ION ACCELERATION FROM ULTRA THIN FOILS ON THE ASTRA GEMINI FACILITY

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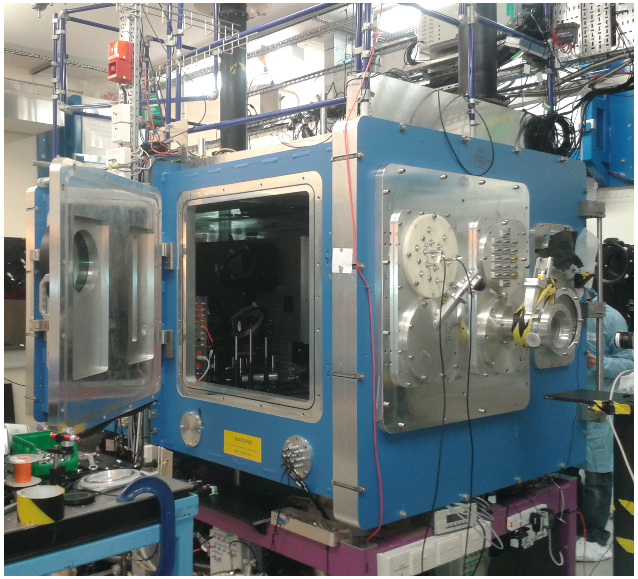


MOTIVATION

Understanding laser-driven ion acceleration mechanisms:
i.e. TNSA, RPA (light sail, hole boring), BOA.

Ion Acceleration Applications:
- biomedical applications (Schardt, D., 2007, Nucl. Phys. A787, 633.)
- proton radiography (Cobble, 2002, J. Appl. Phys. 92, 1775.)
- production of warm dense matter (Koenig,2005, Plasma Phys. Controlled Fusion 47, B441.)
- fast ignition of fusion targets (Roth, M., et al., 2001, Phys. Rev. Lett. 86, 436.)
- nuclear and particle physics (McKenna, P., et al., 2003a, Appl. Phys. Lett. 83, 2763.)

Investigation of biological response to high dose rate ion radiation

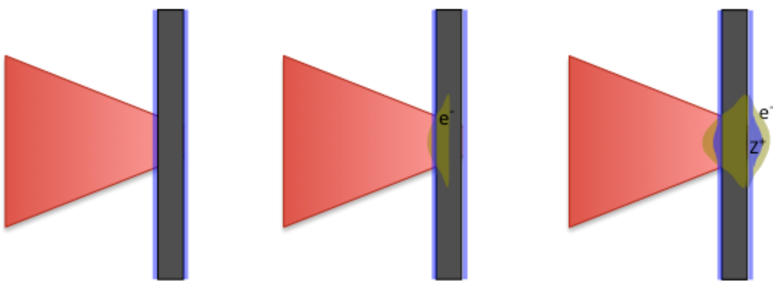
A-SAIL
ADVANCED STRATEGIES FOR ACCELERATING IONS WITH LASERS

"Investigation and optimisation of emerging ion acceleration schemes, with a focus on processes based on the radiation pressure of an intense laser pulse, namely Light Sail, Hole Boring and shock acceleration; and assessment of the radiobiological effects of ultrafast ion energy deposition."

PI: M. Borghesi, *Queen's University Belfast*

Laser driven-ion acceleration

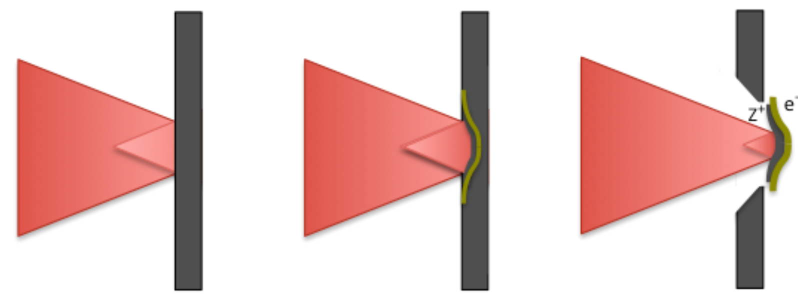
Target Normal Sheath Acceleration (TNSA)



- Intensities above 10^{19} W/cm^2
- Electron acceleration to MeV energies
- Ponderomotive electron heating $T_{HOT} \sim (I\lambda^2)^{0.5}$

Relatively thin foils allow electrons to reach the rear of the target and establish electrostatic sheath that generates a field (10^{12} V/m) able to accelerate protons from contaminants

Radiation Pressure Acceleration (RPA)



