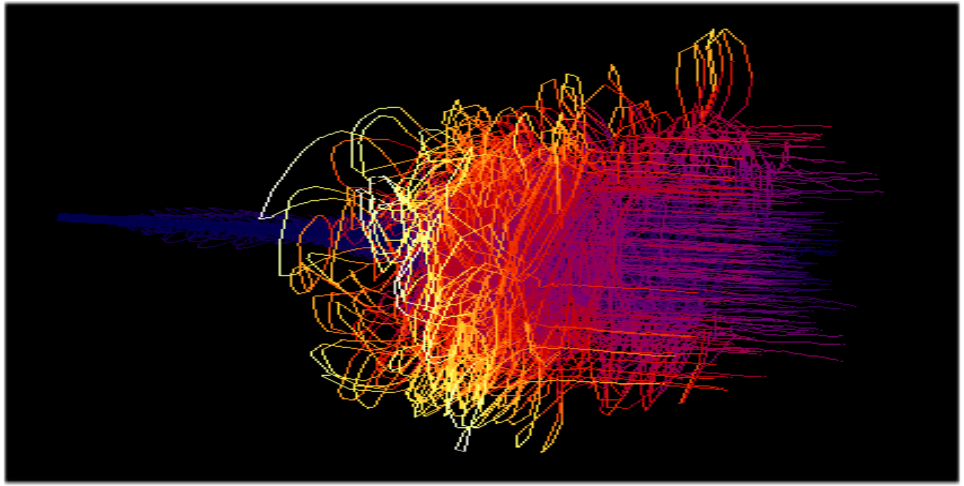
Progress towards 3D simulations of laser-target interactions

Elisabetta Boella

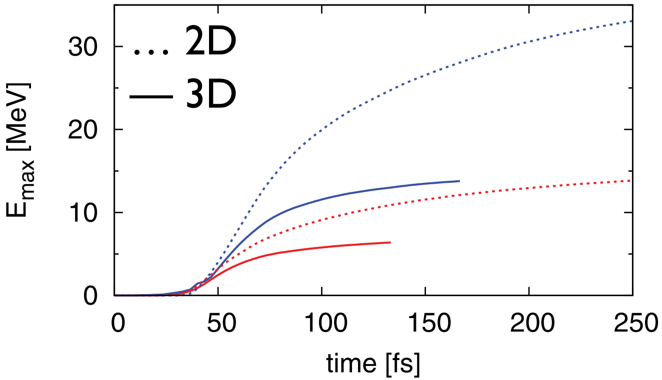
Physics Department
Lancaster University
and
Cockcroft Institute
Daresbury Laboratory
e.boella@lancaster.ac.uk
https://www.lancaster.ac.uk/staff/boella/



Lancaster University

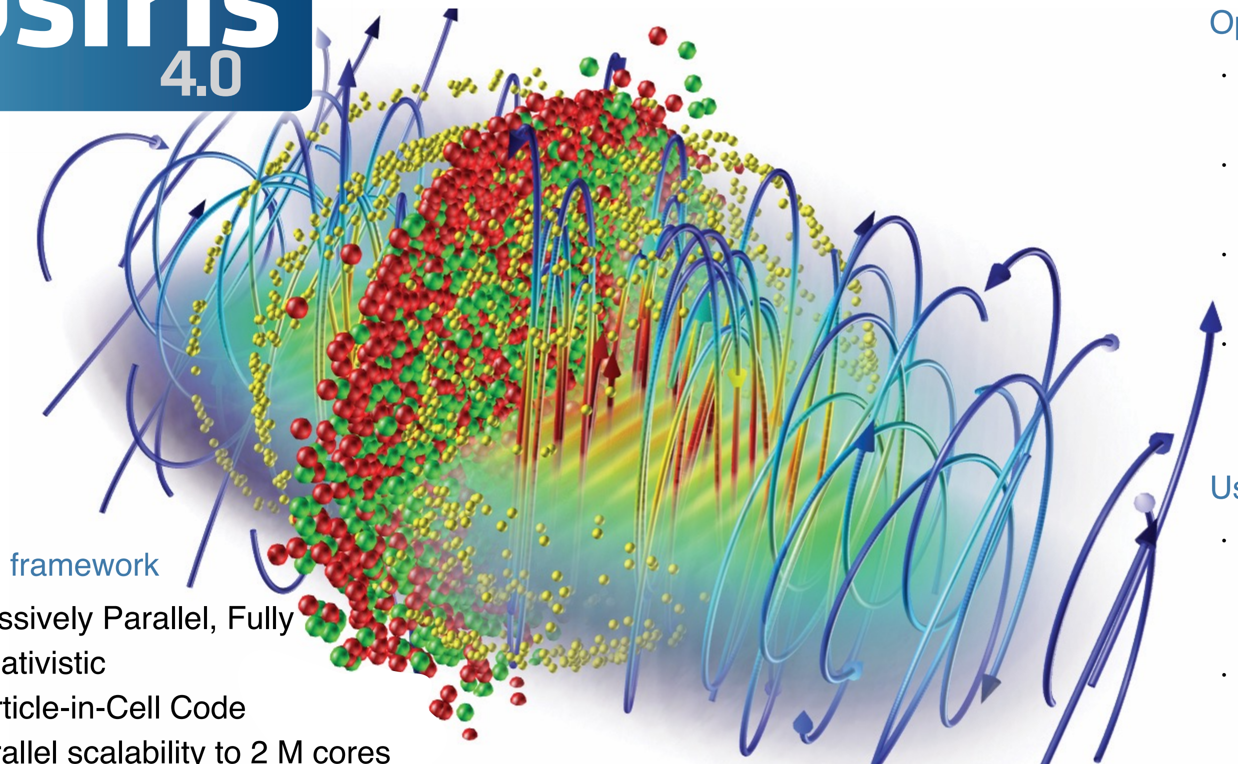
The Cockcroft Institute of Accelerator Science and Technology

