

Simulation study of spatial-temporal properties of a relativistic electron beam at the collision-point with a high-intensity laser pulse : Relevant to nonlinear Compton scattering experiment at CoReLS

VB Pathak

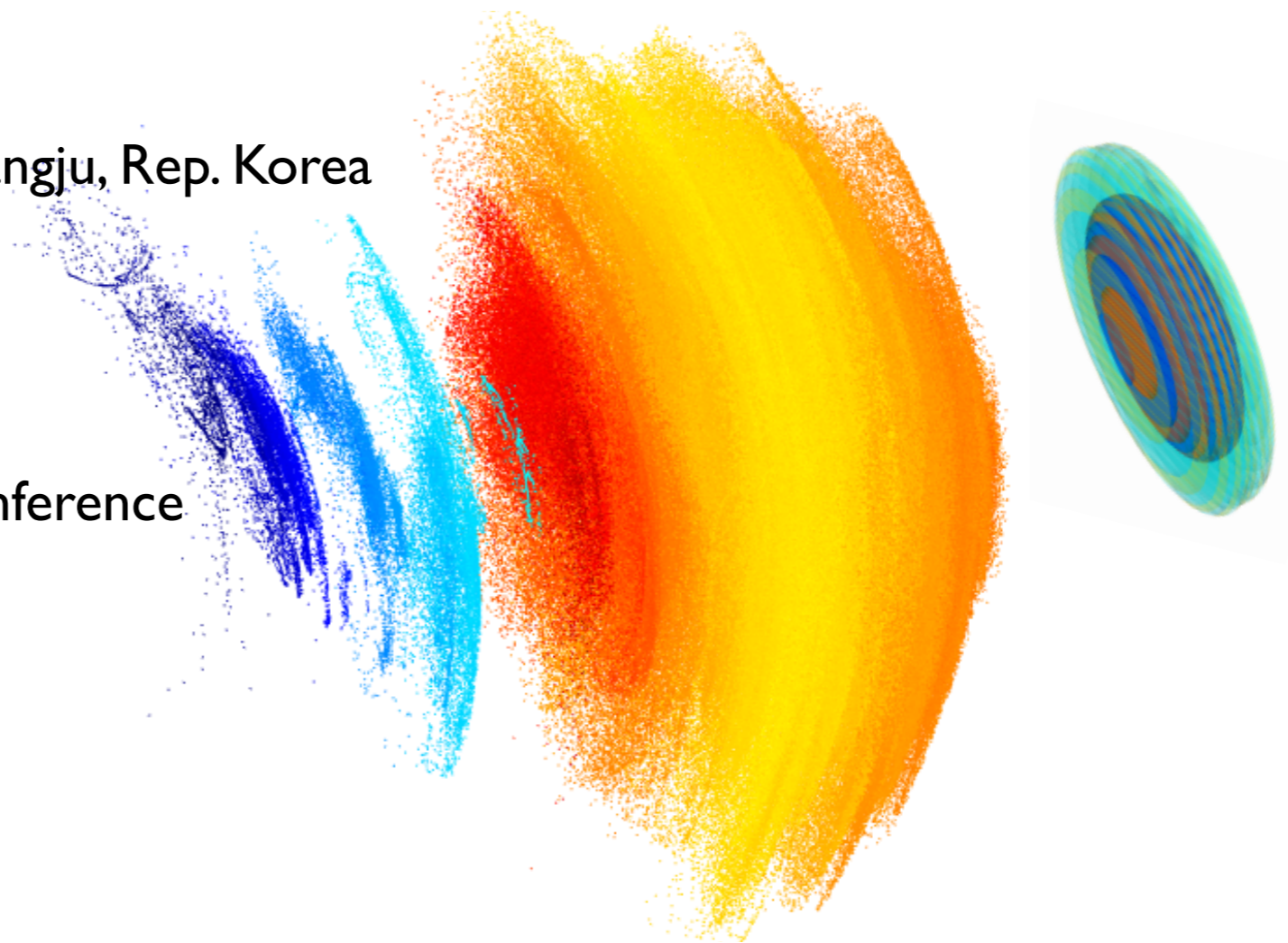
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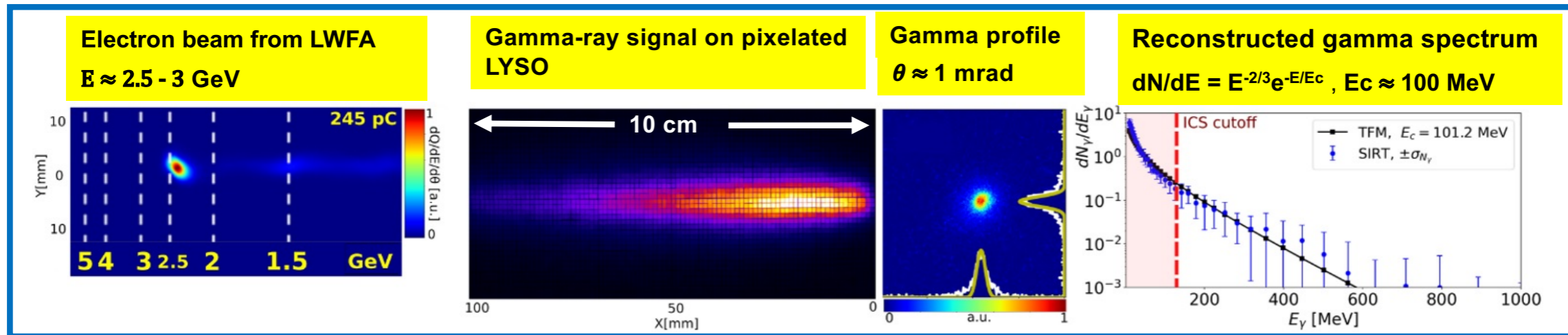
ExHILP 2021-Jena

