# $H^-$ Beam Transport and its Diagnostics

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on behalf of
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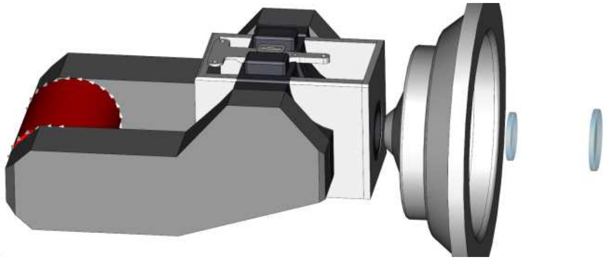
A. Bosco, J.Pozimski, D.Lee
and many more.....

Rutherford Appleton Laboratory (RAL) wants to thank
U.Ratzinger (IAP) for a loan of a powerful laser for 8 month.

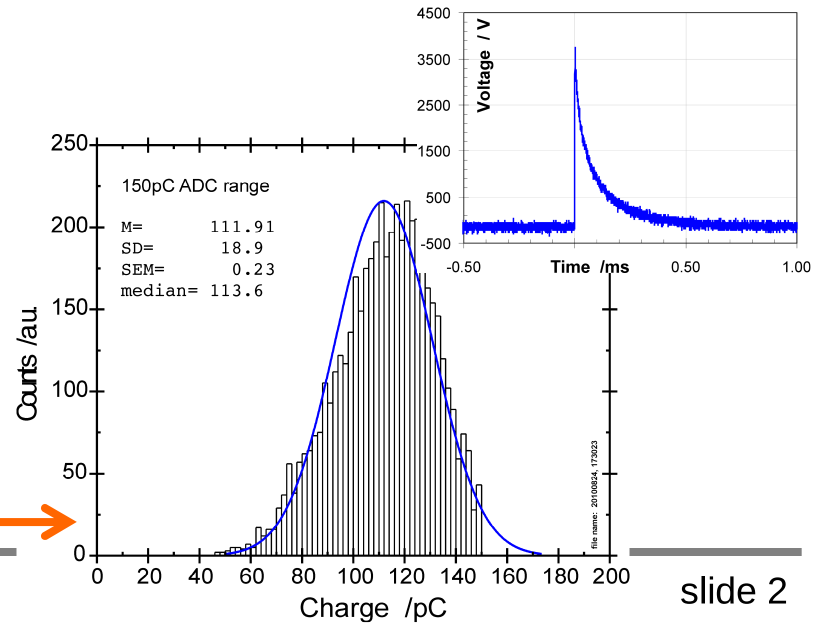
# Outline of the talk

Ion source activities and achieved results, in combination with off beaten diagnostics.

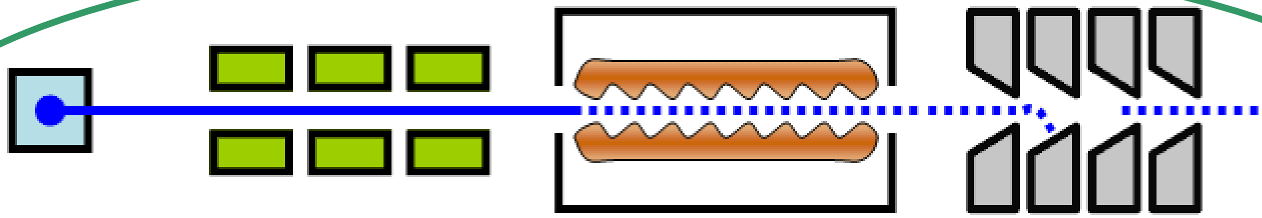


detector of photo detached elect.

Technical design of the electron detector, general beam transport measurements through the detector.




Experimental results and discussion of photo detachment measurements.



# The Front End Test Stand Collaboration

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Diversified Technology
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**Further collaboration:**
CERN
IHEP, China
JAI, Oxford
RHUL, London

IAP, Frankfurt University
(thanks for the laser)

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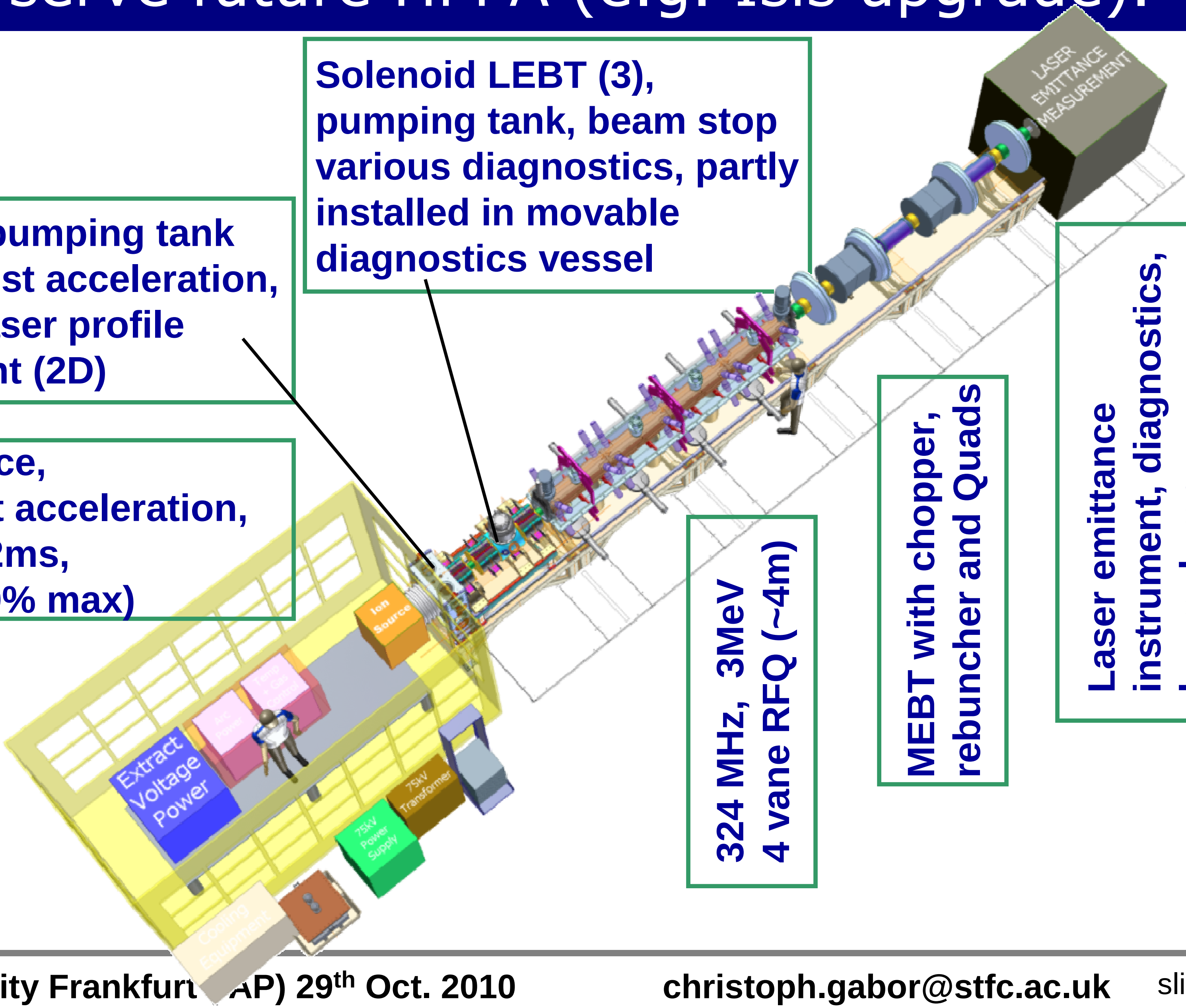
# Overview of Rutherford‘s Front End Test Stand FETS to serve future HPPA (e.g. Isis upgrade).

**Solenoid LEBT (3), pumping tank, beam stop various diagnostics, partly installed in movable diagnostics vessel**

**Differential pumping tank including post acceleration, toroide + laser profile measurement (2D)**

**H- ion source,**
**65 keV post acceleration,**
**60-70mA, 2ms,**
**50Hz (=> 10% max)**

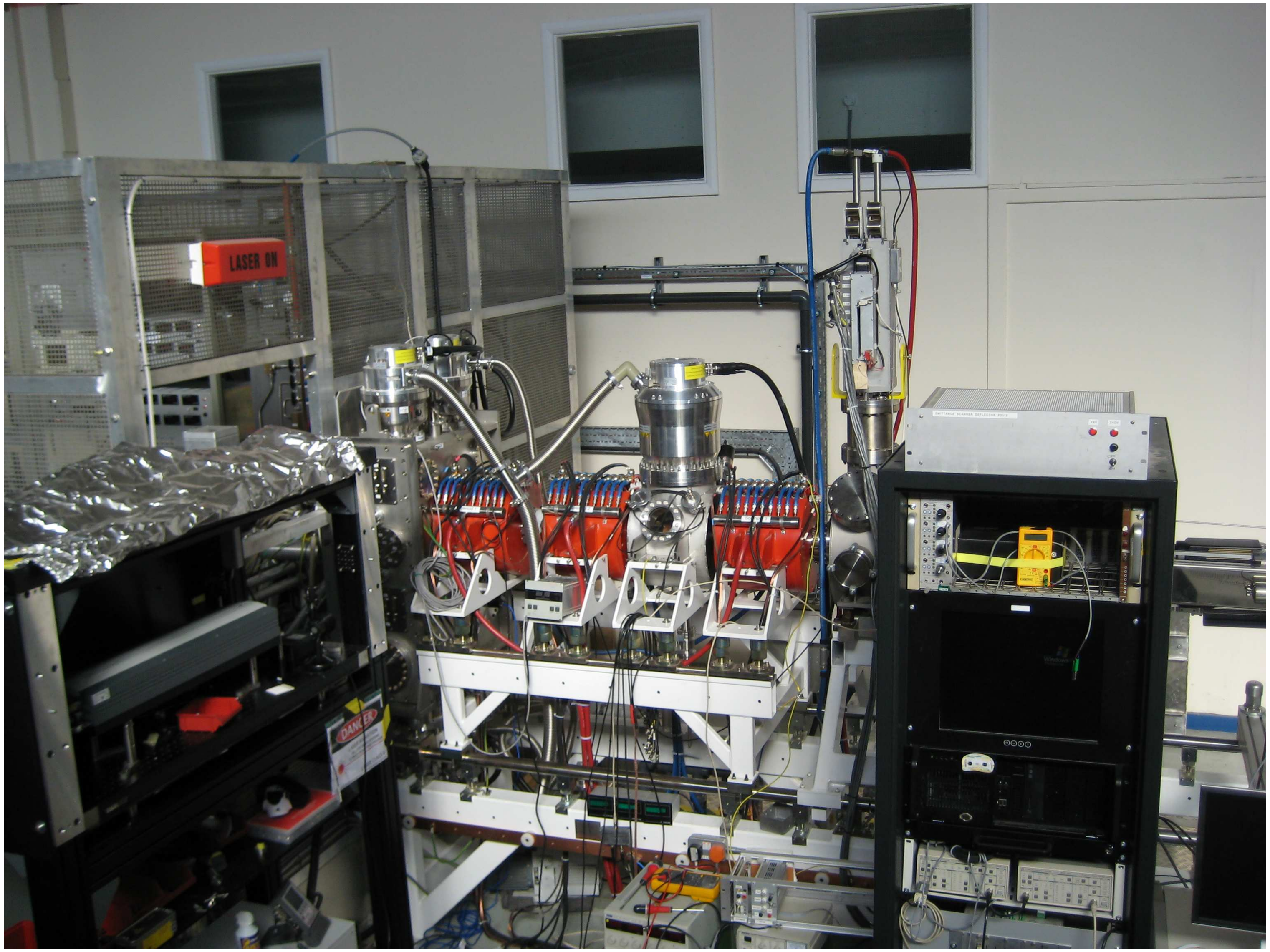



**324 MHz, 3MeV**
**4 vane RFQ (~4m)**

**MEBT with chopper, rebuncher and Quads**

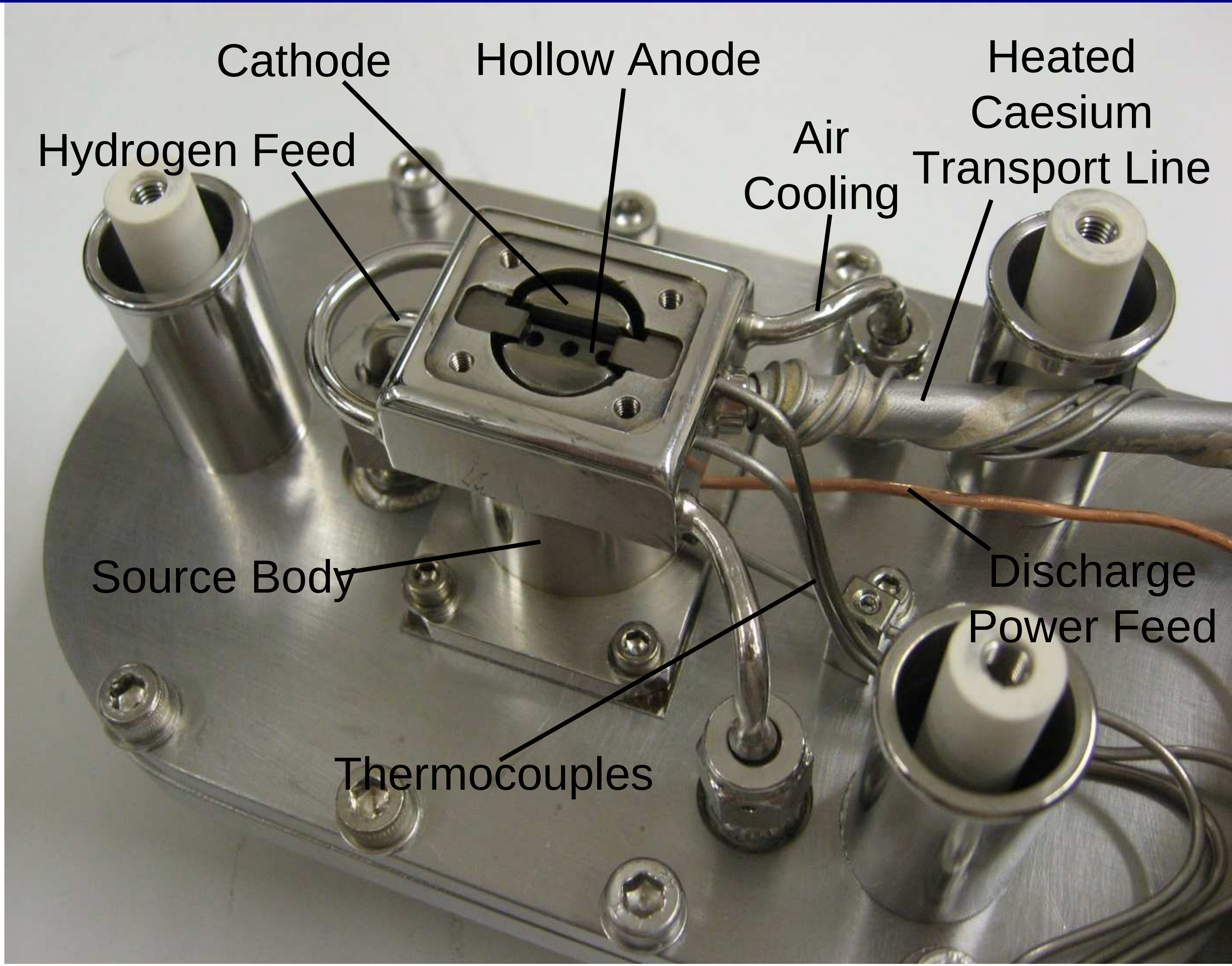
**Laser emittance instrument, diagnostics, beam dump**

