



# ION ACCELERATION FROM ULTRA THIN FOILS ON THE ASTRA GEMINI FACILITY

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# THANKS TO ALL OUR COLLABORATORS

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# OUTLINE

- I Motivations
- II Experimental Setup
- III Experimental results and simulations
- IV Summary



# 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

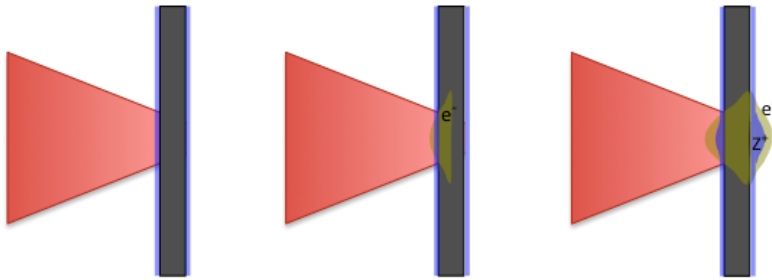


*“Investigation and optimisation of emerging ion acceleration schemes, with a focus on processes based on the radiation pressure of an intense laser pulse, namely Light Sail, Hole Boring and shock acceleration; and assessment of the radiobiological effects of ultrafast ion energy deposition.”*

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

# LASER DRIVEN-ION ACCELERATION

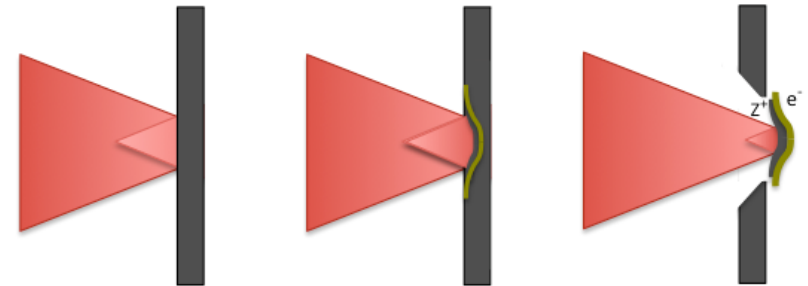
## Target Normal Sheath Acceleration (TNSA)



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

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 ( $\sim 10^{14}$  V/m)
- Narrow band spectrum (whole foil acceleration)

