Mitglied der Helmholtz-Gemeinschaft

4th EMMI workshop on Plasma Physics with Intense Heavy Ion and Laser Beams

Laser-induced Coulomb Implosion in Nanostructured Targets

May 22, 2011 | Anupam Karmakar and Paul Gibbon

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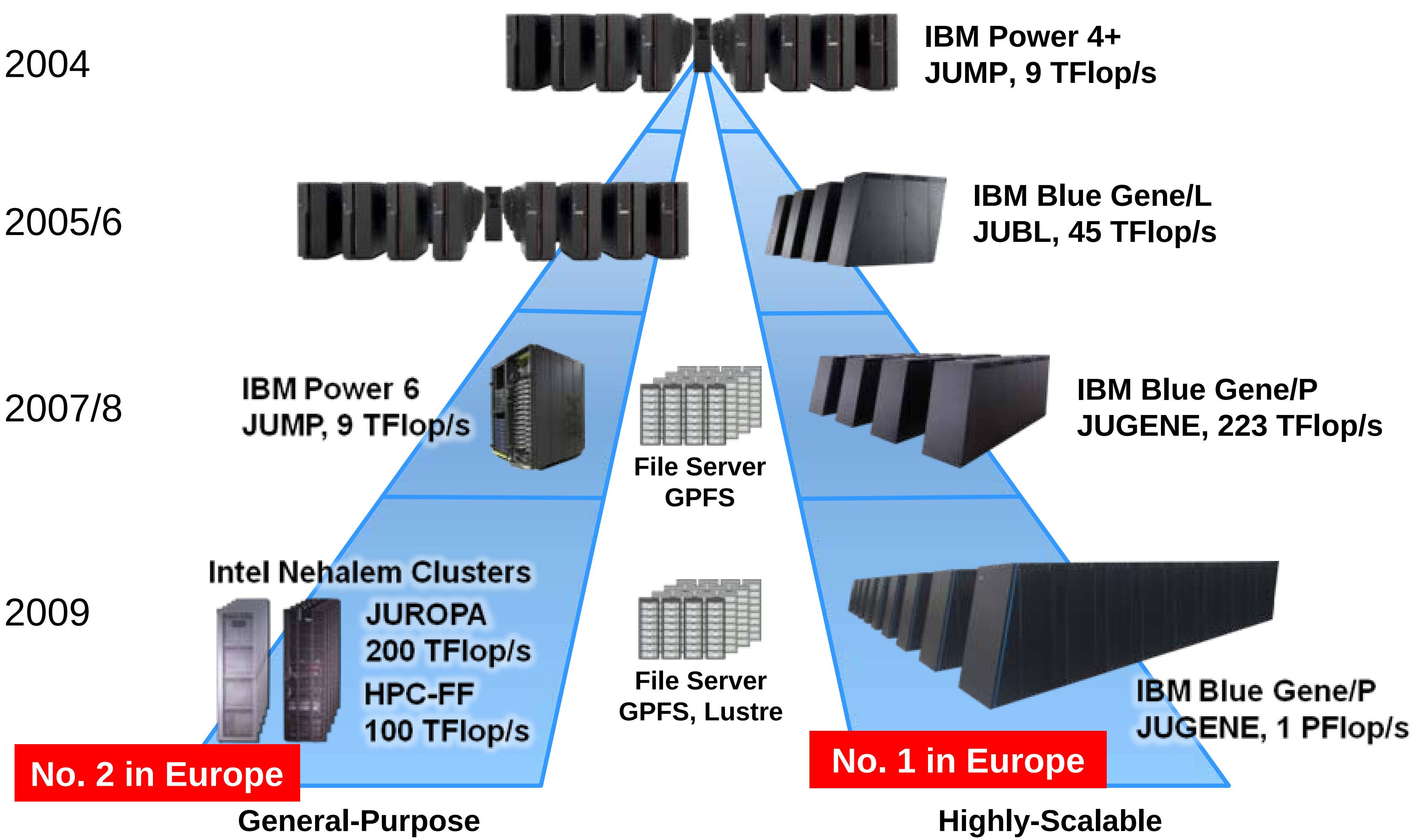
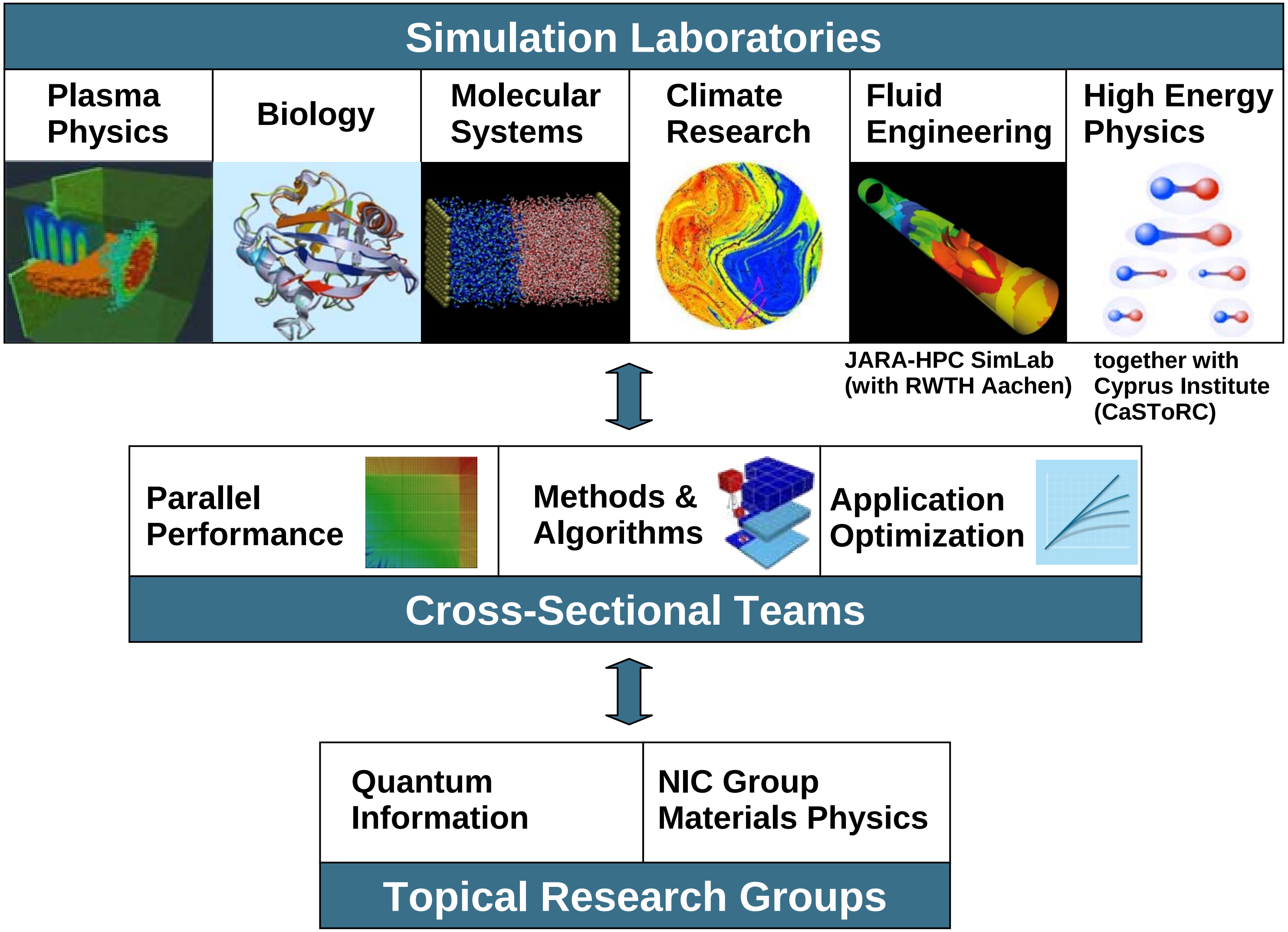
Overview

