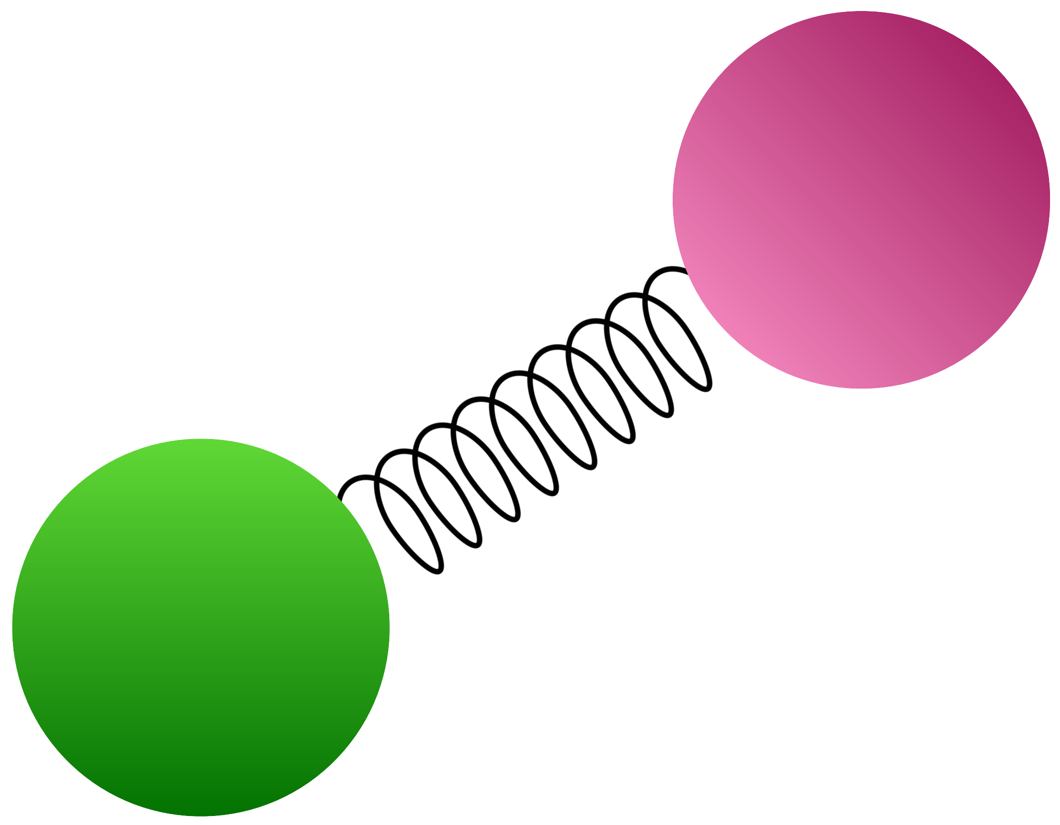
William & Mary
CHARTERED 1693

Amplitude Analysis of $\omega\pi^0$ Photoproduction at GlueX

Kevin Scheuer QNP 2024

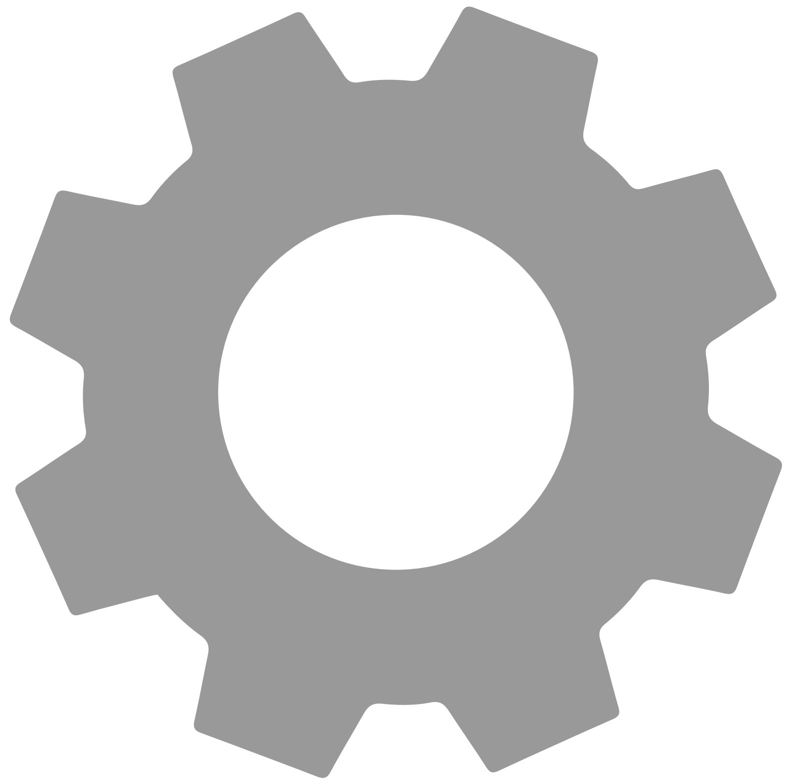


1. GlueX & Mapping the Meson Spectrum

- Understanding the search for mesonic resonances
- How photoproduction at GlueX aids in this search

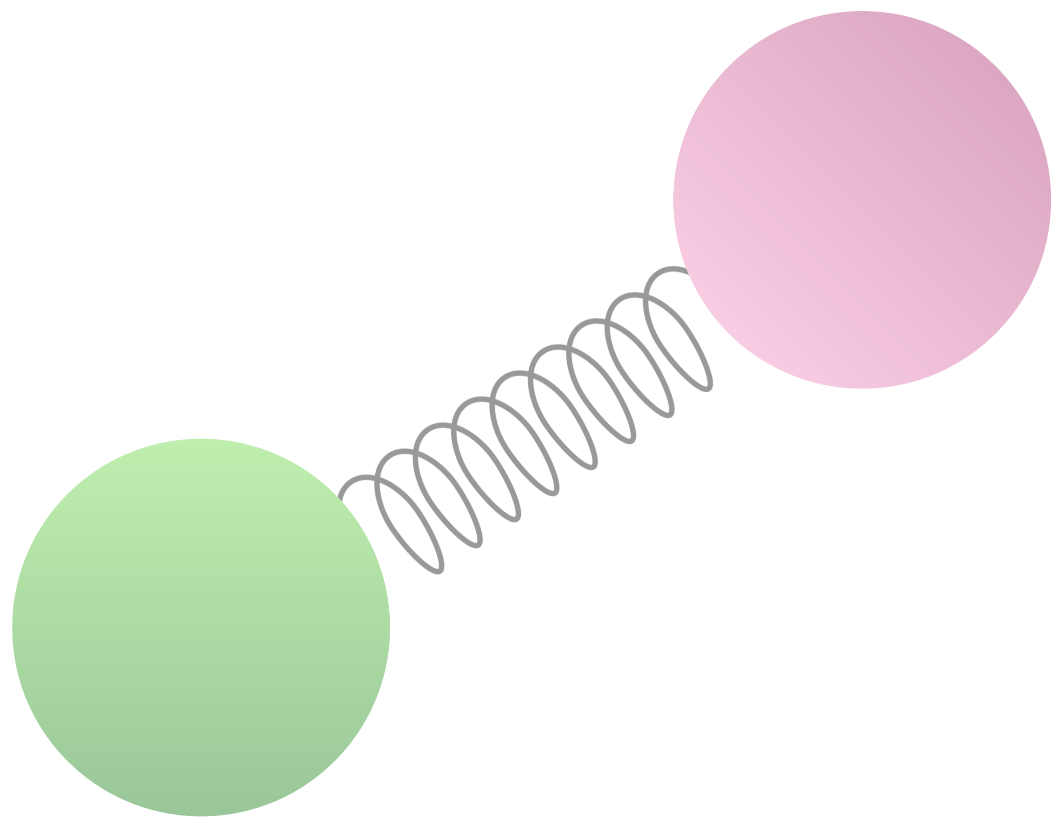
2. Partial Wave Analysis of $\omega\pi^0$ Events

- Resonances beyond the well understood $b_1(1235)$
- PWA provides insight into the physical parameters of these particles



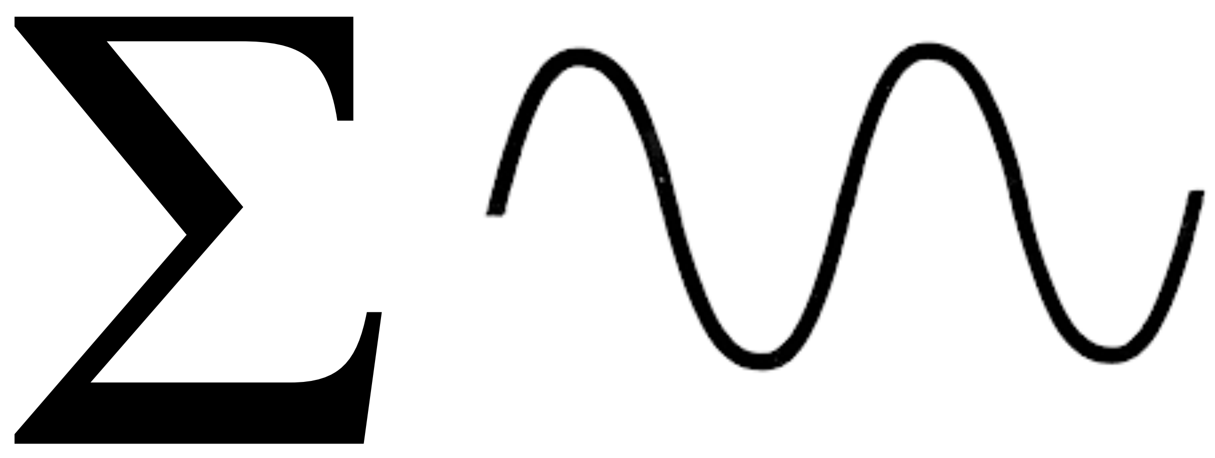
3. Production Mechanisms

- Compare percentage of waves produced naturally and unnaturally using the reflectivity basis



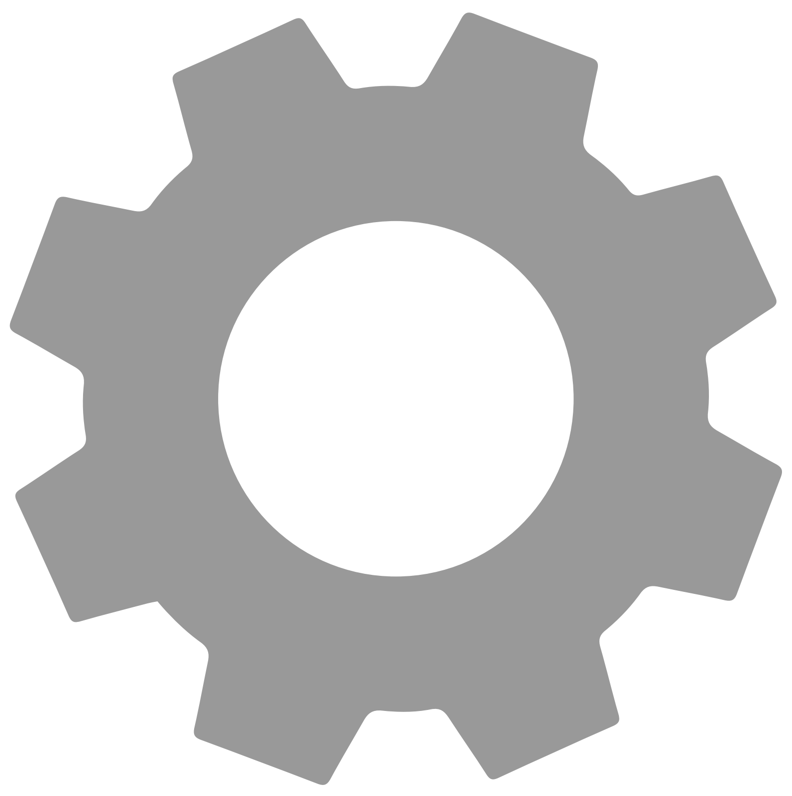
1. GlueX & Mapping the Meson Spectrum

- Understanding the search for mesonic resonances
- How photoproduction at GlueX aids in this search



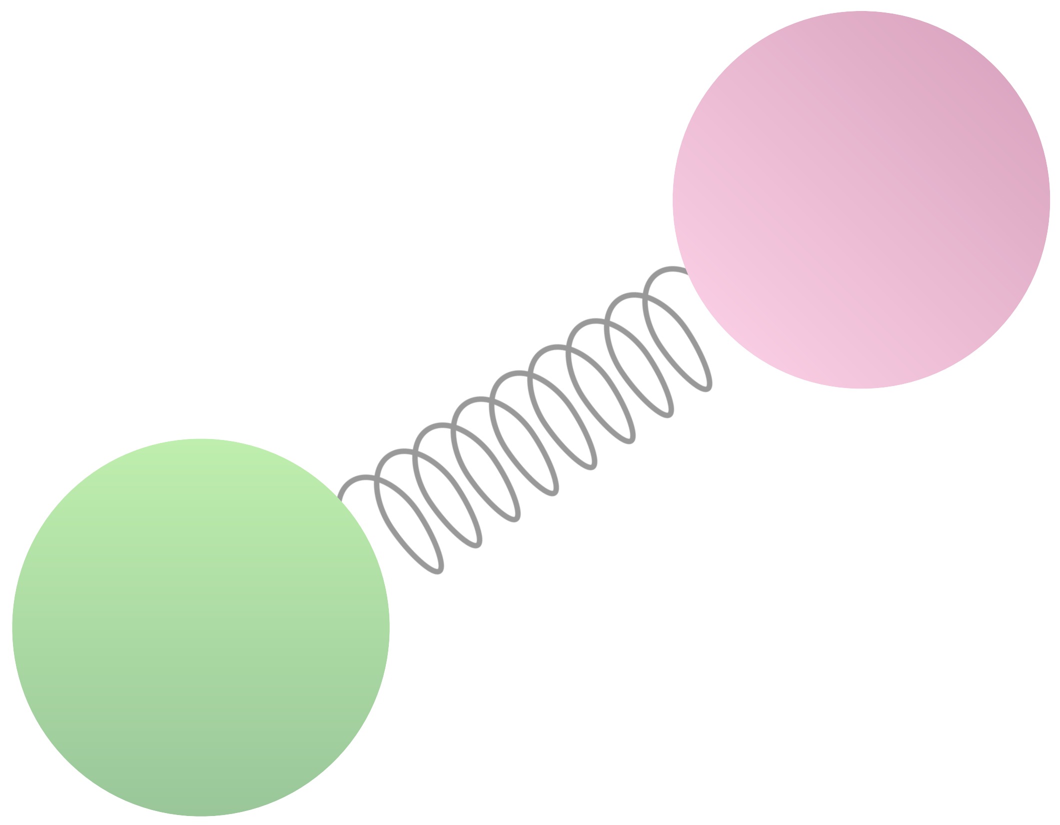
2. Partial Wave Analysis of $\omega\pi^0$ Events

- Resonances beyond the well understood $b_1(1235)$
- PWA provides insight into the physical parameters of these particles



3. Production Mechanisms

- Compare percentage of waves produced naturally and unnaturally using the reflectivity basis

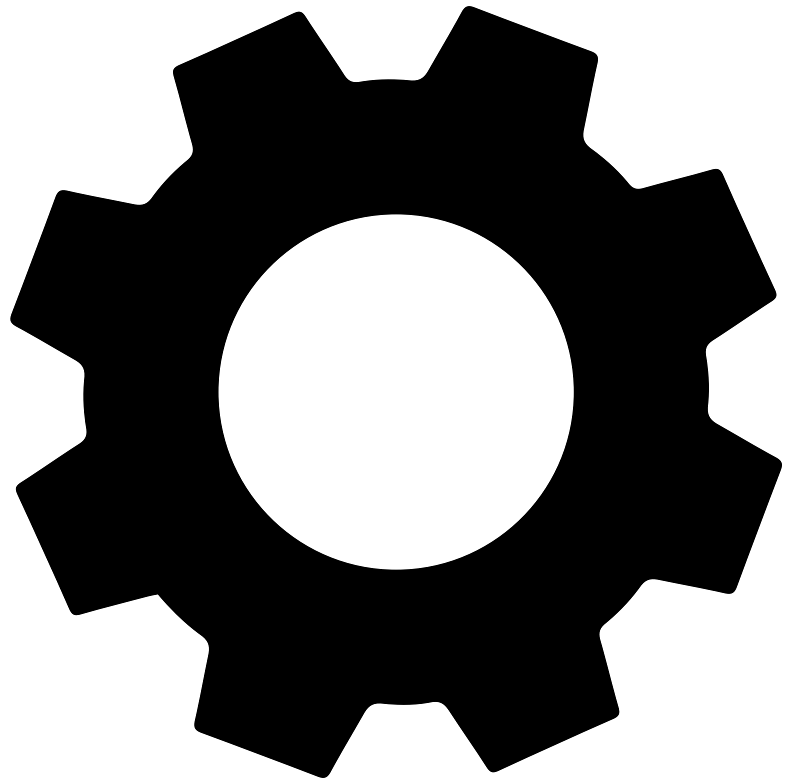


1. GlueX & Mapping the Meson Spectrum

- Understanding the search for mesonic resonances
- How photoproduction at GlueX aids in this search

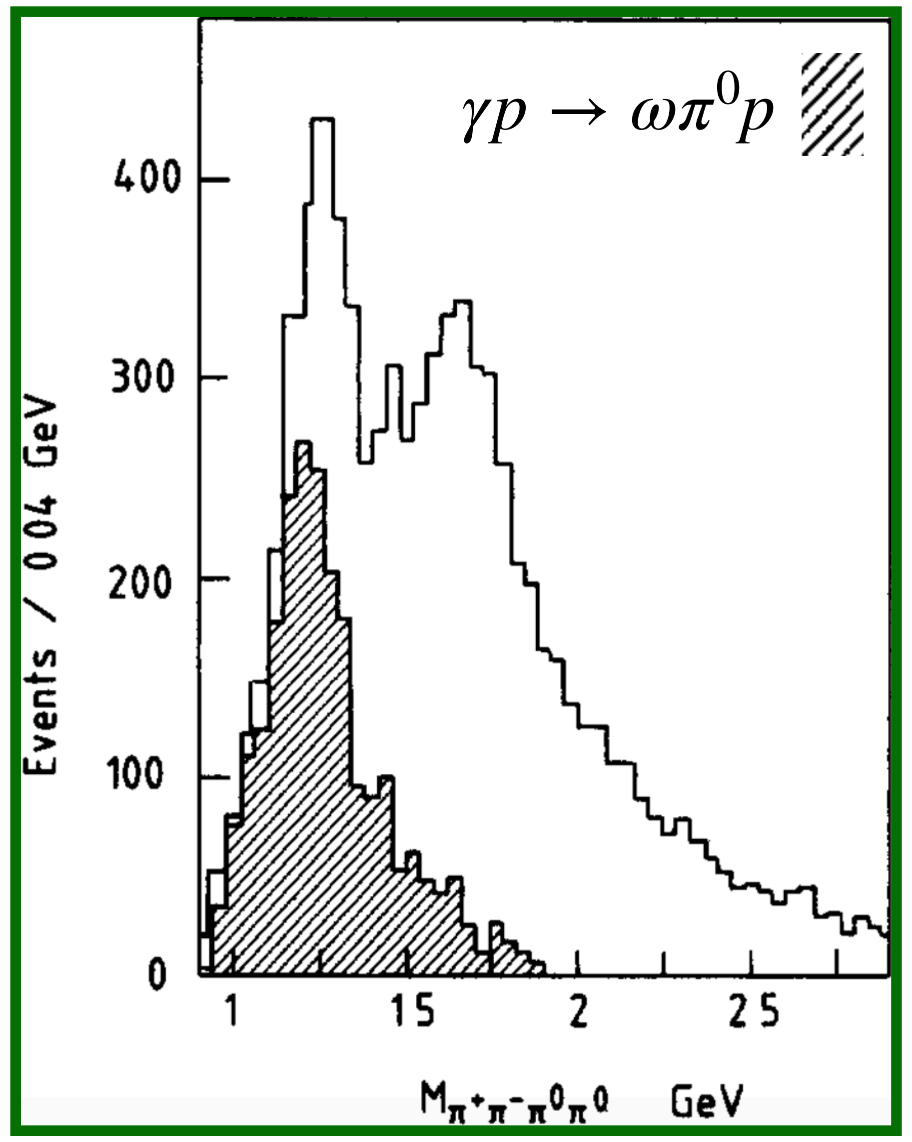
2. Partial Wave Analysis of $\omega\pi^0$ Events

- Resonances beyond the well understood $b_1(1235)$
- PWA provides insight into the physical parameters of these particles

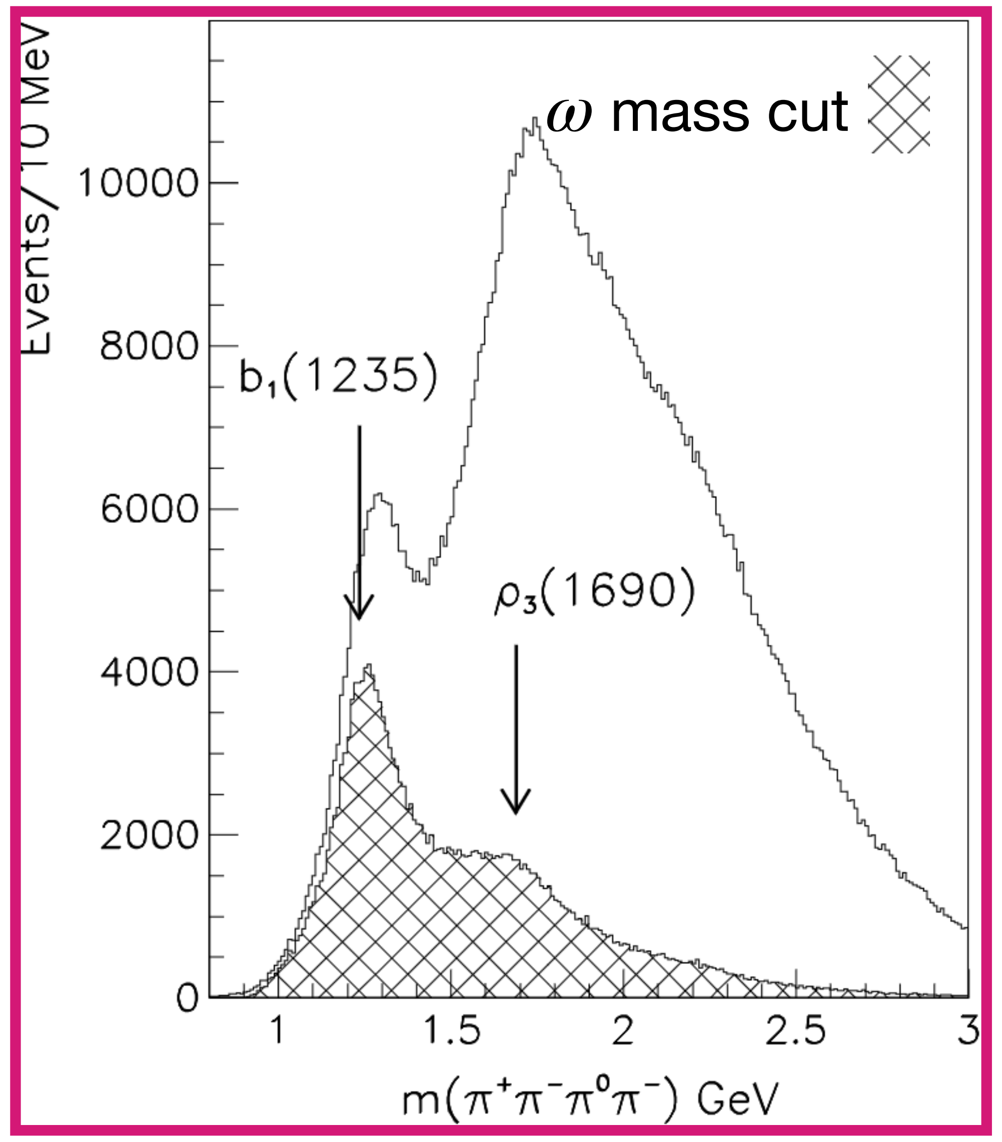


3. Production Mechanisms

- Compare percentage of waves produced naturally and unnaturally using the reflectivity basis