### USING CIRCULAR LASER POLARISATION:

NO JxB ACCELERATION

NO TNSA

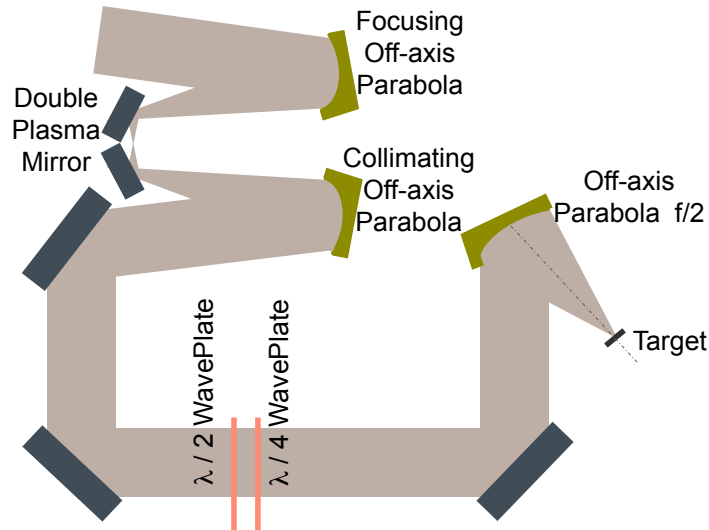
NO TARGET HEATING

QUASI-STATIC PRESSURE DRIVE

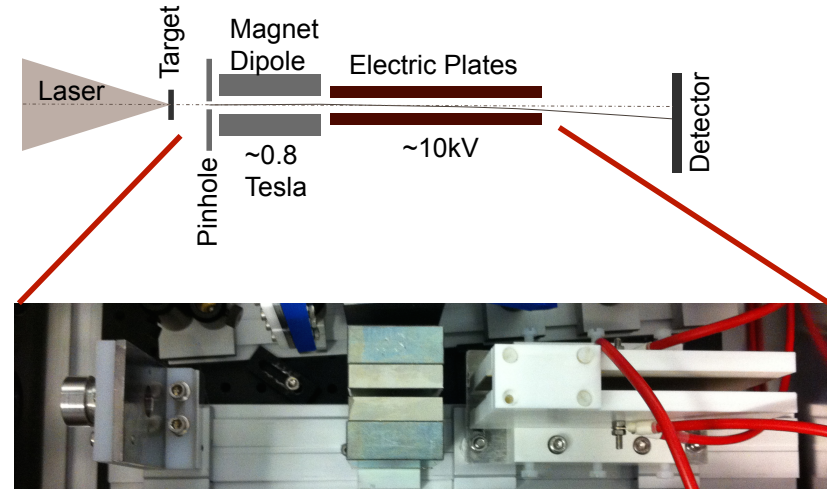
# EXPERIMENTAL SETUP

RUTHERFORD APPLETON LABORATORY  
