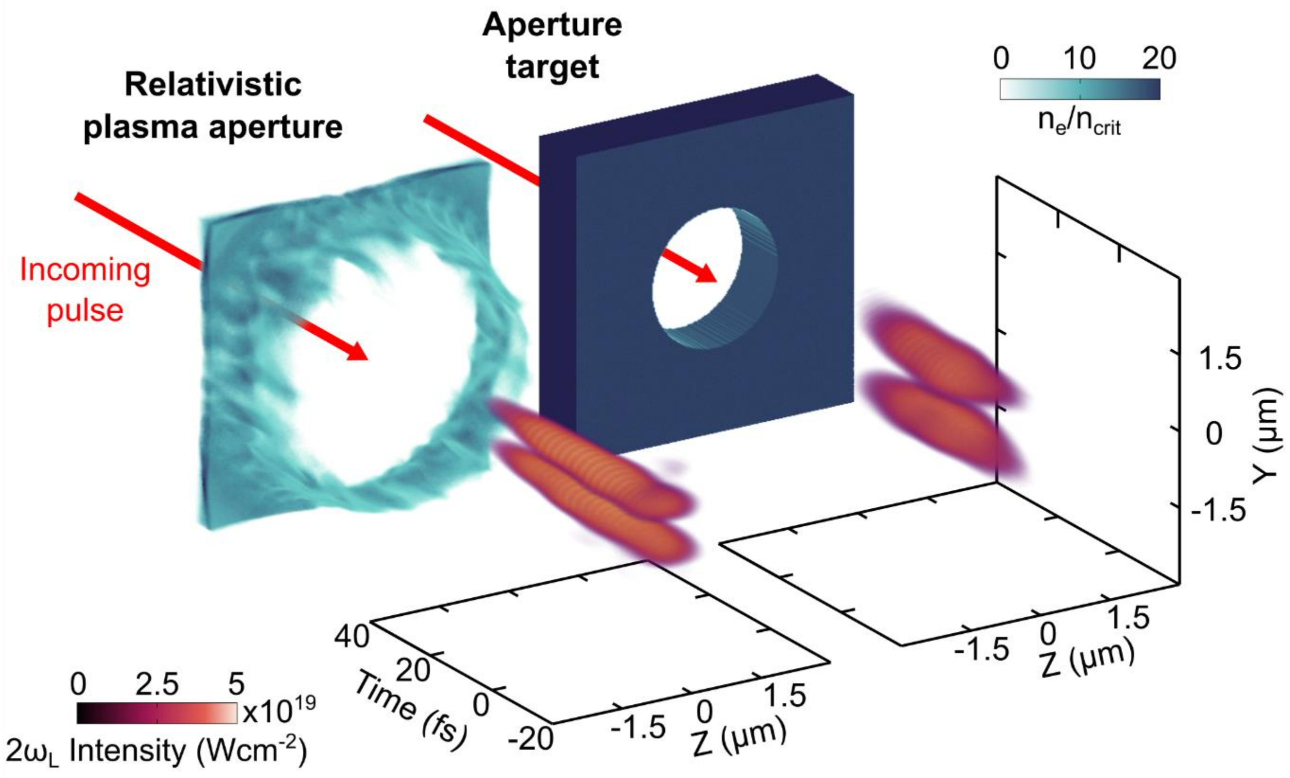
Generation of intense light with high-order modes mediated by a relativistic plasma aperture



University of Strathclyde Glasgow

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The Cockcroft Institute of Accelerator Science and Technology

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36th European Conference on Laser Interaction with Matter, Frascati, Italy, 19-23 Sept. 2022.

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Motivation

- Control of the spatio-temporal properties of high power laser pulses is important to the development of compact laser-plasma-based particle accelerators and radiation sources
- Temporal variability of mode structure
- Production of high harmonics with different mode structures
- Wide ranging potential applications in laser-driven particle acceleration and radiation generation

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High order mode structure of intense light fields generated via a laser-driven relativistic plasma aperture

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M.J. Duff *et al.* Scientific Reports, **10**, 105 (2020)

Matter and Radiation at Extremes | RESEARCH ARTICLE | scitation.org/journal/mre

High order modes of intense second harmonic light produced from a plasma aperture

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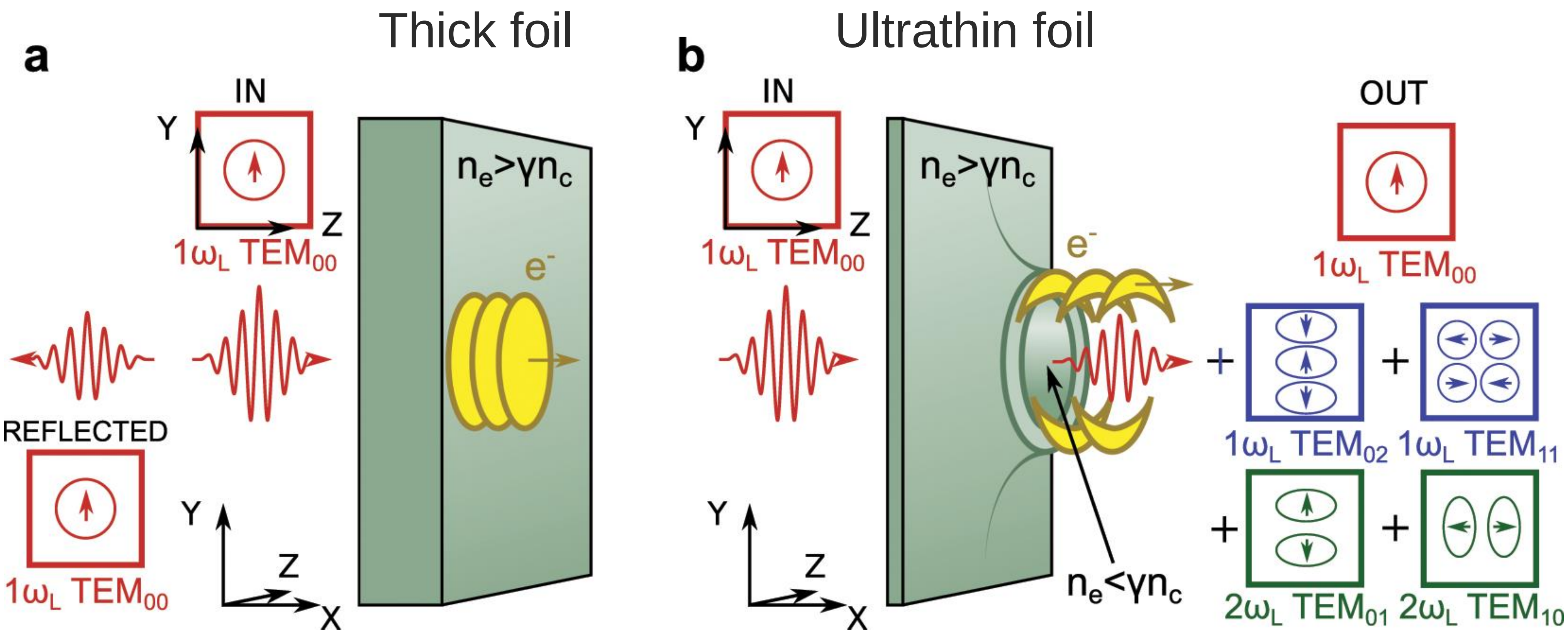
E.F.J. Bacon *et al.* Matter and Radiation at Extremes **7**, 054401 (2022)

