Laser Absorption and plasma coupling

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EMMI workshop
Plasma Physics with Intense Heavy Ion and Laser Beams
GSI, Darmstadt, 2-4th May 2011

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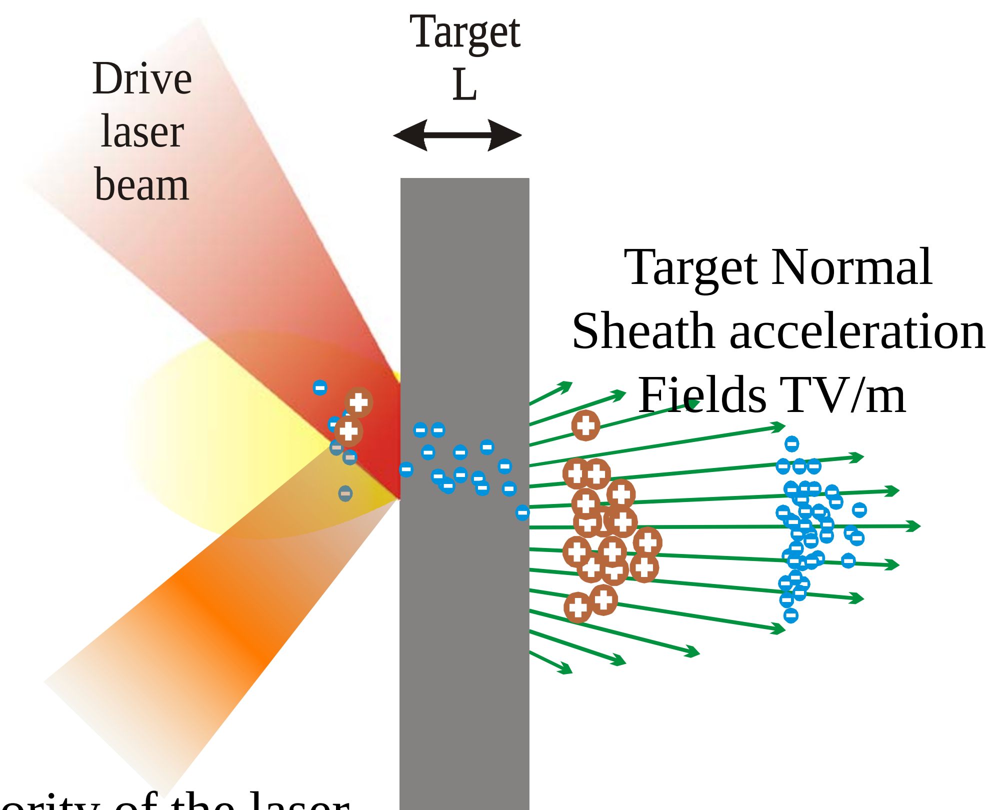
Introduction – scale length effects

- Pre-plasma effects
  - ns timescales
  - Implications
  - ps timescales
  - Implications
- Conclusion



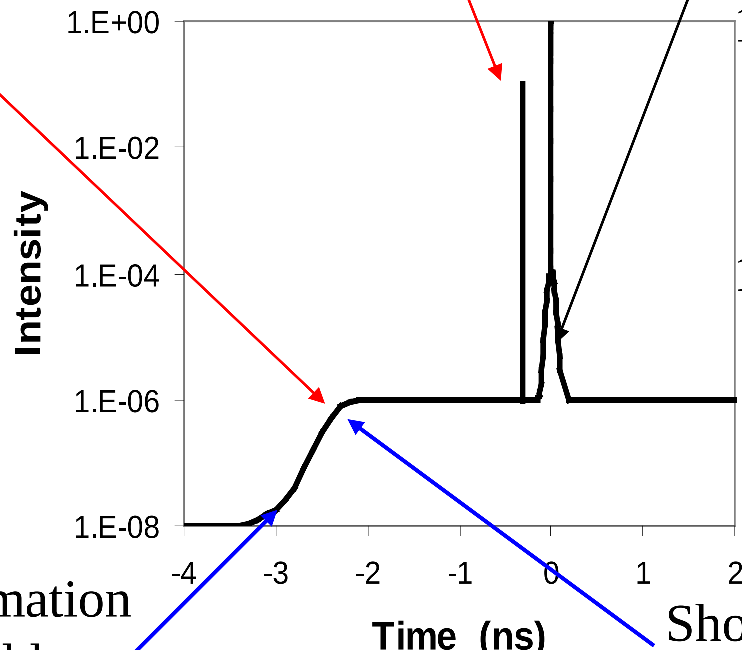
The majority of the laser energy is reflected from a solid target interaction is most cases

Real pulse interaction effects

Optical gating
~ ns rise times

Reflections or
pre pulses on
ps timescales

Finite bandwidth
or phase errors
explodes thin targets



10^{19} Wcm^{-2}

10^{15} Wcm^{-2}

10^{11} Wcm^{-2}

Pulse profile on the
Astra Gemini Ti:S
laser system

Plasma formation
threshold
10^{11} -10^{13} Wcm^{-2}

Plasma expansion
velocity ~10^2 μm ns^{-1}

Shock velocity
~2 μm ns^{-1}

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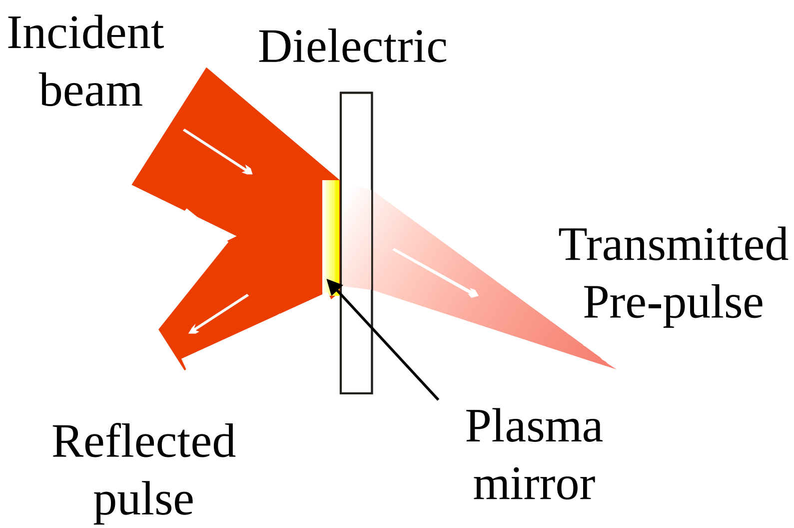
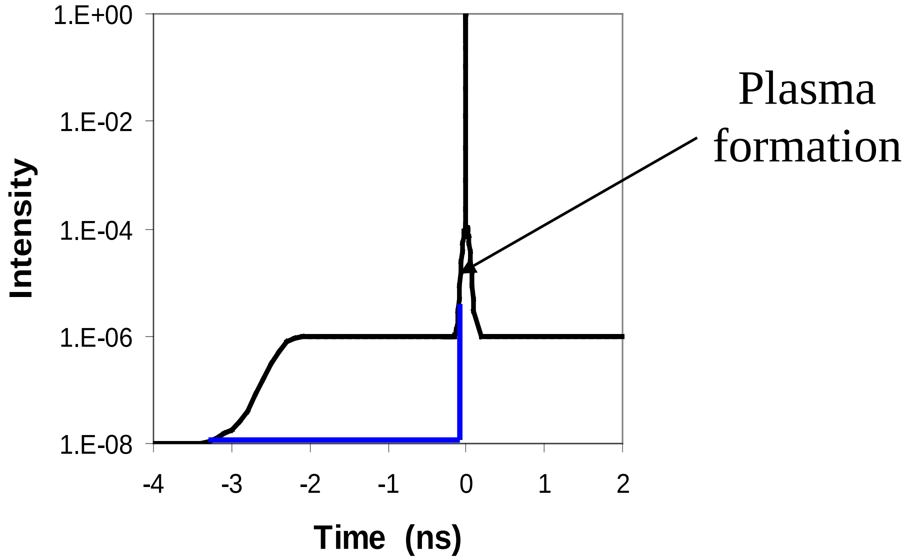
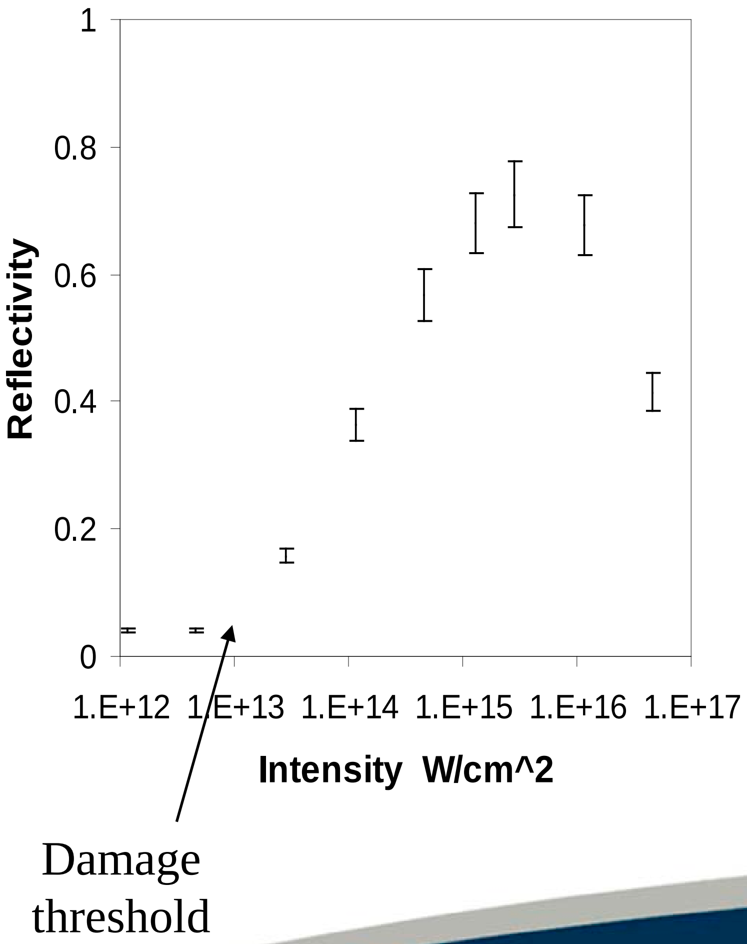
Plasma mirrors for cleaner interactions

