Baryon Spectroscopy with Photoproduction of Mesons at MAMI - Mainz

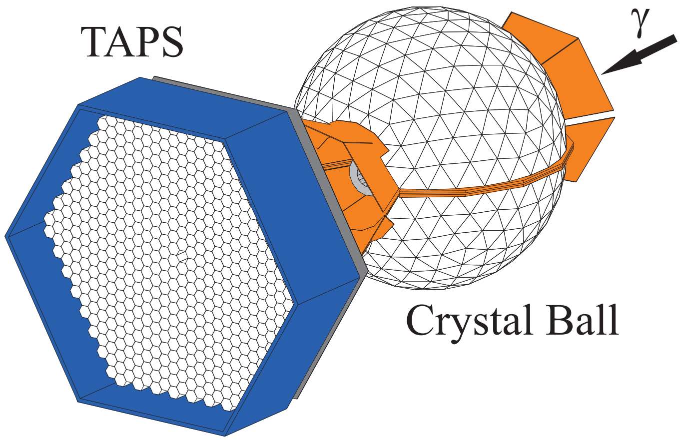
Mainz MAMI accelerator: E<1.6 GeV

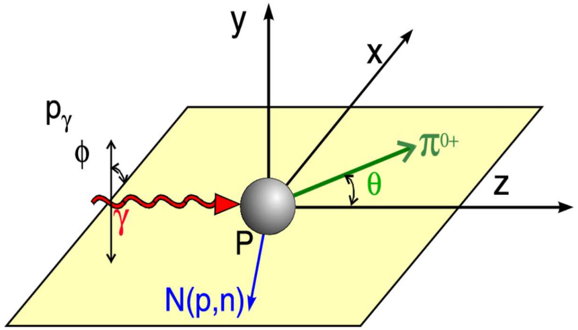
Crystal Ball (NaI), TAPS (BaF_2) forward wall, inner detectors

linearly and circularly polarized photons

Polarized protons, deuterons, ^{3}He

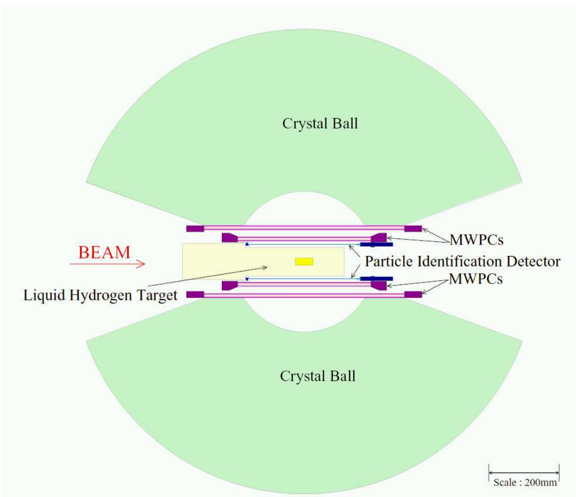
photon polarization	target polarization: -	x	y	z
unpolarized	σ	-	T	-
linearly	Σ	H	-P	-G
circularly	-	F	-	-E





All combinations of beam and target polarization possible!

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\{1 - P_l\Sigma\cos(2\phi) + P_x\left[-P_l H\sin(2\phi) + P_c F\right] - P_y\left[-T + P_l P\cos(2\phi)\right] - P_z\left[-P_l G\sin(2\phi) + P_c E\right]\}$$



Model independent multipole analysis requires measurement of:

4 single polarization observables (σ,Σ,T,P)

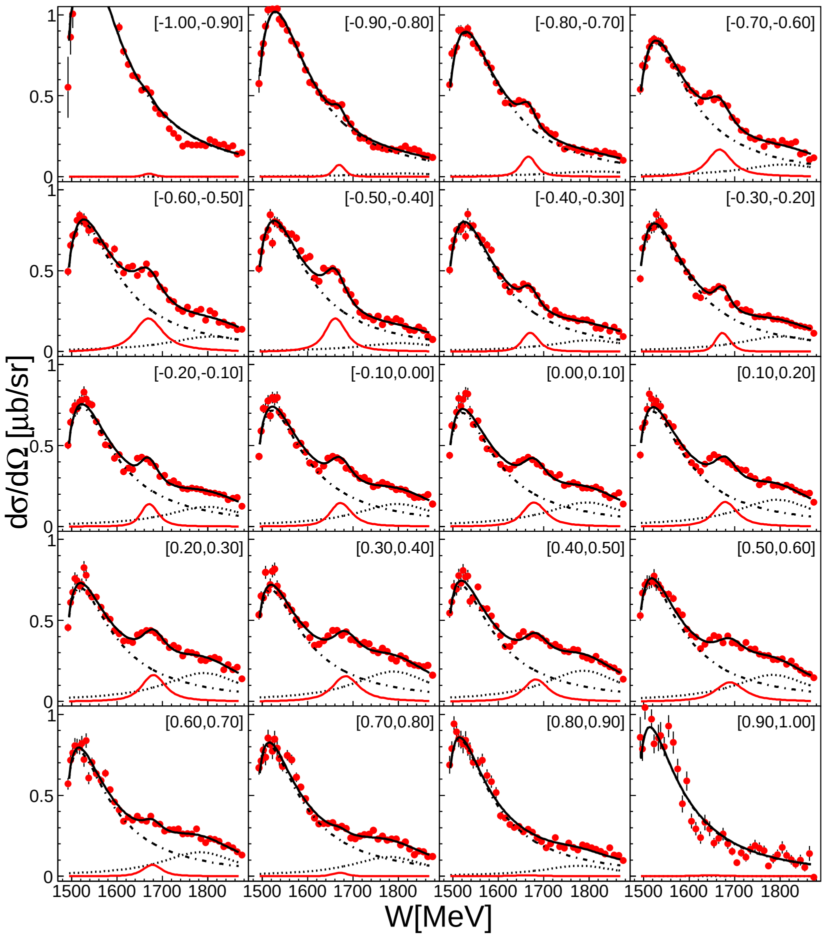
4 carefully chosen double polarization observables

Chiang & Tabakin PRC 55 (1997)

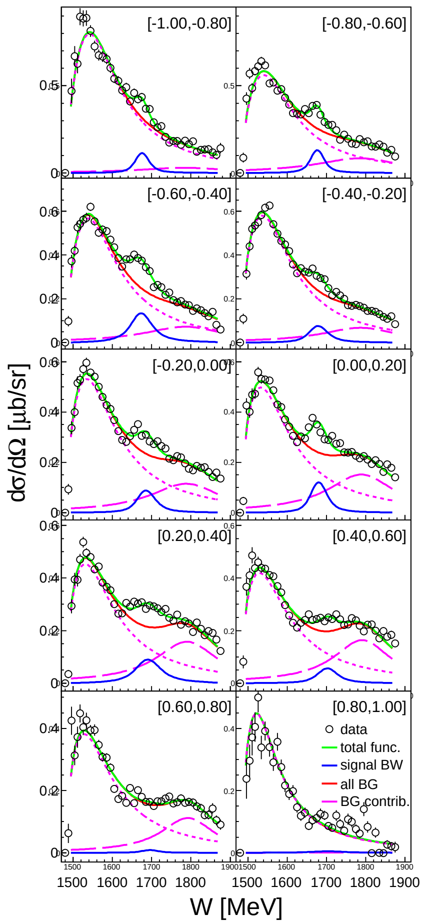
$\gamma n \to n\eta$ - excitations functions for different angular bins

(D. Werthmüller and L. Witthauer et al.)

- **deuteron target**



- **^{3}He target**



Exploraration of polarization observables (beam, target, recoil) to establish a data base allowing almost model independent analyses.

Investigation of different final states including multi-meson production so that coupled-channel analyses can identify excited states decoupled from dominant decays like π^0 emission to the nucleon ground-state.

Investigation of reactions off quasi-free neutrons to establish also the photocouplings for neutron resonances.

- **analysis of polarization observables E, T, F under way**

Why We Need Meson Beams

Bill Briscoe, Michael Döring, Helmut Haberzettl,
*Mark Manley, Megumi Naruki, **Igor Strakovsky**, Eric Swanson*

White Paper in progress

- Reliable **theoretical** and **phenomenological** analyses need **hadron-induced** measurements such as
  πN→πN, ηN, KΛ, KΣ, and
  KN→KN, $\pi\Lambda$, $\pi\Sigma$, $\eta\Lambda$, $\eta\Sigma$, and also **multi-meson** final states.

