Fast simulation of E320 beamline

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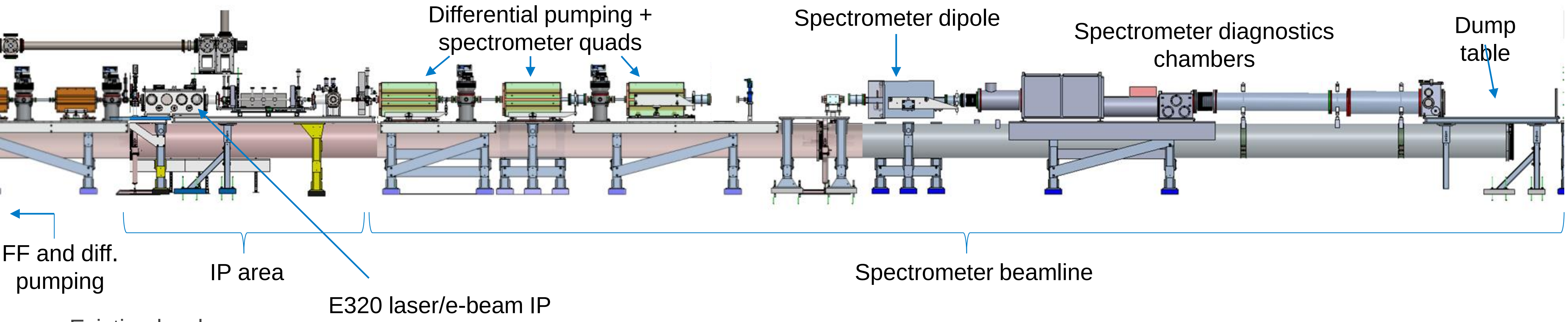
Goals of this study

For Cherenkov tests at E320

- How do we need to dimension our detector to catch the Comptron Spectrum?
- Implement E320 spectrometer in fast simulation
- Run on Ptarmigan signal simulation with E320 parameters
- Challenge: E320 spectrometer is not just a dipole, but has quads!

FACET-II Experimental Area



- Existing hardware:
  - E320 Interaction Point (IP)
    - Details from Sebastian Meuren
  - Differential pumping system – no beam intercepting windows between IP and dump exit window
  - Quad triplet after IP
  - Spectrometer dipole
    - nominal dispersion of ~6cm at dump table
  - Spectrometer diagnostics:
    - Chambers for in vacuum electron diagnostics
    - In air electron, photon diagonotics at “dump table”

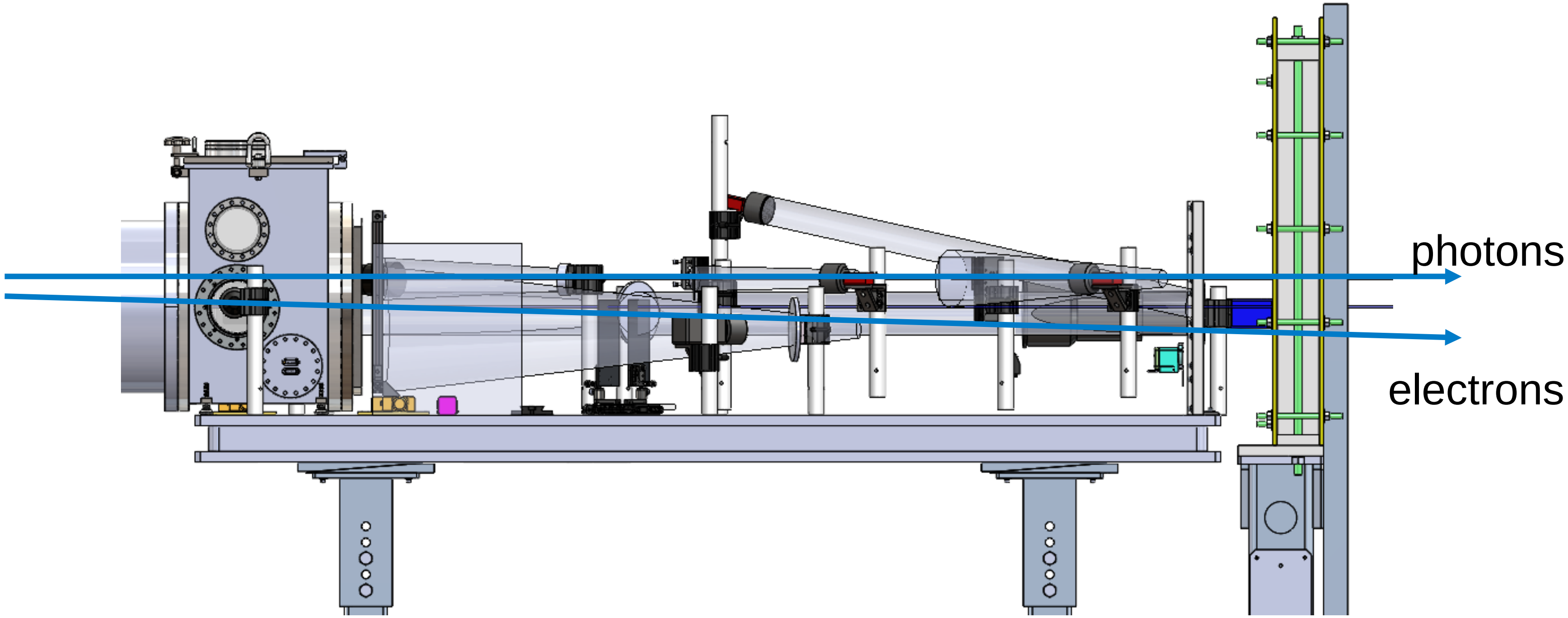
Electron beam parameter	Current[a]	Operational range
Delivered beam energy, (GeV)	10	10 – 13
Norm. emittance, (mm-mrad)	~ 20	3 – 6
Bunch configuration	Single	Two-bunch
Charge per bunch, (nC)	2	1.3/0.6
Peak current, (kA)	–	30/15
RMS energy spread, (%)	~ 1	0.8/0.3
Repetition rate, (Hz)	1 – 30	1 – 30
IP β^*, (cm)	50	5 – 50

