Preparation of mono-isotopic beams:
Isobar purification via HRS

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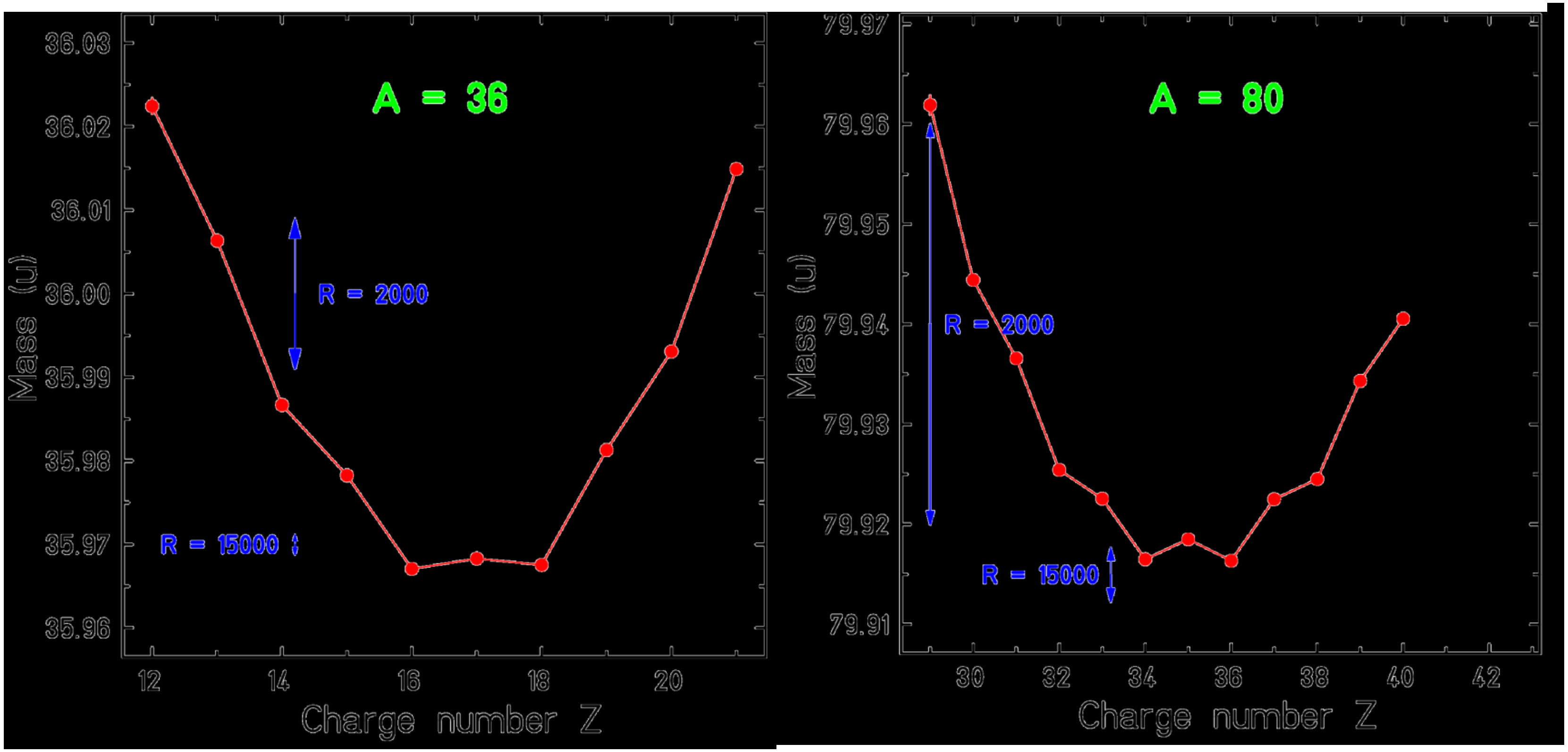
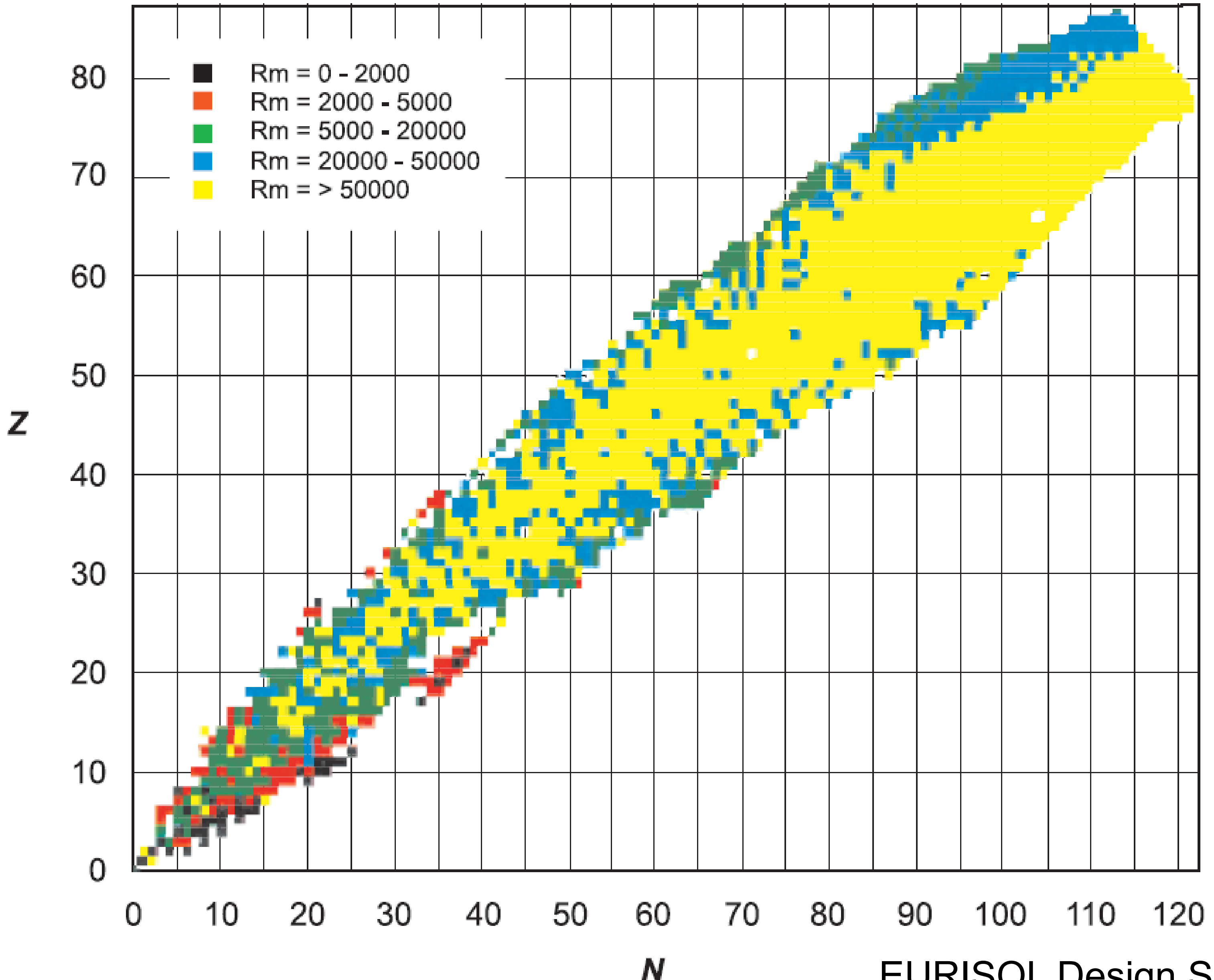
Why a High Resolution Separator?

- The production of the most exotic isotopes generally accompanied with a high contamination by the less exotic isobars of longer half-lives.



Powerful selection methods are mandatory

Why a High Resolution Separator?

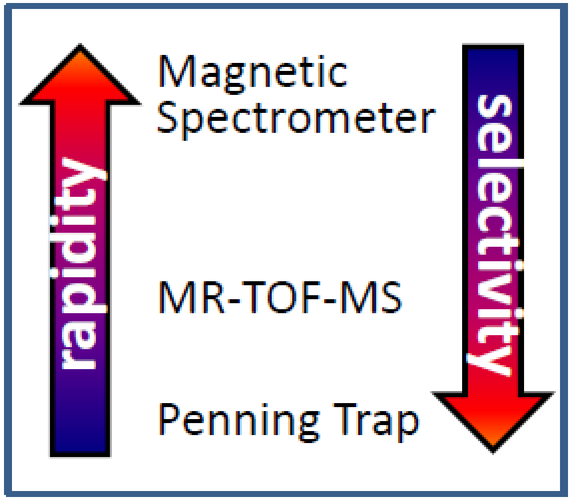


EURISOL Design Study

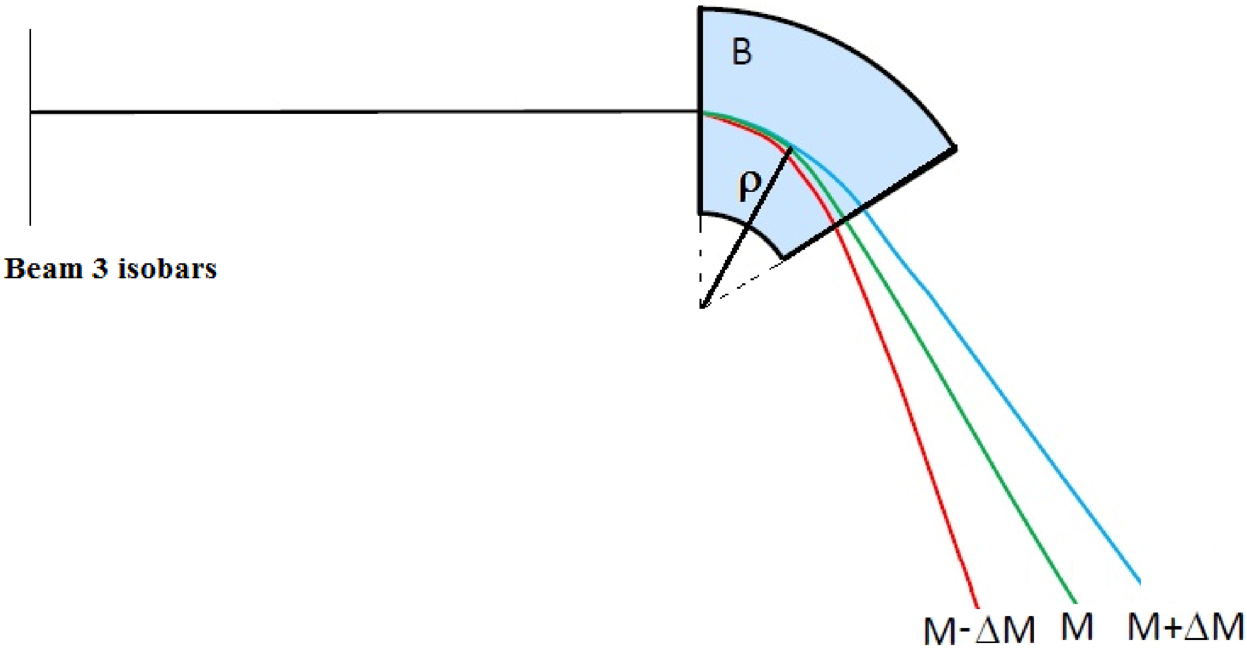
Why a High Resolution Magnetic Separator?

