Imperial College London

A.G.R.Thomas
November 2004

Mono-energetic beams of relativistic electrons from intense laser plasma interactions

Contents

- Background
- Experiments on Astra 2003-2004
  - Production of narrow energy spread electron beams
- Simulations
  - Modification of the laser pulse by the plasma wave
  - Wavebreaking injection
- Conclusions

Imperial College London

Background

Plasma Wave Acceleration

-
  - plasma waves can have longitudinal electric fields up to 100 GeV/m
  - potential for high gradient - small length accelerators
-
  - Difficult to achieve high quality beams because:
    - bunch must be shorter than plasma wave length
    - bunch must be narrower than focal spot of laser
-
  - has previously produced quasi-thermal spectra ($\Delta E/E \sim 100\%$)

Monoenergetic Energy Spectra

- Early simulations by A. Pukhov and J.Meyer-Ter-Vehn* in 2002 show that monoenergetic spectra can be produced by a highly non-linear wake - the bubble.
- 2002 Malka *et al*‡ demonstrate enhanced electron acceleration to 200MeV by moving to a longer focal length geometry
- 2003 Imperial College obtain high resolution electron spectrometer to look for spikes in spectra

*A.Pukhov *and* J.Meyer-Ter-Vehn App. Phys. B 74, 355-361 (2002)

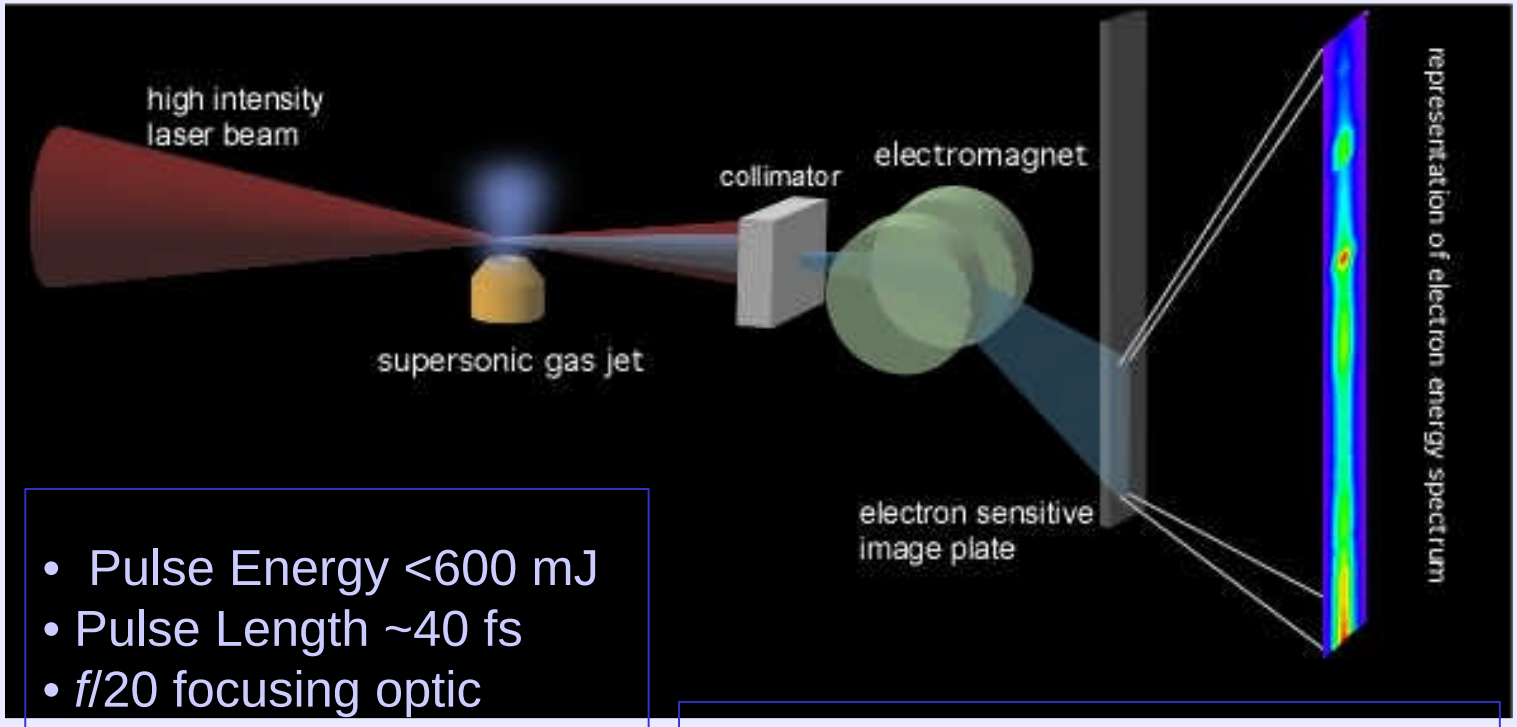
‡V.Malka *et al* Science 298, 1596-1600 (2002)

