Polarization Observables in Kaon Photoprodution

Natalie Walford
The Catholic University of America
University of Basel

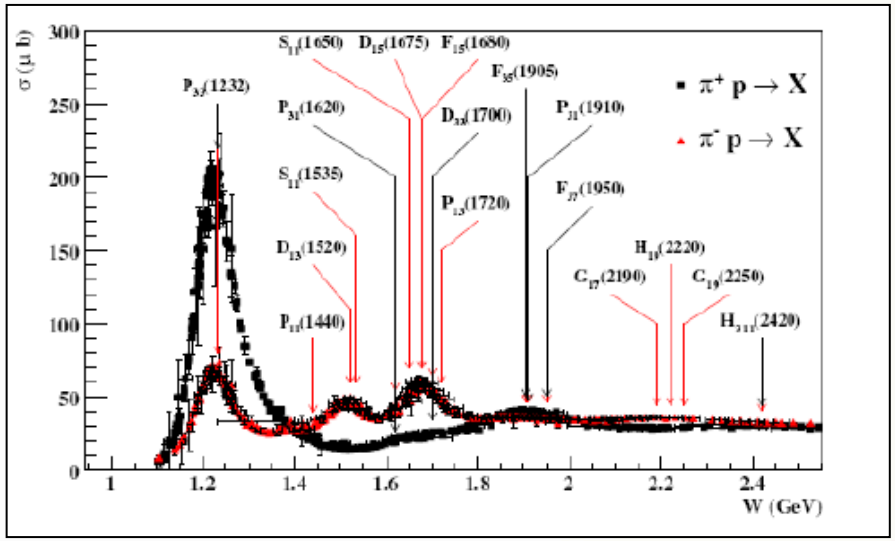
CEBAF Large Acceptance Spectrometer

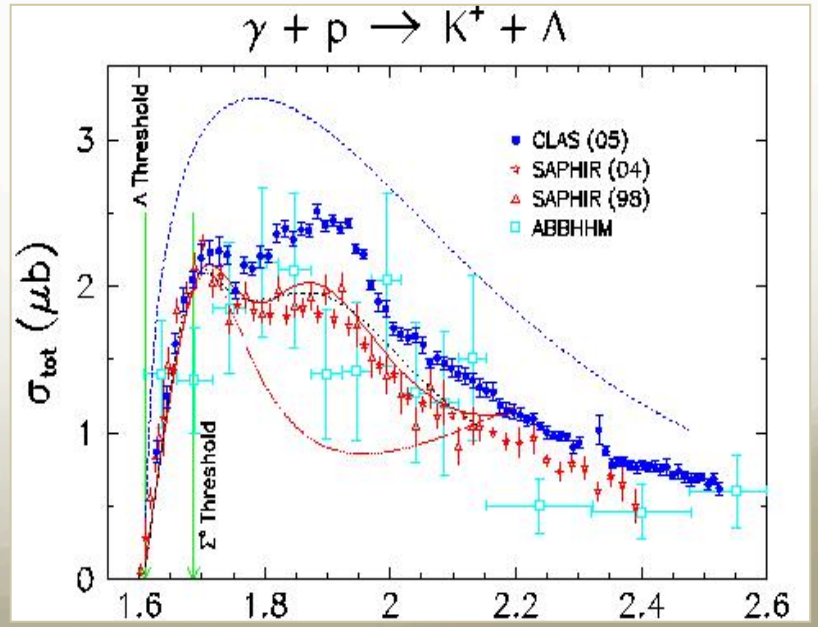
Outline

- Introduction
- Experimental Setup
- Event Selection
- Preliminary Results
- Conclusion

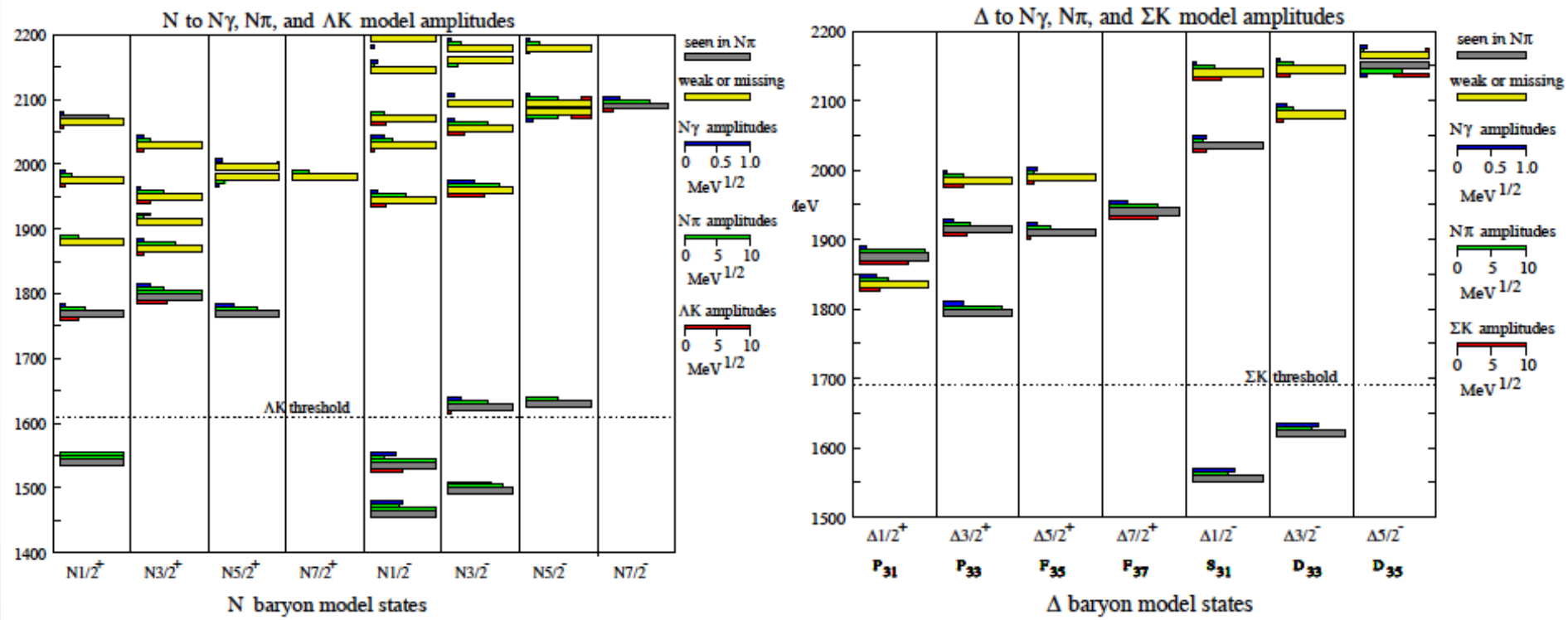
Baryon Resonances

- Approximate models are used to describe the nucleon spectrum
- Most resonances found in πN PWA
- Other channels may provide info on resonances that do NOT couple to πN
- $K^+\Lambda$ is an isospin filter....no coupling to Δ^* (I=3/2)
- $K^+\Lambda$ cross section easier disentangled since it only couples to a few N^* resonances (and those might couple weakly to πN!)





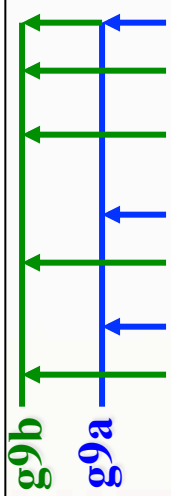
Constituent Quark Model



- Above 1850 MeV (N*) and 1950 MeV (Δ*) most have predicted states that have not been seen experimentally
- More model states predicted than observed so far

Polarization Observables

Spin observable	Helicity representation
$\check{\Omega}^1 \equiv \mathcal{I}(\theta)$	$\frac{1}{2}(\lvert H_1\rvert^2+\lvert H_2\rvert^2+\lvert H_3\rvert^2+\lvert H_4\rvert^2)$
$\check{\Omega}^4 \equiv \check{\Sigma}$	$\mathrm{Re}(-H_1H_4^*+H_2H_3^*)$
$\check{\Omega}^{10} \equiv -\check{T}$	$\mathrm{Im}(H_1H_2^*+H_3H_4^*)$
$\check{\Omega}^{12} \equiv \check{P}$	$\mathrm{Im}(-H_1H_3^*-H_2H_4^*)$
$\check{\Omega}^3 \equiv \check{G}$	$\mathrm{Im}(H_1H_4^*-H_3H_2^*)$
$\check{\Omega}^5 \equiv \check{H}$	$\mathrm{Im}(-H_2H_4^*+H_1H_3^*)$
$\check{\Omega}^9 \equiv \check{E}$	$\frac{1}{2}(\lvert H_1\rvert^2-\lvert H_2\rvert^2+\lvert H_3\rvert^2-\lvert H_4\rvert^2)$
$\check{\Omega}^{11} \equiv \check{F}$	$\mathrm{Re}(-H_2H_1^*-H_4H_3^*)$
$\check{\Omega}^{14} \equiv \check{O}_x$	$\mathrm{Im}(-H_2H_1^*+H_4H_3^*)$
$\check{\Omega}^7 \equiv -\check{O}_z$	$\mathrm{Im}(H_1H_4^*-H_2H_3^*)$
$\check{\Omega}^{16} \equiv -\check{C}_x$	$\mathrm{Re}(H_2H_4^*+H_1H_3^*)$
$\check{\Omega}^2 \equiv -\check{C}_z$	$\frac{1}{2}(\lvert H_1\rvert^2+\lvert H_2\rvert^2-\lvert H_3\rvert^2-\lvert H_4\rvert^2)$
$\check{\Omega}^6 \equiv -\check{T}_x$	$\mathrm{Re}(-H_1H_4^*-H_2H_3^*)$
$\check{\Omega}^{13} \equiv -\check{T}_z$	$\mathrm{Re}(-H_1H_2^*+H_4H_3^*)$
$\check{\Omega}^8 \equiv \check{L}_x$	$\mathrm{Re}(H_2H_4^*-H_1H_3^*)$
$\check{\Omega}^{15} \equiv \check{L}_z$	$\frac{1}{2}(-\lvert H_1\rvert^2+\lvert H_2\rvert^2+\lvert H_3\rvert^2-\lvert H_4\rvert^2)$



- Photoproduction of single pseudoscalar mesons is described by four complex helicity amplitudes, which describe all spin combinations of incoming and outgoing particles, leading to 16 bilinear products
- Polarization observables are combinations of the 16 bilinear products and can be extracted based on target, beam, and recoil polarization
- Not all observables are independent from each other

