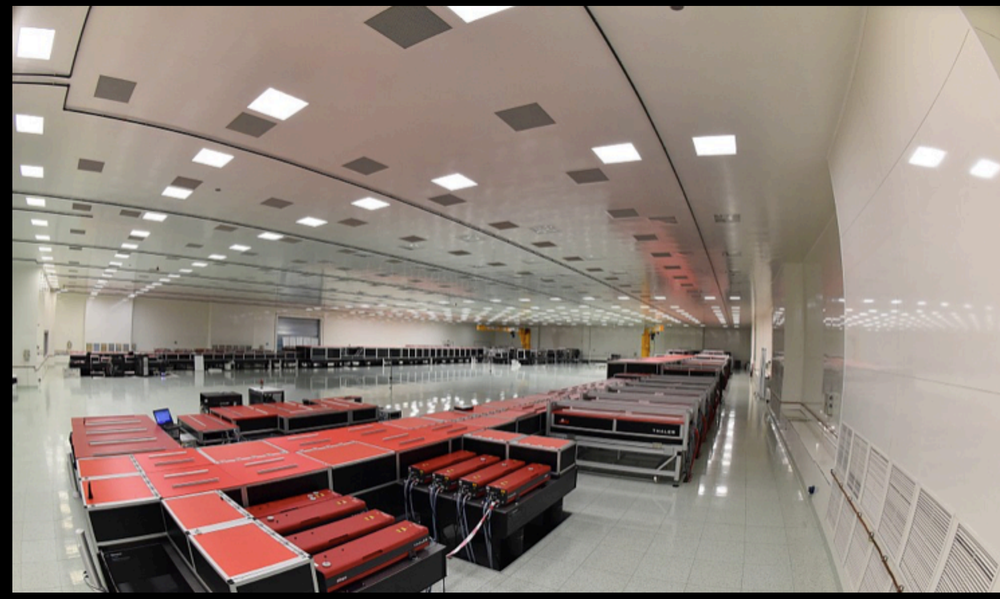
Simulation of high power laser experiments on high performance computer

Extreme Light Infrastructure - Nuclear Physics (ELI-NP), Magurele Romania

Jian Fuh, ONG **3 November 2020**

High Power Laser System at ELI-NP

100 TW, 1 PW, 10 PW; Magurele Romania

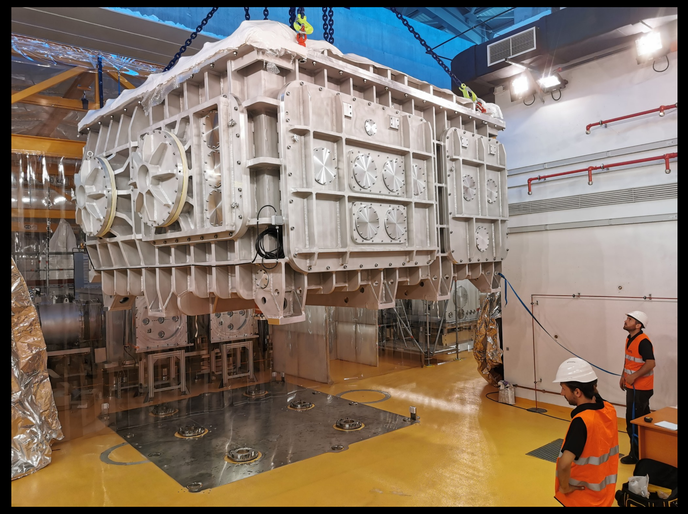


On 19 August 2020 the first 10 PW laser pulse was shot through the entire ELI-NP laser system (amplifiers, compressor and laser beam transport) as part of the endurance test of the laser beam transport system. *10 PW ~ 10% energy produced by the Sun on Earth

Linear Accelerator (Under construction)

A system producing γ radiation by scattering of light photons on high energy electrons, with tunable energy of the photons up to 19.5 MeV, spectral density above 10^{8} ph/s/eV and ~ 0.5 % relative bandwidth.

