



Reverse Ion Acceleration by Laser-Matter Interaction

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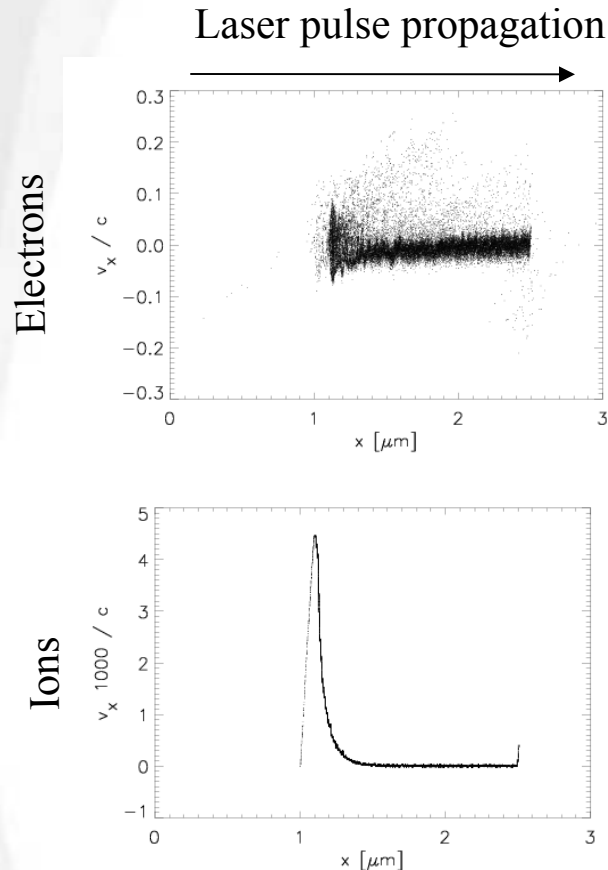
Outline

- Forward Ion Acceleration
- Ion acceleration in reflecting geometry
- Simulations with pre-ionized plasma
- Simulations including ionization
- Conclusions
- References

Introduction

- Ion acceleration via laser-matter interaction is an attractive mechanism for several potential applications, e.g.:
 - compact size accelerators
 - diagnostic sources
- Common setup:
 - ultra-intense, ultra-short laser pulse hits over- or underdense foil target
 - Electrons ponderomotively accelerated and heated
 - Ions accelerated forward (same direction as initial laser pulse)
- Several mechanisms can be responsible for ion acceleration:
 - Sheath normal acceleration
 - Shock acceleration
 - Coulomb explosion
 - Adiabatic expansion
- For some applications, **acceleration in backward direction is preferable!**
- Investigation of different setups for reverse acceleration

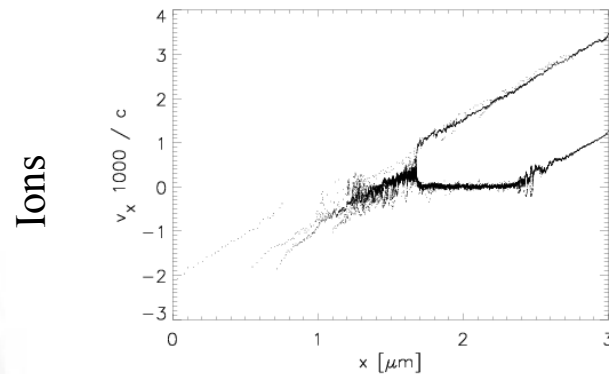
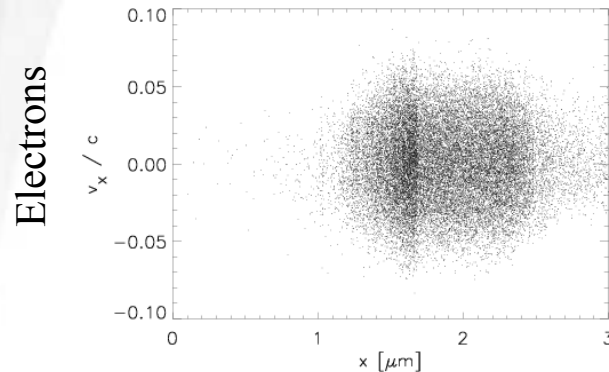
Example of Laser-Matter Interaction



- Interaction of 100 fs laser-pulse with over-dense foil target propagating left to right
- During laser pulse (100 fs):
 - Electrons accelerated into foil via ExB
 - Overshooting at foil backside
 - Electron recirculation
- ⇒ Electrostatic fields at front and back of foil
- ⇒ Ions get accelerated in forward direction

Laser-Matter Interaction (Cont.)

