Spectrometer Optics Calibration for g2p Experiment

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Introduction

• The g2p experiment will measure the proton structure function $g_2$ in the low $Q^2$ region (0.02–0.2 GeV$^2$) for the first time

• Goal: 5% systematic uncertainty when measuring cross section

• Hall A High Resolution Spectrometer (HRS)
  • $10^{-4}$ momentum resolution
HRS Optics

• Optics study:
  • Reconstruct the kinematics variables of the scattered electrons with the tracking information

• Optics Goal:
  • <1.0% systematic uncertainty of scattering angle, which will contribute <4.0% to the uncertainty of cross section
  
  \[ \sigma \sim 1/\sin^4(\theta/2) \]

• The final systematic uncertainty is not sensitive to the uncertainty of the momentum of the scattered electrons
HRS Optics

- HRS has a series of magnets
  - 3 quadrupoles to focus
  - 1 dipole to disperse on momentums
HRS Optics

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- Septa magnet
HRS Optics

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- Septa magnet
- 2.5T/5.0T Target field
HRS Optics

- Optics study will provide a matrix to transform VDC readouts to kinematics variables which represents the effects of these magnets

\[
\begin{pmatrix}
\delta \\
\theta \\
y \\
\phi
\end{pmatrix} = 
\begin{pmatrix}
\langle \delta | x \rangle & \langle \delta | \theta \rangle \\
\langle \theta | x \rangle & \langle \theta | \theta \rangle \\
\langle y | y \rangle & \langle y | \phi \rangle \\
\langle \phi | y \rangle & \langle \phi | \phi \rangle
\end{pmatrix}
\begin{pmatrix}
x \\
\theta \\
y \\
\phi
\end{pmatrix}
\]

First Order Matrix
Angle Calibration

- Angle Calibration:
  - Decide the center scattering angle
  - Calibrate the angle matrix elements

\[ \theta = \arccos \frac{\cos \theta_0 - \phi_{tg} \sin \theta_0}{\sqrt{1 + \theta_{tg}^2 + \phi_{tg}^2}} \]
Angle Calibration

- Angle Calibration:
  - Decide the center scattering angle
  - Calibrate the angle matrix elements

- Decide the center scattering angle

- Direct measurement: \( \sim 1 \text{mrad} \)

- Idea: Use elastic scattering on different target materials (Carbon foil in LHe, or CH\(_2\))

\[
\Delta E' = \frac{E}{1 + \frac{E}{M_1}(1 - \cos \theta)} \quad - \quad \frac{E}{1 + \frac{E}{M_2}(1 - \cos \theta)}
\]

- The accuracy to determine this difference is \(<50\text{KeV} \rightarrow <0.5\text{mrad}\)
Angle Calibration

• Calibrate the matrix elements:
  • Fit with data which we already know the real scattering angle
  • Sieve slit
  • Allow to calculate the scattering angle with geometry

![Diagram of target, sieve slit, and septa with dimensions and labels]

*Dimensions in inches
Angle Calibration

Before Optimize

After Calibration

Resolution (FWHM): ~1.5mrad
Momentum Calibration

- Idea is same as the calibration of the angle matrix element
- Fit with data which we already know the real scattering momentum
- Elastic scattering on Carbon target
- Resolution (FWHM) \(~2 \times 10^{-4}\)
HRS Optics Study

- To include target field
- Sieve slit method is not useful
HRS Optics Study

- To include target field
  - Sieve slit method is not useful
- Idea: separate reconstruction process to 2 parts:
  - Use the no target field result to deal with the reconstruction from VDC to sieve slit
  - Use the field map to do a ray trace of the scattered particle from sieve slit to target
HRS Optics Study

- Use a Monte-Carlo simulation to check this idea
  - Compare the kinematics of the generated electrons and the reconstructed result
  - The result shows a good consistence <1%

![Scattering Angle](image1)

![Relative Momentum](image2)
• Optics study with out target field works well
• Optics study with target field
  • Ideas is tested with simulation and appeared to work
  • Need to check with data
Thanks

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Backups
Experiment Setup

- Hall A High Resolution Spectrometer
  - High momentum resolution: $10^{-4}$ level over a range of 0.8-4.0 GeV/c
  - High momentum acceptance: $|\delta p/p| < 4.5\%$
  - Wide range of angular settings: 12.5°~150° for left arm, 12.5°~130° for right arm
  - Angular acceptance: ±30 mrad (Horizontal) and ±60 mrad (Vertical)