Need for amplitude analysis in the discovery of new hadrons

Snowmass RF7_RF0-081

JPAC

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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.

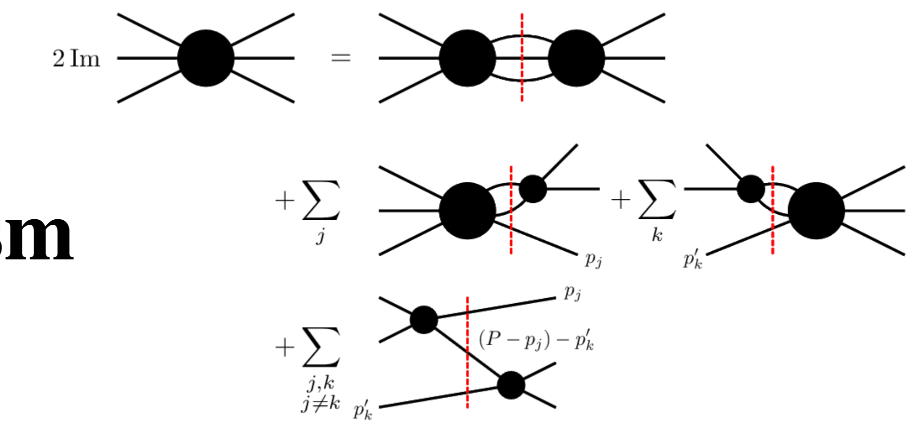
The goal

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

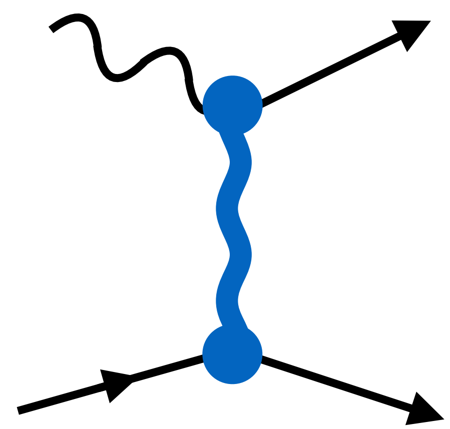
- Data analysis with final-state interactions, statistical learning, feasibility studies, predictions, …

- **Crucial:** close collaboration between experimentalists and theorists.

