Plasma Physics

Intense Ion Beams from relativistic laser plasmas – a promising acceleration mechanism

E. Brambrink

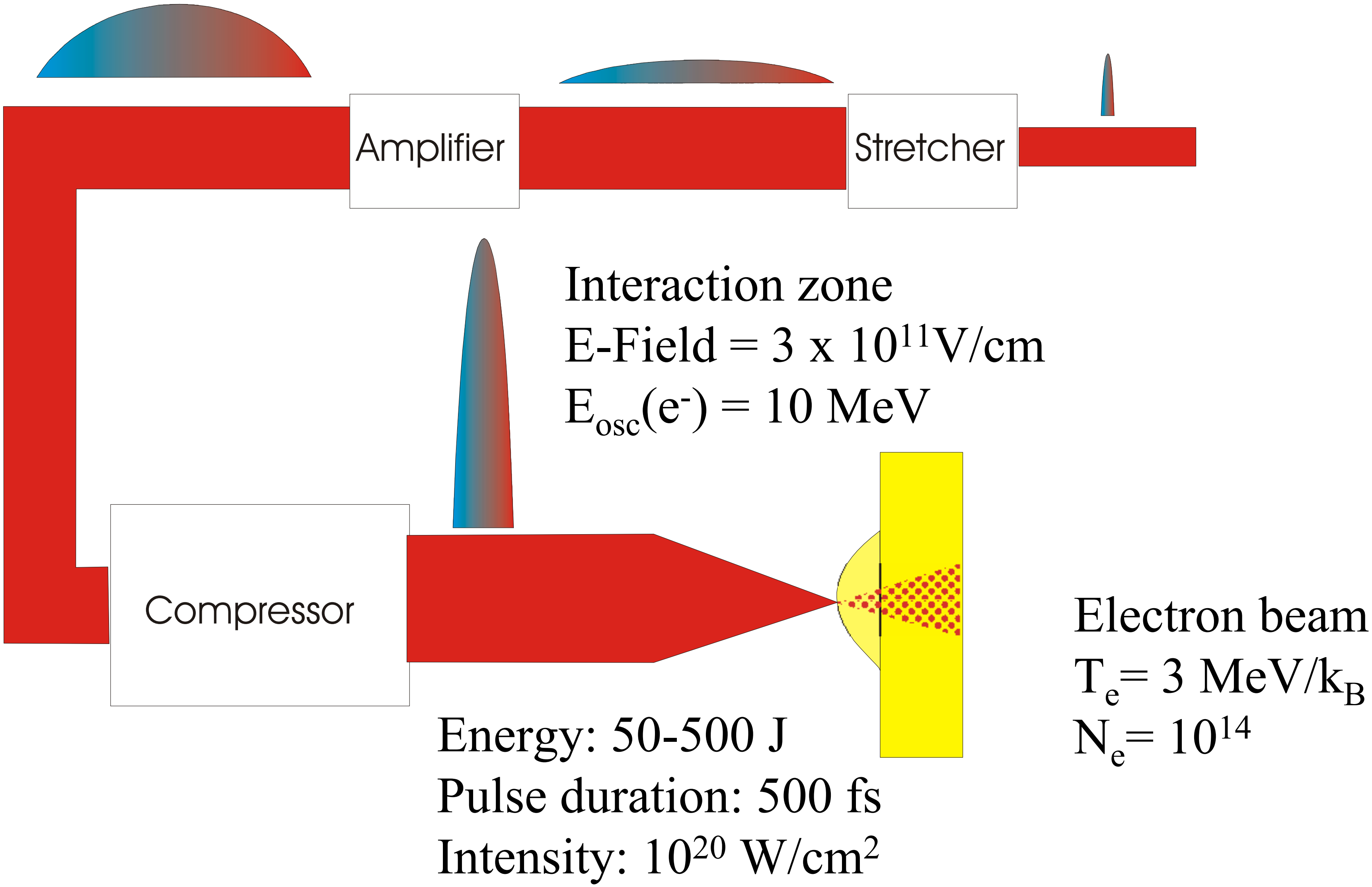
M. Allen
A. Blazevic
J. Fuchs
J.-C. Gauthier
S. Karsch
H. Ruhl

