An aerial photograph of a desert landscape featuring sand dunes. The dunes are characterized by their rhythmic, parallel ridges and valleys, creating a textured, undulating surface. The color of the sand is a mix of light tan and greyish-brown. In the lower-left quadrant, a single, small, bright green plant stands out against the sandy terrain. The overall scene is vast and desolate, with no other vegetation or structures visible.

Electrostatic Beamlines for low-energy particles

Tim Giles

ELENA Workshop - Jan 2012

- 
- An aerial photograph of a desert landscape with sand dunes. The dunes are arranged in a series of parallel ridges and valleys, creating a textured, undulating surface. The color of the sand is a mix of light tan and dark brown. In the lower-left quadrant, a single, small green leaf lies on the sand. The text is overlaid on the image in a dark, serif font with a yellow glow.
- Beamlines
 - Lens Design
 - Putting it all together

Tim Giles

ELENA Workshop - Jan 2012

An aerial photograph of a dry, cracked landscape. The ground is dark and textured, with numerous parallel and intersecting cracks forming a complex pattern. A small, bright green plant with a single leaf is visible in the lower-left quadrant. The overall scene is desolate and arid.

Beamlines

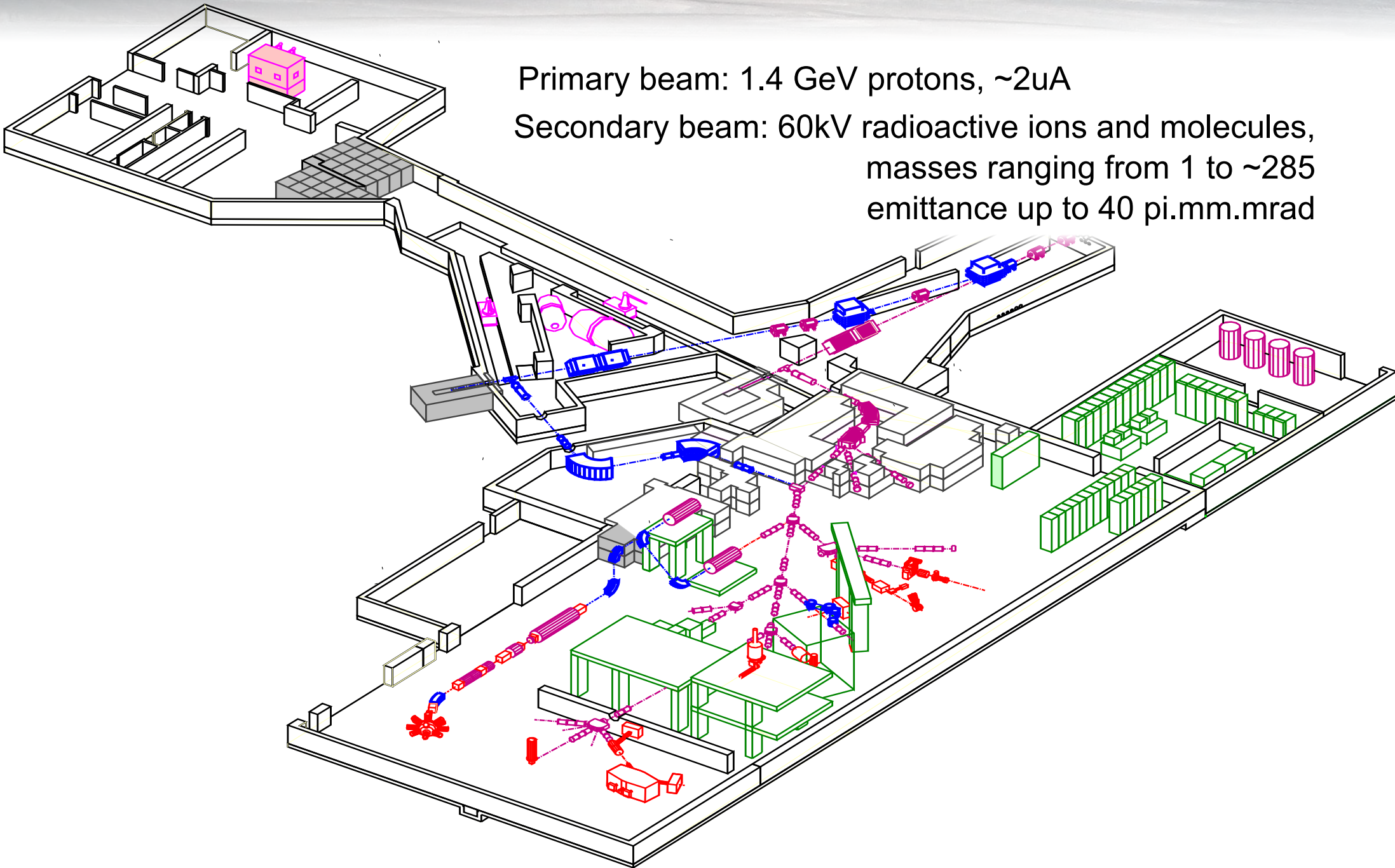
Tim Giles

ELENA Workshop - Jan 2012

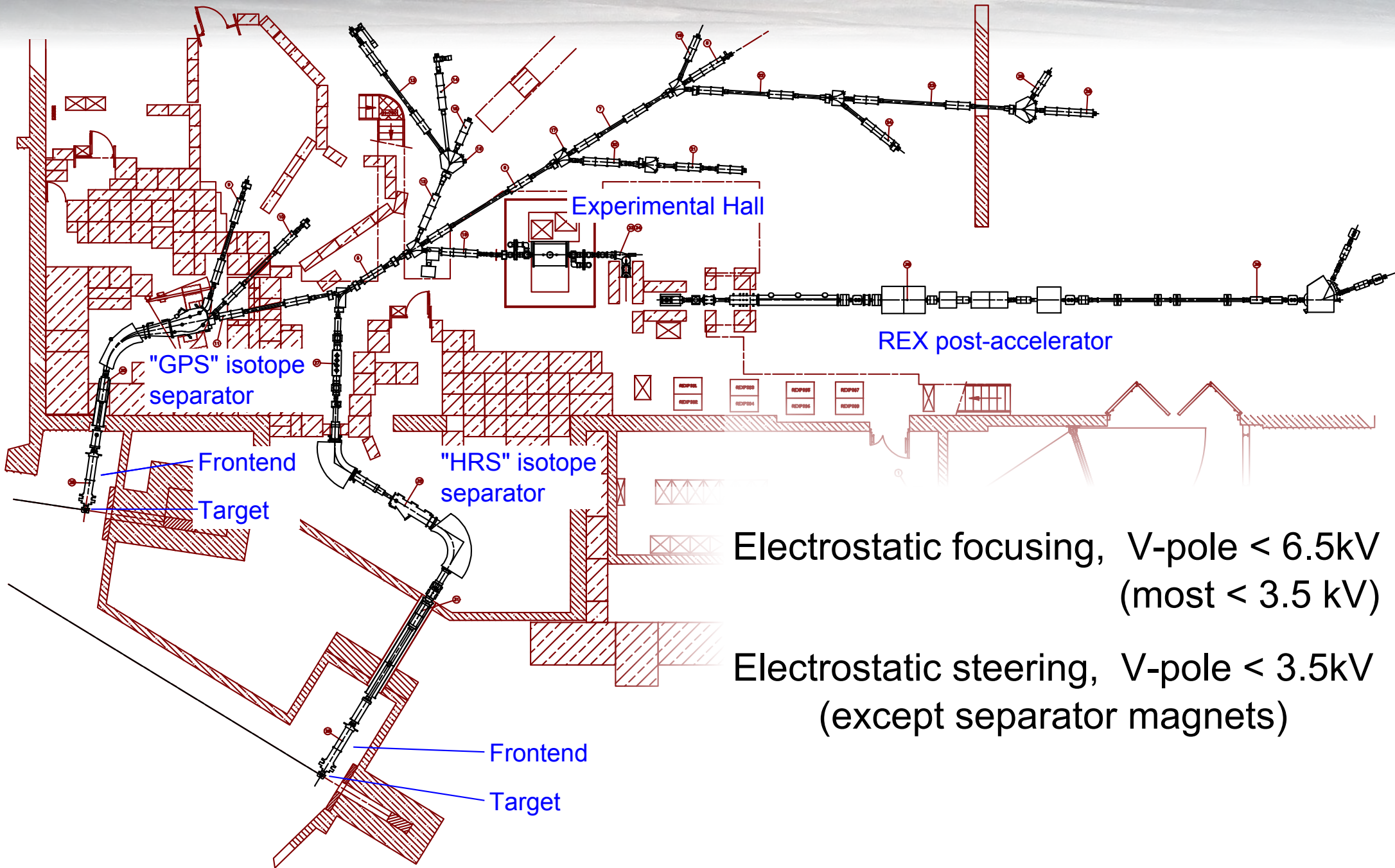
Isolde Layout

Primary beam: 1.4 GeV protons, $\sim 2\mu\text{A}$

Secondary beam: 60kV radioactive ions and molecules,
masses ranging from 1 to ~ 285
emittance up to 40 pi.mm.mrad



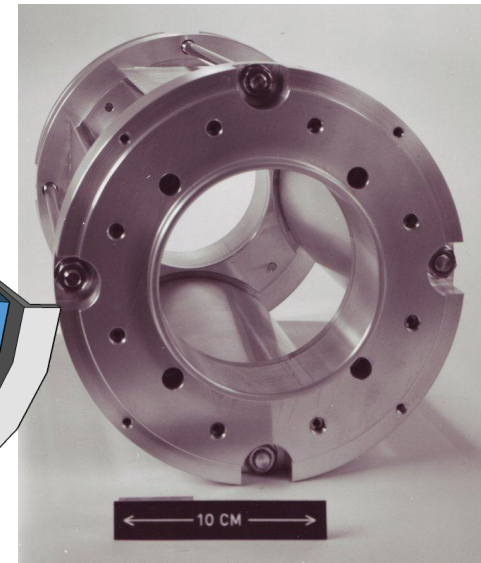
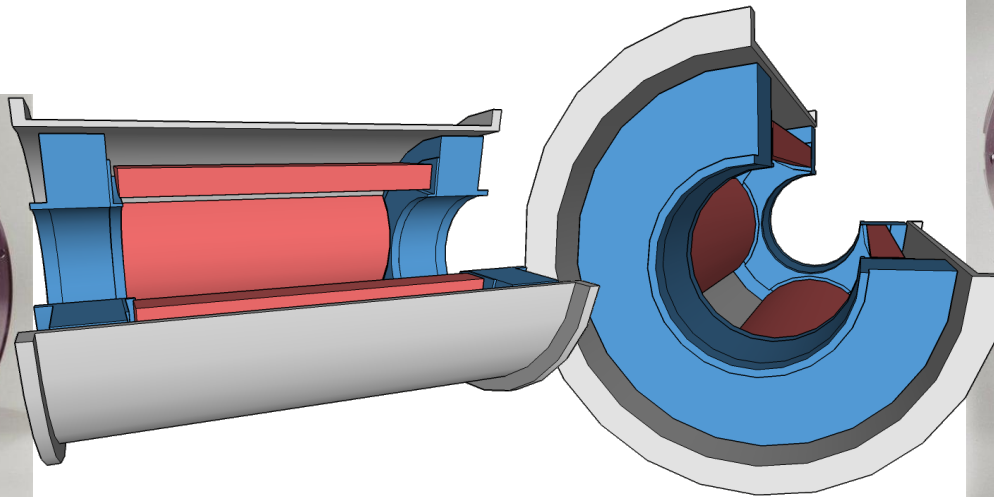
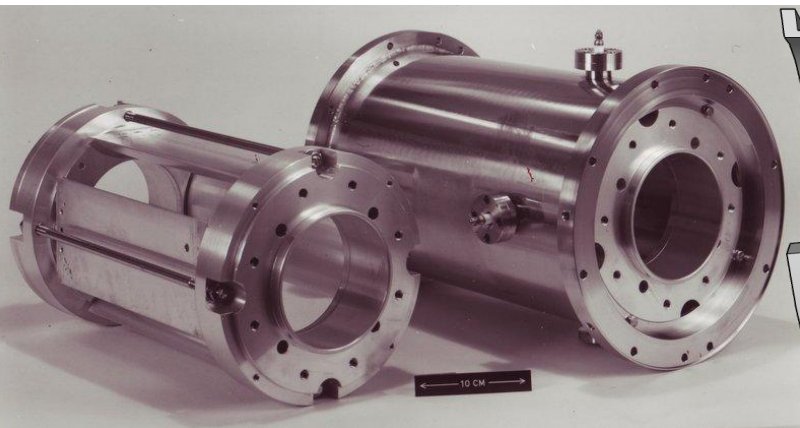
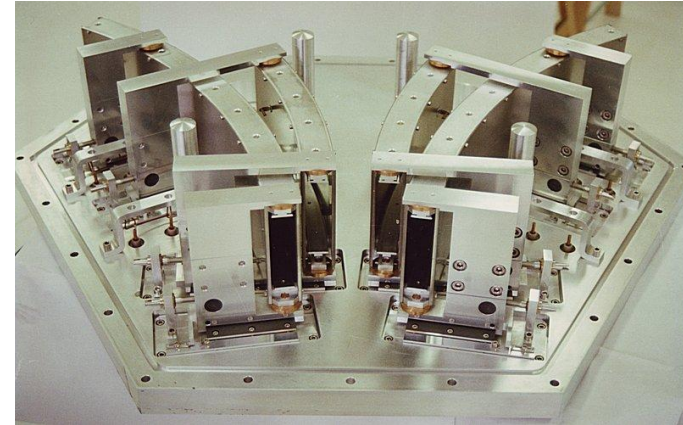
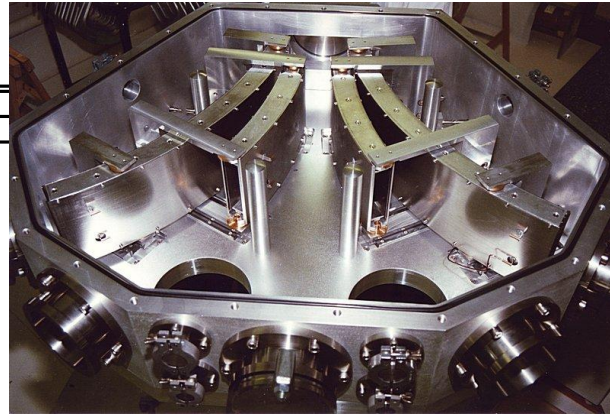
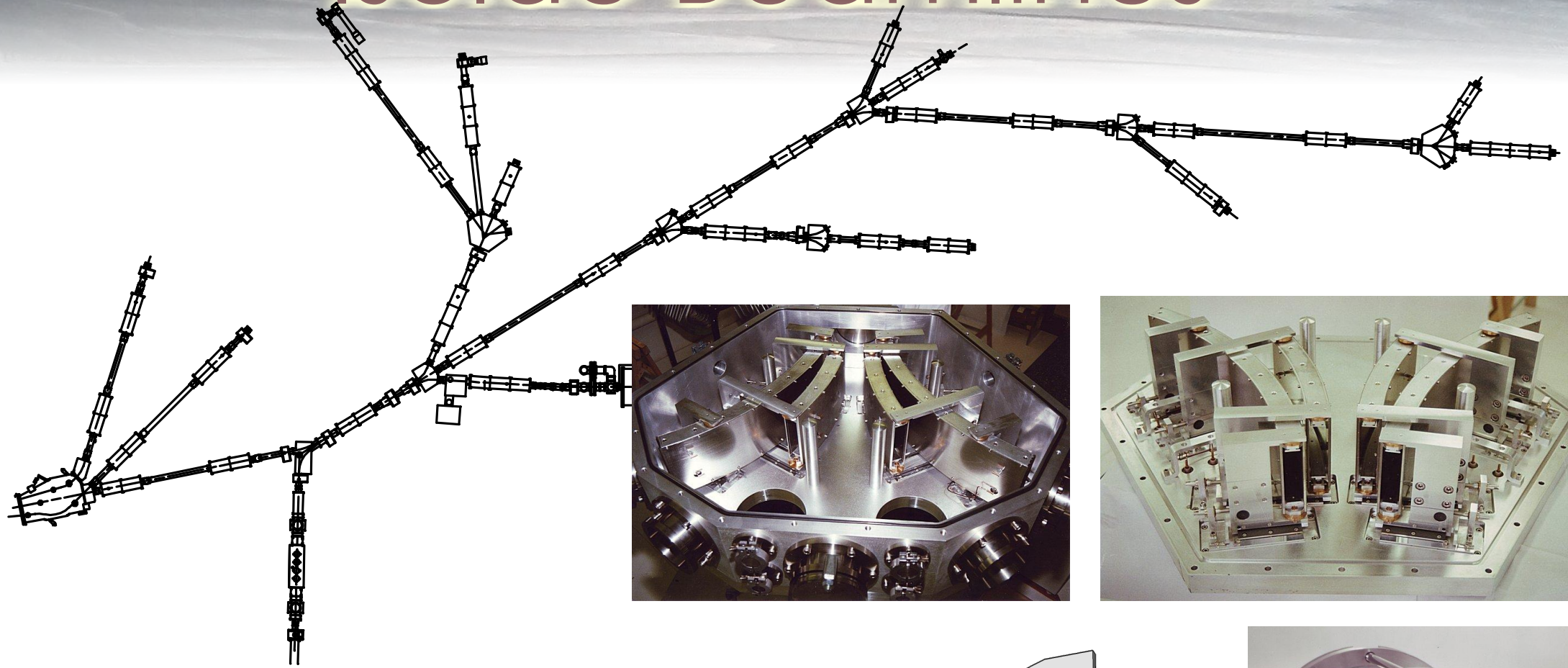
Isolde Beamlines



