Development of the LIPAc Ionization Profile Monitor (IPM)

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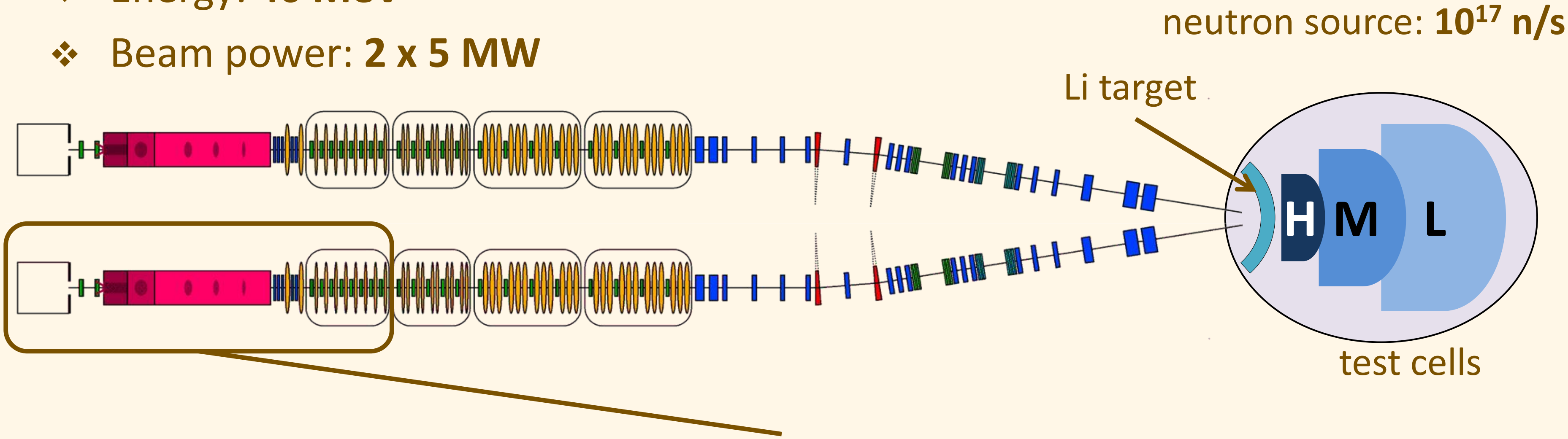
Outline

- LIPAc Accelerator (IFMIF - EVEDA)
- IPM – Characteristics
- IPM Development
  - Prototype Test
  - Final Design
  - Final IPM Test
- Conclusion

IFMIF: International Fusion Material Irradiation Facility

- Beam current: **2 x 125 mA** cw deuterium
- Energy: **40 MeV**
- Beam power: **2 x 5 MW**

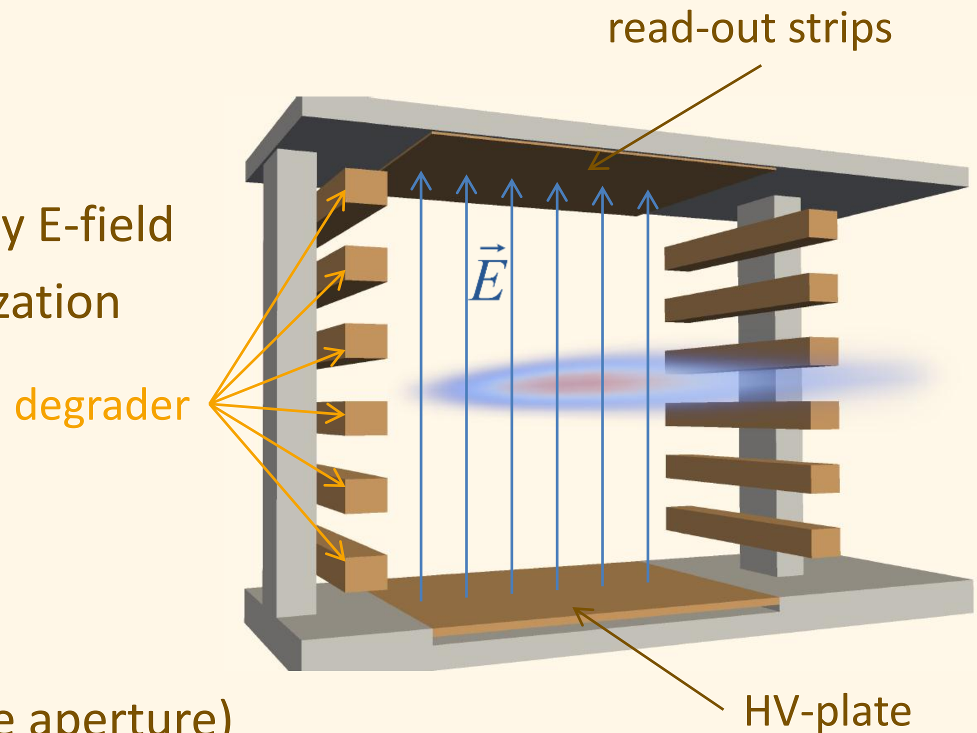


LIPAc: Linear IFMIF Prototype Accelerator

Prototype limited to **1 x 125 mA** cw @ **9 MeV, 1.125 MW**

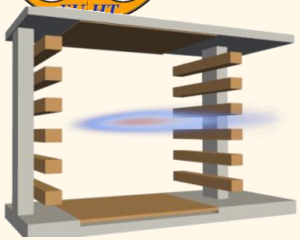
Principle of Operation:

- Beam ionizes residual gas
- Electrons / ions are extracted by E-field
- Beam profile derived from ionization current



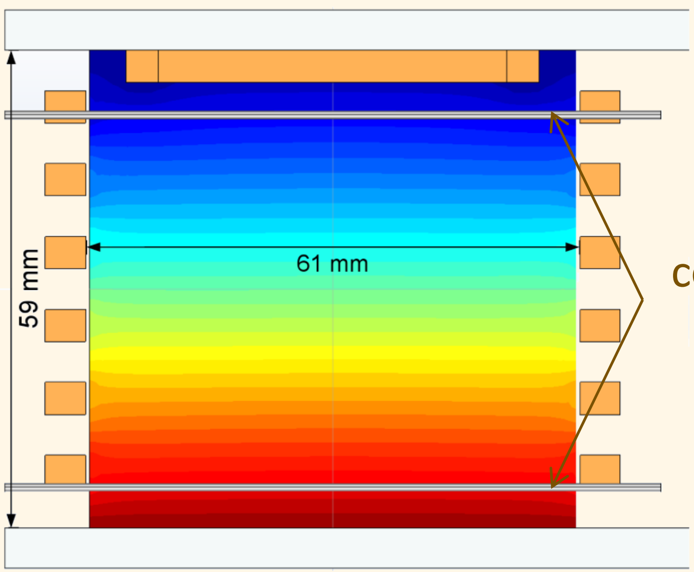
LIPAc Challenges:

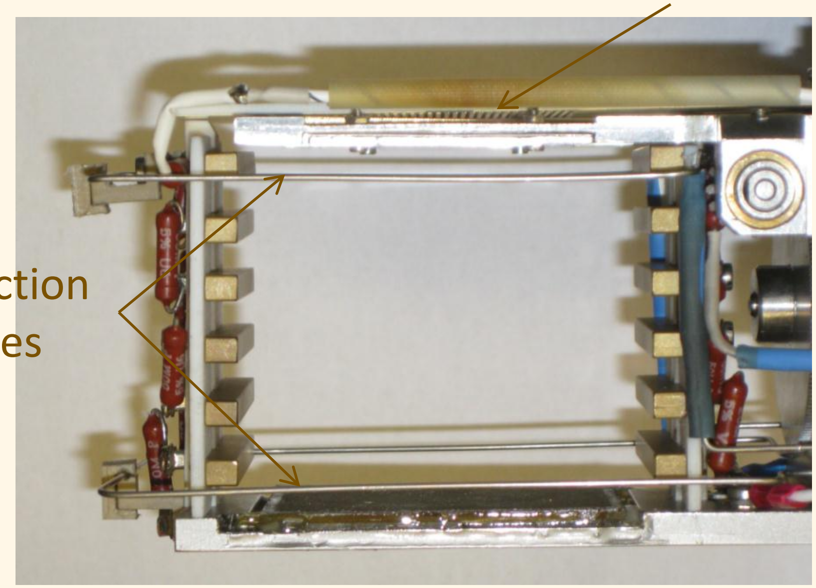
- Limited space
  - ⇒ Compact design (wrt. large aperture)
- High background radiation (~7 kSv/h close to the beam dump)
- Very high space charge effect