P. Audebert
T. E. Cowan
M. Geißel
M. Hegelich
M. Roth
T. Schlegel

GENERAL ATOMICS

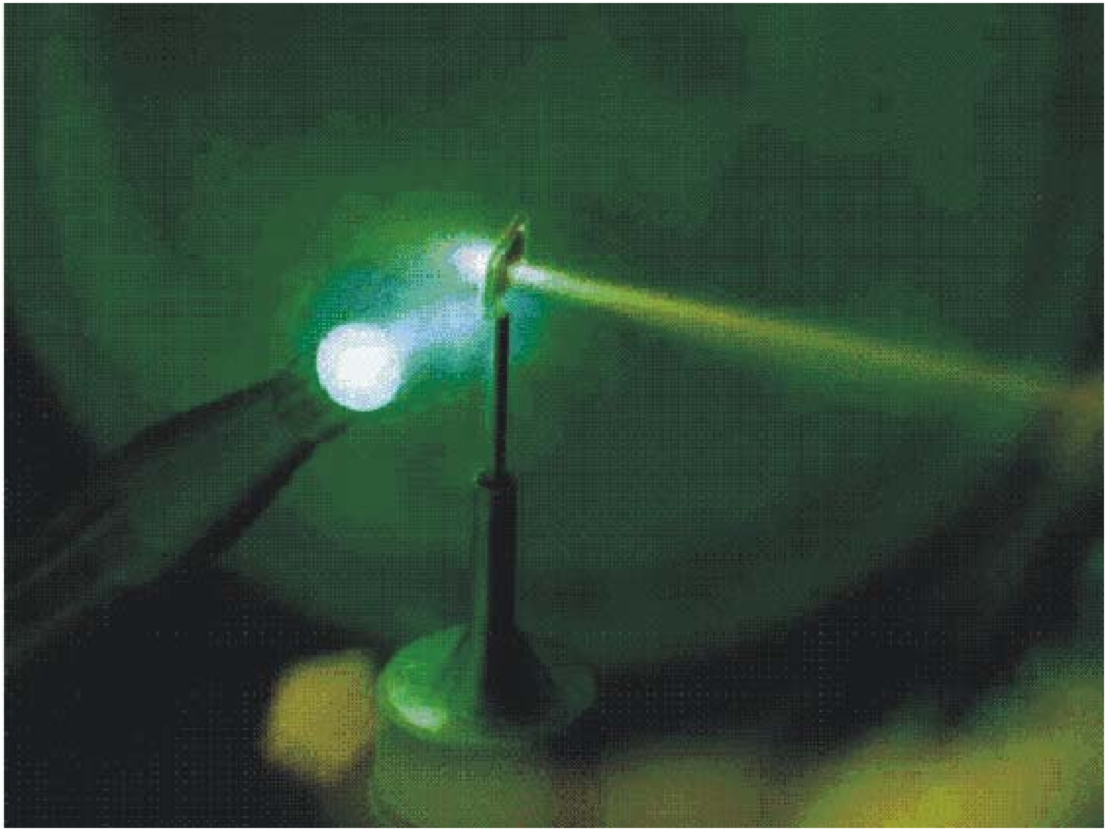
MPQ

Ultra High Intensity Laser



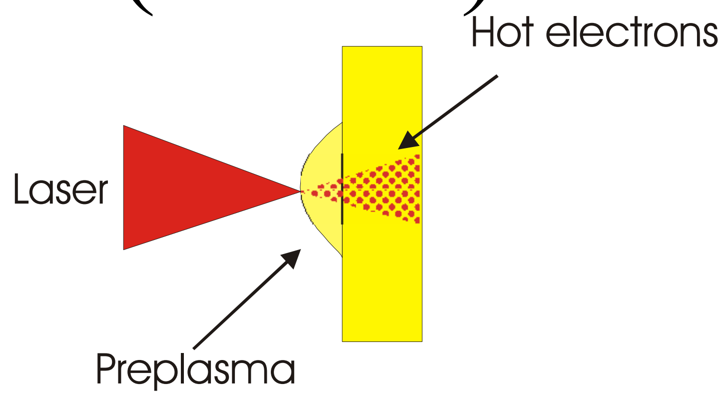
Discovery of intense Proton beams at the Petawatt Laser

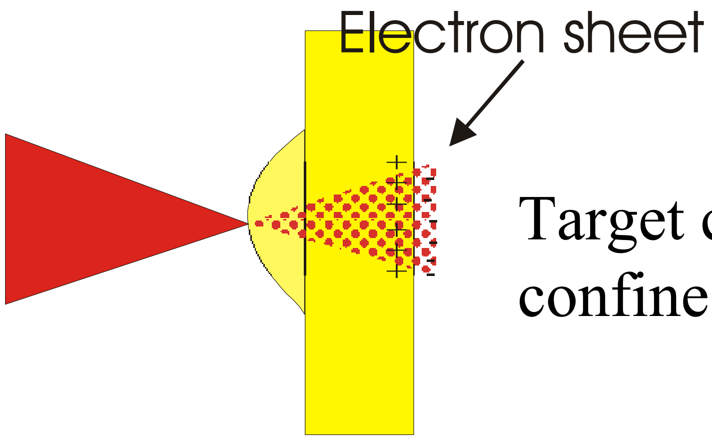
10^{13} Protons per shot
Energy up to 50 MeV
Time < 10 ps
I >50 MA



