Compact Proton Accelerator by Hole-Boring Shock Acceleration

Jinqing Yu[1,2]

1. John Adams Institute for Accelerator Science, Imperial College London

2. Vacuum Electronics National Laboratory, University of Electronic Science and Technology of China

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Outline

- **Introduction**
- **HB-RPA 3D simulations**
- **HB-RPA scaling work by 2D simulations**
- **Summary**

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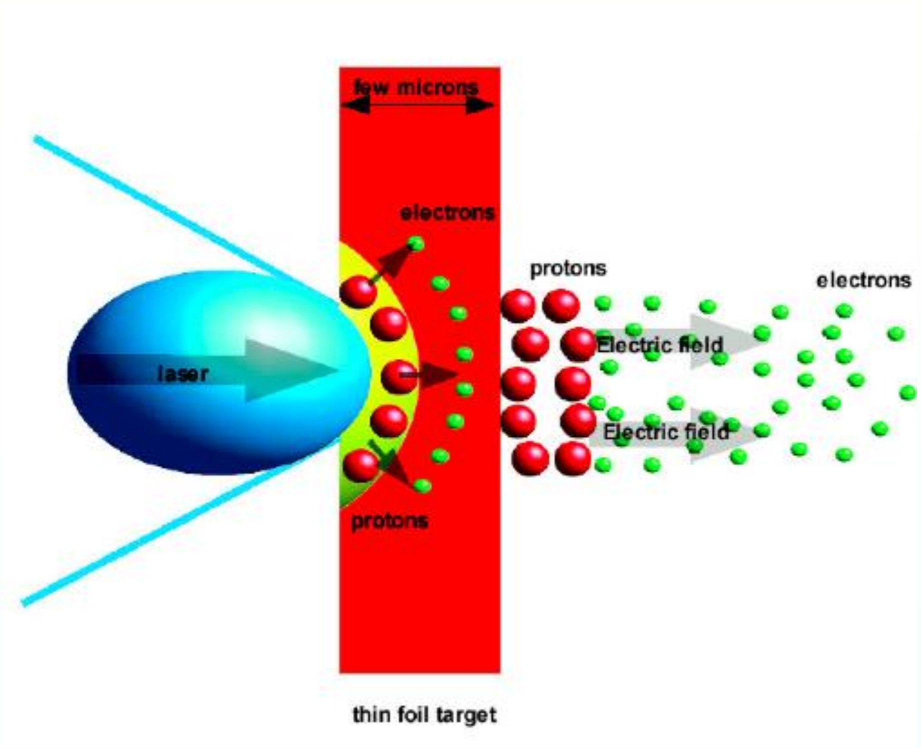
Introduction

Why laser-driven ion beams?

- Characteristic
  - Smaller size
  - ~ps duration
  - High current (~A - MA)
  - Neutralized Beam
- Applications
  - Transient phenomena
  - Higher energy density
  - Sensitive to capital cost
- Examples
  - Cancer therapy
  - Isochoric heating of matter
  - Fast ignition ICF
  - Nuclear interrogation
- Challenges
  - Energy spectrum control
  - Laser technologies (Laser shape, Rep rate)
  - Target technology

Introduction

Target Normal Sheath Acceleration (TNSA)

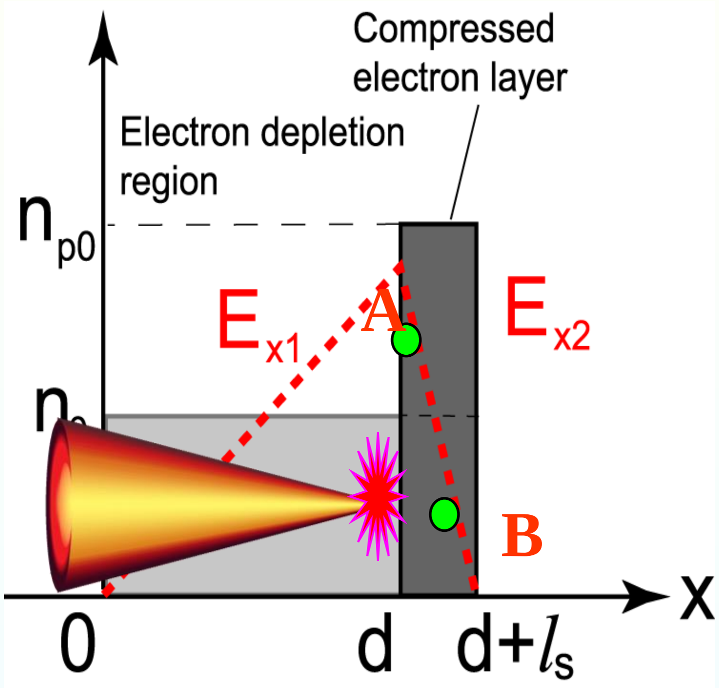


Wilks et al., PoP (2001)