Imperial College London

2003-2004

Experiments on Astra

Experimental Setup

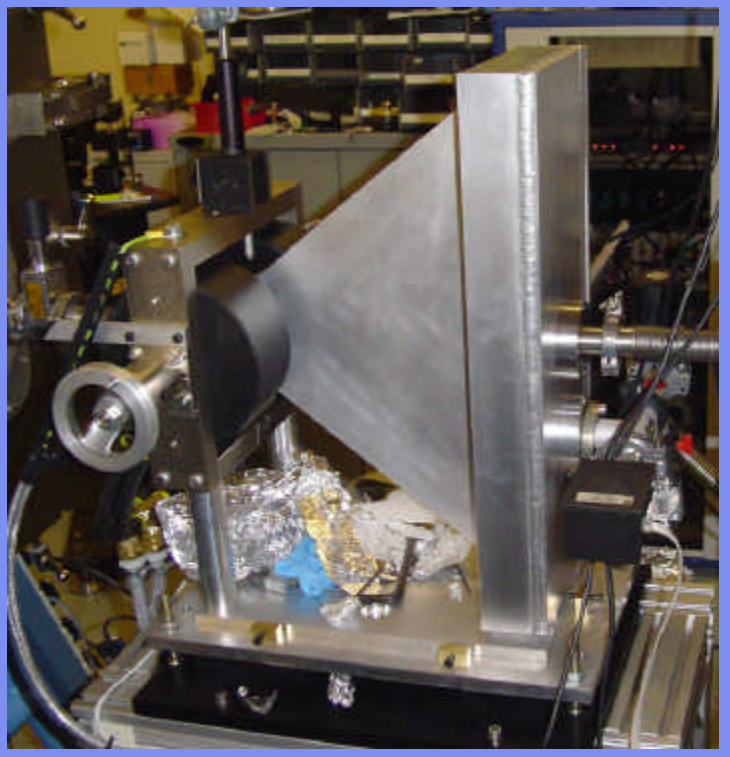


- Pulse Energy <600 mJ
- Pulse Length ~40 fs
- *f*/20 focusing optic
- Focal spot ~ 25 µm
- $a_0 = 1$

- 2mm Supersonic Helium Gas jet
- $0.5 \times 10^{19} < n_e < 5 \times 10^{19}$ (cm^{-3})