Photon		Target			Recoil			Target + Recoil			
	–	–	–	–	x'	y'	z'	x'	x'	z'	z'
	–	x	y	z	–	–	–	x	z	x	z
unpolarized	σ_0	0	T	0	0	P	0	$T_{x'}$	$-L_{x'}$	$T_{z'}$	$L_{z'}$
linear pol.	$-\Sigma$	H	(-P)	$-G$	$O_{x'}$	(-T)	$O_{z'}$	$(-L_{z'})$	$(T_{z'})$	$(-L_{x'})$	$(-T_{x'})$
circular pol.	0	F	0	$-E$	$-C_{x'}$	0	$-C_{z'}$	0	0	0	0

Available World Data

$\gamma p \to K^+\Lambda$	Observ.	N_{data}	χ^2_i/N_{data}
[43] CLAS	$d\sigma/d\Omega$	1320	0.69
[51] LEPS	Σ	45	2.11
[50] GRAAL	Σ	66	2.95
[43] CLAS	P	1270	1.82
[50] GRAAL	P	66	0.59
[52] GRAAL	T	66	1.62
[40] CLAS	C_x	160	1.52
[40] CLAS	C_z	160	1.58
[52] GRAAL	$O_{x'}$	66	1.95
[52] GRAAL	$O_{z'}$	66	1.66

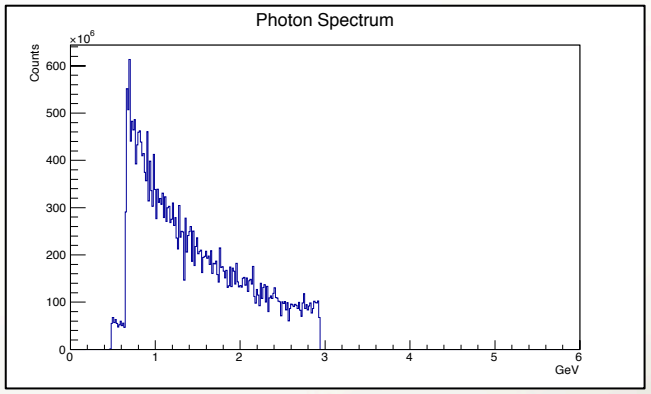
$\gamma p \to K^+\Sigma^0$	Observ.	N_{data}	χ^2_i/N_{data}
[62] CLAS	$d\sigma/d\Omega$	1590	1.44
[51] LEPS	Σ	45	1.23
[52] GRAAL	Σ	42	1.99
[62] CLAS	P	344	2.69
[40] CLAS	C_x	94	1.95
[40] CLAS	C_z	94	1.66
$\gamma p \to K^0\Sigma^+$	Obsv.	N_{data}	χ^2_i/N_{data}
[63] CLAS	$d\sigma/d\Omega$	48	3.84
[64] SAPHIR	$d\sigma/d\Omega$	160	1.91
[65] CBT	$d\sigma/d\Omega$	72	0.76
[66] CBT	$d\sigma/d\Omega$	72	0.62
[65] CBT	P	72	0.90
[66] CBT	P	24	0.94
[66] CBT	Σ	15	1.73

Available data used by Bonn-Gatchina solution (BG2011-12)

Clear lack in data for kaon photoproduction!!

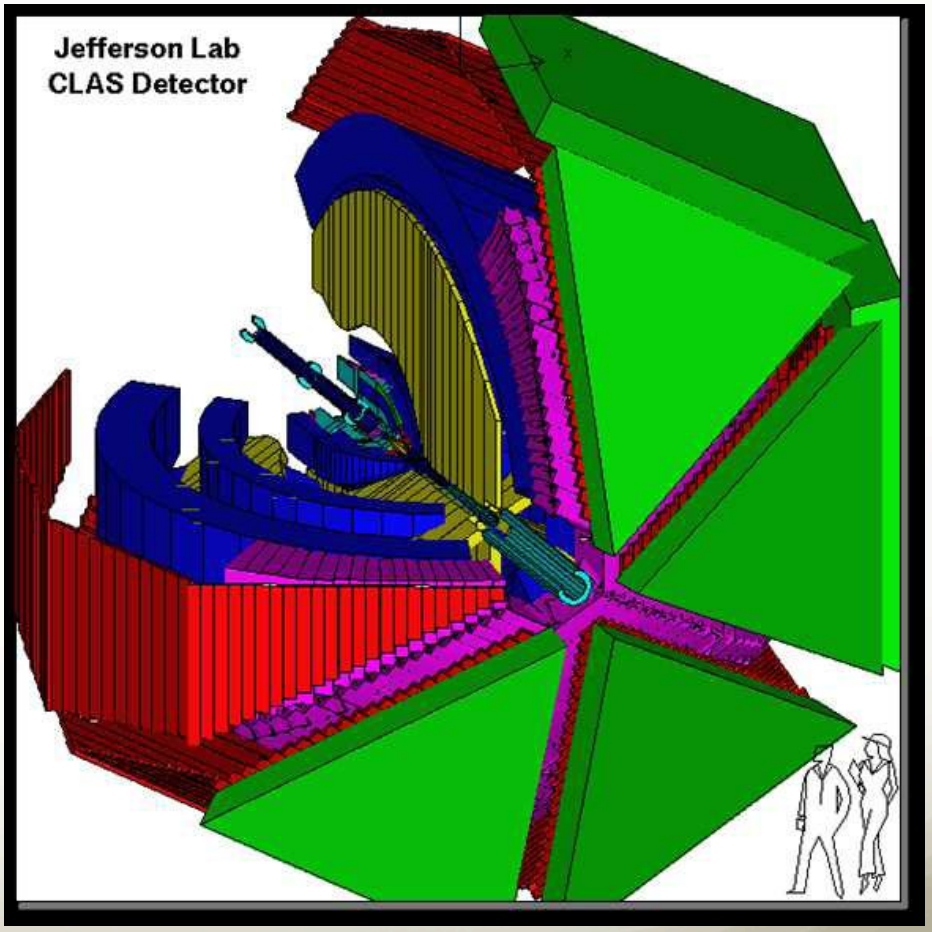
Experimental Setup

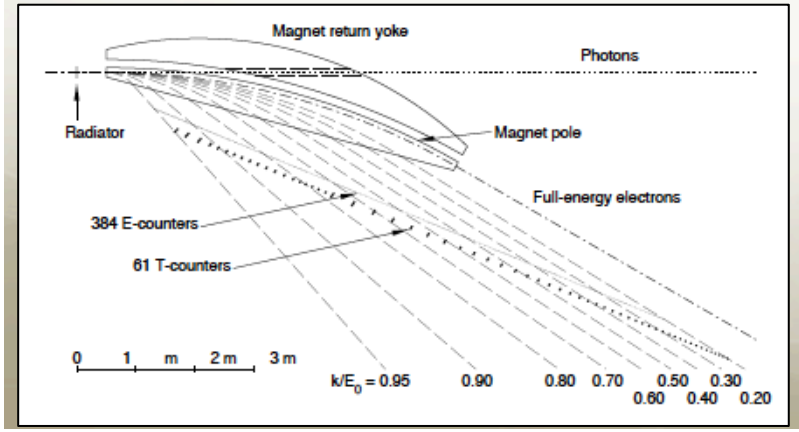
- The FROST experiment was first approved in 2002 with CLAS, ran in two parts in 2007-2008 (g9a-longitudinally polarized target) and 2010 (g9b-transversely polarized target)
- Butanol FROzen Spin Target with free protons polarized
- Polarized photon beam
  - Circularly (Au radiator)
  - Linearly (Diamond radiator)
- Photon beam energies from 0.5 to 3.0 GeV (circular) and 1.1 to 2.1 GeV (linear)
- 10 billion events collected (g9a)
  14 billion events collected (g9b)
- 'Complete measurement': all beam-target and target-recoil observables from $K^+\Lambda$ and $K^+\Sigma^0$ final states



JLab, CLAS, and the Tagger

- Up to 5 passes for a max of ~ 6 GeV (upgrade allows ~12 GeV)
- After bremsstrahlung, recoil electrons are bent towards the electron dump via a dipole magnetic field created by the tagger magnet
- Tagger had ability to measure electron energies that are then used to calculate the energy associated with the photons and timing of accelerator
- CLAS had almost full acceptance, 80% of 4π coverage



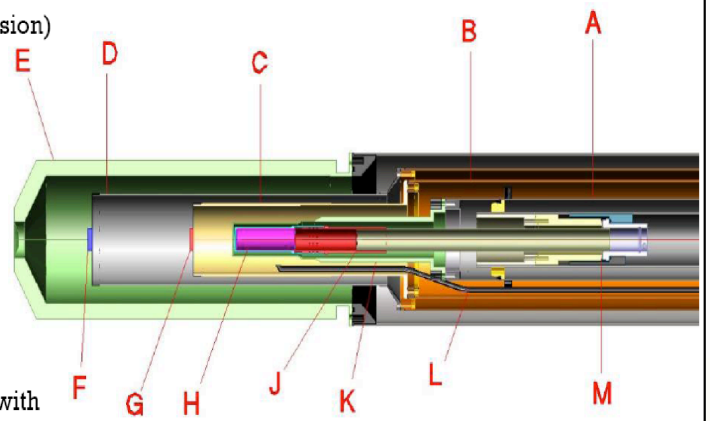


$E_\gamma = E_{beam} - E_{e\ scattered}$

FROST Target

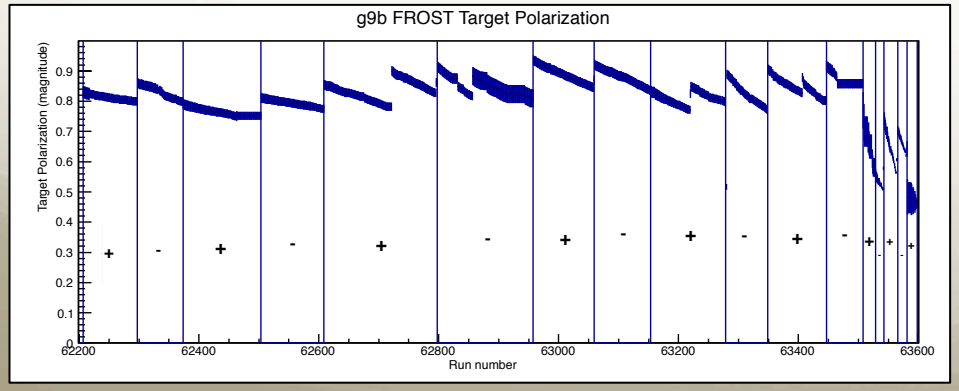
The FroST target and its components:
A: Primary heat exchanger
B: 1 K heat shield
C: Holding coil
D: 20 K heat shield
E: Outer vacuum can (Rohacell extension)
F: CH2 target
G: Carbon target
H: Butanol target
J: Target insert
K: Mixing chamber
L: Microwave waveguide
M: Kapton coldseal

Butanol Composition:
C_4H_9OH + liquid He



Performance Specs:
Base Temp: 28 mK w/o beam, 30 mK with
Cooling Power: 800 μW @ 50 mK, 10 mW @ 100 mK, and 60 mW @ 300 mK
Polarization: +82%, -90%
1/e Relaxation Time: 2800 hours (+Pol), 1600 hours (-Pol)

