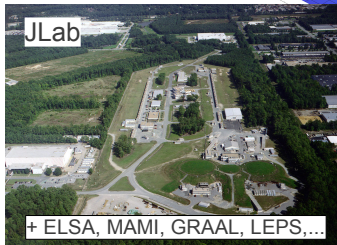
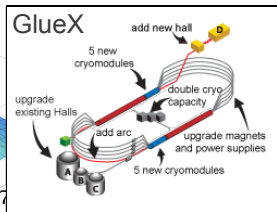
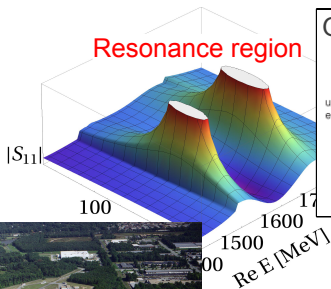


Summary: Discussion Section Theory

M. Döring, B.S. Zou

Athos 2012

Athos 2012
June 22, 2012



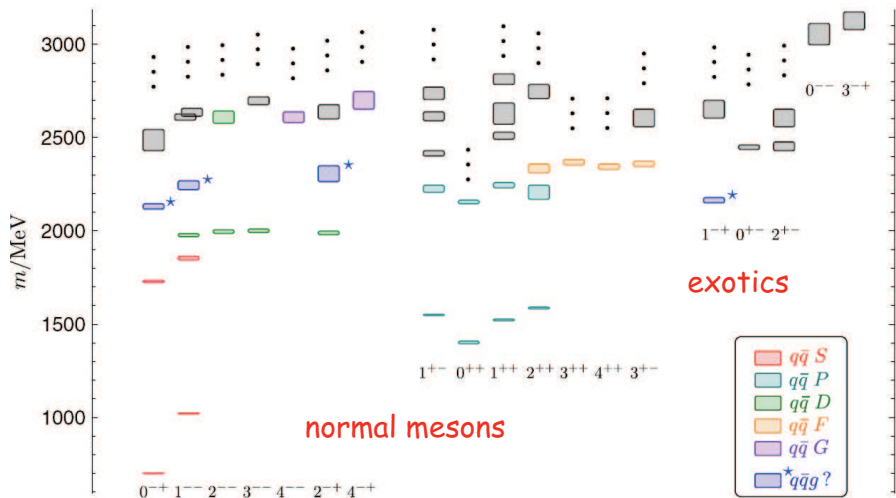
- $\pi N \rightarrow \pi N, \eta N, K\Lambda, K\Sigma, \pi\pi N, \dots$
- $\gamma N \rightarrow \pi N, \dots$
- production reactions $X \rightarrow \pi\pi\pi, \dots$

... and BES III, Compass, LHCb, Panda, ...

- Global analysis of pion- and photon-induced meson-baryon (MB) final states.
- Reliable extraction of amplitudes, multipoles and the spectrum of excited baryons.
- Development of analysis tools for MMM final states (Bes III, Compass, GlueX,...) + ...
- “Good” PWA parameterizations + event-based fitting (!).
- Connection to QCD: quark model, Dyson-Schwinger approaches, lattice; glueballs, hybrids, exotics,

Hybrids and exotics in recent lattice calculations

Dudek PRD 83 (2011) 111502, Dudek PRD 84 (2011) 074023



Multi-hadrons in a finite volume

Cubic box with periodic b.c.s:

$$\vec{p} = \frac{2\pi}{L_S}(n_x, n_y, n_z)$$

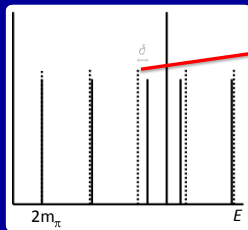
→ discrete spectrum

No clear evidence for multi-hadron states with ops ~

$$\bar{\psi}(x) \dots \psi(x)$$

Need ops that 'look like' multi-hadrons

$$\mathcal{O}(\vec{P}) = \sum_{\vec{p}_1, \vec{p}_2} c_\Lambda(\vec{P}, \vec{p}_1, \vec{p}_2) \mathcal{O}_\pi(\vec{p}_1) \mathcal{O}_\pi(\vec{p}_2)$$