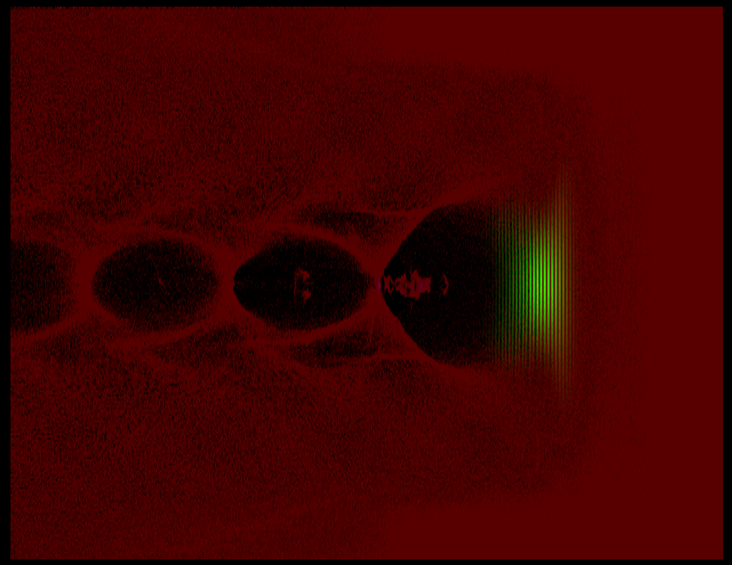
Preliminary Experiments at E4: looking for spectral broadening materials using 100 TW pulses

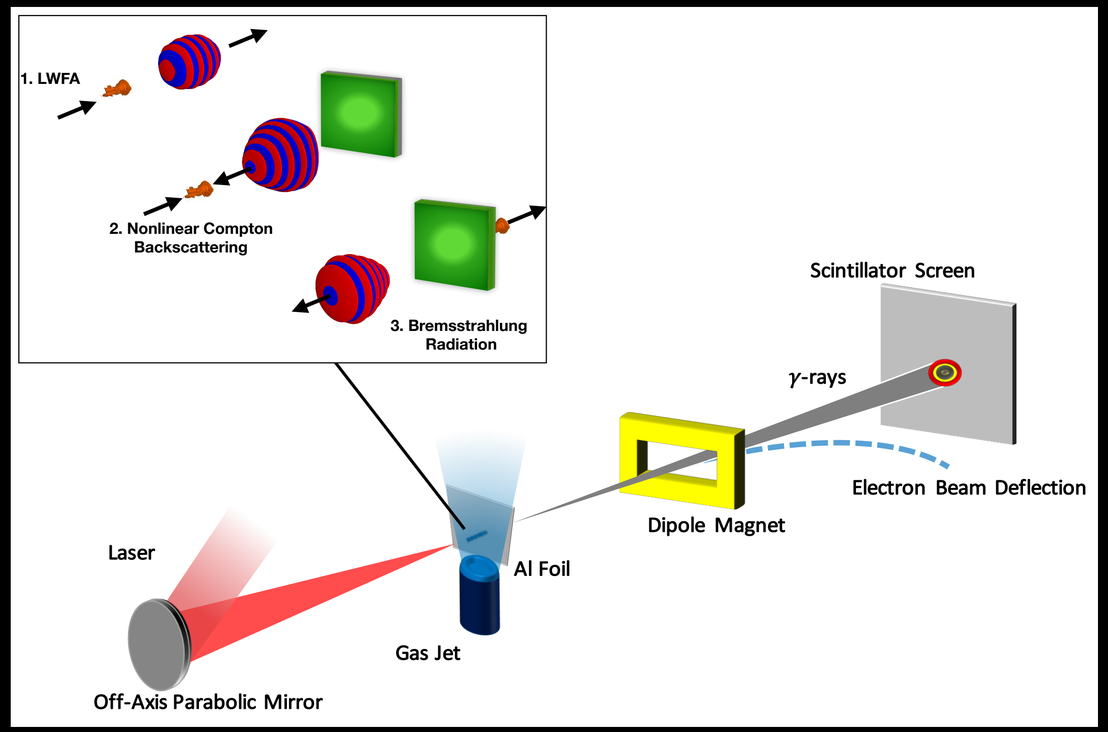


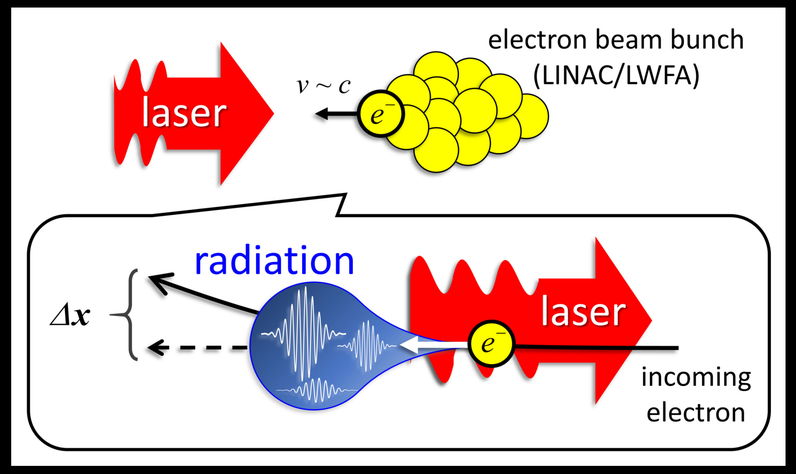
Chamber installation

Laser Plasma Interaction

Particle acceleration as a radiation source







- Simulations are needed before performing experiments
- Lower cost !
- Simulation types

