John Adams Institute for Accelerator Science

Imperial College London

# Target heating in the relativistic transparency regime

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# Motivation

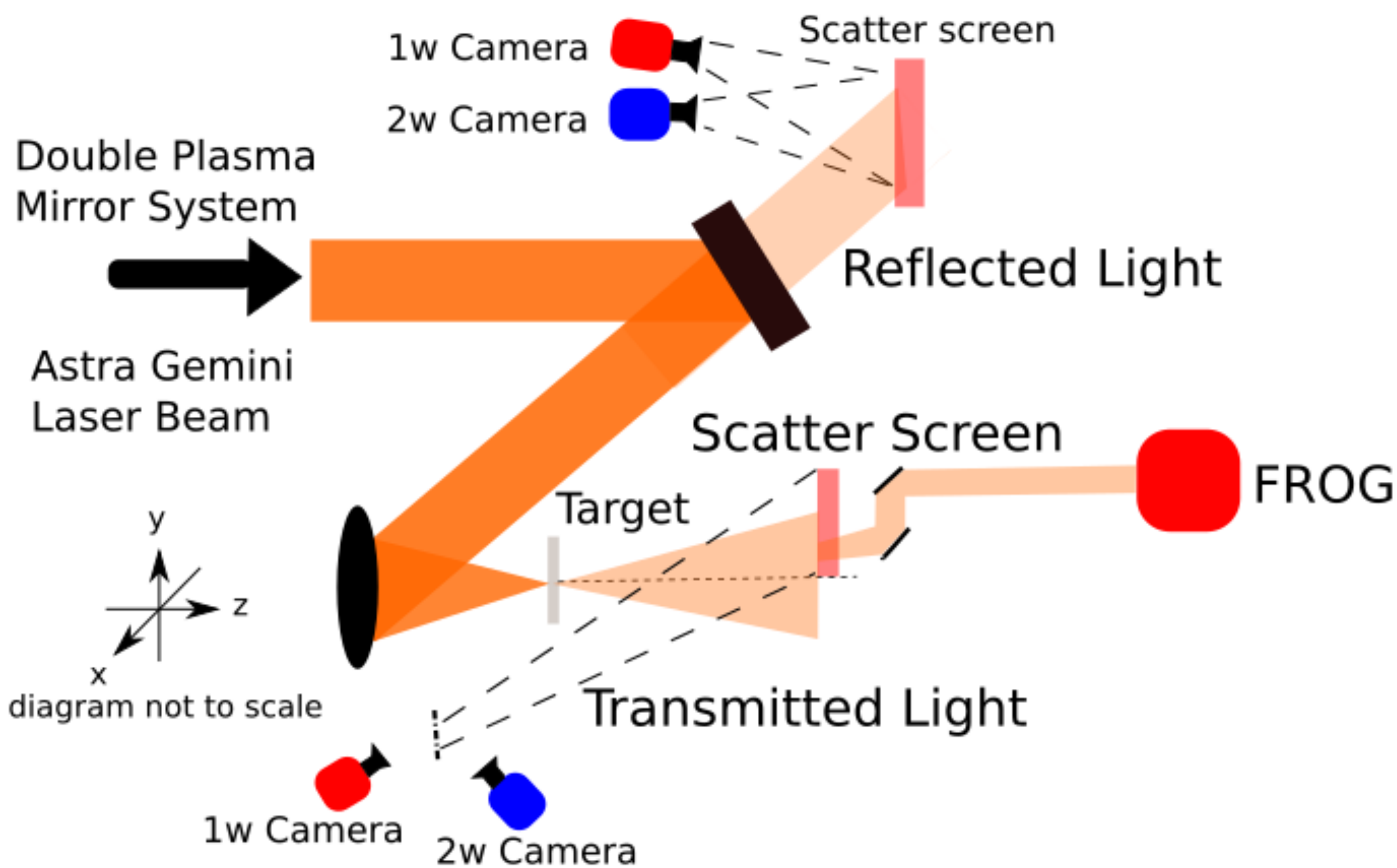
## Experimental Aims

- Ion acceleration from thin foils
- Explore intersection between relativistic transparency and opaque acceleration mechanisms
- Use optical diagnostics to understand the plasma dynamics

## Simulation Aims

- Confirm experimental conclusions
- Track electron heating as a function of density

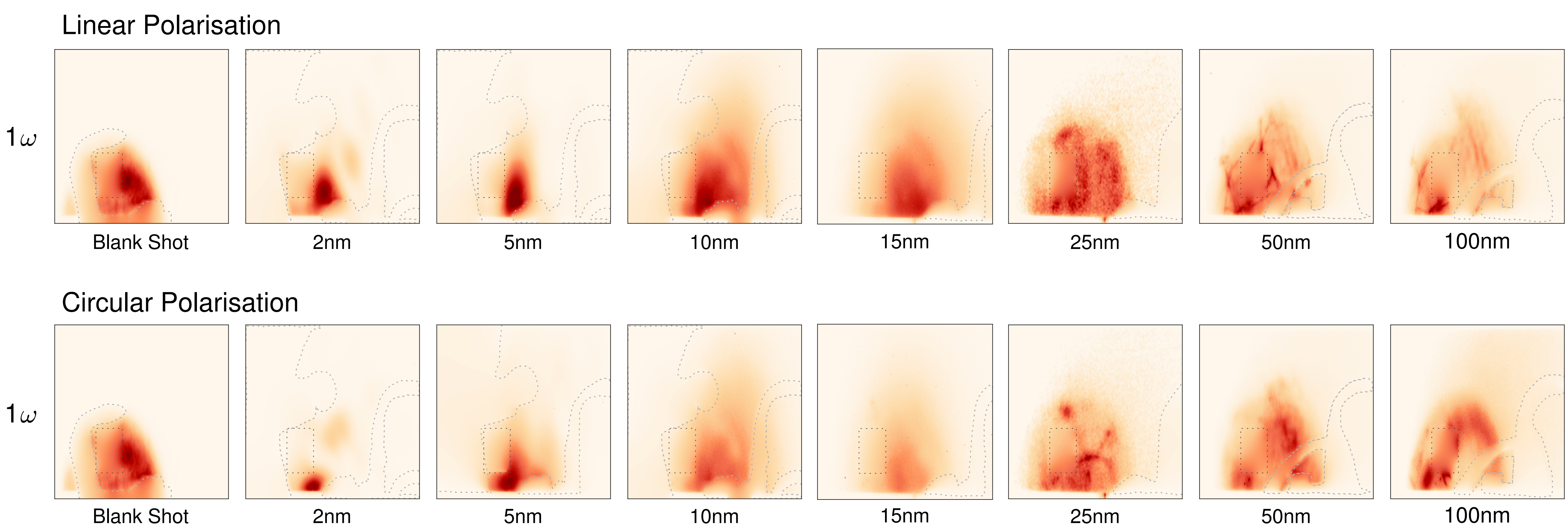
# Experimental Set-Up




- Energy: ~6J on Target
- Pulse Length: 45fs
- Intensity: $3 \times 10^{20}$ $Wcm^{-2}$
- $a_0$: 13

- Amorphous Carbon Targets
- Target thickness range: **2 - 100nm**
- Contrast of $10^{14}$