IPM Prototype Design 2009

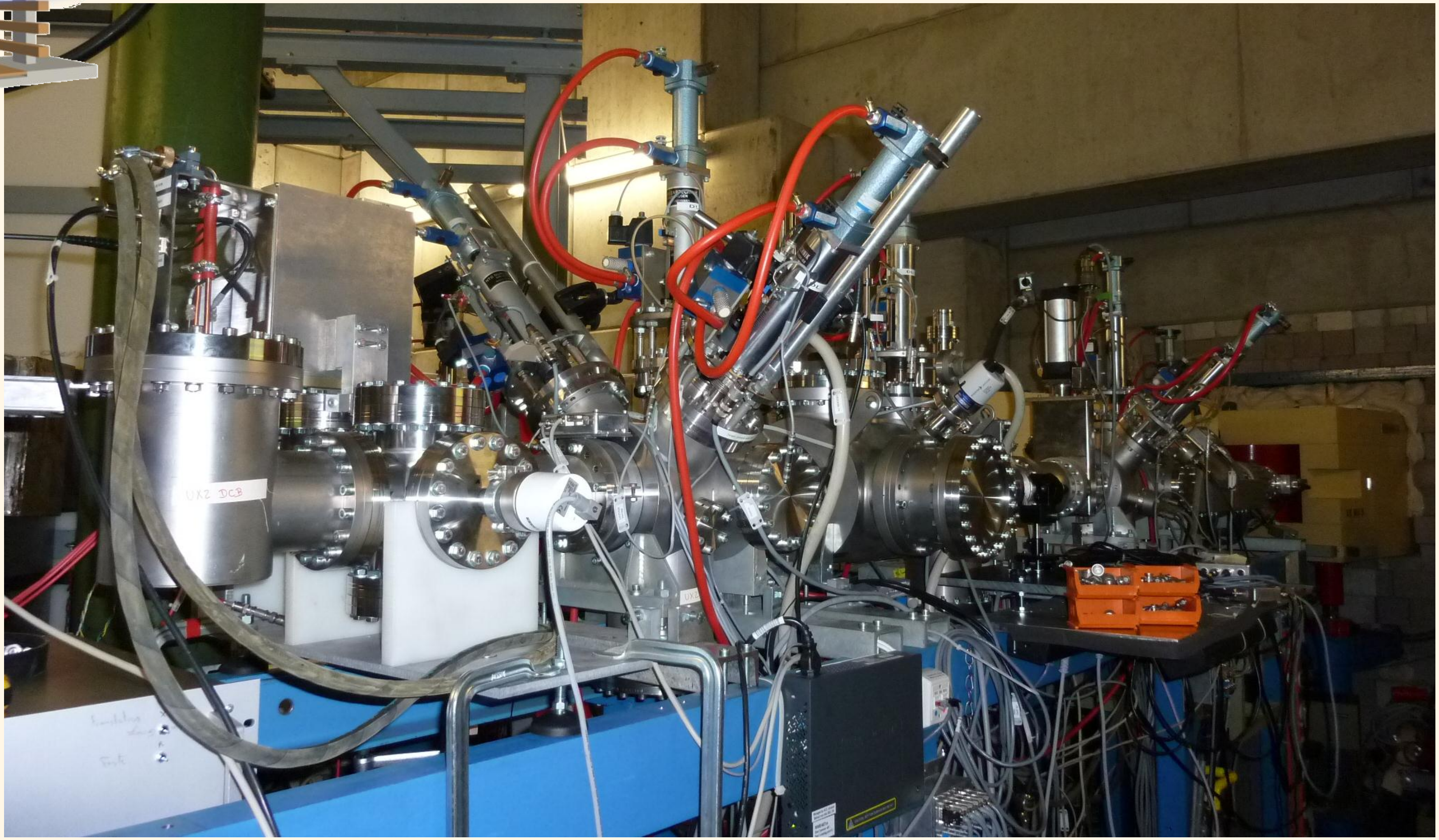
- Charge collected on 32 strips with 1.25 mm pitch
- Uniform electric field required to conserve beam profile
- Prototype designed based on FEM E-field simulations*
- Internal dimensions: 61 mm x 59 mm x 40 mm
- Voltage applied: 5000 V (E = 833 V/cm)



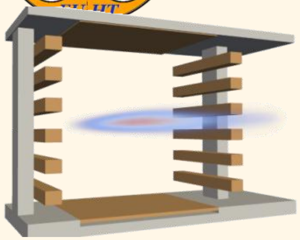


*Lorentz-E Particle Trajectory Solver Copyright © 1998 - 2010 Integrated Engineering Software Sales Inc.

IPM test at the UNILAC at GSI 2010

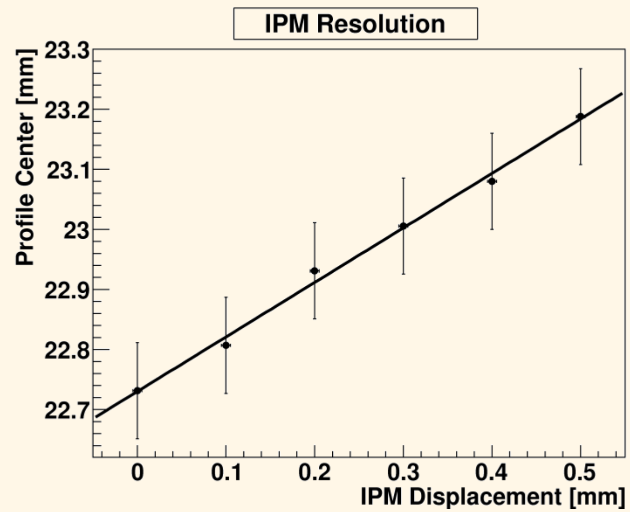


X2 branch at GSI



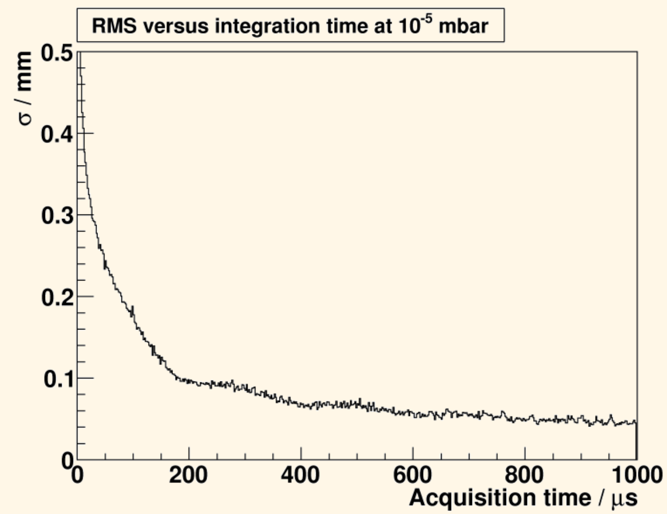
Position Resolution

- Move IPM in 100 µm steps perpendicular to the beam
- Averaged over 60 ms (16.7 Hz)
- Plot profile center versus IPM position

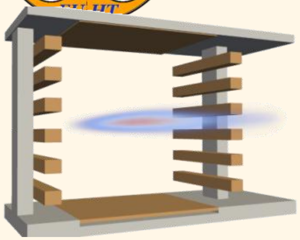


IPM resolves well 100 µm profile shifts

- Fluctuation of beam center versus data acquisition time
- 120 µA Xe^{21+}, 10^{-5} mbar N_2
- Plateau of < 100 µm at ~1kHz



