Coaction of strong electrical fields in laser irradiated thin foils and its relation to field dynamics at the plasma-vacuum interface

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September 30, 2013

Outline

- Motivation
- Basics
- Experiment
- Results
- Discussion
- Conclusion

MBI's High Field Laser Infrastucture

XPW-Frontend:

- Synchronized Laser Operation
- Contrast Ratio[1]: $10^{-10} - 10^{-11}$

Laser Arm 1:

- Ti:Sapphire
- 100 TW
- 25 fs

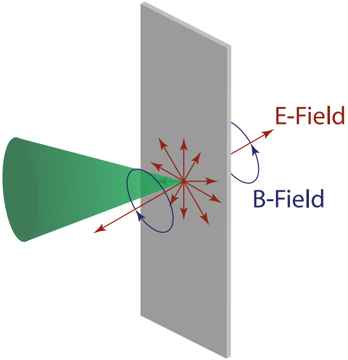
Laser Arm 2:

- Ti:Sapphire
- 70 TW
- 35 fs

[1] M.P. Kalashnikov et al., 2012 AIP Conf. Proc. 1462, 108

Motivation

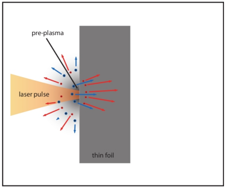
- Quantitative temporal and spatial reconstruction of electromagnetic fields [2, 3, 4]
- Field effects in ultathin foils (30 nm) irradiated with pulses of high temporal contrast
- Post acceleration of ions [5]



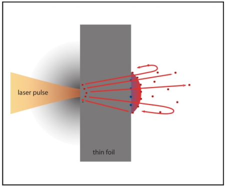
[2] Th. Sokollik et al., 2008 Appl. Phys. Lett.92, 091503, [3] W. Schumaker et al., 2013 Phys. Rev. Lett. 110, 015003, [4] G. Sarri et al., 2012 Phys. Rev. Lett. 109, 205002, [5] S.M. Pfotenhauer et al., 2010 New J. Phys. 12, 103009

Target Normal Sheath Acceleration

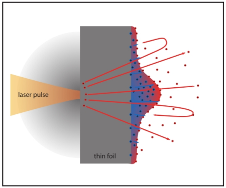
1.) Pre-plasma on thin foil



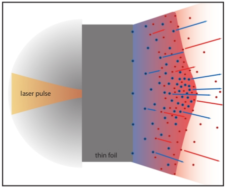
2.) Main pulse interacts with pre-plasma



3.) Formation of an electron sheath



4.) Ion acceleration

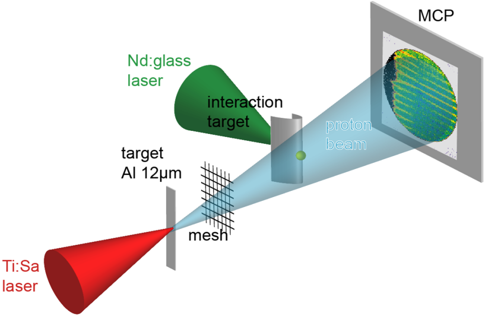


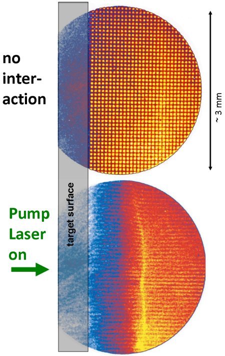
Properties of a laser-accelerated proton beam:

- Divergent beam
- Low emittance
- Broad energy spectrum
- Short acceleration time (200-300fs) for femtosecond laser drive

