Science & Technology Facilities Council

Imperial College London

Summary of work on space charge compensation at FETS

November 2012

by

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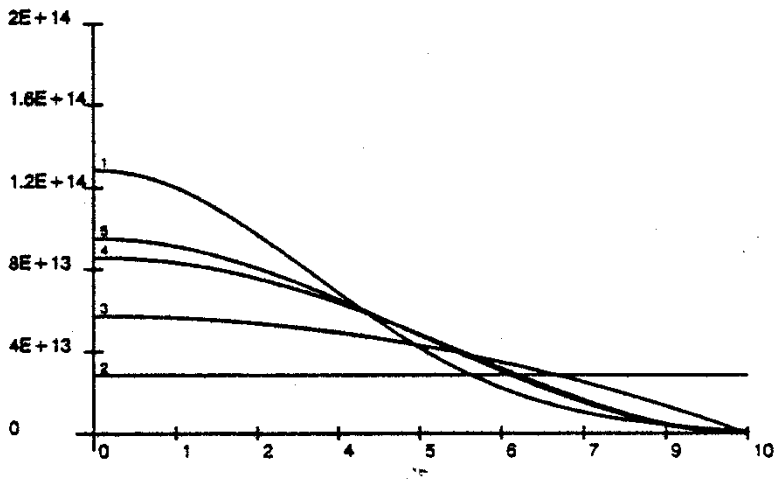
Ion beam transport for FETS and space charge compensation in the LEBT

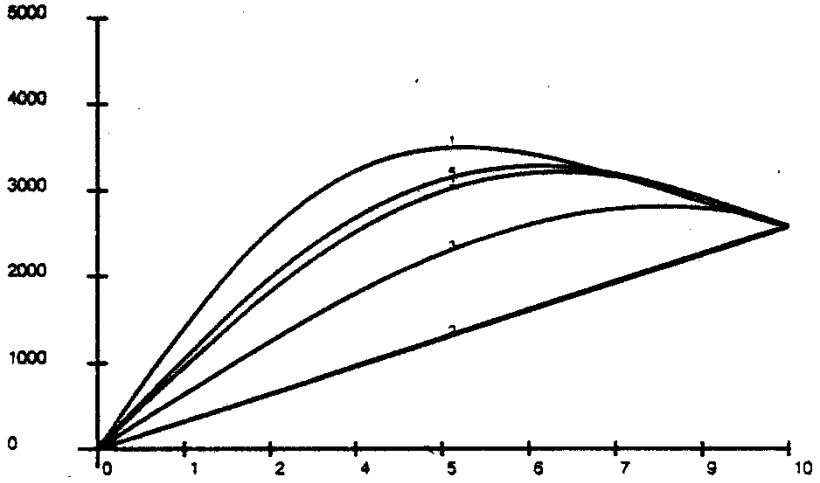
- Beam transport and space charge forces in the LEBT, passive space charge compensation, degree of compensation and self consistent states, rise time of SCC and beam mismatch.

=> For FETS interesting at the beginning of beam pulse with aim to reduce “wasted beam”.

- Experimental setup.
- First preliminary results.

Transversal particle distribution, Electric self fields and emittance growth





Simplest case : KV envelop equation using generalized perveance K

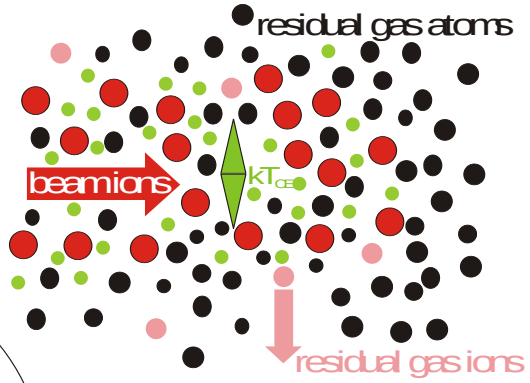
$$\frac{d^2}{dz^2}X + k_x^2 X - \frac{K}{2(X+Y)} - \frac{<\varepsilon_{x,RMS}>^2}{X^3} = 0$$

$$K = \frac{1}{4\pi\epsilon_0}\sqrt{\frac{Am}{2e\zeta}}\frac{I}{U^{3/2}}$$

Non linear fraction of the electric self fields will be converted into growth of the RMS emittance

$$\Delta\varepsilon_{RMS} = \sqrt{\varepsilon_f^2 - \varepsilon_i^2} = \sqrt{\frac{\left\langle \dot{x}^2 \right\rangle K \Delta W_{nl}}{8}}$$

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

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

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

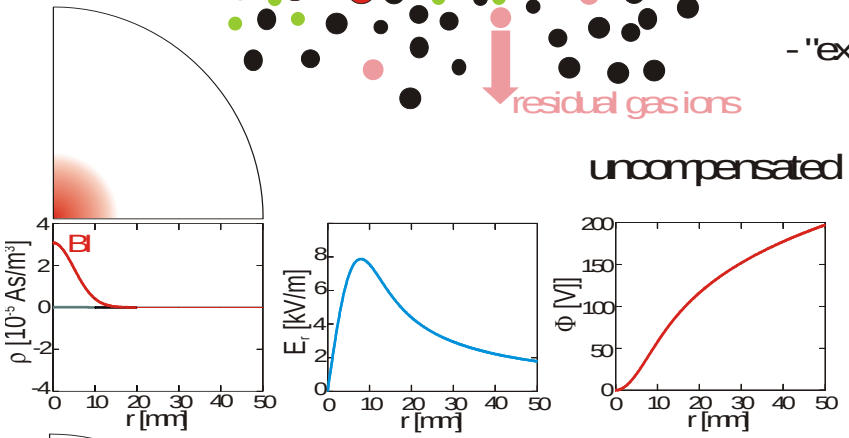
- thermalisation of the trapped electrons (CE)

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

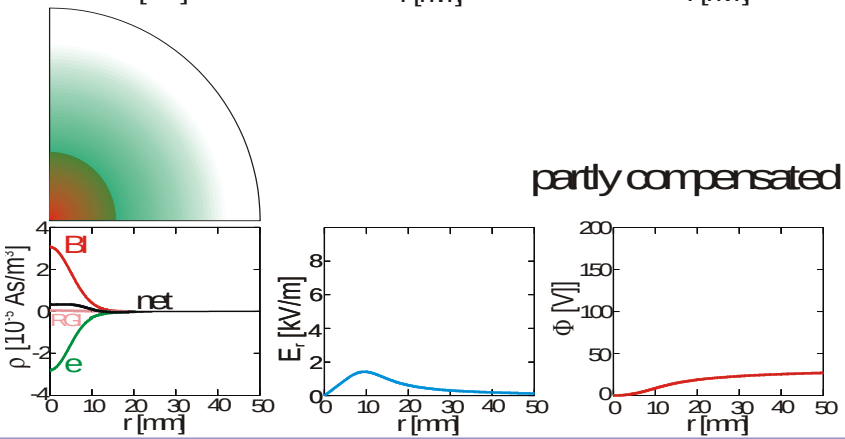
For a determination of the state of the "beamplasma" it is necesary to know:

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

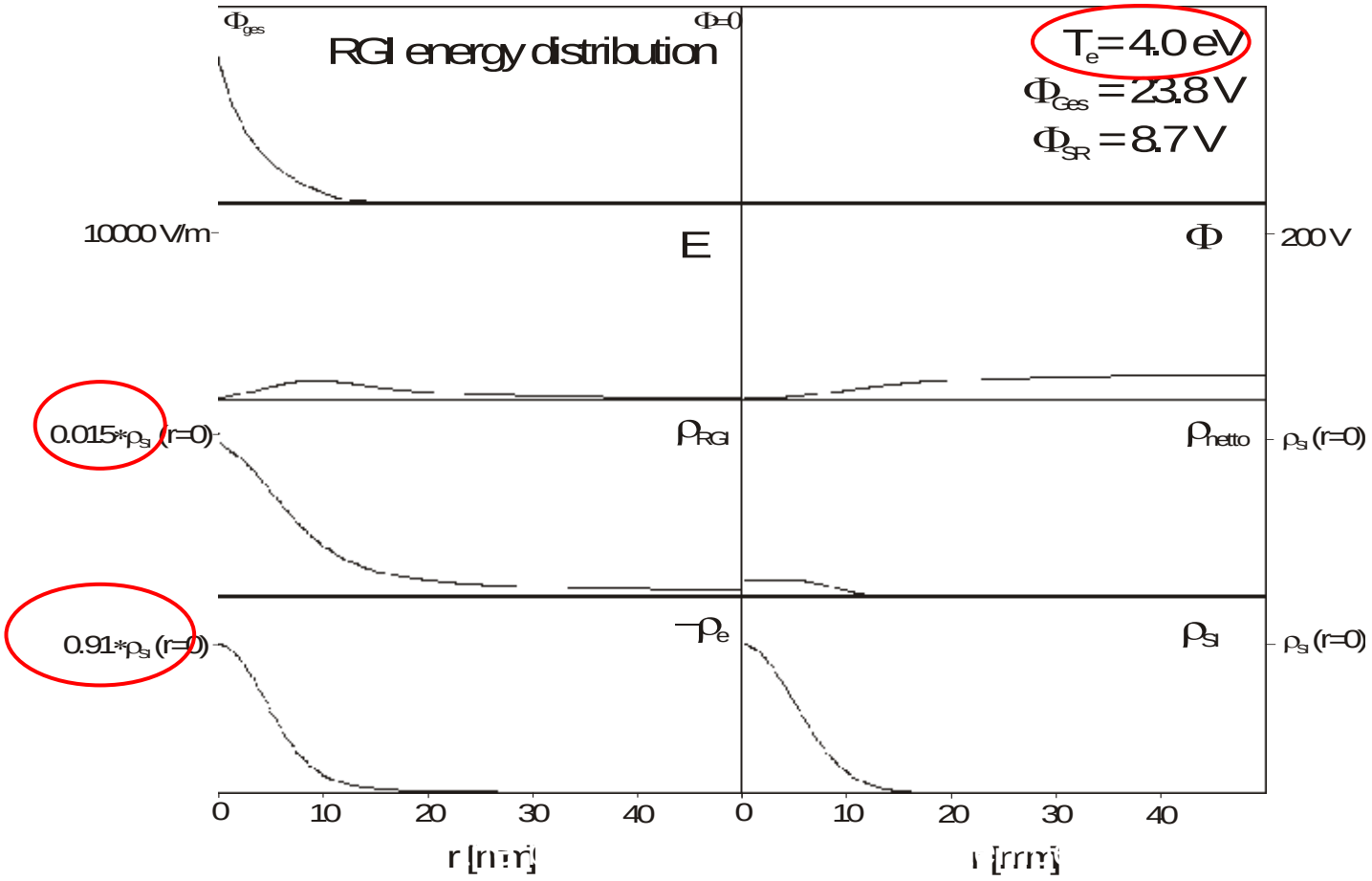
uncompensated



partly compensated

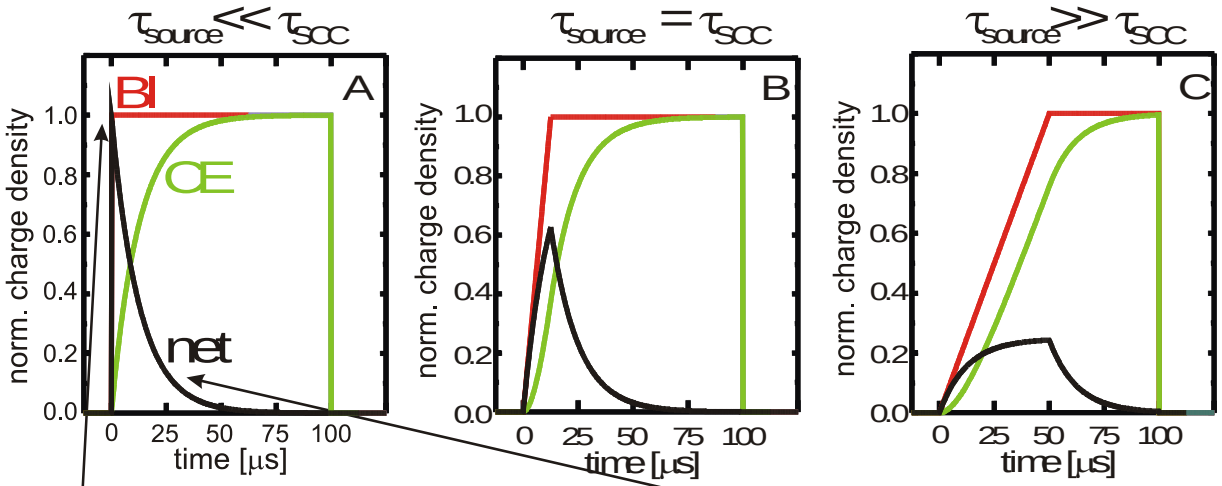


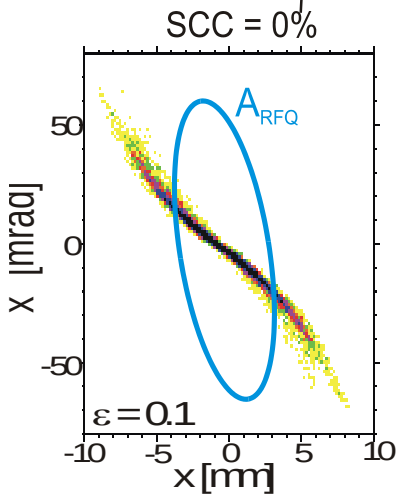
Self consistent state of compensation



Rise time of space charge compensation

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

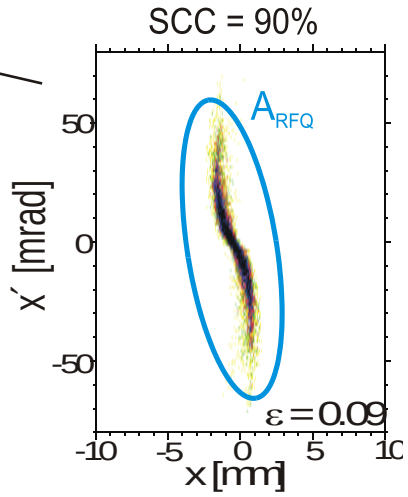




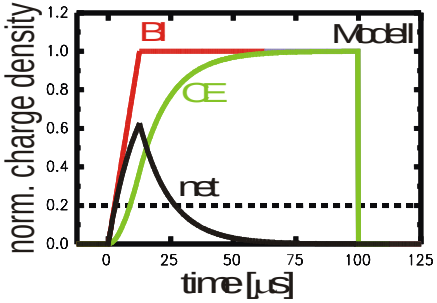
Rotation of phase space density distribution as a function of time

Time dependent mismatch of RFQ injection

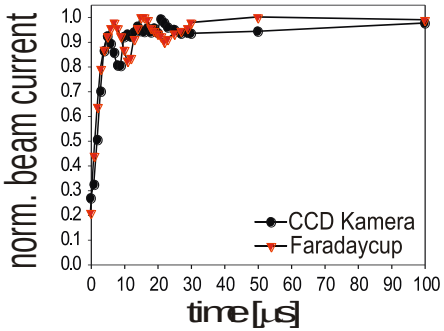
Time dependent emittance growth



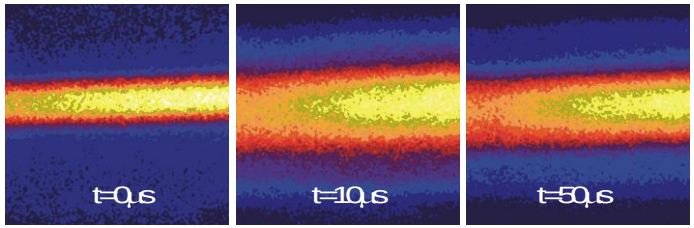
Measurements for the determination of the rise time of space charge compensation



