# Results of Amplitude Analysis in the $b_1\pi$ channel

for the GlueX Collaboration Meeting: October 2012

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# Outline

# Input

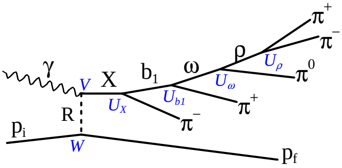
Generated signal put in with the following parameters:

- $X$ resonance: two interfering waves:

| wave $(J^{PC})$ | $L$ | $S$ | $m_0\,(\mathrm{GeV})$ | $\Gamma_0\,(\mathrm{GeV})$ |
|---|---|---|---|---|
| $1^{--}$ | 0 | 1 | 1.89 | 0.16 |
| $2^{+-}$ | 1 | 1 | 2.00 | 0.25 |

- $b_1(1^{+-})$: system allows $L_{b_1} = 0, 2$ with $D/S$ amp. ratio: $0.28$
- $\omega(1^{--})$: known dominant wave - $L_\omega = 1$
- "$\rho$": locked to $\omega \to L_\rho = 1$

Figure $b_1\pi$ photo-production and decay. $\omega$ is modeled as a sequence of two-body decays: pion and di-pion system (not physical $\rho$)

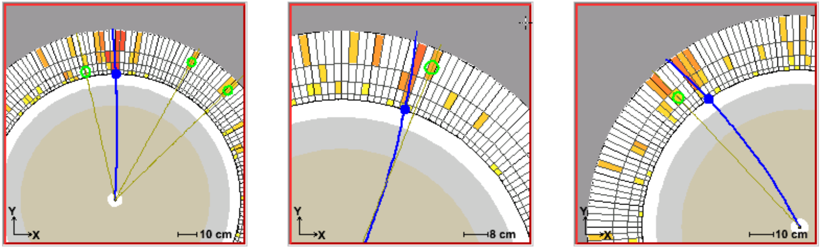


# Reconstructing $b_1\pi$ in Data: $\pi^0 \to 2\gamma$ - summary of issues

Looking for the $\pi^0(\to 2\gamma)$ in the $\omega \to \pi^+\pi^-\pi^0$

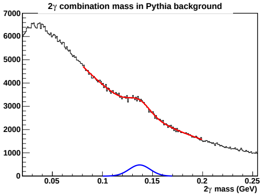
Problem: huge background under $\pi^0$ peak in $M_{2\gamma}$ distribution

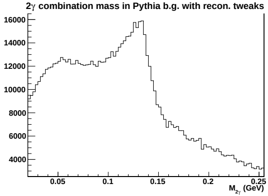
- hadronic split-offs from charged showers
  - shower-track association issue
  - electromagnetic shower ID
- noise hits
  - mcsmear configured realistically?
  - refine cluster/shower algorithm to minimize susceptibility



# Reconstructing $b_1\pi$ in Data: $\pi^0 \to 2\gamma$ background

Distribution of reconstructed invariant mass of $2\gamma$ in Pythia.




Left: Base calorimetry algorithms and current model of BCAL noise.
Right: No BCAL noise hits + tweaks to shower association and photon hypothesis ID

1. BCAL noise hits turned off
2. envelope for deep shower-track association broadened
3. Neutral shower ID disqualified for any of:
   - shower's energy centroid deeper than 65% of BCAL module
   - energy in 4th layer $>$ than 70% of shower total
   - significant gaps between clusters: energy only in the 1st & 4th layers
   - all energy deposited in the first layer

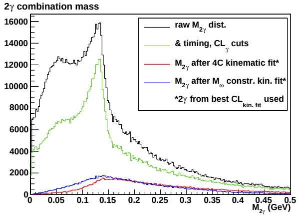
# Reconstructing $b_1\pi$ in Data: $\pi^0$

Looking for the $\pi^0(\rightarrow 2\gamma)$ in the $\omega \rightarrow \pi^+\pi^-\pi^0$ (tested on Pythia)

remaining background under $\pi^0$ peak in $M_{2\gamma}$ distribution - mostly hadronic split-offs from charged showers

Improving purity:

- tweak shower algorithm for better association of shower clusters to charged tracks



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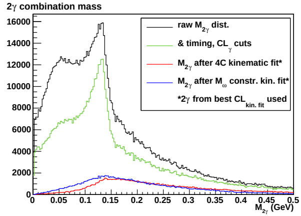


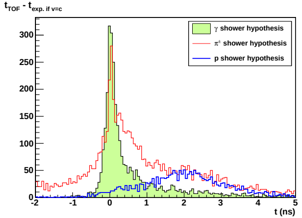

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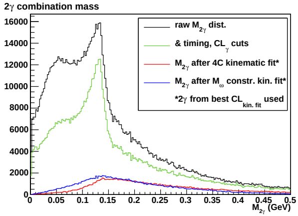


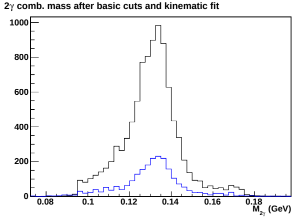

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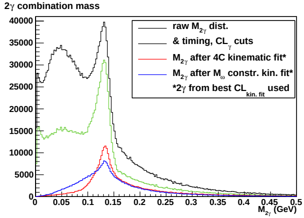



Distributions from reconstructed **signal** sample, for comparison

# Reconstructing $b_1\pi$ in Data: $\omega$

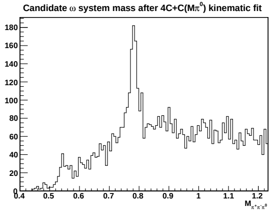
$\omega(782)$ is narrow: $\Gamma = 8.5\,\mathrm{MeV}$ (on the scale of detector resolution) – good filter for signal if mass is constrained in fit.