Spectrometer beamline

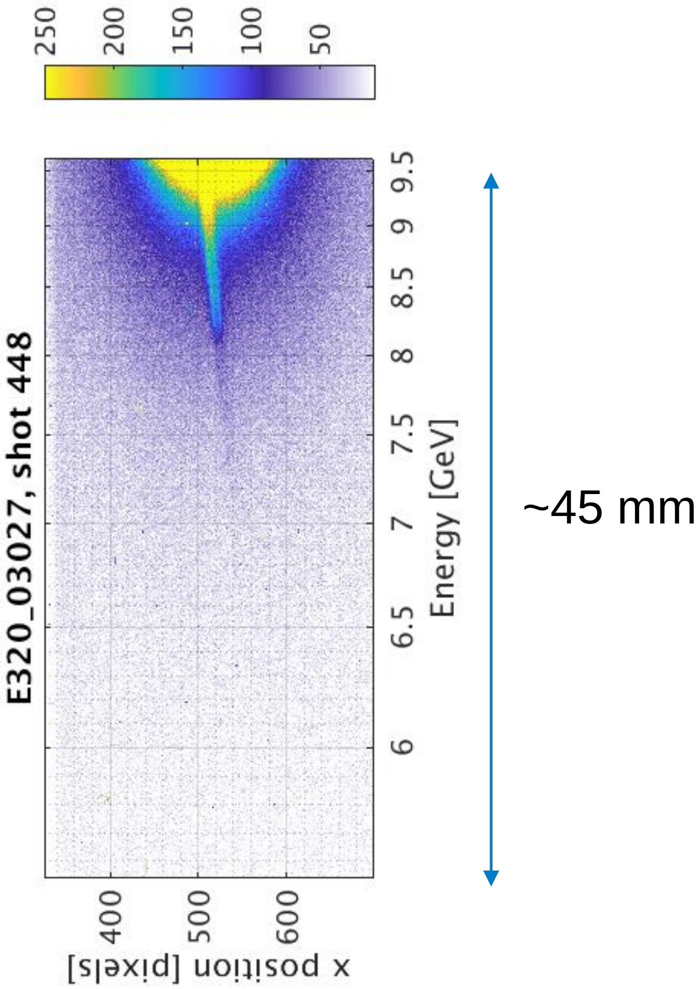
	Z location [m]	Element	Details
Compton IP	~1992.8	e-beam/laser IP	
Q0D quad	1996.98	Quad	Length = 1 m, Integrated gradient $B'L = -14$ T (**)
Q1D quad	1999.21	Quad	Length = 1 m, Integrated gradient $B'L = \quad 22$ T (**)
Q2D quad	2001.43	Quad	Length = 1 m, Integrated gradient $B'L = -14$ T (**)
Spec. Dipole	2005.94	Dipole	Length = 0.98 m, Integrated field $BL = 0.26$ Tm (**)
Vacuum exit window	2015.54	Window	5mm thick aluminum, 6 in. wide
Dump shield	2027.3	Gap	2 in. wide gap in lead wall, 4 in. thick
Dump Entrance	2028.0	Gap	2.5 in. gap in shielding
Dump	2028.6	Beam stop	Water cooled copper block - shielded by 8 in.+ lead, 11in. + borated polyethelyne

*** max (nominal) fields, settings may change to change focal energy and nominal dispersion*

Side view



Spectrometer quads focusing at 8 GeV



- Nominal distance between photons and primary beam ~60mm
- This can change with spectrometer dipole setting
- Photon axis is ~32 cm from optical table surface
  - Primary electron beam at ~26cm, Compton electrons below this

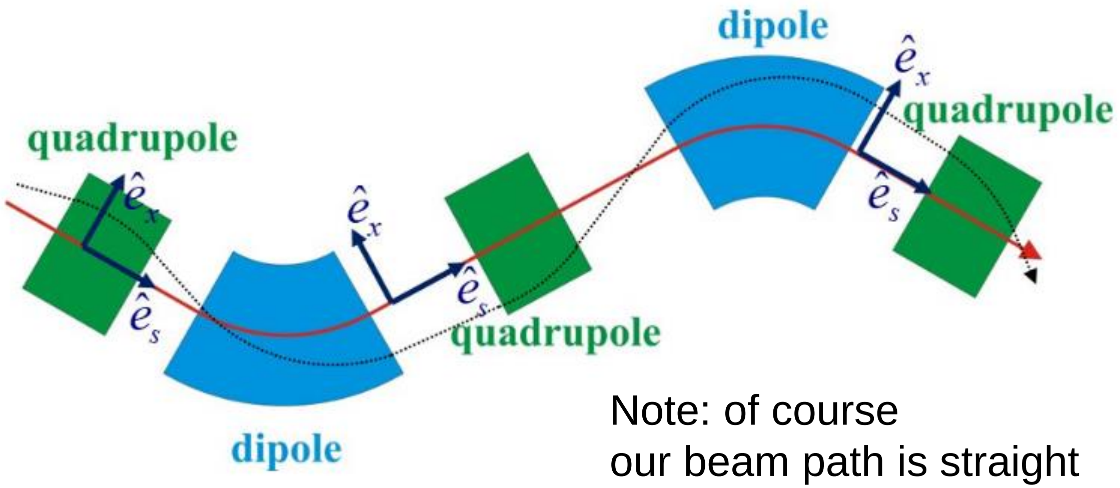
E320 Ptarmigan config

```
control:
  dt_multiplier: 0.5
  radiation_reaction: true
  pair_creation: true
  rng_seed: 0
  increase_pair_rate_by: 1.0

laser:
  a0: a0
  wavelength: wavelength
  fwhm_duration: tau * femto
  #waist: 2.5 * micro
  waist: 0.6 * 0.8 / a0 * sqrt(2 * 0.8 *laser_energy * 100000. / tau) * micro
  #Waist: 147.839 * sqrt(laser_energy) * wavelength / (a0 * sqrt(tau))
  #waist: (1 + 0.1/(2 * pi))*147.839 * sqrt(laser_energy) * wavelength / (a0 * sqrt(tau))
  polarization: linear
```