Beam: 1 mA Xe^{21+}



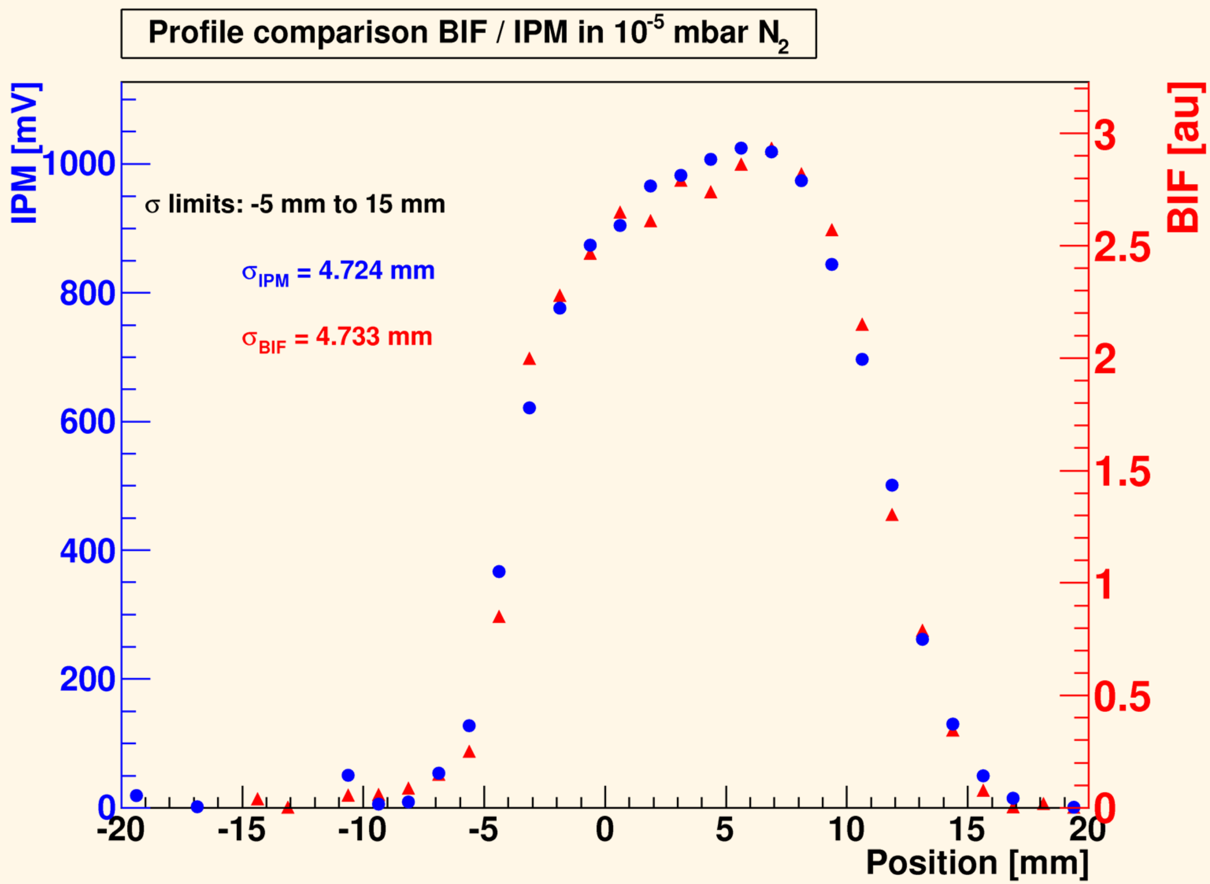
BIF Comparison

10^{-5} mbar N_2

BIF: Beam Induced Fluorescence

BIF Monitor based on light emitted by atoms excited by the beam

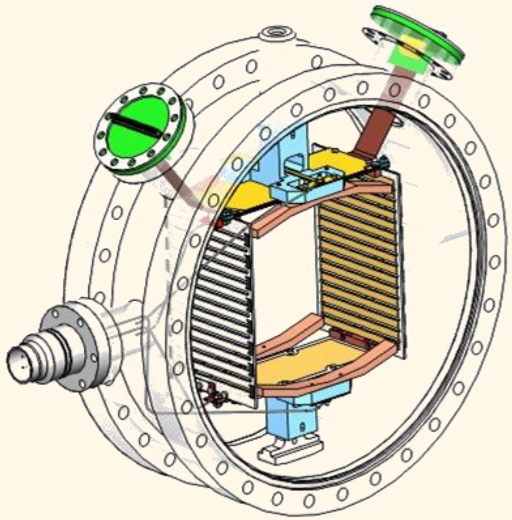
BIF profiles acquired by *Frank Becker, GSI*



Beam: 1 mA Xe^{21+}

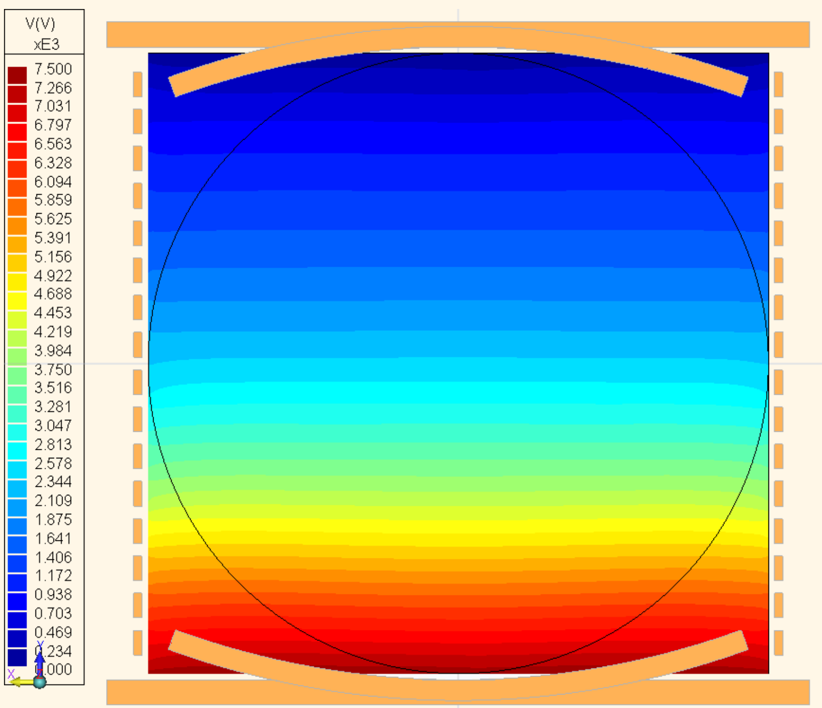
Final Design Challenges:

- Lack of space ⇒ very compact design required
- High radiation level ⇒ radiation hard components exclusively
- Space charge effect

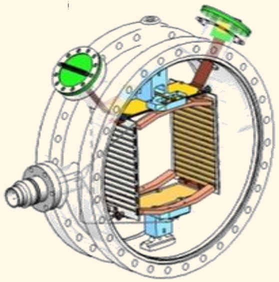


Design results:

- Depth of 100 mm with an aperture of 150 mm
- Active depth: 10 mm
- E-field uniform within ~ 3%



