Photoproduction of $b_1(1235)$ meson in GlueX

Karthik Suresh[1]
Ahmed Foda, Zisis Papandreou

Department of Physics
University of Regina

October 23, 2020

[1] ksv656@uregina.ca

Overview

* Motivation

* b_1 Event Selection in GlueX

* b_1 PWA Model

– Angular distribution of the b_1 meson

– Monte Carlo Event generation of b_1

* Next steps

Motivation

Exotics $\pi_1(1600)^a$, $\pi_1(2015)^b$, $h_0(2400)$ and $b_2(2500)$ could possibly decay to $b_1\pi$ where b_1 decays into $\omega\pi$. In order to precisely measure the exotics, we need to understand the precisely the decay of $b_1(1235)$

GlueX searches for hybrid meson spectrum in the mid-high energy regime (6 - 12 GeV) could measure the complete kinematics of the mentioned exotics.

[a] Reported by E852, VES, COMPASS, and CBAR
[b] Reported by E852

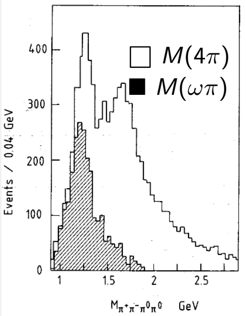
$b_1(1235)$

Flavourless meson: "b" a meson of spin zero and odd orbital momentum. Subscript is total angular momentum of the $q\overline{q}$ system

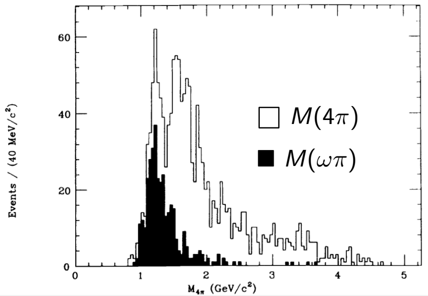
b1(1235)	$1^+(1^{+-})$
Mass	1229.5 ± 3.2 MeV (S $= 1.6$)
Width	142 ± 9 MeV (S $= 1.2$)

History of the $b_1(1235)$ Photo production (in the 1980s)

Omega-Photon Collaboration



SLAC-S.H.F.P Collaboration



$\omega\pi^0$ mass distributions from Omega-Photon Collaboration [1] (Left) and SLAC-H [2] (right) experiments : modest statistics

b_1 Event Selection in GlueX

b_1 Photo production reaction

$$\gamma p \rightarrow p b_1(1235) \rightarrow p\omega\pi^0 \rightarrow p\pi^+\pi^-\pi^0\pi^0 \quad (1)$$

All final state particles are detected in the experiment

π^0 is restricted in the range [0.08, 0.19] GeV

The analysis is done on data from the Fall 2017 run period

Event Selection Cuts

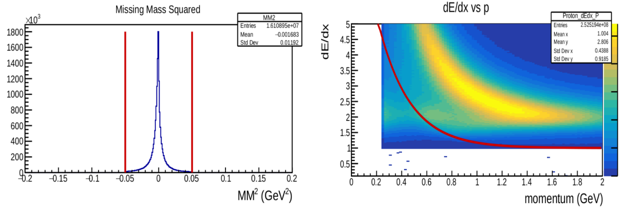
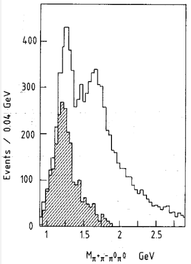
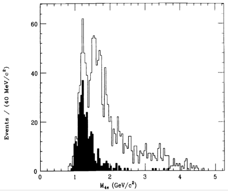


Figure 2: Sample Data cuts that are applied on to data. On the left is the Missing Mass square cut made at $\pm$ 0.05 GeV^2/c^4. On the right is the standard $(\frac{dE}{dX})_{proton}$ cut

