

# Search for Exotic Mesons in Photoproduction at JLAB CLAS



Paul Eugenio  
Florida State University  
Tallahassee, FL USA



**ATHOS12**

Camogli, Italy  
June 19-22 2012

New Partial Wave ANALYSIS TOOLS  
FOR NEXT GENERATION HADRON  
SPECTRSCOPY EXPERIMENTS

# CLAS g12 Run Summary

CLAS geometry optimized for peripheral production acceptance

$E_{e^-}$  5.715 GeV

g12 run period      70 days experimental run

## Production Data

$I = 60\text{-}65$  nA

$E_{\gamma} = 3.584 - 5.453$  GeV

26.2 Billion events

mixed triggers

$68$  pb<sup>-1</sup>

## Hadron Spectroscopy Analyses

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

$\gamma p \rightarrow p \pi^- \pi^+ \pi^0$

$\gamma p \rightarrow p K^+ K^- \eta$

$\gamma p \rightarrow \Delta^{++} \pi^- \eta$

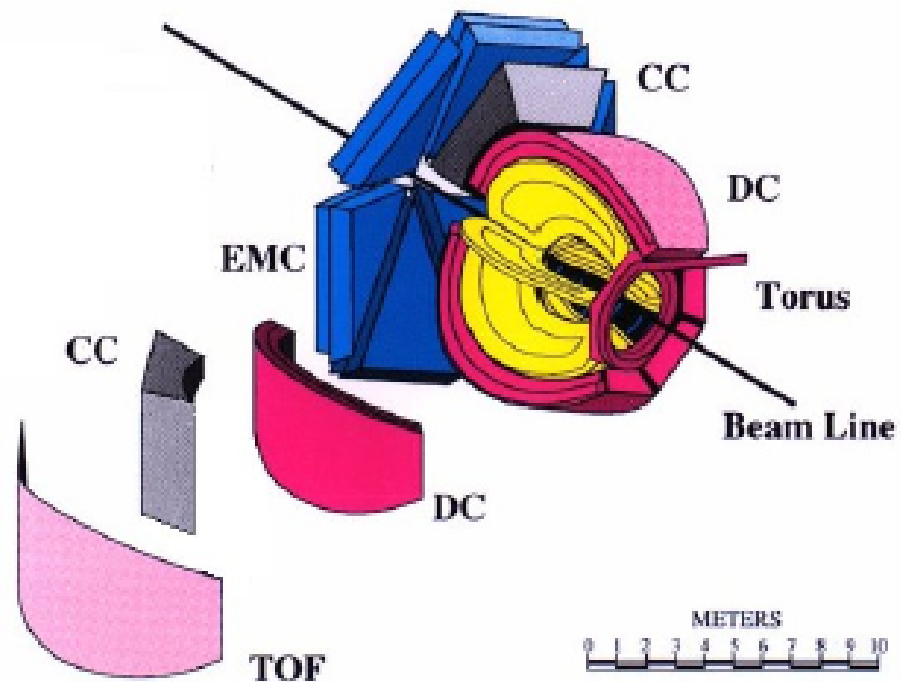
$\gamma p \rightarrow \Delta^{++} \pi^- \pi^+ \pi^+$

$\gamma p \rightarrow \Lambda K^+ \pi^- \pi^+$

$\gamma p \rightarrow \Xi^{*-} K^+ K^+$

$\gamma p \rightarrow p p \text{ anti-}p$

+ ...



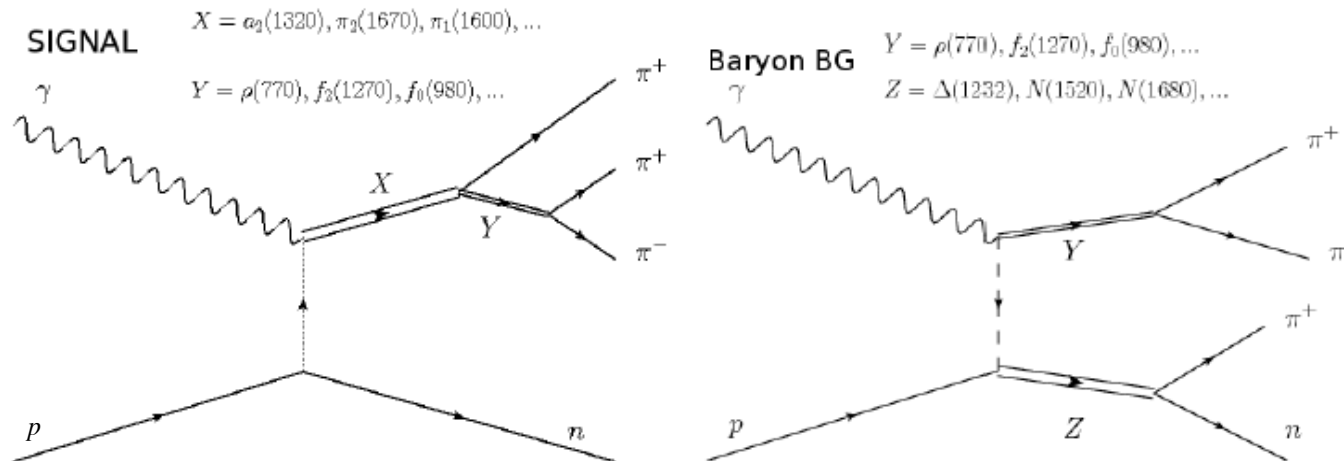
# Analysis of $\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$ \*

## 3 $\pi$ Event Selection

\*FSU dissertation by *Craig Bookwalter*

### Identification of $\gamma p \rightarrow \pi^+ \pi^+ \pi^- n$ events

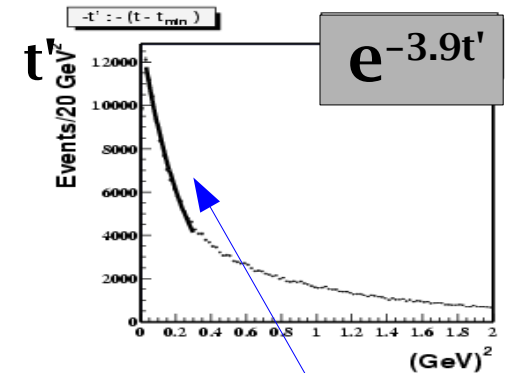
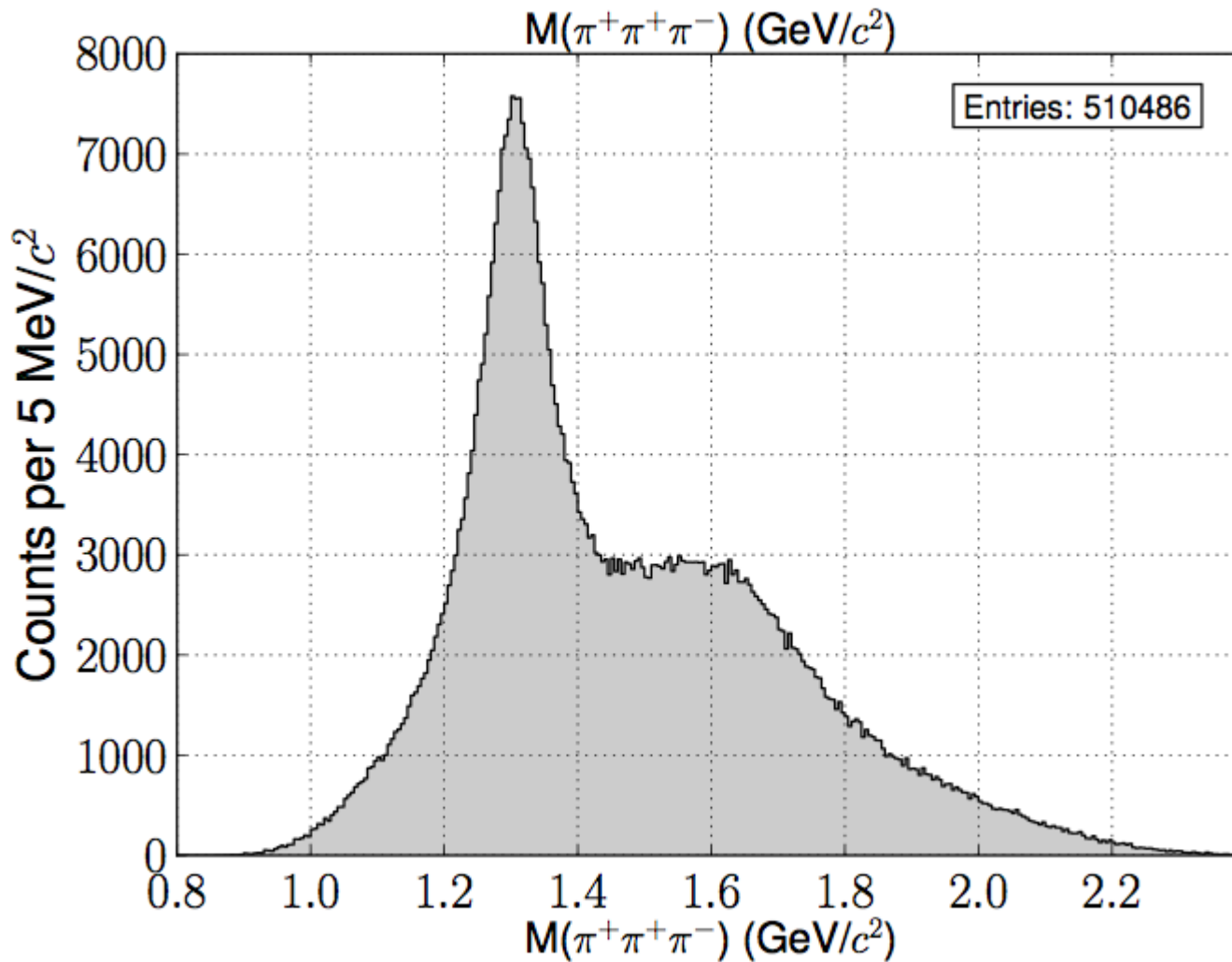
- $\pi^+ \pi^+ \pi^-$  events isolated by vertex and timing cuts
- neutron identified by missing mass



### Identification of $\gamma p \rightarrow Xn \rightarrow \pi^+ \pi^+ \pi^- n$ events

- $\gamma p \rightarrow N^* \pi \pi$  events removed by requiring low- $t'$  and small  $\theta_{lab}$  for both  $\pi^+$

# 3 $\pi$ Invariant Mass



Sharp  $t$  dependence  
consistent with  
 $\pi$ -exchange production

Baryon background cuts:  $|t'| < 0.1$  &  $\theta_{lab}(\pi^+) < 25^\circ$

# PWA wave set

## Major waves

$J^{PC}$	$M^\epsilon$	$L$	$Y$	# waves
$1^{++}$	$1^\pm$	$S$	$\rho(770)$	2
$1^{++}$	$1^\pm, 0^+$	$D$	$\rho(770)$	3
$1^{-+}$	$0^-, 1^\pm$	$P$	$\rho(770)$	3
$2^{++}$	$1^\pm$	$D$	$\rho(770)$	2
$2^{-+}$	$0^-, 1^\pm$	$S, P, D$	$f_2(1270), \rho(770)$	9

+ isotropic background wave

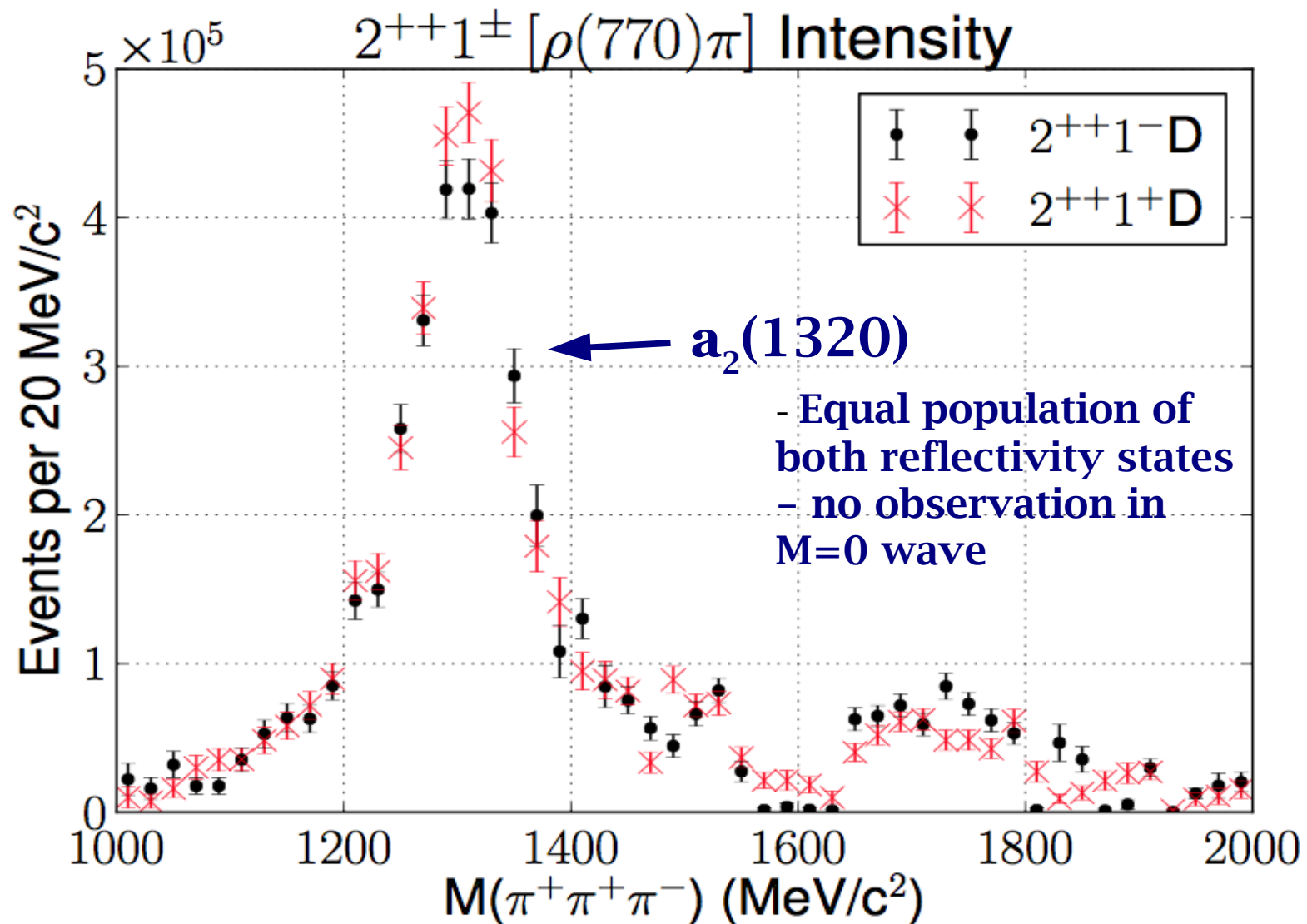
## unpolarized beam

- Photon beam is a coherent mixture of both parity eigenstates
- Final states of different reflectivity do not interfere

