ultrashort PW lasers pulse interaction with target and ion acceleration

Ter-Avetisyan Sargis

ELI-ALPS, Szeged, Hungary

A. A. Andreev – *ELI-ALPS, Szeged, Hungary*
P. K. Singh, M. H. Cho - *Centre for Relativistic Laser Science (CoReLS), IBS, (Korea)*
C. Scullion, H. Ahmed, P. Hadjisolomou, M. Borghesi - *The Queen's University of Belfast*

24-29 September 2017, Isola d'Elba

ion acceleration

- ***protons / ions***

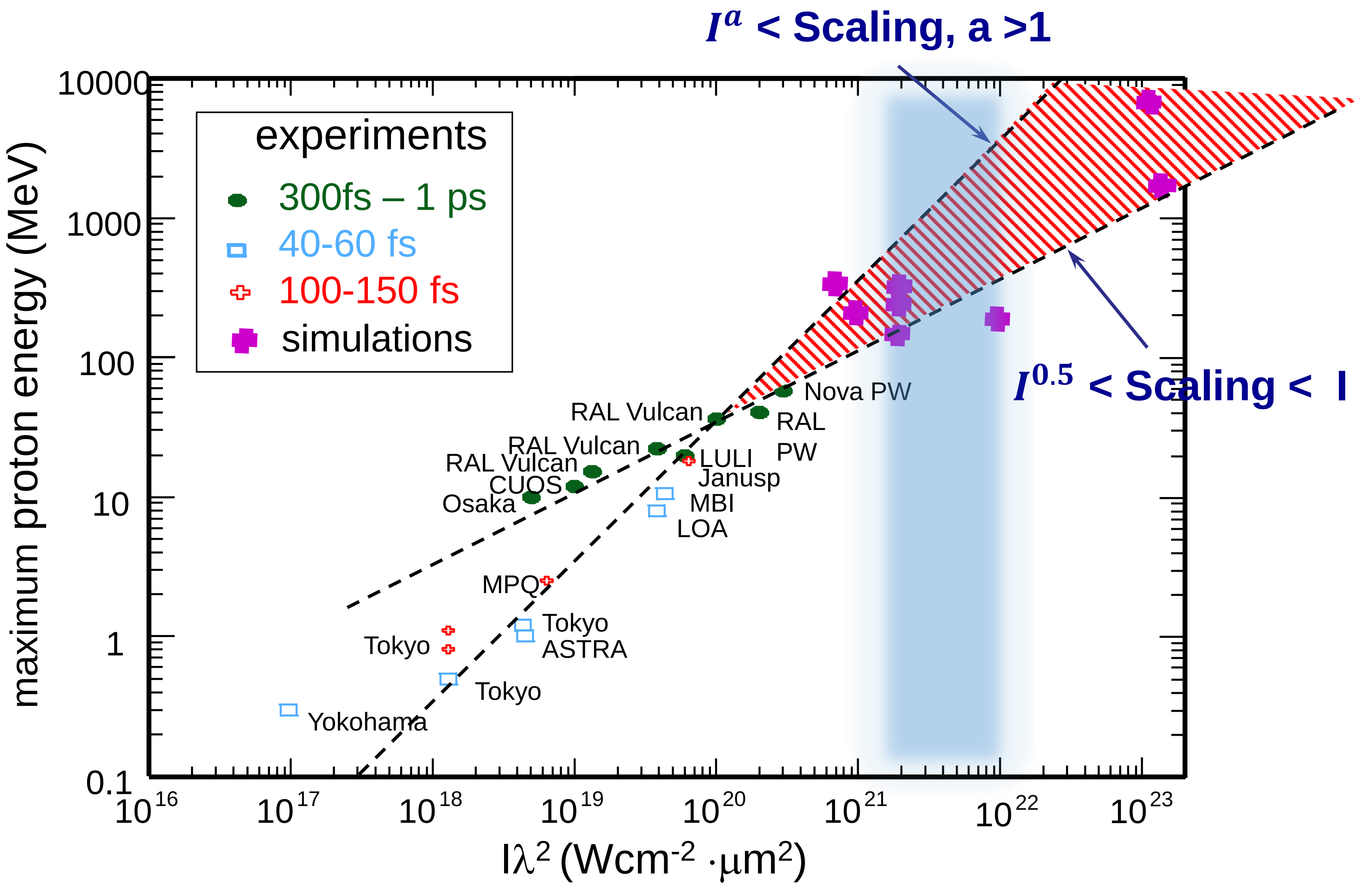
General interest in the field

- physics of laser driven radiation sources and their possible applications
- High energy phenomena and transport
- Knowledge of physics has impact on:
    1. fundamental physics – cosmology
    2. high-field laser physics
    3. fusion
    4. light and particle sources
- Laboratory astrophysics

aim:

to develop laser-driven sources of high energy protons, ions (and gammas) as a reliable, generic technology for applications

what will bring the laser development in the near future?



Andrea Macchi, Marco Borghesi, and Matteo Passoni: Rev. Mod. Phys., Vol. 85, No. 2 (2013)

using PW, short laser pulse for ion acceleration

Research Goals

1. To achieve high proton energies via laser and target parameters optimisation,.

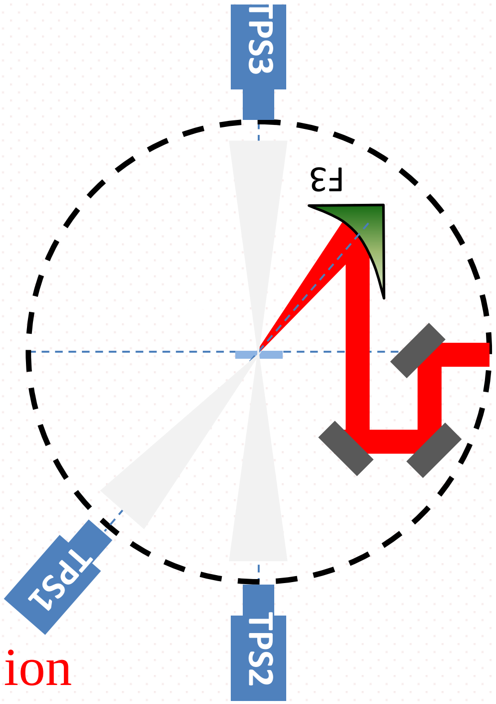
2. Scaling and optimisation of proton beams driven by TNSA mechanism for applications.