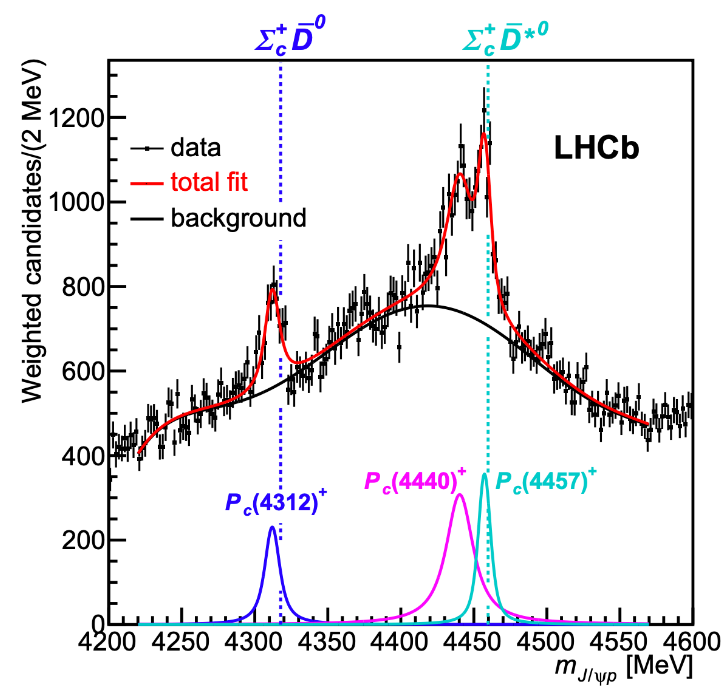
JPAC legacy



1. Amplitude analysis formalism



2. Production mechanisms



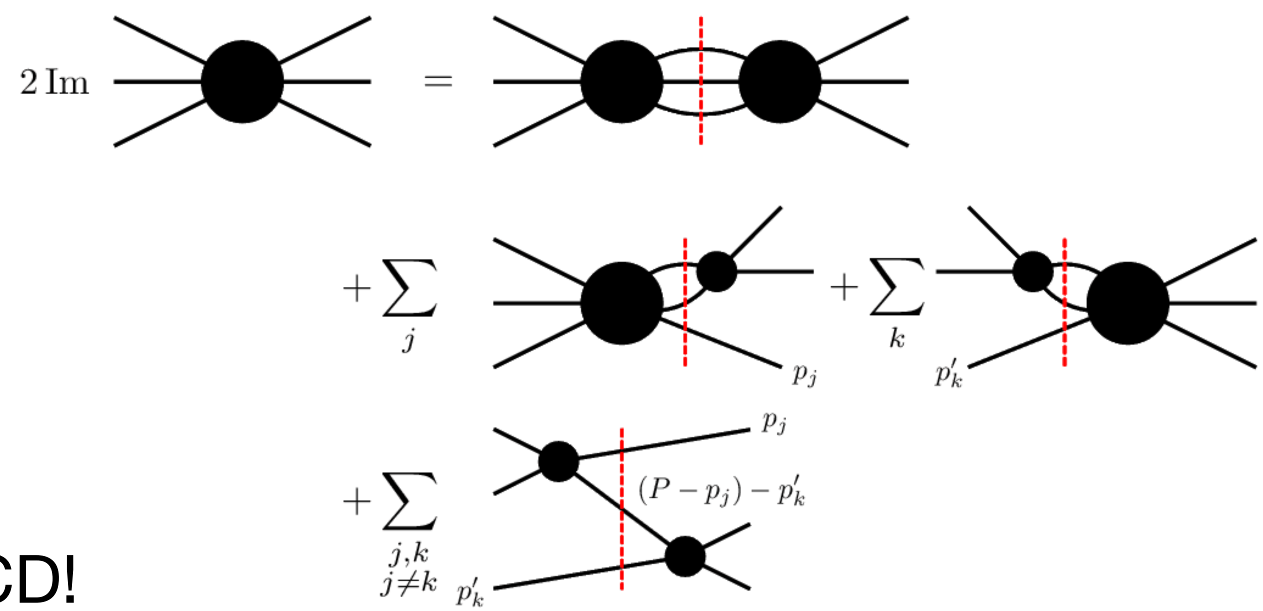
3. Resonance studies

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!

JPAC, EPJC78 (2018) 229 **JPAC**, PRD101 (2020) 034033
JPAC, EPJC78 (2018) 727 **JPAC**, PRD101 (2020) 054018

- 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!

JPAC, EPJC79 (2019) 56
JPAC, PRD100 (2019) 034508
JPAC, JHEP08 (2019) 080

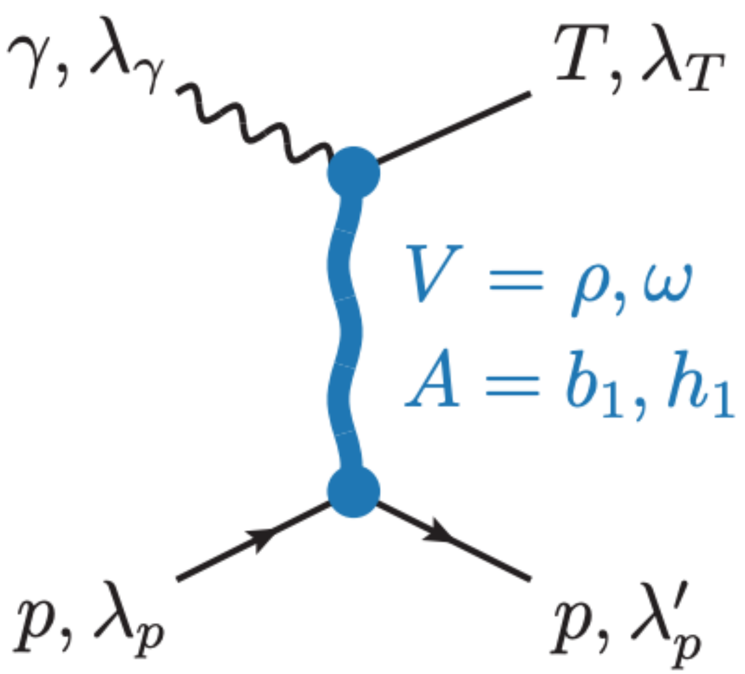
- Extension to quantised volume has been shown as well. **Blanton and Sharpe**, PRD102 (2020) 054515

