An update on JPAC activity

Alessandro Pilloni
Joint Physics Analysis Center

CLAS collaboration meeting, June 17th, 2016
Interpretations on the spectrum leads to understanding fundamental laws of nature.
S-Matrix principles

These are constraints the amplitudes have to satisfy, but do not fix the dynamics.

Resonances (QCD states) are poles in the unphysical Riemann sheets.

At high energies, other constraints from Regge theory (exchanges of towers of particles of any spin)

\[ A(s, t) = \sum_l A_l(s) P_l(z_s) \]

**Analyticity**

\[ A_l(s) = \lim_{\epsilon \to 0} A_l(s + i\epsilon) \]

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s-plane

Unitarity
$\eta\pi$ production at COMPASS

$\eta\pi < 3 \text{ (GeV/c}^2\text{)}^2$

$\theta \sim 0$

$\theta \sim \pi$

$\eta \pi \text{ vs } \eta'\pi$

$A(\theta) - A(-\theta) \sim P$

$P+f_2$

$P+\pi$

$\eta$

$\pi$

COMPASS coll. (2015)

V. Pauk

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Finite energy sum rules

\[ s_1 = m(\eta \pi)^2 \]

\[ \int_0^N ds \, \text{Im} \, A(s) = N^{\alpha+1} V \]

aim: first systematic analysis of peripheral production using FESR

V. Pauk
\( \pi, \rho \) photoproduction

Test factorization on the simplest cases
1. Neutral pion photoproduction
2. Charged pion photoproduction
3. Rho meson photoproduction

\[
\begin{align*}
\text{natural exchanges:} & & \rho/\omega/f_2/a_2/P \\
\text{unnatural exchanges:} & & \pi/b/h
\end{align*}
\]

\[
P = (-)^J
\]

\[
P = -(-)^J
\]

V. Mathieu
$\gamma \ p \rightarrow \pi^0 \ p$

Model based on factorization with parameters fitted

\[ \Sigma = \frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = \frac{|\rho + \omega|^2 - |b + h|^2}{|\rho + \omega|^2 + |b + h|^2} \]

axial-vector exchanges strength decreases with energy

More precise data@JLAB could confirm

VM, Szczepaniak and Fox Phys. Rev. D. 92 074013
\( \gamma p \rightarrow \pi^+ n \)

Pion dominate very small \(|t|\):

\[
\begin{align*}
|\Delta \lambda| &= 1 \\
\gamma &\rightarrow \pi^+ \\
e &\rightarrow \pi \pi NN \\
p &\rightarrow n
\end{align*}
\]

Factorization of Regge residues:

\((\lambda_\gamma, \lambda_\pi) = (1, 0)\) and \((\lambda_p, \lambda_n) = \left(-\frac{1}{2}, \frac{1}{2}\right)\) and \((\lambda_p, \lambda_n) = \left(\frac{1}{2}, -\frac{1}{2}\right)\)

\[
\begin{align*}
A_{10}^{\frac{1}{2}} &\propto \frac{-t}{m_{\pi}^2 - t} \\
A_{10}^{\frac{1}{2}} &\propto \frac{-t}{m_{\pi}^2 - t}
\end{align*}
\]

William's Poor man absorption:

\[
\gamma \rightarrow \pi \pi p
\]

\[
|\lambda_\gamma - \lambda_p| - |\lambda_\pi - \lambda_p| = 0
\]
\( \gamma p \rightarrow \rho^0 p \)

Use beam polarization to extract spin density matrix elements:

\[
\rho^0_{MM'} = \frac{1}{N} \sum_{\lambda} A_{\lambda \gamma \lambda_p \lambda_{p'}} M A^{*}_{\lambda \gamma \lambda_p \lambda_{p'} M'}
\]

\[
\rho^1_{MM'} = \frac{1}{N} \sum_{\lambda} A_{\lambda \gamma \lambda_p \lambda_{p'}} M A^{*}_{\lambda \gamma \lambda_p \lambda_{p'} M'}
\]

\[
N = \sum_{\lambda} |A_{\lambda}|^2
\]

At leading \( s \), one can separate natural and unnatural exchanges.

Test factorization at top vertex: non-flip \( \beta_0 (\sqrt{-t})^0 \), single-flip \( \beta_0 (\sqrt{-t})^0 \), double-flip \( \beta_2 (\sqrt{-t})^2 \)

Fit gives \( \beta_0 : \beta_1 : \beta_2 = 1.00 : 0.14 : -0.09 \), which agrees with the expected trend.

V. Mathieu
PWA of $3\pi$ system

- Develop method of analysis satisfying S-matrix principles, study $J^{PC}$ resonances in $3\pi$
- In this presentation, we focus on $2^{-+}$,
  - long standing puzzle about $\pi_2(1670)-\pi_2(1880)$ interplay,
  - 17 waves out of 88 have $J^{PC} = 2^{-+}$,

A. Jackura, M. Mikhasenko

[C. Adolph et al. [COMPASS Collaboration], arXiv:1509.00992]
PWA of $3\pi$ system

Now use unitarized Deck amplitude developed for this analysis

$$F_i(s) = b_i(s) + \sum_j t_{ij}(s)c_j + \frac{1}{\pi} \sum_j t_{ij}(s) \int_{s_j}^{\infty} ds' \frac{\rho_j(s')b_j(s')}{s' - s}$$

Data: three main waves at low $|t'|$ (0.1 GeV$^2$-0.113 GeV$^2$):

$2^{-+}0^+ f_2\pi S, \quad 2^{-+}0^+ f_2\pi D, \quad 2^{-+}0^+ (\pi\pi)_S\pi D$.

