Partial Wave Amplitudes of K^+K^- with CLAS12

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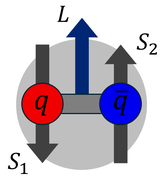
Theory

Meson Spectroscopy

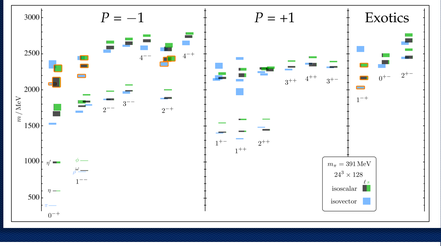
Meson spectroscopy is the study of the mass, width, quantum numbers and production and decay mechanisms of the mesons for the purpose of classification and understanding the strong interaction dynamics.
Additionally, it is desirable to expand the spectrum of known mesons and to test the predictions of lattice quantum chromodynamics.

In the constituent quark model, the meson is a $q\bar{q}$ pair:

$$J = |L + S|$$
$$P = (-1)^L$$
$$C = (-1)^{L+S}$$

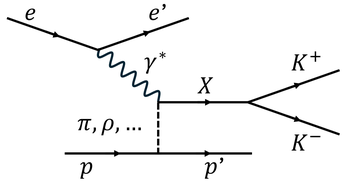


LQCD Meson Spectrum [1]



Reaction of Interest

$ep \to epK^+K^-$, quasi-real photoproduction of meson resonance X.



Low Q^2 reaction

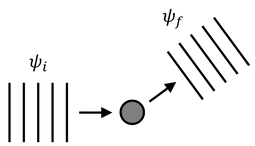
$$Q^2 = 4E_b E_{e'} \sin^2\left(\frac{\theta_{e'}}{2}\right)$$

γ^* linearly-polarized (10-70%)

$$P_\gamma = \left[1 + 2\frac{Q^2 + \nu^2}{Q^2}\tan^2\left(\frac{\theta_{e'}}{2}\right)\right]^{-1}$$

Scattering Theory

Partial waves can be introduced into a simple scattering model.



$$\frac{d\sigma}{d\phi d\cos\theta} = |\psi_s|^2 = |\psi_f - \psi_i|^2 \propto \left|\sum_{l=0}^{\infty}(2l+1)T_l P_l(\cos\theta)\right|^2$$

Partial wave amplitudes — Spherical harmonics

This model can be improved to describe more complicated decays which have additional degrees of freedom.

Reaction Model and Partial Wave Amplitudes

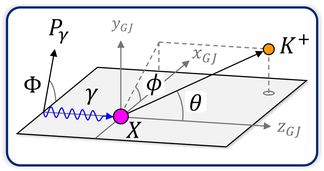
Since K^+ and K^- are each $S = 0$, L is equivalent to J of X. The intensity can be formulated using partial wave amplitudes which essentially correspond to the allowed values J,

$$\mathrm{I}(\Omega,\Phi) \equiv \frac{\mathrm{d}\sigma}{\mathrm{d}t\mathrm{d}m_{K^+K^-}\mathrm{d}\Omega\mathrm{d}\Phi} = 2\kappa\sum_k (1+P_\gamma)\left|[l]^{(+)}_{m;k}\mathrm{Re}Z^m_l(\Omega,\Phi)\right|^2 + (1-P_\gamma)\left|[l]^{(+)}_{m;k}\mathrm{Im}Z^m_l(\Omega,\Phi)\right|^2 + (1-P_\gamma)\left|[l]^{(-)}_{m;k}\mathrm{Re}Z^m_l(\Omega,\Phi)\right|^2 + (1+P_\gamma)\left|[l]^{(-)}_{m;k}\mathrm{Im}Z^m_l(\Omega,\Phi)\right|^2,$$

where $Z^m_l(\Omega,\Phi) = Y^m_l(\Omega)e^{-i\Phi}$ are spherical harmonics and $l_{m;k}$ are the partial wave amplitudes.

The angles in $\mathrm{I}(\Omega,\Phi)$ belong to the Gottfried-Jackson frame which is the rest frame of X with the z-axis defined by the photon direction.

The quantities of interest are $\cos\theta, \phi, \Phi$.



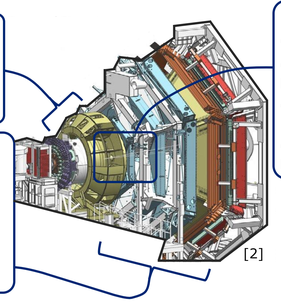
Method & Results

CLAS12

The CEBAF Large Acceptance Spectrometer for 12 GeV beam (CLAS12) located in Hall B was used to collect data.

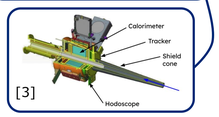
Central Detector:
- Range 35-125º
- CVT measures momenta and vertices
- CTOF identifies charged particles

Forward Detector:
- Range 5-35º
- HTCC separates e^- from hadrons
- DC measures momenta and trajectories
- FTOF identifies charged particles
- ECAL identifies e^- and γ



[2]

Forward Tagger:
- Range 2.5-5º
- Tracker - reconstructs particle trajectories
- Hodoscope – separates e^- and γ
- Calorimeter – measures particle energies