4th Extremely High Intensity Laser Physics Conference

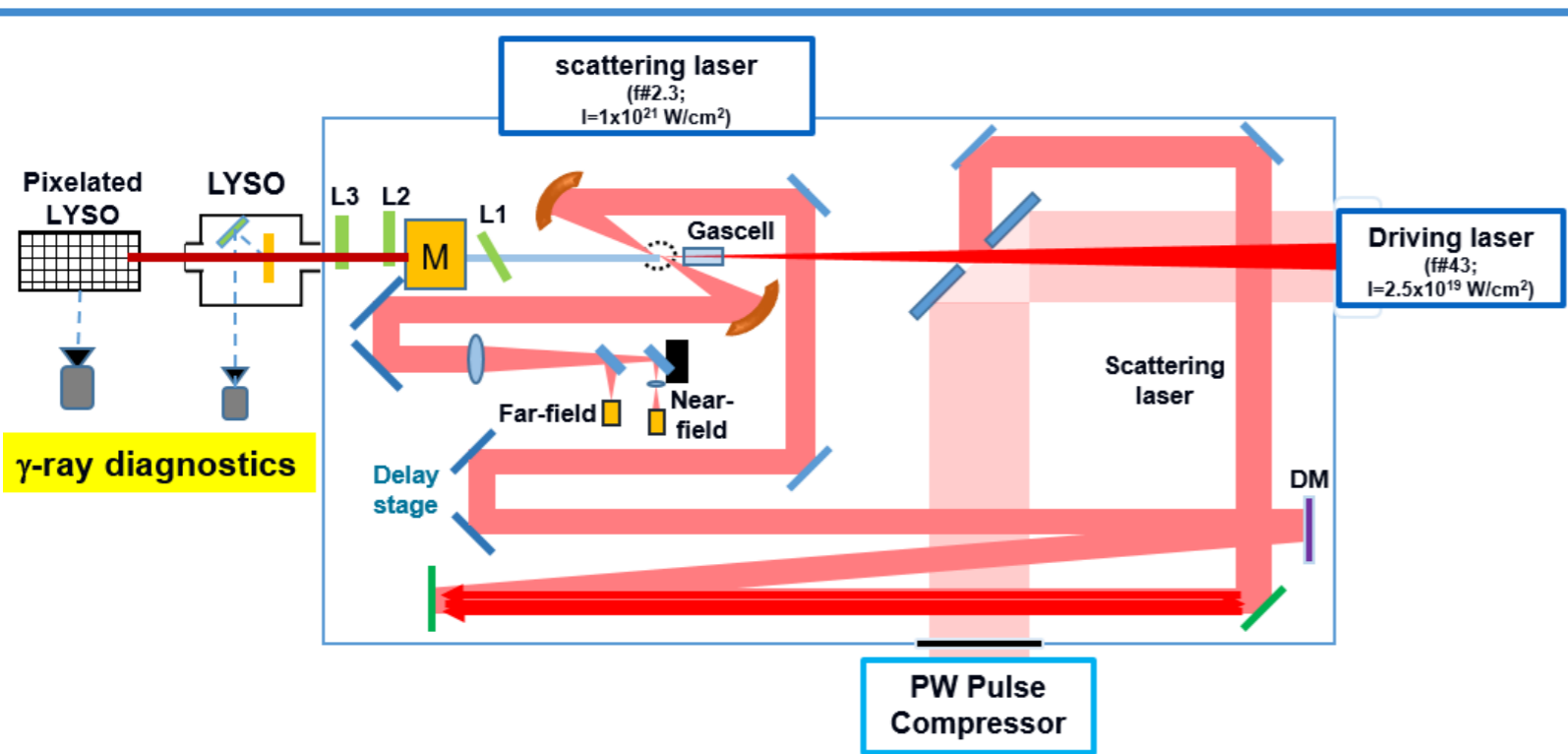
September 13-17, 2021



Nonlinear Compton scattering experiment at CoReLS

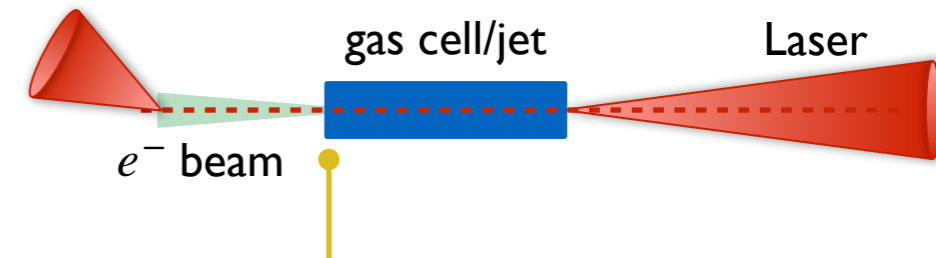


Schematic of laser-electron collision experiments

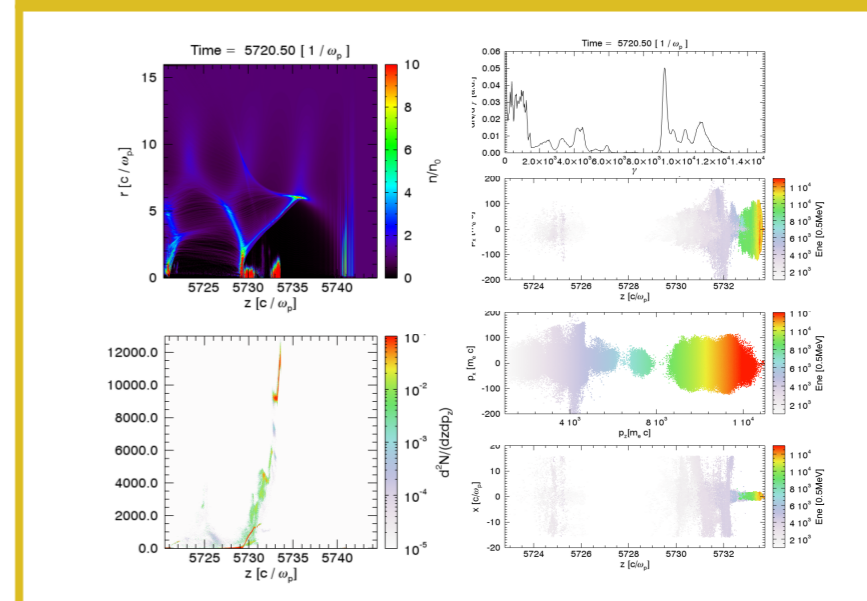


- Laser: 800 nm / 25 fs / 4 PW
- LWFA Target: He gas cell
- $f=12\text{m}$
- Collision point 3 cm after gas cell exit , 30 degree

