Strange and Vector Meson Photoproduction in CLAS of Jefferson Lab: Analysis Highlights from Idaho State University

7th Partial Wave Workshop
Camogli, Italy

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(CLAS Collaboration)

23 September 2013

Supported in part by the U.S. National Science Foundation under grant NSF-PHY-1206082
and

POLARIZATION OBSERVABLES FROM THE PHOTOPRODUCTION OF ω MESONS USING LINEARLY POLARIZED PHOTONS

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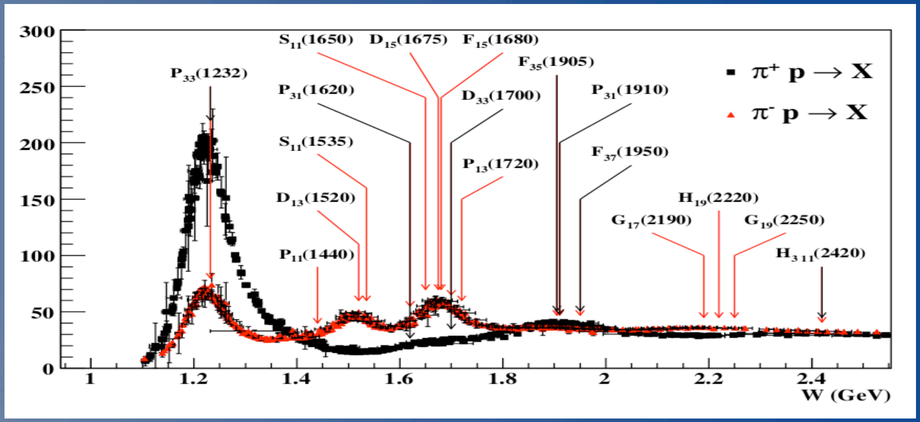
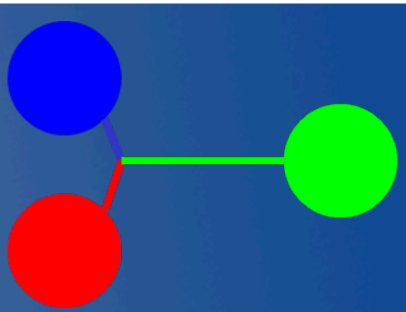
Supported in part by the U.S. National Science Foundation under grant NSF-PHY-1206082

"Missing" Resonances?



N*s are broadly overlapping
Hard to disentangle without polarization observables

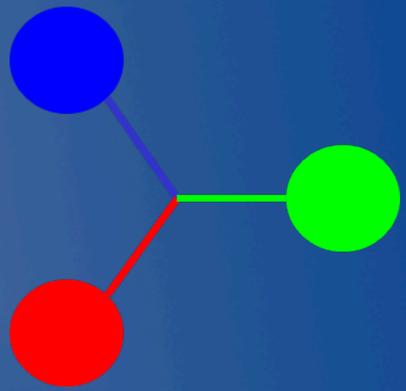
Problem: symmetric CQM predicts many more states than observed (in πN scattering)



Possible solutions:

1. **diquark model**

- fewer degrees-of-freedom
- open question: mechanism for q^2 formation?

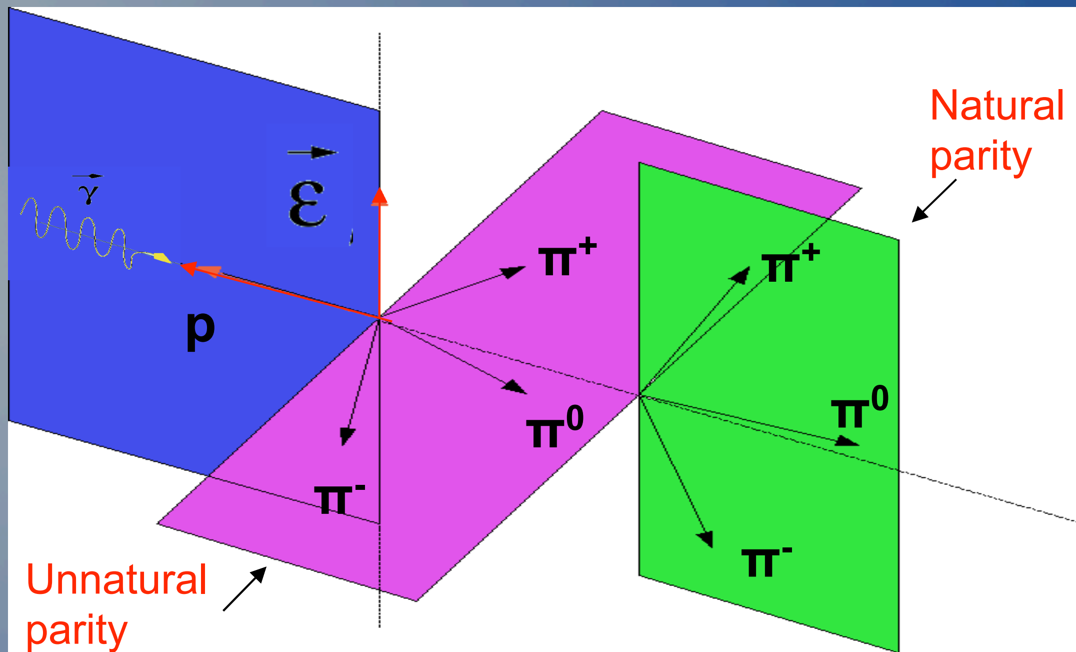


2. **not all states have been found**

- possible reason: decouple from πN-channel; model calculations: missing states couple to

$$\pi\pi N\ (\pi\Delta,\ \rho N),\ \ \omega N,\ \ KY$$

γ-coupling not suppressed – electromagnetic excitation is ideal



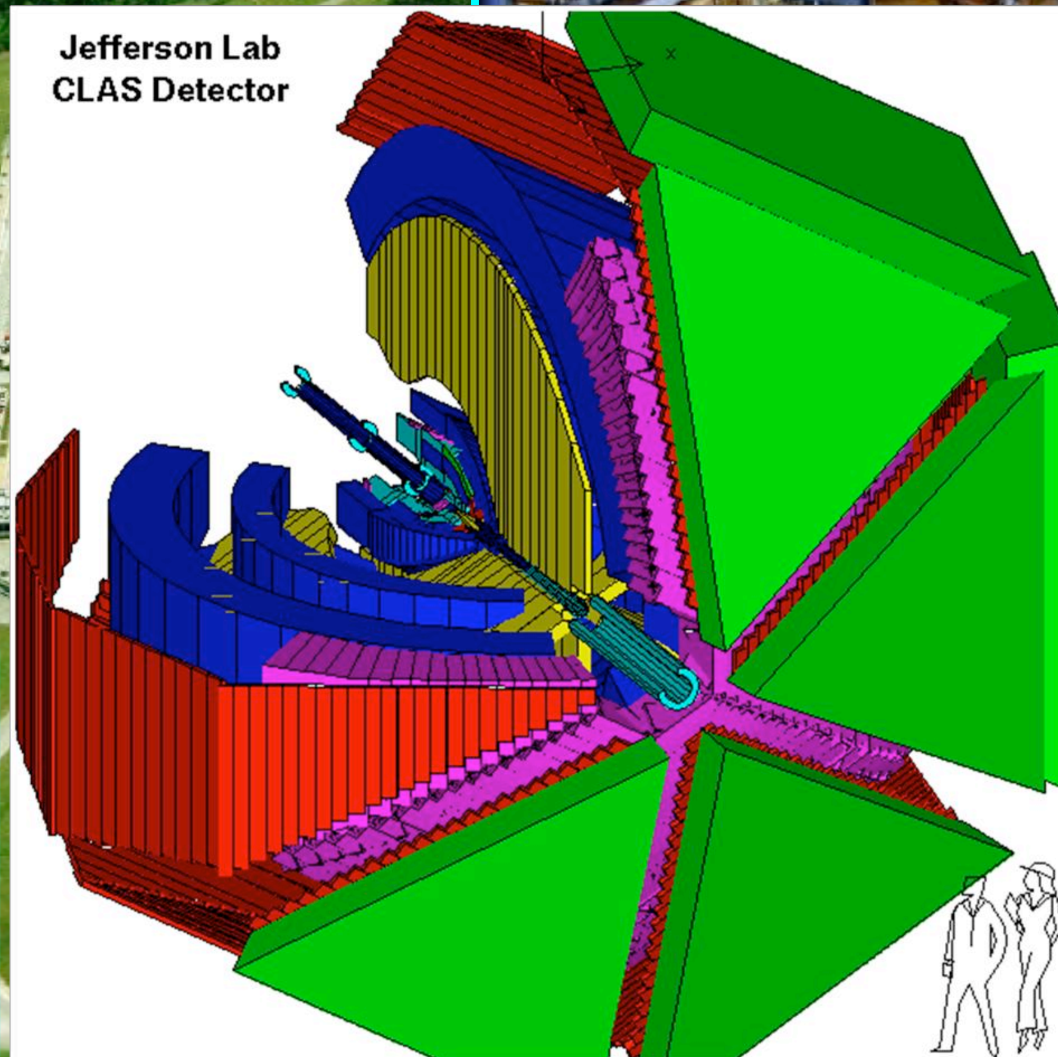
All models agree that:

π^0 exchange (unnatural parity) in the *t*-channel plays a significant role in the cross section of the electro- and photoproduction of ω mesons.

Baryon resonances contribute significantly to both the total and differential cross section in ω electro- and photoproduction in the central *t* regime.

