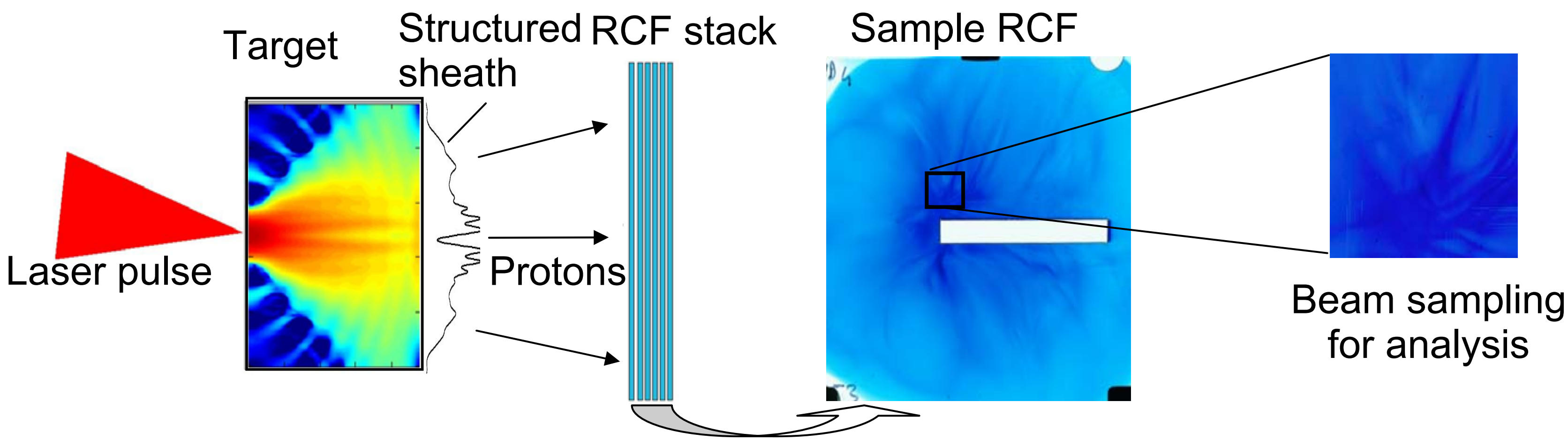
Ion acceleration as a diagnostic of fast electron transport in solid targets

(+ nuclear activation as an ion beam diagnostic)

Paul McKenna

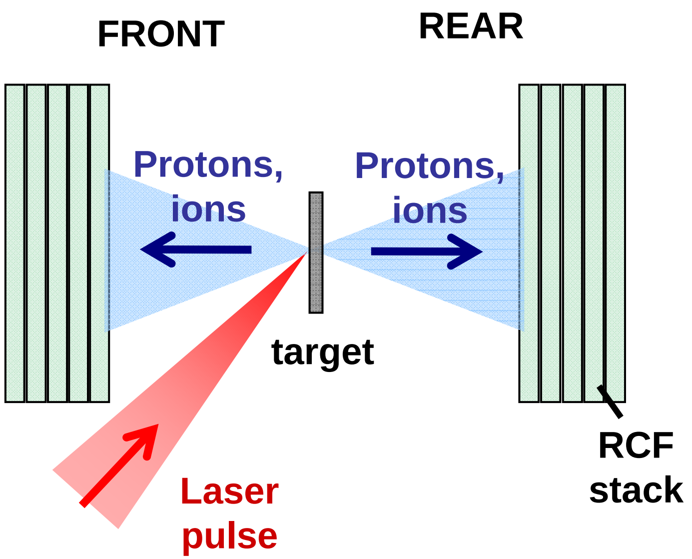
University of Strathclyde

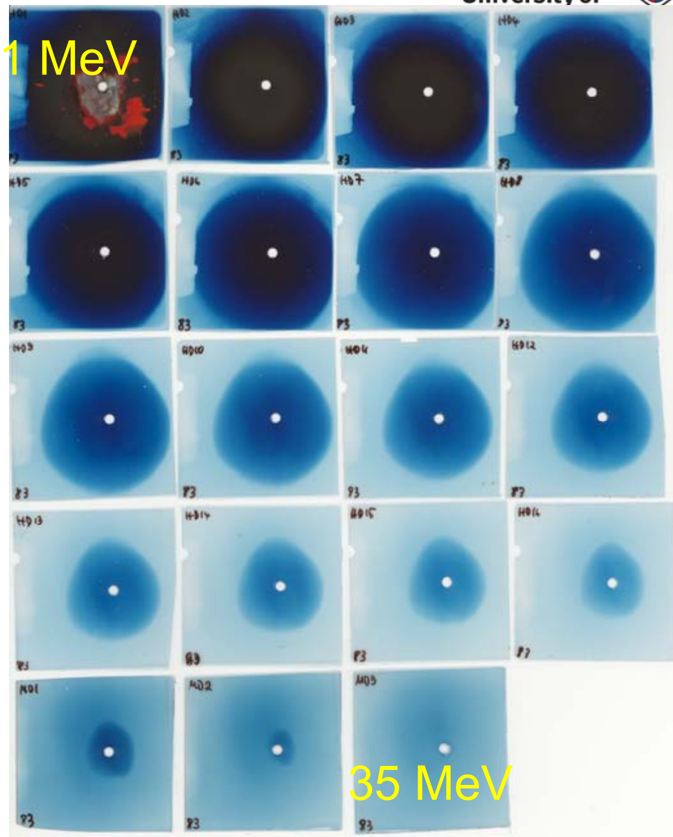
Proton emission as a diagnostic



- Maximum proton energy $\rightarrow$ electron density
- Intensity distribution $\rightarrow$ electron transport filamentation
- Proton divergence with energy $\rightarrow$ electron sheath profile
- Total ion energy $\rightarrow$ laser to electron energy transfer
- Proton spectrum $\rightarrow$ electron temperature (model)

Dosimetry film stack diagnostic





Three main types of dosimetry film:

MD-55

- Clear Polyester - 67 microns
- Active layer - 16 microns
- Adhesive - 25 microns
- Clear Polyester - 25 microns
- Adhesive - 25 microns
- Active layer - 16 microns
- Clear Polyester - 67 microns

HD-810

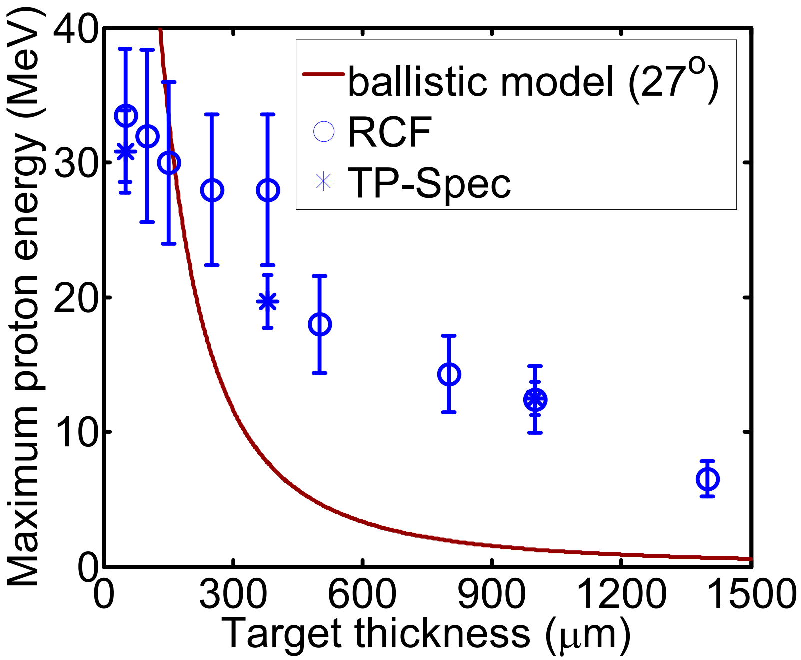
- Surface layer - 0.75 microns
- Active layer - 6.5 microns
- Clear Polyester - 97 microns

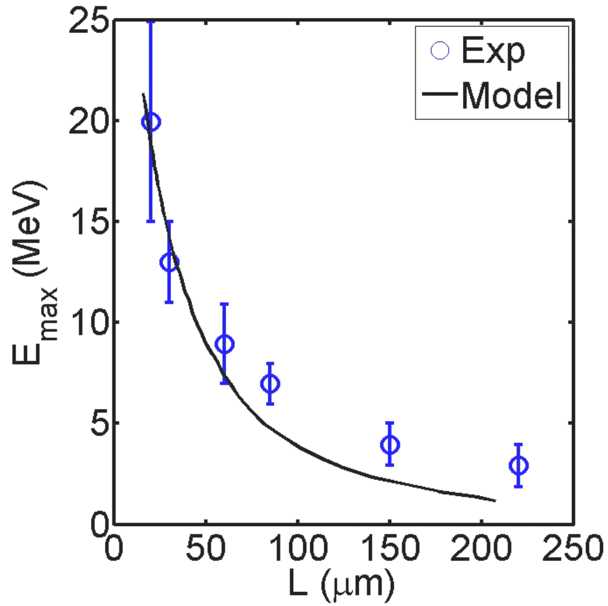
HS

- Clear Polyester - 97 microns
- Active layer - 40 microns
- Clear Polyester - 97 microns