- Activities in Simulation Laboratory Plasma Physics, FZJ
- Importance of porous foam targets.
- Simulation of Coulomb implosion in foam array.
- Dependence on pore size and shell density.
- Neutron yield estimation.
- Conclusion

Supercomputer Systems: Dual Concept

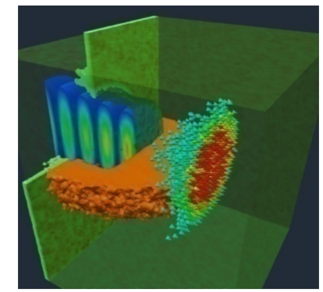


Domain-specific Research and Support

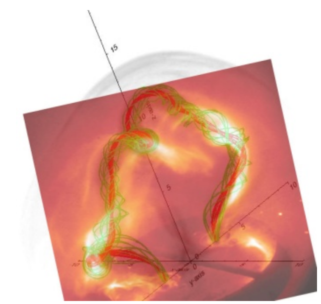


Simulation Laboratory Plasma Physics

- Research
  - Kinetic methods: PIC, Vlasov, Tree codes
  - Fluid + MHD models
  - Transport: Monte Carlo
- Support
  - Plasma model porting & scaling
  - Code benchmarking – eg: 3D PIC
- Codes
  - PSC, ILLUMINATION, PEPC etc.
- Outreach
  - Internal FZJ groups
  - Regional Universities
  - National: GSI (HA-EMMI), MPQ Garching, HZD-Rossendorf

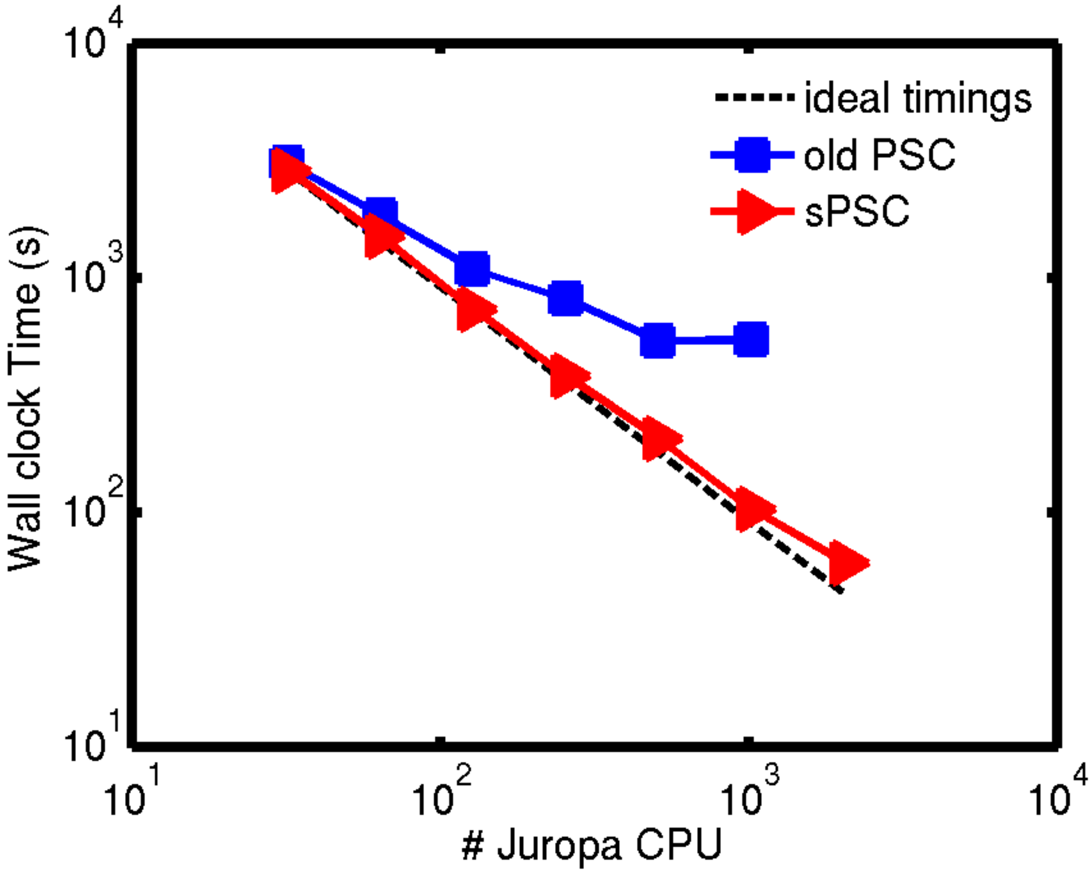


Laser-ion acceleration



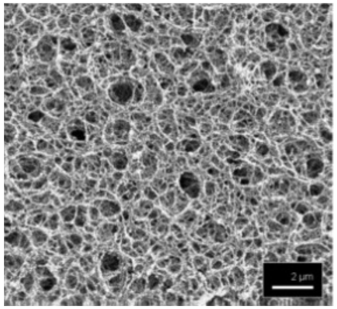
Solar flare modeling

Simulation Laboratory Plasma Physics

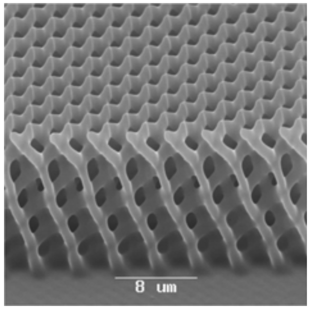


The foam concept

- Solid lattice structure ~ 3-5 nm
- Pores: 20-500 nm
- Ion acceleration in a converging spherical geometry: a multiple Coulomb implosion.
- Potential as efficient hard x-ray or neutron source.