# Experimental Results: Transmission Screen



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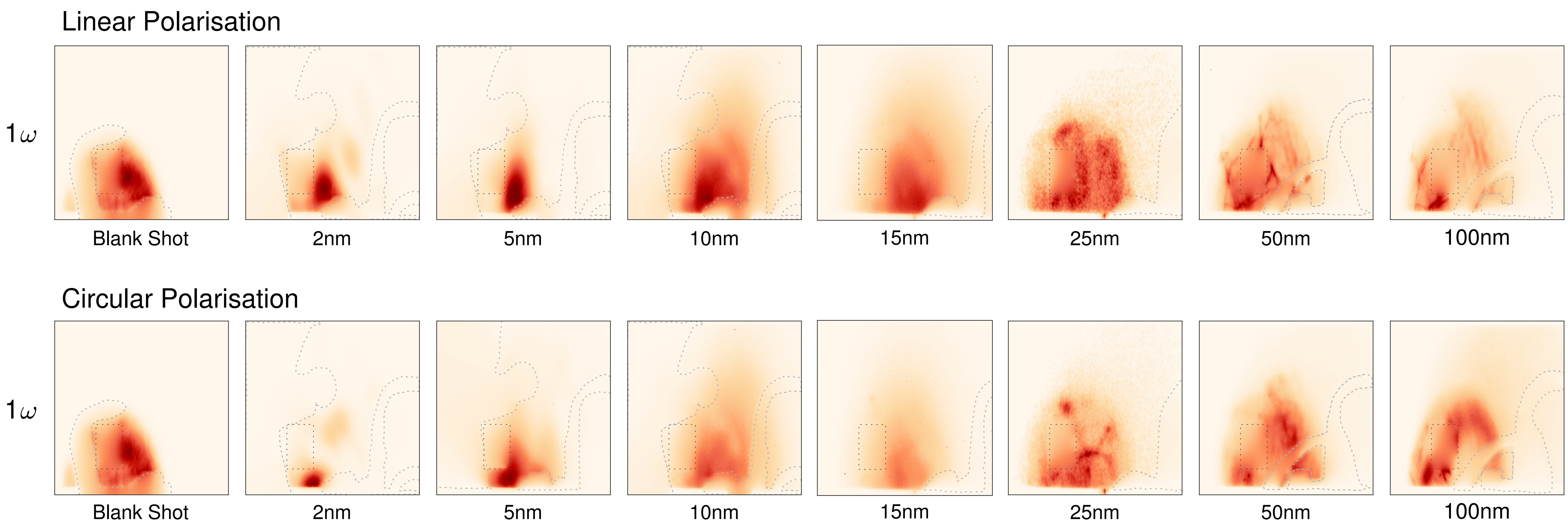
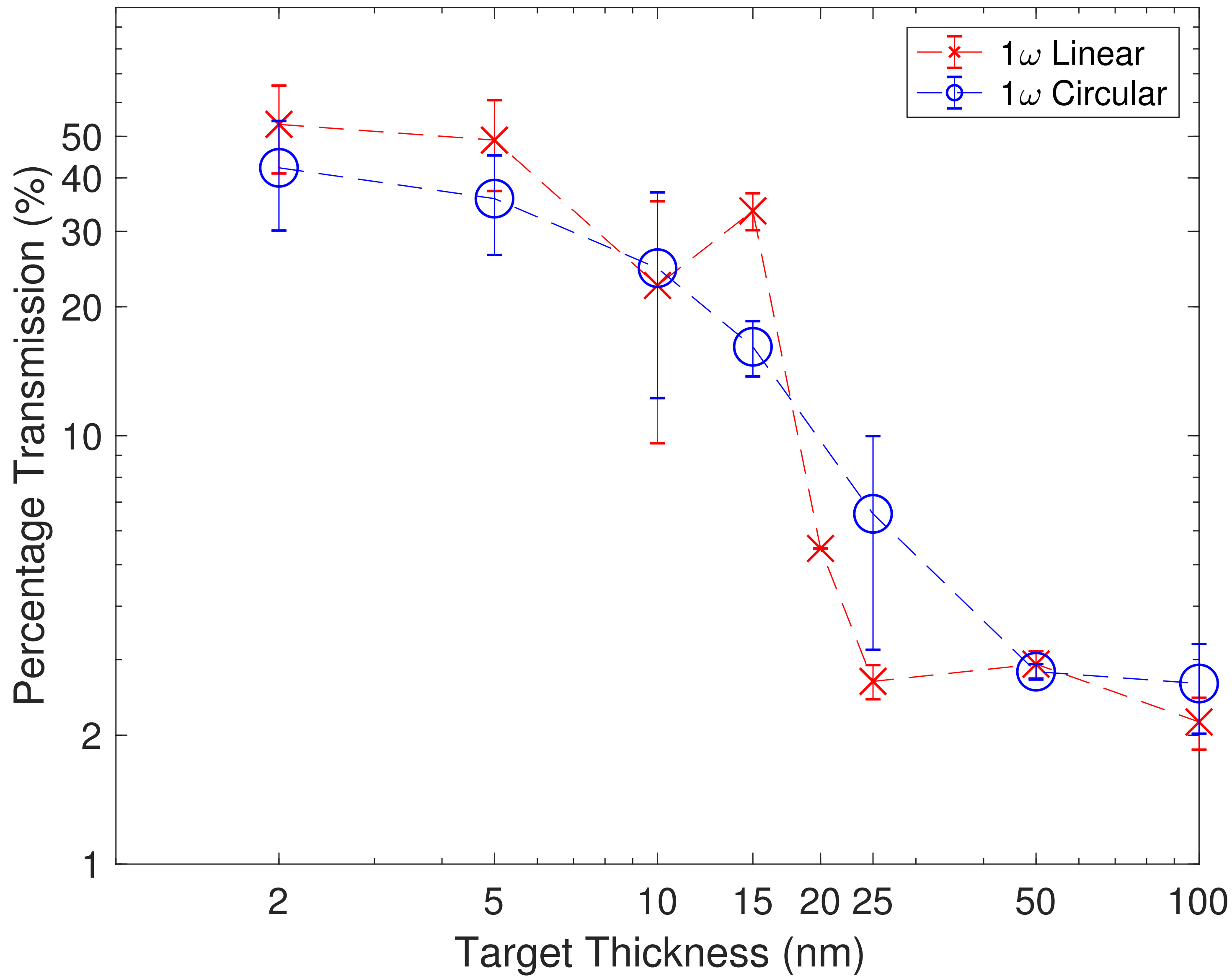



- Pinhole effect occurs
- Targets $\leq$ 15nm go transparent
- Radiation emitted from the rear surface
- Targets $\geq$ 25nm remain overdense

# Experimental Results: Transmitted Energy




- Up to 50% transmission for $\leq$ 15 nm - direct laser light
- Percent level transmission for $\geq$25nm - secondary emitted radiation

# Simulation Parameters

- EPOCH 2D3V code developed by Warwick
- Completed target thickness scan 2nm-100nm
- Linear and Circular polarisation