Scattering laser



PIC simulation upto the end of LWFA

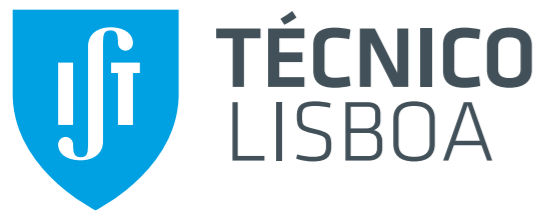
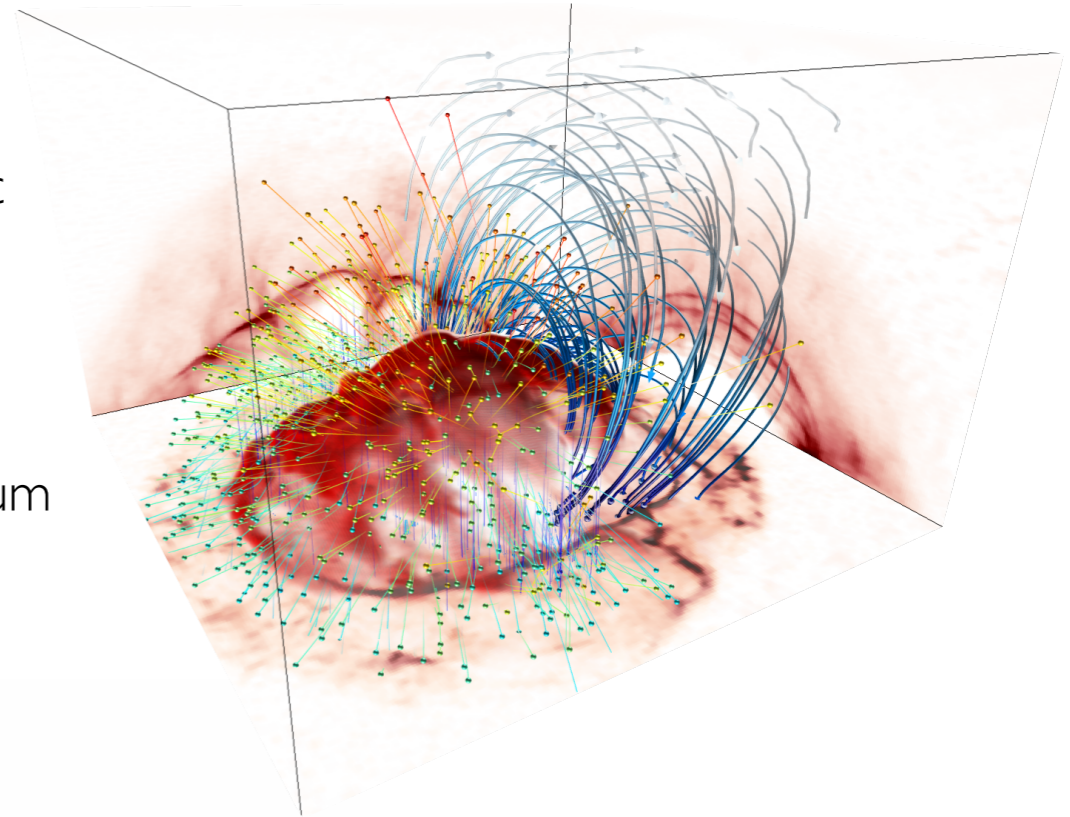


OSIRIS 3.0



osiris framework

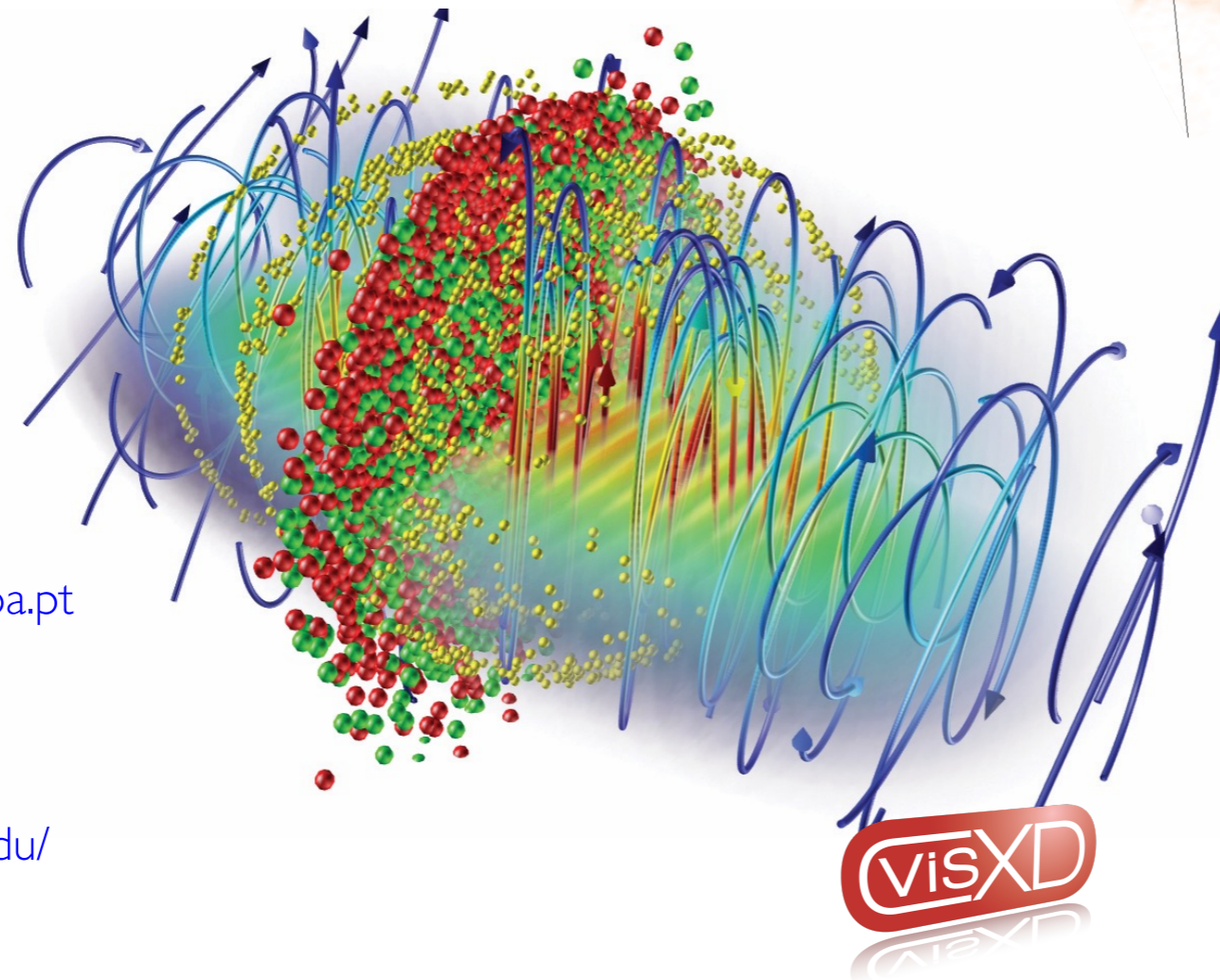
- Massively Parallel, Fully Relativistic Particle-in-Cell (PIC) Code
- Visualization and Data Analysis Infrastructure
- Developed by the osiris.consortium
⇒ UCLA + IST



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code features

- Scalability to ~ 1.6 M cores
- SIMD hardware optimized
- Parallel I/O
- Dynamic Load Balancing
- QED module
- Particle merging
- GPGPU support
- Xeon Phi support

