A Spin-Parity Analysis of the $\omega\pi^0$ Enhancement Photoproduced at GlueX

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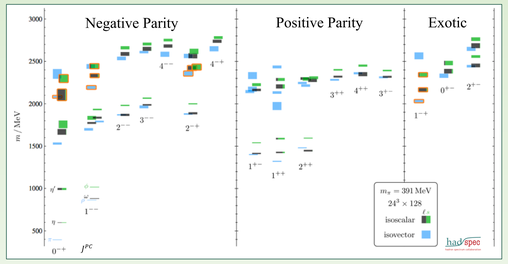
ABSTRACT

The $\omega\pi^0$ system is studied in the reaction $\gamma p \to \pi^+\pi^-\pi^0\pi^0 p$. A preliminary spin-parity analysis is able to qualitatively describe the uncorrected data, and indicates that the main contribution to the enhancement is consistent with a $J^P = 1^+$ axial vector state, with $J^P = 1^-$ vector background. This analysis provides an important stepping stone to analysis of the $\omega\pi^+\pi^-$ system, which is implicated in exotic meson decay.

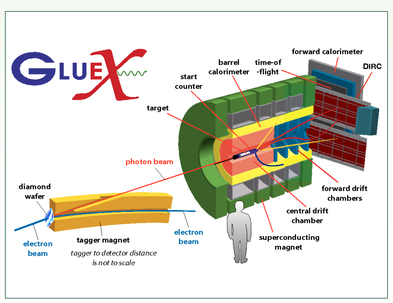
EXOTIC MESONS

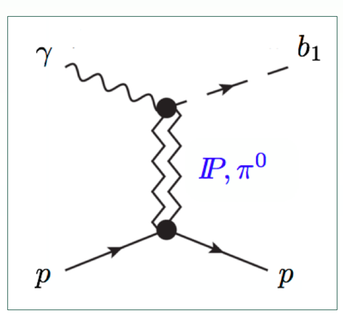
A meson has been traditionally understood as a quark-antiquark pair. Such an object has quantum numbers J^{PC} that must obey certain patterns. Lattice QCD calculations (Ref. [2]) predict the existence of manifestly exotic meson states, which have quantum numbers that do not follow this pattern. One of the main goals of GlueX is to search for exotic meson signals.



THE GLUEX EXPERIMENT

GlueX is a photoproduction experiment performed at Jefferson Lab's newly upgraded 12 GeV accelerator. A 12 GeV electron beam is incident on a diamond wafer, which produces a linearly polarized photon beam through coherent bremsstrahlung. The photon beam is incident on a liquid hydrogen target, and the decay products are detected by the various detector components. The detector has nearly 4π coverage, which gives a full reconstruction of the final state.

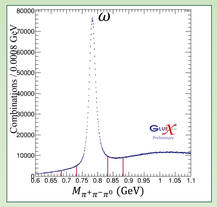


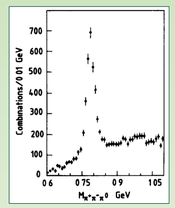


GlueX will allow for mapping of the light meson spectrum, and will play a key role in the search for exotic meson states. Current studies include investigation of polarization observables in an effort to understand meson photoproduction mechanisms, which proceed through t-channel quasi-particle exchange as seen in the figure at left.

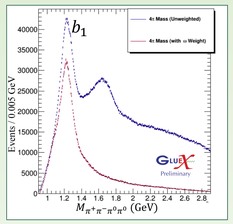
EVENT SELECTION AND WEIGHTING

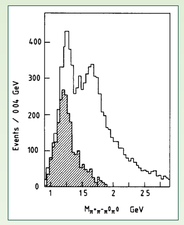
All possible $\pi^+\pi^-\pi^0\pi^0$ combinations are considered. A kinematic fit is performed, and cuts are made on the beam energy and π^0 mass. The 3π events are plotted in a histogram, and a sideband subtraction is performed around the ω peak. The plots from Atkinson (Ref. [1]) are shown on the right for comparison.





