Space Charge Lenses and NNP Diagnostics

HIC for FAIR Workshop

Riezlern, 2011

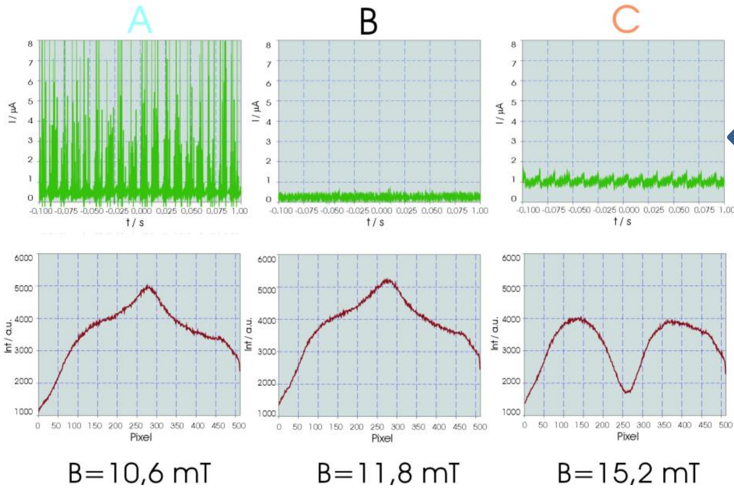
Kathrin Schulte

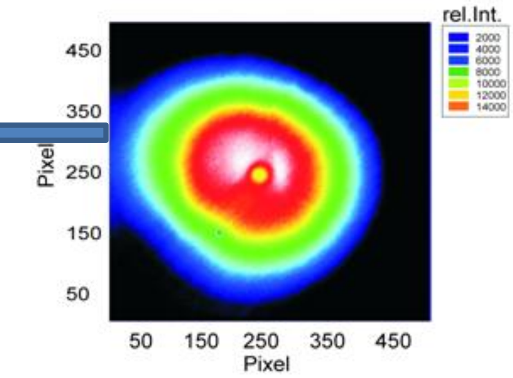
Content

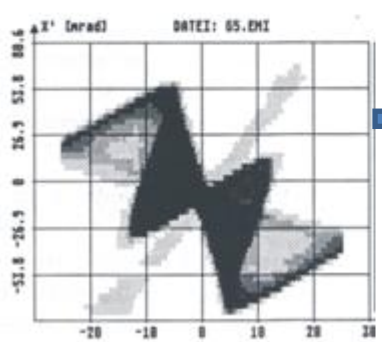
Motivation - Focusing Optics and Fundamental Research

A,C – Fundamental Research

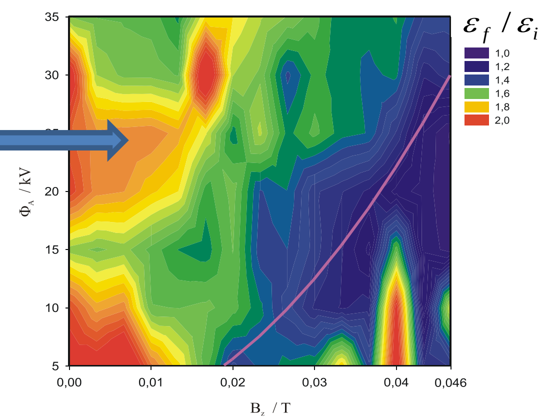
B – Focusing Optics







@ G. Riehl



Understanding of:
- Production and Loss Mechanisms
- Heating and cooling processes
- Plasma-Beam-Interactions
  e.g. ion beam passing NNP
  - Heating?
- Development of Instabilities

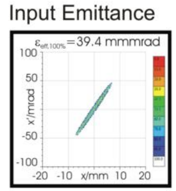
→ Diagnostics

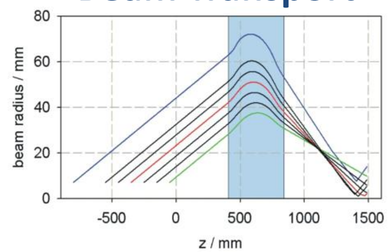
Status of the Space Charge Lens Protype for the HSI Upgrade

Requirements:

- U^{4+}-Ions
- 2,2 AkeV
- beam radius: 50mm

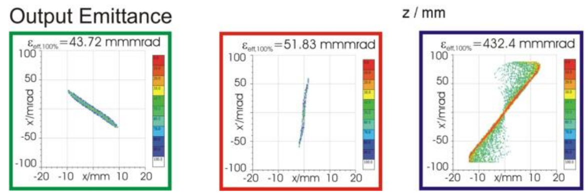
Beam Transport





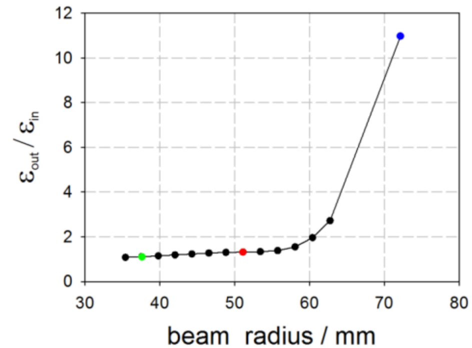
beam parameters:
W_{beam}=2.2 keV/u, U^{4+},
100% space charge compensation

lens parameters:
B_z=13 mT
Φ_A=30 kV

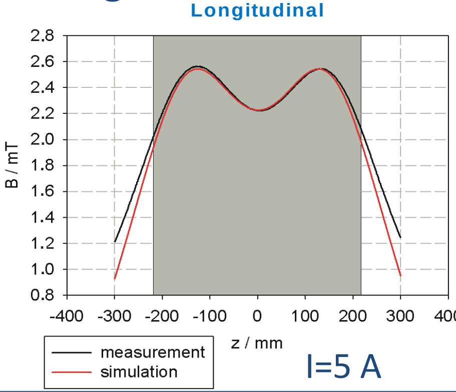


Effective Emittance!