- TNSA regime - is the only virtually stable and reliable way to accelerate ions

We aim to investigate:

- **irradiation conditions**
- **proton acceleration**
- **proton source and beam properties**

➢ *proton beams for applications*



no ion emission

$$\Delta\tau \sim 30\ fs$$

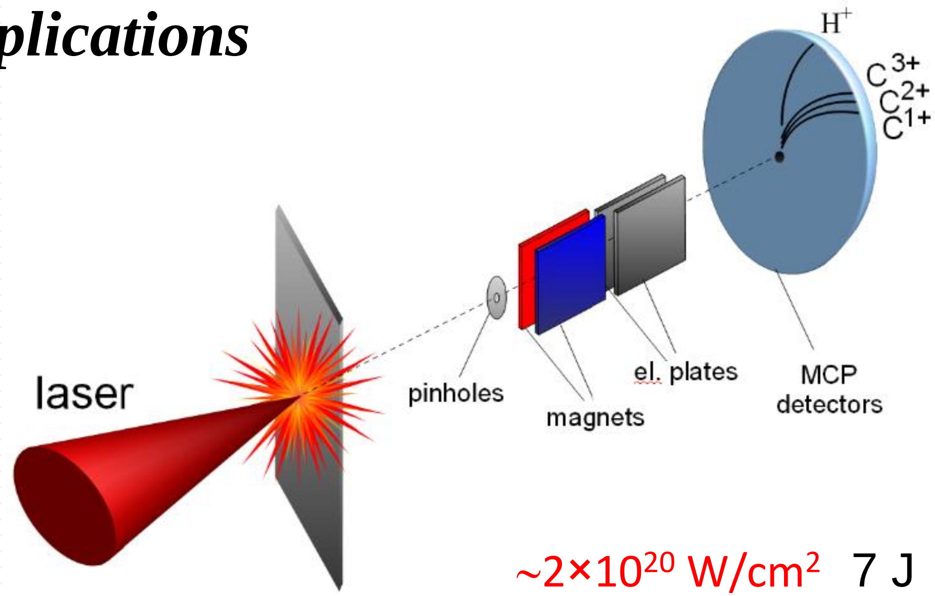
$$\varepsilon = 30\ J$$

$$I \sim (0.5 - 5) \times 10^{21}\ W/cm^2$$

$$Contrast\ > 10^{12}:1\ at\ ns$$

$$10^{8}:1\ at\ 4ps$$

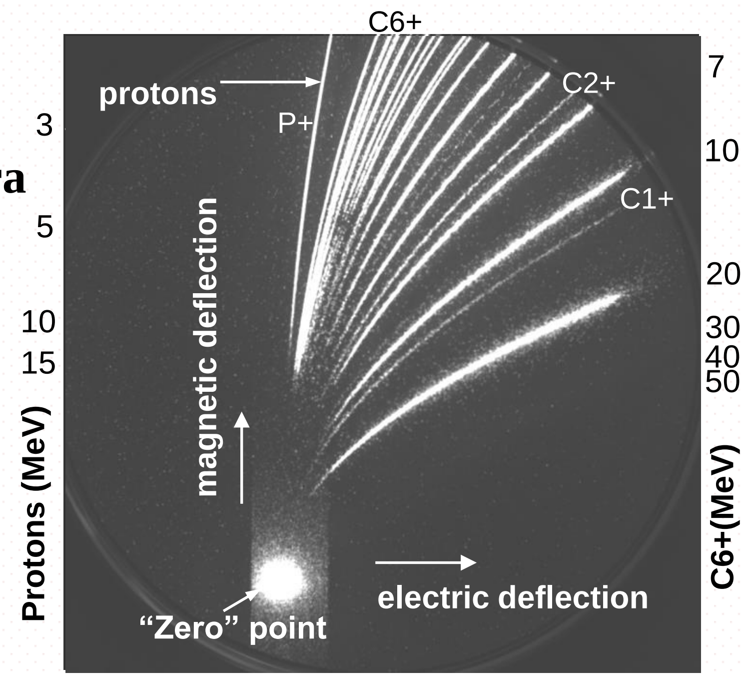
targets - $0.2 - 6\ \mu m\ Al$



~2×10^{20} W/cm^2 7 J

50 nm C

ion spectra

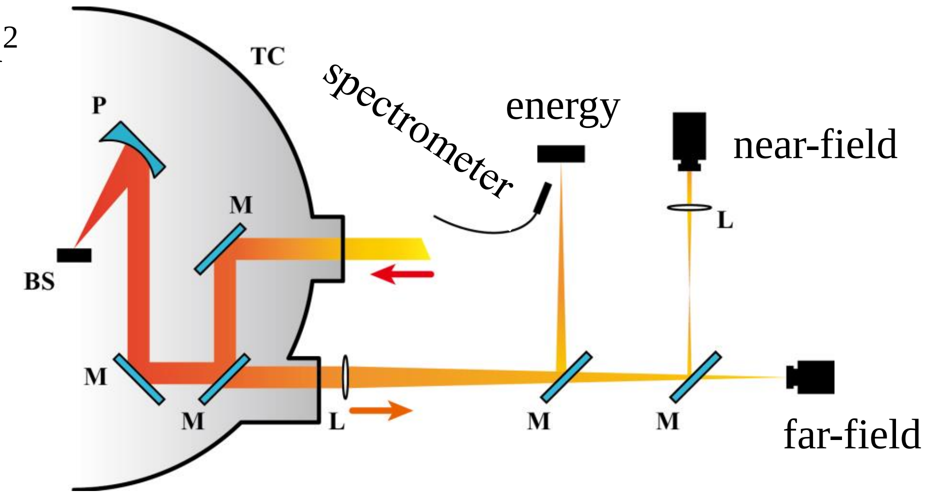


back reflex of PW, fs laser pulse at oblique incidence on the target

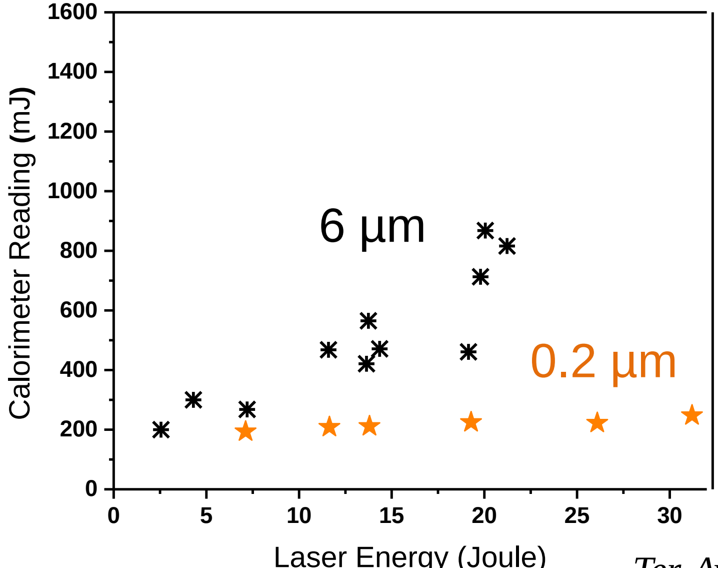
(0.1 - 1.2)×10^{21} W/cm^2

incident angler 30 degree,

***Al* targets**:



The energy and the spectrum of back reflected radiation were monitored throughout the experiments

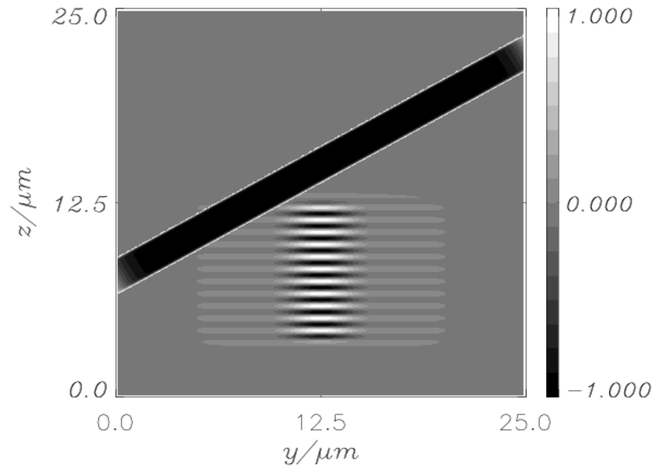


Ter-Avetisyan et al., Opt. Express 24, 28104 (2016).