3D simulations are necessary to evaluate quantitatively proton energy in TNSA



Sgattoni et al., Phys. Rev. E 85, 036405 (2012).

OSIRIS 4.0



OSIRIS framework

- Massively Parallel, Fully Relativistic Particle-in-Cell Code
- Parallel scalability to 2 M cores
- Explicit SSE / AVX / QPX / Xeon Phi / CUDA support
- Extended physics/simulation models

Open-access model

- 40+ research groups worldwide are using OSIRIS
- 300+ publications in leading scientific journals
- Large developer and user community
- Detailed documentation and sample inputs files available

Using OSIRIS 4.0

- The code can be used freely by research institutions after signing an MoU
- Find out more at:

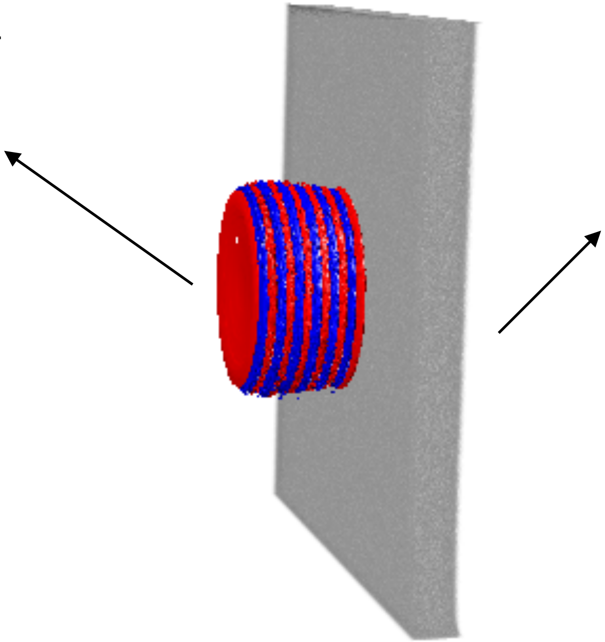
http://epp.tecnico.ulisboa.pt/osiris

UCLA TÉCNICO LISBOA

Ricardo Fonseca: ricardo.fonseca@tecnico.ulisboa.pt

First 3D simulations with Lhara parameters

$I = 5.2 * 10^{20}$ W/cm^2
$\lambda_0 = 800$ nm
$a_0 = 15.56$
$\tau_{FWHM} = 25$ fs
$w_{FWHM} = 4$ µm
p - polarised