Nucl.Phys.B 243 (1984) 1-28



Phys.Lett.B 541 (2002) 35-44

E852 Collaboration

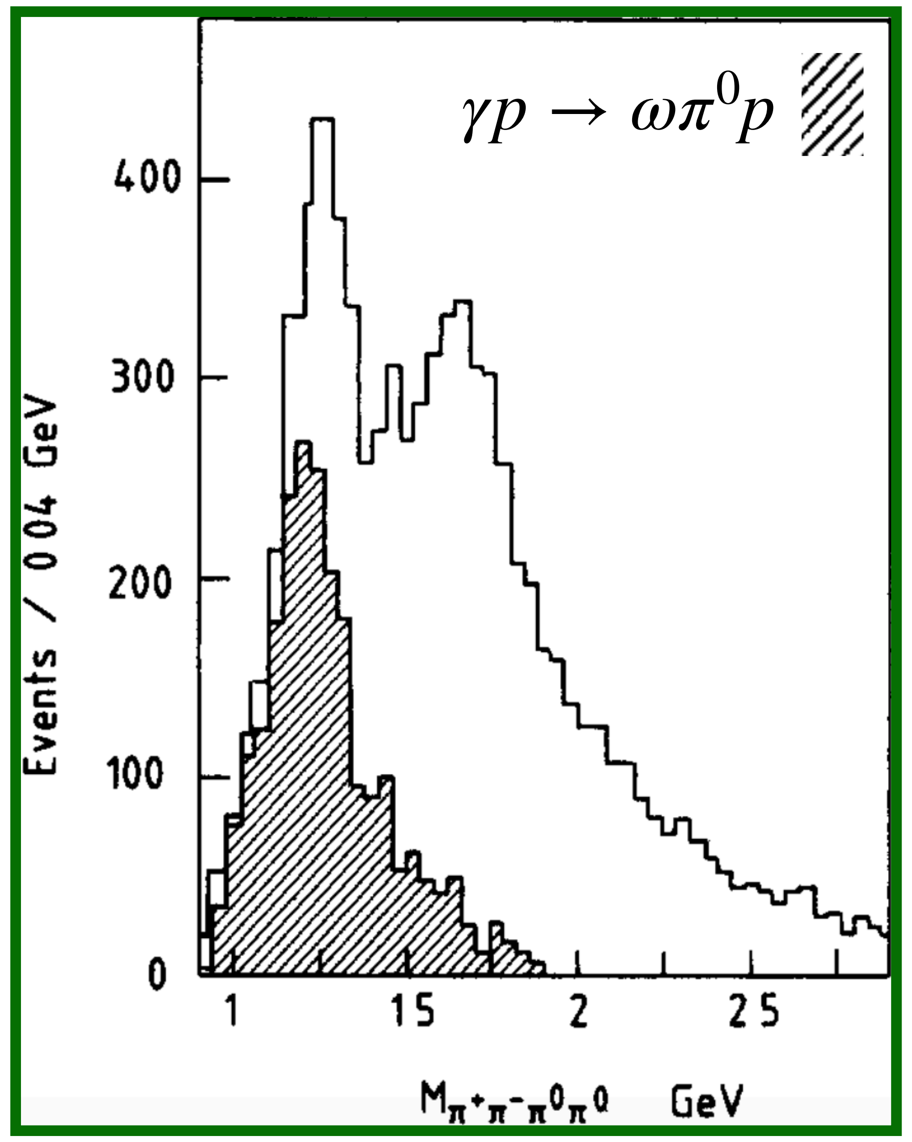
"The $\omega\pi^-$ mass spectrum is found to be dominated by the $b_1(1235)$", which "is dominated by natural parity exchange"

Omega Photon Collaboration

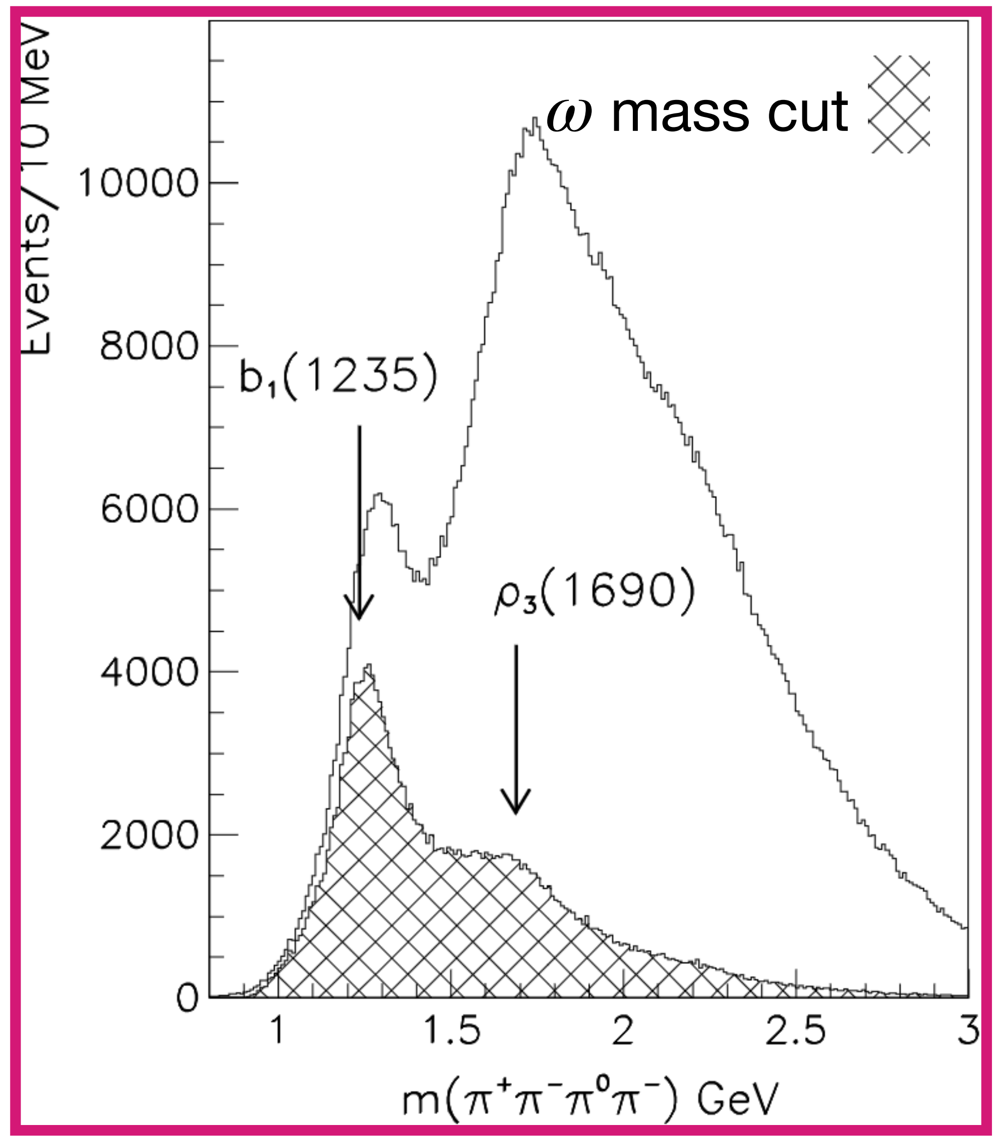
"A predominant 1^+ $b_1(1235)$ production, with ~20% $J^P = 1^-$ background"

1984

2002



Nucl.Phys.B 243 (1984) 1-28



Phys.Lett.B 541 (2002) 35-44

Omega Photon Collaboration

"A predominant 1^+ $b_1(1235)$ production, with ~20% $J^P = 1^-$ background"

1984

E852 Collaboration

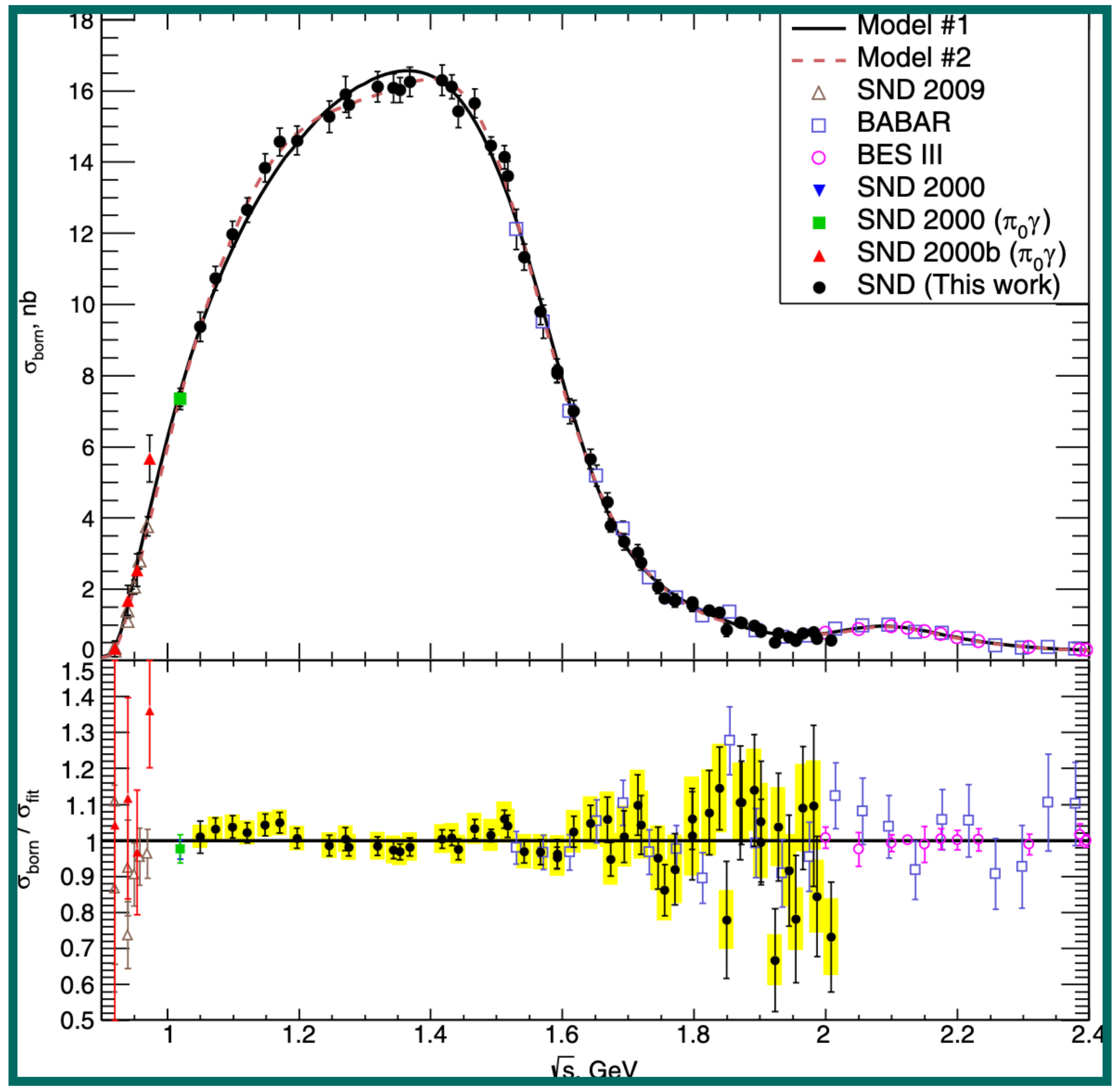
"The $\omega\pi^-$ mass spectrum is found to be dominated by the $b_1(1235)$", which "is dominated by natural parity exchange"

2002

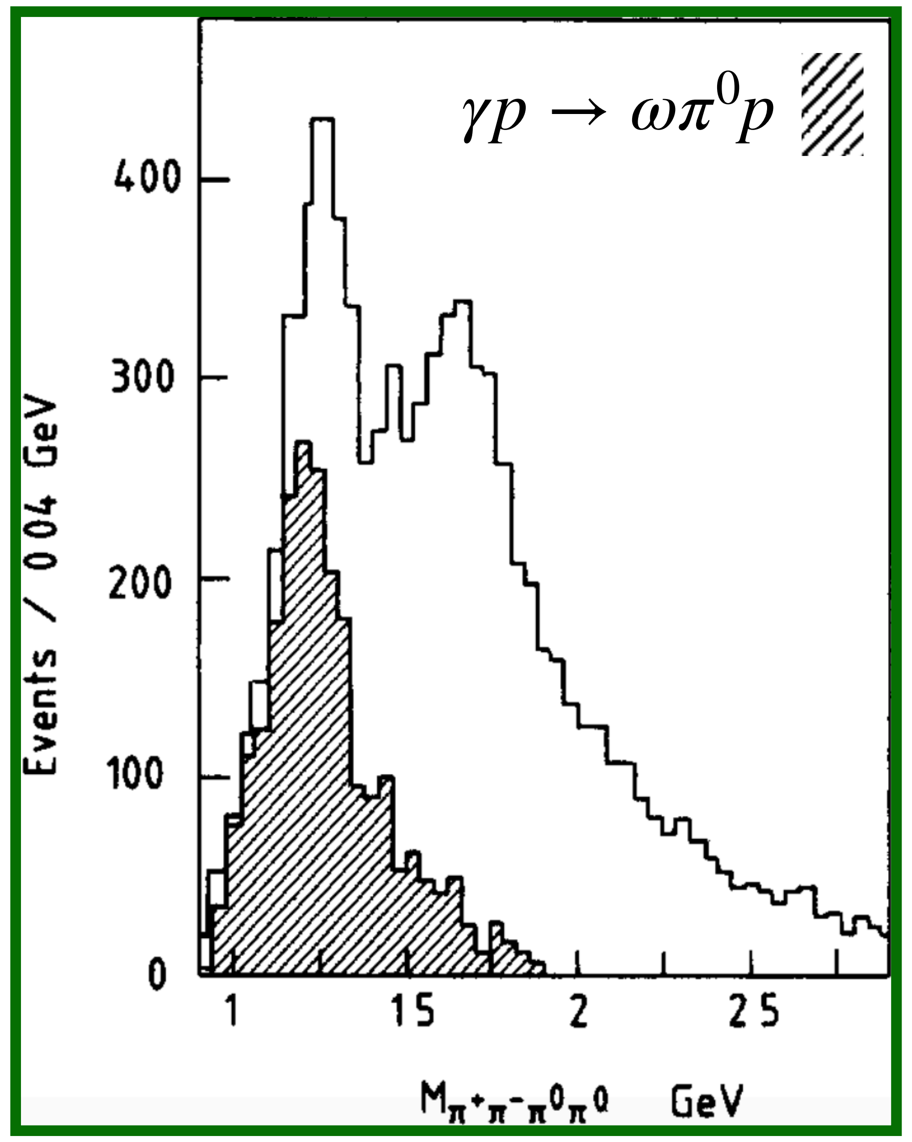
SND Collaboration

Using vector-meson dominance model assumption, measured the $\rho(1450)$ mass & width to be $M, \Gamma = 1523 \pm 4,\ 368 \pm 6$ in an $e^+e^- \to \omega\pi^0$ cross section model.

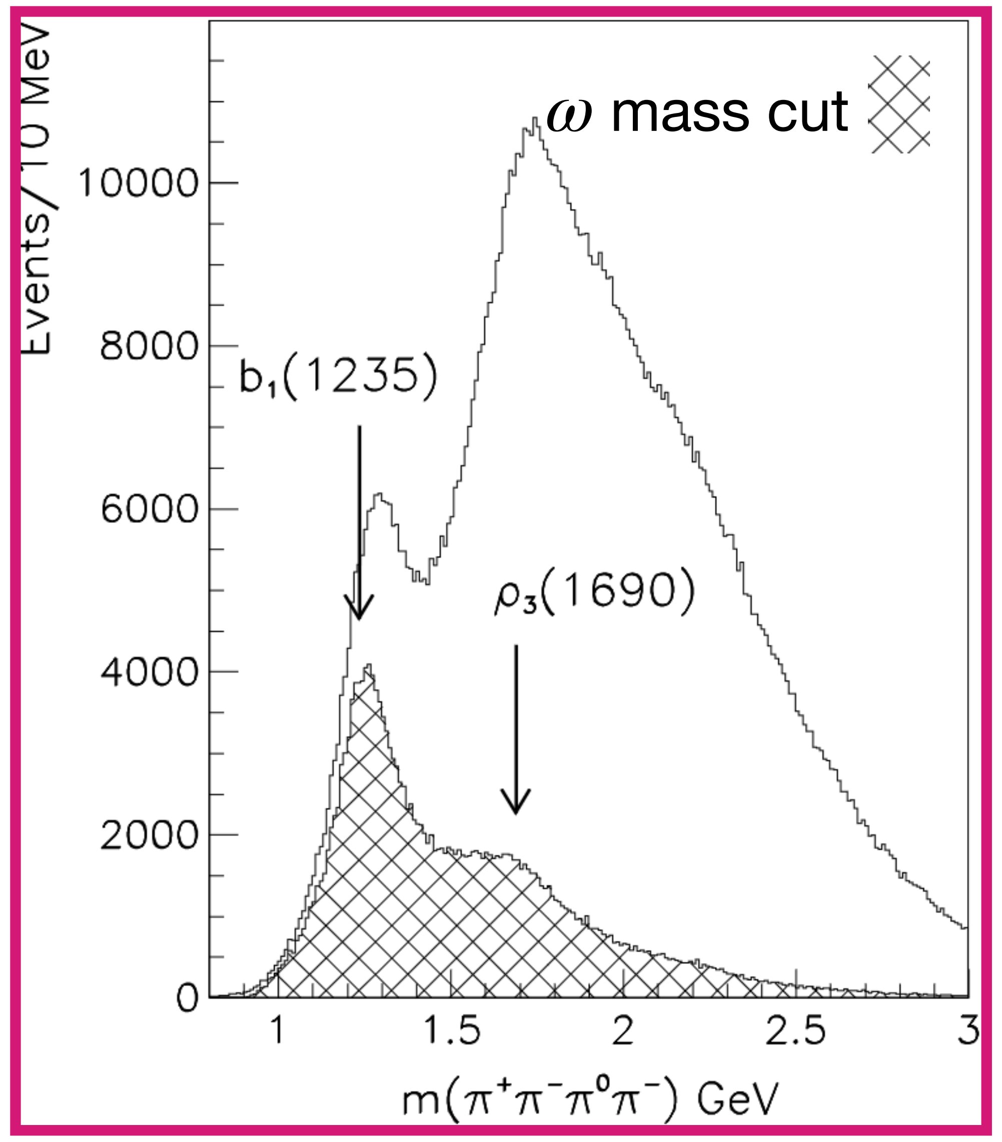
2023



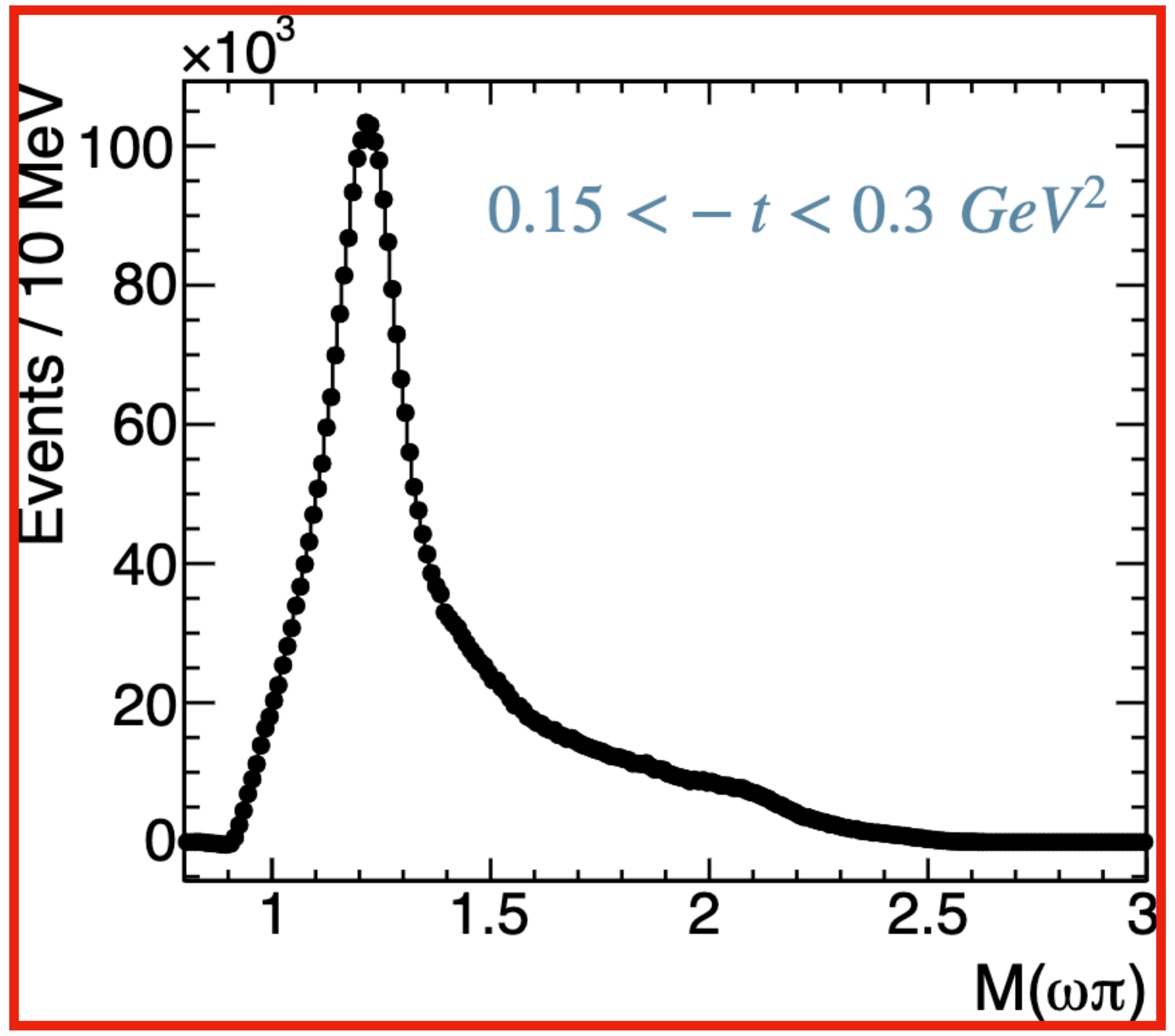
Phys.Rev.D 108 (2023) 9, 092012



Nucl.Phys.B 243 (1984) 1-28



Phys.Lett.B 541 (2002) 35-44



2024

GlueX

A photoproduction experiment (γp collisions): direct comparison to Omega Photon results and complementary results to the E852 pion beam. Much higher statistics, important for determining partial waves

Omega Photon Collaboration

“A predominant $1^+\ b_1(1235)$ production, with ~20% $J^P = 1^-$ background”

1984

E852 Collaboration

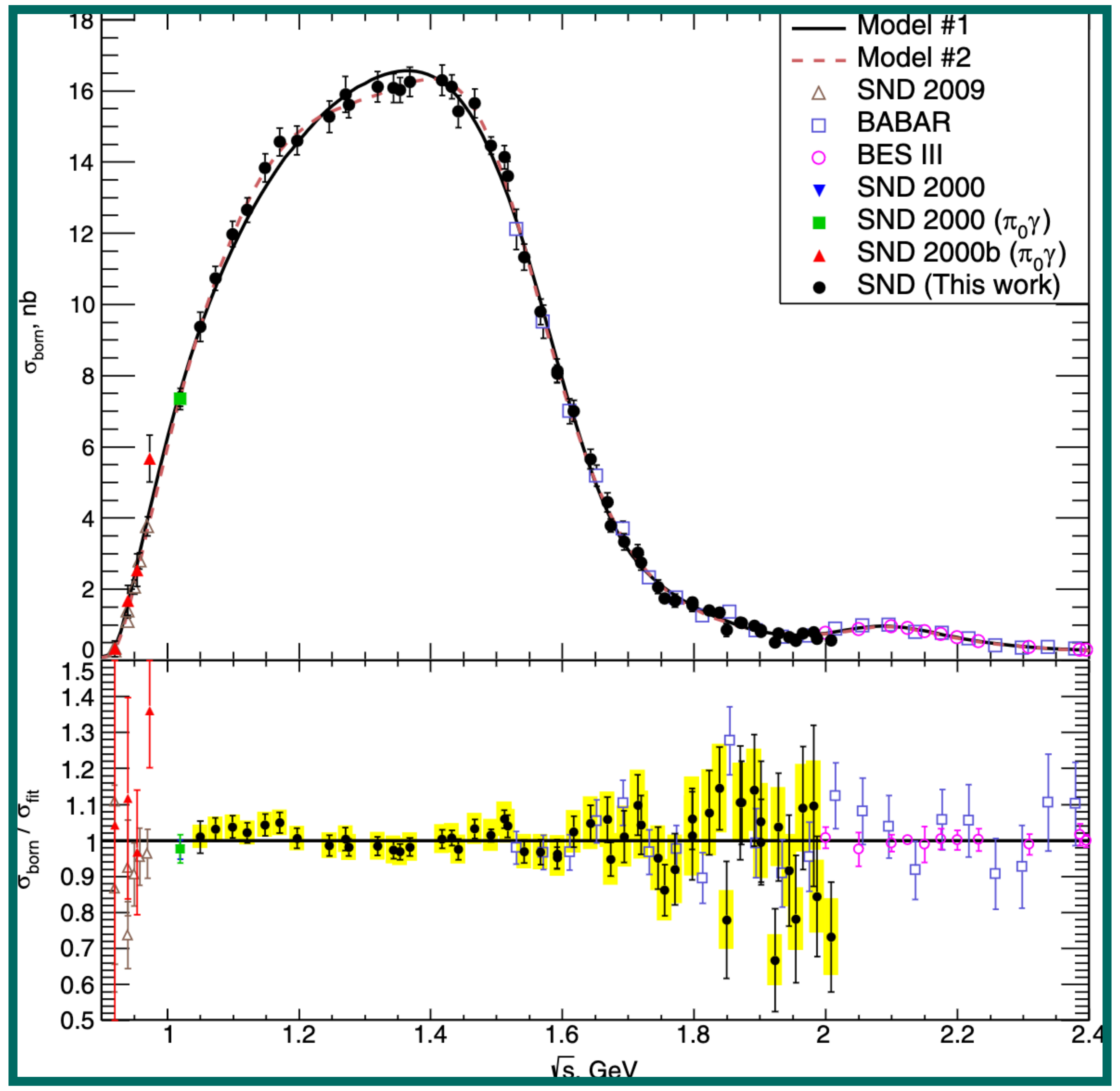
“The $\omega\pi^-$ mass spectrum is found to be dominated by the $b_1(1235)$”,which "is dominated by natural parity exchange”

2002

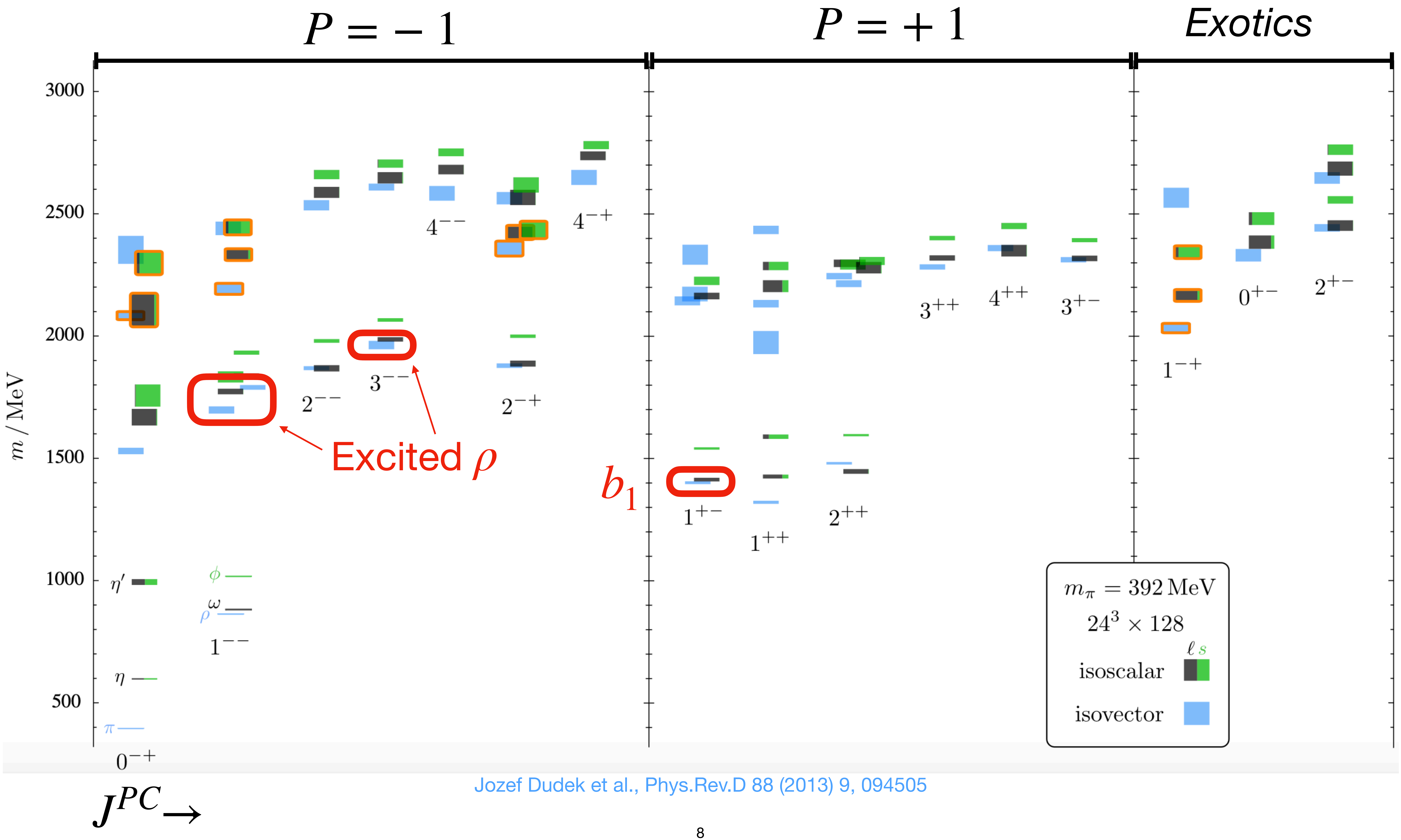
SND Collaboration

Using vector-meson dominance model assumption, measured the $\rho(1450)$ mass & width to be $M, \Gamma = 1523 \pm 4,\ 368 \pm 6$ in an $e^+e^- \to \omega\pi^0$ cross section model.