The important criteria are :

- the selectivity: the capability to separate the ions of interest from contaminants
- the efficiency: keep the maximum of the ions of interest
- the rapidity: the time needed to separate the ions of interest from contaminants



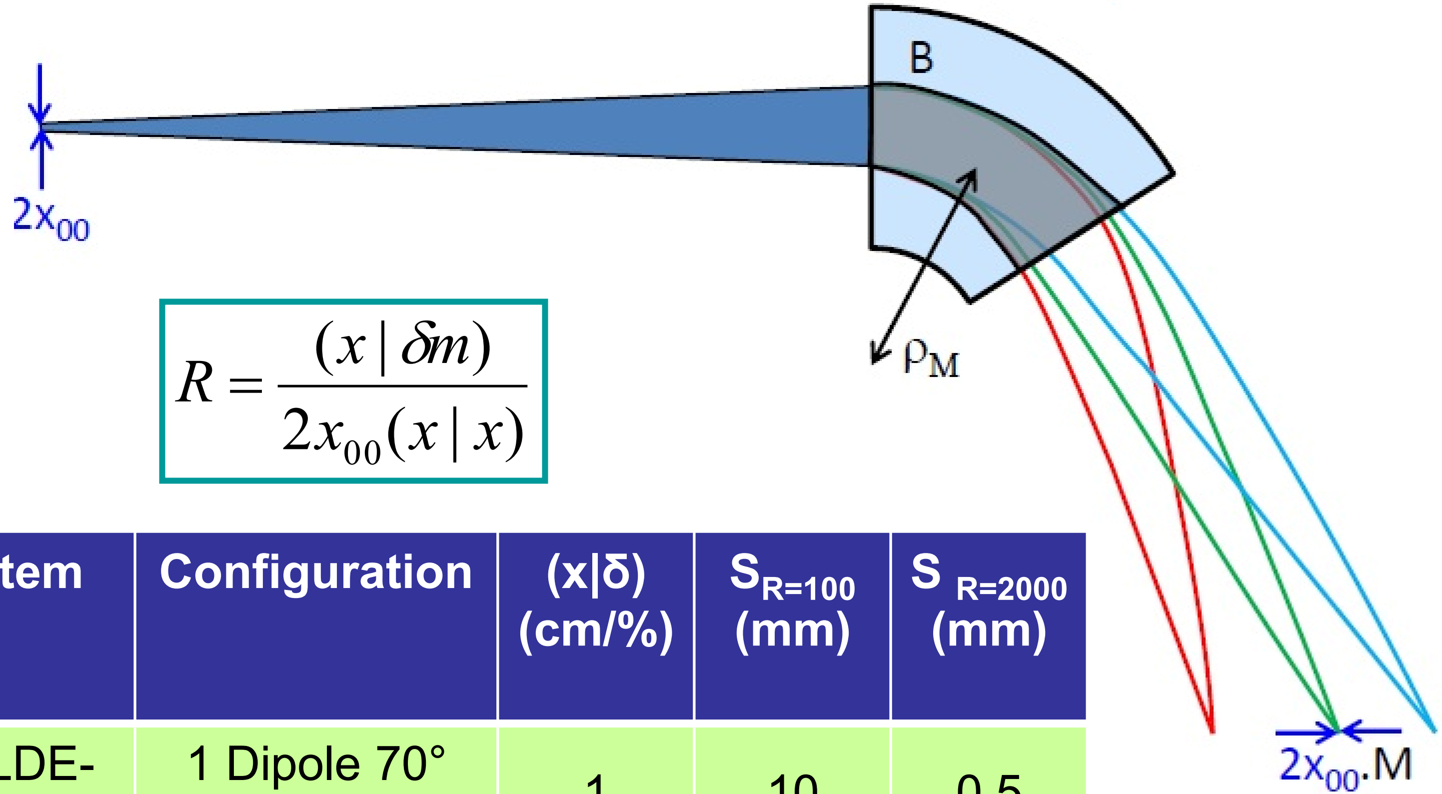
$$B\,\rho = \frac{P}{q} \approx \frac{m \cdot v}{q}$$



Mass-resolving pow

$$R = \frac{\quad}{2x_{00}(x\,|\,x}$$

Performance of a Magnetic Separator

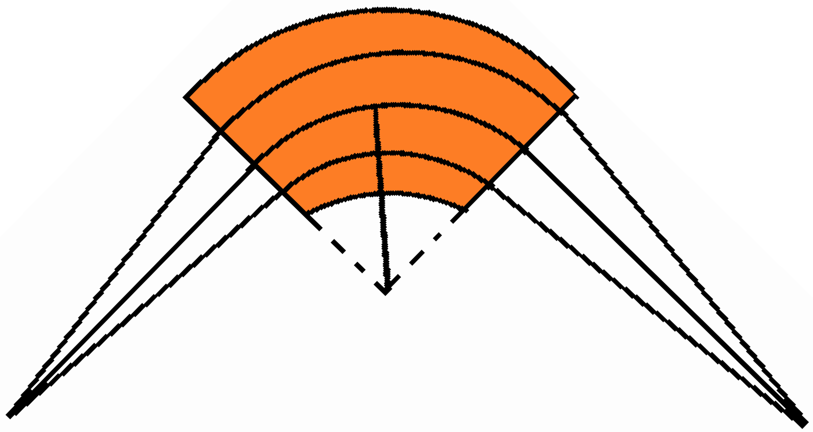


$$R = \frac{(x|\delta m)}{2x_{00}(x|x)}$$

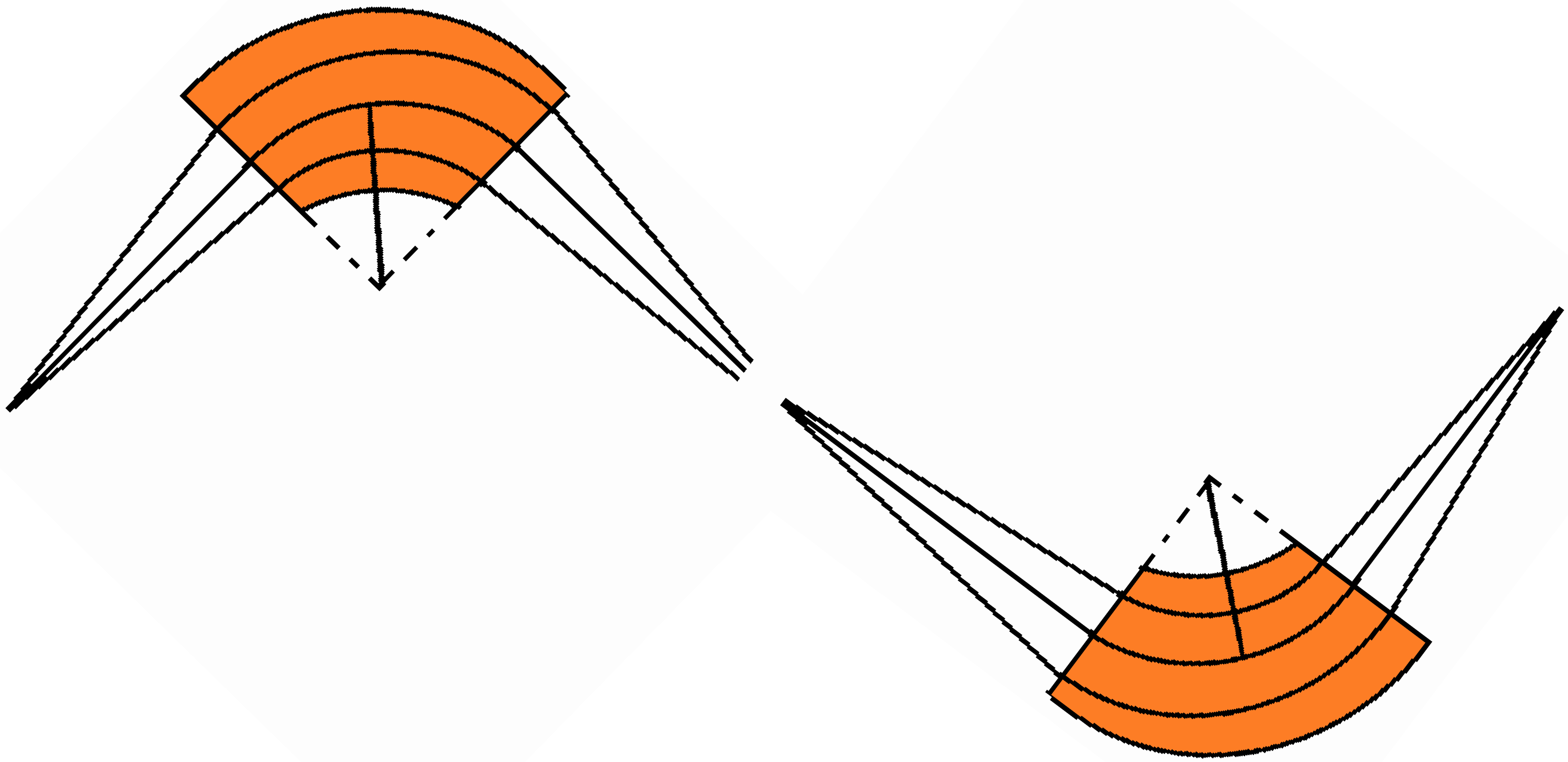
System	Configuration	(x|δ) (cm/%)	$S_{R=100}$ (mm)	$S_{R=2000}$ (mm)
ISOLDE-GPS	1 Dipole 70° ρ=1.5 m	1	10	0.5
TRIUMF-ISAC I	1 Dipole 135° ρ=1.0 m	2.25	22.5	1.1

It means that neighboring beams at mass 100 (± 1 mass unit) are thus separated by 22.5mm at ISACI and by 10mm at GPS, but hardly isobars

How to increase resolution?

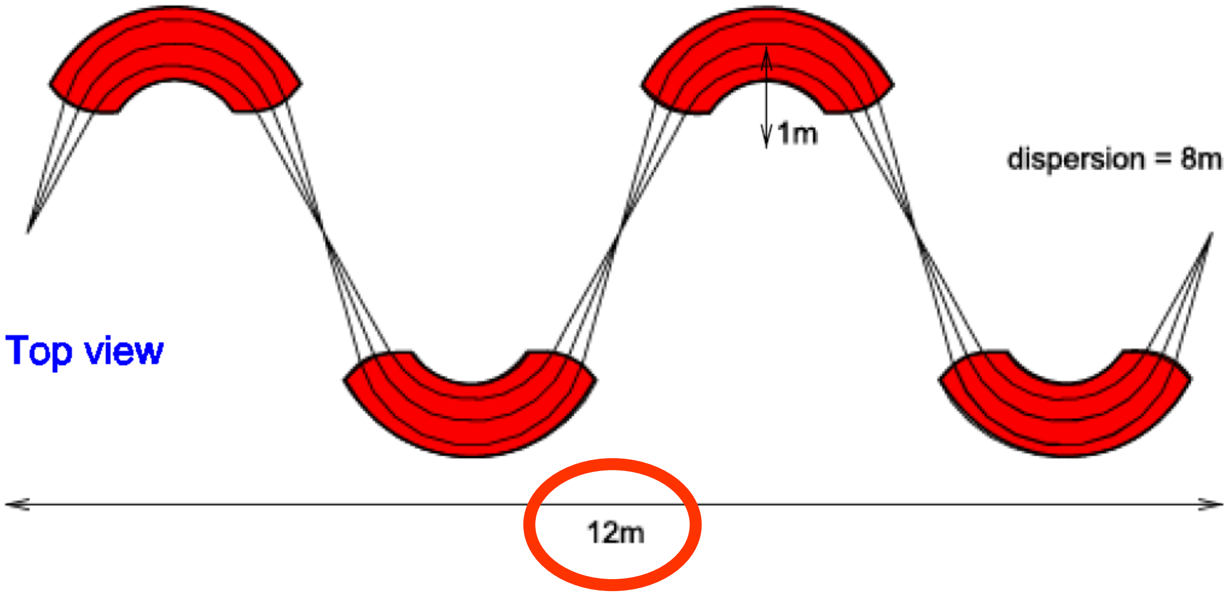


How to increase resolution?