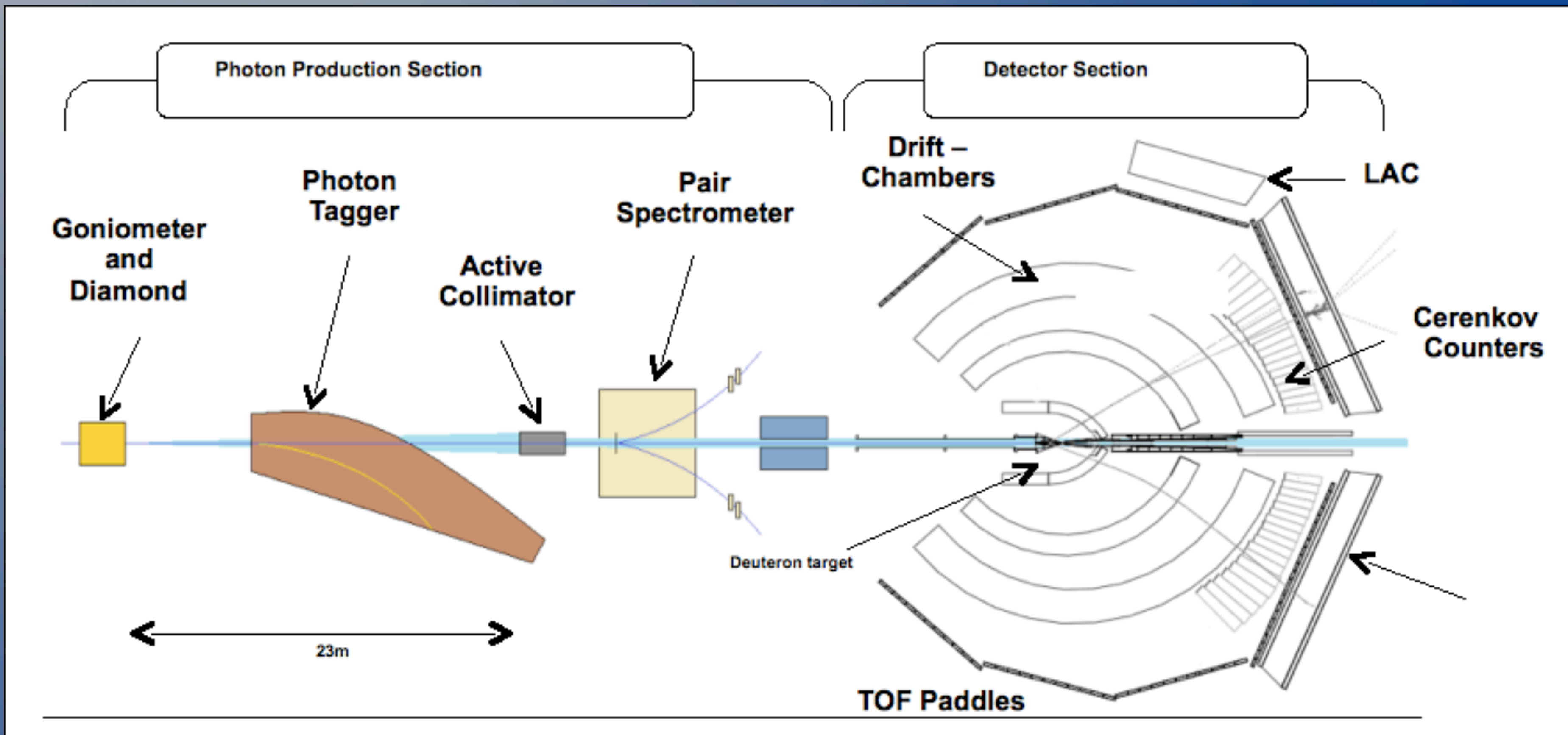
We urgently need polarized observables to disentangle which resonances and by how much these resonances contribute to the cross section.

CLAS and JLab



Jefferson Lab
THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

Coherent Bremsstrahlung Facility
and
The CEBAF* Large Acceptance Spectrometer (CLAS)

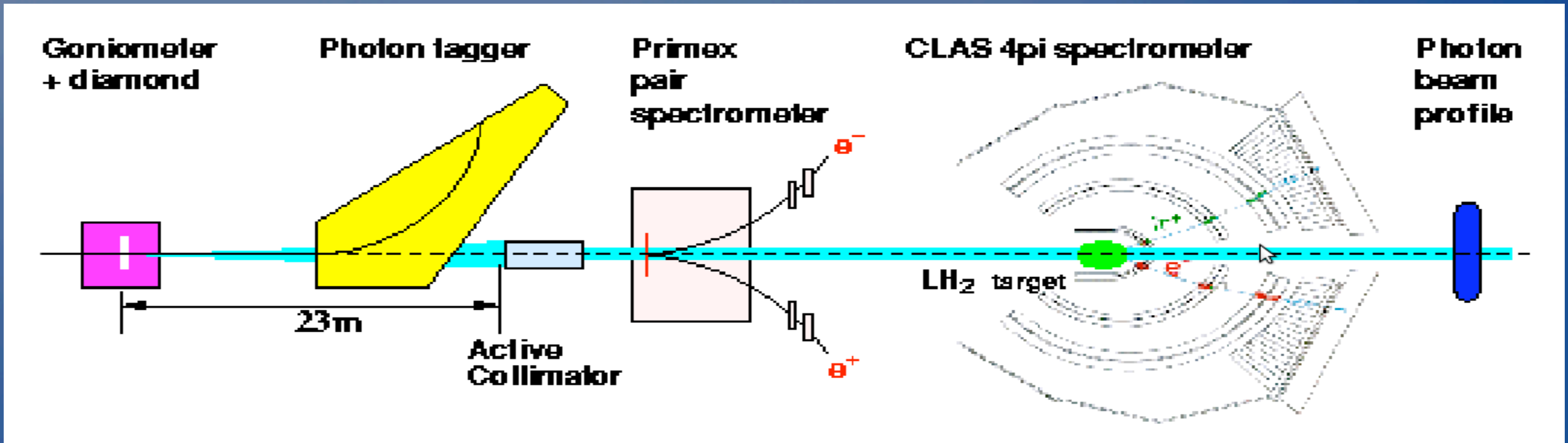


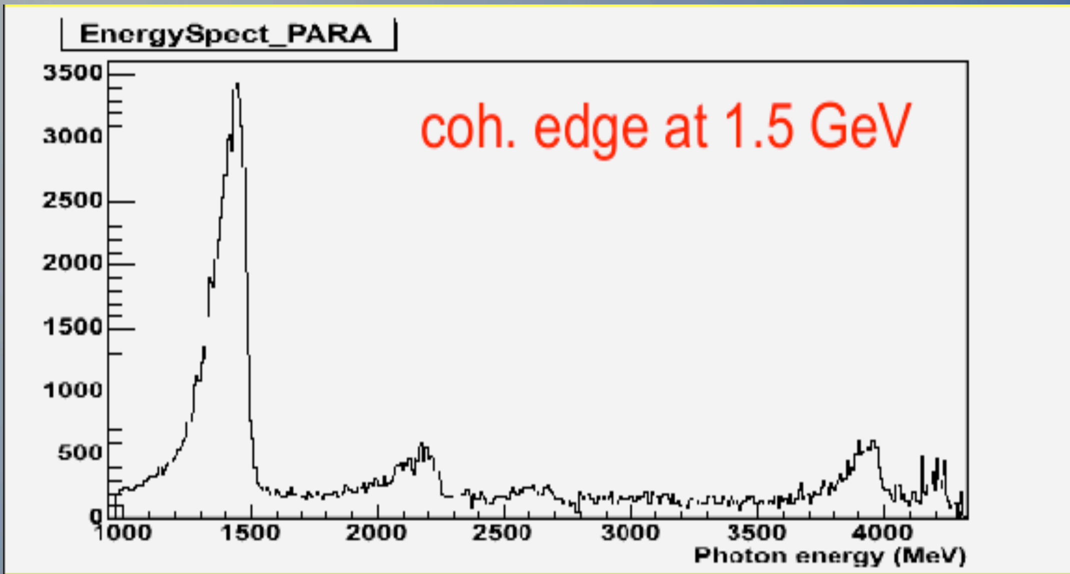
*CEBAF: Continuous Electron Beam Accelerator Facility

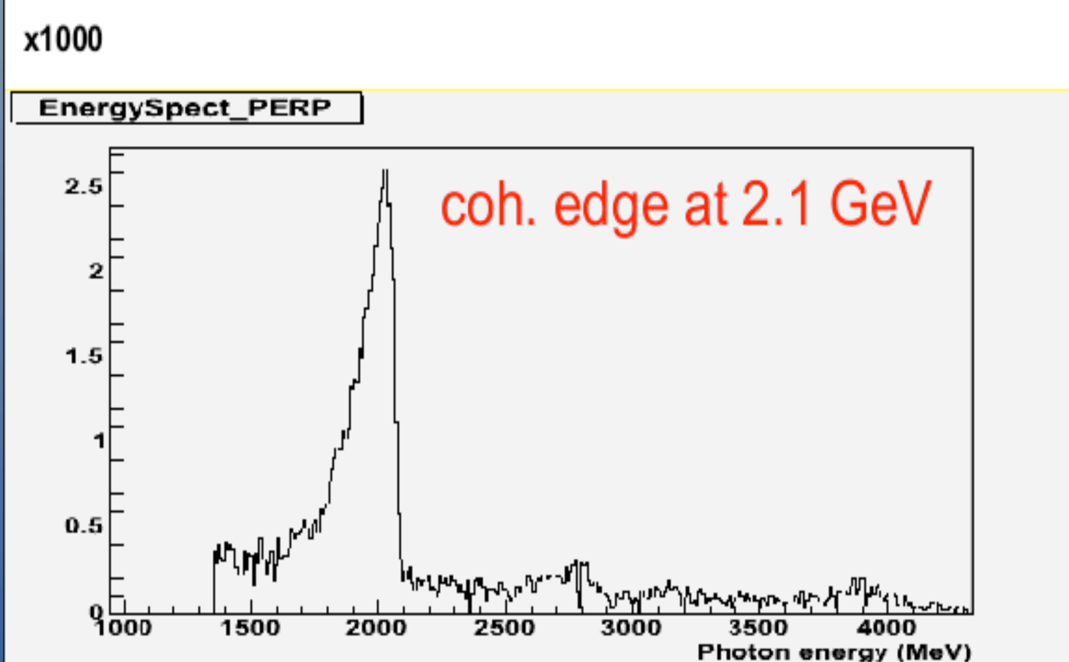
g8b RUN

Target type: Liquid H2
Electron end-point energy: 4.544 GeV
Two orientations for the photon polarization vector (parallel and perpendicular to the lab floor)

E_γ at the coherent peak (GeV)	Events (billion)
1.3	1.5
1.5	1.5
1.7	1.5
1.9	1.0
2.1	1.0
Amorphous data	1.8







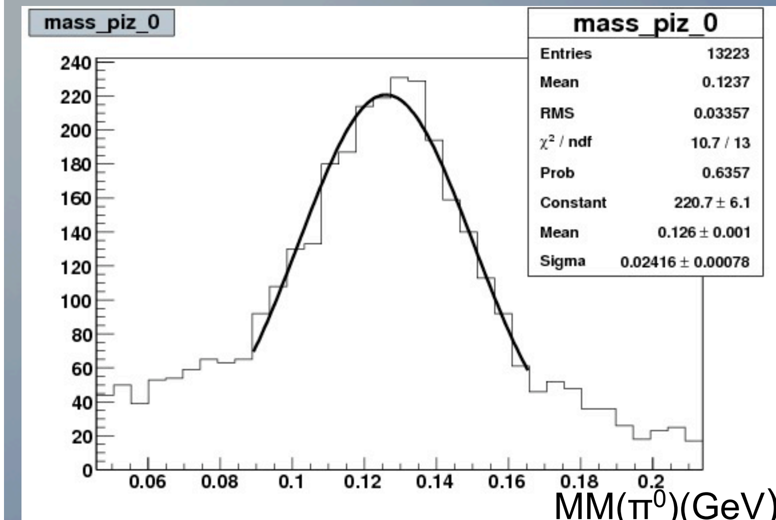
Cuts to the photon energy range are established for each data set.

