g4hrs tune

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Current and momentum scales for magnets

Current scales

- Septum: field map produced at current density $J_0 = -1320$ A cm^{-2}
- HRS: at this time, no current is associated with quadrupole, dipole fields in `g4hrs`

Momentum scale

- For septum and HRS, choose arbitrary momentum scale of $p_0 = 1$ GeV

$\rightarrow$ Septum field map values B_{xyz} (fixed) are scaled by:

$$B'_{xyz} = \left(\frac{J}{J_0}\right) \times \left(\frac{p}{p_0}\right) \times B_{xyz}$$

$\rightarrow$ HRS field settings $B_0^{i=\text{Q1, Q2, D, Q3}}$ (variable) are scaled by:

$$(B_0^i)' = \left(\frac{p}{p_0}\right) \times B_0^i$$

Tuning procedure

1. Septum tune
   - Vary septum current density J and scattering angle θ_0 to minimize x_{tr} and θ_{tr} at Q1 entrance
   - This determines optimal septum current and angle of "central trajectory"
2. Dipole tune
   - Using central trajectory, vary dipole field setting to minimize x_{tr} at Q3 entrance
3. Quadrupole tunes
   - Vary poletip field value for each quad to minimize $\langle x|\theta_{tg}\rangle$ and $\langle y|\phi_{tg}\rangle$
   - Include penalty for allowing $\langle x|\delta p/p\rangle$ to get too small

Dipole results

Tuning the septum and HRS dipole yielded:

Septum current density	$J = -488.5$ A m^{-2}
Central trajectory angle	$\theta_0 = 5.126^\circ$
Dipole field	$B_0^D = -0.4042$ T

Through septum (at Q1 entrance):

$$y_{tr} = 2.055 \times 10^{-5} \text{ m}$$
$$\phi_{tr} = 7.084 \times 10^{-6}$$

Through dipole (at Q3 entrance):

$$x_{tr} = 6.91 \times 10^{-5} \text{ m}$$
$$\theta_{tr} = 2.22 \times 10^{-4}$$

At focal plane:

$$x_{tr} = 1.871 \times 10^{-3} \text{ m}$$
$$\theta_{tr} = 3.06 \times 10^{-4}$$

Quad results

Tuning the HRS quads yielded following field poletip values and gradients:

$$B_0^{Q1} = +0.140065 \text{ T} \;\rightarrow\; K_1 = +0.93877 \text{ T m}^{-1}$$
$$B_0^{Q2} = -0.212361 \text{ T} \;\rightarrow\; K_2 = -0.70787 \text{ T m}^{-1}$$
$$B_0^{Q3} = -0.330965 \text{ T} \;\rightarrow\; K_3 = -1.10322 \text{ T m}^{-1}$$

Gradient ratio	`g4hrs`	`HRSTrans`
Q2/Q1	0.75404	1.09922
Q3/Q1	1.17517	1.38054
Q3/Q2	1.55850	1.25592

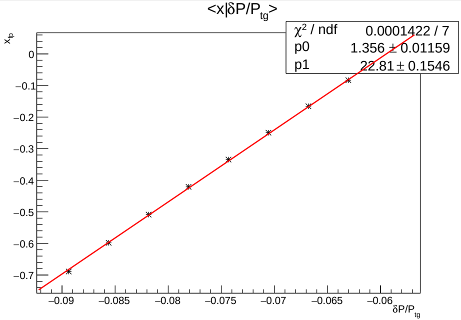
Matrix elements

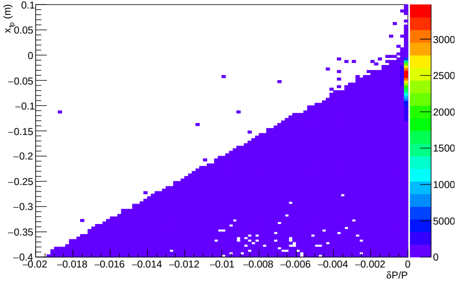
Procedure to obtain matrix elements:

1. Vary $\{x_{tg},\ \theta_{tg},\ y_{tg},\ \phi_{tg},\ \delta p/p\}$ one at a time
2. Look at resulting $\{x_{fp},\ \theta_{fp},\ y_{fp},\ \phi_{fp},\ \delta p/p\}$
3. Linear fit yields first-order matrix element