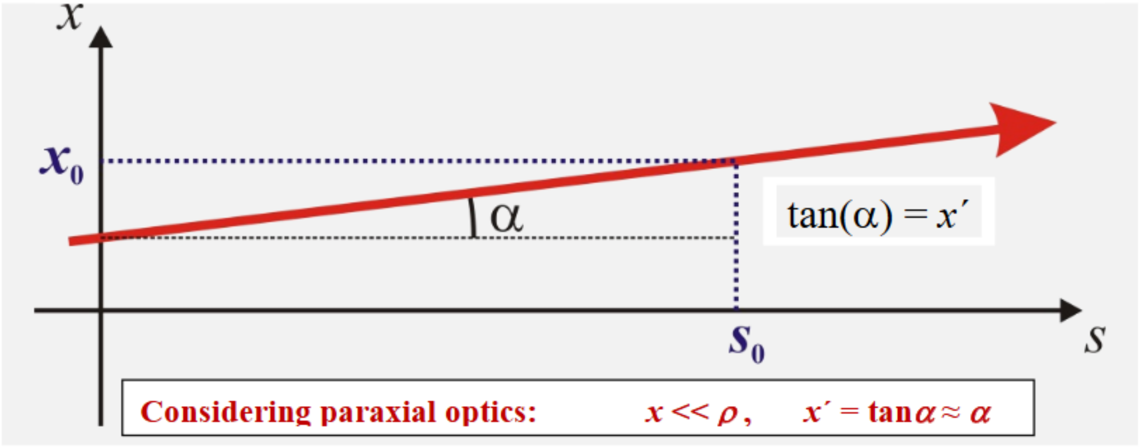
```
beam:
  n: 1000000
  species: electron
  charge: 12.5e9 * e
  gamma: initial_gamma
  sigma: 0.01 * initial_gamma
  radius: [35.0 * micro, normally_distributed]
  length: 30.0 * micro
  collision_angle: -30.0 * degree
  rms_divergence: 70.0 * micro

output:
  ident: auto
  dump_all_particles: hdf5
  discard_background_e: true
  coordinate_system: beam
  units: hep

constants:
  a0: 0.5
  laser_energy: 0.14 # joules (on target)
  laser_energy_uncompressed: 0.6 #joules
  wavelength: 0.8 * micro
  tau: 60.0 # fs
  initial_gamma: 10.0 * GeV / (me * c^2)
  pi: 3.14159
```

Linear Beam Optics

Taken from Slides by W. Hillert
(CERN accelerator school)



Note: of course
our beam path is straight



- Define local coordinate system that follows ideal orbit
- Our beamline consists of: drift volumes, quadrupoles and dipoles
- Effect of beamline elements on trajectory expressed through matrix formalism
- In our case: Dipole treated separately (paraxial approximation doesn’t hold, large deviation)

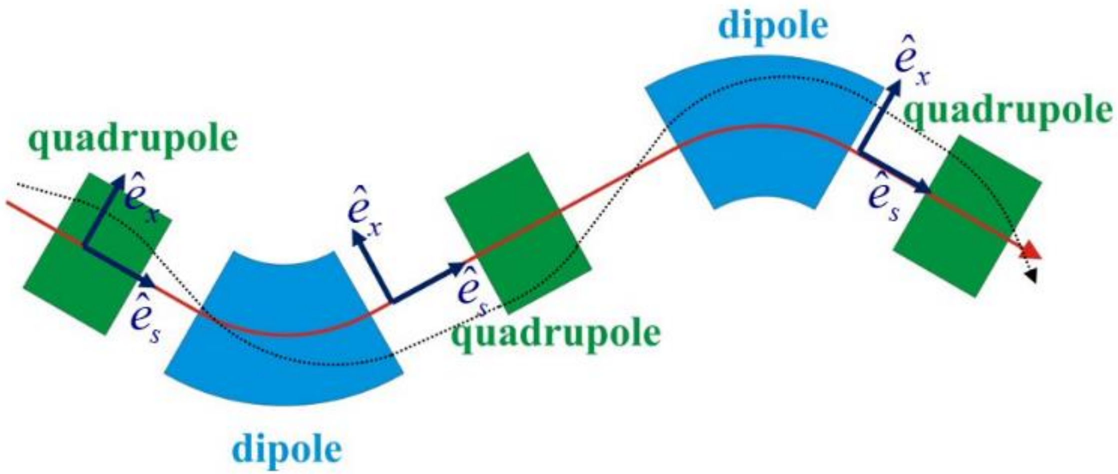
Linear Beam Optics

Taken from [Slides by W. Hillert]
(CERN accelerator school)

$$\begin{pmatrix} x \\ x' \\ y \\ y' \end{pmatrix} = \begin{pmatrix} \text{horizontal displacement} \\ \text{horizontal angular displacement} \\ \text{vertical displacement} \\ \text{vertical angular displacement} \end{pmatrix} \begin{matrix} \left.\begin{matrix} \\ \\ \end{matrix}\right\} \text{hor. trace space} \\ \left.\begin{matrix} \\ \\ \end{matrix}\right\} \text{vert. trace space} \end{matrix}$$

$$\mathbf{M} = \begin{pmatrix} r_{11} & r_{12} & 0 & 0 \\ r_{21} & r_{22} & 0 & 0 \\ 0 & 0 & r_{33} & r_{34} \\ 0 & 0 & r_{43} & r_{44} \end{pmatrix} = \begin{pmatrix} \mathbf{M}_x & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} \\ \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} & \mathbf{M}_y \end{pmatrix}$$

Particle trajectory: $\vec{X} = \mathbf{M} \cdot \vec{X}_0$



$$\vec{x} = \underbrace{\mathbf{M}_d \bullet \mathbf{M}_Q \bullet \mathbf{M}_d \bullet \mathbf{M}_D \bullet \mathbf{M}_d \bullet \mathbf{M}_Q \bullet \mathbf{M}_d \bullet \mathbf{M}_D \bullet \mathbf{M}_d \bullet \mathbf{M}_Q \bullet \mathbf{M}_d}_{= \text{Transfer Matrix } \mathbf{M}} \bullet \vec{x}_0$$

Drift Volumes

Taken from Slides by W. Hillert
(CERN accelerator school)

$$\begin{pmatrix} x \\ x' \\ y \\ y' \end{pmatrix} = \begin{pmatrix} \text{horizontal displacement} \\ \text{horizontal angular displacement} \\ \text{vertical displacement} \\ \text{vertical angular displacement} \end{pmatrix} \begin{matrix} \left.\begin{matrix} \\ \\ \end{matrix}\right\} \text{hor. trace space} \\ \left.\begin{matrix} \\ \\ \end{matrix}\right\} \text{vert. trace space} \end{matrix}$$

$$\mathbf{M} = \begin{pmatrix} r_{11} & r_{12} & 0 & 0 \\ r_{21} & r_{22} & 0 & 0 \\ 0 & 0 & r_{33} & r_{34} \\ 0 & 0 & r_{43} & r_{44} \end{pmatrix} = \begin{pmatrix} \mathbf{M}_x & \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} \\ \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix} & \mathbf{M}_y \end{pmatrix}$$

