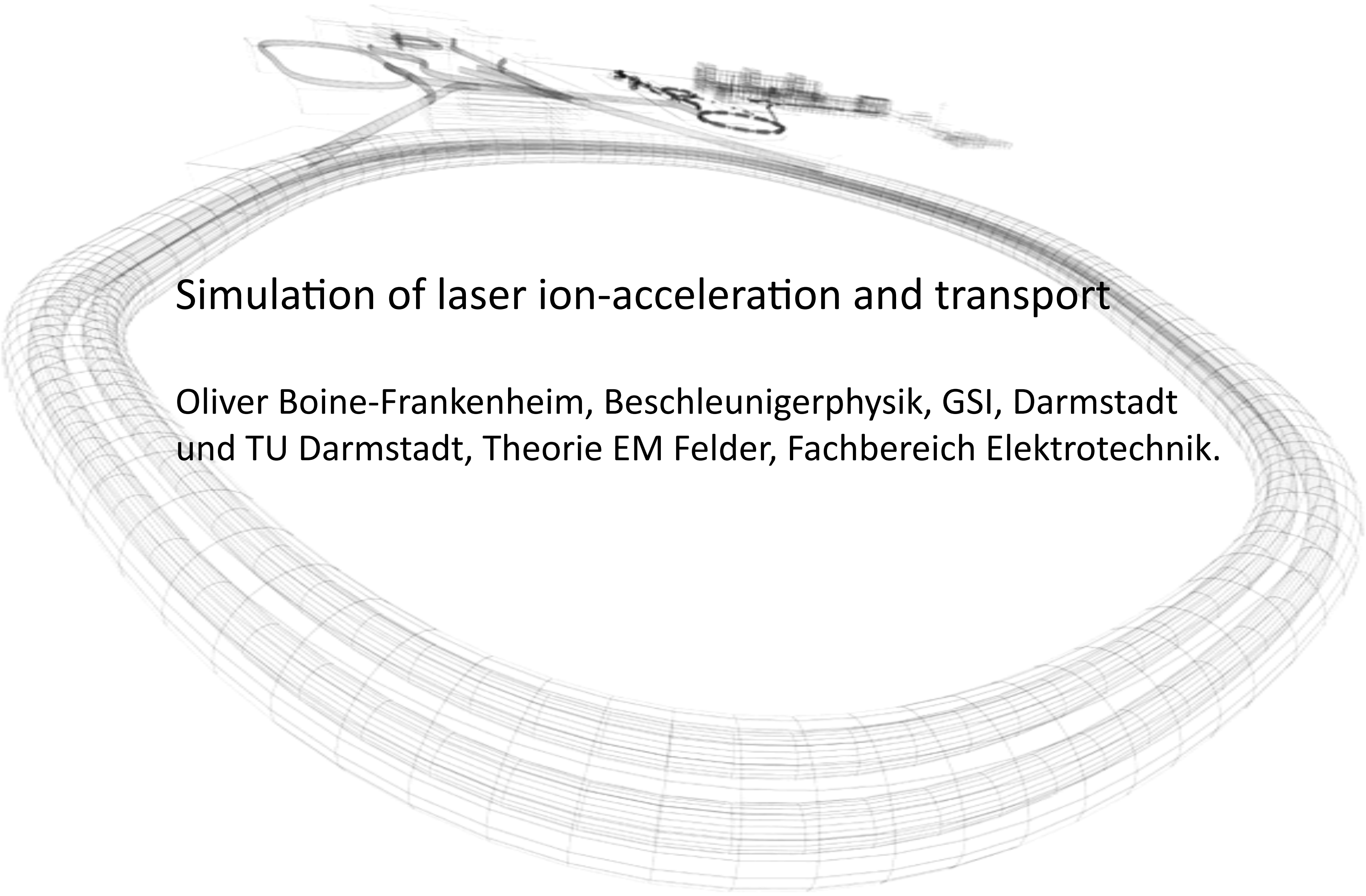


Simulation of laser ion-acceleration and transport

Oliver Boine-Frankenheim, Beschleunigerphysik, GSI, Darmstadt
und TU Darmstadt, Theorie EM Felder, Fachbereich Elektrotechnik.

Simulation of laser ion-acceleration and transport

GSI accelerator physics division:

- theory/simulation of intense ion beams, accelerator experiments, optimization of FAIR rings
- 'new' activity: laser ion-acceleration and transport simulations

Zsolt Lecz (PhD student, TU Darmstadt), Vladimir Kornilov (GSI), Oliver Boine-F. (GSI and TUD)

Planed contributions (related to the project plan):

- Integrated simulations of laser-acceleration and the interface to the accelerator optics.