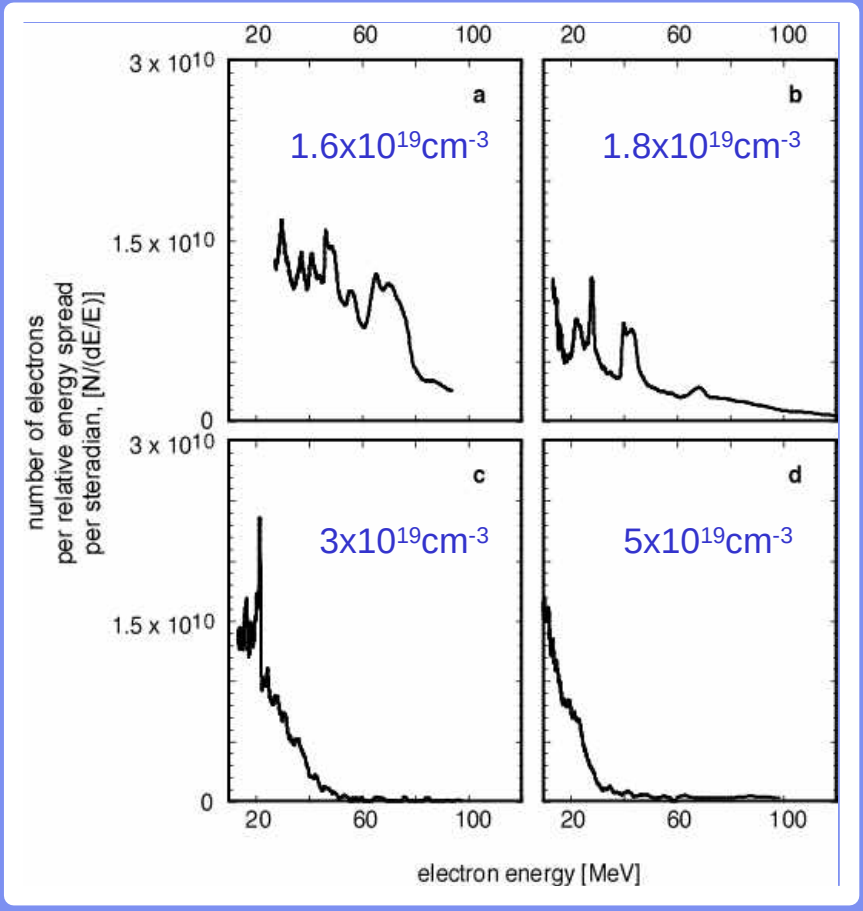
Electron Spectrometer

- Spectrometer:
  - B-field: 30mT - 1.4T
    - 1keV - 500MeV
  - 2” poles
  - 50cm detector plate
    - 25cm signal
    - 25cm background
- Detector: Fujifilm BAS-180011
  - Spatial resolution: 50 - 200μm
  - Corresponds to ~2% error <100MeV
  - Linear response over 10^5 range