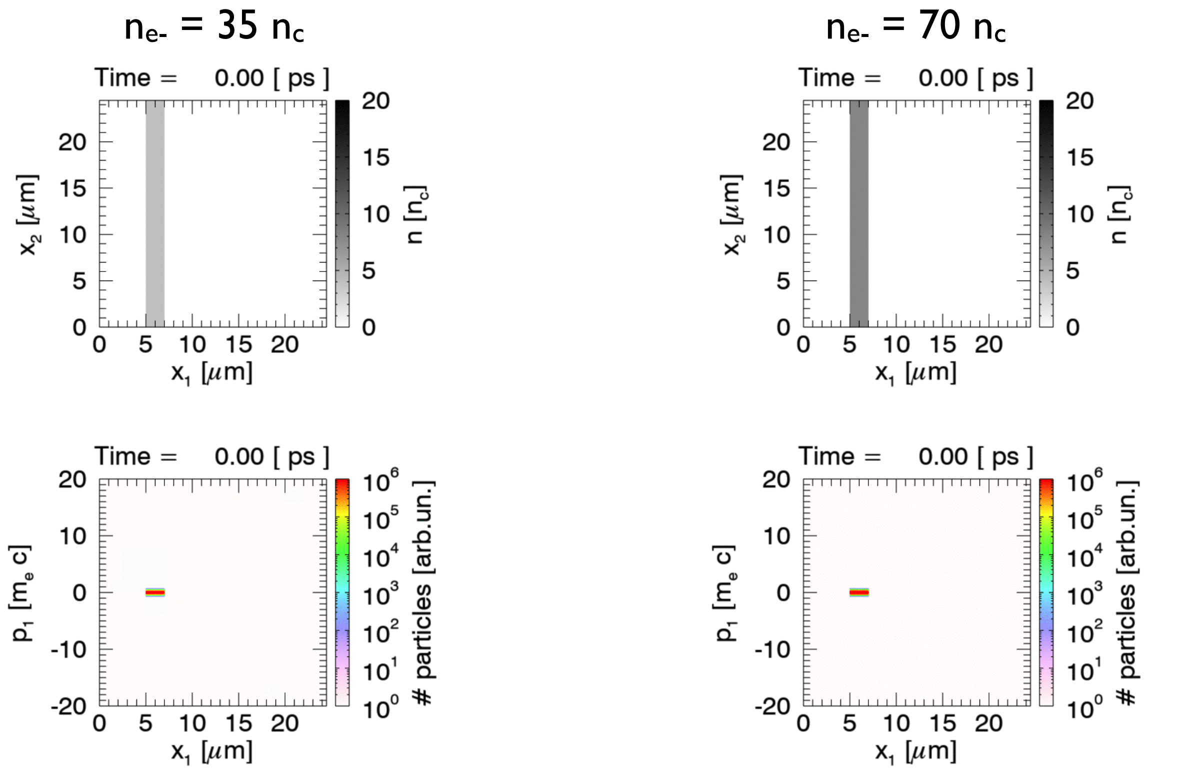


$C^{6+}H^{+}$ foil
$n_{e-} = 35 - 70\ n_c$
$n_H = 0.12\ n_{e-}$
$L = 2$ µm

289,000 time steps (~ 0.9 ps)
13824 CPUs x 24 h
~ 340,000 CPUhours ~ £9,000

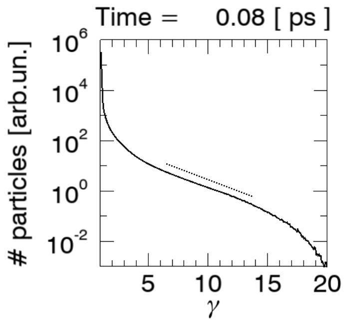
Simulations performed on ARCHER (EPCC, UK) and Marenostrum (BSC, Spain)

Laser bores a hole on the target surface



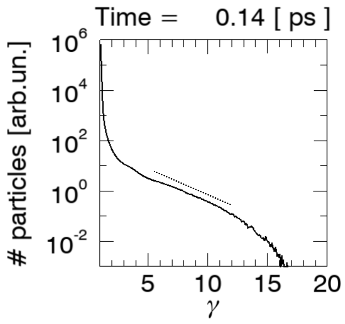
Electron temperature is lower than expected from ponderomotive scaling

