Commissioning of the DESIR HRS

A **H**igh **R**esolution **S**eparator for low energy physics at GANIL

Speaker : Julien Michaud

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EMIS 2022 at RAON

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Contents

SPIRAL2 phase 1+: DESIR *(Désintégration, excitation et stockage des ions radioactifs)*

Large variety of beams:

- Target/beam fragmentation at SP1
  => Light neutron-rich and neutron-deficient nuclei
- Fusion-evaporation at S3
  => (Super-)heavy and neutron-deficient nuclei

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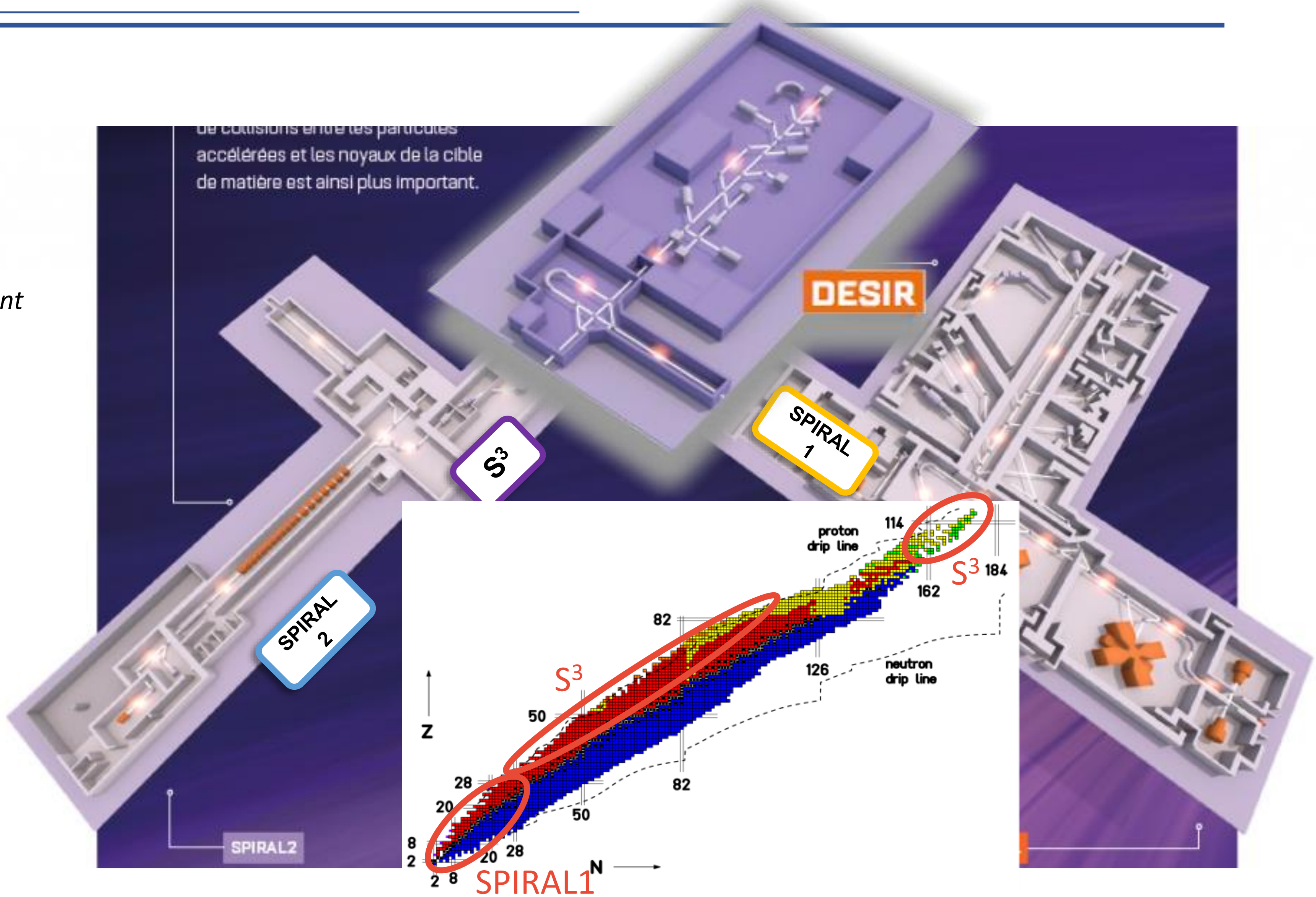
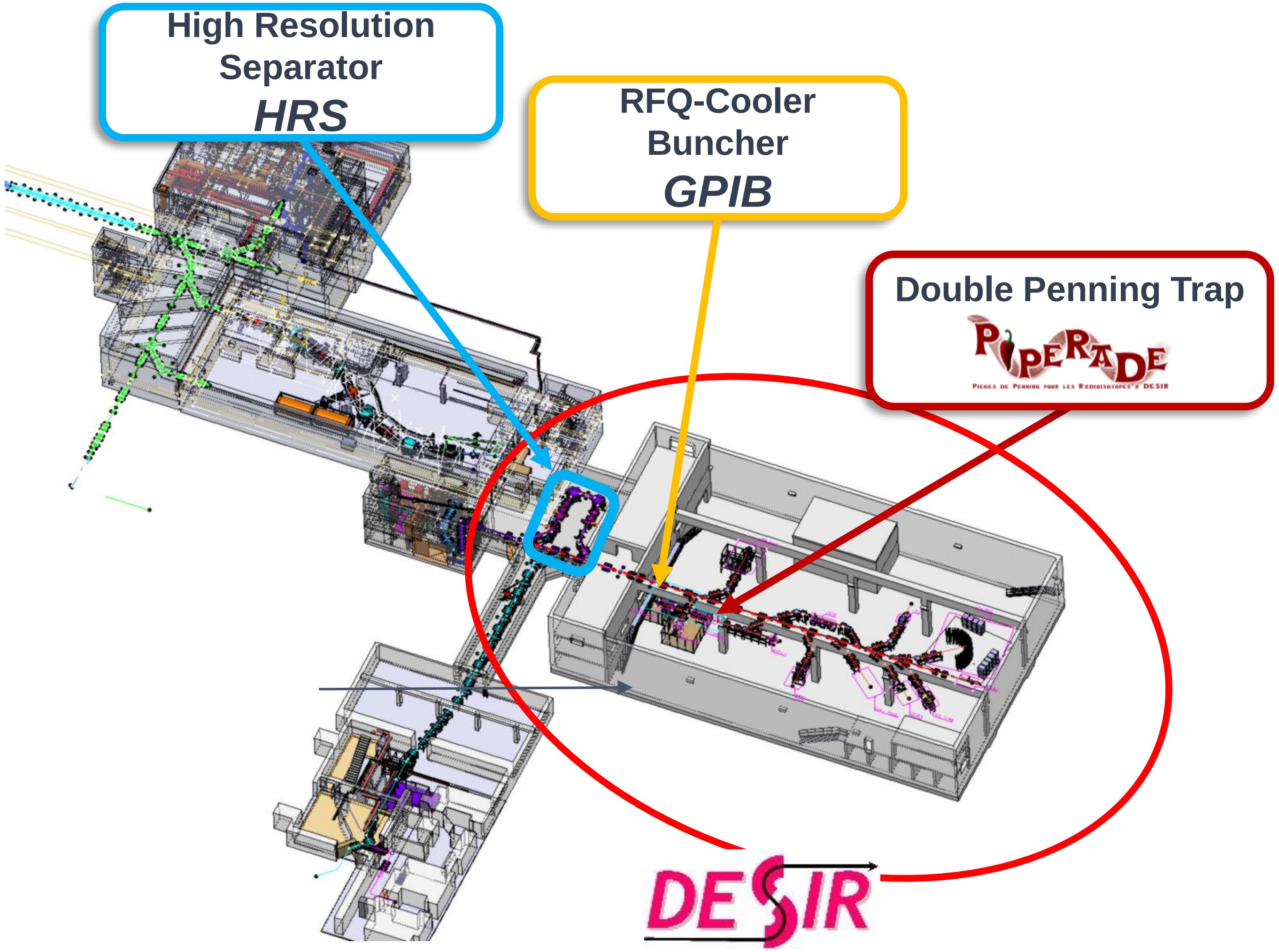


Will allow studies on:

- *Fundamental properties of nuclei*
  => mass, shape, decay modes, structure
- *Fundamental interactions*
  => Weak interaction/beta decay
- *High-resolution laser spectroscopy*

Beam preparation for DESIR – LP2I Bordeaux contribution



Mass separation/beam purification:

HRS
- Up to isobars level $\sim \frac{M_0}{\Delta M} = 20\ 000$

Piperade 1^{st} trap
- $20\ 000 < \frac{M_0}{\Delta M} \leq 10^5$

Piperade 2nd trap
- $R \approx 10^6 - 10^7$

Beam preparation:

GPIB
- Cooling and bunching

Piperade 2nd trap
- Accumulation trap

Mass measurements:

Piperade 2nd trap
- Mass precision: $\approx 10^8$

Optimal performances can be reached only if a 1st good cleaning is done with the HRS

The HRS

*HRS: **H**igh **R**esolution mass **S**eparator*

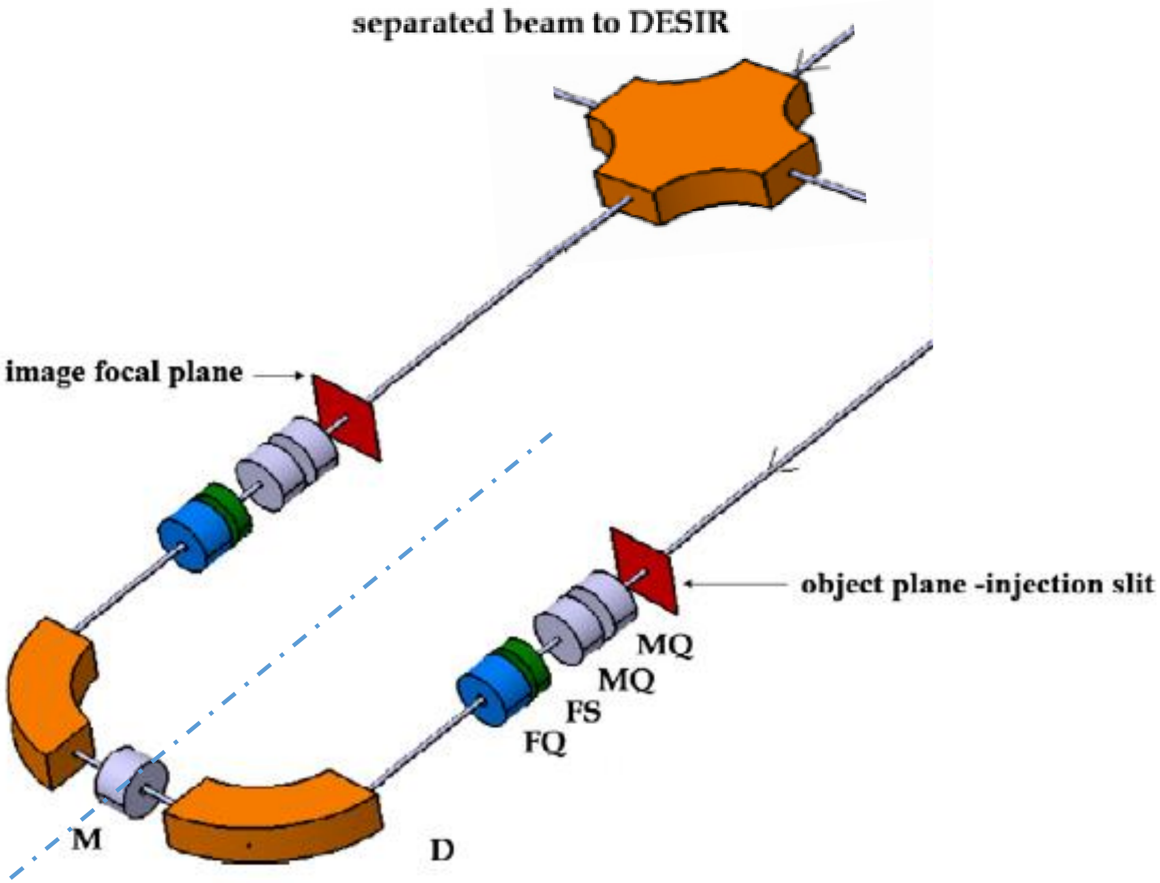
Lattice [1] and elements:

D : Two 90° *magnetic* dipoles (36° entrance/exit angles)
MQ : Matching quadrupoles
FQ : Focusing quadrupoles
FS : Focusing sextupoles
M : A multipole (up to 5th order)

(MQ, FQ, FS, M: *Electrostatic*)

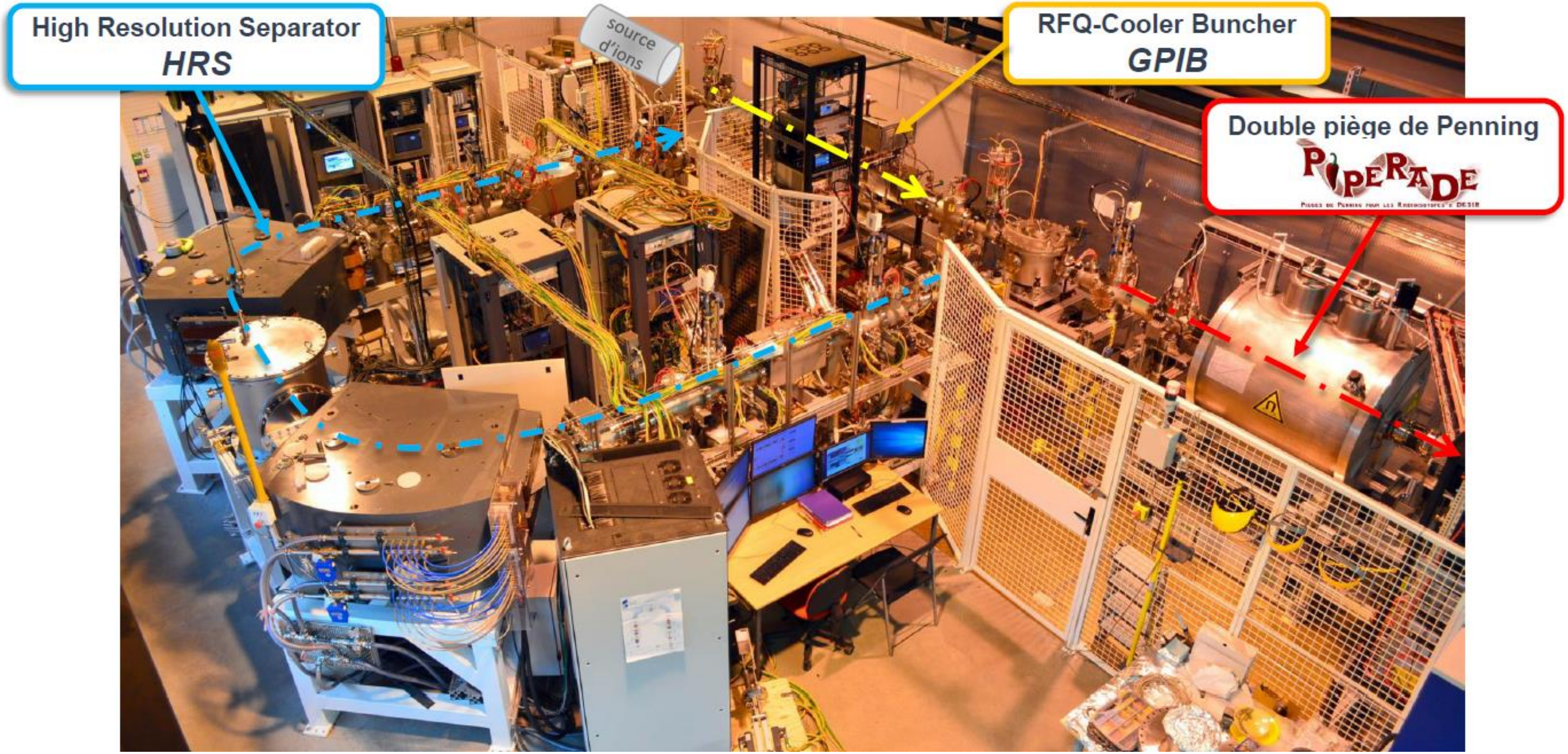
Configuration: MQ-MQ-FS-FQ-D-M-D-FQ-FS-MQ-MQ