Laser pulse propagation



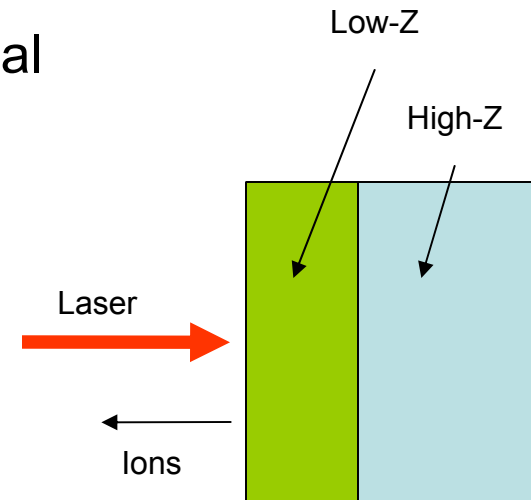
- After laser pulse (≈ 2 ps):
- Electrons thermalize
- Ions continue to be accelerated
 - Sheath normal acceleration at back and front
 - Shock acceleration (if shock forms)

QUESTION:

Is there a way to accelerate ions only in one direction?

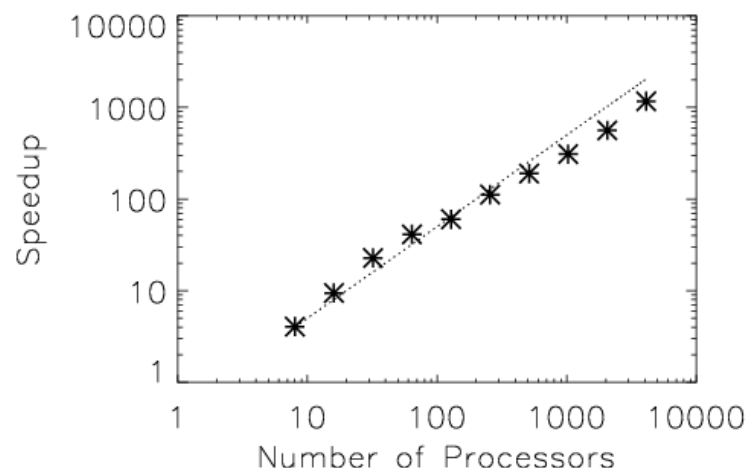
Two-Component Material

- **Overdense, high-Z target**
 - Laser pulse gets reflected
 - High-Z: electrons see strong potential
- **Underdense, low-Z coating**
 - Laser propagates through film
 - Ionizes the film
 - Accelerates some electrons
 - Second pass through film
 - More ionization
 - Accelerates more electrons and esp. ions, but now in backward direction



VORPAL

- Plasma simulation code/framework
 - PIC, Fluid, hybrid model
- Original design: Wakefield acceleration
- Nieter & Cary, J.Comp. Phys., **196**(2), 448, 2004
- Multi-Dimensional (N=1,2,3)
- Fully parallel
 - Scaling for > 4000 PEs
 - Flexible domain decomp
 - Dynamic load balancing
 - C++
- Output format: HDF5
- Postprocessing/Viz:
 - IDL, OpenDX, GnuPlot