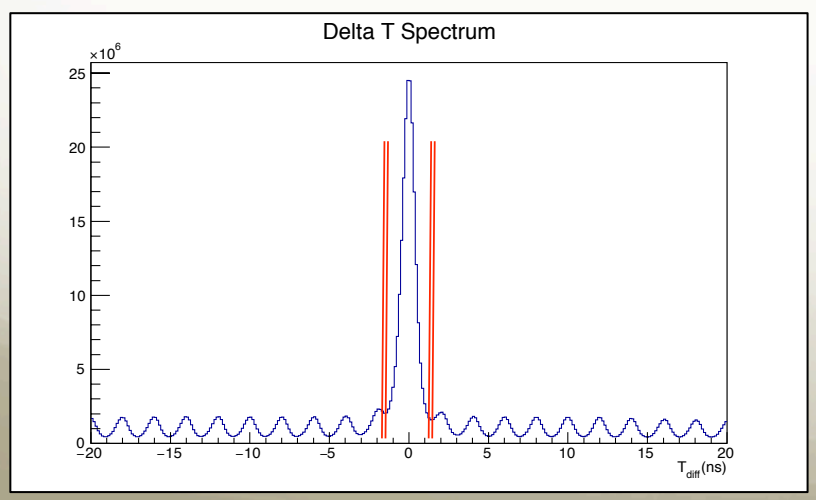
- Butanol in LHe bath
- Polarizing 5 Tesla magnet aligns free proton spins
- Holding coil keeps proton polarized

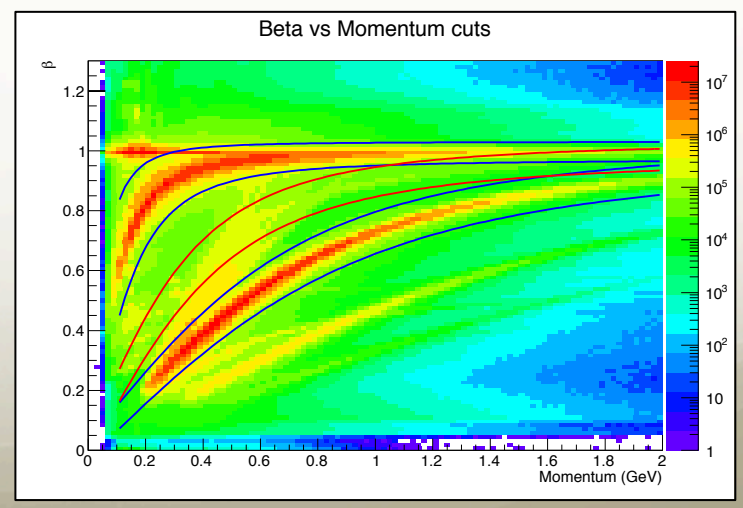


Target re-polarized ~once per week!!

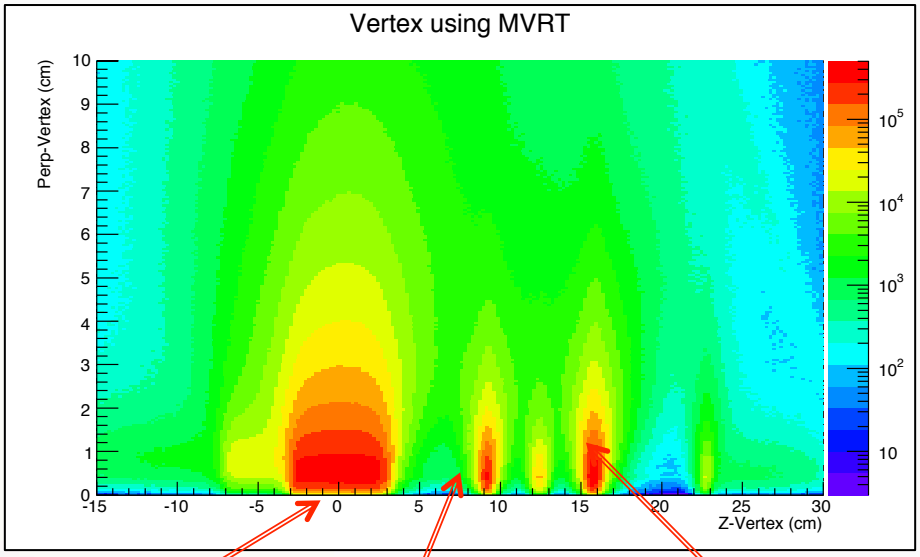
Event Selection

- Skimmed data for events
  - γ p -> $K^+ \Lambda$ -> $K^+ p(\pi^-)$ AND γ p -> $K^+ \Sigma^0$ -> $K^+ \Lambda \gamma$ -> $K^+ p(\gamma \pi^-)$
- One proton, one kaon identified
- One photon identified with cut on coincidence of ± 1 ns
- Only two positively charged particles

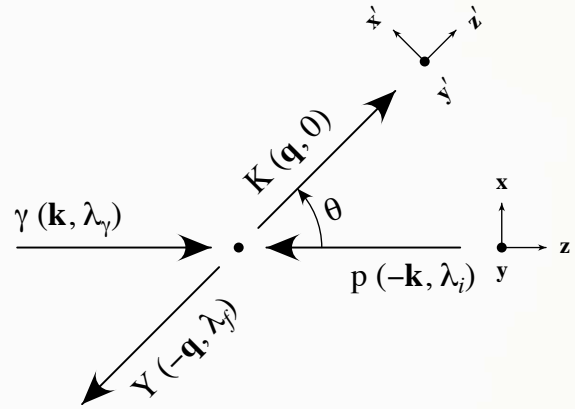


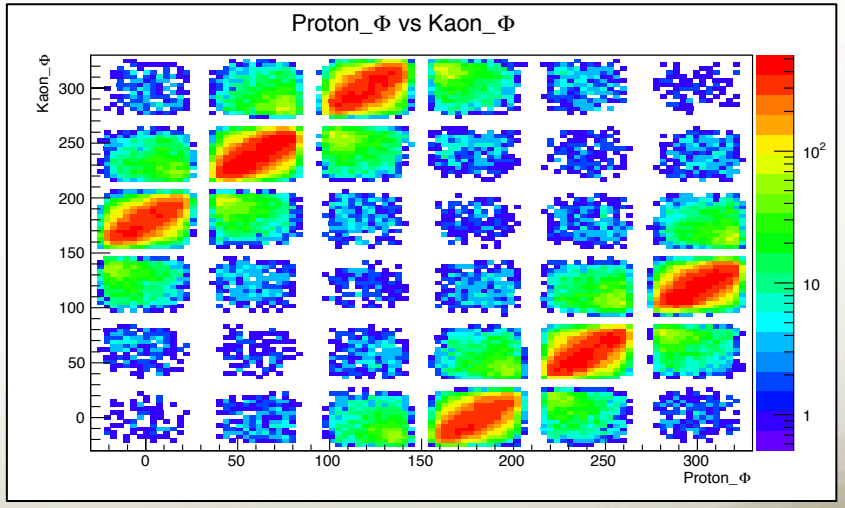


Vertices



Butanol Carbon CH_2

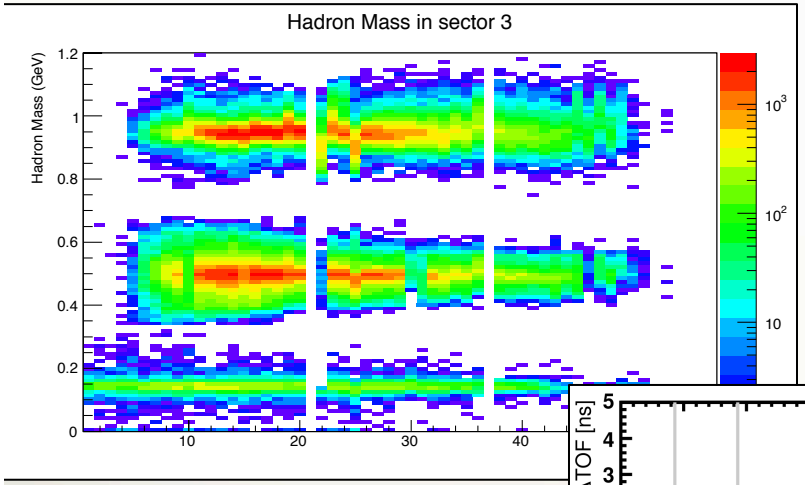


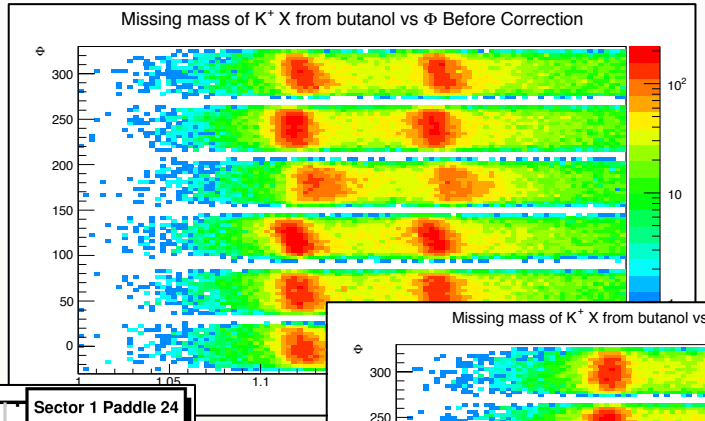


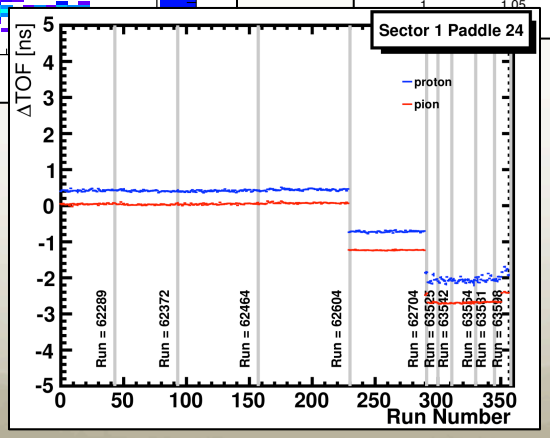
- Cut on kaon event vertex
- Check whether p from Λ decay vertex by comparing azimuthal angles of p and K^+ (p almost in same direction as Λ, which is opposite of K^+ in CM frame)