- Linearly polarized laser
- Electrons heated to MeV temperature via **j x B** force
- Ions accelerated mainly off target rear
- Low beam density, low energy, large divergence, broad energy spread !
- Variations: microdots; double layers; oblique incidence; BOA; …

Introduction

Radiation Pressure Acceleration (RPA)

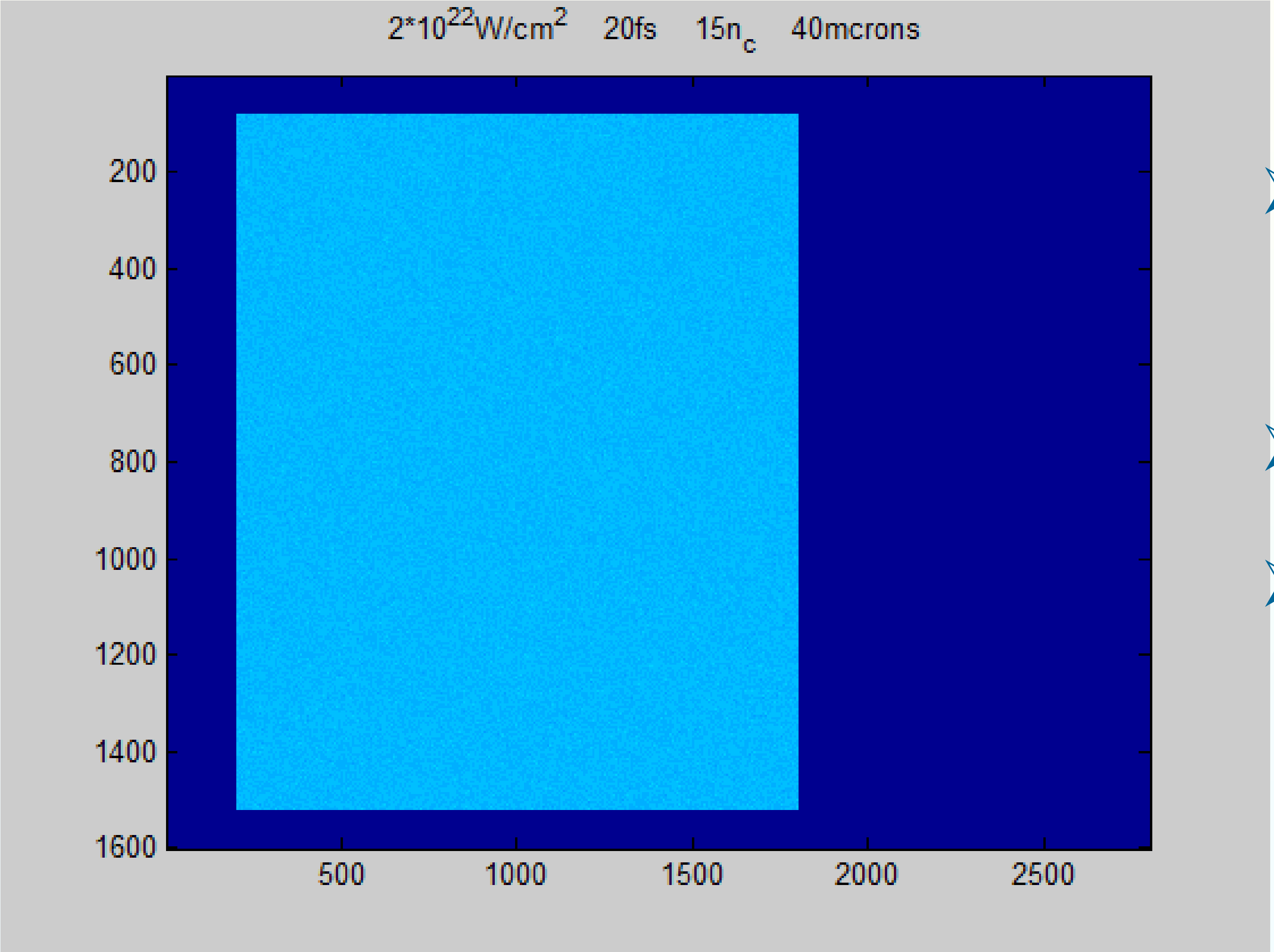


Macchi et al., PRL (2005,2009)

- Circularly polarized or high-intensity LP lasers
- No oscillating jxB, so electrons pile up as compressed layer
- Ions are accelerated by the charge-separation, forming bunched layer.
- High beam density & efficiency; monoenergetic spectrum.
- Growth of transverse instabilities

Introduction

Hole-Boring Radiation Pressure Acceleration (HB-RPA)



- Lower target conditions required.
- Narrow-band spectra.
- Less transverse instabilities

Robinson et al., PPCF (2009,2012); Palmer et al., PRL (2012)

