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The CARIBU Isobar Separator

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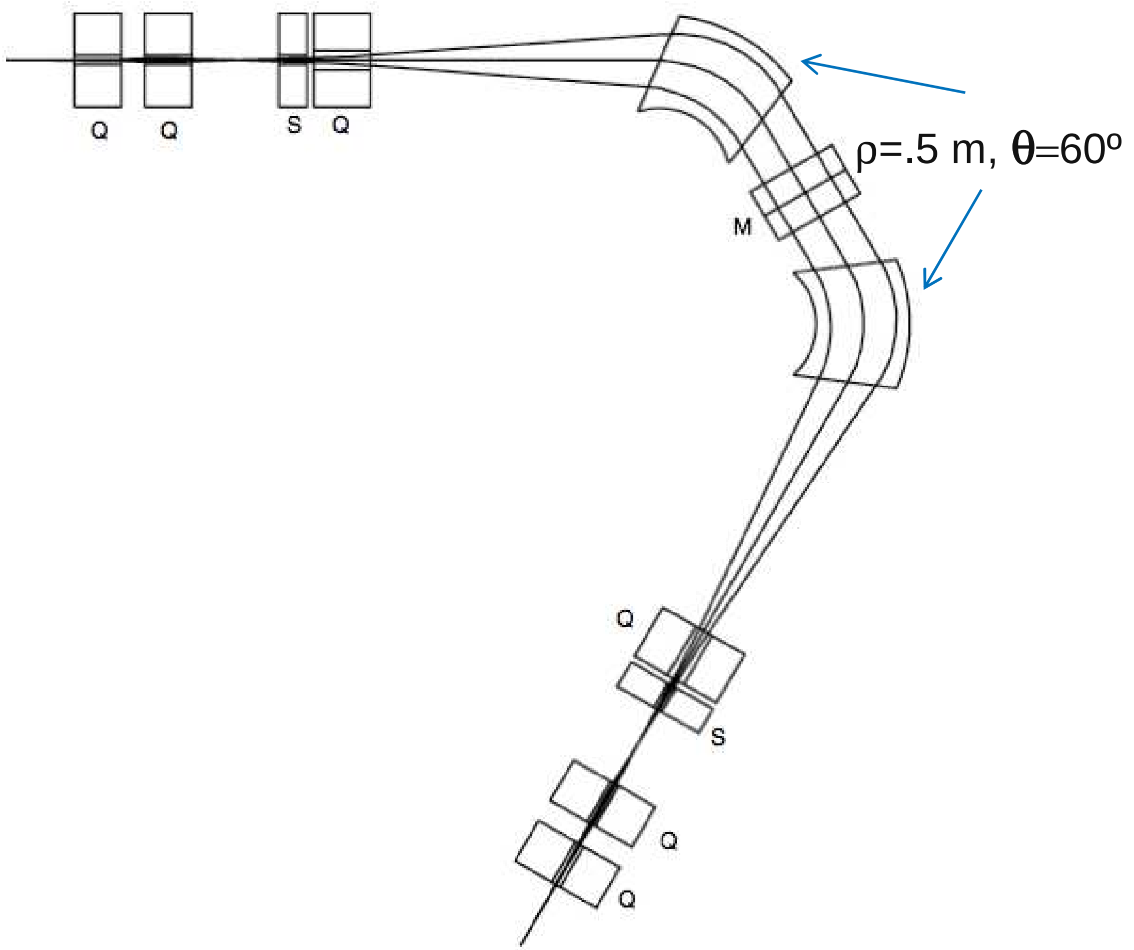
Design Goals

- **Mass resolution M /ΔM > 20,000:1.**
- **High transmission (> 95%).**
- **Compact (must fit on HV platform).**
- **No energy compensation (means no electric dispersive elements).**
- **Match beam emittance from gas catcher (transverse: <3π mm-mr, longitudinal: ΔE<1 eV at 50 keV).**
- **Simple configuration for ease of tuning.**
- **Focussing and corrective elements are all electrostatic, settings are independent of mass.**

Layout of Isobar Separator



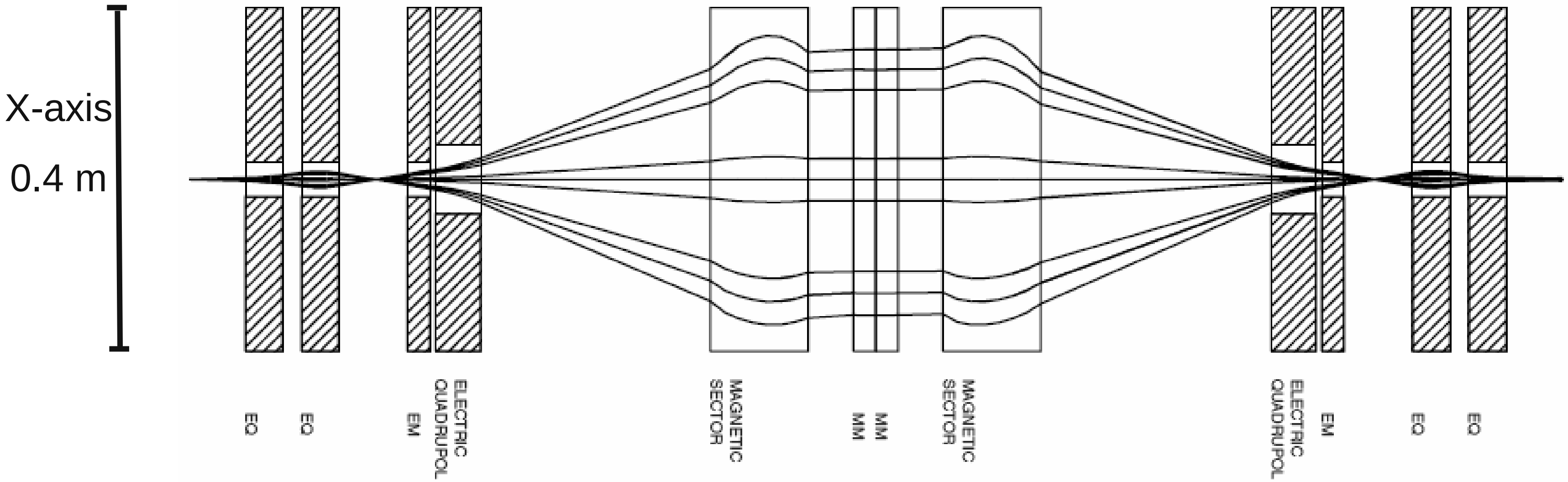
Ion Optics Discussion

- **Input beam conditions: transverse emittance < 3π mm-mr, energy spread < 1 eV at 50 keV (relative energy difference $\delta E < 2 \times 10^{-5}$)**
- **Energy dispersion = mass dispersion = 22.8 m**
- **Start with 1 mm dia. (circular) beam with θ_{max}, φ_{max} = ±6 mr**
- **Symmetric design helps to minimize aberrations**
- **A quadrupole doublet matching section produces a ribbon-shaped beam, with (x,x)=0.19, (y,y)=3.4**
- **This means y-angles are small, minimizing φ aberrations**

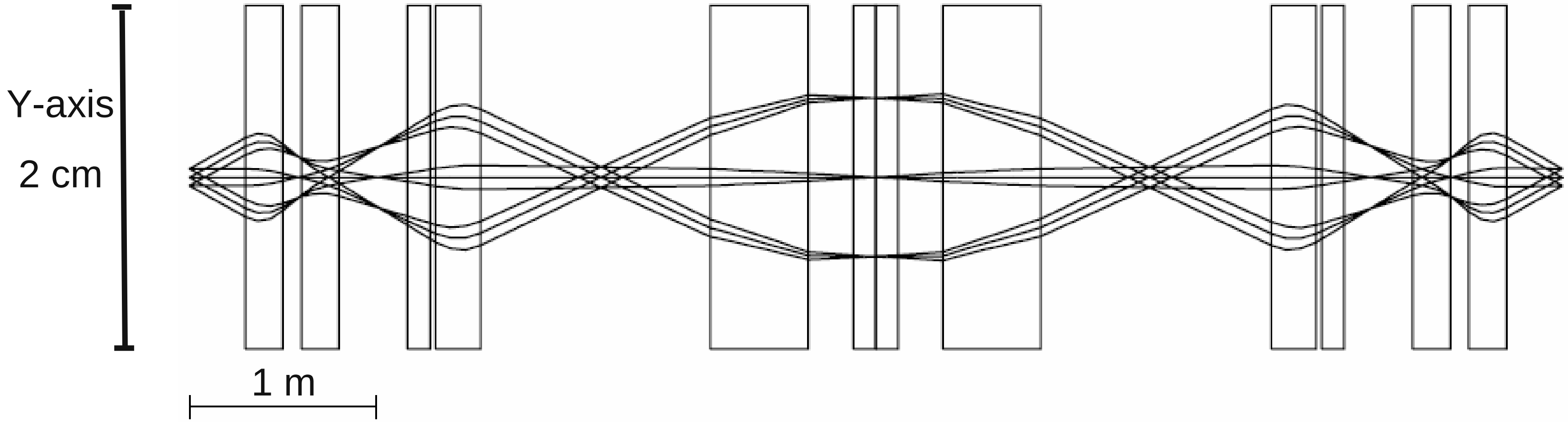
Ion Optics Discussion (continued)

