NNP AND BEAM PHYSICS

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CONTENT

- Non-neutral Plasma
- Examples
- NNP and Beam

NON-NEUTRAL PLASMA

Riezlern 2005 – Birthday of NNP Group – 10 years anniversary

LEBT Group + F8SR Group (3 Members + 1 Associate)

MOTIVATION → Discovering of Terra Incognita

Theory – Simulation – Measurement

Plasma Physics

Thermodynamics

Terra Incognita

Beam Physics

1 specie

$v_{||} >> v_{\perp}$

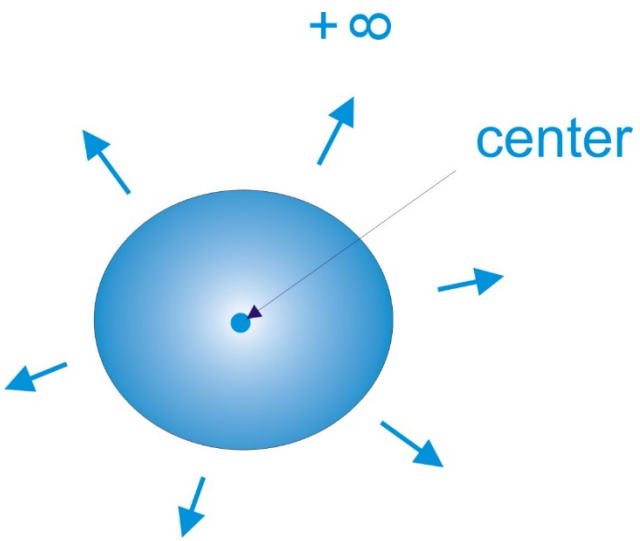
NNP - CONSTRAINT

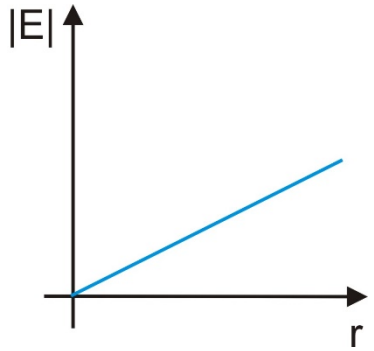
- Number of particles in Debye sphere $n\lambda_D^3 >> 1$
- Debye length smaller than size of plasma $\lambda_D < L$
- Observed time scale longer than $\tau > 2\pi/\omega_p$
- Neutrality -> +=- (quasineutrality)

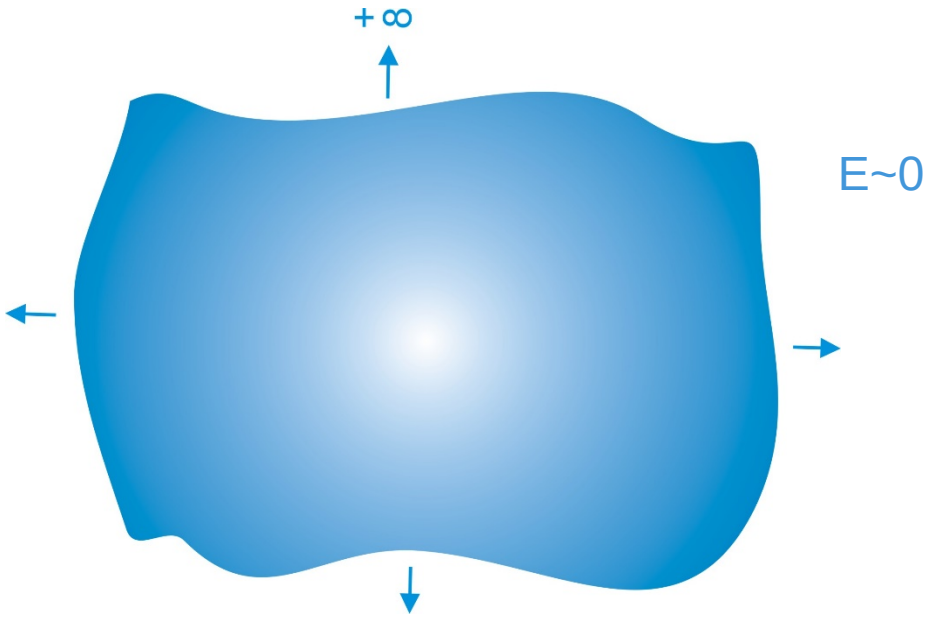
$$\lambda_D^2 = \varepsilon_0 kT/(ne^2)$$

