Space charge compensated beam transport

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Motivation:

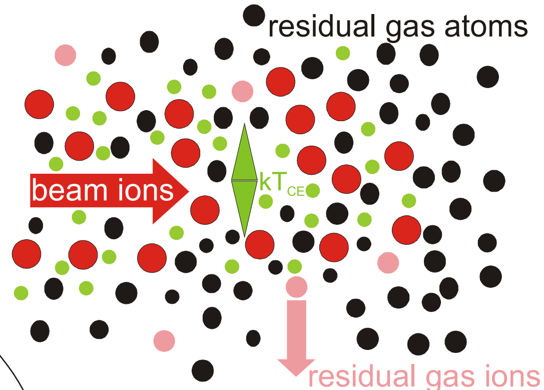
1) Was on the agenda since I started but it was never the time......

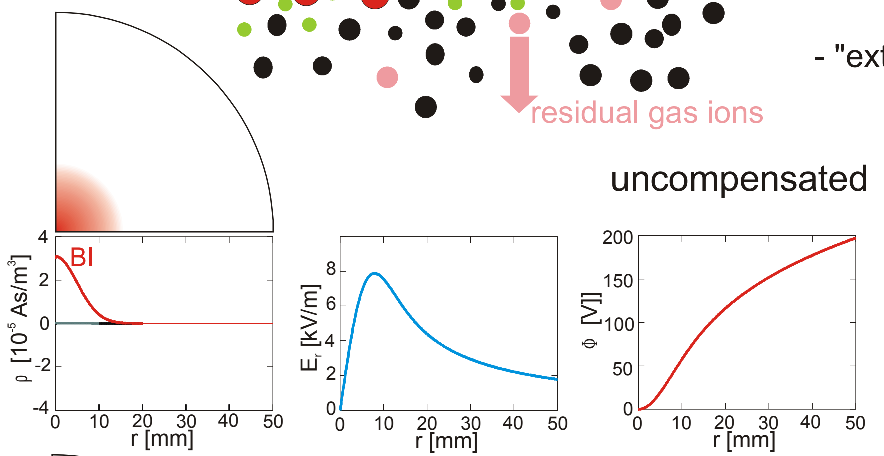
2) FETS is an unique setup to do these studies on H^-

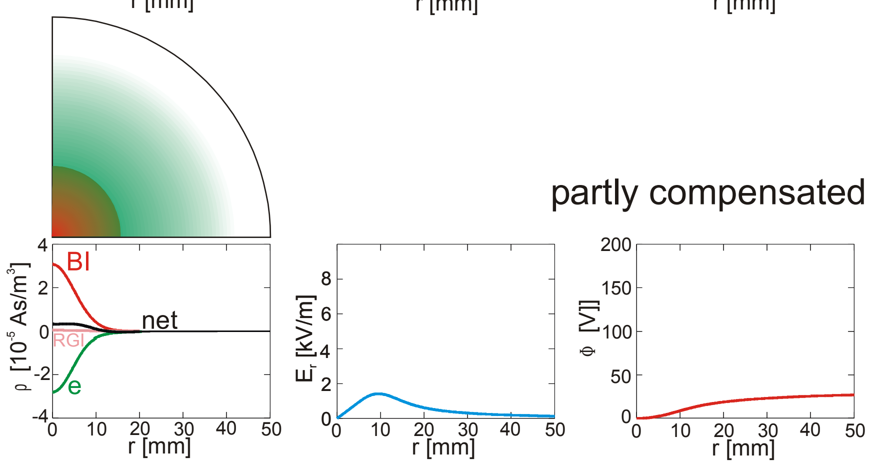
3) Discussion in Lund concerning pre chopping in an magnetic LEBT.

For positively charged beam ions

Space charge compensation by ionisation of residual gas







The net charge density is given by :

$$\rho_{net}(r) = \rho_{BI}(r) + \rho_{RGI}(r) - \rho_{CE}(r)$$

- production of compensation electrons and residual gas ions

$$\dot{\rho}_{[CE;RGI]}(r) = \rho_{BI}(r) \cdot v_{BI} \cdot n_{RGA} \cdot \sigma_{[CE;RGI]}$$

- "extraction" of residual gas ions by the self field of the ion beam

$$\rho_{RGI}(r) = \frac{1}{r} \int_0^r \frac{\dot{\rho}_{RGI}(r^*) r'}{v_{RGI}(r', r^*)} dr'$$

$$v_{RGI}(r) = \sqrt{\frac{2q_{RGI}\left[\Phi(r^*) - \Phi(r)\right]}{m_{RGI}}}$$

- thermalisation of the trapped electrons (CE)

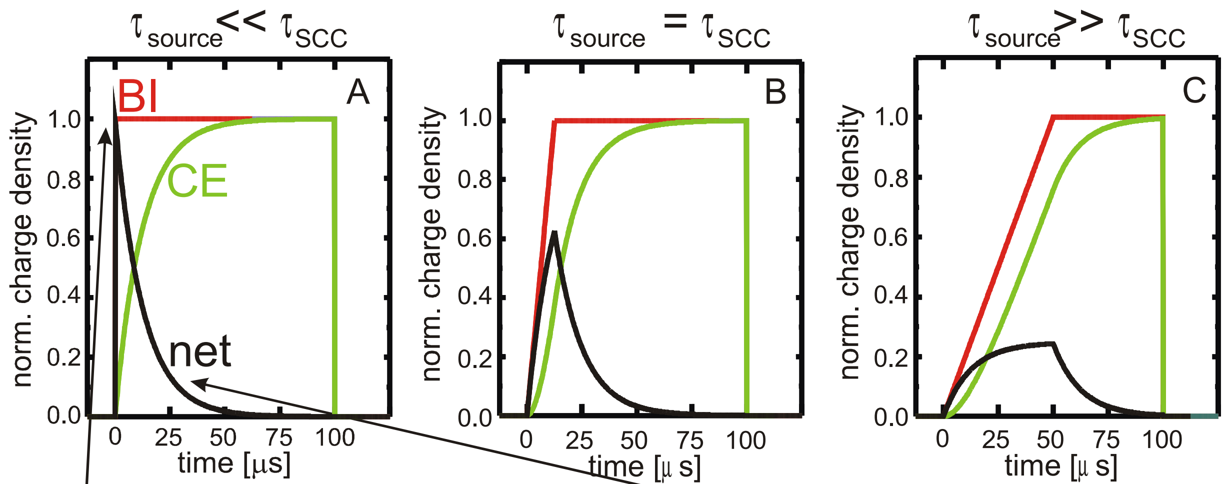
$$\rho_{CE}(r) = \rho_{CE}(r=0) \cdot e^{\left[-\frac{e(\Phi(r=0) - \Phi(r))}{kT_{CE}}\right]}$$