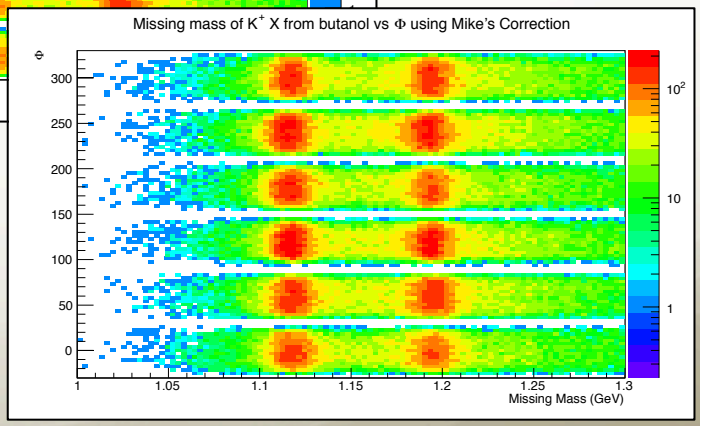
Corrections to Data

- Bad TOF paddles cut
- Sector dependent momentum correction applied
- Timing offset between protons and pions in TOF corrected

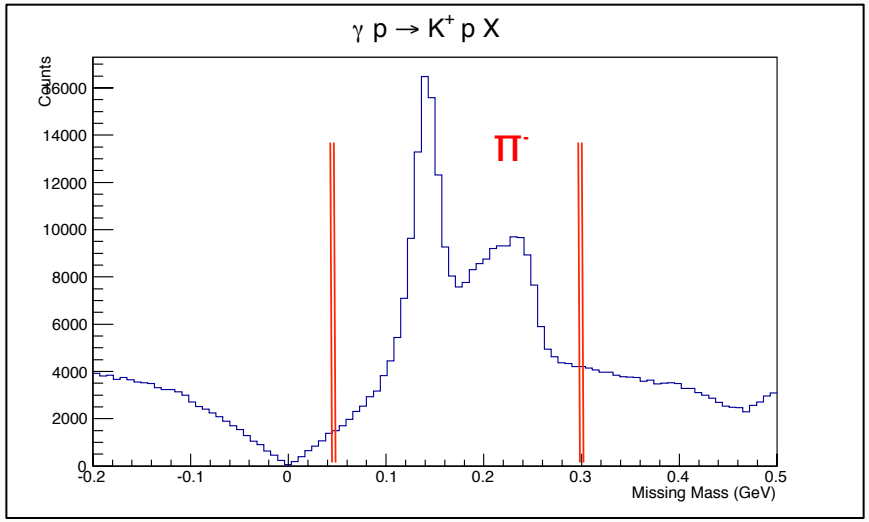


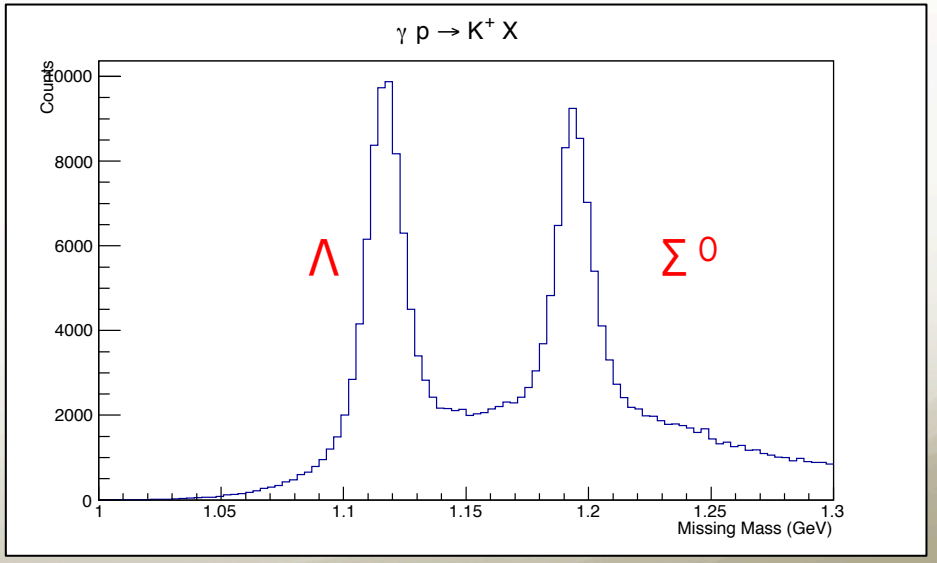






Missing Mass Cuts





Extracting φ-dependent Observables:Moment Method

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}(1 + P_{XY}^{lab} P_c F cos\phi - P_{XY}^{lab} T sin\phi)$$

Define phi dependent density function within each W and cosine bin

$$f^{i,j}(\varphi) \equiv \rho L \int_{E_{i-1}}^{E_i} \int_{\cos\theta_{j-1}}^{\cos\theta_j} \varepsilon(E,\theta,\varphi) \frac{d^3\sigma}{d(\cos\theta)dEd\varphi} d(\cos\theta)dE$$

Expand density function f(ϕ) in Fourier series...

$$f_a^{i,j}(\varphi) = a_0 + \sum_{m=1}^{\infty} [a_m \cos(m\varphi) + b_m \sin(m\varphi)]$$

$$Y_{l,n} = \int_0^{2\pi} f_l^{i,j}(\phi) cos(n\phi) d\phi \qquad Z_{l,n} = \int_0^{2\pi} f_l^{i,j}(\phi) sin(n\phi) d\phi$$

Separate cosine/sin terms

Moment Method Continued

$$Y_{l,n} = \int_0^{2\pi} f_l^{i,j}(\phi) cos(n\phi) d\phi \qquad Z_{l,n} = \int_0^{2\pi} f_l^{i,j}(\phi) sin(n\phi) d\phi$$

$$T = 2\frac{\tilde{Z}_{A,1} + \tilde{Z}_{B,1} - \tilde{Z}_{C,1} - \tilde{Z}_{D,1}}{P_C(\tilde{Y}_{A,0} + \tilde{Y}_{B,0} - \tilde{Y}_{A,2} - \tilde{Y}_{B,2}) + P_A(\tilde{Y}_{C,0} + \tilde{Y}_{D,0} - \tilde{Y}_{C,2} - \tilde{Y}_{D,2})}$$

$$F = \frac{2(P_A + P_C)}{P_A P_C(\lambda_A + \lambda_C)} \frac{P_C(\tilde{Y}_{A,1} - \tilde{Y}_{B,1}) + P_A(\tilde{Y}_{D,1} - \tilde{Y}_{C,1})}{P_C(\tilde{Y}_{A,0} + \tilde{Y}_{B,0} + \tilde{Y}_{A,2} + \tilde{Y}_{B,2}) + P_A(\tilde{Y}_{C,0} + \tilde{Y}_{D,0} + \tilde{Y}_{C,2} + \tilde{Y}_{D,2})}$$

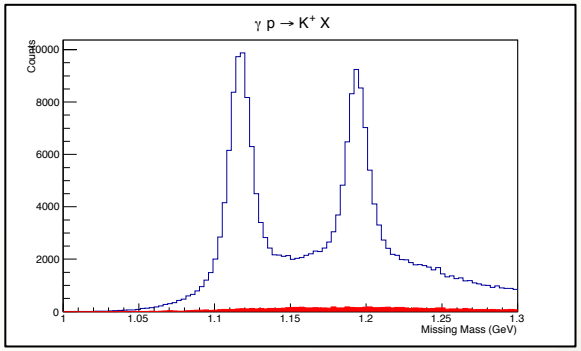
λ_A – positive helicity
λ_C – negitive helicity

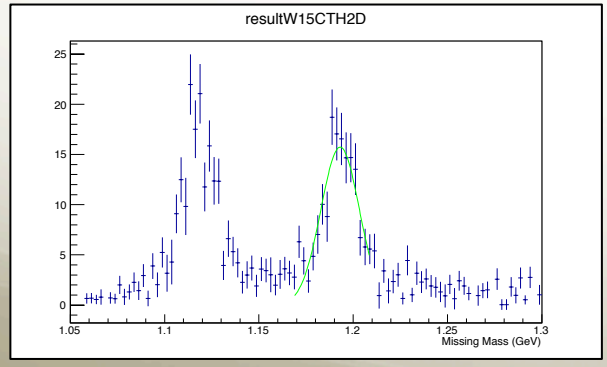
P_A – positive target polarization
P_C – negative target polarization

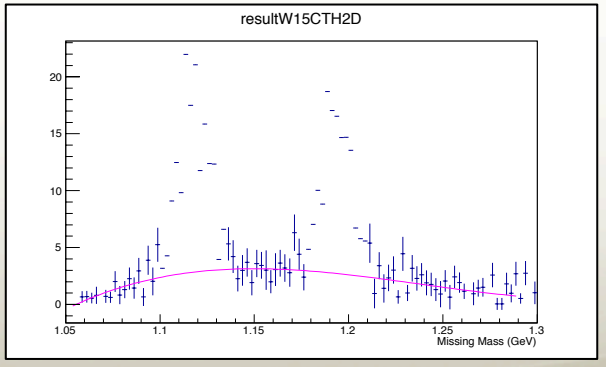
T_x and T_z are double polarization observables with a transverse target polarization and recoil polarization in the Λ decay plane and calculated in similar way with moments!!

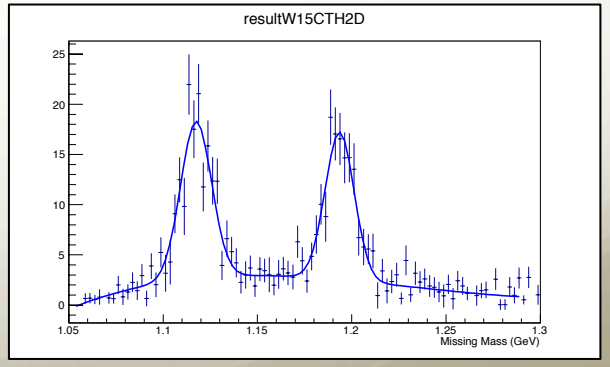
Background Subtraction

- Quasi-free kaon production is suppressed on **carbon** – so need to subtract free protons from bound protons
  - Fit Λ and Σ^0 signals with Gaussian
  - Fit remaining background with cubic polynomial
  - Then make a combined fit
  - Do for every $\cos\theta$ bin in every W bin!







