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Non Neutral Plasma Physics Group

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Experimental Studies of Stable Confined Electron Clouds using Gabor Lenses

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ECLOUD‘12, Isola d'Elba

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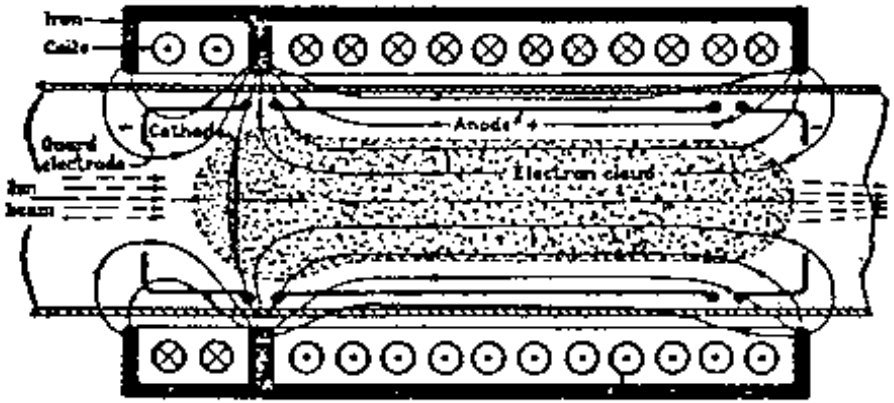
A Space-Charge Lens for the Focusing of Ion Beams

SOME time ago I proposed a magnetron of special design as a divergent lens for electron beams[1]. It now appears that the same device may become useful as a very powerful concentrating lens for positive ions, particularly for ion beams of extreme energy.



MAGNETRON LENS FOR ION BEAMS

Proposal of a SCL by Gabor, July 1947

Dennis Gabor
(1900-1979)

Electrical & Electronic Engineering Department, Imperial College London

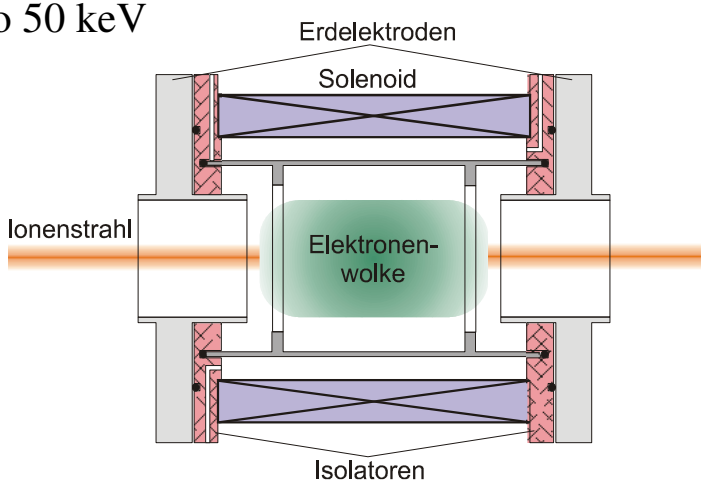
Space Charge Lenses

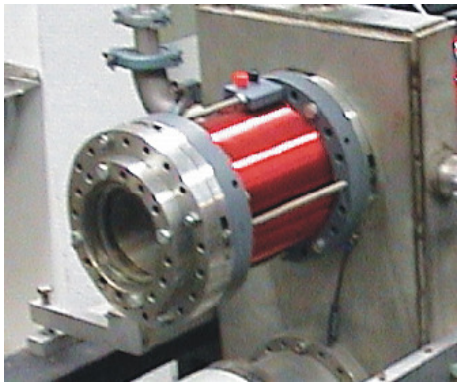
Gabor lens for beam energies up to 50 keV

lens properties:

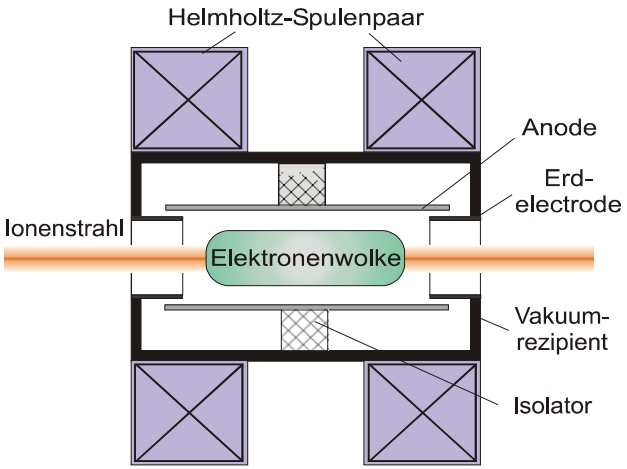
$\Phi_{A,max} = 6.5kV$

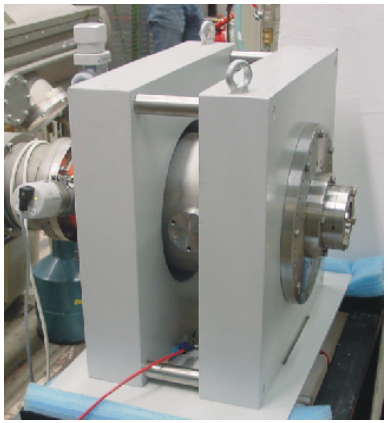
$B_{z,max} = 48mT$





high field Gabor lens for beam energies up to 500keV





lens properties :