Emittance Growth as Function of the Beam Radius

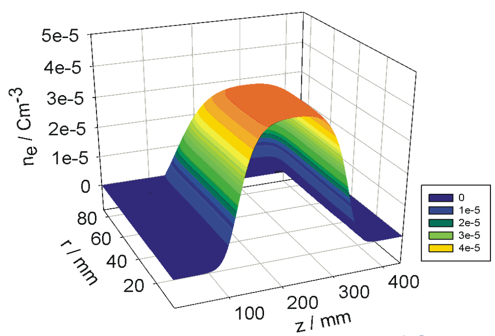


Magnetic Field on Axis

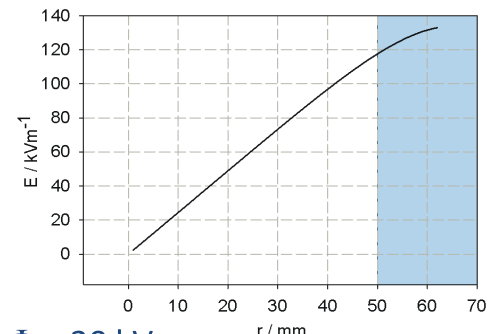


I=5 A

Electron Density

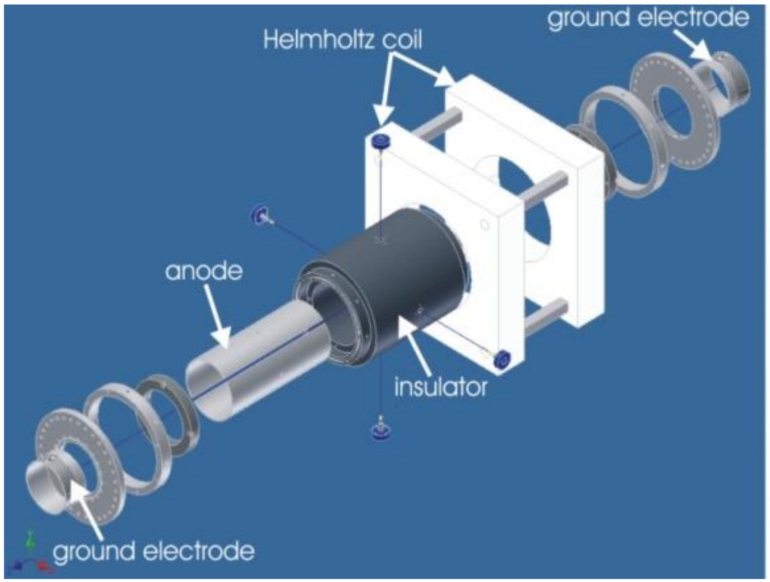


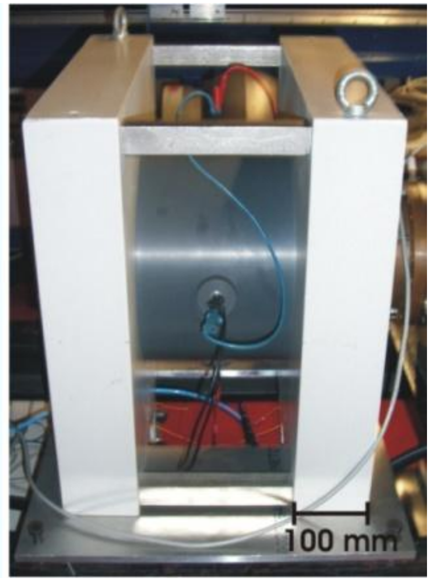
Electric Space Charge Field



B_z=13 mT, Φ_A=30 kV

Space Charge Lens Prototype





Geometry:

r_{anode}: 85 mm

r_{ground}: 75 mm

l_{anode}: 340 mm

L_{total}: 436 mm

Maximum Field and Potential:

$B_{z,max}$: 160 mT

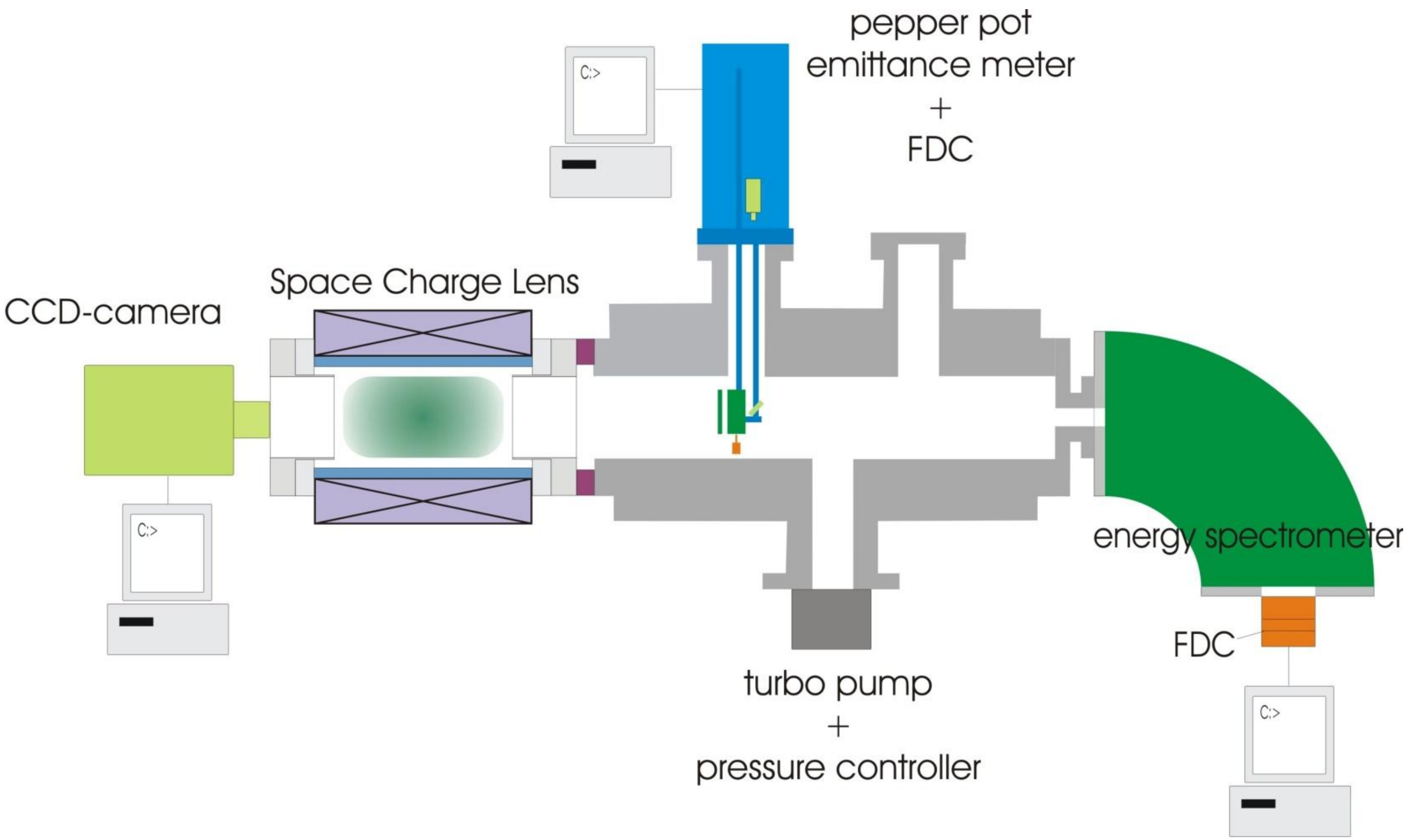
$\Phi_{A,max}$: 50 kV

vaccum test

NNP ignition

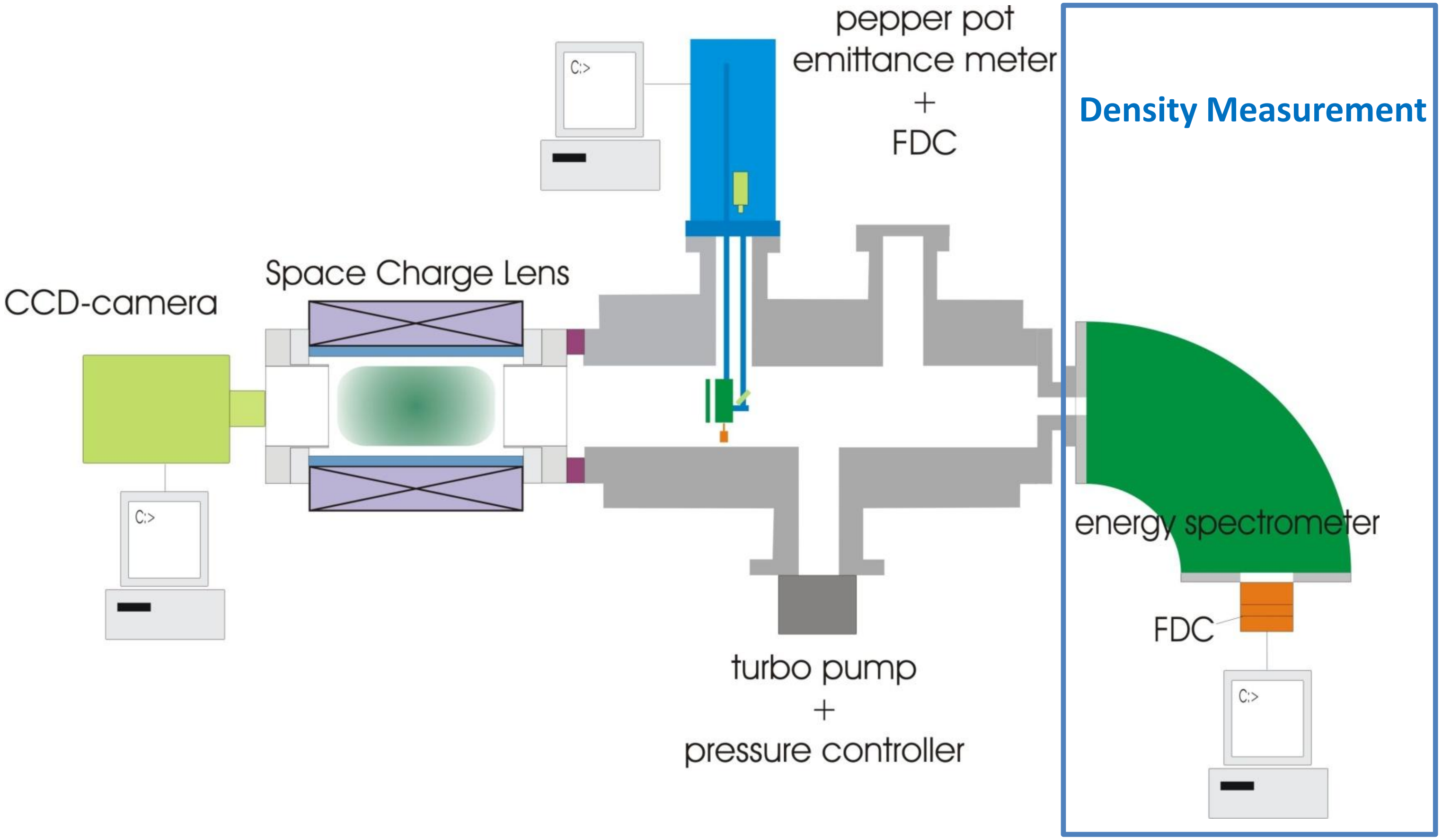
presently conditioning (20kV, 5mT)

Experiment



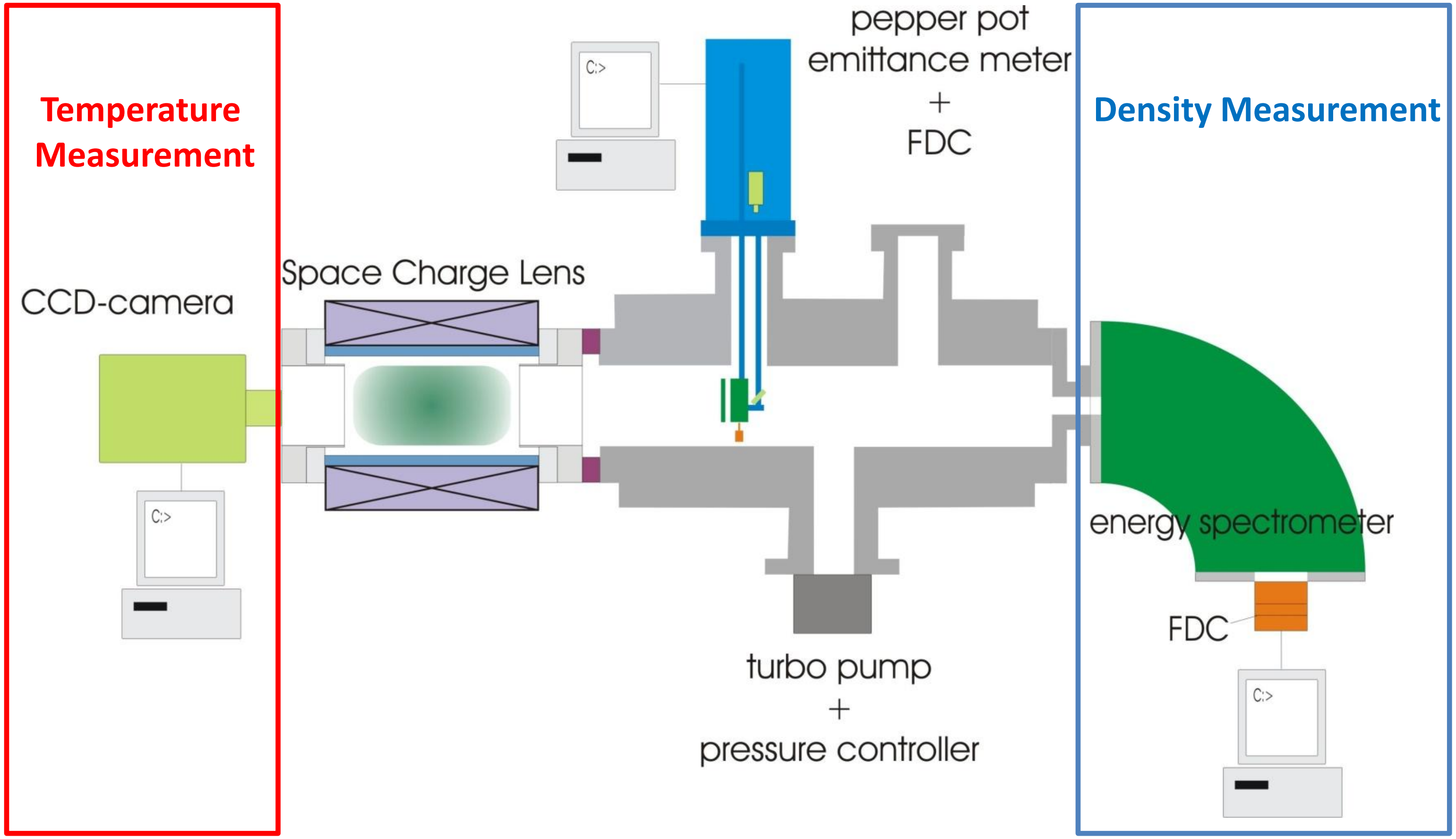
pepper pot
emittance meter
+
FDC
C:>
Space Charge Lens
CCD-camera
C:>
energy spectrometer
FDC
C:>
turbo pump
+
pressure controller