# Faraday cage and Low Energy Beam Transport (LEBT) section of the beam line, current set-up.

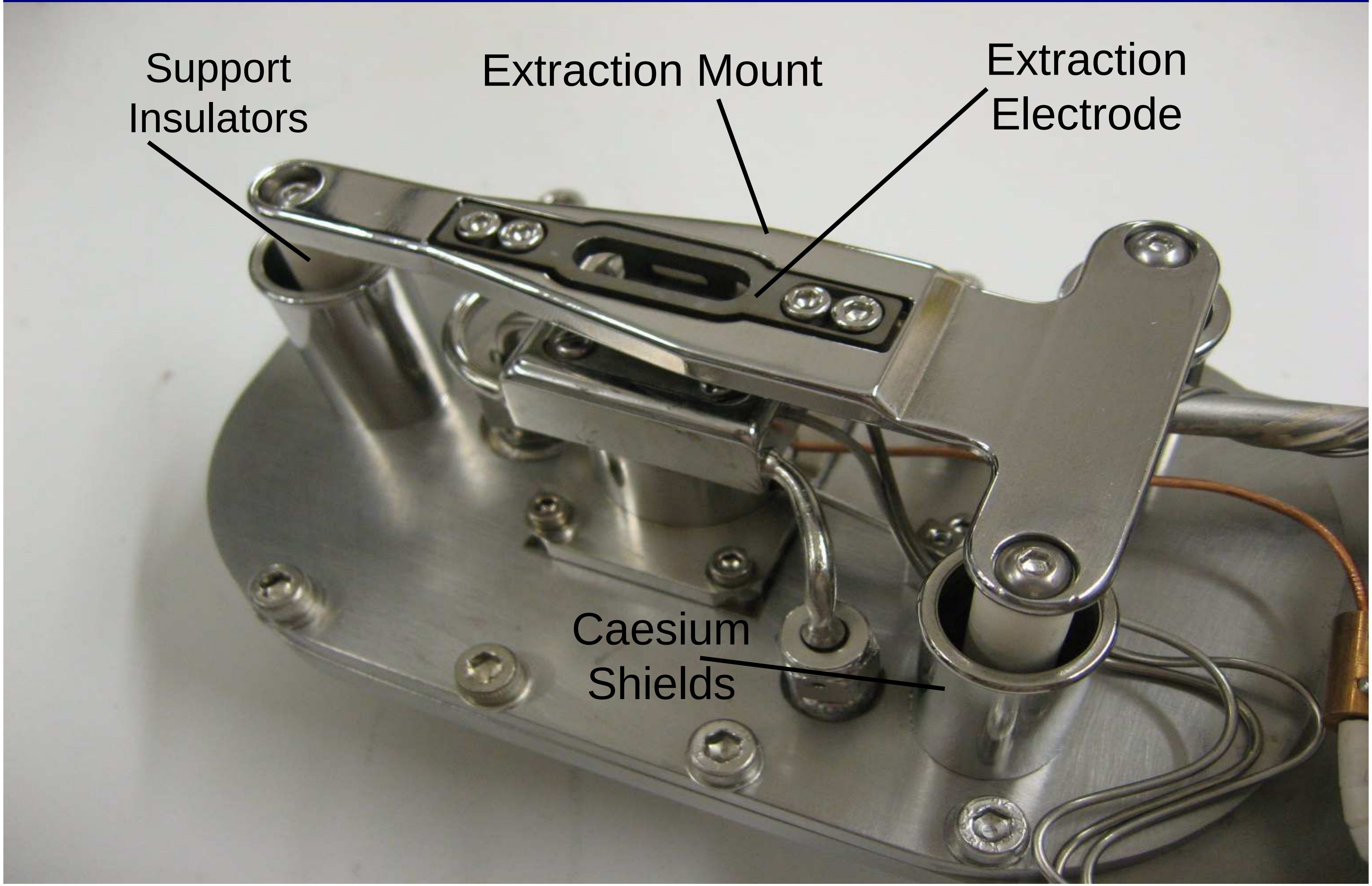


## Ion Source:
## Set-up of the Penning source

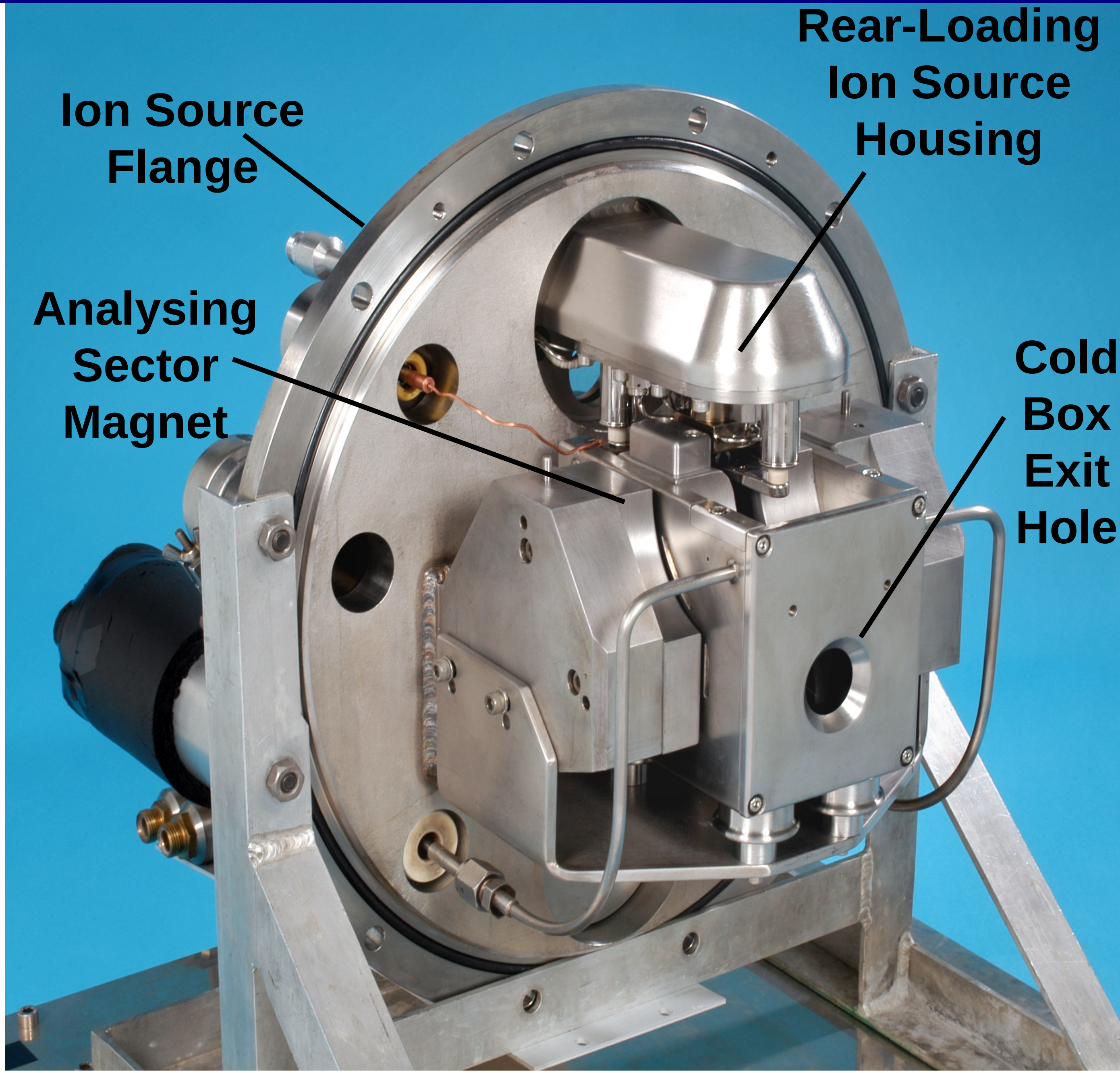
# Isis Penning Ion Source (I)



# Isis Penning Ion Source (II)



# Isis Penning Ion Source (III)



# Isis Penning Ion Source (VI)

**Ion Source and Controls on HT Platform**

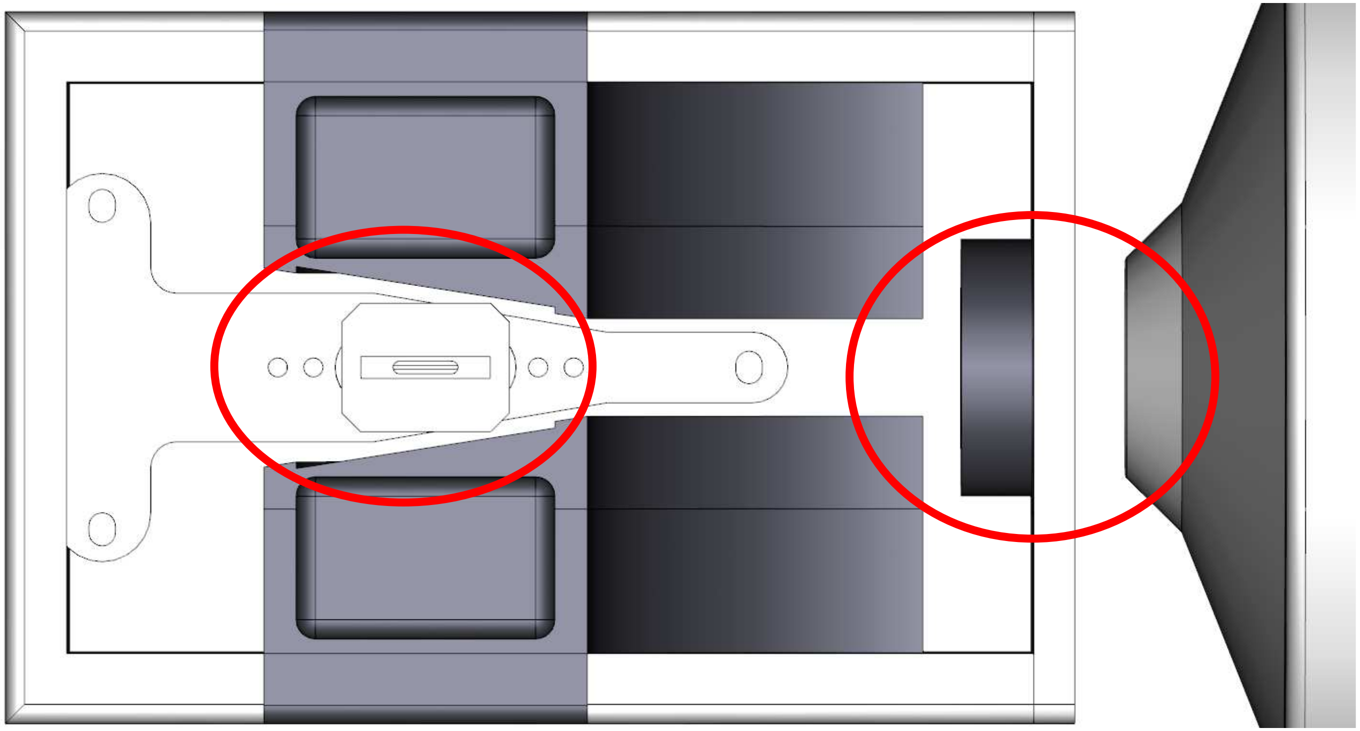
## Ion Source:
## Emittance reduction

# Emittance reduction activities concentrate on sector magnet and post acceleration.

Standard Isis ion source:

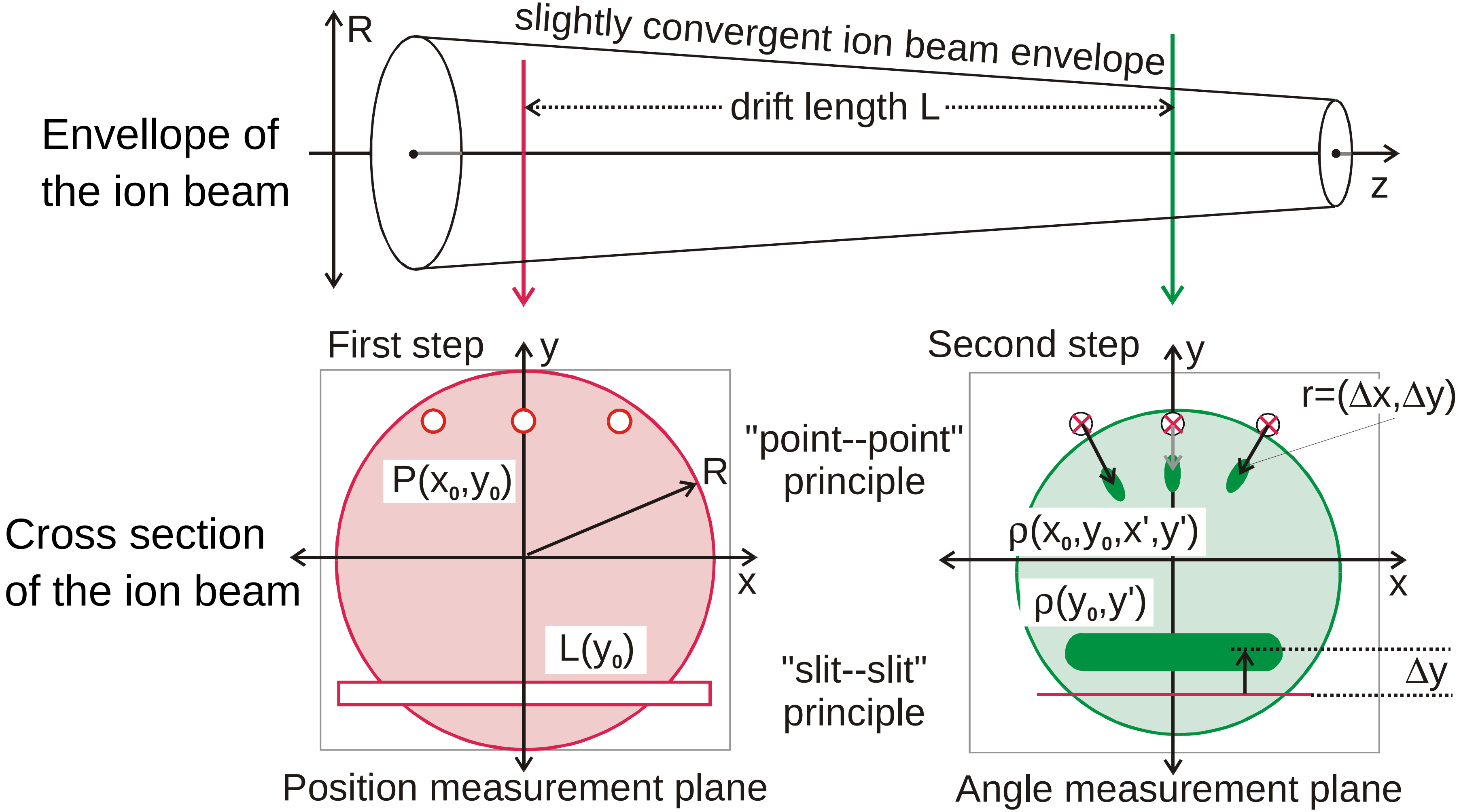
normalised
x-emittance
0.9 π mm mrad

normalised
y-emittance
0.8 π mm mrad



Transport through the dipole
Post Acceleration

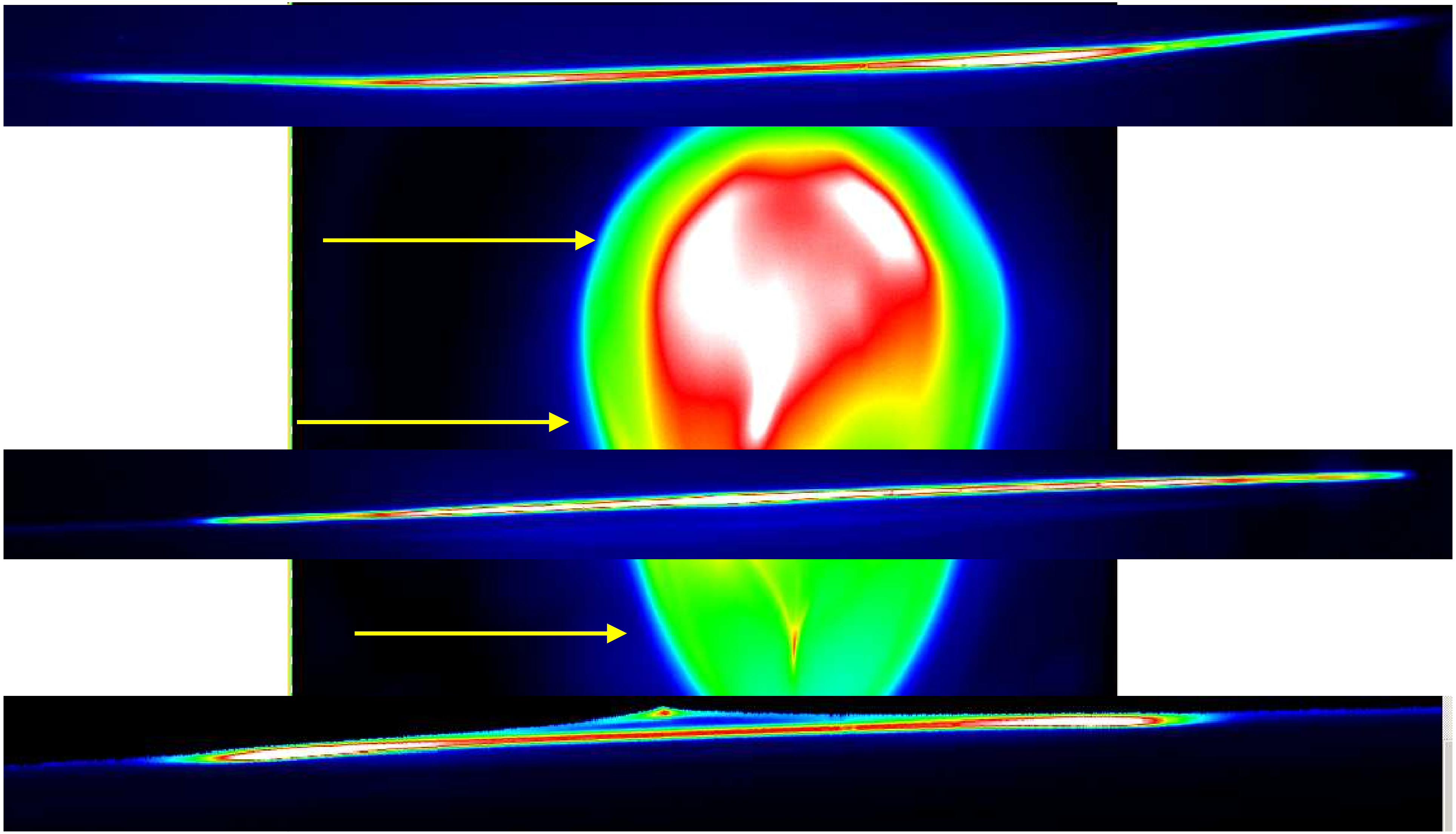
# Different emittance measurement principles.




