Peter Pauli

Exotic meson program at JLab

University of Glasgow

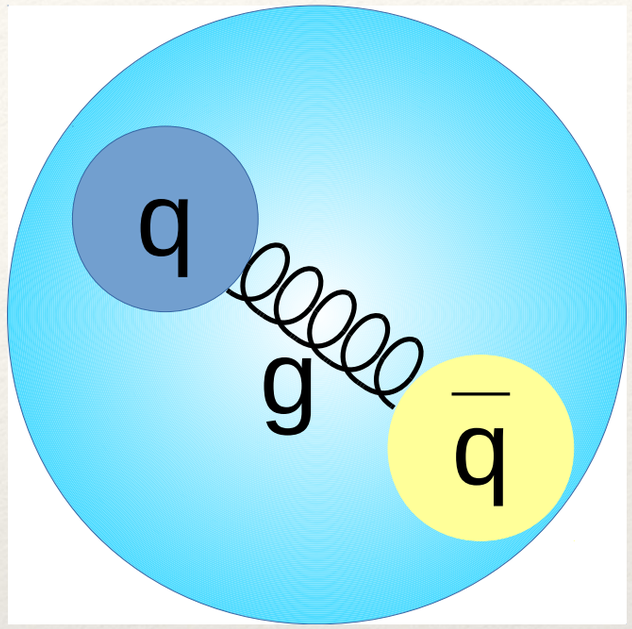
2nd Strong2020 online workshop

Sep 15, 2021

GLUEX

Hybrid mesons

- Many $q\bar{q}$ states have been observed
- $q\bar{q}q\bar{q}$, $q\bar{q}g$, … are not forbidden!
- In quark model:
  $\overrightarrow{J} = \overrightarrow{L} + \overrightarrow{S}$, $P = (-1)^{L+1}$, $C = (-1)^{L+S}$

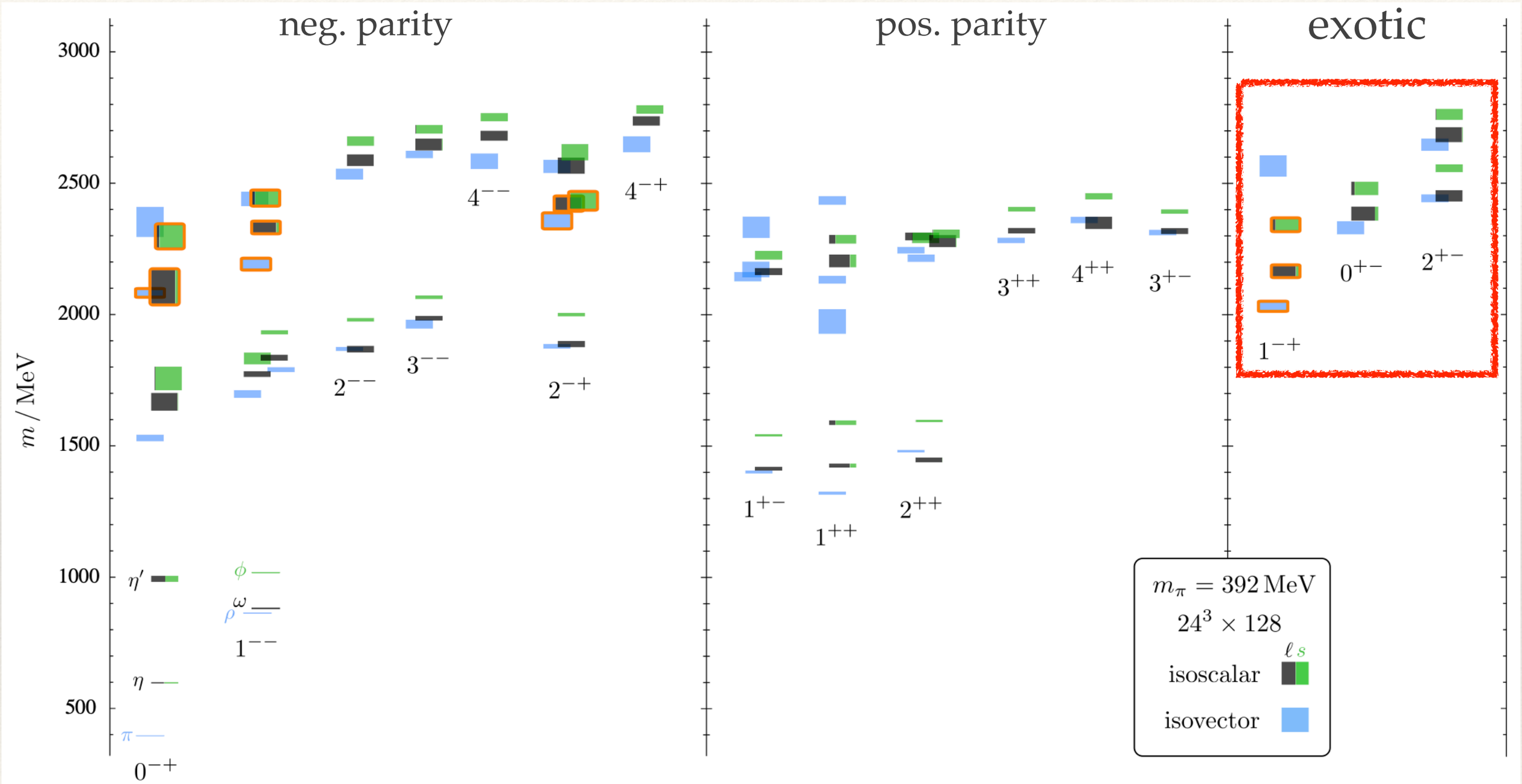


→ <u>not</u> allowed:
$J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

- "Exotic" quantum numbers are "smoking gun" for something not being pure $q\bar{q}$

