Moller Detector Simulation

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Detector Simulation Package

- SVN repository: https://jlabsvn.jlab.org/svnroot/moller12gev/mollersim/branches/MollerDet/
- Based on the Qweak scanner Geant4 simulation package
- For detector study only, not integrated into the main Moller simulation package
- Status and progress: posted on Elog http://ace.phys.virginia.edu/MollerSpectrometer/
Why Utilizing Qweak Scanner Simulation Package

- Similar design: quartz radiator, air-core light guide
- Scanner simulation was well benchmarked against E158 scanner simulation and beam test
- Using the parameter settings of Qweak scanner package to reduce the number of ad-hoc parameters in Moller detector simulation
- Minimizing initial developing work
Example - Benchmark

E158 scanner simulation
(scintillation in air wasn't implemented)

Qweak scanner simulation

Background:
Cerenkov in air

Contribution of scintillation in air

(Figures courtesy Jie Pan)
Example - Test

Qweak scanner cosmic ray test

Qweak scanner beam test

Cosmic ray test and beam test results agree with simulation expectation.
Moller Detector Simulation – Single Detector

- Development of Moller detector simulation: started from a single detector model
- Baseline design, a geometry modification of Qweak scanner detector

**Diagram:**
- **Radiator:** Quartz, wrapped by Millipore paper
- **Light guide:** Alzak aluminum sheet
- **PMT:** Quartz window S20 cathode
- **Scintillation in air**
- **Cerenkov light in quartz and light guide**
- **Electron**
Light Yield Spectrum

- Quartz bar: 25 cm x 5 cm x 2 cm, surface polish quality 99%
- Wrapper: white Millipore paper, reflectivity ~ 90%
- Air-core light guide: 60 cm long, trapezoid shape, Alzak (aluminum) material with surface polish quality 99% and reflectivity 93%
- PMT window: 5 inch diameter, 2 mm thick, quartz
- Photocathode: S20, QE<25%, reflectivity ~25%
- Optical photons: generated from 210 nm to 800 nm

Yield: 10.7 PE, RMS: 4.4 PE
Focal Plane Event Distribution

Hits distribution

Rate distribution

\[ e^+ e^- \rightarrow e^+ e^- \text{ (black)} \text{ and } e^+ p \rightarrow e^+ p \text{ (red)} \]

(Figures taken from proposal)
Recall – Conceptual Design

- looking downstream
- 7 sectors
- radial binning (rings)
- azimuthal binning

View of Detector Rings
Simulation - Moller Detector Array

isotropic view  front view  side view

Radial location of quartz radiators:

<table>
<thead>
<tr>
<th>Radius Range</th>
<th>Super-elastic</th>
<th>E-p Events</th>
<th>E-p Tail</th>
<th>E-e Events</th>
<th>E-e Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>R = 57.5-62.5 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R = 62.5-77.5 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R = 77.5-87.5 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R = 87.5-102.5 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R = 102.5-112.5 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Proposal</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiator shape</td>
<td>rectangular(e-p) &amp; rhomboidal(e-e)</td>
</tr>
<tr>
<td>Radiator size</td>
<td>Segmented radially, 5 cm (H) x 2 cm (T), length 11 to 25 cm (increases with radius)</td>
</tr>
<tr>
<td>PMT</td>
<td>3” PMT with UV glass windows</td>
</tr>
</tbody>
</table>
Moller Detector Array

- Ring 5 is a duplicated e-e ring to test e-e ring at different z-locations
- Proposal suggests: slightly overlap adjacent radiators to avoid missing tracks
- will try both trapezoid radiator and overlapping
Close-up Look

- Wrapping quartz radiator with reflection material could increase 10 – 15% light yield (from E158 and Qweak scanner simulation).

- Additional reflector section could also increase light yield if its geometry were optimized.