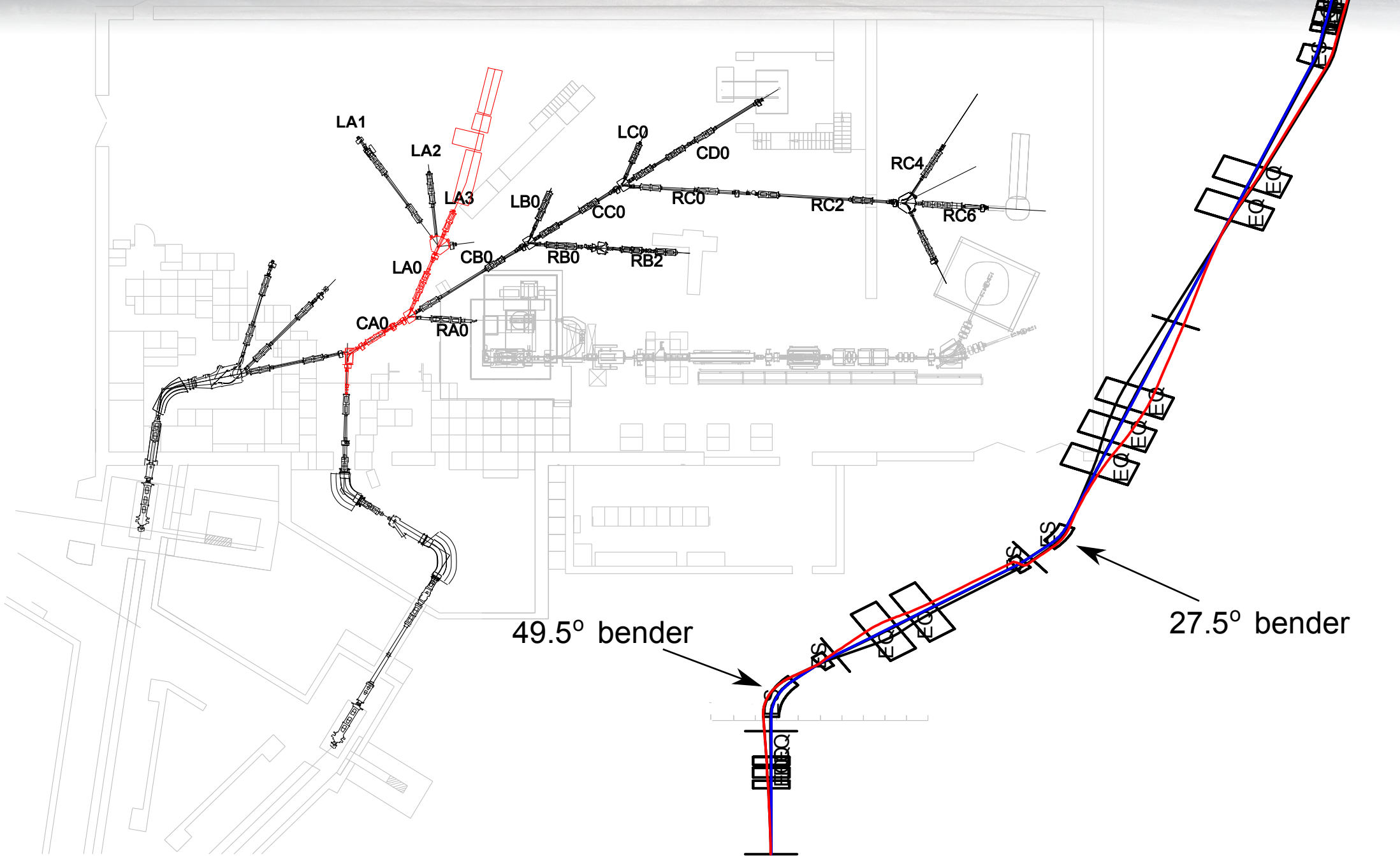
Electrostatic focusing, V-pole < 6.5kV
(most < 3.5 kV)

Electrostatic steering, V-pole < 3.5kV
(except separator magnets)