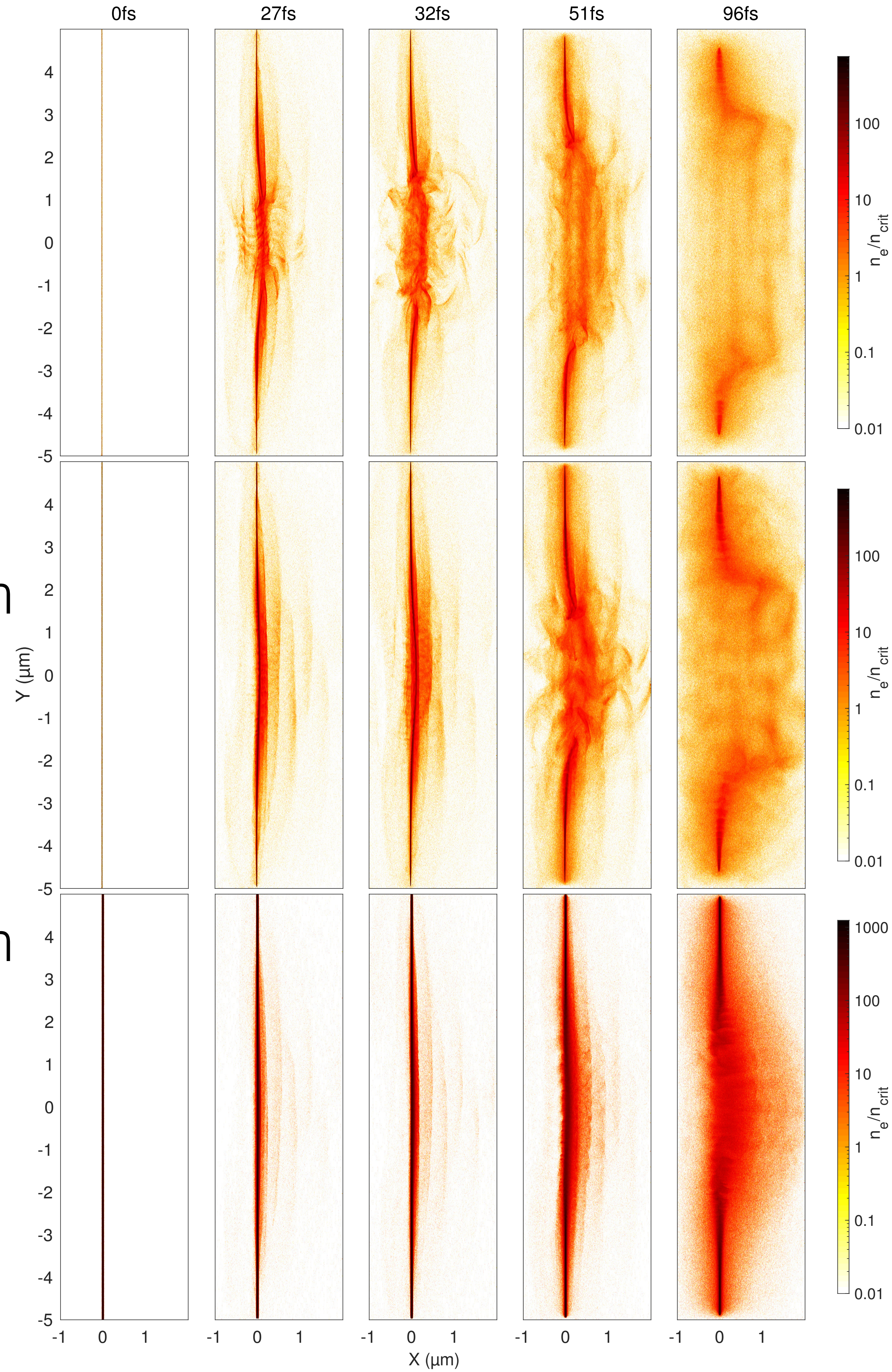
EPOCH
UNIVERSITY OF WARWICK

| | |
|---|---|
| Simulation Resolution | 0.6 nm |
| Box size ( $\hat{x}$ , $\hat{y}$) | 3 $\mu m$ x 10 $\mu m$ |
| Peak a_0 | 17 |
| Initial electron density (n_e/n_crit) | 685 |
| Time of peak intensity | 44 fs |

# Electron Density

Linear Polarisation:

- 5nm: density drops from 685n_crit to ~20n_crit by 27fs, underdense by 32fs
- 10nm: density drops from 685n_crit to ~8n_crit by 51fs
- 50nm: remains overdense and accelerates electron bunches of density ~1n_crit, density drops to ~30n_crit at 96fs



# Electron Density

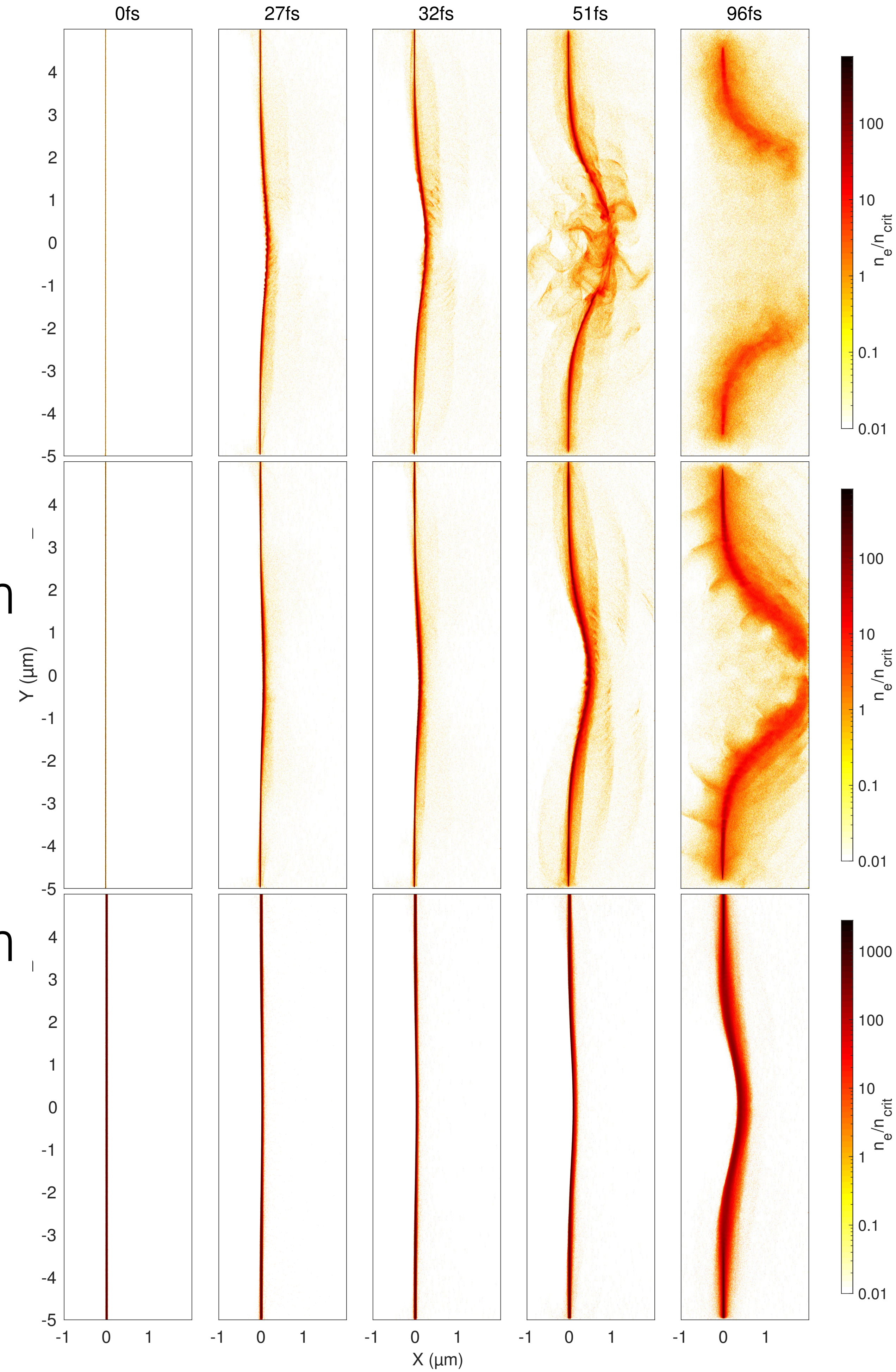
Circular Polarisation:

- 5nm: at 27fs the density remains at 120n_crit compared to ~ 20n_crit for linear polarisation. Underdense by 51fs
- 10nm: by 51fs the front surface has moved 500nm so target no longer normal to incident radiation.
- 50nm: remains overdense. Critical surface has moved by 300nm at 96fs