Mirror symetry is imposed to minimize aberrations

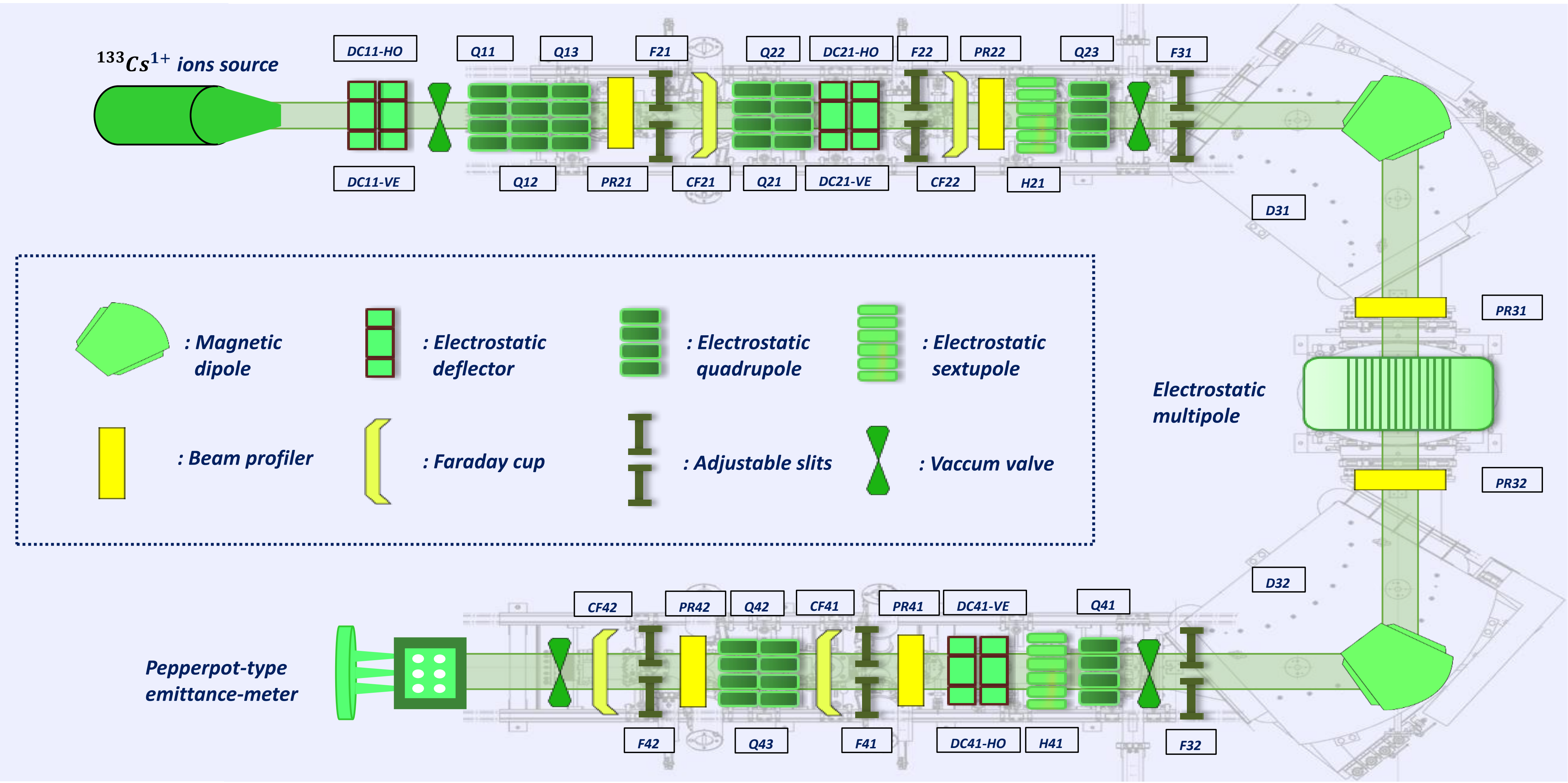


[1] T. Kurtukian Nieto, R. Baartman, B. Blank, T. Chiron, C. Davids, et al.. SPIRAL2/DESIR high resolution mass separator. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, Elsevier, 2013, 317, pp.284-289.

HRS at LP2IB

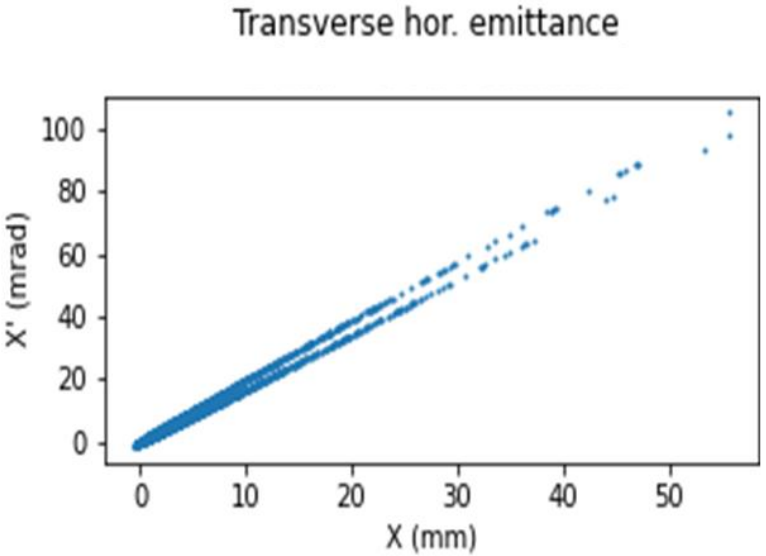

High Resolution Separator
HRS
source d'ions
RFQ-Cooler Buncher
GPIB
Double piège de Penning
PIPERADE

HRS synoptics: a compact beamline



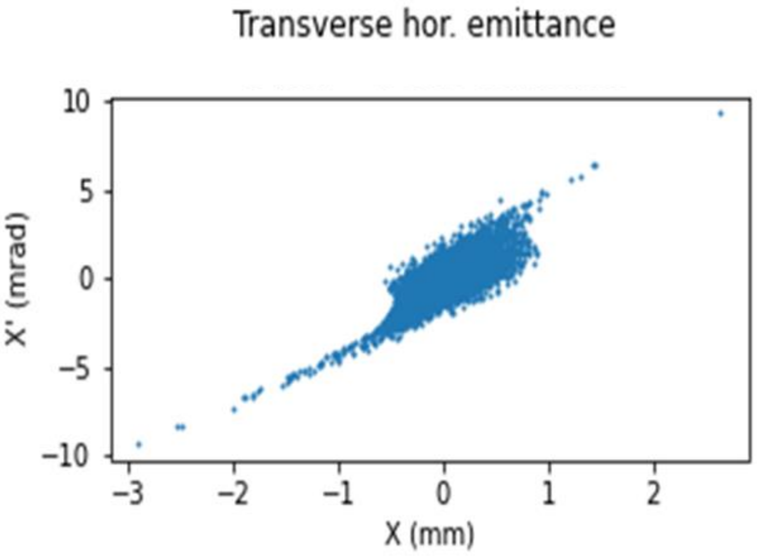
Contents

Different levels of aberrations (simulations)



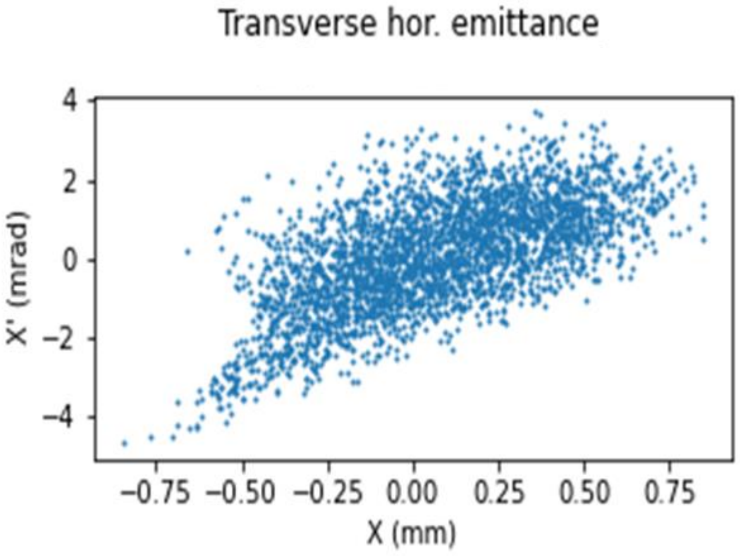
Hexapolar aberration (2^{nd} order)
is dominant

Typically « C-shaped »



Octupolar aberration (3^{rd} order)
Hexapolar corrected

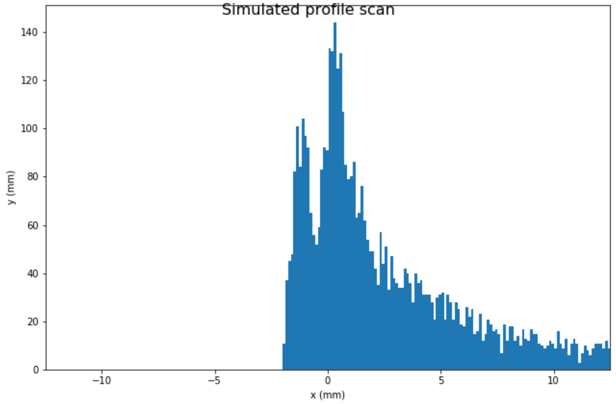
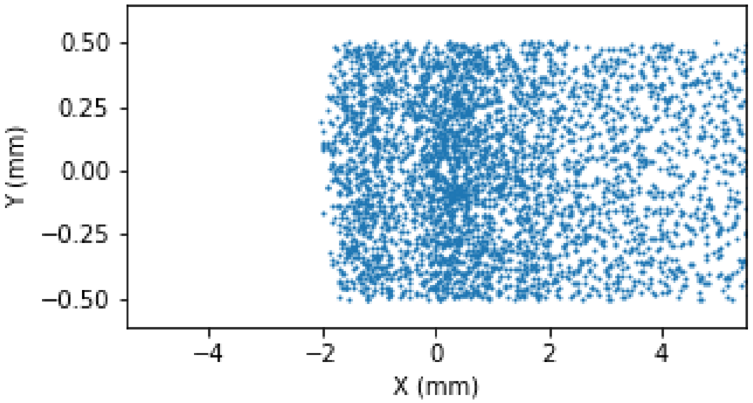
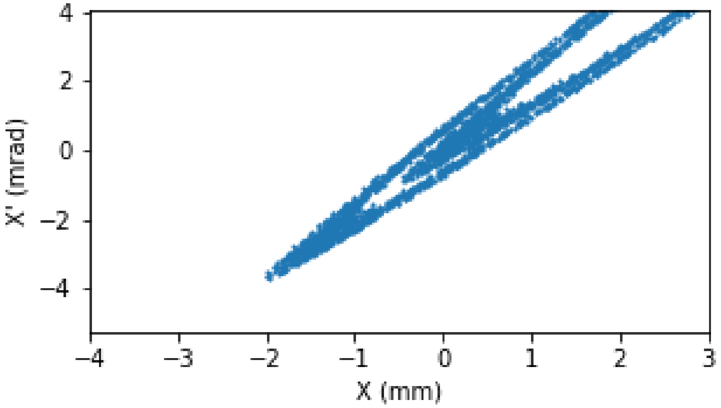
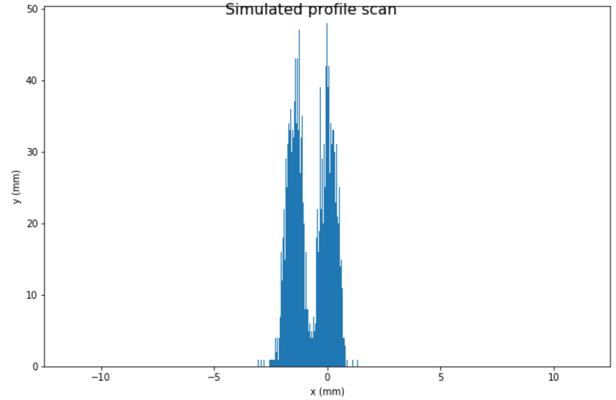
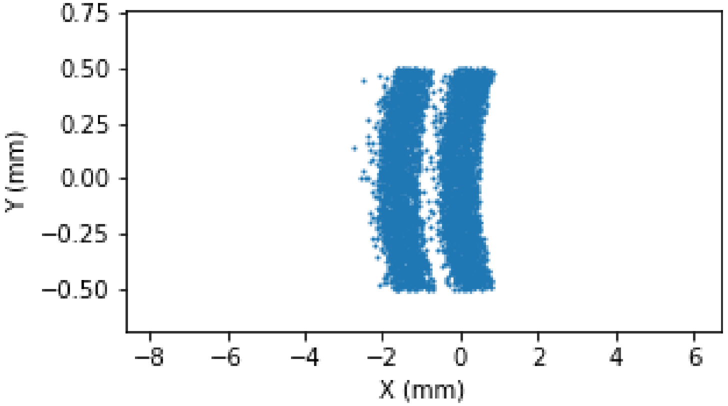
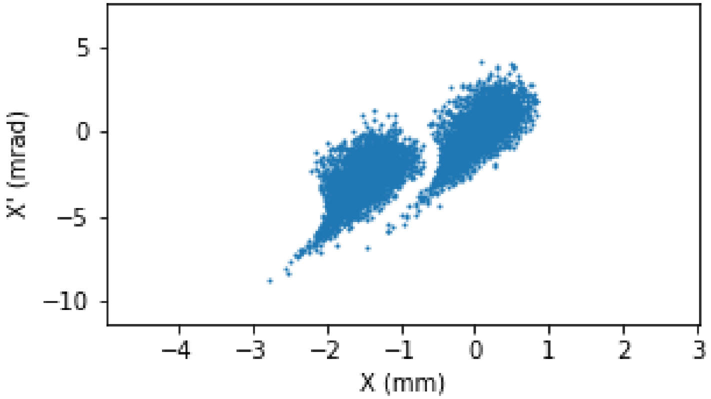
Typically « S-shaped »



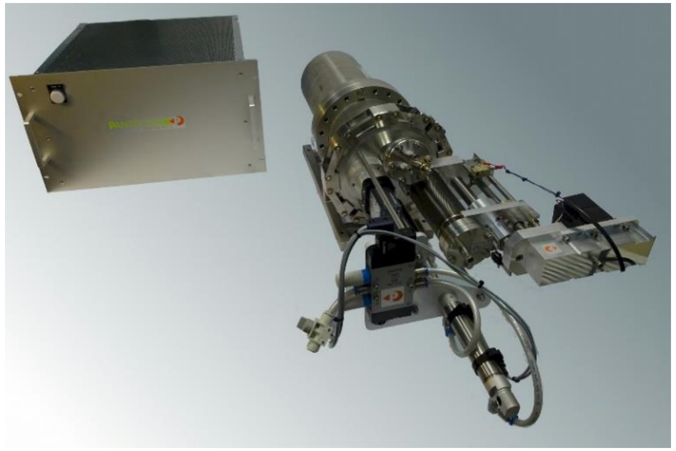
Higher order aberration ($> 3^{rd}$ order)
Octupolar corrected

Optical aberrations tend to increase the beam size and need to be corrected

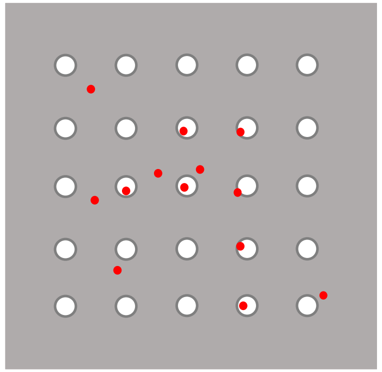
Effect of optical aberrations on beam separation (simulations)

	Beam position spectra	Front view of the beam	Emittance profile (XX’)
Hexapolar aberration dominant (HRS-like)			
Corrected beam (few aberrations)			

