LHRS Analysis for d_2^n

Optics Study

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Outline

1. Optics
   - Coordinate Systems
   - Optimization Matrix
   - Characteristic Plots
2. Summary

Optics (1)

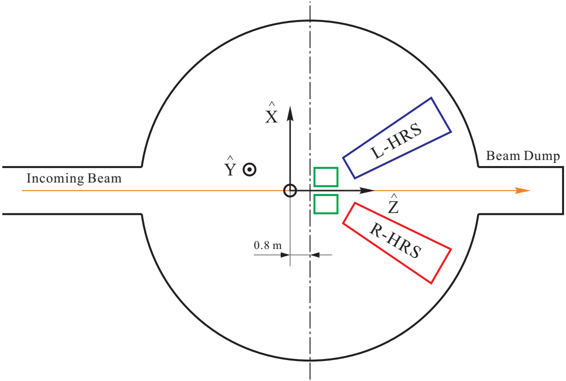
Coordinate Systems

- The optics of the spectrometer serves to transform variables from one set of coordinates to another
- We have five coordinate systems:
  - Hall Coordinate System (HCS)
  - Target Coordinate System (TCS)
  - Detector Coordinate System (DCS)
  - Transport Coordinate System (TRCS)
  - Focal Plane Coordinate System (FCS)

Optics (2)

Coordinate Systems: Hall Coordinate System

- The origin of the HCS is defined by the intersection of the e^- beam and the vertical symmetry axis of the target coordinate system



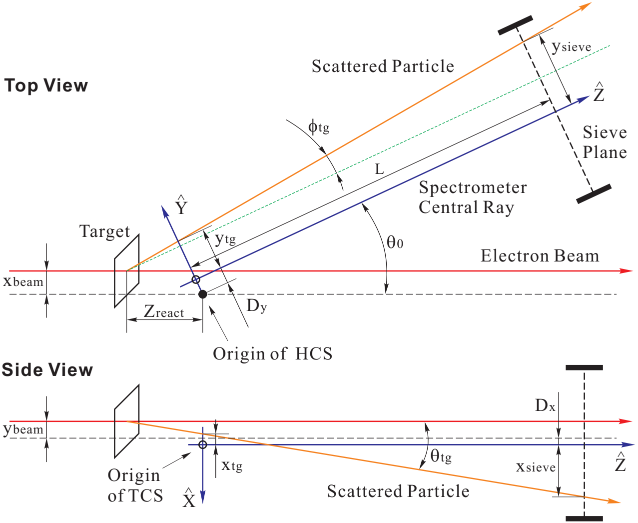
Optics (3)

Coordinate Systems: Target Coordinate System

- The LHRS has its own TCS
- $\hat{z}_{tg}$ is defined by the spectrometer's central ray passing through the center of the sieve collimator
  - The sieve is placed right before the dipole magnet, used for calibration purposes
- Looking along the central ray, $\hat{y}_{tg}$ points to the left, while $\hat{x}_{tg}$ points vertically down
- See next slide for a diagram of the TCS

Optics (4)

Coordinate Systems: Target Coordinate System



Optics (5)

Coordinate Systems: Target Coordinate System

- Careful examination of the previous slide reveals:

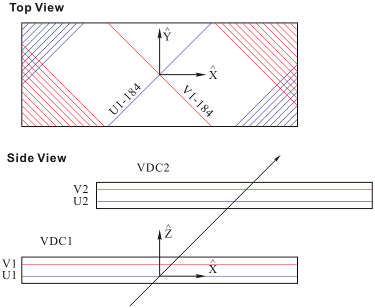
$$
\begin{aligned}
z_{\text{react}} &= -\left(y_{tg} + D_{\text{y}}\right) \frac{\cos \phi_{tg}}{\sin\left(\Theta_0 + \phi_{tg}\right)} + x_{\text{beam}} \cot\left(\Theta_0 + \phi_{tg}\right) \\
y_{tg} &= y_{\text{sieve}} - L \tan \phi_{tg} \\
x_{tg} &= x_{\text{sieve}} - L \tan \theta_{tg} \\
x_{\text{sieve}} &= -\tan \phi_{tg} \frac{z_{\text{react}} \cos \Theta_0}{\cos \phi_{tg}} - y_{\text{beam}} + L \tan \theta_{tg}
\end{aligned}
$$

- These quantities will be important for the check of our current optics matrix, so we list them here

Optics (6)

Coordinate Systems: Detector Coordinate System

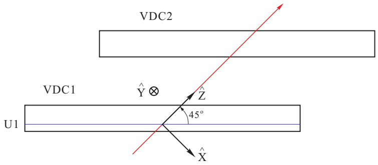
- The intersection of wire $\#184$ of plane u_1 and the perpendicular projection of wire $\#184$ from the v_1 plane forms the origin of the DCS
- $\hat{z}$ points vertically up, with $\hat{x}$ along the (longer) symmetry axis of the lower VDC plane, away from the Hall center



Optics (7)

Coordinate Systems: Transport Coordinate System

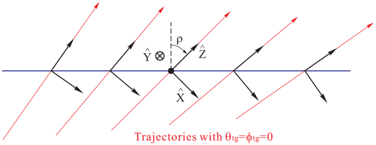
- The TRCS is a rotated coordinate system, with the DCS rotated clockwise about the $\hat{y}$-axis by $45°$
- Ideally, $\hat{z}$ of the TRCS coincides with the central ray of the spectrometer
- Serves as an intermediate stage to get from the DCS to FCS



Optics (8)

