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Low **E**nergy **B**eam **T**ransport
Beam diagnostics

*** Introduction**

*** Destructive methods**

*** RGI - Spectroscopy**

*** CCD - imaging**

*** Tomography**

*** Laser neutralisation**

*** Examples**

Motivation:

A detailed knowledge of the physical properties
defining the beam transport
like

-external field distribution
- residual gas pressure
- beam current
-beam emittance
-beam potential (space charge)

is
necessary for the

design,
optimisation
and
operation

of an

Low Energy Beam Transport section

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Emittance
&
emittance measurement

The behavior of an ion beam consisting of n particles can be totally described in the 6n dimensional phase space

$$\Gamma_{6n}$$

Reduction : Transformation of density distribution

$$f_6 = f(x, y, z, p_x, p_y, p_z)$$

Reduction : transversal density distribution

$$f_4 = f(x, y, p_x, p_y)$$

Reduction : edge emittance, normalizing

$$\varepsilon_{n,x} = \beta\gamma \frac{F(x, x')}{\pi}$$

Redefinition : RMS from particle moments

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

Emittance measurement :

“Simultanious determination
of spatial and transversal impuls
distribution of an particle ensemble“

2 step process :
e.g.

1 step - definition of “place”

=> by extraction of subset of particle distribution

2. step - determination of “angle”

=> determination of particle distribution
after drift

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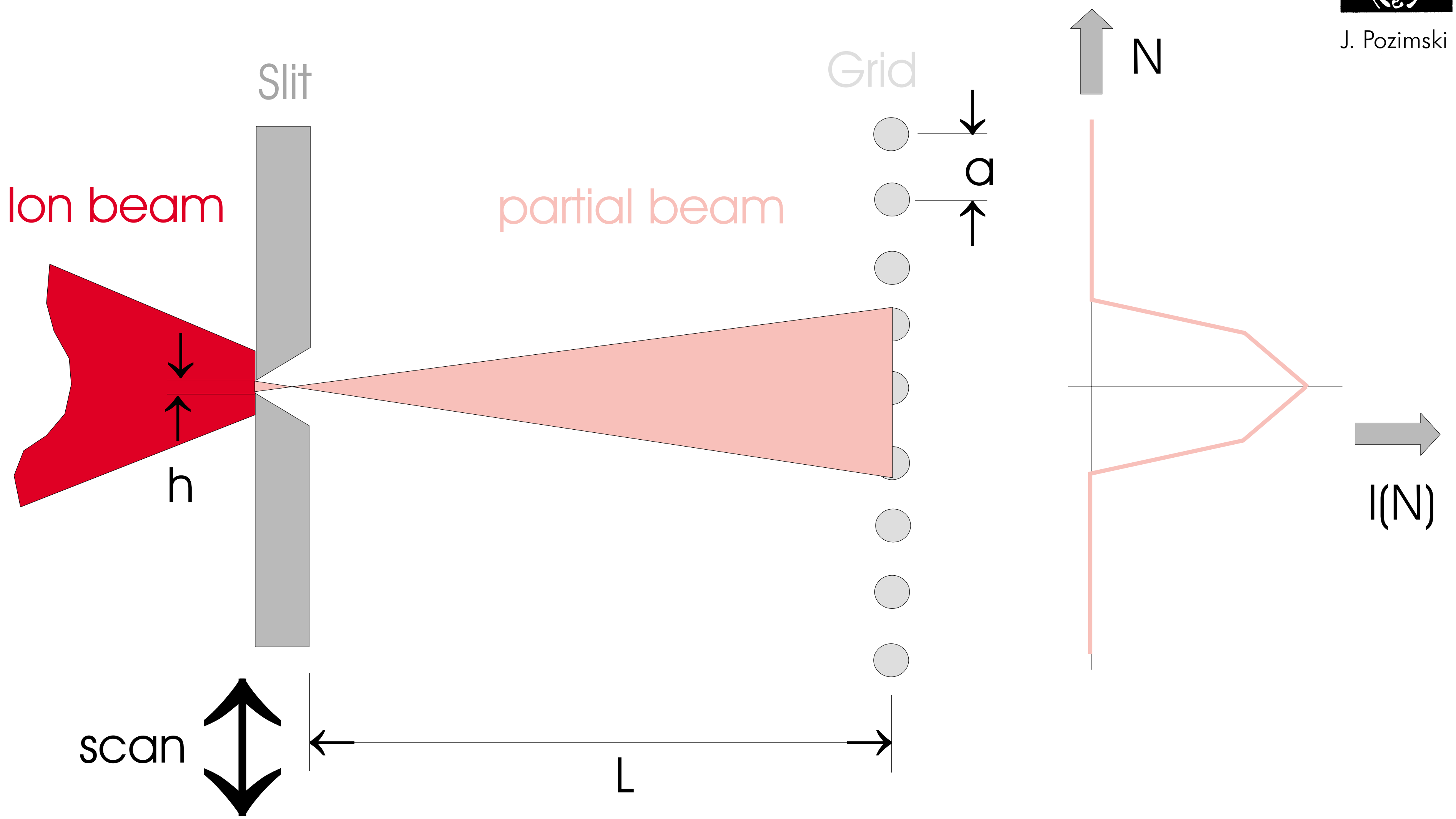
Slit - Grid arrangement



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High resolution
Slit - Grid
emittance scanner
including 2 dimensional profile measurement

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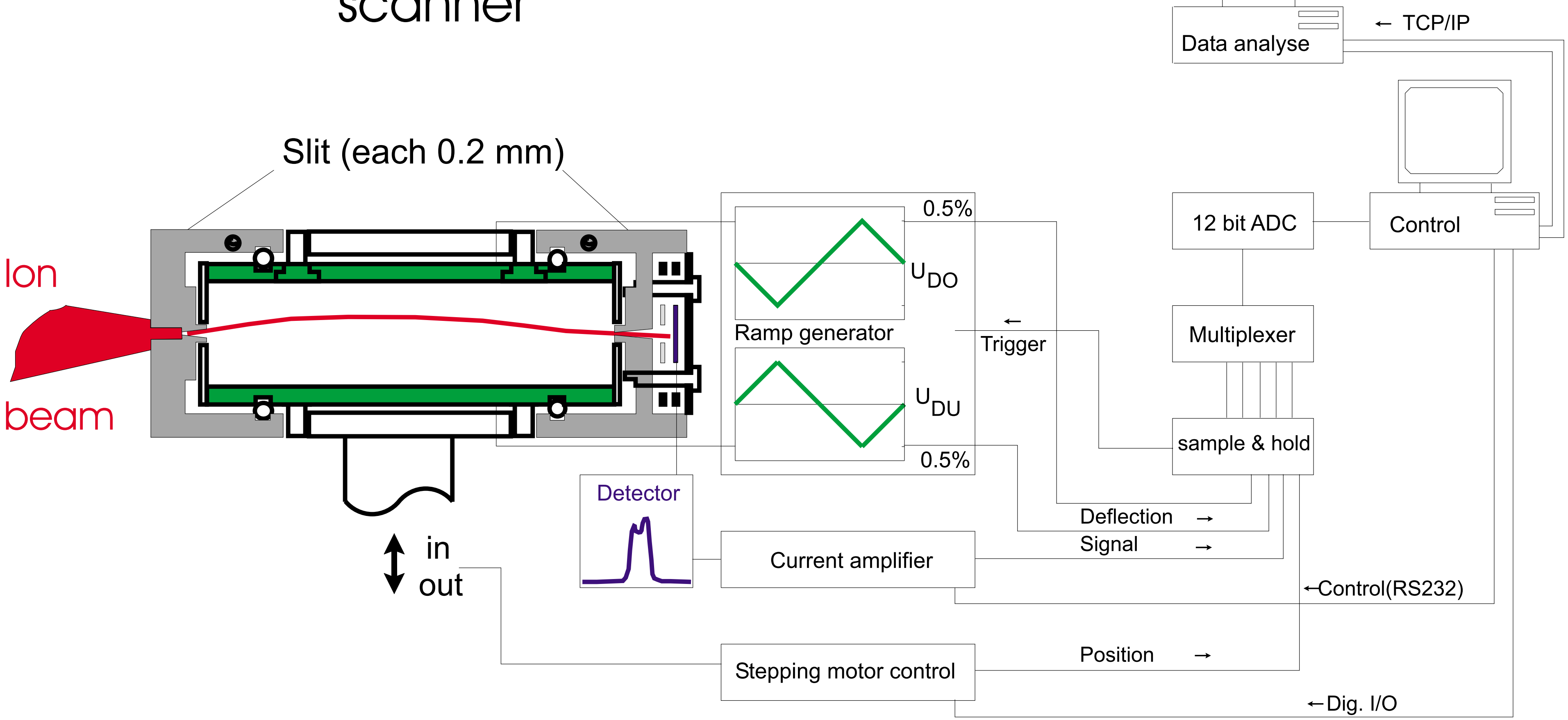
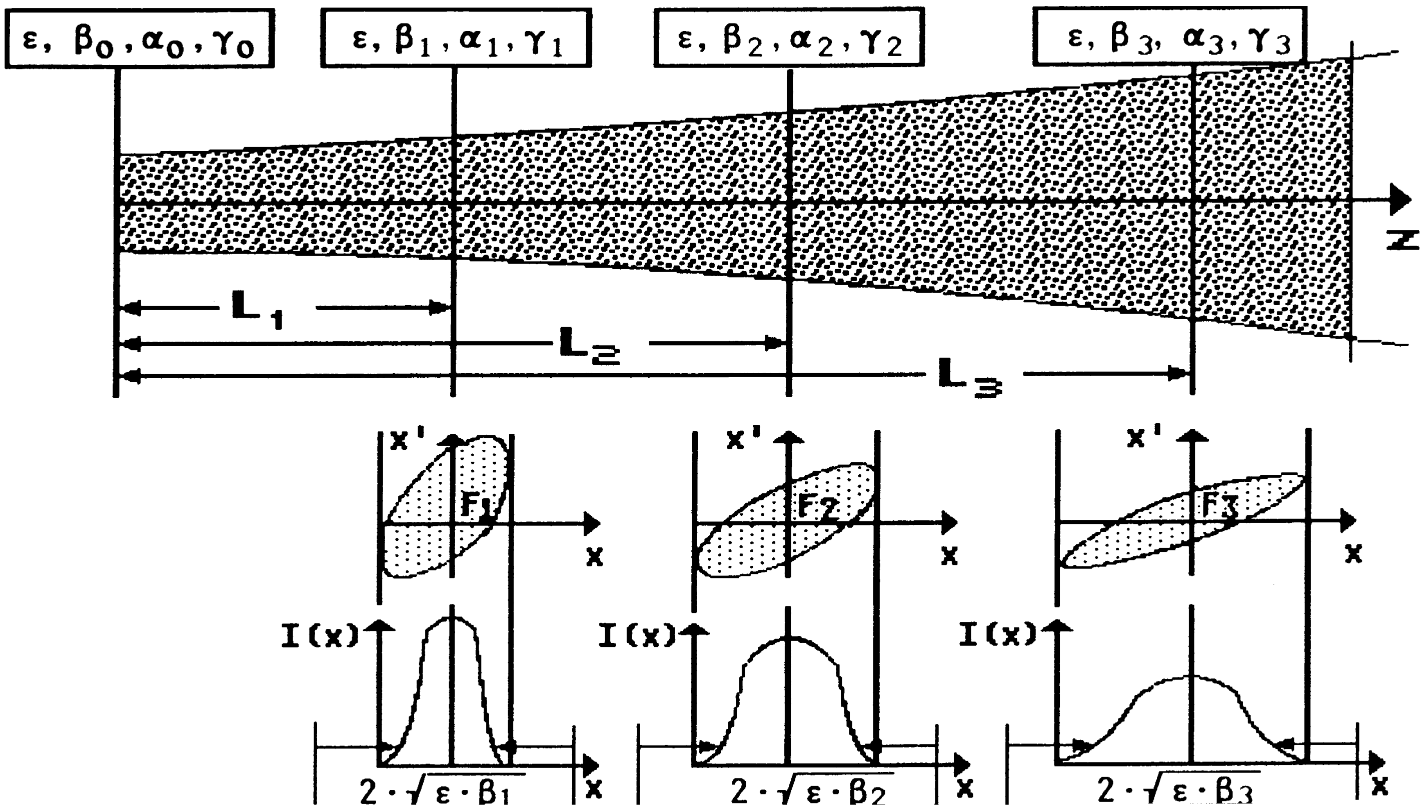
Allison Emittance scanner

*high resolution
*compact



Determination of phase space ellipse from beam profile measurements at 3 places



damit gilt

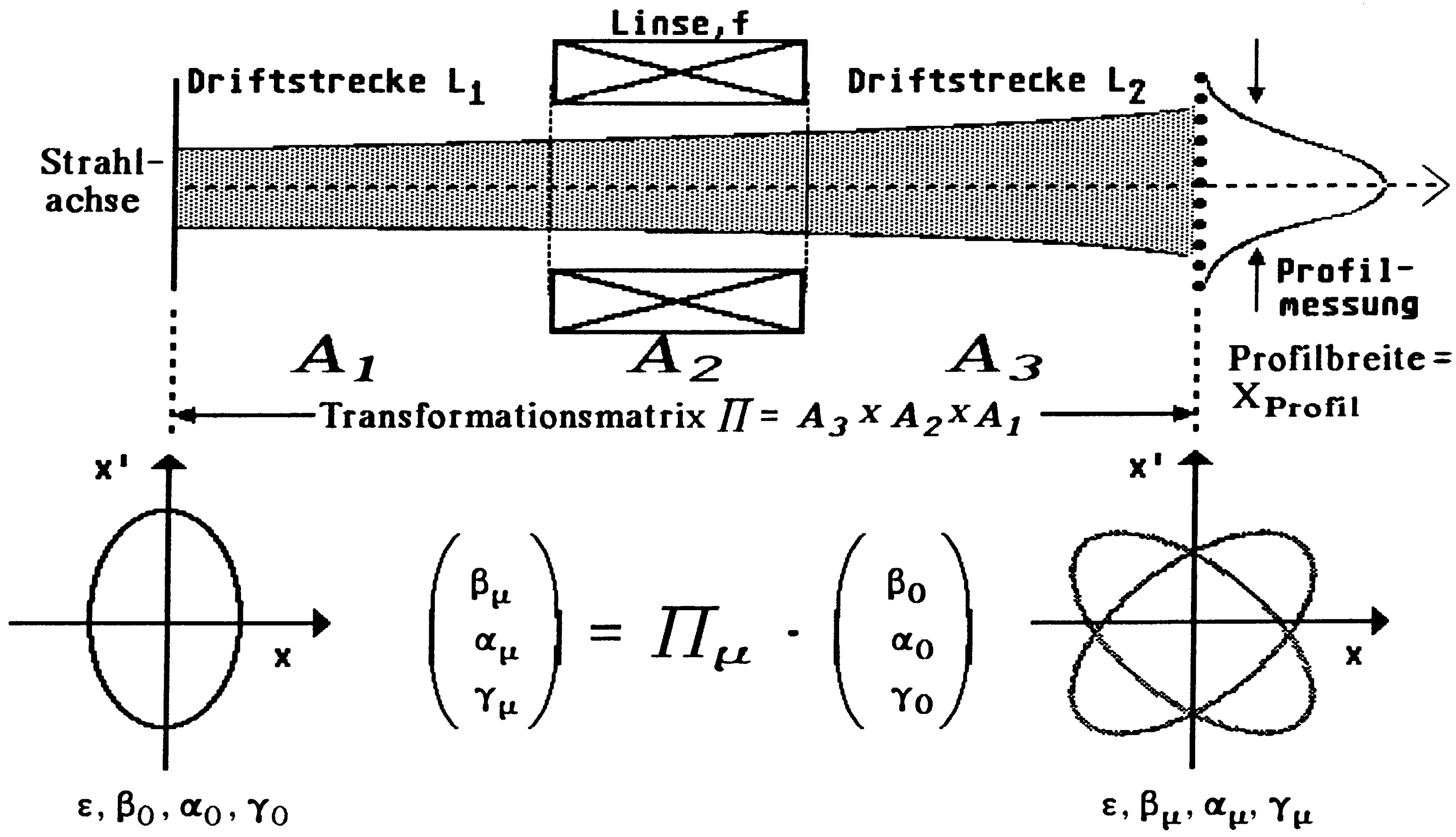
for given

$D_x;D_y;D_z;D$

(space charge !)

