Amplitude Analysis in GlueX

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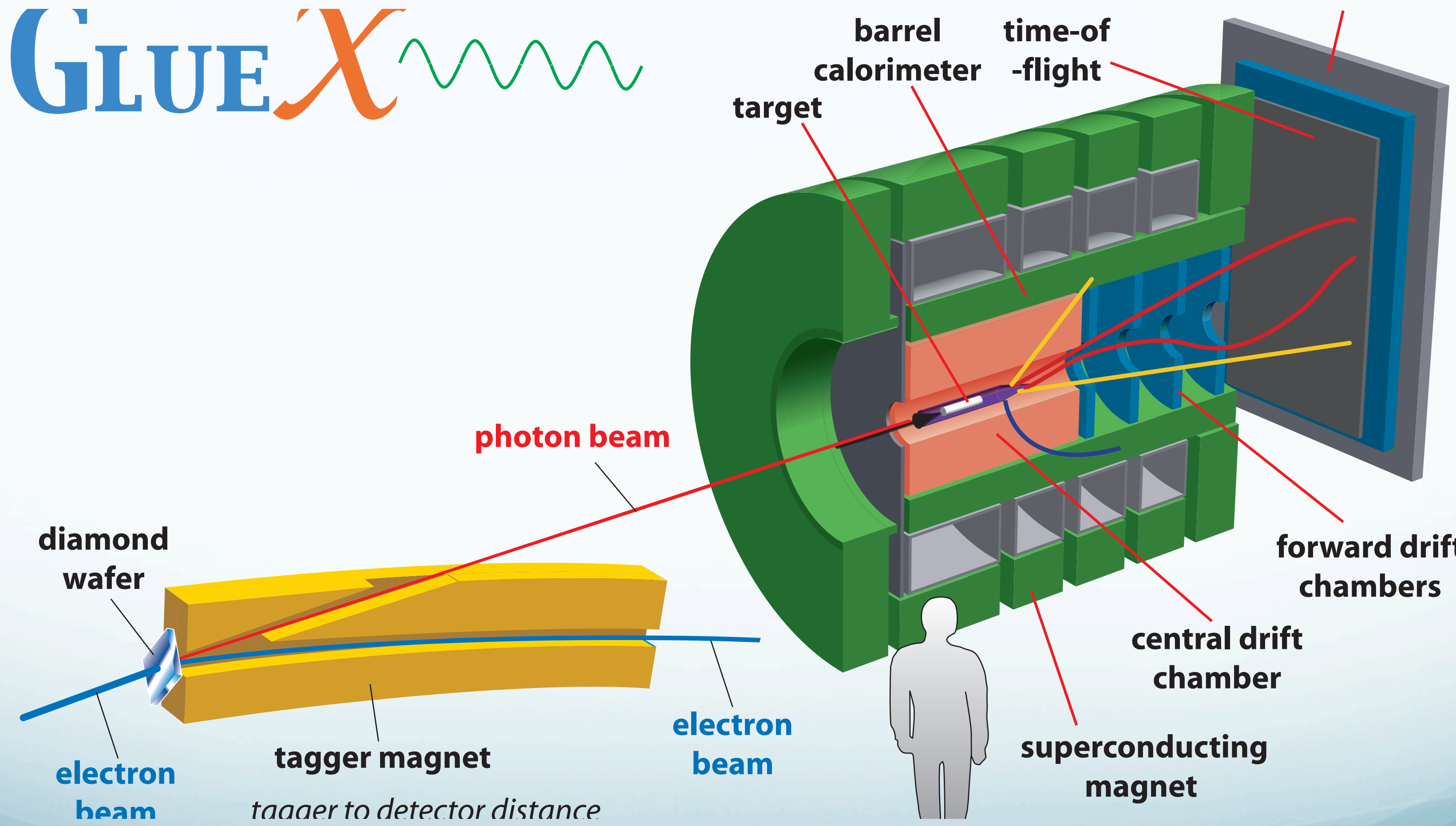
Outline

- The GlueX Detector
- Hybrid Mesons (LQCD)
- Hybrid Mesons (Decays)
- Physics Analyses
- Summary