$\Longrightarrow$ well suited for imaging purposes

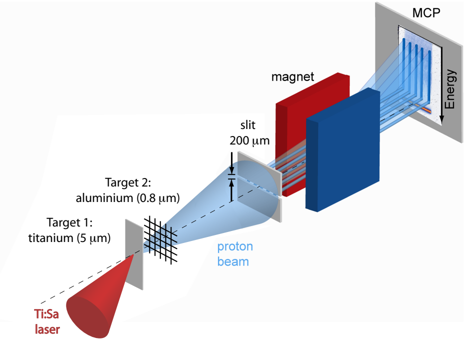
Principle of Proton Imaging

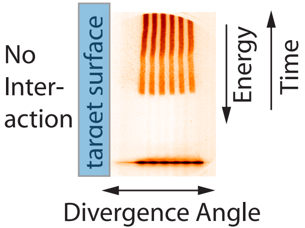




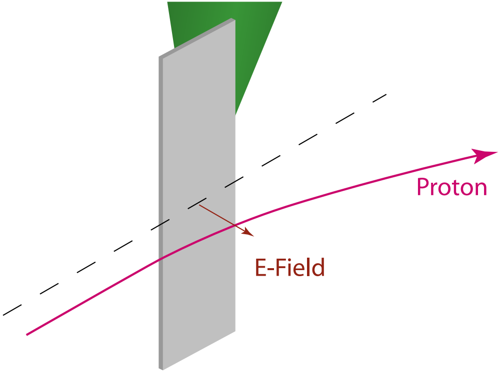
Source:Th. Sokollik

Proton Streak Geometry

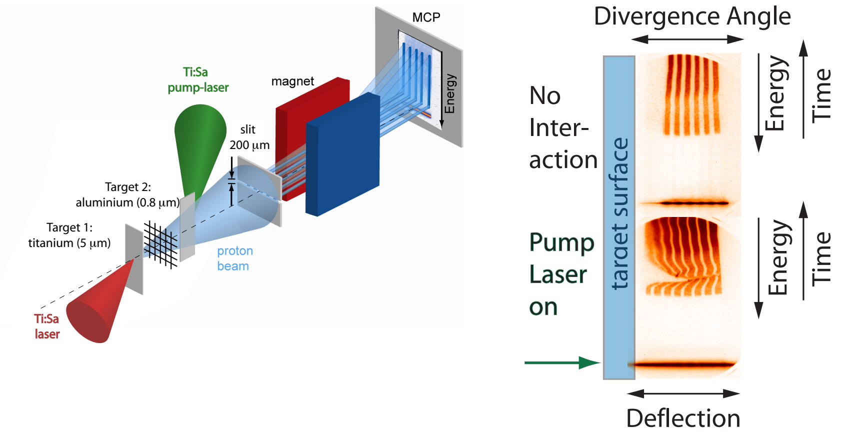




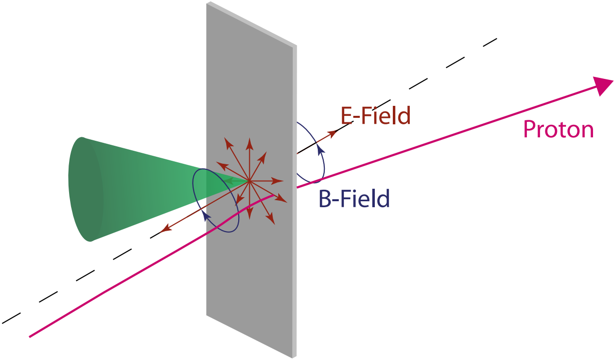
Probing of the target-normal E-Field component



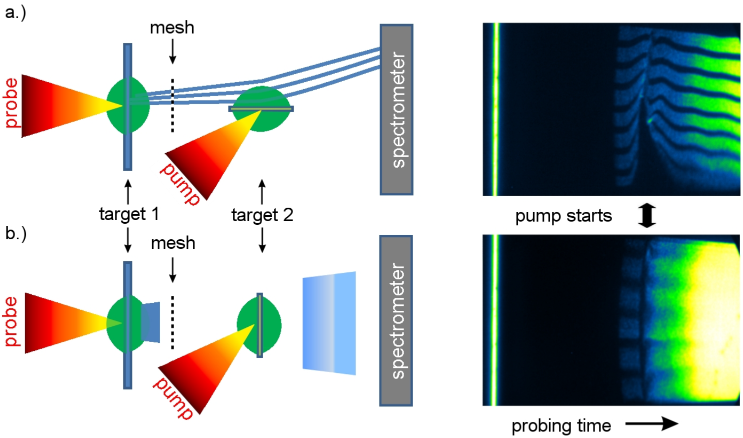
Proton Streak Geometry



Probing of the B-Field and radial E-Field Components

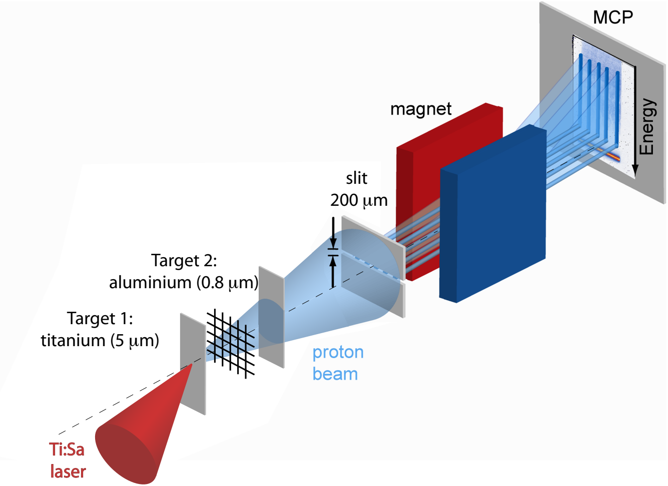


Experimental setups for probing the electromagnetic field distribution of ultrathin foils with high temporal contrast