1. Magnetic Hydrodynamic (MHD) code
2. Particle code
3. Particle-In-Cell (PIC) code *

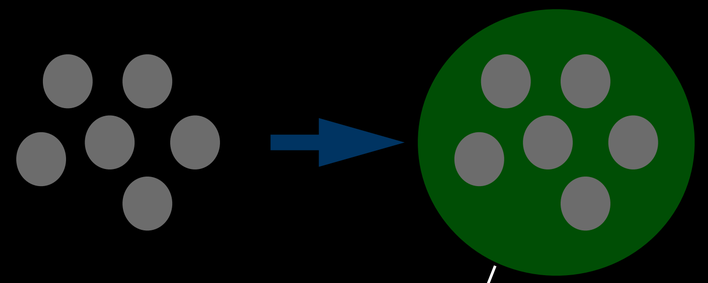
Particle-In-Cell (PIC) simulation

Concept, Lorentz force + Maxwells' equations

C.K. Birdsall and A.B Langdon,
Plasma Physics via Computer Simulation

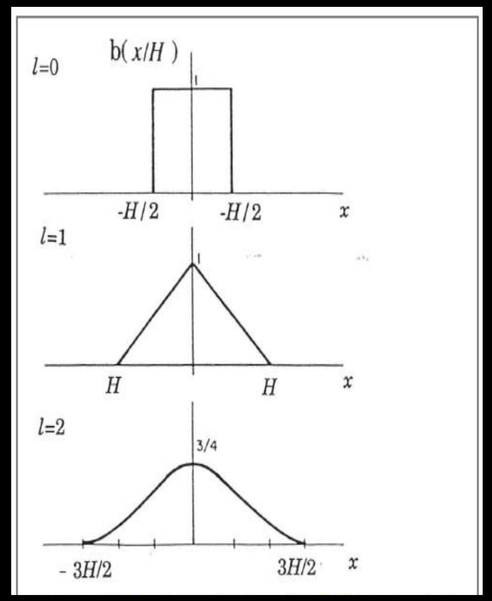
$$\mathbf{F} = e\mathbf{E} + e\mathbf{v} \times \mathbf{B}$$

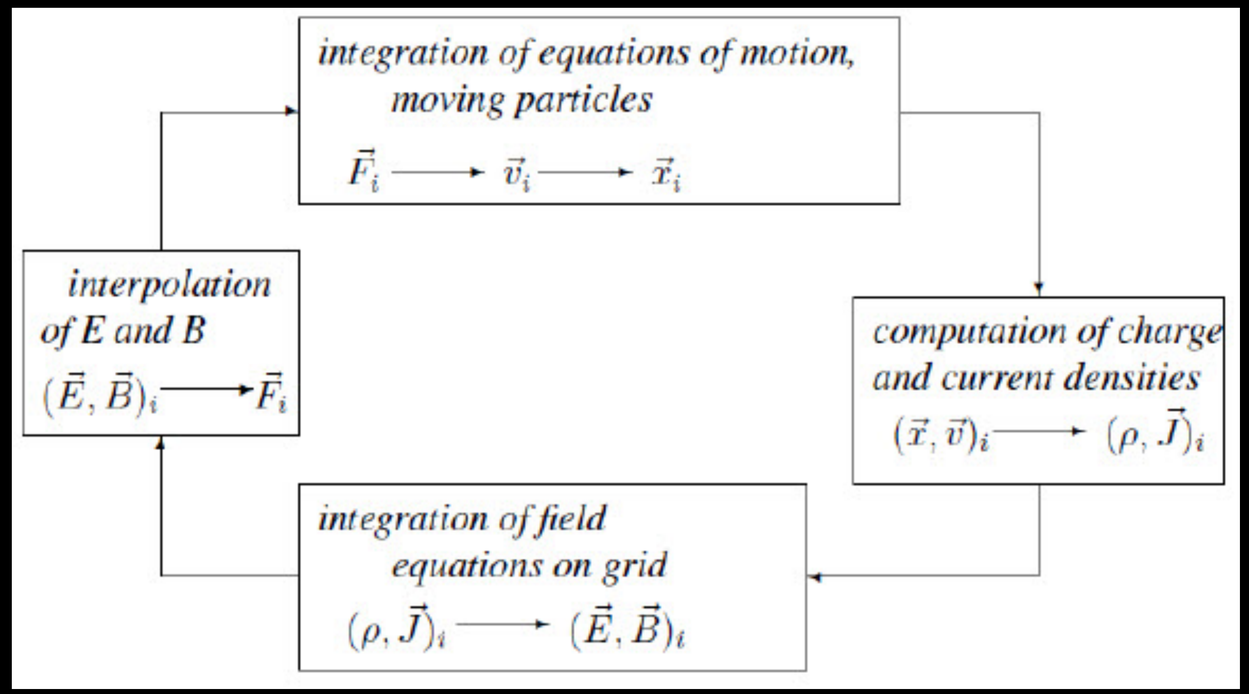
- Simulation approximation for plasma
- Macroparticles
- Particle shapes