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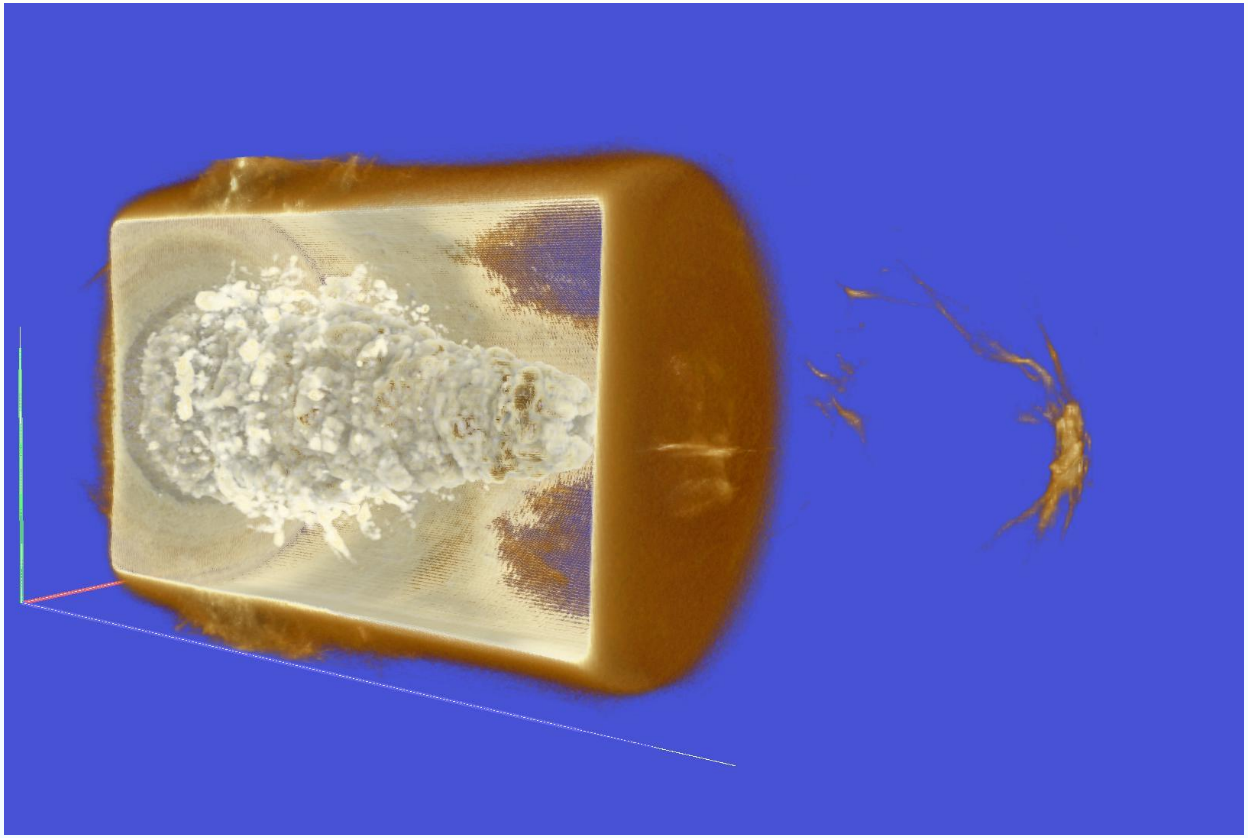
