Acceleration field dynamics and source characteristics of ultrafast laser driven ion acceleration

W. Sandner[1], M. Schnürer[1], S. Ter Avetisyan[2], T. Sokollik[1],

S. Steinke[1], A.A. Andreev[3] , P.V. Nickles[1]

[1] *Max-Born-Institut Berlin*
[2] *Department of Physics and Astronomy, The Queen``s University of Belfast*
[3] *S.I. Vavilov State Optical Institute, St. Petersburg 199034, Russia*
guest scientist at the Max-Born-Institute

ICUIL 2008, Shanghai, 27.-31. October 2008

Motivation

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A detailed understanding of the evolution of strong fields in relativistic laser plasma

→ improvement of predictions and measures
how to reach the desired parameter range for applications.

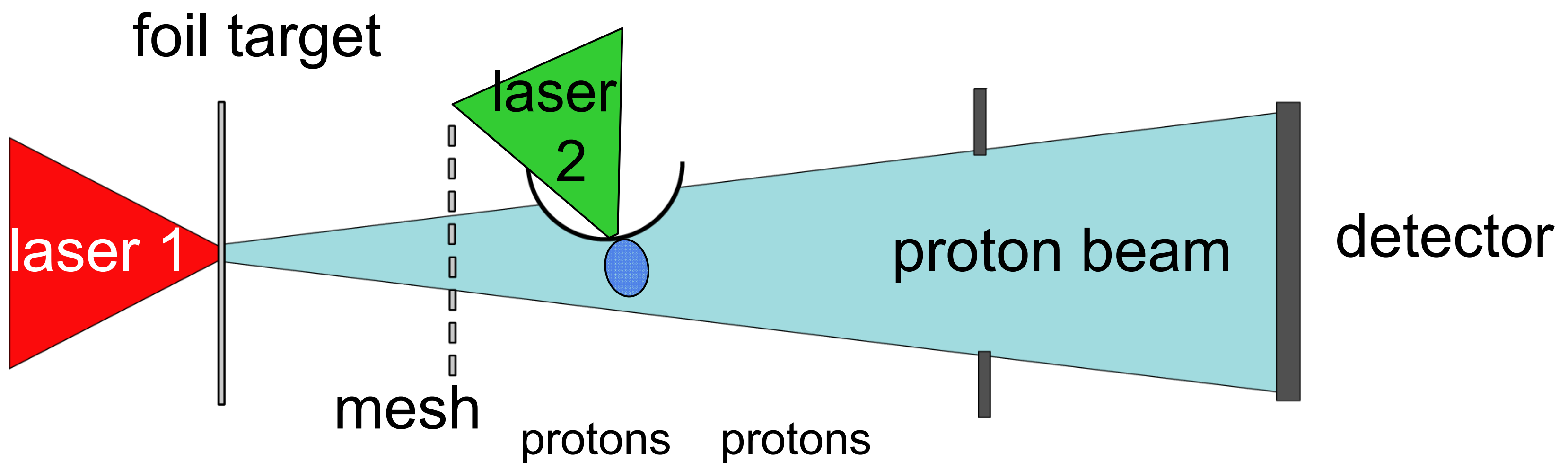
We explore strong field dynamics at different targets with improved proton imaging techniques

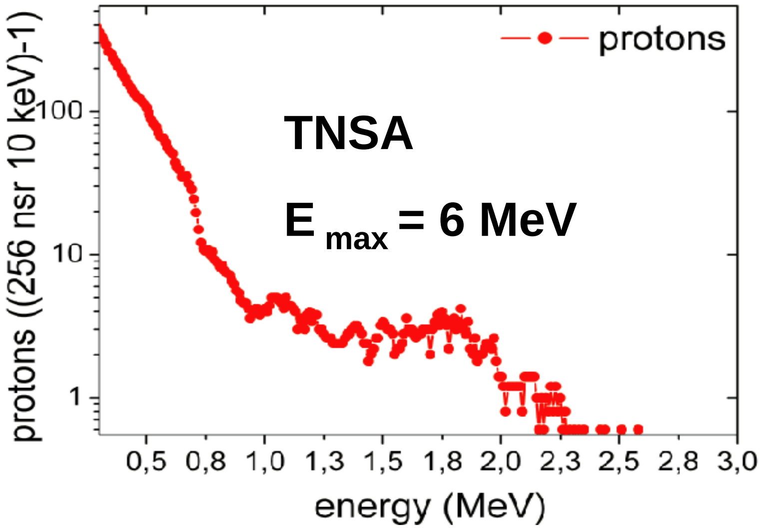
Methodes

- **imaging with ´´online´´ detection (gated MCP/CCD) enabling efficient use of ´pump – probe´ techniques**
- **streaking transient fields**

→ **diagnostic tool for imaging temporal evolution of field structures of laser driven mass- limited micro-targets**

Proton Imaging Scheme





beam features:

- high laminarity
- short bunches
- broad spectra

- 2D snapshots
- detector: MCP
- gating of exposure time determines energy interval and thus the probing time at object