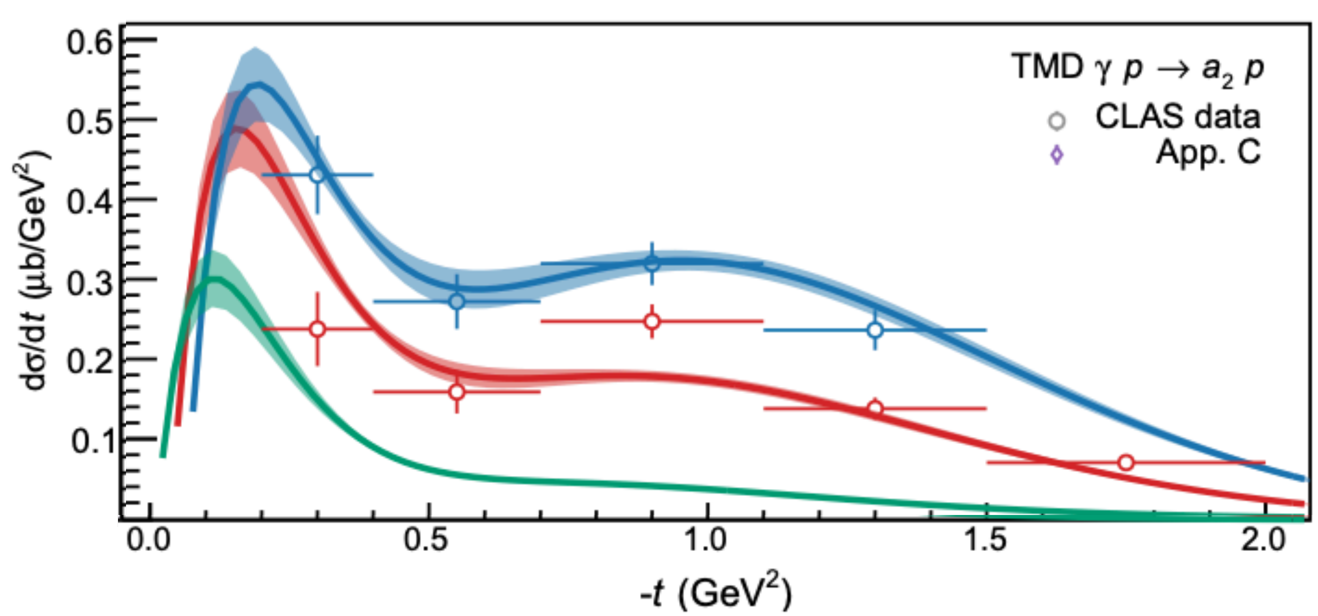
First direct a_2 photoproduction measurement

- Photoproduction studies are very timely considering JLab endeavours.