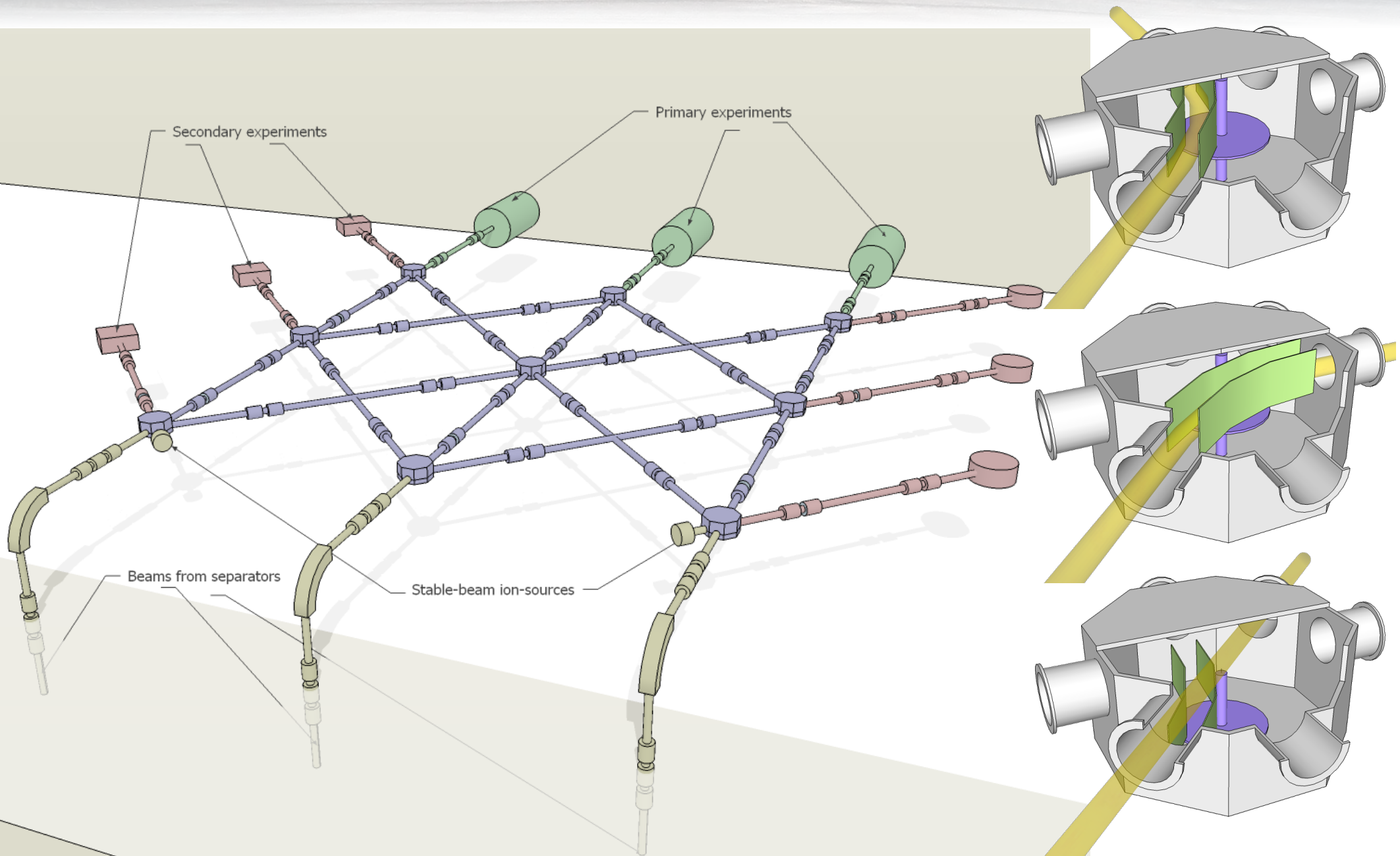
Isolde Beamlines



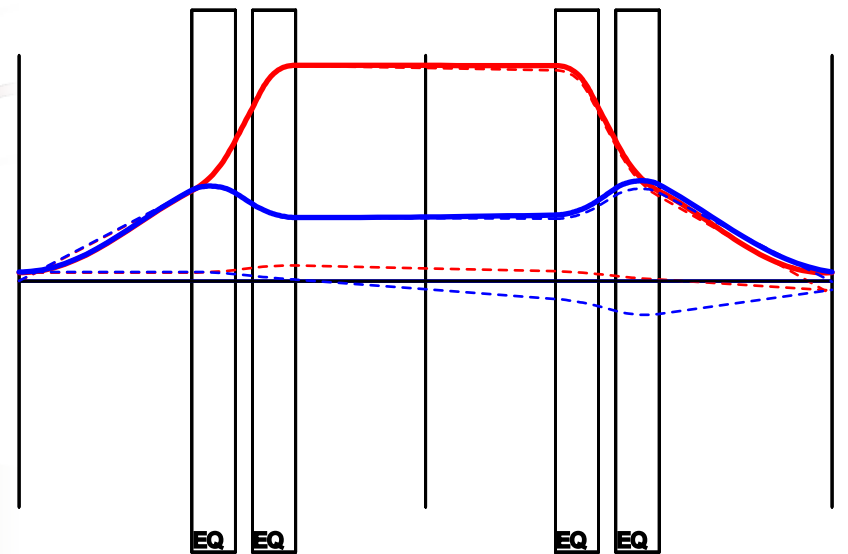
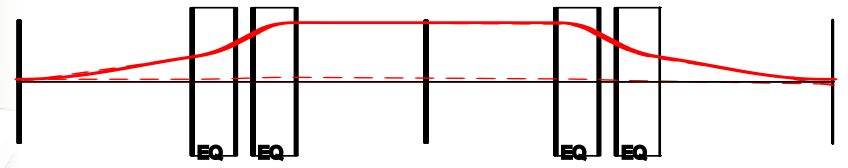
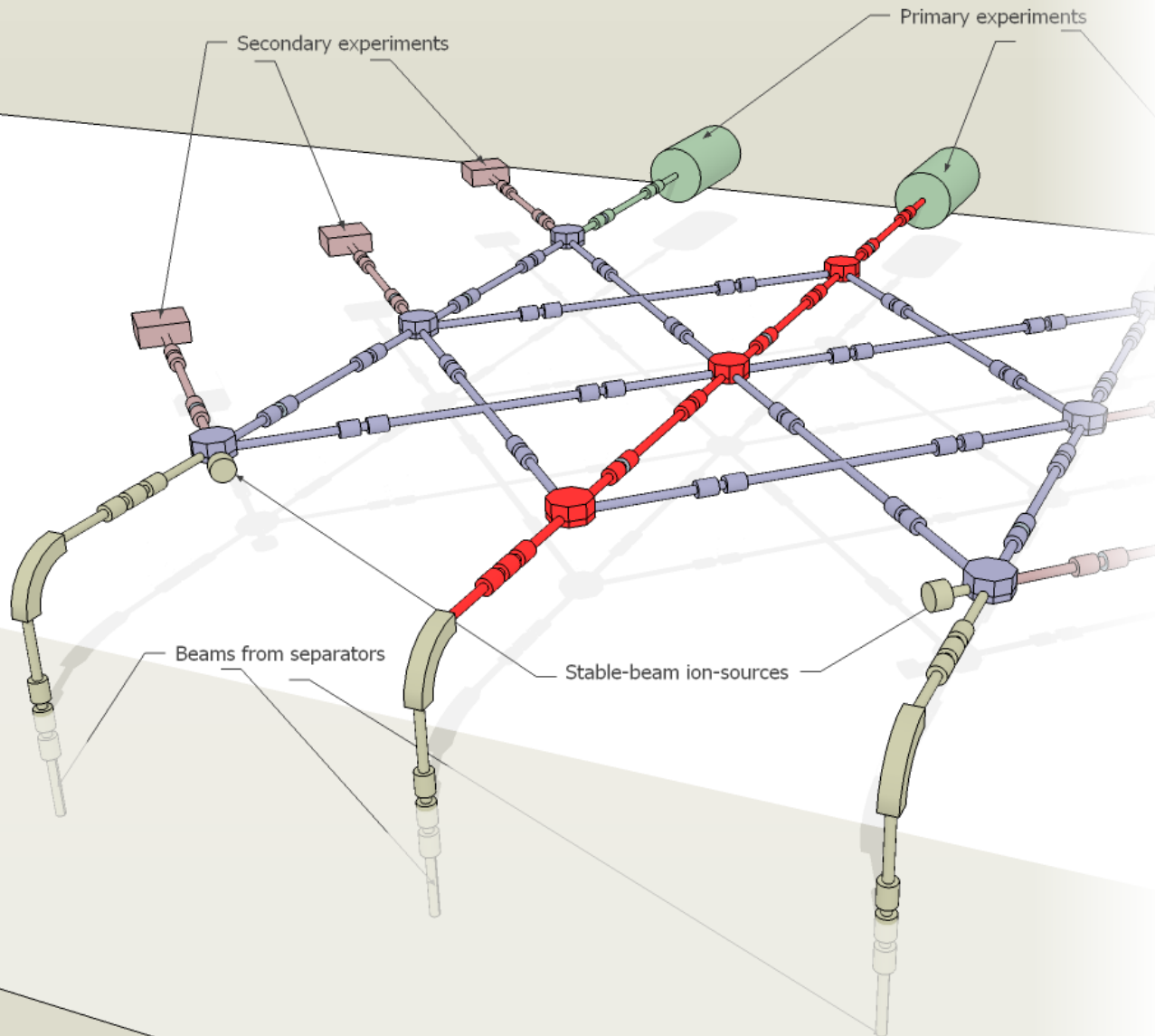
An Isolde Beamline



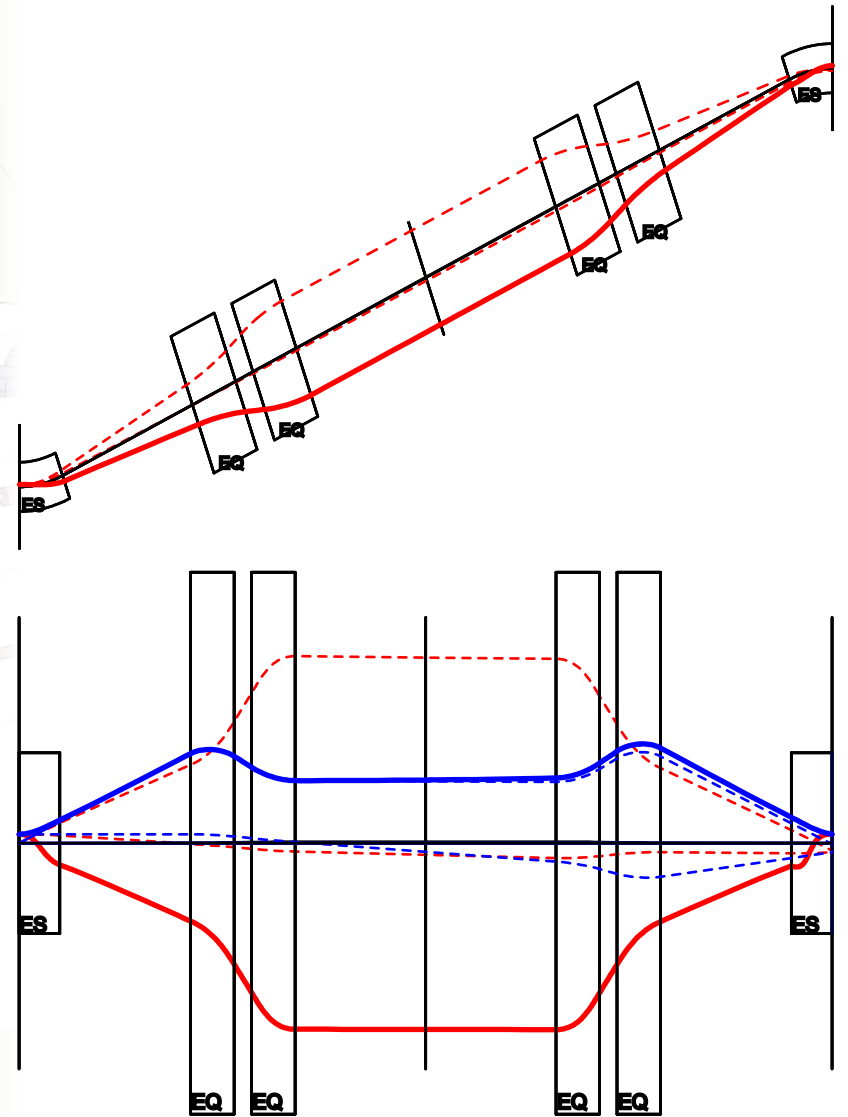
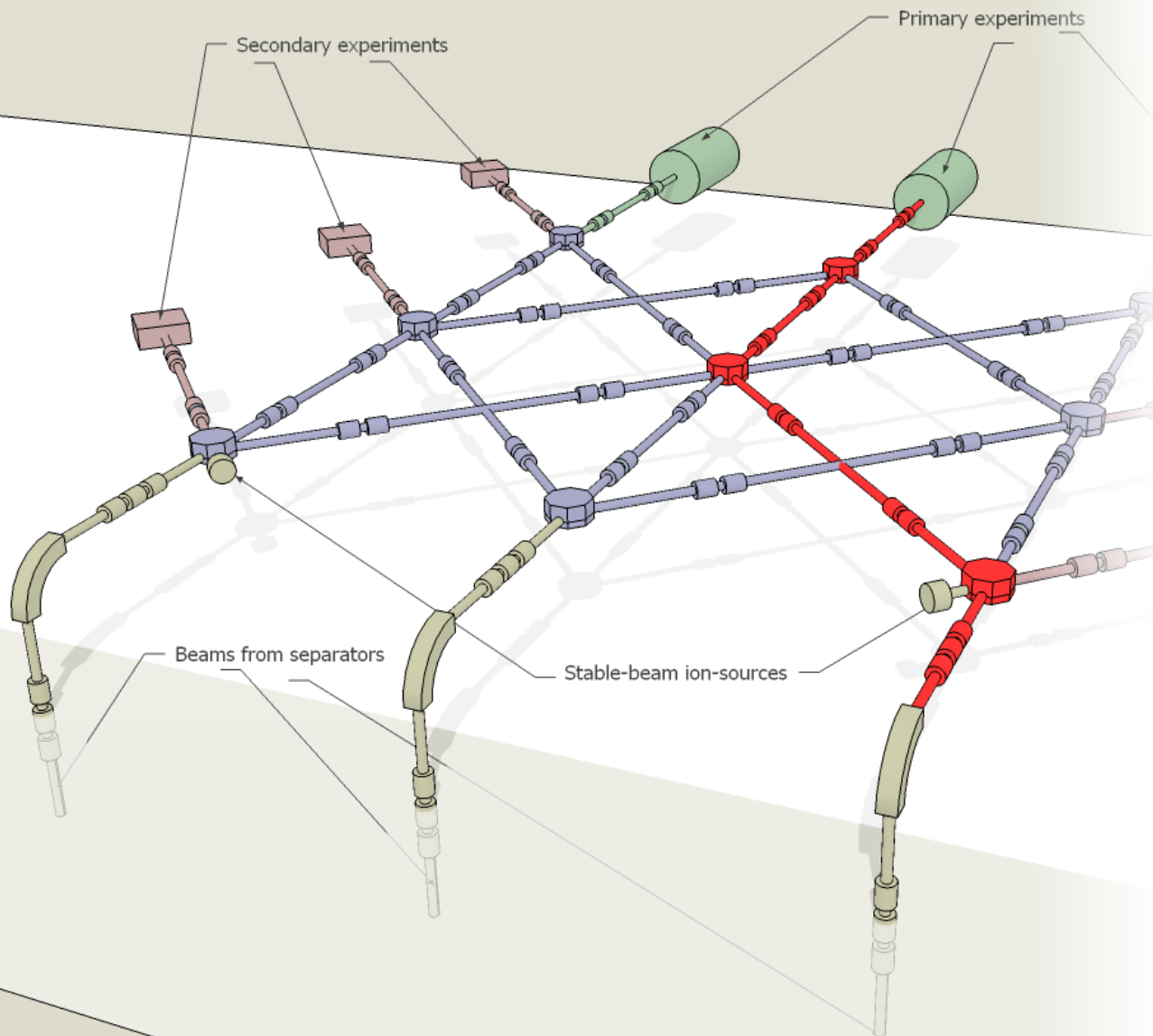
Better Beam Distribution



Better Beam Distribution



Better Beam Distribution



An aerial photograph of a vast, flat, and cracked mud plain. The ground is a mix of grey and brown tones, with numerous deep, winding cracks and smaller fissures creating a complex, textured surface. In the lower-left foreground, a single, bright green leaf lies on the cracked earth, providing a sharp contrast to the otherwise monochromatic landscape. The overall scene is desolate and emphasizes the harsh, dry conditions of the environment.