NNP – CONSTRAINT - BOUNDARY

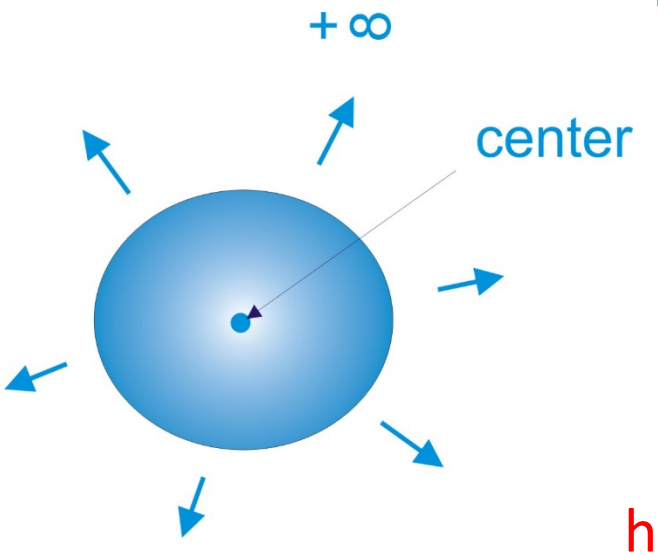
negative universe

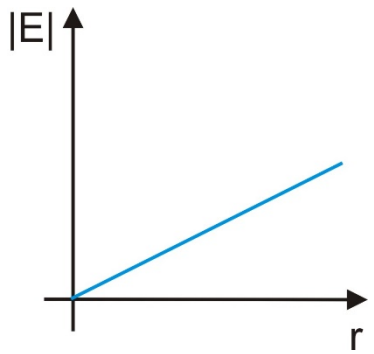






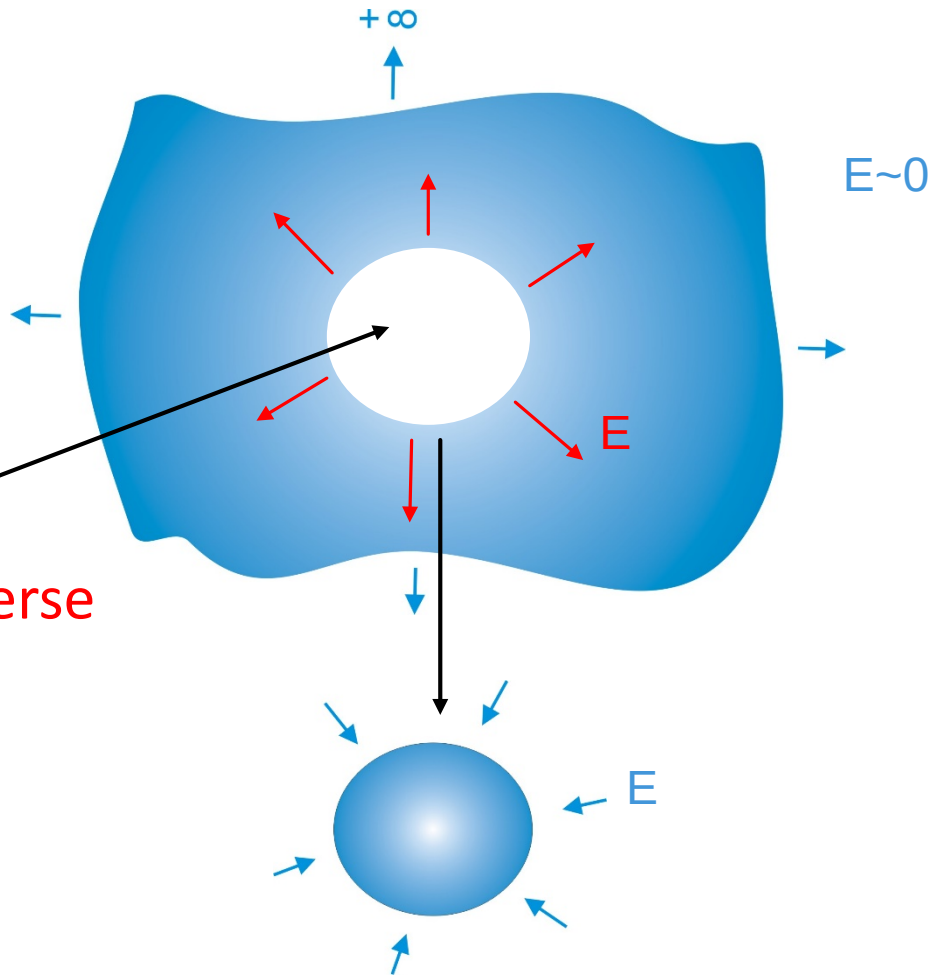
NNP – CONSTRAINT - BOUNDARY





negative universe

hole in negative universe



NNP IN TRAPS – BEAM POTENTIAL AS TRAP?

Riezlern 2006

Force balance equation - MHD

$m \cdot n \cdot (\partial \mathbf{v}/\partial t + \mathbf{v} \cdot \nabla \mathbf{v}) = q \cdot \nabla \Phi - q \cdot \mathbf{v} \times \mathbf{B} - \nabla p$

Equilibrium $\partial \mathbf{v}/\partial t = 0$, neglecting $\mathbf{v} \cdot \nabla \mathbf{v}$ term,
p=nkT and multiplication by **B**

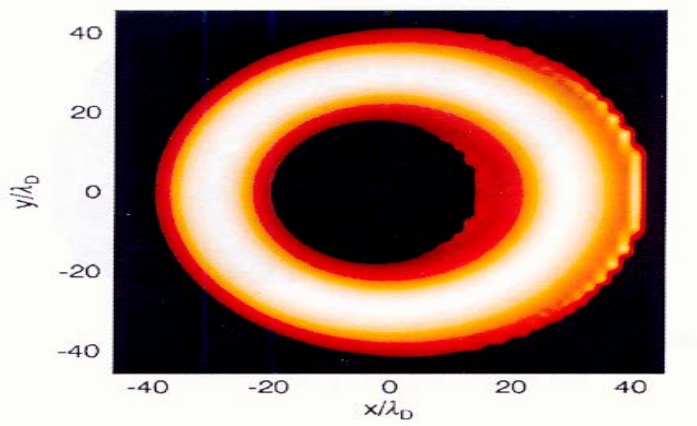
$e \cdot n \cdot \mathbf{B} \cdot \nabla \Phi - e \cdot n \cdot \mathbf{B} \cdot (\mathbf{v} \times \mathbf{B}) - \mathbf{B} \cdot kT \cdot \nabla n - \mathbf{B} \cdot nk \cdot \nabla T = 0$

