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Two-stage acceleration of protons from laser-solid interaction

Z. M. Sheng

Laboratory for Laser Plasmas and Department of Physics,
Shanghai Jiao Tong University, China

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- Proposed two-stage acceleration scheme and target design
- 2D and 3D Particle-in-cell simulation results
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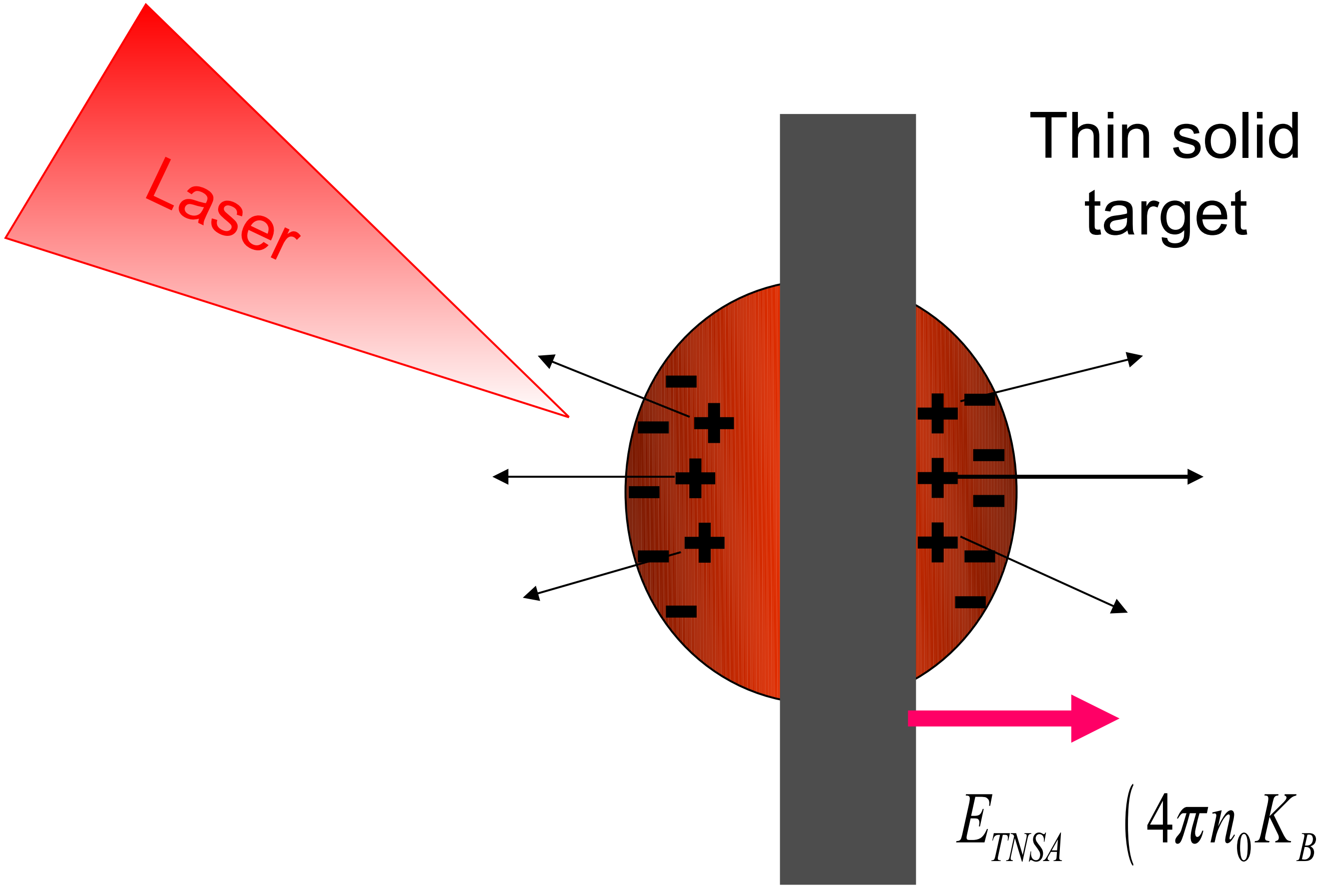
Ion Acceleration from laser-solid interaction