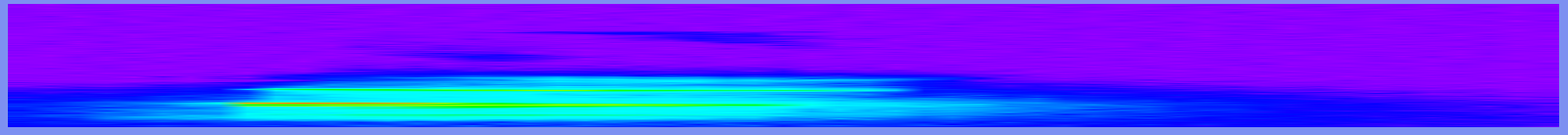


October 2003 Results

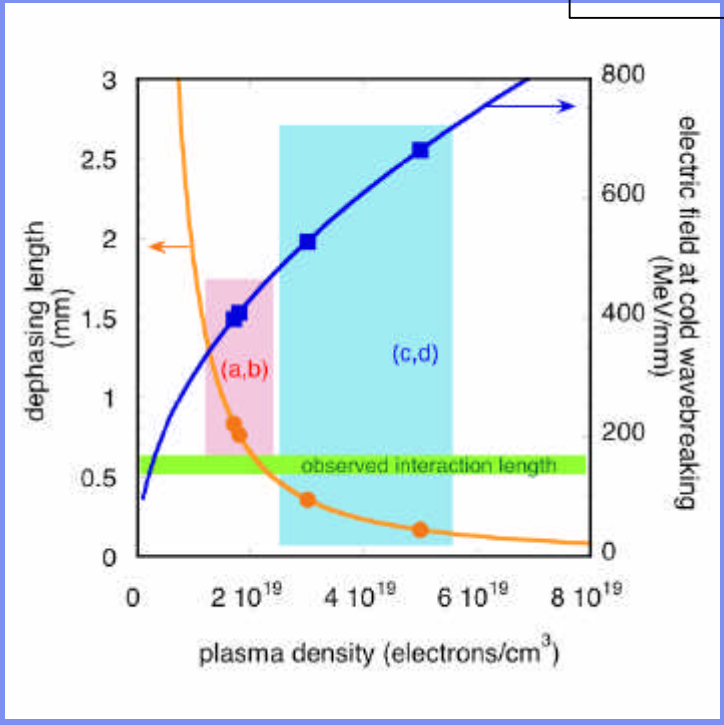
Evolution of energy spectra with density



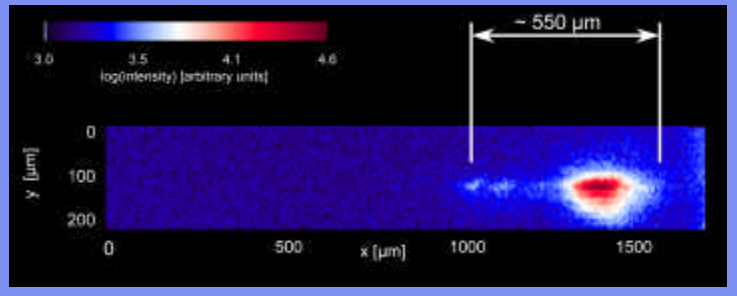
- 350mJ laser energy
- At high density quasi-maxwellian distribution
- As density decreases spiky features appear in spectrum



How does changing density produce narrow energy spread features?



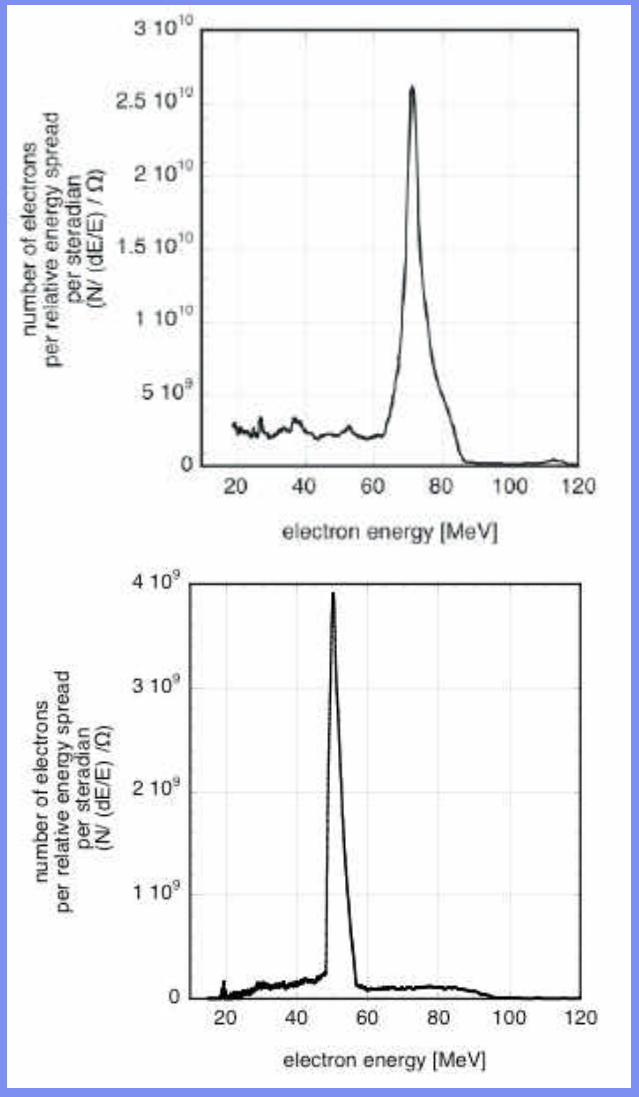
- Maxwellian spectra observed when interaction length > dephasing length
- Mono-energetic spectra observed when observed interaction length ~ dephasing length