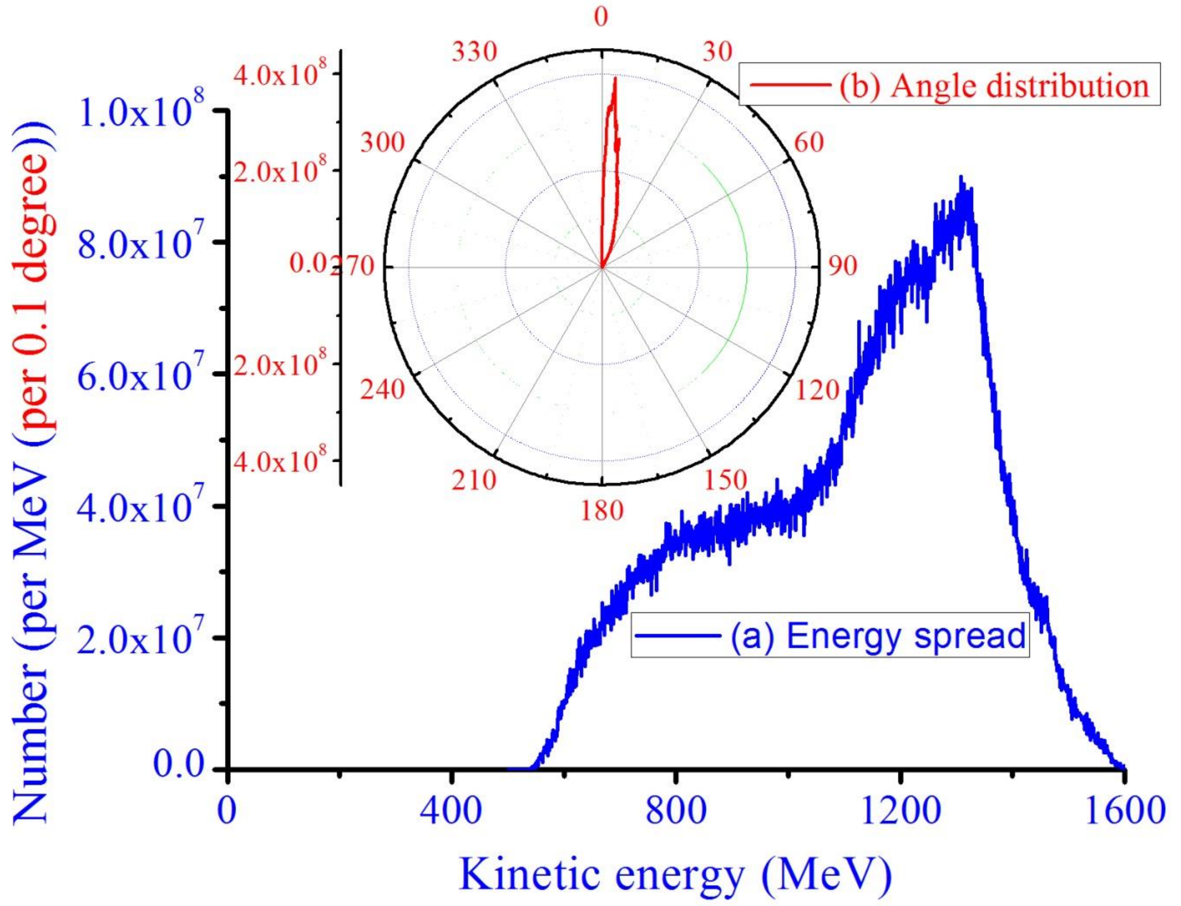
HB-RPA 3D simulations