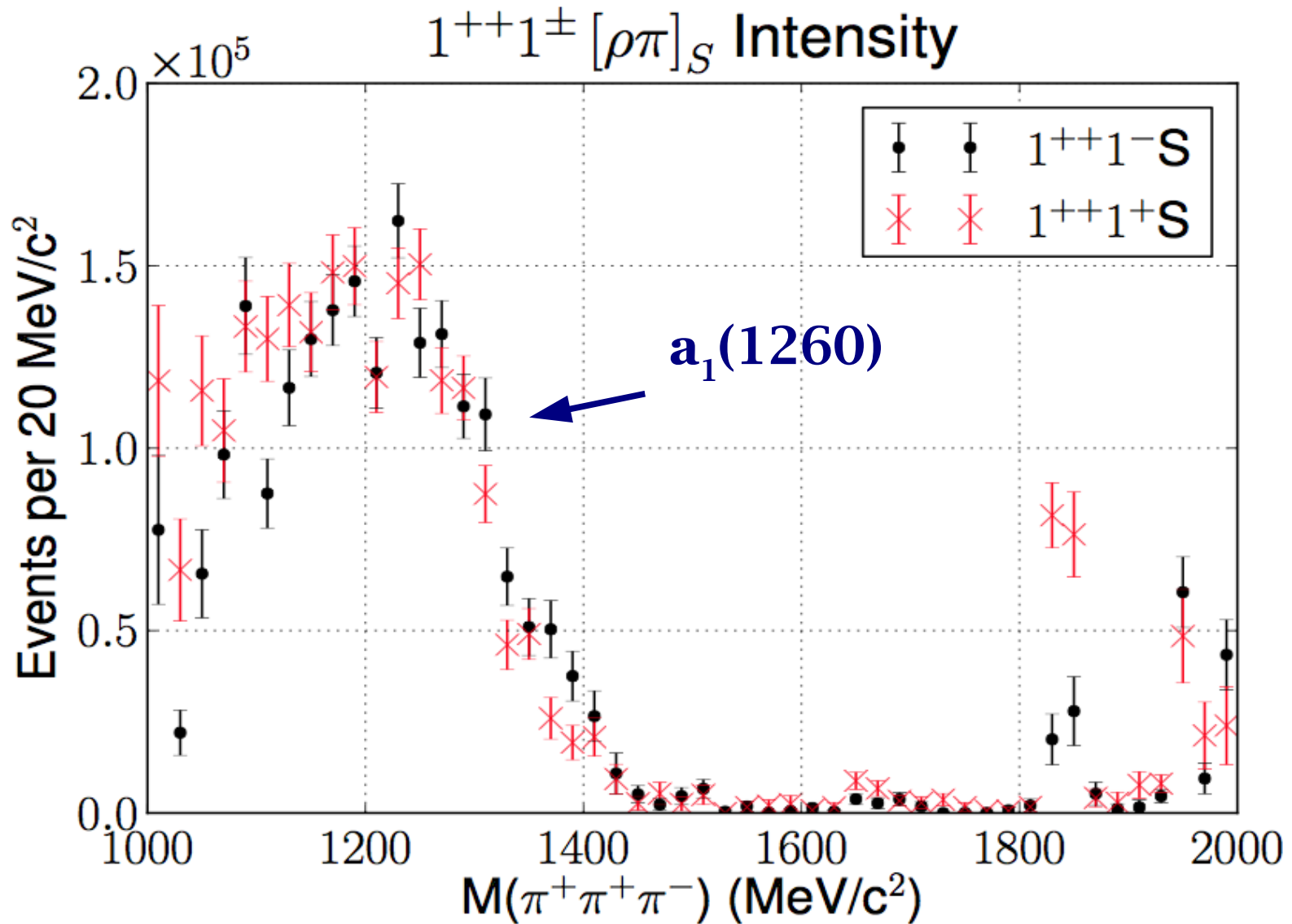
## $\pi$ exchange dominance

- Equal production of  $M^\epsilon = 1^+$  and  $1^-$  (ambiguity)
- No  $M^\epsilon = 0^\epsilon$ 
  - No  $J=0$  meson production (spin zero filter)

# PWA 2++

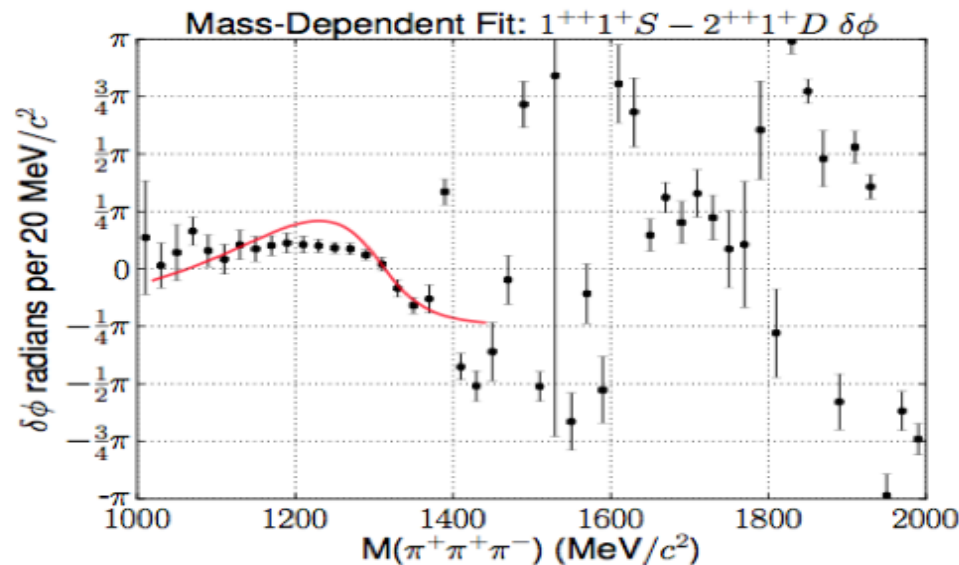
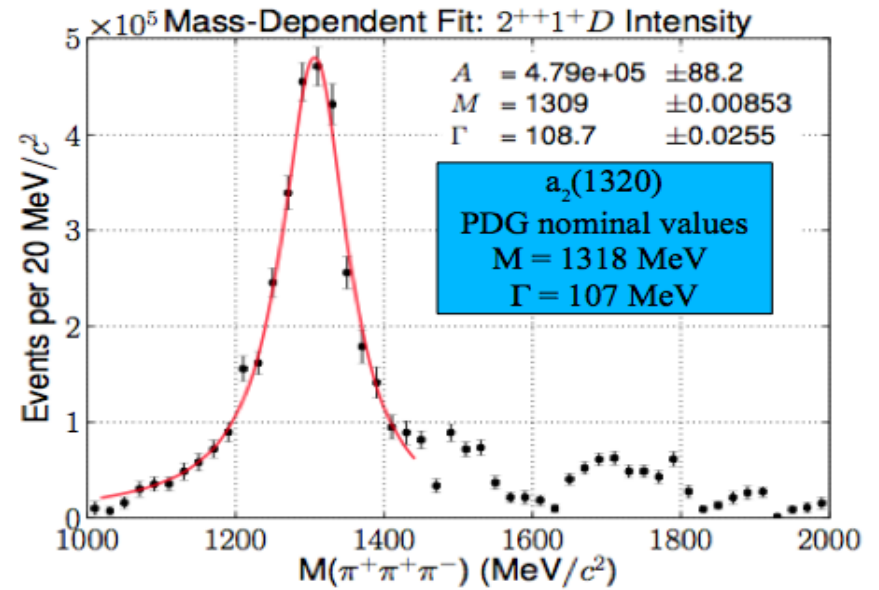
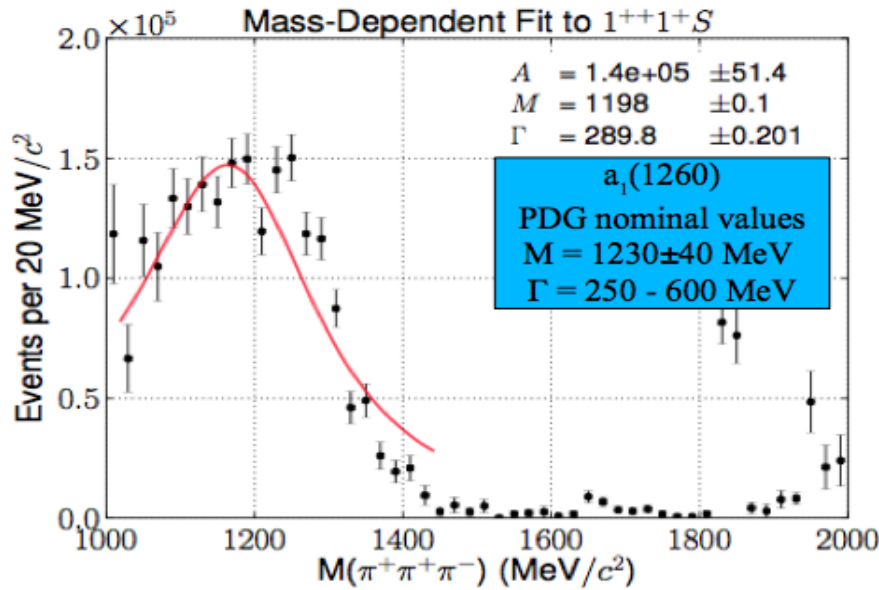


# PWA $1^{++}S$ wave



*preliminary*

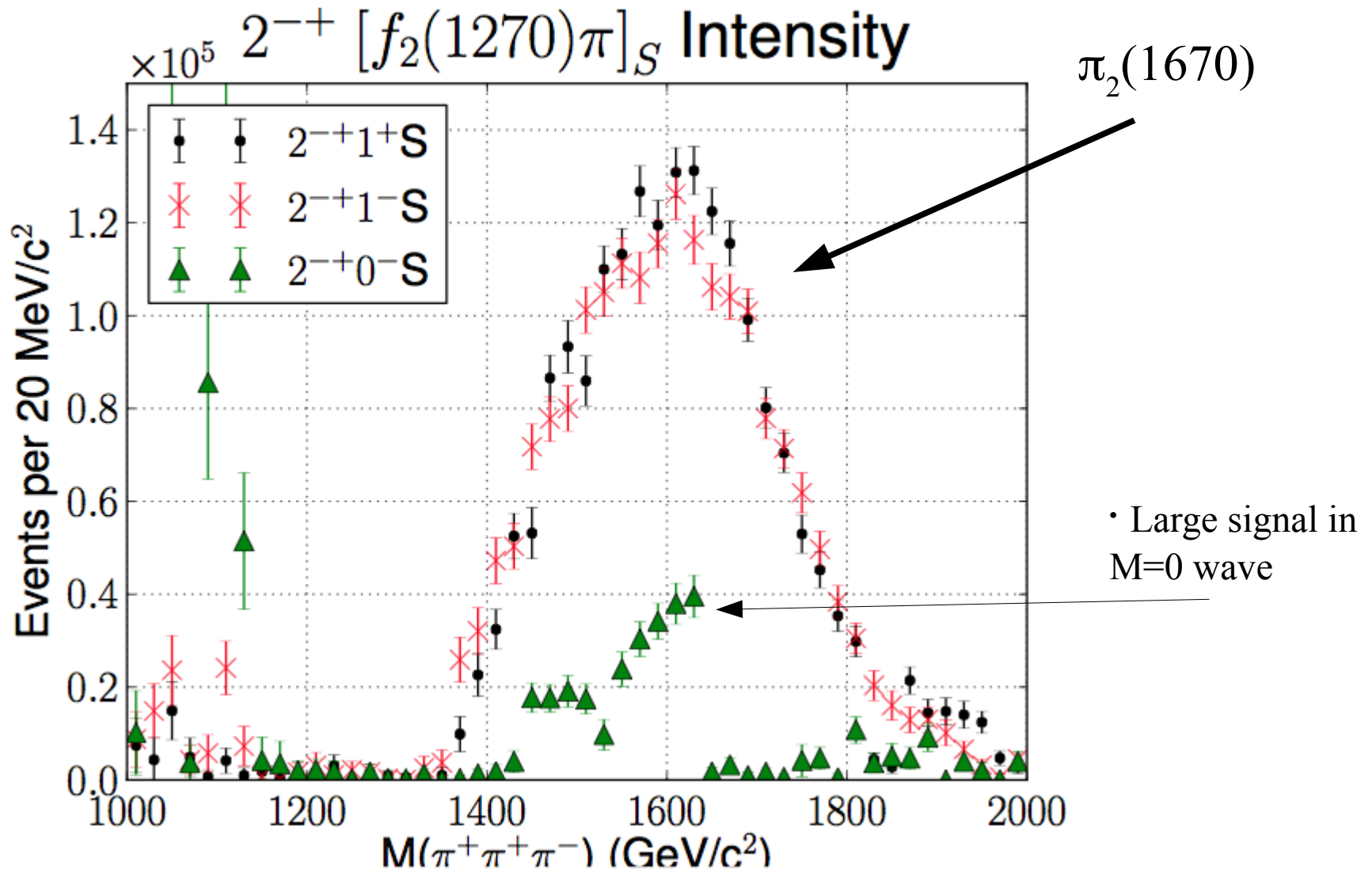
# PWA: $1^{++} - 2^{++}$ Mass Dependency