- **The first quadrupole diverges in x and converges in y, giving a small y size which minimizes y aberrations**
- **The large x area in the magnets gives mass dispersion**
- **Focus conditions in center: $(\theta,\theta)=(y,\varphi)=(\varphi,y)=0$**
- **The reverse matching section transforms the ribbon-shaped beam back to a circular cross-section, allowing a 1 mm x-selection slit at the focal plane**
- **The 2 sextupoles and 1 multipole lens correct aberrations to 5th order. At the focal plane, all aberrations except for energy variation are <0.1 mm**

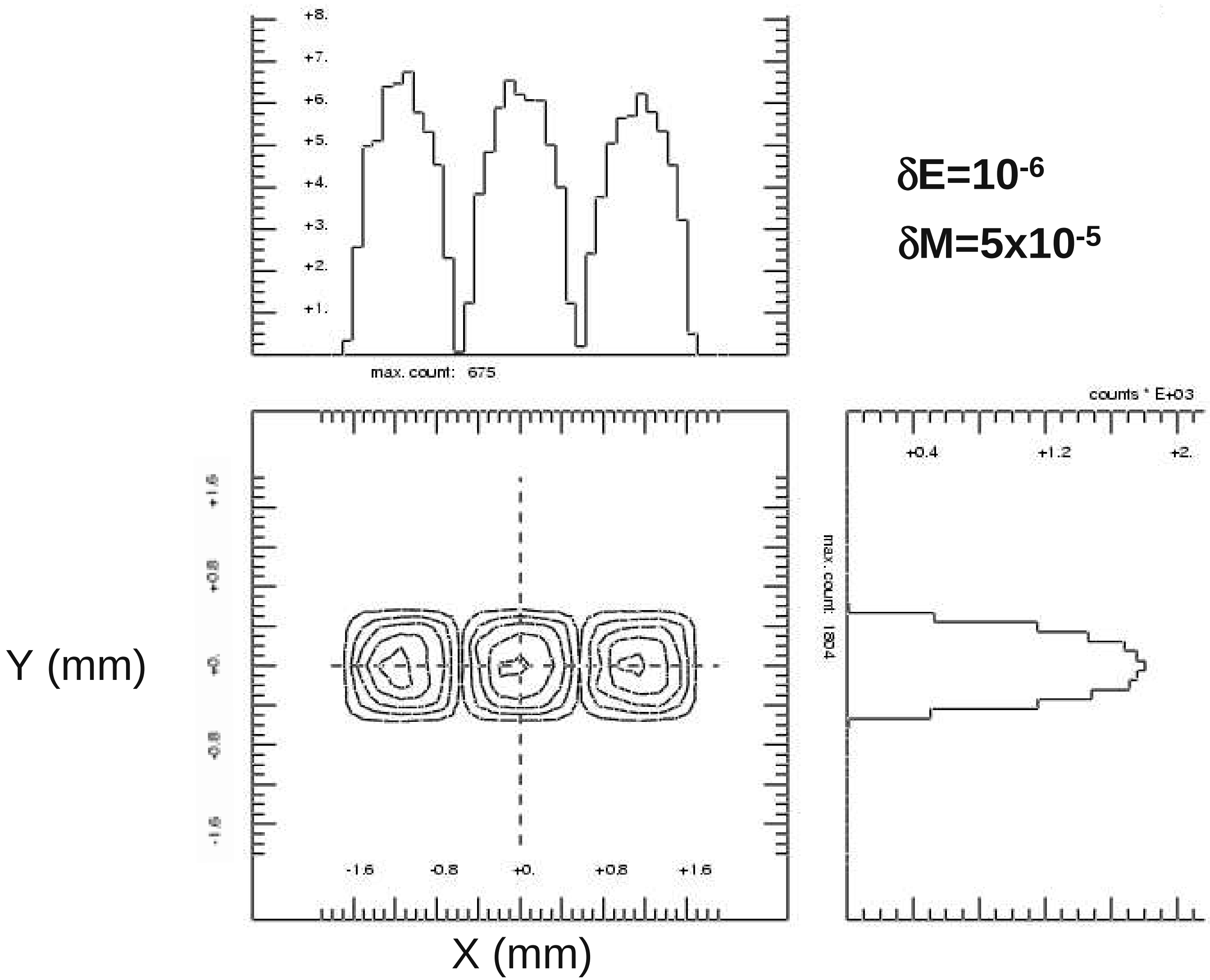
X- and Y-projections of the beam



3 x’s, 3 y’s, 3 θ’s, 3 φ’s, 1 mass, 1 energy



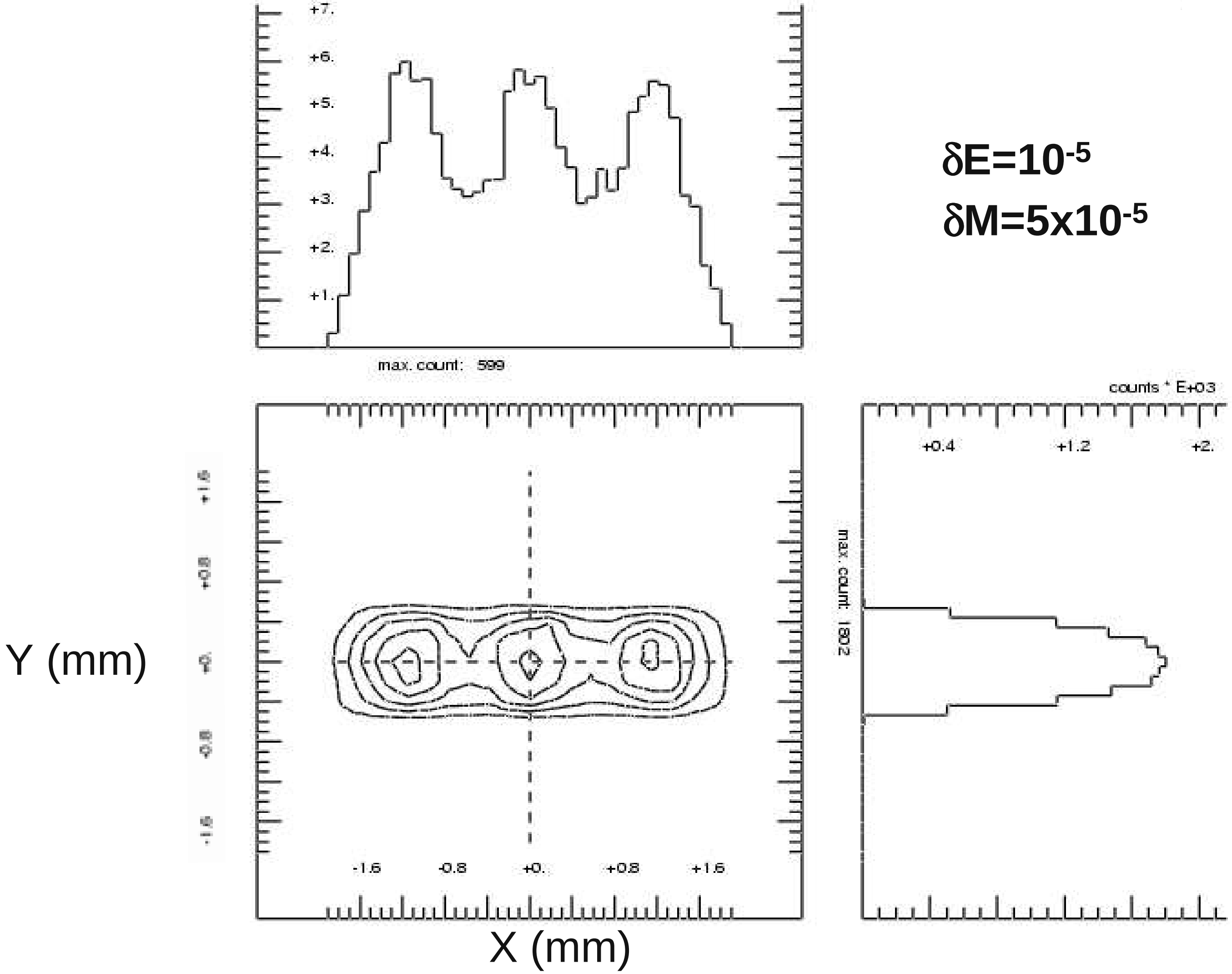
X and Y Projections at Focal Plane



$\delta E=10^{-6}$

$\delta M=5\times10^{-5}$

X and Y Projections at Focal Plane



$\delta E = 10^{-5}$

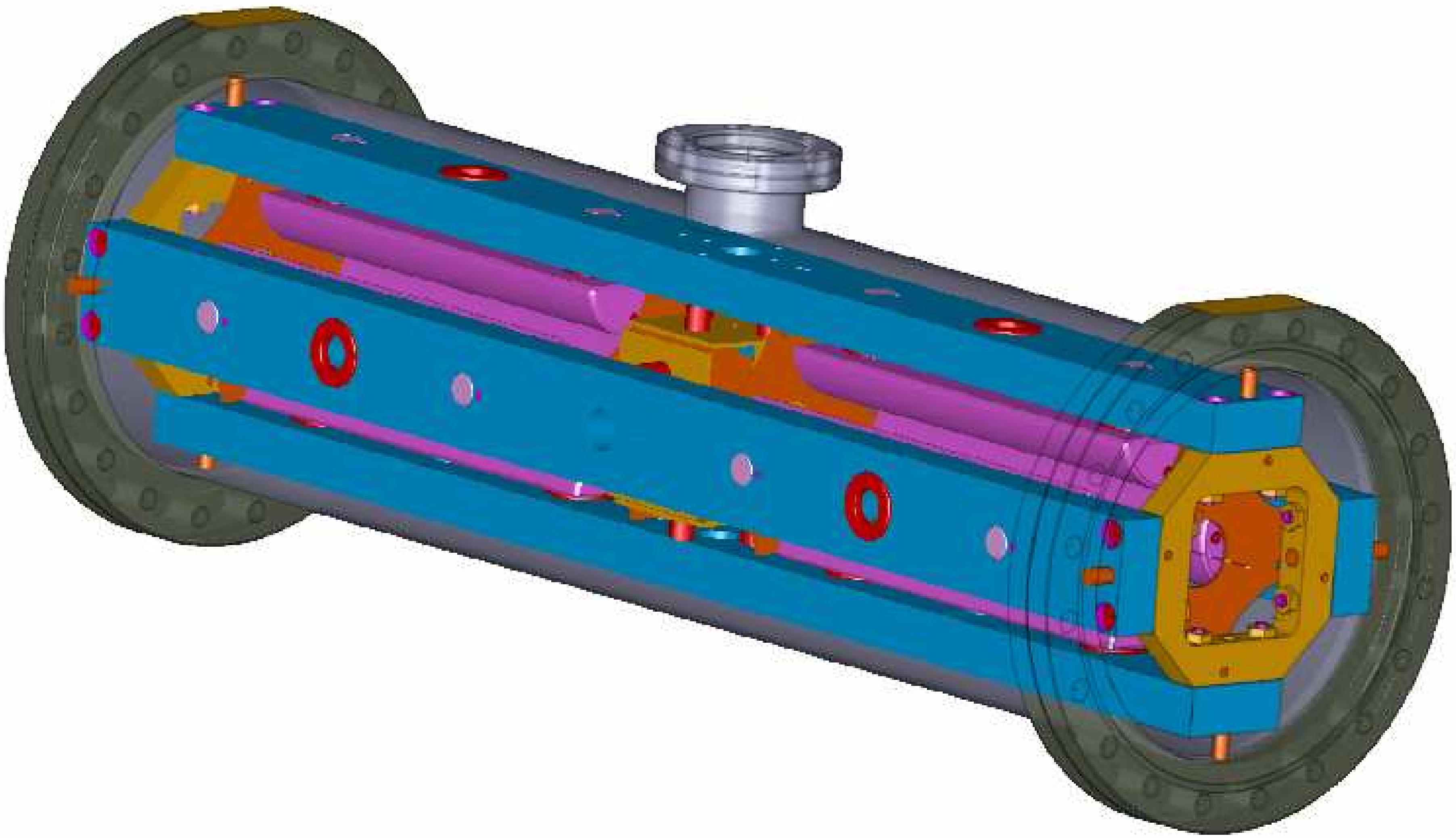
$\delta M = 5 \times 10^{-5}$

Bending and Focussing Elements

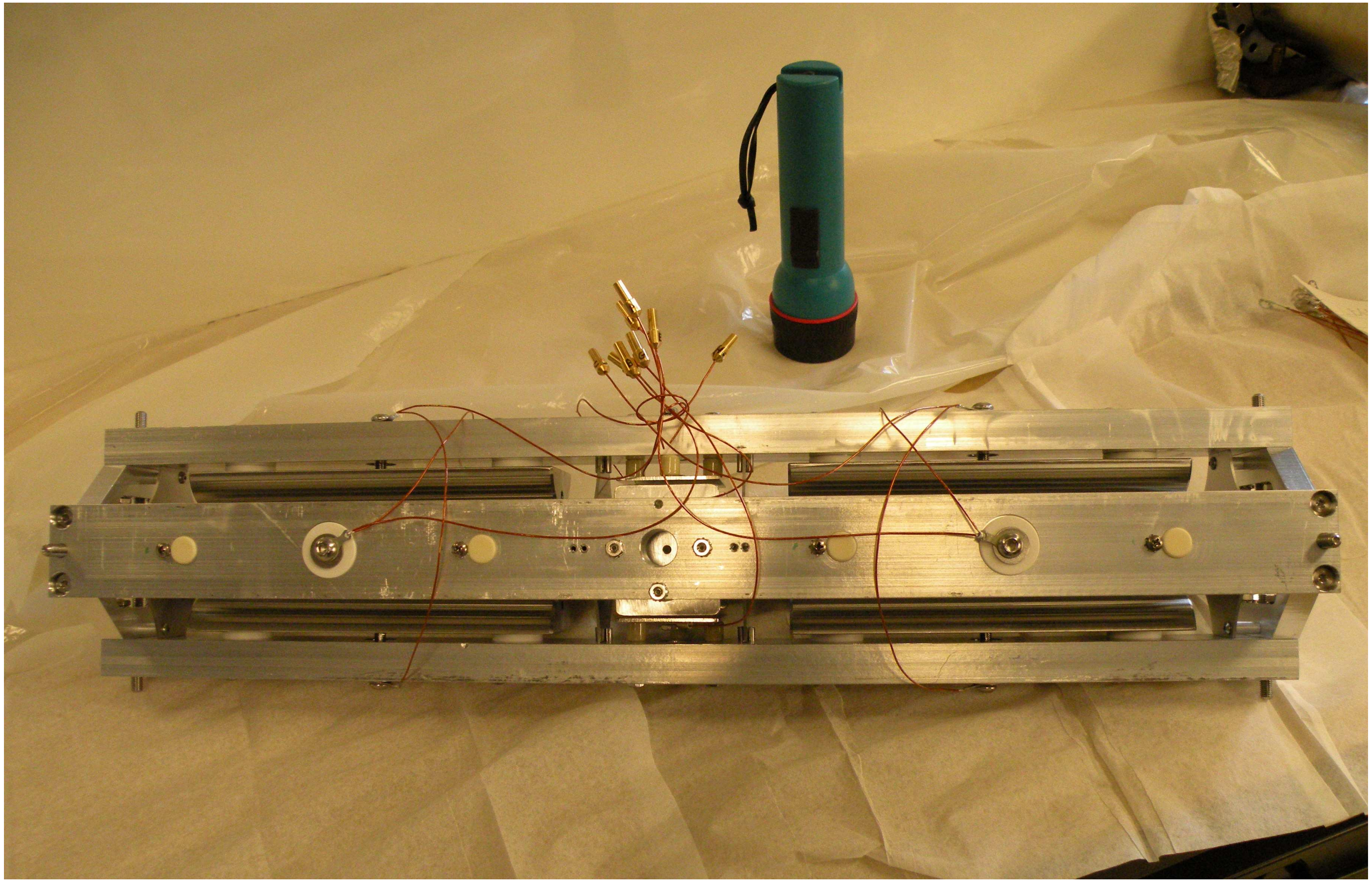
Element	Radius	Pole Gap	Pole Edge Angle	Pole Width	Quantity
60º magnet	0.5 m	8 cm	23º	0.62 m	2