1. Proton energy as a diagnostic of fast electron beam divergence

Results: Maximum proton energy





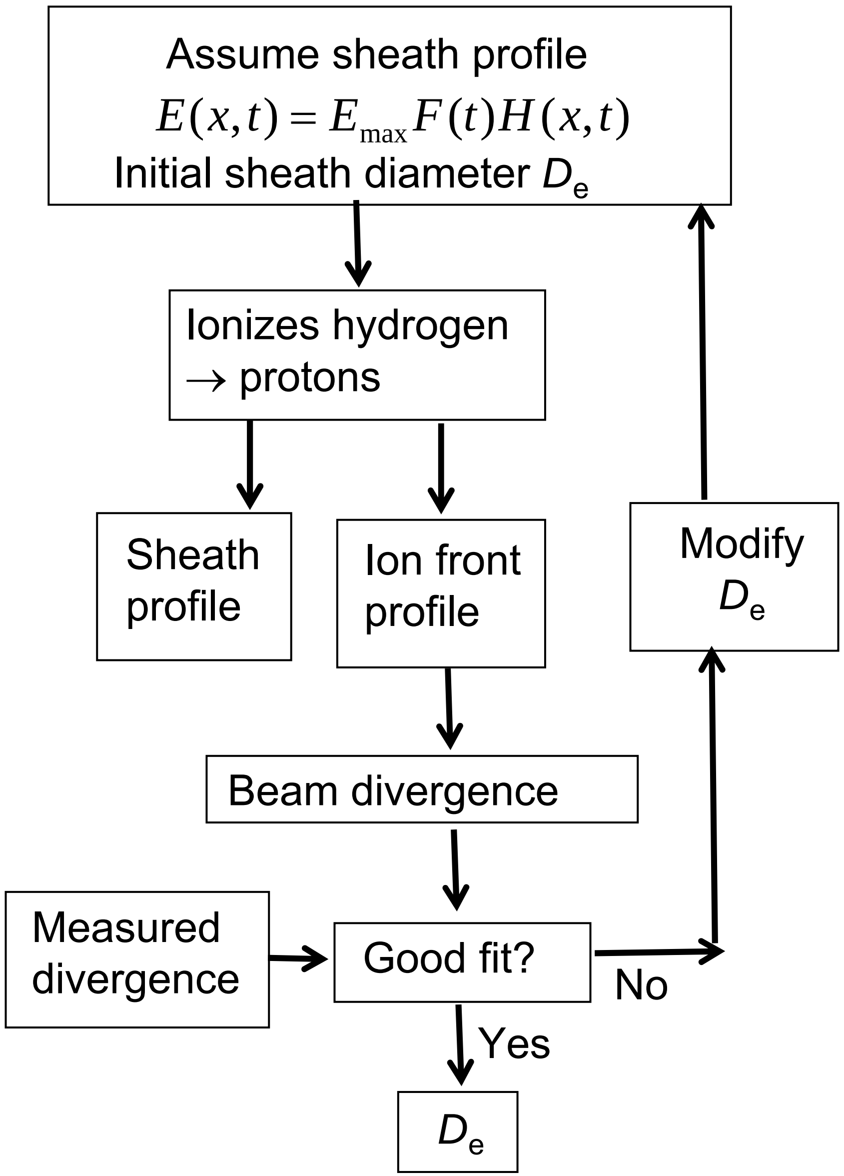
Fuchs et al., LULI (Nat. Phys. 2006)

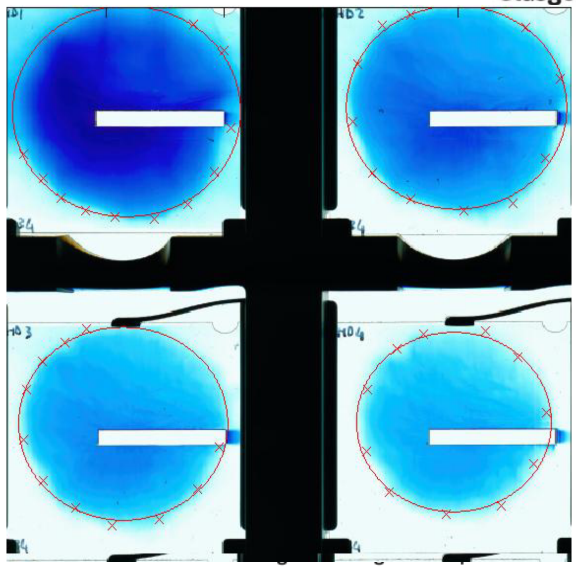
Ballistic transport and P. Mora PRL 2003 plasma expansion model.

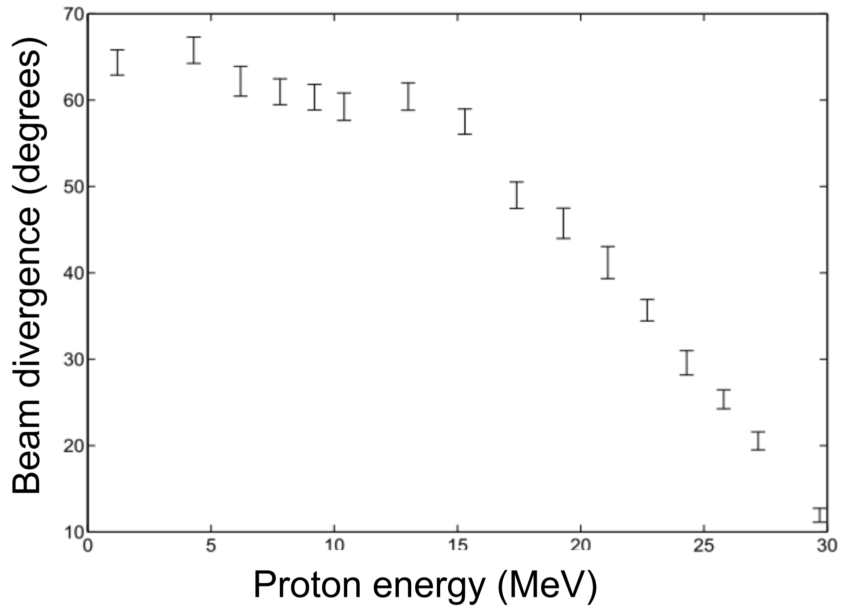
$$E_p \approx 2k_B T[\ln(\tau + \sqrt{\tau^2 + 1})]^2, \quad \tau = t_i \omega_{pp} / \sqrt{2e_N}, \quad \omega_{pp} \sim \sqrt{n_e} \sim 1/\phi_{sheath}$$

The scaling with target thickness is significantly different than expected from ballistic electron transport

Sheath expansion is modelled

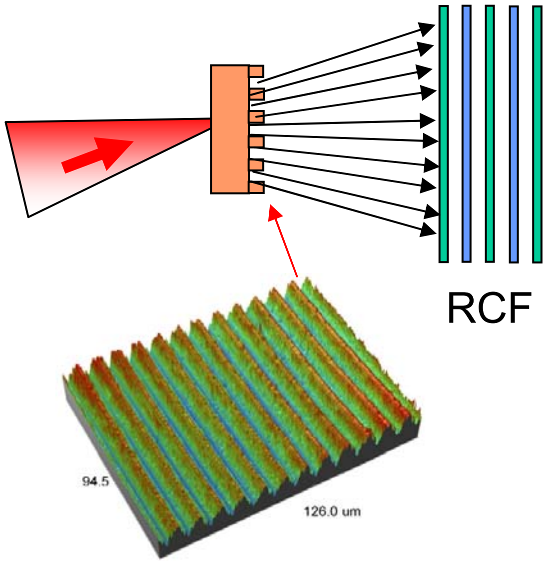


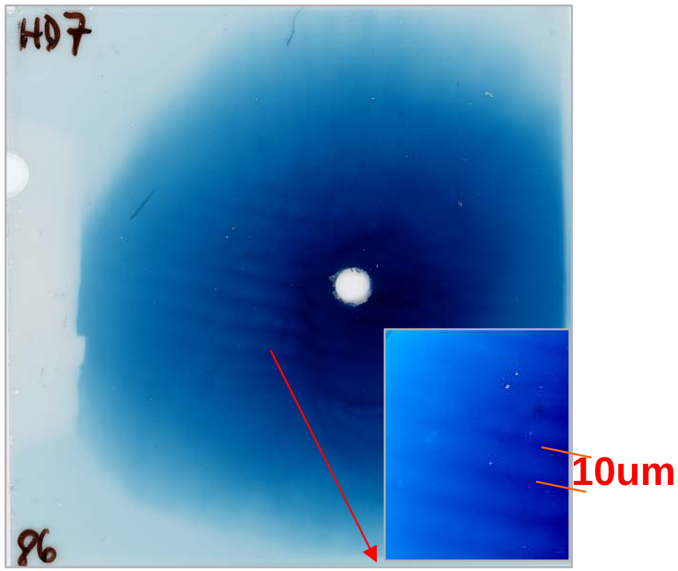




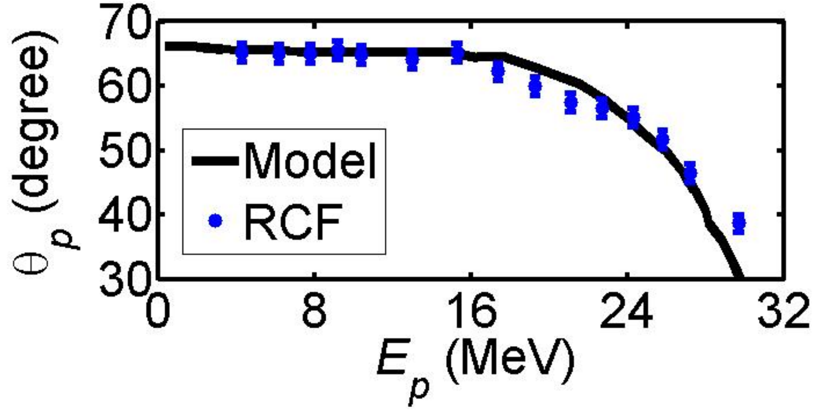
Carroll *et al*, Phys. Rev. E **76**, 065401 (2007)