Lens Design

Tim Giles

ELENA Workshop - Jan 2012

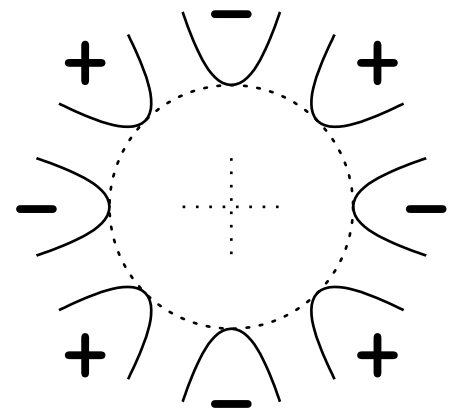
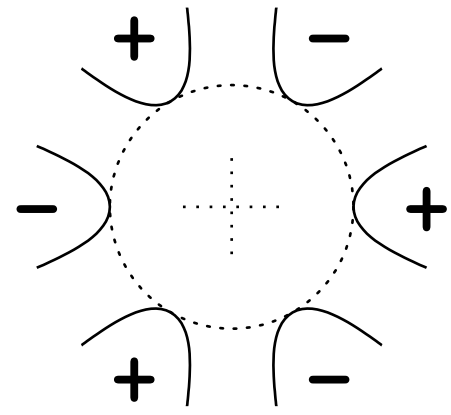
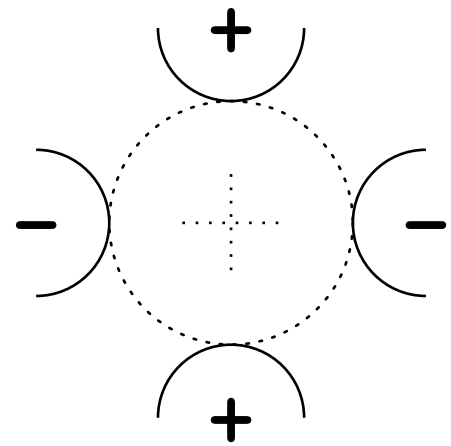
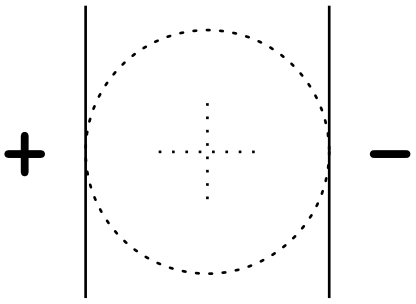
Multipoles vs. Order

Dipole

Quadrupole

Hexapole

Octupole

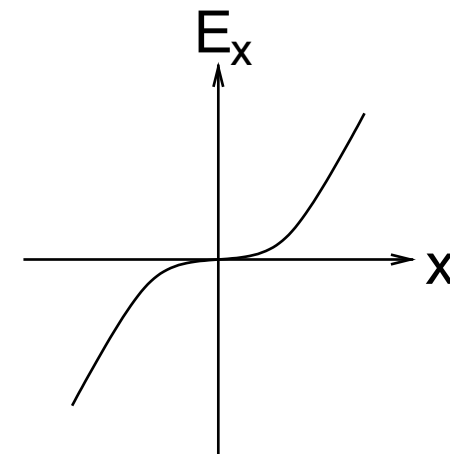
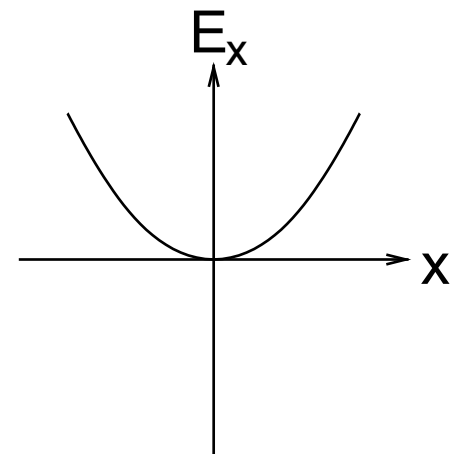
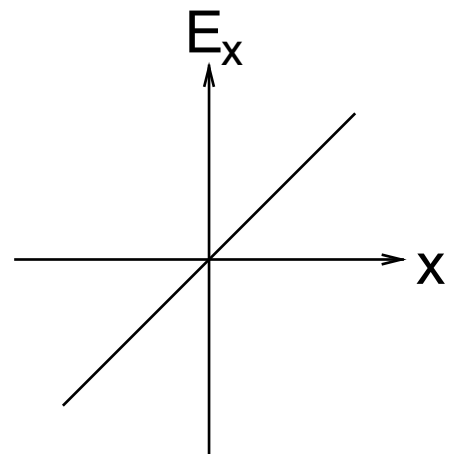
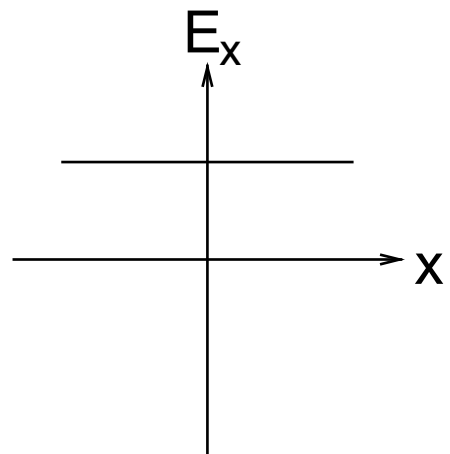


0th

1st

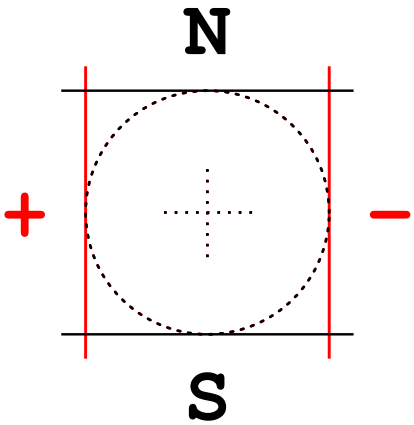
2nd

3rd

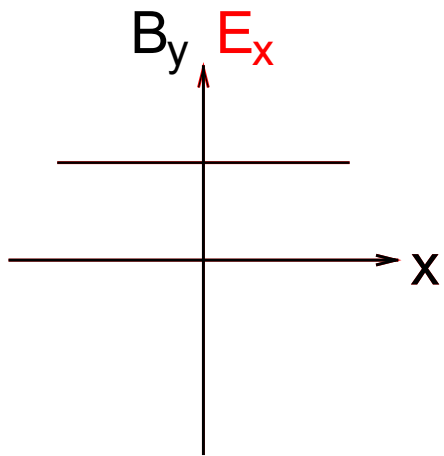


Multipoles vs. Order

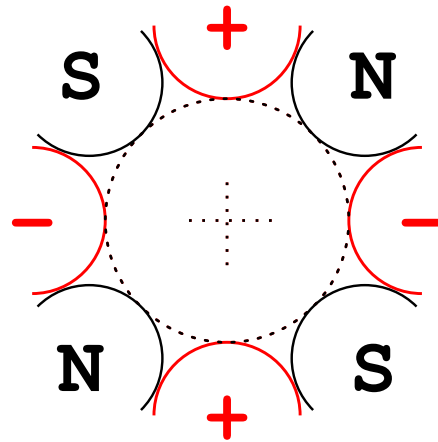
Dipole



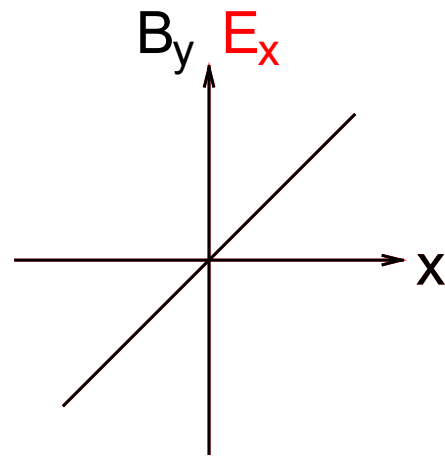
0th



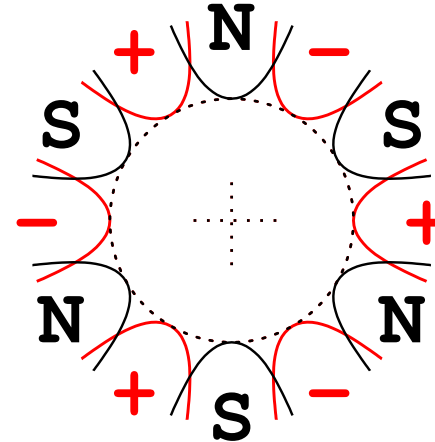
Quadrupole



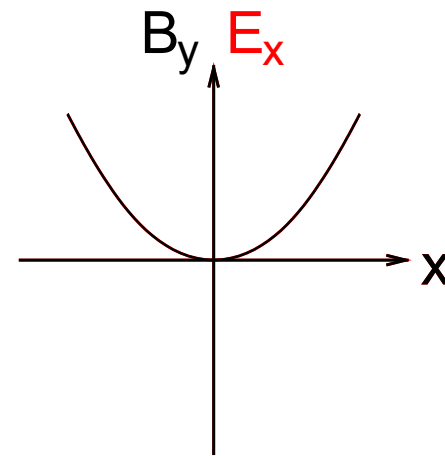
1st



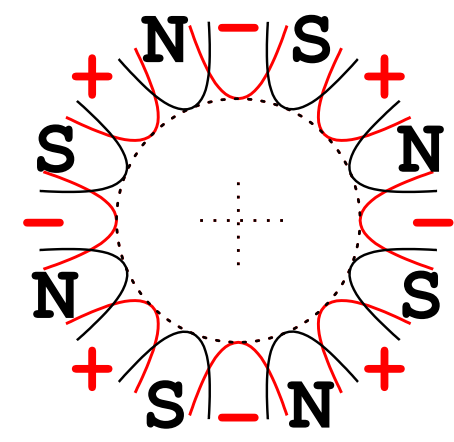
Hexapole



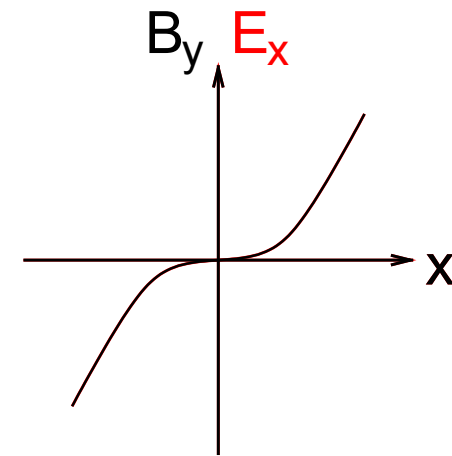
2nd



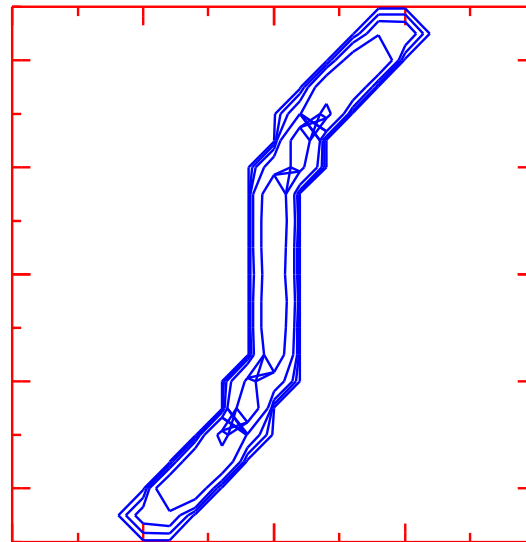
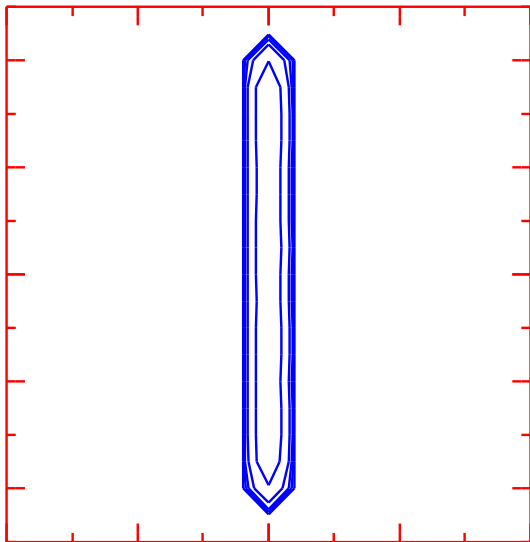
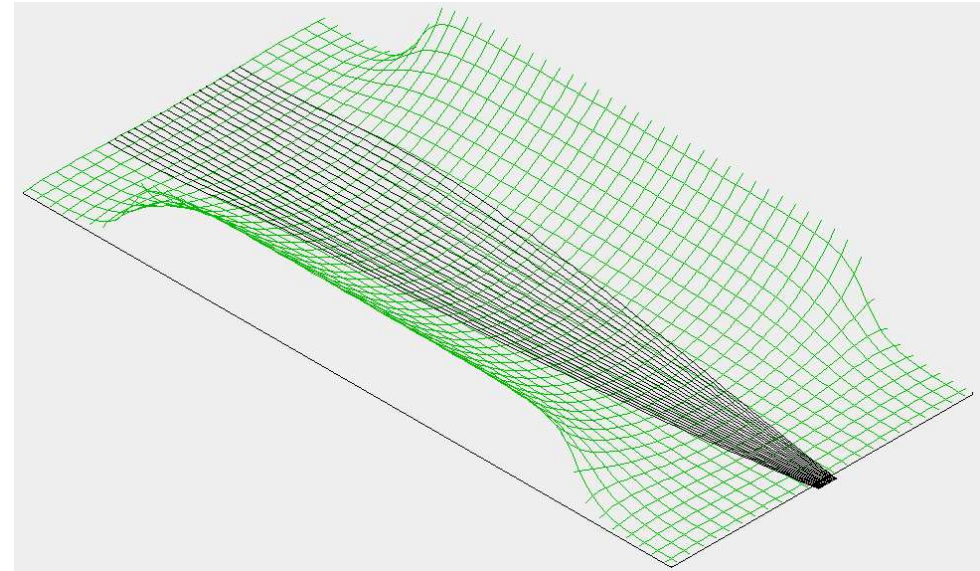
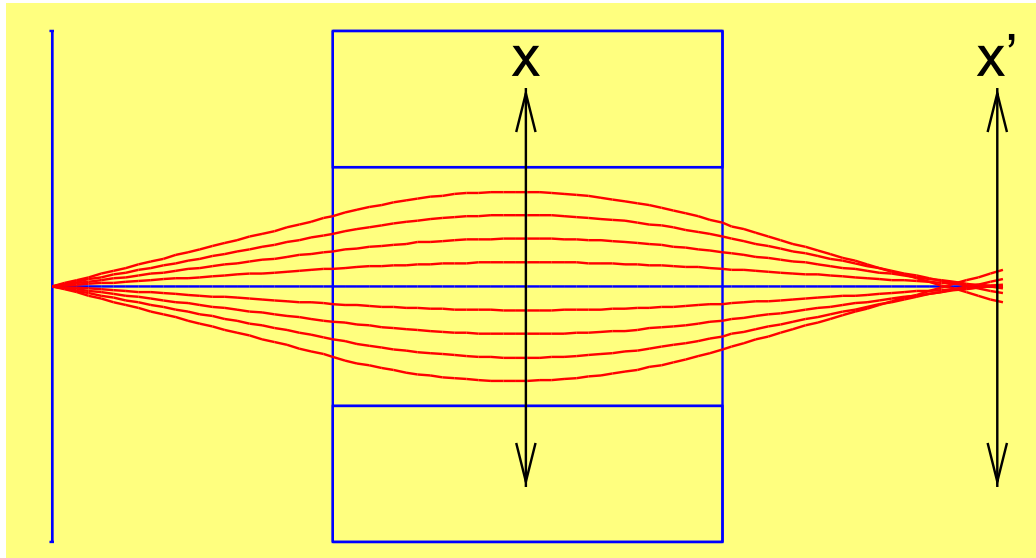
Octupole