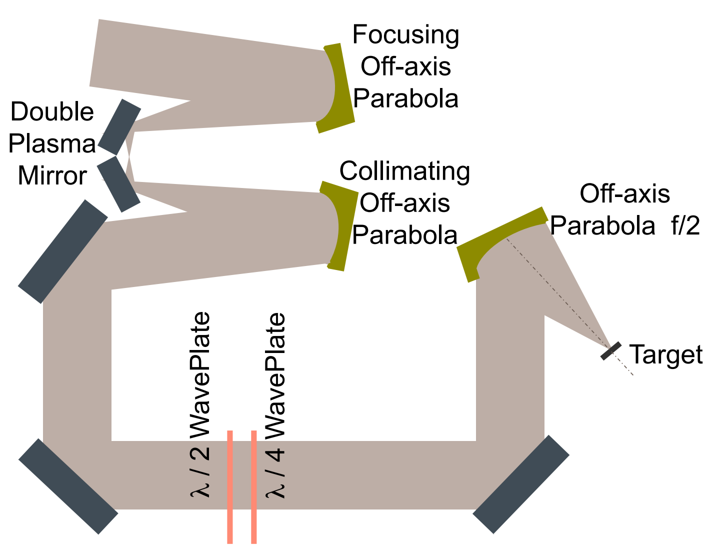
- Ions can be accelerated from target bulk by stronger field (~10^{14} V/m)
- Narrow band spectrum (whole foil acceleration)

Using Circular Laser polarisation:
No JxB acceleration
No TNSA
No target heating
Quasi-static pressure drive

