Cross Sections of $\gamma d \rightarrow K^0 \Lambda(p)$ with g13 Data

N. Compton, C.E. Taylor, K. Hicks, P. Cole, and others

11/3/2016

CLAS Collaboration

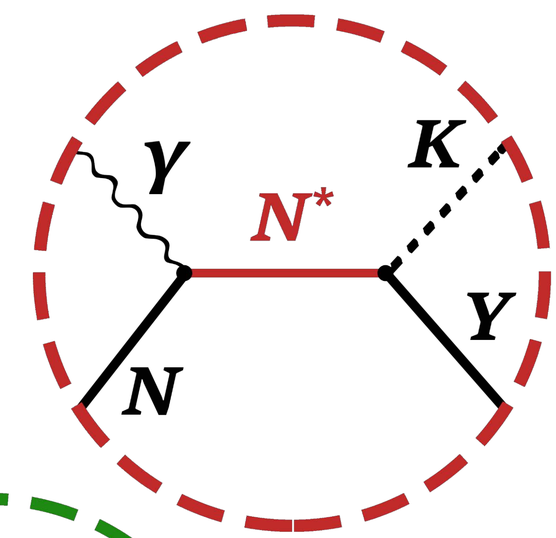
CEBAF Large Acceptance Spectrometer

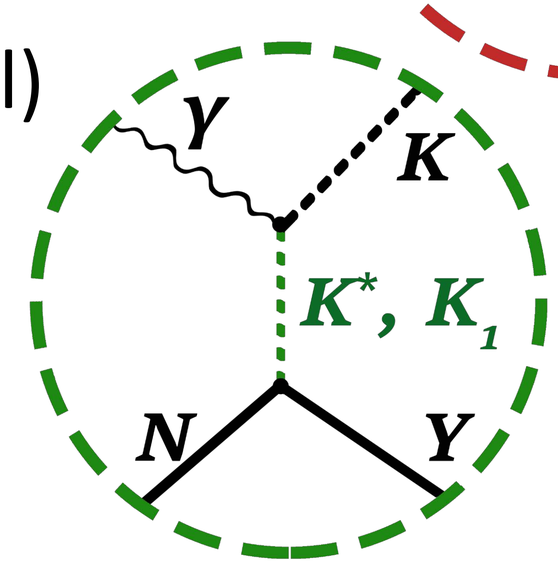
Motivation

- A complete experiment in several reaction channels will improve our understanding of nucleon resonances

- $K^0\Lambda$ provides constraint on resonances found in $K^+\Lambda$ channels through PWA

- This reaction has t-channel suppression
  - Neutrality and spin of the K^0
  - Ideal for resonance studies (s-channel)
  - Cross section is likely lower than $K^+\Lambda$



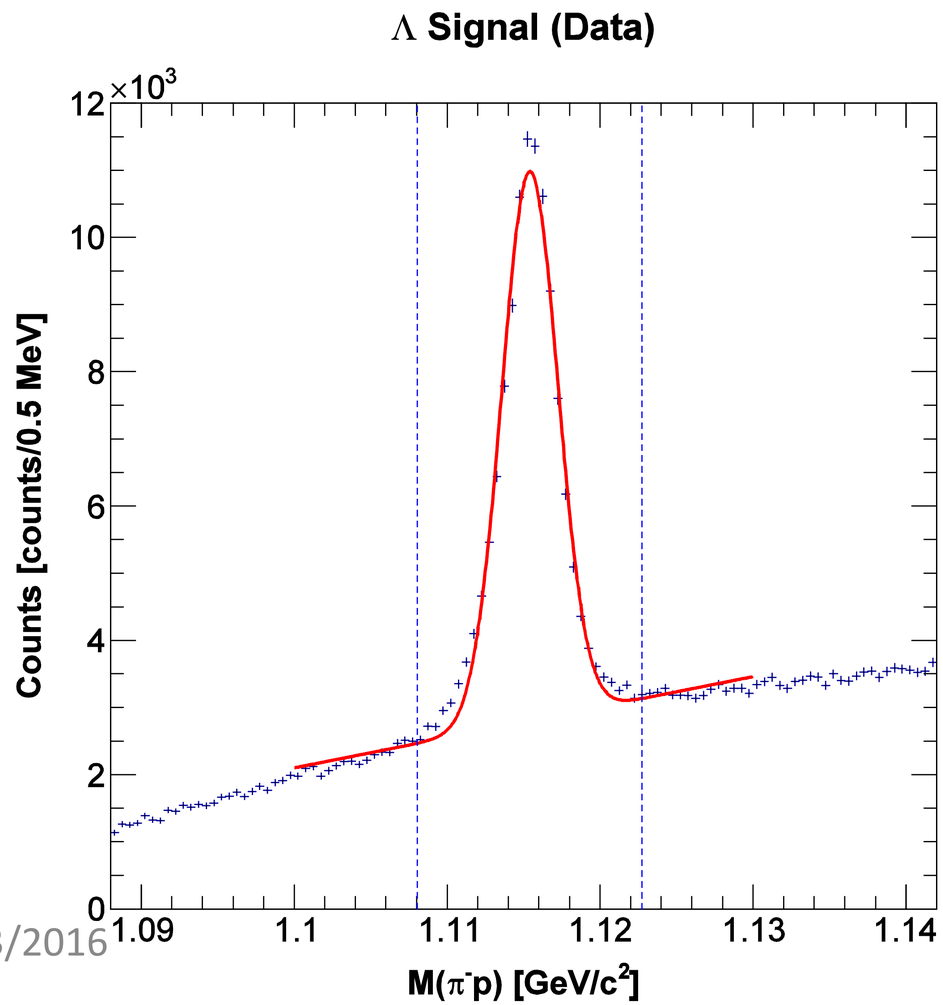


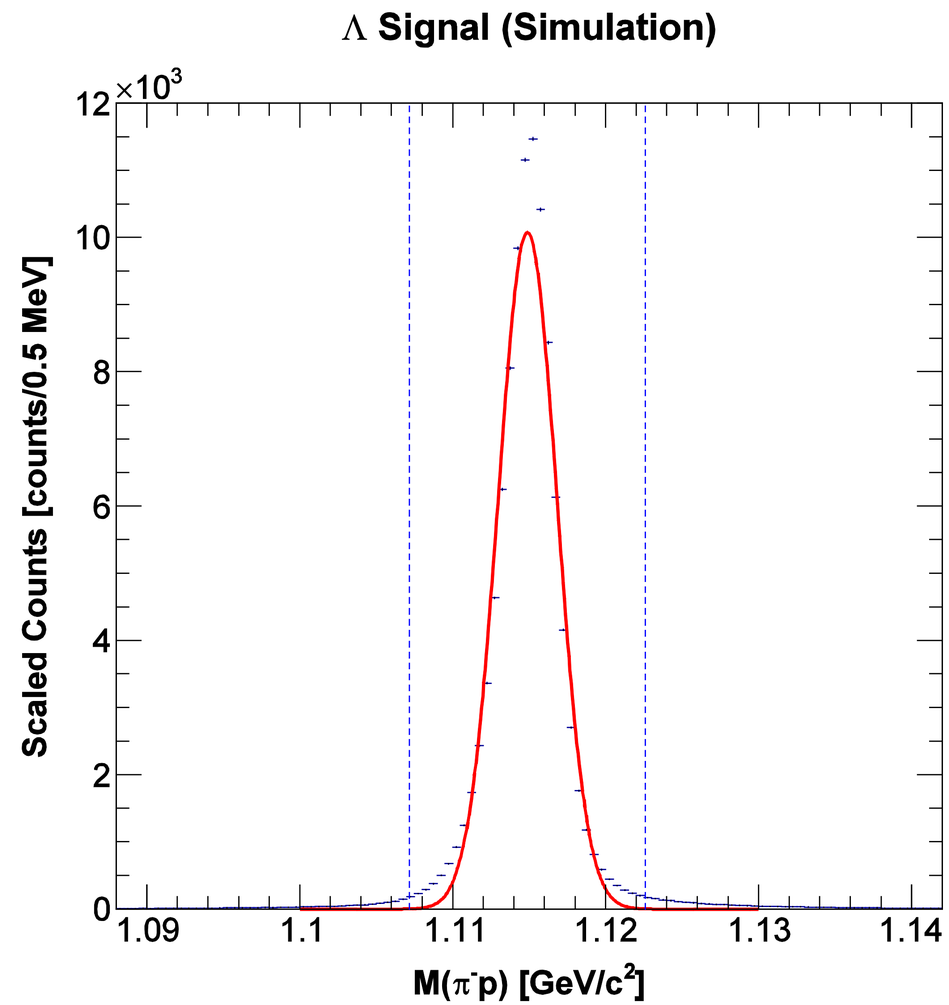
$\gamma d \rightarrow K^0\Lambda(p)$

- Detected with the topology:
  - $\gamma d \rightarrow K^0\Lambda p \rightarrow K_S^0\Lambda p \rightarrow \pi^-\pi^+\pi^- p(p)$
- Backgrounds contributing to this topology:
  - $\gamma d \rightarrow X \rightarrow \pi^-\pi^+\pi^- p(p)$
    - $X \neq K^0\Lambda$, *but could be* $\rho\Delta$
    - *Minimized, but not excluded with invariant mass cuts*
  - $\gamma d \rightarrow K^0\Sigma^0 p \rightarrow K_S^0\Lambda\gamma p \rightarrow \pi^-\pi^+\pi^- p(\gamma p)$
- Cuts and Corrections:
  - removal of problematic tagger bins, removal of junk runs, eloss corrections, momentum corrections, invariant mass cuts, pairing of π^-, fiducial cuts, and reaction vertex cut

