

Recent results on meson spectroscopy from CLAS

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*Results presented at
Hadron 2015 by
Aristeidis Tsaris &
Hussein Al Ghoul*



Overview

- **$n\pi^+\pi^+\pi^-$ from CLAS g12**
 - **analysis issues uncovered**
- **reanalysis of $n\pi^+\pi^+\pi^-$**
- **analysis of $\Delta^{++}\pi^+\pi^-\pi^-$**
- **analysis of $\Lambda K^+\pi^+\pi^-$**

Results from Jefferson Lab CLAS

CLAS g12 Experiment

Photoproduction of meson via unpolarized photons

$E_e = 5.715 \text{ GeV}$

Production Data

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

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

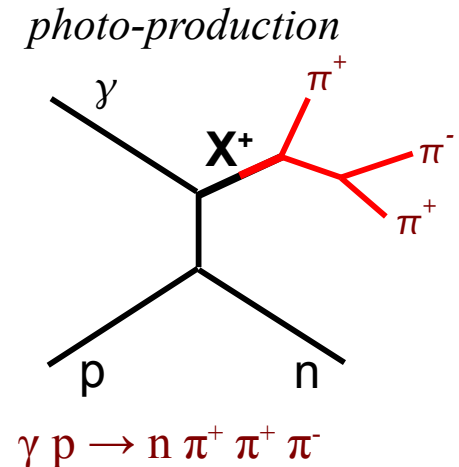
26.2 Billion events

mixed triggers

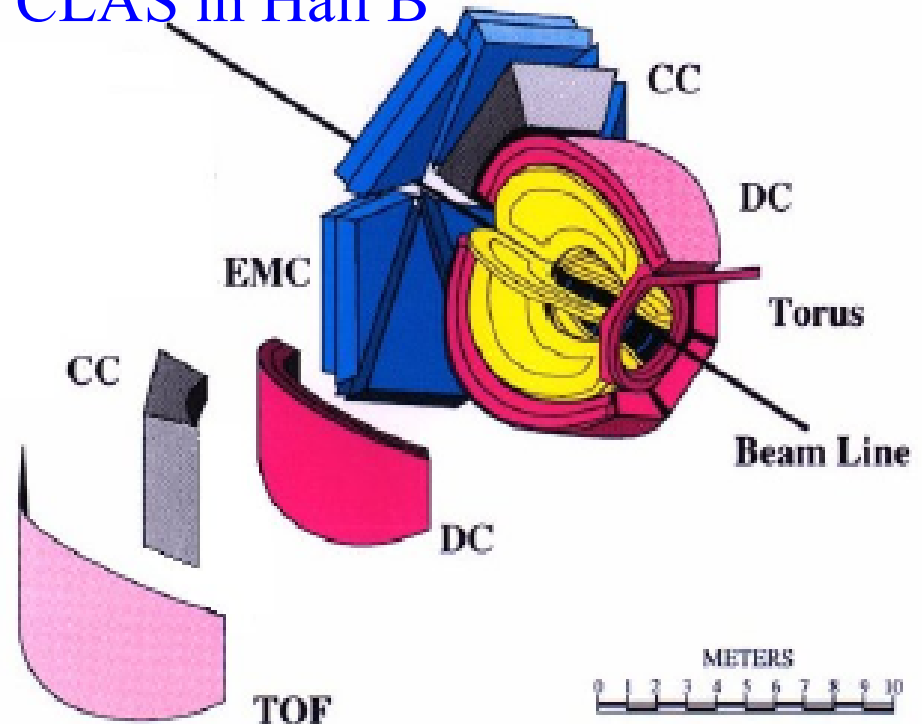
68 pb^{-1}

Hadron Spectroscopy Analyses

- $\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$
- $\gamma p \rightarrow p \pi^- \pi^+ \pi^0$
- $\gamma p \rightarrow p K^+ K^- \eta$
- $\gamma p \rightarrow \Delta^{++} \pi^- \eta$
- $\gamma p \rightarrow \Delta^{++} \pi^- \pi^+ \pi^+$
- $\gamma p \rightarrow \Lambda K^+ \pi^- \pi^+$
- $\gamma p \rightarrow \Xi^{*-} K^+ K^+$
- $\gamma p \rightarrow p p \text{ anti-}p$
- + ...



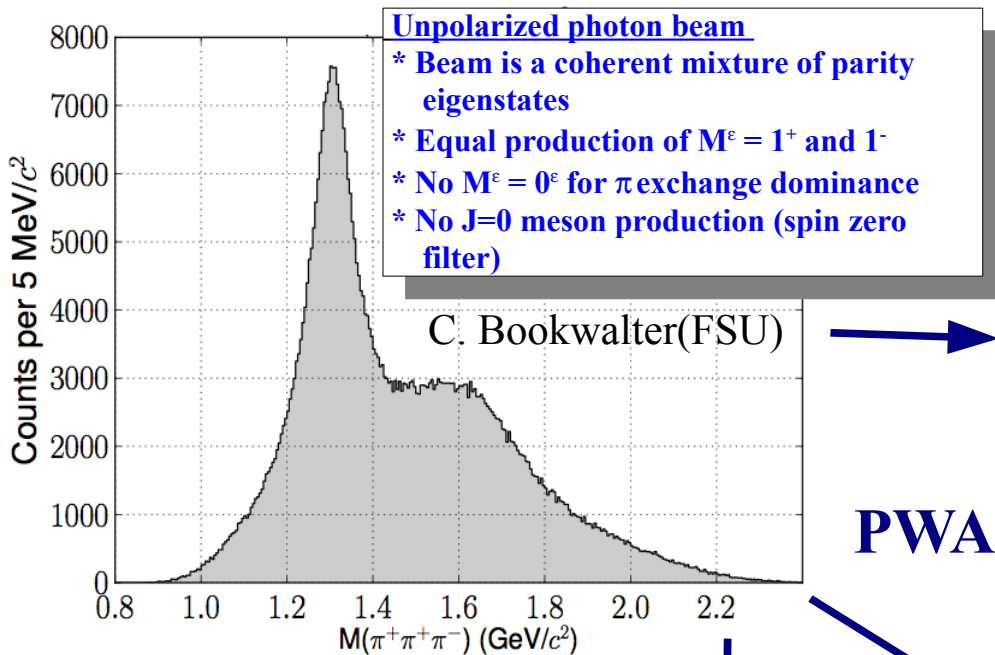
CLAS in Hall B



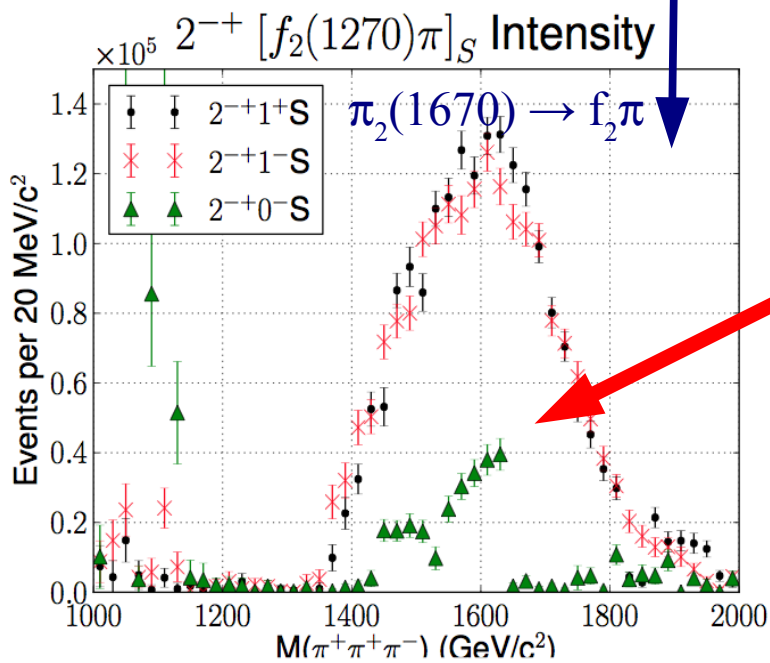
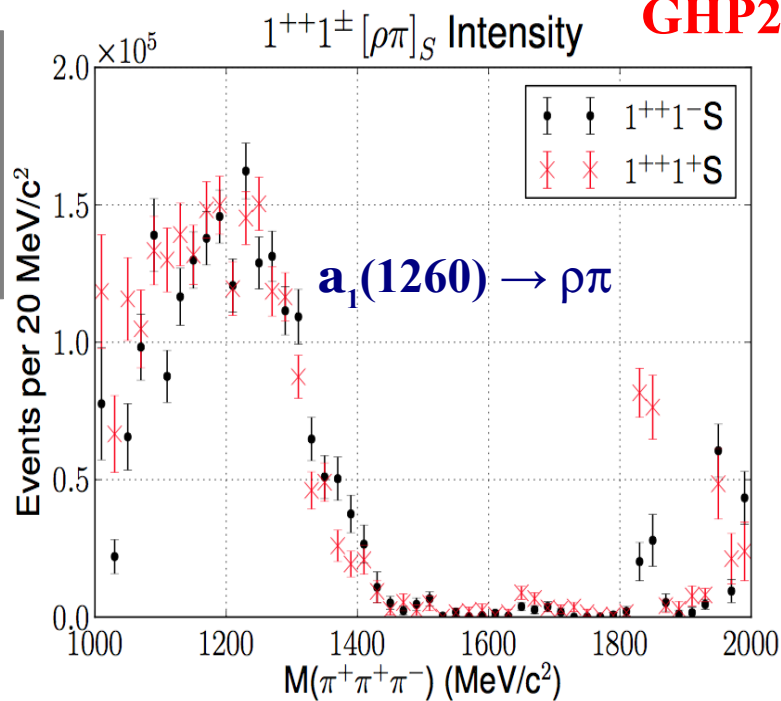
CLAS geometry optimized for peripheral production acceptance

CLAS g12: $\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$

GHP2013

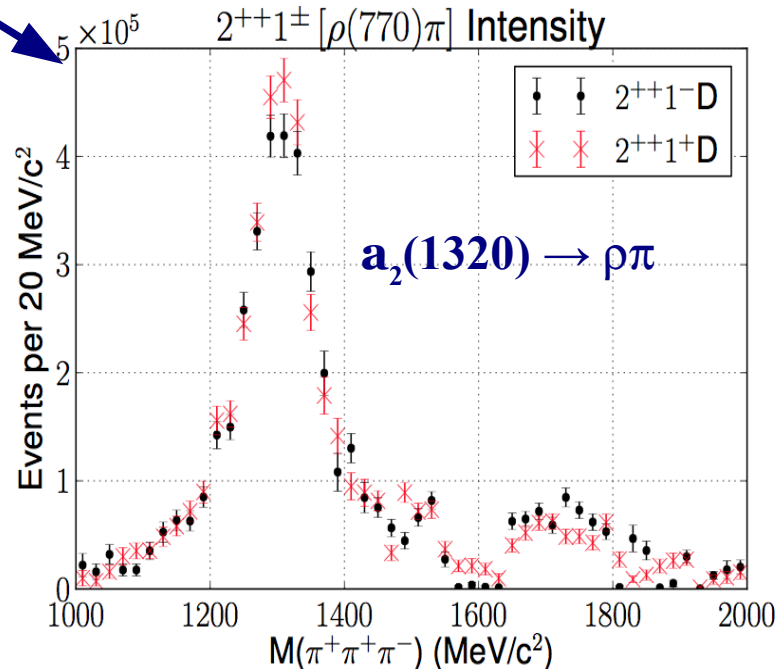


PWA

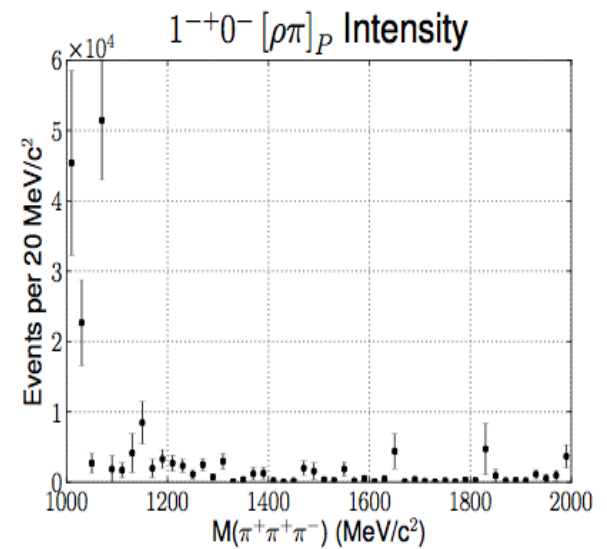
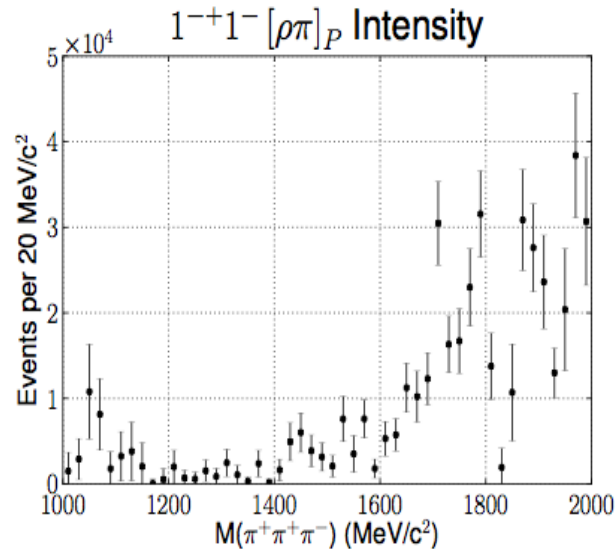
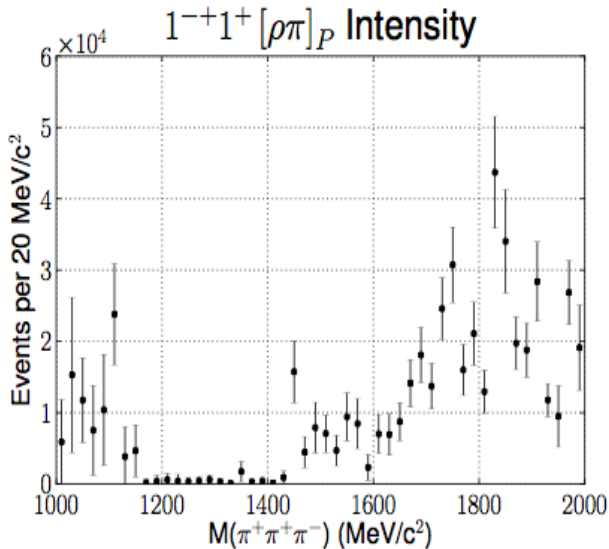


?