Proton imaging of different target types

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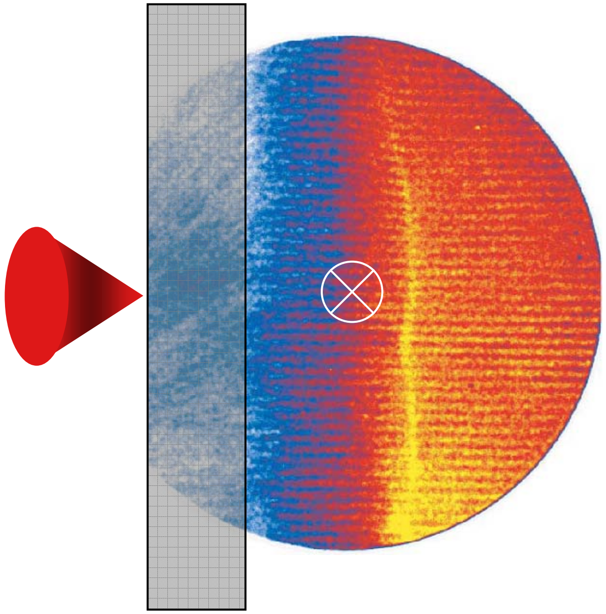


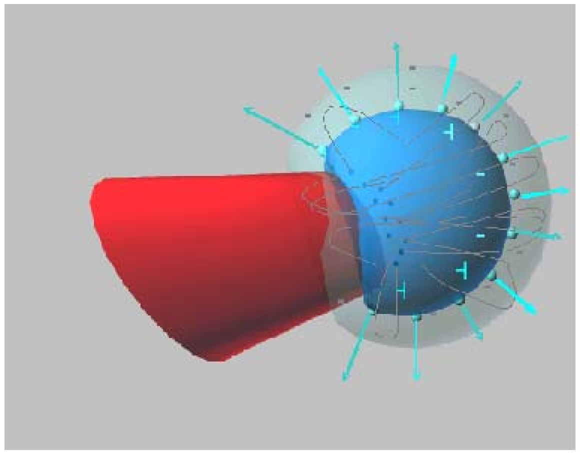
Planar target:

- emission angle ~ 10-20° (half angle)
- continuous energy spectrum
- extended proton source
  → lateral spread of electrons over mm

Mass-limited targets:
- micro-spheres -

- electron spread limited

→ theory predicts
- enhanced laser to ion energy conversion
- enhanced proton energies



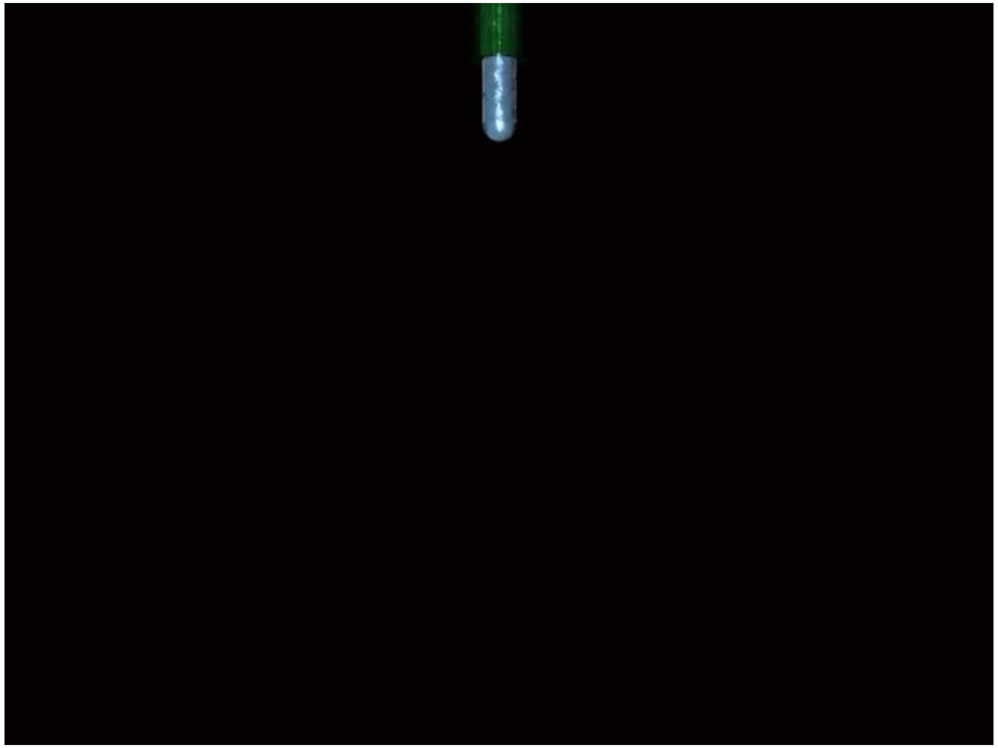
resolve different experimental observations for
water droplets – MBI
bonded micro-spheres - MPQ

?

