Polarization Observables in Kaon Photoproduction

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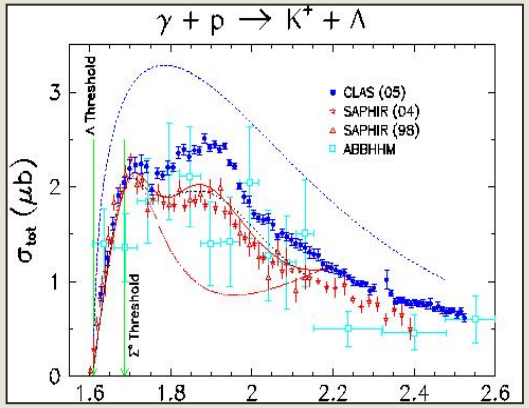
clas
CEBAF Large Acceptance Spectrometer

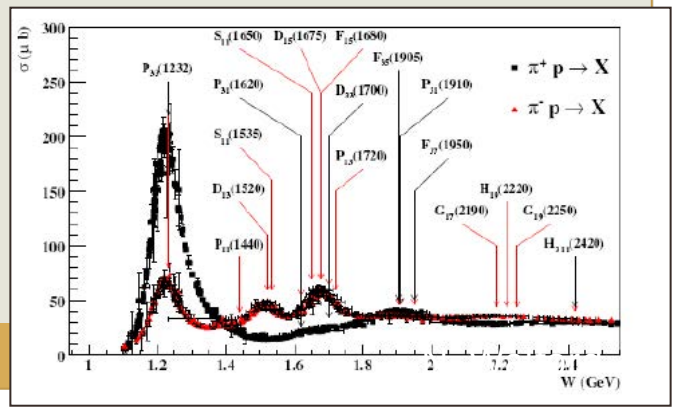
Outline

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

Baryon Resonances

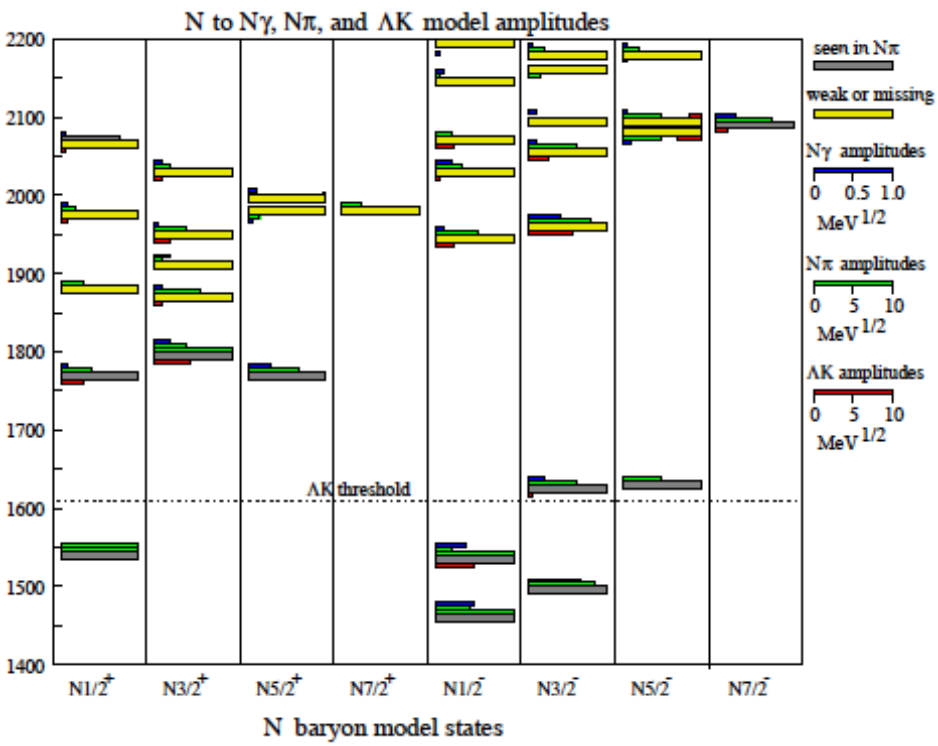
- Approximate models are used to describe the nucleon spectrum
- Most resonances found in πN PWA
- Other channels may provide info on that do NOT couple to πN
- Due to lack of data, little is known about strange quark's role in decay of resonances
- $K^+\Lambda$ is an isospin filter....no coupling to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

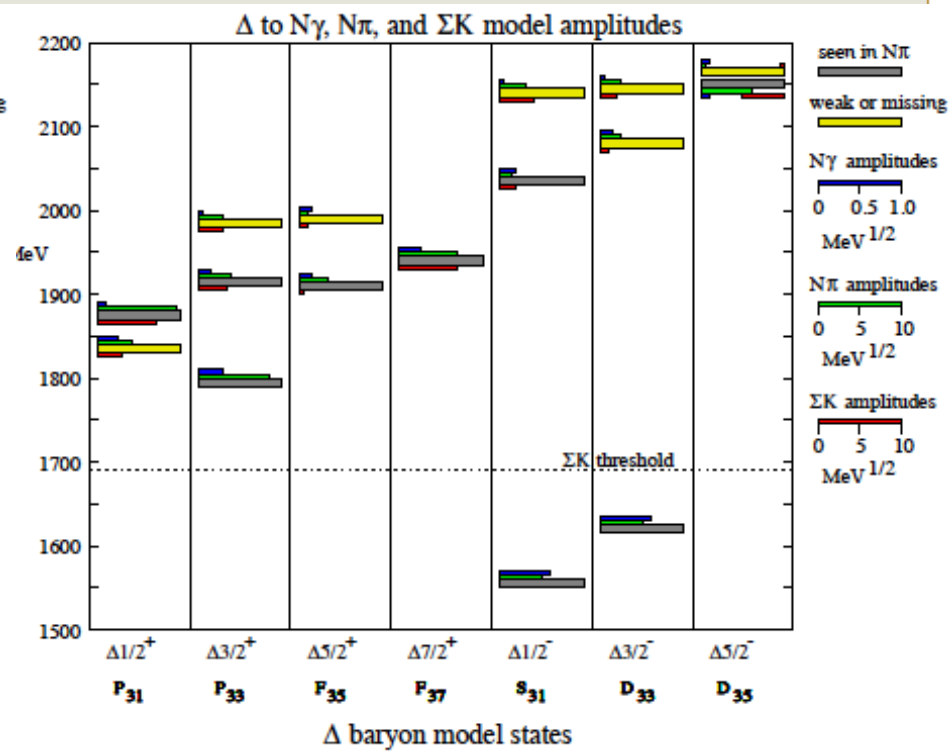




Constituent Quark Model

- 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
- Mass range above 1600 MeV is difficult to study due to many overlapping resonances





Polarization Observables

- Cross section data is not enough to do full PWA on $K^+\Lambda$
- 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