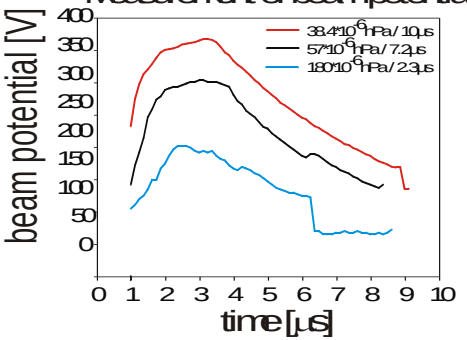
Measurement of beamcurrent

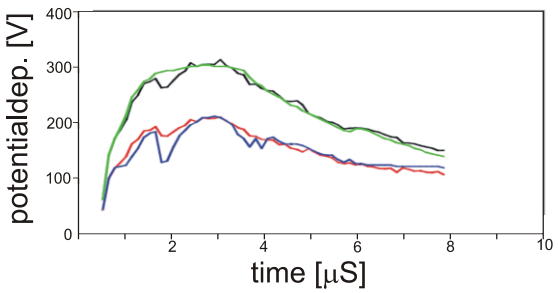


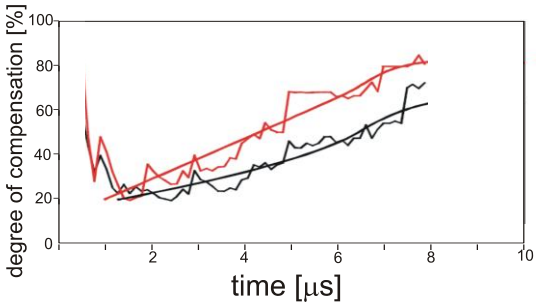
Measurement of beamprofiles

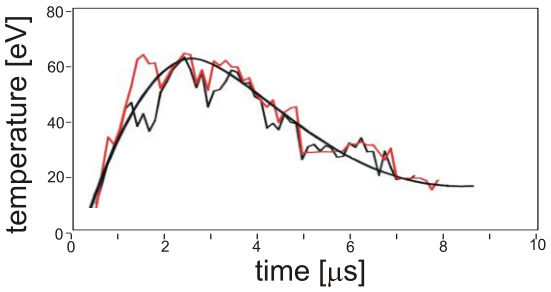


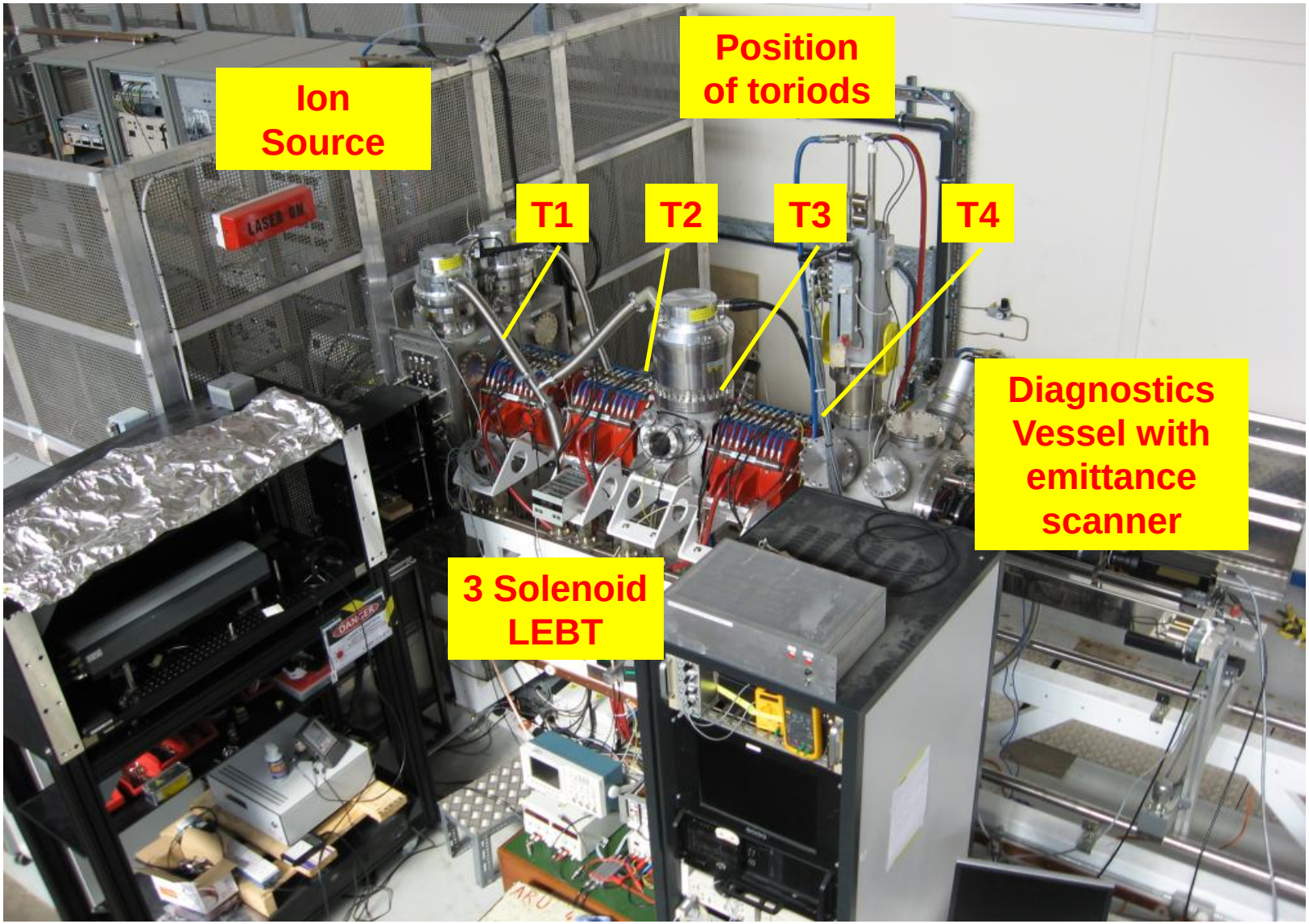
Measurement of beampotential



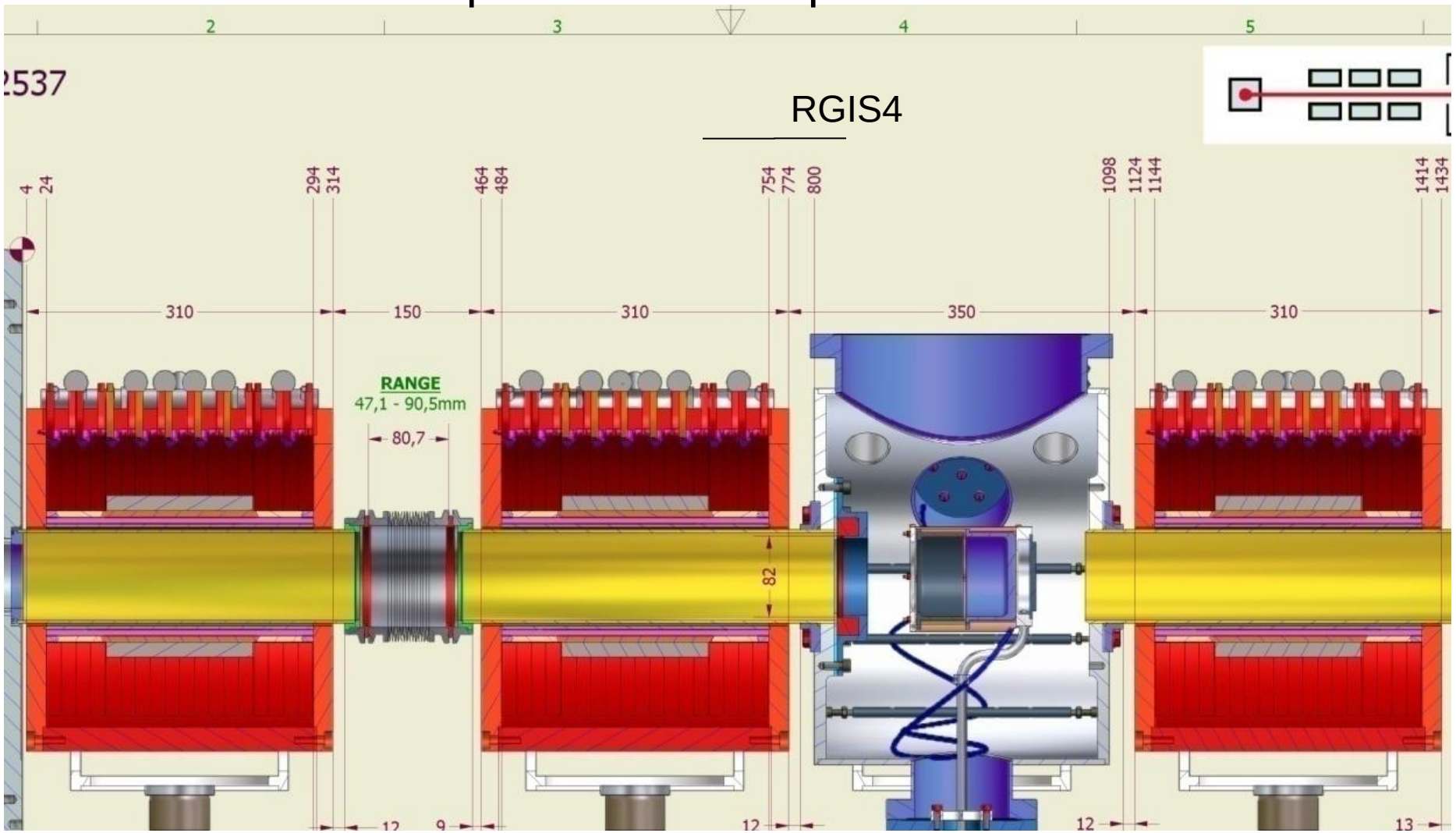


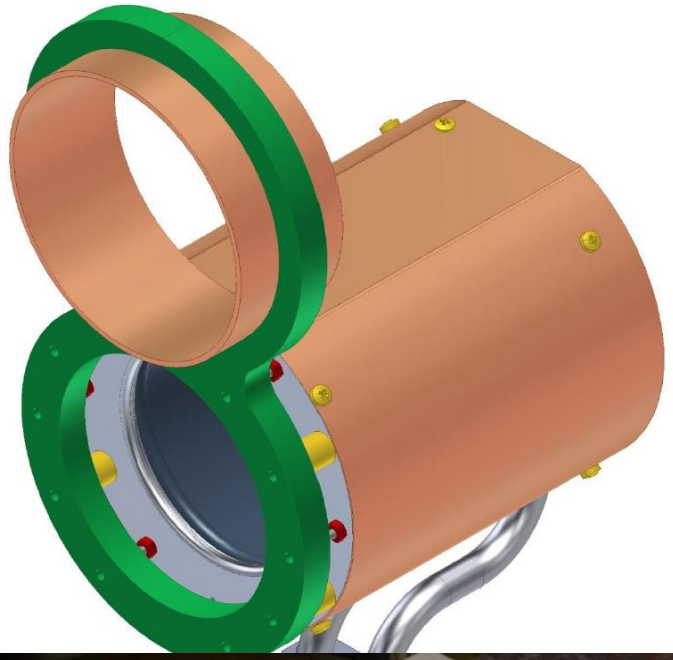




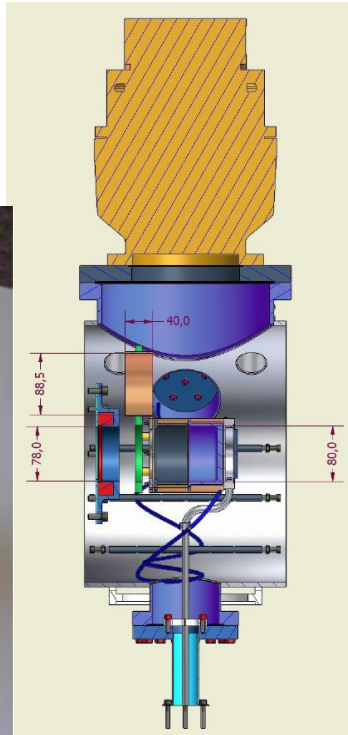

Ion Source
Position of toriods
T1
T2
T3
T4
Diagnostics Vessel with emittance scanner
3 Solenoid LEBT

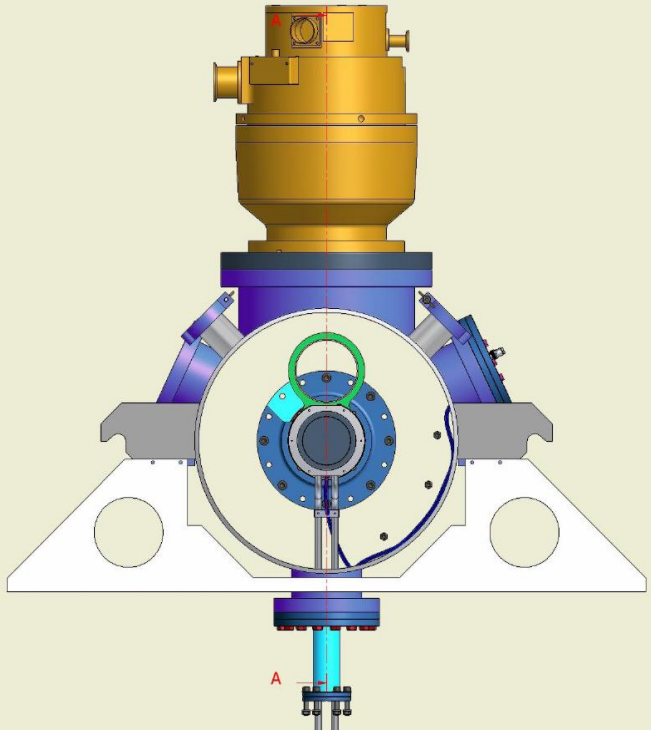
Experimental setup in LEBT





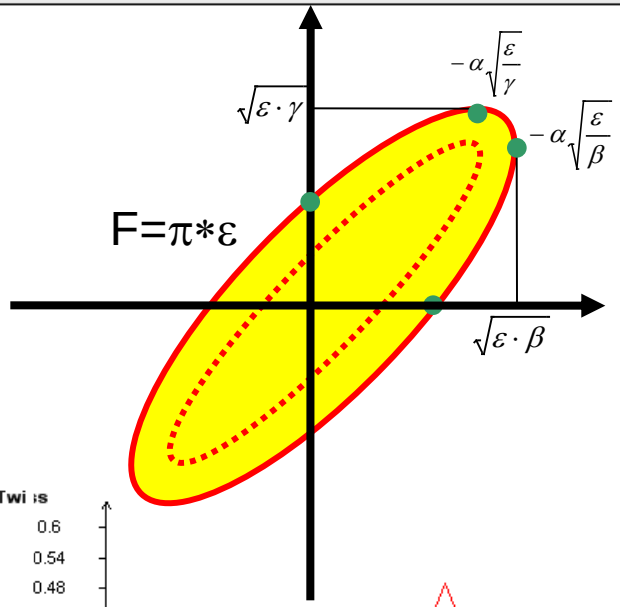
Phase 1:
Decompensation electrode in LEBT drift vessel beam to influence degree of space charge compensation.
Measurements using emittance scanner.

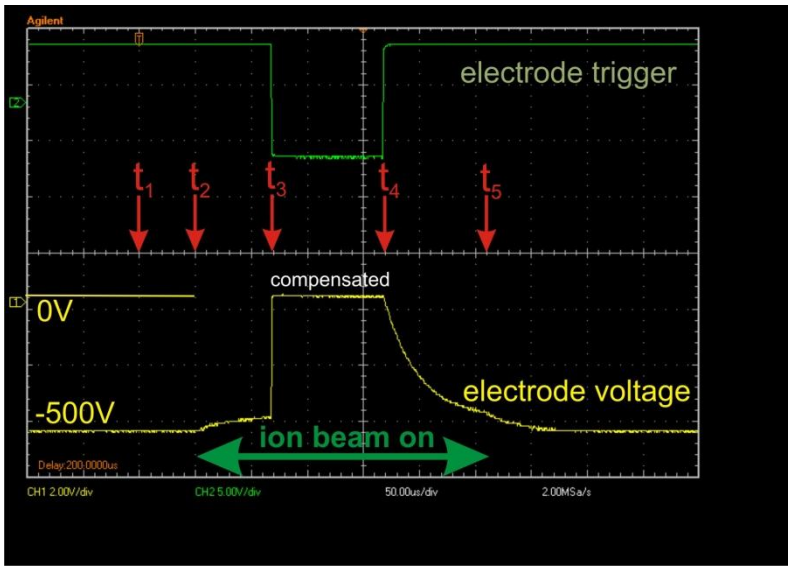




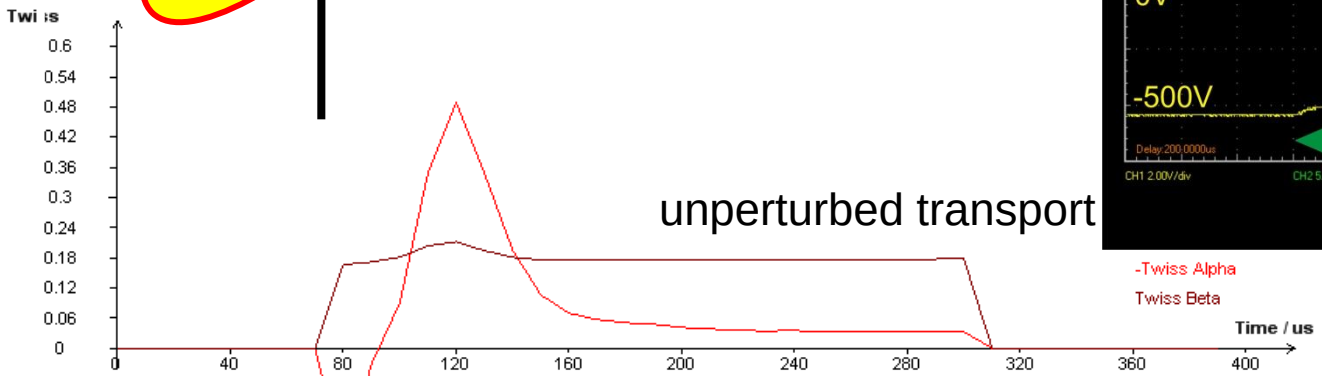
First experimental results September 2011

H- , 65 keV, ~40 mA, ~250 μs pulselength , ~50 μs RSC

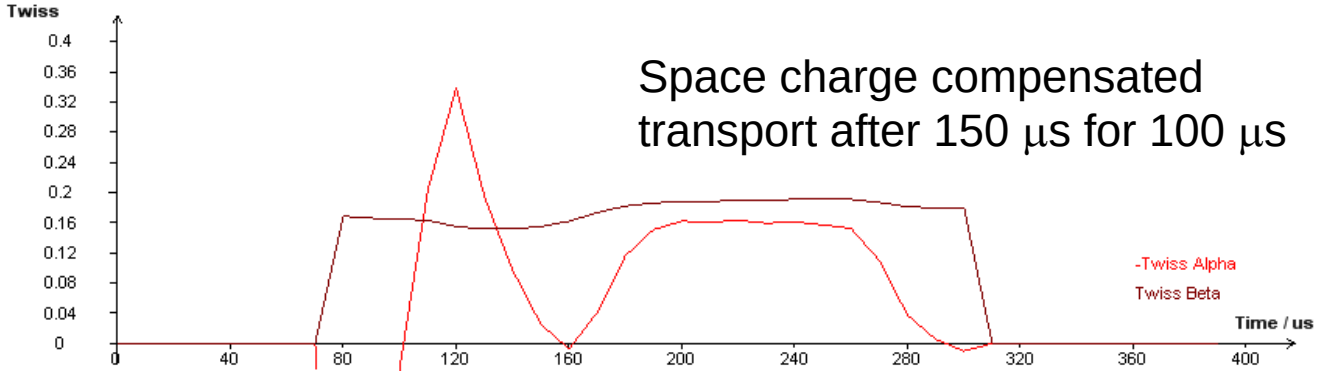




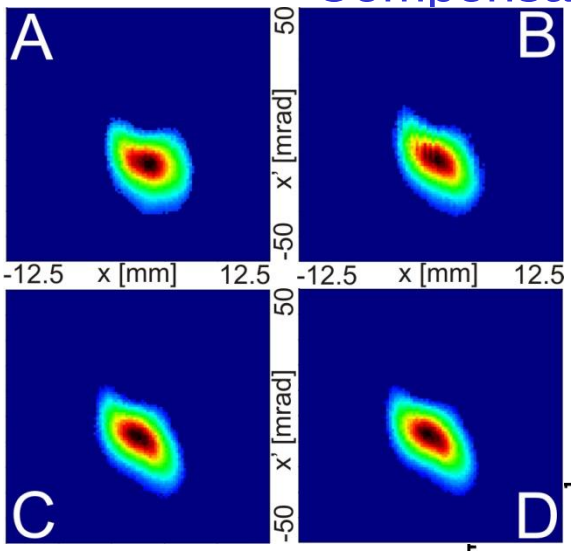
unperturbed transport



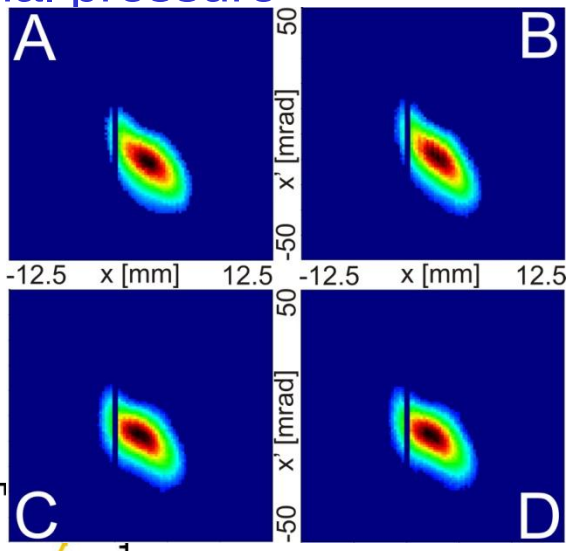
Space charge compensated transport after 150 μs for 100 μs

