Transport and Acceleration of Intense Ion Beams using Space Charge Compensation

Oliver Meusel

Riezlern 2008

Motivation

Requirements on Accelerator physics
- Luminosity

$$L = \frac{\dot{N}}{\sigma_s}$$

→

Current density at „Final Focus"

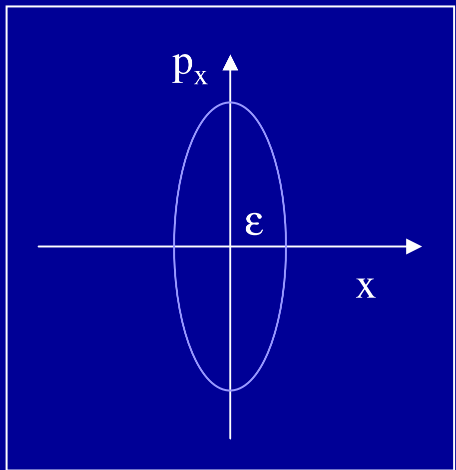
$$J = \frac{1}{A} \cdot \dot{N}$$

minimum spot size

$$r_{\min,x} = \frac{\varepsilon}{\pi \cdot p_x}$$

Beam current I_s

Beam emittance



Space Charge !

↓

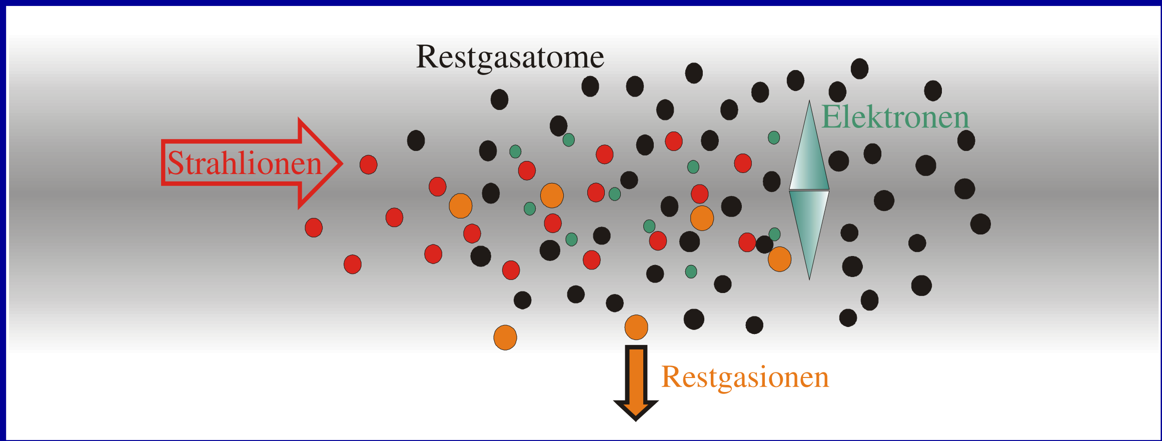
Beam emittance vs. Beam current

Space Charge Compensation

$$\frac{d^2}{dz^2} r_S = \frac{\varepsilon^2}{r_S^3} + \frac{K}{r_S} - \kappa(z) r_S$$

$$K = \frac{1}{4\pi\varepsilon_0} \cdot \sqrt{\frac{m_i}{2q}} \cdot \frac{I}{U^{3/2}}$$

Capturing of compensation electrons (CE) within the beam potential

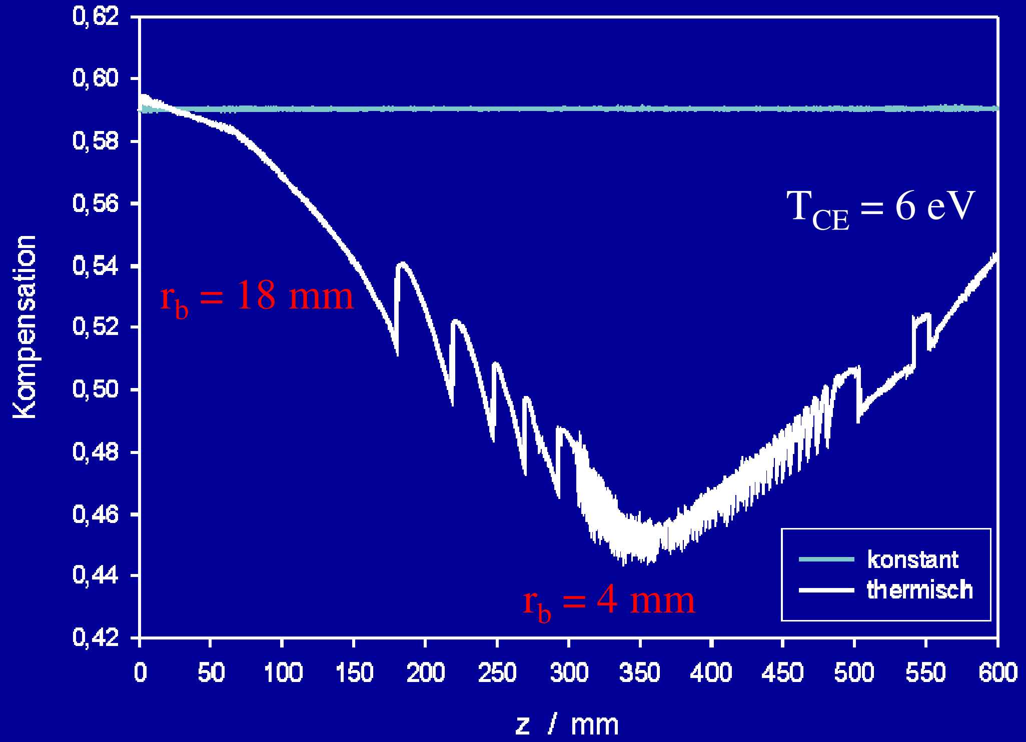


particle distribution within the beam volume

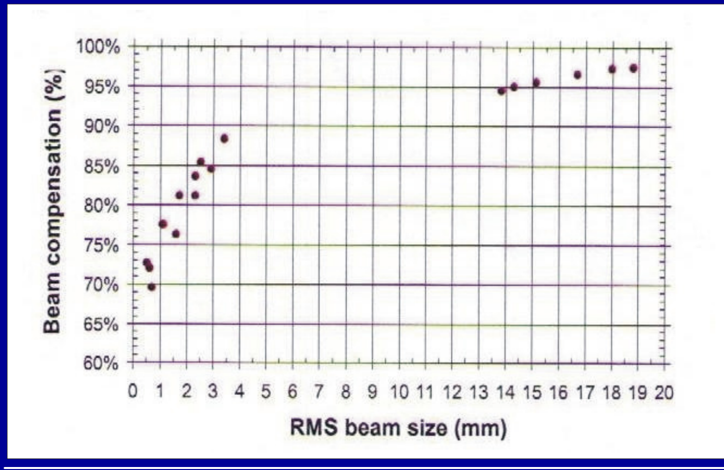
Transport without focussing fields – beam drift