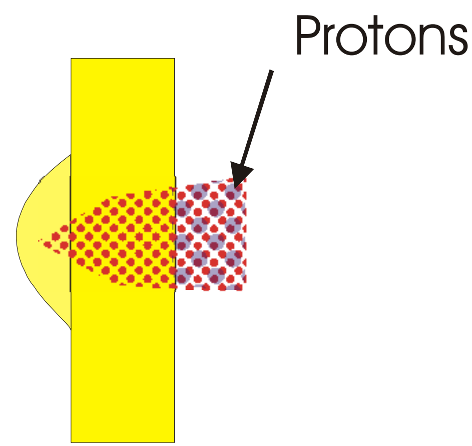
Target Normal Sheath Acceleration (TNSA)

Electrons are accelerated by the ponderomotive force





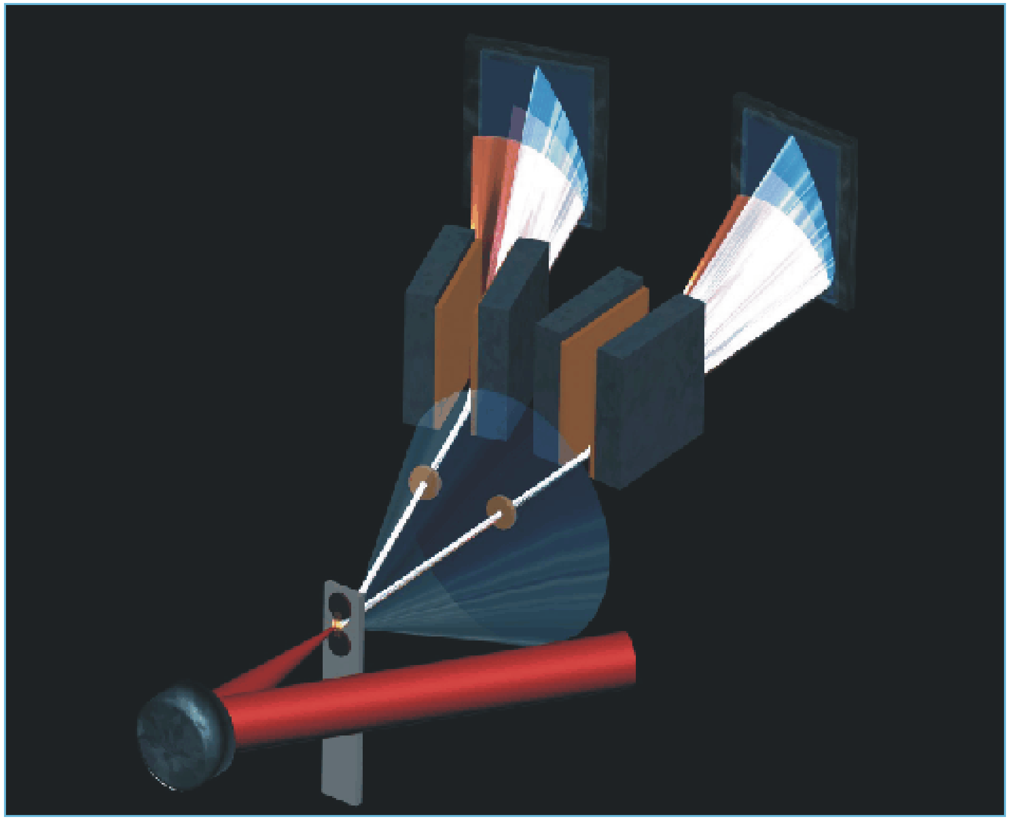
Target charges up and confines electrons