- We should think about the engineering difficulties of making and mounting these components.
# Light Yield - Current Design

(8 GeV electrons, normal incident onto detector centre)

<table>
<thead>
<tr>
<th># Ring</th>
<th>Type</th>
<th>Radiator Radial Location</th>
<th>Quartz Radiator Size (L x H x T) (cm)</th>
<th>Total Length of Light Guide</th>
<th># of PE Yield +/- RMS (no reflector)</th>
<th># of PE Yield +/- RMS (with reflector)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>super-elastic</td>
<td>60 cm</td>
<td>12.9 x 5 x 2</td>
<td>58 cm</td>
<td>20.3 +/- 7.2</td>
<td>32.9 +/- 9.8</td>
</tr>
<tr>
<td>1</td>
<td>e-p</td>
<td>70 cm</td>
<td>14.0 x 15 x 2</td>
<td>43 cm</td>
<td>16.2 +/- 6.4</td>
<td>23.3 +/- 7.9</td>
</tr>
<tr>
<td>2</td>
<td>e-p tail</td>
<td>82.5 cm</td>
<td>17.4 x 10 x 2</td>
<td>33 cm</td>
<td>21.2 +/- 5.4</td>
<td>21.0 +/- 6.3</td>
</tr>
<tr>
<td>3</td>
<td>e-e</td>
<td>95 cm</td>
<td>19.6 x 15 x 2</td>
<td>18 cm</td>
<td>24.3 +/- 8.8</td>
<td>19.9 +/- 9.0</td>
</tr>
<tr>
<td>4</td>
<td>e-e tail</td>
<td>107.5 cm</td>
<td>23.0 x 10 x 2</td>
<td>8 cm</td>
<td>31.6 +/- 6.8</td>
<td>26.7 +/- 9.3</td>
</tr>
<tr>
<td>5</td>
<td>duplicated e-e</td>
<td>95 cm</td>
<td>19.6 x 15 x 2</td>
<td>18 cm</td>
<td>32.0 +/- 19.1</td>
<td>26.8 +/- 15.0</td>
</tr>
</tbody>
</table>

- Larger than 15 PE in general
- Need geometry optimization to maximize light yield and minimize RMS width
- Large RMS due to shower and scintillation in air
Leakage Background

Number of PMT-Has-Been-Hit when shooting 1000 electrons on detector #0

Y-axis indicates how many times a PMT produces non-zero photo-electrons

PMT ID:
- 0 – 27 Super-elastic
- 28 – 55 e-p
- 56 – 83 e-p tail
- 84 – 111 e-e
- 112 – 139 e-e tail
- 140 – 167 e-e

- PMT#0 had ~1000 times of PMT-Has-Been-Hit, as expected.
- Other PMTs also got many times of PMT-Has-Been-Hit. These are mostly at 1 - 2 PE level.

Need more detailed study!
Background

Shoot 1000 electrons per detector (8 GeV, normal incident) on detectors 0, 28, 56, 84, 112

ID = 0 (super-elastic)
ID = 28 (e-p)
ID = 56 (e-p tail)
ID = 84 (e-e), 140 (e-e)
ID = 112 (e-e tail)

(no reflector section)

- In counting mode, these low light signal can be discriminated out.
- In current mode, they will show up as significant noise and background

Total #PE vs PMT
Background

Shoot 1000 electrons per detector (8 GeV, normal incident) on detectors 0, 28, 56, 84, 112

- ID = 0 (super-elastic)
- ID = 28 (e-p)
- ID = 56 (e-p tail)
- ID = 84 (e-e), 140 (e-e)
- ID = 112 (e-e tail)

• In counting mode, these low light signal can be discriminated out.
• In current mode, they will show up as significant noise and background
Shield Light-guide?

Lead doughnut (10 cm thick, upstream PMT shield)

Lead rings (2 cm thick) between detector rings to shield light-guides

Shoot 100 electrons per detector on detectors 0, 28, 56, 84, 112

This simple shielding method makes things worse!
Shield Light-guide?

Lead doughnut (10 cm thick, upstream PMT shield)

Lead rings (2 cm thick) between detector rings to shield light-guides

Shoot 100 electrons per detector on detectors 0, 28, 56, 84, 112

Add that lead shielding between rings makes the separation between e-e and e-p envelopes much worse!
Conclusion & To-do's

Conclusion so far:

- Light yield: 15 – 30 PE (without geometry optimization) – **Good!**
- Large RMS width and background – **Bad!**

To-do's:

- Simulate background due to Cerenkov light in air
- Try rhomboidal radiator and tilted rectangular radiator
- Try to radially segment radiator as per proposal
- Optimize radiator thickness and reflector
- Try to fill light guide with non-scintillation gas or vacuum
- Try different detector & light-guide geometries
- Study pre-radiators
- ...