Particle Tracking – Ion Displacement



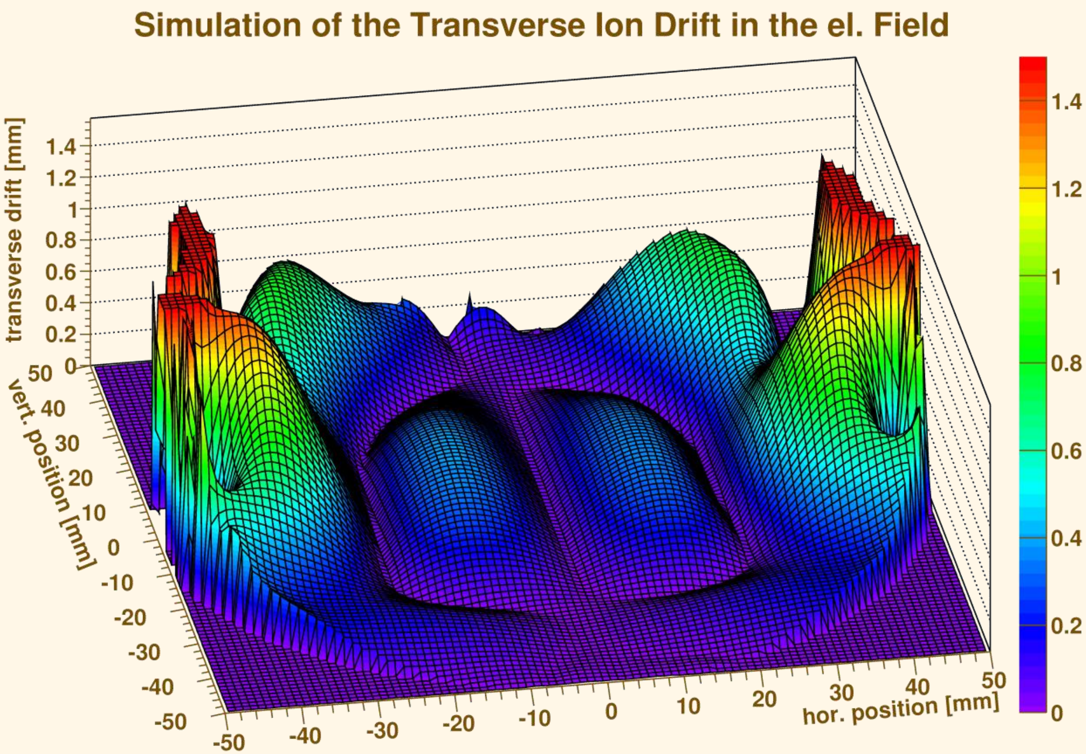
Neglecting Space Charge Effect!

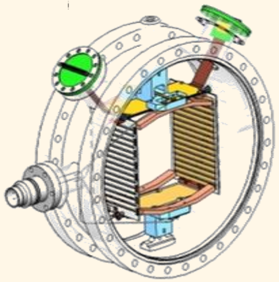
Particle Tracking:

Transverse displacement during ion drift versus starting position

In beam region:

Displacement < 500 µm

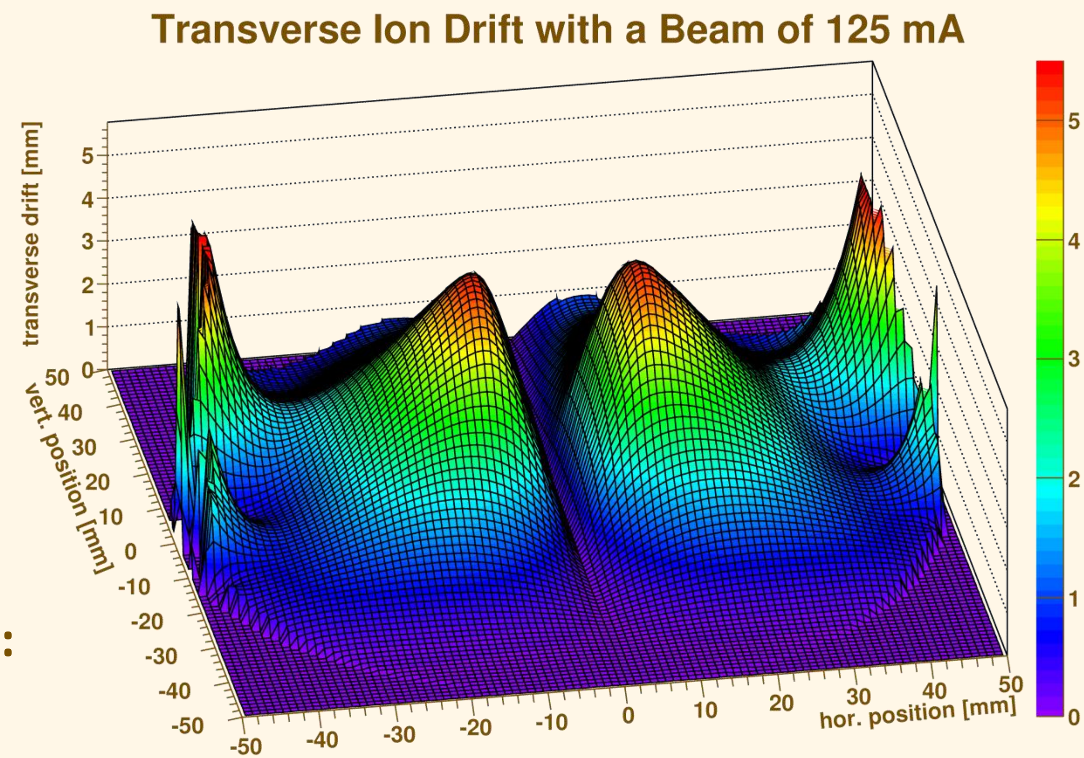




Space Charge for 125 mA Beam

Particle Tracking:

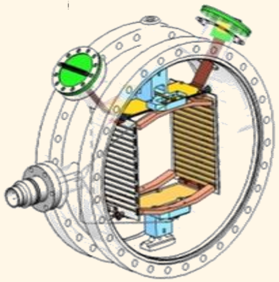
Transverse displacement during ion drift versus starting position



With space charge of 125 mA:

Displacement > 5 mm

Particle Tracking – Ion Displacement



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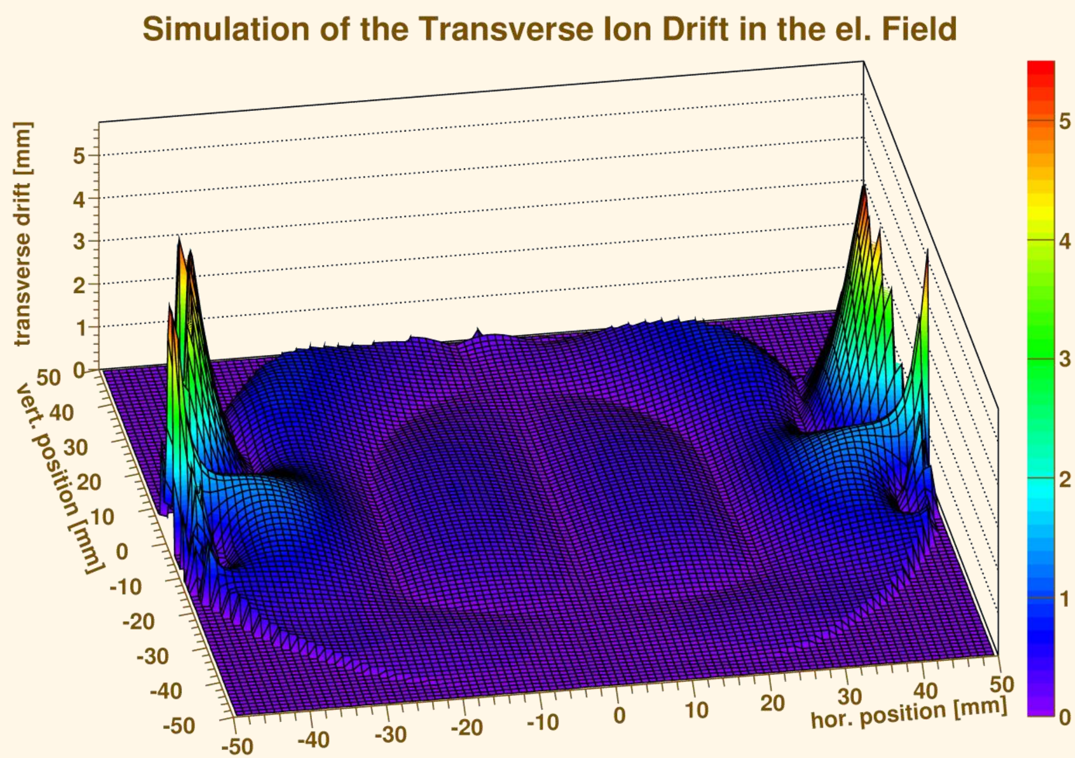
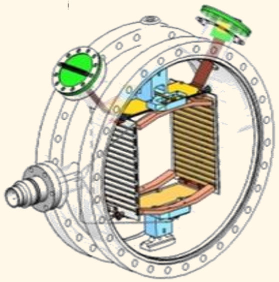


Tracking w/o space charge in same scale!!!