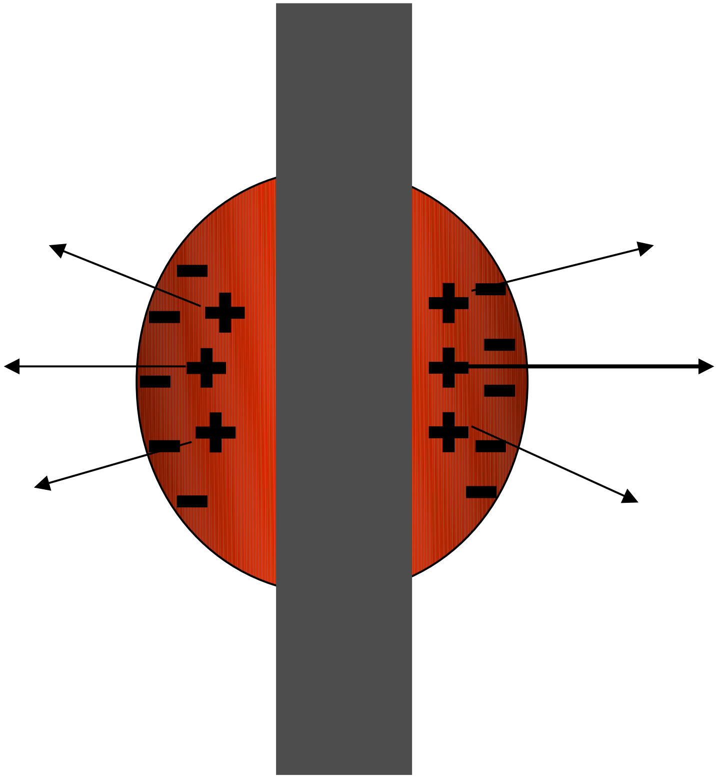


TNSA

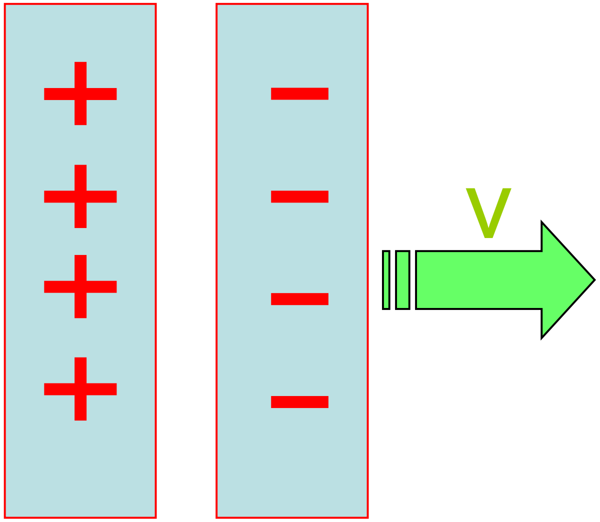
$$E_{TNSA} \quad \left(4\pi n_0 K_B T_e\right)^{1/2} \sim TeV/m$$

Because the acceleration distance is limited within the sheath, the ion energy cannot be very high!