Thomson scattering image

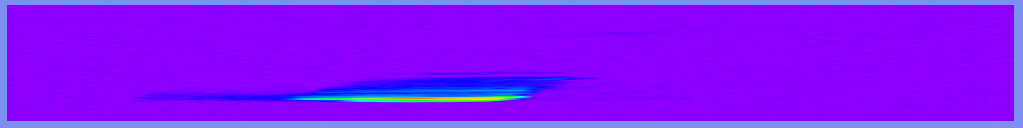
April 2004 Results

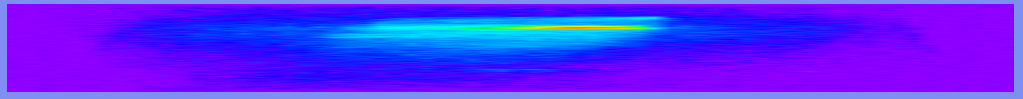
Monoenergetic Spectrum ΔE/E FWHM <5%



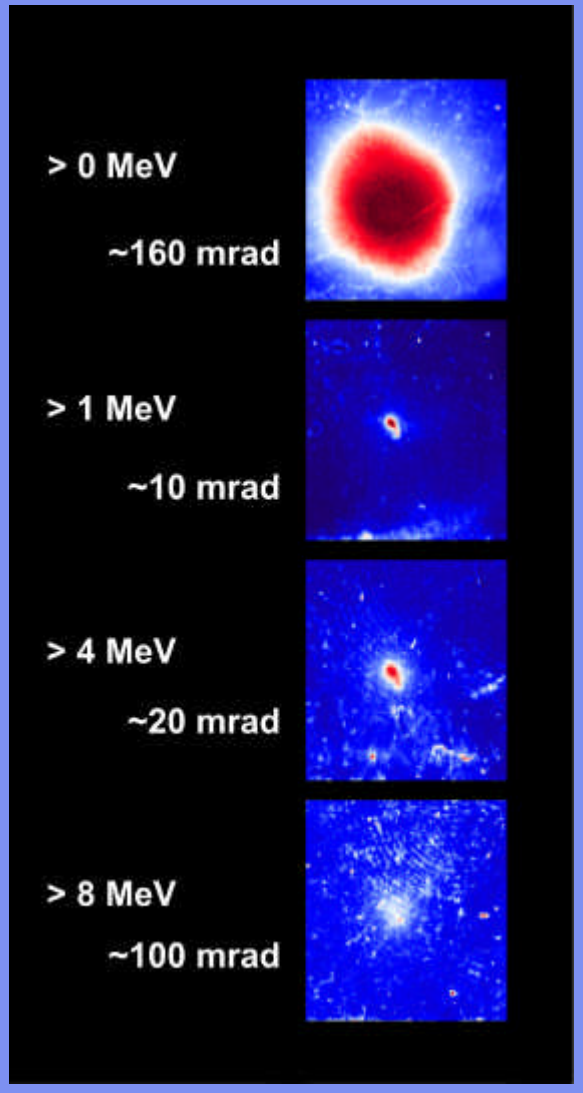
- Higher laser energy (600mJ)
- Finer control of n_e
- Electron beams

  E = 77MeV ΔE = 3%
- Shot-to-shot fluctuations in
  - beam energy ~30%
  - beam charge