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

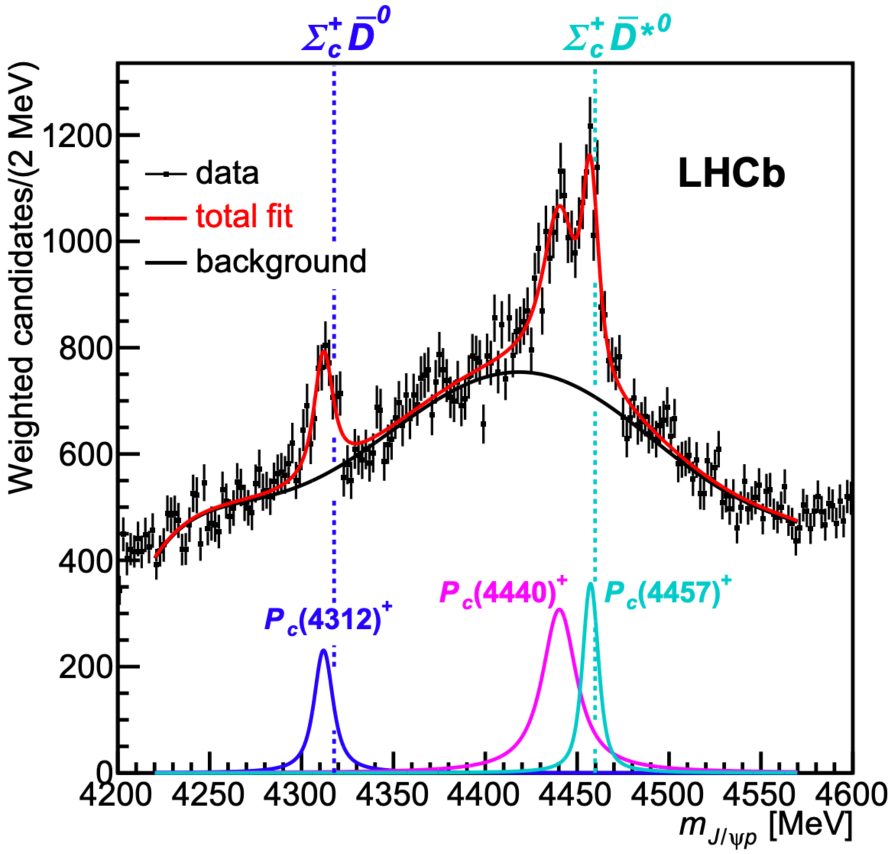
- Regge phenomenology predicts dip in amplitude:
  confirmed in CLAS data!



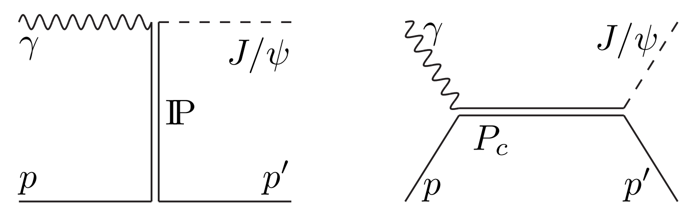


CLAS PRC102 (2020) 032201
JPAC PRD102 (2020) 014003

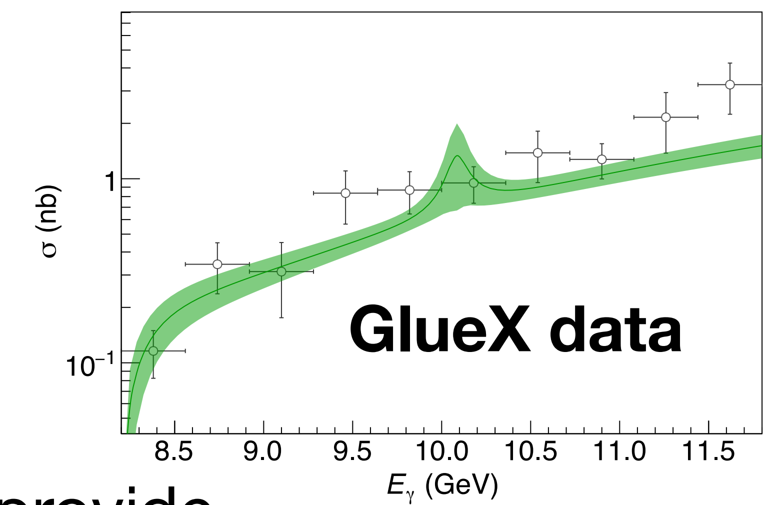
Resonances: pentaquark searches



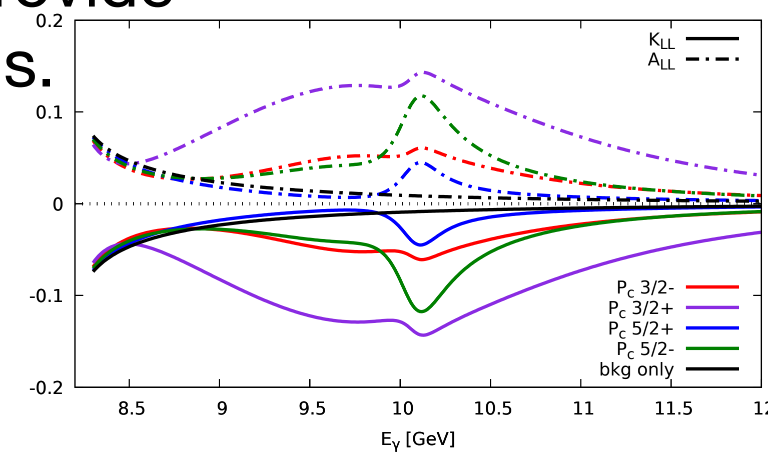
LHCb PRL115 (2015) 072001
LHCb PRL122 (2019) 222001