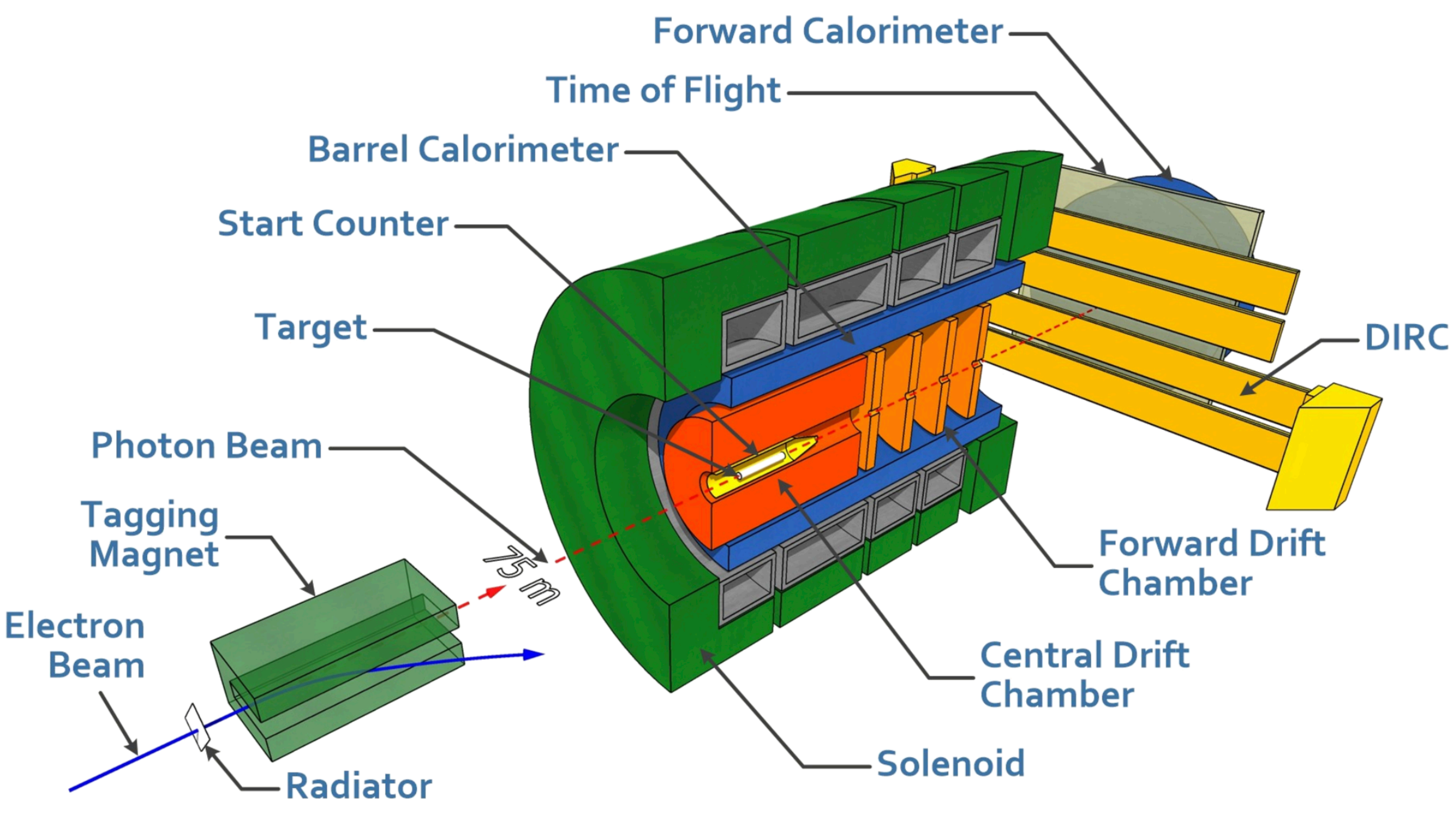
2023



Phys.Rev.D 108 (2023) 9, 092012



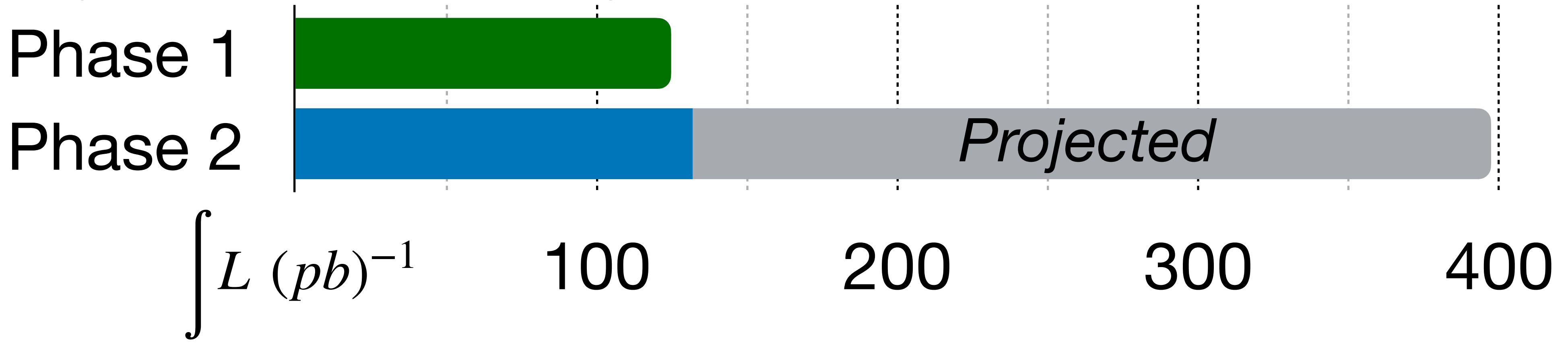
Jozef Dudek et al., Phys.Rev.D 88 (2013) 9, 094505

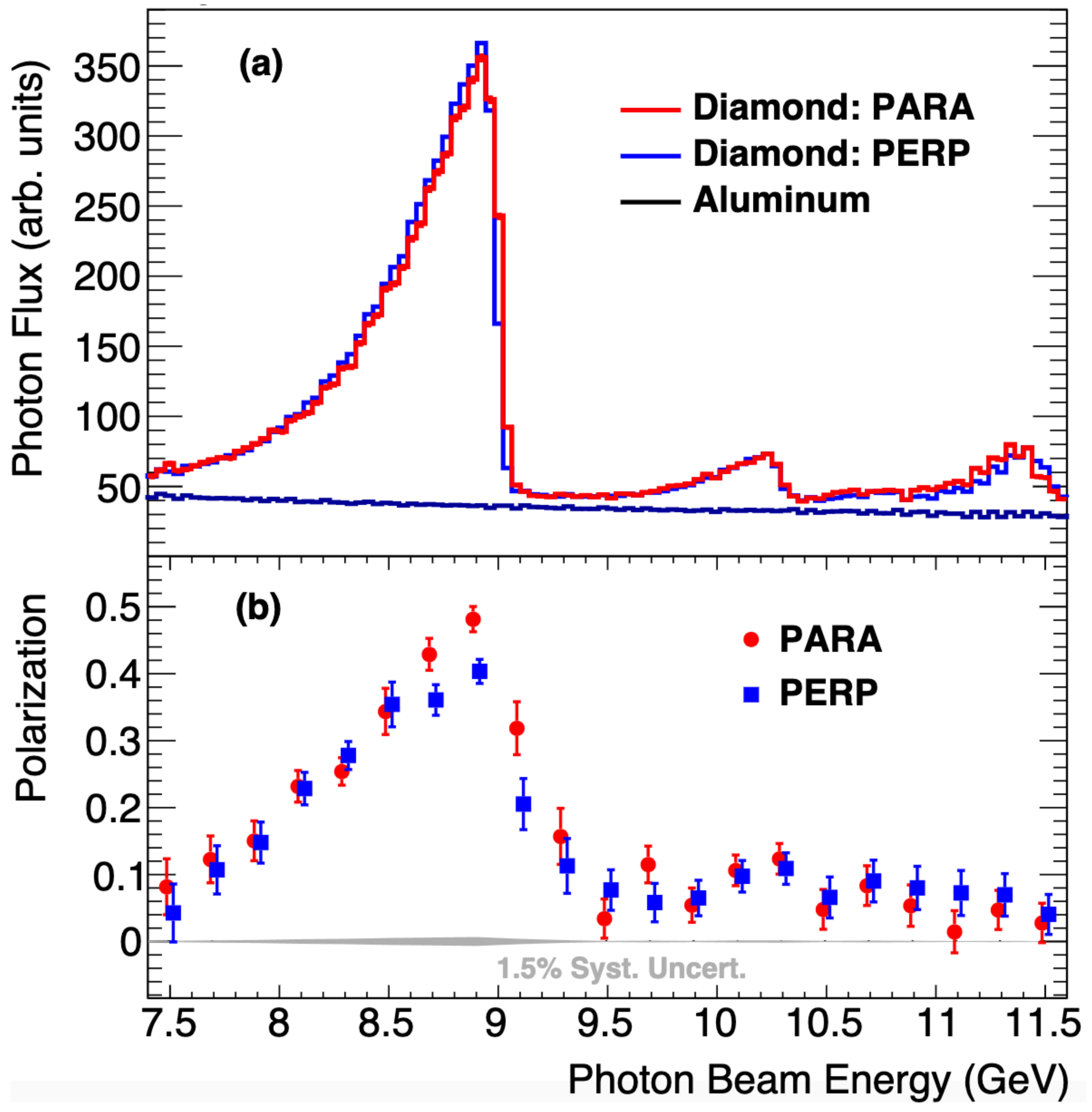


J.Phys.Conf.Ser 2374 (2022) 1, 012009

GlueX at Jefferson Lab

- e^- beam interacts with diamond radiator→ produces linearly polarized photon beam →photons strike stationary proton target
- Good charged & neutral acceptance
- All analysis shown today will be from the completed Phase 1 dataset

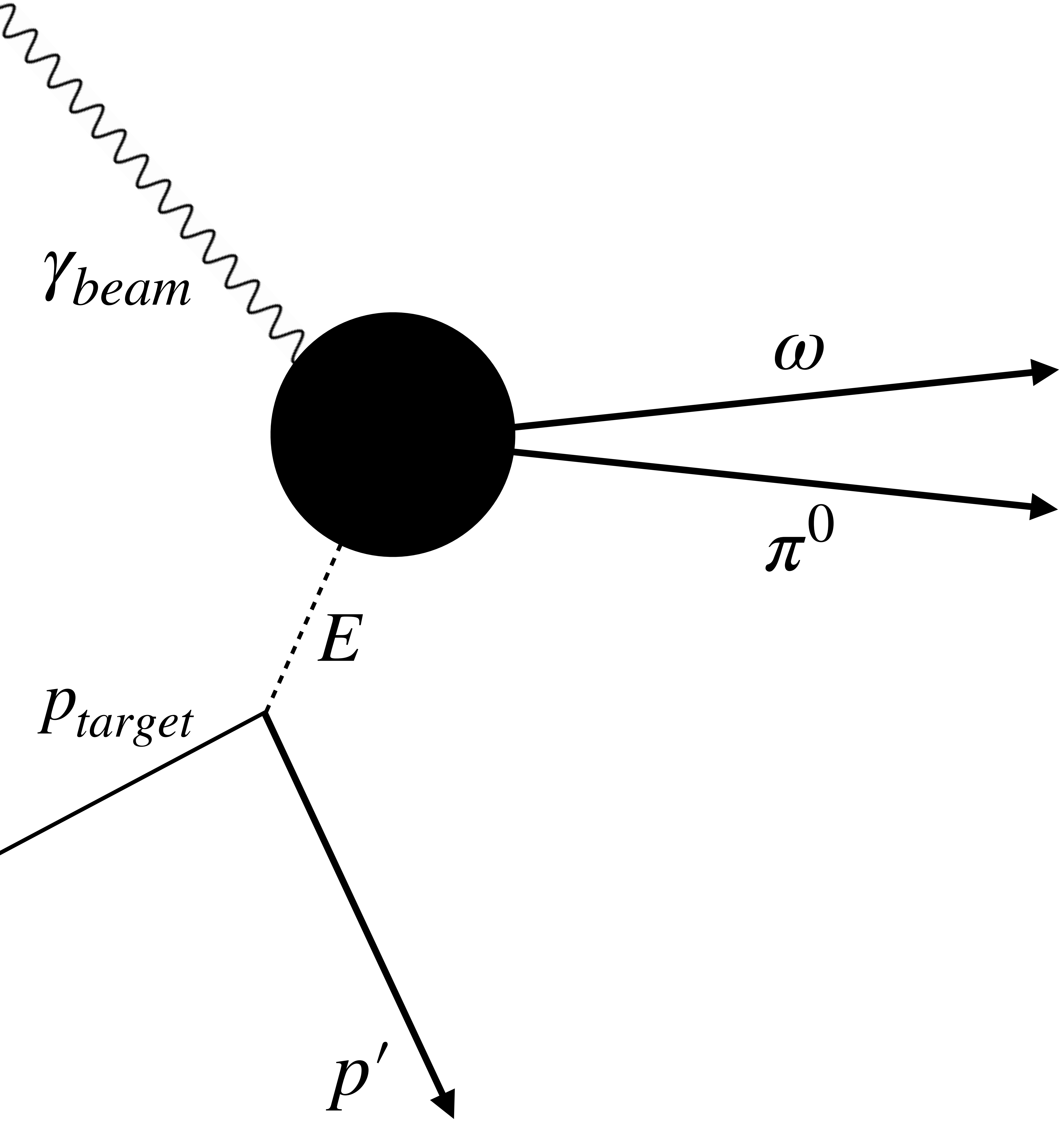




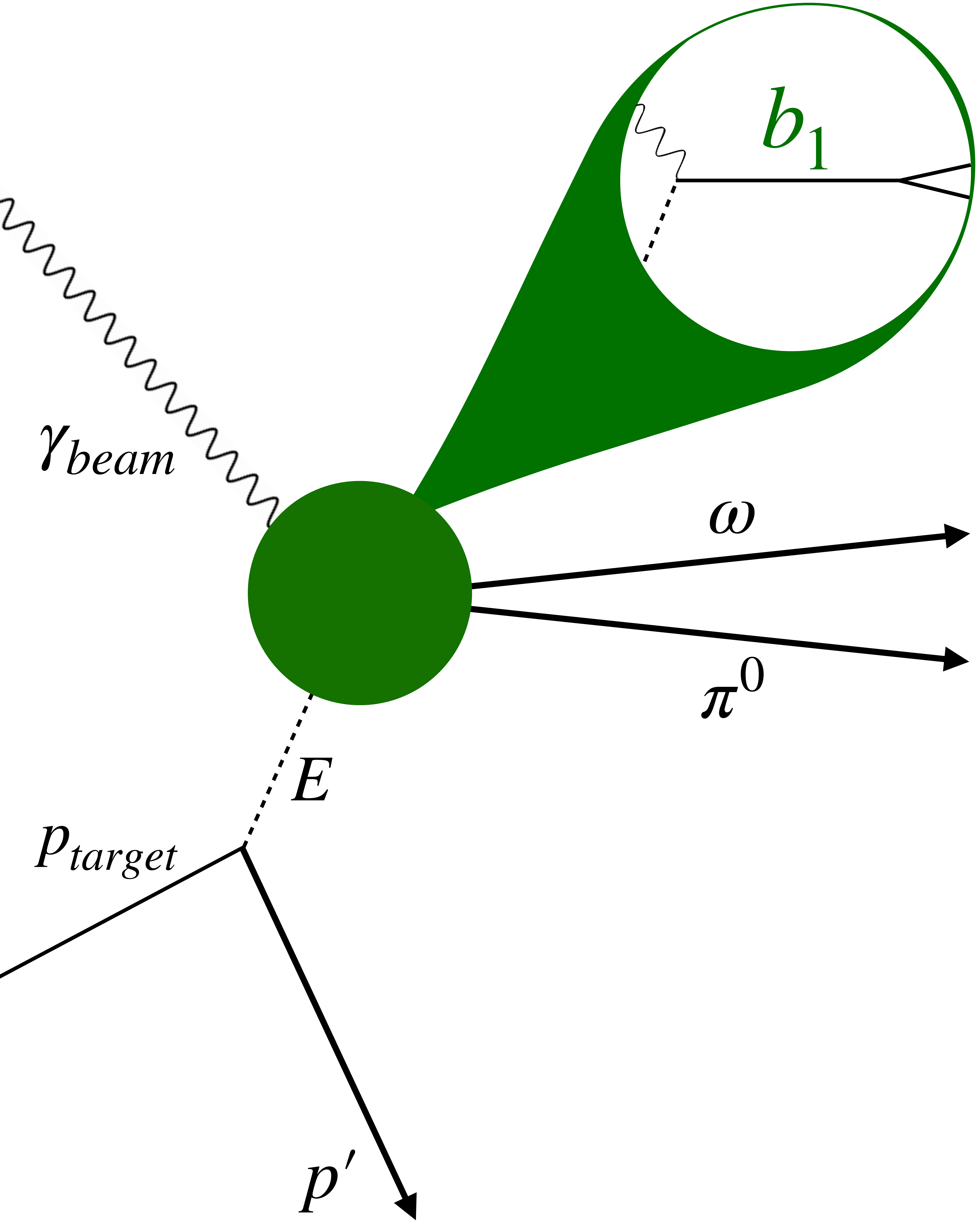
Nucl.Instrum.Meth.A 987 (2021) 164807

Linearly Polarized Photons

- Acquire ~40% polarization in the coherent peak region $E_\gamma = 8.2 - 8.8$
- Partial Wave Analysis model utilizes the measured polarization fraction and angle

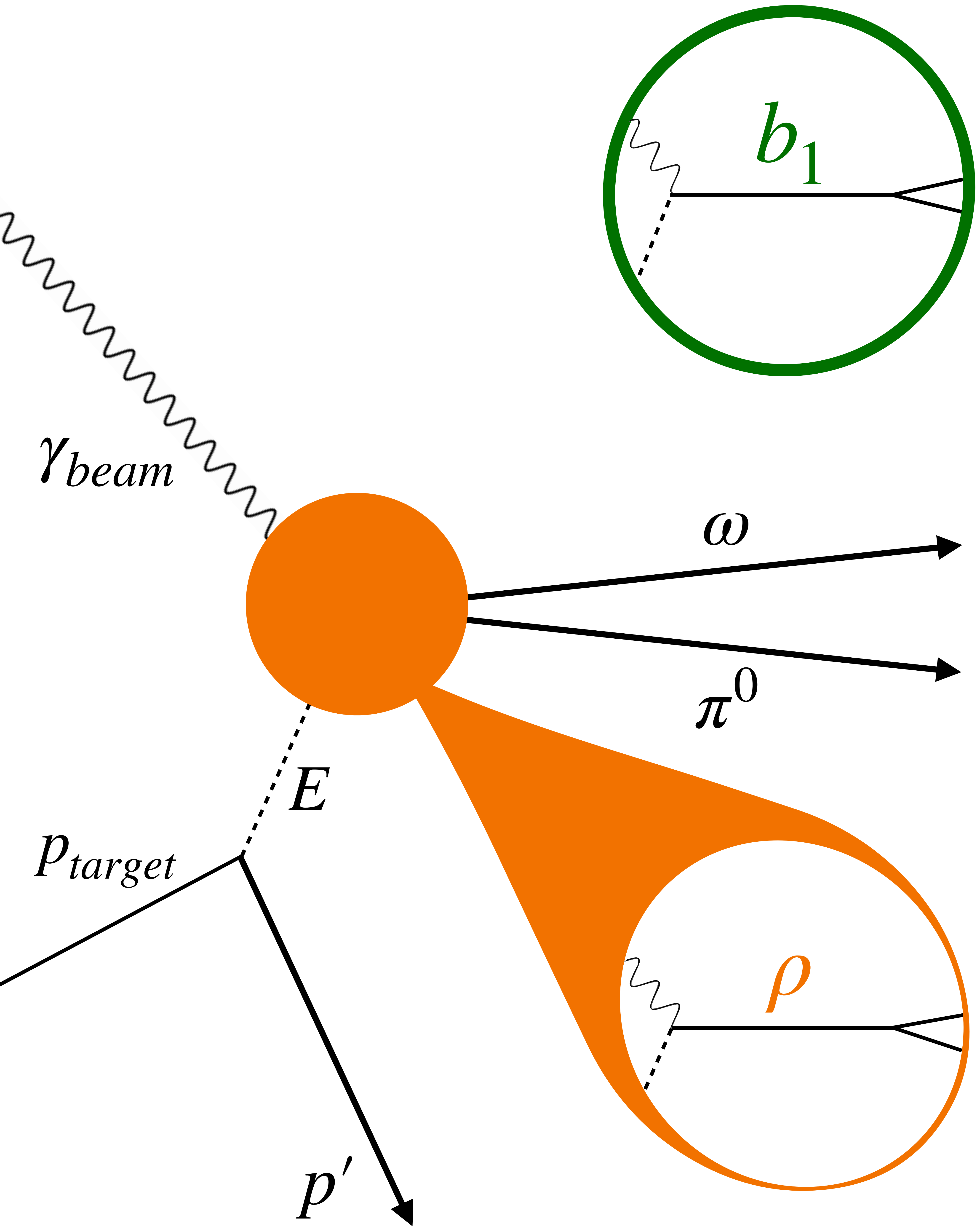


- Reflectivity $\epsilon = \pm 1$ basis is tied to the naturality $\tau = \pm 1 = P(-1)^J$ of the exchange particle E
- Ex: $\epsilon = +1 \rightarrow \tau_E = +1 \rightarrow E = \mathbb{P}$ (Pomeron exchange)



- $I^G(J^{PC}) = 1^+(1^{+-}) \rightarrow \ell = D, S$ wave contributions
  - E852 measured amplitude ratio $D/S = 0.269\ (\pm 0.009)_{stat}\ (\pm 0.01)_{sys}$
- Well know with comparable charged decay $\gamma p \rightarrow b_1^- \Delta^{++}$
- A PWA "standard candle" to help find other resonances

- Reflectivity $\epsilon = \pm 1$ basis is tied to the naturality $\tau = \pm 1 = P(-1)^J$ of the exchange particle E
- Ex: $\epsilon = +1 \rightarrow \tau_E = +1 \rightarrow E = \mathbb{P}$ (Pomeron exchange)



- $I^G(J^{PC}) = 1^+(1^{+-}) \rightarrow \ell = D, S$ wave contributions
  - E852 measured amplitude ratio $D/S = 0.269\ (\pm 0.009)_{stat}\ (\pm 0.01)_{sys}$
- Well know with comparable charged decay $\gamma p \rightarrow b_1^- \Delta^{++}$
- A PWA "standard candle" to help find other resonances

- Reflectivity $\epsilon = \pm 1$ basis is tied to the naturality $\tau = \pm 1 = P(-1)^J$ of the exchange particle E
- Ex: $\epsilon = +1 \rightarrow \tau_E = +1 \rightarrow E = \mathbb{P}$ (Pomeron exchange)

- $I^G(J^{PC}) = 1^+(1^{--}) \rightarrow \ell = P$ wave contributions
- Wide mass width can create interference with b_1