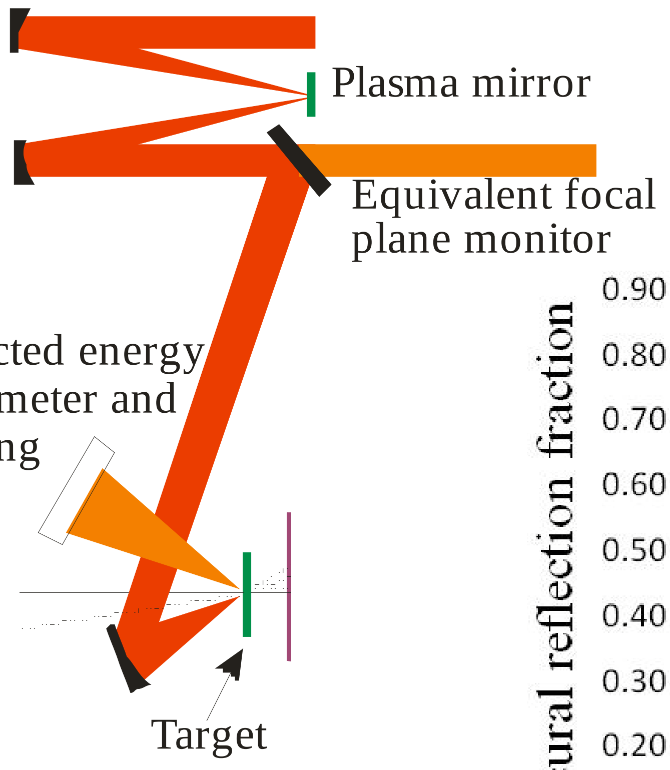


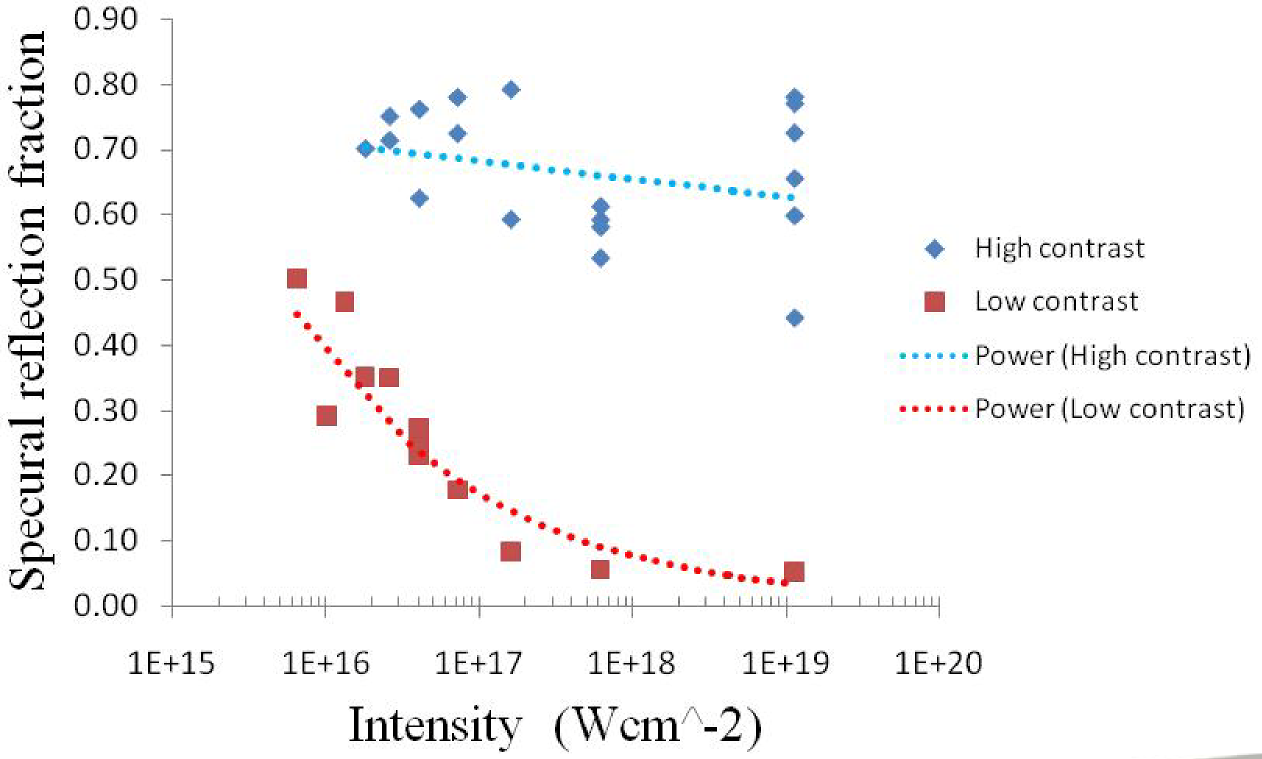




C. Ziener et al , Journal of Applied physics 93, 768 (2003).

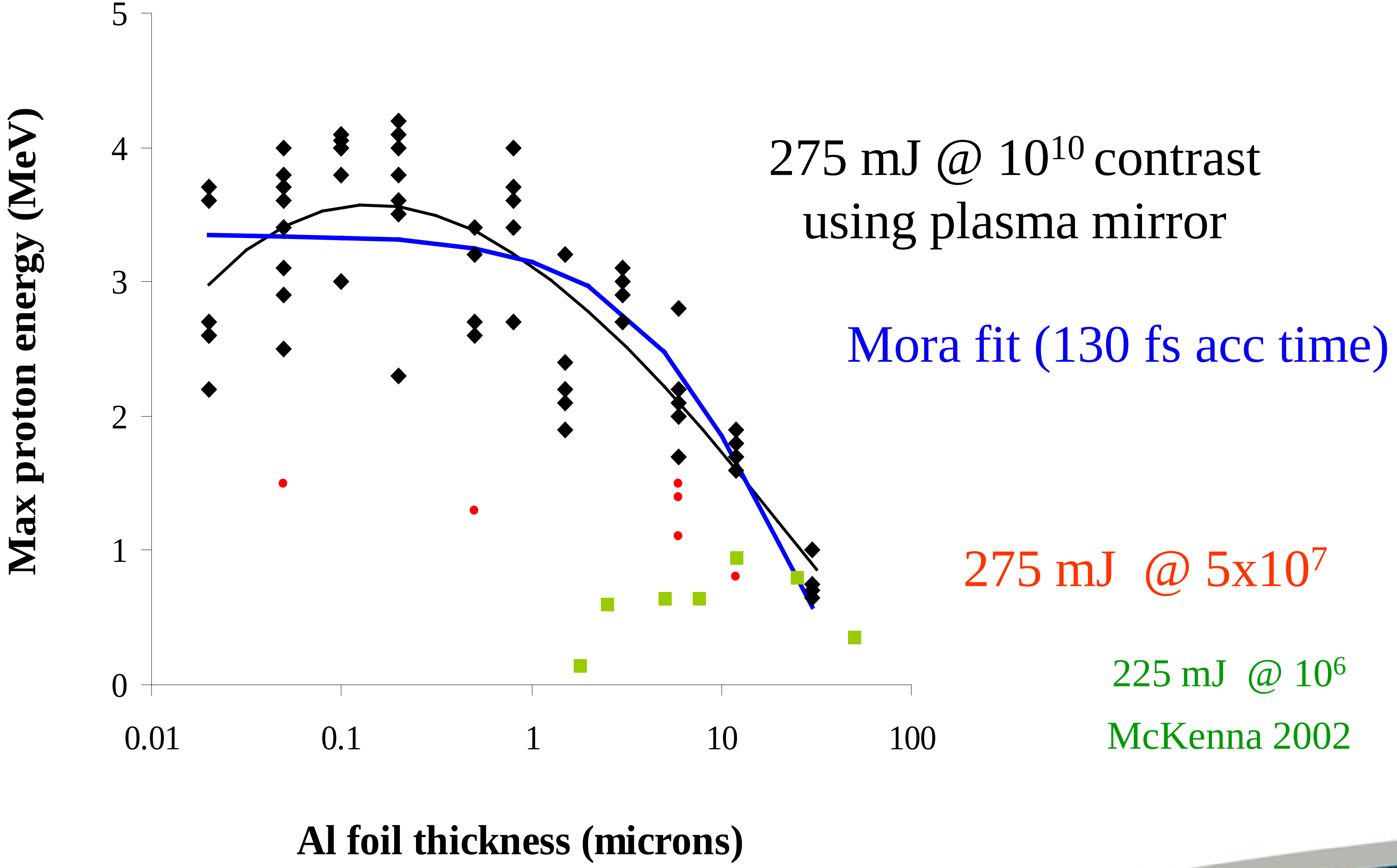
Specular reflectivity 10^{16}-10^{19} Wcm^{-2}