Model is benchmarked using ‘grooved’ target results

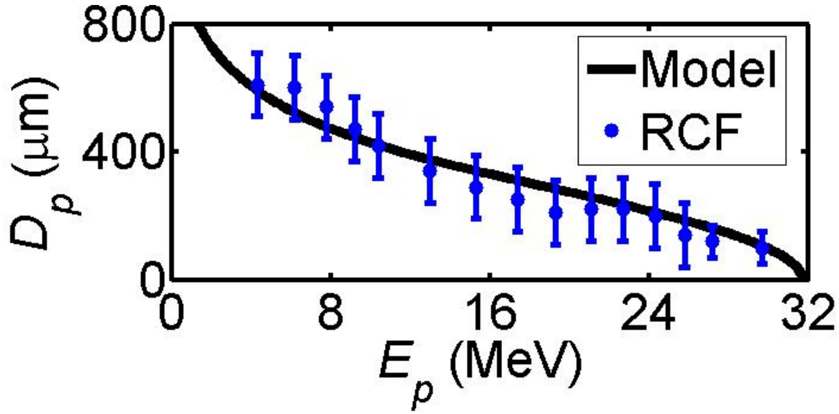




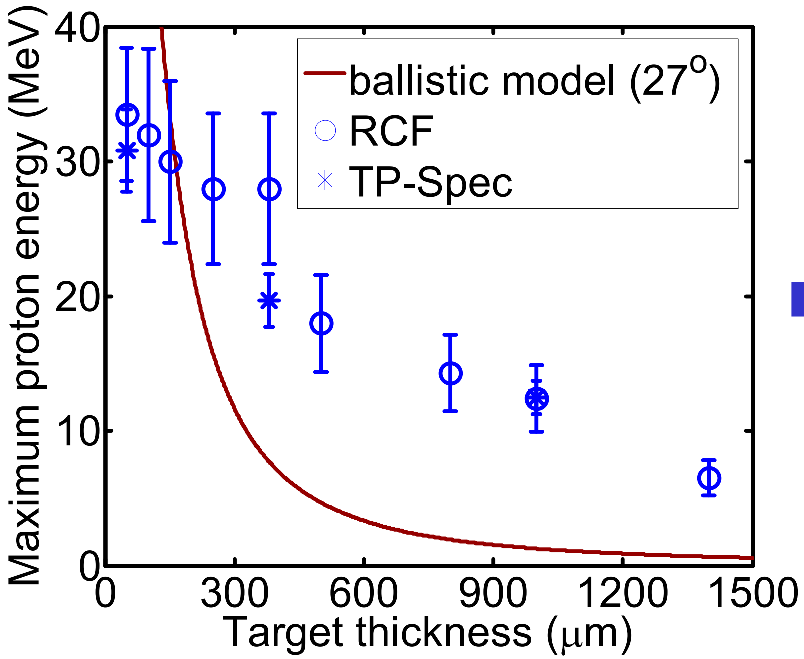
Divergence

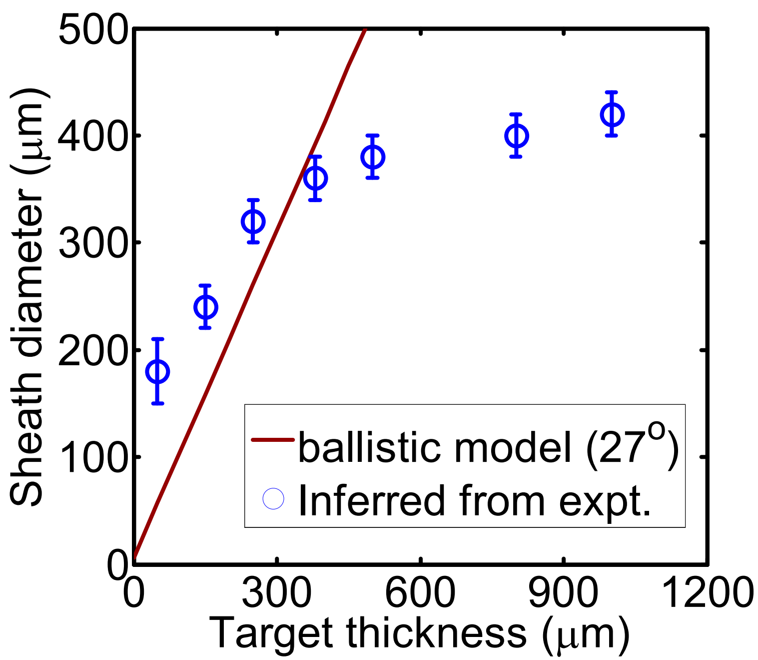


Source size



Proton emission as a function of target thickness



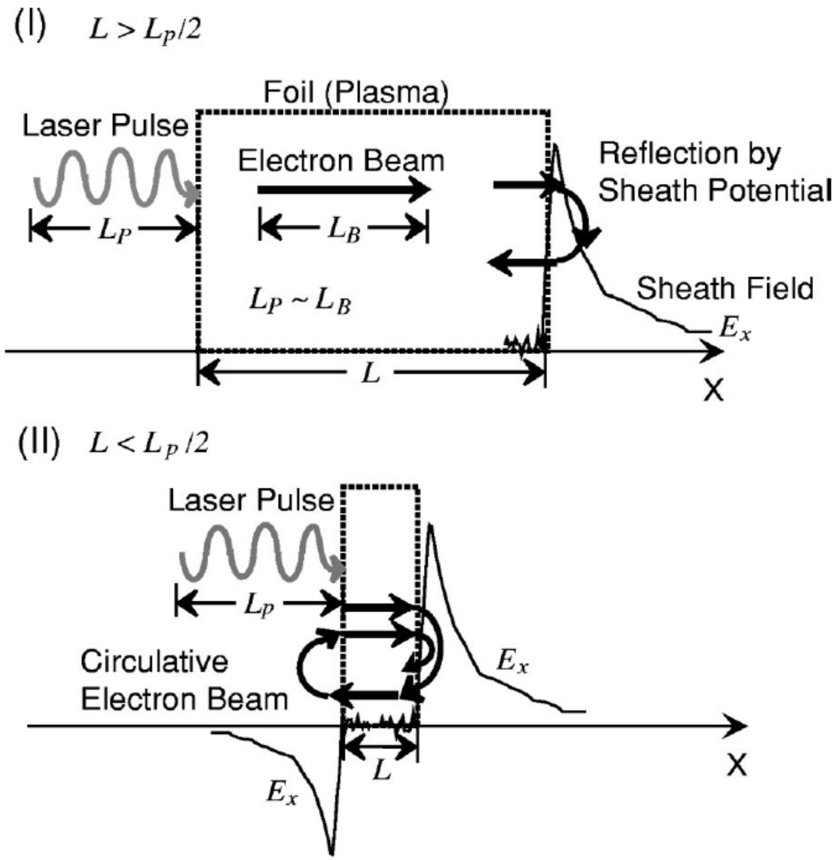


→ Evidence of a restriction in lateral spreading of fast electrons within the target

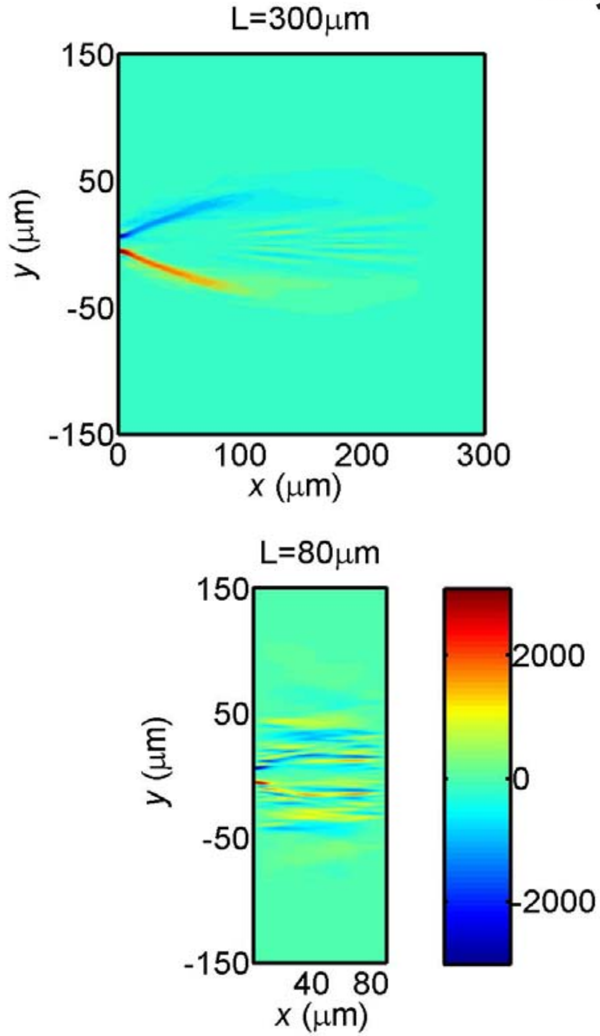
→ Self-generated B-field is an obvious candidate

→ But why should this depend on the target thickness?