<http://www-beams.colorado.edu/vorpal/>

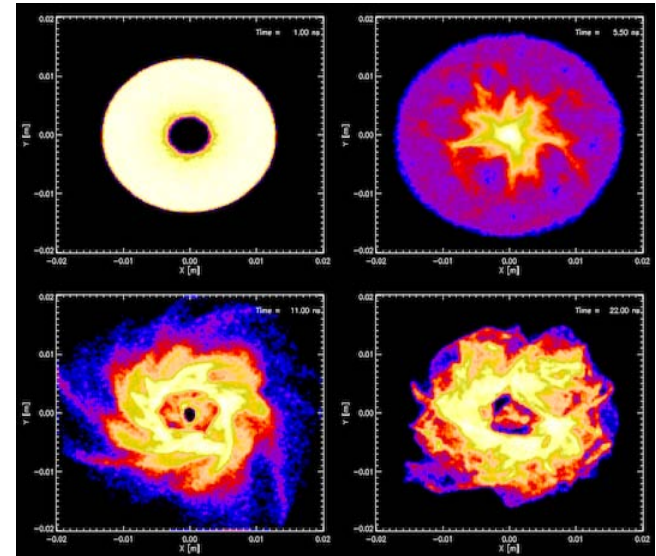
VORPAL Features

- **Full EM PIC model**
 - Moving window
- **Variety of particle sources, emitters**
 - Space Charge limited
 - Fowler-Nordheim
- **Parallel ES solver**
 - Based on Aztec (Sandia)
 - Variety of solvers, preconditioners
- **DSMC**
 - Being implemented
- **Ionization**
 - Field ionization
 - Impact ionization under development
- **Direct Coulomb interaction**
 - Hermite integrator



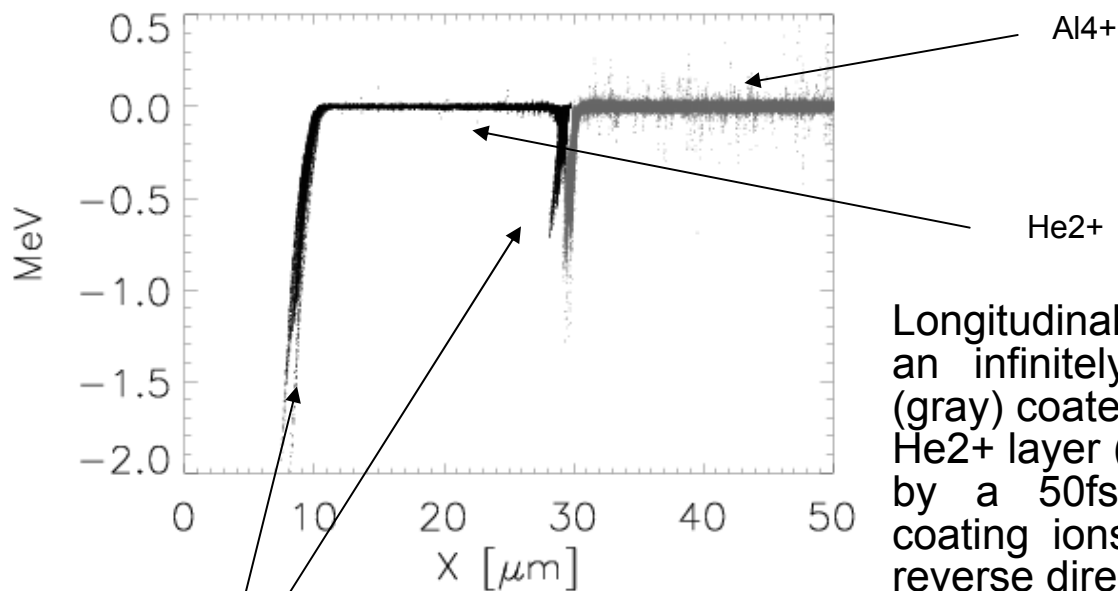
Some Applications of VORPAL

- Wakefield acceleration
- Electron cooling for RHIC
- High-power microwave breakdown
- Photonic bandgap structures
- Debris propagation in IFE chambers
- Dusty plasmas
- Gamma-ray bursts
- Magnetic reconnection
- Laser-Overdense interaction



Time evolution of the ion density in a 2D VORPAL simulation, including debris ions, debris electrons, background ions and background electrons.