How to increase resolution?

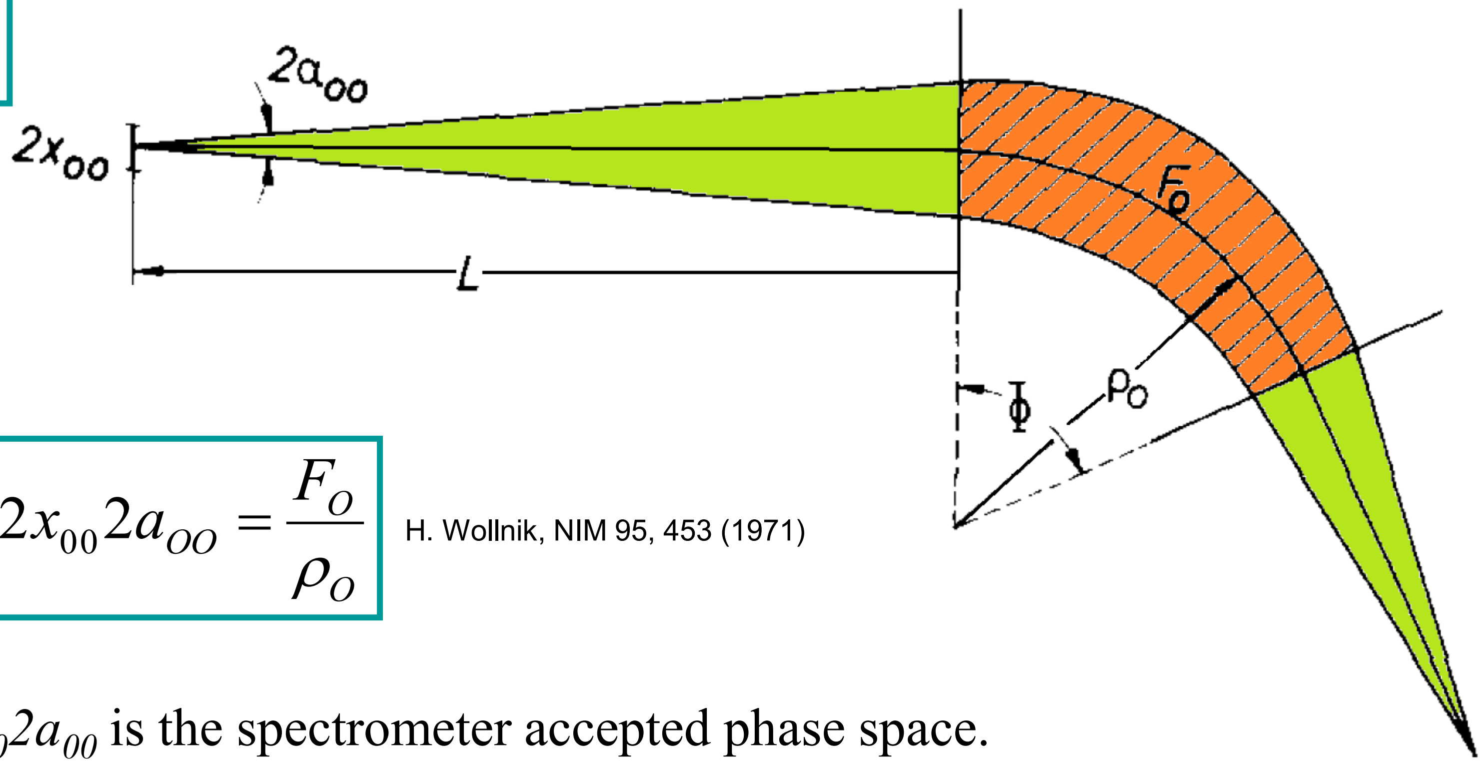
EURISOL



Separator	Configuration	(x|δ) (cm/%)
EURISOL-HRS	4 Dipoles 135° ρ=1.0 m	8
EXCYT-HRMS	2 Dipoles 90° ρ=2.6 m	10.4
ISOLDE- HRS	1 D 90° ρ=1.0 m 1 D 60° ρ=1.0 m	4

How to increase resolution?

$$R = \frac{(x\,|\,\delta m)}{2x_{00}(x\,|\,x)}$$



$$Q = R2x_{00}2a_{OO} = \frac{F_O}{\rho_O}$$

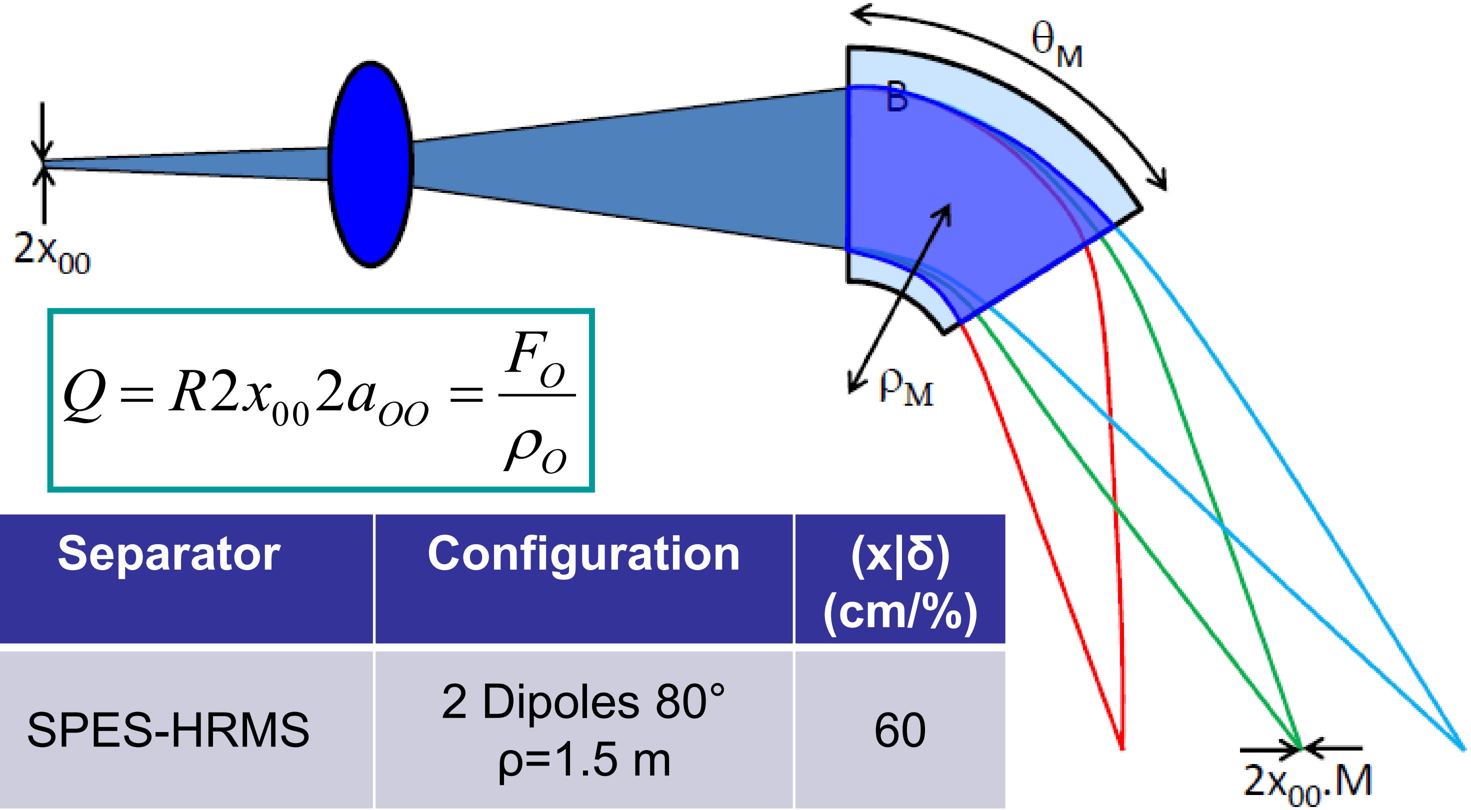
H. Wollnik, NIM 95, 453 (1971)

❖ $2\ x_{00}2a_{00}$ is the spectrometer accepted phase space.

❖R can be increased if accepted phase space is reduced →reduced particle intensity.

❖In order to get simultaneously a large R and a high particle intensity, it is necesary to have a large F_0 and small ρ_0

How to increase resolution?



$$Q = R2x_{00}2a_{OO} = \frac{F_O}{\rho_O}$$

Separator	Configuration	(x|δ) (cm/%)
SPES-HRMS	2 Dipoles 80° ρ=1.5 m	60
ANL/CARIBU-HRS	2 Dipoles 60° ρ=0.5 m	20
SPIRAL2-DESIR	2 Dipoles 90° ρ=0.85 m	31
TRIUMF-ISACIII-HRS	2 Dipoles 90° ρ=0.85 m	1.6

Comparison of High Resolution Magnetic Separators

Separator	Configuration	Shape	(x|δ) (cm/%)
SPES-HRMS	2 Dipoles 80°/90° ρ=1.5 m	C	60
SPIRAL2-RISP	2 Dipoles 90° ρ=0.85 m	C	31
CARIBU-HRS	2 Dipoles 60° ρ=0.5 m	C	20
EXCYT-HRMS	2 Dipoles 90° ρ=2.6 m	S	10.4
EURISOL-HRS	4 Dipoles 135° ρ=1.0 m	S	8
ISOLDE- HRS	1 D 90° ρ=1.0 m 1 D 60° ρ=1.0 m	S	4
TRIUMF-ISACIII-HRS	2 Dipoles 90° ρ=0.85 m	C	1.6

Comparison of High Resolution Magnetic Separators

Separator	Configuration	$(x\|\delta)$ (m)	Slits Δx_{00} (mm)	R
EURISOL-HRS	4 D 135° ρ=1.0 m	8	0.0625	64000
SPES-HRMS	2 D 80° ρ=1.5 m	60	0.5	60000
CARIBU-HRS	2 D 60° ρ=0.5 m	20	0.5	20000
SPIRAL2-RISP	2 D 90° ρ=0.85 m	31	0.5	31000
TRIUMF-ISACIII-HRS	2 D 90° ρ=0.85 m	1.6	0.05	16000
EXCYT-HRMS	2 D 90° ρ=2.6 m	10.4	0.2	25000
ISOLDE- HRS	1 D 90° ρ=1.0 m 1 D 60° ρ=1.0 m	4	0.1	20000

$$R = \frac{(x|\delta)}{2x_{00}(x|x)}$$

Comparison of High Resolution Magnetic Separators

Separator	Configuration	(x|δ) (m)	Slits Δx0 (mm)	R[1]	R[2]
EURISOL-HRS	4 D 135° ρ=1.0 m	8	0.06	57000	20000
ISOLDE- HRS	1 D 90° ρ=1.0 m 1 D 60° ρ=1.0 m	4	0.1	19000	12000
EXCYT-HRMS	2 D 90° ρ=2.6 m	10.4	0.2	25000	14000
SPES-HRMS	2 D 80° ρ=1.5 m	60	0.5	54000	20000
SPIRAL2-RISP	2 D 90° ρ=0.85 m	31	0.5	29000	15000
CARIBU-HRS	2 D 60° ρ=0.5 m	20	0.5	19000	12000
TRIUMF-ISACIII-HRS	2 D 90° ρ=0.85 m	1.6	0.05	15500	10000