and ε constant

Determination of phase space ellipse using one lens and profile measurements



$$\begin{pmatrix} \beta_\mu \\ \alpha_\mu \\ \gamma_\mu \end{pmatrix} = \Pi_\mu \cdot \begin{pmatrix} \beta_0 \\ \alpha_0 \\ \gamma_0 \end{pmatrix}$$

Problems :

Power deposition on Slit (& Grid)

Example IFMIF :
100 keV
140 mA
$r<2$ mm
=> Powerdensity >1 kW/mm^2

can destroy measurement device

High voltage breakdowns :

(especially near ion source or electrostatic LEBT)

The grids akt like "antennas" feeding high voltage pulses into the electronics

(especially for Slit/Grid arrangements)

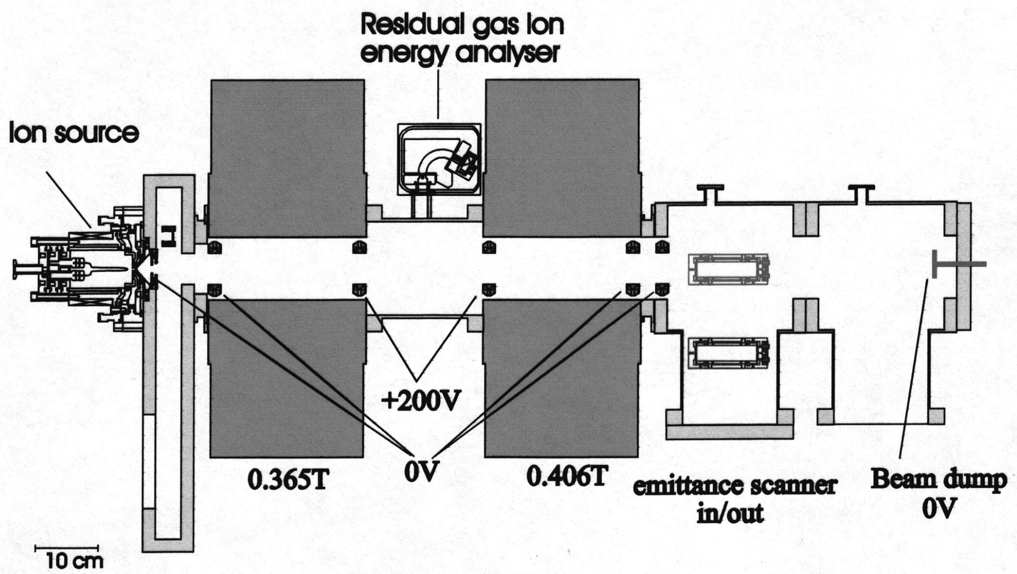
Secondary particles can cause :

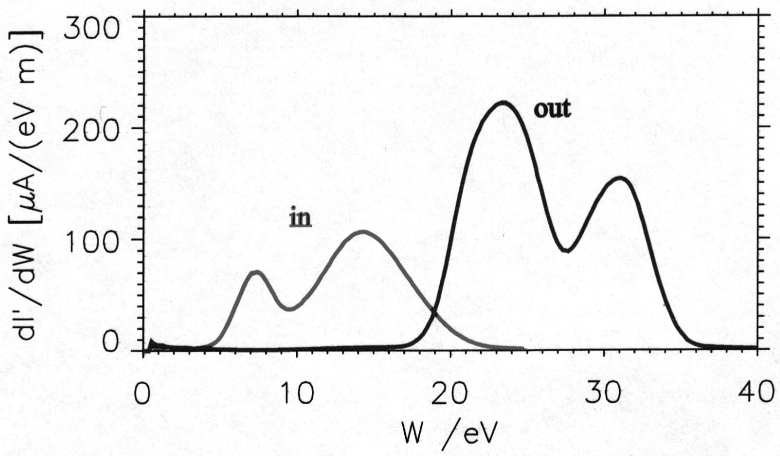
=> High voltage breakdowns
=>Influence space charge compensation
=> Additional currents on detectors (grid !)

Non destructive Methods
Motivation:

Interaction between the ion beam and the measurment device can produce secondary particles and therefrom influence the space charge compensation and change the emittance of the ion beam.

Example :
He^{+} , 10 keV , 3 mA





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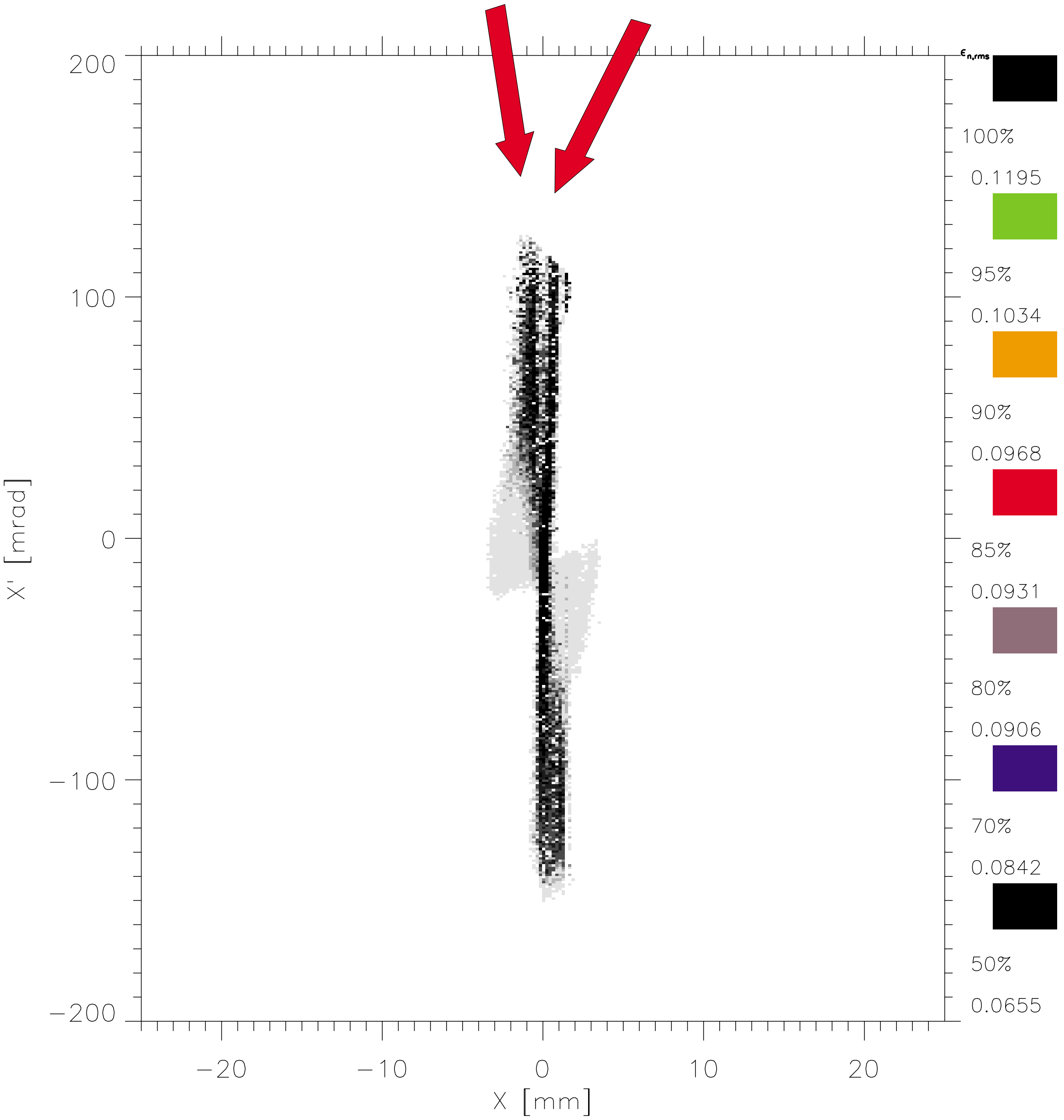
Production of noise and bistable states by disturbance of the beam transport

Example :

Measurement at Gabor lens LEBT
Electrons produced by the interaction between Allison scanner and beam ions influence space charge cloud of the lens.
Two semistable conditions occure.
The revolution frequency was some Hz.



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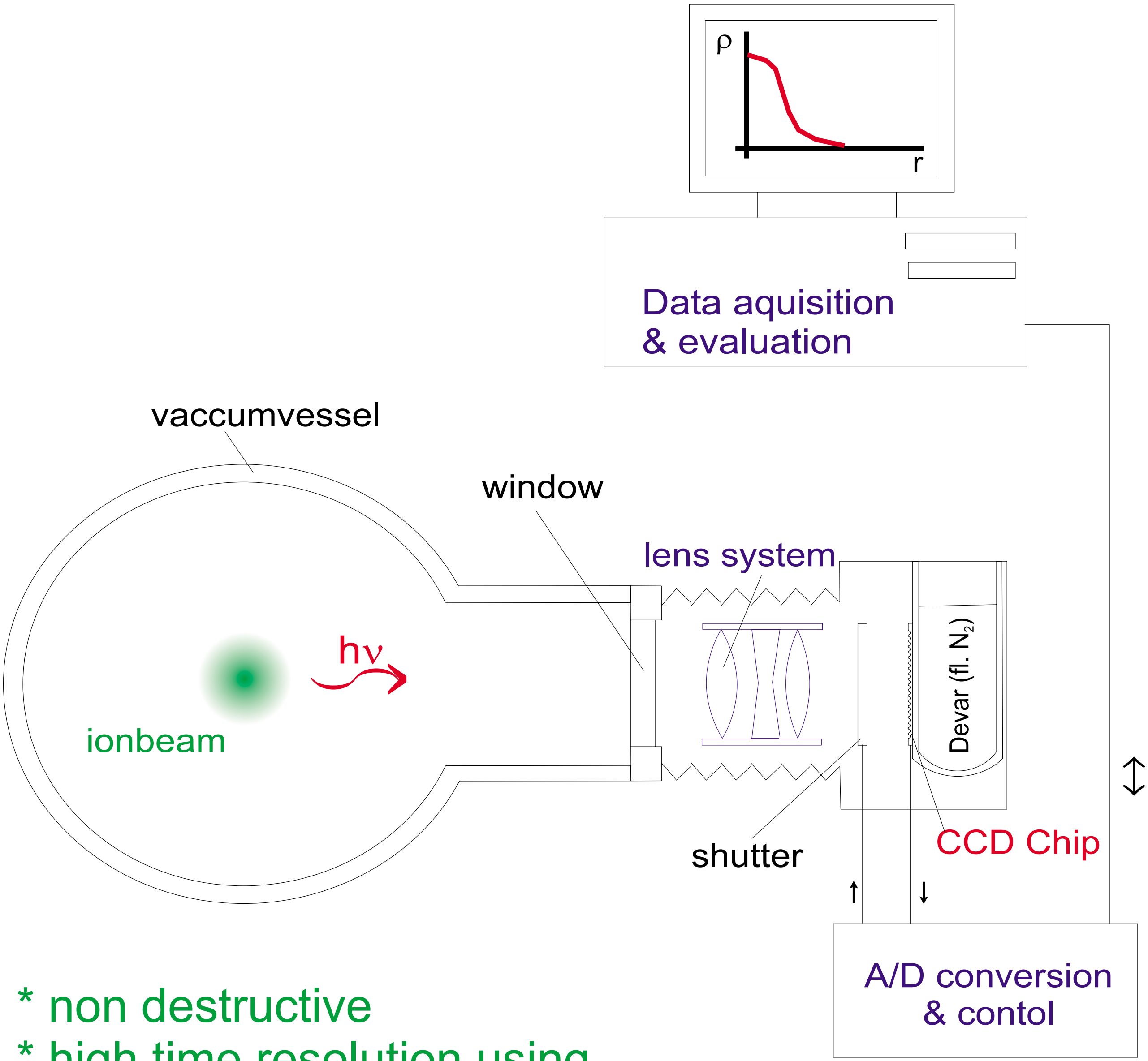
CCD-Camera

Highly efficient spatial resolved electron production by the inner photo effect detecting the incident light emittet by interaction between beam ions and residual gas atoms.