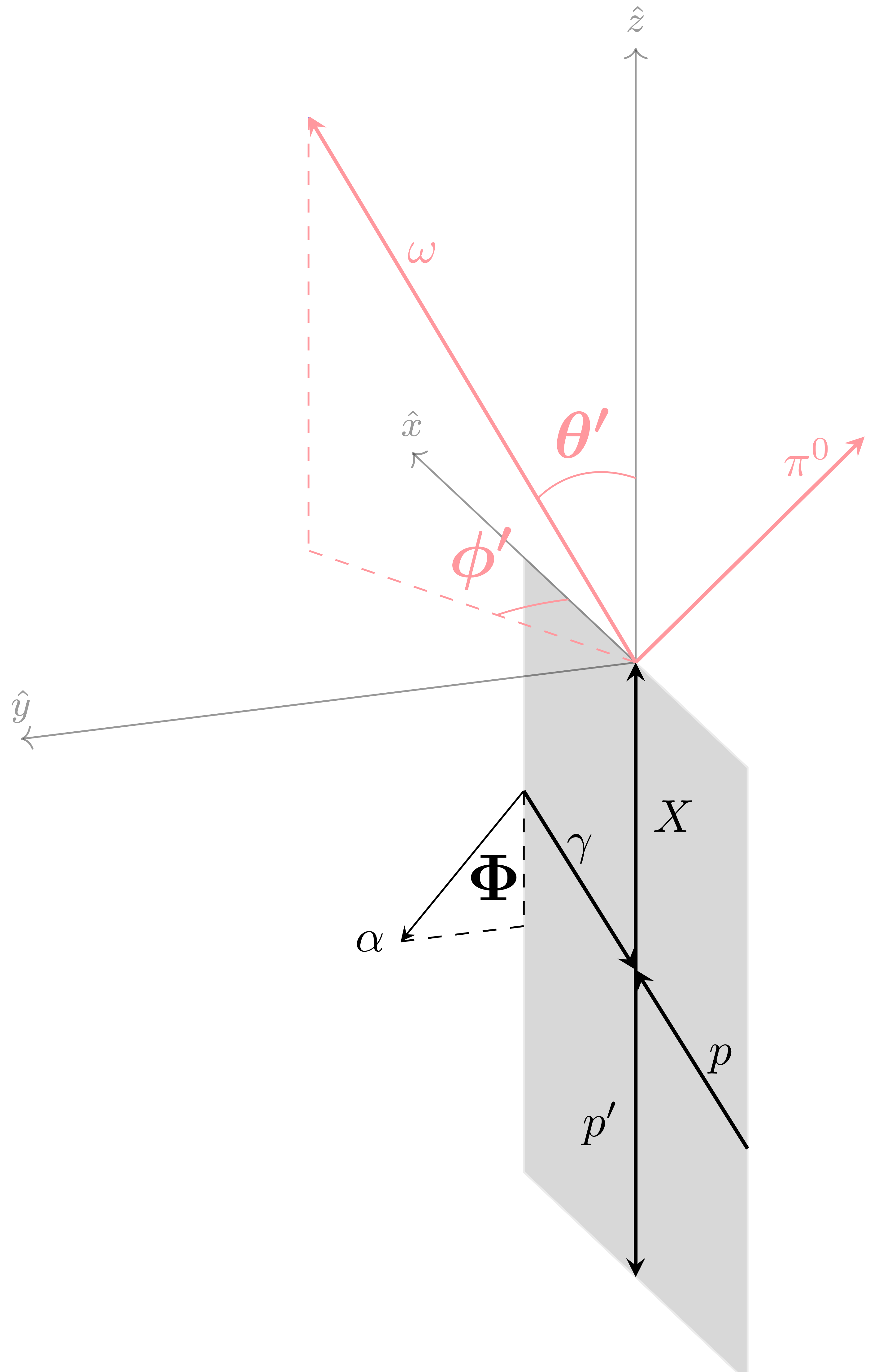
Polarized Photoproduction of $\omega\pi^0$

- Amplitudes defined by Wigner D functions of the decay angles: $Z_m^i(\Phi, \theta, \phi, \theta_H, \phi_H)$

- Interference between $\{J^P \ell\}_i$ allowed, each having $m = -\ell \ldots \ell$ projections

  - Complex production parameters $[c^i]_m^{(\epsilon)} \rightarrow$ provide an amplitude and phase measurement

$$I \approx (1 - P_\gamma)\left[\left|\sum_{i,m} [c^i]_m^- \mathrm{Im}(Z_m^i)\right|^2 + \left|\sum_{i,m} [c^i]_m^+ \mathrm{Re}(Z_m^i)\right|^2\right]$$
$$+(1 + P_\gamma)\left[\left|\sum_{i,m} [c^i]_m^+ \mathrm{Im}(Z_m^i)\right|^2 + \left|\sum_{i,m} [c^i]_m^- \mathrm{Re}(Z_m^i)\right|^2\right]$$



Polarized Photoproduction of $\omega\pi^0$

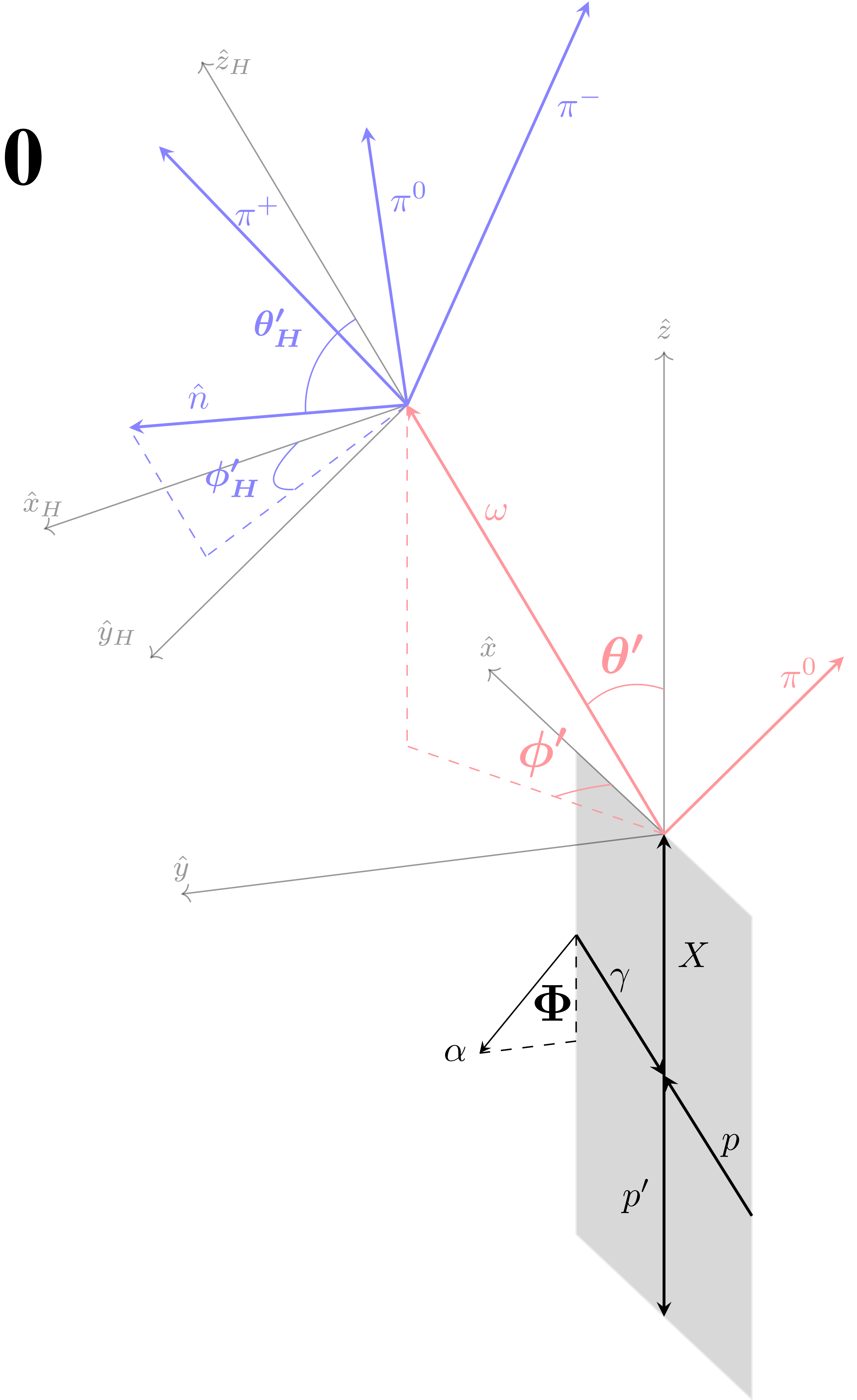
- Amplitudes defined by Wigner D functions of the decay angles: $Z^i_m(\Phi, \theta, \phi, \theta_H, \phi_H)$

- Interference between $\{J^P\ell\}_i$ allowed, each having $m = -\ell \ldots \ell$ projections

    - Complex production parameters $[c^i]^{(\epsilon)}_m$ $\rightarrow$ provide an amplitude and phase measurement

$$I \approx (1 - P_\gamma)\left[\left|\sum_{i,m}[c^i]^-_m \mathrm{Im}(Z^i_m)\right|^2 + \left|\sum_{i,m}[c^i]^+_m \mathrm{Re}(Z^i_m)\right|^2\right]$$

$$+(1 + P_\gamma)\left[\left|\sum_{i,m}[c^i]^+_m \mathrm{Im}(Z^i_m)\right|^2 + \left|\sum_{i,m}[c^i]^-_m \mathrm{Re}(Z^i_m)\right|^2\right]$$



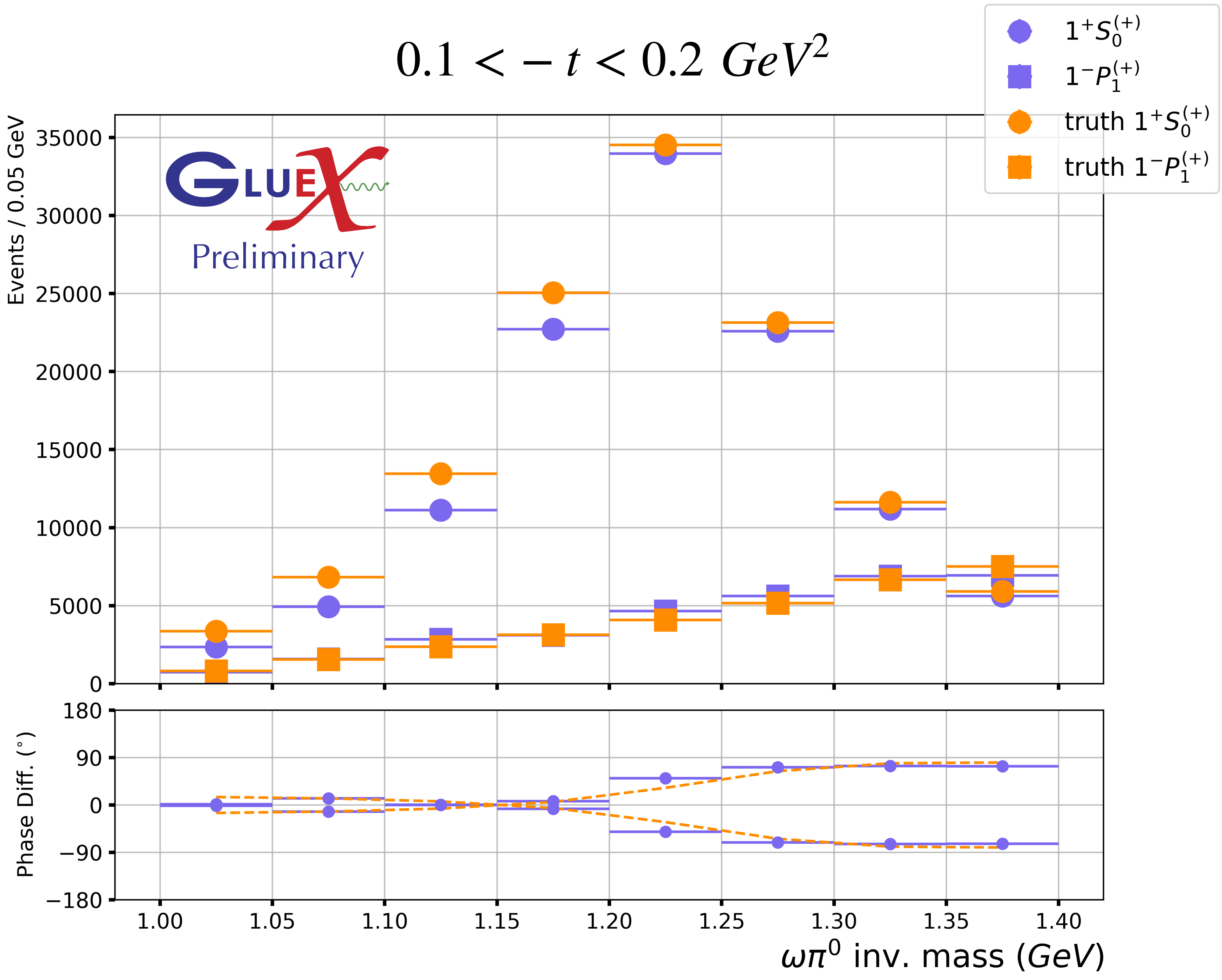
Monte Carlo Input-Output Study

1. Fit data using a Mass-Dependent Model with $b_1(1235)$ and $\rho(1450)$

2. Generate Monte Carlo (MC) from 1.

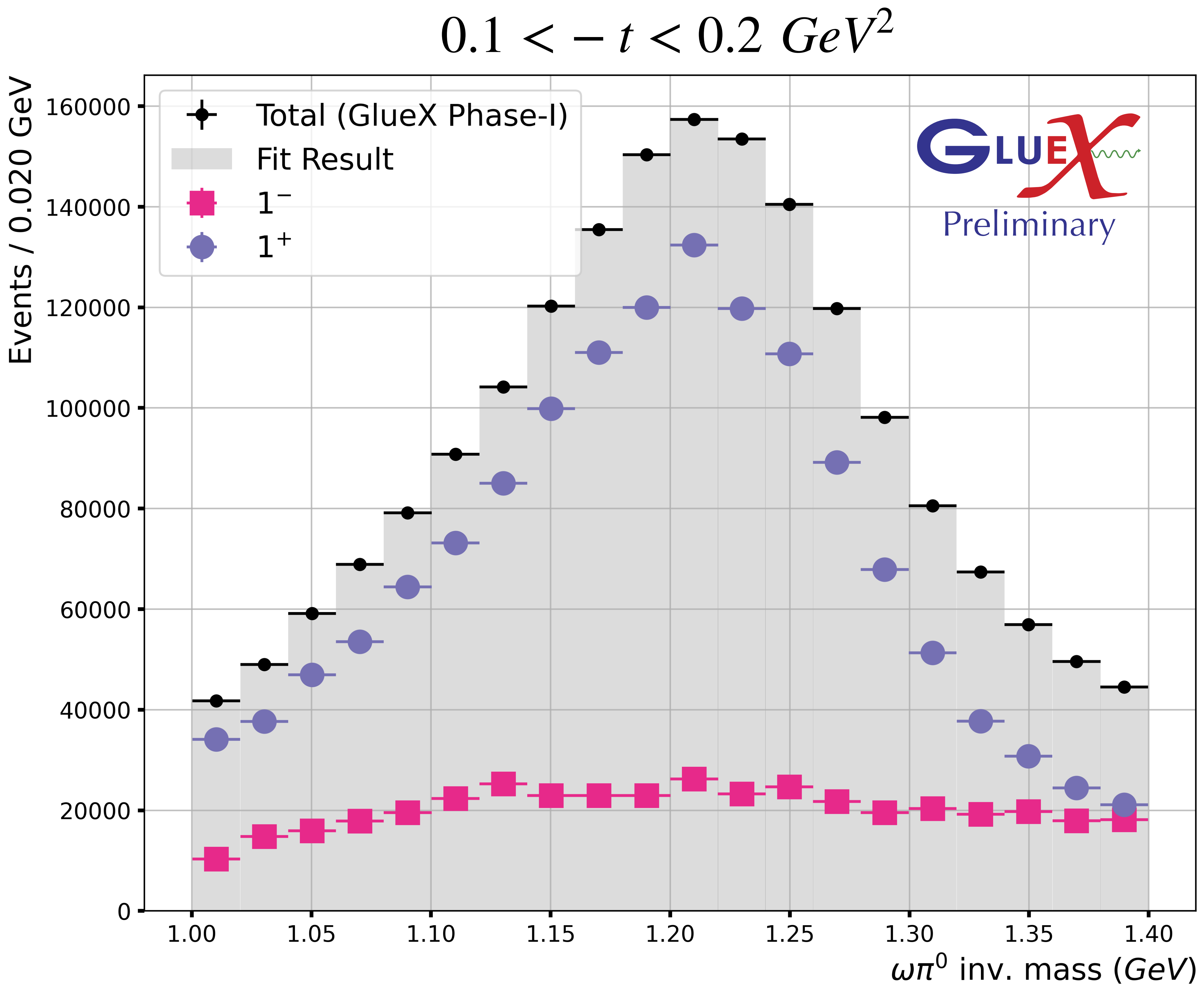
3. Fit MC from 2. with a mass-independent model, using a $J^P\ell = \{1^+(S,D),\ 1^-P\}$ waveset. Compare results to “truth” info

4. Observe that the $J^P\ell_m^{(\epsilon)} = 1^+S_0^+$ and $1^-P_1^+$ waves capture the b_1 and ρ respectively, with a significant phase motion matching the input



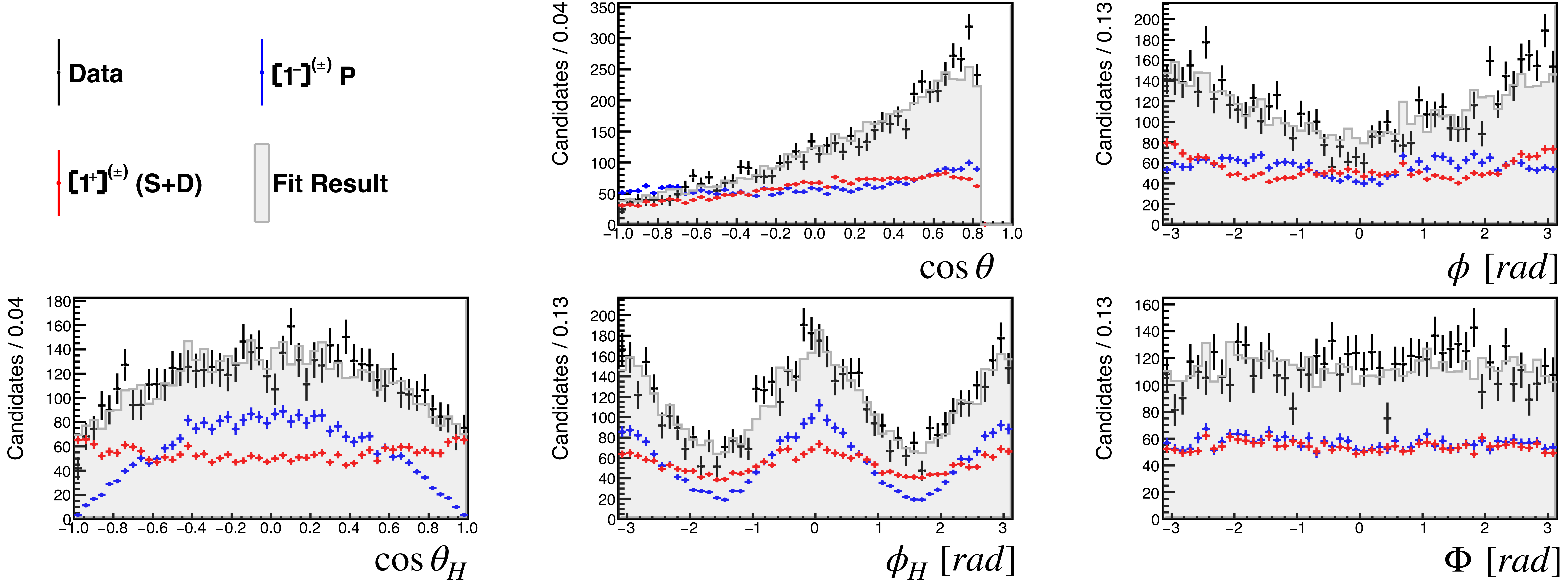
Mass Independent Fit to GlueX Phase 1 Data

- Waveset: $J^P\ell = \{1^+S,\ 1^+D,\ 1^-P\}$
  - Every D wave's phase and magnitude constrained to the S wave. Magnitude constrained like $0 < D/S < 1.0$
  - Incoherent isotropic background to absorb additional contributions
- Required $M_{p\pi^0} > 1.4\ GeV$ to remove excited baryon background



Example Fit Result with $M_{p\pi^0} > 1.4\ GeV$

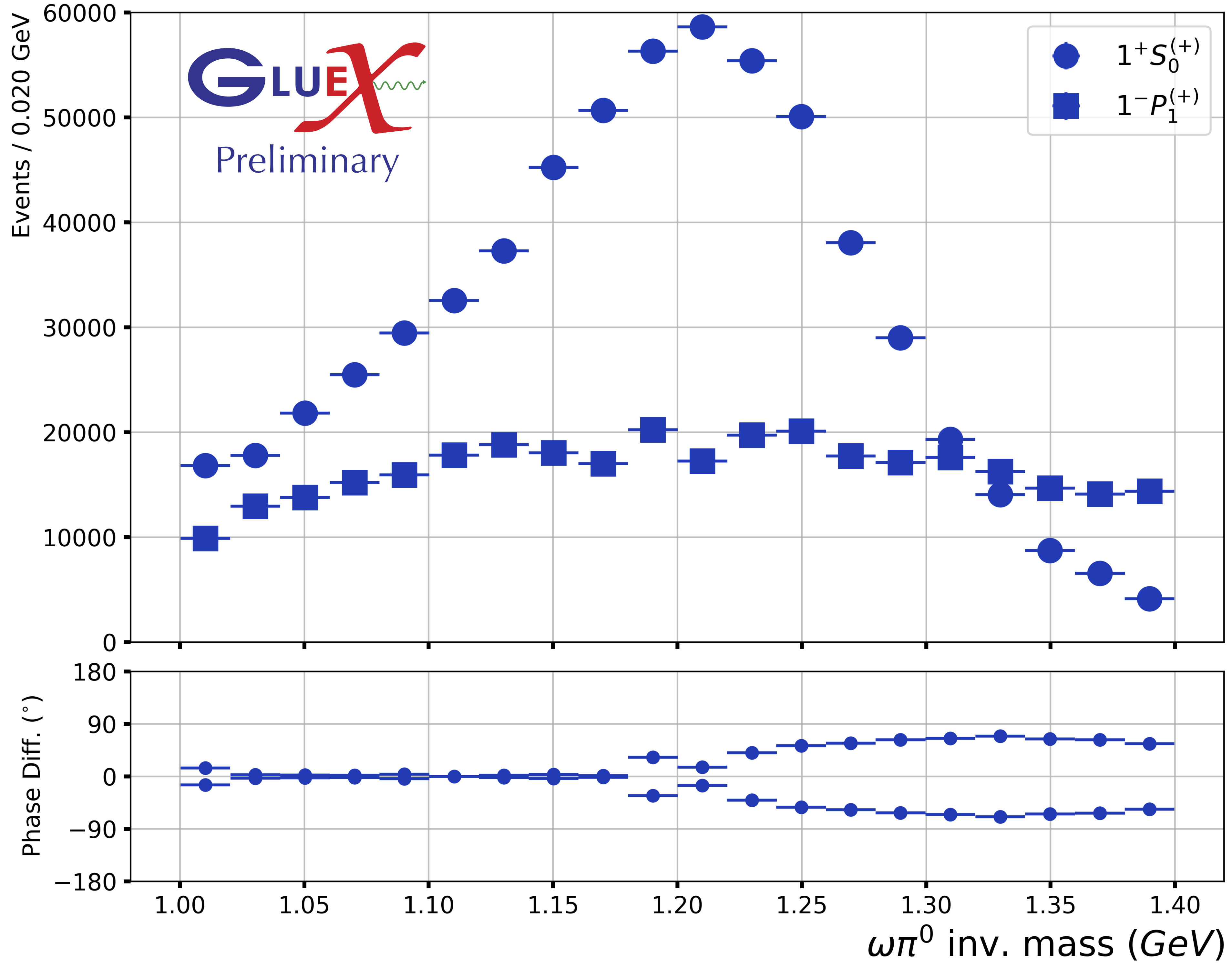
$0.3 < -t < 0.5\ GeV^2, \quad 1.48 < M_{\omega\pi^0} < 1.50\ GeV$