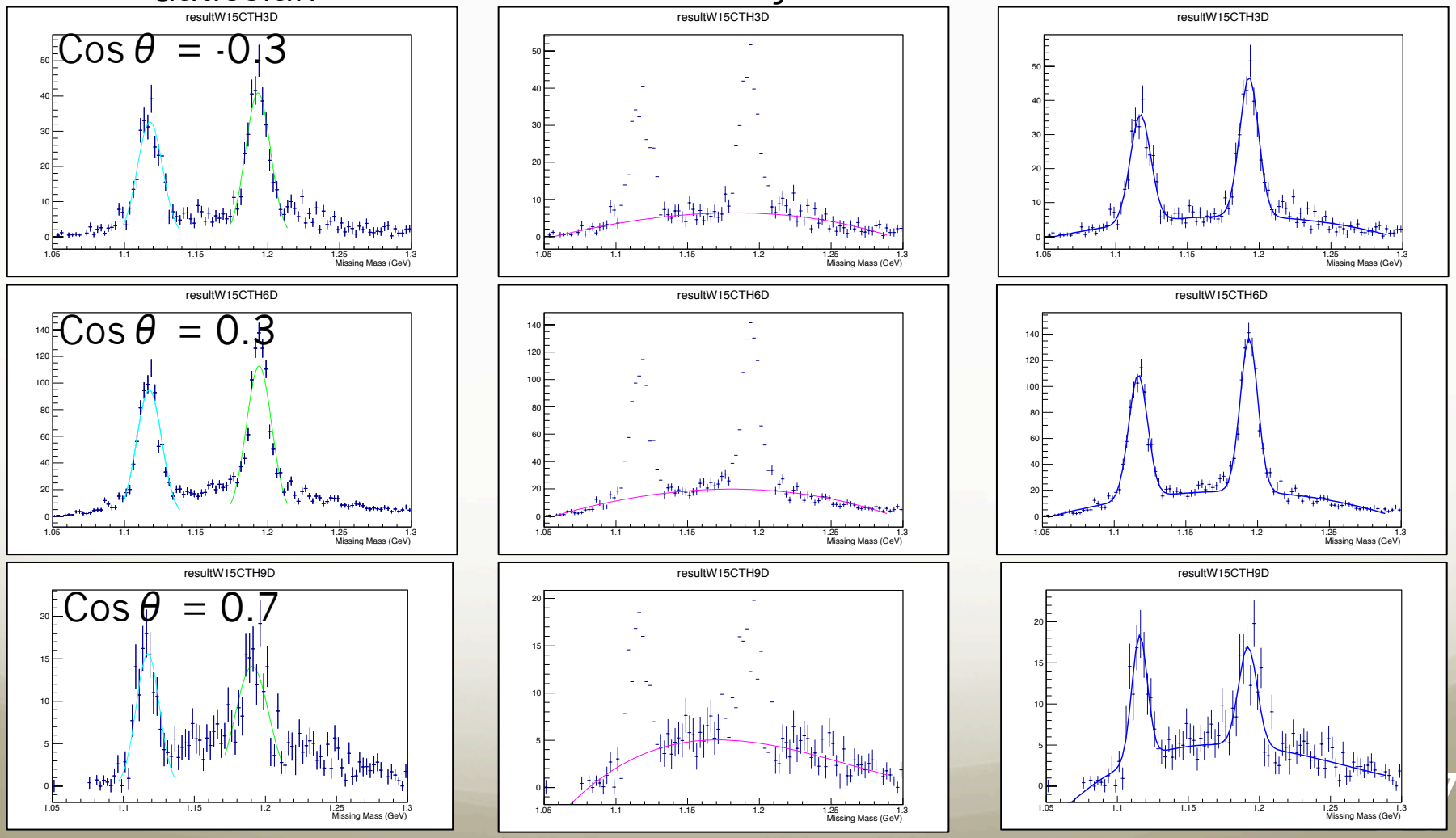


Butanol – C_4H_9OH – only 10 free protons, 64 bound protons!!

Background Subtraction

Example of Background Subtraction for W = 1875 MeV

Gaussian | 3rd Order Polynomial | Global

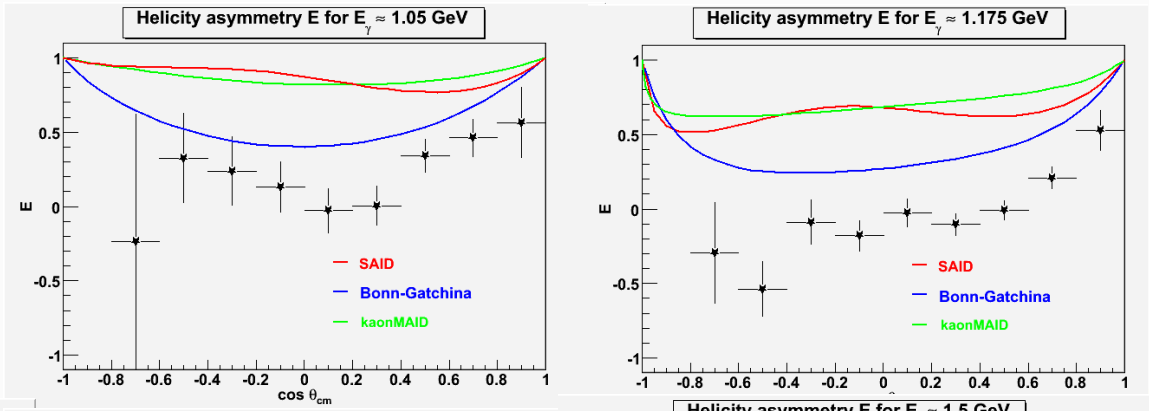


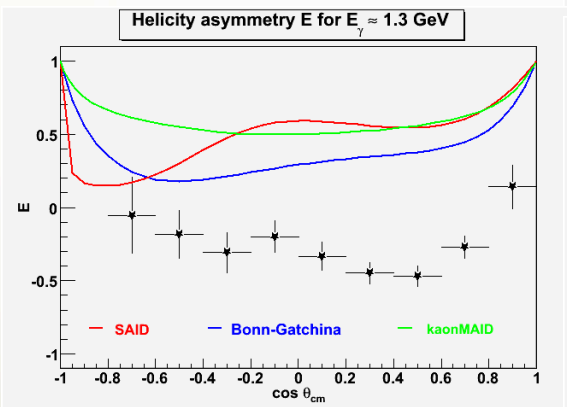
Results

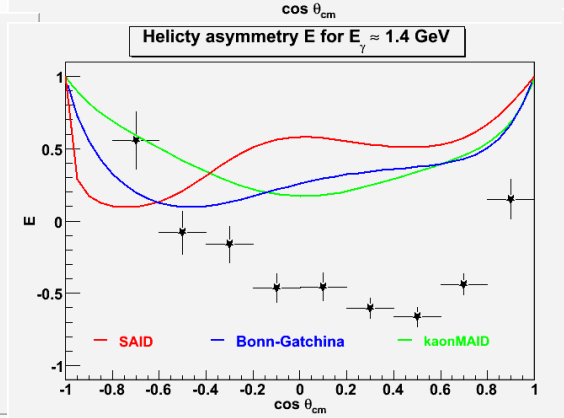
- Results for E, L_x, L_z, T, F, T_x, and T_z
- Compared to theoretical models
  - KAON-MAID…isobar model
  - Bonn-Gatchina (BOGA)…coupled channel PWA
  - RPR-Ghent…isobar model

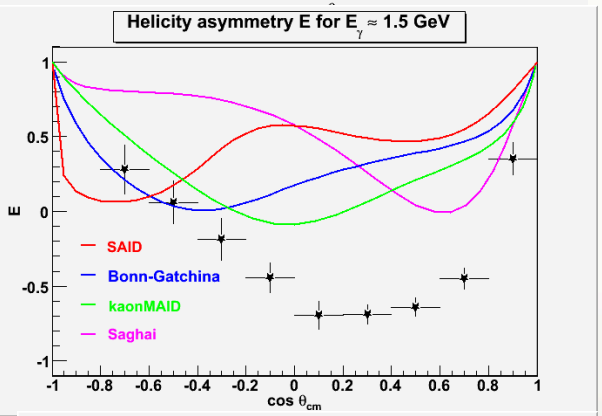
E for $K^+\Lambda$

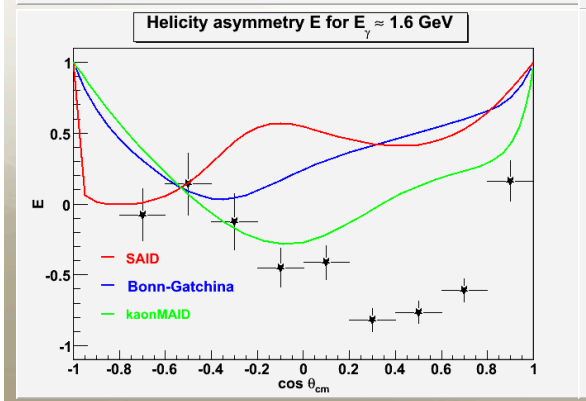
$$E = \frac{D_{eff}}{P_T P_\gamma} \frac{N_{1/2} - N_{3/2}}{N_{1/2} + N_{3/2}}$$