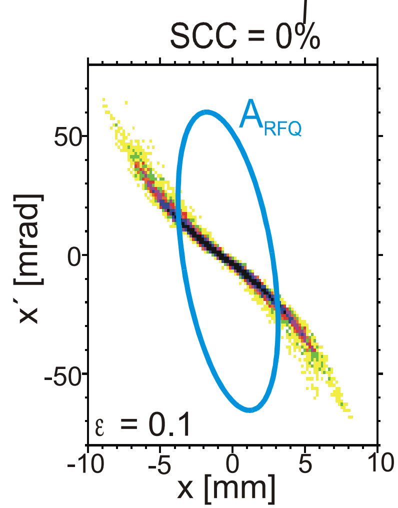
For a determination of the state of the "beamplasma"
it is neccesary to know :

- the radial beam ion density profile
- the residual gas pressure
- cross sections
- electron density on axis
- electron temperature

Rise time of space charge compensation

$$\tau_{SCC} = \frac{1}{n_{RGA} * v_{BI} * \sigma_{CE}}$$

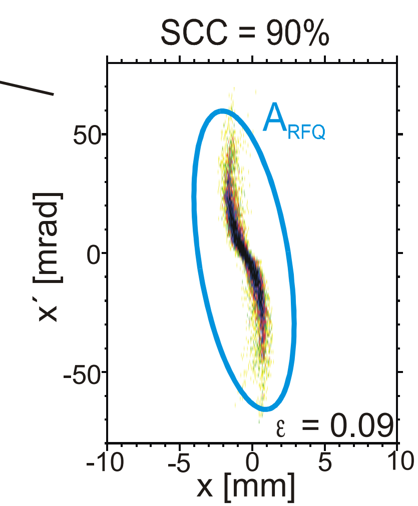




Rotation of phase space density distribution as a function of time

Time dependent mismatch of RFQ injection

Time dependent emittance growth



Cross section for beam losses and space charge neutralisation

$$\sigma_{V,100keV} \cong 2.6 \cdot 10^{-19} [m^2]$$

$$\sigma_{V,10keV} \cong 4.1 \cdot 10^{-19} [m^2]$$

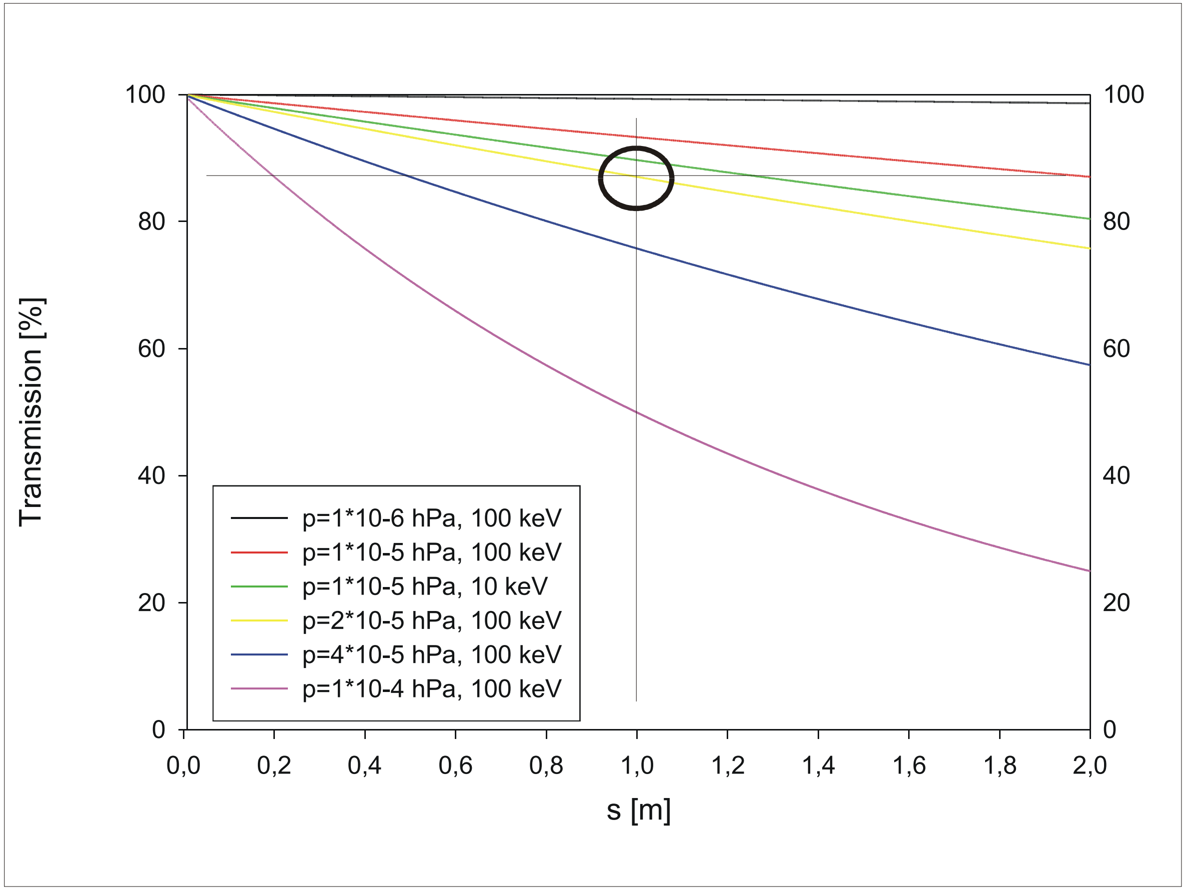
! 2.4 $p_{meas.}$ = p_{real} !