5nm

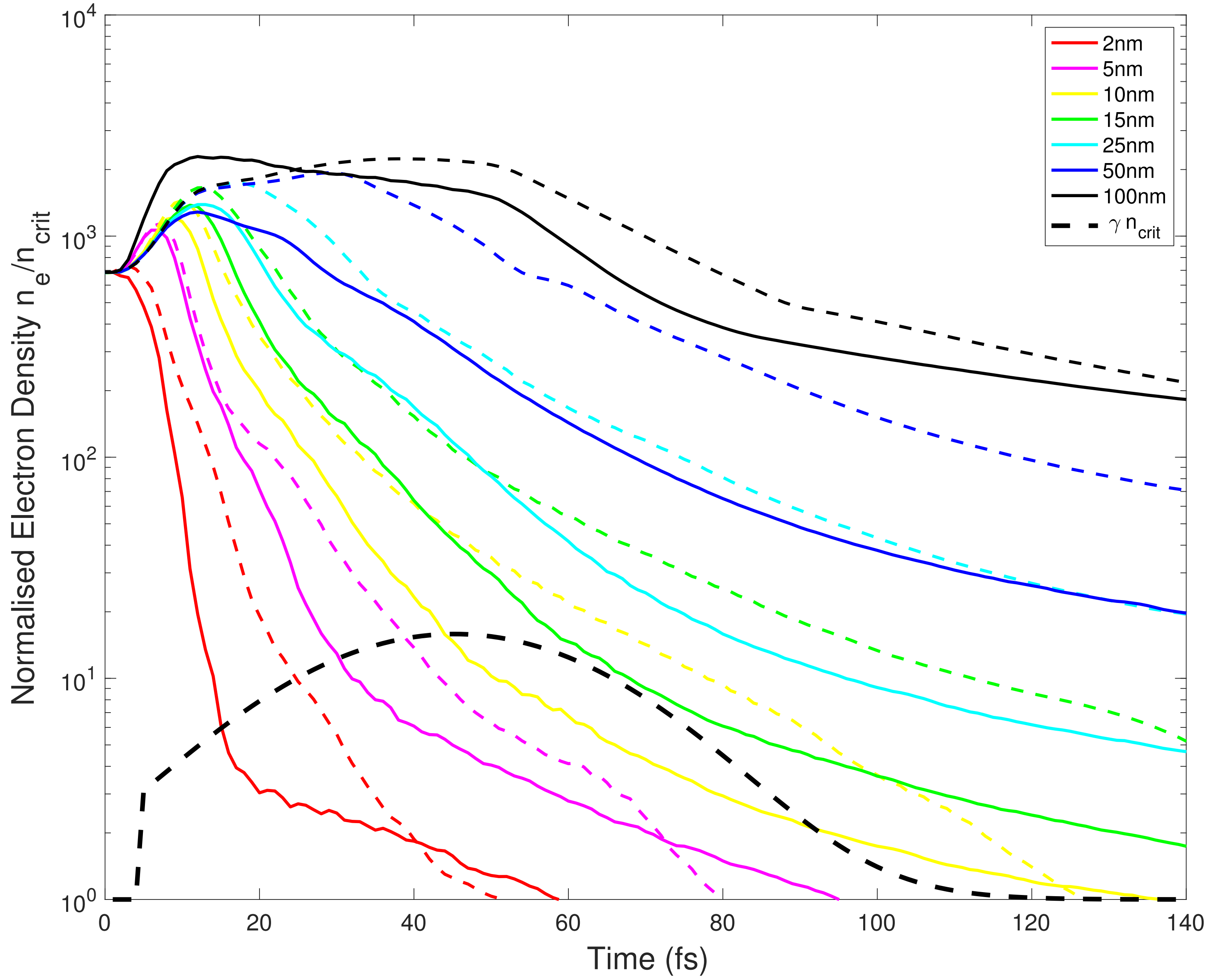
10nm

50nm



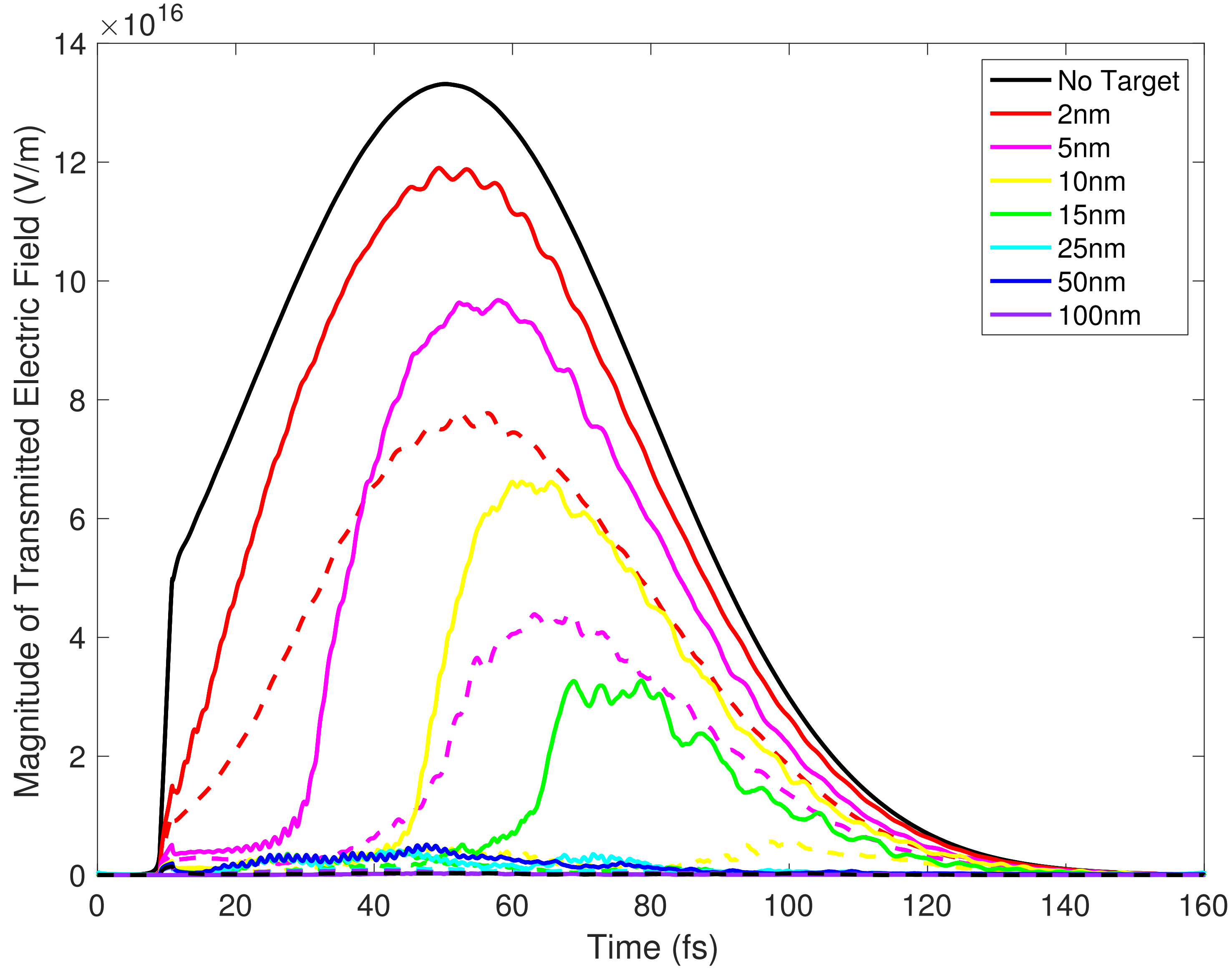
# Electron Density

- Average electron density in focal spot
- —— Linear Polarisation
- - - - Circular Polarisation
- 2 - 10nm go transparent
- Targets ≥ 25nm remain overdense



# Transmitted Electric Field

- Sampled laser electric field at rear of simulation box
- See step-like delay in transparency until 15nm
- Oscillating electric field also for thicker targets