$\Phi_{A,max} = 65kV$

$B_{z,max} = 220mT$

Radial Confinement

radial force balance equation

$$\frac{-m_e v_{e,\Theta}^2}{r} = -eE_r - ev_{e,\Theta}B_z$$

E_r given by Poisson equation:

$$\frac{1}{r}\frac{\partial}{\partial r} rE_r = \frac{en_e(r)}{\varepsilon_0}$$

integration for $0 < r < R_p$:

$$E_r = \frac{1}{2\varepsilon_0} en_e r$$

$$-\omega_e^2 = \frac{\omega_{pe}^2}{2} - \omega_e \Omega_e$$

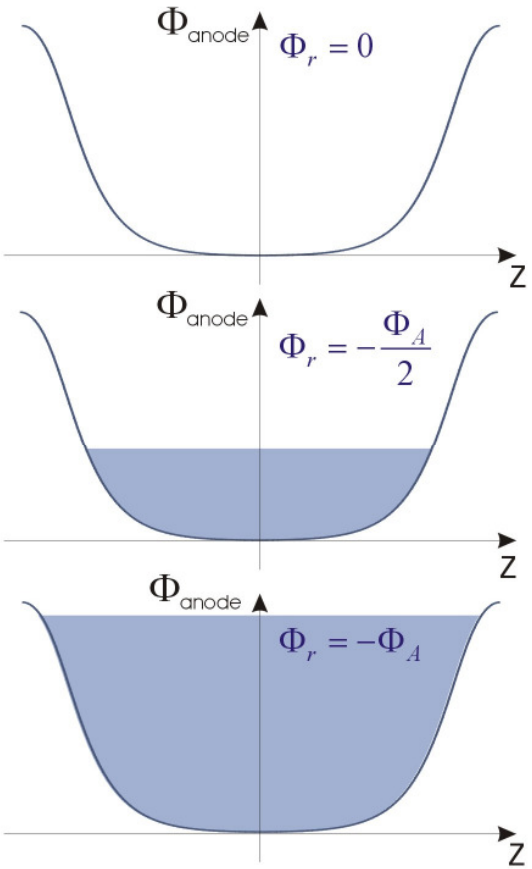
$$\omega_e = \frac{v_{e,\Theta}}{r}$$ **angle velocity**

$$\omega_{pe}^2 = \frac{e^2 n_e}{\varepsilon_0 m_e}$$ **plasma frequency**

$$\Omega_e = \frac{eB_z}{m_e}$$ **cyclotron frequency**

Longitudinal Confinement

longitudinal potential well



Φ_r is determined from Poisson's equation:

$$-\frac{1}{r}\frac{\partial \Phi_r}{\partial r} - \frac{\partial^2 \Phi_r}{\partial r^2} = \frac{e n_e(r)}{\varepsilon_0}$$