$$\sigma_{KI,100keV} \cong 3 \cdot 10^{-21} [m^2]$$

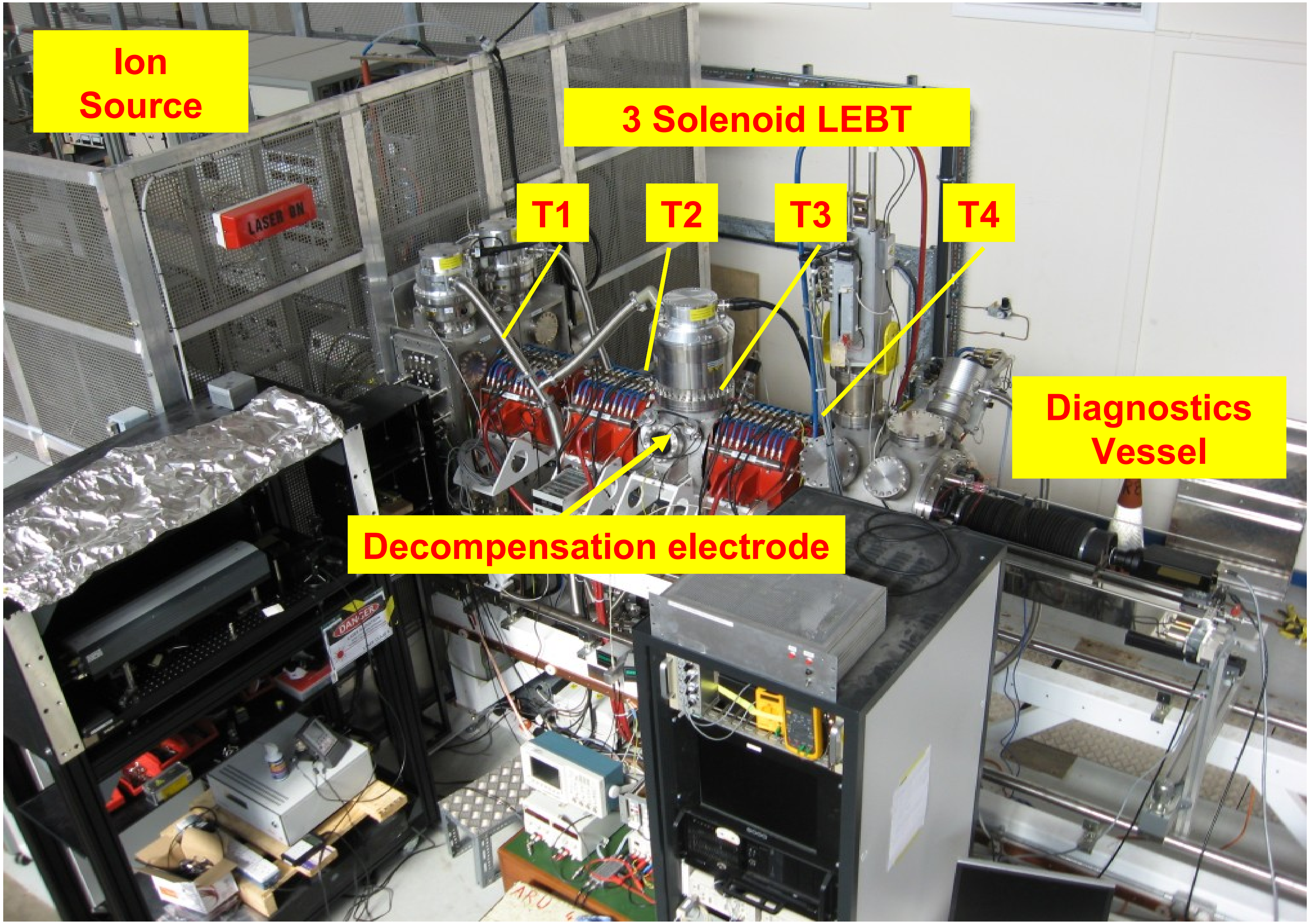
$$\tau_{p=2\cdot 10^{-5} hPa} \approx 140 [\mu s]$$

$$\sigma_{KI,10keV} \cong 3.5 \cdot 10^{-21} [m^2]$$

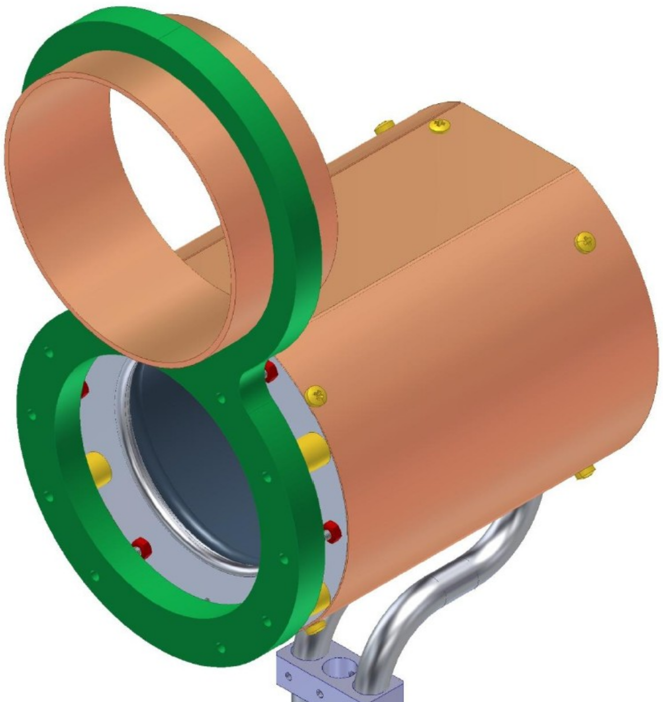
$$\tau_{p=2\cdot 10^{-5} hPa} \approx 390 [\mu s]$$