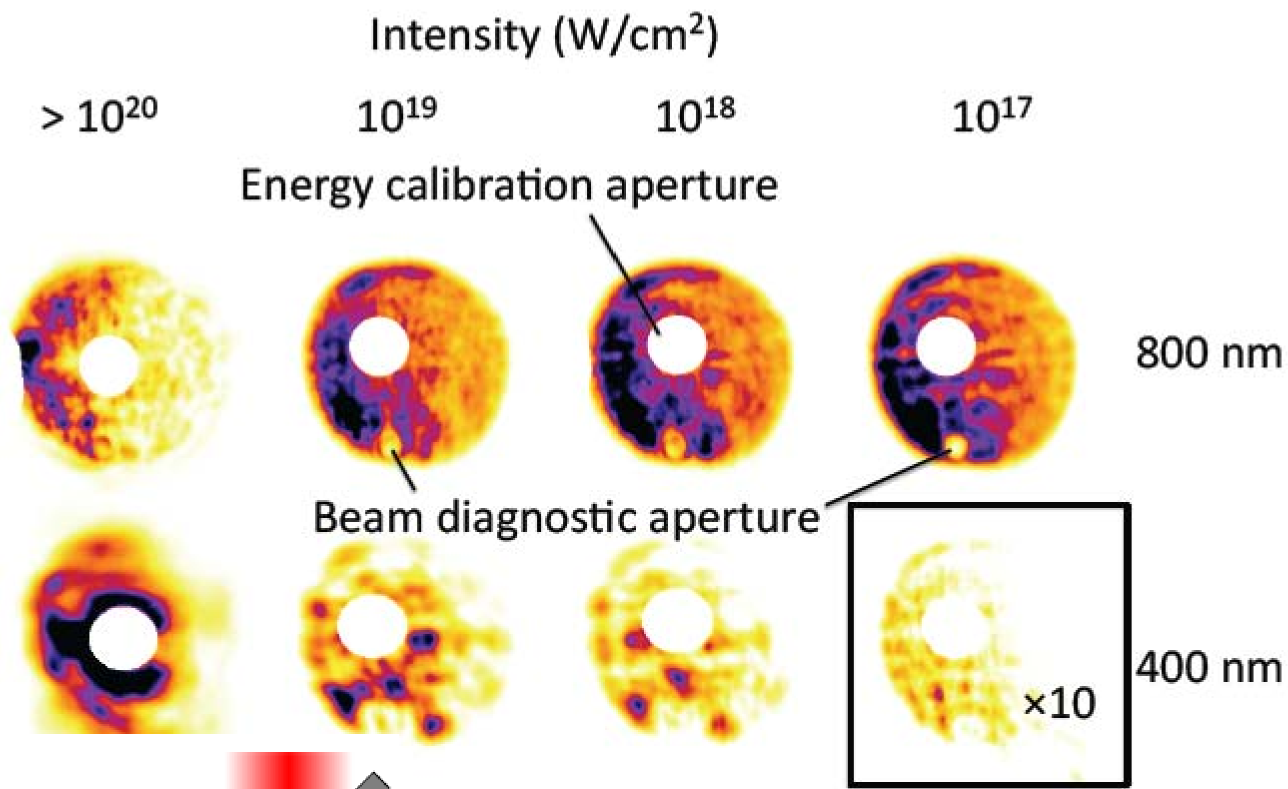
Appl. Phys. Lett., 94, 24, 241102, 2009, Pirozhkov, Diagnostics of laser contrast using target reflectivity

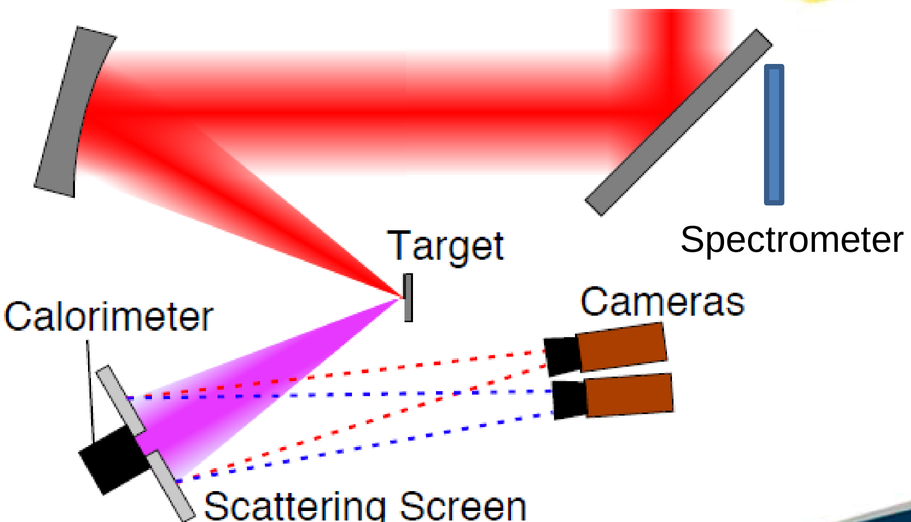
Effect of laser contrast



Neely D, Foster P, Robinson A, et al. *Enhanced proton beams from ultrathin targets driven by high contrast laser pulses*
APPL. PHYSI. LET. 89 (2): Art. No. 021502 JUL 10 2006