From an immobile sheath/double layer to a moving sheath



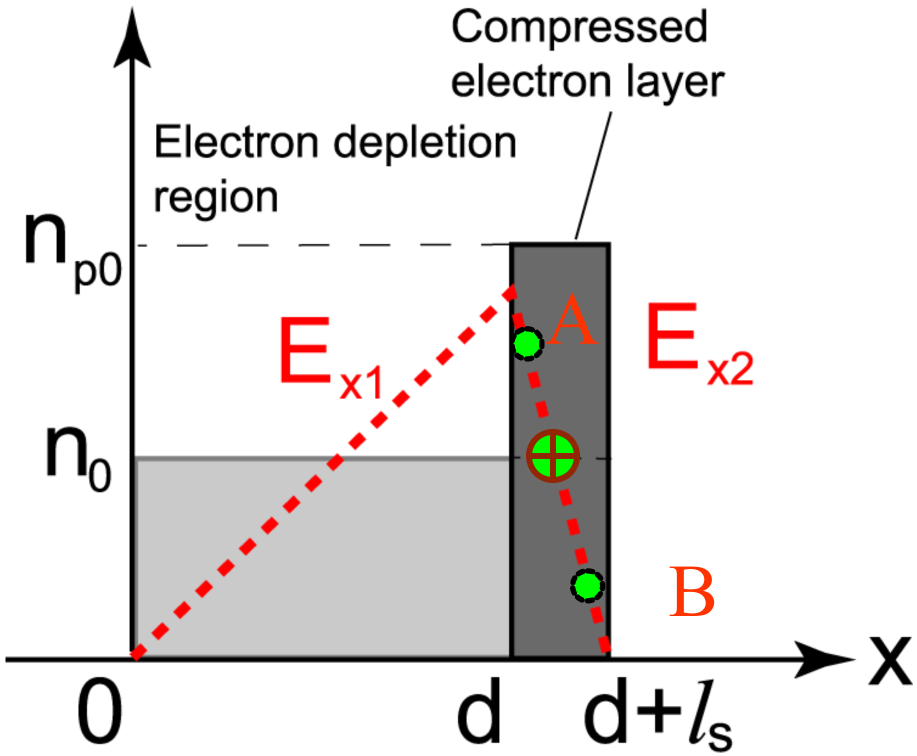
Thin solid target

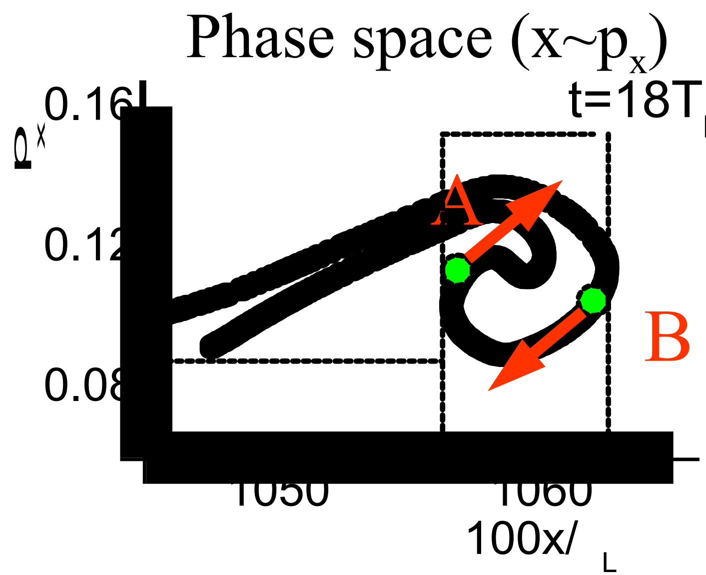


- Long acceleration distance
- High peak energy
- Reduced energy spread

- Collisionless shock waves
- Breakout afterburner (BOA)
- Radiation pressure acceleration
- Wakefield acceleration of ions

Phase Stable Acceleration Regime with circularly-polarized laser pulses





- Protons are:
  - Bunched by E_{x2}
  - Debunched by E_{x1}.
- Phase Oscillations!

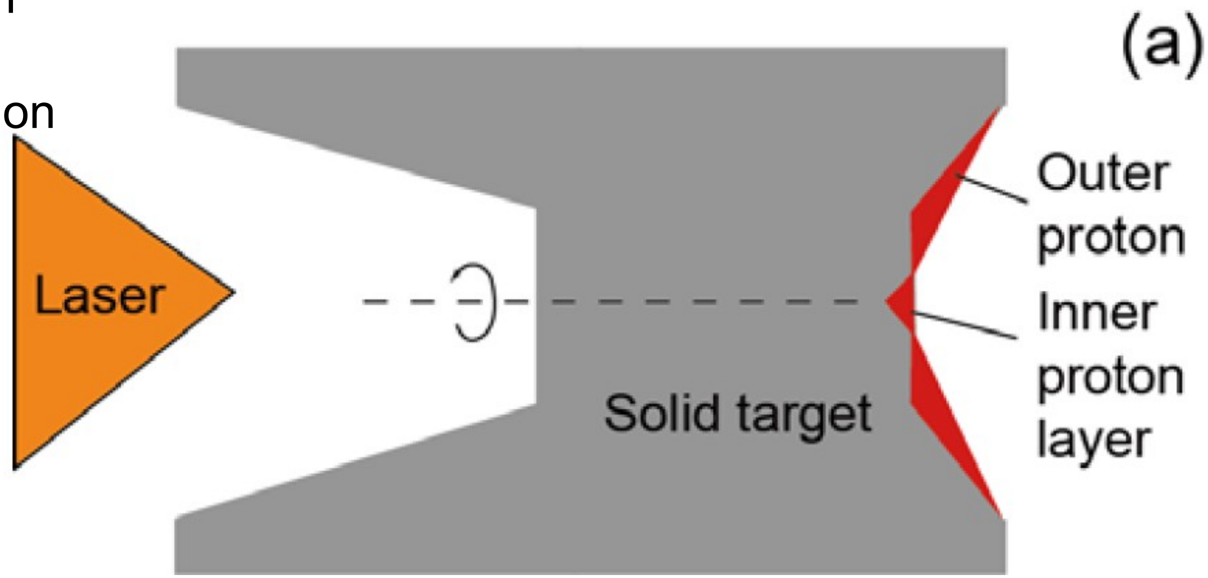
$$E_{//} = 4\pi e n_0 d \sim (v_e \quad B_L / c) \sim E_L$$