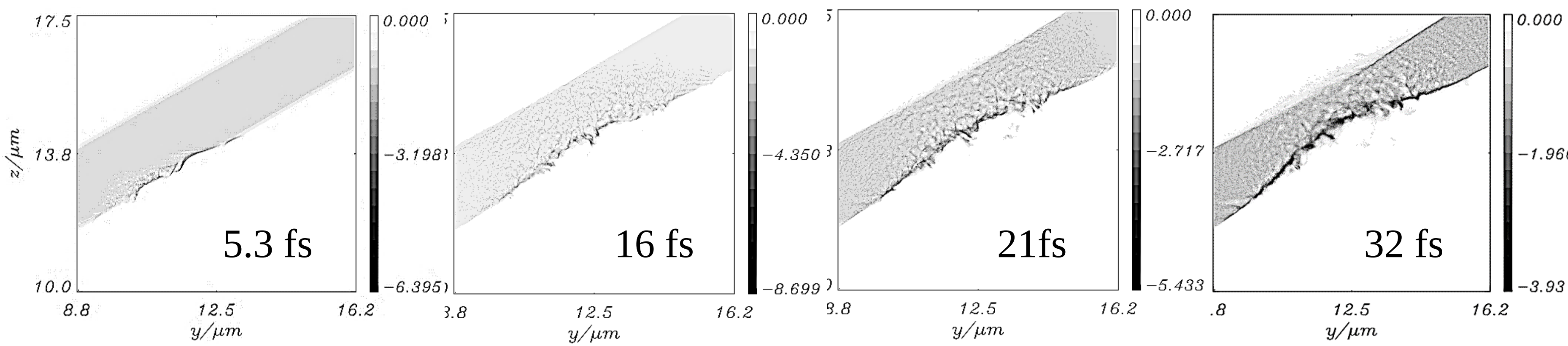
2D PIC simulations

(simulation by Alexander Andreev)

$I = 2{\times}10^{21}$ W/cm^2 in 4 µm, 30 fs, Gaussian, p- pol.,
target - 2 µm Al^{+13}
incident angler 30 degree,
no pre-plasma



electron density profile on the target during the laser pulse



scales are normalized on $n_e = (8{\times}10^{23}\ \mathrm{cm}^{-3})$

PIC simulations have demonstrated:

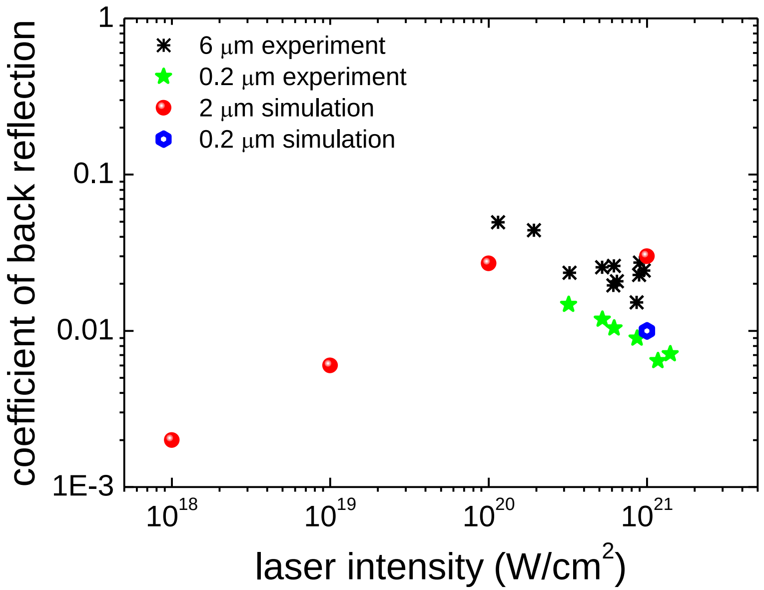
- due to the light pressure the reflecting surface is curved
- the generation of regular structure in the electron density profile.

This structure can act as a grating and a significant amount of laser energy is reflected back

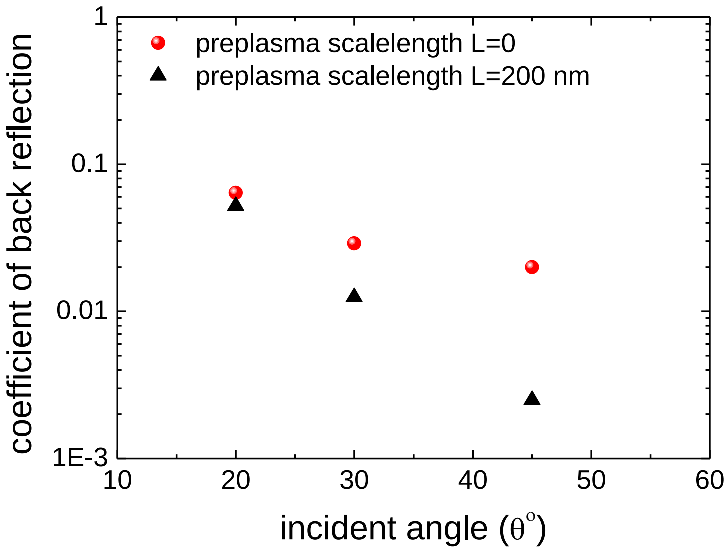
back reflection coefficient

the grating period $d = \lambda/sin\theta$ gives the diffraction peak of second order ($n = 2$) in the backward direction.

