Precision Measurement of Longitudinal and Transverse Response Functions of Quasi-Elastic Electron Scattering in the Momentum Transfer Range

$0.55 \text{ GeV} / c \leq |\mathbf{q}| \leq 0.9 \text{ GeV} / c$

Huan Yao

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Work support DOE Grant: DE-FG02-94ER40844
**Beam:**
E: 0.4-4.0 GeV
I: 0-50 μA

**Target:**
LH$^2$
LH$^2$+Pb
$^4$He
$^{12}$C
$^{56}$Fe
optics

**Spectrometers:**
$\theta_0$: 15, 60, 90, 120
P$_0$: 0.1-4 GeV/c
VDC
S1, S2
Gas Cerenkov
Nal
Coulomb Sum Rule
E05-110

Sieve Slit Survey \( \rightarrow L \)

Target Survey \( \rightarrow Z_{\text{react}} \)

Spectrometer pointing survey \( \rightarrow D_x \, D_y \)

Sieve and Spectrometer survey \( \rightarrow x_{\text{sieve}} \, y_{\text{sieve}} \)

HRS Sieve Hole Pattern \( \rightarrow x_{\text{sieve}} \, y_{\text{sieve}} \)

Harp scan \( \rightarrow \) BPM constants \( \rightarrow x_{\text{beam}} \, y_{\text{beam}} \)
\[ L \]
\[ Z_{\text{react}} \]
\[ D_x \quad D_y \]
\[ x_{\text{sieve}} \quad y_{\text{sieve}} \]
\[ x_{\text{beam}} \quad y_{\text{beam}} \]

\[ \phi_{tg} = \frac{y_{\text{sieve}} + D_y - x_{\text{beam}} \cos(\theta_0) + z_{\text{react}} \sin(\theta_0)}{L - z_{\text{react}} \cos(\theta_0) - x_{\text{beam}} \sin(\theta_0)} \]

\[ \theta_{tg} = \frac{x_{\text{sieve}} + D_x + y_{\text{beam}}}{L - z_{\text{react}} \cos(\theta_0) - x_{\text{beam}} \sin(\theta_0)}. \]

\[ \theta_{\text{scat}} = \arccos\left(\frac{\cos(\theta_0) - \phi_{tg} \sin(\theta_0)}{\sqrt{1 + \theta_{tg}^2 + \phi_{tg}^2}}\right) \]

\[ p(M, \theta) = E' = \frac{E}{1 + E/M(1 - \cos(\theta))} \]

\[ d\rho_{\text{kin}} = dp - \frac{p(M, \theta_{\text{scat}}) - p(M, \theta_0)}{p_0}. \]
First-Order

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

Expansion

\[
\begin{align*}
\delta &= \sum_{j,k,l} D_{jkl} \theta_{fp}^{j} y_{fp}^{k} \phi_{fp}^{l}, \\
\theta_{tg} &= \sum_{j,k,l} T_{jkl} \theta_{fp}^{j} y_{fp}^{k} \phi_{fp}^{l}, \\
y_{tg} &= \sum_{j,k,l} Y_{jkl} \theta_{fp}^{j} y_{fp}^{k} \phi_{fp}^{l}, \\
\phi_{tg} &= \sum_{j,k,l} P_{jkl} \theta_{fp}^{j} y_{fp}^{k} \phi_{fp}^{l},
\end{align*}
\]

\[
D_{jkl} = \sum_{i=0}^{m} C_{ijkl}^{D} x_{fp}^{i}.
\]
Coulomb Sum Rule
E05-110

Software Package:

ROOT v5.18---base package for analyzing data
Hall A analyzer v1.4.12---analyzer package for Hall A experiment
tree2ascii tool v1.1---read data from root file and save to text format
Optimize++ v1.3---optimization code

http://hallaweb.jlab.org/root/index.html
Coulomb Sum Rule
E05-110

Analyzer:
Replay raw data
get root file

Analyzer:
Make graphic cut
to choose data for
each hole for each foil

tree2ascii:
use graphic cut and
momentum cut to
generate input file for
optimization

Optimizer++:
Read survey info
and input file to
generate optimized optics
matrix

Analyzer:
Replay raw data
get root file
and check result
Coulomb Sum Rule
E05-110

Physics
Optics
Future
Coulomb Sum Rule
E05-110

Physics
Experiment
Optics
Future
Issue: For right arm, only 1.1GeV optics can be optimized because it is surveyed, other energy setting is not. For left arm, none can be optimized because even for 1.1GeV, the beam readout is totally wrong.