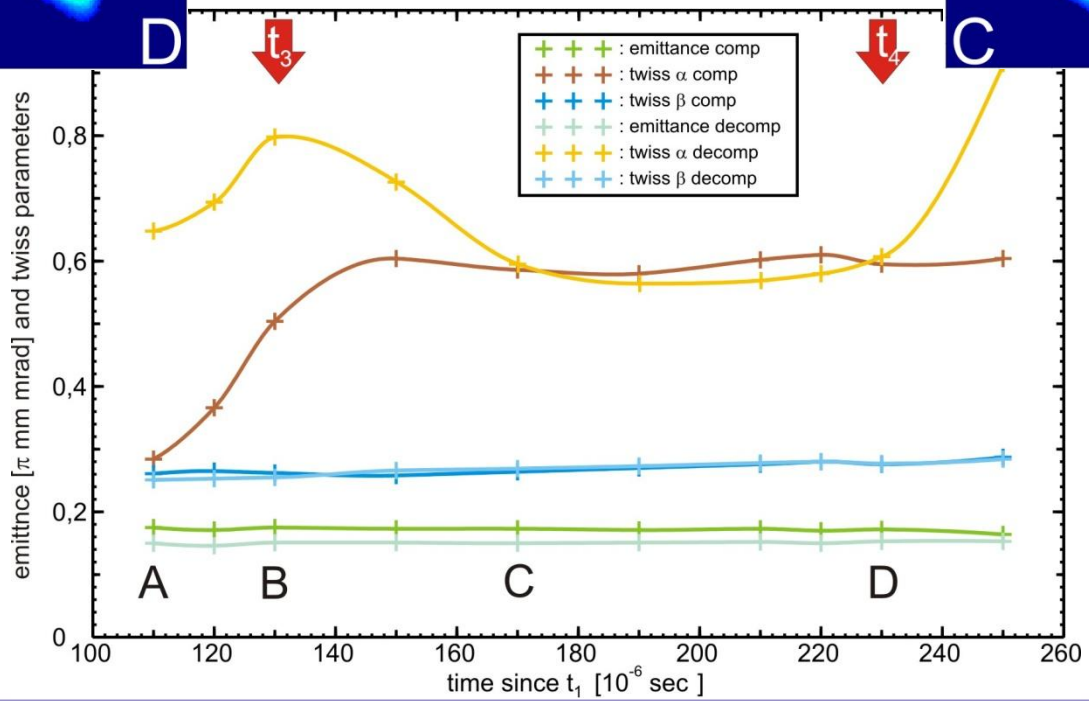


Compensation / decompensation at nominal pressure



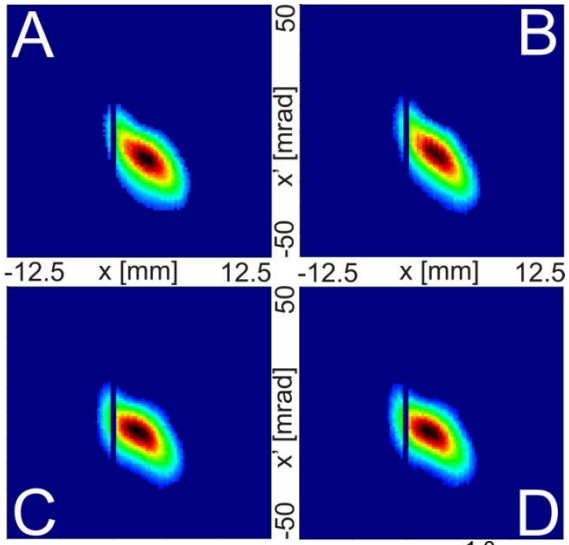
Left
unperturbed,
Right :
pertubation
by electrode voltage

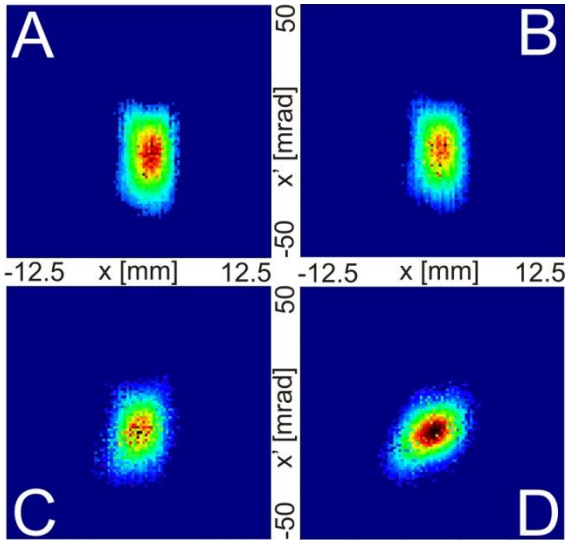


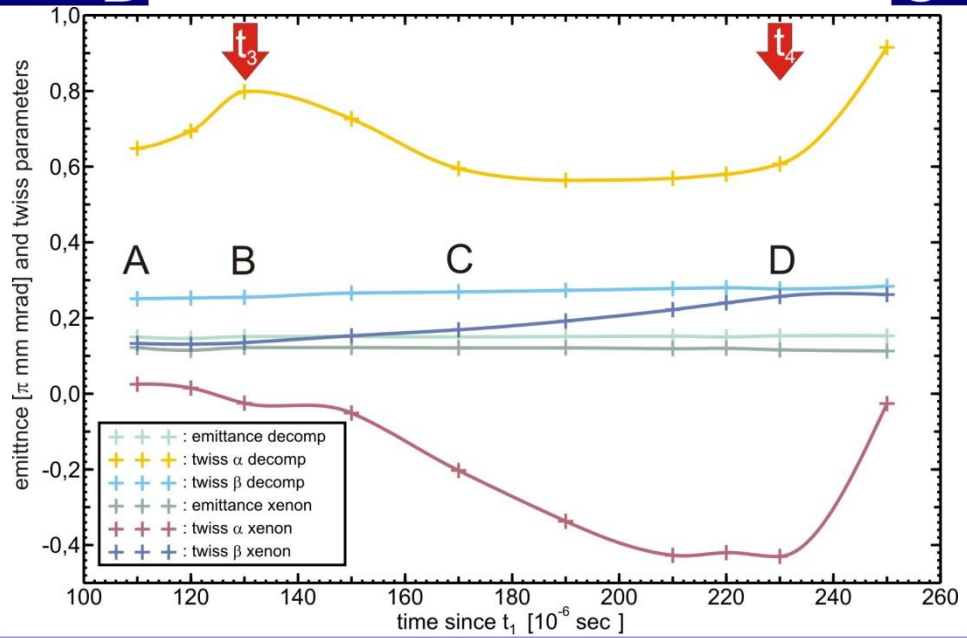


Beam transport at increased pressure (Xenon ~7*10^{-6} hPa)

Left
Nominal pressure,
Right :
Increase pressure
=>
With higher pressure it takes longer to reach equilibrium
Overcompensation ?







First preliminary summary of first phase :

Preliminary measurements confirm expectations

Clear influence of electrode voltage on twiss parameters

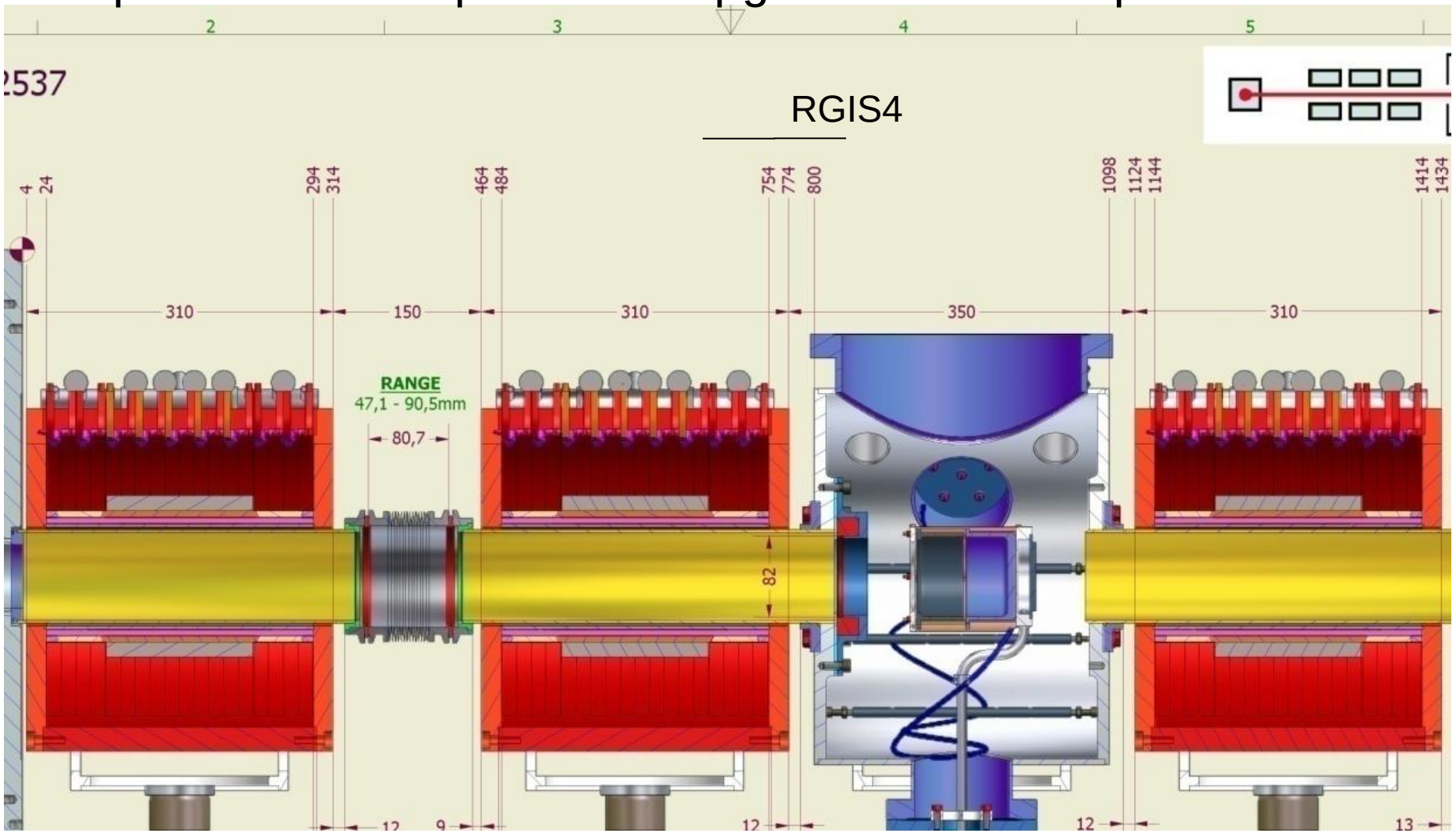
Strong influence of xenon

More measurements to be performed

Experimental setup extended with RGI spectrometer to determine if overcompensation occurs....