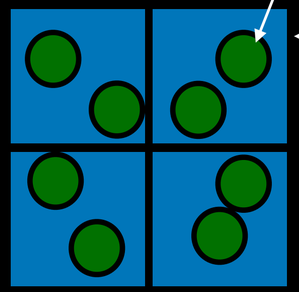


Real particle

Simulation/Macro-particle







Computational cell

2 macroparticle/cell
N_{ppc}=2

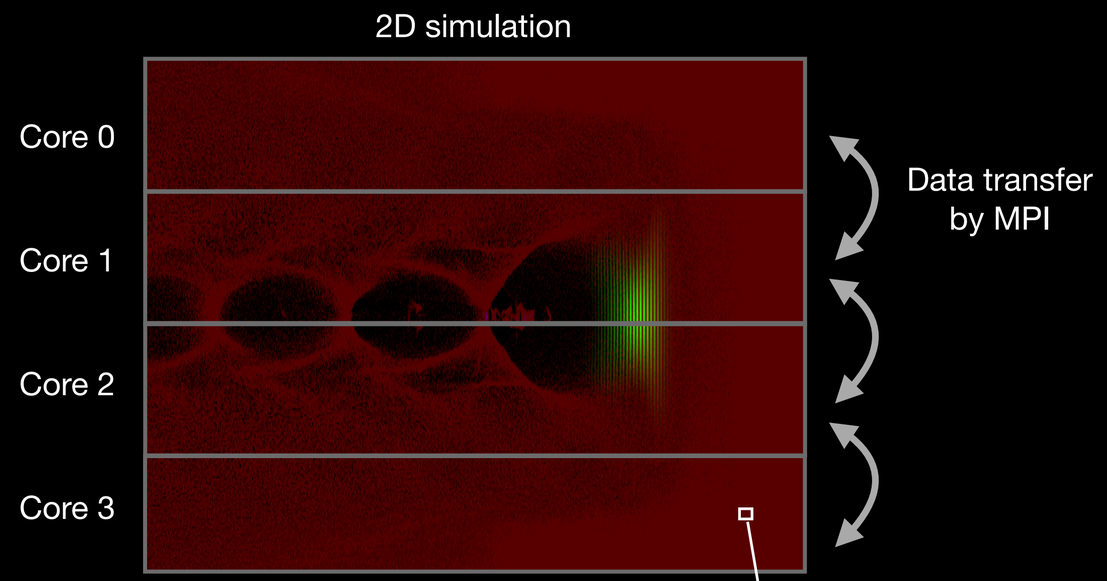
1 particle: 3 positions + 3 momenta + 1 weight
fields: 3 E-fields + 3 B-fields + 3 currents
grids: e.g. 128 x 128 x128
particle-per-cell: e.g. 2
Memory required: ~400 MB (double precisions)
Higher resolutions ~1-2 GB

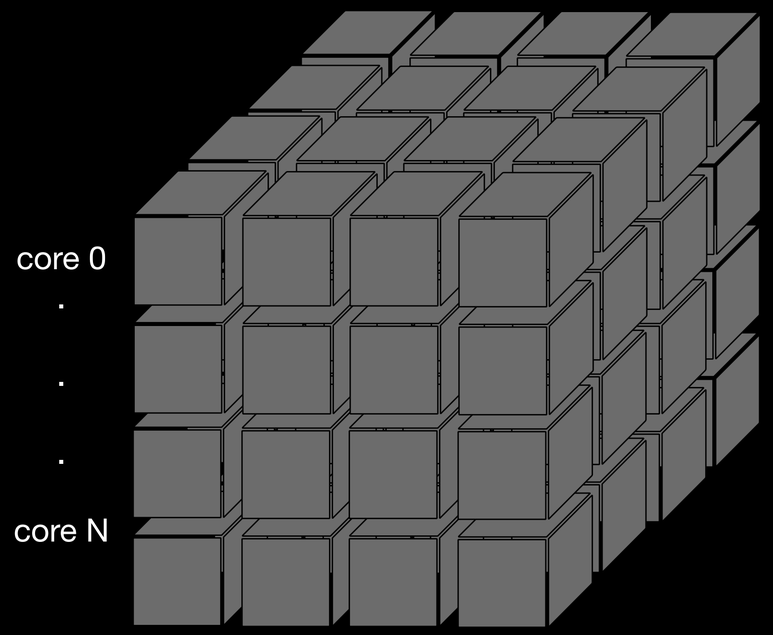
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