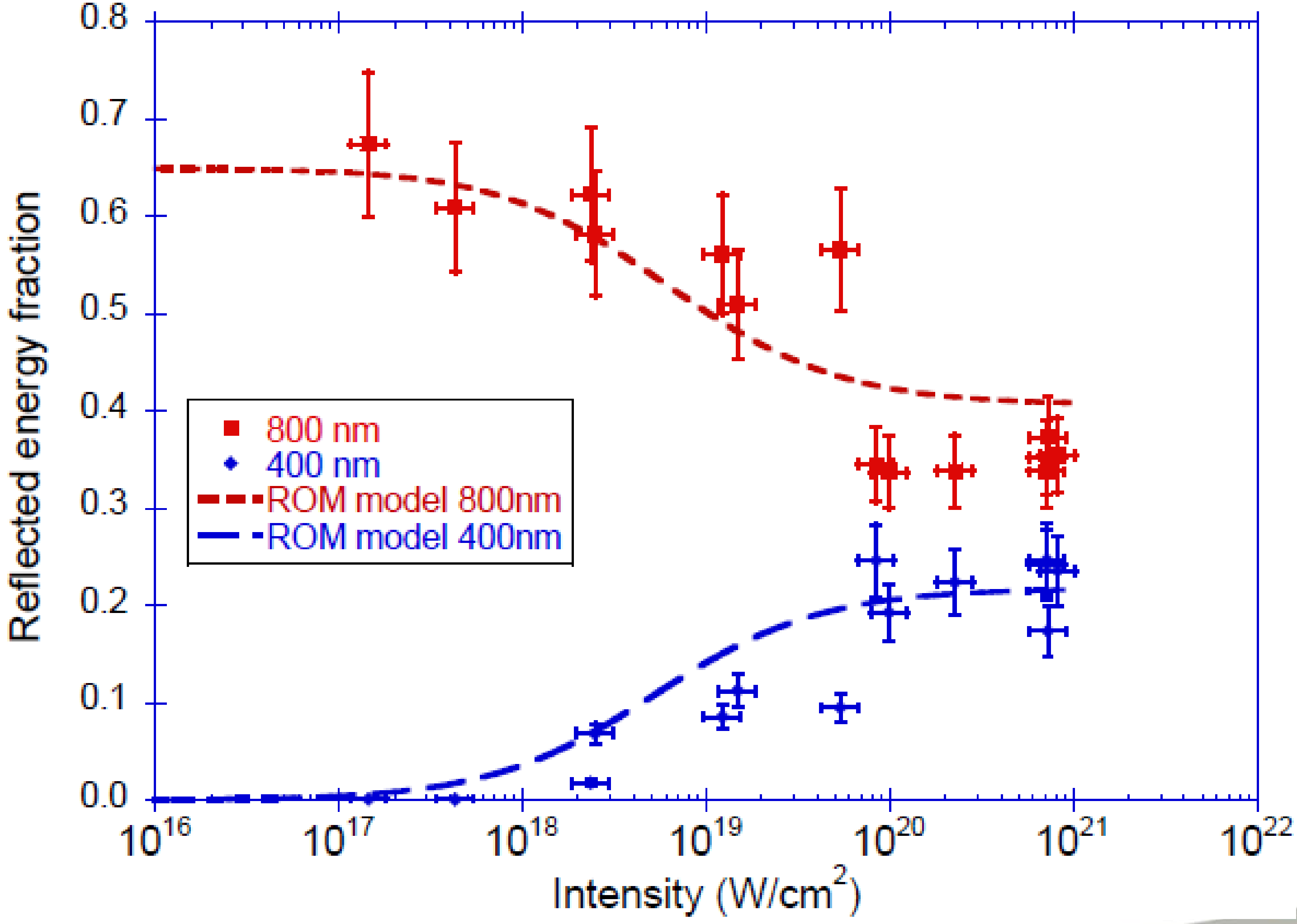
Laser Reflection at 10^{21} Wcm^{-2}



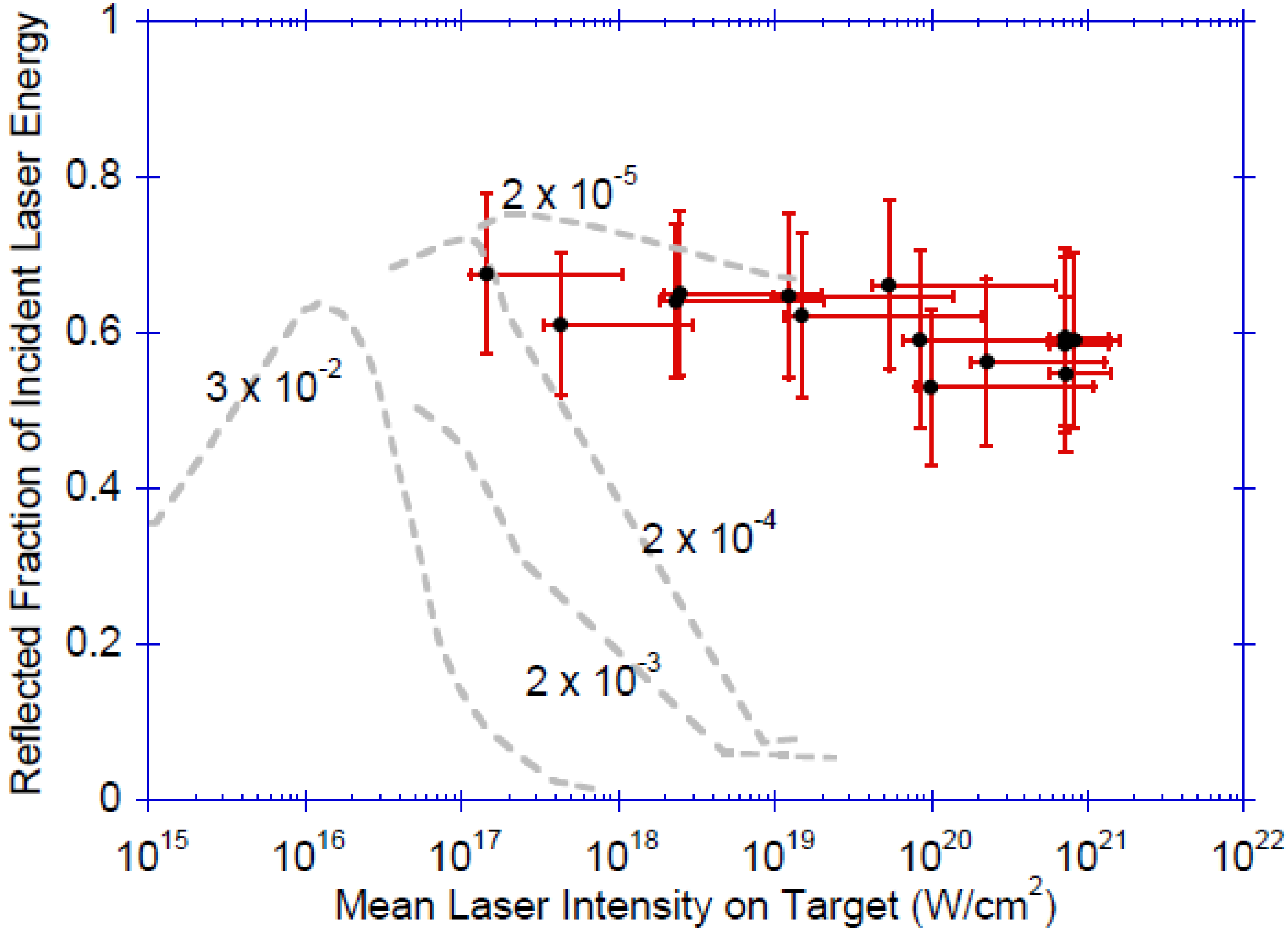


NJP. 10, 083002, 1-12, 2008, Horlein et al, High contrast plasma mirror, spatial filtering and second harmonic generation at 10^{19} Wcm^{-2}

Laser Reflection Measurements



Contrast Vs Reflectivity



NJP. 2010, Streeter et al, Relativistic plasma surfaces as an efficient second harmonic generator

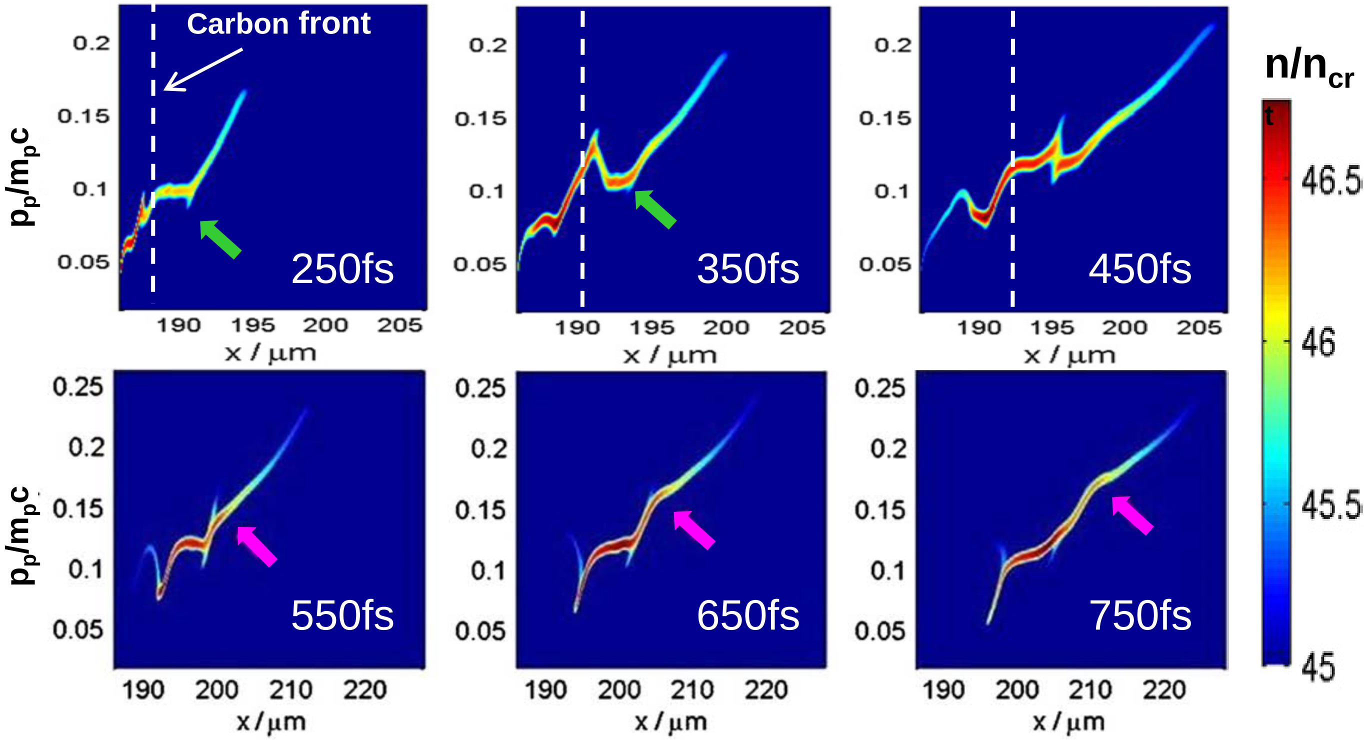
Double pulse regime of ps pre-pulse studies

Outline

- Front surface absorption changes ?
- Rear surface Sheath expansion with multiple pulses – theory
- Experimental setup
- Results –

Multiple Pulse Sheath Acceleration

• Vlasov and PIC simulations by Robinson *et al.* indicate spectral peaks and increase in conversion efficiency with appropriate double pulse configuration.



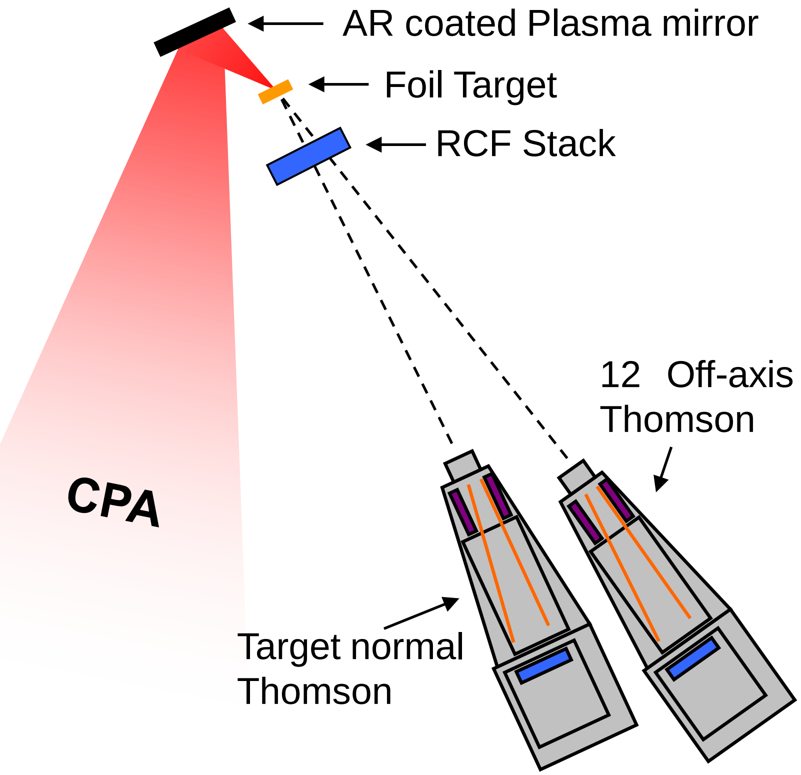
<u>Stage 1</u>: 1st pulse drives multi-species TNSA - proton density modulation builds up ahead of carbon front

<u>Stage 2</u>: 2nd pulse causes rapid rise in T_e. Protons surge away from density spike, accumulating in velocity space.

