MOLLER/PREX Detector Development

Dustin McNulty
Idaho State University
mcnulty@jlab.org

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Introduction: Integrating detectors for PVeS

- PVES expts measure tiny asymmetries and require large statistical samples—need high luminosity and deadtime-less signal integration

- Over time, high intensity physics frontier pushes to smaller asymmetries thus requiring higher intensities...

- PVeS integrating detectors must meet the challenge of increasing demands on radiation hardness and performance

- We are currently pursuing the use of high-purity thin quartz (Cherenkov medium) coupled to air-core light guide and pmt

- This talk gives current conceptual designs and prototype test results for MOLLER and PREX-II/CREX quartz detectors

- The new Jefferson Lab Hall A luminosity monitor will also be discussed briefly (time permitting)


**MOLLER target, spectrometer, and detectors**  
(Hall A, Jefferson Lab)

\[
\langle A_{\text{pv}} \rangle = 35 \text{ ppb} ; \quad \langle Q^2 \rangle = 0.0056 \text{ GeV}^2
\]

\[
\delta(A_{\text{pv}}) = 0.8 \text{ ppb}
\]

\[
\delta(Q_w^c)/Q_w^e = 2.1\%\text{(stat)} \pm 1.0\%\text{(syst)}
\]

\[
\delta(\theta_w) = 0.00026\text{(stat)} \pm 0.00012\text{(syst)} \sim 0.1\% \text{ precision!}
\]

Motivation: BSM search
MOLLER Integrating Detector Group

Who is involved in detector work (likely incomplete):

- **U. Manitoba:** M. Gericke, J. Mammei, Jie Pan, S. Rahman
- **SBU:** K. Kumar, S. Riordan, Tyler Kunz (?), Yuxiang Zhao
- **ISU:** D. McNulty
- **U. Mainz:** F. Mass, S. Baunack, K. Gerz, D. Becker, T. Jennewein
- **U. Syracuse:** P. Souder
- **JLab:** R. Michaels (DAQ / electronics)
- **Ohio U.:** P. King (DAQ / electronics)
- **W&M:** D. Armstrong, W. Deconinck
MOLLER Integrating Detector Layout and Rates

- Spectrometer separates signal from bkgd and radially focuses at detector plane
- Rates for 11 GeV/75 µA (80% pol.) beam, 1.5m liquid hydrogen target. See fig.
- Six radial rings, 28 phi segments per ring*
- Ring 5 intercepts Moller peak (≈150 GHz), Ring 2 intercepts bkgd "ep" peaks
- 250 quartz tiles: allow full characterization and deconvolution of bkgd and signal processes

* Six radial rings, 28 phi segments per ring
MOLLER Prototype Detector Development

- Two quartz-lightguide configurations under consideration: Straight and Angled
- Spectrosil 2000 quartz (15mm thick), Miro Silver 4270 lightguide, 3 inch PMT
- Lightguide lengths range from 15 to 80 cm
- Prototypes for all six rings tested
- Benchmarked optical G4 Monte Carlo
MOLLER Prototype Detector Beam Tests

- Several beam tests conducted since fall 2013 at MAMI with the P2 collaboration
- What’s been studied: Pk # of PE’s and Resolution
  - Different quartz polishes and thicknesses
  - Different quartz wrappings: Al. mylar, Tyvek,...
  - Different LG materials: UVS, MIRO-silver, ...
  - Beam - quartz position and angle scans
  - Scintillation/Cherenkov bkgds from air in LG
  - Angled vs. Straight configurations