*preliminary*

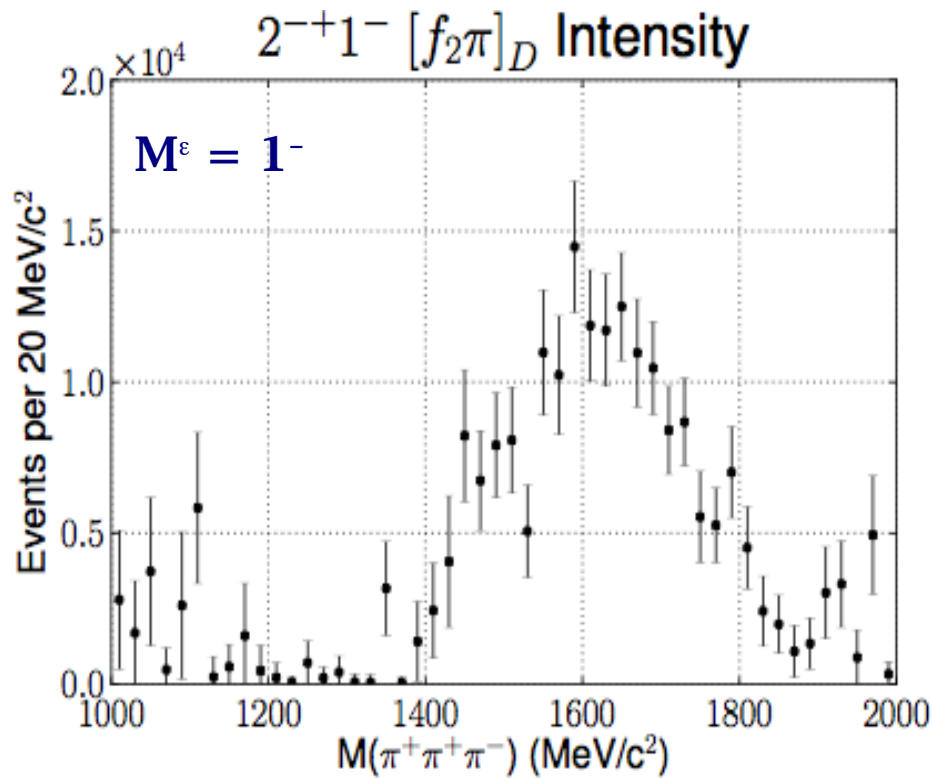


# PWA: $2^{-+} f_2\pi$ S-waves

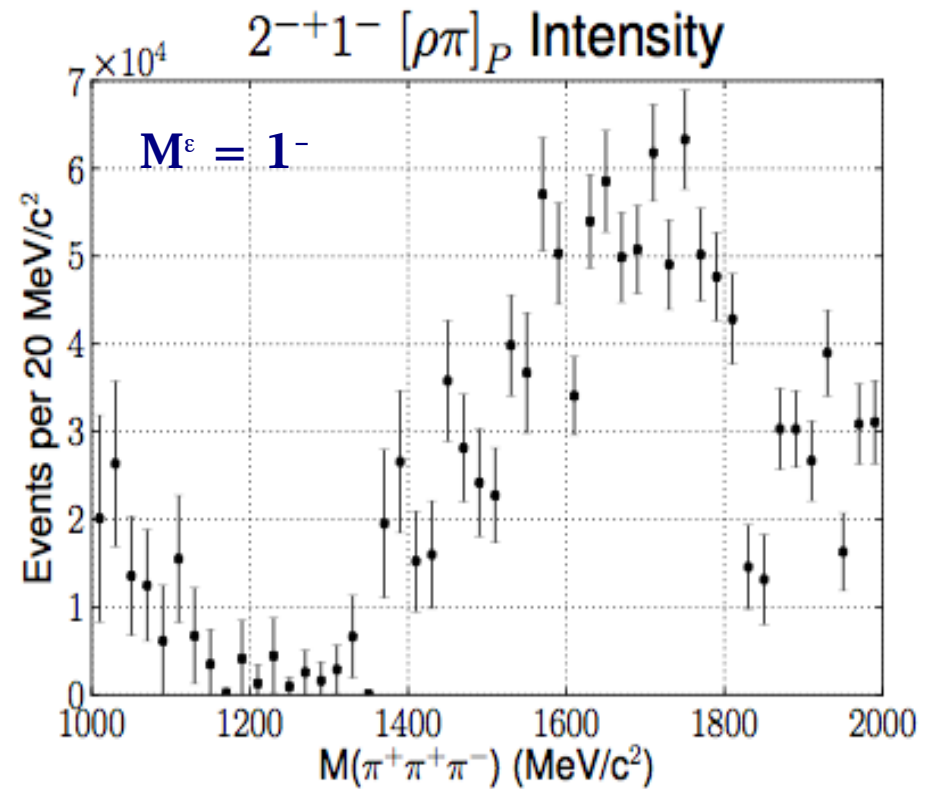


# PWA: 2-+ D & P waves

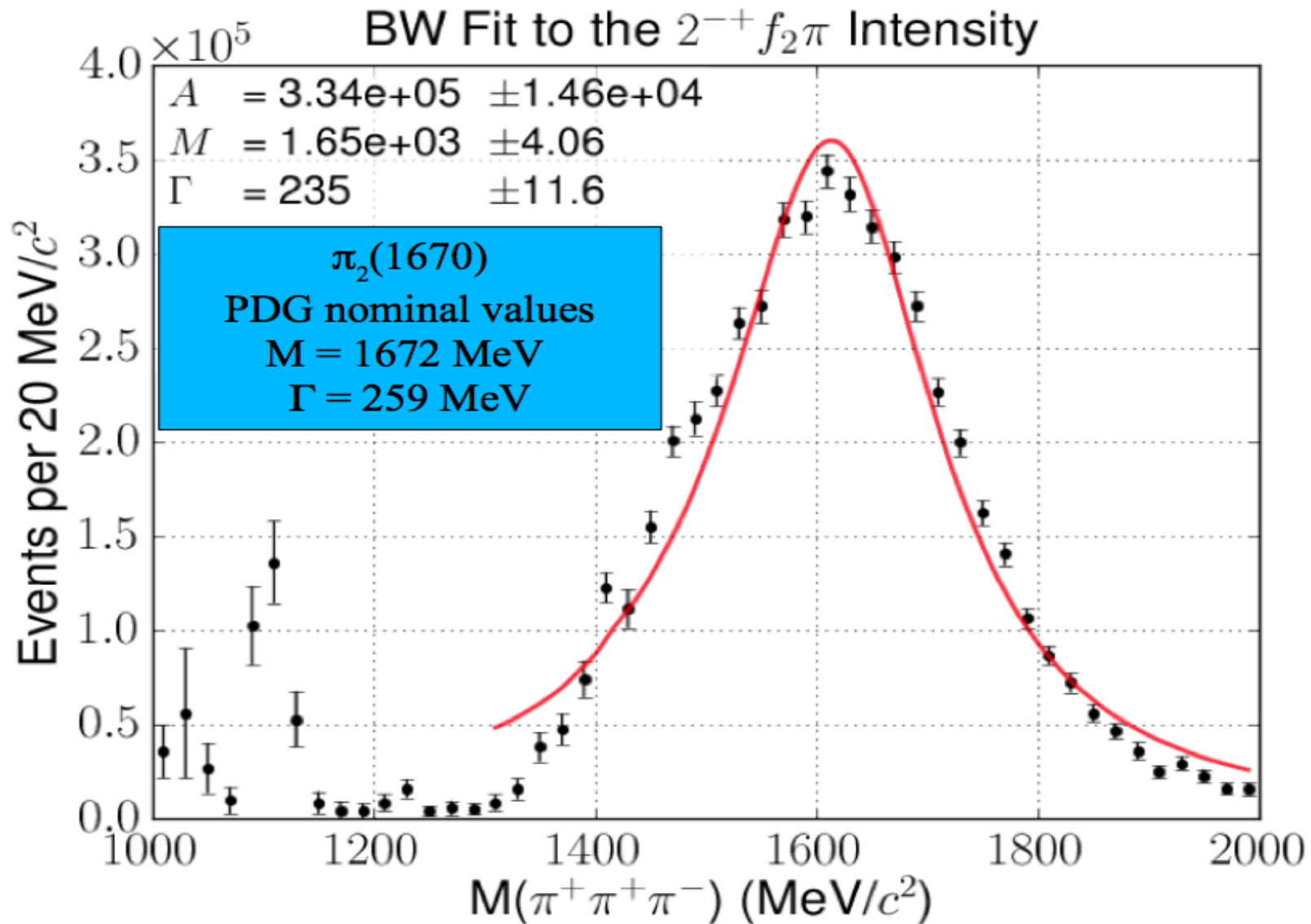
$\pi_2(1670) \rightarrow f_2\pi$   
D-wave



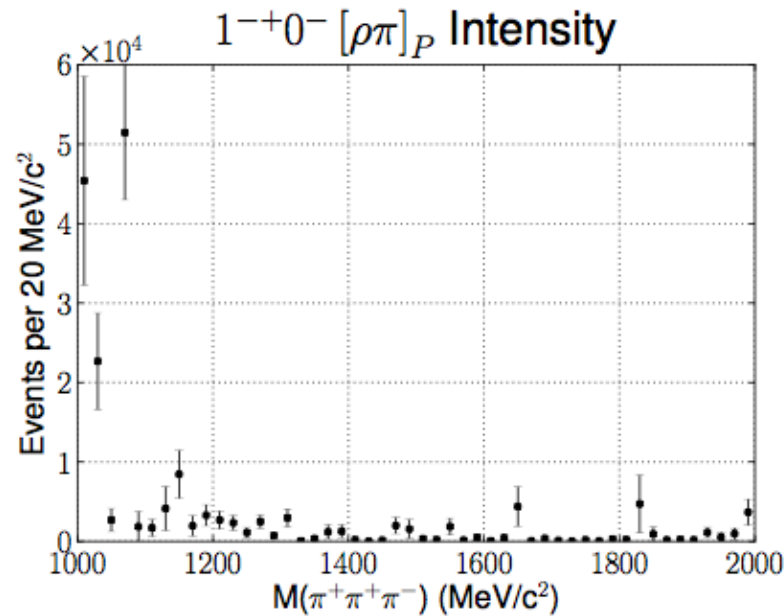
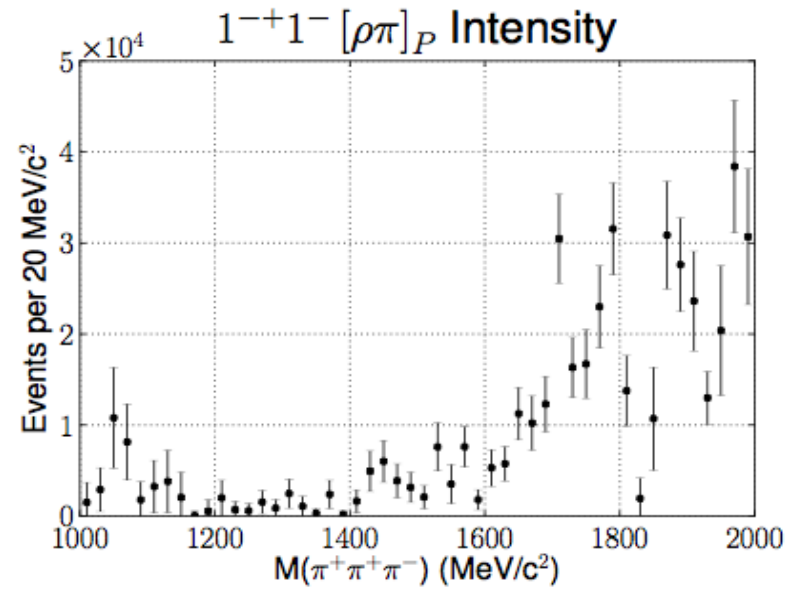
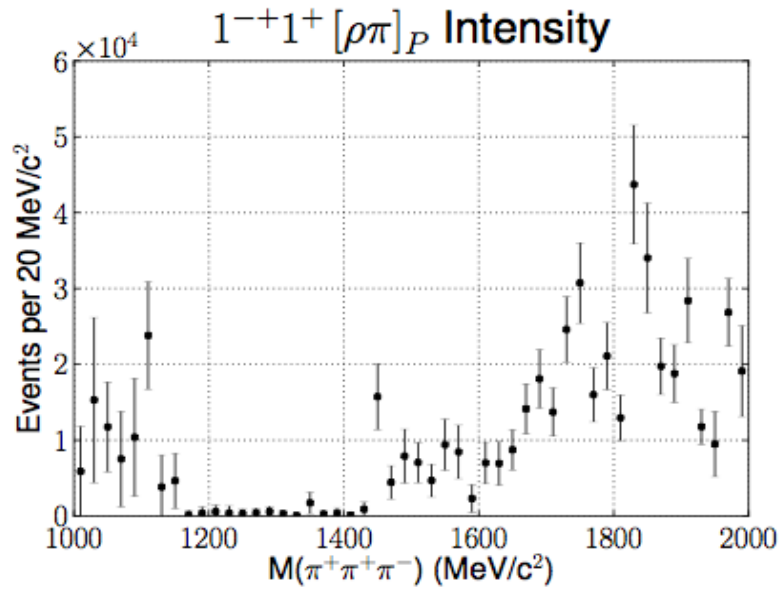
$\pi_2(1670) \rightarrow \rho\pi$   
P-wave



# PWA 2-+ Intensity



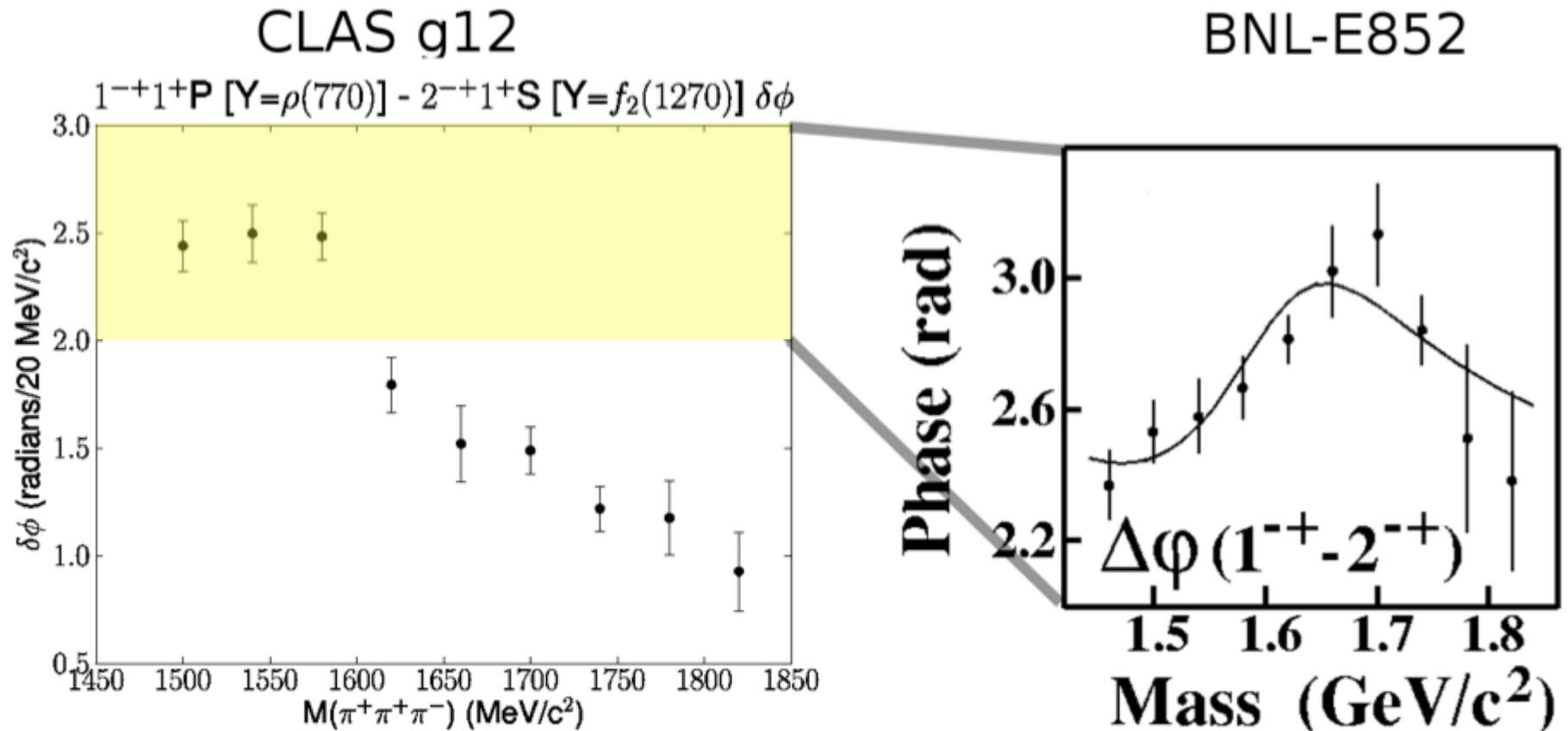
# PWA 1-+ Exotic Wave



- No clear resonance signal
- High mass results fluctuate
- Accounts for at most 2% of total intensity