TAC foam (Khalenkov 2006)



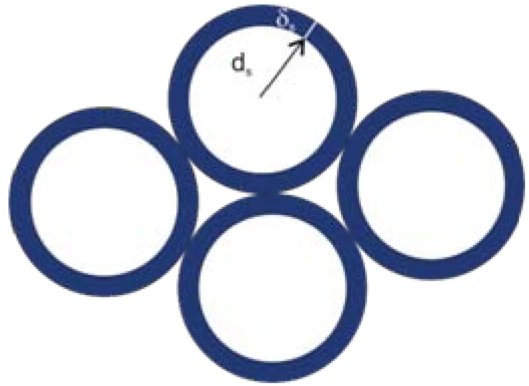
hybrid polymer foam (Hannover 2006)

The foam concept

Necessary conditions for this scheme:

a)Condition of shell ionization:

$$a_0 > \frac{n_s}{n_c} \cdot \frac{\delta_s}{\lambda_L}$$



Schematic model

b)Condition for transparency for the short pulse:

$$\frac{\overline{n_e}}{n_c} \equiv \frac{n_s}{n_c} \cdot \frac{\delta_s}{d_s} < 1$$

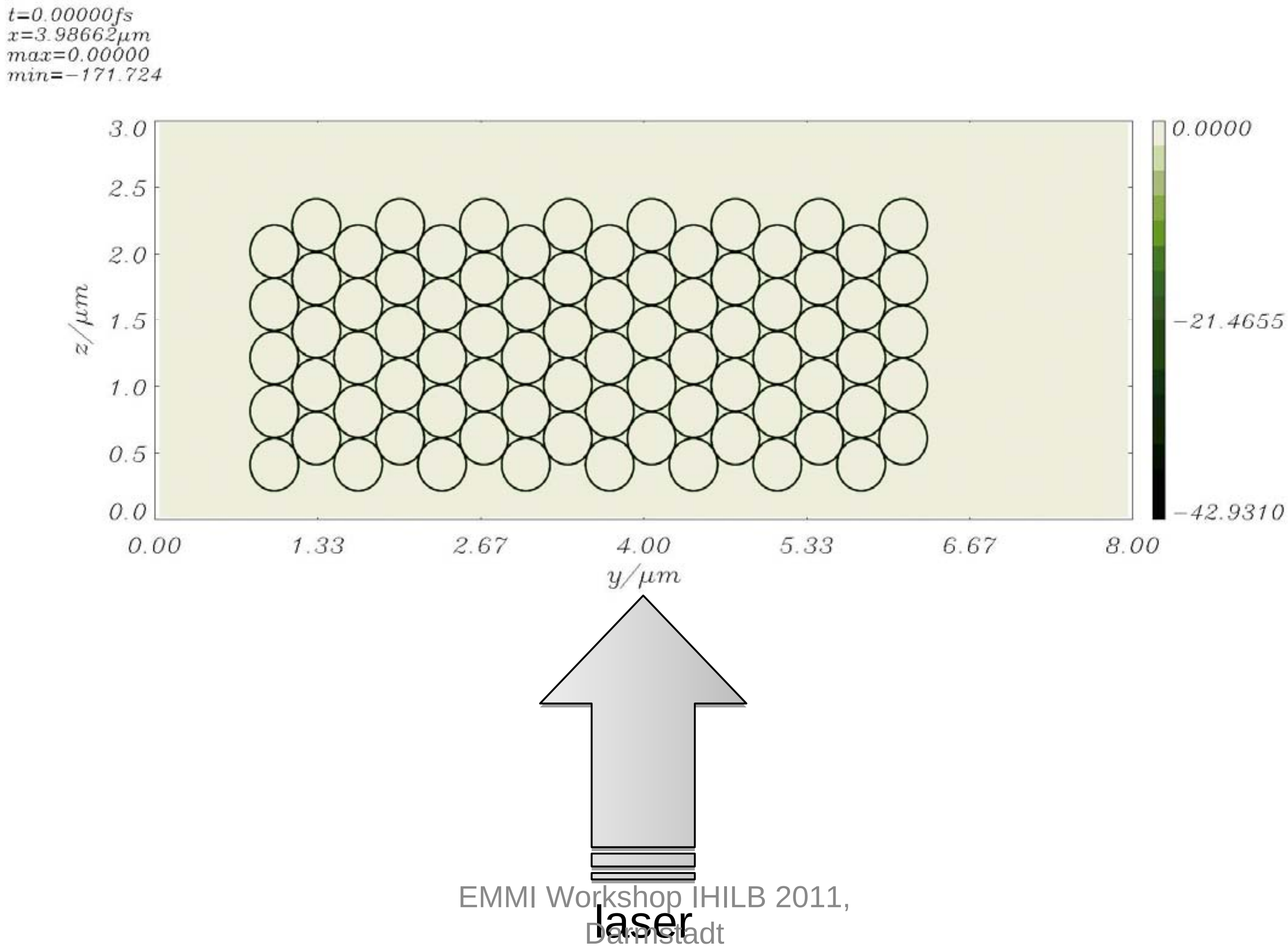
Analogous to TNSA in concave solid targets
➡ realized in nanostructured foam

Coulomb Implosion in converging spherical geometry

- Laser : 1 µm, I0 ~ 10^{18} W/cm^2, p-polarized, 30 fs (FWHM)
- 2D Foam array:
  - ∅ = 400 nm, wall thickness = 3 nm,
  - wall density = 80nc, skin depth = 18.77 nm
  - Arranged in 2d array of 16x5 shells
- Total 1.2 million simulation particles.
- Resolutions < shell wall thickness.
- Runs on 1024 Intel cores for few hours.
- Cold electrons, fully ionized plasma.

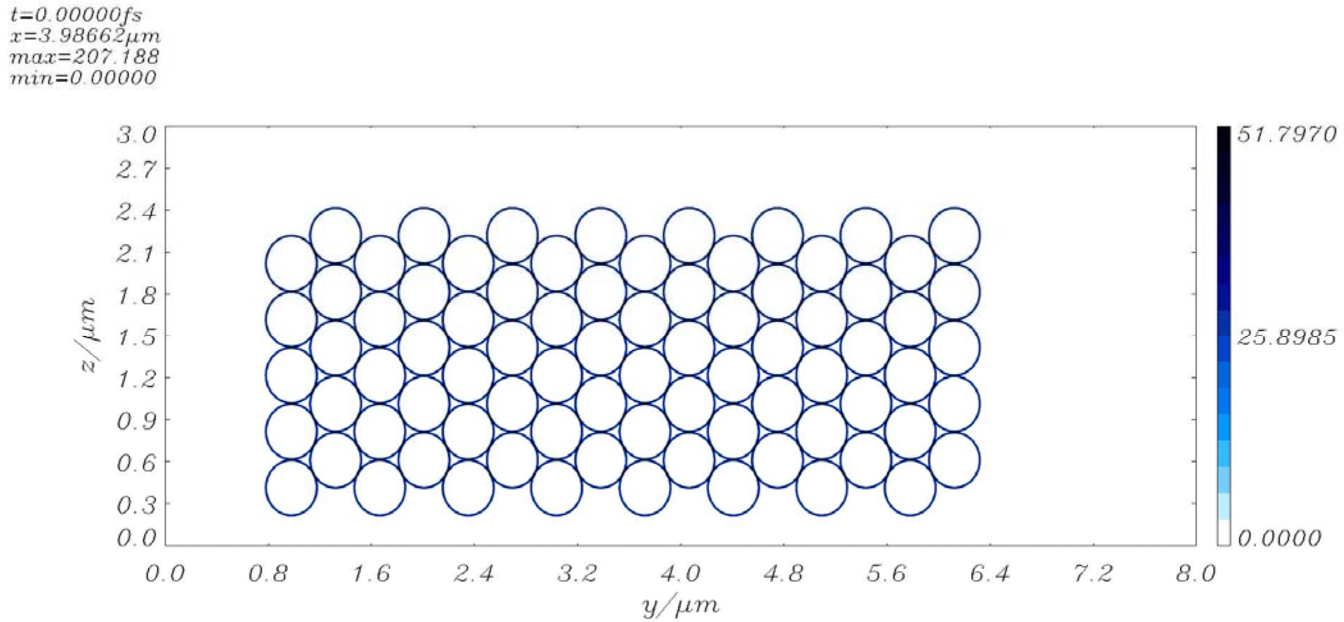
Coulomb Implosion in converging spherical geometry