$\rightarrow e \cdot n \cdot \nabla \Phi = kT \cdot \nabla n \rightarrow$ density $n = n_0(\Psi)$
$\exp\{e \cdot \Phi / k \cdot T(\Psi)\}$

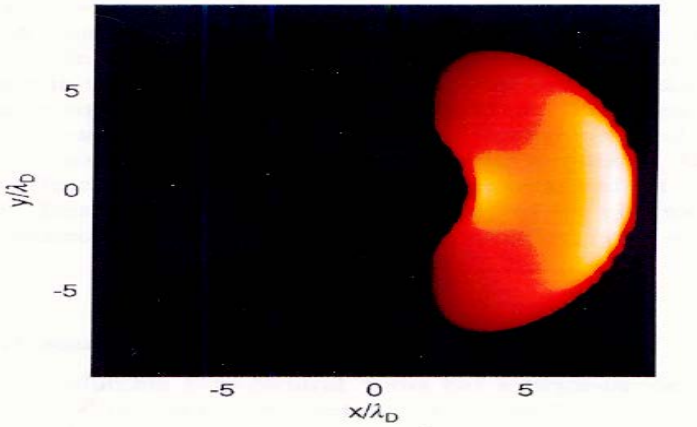
Self consistent potential - Poisson-Boltzmann Eq.

$\Delta \Phi = e \cdot n_0(\Psi)/\varepsilon_0 \cdot \exp\{e \cdot \Phi / k \cdot T(\Psi)\}$

Cold plasma
$a/\lambda_D \sim 10$



Warm plasma
$a/\lambda_D \sim 1$



cylindrical symmetry:

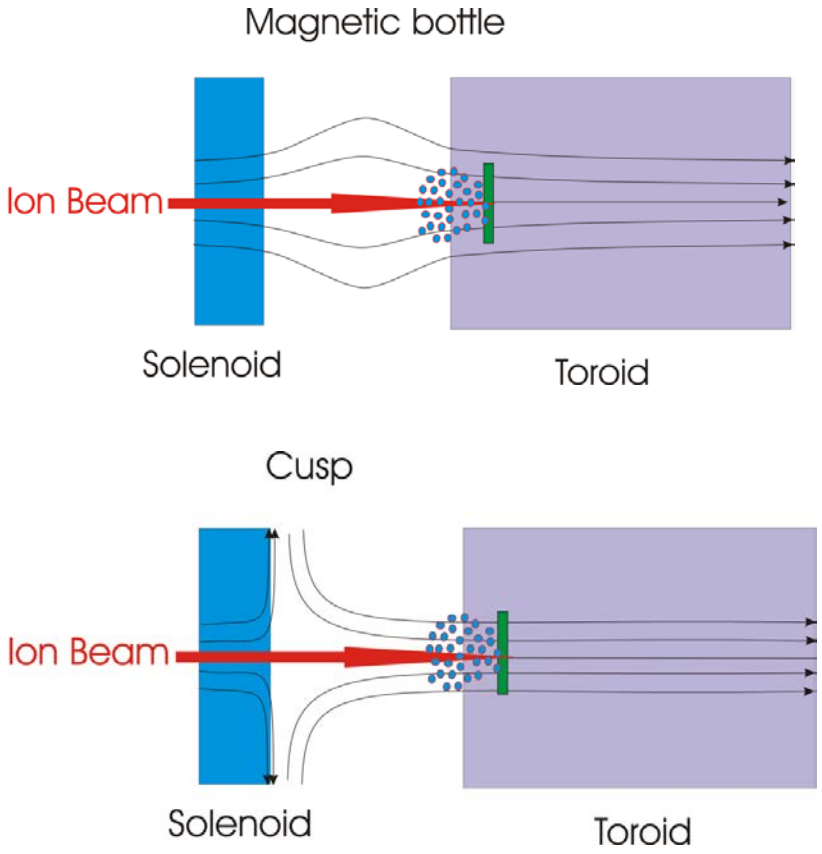
Thermodynamic properties $TdS = dE + \omega dL$, $dN=0, dV=0, dB=0$

Equilibrium → shear-free flow → rigid rotor

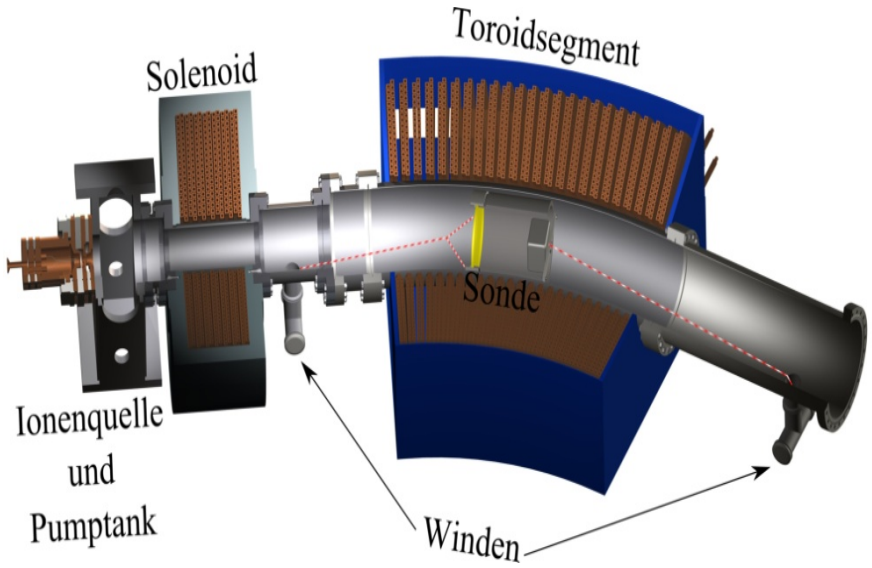
O´Neil, Rev.Mod.Phys. Vol71, No1, (1999)