Numerical simulation using the LINTRA code

selfconsistent estimation of the CE-density distribution



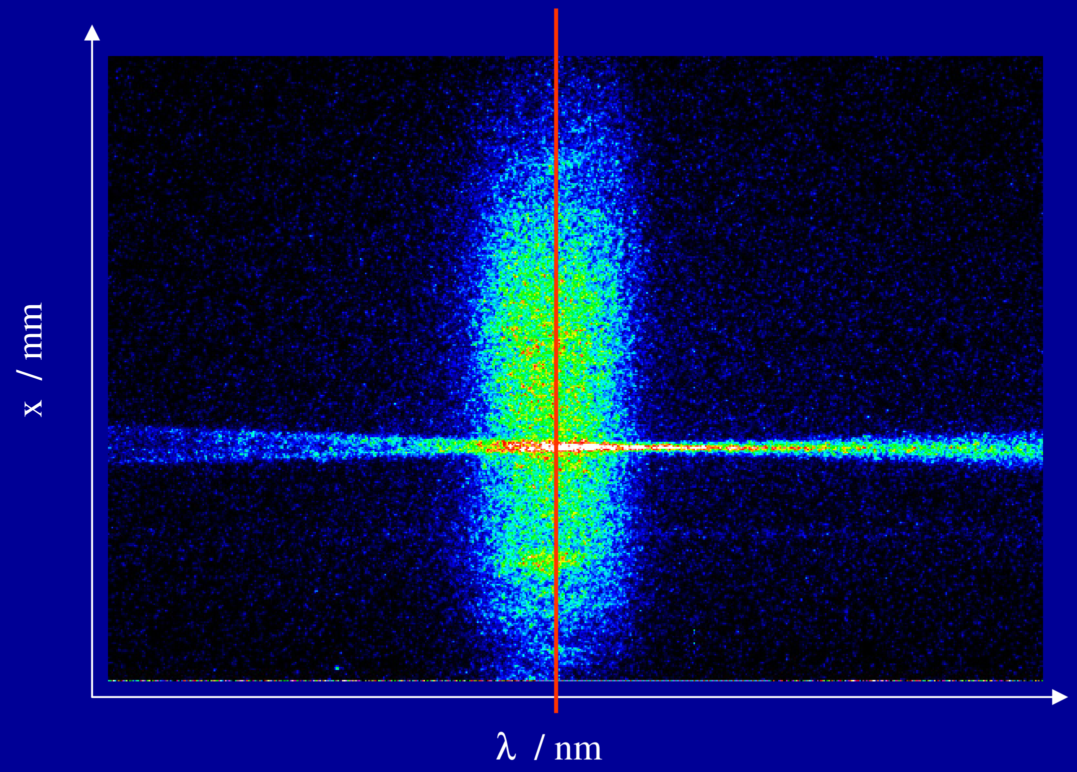
$$n_e(r) = n_e(r = \Phi_{b,\max}) \cdot e^{-\frac{\Phi_b}{kT_e}}$$