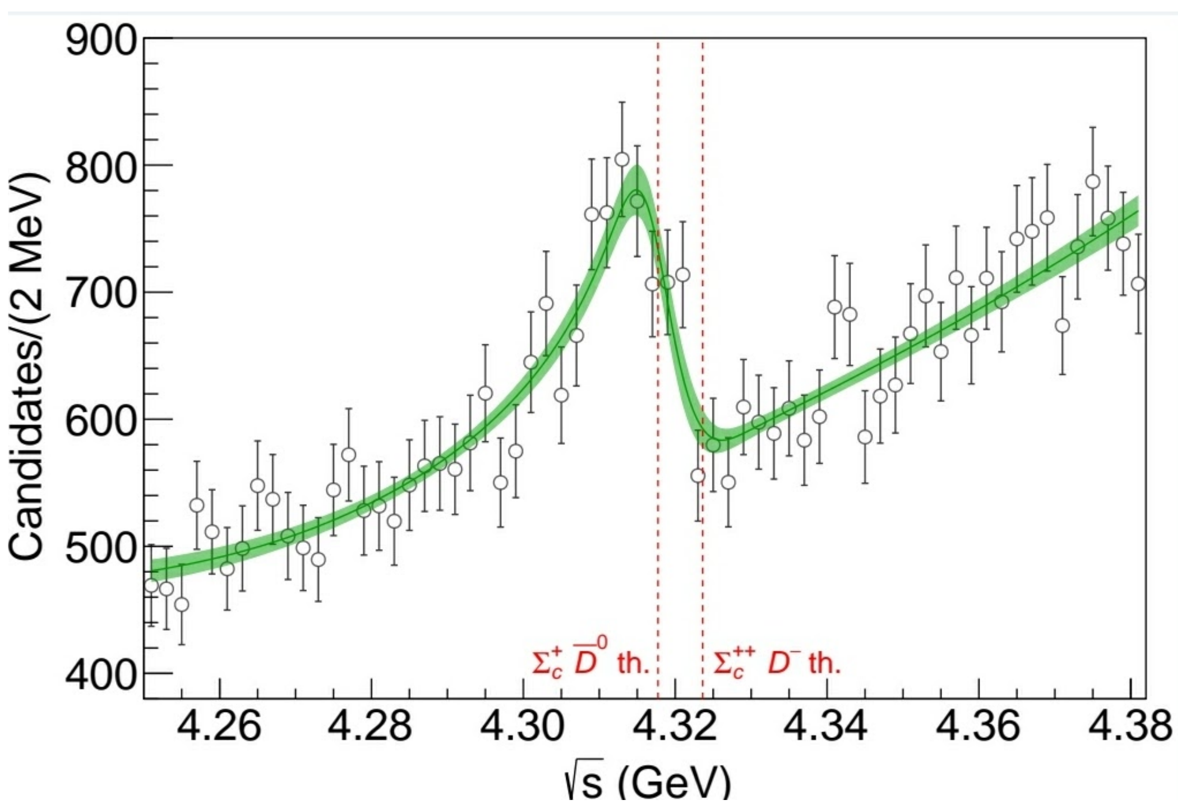
JPAC PRD94 (2016) 034002
JPAC PRD100 (2019) 034019



Polarization observables to provide better sensitivity to signals.