Experimental setup 1 - externals

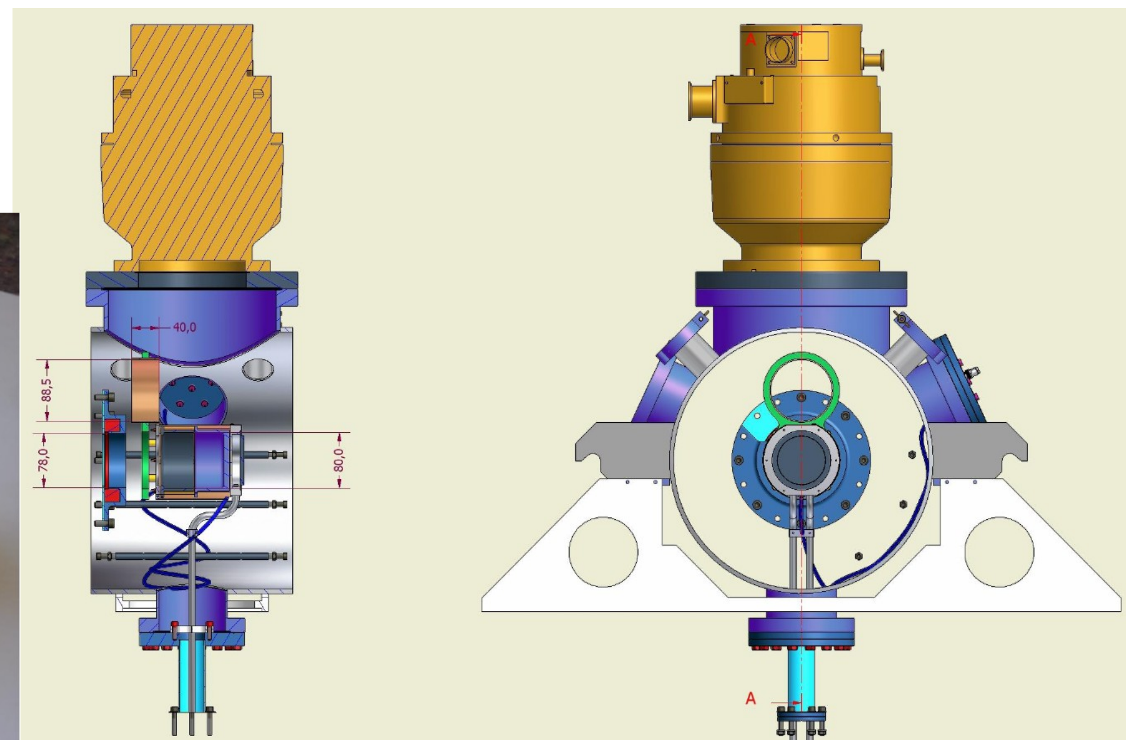


Experimental setup 2 - internals



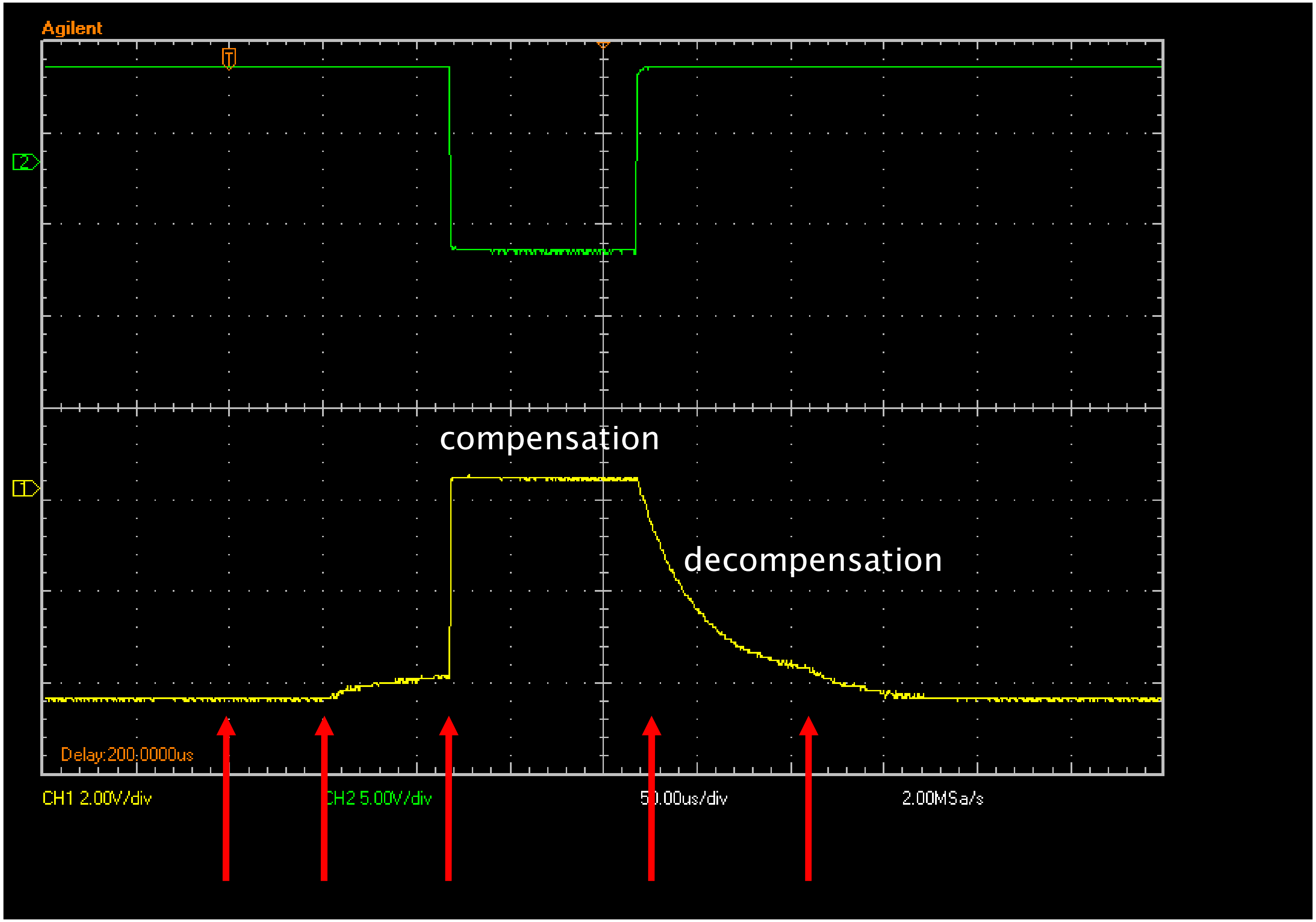
Decompensation electrode in LEBT drift vessel beam to influence degree of space charge compensation

The electrode can be biased to ~ -500 V by a fast switch
(off ~ 100 ns; on ~ 50 μs)



Decompensation electrode voltage timing

H- , Beam energy 65 keV, current ~40 mA, ~250 μs pulselength , ~50 μs trigger delay, HV off 120 μs after trigger on 220 μs after trigger

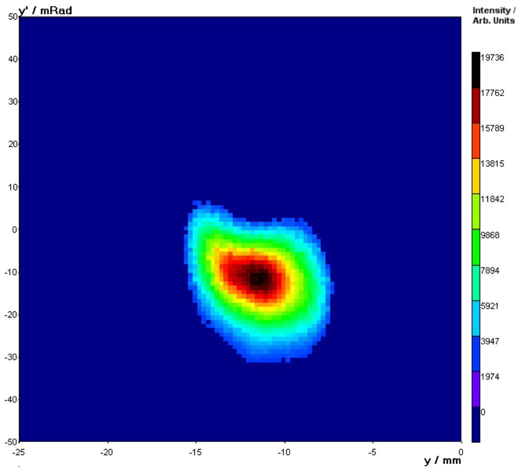


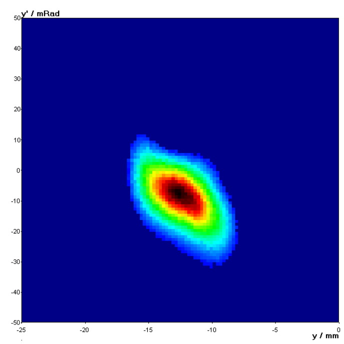
Compensation / decompensated transport at nominal pressure