M=0



PWA 1^-+ Exotic Wave



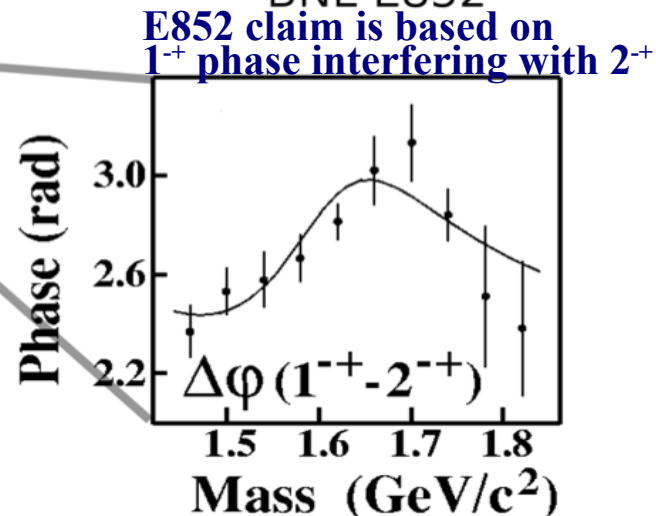
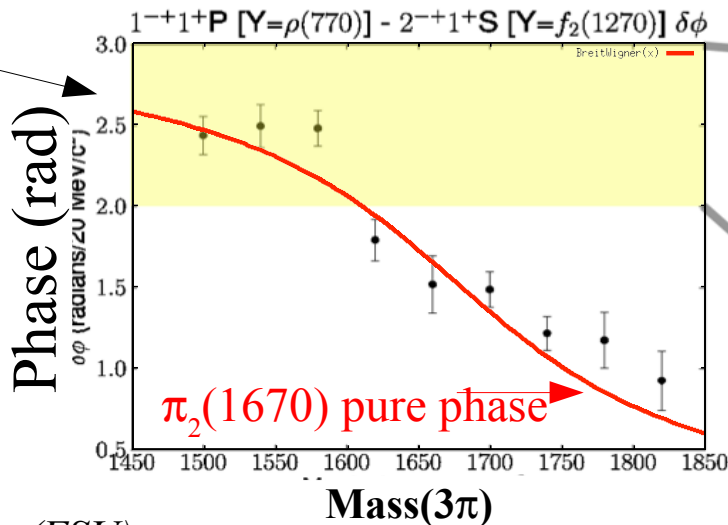
$\phi[1^-+ - 2^-+] Phase Motion$

CLAS g12

BNL-E852

GHP2013

no
evidence
of
 $\pi_1(1600)$



Error found in the amplitude calculation

1-+0-P:iso=rho -1	1-+0-P:iso=rho -1
1-+1-P:iso=rho -1	2-+1-D:iso=f2 -1
1++1-S:iso=rho -1	2++1-D:iso=rho -1
2-+0-D:iso=f2 -1	2-+1-P:iso=rho -1
2-+0-P:iso=rho -1	2-+1-S:iso=f2 -1
2-+0-S:iso=f2 -1	1-+1-P:iso=rho -1
2-+1-D:iso=f2 -1	1++1-S:iso=rho -1
2++1-D:iso=rho -1	1-+1+P:iso=rho +1
2-+1-P:iso=rho -1	1++1+S:iso=rho +1
2-+1-S:iso=f2 -1	2-+0+P:iso=rho +1
1-+1+P:iso=rho +1	2-+0+D:iso=f2 +1
1++1+S:iso=rho +1	2-+0+S:iso=f2 +1
2-+1+D:iso=f2 +1	2-+1+D:iso=f2 +1
2++1+D:iso=rho +1	2++1+D:iso=rho +1
2-+1+P:iso=rho +1	2-+1+P:iso=rho +1
2-+1+S:iso=f2 +1	2-+1+S:iso=f2 +1
flatbg 0	flatbg 0

Craig

Aris

- helicity amplitudes are not parity eigenstates

- reflectivity amplitudes are linear combinations of helicity amps which are parity eigenstates.

$$|\epsilon am\rangle = \left[|am\rangle - \epsilon P(-1)^{J-m} |a-m\rangle \right] \theta(m) \quad (38)$$

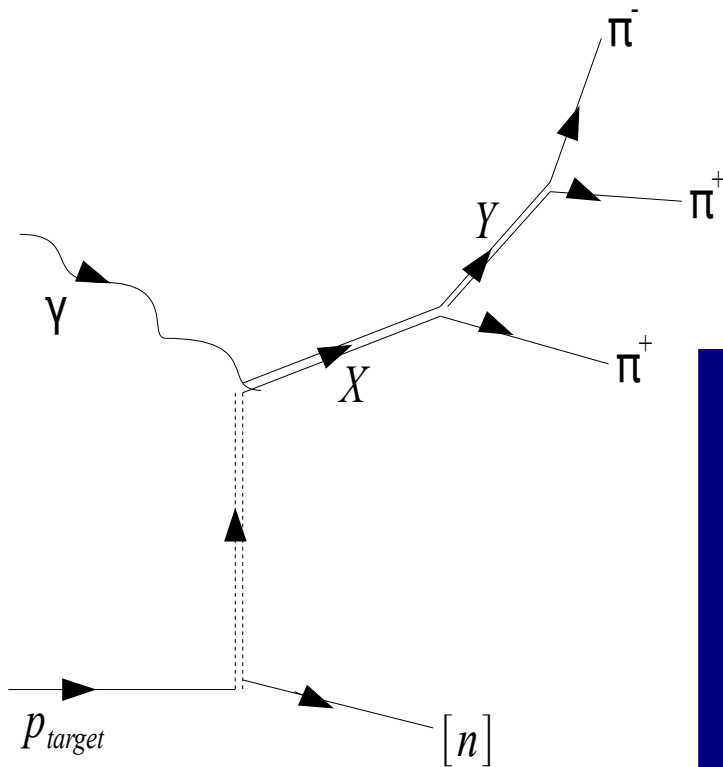
where P is the parity of the state 'a' and

$$\begin{aligned} \theta(m) &= \frac{1}{\sqrt{2}}, & m > 0 \\ &= \frac{1}{2}, & m = 0 \\ &= 0, & m < 0 \end{aligned} \quad (39)$$

The reflectivity ϵ is here defined such that it coincides with the naturality of exchanged Regge trajectories. Note that

$$|\epsilon am\rangle = 0 \text{ for } m = 0, \quad \text{if } \epsilon = P(-1)^J \quad (40)$$

----- Chung -----

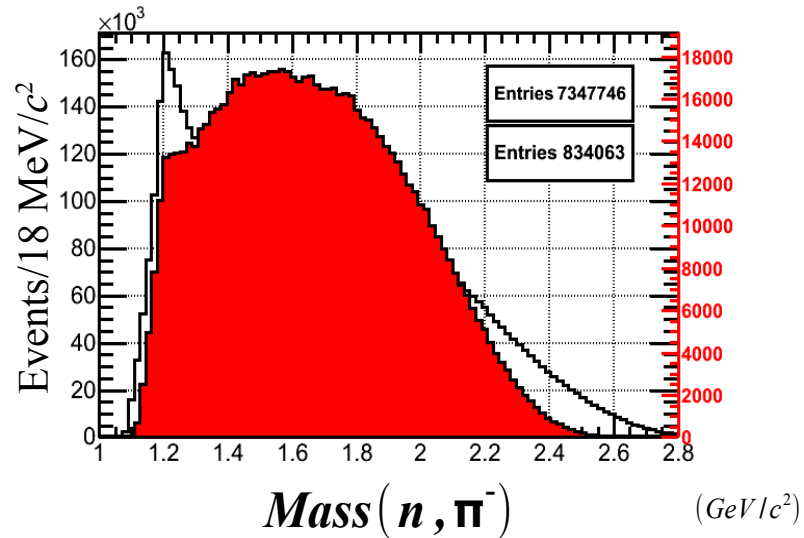
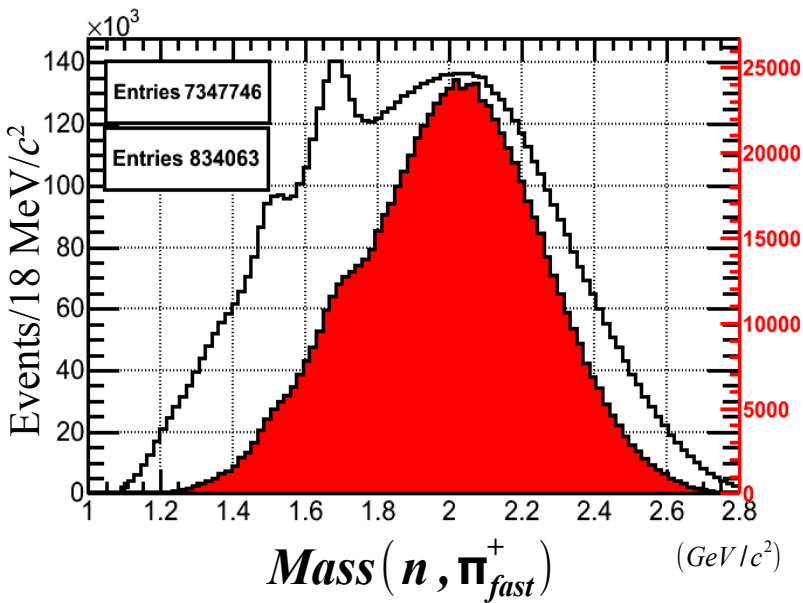
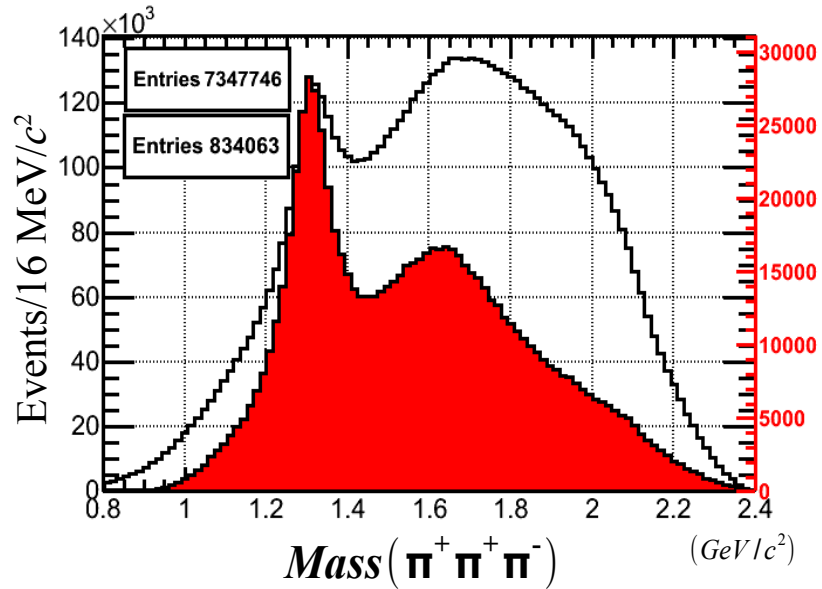
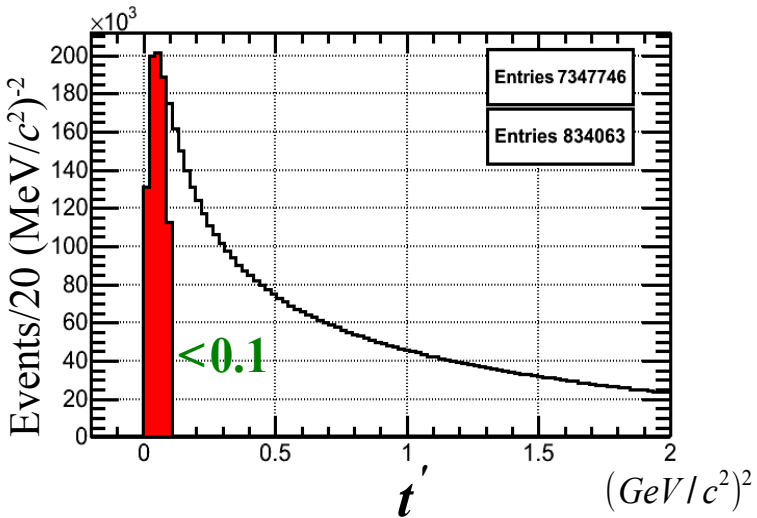


Using the CLAS-g12 dataset we selected events with three charge pions, measured by the CLAS spectrometer and identifying a neutron by energy and momentum conservation.

A mass independent partial wave analysis was performed using an event based likelihood fit.

Enhance Peripheral Production

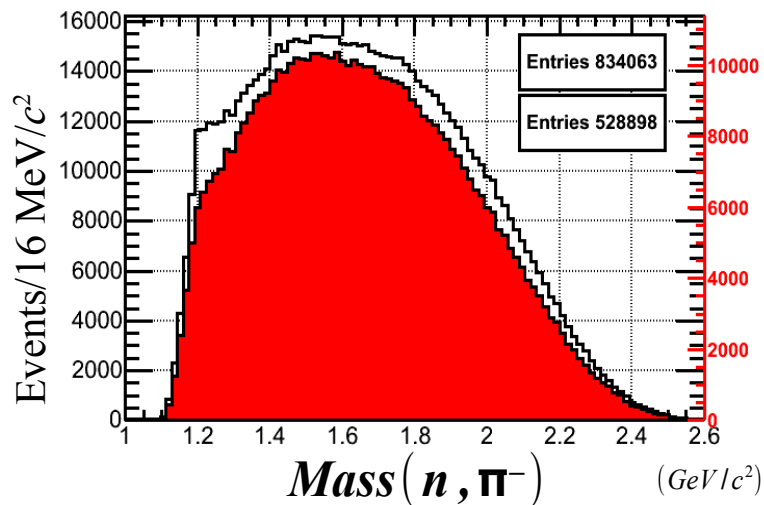
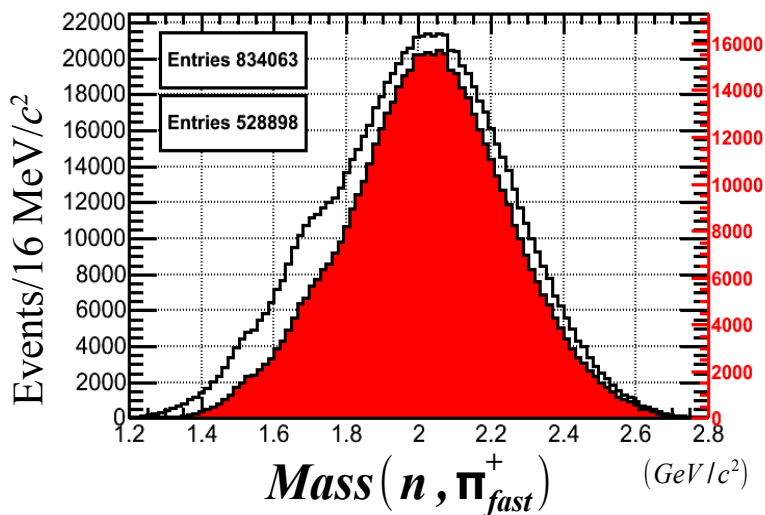
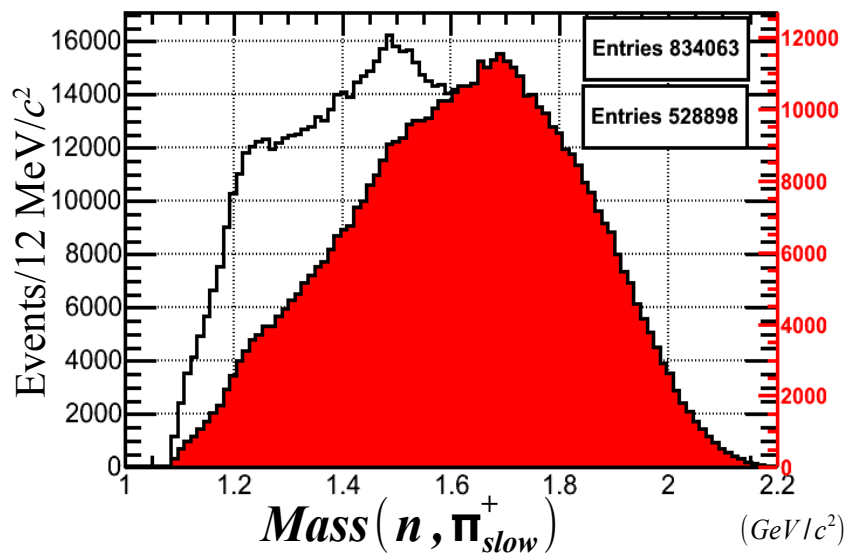
$$\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$$