Solution: For right arm, use 1.1GeV optimized optics to get mispoint for high energy (>1GeV). Then use same optics to get mispoint to make sure the central foil is in agreement with data for low energies (739 646 399 MeV), try to work out another optics. For Left arm, still working on it.
Coulomb Sum Rule
E05-110
Coulomb Sum Rule
E05-110

\[ \Delta \phi \text{ vs } \phi_{fp}, x_{fp}, \theta_{fp}, y_{fp} \]

\[ \Delta y \text{ vs } \phi_{fp}, x_{fp}, \theta_{fp}, y_{fp} \]

739_R_with_1102_optics (wrong)
Coulomb Sum Rule
E05-110

\[ \Delta \phi \text{ vs } \phi_{fp}, x_{fp}, \theta_{fp}, y_{fp} \]

\[ \Delta y \text{ vs } \phi_{fp}, x_{fp}, \theta_{fp}, y_{fp} \]

739_R_with_low_energy_optics

Physics
Optics
Future
Coulomb Sum Rule
E05-110

Physics
Experiment
Optics
Future

\[ \Delta \phi \text{ vs } \phi_{fp}, x_{fp}, \theta_{fp}, y_{fp} \]

\[ \Delta y \text{ vs } \phi_{fp}, x_{fp}, \theta_{fp}, y_{fp} \]

646_R_with_low_energy_optics
Coulomb Sum Rule
E05-110

$\Delta \phi \text{ vs } \phi_{fp}, x_{fp}, \theta_{fp}, y_{fp}$

$\Delta y \text{ vs } \phi_{fp}, x_{fp}, \theta_{fp}, y_{fp}$

$\Delta \theta \text{ vs } \phi_{fp}, x_{fp}, \theta_{fp}, y_{fp}$

399_R_with_low_energy_optics
Coulomb Sum Rule
E05-110

Simulation Procedure

Generate
\(x_{tg}, y_{tg}, \theta_{tg}, \phi_{tg}, dp\)

Energy loss and multiple scattering due to materials between target and Q1 entrance

Back to target to get new
\(x_{tg}, y_{tg}, \theta_{tg}, \phi_{tg}\)

J.LeRose forward matrix

Test if valid at Q1, Q2, Dipole, Q3 along the trajectory

Get focal plane variables

J.LeRose backward matrix

Reconstruct target variables

Physics
Experiment
Acceptance
3925: Carbon Left, 60 deg, 739MeV beam, Momentum 539MeV with new code
3927: LH2, 60 deg, 739MeV beam, Momentum 539MeV with old code
3929: He4, 60 deg, 739MeV beam, Momentum 539MeV with old code
Coulomb Sum Rule

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Hall A Collaboration

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Qiang, Yi
Sulkosky, Vincent

and all people who gave me help
# Jefferson Lab Alignment Group

**Data Transmittal**

**TO:** J.P. Shen, J. Gomez, J. LeRose  
**FROM:** J. Dainberg  
**DATE:** 12 Feb 2006  
**CHECKED:** Qt  
**# 1:** A1706

## Details:

The following results from the left and right spectrometer calibration surveys carried out on the 2nd of July, 2006, and the 6th of February, 2006. The coordinates are given in millimeters and degrees relative to the local lab A frame and reading with Y along the beam, X to the beam left, and Z up. Measurements are to the up to the next fraction of the calibration.