Invariant Mass of Λ

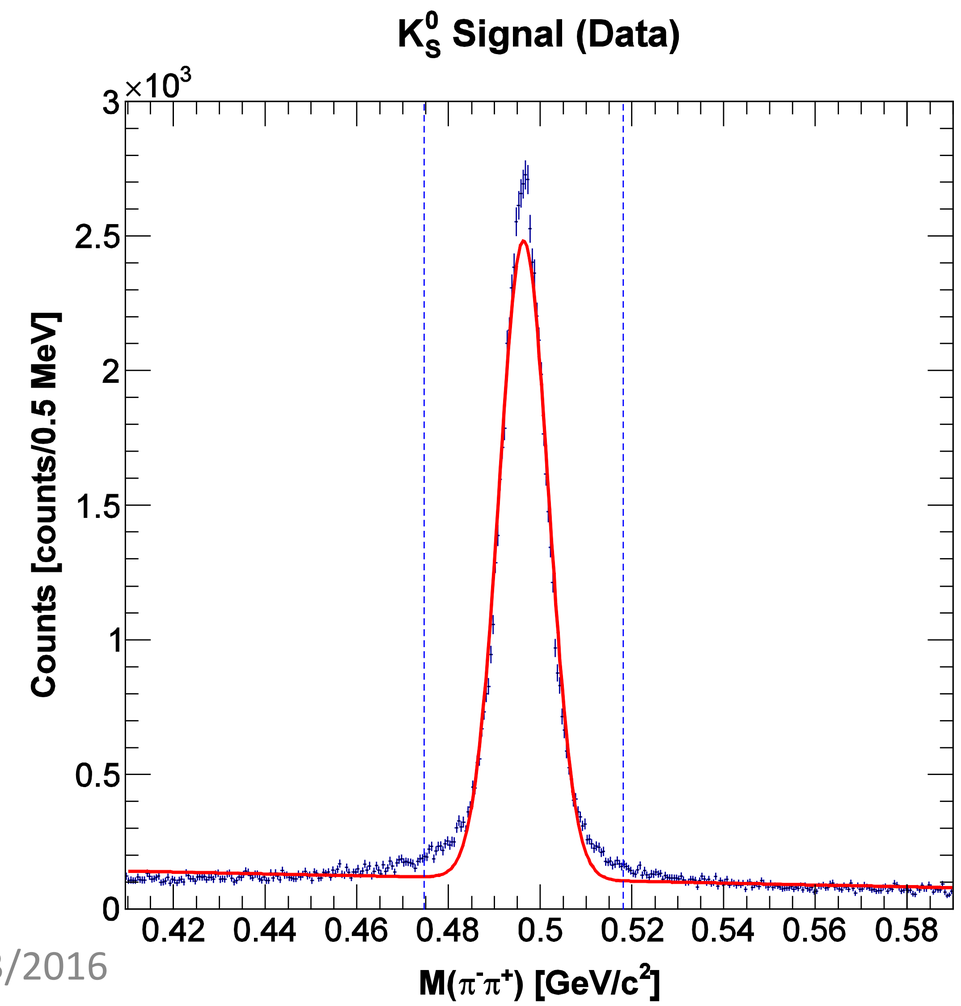
- Shown is $M(\pi^- p)$
- The pairing of the $\pi^- p$ was determined based on reproducibility of the Λ
- Gaussian fit is applied to the peak
  - Only used for determining a cut location
  - Systematics of this cut were investigated (typically on the order of 1%)

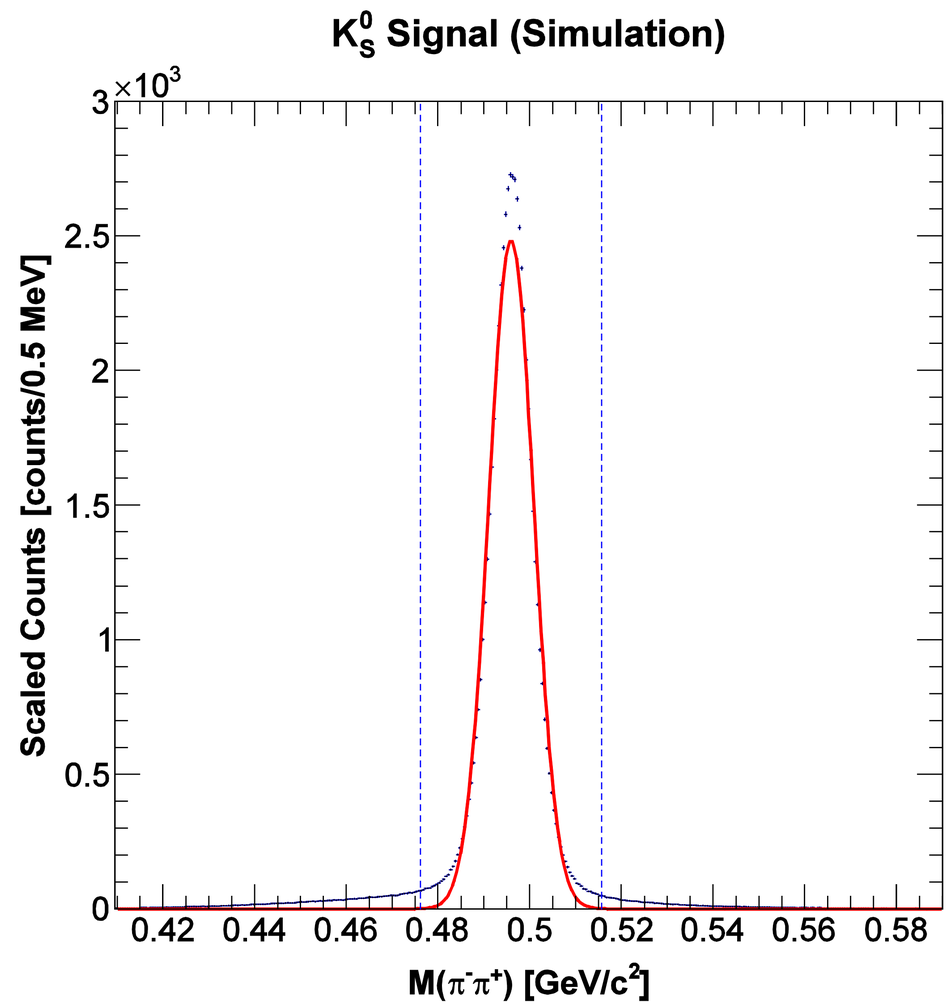




Invariant Mass of K^0

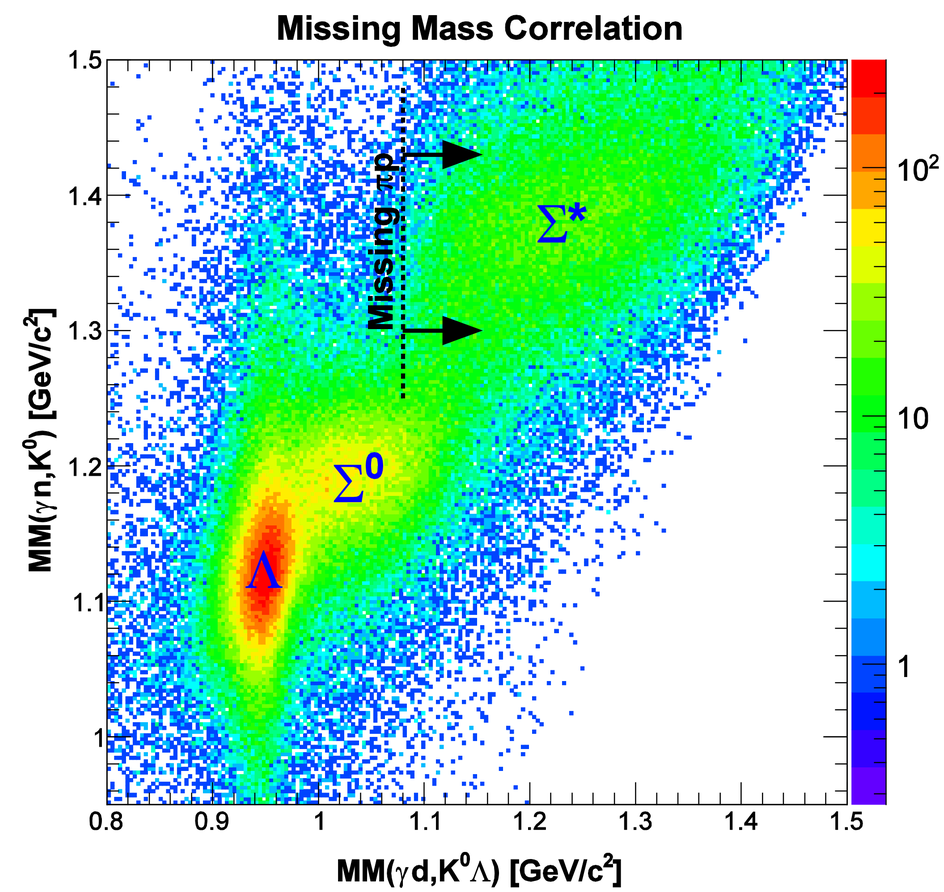
- Shown is $M(\pi^-\pi^+)$
- The π^- from the K^0 decay typically has more momentum
- Gaussian fit is applied to this peak as well
  - Only used for determining a cut location
  - Systematics of this cut were investigated (typically on the order of 1%)