Comparison of slit-slit & pepperpot emittance measurement principles.

# Beam profile and collimated ion beam.

1.) Beam distribution at 260mm
2.) Collimated beam parts after a separation drift of 107mm

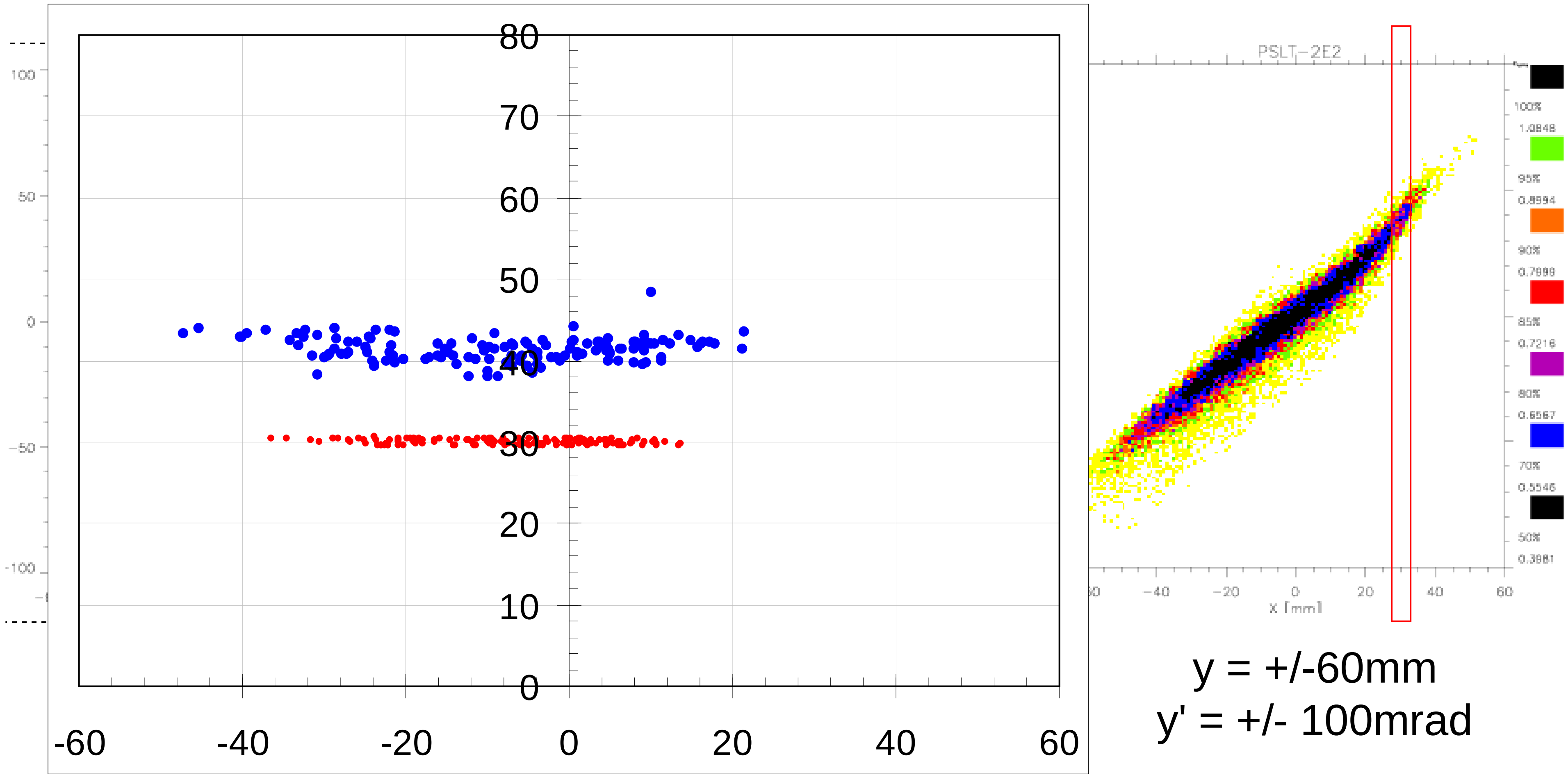


# Comparison with 4D beam distribution.

xy-distribution

xx' emittance

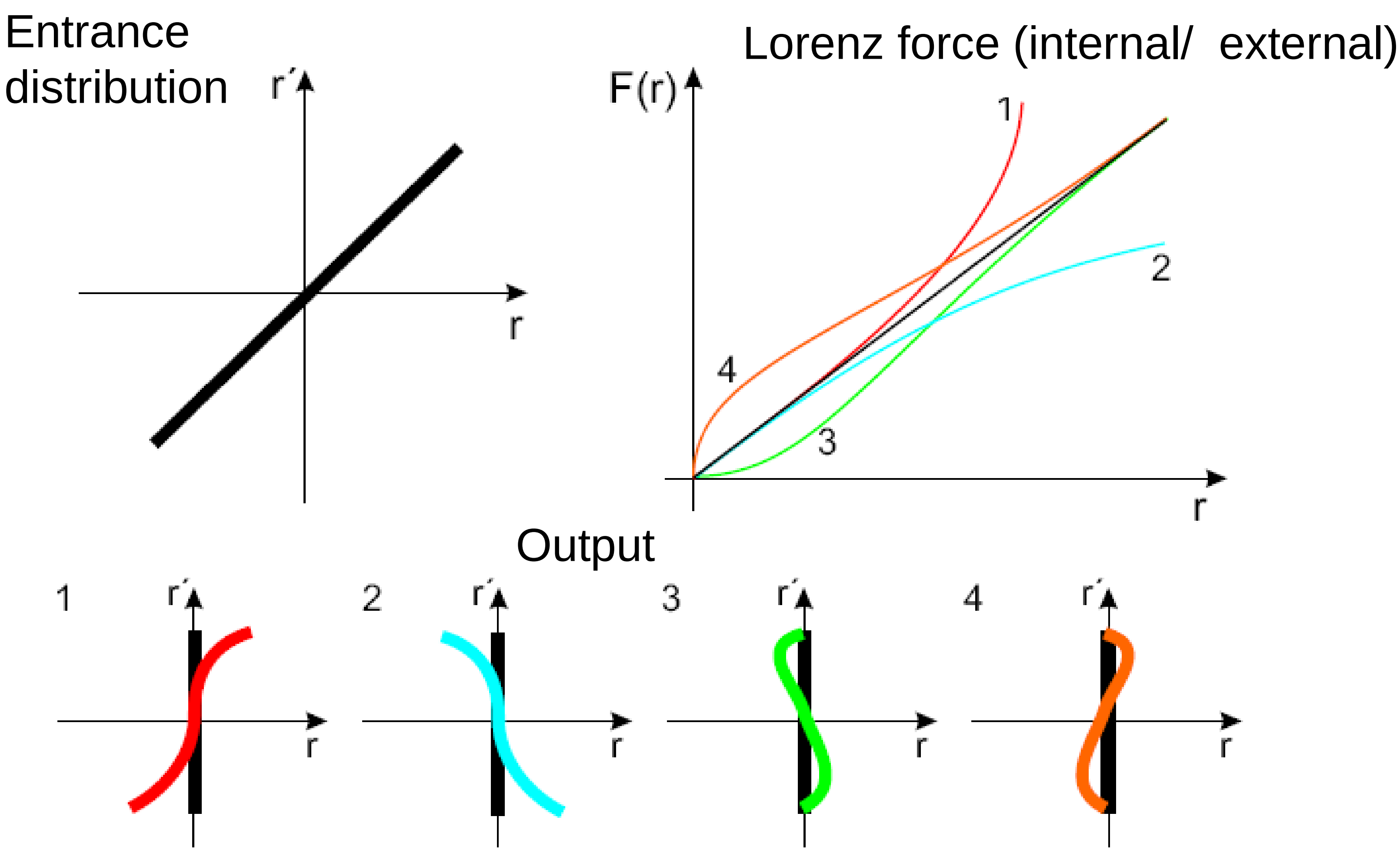
yy' emittance




y = +/-60mm

y' = +/- 100mrad

# Change of output rms emittance if forces are not linear anymore, shown as phase space section.




Phase space projections show closed areas between the S-shaped tips.

# Weak focusing of the Isis (ions source) sector magnet.

$$B = B(R)$$

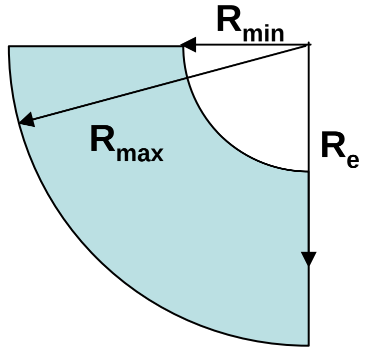
$$B = B_e\left(\frac{R_e}{R}\right)^n$$

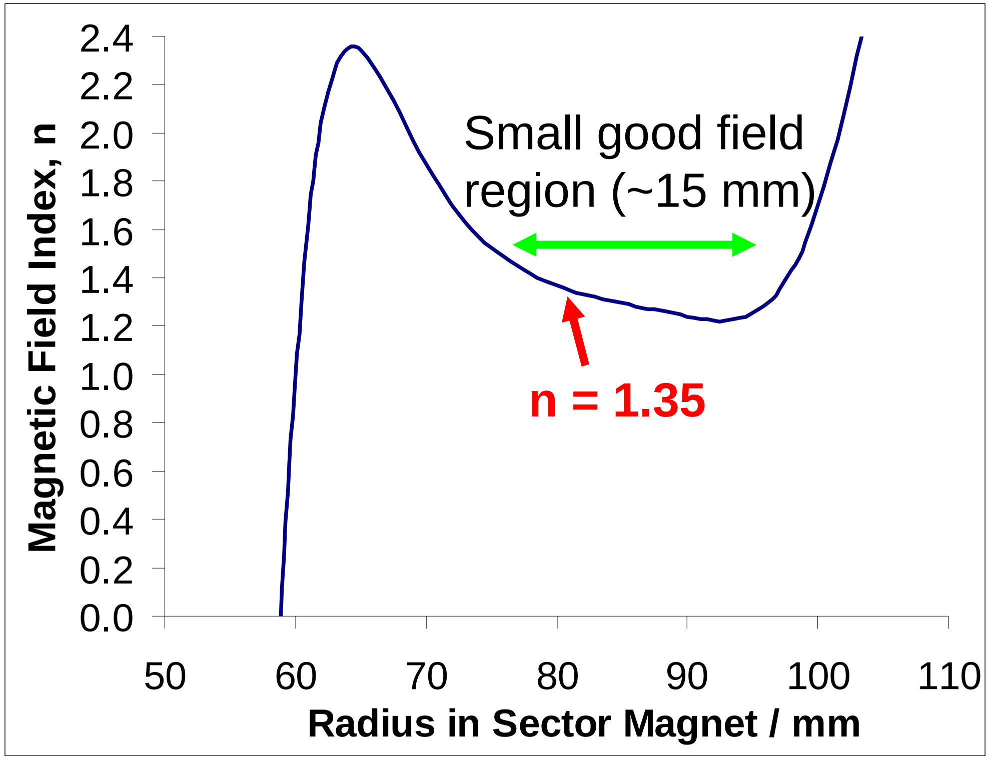
$$n = -\frac{R_e}{B_e}\left(\frac{dB}{dR}\right)$$

n = 1 → Parallel

n < 1 → Focus

n > 1 → Defocus



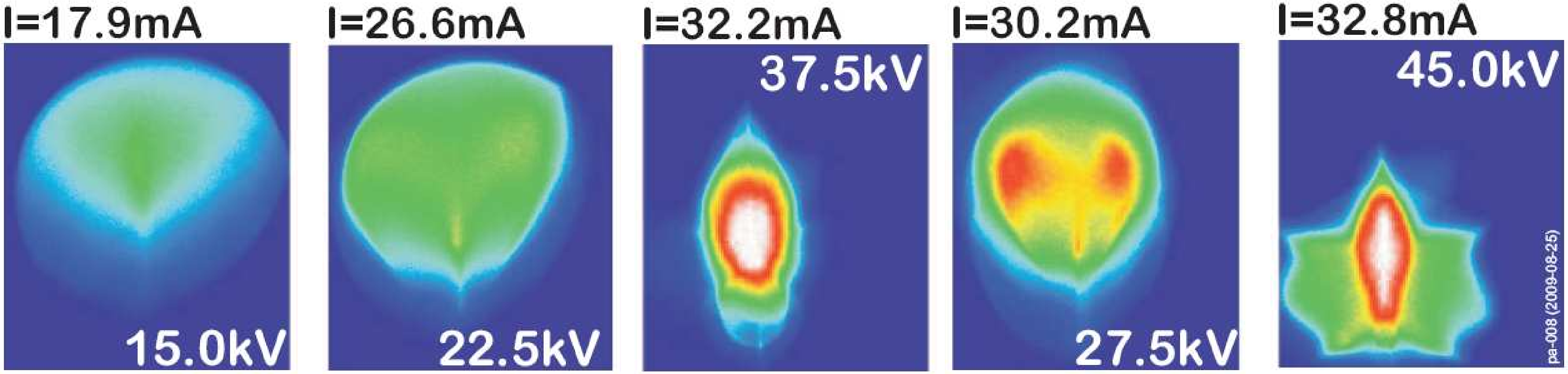




**Field index of ISIS sector magnet pole pieces**

$R_{min}$ = 55 mm
$R_{max}$ = 105 mm
$R_e = (R_{min} + R_{max}) / 2$ = 80 mm
∴For 17 keV beam, $B_e$ = 0.235 T