# Transmitted Electric Field

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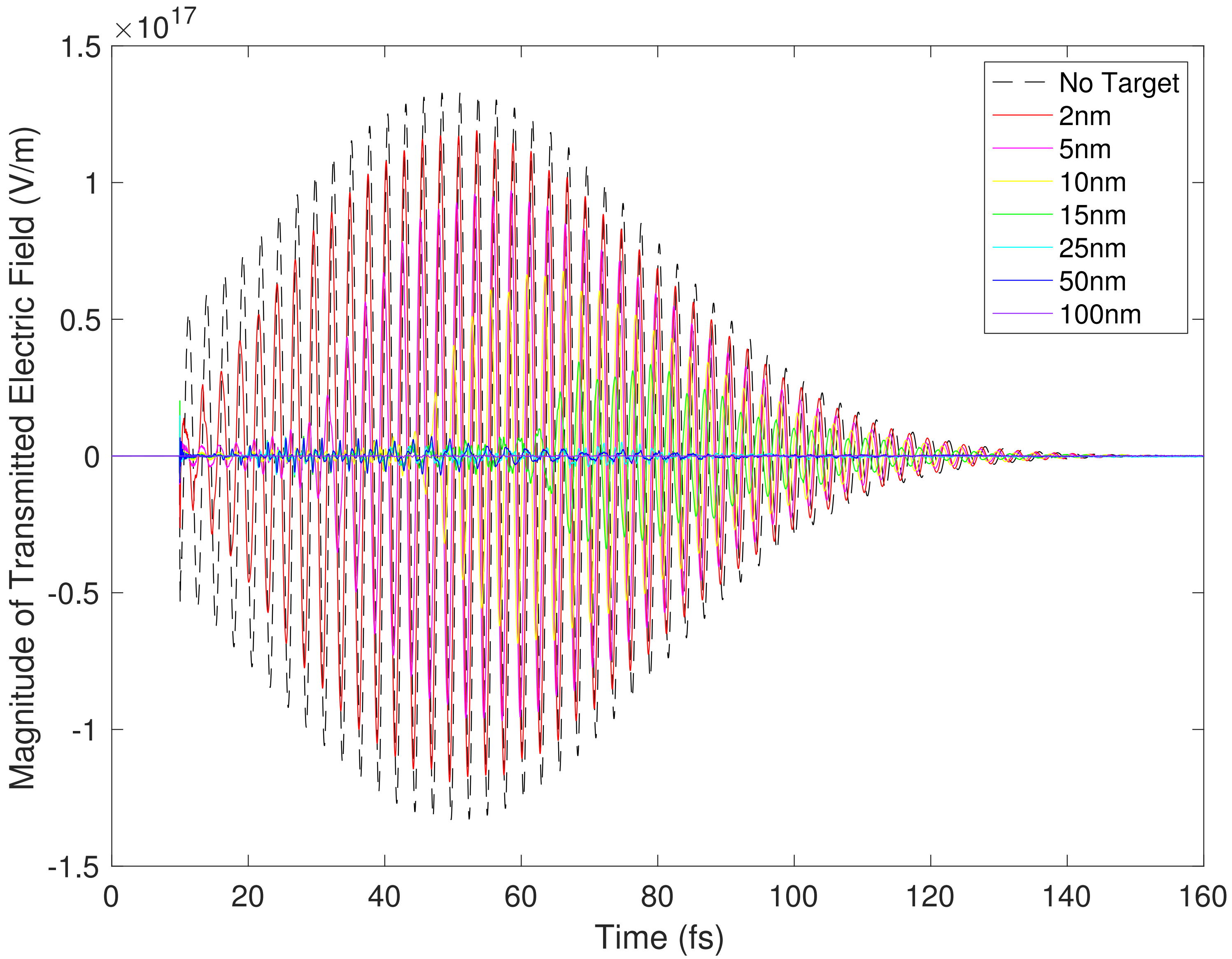
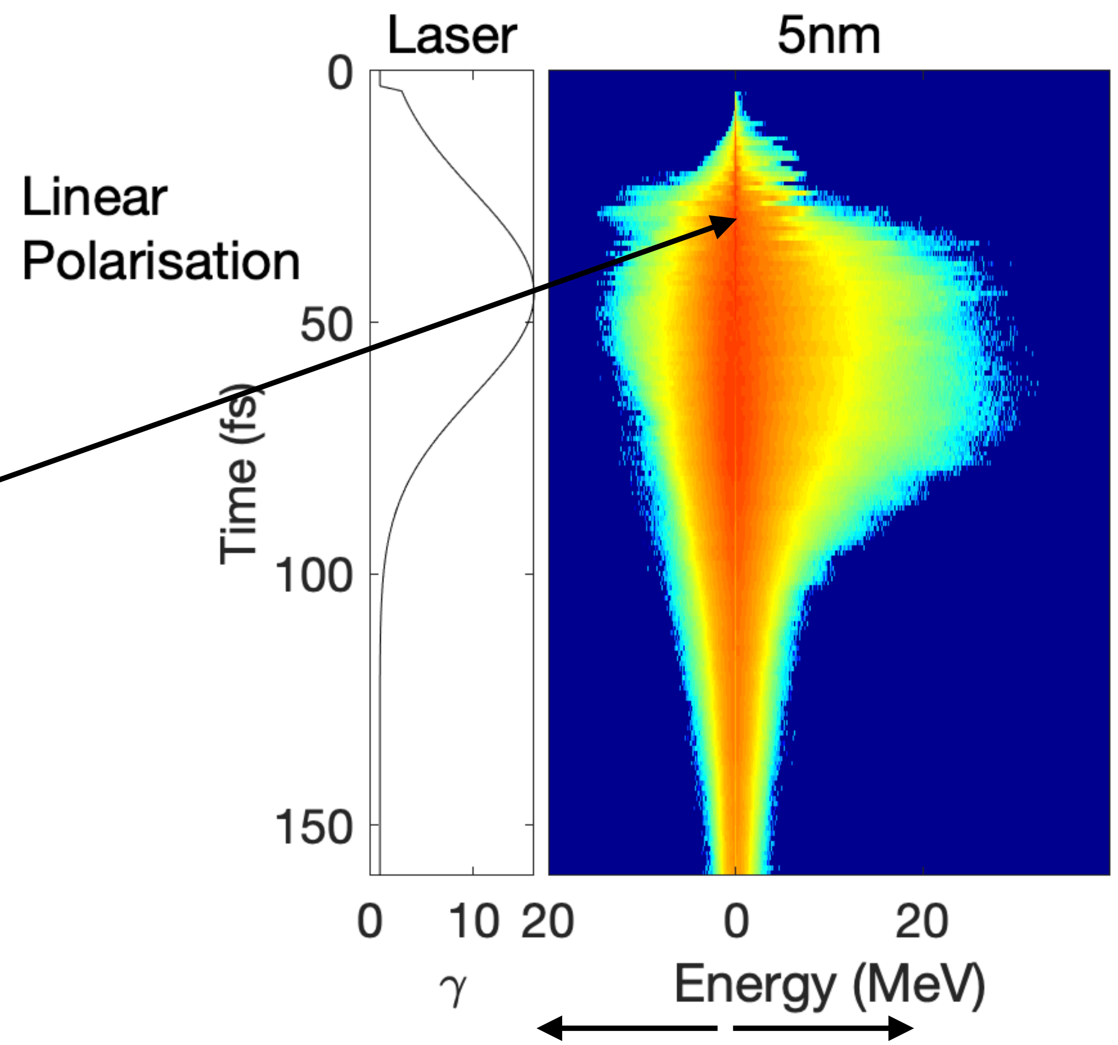
- Coherent transition radiation



# Electron Spectrum

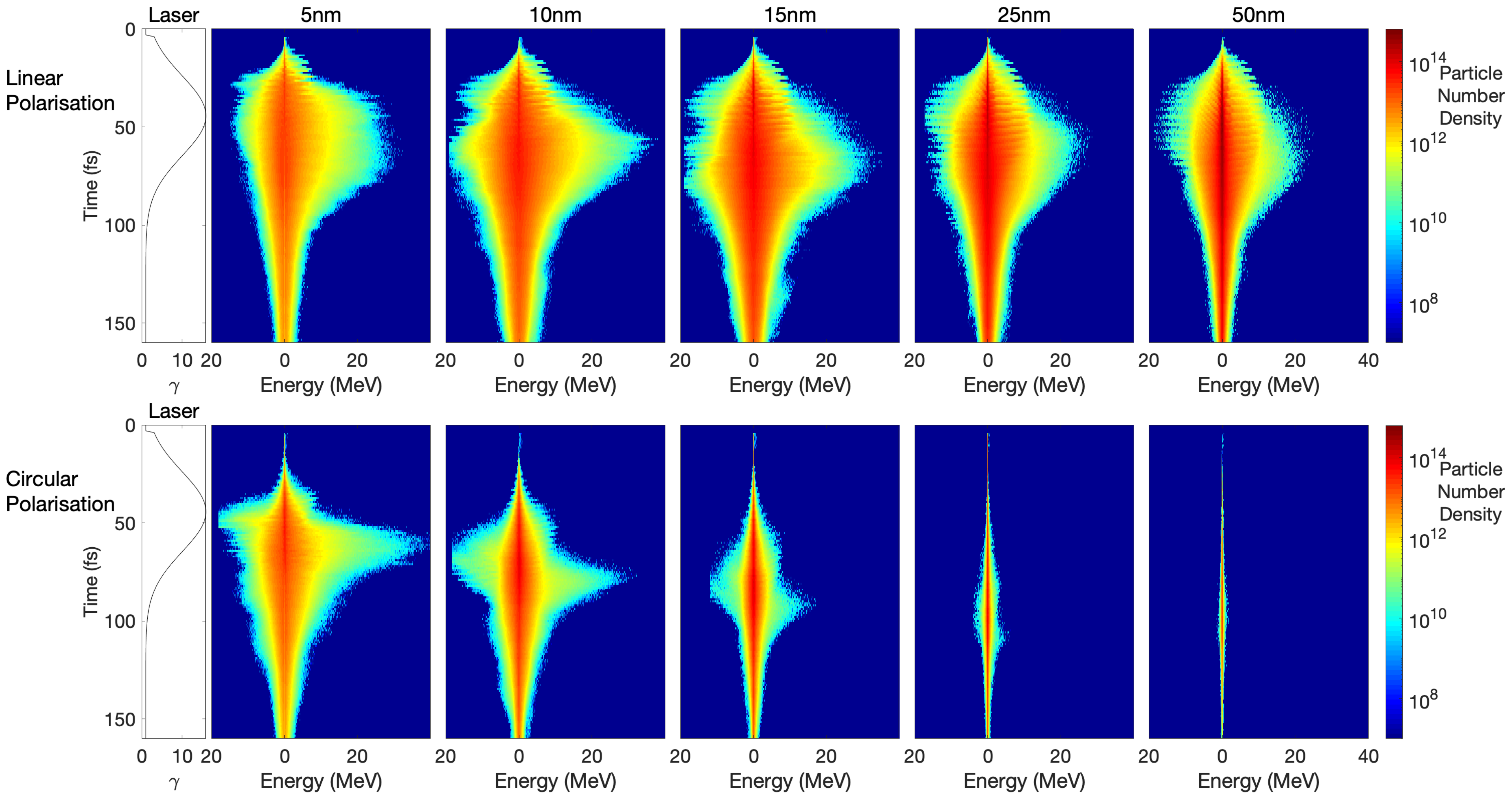
- Electron energies on laser axis
- Sudden increase in hot electrons in the forward direction
- At late times electrons transfer energy to ions or leave the box