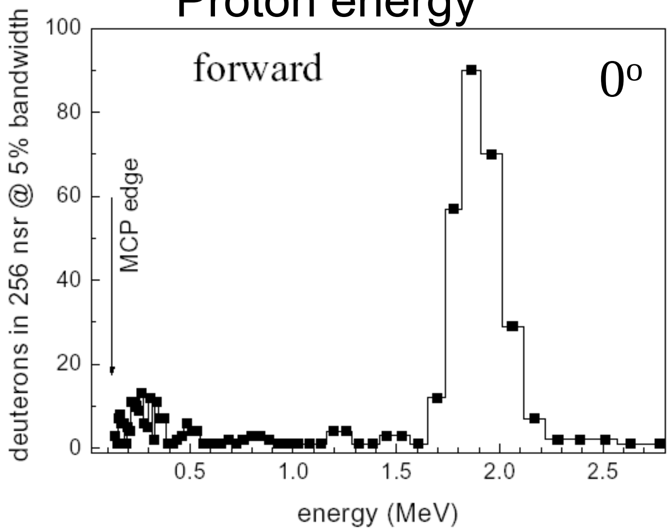
*A.V. Brantov et al. PoP **13**, 122705 (2006), M. Schnürer et al. PoP **14**, 033101 (2007)*

Mass-limited targets - water droplets

S. Ter-Avetisyan et al., PRL **96** 145006 (2006)



Proton energy



- monoenergetic deuterons around 2 MeV
- non-isotropic forward ion emission
- relevant for applications

Further investigations using proton imaging

Proton imaging of mass-limited targets

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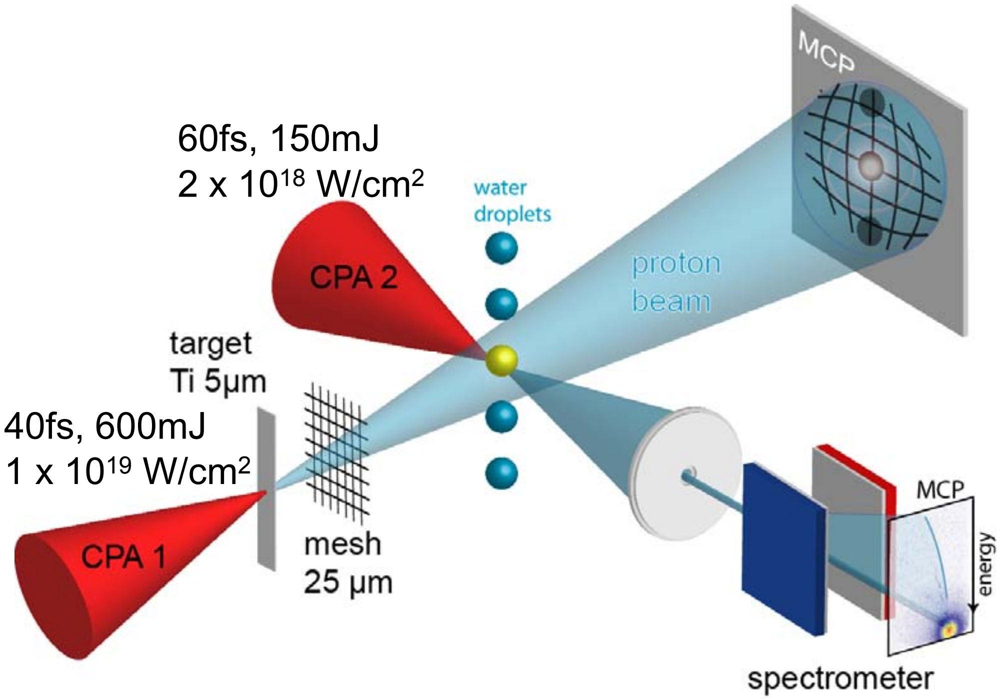
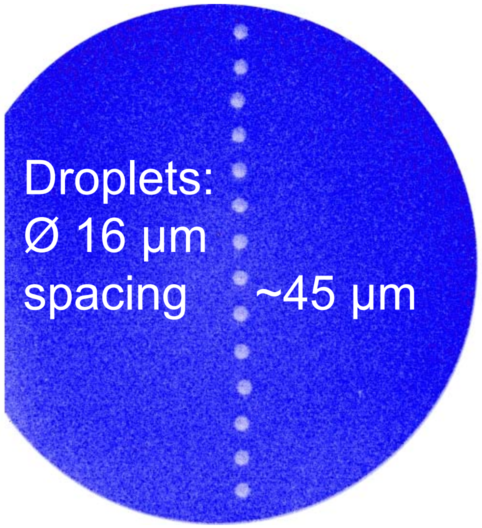
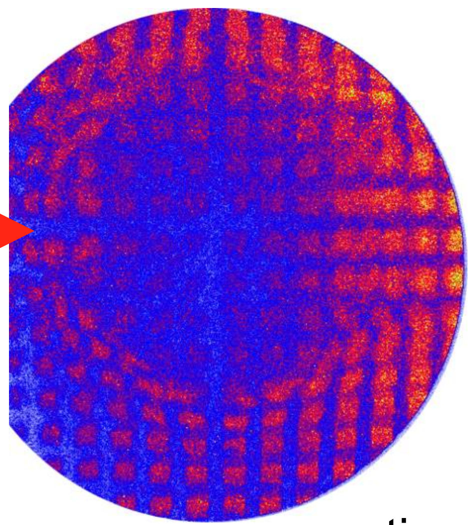
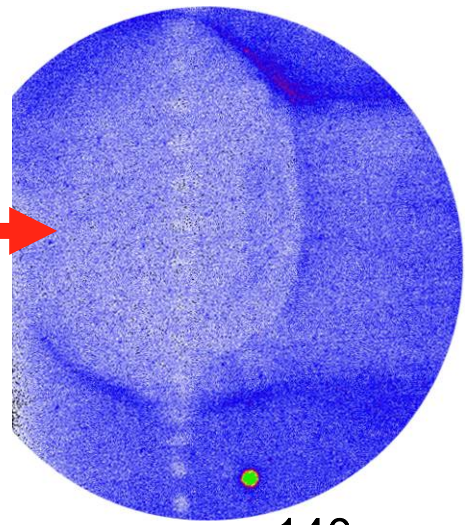


