Electroproduction of $\Lambda(1405)$

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Outline

1 Motivation

2 Data Processing

3 Acceptance Correction and Fitting

4 Summary and References
Motivation

Reaction

$\Lambda (1405)$ From PDG

- $e^- p \rightarrow e^- K^+ \Lambda (1405)$
- $I(J^P) = 0(\frac{1}{2}^-)$
- Mass 1406 MeV, full width 50 MeV
- Decay 100% $\Sigma \pi$
- Three charge modes: $\Sigma^+ \pi^-$, $\Sigma^- \pi^+$, $\Sigma^0 \pi^0$
Two poles are at 1390+66i and 1426+16i [1].
Different Coupling

Fig. 4. The $\pi \Sigma$ mass distributions with $I = 0$ constructed from the $\bar{K}N \rightarrow \pi \Sigma$ and $\pi \Sigma \rightarrow \pi \Sigma$ amplitudes. The solid and dashed lines denote $|T_{\bar{K}N \rightarrow \pi \Sigma}|^2 q_{\pi}$ and $|T_{\pi \Sigma \rightarrow \pi \Sigma}|^2 q_{\pi}$, respectively. Units are arbitrary.

Two poles couple differently with $\pi \Sigma$ and $\bar{K}N$ [1].
Latest Results

Lineshapes of different charge channels [2].
Data Set

- E1F data set from Hall B in JLab
- Electron beam with 5.5 GeV
- Weak torus field (I=2250 A) for better acceptance
- $K^+$ skim
Event Selection

Decay mode: $\Sigma^+\pi^-$
Final particles: $e^-K^+p\pi^-$ with $\pi^0$ missing
Q2 Distribution

Λ (1520) as a reference
Simulation and Mix

Simulation

- Non-resonance background
  \[ e^- p \rightarrow e^- K^+ \Sigma^+ \pi^- \]

- \( K^* \) production
  \[ e^- p \rightarrow e^- K^{*0} \Sigma^+ \rightarrow e^- K^+ \pi^- \Sigma^+ \]

Mix of two channels

The ratio of the two channels are determined by matching simulation with data.
Comparison of Simulation

- Data Processing
- Simulation and Background
Mixture of Two Channels

- Invariant mass square of $K^+\pi^-$
- Black:E1F data points
- Red:overall fit
- Blue:component of non-resonance production
- Green:component of $K^*$ production
- Ratio:0.137
\( \Sigma^*^0 \) Contamination

- \( \Sigma^*^0 \) can decay into \( \Sigma^+ \pi^- \) too
- Extract yield from the \( \Lambda \pi \) decay mode
- Scale the yield into the \( \Sigma^+ \pi^- \) mode
- Both \( \Sigma \pi \) and \( \Lambda \pi \) modes have the final particles \( e^- K^+ p \pi^- \)
- Conclusion is that little contamination from \( \Sigma^*^0 \)
3D Acceptance Correction

Acceptance Calculation

- Non-resonance channel $K^+ \Sigma^+ \pi^-$ is used to calculate acceptance
- Raw and simulated data are binned in $Q^2$ (1.0 - 3.0 GeV$^2$), $W$ (1.5 - 3.5 GeV) and $\cos(\Theta_K)$ in center-of-mass frame
- Data in low-acceptance areas are dropped (16 out of 9K events)
Lineshape at High $Q^2$

Acceptance-corrected yield in $Q^2$ from 1.5 to 3.0 GeV$^2$
Acceptance-corrected yield in $Q^2$ from 1.0 to 1.5 GeV$^2$
Brief

- Data is acceptance corrected
- Background is interpreted as mixture of two channels
- Lineshape in Λ (1405) region looks different from one resonance
- Lineshape looks dependent on $Q^2$
Lineshape and Electroproduction of Λ (1405)