* non destructive
* high time resolution using gated residual light amplifiers(>50 ns)

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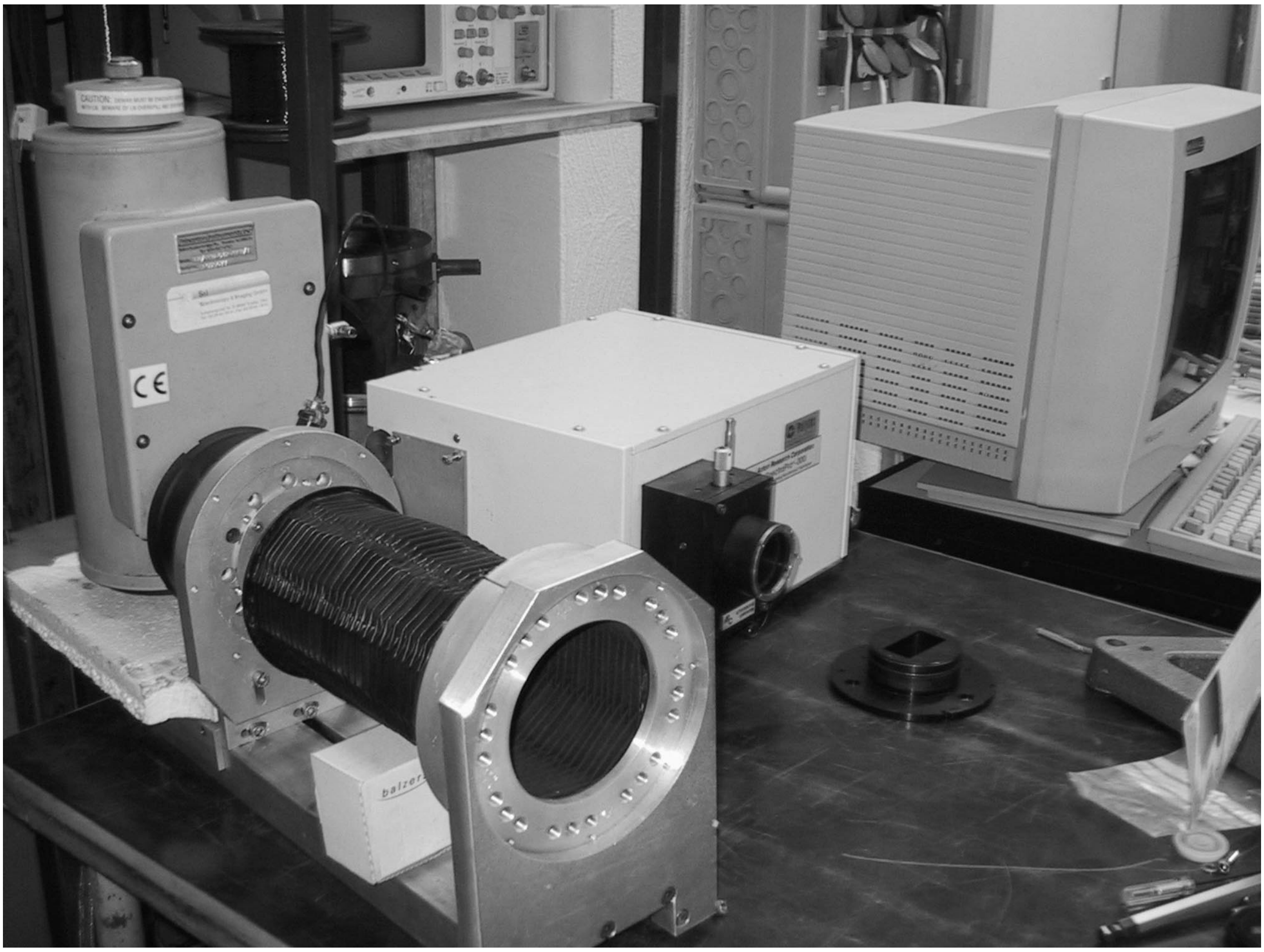
CCD camera

and

optical spectrometer



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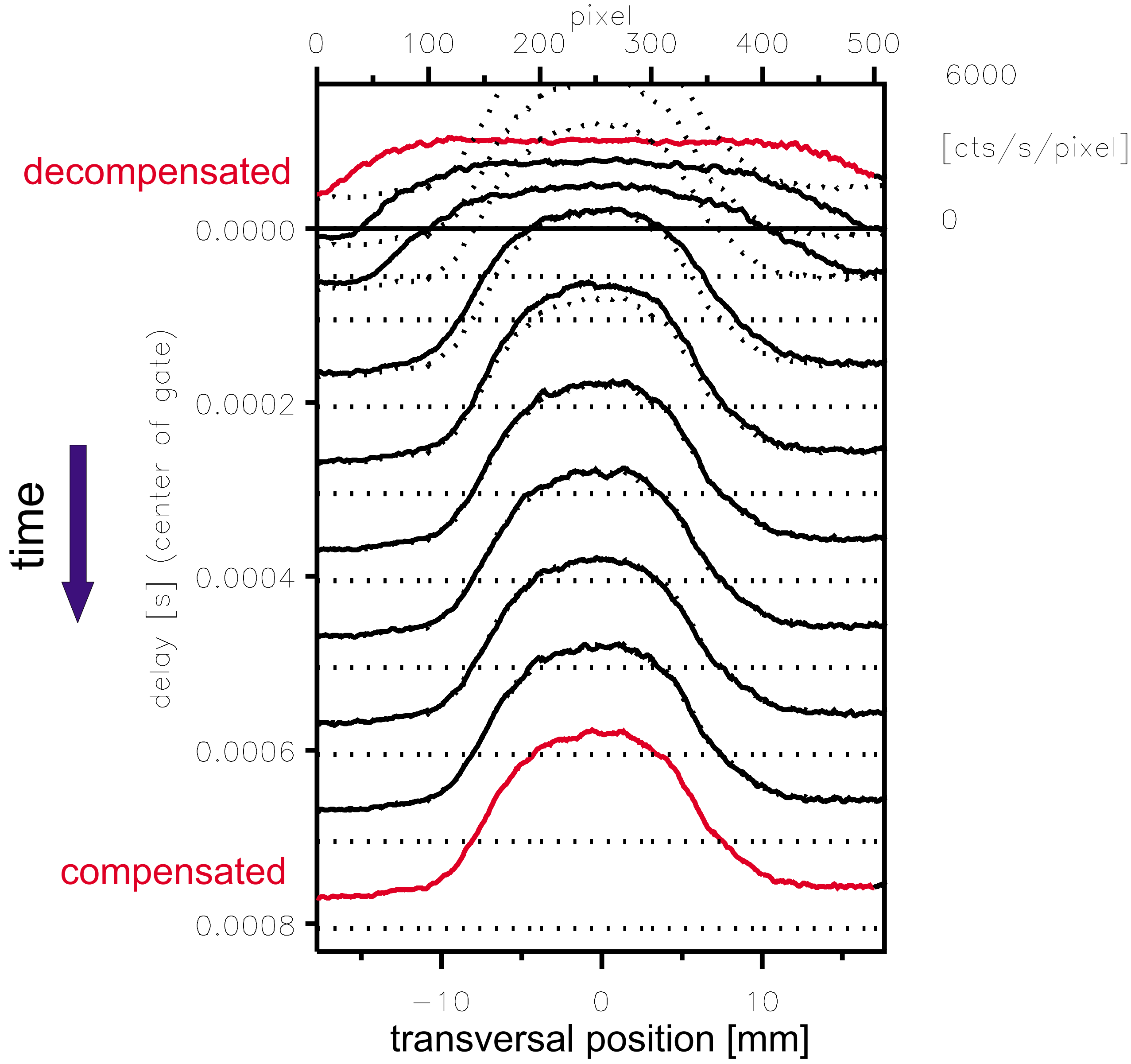
Time resolved CCD camera mesurements to determine non destructive the rise time of space charge compensation



high spatial (0.1 mm) and temporal (50 ns) resolution.

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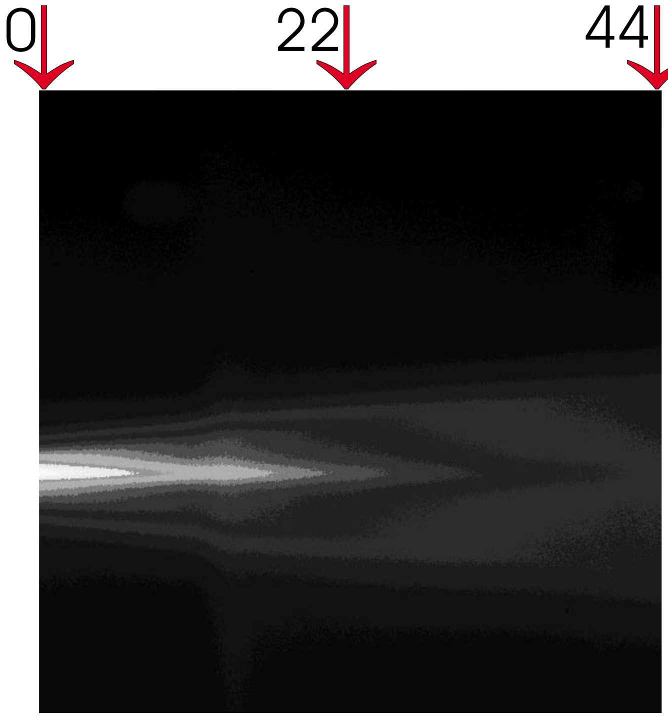
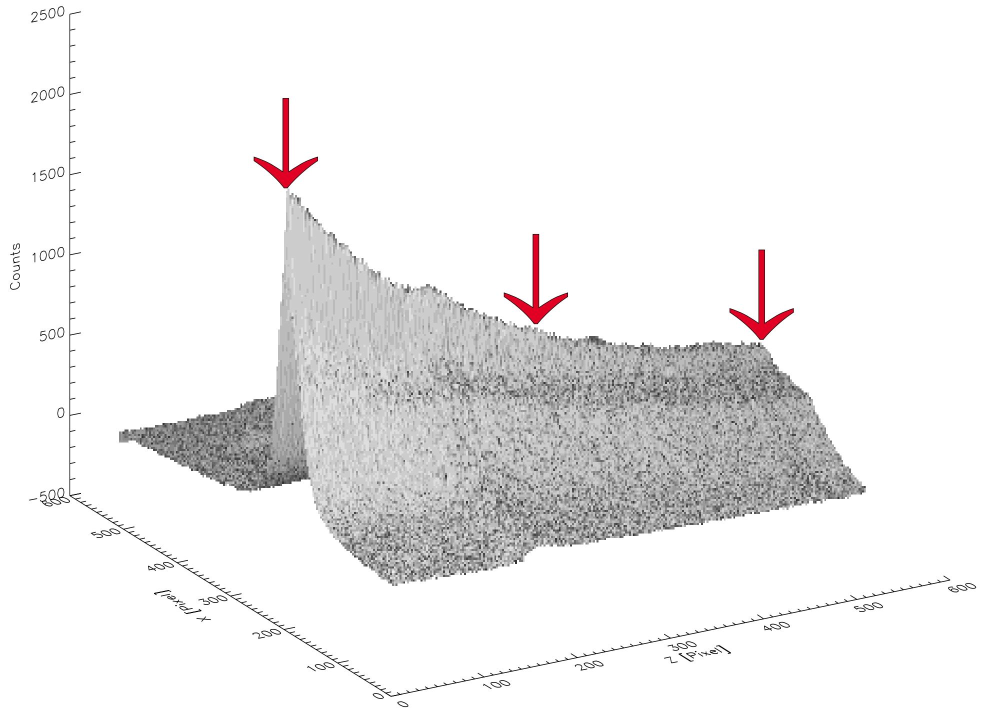
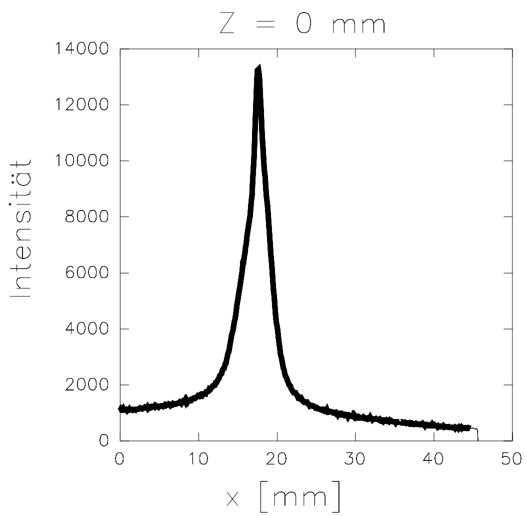
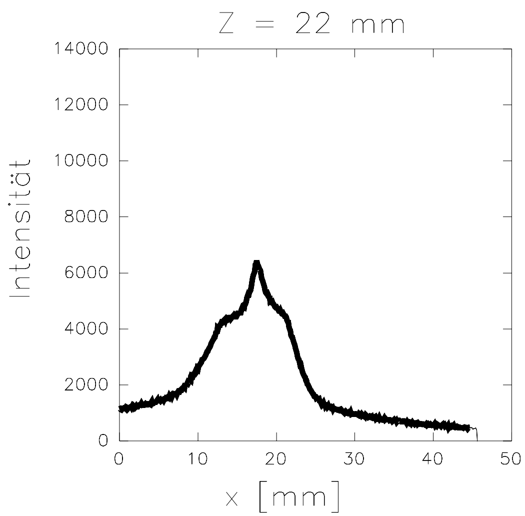
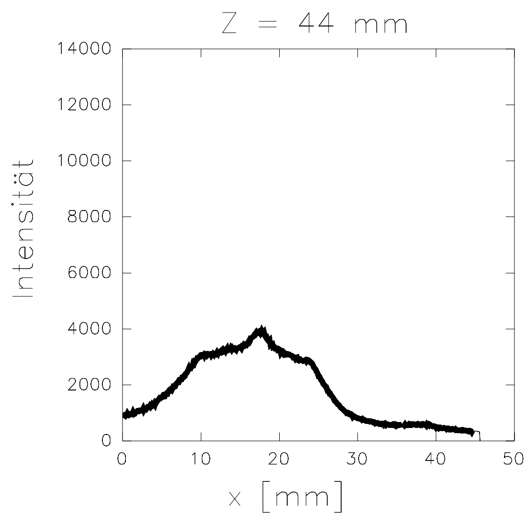
CCD image - multiple profile measurements











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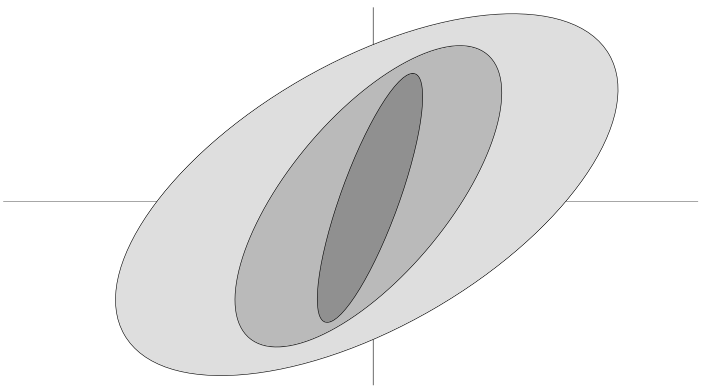
Determination of beam emittence by use of CCD camera measurements

"A single CCD image
has all necessary information to
determine the emittance using the 3 profile method"

Advantages :

a) easy setup

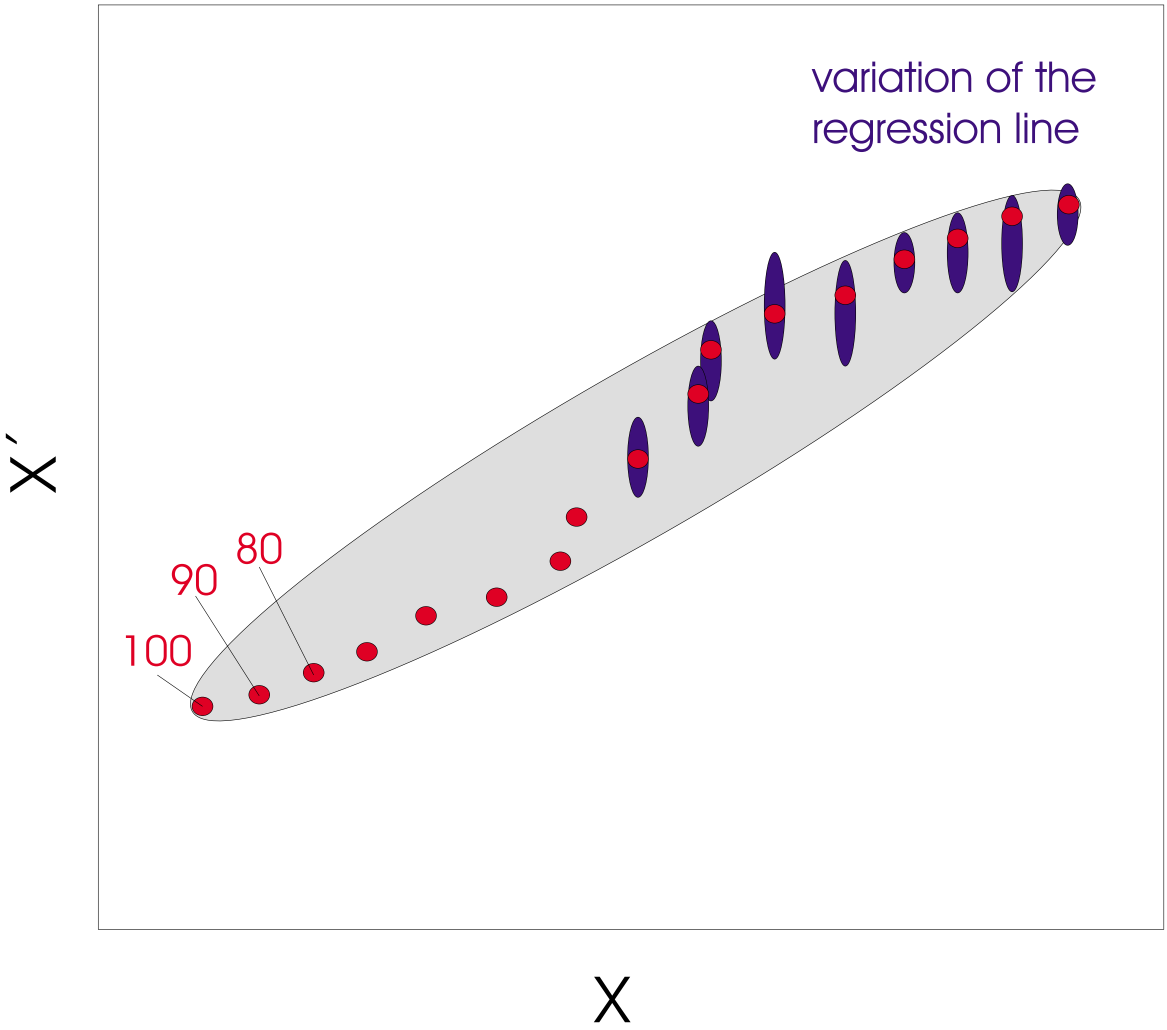
b) high signal to noise ratio allows
use of radial intensity profile information
(determination for different intensity fractions10, 20, 30...%)