Omega-Photon Colab



S.H.F.P Colab



Invariant Mass of $\omega\pi$ events

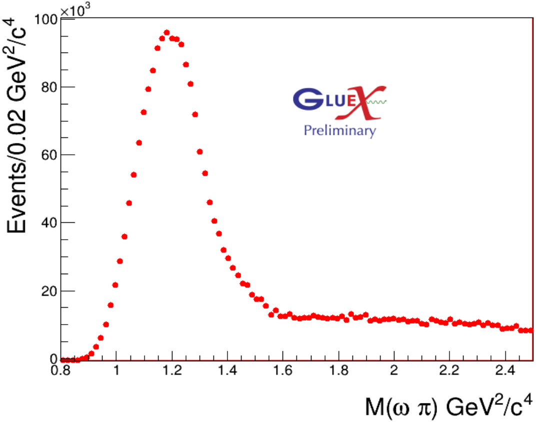
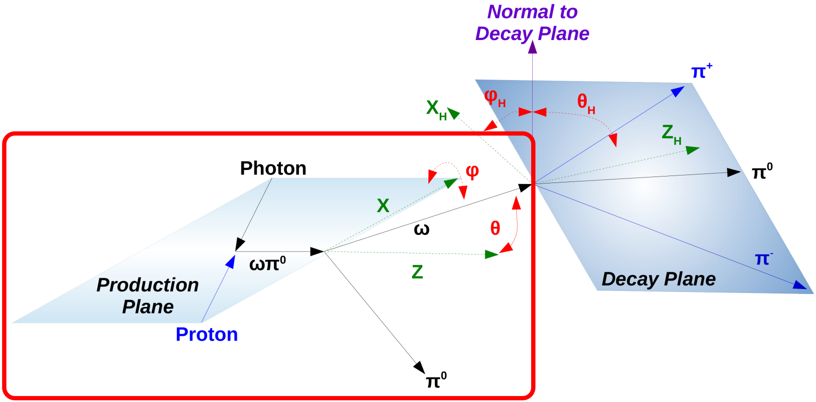
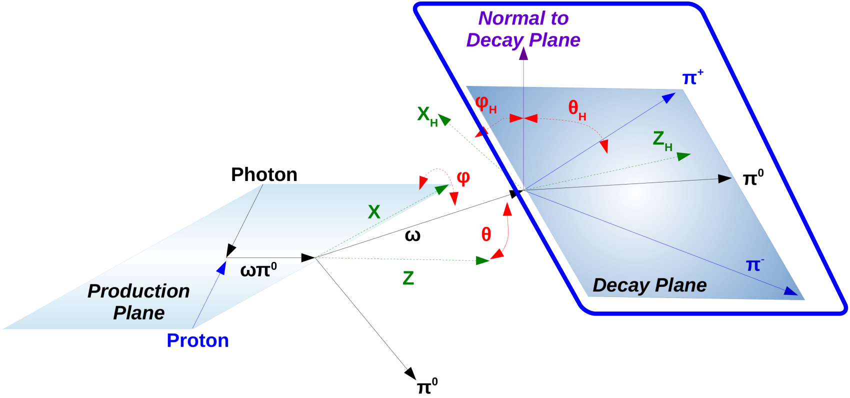


Figure 3: Reconstructed $\omega\pi$ events. The M($\omega\pi$) events are not acceptance corrected. Vertical errors bars are contained in the points. A high statistics channel



$\omega\pi$ decay plane

θ and ϕ describe the decay kinematics of ω in the $\omega\pi$ helicity frame.



3π decay plane

θ_H and ϕ_H describe the decay kinematics of normal ($\hat{n}$) to three-pion (ω) decay plane in its helicity frame

Amplitude Analysis Model

Intensity I is given by

$$I = \frac{1}{2}(1 - P_\gamma)|e^{i\phi}A_+ + e^{-i\phi}A_-|^2 + \frac{1}{2}(1 + P_\gamma)|e^{i\phi}A_+ - e^{-i\phi}A_-|^2 \quad (2)$$

Amplitude Analysis Model (cont.)

Polarisation fraction

Production angle

$$I = \frac{1}{2}(1 - P_\gamma)|e^{i\phi}A_+ + e^{-i\phi}A_-|^2 + \frac{1}{2}(1 + P_\gamma)|e^{i\phi}A_+ - e^{-i\phi}A_-|^2$$

Where $A_\pm$ can be expressed as

$$A_{\lambda_\gamma} = \sum_{J_i=0,1,2}^{\omega\pi Spin} \sum_{\eta_i=-1,1}^{\omega\pi Parity} \sum_{\Lambda=-J_i,..,J_i}^{\omega\pi SpinProj} V^{GJ}_{\lambda_\gamma,\Lambda} \sum_{\lambda=-1,0,1}^{\omega Helicity} D^{J_i}_{\Lambda,\lambda}(\Omega) F^i_\lambda D^1_{\Lambda,0}(\Omega_H) G$$

Amplitude Analysis Model (cont.)