*preliminary*

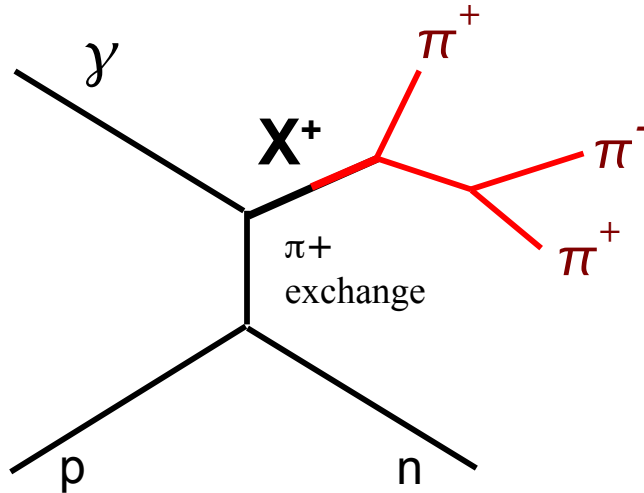
# PWA $1^-+ - 2^-+$ phase motion



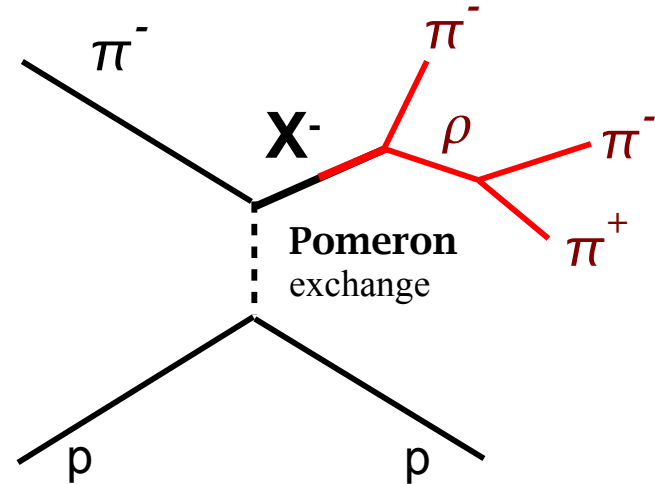
- **No evidence for exotic  $1^-+$  phase motion**
- **Phase motion consistent with resonating  $2^-+$**

# Where is the $\pi_1(1600)$ in photoproduction?

Current CLAS g12 analysis



$\pi$  production analysis



Also observed via:  $X^- \rightarrow \eta'\pi^-, f_1\pi^-, (b_1\pi)^-$

Non-observation of  $\pi_1(1600)$  in charge exchange photoproduction is consistent with exotic production via Pomeron

however,  $\pi_1(1600) \rightarrow \rho\pi$  but not  $\rho\pi \rightarrow \pi_1(1600)$

**If true then C-Parity forbids photoproduction of  $\pi_1(1600)$**

Allowed  $J^{PC}$ :

[S,P, D wave pomeron production]

1--, **0+-**, 1+-, **2+-**, 1--, 2--, 3--

*exotic*

Isovector  $G = +1$  channels:

$2\pi, 2\pi\eta, ..$

Isoscalar  $G = -1$  channels:

$\pi\eta, \pi\eta\eta, \mathbf{3\pi}, 3\pi\eta, ..$

# Conclusions

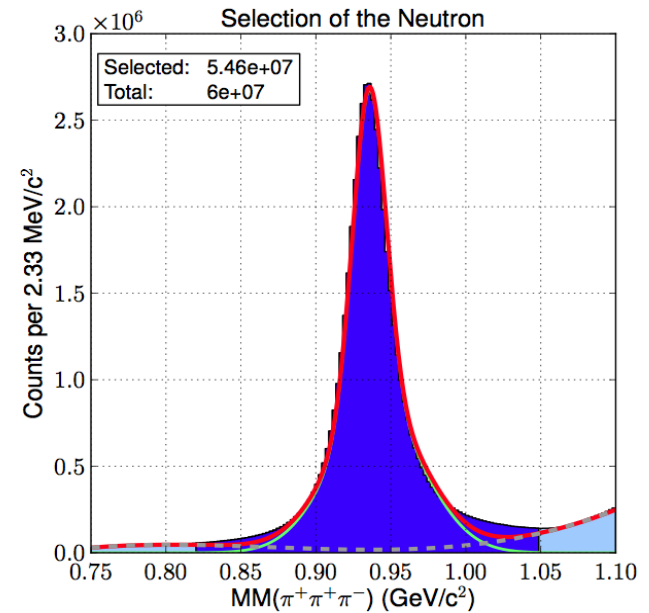
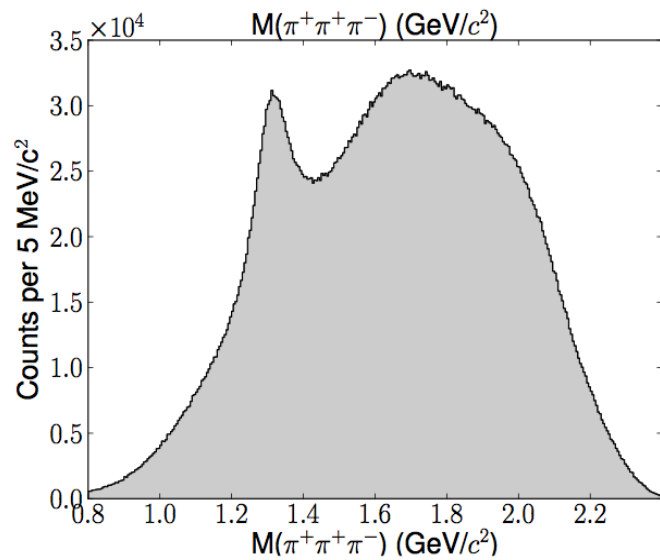
- CLAS-g12 acquired new data set of  $\sim 1\text{M}$  exclusive  $\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$  events
- Performed mass independent PWA from 1.0 – 2.0 GeV/c<sup>2</sup> on several subset of events
  - Unpolarized photon beam with pion exchange dominance (low  $t'$  cut)
    - $J = 0$  and  $M = 0$  suppression, equal production of  $M^\epsilon = 1^+ \& 1^-$
- Cleanly observe  $1^{++}$ ,  $2^{++}$ , and  $2^{-+}$  well known resonance features
  - Narrow  $1^{++}$  may indicate a Deck free  $a_1(1260)$  observation
- $\pi_1(1600)$  exotic signal is not observed in charged exchanged photoproduction
  - If  $\pi_1(1600) \rightarrow \rho\pi$  exists, then non-observation in charge exchange photoproduction is consistent with hybrid production via Pomeron
    - If true then C-Parity forbids photoproduction of  $\pi_1(1600)$



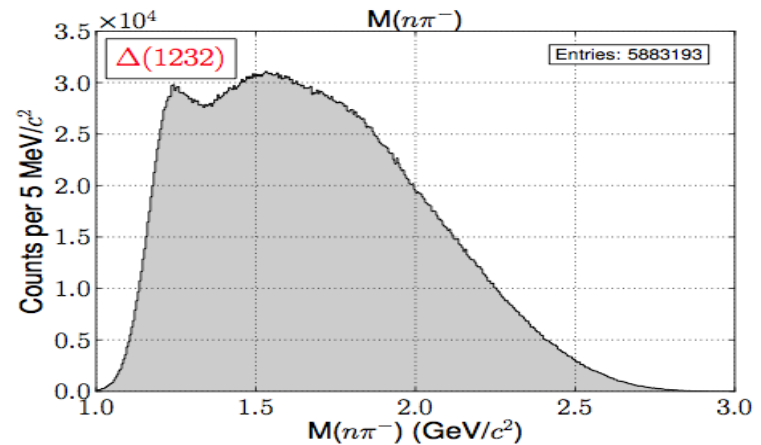
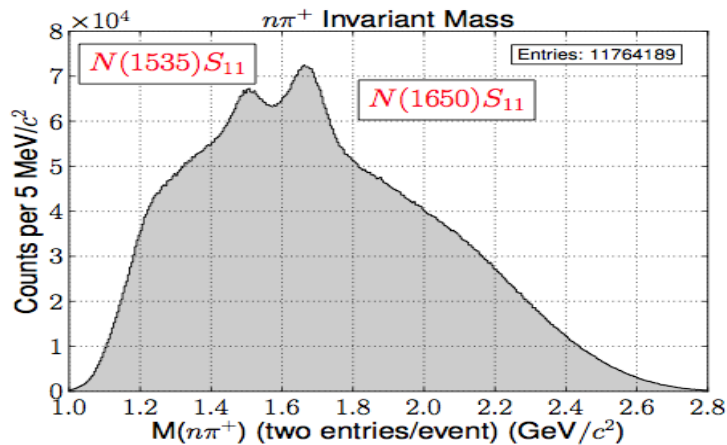


# 3 $\pi$ Data Features

*before final selections*



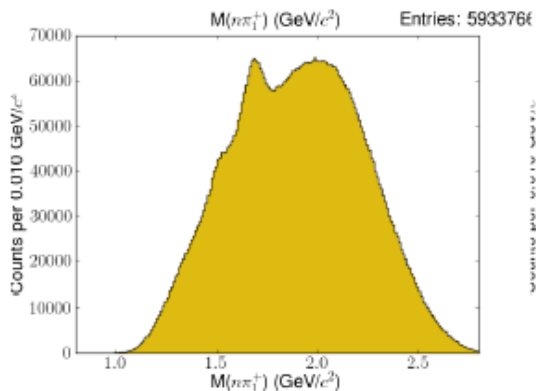
Copious baryon backgrounds present!



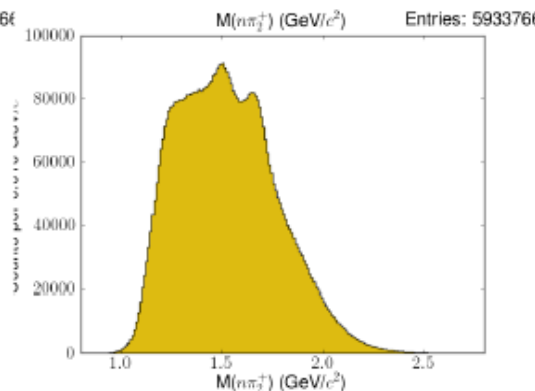
# Baryon background reduction

Before Selection

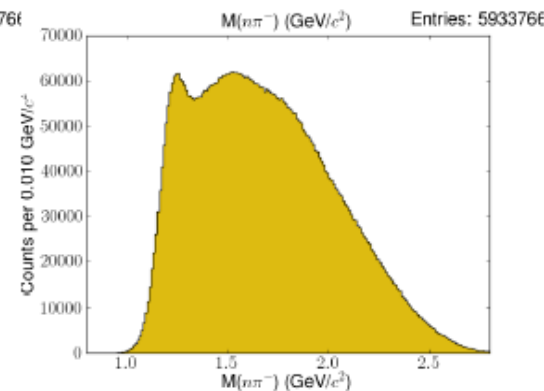
Mass( $n\pi^+_1$ )



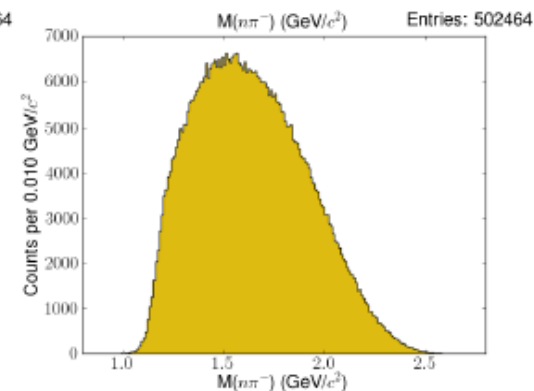
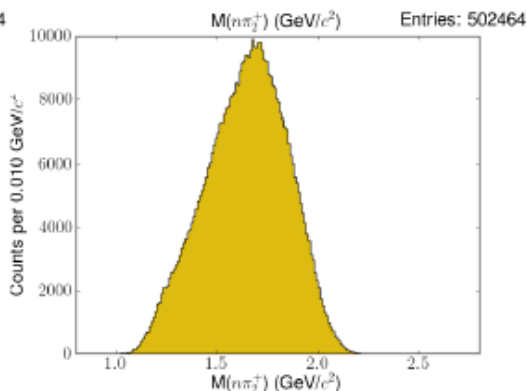
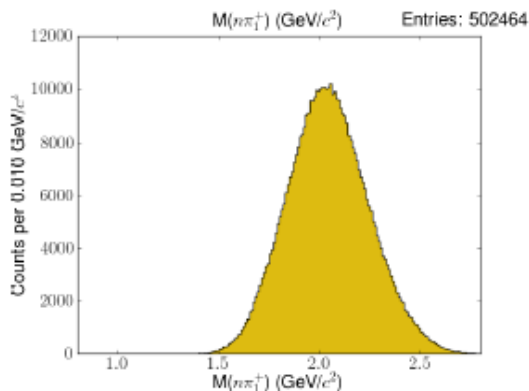
Mass( $n\pi^+_2$ )



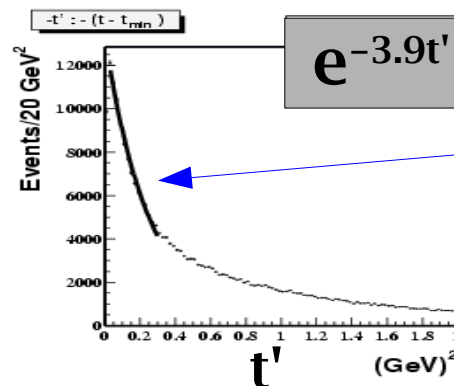
Mass( $n\pi^-$ )



After Selection



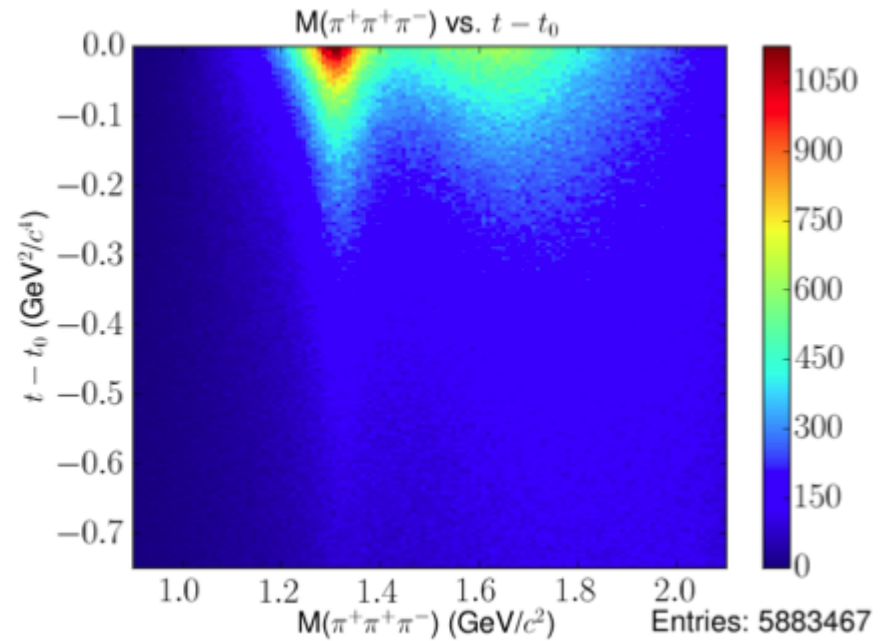
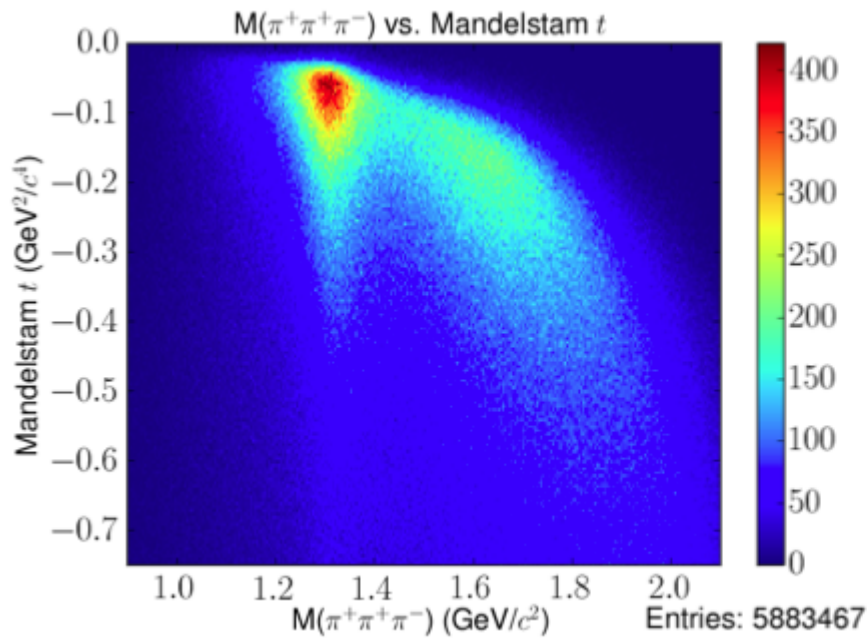
$|t'| < 0.105$   
 $\theta_{lab}(\pi^+) < 25^\circ$  (both)