integrated for $0 < r < R_p$

$$\Phi_r = -\frac{e n_e r^2}{4\varepsilon_0}$$

maximum density at $\Phi_{anode} = -\Phi_r$

$$\Rightarrow \quad n_e = \frac{4\varepsilon_0 \Phi_A}{e r^2}$$

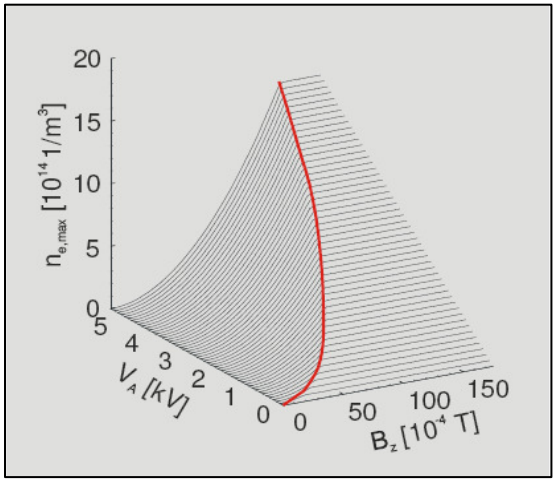
Numerical Simulation

two different simulation methods

GaborM

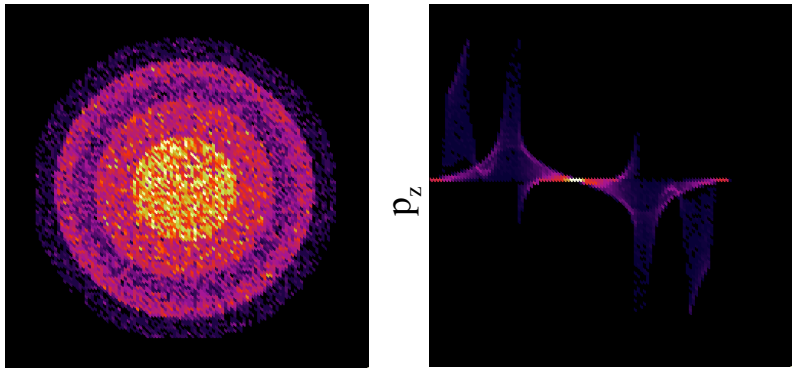
- fluid description
- steady state

$$\Phi_A = \frac{er^2 B_z^2}{8m_e}$$



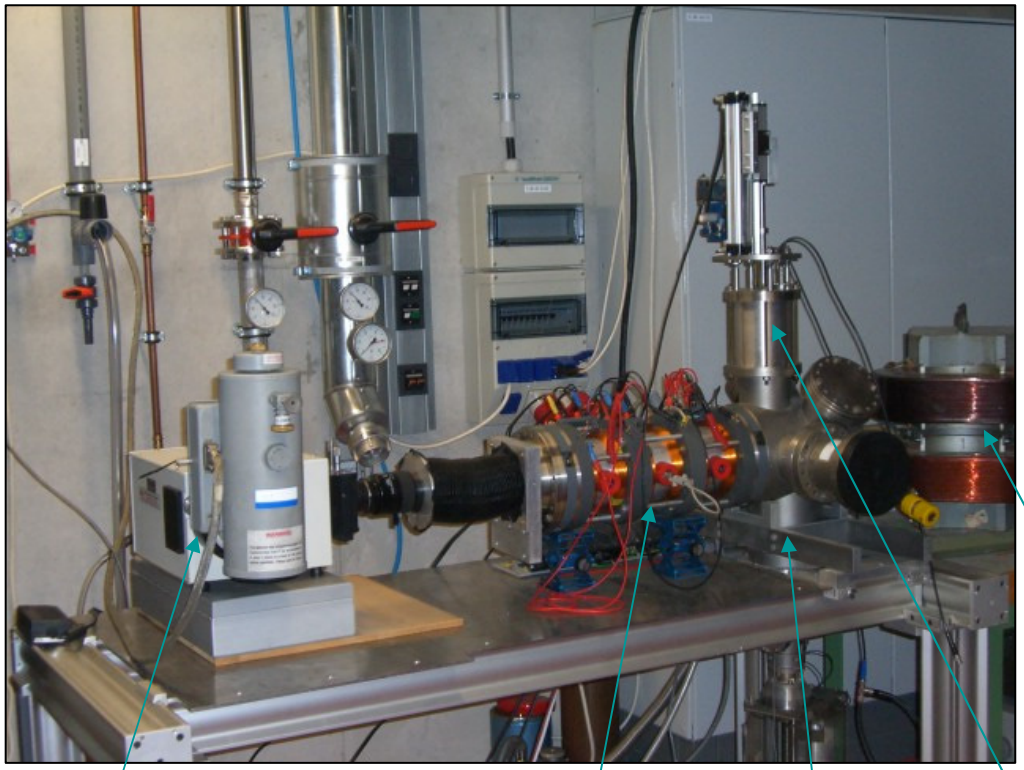
GabLensM2

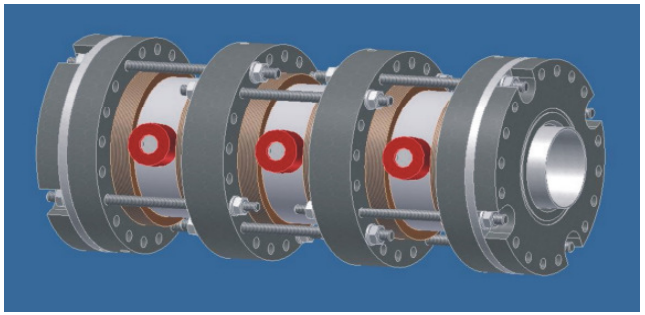
- kinetic description
- dynamic processes
- 3D-Particle-In-Cell Simulation