$$(n_0 / n_c)(d / \lambda_L) \sim a_L$$

X. Q. Yan et al., PRL 100, 135003 (2008).

Proposed new target design

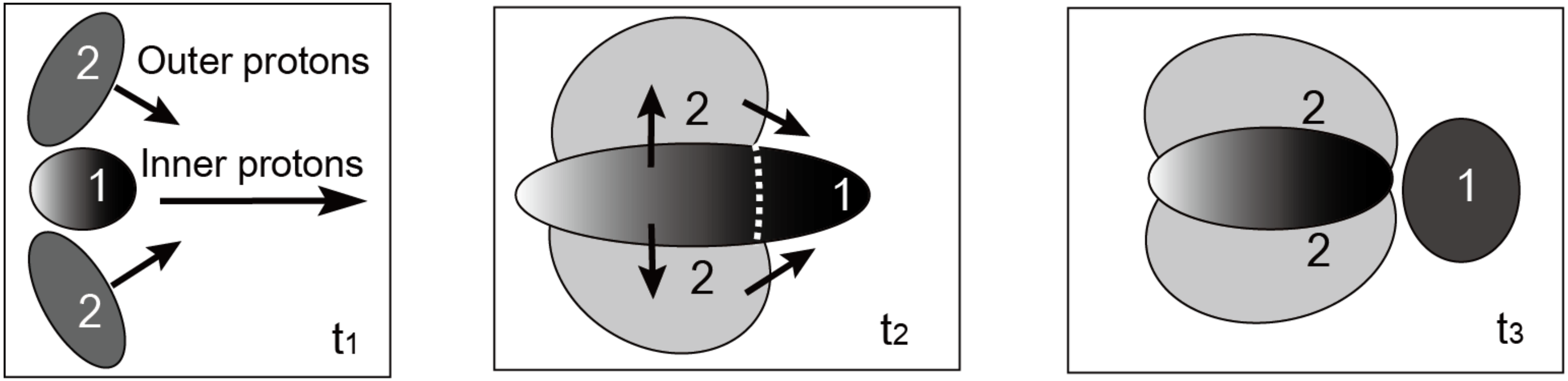
$I \sim 3.1 \times 10^{20} W/cm^2$
Duration~ 80fs
Linear polarization



The target thickness is a few micrometers (simulations take the density of 100nc for all target components)

- At the center of the dish-like flared rear surface is a tapered **inner proton layer**, which is surrounded by **outer proton layers** at an angle to it (here 70^o).