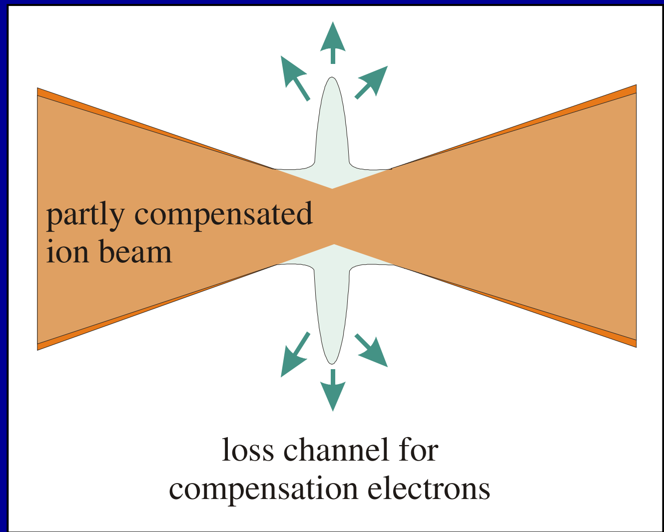


measured space charge compensation as a function of the beam radius

Loss Channel for the CE

beam focussing leads to global decompensation

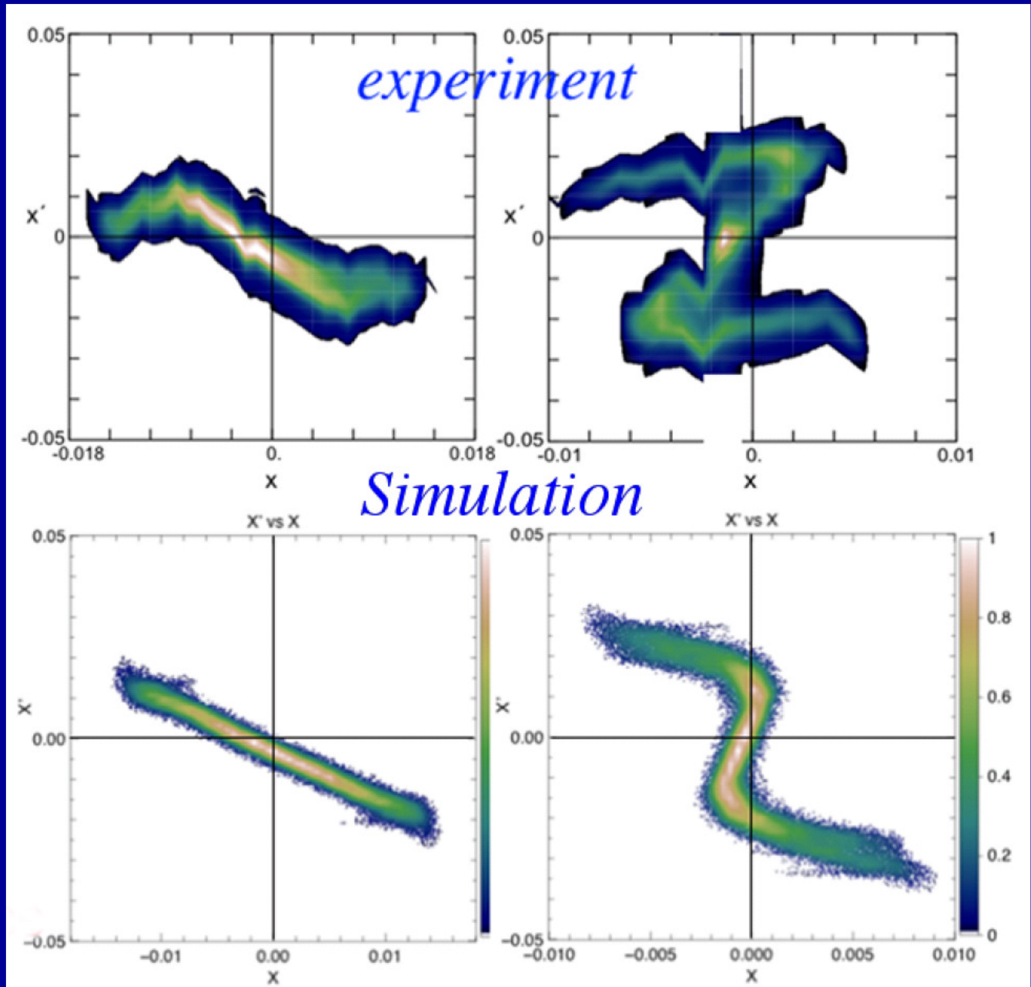




λ = 820 nm exciting of vacuum window by lost compensation electrons

Influence of beam optics on CE density distribution

decompensation compensation

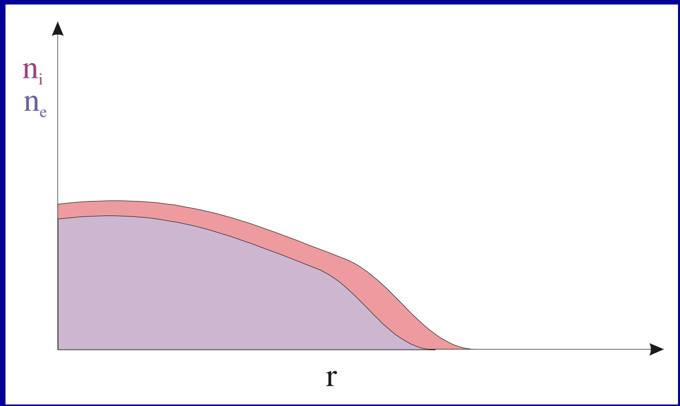


Example: MSQ

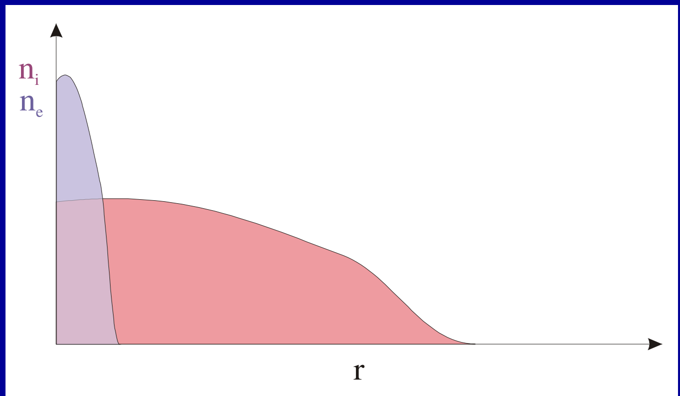
K^+ beam

$5\mu s$ / I_{peak} = 190 mA / 1 MeV

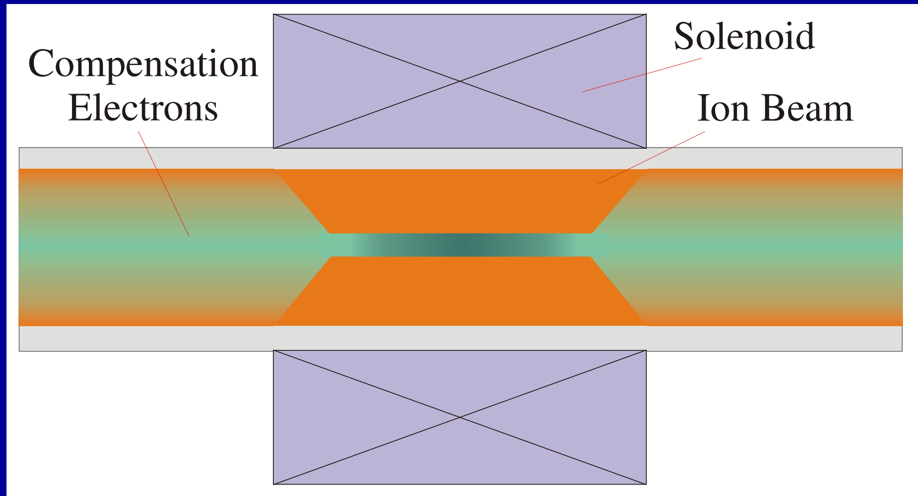
Influence of beam optics on CE density distribution - Solenoid



particle density distribution outside of the solenoid



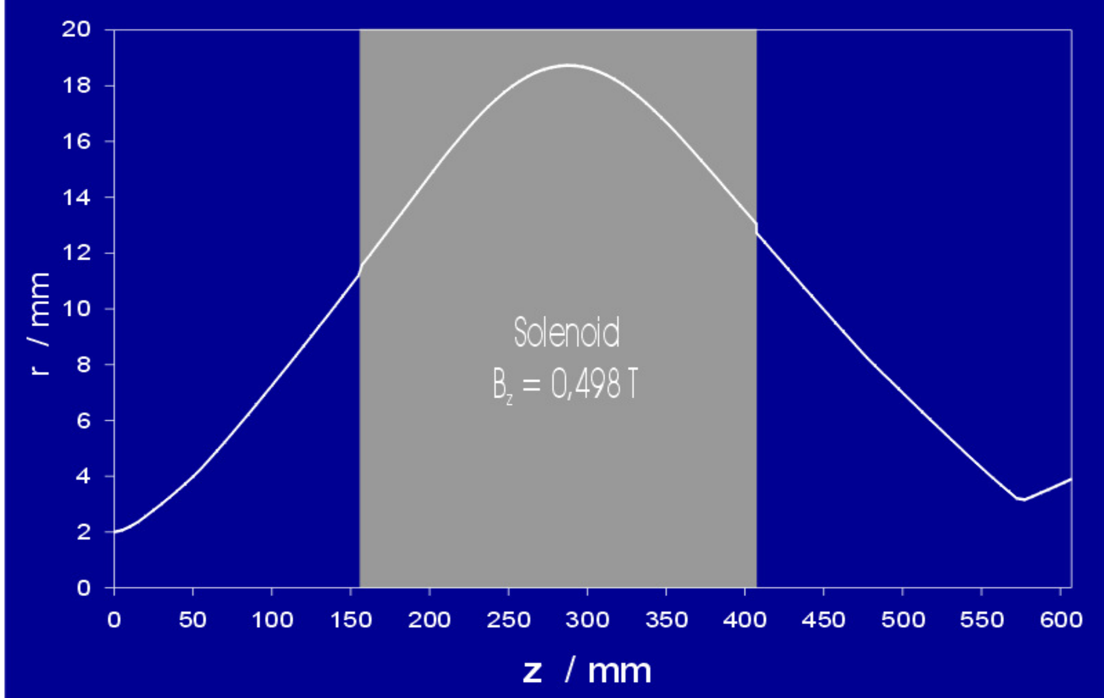
particle density distribution inside of the solenoid

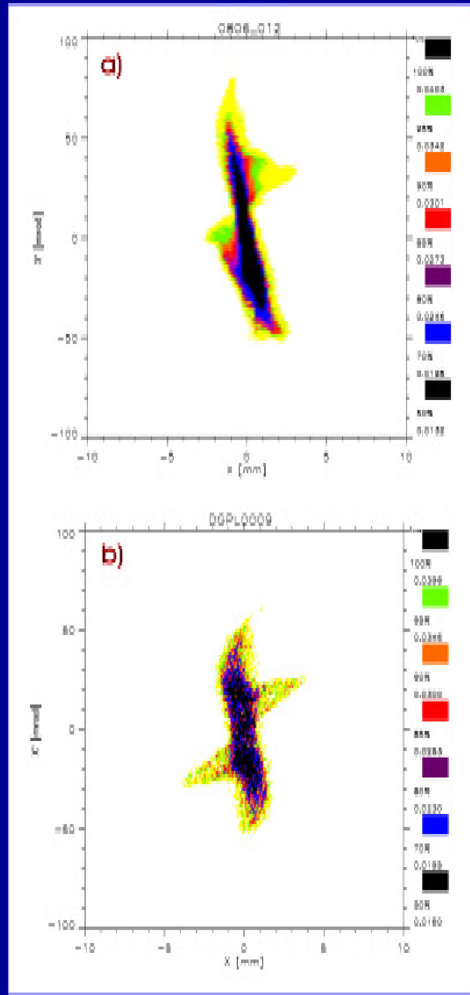


changing of the density distribution of the compensation electrons along the beam path through a solenoid

$$\Phi_b = \frac{e r_b^2}{8 m_e} \cdot B_z^2$$

Numerical Simulation of Space Charge Compensation in a Solenoid





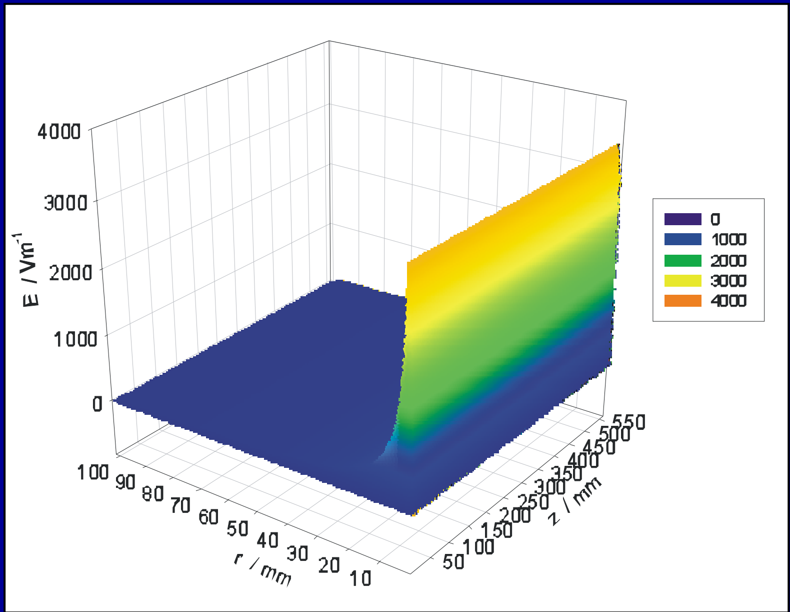
a) Measured phase space distribution He^+ -beam 9 mA @ 12 keV, b) transport simulation and calculated envelope