Caution: must minimize bias toward $\omega$

Procedure: progressive kinematic fits:

- fit candidate $\omega$ with all permutations of last 2 pions using 4C+C($M_{\pi^0}$) only
- identify best-fit permutation
- check if fit-tuned $M_{\pi^+\pi^-\pi^0}$ within $\pm 36\,\mathrm{MeV}$
- if so, proceed to full 6C fit (candidate can still be vetoed by poor fit with $\omega$ constraint)

Plot: 4C+C($M_{\pi^0}$) fit-tuned $M_{\pi^+\pi^-\pi^0}$ from Pythia sample



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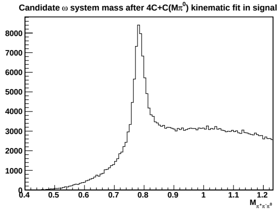
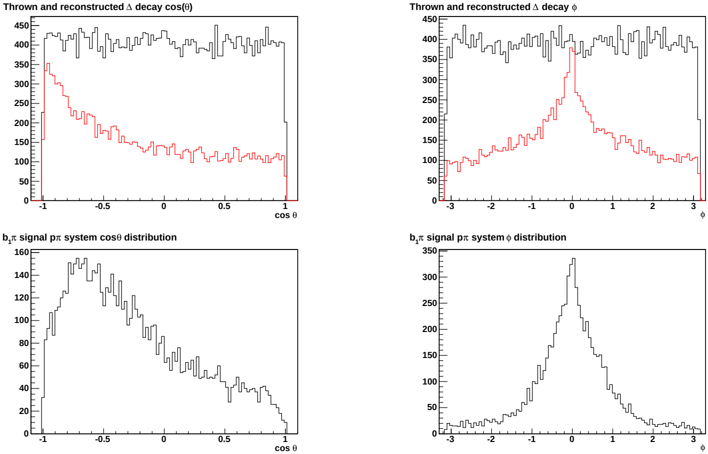
Plot: 4C+C($M_{\pi^0}$) fit-tuned $M_{\pi^+\pi^-\pi^0}$ from $b_1\pi$ signal sample



# Reconstructing $b_1\pi$ in Data: Suppressing $\Delta \to \pi p$

Common contaminating process: excitation of proton into $\Delta(1232)$
How to recognize pion from $\Delta$ vs forward system. ($M_{\pi p}$ not sufficient)
Solution: angular distribution – will be spoiled for false decay daughter pairing:



# Cut Optimization

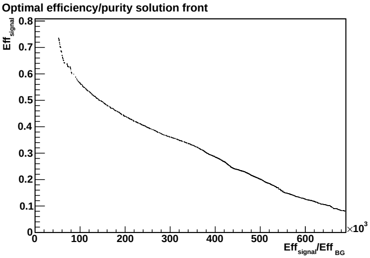
Parameters remaining after basic analysis:

- event reconstruction quality:
  $CL_{\mathrm{kin.fit}}$, $CL_{\pi^0 \mathrm{fit}}$, $dE/dx_{\mathrm{proton}}$ hard cut
- purity: $M_{b_1}$
- purity: filtering $\Delta$ resonances: $M_\Delta$, $\phi_\Delta$, $\cos\theta_\Delta$

Two goals: signal reconstruction efficiency and purity
$\Rightarrow$ multi-objective optimization, genetic algorithm used

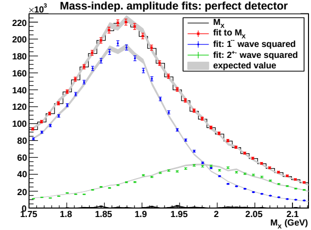
The Pareto-optimal front of solutions optimizing efficiency and purity of a data sample.

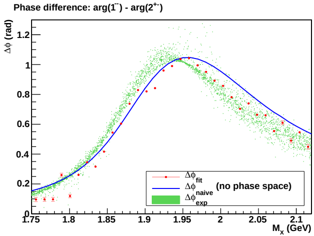
Note: The units are not meaningful in themselves as they scale from rates and efficiencies of a baseline set of cuts.