Further Reducing the Baryon Background

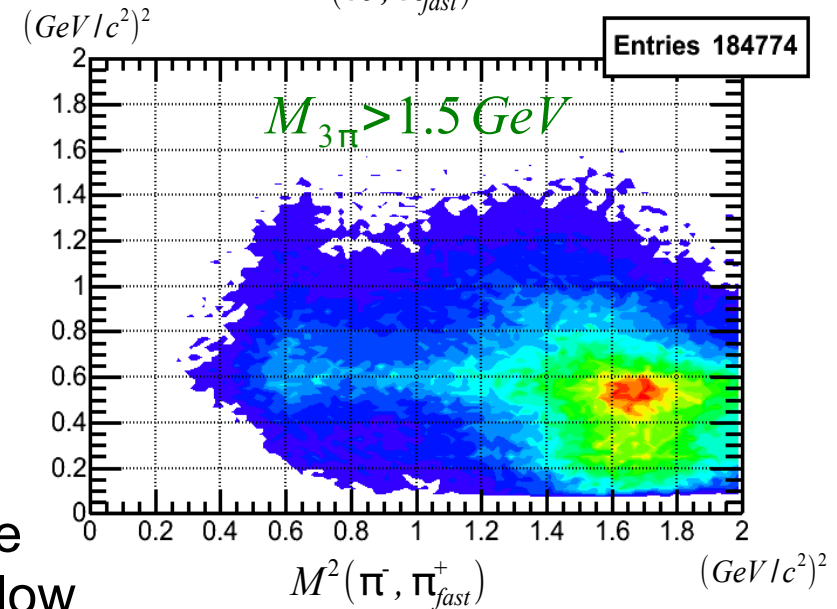
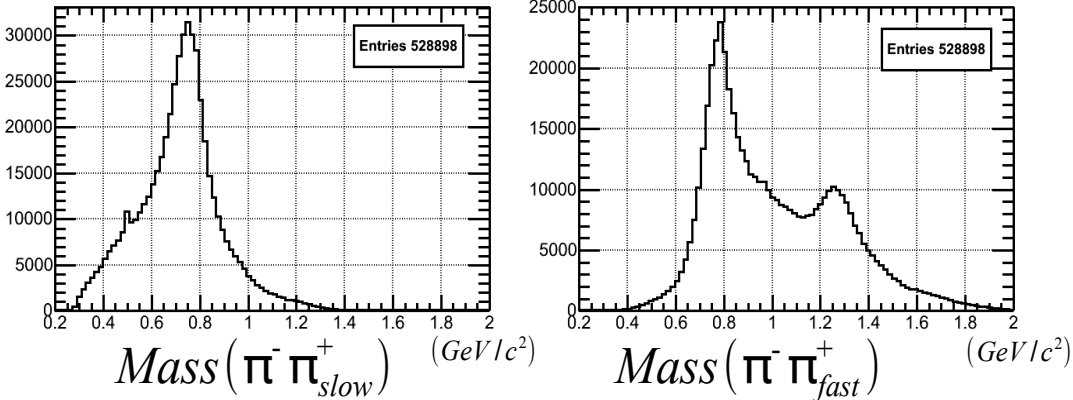
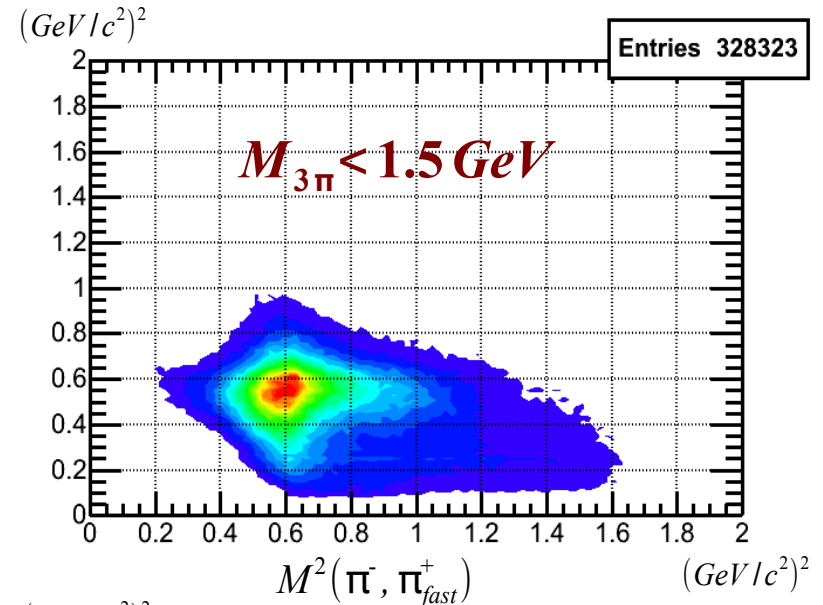
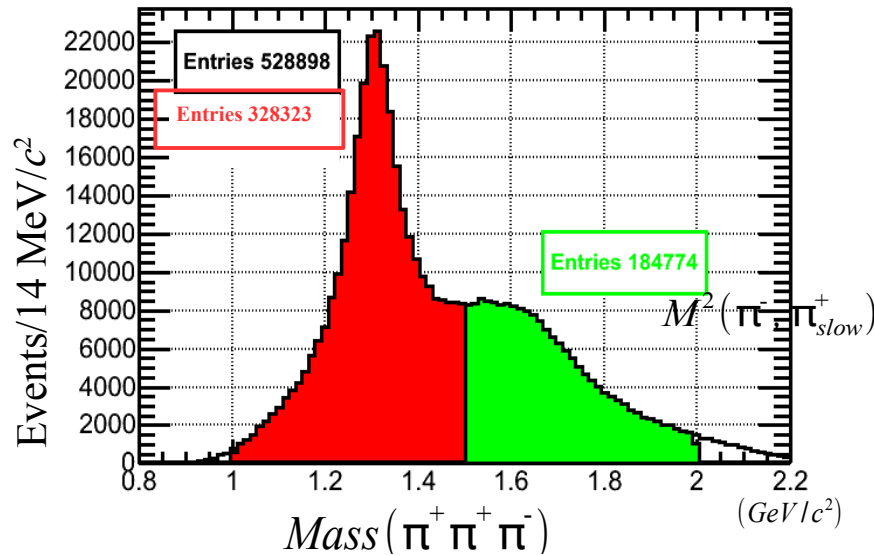
$$\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$$

$$\theta_{lab} [\pi^+_{slow}] < 25^\circ$$



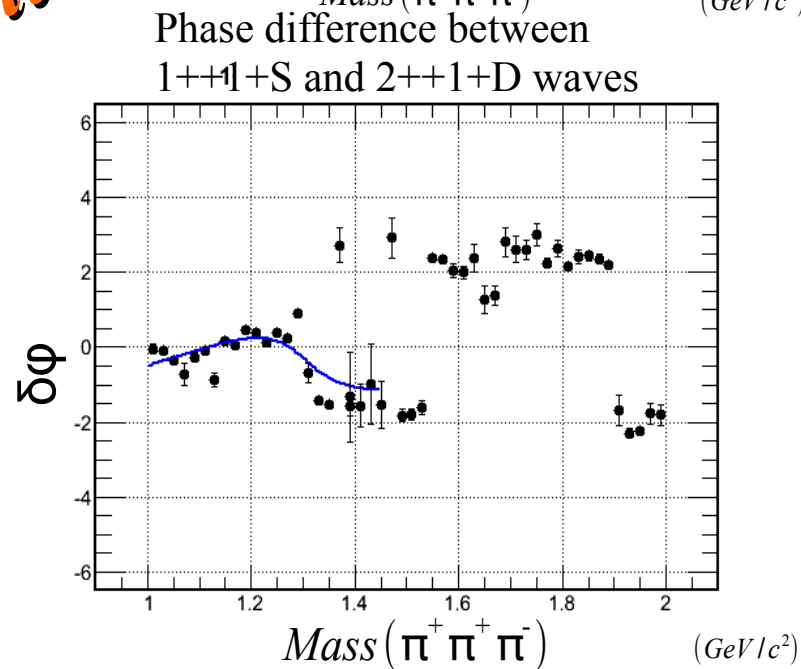
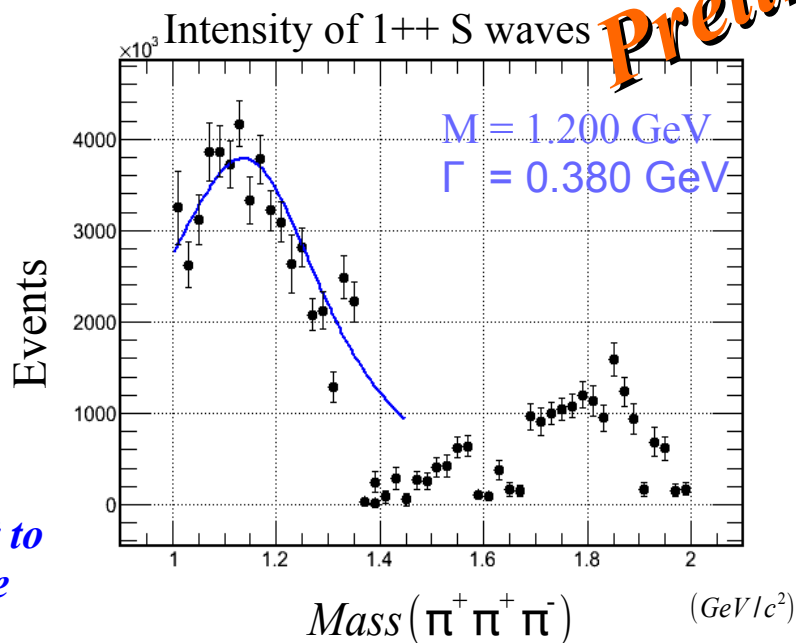
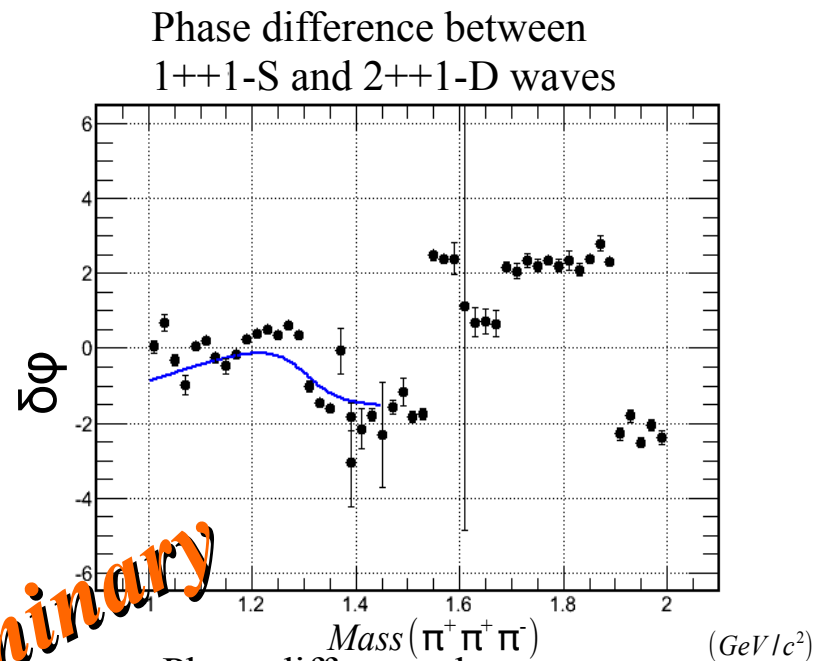
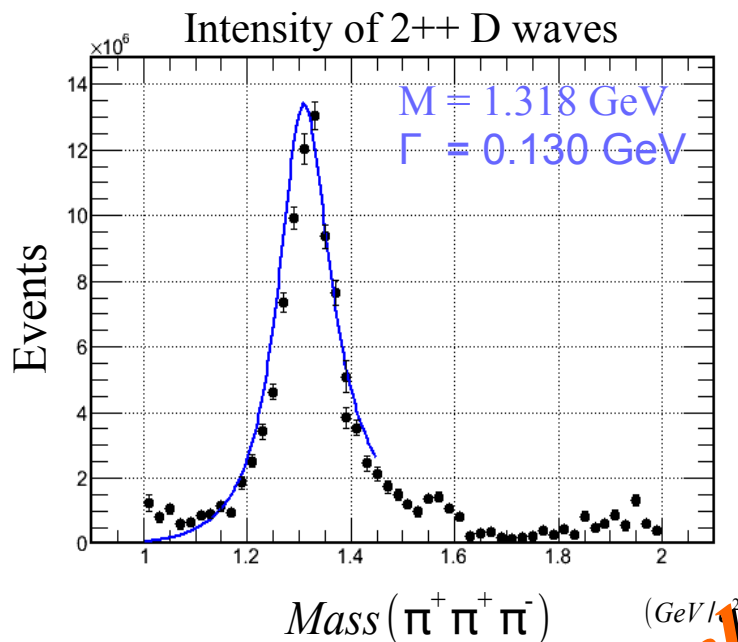
Features of the 3π sample

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



A total of 17 partial waves were included in the high mass region and 13 partial waves in the low mass region for the PWA fit presented here.

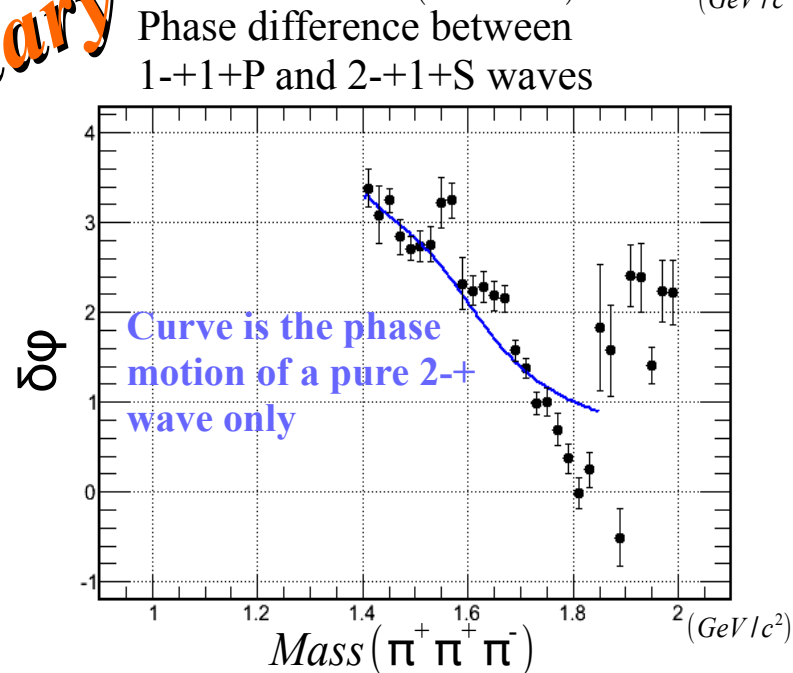
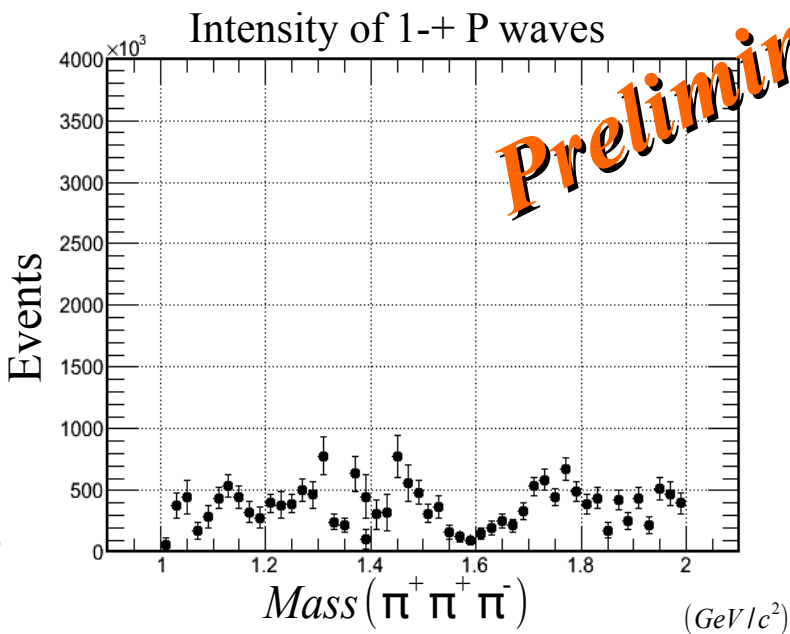
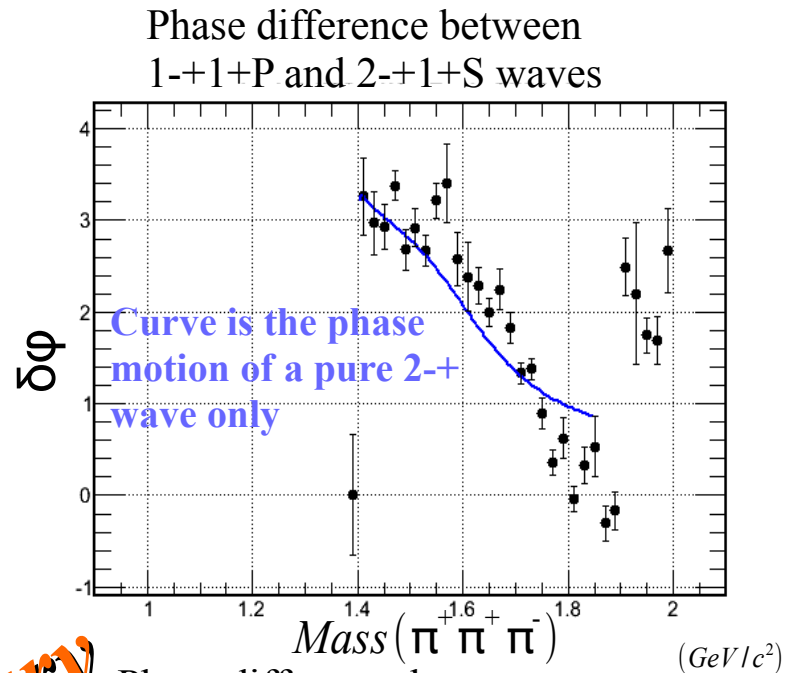
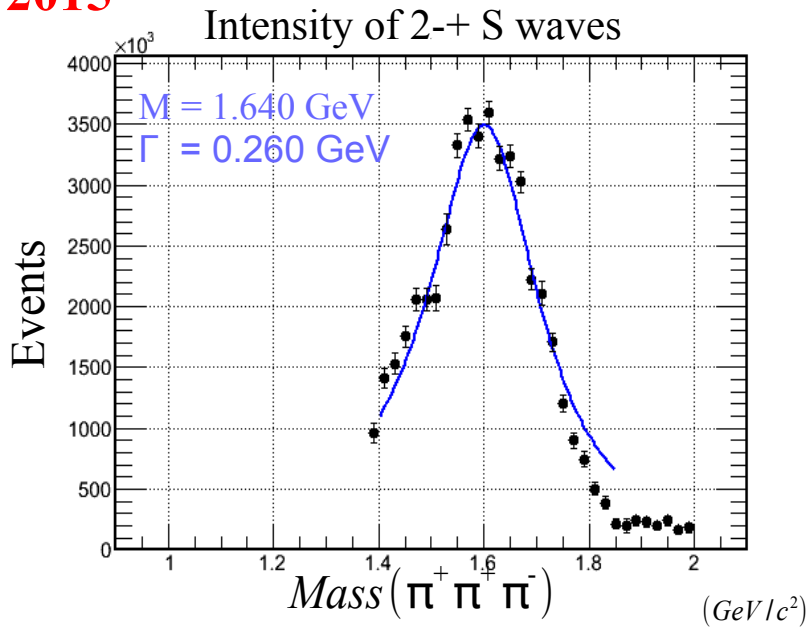
Partial waves of the 3π System for $\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$