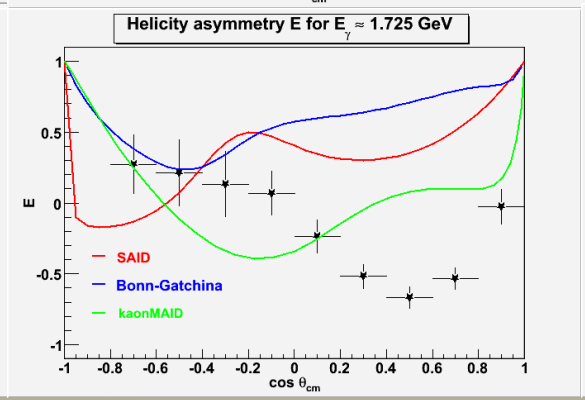


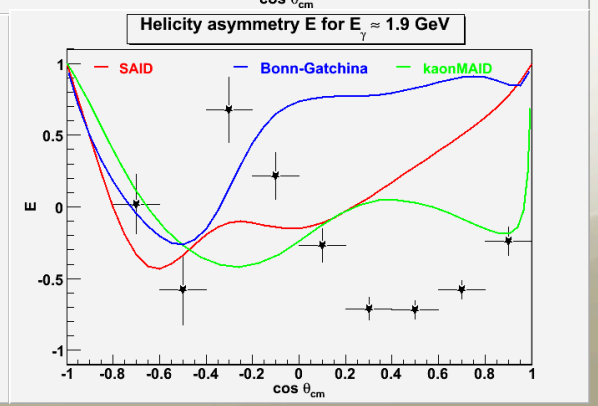




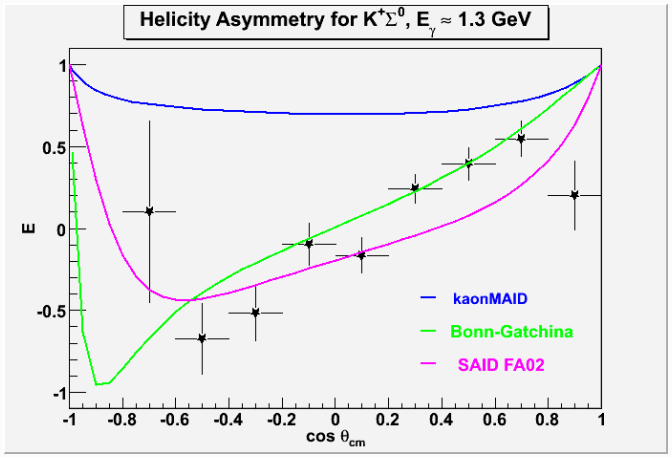


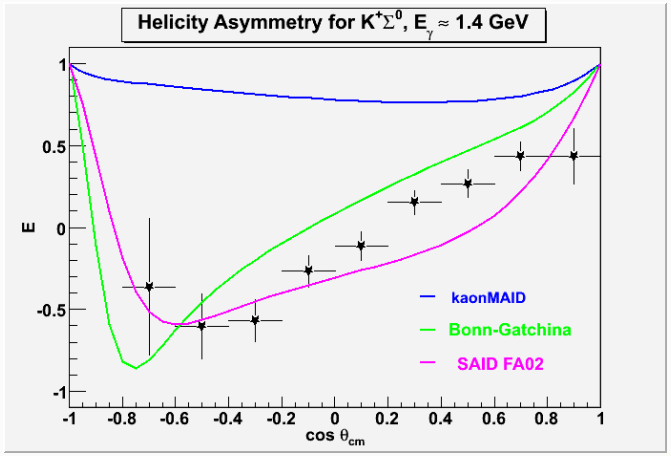


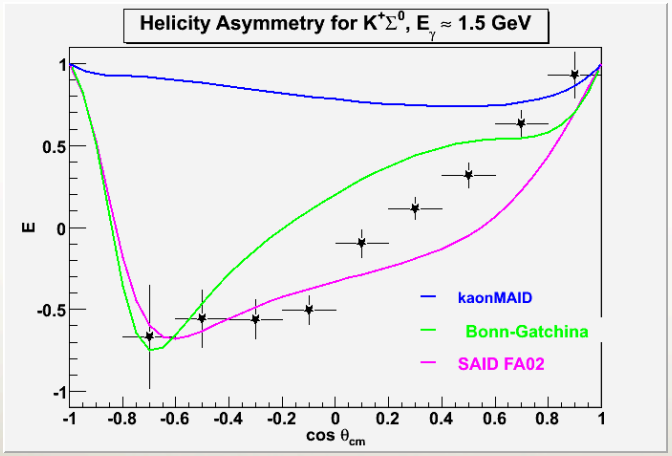


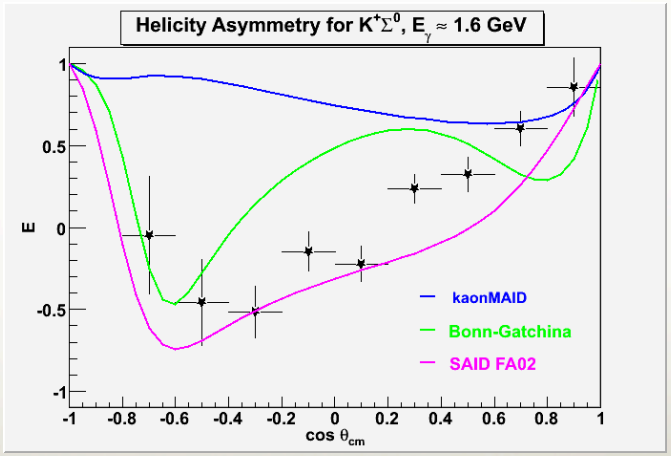


E for $K^+\Sigma^0$



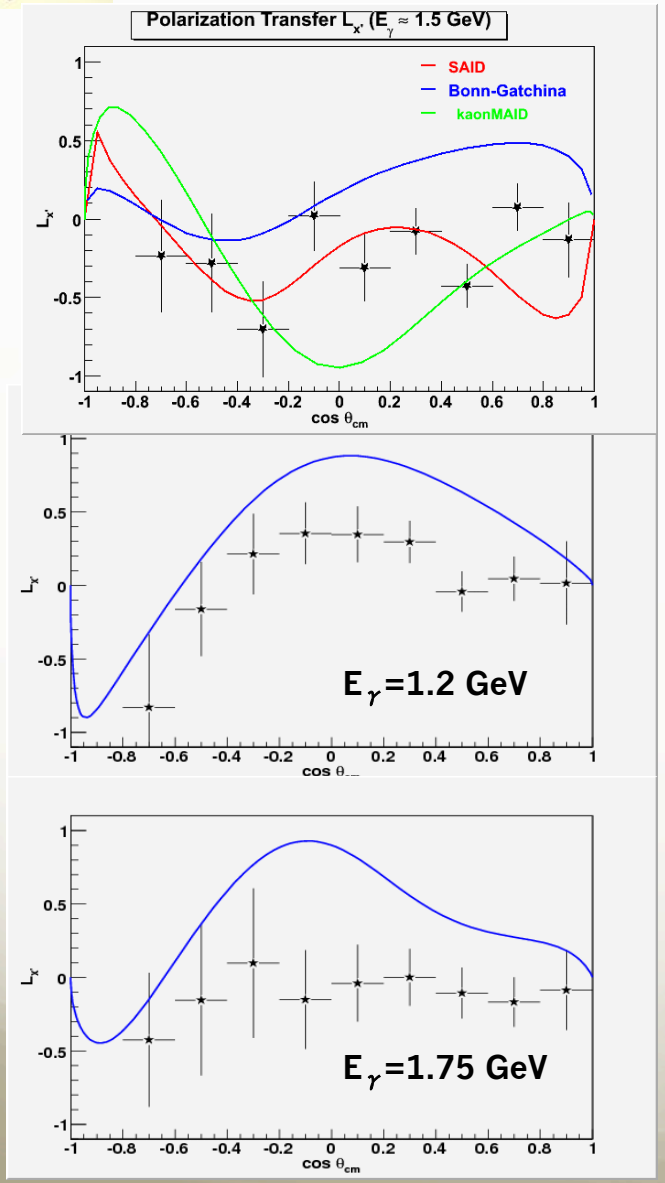


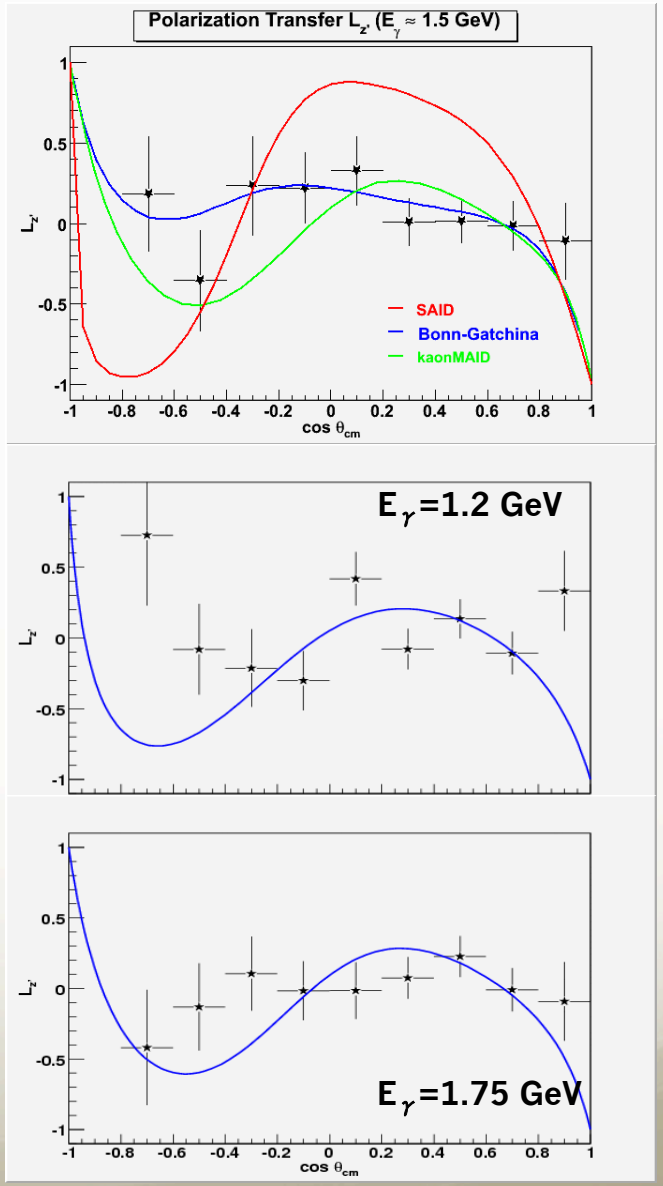




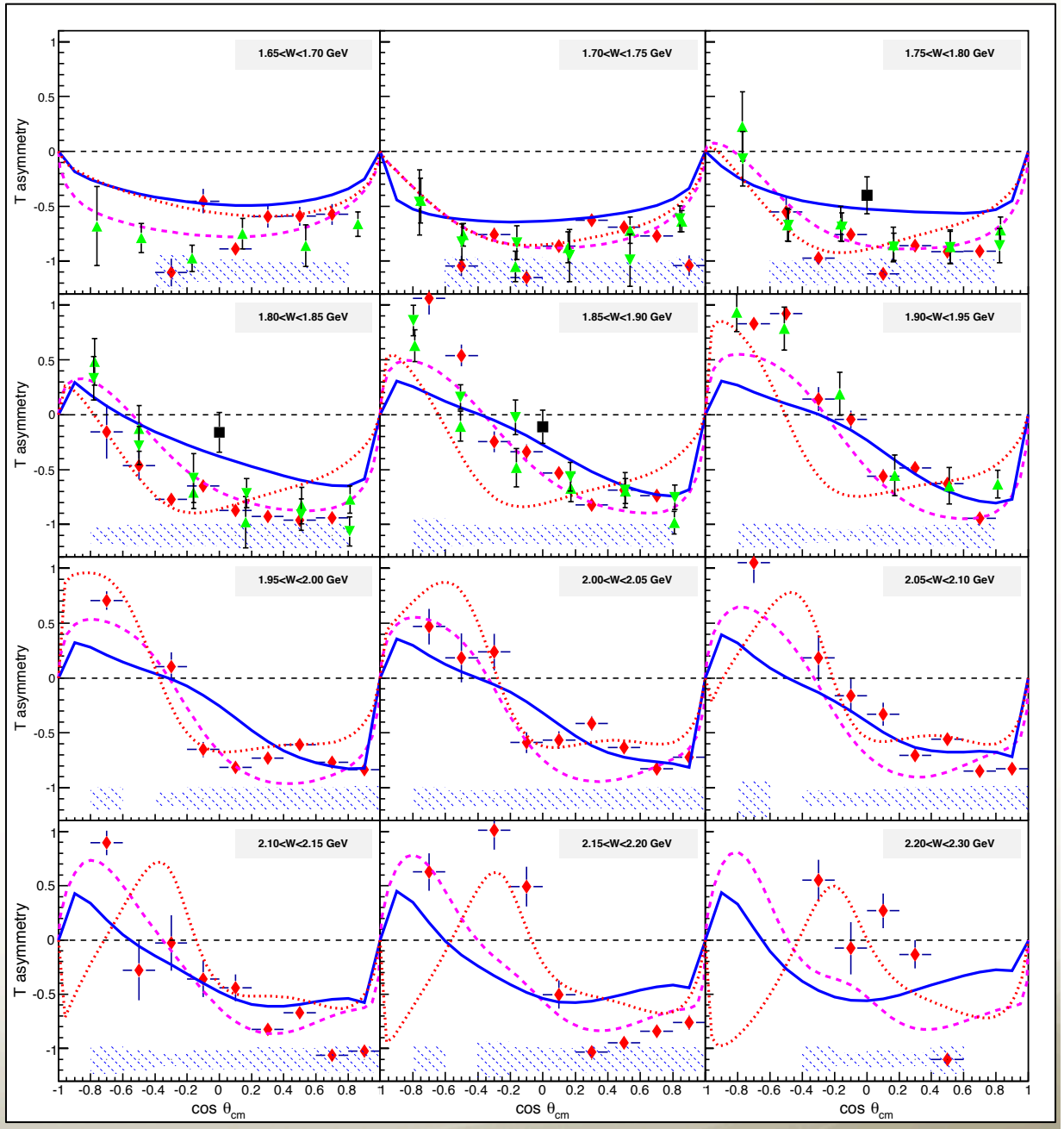
$$E = \frac{D_{eff}}{P_T P_\gamma} \frac{N_{1/2} - N_{3/2}}{N_{1/2} + N_{3/2}}$$