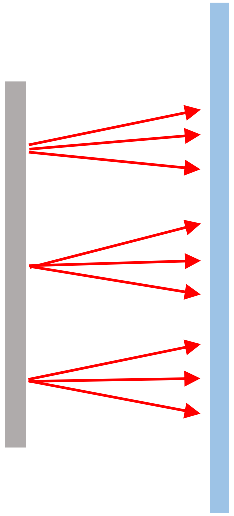
Measurement of aberrations



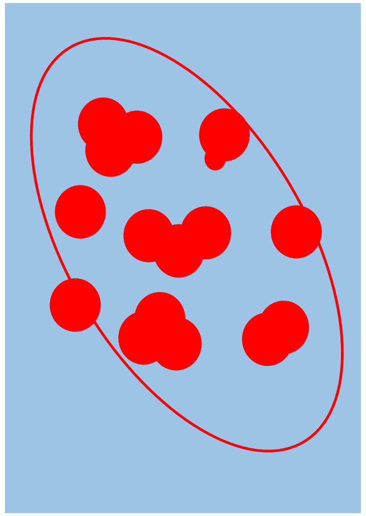
Pepperpot
Emittance-meter



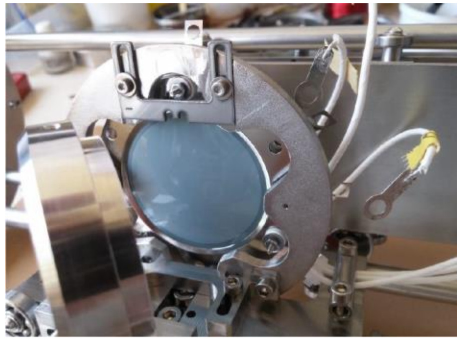
Front view:
tantal mask



Side view:
MCP + Phosphore screen



Front view:
CCD camera



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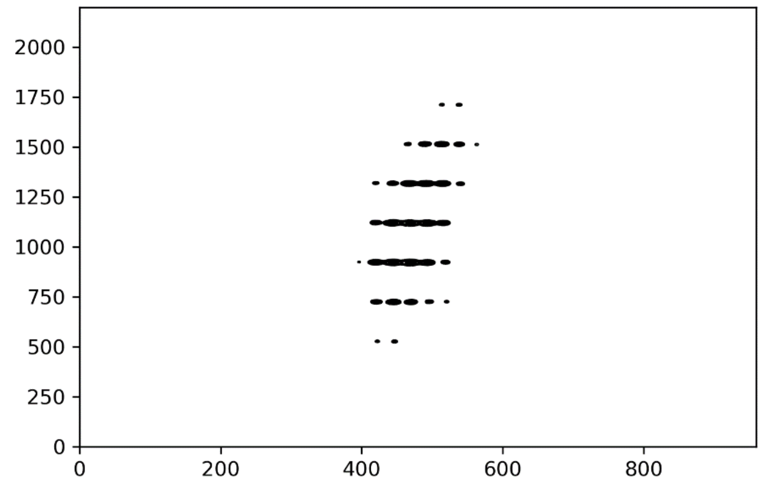
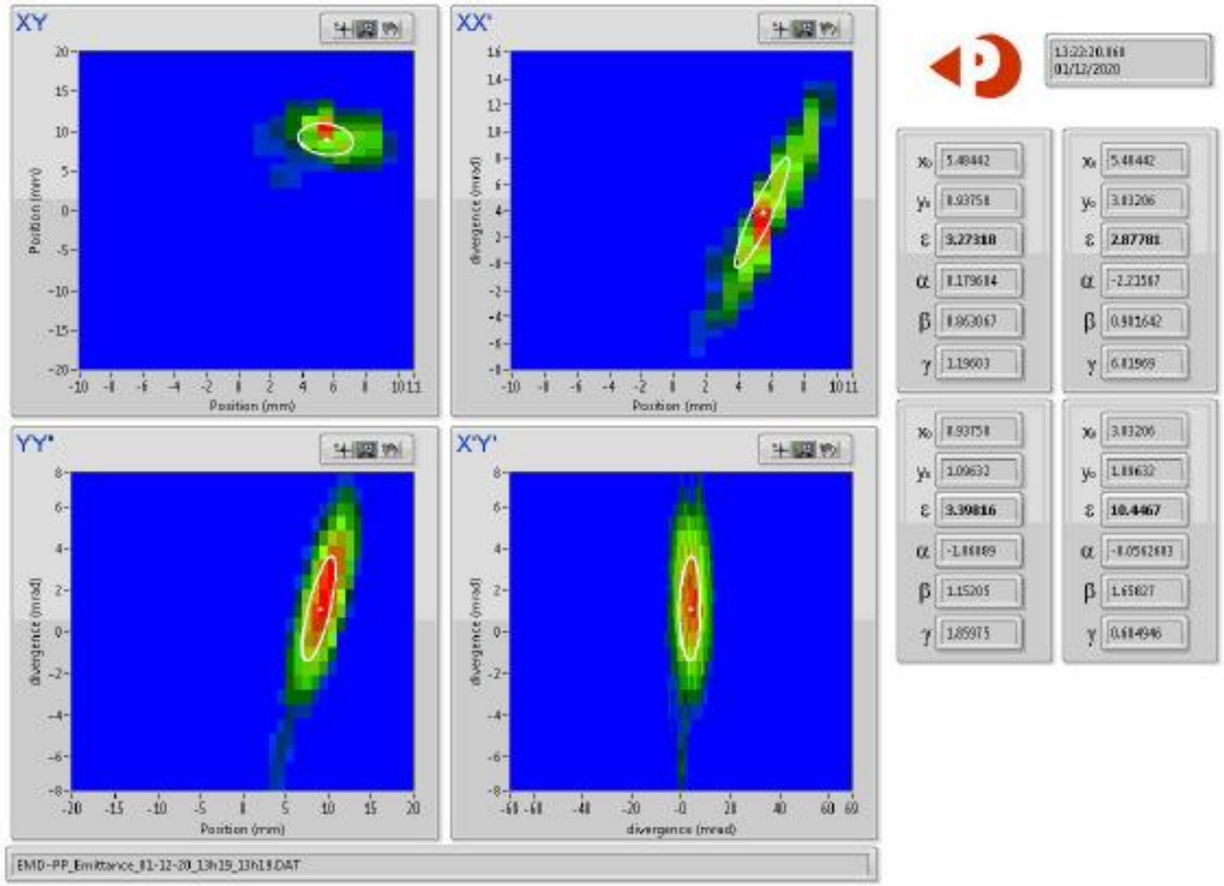
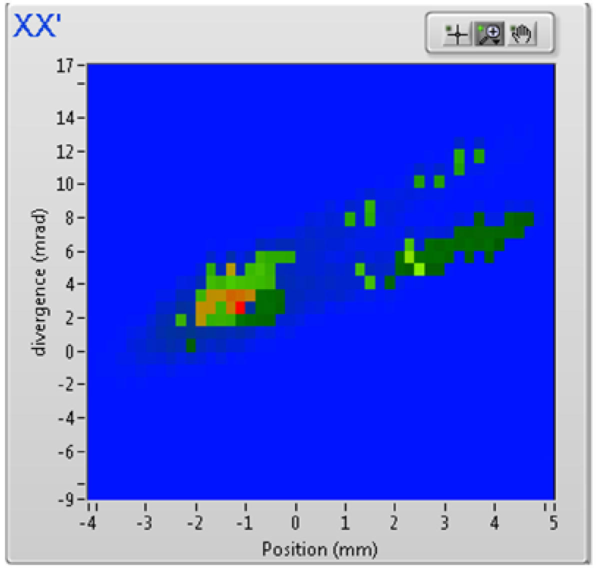


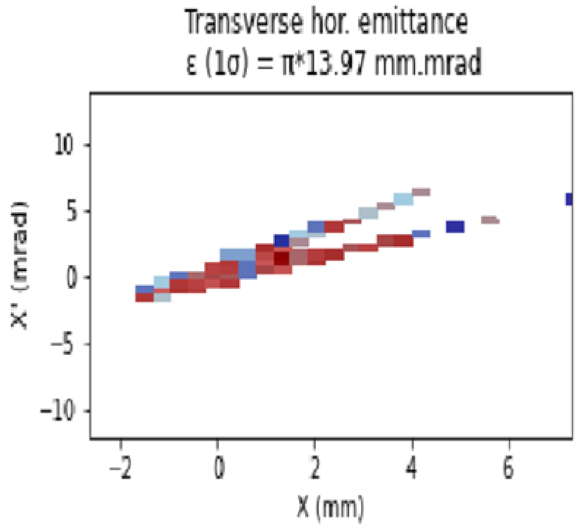
66	65	66	66	68	68	69	67	69	67	67	67	66	65	64	65	64	65
66	66	68	66	66	67	68	71	68	69	69	67	67	67	67	65	65	66
66	67	67	68	70	72	73	72	74	69	67	68	66	66	68	66	66	66
65	68	69	70	72	77	79	81	78	75	74	71	70	67	67	66	67	65
64	69	68	73	73	81	88	93	87	85	78	78	71	70	69	68	65	68
67	69	72	76	82	95	104	107	110	102	89	80	74	70	69	67	66	65
68	68	73	78	93	115	146	166	156	134	111	92	80	76	72	70	66	65
68	68	72	84	102	150	207	253	226	179	134	103	83	72	71	68	66	68
67	70	73	87	110	161	245	287	264	214	151	111	89	75	70	67	65	64
68	70	76	82	105	139	193	203	202	190	149	105	82	74	71	69	67	67
68	69	70	81	93	110	136	141	141	138	116	91	77	73	69	68	67	65
67	71	71	74	80	91	99	110	106	104	93	83	75	71	67	66	65	65
67	69	69	71	74	77	83	86	88	86	82	75	74	69	68	65	67	65
65	67	67	69	70	73	73	75	75	75	75	70	70	70	66	67	65	65
67	65	64	67	69	69	72	70	72	74	72	70	68	67	67	66	66	65
68	67	64	66	67	68	70	67	69	69	67	68	66	66	67	64	66	65
66	65	65	64	66	67	68	67	67	66	66	66	65	64	64	63	65	63
66	64	64	67	63	67	67	66	66	64	67	67	65	66	64	65	64	66

Image analysis (pantechnik Software
+
Homemade Software)



Comparison of experimental measurements / simulations

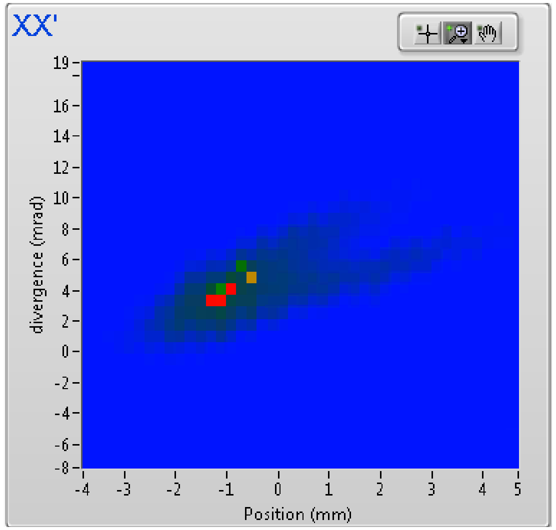


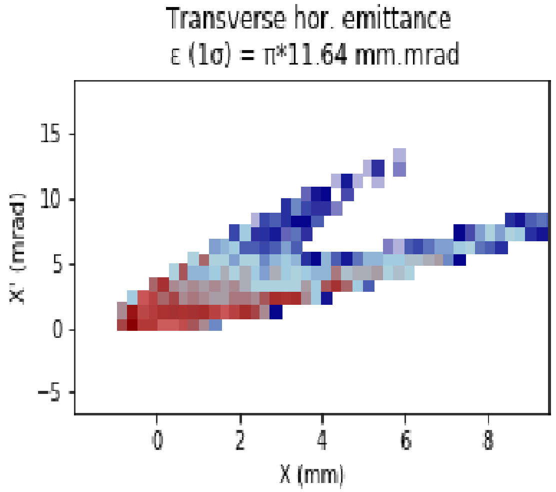


Experimental measurements correspond to simulations

2nd order aberrations can be observed with the emittance-meter
➔ Order 3 ??? Not by eye, but a computer could

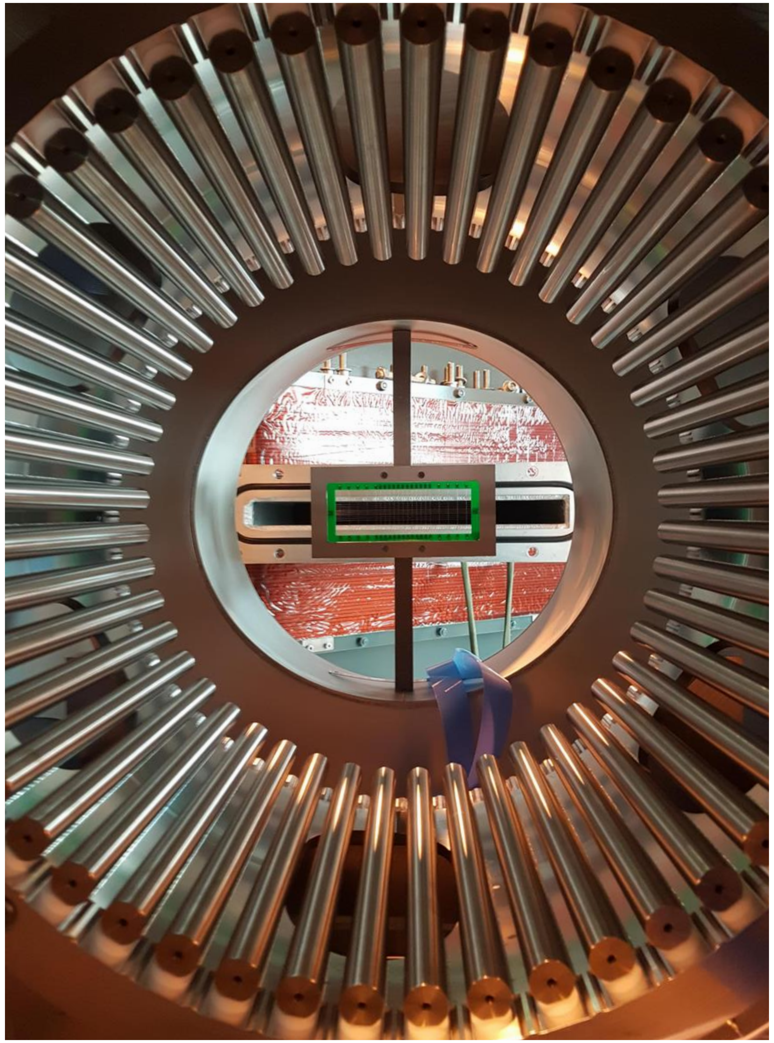
<u>Image analysis software under development</u>