Pseudo 2D simulations



Longitudinal ion phase space of an infinitely thick Al^{4+} target (gray) coated with a 30 nm thick He^{2+} layer (black) after being hit by a 50fs laser pulse. The coating ions are accelerated in reverse direction.

Mechanism works!

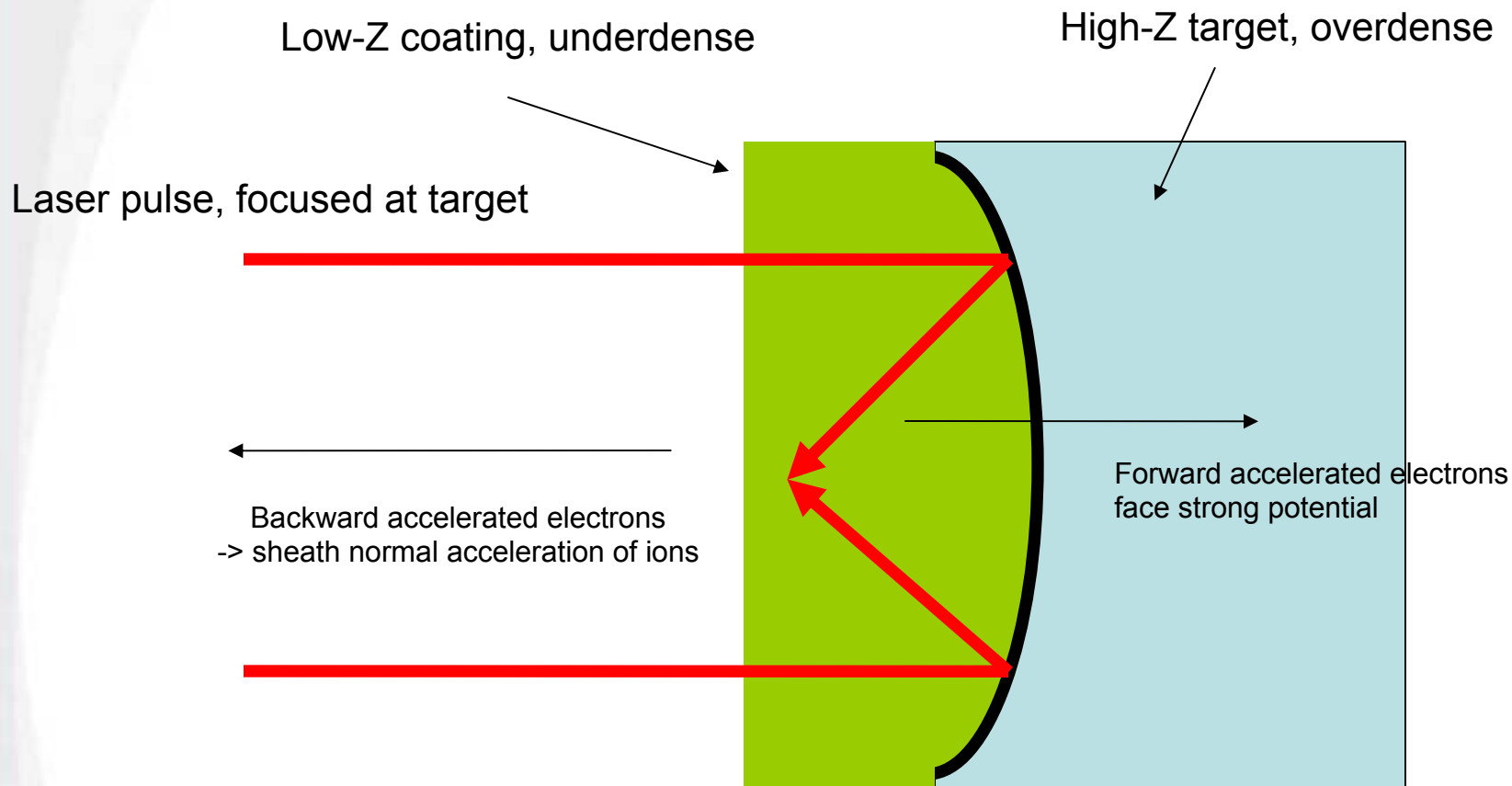
Backward accelerated ions

What about ionization? Peak intensity?