Where $A_\pm$ can be expressed as

$$A_{\lambda_\gamma} = \sum_{J_i=0,1,2}^{\omega\pi Spin} \sum_{\eta_i=-1,1}^{\omega\pi Parity} \sum_{\Lambda=-J_i,..,J_i}^{\omega\pi SpinProj} V^{GJ}_{\lambda_\gamma,\Lambda} \sum_{\lambda=-1,0,1}^{\omega Helicity} D^{J_i}_{\Lambda,\lambda}(\Omega) F^i_\lambda D^1_{\Lambda,0}(\Omega_H) G$$

$V^{GJ}_{\lambda_\gamma,\Lambda}$

Vertices

$D^{J_i}_{\Lambda,\lambda}(\Omega \text{ or } \Omega_H)$

Wigner function with Ω and Ω_H being decay angles in Helicity frame

F^i_λ Helicity amplitudes

$$F^i_\lambda = \sum_{l=0,1,2}^{PartialWaves} \langle J_i \lambda | l0, 1\lambda \rangle \, C^i_l$$

Amplitude Analysis Model (cont.)

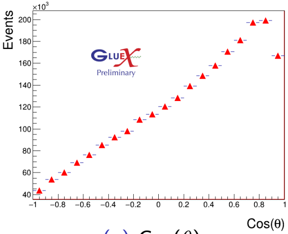
J^{PC} states of 0^-, $1^\pm$, $2^\pm$ and the partial waves $l = 0, 1, 2$ could potentially reproduce the angular distibution of the $\omega\pi$. The total fit parameters corresponding to these are

- 17 Vertices ($V^i_{\lambda_\gamma,\Lambda}$) which depends on Mandelstam t, beam energy and $M(\omega\pi)$
- 6 partial wave amplitudes C^i_l that depend only on $M(\omega\pi)$
- 4 Dalitz parameters α, β, γ, δ

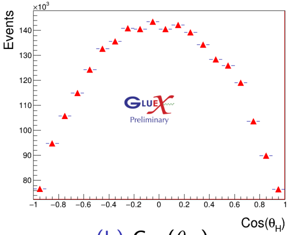
Angular distribution of the b_1 meson

$1.185 < M(\omega\pi) < 1.285\ GeV/c^2$

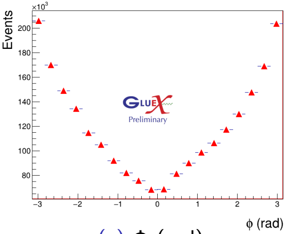
The distributions are not corrected for acceptance



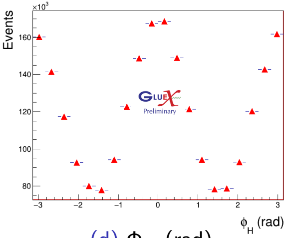
(a) Cos(θ)



(b) Cos(θ_H)



(c) Φ (rad)



(d) Φ_H (rad)

Figure 4: Distribution of M($\omega\pi$) in various decay angles (Ω, Ω_H)

Monte Carlo Event generation of b_1 (Not for DNP 2020)

- Worked closely with the JPAC Theory group[2] on the model development and had implemented a preliminary model by fixing majority of the parameters.
- The amplitude generator does seem to produce desired distributions to the first order.

In order to test the developed generator,

- A sample of 4 vectors are generated using the *gen_omegapi* generator with a specific J^{PC} state.
- Then use AmpTools to fit the generated MC to extract the parameters ($V^i_{\lambda_\gamma,\Lambda}$, C^i_l).
- These extracted parameters has to be equal to the parameters given during generation.