Experiment

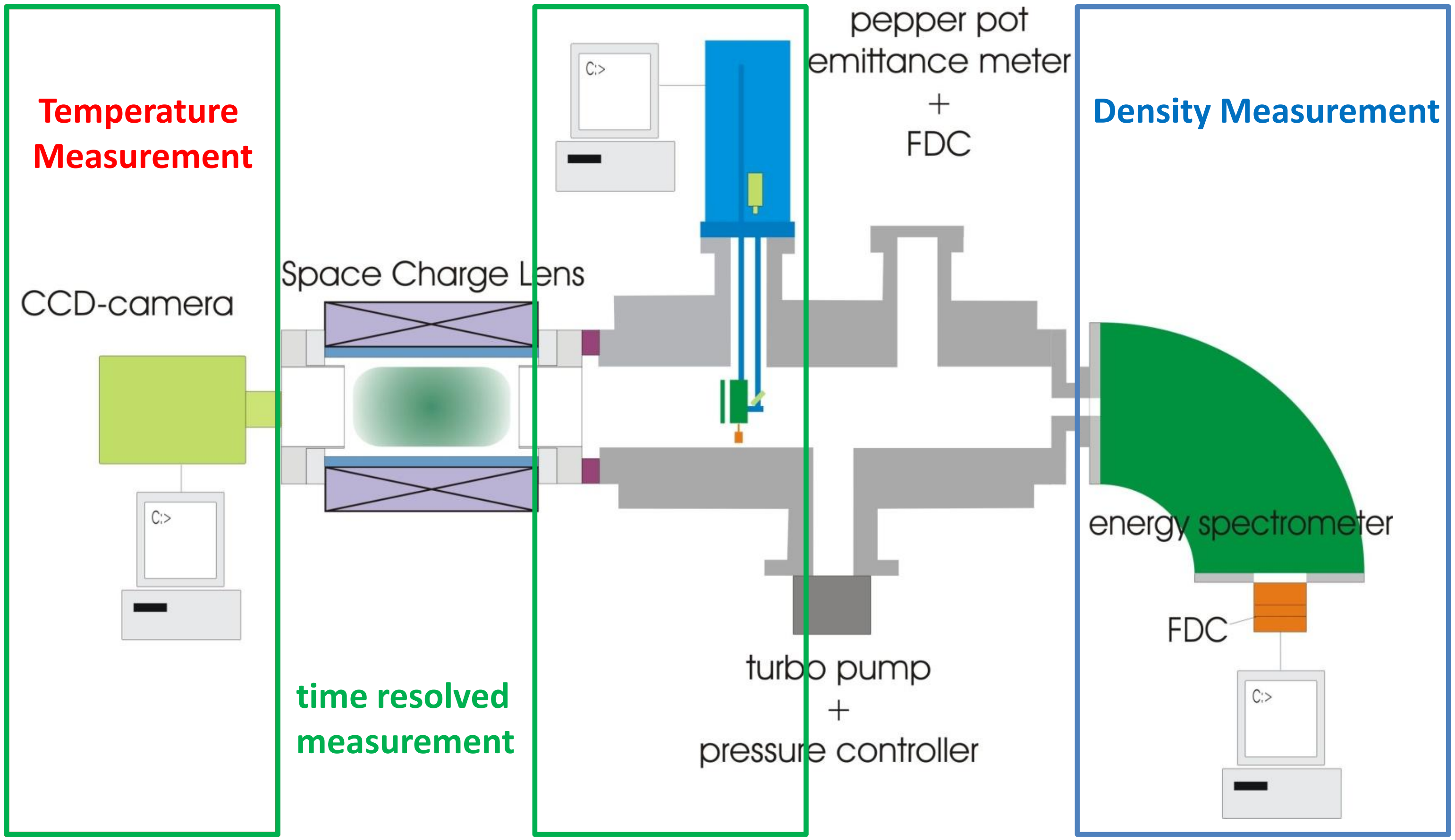


pepper pot
emittance meter
+
FDC
Density Measurement
Space Charge Lens
CCD-camera
C:>
C:>
C:>
energy spectrometer
FDC
turbo pump
+
pressure controller

Experiment


Temperature Measurement
CCD-camera
C:>
Space Charge Lens
C:>
pepper pot
emittance meter
+
FDC
Density Measurement
energy spectrometer
FDC
C:>
turbo pump
+
pressure controller

Experiment

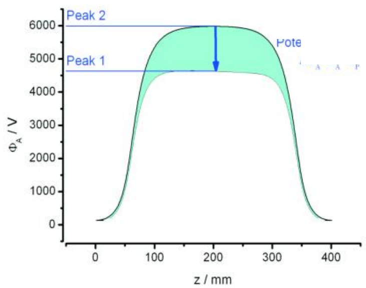


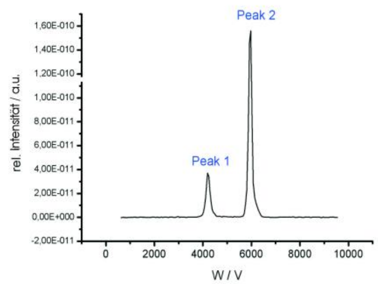
Temperature Measurement
CCD-camera
C:>
Space Charge Lens
time resolved measurement
C:>
pepper pot emittance meter
+
FDC
turbo pump
+
pressure controller
Density Measurement
energy spectrometer
FDC
C:>

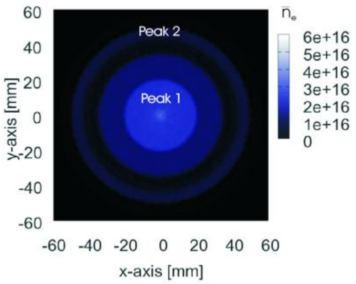
Diagnostics

- Density Measurement

potential depression **ion energy** **location**







potential depression

$\Delta\Phi_A = \Phi_A - \Phi_P$

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

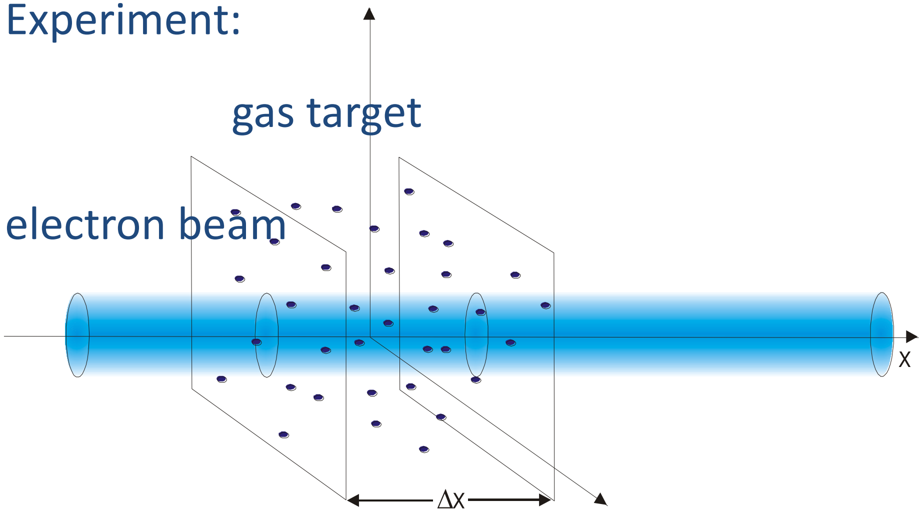
- Temperature Measurement
  - plasma far from thermal equilibrium
  - optical cross sections

$$Q_{ji} = \frac{\Phi_{ji} \cdot e}{I \cdot n_0}$$

$$\Phi_{ji} = \frac{photons}{t \cdot \Delta x}$$

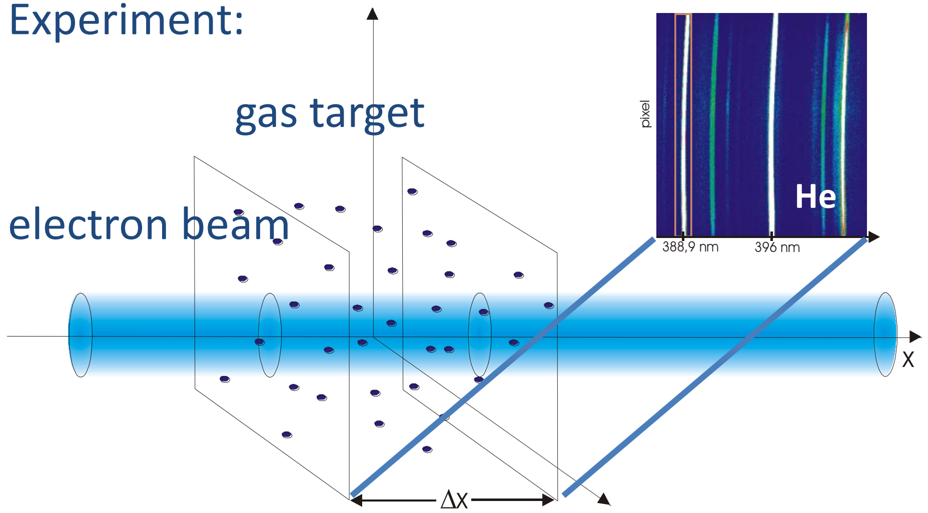
Optical Cross Section

Experiment:



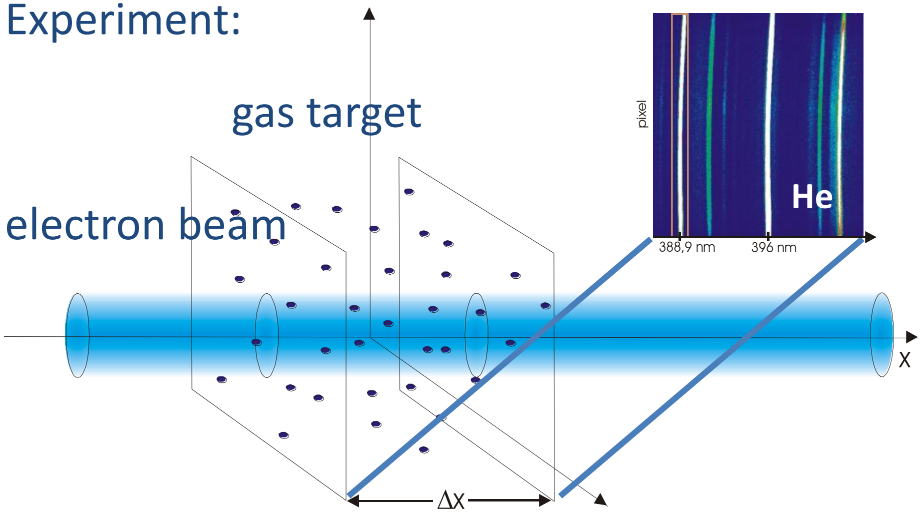
Optical Cross Section

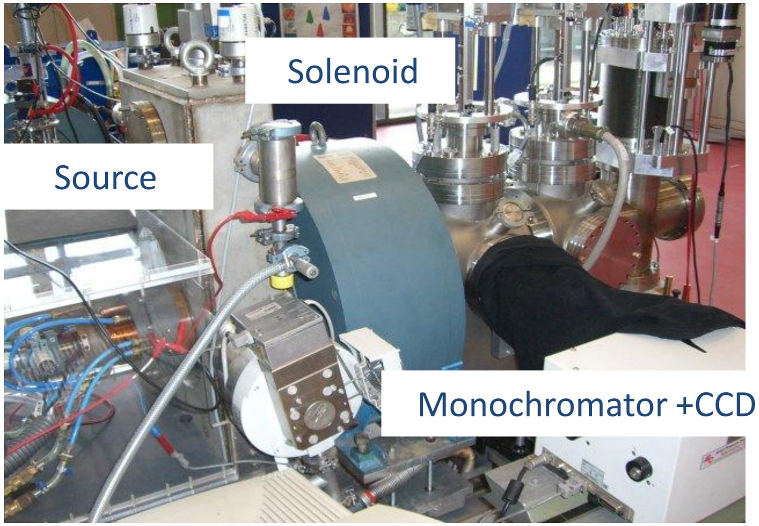
Experiment:

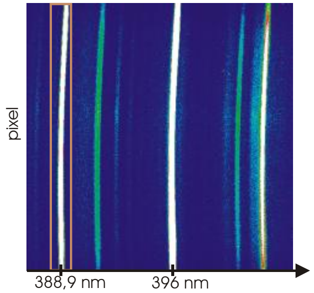


Optical Cross Section

Experiment:

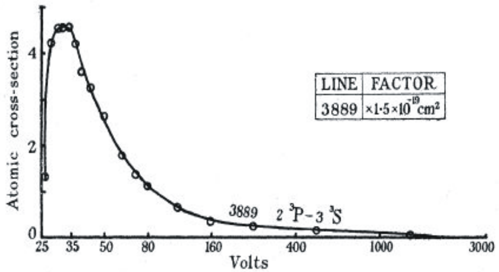






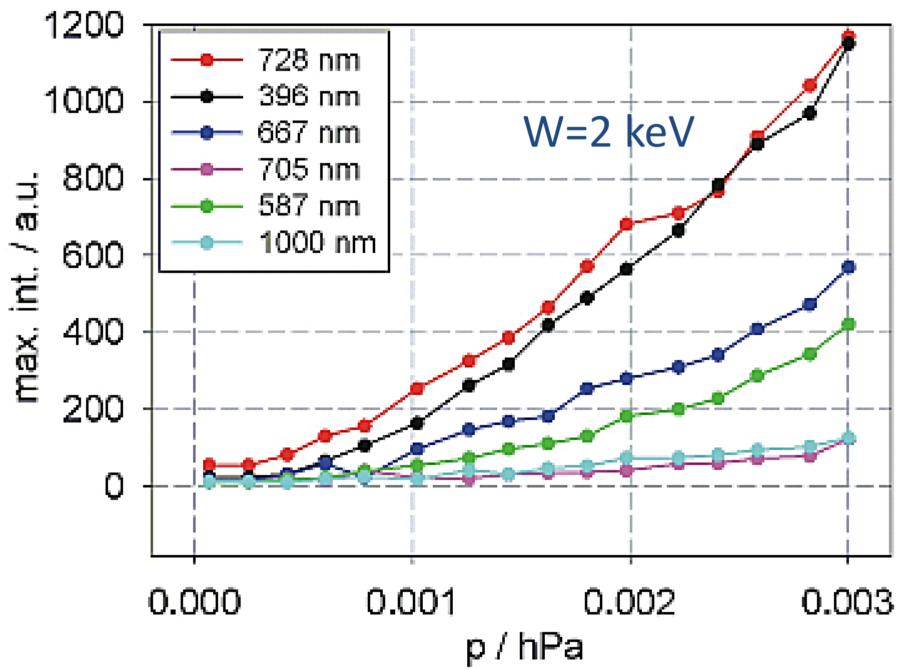
$$Q_{ji} = \frac{\Phi_{ji} \cdot e}{I \cdot n_0}$$