The GlueX Experiment

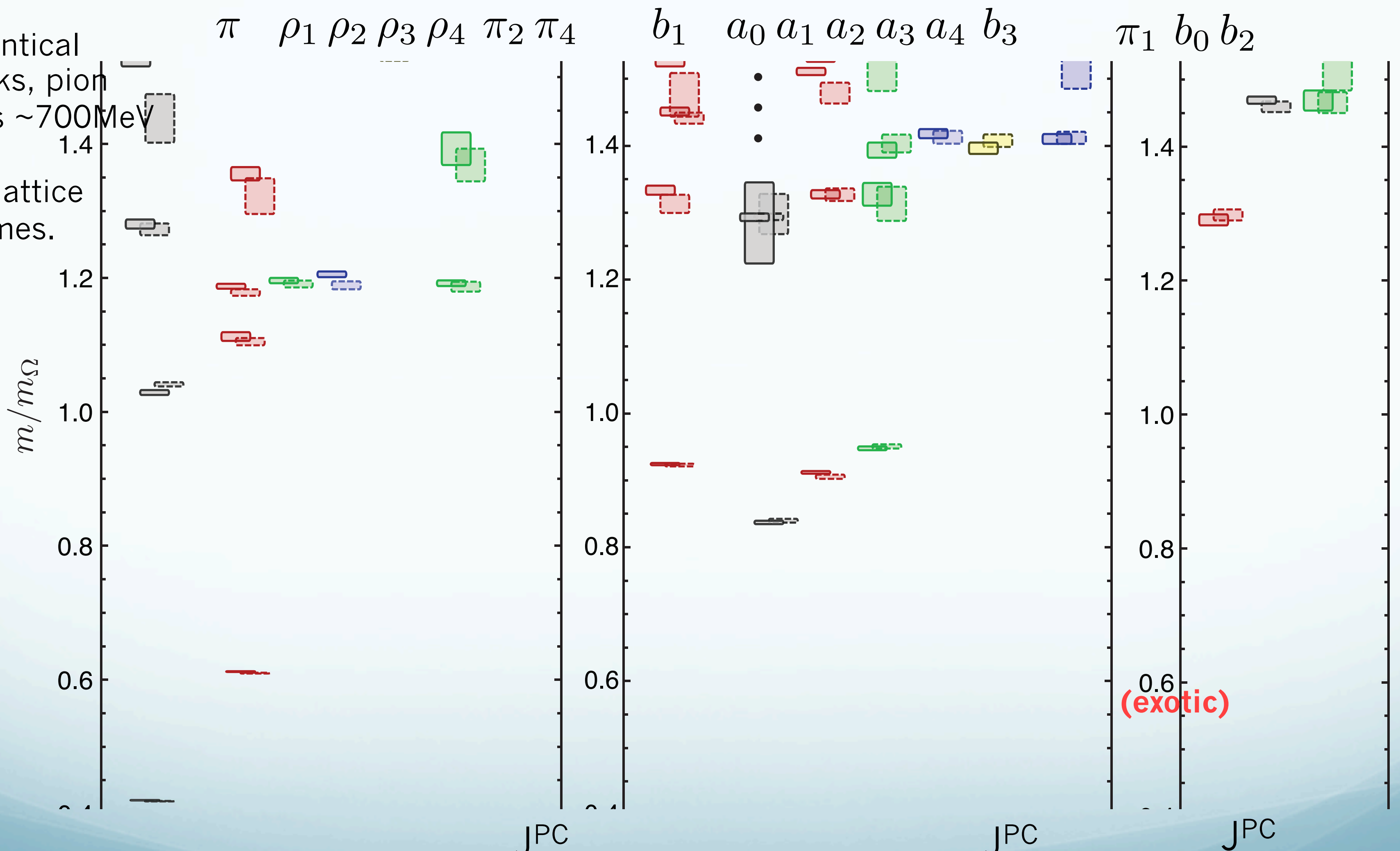


LQCD: The Spectrum of Mesons

Dynamical calculation of the isospin-one light-quark mesons.

3 identical quarks, pion mass ~700MeV

Two lattice volumes.