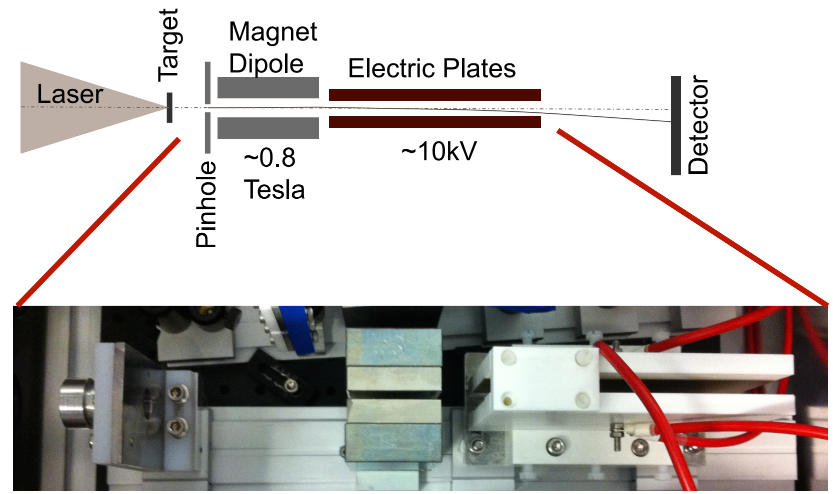
Experimental Setup

Rutherford Appleton Laboratory
Astra Gemini Facility

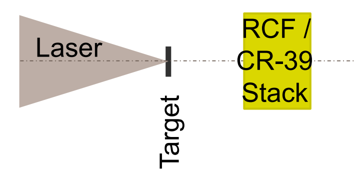
Set Up



Thomson Parabola Spectrometer



Stack of Radiochromic Film / CR-39



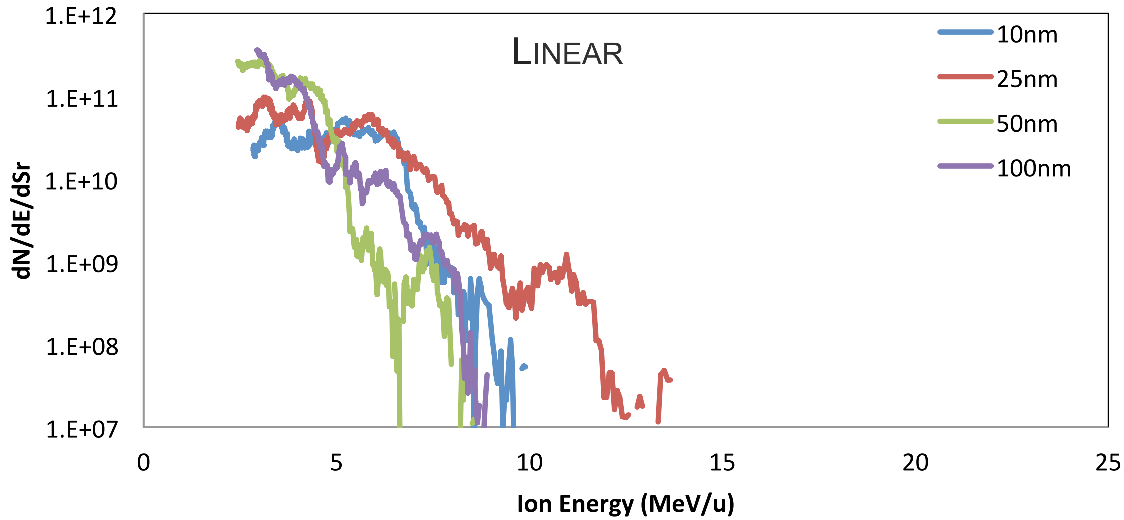
GEMINI Laser

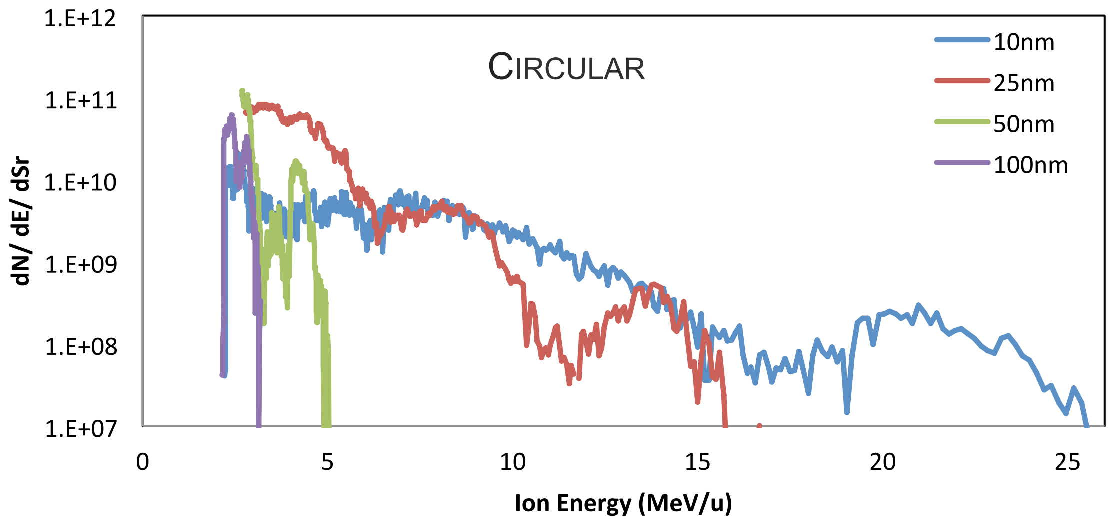
Pulse length ~ 40 fs
Energy < 15 J
Intensity ~ 10^{21}-10^{22} W/cm^2

Experimental Conditions

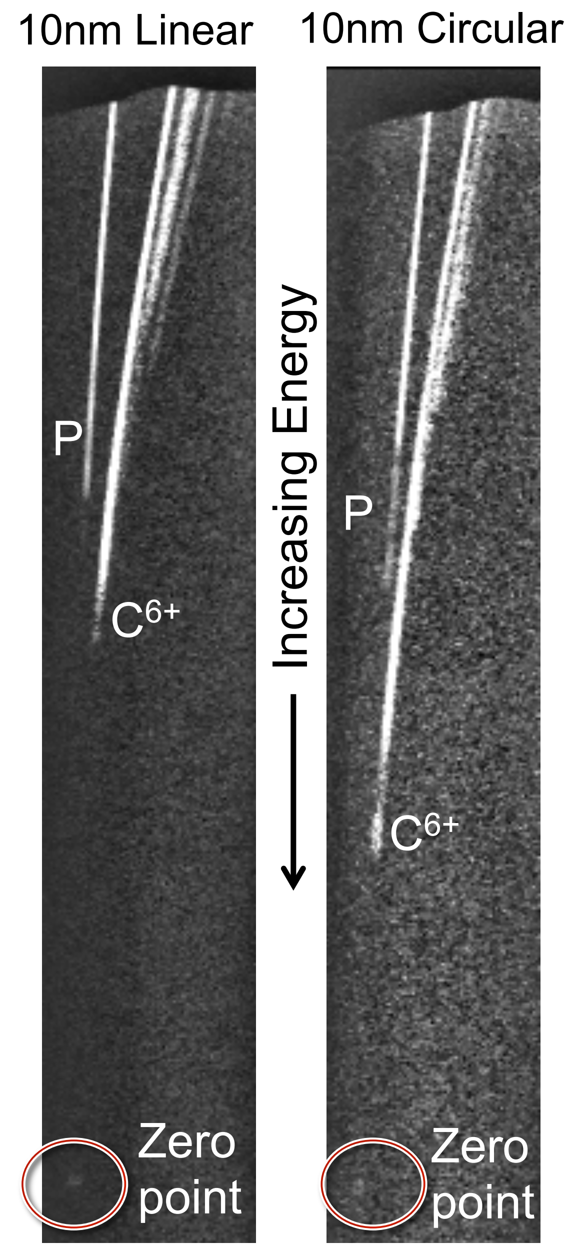
Pulse length ~ 40-45 fs
Energy ~ 13 J → ~ 6.5 J on target
PM ~ 50% and 10^{12} contrast
Intensity = 2.7x10^{20} ± 25% W/cm^2

