Need for amplitude analysis in the discovery of new hadrons

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Joint theory and experimental efforts

The status quo

- Panoply of data from experiments and recent lattice advancements: unexpected signals, but statistic limitations and multi-body complications.

- Also near future has many planned new experimental facilities.

- JPAC has strong record of interaction with experiments: BaBar, BESIII, CLAS, COMPASS, GlueX, LHCb.

The goal

- Theory tools from first principles: establish full multiplets of seen signals and their properties.

- Data analysis with final-state interactions, statistical learning, feasibility studies, predictions, …

- **Crucial:** close collaboration between experimentalists and theorists.
1. Amplitude analysis formalism

2. Production mechanisms

3. Resonance studies
Formalism: 3-body decays and scattering

- JPAC very active in the construction of theoretically sounded amplitudes!
  **Maximise** fundamental principles: analyticity, unitarity, crossing, Lorentz symmetry, …
  **Minimise** model dependence and factor it out!

- Study of equivalence between formalisms of resonance searches in $1 \to 3$ decays:
  very timely for spectroscopy, since most (exotic) hadrons couple strongly to 3 particles!

- Timely also for lattice QCD!
  Equivalence of $3 \to 3$ scattering formalisms in infinite volume:
  reduces systematic uncertainties!

- Extension to quantised volume has been shown as well.
  Blanton and Sharpe, PRD102 (2020) 054515
First direct $a_2$ photoproduction measurement

- Photoproduction studies are very timely considering JLab endeavours.

- Particular interest in $\gamma p \rightarrow \pi^0 \eta p$ for exotic searches. Here, $a_2^0$ resonance is dominant reference state.

- Regge phenomenology predicts dip in amplitude: confirmed in CLAS data!

\[ \gamma, \lambda_\gamma \rightarrow T, \lambda_T \]
\[ V = \rho, \omega \]
\[ A = b_1, h_1 \]

\[ p, \lambda_p \rightarrow p, \lambda'_p \]
Resonances: pentaquark searches

LHCb PRL115 (2015) 072001
LHCb PRL122 (2019) 222001

 JPAC PRD94 (2016) 034002
 JPAC PRD100 (2019) 034019

Polarization observables to provide better sensitivity to signals.

GlueX data

$P_c(4312)^\dagger$: First determination of pole position from data analysis!

JPAC PRL123 (2019) 092001

https://github.com/dwinney/jpacPhoto
Hunting the hybrid $\pi_1(1600)$

- Experiments announce TWO states, separately coupling to $\eta\pi$ and $\eta'\pi$: Inconsistent with lattice and phenomenology expectations.

- Analyticity, unitarity: coupled-channel analysis of P,D waves in $\pi p \to \eta^{(\prime)}\pi p$.

- Need for a SINGLE pole in P wave: $\pi_1$ (two poles show no improvement), two poles in D wave: $a_2$ and $a'_2$.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{plot.png}
\caption{JPAC, PRL122 (2019) 042002}
\end{figure}
Ultimately and in a nutshell

- Apply **improved analysis tools** to experimental analyses (e.g. COMPASS, CLAS, future facilities).

- Need **precise measurements** of hadron spectrum.

- Use resources of **computational power**: Monte Carlo, machine learning, …

*For the best possible results, theory and experiment must work together!*