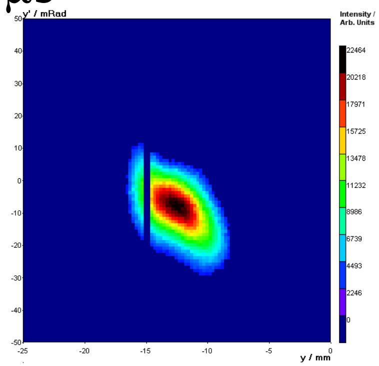
110µs

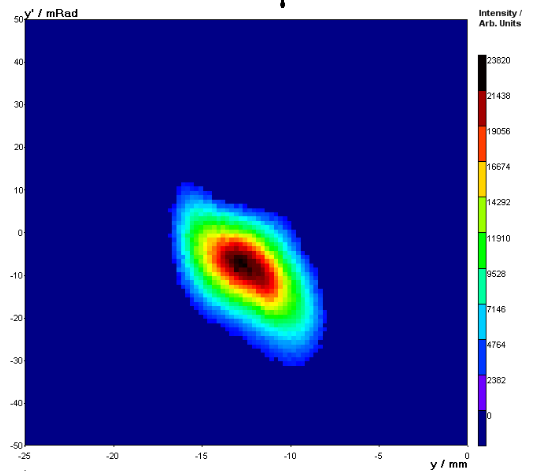
190 µs

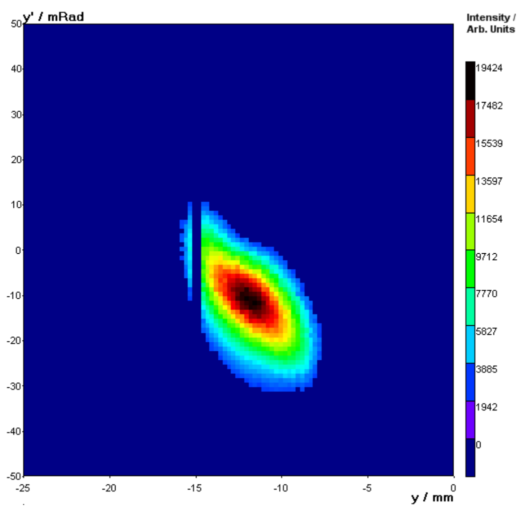
250 µs

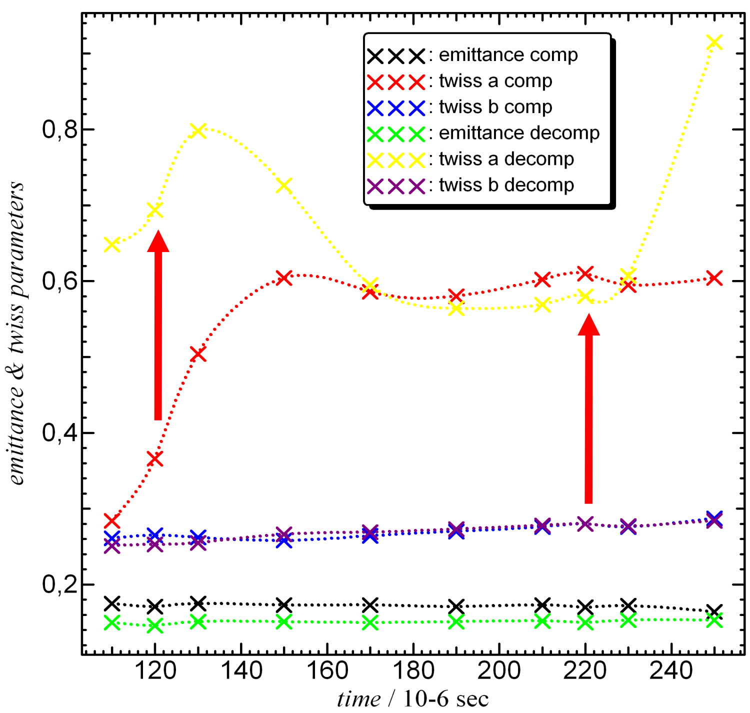


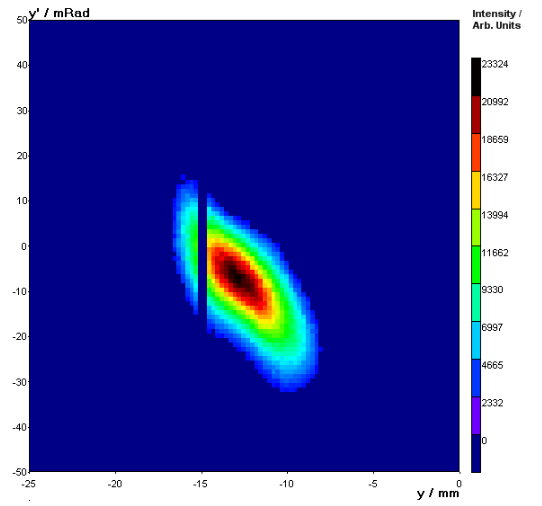








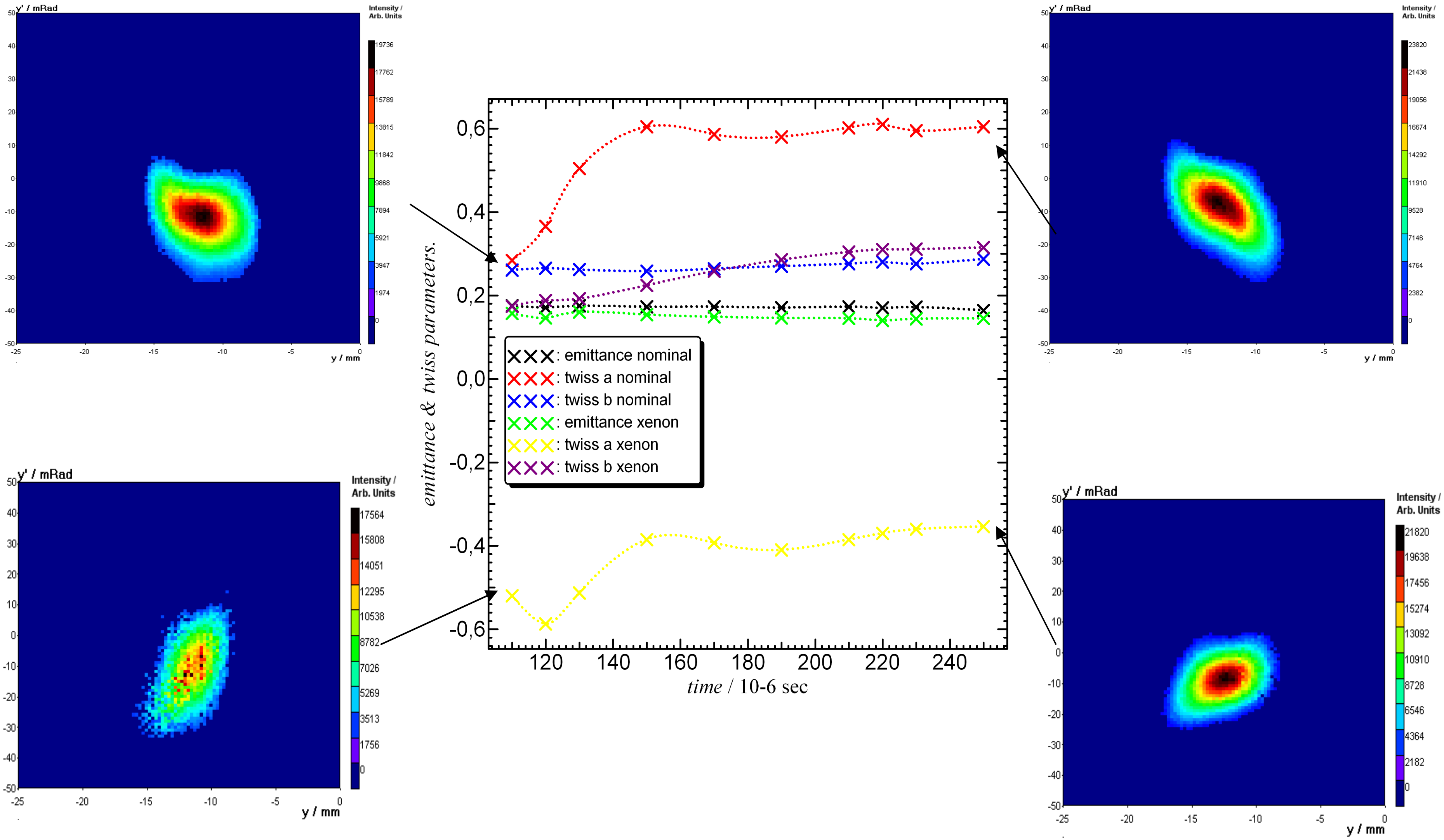




Effect of increased residual gas pressure on beam transport (nominal: $8*10^{-6}$ hPa and additional Xenon $+7*10^{-6}$ hPa)

110µs

250 µs



focus shifts several cm towards then ion source => less space charge, better compensation