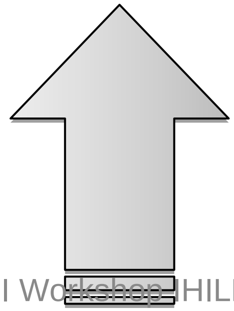
Electron density distribution



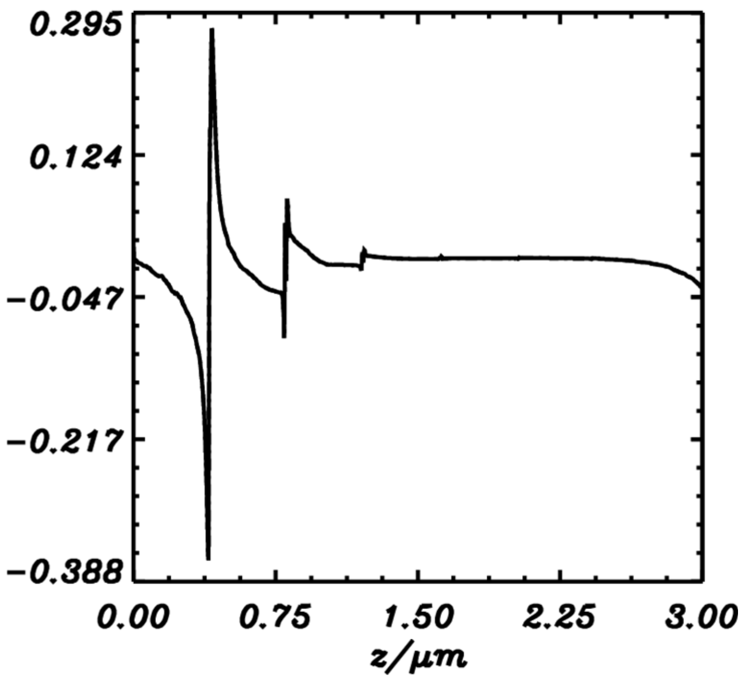
Coulomb Implosion in converging spherical geometry

Ion density distribution

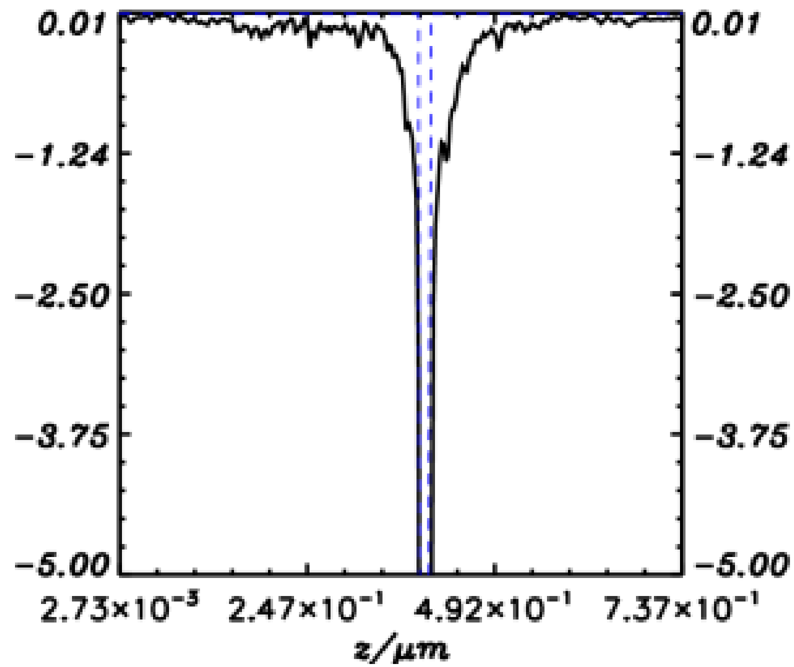




Analysis of CI dynamics: field & density line outs



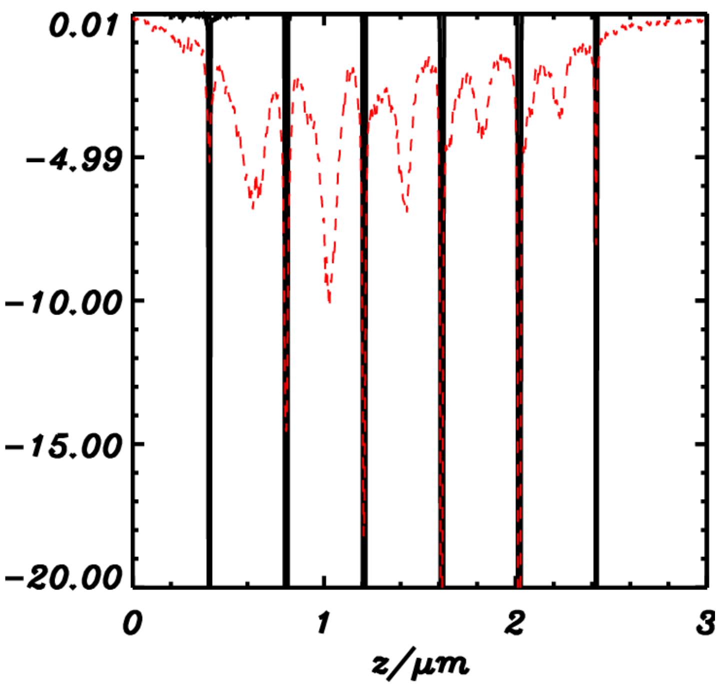
Longitudinal field few fs after irradiation



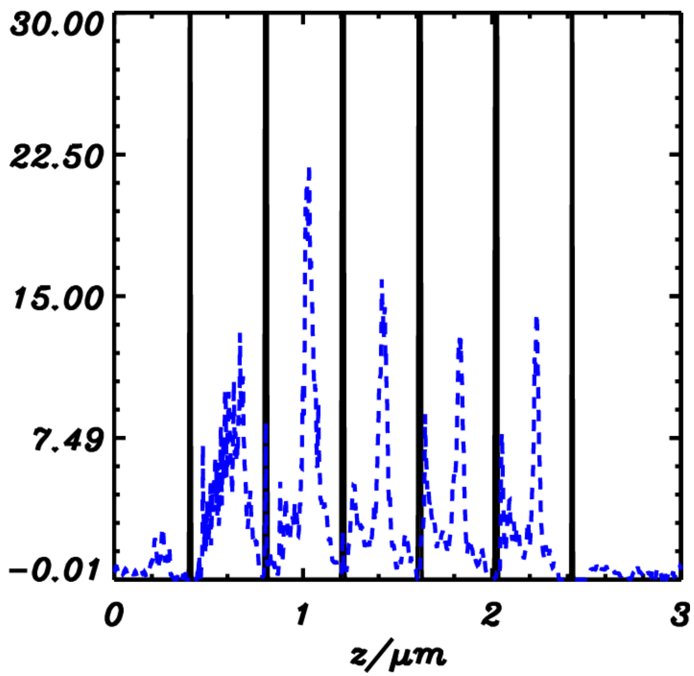
Debye sheath formation on the shell surface