Curve is just to guide the eye

Partial waves of the 3π System for $\gamma p \rightarrow n \pi^+ \pi^+ \pi^-$

HADRON 2015



Preliminary

Curve is just to guide the eye

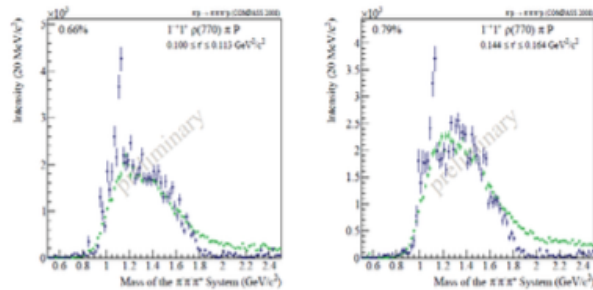
It was found that the M=0 waves are no longer required!

COMPASS Result Presented at Hadron 2015

Diffractionally produced 3-pion and 2-pseudoscalar final states at COMPASS
Bernhard Ketzer



Data vs Deck



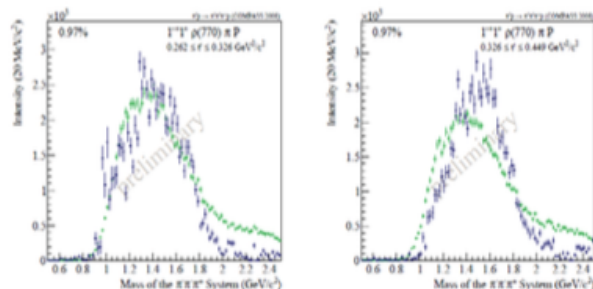
(a)

(b)

1^{-+}
←

Low values of t' :

- Mostly non-resonant production
- Good description by Deck model



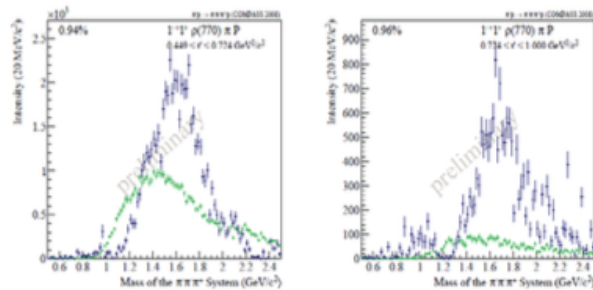
(c)

(d)

↓ t'

High values of t' :

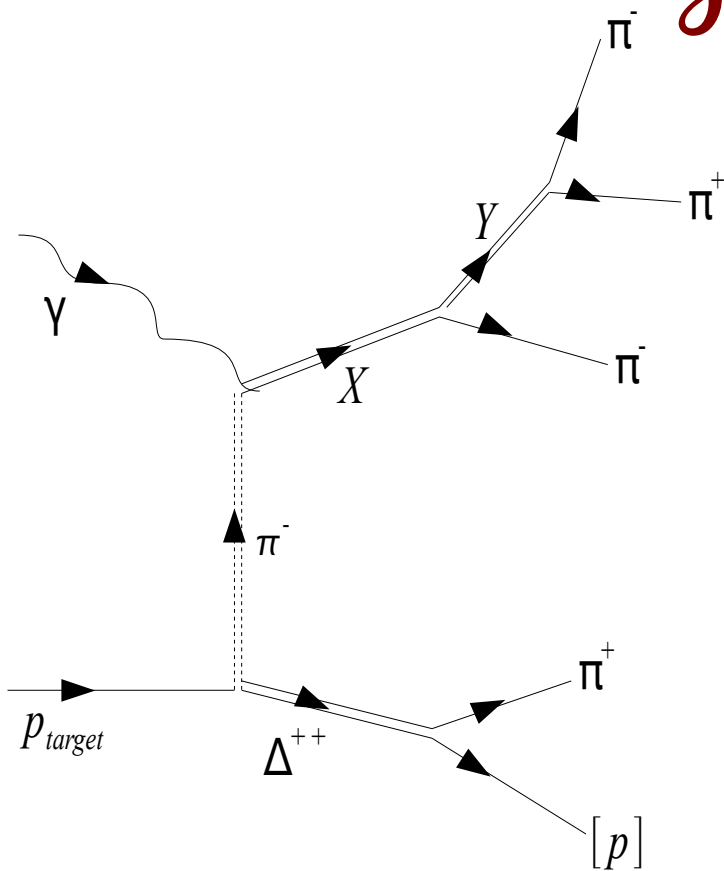
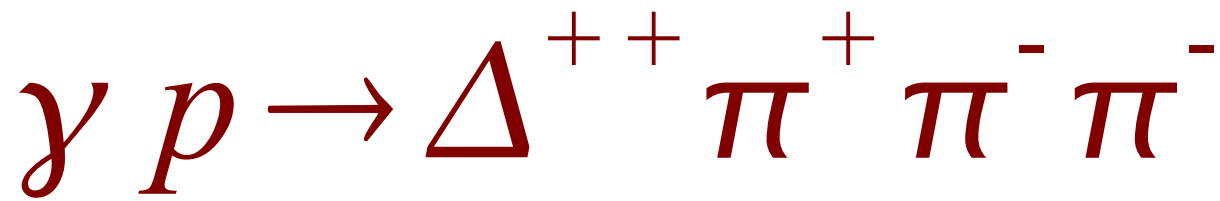
- Deck background disappears
- Resonant component increasing
- Dominates highest t' - bin



(e)

(f)

— Data
— Deck



Aristeidis Tsaris
FSU

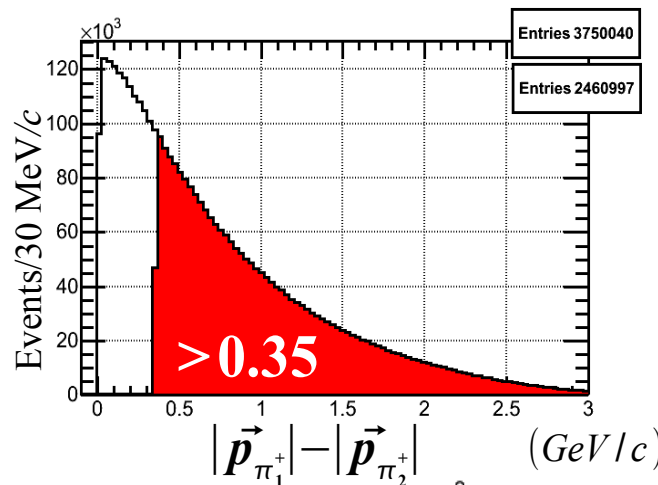
Using the CLAS-g12 dataset we selected events with four charge pions, measured by the CLAS spectrometer and identifying a proton by energy and momentum conservation.

A mass independent partial wave analysis was performed using an event based likelihood fit.

Kinematic Separation of the Δ^{++}

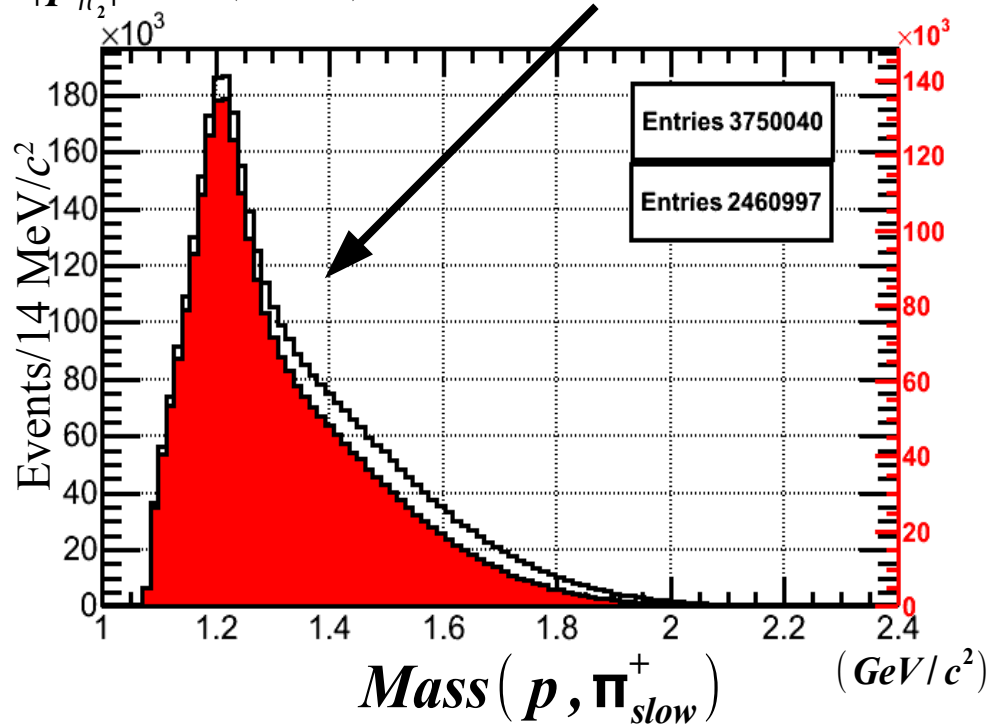
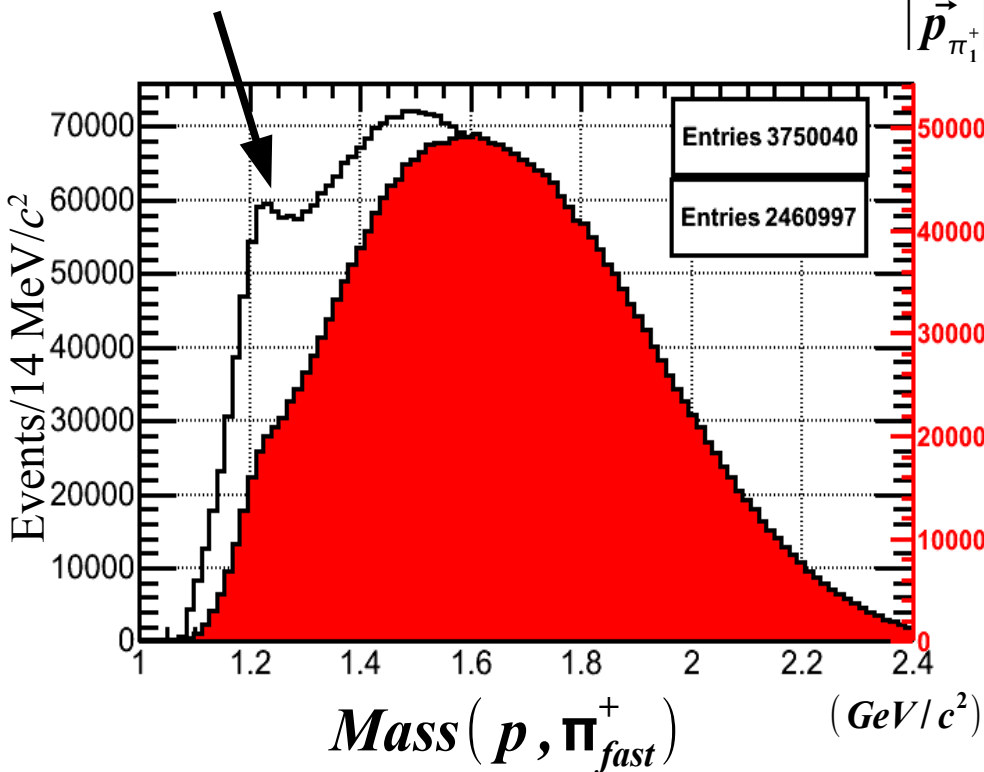
$$\gamma p \rightarrow \Delta^{++} \pi^+ \pi^- \pi^-$$

Momentum
Difference:



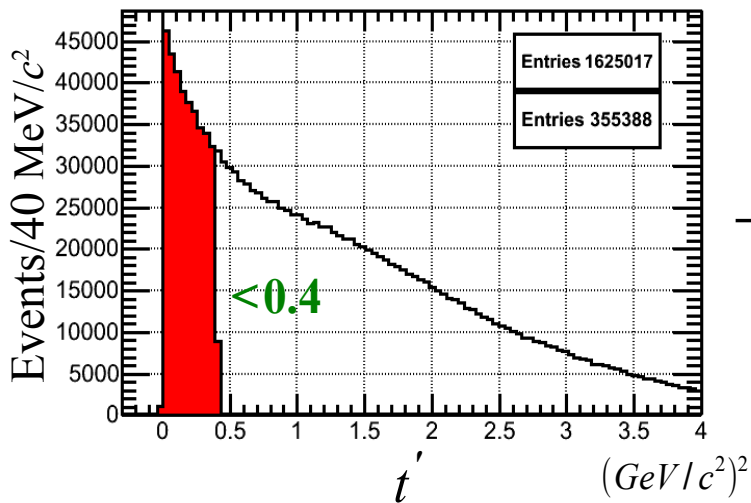
Background Δ^{++}

Signal Δ^{++}

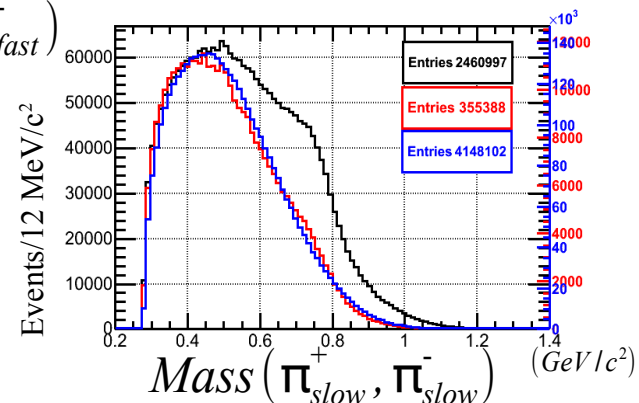
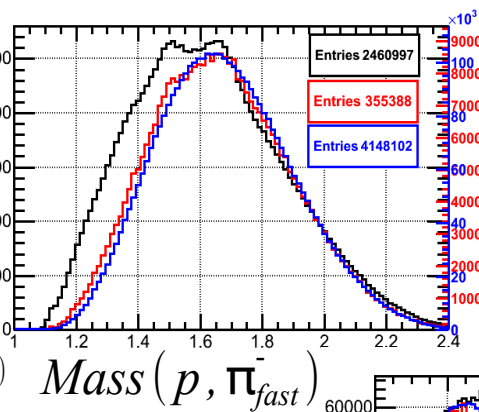
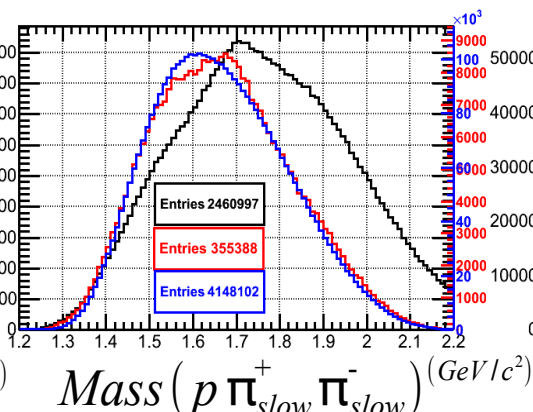
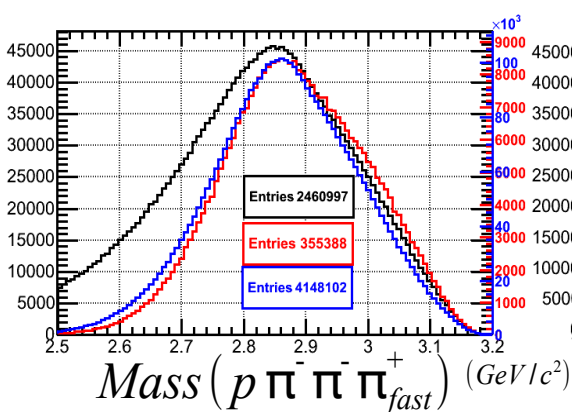
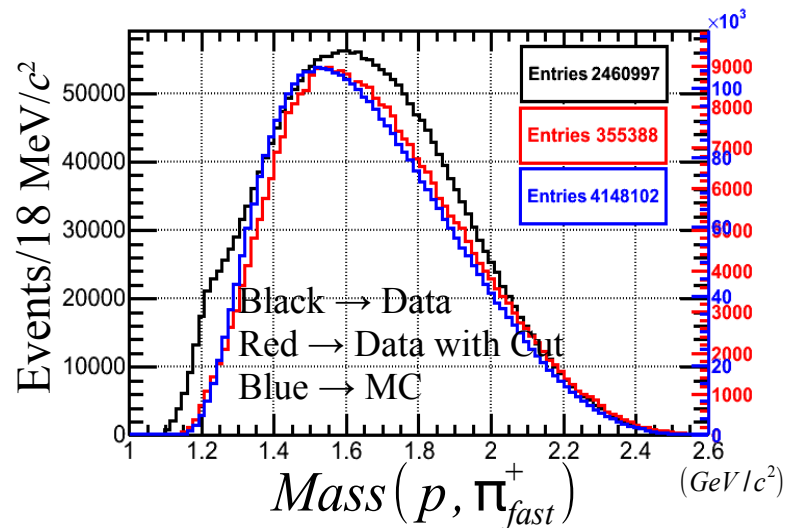


Data Selection and Background Reduction

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



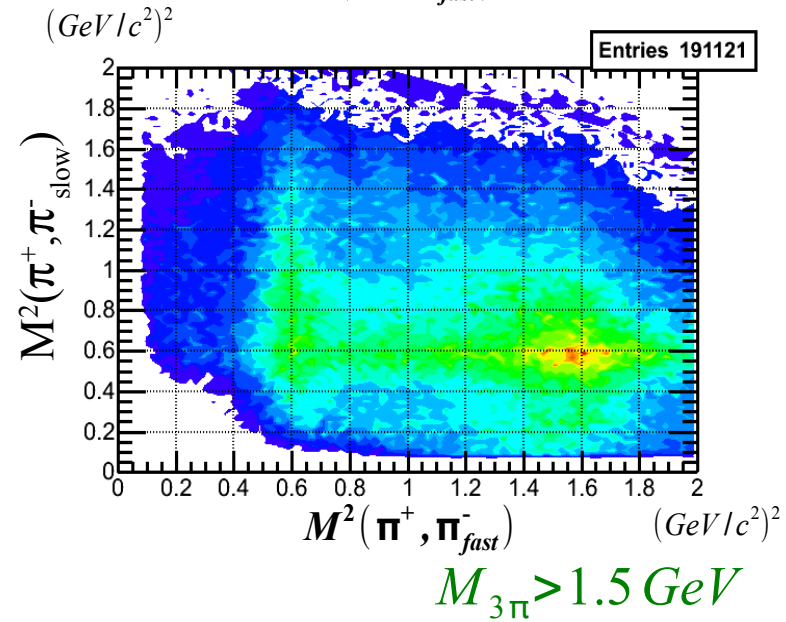
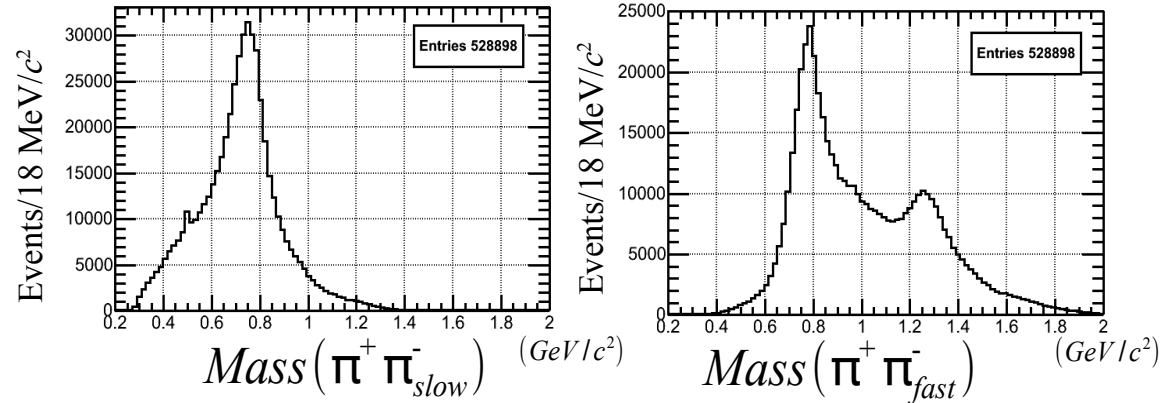
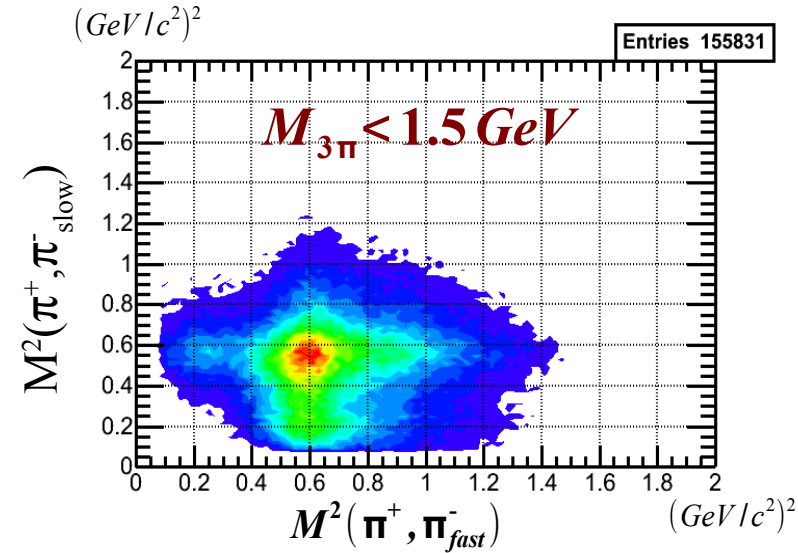
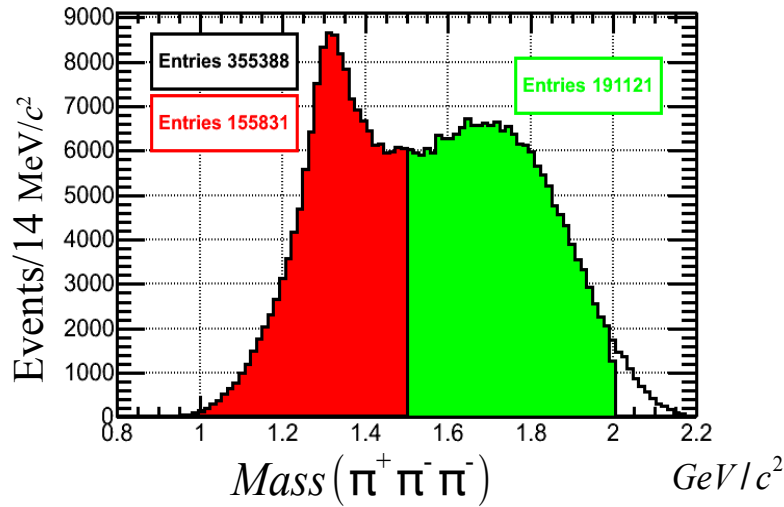
$$+ M_{p \pi_{slow}^+} < 1.35$$



Black → Data
Red → Data with Cuts
Blue → MC with Cuts

Features of the 3π sample

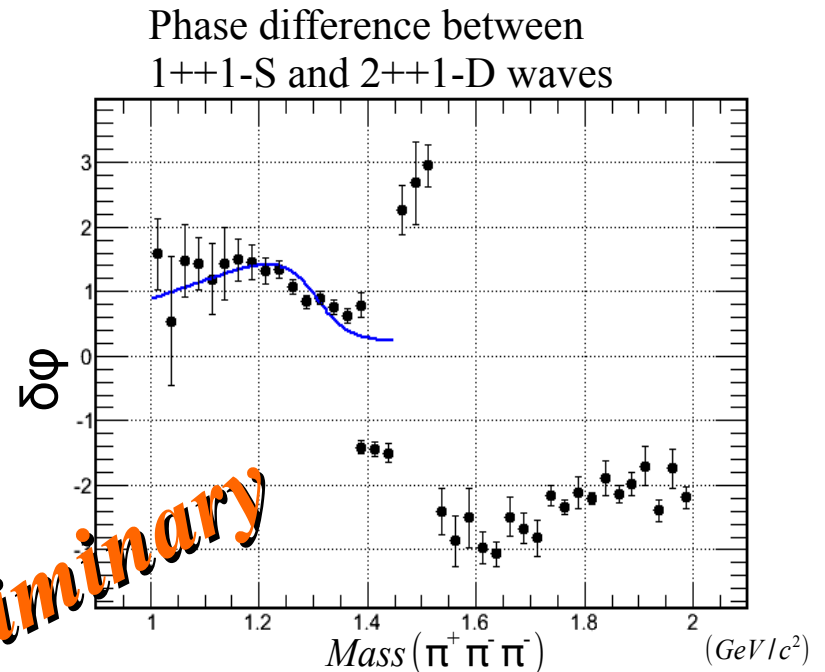
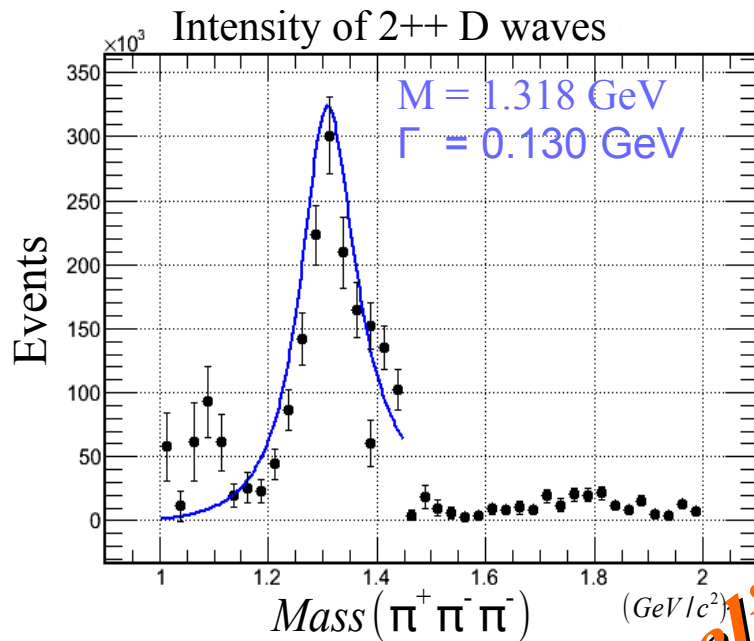
$$\gamma p \rightarrow \Delta^{++} \pi^+ \pi^- \pi^-$$



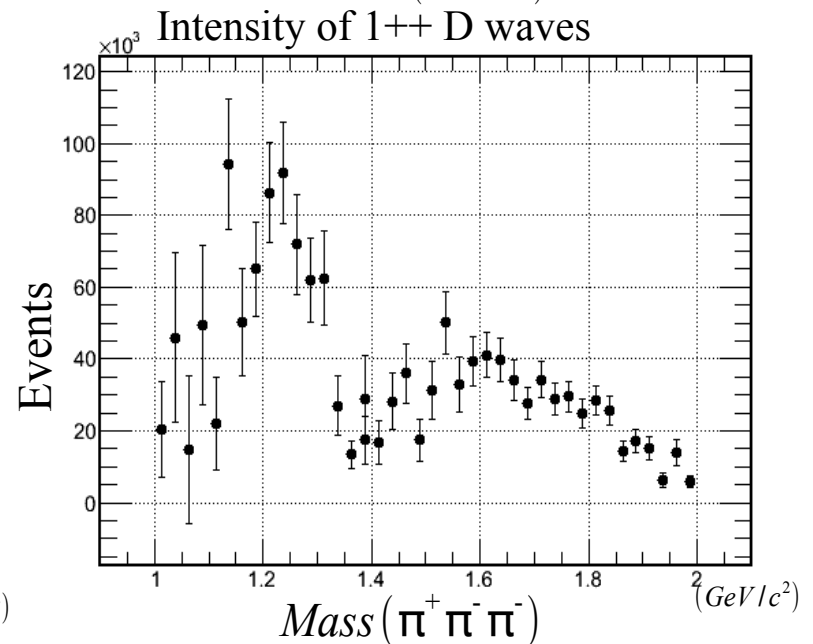
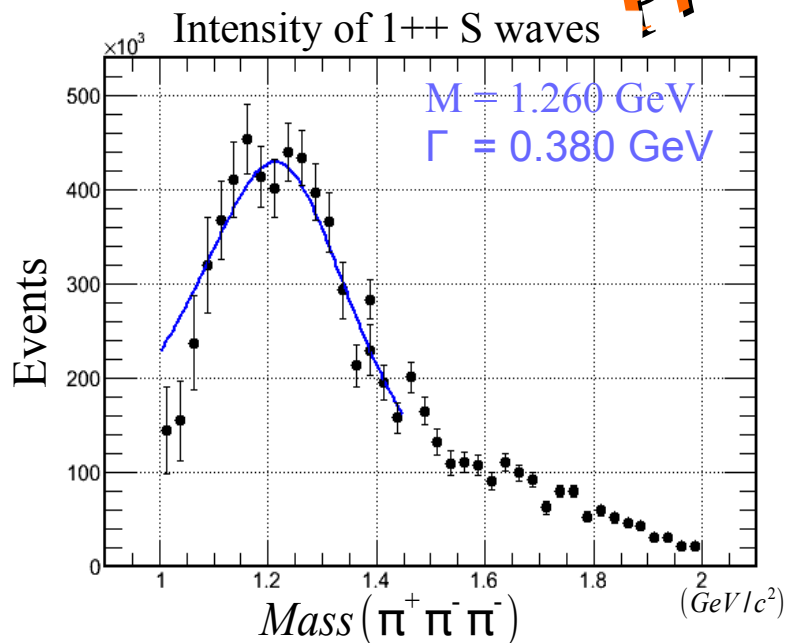
A total of 13 partial waves were included in the high mass region and 9 partial waves in the low mass region for the PWA fit presented here.