Light quark mesons from lattice QCD

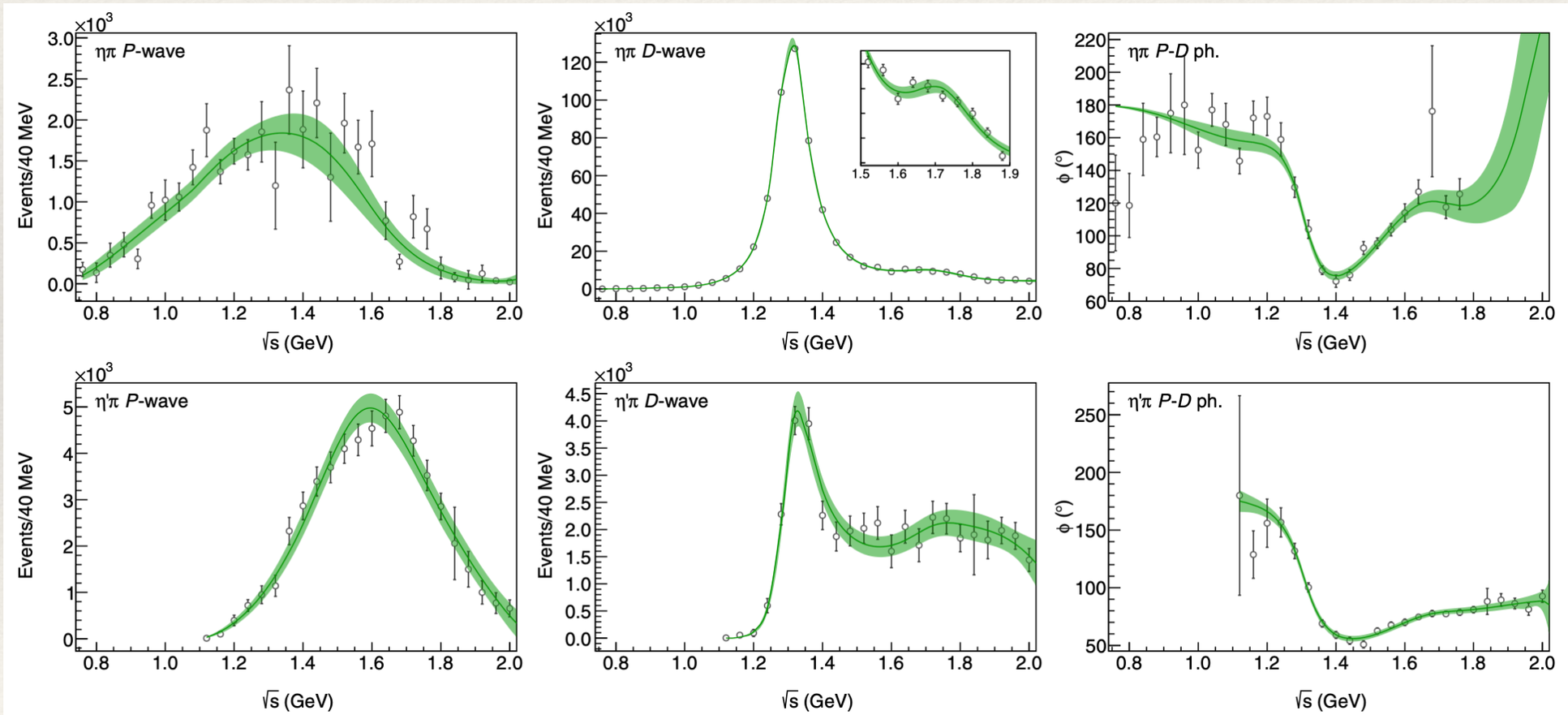
hadspec collaboration



*hadspec, Phys. Rev. D **88**, 094505*

Hybrid mesons - evidence

- Experimental evidence for a 1^{-+}:
  - $\pi_1(1400)$: GAMS, VES, E852, CBAR, COMPASS
  - $\pi_1(1600)$: VES, E852, COMPASS
- JPAC coupled channel fit to $\eta\pi$ and $\eta'\pi$ data from COMPASS



$$\text{mass} = 1564 \pm 24 \pm 86 \text{ MeV} \quad \text{width} = 492 \pm 54 \pm 102 \text{ MeV}$$