Fast electron refluxing



Sentoku *et al*, Phys Plasmas, 10, 2009 (2003)



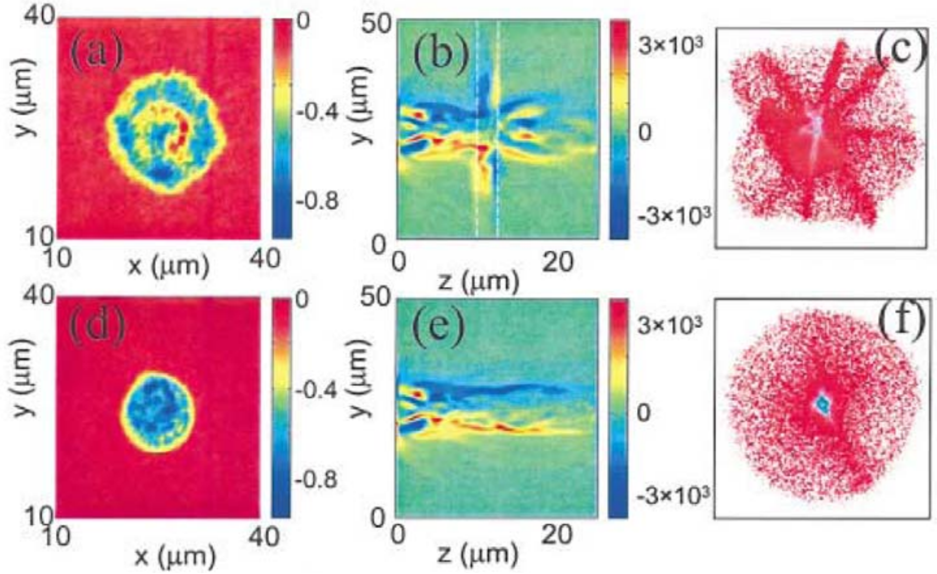
Electron refluxing within thin targets perturbs B-field and therefore collimation

X. H. Yuan *et al,* New Journal of Physics 12 063018 (2010)

2. Proton spatial-intensity distribution as a diagnostic of fast electron beam filamentation

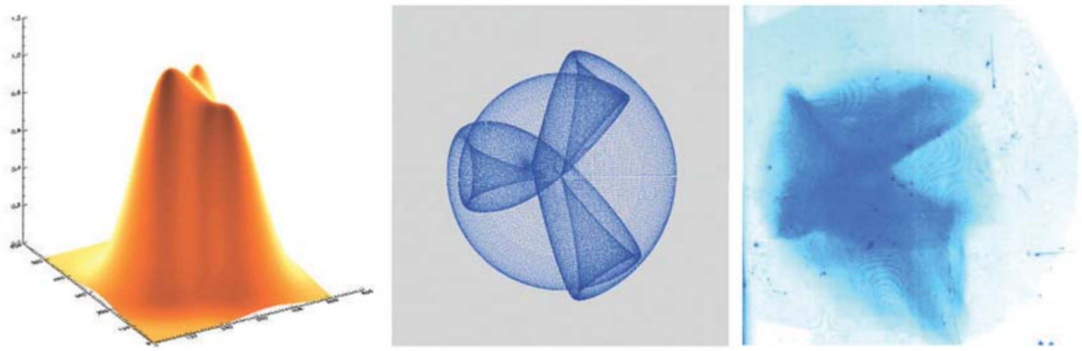
Mapping of electron distribution into protons

Simulated electron density → Simulated Proton Beam



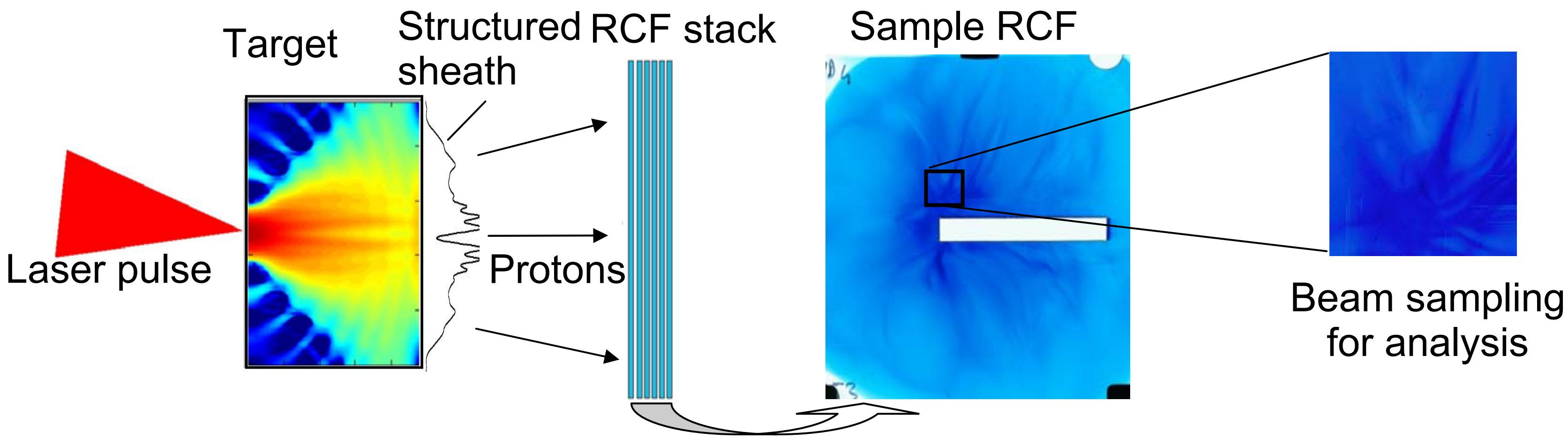
J Fuchs et al. Phys. Rev. Lett. 91, 255002 (2003).

Simulated electron sheath → Simulated Proton Beam → RCF



M Roth, M. et al. PPCF 44, B99 (2002).

Effects of target material on beam filamentation

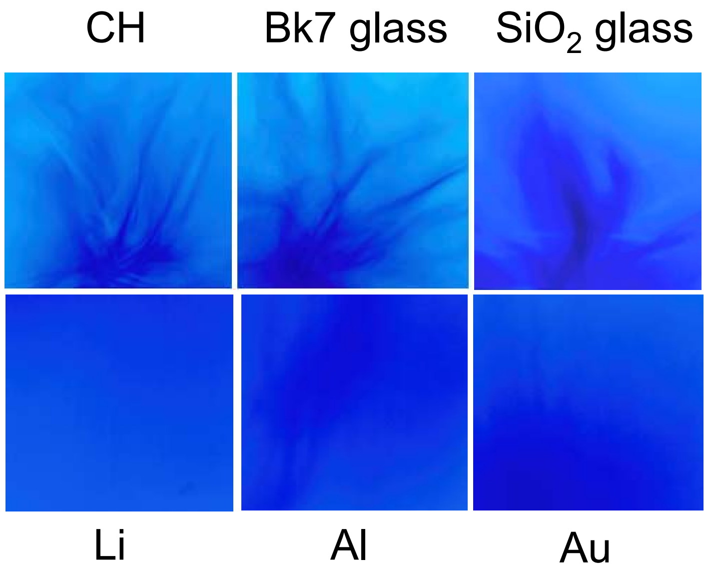


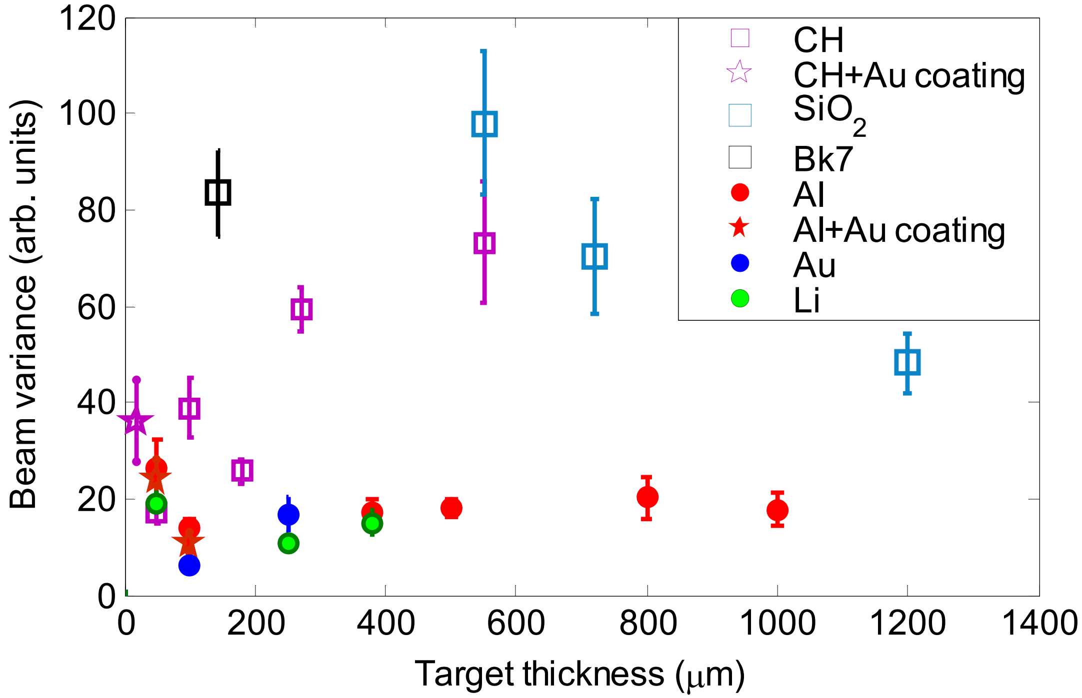
Differences in electron transport in CH & Al target – why?