Ionization within coating

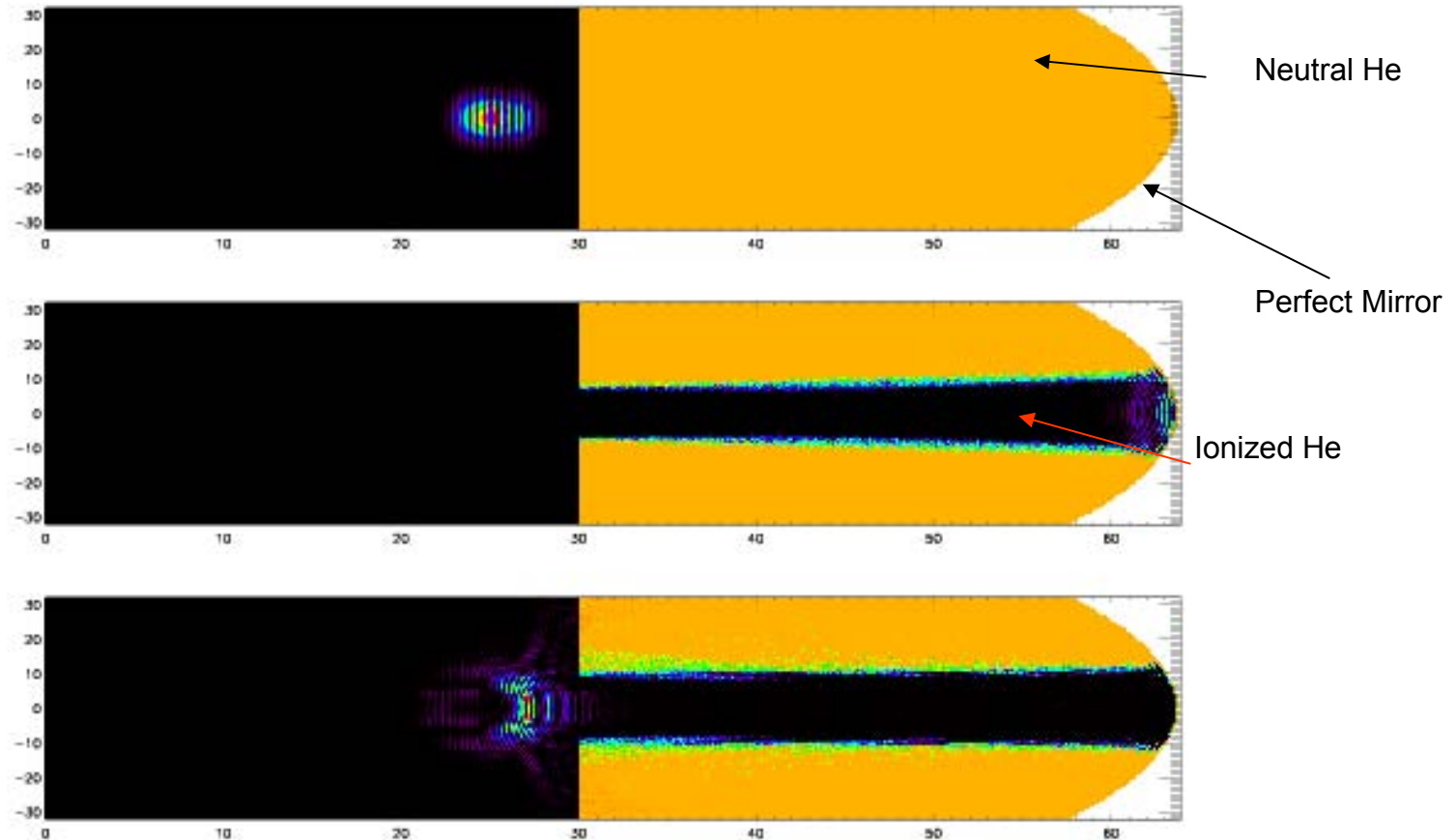
- Acceleration in backward direction if ionization happens only after reflection off the target
- Shape target as focusing mirror