Partial waves of the 3π System off of the Δ^{++}

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



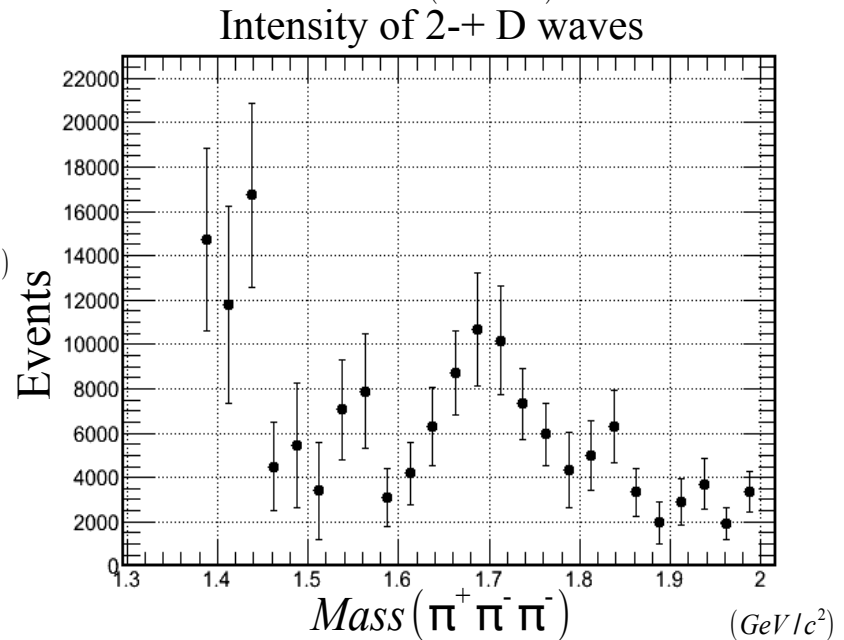
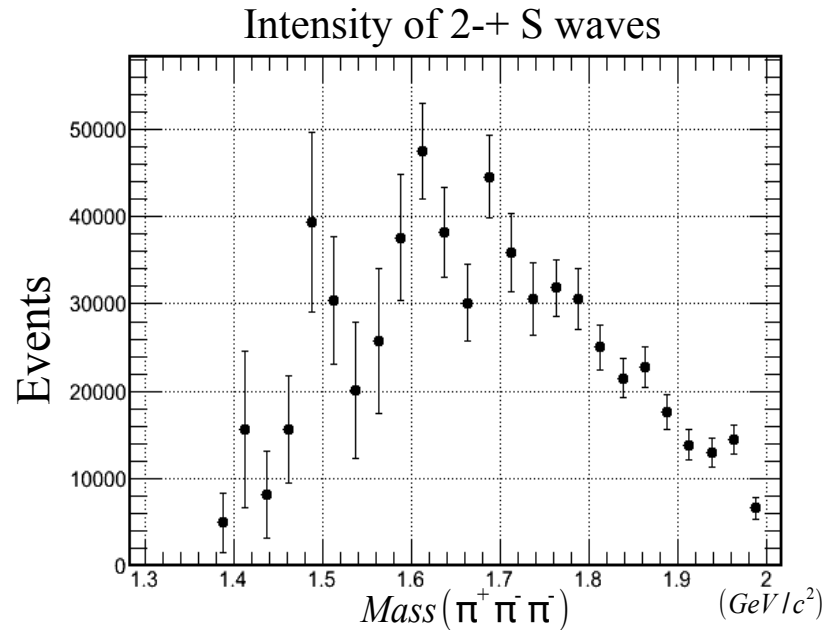
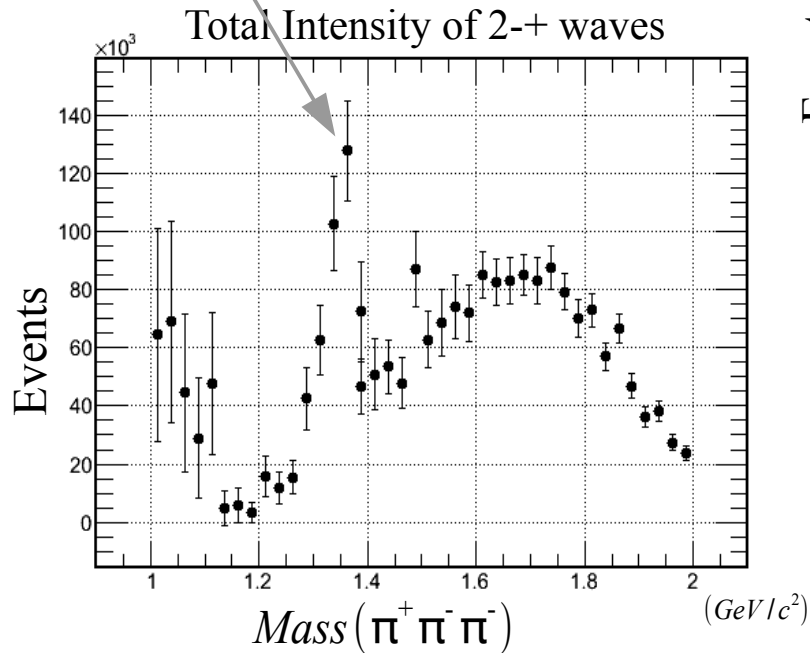
Preliminary



Curve is just to guide the eye

Preliminary

leakage of $a_2(1320)$ from the P-wave



The importance of the $J^{PC} = 1^{-+}$ partial wave is still being investigated.

The Photoproduction of Excited Strange Mesons in

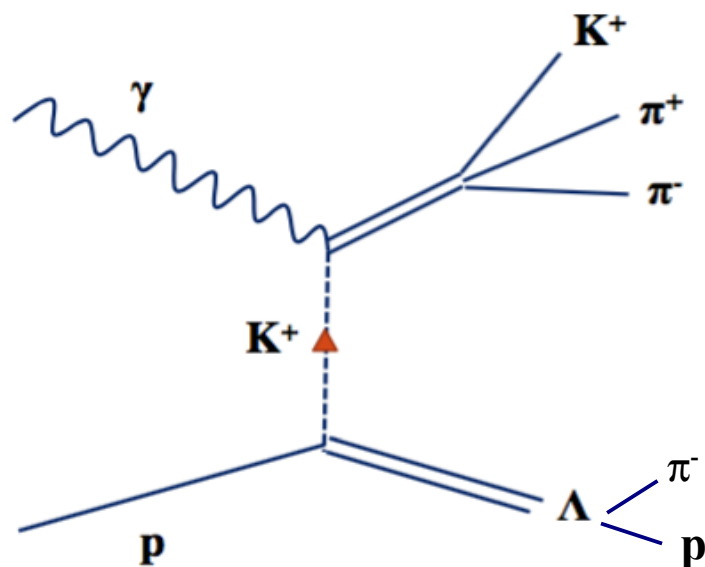
$$\gamma p \rightarrow \Lambda K^+ \pi^+ \pi^-$$

With CLAS at Jefferson Lab

Hussein Al Ghoul

Florida State University

Hadron 2015

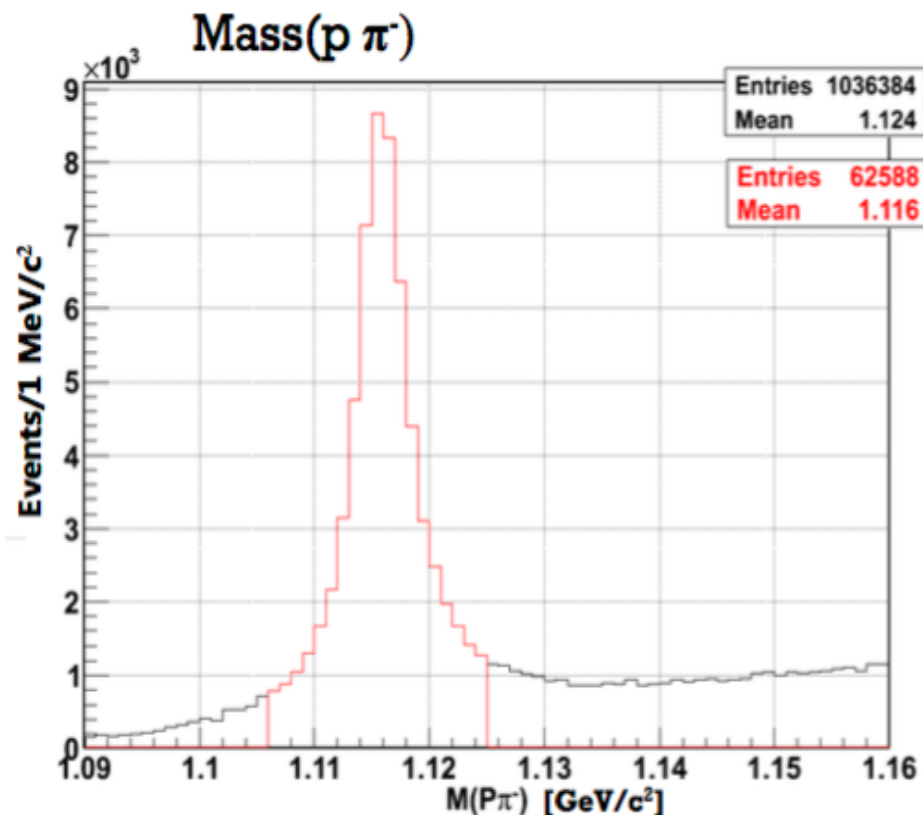
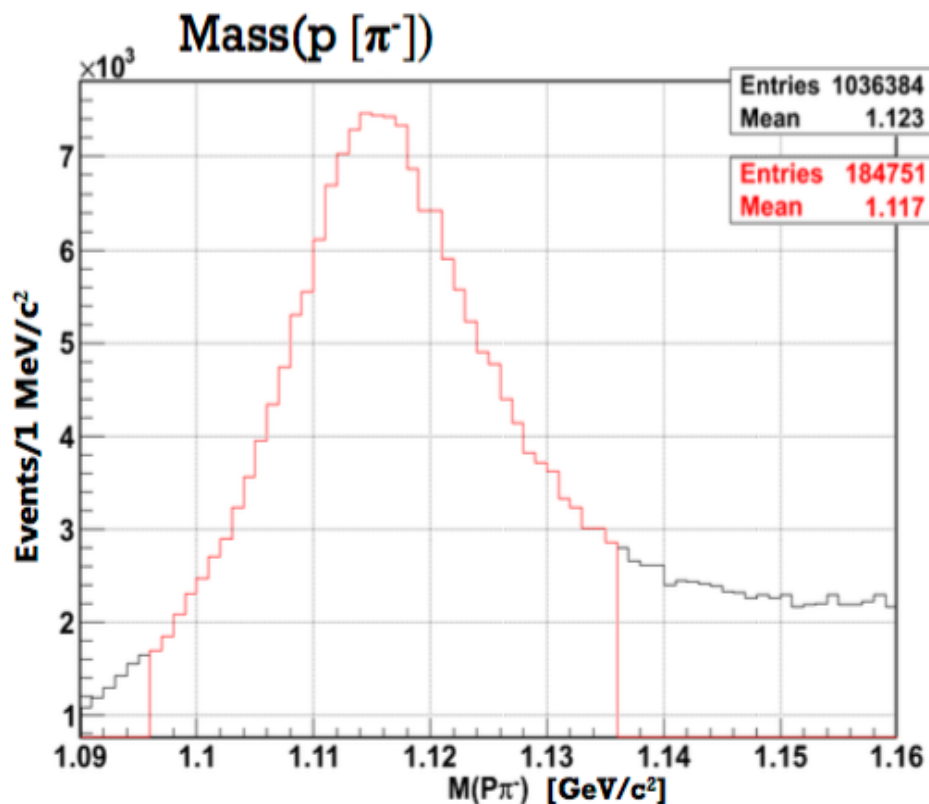


Lambda identification

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

All particles are observed in CLAS except for a missing π^- which is obtained via energy-momentum conservation.

$$\Lambda \rightarrow p \pi^-$$

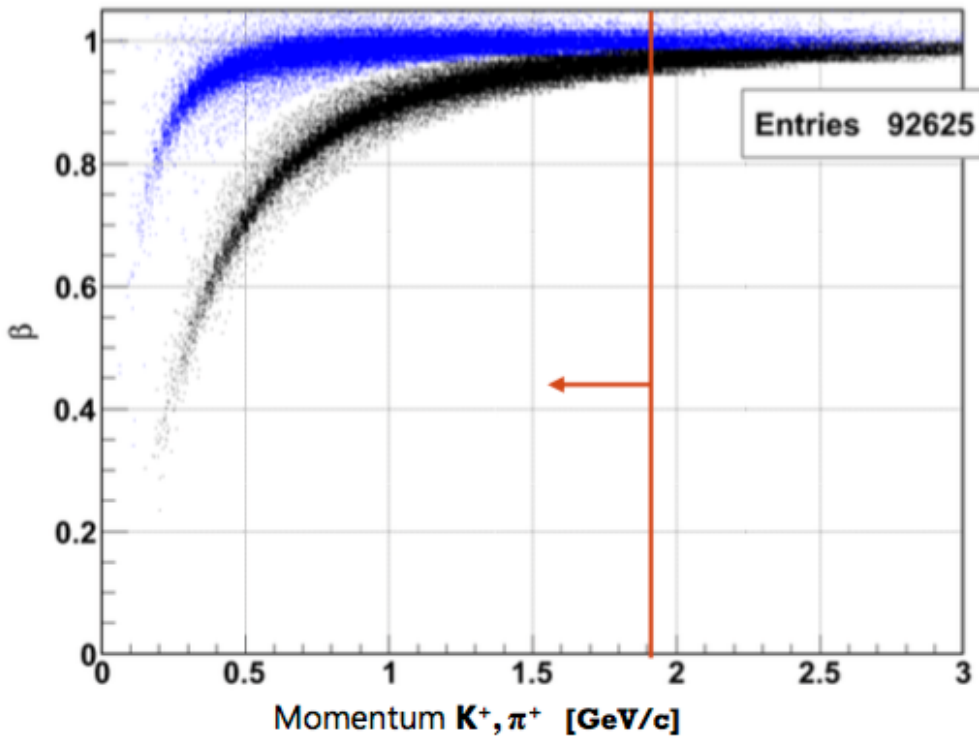


Future plans include kinematically constraining the Λ invariant mass

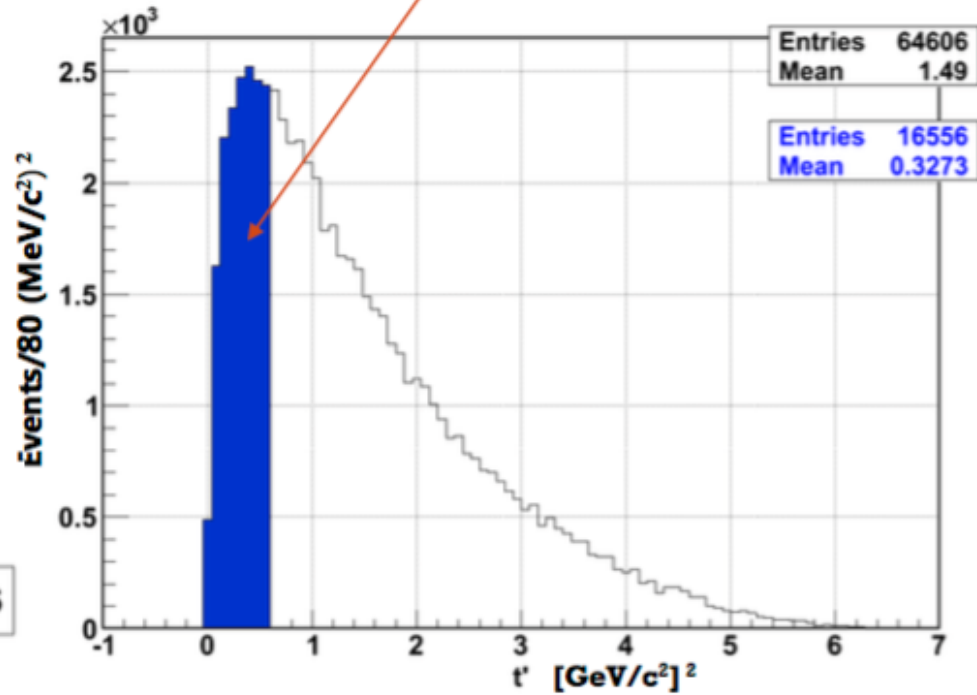


Background Reduction

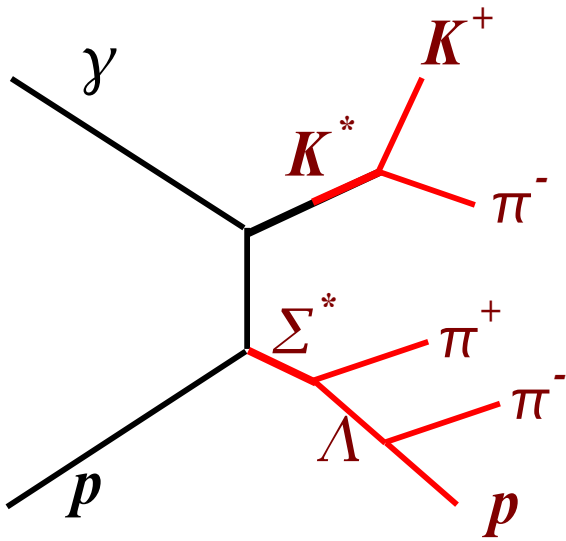
Only Events below the K/ π separation threshold are chosen.