- Measurements with pion and Kaon beams make possible studies of **baryon** and **meson spectroscopy** that are complementary to programs underway worldwide at major **EM** facilities such as **JLab**, **Mainz**, **SPring-8**, **Bonn**, and elsewhere.

- The **key** instrument is a **coupled-channel** analysis that requires precise data for several channels at many energies and angles.

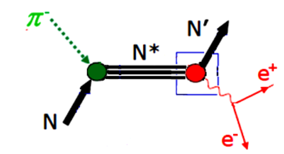
$\pi^- p \to \eta n$

- $\gamma p \to \eta p$ is one of the **key reactions** for which colleagues in the **EM** community hope to do a ``*complete measurement*''.
  Any **coupled-channel analysis** of those measurements will need precise data for $\pi^- p \to \eta n$.
- Most of the available data for that reaction come from measurements published in the **1970**s, which have been evaluated by several groups as being **unreliable** above **1620** MeV.
- Precise new data were measured by the **Crystal Ball** Collaboration (Prakhov 2005), but these extend only up to the peak of the first S_{11}-resonance.

• Very few polarization data for these reactions exist.

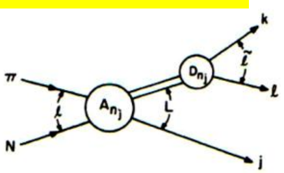
- Available data for $\pi^- p$ reactions with **KY**, **η'N**, **ωN**, and **ϕN** final states are generally as **bad** or **worse**.

$\pi^- p \to e^+ e^- n$



- **IPE** is the **only process** that allows the determination of **EM nucleon** and **pion form-factors** in the intervals: $0 < k^2 < 4\,M^2 = 3.53$ GeV^2 $0 < k^2 < 4\,m_\pi^2 = 0.08$ GeV^2 which are **kinematically unattainable** from e^+e^- initial state.
- **IPE** measurements will significantly complement **electroproduction** $\gamma^* N \to \pi N$ studies.

$\pi N \to \pi\pi N$



- For most established **N** and **Δ** resonances, their dominant inelastic decays are to **ππN** final states. A large experimental **database** (including **pol** measurements) is **needed** to determine precisely the PW amplitudes because so many amplitudes are needed to describe **three-body** final states.
- **241,214** **Bubble Chamber** events for $\pi N \to \pi\pi N$ have been analyzed in **Isobar-model PWA** at W = **1320 to 1930** MeV [Manley, Arndt *et al* Phys Rev D **30**, 904 (1984)] .
- This **30**-yr old result remains the main source of our knowledge about $\pi N \to \pi\pi N$.

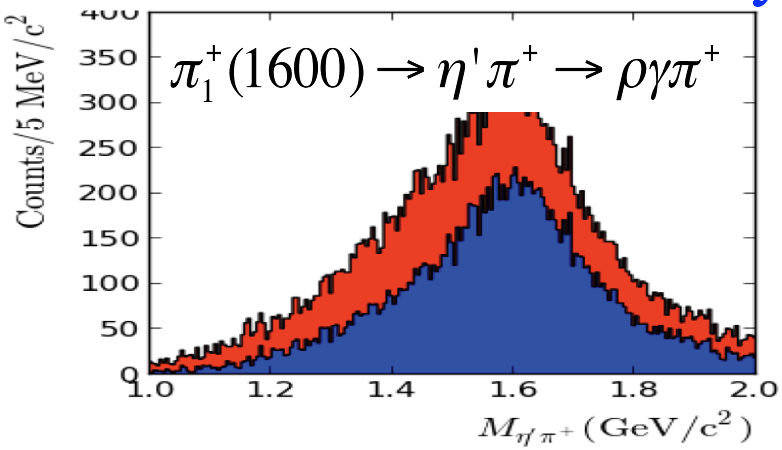
- The **Hadronic Complex** can longer keep the **JLab** *MEIC* **pre-Booster** and **Linac** busy [to use more than ``**several minutes**'' a day], which would be much more effective use of the *MEIC* facility.

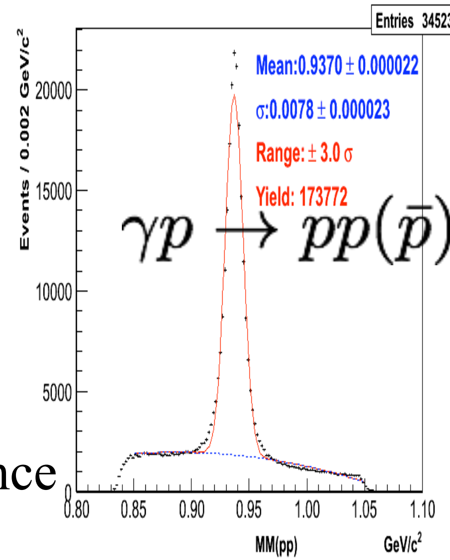
Hadron Spectroscopy at FIU: Some New Opportunities

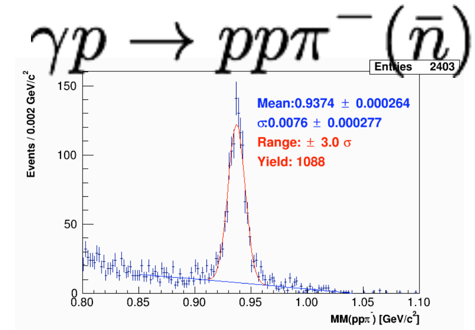
Lei Guo

Florida International University, Miami, FL

Searching for Missing States
Exotic Meson/Baryon-Antibaryon/Cascades

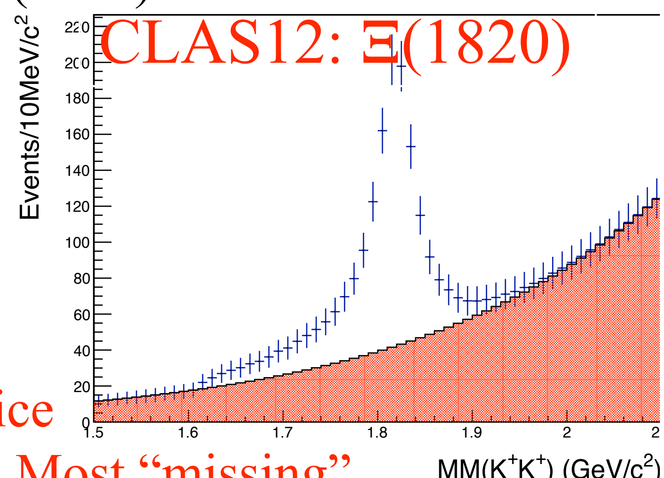


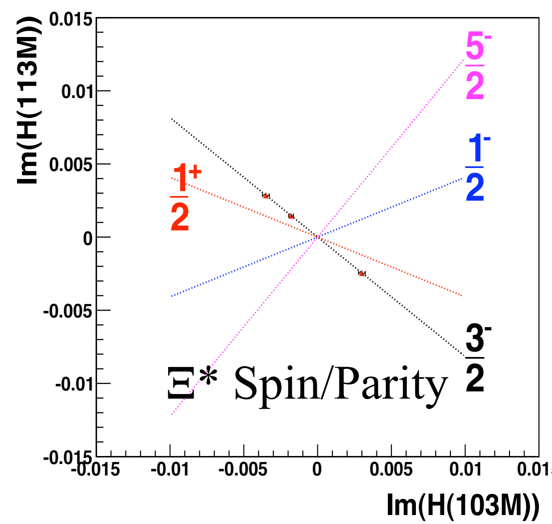




- High mass mesons >2GeV decaying to $N\bar{N}$
- Puzzle: Abundance
- PWA/Xsection ongoing, W. Phelps, Thesis (2016)

- ◆ π_1(1600) remain the strongest evidence
- ◆ Recent COMPASS results
- ◆ GlueX: E. Pooser, Thesis (2015)