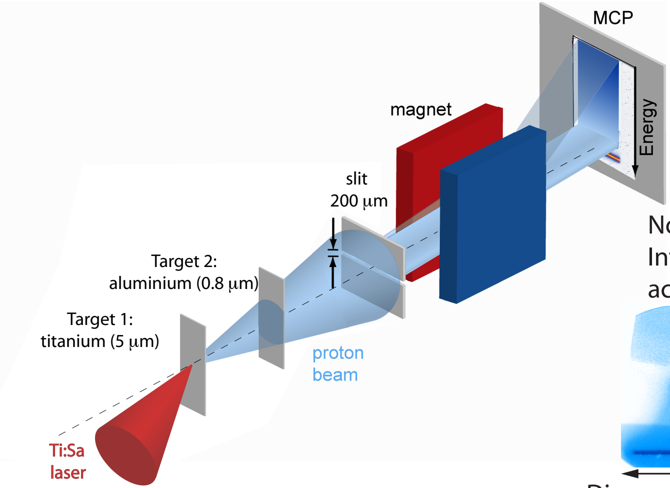


Different probing geometries together with recorded spectrograms

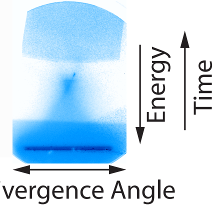
Experimental setup for post acceleration



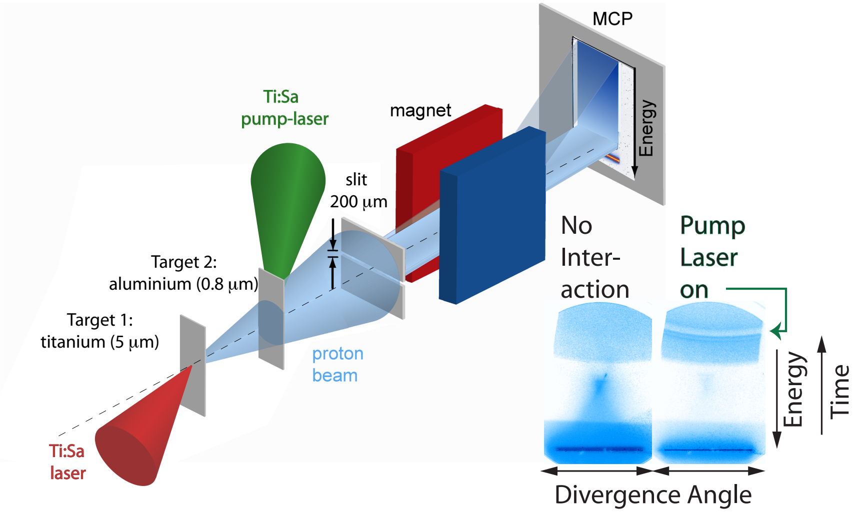
Experimental setup for post acceleration



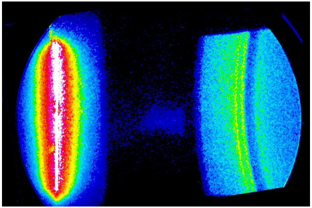
No Inter-action



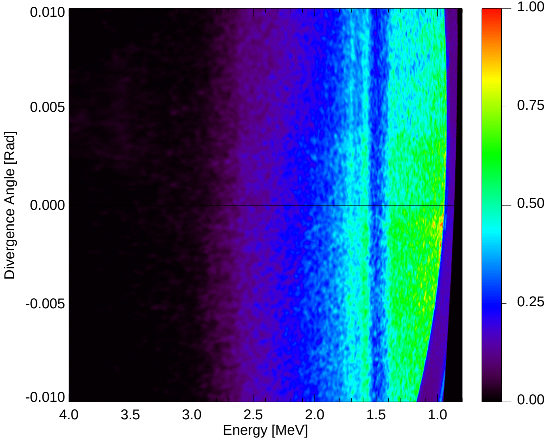
Experimental setup for post acceleration