Simulation Parameters

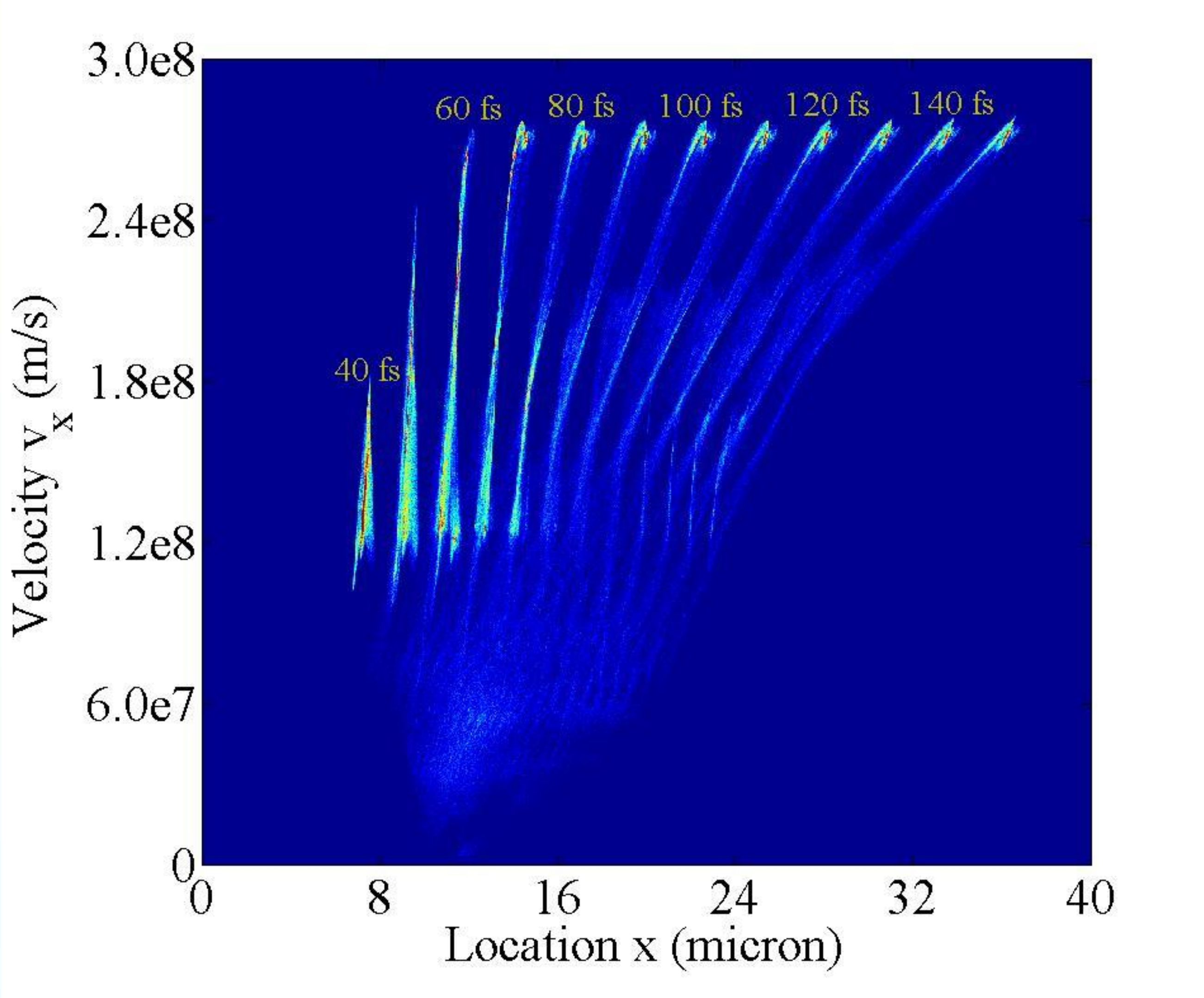
- Laser intensity 4.0×10^{22} W/cm^2
- Laser duration 15 fs
- Focal spot 4.2 micron (FWHM)
- Target density 15 n_c
- Simulation time 150 fs