PIC simulations for LWFA with CoReLS parameters

3D simulation parameters

Box size
 $40 \times 36 \times 36 (c/\omega_p)^3$

Laser
 $a_0 = 3.6, W_{FWHM} = 40 \mu m, \tau_{FWHM} = 25 fs$

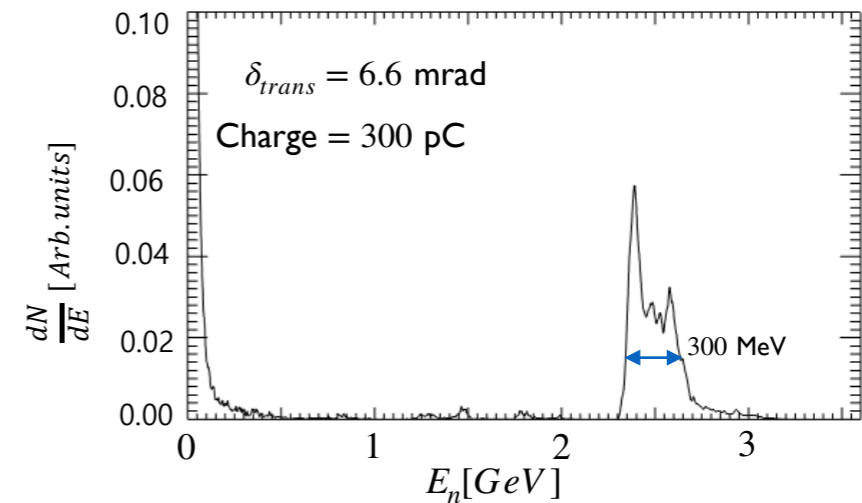
Grid number
 $5200 \times 360 \times 360$

Plasma [homogeneous density]
 $n_0 = 7.0 \times 10^{17} cm^{-3}$

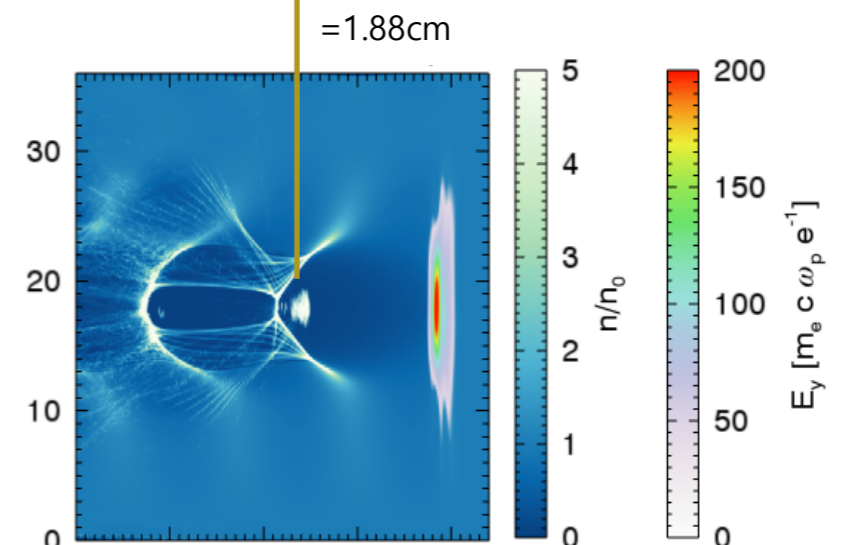
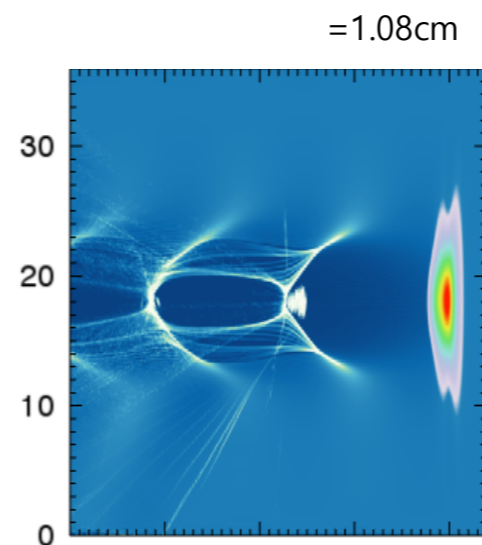
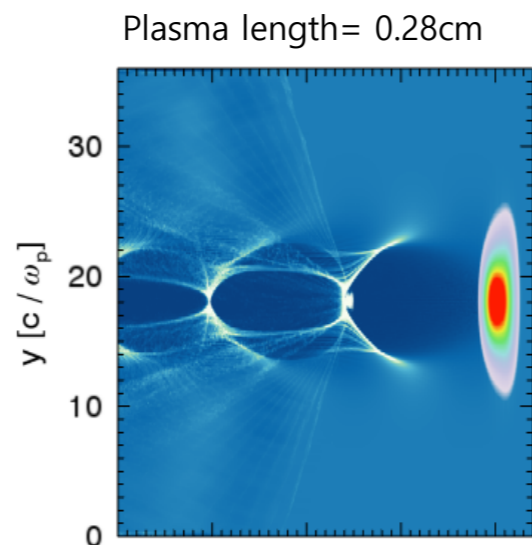
Simulation run time
 10 days on 1000 CPUs

$1/\omega_p = 21.2 fs$
 $c/\omega_p = 6.36 \mu m$

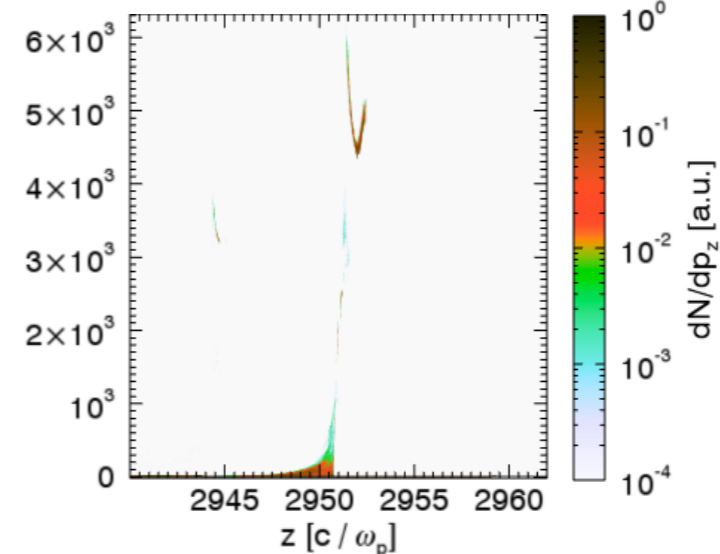
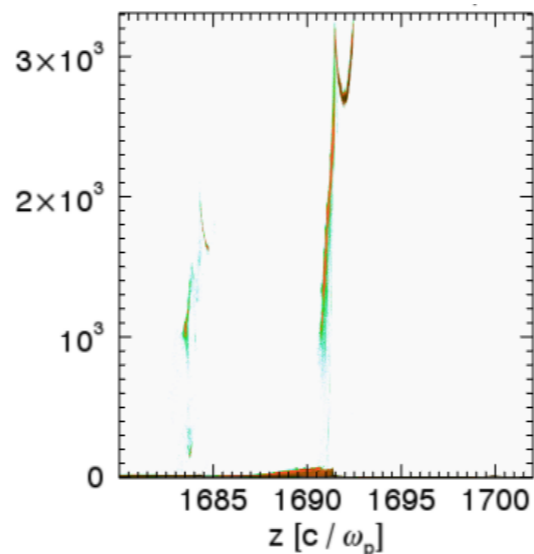
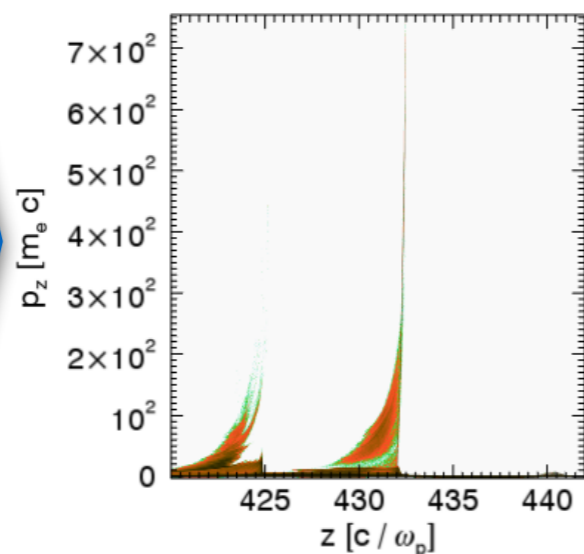
Electron spectrum