Particle trajectory: $\vec{X} = \mathbf{M} \cdot \vec{X}_0$

$$\mathbf{M}_{drift} = \begin{pmatrix} \boxed{\begin{matrix} 1 & L \\ 0 & 1 \end{matrix}} & \begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix} \\ \begin{matrix} 0 & 0 \\ 0 & 0 \end{matrix} & \boxed{\begin{matrix} 1 & L \\ 0 & 1 \end{matrix}} \end{pmatrix}$$

Quadrupoles

Taken from Slides by W. Hillert (CERN accelerator school)

Quadrupole Strength

$$\boxed{k = \frac{q}{p} g = \frac{2 q \mu_0}{p} \frac{n \cdot I}{a^2}}, \quad [k] = \mathrm{m}^{-2}$$

$$\Omega = \sqrt{|k|} \cdot L$$

length of the Quad

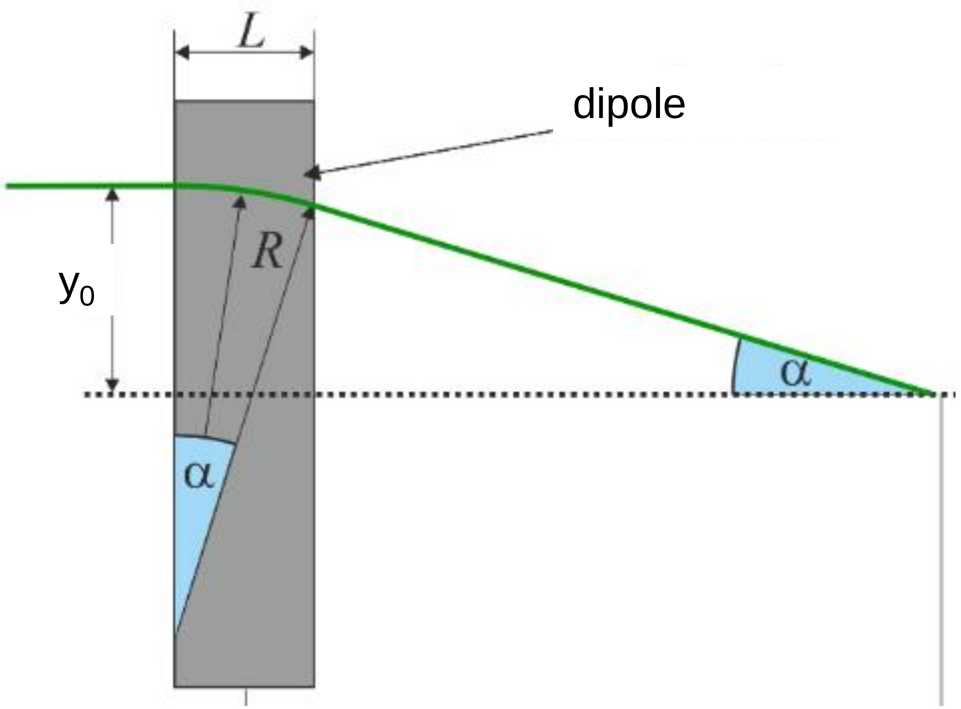
QF ($k < 0$): „horizontally focusing“

$$\mathbf{M}_{QF} = \begin{pmatrix} \cos\Omega & \frac{1}{\sqrt{|k|}}\sin\Omega & 0 & 0 \\ -\sqrt{|k|}\sin\Omega & \cos\Omega & 0 & 0 \\ 0 & 0 & \cosh\Omega & \frac{1}{\sqrt{|k|}}\sinh\Omega \\ 0 & 0 & \sqrt{|k|}\sinh\Omega & \cosh\Omega \end{pmatrix} \xrightarrow{L\to 0} \begin{pmatrix} 1 & 0 & 0 & 0 \\ -\frac{1}{f} & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \frac{1}{f} & 1 \end{pmatrix}$$

QD ($k > 0$): „horizontally de-focusing“

$$\mathbf{M}_{QD} = \begin{pmatrix} \cosh\Omega & \frac{1}{\sqrt{|k|}}\sinh\Omega & 0 & 0 \\ \sqrt{|k|}\sinh\Omega & \cosh\Omega & 0 & 0 \\ 0 & 0 & \cos\Omega & \frac{1}{\sqrt{|k|}}\sin\Omega \\ 0 & 0 & -\sqrt{|k|}\sin\Omega & \cos\Omega \end{pmatrix} \xrightarrow{L\to 0} \begin{pmatrix} 1 & 0 & 0 & 0 \\ \frac{1}{f} & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -\frac{1}{f} & 1 \end{pmatrix}$$