Simulation of a 9 MeV beam profile measurement @ 125mA:

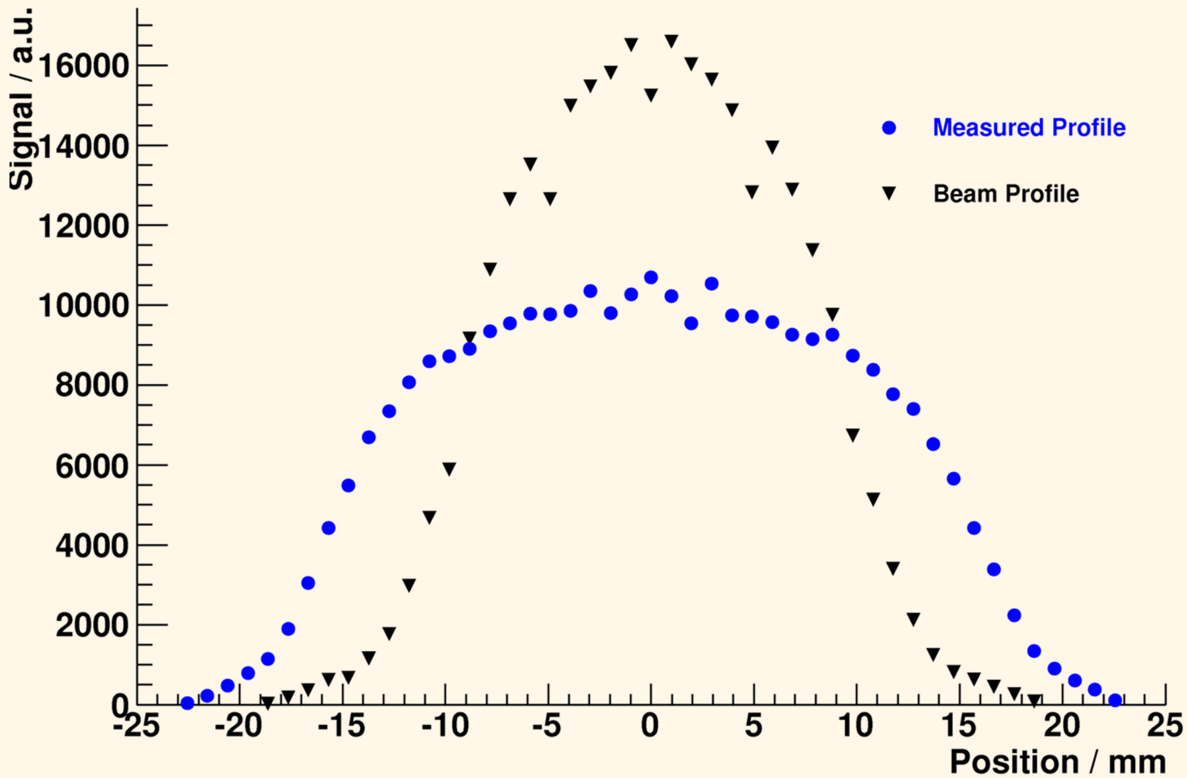


Resulting Profile:

Strong Distortions due to space charge

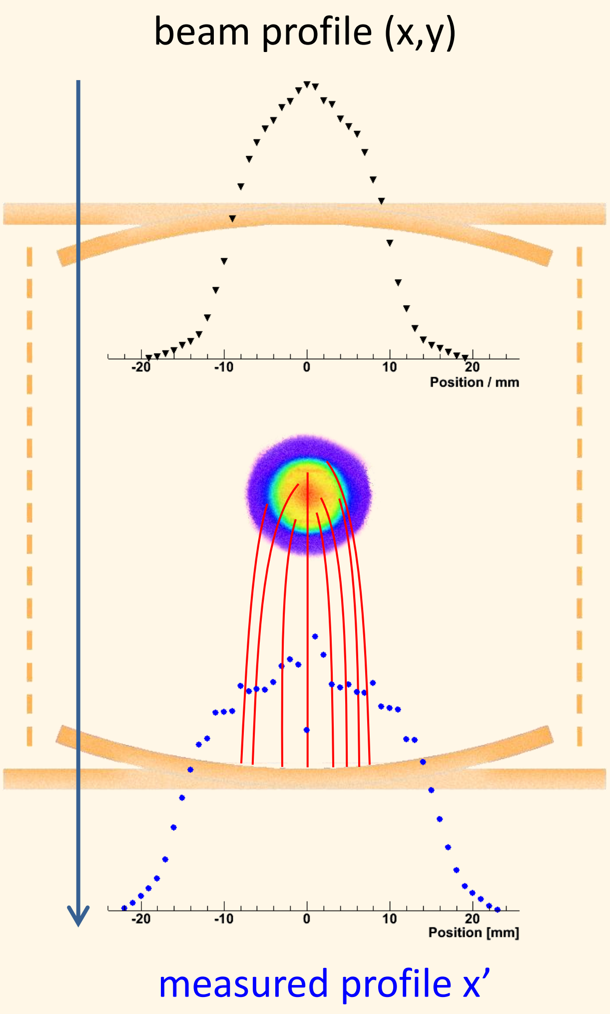
original beam profile

measured profile (simulation)



Idea:

- Calculate space charge force
- Determine ion displacement at each position
- Correct the profile



Idea:

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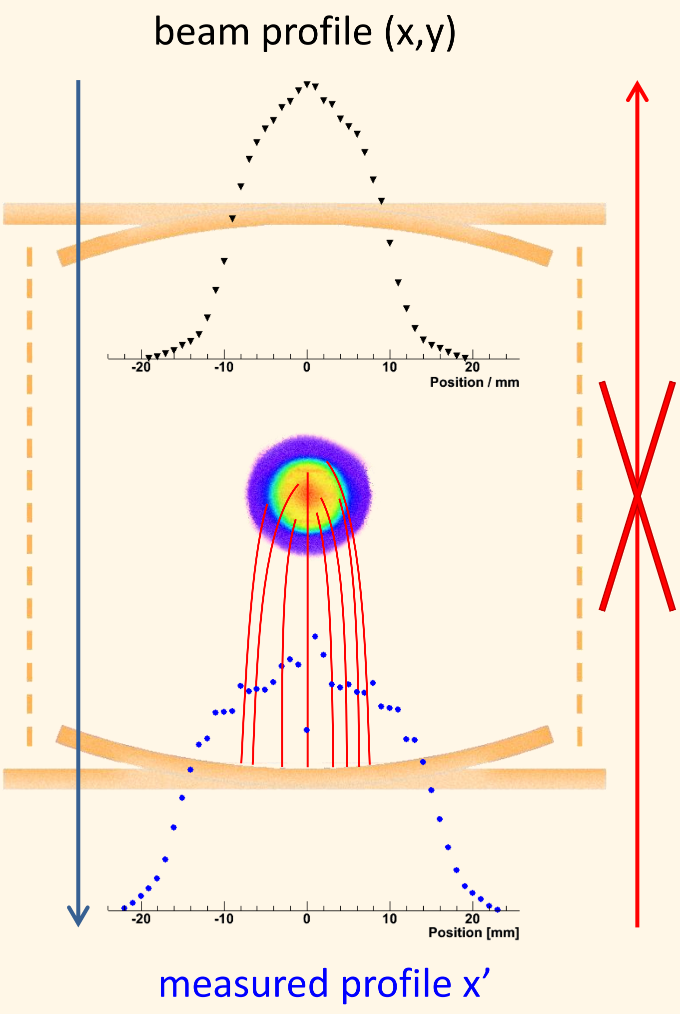
Problem:

Beam particle distribution required to calculate space charge force

Approach:

Assume *beam distribution*….



SC Correction Algorithm

Idea:

- Calculate space charge force
- Determine ion displacement at each position
- Correct the profile

Problem:

Beam particle distribution required to calculate space charge force

Approach:

Assume *beam distribution*….