Experiments

three segmented Gabor lens for the development electron cloud diagnostics

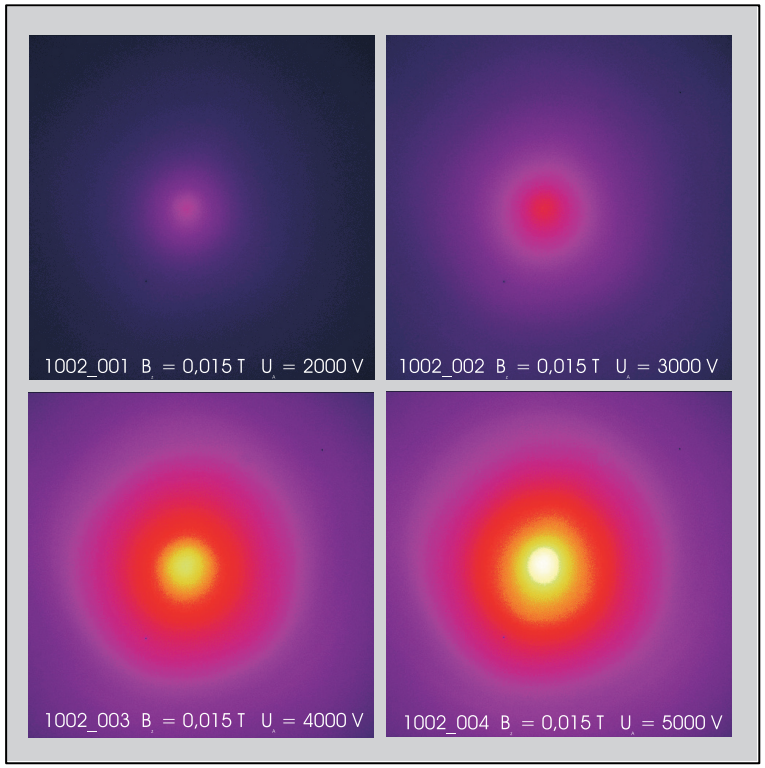




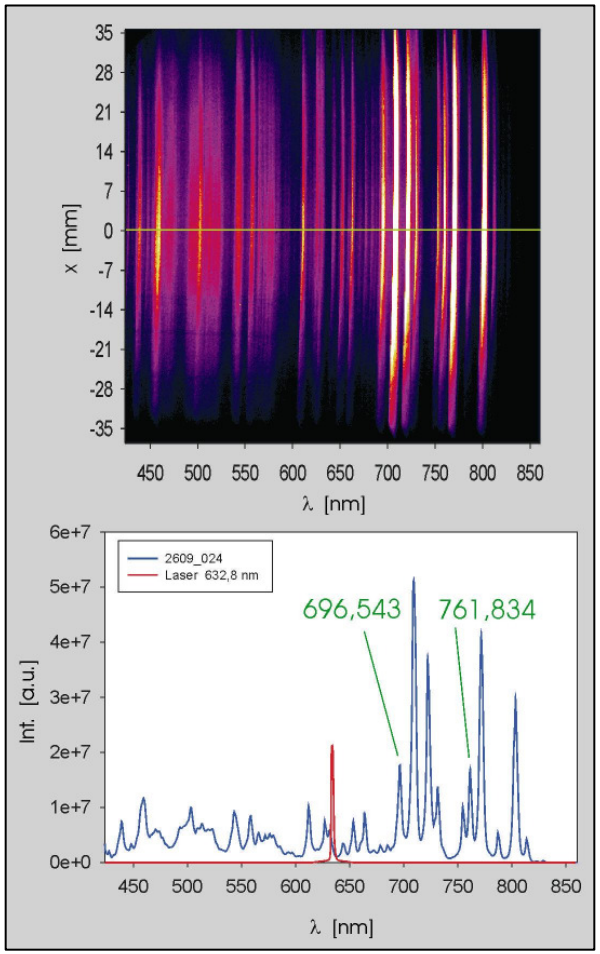
CCD - Camera & Monochromator SCL Allison Type Emi FDC Momentum Spectrometer

Diagnostics of the Confined Electron Cloud

optical diagnostics

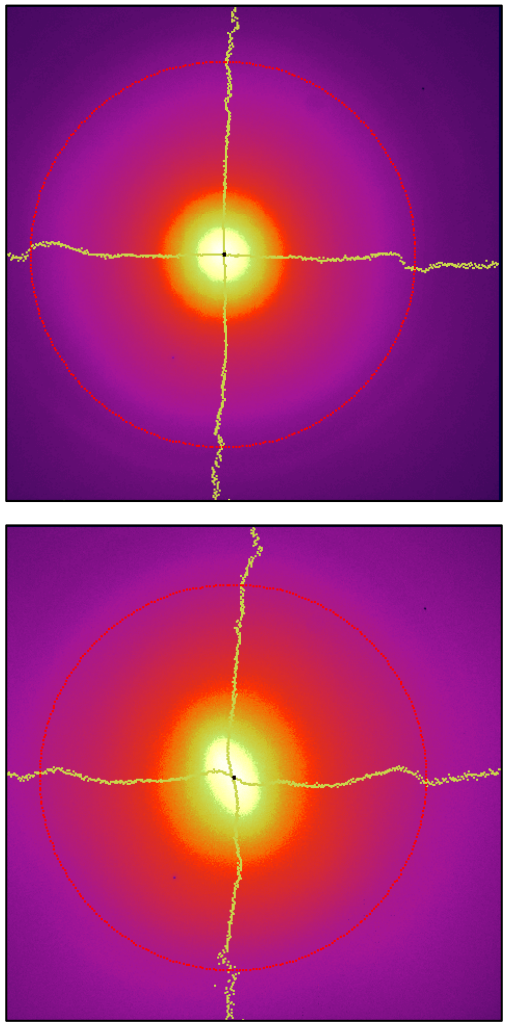


electron density distribution as a function of the confinement



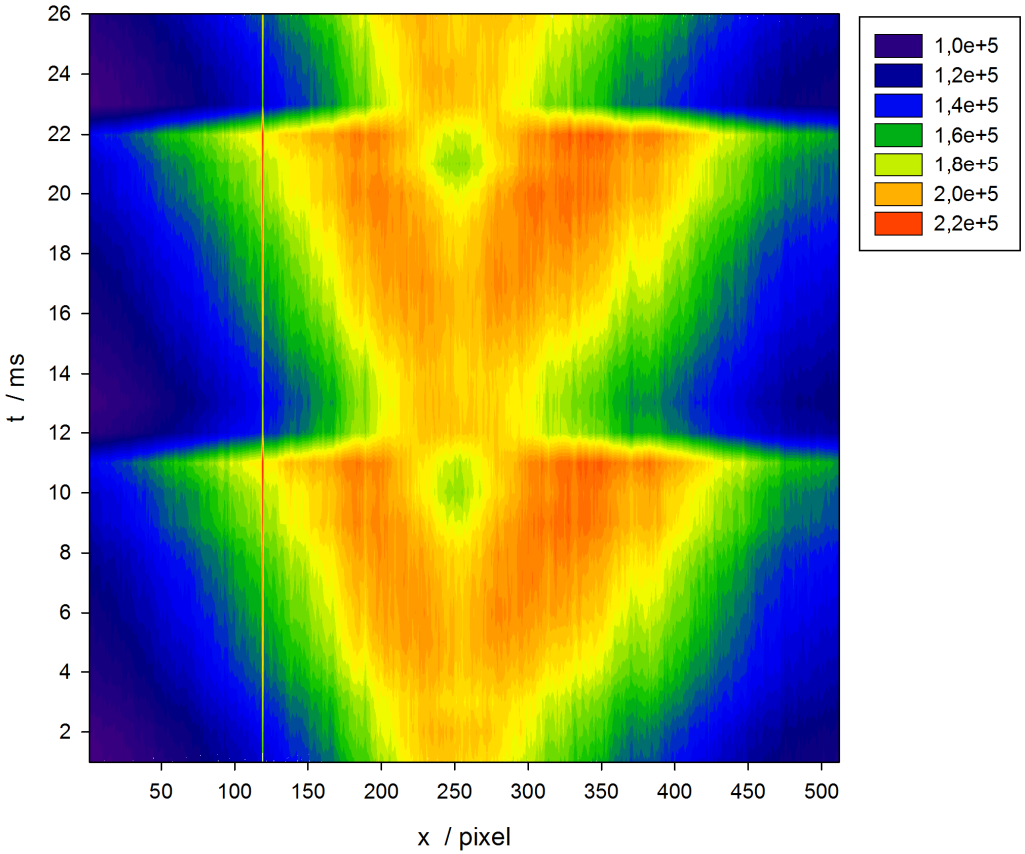
estimation of T_e using opt. spectroscopy