Schematic concept from solid density foil targets



Thin foils experiment investigating polarisation change

GEMINI laser system at CLF Rutherford Appleton Laboratory

Intensity = (2.8 ± 0.4) x 10^{20} Wcm^{-2}

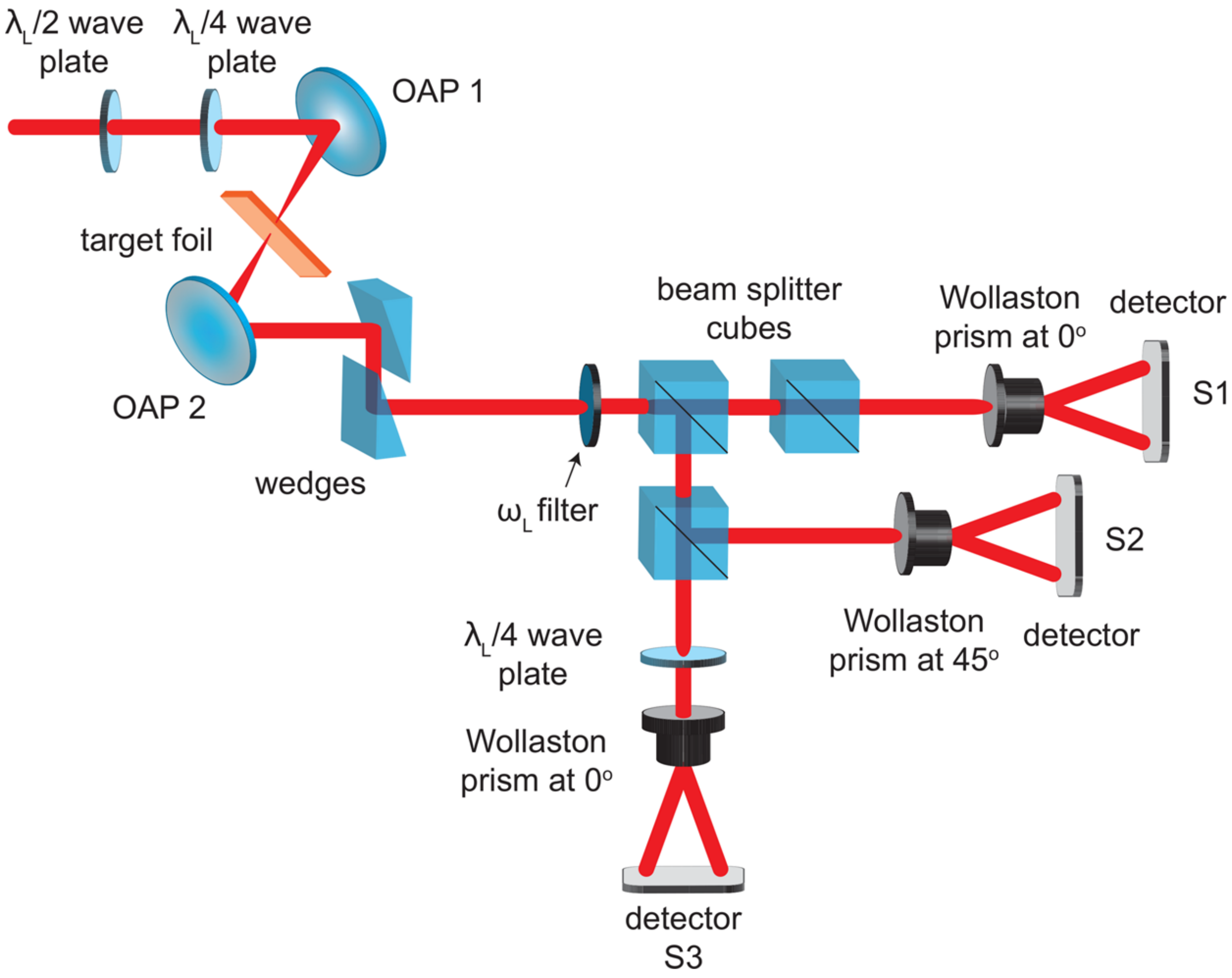
Focal spot diameter = (3.9 ± 0.7) μm

Pulse duration = (40 ± 5) fs

Polarisation varied from linear to circular

Target thickness = 10-60 nm

Polarisation change in near critical plasma predicted by Stark *et al.* Phys. Rev. Lett. **115**, 025002 (2015)

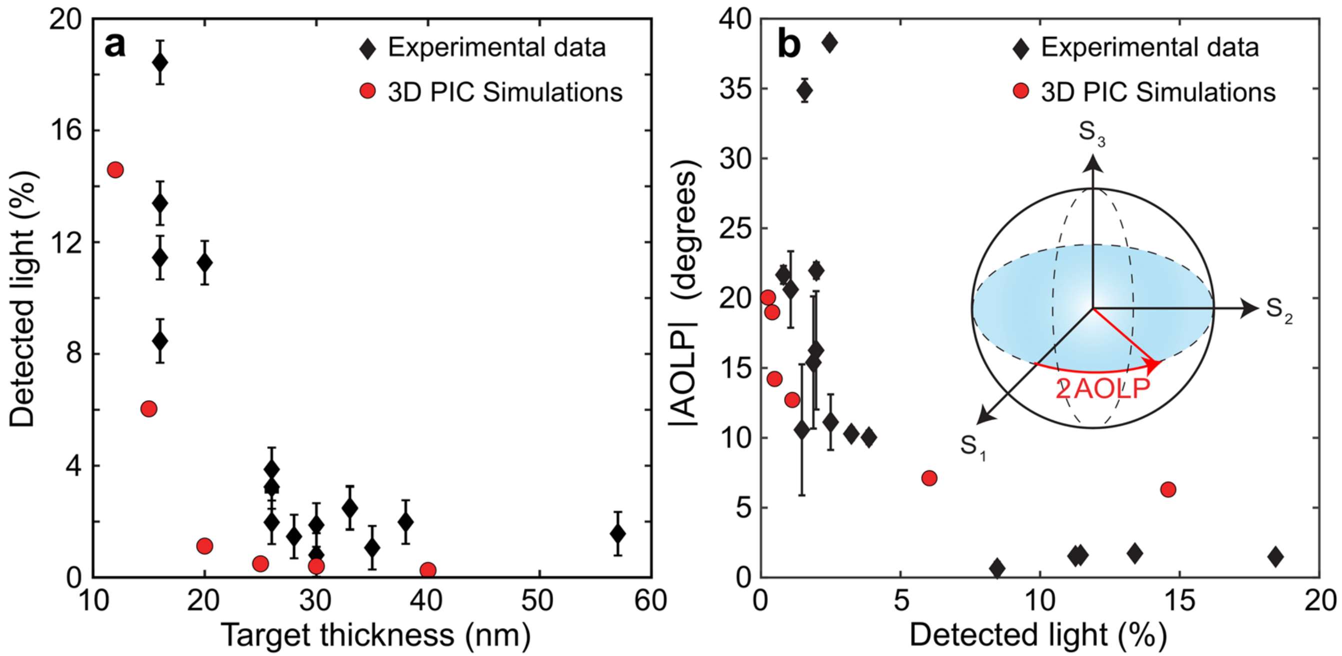


Thin foils – GEMINI Experiment

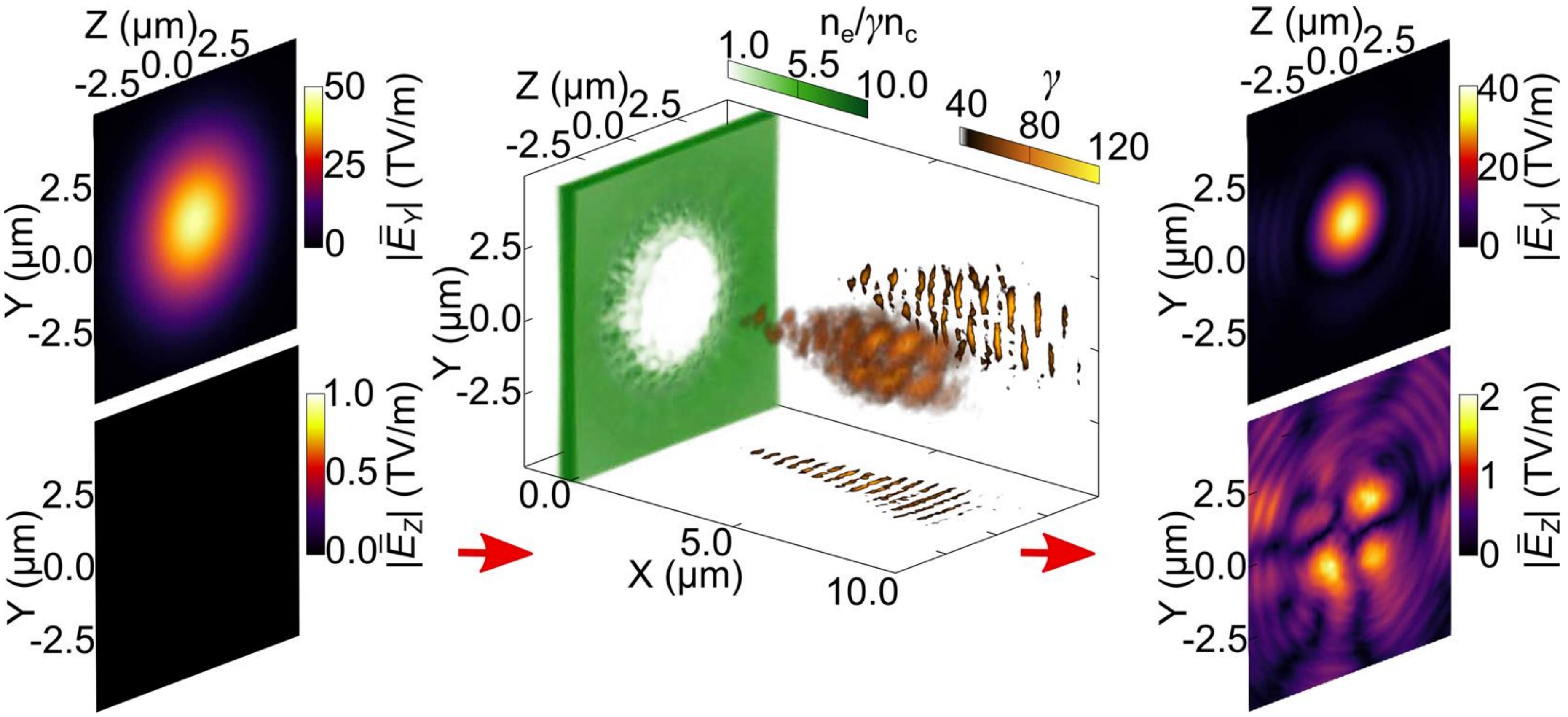
Observed an angle of linear polarisation (AOLP) shift