Laser & Electron density

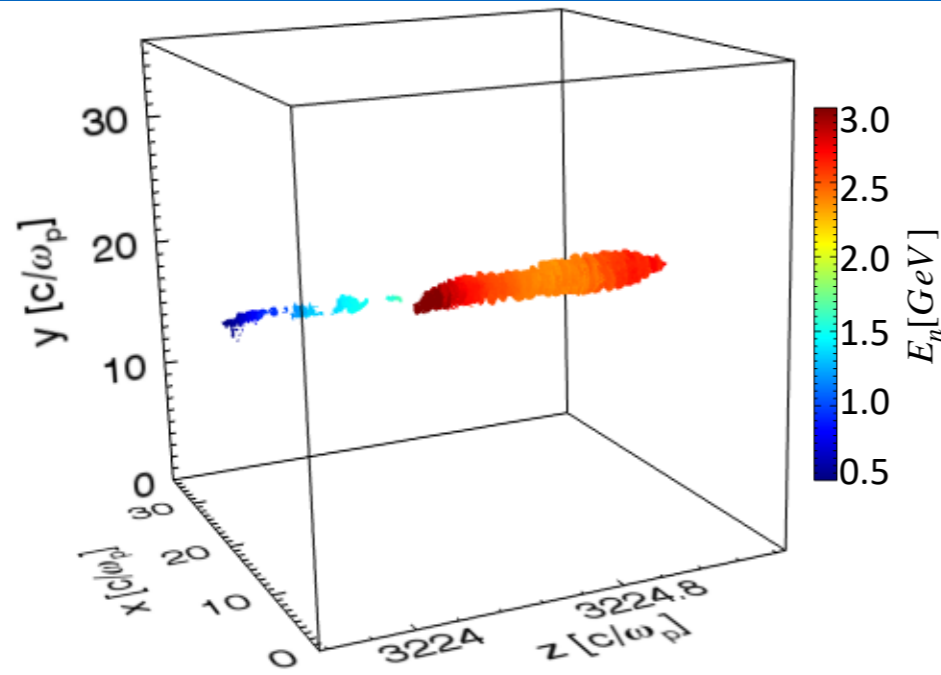


Electron acceleration



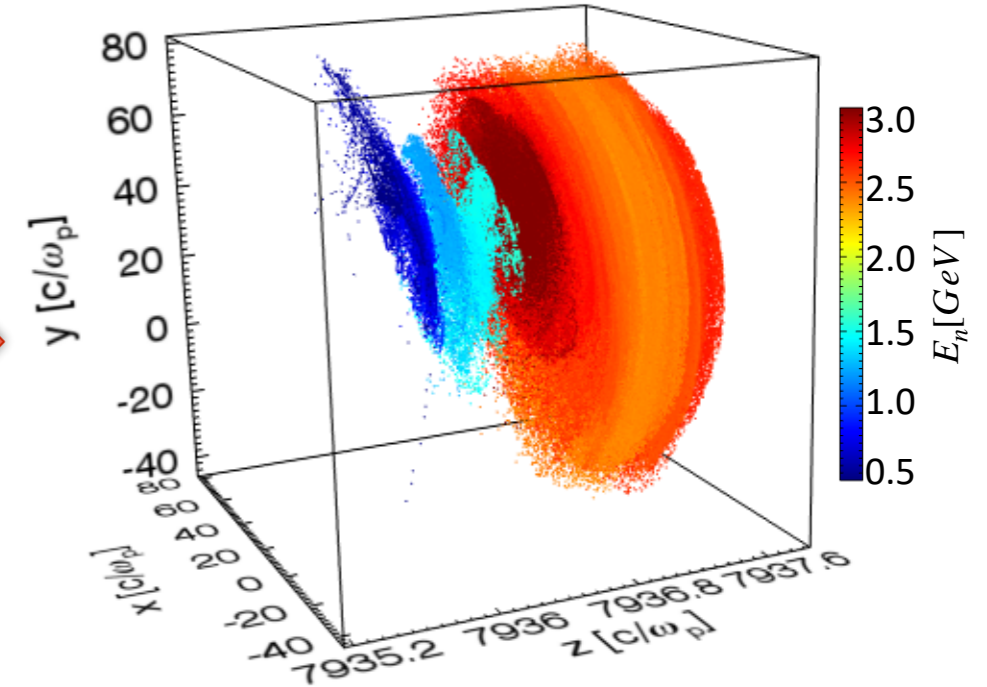
Electron beam profile at the collision point

Just after the plasma source (End of the simulation)