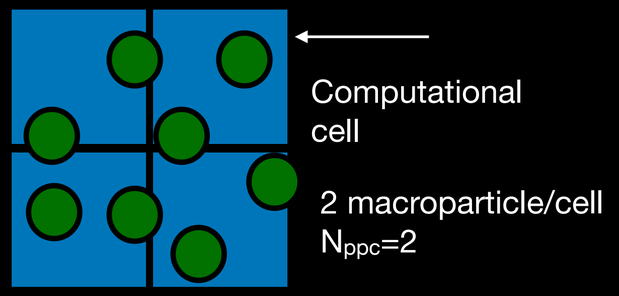
$$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t} \right)$$

Particle-In-Cell (PIC) simulation

- Parallelisation
- Domain decomposition
- Split simulation domain across different processors
- Data transfer among processors are performed by Massage Passing Interface (MPI)
- IntelMPI or OpenMPI (open source), support C++ & FORTRAN







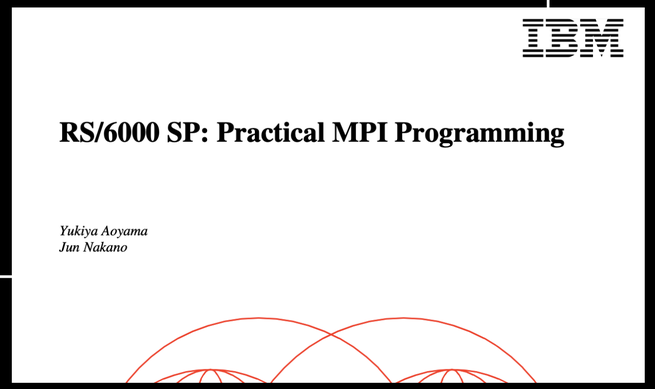
EPOCH

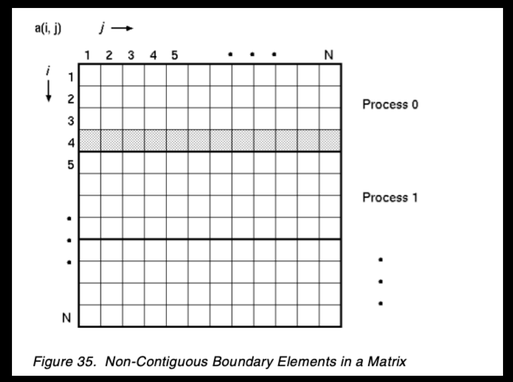
- EPOCH developed in University of Warwick, UK
- Written in FORTRAN90
- Parallelised with MPI
- Open source