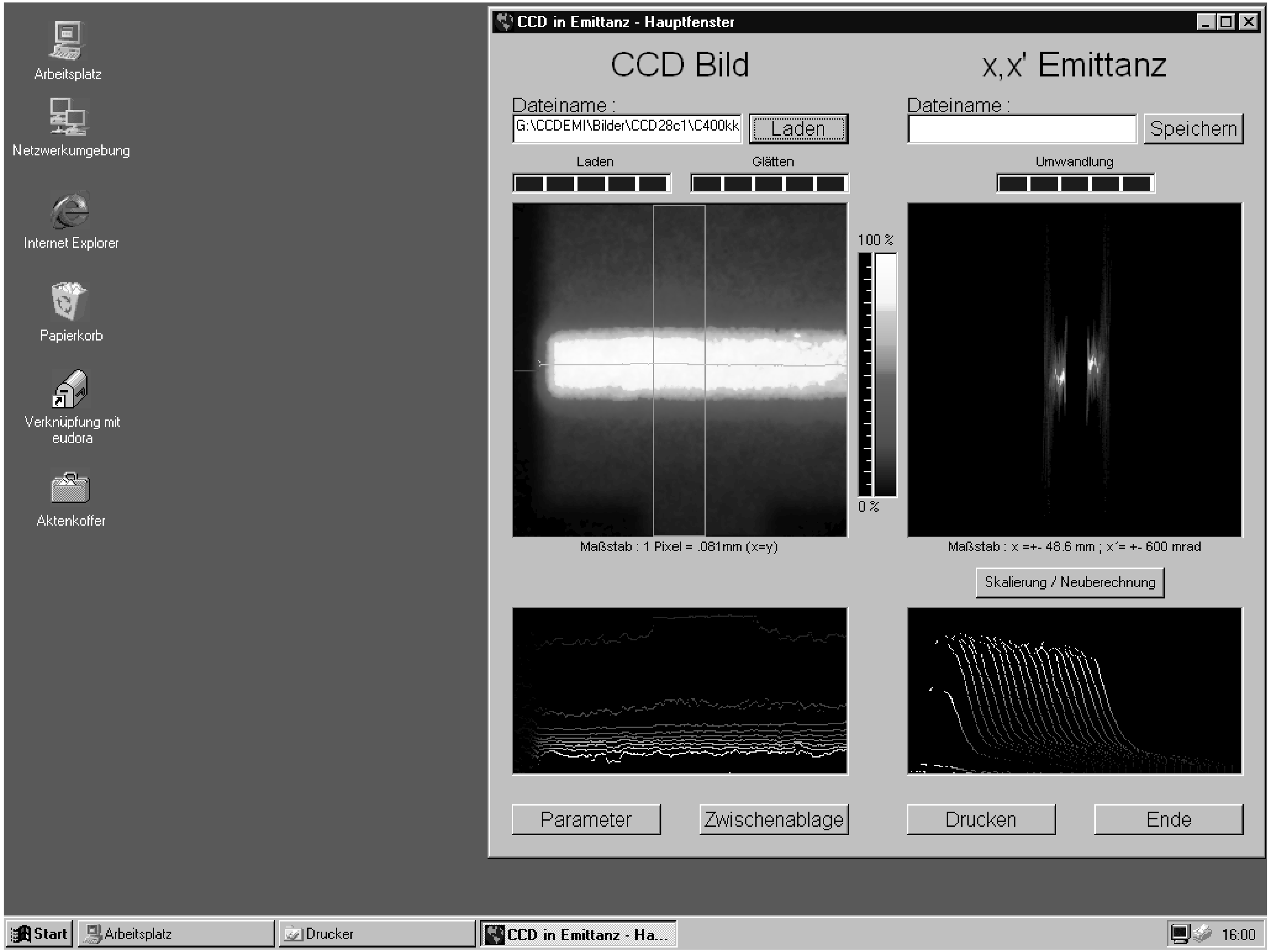
$$E(\langle x\rangle,\langle x'\rangle) = k(I(x,z))$$

c) the set of equation is overdetermined
(3 profils nessesary, 512 profils available)
=> can be used to gain additional informations
(space charge !)

Variing the fraction of beam current taken into account and using the over determination of the system the emittance ellipse can be filled



A Windows program code has been developed to determine beam "emittance" from CCD images



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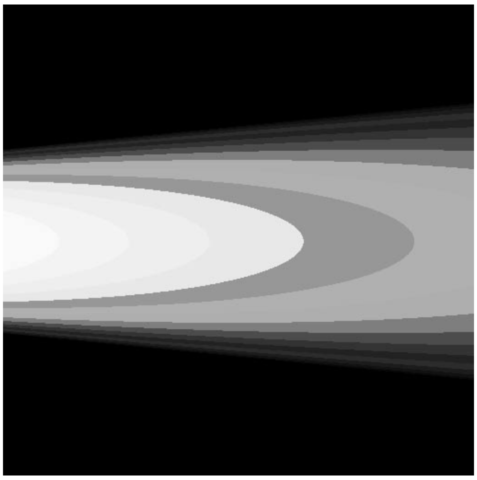
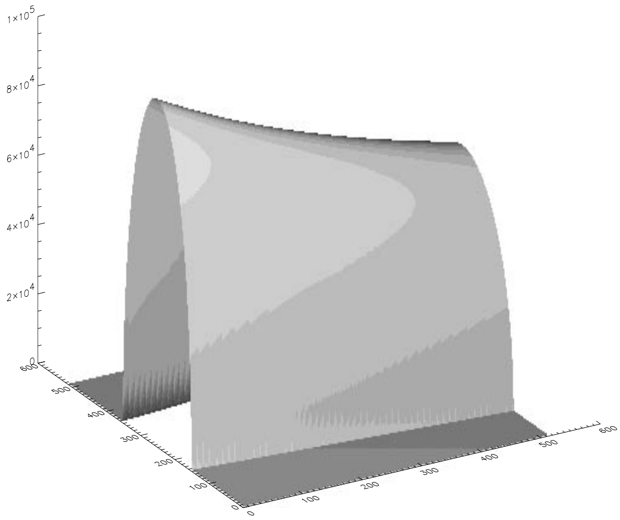
Example
Use of numerical simulated CCD image
(laminary beam)

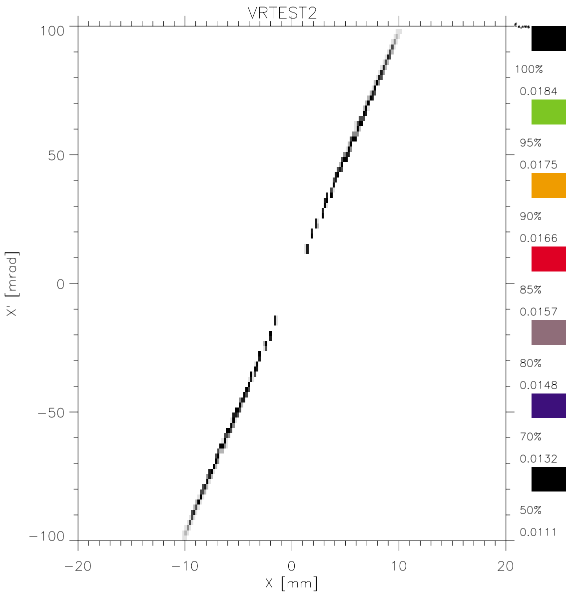


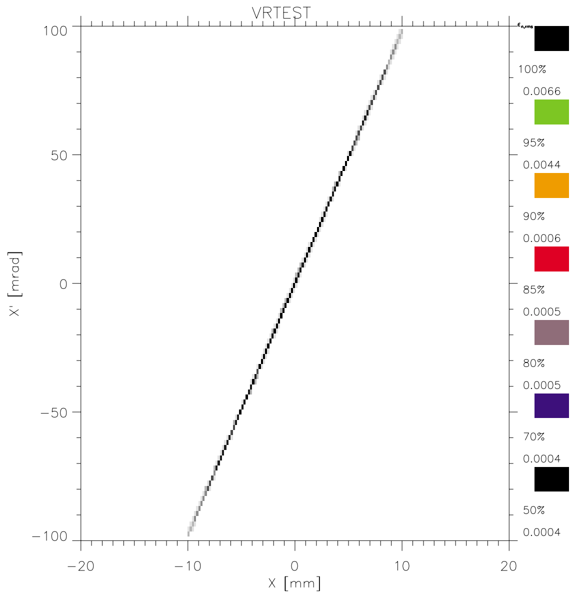


without

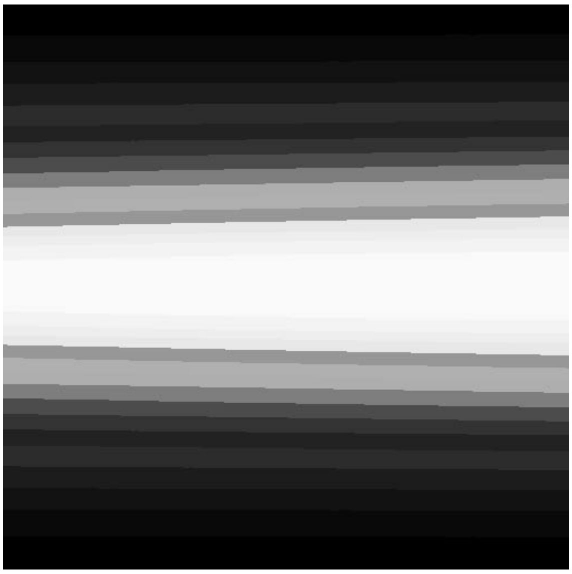
with

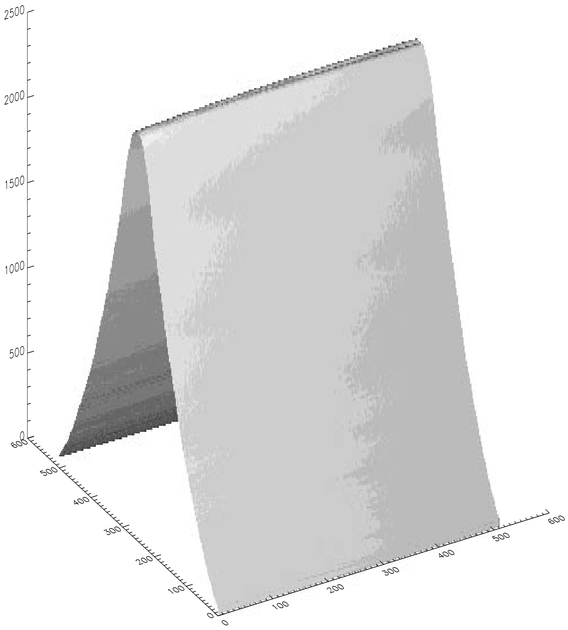
Interpolation

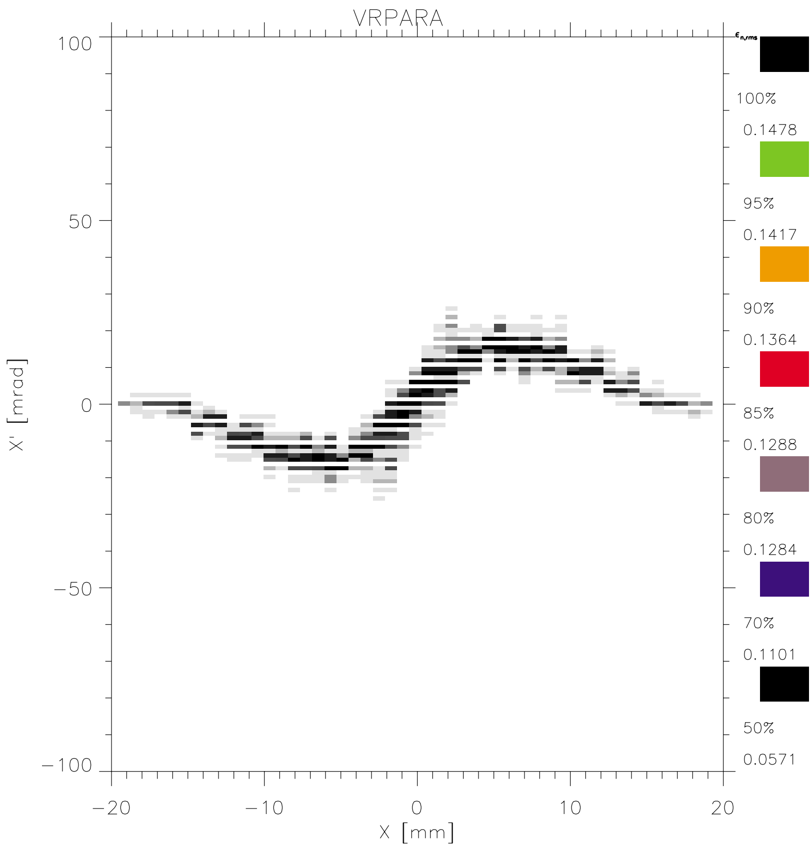




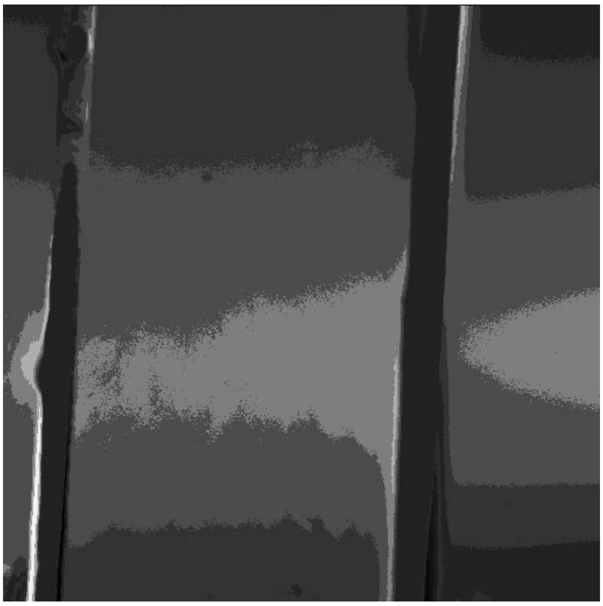
Example 2
Use of numerical simulated CCD image
(using measured emittance of real beam)