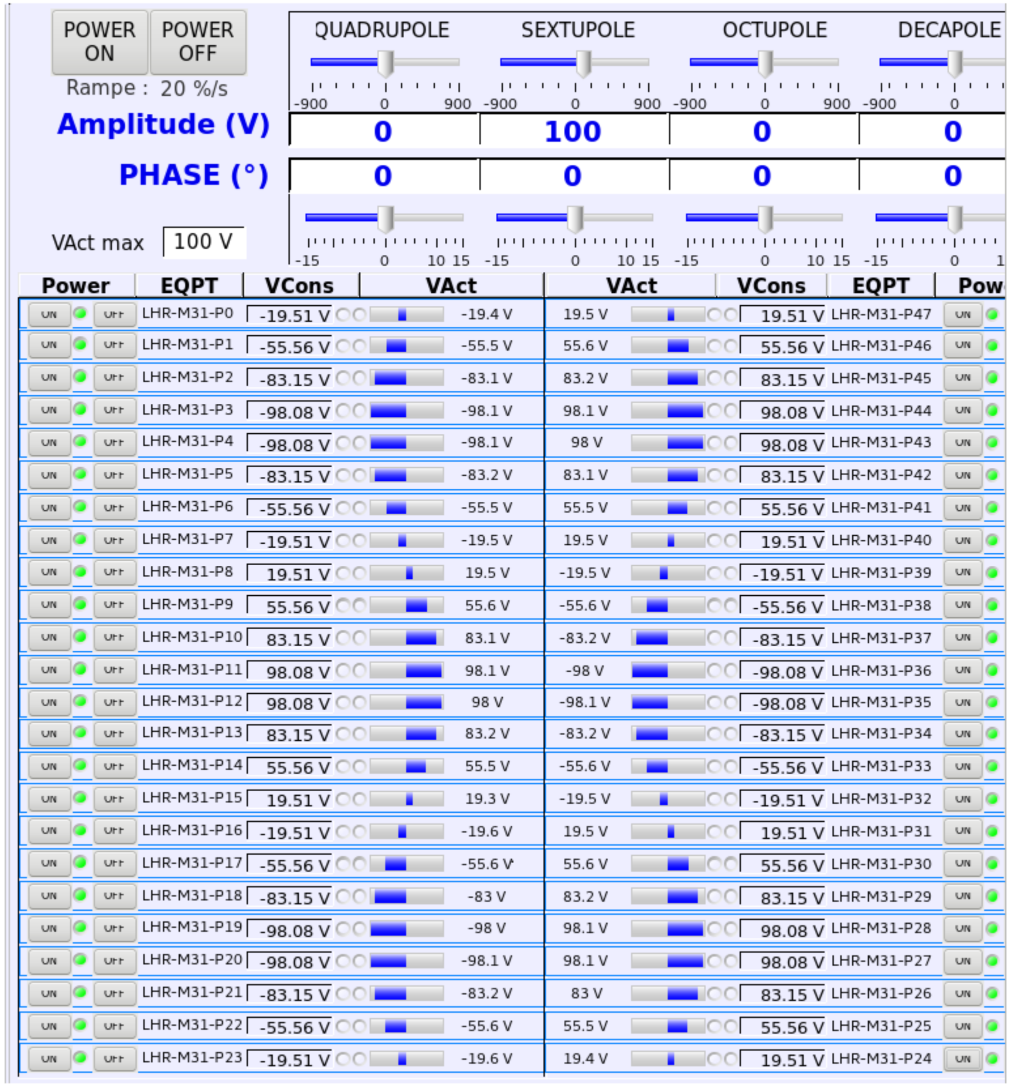




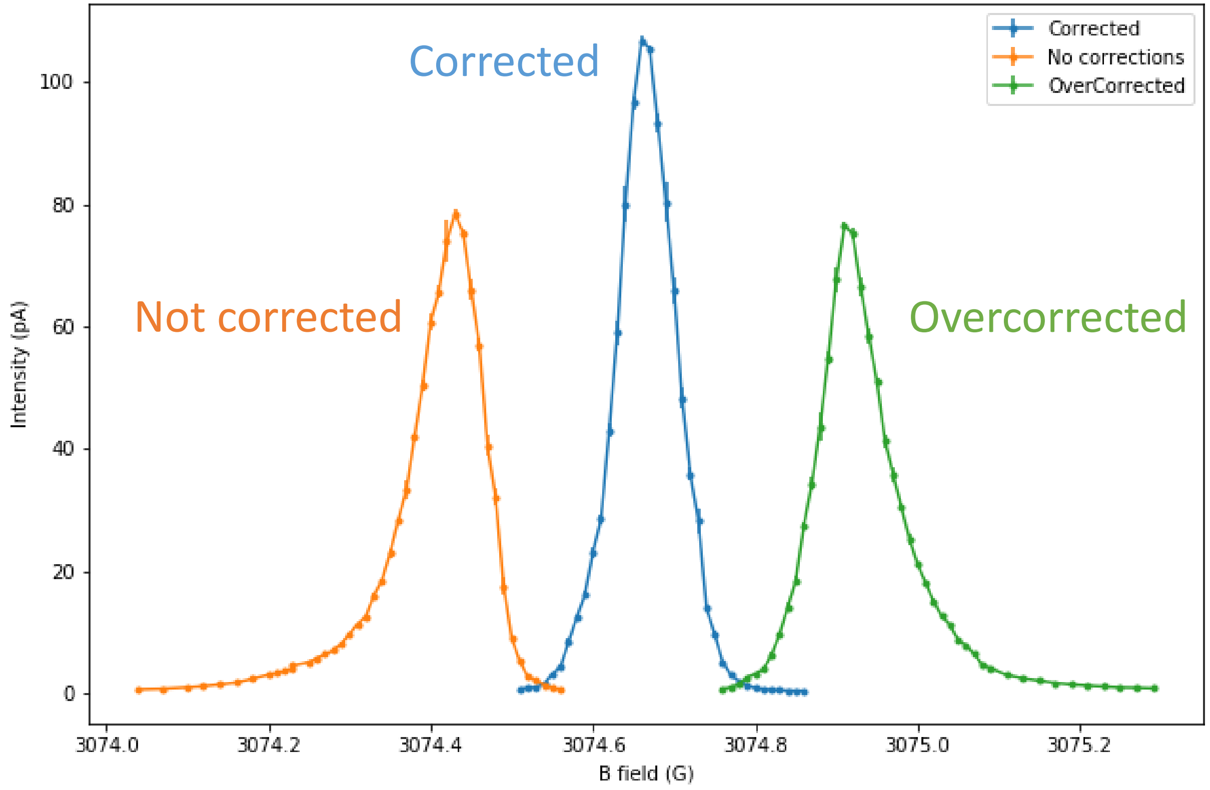
Contents

Multipole tuning and CC



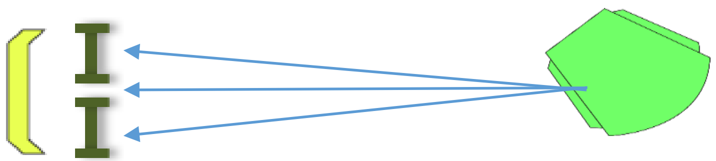


Hexapolar correction (2nd order): on slits

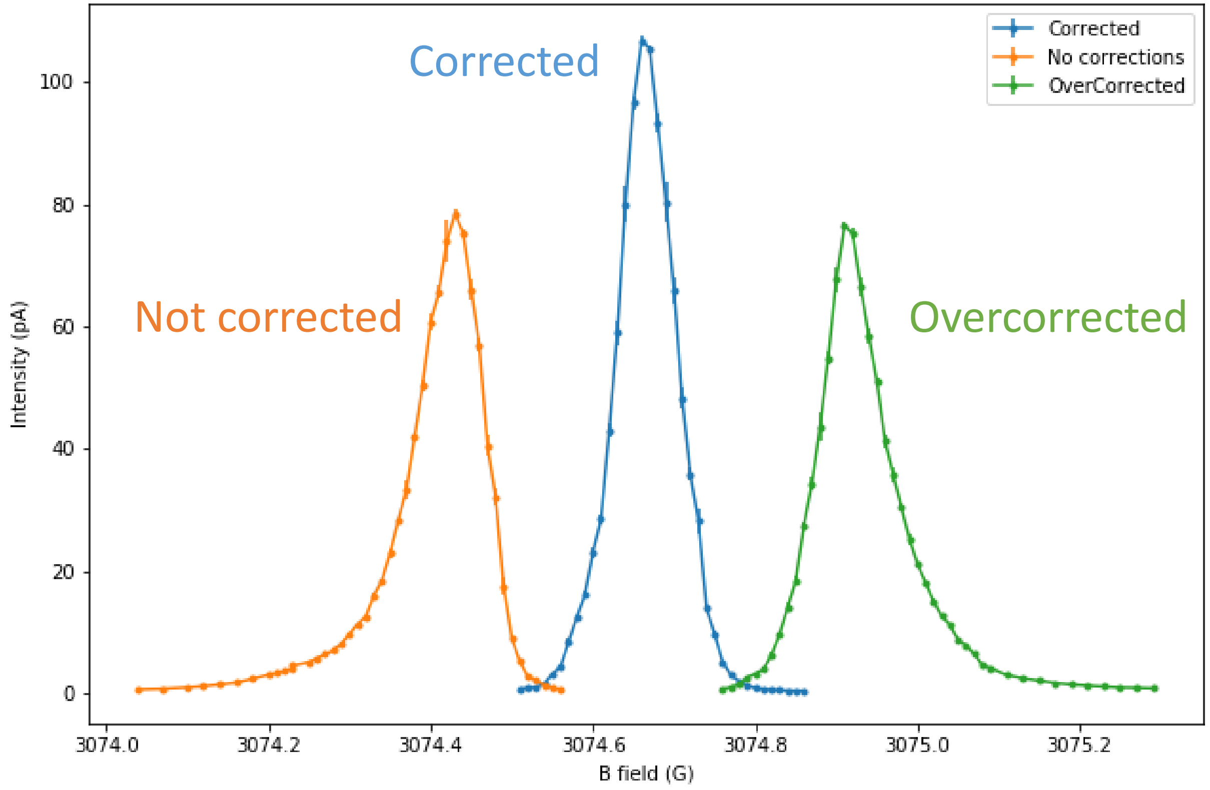


-> Shifted left -0,2G
-> Shifted right +0,2G

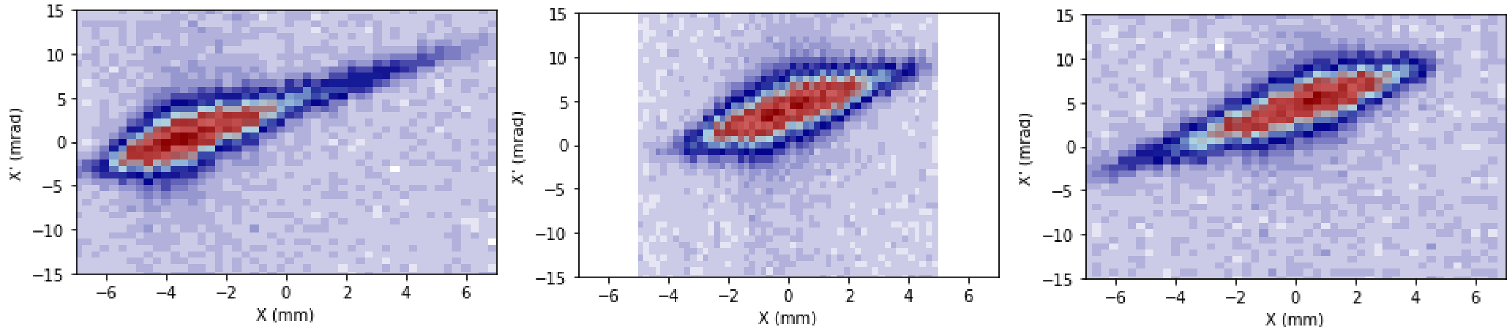
Beam can be scanned with the dipoles through end slits to obtain a precise beam profile



Hexapolar correction (2^{nd} order): on emittance figure

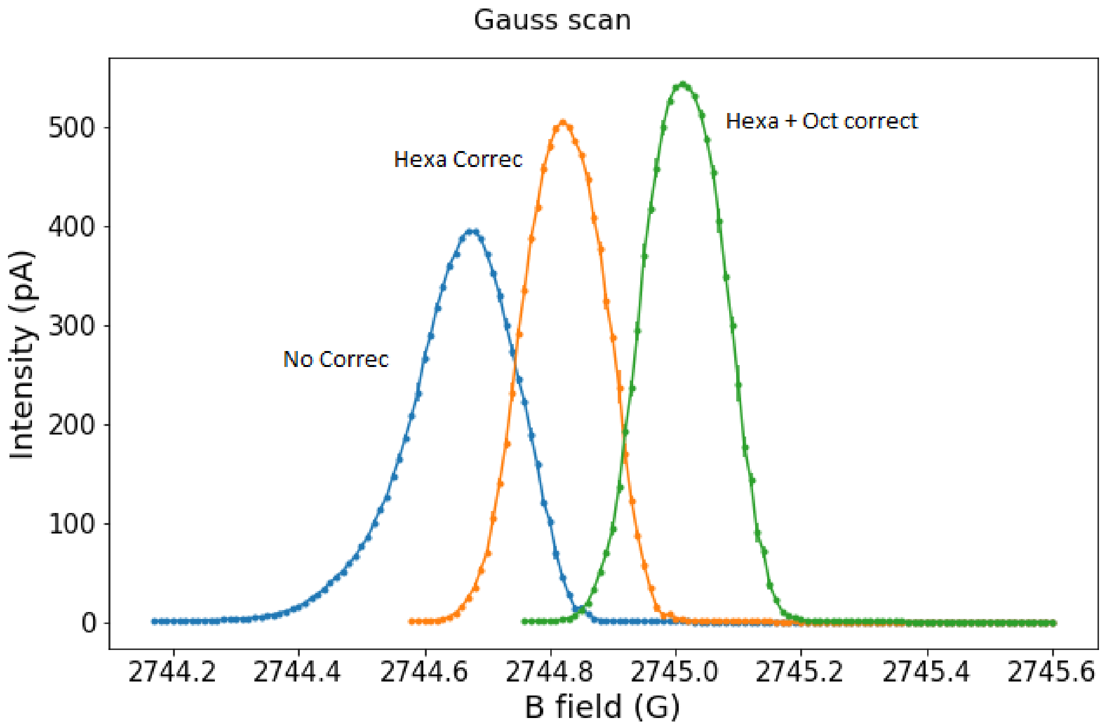


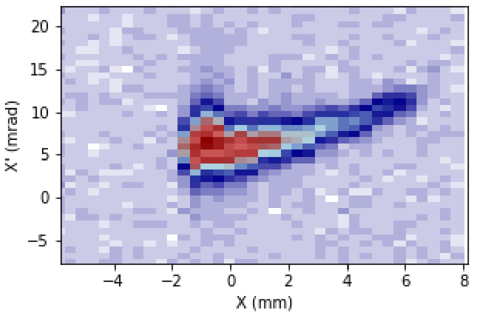
Emittance measurements

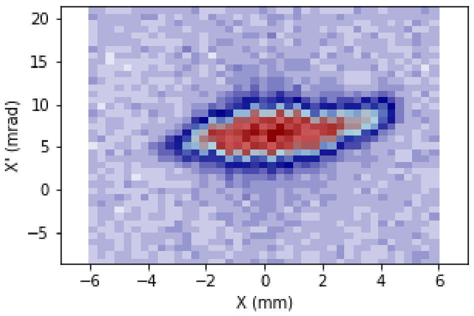


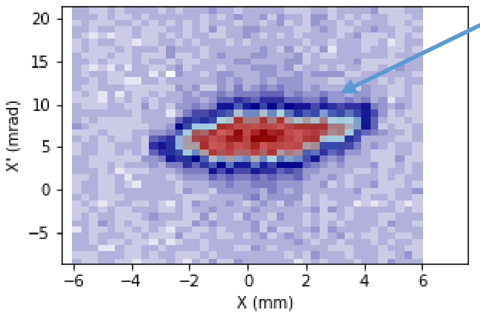
Projection on x axis gives beam profiles

Higher order correction (up to 3rd order)









Hard to see a change, but a computer should

Contents

Measuring the resolution of a spectrometer/separator

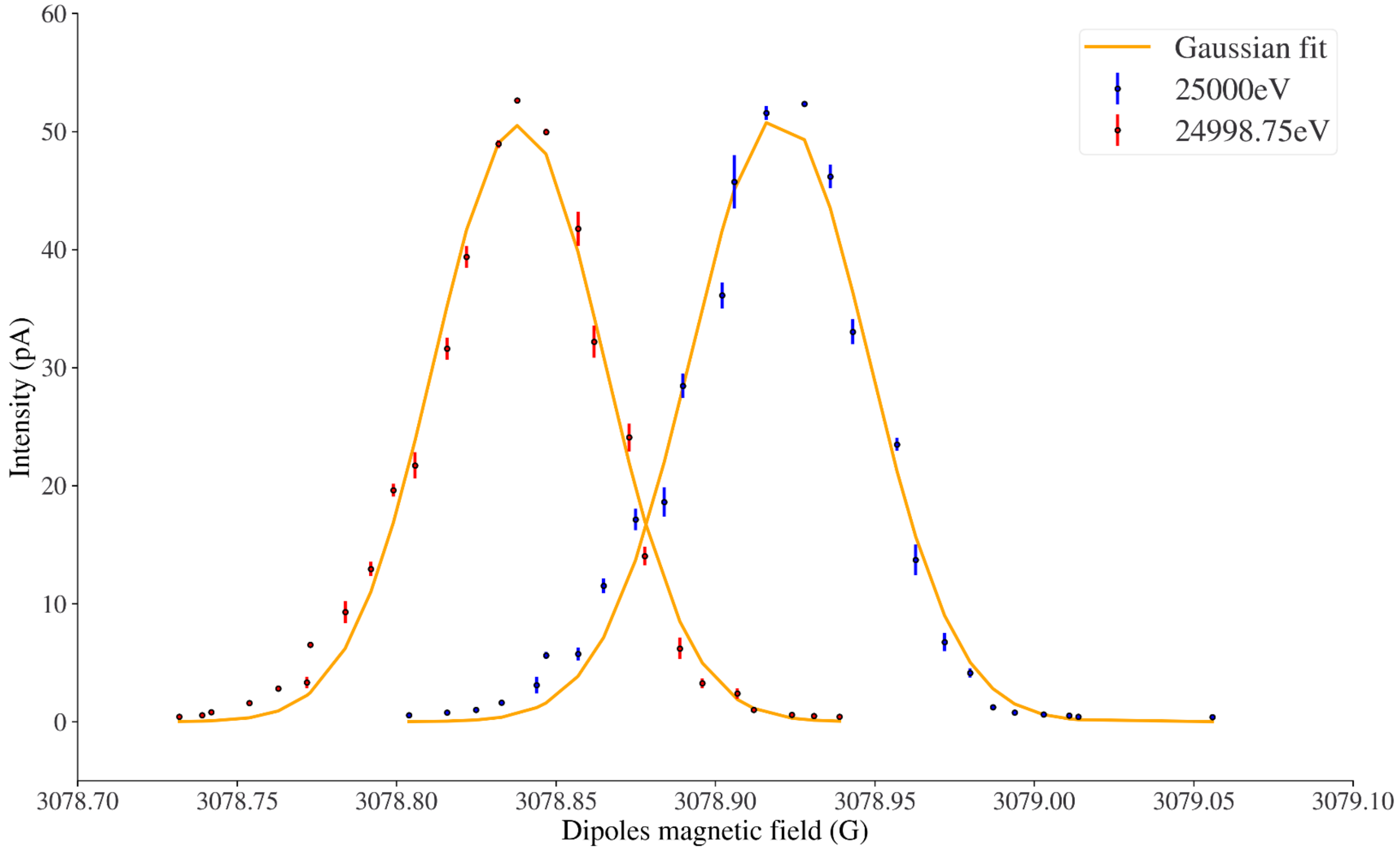
HRS source: $^{133}Cs^{1+}$ ⇒ monoisotopic ion source: no direct mass measurement/separation possible