BEAM-NNP AND MAGNETIC FIELD

Riezlern 2010



10keV, p, ~1mA, 0.6T

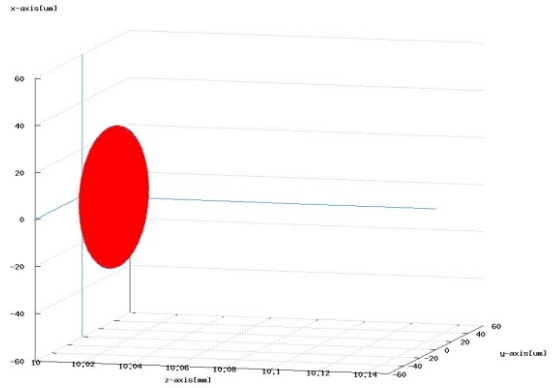


secondary electrons →Production on surface rest gas electrons

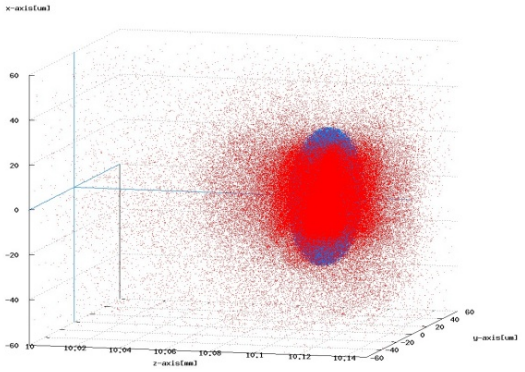
SIMULATION

Project LIGHT – Simulation PIC Code LASIN

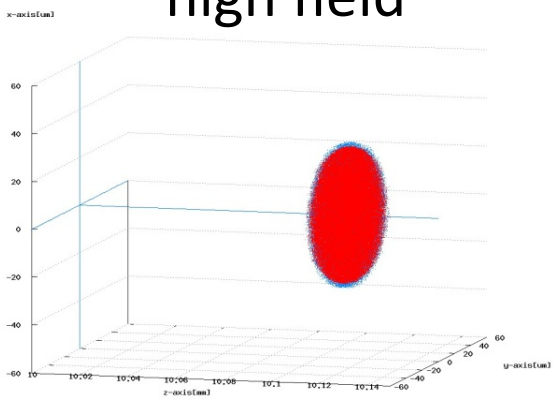
co-moving protons W=10MeV
electrons W=5.5keV