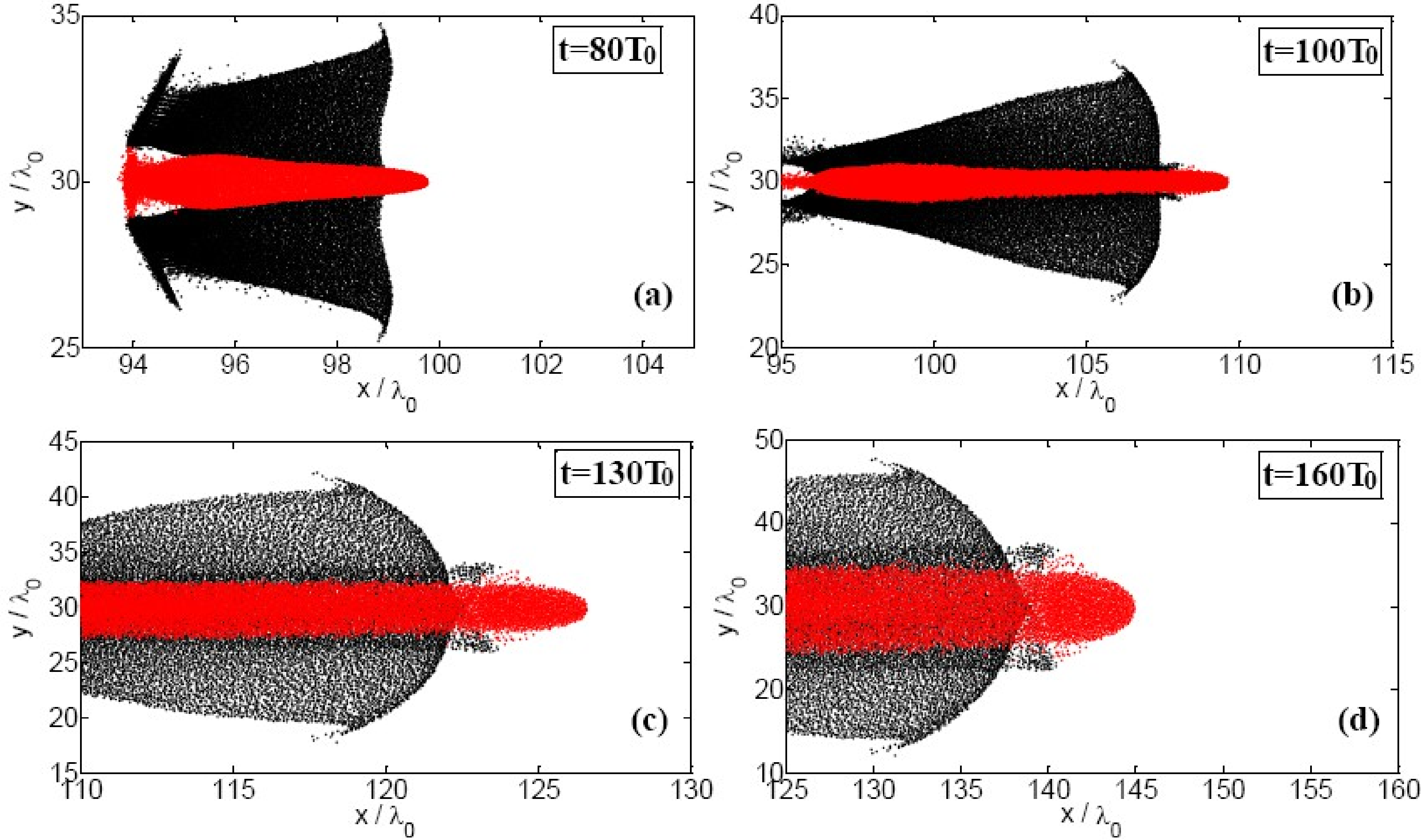
Two-stage acceleration process



- Phase I, target normal sheath acceleration, leading to **the first acceleration stage**
- Phase II, propagating of the protons from the first stage, merging of the side-layer protons
- Phase III, the side-layer protons radially compress as well as axially further accelerate the front part of the accelerating center-layer protons, leading to **the second acceleration stage**
- Phase IV, the front running inner protons are detaching from the rest of the bunch. They form a nearly monoenergetic bunch