# Amplitude Fit Results: Signal Only, Perfect Detector

- leakage to false waves – negligible ✓
- consistency with expected: $\chi^2$ is 2.6 and 8.8! poor convergence to true minimum?
- phase motion: error bars inconsistent with local fluctuation.
  - further proof of poor convergence?
  - contributions to uncertainty not fully understood?
- reasonable functionality to attempt fitting reconstructed events ✓

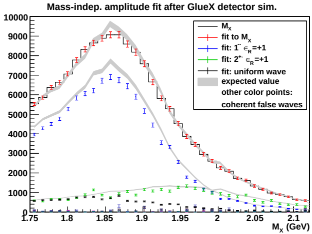


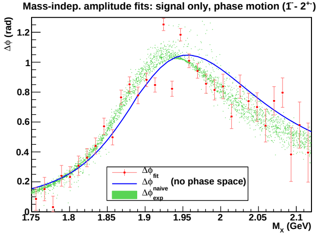




Note: $\Delta\phi_{\text{exp}}$ calculated for each generated event individually. Phase difference is only meaningful inside an event's amplitude mixture.

# Amplitude Fit Results: Signal Only, GlueX Detector

Invariant mass figure:
results with expected values bands



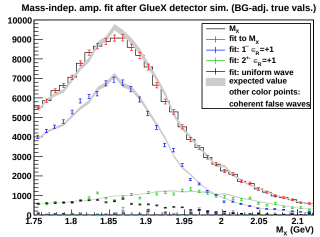

Conclusions:

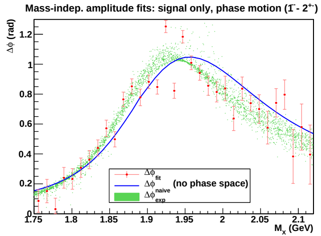
- significant leakage to the uniform wave ○
  - mostly from from $1^{--}$
  - stronger at lower invariant mass
- phase motion error bars inconsistent with fluctuations – fit convergence issues? ○

# Amplitude Fit Results: Signal Only, GlueX Detector

## Invariant mass figure:

results with expected values rescaled for the leakage fraction

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# Amplitude Fit Results: $40\,\text{nb}\ 2^{+-}$ & Pythia (GlueX)

Cross-section scaling:

- Pythia: $13.9\,\text{G evts}\ (9\,\text{GeV})$ generated $\sim 260\,\text{h}$ run time
- $b_1\pi$: $18\,\text{M evts}$, $\sim 25\%\ 2^{+-}$

Cuts: $CL_{\text{kin.fit}} > 0.02$, $CL_{\pi^0\text{fit}} > 0.02$, $M_\Delta > 1.37$, $|\phi_\Delta| < 1.34$, $\cos\theta_\Delta < 0.33$

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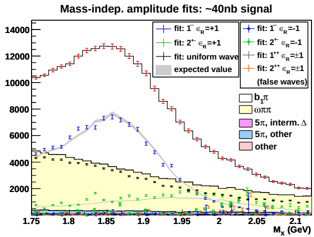


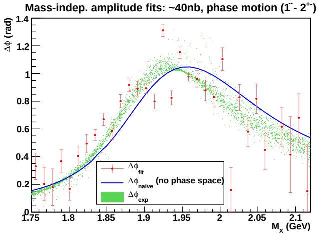

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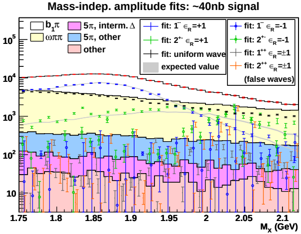
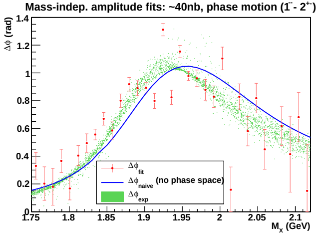


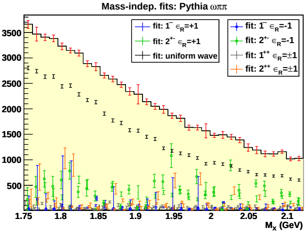
# Amplitude Fit Results: Pythia's $\omega\pi\pi$ (GlueX)

- understanding how this dominant contribution from Pythia (as reconstructed, analyzed) projects onto our wave set. Isolated reconstructed events labeled with the following truth info:

- $2\pi^+ 2\pi^- \pi^0 p$ final state only
- an intermediate $\omega$ seen
- no intermediate baryons

Observations:

- ostensibly isotropic decays in Pythia not fully absorbed by the uniform wave
- non-trivial $\theta, \phi$ features seen
  - can be generated by false identification of decay's daughters
  - $> 1\ \omega$, other low-lying mesons?
  - other topologies, without interm. baryons passing filter?



# Summary and Outlook

Performed an analysis of a possible exotic state physics channel:
$\gamma p \to X p \to b_1 \pi p$

- reconstruction and analysis of this signal in light of photo-production background
- Amplitude Analysis of the simulated data comparable to $\sim 260\,\mathrm{h}$ of running and assuming a $40\,\mathrm{nb}$ signal

Outlook - much to do to further this effort:

- need broad $\gamma$ spectrum with tagging with accidentals included in analysis
- generate more background
- understand fit uncertainty and convergence in the limit of high statistics
- test for leakage with more waves and understand it
- put in more realistic angular distribution than Pythia's for competing processes
- ...