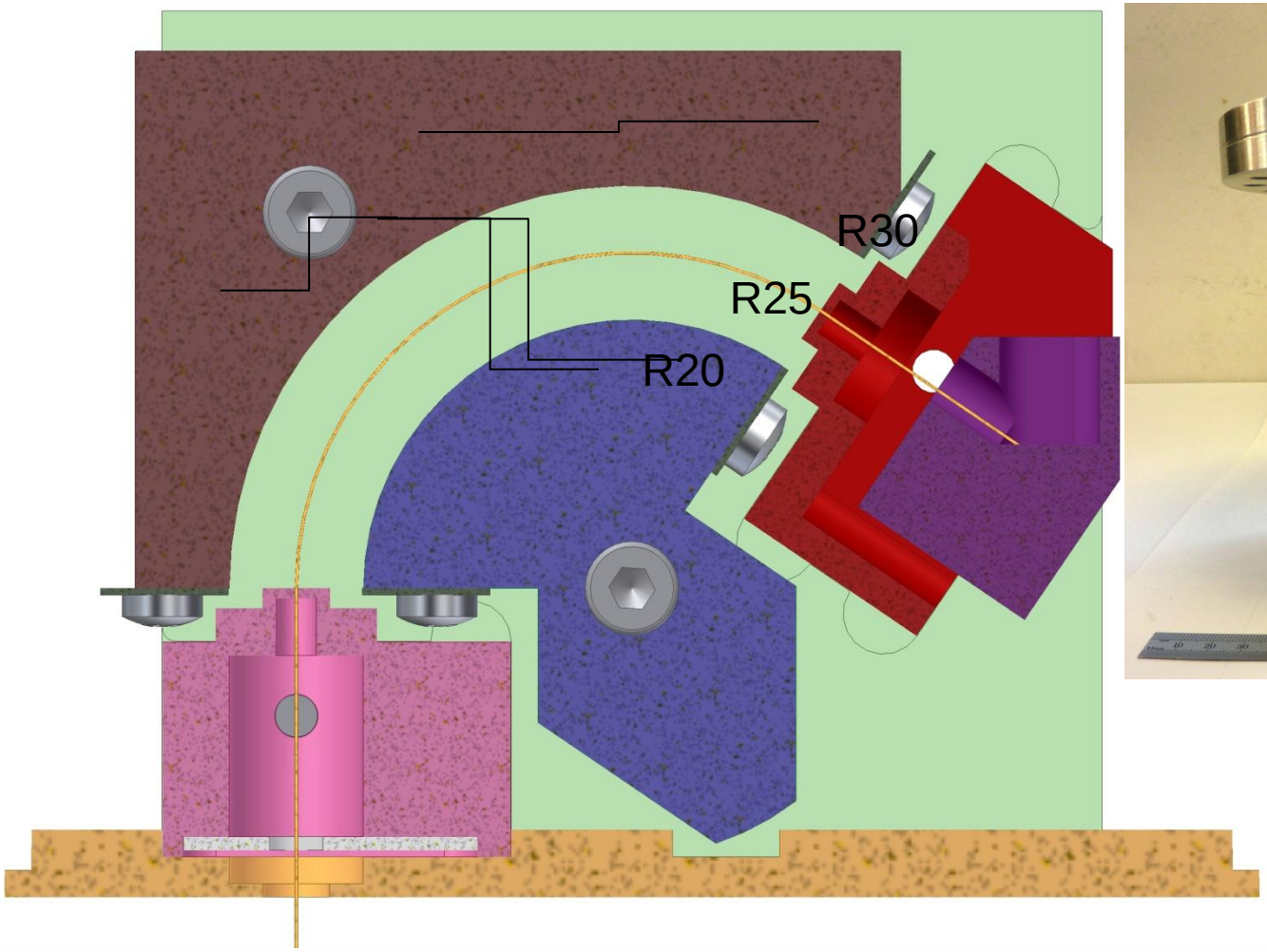
… need someone to do the work ;-)

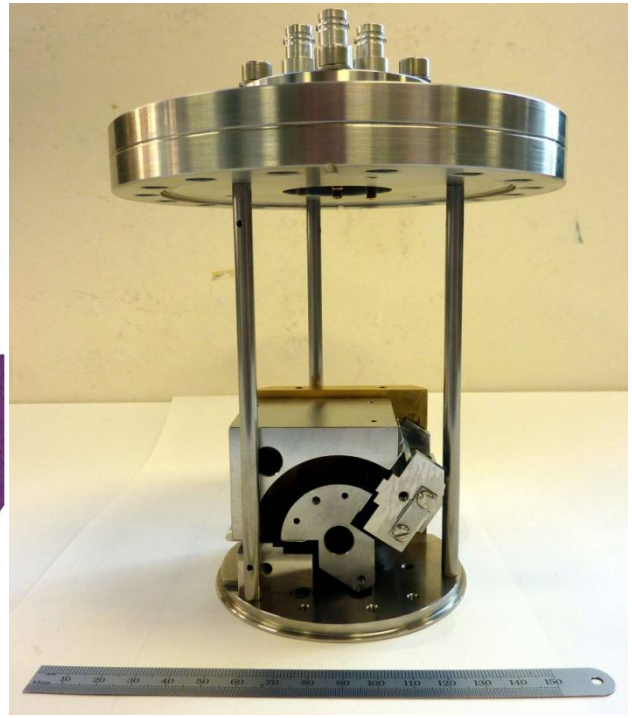
Experimental setup in LEBT upgrade with RGI spectrometer



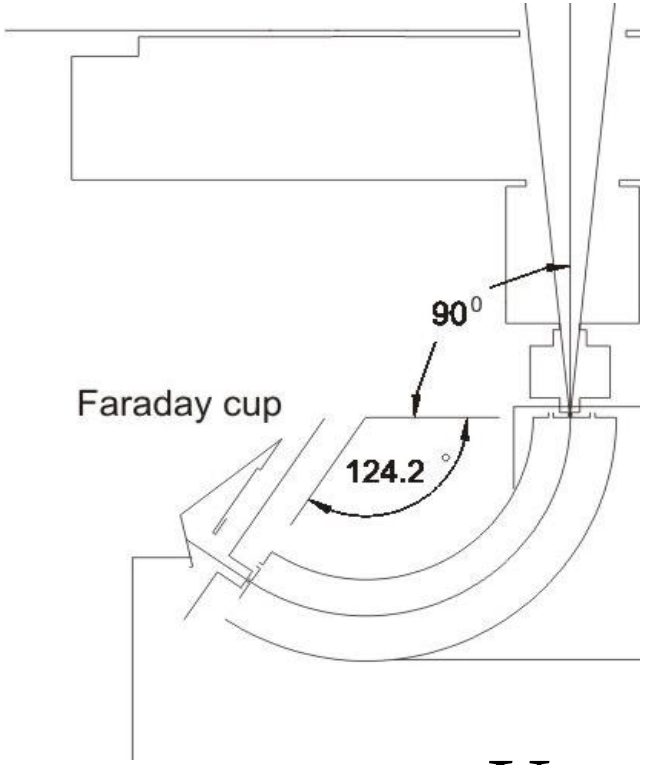
Residual Gas Ion Spectrometer v4 (RGIS4)

Fully shielded





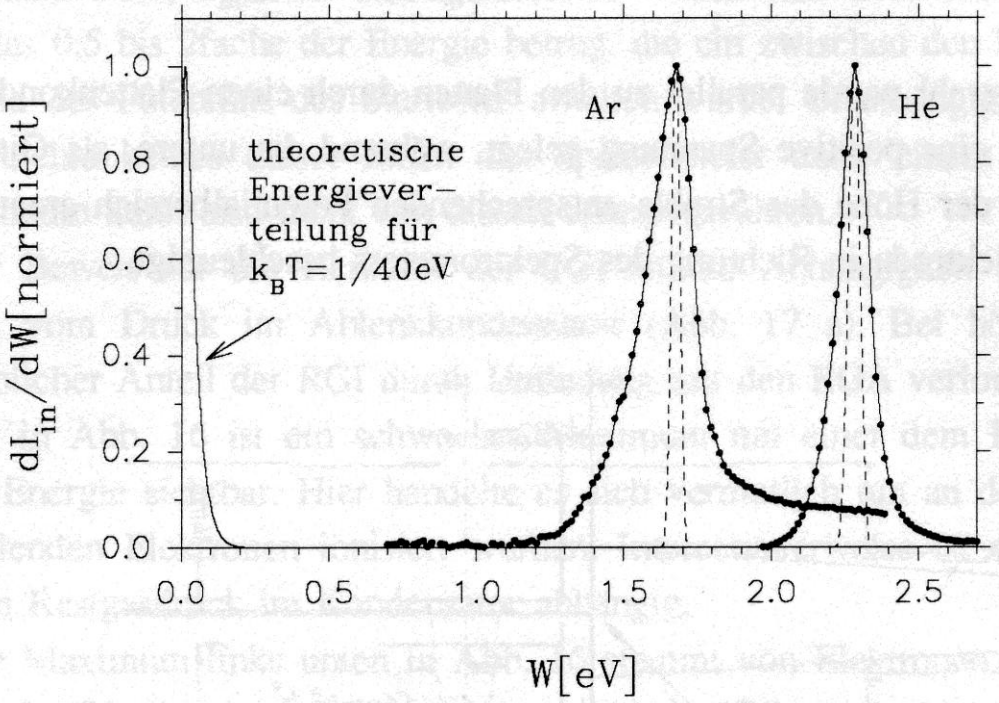
Relation between particles energies detected and voltage on electrodes




```
Rem Offset correction might be required for data analyses in step 3

    INPUT "Offset : "; Offset

    Rem or an automatic offset

    OFMAX = 1E+25

    For M = 1 To NumberofDatapoints
       If OFMAX > Abs(Voltage(M)) Then OFMAX = Abs(Voltage(M)) : Offset
= Current(M)
    Next

    Rem Step 1 reducing measured current by offset

    For M = 1 To NumberofDatapoints
       Current(M) = Current(M) - Offset
    Next

    Rem Step 2 Relation between voltage on electrode

    For M = 1 To NumberofDatapoints
         Particleenergy(M) = Voltage(M) * 1.233
    Next
```

$$W_{particle} = \frac{q \cdot U_{spectrometer}}{2 \cdot \ln \frac{r_{out}}{r_{in}}} = 1.233 \cdot q \cdot U_{spectrometer}$$

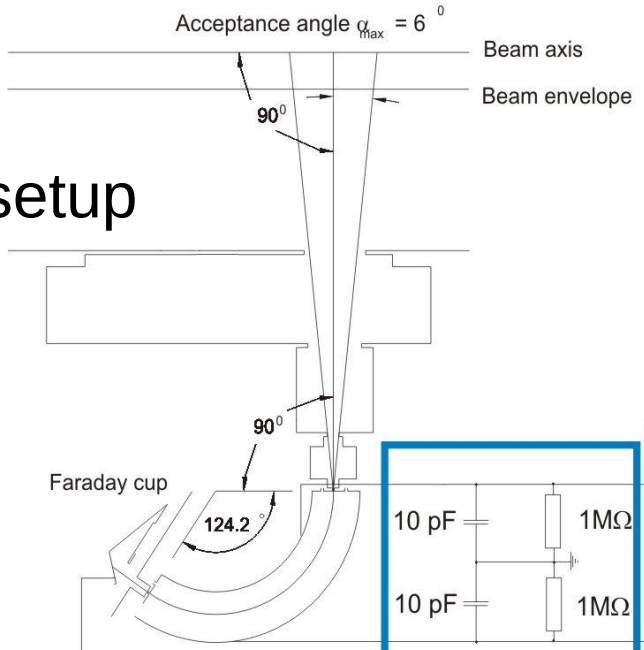
Resolution of spectrometer and transfer function

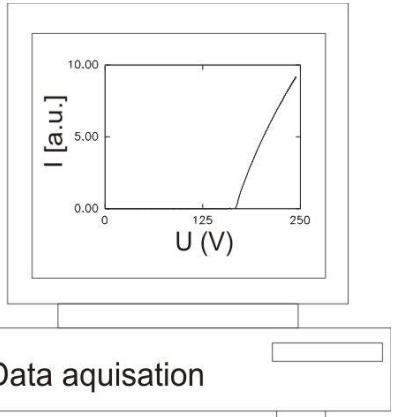


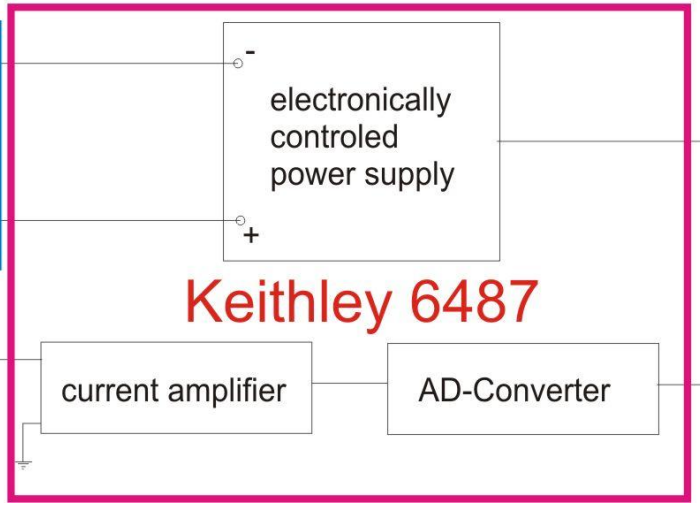

```
    Rem Step 3 correction of current by sensitity function for basewidth of 1.2 %
    For M = 1 To NumberofDatapoints
      If 0.05 < Abs(Particleenergy(M))) Then
        Normalizedparticlerate(M) = (Current(M) * 83.33) / Abs(Particleenergy(M))
      Else
        Normalizedparticlerate(M) = 0
      End If

      REM not sure what this correction is for (only "positive" particles ?) but it was in the
      REM code, surely comes from Rudolph (names of variables ;-)) looks like a Taylorexpansion...

      If 0.05 < Particleenergy(M)) Then
        A = (0.6611 * Sqr(Particleenergy(M)))
        X = 1 / (1 + 0.47047 * A)
        UWERT = 1 - (0.3480242 * X - 0.0958798 * X * X + 0.7478556 * X * X * X) * Exp(-A * A)
        Current(M) = Current(M) / UWERT
      End If

    Next
```