- Resistive effects?
- Scattering/transverse temperature?

Target	Effective Z	Resistivity [Ω.m]
Al	13	10^{-8}
CH	3	10^{13}
Li	3	10^{-7}
SiO_2	12	10^{14}

Effects of target material on beam filamentation





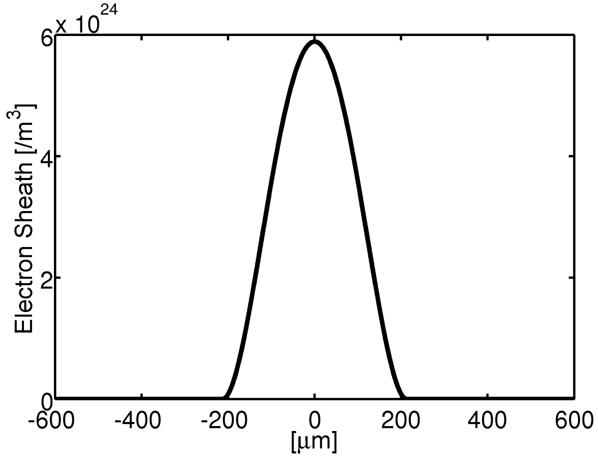
Filamentation is independent of target Z and therefore beam transverse temperature (for PW parameters)

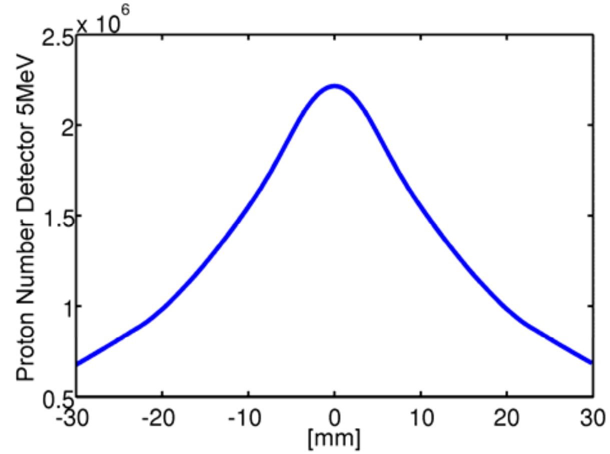
Analytical model of sheath profile mapping under development (Mark Quinn)

Electron density profile in sheath from hybrid transport simulation

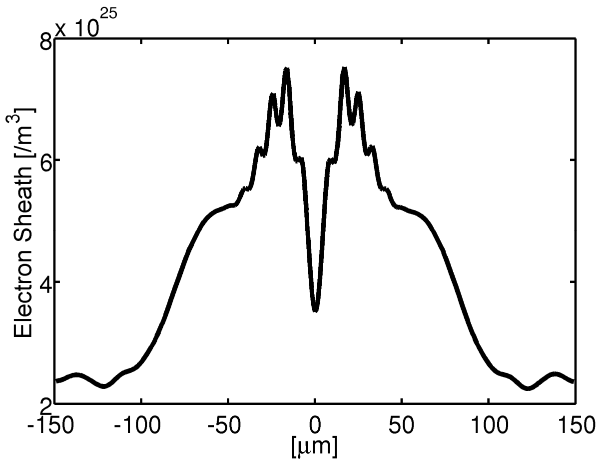
Predicted proton distribution at detector plane (5 MeV)