But : $$B\,\rho = \frac{p}{q} = \frac{\sqrt{2\,m\,E}}{q}$$ Dipoles work the same for mass or energy shift (momentum separation) at first order

It can also be observed in the HRS transfer matrices where: {x , $\frac{\Delta M}{M}$} = {x , $\frac{\Delta E}{E}$} = -31 cm/%

<u>Resolution can be measured by measuring position/size of two beams with close energies</u>

Resolution measurement of the HRS



$$\frac{\Delta E}{E} = \frac{1}{20000}$$

1:1 transmission > 80%

$\epsilon \sim 1 - 2\ \pi . mm . mrad$

Hexapolar and octupolar corrections applied

R_{FWHM}= 23400

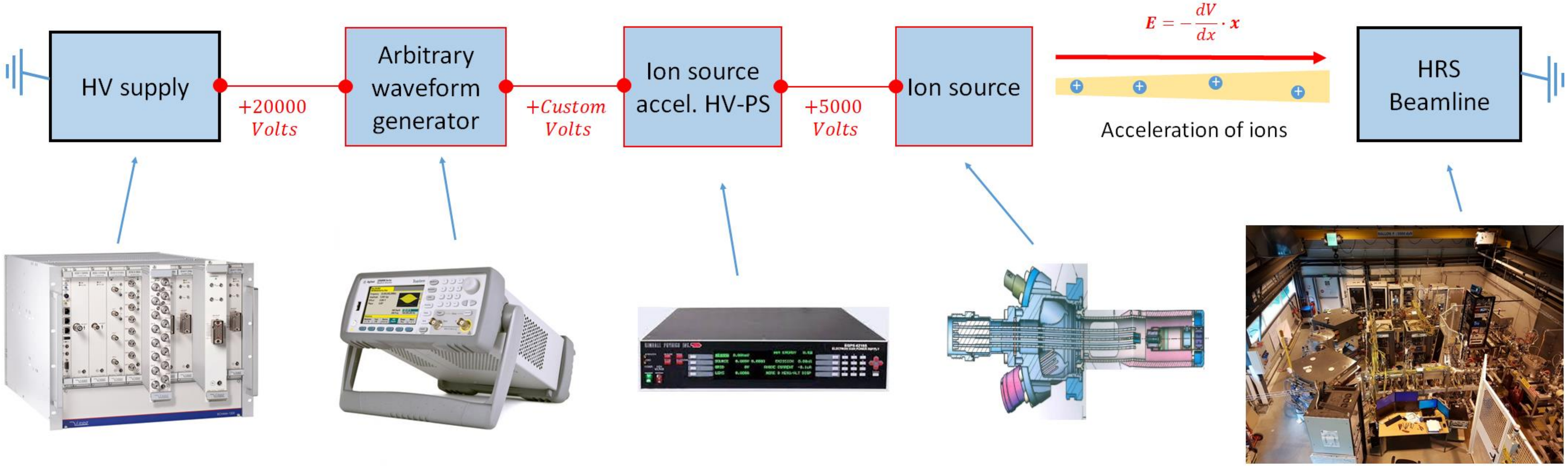
$R_{10\%valley}$= 13500

$R_{\mu/FWHM}$= 23400

The HRS can separate two identical beams with $\frac{\Delta E}{E_0} = 1/23400$ *at their FWHM or* $\frac{\Delta E}{E_0} = 1/13500$ *at 10% valley*

Populate multiple energies of a beam : see poster PS-6-4

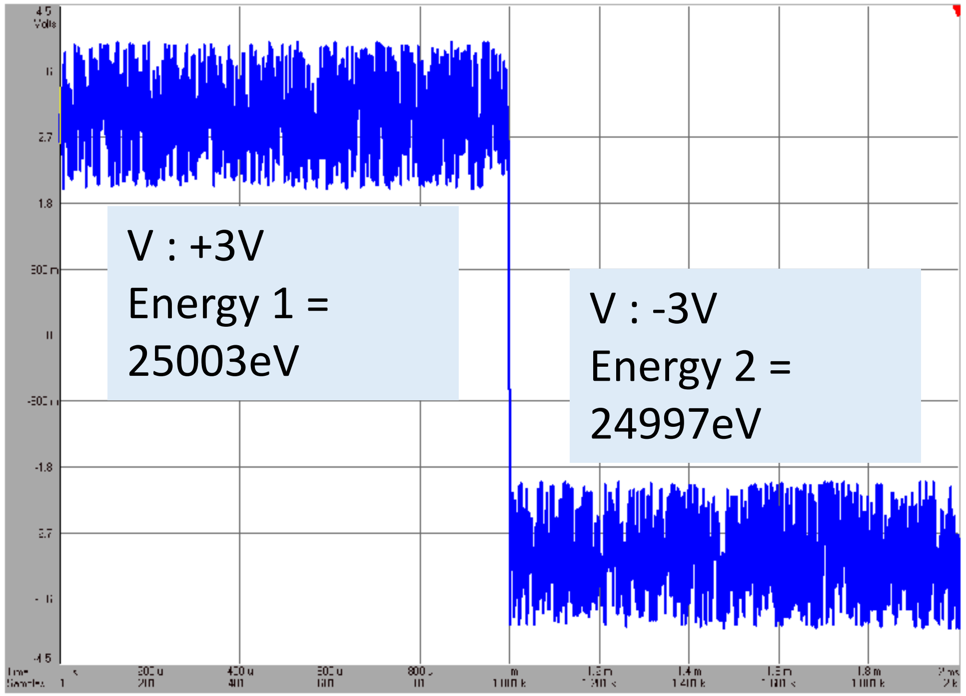
- Acceleration of ions depends on the potential between the source and the beamline
- High voltage supplies can't handle fast and small voltage variations (less than 1V on many kV)
- A pulse generator can supply such variations

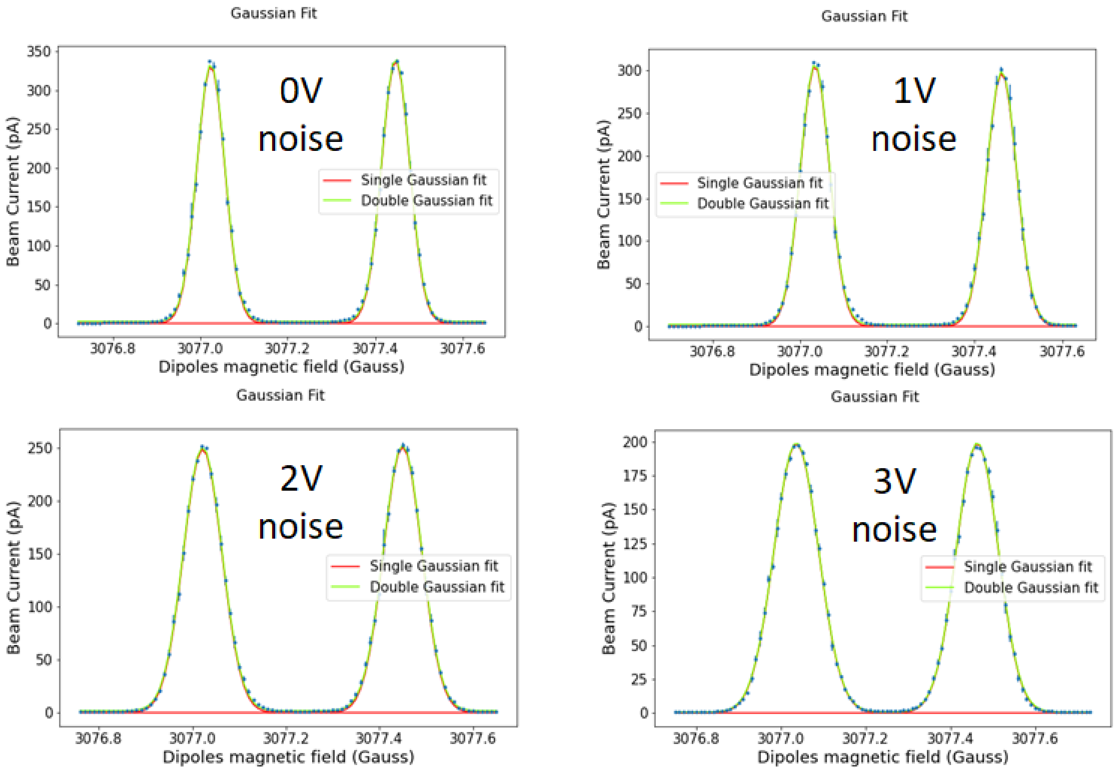


$$Energy_{total} = 25000eV + custom\ distribution\ (\pm 5eV)$$

Square signal with noise

A square signal populates two and only two energies.
Adding noise to the signal increases the energy dispersion of the beam.





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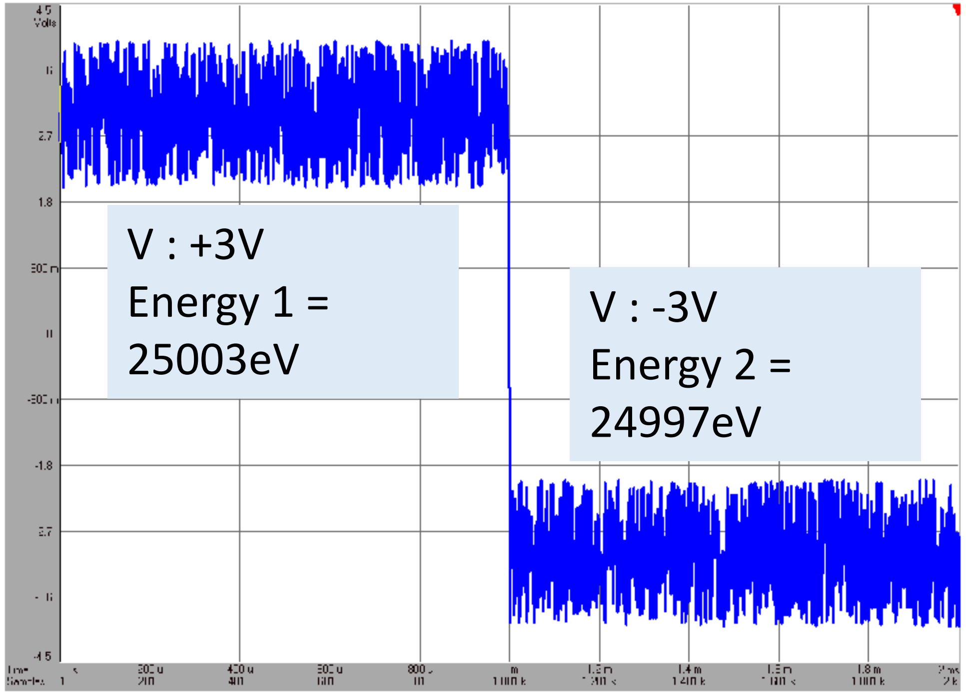
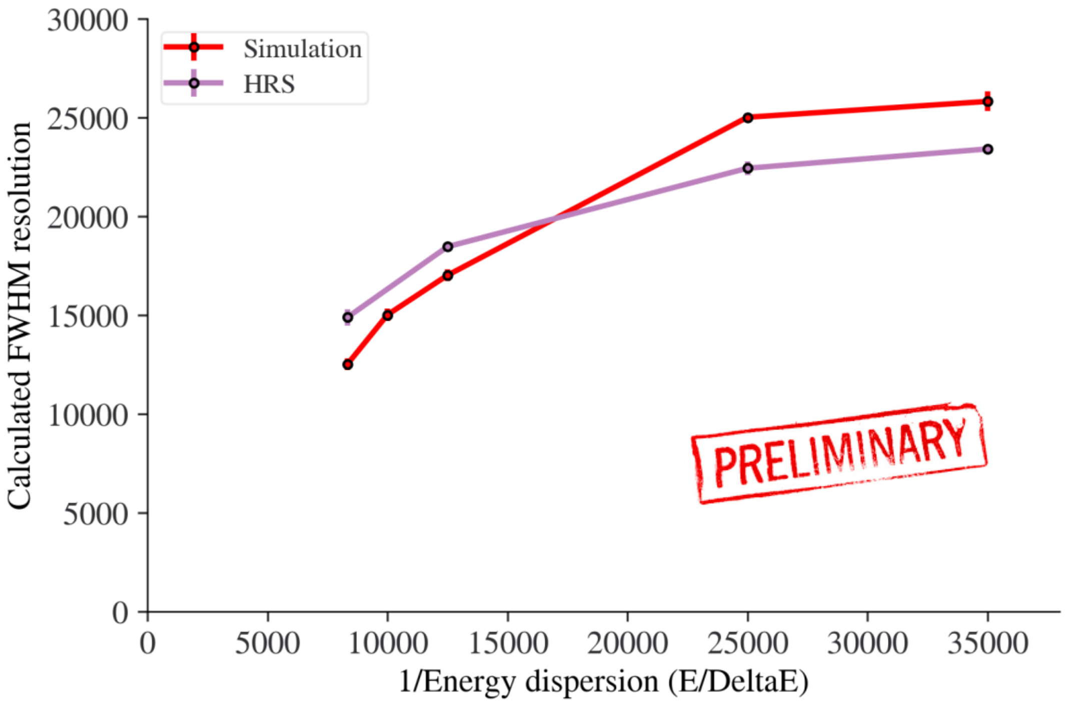
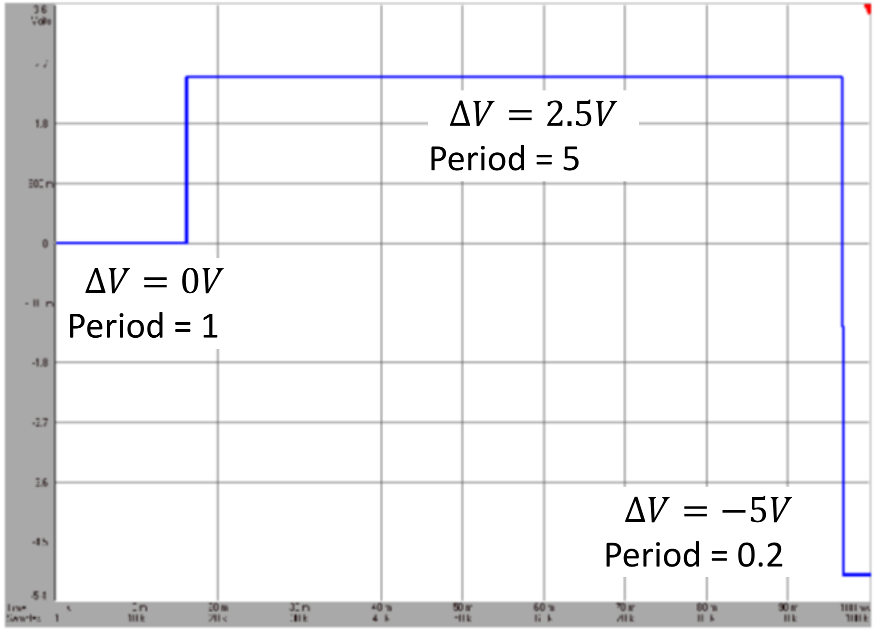