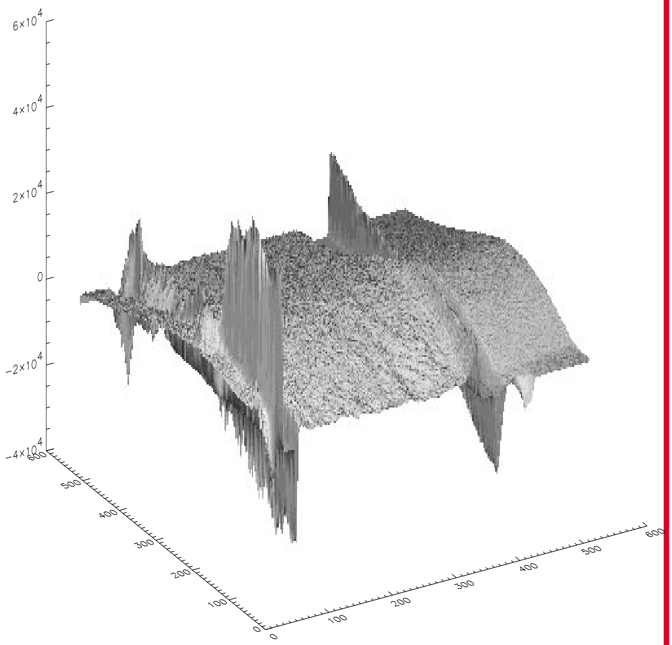




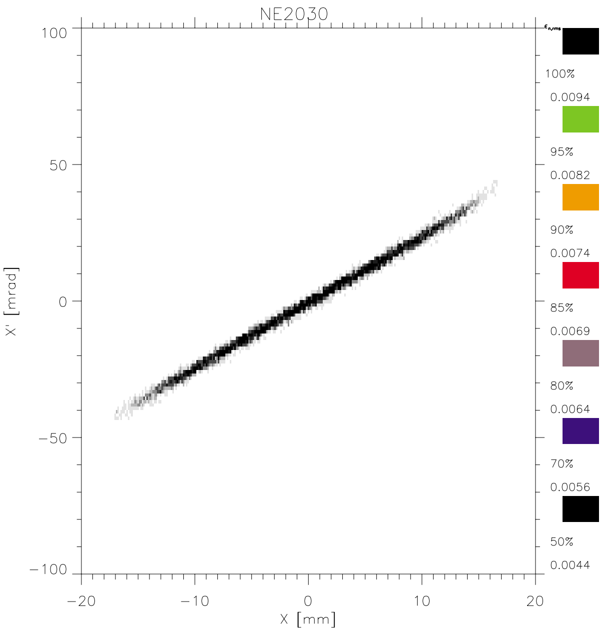


Example 3
Use of measured CCD image
(Ne+, 8 keV, 1 mA)
and comparison with classically measured emittance. Influence of noise and reflections on transformation.

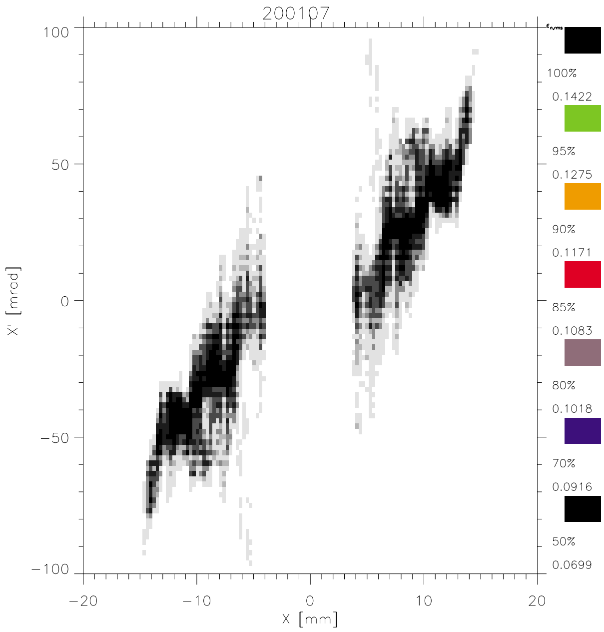




measurement



from CCD



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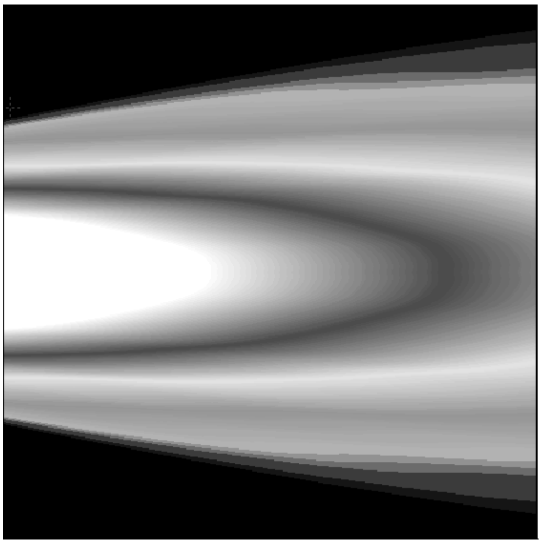
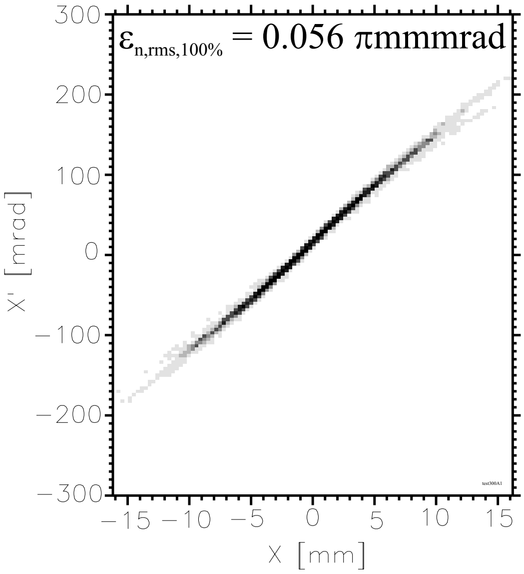
Example 4
Use of measured "high quality" CCD image
(He^{+}, 10 keV , 5 mA)

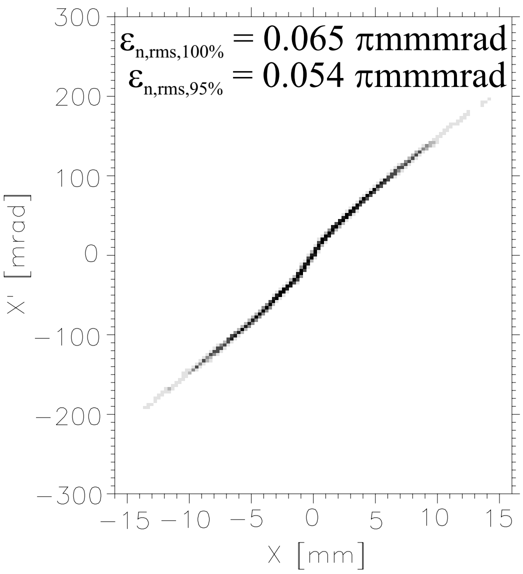
CCD-image



Emittance



Emittance determined by use of CCD image



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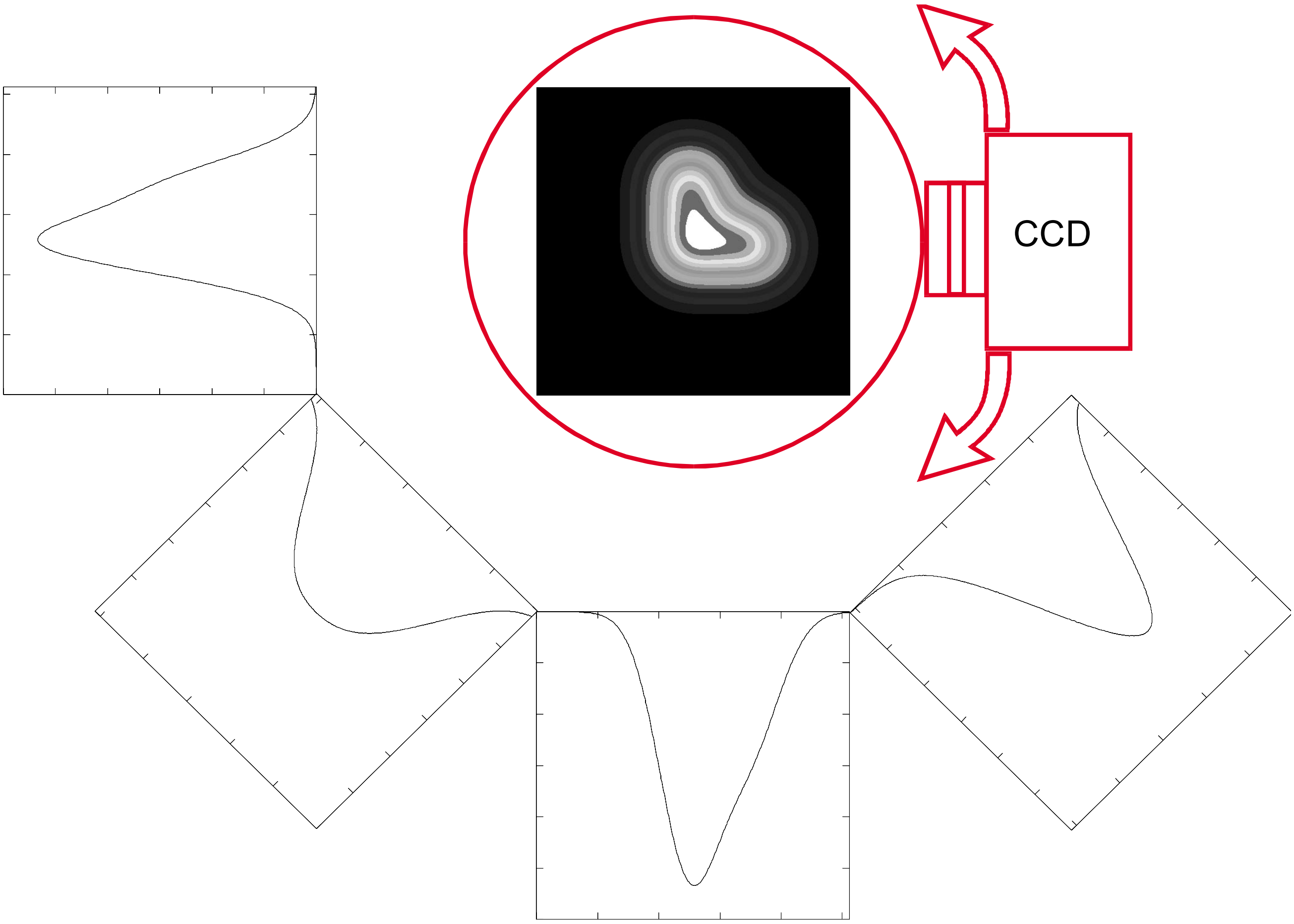
CCD - tomography for determination of non symmetric particle distributions



By use of an sufficient number of profile images of the ion beam the transversal density distribution of the ion beam can be unequivocal determined.

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CCD - tomography
for determination of non symmetric particle distributions

Set up of plexiglass cylinder

Preexperiments to test the optical and vaccum technical properties of certain materials to build a transparant cylindrical "vaccum window"

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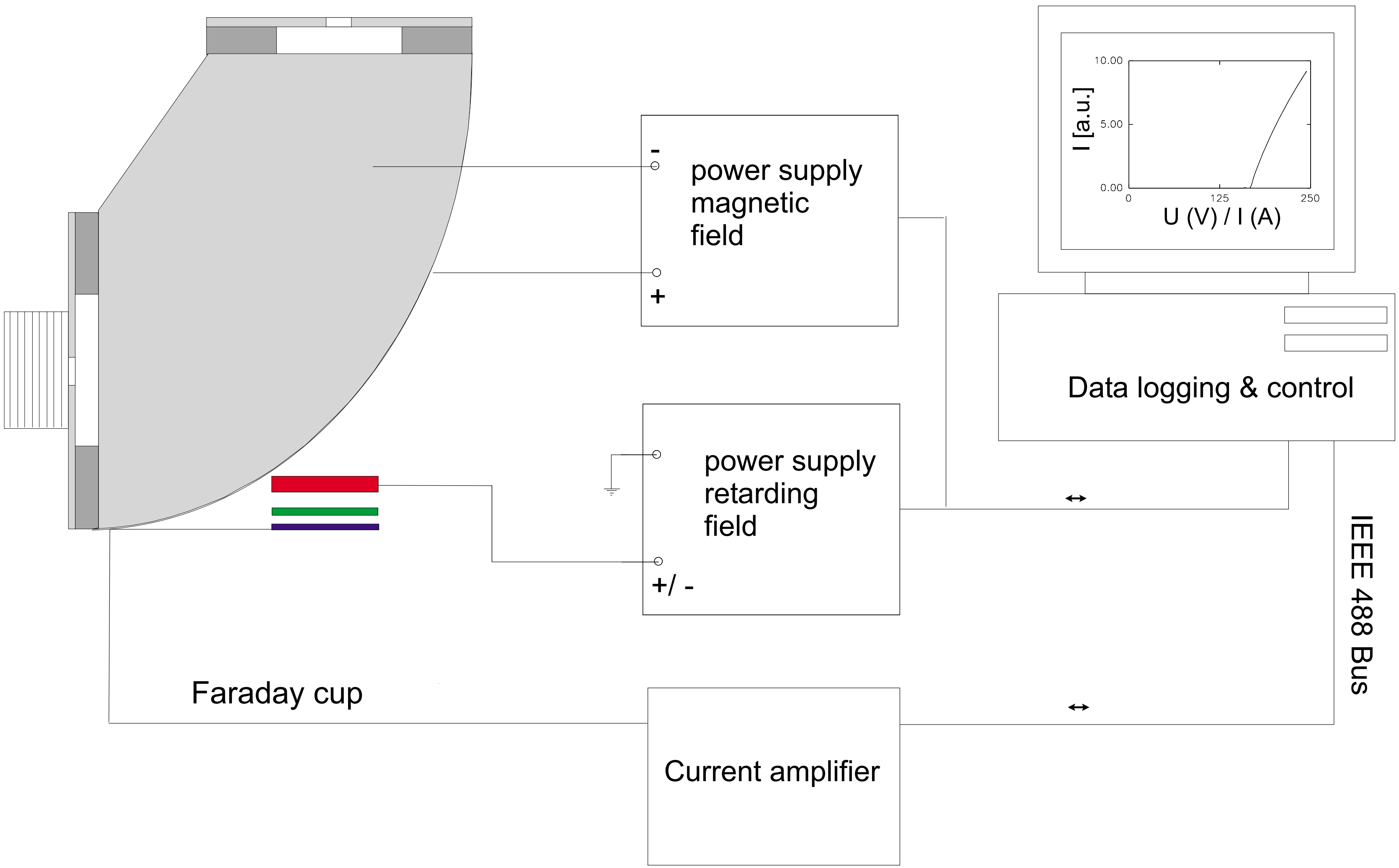
Magnetic dipole and electrostatic retarding field spectrometer to determine simultaniously mass and energy of charged particles