- Optimization of the laser and target configurations.

- Studies of the de-neutralization, the interaction with intense B-fields for de-neutralization and ion-electron space charge effects during the early beam transport phase.

Plasma/beam simulation codes available at GSI

(list incomplete)

CST particle studio

-3D particle tracking with 3D EM and ES field solvers, not a plasma code

- (expensive) GSI license (5 frontends/3 simulation processes), Windows (Linux solvers)

OOPIC (Tech-X Corp., Boulder)

- 2D (x-y or r-z) EM or ES Particle-In-Cell (PIC) plasma code.
- Based on the Berkeley XOOPIC code
- Monte-Carlo collisions and ionization
- inexpensive licenses for educational use, Mac/Win/Linux

VORPAL (Tech-X Corp., Boulder)

-3D EM plasma and beam simulation tool.

-one of the most flexible, high performance plasma/beam simulation tool available
  ('alternative': LSP code from ATK, D. Welch et al.)

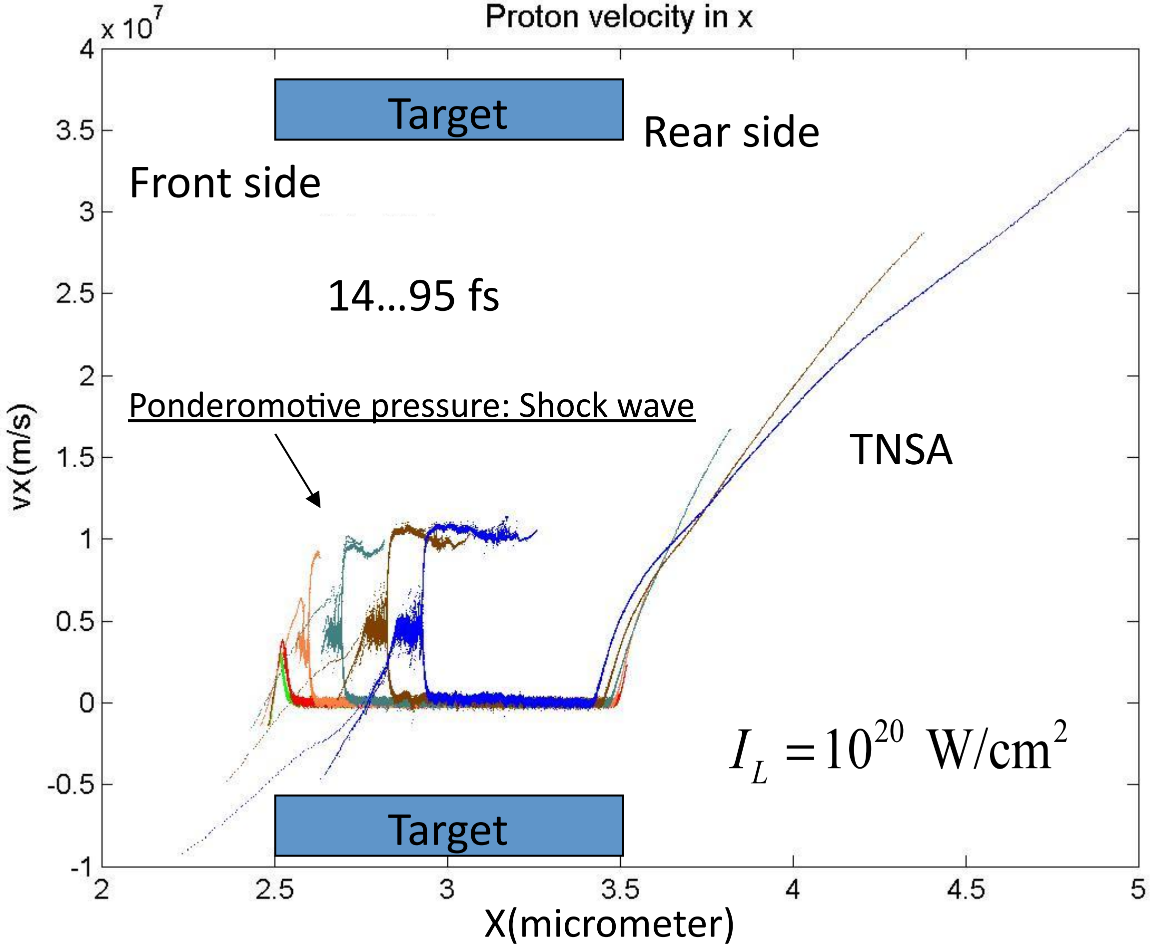
-(moderately expensive) GSI license: Linux, limited to 16 CPU cores