ASTRA GEMINI FACILITY

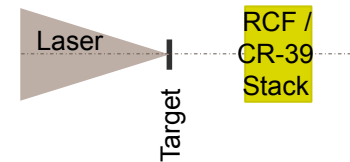
## Set Up



## 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<sup>2</sup>

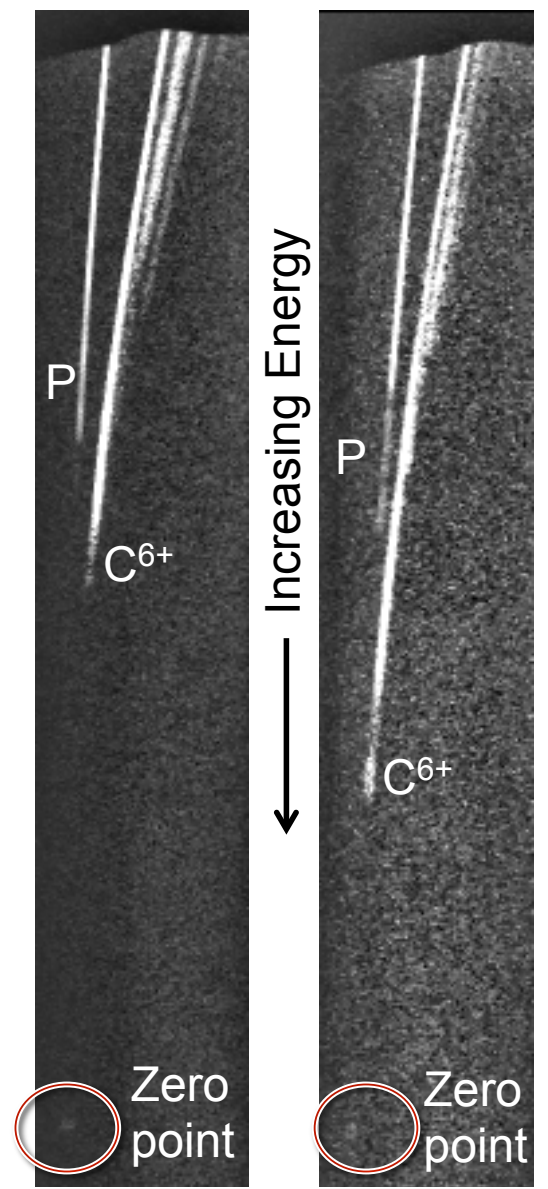
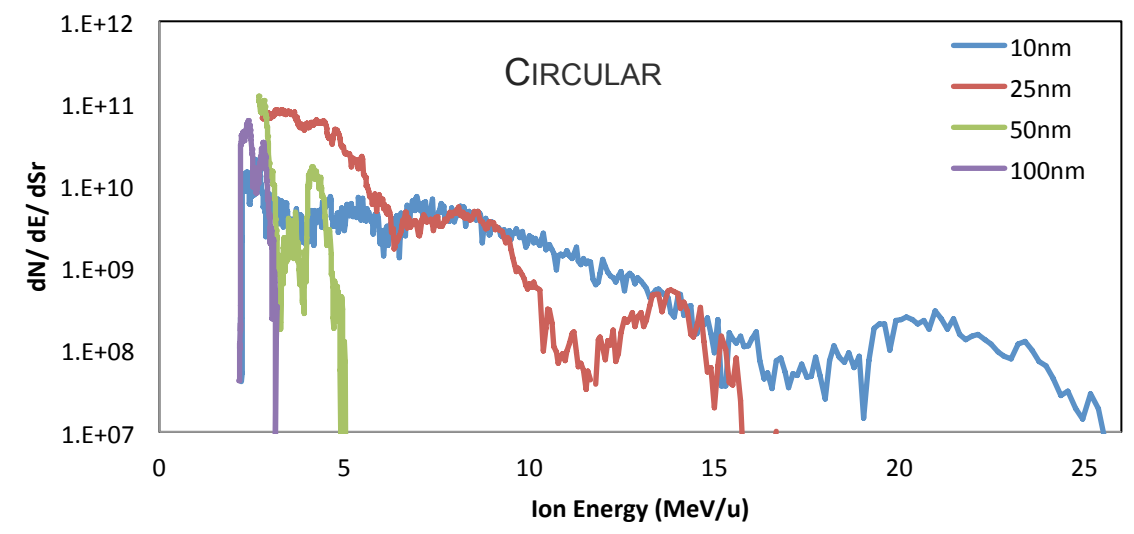
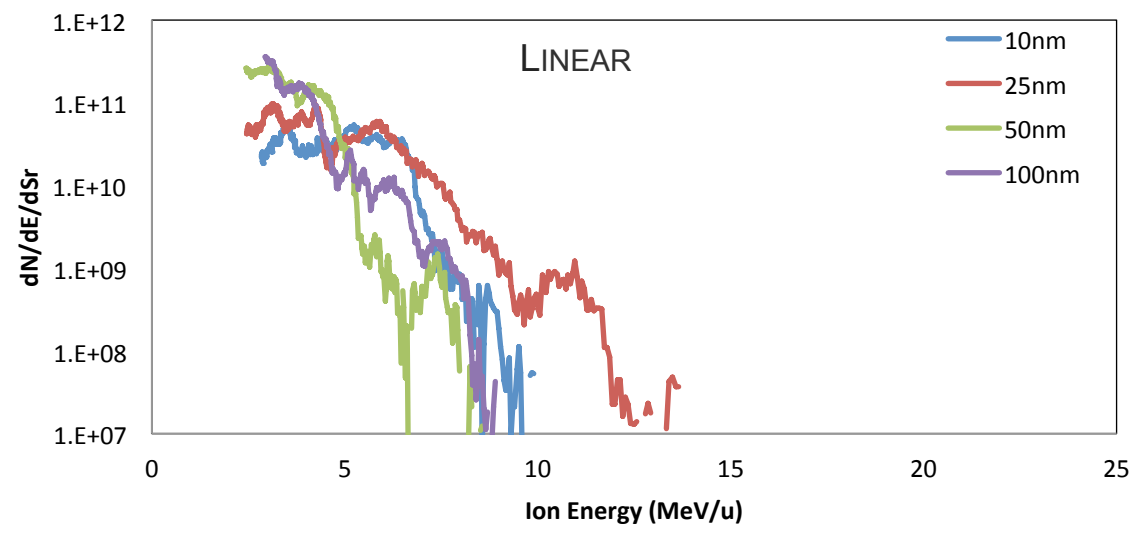