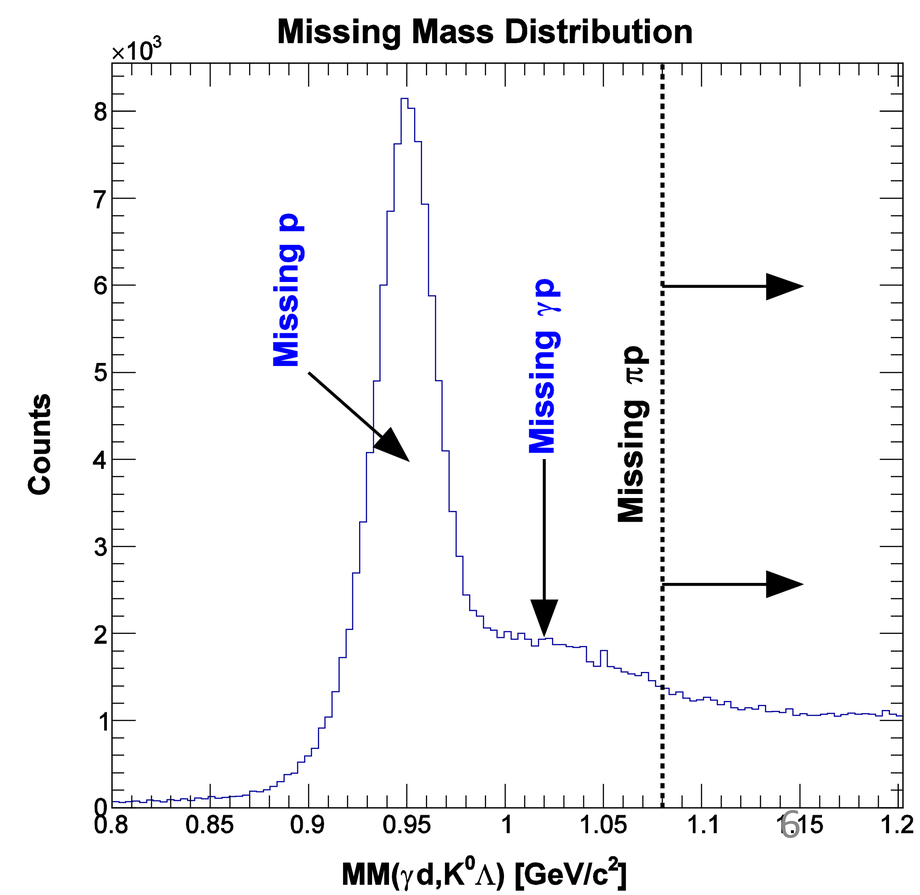




Missing Mass Spectra

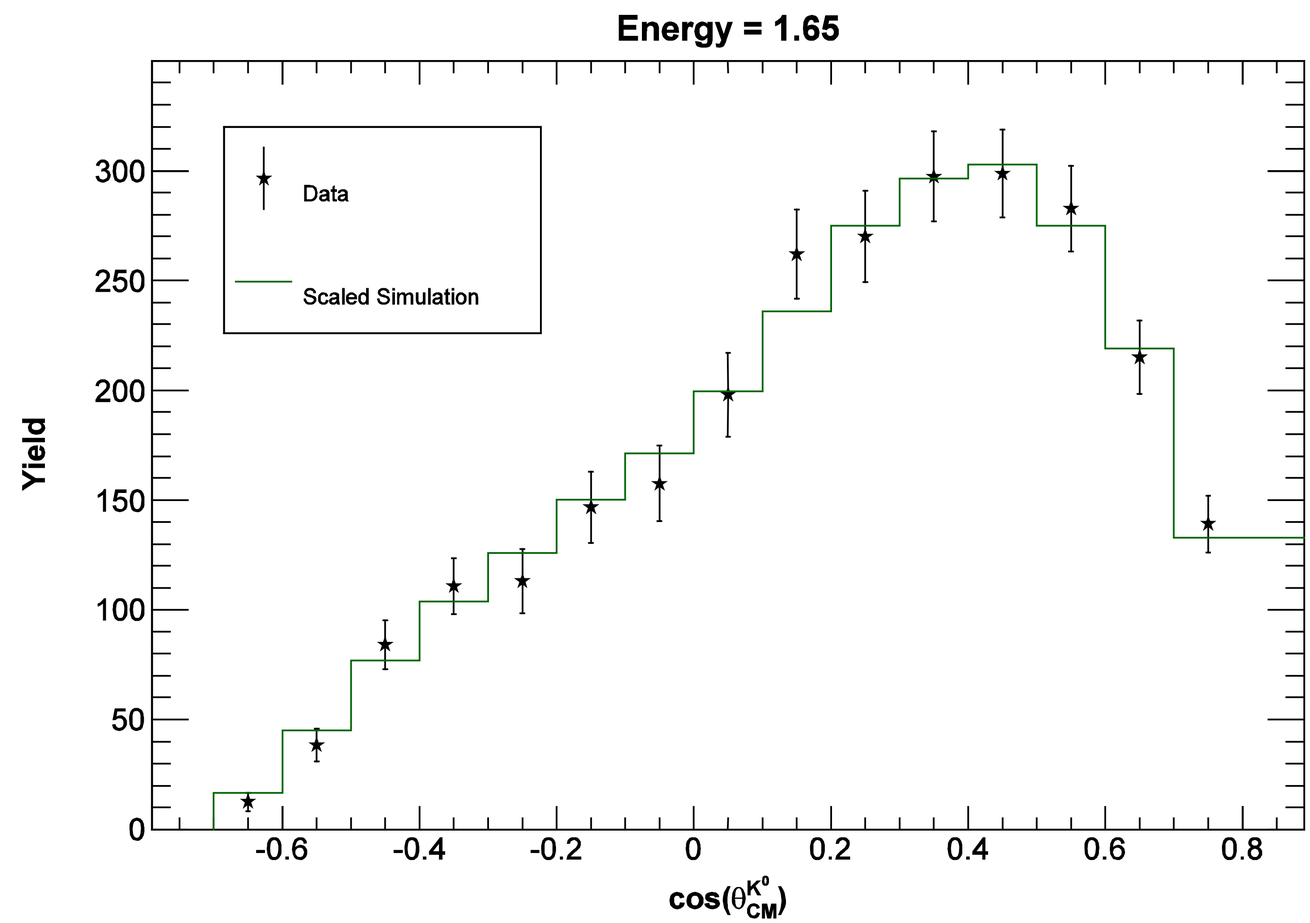
- Possible topologies
  - $\gamma d \rightarrow X \rightarrow \pi^-\pi^+\pi^- p(p)$
    - *Non-strange background*
    - $K^0\Lambda$
  - $\gamma d \rightarrow X \rightarrow \pi^-\pi^+\pi^- p(\gamma p)$
    - $K^0\Sigma^0$
    - *Non-strange background (minimal)*
  - $\gamma d \rightarrow X \rightarrow \pi^-\pi^+\pi^- p(\pi p Y)$
    - $K^0\Sigma^*$
    - $K^*\Sigma^0$
    - *Non-strange background*
  - Where X and Y could be anything
- Higher mass resonances
  - Assuming an on shell neutron
  - Assuming zero momentum





Simulation Weighting

- Comparison to Data
  - Extracted Yield (top right)
  - Proton Momentum (bottom left)
  - π^- Momentum (bottom mid.)
  - π^+ Momentum (bottom right)

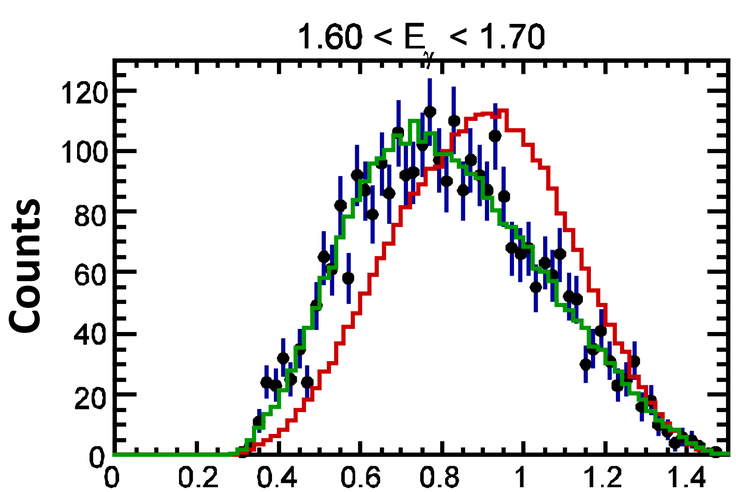


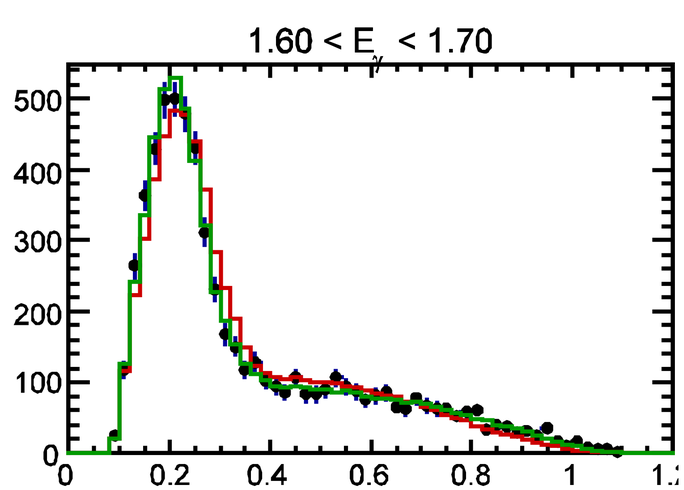
Legend

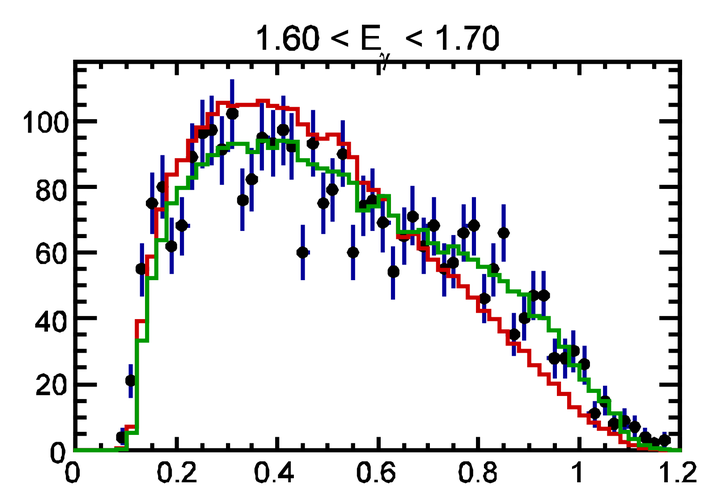
Scaled simulation uniform in $\cos\theta^{K^0}_{CM}$