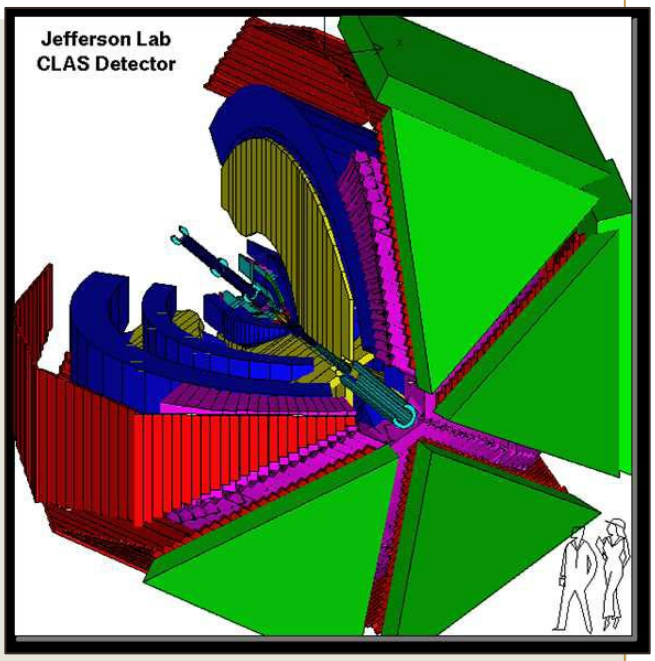
g9b g9a

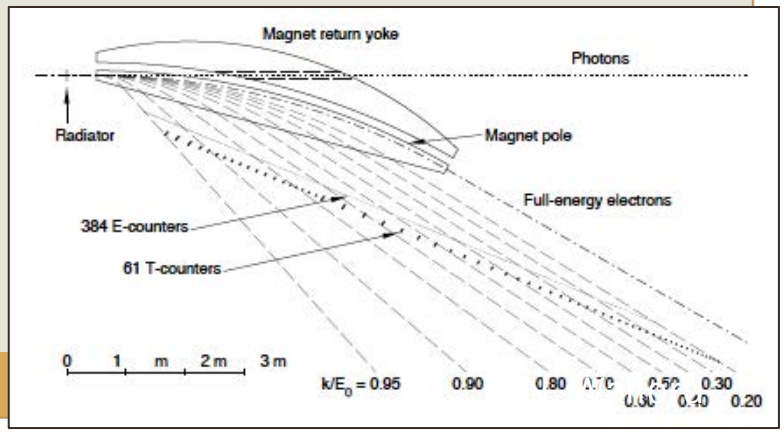
Spin observable	Helicity representation
$\check{\Omega}^1 \equiv \mathcal{I}(\theta)$	$\frac{1}{2}(\lvert H_1\rvert^2+\lvert H_2\rvert^2+\lvert H_3\rvert^2+\lvert H_4\rvert^2)$
$\check{\Omega}^4 \equiv \check{\Sigma}$	$\mathrm{Re}(-H_1H_4^*+H_2H_3^*)$
$\check{\Omega}^{10} \equiv -\check{T}$	$\mathrm{Im}(H_1H_2^*+H_3H_4^*)$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

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

Experimental Setup

- The FROST experiment was first approved with CLAS, ran in two parts (g9a-longitudinally polarized target and g9b-transversely polarized target)
- Butanol FROzen Spin Target with free protons polarized
- Up to 5 passes for max of ~6 GeV (upgrade allows for 12 GeV) and a polarized photon beam with recoil electrons measured by tagger
- Photon beam energies from 0.5 to 3.0 GeV (circular) and 1.1 to 2.1 GeV (linear) and 24 billion events collected between two experiments
- CLAS had almost full acceptance, 80% of 4π coverage
- 'Complete measurement': all beam-target and target-recoil observables from $K^+\Lambda$ and $K^+\Sigma^0$ final states

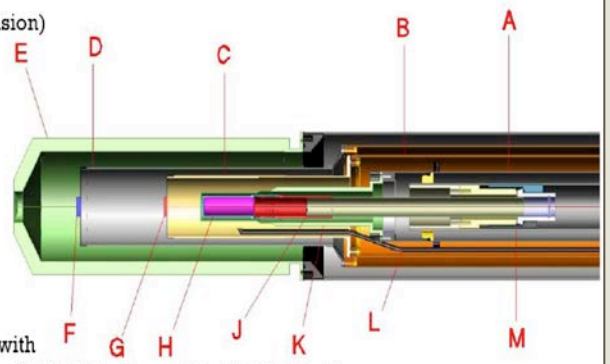




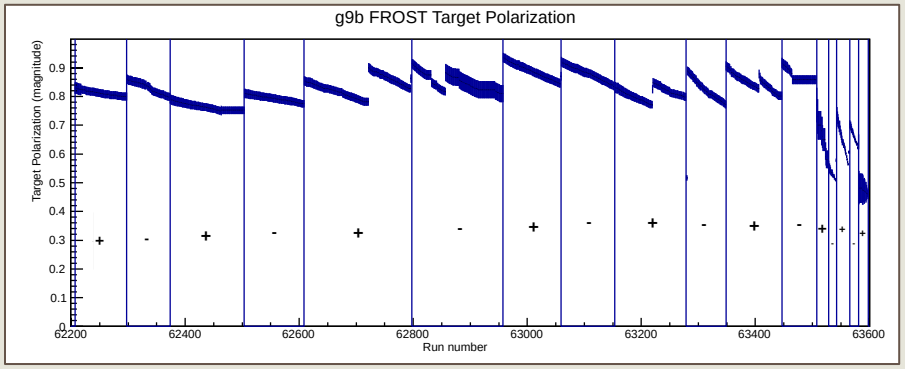
FROST Target

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



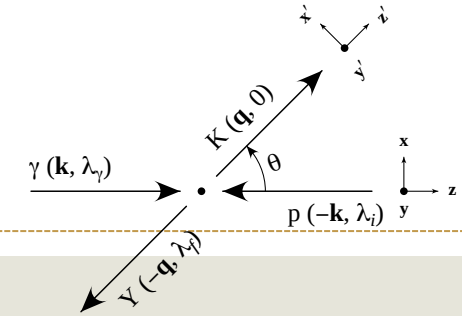
Performance Specs:
Base Temp: 28 mK w/o beam, 30 mK with
Cooling Power: 800 μW @ 50 mK, 10 mW @ 100 mK, and 60 mW @ 300 mK
Polarization: +82%, -90%
1/e Relaxation Time: 2800 hours (+Pol), 1600 hours (-Pol)



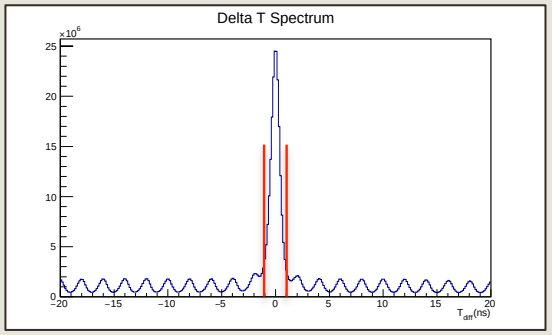
- Butanol in LHe bath
- Polarizing 5 Tesla magnet aligns free proton spins
- Holding coil keeps proton polarized

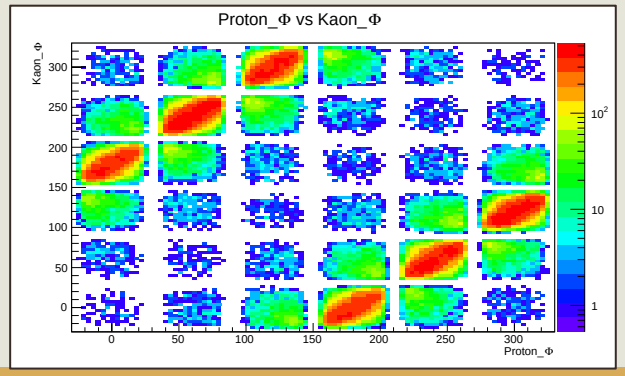
Target re-polarized ~once per week!!