The initial cuts for the data sets are:

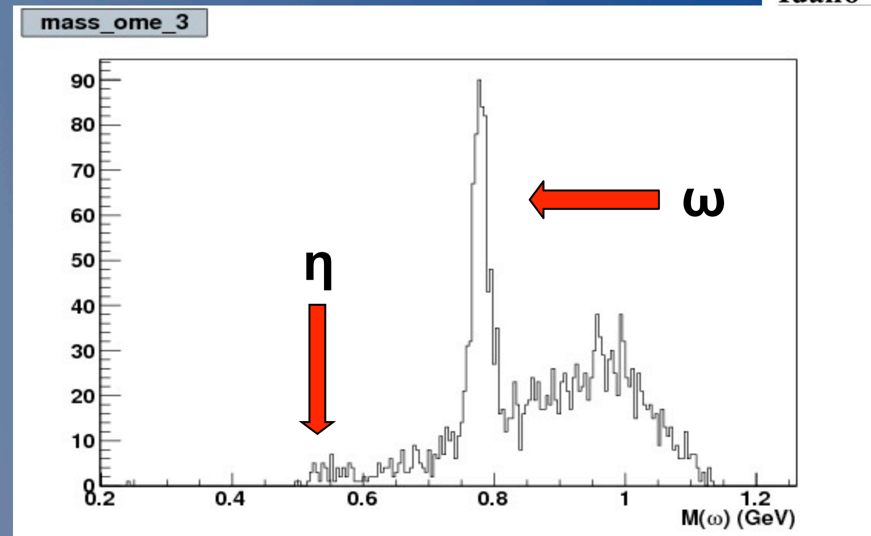
1.3 GeV –> 1.1 to 1.32 GeV
1.7 GeV –> 1.3 to 1.52 GeV
1.7 GeV –> 1.5 to 1.72 GeV
1.9 GeV –> 1.7 to 1.92 GeV
2.1 GeV –> 1.8 to 2.12 GeV

Idaho State UNIVERSITY

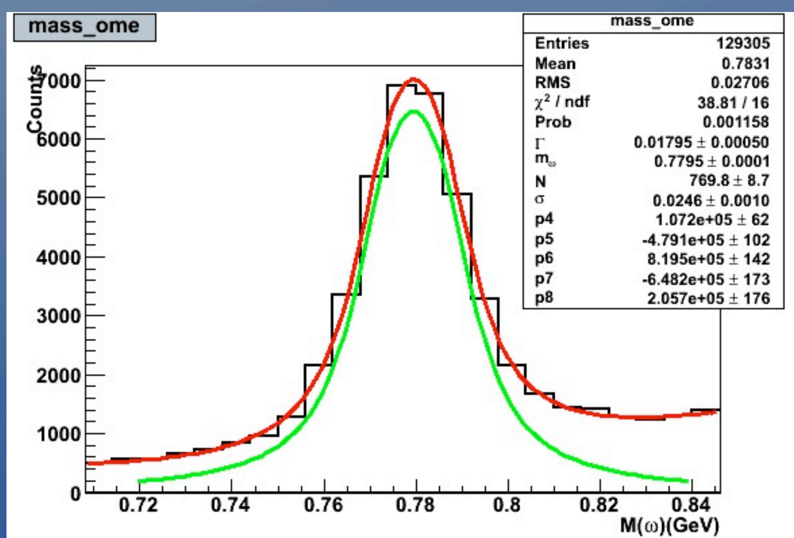
π^0 AND ω RECONSTRUCTION



Gaussian fit to the π^0 mass peak (PDG value: 134.9 MeV), found by using missing mass technique. 3 to 5 sigma cut is made.



ω meson invariant mass obtained by using the 4-momentum of the detected π^+ and π^-, and also from the reconstructed π^0.



Fitting function:

- Voigtian function for the ω signal.
- 4^{th} degree polynomial for the background.
- No constraints to the parameters.

The Decay Angular Distribution

The complete angular distribution $W(\cos\theta, \phi, \Phi)$ is given by,

$$\begin{aligned} W(\cos\theta, \phi, \Phi) &= W^0(\cos\theta, \phi, \rho^0_{\alpha\beta}) - P_\gamma \cos 2\Phi\, W^1(\cos\theta, \phi, \rho^1_{\alpha\beta}) \\ &\quad - P_\gamma \sin 2\Phi\, W^2(\cos\theta, \phi, \rho^2_{\alpha\beta}), \end{aligned}$$

where

$$\begin{aligned} W^0(\cos\theta, \phi, \rho^0_{\alpha\beta}) &= \frac{3}{4\pi}[\frac{1}{2}\sin^2\theta + \frac{1}{2}(3\cos^2\theta - 1)\rho^0_{00} \\ &\quad -\sqrt{2}\,\mathrm{Re}\,\rho^0_{10}\sin 2\theta\cos\phi - \rho^0_{1-1}\sin^2\theta\cos 2\phi] \end{aligned}$$

$$\begin{aligned} W^1(\cos\theta, \phi, \rho^1_{\alpha\beta}) &= \frac{3}{4\pi}[\rho^1_{11}\sin^2\theta + \rho^1_{00}\cos^2\theta \\ &\quad -\sqrt{2}\,\mathrm{Re}\,\rho^1_{10}\sin 2\theta\cos\phi - \rho^1_{1-1}\sin^2\theta\cos 2\phi] \end{aligned}$$

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

Linearly polarization gives access to six more density matrix elements

Those are calculated in ω-meson rest frame (e.g. Helicity Frame)

Density Matrix Elements

IF VDM:

All density matrix elements should be equal to **ZERO** except for two (ρ^1_{1-1} and $Im\{\rho^2_{1-1}\}$)

- ρ^1_{1-1}, $Im\{\rho^2_{1-1}\}$ = (1/2, -1/2 : Pomeron)
- ρ^1_{1-1}, $Im\{\rho^2_{1-1}\}$ = (-1/2, 1/2 : Meson)

If any of the other SDMEs are nonzero:

Interesting physics beyond VDM

SDMEs parametrization

calculated in ω-meson rest frame (e.g. Helicity Frame)

Acceptance

$$W(\cos\theta) = N[\tfrac{1}{2}(1 - \rho^0_{00})\sin^2\theta + \rho^0_{00}\cos^2\theta] \qquad \rho^0_{00} = \rho^1$$

$$W(\phi) = N[1 - 2\rho^0_{1-1}\cos 2\phi] \qquad \rho^0_{1-1} = \rho^2$$

$$W(\phi - \Phi) = N[1 + 2P_\gamma(\rho^1_{1-1} - \mathrm{Im}\rho^2_{1-1})\cos 2(\phi - \Phi)] \qquad \tfrac{1}{2}(\rho^1_{1-1} - \mathrm{Im}\rho^2_{1-1}) = \rho^3$$

$$W(\phi + \Phi) = N[1 + 2P_\gamma(\rho^1_{1-1} + \mathrm{Im}\rho^2_{1-1})\cos 2(\phi + \Phi)] \qquad \tfrac{1}{2}(\rho^1_{1-1} + \mathrm{Im}\rho^2_{1-1}) = \rho^4$$

$$W(\Phi) = N[1 - P_\gamma(2\rho^0_{1-1} + \rho^1_{00})\cos 2\Phi] \qquad 2\rho^1_{11} + \rho^1_{00} = \rho^5$$

$$\rho^1_{1-1} = \rho^3 + \rho^4$$

$$Im\rho^2_{1-1} = \rho^3 - \rho^4.$$

Acceptance effects cancels out

$$P_\gamma\rho^5\cos 2\Phi = \frac{W_{PARA} - W_{PERP}}{W_{PARA} + W_{PERP}}$$

From the Angular Distributions in the rest frame of the phi-meson we can extract:

SPIN DENSITY MATRIX ELEMENTS

$$\rho^1 = \rho^0_{00}$$

$$\rho^2 = \rho^0_{1-1}$$

$$\rho^3 = \frac{1}{2}(\rho^1_{1-1} - Im\rho^2_{1-1})$$

$$\rho^4 = \frac{1}{2}(\rho^1_{1-1} + Im\rho^2_{1-1})$$

$$\rho^1_{1-1} = \rho^3 + \rho^4$$

$$Im\rho^2_{1-1} = \rho^3 - \rho^4.$$

Those are calculated in ω-meson rest frame (e.g. Helicity Frame)

Σ can be used as a constraint for several SDMEs, since:

$$\Sigma = P_\gamma \frac{2(\rho^1_{11} + \rho^1_{1-1})}{1 - \rho^0_{00} + 2\rho^0_{1-1}}$$

If Helicity is conserved in the s-channel, then only two of the nine SDMEs are nonzero: $\rho^1_{1-1} = 0.5$ and $Im\rho^2_{1-1} = 0.5$, hence $\Sigma = 1$ when $P_\gamma = 1$ (with θ, ϕ determined in the helicity frame). Any deviation from this value is an indication that nondiffractive processes are present. If we assume natural parity as the production mechanism, then

$$\rho^1_{1-1} = 0.5,\ \rho^1_{00} = 0$$

If unnatural-parity exchange dominates, then

$$\rho^1_{1-1} = -0.5,\ \rho^1_{00} = 0$$

BEAM ASYMMETRY EXTRACTION

The Beam Asymmetry is determined by fitting the ratio PERP-PARA/PERP+PARA for each Cos Θ_{cm} and E_γ bin, to a cosine 2φ like function.