Interference Between $\ell_m^{(\epsilon)} = S_0^{(+)}, P_1^{(+)}$ Waves

Grouped in bins of $-t$, errors are purely statistical

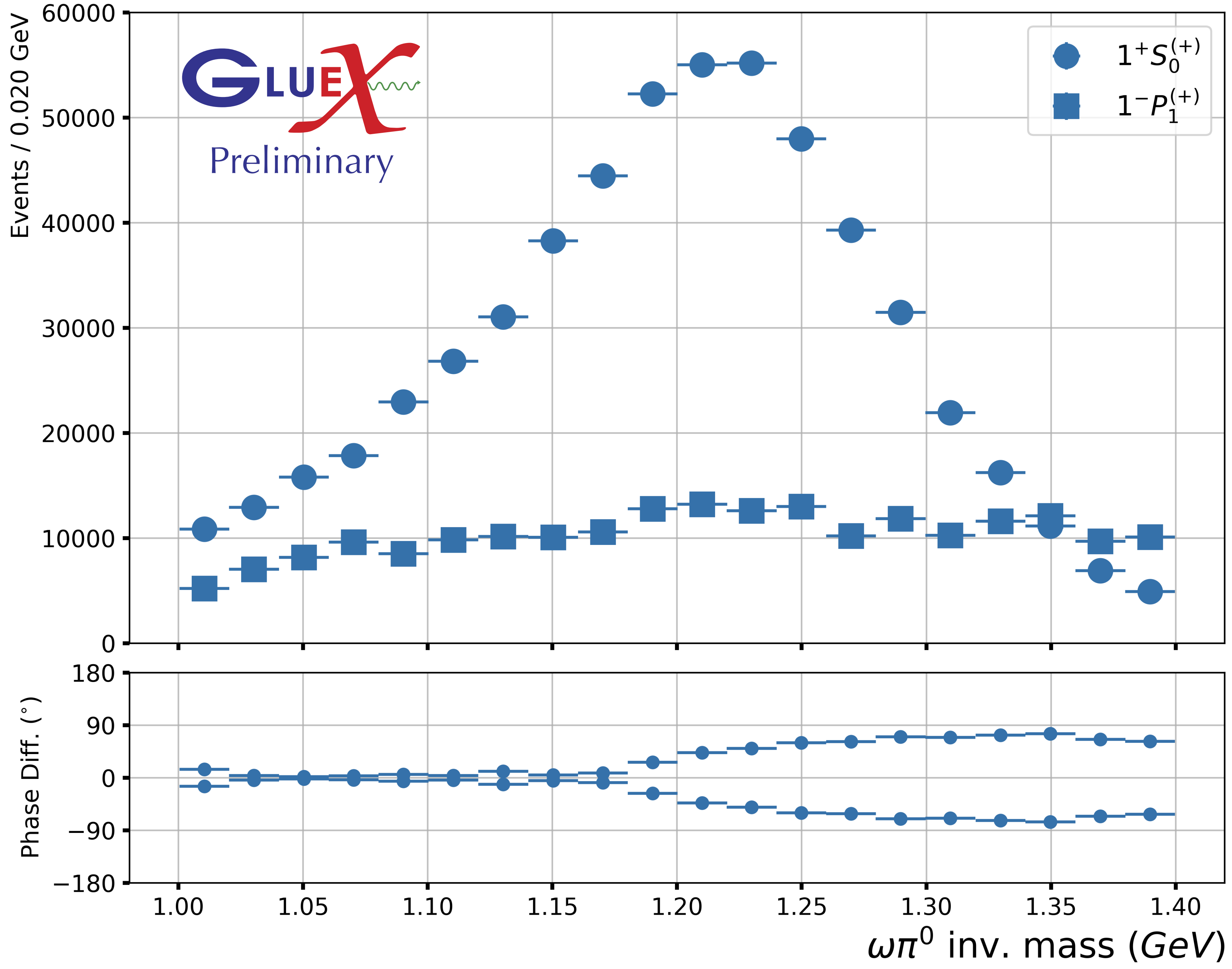
$0.1 < -t < 0.2\ GeV^2$



Wide 1^- contribution

Phase motion matches previous input-output Monte Carlo study

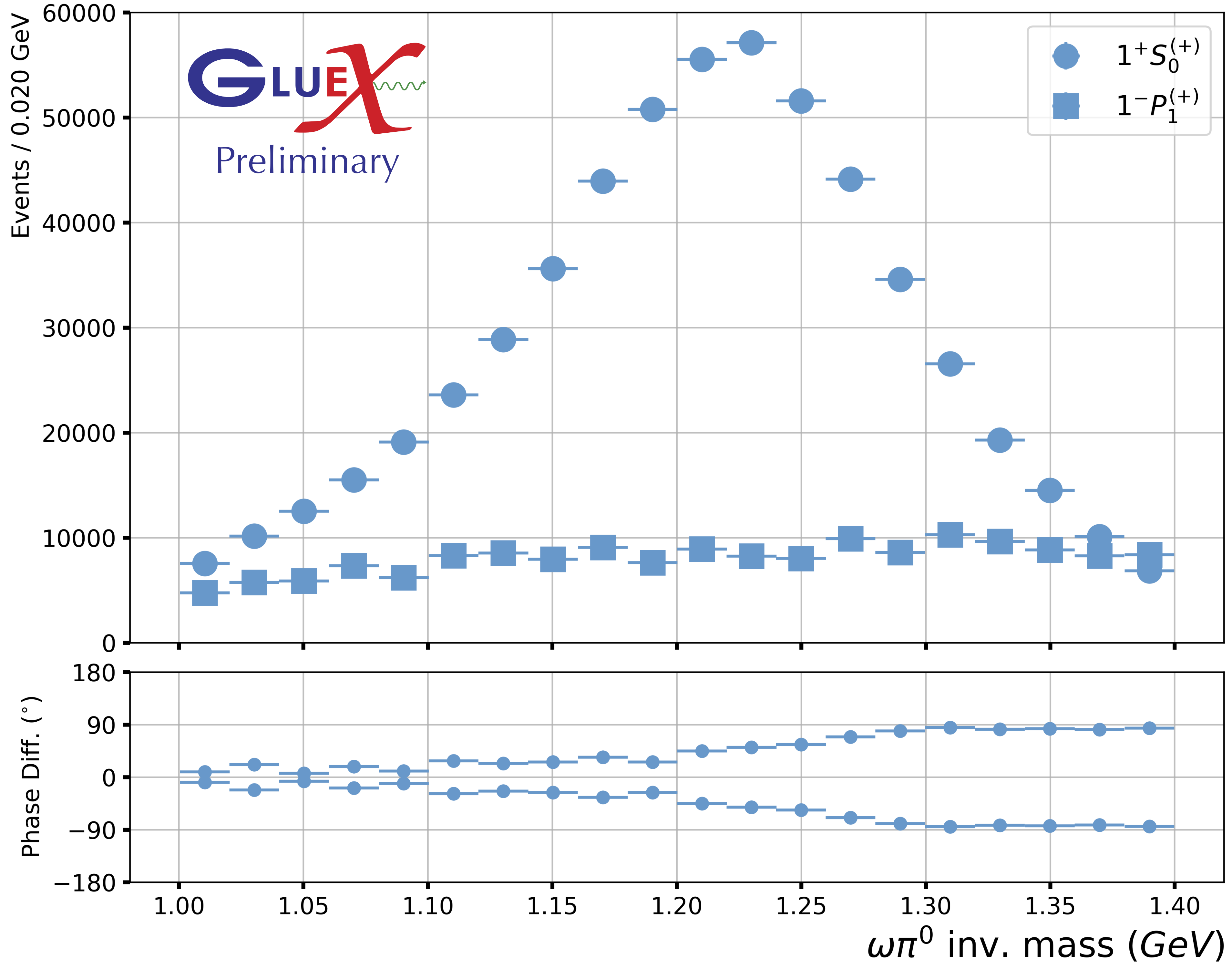
$0.2 < -t < 0.3\ GeV^2$



Interference Between $\ell_m^{(\epsilon)} = S_0^{(+)}, P_1^{(+)}$ Waves

Grouped in bins of $-t$, errors are purely statistical

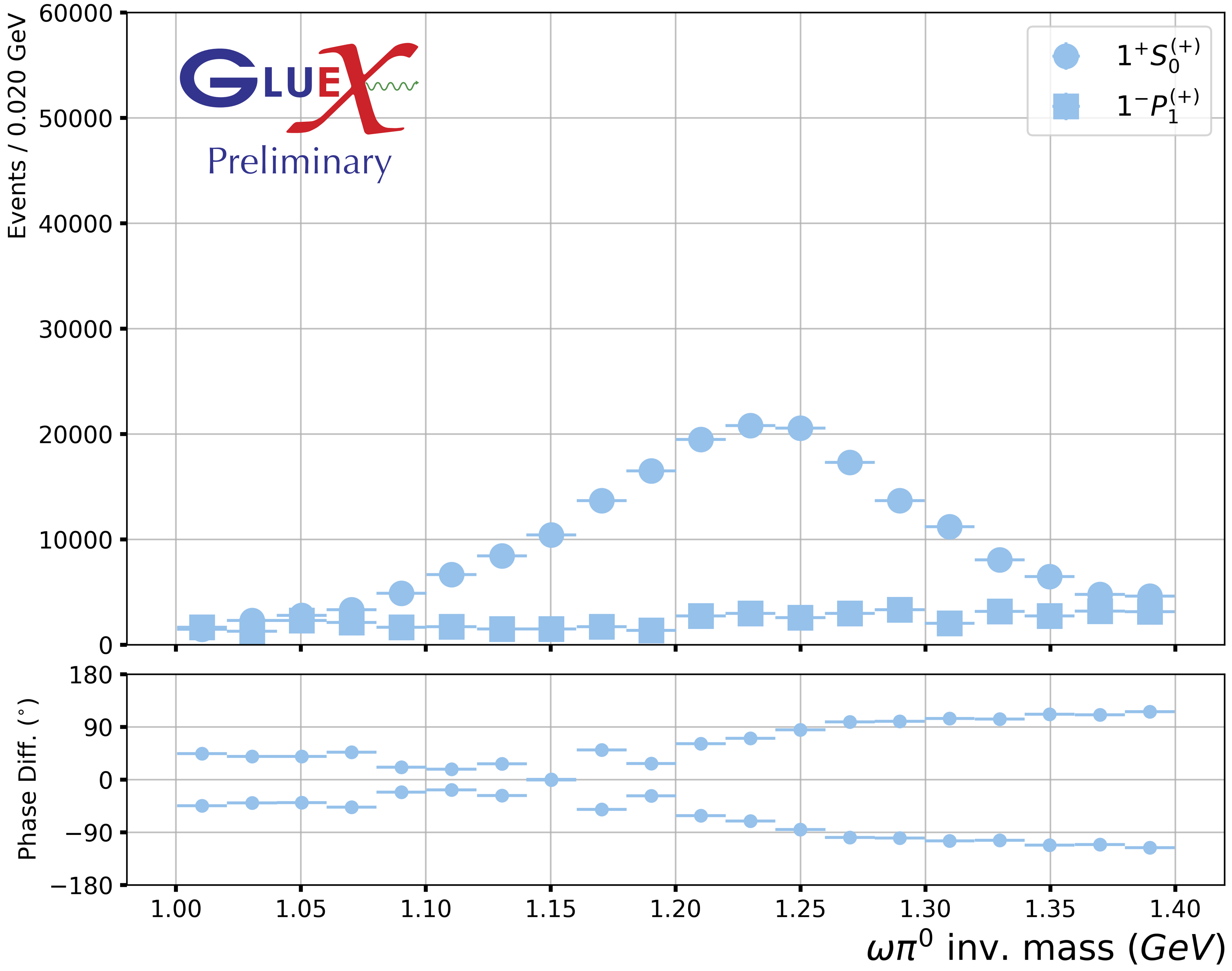
$0.3 < -t < 0.5\ GeV^2$



Wide 1^- contribution

Phase motion matches previous input-output Monte Carlo study

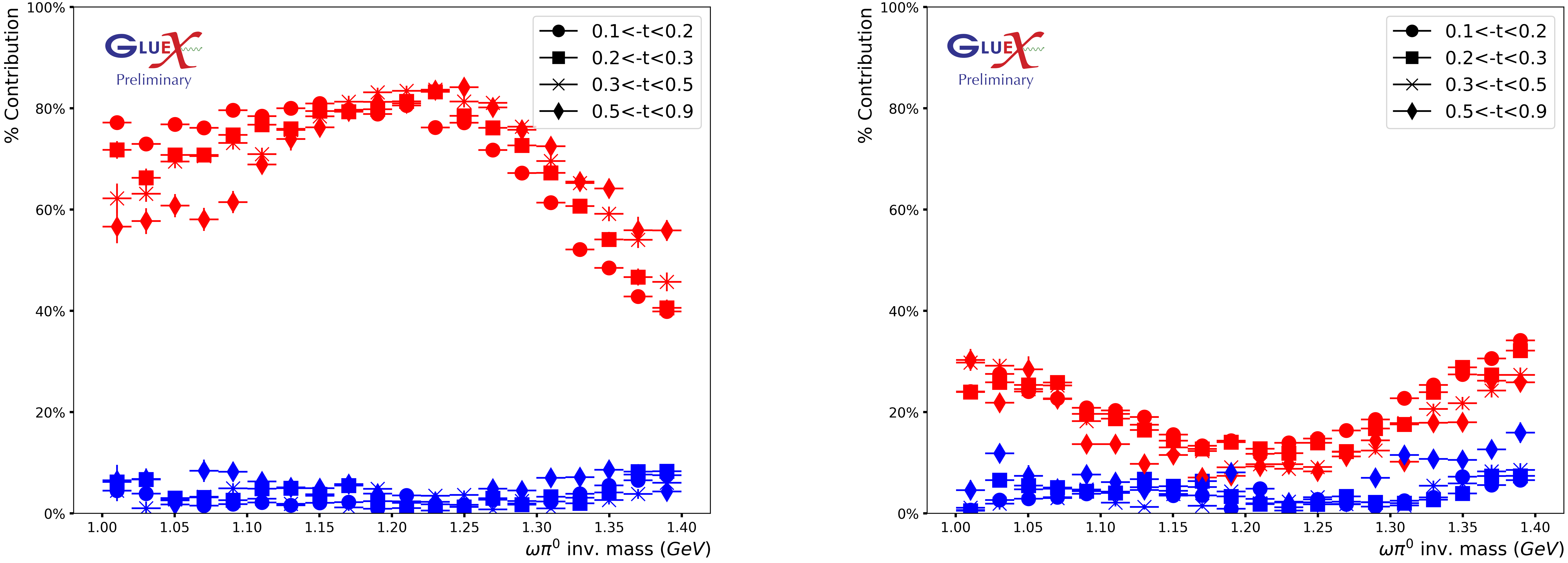
$0.5 < -t < 0.9\ GeV^2$



Production Mechanism Dominance

Colored by exchange particle naturality τ_E (natural / unnatural)

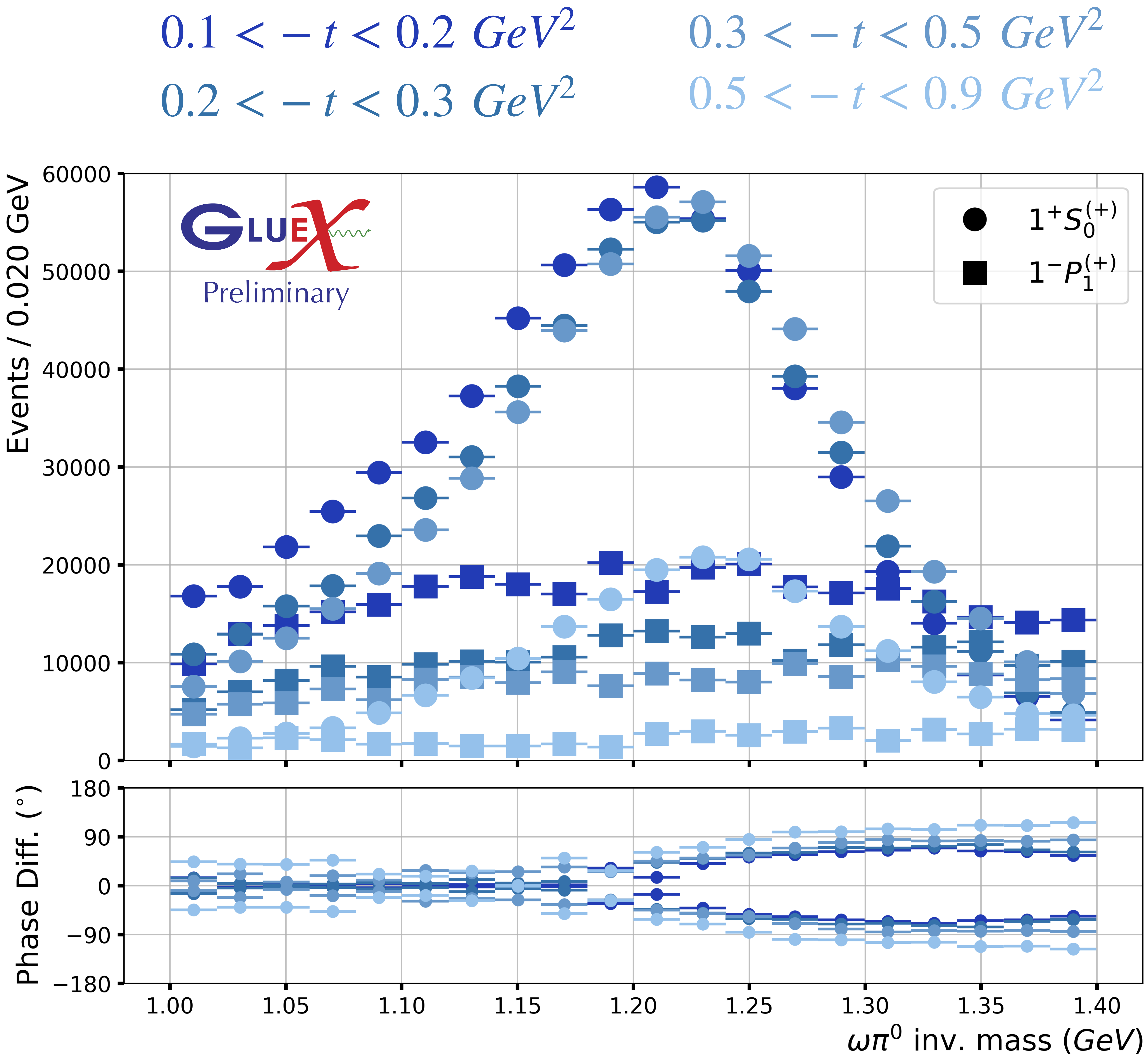
$J^P\ell = 1^+S, D$ $\qquad$ $J^P\ell = 1^-P$



Note: Errors are purely statistical, and unnatural results are likely very susceptible to model changes

Conclusions

- Largest $\gamma p \rightarrow \omega\pi^0 p$ photoproduction dataset
- Observe $J^P = 1^+$ and 1^- contributions consistent with an interference between the $b_1(1235)$ and vector amplitude
- 1^+ production dominated by natural diffractive Pomeron exchange mechanisms

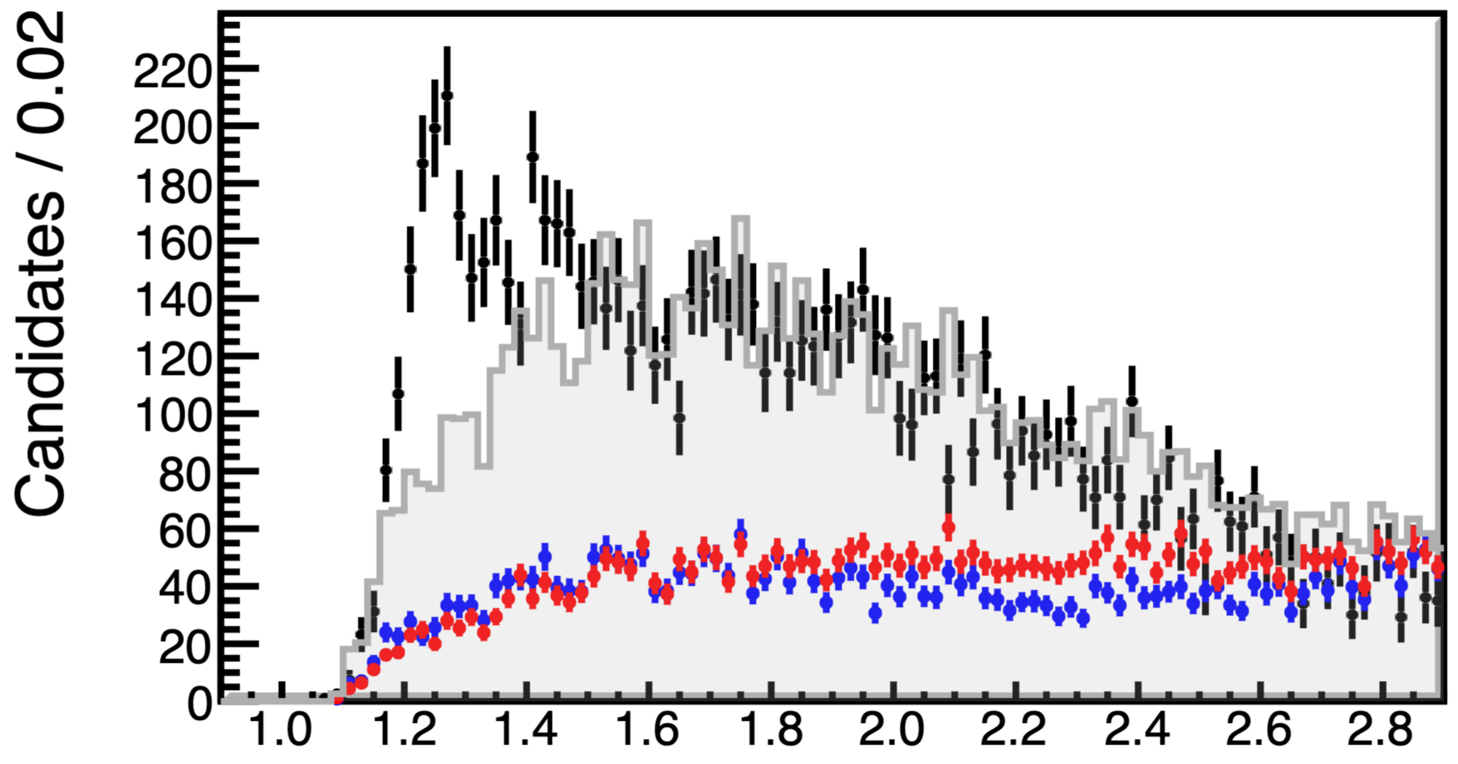


BACKUP SLIDES: Index

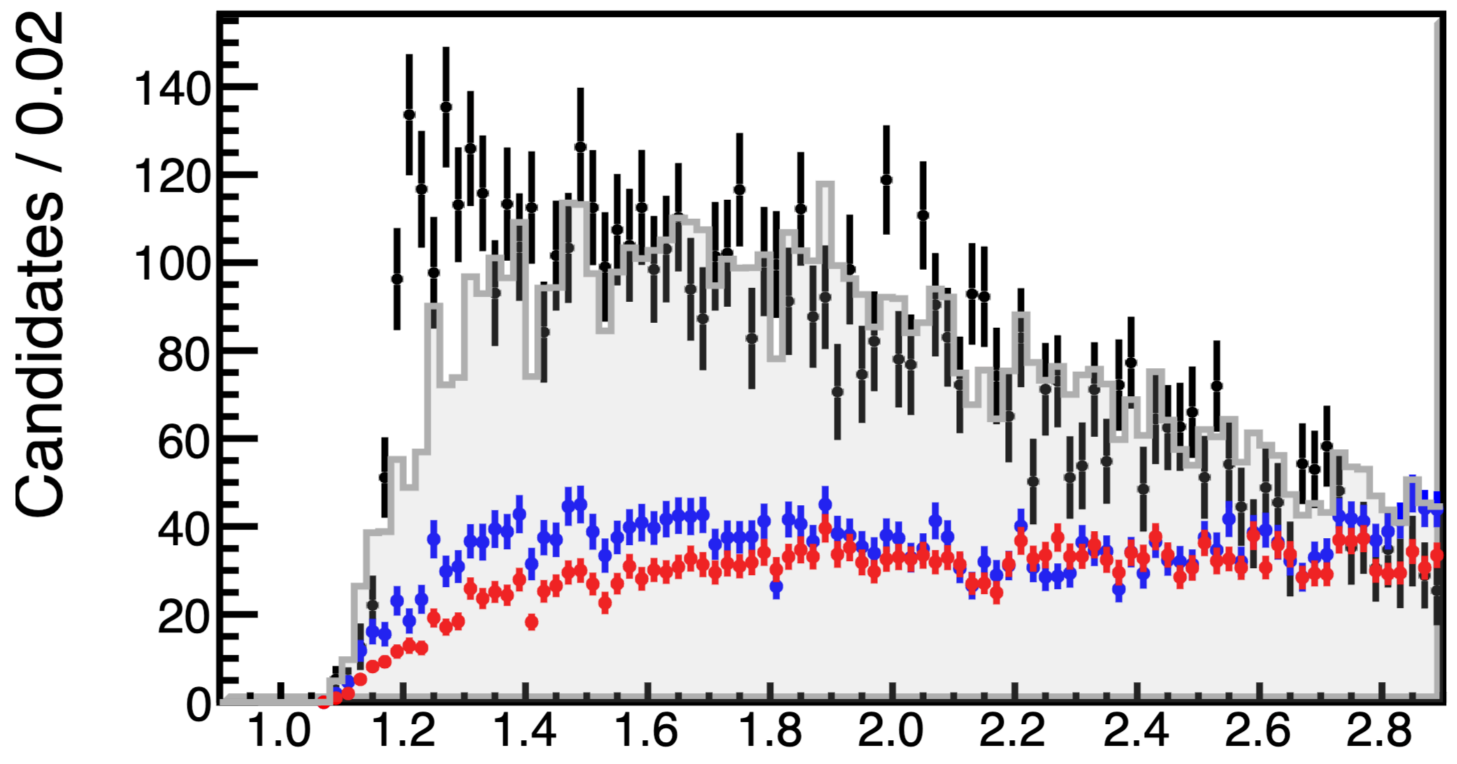
BACKUP: Baryon Background

Cut at $M_{N\pi} > 1.4\ GeV$ influenced by Δ baryon peaks at large $\omega\pi^0$ masses