First Approximation of CE Density Distribution

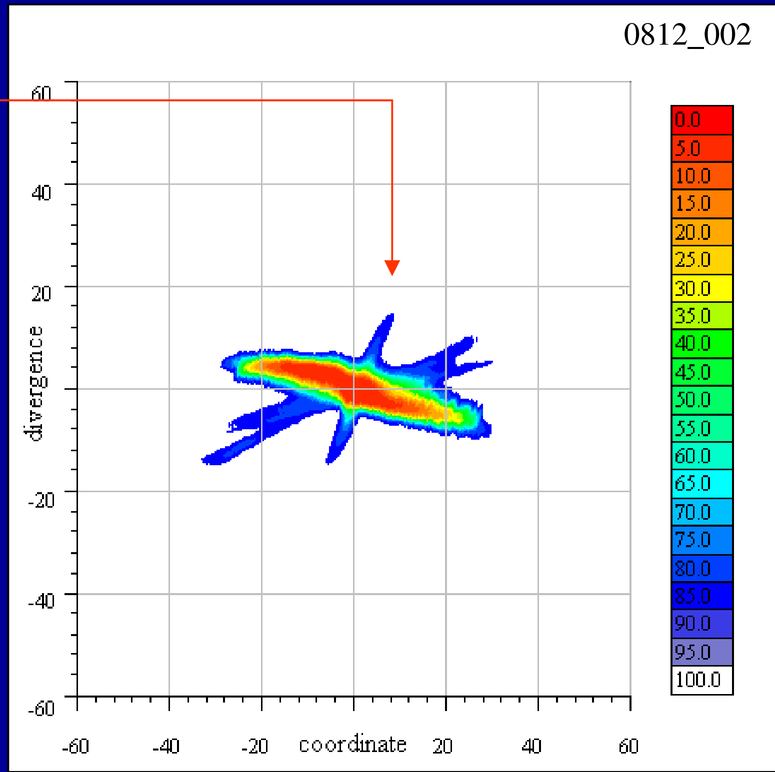
$n_e = 3.12\cdot10^{14}\ m^{-3}$

$r_e = 1\ mm$

Leads to „Satelits“



Field distribution of an homogenious filled electron columne inserted into the solenoid

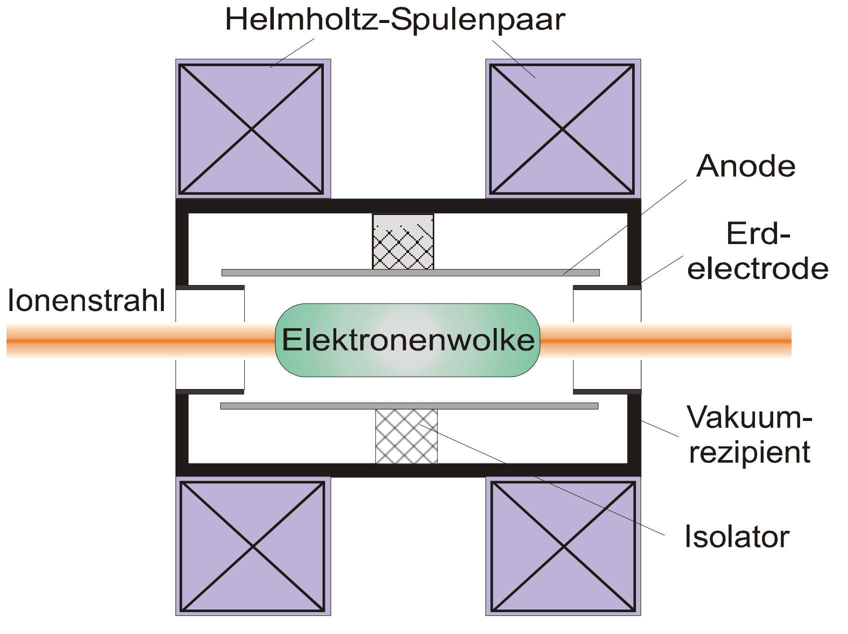


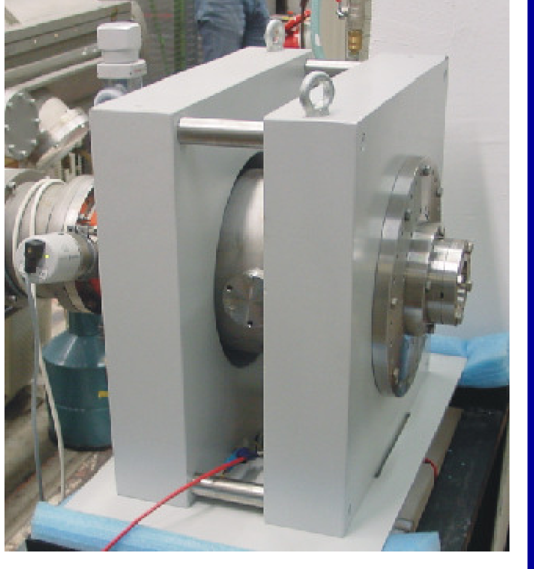
Measured phase space distribution of an intense proton beam W_b = 95 keV I = 98 mA

Gabor Lenses

Focussing under fully space charge compensation

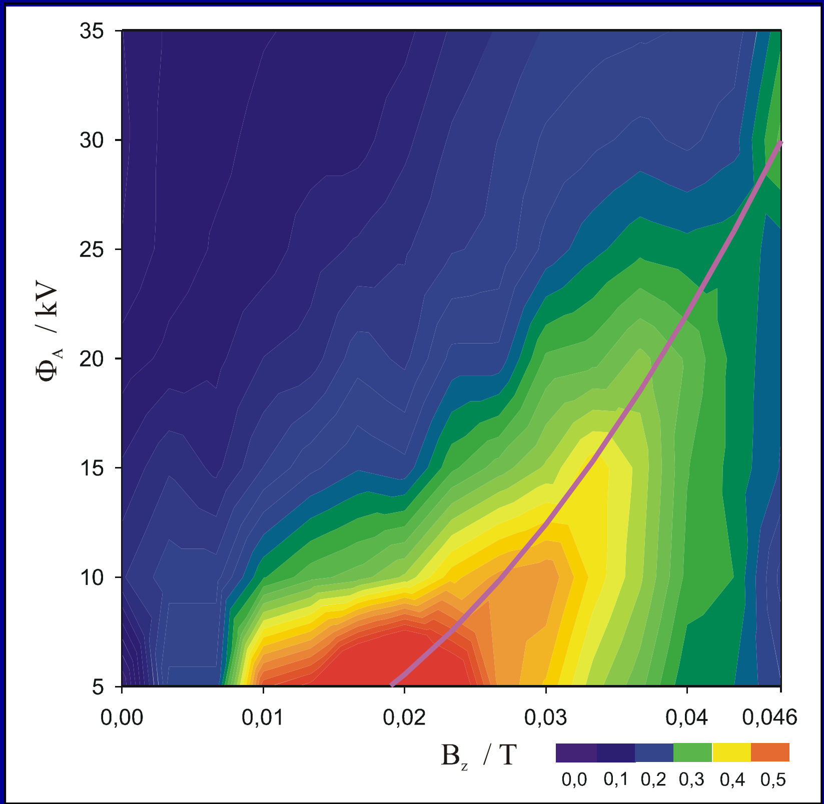
Parameters of the lens: $\Phi_{A,max} = 65\ kV$ $B_{z,max} = 2{,}2\ kG$