- K-matrix assumes elasticity, so simultaneous fit of all decay channels are needed (all $3\pi$ waves),
- data for 11 $|t'|$ intervals are available. $|t'|$-dependence of non-resonance component is fixed by “Deck” model.
Pentaquark photoproduction

We propose to search the $P_c(4450)$ state in photoproduction.

We use the (few) existing data and VMD + pomeron inspired bkg to estimate the cross section.

$J^P = (3/2)^-$

<table>
<thead>
<tr>
<th>$\sigma_s$ (MeV)</th>
<th>0</th>
<th>60</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A$</td>
<td>$0.156^{+0.029}_{-0.020}$</td>
<td>$0.157^{+0.039}_{-0.021}$</td>
<td>$0.157^{+0.037}_{-0.022}$</td>
</tr>
<tr>
<td>$\alpha_0$</td>
<td>$1.151^{+0.018}_{-0.020}$</td>
<td>$1.150^{+0.008}_{-0.026}$</td>
<td>$1.150^{+0.015}_{-0.023}$</td>
</tr>
<tr>
<td>$\alpha'$ (GeV$^{-2}$)</td>
<td>$0.112^{+0.033}_{-0.034}$</td>
<td>$0.111^{+0.037}_{-0.064}$</td>
<td>$0.111^{+0.038}_{-0.054}$</td>
</tr>
<tr>
<td>$s_t$ (GeV$^2$)</td>
<td>$16.8^{+1.7}_{-0.9}$</td>
<td>$16.9^{+2.0}_{-1.6}$</td>
<td>$16.9^{+2.0}_{-1.3}$</td>
</tr>
<tr>
<td>$b_0$ (GeV$^{-2}$)</td>
<td>$1.01^{+0.47}_{-0.29}$</td>
<td>$1.02^{+0.61}_{-0.32}$</td>
<td>$1.03^{+0.49}_{-0.31}$</td>
</tr>
<tr>
<td>$B_{\psi p}$</td>
<td>$\leq 29%$</td>
<td>$\leq 30%$</td>
<td>$\leq 22%$</td>
</tr>
</tbody>
</table>
$J/\psi \rightarrow \gamma \pi^0 \pi^0$

BESIII published in 2015 a partial wave analysis of $J/\psi \rightarrow \gamma \pi^0 \pi^0$

Bose symmetry and charge conjugation force the dipion to have $J^{PC} I^G = \text{(even)}^{++} 0^+$

This is a gluon-rich process, expected to be one of the golden channels for the search of the scalar glueball
We start approximating the problem to 1 channel, i.e. neglecting inelasticities. Unitarity and dispersion relations allow us to write the solution in terms of the Omnès function

\[
\text{Disc}_R \ f^J_\mu = \rho(s) f^J_\mu A^{J*}_{\pi \pi} = f^J_\mu e^{-i\delta_J} \sin \delta_J
\]

\[
f^J_\mu(s) = \nu^J_\mu(s) + \Omega(s) \left( P_k(s) + \frac{1}{\pi} \int_4^{\infty} ds' \nu^J_\mu(s') e^{i\delta_J(s')} \sin \delta_J(s') \Omega^{-1}(s') (s')^k (s' - s) \right)
\]

Depends on the \(\pi\pi\) scattering phase, parametrized with K matrix

\[
K_\pi = \frac{m^2_\pi - 2s}{2f^2_\pi}
\]

\[
K_R = \sum_i \frac{g_i}{M_i^2 - s} + \sum_j \gamma_j s^j
\]

A. Pilloni

Adler zero describes the \(\sigma\) region

K-matrix poles

Background terms (effective LHC)
$J/\psi \to \gamma \pi^0\pi^0$: preliminary fit

The fit qualitatively reproduces the $\sigma$ region and the higher resonances, but as expected fails to describe the $f_0(980)$ region: an effective $K\bar{K}$ threshold has to be included.

A. Pilloni
Interactive tools

• Completed projects are fully documented on interactive portals
• These include description on physics, conventions, formalism, etc.
• The web pages contain source codes with detailed explanation how to use them. Users can run codes online, change parameters, display results.

http://www.indiana.edu/~jpac/
Overview

\[ K N \rightarrow K N \]
\[ \pi N \rightarrow \pi N \]
\[ \gamma p \rightarrow \pi^0 p \]
\[ \eta \rightarrow \pi^+ \pi^- \pi^0 \]
\[ \omega, \phi \rightarrow \pi^+ \pi^- \pi^0 \]
\[ \gamma p \rightarrow K^+ K^- p \]

C. Fernandez-Ramirez et al., V. Mathieu et al., V. Mathieu et al., P. Guo et al., I. Danilkin et al., M. Shi et al.,

PRD93, 034029 PRD92, 074004 PRD92, 074013 PRD92, 054016 PRD91, 094029 PRD91, 034007

Thank you!
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