HB-RPA 3D simulations



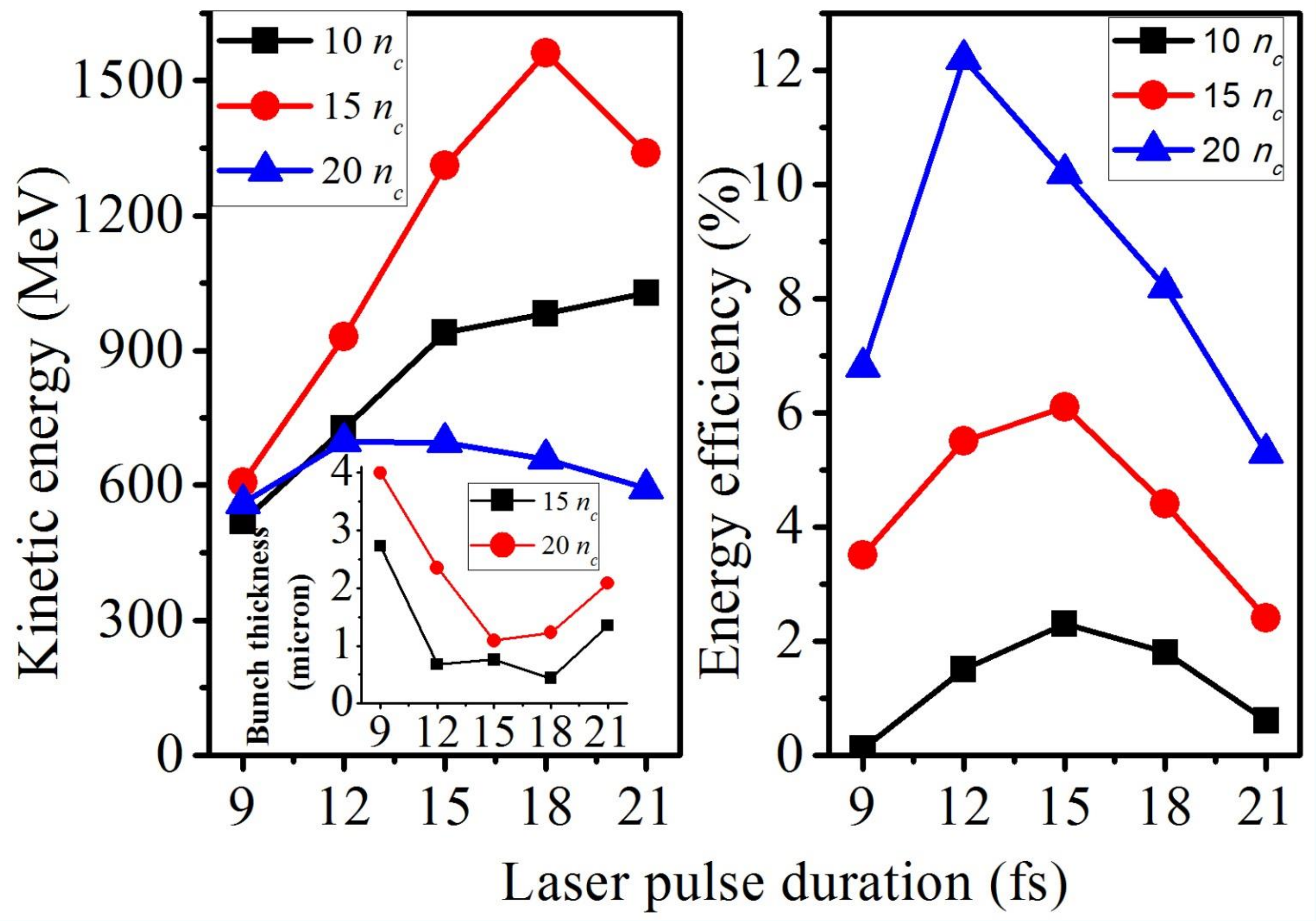
- The spot size of the proton bunch was 2.9 micron (FWHM) with thickness of 0.8 micron (FWHM);
- The total number 4.06×10^{10}.
- It is found that the peak energy is 1.32 GeV with energy spread less than 28% and the angular spread is 9.2 degrees (HWHM).

HB-RPA 3D simulations



Phase space shows the proton bunch can be accelerated to GeV in less than 40 fs

HB-RPA 3D simulations



Proton bunch peak energy, bunch thickness and energy efficiency VS. laser pulse duration and plasma density.