**Reduced field index**
**Wider pole tips**

# The post acceleration gap needs to be adapted to the demands of best matching LEBT.

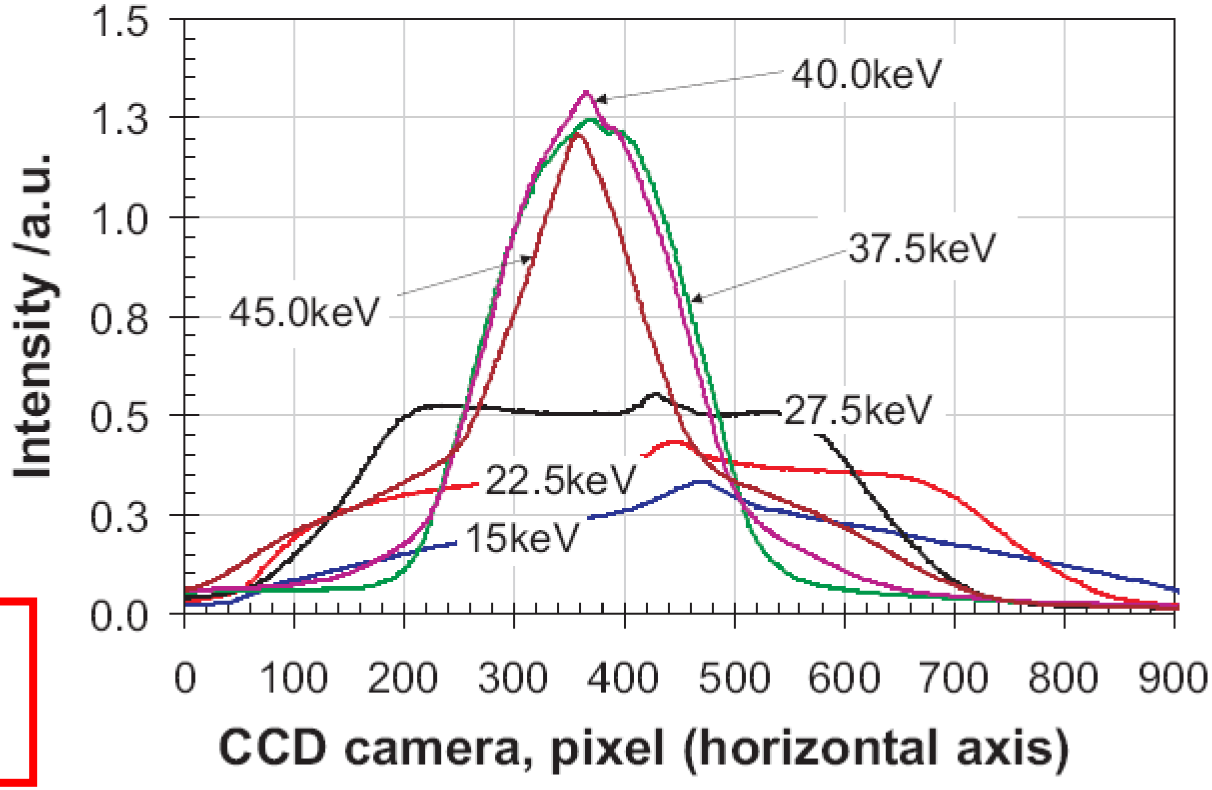



aperture lens effect

1pixel⇔0.1102mm

normalized to integrated toroid current

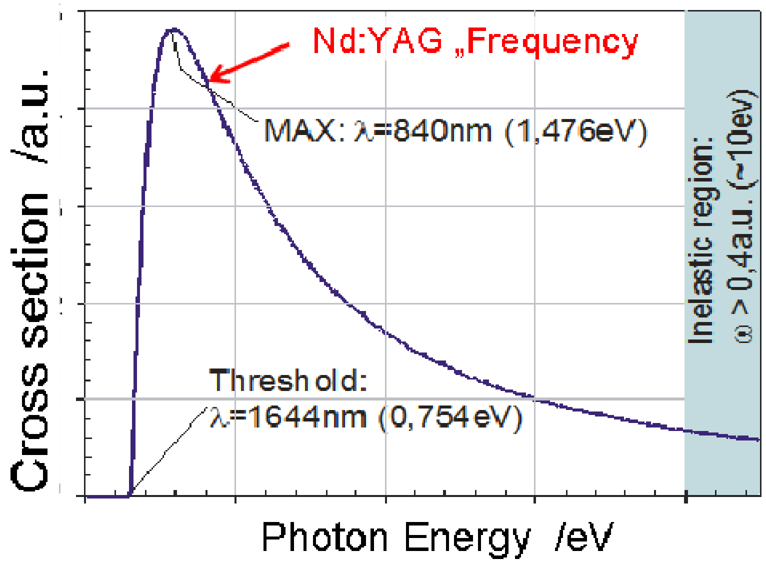
very difficult to simulate

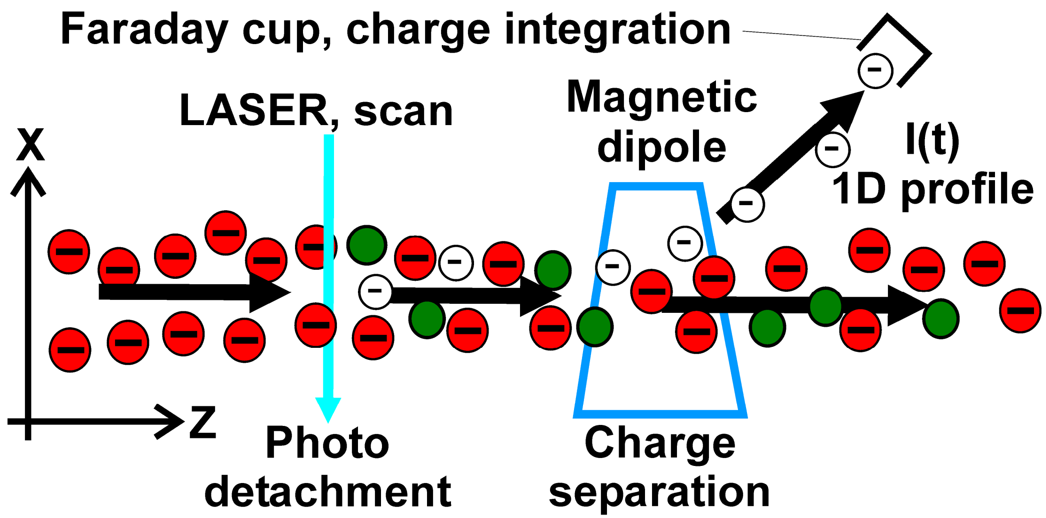



emittance down to $\varepsilon_{rms,norm}$=0.35 $\pi$mmmrad

# Photo-Detachment
# and
# Experimental set-up

# Photo detachment can be used to diagnose the H- ion beam non destructive.



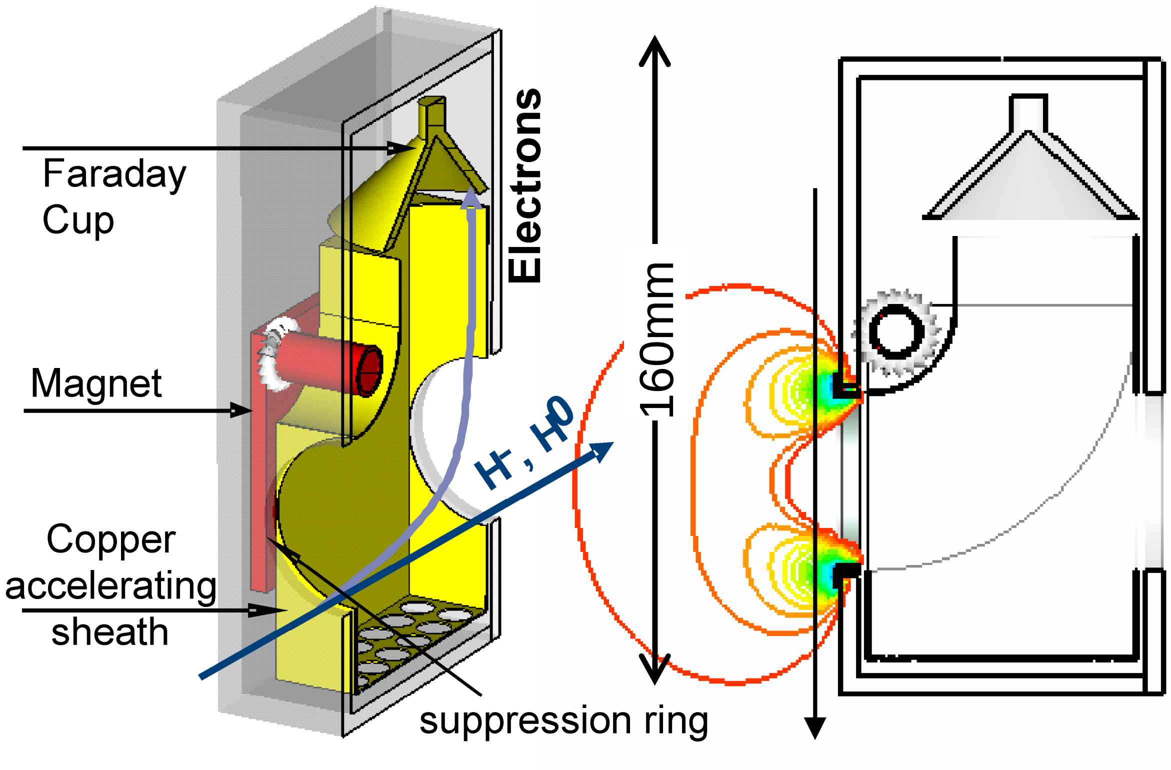




$$\hbar\omega + H^{-} \longrightarrow H^{o} + e^{-}$$

~75% of cross section
with Nd:YAG or 2nd harmonics

- non destructive
- online measurements
- final aim: tomography (2D)
- other variants also possible

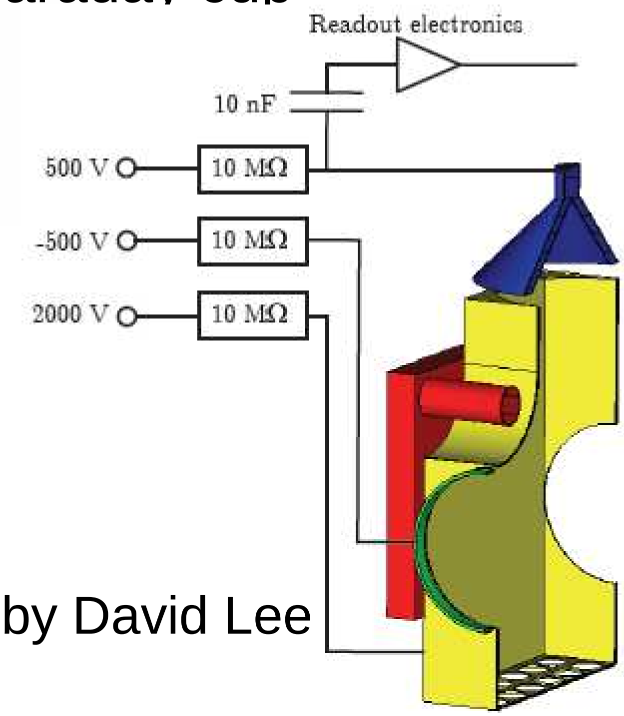
# The detector set up to collect the electrons.




Components

J (jacket) acceleration sheath
I dipole magnet
S suppression ring
G grid

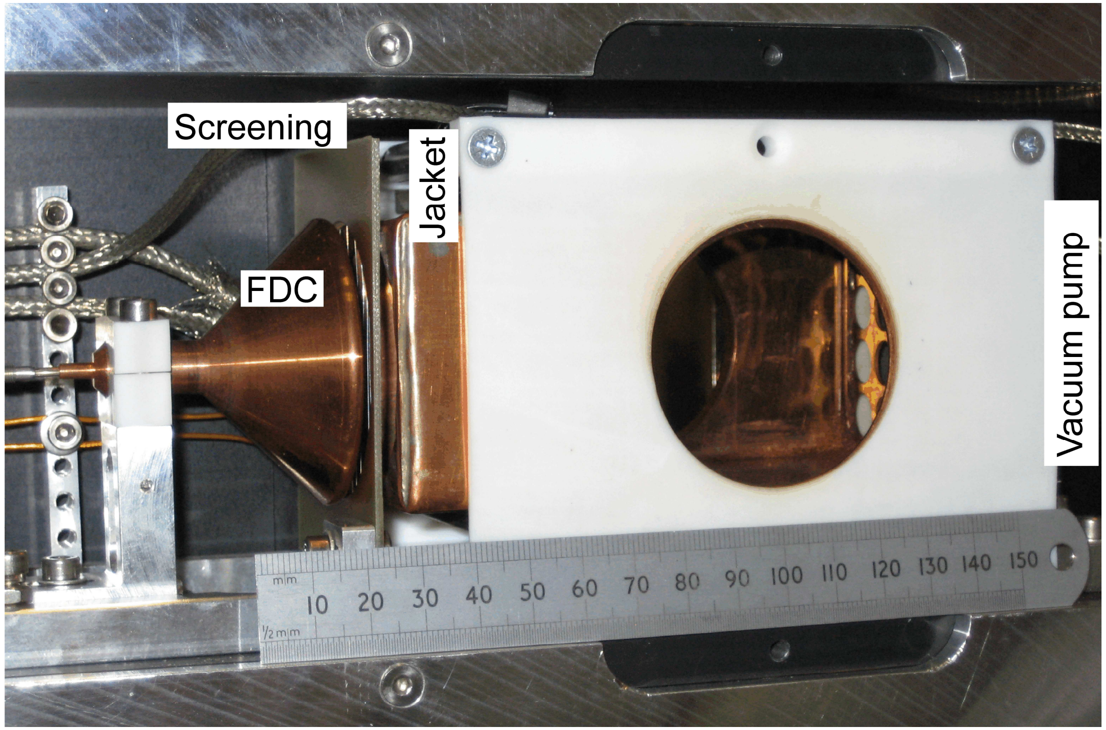
Faraday cup



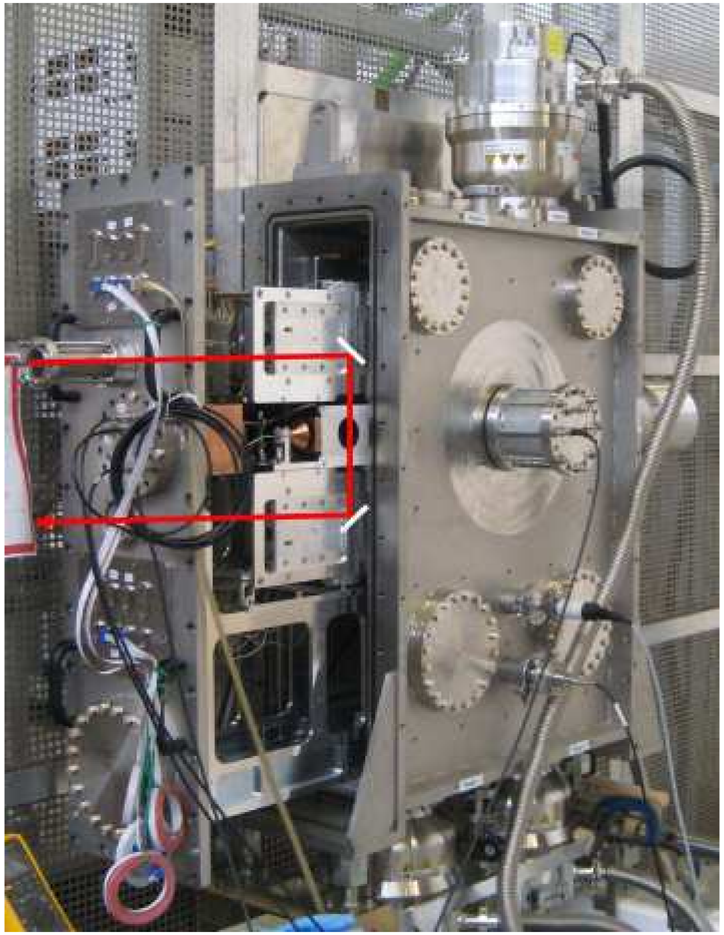

- ~ suppression ring: - 500 V
- ~ acceleration sheath: + 2 kV
- ~ grid: +200....+400
- ~ Faraday cup: + 500 V
- ~ magnet current: + 1A

work done by David Lee

# Detector & optical beam path. The diagnostics is integrated in the 1st (differential) pumping vessel

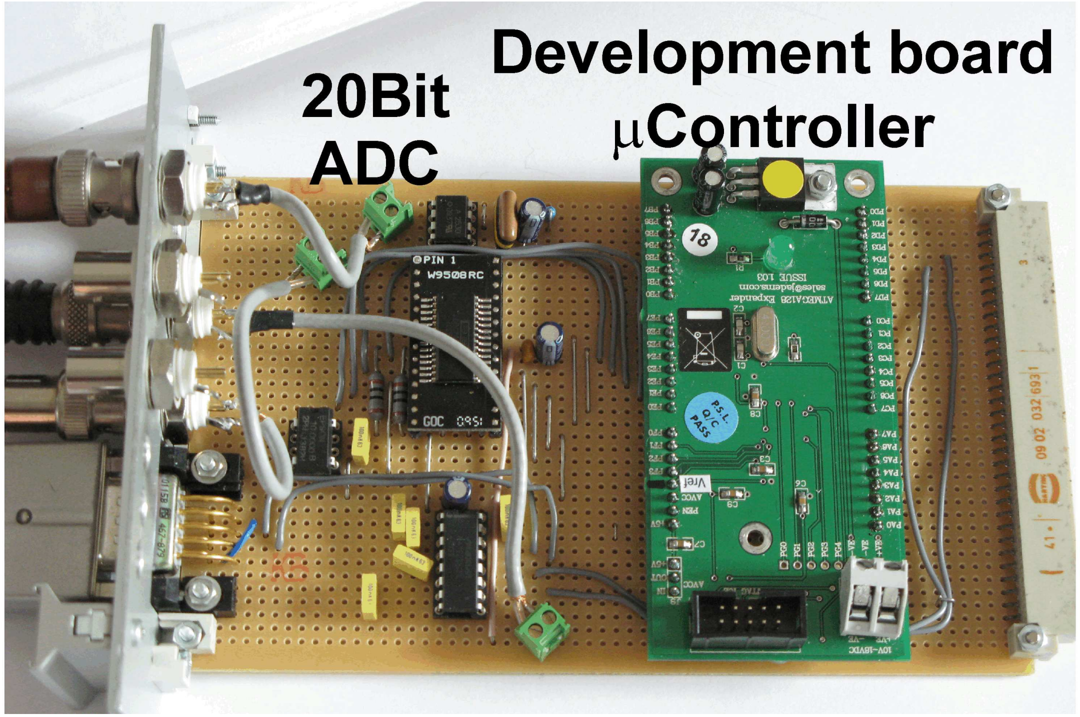



Blow up of the electron detector. All components isolated well beyond specifications. Opening hole is 50mm in diameter.