[2] A. Sczepaniak et. al JPAC

Example MC generation (Not for DNP 2020)

A sample of 4 vectors are generated using the *gen_omegapi* generator with the following conditions

Parameters used to generate MC

- M(b_1 = 1.235 GeV)
- M(ω) = 0.782 GeV
- orbital-l between ω and $\pi^0 = 0$
- $C_0^{1+} = 1$
- Re($V_{+1,-1}^{+1}$) = 1.0
- Re($V_{+1,0}^{+1}$) = 1
- Re($V_{+1,+1}^{+1}$) = 0.5
- Re(Uniform) = 0.01
- $\Gamma(b_1)$ = 0.142 GeV
- $\Gamma(\omega)$ = 0.008 GeV
- Pol. Frac = 0.4
- $C_2^{1+} = 0.27$
- Im($V_{+1,-1}^{+1}$) = 0.0
- Im($V_{+1,0}^{+1}$) = 0.0
- Im($V_{+1,+1}^{+1}$) = 0.0
- Im(Uniform) = 0.0

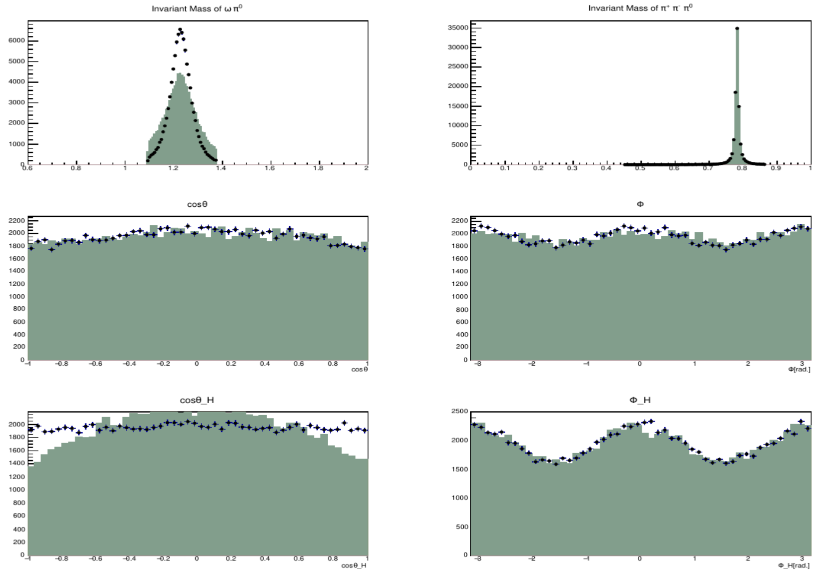
Example MC fit (Not for DNP 2020)

The generated sample events are fit using AmpTools.
Some of the parameters are fixed during fitting (in green) and other parameters are calculated (in red)