Protons are accelerated by the electron sheath

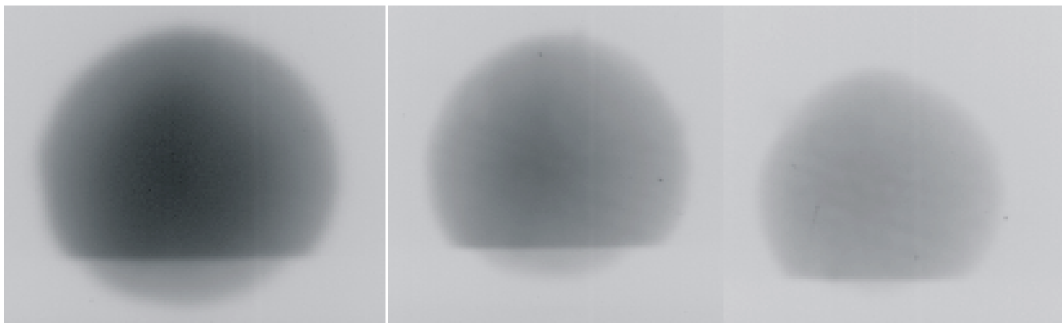
Experimental Setup

Laser:
Luli 100 TW Laser System
30-35 J in 300-500 fs
Intensity: 5×10^{19} W/cm^2



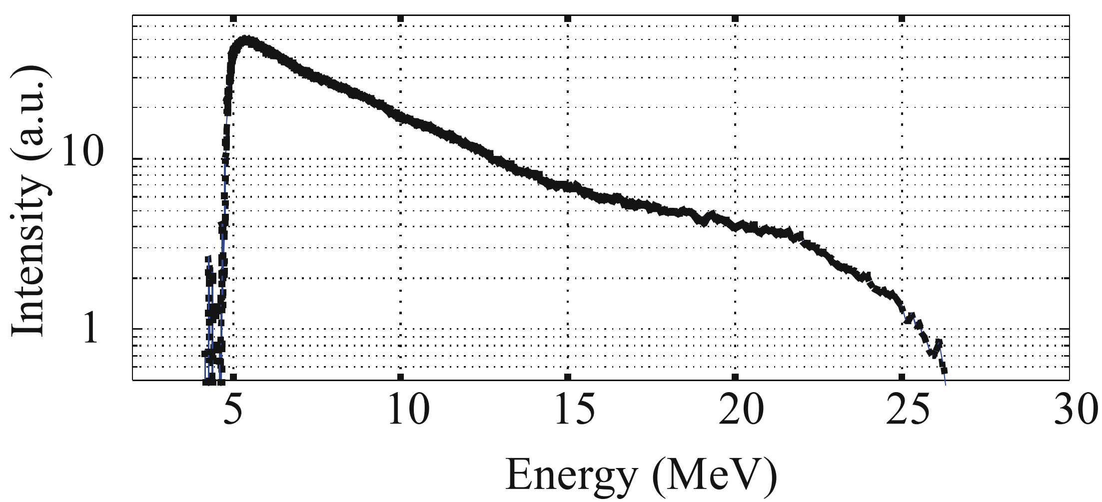
Diagnostics:
Proton spectrometer
Thomson parabola
RCF
Neutron TOF
Nuclear activation

Beam parameters



RCFs placed behind the target show homogenous spatial distribution and energies > 25 MeV

10^{12} Protons
Time < 10 ps
Energy > 25 MeV



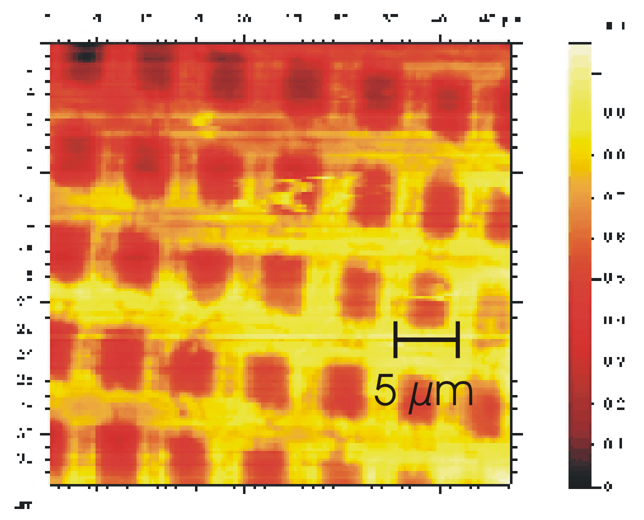
Transverse beam profile

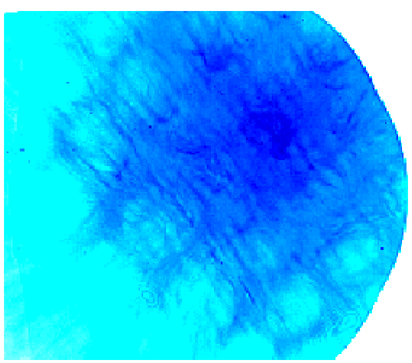
- Experiments at Petawatt showed normalized emittance < 0.53 π mm mrad (limited by detector resolution)
- Improved diagnostic at LULI could lower this value to 0.06 π mm mrad