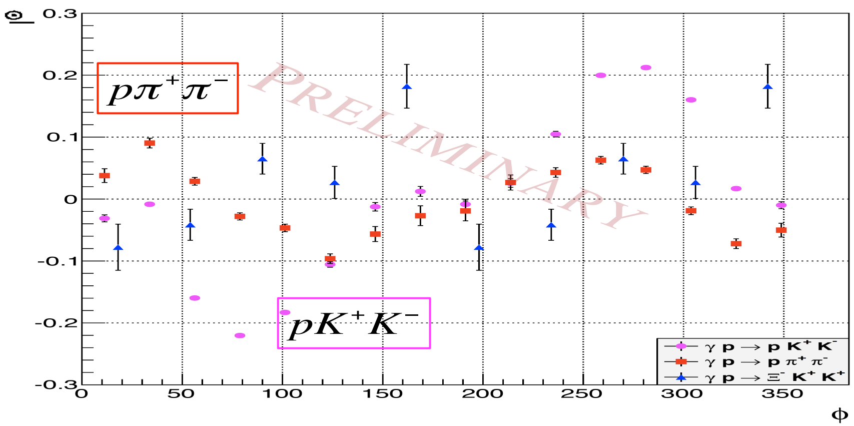


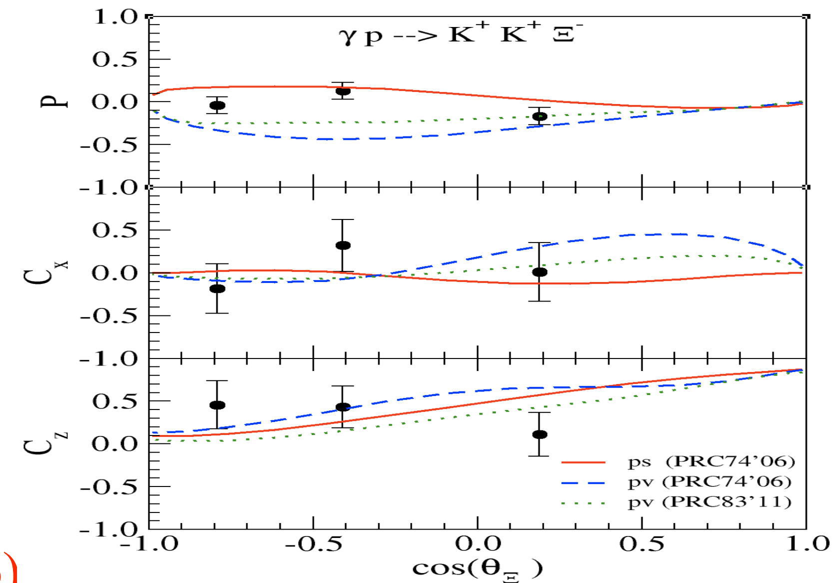


- GlueX/CLAS12 expect unprecedented statistics for Ξ* and Y*
- Exclusive reactions
- PWA/DMA feasible: J^P
- Comparison with QM/Lattice
  - Many predicted states; Most "missing"
  - Typically narrower

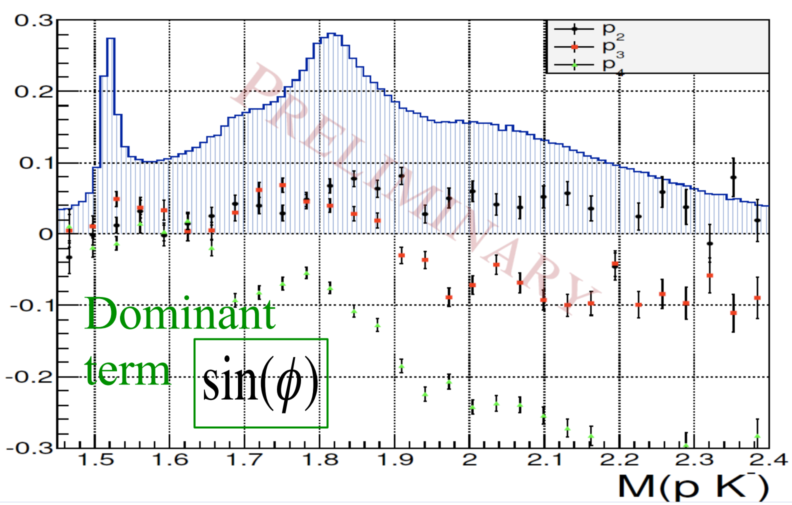
Polarization Observable:

$\gamma p \rightarrow K^+ K^- p$ and $\gamma p \rightarrow K^+ K^+ \Xi^-$

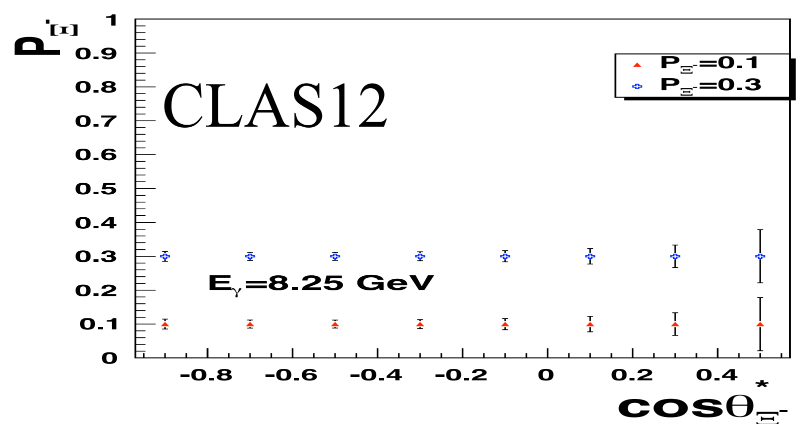




- Beam helicity asymmetry two Kaon photoproduction, R. Badui, Thesis(2016)



Induced/transferred polarization of Ξ^- in photoproduction, J. Bono, Thesis (2014)

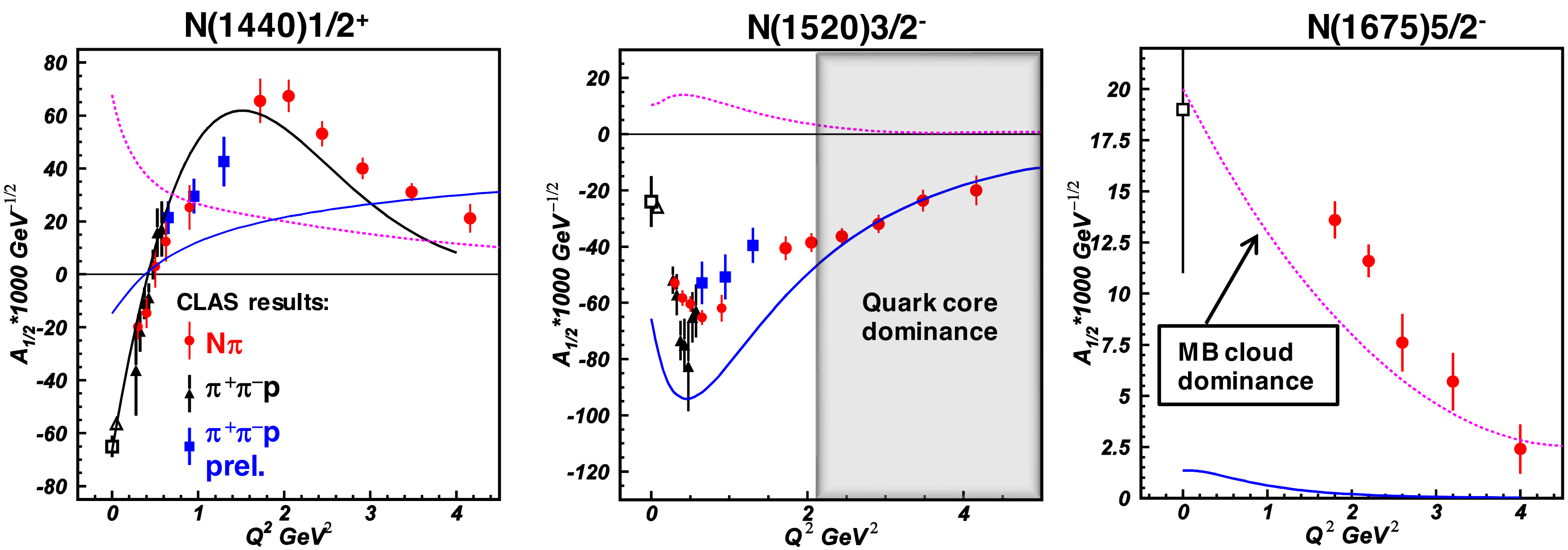


Polarization observables are essential in understanding the production mechanisms

The Need to Extend the Studies of N* Structure

Studies of N*-electrocouplings over a broad range of photon virtuality Q^2 offer unique information on the non-perturbative strong interaction that determines the structure of different excited nucleons.

Insight on N* structure from the CLAS@JLAB data on exclusive meson electroproduction (Review papers: I.G. Aznauryan & V.D. Burkert, Progr. Part. Nucl. Phys. 67 (2012) 1; I.G.Aznauryan et al., Int. J. Mod. Phys. E22 (2013) 1330015) .



Meson-baryon cloud and quark core

Meson-baryon cloud

Quark core

Consistent results on N*-electrocouplings from independent analyses of different meson electroproduction channels suggest reliable extraction of these fundamental quantities.