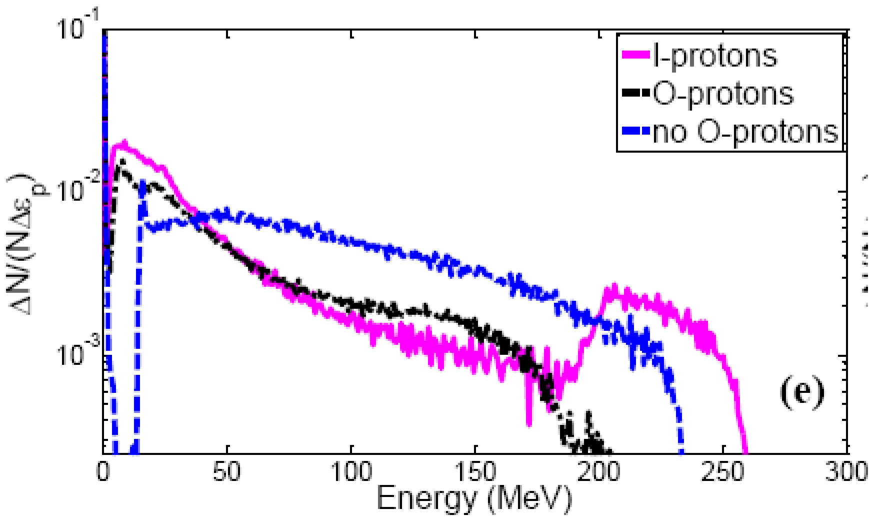
2D PIC simulation results

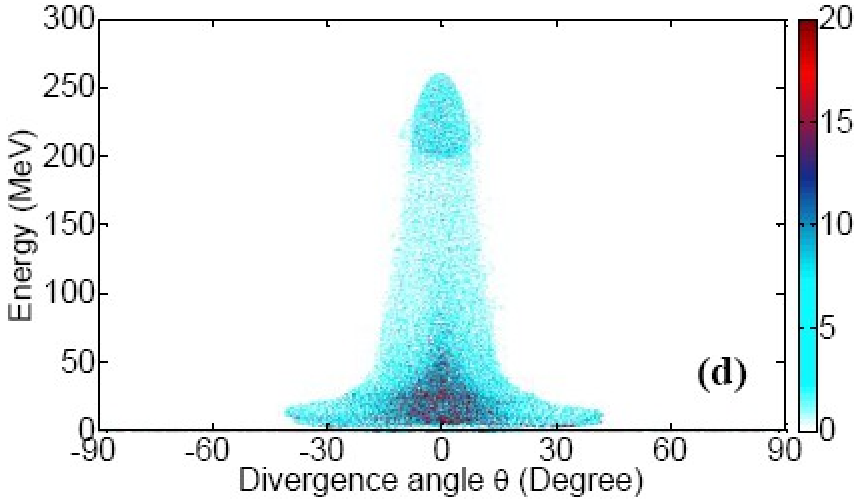
- Time evolution of the inner protons (**red dots**) and the outer protons (**black dots**)



2D PIC simulation results

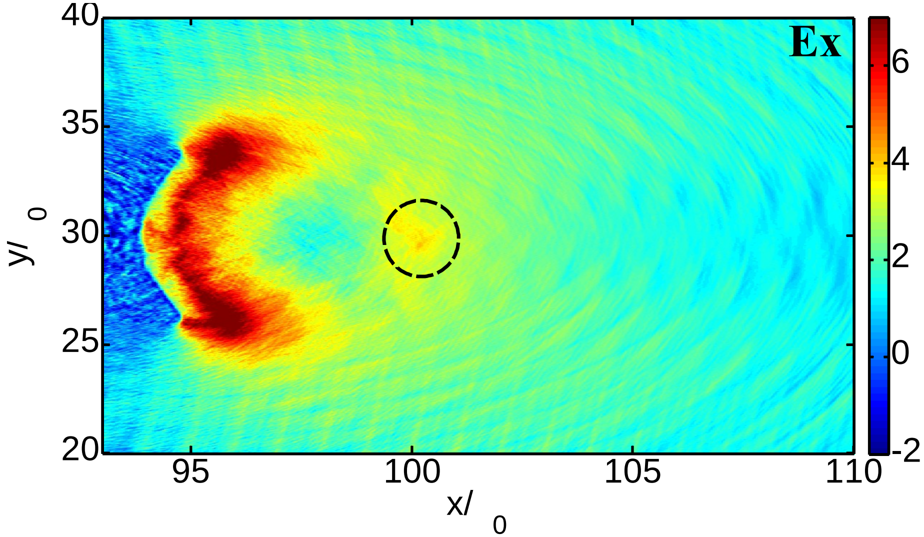
LP Laser: 3.1×10[20] W/cm[2], 80fs duration

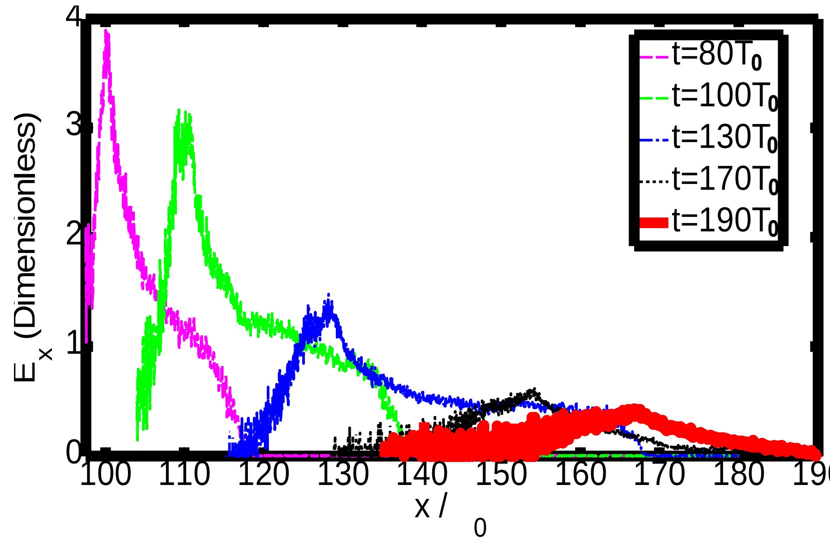




- A quasi-monoenergetic beam at 255MeV with 17% spread is obtained. It has a small divergence angle (<10°)
- Without the O-proton layer, no quasimonoenergetic beam (blue line)

2D PIC simulation results





- A strong sheath field region (in **black circle**) is just at the interface between the I and O-protons at $t=80T_0$

- The evolution of the sheath field along the axis shows that the accelerating field moves forward with time, which enables the proton acceleration in a long distance as in RPA, though its strength decreases with time