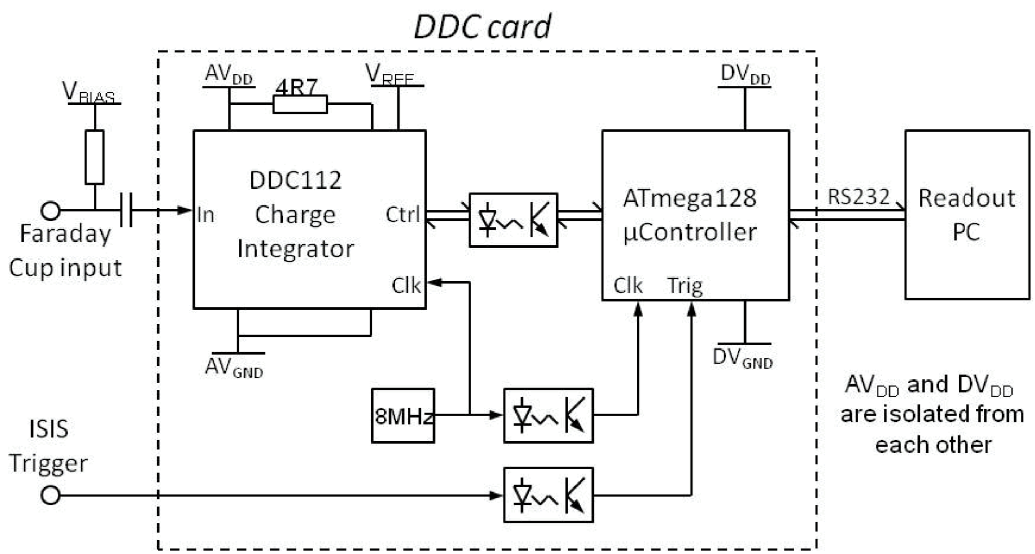
Optical beam path. The Laser is vertical orientated to the ion beam. Initial alignment takes place with open drawer.

# Schematics circuit diagram and ADC-stripboard



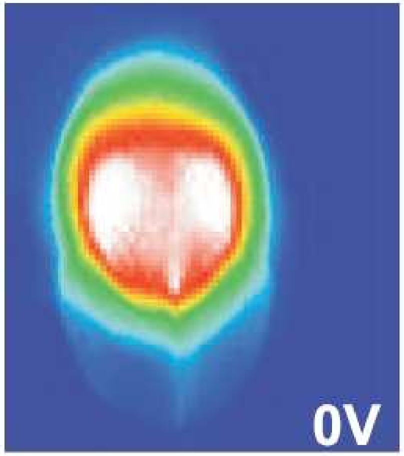

@ Gary Boorman, RHUL

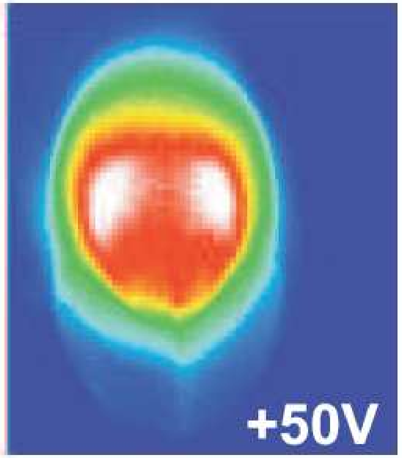
Careful design with several opto-isolator couplers are necessary to avoid any ground loop.

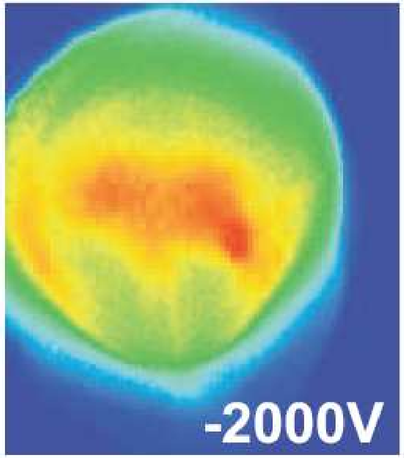


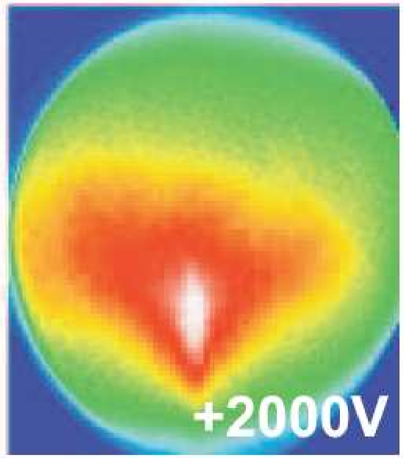
## Differential Pumping Tank:
## Beam Transport

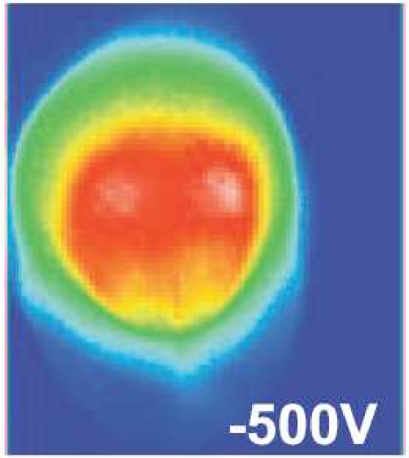
# Ion beam transport through the detector at various acceleration sheeth potentials.

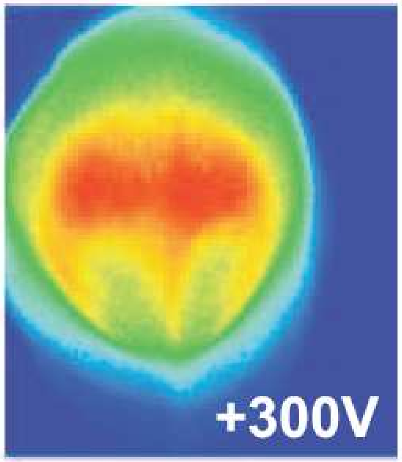


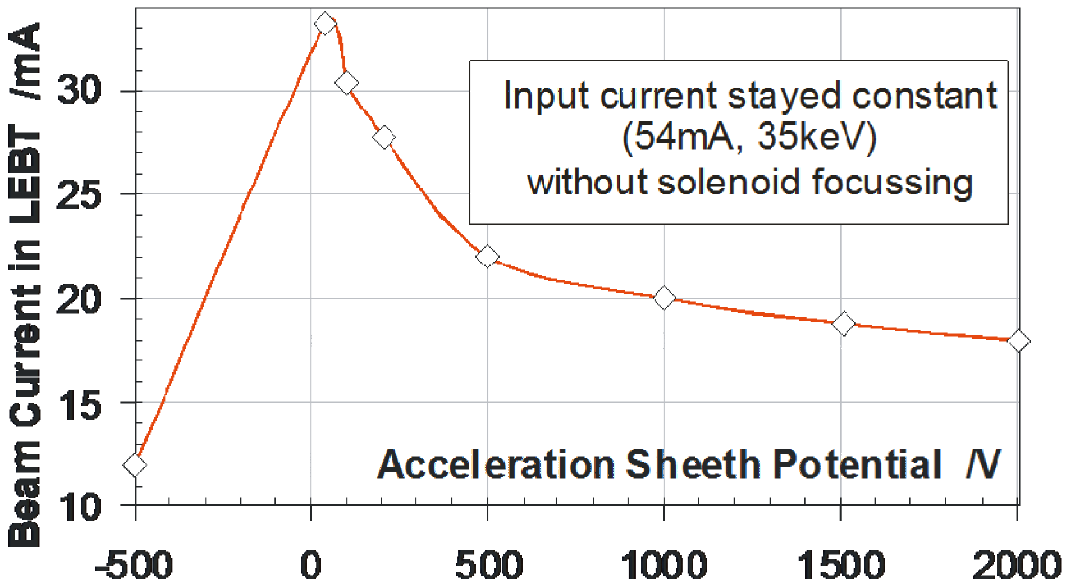



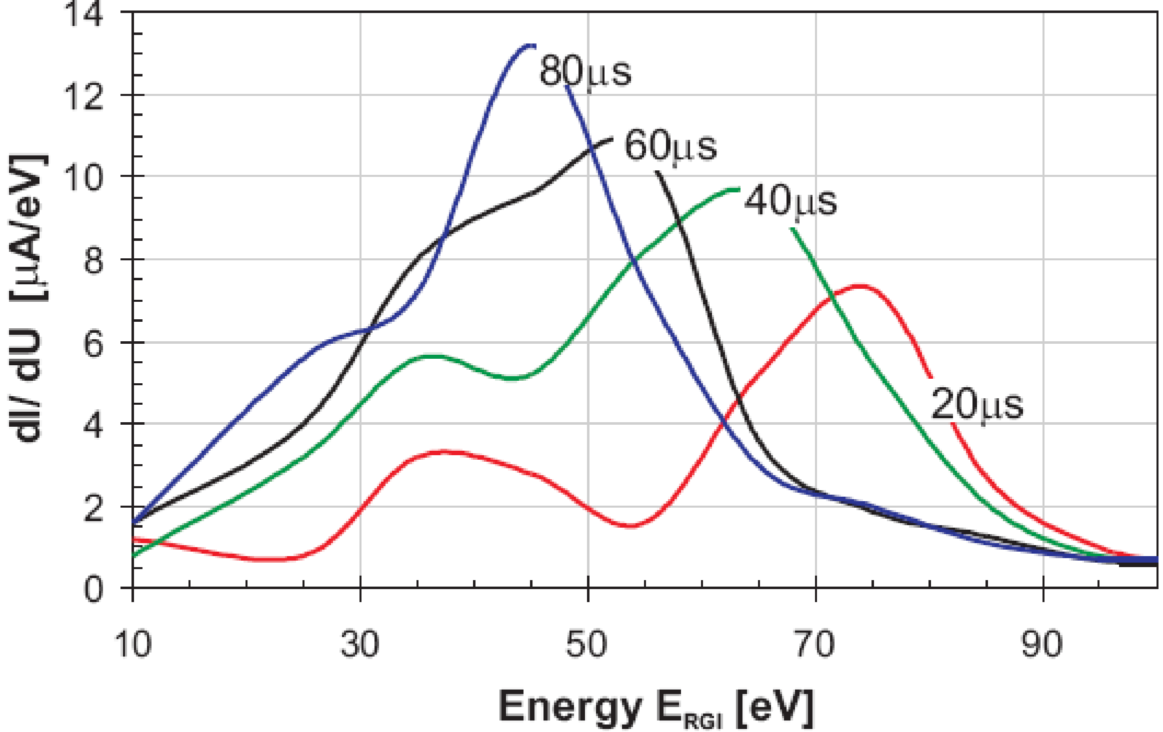




Ion beam is actually bigger than the assumed design values.

# Spectrum of the residual gas electrons.

Energy has been determined by grid voltage variation.




Integrated FDC signal for various time steps

↓

discrete differential of this data

t < 20µs: rise time of extraction power supply (toroid T1 shows max current after ~20-30µs

t > 80µs: beam has stabilised

time in between is thought to be space charge, i.e beam potential decreases the longer the pulse takes place