Complex interplay between internal core of three dressed quarks and external meson-baryon cloud in the structure of N* states is strongly dependent on the resonance quantum numbers.

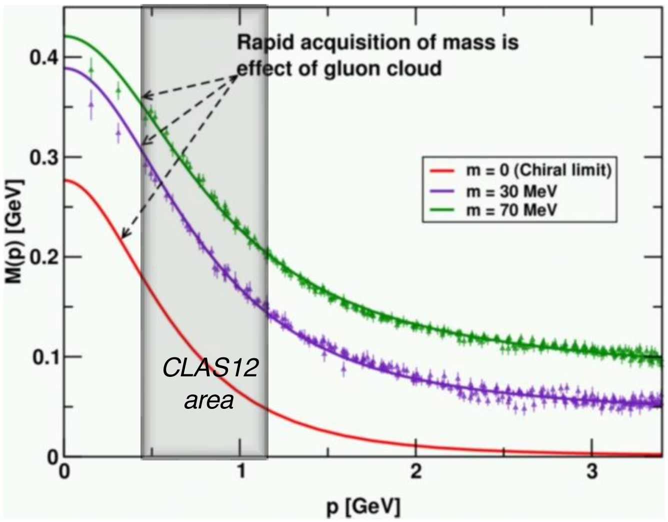
- **Growth of relative quark core contribution with Q^2 in gradual transition to <u>almost unexplored domain of quark core dominance at Q^2>5.0 GeV^2.</u>**

N* Structure at High Photon Virtualities in Exploration of Strong Interaction

CLAS12 is the only facility foreseen in the world capable of determining electrocouplings of all prominent N* at $5<Q^2<12$ GeV^2. For the first time, almost direct access to the quark core at the distances where the transition from quark-gluon confinement to perturbative QCD regime is expected.

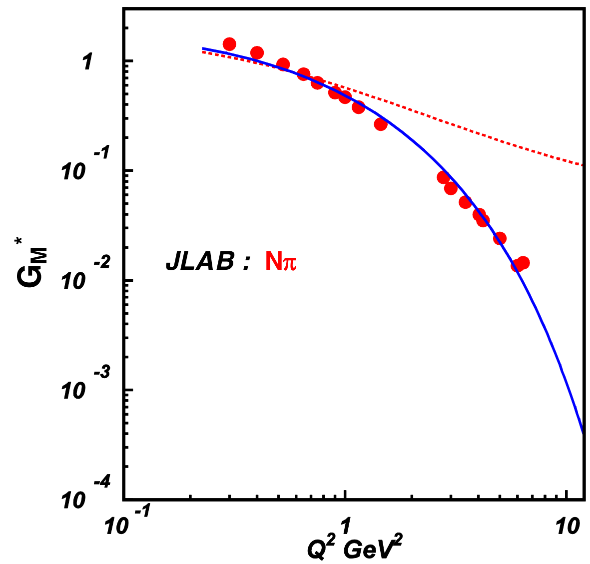
Dressed quark mass function

C.D. Roberts, Prog. Part. Nucl. Phys. (2008) 50.



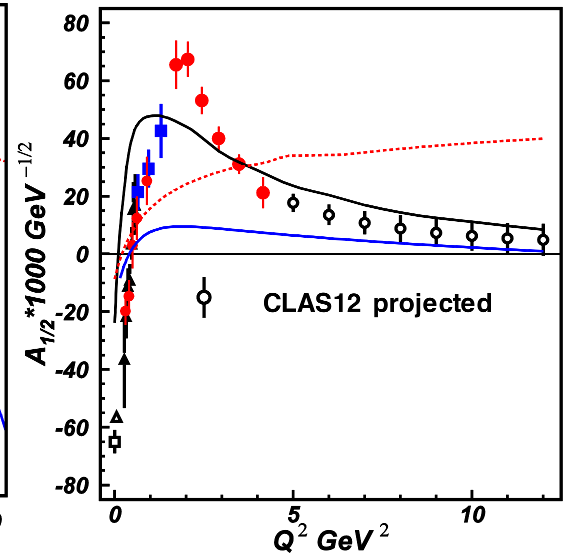
Δ(1232)3/2⁺
Jones-Scadron convention

J. Segovia et al., arXiv:1408,2919 [nucl-th].



N(1440)1/2 ⁺

D.J. Wilson et al., Phys. Rev C85 (2012) 045205 DSEQCD.
I.G. Aznauryan & V.D. Burkert, Phys. Rev. C85 (2012) 055202 LF QM.



Consistent results on quark mass function from electrocouplings of different resonances at $Q^2 > 5$ GeV^2:

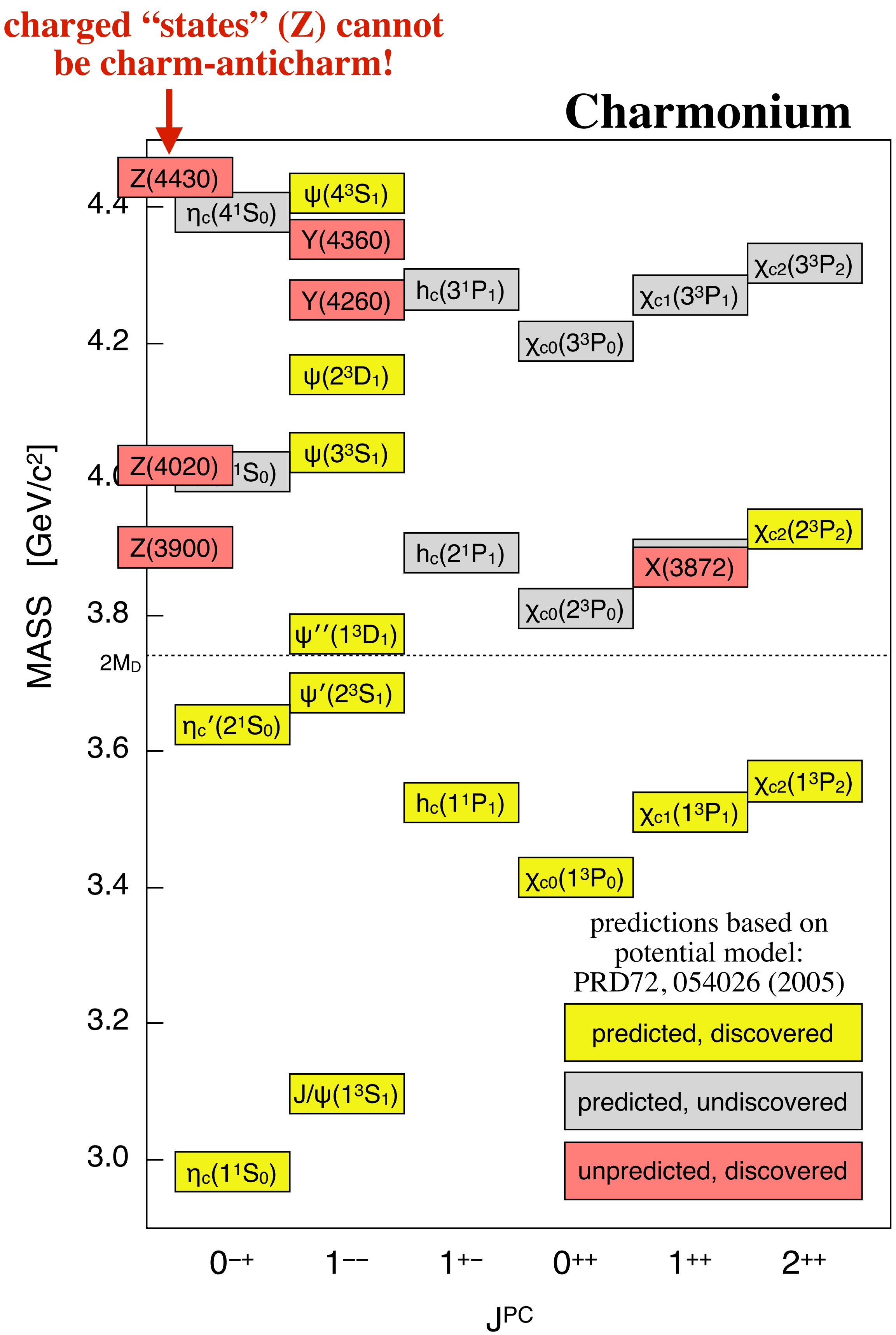
- **will prove relevance and reliable access to this fundamental ingredient;**
- ***address two of the most challenging problems in the Standard Model: the emergence of the dominant part of hadron masses and quark-gluon confinement.***

DSEQCD : (quark core only) ········ *constant quark mass.* —— *running quark mass.*

Light Front Quark Model (quark core & MB cloud) —— *running quark mass from DSEQCD.*

Studies of Nucleon Resonance Structure from the exclusive meson electroproduction experiments with CLAS12@JLAB offer an important contribution to the Long Range Plan.