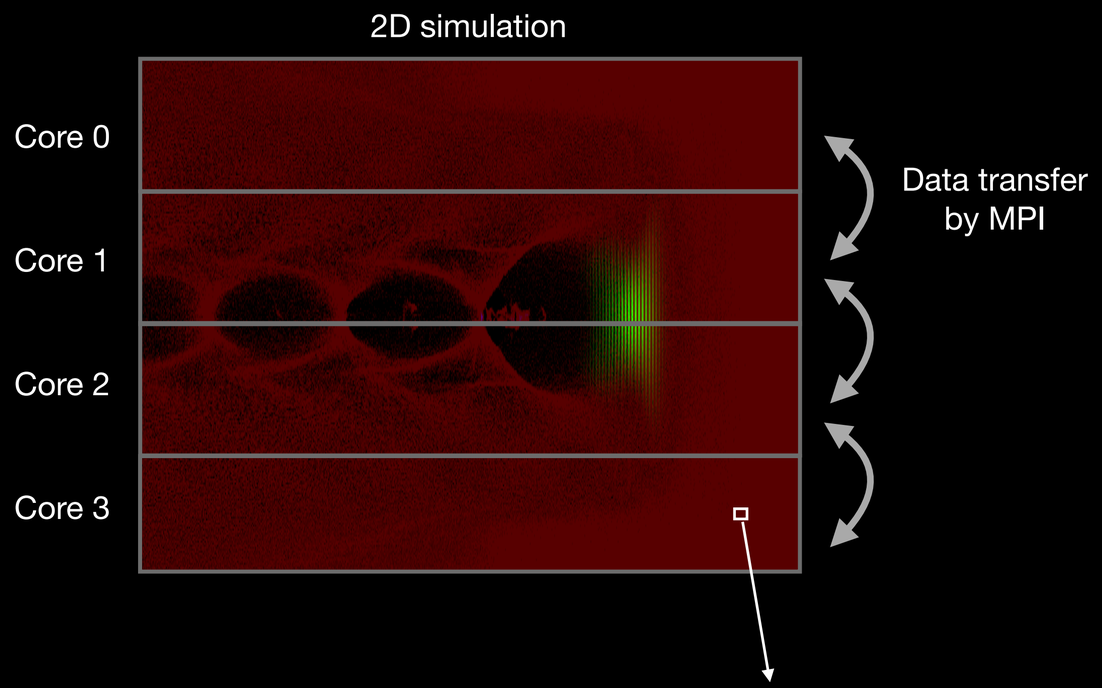
Particle-In-Cell (PIC) simulation

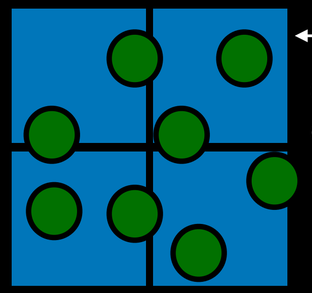
```
PROGRAM main
IMPLICIT NONE
INCLUDE “mpif.h”

CALL MPI_INIT(IERR)
CALL MPI_COMM_SIZE(MPI_COMM_WORLD,NPROCS,IERR)
CALL MPI_COMM_RANK(MPI_COMM_WORLD,MYRANK,IERR)          !initialize MPI
.
.
.

CALL MPI_BCAST(data_dir,100,MPI_CHARACTER,0,MPI_COMM_WORLD,ierr)
.
.
.
CALL MPI_REDUCE(data,datasummed,128,mpi_real8,mpi_sum,mpi_comm_world,ierr)
CALL other MPI functions
.
.
.
CALL MPI_FINALIZE(IERR)

STOP
END
```

Introductory manual on MPI









Computational cell

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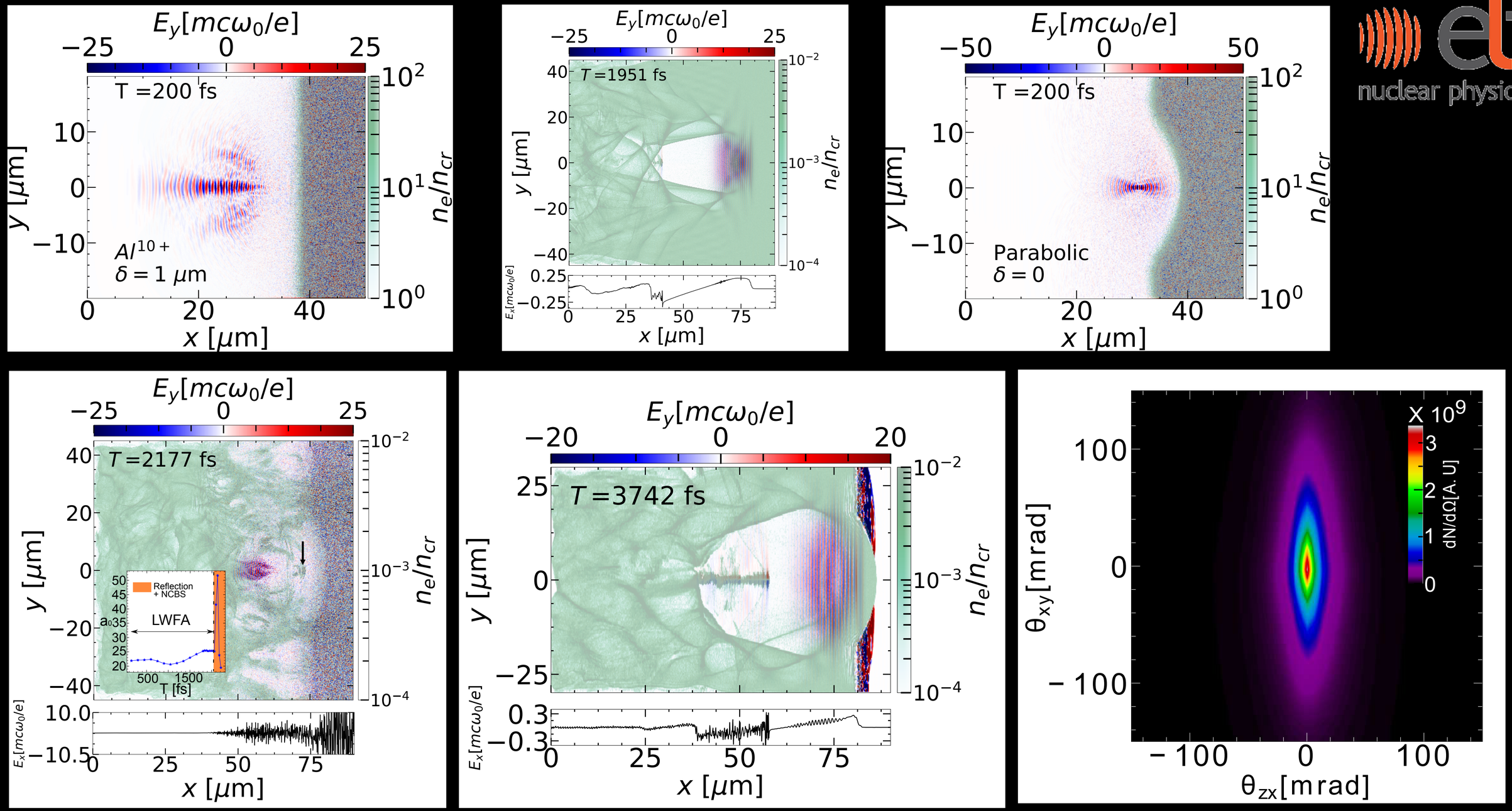
$N_{ppc}=2$