Analysis of CI dynamics: final density line outs

T = 130 fs

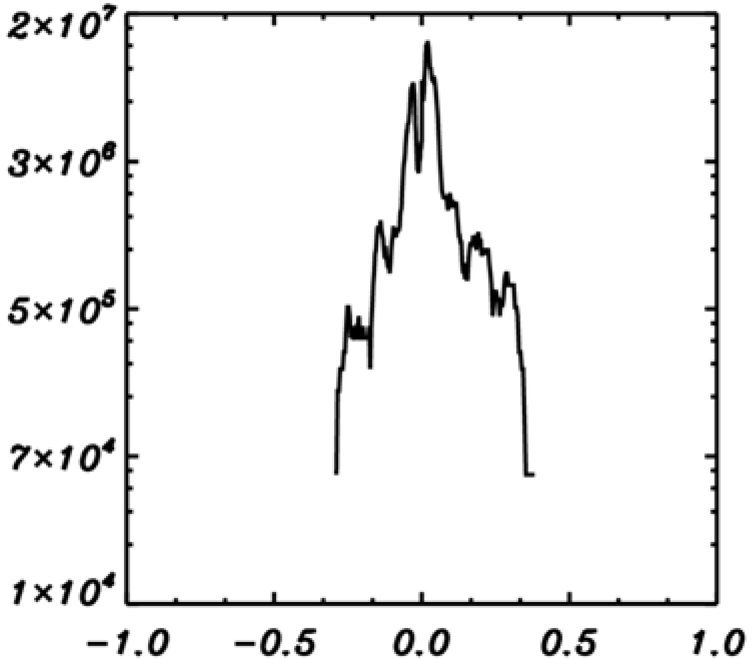


Electron density maxima at the shell centers

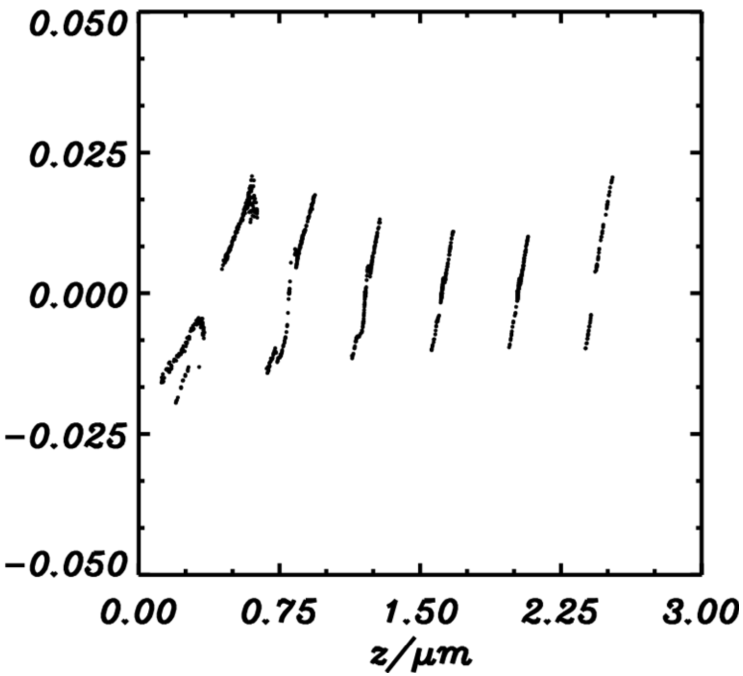


Ion density maxima at the shell centers

Analysis of CI dynamics: ion energies at centers



Ion energy spectrum

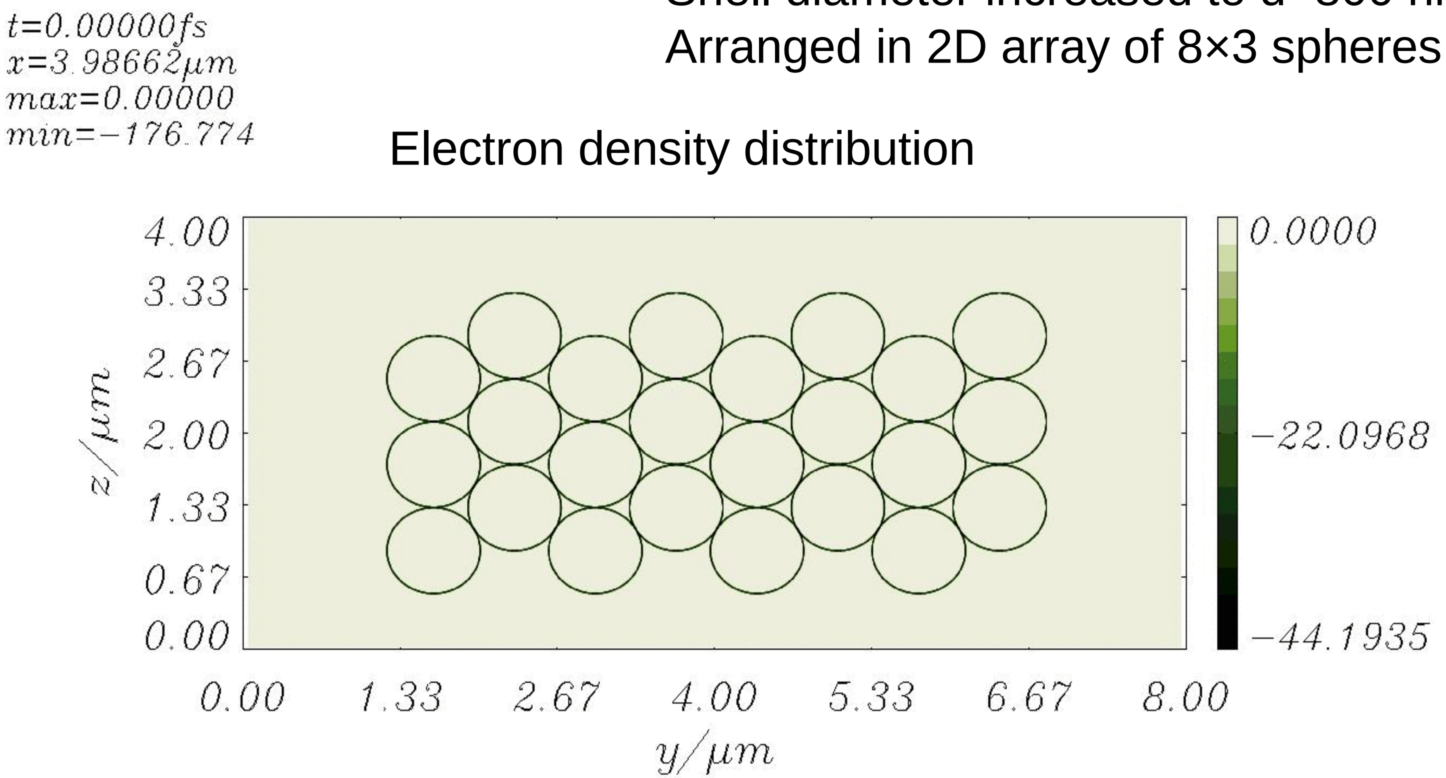


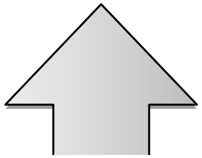
Ion phase diagram