1. XYZ "States" in Charmonium and Bottomonium



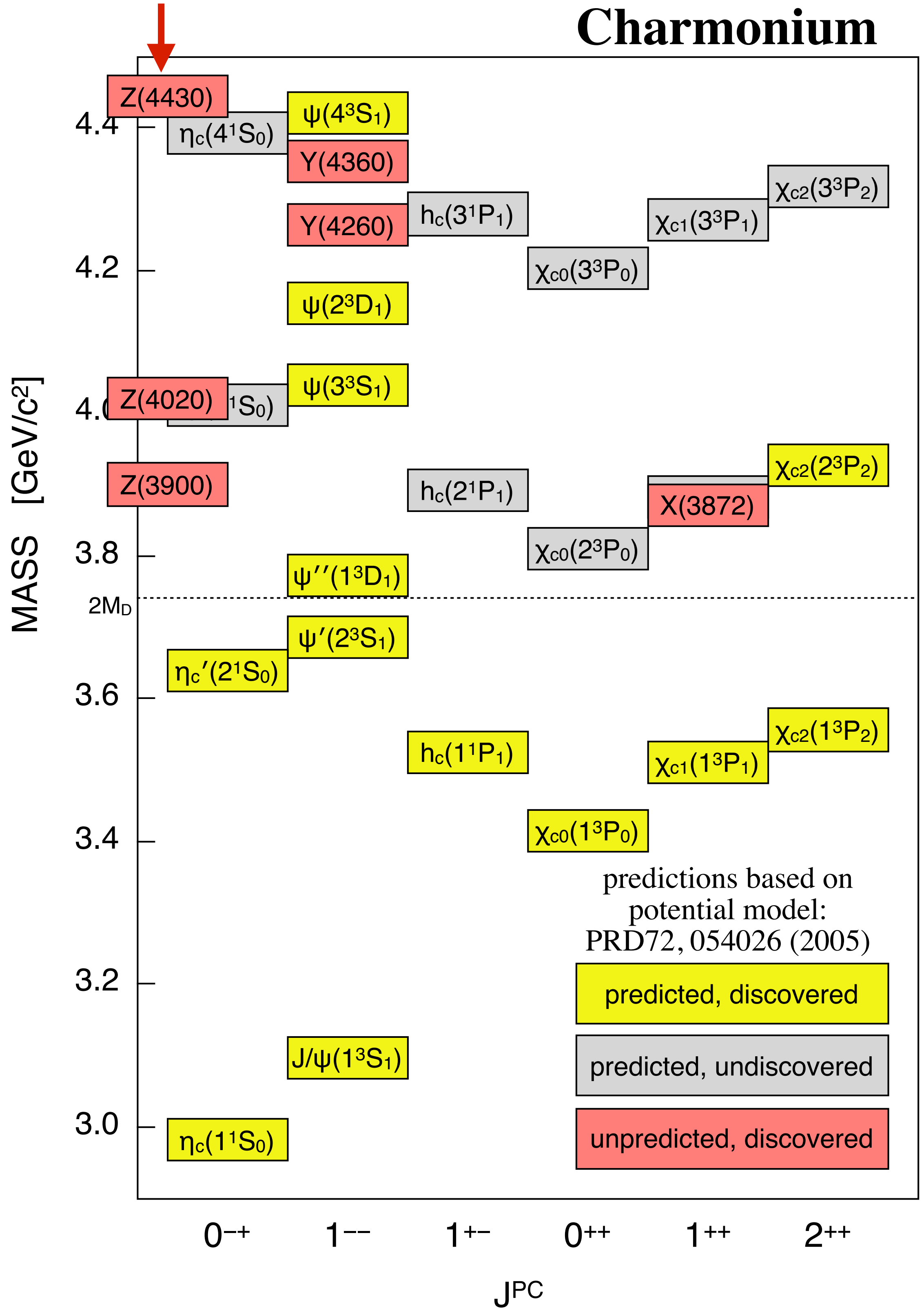
A. Charmonium and bottomonium are simple quark-antiquark bound states in which both potential models and QCD calculations work remarkably well below open-flavor threshold.

B. Experiment indicates a variety of phenomena above open-flavor threshold (the "XYZ") in which this simple quark-antiquark picture breaks down.

C. This is a prime opportunity to study meson spectroscopy, meson-meson interactions, and QCD in general in a region that is still simple, but beyond quark-antiquark dynamics.

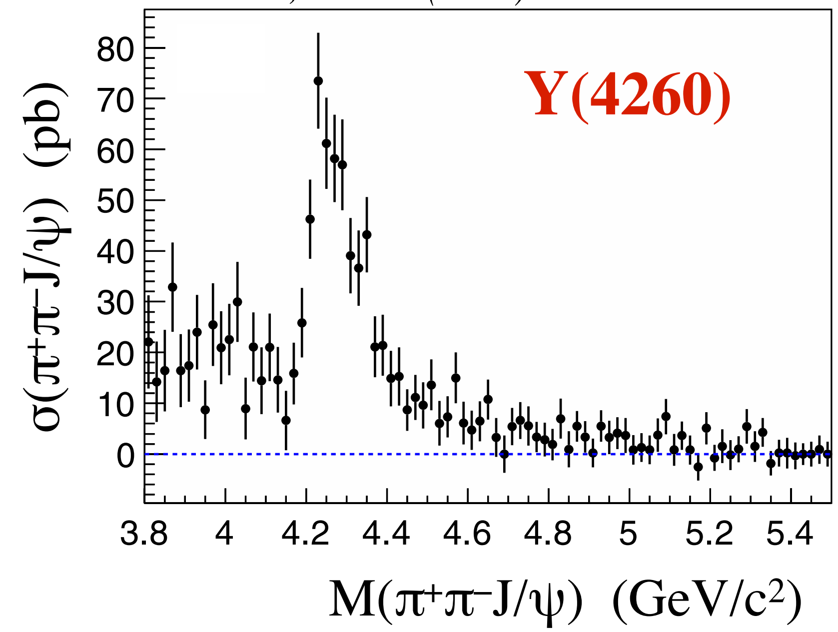
2. The Status of Experiment *(by example)*

charged "states" (Z) cannot be charm-anticharm!



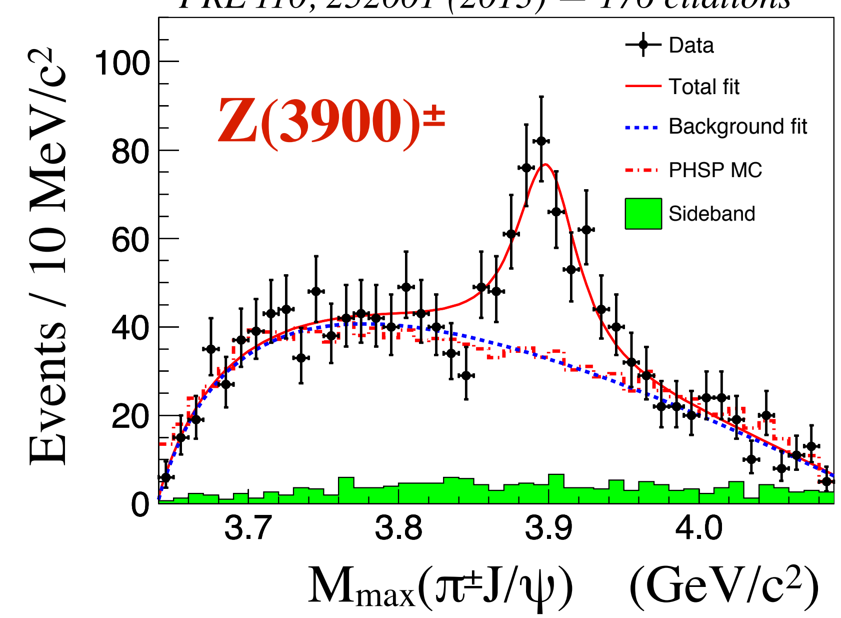
A. $e^+e^-(\gamma_{ISR}) \rightarrow \pi^+\pi^- J/\psi$ at Belle