back reflection coefficient, 0.2 and 6 μm *Al* targets



back reflection coefficient vs incident angle on the target

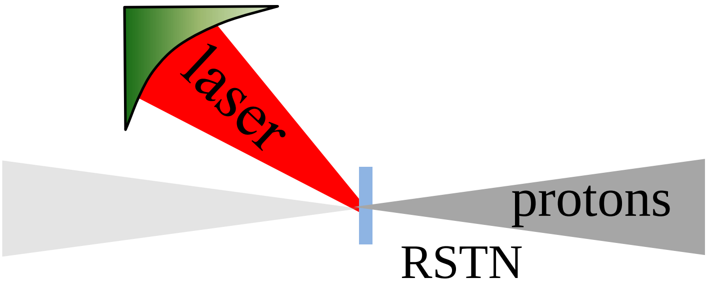


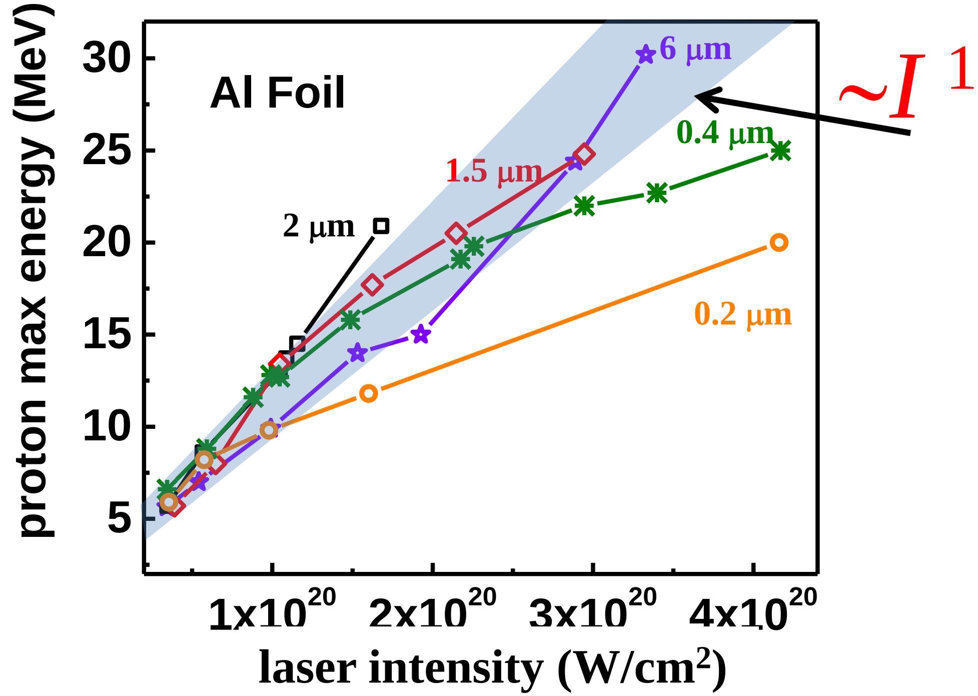
The observed phenomena can have serious consequences when using PW laser systems in the interaction experiments.

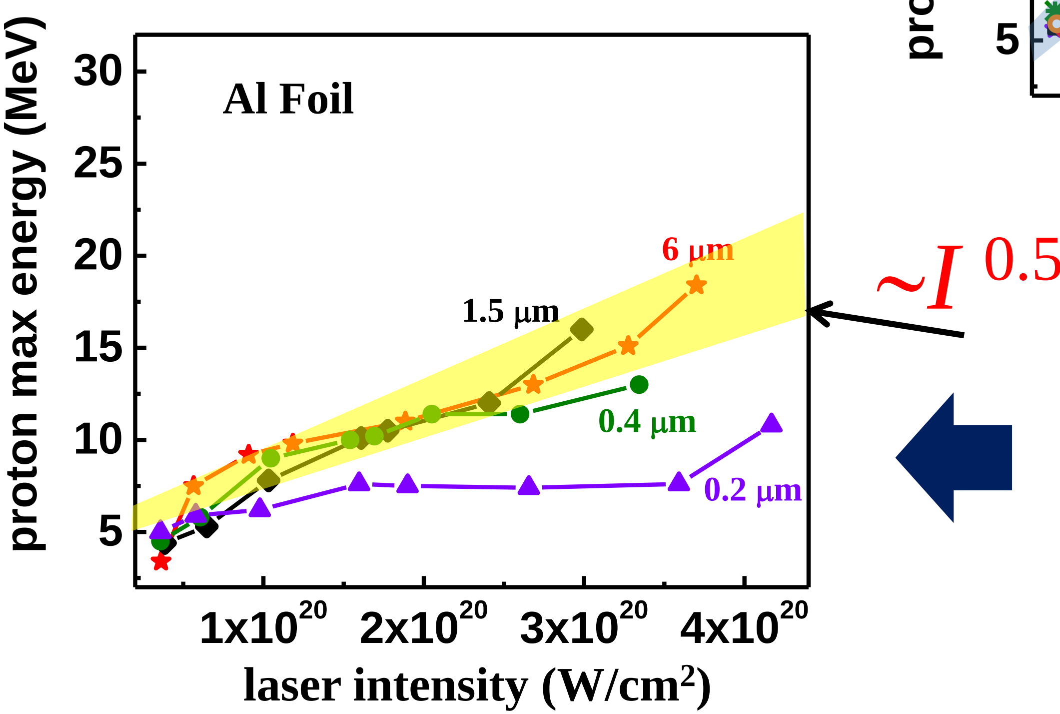
Ter-Avetisyan et al., Opt. Express 24, 28104 (2016).