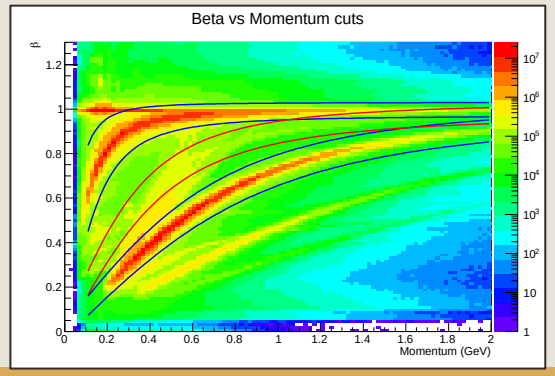
Event Selection

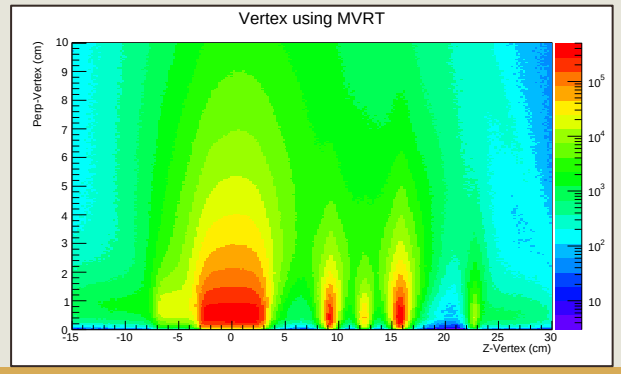


- Skimmed data for events
  - $\gamma p \rightarrow K^+\Lambda \rightarrow K^+p(\pi^-)$ AND $\gamma p \rightarrow K^+\Sigma^0 \rightarrow K^+\Lambda\gamma \rightarrow K^+ p(\gamma\pi^-)$
- One proton, one kaon identified
- One photon identified with cut on coincidence of ±1 ns
- Only two positively charged particles
- Cut on kaon event vertex
- Check whether p from Λ decay vertex by comparing azimuthal angles p and K^+