# Temporal behaviour of the detector signal compared with toroid rise times.

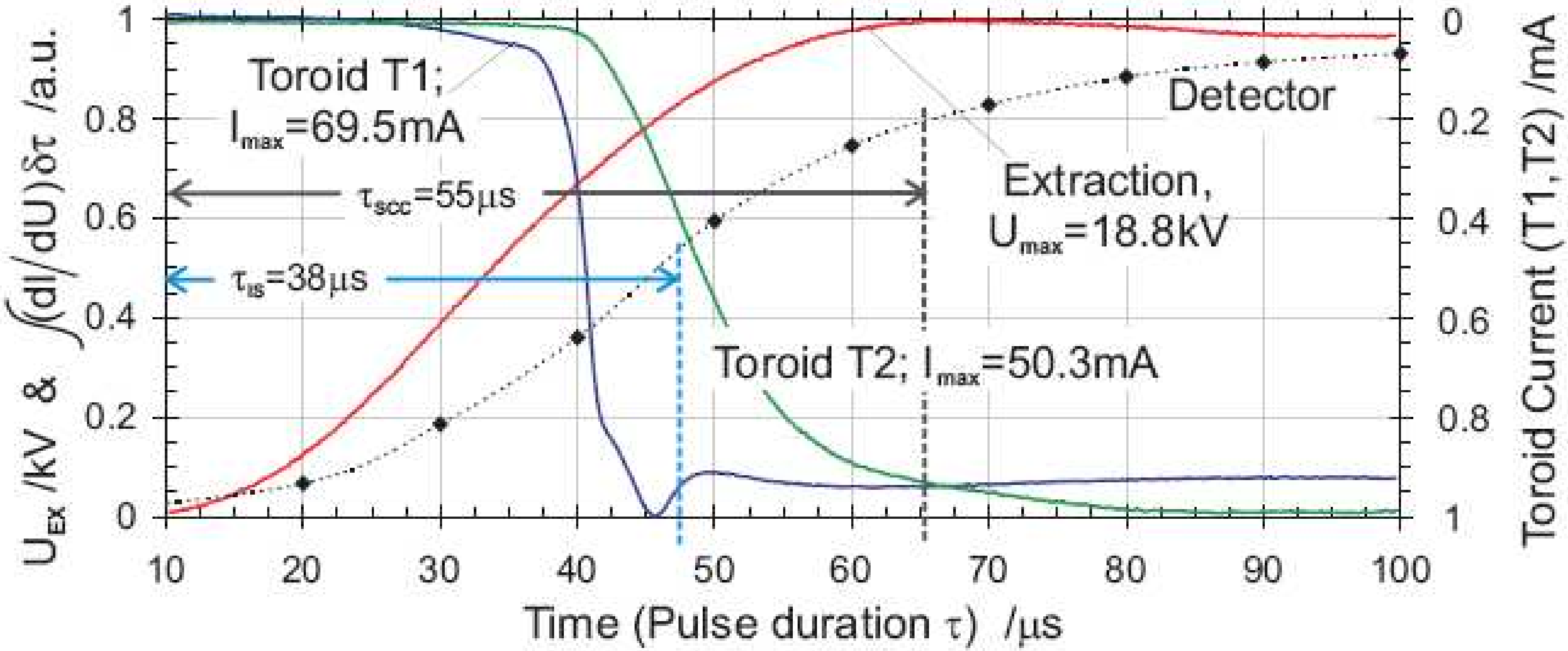
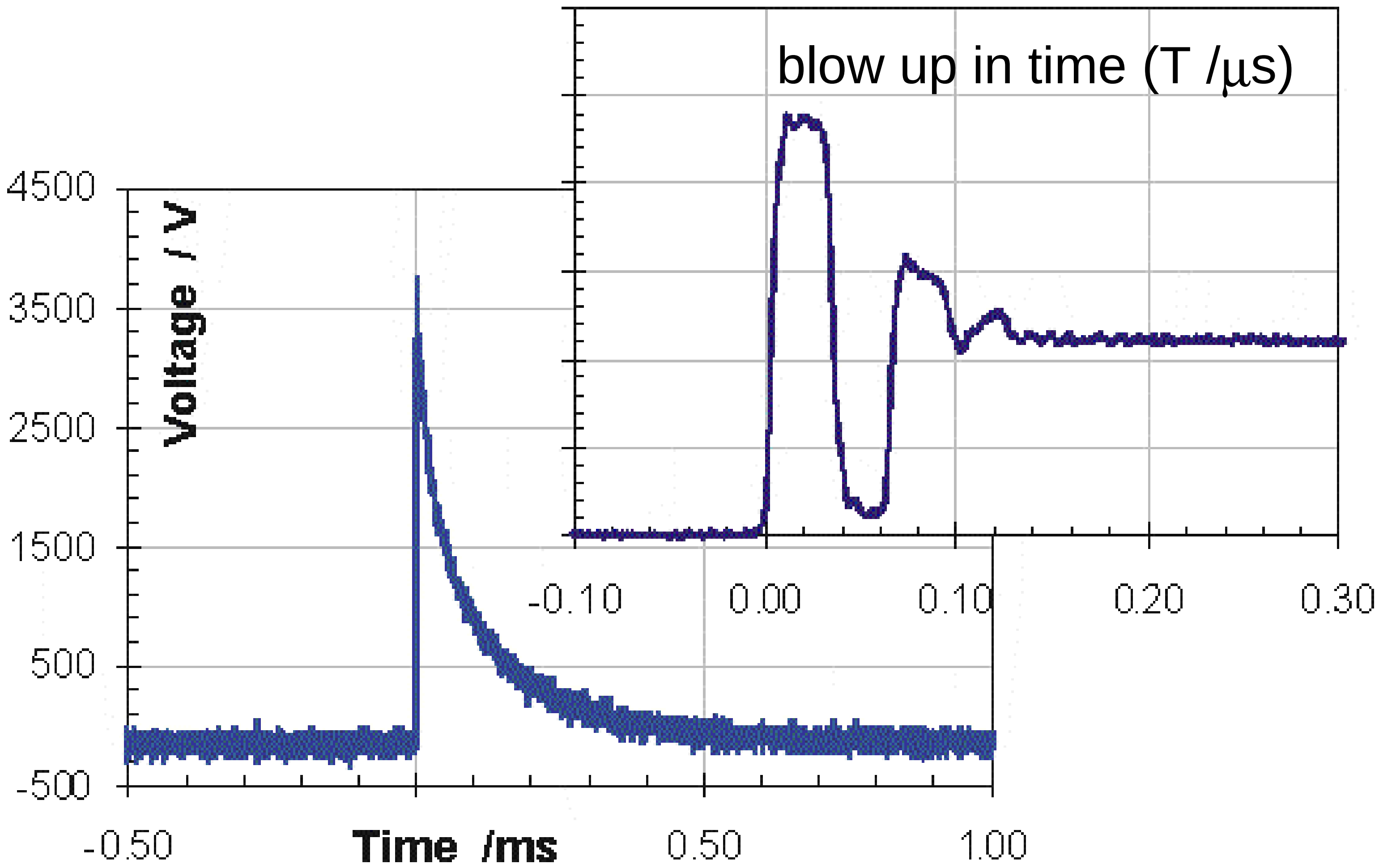



FIG. 8 Normalized blow–up of the extraction voltage, toroid 1 and 2 signal and the energy–depended integrated detector current of the compensation particles. The rise time of the space charge compensation $\tau$ is $\approx 48\mu s$

**(Further) Problems with the detector and Measurements, indeed!**

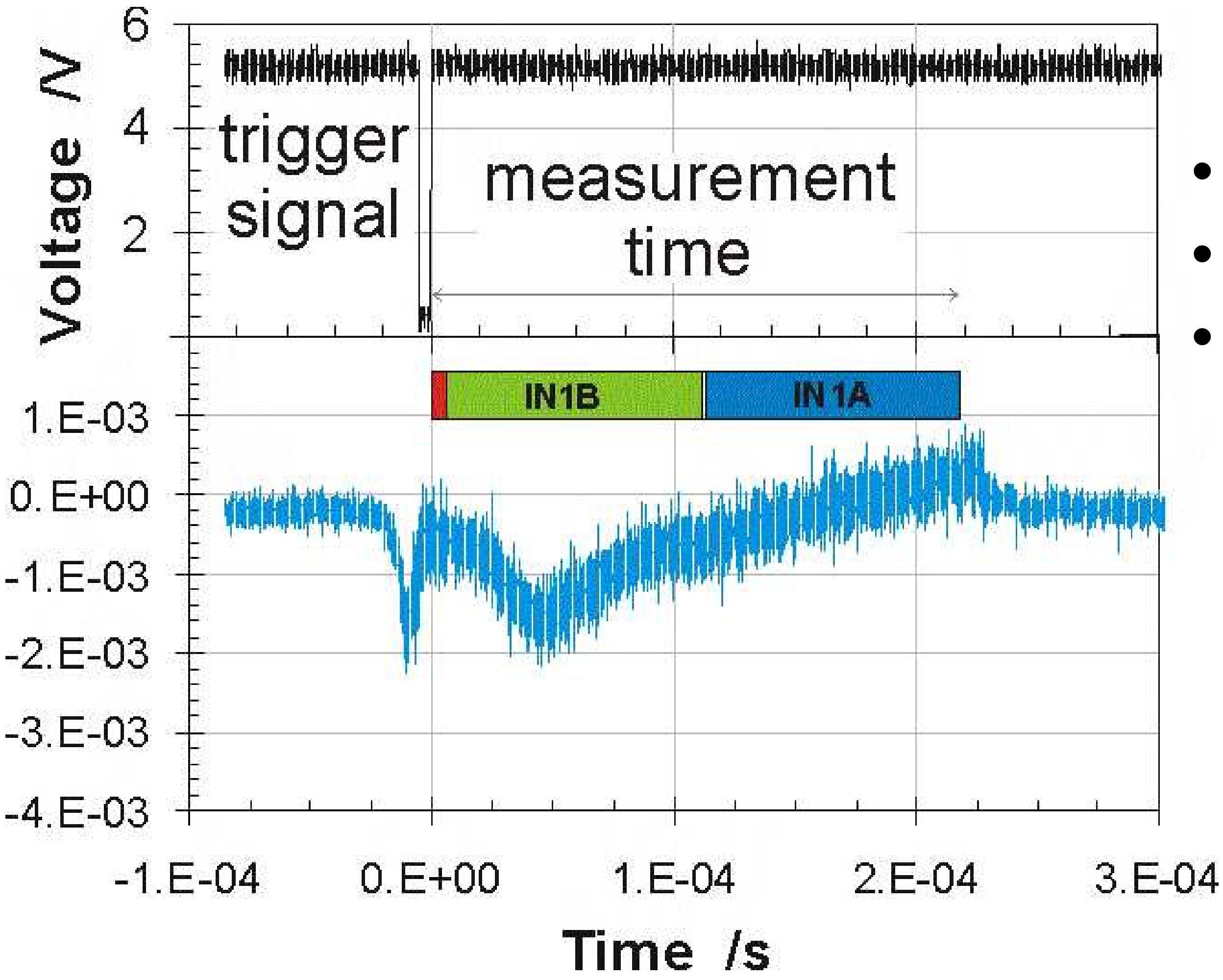
# Electrodes become charged due to beam losses which leads to HV breakdowns.

That depends heavily on input impeadance and is especially critical if the ADC amplifier is connected.



# The signal will be sampled and digitized with a current amplifier.

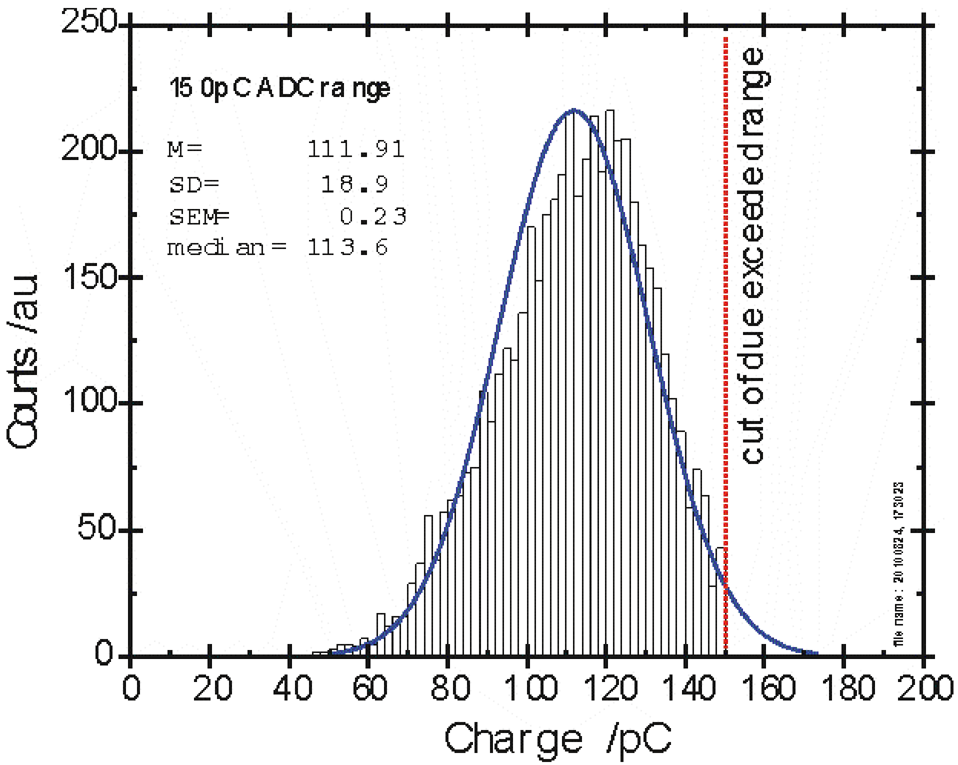
**Electronics: rise time µs & resolution pC**




- 50.....350pC range
- 20 bit resolution
- 2 integration cycles with 103µs length

# The background is large compared to the photo detachment effect & needs carefull substraction.

**High beam losses cause a large background signal.**



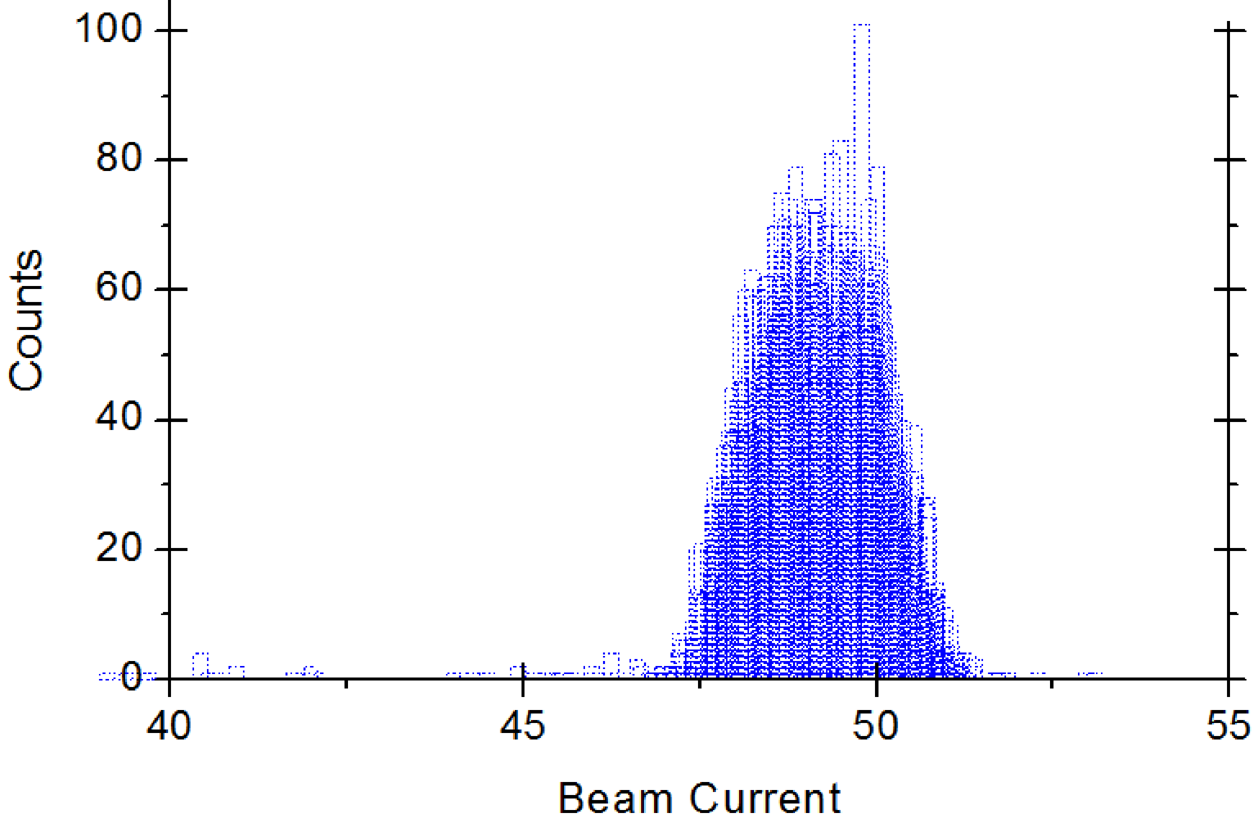

Two different types of sources affect the background:

- slow variations → **SD** (stability of theion source
- fast variations → **Means** (secondary effects, ion beam noise)

**It is NOT possible to run the detector as it is supposed to do.**
**Needs to find empirical settings to min. background + max. PD electrons.**

# Due to beam current fluctuations Isis needs to limit the pulse length to keep charge constant.

| N total | N missing | Mean | Standard Deviation | SE of mean |
|---|---|---|---|---|
| 8350 | 0 | 49.09077 | 1.80646 | 0.01977 |




Beam current is sampled after 100μs pulse length, population taken for several hours. The charge needs to be constant to run the synchrotron.

# Is the location of detector a good idea?

**Of course NOT, But only in *Hindsight***

Background, source variations, beam losses, low electron energy, charging effects, beam noise, secondary effects

➔ you may conclude to measure in a harsh environment

---

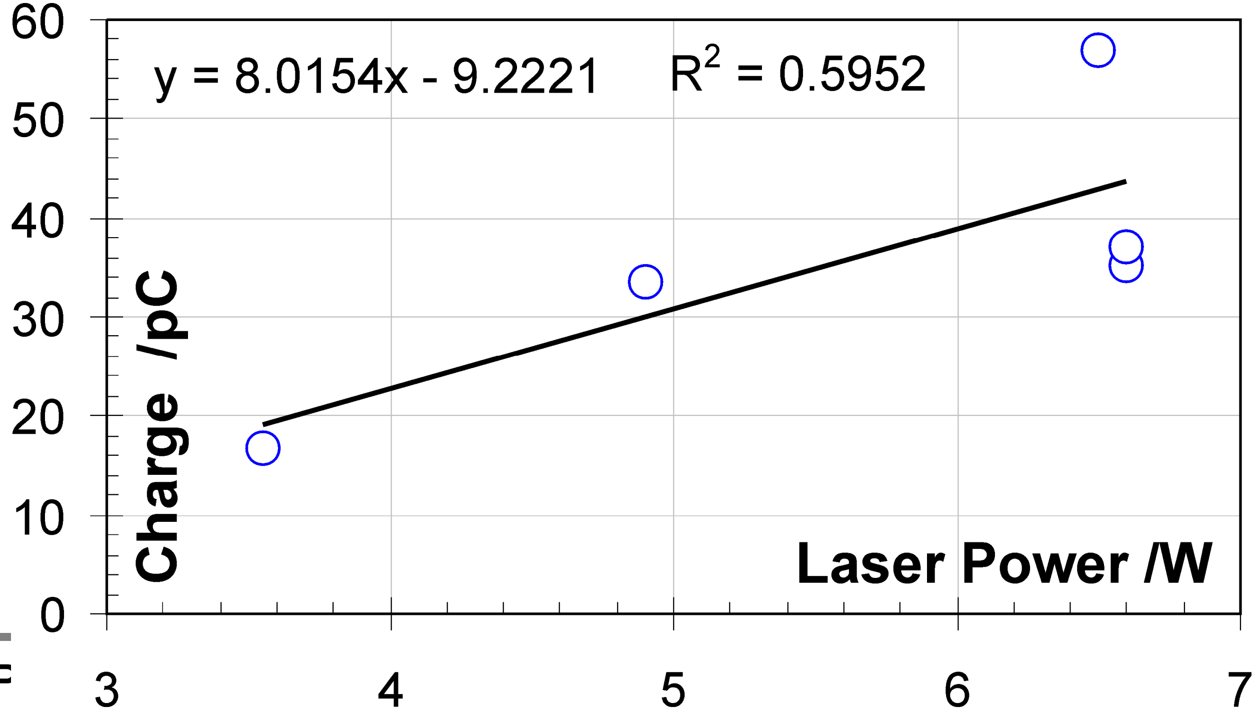
- time constraints because it started as a Ph.D.
- true beam size not fully appreciated
- may be to much concentrated on simulations and technical issues
- still a reasonable place to get input LEBT distributions, if the diagnostics works
- if it’s challenging science makes more fun ;-) (sometimes) !