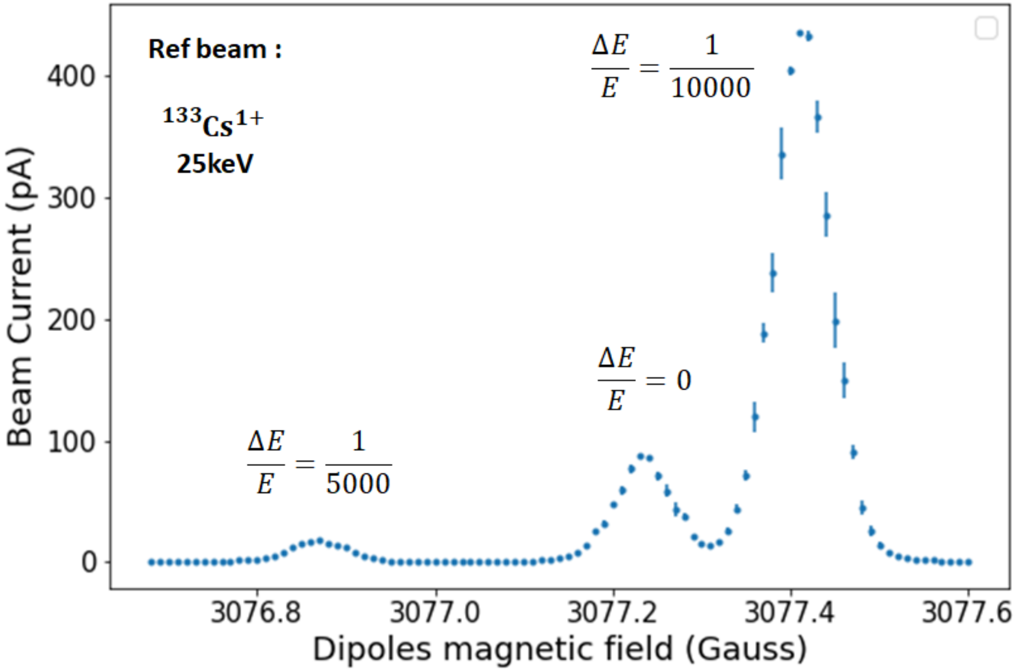
The HRS resolution can be caracterized as a function of the beam energy dispersion

To go further…

A signal with multiple steps with adjustable amplitude and length can create (almost real) beam contaminants



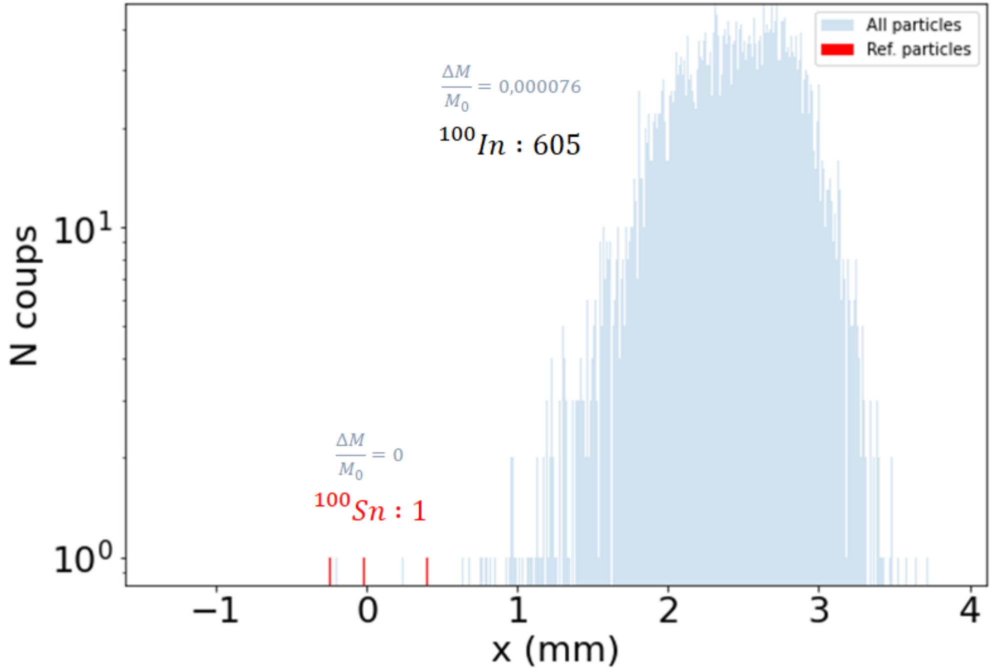
Create custom beam contaminants



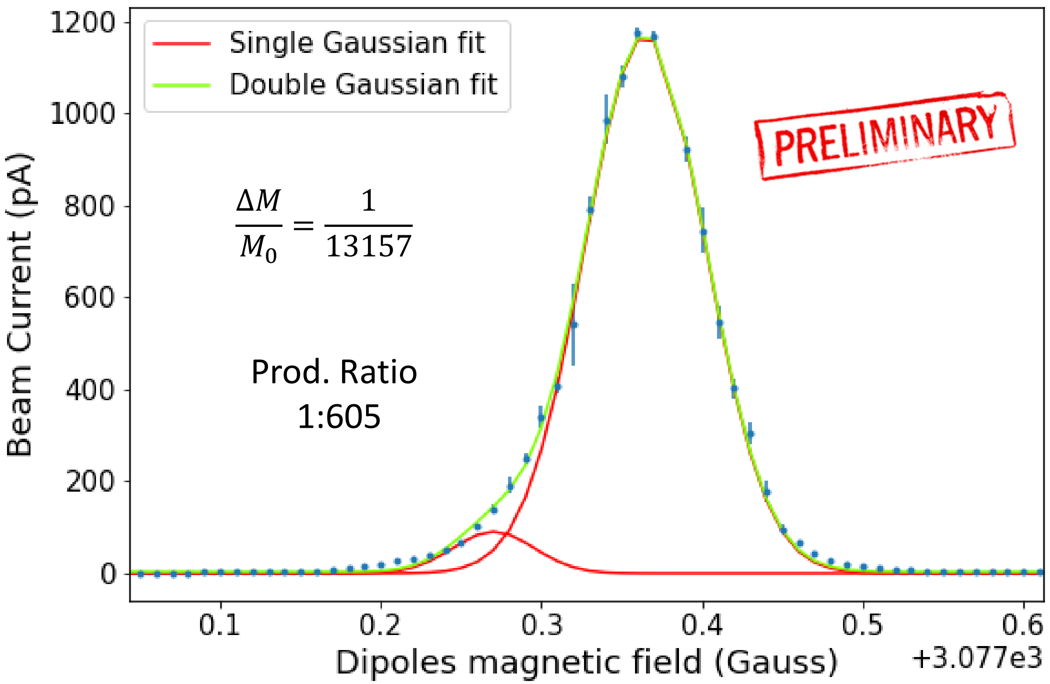
<u>The HRS can be commissioned in almost real operating conditions, with no radioactive beam and (relatively) high intensities</u>

A concrete example : separation of 100Sn and 100In

Simulation (COSY infinity)



Experimental separation



Highly produced contaminants with close masses are still difficult to separate, in our case :

- The major quantity of the contaminant can be separated.
- Beam can be almost totally purified by sacrifying a part of the beam of interest.
- Send the beam to a higher-level purification device (Penning trap : PIPERADE).

Conclusion

- Optical aberrations fully corrected at 2nd order and partially at 3rd order

- Best resolution at FWHM : R = 23400 for 25keV Cs beam with 1-2 πmm.mrad emittance and 1mm beam
- Contaminants creation technique to test HRS in real conditions

- To do:
  i. Correction coils to fix dipoles magnetic lenght
  ii. Auto-tuning CorrAb software
  iii. New emittance-meter under development at LP2i Bordeaux (HRS specific)
  iv. Poles re-shaped at 6,9m to naturally correct 2nd order => ongoing

➔ HRS should be sent fully operational to DESIR by 2024-2025

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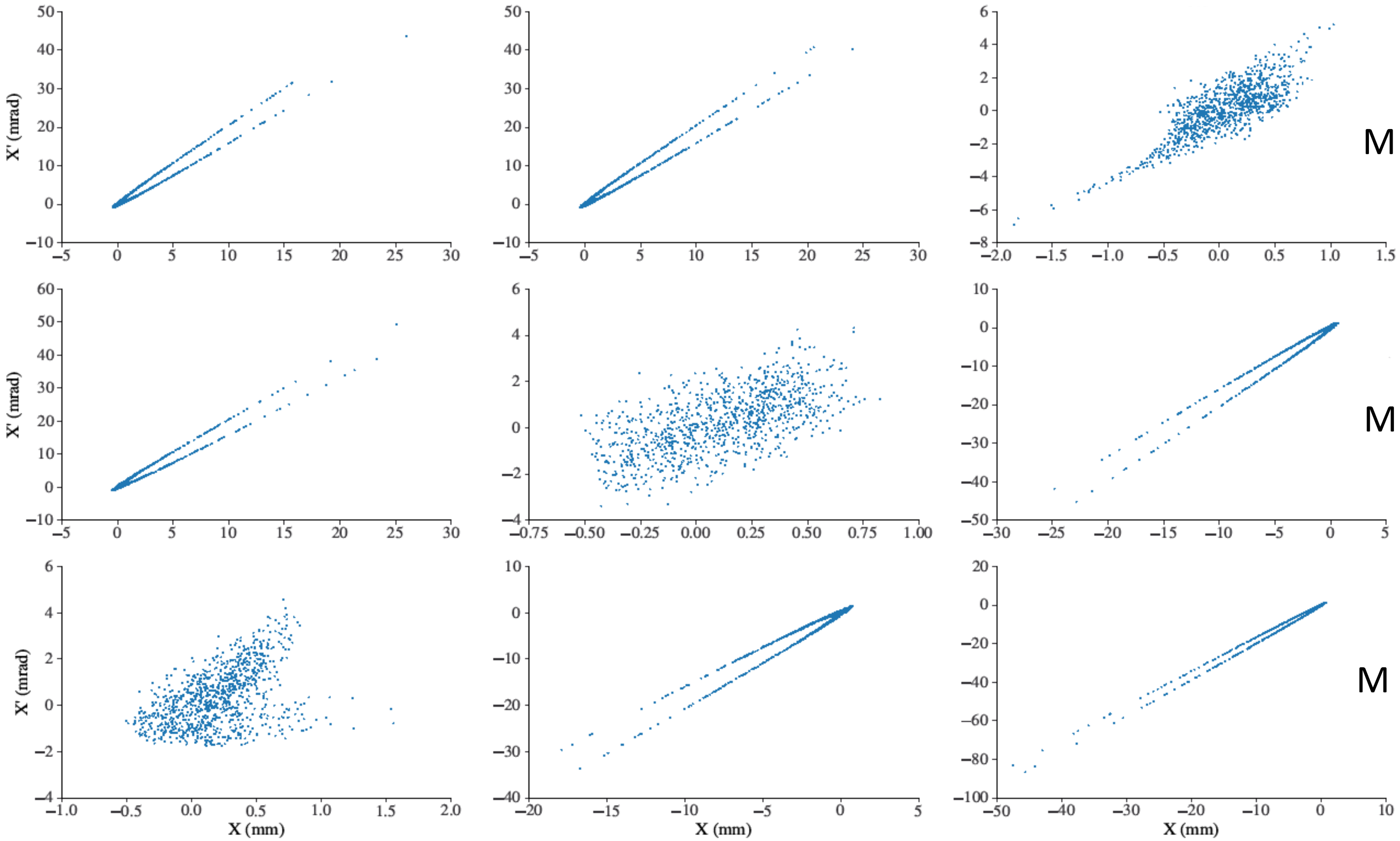
THANK YOU !

Perspectives – dipole poles re-shaping

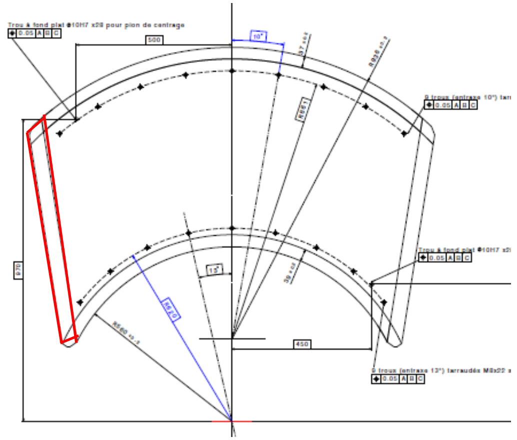
R = ∞ (No curvature) | R = 6,9m | R = 3,6m