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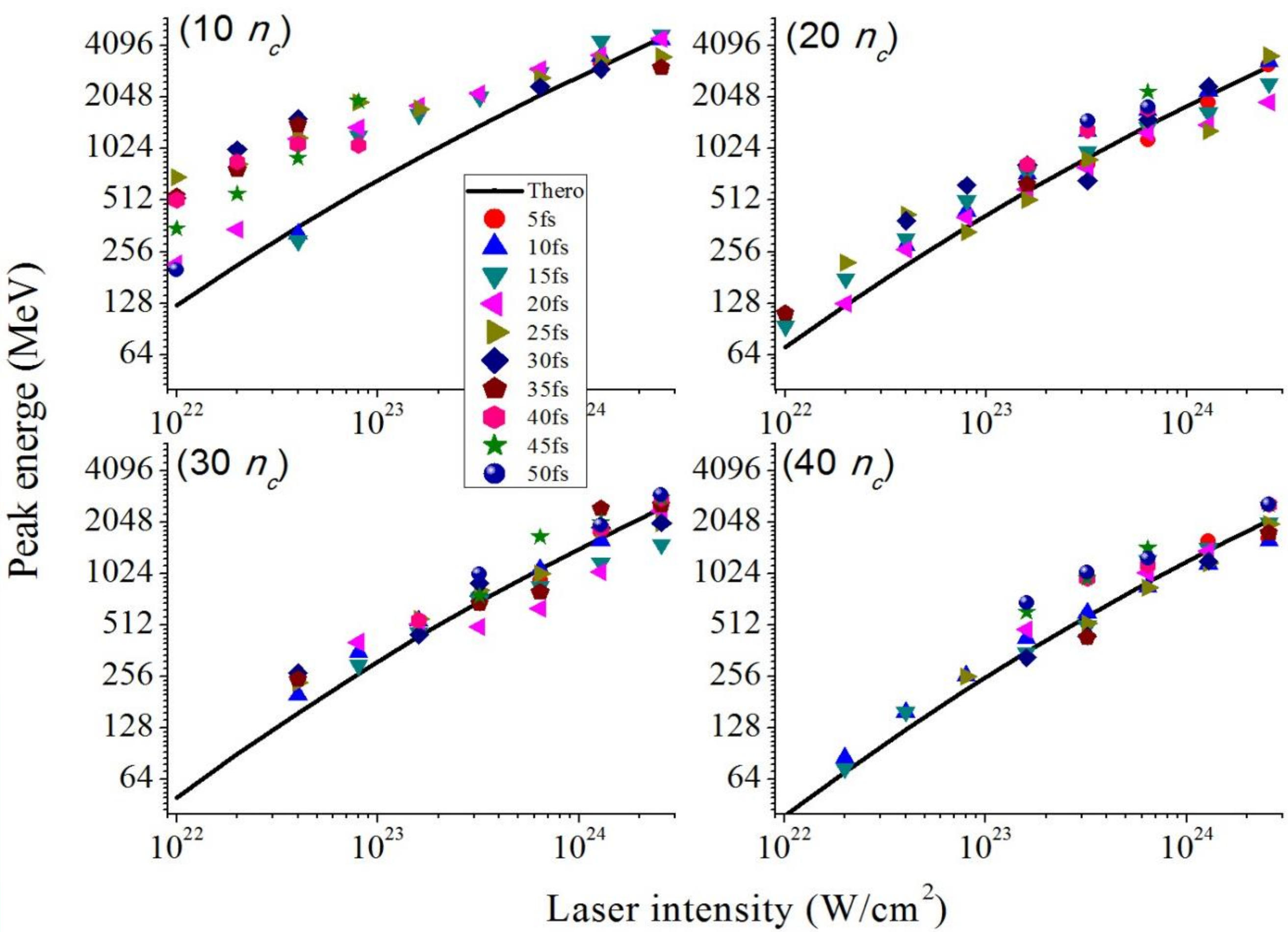
HB-RPA scaling work by 2D simulations

