Blinded by the Light: a Cherenkov Calibration

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What are the form factors for strange mesons?
How accurately does QCD predict hadronic structure?

Meson valence structure $\langle q\bar{q}\rangle$ provides easy testing grounds

Pions have been studied $(u\bar{d})$, however not much is known about strangeness
Scientific Motivation – $p(e,e'K^+)\Lambda,\Sigma^0$

- Coupling constants & form factors measured indirectly
  - “Meson Cloud”
  
  $$|p\rangle = |p\rangle_o + |n\pi^+\rangle + |\Lambda K^+\rangle + \cdots$$

- $\sigma_L \approx \frac{-tQ^2}{(t-m_K^2)^2} \left(g_{K\Lambda p}\right)^2 F_K^2(Q^2)$
Experimental Goals

• Can proton “kaon cloud” be used to extract kaon form factor?

• Can study Λ, Σ⁰ channels

\[
\frac{\sigma_L(\gamma^* p \rightarrow K^+\Sigma^0)}{\sigma_L(\gamma^* p \rightarrow K^+\Lambda)} \propto \frac{g_{K\Sigma p}^2}{g_{K\Lambda p}^2}
\]

• Reveals new flavor degrees of freedom for QCD model building
Experimental Goals

• Can kaon electroproduction reveal transition from hadronic to partonic degrees of freedom?

• Test $Q^2$ dependence of $p(e,e'K^+)$Λ,Σ⁰ cross section

• $\sigma_L \propto Q^{-6}$
• $\sigma_T \propto Q^{-8}$
• As $Q^2$ gets large, $\sigma_L \gg \sigma_T$
Experimental Set-up

- Beam Energy 2.2 - 12 GeV
- Beam Current up to 80 $\mu$A
- $K^+$ & $e^-$ detected in coincidence
  - HMS for $e^-$ detection
    - 10.6° minimum angle
    - 0.9 – 6.9 GeV/c
  - SHMS for $K^+$ detection
    - 5.5° minimum angle
    - 2.6 – 7.1 GeV/c
- LH2 & Al Dummy Target

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Experimental Set-up

• Particle Identification
  • Heavy Gas Cherenkov for **pion/kaon** separation
    • $n = 1.0011$
  • Aerogel Cherenkov for **kaon/proton** separation
    • $n = 1.030, 1.011$
  • Noble Gas Cherenkov for **electron/pion** separation
    • $n = 1.0003$
  • Calorimeter for **electron/hadron** separation
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Detector Calibration

• Separate signal for each PMT to get SPE
Detector Calibration

- Verify calibration with 2\textsuperscript{nd} and 3\textsuperscript{rd} peak’s linearity
Detector Calibration

- Same method can be used to verify PMT gain

Can determine “gain” in number of electrons
Detector Calibration

• Same method can be used to verify PMT gain

<table>
<thead>
<tr>
<th>PMT Number</th>
<th>Previous Measurement</th>
<th>Current Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMT 1</td>
<td>$3.06 \times 10^7$</td>
<td>$1.55 \times 10^7$</td>
</tr>
<tr>
<td>PMT 2</td>
<td>$7.47 \times 10^7$</td>
<td>$4.22 \times 10^7$</td>
</tr>
<tr>
<td>PMT 3</td>
<td>$9.62 \times 10^7$</td>
<td>$5.36 \times 10^7$</td>
</tr>
<tr>
<td>PMT 4</td>
<td>$5.81 \times 10^7$</td>
<td>$3.41 \times 10^7$</td>
</tr>
</tbody>
</table>

• Off by a factor of 2?
  • Signal now passes through a 50:50 splitter
Detector Calibration

- Verify calibration by checking distribution profile

- Fit with sum of two Poison distributions:
  \[ \frac{\mu^x e^{-\mu}}{\Gamma(x + 1)} \]

- Two sources from different focusing?
Particle Identification

- Calibrated HGC and AGC
- Able to perform particle ID based off number of photoelectrons (NPE)
Particle Identification – $p(e,e'K^+)\Lambda$