3rd



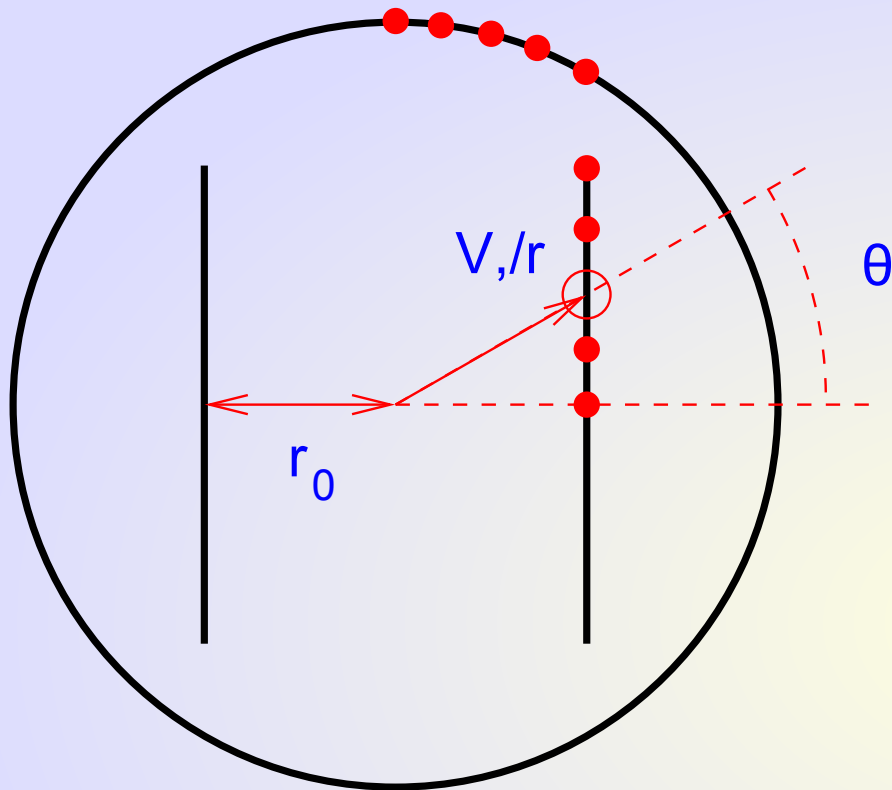
Intrinsic Distortions



$$f = f_0 \left(1 - \frac{k/x^2}{Q_0} \right)$$

$$x' = - \frac{k/x^3}{Q_0}$$

Multipole Distortions



$$V = V_0 \sum_n a_n \frac{r^n}{r_0^n} \cos(n \theta)$$

For a dipole, $n \neq 1, 3, 5 \dots$

For a quadrupole, $n \neq 2, 6, 10 \dots$

Emittance growth $\varepsilon' = \varepsilon(1 + tol)$

Dipole

$$\frac{\varepsilon}{x_0 \cdot tol} = \delta A_1 \cdot \frac{a_n}{a_1} \cdot n \cdot \frac{x_0^{(n-1)}}{r_0^{(n-1)}}$$

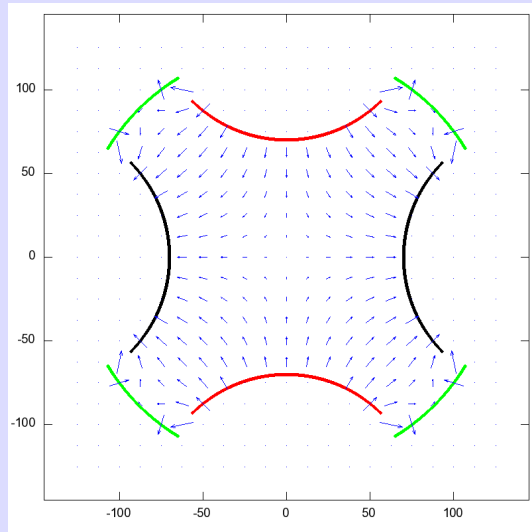
↑
deflection angle

Quadrupole

$$\frac{\varepsilon}{x_0 \cdot tol} = \delta A_2 \cdot \frac{a_n}{a_2} \cdot n \cdot \frac{x_0^{(n-2)}}{r_0^{(n-2)}}$$

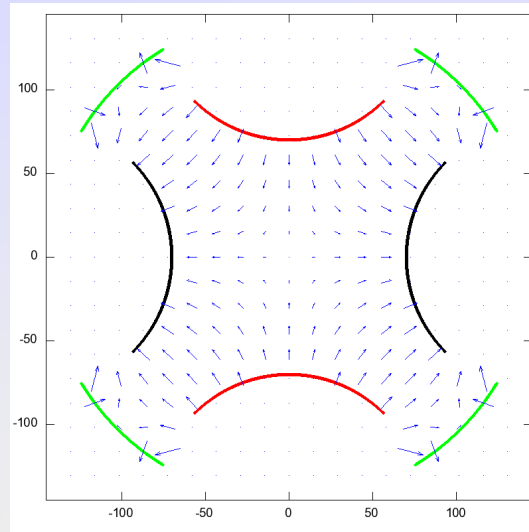
↑
 x_0 / focal length

Transverse Fields in Quadrupole Lenses



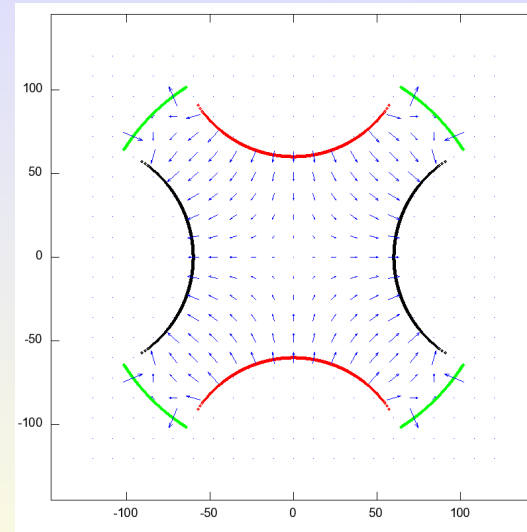
Beamline Quadrupole

$$\begin{aligned} a_2 &= +1.004 \\ a_6 &= -0.0044 \\ a_{10} &= -0.0057 \\ a_{14} &= -0.0003 \end{aligned}$$



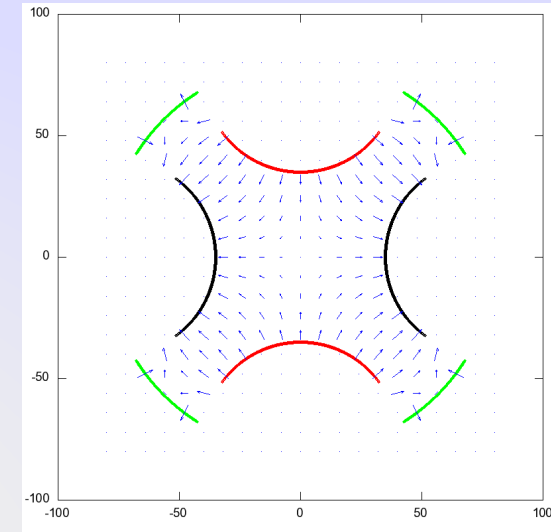
Frontend Quadrupole
(old)

$$\begin{aligned} a_2 &= +1.008 \\ a_6 &= +0.0062 \\ a_{10} &= -0.0012 \\ a_{14} &= -0.0000 \end{aligned}$$



Frontend Quadrupole
(new)

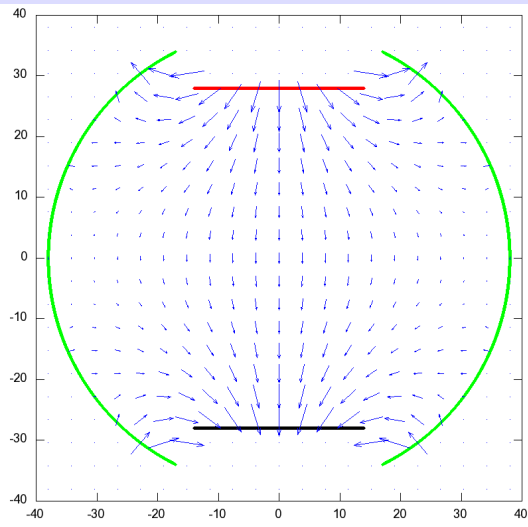
$$\begin{aligned} a_2 &= +1.003 \\ a_6 &= +0.0012 \\ a_{10} &= -0.0019 \\ a_{14} &= -0.0001 \end{aligned}$$



Compact Lens for
RFQ Matching

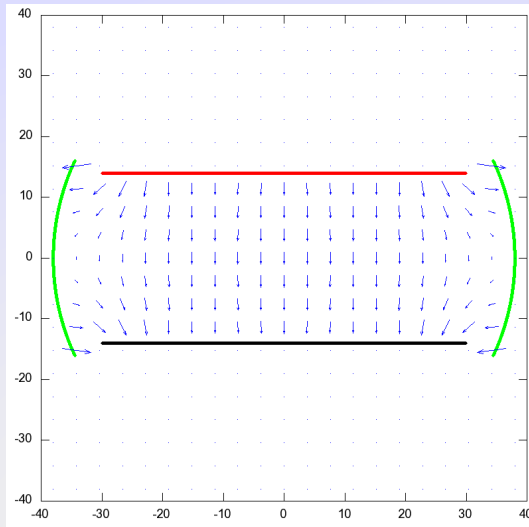
$$\begin{aligned} a_2 &= +1.009 \\ a_6 &= +0.0076 \\ a_{10} &= -0.0004 \\ a_{14} &= -0.0000 \end{aligned}$$

Transverse Fields in Deflectors



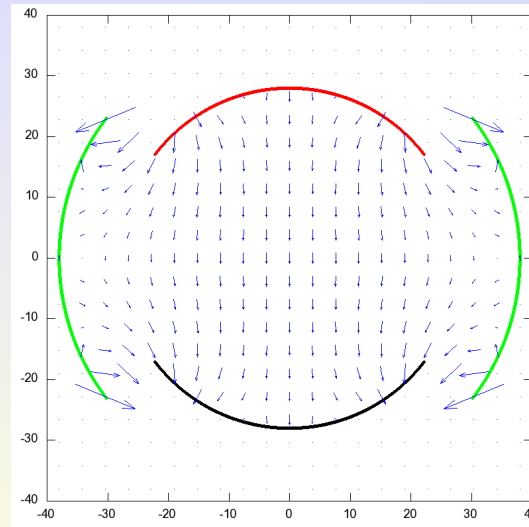
Wide Aperture

$$\begin{aligned}
 a_1 &= +0.699 \\
 a_3 &= +0.311 \\
 a_5 &= +0.113 \\
 a_7 &= +0.031 \\
 a_9 &= +0.005 \\
 a_{11} &= -0.001
 \end{aligned}$$



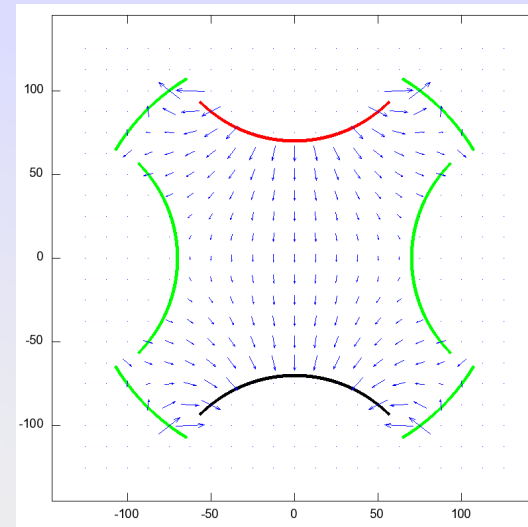
Narrow Aperture

$$\begin{aligned}
 a_1 &= +1.000 \\
 a_3 &= +0.012 \\
 a_5 &= +0.007 \\
 a_7 &= +0.003 \\
 a_9 &= +0.000 \\
 a_{11} &= +0.000
 \end{aligned}$$



Compact Curved
(new frontend)

$$\begin{aligned}
 a_1 &= +1.096 \\
 a_3 &= -0.002 \\
 a_5 &= -0.149 \\
 a_7 &= +0.016 \\
 a_9 &= +0.053 \\
 a_{11} &= +0.018
 \end{aligned}$$



Quadrupole as
Deflector

$$\begin{aligned}
 a_1 &= +0.784 \\
 a_3 &= +0.240 \\
 a_5 &= +0.023 \\
 a_7 &= +0.007 \\
 a_9 &= -0.001 \\
 a_{11} &= -0.000
 \end{aligned}$$