Shift increases for least amount of detected light at the target rear

3D EPOCH simulations show similar AOLP shift behaviour



Thin foils – 3D EPOCH simulations generation of intense ω_L light

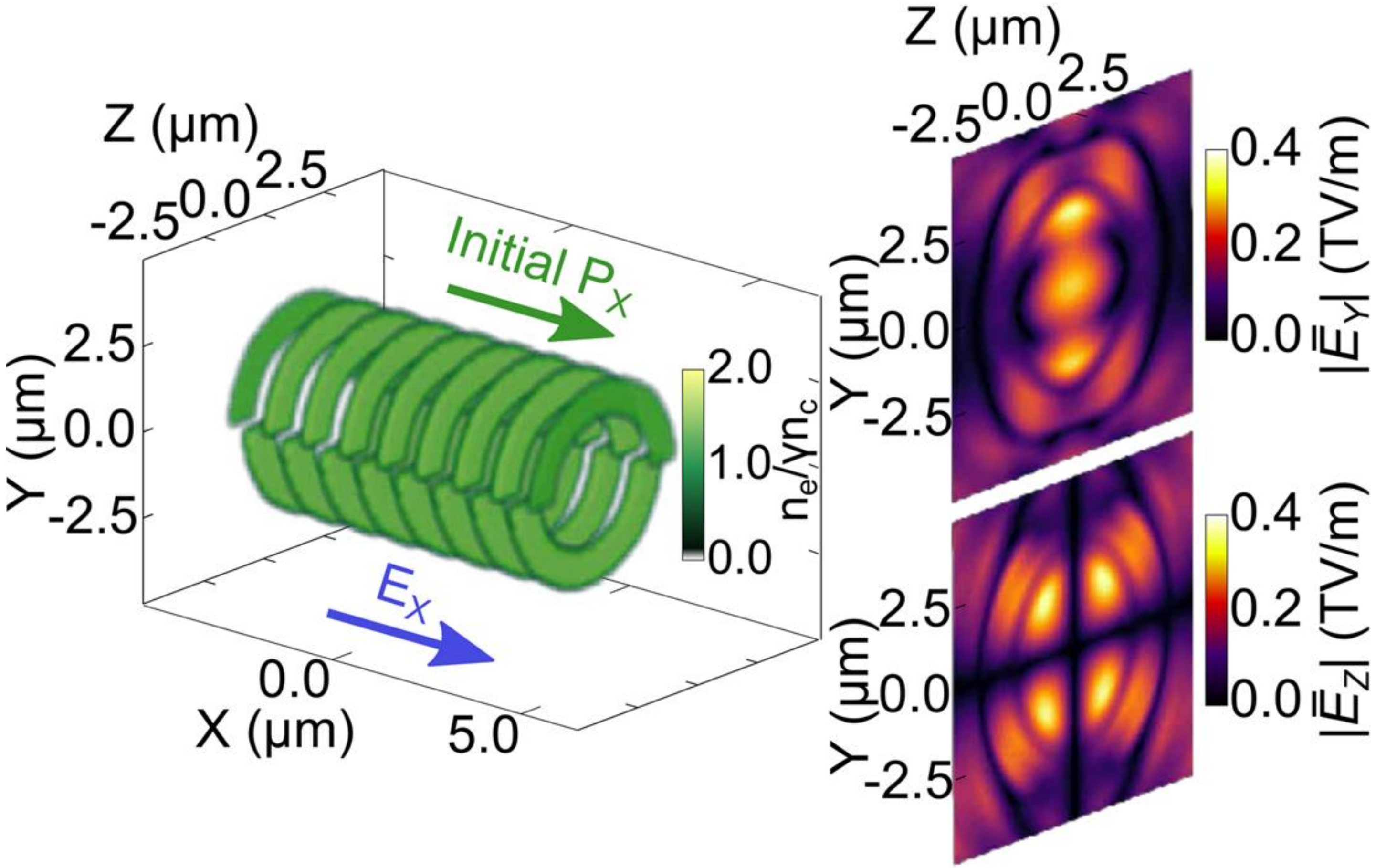


Thin foils – ω_L generation from bunch structure

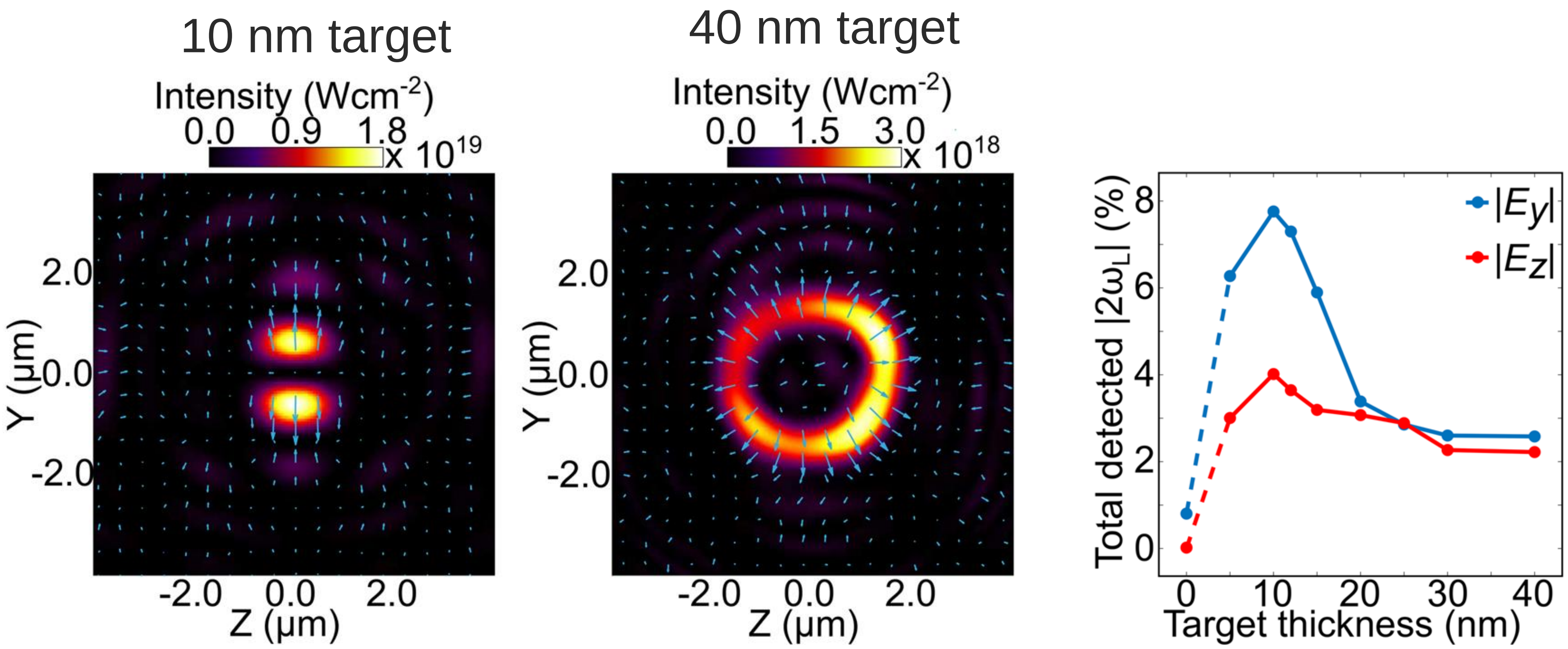
Simulating predefined electron bunches with similar structure

10 MeV initial electron energy in the positive X direction

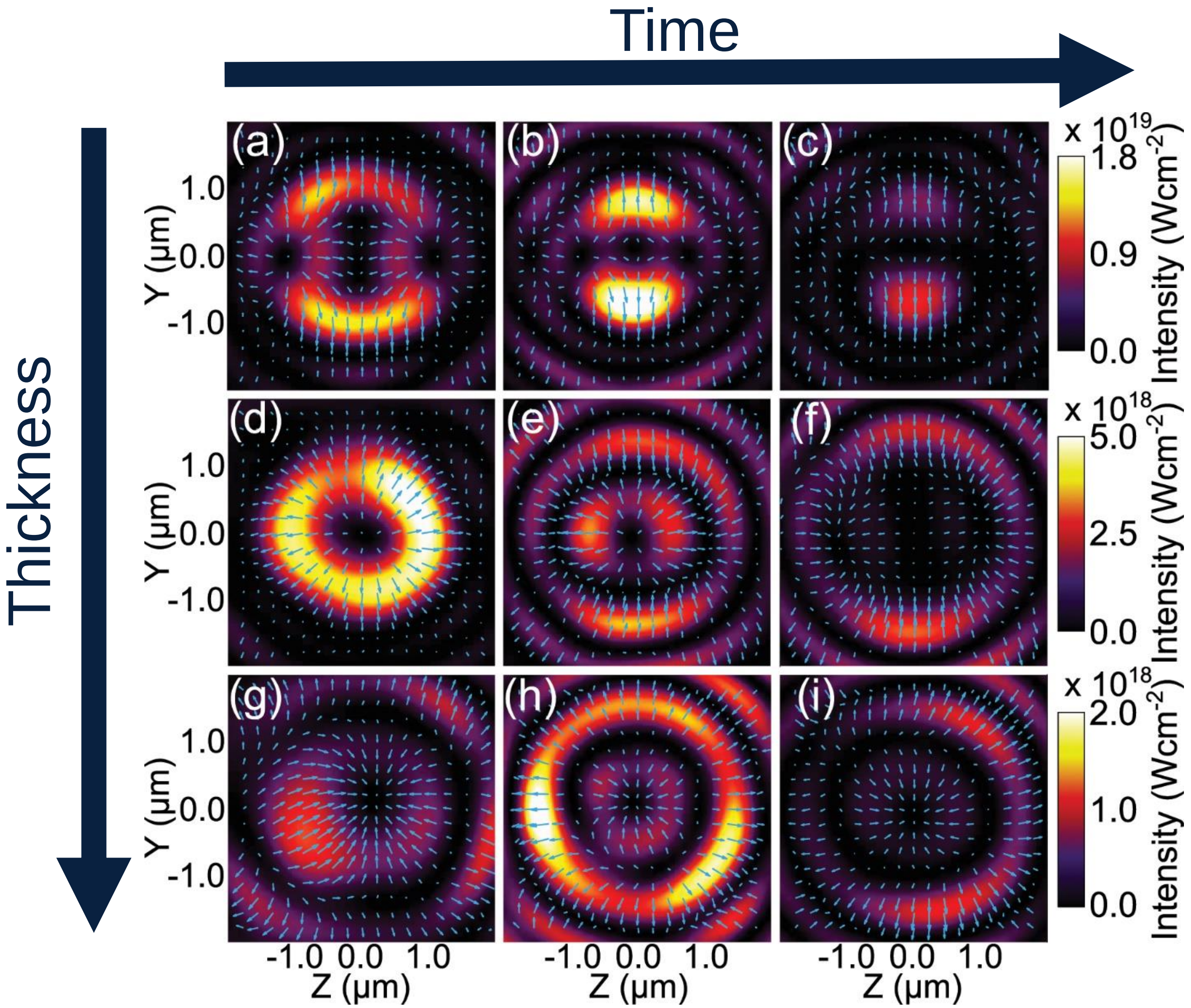
Constant longitudinal field = 1 TVm^{-1}