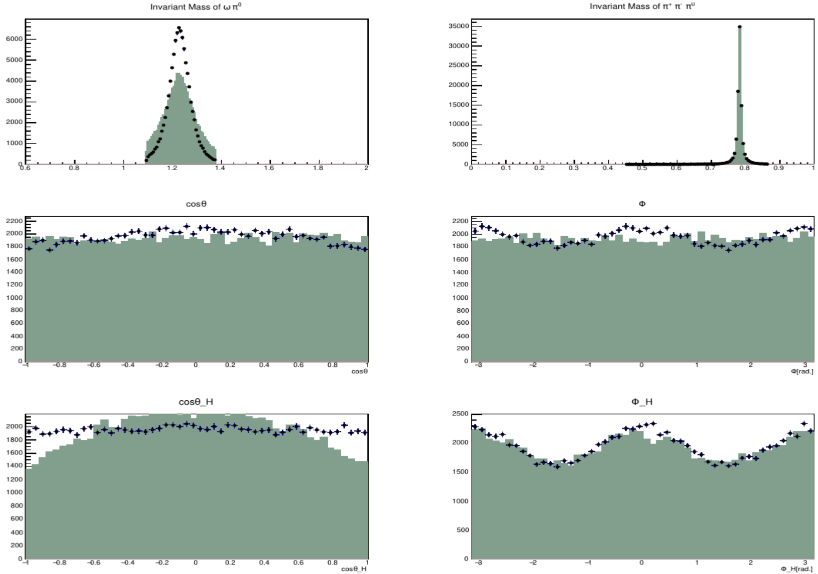
AmpTools Fit results

- M(b_1 = 1.235 GeV)
- M(ω) = 0.782 GeV
- orbital-l between ω and π^0 = 0
- C_0^{1+} = 1
- Re($V^{+1}_{+1,-1}$) = 257.26
- Re($V^{+1}_{+1,0}$) = 259
- Re($V^{+1}_{+1,+1}$) = 83.113
- Re(Uniform) = 0.008
- $\Gamma(b_1)$ = 0.142 GeV
- $\Gamma(\omega)$ = 0.008 GeV
- Pol. Frac = 0.4
- C_2^{1+} = 0.27
- Im($V^{+1}_{+1,-1}$) = 25.553
- Im($V^{+1}_{+1,0}$) = 0.0
- Im($V^{+1}_{+1,+1}$) = -29.867
- Im(Uniform) = 0.0

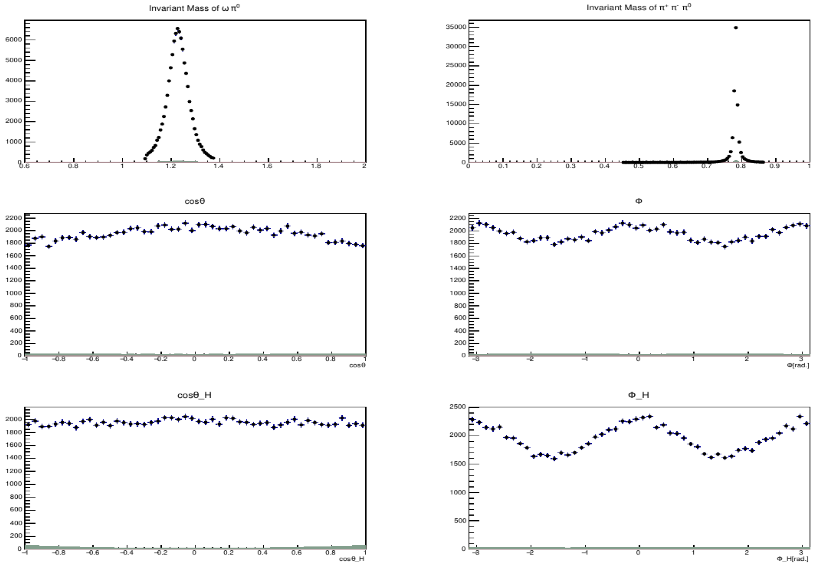
S + D Wave Fit (Not for DNP 2020)



S Wave Fit (Not for DNP 2020)



D Wave Fit (Not for DNP 2020)



Summary and Next Steps

Summary

- GlueX maps the meson spectrum and search for exotics. The b_1 meson is important part of measuring the lightest hybrid multiplet, because hybrids decay into $b_1\pi$
- Cos(θ_H) distribution for signal MC and Fitted MC do not match, This issue is being investigated
- Preliminary angular distribution of the b_1 meson is produced using the 2017 data.
- A preliminary model for angular distribution has been developed and is being rigorously tested.

Current Analysis

- Analysing the same 2017 data with acceptance correction
- Working closely with JPAC[a] to fully develop and test the amplitude model and implementing in the GlueX framework
- Working on solving the discrepancy in the Cos(θ_H) distribution in fitting.

[a] A. Sczepaniak et. al JPAC

Summary and Next Steps (cont.)

Next steps

- Once the generator is rigorously tested, need to fit the same (MC) with setting the C_l^j as free parameters and calculating them by fitting.
- Should move on to perform fitting on the data to extract the fit parameters
- To start with, intending to do a fit by constraining the Mass of the $M(\omega\pi)$ system and setting the C_l^j free.
- C_l^J depends only on $M(\omega\pi)$. Therefore, intending to restrict the beam energy in a narrow coherent region and limit the t range to extract the C_l^j. thereby extracting the D/S ratio for the 1+ state

Bibliography

[1] M. Atkinson *et al.*, "Diffractive Photoproduction of a $b_1\pi$ System," *Z. Phys. C*, vol. 34, p. 157, 1987.

[2] S. H. F. P. Collaboration, "Production and decay properties of the $\omega\pi^0$ state at 1250 mev$/c^2$ produced by 20-gev polarized photons on hydrogen," *Phys. Rev. D*, vol. 37, pp. 2379–2390, 9 May 1988. DOI: 10.1103/PhysRevD.37.2379. [Online]. Available: https://link.aps.org/doi/10.1103/PhysRevD.37.2379.