magnification ~70 fold
MCP gating ~ 5-15 ns





exposure time 65 ps



140 ps

Mass-limited targets – droplet charge up

Estimation of laser-produced hot electrons

energy (temperature) $T_h \approx m_e c^2(\gamma - 1)$

with $\gamma = (1 + 0.7\, I_{18}\, \lambda^2_{L,\mu m})^{1/2}$ and $I_{18} = 2$

$$T_h \approx 190 \text{ keV}$$

and the number of electrons which can escape (charge up)

$$N_{eh} \approx \frac{m_e c^2 4\pi\varepsilon_0 r_L}{e^2}(\gamma - 1)$$

$$N_{eh} \approx 5 \cdot 10^8 \text{ for } r_L = 5 - 8\, \mu m$$

gives $0.10\text{-}0.17 \text{ nC}$ droplet charge up

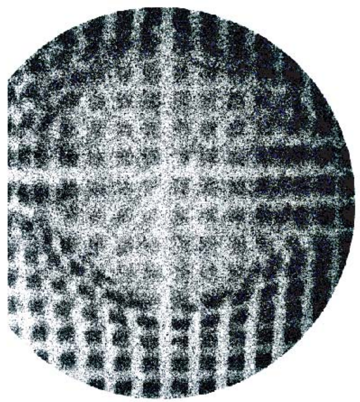
and fits well with the following result of proton ray-tracing