Lüscher: (elastic) energy shifts in **finite volume** → phase shift

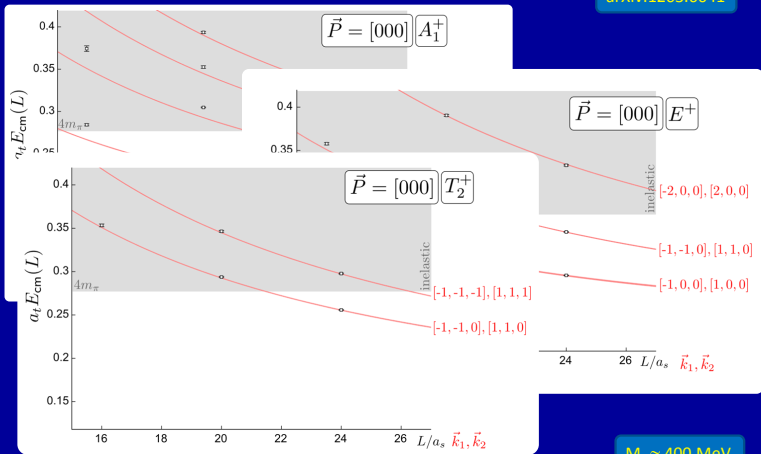
$$\Delta E(L_S) \rightarrow \delta(E, L_S)$$

Extract phase shift at discrete p_{cm}

Map out phase shift → resonance parameters (mass, width)