Diagnostics of Collective Behaviour



symmetry breaking within
a symmetric confinement

diocotron instability



rise and fall of instabilities

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Diagnostics Using the Emitted RF

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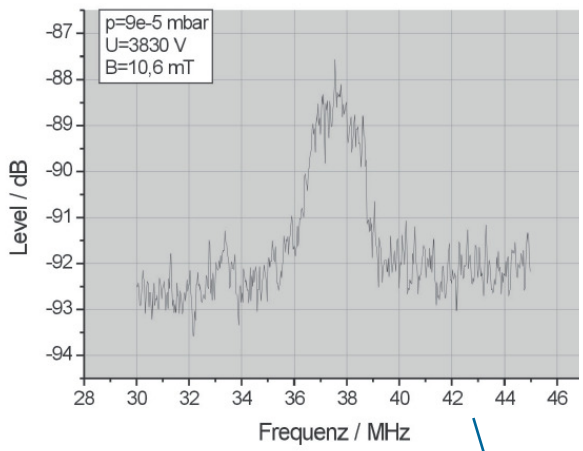
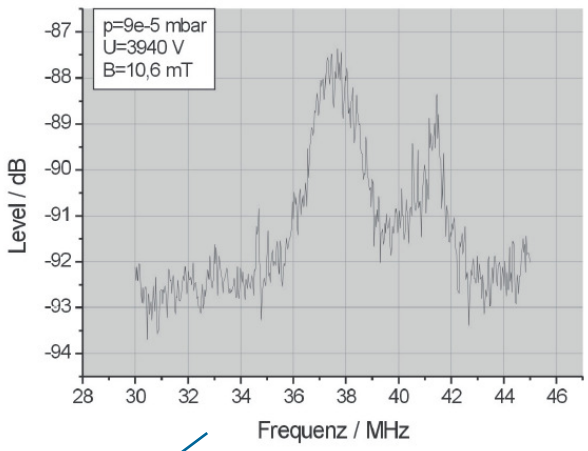
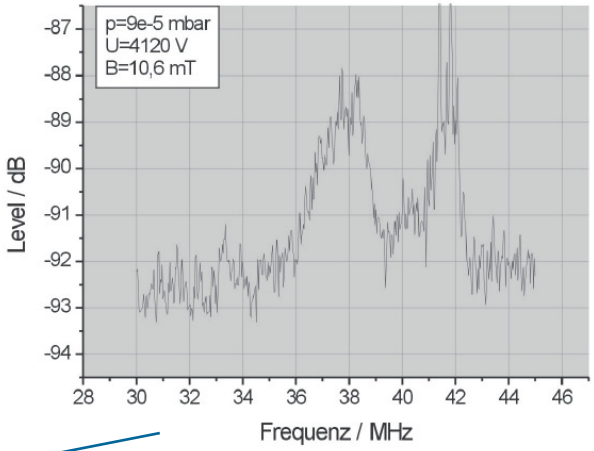
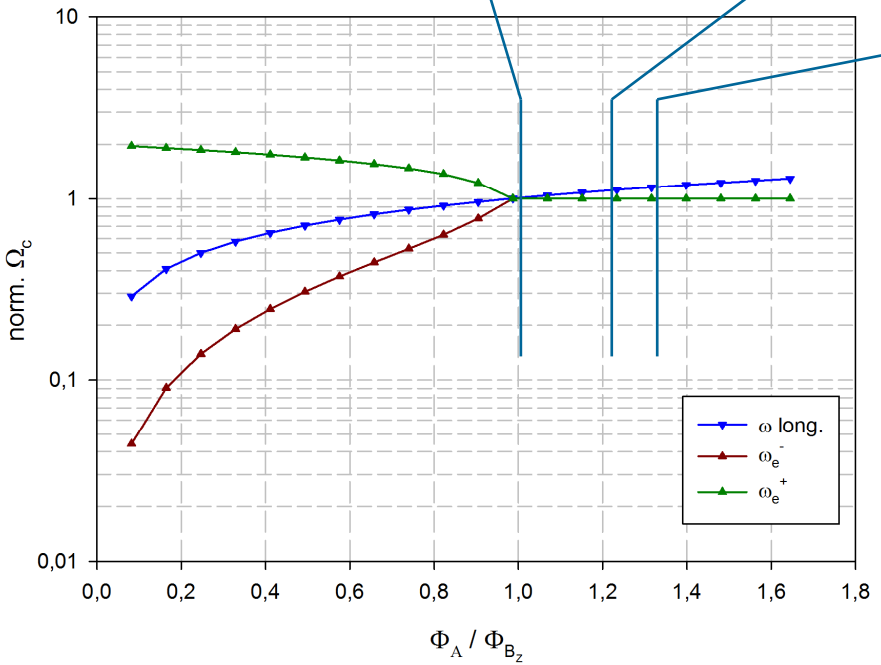
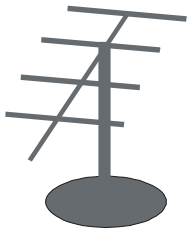
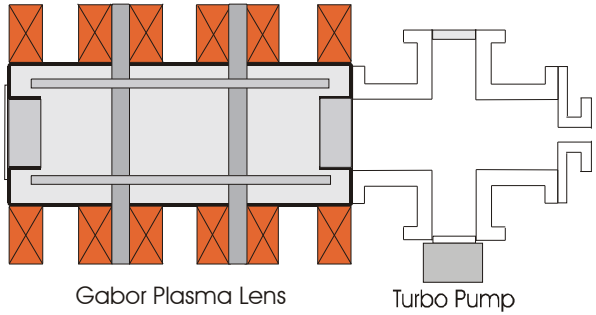