Dipole



$$x = x_0 + x' * L$$

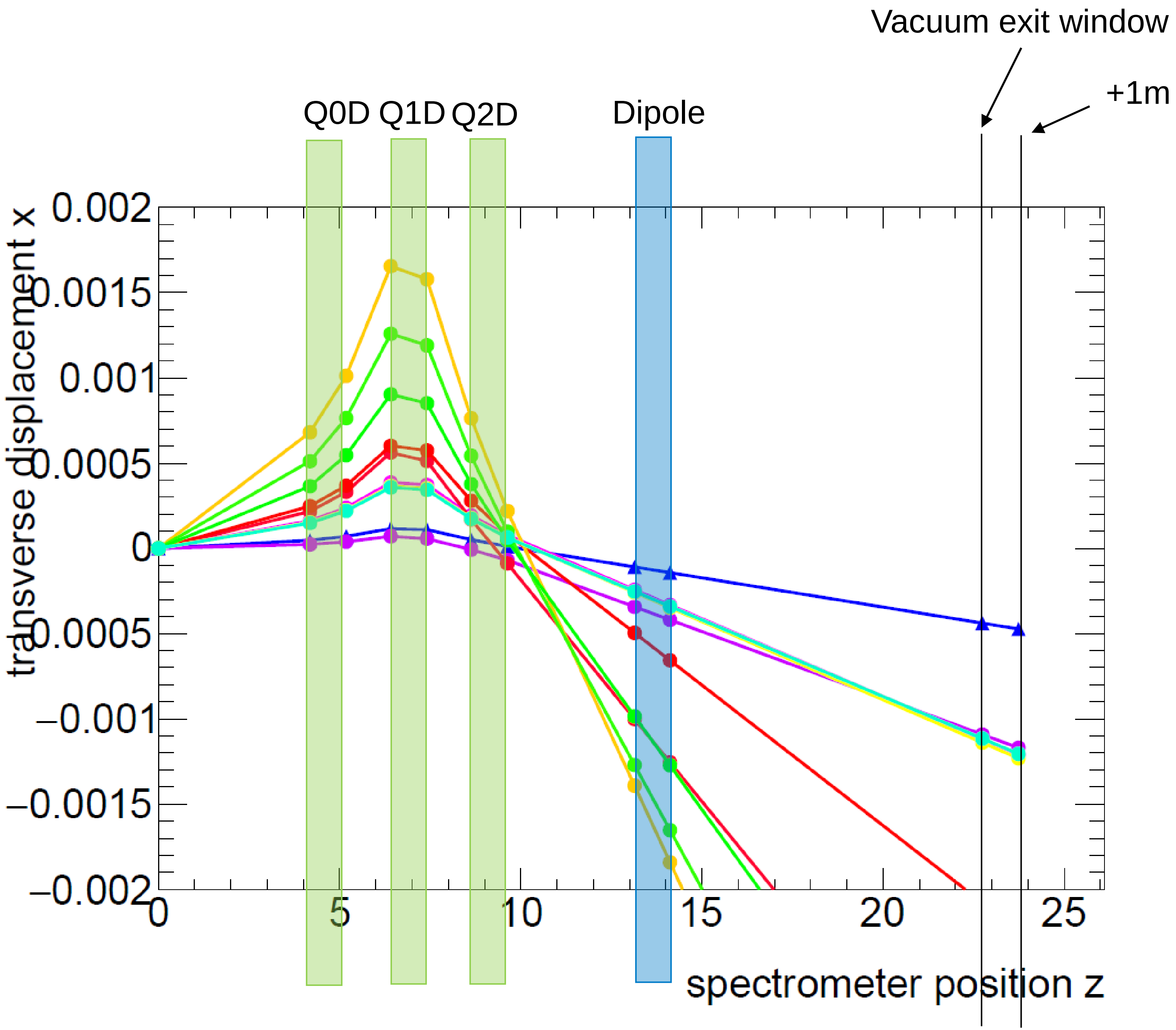
$$x' = x'_0$$

$$y = y_0 - L * \tan\alpha$$

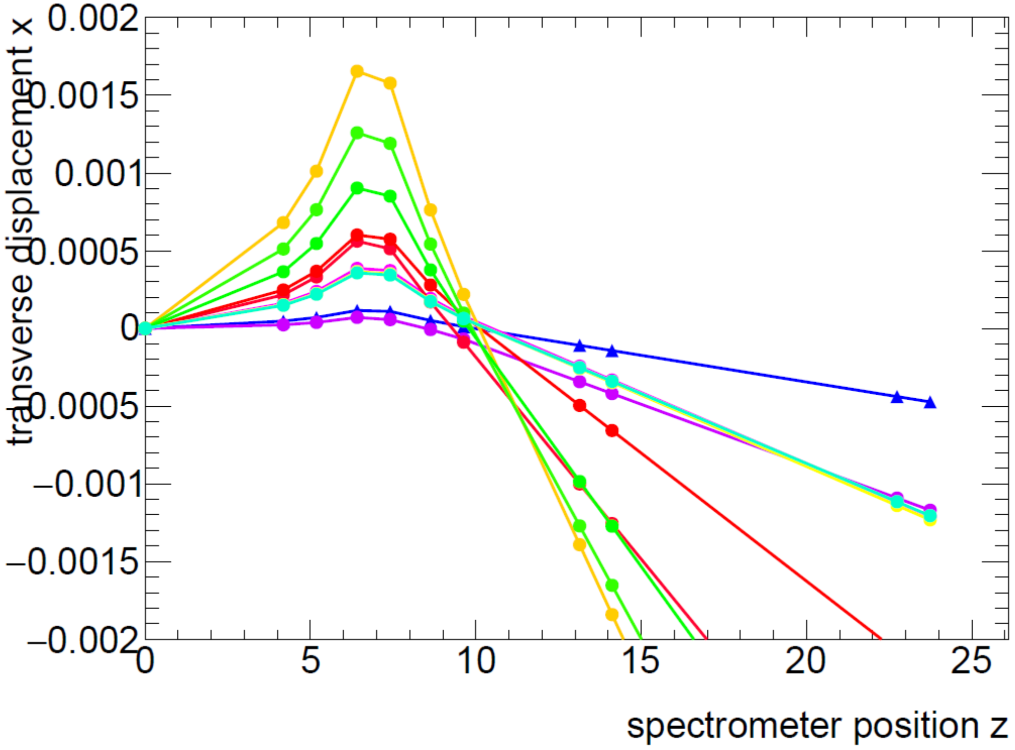
$$y' = y'_0 + \tan\alpha$$

- Dipole: effect of a drift volume in x-direction
- Bending in y-direction