Electrons accelerated in the backward direction

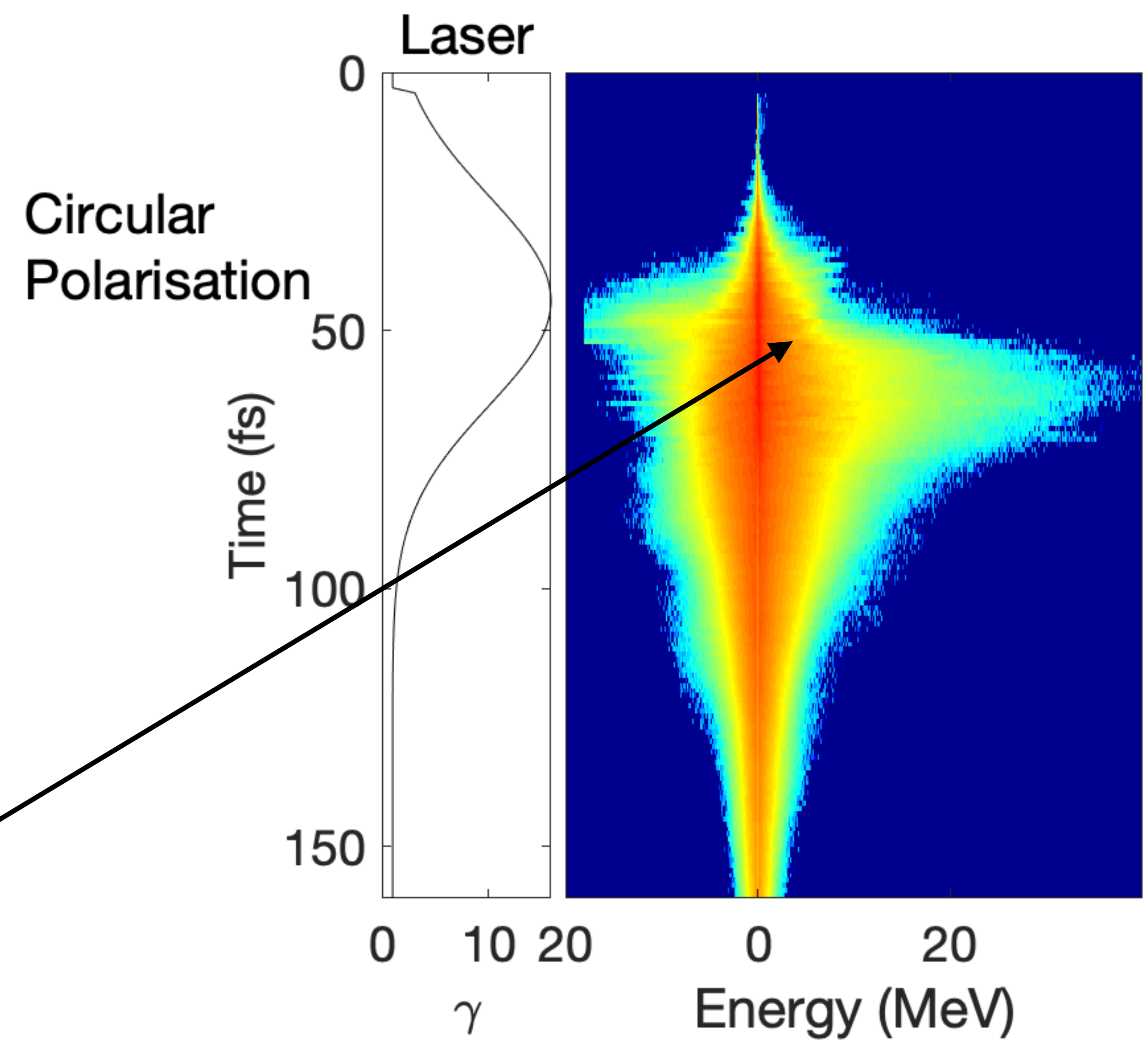
Electrons accelerated in the forward direction

# Electron Spectrum



# Electron Spectrum

- Maximum electron energies seen for the 10nm target irradiated by a linearly polarised pulse
- Circular polarisation has lower electron temperatures (∼75% of linear)
- Symmetric distribution for targets ≥ 25nm
- **Is this an indication of transparency?**