J.J. Dudek (et al.) Phys. Rev. D82, 034508 (2010)

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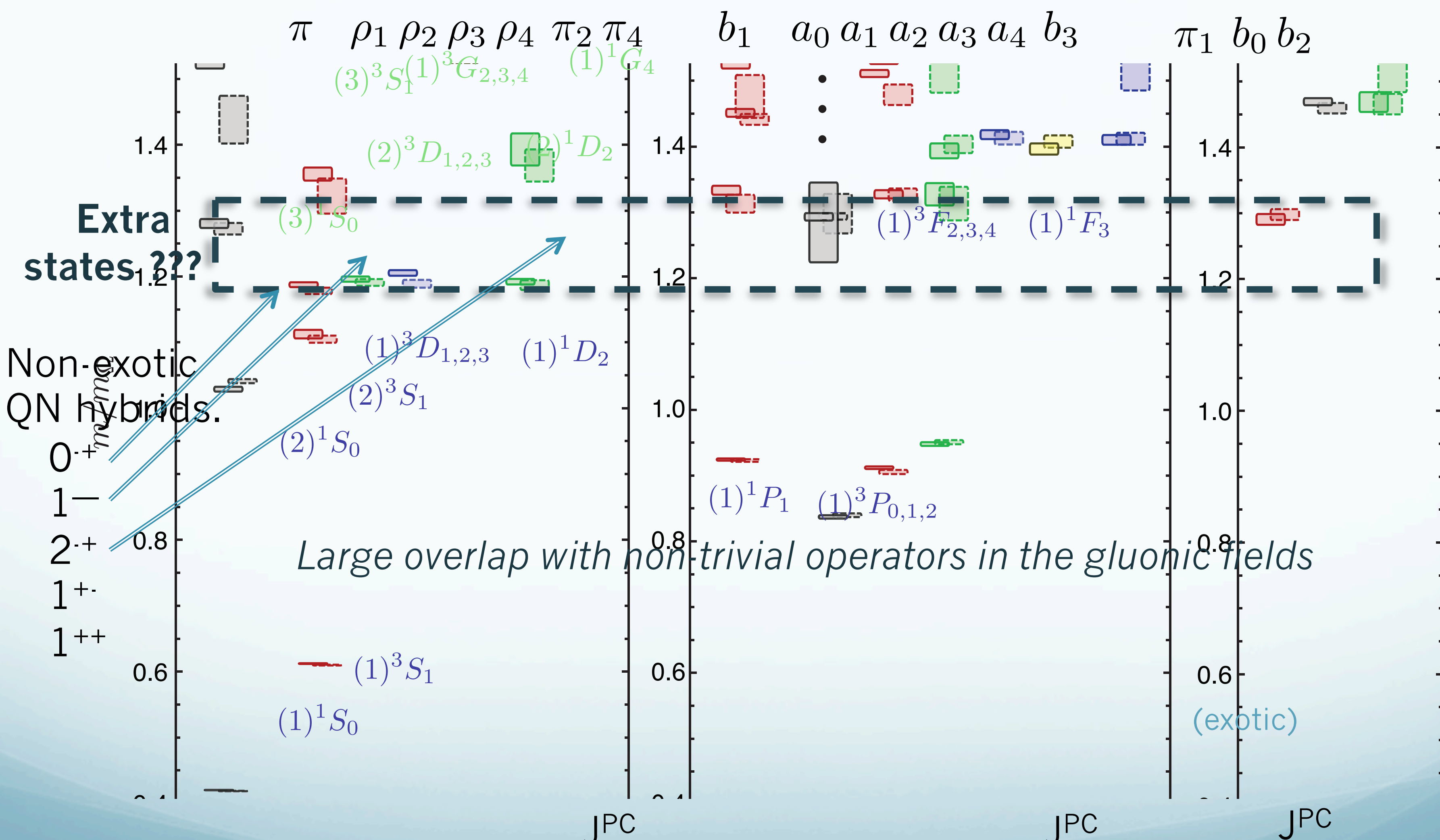