Setup



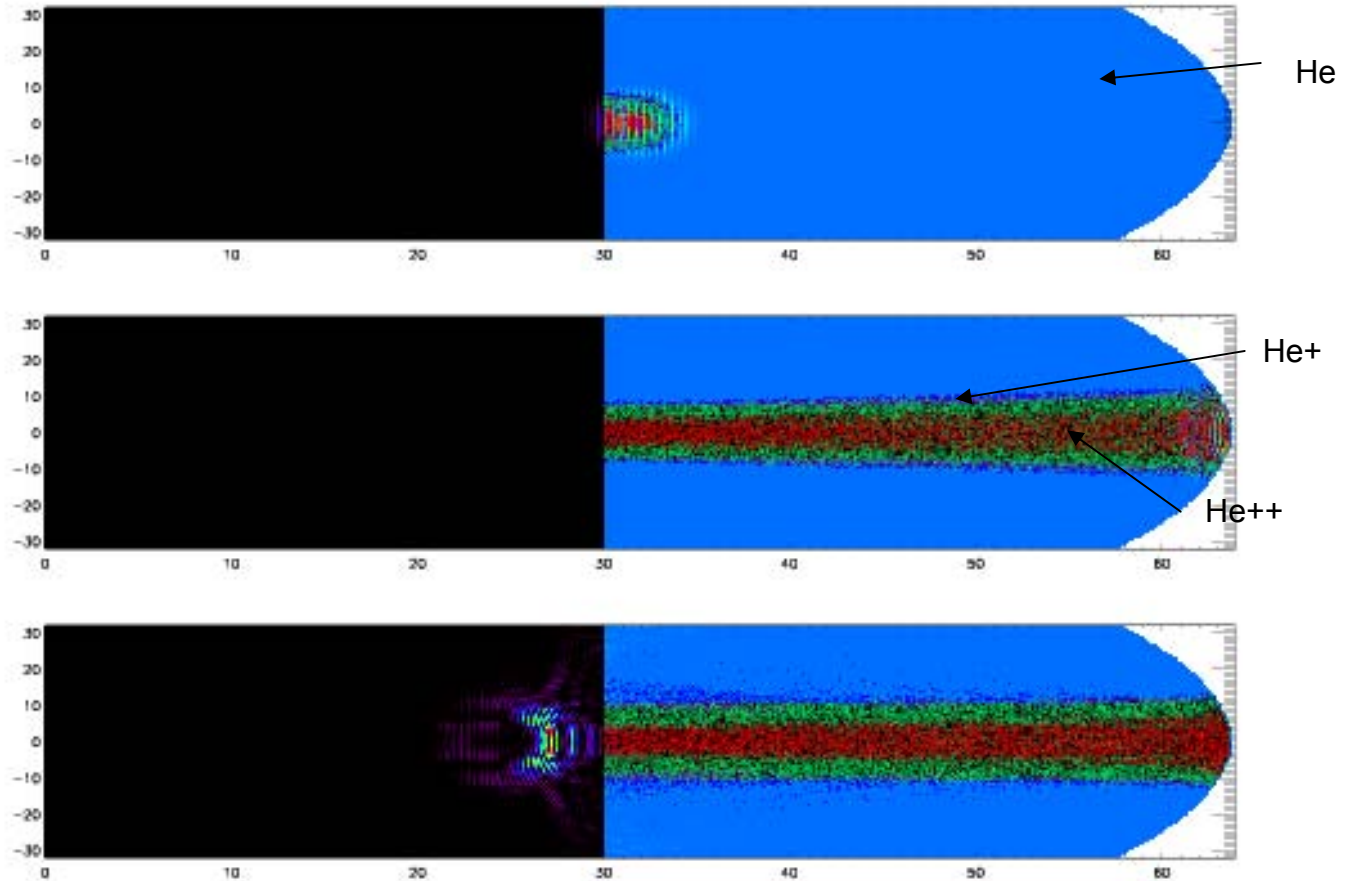
Coated mirror (incl. ionization)

Neutral He contours



Coated mirror (incl. ionization)