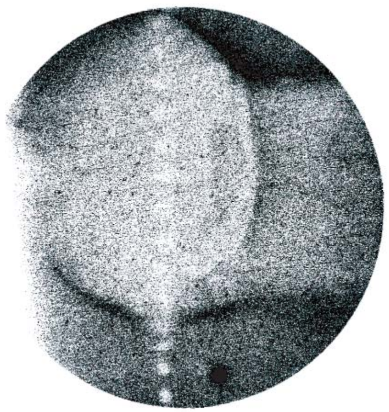
Proton Imaging of mass-limited targets

Q_0~ 0.14 nC
decay:
t ~ 50 ps

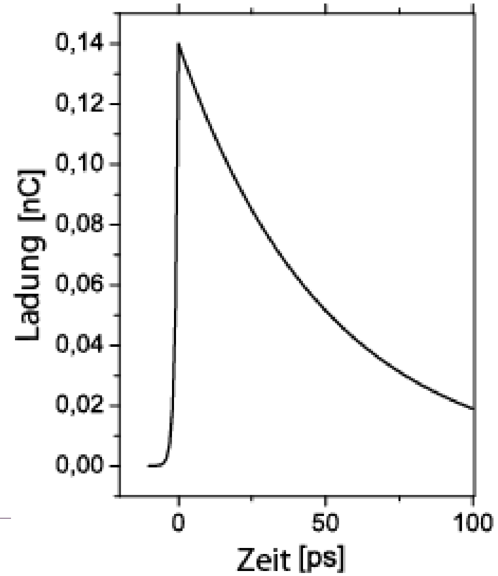
+ion front **Laser**

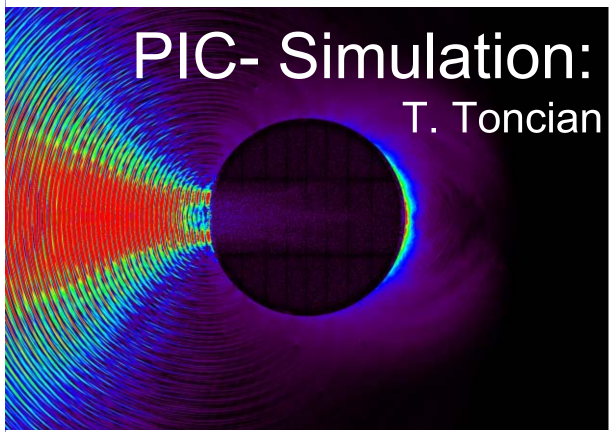
Experiment





1/6 Q_0
2/3 Q_0
1/6 Q_0





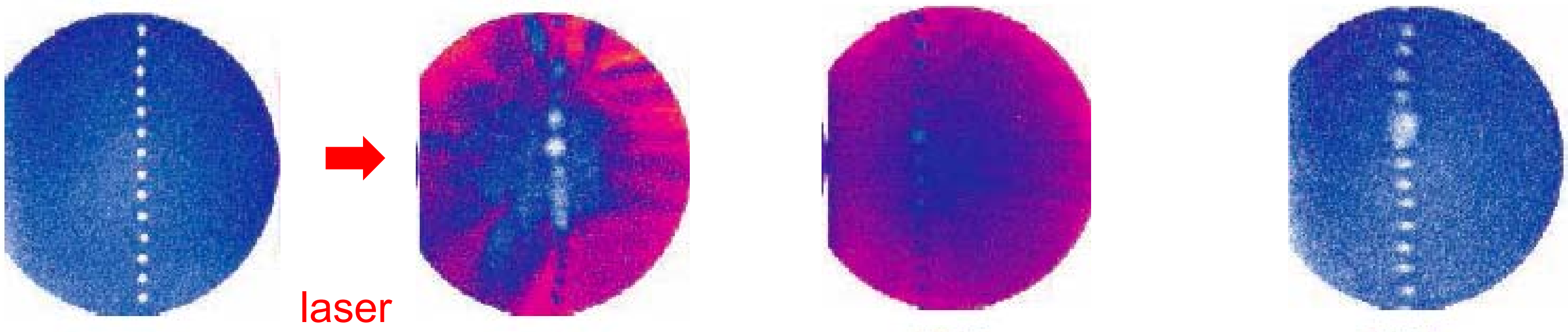
electric field distribution

General particle tracer

T. Sokollik, PhD-thesis

Proton Imaging of mass-limited targets

Snapshot series:



-100 ps | 0 ps | +153 ps | +634 ps

magnified image of droplet
(action of field)

field fades away
hydrodynamic expansion

Next step: investigation of micro-spheres
without ambient plasma background

Summary

Novel imaging techniques:

- “proton streak deflectometry”
- proton imaging using gated MCP-detectors

Foil-targets:

- Dynamics of different electric field components up to 10^8-10^9 V/m varying at ps/ns time scale

Micro-sphere-targets:

- Proton images of isolated micro-spheres, for the first time
- enhanced electric field at the rear side observed, associated with a directional ion emission

Outlook:

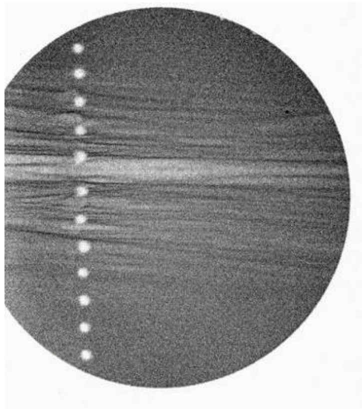
→ TNSA modification and especially realization of photon pressure acceleration should be accompanied by typical fingerprints of field dynamics

need:

ultra-short, intense, high temporal contrast laser pulses
targets with low mass and/or real isolation
increased (temporal) resolution in measurement

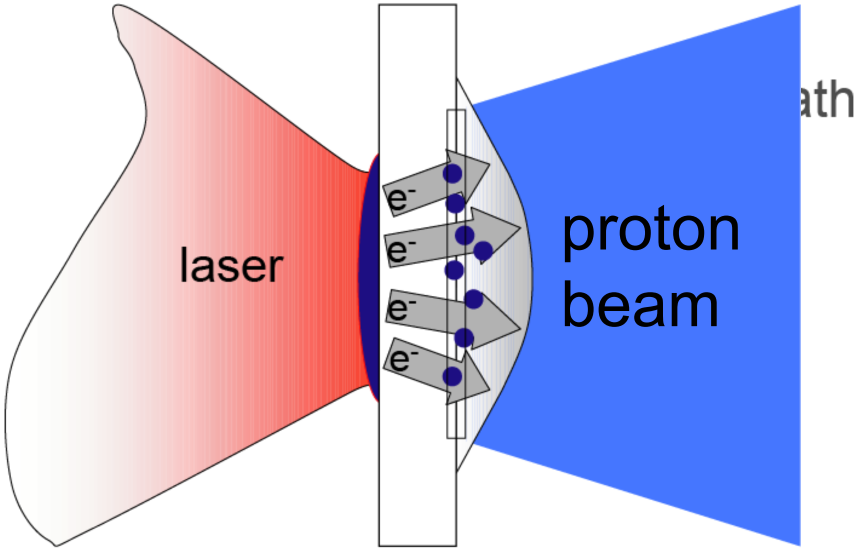
Thank you

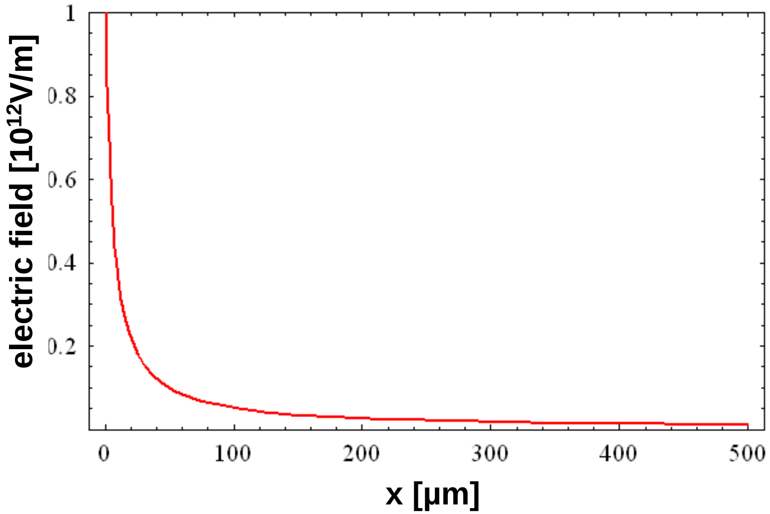
Beam break up in the ambient gas created by evaporation of the droplets



Proton Acceleration

Target Normal Sheath Acceleration (TNSA)