# Comparison of some measurements from different days/ different detector settings.

| | No. 1 | No. 2 | No. 3 | No. 4 | No. 5 |
|---|---|---|---|---|---|
| Range /pC | 150 | 100 | 350 | 350 | 150 |
| $P_{laser}$ /W | 6.62 | 6.62 | 6.4 | 6.4 | 6.5 |
| $\Delta_{mean}$ | 1.84 | 2.17 | 46.0 | 34.0 | 56.9 |
| Dipole $I$ /A | 0.62 | 0.62 | 0.41 | 0.41 | 0.34 |
| Grid $G$ /V | 109 | 109 | 159 | 159 | 155 |
| Bias $B$ /V | 0 | 0 | 89 | 89 | 94 |

- Grid and Bias have strong impact
- variation of the means
- secondary effects

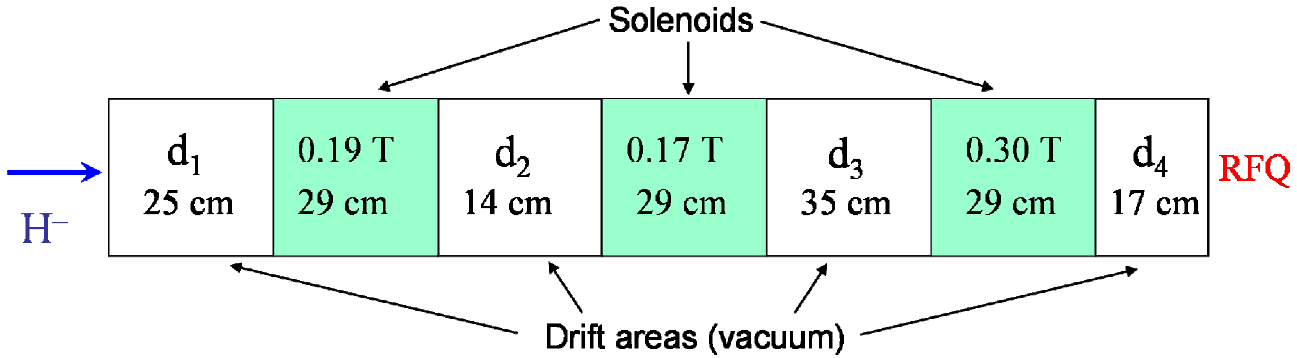
Linear Regression suffers from instabilities caused by the ion source.

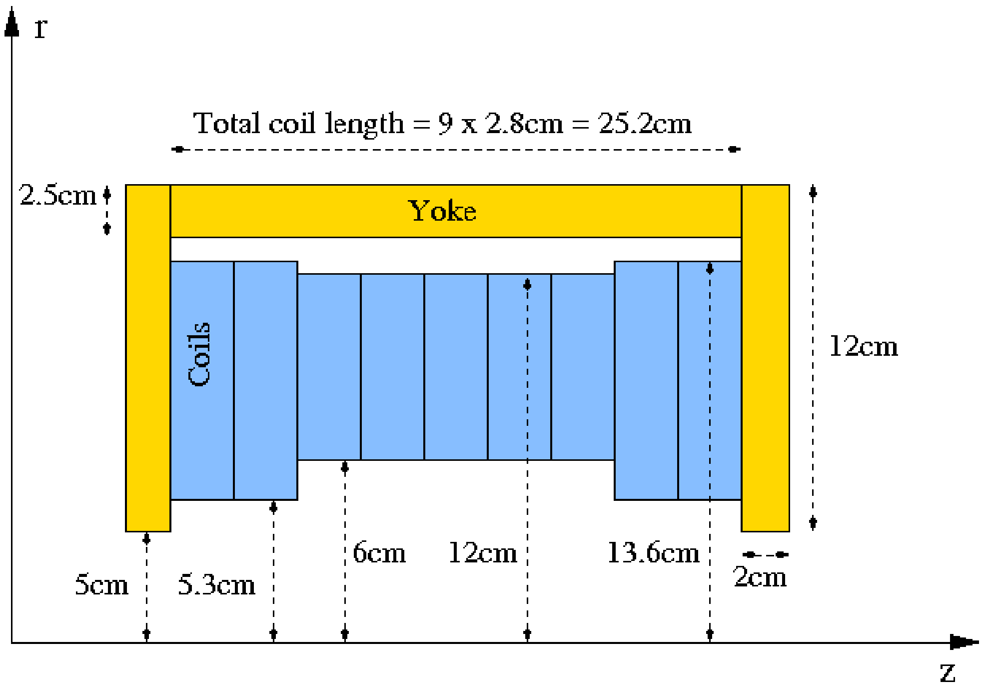


# Summary and Outlook.

- Programm to reduce the Isis emittance (dipole, post acceleration) by a factor of almost 3 down to $\varepsilon_{norm}$=0.35 $\pi$mmmrad
- Beam transport through the photo detachment beam profile detector
- Despite rough conditions photo detached electrons have been measured
- A redesign of the detector is necessary, advisable another place as well
- nothing said about:
  reconstruction of the beam distribution, PD—EMI, LEBT commissioning, long pulse measurements ......

# LEBT design overview



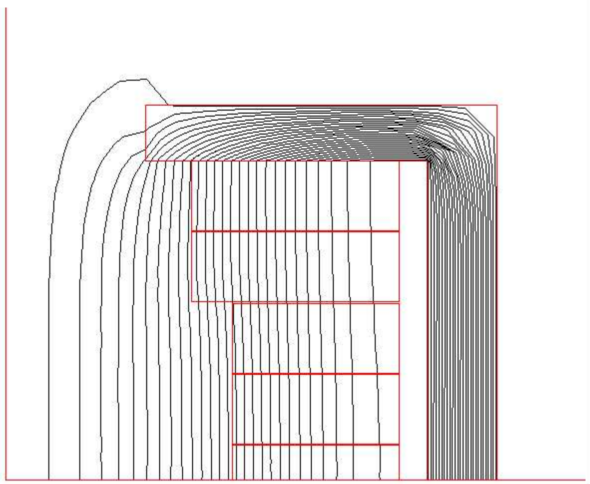



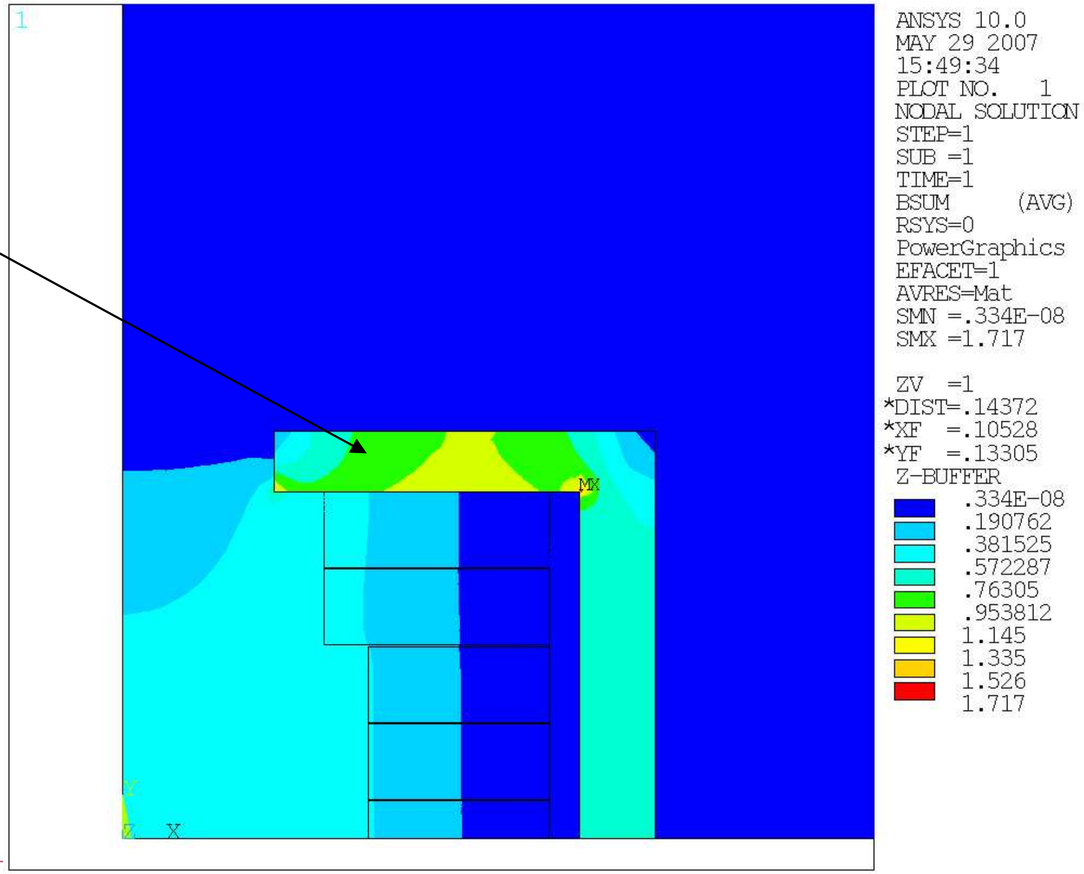
# Field distribution of the LEBT solenoids (1).