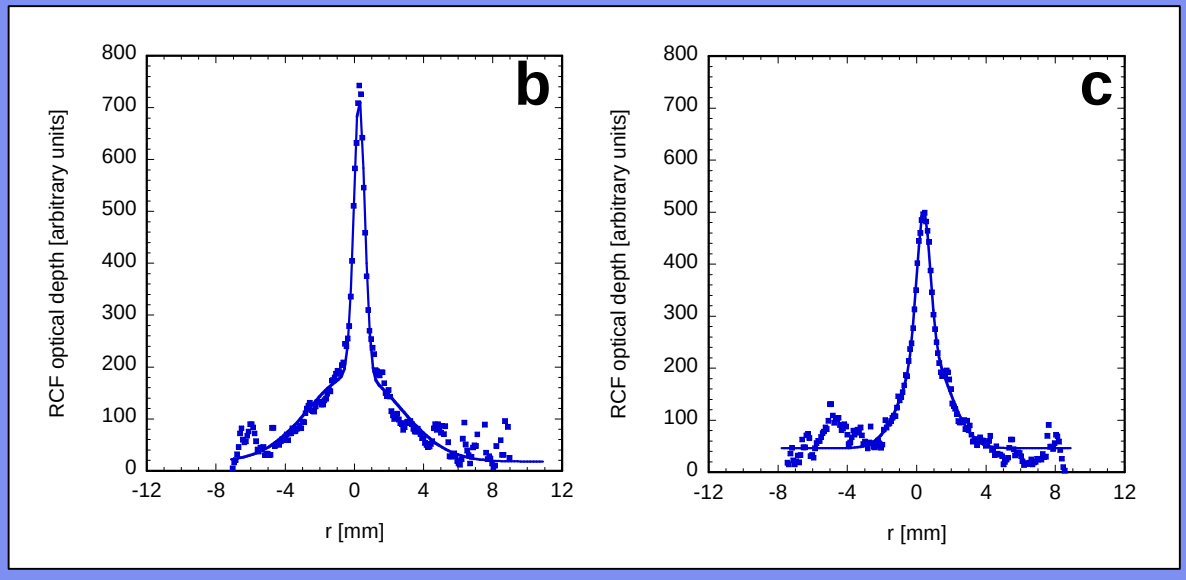
April 2004 Results



Divergence Measurements

Beam has two components

- Low energy (< 1 MeV) has high divergence θFWHM ~ 15º
- High energy has low divergence θFWHM < 2º