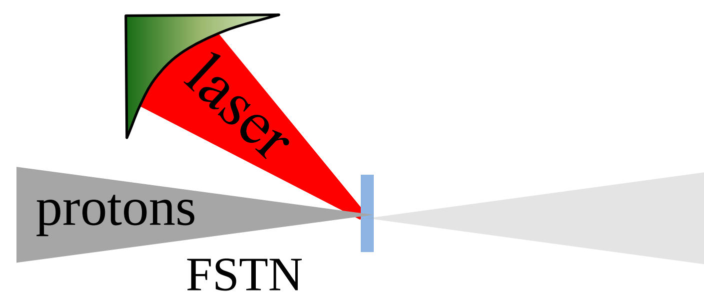
➢ *proton ion acceleration*

"best" shots

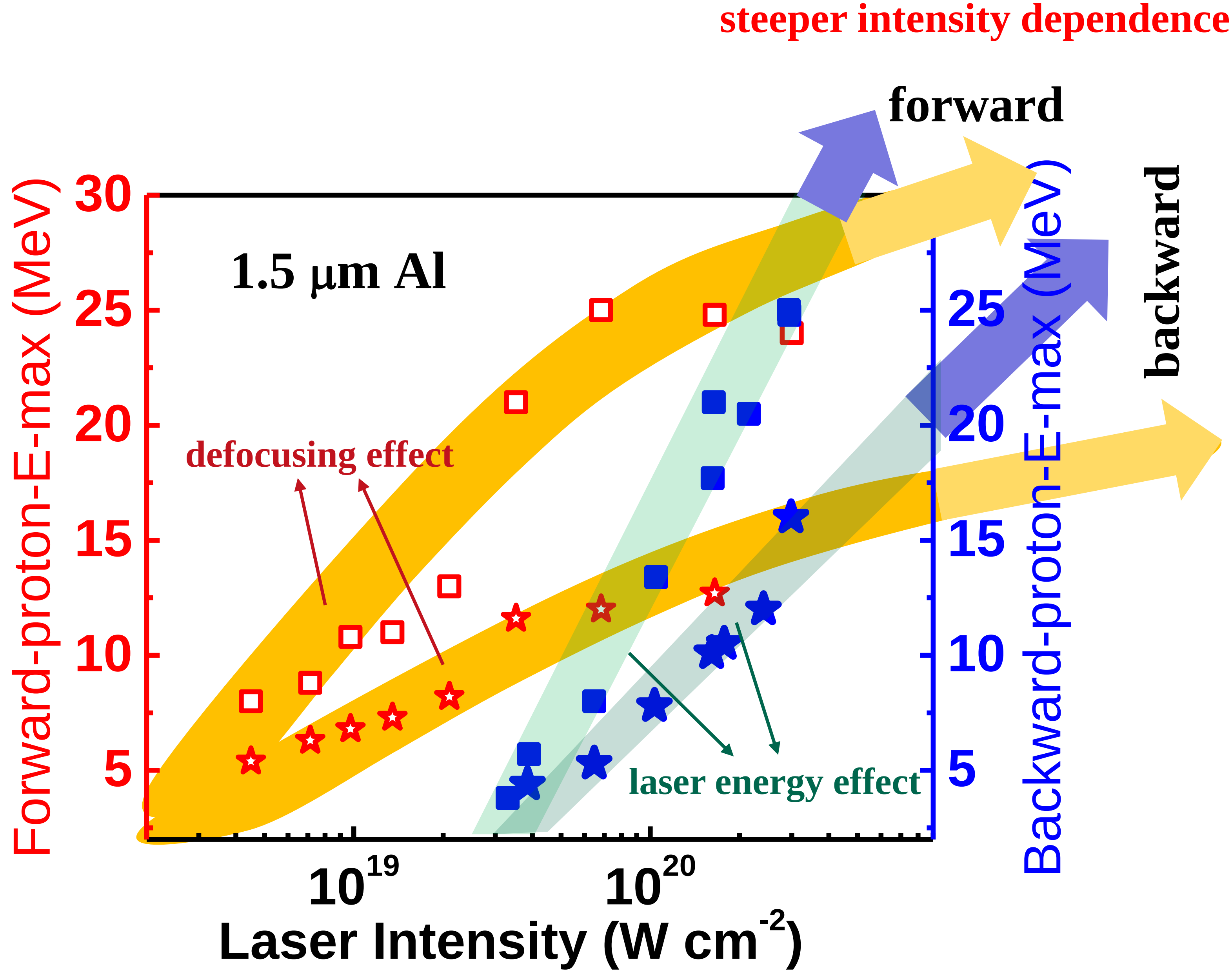




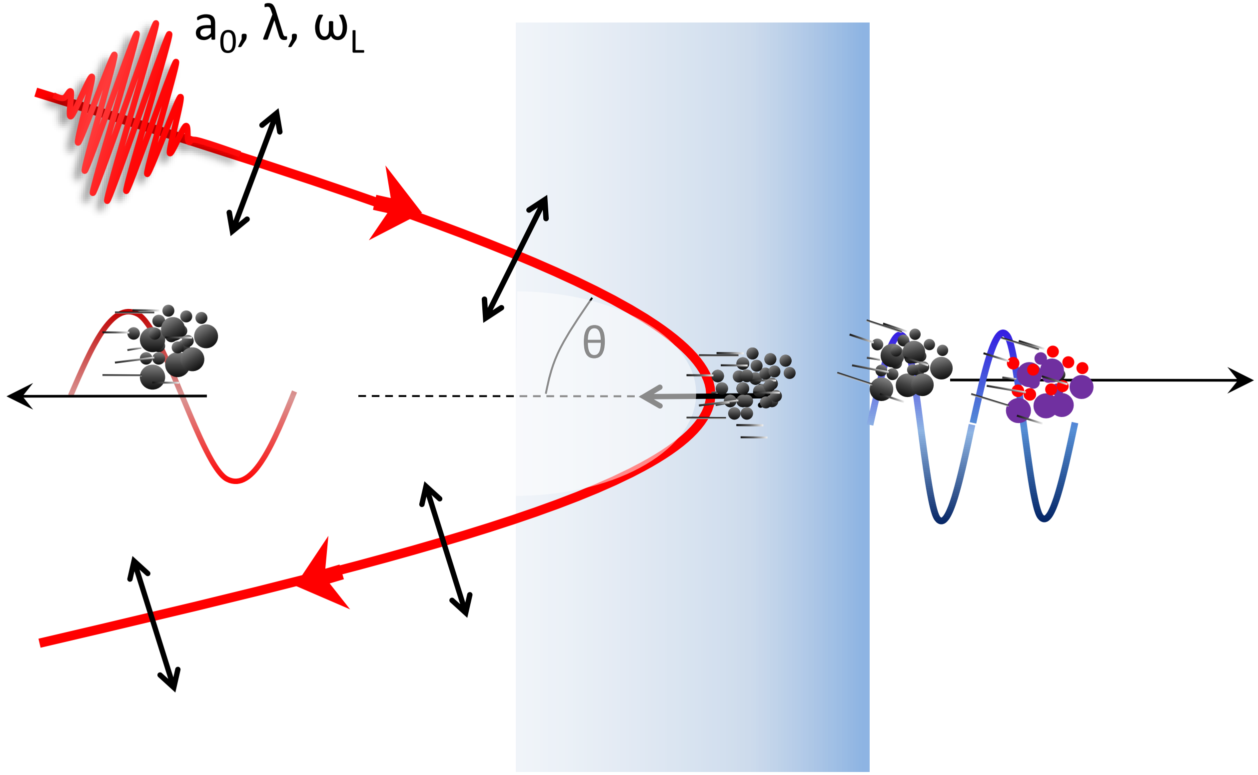




intensity scaling of proton-energy



proton acceleration by High contrast, relativistic laser pulse



- The electrostatic field within the positively charged cavity crated at the target front accelerates the ions to high energy

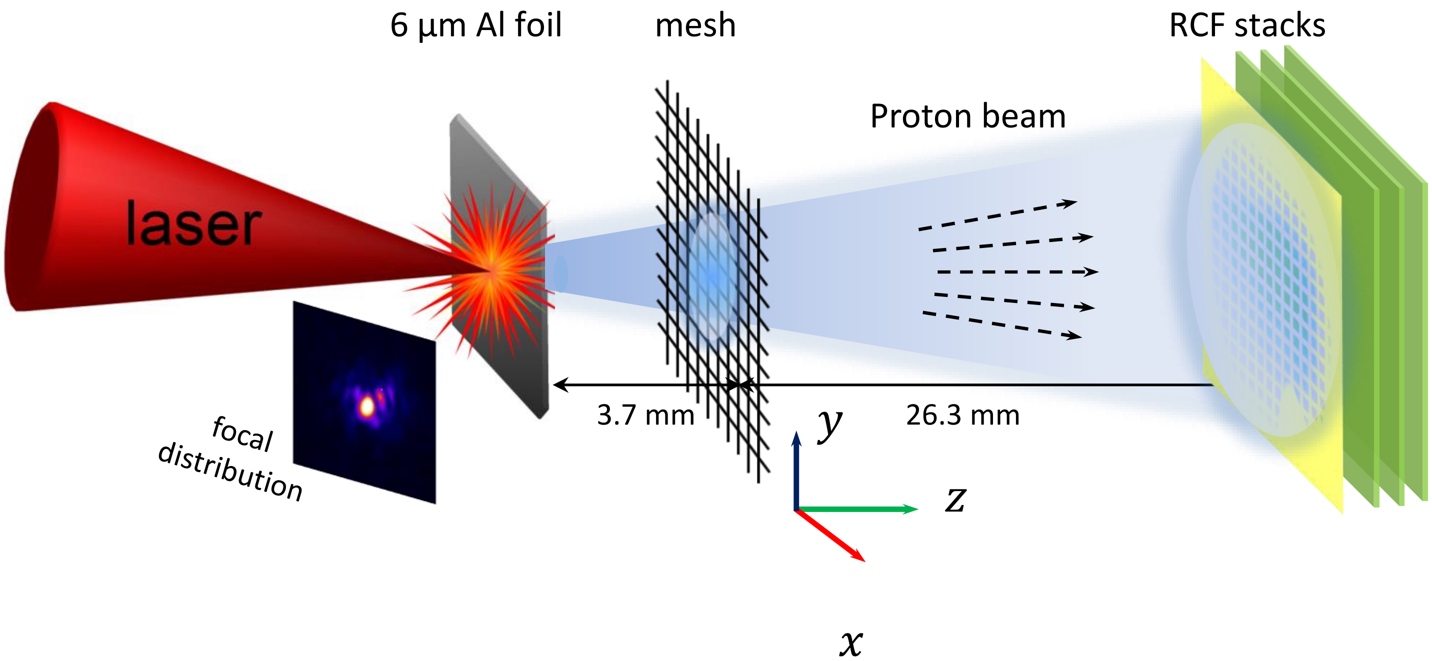
Bychenkov, et al., Ter-Avetisyan, Phys. Plasmas, 24, 010704(6) (2017)