$\pi\pi$ $I=2$ spectra

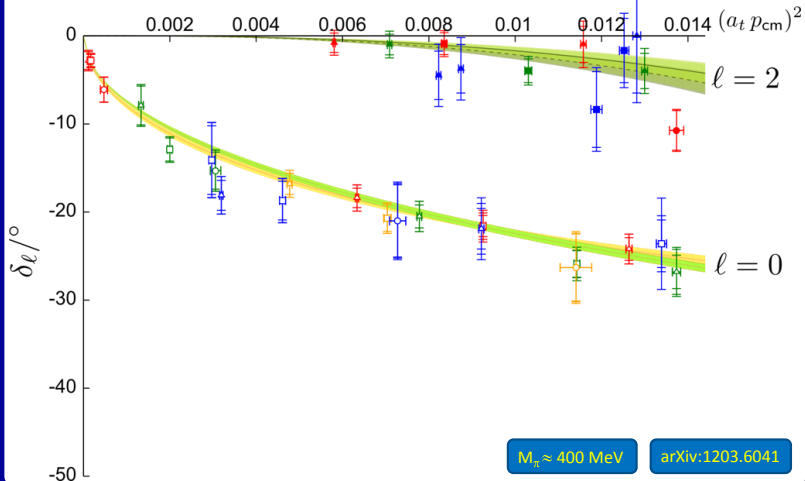
arXiv:1203.6041



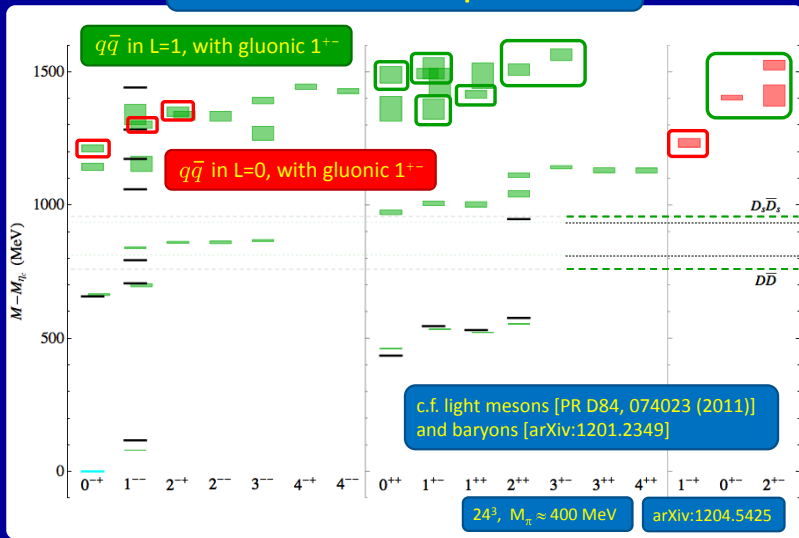
$M_\pi \approx 400$ MeV

31

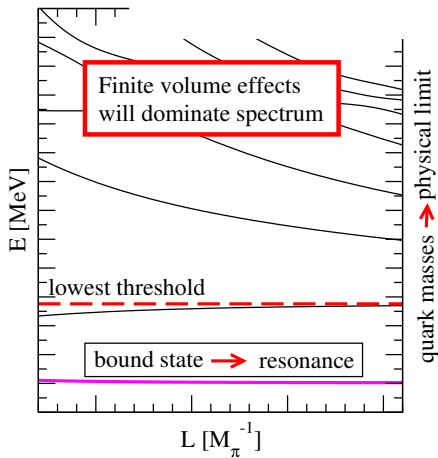
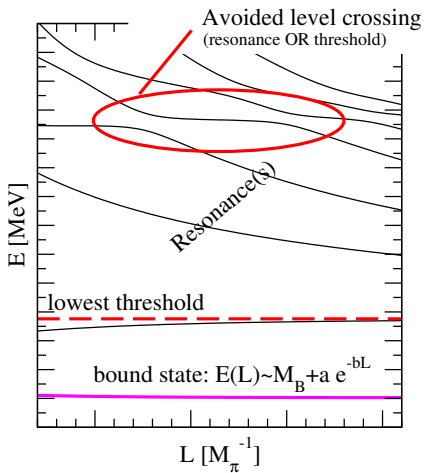


$\pi\pi$ $l=2$ phase shift

Charmonium Spectrum



Resonances decaying on the lattice



- Coupled channels, twisted boundary conditions (?) ($f_0(980)$, $a_0(980)$) three-body finite volume effects.
- Broad scalar resonances at next-to-leading order:
Stabilization of resonance extraction using $U\chi PT$.
- K-matrix/ Dynamical coupled-channel approaches in a finite volume
- Moving frames in a finite volume, partial wave mixing.
- Opportunities for mutual benefit: As in PWA of exp. data, resonances extraction vs. model dependence is a question of available precision on the data.



Single Pion Photoproduction

- Only with good data on both **proton** and **neutron** targets, one can hope to disentangle the **isoscalar** & **isovector EM** couplings of the various **N^*** & **Δ^*** resonances, [K.M. Watson, Phys Rev **95**, 228 (1954);
R.L. Walker Phys Rev **182**, 1729 (1969)]
as well as the **isospin** properties of the non-resonant **background amplitudes**.
 - The **radiative decay** width of the neutral baryons may be extracted from π^- & π^0 photoproduction off a **neutron**, which involves a **bound neutron target** and requires the use of a **model-dependent nuclear (FSI) corrections**.
 - The lack of $\gamma n \rightarrow \pi^- p$ & $\gamma n \rightarrow \pi^0 n$ data (**15%** of proton database) does not allow us to be as confident about the determination of **neutron** couplings relative to those of the **proton**.
- The new **CLAS** cross section set has **quadrupled** the world database for $\gamma n \rightarrow \pi p$ above $E_\gamma = 1$ GeV.



6/21/2012

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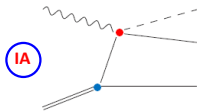


FSI and $\gamma d \rightarrow \pi^- p p \rightarrow \gamma n \rightarrow \pi^- p$

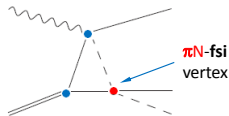
[V. Tarasov, A. Kudryavtsev, W. Briscoe, H. Gao, & IS, Phys Rev C **84**, 035203 (2011)]

- **FSI** plays a critical role in the **state-of-the-art** analysis
- Effect: **5% - 60%** It depends on (E, θ)

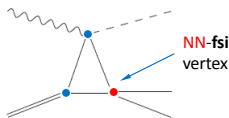
Input: SAID $\gamma N \rightarrow \pi N$, πN , NN amplitudes
for 3 leading terms
DWF: Bonn Pot.



Dominant



πN -fsi
vertex



NN-fsi
vertex

Fermi motion of nucleons
included

$$R_{FSI} = (d\sigma/d\Omega_{\pi p}) / (d\sigma^{IA}/d\Omega_{\pi p})$$



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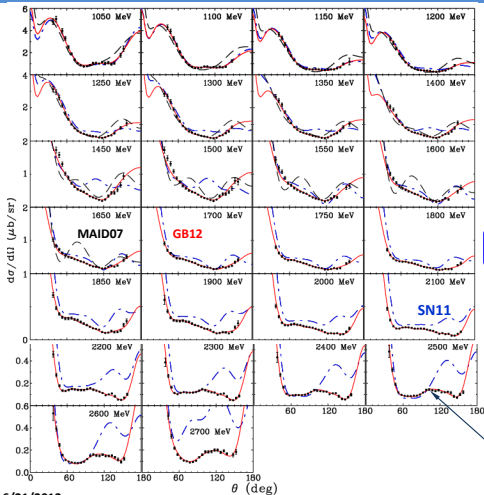
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CLAS for $\gamma\kappa \rightarrow \pi^-p$

[W. Chen, et al, arXiv:1203.4412 [hep-ph]

**Systematics:**

Exp: 6-9%

FSI: 2-3%

$$\chi^2/dp = 45636/626 = 72.9 \text{ [SN11 - no fit]}$$

$$\chi^2/dp = 1580/626 = 2.5 \text{ [GB12 - fit]}$$

- CLAS data appear to have fewer angular structures than the earlier fits.