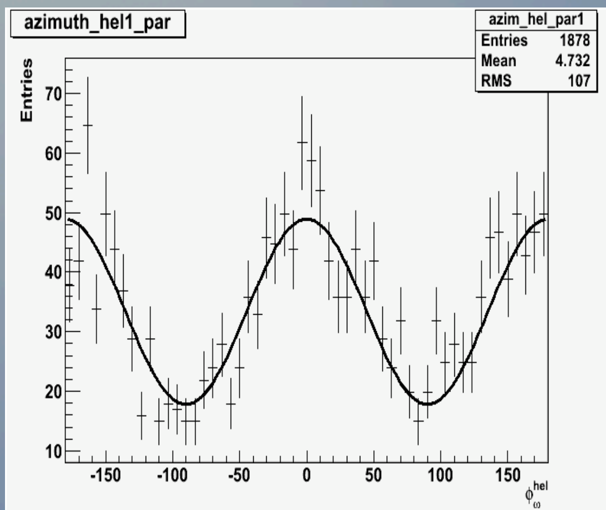
$$\begin{aligned}
\sigma_\perp &= \sigma_0(1 + P_\perp \Sigma \cos 2\phi) \\
\sigma_\parallel &= \sigma_0(1 + P_\parallel \Sigma \cos 2\phi + \pi) \\
\sigma_\parallel &= \sigma_0(1 - P_\parallel \Sigma \cos 2\phi)
\end{aligned}$$

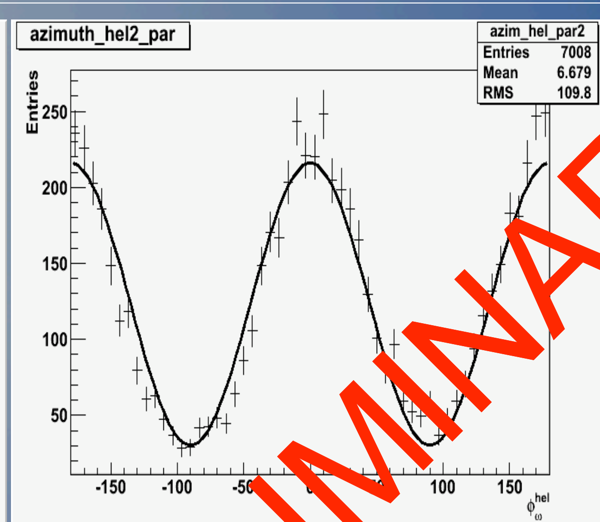
$$\frac{\sigma_\perp - \sigma_\parallel}{\sigma_\perp + \sigma_\parallel} = \frac{(\frac{N_\perp}{N_\parallel} - 1) - (\frac{N_\perp}{N_\parallel} P_\perp + P_\parallel)\Sigma \cos(2(\phi))}{(\frac{N_\perp}{N_\parallel} + 1) - (\frac{N_\perp}{N_\parallel} P_\perp - P_\parallel)\Sigma \cos(2(\phi))}$$

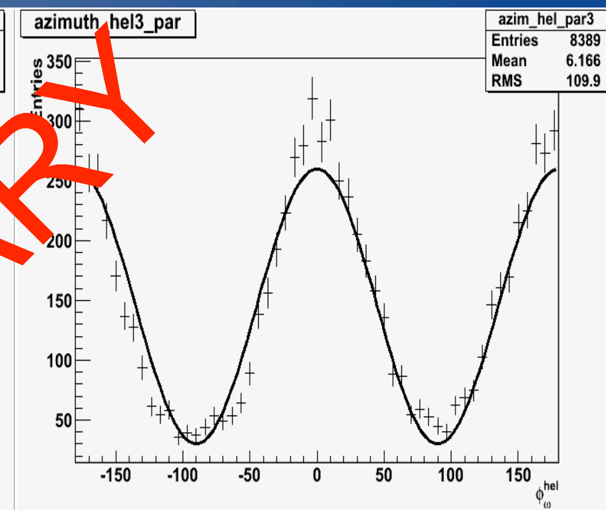
The ranges for the beam asymmetry cos theta bins are

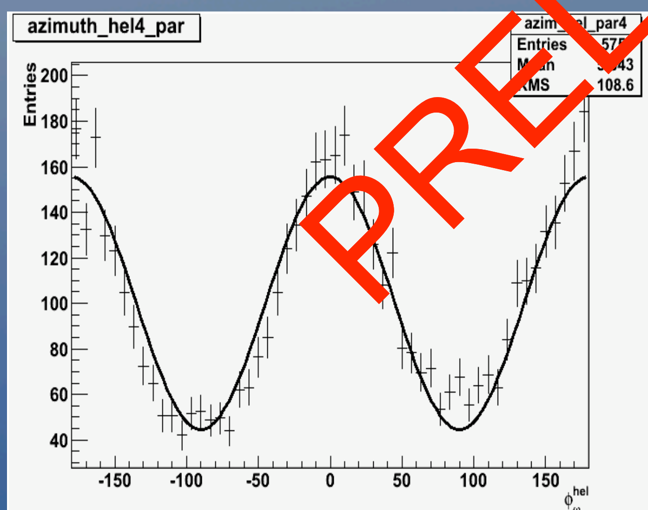
1. -0.9 to -0.6
2. -0.6 to -0.4
3. -0.4 to -0.2
4. -0.2 to 0.0
5. 0.0 to 0.2
6. 0.2 to 0.4
7. 0.4 to 0.6
8. 0.6 to 1.0

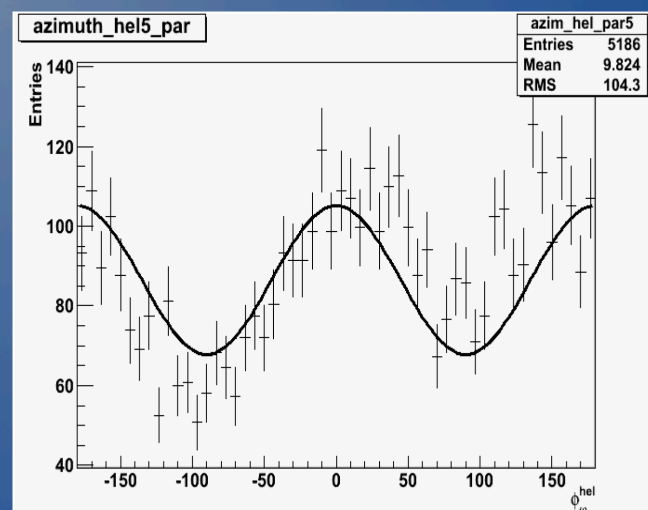
AZIMUTHAL DISTRIBUTIONS HELICITY FRAME
1.3 GeV, PARA