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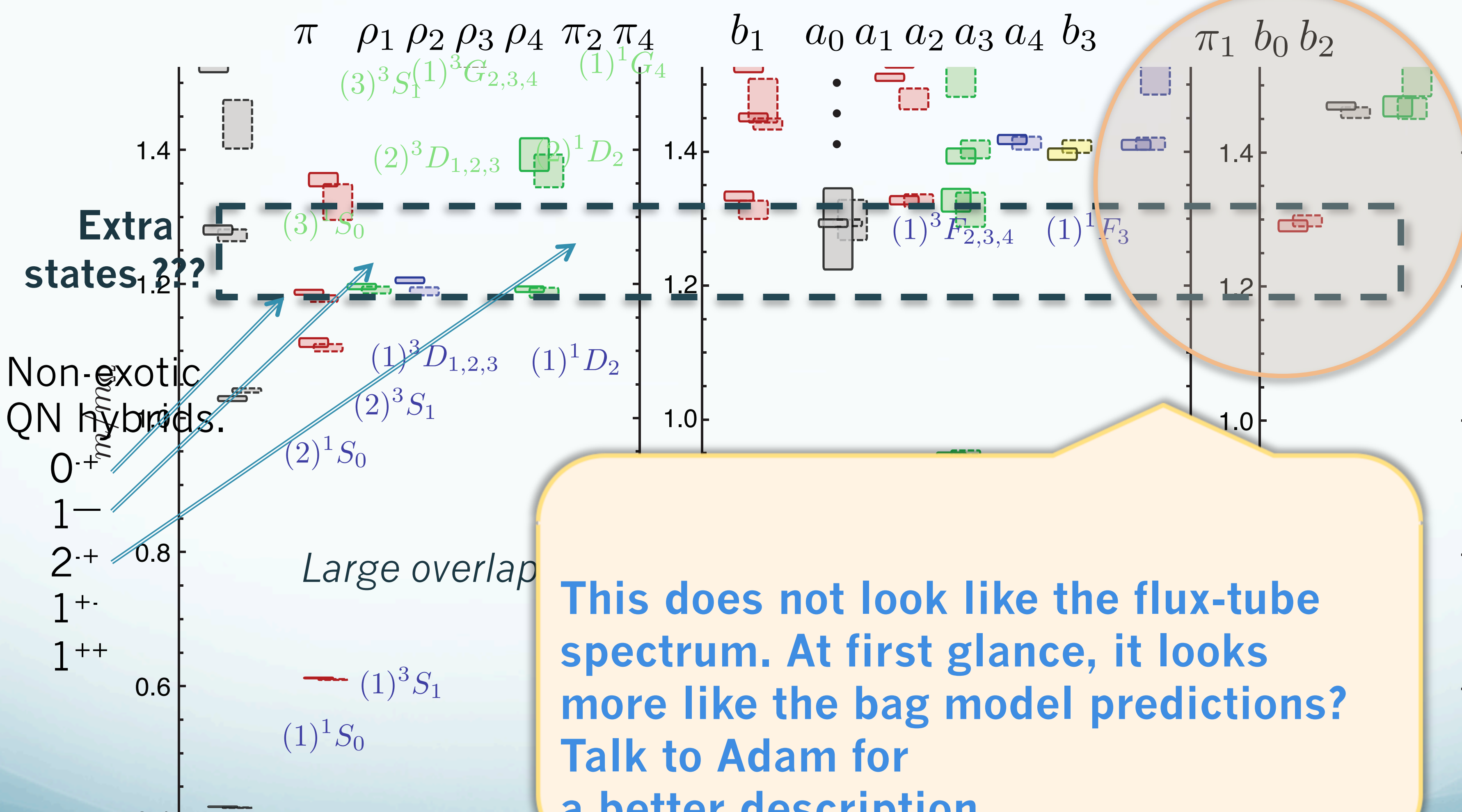

This does not look like the flux-tube spectrum. At first glance, it looks more like the bag model predictions? Talk to Adam for a better description.

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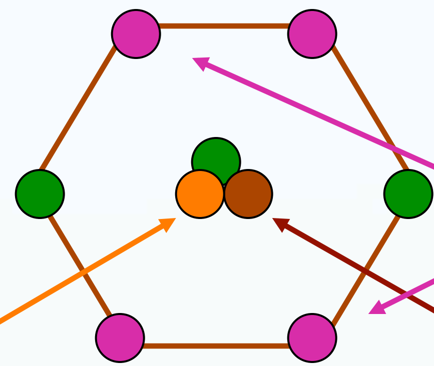
QCD Exotics

We expect 3 nonets of exotic-quantum-number mesons: 0^{+-}, 1^{-+}, 2^{+-}



$\pi_1(2015)$

$\pi_1(1600)$

Lattice shows two states here.