### JULY 2nd 2006 Survey

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Z</th>
<th>X</th>
<th>Y</th>
<th>Yaw Angle</th>
<th>3D Dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left arm slave s</td>
<td>597.32</td>
<td>-1094.13</td>
<td>-0.12</td>
<td>72.124</td>
<td>1162.29</td>
</tr>
<tr>
<td>Left arm drift</td>
<td>598.65</td>
<td>-1038.28</td>
<td>0.55</td>
<td>72.978</td>
<td>1051.06</td>
</tr>
<tr>
<td>Right arm slave s</td>
<td>951.17</td>
<td>-957.67</td>
<td>-0.16</td>
<td>-33.563</td>
<td>1192.48</td>
</tr>
<tr>
<td>Right arm drift</td>
<td>959.01</td>
<td>-916.17</td>
<td>0.13</td>
<td>33.338</td>
<td>1117.56</td>
</tr>
</tbody>
</table>

### FEBRUARY 6th 2006 Survey

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Z</th>
<th>X</th>
<th>Y</th>
<th>Yaw Angle</th>
<th>3D Dist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left arm slave s</td>
<td>146.65</td>
<td>677.50</td>
<td>2.25</td>
<td>33.564</td>
<td>1162.28</td>
</tr>
<tr>
<td>Left arm drift</td>
<td>608.37</td>
<td>633.35</td>
<td>2.32</td>
<td>33.468</td>
<td>1096.95</td>
</tr>
</tbody>
</table>
Below are the results of the recent Hall A target survey. A X is beam left from ideal target, containing a Y Tokamak, and a Z downstream. A Yaw is counter clockwise looking from the beam right, a yaw is counterclockwise looking from the beam right, a pitch is crown view above, and a roll is crown looking from upstream. Values are in millimeters and degrees.

Note: A second survey of the target can while under vacuum revealed movements on the fiducial points of up to 0.50 mm. Therefore, the accuracy of the final positions listed below is estimated to be around 1 millimeter.

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>Z</th>
<th>X</th>
<th>Y</th>
<th>Yaw</th>
<th>Pitch</th>
<th>Roll</th>
</tr>
</thead>
<tbody>
<tr>
<td>Racetrack tgt (top)</td>
<td>0.12</td>
<td>0.03</td>
<td>0.09</td>
<td>-3.65</td>
<td>0.06</td>
<td>0.01</td>
</tr>
<tr>
<td>Rear</td>
<td>0.13</td>
<td>0.14</td>
<td>0.09</td>
<td>-3.61</td>
<td>0.07</td>
<td>0.07</td>
</tr>
<tr>
<td>L2 Target block (top):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L2 Top cell CL</td>
<td>0.43</td>
<td>0.61</td>
<td>0.64</td>
<td>-3.61</td>
<td>0.03</td>
<td>0.12</td>
</tr>
<tr>
<td>L2 Roll, cell CL</td>
<td>0.34</td>
<td>0.16</td>
<td>-3.34</td>
<td>-3.58</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>L3 Target block (bot):</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L3 Top cell CL</td>
<td>0.14</td>
<td>0.29</td>
<td>0.41</td>
<td>-3.61</td>
<td>0.11</td>
<td>0.22</td>
</tr>
<tr>
<td>L3 Roll, cell CL</td>
<td>0.56</td>
<td>0.32</td>
<td>-0.17</td>
<td>-0.66</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>Top lower solid targets:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drift face top sol</td>
<td>0.23</td>
<td>0.21</td>
<td>0.16</td>
<td>-0.61</td>
<td>0.16</td>
<td>0.06</td>
</tr>
<tr>
<td>Drift face bot sol</td>
<td>0.33</td>
<td>0.27</td>
<td>-0.06</td>
<td>-0.61</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>Bot lower solid targets:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drift face top sol</td>
<td>0.51</td>
<td>0.08</td>
<td>0.04</td>
<td>49.35</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Drift face bot sol</td>
<td>0.59</td>
<td>0.12</td>
<td>-0.35</td>
<td>-49.35</td>
<td>0.15</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Jefferson Lab Alignment Group  
Data Transmittal

TO: J. P. Chen, J. Gomez, J. LeRose  
FROM: Chris O'Neil

Below are the results from the left spectrometer survey conducted on 4th October, and the spectrometer survey from the 6th October, 2007. The coordinates of the three points located on the x-axis are given in millimeters relative to the Hall A target and beamline, with +Z along the beam, +X to the beam left, and +Y up. The horizontal offset from each point to a line between the ideal target and the spectrometer's Z axis is also shown.