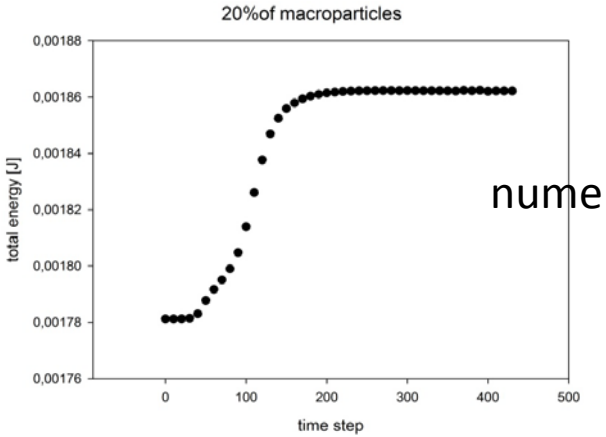


start condition E→0
longitudinal magnetic field B_z

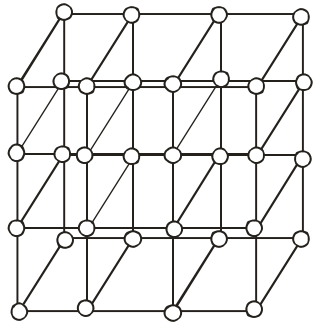


high field





numerical heating



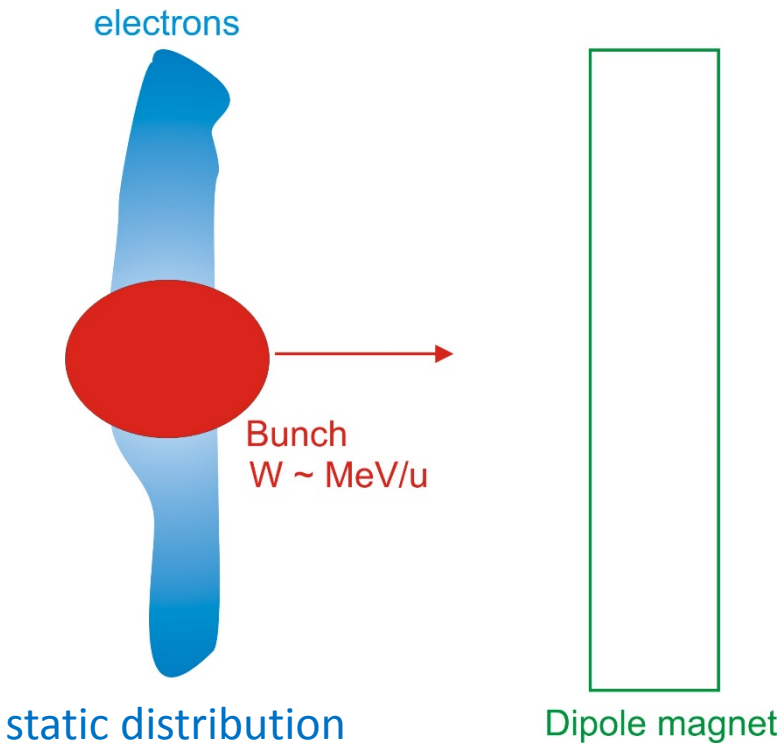
shielding distance

$\lambda_D \leftrightarrow \Delta x, \Delta y, \Delta z$

density variation << Δx
not seen by PIC-code

Riezlern*2011*

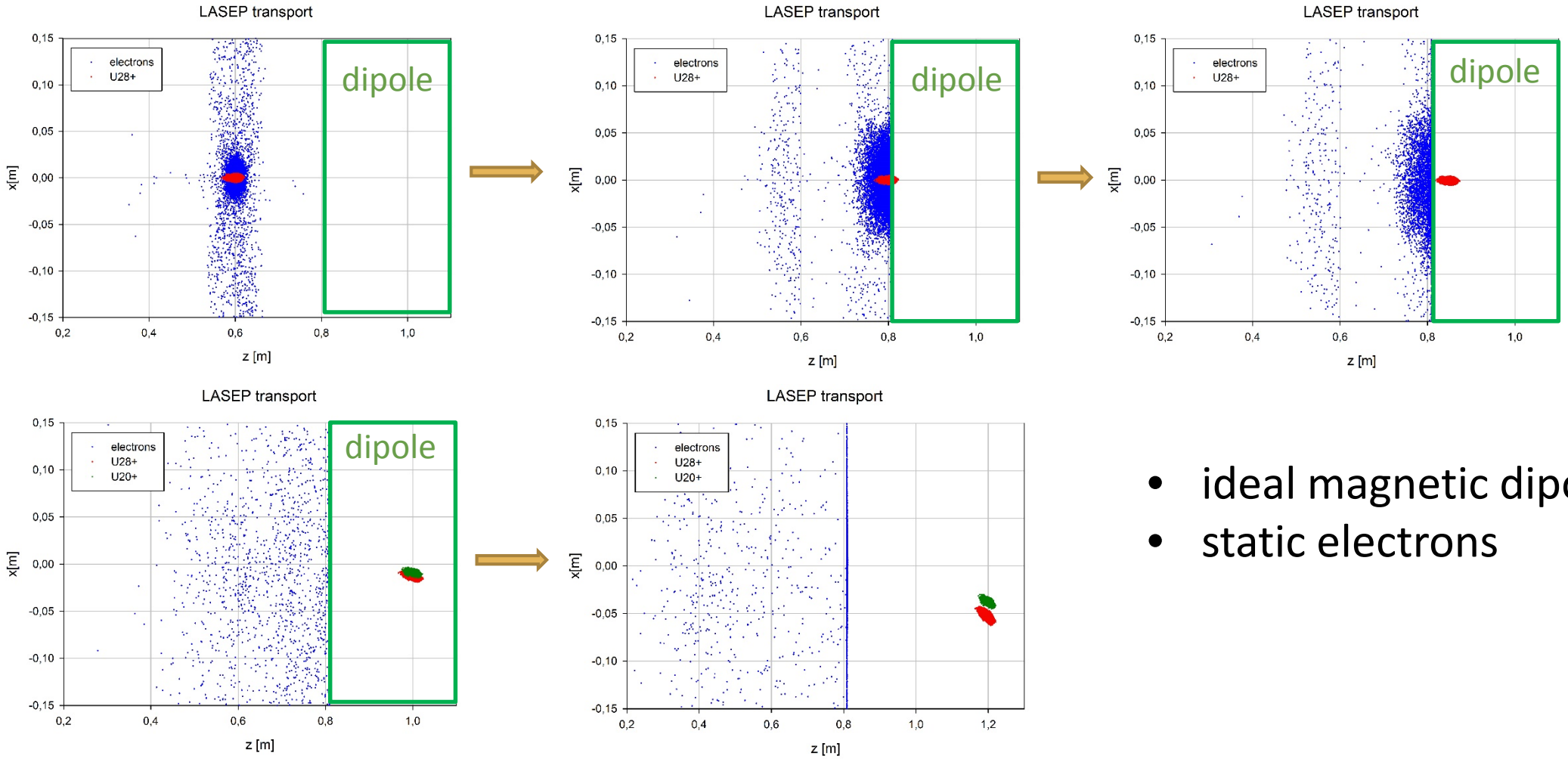
MULTISPECIES - SIMULATION



(electron traps, stripper, clouds)