https://github.com/dwinney/jpacPhoto



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

JPAC PRL123 (2019) 092001

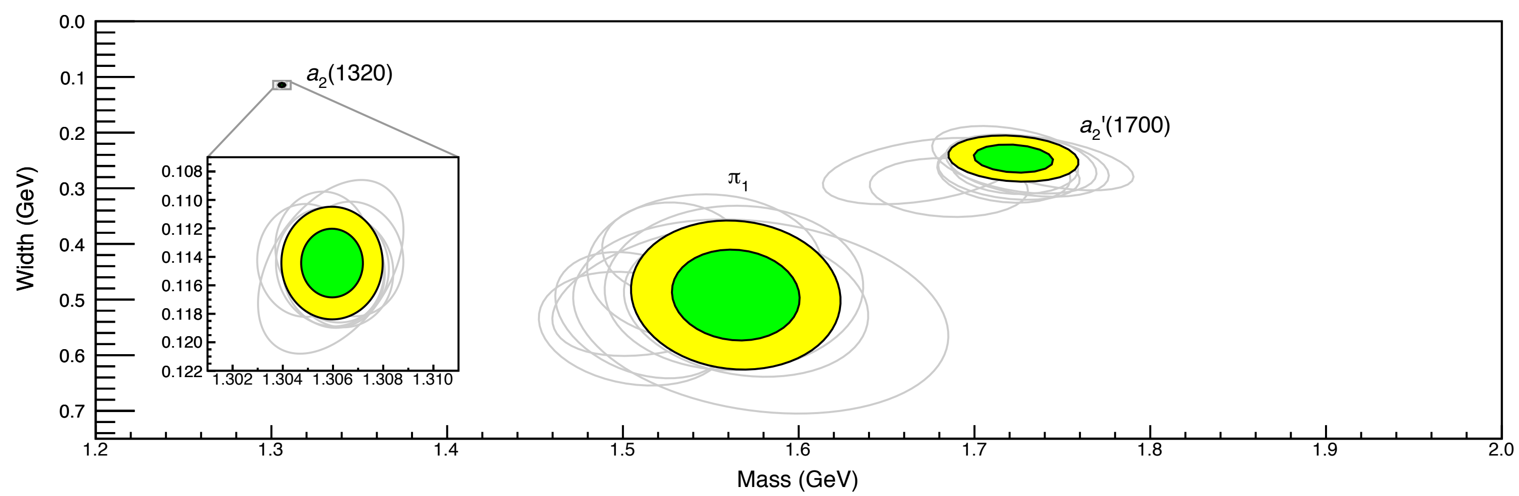
Hunting the hybrid $\pi_1(1600)$

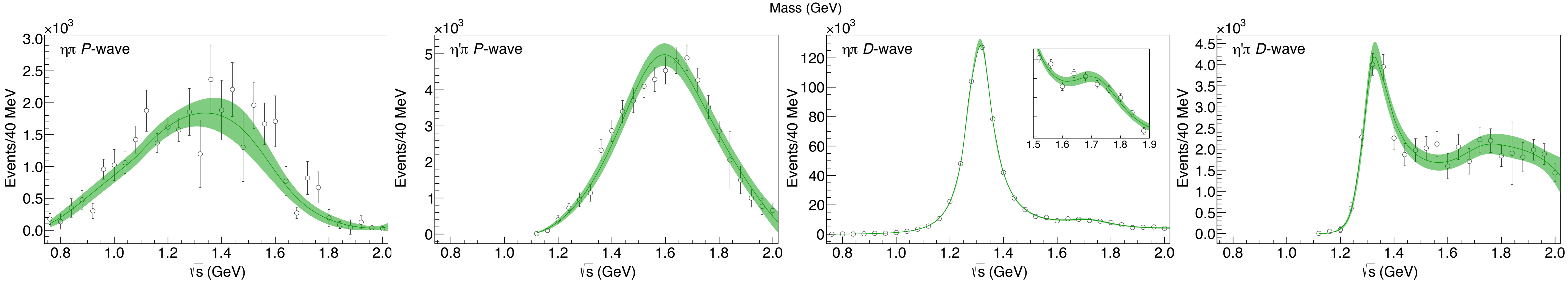
- Experiments announce TWO states, separately coupling to $\eta\pi$ and $\eta'\pi$: Inconsistent with lattice and phenomenology expectations.

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

COMPASS, PLB740 (2015) 303

- Need for a SINGLE pole in P wave: π_1 (two poles show no improvement), two poles in D wave: a_2 and a_2'.





JPAC, PRL122 (2019) 042002

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, …

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