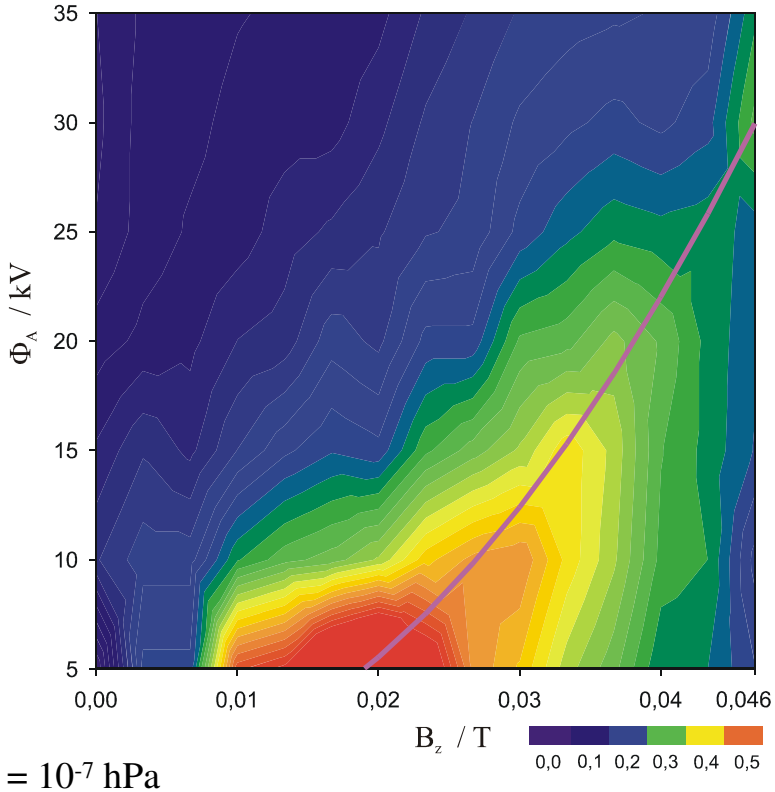



Antenna


Gabor Plasma Lens

Turbo Pump

measurement of the electron density using an ion beam



p = 10^{-7} hPa

$$\frac{1}{f} = \frac{\Delta x'}{x_0} = k^2 l = \frac{e n_{e,\exp}}{4\varepsilon_0} \frac{l}{W_b}$$

$$\kappa_r = \frac{n_{e.\exp}}{n_{e,theo}}$$

beam properties:

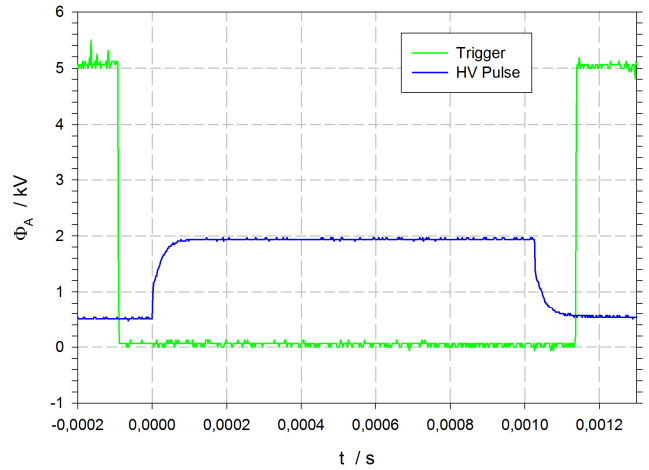
W_b = 110 keV/u

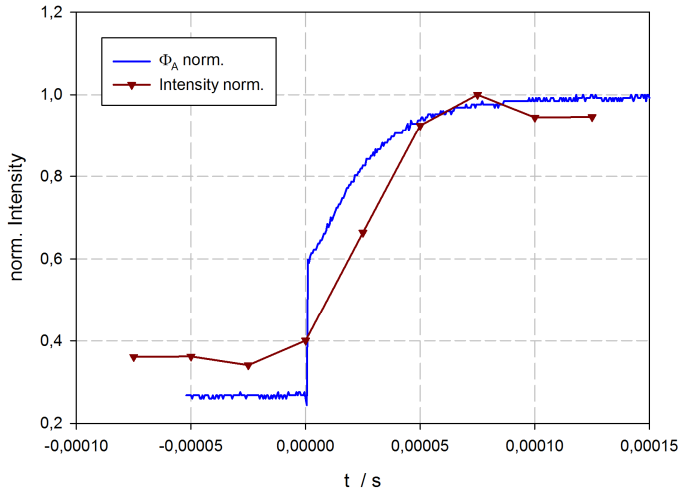
I = 1.2 mA

He^+

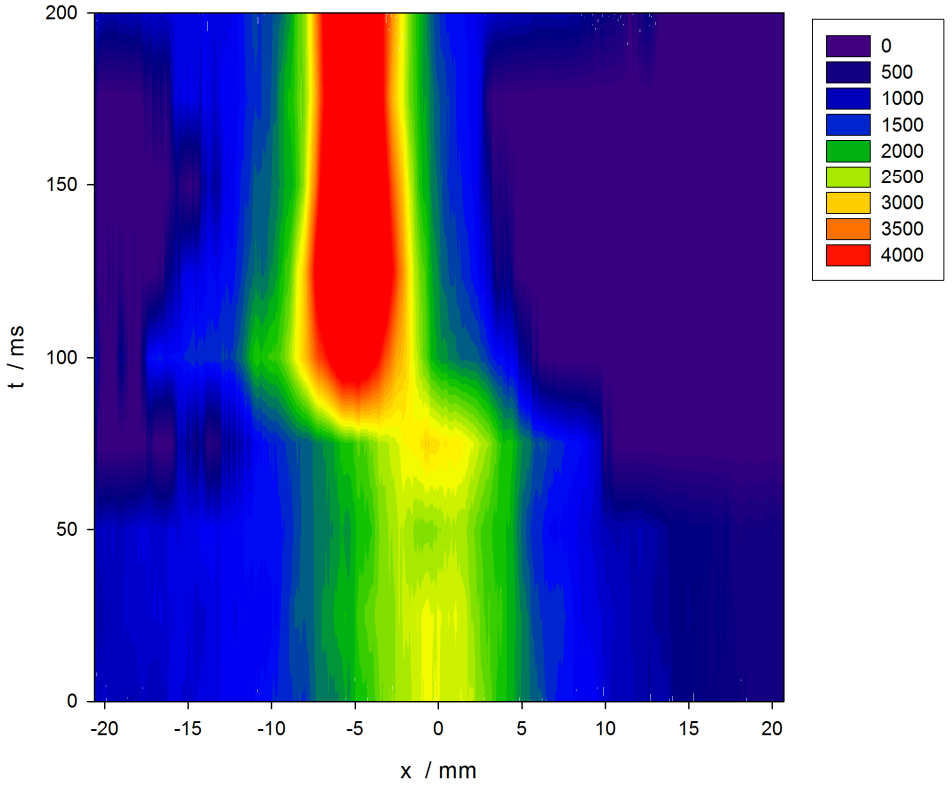
Time Resolved Measurements

measurement of the rise time of the electron density using an ion beam



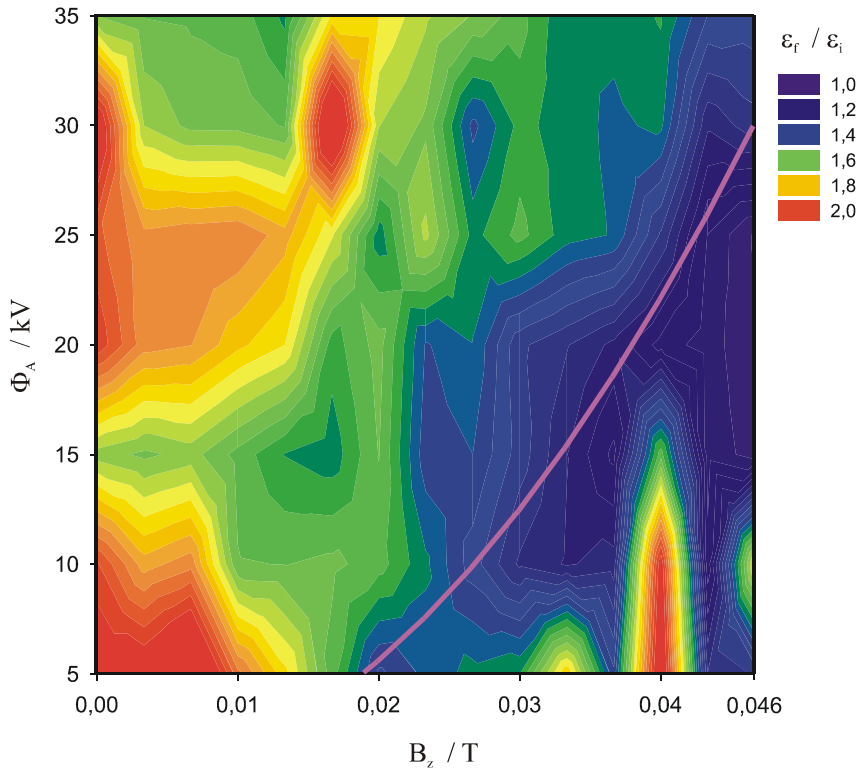


focussing and deflection?