Larger shell size : dependence

Shell diameter increased to d=800 nm
Arranged in 2D array of 8×3 spheres

Electron density distribution

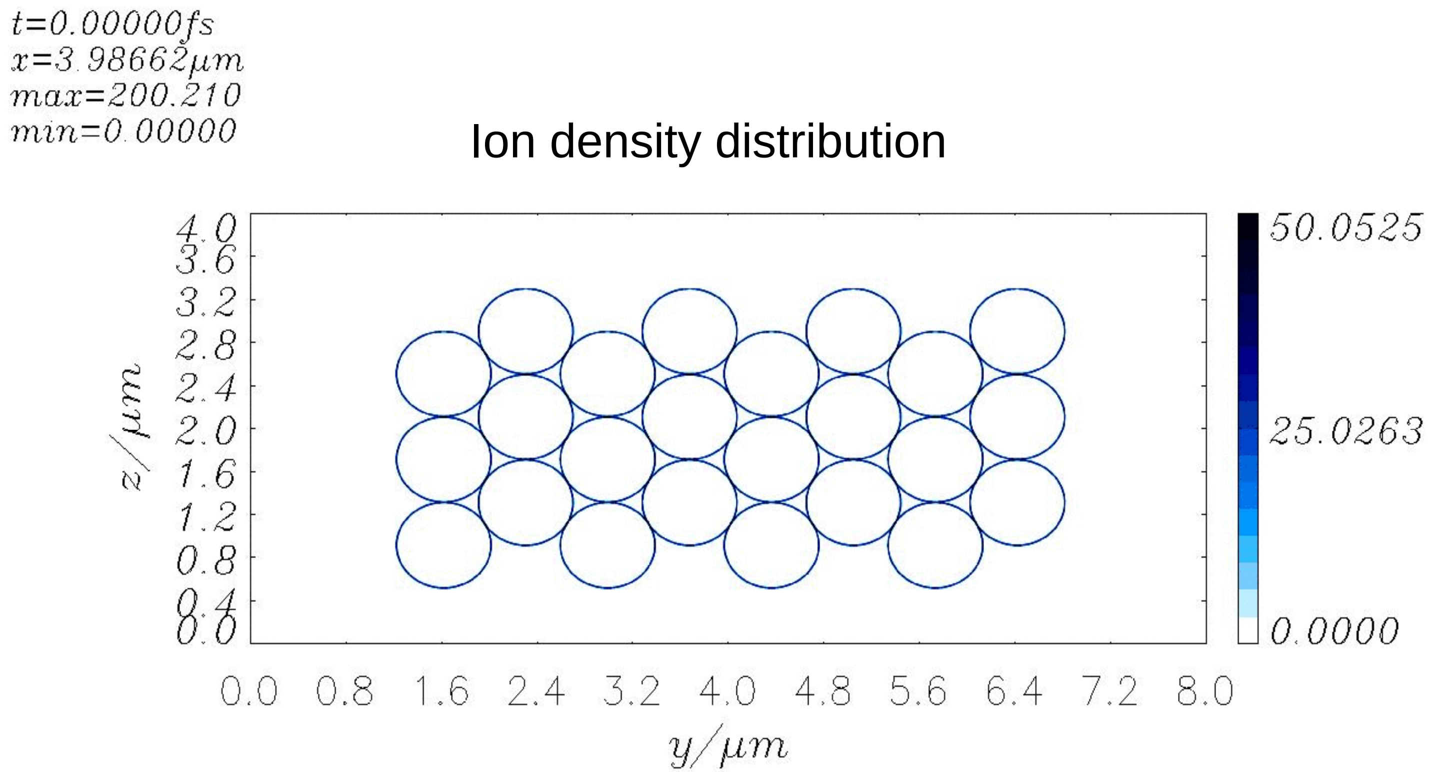


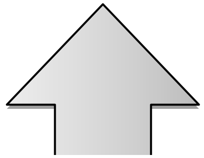


laser

Larger shell size : dependence

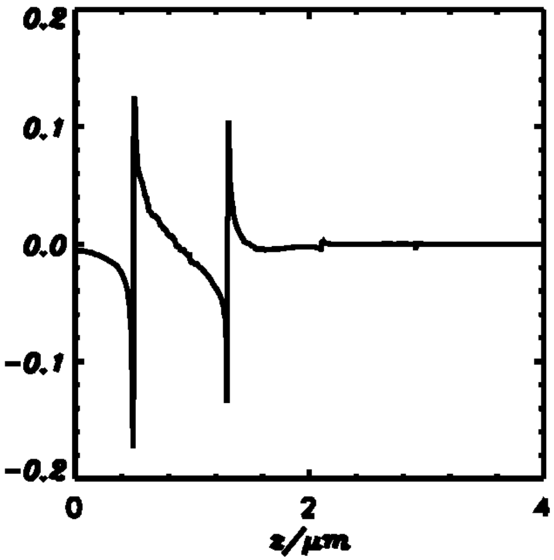
Ion density distribution



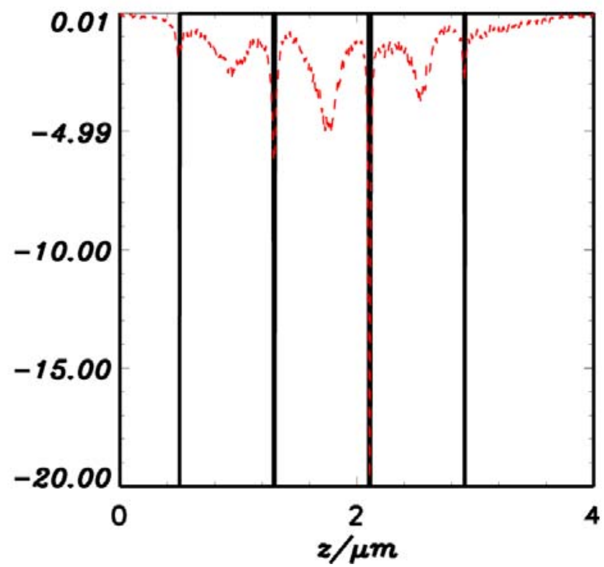


laser

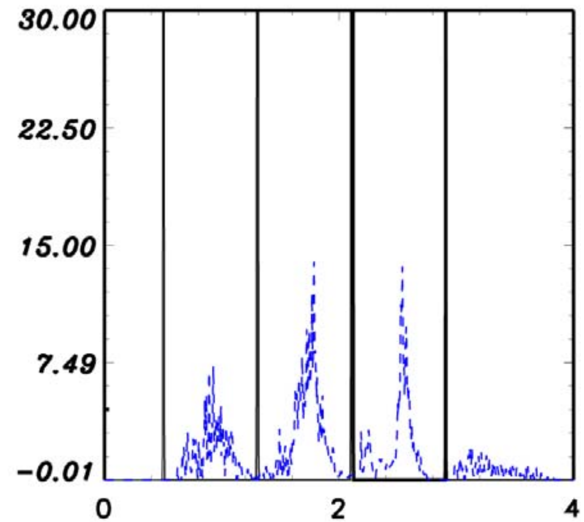