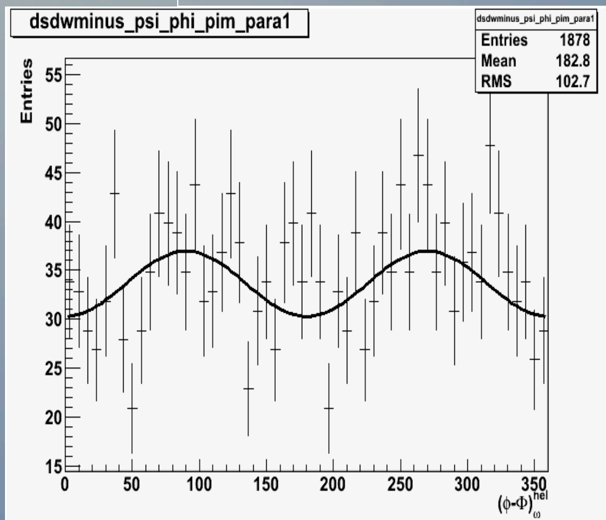


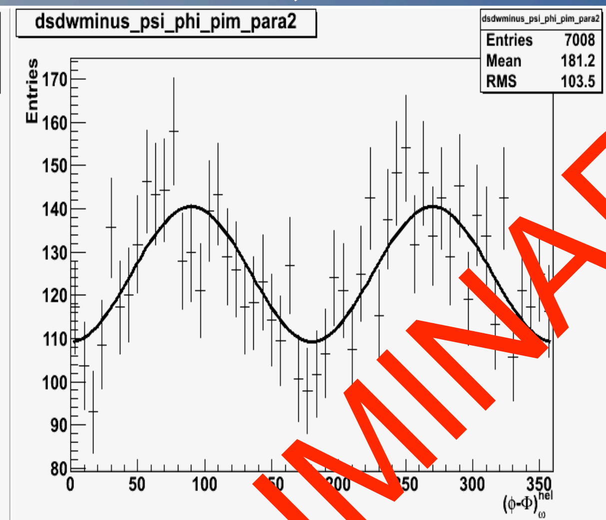


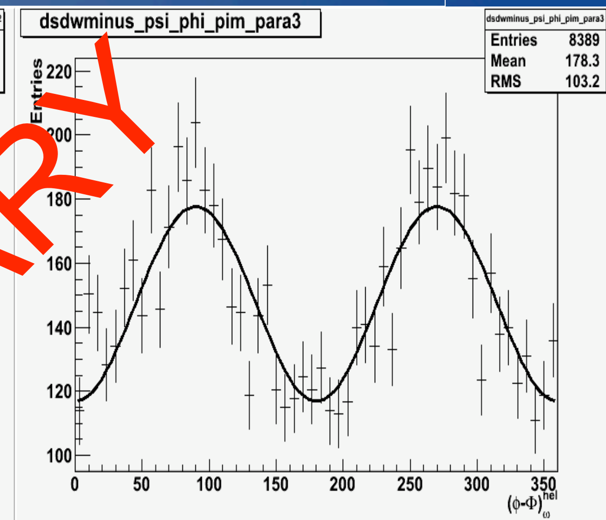


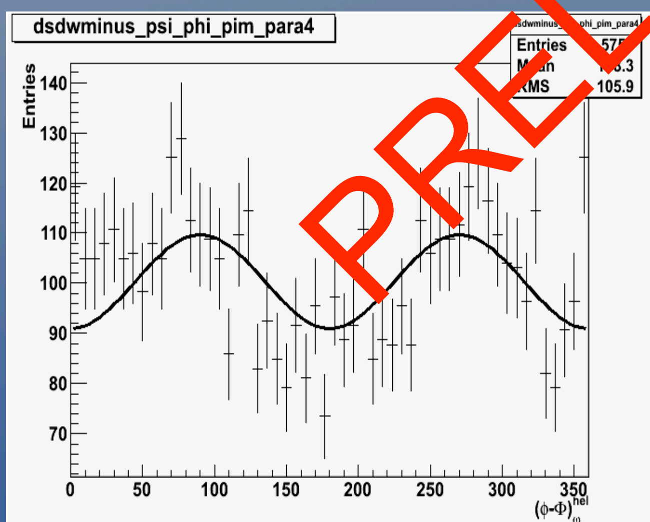
$$W(\phi) = N[1 - \rho^2 \cos 2\phi]$$

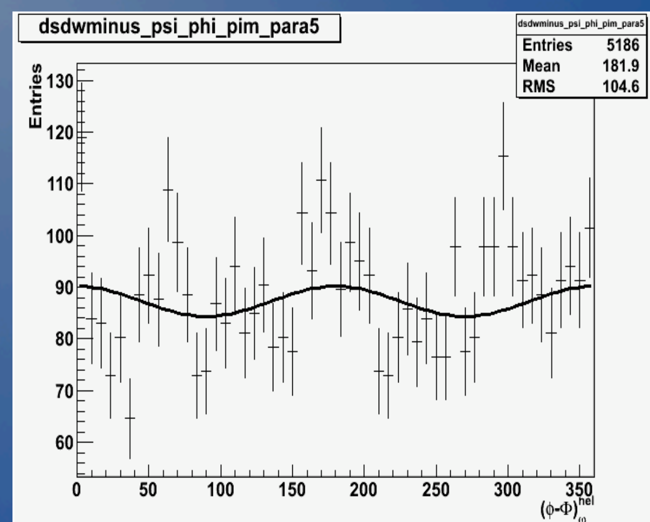
(φ-Φ) DISTRIBUTIONS
1.3 GeV, PARA





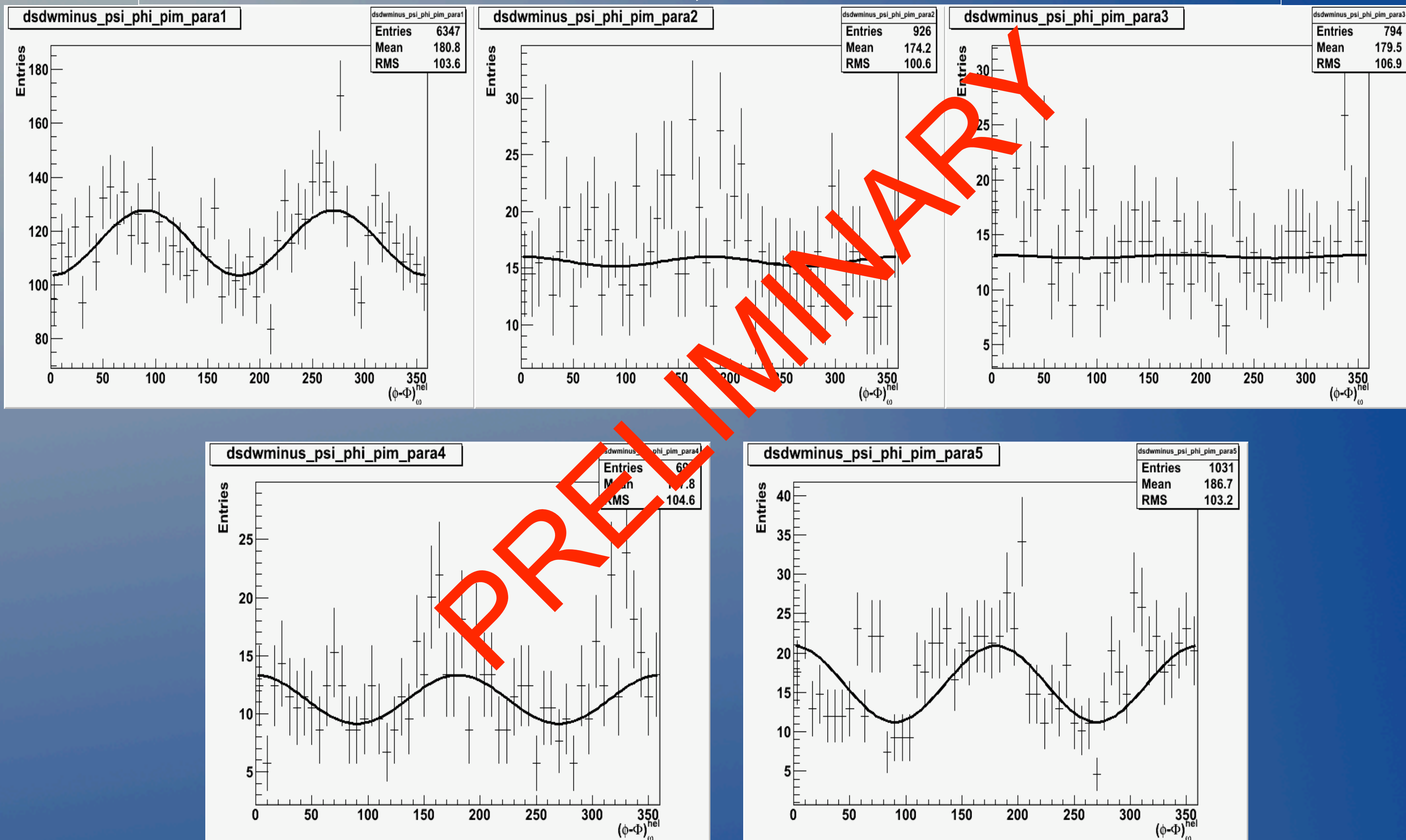






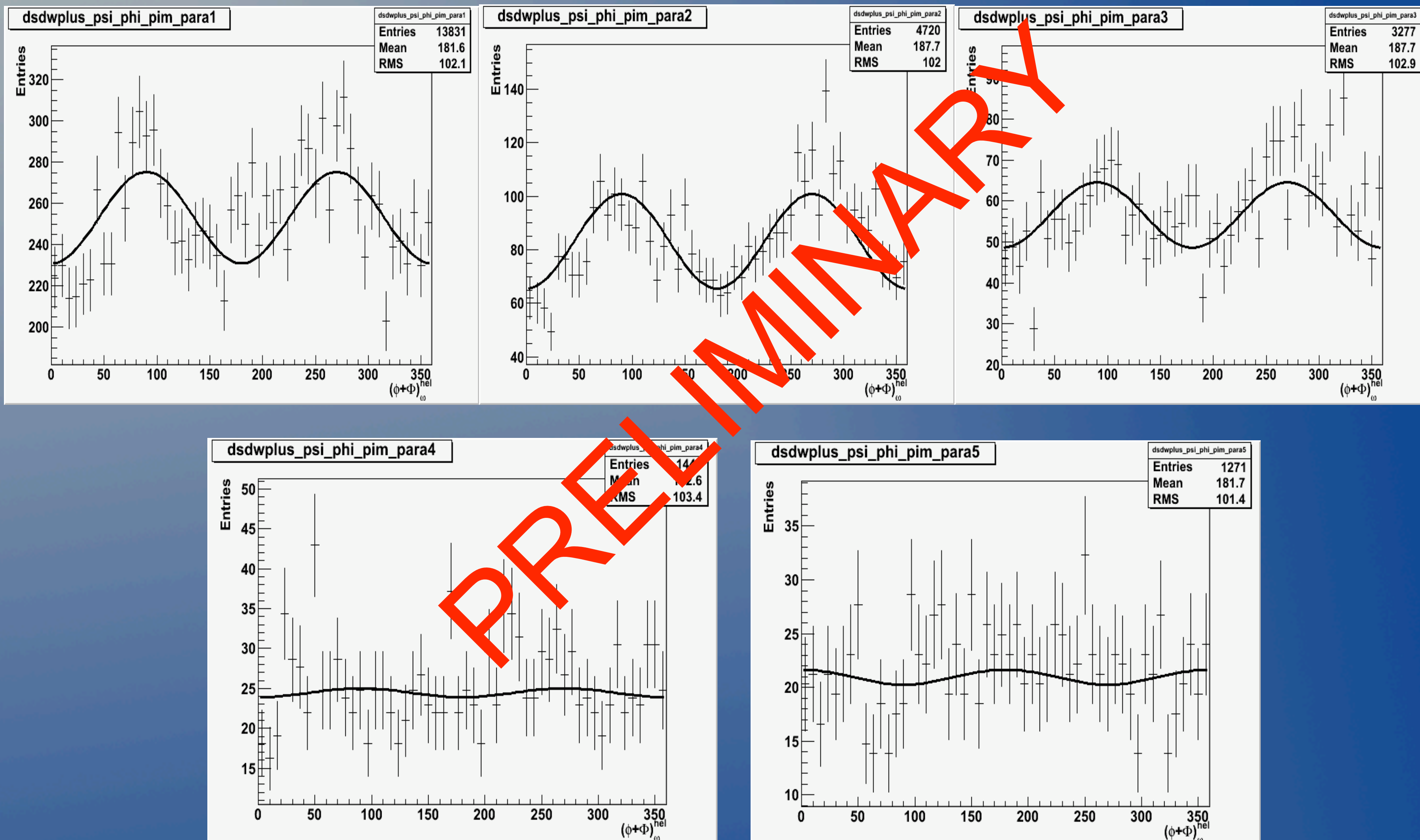
$$W(\phi - \Phi) \quad = \quad N[1 + 2P_\gamma \rho^3 \cos 2(\phi - \Phi)]$$

(φ-Φ) DISTRIBUTIONS
1.7 GeV, PARA



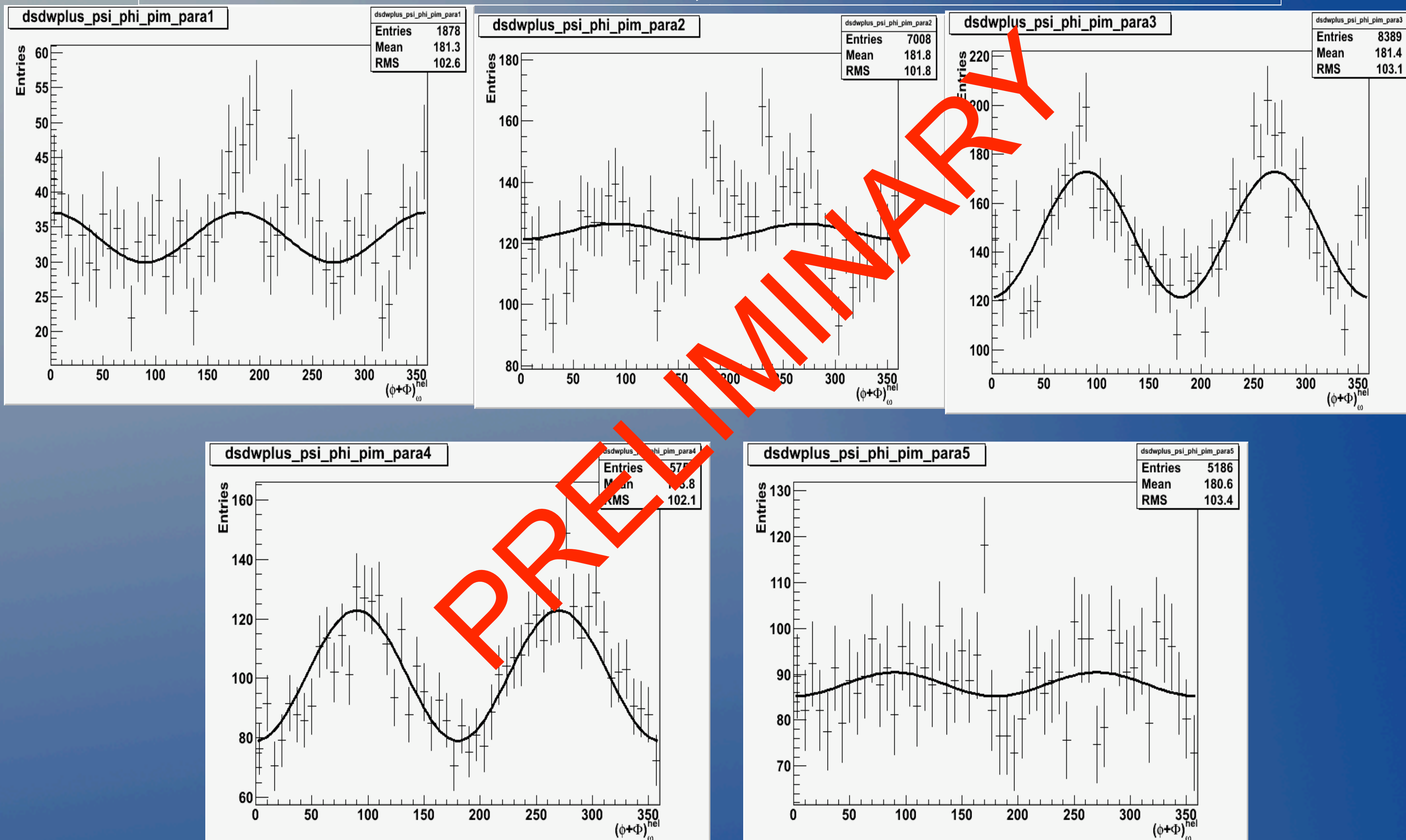
$$W(\phi - \Phi) \quad = \quad N[1 + 2P_\gamma \rho^3 \cos 2(\phi - \Phi)]$$