$n_{e-} = 35\ n_c$



$T_{e,hot} = 0.84$ MeV

$n_{e-} = 70\ n_c$

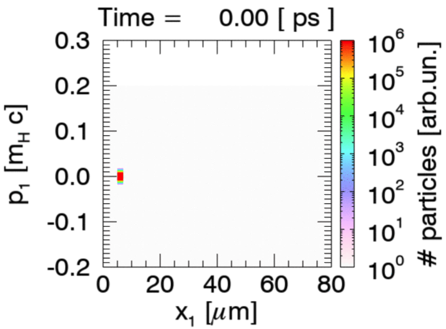


$T_{e,hot} = 0.72$ MeV

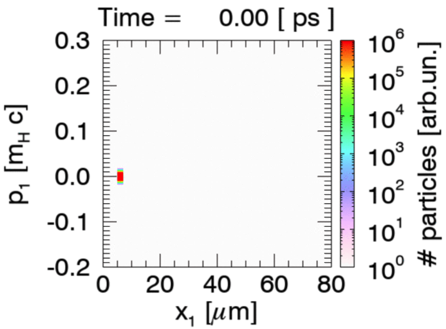
$T_{e,pond} = 1.57$ MeV

Protons are accelerated also from the front of the target

$n_{e-} = 35\ n_c$

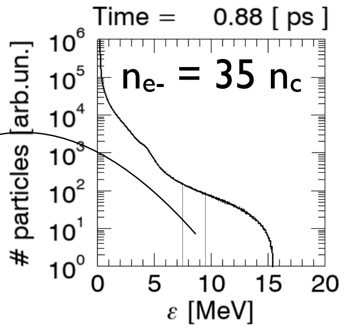


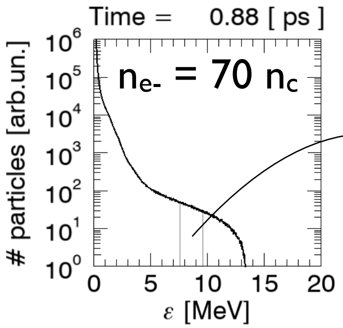
$n_{e-} = 70\ n_c$



Ions are very collimated

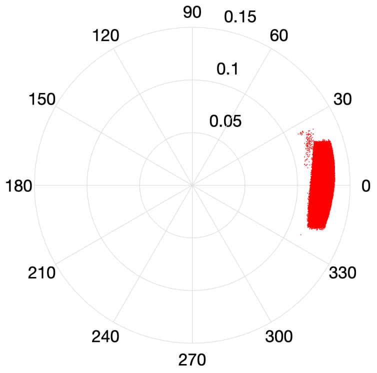
~ 81 pC

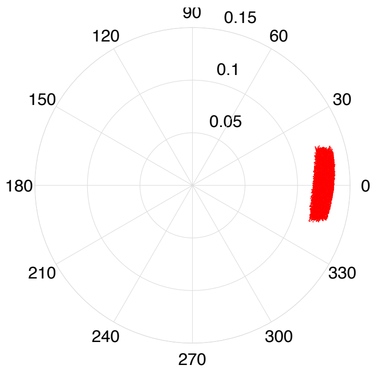




~ 28 pC

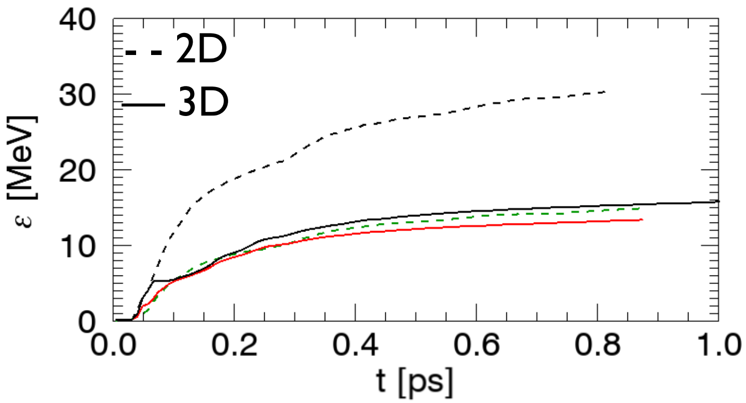
$\theta_{rms} = 9.2°$





$\theta_{rms} = 7.5°$

2D simulations overestimate final proton cutoff energy by a factor ~2



— n_{e-} = 35 n_c, — n_{e-} = 70 n_c, — n_{e-} = 252 n_c

The Amplified Spontaneous Emission of the laser cannot be neglected

Titan laser (LLNL, US)

$I = 10^{20}$ W/cm^2

$\lambda_0 = 1.054$ µm

$a_0 = 15.56$

$\tau_{FWHM} = 700$ fs

$w_{FWHM} = 6$ µm

INO laser (CNR, Italy)