Backups

Event Selection List

- Kin. Fit Confidence level $> 10^{-5}$.
- Missing Mass Squared $< 0.05\ GeV^2/c^4$
- PID ΔT Cuts (FCAL, BCAL, ST and TOF)
- Four momentum Kinematic fit for neutral particles
- $P_{recoil} > 350$ MeV
- Standard $(\frac{dE}{dX})_{proton}$ curve cut
- Target vertex cuts: 52cm $<$ Z $<$ 78cm, R $<$ 1cm
- $E_{beam} > 6.5$ GeV
- Four-momentum + vertex kinematic fit for charged particles

Backups (cont.)

Accidental and Background Subtractions

- Accidental Subtraction: 3 accidental peaks on either side of the coincidence peak ($\frac{coincidence}{accidentals} = \frac{1}{6}$)
- 6 σ wide ω and 2 side-bands on either side of the 1-σ wide ($\frac{peak}{side-band}$ $\frac{6}{2} = 3$)

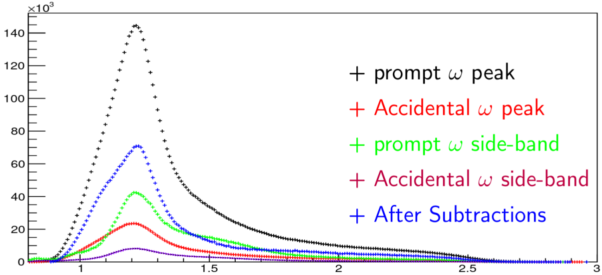


Figure 6: M($\omega\pi$) distribution at every stage of subtraction

Backups (cont.)

Accidental and Background Subtractions

- Accidental Subtraction: 3 accidental peaks on either side of the coincidence peak ($\frac{coincidence}{accidentals} = \frac{1}{6}$)
- 6 σ wide ω and 2 side-bands on either side of the 1-σ wide ($\frac{peak}{side-band}$ $\frac{6}{2} = 3$)

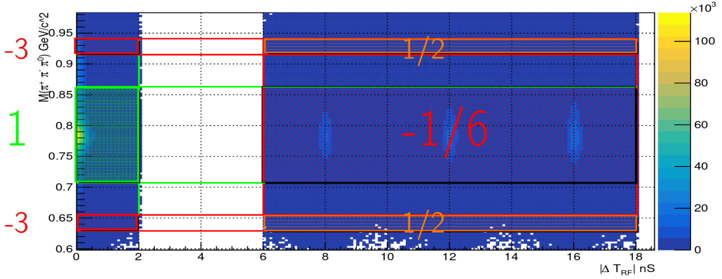


Figure 7: Weighting the events based on their occurrence in the plot for accidental and background subtraction

Dalitz Function

The Dalitz function can be written as

$$G(Z,\theta) = \sqrt{1 + 2\alpha Z + 2\beta Z^{3/2} Sin(3\theta) + 2\gamma Z^2 + 2\delta Z^{5/2} Sin(3\theta)}$$

where Z, θ are defined as

$$Z = \sqrt{x^2 + y^2}\ ,\ \theta = \frac{y}{Z}$$

and the Mandelstam variables of the ω decay are defined as

$$s = (p_\omega - p_{\pi^0})^2\ ,\ t = (p_\omega - p_{\pi^-})^2\ ,\ u = (p_\omega - p_{\pi^+})^2$$

where x, y are defined as

$$x = \frac{\sqrt{3}(t-u)}{2M(M-3m_\pi)}\ ,\ y = \frac{3(s_c - s)}{2M(M-3m_\pi)}$$