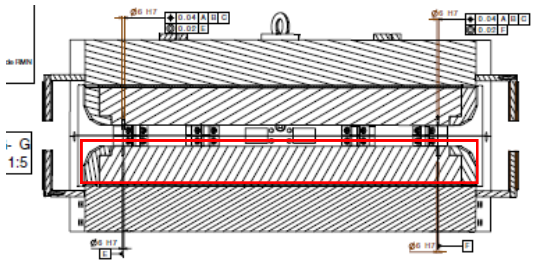


M = 0V

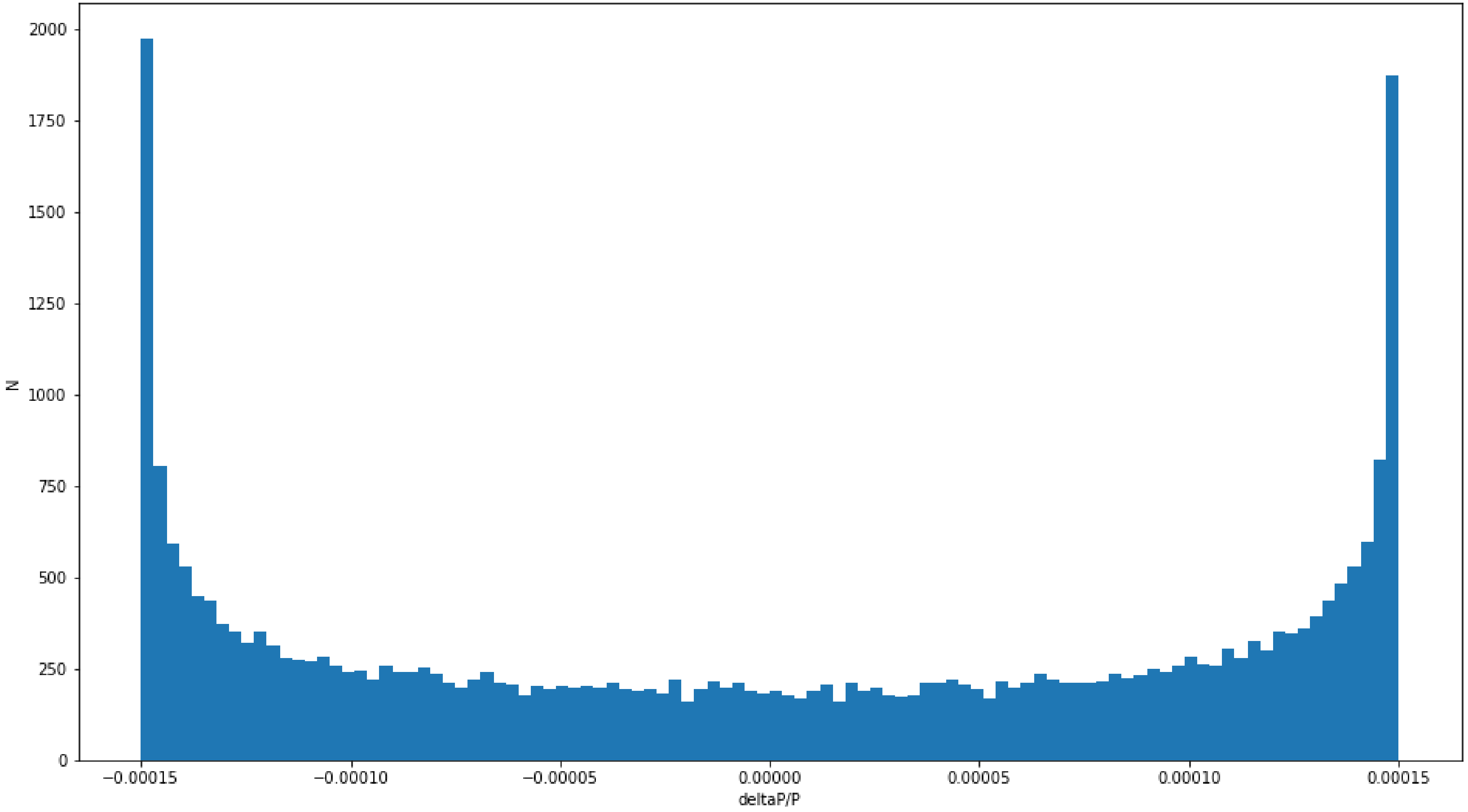
M = 150V

M = 300V





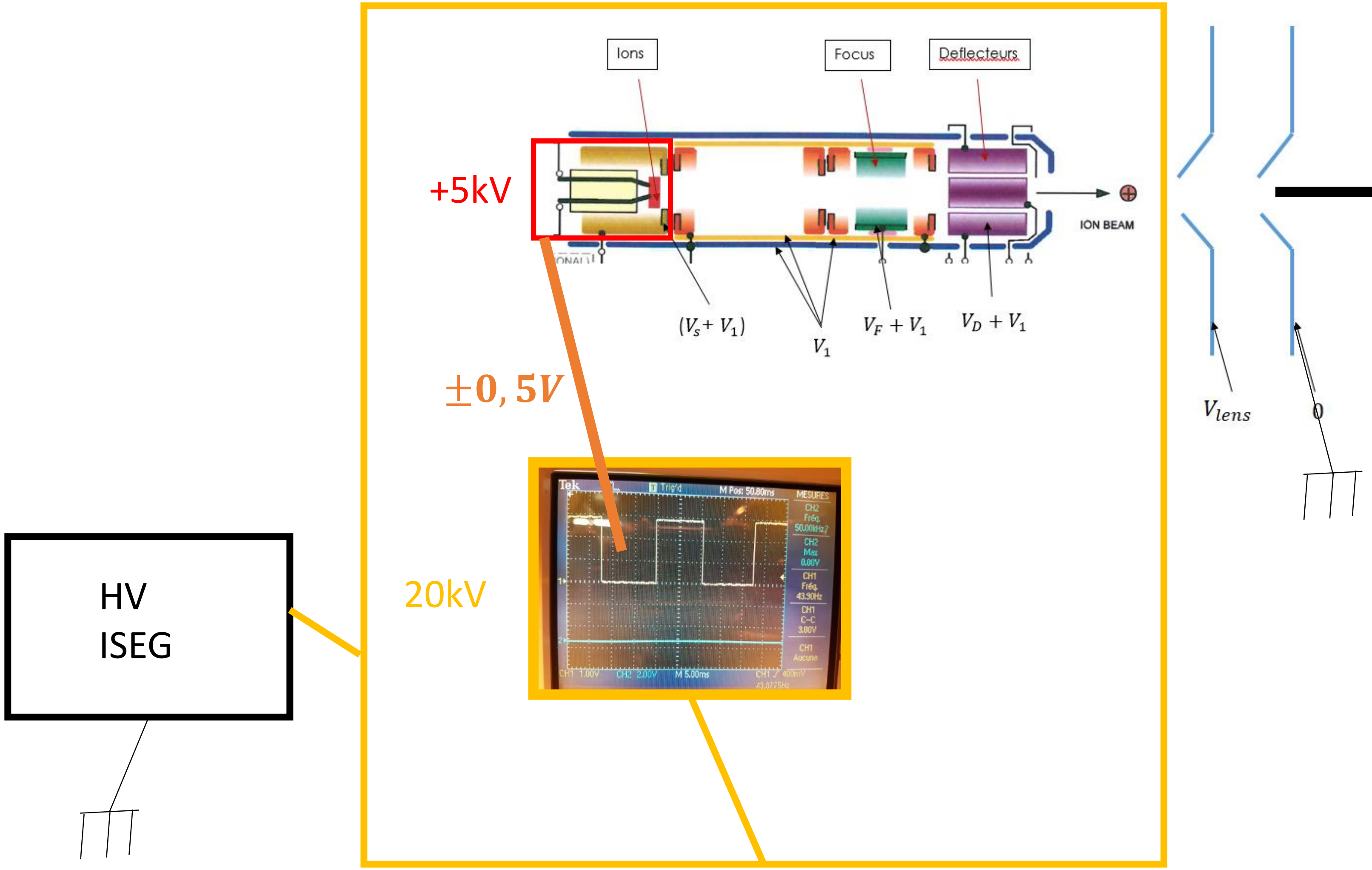
Backup 1: Sine distribution



$\theta \in [0; 2\pi]$ aléatoire uniforme

$$\frac{\Delta E}{E} = \frac{(20000 + 3 * \sin(\theta)) - 20000}{20000}$$

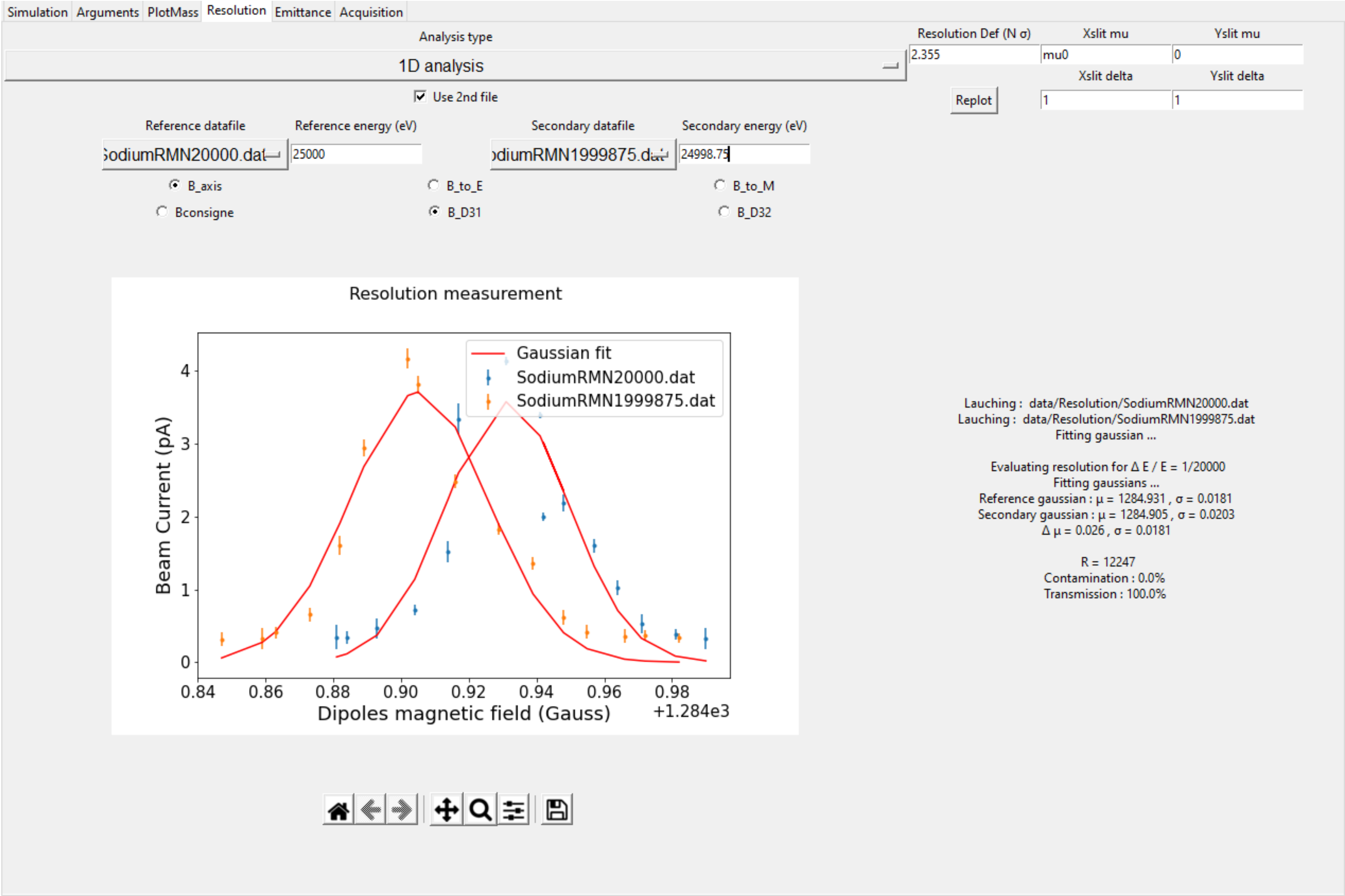
Montage electrique



$$E_{beam} = 20 + 5 \pm 0,5\ V$$

$$\frac{\Delta E}{E_0} = \frac{1}{25000}$$

Na beam


Simulation
Arguments
PlotMass
Resolution
Emittance
Acquisition
Analysis type
1D analysis
Use 2nd file
Reference datafile
Reference energy (eV)
Secondary datafile
Secondary energy (eV)
SodiumRMN20000.dat
25000
24998.75
B_axis
Bconsigne
B_to_E
B_D31
B_to_M
B_D32
Resolution Def (N σ)
Xslit mu
Yslit mu
2.355
mu0
0
Xslit delta
Yslit delta
Replot
1
1
Resolution measurement
Gaussian fit
SodiumRMN20000.dat
SodiumRMN1999875.dat
Beam Current (pA)
Dipoles magnetic field (Gauss)
+1.284e3
Lauching : data/Resolution/SodiumRMN20000.dat
Lauching : data/Resolution/SodiumRMN1999875.dat
Fitting gaussian ...
Evaluating resolution for Δ E / E = 1/20000
Fitting gaussians ...
Reference gaussian : μ = 1284.931 , σ = 0.0181
Secondary gaussian : μ = 1284.905 , σ = 0.0203
Δ μ = 0.026 , σ = 0.0181
R = 12247
Contamination : 0.0%
Transmission : 100.0%

H. Wollnik, A "Q-value" for particle spectrometers

with $ds = \rho_0 d\phi$ and $L = \rho_0 \phi$. After comparing D_α, D_x, D_δ and D'_δ in eqs. (2), this relation can be written also as:

$$F_0 = 2\alpha_{00}\rho_0 [D_\delta + D'_\delta L_1]. \quad (15)$$

Combining eqs. (14) and (15) we get[8])

$$Q = R 2x_{00} 2\alpha_{00} = F_0/\rho_0 . \quad (16)$$

intensity. Thus for any system the resolving power can be increased if the particle intensity is reduced. An increase in resolving power without a loss in particle intensity is possible only if we increase the Q-value. In order to get simultaneously a large resolving power and a high particle intensity it is necessary because of eq. (16) to have a large Q and consequently a large F_0 and also a small ρ_0.

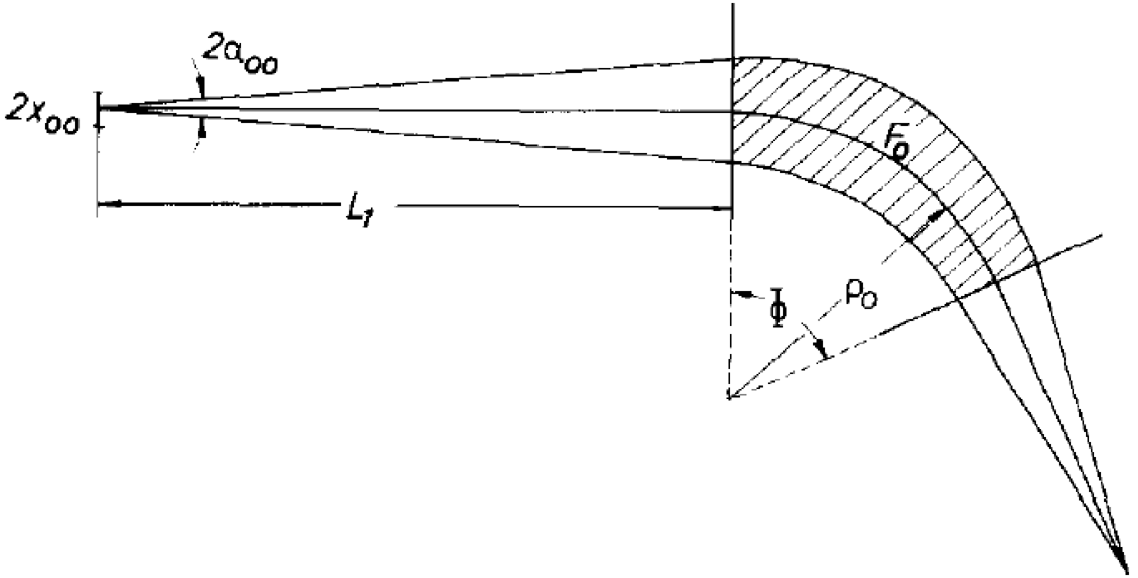
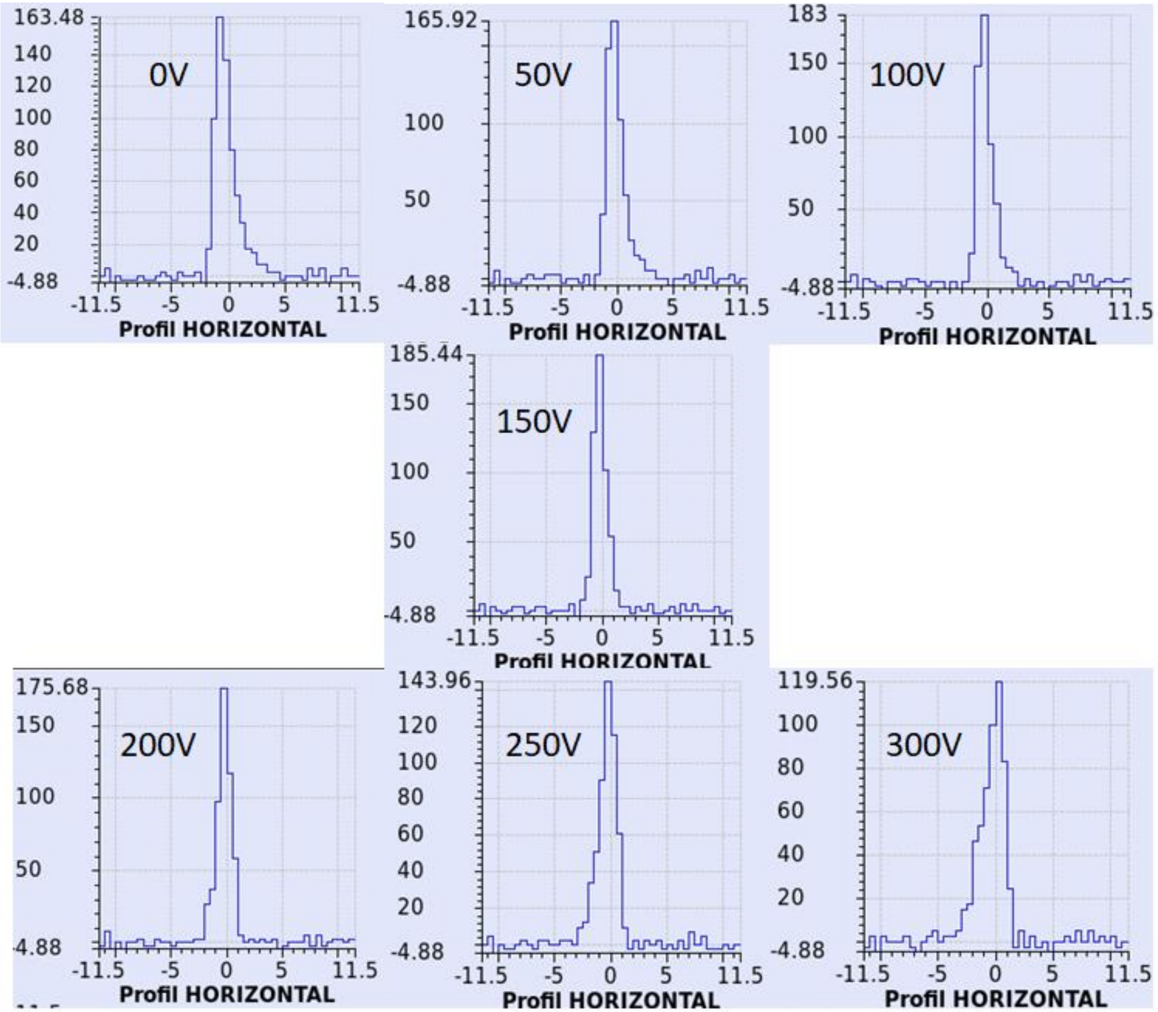
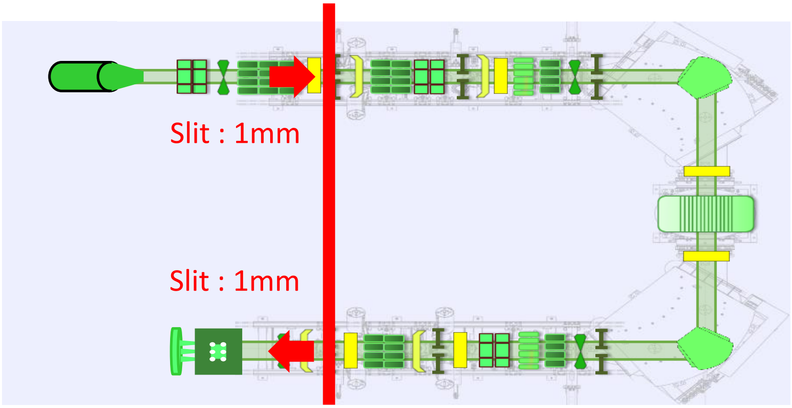
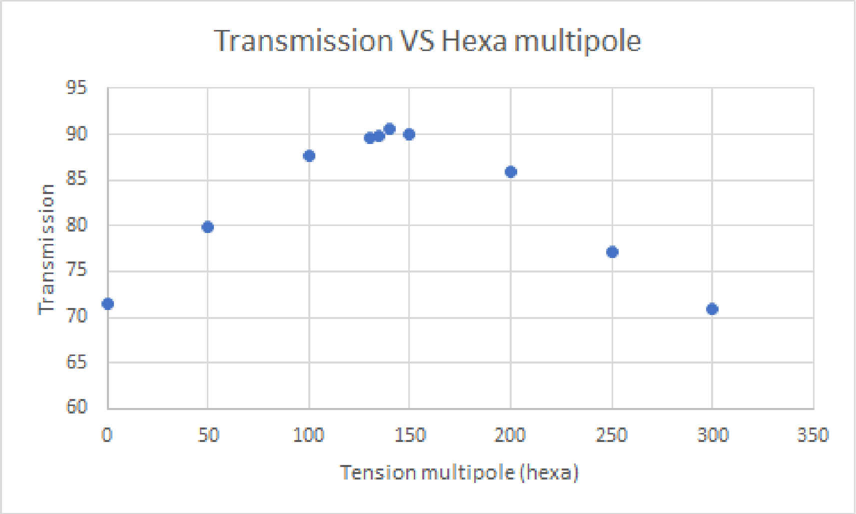


Fig. 2. For a focusing sector field the two outermost trajectories are shown that leave the center of a source of size $2x_{00}$ under angles $+\alpha_{00}$ and $-\alpha_{00}$. If the radius of the main path ρ_0, the sector angle ϕ and the object distance L_1 are given the shaded area F_0 and thus the Q-value F_0/ρ_0 is defined [see also eqs. (15, 16)].