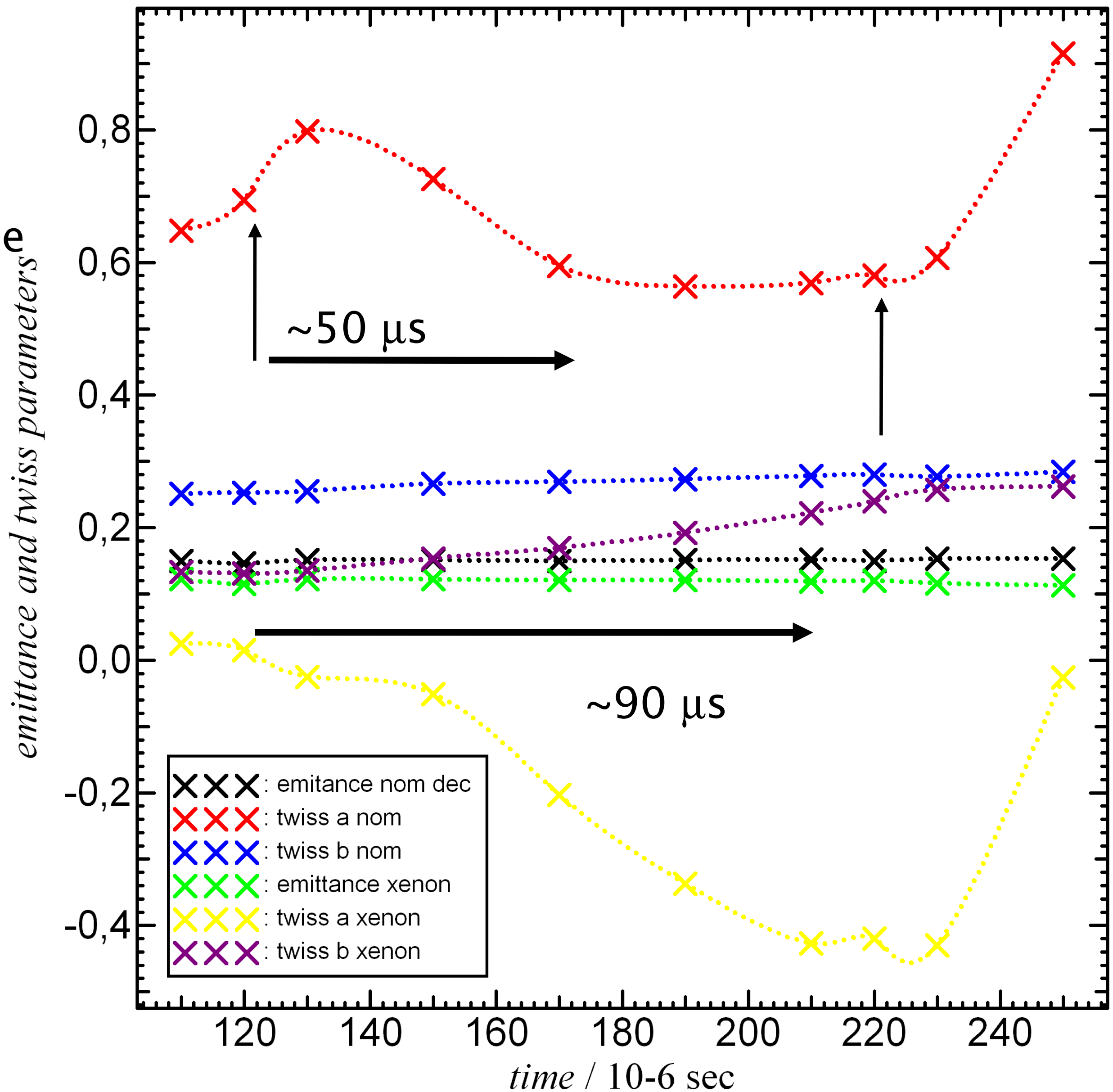
Decompensation at different pressure

Even stranger :
An increase in
residual gas pressure
increases the
rise time of space charge
compensation.

One effect specific for
Negatively charged ion
beam could give an
explanation for both
observations.....

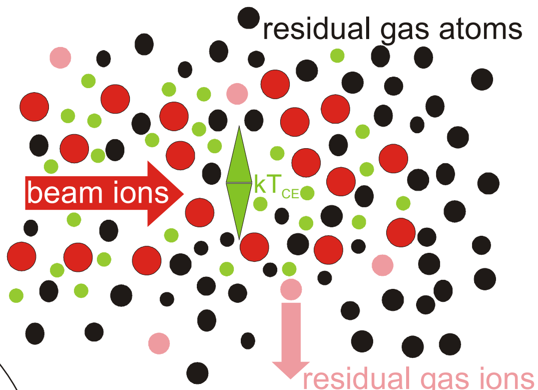
Overcompensation....

Reported by russians in
the '80s, should work
very well with heavy
gases....