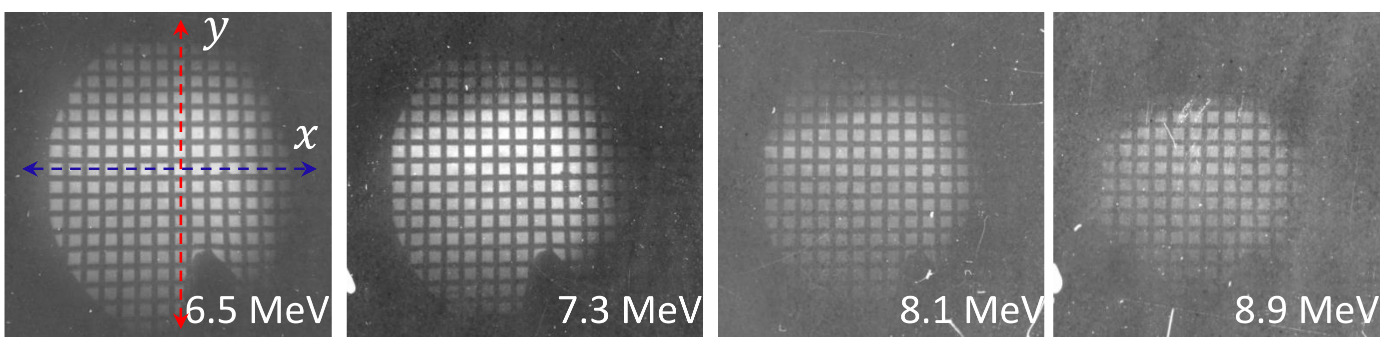
conclusions

- Rear side protons energy scaling $\sim I^{1}$
- Front side energy scaling $\sim I^{0.5}$
- It is also unclear why the intensity scaling is different when the focusing is changed and the energy is changed (??)
- almost independent on target thickness(??)

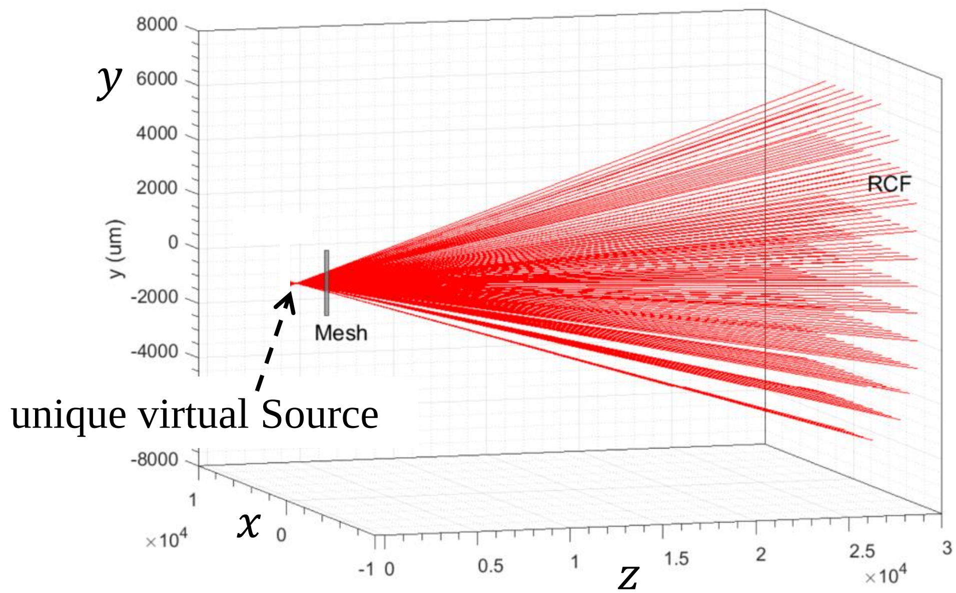
There is still life in the established TNSA mechanism

➢ *proton source and beam properties*



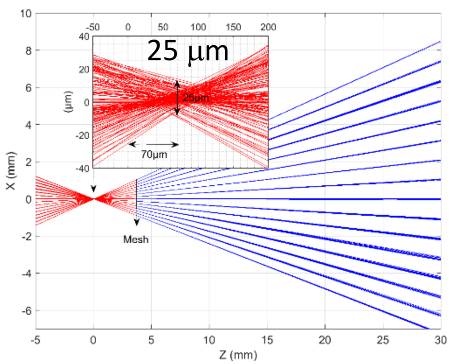


- propagation of protons is ballistic
- no ion interaction within the beam

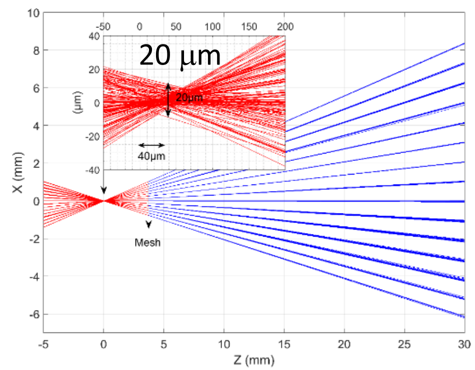


- **the size and relative change of “virtual source” position dependant on proton energy**

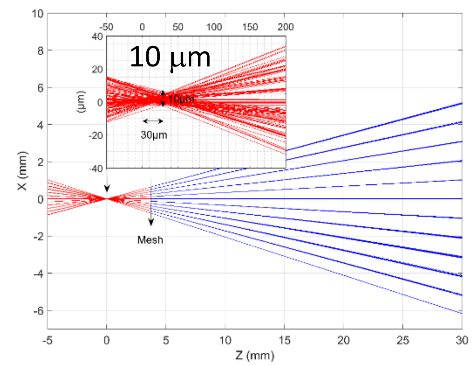
3 MeV



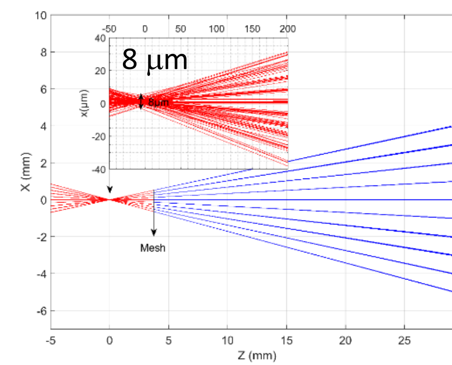
4 MeV



5 MeV



6 MeV



for any projection imaging experiments, e.g., in proton radiography or deflectometery, source size largely affects the spatial resolution of the image