Electrostatic Focussing Element	Length (cm)	Diameter (cm)	Quantity
Matching Quadrupole	20	4	4
Focus Quadrupole	24	8	2
Focus Sextupole	12	4	2
Large Multipole	25	40	1

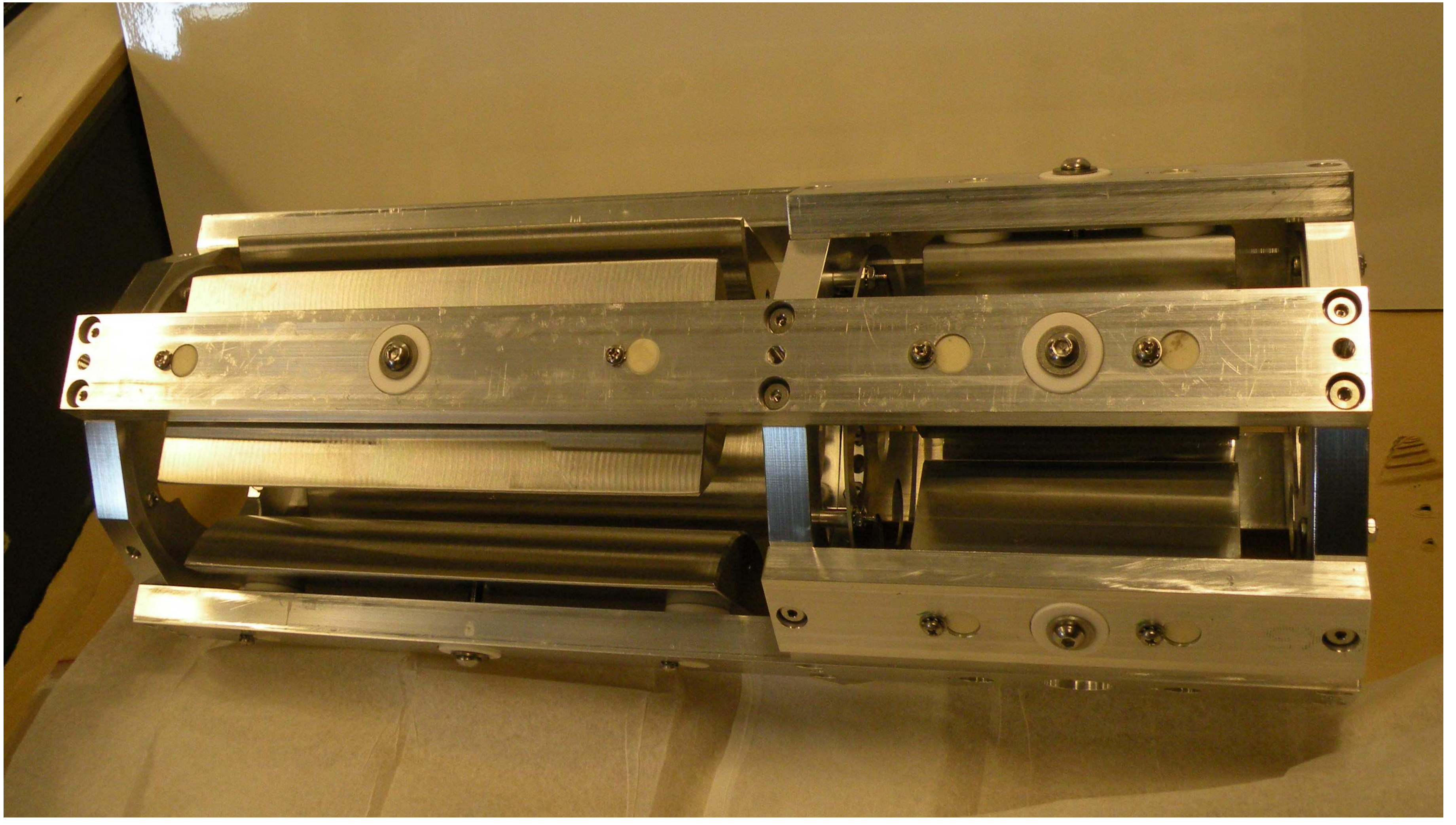
Electrostatic Quadrupole Doublet



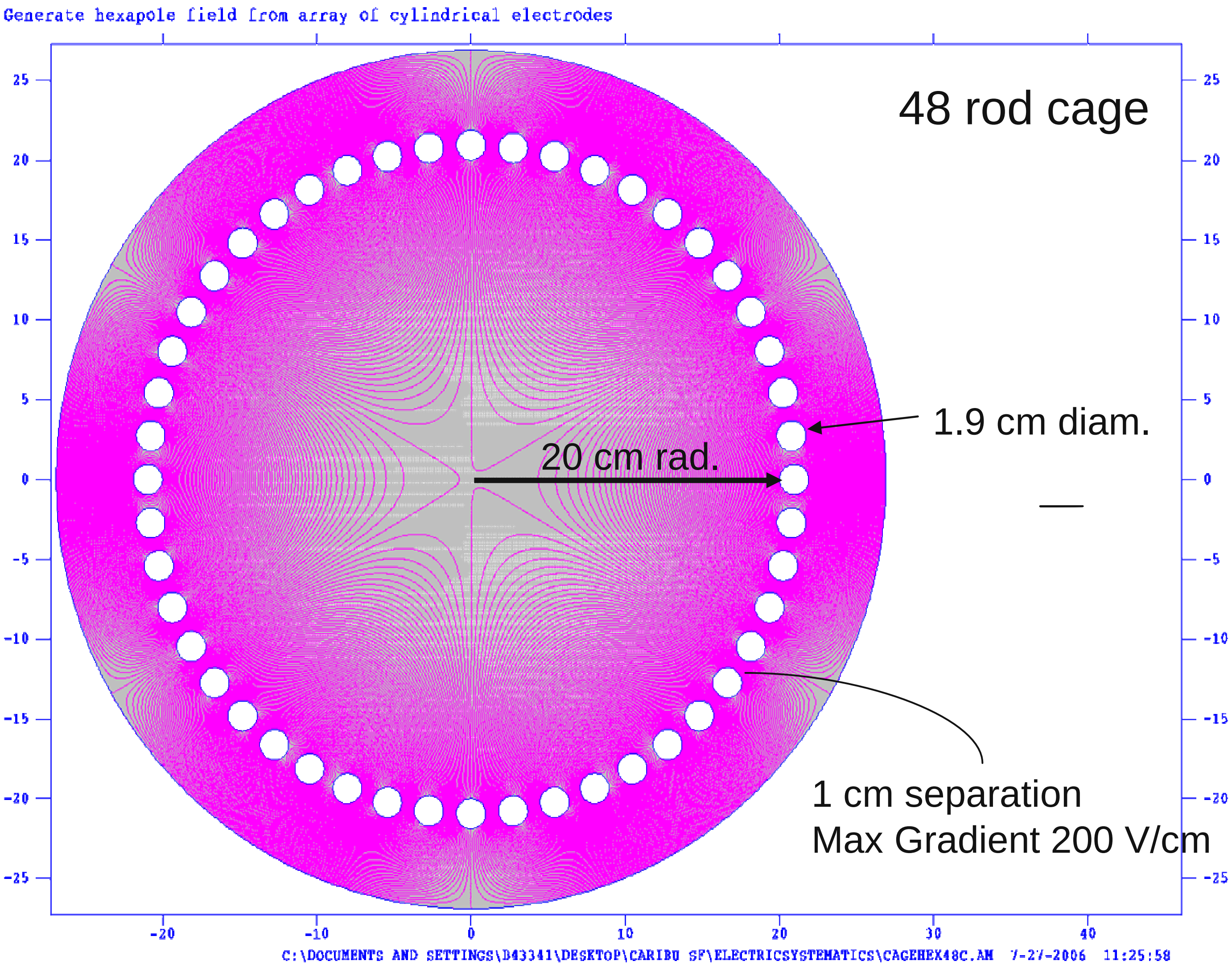
Electrostatic Quadrupole Doublet



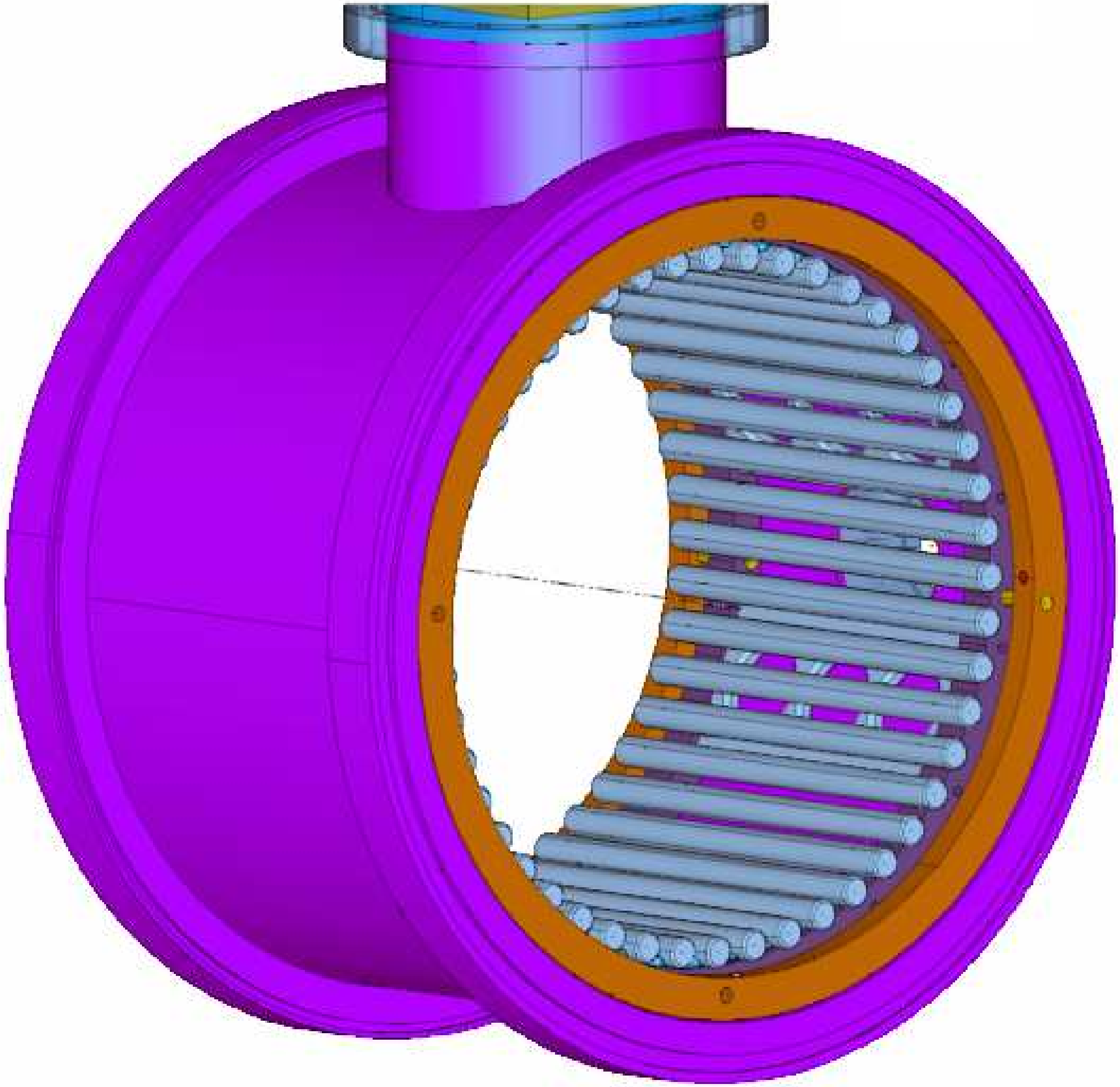
Electrostatic Quadrupole/Hexapole



Squirrel-Cage Multipole Lens



Electrostatic Multipole Lens



Electrostatic Lens Properties

Lens	V_{max} (V)	V_{tol} (V)	$R_{max\ 1\%}$ (cm)
Focusing Quad	~1000	± 1	(~2.4) 3.6/4.0