For negatively charged overcompensatedbeam ions

Space charge compensation by ionisation of residual gas



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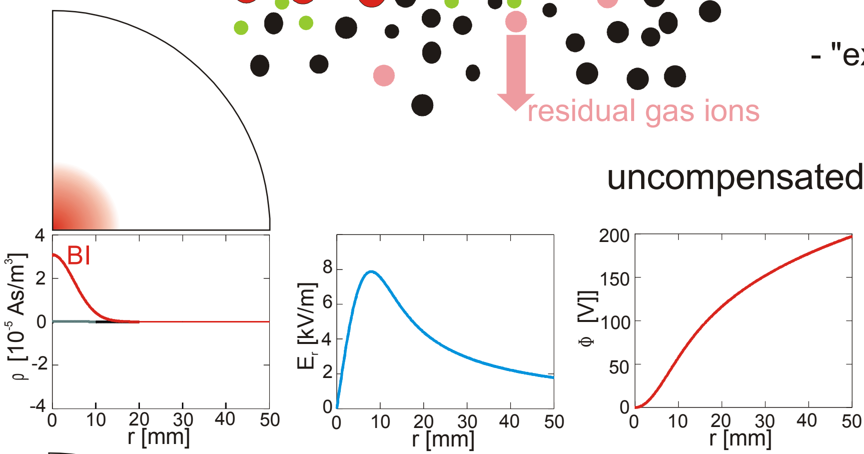
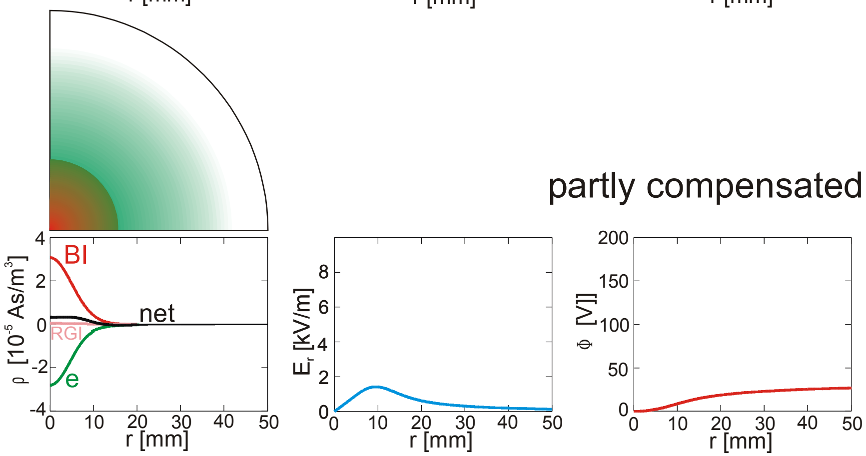
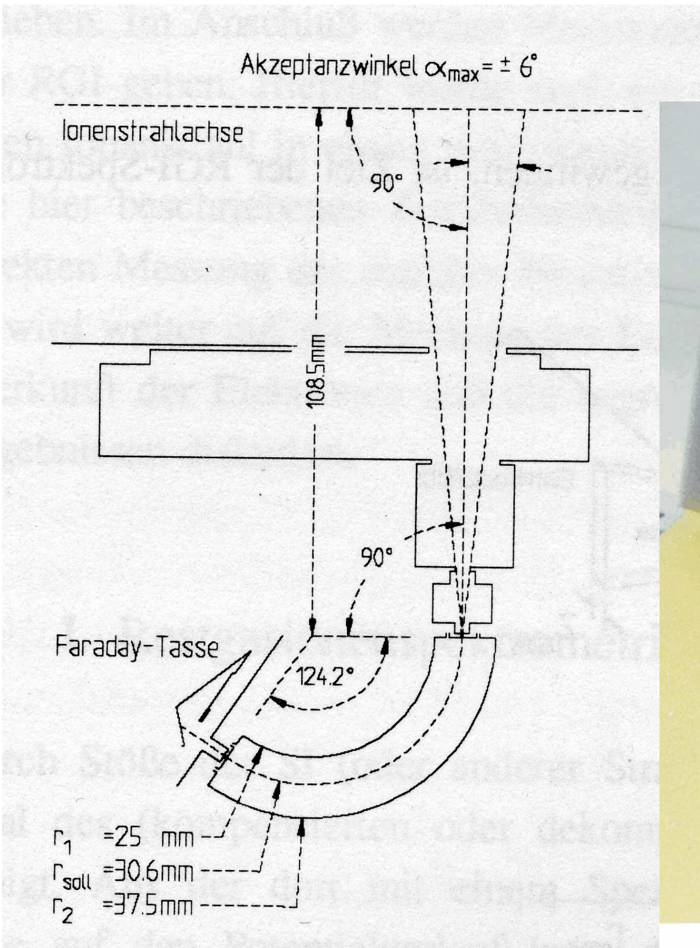


