Charged Meson Form Factors At Jefferson Lab Hall C

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Background

- Mesons are particles made up of 2 quarks, of note the Pion (π) is the lightest meson, while the Kaon (K) is the lightest strange meson.

The Form Factor of a particle is defined in Quantum Field Theory as: \( F_\pi(Q^2) = \int \phi_\pi^*(p)\phi_\pi(p+q)dp \) where \( \phi \) is the wave function.

Is an important variable to study as it allows for comparison with theory:

\[
\frac{d\sigma}{d\Omega} \rightarrow |F(q^2)| \leftrightarrow F(q^2) \leftrightarrow \rho(\vec{r}) \leftrightarrow \psi(\vec{r})
\]

Charge Density

Experiment

Comparison

Theory

Dirac\Schrödinger equation
Motivation

This talk covers the Pion-LT and Kaon-LT experiments being done at Jefferson Lab Hall C.

These experiments seek to measure the form factors of the Pion and Kaon which to date have only been measured in the experimentally accessible low $Q^2$ region, and the high $Q^2$ region theoretically accessible with pertubative QCD.

These experiments will measure these form factors in the space between these two regions.

Understanding the form factors of these light mesons will be crucial guidance to theory in this ‘transition’ region.
Since standard $\pi$ and $K$ targets are impossible to obtain due to short half lives, we must scatter off of the virtual $\pi$ (or $K$) cloud inside a nucleon.

Scattering off of the virtual particle now requires a model dependent form factor extraction so from the Born Term Model Obtain:

$$\frac{d\sigma_L}{dt} \propto \frac{-tQ^2}{(t-m^2_\pi)} \ g^2_{\pi NN}(t) \ F^2_{\pi}(Q^2, t)$$

But determining $\sigma_L$ is difficult. (see next slide)

A similar reaction applies to $K$.

- first designated experiment with this technique on $K$
Only 3 of $Q^2$, $W$, $t$, and $\theta_\pi$ independent

Vary $\theta_\pi$ to get multiple values of $t$

Since $\theta_\pi$ non-zero, must obtain $\sigma_{LT}$ and $\sigma_{TT}$ by varying $\phi$ at two values of $\epsilon$

Control of systematic uncertainties critical as:

$$\frac{\Delta \sigma_L}{\sigma_L} = \frac{1}{(\epsilon_1 - \epsilon_2)} \frac{1}{\sigma_L} \sqrt{\Delta \sigma^2_1 + \Delta \sigma^2_2},$$

$$\sigma_1 = \sigma_T + \epsilon_1 \sigma_L$$

$$\sigma_2 = \sigma_T + \epsilon_2 \sigma_L$$
Jlab And Accelerator

- Located in Newport News, Virginia
- 2 Superconducting LINACs configured in “Racetrack”
- Produces continuous $e^-$ beam at 1497MHz
- Capable of 12GeV polarized $e^-$ at up to 200μA
- 4 halls all running unique experiments
  - Capable of running simultaneously
The Hall Contains a target and two detector arms.

- Target can have Liquid H$_2$, Liquid D$_2$, or solid targets
  - High Luminosity of $10^{38}$ cm$^{-2}$s$^{-1}$
- High Momentum Spectrometer (HMS) and Super High Momentum Spectrometer (SHMS):
  - Both arms have 3 Quadrupole and 1 Dipole super conducting magnet
  - Dipole allows studies at specific momenta
  - Both contain similar detector packages that support high rate (<1MHz)

<table>
<thead>
<tr>
<th>Spec</th>
<th>Angle Range</th>
<th>Momentum Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMS</td>
<td>10.5 - 90</td>
<td>0.5 – 7 GeV/c</td>
</tr>
<tr>
<td>SHMS</td>
<td>5.5 - 40</td>
<td>0.5 – 11 GeV/c</td>
</tr>
</tbody>
</table>
## Detectors

<table>
<thead>
<tr>
<th>Detector</th>
<th>Purpose</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerogel Cerenkov</td>
<td>Particle ID, $K^+$/p discrimination</td>
<td>$n = 1.011, 1.015, 1.03, 1.05$</td>
</tr>
<tr>
<td>Heavy Gas Cerenkov (HGC)</td>
<td>Particle ID, Trigger, $\pi^\pm/K^\pm$ discrimination</td>
<td>$C_4F_8O$ – Vary pressure to set $n$ at $K^\pm$ threshold</td>
</tr>
<tr>
<td>Nobel Gas Cerenkov</td>
<td>Particle ID, Trigger. $e^+/\pi^+$ at high momentum</td>
<td>Not used in Kaon-LT, Only in SHMS</td>
</tr>
<tr>
<td>Hodoscopes</td>
<td>Trigger, Time reference, Measure $\beta$</td>
<td></td>
</tr>
<tr>
<td>Drift Chambers</td>
<td>Momentum measurement, Tracking</td>
<td>5mm max. Drift, 300 micron resolution</td>
</tr>
<tr>
<td>Preshower and Shower Counters</td>
<td>Particle ID, Trigger, $e^\pm$ Tagging</td>
<td></td>
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</table>
Unique Particle ID

These detectors have a relatively unique method of particle ID.

- $\pi^\pm$ and $K^\pm$ separated by HGC (here $n = 1.00143$ at 1 atm)
- $K$ and the $p$ separated by the Aerogel Cerenkov (here $n = 1.015$)
- Preshower vs Shower counter separates $\pi^\pm$ from $e^\pm$

The combination of multiple threshold Cerenkov detectors in this way allows for efficient particle ID at our highest rates.
In order to understand systematics the analysis will be iterated multiple times.
Kaon-LT Status

The Kaon-LT experiment has finished taking data in 2018-2019, and analysis is progressing steadily.

First results are expected sometime in the next 2-3 years.

This data will also be used to extract extra \( \pi \) data points!
The first round of data taking finished in Summer 2019.

Another round of data taking is Scheduled for this fall, and a further third round is set to take place sometime 2023.
Recap/Overview

- The Pion and Kaon Form factors are important for understanding QCD in transition region.
- Jefferson Lab Hall C is uniquely poised to perform precision measurement of the form factor.

<table>
<thead>
<tr>
<th>Kaon-LT</th>
<th>Pion-LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data collection finished</td>
<td>Data collection in progress</td>
</tr>
<tr>
<td>Analysis in progress</td>
<td>Set to continue into 2023</td>
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</table>

Stay Tuned
Thank You

Co Authors: G.M. Huber, T. Horn, S.J.D. Kay, A. Usman, R.L. Trotta, M. Junaid, D. Gaskell

Collaborators: P. Markowtiz, P. Stepanov, J. Murphy, C. Yero
Backup
LT Separation extra

\[ \sigma_L \text{ vs } -t \text{ (shape comparison)} \]

\[ \begin{align*}
E_{\text{beam}} &= 10.6 \text{ GeV} \\
Q^2 &= 3.0 \text{ GeV}^2 \\
W^2 &= 3.14 \text{ GeV}^2 \\
\theta_{\text{SHMS}} &= 12.42 \\
\theta_{\text{SHMS}} &= 9.42 \\
\theta_{\text{SHMS}} &= 6.65
\end{align*} \]
PID example

NPE in SHMS Aerogel and Heavy Gas

Normalized HMS Calorimeter Energy vs Cherenkov

Placed cut
Reaction Clarified
Missing Mass