Acceptance Correction and Fitting

Fit the Lineshape

Two Pole Fitting

- Black: acceptance-corrected data
- **Yellow: background** from mixture of two simulated channels
- Green: simulated Λ (1520)
- Blue: two relativistic Breit-Wigner functions

Model:
- $1.426 \pm 0.016$
- $1.390 \pm 0.066$

Fitting results:
- Mean: 1.422, 1.393
- Width: 0.016, 0.10
- Left top: $Q^2$ from 1.0 - 3.0 GeV$^2$
- Right top: $Q^2$ from 1.4 - 3.0 GeV$^2$
- Left bottom: $Q^2$ from 1.8 - 3.0 GeV$^2$
- Right bottom: $Q^2$ from 2.2 - 3.0 GeV$^2$
Comparison with other choices

- Left top: fitting with two relativistic Breit-Wigner functions
- Right top: fitting with simulation with PDG values
- Bottom: fitting with one relativistic Breit-Wigner function
**Comparison of different fits**

<table>
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<tr>
<th>Low limit of $Q^2$</th>
<th>High limit of $Q^2$</th>
<th>two-pole fit</th>
<th>PDG value</th>
<th>one-pole fit</th>
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Lineshape and Electroproduction of $\Lambda$ (1405)

- Acceptance Correction and Fitting
- Other Choices

Reduced $\chi^2$ of Another Loop

Comparison of different fits

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Amplitudes are in relativistic Briet-Wigner form [3] and an overall relative phase is fitted:

\[
BW(m)_{1420} = \frac{\sqrt{mm_{1420}\Gamma_{1420}(q)}}{m^2 - m_{1420}^2 - im_{1420}\Gamma_{1420}(q)}
\]

\[
BW(m)_{1390} = Ae^{i\phi} \frac{\sqrt{mm_{1390}\Gamma_{1390}(q)}}{m^2 - m_{1390}^2 - im_{1390}\Gamma_{1390}(q)}
\]
Lineshape and Electroproduction of Λ (1405)

Acceptance Correction and Fitting

Amplitude Fitting

Fitting

**RooPlot of Missing mass of eK**

$Q^2$: 1.0 - 3.0 GeV$^2$ phase: 24.89° ± 6.60°

$Q^2$: 1.4 - 3.0 GeV$^2$ phase: 30.73° ± 12.55°

$Q^2$: 1.8 - 3.0 GeV$^2$ phase: 24.57° ± 6.50°

$Q^2$: 2.2 - 3.0 GeV$^2$ phase: 27.41° ± 14.19°
Summary

- Lineshape of $\Lambda (1405)$ is not consistent with PDG values
- Lineshape of electroproduction varies with $Q^2$
- Two-pole physics nature of $\Lambda (1405)$ is the best fit with data
References

D. Jido et al


Kei Moriya

*PhD Thesis*


R. Schumacher and M. Sargsian


Lineshape and Electroproduction of \( \Lambda (1405) \)

Event Selection

Hyperon Spectrum

\( \Lambda (1520) \) as a reference
Scale Factor

**Λπ mode**
- Σ*^0 decays into Λπ with 87%
- Λ decays into pπ^- with 64%
- Total branching ratio is 56%

**Σπ mode**
- Σ*^0 decays into Σπ with 11.7%
- Σ^+π^- takes half of it
- Σ^+ decays into pπ^0 with 51.6%
- Overall branching ratio is 3%
- Scale Factor is 3/56 = 0.054
Select Λ to clean the data set
Exclusive Channel

Select exclusive $e^- K^+ \Sigma^*^0$ channel
Yield

Exclusive yield on $Q^2$
Example of Fits to Extract Yield

Example of fits at the two lowest $Q^2$ region
Fitting Results of Mean and Width of 1420 Dependence on $Q^2$
Fitting Results of Mean and Width of 1390 Dependence on $Q^2$
Fitting Acceptance-Corrected Yield of 1420 and 1390 Dependence on $Q^2$