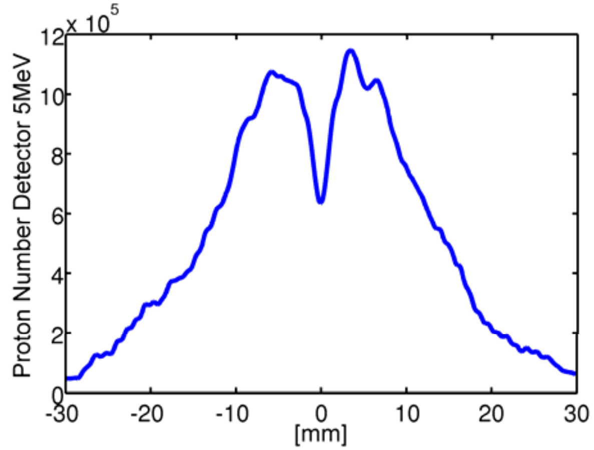
Al





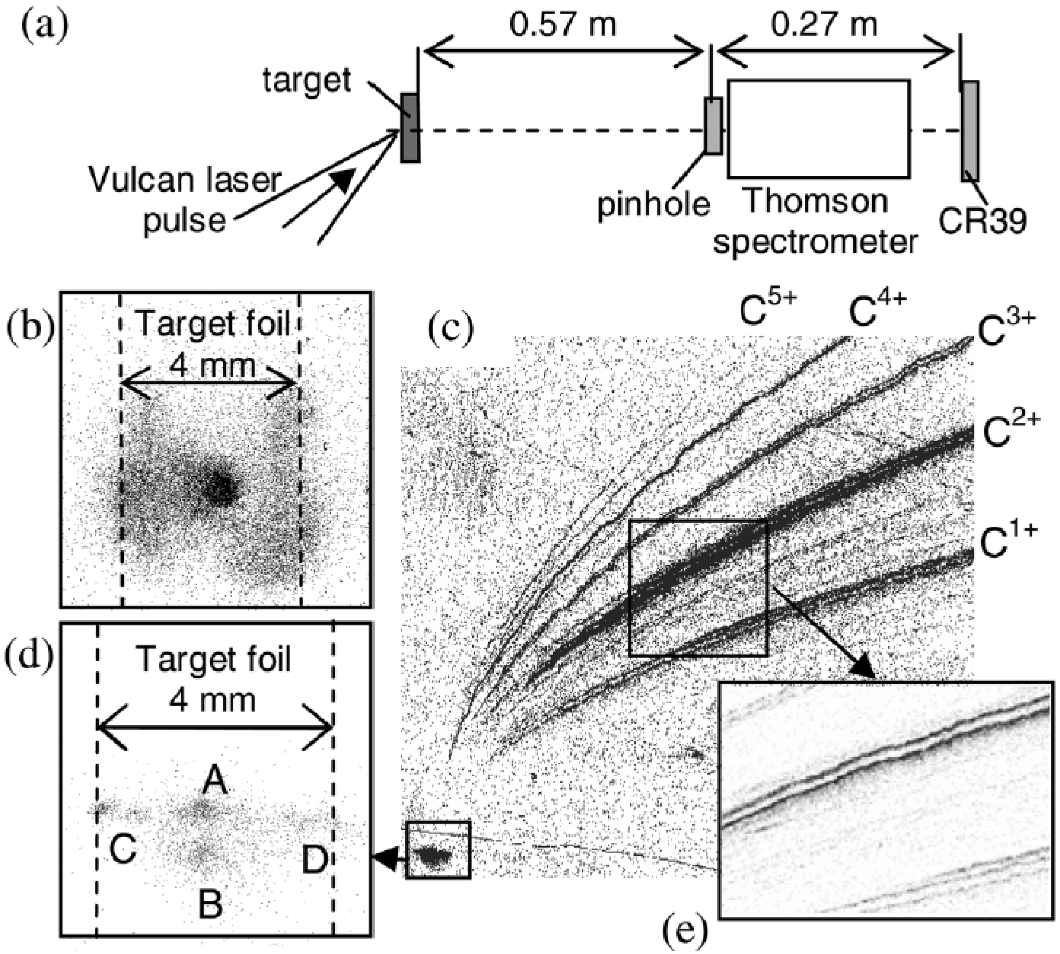
CH

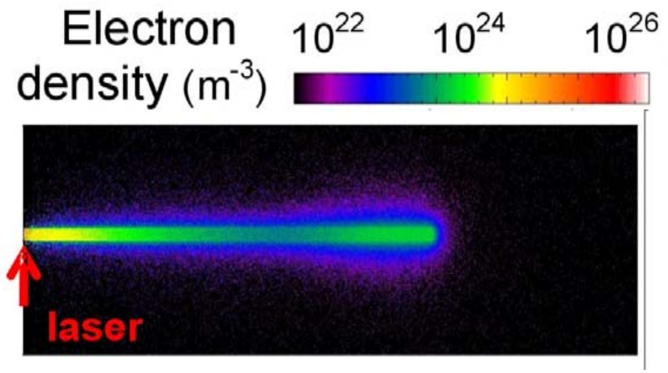




3. Ion pinhole imaging as a diagnostic of lateral transport of fast electrons

Lateral fast electron transport in thin foils



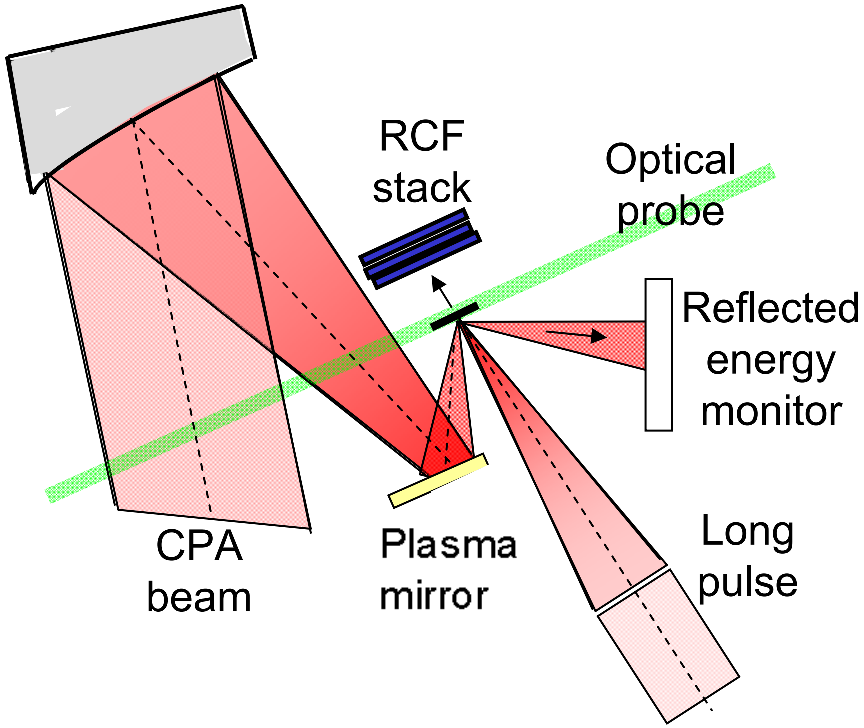


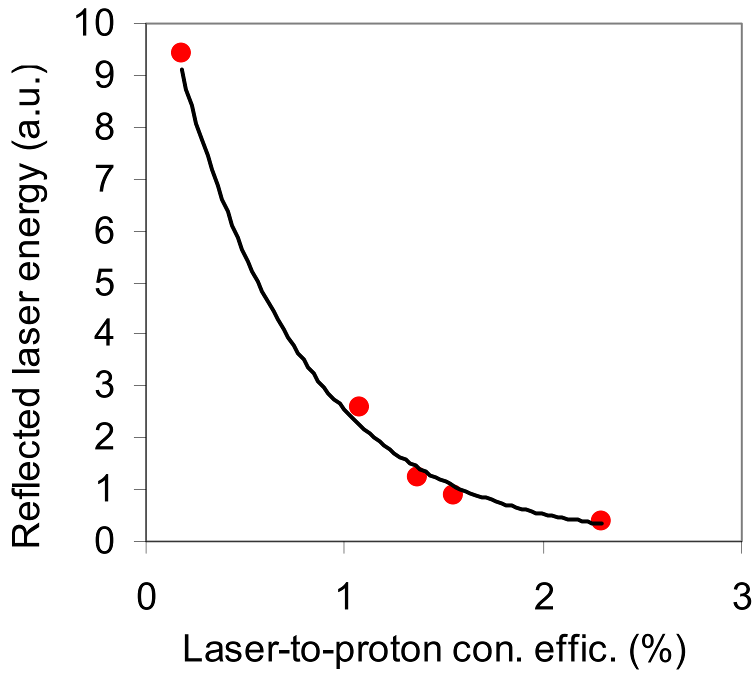
McKenna et al, Phys Rev Lett 98, 145001 (2007)

4. Total proton energy as a diagnostic of laser-to-electron energy transfer

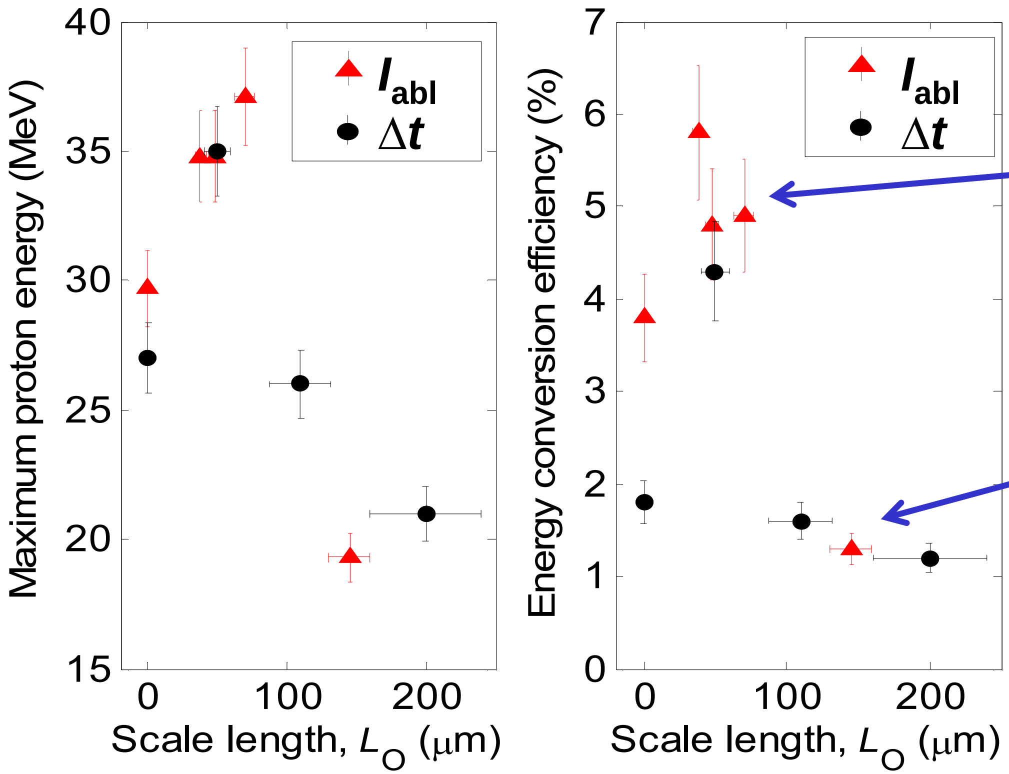
Total proton energy as a diagnostic of absorption

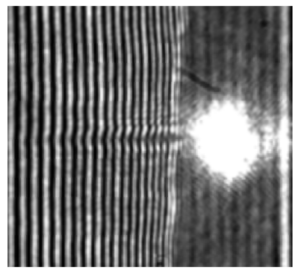
University of Strathclyde Glasgow

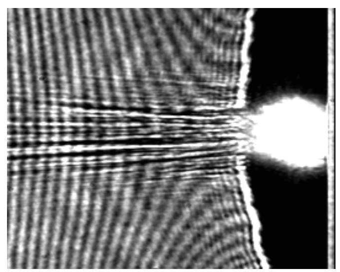




Example results







→ Proton measurements show that controlled preplasma expansion leads to enhanced energy coupling to fast electrons

P. McKenna et al, LPB **26** 591-596 (2008)

D.C. Carroll et al, CRP **10** 188-196 (2009)

5. Nuclear activation as a diagnostic of proton and ion acceleration

Nuclear activation as a diagnostic

Diagnostic of particles and radiation above a few MeV

Number of reactions:

$$N = D\int_{E_{Thres.}}^{\infty} \sigma(E)I(E)l(E)dE$$

D Number density of sample

$\sigma(E)$ Cross section

$I(E)$ Photon/Particle distribution

$l(E)$ Stopping range (Sample thickness)

Single activation foil: measure at least 2 reactions with different cross sections