π , η , η' , K $\rightarrow$ π_1 , η_1 , η'_1, K_1 1^{-+}

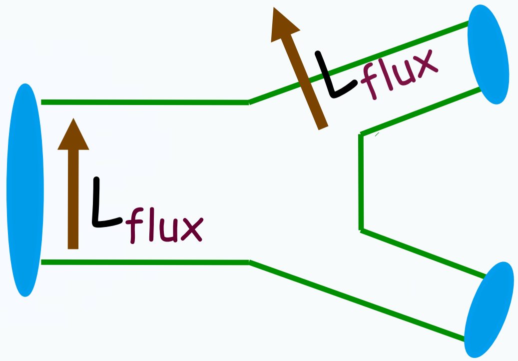
b_0, h_0, h_0', K_0 0^{+-}

b_2, h_2, h_2', K_2 2^{+-}

What are the mixing angles between the isoscalar states?

Hybrid Decays

The angular momentum in the flux tube stays in one of the daughter mesons (an (L=1) and (L=0) meson).



Exotic Quantum Number Hybrids

$\pi_1 \to \pi b_1$, πf_1 , $\pi\rho$, ηa_1
$\eta_1 \to \pi(1300)\pi$, $a_1\pi$

$b_2 \to a_1\pi$, $h_1\pi$, $\omega\pi$, $a_2\pi$
$h_2 \to b_1\pi$, $\rho\pi$, $\omega\eta$

$b_0 \to \pi(1300)\pi$, $h_1\pi$
$h_0 \to b_1\pi$, $h_1\eta$

Mass and model dependent predictions

Populate final states with $\pi^{\pm}, \pi^0, K^{\pm}, K^0, \eta$, (photons)

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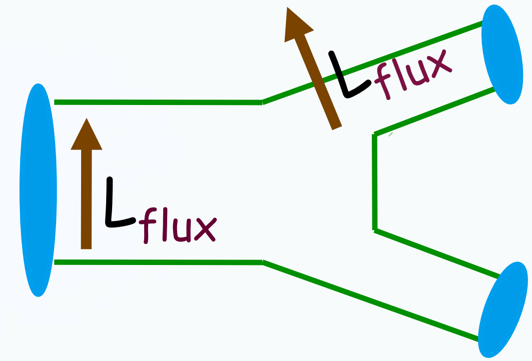

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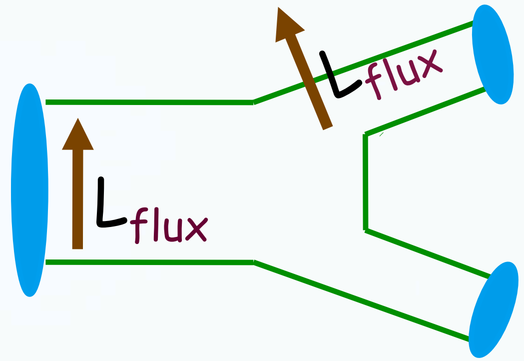

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Other interesting channels for amplitude analysis.

Analysis Amplitude

$$\mathcal{L} = \left(\frac{\overline{n}^n}{n!} e^{-n}\right) \Pi_{i=1}^n \mathcal{P}(\vec{x}, X_i)$$

Likelihood is a product of probabilities over all measured events, n.

Take the natural log to turn into a sum over the data. We need a Monte Carlo sample to be able to integrate over all phase space and normalize the probabilities.

data

Monte Carlo

$$-\ln \mathcal{L} = -\sum_{i=1}^{n} \ln \mid \mathcal{M}(\vec{x}, X_i) \mid^2 + \frac{S(s)}{N_{mc}} \sum_{j=1}^{N_{acc}} \mid \mathcal{M}(\vec{x}, X_j) \mid^2 + C$$

Minimize

Physics Model

Un-binned Likelihood Fitting

Amplitude analysis fits coherent and incoherent sums of amplitudes to experimental distributions . These fits are done to individual events, and the un-binned likelihood fitting is reduced to a sum over events which can trivially parallelize on computers.

A historic issue has been that unlike a binned fit where a χ^2 can be defined, and a goodness of fit defined, with likelihood fitting, only relative goodness of fits were possible. Thus, one could tell if one fit were better than another, but not how good either fit really was.

Motivated by work started at CMU [arXiv:0807.1582], Mike Williams has showen several robust methods to obtain a true goodness of fit from these procedures.