Thin foils – $2\omega_L$ generation

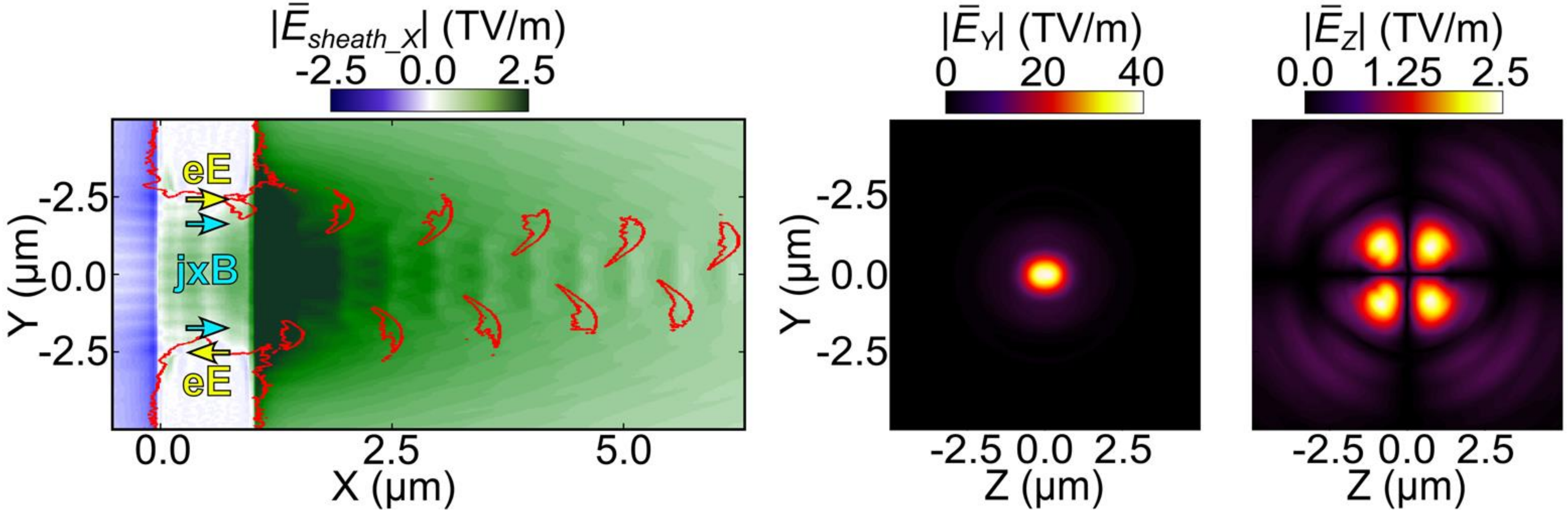


Thin foils – $2\omega_L$ temporal variation

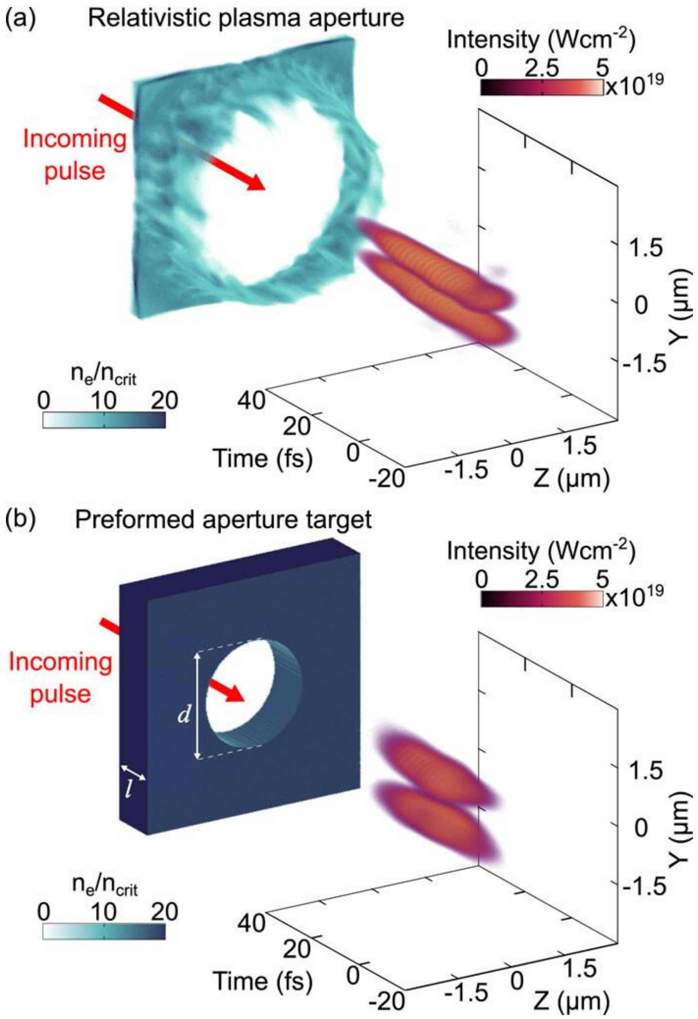


Aperture targets – ω_L generation

Similar behaviour can be seen when using a target with a predefined aperture



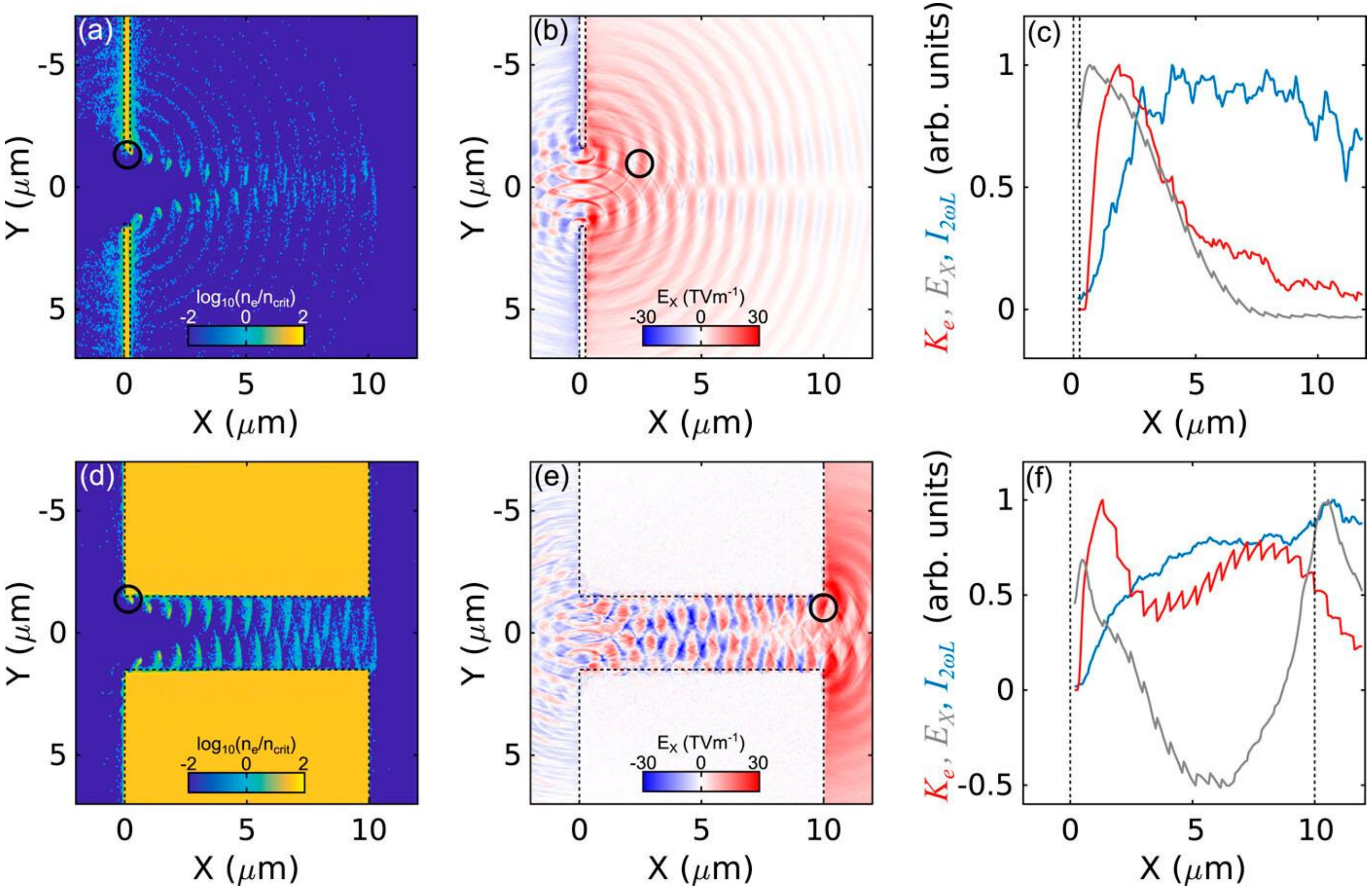
Aperture targets – $2\omega_L$ generation