PRL 110, 252002 (2013) — 148 citations



B. e^+e^- (at 4.26 GeV) $\rightarrow \pi^+\pi^- J/\psi$ at BESIII

PRL 110, 252001 (2013) — 176 citations



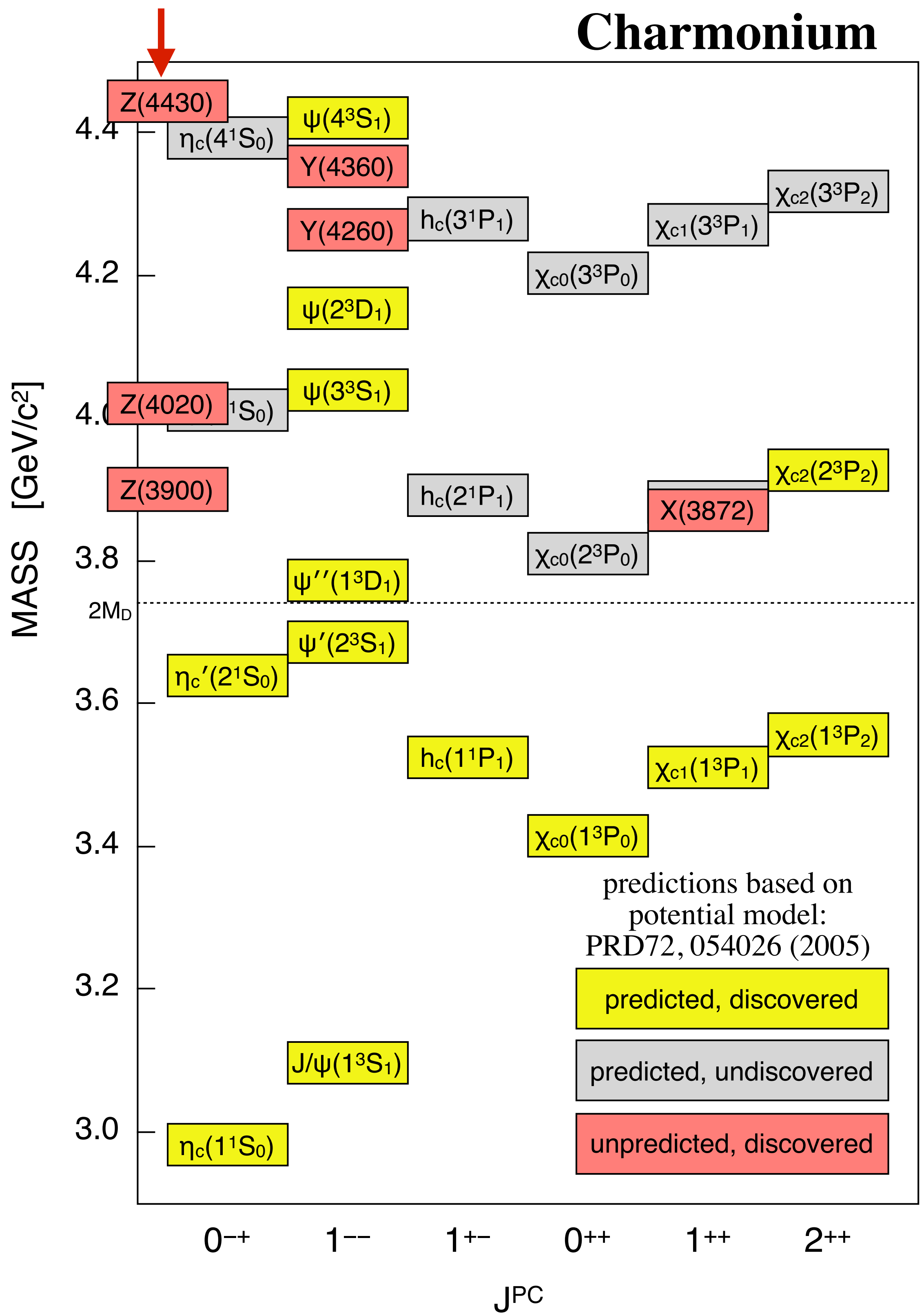
D. Patterns are emerging!

C. Striking parallels in bottomonium:

$Y(4260) \rightarrow Y_b(10890)$, $Z(3900) \rightarrow Z_b(10600)$, $Z(4020) \rightarrow Z_b(10650)$

3. The Outlook for Experiment

charged "states" (Z) cannot be charm-anticharm!



A. To progress, Belle, BaBar, BESIII, LHCb, etc. will keep adding pieces to the puzzle.

B. Two experiments are especially unique and timely:

B1. **Belle-II**

facts	broad QCD topics
KEK, Tsukuba, Japan	bottomonium
e^+e^- in bottomonium	ISR to charmonium
50× data of Belle	charmonium in bottomonium and B decays
start date in 2018	

B2. **BESIII**

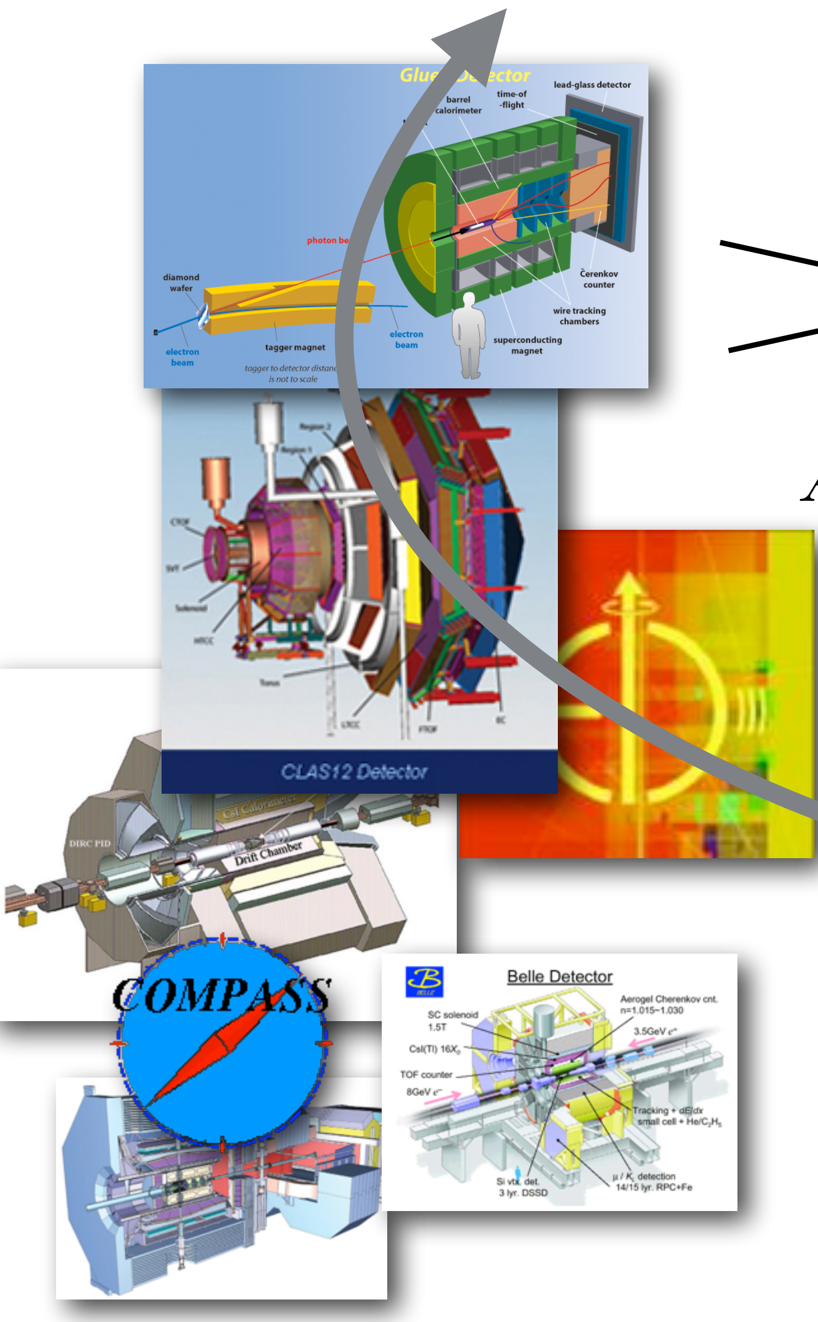
facts	broad QCD topics
IHEP, Beijing, China	charmonium
e^+e^- in charmonium	ISR to light quarks
running since 2009	light quarks in charmonium and D decays
10 more years?	