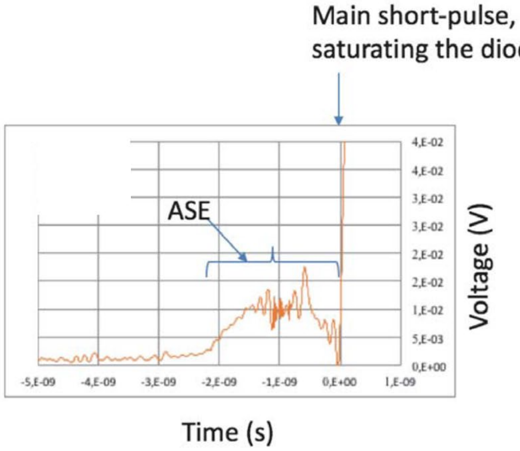
$I = 2.4 * 10^{20}$ W/cm^2

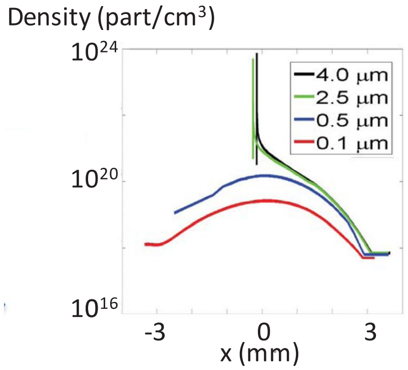
$\lambda_0 = 795$ nm

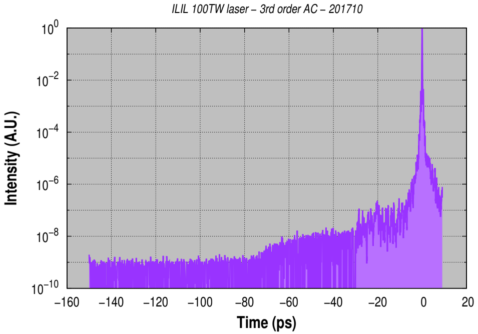
$a_0 = 10.6$

$\tau_{FWHM} = 27$ fs

$w_0 = 2.2$ µm



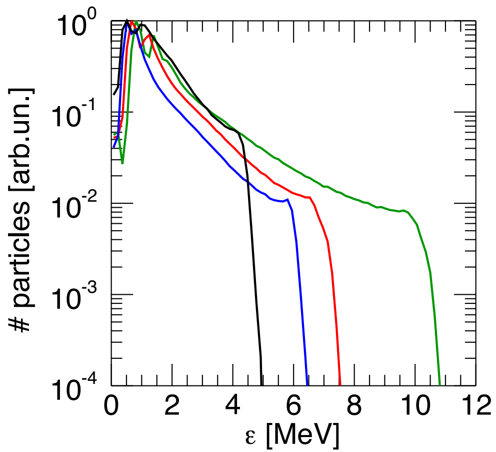


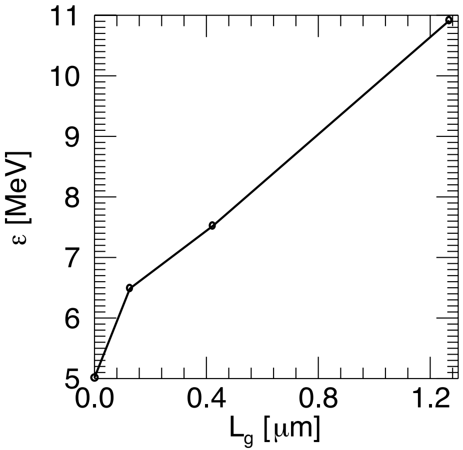


Antici et al., Sci. Rep. 7, 16463 (2017). Gizzi et al. arXiv pre-print, arXiv:2106.00814 (2021).

Pre-plasma can aid the laser absorption and lead to energy enhancement

3D PIC simulations modelling the interaction between in intense pulse and a 10 μm Al target





— sharp plasma-vacuum transition, — L_g = 0.13 μm, — L_g = 0.42 μm, — L_g = 1.27 μm

Summary

- 3D simulations appear necessary for quantitative analysis, but are computationally very challenging.
- Scaling laws between 2D and 3D simulations could be derived for our specific case, similarly to Babaei et al., Phys. Plasmas 24, 043106 (2017).
- The role of the laser Amplified Spontaneous Emission should be considered, especially when dealing with very thin targets.
- A very sharp plasma-vacuum transition at the target front might not be realistic.