The events in the 4π mass plot are then weighted according to the 3π mass, with the ω mass range receiving a weight of +1 and the side-bands receiving a weight of -1.



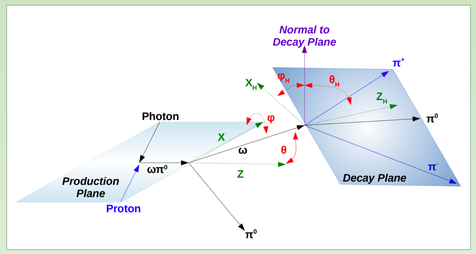


The 4π mass plot is then weighted with 25 moment functions of the angular variables, defined in terms of the Wigner D-functions:

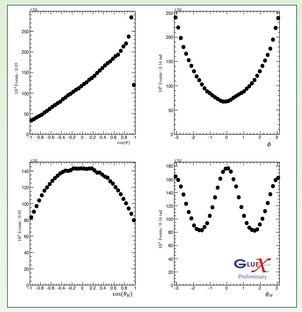
$$H^{\pm}_{lmLM}(\theta,\phi,\theta_H,\phi_H) = \frac{1}{2}\Re\{D^L_{Mm}(\phi,\theta,0)D^l_{m0}(\phi_H,\theta_H,0) \pm (-1)^{L+M}D^L_{-Mm}D^l_{m0}\}$$

ANGULAR DISTRIBUTION

In order to determine the quantum numbers of the $\omega\pi^0$ system, an analysis of its decay angles is needed. A two-step decay process such as this one can be described in terms of four angles, θ, ϕ, θ_H, and ϕ_H.



The angles θ and ϕ describe the direction of the ω particle in the $\omega\pi^0$ rest frame, while θ_H and ϕ_H describe the direction of the normal vector to the $\omega \to 3\pi$ decay plane in the ω rest frame.
The $\sin^2(\theta_H)$ component in the $\cos(\theta_H)$ distribution indicates that the dominant J^P state cannot be 0^-. The ϕ distribution shows a $\sin(\phi)$ contribution, which indicates interference between $\omega\pi^0$ helicities ±1 and 0.



FIT EQUATION

In order to extract information about the contributions to the $\omega\pi^0$ channel and compare to the results of Ref. [1], we fit the data with a function involving a sum over the Breit-Wigner amplitudes of the J^P states 1^+ and 1^-, $\begin{cases} H^+(lmLM) = \sum_i \Re H_{ii}(lmLM) \\ H^-(lmLM) = 2\sum_{i>j}\Re H_{ij}(lmLM) \end{cases}$,

where i and j stand for the different J^P states. These complex sums can be related to the production density matrix $\left(\rho^{ij}_{\Lambda\Lambda'}\right)$ and the decay amplitudes $\left(F^i_\lambda\right)$ using $H_{ij}(lmLM) = t^{ij*}_{LM} f^{ij}_{Llm}\langle 10l0|10\rangle$.

The function t^{ij*}_{LM} is related to the production density matrix by

$t^{ij*}_{LM} = \left(\frac{2J_i+1}{2J_i+1}\right)^{1/2}\sum_{\Lambda\Lambda'}\rho^{ij}_{\Lambda\Lambda'}\langle J_i\Lambda' LM|J_i\Lambda\rangle$, and f^{ij}_{Llm} is related to the decay amplitudes by

$f^{ij}_{Llm} = \sum_{\lambda\lambda'} F^i_\lambda F^{j*}_{\lambda'}\langle J_j\lambda' Lm|J_i\lambda\rangle\langle 1\lambda' lm|1\lambda\rangle$.