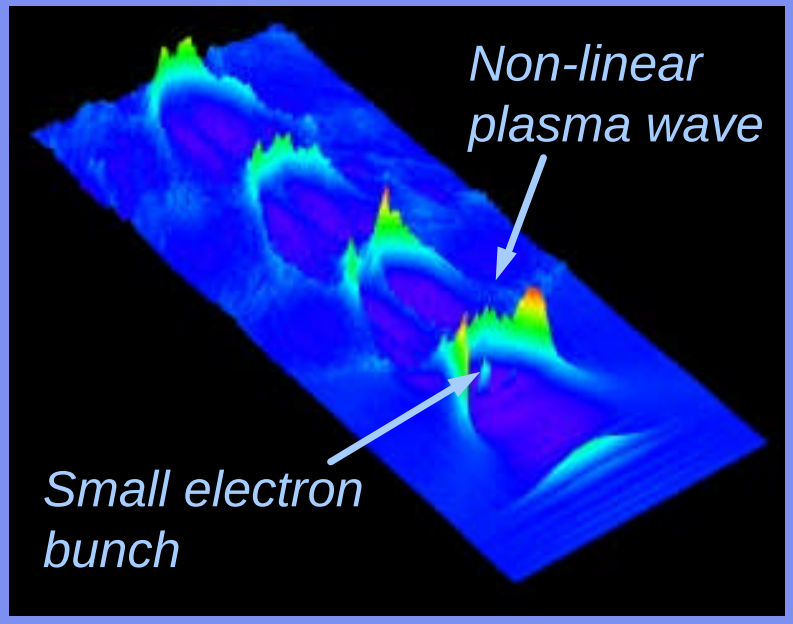


Imperial College London

Simulations

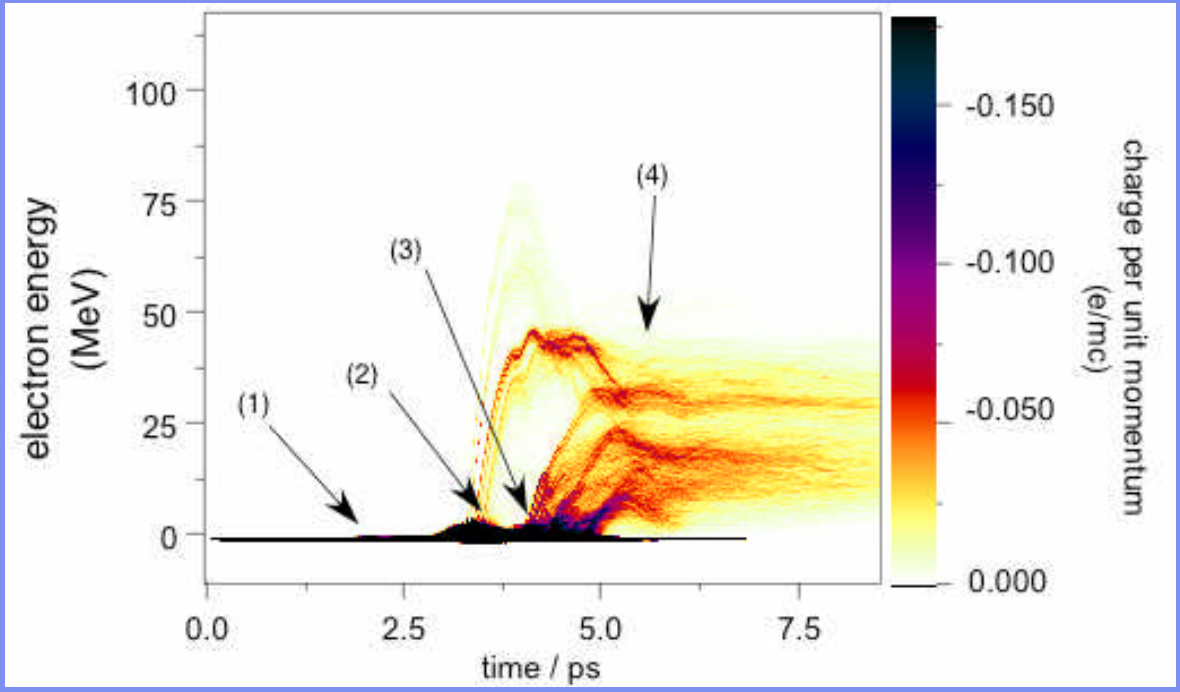
- 2D3V particle-in-cell simulations with OSIRIS
- laser and plasma parameters close to experiment
- range of densities studied

Strongly non-linear wakefield

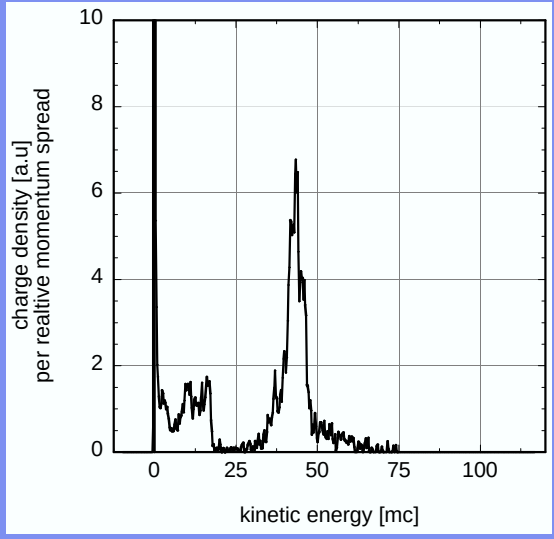


- Simulations show that the laser pulse and plasma wave co-evolve until transverse wavebreaking occurs.
- If growth occurs slowly, bunch injection can occur without destruction of wake structure
- After injection bunch can dephase from wake - results in increased energy spread