Structured Targets

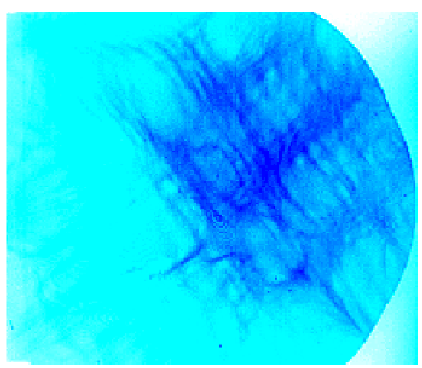
Structures on the backside of the target shape the accelerating electric field and the proton beam

The profile is kept due to the beam quality





6 MeV



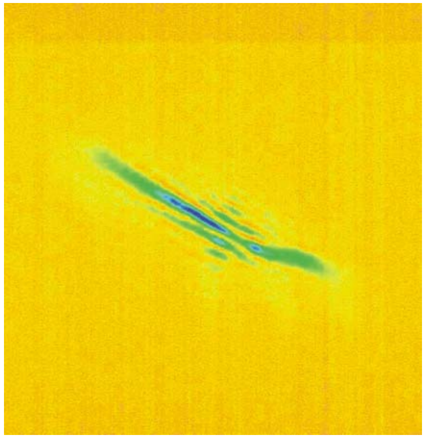
10 MeV

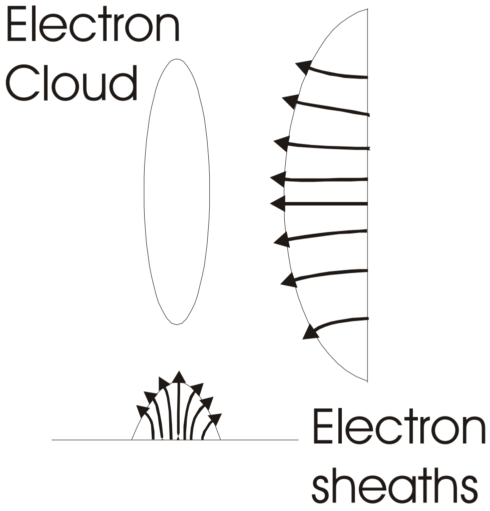
⇨ Beam profile can be shaped by specially designed targets