Data Analysis

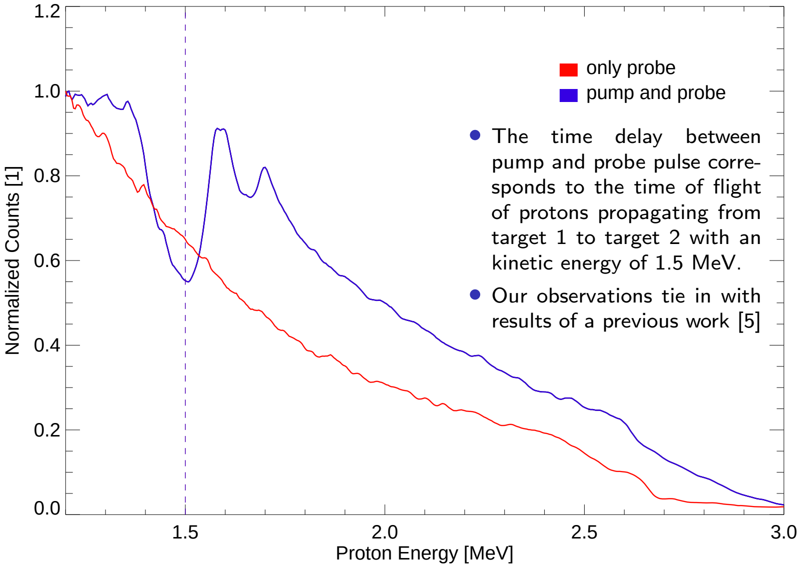


- Bending due to the inhomogeneous field of the permanent magnet
- Measurement of all field components, Particle Tracing & Interpolation ⇒



Processed density distribution of the detector

Results - Averaged Energy Distribution



- The time delay between pump and probe pulse corresponds to the time of flight of protons propagating from target 1 to target 2 with an kinetic energy of 1.5 MeV.
- Our observations tie in with results of a previous work [5]

[5] S.M. Pfotenhauer et al., 2010 New J. Phys. 12, 103009

Discussion

2D3V PIC Simulation

Modelling of the experiment:

- Field lifetime $t \approx 100$fs
- Field Extension d $\approx 2\mu$m
- Ambipolar Field with an amplitude $E \approx 0.15\ E_{Laser}$
- Dips and Peaks depend on target distance and proton energy (time delay)
- Protons move in a temporally and spacially changing field geometry
  $\Rightarrow$ Field components from target rear and front side do not cancel out
- For a small part of protons an averaged field acts which points in one direction

Discussion

Analytical Model

- Force located in some point:

$$F(x,t) = U(t)\delta(x - l_t)$$

- Time dependance:

$$U(t) = \frac{\pm U_2}{1 + [\omega_{pi}(t - t_{12})]^2}\Theta(t - t_{12})$$

ω_{pi} : ion plasma frequency

$t_{12} = l_t/\sqrt{\epsilon_{p12}/2m_p}$

l_t : target distance

Θ : Heaviside step function

$U_2 \approx \epsilon_{e2}$: fast electron energy pulse 2

ϵ_{e1} : fast electron energy pulse 1

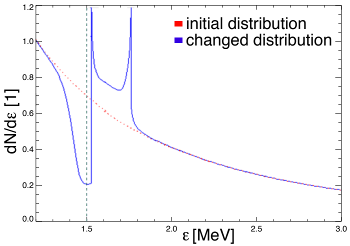
- Isothermal model spectrum:

$$f_i = \frac{\alpha exp(-\alpha\sqrt{\epsilon_0/\epsilon_{e1}})}{2\sqrt{\epsilon_0\epsilon_{e1}}}$$

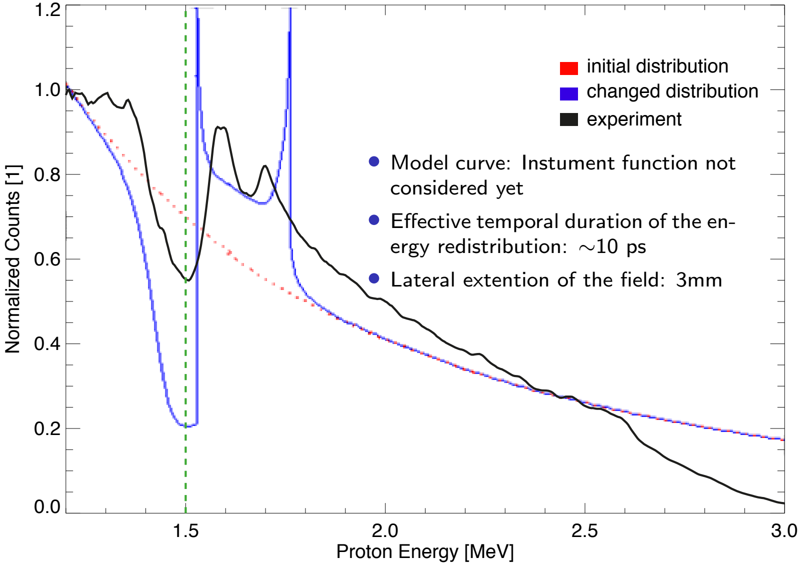
- Changed proton energy distribution:

$$f_c = \frac{\alpha exp(-\alpha\sqrt{\epsilon_0/\epsilon_{e1}})}{2\sqrt{\epsilon_0\epsilon_{e1}}}\frac{d\epsilon_0}{d\epsilon}$$

$$\epsilon(\epsilon_0) = \epsilon_0 + U(L_t/\sqrt{\epsilon_0/2m_p})$$



Discussion



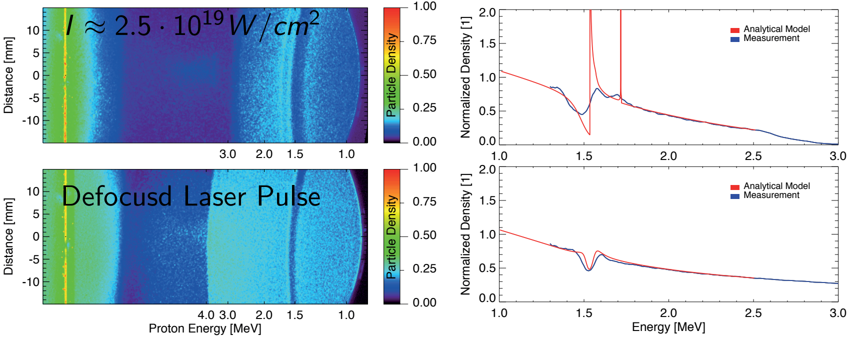
- Model curve: Instument function not considered yet
- Effective temporal duration of the energy redistribution: ∼10 ps
- Lateral extention of the field: 3mm

Discussion

Extension of the model (preliminary):

- Two potentials for front (U_1) and back surface (U_2) of the foil
- Expansion of the foil

The proton redistribution depends strongly on the amplitude ratio U_1/U_2!



Conclusion

- The coaction of strong electrical fields at a laser irradiated foil can have a pronounced influence on the propagation of a proton probe beam.
- The redistribution of kinetic energies is restricted to a sharp but relatively narrow energy range.
- A strong effect to proposed staged laser driven TNSA-like acceleration has not been observed experimentally.
- With our experiments and comparison to model calculation and simulation a better knowledge of the field dynamics will be obtained in order to discuss modified additive acceleration scenarios in laser ion acceleration.

Acknowledgements

Thank you!

This research was supported by Transregio18 (DFG). A.A.A. acknowledges support from LaserLab Europe (Charpac Programme.)

[1] M. P. Kalashnikov, K. Osvay, G. Priebe, L. Ehrentraut, S. Steinke, and W. Sandner. Temporal contrast of high intensity laser systems above 10^11 with double cpa technique. *AIP Conf. Proc.*, 1462:108–111, 2011.

[2] T. Sokollik, M. Schnurer, S. Ter-Avetisyan, P. V. Nickles, E. Risse, M. Kalashnikov, W. Sandner, G. Priebe, M. Amin, T. Toncian, O. Willi, and A. A. Andreev. Transient electric fields in laser plasmas observed by proton streak deflectometry. *Applied Physics Letters*, 92(9), 2008.

[3] W. Schumaker, N. Nakanii, C. McGuffey, C. Zulick, V. Chyvkov, F. Dollar, H. Habara, G. Kalintchenko, A. Maksimchuk, K. A. Tanaka, A. G. R. Thomas, V. Yanovsky, and K. Krushelnick. Ultrafast electron radiography of magnetic fields in high-intensity laser-solid interactions. *Phys. Rev. Lett.*, 110:015003, Jan 2013.

[4] G. Sarri, A. Macchi, C. A. Cecchetti, S. Kar, T. V. Liseykina, X. H. Yang, M. E. Dieckmann, J. Fuchs, M. Galimberti, L. A. Gizzi, R. Jung, I. Kourakis, J. Osterholz, F. Pegoraro, A. P. L. Robinson, L. Romagnani, O. Willi, and M. Borghesi. Dynamics of self-generated, large amplitude magnetic fields following high-intensity laser matter interaction. *Phys. Rev. Lett.*, 109:205002, Nov 2012.

[5] S M Pfotenhauer, O Jäckel, J Polz, S Steinke, H-P Schlenvoigt, J Heymann, A P L Robinson, and M C Kaluza. A cascaded laser acceleration scheme for the generation of spectrally controlled proton beams. *New Journal of Physics*, 12(10):103009, 2010.