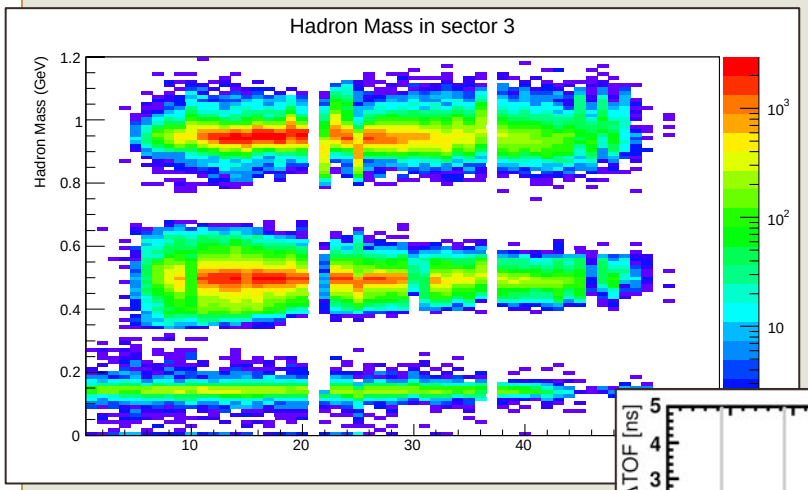


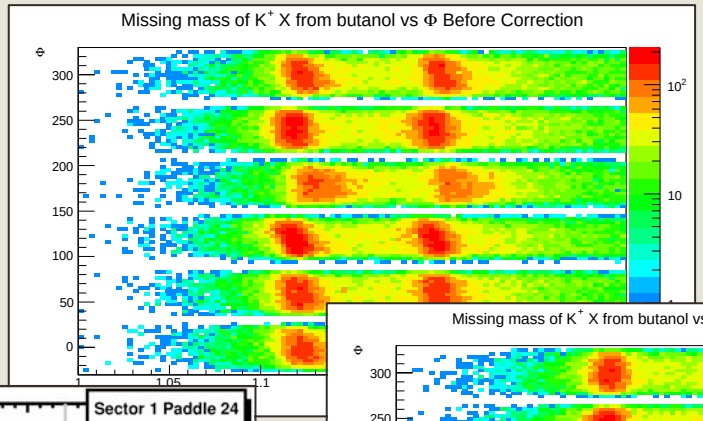


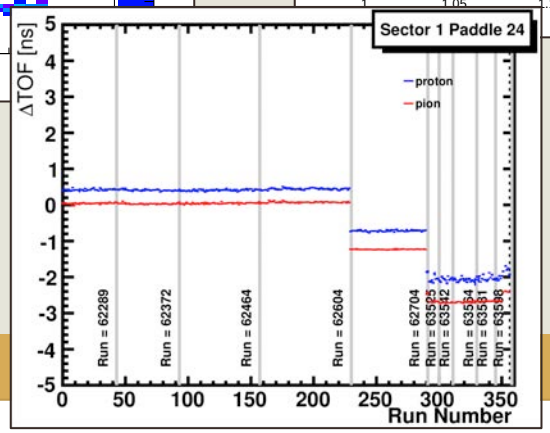


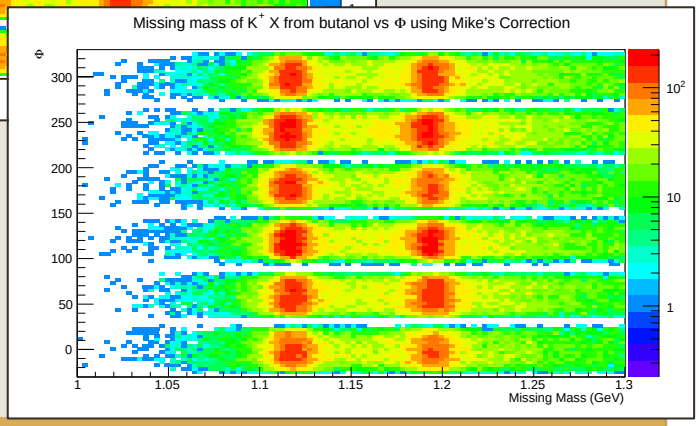
Corrections to Data

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

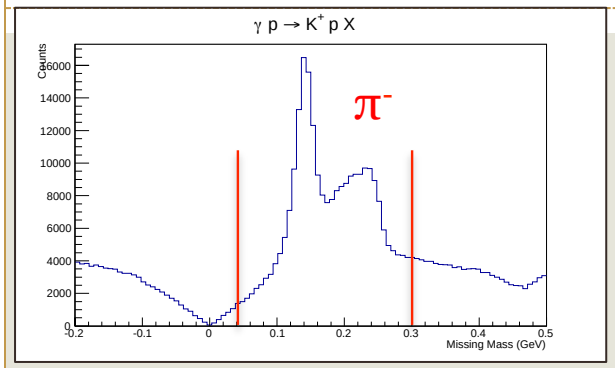


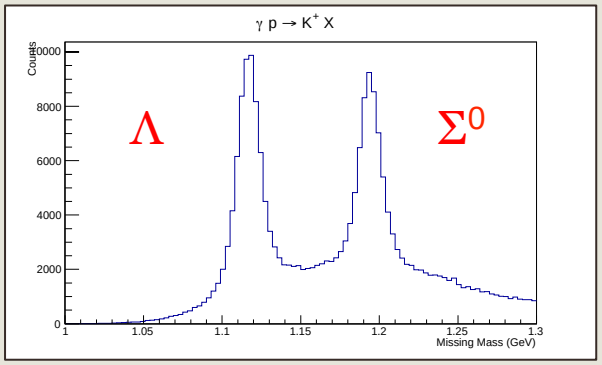




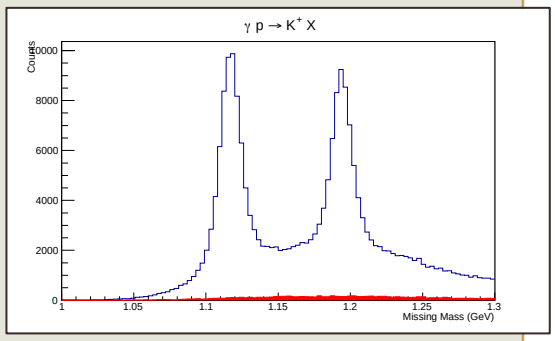


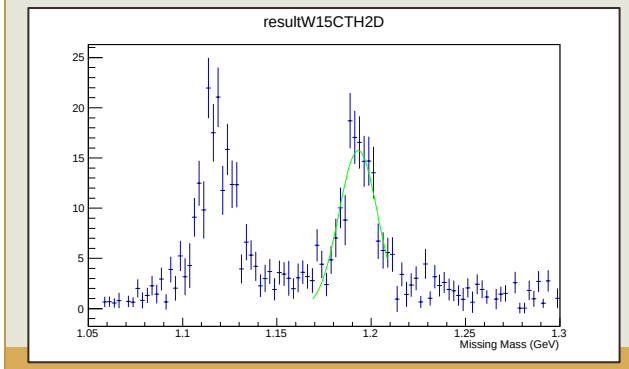
Missing Mass and Background Subtraction

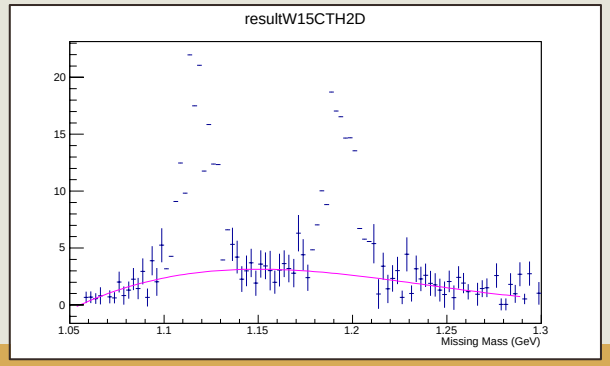


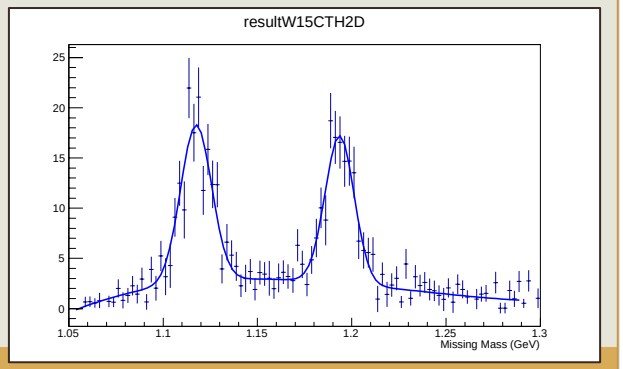


- Quasi-free kaon production is suppressed on carbon – so need to subtract free protons from bound protons
  - Fit Λ and Σ^0 signals with Gaussian
  - Fit remaining background with cubic polynomial
  - Then make a combined fit
  - Do for every $\cos\theta$ bin in every W bin!