R[1] $\Delta E_0/E_0 = \pm 1 \times 10^{-6}$

R[2] $\Delta E_0/E_0 = \pm 1.67\times 10^{-5}$ **(1 eV/60keV)**

$$R = \frac{(x\,|\,\delta m)}{2x_{00}(x\,|\,x) + 2(x\,|\,\delta E)\dfrac{\Delta E}{E}}$$

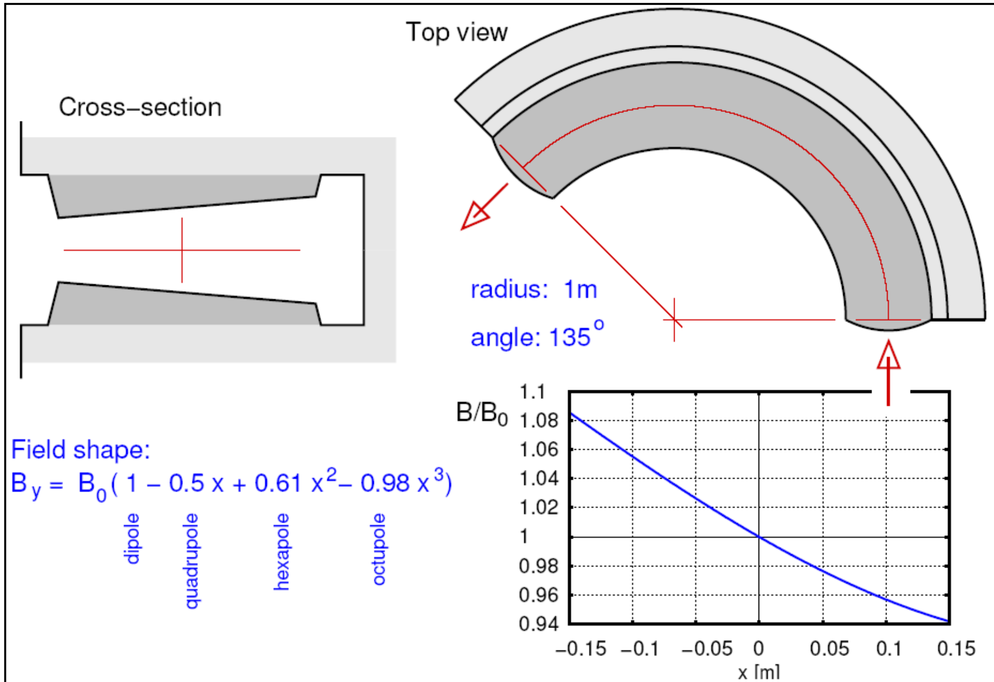
Comparison of High Resolution Magnetic Separators

Separator	Configuration	(x|δ) (m)	R[1]
EURISOL-HRS	4 D 135° ρ=1.0 m	8	4400
ISOLDE- HRS	1 D 90° ρ=1.0 m 1 D 60° ρ=1.0 m	4	2800
EXCYT-HRMS	2 D 90° ρ=2.6 m	10.4	5000
SPES-HRMS	2 D 80° ρ=1.5 m	60	8500
SPIRAL2-RISP	2 D 90° ρ=0.85 m	31	7500
CARIBU-HRS	2 D 60° ρ=0.5 m	20	6700
TRIUMF-ISACIII-HRS	2 D 90° ρ=0.85 m	1.6	1300

R[1] ΔX_0=0.5mm, $\Delta E_0/E_0 = \pm 5\times 10^{-5}$ (3eV/60 keV)

High resolution separation requires cold beams

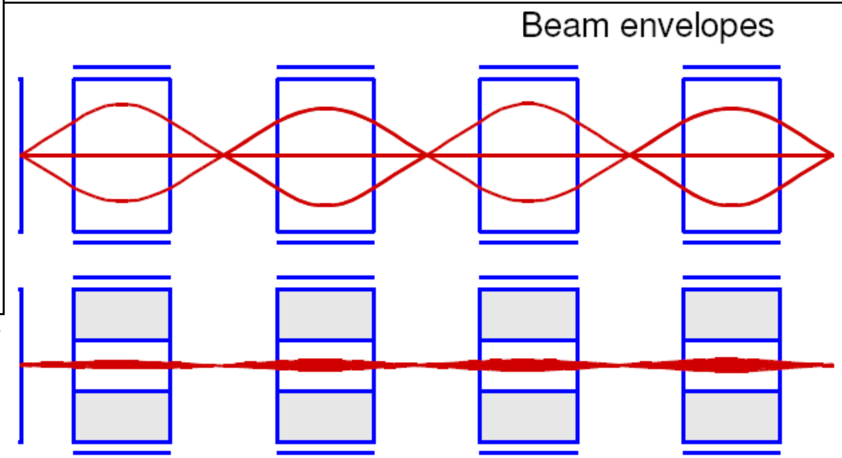
EURISOL-HRS

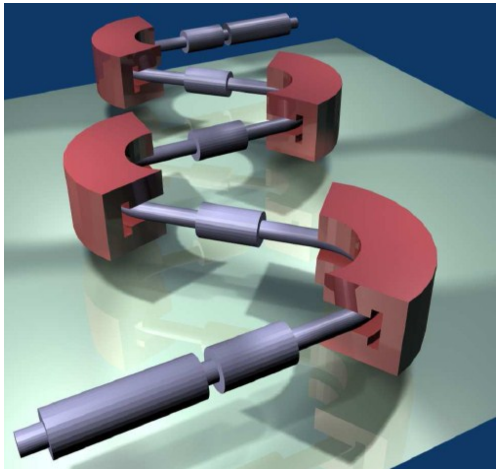


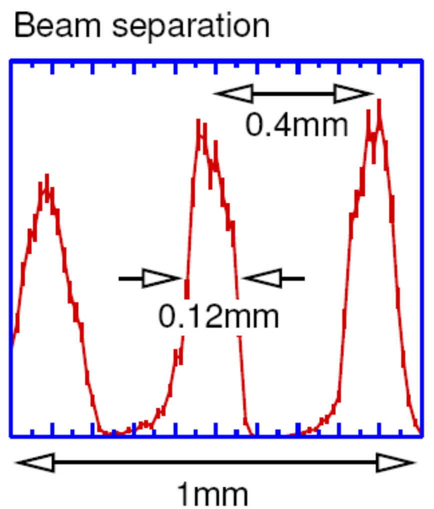
Multiple multipolar dipoles

Large dispersion

Corrections





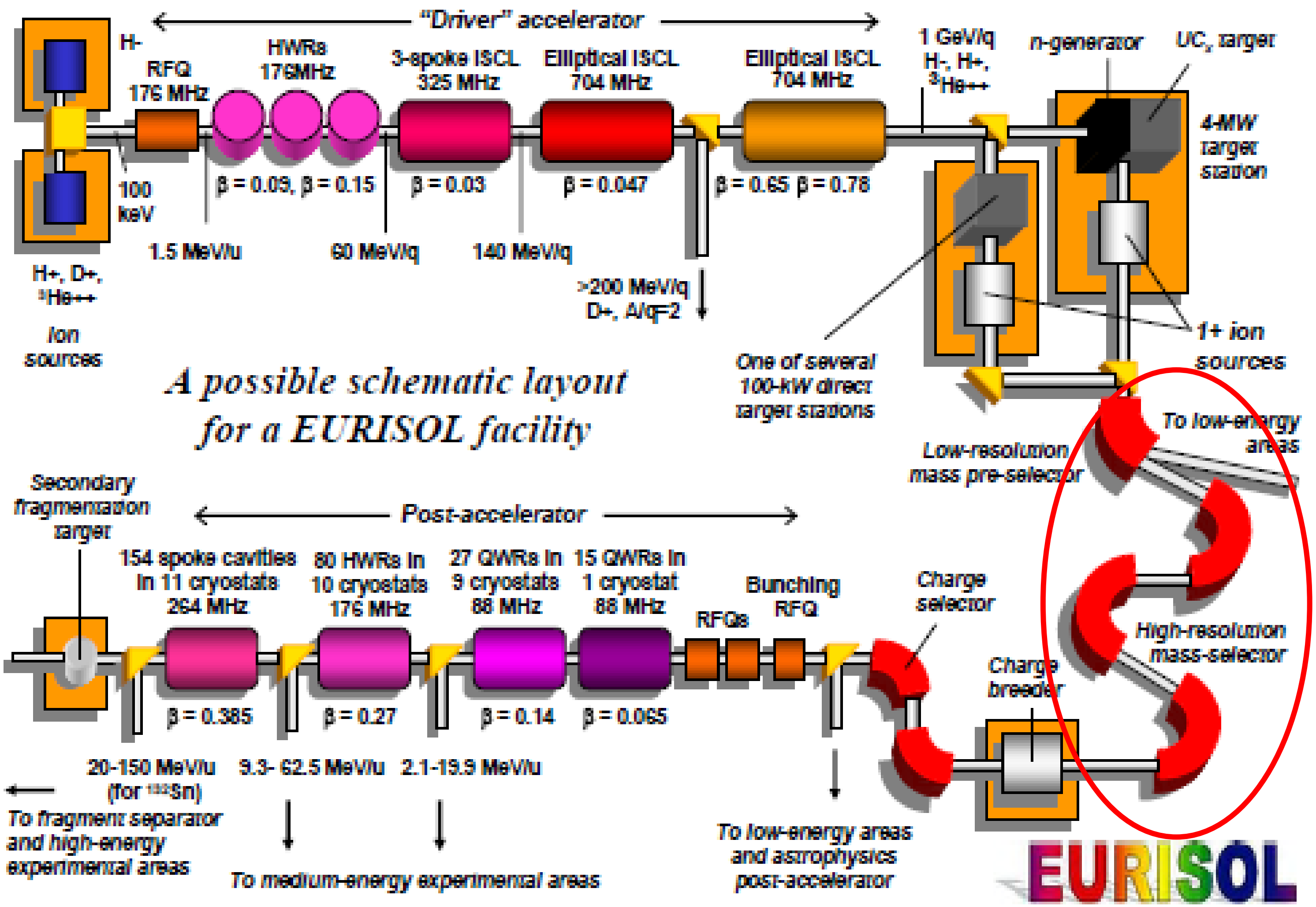


Ultimate resolution:
64 000 for 3 pi.mm.mrad emittance

eg. ^{126}In / Cd Q_β = 5.5 MeV $\frac{M}{\Delta M}$ = 20 000

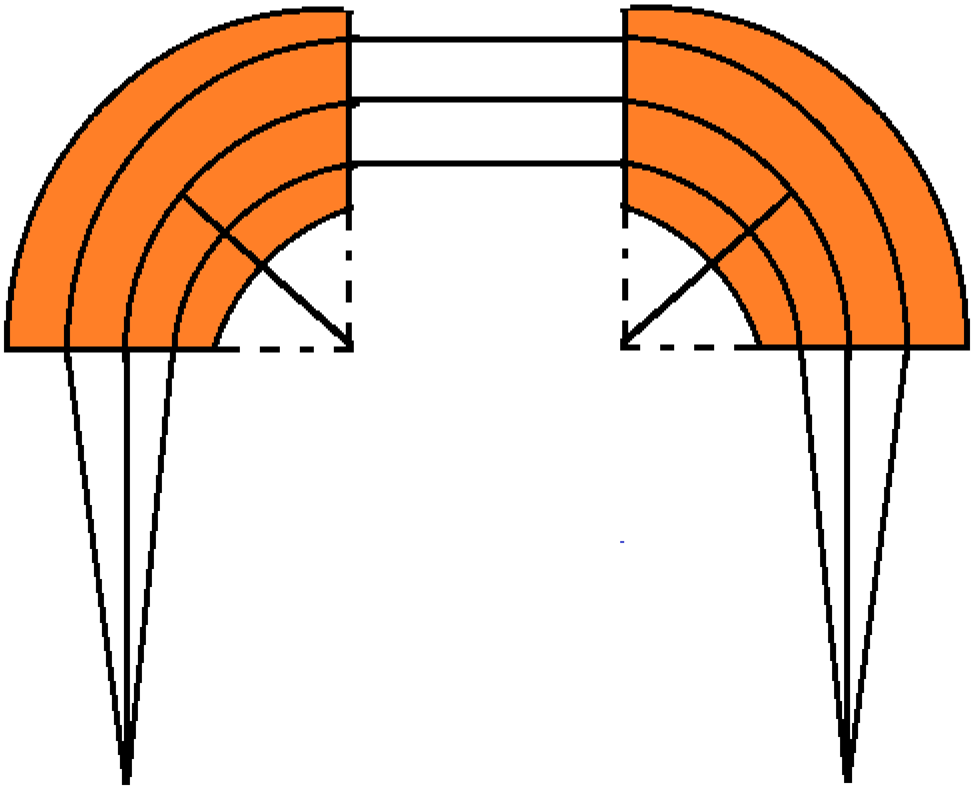
(T. Giles, CERN)