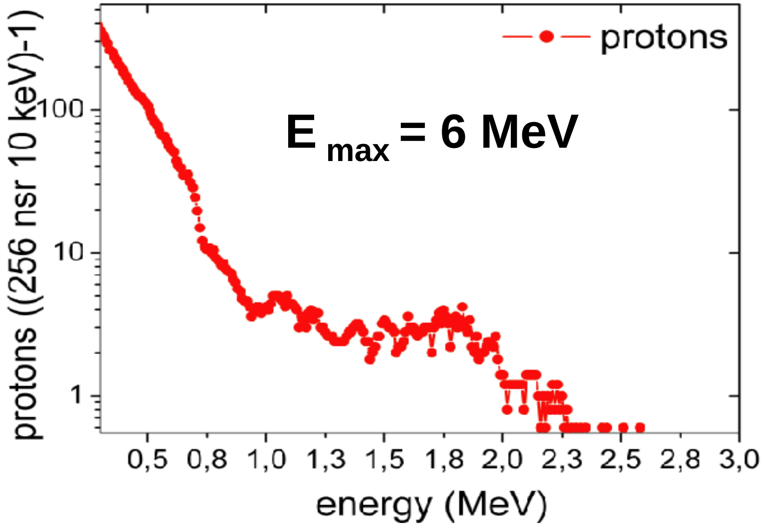




MBI HFLaser
40 fs Ti:Sa
2×10^{19} W/cm^2

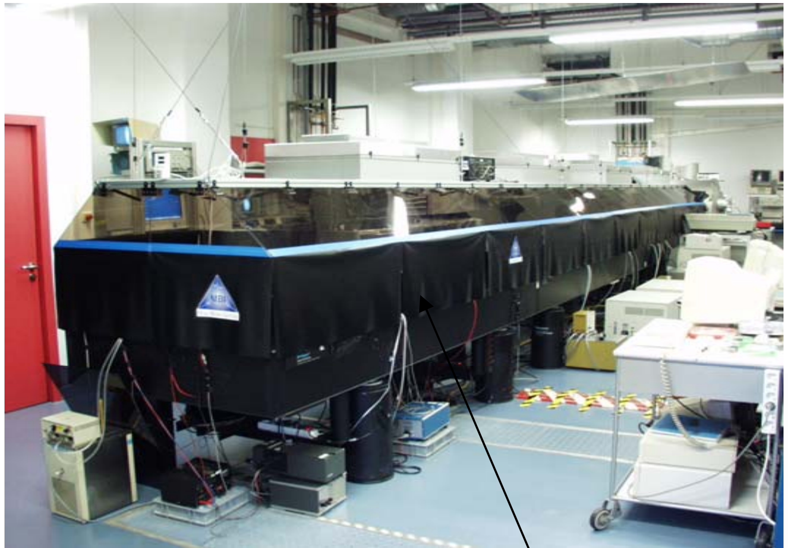
beam features:

- high laminarity
- short bunches
- broad spectra



Proton imaging: MBI approach

Two separate, synchronized ultra-high intensity lasers



Synchronization

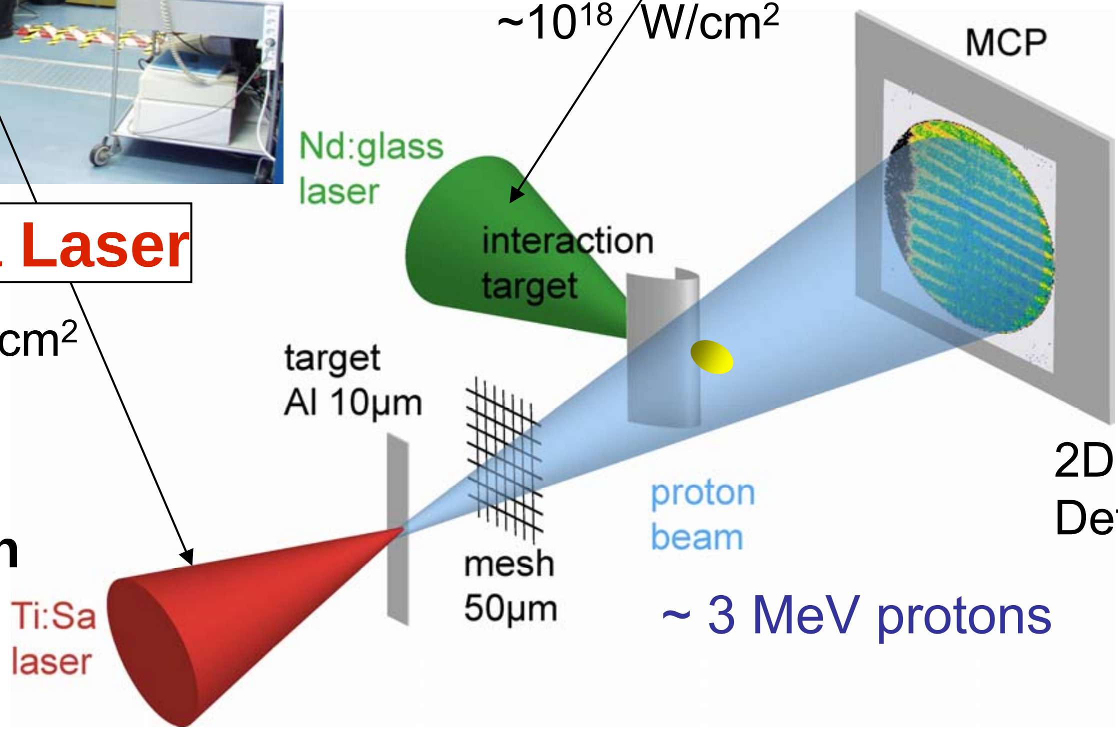
(~ ps)