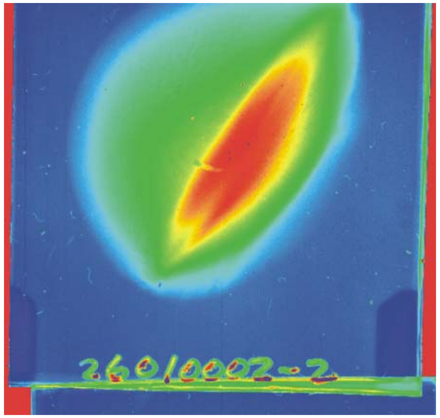
Influence of the laser focus

Asymmetric laser focus produces an asymmetric proton beam

Laser focus







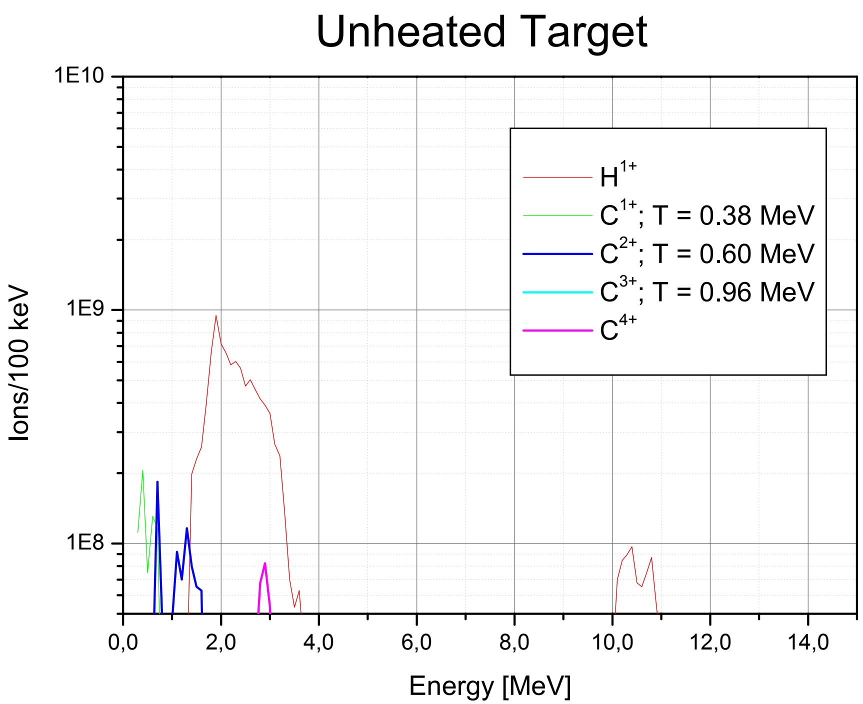
Ion distribution

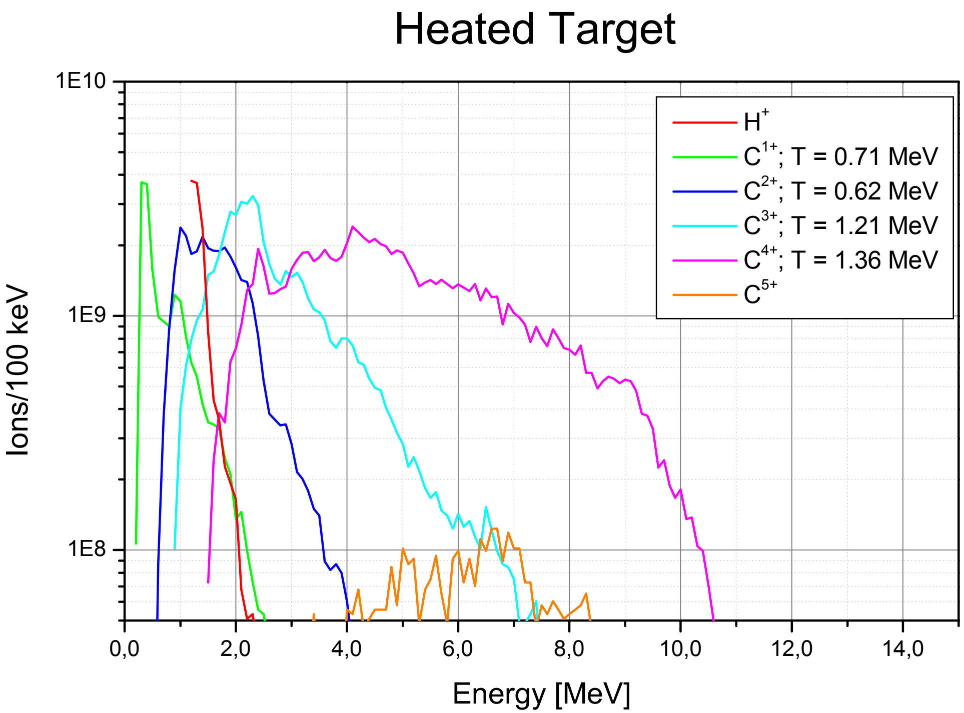
☞Proton beam shaping possible with a suitable laser focus

Acceleration of Ions

Ions are shielded by the accelerated protons

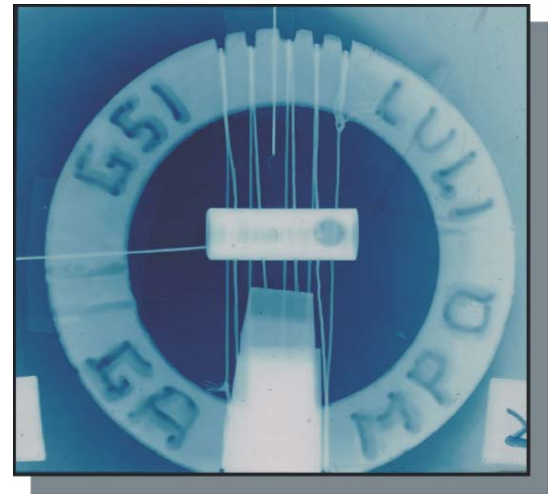
➔ Removing the hydrogen of the target by heating

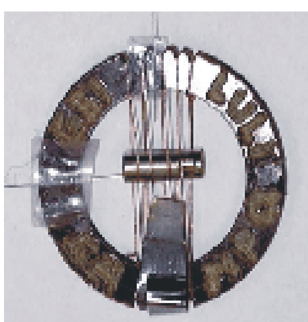




Proton radiography

Due to the proton-matter interaction proton radiography can shadowgraph light ions in an enviroment of heavy material
⇨Complementary diagnostic to x-ray radiography