He Ions contours

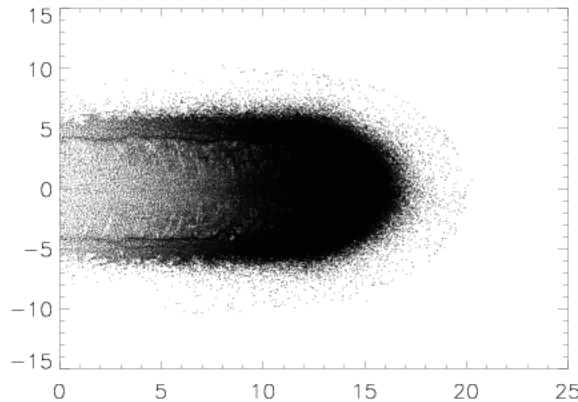


Backward Ion acceleration ?

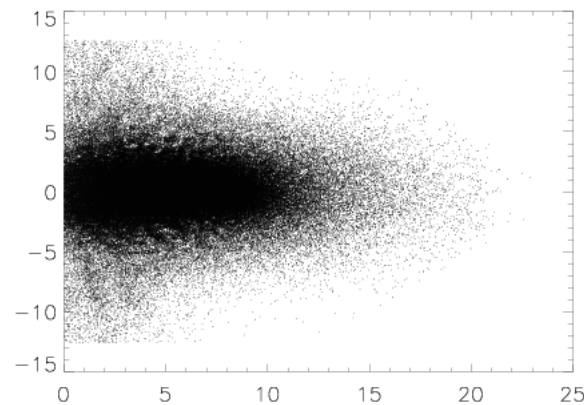
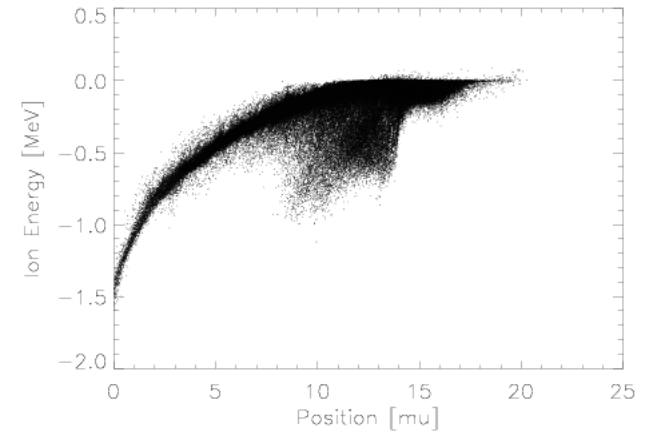
He++ Position

YES!

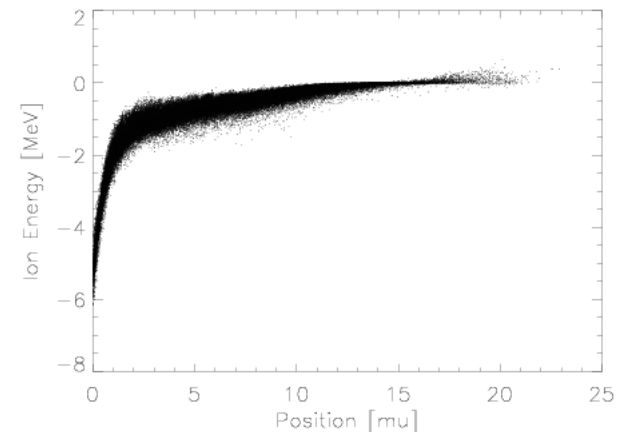
He++ Energy



$t=3.7\text{fs}$



$t=7.2\text{fs}$



Summary

- Presented simulations of laser-matter interaction
 - Different model for matter: pre-ionized, including ionization
 - Different geometries: plane parallel coating, focusing mirror
- Ion acceleration in reverse direction has been observed
- Future work:
 - More parameter studies to optimize process: coating thickness, Z-ratio, laser focus, mirror geometry
 - Dynamic focusing (pre-pulse creating “mirror”)

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