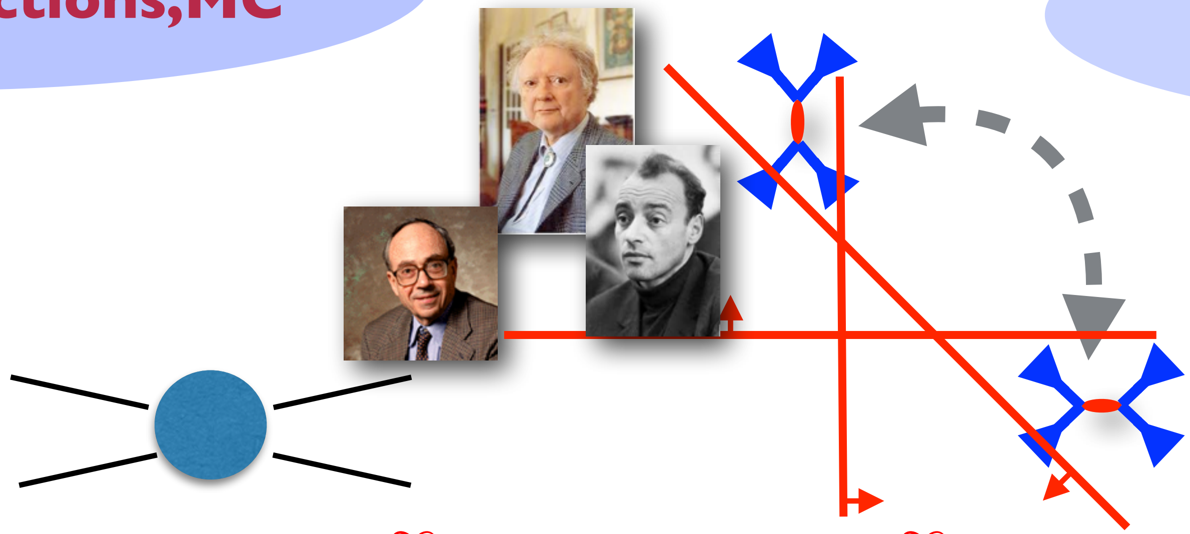
C. The puzzle of the XYZ's seems imminently solvable, which would push QCD studies of mesons beyond quark-antiquark dynamics.

D. These efforts will provide critical input to similar programs in the light quark sector (e.g. GlueX at JLab).

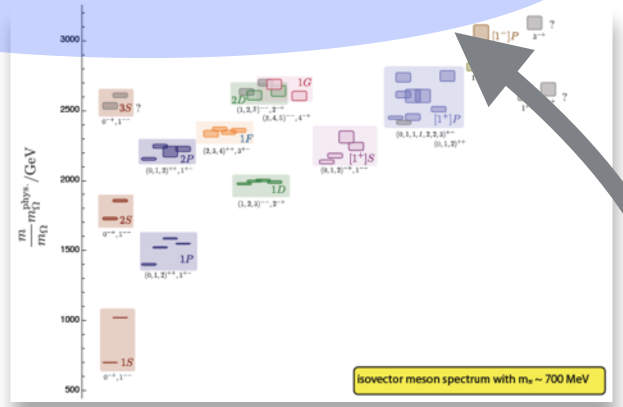
Support Amplitude Analysis !

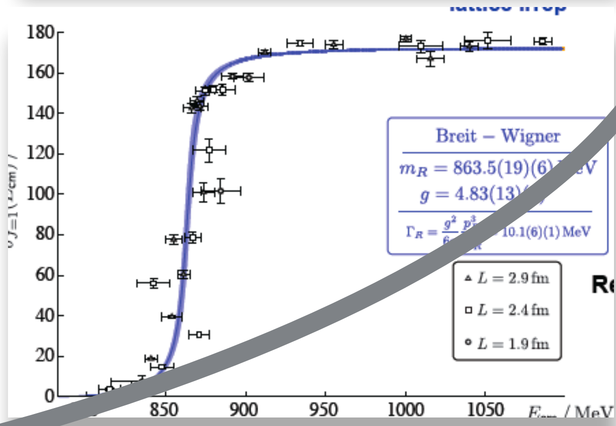
Events, X-sections,MC





QCD Predictions





$$A(s,t)=\sum_{l=0}^{\infty} f_l(s)P_l(z_s)=\sum_{l=0}^{\infty} g_l(t)P_l(z_t)$$

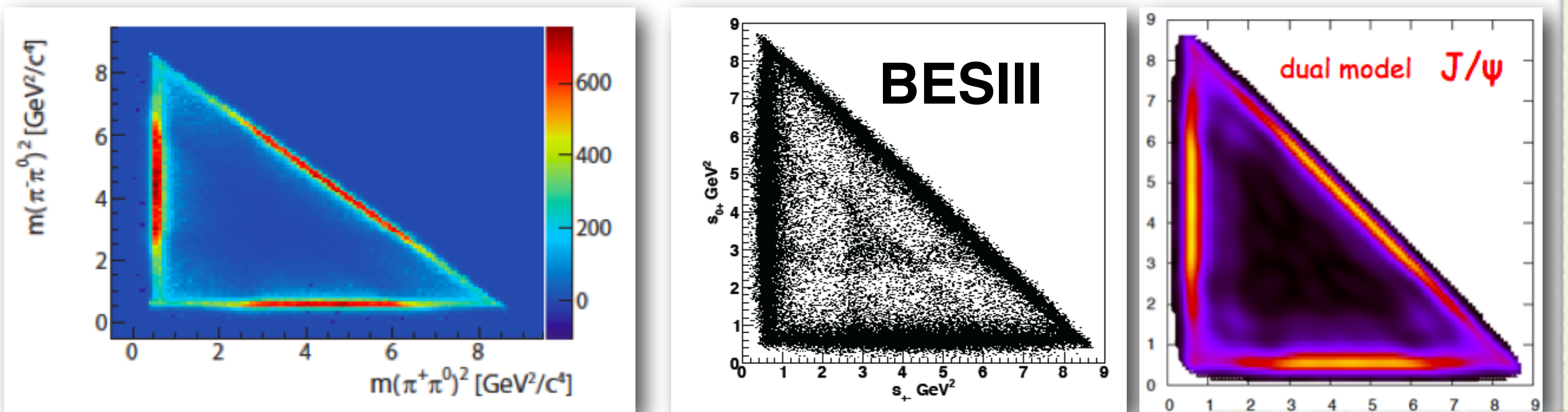
Amplitude analysis:
based on S-matrix principles:

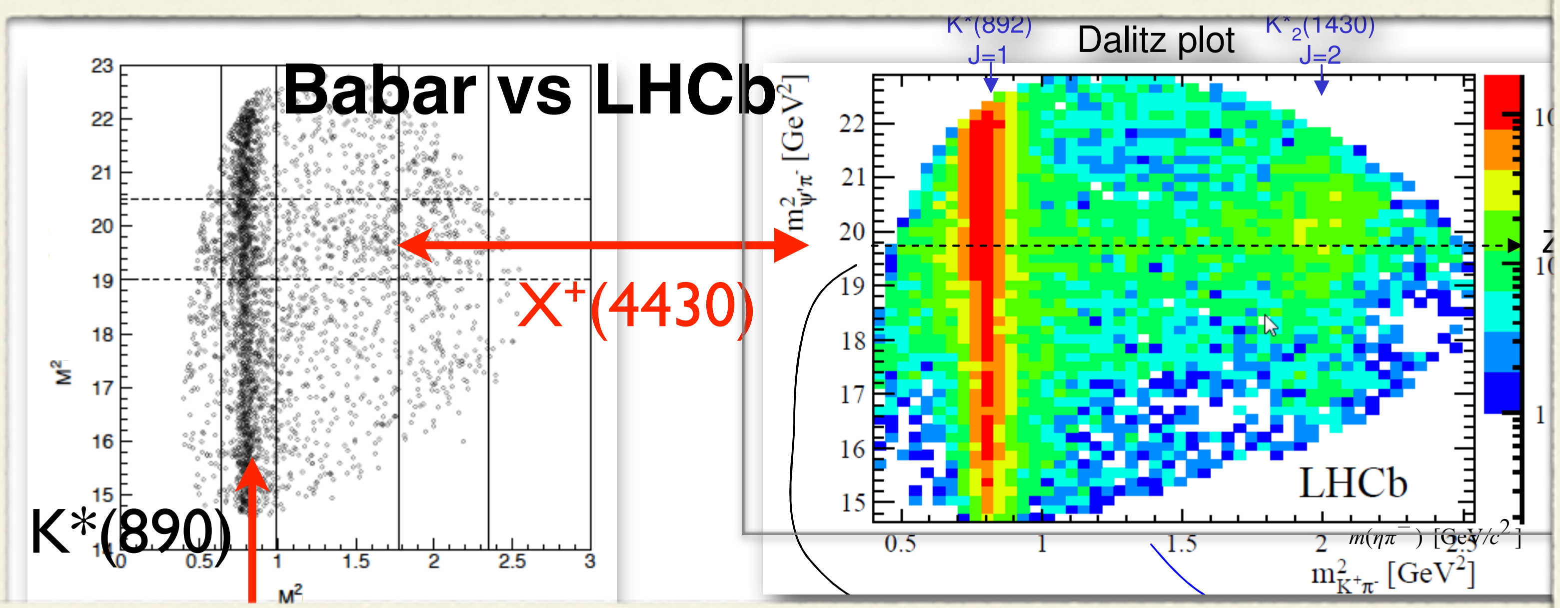
- analyticity
- unitarity
- crossing

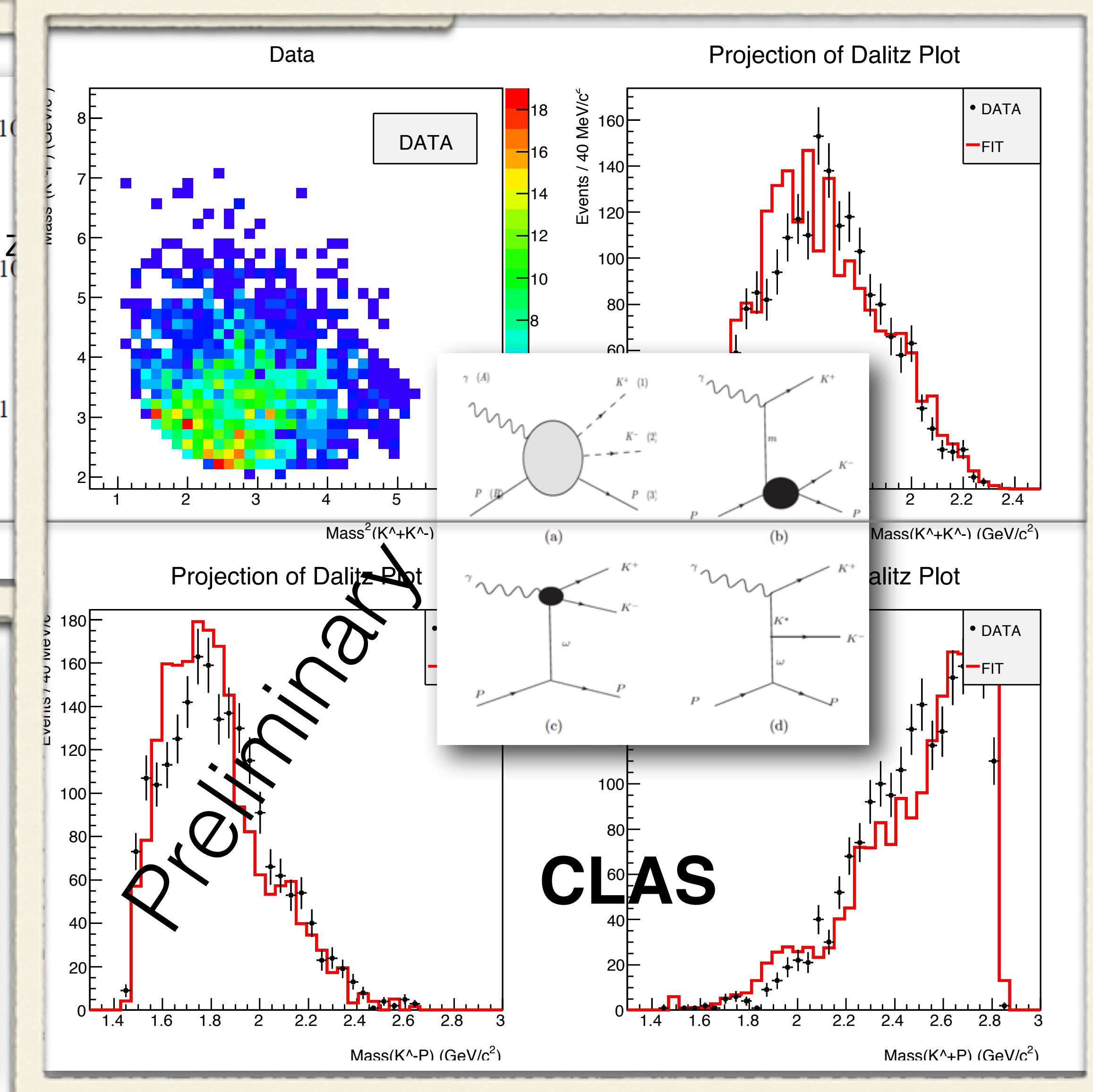
Physics of interest: form factors, GPD's, resonance parameters, etc. resides outside experimentally accessible range of kinematic variables.

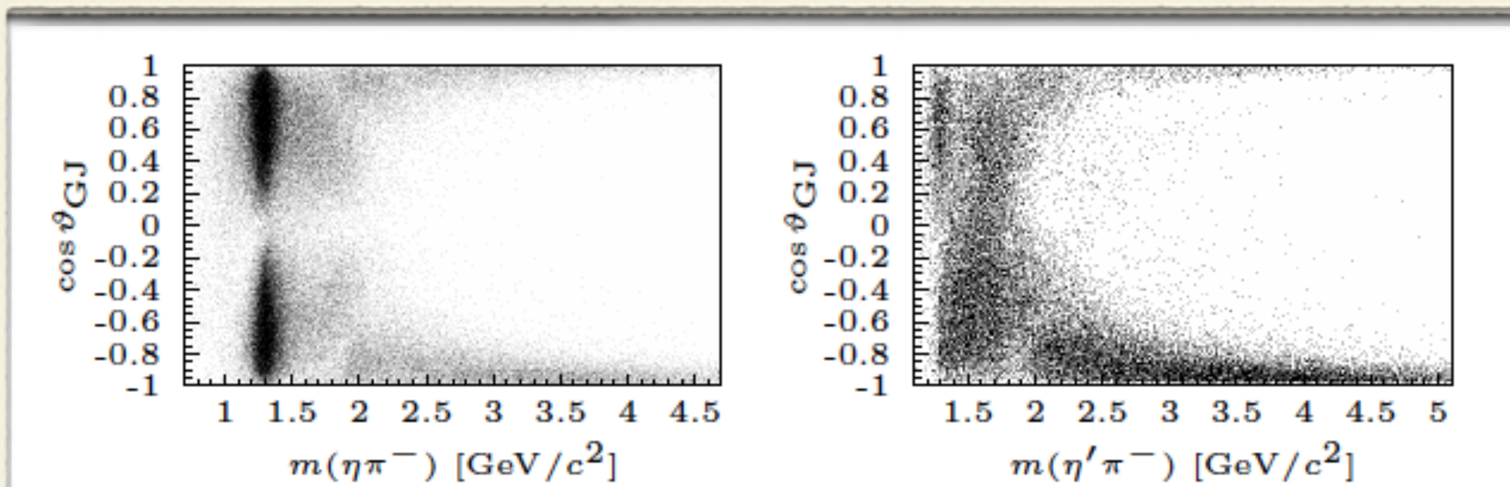
Global effort
JLab/IU/GWU Physics Analysis Center

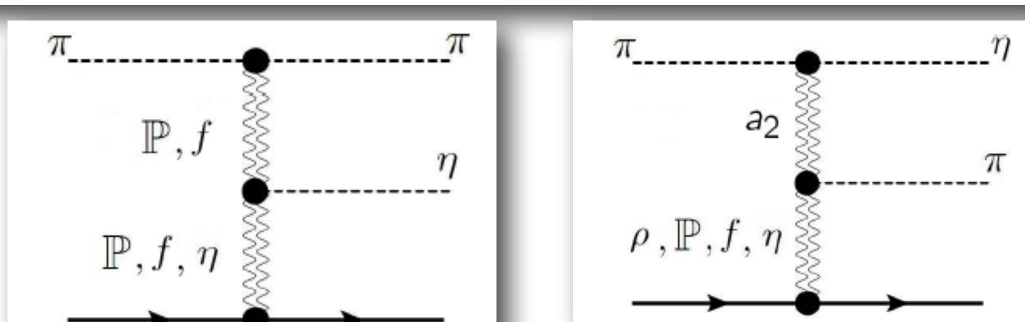
Amplitude analysis:examples











1-+ Exotic COMPASS