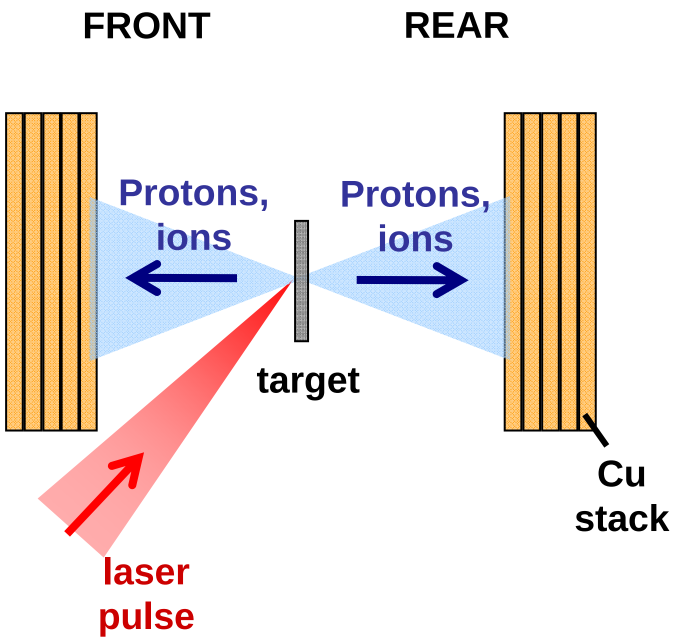
OR

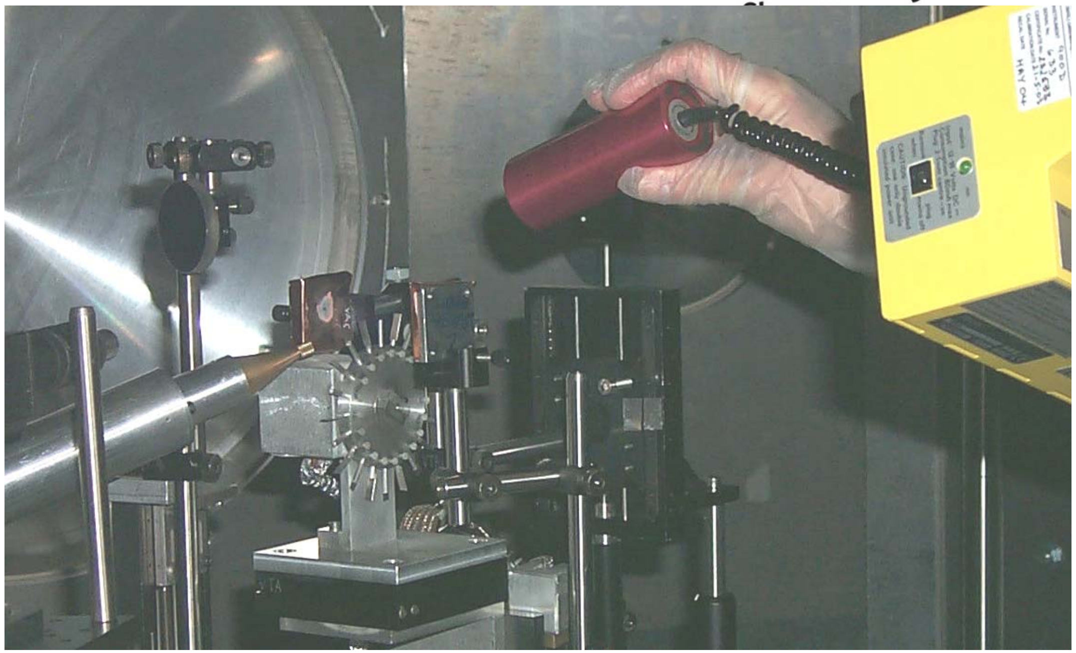
Stacked activation foils: measure at least 1 reaction in each foil

→ $I(E)$: temperature and yield

Uncertainty usually depends on uncertainty in $\sigma(E)$

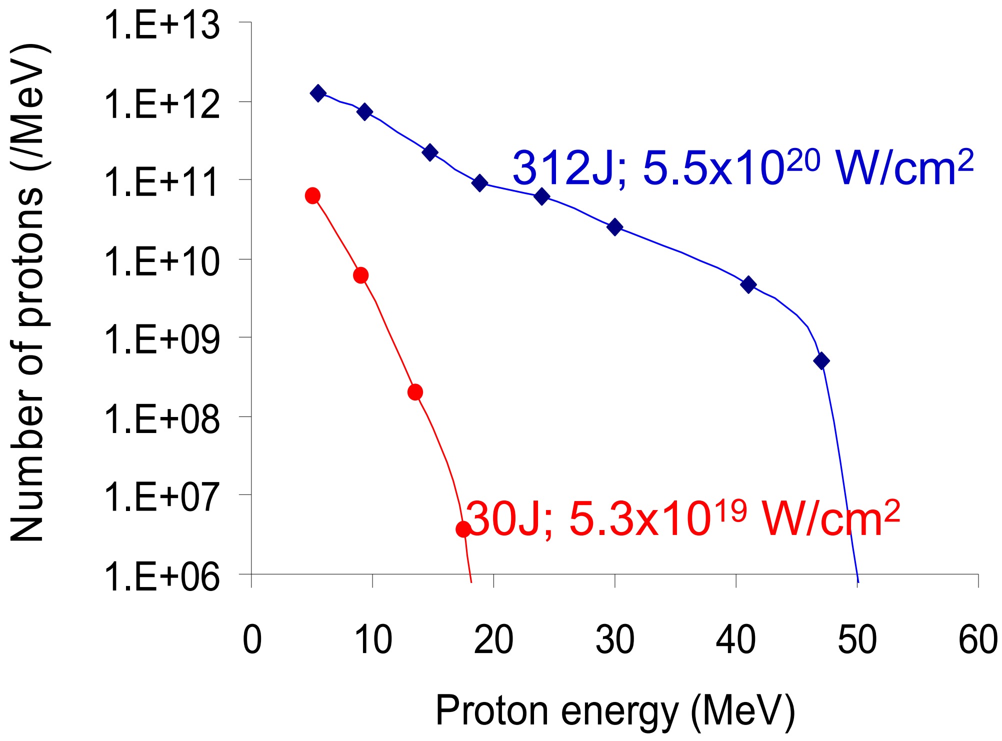
Proton activation



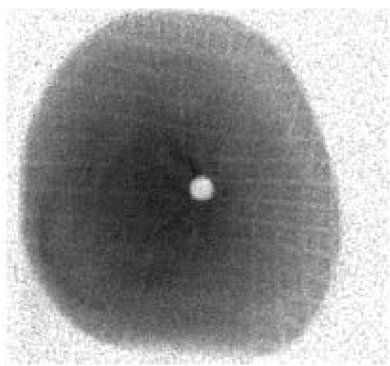


NaI(PMT) detectors arranged for coincidence counting to detect positron signature γs (511 keV)

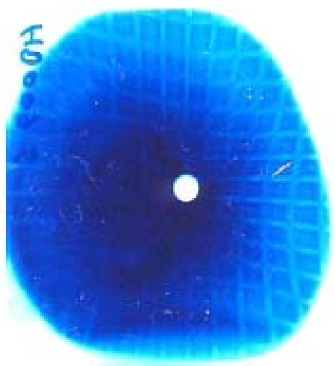
Example measurements



Cu activation



RCF film



Clarke et al, Appl. Phys. Lett, **89**, 141117 (2006)

Advantages:

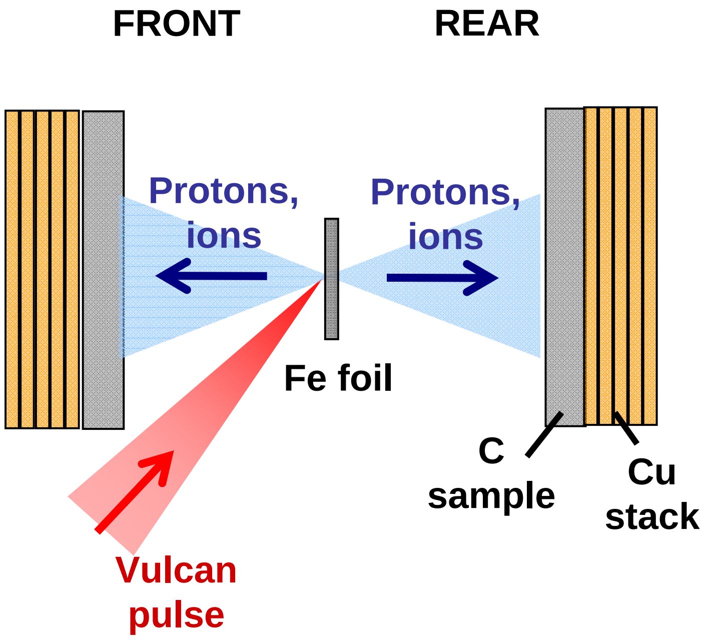
- 6 orders of magnitude dynamic range
- spatially integrated or resolved proton detection
- Half-life measurement confirms proton activation

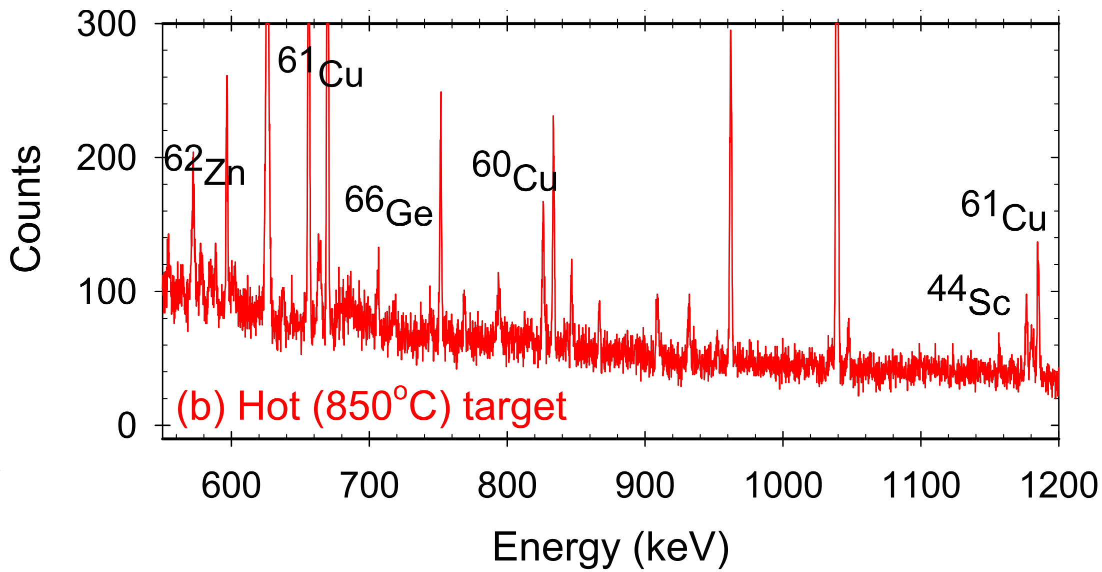
Disadvantages:

- Analysis off-line, time-consuming;
- Relies on knowledge of cross sections
- Limitation on proton upper energy due to other reactions eg Gamma-induced