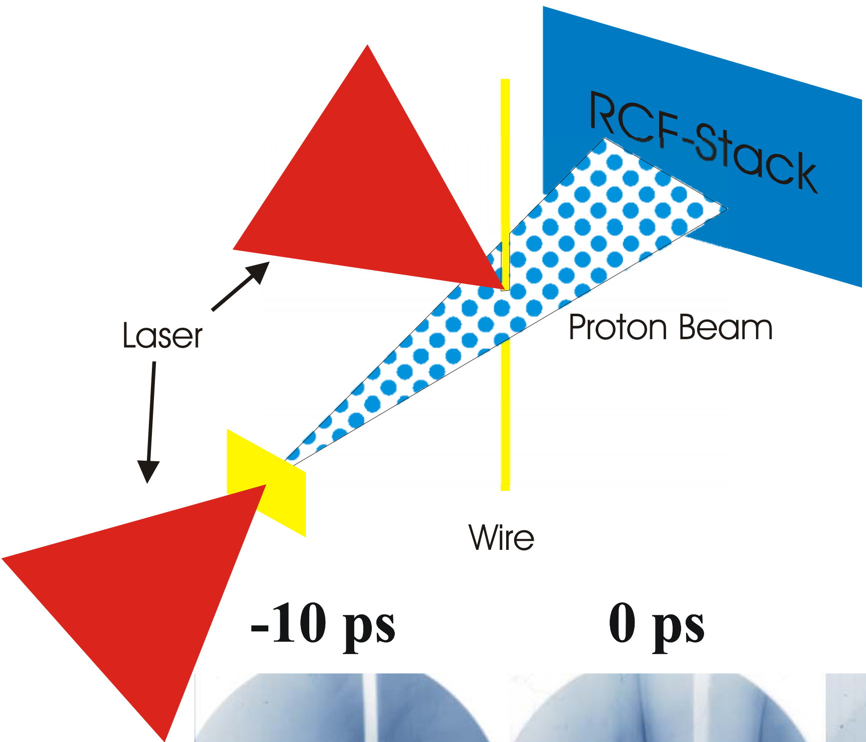




Cu-wires 250μm
Steel Hohlraum
300 μm wall thickness
Ti - layers 100μm
Epoxy-ring 1.5mm
Glass semi - spheres
900 μm dia., 20 μm wall

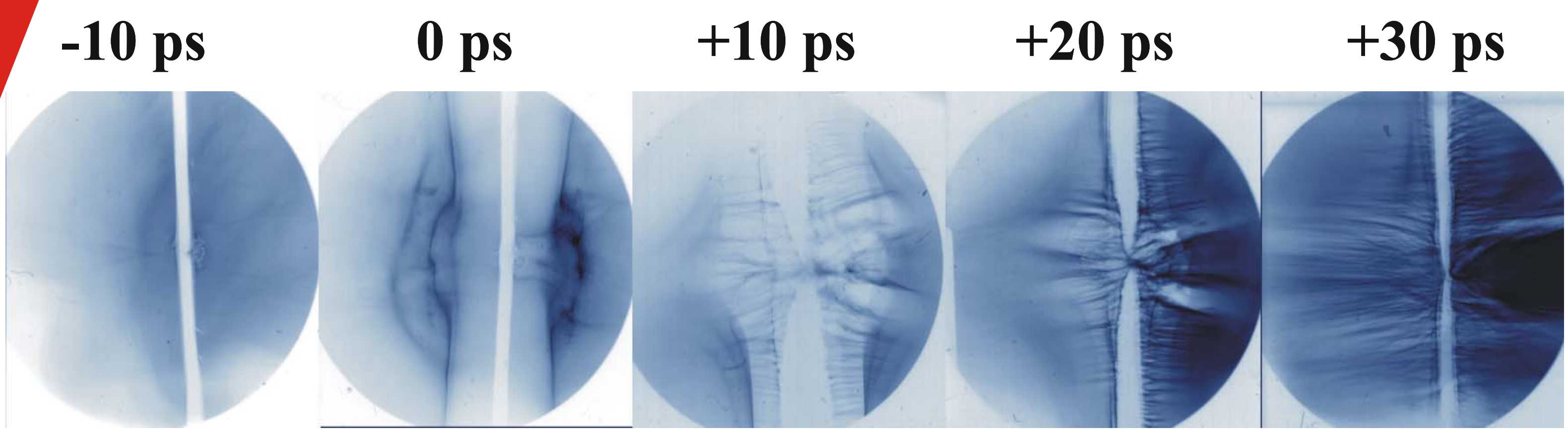
Laser accelerated protons with their excellent beam quality offer radiography with high spatial and temporal resolution