DYNAID

- 1D implicit fluid/PIC hybrid solver

Simulation of laser proton acceleration with OOPIC

Zsolt Lecz



Front side

Rear side

14…95 fs

Ponderomotive pressure: Shock wave

TNSA

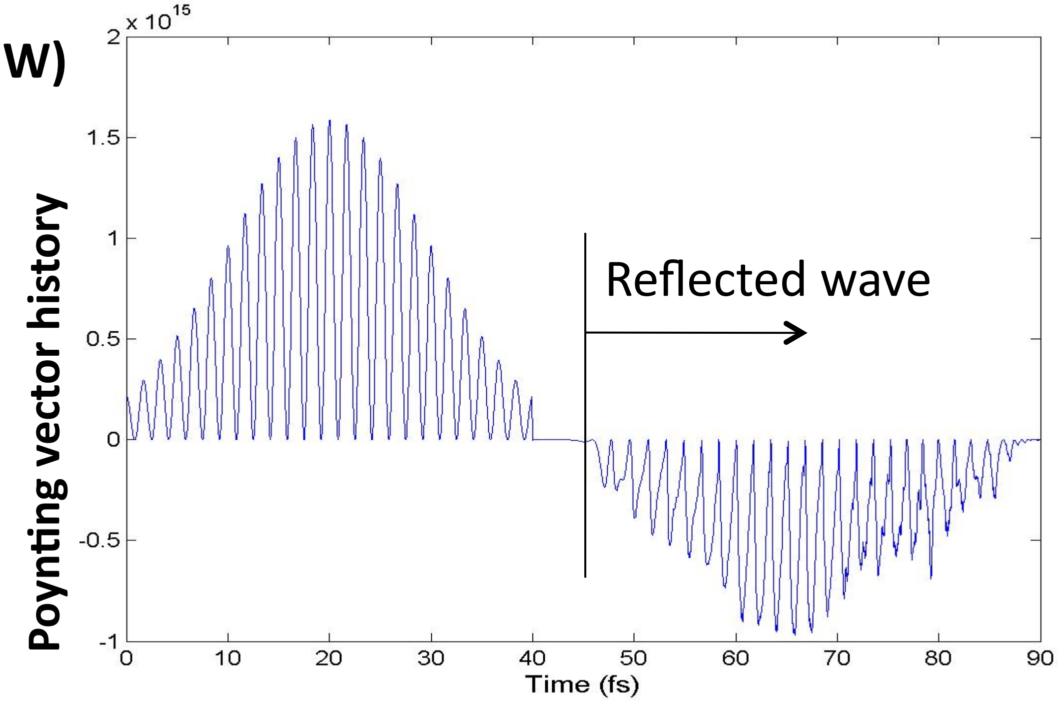
$$I_L = 10^{20}\ \mathrm{W/cm^2}$$

1D simulation
OOPic code

Laser absorption

1D OOPIC simulation (perpendicular incidence)

Zsolt Lecz



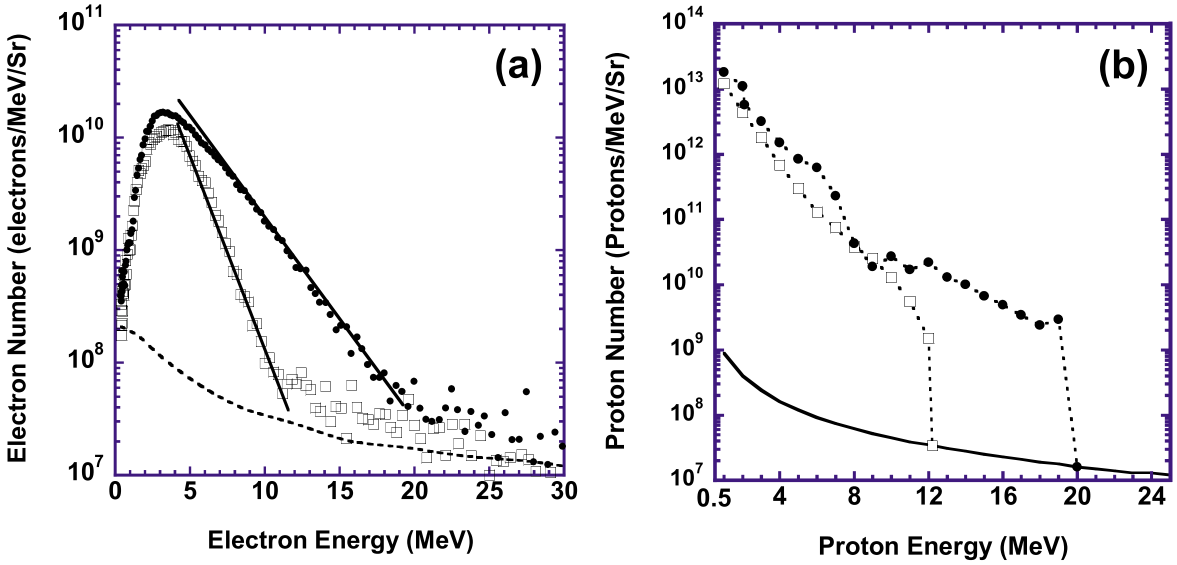
The energy of laser pulse is converted into hot electron energy:

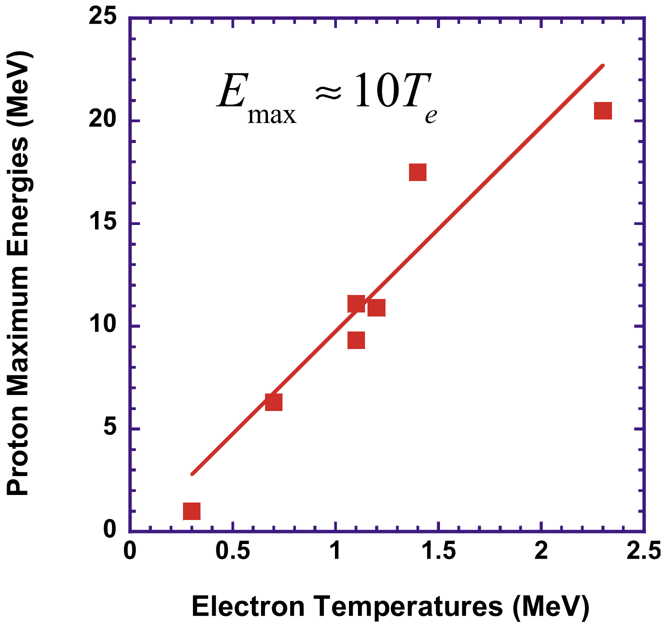
- Resonant absorption, vacuum heating, different skin effects, ponderomotive absorption,….

Correlation between hot electron temperature and maximum proton energy

M. Tampo et al., PoP 2010

Measured electron and proton spectra (GEKKO, Osaka)





Fluid expansion: P. Mora, PRL 2003:

$$E_{\max} = 2T_e\left(\ln\left\{\left[\frac{\omega_p(n_e)\Delta t}{\sqrt{2e}}\right] + \sqrt{1+\left[\frac{\omega_p(n_e)\Delta t}{\sqrt{2e}}\right]^2}\right\}\right)^2$$

Proton and electron energy distribution

OOPIC simulations

Simulation parameters:

Laser intensity: $I = 4 \cdot 10^{18} \ldots 4 \cdot 10^{19}\ \mathrm{W/cm^2}$

Pulse length: $\tau_L = 100\ \mathrm{fs}$

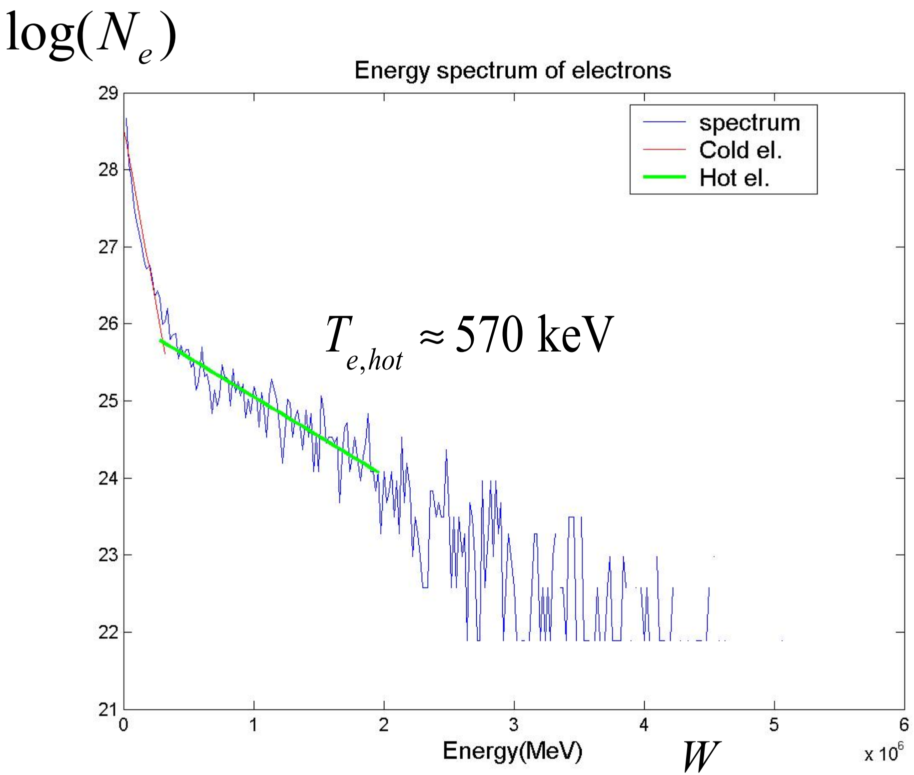
Density: $n_e / n_c = 10$

P. Mora, PRL 2003; M. Tampo, et al. PoP 2010

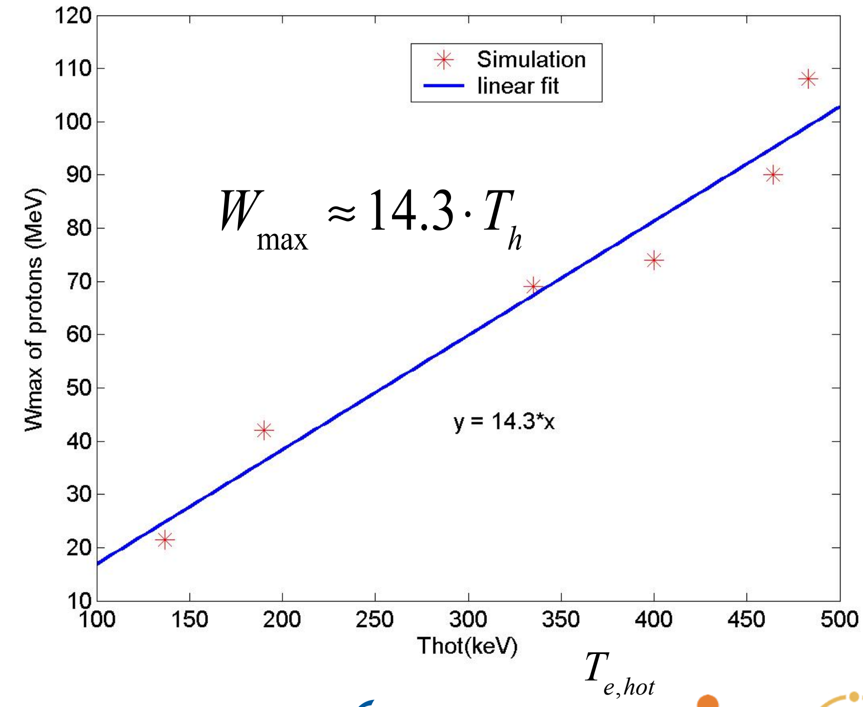
Maximum proton energy W$_{\max}$ from fluid expansion model:

$$W_{\max} = 2T_h[\ln(t_p + \sqrt{t_p^2 + 1})]^2$$

$$\Rightarrow W_{p,\max} \approx 27 \cdot T_{e,hot}$$



$T_{e,hot} \approx 570\ \mathrm{keV}$



$W_{\max} \approx 14.3 \cdot T_h$

Zsolt Lecz

OOPIC limitations

- Great for learning/lectures and for studying reduced models.
- Can be run parallel (Linux only) with mpi, but only with many restrictions concerning the geometry and boundaries.
- Serial mode: only 1D simulation studies
- No visualization in the parallel mode (dumps HDF5 files).
- Restricted input particle distributions and EM wave launcher.

VORPAL 4.2

TECH-X CORPORATION

Relativistic EM PIC model

-FDTD with cut-cell boundaries (complex geometries)
-Moving window
-1D, 2D, 3D
-higher-order PIC macro-particles, fluid-PIC hybrid