Scaled simulation weighted in $\cos\theta^{K^0}_{CM}$

Data Points

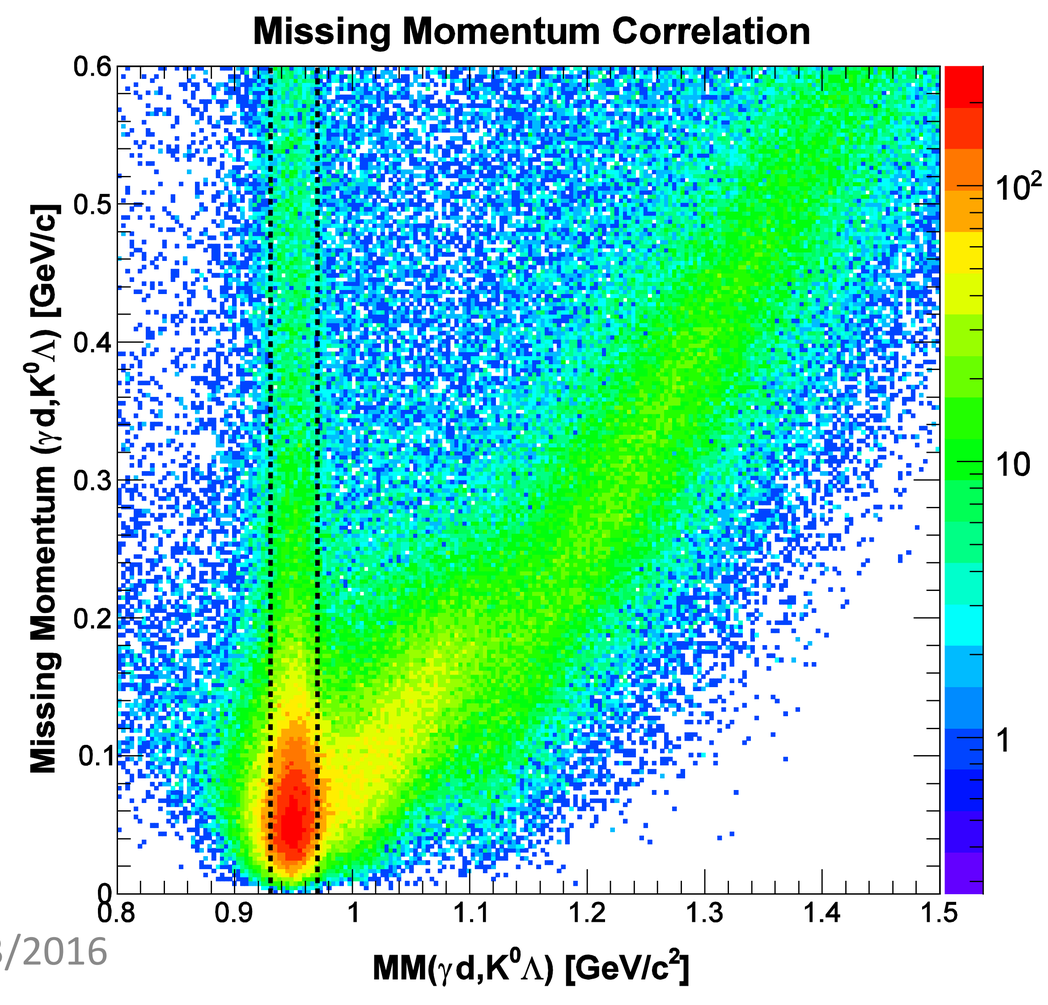


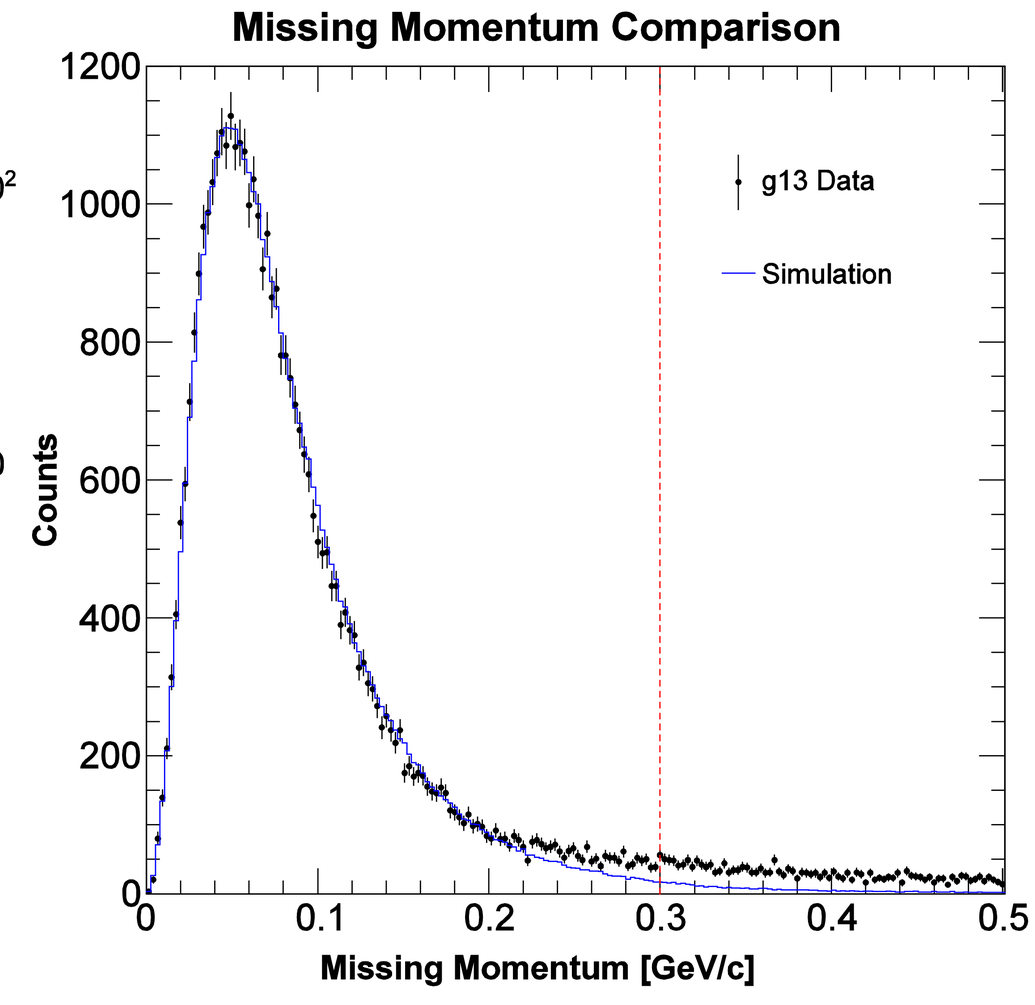




Comparison of Missing Momenta

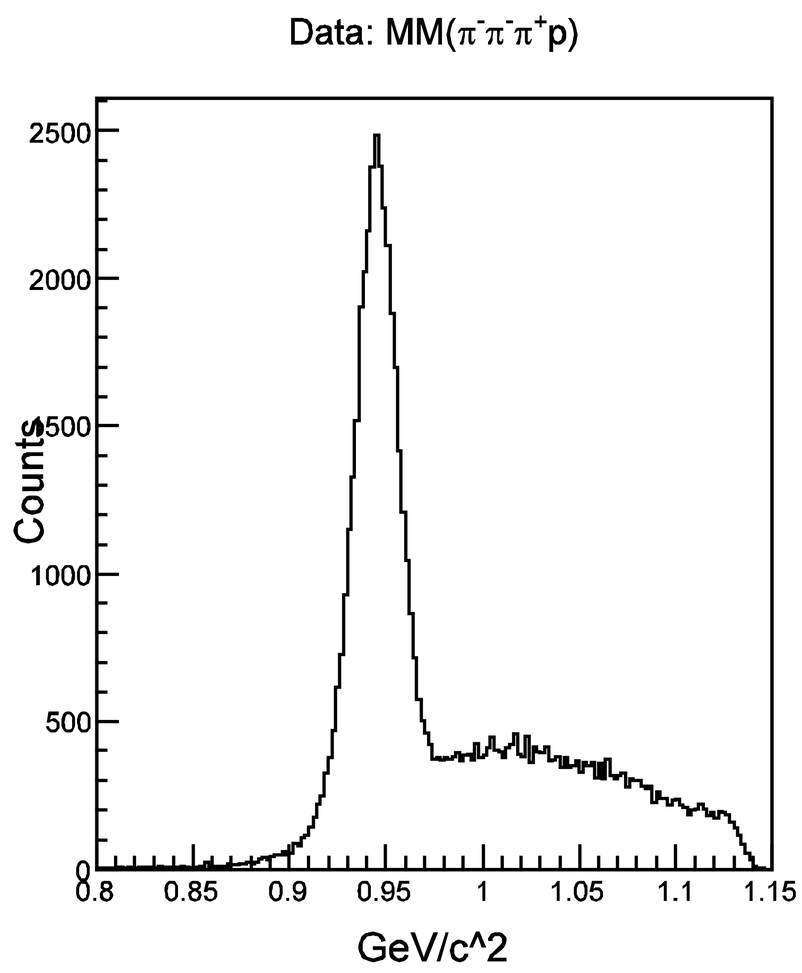
- Missing momentum (of the assumed spectator proton) can only be compared from data to simulation with a strict missing mass cut
- A missing particle will result in more missing momentum
- A missing momentum cut of 300 MeV was employed (typically ~1-2%)

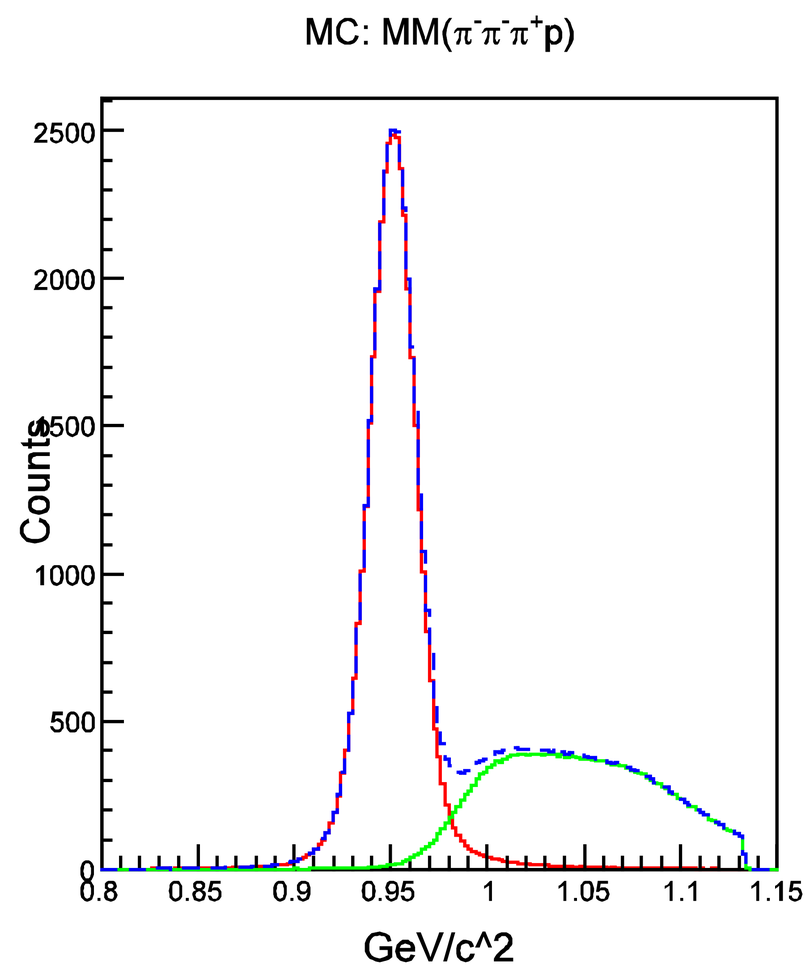




Comparison of Missing Masses

- The reconstructed missing mass
  - Peak at the proton mass
    - Non-Strange background
    - Signal
  - Shoulder to that peak
    - Σ^0 contribution