EURISOL-HRS



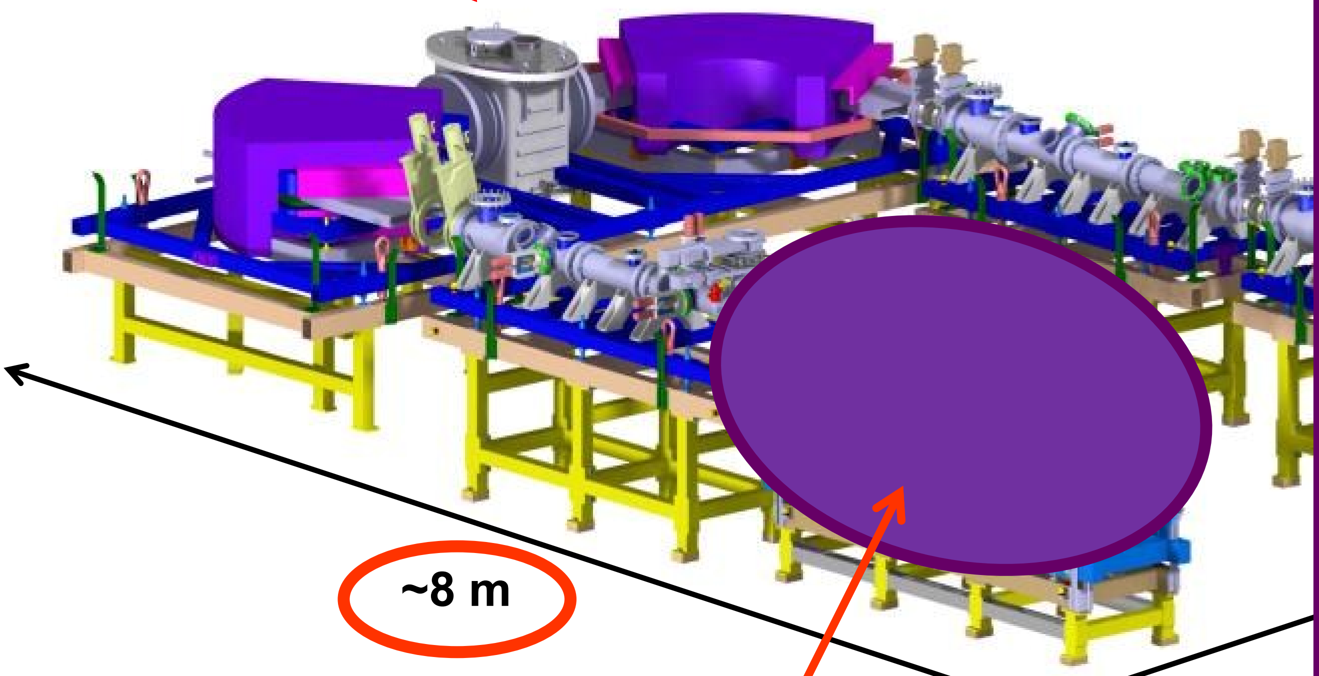
A schematic diagram of the envisaged EURISOL facility.