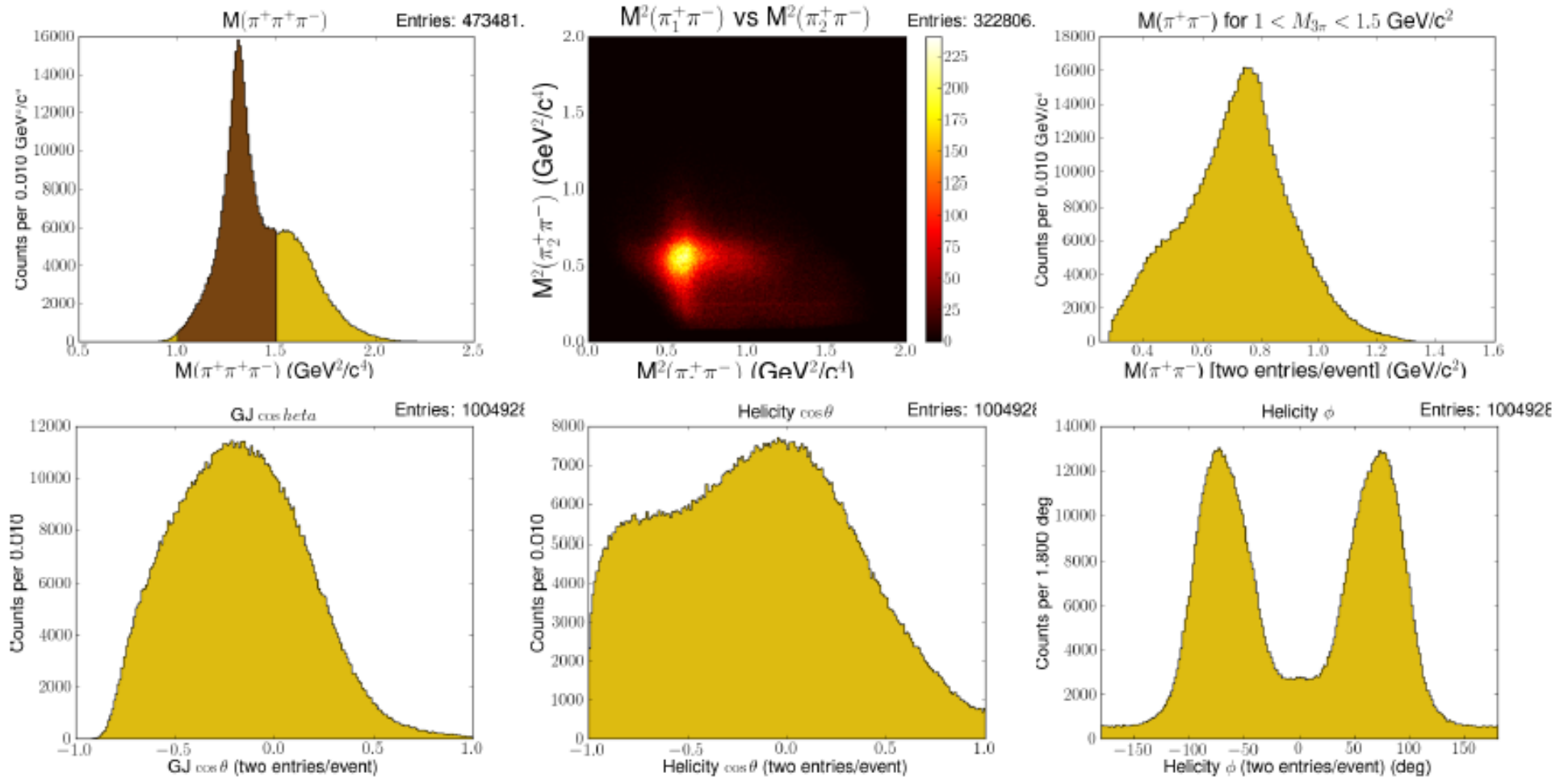
Sharp  $t$  dependence  
 consistent with  
 $\pi$ -exchange production

# Data Features

Mandelstam  $t$  &  $t'$

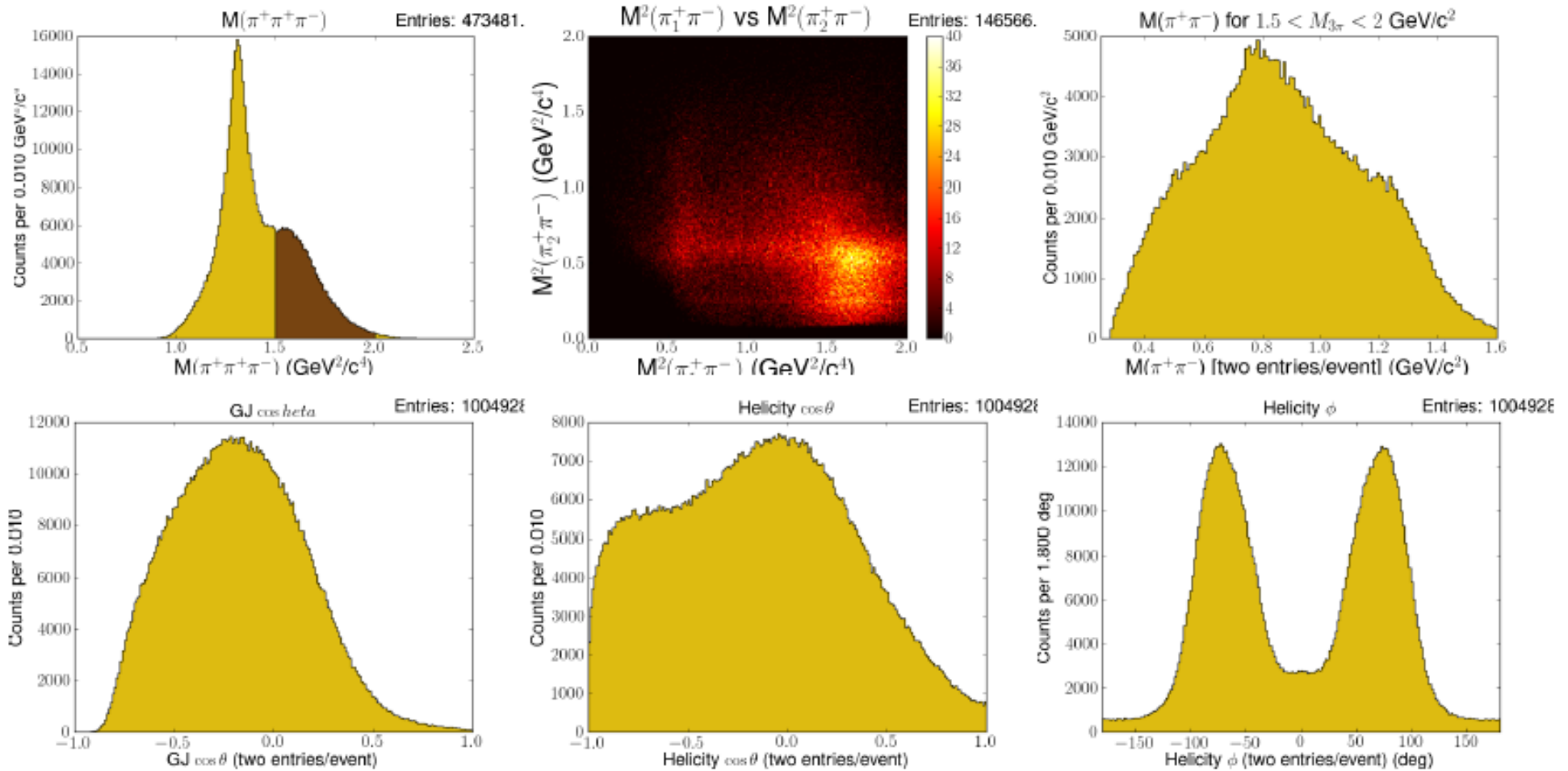


# Data Features



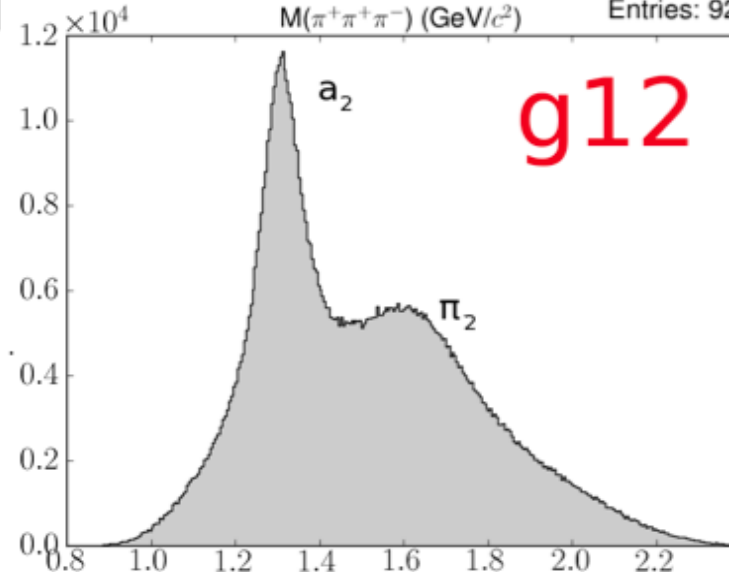
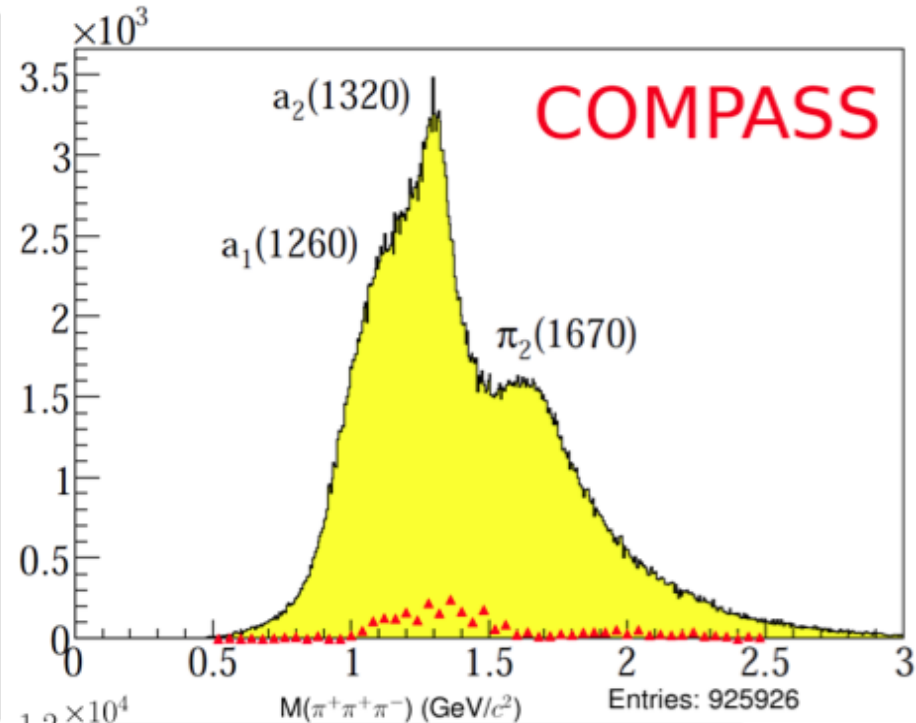
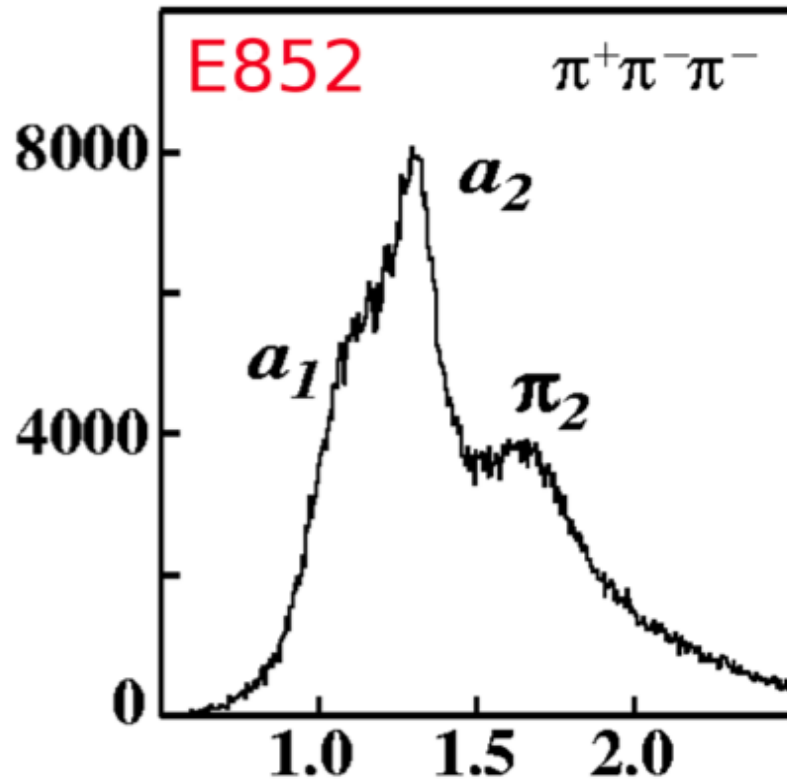
Accepted Yields