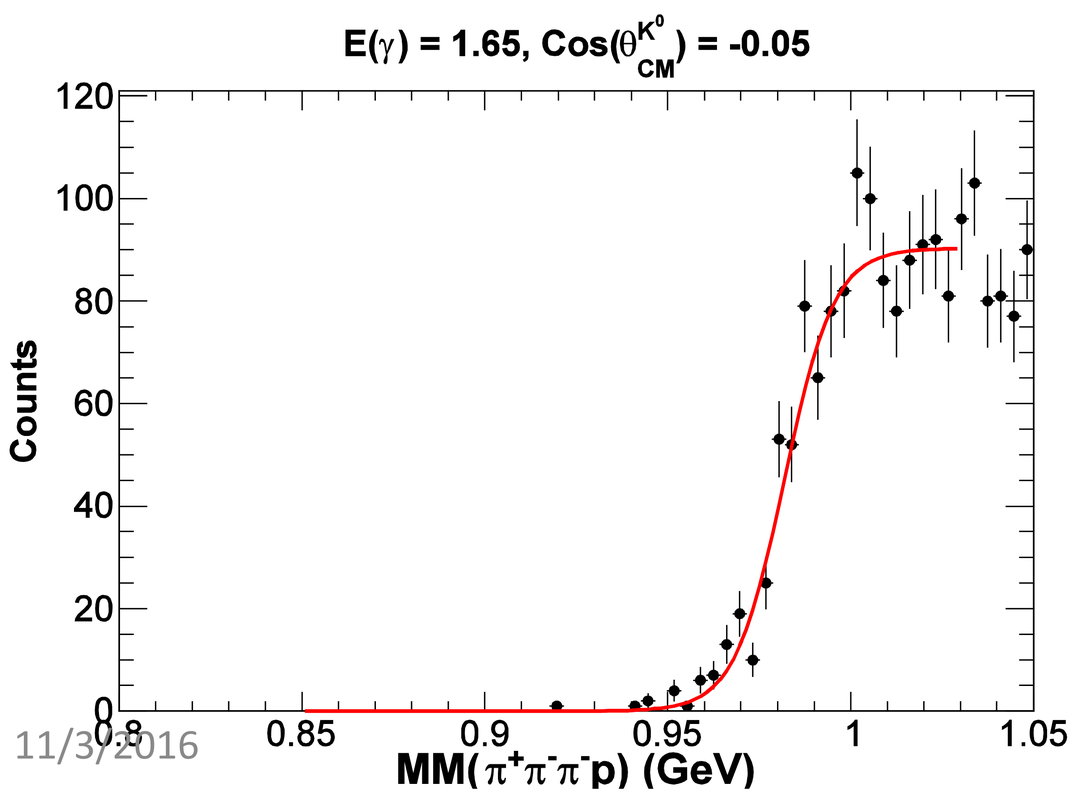


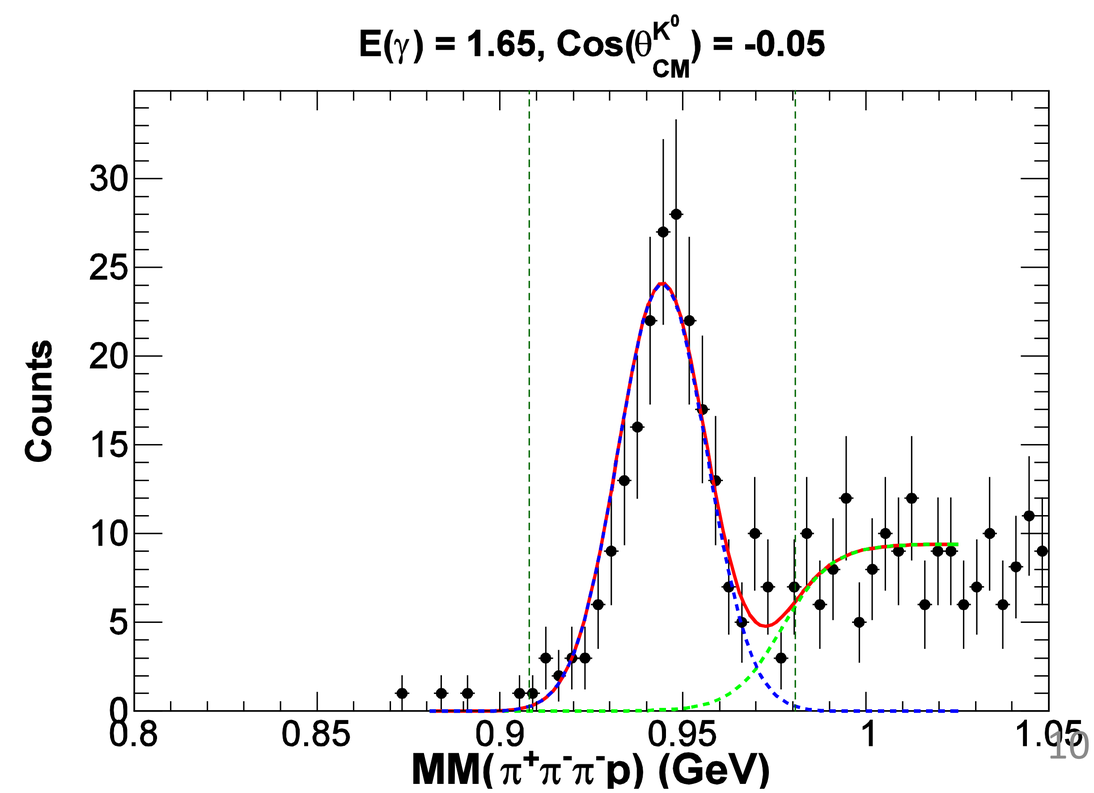


Yield Extraction (Fits)

Steps Taken to Fit the Data

1. Fit the $K^0\Lambda$ Simulation (Gaussian)
2. Fit the $K^0\Sigma^0$ Simulation (Sigmoidal Shape)
3. Use these parameters to constrain fit to Data
   a) Shape fit the Σ^0
4. Subtract Non-Strange Background (next slide)