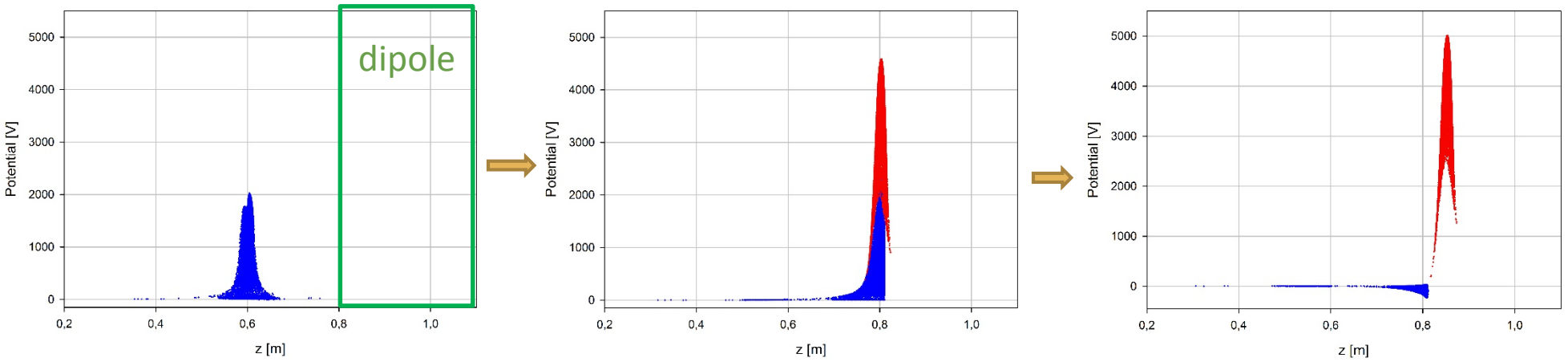
- electrons captured by beam?
- electrons stopped and/or reflected by dipol magnet?
- space charge compensation ?
- emittance ?