JPAC, Phys. Rev. Lett. ***122****, 042002*

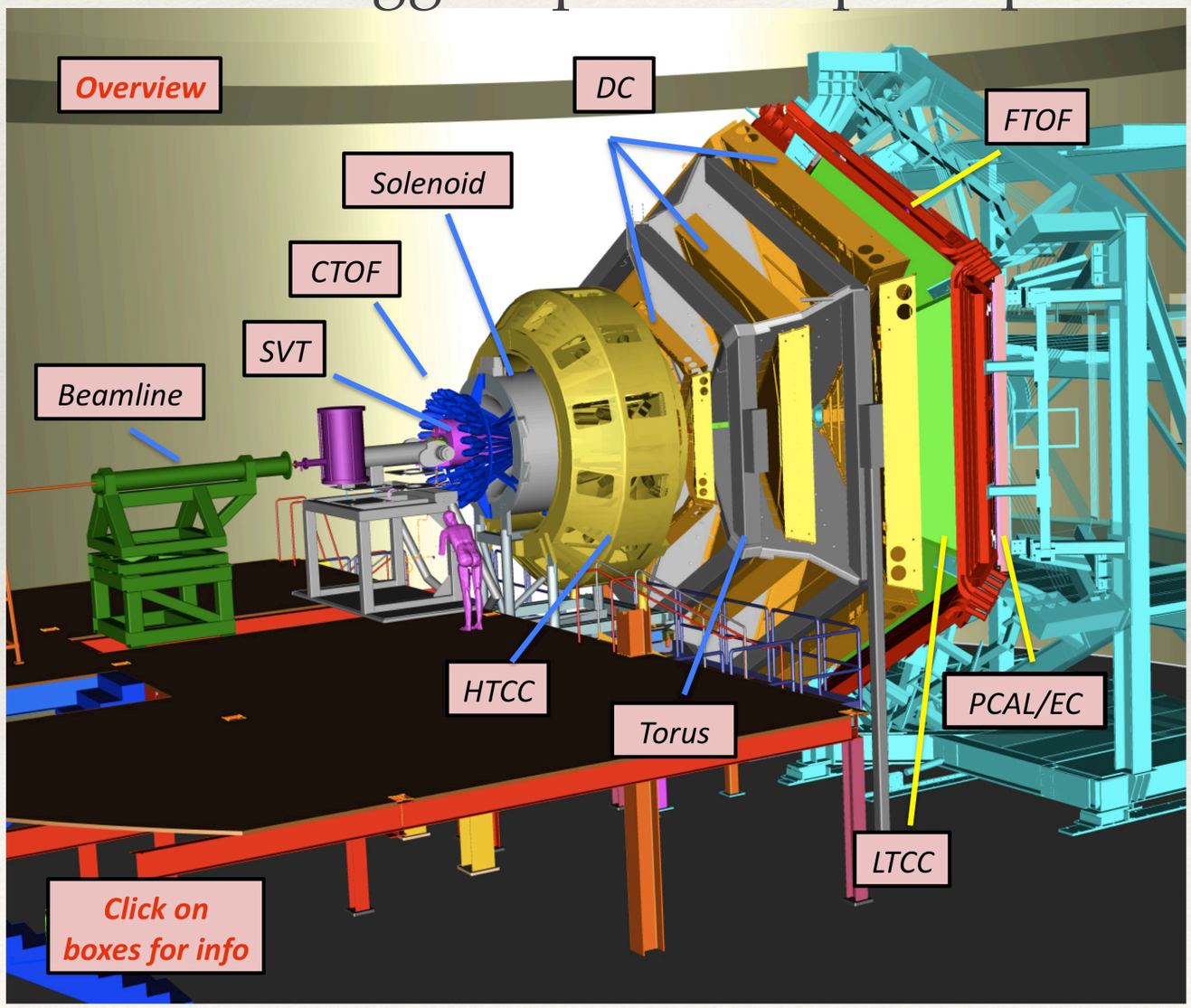
CEBAF at Jefferson Lab

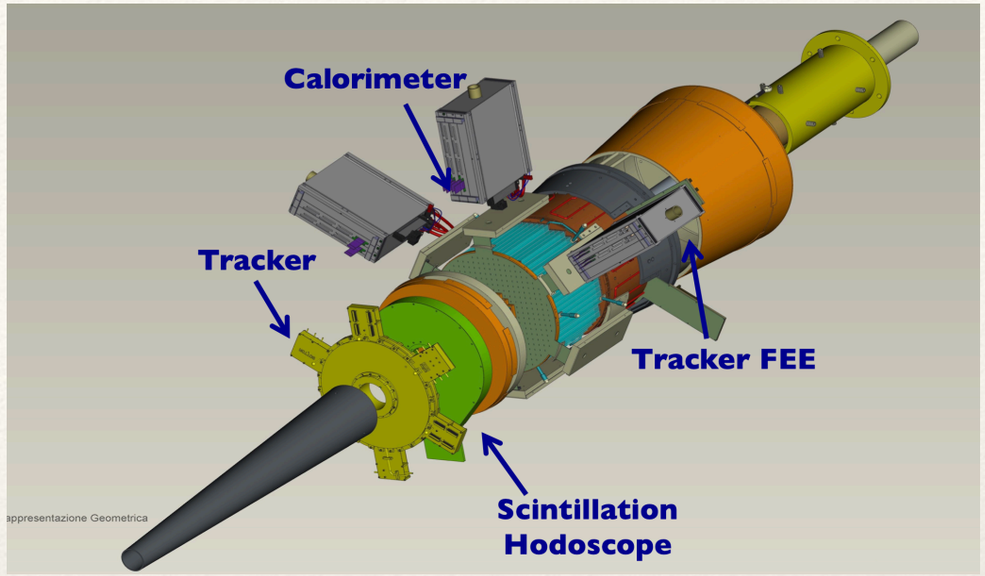
- Up to 12 GeV e^- beam

Hall B: CLAS12
Hall D: GlueX

CLAS12 in Hall B

- Solenoid and toroidal magnetic fields
- Excellent PID for multi-particle FS
- Wide physics program
- Forward tagger: quasi-real photoproduction



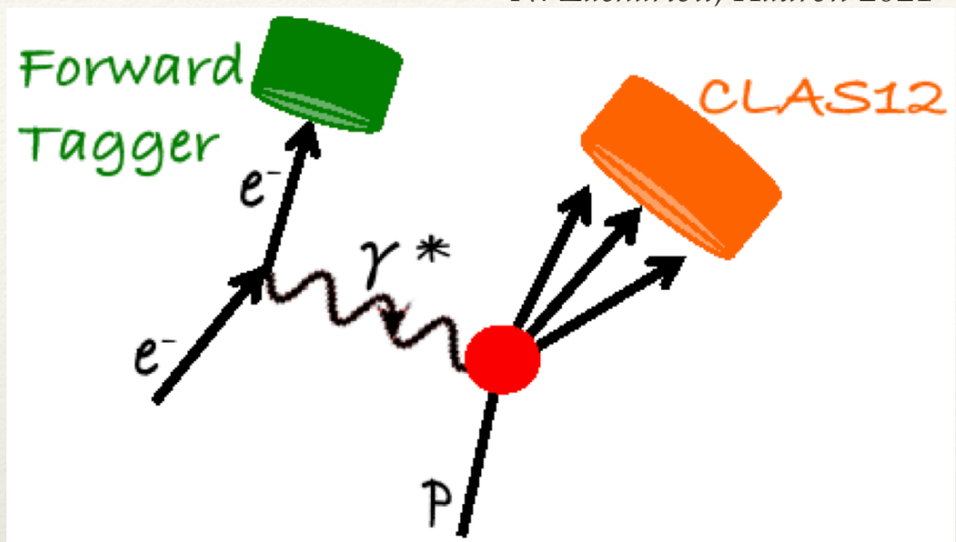


- Momentum resolution:
  $dp/p < 1\,\%$
- 4σ separation:
  π/K up to 2.8 GeV
  K/p up to 4.8 GeV
  π/p up to 5.4 GeV
- Quasi-real photon energies
  $\approx$ 5.5-9.5 GeV

MesonEx

- Quasi-real photo production on proton target with dedicated trigger
- Study light-quark mesons and search for exotics
- Data taking started 2018, still ongoing

N. Zachariou, Hadron 2021

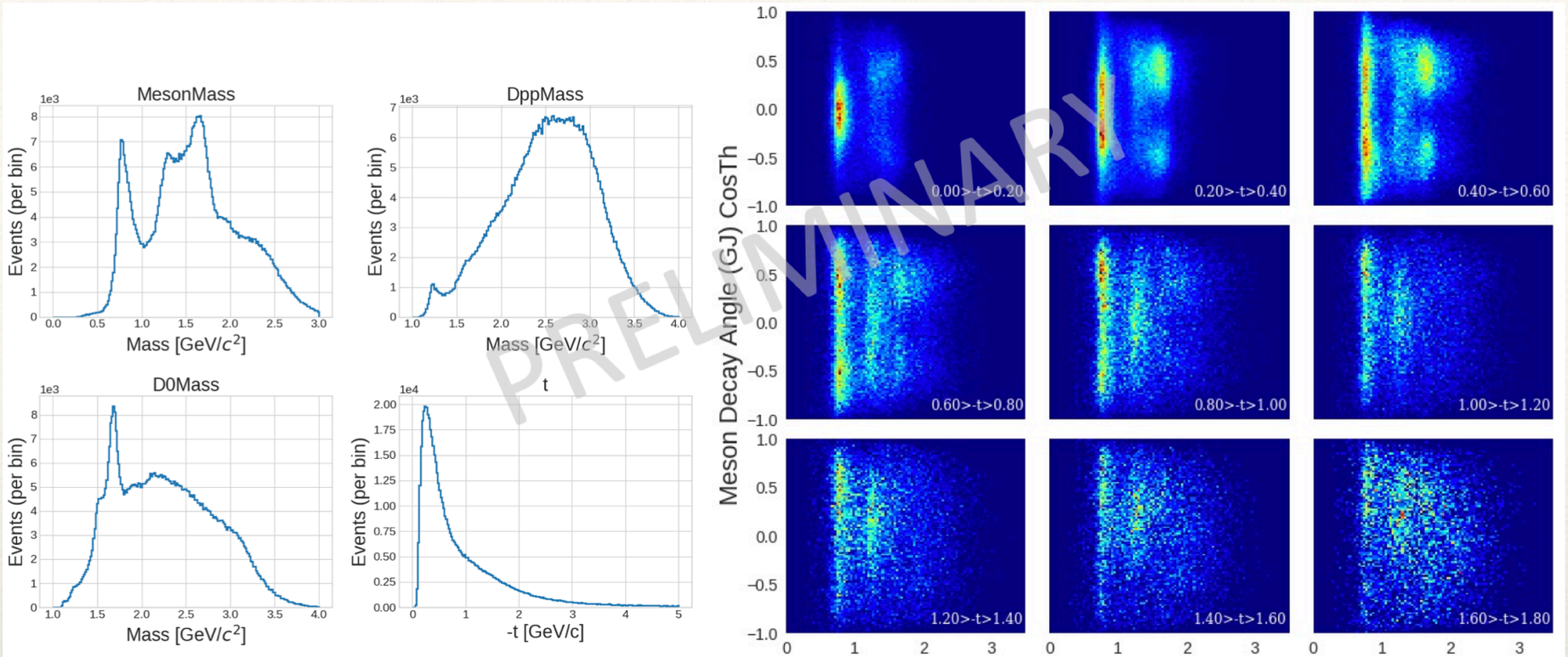


- Early analysis goals:
  - beam asymmetries
  - diff. cross section
  - moment analysis
- First results (beam asymmetries) expected early 2022