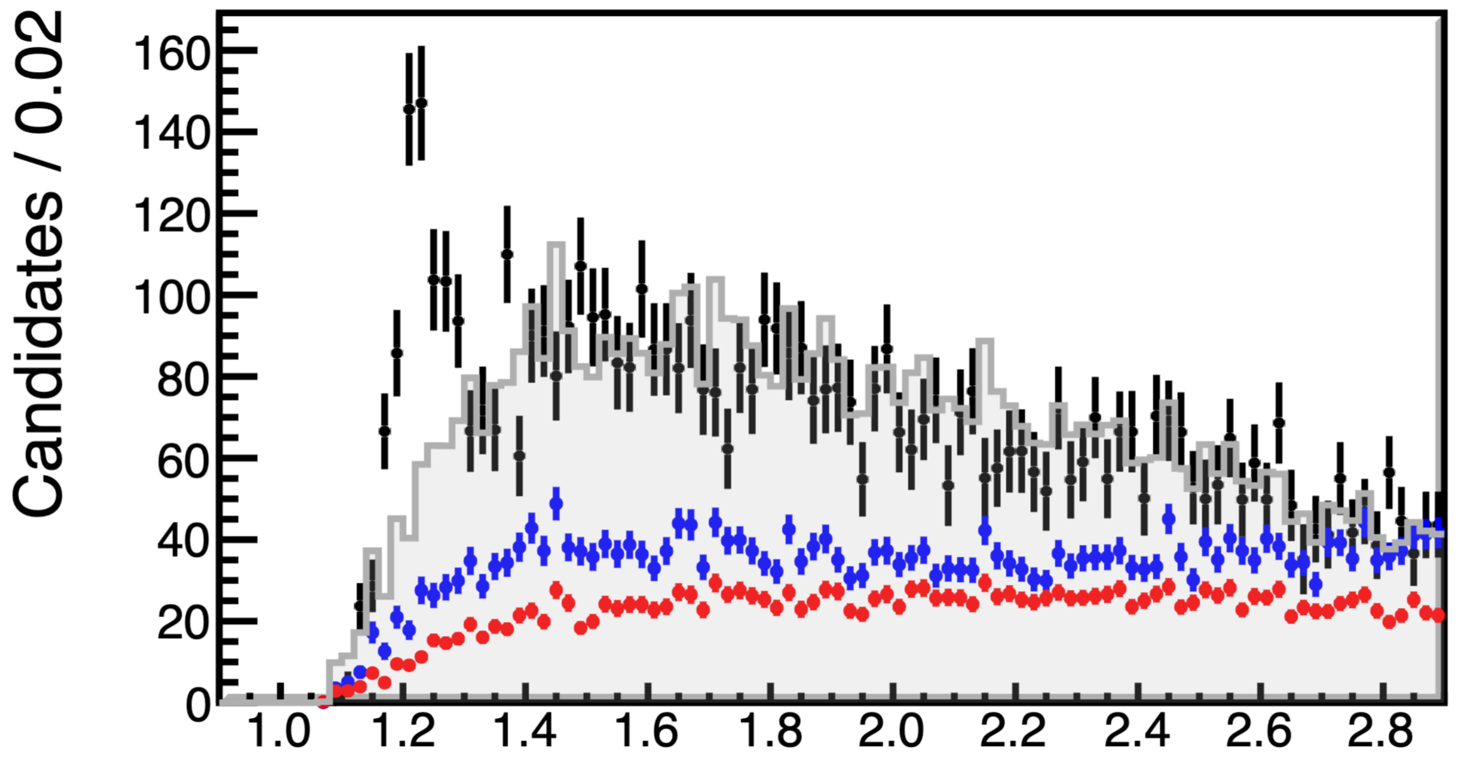
$0.1 < -t < 0.2$



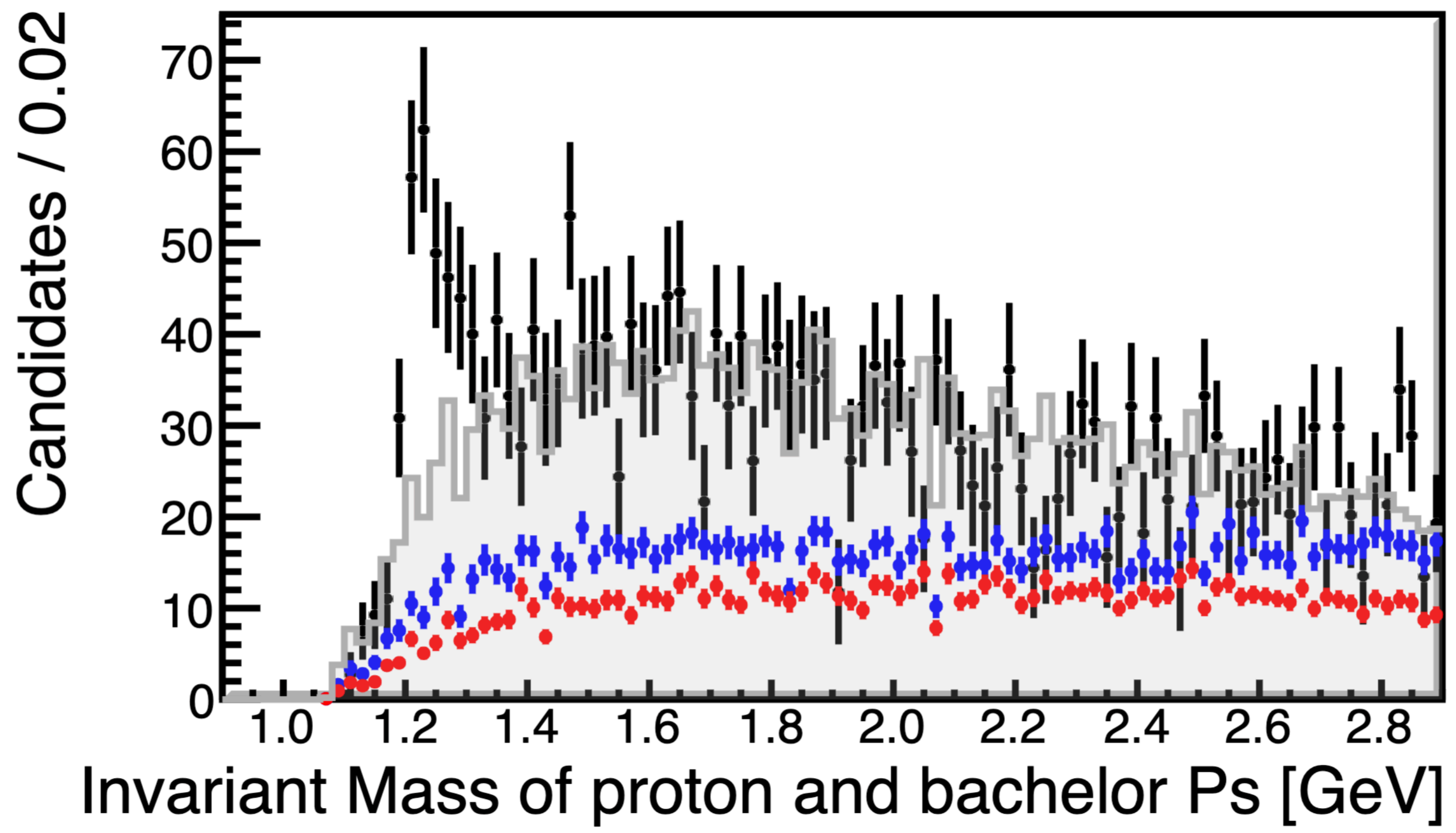
$0.2 < -t < 0.3$



$0.3 < -t < 0.5$

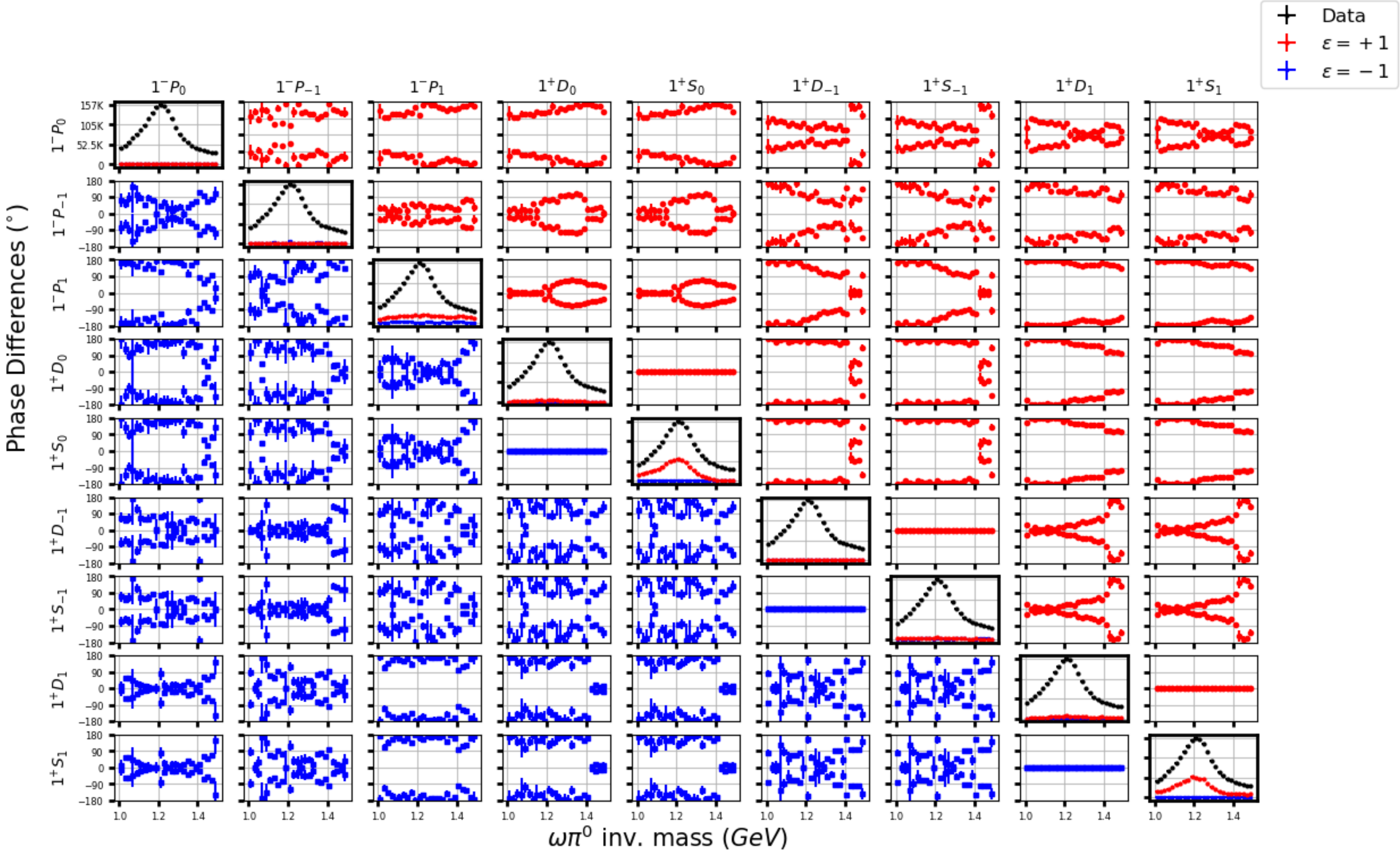


$0.5 < -t < 0.9$



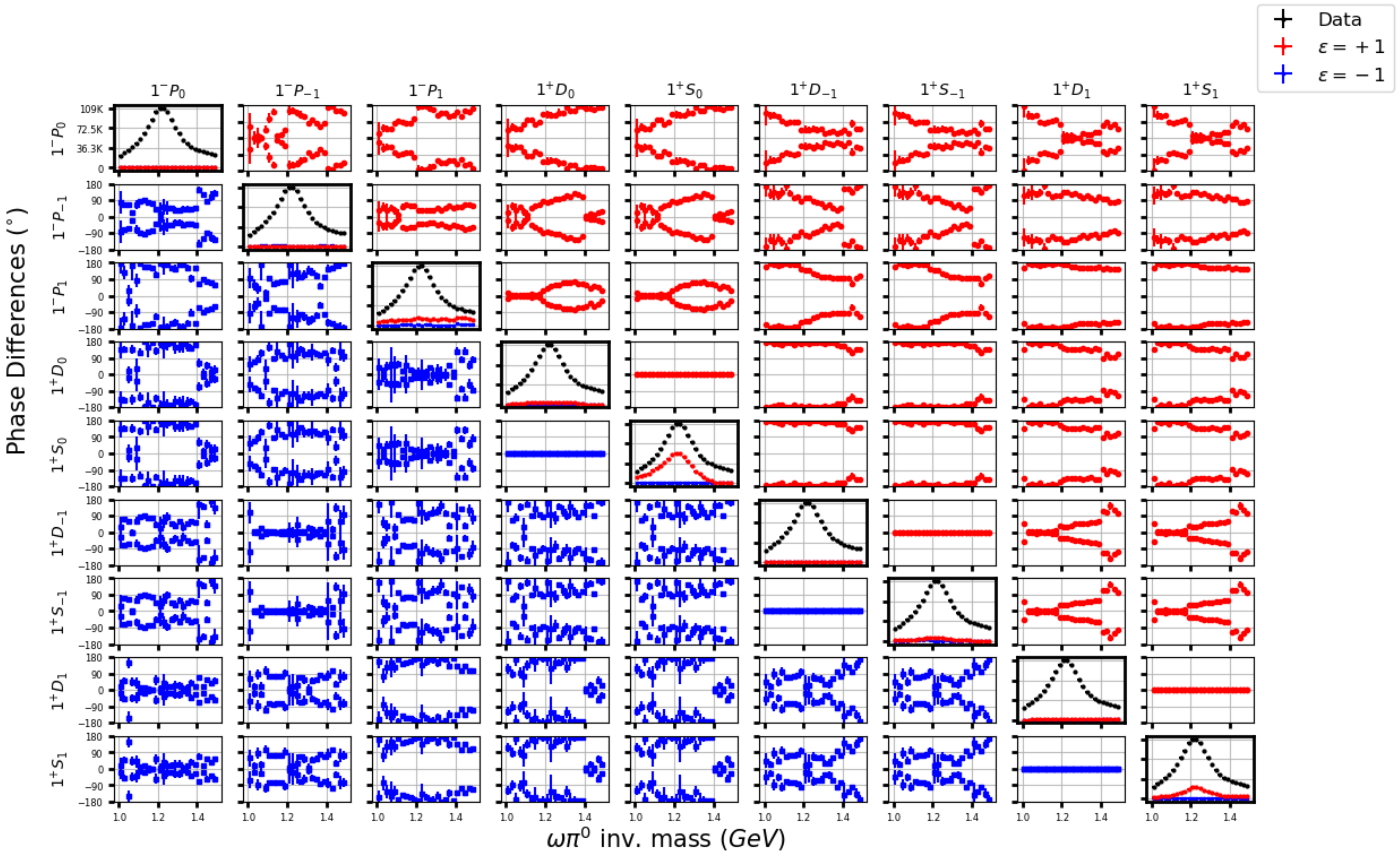
Back to Index Slide

BACKUP: Model Matrix $0.1 < -t < 0.2$



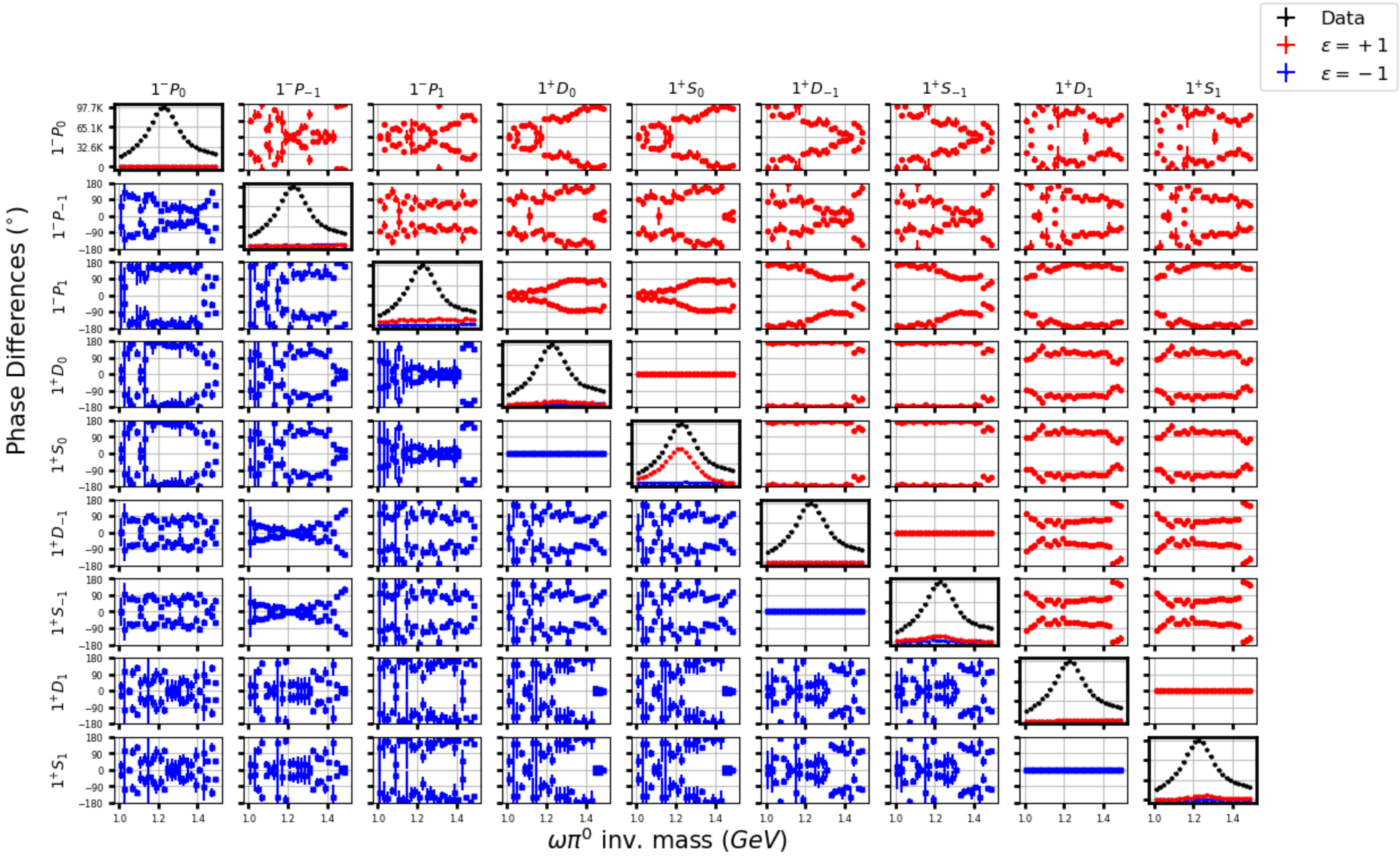
Back to Index Slide

BACKUP: Model Matrix $0.2 < -t < 0.3$



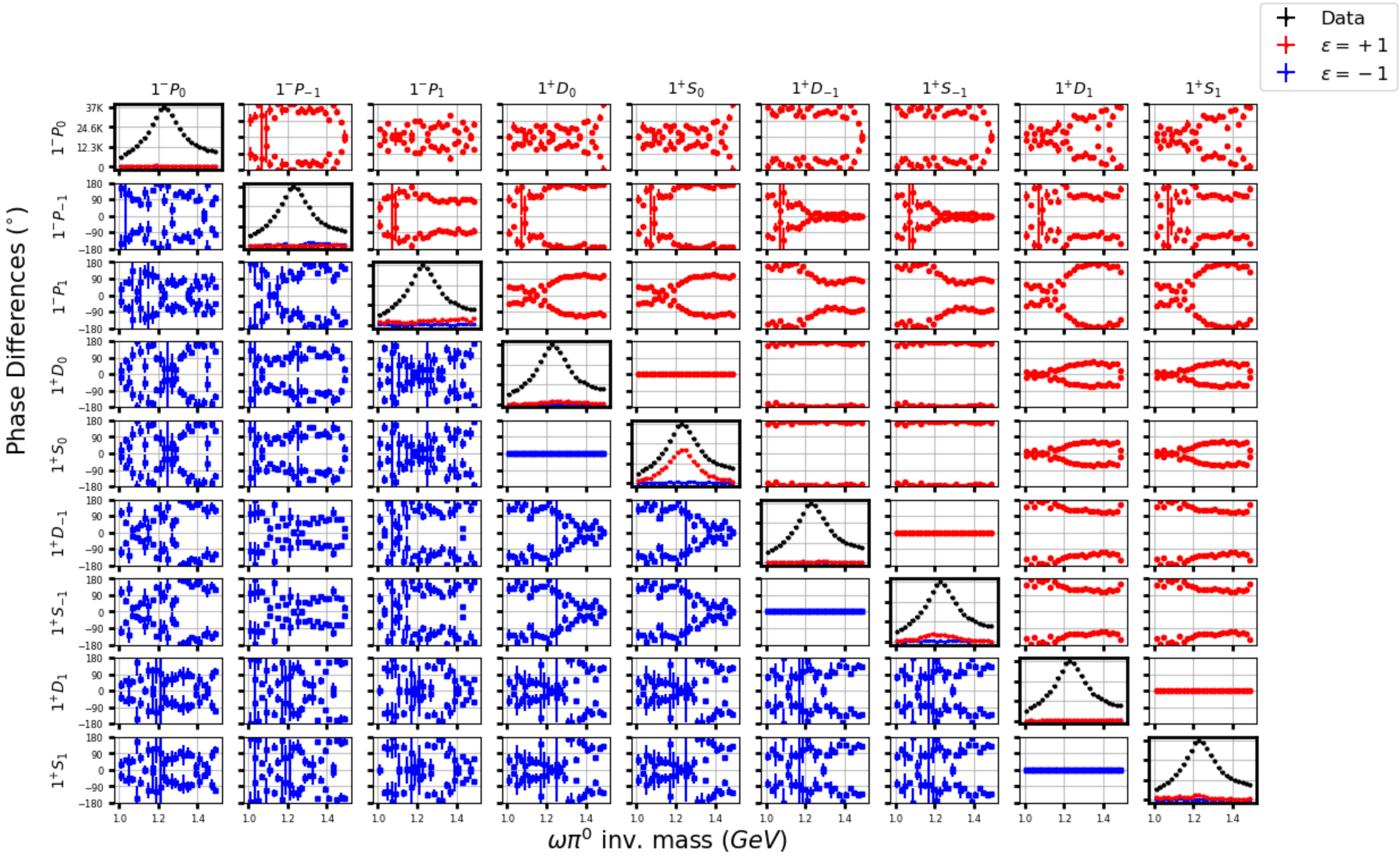
Back to Index Slide

BACKUP: Model Matrix $0.3 < -t < 0.5$