Electron density

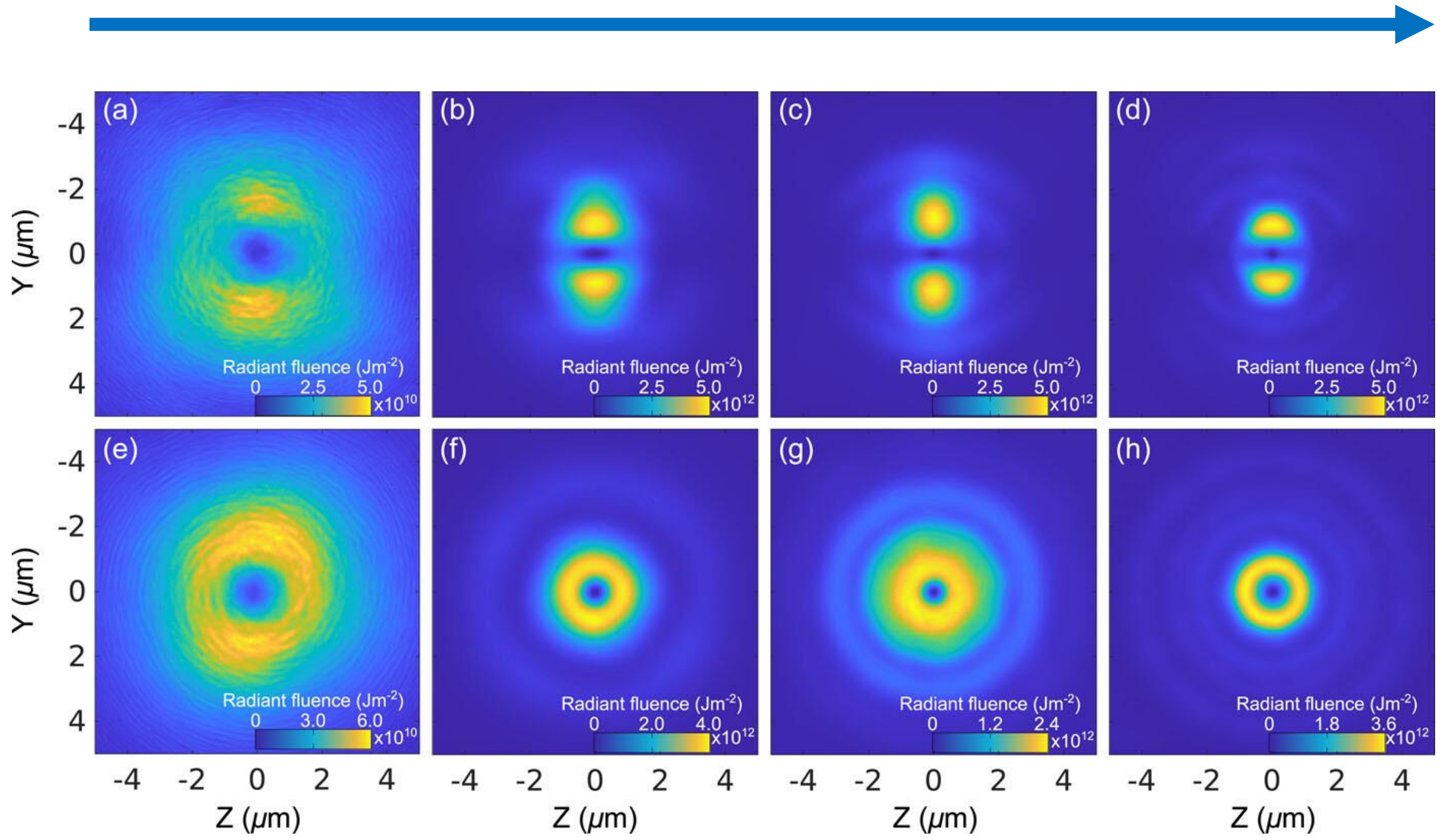
Longitudinal electric field

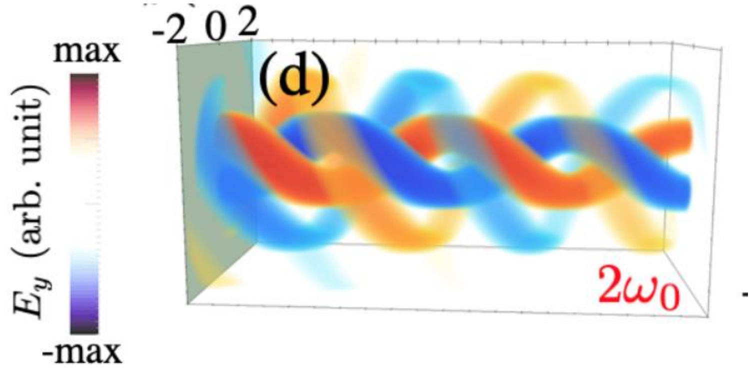
$2\omega_L$ emission from a tracked bunch



Aperture targets – $2\omega_L$ generation mode structure

Radius

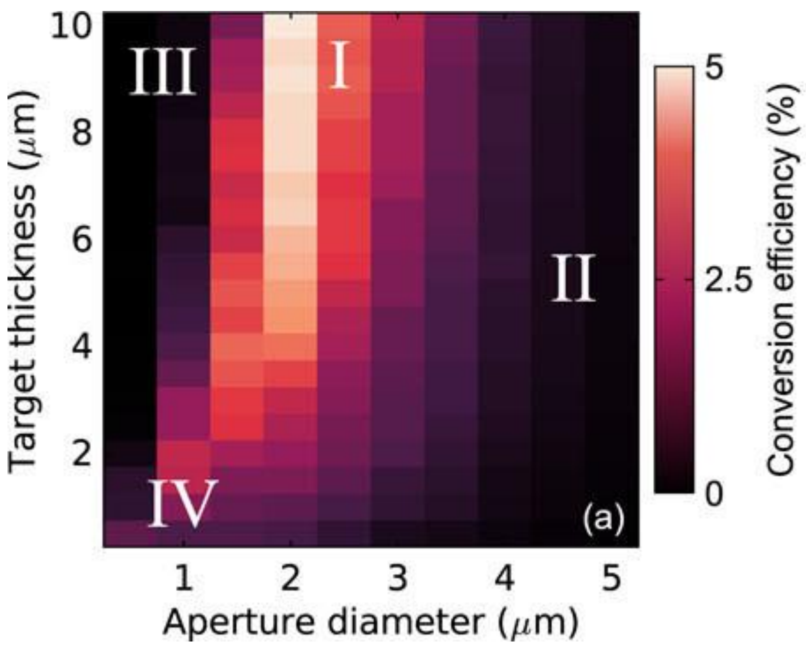




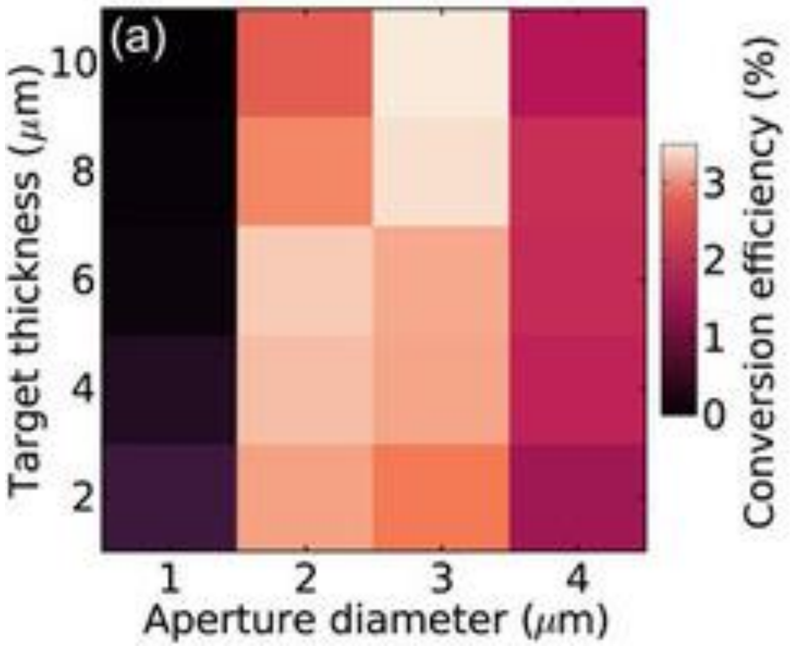
L. Yi Phys. Rev. Lett. **126**, 134801 (2021)

Aperture targets – $2\omega_L$ generation efficiency

2D



3D



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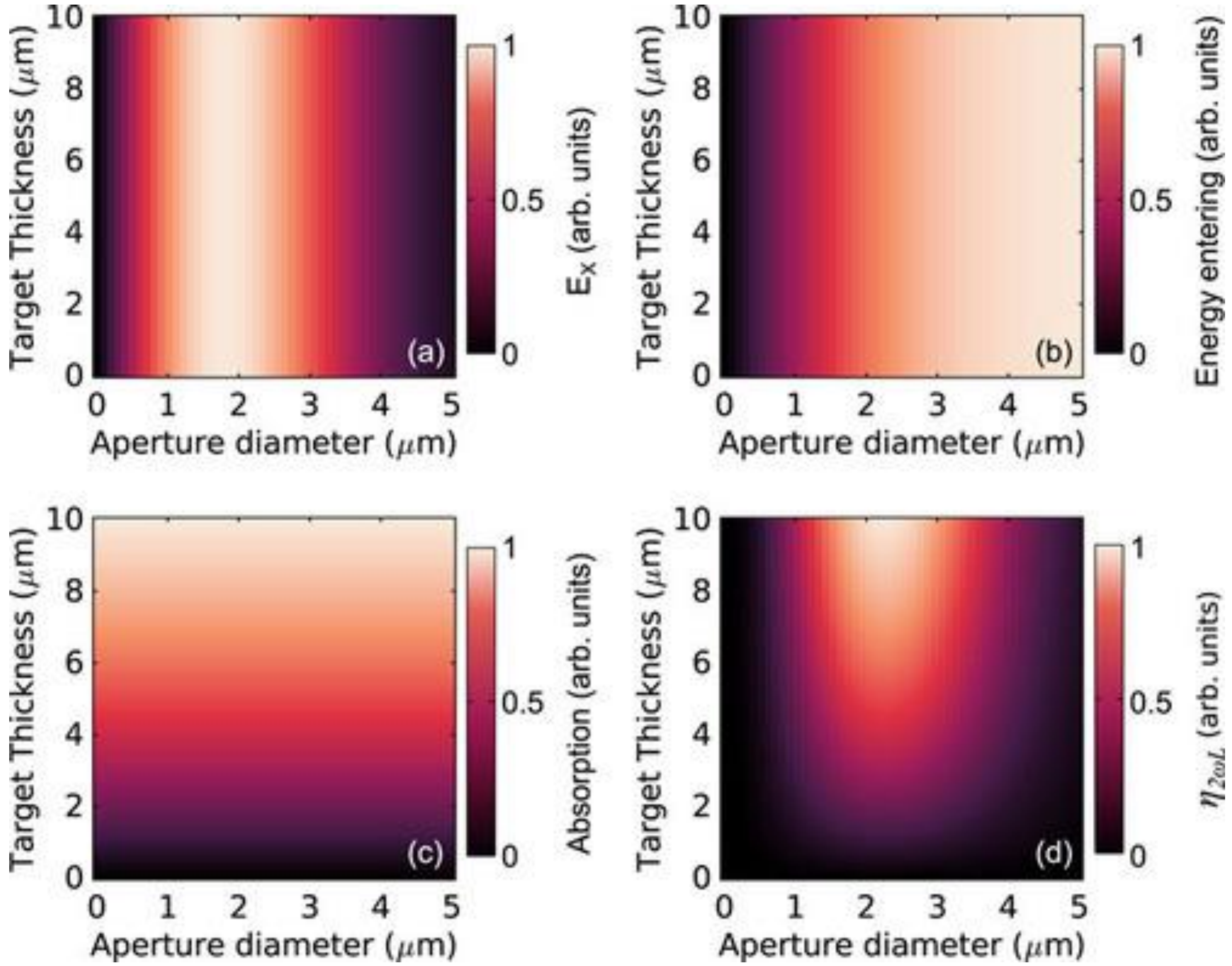
Aperture targets – Simple efficiency modelling