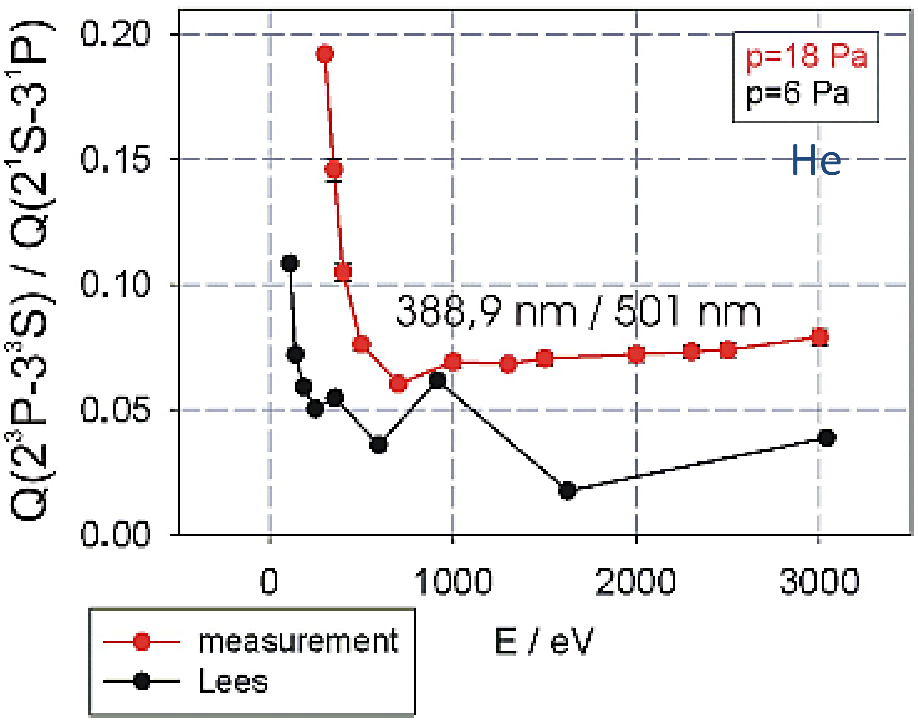
$$\Phi_{ji} = \frac{photons}{t \cdot \Delta x}$$



@ J.H. Lees, The Excitation Function of Helium,
H.H. Wills Physical Laboratory, University of Bristol

Preliminary Results





Condition I ~ n is not fullfilled

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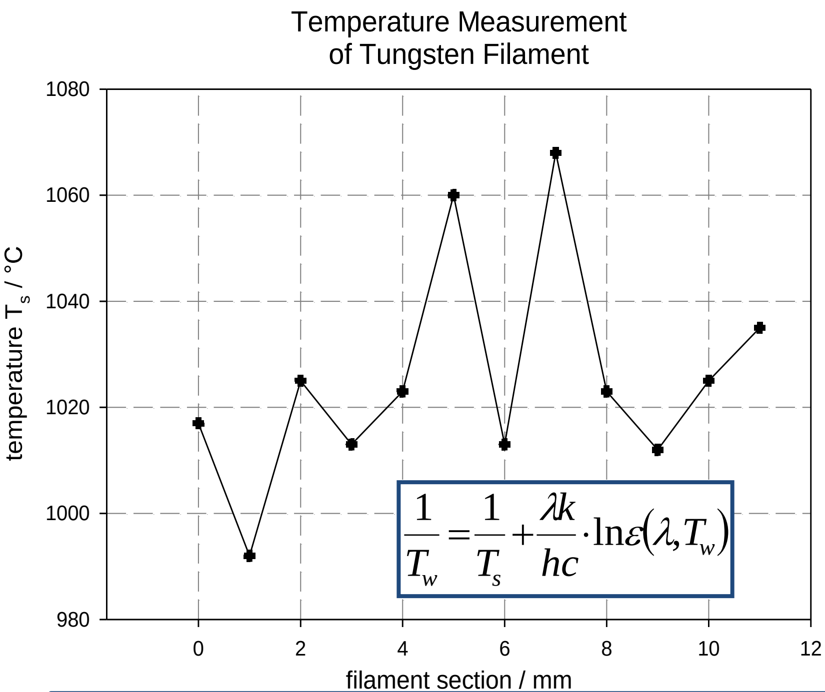
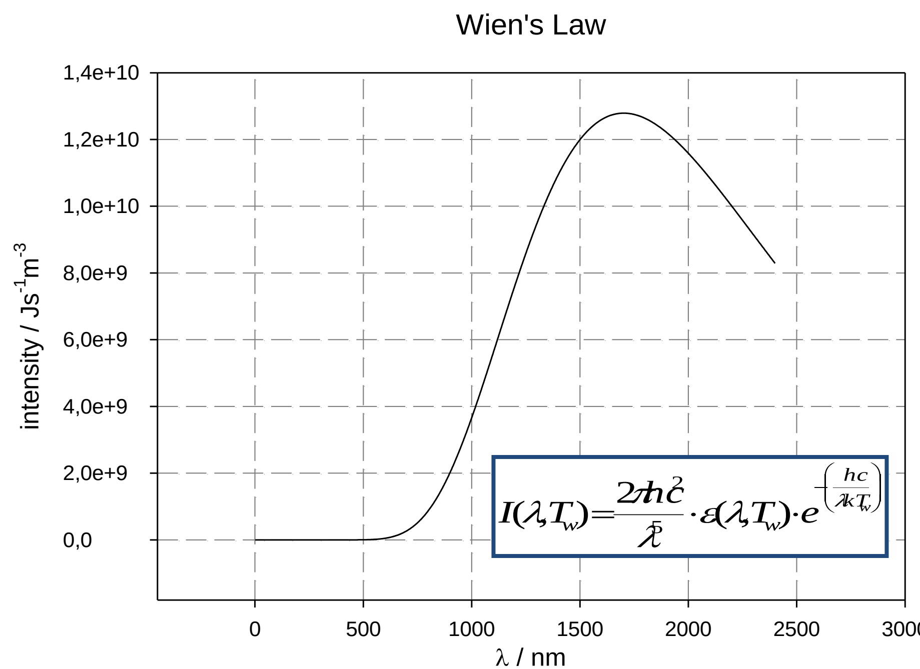
separate measurement of emission ratios for different pressure ranges

Absolute Intensity Calibration



$$\frac{1}{T_w} = \frac{1}{T_s} + \frac{\lambda k}{hc} \cdot \ln \varepsilon(\lambda, T_w)$$



$$I(\lambda, T_w) = \frac{2\pi h c^2}{\lambda^5} \cdot \varepsilon(\lambda, T_w) \cdot e^{-\left(\frac{hc}{\lambda k T_w}\right)}$$

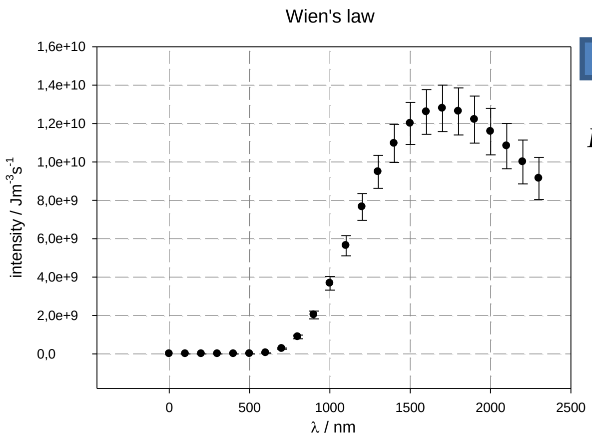
$$\Delta T_s = \sqrt{\left(\frac{\sigma}{\sqrt{n}}\right)^2 + (3K)^2} = \sqrt{\left(\frac{20{,}8654K}{\sqrt{12}}\right)^2 + (3K)^2} = 6{,}729K$$

$$\Delta T_w = \frac{\partial T_w}{\partial T_s} \Delta T_s = \left[\frac{1}{T_s} + \frac{\lambda k}{hc} \ln(\varepsilon(\lambda, T_w))\right]^{-2} \frac{1}{T_s^2} \cdot \Delta T_s = 7{,}4K$$