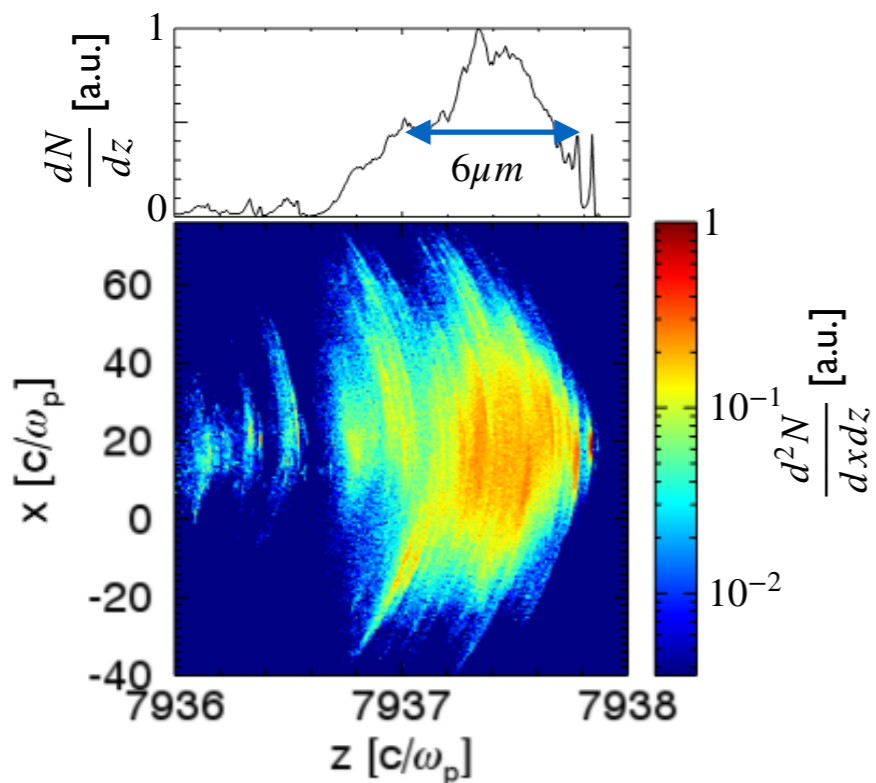


Free propagation

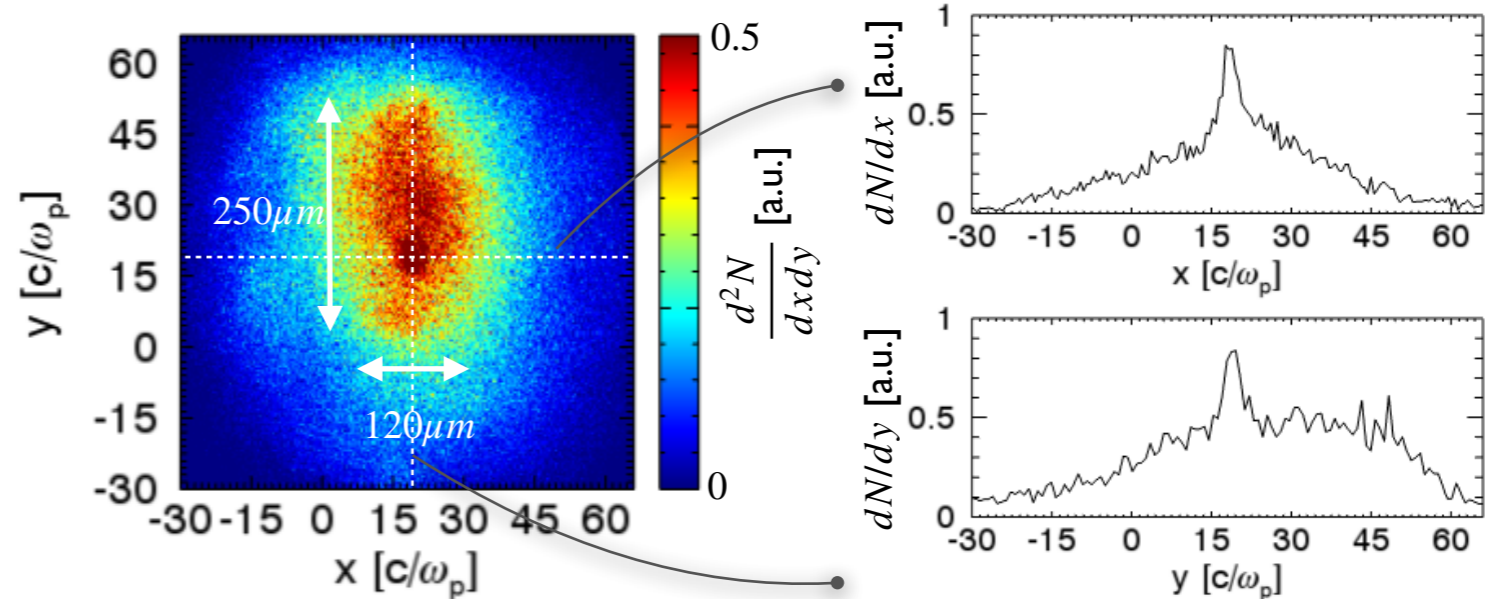
3cm away from the plasma source



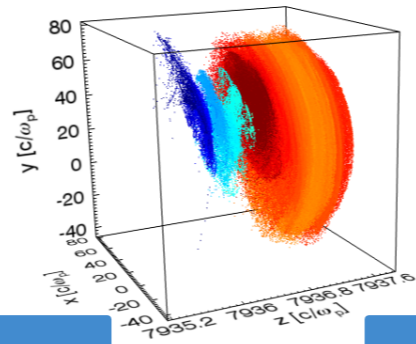
Side view



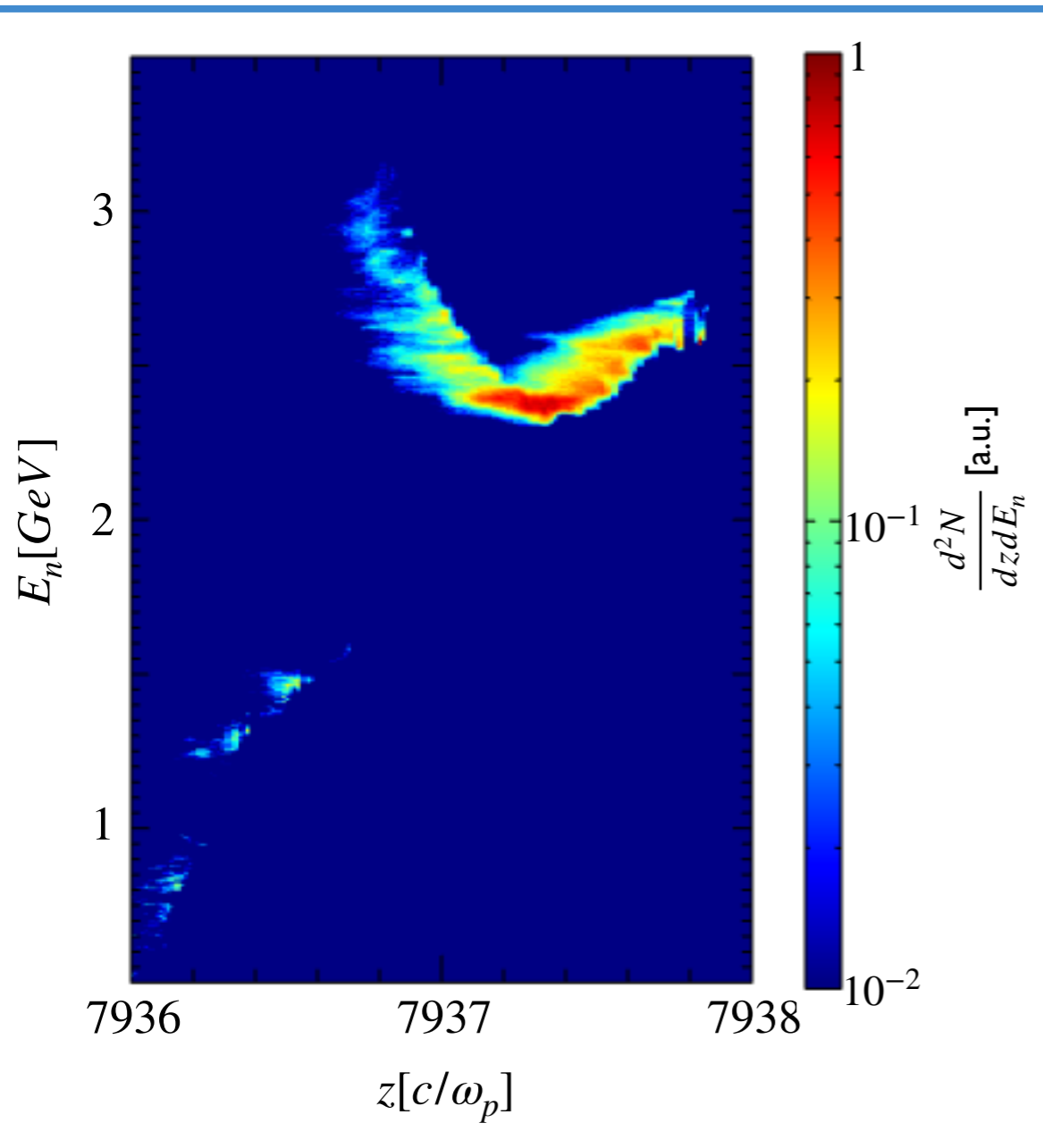
Front view



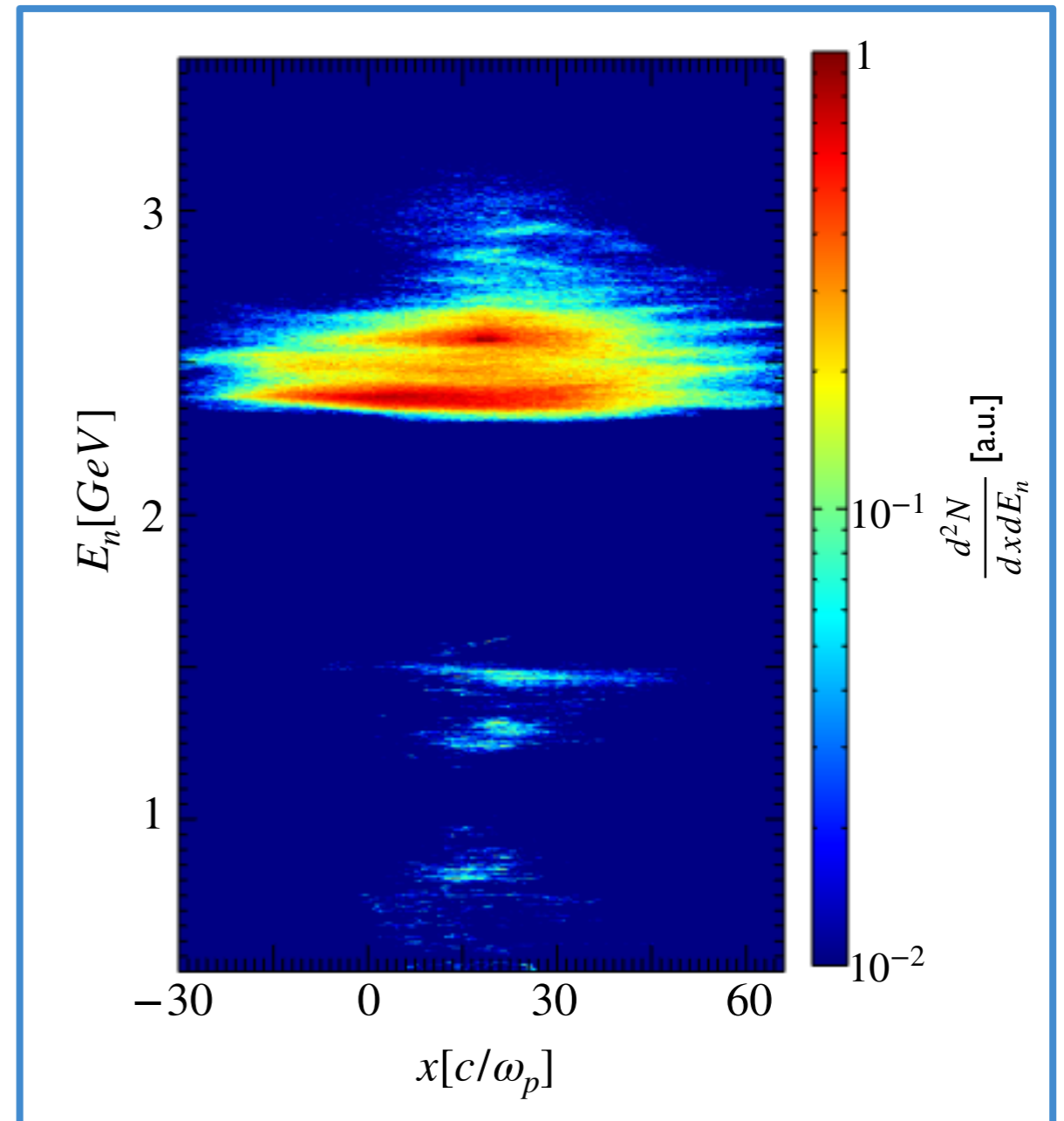