$$E_X(Y) = \frac{\mathrm{d}}{\mathrm{d}Y} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2}$$

$$K_{in}(d) = \int_{-d/2}^{d/2} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2} \mathrm{d}Y$$

$$Abs_L(l) = \alpha l e^{-\beta l}.$$

$$\eta_{2\omega_L} \propto |E_X(d/2)|\, Abs_L(l)\, K_{in}(d)$$



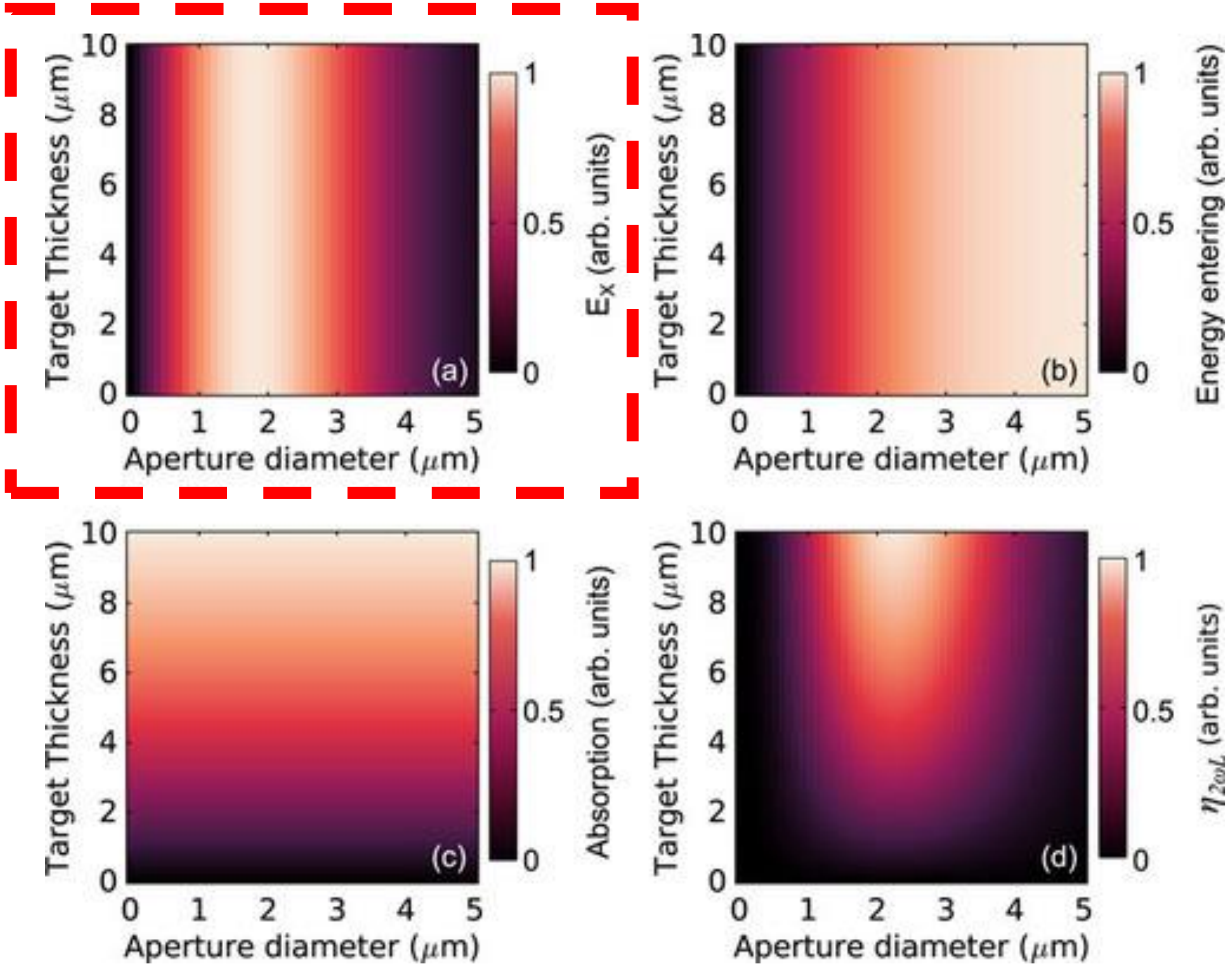
Aperture targets – Longitudinal electric field

$$E_X(Y) = \frac{d}{dY} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2}$$

$$K_{in}(d) = \int_{-d/2}^{d/2} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2} dY$$

$$Abs_L(l) = \alpha l e^{-\beta l}$$

$$\eta_{2\omega_L} \propto |E_X(d/2)| Abs_L(l) K_{in}(d)$$



Aperture targets – Energy inside aperture

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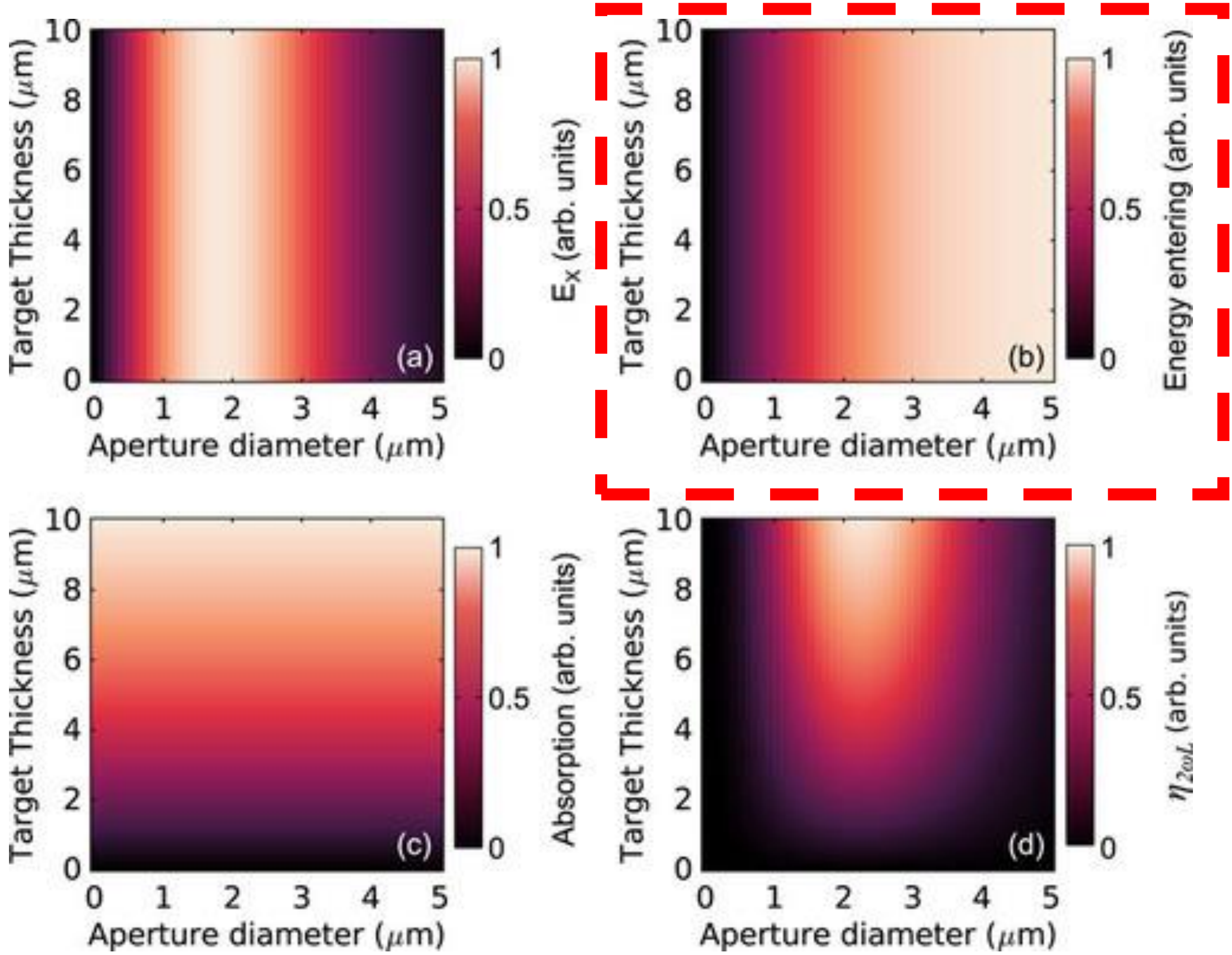
$$E_X(Y) = \frac{d}{dY} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2}$$

$$K_{in}(d) = \int_{-d/2}^{d/2} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2} dY$$