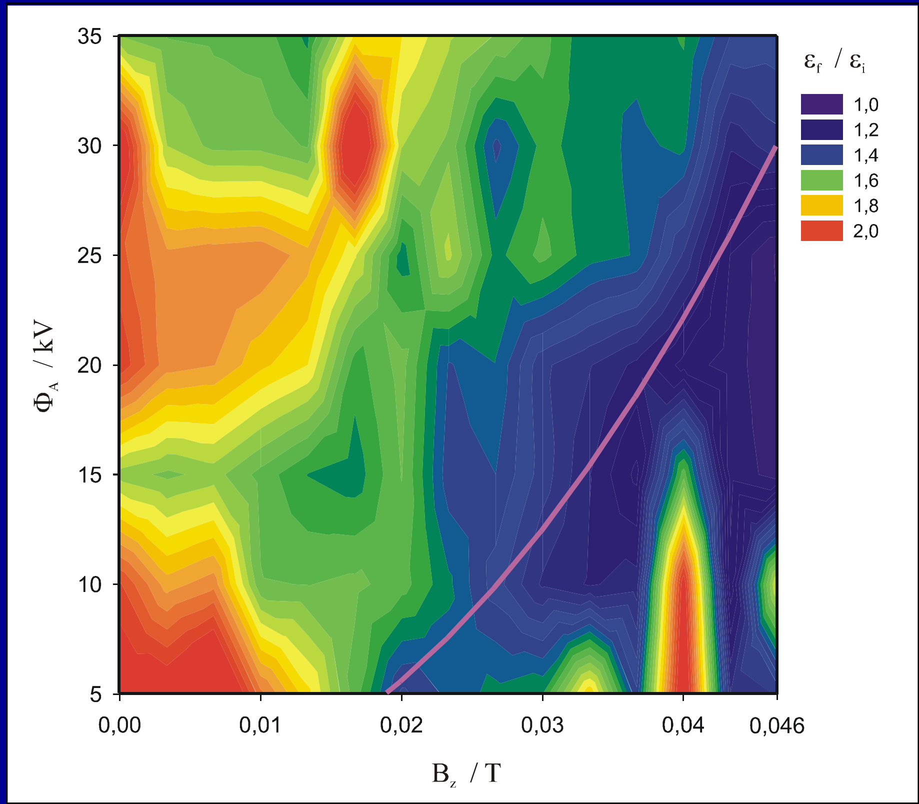


High field Gabor lens (HGL) for beam energies up to 500 keV

Focussing and Mapping capabilities of Gabor Lenses



Filling factor as a function of the lens parameters



Emittance growth as a function of the lens parameters

and Acceleration of Particles ?

Plasma filled wave guide

SPECIAL ARTICLE

Plasma oscillations*

By D. Gabor, Dr. Ing., M.I.E.E., F.Inst.P., Imperial College of Science and Technology, London, S.W.7

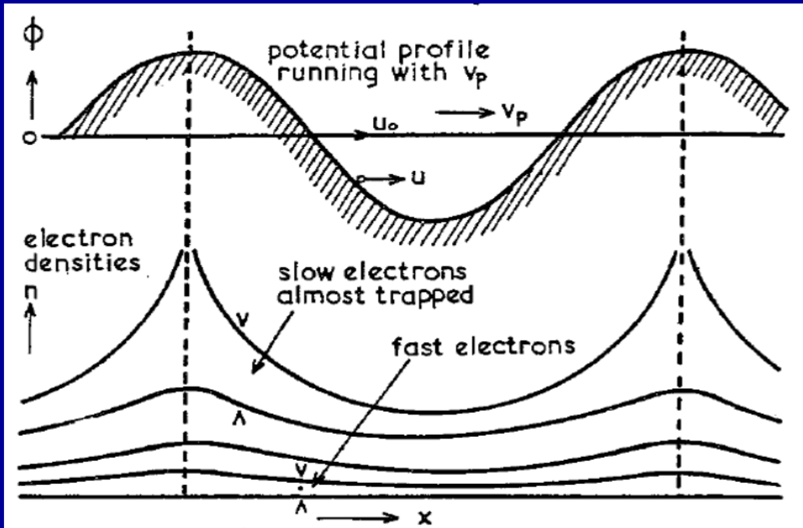
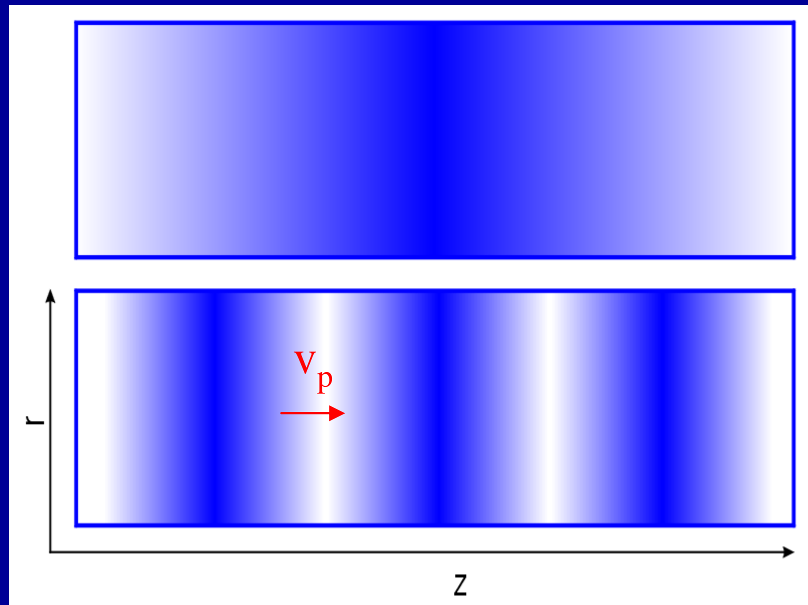
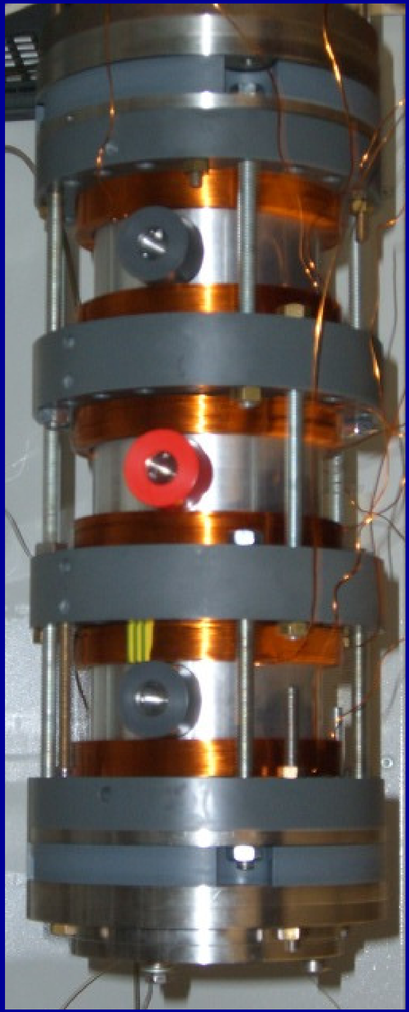