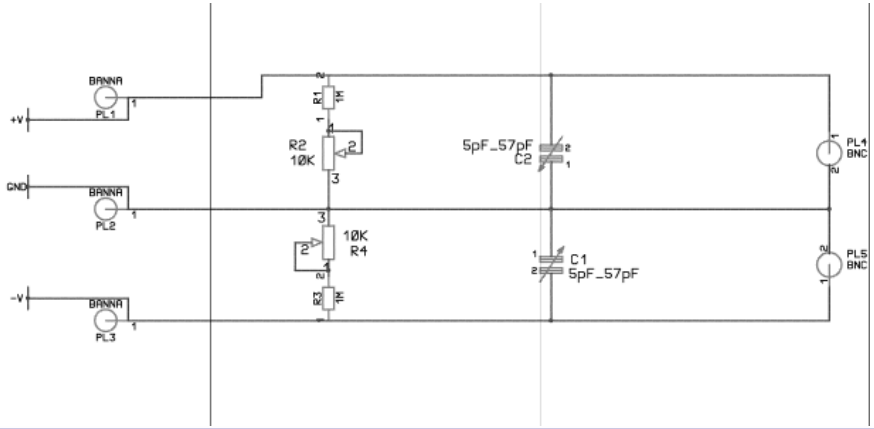
$$2 \cdot \Delta W_{particle} = W_{particle} \frac{d_{slit,in} + d_{slit,out}}{r_{slit}} = \pm 1{,}2\%$$

Wiring of experimental setup

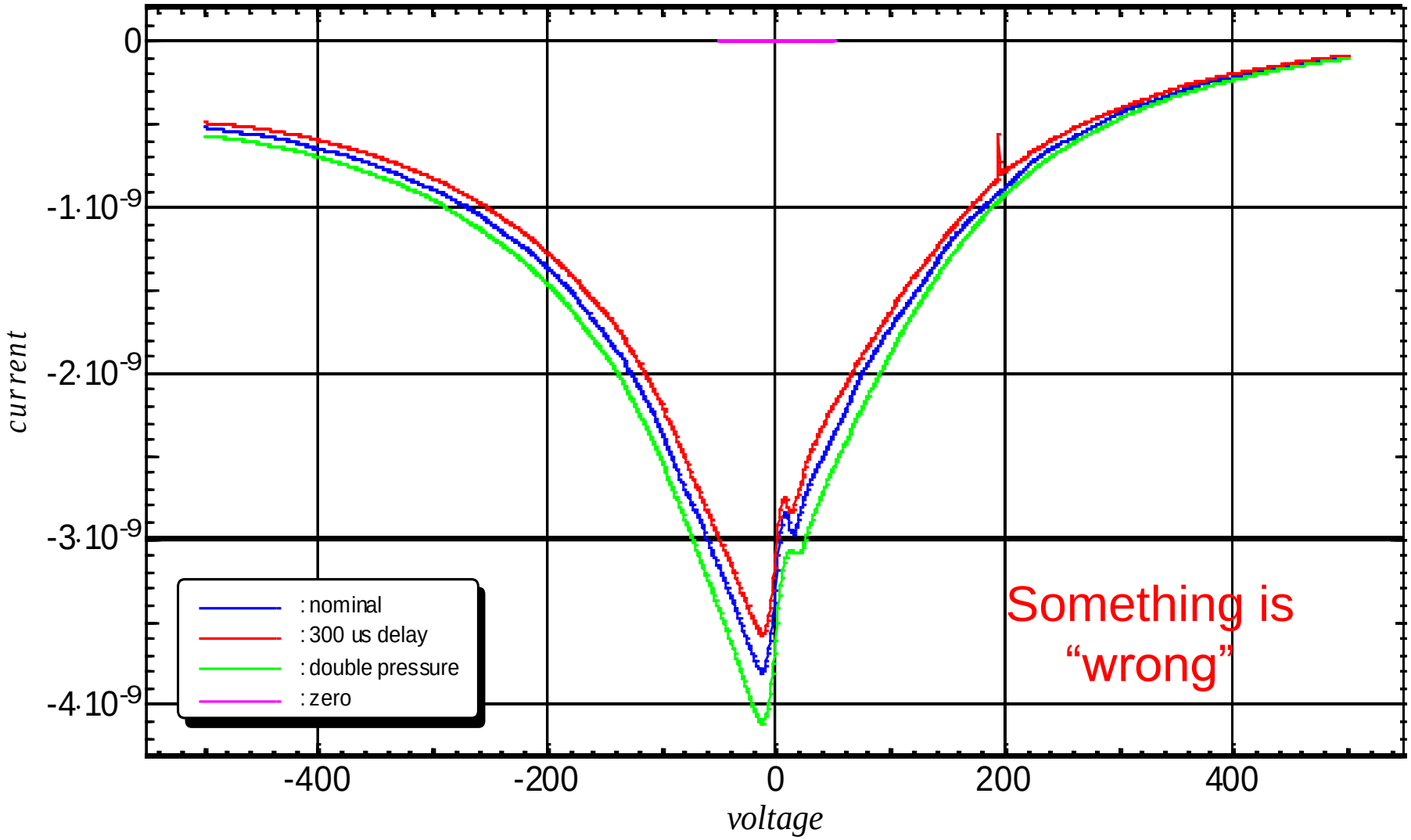








Second set of measurements : 1st March 2012 – measurements 2

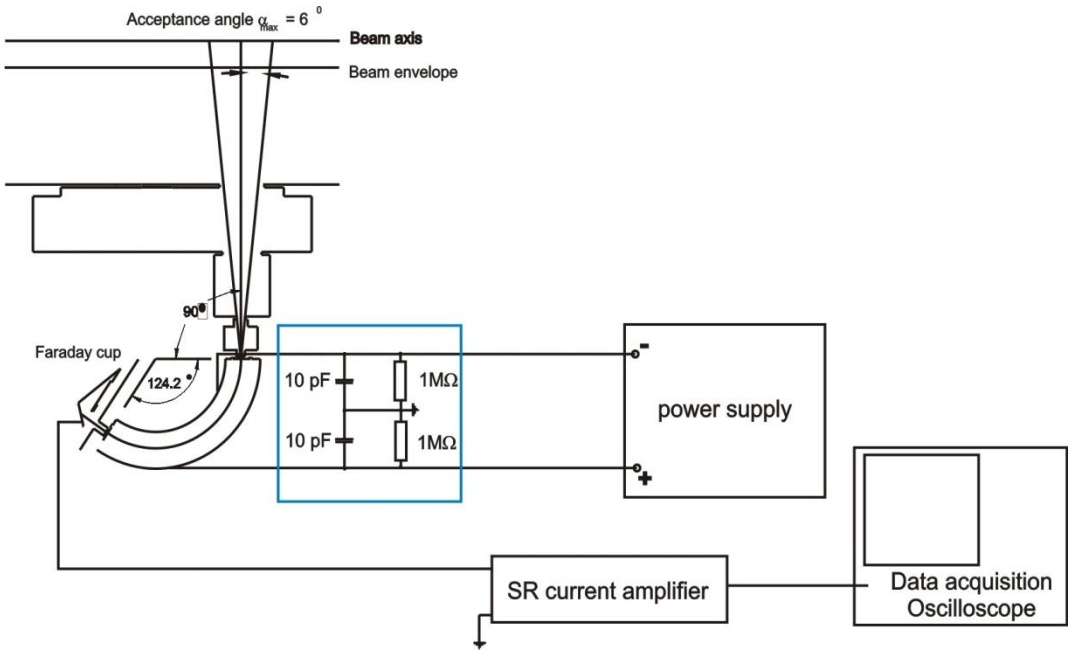


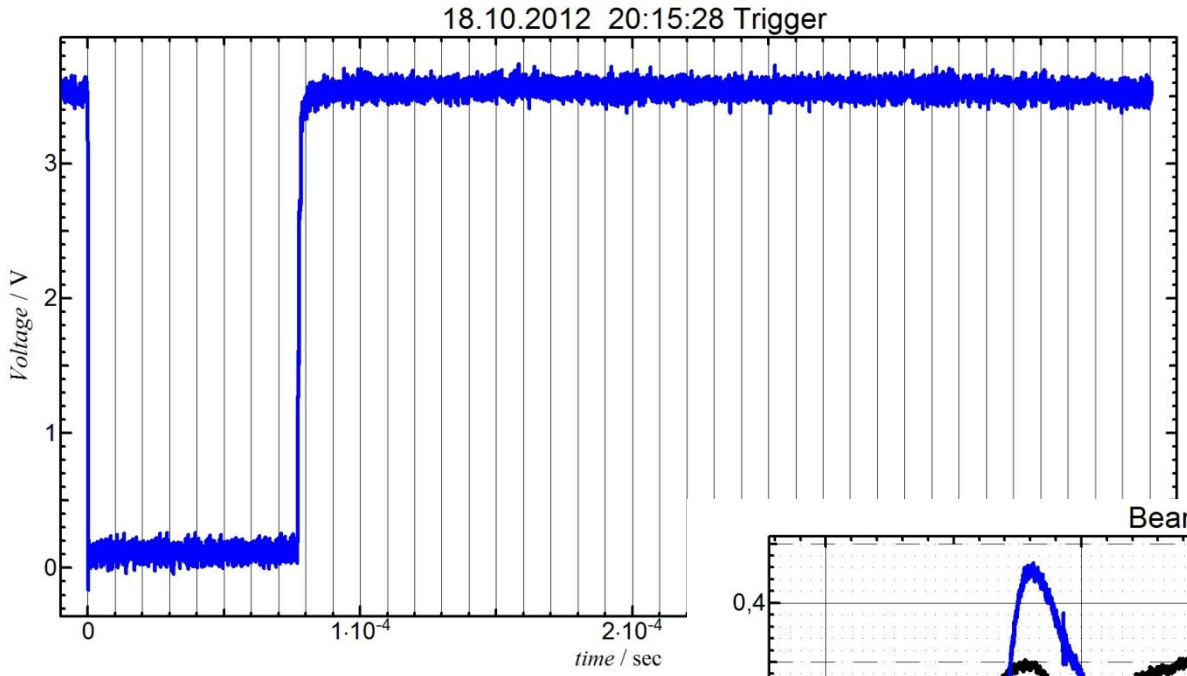
Due to persisting difficulties :

Change of experimental setup:

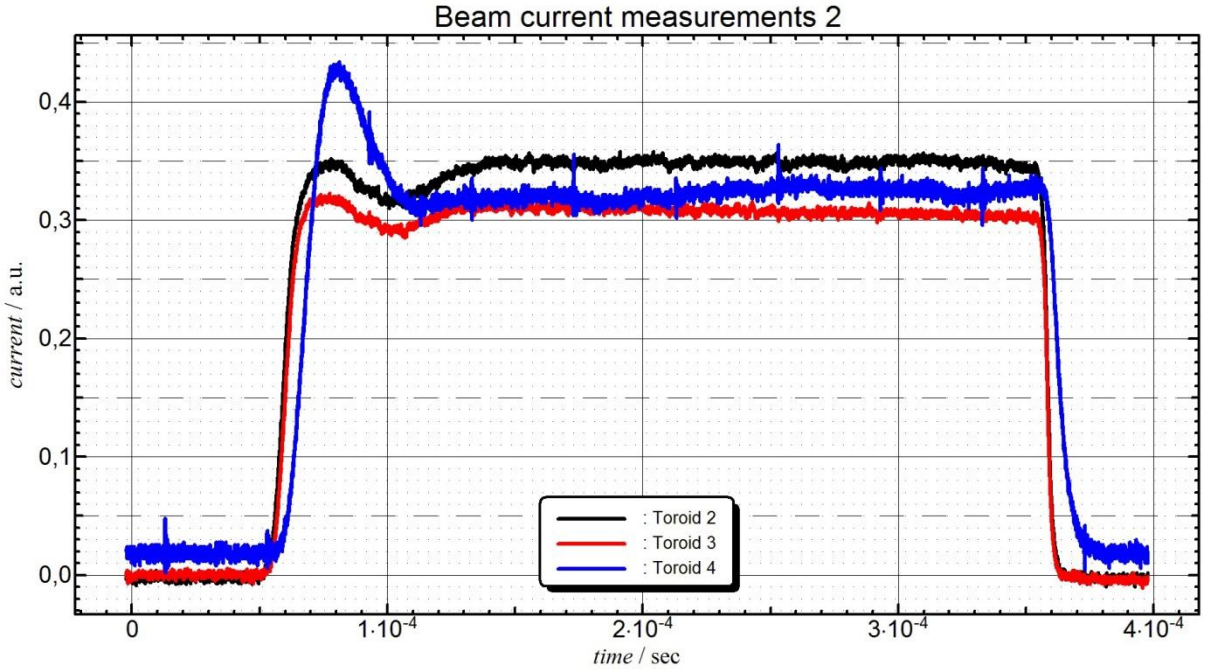
PS independent of data acquisition

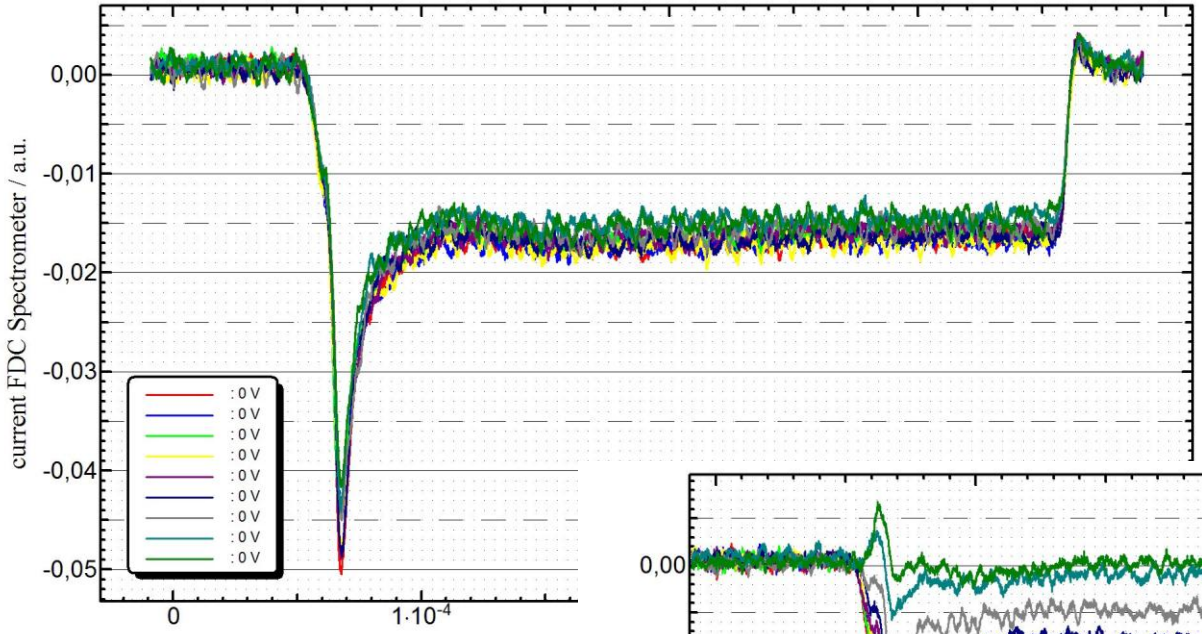
Data acquisition by Fast amplifier & Oscilloscope





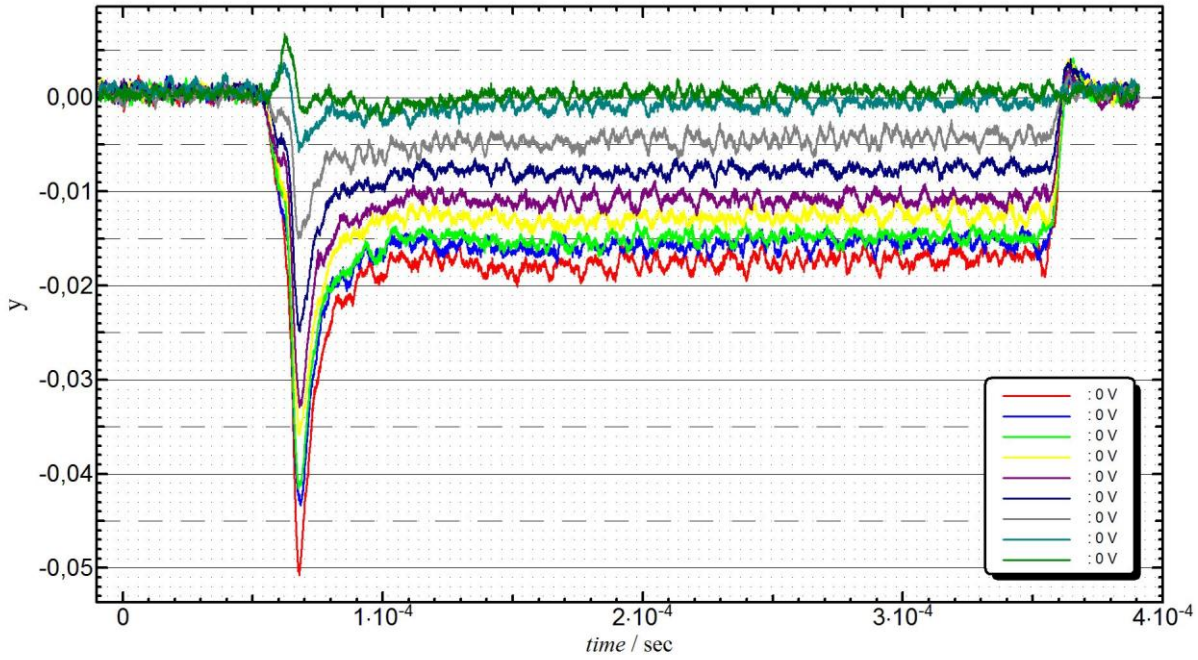
Currents observed by toroids at different positions in z. Toroid 4 has a different number of windings....



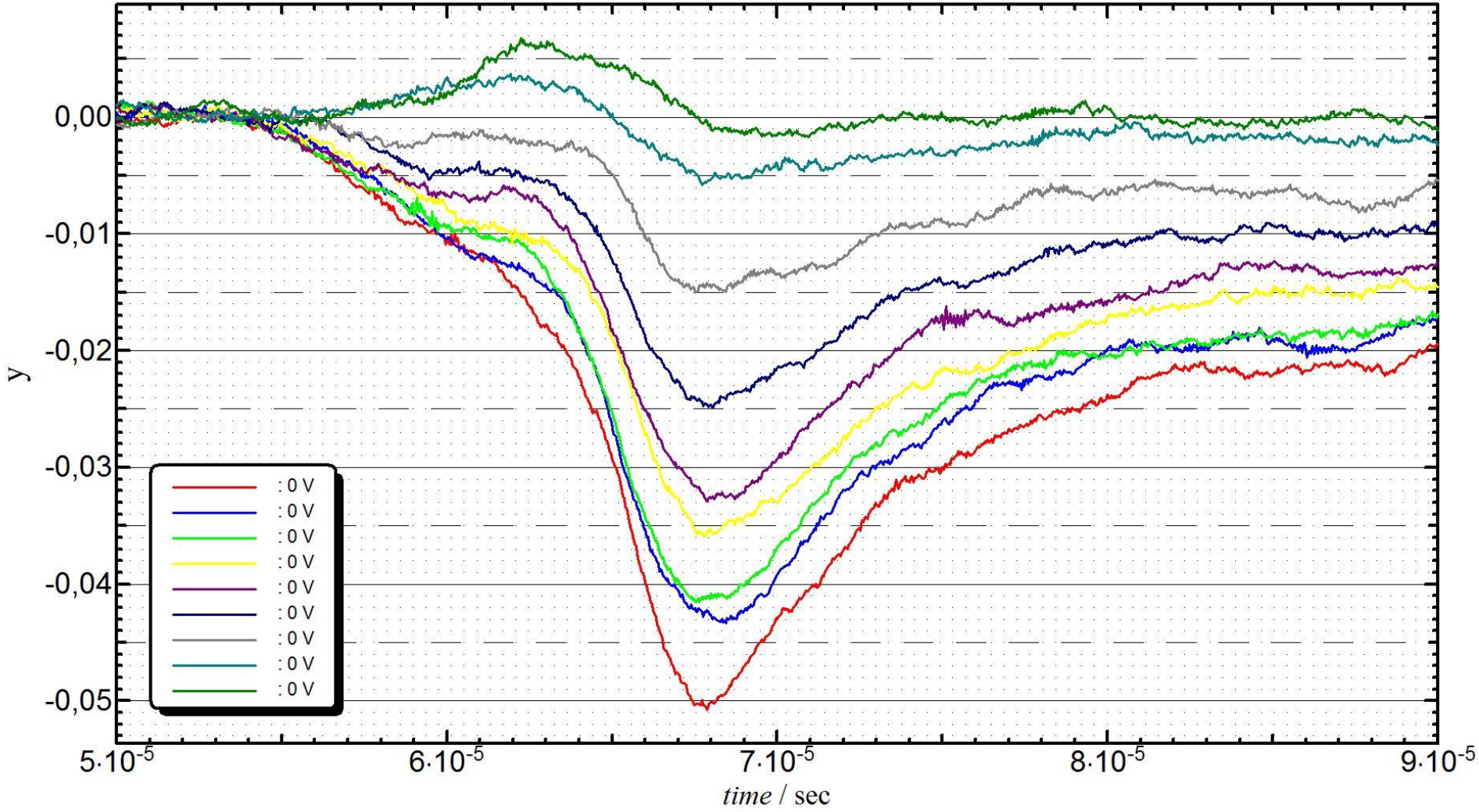


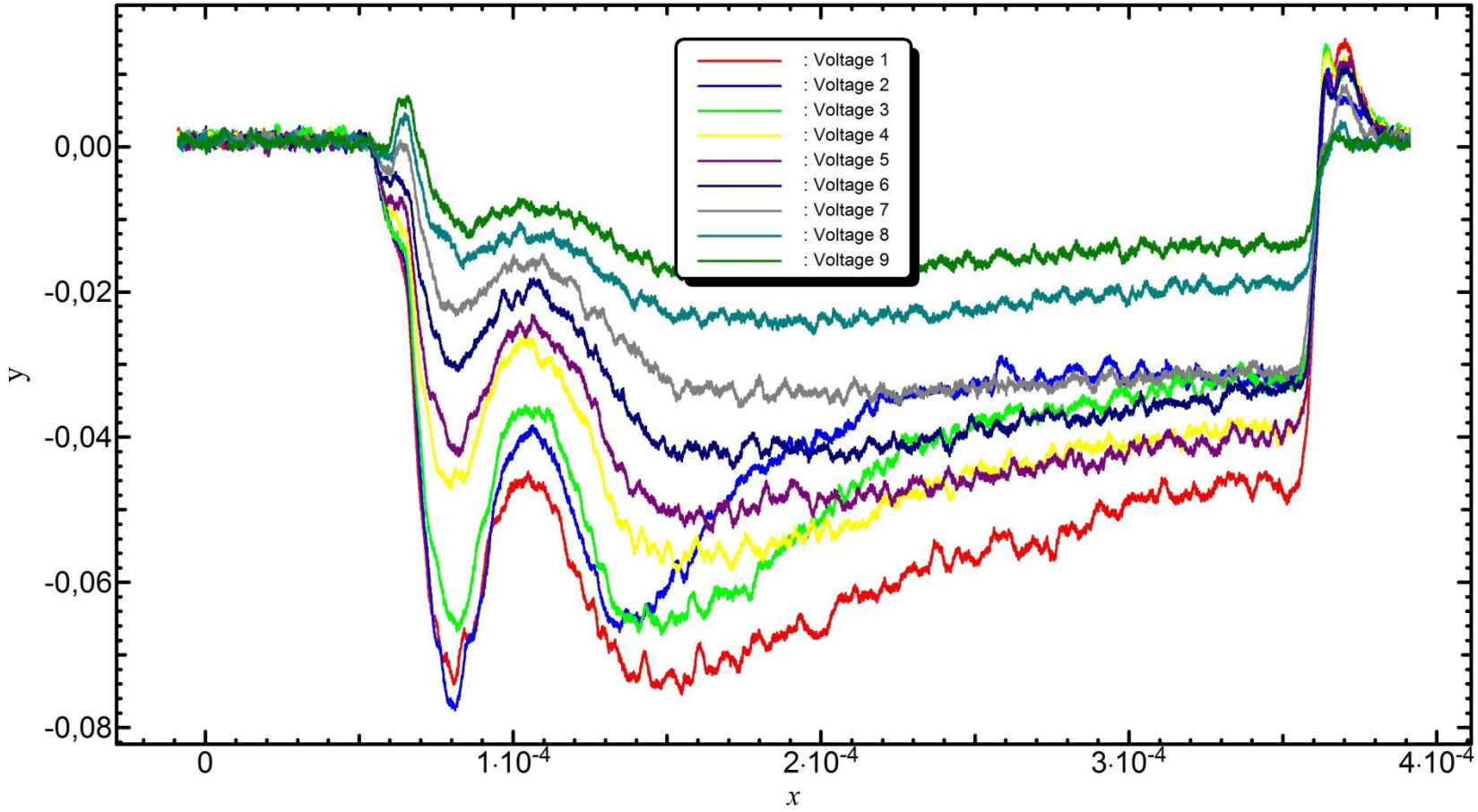
Bandwidth issue seems resolved!