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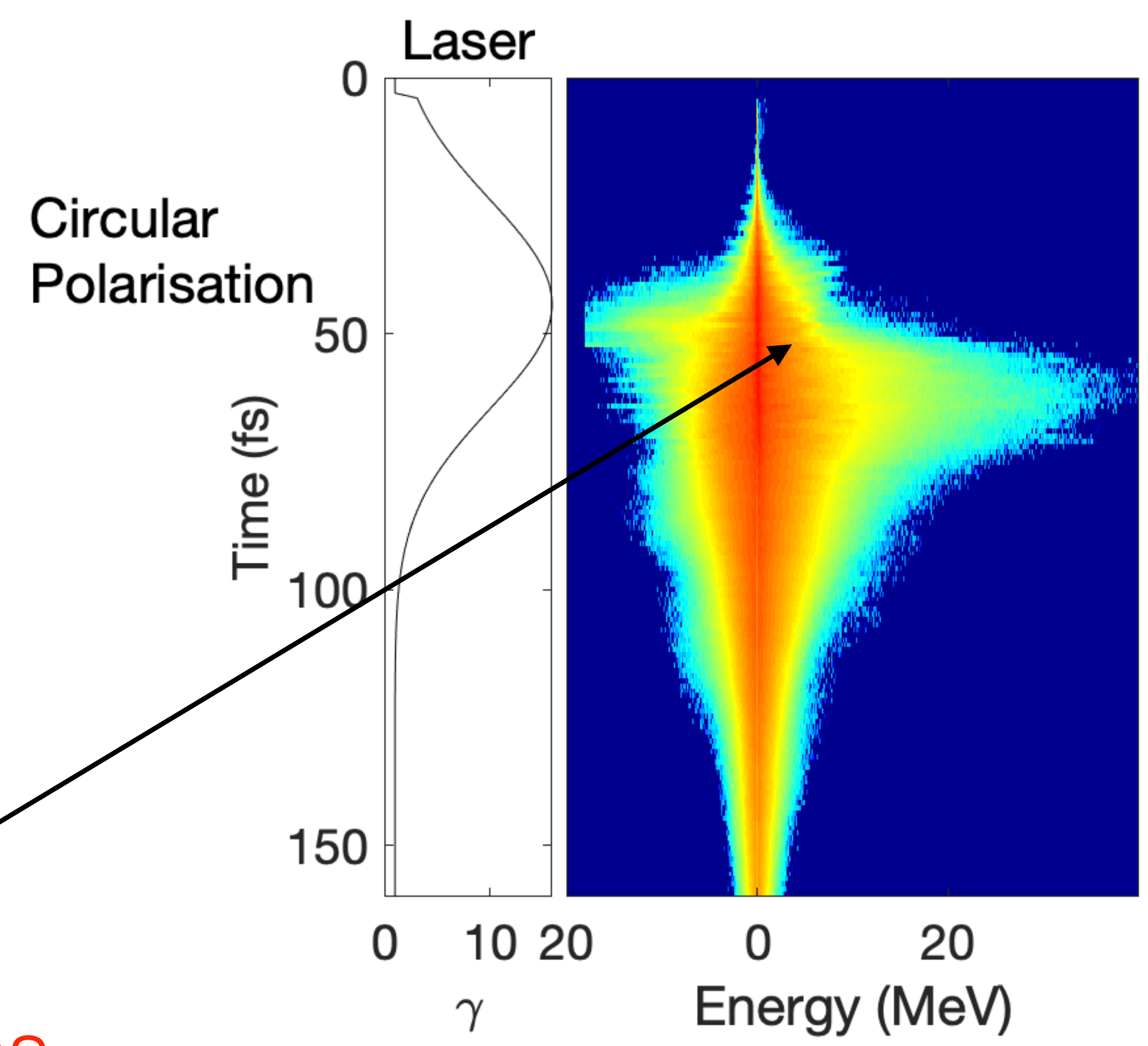
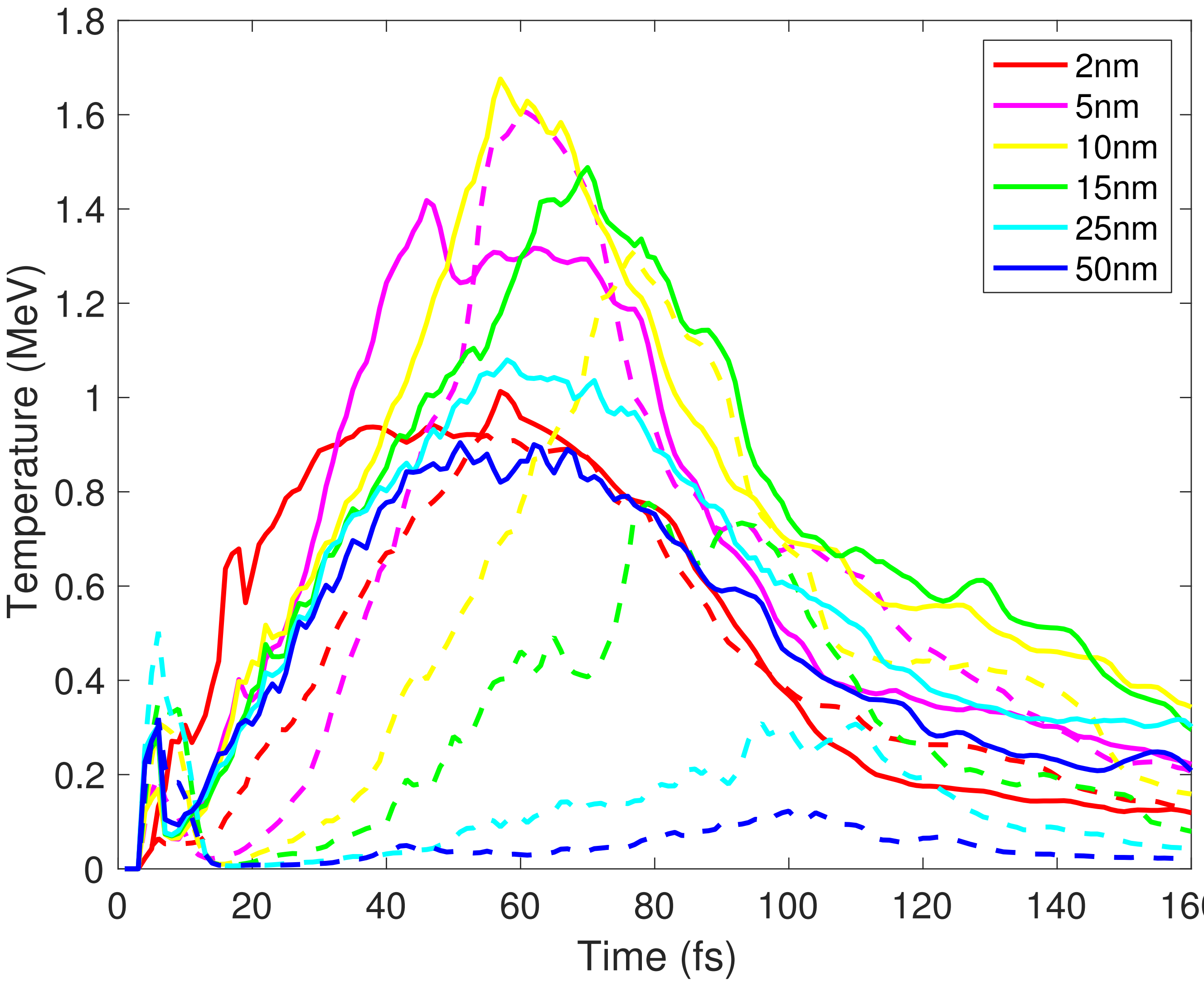



Yes

# Electron Temperature

- Fit an exponential to the electron spectrum
- Peak temperature reached for 10nm target with linear polarisation
- Approximately same temperature plasma for thinner targets and linear/circular polarisation
- Similar heating rates of almost all linear polarised pulses



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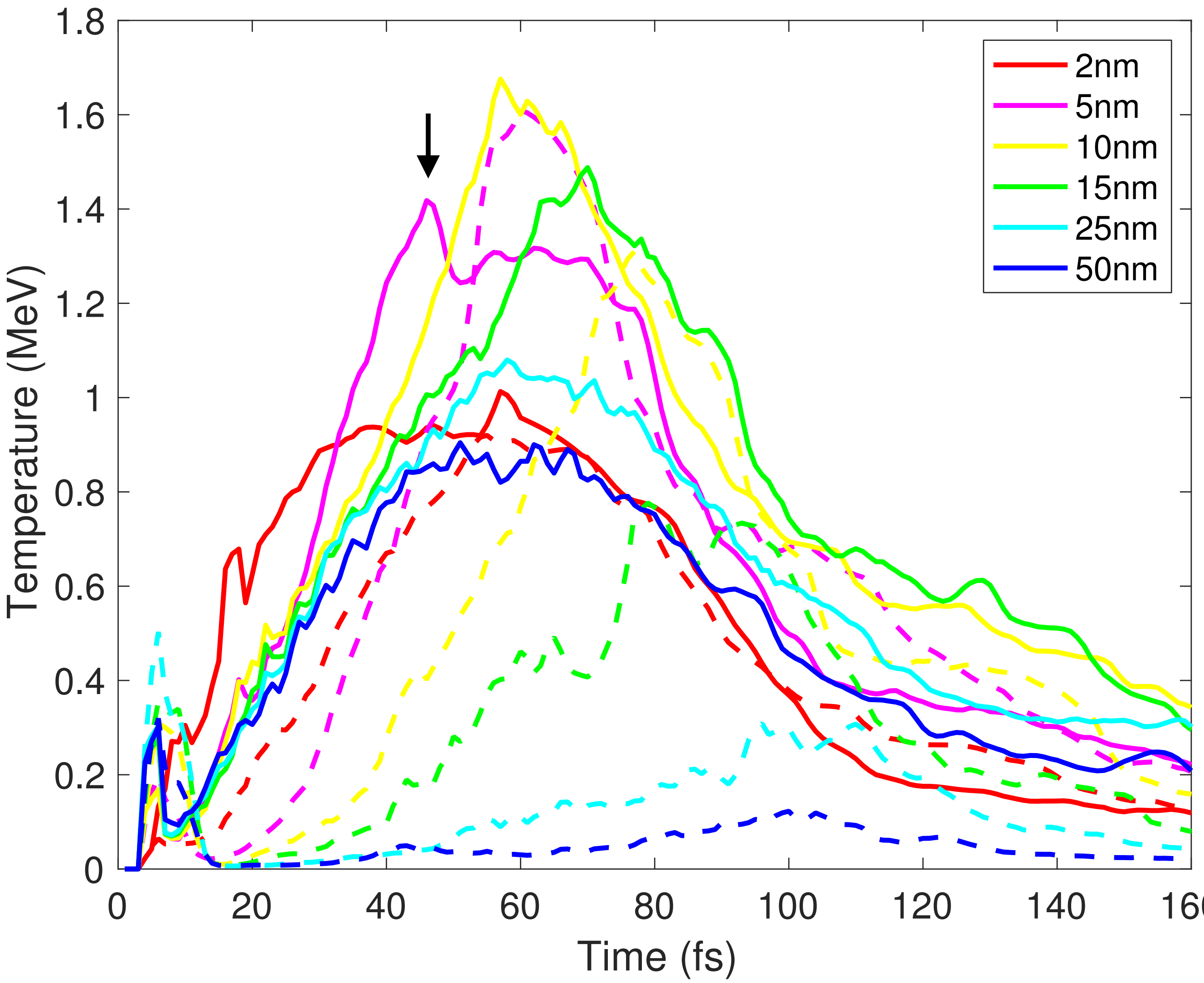