CARIBU/SPIRAL2/SPES/RISP-HRS

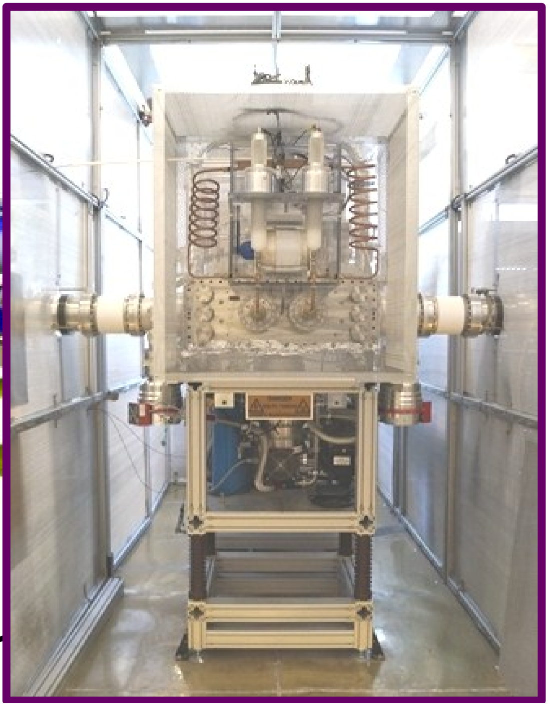


SPIRAL2/DESIR-HRS

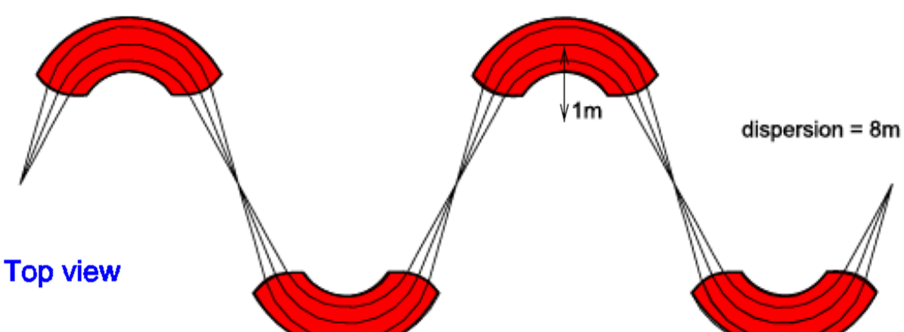
HRS
CENBG



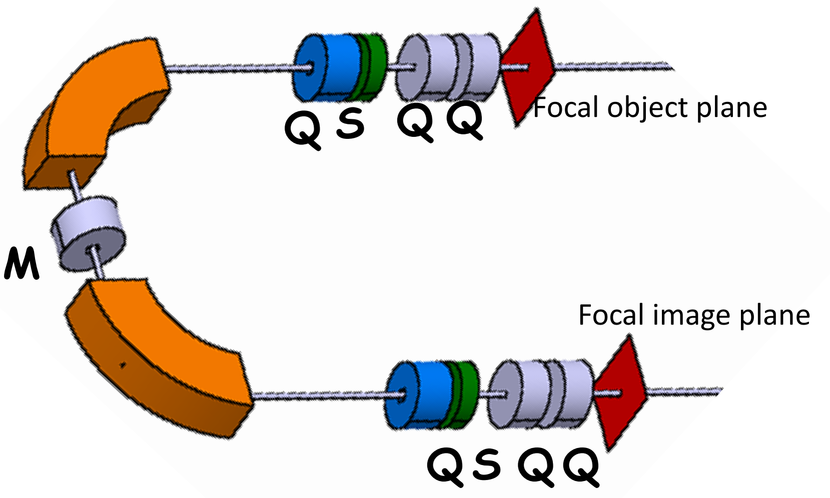
~8 m

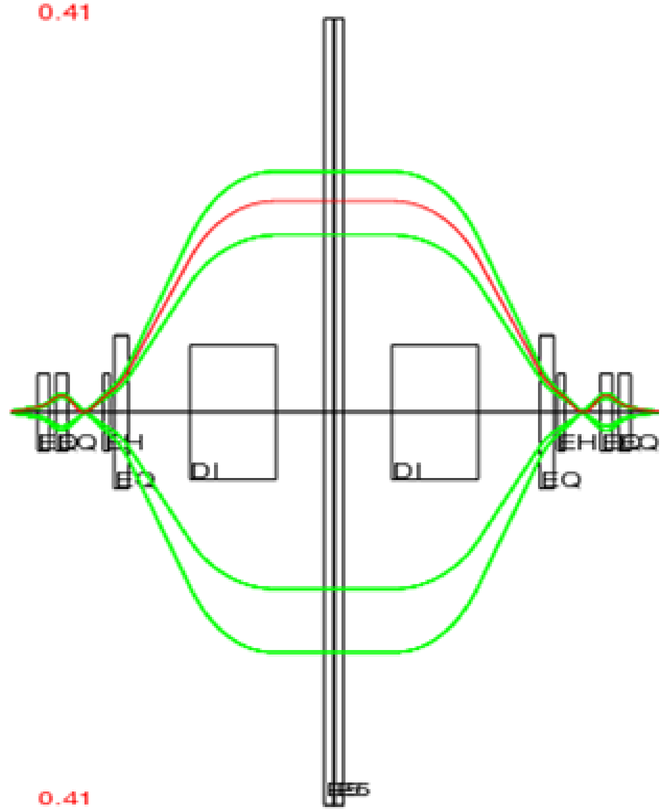


RFQ Cooler LPC Caen



R ~ 31000

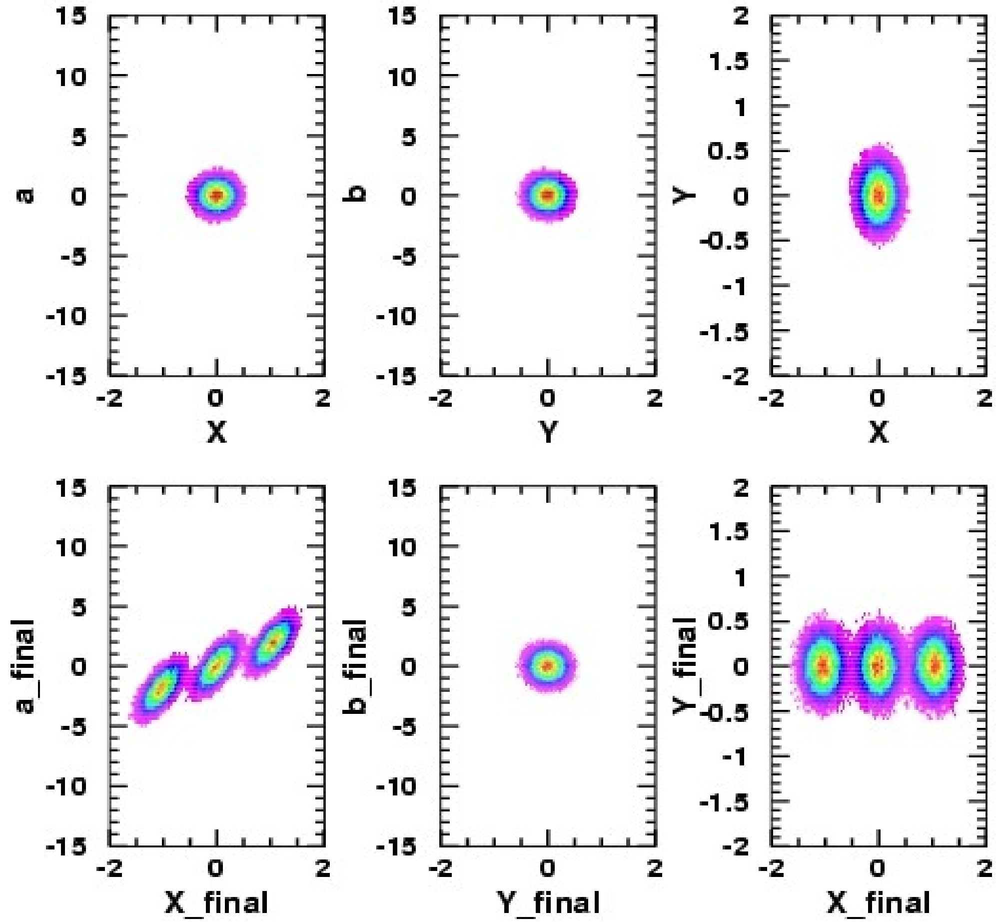


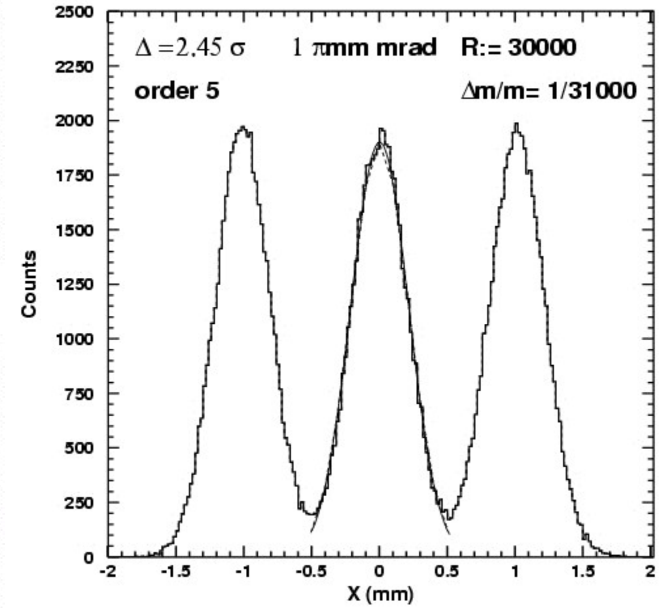


- Optimal pe… a 1 π.mm.mrad.
- Acceptance :
  - 5 π.mm.mrad (90% transmission)

Trans…

	(x,)	(a,)	(y,)	(b,)
x	−1.0000	−3.6499	0.0	0.0
a	−0.40E−5	−1.0000	0.0	0.0
y	0.0	0.0	1.0000	0.50E−4
b	0.0	0.0	−0.60E−6	1.0000
δ m	−31.32	−57.16	0.0	0.0

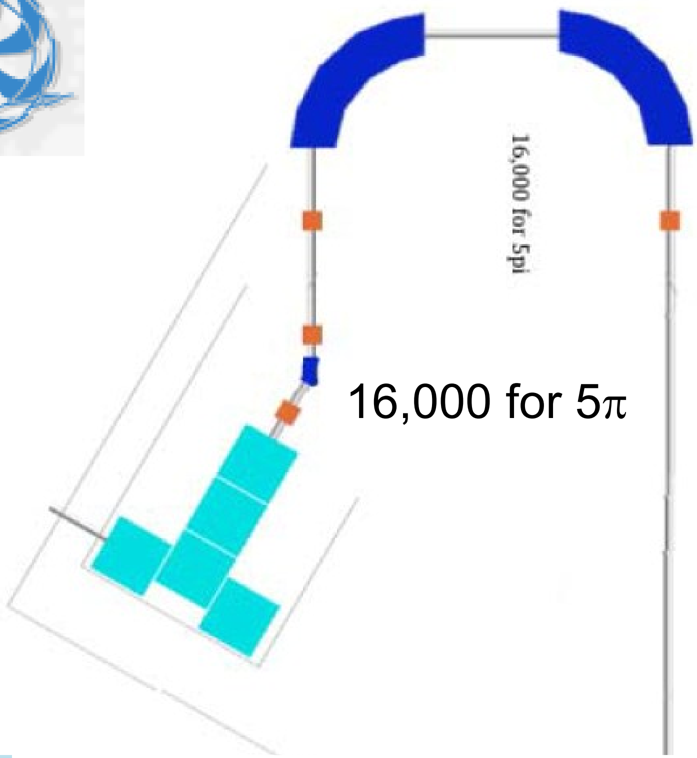


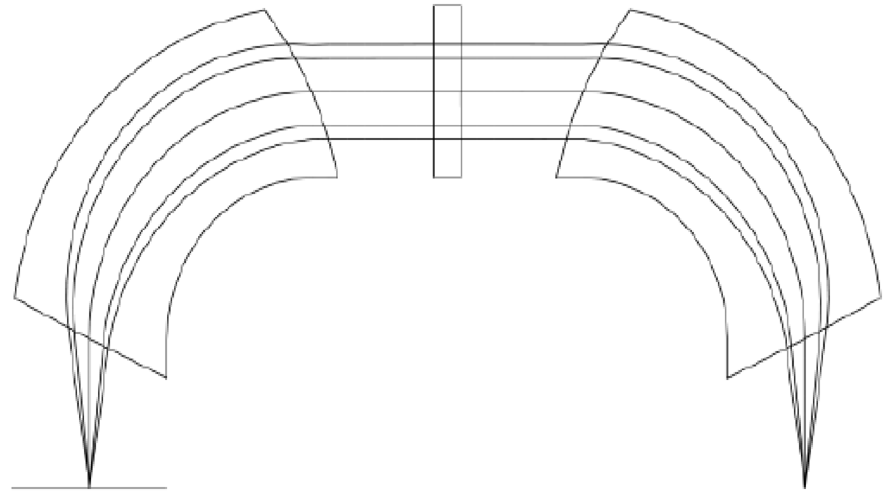


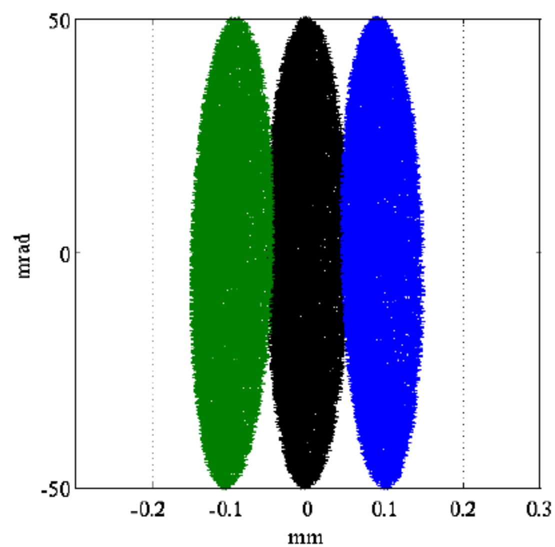
TKN-montecarlo

High order aberrations corrected up to 5th order allows to obtain a Resolution of ~30000

TRIUMF/ISAC3-HRS



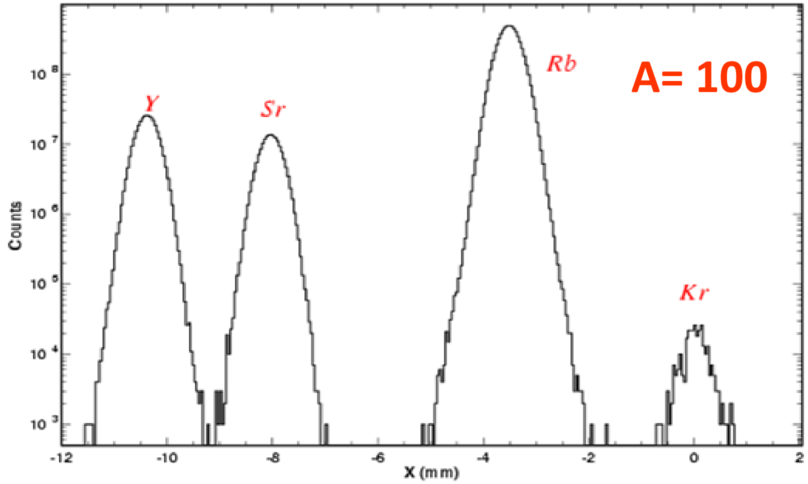




R. Baartman, TRIUMF

Examples of physics cases

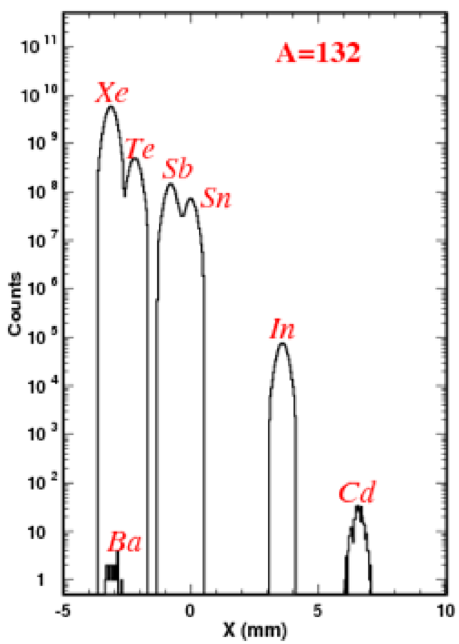
Mass spectra calculated, for A=132 and A = 100 isobares, setting on ^{132}Sn and ^{100}Kr.

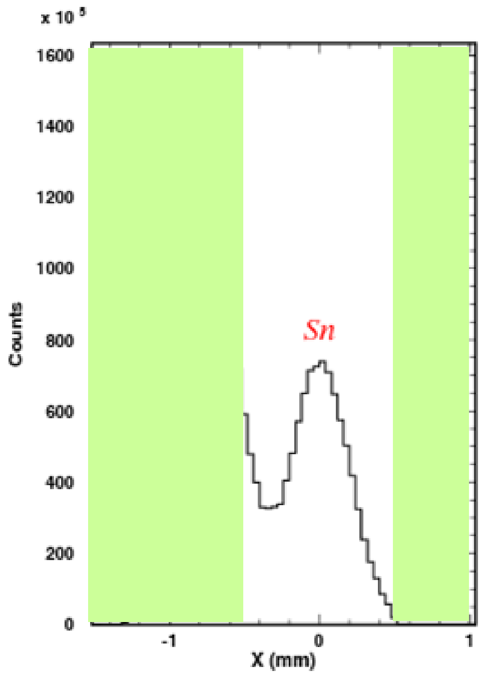


Slits at ±0.5mm →

0% of contaminants

100% mono-isotopic ^{100}Kr beam





Slits at ±0.5mm →

13.3% of contaminant ^{132}Sb

Transmission ^{132}Sn = 97%*

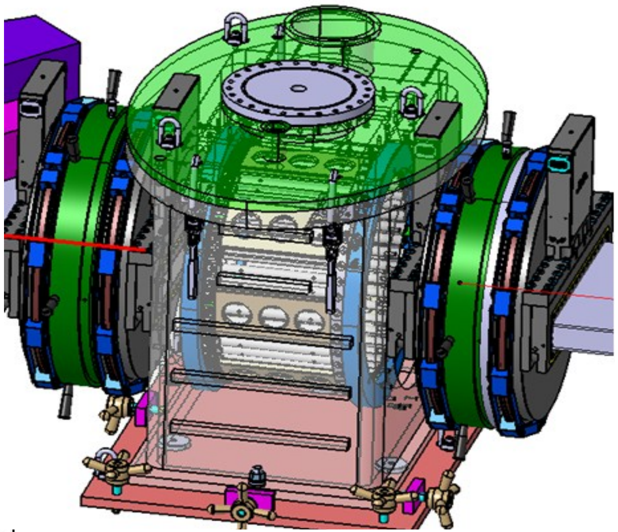
For 0% of contaminant ^{132}Sb

Send to Penning trap

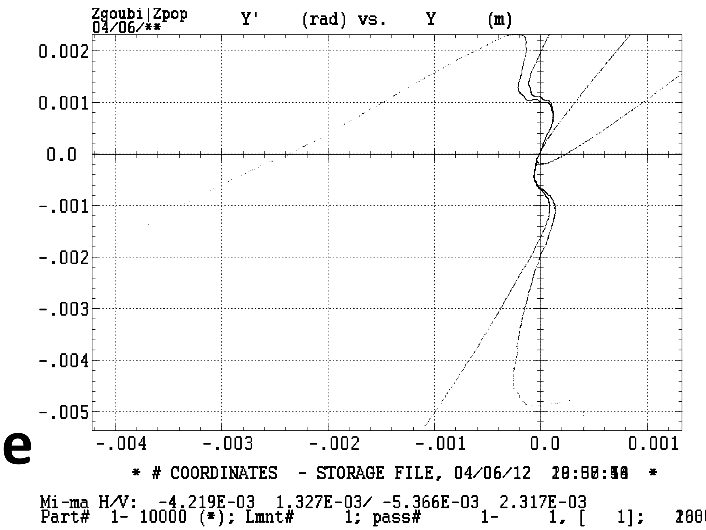
What can decrease the calculated resolution?