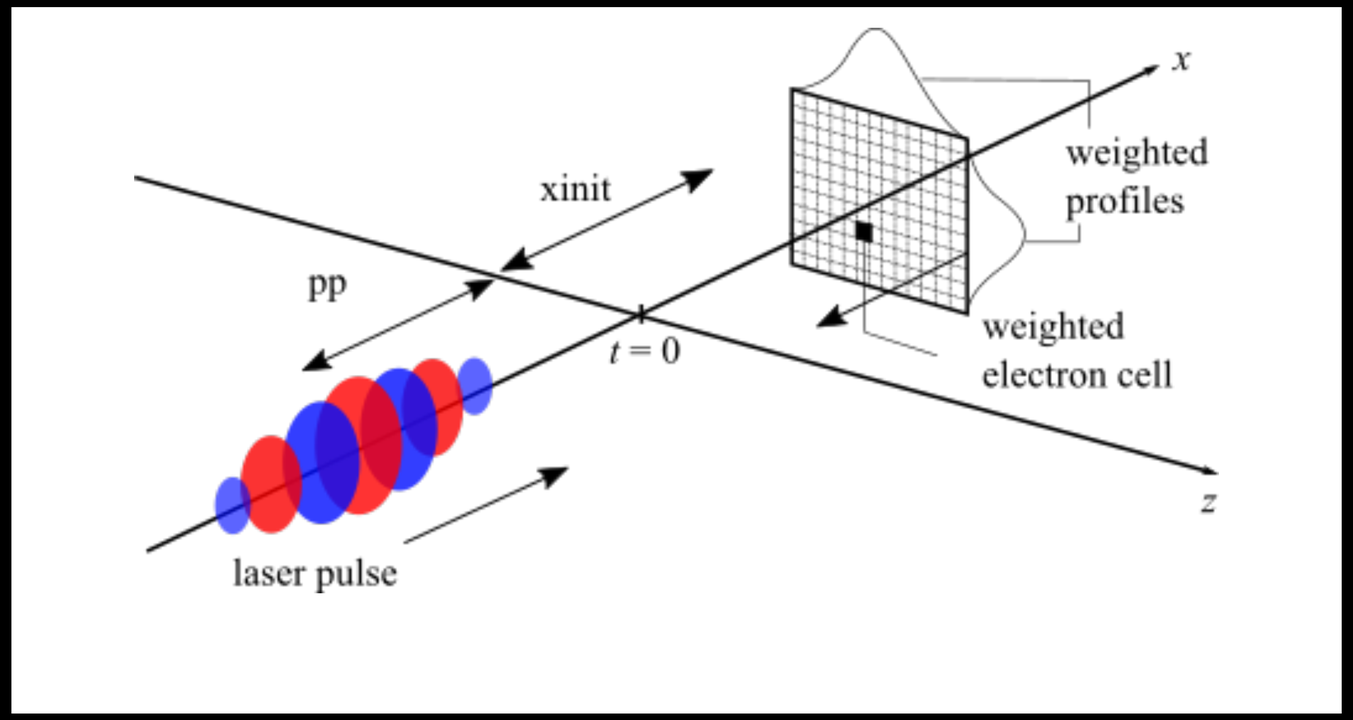
https://www.cs.kent.ac.uk/people/staff/trh/MPI/mpi_ibm.pdf