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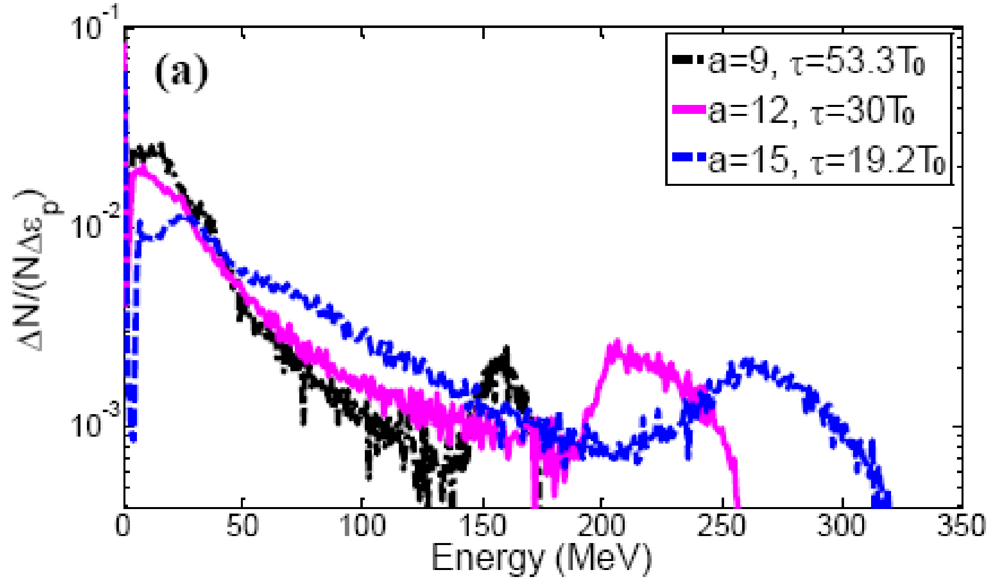
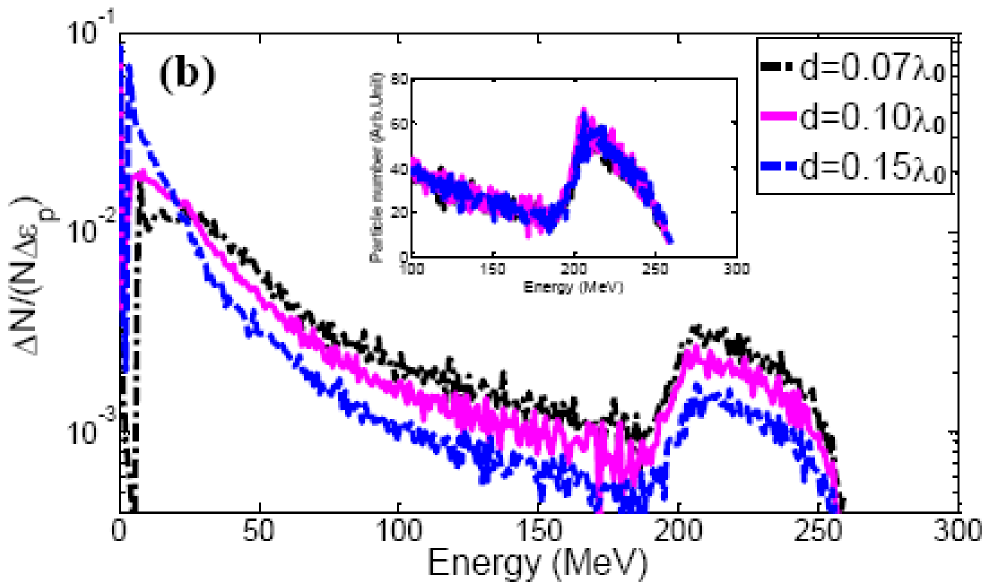
Scaling with the laser intensity and target thickness