Focusing Hex	~100	± 15	(~0.9) 1.8/2.0
(Maximum x size=15 cm for 3π mm-mr emittance)			
Middle Hex	~500	± 1	18.0/20.0
Middle Oct	~20	± 1	17.5/20.0
Middle Dec	~2	± 1	17.0/20.0
Middle DoDec	~2	± 1	17.0/20.0

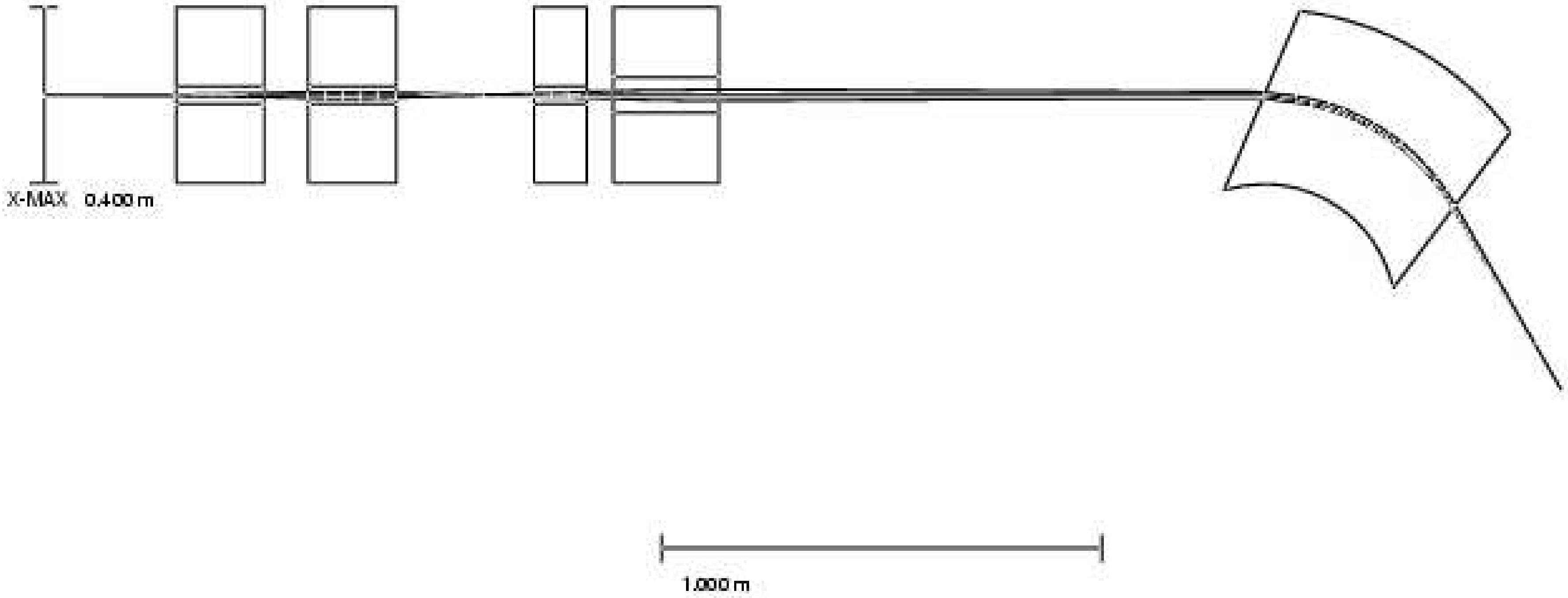
Treatment of Fringe Fields

- **Fringe fields have been calculated for all electrostatic devices using SIMION8, and are used in the COSY Infinity ion optics calculations.**
- **Dipole magnet fringe fields have been obtained from magnetic field maps, and incorporated into the ion optics calculations.**

