Experimental studies of the $\Lambda(1405)$

physics654 – Seminar on exotic multi-quark states

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Motivation

What is special about the $\Lambda(1405)$?

- its mass does not fit well into constituent quark models which do predict baryon masses well for other baryons
- invariant mass distribution (line shape) differs significantly from usual Breit-Wigner shapes
- candidate for an exotic multiquark state (bound system of $\overline{K}N$) since its mass lies just below threshold

There are (very) many different theoretical approaches to explain this behavior
$\rightarrow$ There is need for more experimental data!

some plots/pictures?

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1. Experimental setup

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Continuous Electron Beam Accelerator Facility (CEBAF)

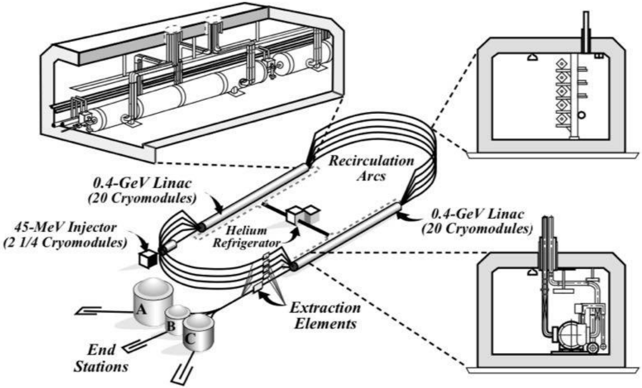

Figure 1: CEBAF layout at Jefferson Lab, [Mecking et al. 2003]

CEBAF Large Acceptance Spectrometer (CLAS)

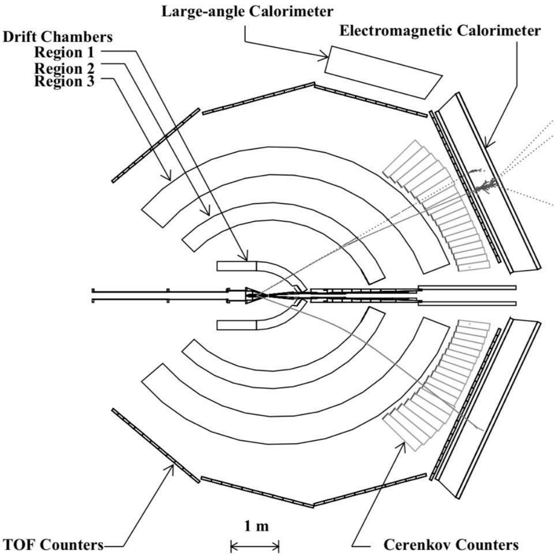

Figure 2: CLAS layout at Jefferson Lab, [Mecking et al. 2003]

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Reaction kinematics

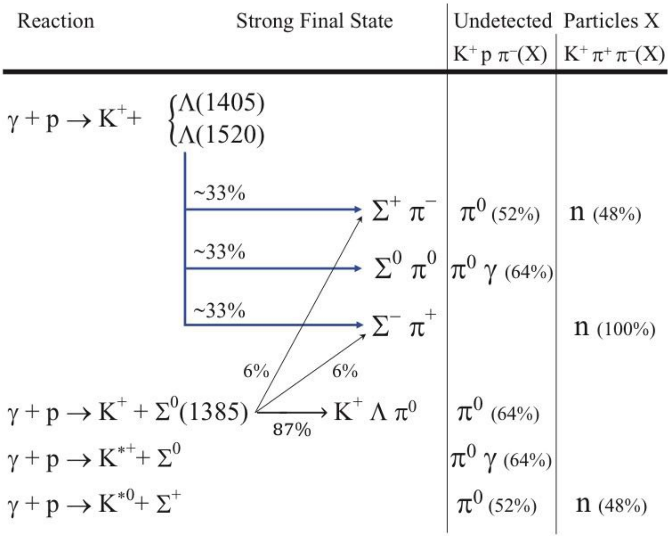

Figure 3: Possible and studied reactions in the analysis of the lineshapes of $\Lambda(1405)$, taken from [Moriya, Schumacher, Adhikari et al. 2013]

Event selection

Inhalt...