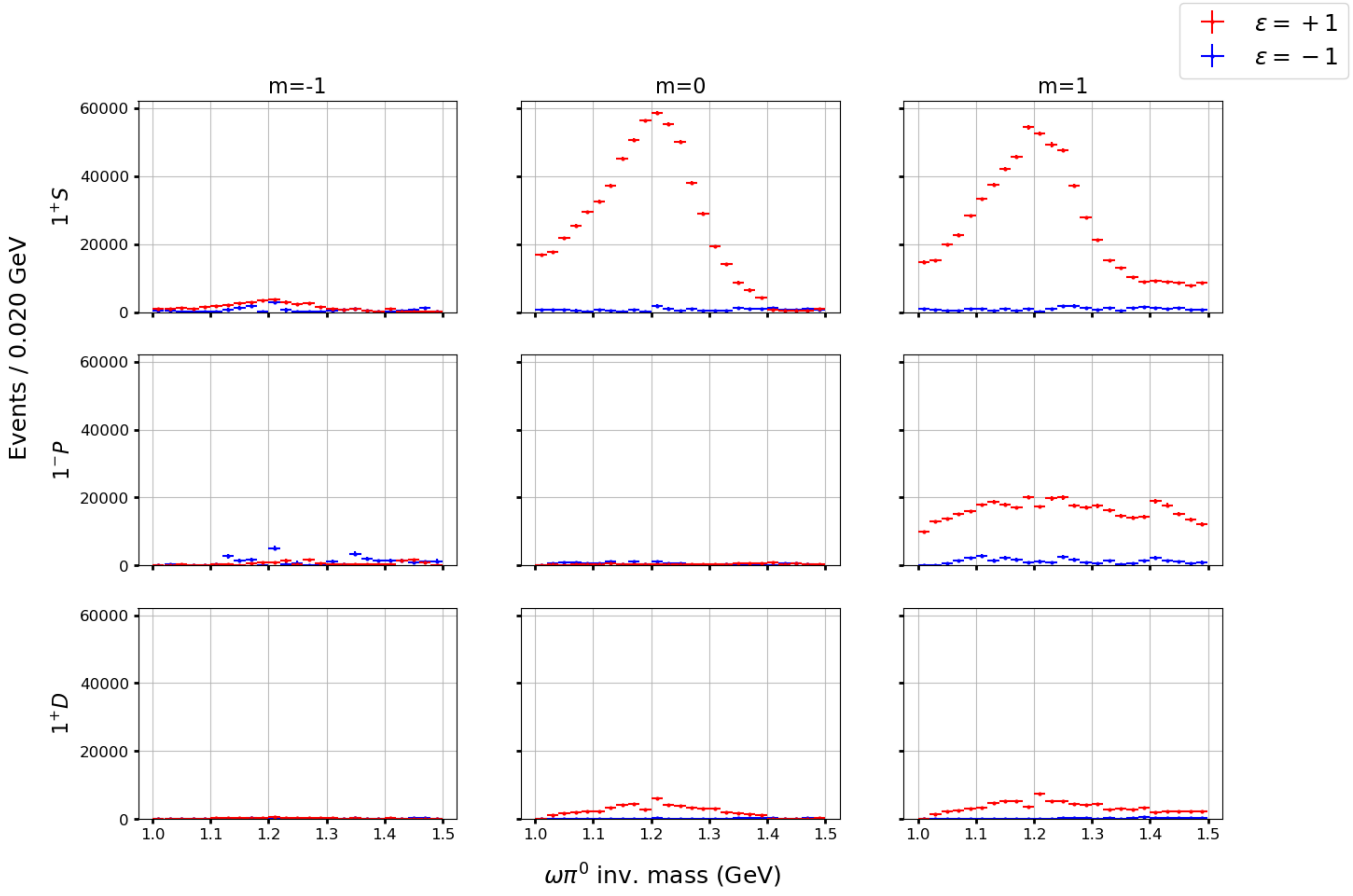
Back to Index Slide

BACKUP: Model Matrix $0.5 < -t < 0.9$



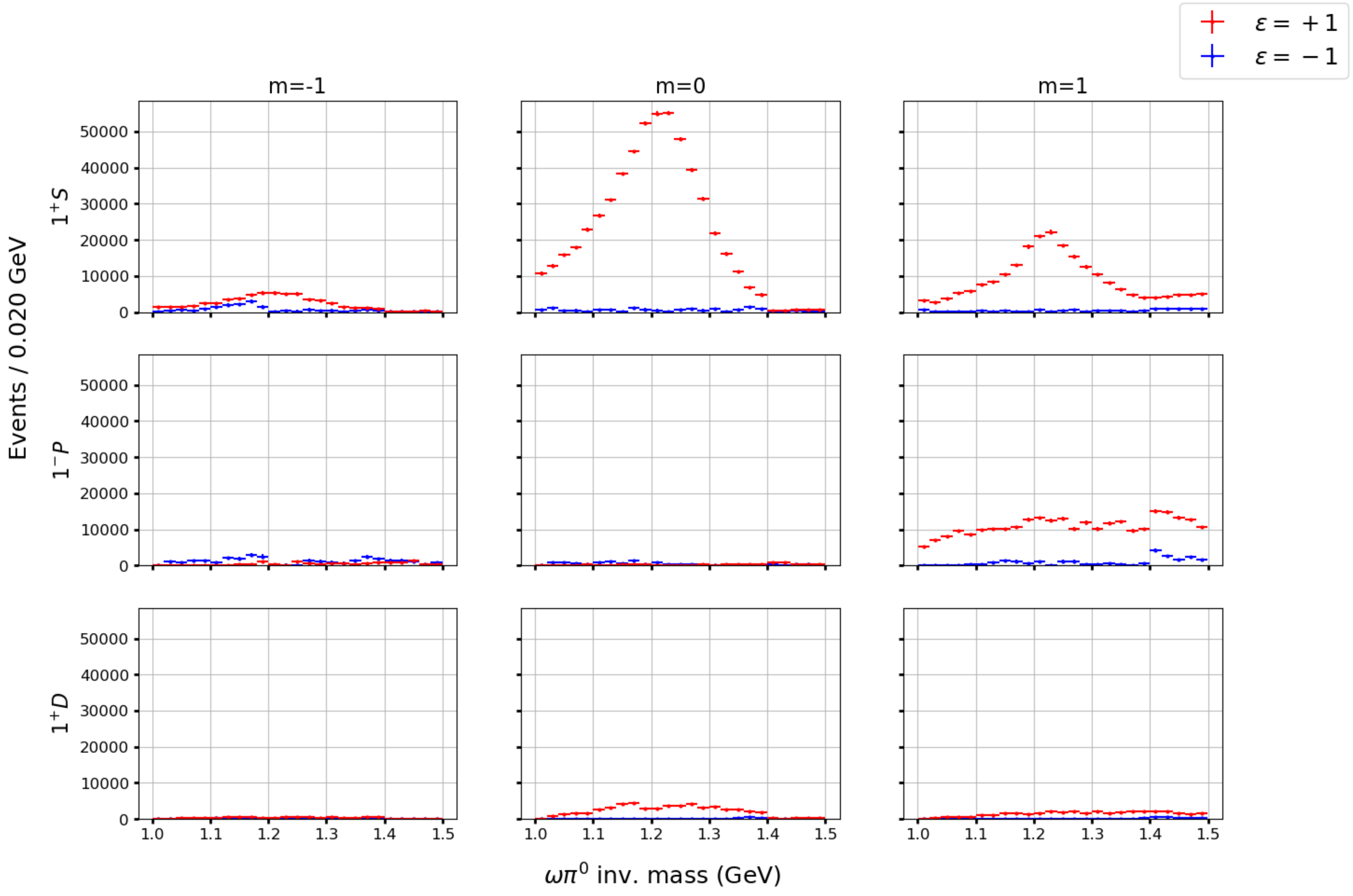
Back to Index Slide

BACKUP: Wave Intensities $0.1 < -t < 0.2$



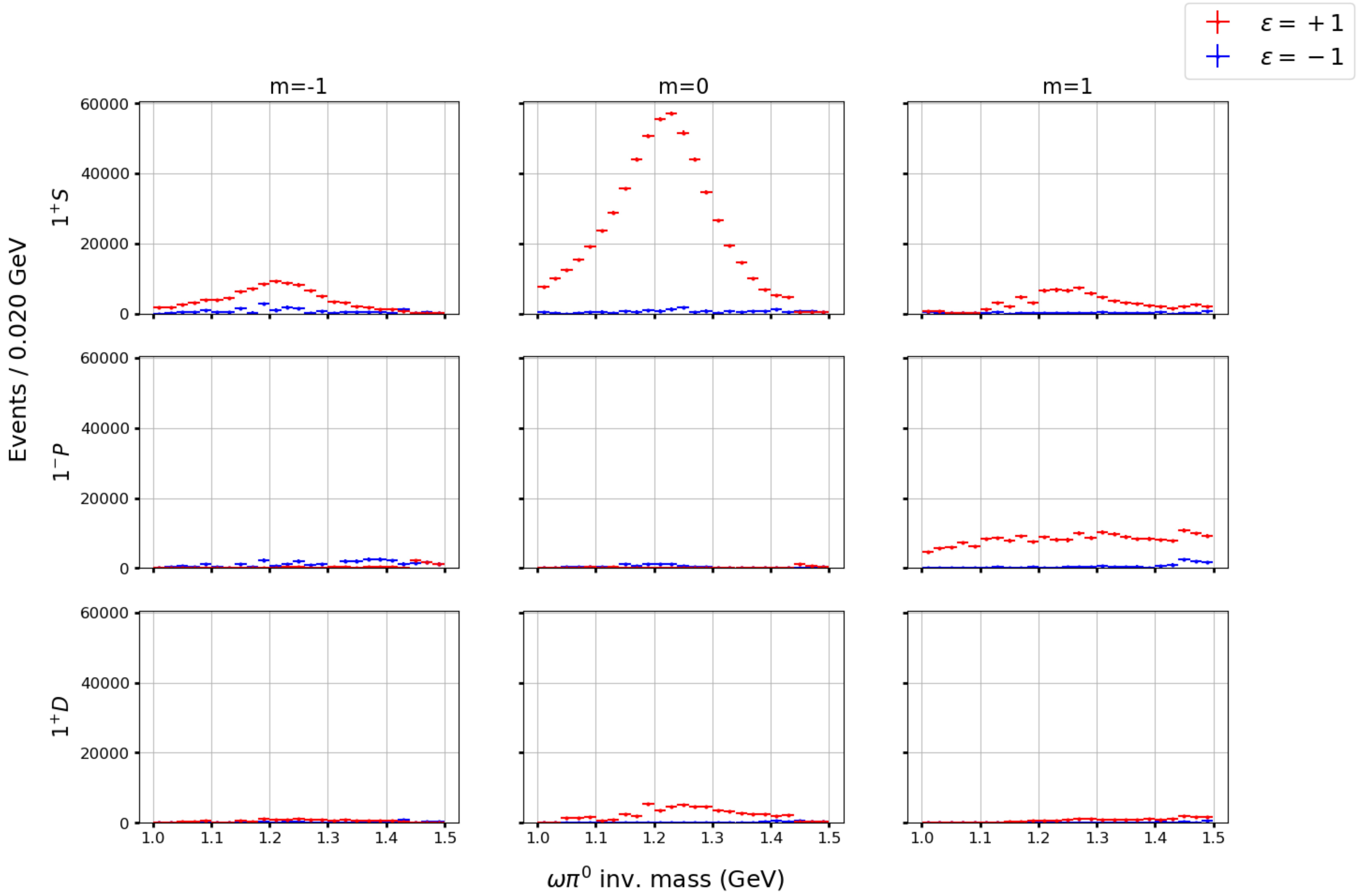
Back to Index Slide

BACKUP: Wave Intensities $0.2 < -t < 0.3$



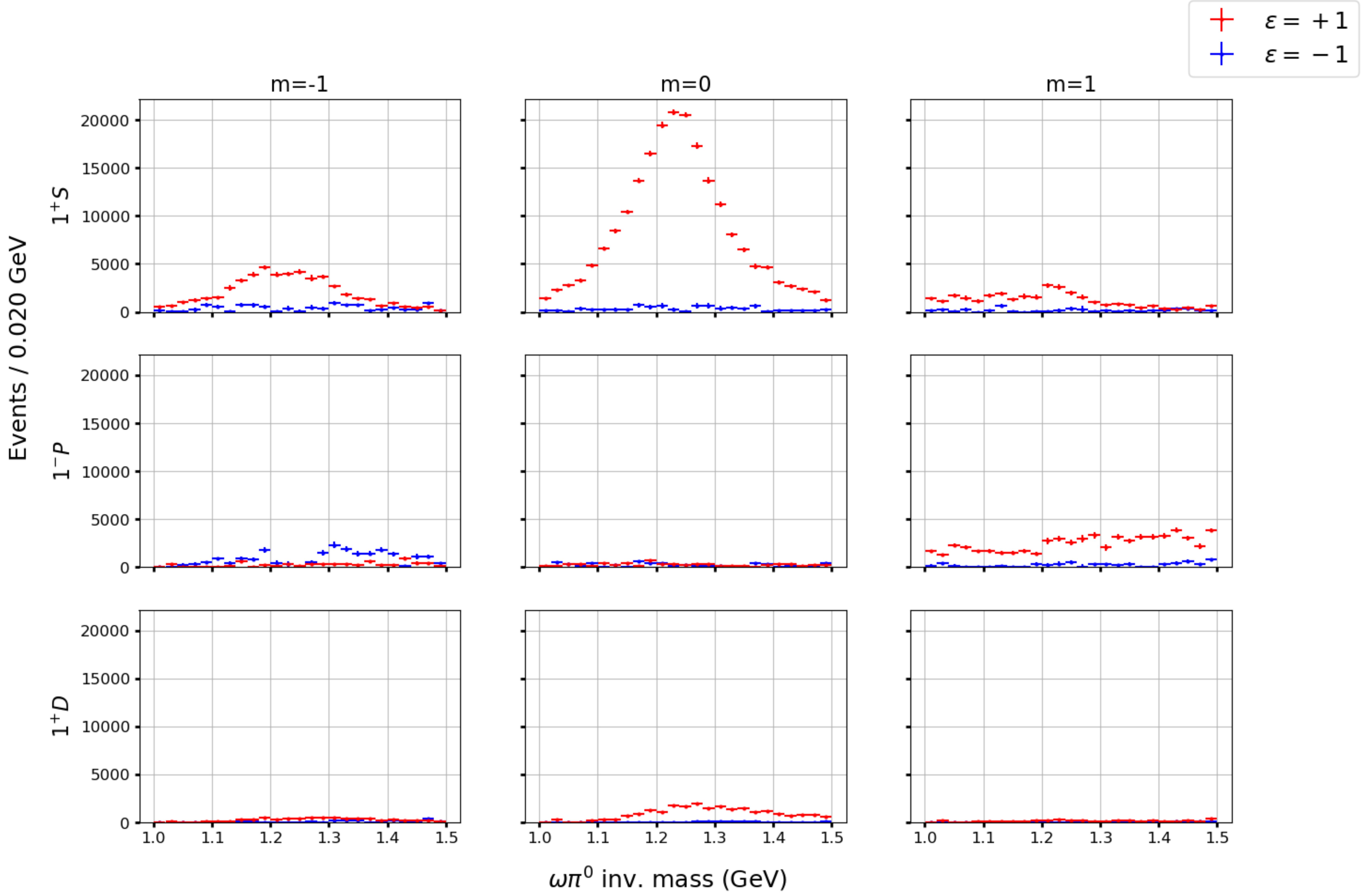
Back to Index Slide

BACKUP: Wave Intensities $0.3 < -t < 0.5$



Back to Index Slide

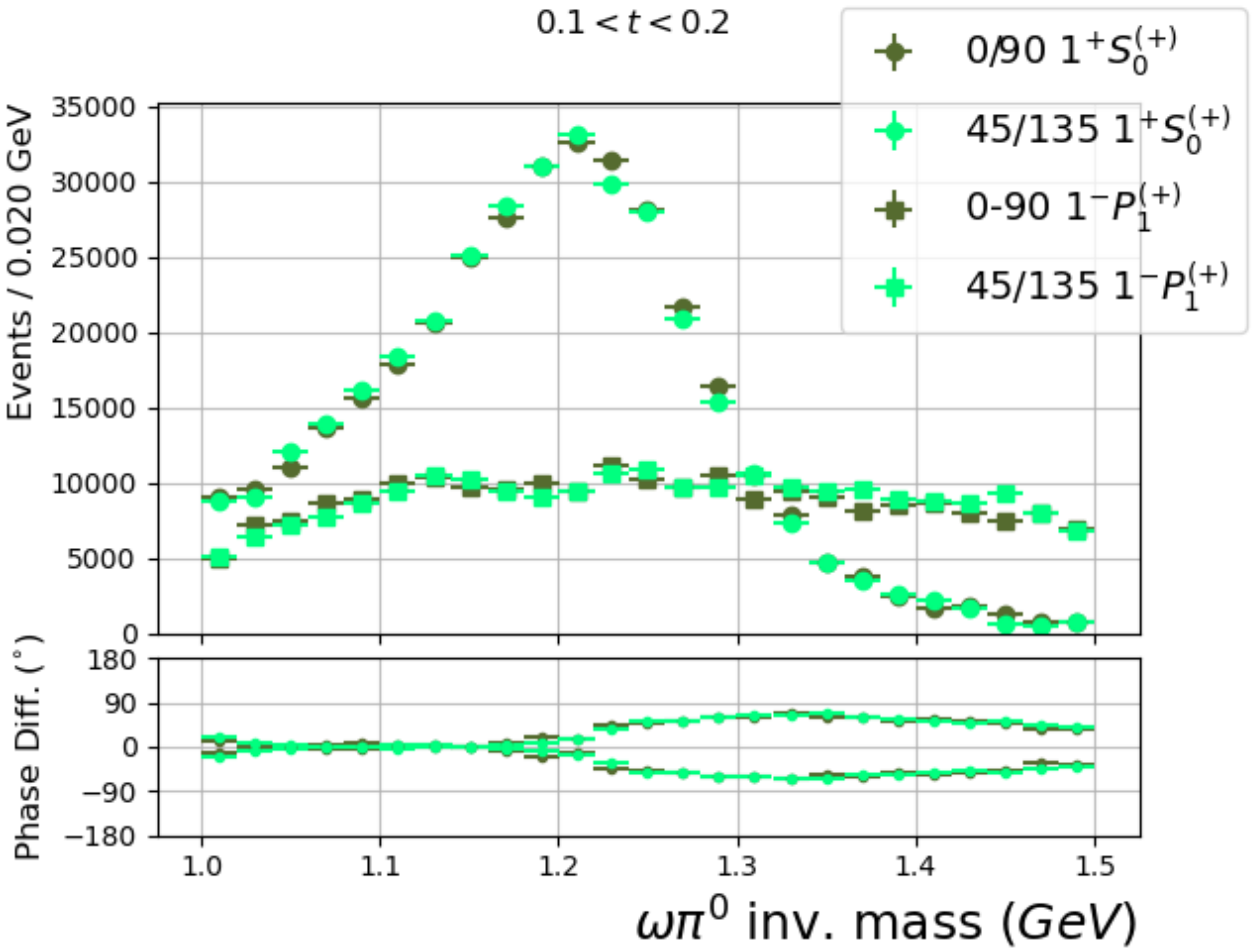
BACKUP: Wave Intensities $0.5 < -t < 0.9$