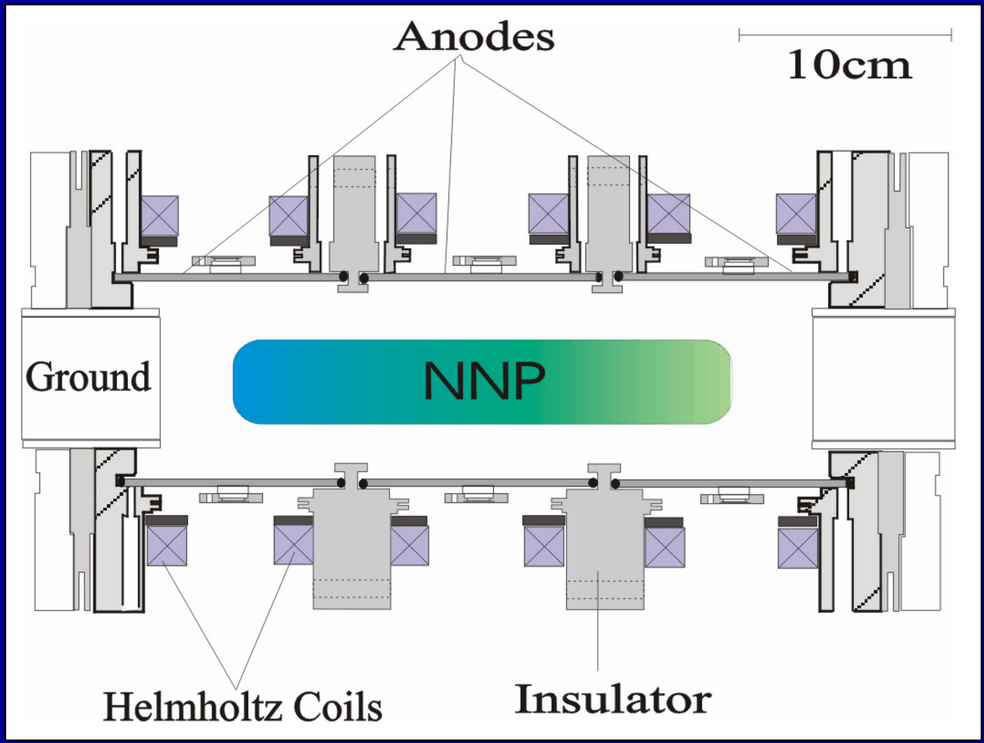
Fig. 4. Deriving the dispersion relation after Bohm and Gross (1949)



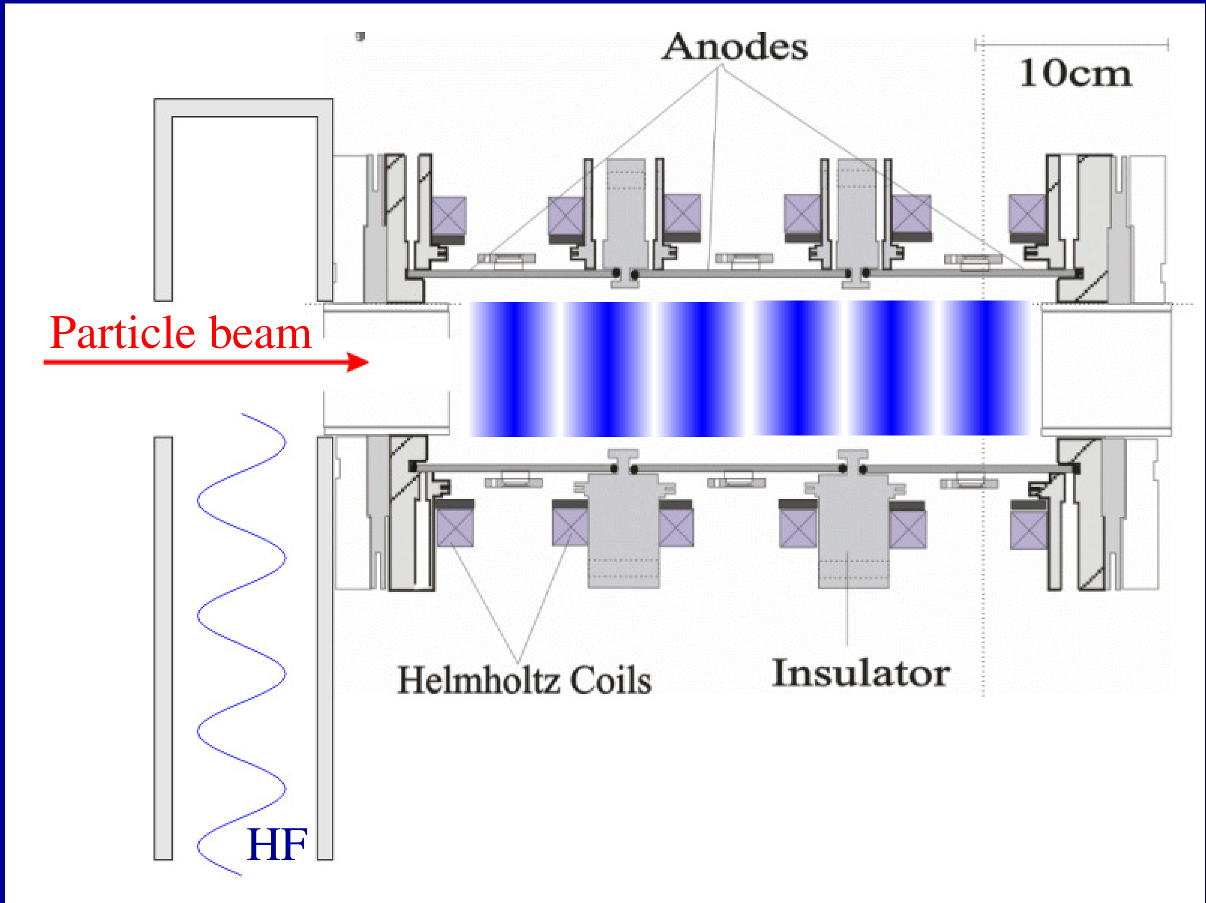
Traveling wave through a plasma filled wave guide