L_x and L_z for $K^+\Lambda$





T for $K^+\Lambda$



Data:
CLAS g9b
Bonn78
GRAAL09

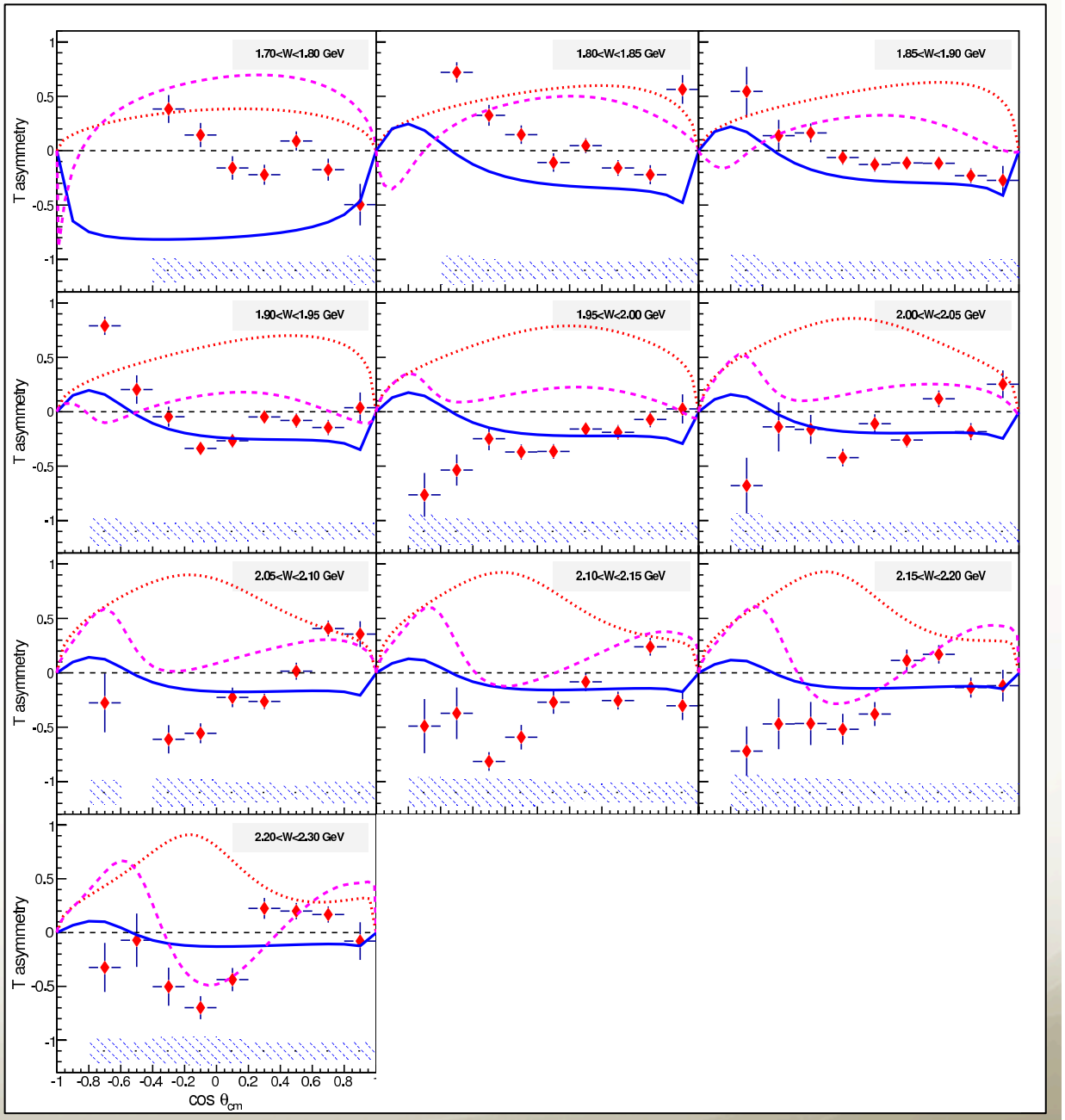
Models:
RPR-Ghent
Kaon-MAID
BOGA

Not yet compared to Paterson *et al.*, PRC **93** 065201 (2016)

T for $K^+\Sigma^0$

Data:
CLAS g9b

Models:
RPR-Ghent
Kaon-MAID
BOGA

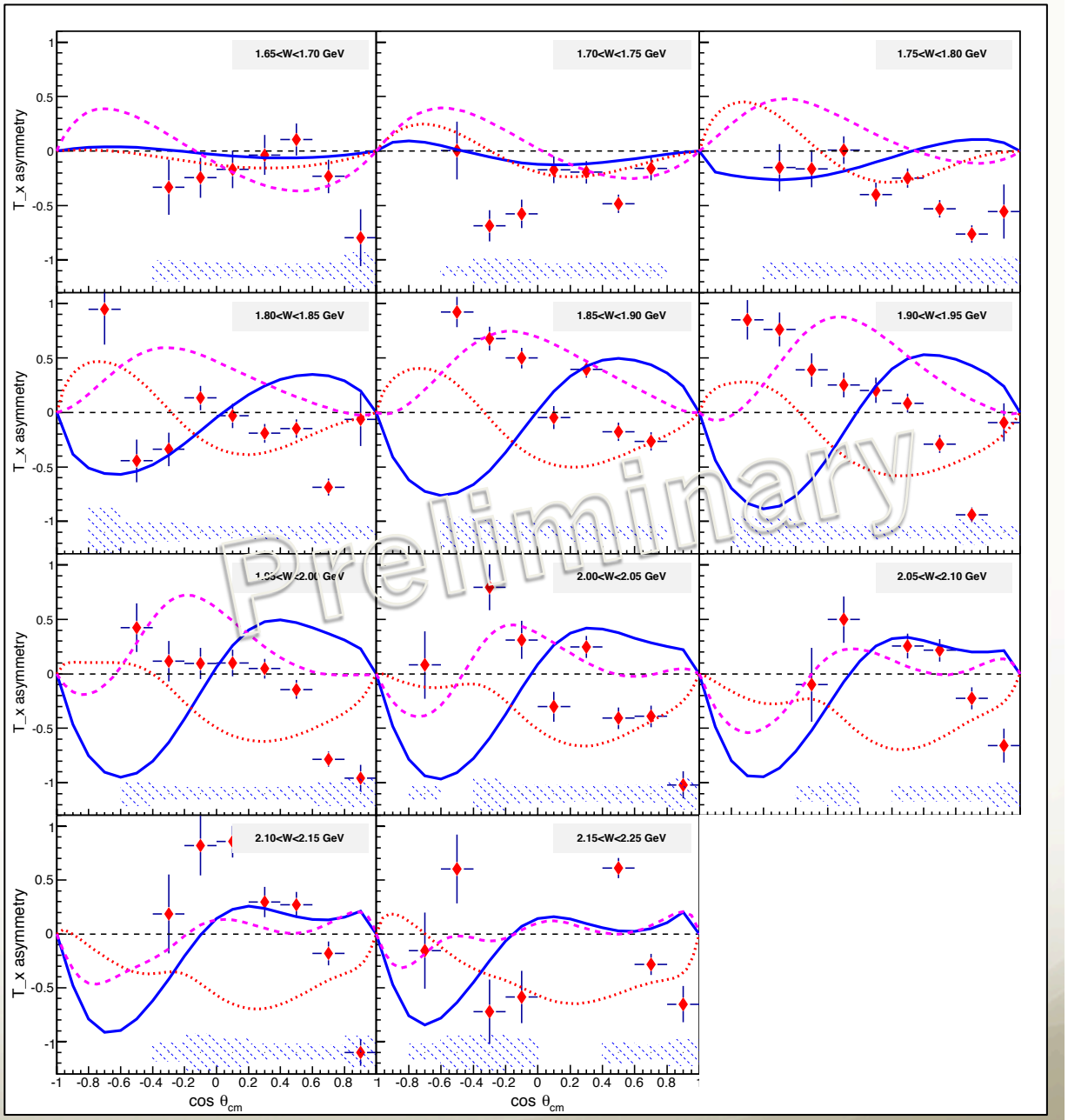


Not yet compared to Paterson *et al.*, PRC **93** 065201 (2016)