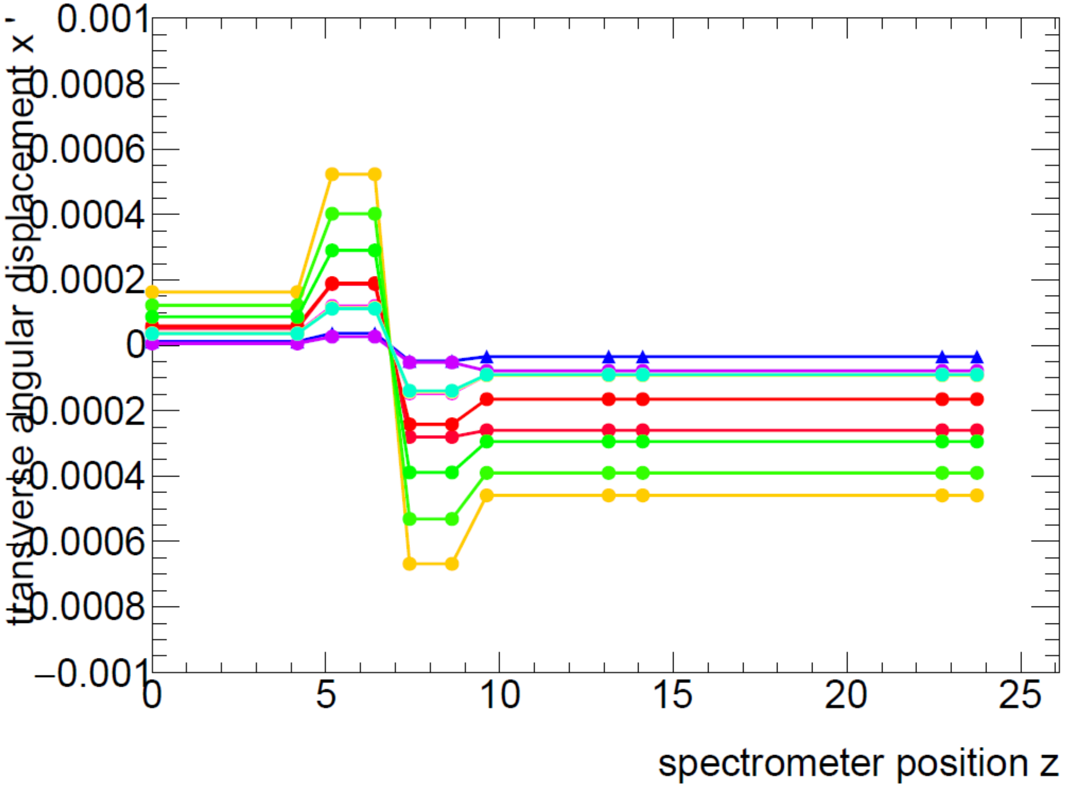
First checks



X-direction

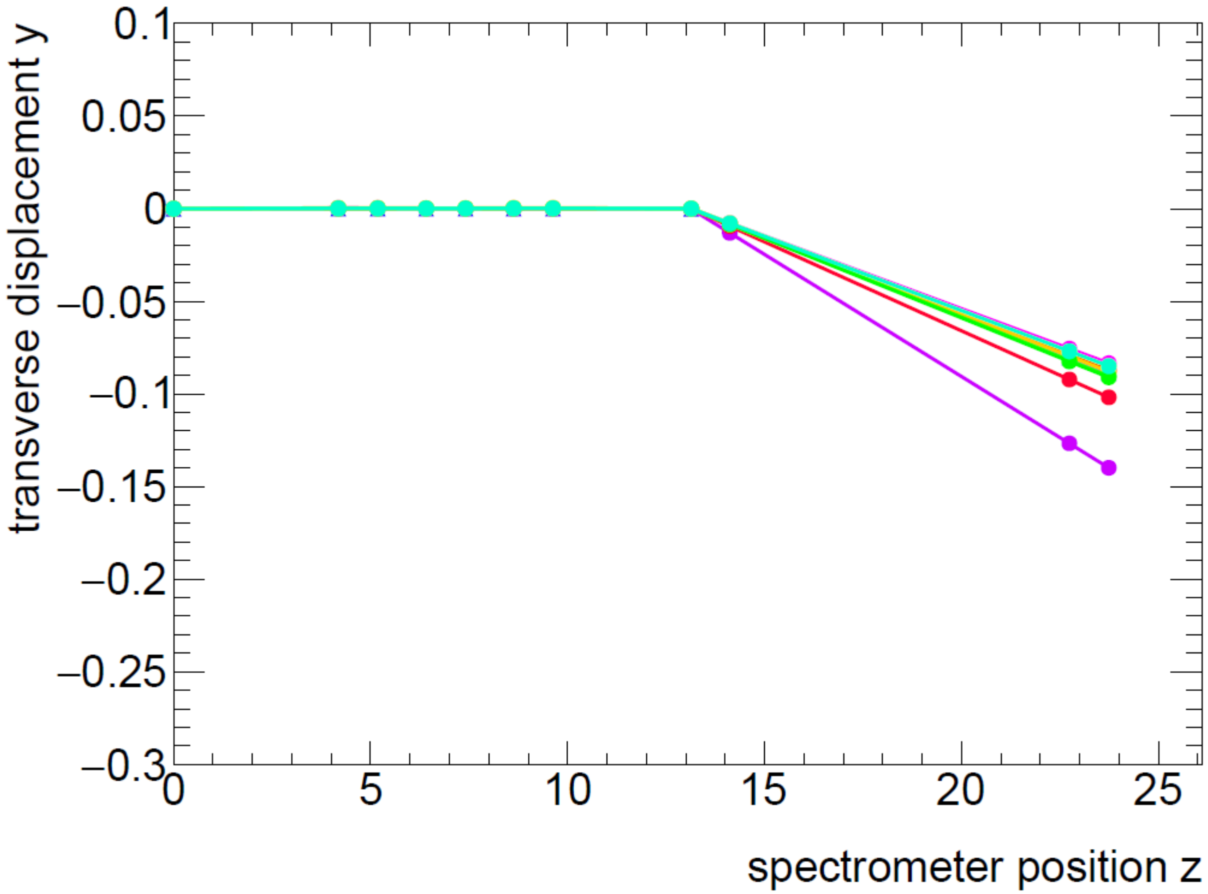


transverse displacement x
0.002
0.0015
0.001
0.0005
0
−0.0005
−0.001
−0.0015
−0.002
0
5
10
15
20
25
spectrometer position z