Broad range of particle sources and emitters

Collision models

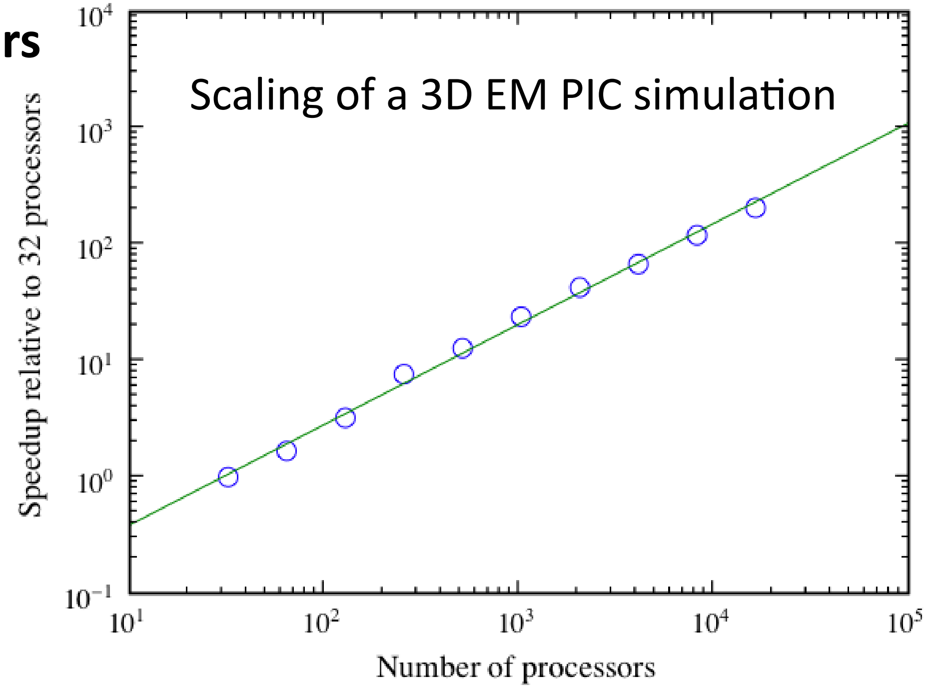
-Direct Simulation Monte Carlo (DSMC)
-Reactions, field/impact ionization

Massively parallel

-visualization with IDL

Accelerator elements

….


Scaling of a 3D EM PIC simulation

Plasma and accelerator simulations with VORPAL

30 September 2004

International weekly journal of science

nature

£10.00

www.nature.com/nature

Dream beam

The dawn of compact particle accelerators

Disease control
Europe plays catch-up

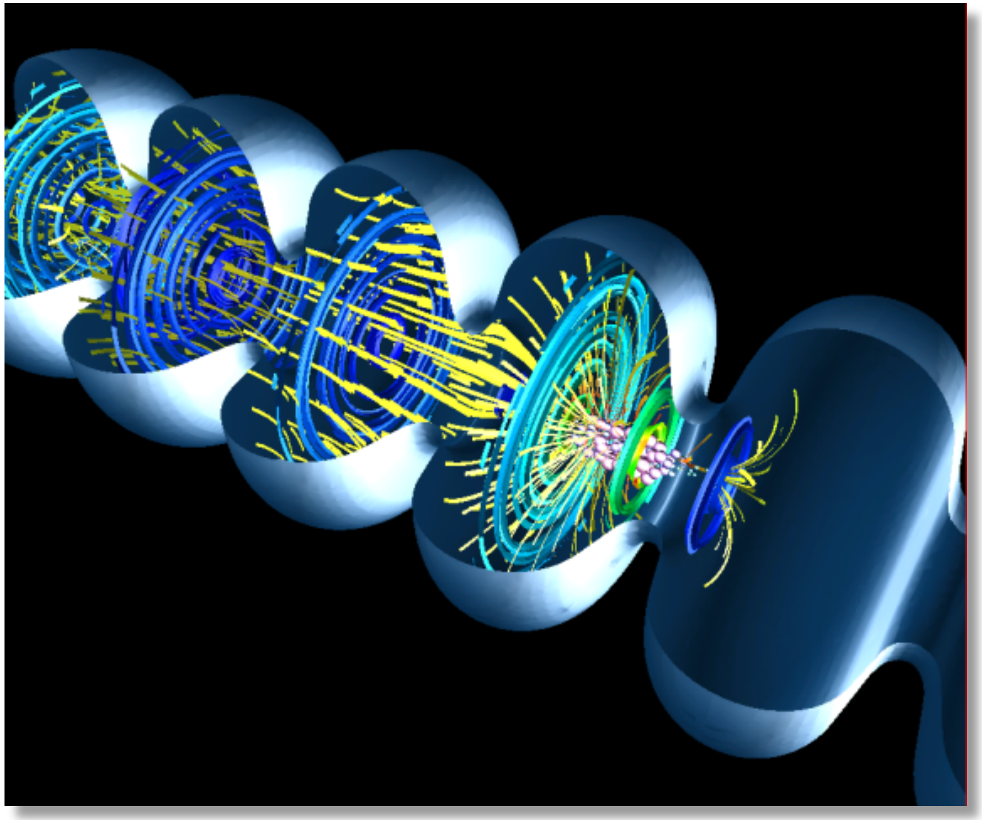
The Earth's hum
Sounds of air and sea

Protein folding
Escape from the ribosome

Human ancestry
One from all and all from one

technology feature RNA interference

Plasma wakefield acceleration



Conventional acceleration
(RF cavity)

Plans with VORPAL at GSI

‘Integrated simulations’:

Simulation of the laser target interaction for PHELIX parameters

Study of the resulting neutralized beam distribution (2D/3D).