$$Abs_L(l) = \alpha l e^{-\beta l}$$

$$\eta_{2\omega_L} \propto |E_X(d/2)| Abs_L(l) K_{in}(d)$$



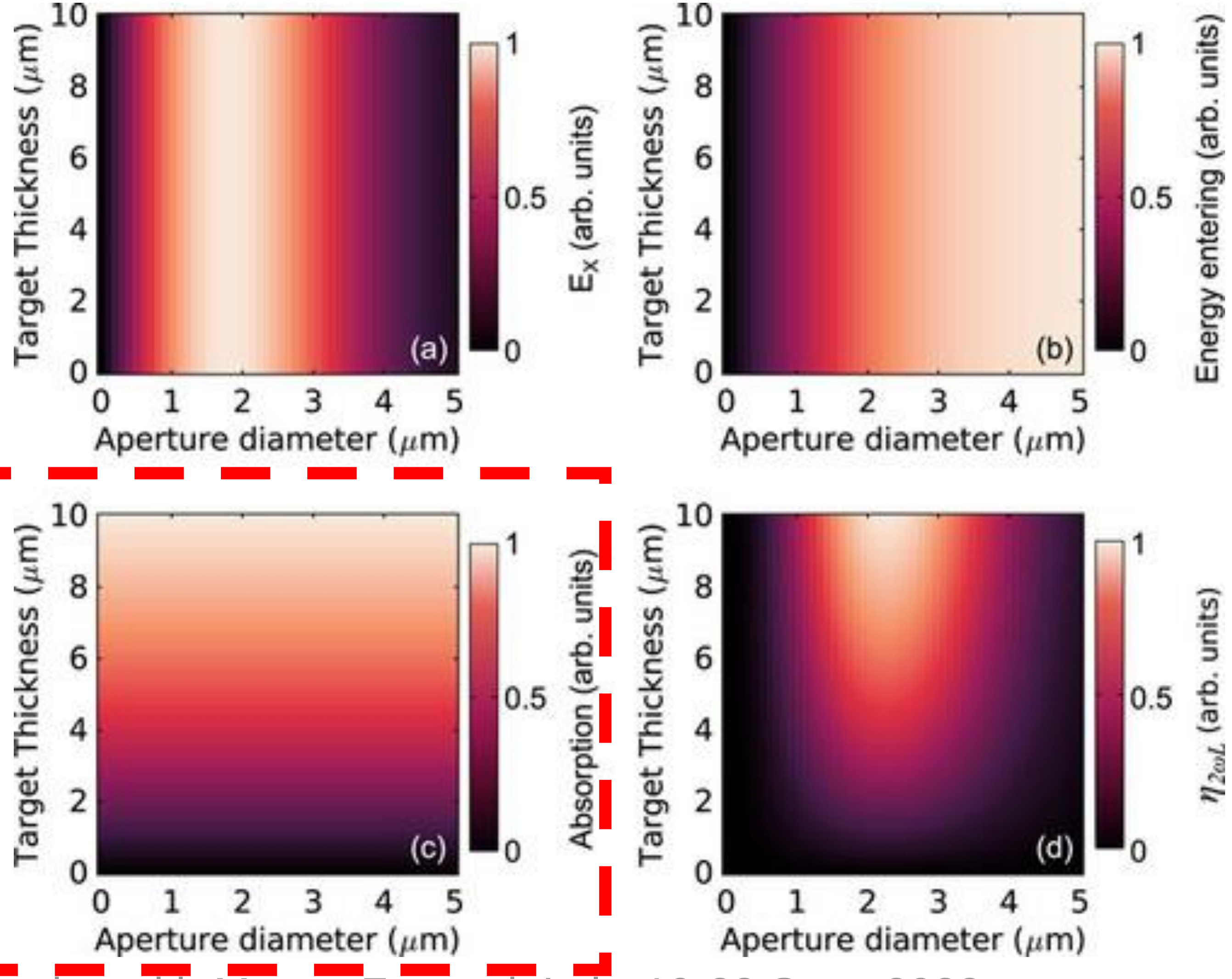
Aperture targets – Generation with length

$$E_X(Y) = \frac{d}{dY} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2}$$

$$K_{in}(d) = \int_{-d/2}^{d/2} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2} dY$$

$$Abs_L(l) = \alpha l e^{-\beta l}.$$

$$\eta_{2\omega_L} \propto |E_X(d/2)| Abs_L(l) K_{in}(d)$$



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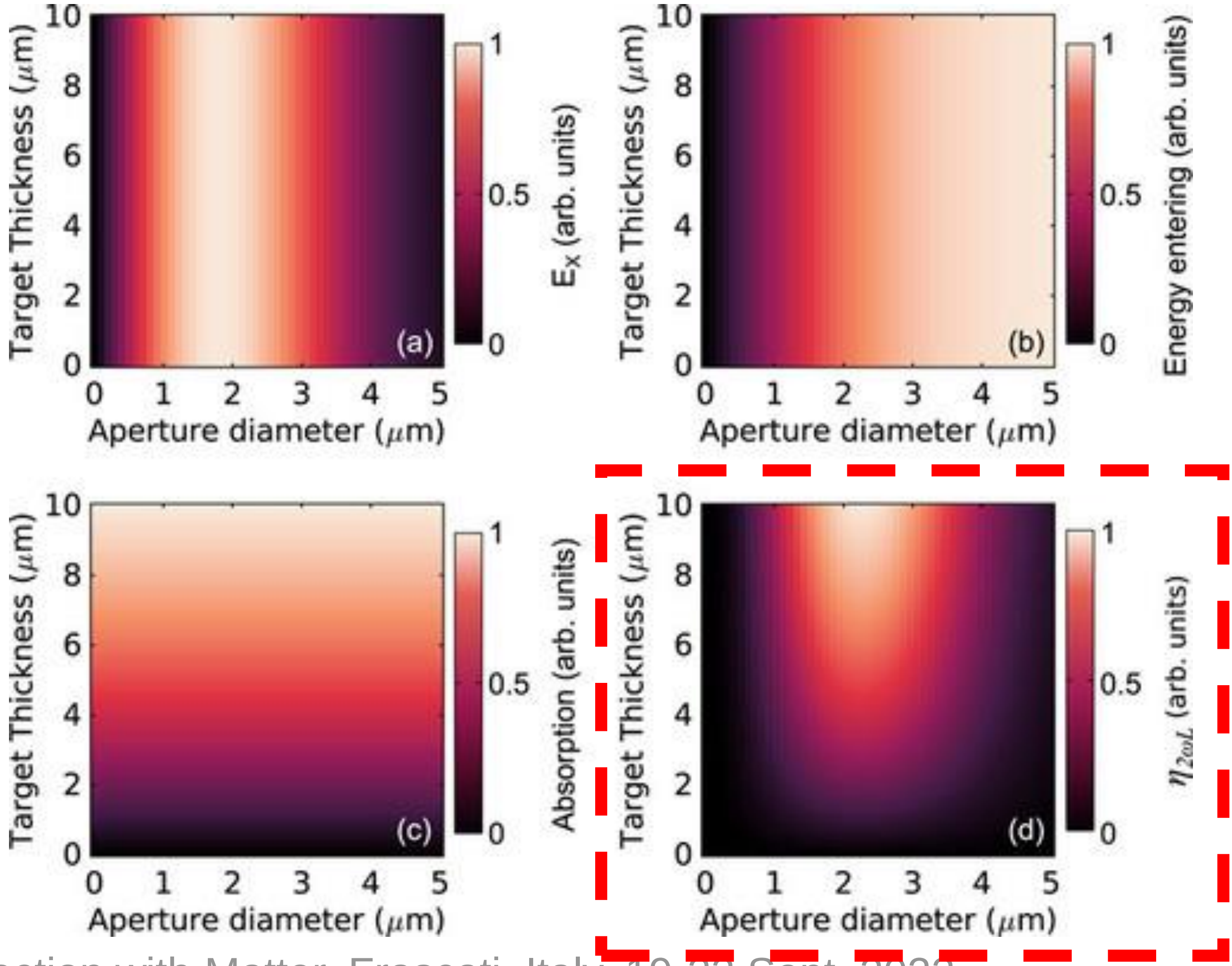
Aperture targets – Combined efficiency

$$E_X(Y) = \frac{\mathrm{d}}{\mathrm{d}Y} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2}$$

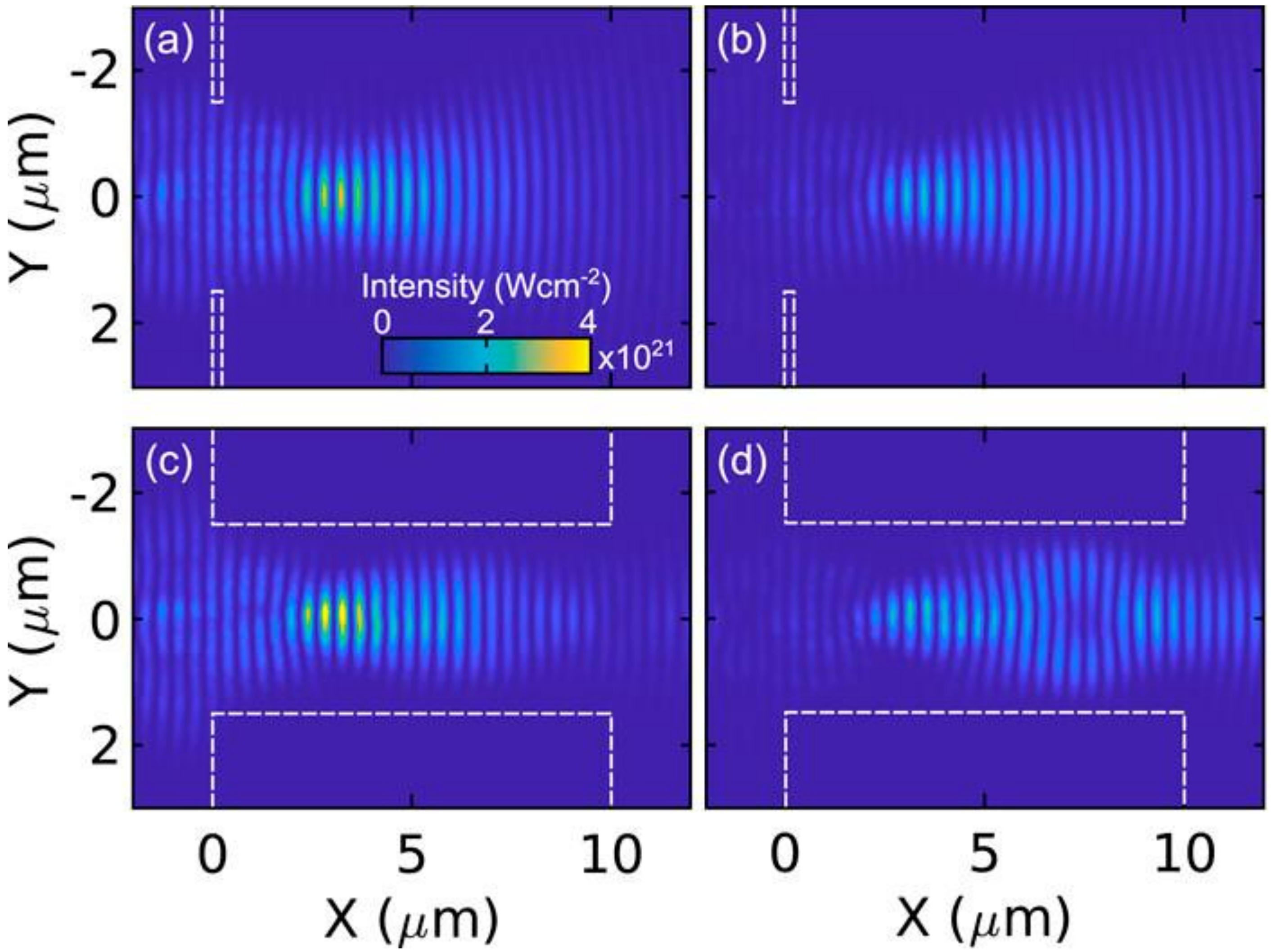
$$K_{in}(d) = \int_{-d/2}^{d/2} e^{-\left(\frac{2\sqrt{\ln(2)}Y}{\phi_L}\right)^2} \mathrm{d}Y$$