MesonEx - first look

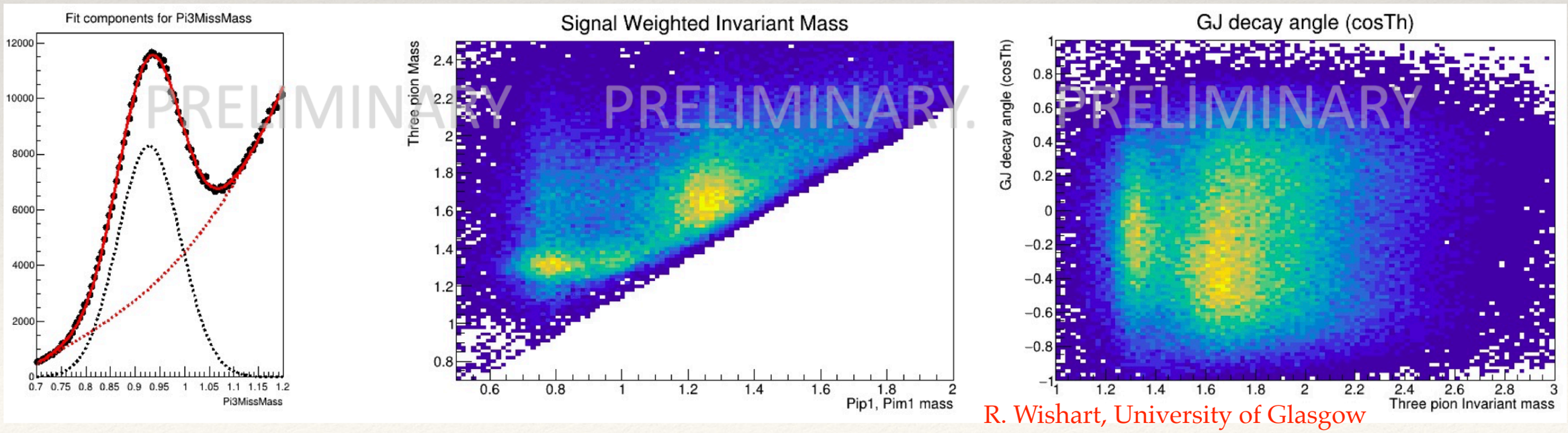
N. Zachariou, Hadron 2021

$\gamma p \to p\pi^+\pi^-$



A. Thorton University of Glasgow

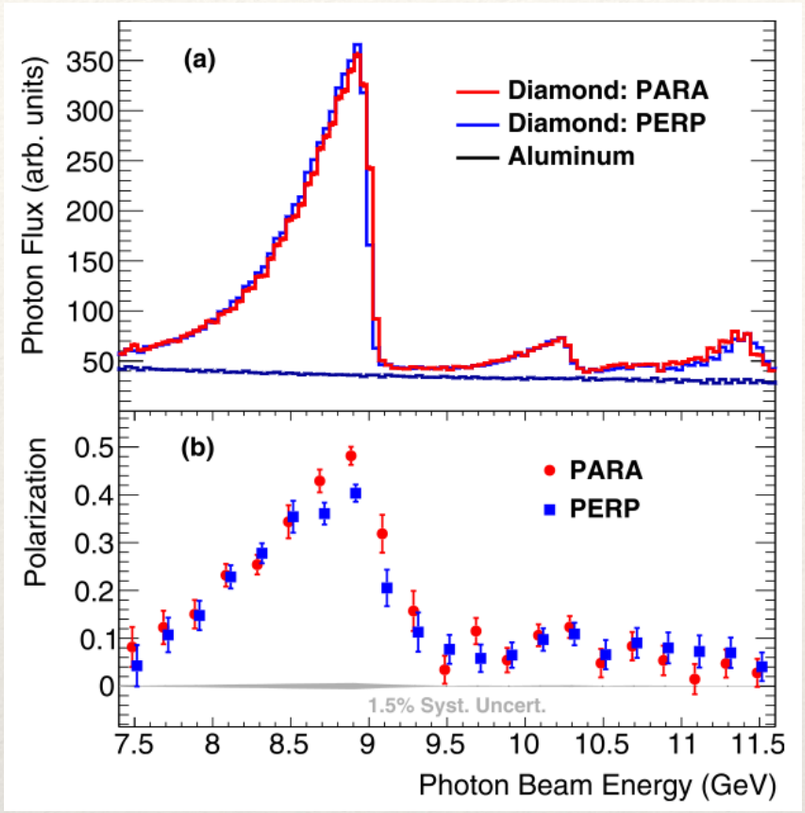
$\gamma p \to n\pi^+\pi^+\pi^-$



R. Wishart, University of Glasgow

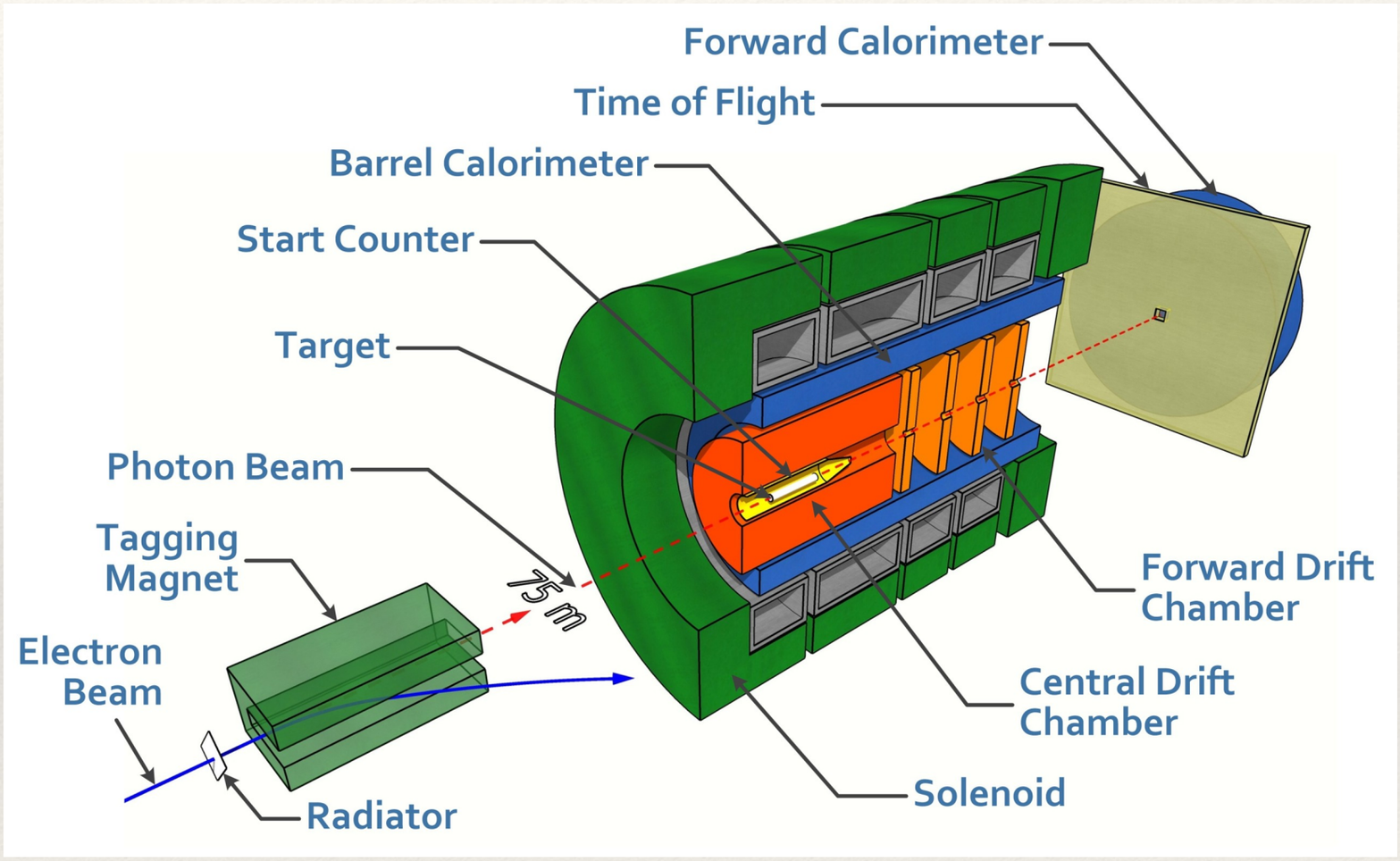
GlueX experiment in Hall D

121 pb^{-1} in coherent peak



GlueX, Nucl. Instrum. Meth. A 987 (2021) 164807

- produce linearly polarized photon beam via coherent bremsstrahlung on thin diamond