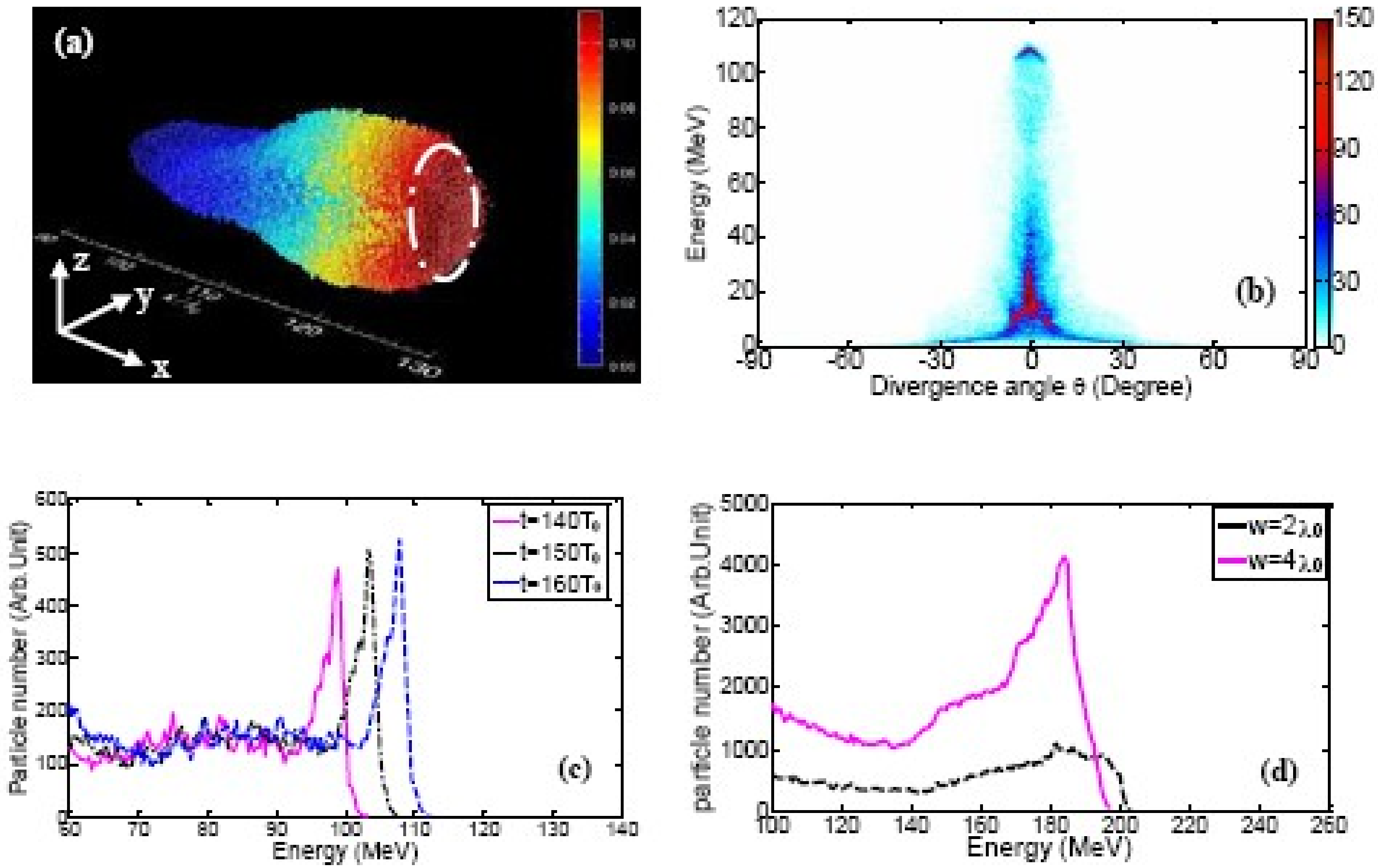




$$\mathcal{E}_{2D} \sim 2.1 a\sqrt{n}$$

[MeV]

3D PIC simulation (with OSIRIS 2.0)



$$\mathcal{E}_{3D} \sim 0.93a\sqrt{n} \quad [\mathrm{MeV}]$$

Scaling reduced by half compared 2D
Spread reduced to 3%

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Summary

- We propose a target design to achieve two-stage acceleration for generating high quality proton beams.
  - First stage, TNSA
  - Second stage, a mobile Coulomb explosion field

- 2D PIC: energy peak~250 MeV and spread ~17% by the laser of 24J and 80fs
- 3D PIC: energy peak ~112 MeV and spread ~3% by the same laser

- This new target design use solid target components with thickness of a few micrometers, it can apply under multi-100TW laser with contrast ratio available currently.

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J. L. Liu, J. Zheng, J. Zhang
Laboratory for Laser Plasmas and Department of Physics, Shanghai Jiao Tong University, Shanghai 200240, China

W. M. Wang
Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China

M. Y. Yu
Institute for Fusion Theory and Simulation, Zhejiang University, Hangzhou 310027, China
Institute for Theoretical Physics I, Ruhr University, Bochum D-44780, Germany

C. S. Liu
East-West Space Science Center, University of Maryland, College Park, MD, USA

W. B. Mori
Department of Physics and Astronomy and Department of Electrical Engineering, University of California, Los Angeles, USA

Thank you for your attention !