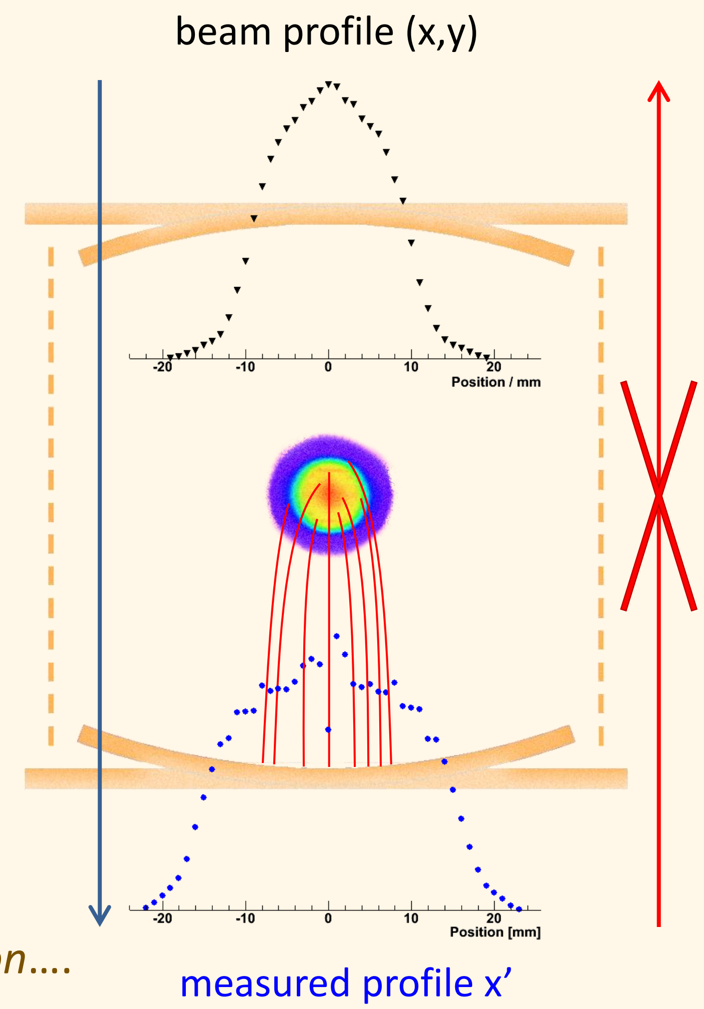
Problem:

No bijective mapping between (x,y) and x’

Approach:

Apply statistics: $g(x') = \Sigma\, p_{x'}(x,y)\cdot(x,y)$

$p_{x'}(x,y)$ is given by *beam distribution*….



Idea:

- Calculate space charge force
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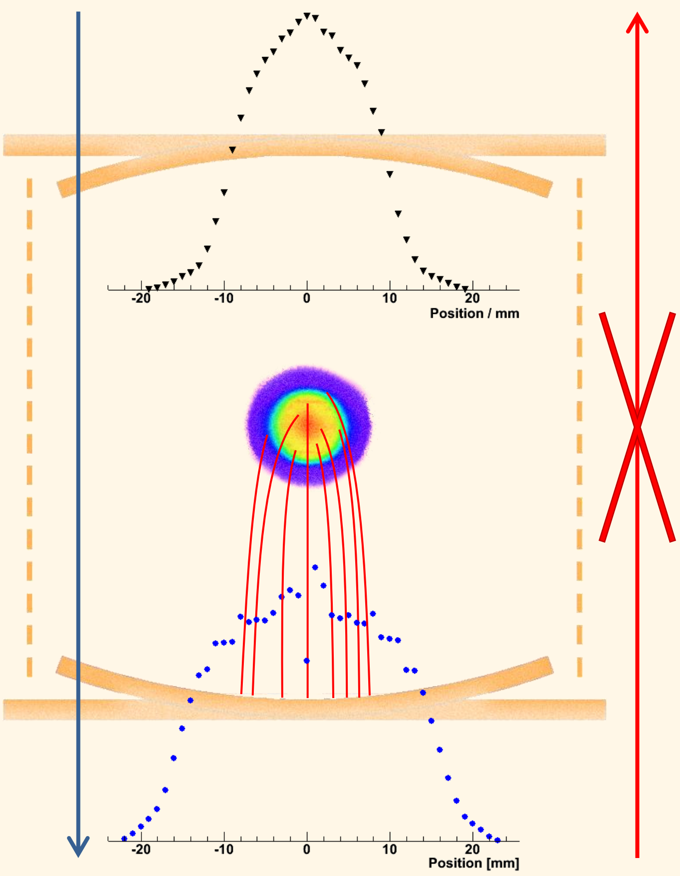
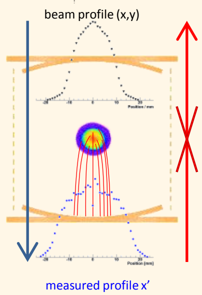


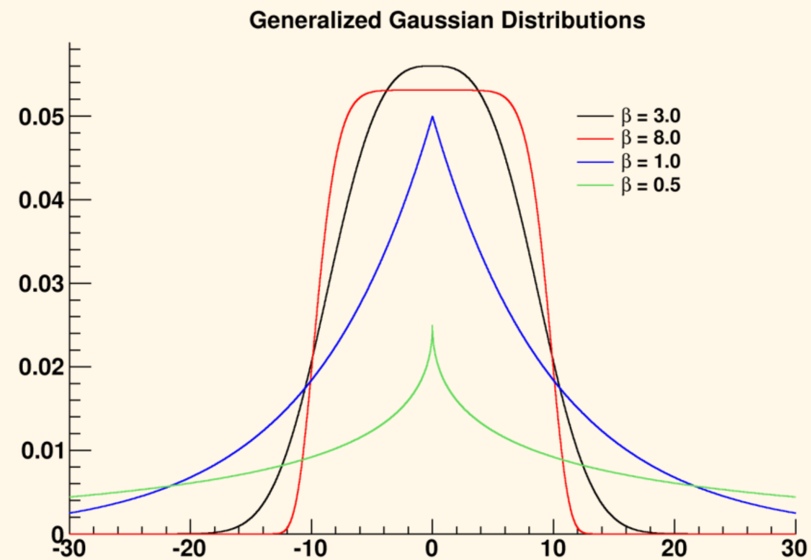
⇒ Use test distribution as input!



What could be a proper test distribution?

Candidate for test distribution: Generalized Gaussian

$$p_{\alpha,\beta,\mu}(x) = \frac{\beta}{2\alpha\Gamma(1/\beta)} e^{-\left(\frac{|x-\mu|}{\alpha}\right)^{\beta}}$$

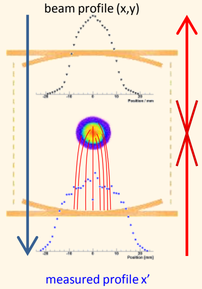


µ given by profile center

$\rightarrow$ two degrees of freedom!

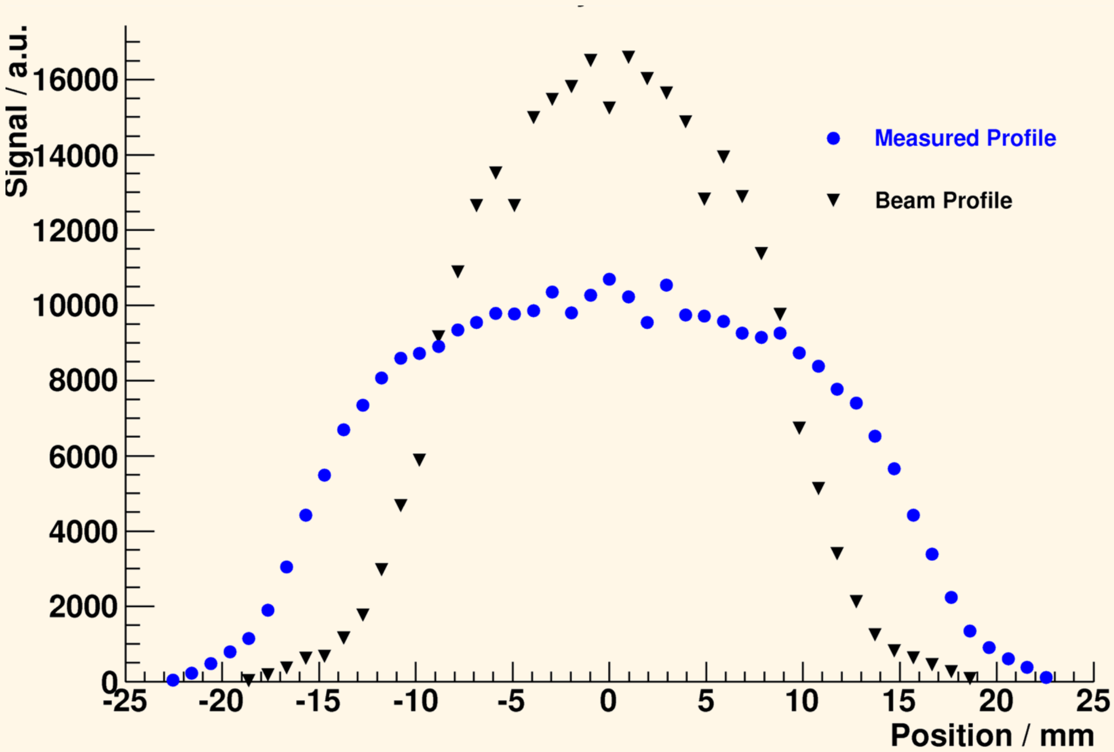
Cover any shape ranging from peaked Gaussian to rectangular distributions!