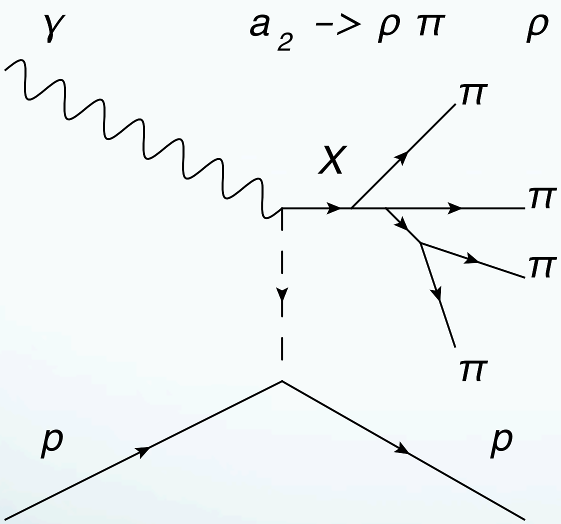
M. Williams, *How good are your fits? Un-binned multivariate goodness-of-fit tests in high energy physics, JINST 5, P09004, (2010).* [arXiv:1006.3019]

Physics Analysis

$\gamma\, p \to X\, p$

$X \to a_2\, \pi$

$a_2 \to \rho\, \pi$ $\quad \rho \to \pi\pi$



<u>Make Amplitude generation straightforward:</u>

AmpTools – see Matt Shepherd.

qft++ - developed for CLAS, M. Williams, Comp. Phys. Comm. 180, 1847 (2009).

<u>Amplitudes Issues:</u>

- more than just simple t-channel productio
- final state particles with non-zero spin.
- move beyond the isobar model
- direct 3-body processes
- Unitarity, analyticity, ...

CLAS Photoproduction: γp→ωp

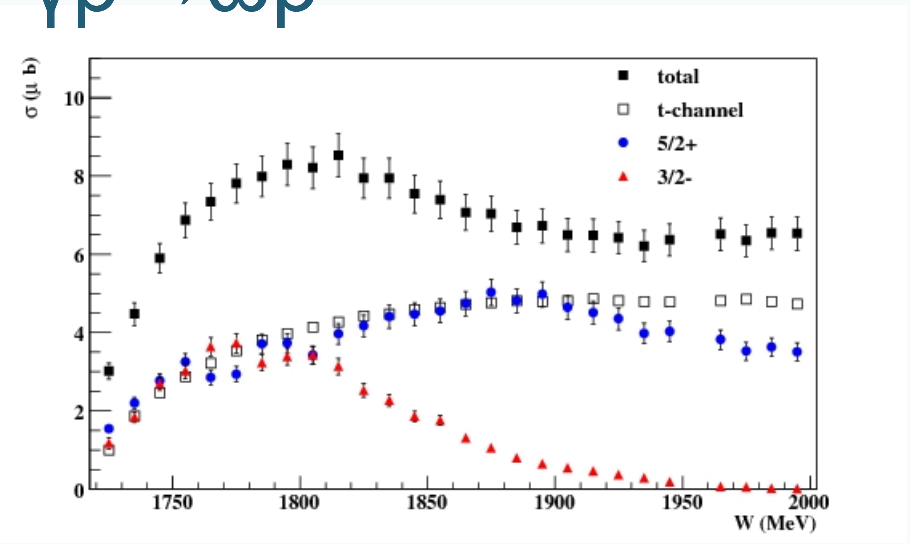
Fit showing three amplitudes.

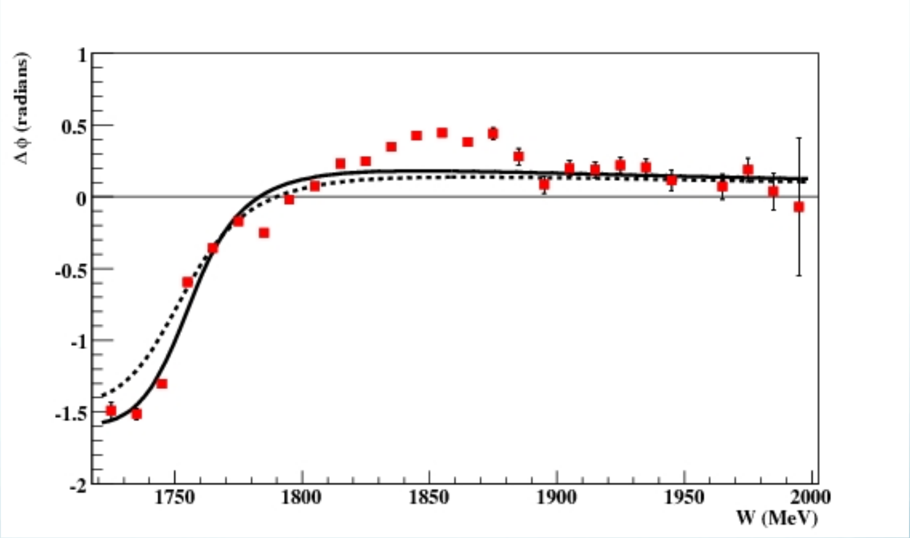
$(3/2)^-$ D_{13}
$(5/2)^+$ F_{15}
t-channel

Can also include u-channel

Intensities

Phase Difference





Proper coherence between amplitudes is needed to describe the physics.