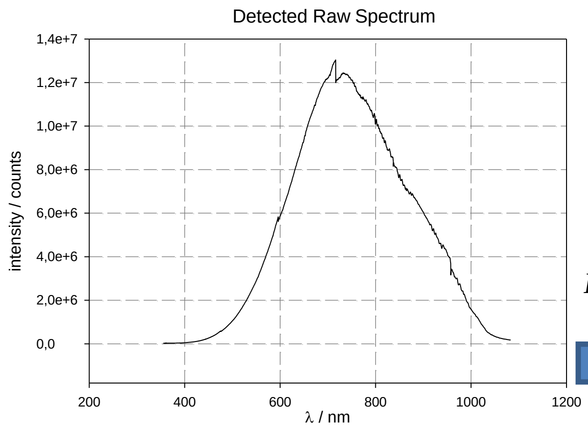
$$\Delta I = \frac{\partial I}{\partial T_w} \Delta T_w$$

$$\frac{\partial I}{\partial T} = \frac{2\pi h^2 c^3}{\lambda^6 k T_w^2} \cdot \varepsilon(\lambda, T_w) \cdot e^{-\left(\frac{hc}{\lambda k T_w}\right)} + \frac{2\pi h c^2}{\lambda^5} \cdot e^{-\left(\frac{hc}{\lambda k T_w}\right)} \cdot \frac{\partial \varepsilon(\lambda, T_w)}{\partial T_w}$$

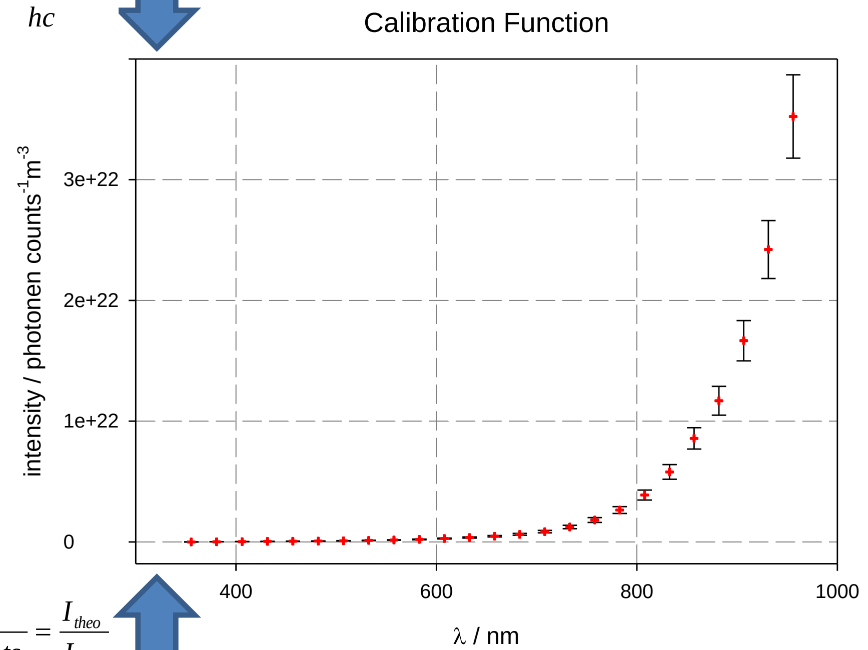
Absolute Intensity Calibration



$$I_{theo} = \frac{photons}{volume} = \frac{I(\lambda, T_w) \cdot \lambda \cdot t}{hc}$$