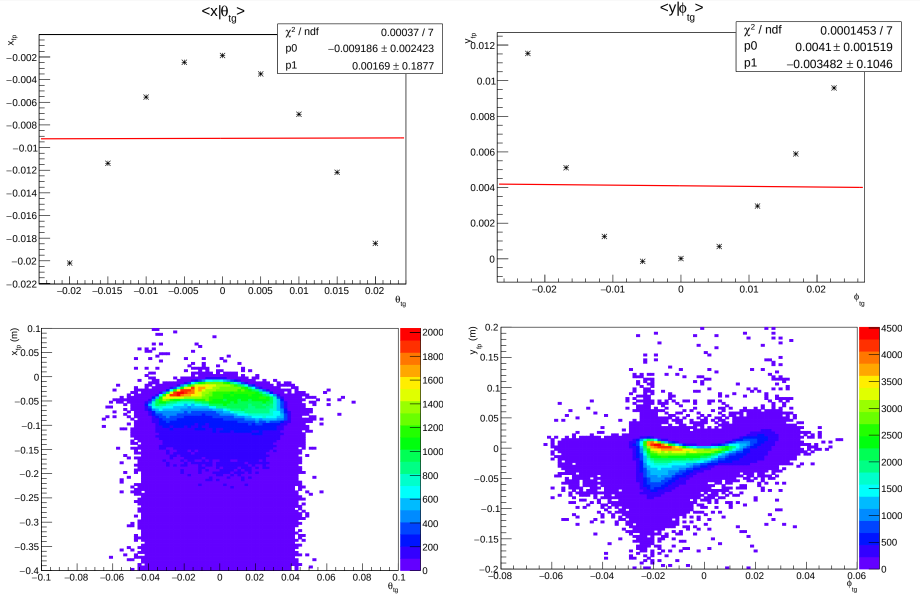
$$
\begin{array}{c} \\ x \\ \theta \\ y \\ \phi \\ \delta p \end{array}
\begin{array}{c}
\begin{array}{ccccc} x_{tg} & \theta_{tg} & y_{tg} & \phi_{tg} & \delta p/p \end{array} \\
\begin{pmatrix}
-2.48 & 0.00169 & -0.000239 & 0.169 & 22.8 \\
-0.287 & -0.404 & 0 & 0.0238 & 3.33 \\
-0.000297 & 0.0342 & 3.28 & -0.00348 & 0.698 \\
0 & 0.0104 & 1.09 & 0.311 & 0.184 \\
0 & 0 & 0 & 0 & 1
\end{pmatrix}
\end{array}
$$

$\langle x|\delta p/p\rangle$

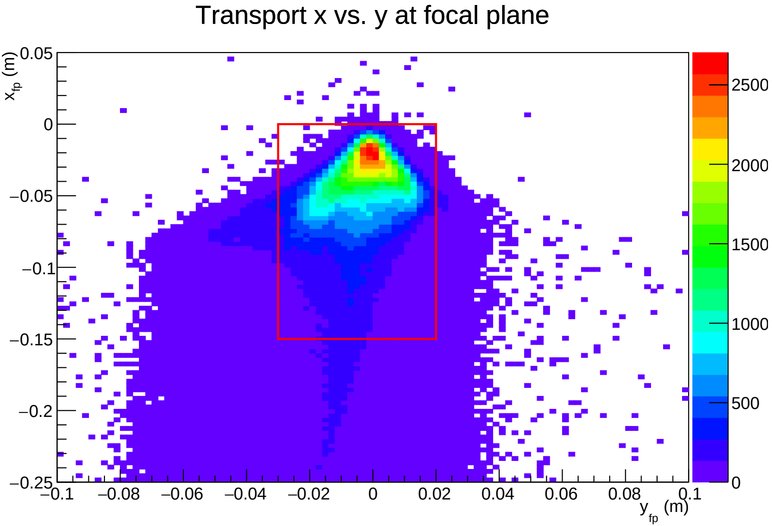




$\langle x|\theta_{tg}\rangle$ and $\langle y|\phi_{tg}\rangle$

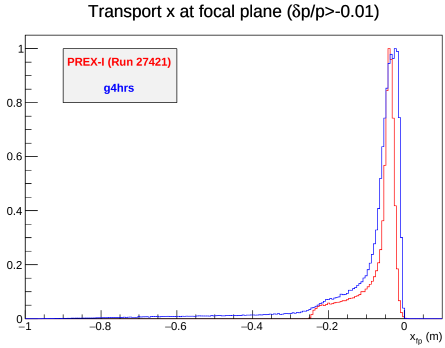


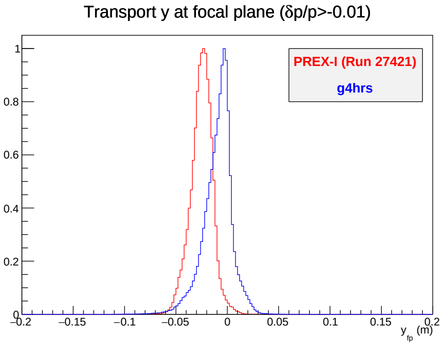
Detector focus



Approximate detector footprint (15 cm x 5 cm) outlined in red

Compare to data





- Focal plane 1.43 m downstream of VDCs
- Overlaid histograms have identical binning, and all histograms are scaled by inverse of max bin content
- PREX-I collimator cut applied to `g4hrs`
- $\delta p/p$ cut in `g4hrs` clearly not reproducing x_{fp} cutoff seen in data

Miscellaneous improvements

- Multiple scattering
  - Multiple scattering angles were being applied to “real” momentum, but particle was being created with “true” momentum (unpolished values from generator)
  - Create particle with “real” momentum to include multiple scattering effects
- Tracking in septum
  - Added additional virtual detectors in parallel world at critical pinch points: $z = 21.3$, 109.5 cm (HCS)
  - Can easily add more planes as things develop (would require rerunning simulation, ≈ 8 hours for 10e6 events)

Summary

- Nominal tune requirements (large $\langle x|\delta p/p \rangle$, small $\langle x|\theta_{tg} \rangle$ and $\langle y|\phi_{tg} \rangle$) have been achieved
- However...
  - Gradient ratios do not match those from `HRSTrans`
  - Certain matrix elements that should vanish are non-zero
  - $\delta p/p$ cut does not truncate x_{fp} distribution as expected
- Bug in simulation? Bug in tuning algorithm?
- Multiple scattering and additional septum tracking detectors added