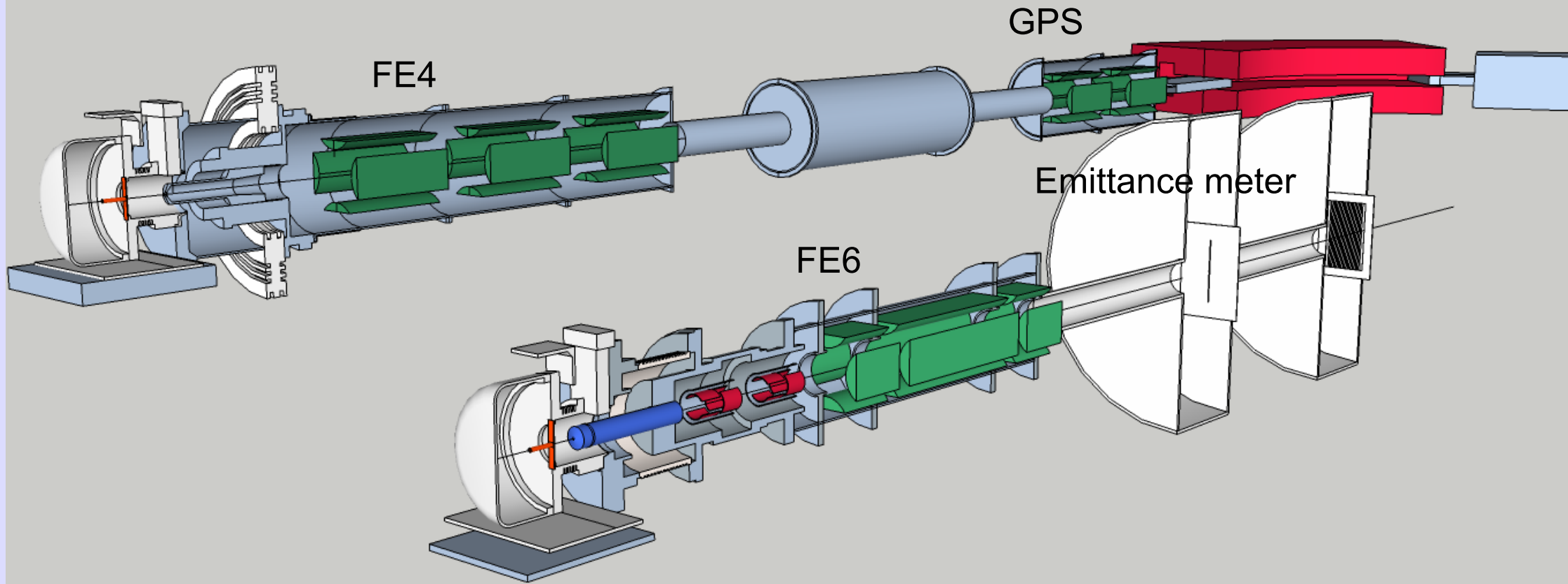
An aerial photograph of a vast, flat, brown landscape, possibly a dry lake bed or a salt flat. The ground is covered in a dense, textured layer of brown material, with some darker, more saturated areas. A single, small, bright green leaf lies on the ground in the lower-left quadrant. The overall scene is desolate and expansive.