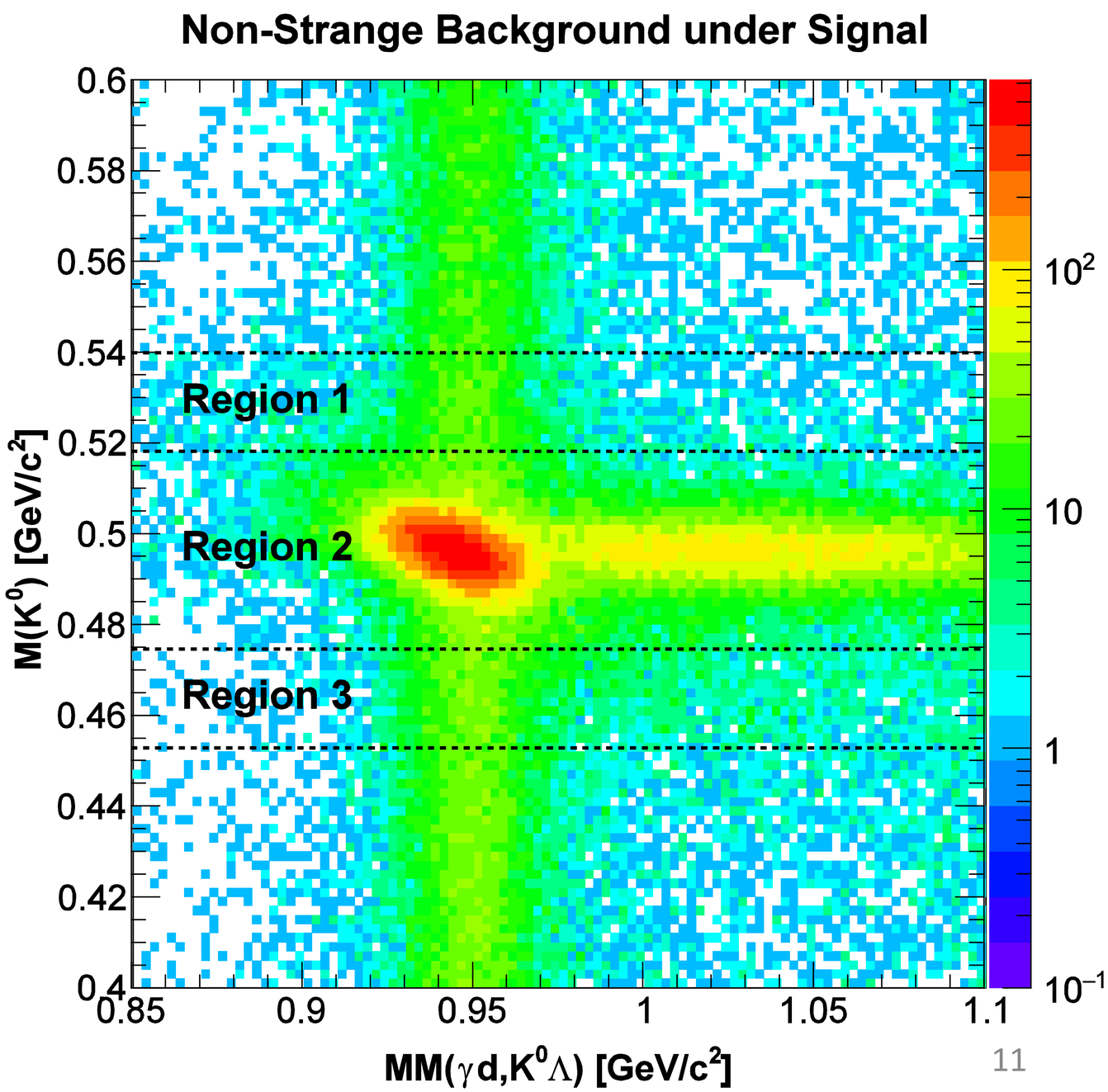




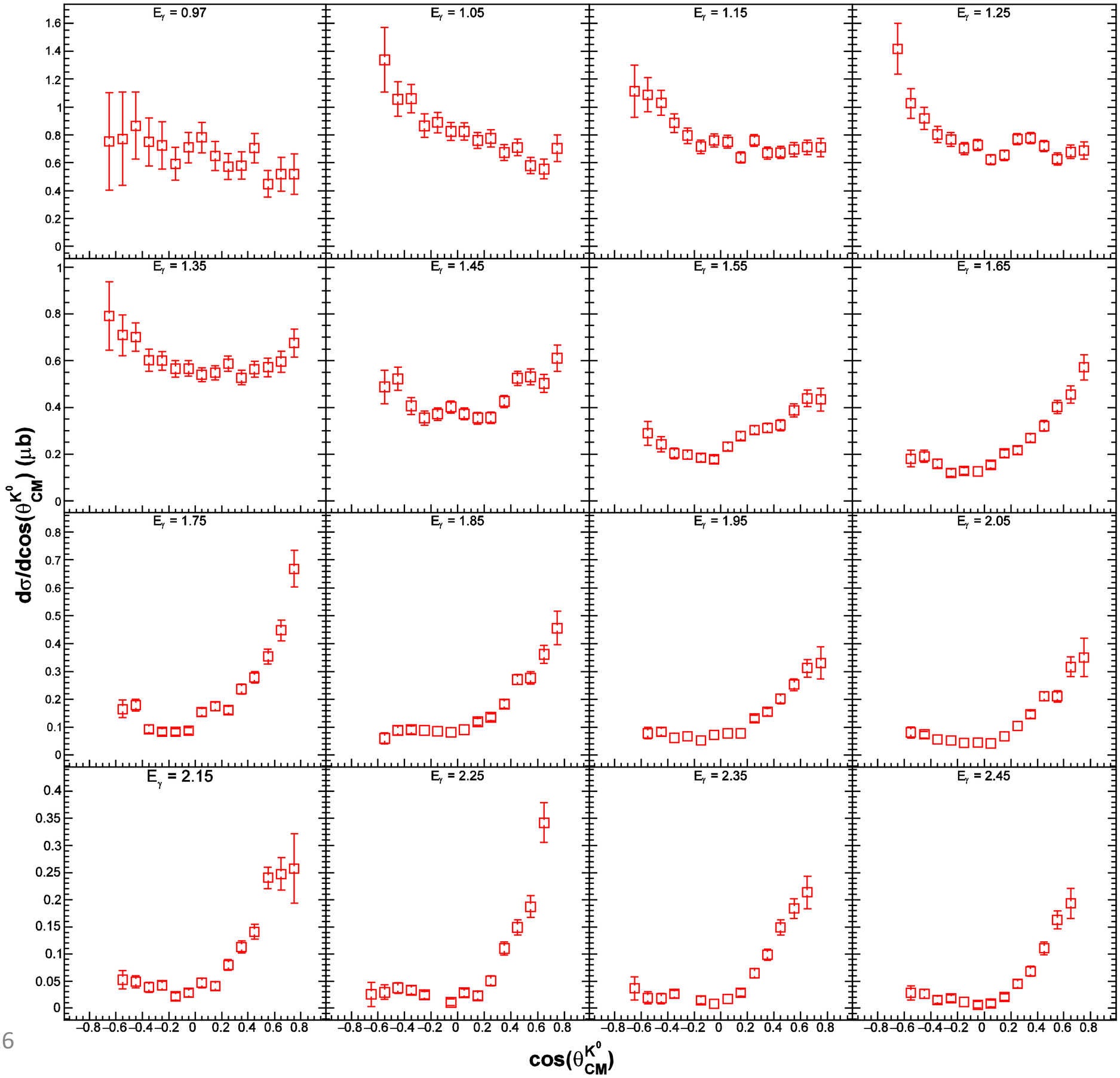
Background Subtraction

1. Cut on the K^0
2. Estimate the background in region 2 from region 1 and 3
3. Subtract background from previously obtained yield

Background contribution ranged from 0-20% of the total counts depending on the kinematic bin

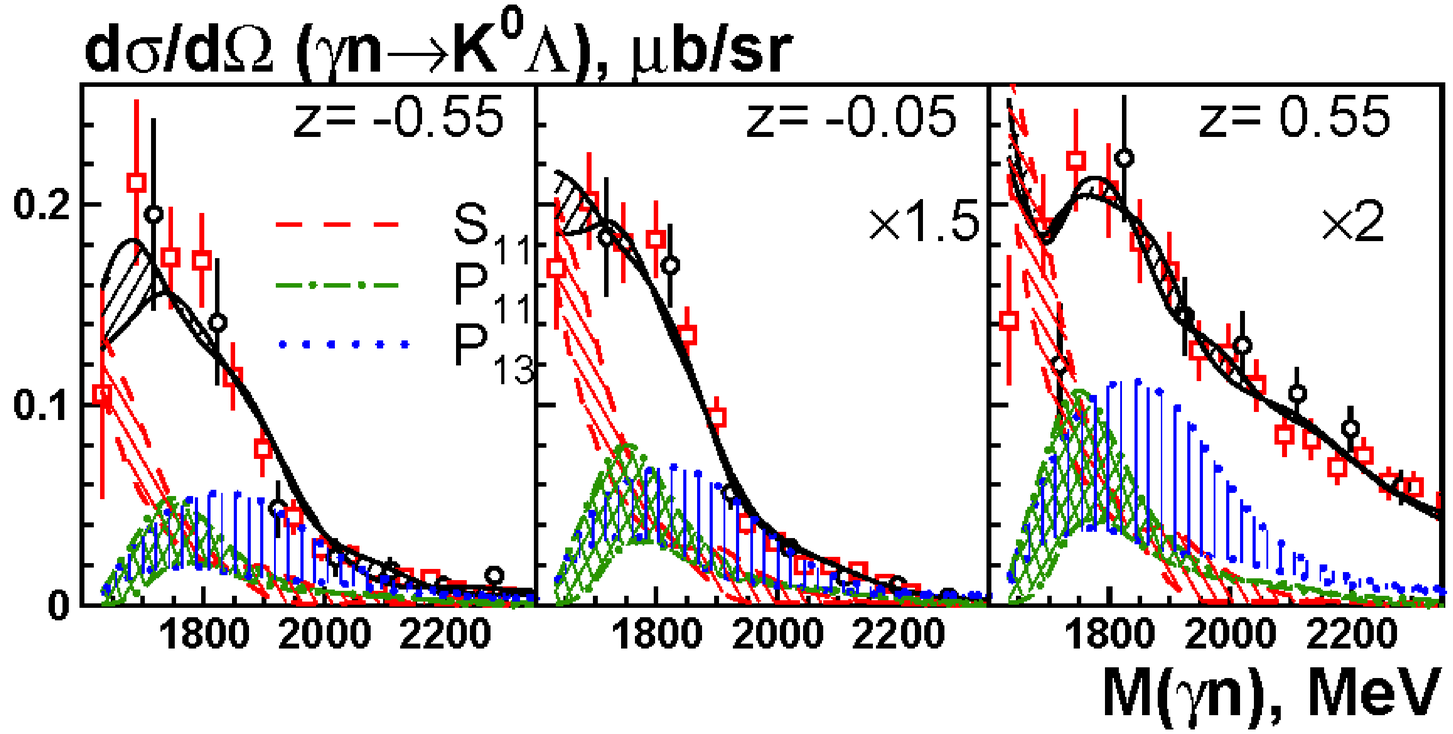


Differential Cross Section of $\gamma d \rightarrow K^0 \Lambda(p)$



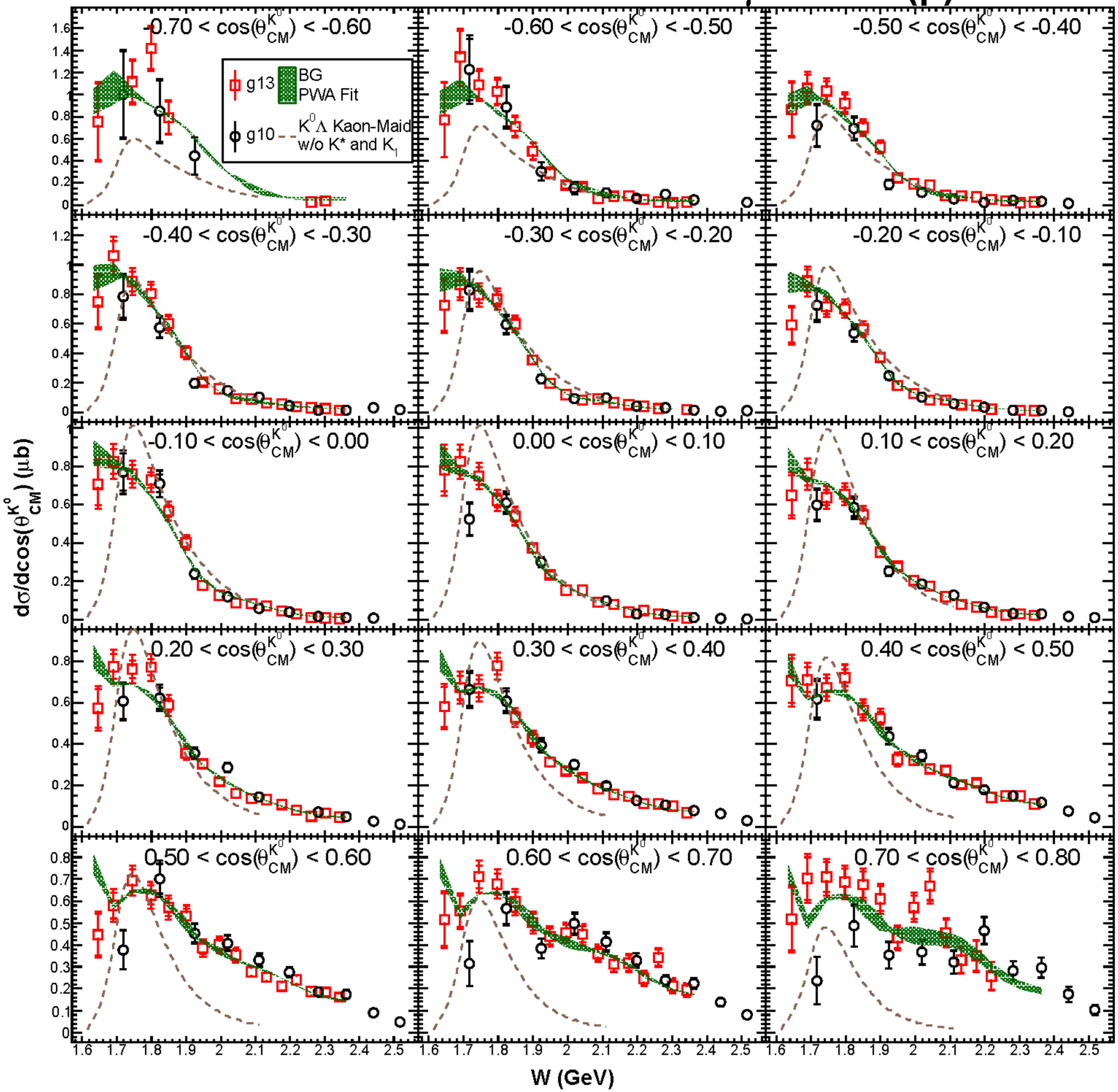
Differential Cross Section

1. Comparison to g10 results
2. BoGa Fit including $K^0\Lambda$ ($\chi^2_\nu \sim 1$)
   a) Two Solutions
   b) $z = \cos\left(\theta_{CM}^{K^0}\right)$