- **Employing theoretical expression on proton energy**

$$E_k = m_p c^2 \left(\frac{2I / \rho c^3}{1 + 2\sqrt{2I / \rho c^3}} \right).$$

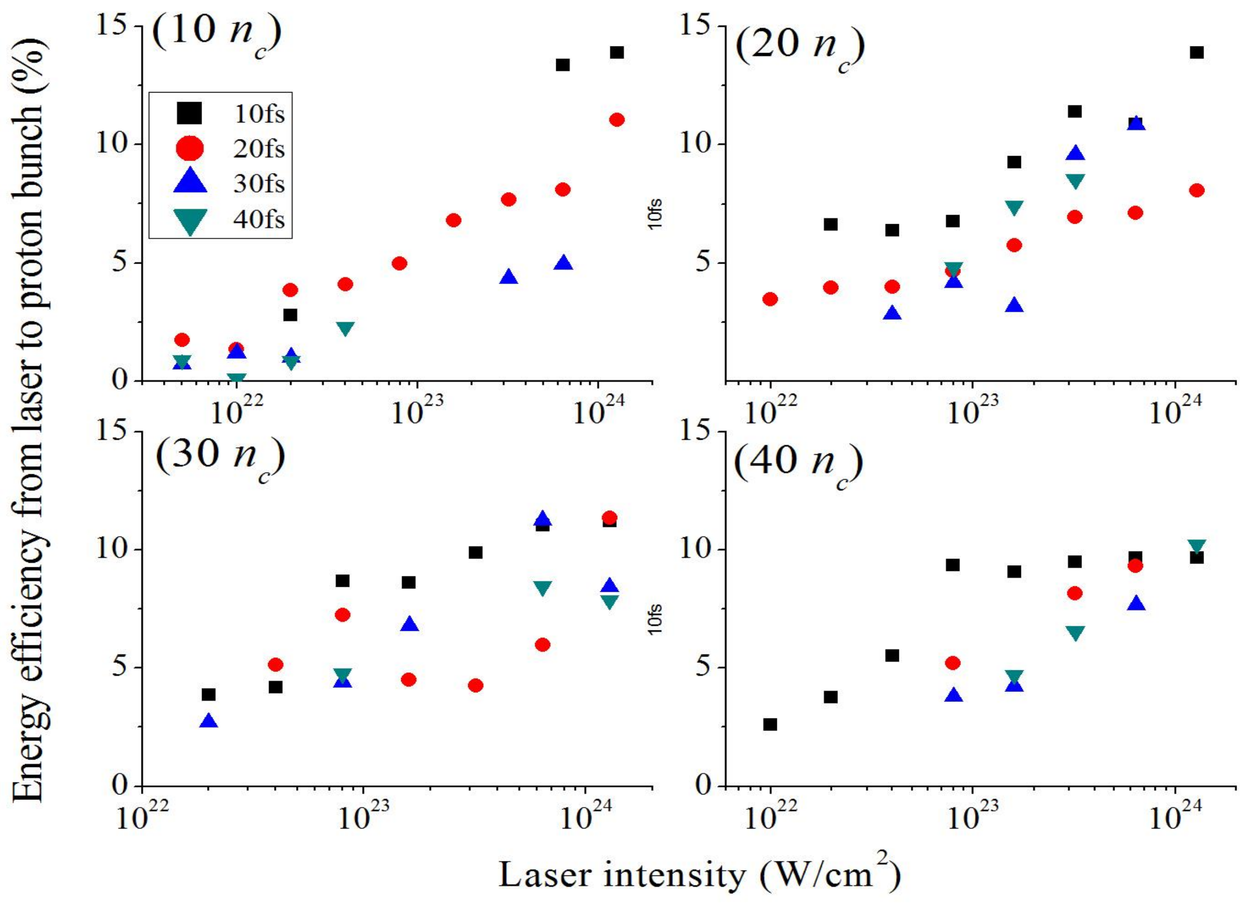
- **2D simulations were carried out to investigate the effect of laser pulse intensity, duration and plasma initial density on proton bunch peak energy.**

HB-RPA scaling work by 2D simulations



It is found that the theoretical expression (black line) works well for plasma initial density above 20 n_c,

HB-RPA scaling work by 2D simulations



It is found that energy efficiency increases with laser intensity. The highest efficiency can reach up to 15%. For a given laser pulse intensity, duration around 10 to 20 fs can obtain a higher efficiency.

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Summary

- We have studied HB-RPA proton acceleration at near-critical density targets by 3D and 2D PIC simulations.
- High collimated proton bunches of more than 1.3 GeV can be accelerated in 3D simulation.
- Optimal acceleration conditions have been considered in detail.
- Scaling of proton peak energy and energy efficiency with laser parameters such as laser intensity and laser pulse duration have been studied in detail by 2D simulations.

Thank you very much for your attentions