The decay amplitudes can be expanded as functions of mass using the partial wave amplitudes C^i_l:

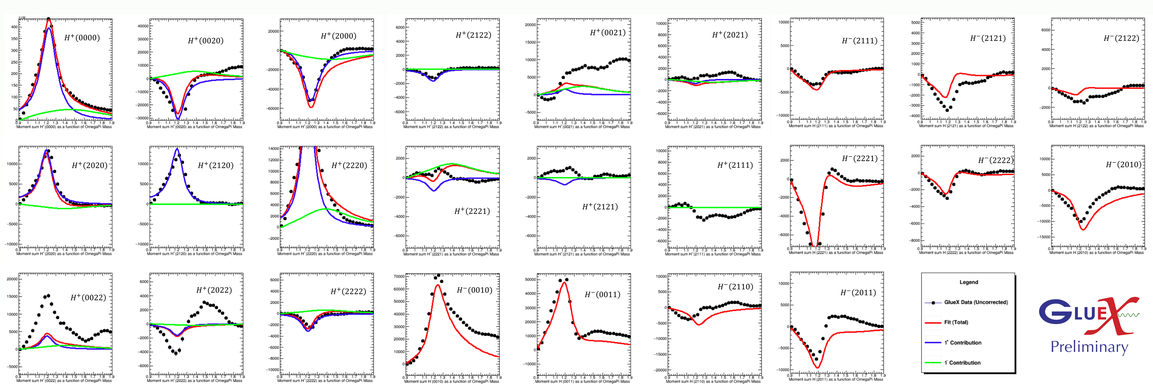
$F^i_\lambda = D_i(m)G_i\sum_l\left(\frac{2l+1}{2J_i+1}\right)^{1/2}\langle J_i\lambda|l01\lambda\rangle C^i_l\frac{B_l(m)}{B_l(m_i)}$, with Breit-Wigner shapes parameterized as

$D_i(m) = \frac{m_i\Gamma_i}{(m^2-m_i^2)-im_i\Gamma_i(m)}$, where

$\Gamma_i(m) = \Gamma_i\left(\frac{q}{q_i}\right)\left[\frac{B_L(m)}{B_L(m_i)}\right]^2$.

RESULTS OF FIT

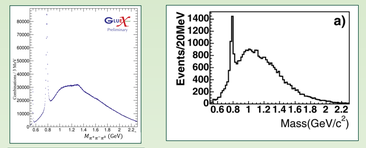
The extracted moments are not acceptance corrected and the results presented here are very preliminary.



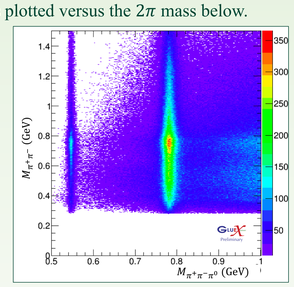
OUTLOOK

The GlueX data are described qualitatively by this model, which could be improved by performing a full acceptance correction, including more J^P states and accounting for additional background contributions. Performing the fit in separate bins of $-t$ will also enhance the interpretation of the b_1 production mechanism.

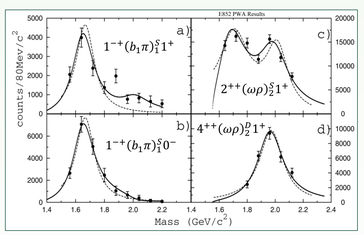
Currently transitioning to an analysis of $\omega\pi^+\pi^-$. The E852 collaboration reported an exotic signal in 2005 (Ref. [3]), in the reaction $\pi^-p \to \pi^+\pi^-\pi^-\pi^0\pi^0 p$, but a similar channel has not been analyzed in photoproduction. Below are shown some very preliminary plots of the 3π mass and the "bachelor" 2π mass, along with the corresponding E852 plots. The ω and η enhancements can both be seen in the 3π mass distribution.



The 3π mass is plotted versus the 2π mass below.



Below are the results from a partial wave analysis done by E852 (Ref. [3]), where a pair of $J^{PC} = 1^{-+}$ $b_1\pi$ enhancements and a pair of $\omega\rho$ enhancements were reported.



REFERENCES

[1] M. Atkinson, et al. *Nuclear Physics B,* 243:1-28, 1984.

[2] J. J. Dudek et al. *Physical Review D,* 88:094505, 2013.

[3] M. Lu, et al. *Physical Review Letters*, 94:032002, 2005.

ACKNOWLEDGMENTS

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