Putting it all together

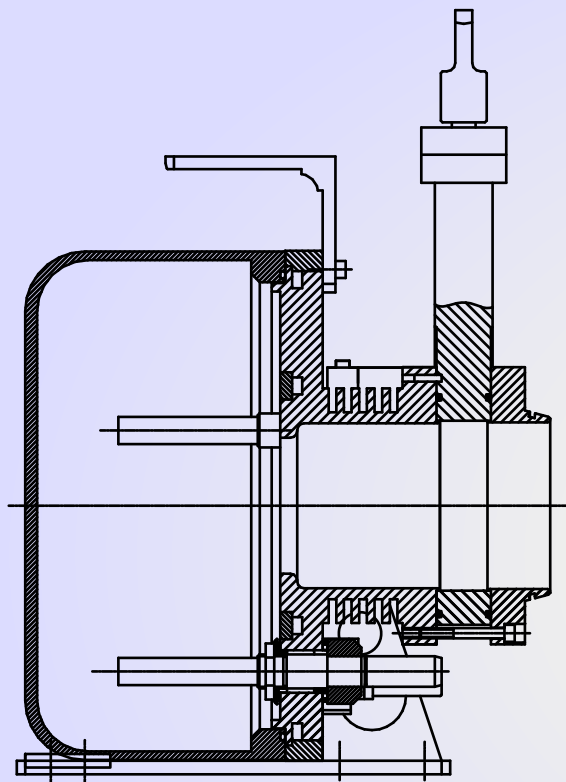
Tim Giles

ELENA Workshop - Jan 2012

Tune testing method

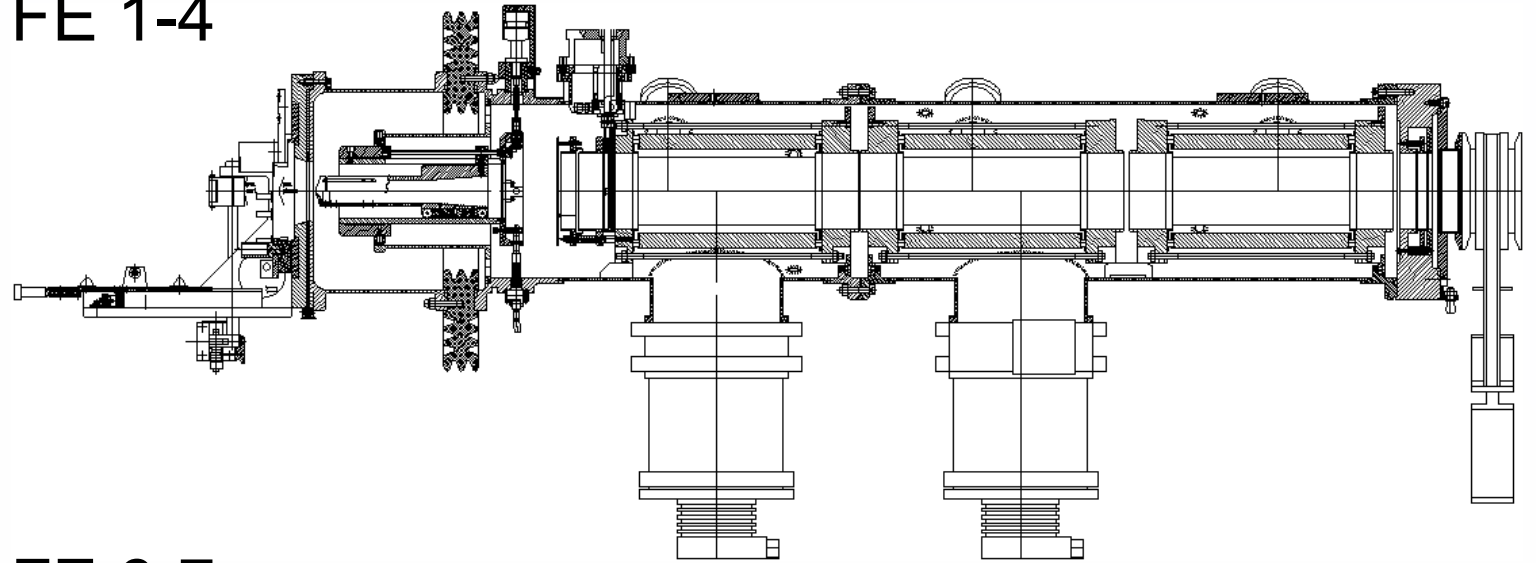


The Isolde Frontends

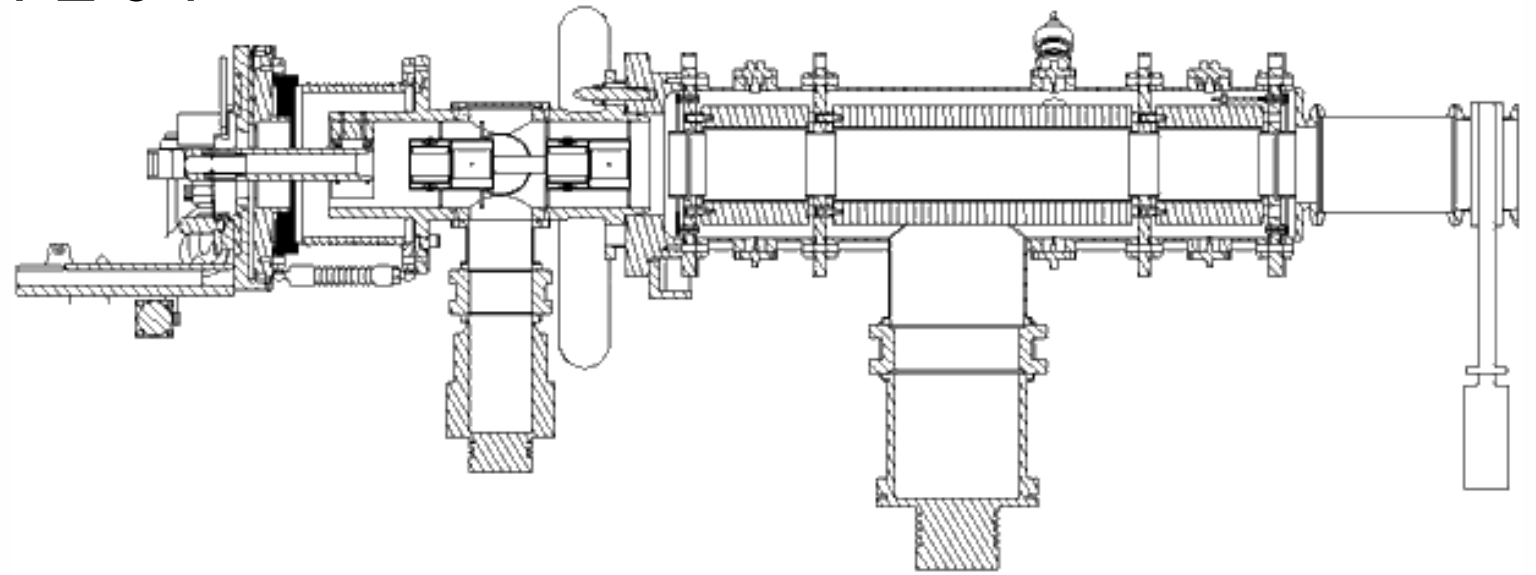


Target unit
x2.5

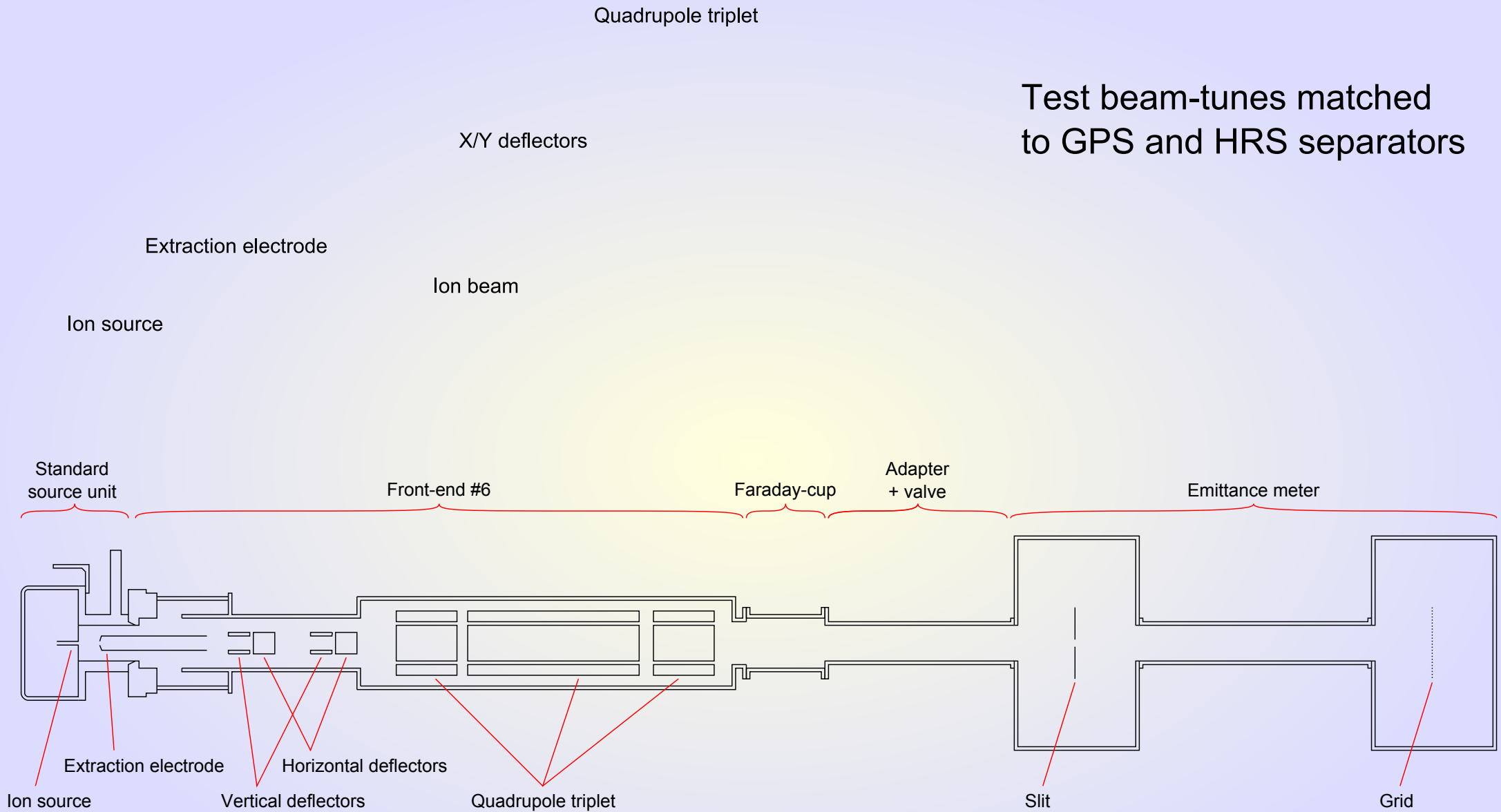
FE 1-4



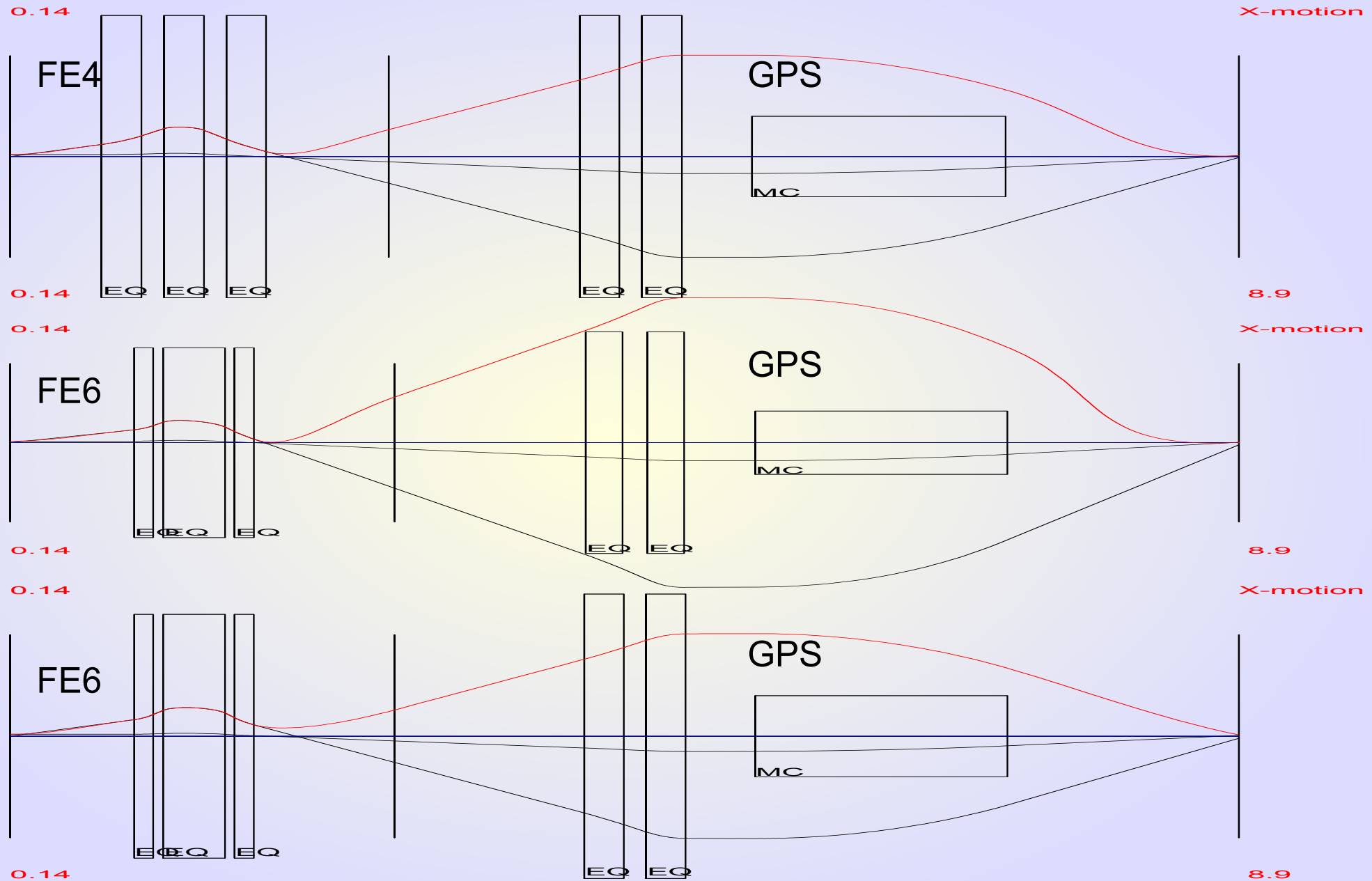
FE 6-7



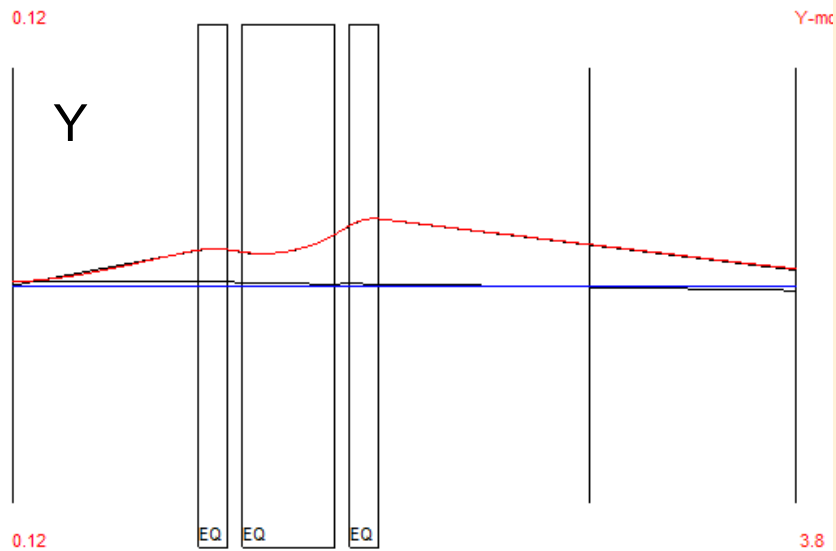
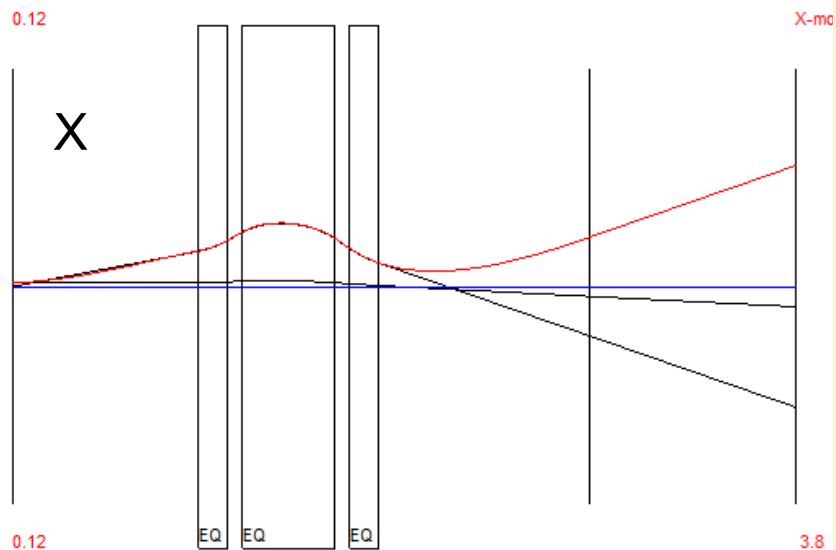
FE6 test setup



Tune testing method



GPS tune #1



Simulation

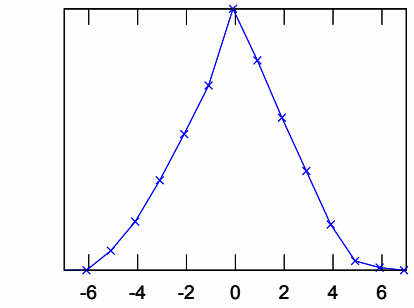
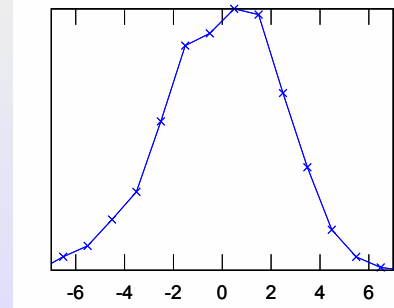
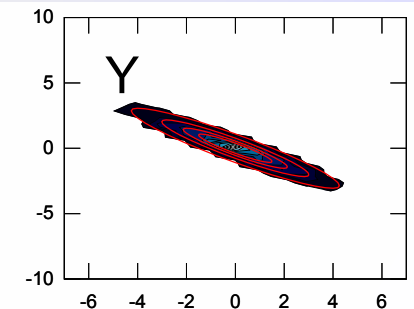
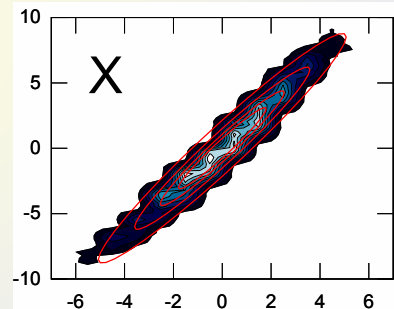
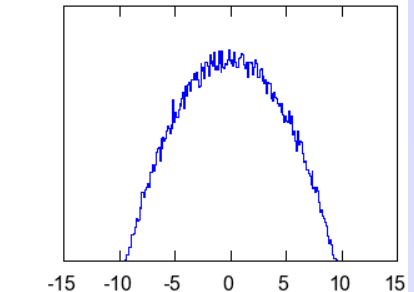
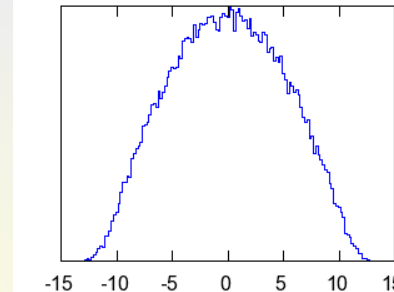
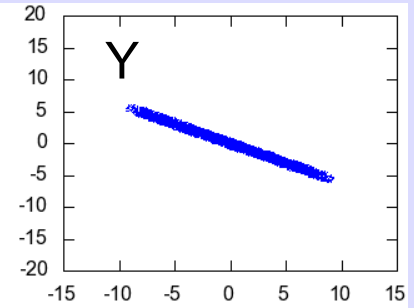
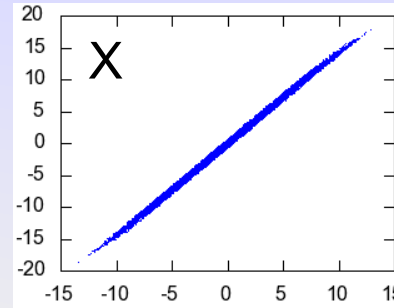
$$\begin{aligned} \alpha_x &= -20.9 & \Theta_x &= -2.4 \\ \beta_x &= 14.5 & \rho_x &= 59 \\ \gamma_x &= 30.2 \end{aligned}$$

$$\begin{aligned} \alpha_y &= 6.0 & \Theta_y &= -2.2 \\ \beta_y &= 9.9 & \rho_y &= 24 \\ \gamma_y &= 3.8 \end{aligned}$$

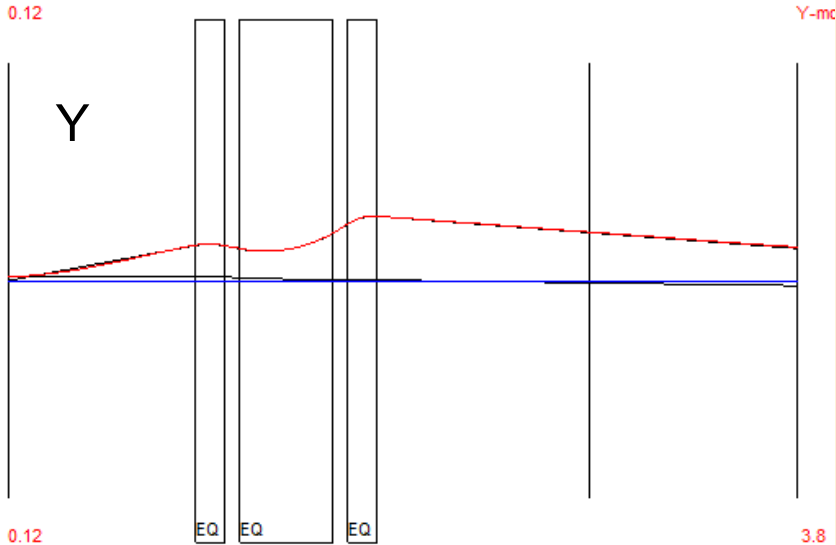
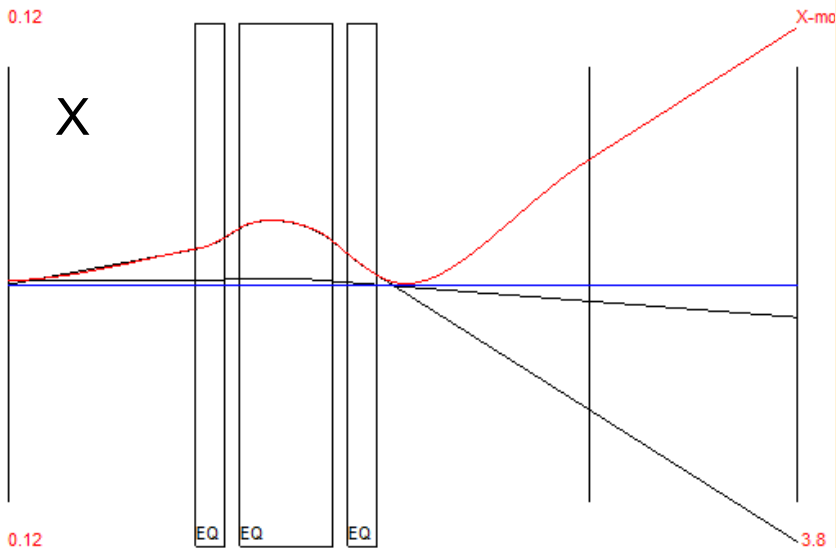
Measurement

$$\begin{aligned} \alpha_x &= -4.0 & \Theta_x &= -2.1 \\ \beta_x &= 2.4 & \rho_x &= 12 \\ \gamma_x &= 7.1 \end{aligned}$$

$$\begin{aligned} \alpha_y &= 2.6 & \Theta_y &= -2.5 \\ \beta_y &= 3.9 & \rho_y &= 10 \\ \gamma_y &= 2.0 \end{aligned}$$