### Experimental Conditions

Pulse length ~ 40-45 fs  
Energy ~ 13 J → ~ 6.5 J on target  
PM ~ 50% and  $10^{12}$  contrast  
Intensity =  $2.7 \times 10^{20} \pm 25\%$  W/cm<sup>2</sup>

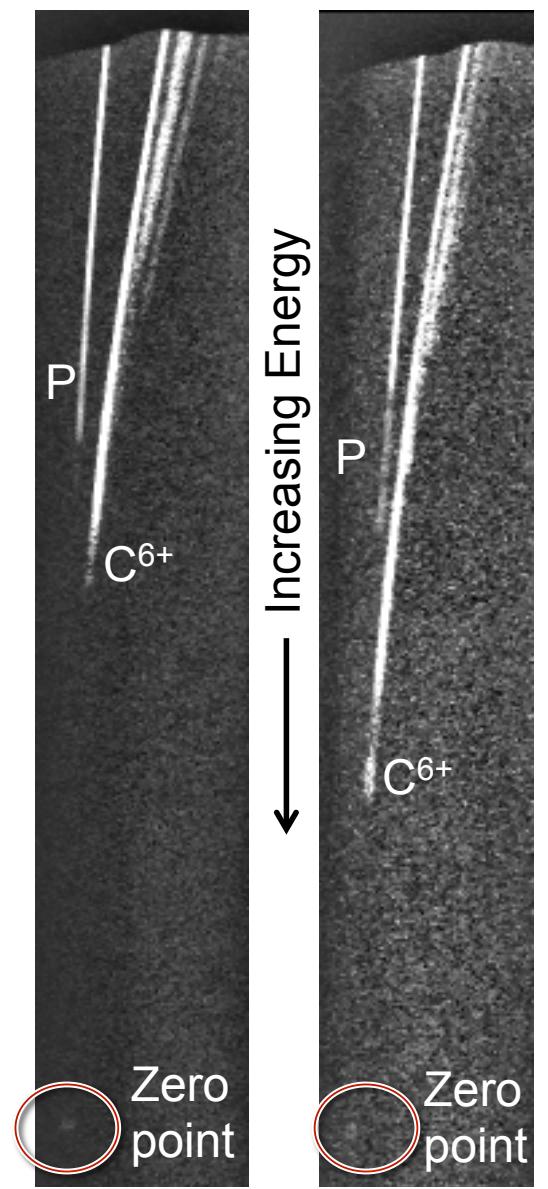
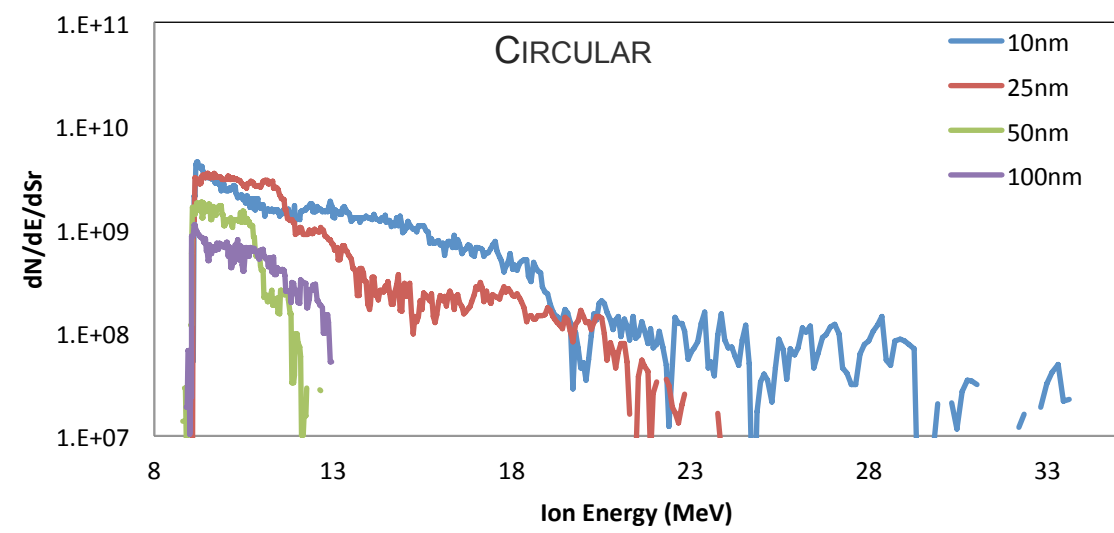
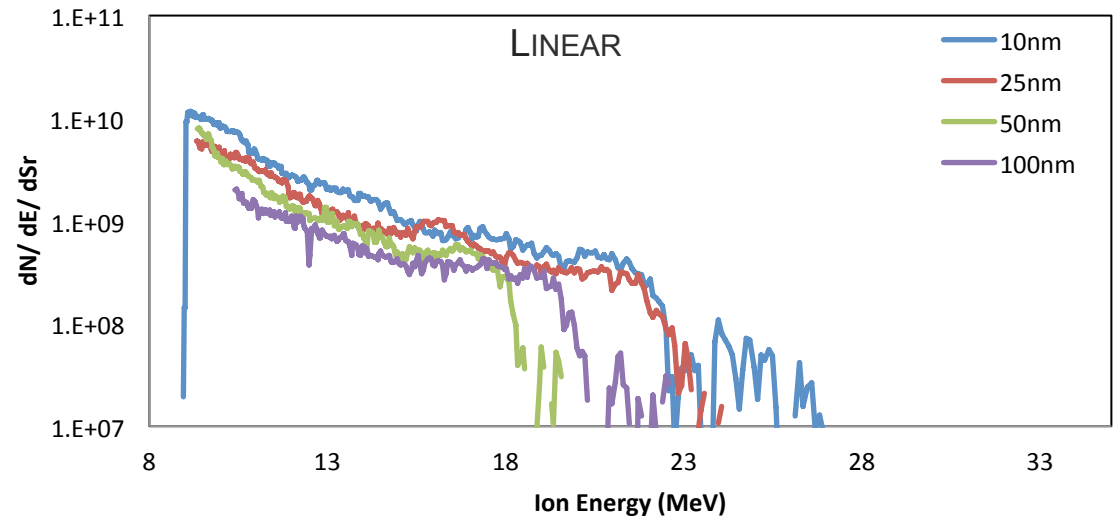
# EXPERIMENTAL RESULTS: C<sup>6+</sup> ION SPECTRA