- Able to identify neutron and $\Lambda$ missing masses

+ : Data

- : Particle ID

- : Simulation
Particle Identification – $p(e, e'K^+)\Lambda$

- Able to identify neutron and $\Lambda$ missing masses

$\begin{array}{c}
\text{Counts} \\
\text{Normalized Mass}
\end{array}$

+ : Data

---

: Particle ID

---

: Simulation
Particle Identification – $p(e,e'K^+){\Lambda}$

- Able to identify neutron and $\Lambda$ missing masses

+ : Data

: Particle ID

: Simulation

Counts

Neutron Mass

$\Lambda$ Mass

Normalized Mass

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Detector Calibration

- Determine efficiency with other detectors

\[
electron\ efficiency = \frac{[\text{calorimeter } e^-][\text{NGC } e^-][\text{HGC } e^-]}{[\text{calorimeter } e^-][\text{NGC } e^-]} \times 100%
\]

\[
pion\ contamination = 1:\frac{[\text{calorimeter } e^-][\text{NGC } e^-][\text{HGC } e^-]}{[\text{calorimeter } \pi^-][\text{NGC } \pi^-][\text{HGC } e^-]}
\]

<table>
<thead>
<tr>
<th>NPE cut on HGC</th>
<th>Electron efficiency</th>
<th>Pion contamination</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>99.97%</td>
<td>1:41</td>
</tr>
<tr>
<td>1.0</td>
<td>99.73%</td>
<td>1:49</td>
</tr>
<tr>
<td>1.5</td>
<td>99.35%</td>
<td>1:64</td>
</tr>
<tr>
<td>2.0</td>
<td>99.02%</td>
<td>1:75</td>
</tr>
</tbody>
</table>
Outlook

- Detector performance can be improved
  - Localized inefficiencies
  - Disagreement with simulation

- Currently testing optical alignment

- Testing new optical configuration to improve performance
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Back up Slides
Experimental Goals

• Rosenbluth Separation to isolate $\sigma_L$

$$2\pi \frac{d^2\sigma}{dt d\phi} = \varepsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\varepsilon (\varepsilon + 1)} \frac{d\sigma_{LT}}{dt} \cos \phi + \varepsilon \frac{d\sigma_{TT}}{dt} \cos 2\phi$$

$$\varepsilon = \left(1 + 2 \frac{(E_e - E_{e'})^2 + Q^2}{Q^2} \left(\tan \frac{\theta_{e'}}{2}\right)^2 \right)^{-1}$$

• Measure cross section at fixed $(W, Q^2, -t)$ at two beam energies
• Simultaneous fit of two $\varepsilon$ values to determine contributions
Experimental Goals

• In quantum theory, form factor is the overlap integral

\[ F_K(Q^2) = \int \varphi_i^*(p) \varphi_f(p + q) dp \]
Experimental Goals

- Can proton “kaon cloud” be used to extract kaon form factor?
- Kaon pole further from kinematically allowed region
- Form factor from Regge VGL model

\[
\sigma_L \approx \frac{-2tQ^2}{(t - m_K^2)^2} k (e g_{K\Lambda p})^2 F_K^2(Q^2)
\]
Experimental Goals

• What $Q^2$ is needed for factorization to apply?

• Nothing is known with strangeness dimension

• Can kaon electroproduction shed light on factorization regime?
Detector Calibration

- Verify calibration by checking distribution profile

- Fit with sum of Poison and Gaussian Distribution

$$\frac{\mu^x e^{-\mu}}{\Gamma(x + 1)} + e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$
Detector Calibration

Operating Pressure for Different Particles in $\text{C}_4\text{F}_8\text{O}$

- **Electron**
- **Proton**
- **Koan**
- **Proton**

Pressure (atm) vs. Momentum (GeV/c)
Detector Calibration

Operating Pressure for Different Particles in C O₂

- Electron
- Positron
- Kaon
- Proton

Pressure (atm) vs. Momentum (GeV/c)
Detector Calibration

NPE in All PMTs with no Detector Cut

NPE in All PMTs with Detector Cut

- Counts
- NPE
- Entries

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Run Conditions

• Run 1583
  • SHMS set to -2.214 GeV with 10 uA beam, HGC filled with 1 atm CO2

• Run 3423
  • SHMS set to +5.05 GeV with 10 uA beam, HGC filled with 1 atm C4F8O