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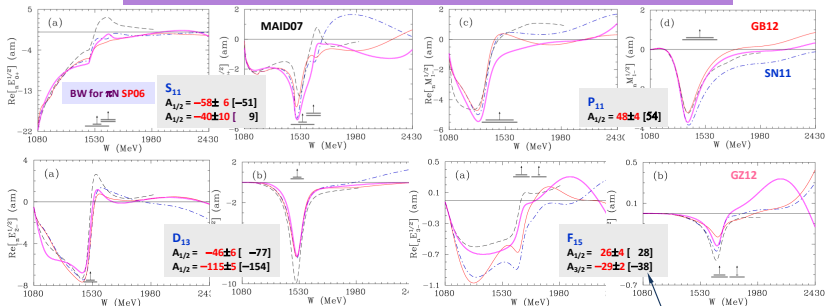
Igor Strakovsky 3



Neutron Multipoles from $G\bar{B}12$

[W. Chen, *et al*, arXiv:1203.4412 [hep-ph]

- Overall: the difference between MAID07 and SAID-GB12 is rather small but... Resonances may be essentially different



- Any meson Photo Prod treatment on the 'neutron' target requires a FSI study

MAID07

MAID07: D. Drechsel, *et al*, Eur Phys J A 34, 69 (2007)



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Toward a Model Independent Determination of Resonance Parameters

Lothar Tiator

Universität Mainz in collaboration with CB@MAMI, Dubna and GWU

basic question:

How can we improve our knowledge on the Baryon Resonance Spectrum with meson photo- and electroproduction experiments?

Baryon resonance analysis is a very difficult task.

The resonances are broad and the background is in many channels very large and partly unknown.

Therefore, very accurate data in many different channels have to be measured and analyzed, best in a 2-step process:

First, we need model-independent partial wave amplitudes from complete experiment analysis.

This must be done for each channel separately.

Second, we need to analyze those model-independent partial waves of different channels by use of sophisticated reaction models using all possible theoretical constraints.



Summary on the Complete Experiment Analysis

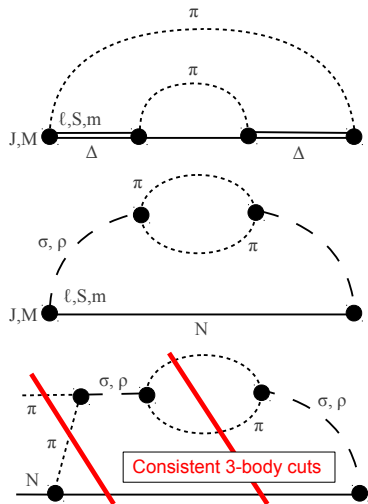
- The „classical“ Complete Experiment requires 8 well selected observables but it can not give us information on N^* physics because it does not give us partial waves due to an unknown angle-dependent overall phase $\phi(W,\theta)$
- The „new“ Complete Experiment aims directly on partial waves and requires only 5 well selected observables
 these can be: $d\sigma, \Sigma, T, P, F$
 or: $d\sigma, \Sigma, T, F, G$
 or: $d\sigma, \Sigma, O_X^{\pm}, O_Z^{\pm}, C_Z^{\pm}$
 or many more

In simulations with Monte-Carlo pseudo data it works for γ, π !



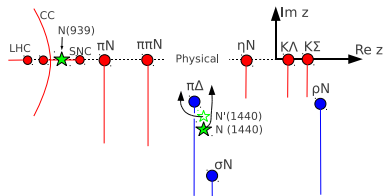
- Attractive new approach to eliminate model dependence.
- No guarantee to get the entire baryonic spectrum.
- Small multipoles: challenging.
- Pion-induced reactions: Opportunity for additional experimental information; measurement of, e.g., $ds/d\Omega$, P , β is in principle enough to determine hadronic amplitude.
- The hunt for the “best” parameterization of the amplitude.
 - MAID: unitary isobar model, final state interaction from SAID.
 - SAID: Chew-Mandelstam, generation of resonances.
 - Bonn-Gatchina: K-matrix; many decay channels of resonances make background.
 - CMB/Zagreb: subthreshold resonances \rightarrow background.
 - Dynamical coupled-channel approaches: Lagrangian-based, solution of the Lippman-Schwinger equation.
 - This meeting: Can three-body PWA's conceptually benefit from these two(three)-body PWA analyses?