RAW DATA FROM IP  
 10nm Linear    10nm Circular



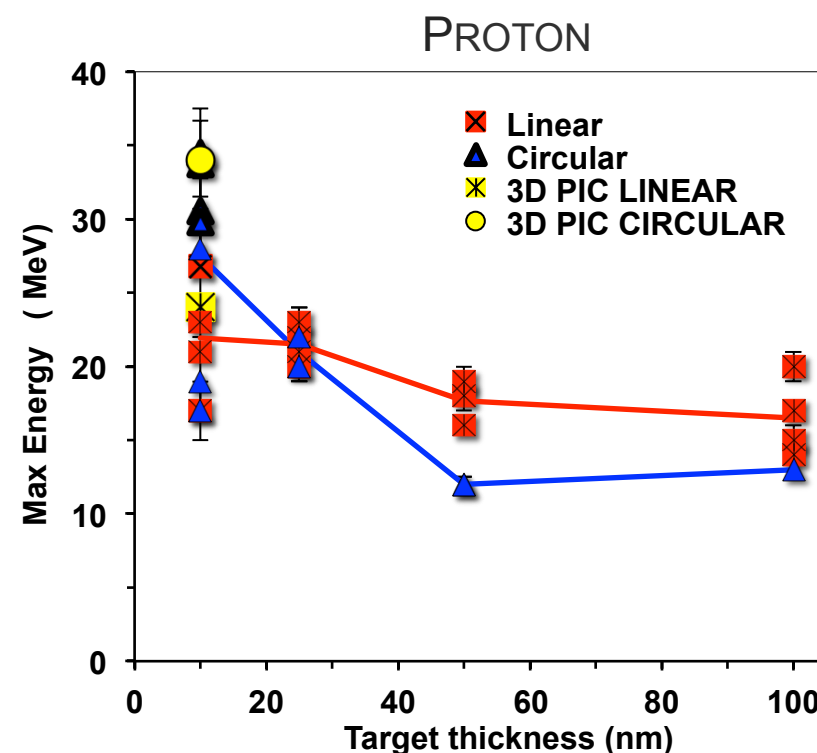
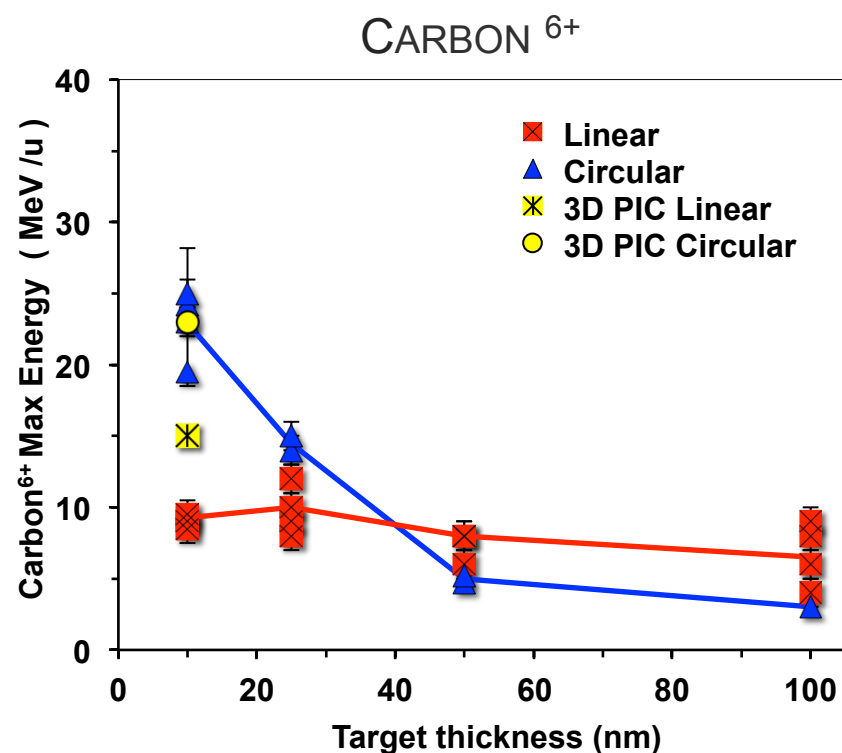
# EXPERIMENTAL RESULTS: PROTON SPECTRA