Experimental Results: C^{6+} Ion Spectra

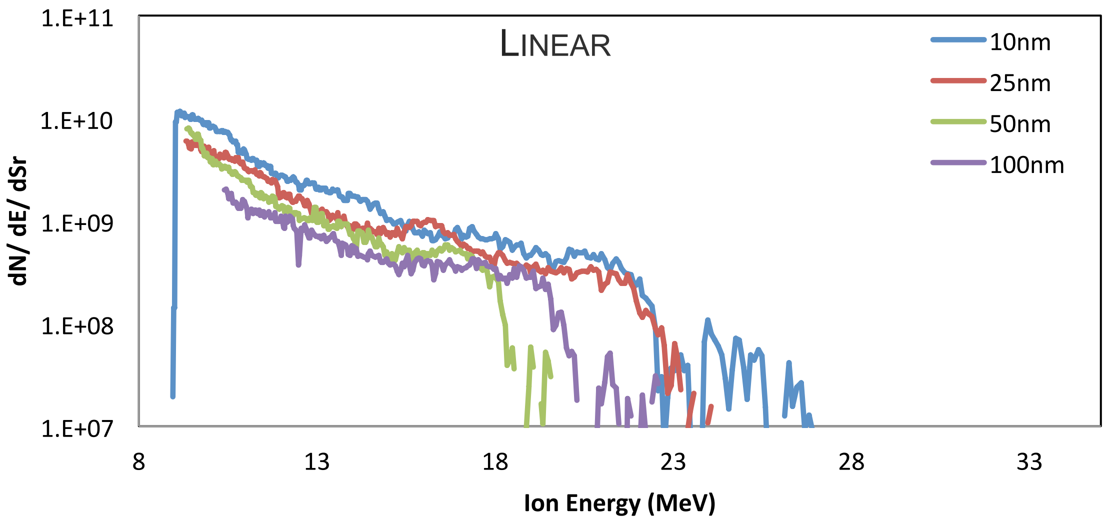


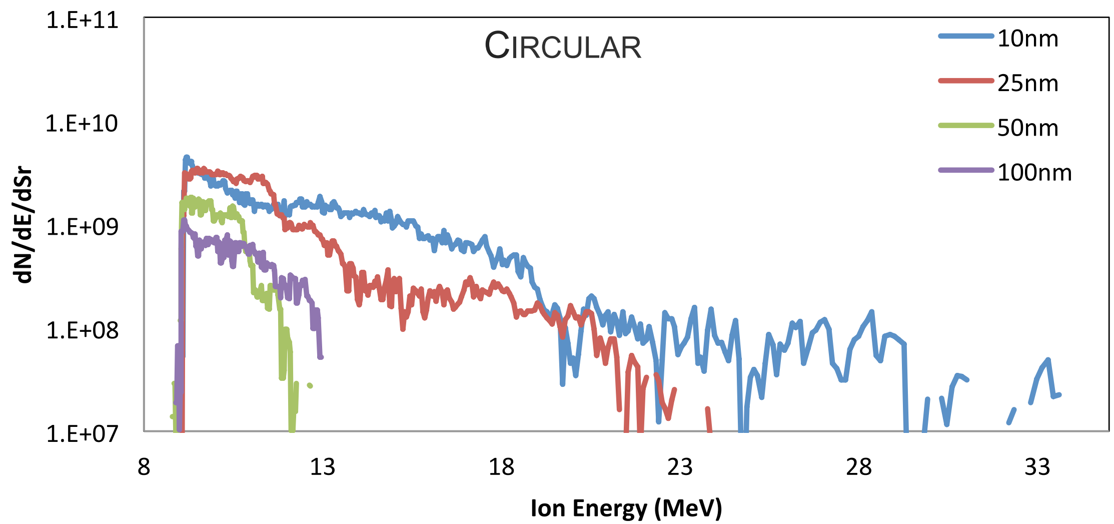


Raw Data from IP

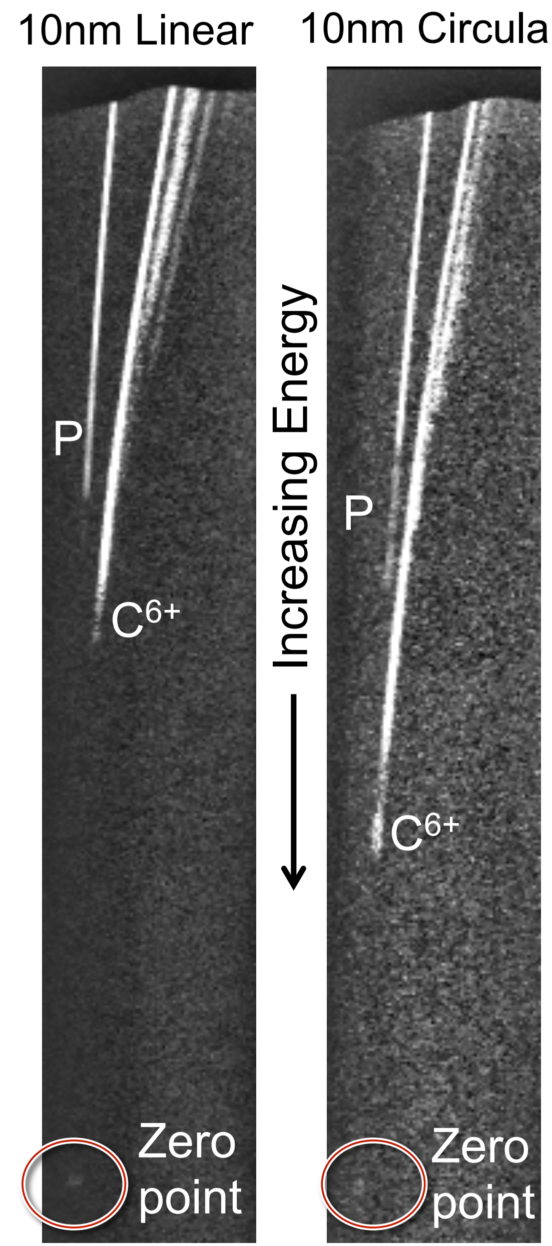


Experimental Results: Proton Spectra

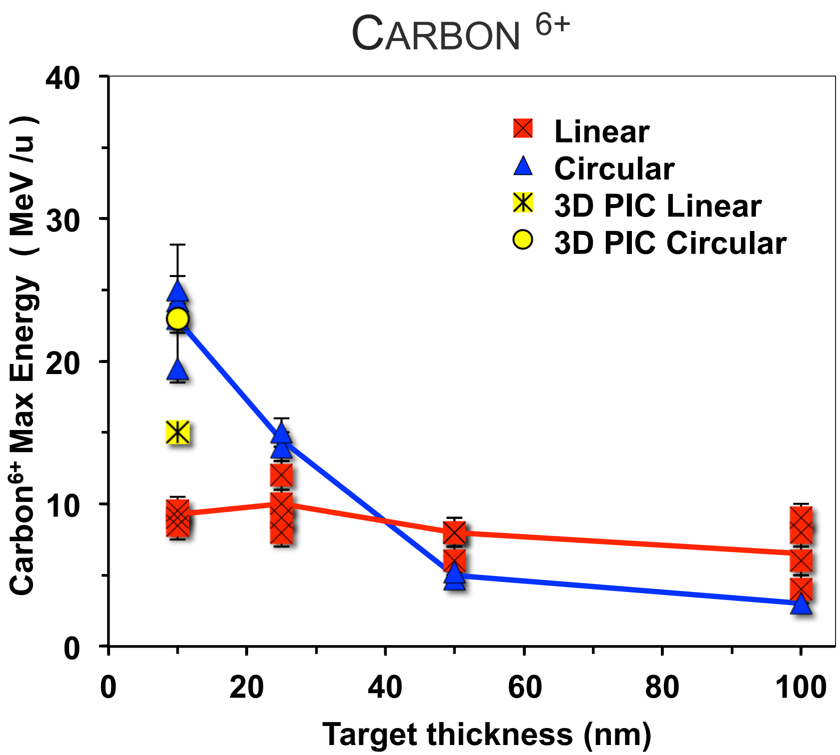


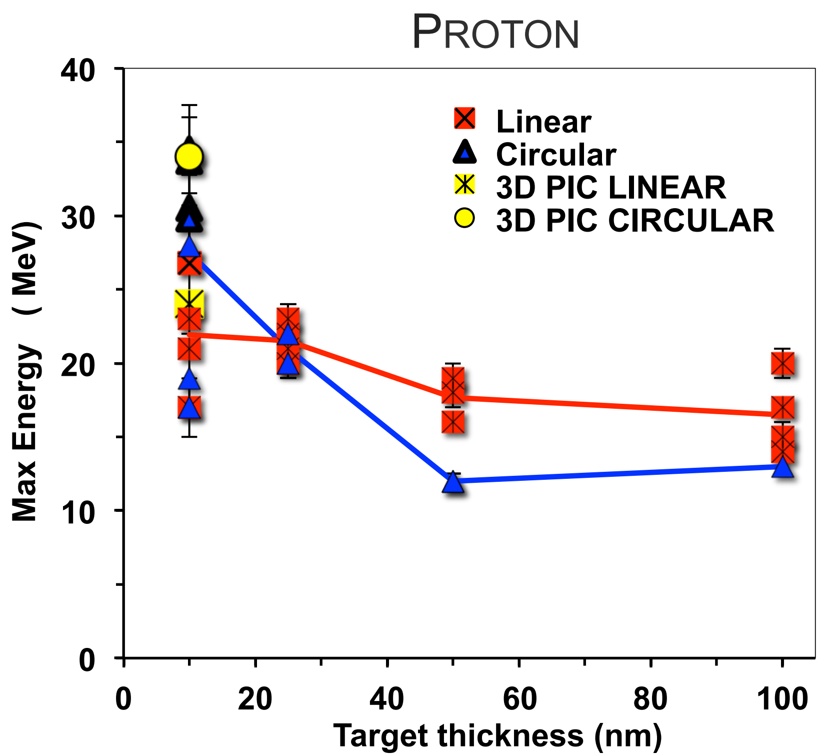


Raw Data from IP



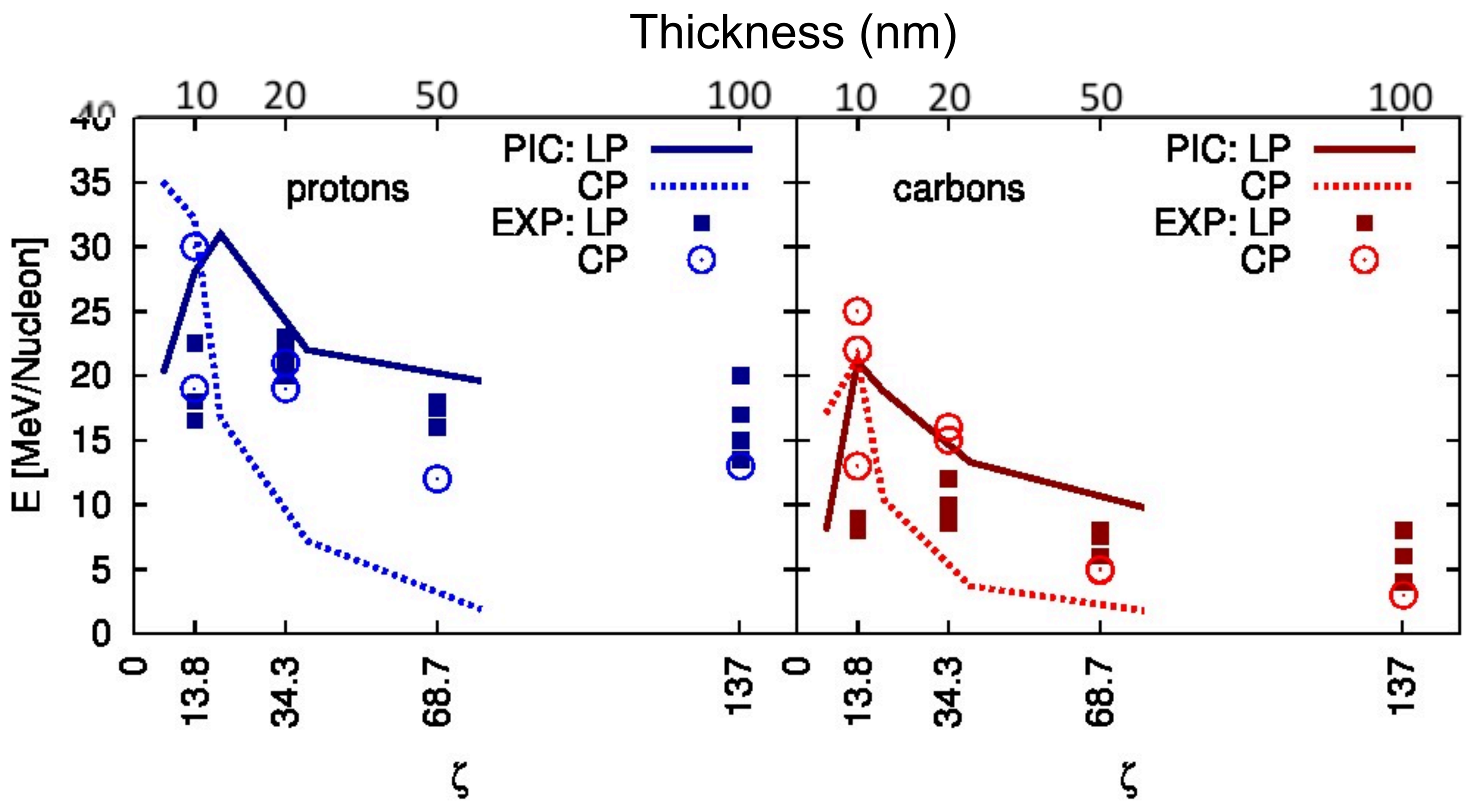