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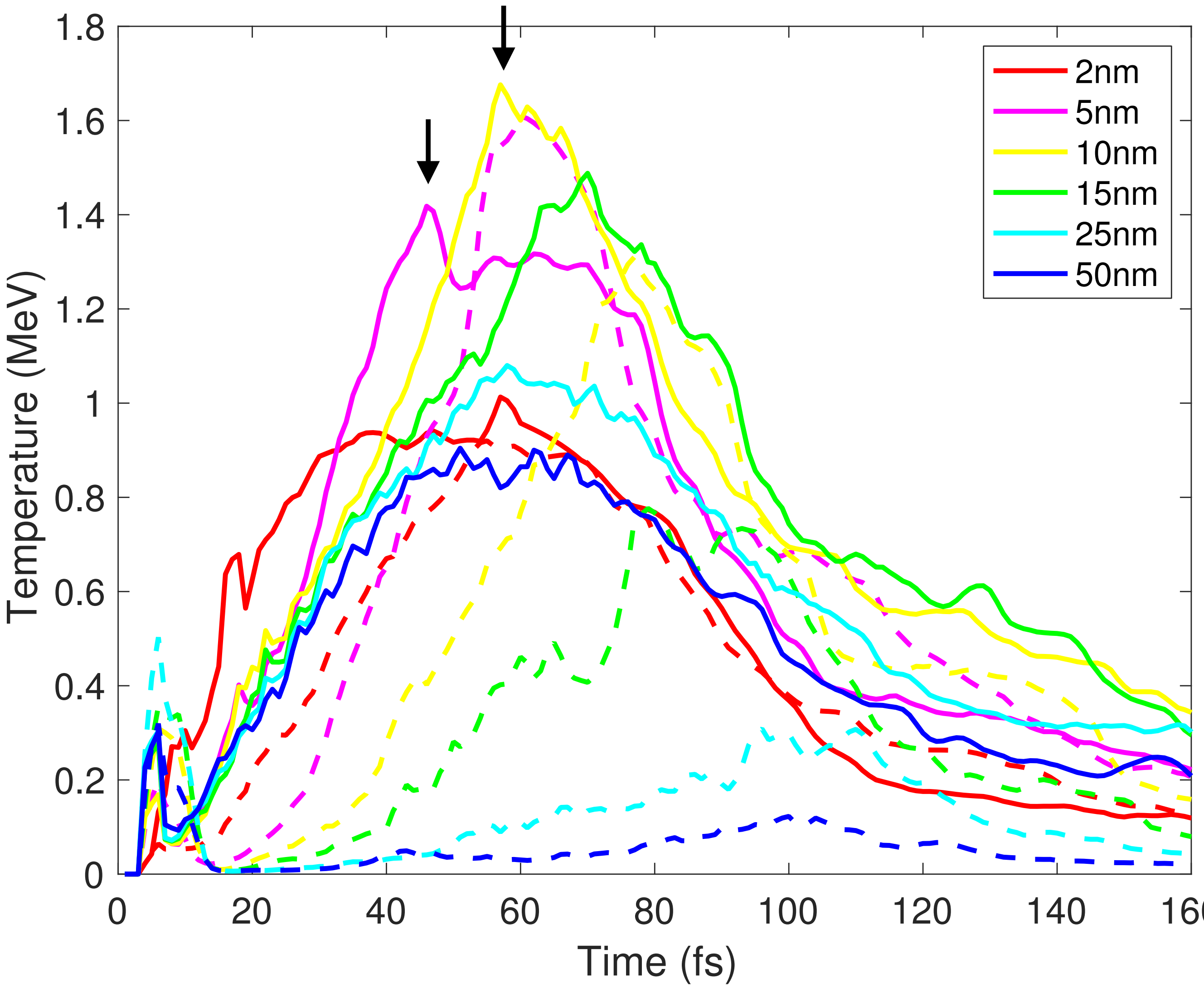

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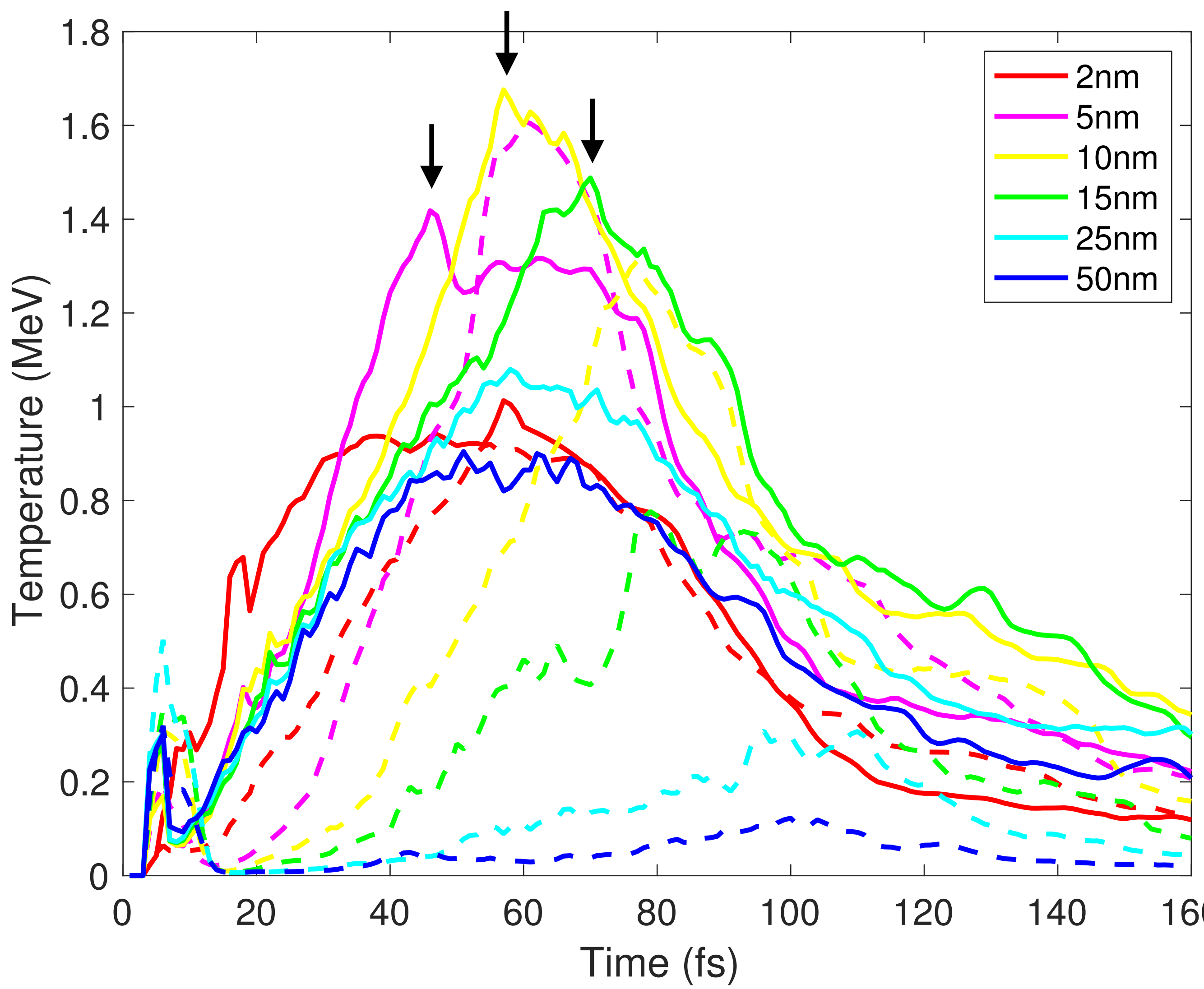

# Summary

- Strong target heating causes targets $< 25$nm to go transparent
- Electron bunches of density $\sim 1 n_{crit}$ accelerated off 50nm target
- Temporal delay in transparency by $\sim$15fs per thickness increment
- Electron temperatures up to 1.7MeV measured in simulations
- Big difference in plasma temperatures for different polarisations - up to 50% for $\geq$15nm targets

# Acknowledgements

## ASAIL Collaborators:

G. Hicks[1], O. Ettlinger[1], D. Doria[2], L. Romagnani[3], H. Ahmed[2], P. Martin[2], S. Williamson[4], A. McIlvenny[2], G. Scott[5], N. Booth[5], D. Neely[5], P. McKenna[4], M. Borghesi[2] and Z. Najmudin[1]

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