Electric field mapping



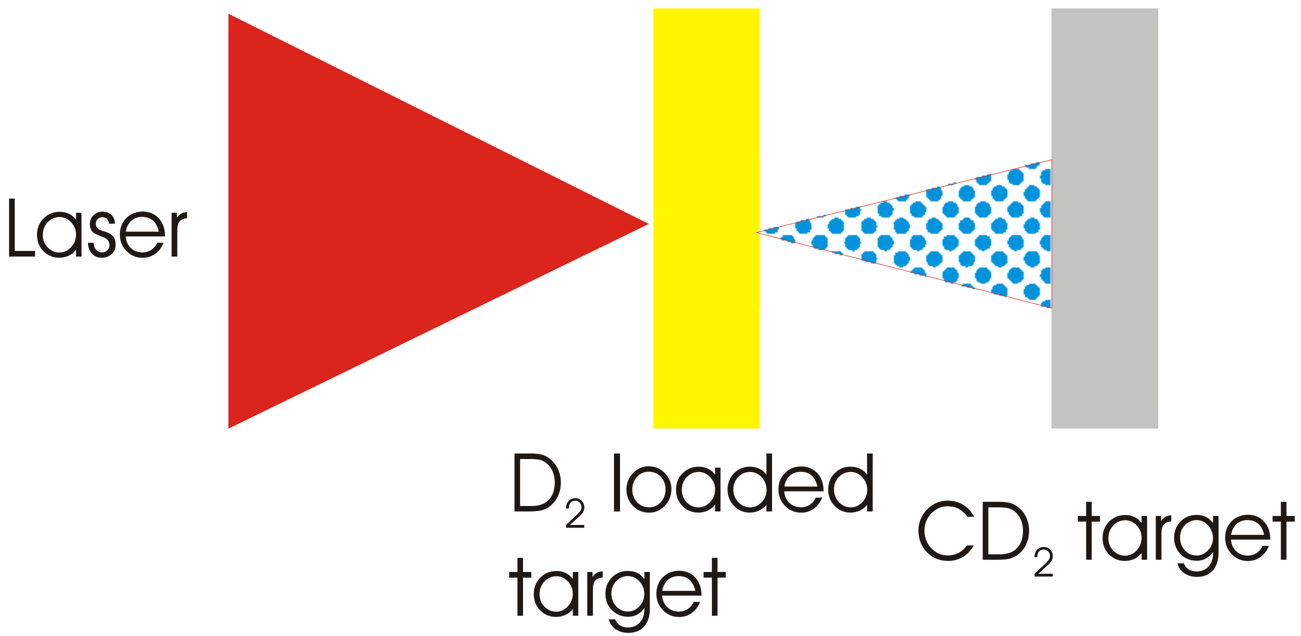
-Direct mapping of electric fields with high temporal resolution

-Different time of flight for different energies offers mapping at different times in one shot



M. Borghesi *et al*. Plas. Phys. and contr. Fusion **43**,A267 (2001)

Pulsed neutron source



10^8 neutrons per shot

Accelerated deuterons are used for
$D+D \rightarrow {}^3He+n$ reactions

Injector for accelerators

Laser accelerated ions could be an alternative for classical ion sources and injectors

Advantages:

- Beam parameters and quality are comparable or better
- Smaller size and easier to operate

Open questions:

- Phase space matching
- Low repetition rate

Phase space matching

Transverse:

- Large divergence requires strong focusing quadrupoles (B$\sim$2.5 T)

Longitudinal:

- use only a small part of energy spectrum for classic accelerators ($5x10^9$ at 20 MeV)
- high gradient accelerator (DWA)

Laser improvement

- Practical applications require high repetition rate
- Repetition rate limited by cooling time due to inefficient pumping with flash lamps

➔ Pumping of the laser with laser-diodes

POLARIS project (Jena, Germany):

150 J in 150 fs → 1 PW

0.1 Hz repetition rate

Conclusion and Outlook

- Ion beams from relativistic laser plasmas have unique properties
- Beam shaping possible (focus, target)
- Serveral applications (radiography, fast ignitor, neutron source)
- Alternative for classical injectors in special cases

Thanks to

Abel Blazevic, Matthias Geißel, Markus Roth, Theodor Schlegel
Gesellschaft für Schwerionenforschung, Darmstadt

Patrick Audebert, Julien Fuchs, Jean-Claude Gauthier
Laboratoire pour l'utilisatoin des laser intense, Paliseau

Stefan Karsch, Manuel Hegelich, Alexander Pukhov
Max-Planck-Institut für Quantenoptik, Garching

Tom Cowan, Matt Allen, Hartmut Ruhl
General Atomics, San Diego

Laser staff of LULI

Supported by EU programm № HPRI CT 1999-0052