# Data Features

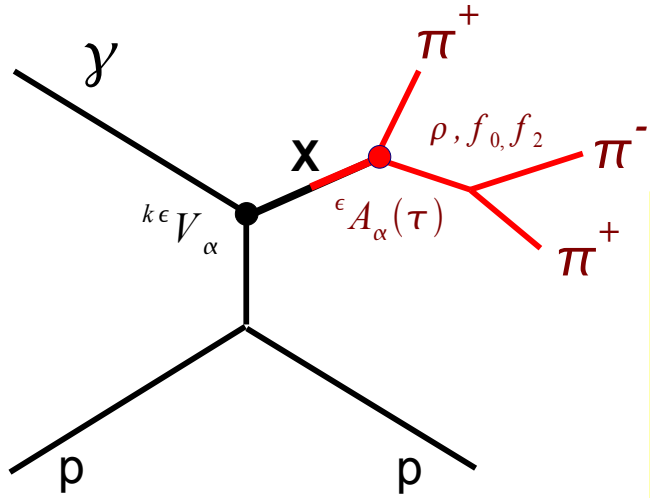


Accepted Yields

# $3\pi$ from other experiments



# Partial Wave Analysis



$$I(\tau) = \sum_{k \epsilon \epsilon'} \rho_{\epsilon \epsilon'}(\delta) \sum_{\alpha \alpha'} k \epsilon' V_{\alpha'}^* A_{\alpha'}^*(\tau) k \epsilon V_{\alpha}^{\epsilon} A_{\alpha}(\tau)$$

For unpolarized beam & target:

$$I(\tau) = \frac{1}{2} \sum_{k \epsilon} \left| \sum_{\alpha} k \epsilon V_{\alpha}^{\epsilon} A_{\alpha}(\tau) \right|^2$$

unknown

Complex parameters varied in the PWA to fit the data

## Helicity Decay Amplitudes

$$A_{\alpha, M}(\tau) = A_X^{\lambda_1 \lambda_2; M} * A_{iso}^{\nu_1 \nu_2; \lambda_1} \dots$$

$$A_X^{\lambda_1 \lambda_2; M} = D_{\lambda M}^J(\theta, \phi) \frac{\tilde{L}}{\tilde{J}} (L 0; S \lambda | J \lambda) (S_1 \lambda_1; S_2 - \lambda_2 | S \lambda) K$$

Wigner D-functions

Clebsch-Gordan Coefficients

Mass Dependent Isobar Propagator

$$\tilde{J} = \sqrt{J(J+1)}$$

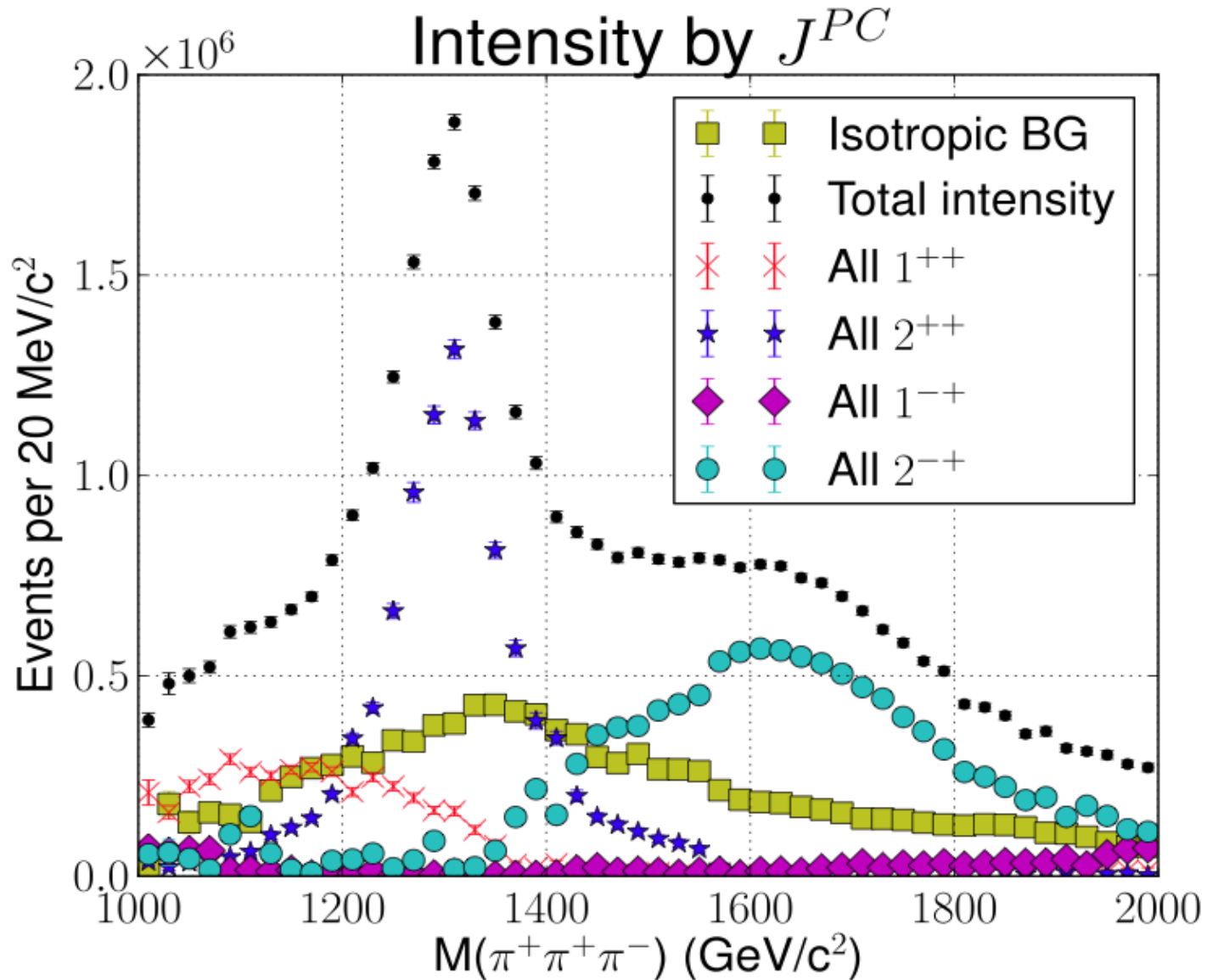
$$\rho_{\epsilon \epsilon'}(\delta) = \begin{pmatrix} \frac{1}{2}(1 - P(\cos^2(\delta) - \sin^2(\delta))) & P \cos(\delta) \sin(\delta) \\ P \cos(\delta) \sin(\delta) & \frac{1}{2}(1 + P(\cos^2(\delta) - \sin^2(\delta))) \end{pmatrix}$$

$\delta$  - angle between polarization vector and the normal to the production plane

$${}^{\epsilon} A_{\alpha}(\tau) = a [A_{\alpha, M}(\tau) \pm b A_{\alpha, -M}(\tau)]$$

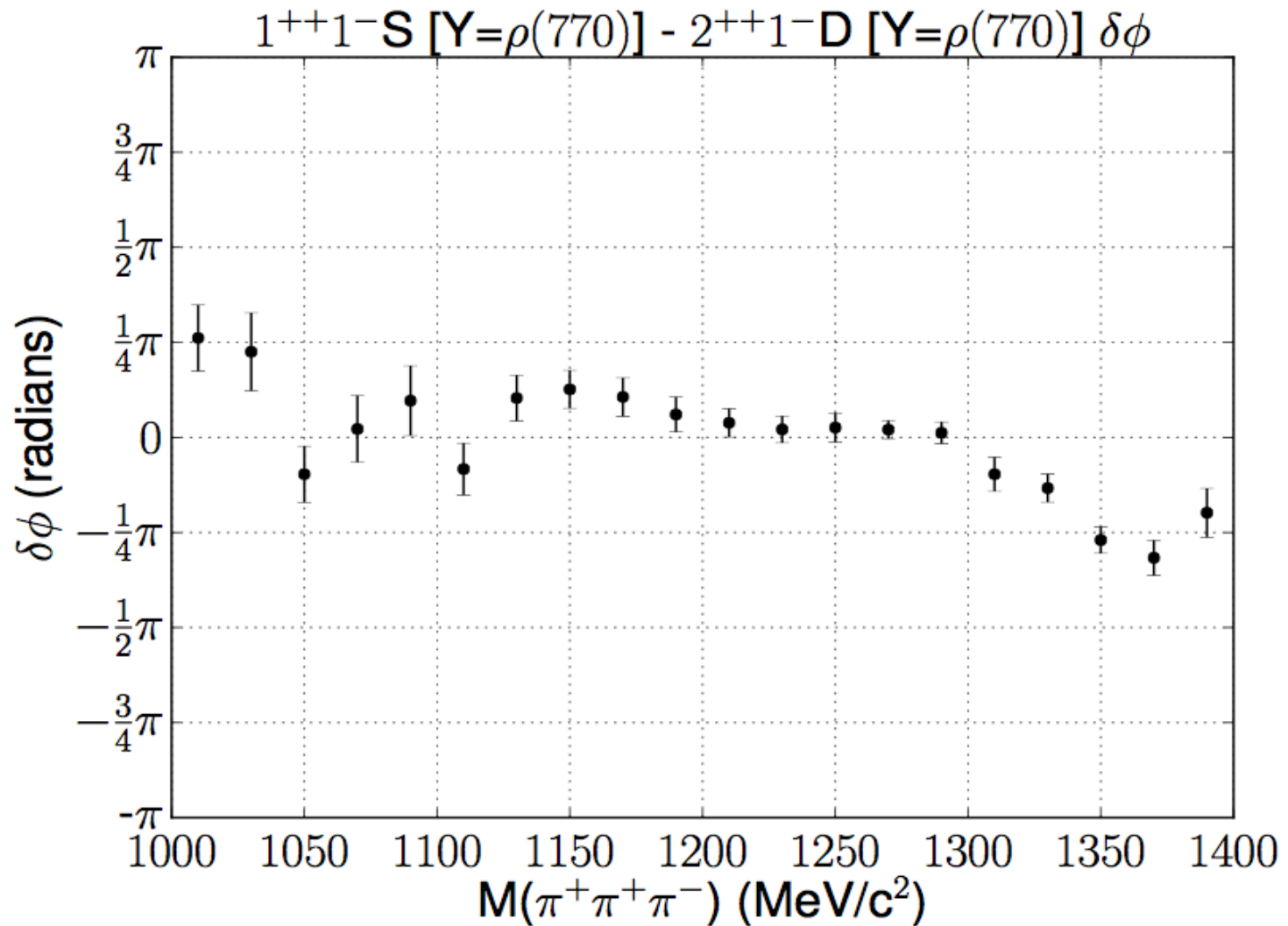
Helicity states are not eigenstate of parity