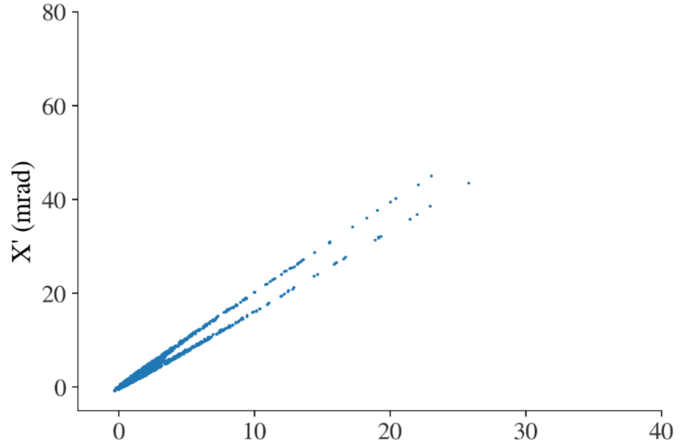
Hexapolar correction (2nd order): on BPMs





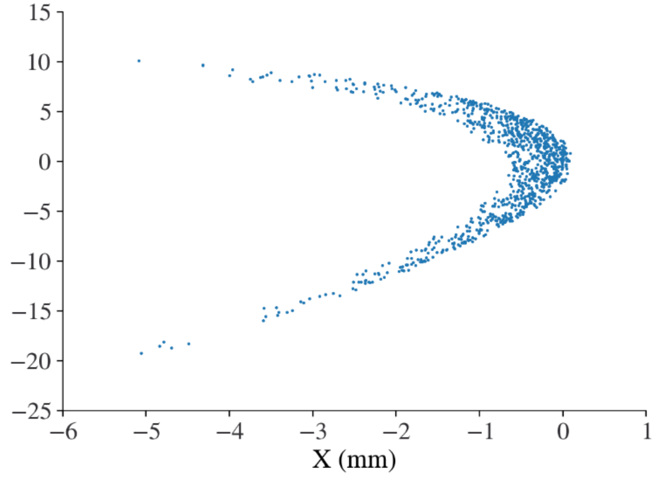


But measuring the aberrations is sometimes difficult… (simulations)



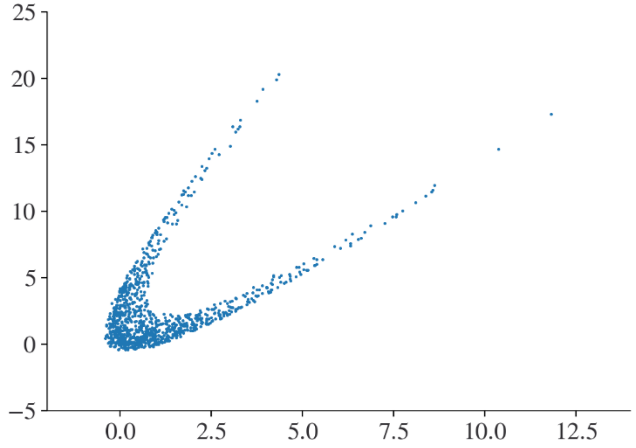
Normal optical conditions

Hard to dissociate
2^{nd} order « C-shape »



Emittance-meter placed at different position (F41)

But only possible in simulations…



Changing optical conditions

Works!! But only if we change post-dipole quads

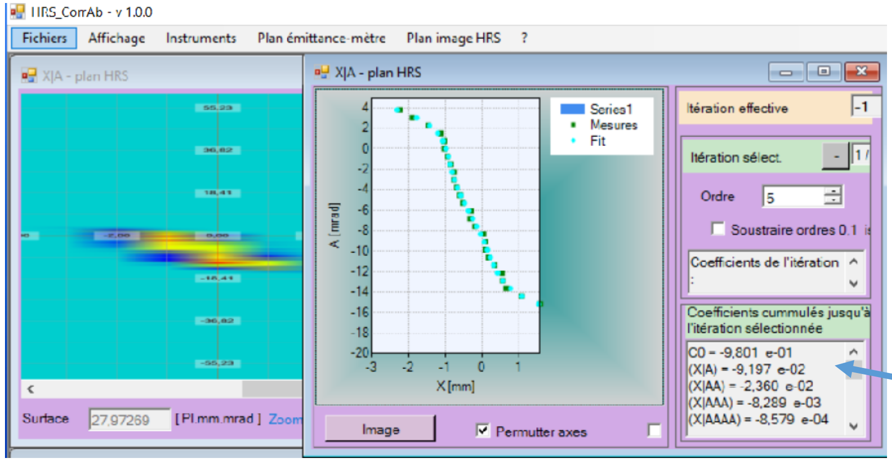
We can measure the aberration figure by changing the optical conditions of the HRS post-dipoles, but no resolution can be achieved

Automatic aberration correction

CorrAb to analyse emittance-meter data and correct it with mutipole :

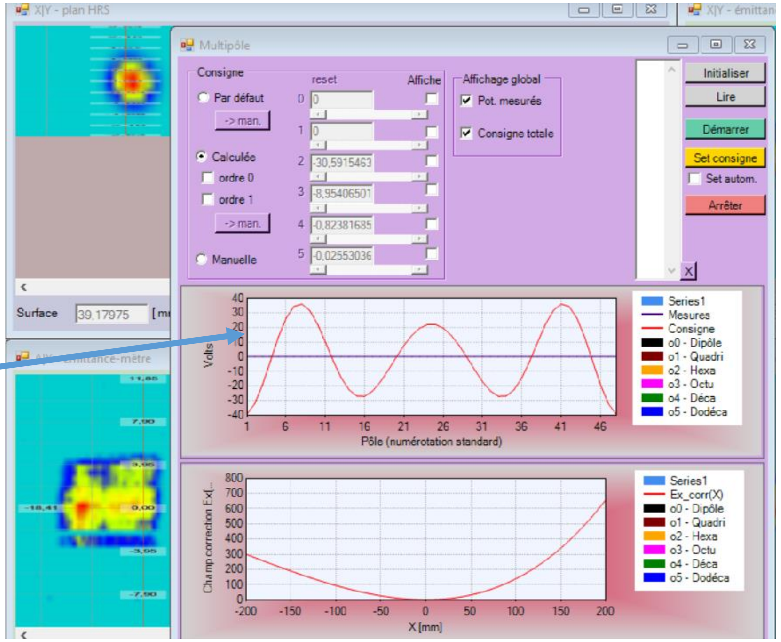
- Emittance figures on emittance-meter
- Propagate emittance figure to separation point of HRS
- Automatic analysis of emittance figure
- Send commands to multipole
- Repeat in iterative process

In development !

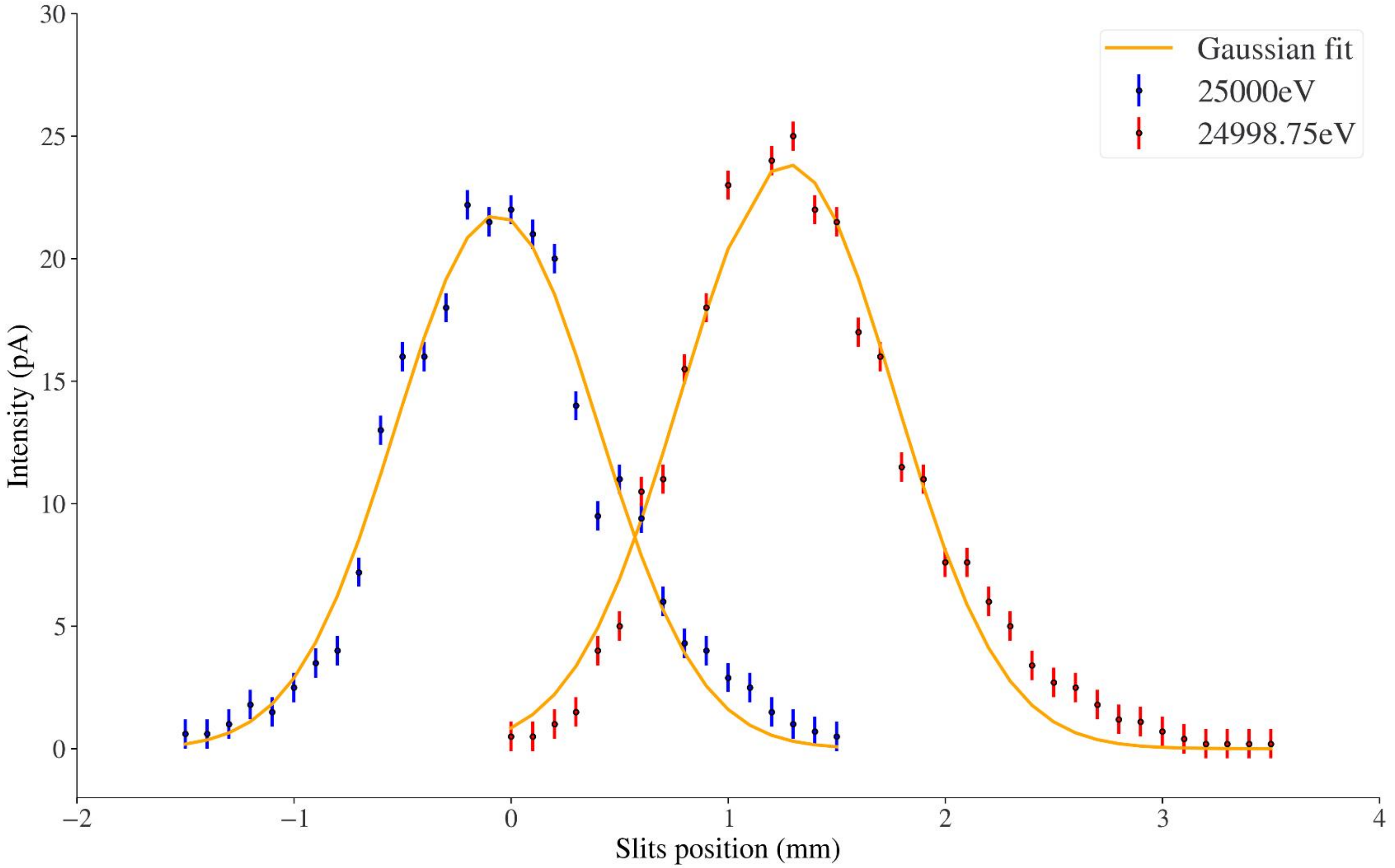


Multipolar coefficients

Multipole voltages



Resolution measurement: slits scan



$$\frac{\Delta E}{E} = \frac{1}{20000}$$

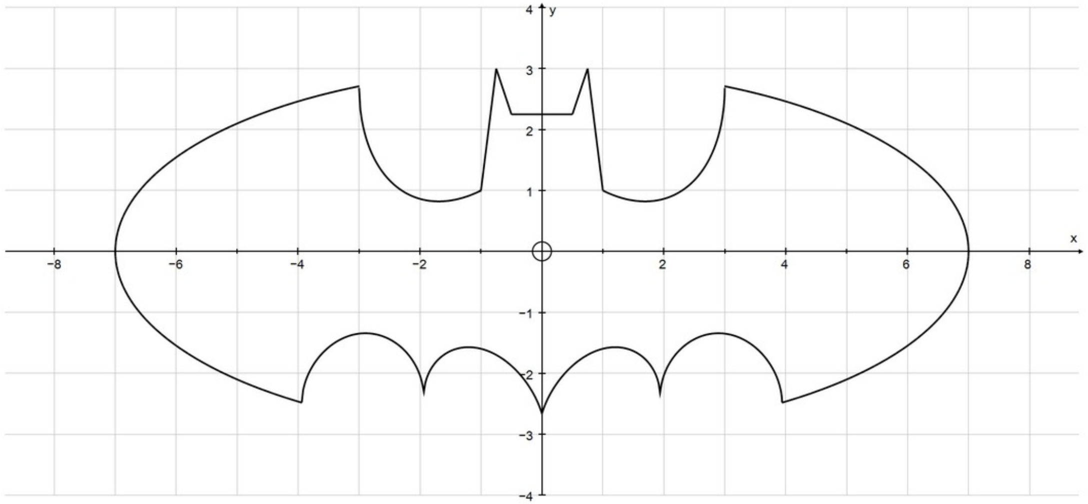
Transmission > 80%

$\epsilon \sim 1 - 2\, \pi . mm . mrad$

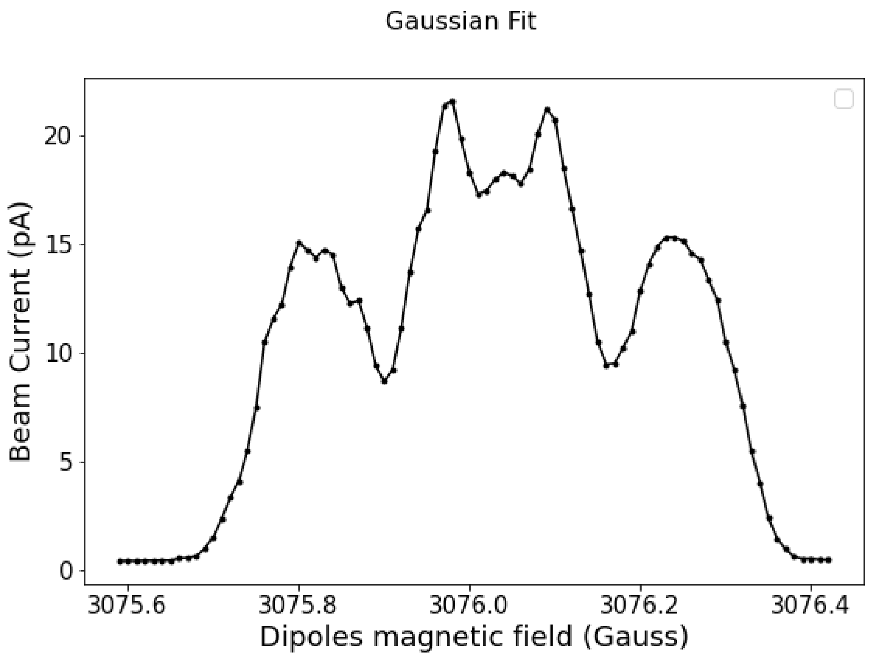
Hexapolar and octupolar corrections applied

R_{FWHM}= 24500

The dark knight



Model



Result