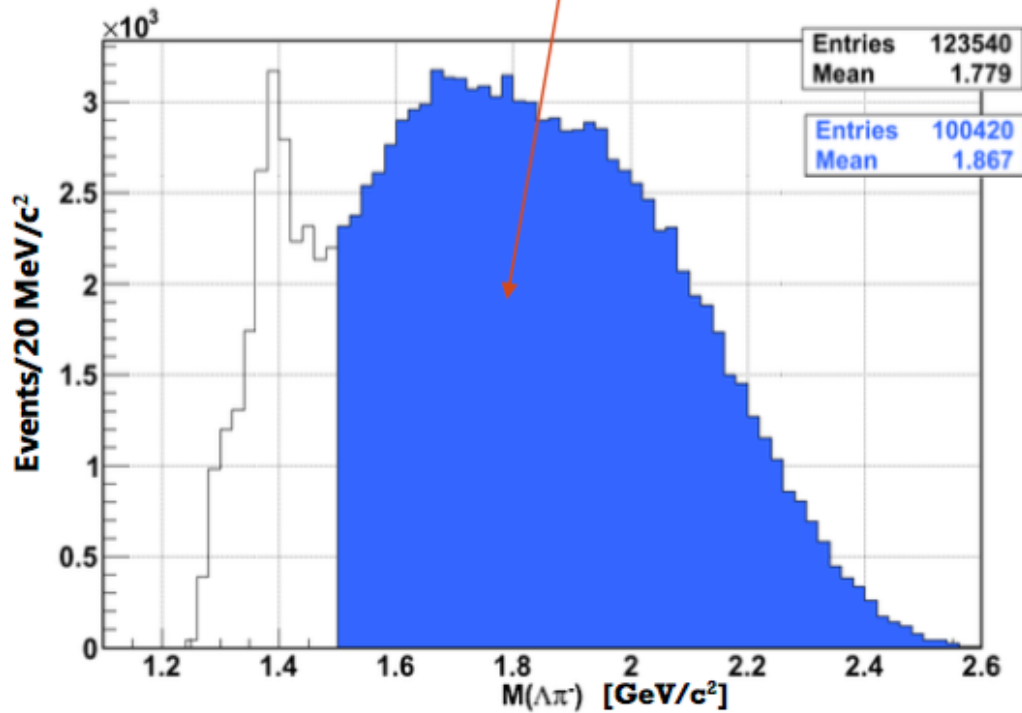
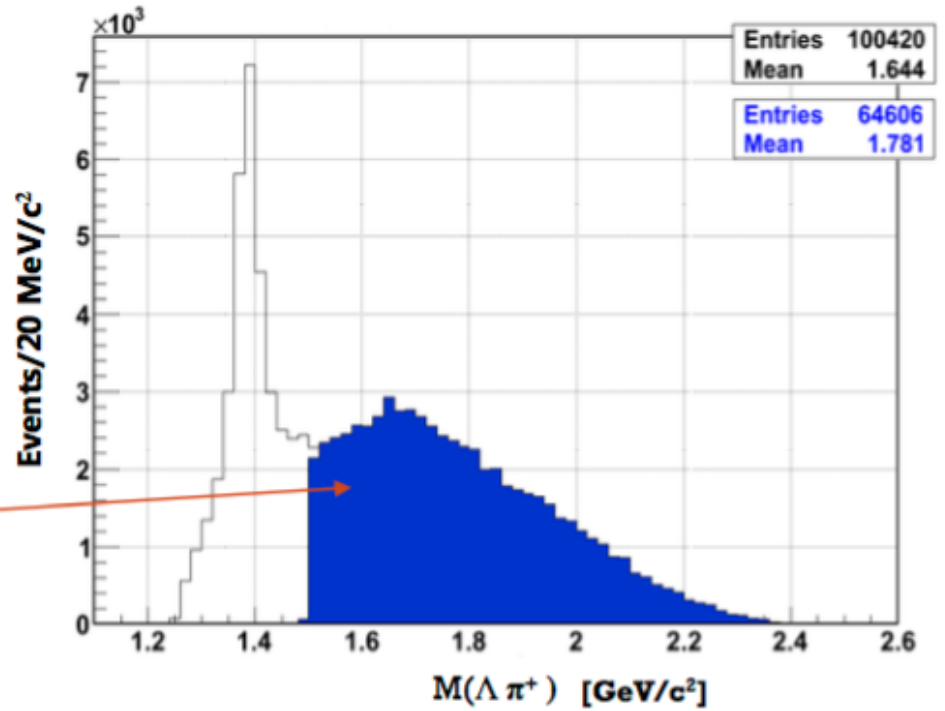
Low t' cut to enhance peripheral production



Baryon Backgrounds



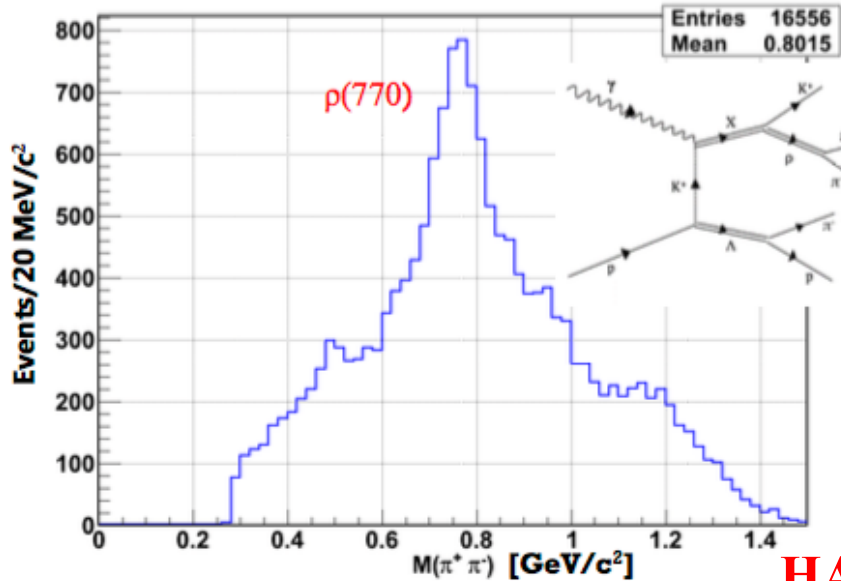
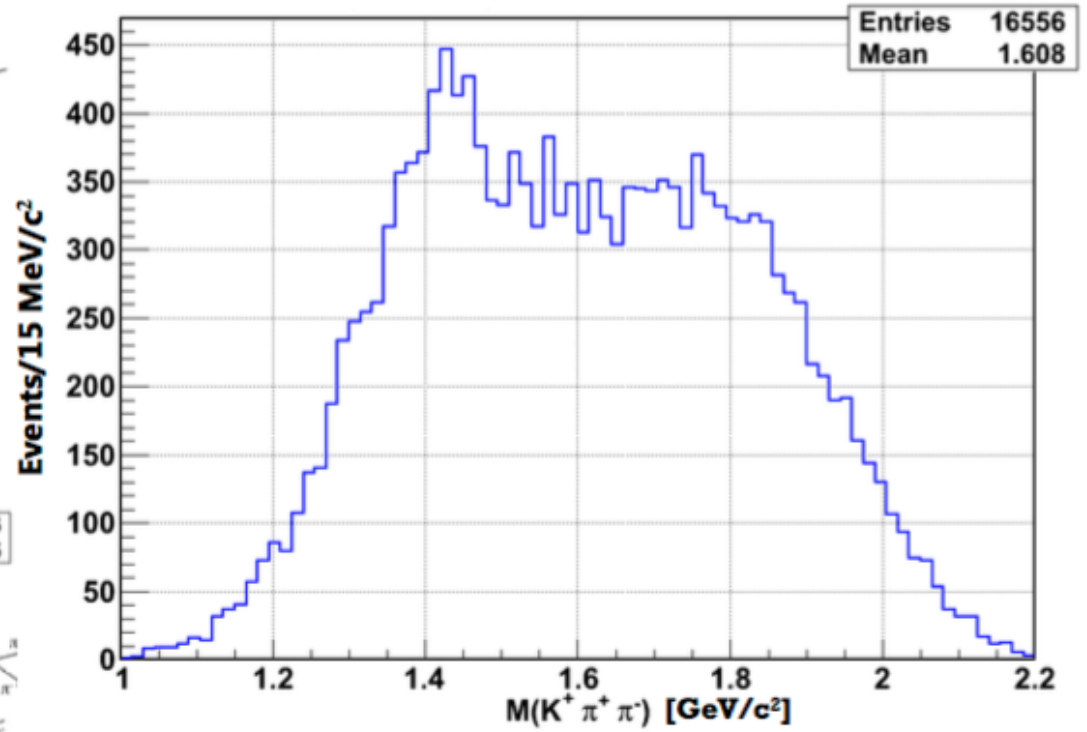
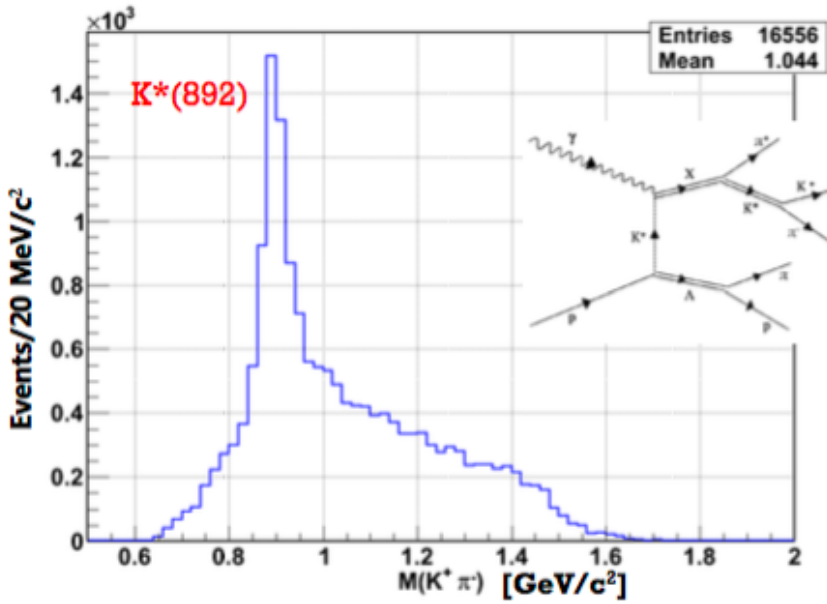
$\Sigma(1385)$ Background Eliminated



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Final Features



Partial Wave Analysis

- * 16,500 events subjected to mass independent partial wave analysis
 - worlds largest $\Lambda K^+ \pi^+ \pi^-$ photoproduction dataset to date
- * Isospin = $\frac{1}{2}$ amplitudes parameterized by $J^P M^E(\text{isobar})$
- * Main decay mode are $K^*(892)\pi^+$ & ρK^+ but also include: $K_2^*(1430)\pi^+$, σK^+ , $\kappa\pi^+$

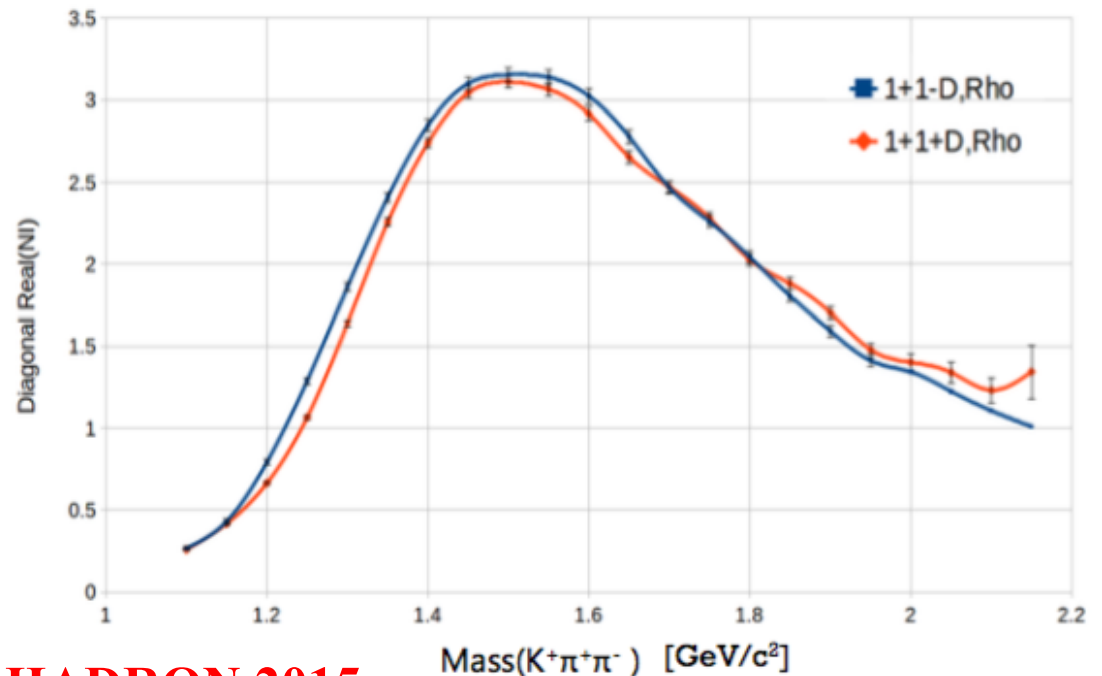
Normalization Integrals

$$\Psi = \int A_\alpha(\tau_i) A_\alpha^*(\tau_i) \eta(\tau_i) d\tau_i$$

- A Study of the dependence of the decay amplitudes on the $(K^+ \pi^+ \pi^-)$ mass