(φ+Φ) DISTRIBUTIONS
1.5 GeV, PARA



$$W(\phi + \Phi) = N[1 + 2P_\gamma \rho^4 \cos 2(\phi + \Phi)]$$

(φ+Φ) DISTRIBUTIONS
1.3 GeV, PARA



$$W(\phi+\Phi) \quad = \quad N[1 + 2P_\gamma \rho^4 \cos 2(\phi+\Phi)]$$

Status for ω-meson analysis

- conducting MC Acceptance studies
- extracting the acceptance dependent SDMEs and comparing to Σ
- recooking g8b dataset (will increase statistics 2 to 3x)
- analyzing omegas off LH2 and LD2 (g8b and g13b)
-

$K_s\Lambda$ Photoproduction on the Neutron within the Resonance Region

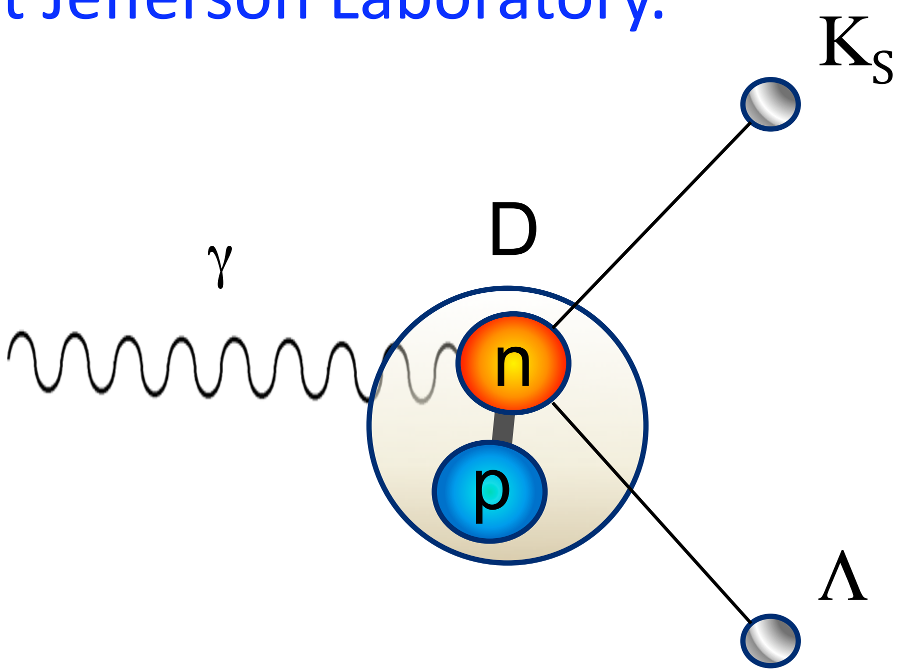
Charles Taylor, PhD (Dec. 2012)

Advisor: Phil Cole

Supported in part by the U.S. National Science Foundation under grant NSF-PHY-1206082

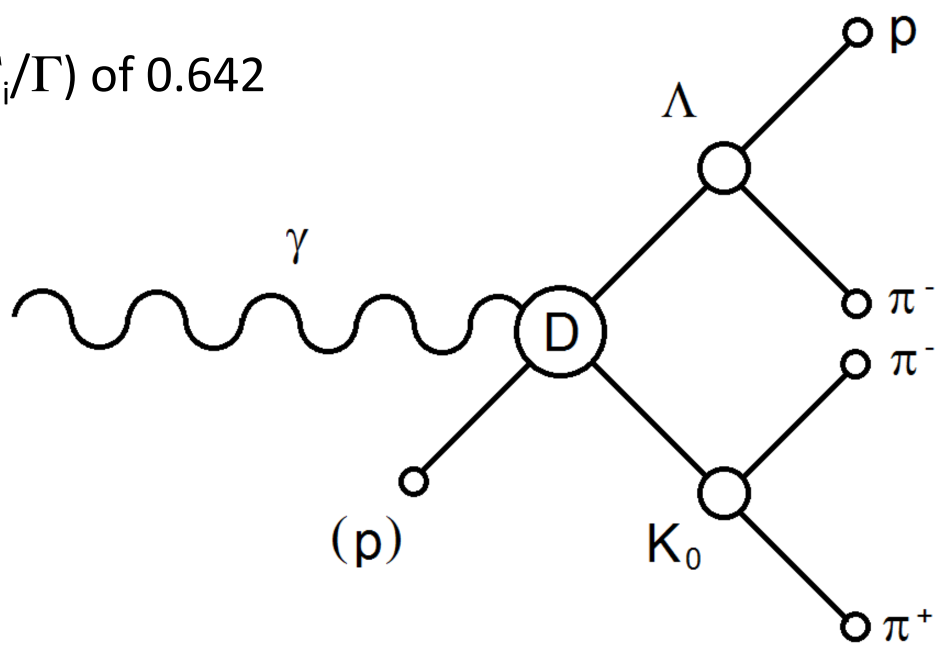
Objective of Study

The differential cross section of the $\gamma n \rightarrow K_S \Lambda$ reaction using the g13a data set collected by the CLAS detector system at Jefferson Laboratory.



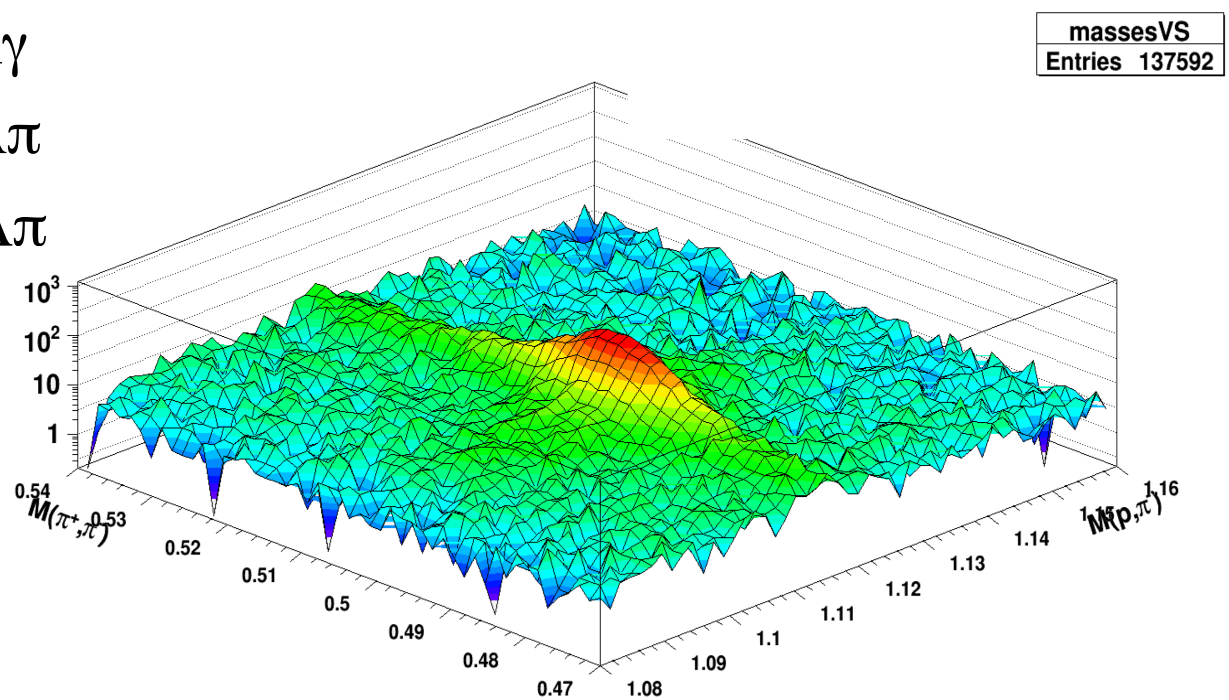
The $\gamma n \rightarrow K_S\Lambda$ Reaction

- A photon excites or exchanges a boson with the neutron inside the deuteron producing a neutral kaon and lambda
- The missing mass of the spectator proton is used to identify the K_SL events for development of the cross section
- The kaon decays to a $\pi^+\pi^-$
  - Branching ratio (Fraction Γ_i/Γ) of 0.642
  - Path length of ~ 3 cm
- The lambda decays to $\pi\pi^-$
  - Branching ratio of 0.639
  - Path length of ~ 7 cm

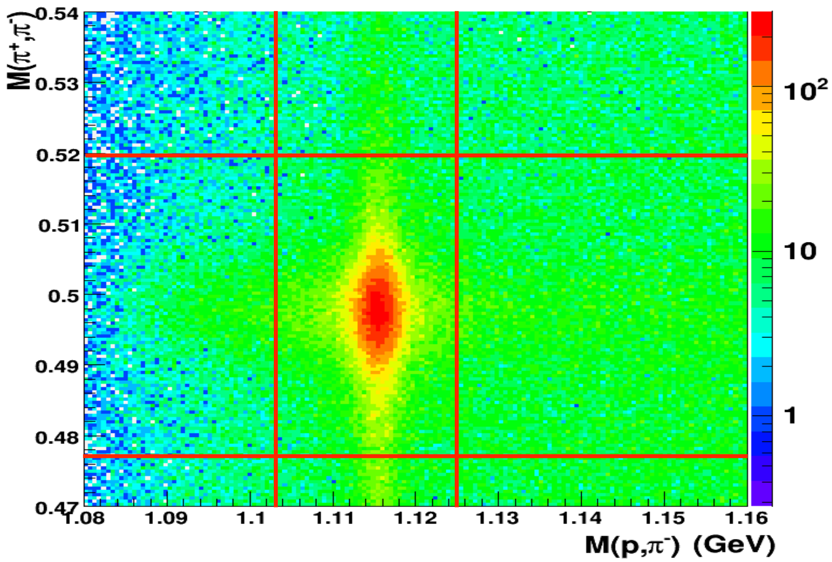


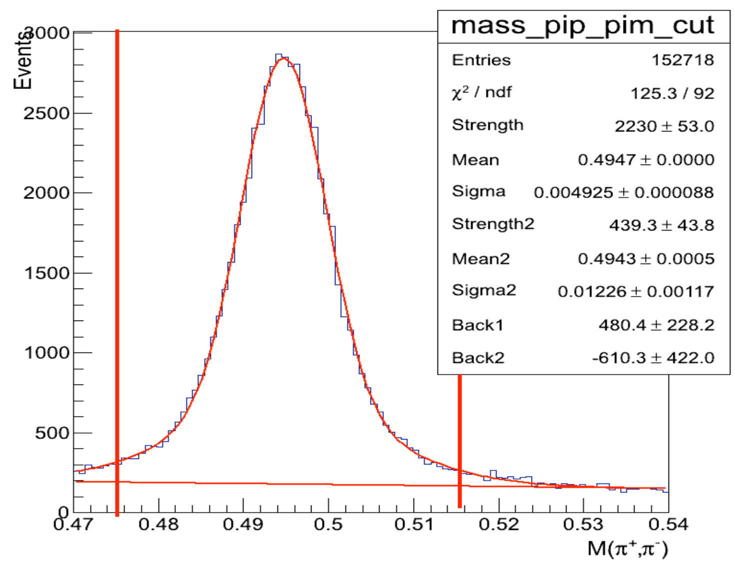
Background Reactions

- Channels with similar final-state particles
  - $\gamma n \rightarrow \pi^+\pi^-\pi^- p$ (non-resonant phase space)
  - $\gamma n \rightarrow K^+\pi^-\pi^- p$ (misidentified Kaon)
- Resonant channels with the $K_S\Lambda$ plus an extra particle
  - $\gamma n \rightarrow K_S\Sigma^0 \rightarrow K_S\Lambda\gamma$
  - $\gamma n \rightarrow K_S\Sigma^* \rightarrow K_S\Lambda\pi$
  - $\gamma n \rightarrow K_S\Lambda^* \rightarrow K_S\Lambda\pi$