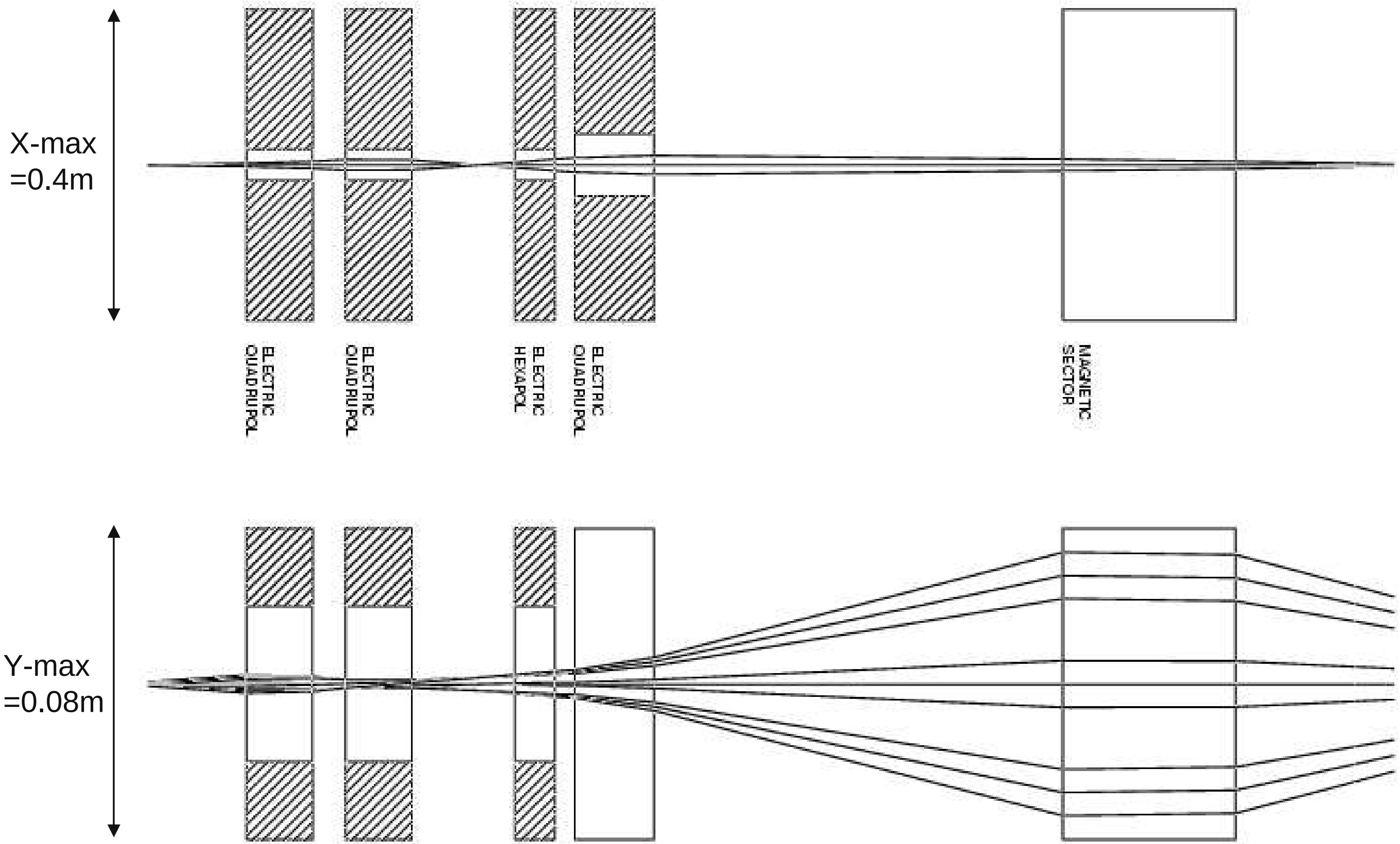
Commissioning of the Separator

- **Use stable beams from gas catcher: ^{82,83,84,86}Kr (12%, 12%, 57%, 17%).**
- **Diagnostics: Faraday cup, narrow slit with small electric deflector in front, scintillator.**
- **Use reverse voltages to make an x-focus at the middle of the separator. The resulting mass dispersion=0.384 m. This produces a separation of 4.6 mm between adjacent masses at A=84.**
- **Use entire separator to calibrate central sextupole and thus higher multipoles.**