CI dynamics: larger shell size



Longitudinal E-field



Line outs of final electron density at shell centers



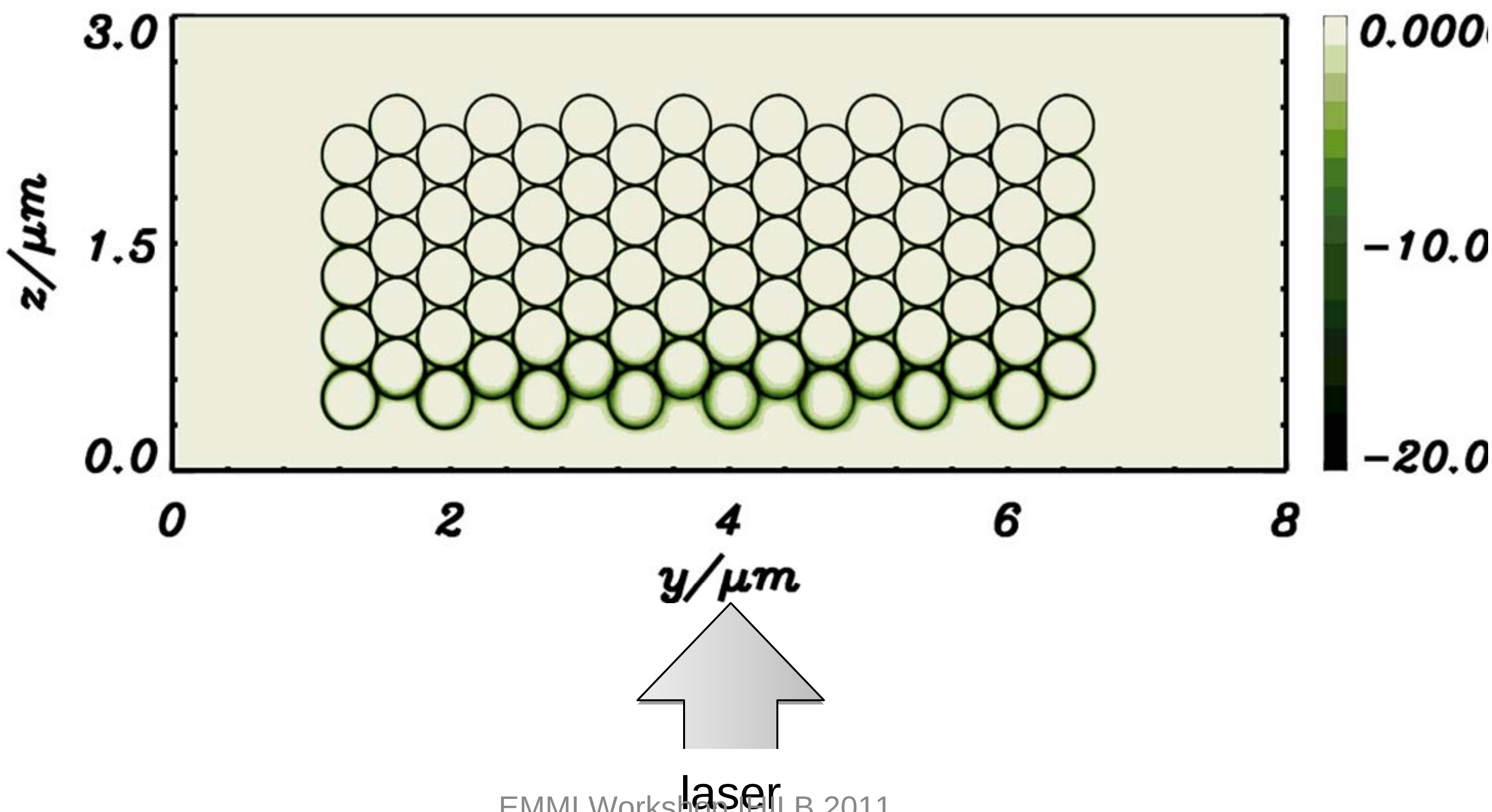
Line outs of final ion density at shell centers

Larger sphere leads to lower peak density – why?

Higher shell wall density : dependence

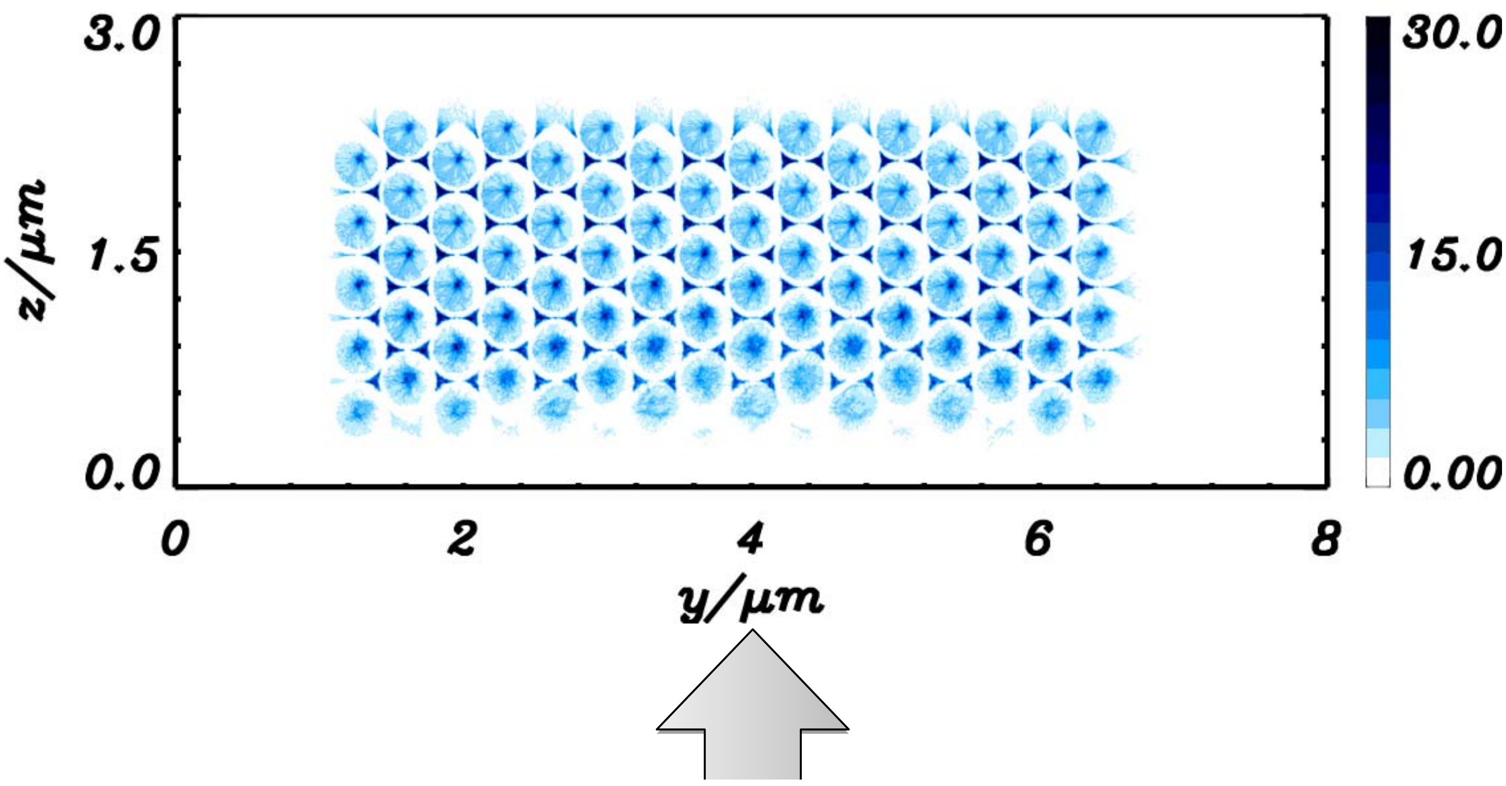
Shell wall density increased to n_0=120 n_c
Arranged in 2D array of 16×5 spheres