RAW DATA FROM IP  
10nm Linear    10nm Circular



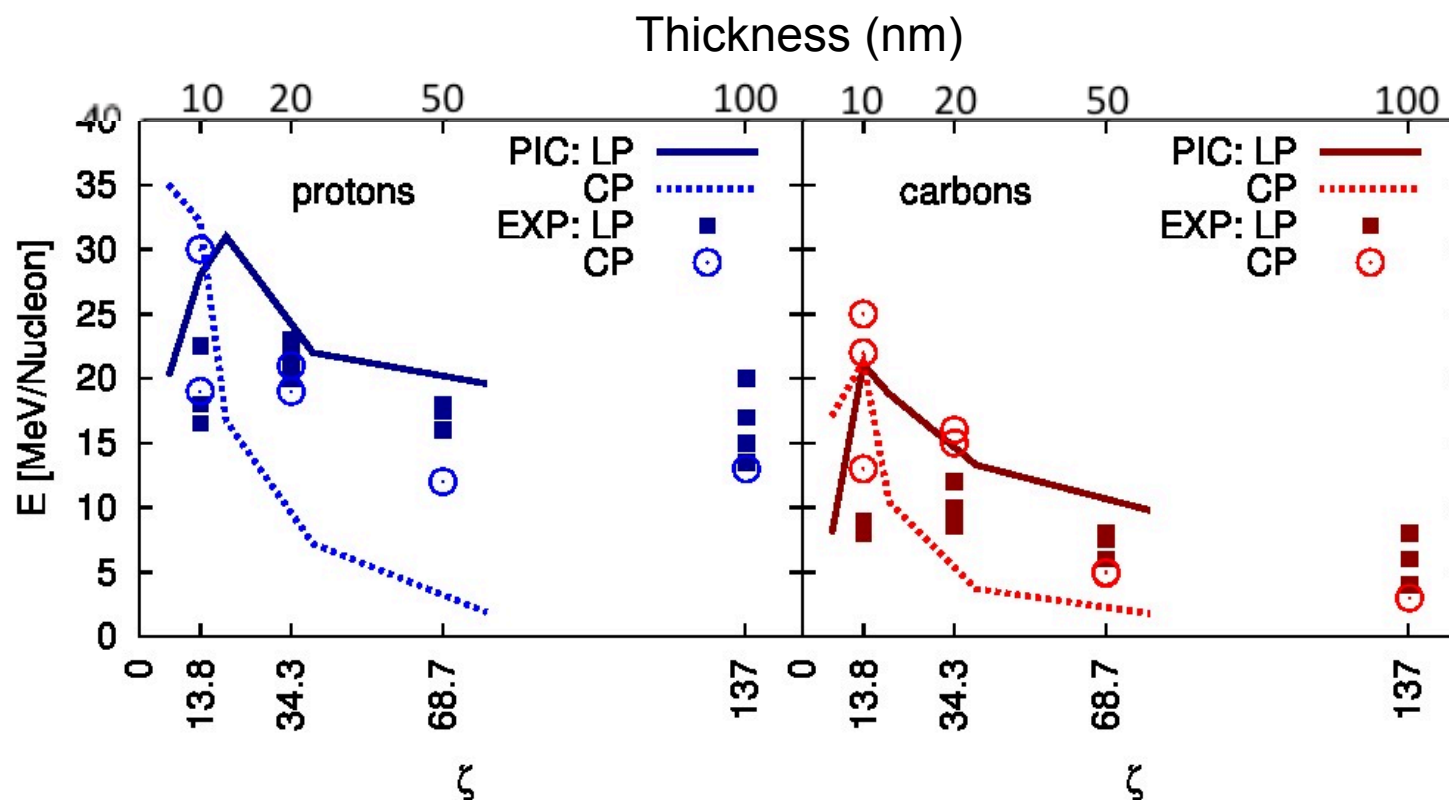


# EXPERIMENTAL - ION ENERGY VERSUS TARGET THICKNESS



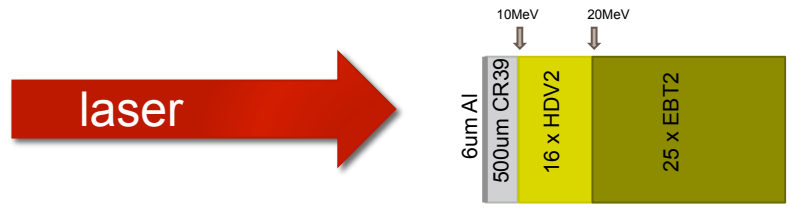
- Very significant energies for CP at 10nm targets (35 MeV for protons and ~300 MeV for  $C^{6+}$ )
- Energies for CP higher for the thinnest targets: possibly RPA Light Sail dominates?
- 3D PIC simulations (A. Macchi, A. Sgattoni - Pisa University) reproduce the difference between CP and LP data with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

# 2D SIMULATIONS - ION ENERGY VERSUS THICKNESS



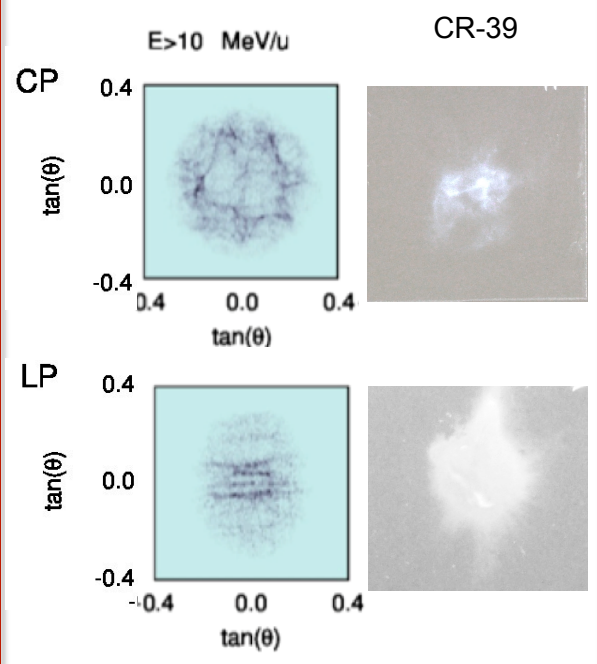
- 2D PIC simulations – good agreement with experiment
- LP irradiation leads to electron heating, target disassembly and transparency below 20nm C. CP pulses allow 20nm targets to stay opaque and to be driven by radiation pressure (A. Macchi, A. Sgattoni – Pisa University)