Measurements and analysis

Interpretation of the results

1. Experimental setup
2. Line-shape measurement
3. Spin-parity measurement
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Theoretical basics

The $\Lambda(1405)$ is so far (mostly) assumed to have $J^P = \frac{1}{2}^-$, but this has not been determined experimentally

Measuring spin

- consider the strong decay $Y^* \to Y\pi$, with J^P the spin and parity of Y^*
- the $Y\pi$ angular distribution will only depend on J

$$I(\theta_Y) = \text{const.} \qquad J = 1/2$$

$$I(\theta_Y) \propto 1 + \frac{3(1-2p)}{2p+1}\cos^2\theta_Y \qquad J = 3/2,$$

where θ_Y is the polar angle of the decay direction of Y in the Y^* rest frame, p describes the fraction of spin projections along the z axis

- uniform decay pattern is best evidence for spin $J = 1/2$

[Moriya, Schumacher, Aghasyan et al. 2014]

Theoretical basics

Measuring parity

- the key to accessing the parity lies in determining the Polarization transfer to the decay product Y which we will denote $\mathbf{Q}$
- the angular distribution of $\mathbf{Q}$ will only depend on $\mathbf{P}$

$$\mathbf{Q}(\theta_Y) = \text{const.} \qquad J^P = 1/2^-$$
$$\mathbf{Q}(\theta_Y) = -\mathbf{P} + 2(\mathbf{P}\cdot\mathbf{q})\mathbf{q} \qquad J^P = 1/2^+$$

- $\mathbf{Q}$ can be measured from weak decay angular distribution of Y

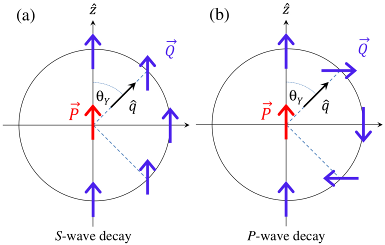

Figure 4: Polarization transfer in the strong decay $Y^* \to Y\pi$, taken from [Moriya, Schumacher, Aghasyan et al. 2014]

[Moriya, Schumacher, Aghasyan et al. 2014 and Ref. therein]

Measurements and analysis

Event selection

- select kinematic region where the $\Sigma\pi$ invariant mass is dominated by the $\Lambda(1405) \rightarrow M_{\Sigma\pi} \in$ 1.30 GeV to 1.45 GeV
- inspect nine bins in energy and angle, namely with CM energy at $2.6, 2.7$ and 2.8 GeV and the three forwardmost kaon angle bins each

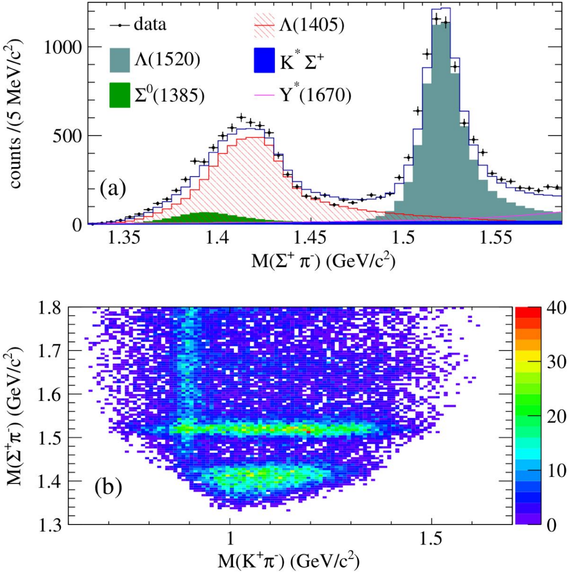

Figure 5: $\Sigma\pi$ and $K\pi$ invariant mass in the vicinity of the $\Lambda(1405)$, taken from [Moriya, Schumacher, Aghasyan et al.