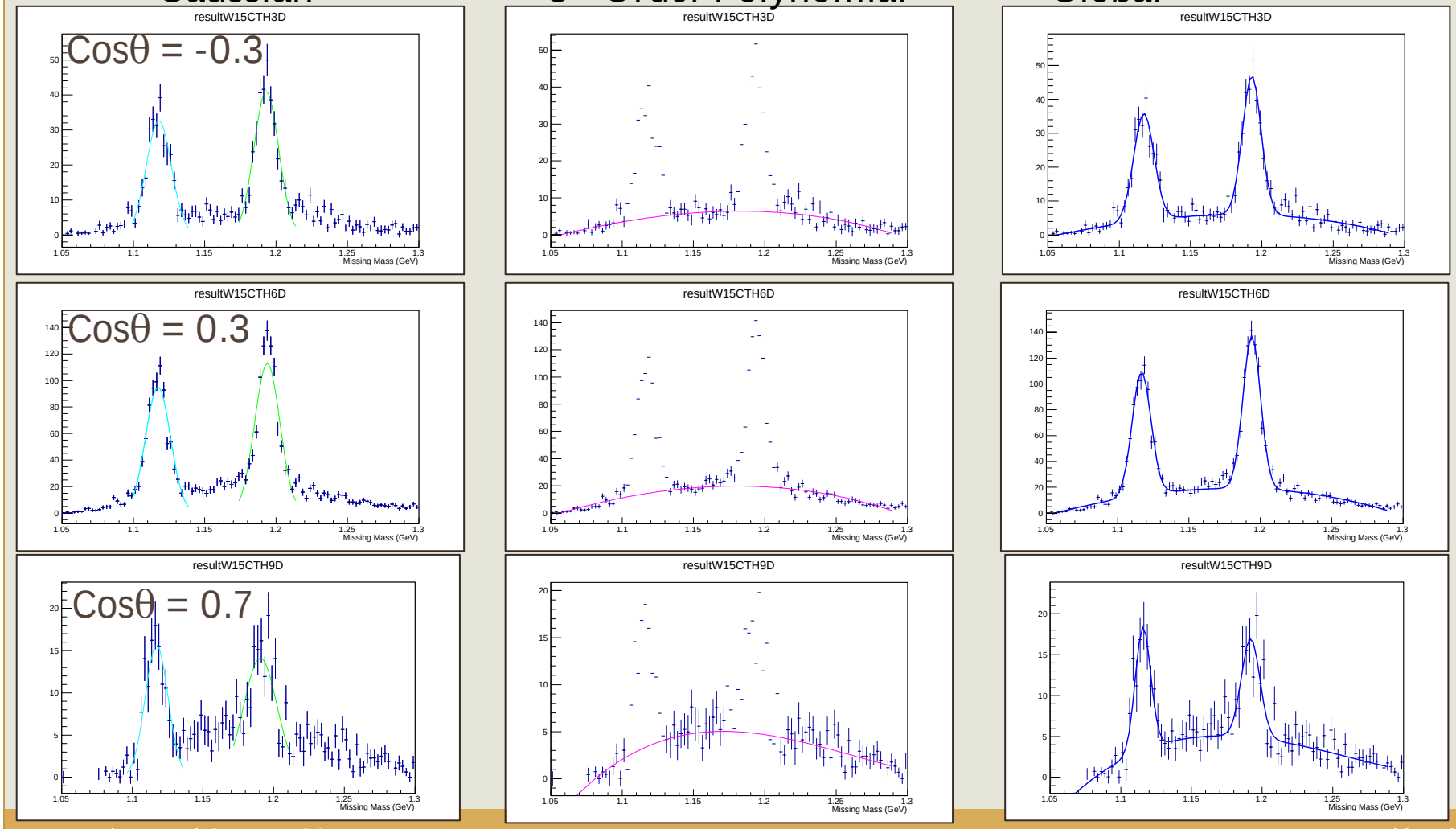






Background Subtraction

Gaussian | 3rd Order Polynomial | Global



Example of Background Subtraction for W = 1875 MeV

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

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

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

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

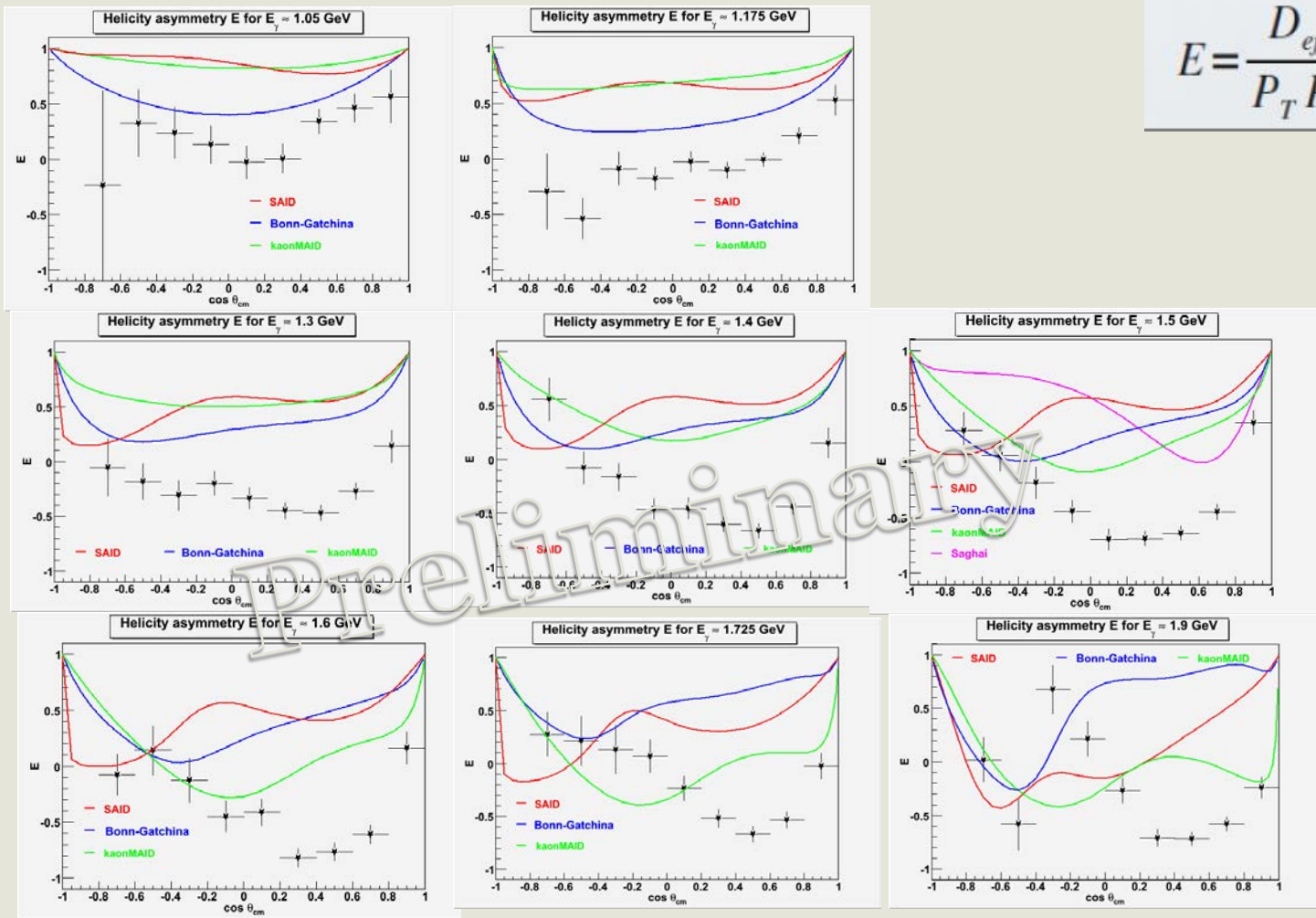
λ_A – positive helicity
λ_C – negitive helicity

P_A – positive target polarization
P_C – negative target polarization

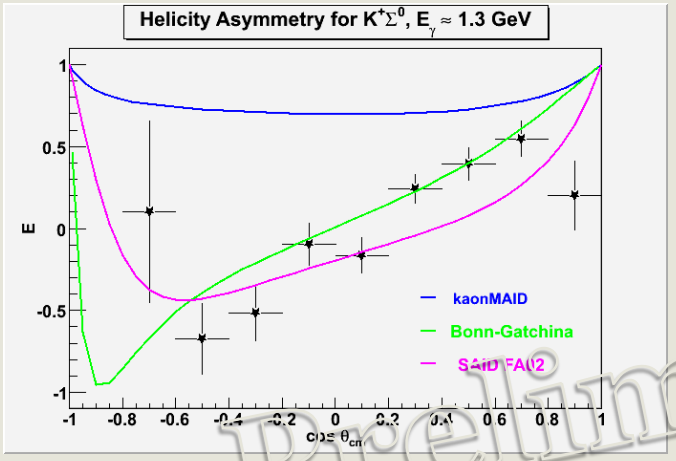
L_x, L_z, T_x and T_z are double polarization observables with a transverse target polarization and recoil polarization in the Λ decay plane and calculated in similar way with moments!!