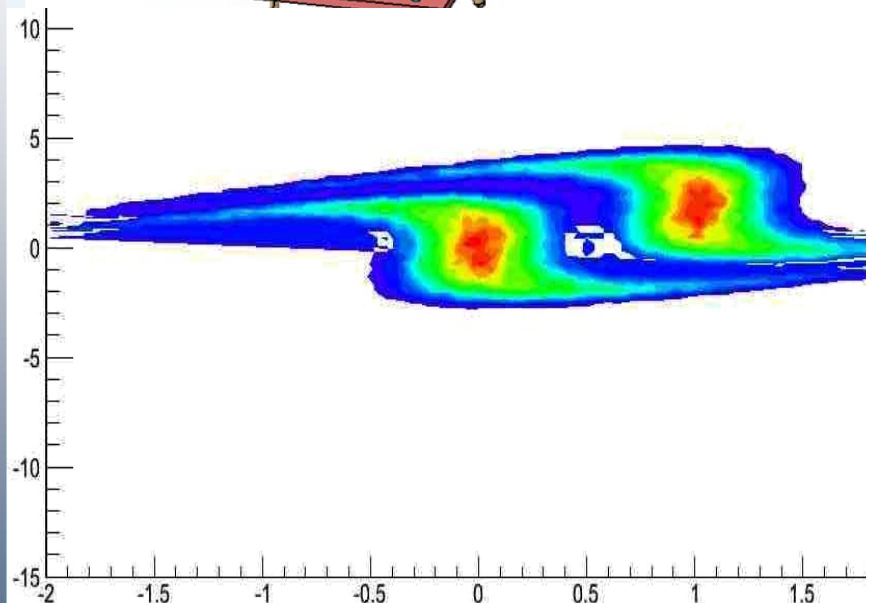
- Aberrations
- Field inhomogeneity
- Mechanical defects and positioning precision
- Beam quality:
  - Beam emittance
  - Energy dispersion

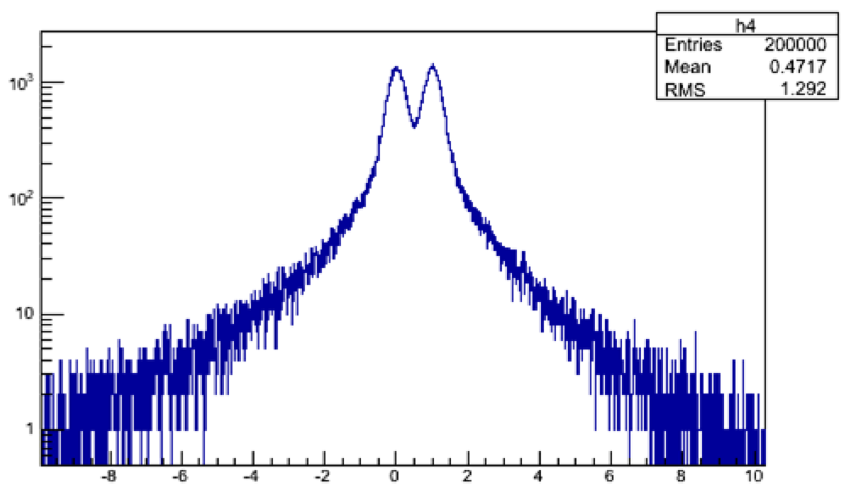
High order aberrations



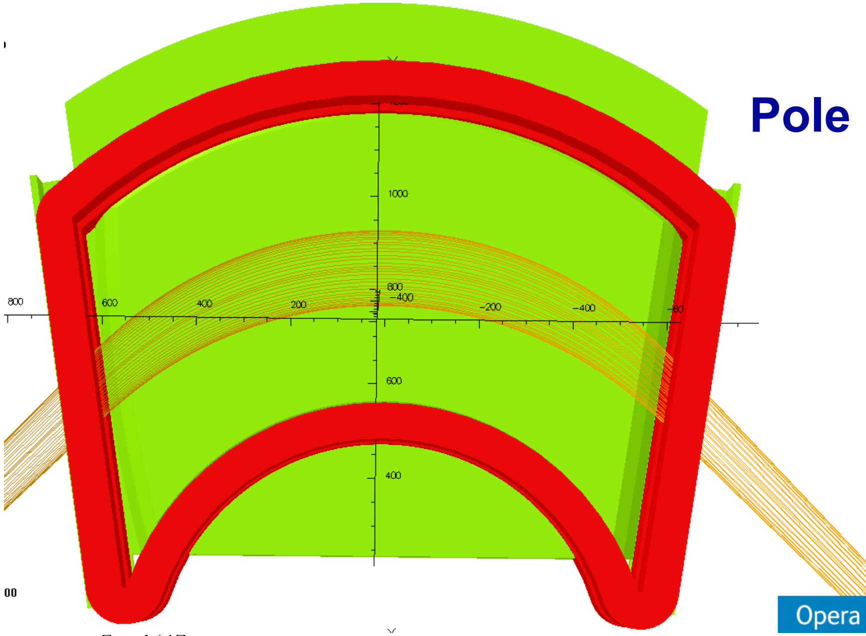
- Hexapole
- Octupole
- Decapole
- Dodecapole





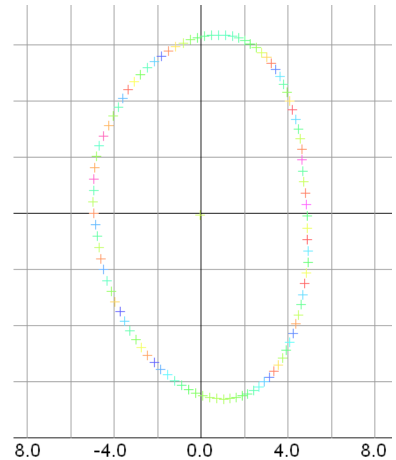


Dipoles: 2nd order correction

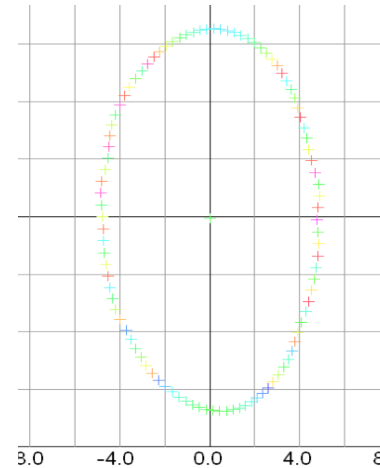


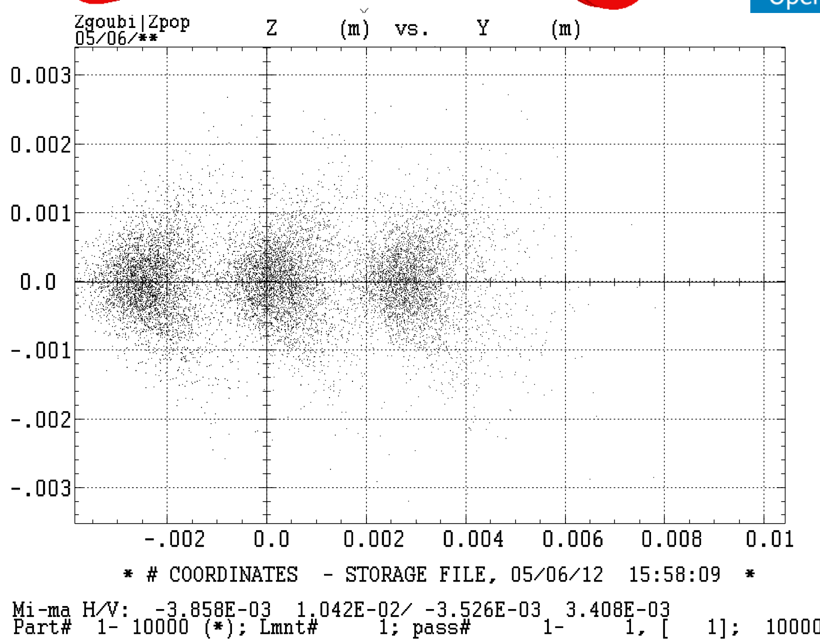
Pole curvature R

R=4500mm



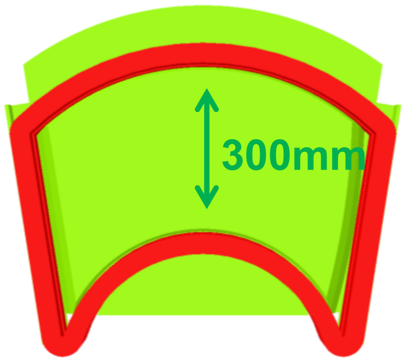
R=3000mm





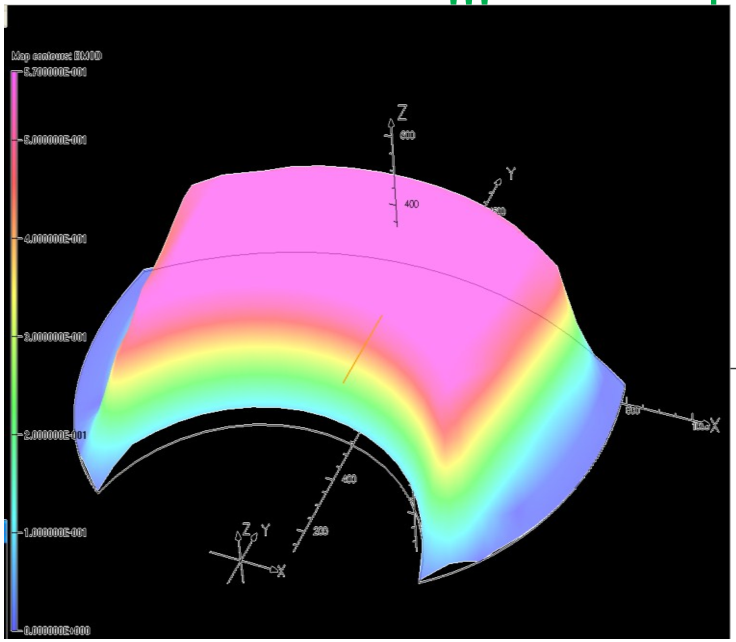
R = 4 m on both side of each Dipole without correction with the Multipole