Example QDC spectra from beam studies

- 32% drop in pk brightness

D. McNulty  MOLLER/PREX Detector Development  Sante Fe, NM
Recent Testbeam Results

<table>
<thead>
<tr>
<th>Detector Ring</th>
<th>Moller</th>
<th>Moller</th>
<th>Super-elastic</th>
<th>Super-elastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Config</td>
<td>Angled</td>
<td>Straight</td>
<td>Angled</td>
<td>Straight</td>
</tr>
<tr>
<td>LG length (cm)</td>
<td>35</td>
<td>25</td>
<td>80</td>
<td>56</td>
</tr>
<tr>
<td>Mean (PE’s)</td>
<td>32.9</td>
<td>24.2</td>
<td>20.6</td>
<td>16.2</td>
</tr>
<tr>
<td>RMS (PE’s)</td>
<td>8.45</td>
<td>8.04</td>
<td>8.94</td>
<td>8.3</td>
</tr>
<tr>
<td>Res. (%)</td>
<td>25.7</td>
<td>33.2</td>
<td>43.4</td>
<td>51.2</td>
</tr>
<tr>
<td>Excess Noise (%)</td>
<td>3.2</td>
<td>5.4</td>
<td>9.0</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Excess noise $\equiv \sqrt{1 + \left(\frac{\sigma}{\langle n \rangle}\right)^2} - 1$

- ”Angled” configuration gives better results (a bit surprising)
- Note: ”Straight” config quartz not double bevelled and its LG funnel not optimized for these results. Will repeat test at MAMI next June.
PREX/CREX Experimental Setup in Hall A
(Spectrometer & Detectors)

- PREX: $\langle A_{PV} \rangle = 0.6\,\text{ppm}, \quad \delta(A_{PV}) = 3\% \implies R^Pb_n \sim 1\%$
  $\rightarrow$ 1 GeV beam, $\theta_e = 5^\circ$, $Q^2 \approx 0.009$ GeV, 10% $X_o^{208}$Pb tgt
- CREX: $\langle A_{PV} \rangle = 2\,\text{ppm}, \quad \delta(A_{PV}) = 2.4\% \implies R^Ca_n \sim 0.6\%$
  $\rightarrow$ 2.2 GeV beam, $\theta_e = 4^\circ$, $Q^2 \approx 0.022$ GeV, 6% $X_o^{48}$Ca tgt

- Scattered electrons transported to detector plane quartz; HRS separates elastic and inelastic events — Only elastic events detected
Detector designs: PREX I (ran in spring 2010)

- Conservative design with modest light output per electron
- Used Spectrosil 2000 quartz, UVS LGs, and 2 inch pmts
- $45^\circ$ incident electrons $\Rightarrow$ only get $\sim$half the Cherenkov light cone
- Focal plane elastic-env. footprint (at quartz) is small $\sim$3 by 12 cm$^2$
- Quartz bar dimensions: 15cm long $\times$ 3.5cm wide $\times$ 6(10)mm thick
- Overall performance: $\sim$20 PEs/e$^-$ with 30% relative width
Detector design: PREX II & CREX

- More aggressive design – maximizes light output per electron
- PREX II will run at same kinematics as PREX I ⇒ FP dists same
- CREX kinematics are different ... FP simulations underway
- Major design change: electrons enter quartz at normal incidence
- Quartz - PMT separation is 0cm (instead of 7.7cm for PREX I)
  → Quartz bars are longer...so can use quartz TIR as the light guide
- 45° angle between scattered flux and pmt – reduces Landau tail
- Overall performance: ∼60 PEs/e⁻ with 15% relative width
New (re-designed) Hall A Luminosity Monitor

- 8 quartz Cherenkov detectors with air-core light guides placed symmetrically around beam line 7.5m downstream of target
- Uses 3.3cm long × 2.0cm wide × 1.3cm thick quartz placed 5.5 cm from beamline center ⇒ 0.5° polar angle acceptance
- 40cm Miro-silver 4270 LG, 2 inch PMT with unity gain base
Summary

- MOLLER integrating detector baseline design and performance specs nearly complete

- Plans for MAMI test beam run in June 2016 — should decide on angled or straight config

- General findings:
  - Miro-silver 4270 LG gives best performance
  - Minimum quartz thickness for Moller ring is 15mm
  - Standard optical polish from vendor is good enough
  - Wrapping quartz in Al. mylar $\sim$ doubled light output

- New PREX II and CREX detector designs give 3x better performance as compared to PREX I

- New Hall A Lumi detectors built this fall; installing next week and plans for beam tests in December

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