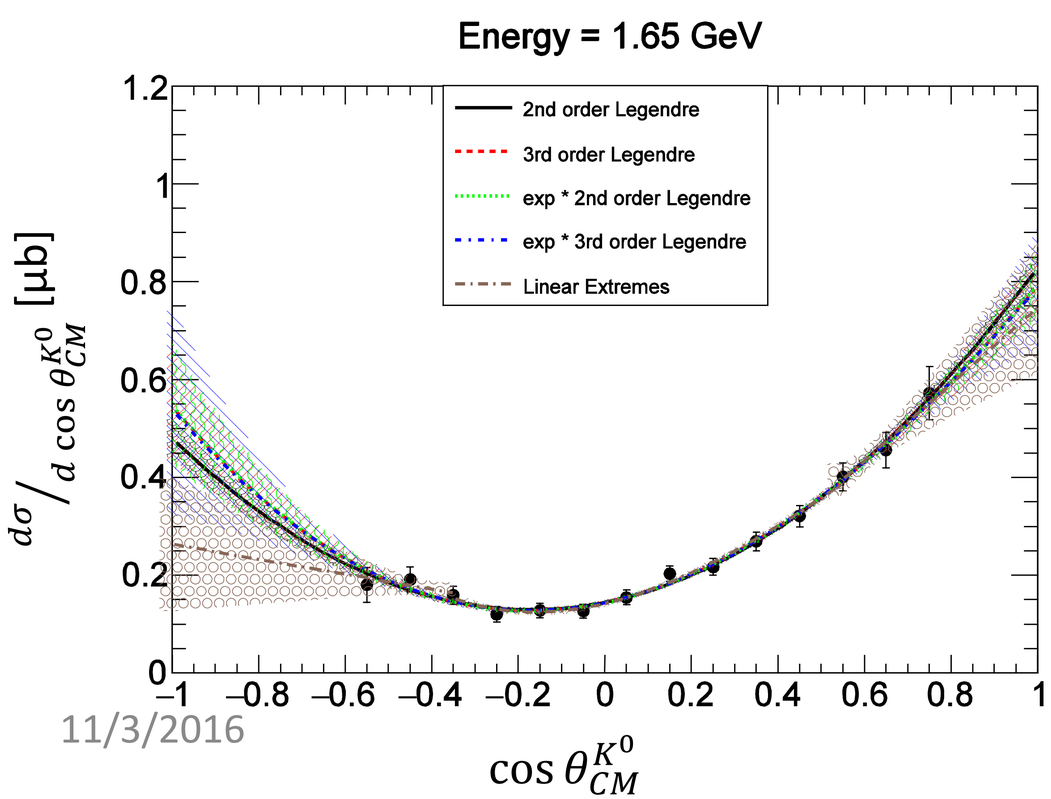
3. Comparison to KaonMaid w/o K^* or K_1 exchange
   a) Accessed via website
   b) NOT A FIT

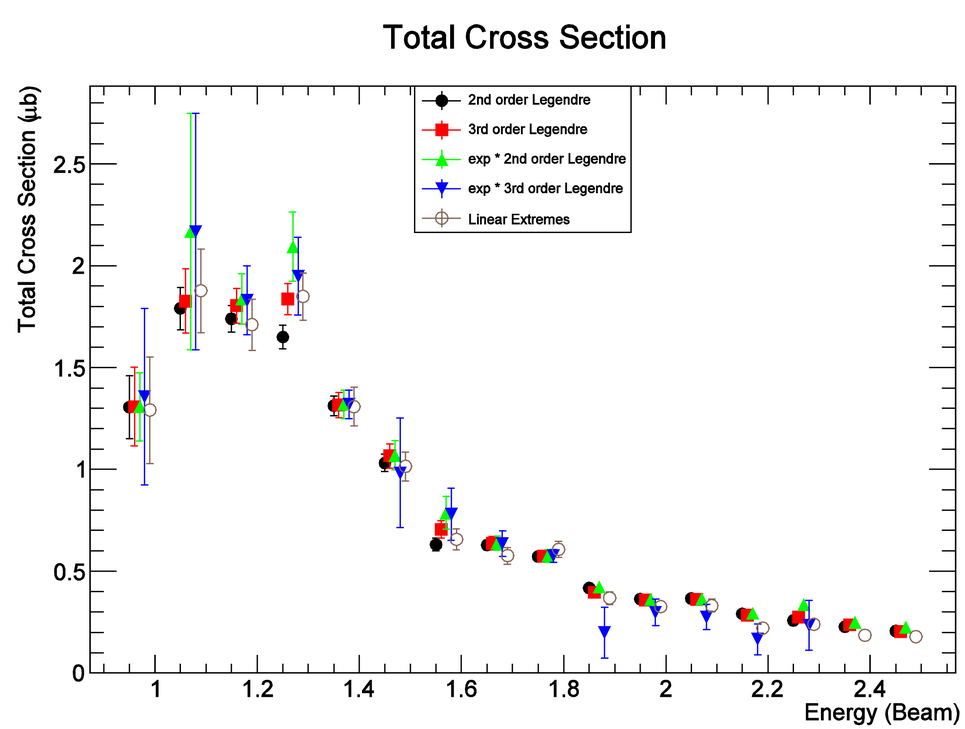
Differential Cross Section of $\gamma d \rightarrow K^0\Lambda(p)$



Total Cross Section Estimation

- Fit differential cross section
  - Multiple functions
  - Utilize 1σ error bands
- Integral represents the total cross section
  - Each integral has an uncertainty
- Systematic Uncertainty
  - Calculated standard deviation

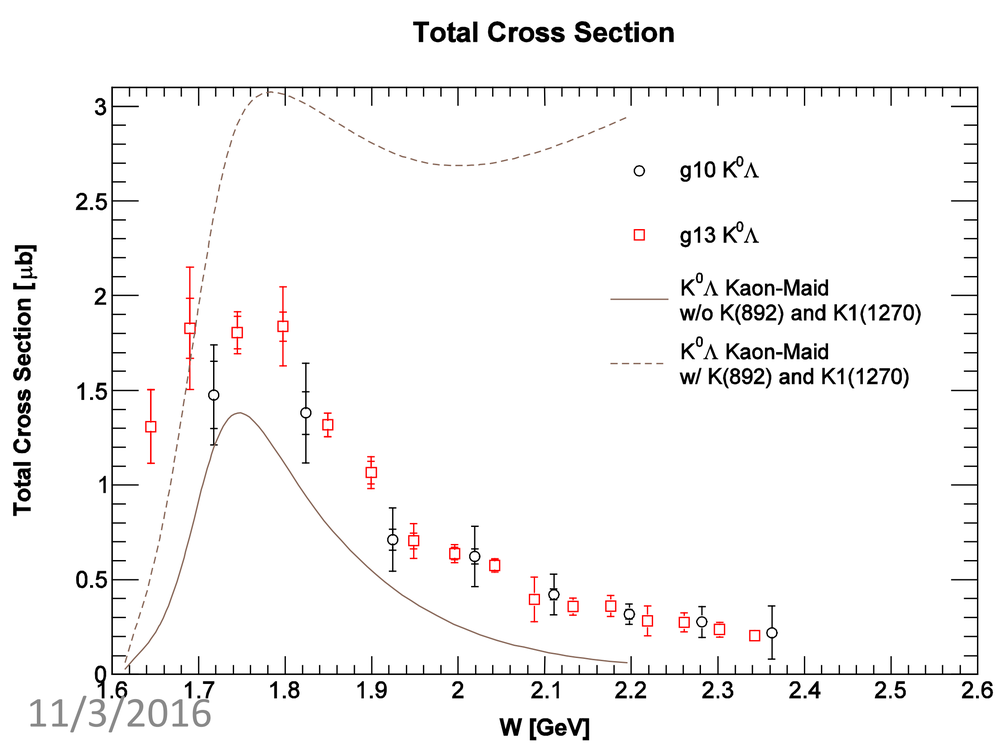


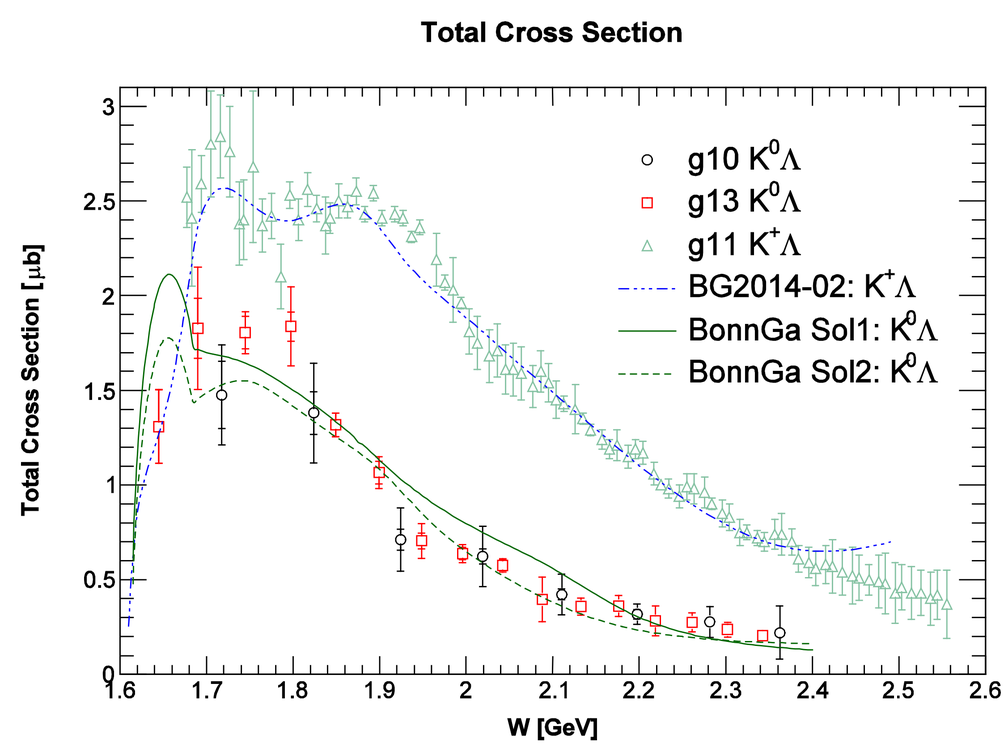


Total Cross Section

w/ BoGa, KaonMaid, and $K^+\Lambda$

- Left Figure
  - Kaon Maid is shown as a comparison with two different options
- Right Figure
  - Comparison between $\gamma p \rightarrow K^+\Lambda$ (g11) and its BoGa solution (web)
  - No "bump" is seen in $\gamma d \rightarrow K^0\Lambda(p)$ at 1900 MeV
  - Preliminary $K^0\Lambda$ BoGa solutions shown
    - Minor changes in fit parameters





