An Update on JPAC Activities

Vincent MATHIEU

Indiana University
- Joint Physics Analysis Center

EINN 2015
November 2015
Joint Physics Analysis Center (JPAC)

JPAC members

Mike Pennington (JLab)
Adam Szczepaniak (IU/JLab)
Tim Londergan (IU)
Geoffrey Fox (IU)
Emilie Passemar (IU/JLab)
Peng Guo (IU/JLab)
Cesar Fernandez-Ramirez (JLab)
Ron Workman (GWU)
Michael Döring (GWU)

Vladyslav Pauk (Mainz → JLab)
Alessandro Pilloni (Rome → JLab)
Igor Danilkin (JLab → Mainz)
Lingyun Dai (IU/JLab → Valencia)
Meng Shi (JLab → Beijing)
Astrid Blin (Valencia)
Andrew Jackura (IU)
Vincent Mathieu (IU)

CLAS collaboration
Diane Schott (GWU/JLab)
Viktor Mokeev (JLab)

GlueX collaboration
Matthew Shepherd (IU)
Justin Stevens (JLab)

COMPASS collaboration
Mikhail Mikhasenko (Bonn)
Fabian Krinner (TUM)
Boris Grube (TUM)

HASPECT:
Marco Battaglieri (Genova)
Derek Glazier (Glasgow)

...
Hadron Physics Experiments

Direct Production

\[ \pi, \gamma \rightarrow N^*, \Delta \rightarrow \pi \]

Annihilation

\[ e^+ \rightarrow e^- \]

Beam Fragmentation

\[ \pi, \gamma \rightarrow a \rightarrow 1 \]

\[ \rightarrow b \rightarrow 2 \]

\[ \rightarrow P \rightarrow 3 \]

Central Production

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

Heavy Meson Decay

\[ B^0 \rightarrow \pi^- K^+ \psi \]

VM et al arXiv:1412.6393
1. Extract properties of resonances
2. Extract value of fundamental parameters
3. Possibly discover new resonances/new state of matter
4. Preserve material
Theory: Quantum Chromodynamics

Lattice, models, ...

Resonances properties

Experiments: JLab, CERN, ...

Amplitudes analysis

Collaborative efforts between theorists and experimentalists
Resonances are poles in complex functions

- **Theory:** Quantum Chromodynamics
- **Lattice, models,...**
- **Resonances properties**
- **Experiments:** JLab, CERN,...

Amplitudes analysis
Collaborative efforts between theorists and experimentalists

Properties (math.): real, imaginary parts and residue
Properties (phys.): mass, width and coupling
analyticity & complex energy plane

Left hand cut (cross channel dyn.)

Unitarity cut data (real E)

resonance pole
analyticity & complex energy plane

Left hand cut (cross channel dyn.)

Unitarity cut
data (real E)

resonance pole

COMPASS
1509.00992

A2(1320)

PRL 115 072001
(2015)
1. Extract Resonance Properties: $\Sigma$ Baryon Spectrum

\[ K^- \rightarrow \Sigma, \Lambda \rightarrow K^- \]

\[ p \rightarrow p \]

C. Fernandez-Ramirez et al. (JPAC) ArXiv:1510:07065
1. Extract Resonance Properties: $\Sigma$ Baryon Spectrum

\[ K^- \leftrightarrow \Sigma, \Lambda \leftrightarrow K^- \]

\[ p \rightarrow \Sigma, \Lambda \rightarrow p \]

\[ M_p (\text{MeV}) \]

\[ \Gamma_p (\text{MeV}) \]

\[ I = 1 \]

C. Fernandez-Ramirez et al. (JPAC) ArXiv:1510:07065
1. **Extract Resonance Properties: \( \Sigma \) Baryon Spectrum**

\[
\begin{align*}
\text{physical axis}
\end{align*}
\]

\( I = 0 \)