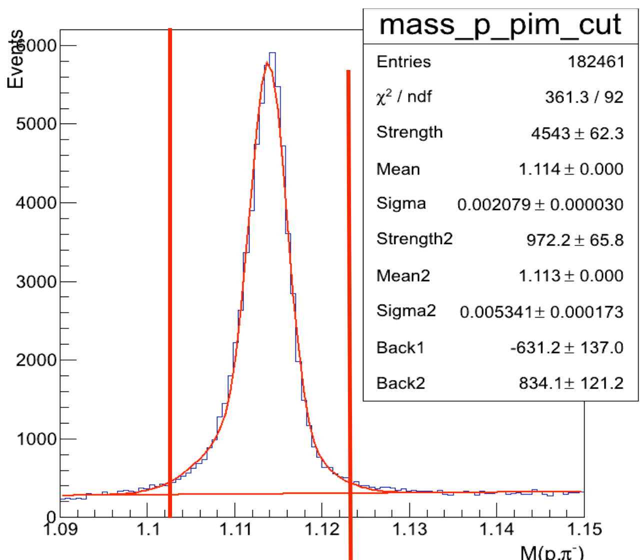


Event Reconstruction- K_S and Λ candidates





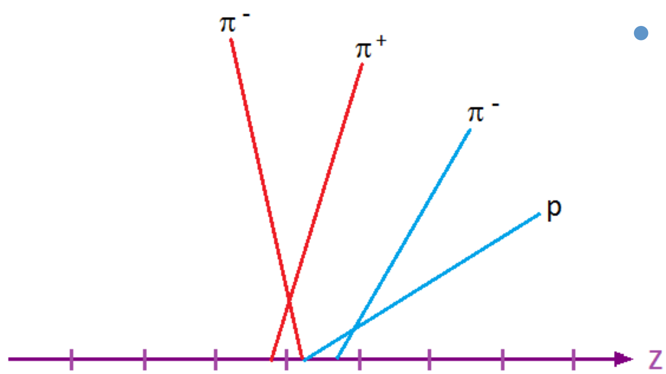
$1.108 < M(p,\pi^-) < 1.122$

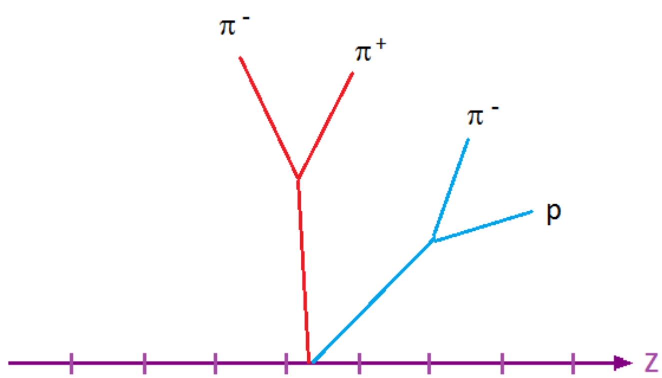


$0.485 < M(\pi^+,\pi^-) < 0.51$

- To select the inclusive $K_S\Lambda$ events: 3σ cuts were placed on the invariant mass peaks

Photon Selection



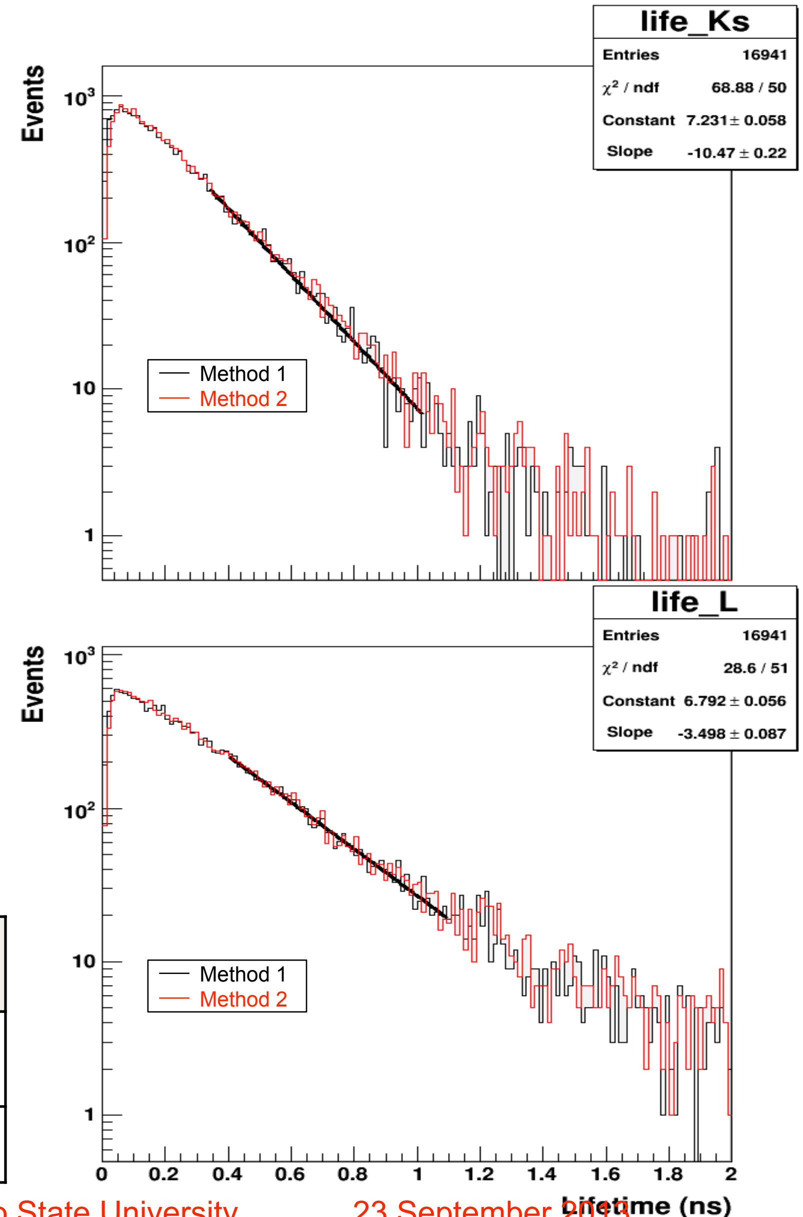


- Event Position Timing Corrections
  - The tagger databank stores the time of the photon from the center of the target
  - The vertex for each particle from the event databank is constructed tracking assuming it came from the vertex
  - For K_SL the precise determination of the vertex requires more advance reconstruction
  - The correct photon is then selected from the tagger bank based on a correction using the new vertex information

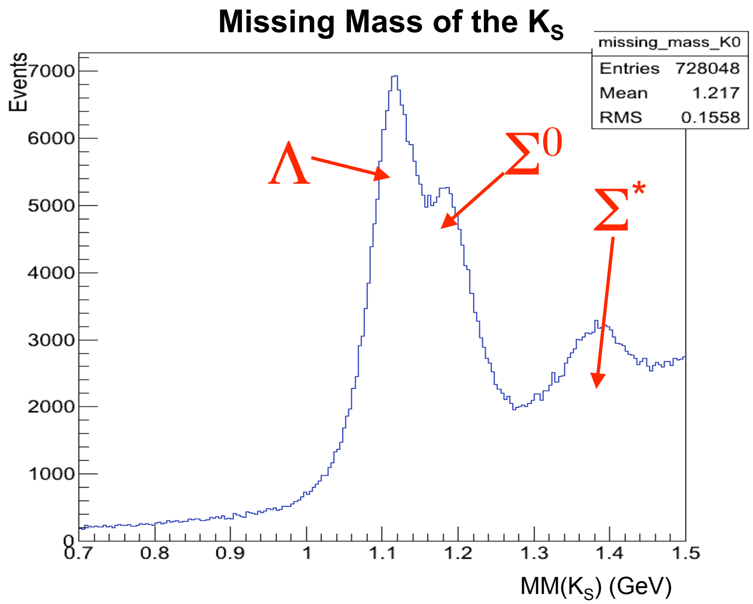
Lifetime Estimation

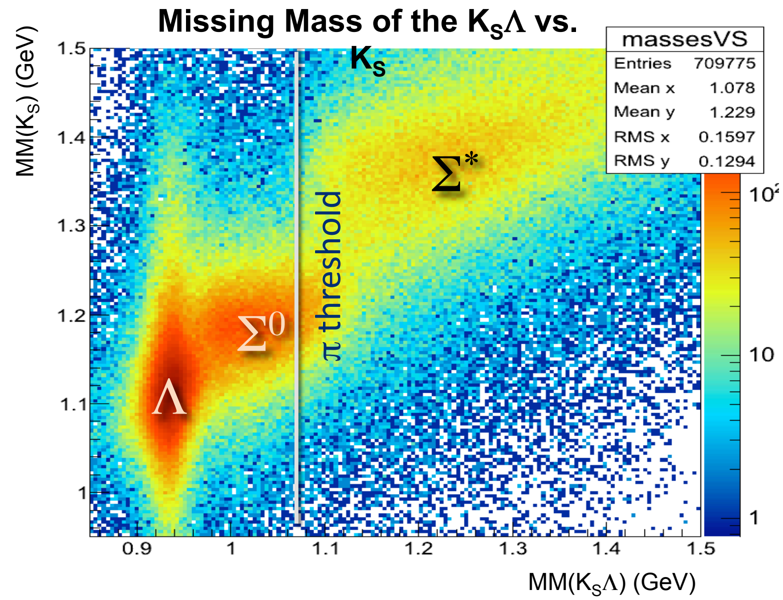
- The lifetime distribution is deter-mined from the path lengths
- Fits to the curves give the range of the most reliable particle lifetimes
- Short lifetimes challenges
  - Detector resolution
  - Longer lifetimes have low statistics
- Decays outside start counter