Determination of Mass and energy of secondary particles produced by interaction between beam ions and residual gas

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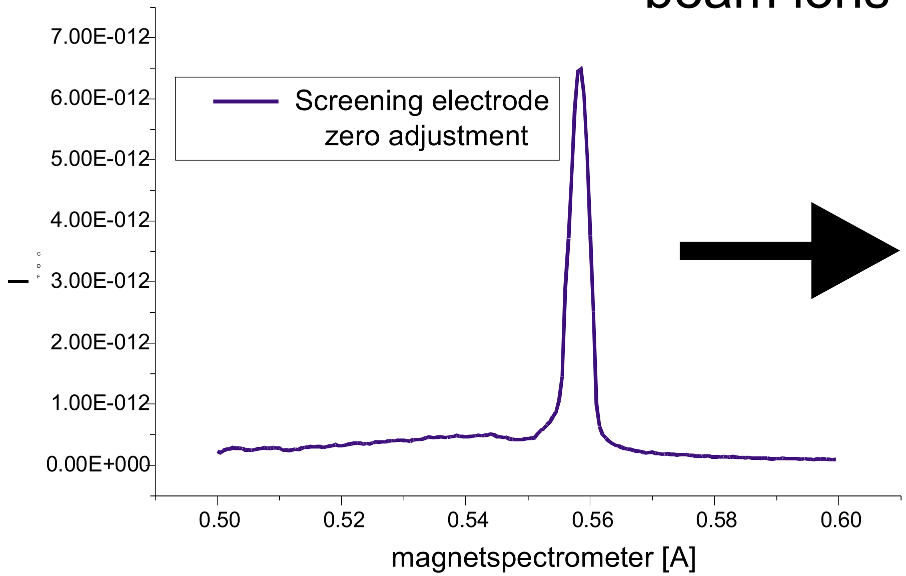

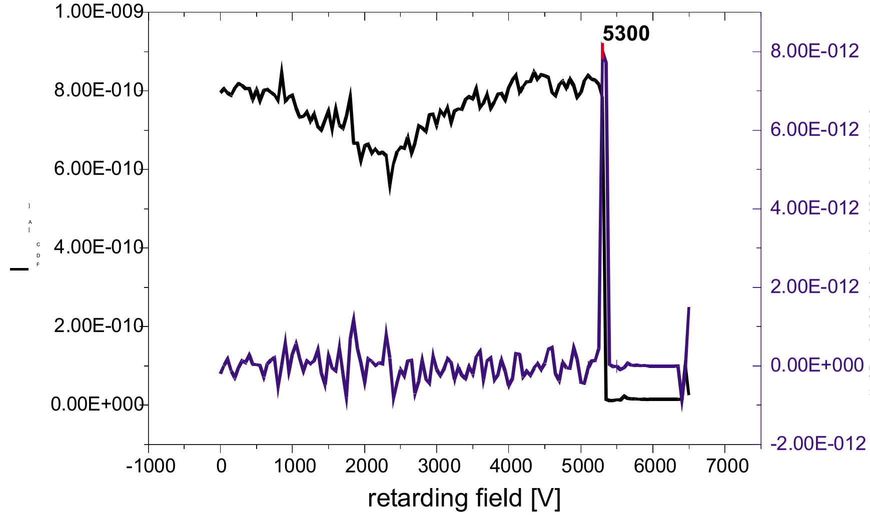

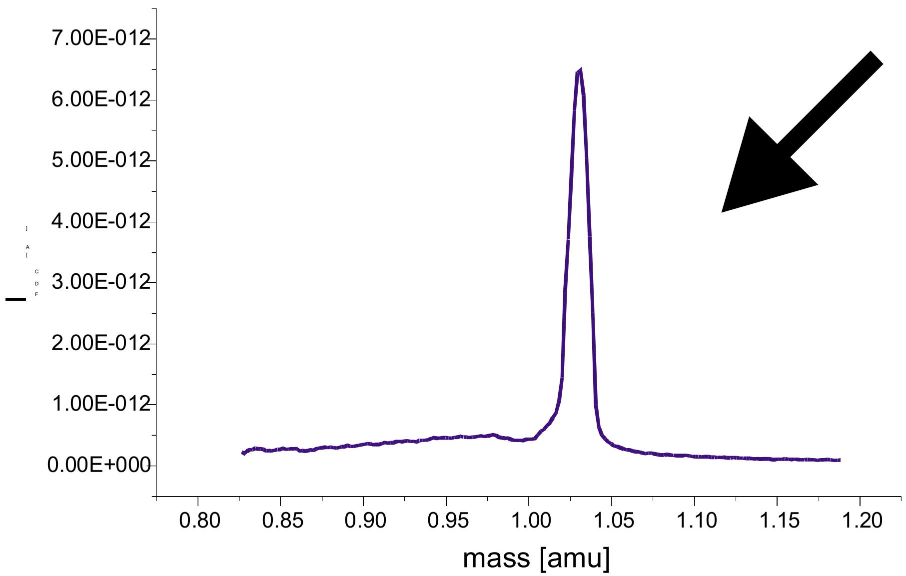

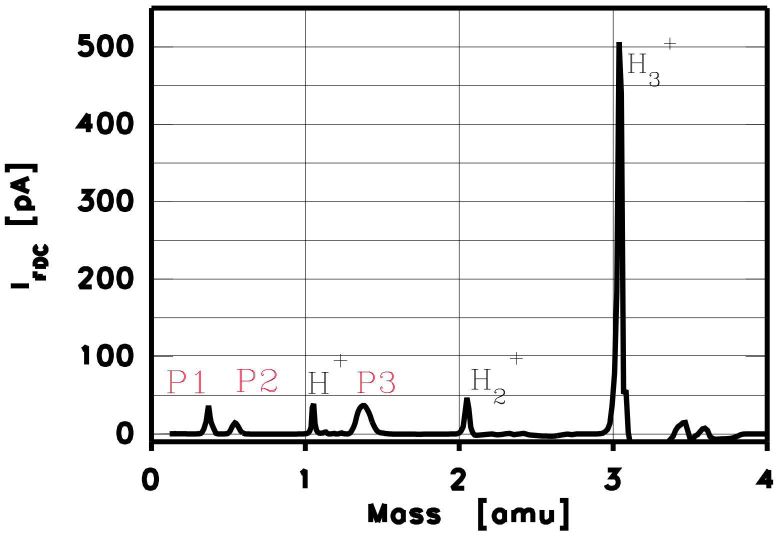

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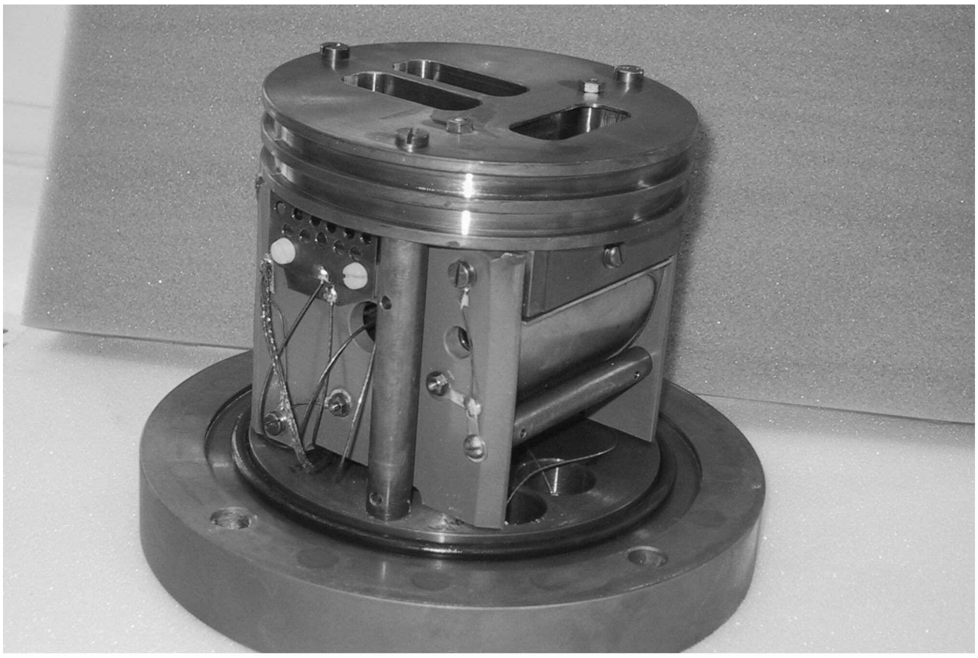
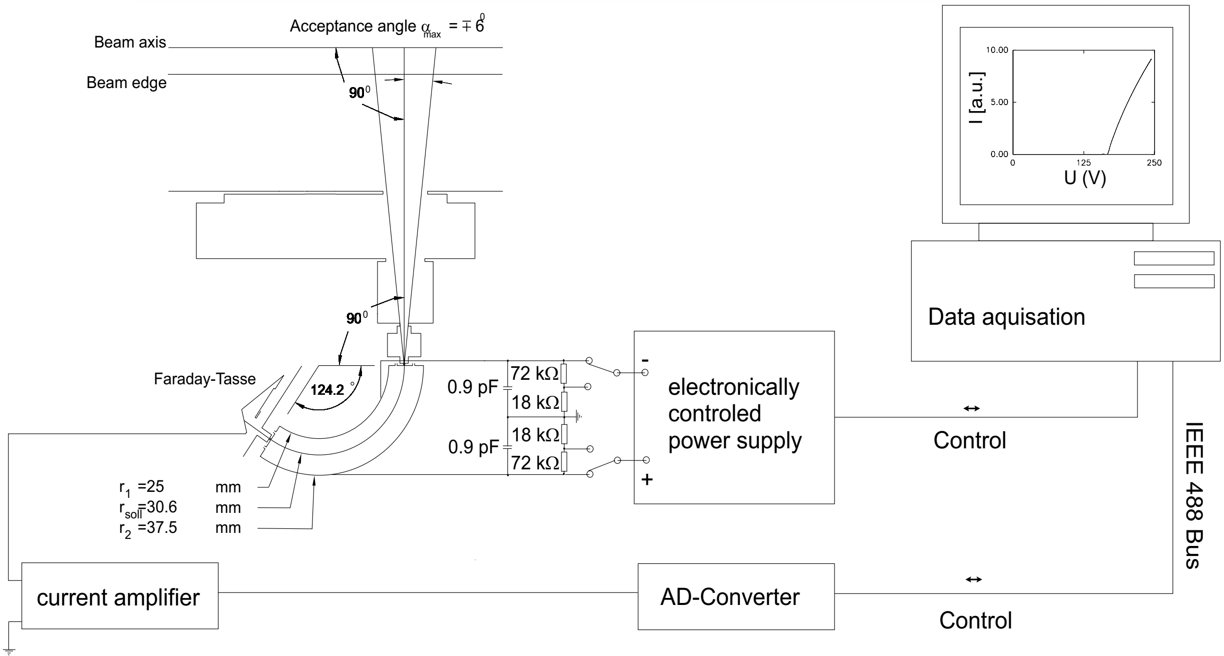
Residual ion energy spectroscopy for non destructive potential measurements using an electrostatic analyser of the Hugh-Rojanski type

Spectrometer No. 1 -Faradycup





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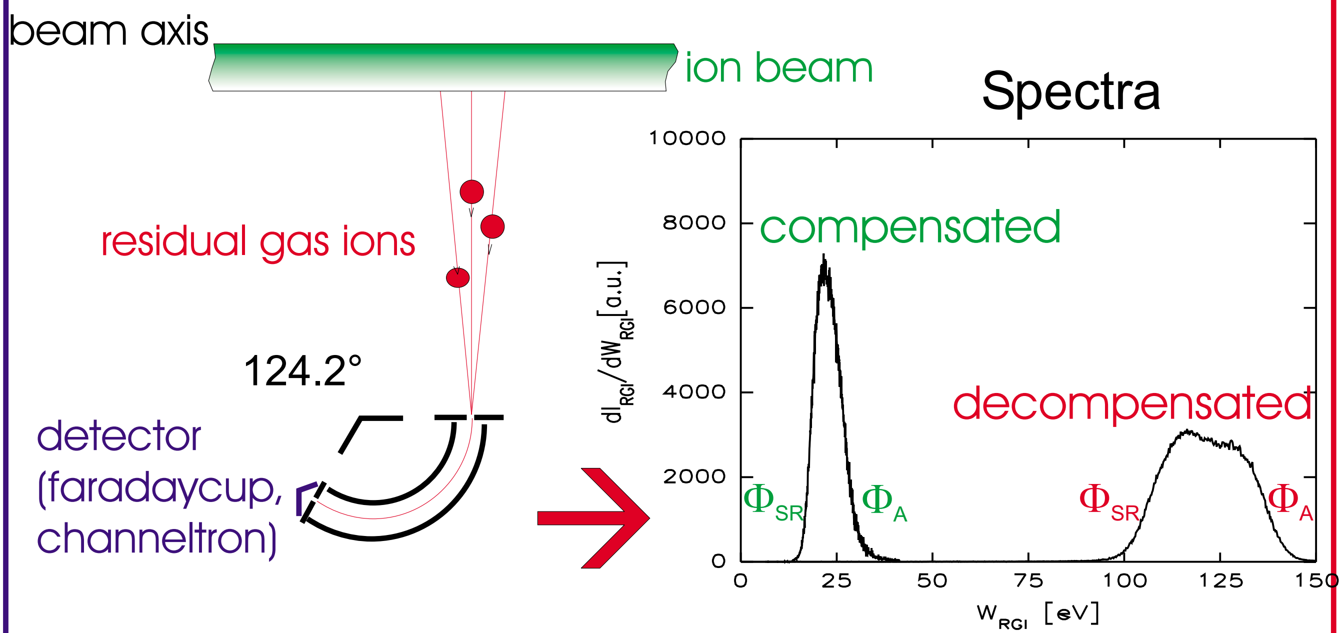
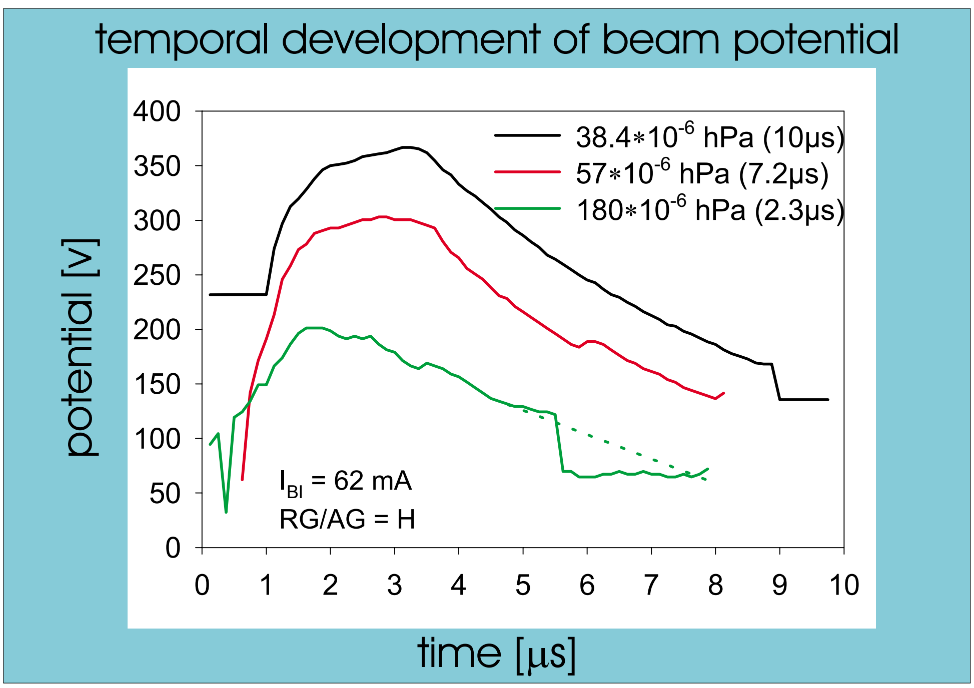