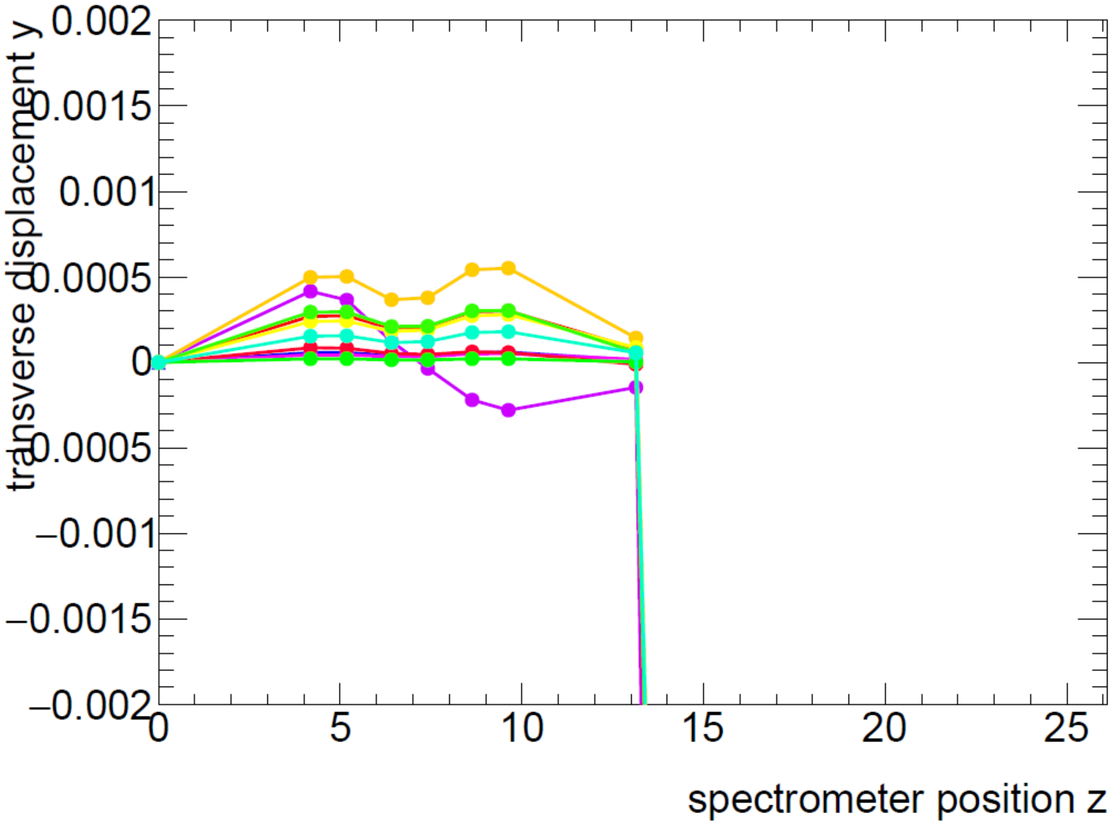
transverse angular displacement x '
0.001
0.0008
0.0006
0.0004
0.0002
0
−0.0002
−0.0004
−0.0006
−0.0008
−0.001
0
5
10
15
20
25
spectrometer position z