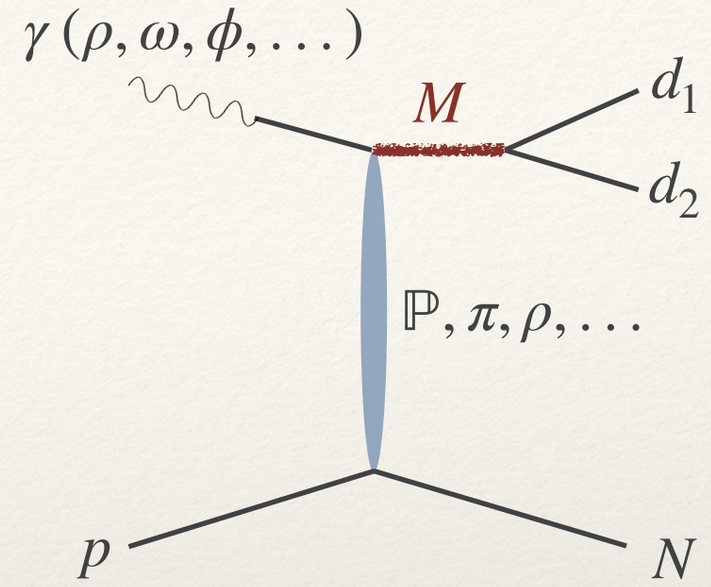


- tag electrons to determine photon energy

- Acceptance: $\theta_{lab} \approx 1^\circ - 120^\circ$
- Charged particles: $\sigma_p/p \approx 1\% - 3\,\%$ ($8\% - 9\,\%$ very-forward high-momentum tracks)
- Photons: $\sigma_E/E = 6\,\%/\sqrt{E} \oplus 2\,\%$

Towards hybrids at GlueX

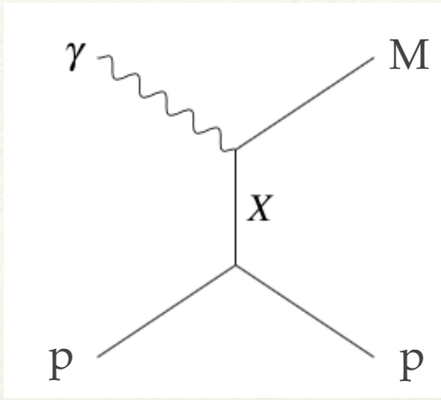
- Photoproduction complementary to pion production
  - Utilize polarization to understand production mechanisms



- Study production mechanisms to inform choice of wave sets for PWA (beam asymmetries, spin density matrix elements)
- Reproduce previous results by COMPASS
- Study $b_1 \to \omega\pi$ as first step towards $b_1\pi$ PWA
- Work closely with theory colleagues

Spin density matrix elements

- SDMEs ρ^i_{jk} contain information on the spin-polarization of the produced state
- Measure angular distribution of decay products
- Learn about production mechanism
  - Study the naturality $\eta = P(-1)^J$ of the exchanged particle X



For vector meson to pseudo-scalar decays:

$$W(\cos\theta,\phi,\Phi) = W^0(\cos\theta,\phi,\Phi) + P_\gamma\cos(2\Phi)W^1(\cos\theta,\phi,\Phi) + P_\gamma\sin(2\Phi)W^2(\cos\theta,\phi,\Phi)$$

$$W^0(\cos\theta,\phi) = \frac{3}{4\pi}\left(\frac{1}{2}(1-\rho^0_{00}) + \frac{1}{2}(3\rho^0_{00}-1)\cos^2\theta - \sqrt{2}\mathrm{Re}\rho^0_{10}\sin 2\theta\cos\phi - \rho^0_{1-1}\sin^2\theta\cos 2\phi\right)$$

$$W^1(\cos\theta,\phi) = \frac{3}{4\pi}\left(\rho^1_{11}\sin^2\theta + \rho^1_{00}\cos^2\theta - \sqrt{2}\mathrm{Re}\rho^1_{10}\sin 2\theta\cos\phi - \rho^1_{1-1}\sin^2\theta\cos 2\phi\right)$$

$$W^2(\cos\theta,\phi) = \frac{3}{4\pi}\left(\sqrt{2}\mathrm{Im}\rho^2_{10}\sin 2\theta\sin\phi + \rho^2_{1-1}\sin^2\theta\sin 2\phi\right)$$