Spatial-temporal distribution of electron energy



Longitudinal distribution

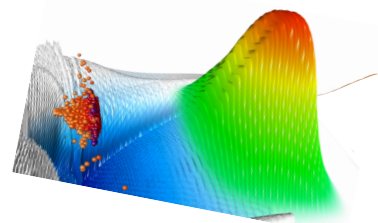
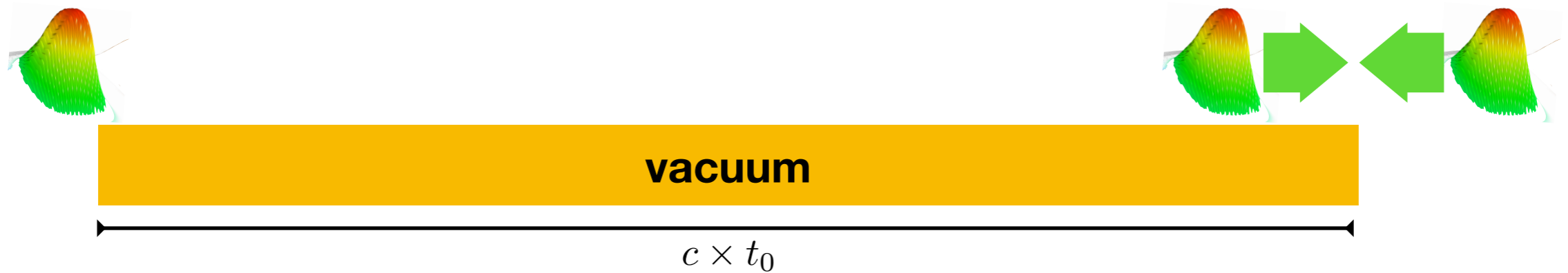


Transverse distribution



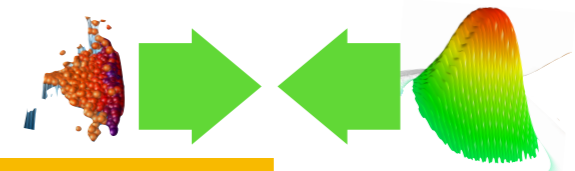
Time mismatch between the calculation considering only vacuum and calculations considering plasma + vacuum