C. Fernandez-Ramirez et al. (JPAC) ArXiv:1510:07065
2. Extract Fundamental Parameters: Quark Mass Difference

Isospin violating decay sensitive to quark mass difference
2. Extract Fundamental Parameters: Quark Mass Difference

$\eta, \pi \sim u \bar{d}$

Isospin violating decay sensitive to quark mass difference

fit Dalitz distribution
WASA@COSY

fit event by event
g12 CLAS6 data
2. Extract Fundamental Parameters: Quark Mass Difference

\[ Q^2 = \frac{m_s^2 - (m_u + m_d)^2 / 4}{m_d^2 - m_u^2} \]

\( Q = 21.4 \pm 0.4 \)

WASA@COSY

CLAS@CEBAF in preparation

KLOE@DAPHNE in preparation

P. Guo et al (JPAC) PRD92 5 054016

Fit Dalitz distribution WASA@COSY

Fit event by event g12 CLAS6 data
2. Extract Fundamental Parameters: Quark Mass Difference

\[ Q^2 = \frac{m_s^2 - (m_u + m_d)^2/4}{m_d^2 - m_u^2} \]

\( Q = 21.4 \pm 0.4 \)

WASA@COSY

CLAS@CEBAF in preparation

KLOE@DAPHNE in preparation

P. Guo et al (JPAC) PRD92 5 054016

Isospin violating decay sensitive to quark mass difference

\( \omega, \phi \rightarrow 3\pi, \gamma^* \pi^0 \)

I. Danilkin et al (JPAC) PRD91 9 094029
3. Discovering (?) New Resonances: Eta(′)-Pi @COMPASS
3. Discovering (?) New Resonances: Eta(′)-Pi @COMPASS

\[ \pi^-, \eta, \eta', \pi^- \rightarrow P, \eta, \pi^- \]

\[ m(\eta\pi^-) \text{ [GeV/c}^2\text{]} \]

\[ m(\eta'\pi^-) \text{ [GeV/c}^2\text{]} \]

\[ \cos \phi_{GJ} \]

\( \pi_1(1600)? \)  
\( L = 1 \)  
\( a_2(1320) \)  
\( L = 2 \)  
\( a_4(2040) \)  
\( L = 4 \)

\[ \text{black: } \pi\eta' \]
\[ \text{red: } \pi\eta \text{ (scaled)} \]

Resonance in angular mom. L = 1?
\[ \pi N \rightarrow \pi N \quad \text{VM et al (JPAC)} \quad \text{arXiv:1506.01764} \quad \text{PRD92 7 074004} \]

\[ \gamma p \rightarrow \pi^0 p \quad \text{VM et al} \quad \text{arXiv:1505.02321} \quad \text{PRD92 7 074013} \]

\[ \eta \rightarrow \pi^+ \pi^- \pi^0 \quad \text{P. Guo et al (JPAC)} \quad \text{arXiv:1505.01715} \quad \text{PRD92 5 054016} \]

\[ \omega, \phi \rightarrow \pi^+ \pi^- \pi^0 \quad \text{I. Danilkin et al (JPAC)} \quad \text{arXiv:1409.7708} \quad \text{PRD91 9 094029} \]

\[ \omega, \phi \rightarrow \gamma^* \pi^0 \quad \text{I. Danilkin et al (JPAC)} \quad \text{arXiv:1409.7708} \quad \text{PRD91 9 094029} \]

\[ \gamma p \rightarrow K^+ K^- p \quad \text{M. Shi et al (JPAC)} \quad \text{arXiv:1411.6237} \quad \text{PRD91 3 034007} \]

\[ KN \rightarrow KN \quad \text{C. Fernandez-Ramirez et al (JPAC)} \quad \text{arXiv:1510.07065} \]

\[ AB \rightarrow \pi \pi X \quad \text{L.Y. Dai et al (JPAC)} \quad \text{in preparation} \]

\[ \pi^- p \rightarrow \pi^- \pi^+ \pi^- p \quad \text{A. Jackura et al (JPAC)} \quad \text{in preparation} \]
4. Preserving and Sharing Material: $\gamma p \rightarrow \pi^0 p$