Schilling et. al., Nucl. Phys. B ***15*** *(1970) 397-412*

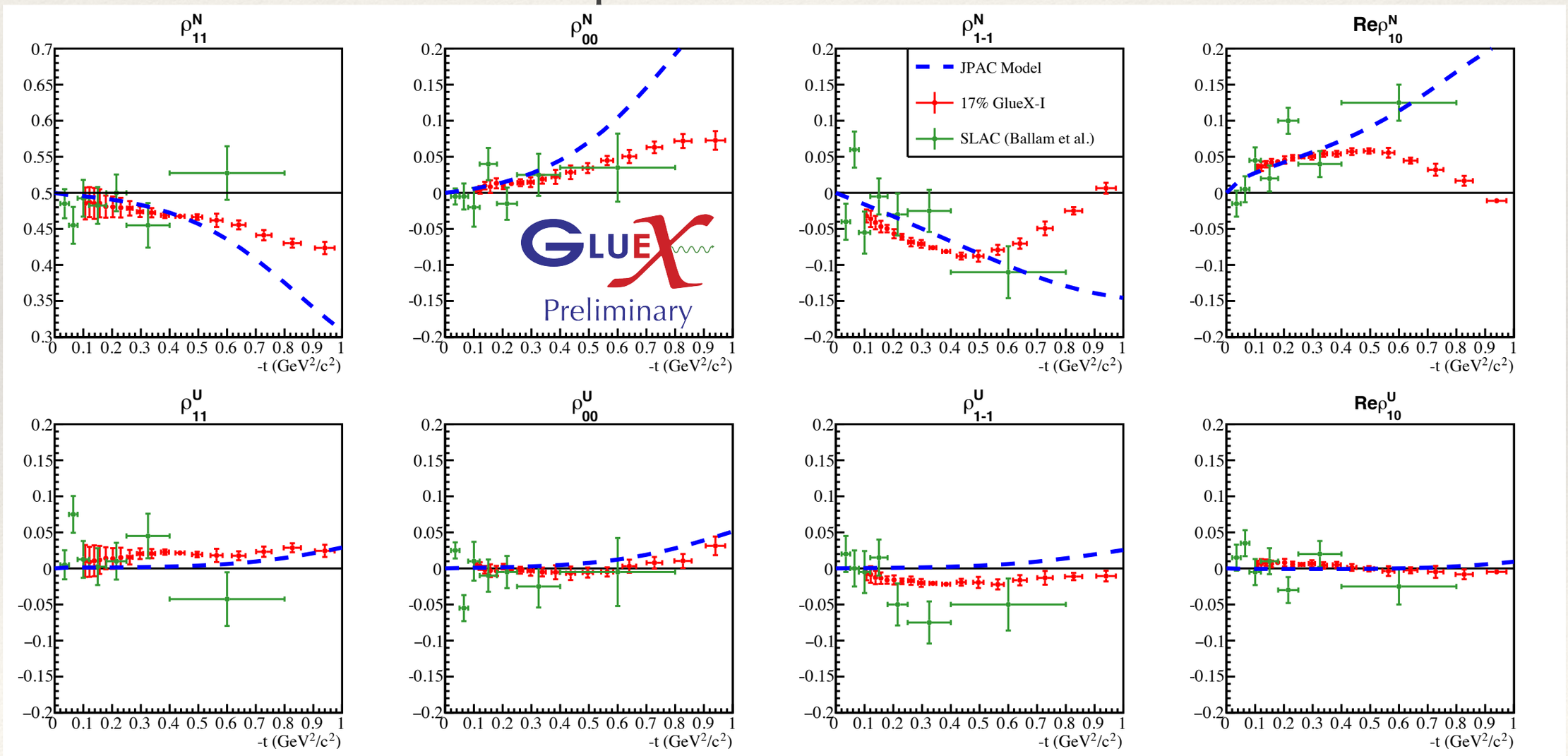
$\rho(770)$ SDMEs

- Study combinations of SDMEs which are purely natural or unnatural
  - $\rho^{N,U}_{jk} = \frac{1}{2}\left(\rho^{0}_{jk} \mp (-1)^{i}\rho^{1}_{-jk}\right)$