How three-body unitarity induces hadron exchange



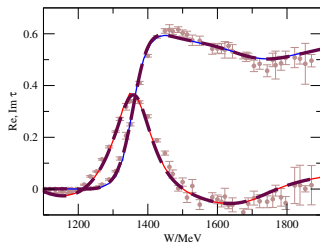
- $\pi\pi/\pi N$ subsystems fit the respective phase shifts.
- Consistent inclusion of 3-body cuts.
- Allows for *a-priori* 3-body unitarity per construction

[Aron, Almodo, Young, PR 174 (1968) 2022].



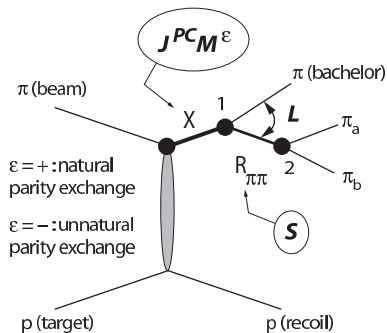
- $N(\pi\pi)_{L=I=0}$ channel important (chiral σ); Roper dynamically generated in Jülich model.
- Roper pole $N(1440) + \pi\Delta$ branch point \rightarrow non-standard resonance shape.
- Sub-threshold cuts from crossing symmetry.

- Where is the $3^* N(1710)$? [S. Ceci, M.D. et al., PRC 84 (2011)]



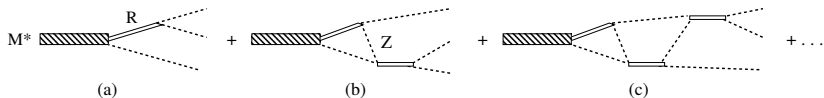
Fit of a model without ρN branch point (CMB type) [solid lines] to the Jülich amplitude [dashed lines]

- CMB fit to JM has pole at $1698 - 130 i$ MeV, simulates missing branch point.
- \rightarrow Inclusion of full analytic structure important to avoid false pole signals.



Setup

- Selection of final states.
- Selection of relevant partial waves.
- Binning in $m_{3\pi}$ and t .
- → No assumption on resonances!
- Event-based log-likelihood fit.
- see also: CLAS, Phys.Rev. C80 (2009): event-based analysis of spin-density matrix elements in $\gamma p \rightarrow \omega p$



- Coupled channels: e.g. P. Guo @ Indiana univ.
- Isobar parameterization: beyond Breit-Wigner (Unitarized chiral perturbation theory: Adler zero and other good properties)

- FDC-PWA: Powerful Tool
- To work with high spin states ($0, 1/2, 1, 3/2, 2, 5/2, 3, 7/2, 4, 9/2$) and construct effective Lagrangians.
- The expression of the effective interaction vertices and the propagators for the high spin states are quite lengthy.
- The related amplitudes and amplitude squares are complicated.
- There are many free parameters in the effective Lagrangian and these parameters will be fixed when the generated program is used to do Likelihood fitting of experimental data.
- To generate a complete set of the Fortran sources to do the partial wave analysis on experimental data.



Rules for construction of Effective Lagrangian:

- Lorentz invariance
- C-parity conservation
- P-parity conservation
- CP conservation



Physical Process

Input for a physical process: process, physical model,
Many options, histograms, scatter plots.

Generate Feynman Diagram

Manipulate amplitudes for each diagram and generate FORTRAN
source for calculation of amplitudes square

Find and properly treat all the resonance, t-channel
singularities, ...
and generate FORTRAN source for phase space integral and
fitting

Control flag and parameters
files
generated by FDC which can be
changed later by users:
flag.inp, amptable.inp,
fpara.inp, reson.inp

Users should prepare two files:
pdata1.dat –
 experiment events data file
pdata1.mc –
 phase space monte carlo event file

Compile FORTRAN programs and run 'fit' for likelihood fitting

Output: mplot.info, pep.res, mplot.hbook, dplot.hbook

4. Summary

We supply a powerful tool: FDC-PWA

<http://v-www.ihep.ac.cn/~wjx/pwa/index.html>

- **To constructe the effective Lagrangian.**
- **To generate the complete set of Fortran source for PWA analysis.**
- **To generate an event generator.**
- **be used in BES PWA analysis since 1999.**
- **Could be used for any possible experiment.**



- Event-based fitting techniques developed for three-meson final states: perspectives for the analyses of excited baryons.
- General properties of the S -matrix (analyticity, three-body unitarity, approximations to crossing symmetry): developments in meson-baryon analyses may benefit three-body analyses.
- Lattice QCD: hadronic tools for finite volume effects, for upcoming lattice analyses of resonance decays; lattice QCD is the connection to QCD.