Blue line: Model from VM et al arXiv:1505.02321

Red points: Data from CLAS (in preparation)

courtesy of M Kunkel
Backup Slides
25k events

PRL112 (2014) 222002
$B^0 \rightarrow \pi^- K^+$

$Z(4430)^-$

25k events

PRL112 (2014) 222002
$B^0 \rightarrow \pi^- K^+ \psi$

$Z(4430)^-$

$K^*(892)^0$  $K_2^*(1430)$

PRL112 (2014) 222002

25k events

Tetraquark?

Everything except the $Z \rightarrow$ large interference between $Z$ and $K^+ \pi^-$ sector

$J^P = 1^+$  
$Z$ component
Z(3900)

- Discovered by Belle & BESIII 2013
- Seen in decay \( Y(4260) \rightarrow J/\psi \pi \pi \)

Liu, BESIII & Belle Collaboration, arXiv:1311.0762v1

Close to \( \bar{D}D^* \) threshold
Special case: Szczepaniak arXiv:1501.01691
Real case: JPAC, in preparation
Special case: Szczepaniak arXiv:1501.01691
Real case: JPAC, in preparation
Special case: Szczepaniak arXiv:1501.01691
Real case: JPAC, in preparation

\[ \mu = 0 \]
\[ m = m^* \]
Special case: Szczepaniak arXiv:1501.01691
Real case: JPAC, in preparation

Analytic structure of $C(s)$ S-wave

LHC (crossed channel cuts)  

RHC (unitarity cut)
Special case: Szczepaniak arXiv:1501.01691
Real case: JPAC, in preparation

$$J/\psi(M')$$
$$Y(M)$$
$$\pi(\mu)$$

$$Y(M)$$
$$\pi_1(\mu)$$
$$\pi_2(\mu)$$
$$B(s, t_2)$$

Analytic structure of C(s) S-wave

$$\lambda^2 < \frac{M^2}{2} - m^2$$

LHC (crossed channel cuts)

RHC (unitarity cut)

$$\mu = 0$$
$$m = m^*$$
Special case: Szczepaniak arXiv:1501.01691
Real case: JPAC, in preparation

\[(M - m)^2 > \lambda^2 > M^2 / 2 - m^2\]

Analytic structure of \(C(s)\) S-wave

\[\alpha = 0\]
Special case: Szczepaniak arXiv:1501.01691
Real case: JPAC, in preparation

\[(M - m)^2 > \lambda^2 > \frac{M^2}{2} - m^2\]

Analytic structure of \(C(s)\) S-wave

LHC (crossed channel cuts)  \(Y(M)\)

RHC (unitarity cut)  \(\pi_1(\mu)\)

\(\bar{D}(m)\)

\(D^*(m)\)

\(\mu = 0\)

\(m = m^*\)
Special case: Szczepaniak arXiv:1501.01691
Real case: JPAC, in preparation

\[(M - m)^2 > \lambda^2 > M^2/2 - m^2\]

Analytic structure of C(s) S-wave
Unitarity: $|S_{11}|^2 + |S_{21}|^2 + \ldots = 1$

depletion?

effhusement

BESIII ArXiv: 1303.5949
PRL 110 (2013) 252001
Unitarity: \[ |S_{11}|^2 + |S_{21}|^2 + \ldots = 1 \]
Unitarity: \[ |S_{11}|^2 + |S_{21}|^2 + \ldots = 1 \]
- $Y \rightarrow \pi \bar{D} D^*$ DATA
- $Y \rightarrow \bar{D} D_1(2420)$
- $Y \rightarrow \pi Z_c \rightarrow \pi \bar{D} D^*$
  + $\pi \bar{D} D^*$ p.s.