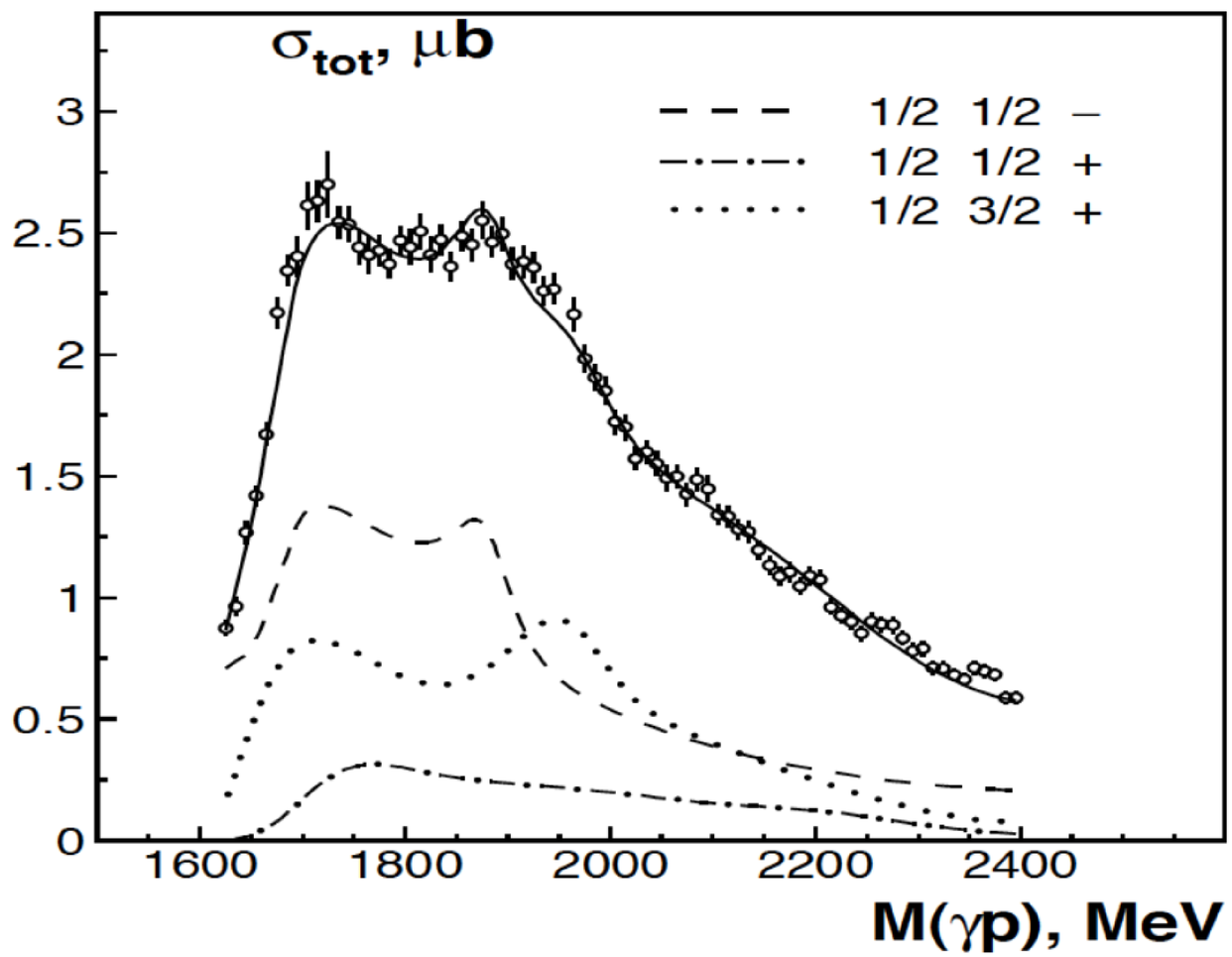
Summary

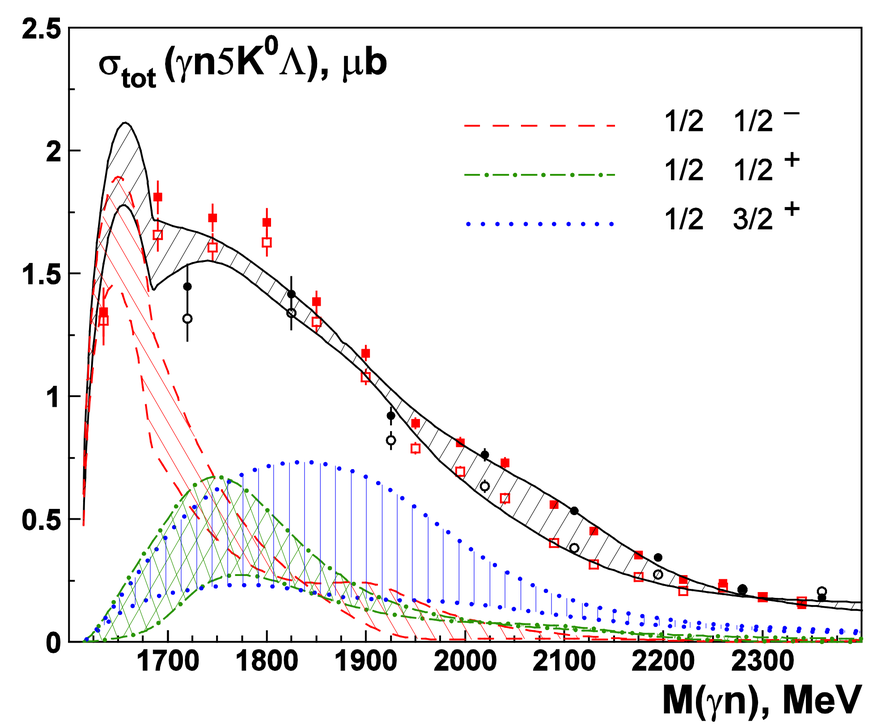
- $\gamma d \rightarrow K^0\Lambda(p)$ cross sections were measured with g13 data
- These data agree with previous g10 measurements
- These cross sections appear to be *missing* a "bump" at 1900 MeV
  - Contribute valuable information on complex amplitudes
- Preliminary PWA fits were provided by BoGa
  - These fits are very close to a "predicted" value
- Analysis review is complete
- Ad-Hoc started

Back-Up Slides

Total Cross Section

BoGa Estimation and Fit Compared to K+Lambda





Burkert, Volker D., EPJ Web Conf. 37, 2012

BoGa Coupled Channel Fits

- Neutron coupled channels listed
- References not given here, but will be reported in the paper
- Most chi-squares improved

Preliminary

$\gamma d \to \pi^- p(p)$	Observ.	N_{data}	χ^2_{old}	χ^2_{new}
[19, 20]	$d\sigma/d\Omega$	529	3.08	3.10
[21–27]	$d\sigma/d\Omega$	1298	2.32	2.92
[28–36]	Σ	316	3.08	2.99
[37–40]	T	105	3.18	1.88
[41–43]	P	20	3.17	1.55
$\pi^- p \to \gamma n$				
[44–50]	$d\sigma/d\Omega$	495	1.53	1.60
[51–53]	P	55	3.11	1.96
$\gamma d \to \pi^0 n(p)$				
[54–57]	$d\sigma/d\Omega$	147	2.98	2.97
[58]	Σ	216	1.90	1.85
[16]	$d\sigma/d\Omega$	969	—	3.38
$\gamma d \to \eta n(p)$				
[59]	$d\sigma/d\Omega$	330	1.40	6.59
[60]	Σ	88	2.17	1.85
[11, 12]	$d\sigma/d\Omega$	880	–	1.01
$\gamma d \to K^0 \Lambda(p)$				
[13]	$d\sigma/d\Omega$	364	–	0.96
$\gamma d \to K^+ \Sigma^-(p)$				
[14]	$d\sigma/d\Omega$	229	–	0.72

Neutron Helicity Amplitude

Preliminary

TABLE II: The γN helicity couplings of nucleon states ($\mathrm{GeV}^{-1/2}10^{-3}$) calculated as residues in the pole position and corresponding Breit-Wigner couplings.

	E	Phase	$E_{(BW)}$	M	Phase	$M_{(BW)}$
$N(1535)1/2^-$	88±4	5±4°	81±6			
$N(1650)1/2^-$	-16±4	-28±10°	-16±5			
$N(1895)1/2^-$	15±10	60±25°	14±10			
$N(1440)1/2^+$				41±5	23±10°	53±7
$N(1710)1/2^+$				29±7	80±20°	±(30±7)
$N(1880)1/2^+$				72±24	-30±30°	70±22
$N(2100)1/2^+$				29±9	35±20°	29±10
$N(1520)3/2^-$	126±5	5±5°	125±6	13±3	26±3°	13±3
$N(1875)3/2^-$	3±2	-50±40	3±2	3±2	-80±40	±(3±2)
$N(2120)3/2^-$	-33±15	75±40°	-33±15	43±20	5±20°	43±20
$N(1720)3/2^+$	(20^{+30}_{-10})	-75±30°	(20^{+30}_{-10})	-85±30	-80±30°	±(85±30)
$N(1900)3/2^+$	70±17	-8±20°	71±17	-22±12	40±40°	-21±11
$N(1975)3/2^+$	-12±10	-10±35°	-12±9	80±15	5±20°	79±14
$N(1675)5/2^-$	3±2	60±30°	3±2	52±5	-10±5°	51±4
$N(2060)5/2^-$	-20±10	5±15°	-20±9	-27±9	5±20°	-26±9
$N(1680)5/2^+$	19±2	-13±7°	19±2	25±2	-9±4°	26±2
$N(2000)5/2^+$	-3±4	not defined	-3±4	8±4	-86±30°	±(8±4)
$N(1990)7/2^+$	-7±4	-12±20°	-5±4	30±15	-5±25°	30±15
$N(2190)7/2^-$	-5±2	-5±10°	-5±2	7±2	5±10°	7±2