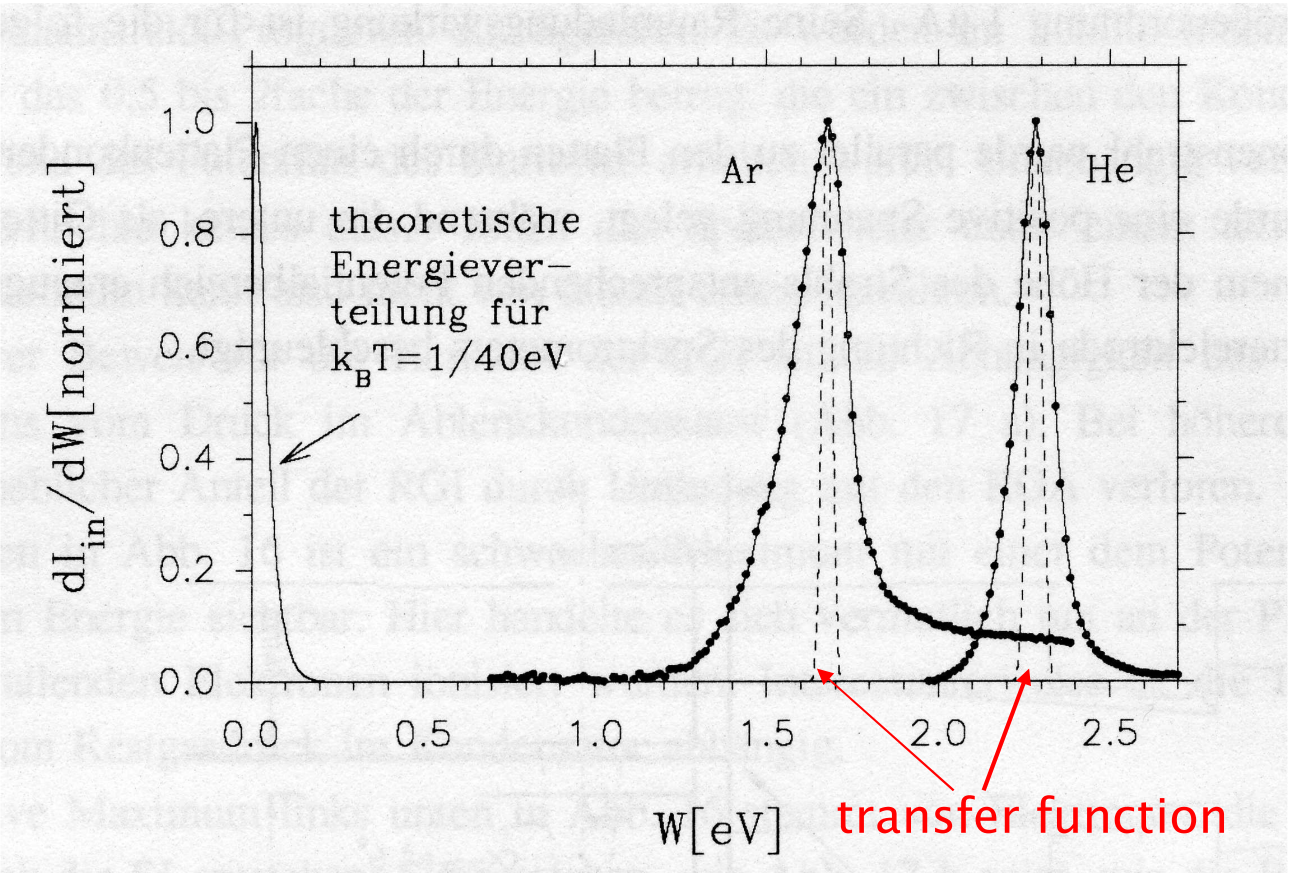


Possible as the low loss rate of RGI (= production in equilibrium) due To the high inertia allows for a limited RGI density. This density increases with mass of the RGI.

Electrostatic Spectrometer of the Hugh Rojanski type

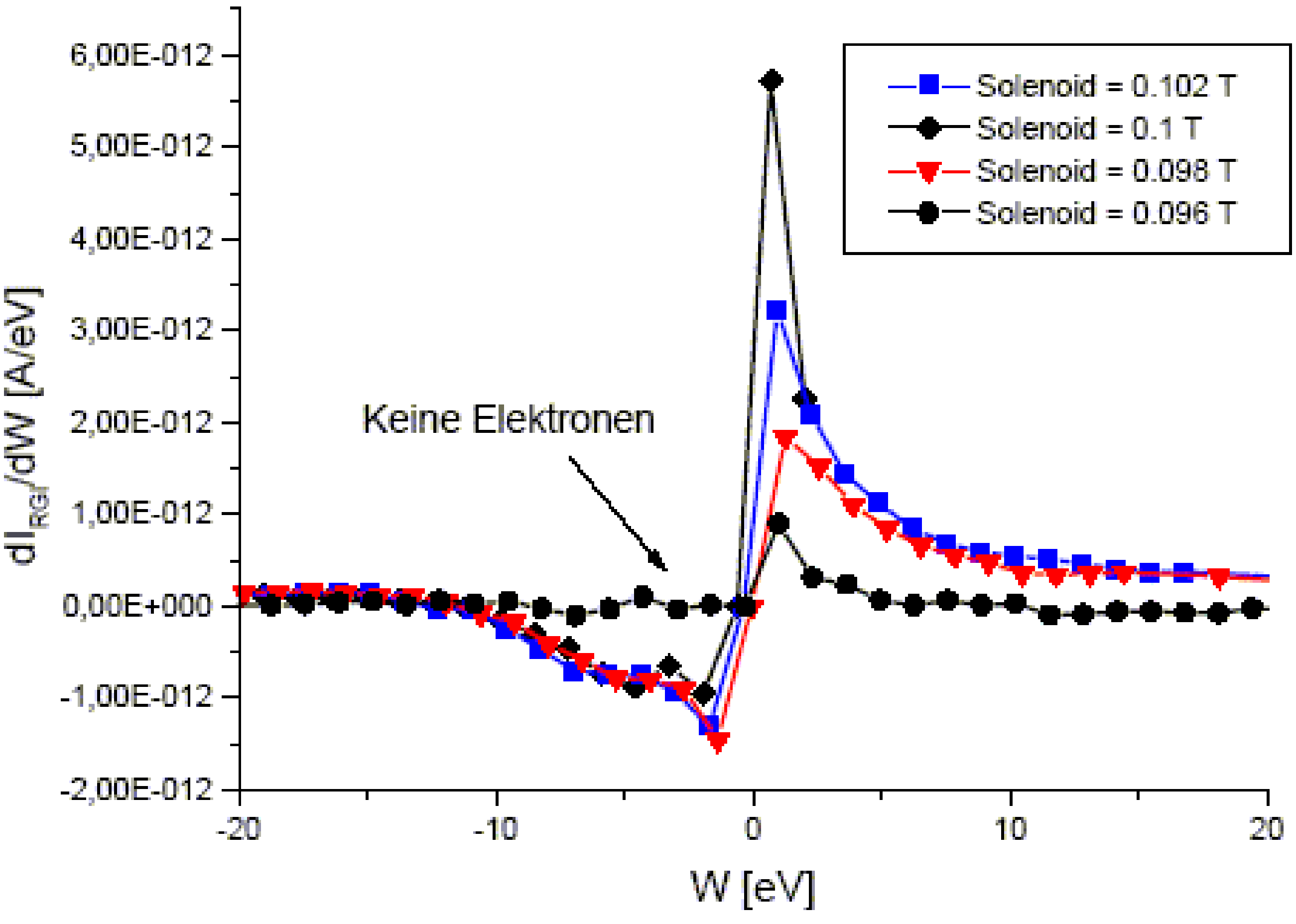


Performance measurements of the HR Spectrometer by use of electron impact



The results of the measurements proofed for He, that the gained ion energy spectra are given by the transfer function and the thermal energy only.

“Measurement” of degree of space charge compensation for the transport of H^- ions



Next steps:

- Rise time of SCC under nominal conditions is ~ 50 μs as expected, results on emittance not conclusive

- Experiment with heavy residual gas indicate overcompensation.

- Further measurements :

- Beam cross over in drift 3 => emittance growth should be stronger

- Investigate overcompensation together with an RGIS.

- RGI could be ready until January, cost ~500£ (without channeltron)

- Measurements in February / March ?

- Effect might be academic for the beam transport in the LEBT, but should give a strong indication on the processes to be expected in the ion source under similar conditions. I would strongly recommend measurements with heavy gases in the ion source (especially spectrums first) before times 2 source is constructed.