CAUTION
SAFETY
F. Hanachi et al, University of Bordeaux

Nuclear activation as an ion diagnostic





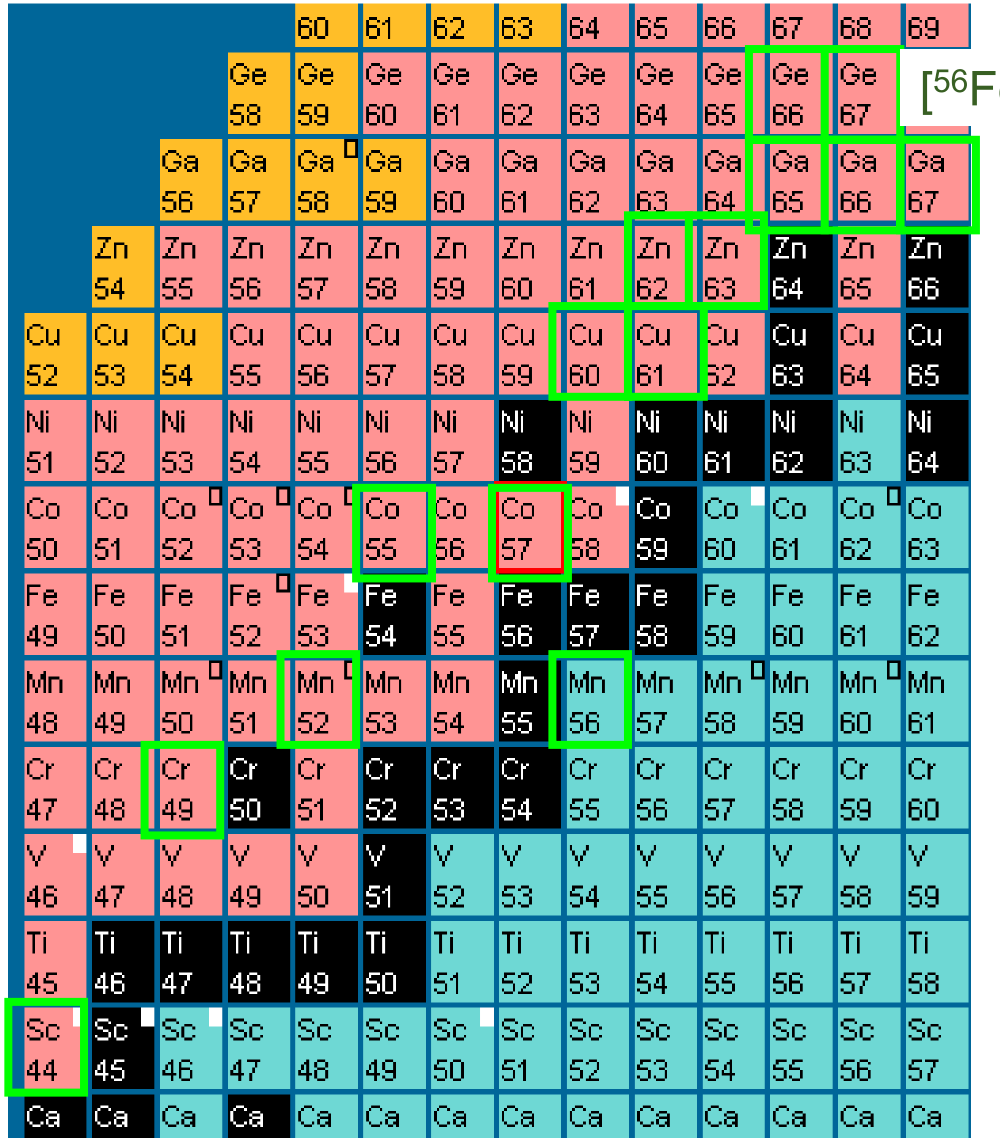
Cooled high resolution Ge detector

McKenna *et al.,* Phys. Rev. Lett., 91, 075006 (2003)

McKenna *et al.,* Appl. Phys. Lett., 83, 2763 (2003)

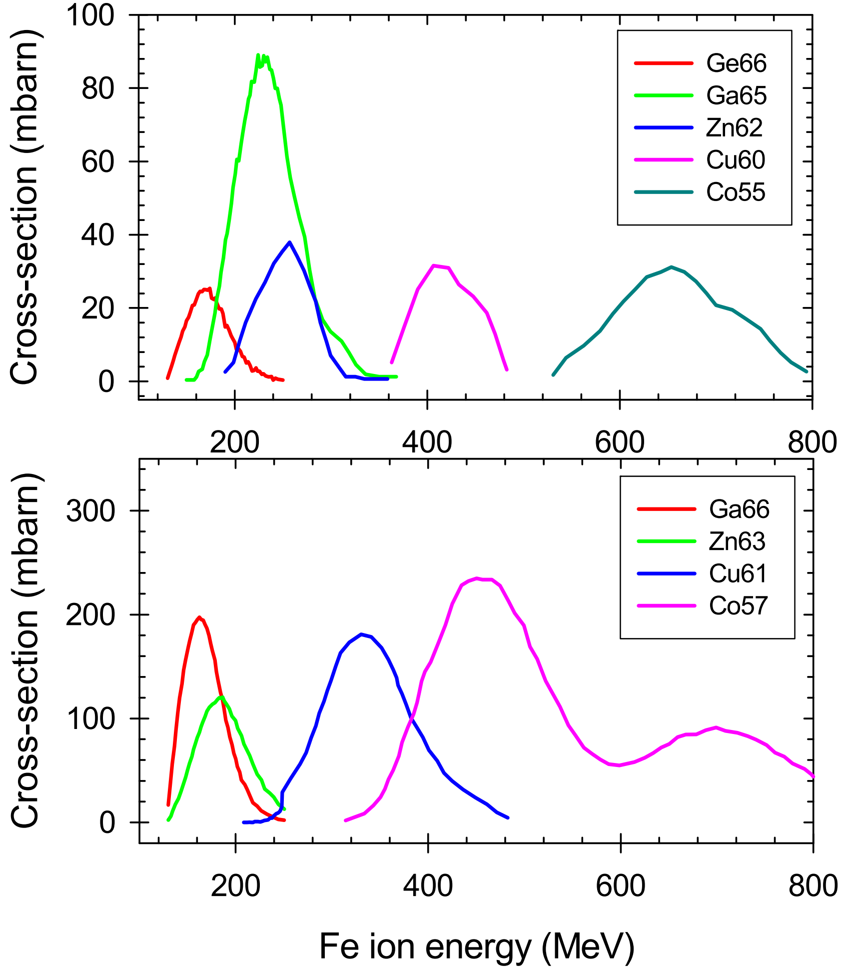
McKenna *et al.,* Phys. Rev. E, 70, 036405 (2004)

Ion diagnostic: Fusion-evaporation reactions

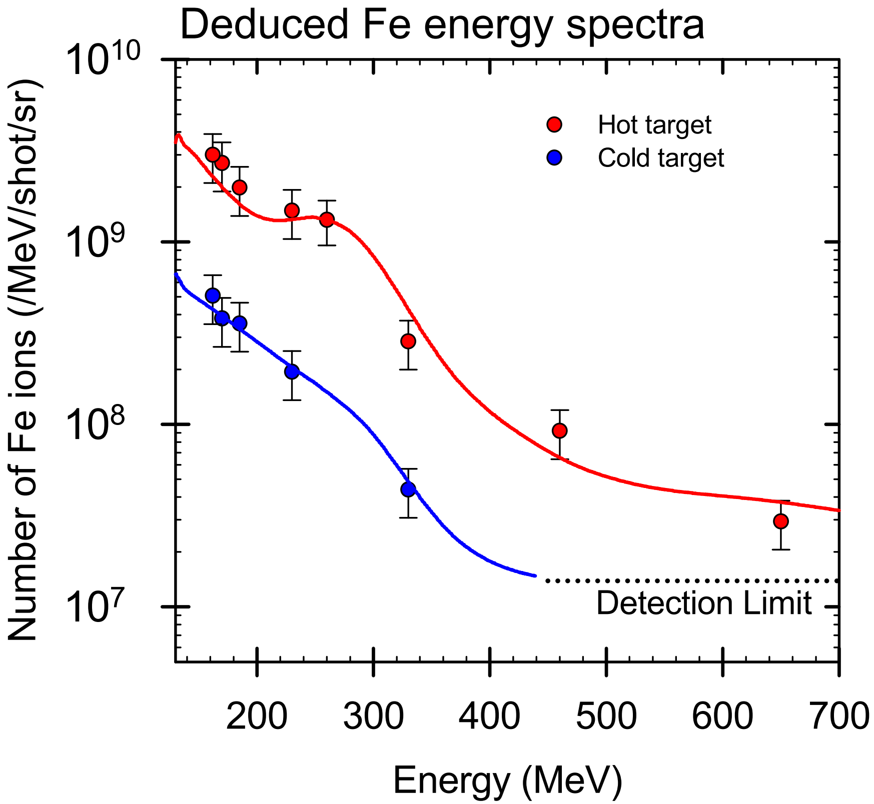


[$^{56}Fe+^{12}C$]

PACE2 MonteCarlo calculations:



Example measurement of ion energy spectra



Advantages:

- Direct evidence of ion species
- Enables spatially integrated ion detection

Disadvantages:

- Analysis off-line, time-consuming and cumbersome
- Relies on knowledge of cross sections
- No charge information

University of Strathclyde Glasgow

Thank you for your attention!