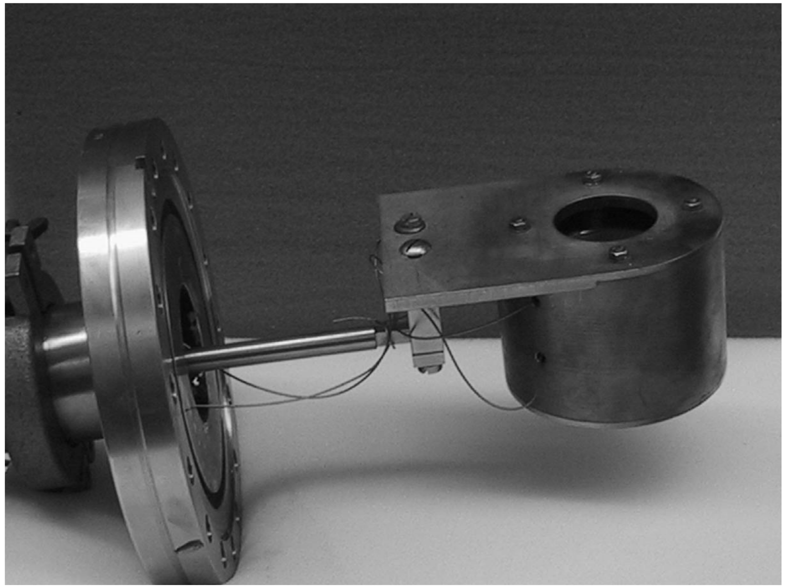
Measurements at the SILHI-LEBT at CEA-Saclay

H^+; 92keV ; 62mA ; $P_{RG} = 57*10^{-4}$ Pa ; $\tau_{min,100\%} = 7.2\ \mu s$

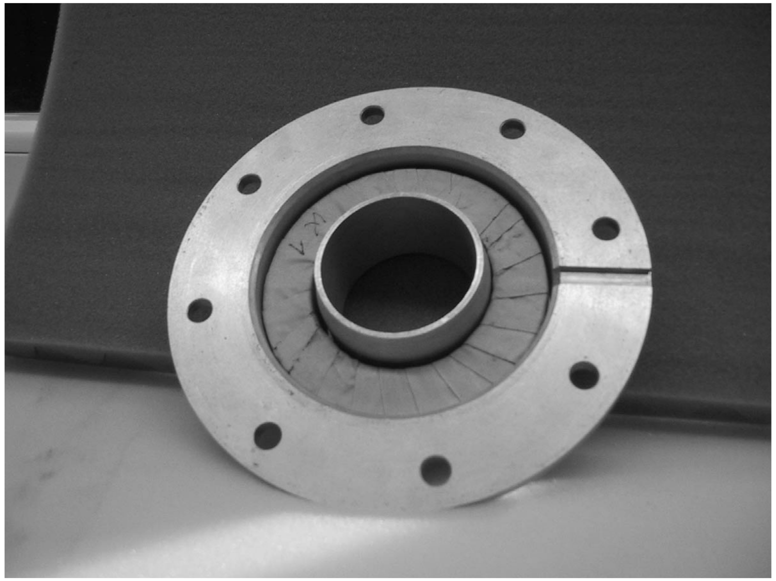


Other diagnostics

Faraday cup



Current transformer



* Langmuir probes
* RF - probes
* Electron beam probe
* Pickups

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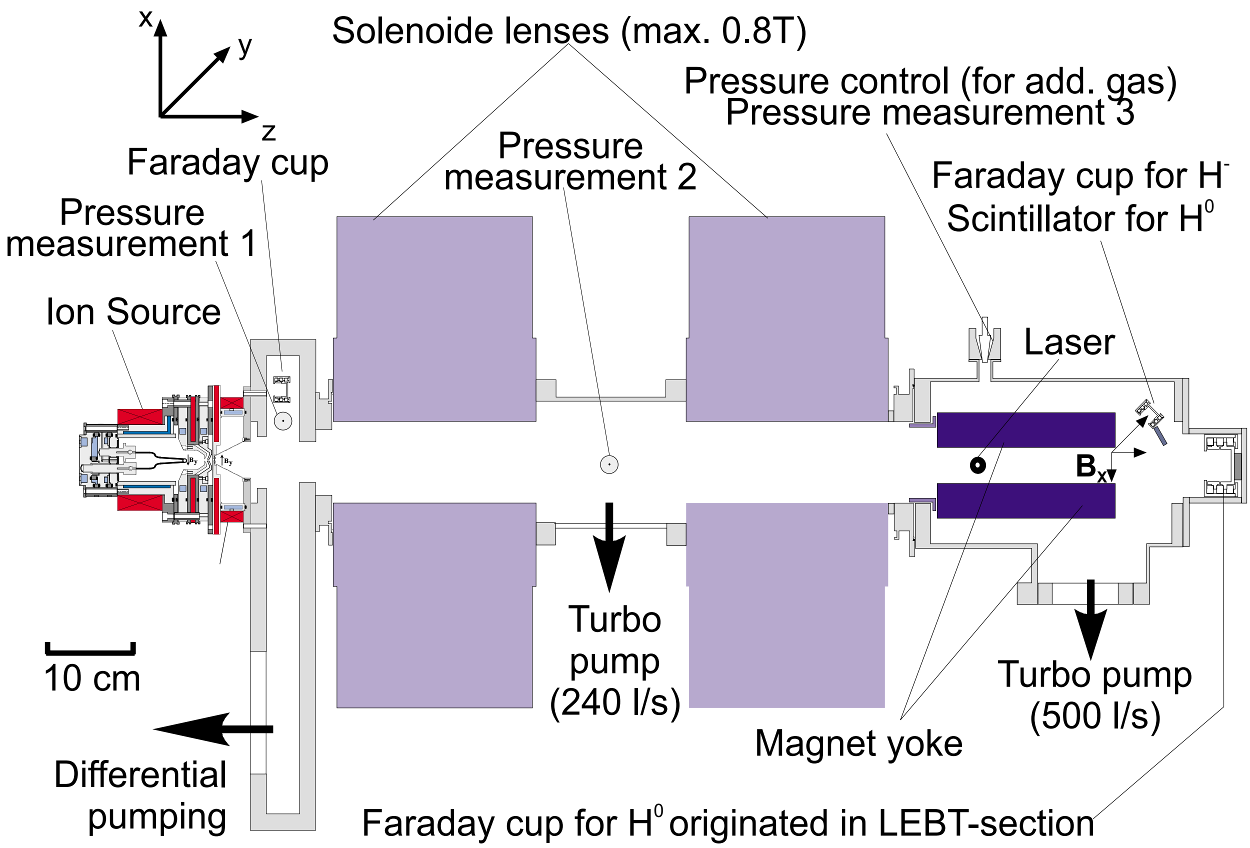
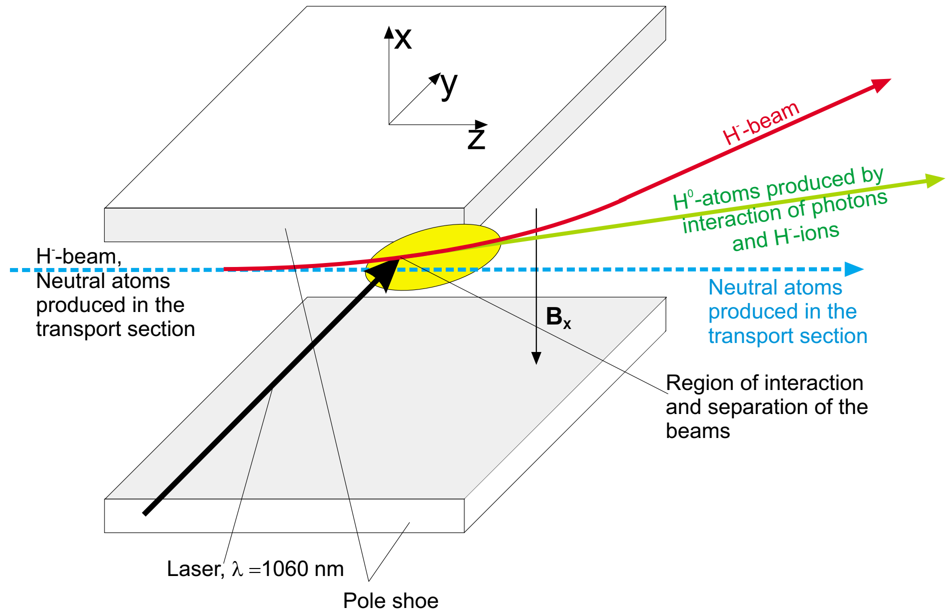
Laser neutralized emittance measurement
(C. Gabor)