Further expansion and transport of the initial distribution on a coarser grid using the low-frequency E,B solvers.

-> Optimization of experimental set-up.

Large scale plasma simulations with DYNAID

implict multi-fluid/PIC hybrid code

Implicit time-advance schemes:

$\omega_{pe}\Delta t \gtrsim 1 \quad \omega_{ce}\Delta t \gtrsim 1 \qquad \nu\Delta t \gtrsim 1$

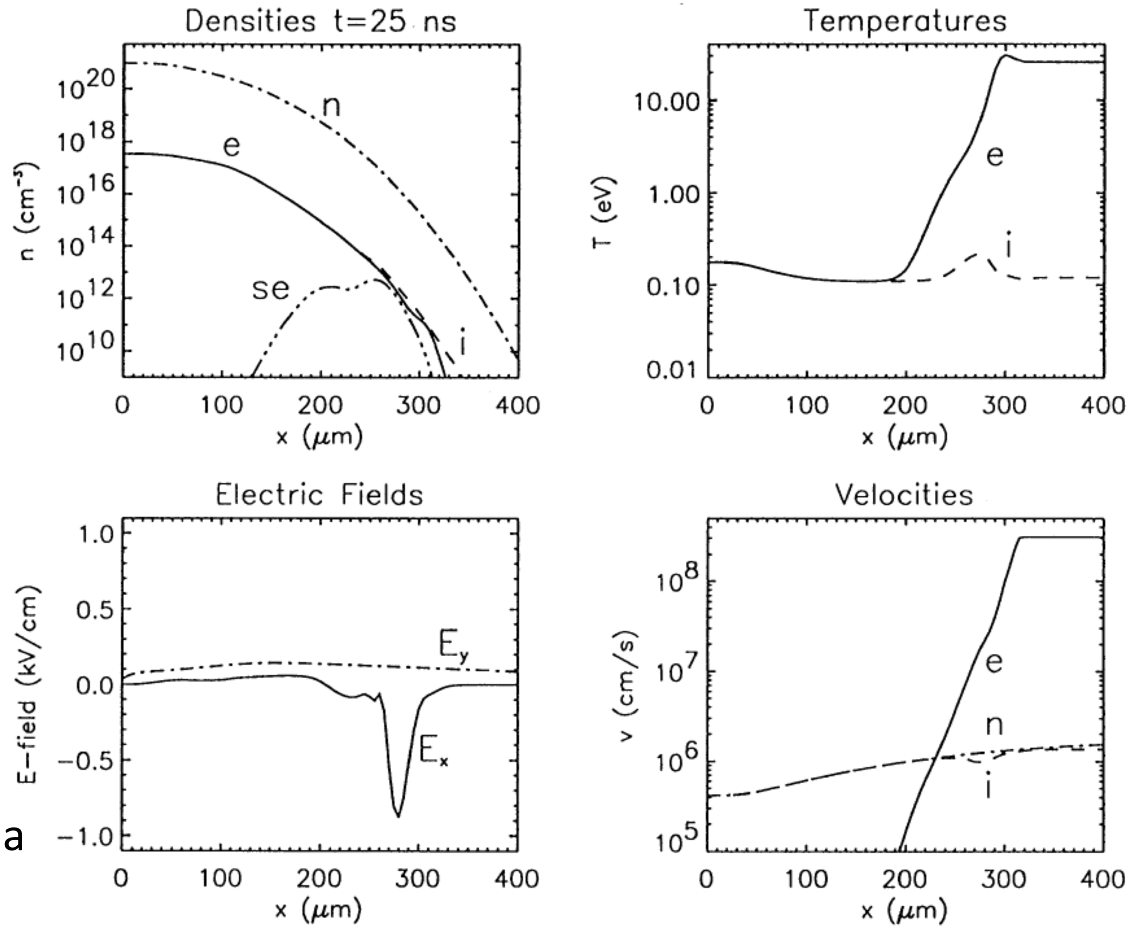
Example: Expansion of a partially ionized gas (Li, Li$^+$, e) across a strong magnetic field with B_z=2 T.