Plasma Physics and Controlled Fusion, 49, 4, 373-384, 2007, Robinson, Spectral control in proton acceleration with multiple laser pulses

Double pulse experimental setup

- Off-axis parabola focuses the beam to a 30μm focal spot. Pulse duration is 0.7ps.
- Intensity in the focus is ~10^{19} Wcm.
- Laser energy is divided into two collinear pulses at a ratio of 0.1:1 (typically 130J on target) and 0.4:1 (typically 57J on target).



•Temporal separation between two pulses is varied between 0 and 2.5 picoseconds.

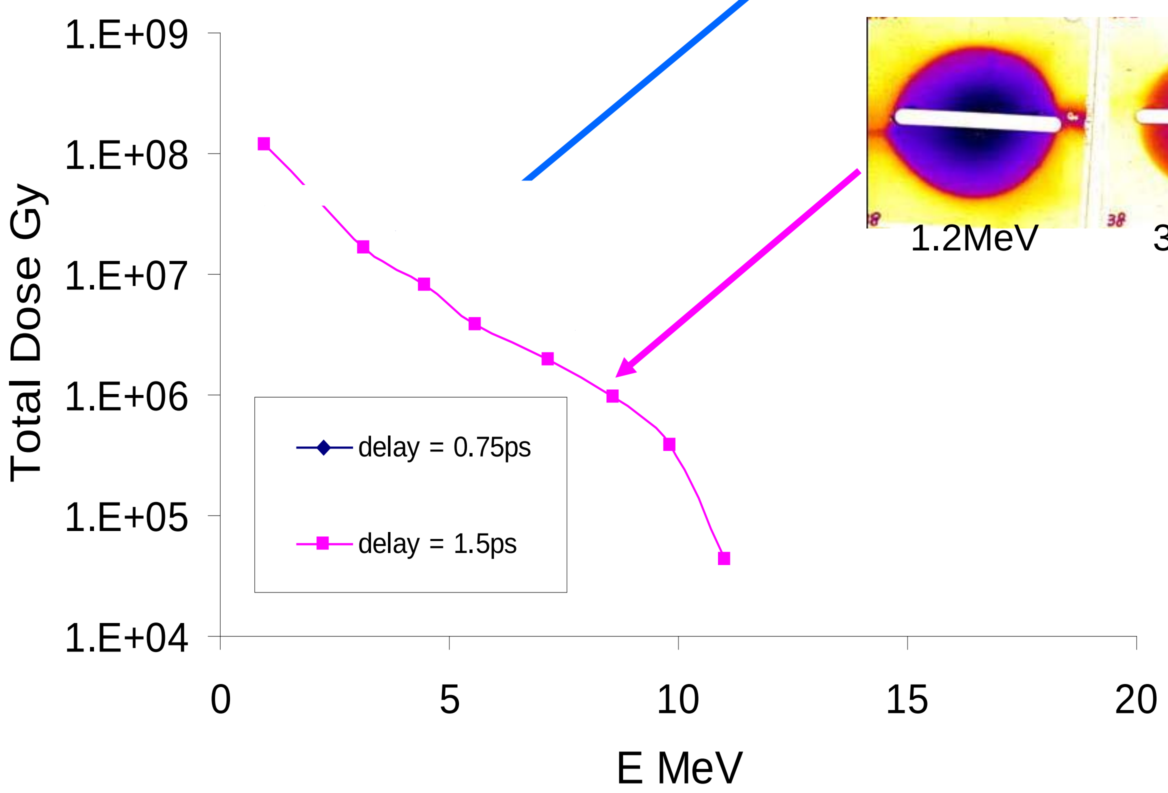
•Proton spectra monitored with radiochromic film for total integrated flux and thomson parabola spectrometers for high resolution spectra at discrete angles.