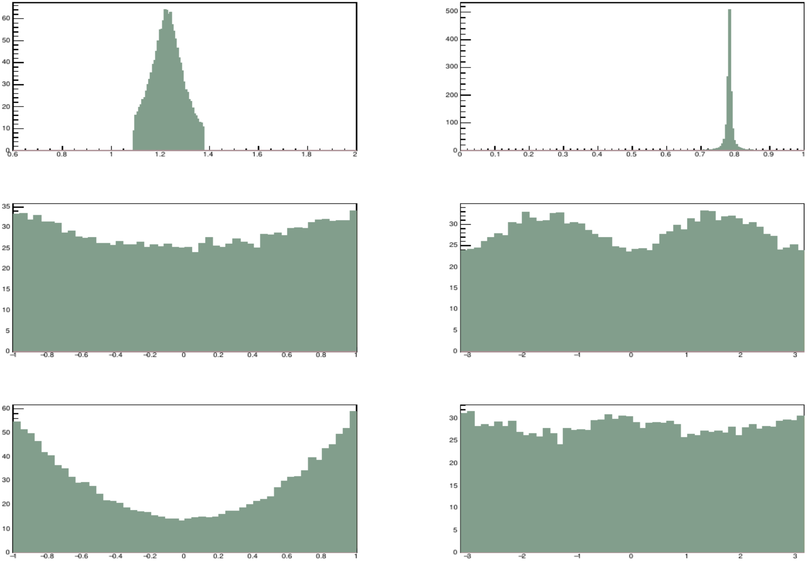
Backups

With the J^{PC} of $0^{\pm}$, $1^{\pm}$, $2^{\pm}$ for the $\omega\pi$ and partial wave l = 0, 1, 2; one can reproduce the complete $\omega\pi$ spectrum.
The fit parameters corresponding to the states and partial waves are:

- 12 Vertices $V^{i}_{\lambda_\gamma,\Lambda}$
  - $0^- \rightarrow V^{0^-}_{+1,0}$
  - $1^+ \rightarrow V^{1^+}_{+1,-1}, V^{1^+}_{+1,0}, V^{1^+}_{+1,+1}$
  - $1^- \rightarrow V^{1^-}_{+1,-1}, V^{1^-}_{+1,0}, V^{1^-}_{+1,+1}$
  - $2^+ \rightarrow V^{2^+}_{+1,-2}, V^{2^+}_{+1,-1}, V^{2^+}_{+1,0}, V^{2^+}_{+1,+1}, V^{2^+}_{+1,+2}$
  - $2^- \rightarrow V^{2^-}_{+1,-2}, V^{2^-}_{+1,-1}, V^{2^-}_{+1,0}, V^{2^-}_{+1,+1}, V^{2^-}_{+1,+2}$

- 6 real partial wave amplitudes C_l^i
  - $0^- \rightarrow C_1^{0-}$
  - $1^\pm \rightarrow C_1^{1-}, C_0^{1+}, C_2^{1+}$
  - $2^\pm \rightarrow C_1^{2-}, C_2^{2+}$
- Four Dalitz parameters α, β, γ and δ.

D Wave Fit (Without Signal) (Not for DNP 2020)



Testing the generator against JPAC Theory predictions.

$$A_{\lambda_\gamma} = \sum_{J_i=0,1,2}^{\omega\pi Spin} \sum_{\eta_i=-1,1}^{\omega\pi Parity} \sum_{\Lambda=-J_i,..,J_i}^{\omega\pi SpinProj} V^{GJ}_{\lambda_\gamma,\Lambda} \sum_{\lambda=-1,0,1}^{\omega Helicity} D^{J_i}_{\Lambda,\lambda}(\Omega) F^i_\lambda D^1_{\Lambda,0}(\Omega_H) G$$

Below are the parameters that are kept constant for the study

- Spin (J) = 1
- $\omega\pi$ Parity (η) = +1
- Spin Projection (J_z or Λ) = +1, 0, 1
- Helicity (λ) = +1, 0, 1
- All the vertices are turned off except V(+1, 0) and V(-1, 0) are set to constant
- $C^i_l = (0, 0, 1)$
- We can now turn on or off the differential partial waves (turn on **F** for each λ) in the formula for F. F has three parts $F(\lambda = -1)$, $F(\lambda = 0)$, $F(\lambda = 1)$

Backups (cont.)