Currents observed for different deflection voltages with neg (upper) and positive (right) polarity (Range : 500nA/Volt)

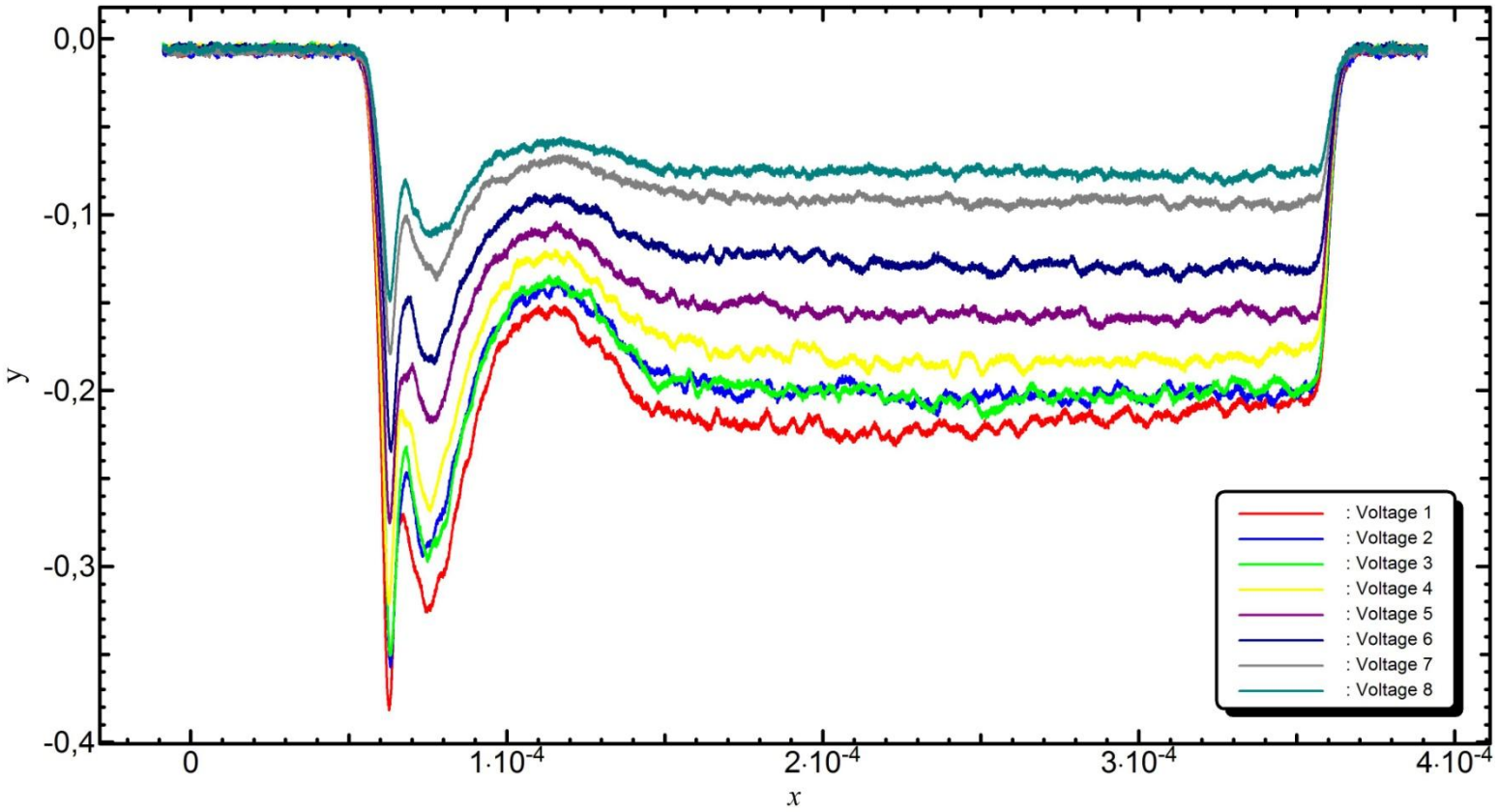


Detail of previous measurement – there is something...

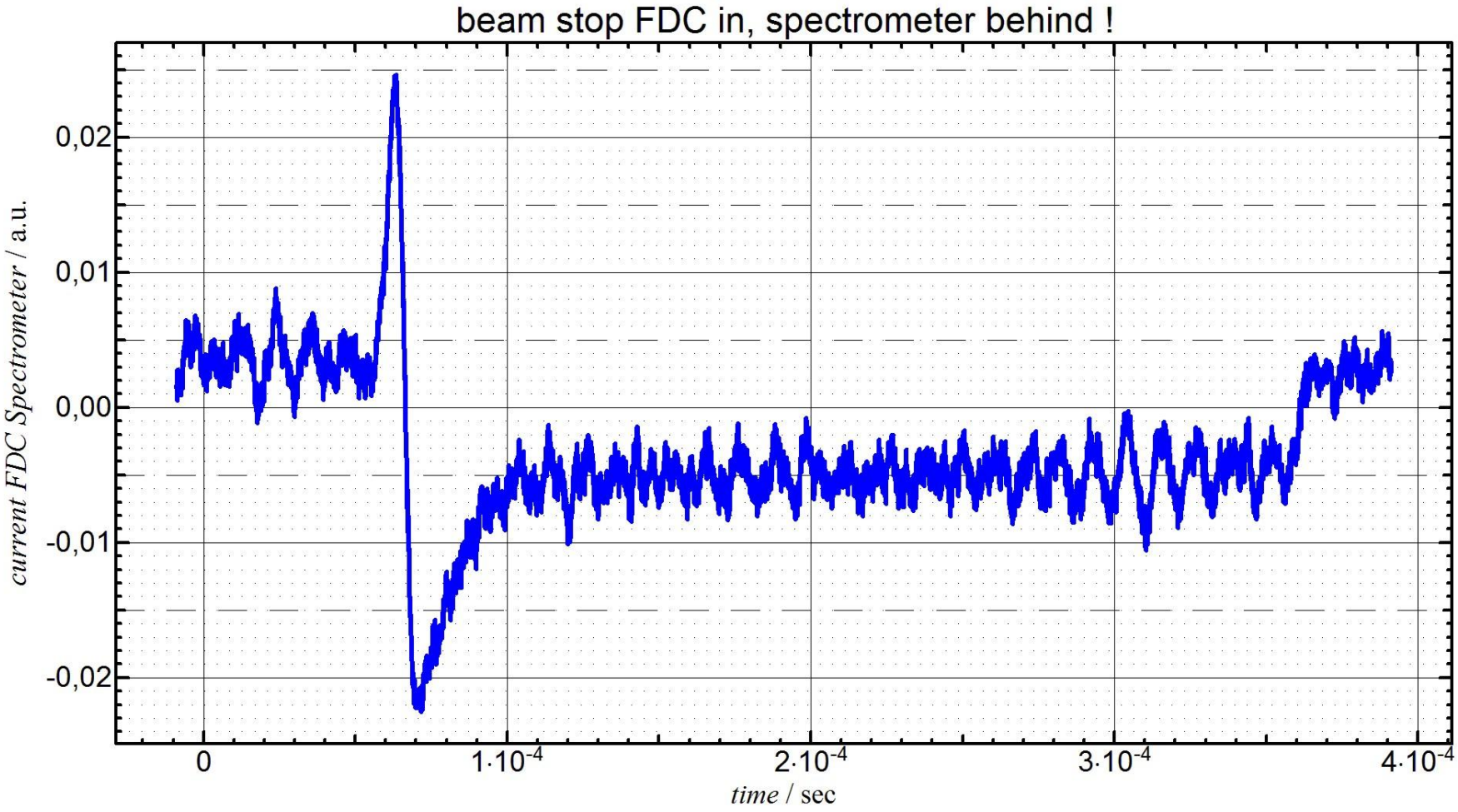




Gas pressure : 1.53 10-5 hpa H2 + Krypton
Solenoid settings 150 / 0 A



Gas pressure: 1.53 10-5 hpa H2 +Krypton
Solenoid settings : 150 / 0 A
decompensated (0-75 V)


beam stop FDC in, spectrometer behind !
current FDC Spectrometer / a.u.
0,02
0,01
0,00
-0,01
-0,02
0
1·10-4
2·10-4
3·10-4
4·10-4
time / sec

Next steps

PS independent of data acquisition -> replace by Keithley (energy range & computer controlled PS)

Data acquisition by Fast amplifier & Oscilloscope -> might add pre amplifier to see if amplifier noise (oscilloscope)

Still some way to go, but already a major improvement !
Time resolved measurement allowed to identify “electron problem” – electron suppression possible ? (magnetic -> 3 rd solenoid, electrostatic -> retarding field)

Require more measurements – solenoid settings, gas pressure, pulsed decomp. Electrode.1 beam day for improvements – 3 days with emittance measurements for data taking.... If possible before Christmas...

Publications

POZIMSKI J, DOLLING R, GROSS P, et al, DETERMINATION OF ELECTRON-TEMPERATURE IN PARTIAL SPACE-CHARGE-COMPENSATED HIGH-PERVEANCE ION-BEAMS, International Symposium on Heavy Ion Inertial Fusion, 1993, Il Nuovo Cimento 106A (1993), Pages:1713-1718

GROSS P, POZIMSKI J, WEIS T, et al, LOW-ENERGY BEAM TRANSPORT OF INTENSE AND PARTIALLY SPACE-CHARGE-NEUTRALIZED ION-BEAMS, International Symposium on Heavy Ion Inertial Fusion, 1993, Il Nuovo Cimento 106A (1993) ,Pages:1657-1664

R. Dölling, J. Pozimski, and P. Gross
Radial distribution of space-charge force in compensated positive-ion beams (invited)
Rev. Sci. Instrum. 69, 1094 (1998)

Jakob A, Beauvais PY, Gobin R, et al,
Time resolving diagnostic of the compensation process of pulsed ion beams at high-intensity light ion source, REVIEW OF SCIENTIFIC INSTRUMENTS, 2000, Vol:71, Pages:1107-1109, ISSN:0034-6748(publication doi)

Reidelbach,K. , Gross,P. , Pozimski,J. , et al, Investigations of Space Charge Compensation of Pulsed Ion Beams, 4th Conference on European particle accelerator: EPAC 94, London, New Jersey; World Scientific, 1994, Pages:1758-176

Jacow => search Author: “Pozimski” and Title = “Compensation” = 9 hits

Very useful but in German :

PhD Thesis of Rudolf Doelling => most complete description (theory, simulations, experimental) of space charge compensation for positive ion beams.
PhD Thesis of Peter Gross => Emittance growth due to space charge forces for uncompensated and partly compensated beams.