Electron density distribution

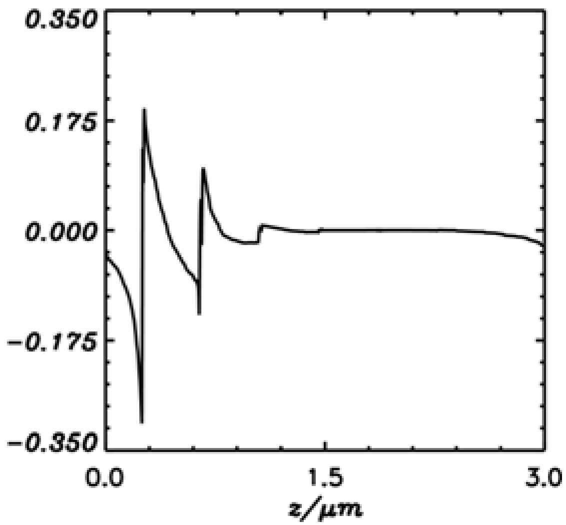


Higher shell wall density : dependence

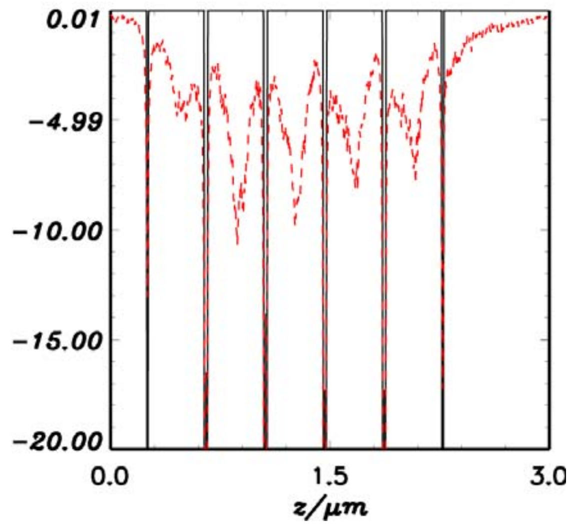
Ion density distribution



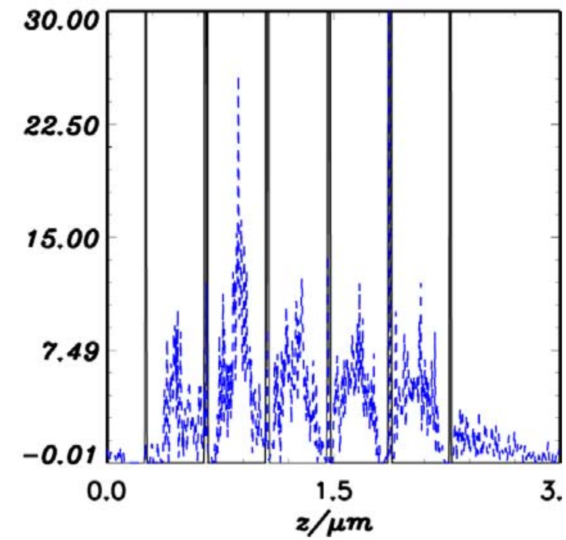
CI dynamics: Higher wall density



Longitudinal E-field



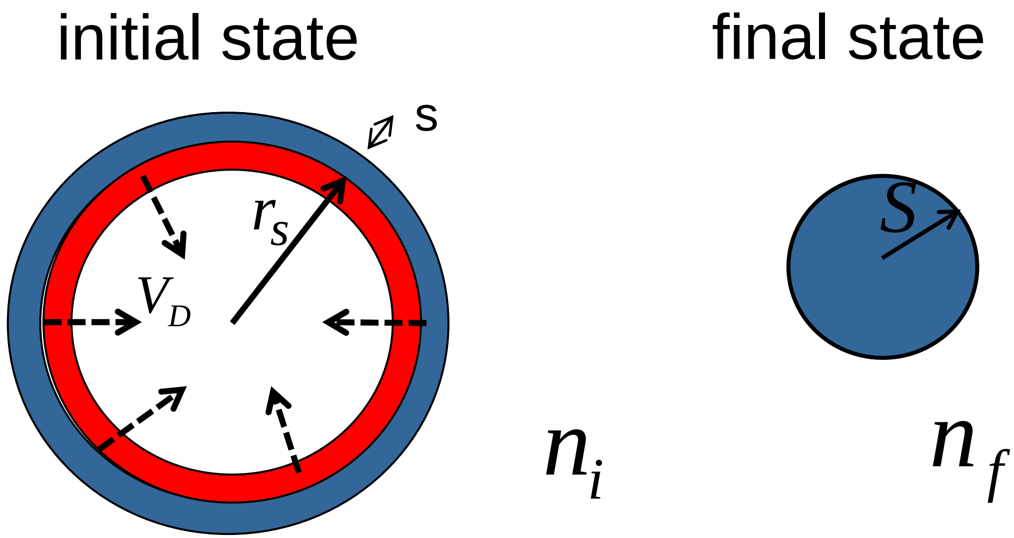
Line outs of final electron density at shell centers



Line outs of final ion density at shell centers

Comparable final peak ion densities , more charge particles at the shell centers.

Neutron yield estimation



Neutron yield estimation

Standard expression for neutron yield from DD fusion:

$$Y_n^{\rm DD} = \frac{\tau_D}{2}\int \overline{\sigma v}\, n_f^2\, d^3r$$

$$= \frac{\tau_D}{2}\cdot \overline{\sigma v}(T_D)\cdot\left(\frac{5\varepsilon_0 T_D}{s^2 e}\right)^2\cdot\frac{4\pi}{3}s^3$$

'transit' time
= s / v_D

fusion cross-section
(NRL formulary)

$$\simeq \quad 10^{-2}\, T_{\rm keV}^{5/6}\, e^{-18.76/T_{\rm keV}^{1/3}}$$

Summary

- Foam array geometry – **nanoscale Coulomb implosion** of positively charged light ions.
- Inwardly driven ion acceleration mechanism similar to TNSA for curved surface.
- Implosion depends upon higher shell densities and larger shell dimensions.
- Proposal for laser induced femtosecond fusion neutron and hard x-ray source