GPS tune #2



Simulation

$$\alpha_x = -97$$

$$\beta_x = 92$$

$$\gamma_x = 102$$

$$\Theta_x = -3.0$$

$$\rho_x = 287$$

$$\alpha_y = 4.4$$

$$\beta_y = 13.9$$

$$\gamma_y = 1.5$$

$$\Theta_y = -1.2$$

$$\rho_y = 29$$

Measurement

$$\alpha_x = -25$$

$$\beta_x = 23$$

$$\gamma_x = 28$$

$$\Theta_x = -2.9$$

$$\rho_x = 74$$

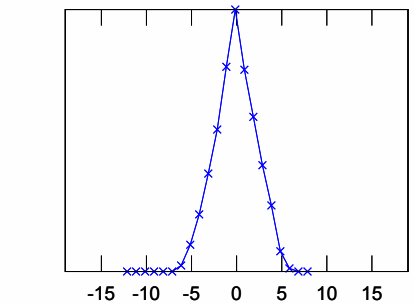
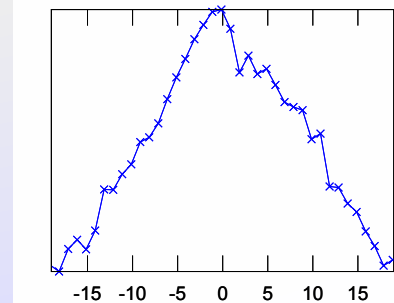
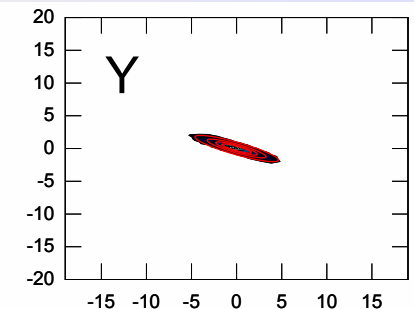
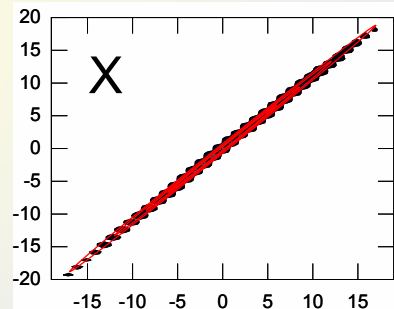
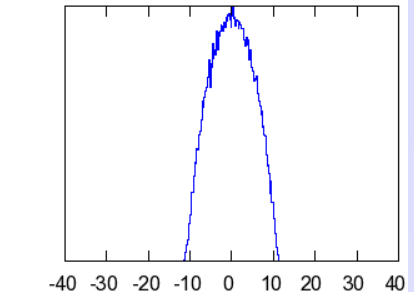
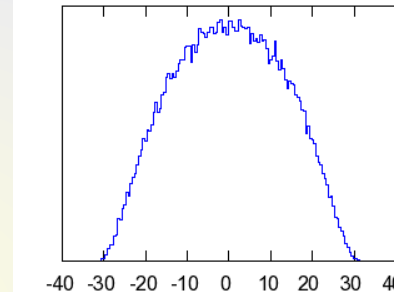
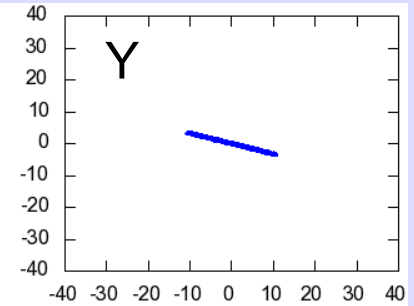
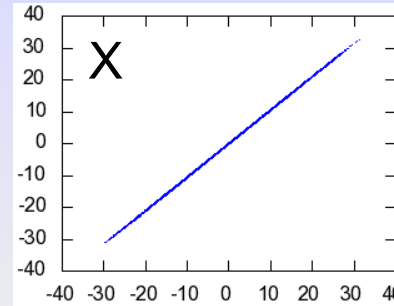
$$\alpha_y = 1.8$$

$$\beta_y = 4.7$$

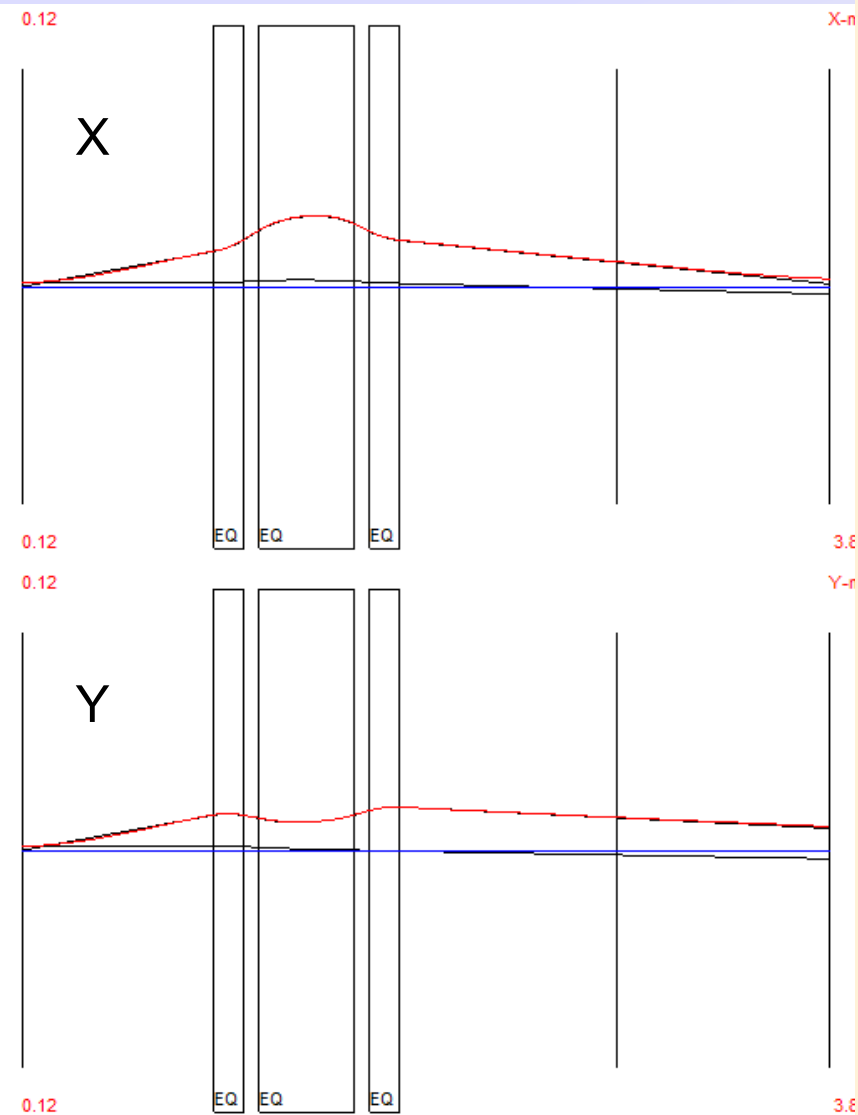
$$\gamma_y = 0.9$$

$$\Theta_y = -1.5$$

$$\rho_y = 10$$



HRS tune



Simulation

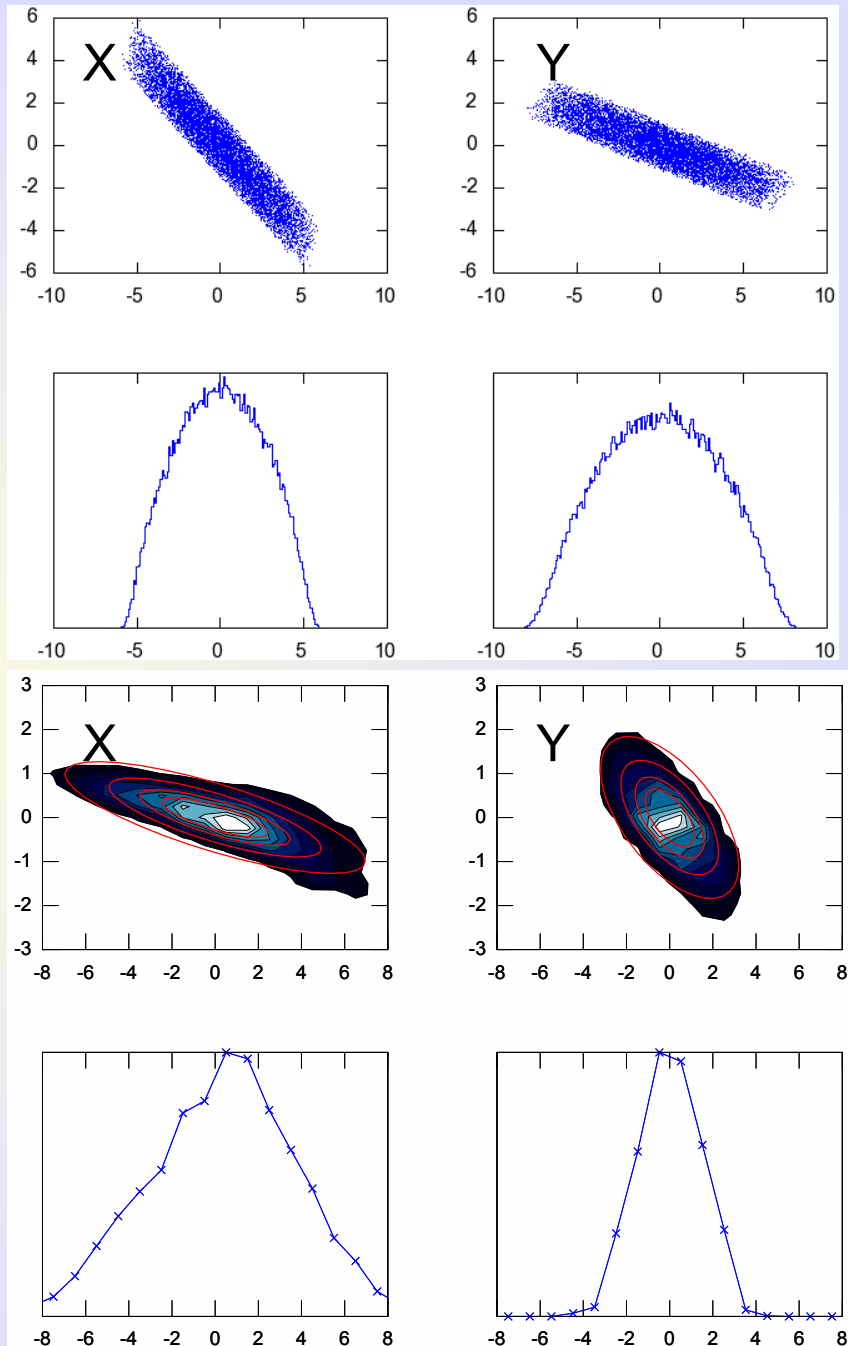
$$\begin{aligned} \alpha_x &= 3.0 & \Theta_x &= -2.9 \\ \beta_x &= 3.6 & \rho_x &= 10 \\ \gamma_x &= 2.8 \end{aligned}$$

$$\begin{aligned} \alpha_y &= 1.9 & \Theta_y &= -1.2 \\ \beta_y &= 6.4 & \rho_y &= 13 \\ \gamma_y &= 0.7 \end{aligned}$$

Measurement

$$\begin{aligned} \alpha_x &= 1.2 & \Theta_x &= -0.6 \\ \beta_x &= 8.8 & \rho_x &= 18 \\ \gamma_x &= 0.3 \end{aligned}$$

$$\begin{aligned} \alpha_y &= 0.7 & \Theta_y &= -1.6 \\ \beta_y &= 2.2 & \rho_y &= 5 \\ \gamma_y &= 0.7 \end{aligned}$$



Summary

Pros & Cons of electrostatic beamlines

Cheap power supplies and cabling

Mass-independent

No hysteresis (easy to operate)

No power used (no cooling)

Transverse field shape easy to optimise

Difficult to measure field shape
(esp. effective length)

Large internal surface area (outgassing)

Vulnerable to dirt inside vacuum

Bad connections can cause beam movement

Difficult to diagnose bad connections

Must be interlocked with vacuum
(arcing + safety)

Repairs require opening vacuum

Limited choice of vacuum-compatible insulators