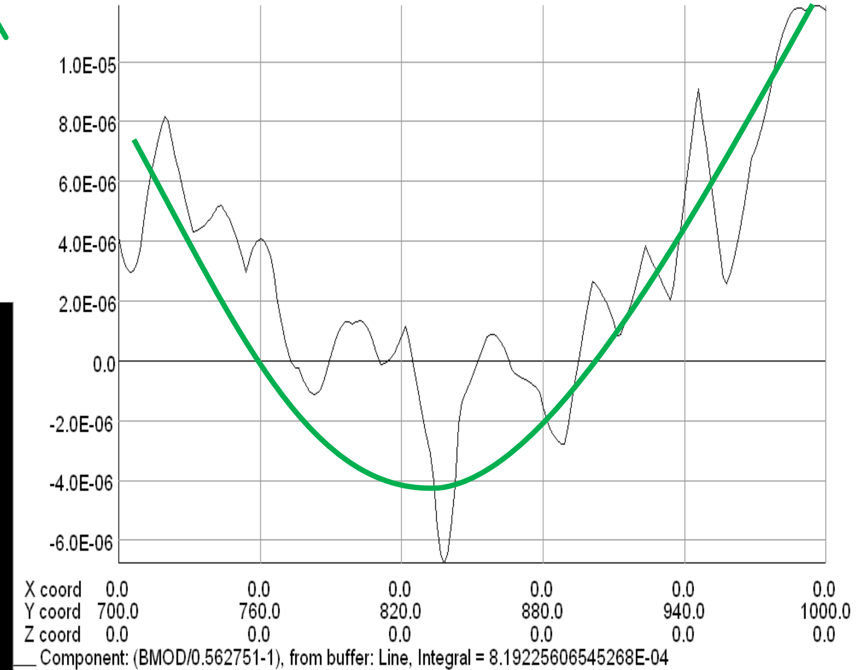
Field Homogeneity in Dipole Magnets



Homogeneity 1.6 10^{-5}

0.09 Gauss !!!





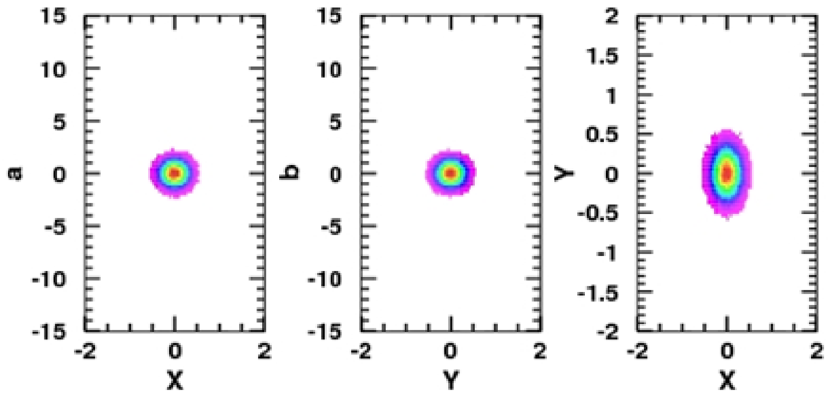
Maurice Duval,

Marc-Hervé Stodel

GANIL

Positioning precision

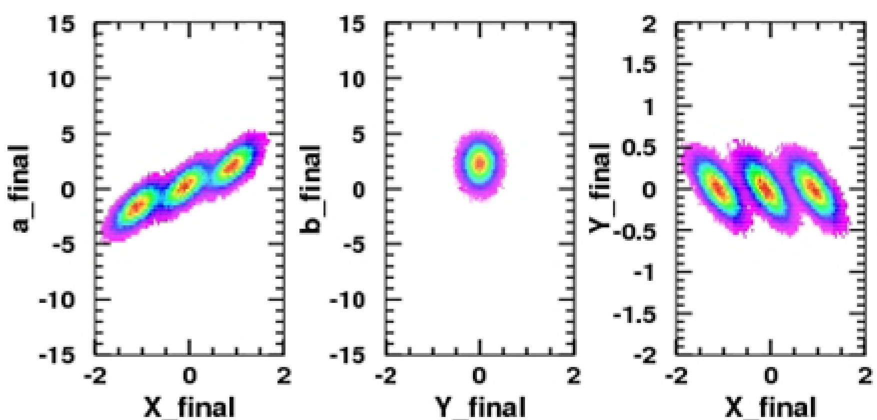
Entrance beam to HRS

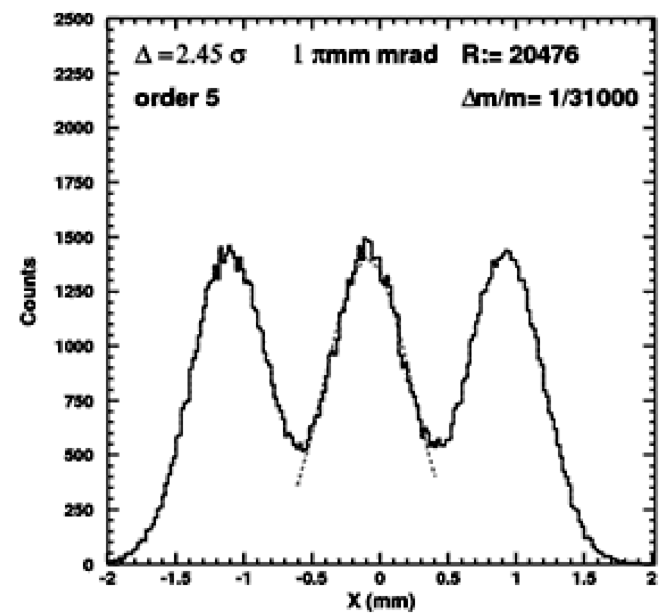


Misalignment tolerances

	X shift (mm)	Y shift (mm)	X Tilt (mrad)	Y Tilt (mrad)	Θ (mrad)
QQ1	±0.1	±0.1	±3.5	±3.5	±3.5
HQ1	±0.1	±0.1	±0.35	±3.5	±3.5
D1	±0.1	±0.1	±0.35	±3.5	±3.5
M	±0.1	±0.1	±3.5	±3.5	±3.5
D2	±0.1	±0.1	±0.35	±3.5	±3.5
HQ2	±0.1	±0.1	±0.35	±3.5	±3.5
QQ2	±0.1	±0.1	±3.5	±3.5	±3.5

Exit beam from HRS

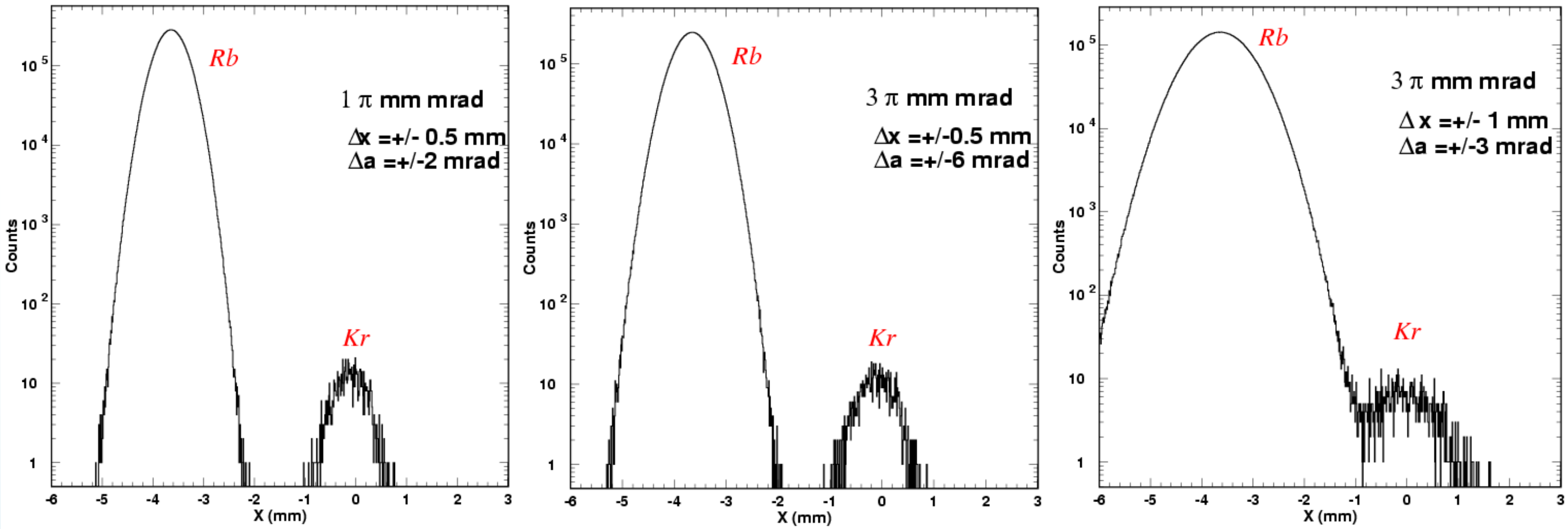




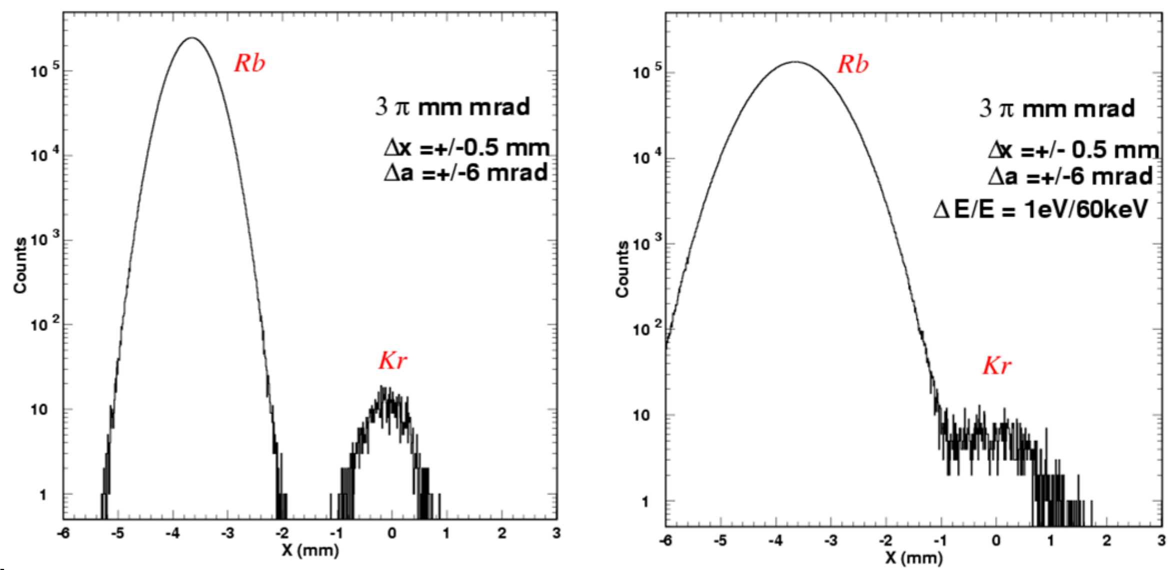
Beam Emittance and Energy dispersion

^{100}Kr :

Beam emittance



Energy dispersion



Final remarks

- High resolution magnetic separators are fast (no half-life limitation), high transmission (close to 100%) and able to handle high intensity beams (no charge space problem).

- The choice of the technical solution is a compromise between mass dispersion and accepted phase space.

- C-shape separator is more compact than S-shape (reduce costs)

- Less optics in the beam line make the system more easy to tune (very important for experiments!!) but high order aberrations are a critical point.
  - Enough commissioning time is important.

- The “working high resolution” of a separator is an engineering problem:
  - Magnetic field homogeneity
  - Mechanical defects
  - Positioning precision

- High quality beams (cold beams) is required in order to get R>15000

Thank you