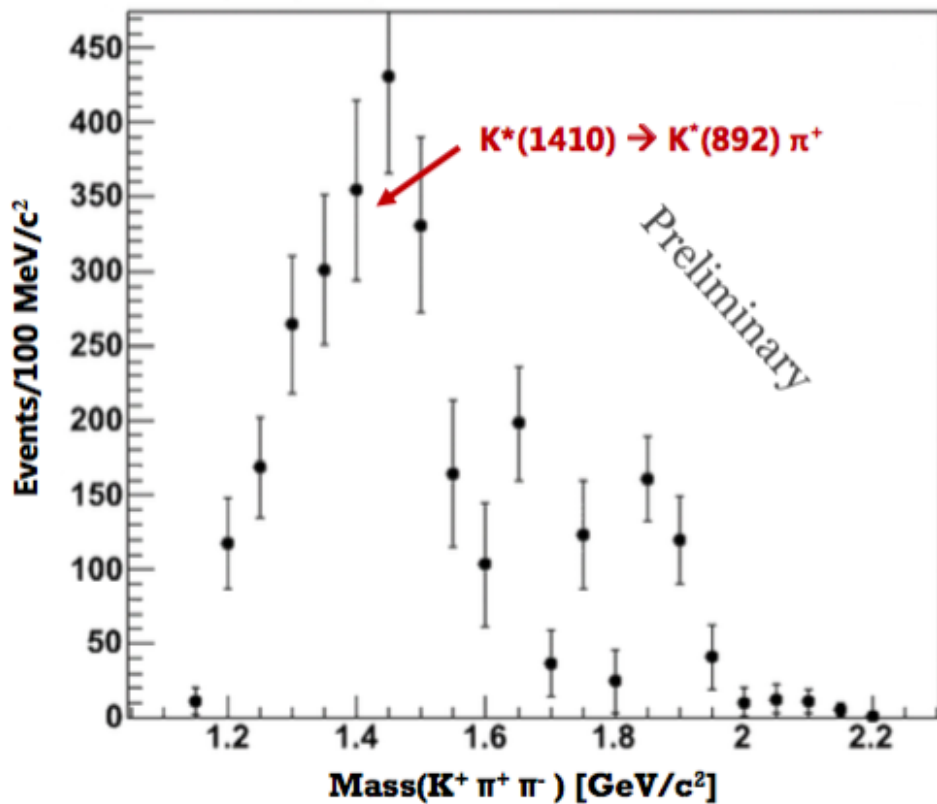
AccNI 1+D,Rho VS Mass(KPiPi)

- Mass independent fit
- Data is binned in 100 MeV bins, then shifted by 50 MeV
- 19 waves included in the fit
- Flat background included in the fit
- Rank 1 Spin density matrix



PWA Results

$1^- P, K^*(892) \pi^+$



$K^*(1410)$

$$I(J^P) = \frac{1}{2}(1^-)$$

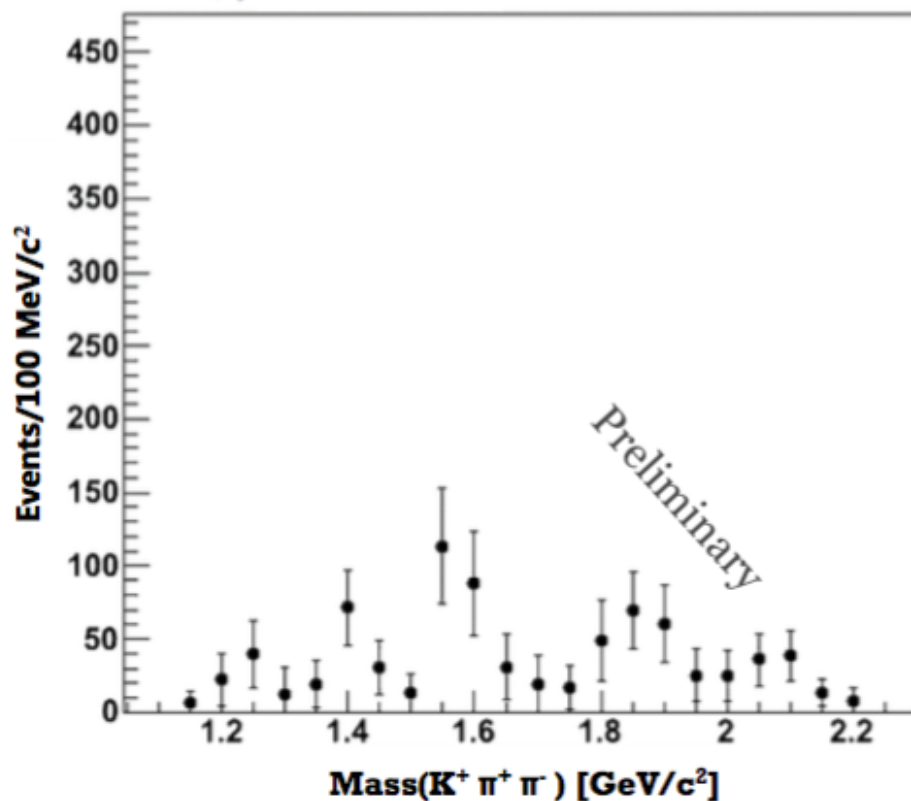
$1^- P$

Mass $m = 1414 \pm 15$ MeV ($S = 1.3$)

Full width $\Gamma = 232 \pm 21$ MeV ($S = 1.1$)

$K^*(1410)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	ρ (MeV/c)
$K^*(892) \pi$	> 40 %	95%	410
$K \pi$	(6.6 ± 1.3) %		612
$K \rho$	< 7 %	95%	305
γK^0	seen		619

$1^- P, \rho K^+$



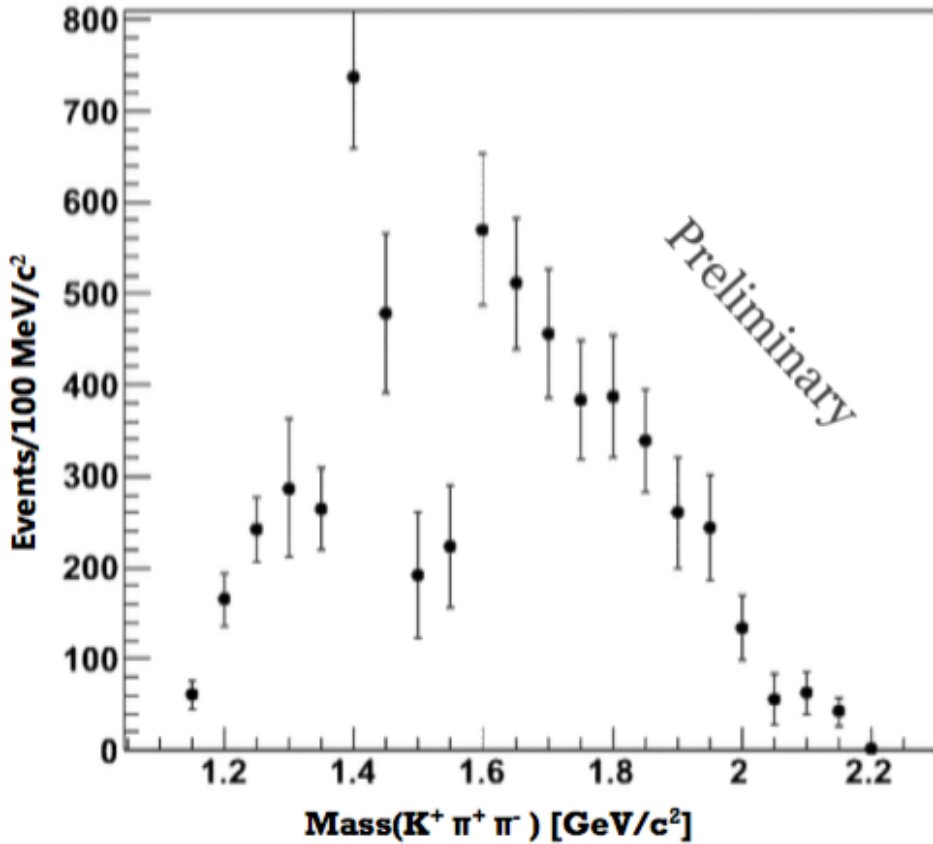
shown are the accepted yields



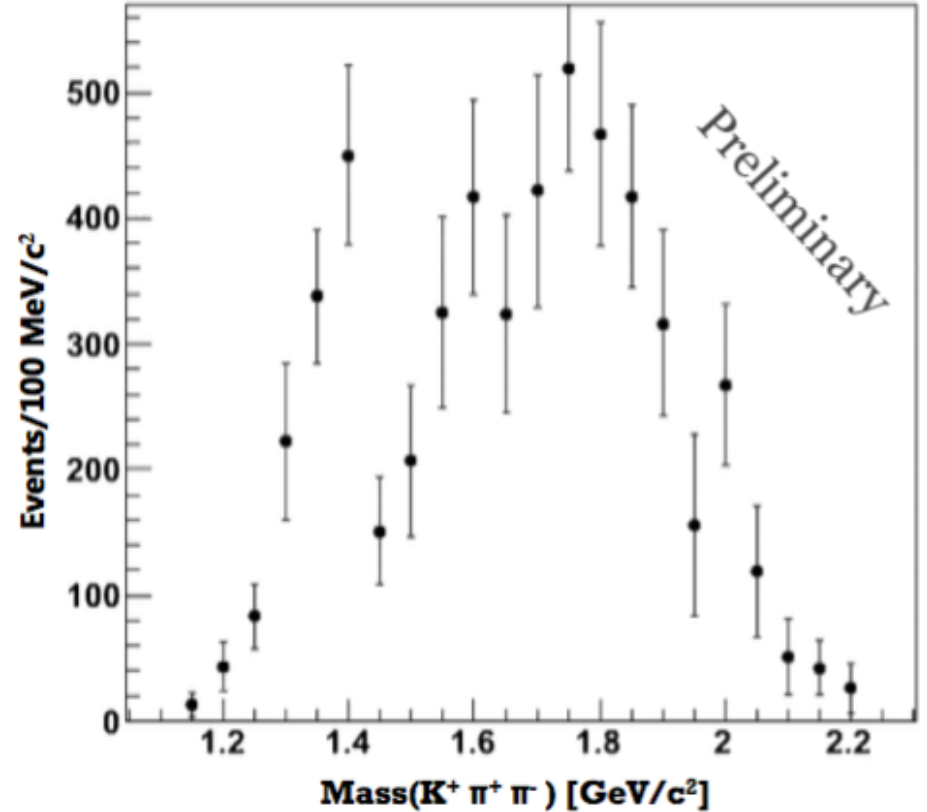
PWA Results

1⁺

1⁺, K*(892) π⁺ Intensity



1⁺, ρ K⁺ Intensity



K₁(1400)

$$I(J^P) = \frac{1}{2}(1^+)$$

Mass $m = 1403 \pm 7$ MeV

Full width $\Gamma = 174 \pm 13$ MeV (S = 1.6)

The K₁(1650), reported but not confirmed

- Mass: 1600-1900 MeV

- Width: 150 – 250 MeV

- Reported decay modes: K π π , KΦ

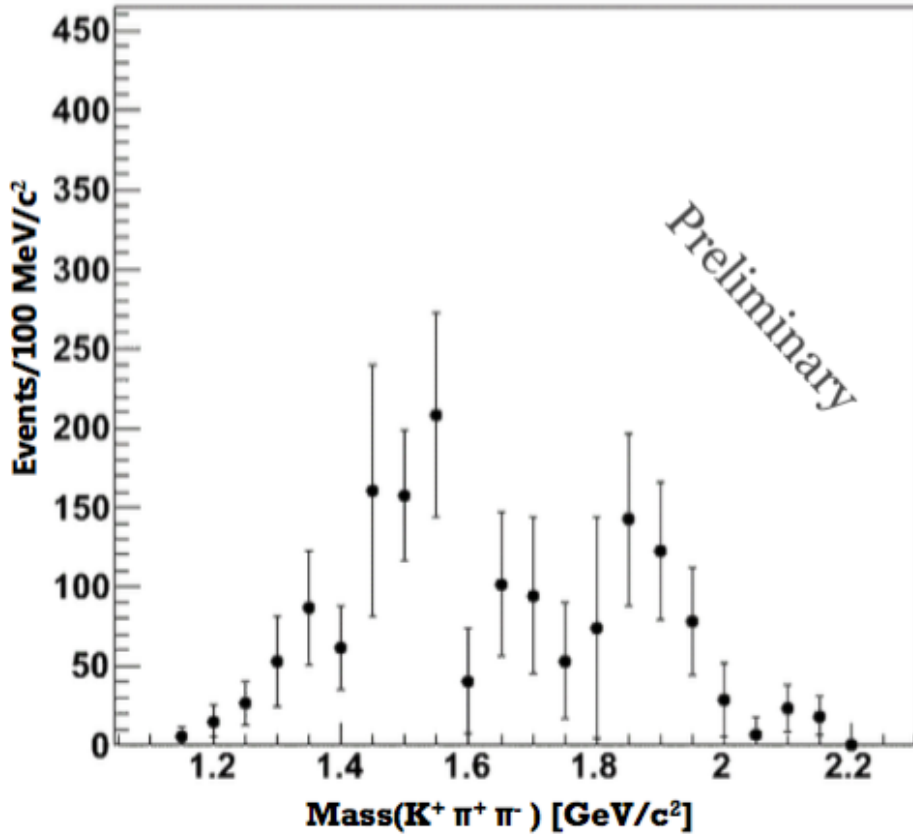


shown are the accepted yields

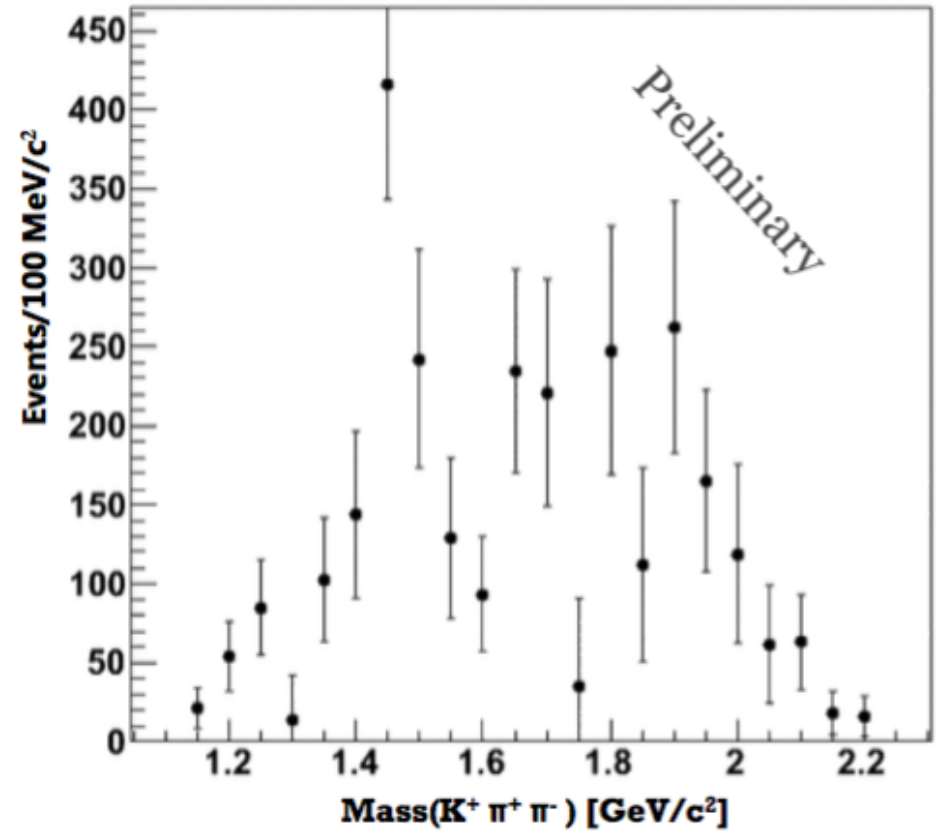
PWA Results

2⁺ D

2⁺ , K*(892) π⁺ Intensity



2⁺ , ρ K⁺ Intensity



K₂^{*}(1430)

$$I(J^P) = \frac{1}{2}(2^+)$$

- K₂^{*}(1430)[±] mass $m = 1425.6 \pm 1.5$ MeV (S = 1.1)
- K₂^{*}(1430)⁰ mass $m = 1432.4 \pm 1.3$ MeV
- K₂^{*}(1430)[±] full width $\Gamma = 98.5 \pm 2.7$ MeV (S = 1.1)
- K₂^{*}(1430)⁰ full width $\Gamma = 109 \pm 5$ MeV (S = 1.9)



shown are the accepted yields

See Aristeidis and Hussein for details