Coordinate Systems: Focal Plane Coordinate System

- Another rotated coordinate system
- Due to the focusing of the magnets, particles incident on the detector package at different angles that have the same $|\vec{p}|$ will be focused at the focal plane
- Therefore, the relative momentum $\delta \equiv \Delta p/p = (p - p_0)/p_0$ is a function of only x_{tr} and p_0
- The FCS is obtained by rotating the DCS about its $\hat{y}$-axis through an angle $\rho(x_{tr})$ with the $\hat{z}$-axis parallel to the alertlocal central ray
  - This has the condition $\theta_{tg} = \phi_{tg} = 0$ for a given δ, x_{tr}



Optics (9)

Connecting the Coordinate Systems

- For each event, the two angular coordinates $(\theta_{det}, \phi_{det})$ and two spatial coordinates (x_{det}, y_{det}) are measured at the focal plane (S1)
  - x_{det}, θ_{det} give the position of the particle and the tangent of the angle made by the trajectory along the vertical (dispersive) direction
  - y_{det}, ϕ_{det} give the position of the particle and the tangent of the angle made by the trajectory along the horizontal (lateral) direction
- Corrections to these variables are made to account for any detector offsets from the ideal central ray, which yields the focal plane coordinates $(x_{fp}, \theta_{fp}, y_{fp}, \phi_{fp})$
- The focal plane variables are then used to determine the corresponding target system variables by use of the optics matrix

Optics (10)

Optimization Matrix: First Order

- The optics matrix transforms our variables from the detector system to the target system
  - Allows for the realization of the full potential of the hardware
- To first order, due to the mid-plane symmetery of the LHRS, we have:

$$\begin{pmatrix} \delta \\ \theta \\ y \\ \phi \end{pmatrix}_{tg} = \begin{pmatrix} \langle\delta|x\rangle & \langle\delta|\theta\rangle & 0 & 0 \\ \langle\theta|x\rangle & \langle\theta|\theta\rangle & 0 & 0 \\ 0 & 0 & \langle y|y\rangle & \langle y|\phi\rangle \\ 0 & 0 & \langle\phi|y\rangle & \langle\phi|\phi\rangle \end{pmatrix} \cdot \begin{pmatrix} x \\ \theta \\ y \\ \phi \end{pmatrix}_{fp}$$

Optics (11)

Optimization Matrix: Fourth Order

- The optimization is usually performed to fourth order, using:

$$\begin{pmatrix} \delta \\ \theta \\ y \\ \phi \end{pmatrix}_{tg} = \begin{pmatrix} \langle\delta|x\rangle & \langle\delta|\theta\rangle & \langle\delta|y\rangle & \langle\delta|\phi\rangle \\ \langle\theta|x\rangle & \langle\theta|\theta\rangle & \langle\theta|y\rangle & \langle\theta|\phi\rangle \\ \langle y|x\rangle & \langle y|\theta\rangle & \langle y|y\rangle & \langle y|\phi\rangle \\ \langle\phi|x\rangle & \langle\phi|\theta\rangle & \langle\phi|y\rangle & \langle\phi|\phi\rangle \end{pmatrix} \cdot \begin{pmatrix} x \\ \theta \\ y \\ \phi \end{pmatrix}_{fp}$$

- The explicit equations for each variable take the form:

$$\begin{aligned} \delta &= D_{jkl}\theta^j_{fp}y^k_{fp}\phi^l_{fp} \\ \theta_{tg} &= T_{jkl}\theta^j_{fp}y^k_{fp}\phi^l_{fp} \\ y_{tg} &= Y_{jkl}\theta^j_{fp}y^k_{fp}\phi^l_{fp} \\ \phi_{tg} &= P_{jkl}\theta^j_{fp}y^k_{fp}\phi^l_{fp} \end{aligned}$$

Optics (12)

Optimization Matrix: Fourth Order

- The tensors $D_{jkl}, T_{jkl}, Y_{jkl}, P_{jkl}$ are polynomials in x_{fp}:

$$
\begin{aligned}
D_{jkl} &= C^{D}_{ijkl} x^{i}_{fp} \\
T_{jkl} &= C^{T}_{ijkl} x^{i}_{fp} \\
Y_{jkl} &= C^{Y}_{ijkl} x^{i}_{fp} \\
P_{jkl} &= C^{P}_{ijkl} x^{i}_{fp}
\end{aligned}
$$

  - We sum over repeated indices (pp. 11-12)

Optics (13)

Characteristic Plots

- In order to test our current matrix, we need certain plots to see how ‘aligned’ our coordinates are
- We examine six plots:
  - z_{react}: shows the reaction vertex for each foil from the multi-Carbon foil target is, as compared to the nominal (survey) values
  - θ_{tg} vs. ϕ_{tg} for each foil
  - y_{tg} vs. ϕ_{tg} for each foil
  - dp_{kin} for each foil: shows the elastic peak reconstruction when performing a delta (momentum) scan on the Carbon target
  - x_{sieve} vs. y_{sieve}: shows how well the sieve is reconstructed w.r.t. nominal values
  - $p_0(1+\delta)$ for each foil

What's Next?

- Investigate the significance behind a few of the plots I've mentioned (θ_{tg} vs. ϕ_{tg}, y_{tg} vs. ϕ_{tg}, $p_0(1+\delta)$) as the phase space plots seem to be superfluous w.r.t. x_{sieve} vs. y_{sieve}, and the latter being superfluous w.r.t. the dp_{kin} plot...
- Get together needed data (d_2^n/transversity?) and generate the plots mentioned