## LEBT field distribution of solenoids 1

Nominal field at 245 A

Low levels of saturation allow the use of standard low carbon iron

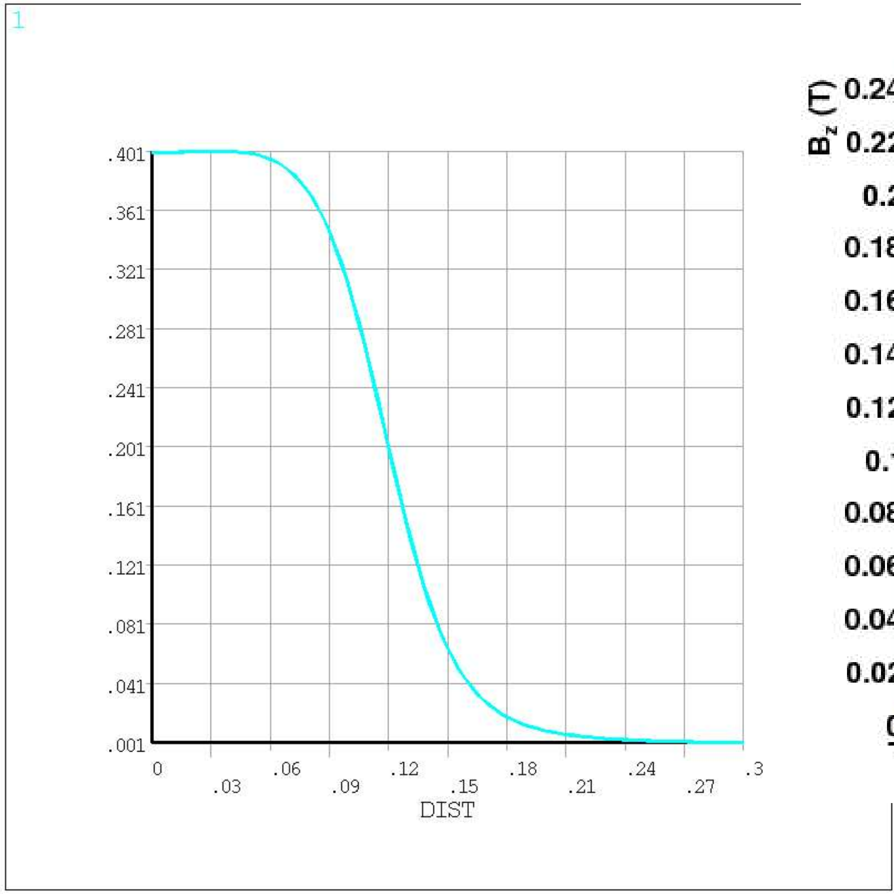


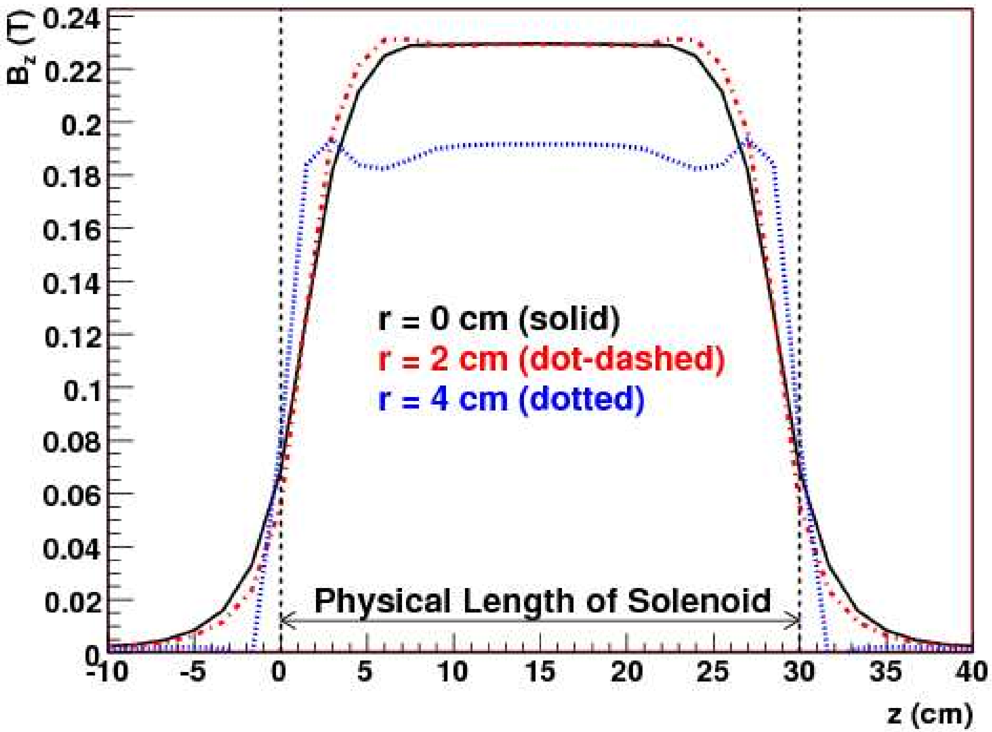


# Field distribution of the LEBT solenoids (2).

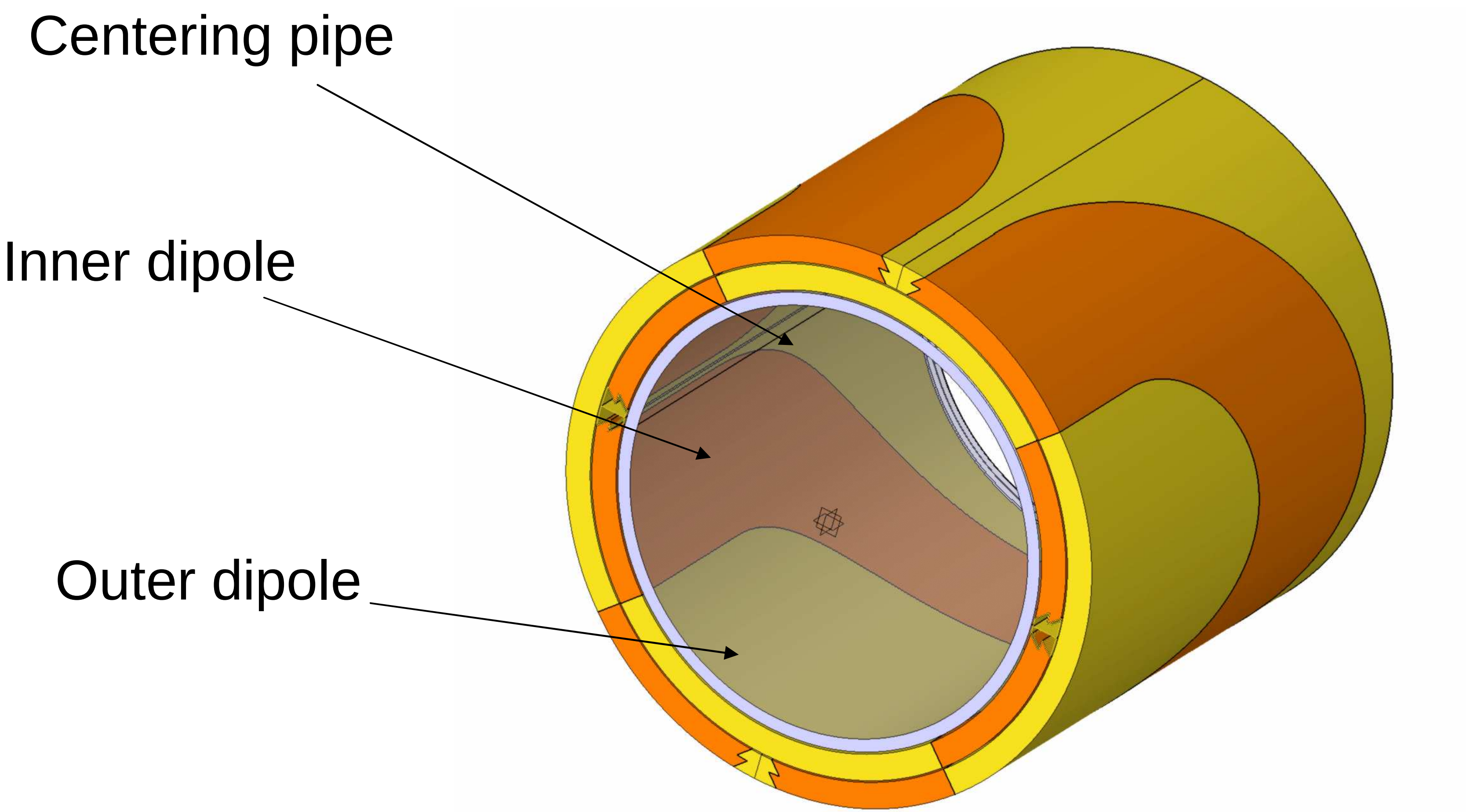
Field along the z axis [T @ 245 A]

Field as a function of r @ 150 A

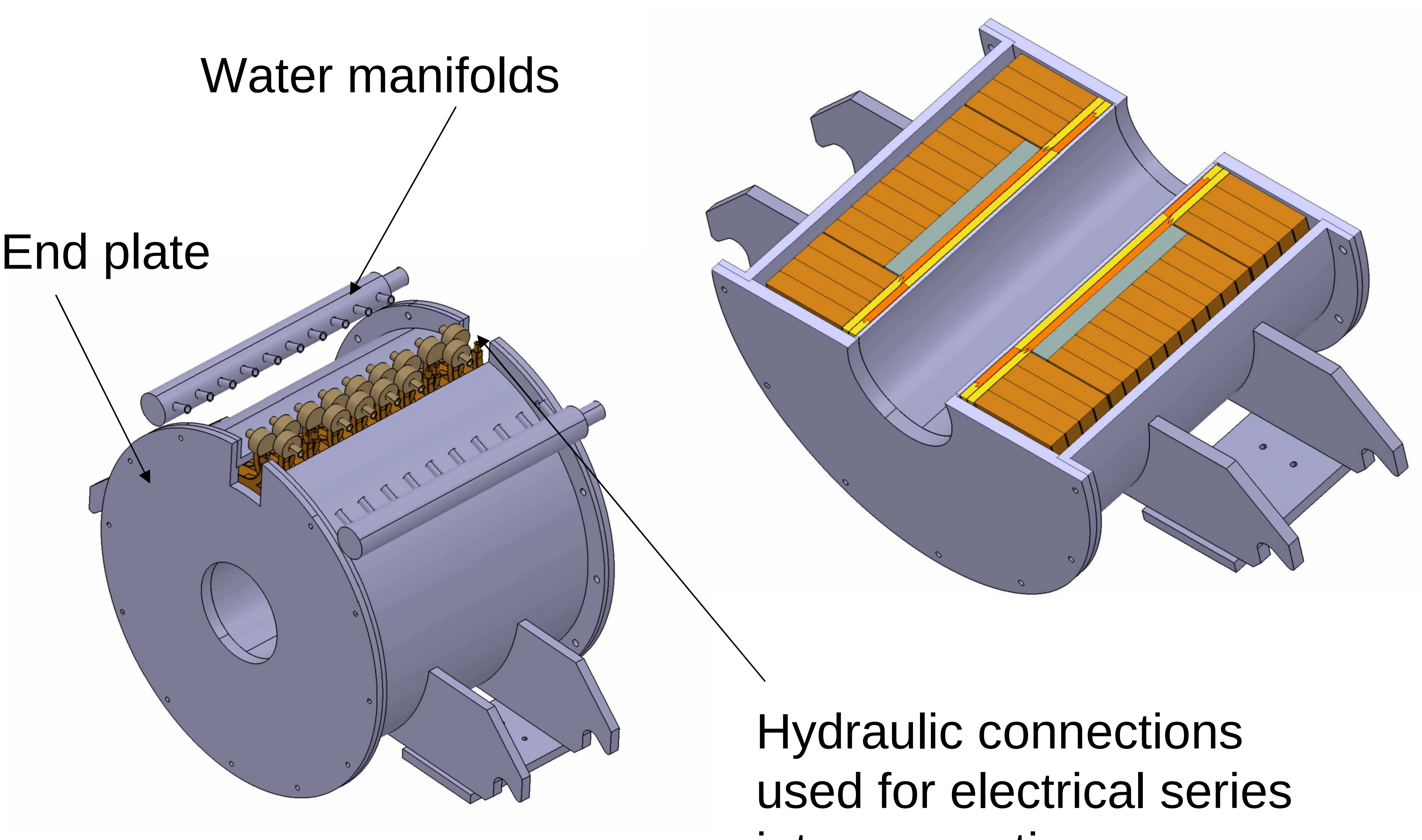


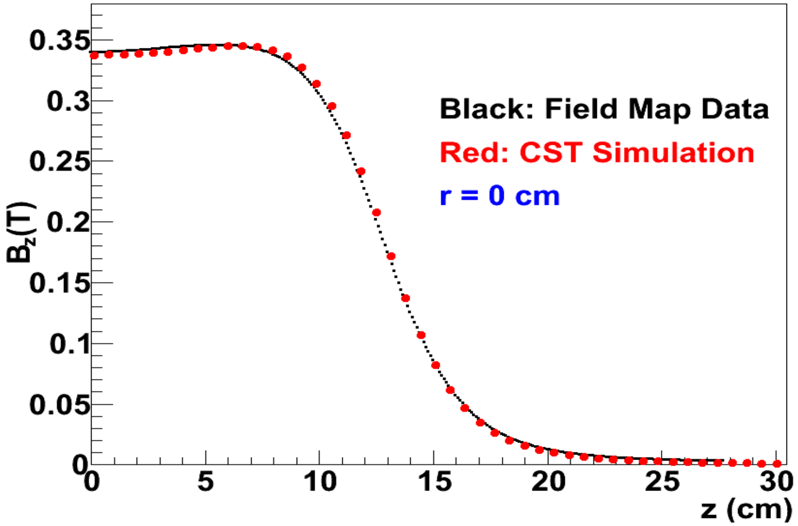
# Solenoid, correction & steering dipole components.

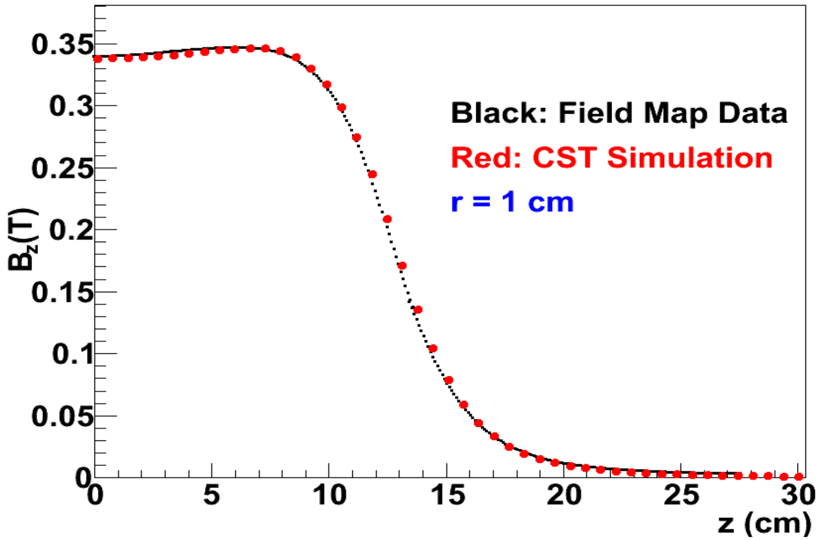


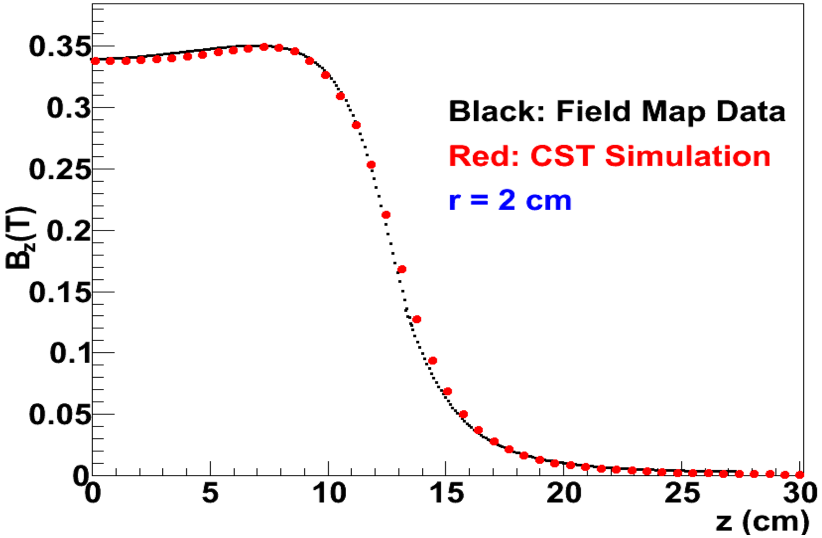
# Engineering design of the LEBT solenoids.

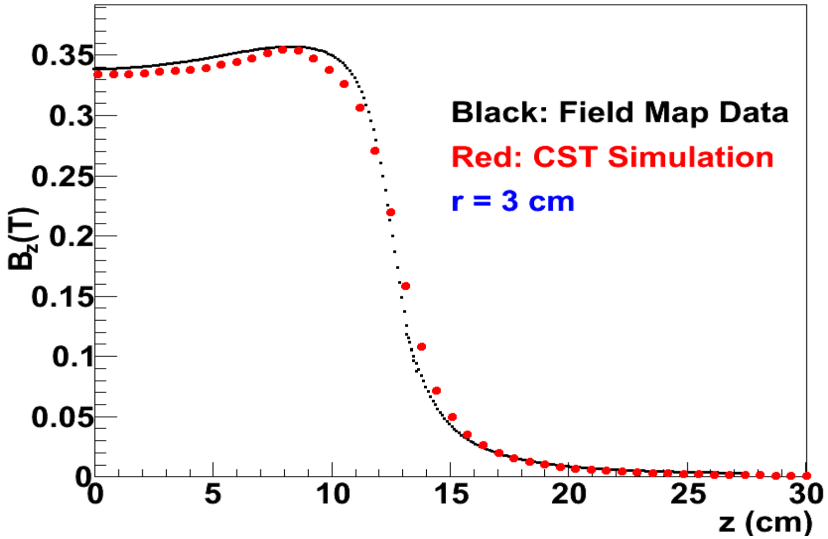


# Hall probe measurements and CST simulations.

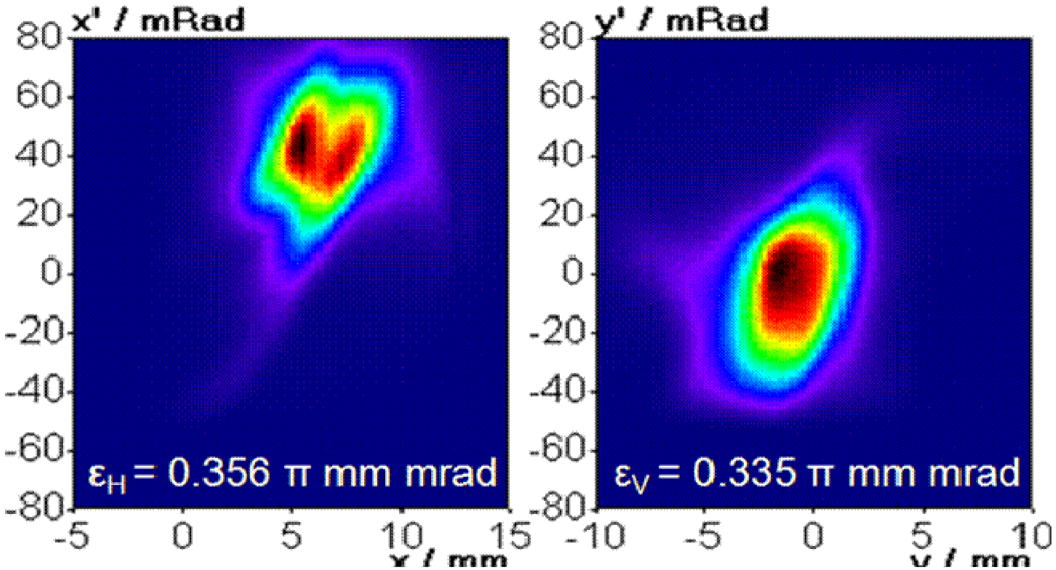


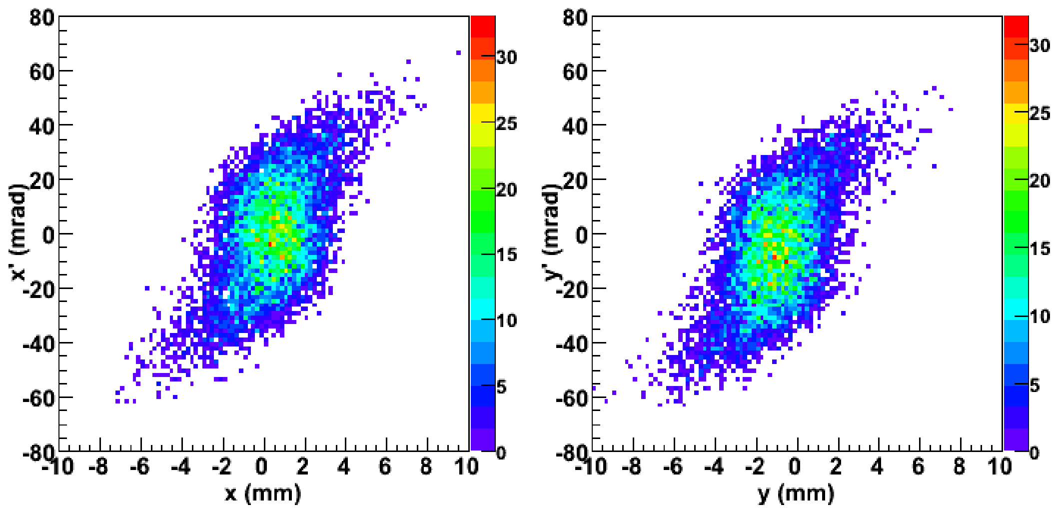



# (First) Beam transport measurements.




Emittance scanner data at the end of the LEBT




GPT simulation of the beam at the end of the LEBT

# Beam envelopes tracked through solenoids.

Beam envelopes along the LEBT simulated using GPT, based on the design parameters & assuming 10% space charge. The dotted lines show the solenoid/drift section boundaries.