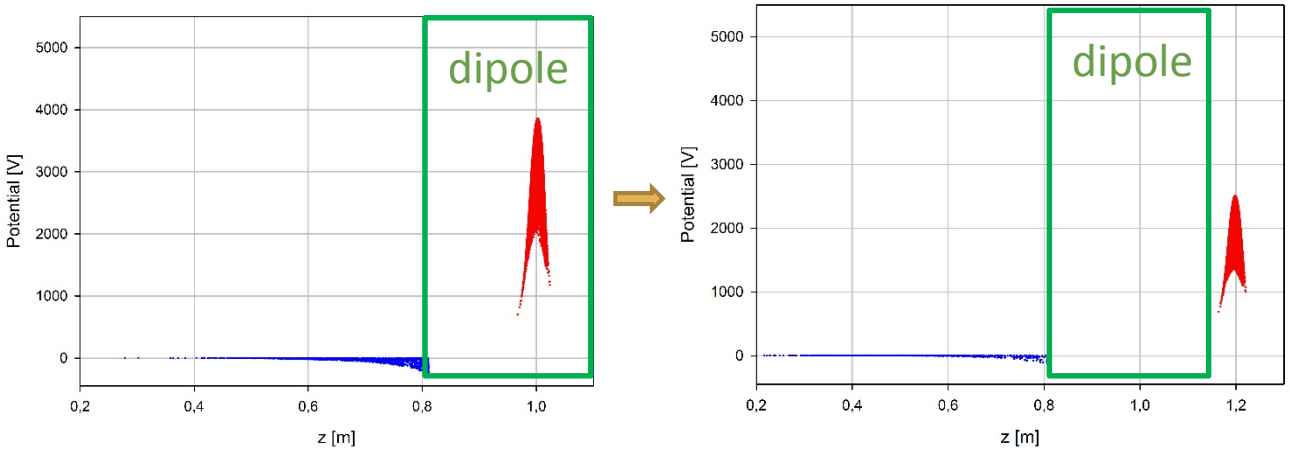
MULTISPECIES - SIMULATION



- ideal magnetic dipole field
- static electrons

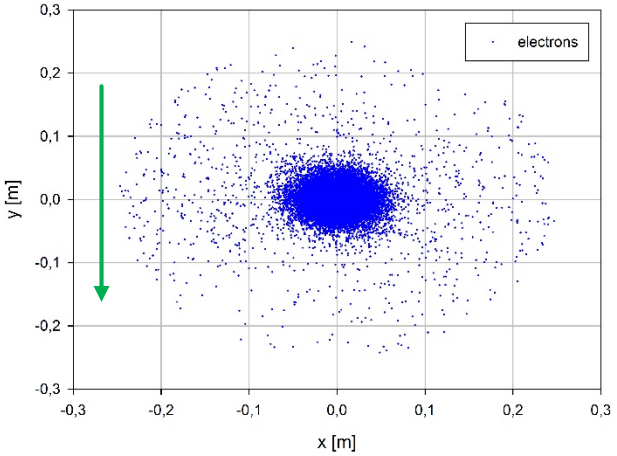
MULTISPECIES - SIMULATION

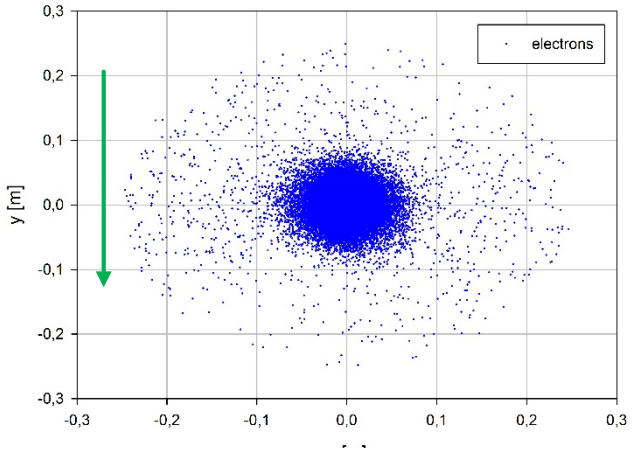




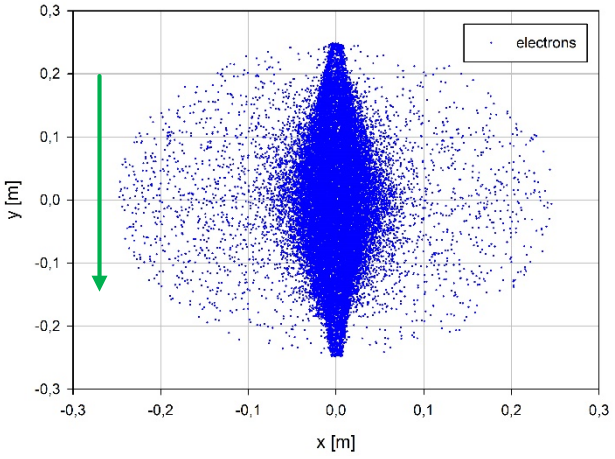
Beam – Potential 1kV→5kV→1kV

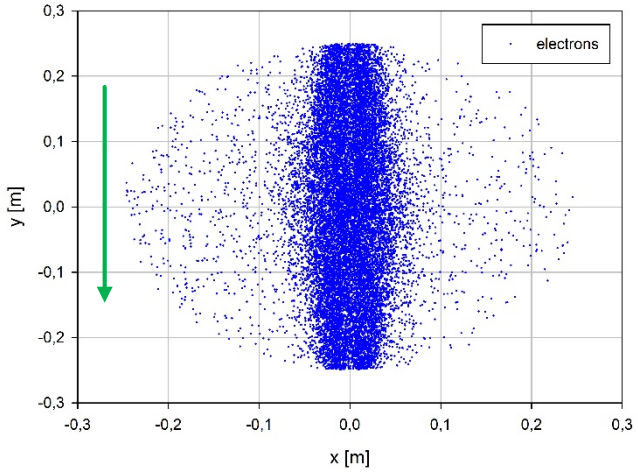
ELECTRON DISTRIBUTION





magnetic dipole field





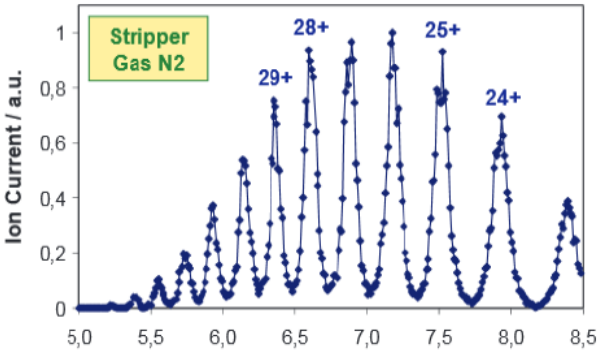
TODO:

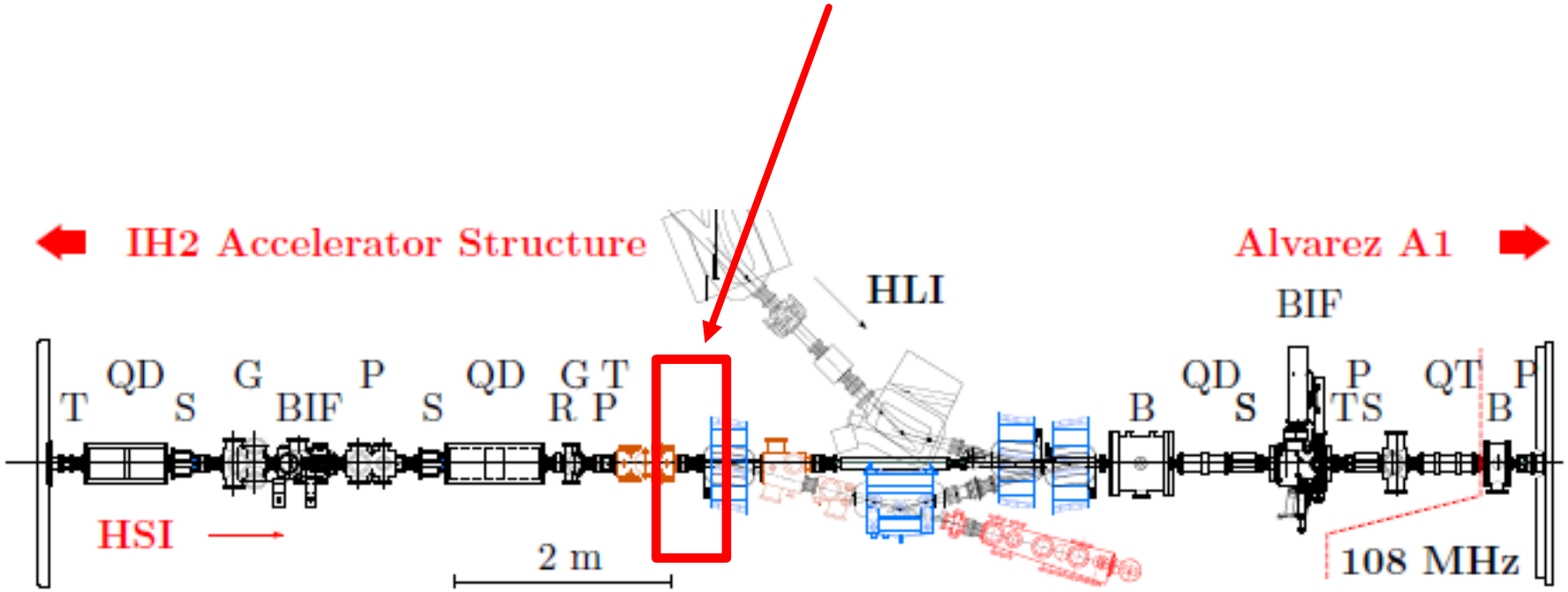
- emittance
- start distribution – electrons
- periodic bunch train