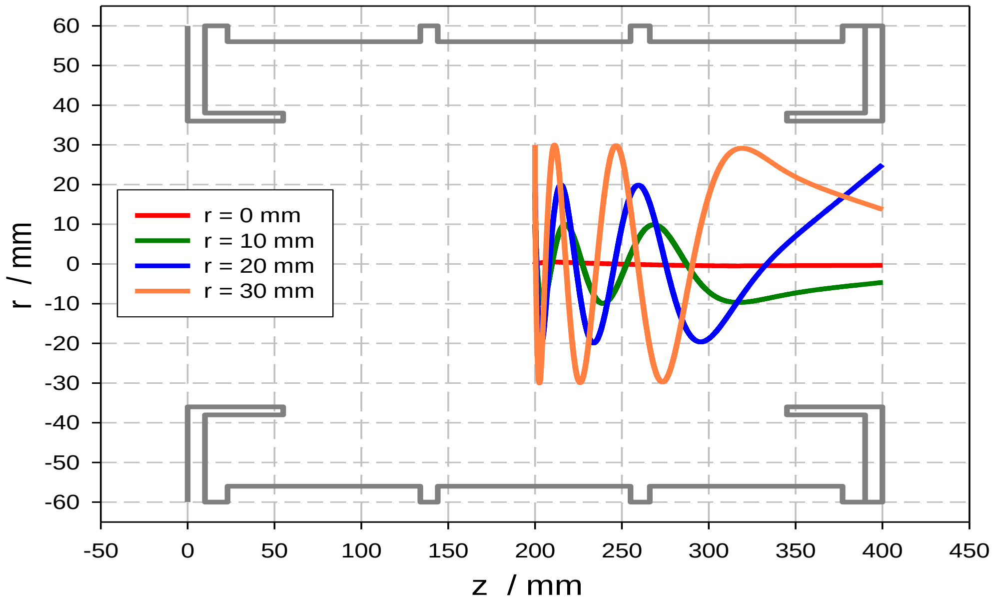


$$I_{cal} = \frac{photons}{volume \cdot counts} = \frac{I_{theo}}{I_{raw}}$$

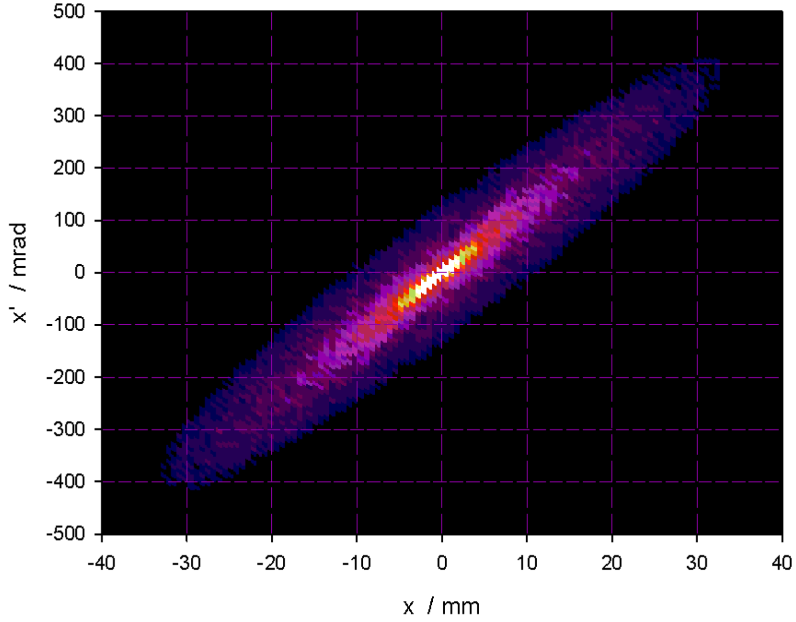


Phase Space Distribution – Time Resolved Measurements

Trajectories of Residual Gas Ions

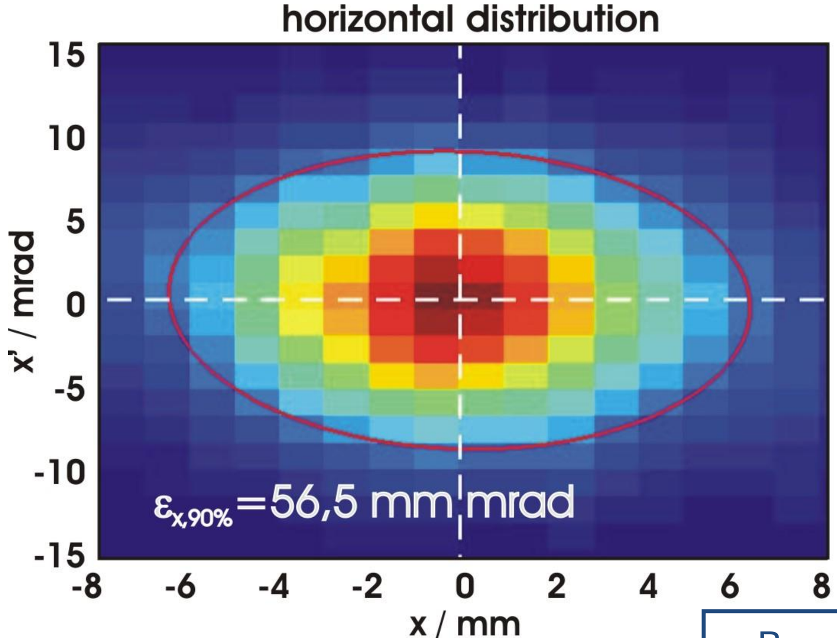


Residual Gas Ion Distribution

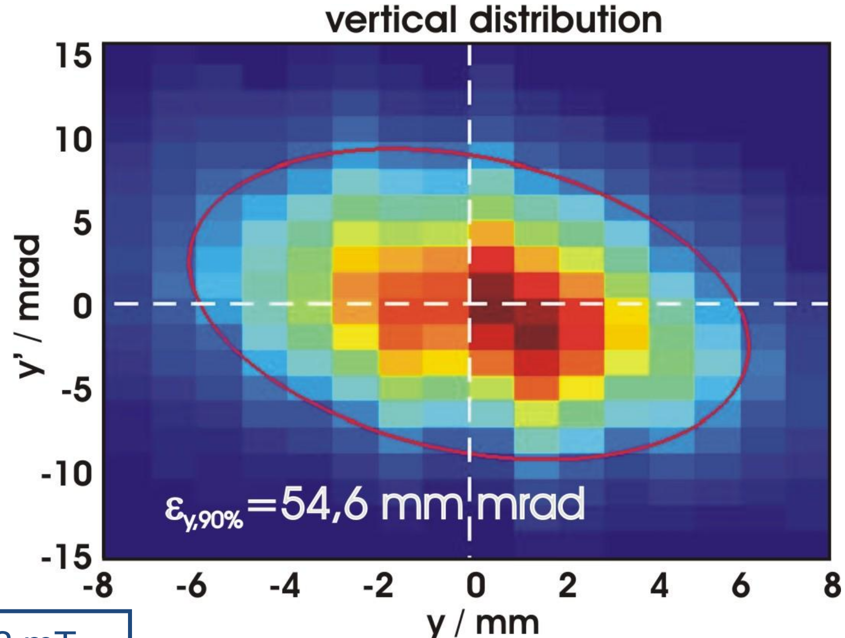


- transverse, time resolved diagnostics
- place of production, rate of production

Phase Space Distribution – Time Resolved Measurements



α=0.05
β=0.74 mm/mrad
γ=1.36 mrad/mm



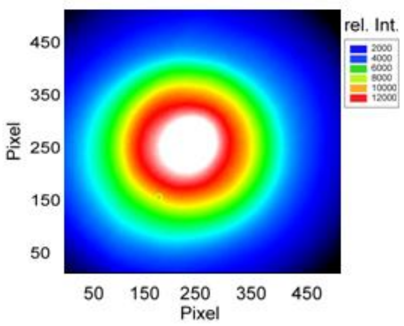
α=0.29
β=0.70 mm/mrad
γ=1.56 mrad/mm

B_z = 8,3 mT
Φ_A = 2,0 kV
p=6e-5 mbar (He)

Additionally: Time Resolved Light Density Distribution Measurements @ B. Gläser

Instabilities

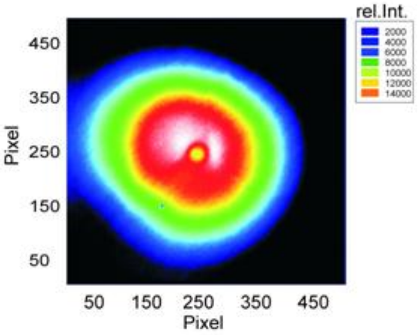
Experiment



B_z = 12,1 mT

Φ_A = 6,5 kV

p=7,8e-5 mbar



B_z = 12,1 mT

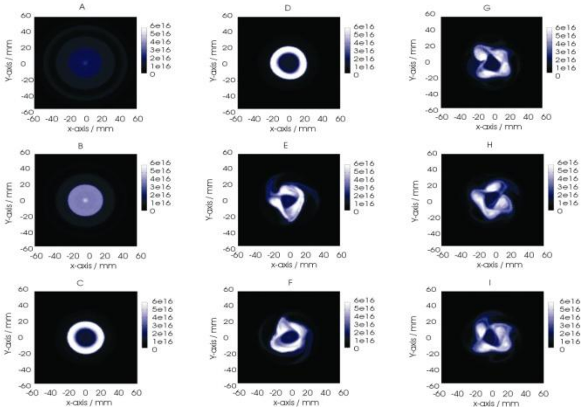
Φ_A = 6,0 kV

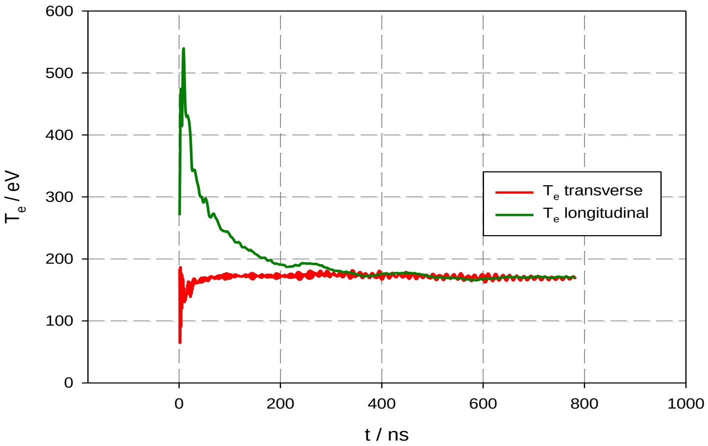
p=6,0e-4 mbar

Result of Cooling: any process that takes energy out of the diocotronmode causes it to grow

@ S.A. Prasad, et al., Phys. Fluids 29 (7), 1986

Numerical Simulation





Outlook

- Space Charge Lens Prototype
  - Conditioning up to 40 kV
  - Temperature measurement
  - experimental setup
  - optical diagnostic (including temperature measurement) and density measurement
  - time resolved investigation of NNP (*Bachelorarbeit B. Glaeser*)
  - beam experiments

THANK YOU!