T_x for $K^+\Lambda$

Data:
CLAS g9b

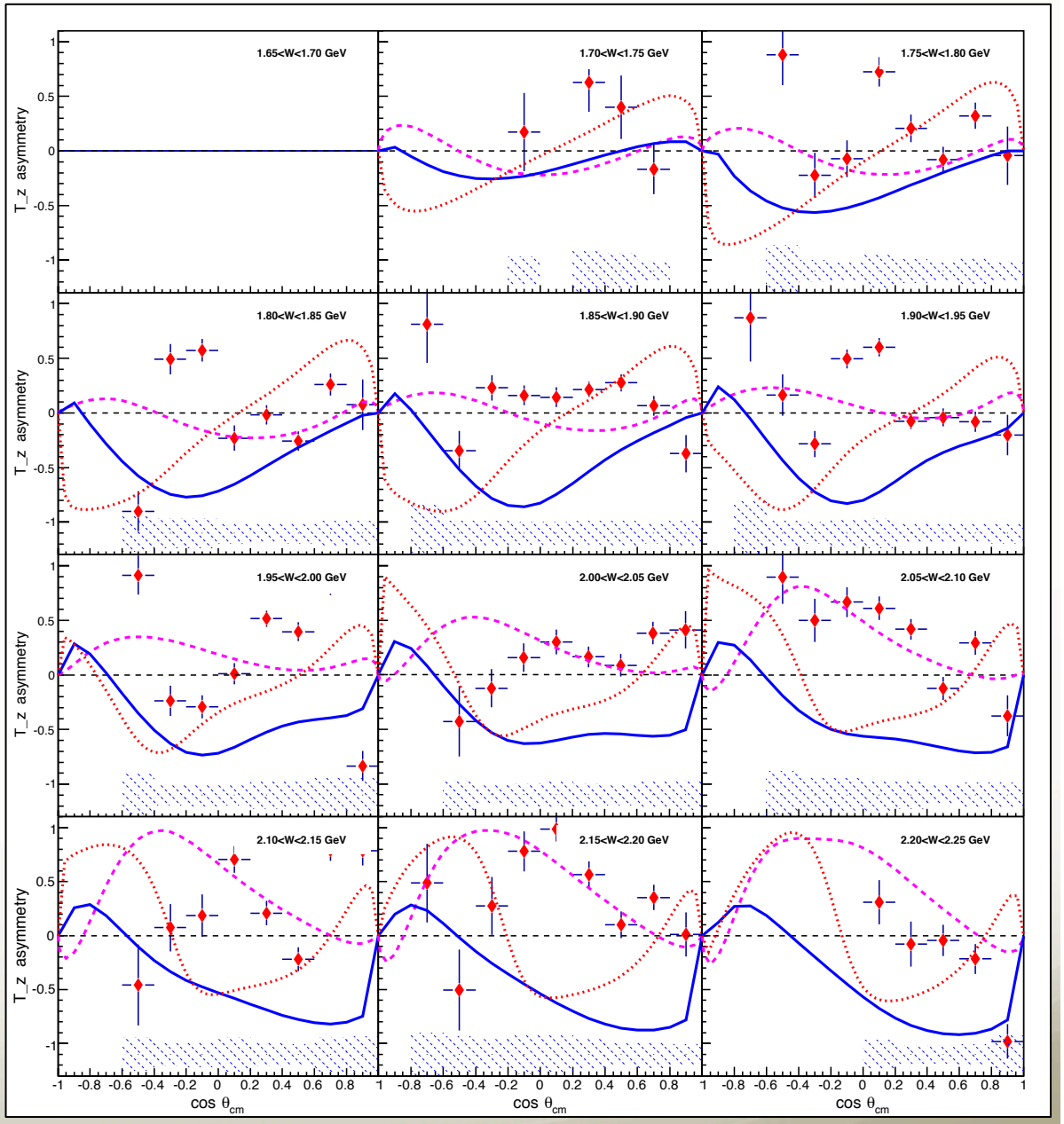
Models:
RPR-Ghent
Kaon-MAID
BOGA



T_z for $K^+\Lambda$

Data:
CLAS g9b

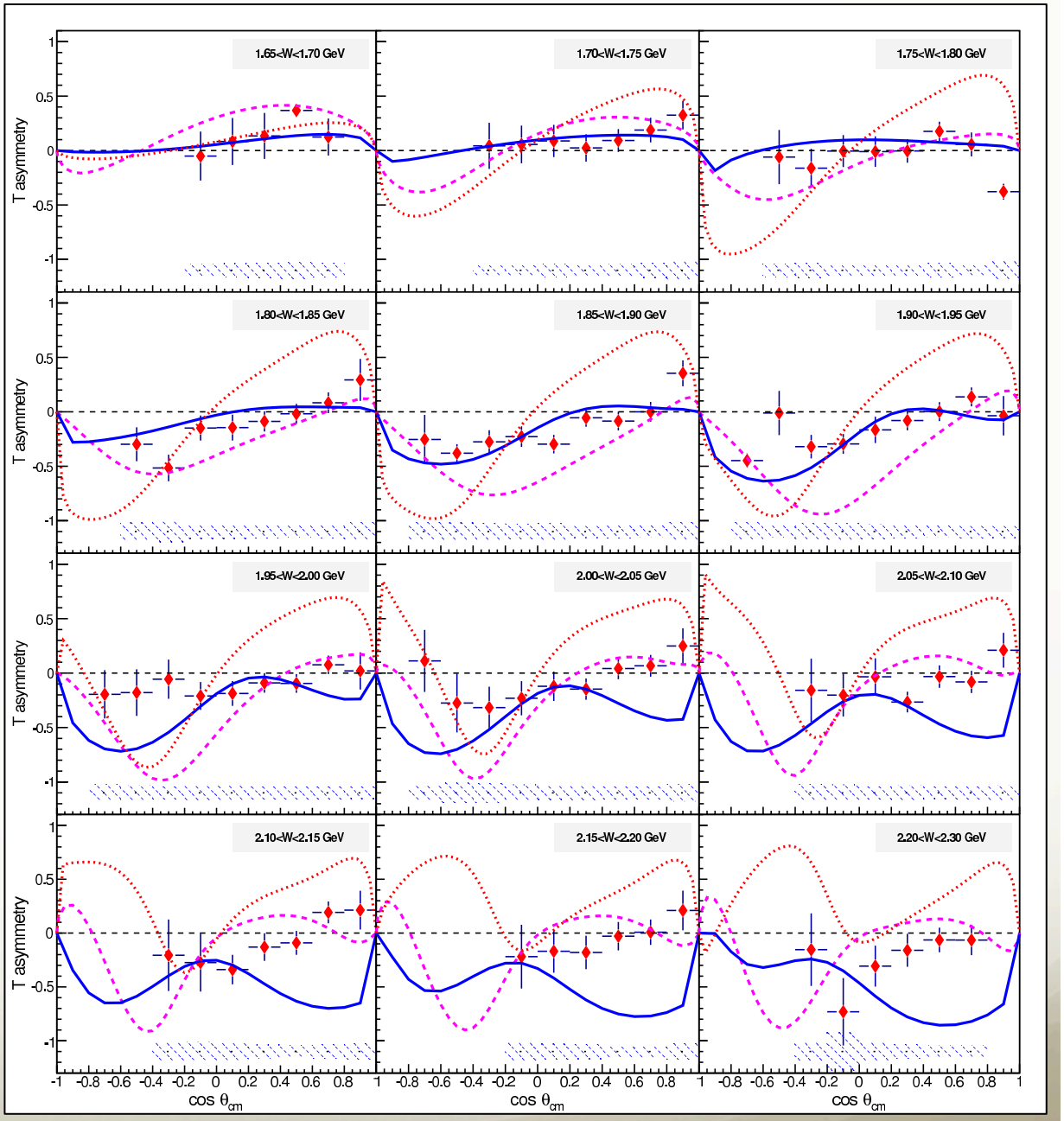
Models:
RPR-Ghent
Kaon-MAID
BOGA



F for $K^+\Lambda$

Data:
CLAS g9b

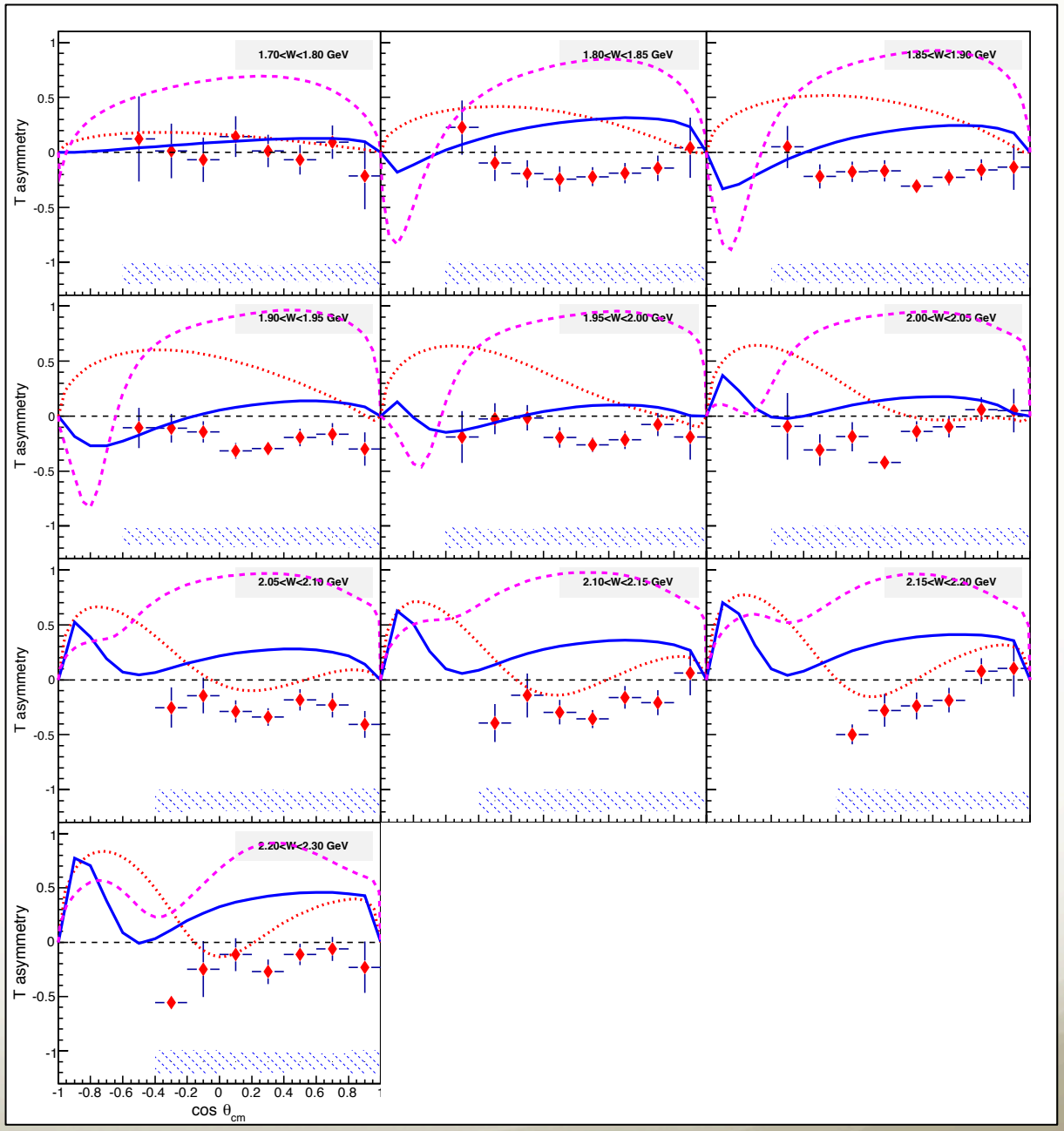
Models:
RPR-Ghent
Kaon-MAID
BOGA



F for $K^+\Sigma^0$

Data:
CLAS g9b

Models:
RPR-Ghent
Kaon-MAID
BOGA



Conclusion

- More kaon photoproduction data necessary to help solve missing resonance problem
- First results for many of the observables for kaon photoproduction
- Working on publishing results...slowly...
- Models and PWA results only partially consistent with data: can expect that resonance parameters will greatly improve with this data