# Overview of PWA results

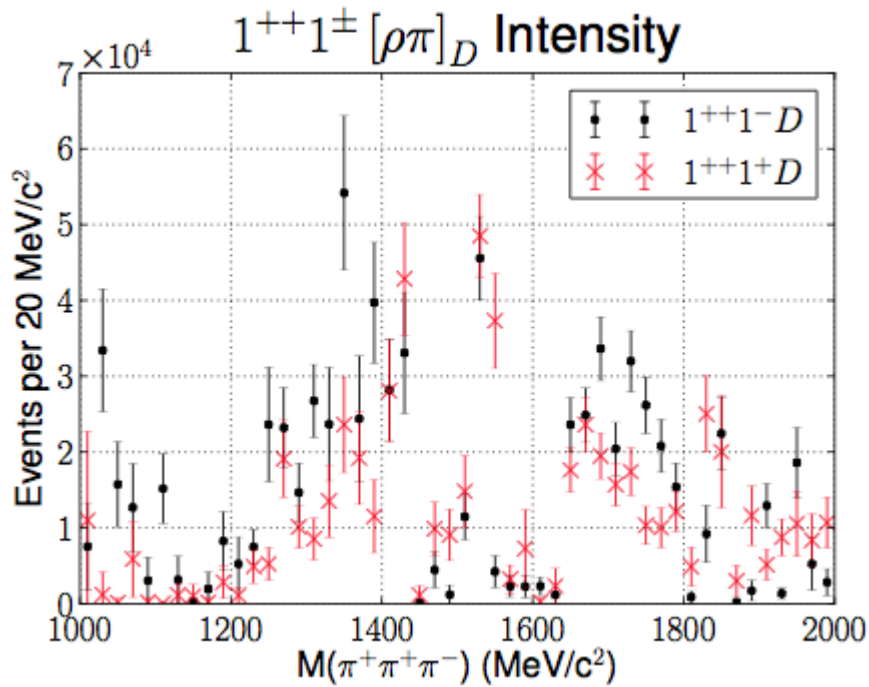




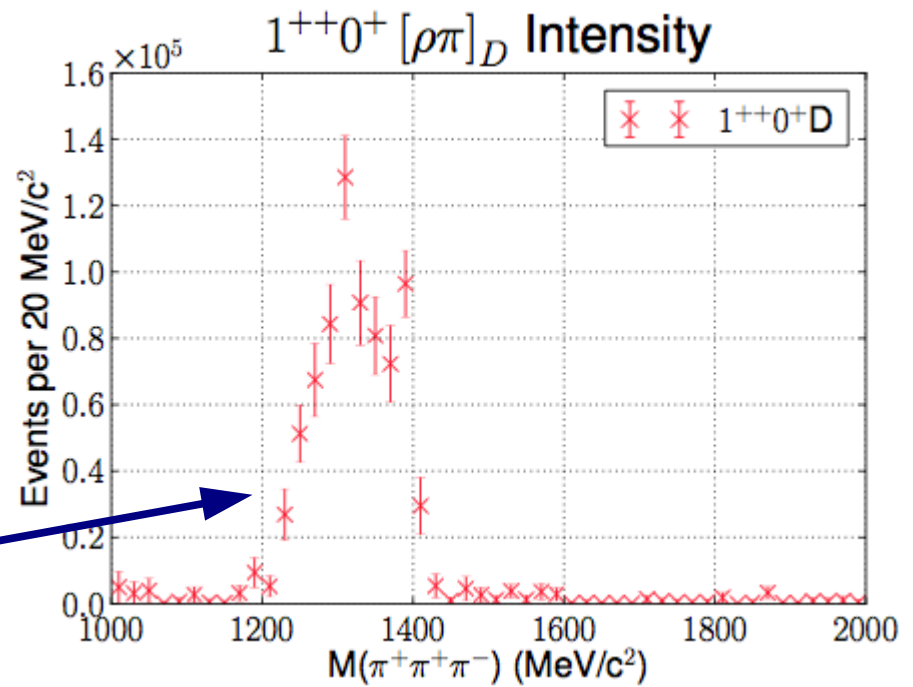
# PWA $1^{++} - 2^{++}$ phase motion



# PWA $1^{++} D$ waves

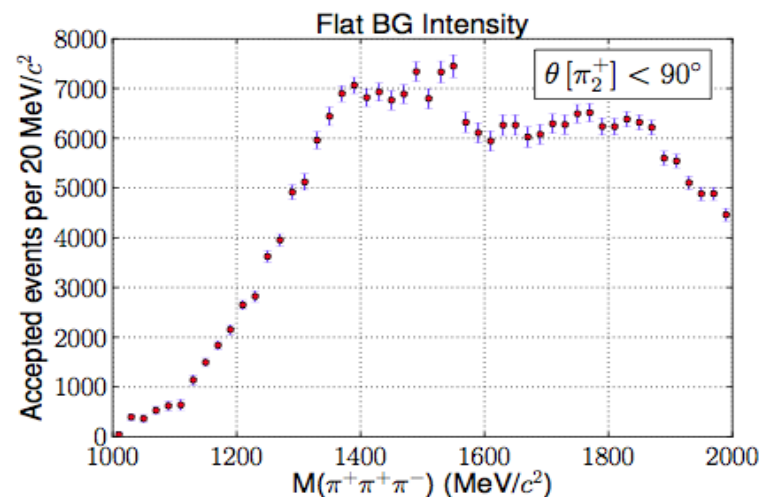
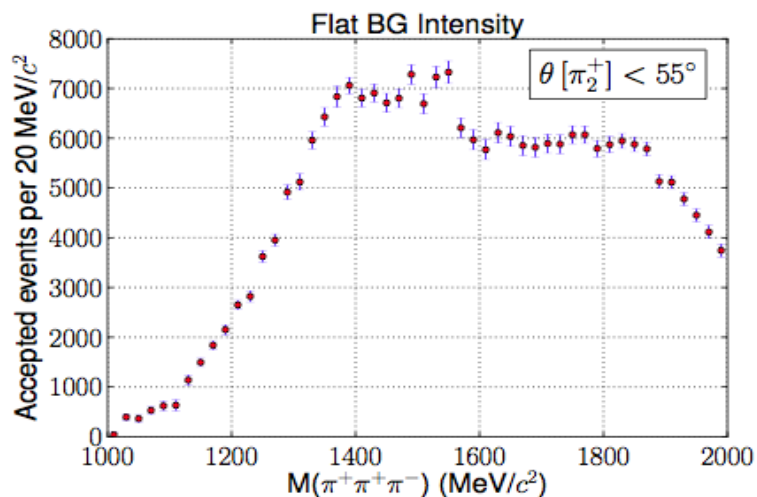
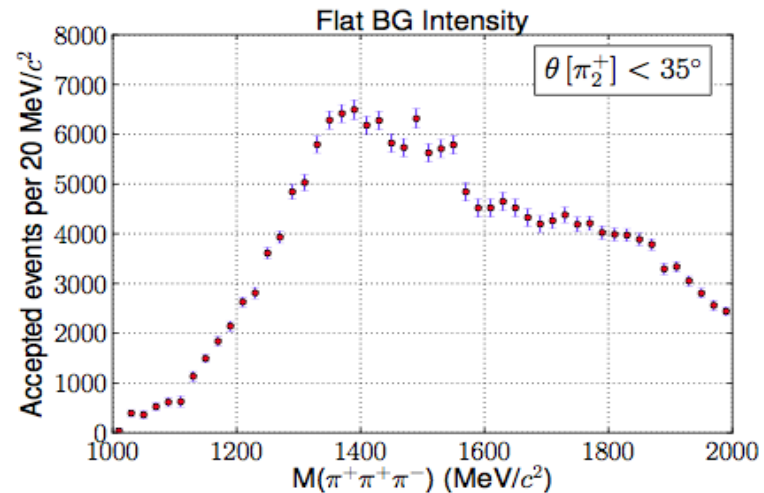
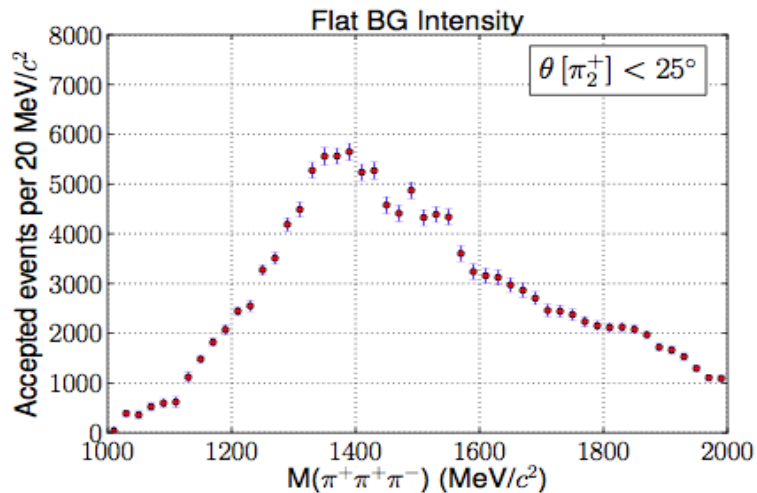


consistent with  
leakage from  
 $a_2$  signal



# PWA Systematic effects from baryon background

effects from  $\pi^+$  angle cut

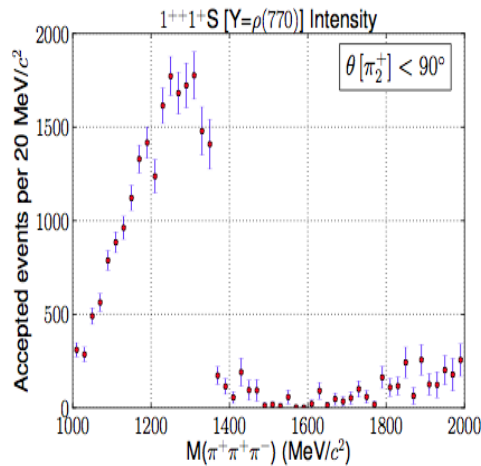
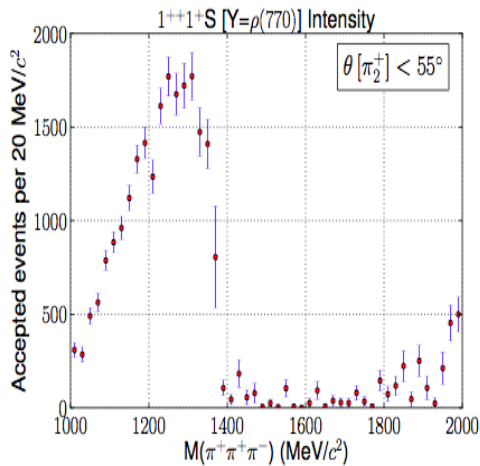
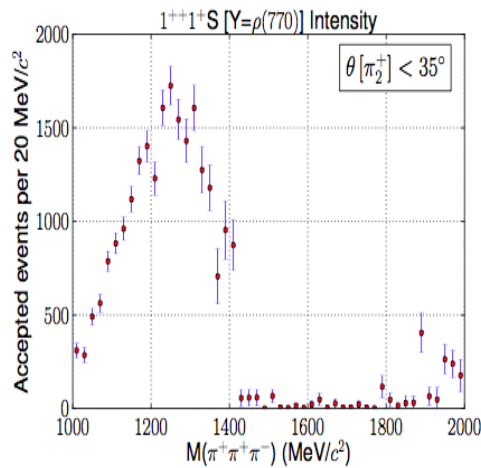
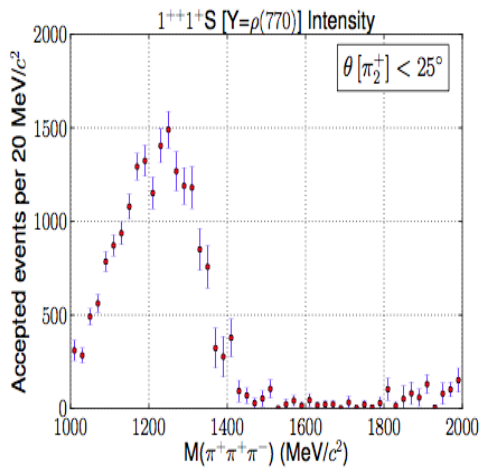


Isotropic Background Wave Intensity

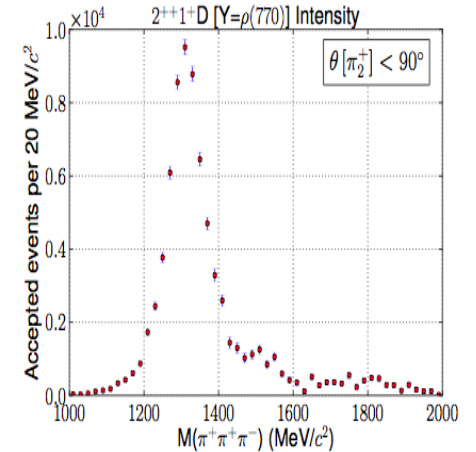
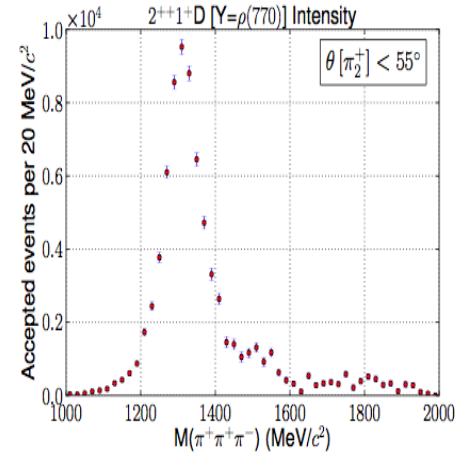
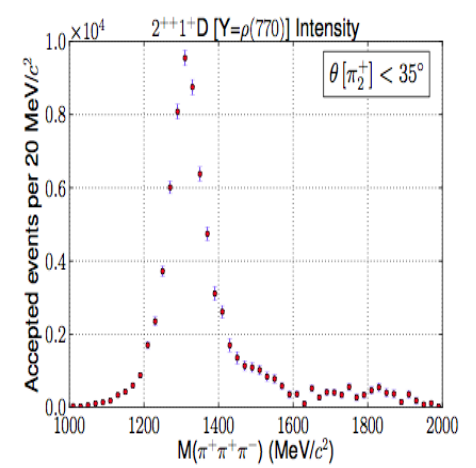
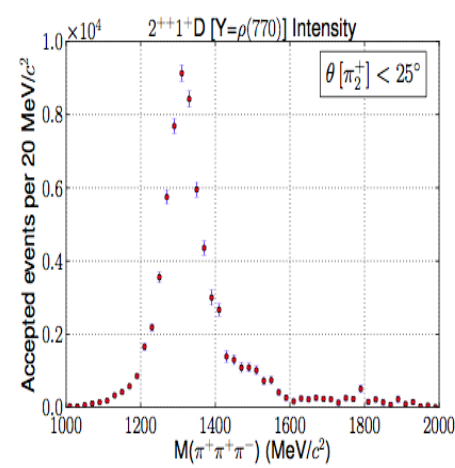
# PWA Systematic effects from baryon background

## effects from $\pi^+$ angle cut

### $1^{++}1^+S$ Intensities

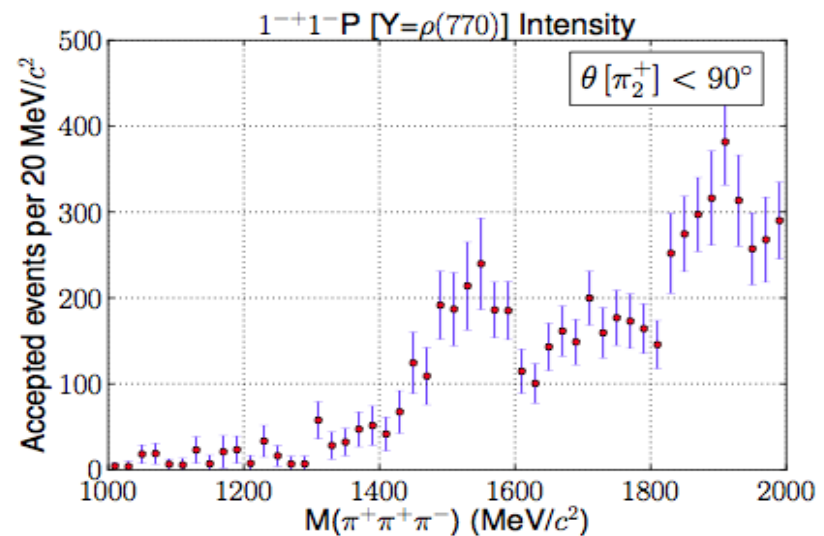
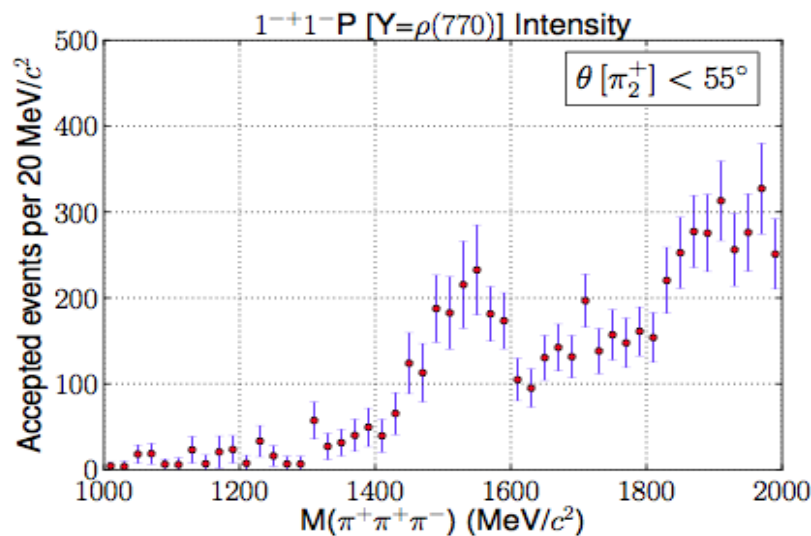
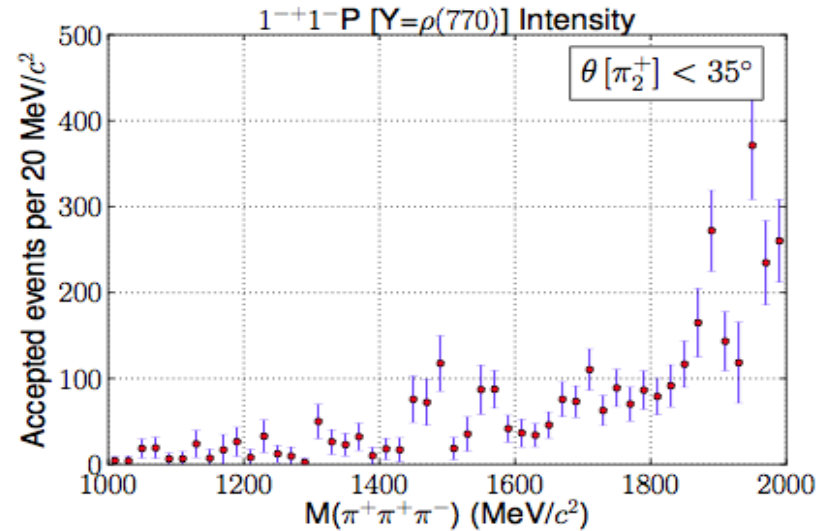
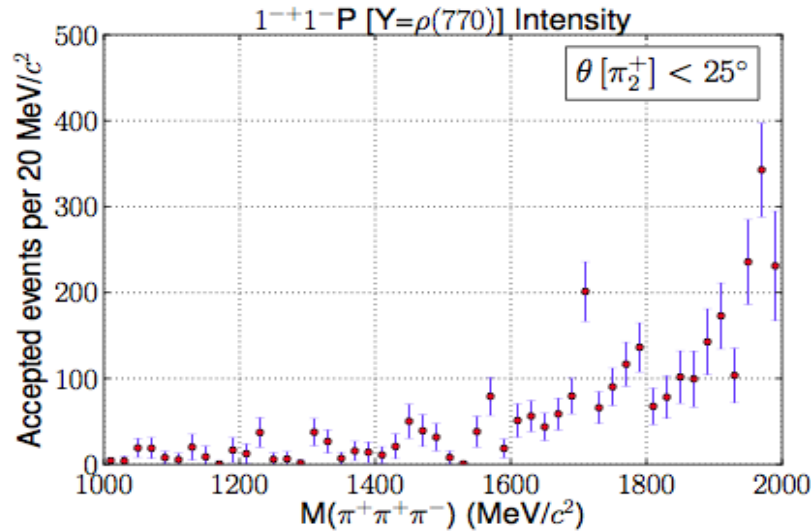