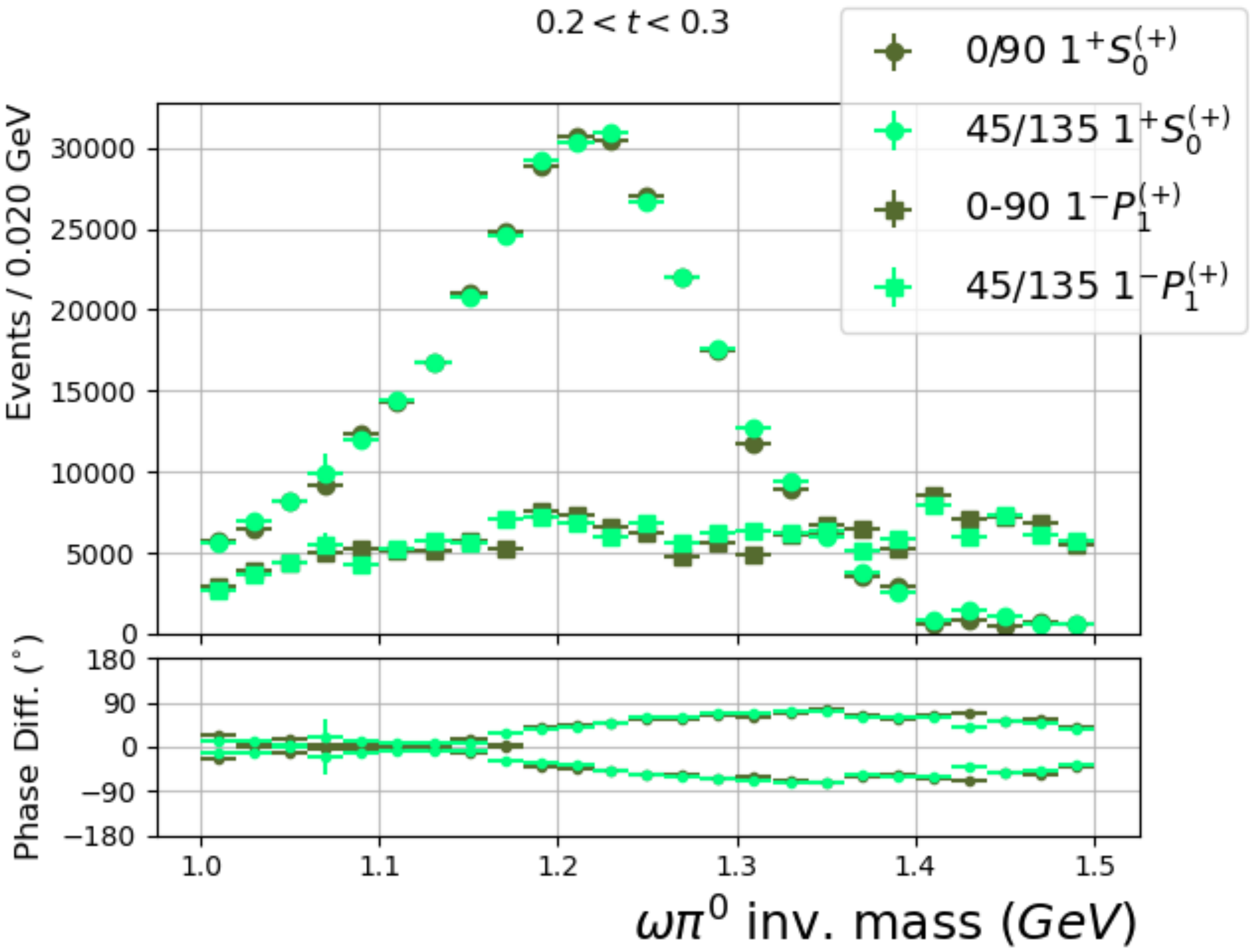


Back to Index Slide

BACKUP: Orientation Pairing Comparison

Functions effectively as 2 independent datasets

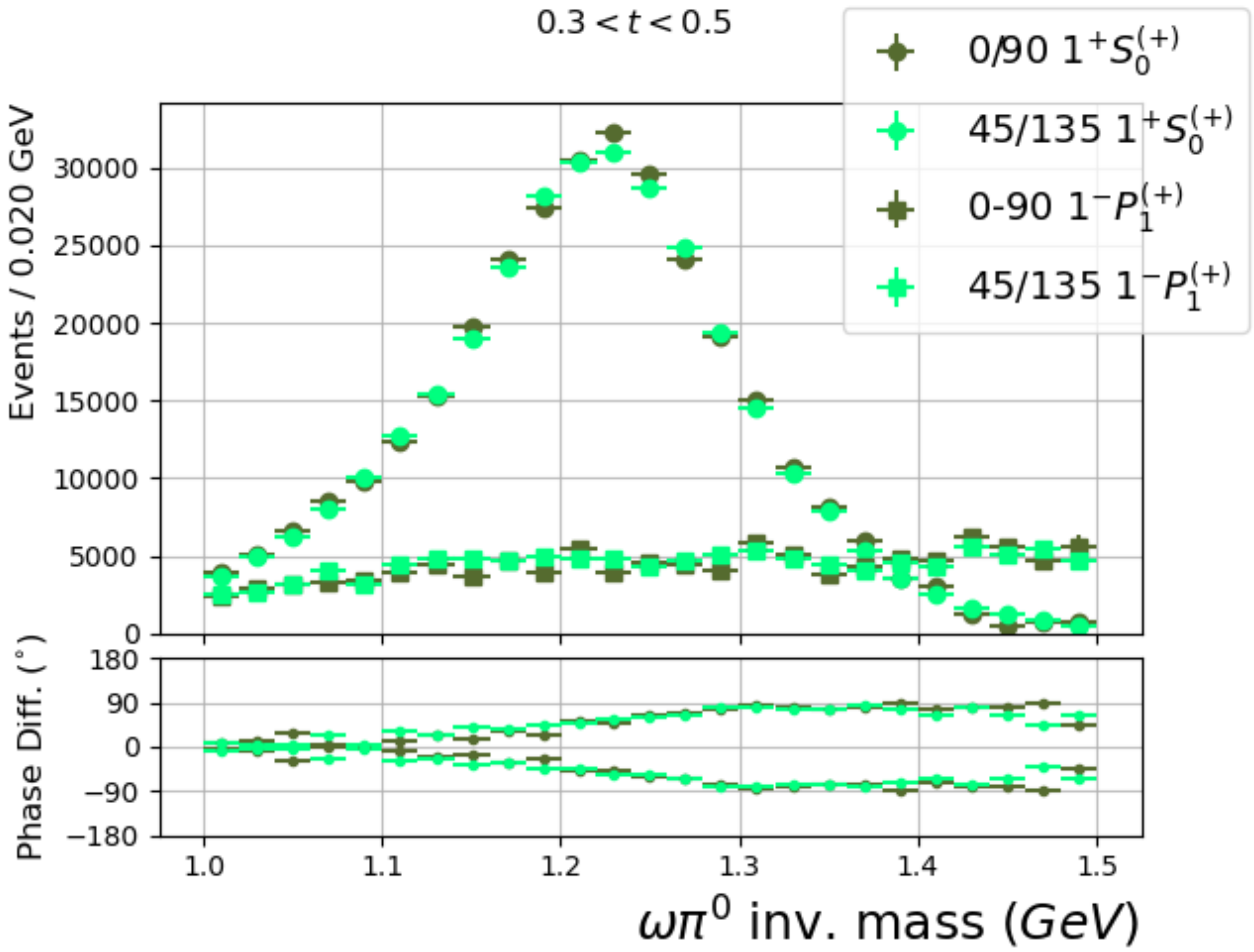


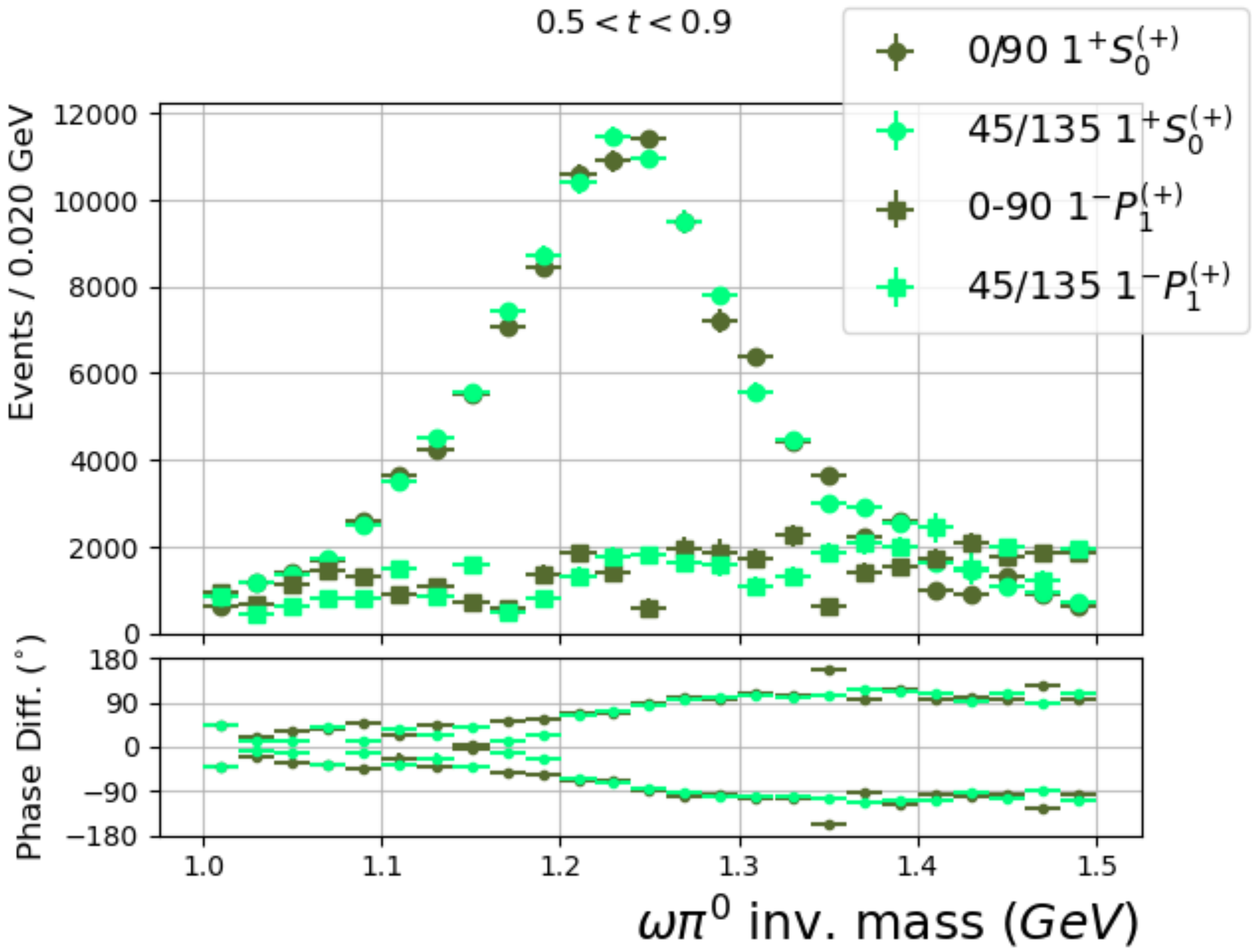


Back to Index Slide

BACKUP: Orientation Pairing Comparison

Functions effectively as 2 independent datasets

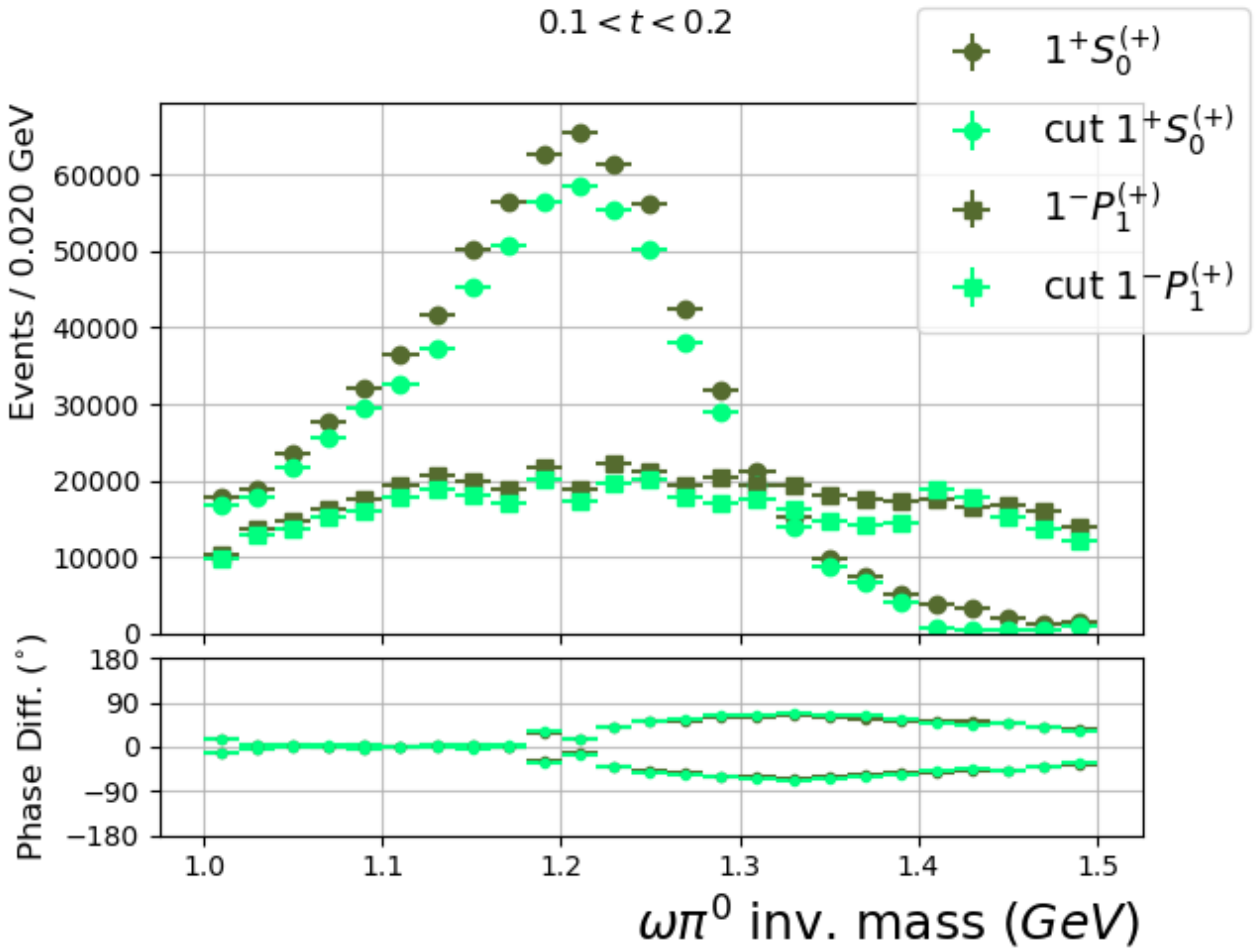


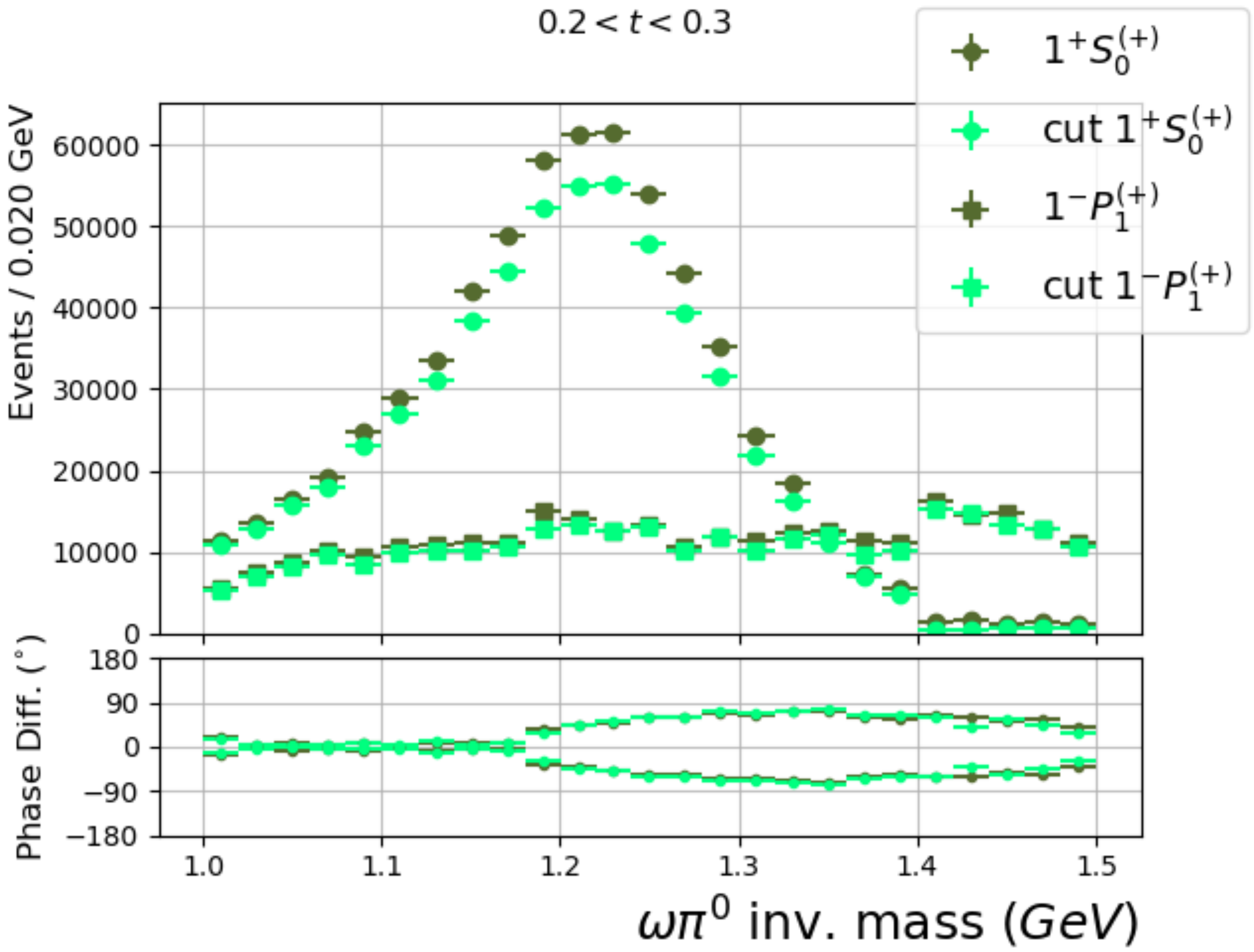


Back to Index Slide

BACKUP: $M_{p\pi^0}$ Cut Comparison

Compare the effects without the cut, and enforcing $M_{p\pi^0} > 1.4\ GeV$

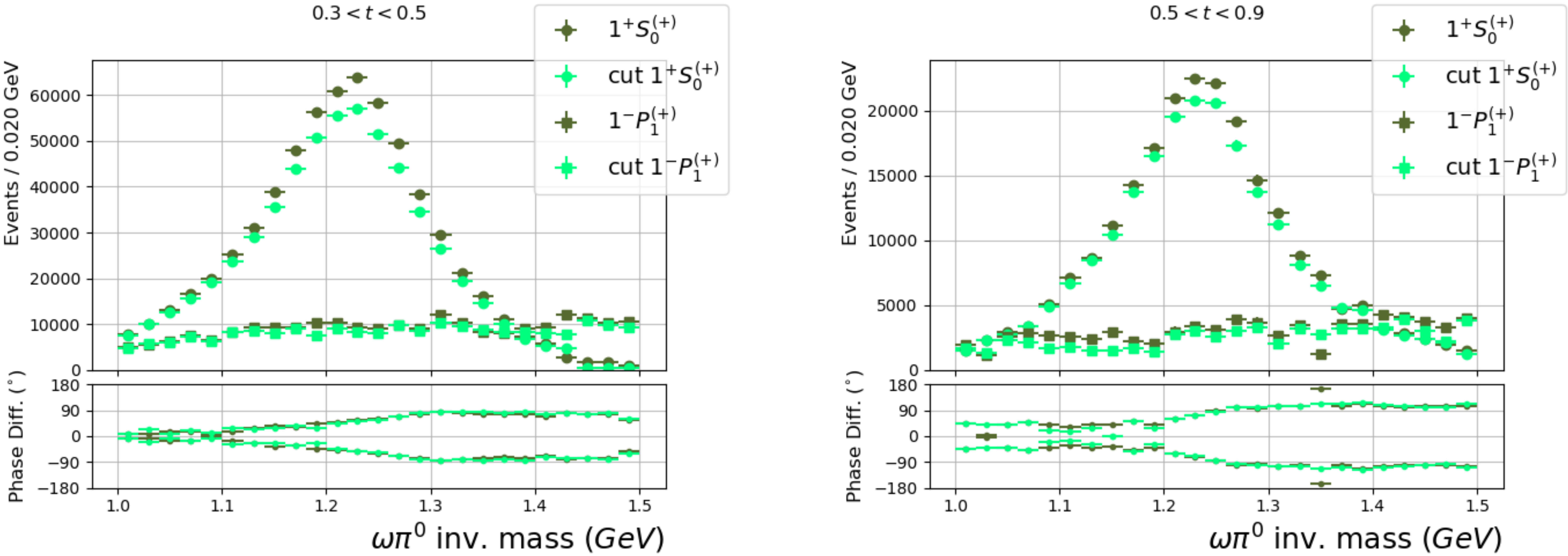




Back to Index Slide

BACKUP: $M_{p\pi^0}$ Cut Comparison

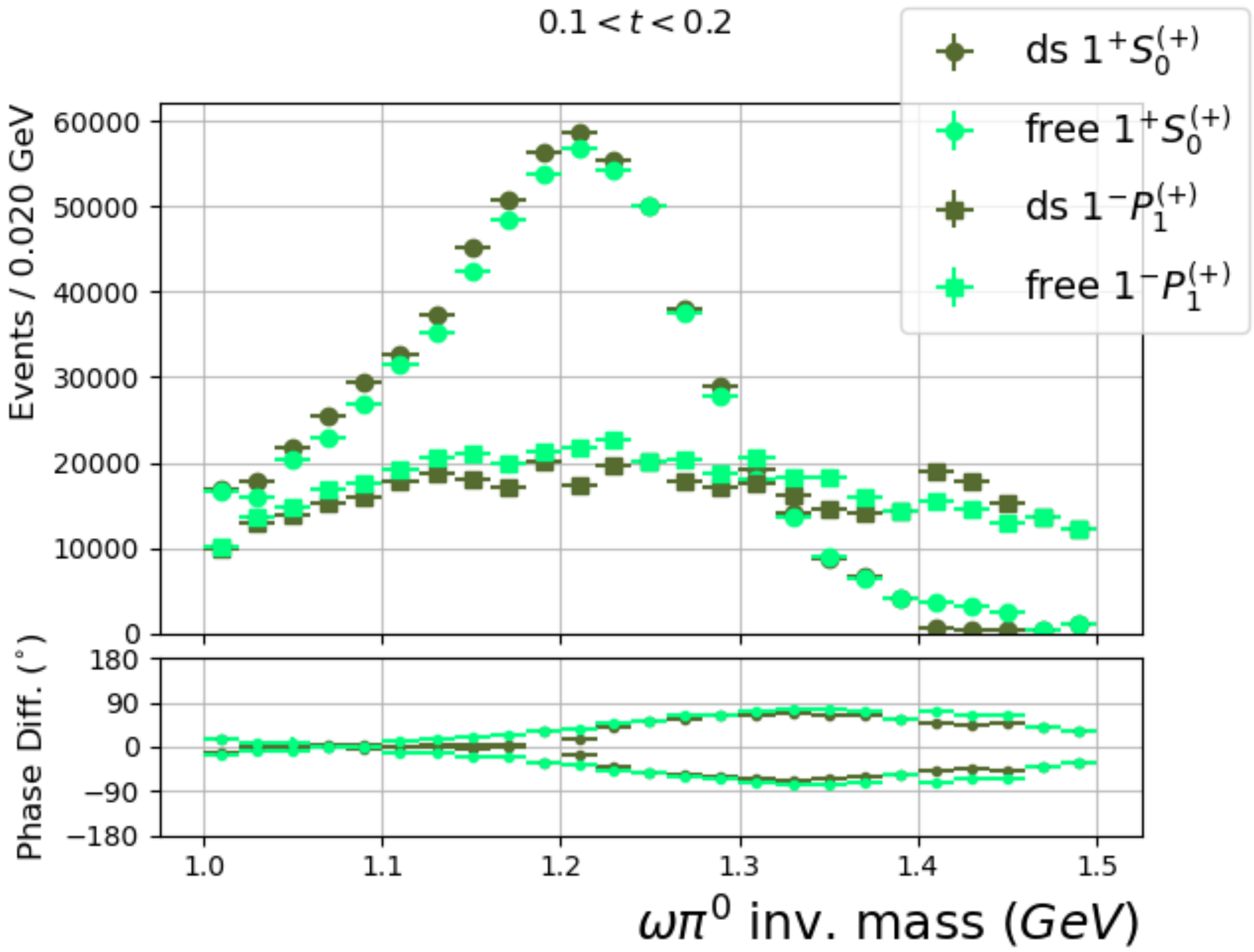
Compare the effects without the cut, and enforcing $M_{p\pi^0} > 1.4\ GeV$

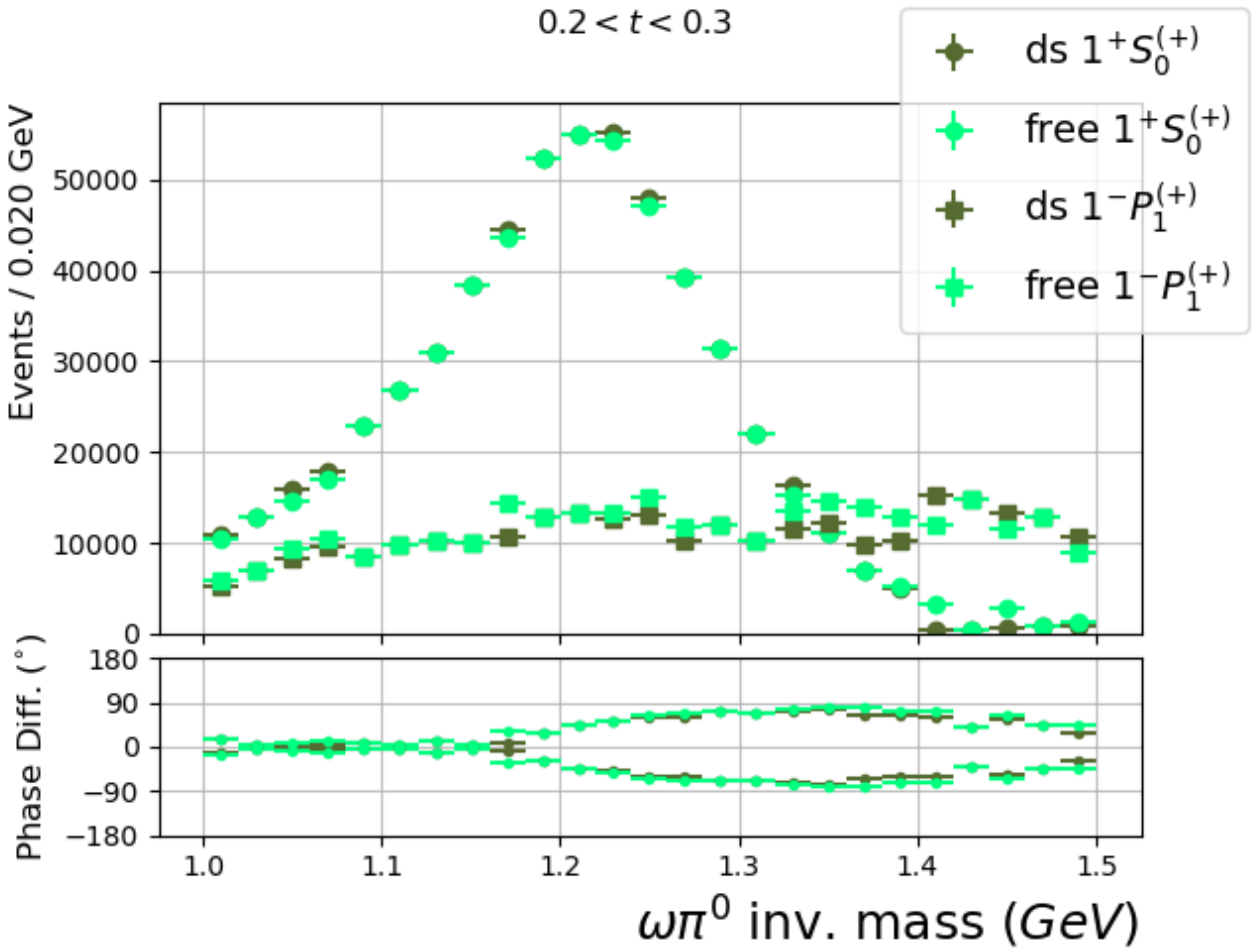


Back to Index Slide

BACKUP: D/S Constraint Comparison

Compare the effects with the constraint, and without

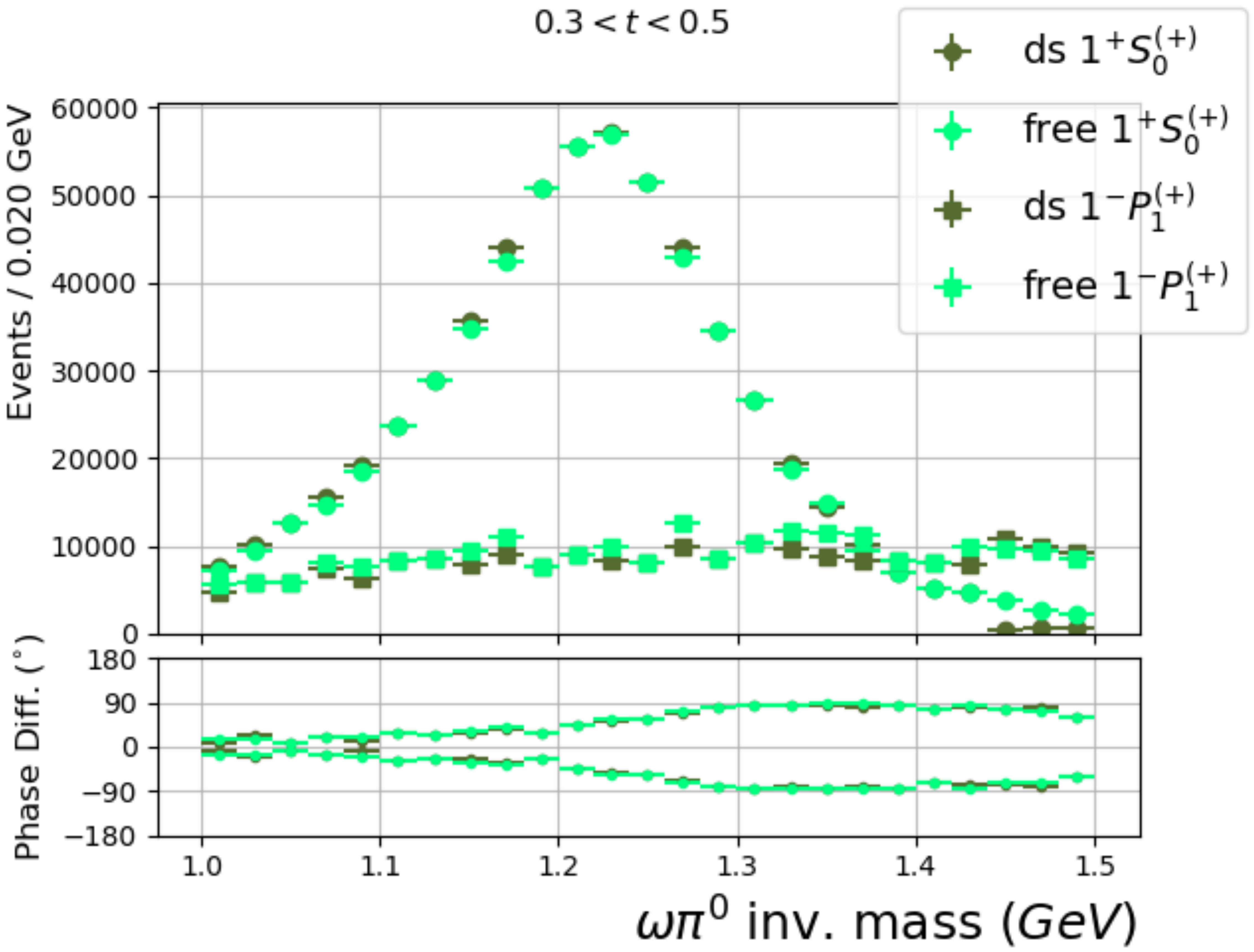


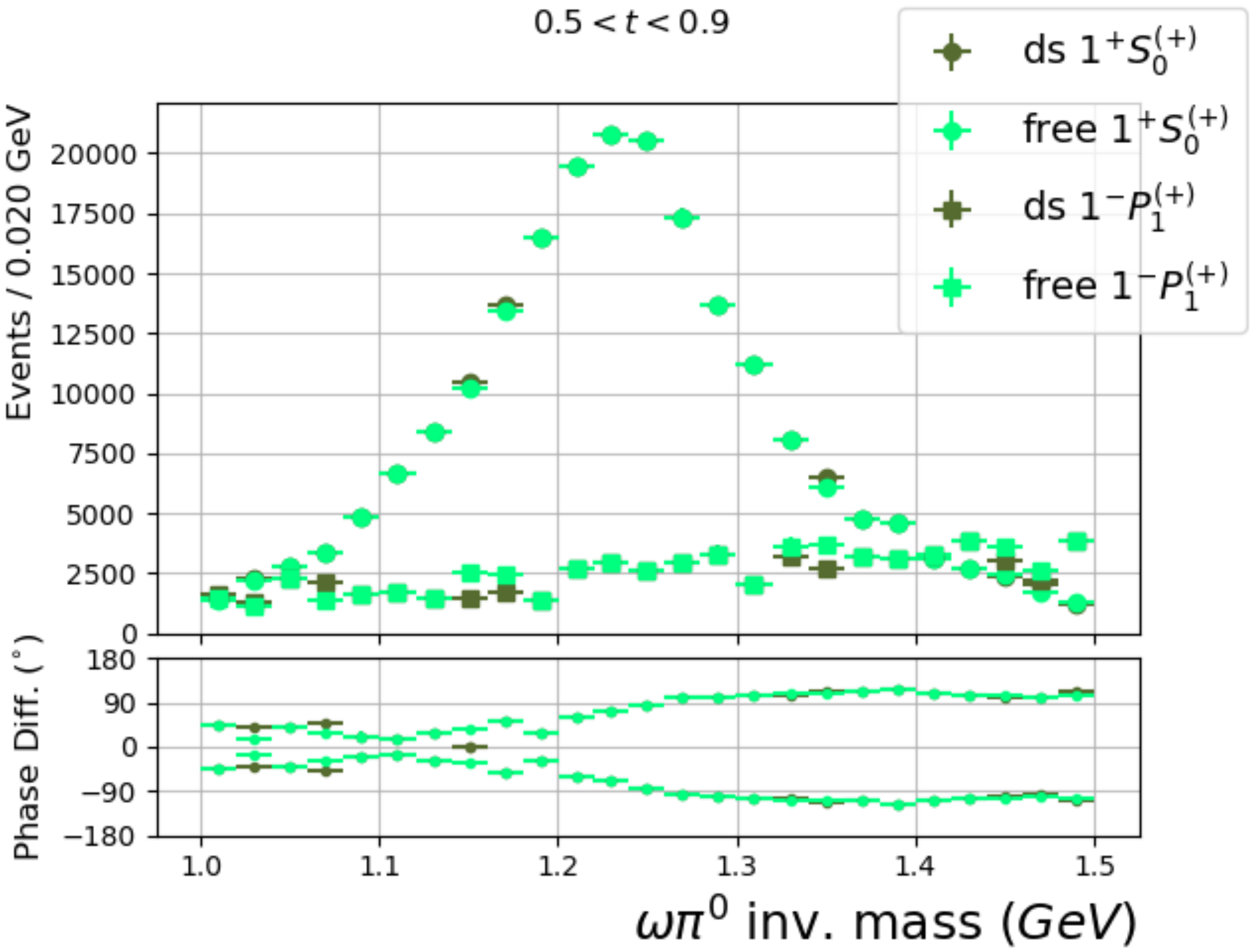


Back to Index Slide

BACKUP: D/S Constraint Comparison

Compare the effects with the constraint, and without





Back to Index Slide