Experimental - Ion energy versus target thickness





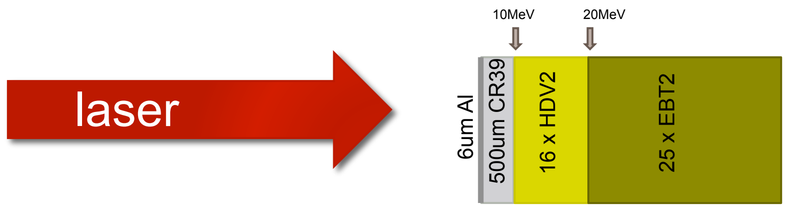
- Very significant energies for CP at 10nm targets (35 MeV for protons and ~300 MeV for C^{6+})
- Energies for CP higher for the thinnest targets: possibly RPA Light Sail dominates?
- 3D PIC simulations (A. Macchi, A. Sgattoni - Pisa University) reproduce the difference between CP and LP data with very good agreement

2D SIMULATIONS - ION ENERGY VERSUS THICKNESS



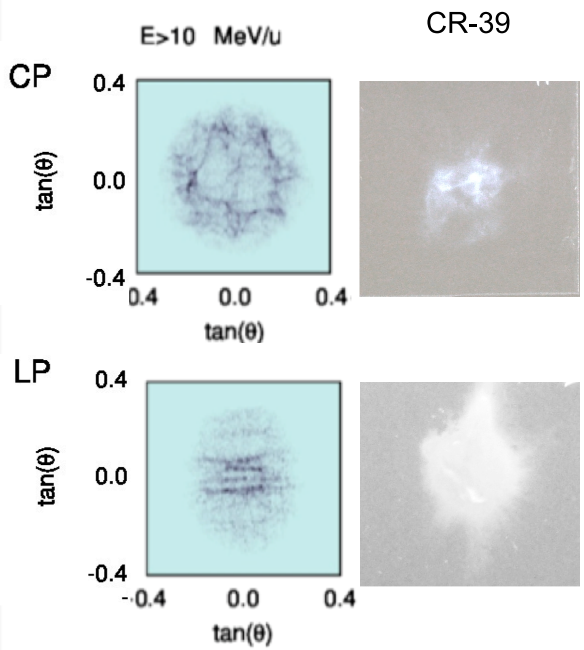
- 2D PIC simulations – good agreement with experiment
- LP irradiation leads to electron heating, target disassembly and transparency below 20nm C. CP pulses allow 20nm targets to stay opaque and to be driven by radiation pressure (A. Macchi, A. Sgattoni – Pisa University)