Simulation Time History

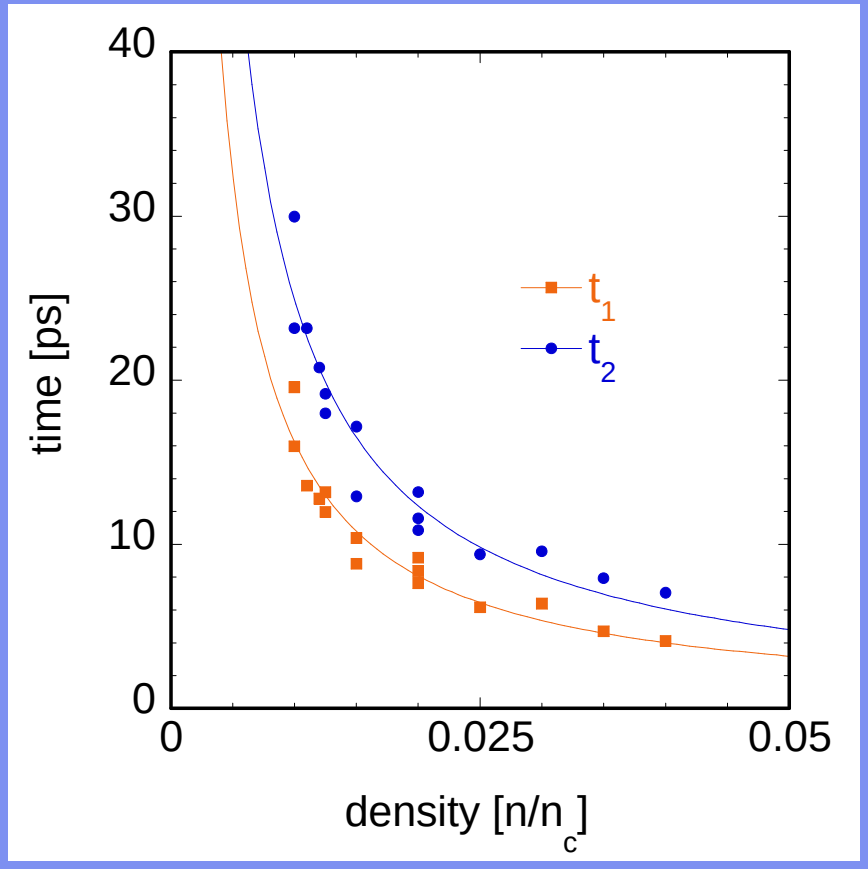


Electron spectrum at 4.3 ps



1) Plasma wave becomes non-linear
2) Transverse wave breaking takes place - particles injected into wave
3) Further wave periods also break
4) Dephasing has occurred and energy spread is increased

Density Dependence



- 2D Simulation data
- t_1 wake evolution time
- t_2 injection time
- Both t_1 and t_2 inversely proportional to density

Imperial College London

Conclusions

- Monoenergetic electron bunches from ~10TW system
- Data suggests dephasing length and interaction length crucial parameters
- High fluctuations within the laser parameters used here:

$\Rightarrow$ Need higher power?

Imperial College London

Acknowledgements

Co-authors: S.P.D.Mangles, C.D.Murphy Z.Najmudin, J.L.Collier, A.E.Dangor, E.J.Divall, P.S.Foster, J.G.Gallacher, C.J.Hooker, D.A.Jaroszynski, A.J.Langley, W.B.Mori, P.A.Norreys, R.Viskup, B.R.Walton, and K.Krushelnick

CLF laser, target area and engineering staff.

Alpha-X (Funded by Research Councils UK)

EPSRC