Measurements and analysis

Analysis procedure

- plot the angular distribution of the projections $\cos\theta_\Sigma$ and $\cos\theta_p$ for each bin
- test each spin hypothesis using Monte-Carlo maximum likelihood fits, which employ angular decay probability distributions according to each hypothesis for $\Sigma\pi$ and $p\pi$. From the fit Q_z will be determined
- test parity hypotheses by determining $Q_z(\cos\theta_\Sigma)$
- compare each hypothesis by calculating a χ^2 probability

Result: data is consistent with $J^P = 1/2^-$ but does in principle not rule out $J^P = 3/2^+$. $1/2^+$ and $3/2^-$ can be discarded.

Measurements and analysis

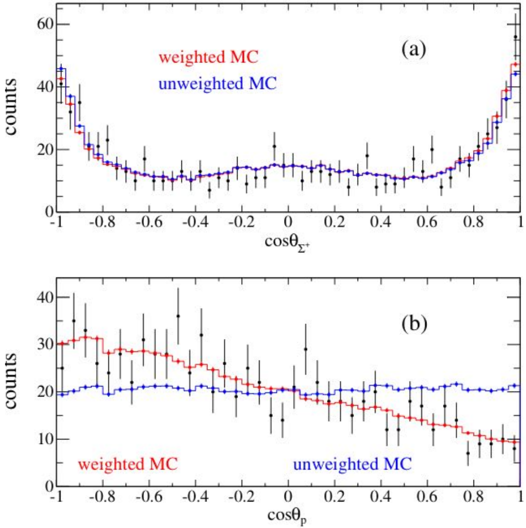

Figure 6: Distributions of the projections of (a)$\cos\theta_\Sigma$ and (b) $\cos\theta_p$ @ $2.65 < W < 2.75\,\mathrm{GeV}$ and $0.70 < \cos\theta < 0.80$, taken from [Moriya, Schumacher, Aghasyan et al. 2014]

Measurements and analysis

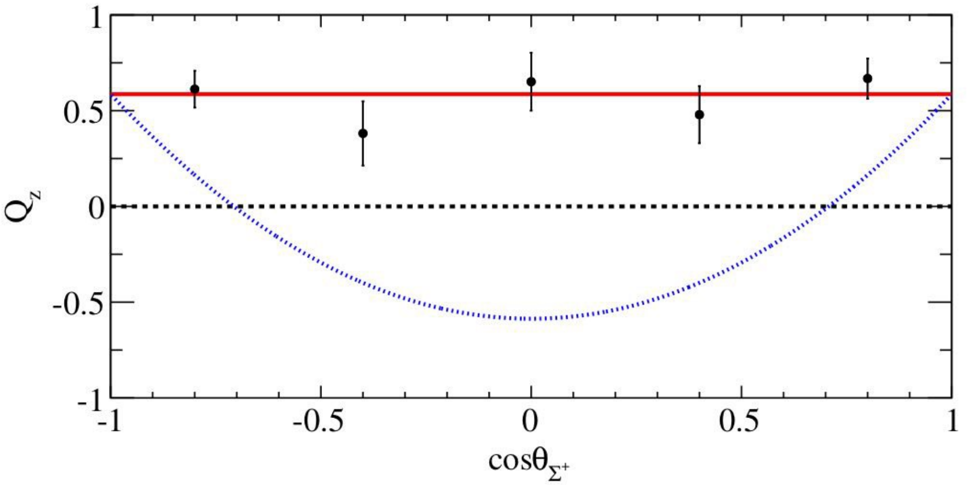

Figure 7: angular distribution of the polarization Q_z @ $2.65 < W < 2.75\,\mathrm{GeV}$ and $0.70 < \cos\theta < 0.80$. Red: average, blue: expectation for P-wave decay. Taken from [Moriya, Schumacher, Aghasyan et al. 2014]

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Conclusion

References

Mecking, B.A. et al. (2003). 'The CEBAF large acceptance spectrometer (CLAS)'. In: *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 503.3, pp. 513–553. ISSN: 0168-9002. DOI: https://doi.org/10.1016/S0168-9002(03)01001-5. URL: https://www.sciencedirect.com/science/article/pii/S0168900203010015.

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