Internal electric field: $E_y + u_x \times B_z = 0$

->$E \times B$ drift across the magnetic field

Time-step: $\omega_{pe}\Delta t \lesssim 100 \quad \omega_{ce}\Delta t \approx 1$

Plan: Develop a 2D r-z implicit PIC code for the expanding beam/plasma to study the de-neutralization.



Implicit PIC: A.Friedman, A. B. Langdon, and B. I. Cohen, Plasma Physics and Controlled Fusion **6, 225 (1981)**

Implicit multi-fluid: P.W. Rambo, J. Denavit, J. Comput. Phys. 98 (1992) 317.

DYNAID: O. Boine-F., T. Pointon, Th. Mehlhorn, Nucl. Instr. and Meth. A 415 (1998) 473

Summary

Integrated simulation of the laser acceleration and transport using the VORPAL code.

Reduced models (plasma expansion, …..) and their numerical/analytical solutions.

Support the experimental activities with plasma/beam simulation studies.

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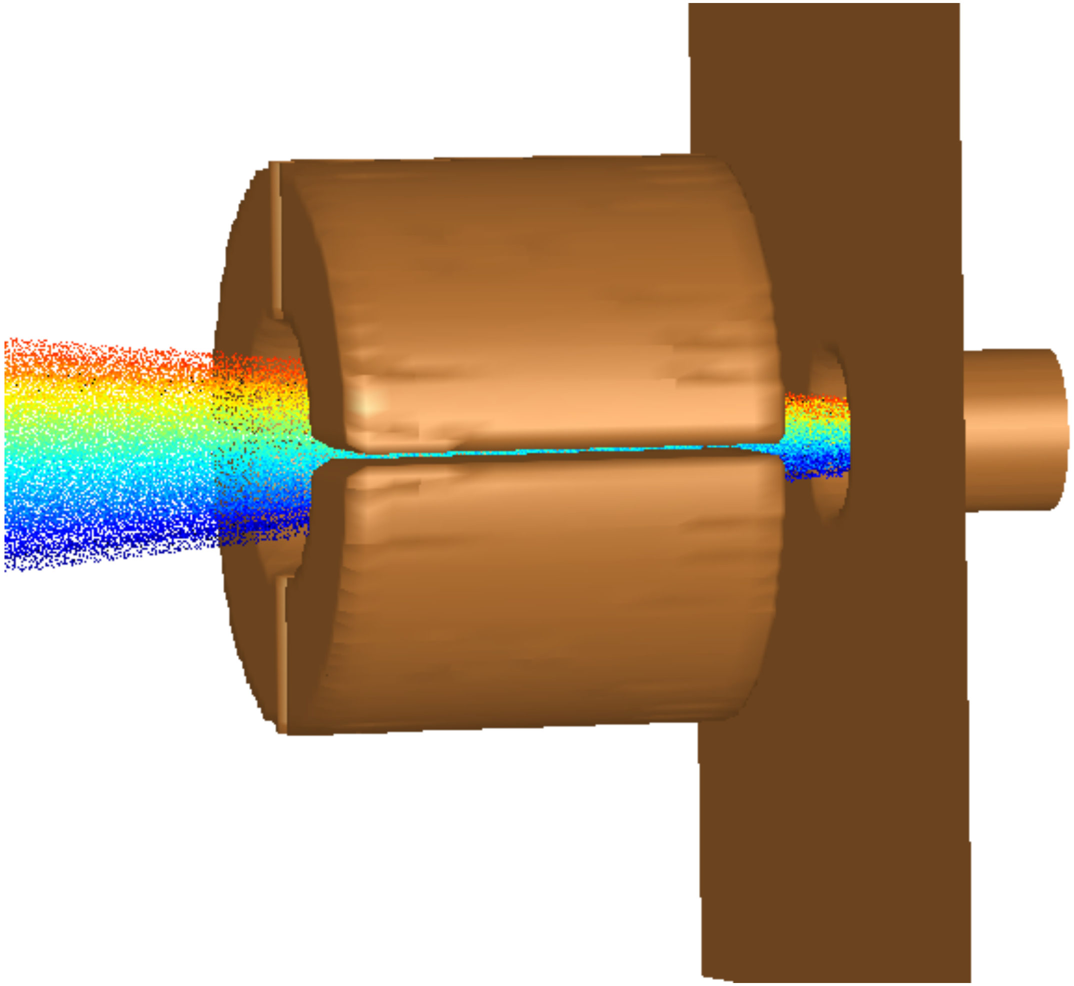
VORPAL example: Chopper for low energy ion beams



- Demonstrate beam tracking with realistic beam

- Investigate effects of neutralization due to plasma

- Investigate effects of bias potential for expelling positive ions

- Demonstrate beam steering with applied +/- 2.5kV potential