	Measured (ns)	PDG (ns)
K_S	0.095 ± 0.006	0.090
Λ	0.286 ± 0.018	0.263

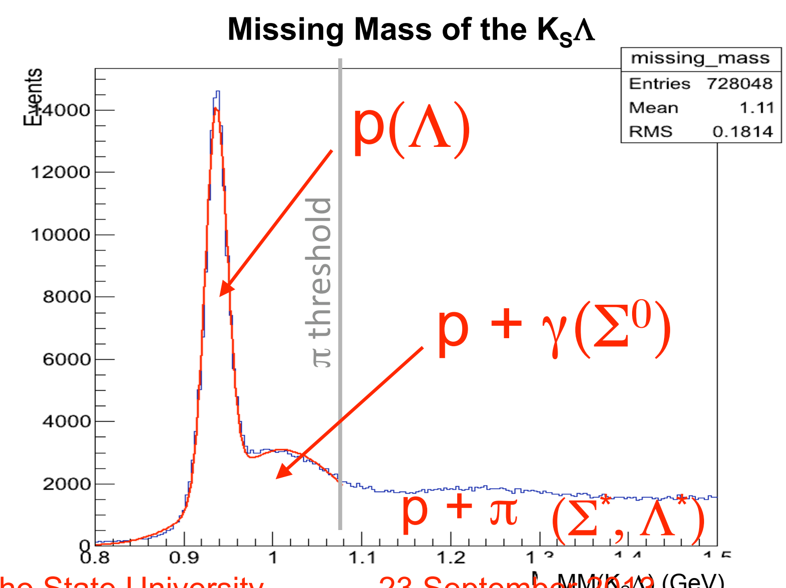


Event Selection





- Exclusive $K_s\Lambda$ and $K_s\Sigma^0$ yields can be extracted by fitting the MM($K_s\Lambda$)
- Background from higher states can be suppressed by a cut on the MM(K_s) as calculated by assuming the target neutron was at rest



Differential Cross Section

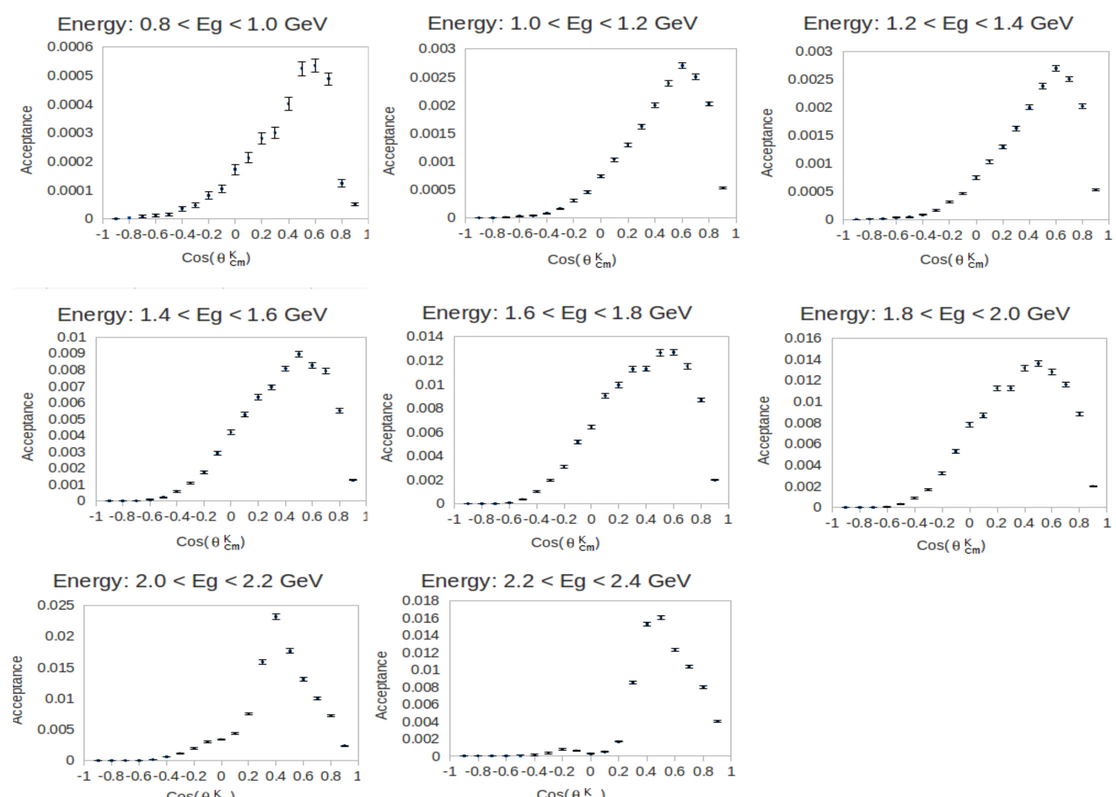
Calculated for each bin of photon energy and $\cos\theta_{K^o}$;

$$\frac{d\sigma}{d\cos\theta_{K^o}}(E_\gamma,\theta_{K^o}) = \frac{1}{\Delta\cos\theta_{K^o}}\frac{A_r}{\rho L N_A}\frac{Y(E_\gamma,\theta_{K^o})Y_{CF}}{\Phi(E_\gamma,)A(E_\gamma,\theta_{K^o})}\frac{\Gamma_{K^o}}{\Gamma_{K^o\to\pi^+\pi^-}}\frac{\Gamma_\Lambda}{\Gamma_{\Lambda\to p\pi^-}} \quad .$$

- $E\gamma$ = energy of the photon
- θ_{Ko} = angle between the photon and K^o in the center-of-mass frame
- A_r = atomic weight of the target
- ρ = target density
- L = target length
- N_A = Avogadro's number
- ϕ = photon flux in the given photon energy bin
- Y = experimental yield
- A = simulated acceptance
- Y_{CF} = yield correction factor
- Γ = the ratios of the total widths of the reconstructed particles K_s and Λ to the widths of the decay channels (inverse of the Branching Ratios)

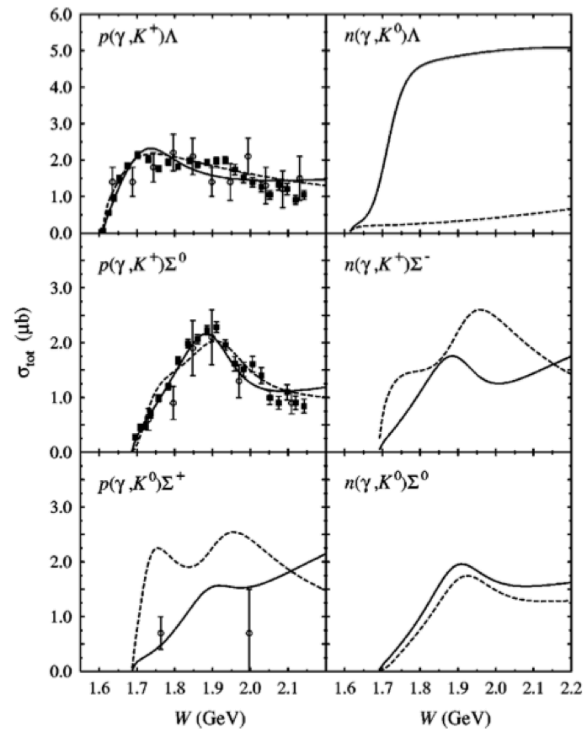
Simulation and Acceptance

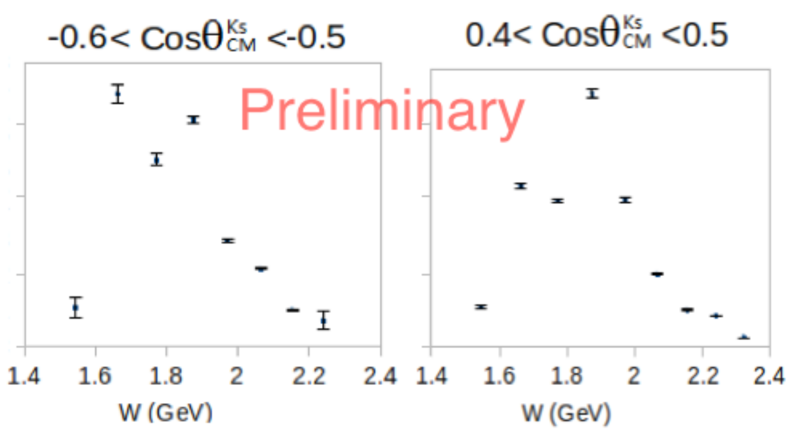
- The *fsgen* software package was used for the event generation
- Generated events are passed to the GSIM routines
- The *gpp* package was used to correct for the well established inefficiencies of the sub-detector systems
- The simulated data is cooked and analyzed same way as the experimental data
  - The results are compared with the known generated events to produce the acceptances
  - Loss in acceptance in the backward region is due to loss of L particles in the forward “blind” nose region



Differential Cross Section

- Theoretical kaon cross sections were detailed in H. Yamamura *et al.*, Phys. Rev. C 61, 014001 (1999)
  - Solid line was the theory proposed 1999 and the dashed line was from 1997
- The positive kaon channels have been well measured and are in agreement with the theory
- Theory for the neutral kaon channels vary significantly





- The cross section for the $\gamma n \rightarrow K_S\Lambda$ reaction is consistent with the parallel reaction $\gamma p \rightarrow K^+\Lambda$
- With only 10 energy bins, the $K_S\Lambda$ channel has two apparent peaks at 1.7 and 1.9 GeV. **PRELIMINARY**

Summary for $K_S\Lambda$

- Strong evidence of baryon resonances in the energy ranges between 1.7 to 2.0 GeV.
  - The cross section is the first step in the identification of the missing baryon resonances.
  - New studies can be made on recoil polarization, the polarization observables, and the asymmetry.
- Final checks are being made by the g13 group on data quality before publication
  - Cross sections are being binned into finer energy intervals.
  - The $K_S\Sigma^0$ channel is being integrated into the MC simulation.
    (We will study this channel as well – *necessary for yield understanding*)
  - Studies are being made on the lost events in the backward regions
  - Attempts are being made to recover lost runs from missing photon flux files (increase statistics)

Path Forward
(augmenting the photonucleon database for PWA)

- ω mesons
  - SDMEs from proton in LH2 (g8b)
    - Danny Martinez
  - SDMEs from proton and neutron in deteuron (g13b)
    - Olga Cortes
- K_S and Λ (and Σ^0 ← *under study*)
  - Differential cross sections from g13a
    - Charles Taylor (PhD – Dec. 2012).