Glass Laser

1-2 ps ,
~10^{18} W/cm^2

Ti:Sa Laser

40 fs , ~10^{19} W/cm^2



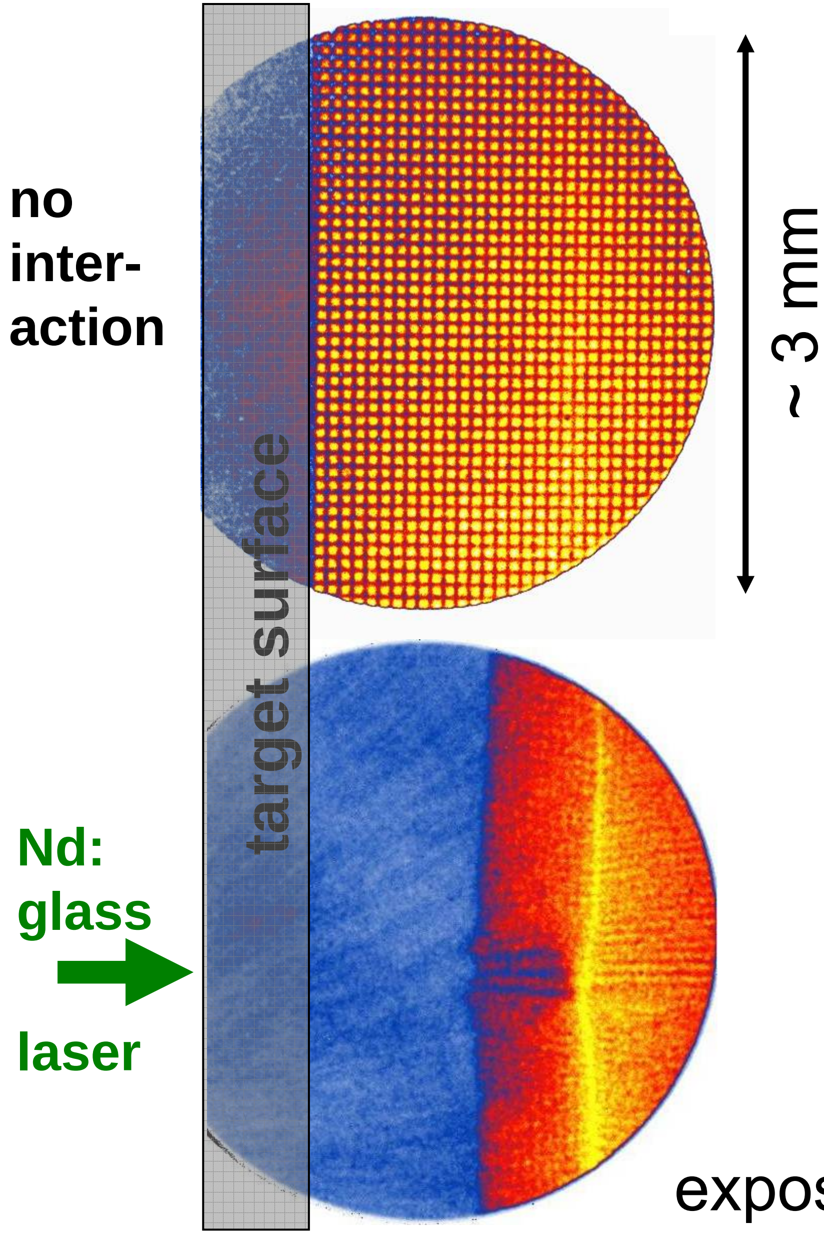
Plasma – Proton Pump

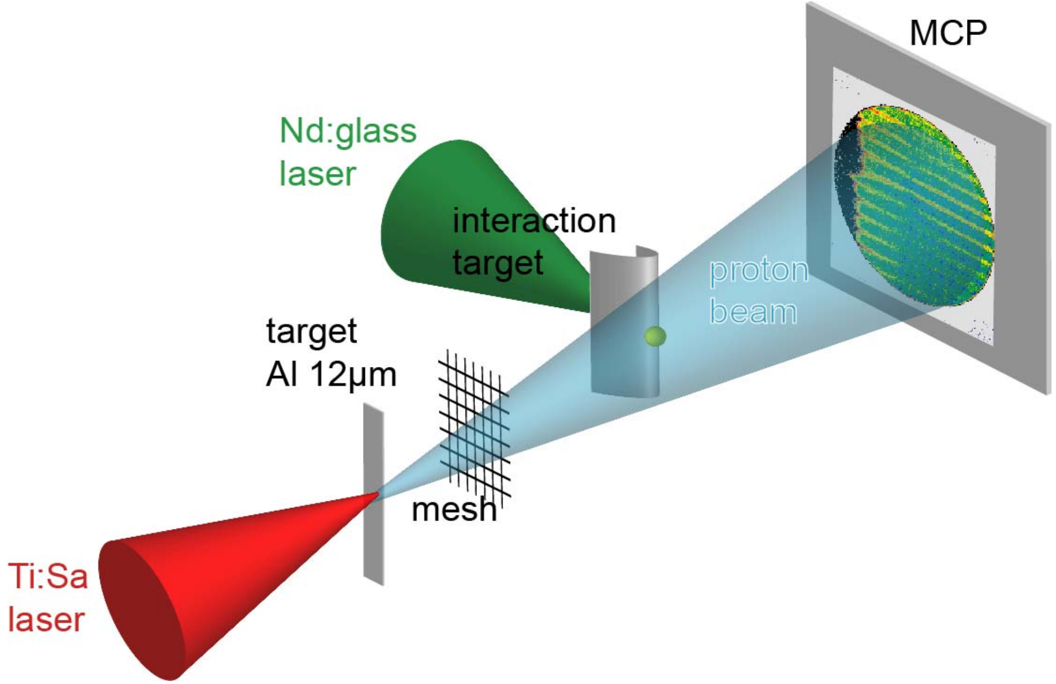
2D – Proton Detector

~ 3 MeV protons

Nickles, 3.9.07

2D Proton Imaging – with MCP





Ti:Sa	Nd:glass
40 fs,	1.5 ps
~ 10^{19} W/cm^2	~10^{18} W/cm^2

synchronized

exposure time: ≤ 400 ps

Motivation

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Proton imaging gives insight in high field physics phenomena…

- structure of acceleration fields in laser driven ion acceleration
  M. Borghesi et al. PoP **9**, 2214 (2002)
  L. Romagniani et al. PRL **95**, 195001 (2005)

- electric and magnetic field measurement in plasmas
  C.K. Li et al. PRL **97**, 135003 (2006)

- magnetic field reconnection in plasmas
  P.M. Nilson et al. PRL **92**, 255001 (2006)