Beam Emittance Growth

characterisation of lens aberration by estimation of emittance growth



$$\varepsilon_{rms} = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2}$$

$$\Delta\varepsilon_{rms} = \frac{\varepsilon_{rms,out}}{\varepsilon_{rms,in}}$$

beam properties:

W_b = 110 keV/u

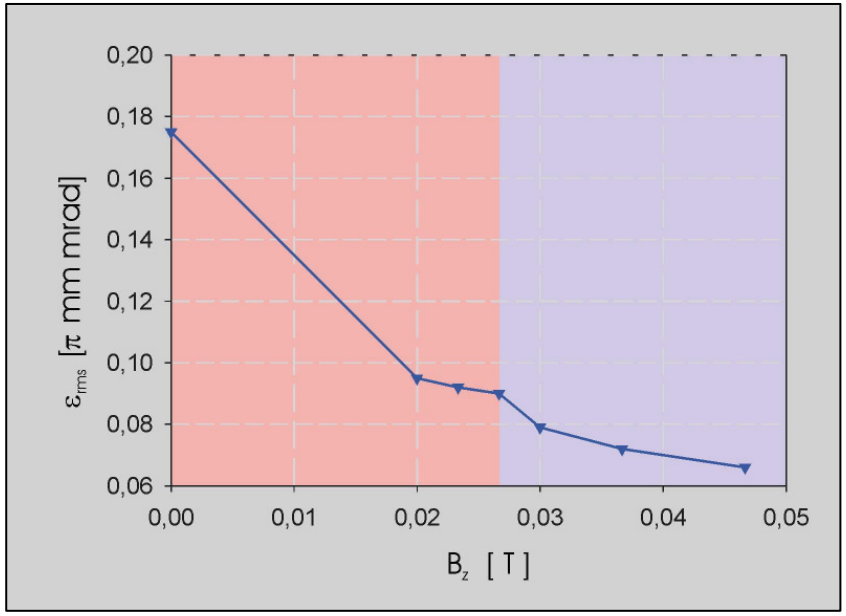
I = 1.2 mA

He^+

p = 10^{-7} hPa

Transport of Bunched Beams

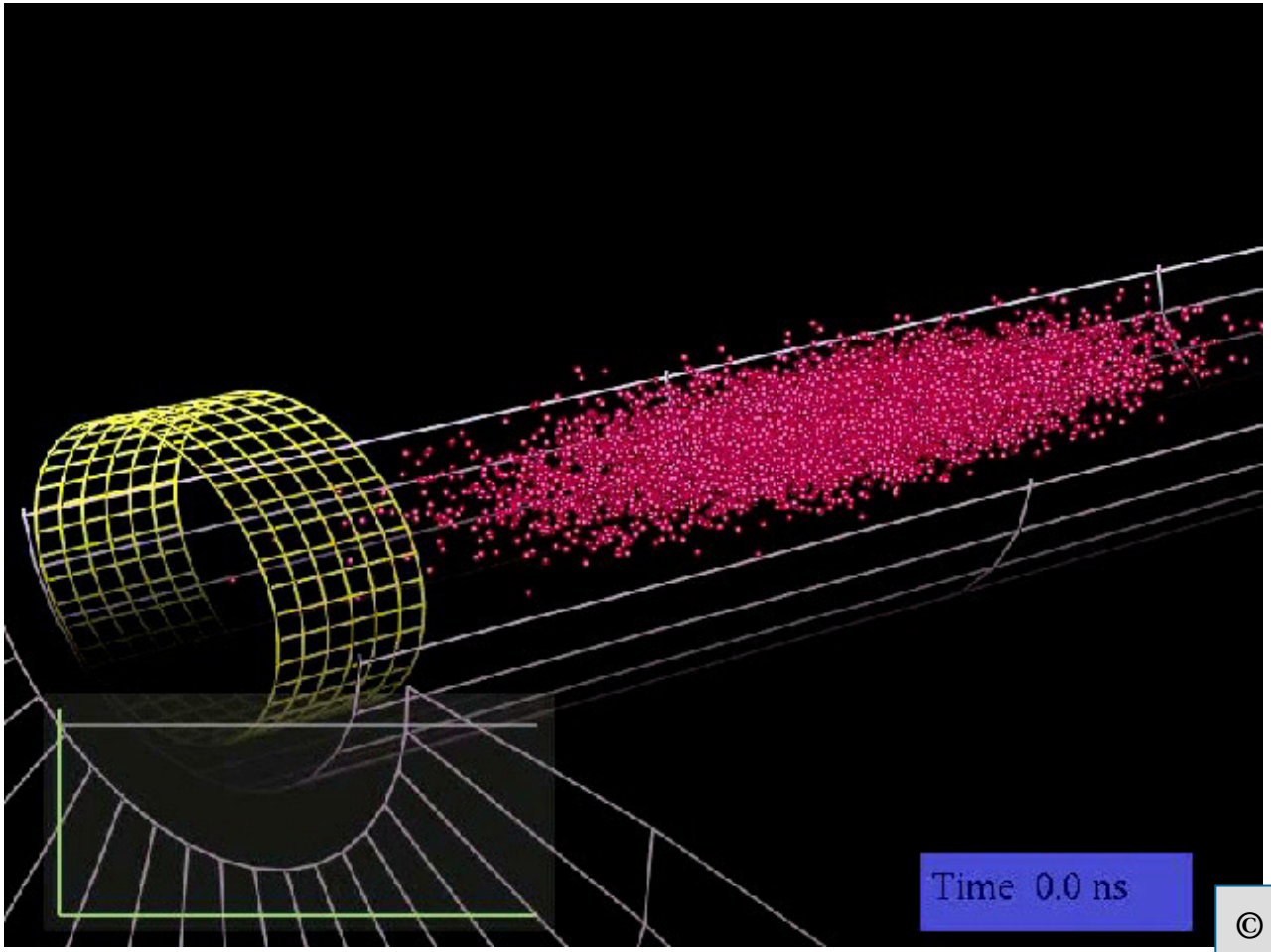
focussing of micro bunches passing a Gabor lens @ 108MHz, $\Delta\phi = 60°$



emittance as a function of the transverse electron confinement

- losses due to chromatic aberrations
- apparent beam cooling due to Landau damping
- space charge compensation
- no beam induced instabilities were observed

Simulation of EC – Beam Interaction



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