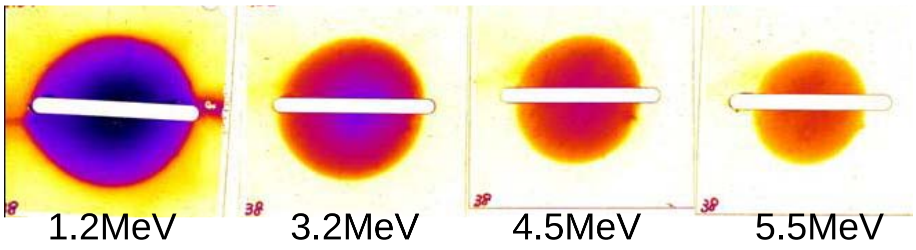
Integrated dose dual-pulse

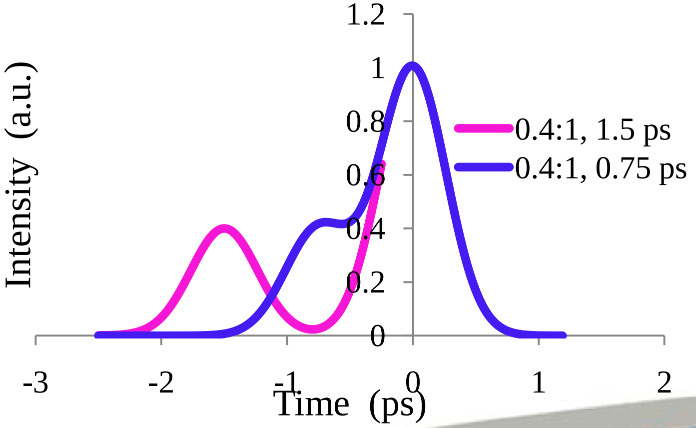
Pulse ratio 0.4:1 @ mid10^{19} Wcm^{-2}

- reduces low energy ~1.2MeV
- increases high energies

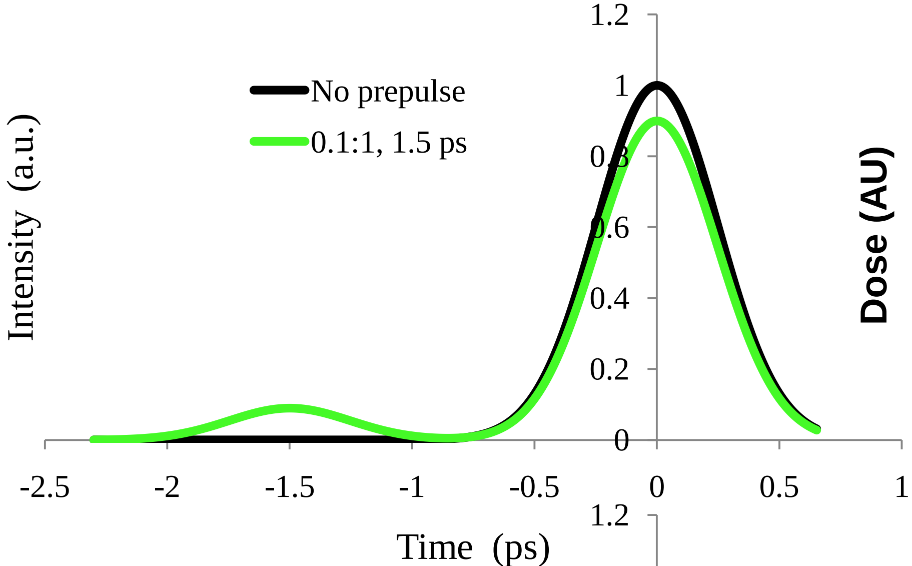
RCF Beam images

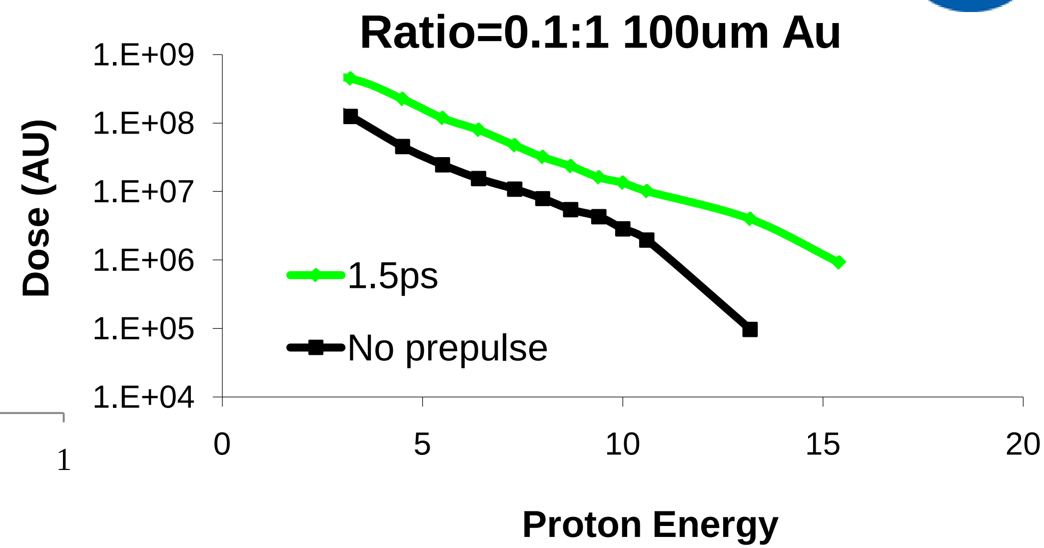


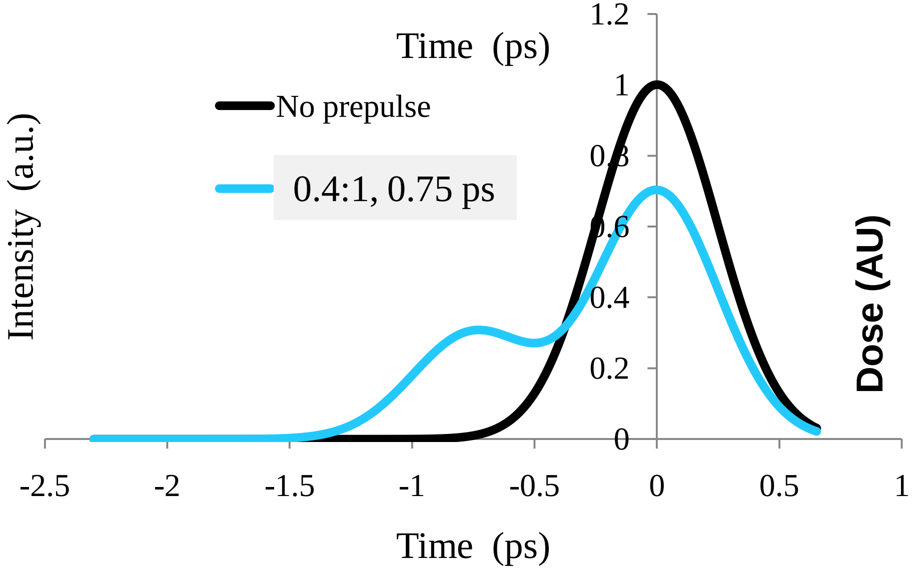


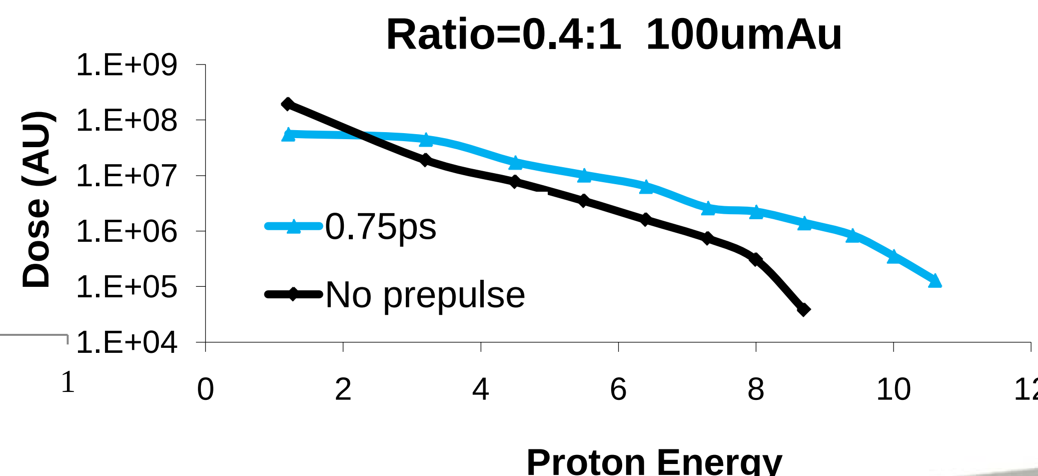


Single Vs Dual-pulse drive







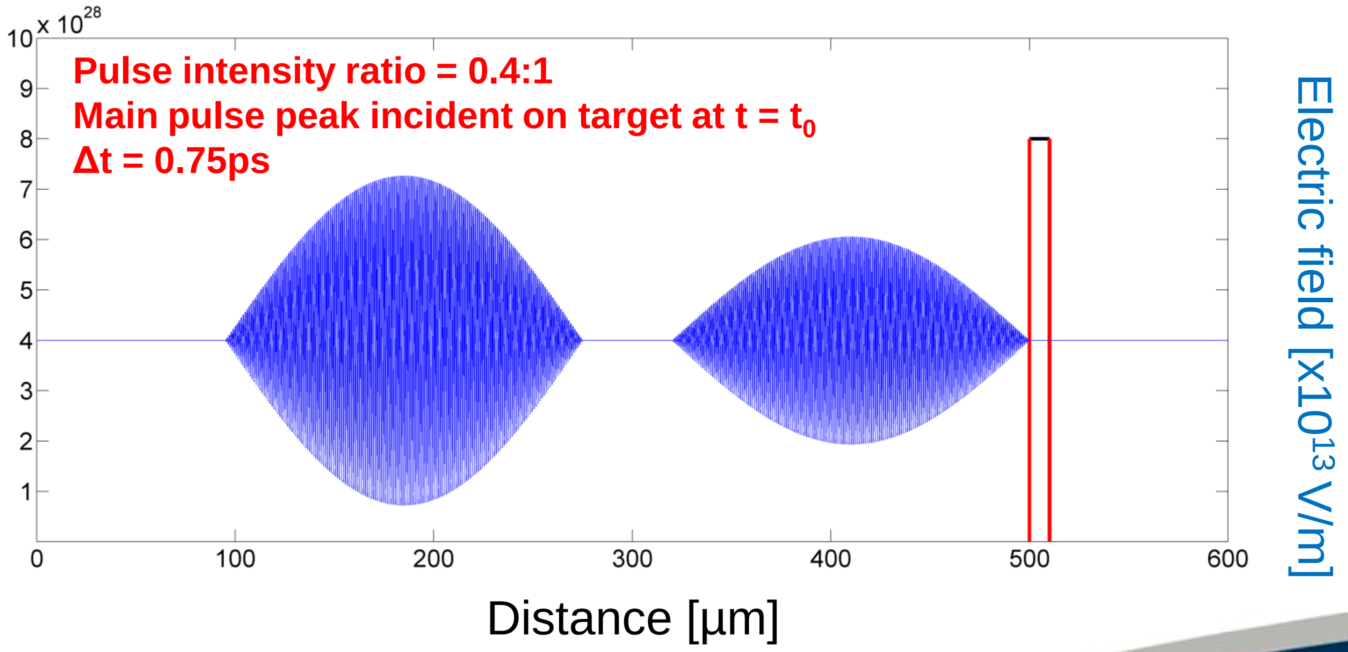


Intensity on target mid 10^{19} Wcm^{-2}

•Lower pre-pulse must come earlier

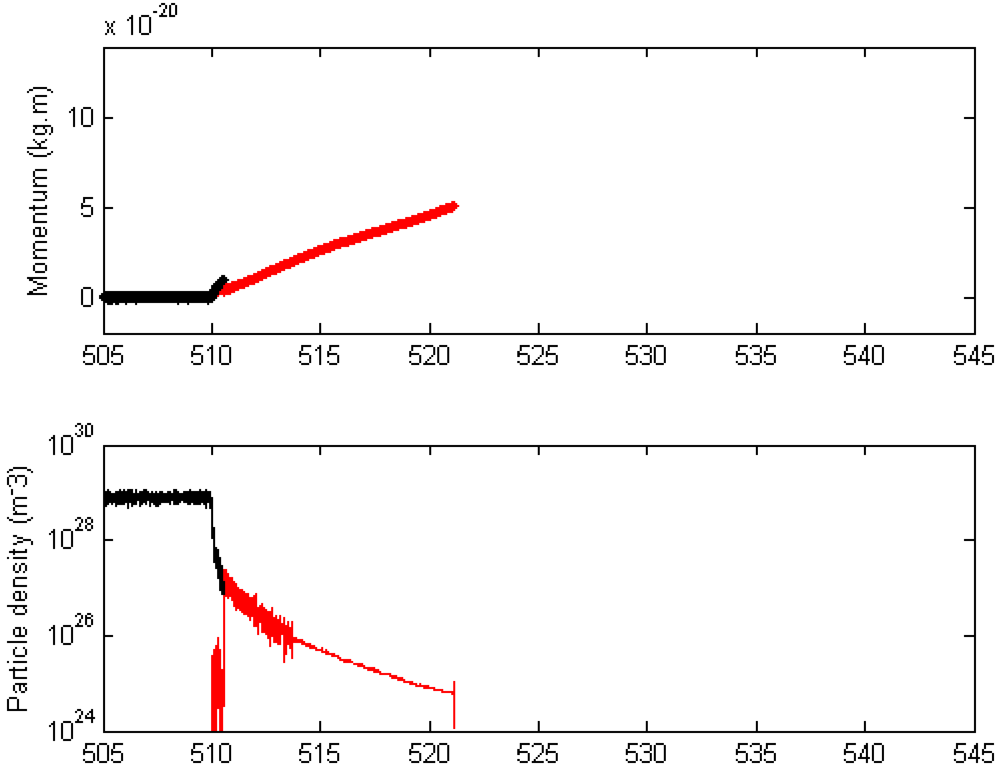
Numerical Simulations

- 1-D particle in cell (PIC) code used to model experimental parameters.
- Several parameters scaled down for run time and numerical heating considerations
  - Laser pulse duration 300fs, $I_{laser} = 10^{20}$ W/cm^2. Higher intensity but shorter pulse than experiment.
  - Target: thickness 10 microns, bulk composition: heavy ions($m_{ion} = 3m_p$, $Z_{ion} = +1$, q/m same as C^{+4}) and 20nm proton layer on front and rear surfaces). $n_i = n_p = n_e = 8 \times 10^{28}$ m^{-3}.