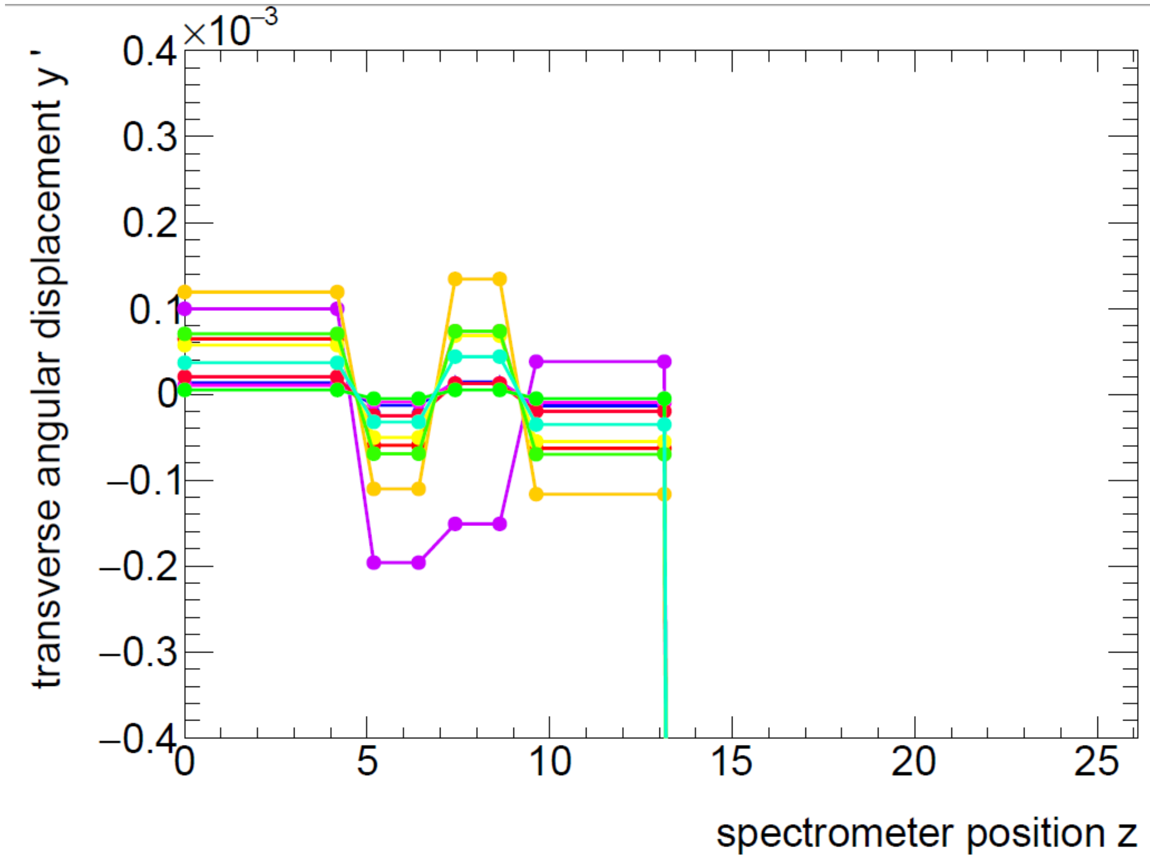
Y-direction



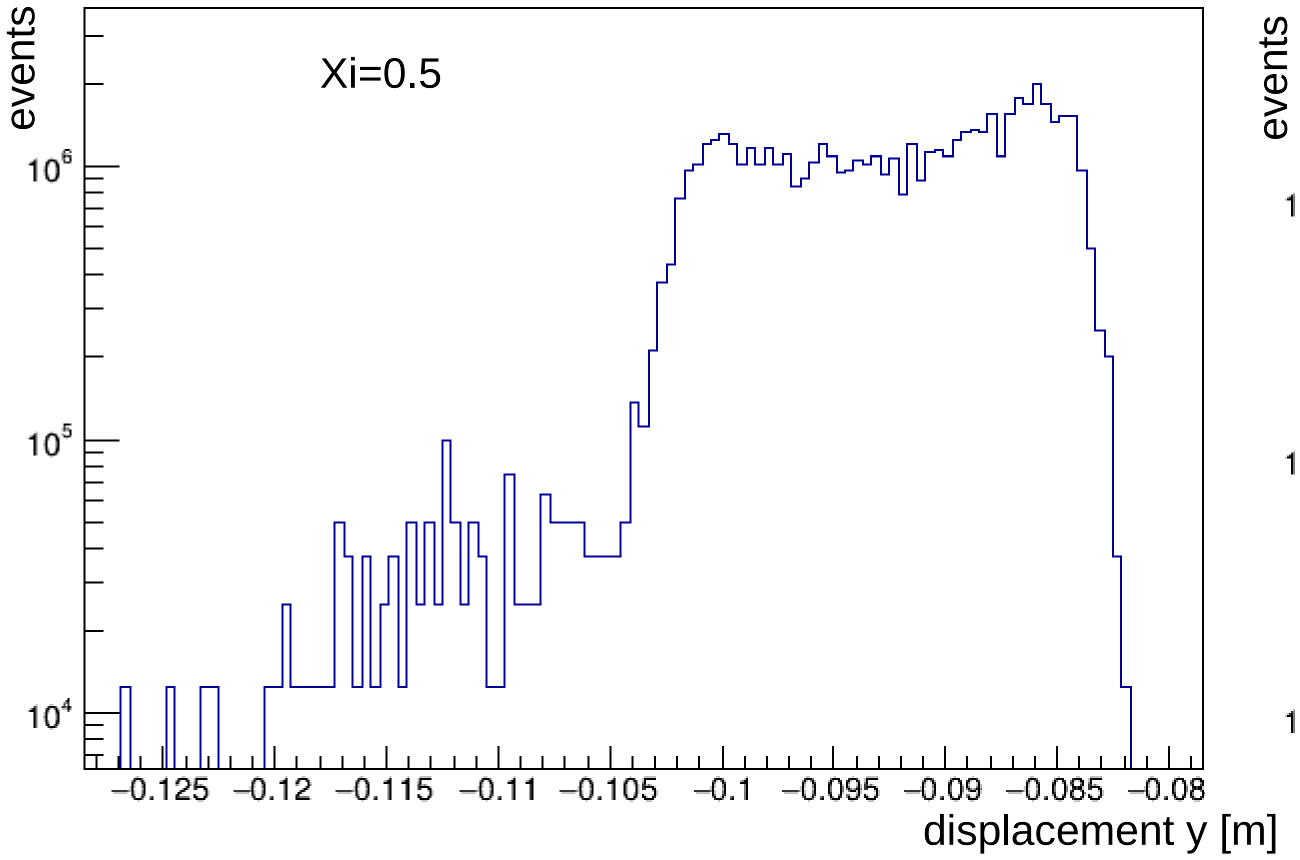
10GeV electrons 7.6cm below beam axis

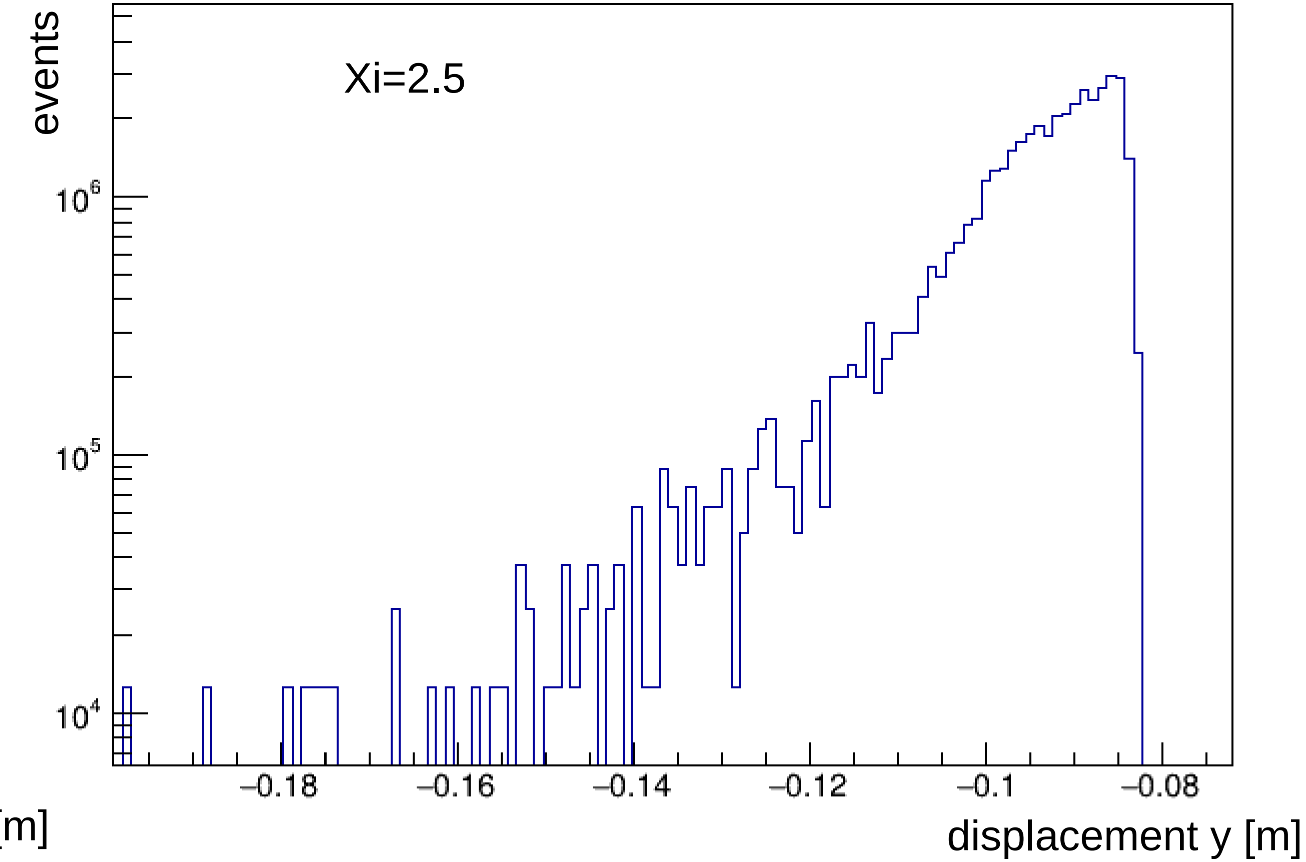
Y-direction ZOOMED





Compton Spectra





- Should be ok to map with 3mm straws