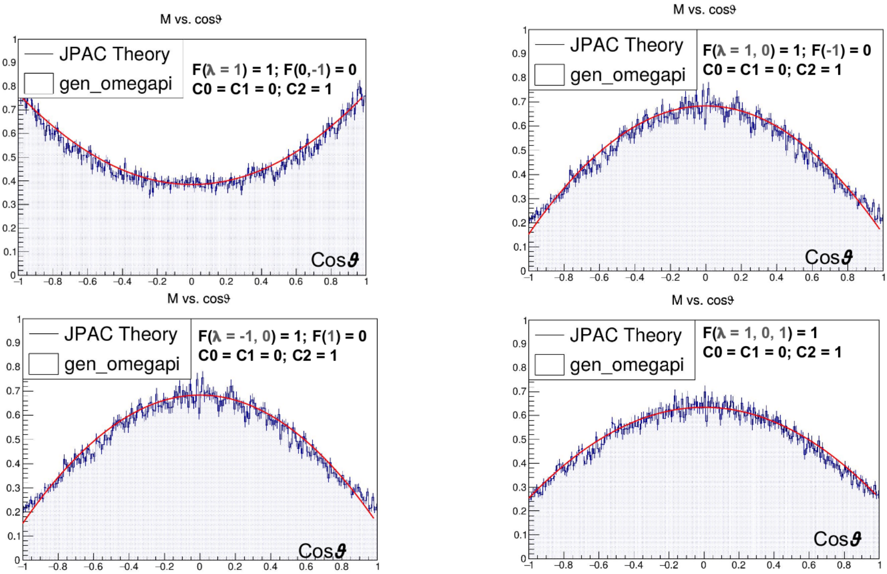


Figure 8: Testing the generator and JPAC predictions

Testing the generator against JPAC Theory predictions.

$$A_{\lambda_\gamma} = \sum_{J_i=0,1,2}^{\omega\pi Spin} \sum_{\eta_i=-1,1}^{\omega\pi Parity} \sum_{\Lambda=-J_i,..,J_i}^{\omega\pi SpinProj} V^{GJ}_{\lambda_\gamma,\Lambda} \sum_{\lambda=-1,0,1}^{\omega Helicity} D^{J_i}_{\Lambda,\lambda}(\Omega) F^i_\lambda D^1_{\Lambda,0}(\Omega_H) G$$

Below are the parameters that are kept constant for the study

- Spin (J) = 1
- $\omega\pi$ Parity (η) = +1
- Spin Projection (J_z or Λ) = +1, 0, 1
- Helicity (λ) = +1, 0, 1
- All the vertices are turned off except V(+1, 0) and V(-1, 0) are set to constant
- $C^i_l = (1, 0, 1)$
- We can now turn on or off the differential partial waves (turn on **F** for each C^i_l).

Backups (cont.)

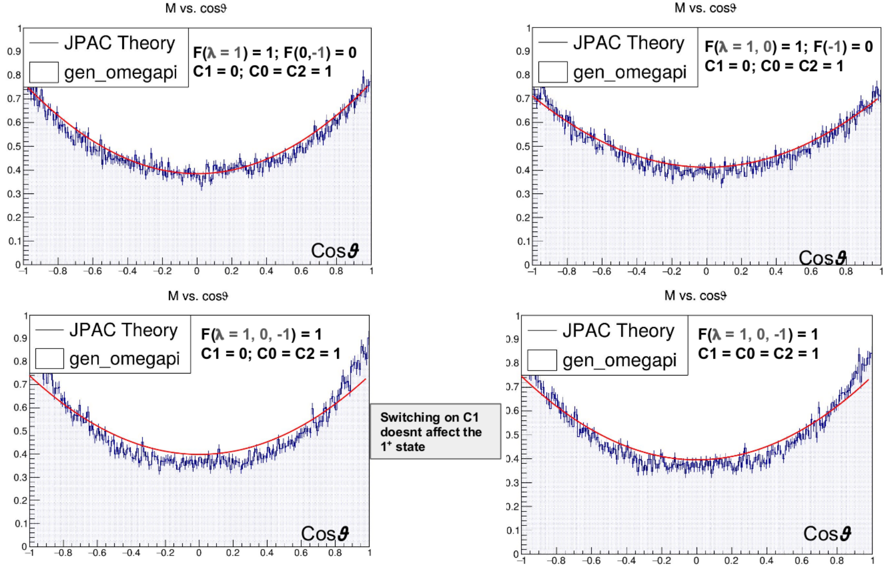


Figure 9: Testing the generator and JPAC predictions