- transport processes in plasmas (soliton structures)
  M. Borghesi et al. PRL **88**, 135002 (2002)

- compression of matter in fusion research
  J.R. Rygg et al. Science **319**, 1223 (2008)

- spatially extended strong fields for ion beam deflection
  T. Toncian et al. Science **312**, 410 (2006)

Experimentally, present knowledge has been derived from few images spotting the dynamics of the process

2D Proton Imaging – with MCP

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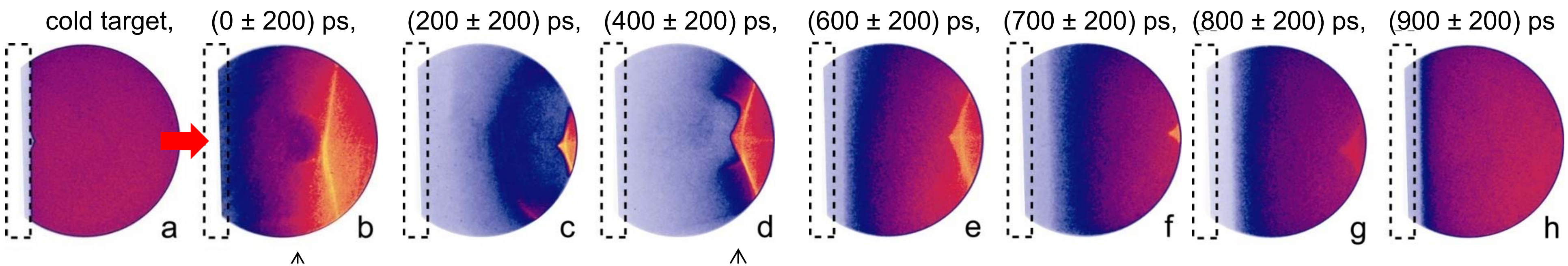
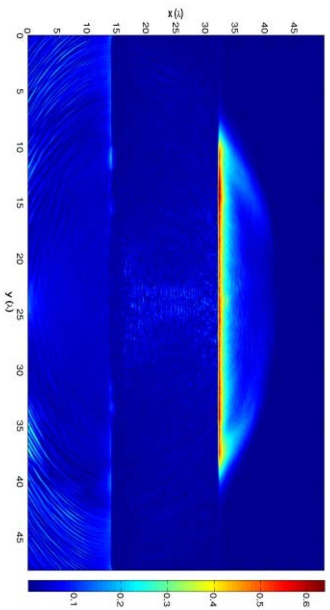
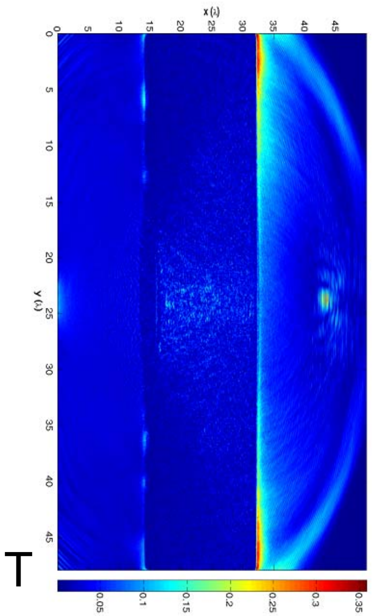
Snapshot series:





t = 50 T



t = 60 T

2D – PIC Simulation
(A. Andreev)

development of electrical field strength

laser a=2 driven CH-foil (13 μm)

Does this also relate to ps@mm scale?