### $2^{++}1^+D$ Intensities



# PWA Systematic effects from baryon background

## effects from $\pi^+$ angle cut

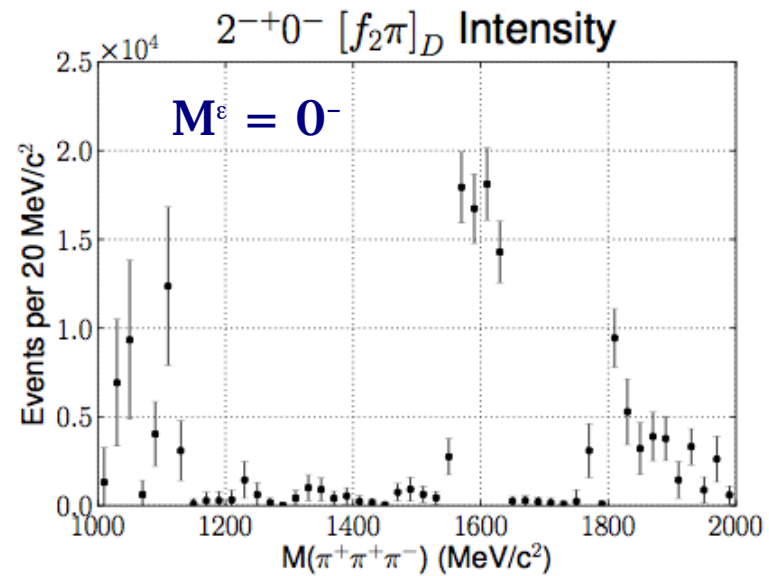
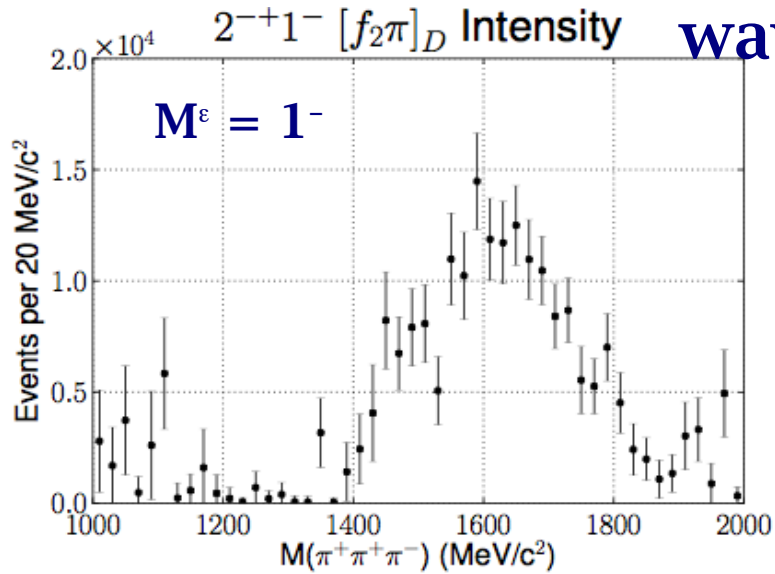


Exotic  $1^-+1^-P$  Intensities

# PWA: $2^-+ D$ & $P$ waves

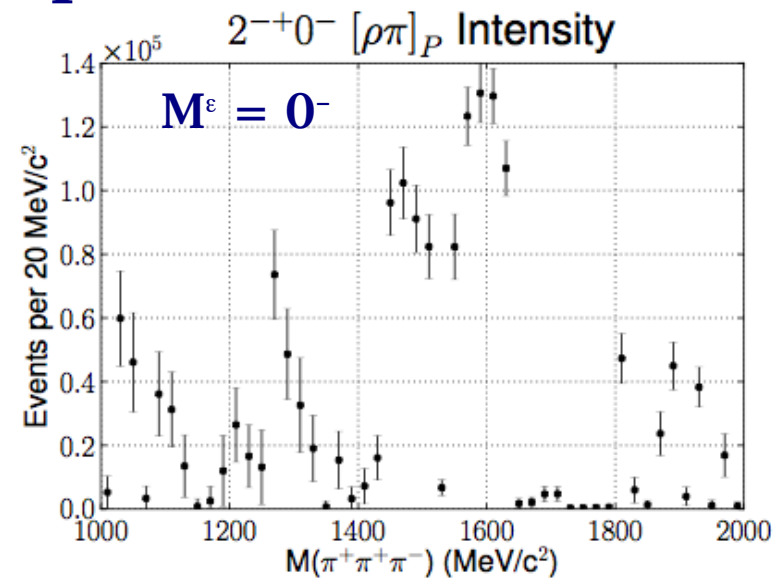
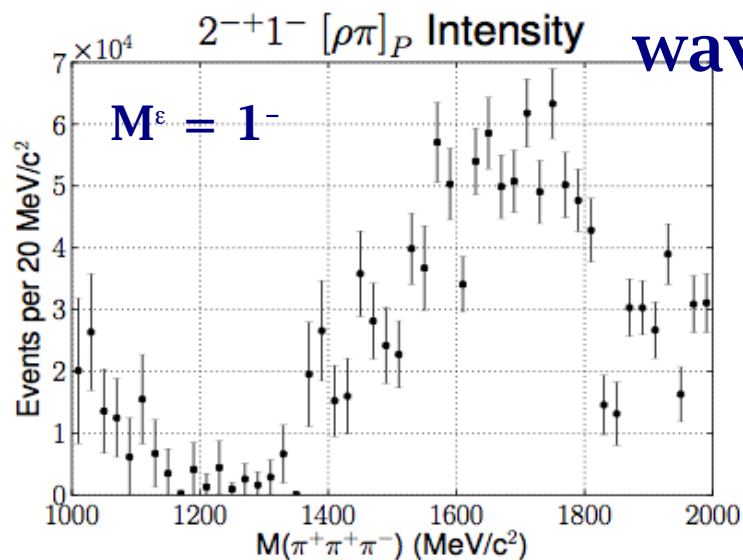
$2^-+ \rightarrow f_2\pi$

$D^-$



$2^-+ \rightarrow \rho\pi$

$P^-$



# $\pi\pi$ S-wave variations in BNL-E852

$0^{-+}$  intensity  
vs  $\pi\pi$  S-wave parametrization

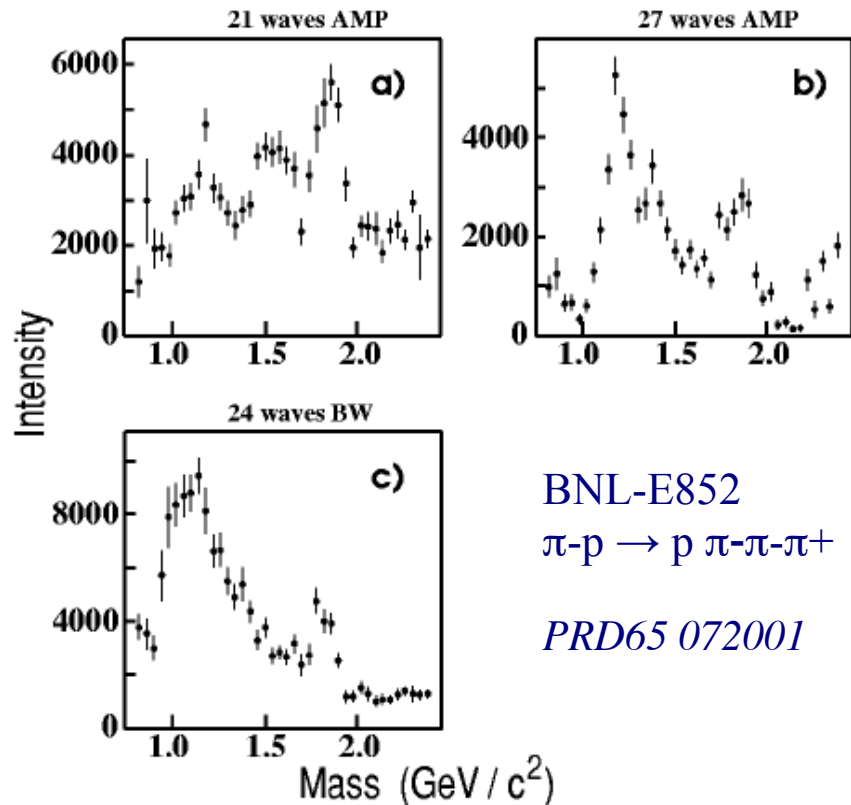


FIG. 13. Intensity of the  $0^{-+}S_0^+$  waves summed over  $\pi\pi$  S-wave isobars for the different  $\pi\pi$  S-wave parametrizations: (a) 21-wave fit, modified “M” solution parametrization; (b) 27-wave fit, same parametrization; (c) 24-wave fit, simple Breit-Wigner parametrization. See text for details.

$1^{-+}$  intensity  
vs  $\pi\pi$  S-wave parametrization

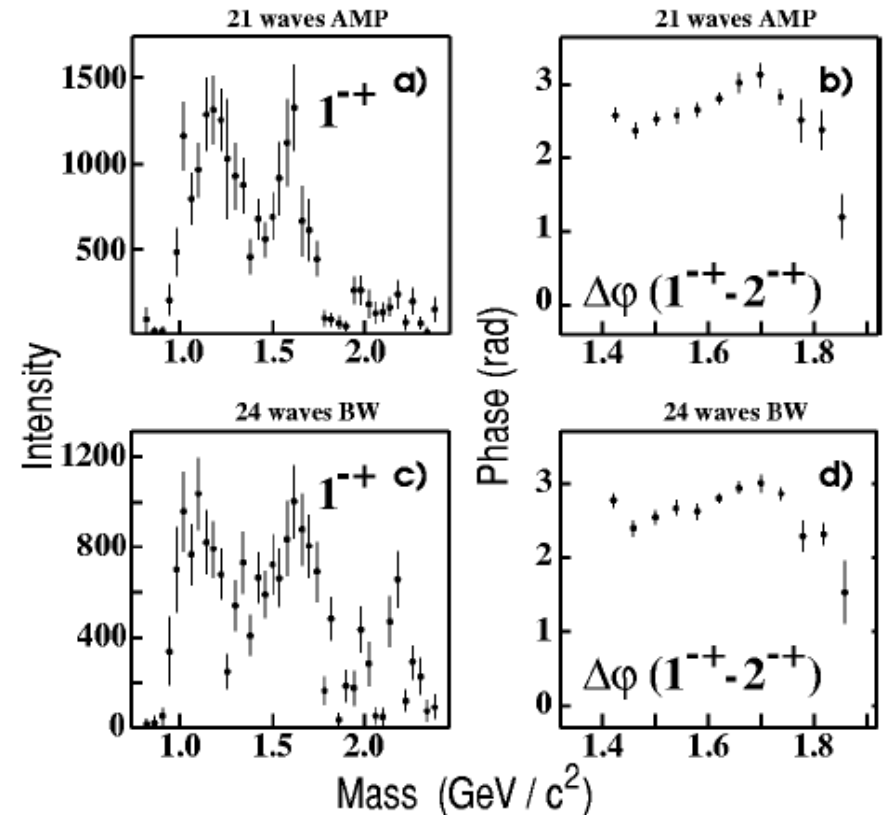


FIG. 20. Intensity of the  $1^{-+}[\rho]P_1^+$  wave (a,c) and its phase difference with respect to the  $2^{-+}[f_2]S_0^+$  wave (b,d) in the 21-wave PWA fit with the Au-Morgan-Pennington parametrization of the  $\pi\pi$  S-wave (a,b), and the 24-wave PWA fit with the Breit-Wigner parametrization (c,d).

# Acceptance ~~Correcting~~ Accounting

Extended Likelihood Function

$$\mathcal{L} = e^{-\bar{N}_o(k^\epsilon V_\alpha)} \prod_i I(k^\epsilon V_\alpha; \tau_i)$$

acceptance

$$\bar{N}_o(k^\epsilon V_\alpha) = \int I(k^\epsilon V_\alpha; \tau) \eta(\tau) dLips$$

average number of events one would expect if the same experiment were repeated many times

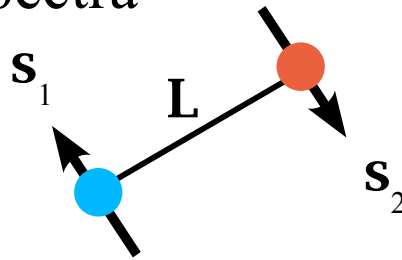
$$-\ln \mathcal{L} = \ln \left( \prod_i I(k^\epsilon V_\alpha; \tau_i) \right) - \sum_{\alpha \alpha'} k^\epsilon V_\alpha^* k^\epsilon V_{\alpha'} \int \epsilon A_\alpha^* \epsilon A_{\alpha'} \eta(\tau) dLips$$

$$\epsilon \Phi_{\alpha \alpha'}^{accepted} = \frac{1}{N_g} \sum_i \epsilon A_\alpha^* (\tau_i) \epsilon A_{\alpha'} (\tau_i)$$



# Identification of QCD Exotics

Quark Model Meson Spectra



$$S=0, 1$$

$$L=0, 1, 2, 3, \dots$$

$$\vec{J} = \vec{L} + \vec{S}$$

$$P = (-1)^{L+1}$$

$$C = (-1)^{L+S}$$

Meson quantum numbers characterized by given  $J^{PC}$

**Allowed States:**

$$J^{PC} = 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 1^{++}, 2^{--}, 2^{-+}, 2^{++}, \dots$$

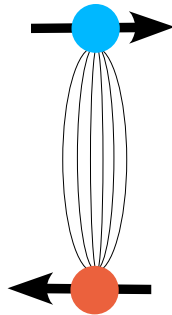
**Forbidden States (Exotics):**

$$J^{PC} = 0^{+-}, 0^{--}, 1^{-+}, 2^{+-}, 3^{-+}, 4^{+-}, \dots$$

# Photoproduction of Gluonic Excitations

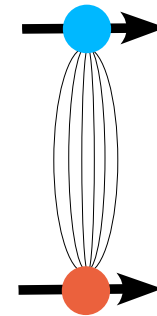
- It has been pointed out<sup>1,2,3</sup> that in the case of photoproduction exotic hybrids should be produced copiously.

pseudoscalar probe

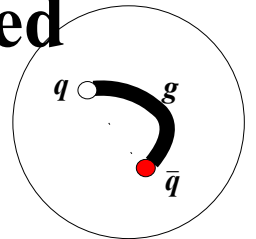


$$\text{quarks } J^{PC} \otimes \text{gluonic flux } J^{PC} = 1^{--}, 1^{++}$$

vector probe



$$\text{quarks } J^{PC} \otimes \text{gluonic flux } J^{PC} = 0^{-+}, 1^{-+}, 2^{-+}, 0^{+-}, 1^{+-}, 2^{+-}$$



<sup>1</sup>Close *et al.* Phys. Rev. D52:1706 (1995)

<sup>2</sup>Afanasev *et al.* Phys. Rev. D57:6771 (1998)

<sup>3</sup>Szczepaniak *et al.* Phys. Lett. B516:72 (2001)