In experiments synchronization of the two laser pulses is checked in vacuum



- t_1 : Time of injection
- t_2 : Time of travel by electrons
- t_d : time difference between driver (laser) and injected electrons
- t_0 : Total time of flight in vacuum for the driver (laser)

point of collision



plasma

$v_g \times t_1$

$$v_g = c \sqrt{1 - \frac{\omega_p^2}{\omega_0^2}}$$

$$c \times t_0 = v_g \times t_1 + c \times t_2$$

$$t_1 + t_2 = t_0 + t_1 \times \frac{\omega_p^2}{2\omega_0^2}$$

Time mismatch

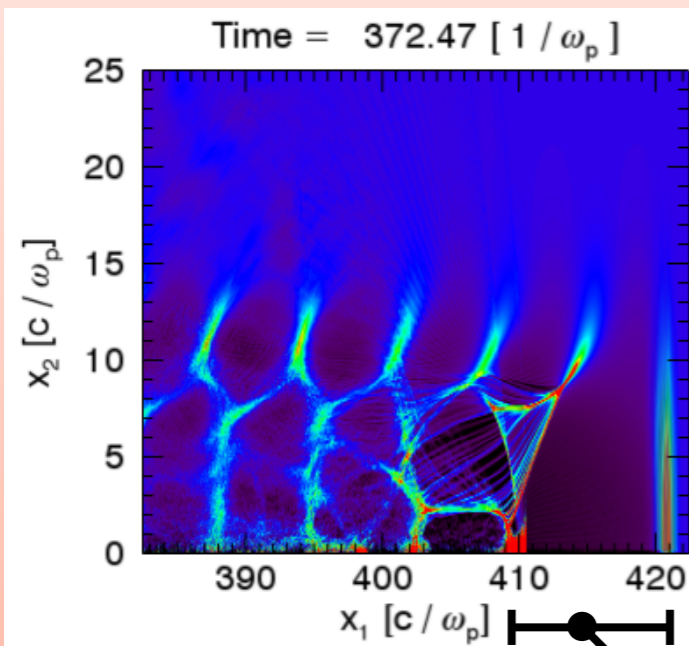
$$\Delta t = t_1 + t_2 + t_d - t_0 = t_d + t_1 \times \frac{\omega_p^2}{2\omega_0^2}$$

Collision of interest (laser-electron collision) occur at later times compare laser-laser collision

Delay between laser and electron beam at the time of self-injection

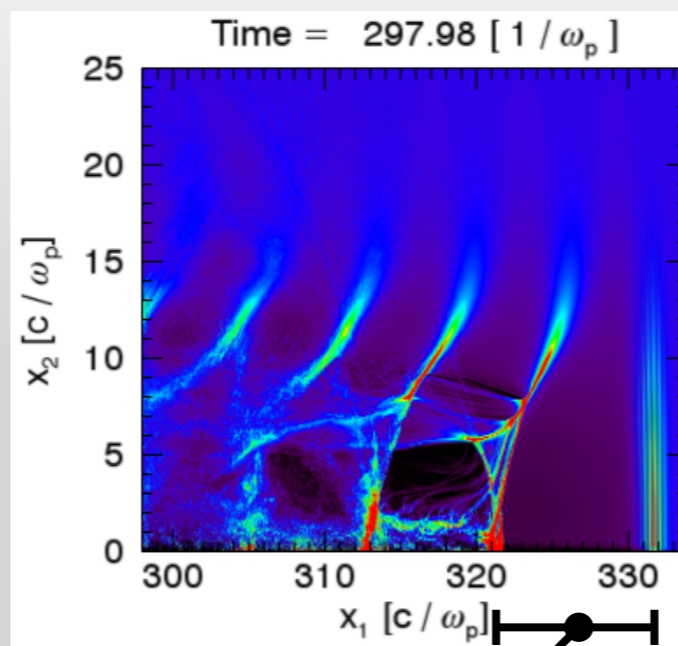
Electron density distribution at self-injection

Vector potential: $a_0 = 4.0$
 Laser frequency: $\omega_0 = 20\omega_p$
 Spot size: $W_0 = 13c/\omega_p$
 Pulse length: $\tau_0 = 2.8/\omega_p$



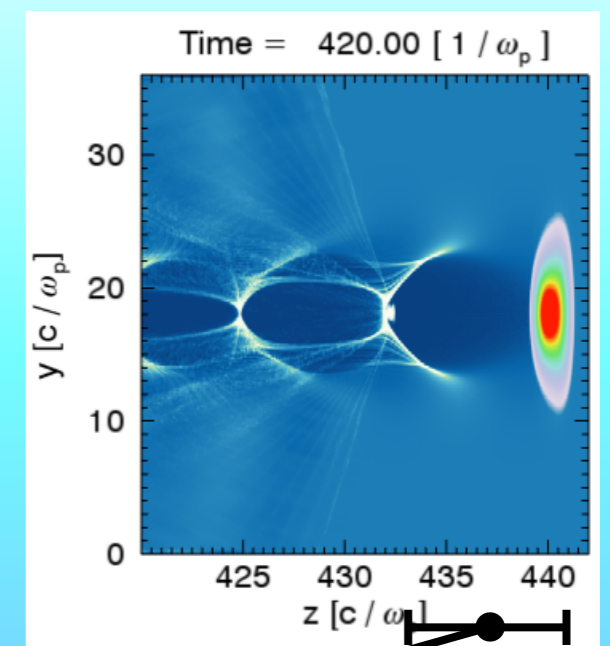
$$t_d = 85 fs$$

Vector potential: $a_0 = 5.0$
 Laser frequency: $\omega_0 = 30\omega_p$
 Spot size: $W_0 = 11c/\omega_p$
 Pulse length: $\tau_0 = 2/\omega_p$



$$t_d = 127 fs$$

Vector potential: $a_0 = 3.6$
 Laser frequency: $\omega_0 = 50\omega_p$
 Spot size: $W_0 = 6c/\omega_p$
 Pulse length: $\tau_0 = 1.67/\omega_p$



$$t_d = 212.2 fs$$

Separation b/w laser and electron bunch

$$ct_d \sim 2R_b \approx 4\sqrt{a_0} \frac{c}{\omega_p}$$

$$\gg ct_1 \times \frac{\omega_p^2}{2\omega_0^2}$$

$$\Delta t \sim 4\sqrt{a_0} \frac{c}{\omega_p}$$

Conclusion



Systematic particle-in-cell simulations (PICS) may fill (partially) the blanks in experimental diagnostics for laser-electron collision study

- 3D PIC simulations for the laser-plasma parameters at CoReLS PW laboratory.
- Post-processing of PICS-generated electron beam to characterize spatial-temporal properties of electron beam at the collision point.
- Time mismatch between laser-electron and laser-laser collision goes $\Delta t \sim 4\sqrt{a_0} \frac{c}{\omega_p}$

Collaborators

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GoLP Team: IST Lisbon

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