JPAC activities
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CLAS collaboration meeting
JLab
February 25, 2016
- Extract values of fundamental parameters
- Extract properties of resonances
- Searches for new resonances/new states of matter
- Understand fundamental laws (matching QCD with exp.)
Amplitude analysis

Unitarity:

$$2 \text{Im} \ T = iTT^\dagger$$

crossing symmetry:

$s$: $1 + 2 \rightarrow 3 + 4$
$t$: $1 + \bar{3} \rightarrow \bar{2} + 4$
$u$: $1 + \bar{4} \rightarrow 2 + \bar{3}$

Lorentz symmetry, quantum numbers, etc.

Analyticity:

$$A(s, t) = \frac{2}{\pi} \int_{s_{th}}^{\infty} \frac{\text{Im}(s', t)}{s' - s} \, ds'$$

consistent fitting functions
constraints from existing data
Finite Energy Sum Rules (FESR)

model predictions
data
lattice simulations
Finite Energy Sum Rules

\[ A(\nu, t) = \frac{2}{\pi} \int_{\nu_{th}}^{\infty} \frac{\text{Im} A(\nu', t)}{\nu'^2 - \nu^2} \nu d\nu' \]

fixed-t dispersion relation

\[ \nu = \frac{s - u}{2} \]

\[ \frac{1}{\Lambda^n} \int_{\nu_{th}}^{\Lambda} \text{Im} A(\nu, t) \nu^n d\nu = \frac{\beta(t)\Lambda^{\alpha(t)} + 1}{\alpha(t) + n + 1} \]

Finite Energy Sum Rules

\[ A(\nu, t) \rightarrow A(\nu, t) - A(\nu \rightarrow \infty, t) \]

\[ A(\nu, t) \xrightarrow{\nu \rightarrow \infty} \beta(t)\nu^{\alpha(t)} \]

high-energy behavior

![Graph](image)
Pion-Nucleon Amplitudes

high-energy fit to total and differential cross sections

\[ \pi^\pm p \rightarrow \pi^\pm p \quad \pi^- p \rightarrow \pi^0 n \]

Mathieu, V., et al. PRD, 92(7), arXiv:1506.01764
**ηπ** production at COMPASS

\[ \pi^- p \rightarrow \eta\pi^- p \]
\[ \pi^- p \rightarrow \eta'\pi^- p \]

\[ J^{PC} = 1^{--}, 3^{--}, 5^{--}, \ldots \]

exotic quantum numbers
Kinematic ranges

\[ 0.5 \text{ GeV} < s_1 = (p_1 + p_2)^2 < 5 - 6 \text{ GeV} \]

\[ 15 \text{ GeV} < s_2 = (p_2 + p_3)^2 < 350 \text{ GeV} \]

\[ 0 \text{ GeV} > t_1 = (p_a - p_1)^2 > -2 \text{ GeV} \]

\[ t_2 = (p_b - p_3)^2 \approx -0.1 \text{ GeV} \]
Production mechanism

\[ A_{\mu\mu'}(s_1, s_2, t_1, t_2) = \sum_{\lambda=-J}^{J} A_{\lambda}^J(s_1, t_2) \frac{g_J(s_1)}{m_J^2 - i m_J \Gamma(s_1) - s_1} d_J^J(z) e^{i\lambda\phi} \]

× \eta(\alpha_2(t_2)) \gamma_{2\mu'}(t_2) s_2^{\alpha_2(t_2)}

Regge behavior

\[ A_{\mu\mu'}(s_1, s_2, t_1, t_2) = \eta(\alpha_1(t_1)) \gamma_1(t_1) s_1^{\alpha_1(t_1)} \sum_{\lambda} e^{i\lambda\omega} \gamma_{\lambda}(t_1, t_2) \]

× \eta(\alpha_2(t_2)) \gamma_{2\mu'}(t_2) s_2^{\alpha_2(t_2)}

Toller angle

\[ \cos \omega = \frac{(p_a \times p_1) \cdot (p_b \times p_3)}{|p_a \times p_1||p_b \times p_3|} \bigg|_{p_2=0} \]
Kinematic constraints

\[ A_{H_s}(s, t) = 16\pi \sum_{J=M}^{\infty} (2J + 1) A_{HJ}(s) D_{\mu\mu'}^{J*}(\phi_s, \theta_s, -\phi_s) \]

\[ \zeta_{\mu\mu'}(z_s) = \left( \frac{1 - z_s}{2} \right)^{1/2|\mu - \mu'|} \left( \frac{1 + z_s}{2} \right)^{1/2|\mu + \mu'|} + \text{crossing symmetry or threshold behavior} \]

low-t dependence

\[ \gamma^{\lambda_1\lambda_2}(t) \sim (-t)^{|\lambda_1 - \lambda_2|/2} \]
\[ \gamma^{\lambda_2}_{\lambda\lambda_2 - \lambda} \sim (-t_1)^{|\lambda_1|/2} (-t_2)^{|\lambda_2|/2} \]

general form of the double-Regge residue

parity

\[ \gamma^{\lambda_h}_{\lambda_1\lambda_2} = - \gamma^{\lambda_h}_{-\lambda_1 - \lambda_2} \]
\[ \gamma_0(t_1, t_2, \omega) = 0 \]

\[ \beta(t_1, t_2, \omega) \sim 2i(-t_1)^{1/2}(-t_2)^{1/2} \sin \omega \sum_{\lambda=0}^{\infty} \sin^{\lambda} \omega \tilde{\gamma}_{\lambda}(t_1, t_2) \]
\[ \beta(t_1, t_2, \omega) = \sum_{\lambda=-\infty}^{\infty} e^{i\lambda\omega} \gamma_{\lambda}(t_1, t_2) \]
Studying the pentaquark in the $J/\Psi$ photoproduction