Strong evidence for:

$(3/2)^-$ N(1700) ***
$(5/2)^+$ N(1680) ****
$(5/2)^+$ N(2000) **

Phys. Rev. C80, 065209, (2009

Isospin Aspects of Analysis

Consistent results over related channels

$$\gamma p \to h_2 p$$
$$h_2 \to b_1^{\pm}\pi^{\mp} \to \omega\pi^+\pi^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$$
$$h_2 \to b_1^0\pi^0 \to \omega\pi^0\pi^0 \to \pi^+\pi^-\pi^0\pi^0\pi^0$$

$$\gamma p \to h_2 p$$
$$h_2 \to \rho^{\pm}\pi^{\mp} \to \pi^+\pi^-\pi^0$$
$$h_2 \to \rho^0\pi^0 \to \pi^+\pi^-\pi^0$$

Consistent results across different decay modes.

$$\gamma p \to \pi_1^0 p$$
$$\pi_1^0 \to b_1^{\pm}\pi^{\mp} \to \omega\pi^{\pm}\pi^{\mp} \to \pi^+\pi^-\pi^+\pi^-\pi^0$$

$$\gamma p \to \pi_1^0 p$$
$$\pi_1^0 \to \rho^{\pm}\pi^{\mp} \to \pi^+\pi^-\pi^0$$

Consistent results across different decay modes.

Non-strange final states

Ultimately we need to be able to analyze all of these data simultaneously in the same fit. This will allow constraints between fits and give us the best access to decay rates.

We have the capability to do this now with CLAS data at CMU, and it will be part of the GlueX analysis framework.

Final Mesons	Exotics
$\pi^+\pi^-\pi^0$	π_1, h_2
$\eta\pi^+\pi^-$	b_2
$\pi^+\pi^-\pi^+\pi^-$	b_0, η_1, b_2
$\pi^+\pi^-\pi^0\pi^0$	b_0, η_1, b_2
$\eta\pi^+\pi^-\pi^0$	h_0, π_1, h_2
$\eta\pi^0\pi^0\pi^0$	π_1
$\pi^+\pi^-\pi^+\pi^-\pi^0$	h_0, π_1, h_2
$\pi^+\pi^-\pi^0\pi^0\pi^0$	h_0, h_2

On-going Analyses

$$\gamma p \to p\pi_1 \ \ (\pi_1 \to \pi^+\pi^-\pi^0)$$

@Indiana University

$$\gamma p \to ph_2 \ \ (h_2 \to b_1^{\pm}\pi^{\mp} \ \ , b_1 \to \omega\pi)$$

@CMU and @UCONN

$$\gamma p \to \Xi^* K K$$

@FSU

Procedures

IU 3-pion analysis:

- Monte Carlo generation on the grid. PYTHIA background events generated that can be mixed into the sample in addition to the physics events.
- Full event reconstruction.
- Amplitude Analysis based on AmpTools

CMU b1-pi analysis:

- Local Monte Carlo generation. Pythia background events that can be mixed into the event sample.
- Full event reconstruction, event selection by kinematic fitting.
- Amplitude Analysis based on CLAS codes at CMU.

UCONN b1-pi analysis:

- Monte Carlo generation in the grid.
- Plan to use the AmpTools.

FSU Cascade analysis:

- Local Monte Carlo generation.
- Reconstruction and studies of event selection.

Summary

- GlueX has been working to develop a fitting framework that will enable us to fit the large expected data sets.
- The framework takes advantage of highly-parallel computing on GPUs.
- This framework should allow us to ``easily'' input amplitudes from theorists and let them confront the data.
- The framework should allow us to perform more global fits across several data sets to more accurately pin down the the properties of the exotics.
- All theoretical work is welcome and needed!