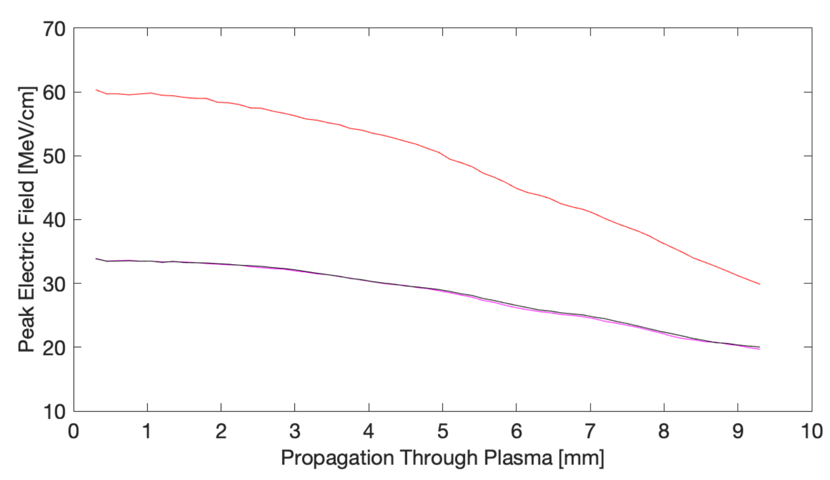


Fig. right: Peak of the longitudinal electric field in MeV/cm. The higher dense simulation has an electric field twice as high as the other two simulations as expected, however it decreases faster.

TO NOTE: The similarity of the accelerating field for the 7-mode Gaussian beam and the single-mode Gaussian. Only the central Gaussian contributes to the acceleration of the electrons thus the energy in the wings is lost energy for the purpose of LPWA!

Furthermore the achieved accelerating fields are with 30/60 MeV way below the expectations and a higher density should be considered.

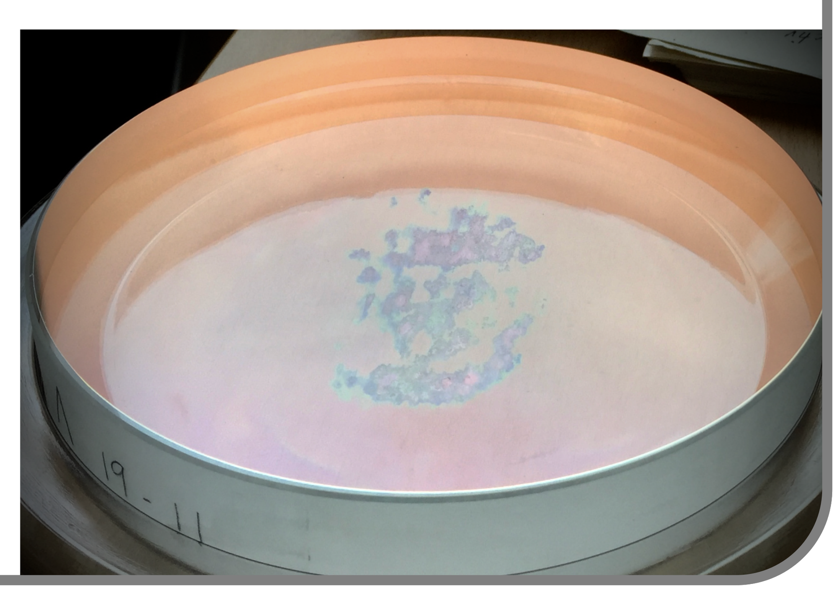
Conclusions for 2-Laser Staged LPWA

The simulation showed the high importance of a clean laser focus.

- Wings outside of the main focus do not contribute to the acceleration
- Using section 2, that means 75.5% of the energy was lost
- Higher density even without guiding should be considered for higher acceleration

Enhancing the reflected focus spot:

- A big issue were the dielectric mirrors as their damage threshold was too low for our set-up (see **Fig. right**) -> lower fluence on mirrors
- Potentially a more complex plasma mirror set-up to enhance the optical quality of the focus spot (3)



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