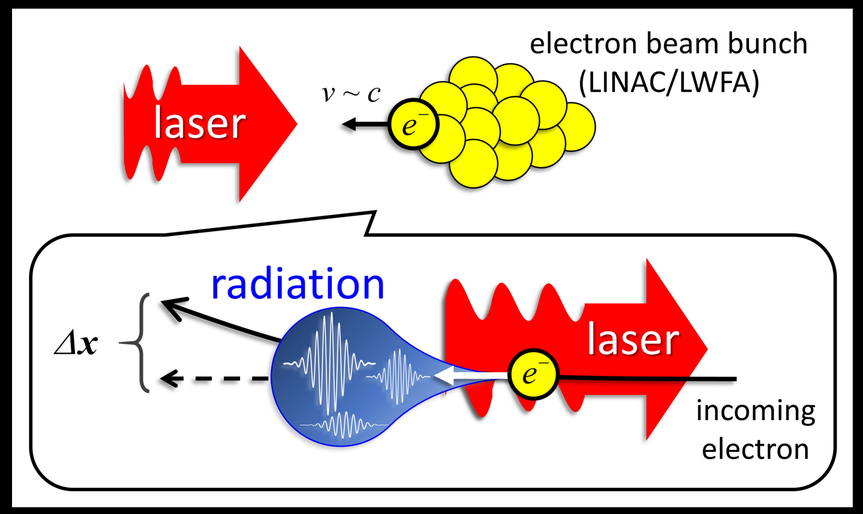


Feasibility studies of an all-optical and compact γ-ray blaster using a 1 PW laser pulse,

Plasma Phys. Control. Fusion 61 (2019) 084009

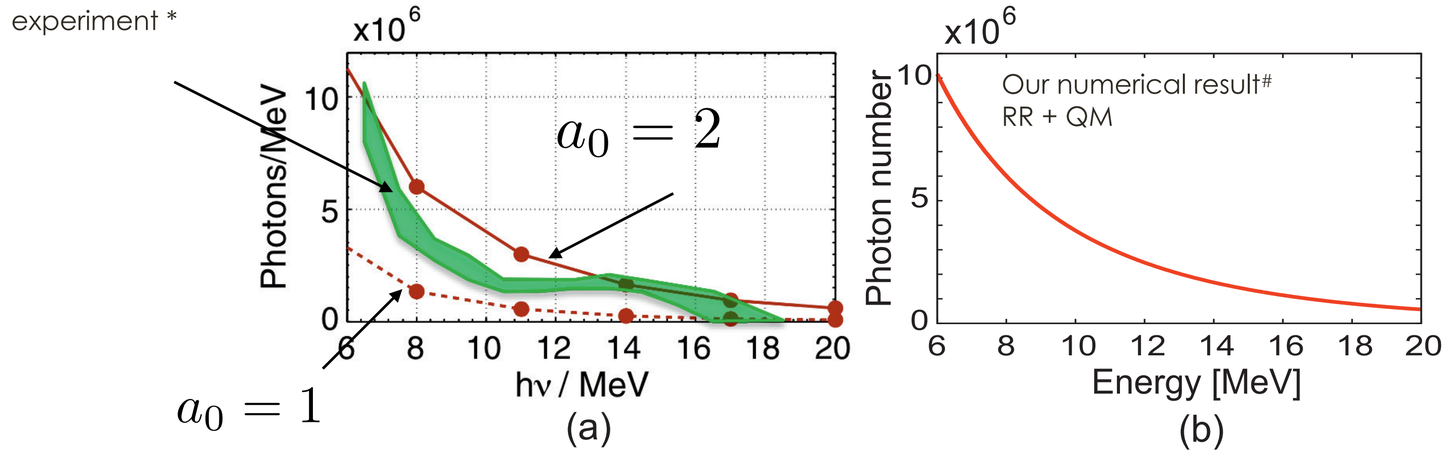
Results of simulation with parallelisation





* G. Sarri et.al , Phys. Rev. Lett. 113, 224801

J. F. Ong, T. Moritaka & H. Takabe, Phys. Plasmas **23**, 053117



- study underlying physics
- compare with experimental data
- cheaper optimisation cost

Thank you