Mesh image as a pepper pot emittance probe was used to measure the transverse emittance of the ion beams:

$$\varepsilon_{nt} < 0.05\ \pi\ \text{mm mrad}$$

the emittance of the beam is preserved in the whole measured spectral range

emission characteristics along and perpendicular to the laser polarisation direction:

in laser polarisation direction:

- the proton beams at different energies have the same divergence.

in perpendicular to laser polarisation direction:

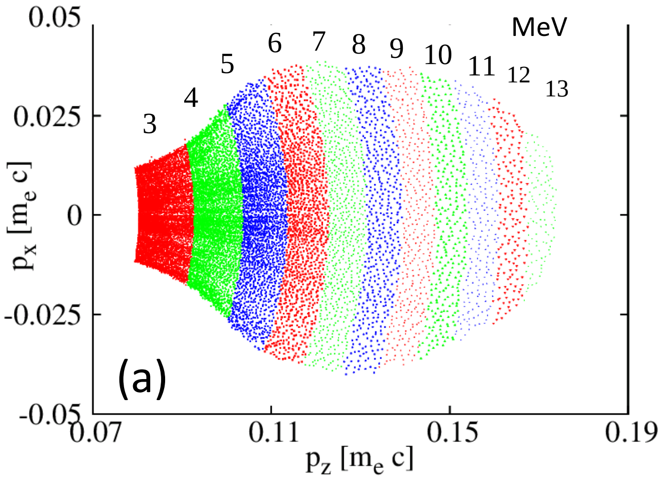
- the divergence is increasing when particle energy is increasing.

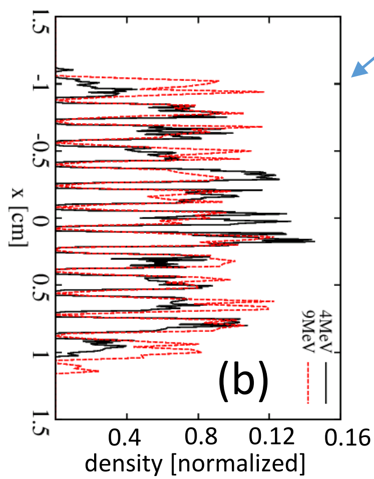
the protons “virtual source” position was changing towards to the target when particles energy is increased.

These findings show the complex dynamic of the ion acceleration process which differs in parallel and perpendicular to laser polarisation direction.

the momentum distribution of protons in phase space

at the distance 50 μm from the target





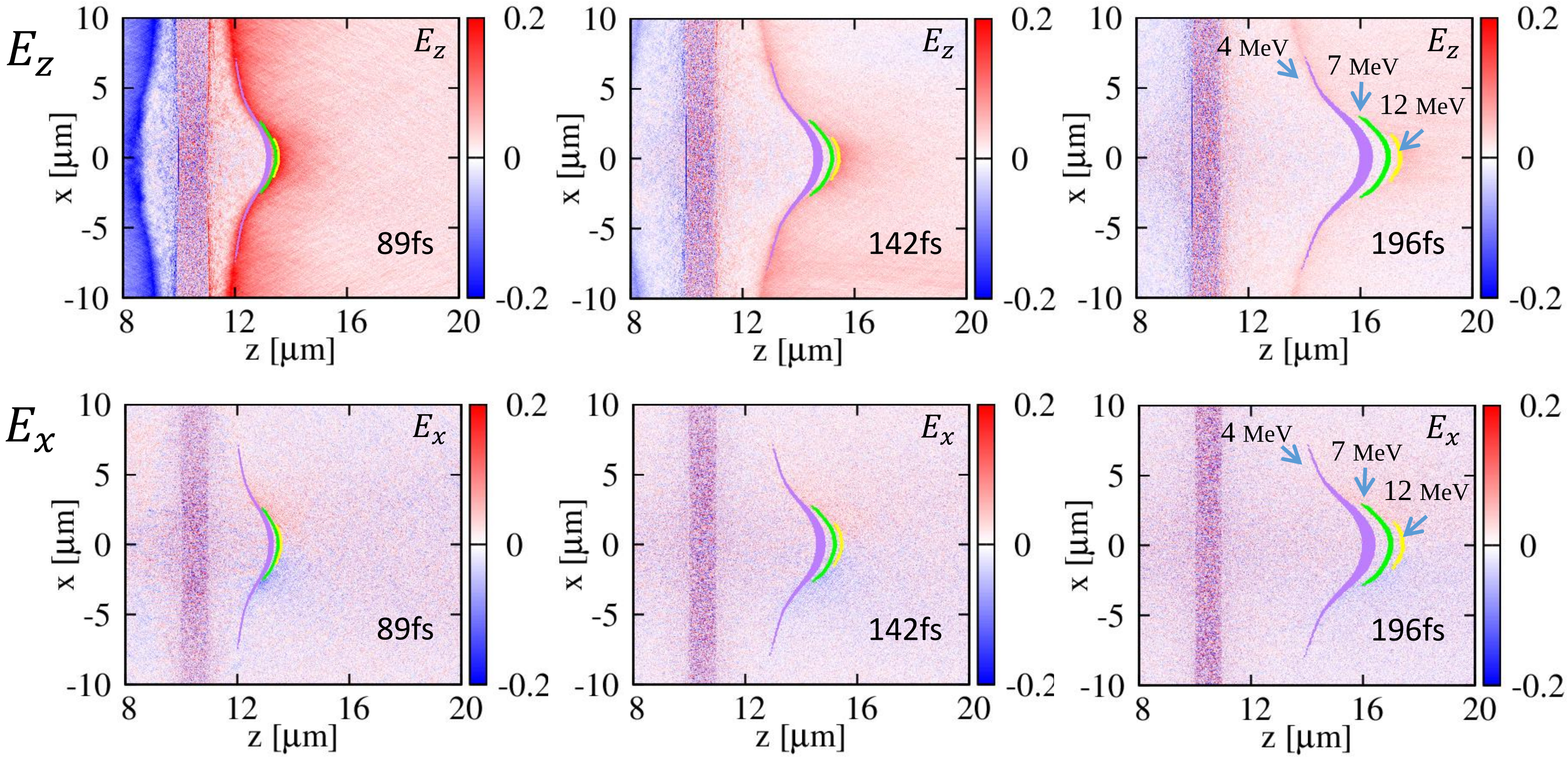
simulated proton image of the mesh

- mesh image formed by 4 MeV and 9 MeV beams are the same

- the protons with different energies exhibit different transverse momentum and therefore different divergence

- During further propagation the transvers momentum stays unchanged.