*Schilling et. al., Nucl. Phys. B **15** (1970) 397-412*

Natural: e.g. f_2, a_2
Unnatural: e.g. π, η

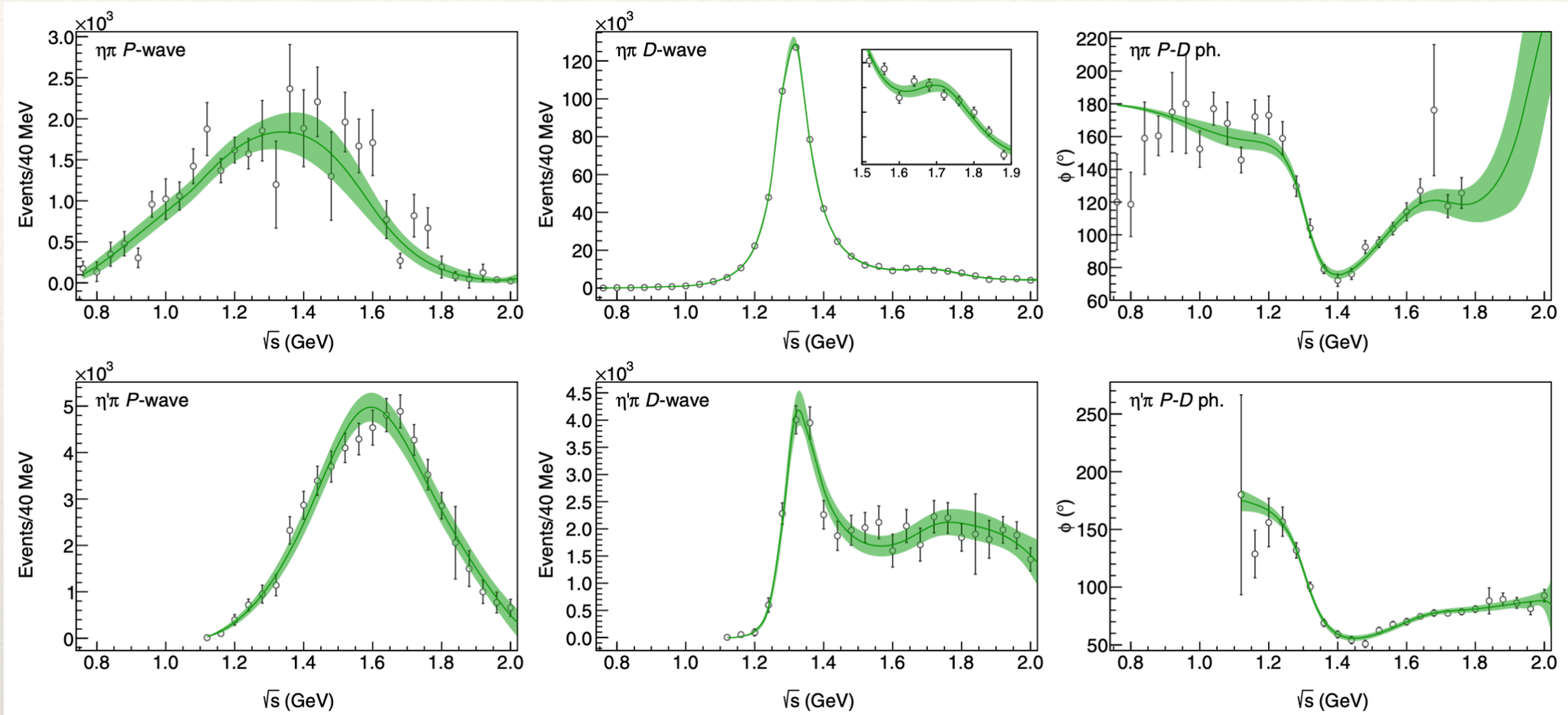
- Dominance of natural amplitudes



*JPAC, Phys. Rev. D **97**, 094003 (2018)*

Hybrid search in $\eta\pi$

JPAC, Phys. Rev. Lett. **122**, *042002*



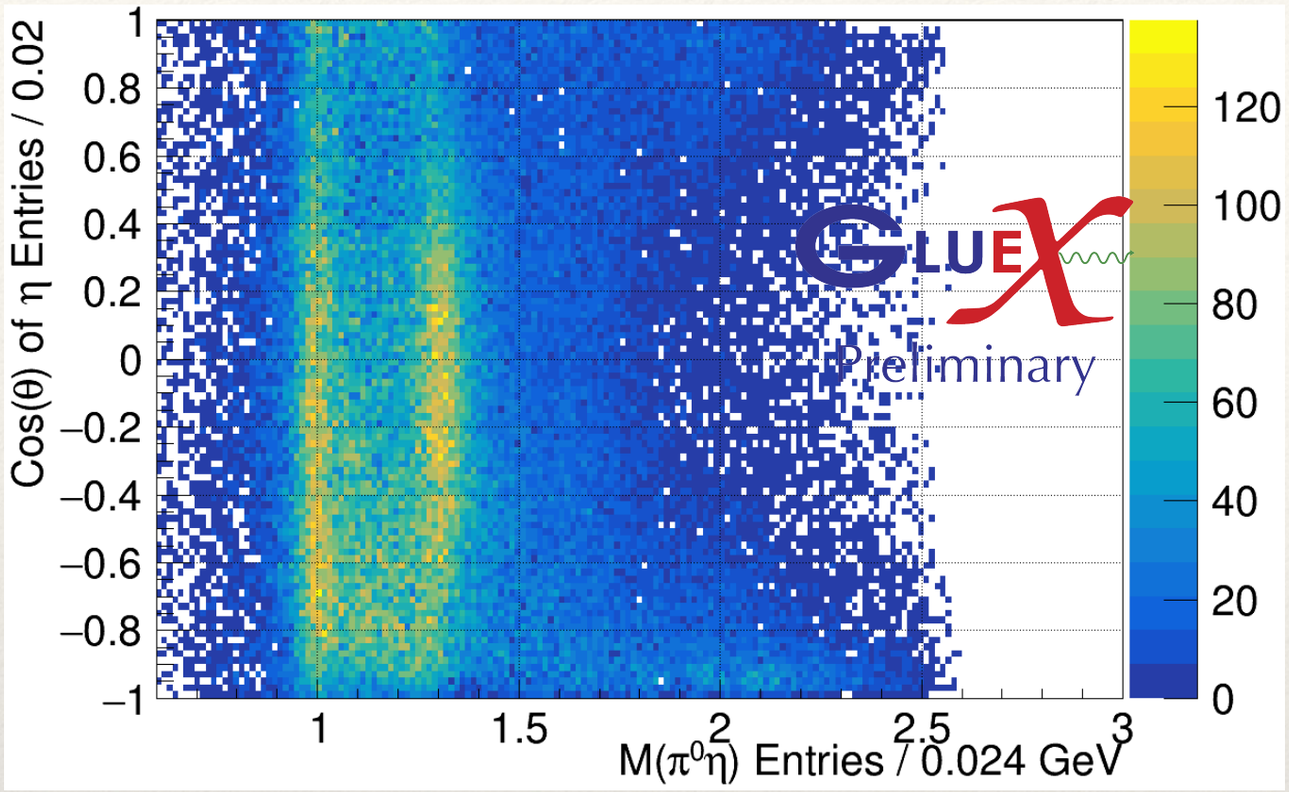
- JPAC coupled channel fit to $\eta\pi$ and $\eta'\pi$ data from COMPASS
- GlueX has access to different decay modes in multiple final states
- $\gamma p \to \eta\pi^0 p,\ \eta \to \gamma\gamma$
- $\gamma p \to \eta\pi^0 p,\ \eta \to \pi^+\pi^-\pi^0$
- $\gamma p \to \eta\pi^-\Delta^{++},\ \eta \to \gamma\gamma$
- $\gamma p \to \eta\pi^-\Delta^{++},\ \eta \to \pi^+\pi^-\pi^0$
- $\gamma p \to \eta'\pi^0 p,\ \eta' \to \pi^+\pi^-\eta,\ \eta \to \gamma\gamma$
- $\gamma p \to \eta'\pi^-\Delta^{++},\ \eta' \to \pi^+\pi^-\eta,\ \eta \to \gamma\gamma$