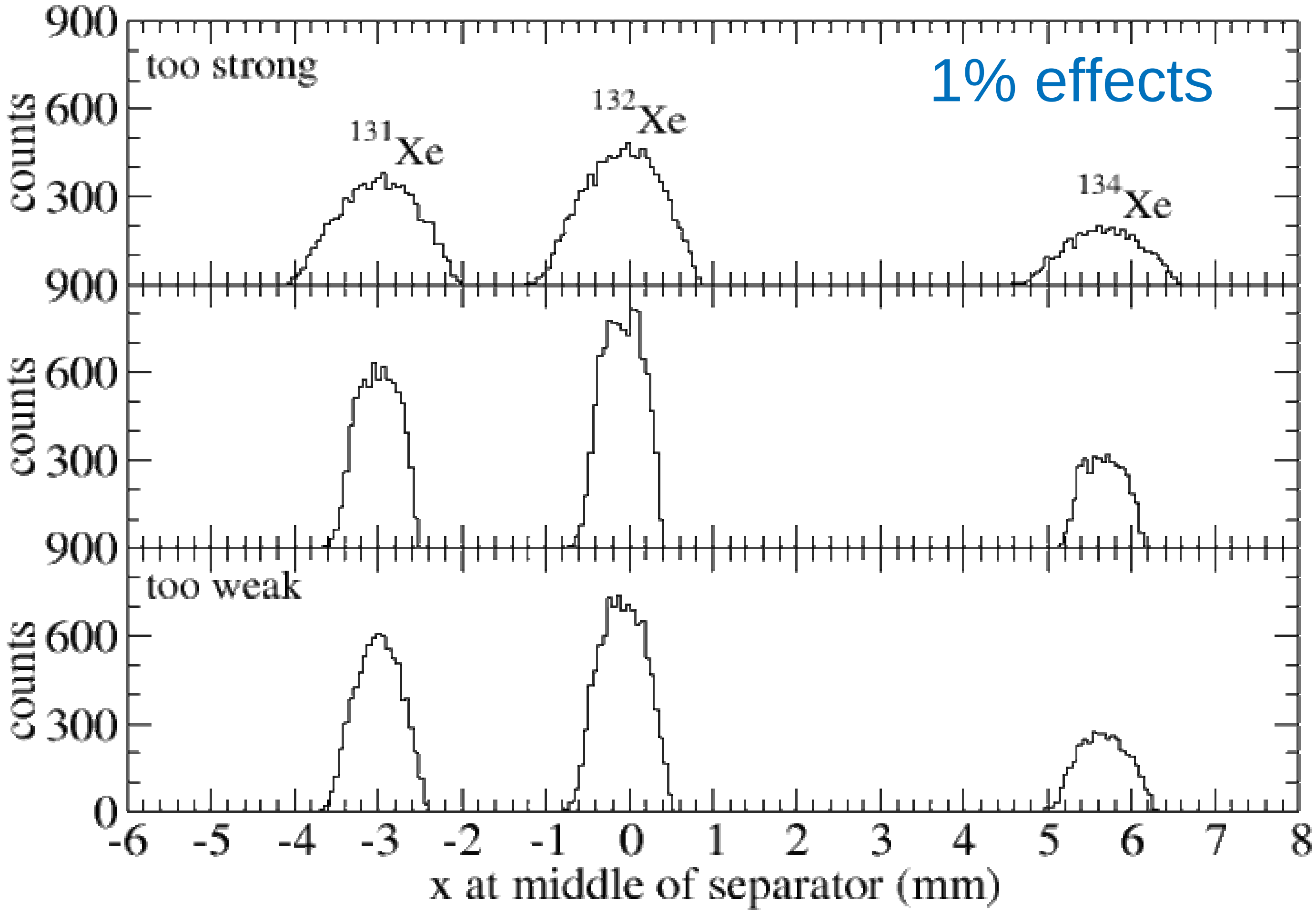
Half Separator with X-focus



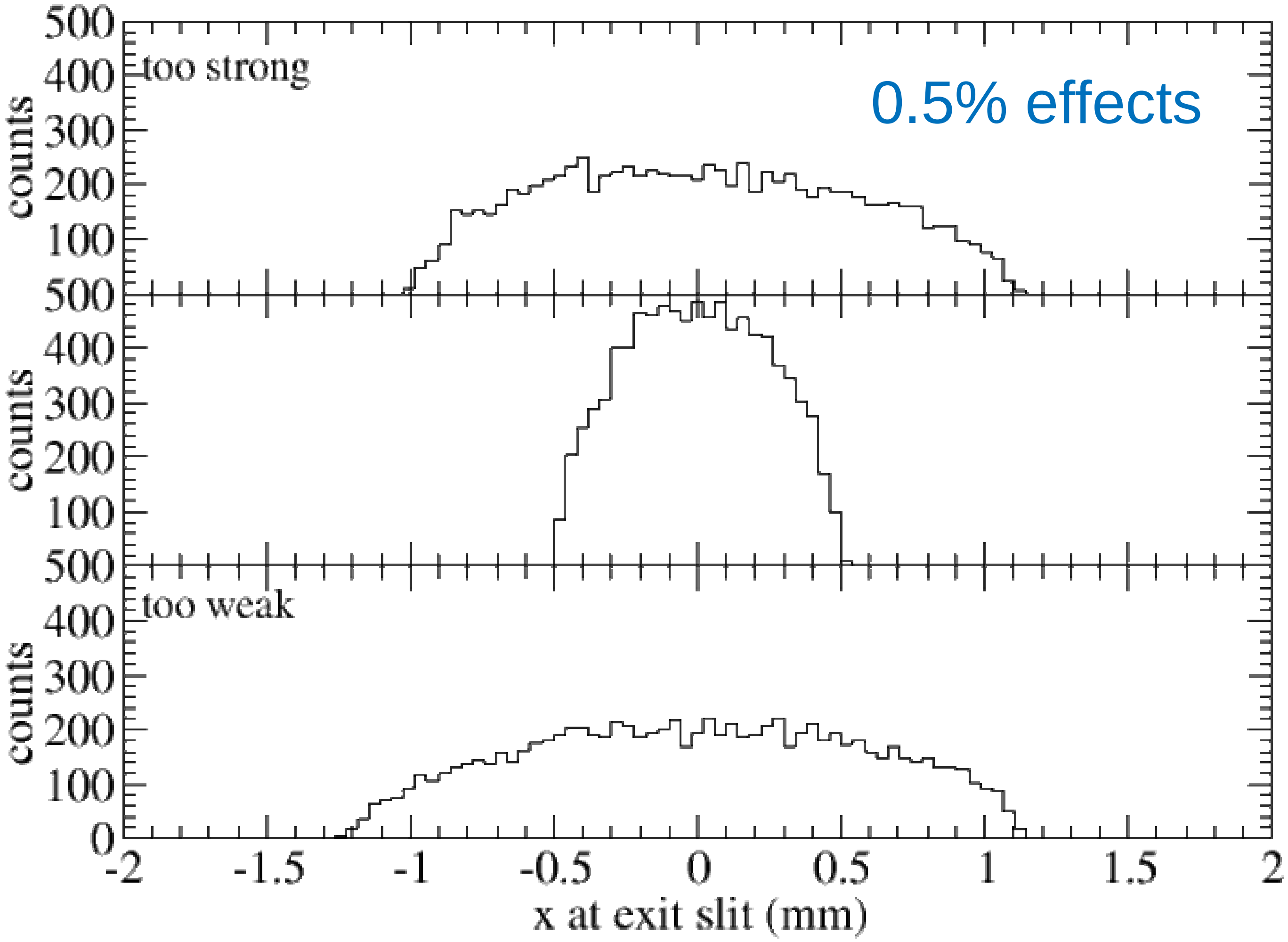
Half Separator with X-focus



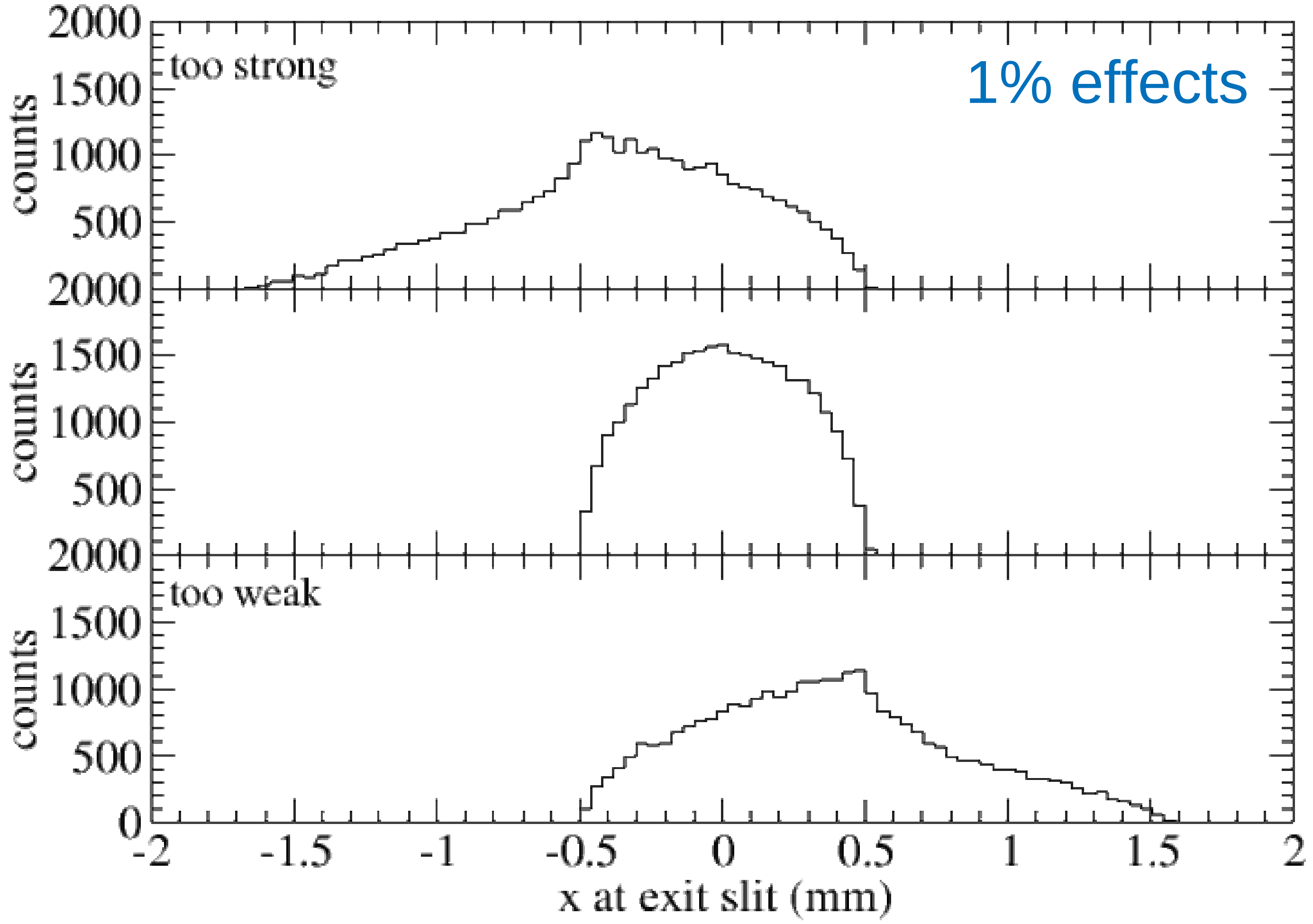
Focusing Quad Signatures (mid-plane image)