For the spectrometer glider components, the DX and DY values represent the difference in millimeters from the ideal position of each fiducial, excluding the calormeter which represents the centerline.

RESULTS

The central ray of the spectrometer is at -14.635 degrees. It is missing the defined target center by -1.42 mm upstream, and -0.59 mm vertically (positive = up).

If the offset is corrected by secondary alignment, the spectrometer will be at -14.645 degrees.

<table>
<thead>
<tr>
<th></th>
<th>BPR: 0.136</th>
<th>JDD: 2.01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z (mm)</td>
<td>X (mm)</td>
<td>Y (mm)</td>
</tr>
<tr>
<td>JACK</td>
<td>1082.56</td>
<td>2318.33</td>
</tr>
<tr>
<td>ESPECTX</td>
<td>1358.56</td>
<td>2612.05</td>
</tr>
<tr>
<td>ESPECTY</td>
<td>5409.62</td>
<td>3167.79</td>
</tr>
<tr>
<td>ESPECTZ</td>
<td>5578.31</td>
<td>4144.68</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DX</th>
<th>DY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superharp</td>
<td></td>
</tr>
<tr>
<td>BH1H01A</td>
<td>-0.03</td>
</tr>
<tr>
<td>BH1H01B</td>
<td>0.07</td>
</tr>
<tr>
<td>BH1H01C</td>
<td>0.05</td>
</tr>
<tr>
<td>BH1H01A</td>
<td>-0.89</td>
</tr>
<tr>
<td>BH1H02B</td>
<td>-0.72</td>
</tr>
<tr>
<td>BH1H02C</td>
<td>-0.73</td>
</tr>
<tr>
<td>Cavity BPMs</td>
<td></td>
</tr>
<tr>
<td>BCM1H1B</td>
<td>-0.04</td>
</tr>
<tr>
<td>BCM1H1C</td>
<td>0.10</td>
</tr>
<tr>
<td>BCM1H2A</td>
<td>-0.79</td>
</tr>
<tr>
<td>BCM1H2D</td>
<td>-0.33</td>
</tr>
<tr>
<td>Calorimeter</td>
<td></td>
</tr>
<tr>
<td>MBC1H04</td>
<td>-0.42</td>
</tr>
</tbody>
</table>
HRS Sieve Hole Pattern

25.0 mm

- 12.5 mm

- 2.0 mm

- 4.0 mm

Electron Arm

25.0 mm

- 12.5 mm

- 2.0 mm

- 4.0 mm

Hadron Arm

Thickness = 5 mm

RELATIVE TO THE SPECTROMETER CENTER LINE
LOCATION | Z  | X  | Y  |
Left (electron slit)  | 974 | 1.48 | 2.76 |
Right (hadron slit)  | 1002 | -1.31 | -2.67 |

RELATIVE TO THE HALL A BEAM LINE
LOCATION | Z  | X  | Y  |
Left (electron slit)  | 949 | 213.93 | 2.12 |
Right (hadron slit)  | 977 | -215.76 | -3.19 |

Beam direction

approx 6 mm

survey target

silt

- 6 mm

- survey target

Temple University

Department of Physics
Coulomb Sum Rule
E05-110
Coulomb Sum Rule
E05-110
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E05-110

delta_ytg vs phfp

delta_ytg vs xfp

delta_ytg vs thfp

delta_ytg vs yfp
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Coulomb Sum Rule
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Back
Coulomb Sum Rule
E05-110

![Graphs showing scatter plots for different variables: delta_ytg vs phfp, delta_ytg vs xfp, delta_ytg vs thfp, delta_ytg vs yfp.](image)