Simulation of a 9 MeV beam profile measurement @ 125mA:

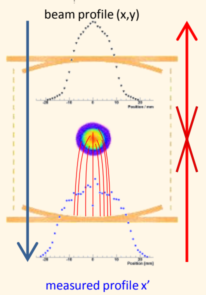


Original beam profile:

RMS: 6.27 mm
Kurtosis: -0.56



Simulation of a 9 MeV beam profile measurement @ 125mA:



Original beam profile:

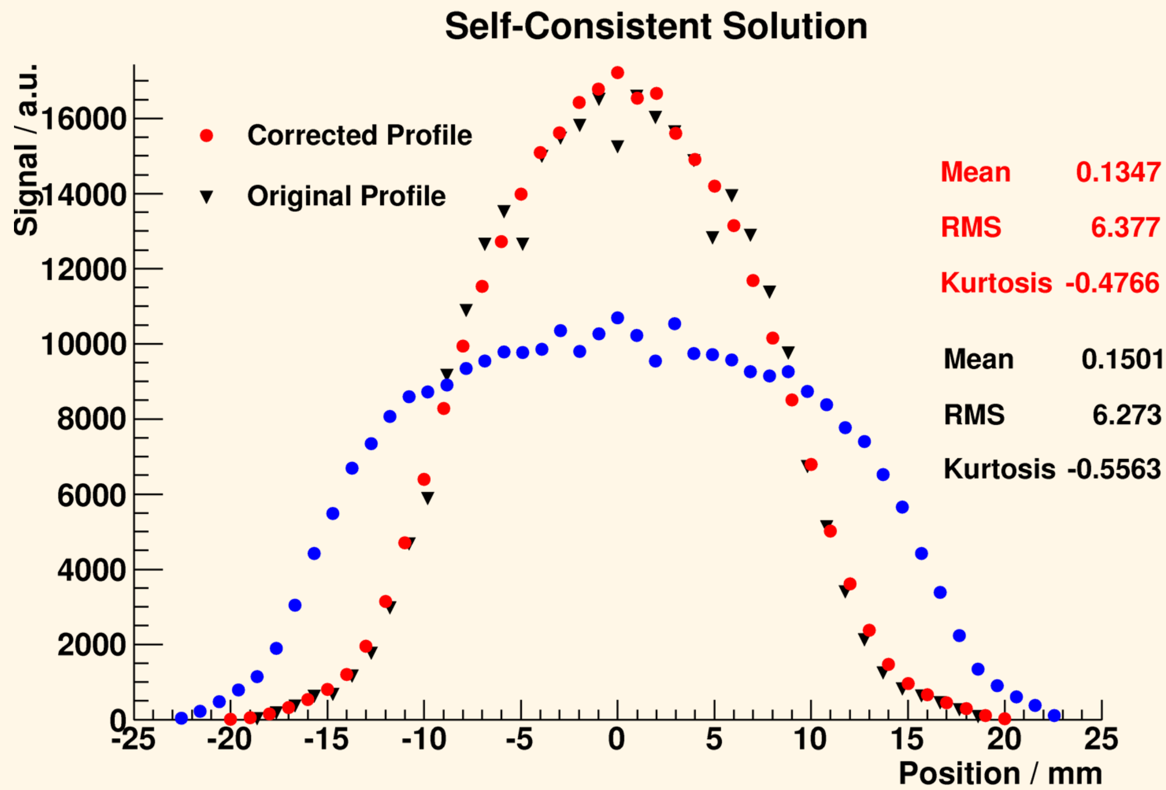
RMS: 6.27 mm
Kurtosis: -0.56

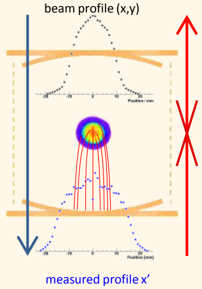
Parameters of test distribution:

RMS: 6.30 mm
Kurtosis: -0.50

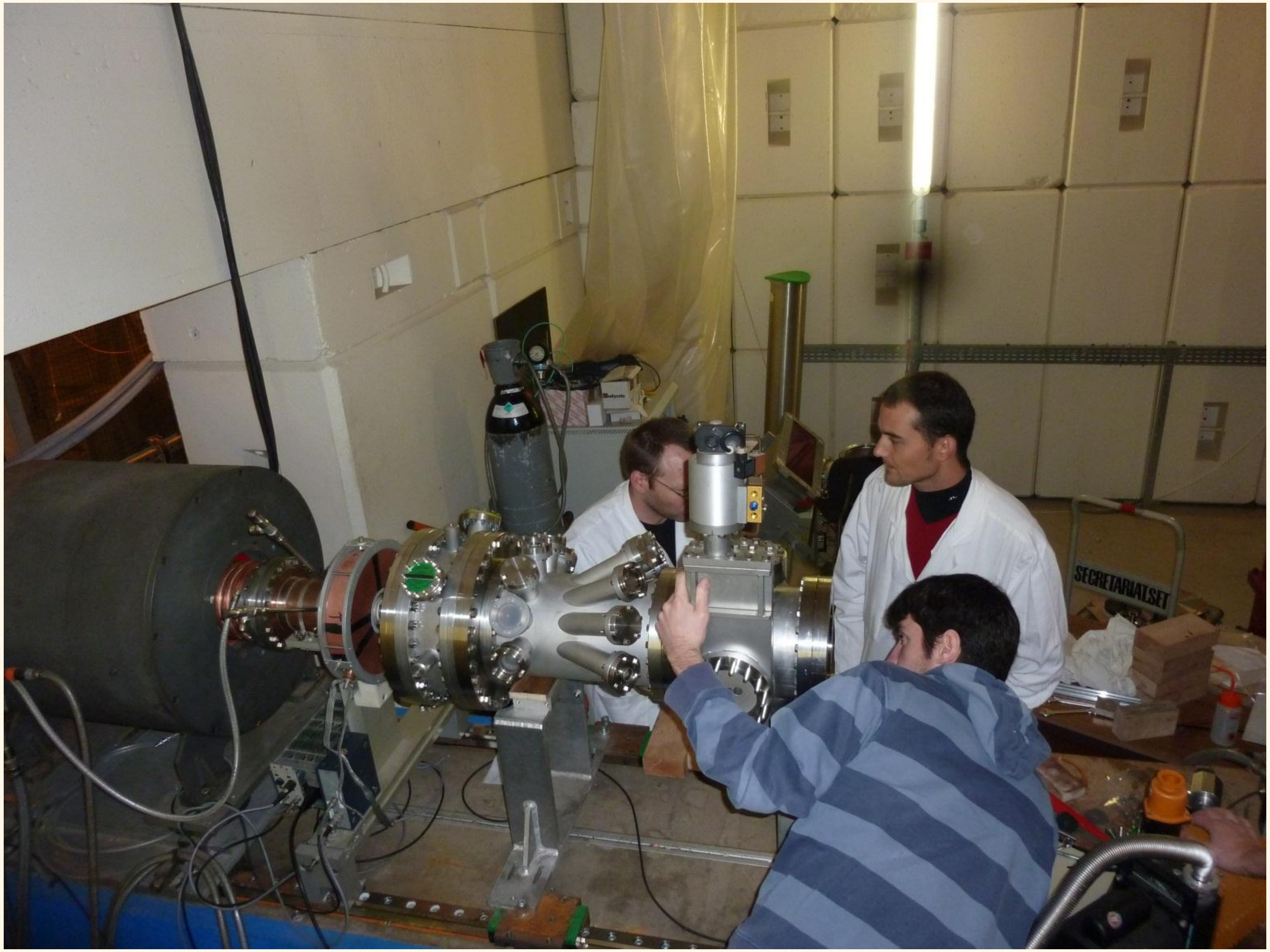
Consistent with:

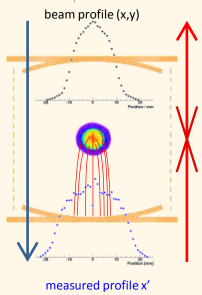
RMS: 6.38 mm
Kurtosis: -0.48





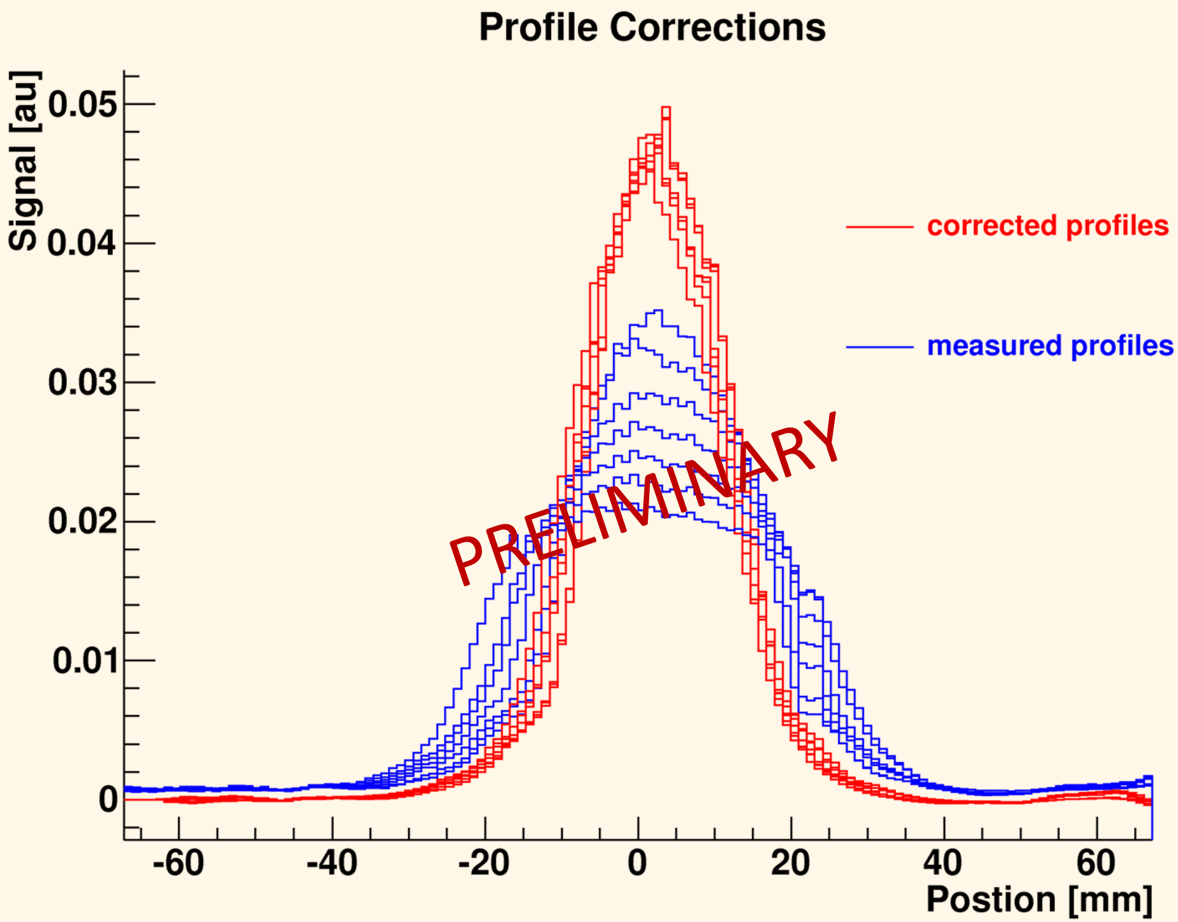
IPM test at SILHI source at CEA Saclay 2012



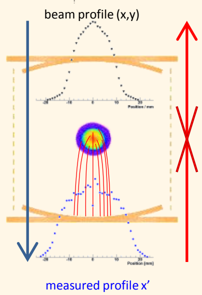


Test at SILHI source at CEA Saclay

- 6 mA beam @ 90 keV
- Profiles at different IPM voltages (blue)
- SC correction for each voltage
- Corrected profiles (red) should match!



SC Correction Algorithm - Conclusion



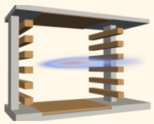
__Advantages__:

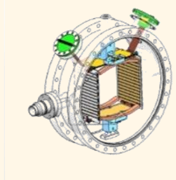
- Cheap - no additional hardware components required
- Option to correct for other well-known distortions
- Generalized Gaussians grant wide range of possible profile shapes
- Good correction results according to simulations
- Experimental tests look promising (Analysis not yet terminated!)

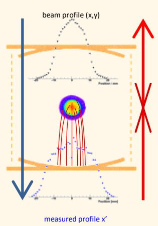
__Disadvantages__:

- Still in a very preliminary phase!
- No correction possible for profiles that cannot be approximated by generalized Gaussians!

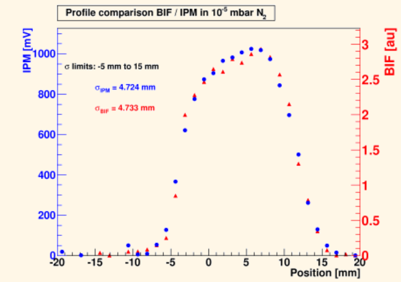
Conclusion

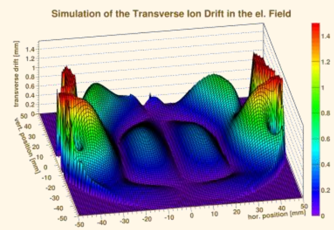


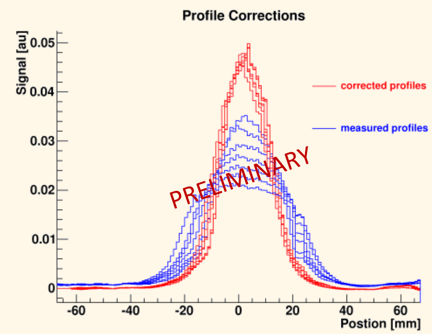




- IPM prototype extensively tested at GSI
- Final IPMs designed
- Final IPM tested
- Space Effect broadens profile
- SC correction algorithm
  - Works well in simulation
  - Experimental tests look promising







Acknowledgments

Sincere Thanks *to all the people*

that have contributed the work!

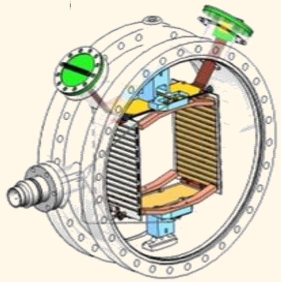
Particular Thanks to

the ***SILHI group*** and

the ***Beam Diagnostics group at GSI***!

Backups

*Example of a **not** self-consistent solution:*



Parameters of test distribution:

RMS: 8.72 mm
Kurtosis: -0.81

Not consistent with:

RMS: 7.15 mm
Kurtosis: -0.75

Original beam profile:

RMS: 6.27 mm
Kurtosis: -0.56