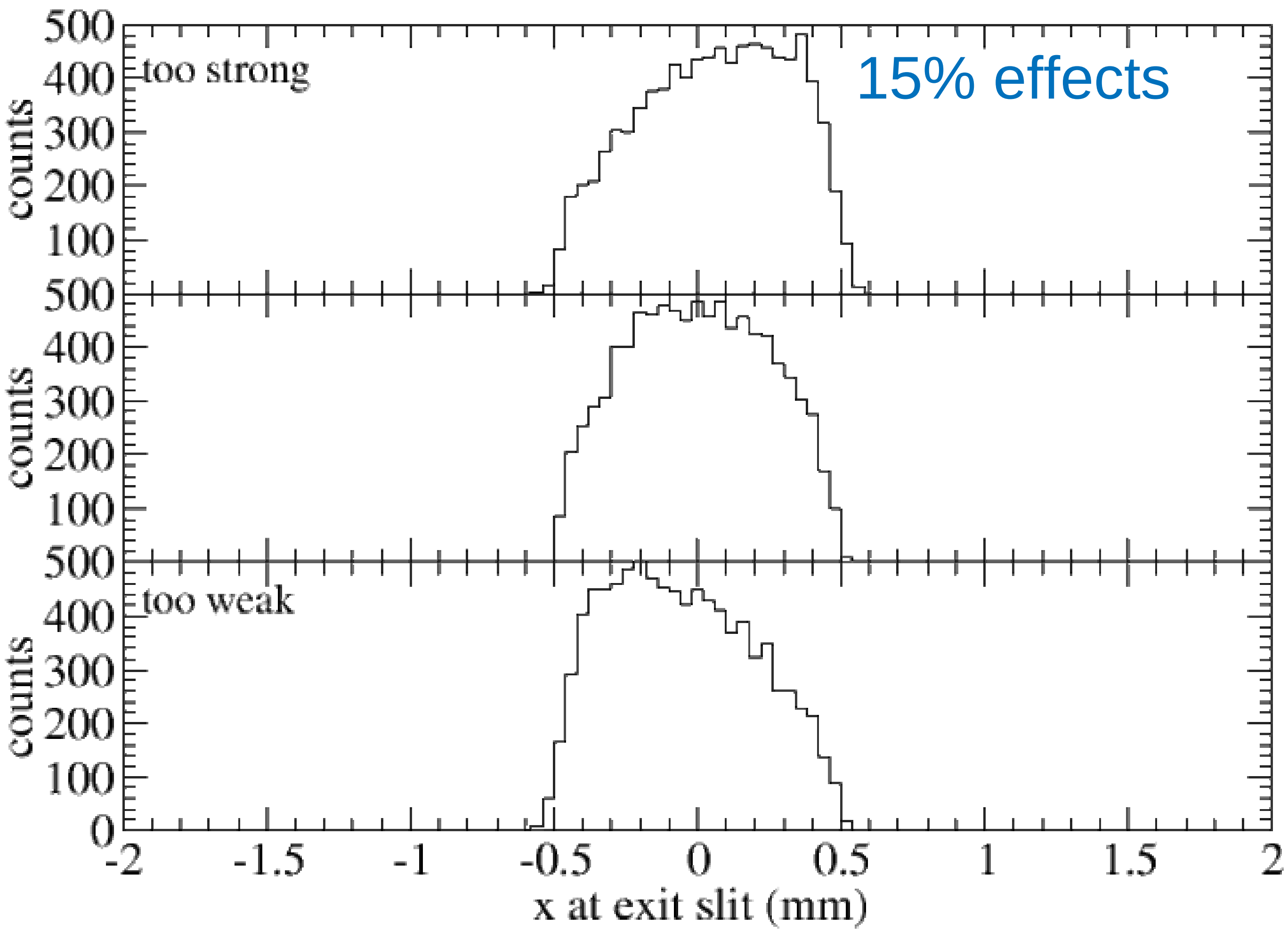
Focusing Quad Signatures (focal plane image)



Middle Hex Signatures (focal plane image)

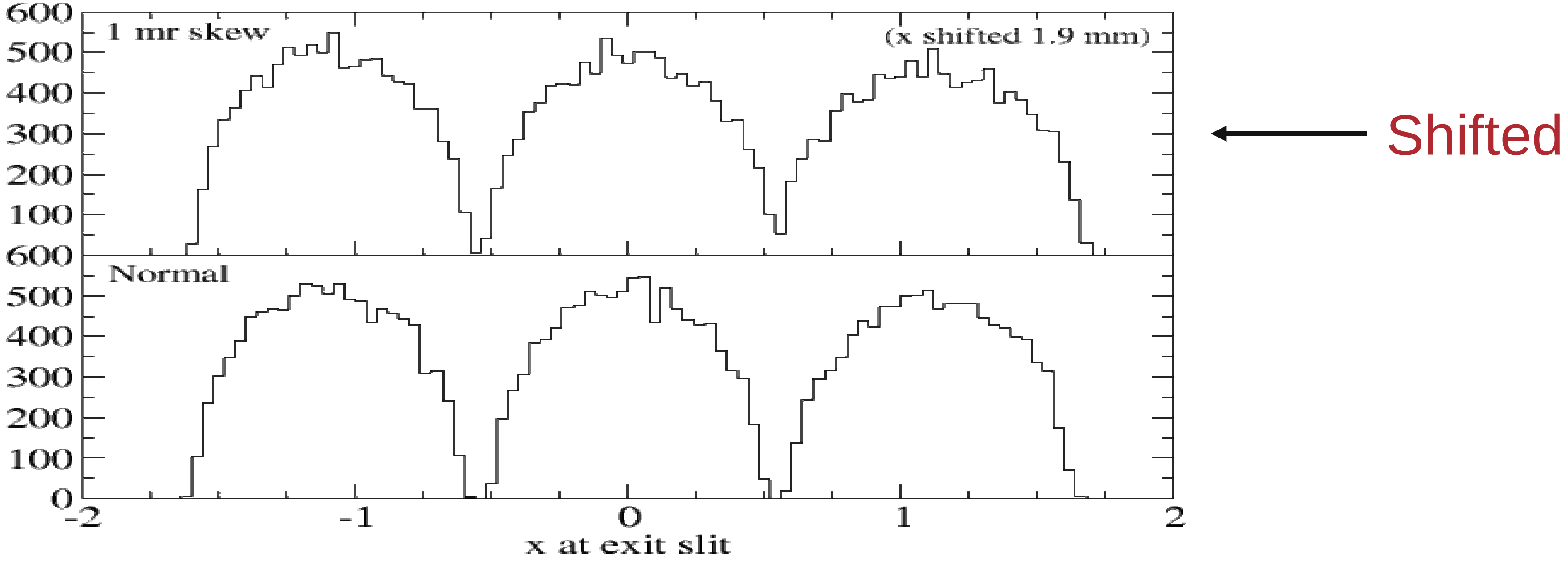


Focusing Hex Signatures (focal plane image)



Alignment Effects

- Misalignment of focusing Quadrupole (dispersive direction, x)
  - 0.1 mm offset shifts focal plane transversely 0.65 mm
  - 1 mrad skew (0.24 mm from front to back) shifts focal plane transversely 1.9 mm and begins to blur mass separation



Alignment Effects (cont.)

- Misalignment of first Dipole
  - Offset just shifts x-position of focal plane
  - Skew changes effective edge angles, which affect dispersion
    - *Can be compensated by different lens focusing*
    - *High-order (5th/6th) aberrations stronger*

- Misalignment of Middle Multipole
  - Offset of 0.1 mm begins to blur mass separation
  - Essentially insensitive to skew of 2 mrad

Installation Notes

- **Field clamps on magnets have made installation more difficult because of cramped space between magnets.**
- **Electrostatic focussing elements before and after magnets (quadrupole doublet, quadrupole-hexapole) have been bolted together and aligned as a unit.**

Some Technical Specifications

- **Vendor will map bending magnets with ANL-supplied requirements for interior and exterior grid.**
- **Magnet homogeneity requirement: 3×10^{-5} on field integral.**
- **Vacuum to be $\leq 3 \times 10^{-8}$ Torr, obtained with three 1000 l/s turbopumps.**

Location of Pumps, Diagnostic Slits