Thank you !!!

LASEP - SIMULATION

- electron dynamics in stripper region → space charge compensation? (simulation and comparison with experiments)
- charge state separation in dipole magnets → emittance



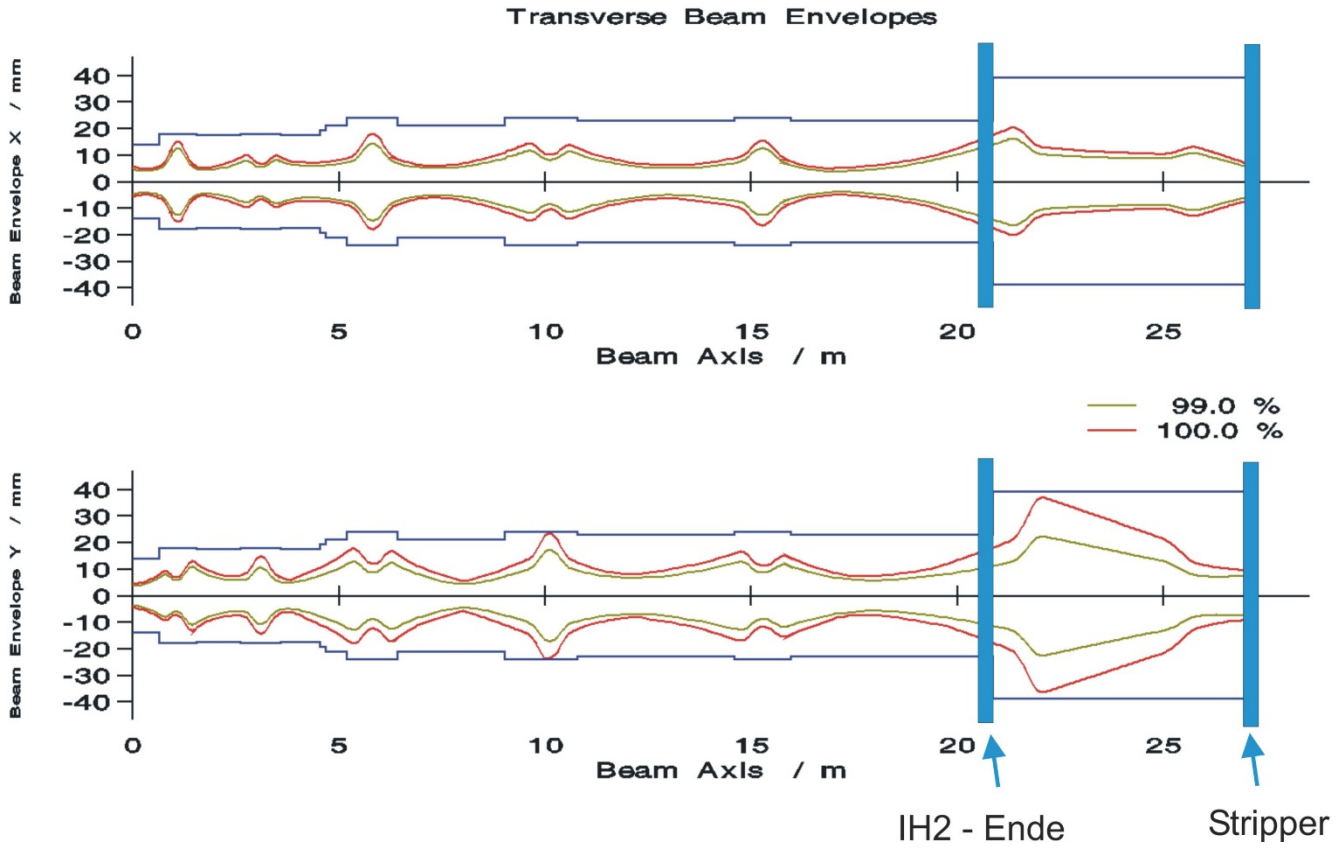


LASEP - SIMULATION

Simulation LASIN

drift+dipol

- 20+ → 35+ Gauss
- distribution → equal to 4+
- 4+ → 1.4MeV/u
- electrons x,y,z → equal to 4+ but gaussian noise
- Mesh cylindrical 1mmx1mmx2π/30 rad
- Δt = 6.1e-11 s, TOF 31ns
- 42 Processor
- 1.3*e+6 macroparticles
- Poisson eqaution on 10 processors BiCGSTAB method



STATIONARY STATE