# EXPERIMENT AND 3D SIMULATION – BEAM PROFILE

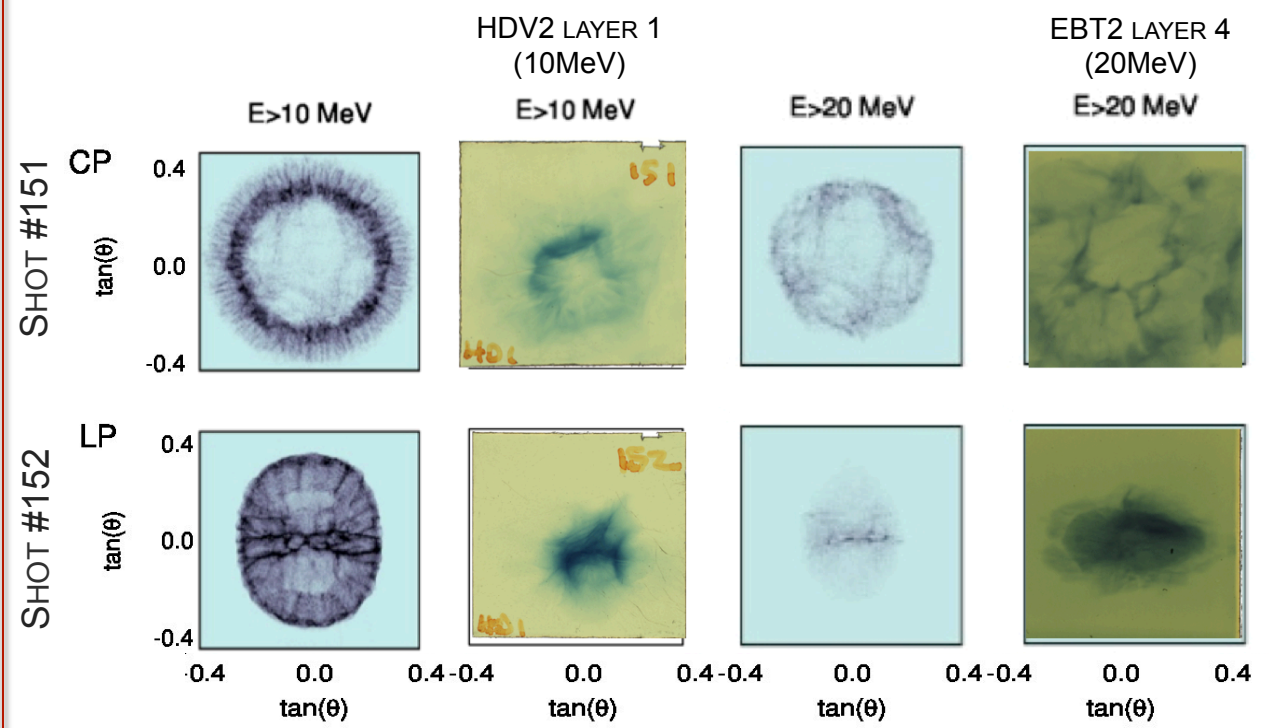


**RCF/CR-39  
STACK**

## CARBON ION PROFILE USING CR-39



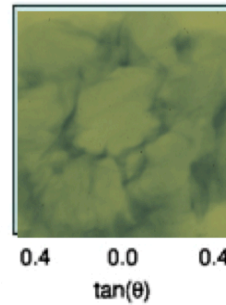
## PROTON PROFILE USING RADIOCHROMIC FILM