Three Segmented Gabor Lens





Three Segmented Gabor Lens as a Wave Guide



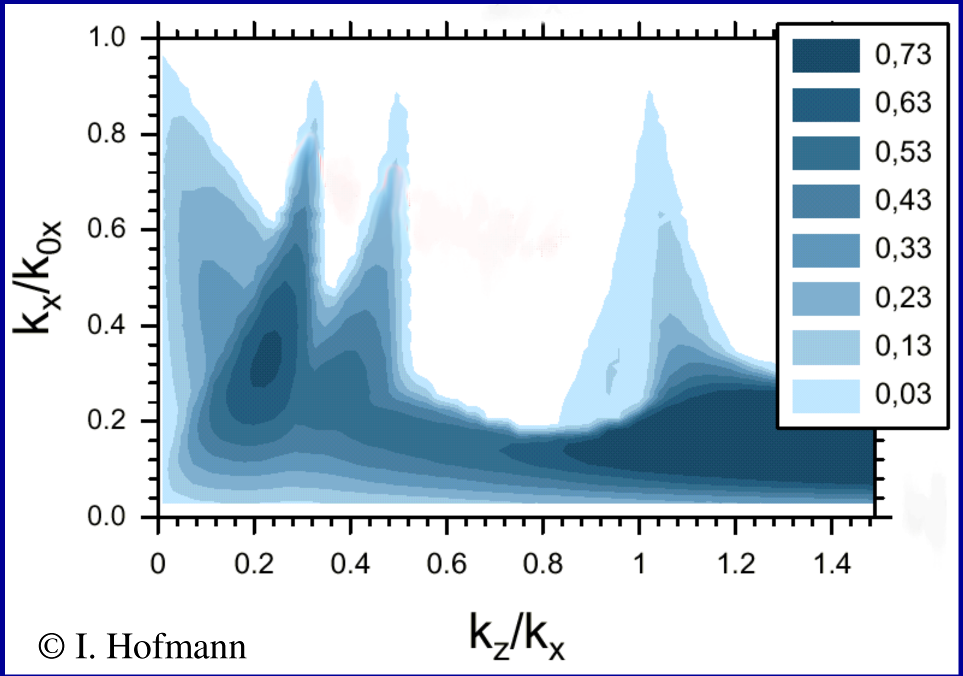
Alfven wave propagation

$$v_p = \frac{c_0}{\sqrt{1 + \frac{\mu_0 c_0^2 \rho_m}{B_z^2}}}$$

Δn_e Δv_p

Open Questions

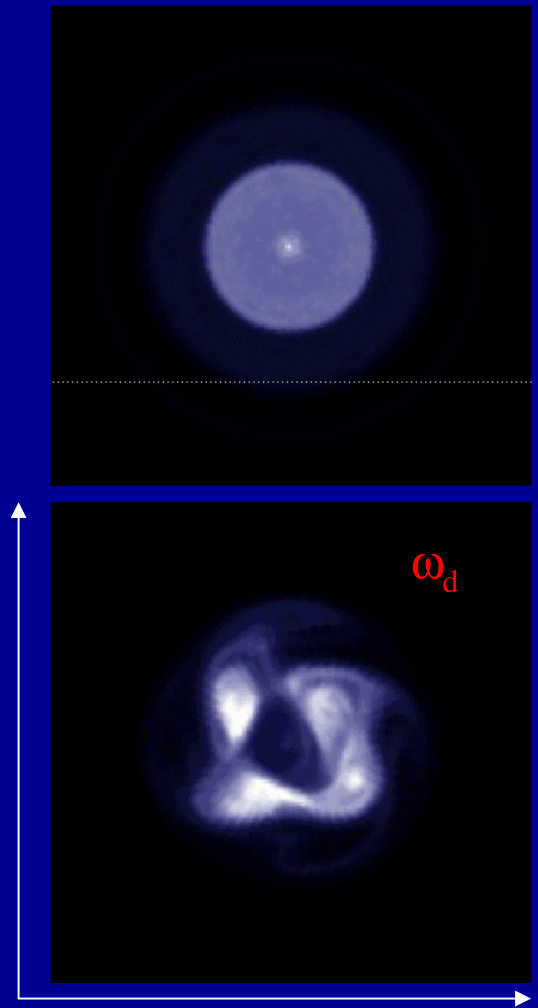
- stable confinement with longitudinal density gradient ?
- thermalization with longitudinal density gradient ?



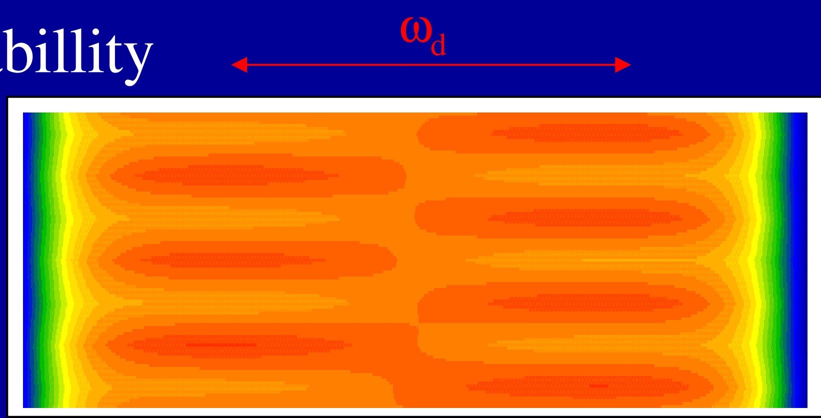
- diagnostic of wave propagation ?