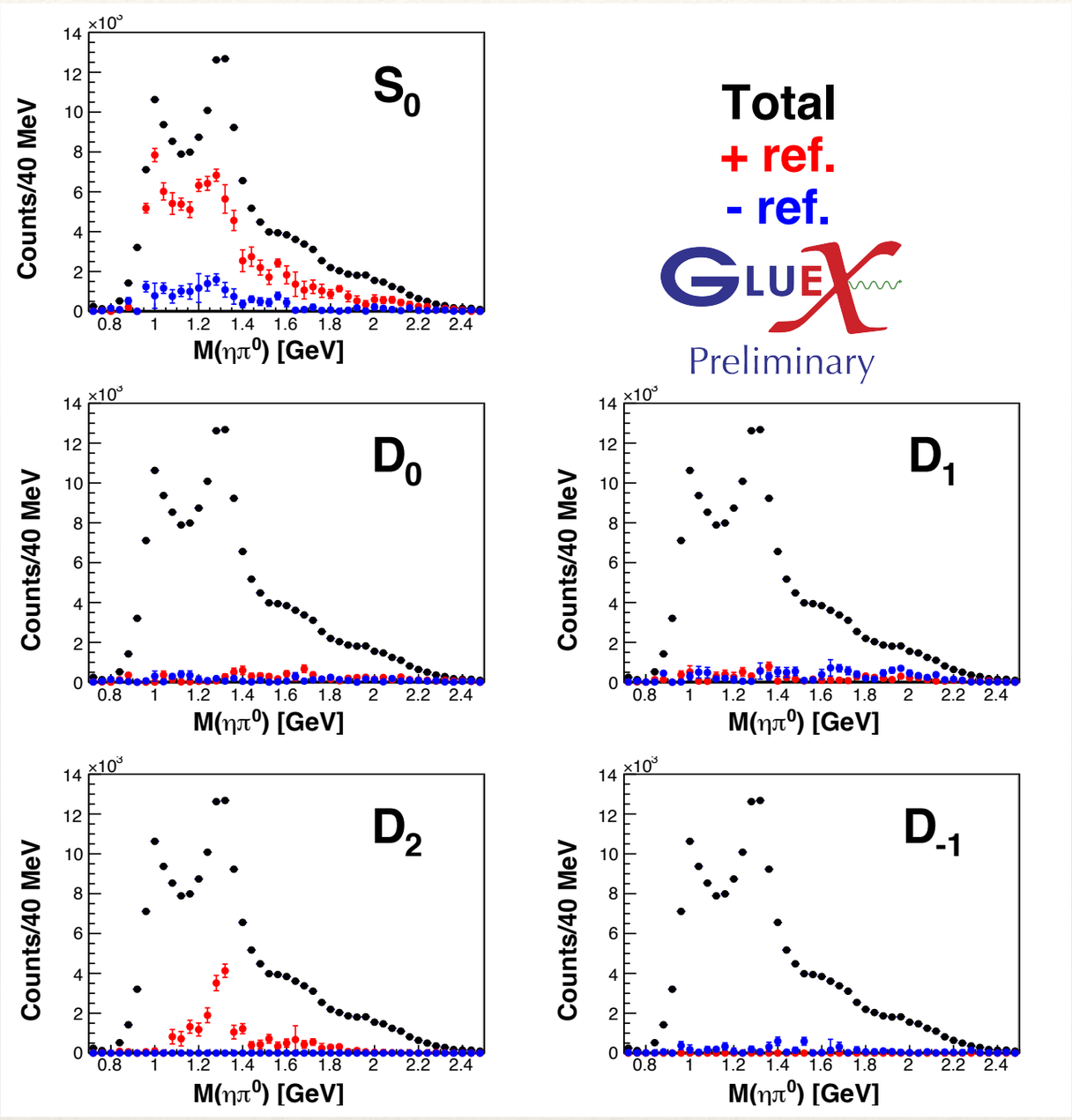
M. Albrecht
L. Ng

Towards a PWA in $\eta\pi^0$

Hadron 2021

0.1<t<0.3



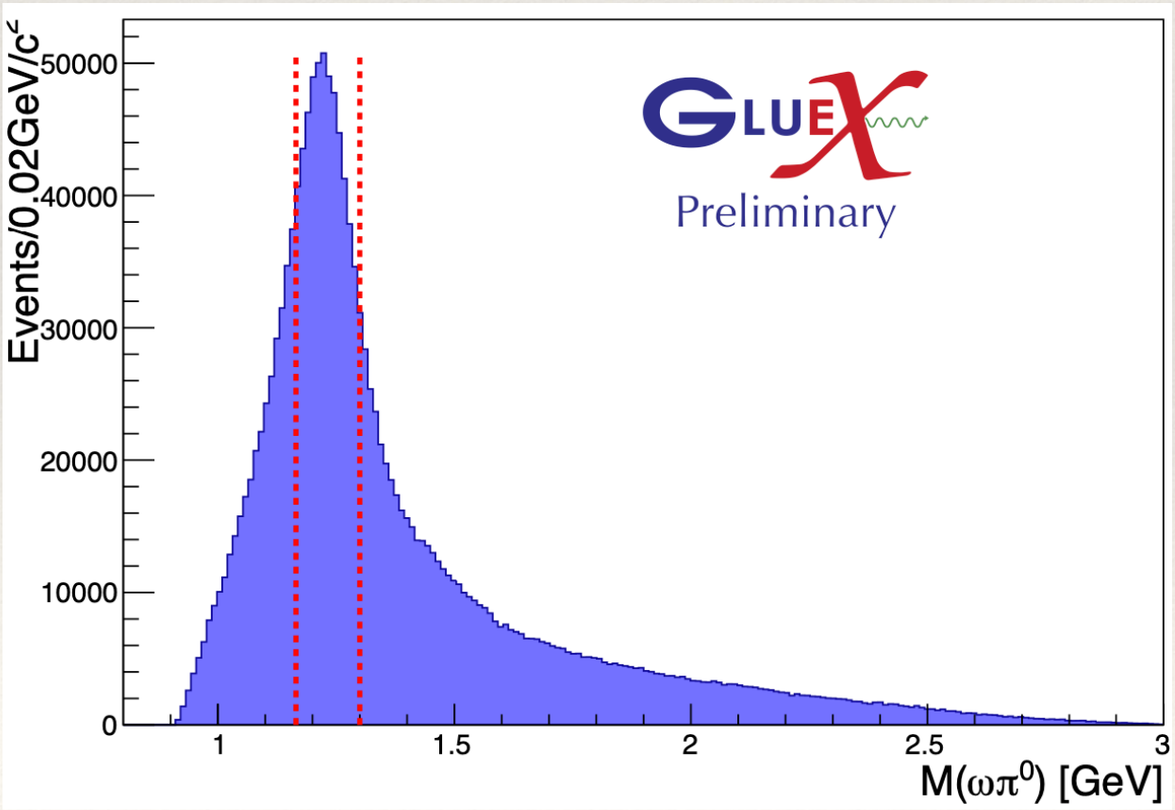


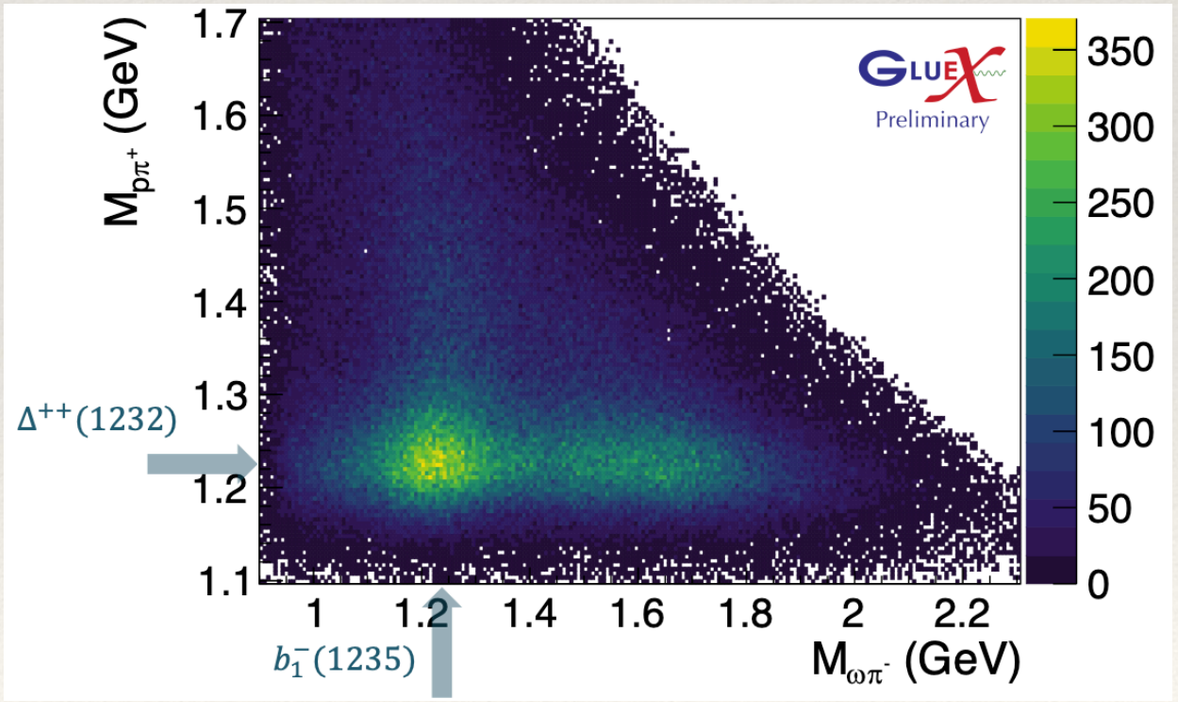
- First look at PWA in $\eta\pi^0$
- Study $a_0(980)$ and $a_2(1320)$
  - Positive helicity (natural exchange, e.g. ρ) dominates
  - a_2 predominantly D_2 wave, consistent with helicity=2 dominance at Belle ($\gamma\gamma \to \eta\pi^0$)

Belle, Phys. Rev. D ***80****, 032001*

b_1 decay

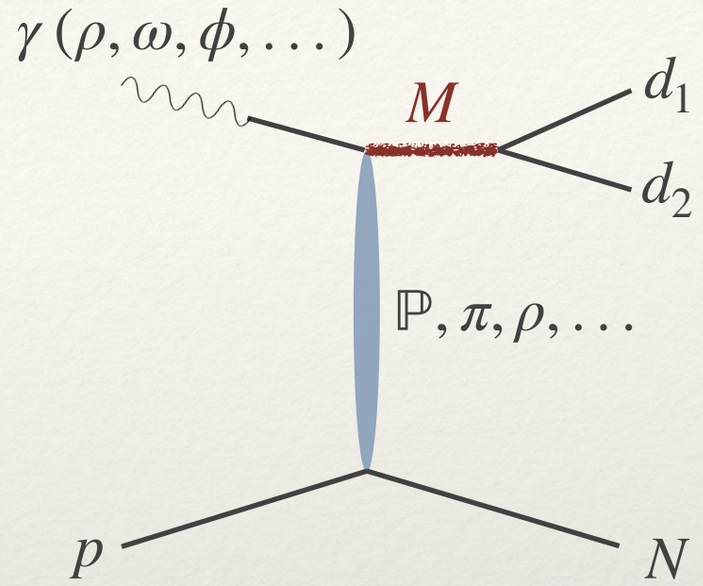
- LQCD: $b_1\pi$ is dominating decay mode of 1^{-+} exotic
- First step: study b_1
  - $\gamma p \to b_1 p \to \omega\pi^0 p \to \pi^+\pi^-\pi^0\pi^0 p$
  - $\gamma p \to b_1^-\Delta^{++} \to \omega\pi^-\Delta^{++} \to \pi^+\pi^-\pi^0\pi^-\pi^+ p$





Summary

- JLab has a strong program dedicated to studying exotic mesons
- GlueX and CLAS12 collect unique data sets with unprecedented statistical precision
- Start with studying production mechanisms and moments and develop PWA in parallel



- Many interesting analyses in the pipeline