# CIRCULAR POLARISATION – BEAM STRUCTURE

Structured larger divergence beam; unstabilised radiation pressure drive

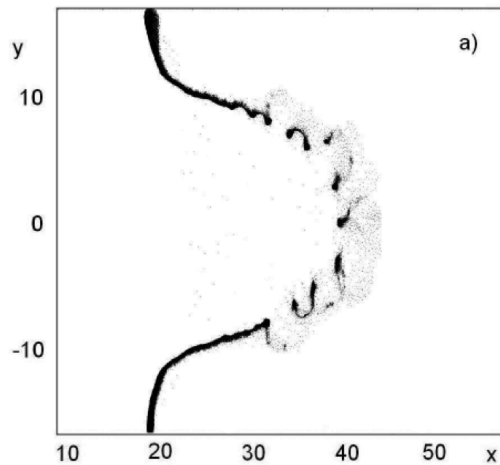
SHOT #151



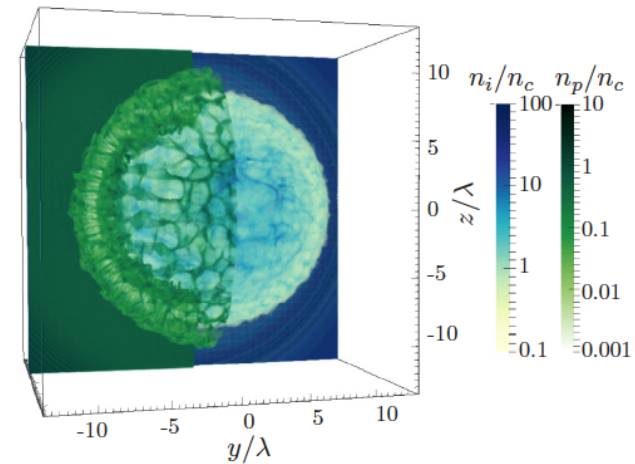
EBT2 LAYER 4 (20MeV)



“Rayleigh Taylor” like instability

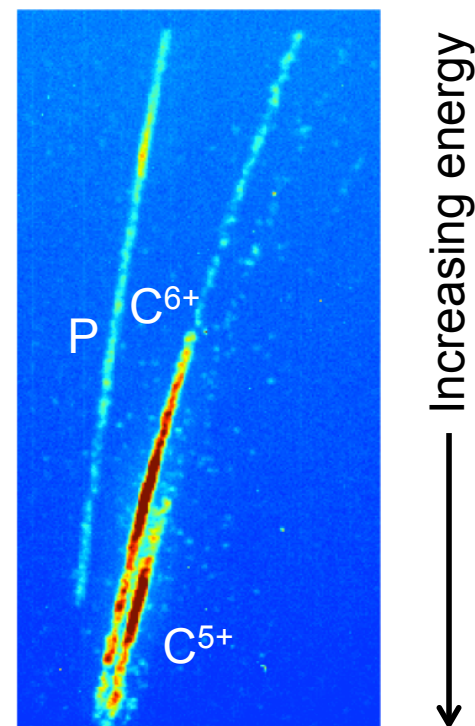
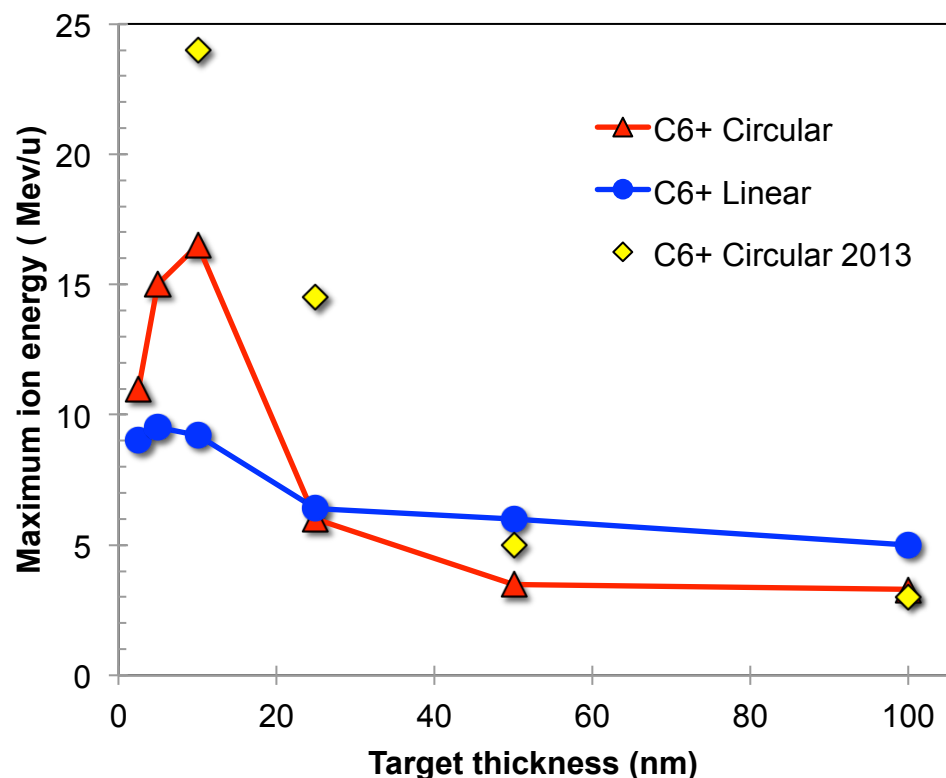


(a) Ion density distribution in the x-y plane



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

# 2014 FOLLOW UP EXPERIMENT



- Similar trends for Thomson Parabola Spectrometers at  $4^\circ$  and  $-9^\circ$
- 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