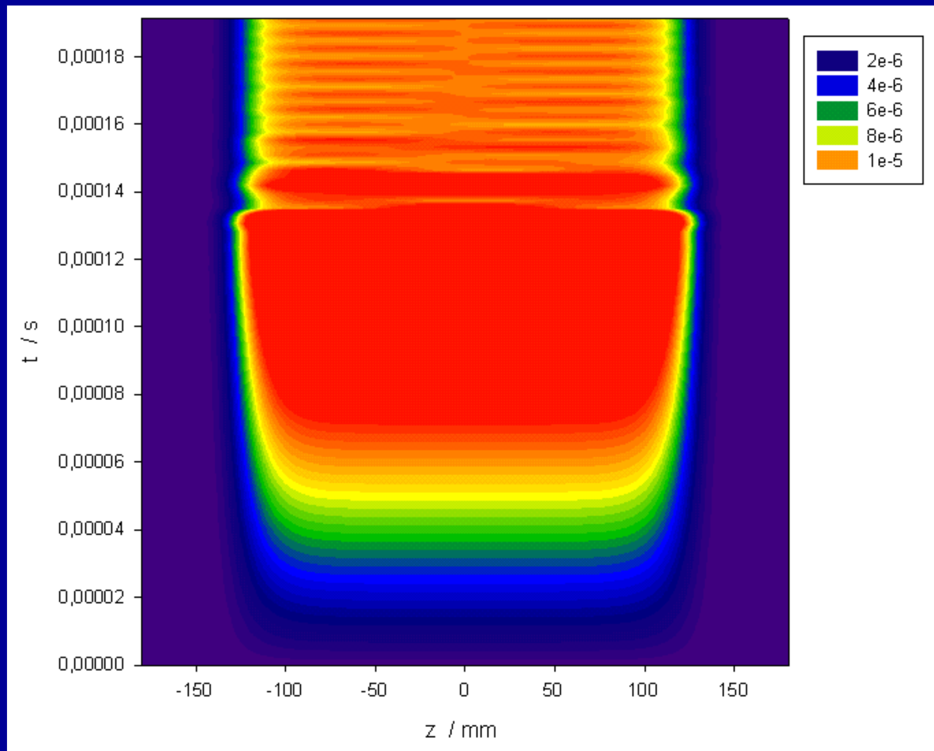
Diocotron Instabillity

transverse

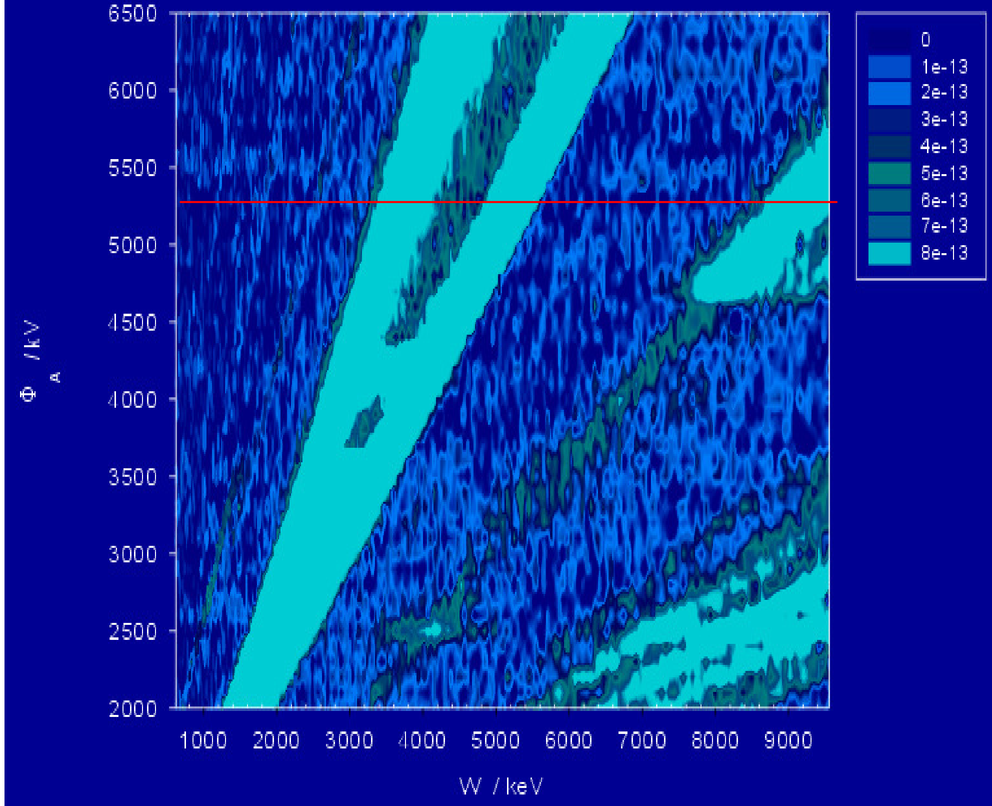


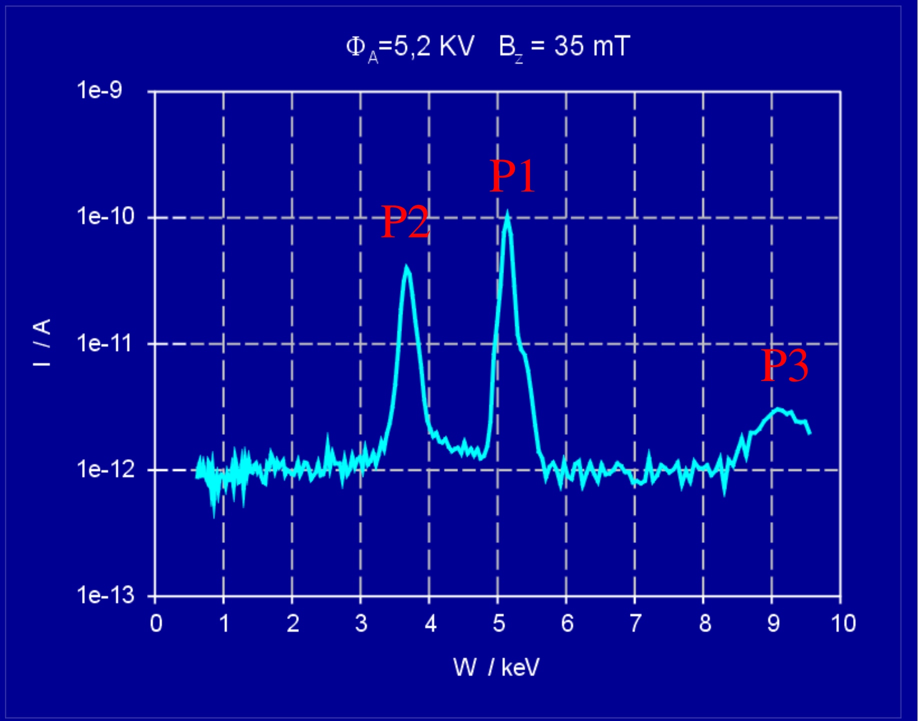
longitudinal



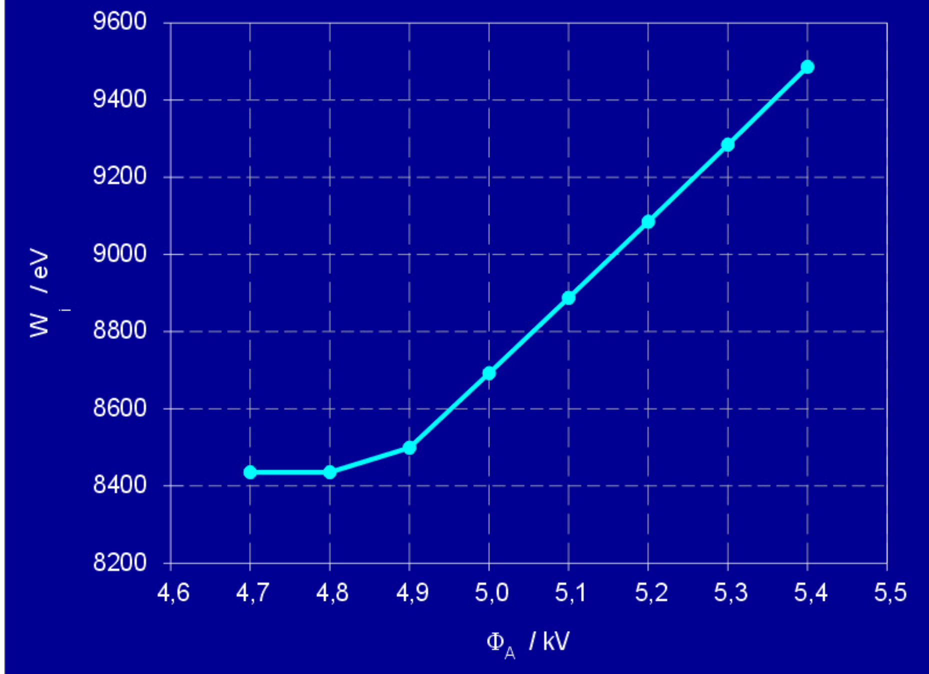


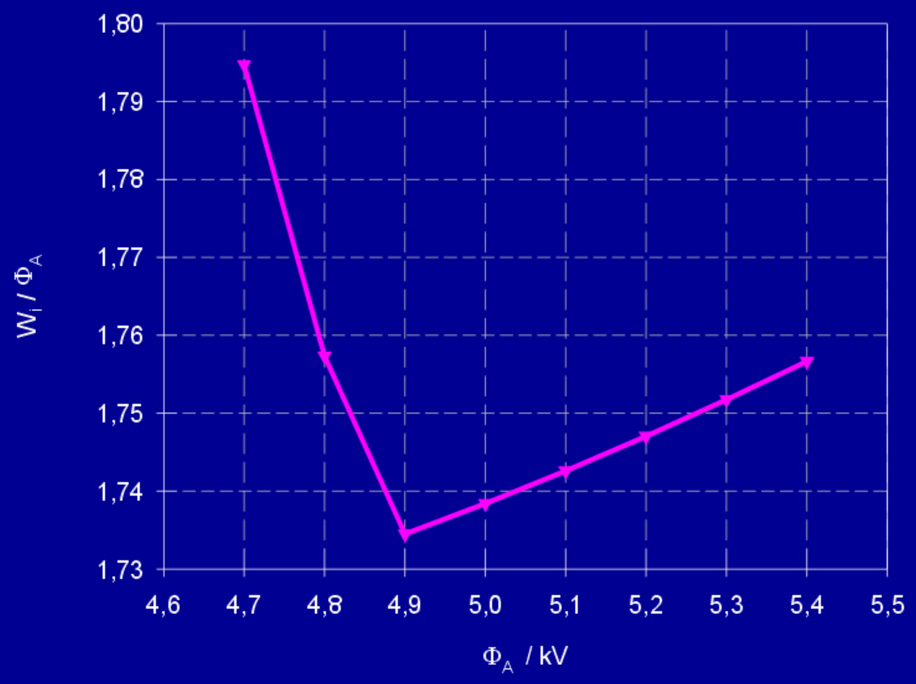
Energy Spectra of Extracted RGI‘s





Acceleration of the RGI's





Finally

an old idea

LASER based systems

Collective accelerators

Nonneutral plasma filled wave guids

$$L = \frac{\dot{N}}{\sigma}$$

Requirements on Accelerator physics
- Luminosity -