Numerical Simulations

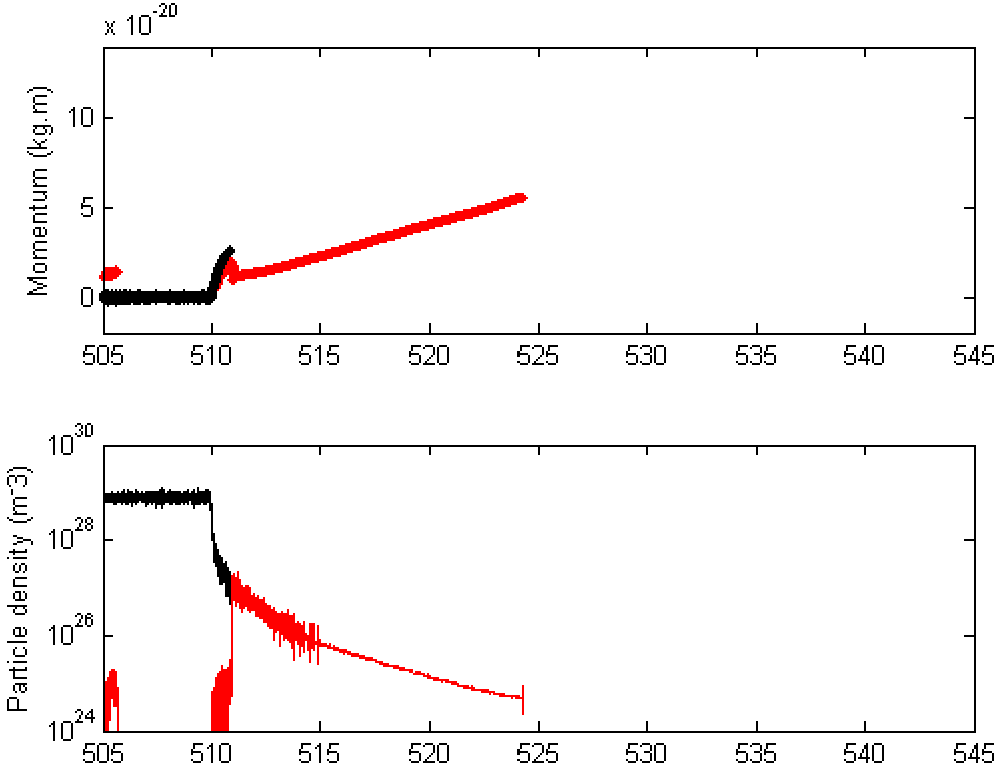
t = t_0-250fs



- **Protons**
- **Ions**

Numerical Simulations

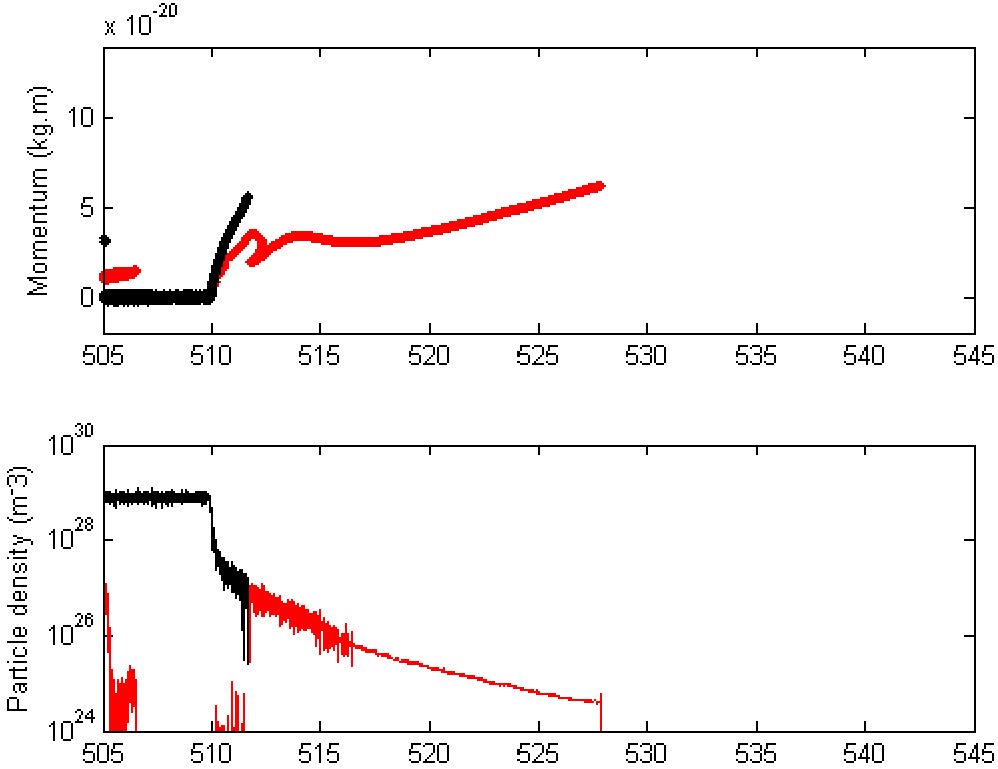
t = t_0-150fs



- Protons
- Ions

Numerical Simulations

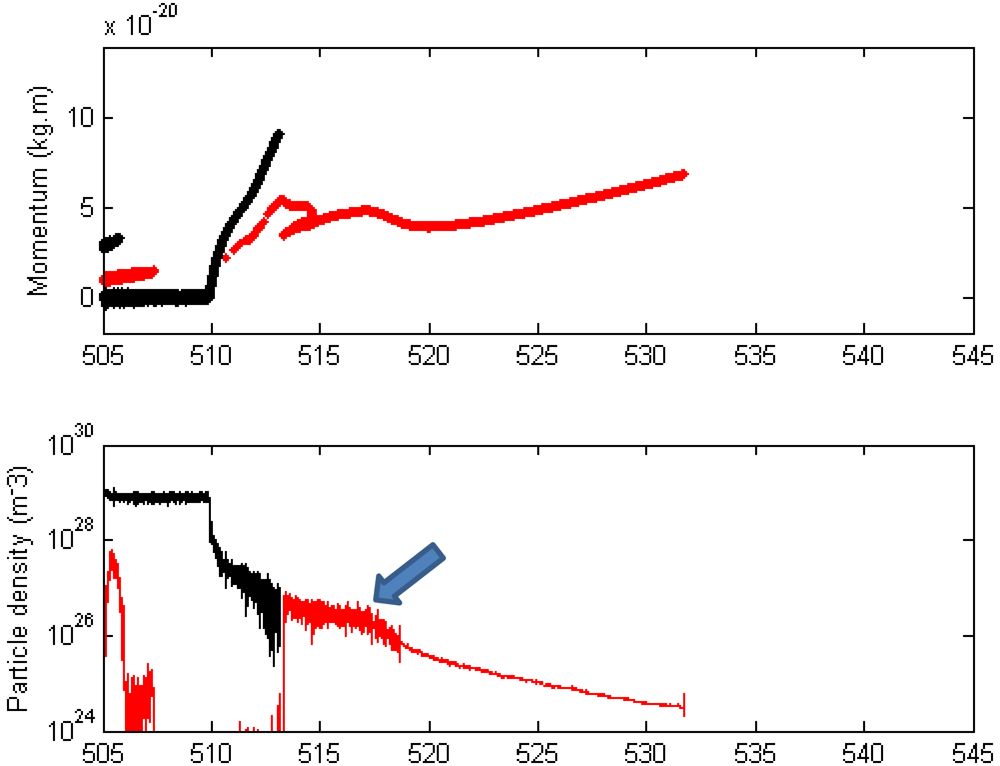
t = t_0-50fs



- **Protons**
- **Ions**

Numerical Simulations

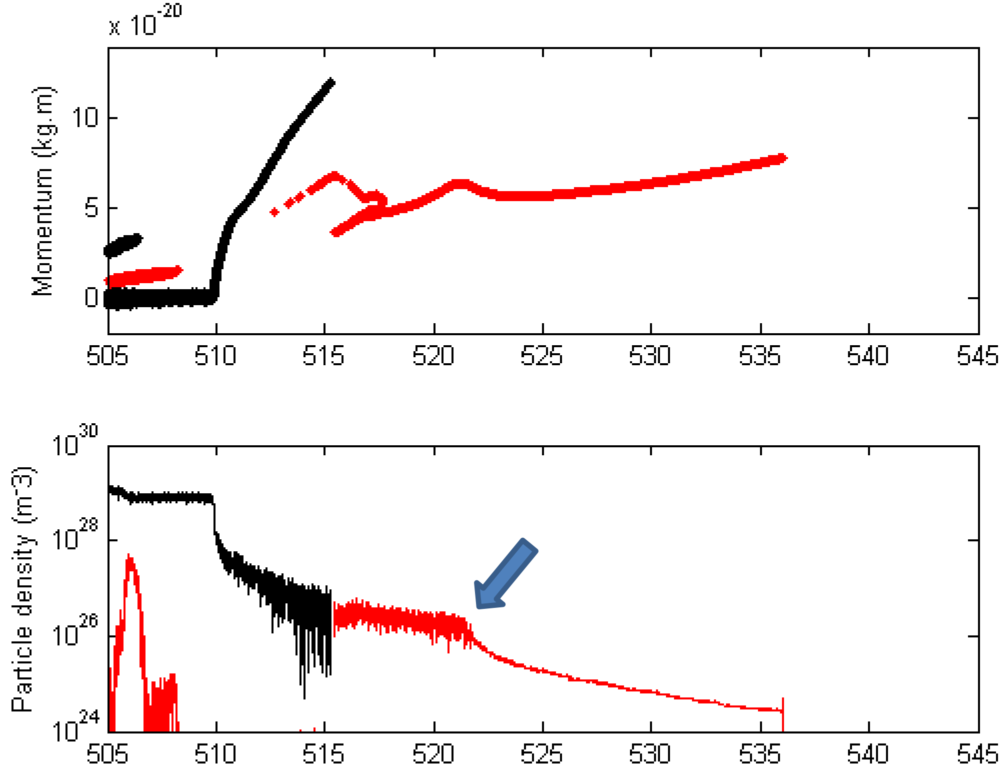
t = t_0+50fs



- **Protons**
- **Ions**

Numerical Simulations

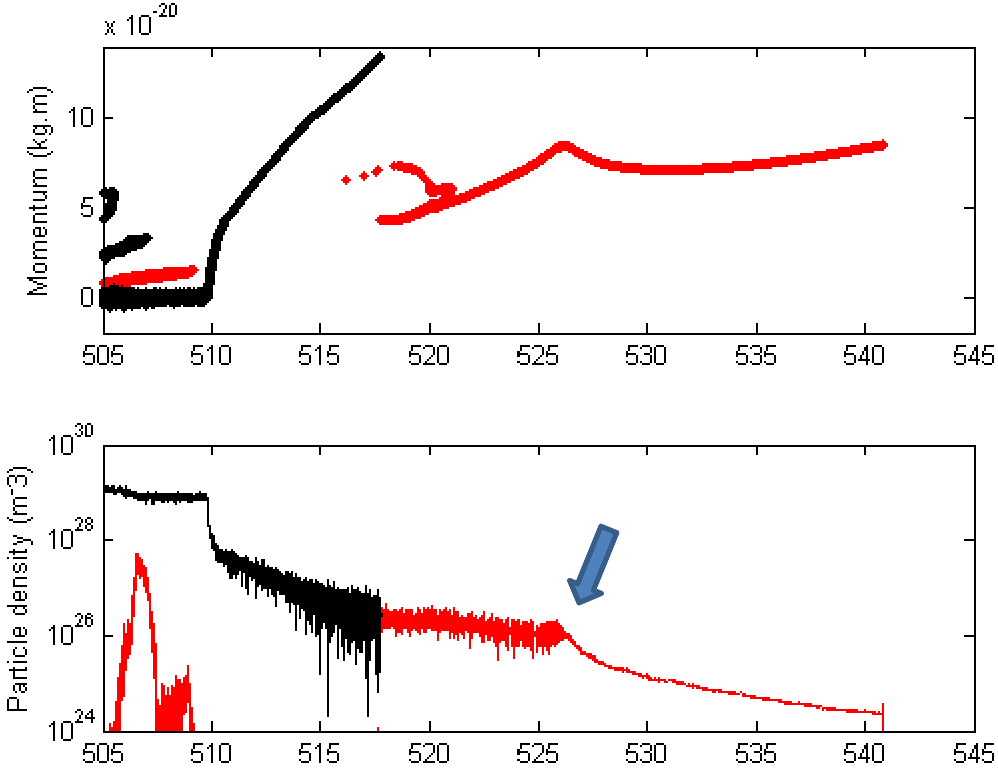
t = t_0+150fs



- **Protons**
- **Ions**

Numerical Simulations

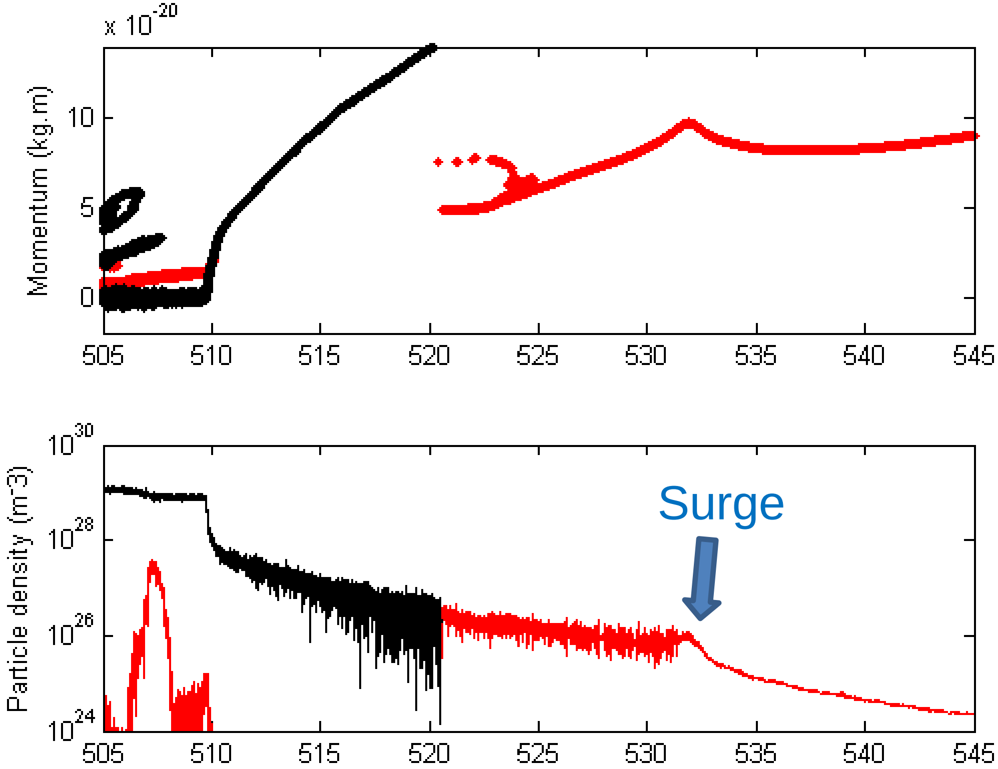
$t = t_0 + 250fs$



- **Protons**
- **Ions**

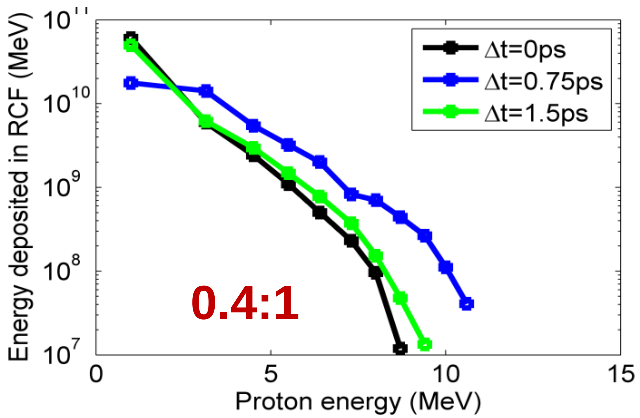
Numerical Simulations

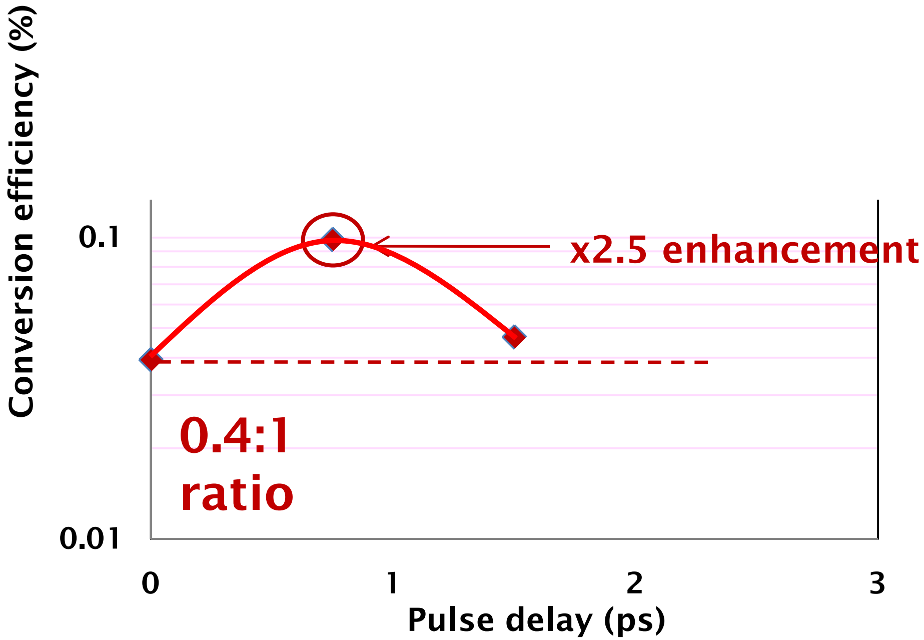
$t = t_0 + 350fs$



- **Protons**
- **Ions**

Dual pulse Ion energy beam data





Increase in flux and E_{max}:

- **Clearly an optimum delay for maximum conversion efficiency**
- **Trend with delay appears more abrupt with 0.4: ratio (higher prepulse and lower main pulse intensity and energy than 0.1:1).**
- **Conversion efficiency boosted by factor of 3.3 for 0.1:1 ratio**

Co-workers

www.strath.ac.uk

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Conclusion

- Dual-pulse drive
  - Simple optical control mechanism
  - Increased front surface absorption
    - may play a small role at ps
    - plays a significant role at ns
  - See C Brenner for multi ps details Wed 9:00

- Pulse temporal control
  - Multiple pulses on ps timescale will be required for spectral control
  - ns pre-pulses can have their uses if controlled
  - Slope of rising edge has influence
  - Ultra high contrast essential for some experiments

- Future directions
  - Multi pulse at higher drive energies
  - Specular reflectivity a simple contrast diagnostic
  - Targetry