Experiment and 3D Simulation – Beam profile

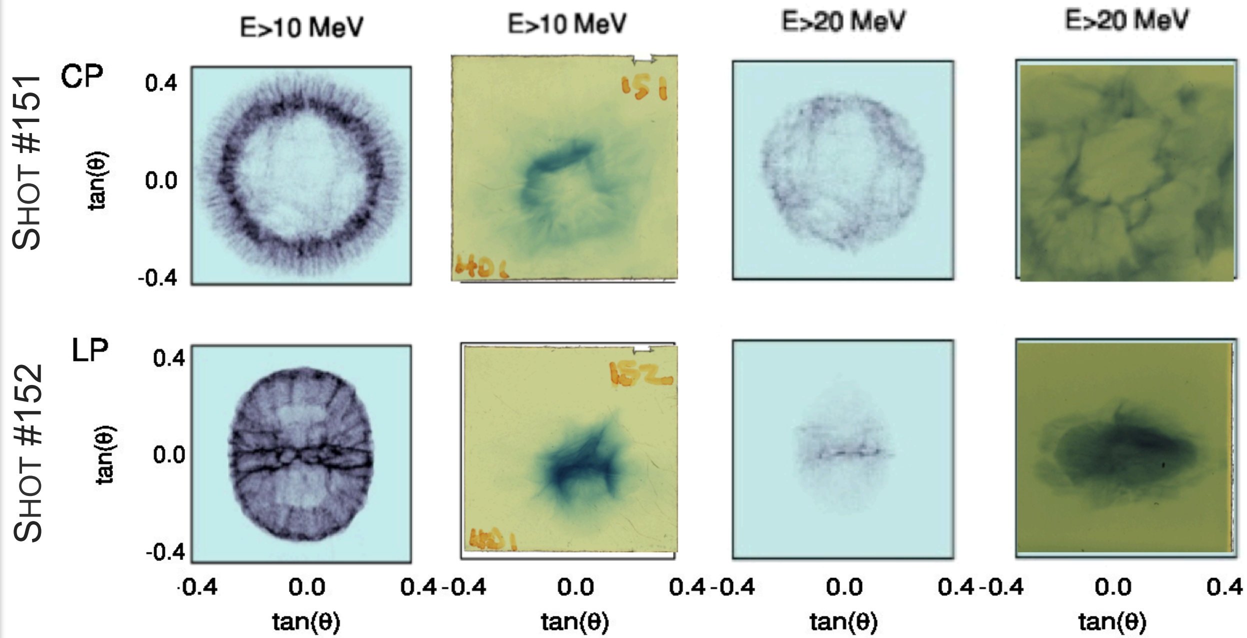


RCF/CR-39 Stack

Carbon ion profile using CR-39

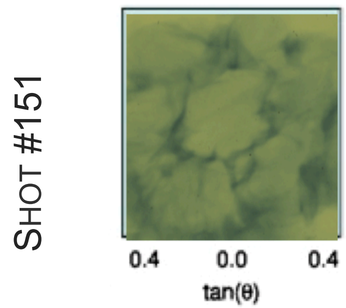


Proton profile using Radiochromic Film



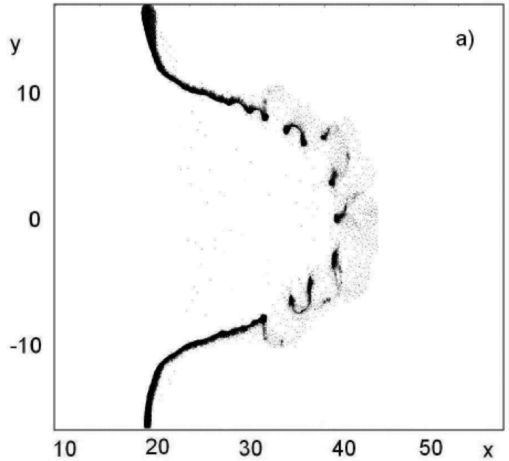
Circular Polarisation – Beam structure

Structured larger divergence beam; unstabilised radiation pressure drive



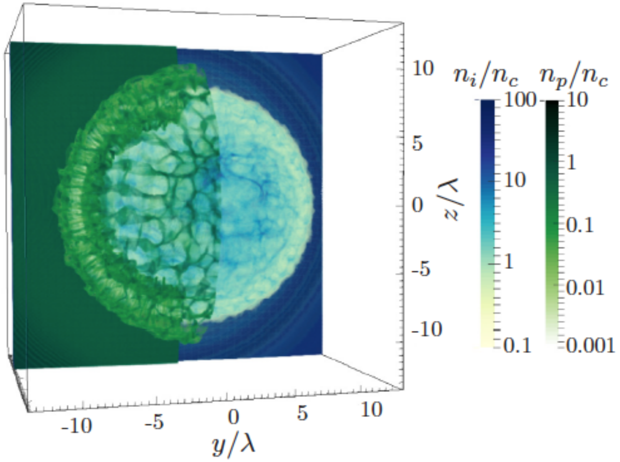
EBT2 layer 4 (20MeV)