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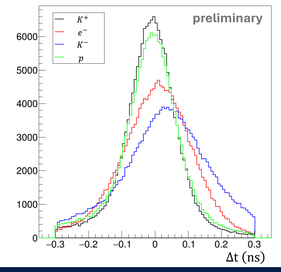
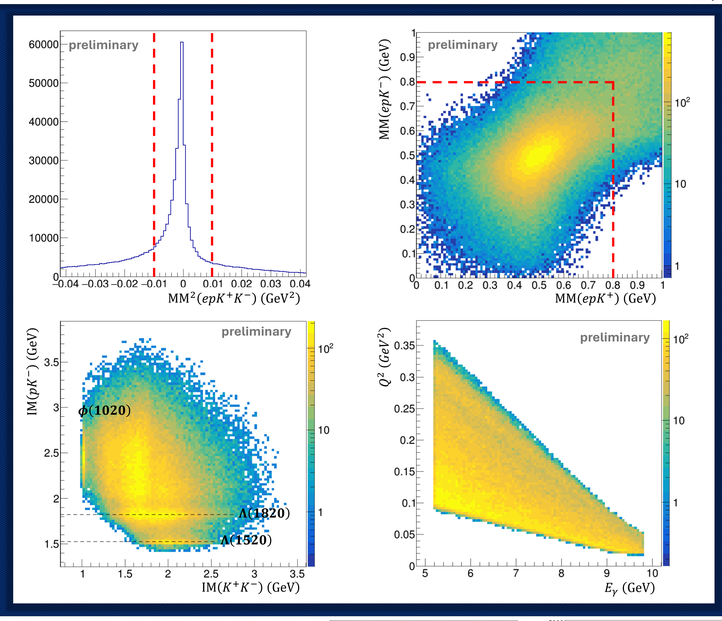
Event Selection and Reaction Reconstruction

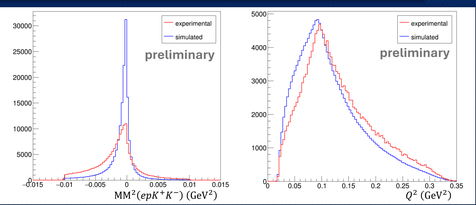
All runs from RG-A Spring 2019 (10.2 GeV beam, LH_2 target) were skimmed by selecting events which satisfied the following conditions:
- exclusive epK^+K^- topology
- $|\Delta t| < 0.3$ ns for every charged track
- e^- in forward tagger
- $0.4 < E_e < 5$ GeV
- $|\mathrm{MM}^2(epK^+K^-)| < 0.01$ GeV^2
- $\mathrm{MM}(epK^\pm) < 0.8$ GeV





Simulations

Simulated data was generated using a MC event generator and passed through a GEANT4 model of CLAS12. Simulated data was used to calculated the acceptance in the likelihood function.



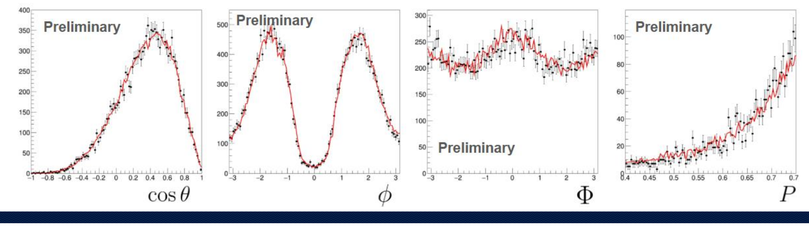
Event-by-event Extended Maximum Likelihood Fitting

Fitting the experimental intensity involved fitting distributions of $\cos\theta, \phi, \Phi$ and P_γ by varying the partial wave amplitudes and phases.

A suitable set of parameters corresponds to when the following acceptance-corrected log-likelihood function was minimized,

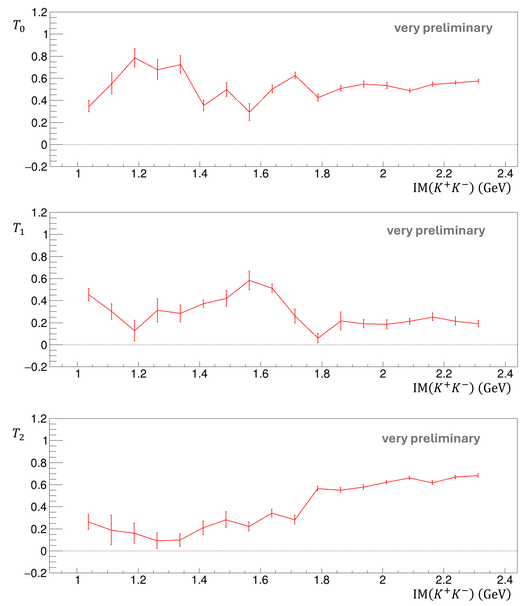
$$-\ln L(p) \propto -\sum_i^N f(x_i;p) + A(p), \qquad A(p) = \int f(x_i;p)\eta(x_i)\,dx \approx \sum_j^M f(x_i;p).$$

Experimental data (black) and acceptance-corrected projections of the intensity function (red) for $\cos\theta, \phi, \Phi$ and P_γ are shown below,



Partial Wave Amplitudes for K^+K^-

The data was divided into $\mathrm{IM}(K^+K^-)$ bins across the $\mathrm{IM}(K^+K^-)$ range $1.0 - 2.5$ GeV. The partial wave amplitudes were extracted independently in each bin for the S, P and D-waves.



Outlook

- Apply signal-background separation methods to remove baryon contamination
- Obtain expected enhancement in P-wave amplitude at $\phi(1020)$ mass
- Account for overlapping resonances in reaction model
- Apply workflow to other reactions such as $ep \to epK^+K^{*-} \to epK^+K^-\pi^0$

References

[1] https://arxiv.org/pdf/1909.06366
[2] https://doi.org/10.1016/j.nima.2020.163472
[3] https://etheses.whiterose.ac.uk/id/eprint/36409/