- Recent discovery of a narrow (39 MeV) exotic resonance compatible with a pentaquark $P_c(4459)$ in the $J/\Psi p$ channel. LHCb collaboration (2015) arXiv:1507.03414

Testing these predictions is within the capabilities of JLAB’s CLAS detector, also in a wider range of scattering angles!
Good channel for the search of ground-state scalar glueball
Data provided by BESIII both for the charged and neutral channel

\[ J/\Psi \rightarrow \gamma \pi \pi \]

\( t \)-channel dominated by \( \rho \) exchange \( \rightarrow \) model for LHC

\[
 f_J(s) = \frac{1}{\pi} \int \frac{\text{disc} f_J^\rho(s')}{s' - s} + \frac{1}{\pi} \int_4^{\infty} \frac{\eta \sin \delta_J e^{-i\delta_J} f_J(s')}{s' - s} ds'
\]

Solved in terms of the Omnès function up to \( \sqrt{s} \sim 1.2 \text{ GeV} \)

new parametrizations tested in the \( 1.2 \text{ GeV} < \sqrt{s} < M_\psi \)

A. Pilloni
The dominant binding mechanism is expected to be the exchange of one pion in the u channel, but in the literature, this has been evaluated in the static limit only (virtual pion). However, the \( \pi \) can happen to be on shell: this creates another cut, which might spoil the binding mechanism of \( DD^* \). Cusp effect if the branch points pinch the real axis.

Once developed, the formalism can be extended to other 3 \( \rightarrow \) 3 channels, like \( \rho \pi \rightarrow \rho \pi \).
**3π production at COMPASS experiment**

COMPASS is a fixed-target experiment. 190 GeV pion beam. The recoil proton gives trigger (veto). Charged particles are measured by a spectrometer.

**JPAC (JLab Physics Analysis Center)**

**Introduction**

- Unitarity has to be respected: \( \hat{S} \times \hat{S}^\dagger = I \)

\[
2\text{Im}\, T = iT \rho T^\dagger \\
\hat{S} = I + i\hat{T}
\]

- Convenient parameterization of \( T \) is a \( K \)-matrix

- Non-resonance processes is a physical background?

\[
2\text{Im}\, A = iA \rho T^\dagger \\
A(m_{3\pi}) = \alpha(m_{3\pi}) \times T(m_{3\pi})
\]

- Quasi-two-body phase space (\( f_2 \) is \( \pi\pi\pi \)D-state)

M. Mikhashenko, A. Jackura
2$^{-+}$ sector of the 3$\pi$ final state

Long standing puzzle about $\pi_2(1670) - \pi_2(1880)$ interplay

The goal is to develop a method of the analysis and demonstrate an applicability.
Measure the ratio of the e vs μ cross sections

\[ R_{μ/e} = \frac{dσ(μ^- + μ^+ + e^- + e^+)}{dσ(e^- + e^+)} - 1 \]

at small t the ratio \( R_{μ/e} \) gives **direct access** to the ratio of the **proton electric form factor** in the \( μp \) versus \( ep \) scattering

the deviation from the unity will be a sign of **violation of the lepton universality**

**JLab** access the proton form factor by analyzing angular distributions of the lepton pairs
### Overview

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<th>Reaction</th>
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<th>Reference</th>
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<tr>
<td>( \pi N \to \pi N )</td>
<td>V. Mathieu, et al.</td>
<td>arXiv:1506.01764 PRD92 7 074004</td>
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<tr>
<td>( \gamma p \to \pi^0 p )</td>
<td>V. Mathieu, et al.</td>
<td>arXiv:1505.02321 PRD92 7 074013</td>
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<td>( \eta \to \pi^+ \pi^- \pi^0 )</td>
<td>P. Guo, et al.</td>
<td>arXiv:1505.01715 PRD92 5 054016</td>
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<tr>
<td>( \omega, \phi \to \pi^+ \pi^- \pi^0 )</td>
<td>I. Danilkin, et al.</td>
<td>arXiv:1409.7708 PRD91 9 094029</td>
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<td>( \gamma p \to K^+ K^- p )</td>
<td>M. Shi, et al.</td>
<td>arXiv:1411.6237 PRD91 3 034007</td>
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<tr>
<td>( K N \to K N )</td>
<td>C. Fernandez-Ramirez, et al.</td>
<td>arXiv:1510.07065</td>
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