$$Abs_L(l) = \alpha l e^{-\beta l}$$

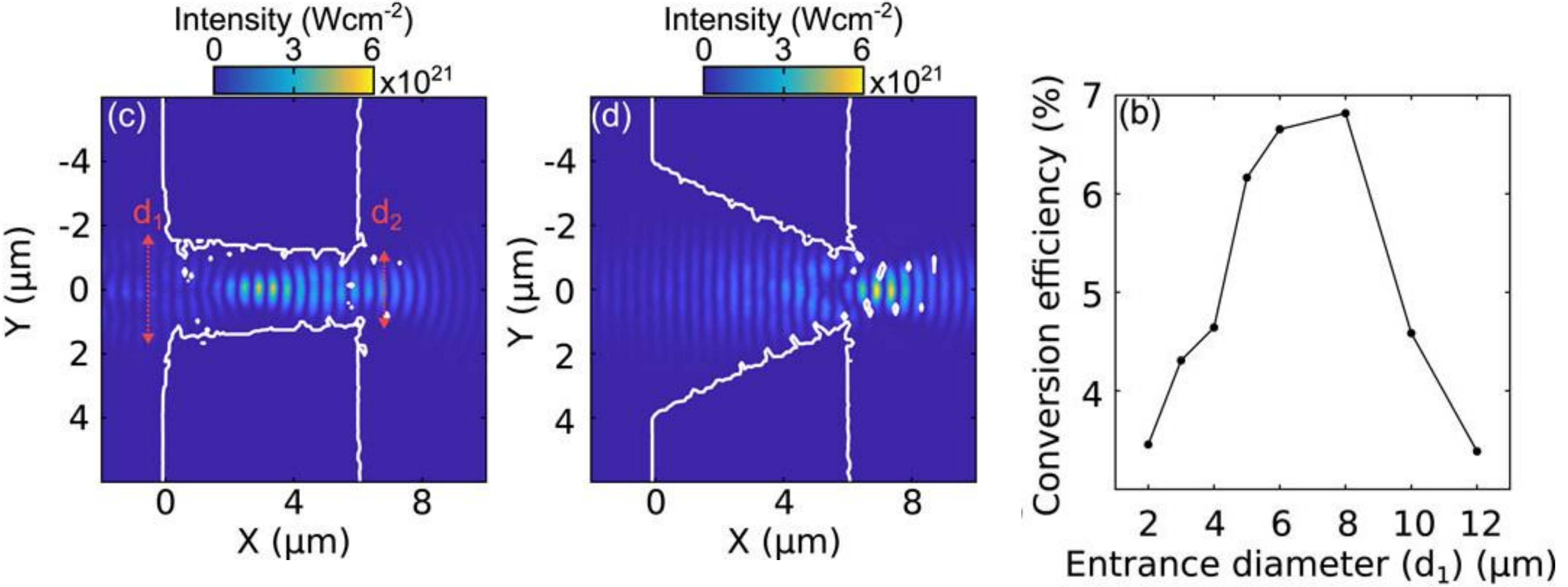
$$\eta_{2\omega_L} \propto |E_X(d/2)|\, Abs_L(l)\, K_{in}(d)$$



Aperture targets – non-linear behaviour



Aperture targets – Geometry optimisation



36th European Conference on Laser Interaction with Matter, Frascati, Italy, 19-23 Sept. 2022.

Summary

Intense light with higher order mode structure can be generated from the interaction of an intense laser pulse with a thin foil target and preformed aperture target

This mode structure can temporally vary over the course of the pulse duration in the case of thin foil targets

$2\omega_L$ emission can be optimised by tailoring an aperture target

This provides a new potential method of generating unique intense pulses of light for further interactions

Acknowledgements

University of Strathclyde

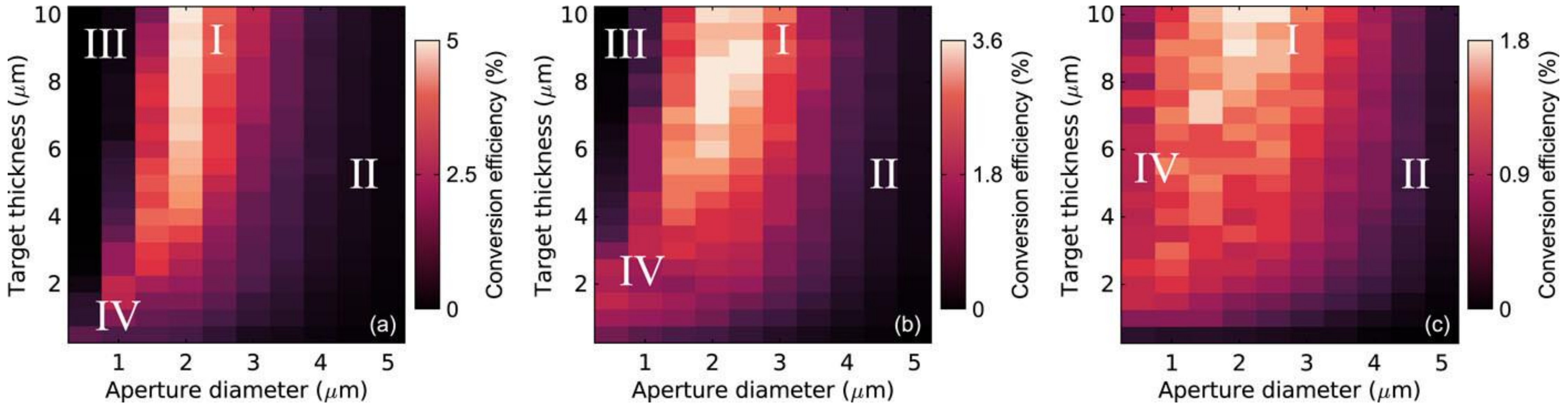
M. J. Duff, E. F. J. Bacon, R. Wilson, T. P. Frazer, B. Gonzalez-Izquierdo, A. Higginson, S. D. R. Williamson, Z. E. Davidson, R. Capdessus, R. J. Gray & P. McKenna

Central Laser Facility

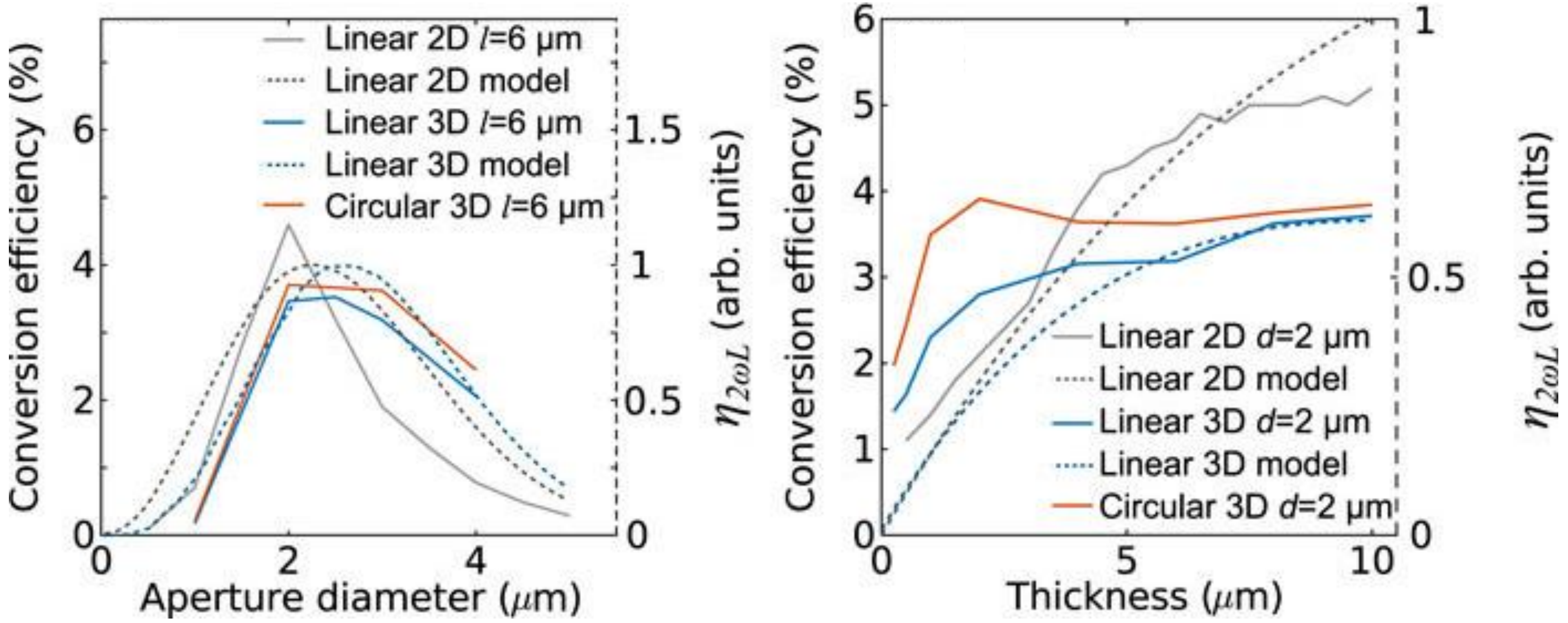
N. Booth, S. Hawkes & D. Neely

Aperture targets – $2\omega_L$ generation efficiency

10^{21} Wcm^{-2} 10^{22} Wcm^{-2} 10^{23} Wcm^{-2}



Supplementary
Aperture targets – Model comparison



Supplementary
Aperture targets – Plasma expansion