“Rayleigh Taylor” like instability



(a) Ion density distribution in the x-y plane

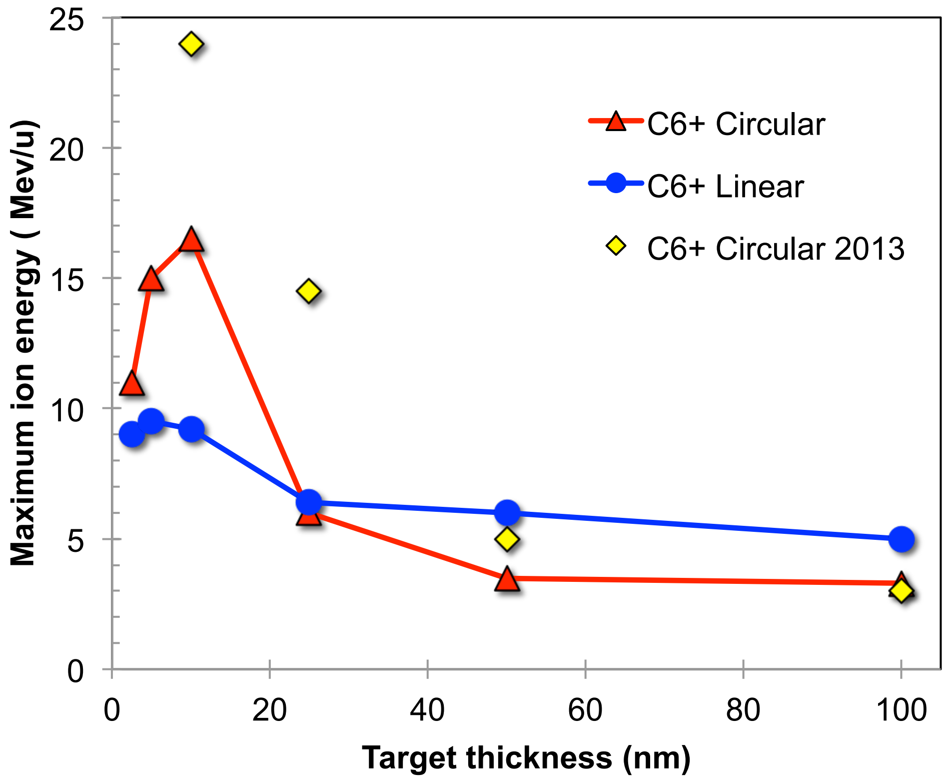
F.Pegoraro and S.V. Bulanov, PRL, **99**, 065002 (2007)

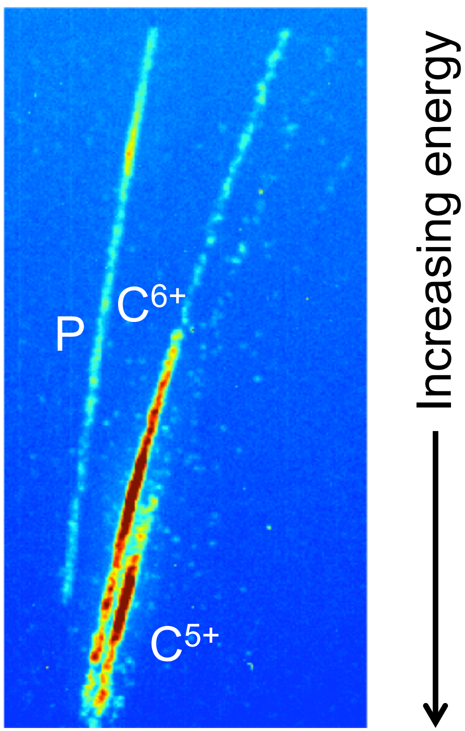


Snapshot at t = 30T showing the densities of Carbon ions (blue tones) and of protons (green tones).

A.Sgattoni et al., PRE **91**, 013106 (2015)

2014 Follow up experiment





- Similar trends for Thomson Parabola Spectrometers at 4° and -9°
- Lower energies compared to preliminary experiment
- Shot to shot variation – unstable regime; target, laser, interaction is hard to reproduce

SUMMARY

We see higher energy proton and carbon ions for circular polarisation laser pulses compared to linear polarisation when using thin targets (<20nm).

3D simulations reproduce the cut-off energies for proton and carbon ions. 2D simulations generally underestimate the ion maximum energies, but the trend is well reproduced.

3D simulations also reproduce the beam profiles.

THANK YOU FOR YOUR ATTENTION