- temporal evolution of the transvers and longitudinal electric fields created by electron cloud around proton beam

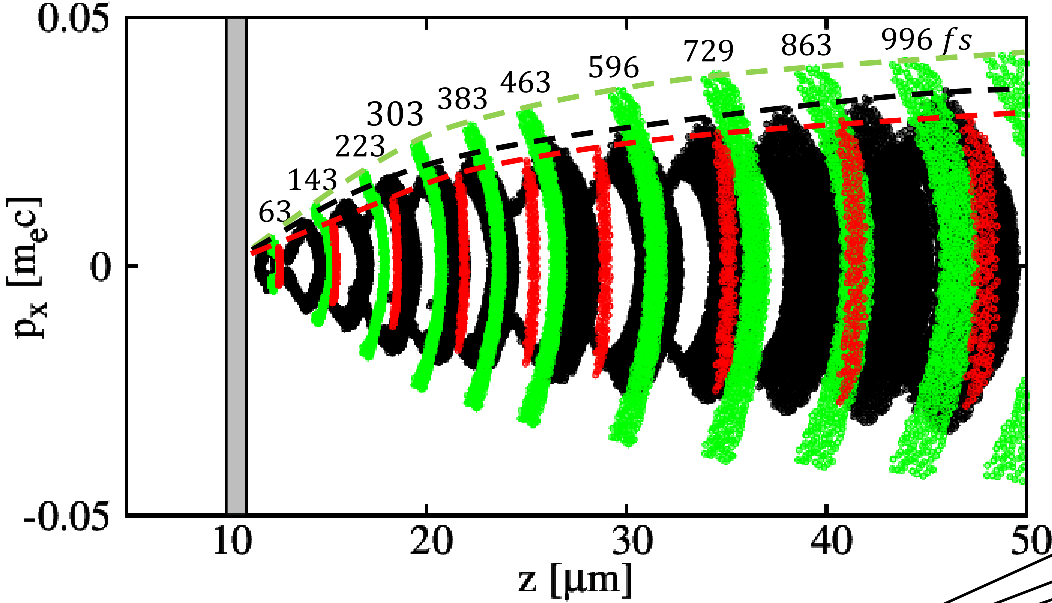


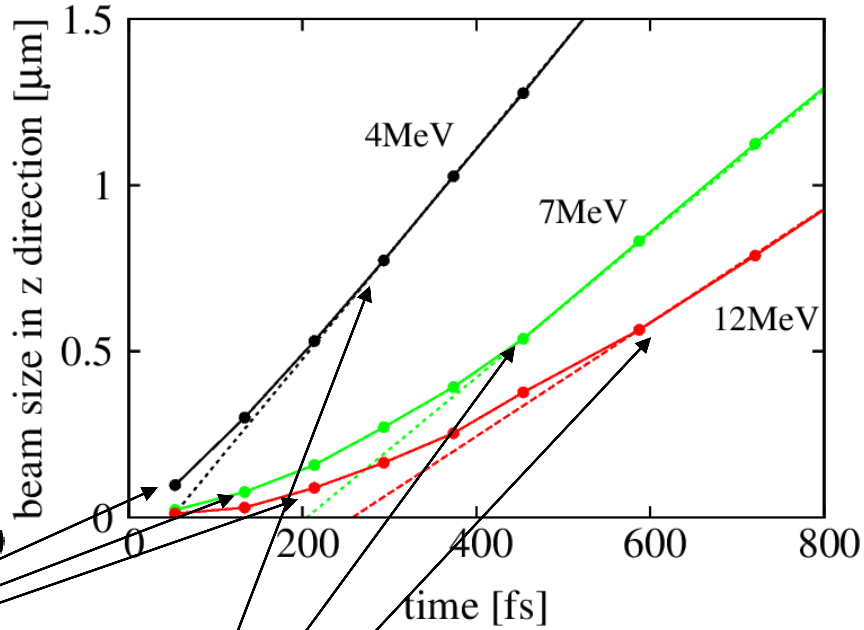
- The transvers electric field at any time step is weak
- longitudinal electric contributes to the divergence of the beam

Fig. 5.

the duration of proton bunch is increased during the propagation

- the proton bunch width is shown for different energies



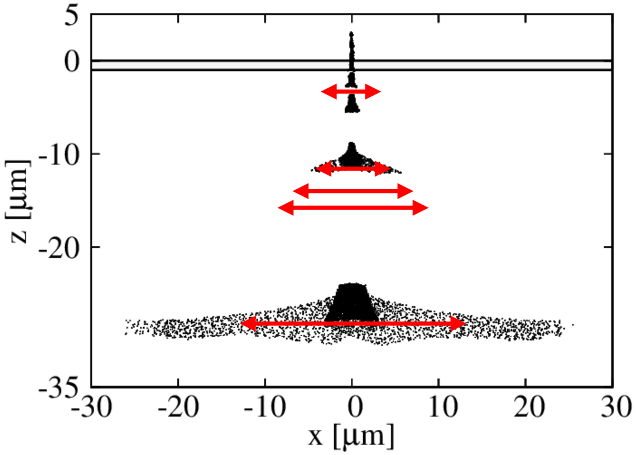


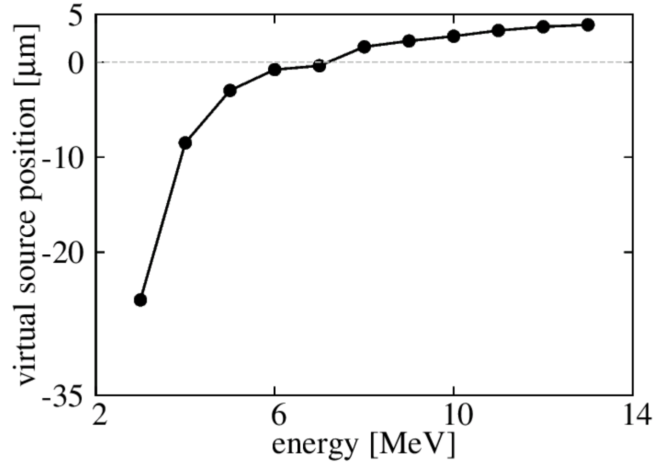
at early time:
a rapid increase of particles momentum takes place

at later time:
the particles momentum becomes constant and bunch is expanding by their TOF

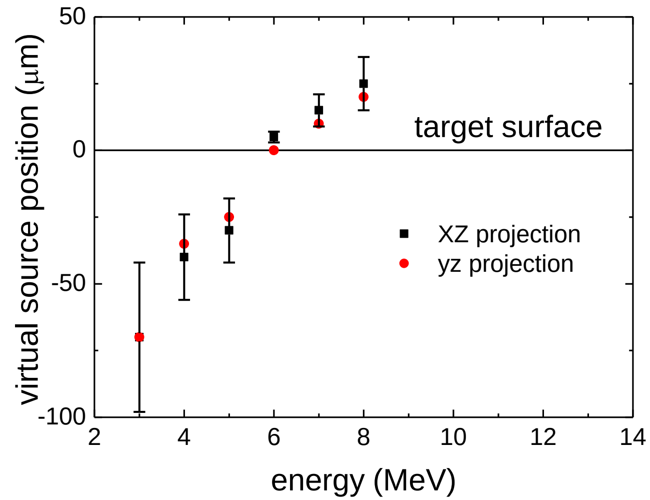
- **high energies are affected more that low energies**

particles trajectories are ray-traced from their given momentum values





the transvers and longitudinal el. fields in the beam have direct impact on the virtual source position at each energy



conclusions

in the determination of the field evolution

- the ultra-short burst duration ensures - high temporal resolution (~ps),
- the laminarity, ultra-low emittance and small source size - high spatial resolution (~μm)

- moving source, which exhibit also different characteristics dependent on laser polarization direction may affect the quantitative analyses of the data

Further development of "proton deflectometry"

for continuous and 3D recording

of transient plasma fields

with sub-ps temporal resolution