Experimental setup

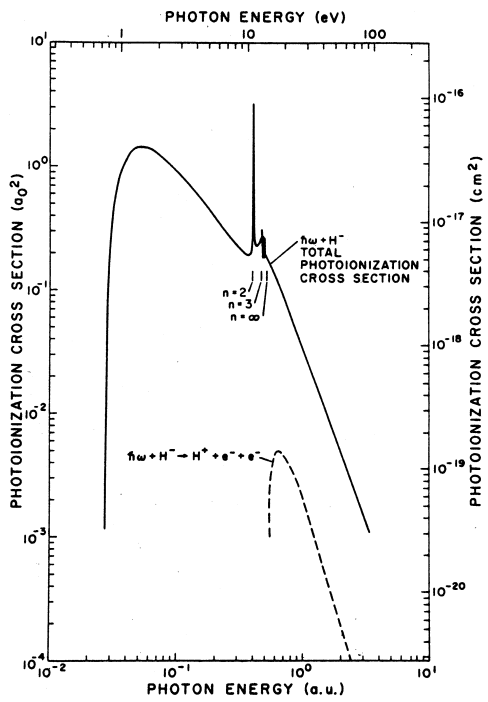


Principle of a laserinduced emittance measurement for H$^-$-beams

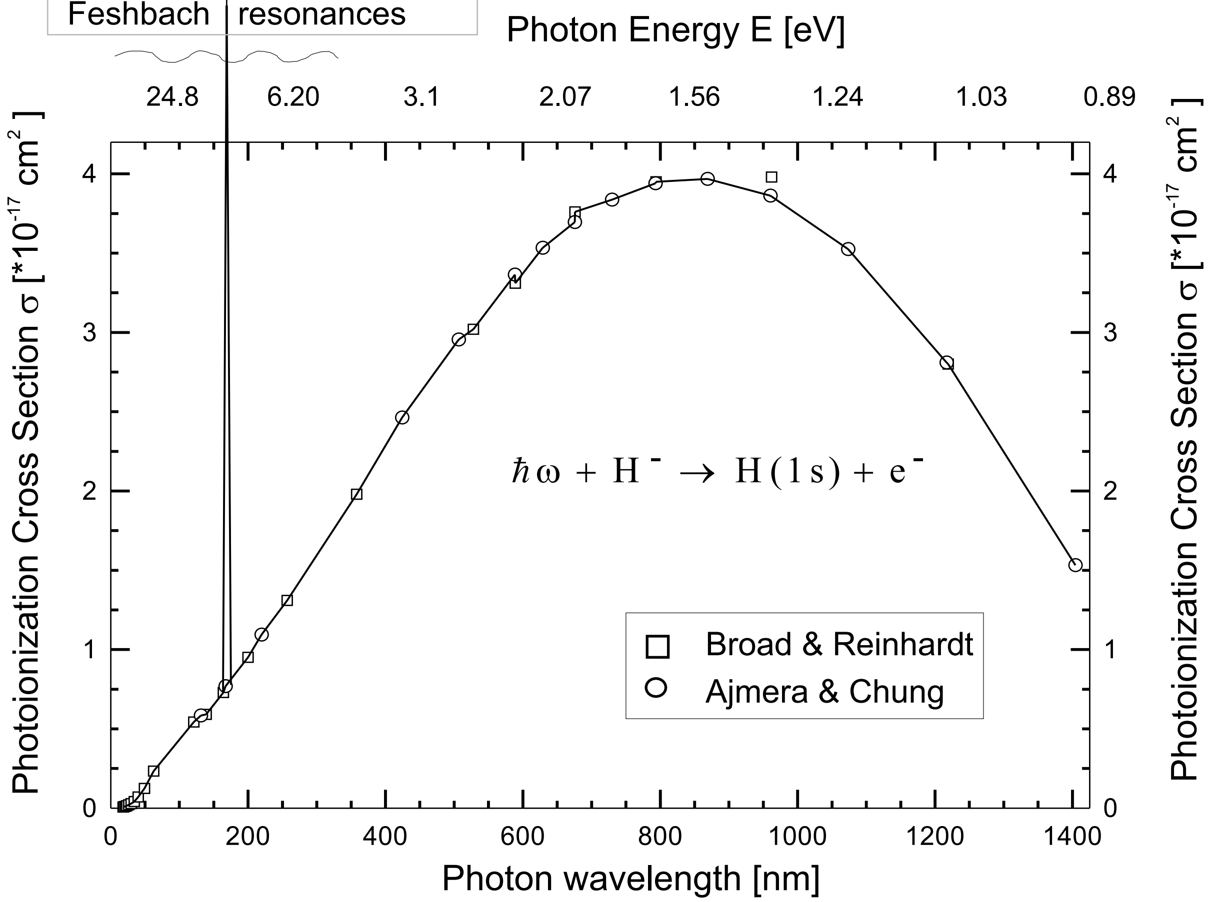


Photoneutralization

a_0^2 is a special unit in the theoretical atomic physic

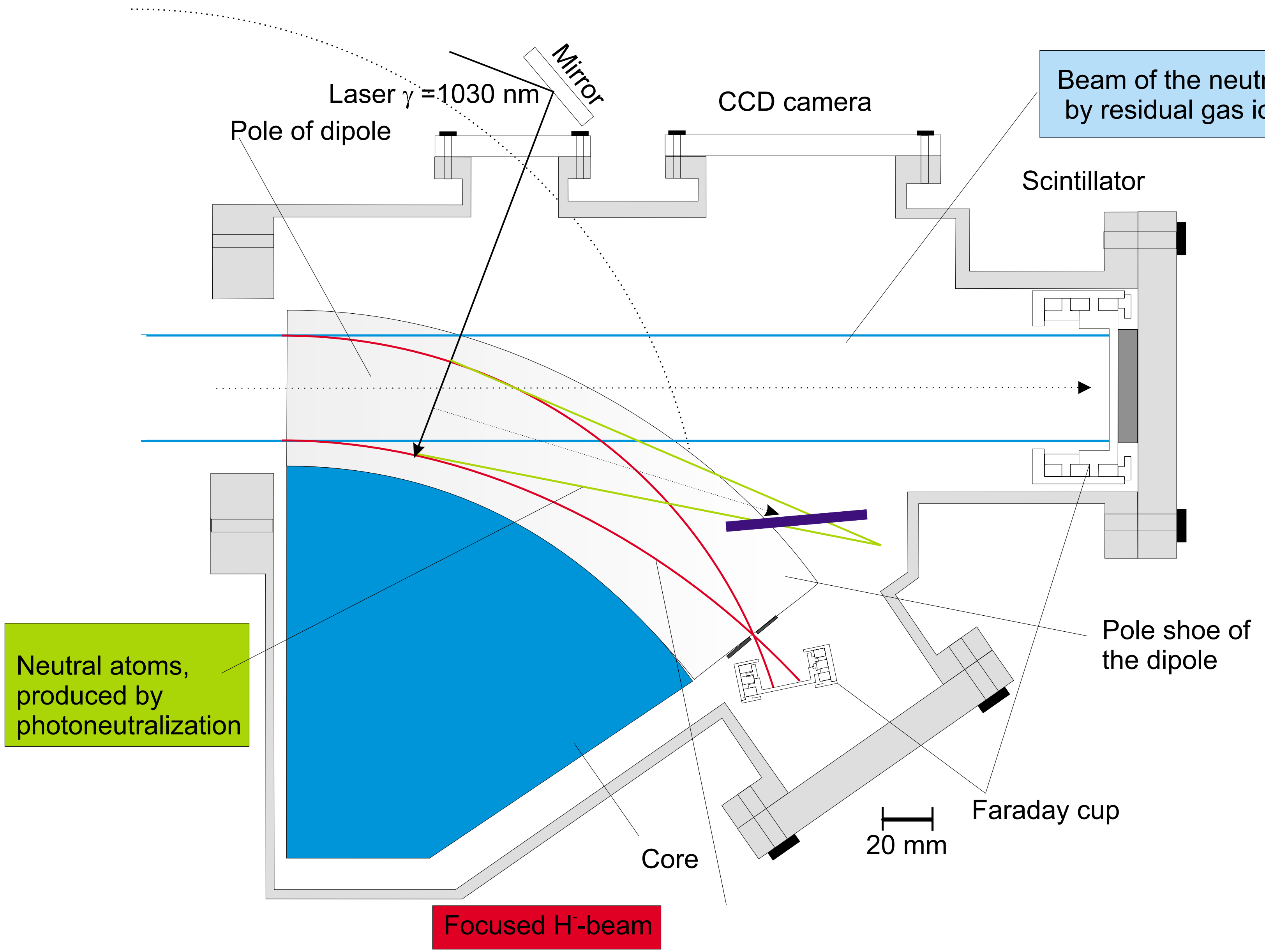


At about 10 eV (=123.9 nm) are the shape- and Feshbach resonances



[1] J. T. Broad and W. P. Reinhardt, „One and Two Electron Photojection from H⁻ Atoms“, Phys. Rev. A14, 1976
[2] M. P. Ajmera and K. T. Chung, „Photodetachment of Negative Hydrogen Ions“, Phys. Rev. A12, 1979

Experimental setup of diagnostic chamber and dipole



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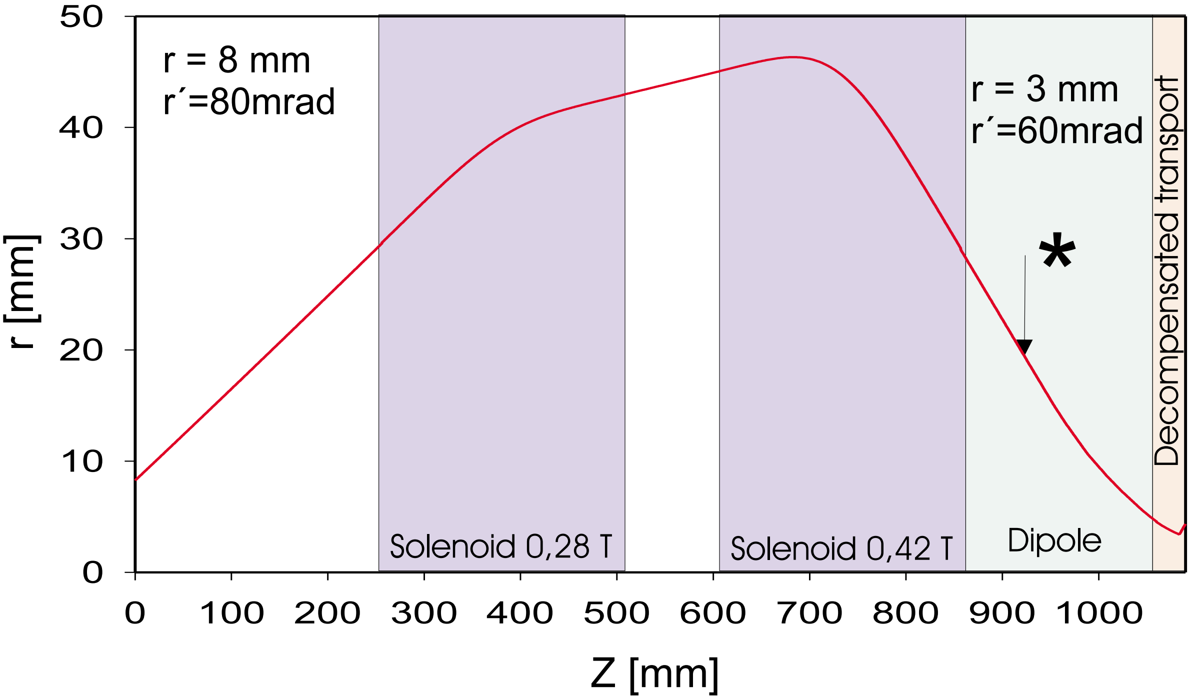
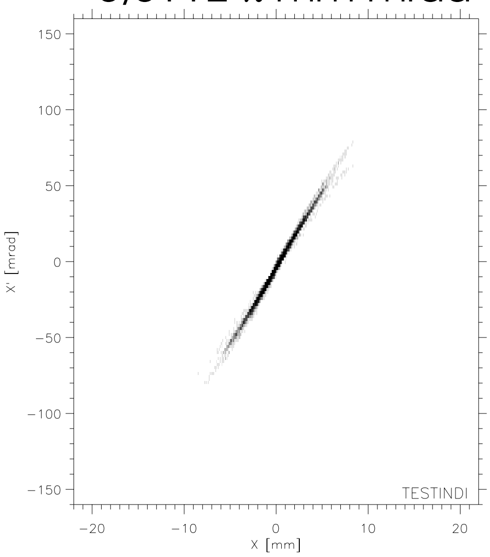
Numerical calculation of beam transport

Beam envelope of 55kV, 70mA, H^--beam

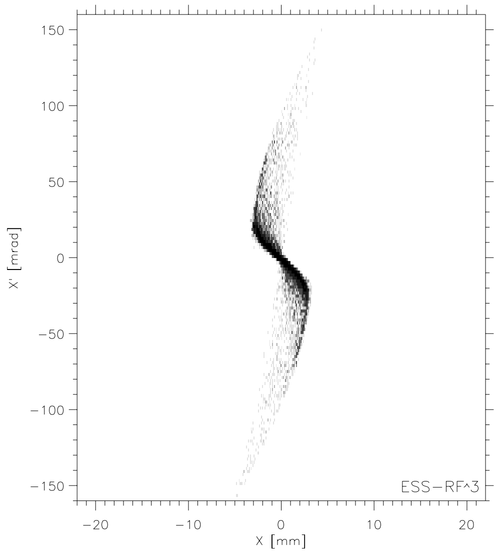


$\varepsilon_{rms,n,100\%} =$ 0,0112 π mm mrad



Initial (calculated)

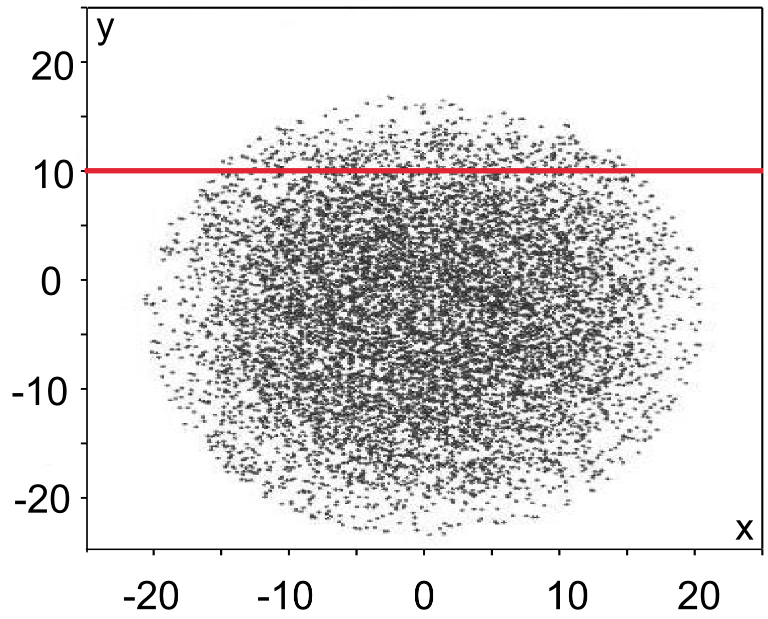
$\varepsilon_{rms,n,100\%} =$ 0,0929 π mm mrad



Entrance of RFQ

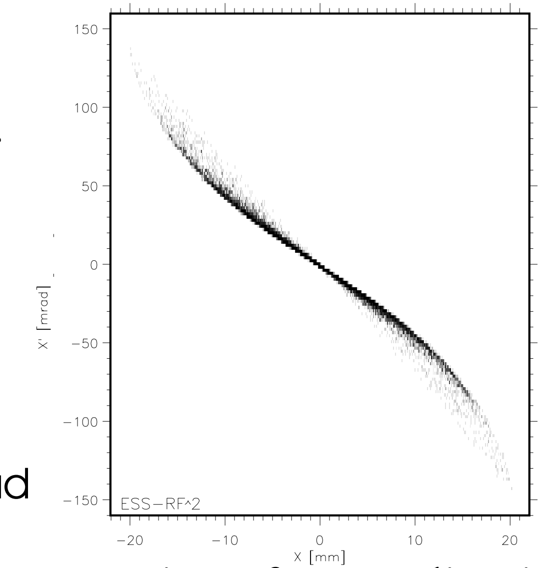
* In this plane the laser scanns transversly through the ion beam. That is app. after the first third in the magnet field.

Simulation of interaction between laserbeam and H^--beam

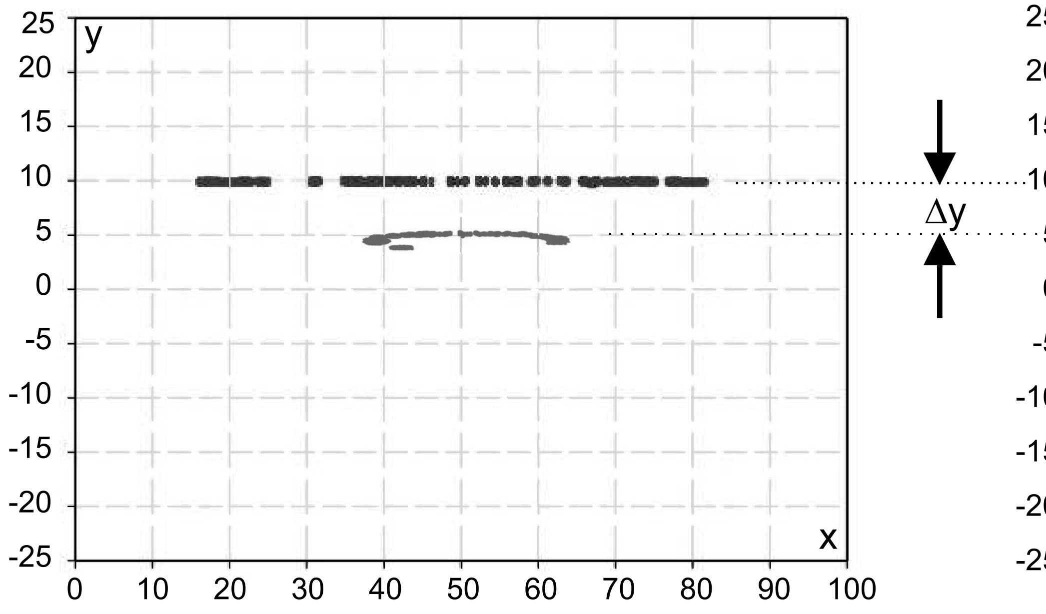


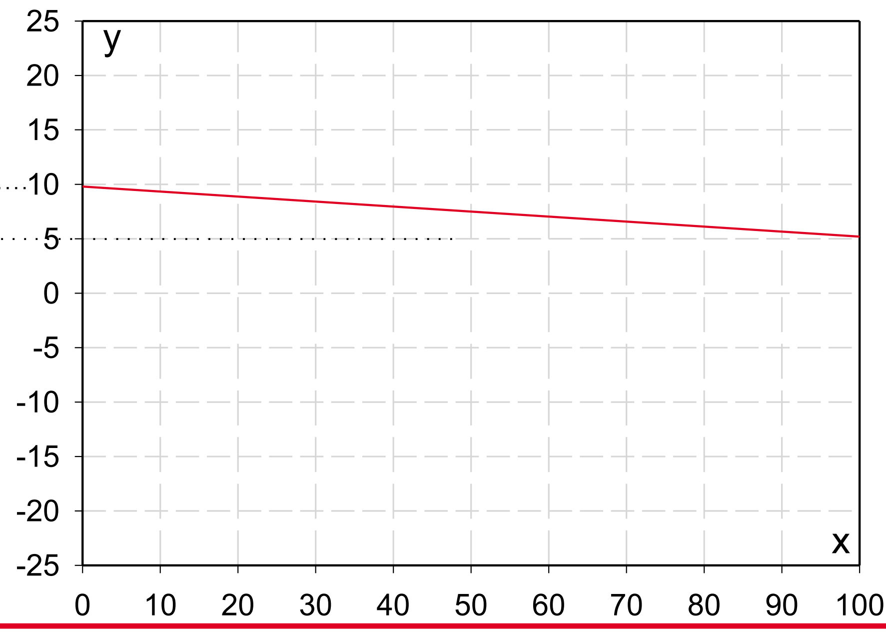
Position of the laser

$\varepsilon_{rms,n,100\%}=$
$0{,}1036\ \pi$ mm mrad



Region of neutralisation





Summary

Beam diagnostics is
an important subject
for design, optimisation
and operation
of an Low Energy Beam Transport section

* Destructive methods like
Faraday cups
Emittance scanner
....
are well known but suffer
from high power density and their
influence on beam transport

* non destructive methods like
RGI -spectroscopy
CCD - imaging
laser neutralisation
....
do not desturb beam transport
but some applications
are still subject of
investigation themself.