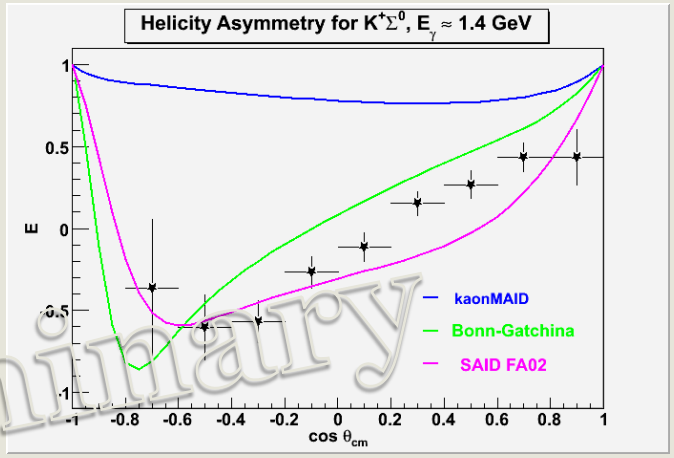
E for $K^+\Lambda$

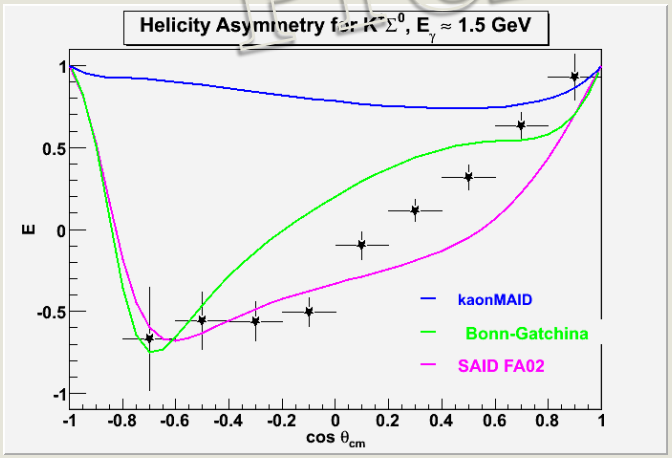
$$E = \frac{D_{eff}}{P_T P_\gamma} \frac{N_{1/2} - N_{3/2}}{N_{1/2} + N_{3/2}}$$

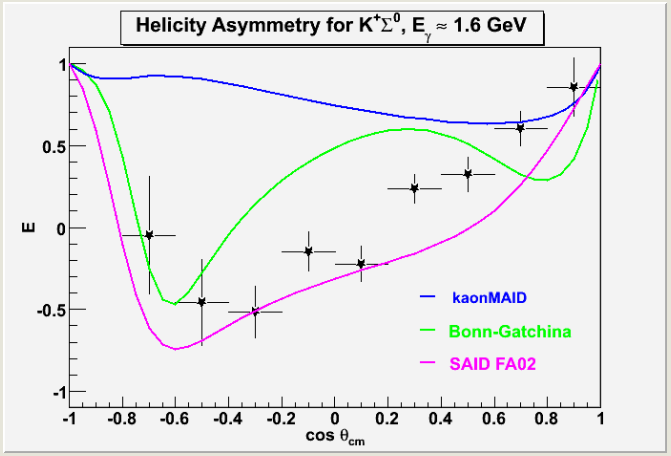


E for $K^+\Sigma^0$



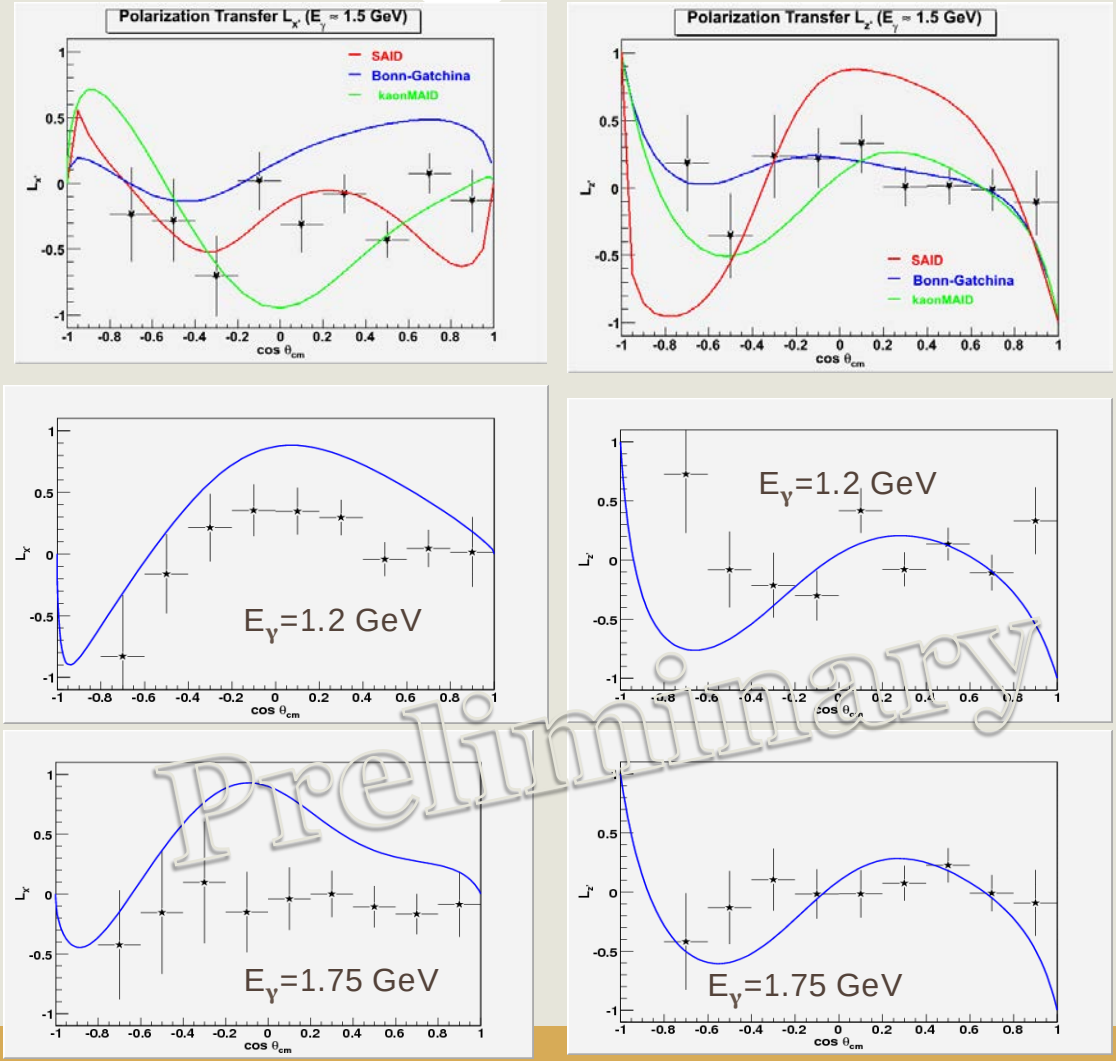






$$E = \frac{D_{eff}}{P_T P_\gamma} \frac{N_{1/2} - N_{3/2}}{N_{1/2} + N_{3/2}}$$

L_x and L_z for $K^+\Lambda$



T for $K^+\Lambda$

Data:

CLAS g9b

Bonn78

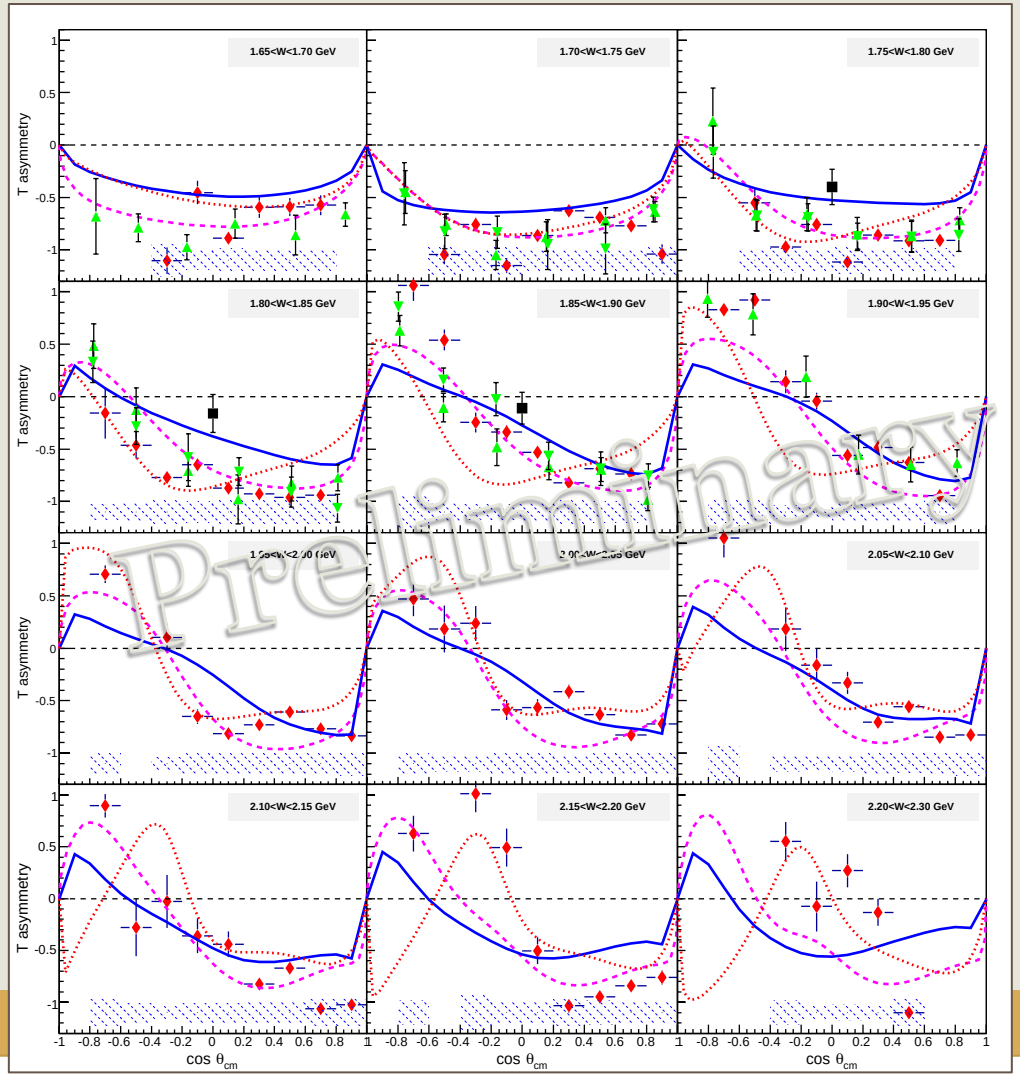
GRAAL09

Models:

RPR-Ghent

Kaon-MAID

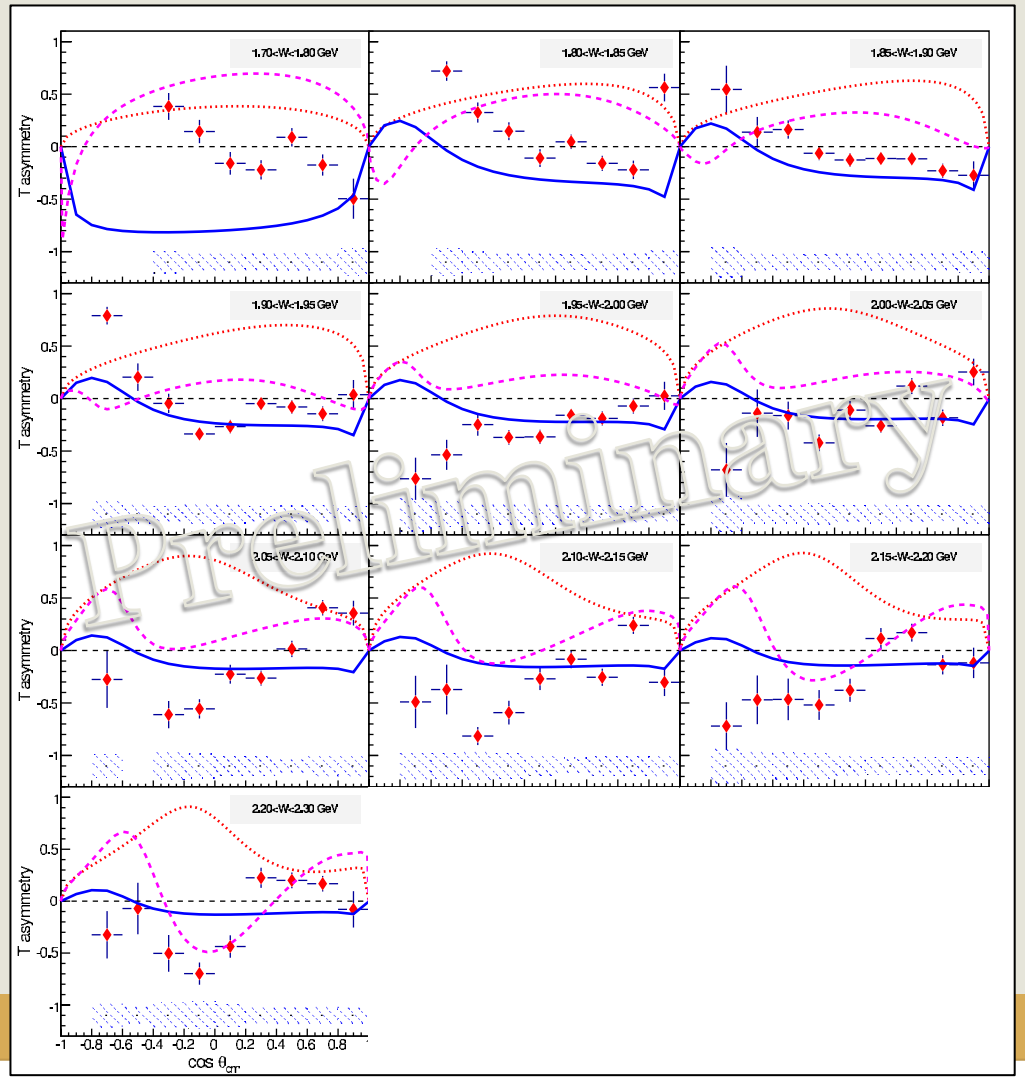
BOGA



T for $K^+\Sigma^0$

Data:
CLAS g9b

Models:
RPR-Ghent
Kaon-MAID
BOGA



T_x for $K^+\Lambda$

Data:
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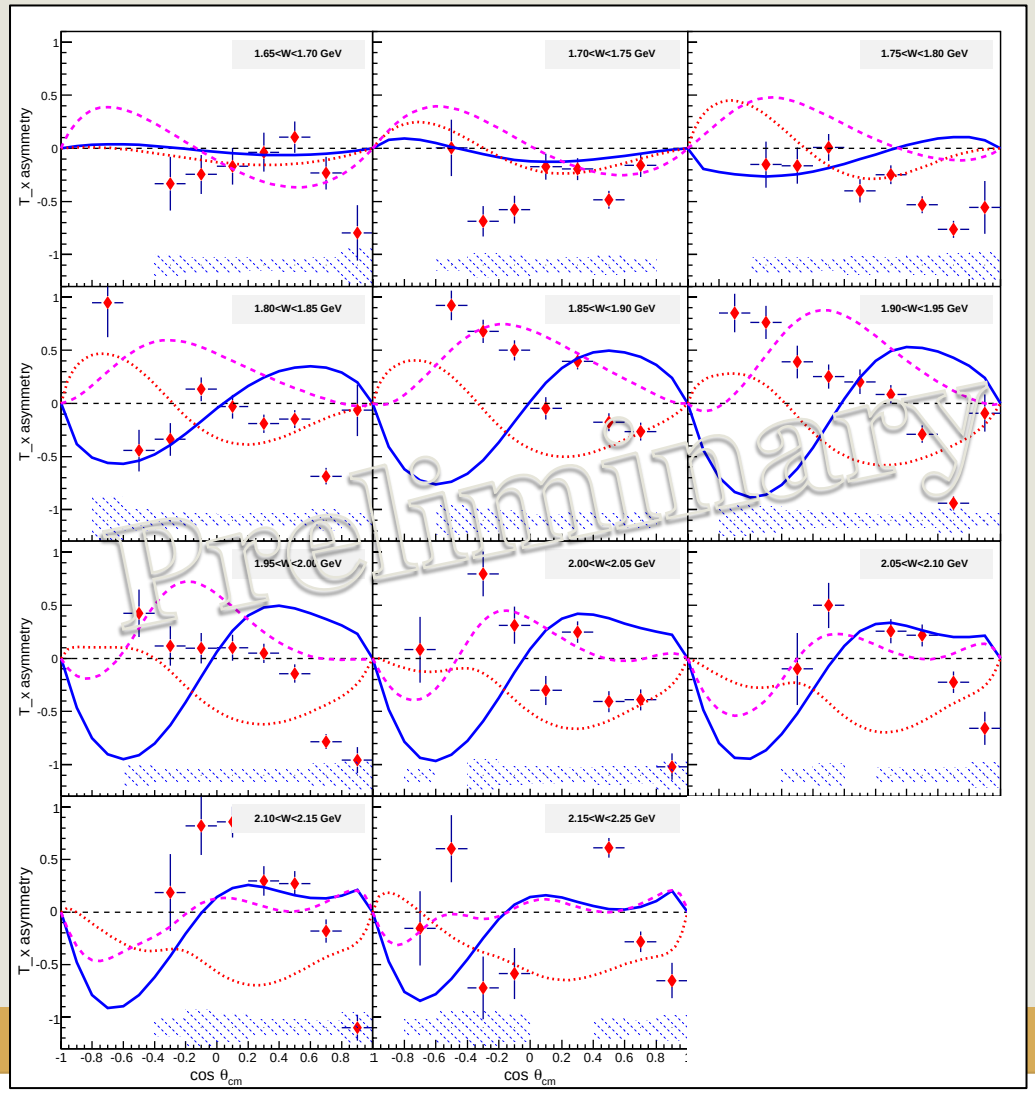
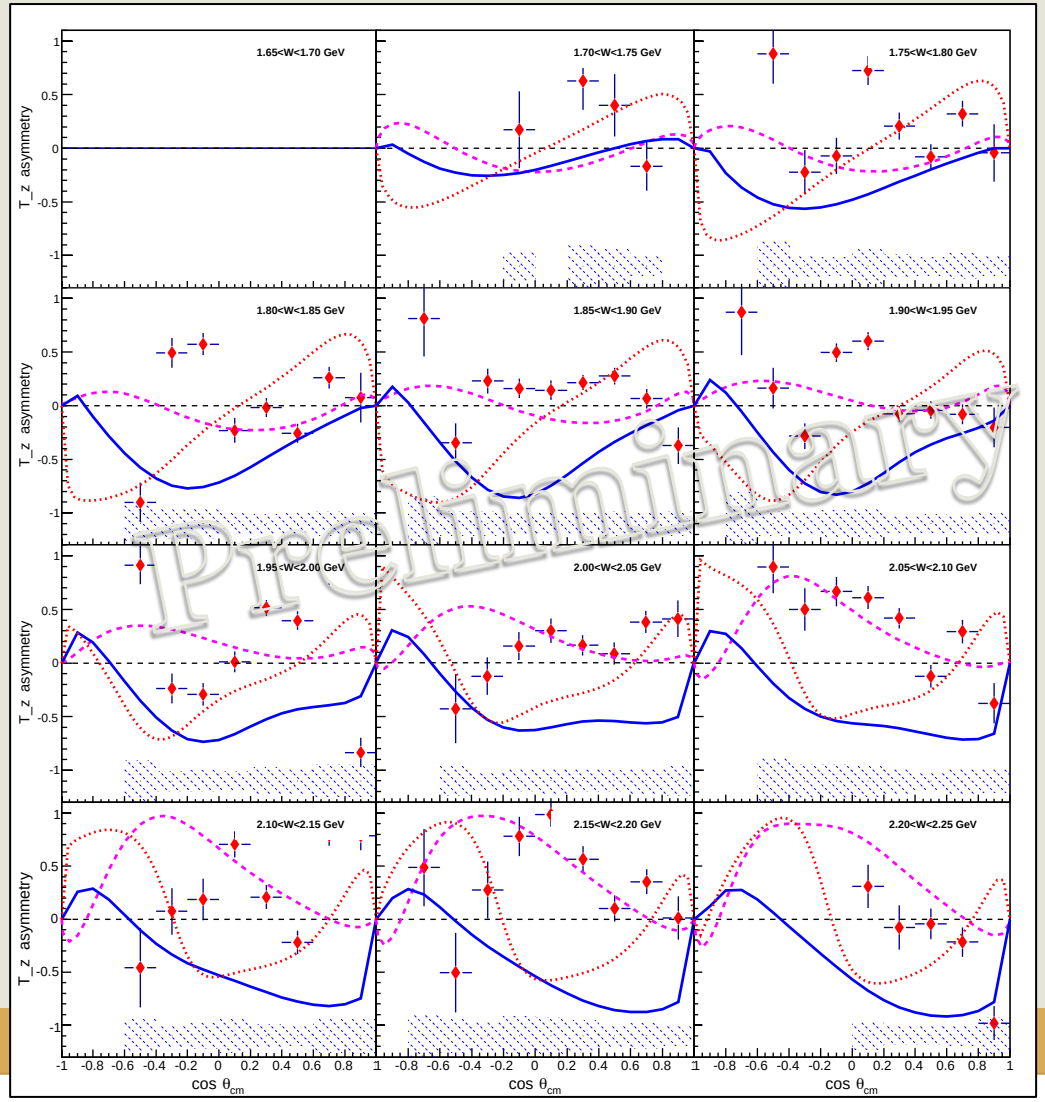
Models:
RPR-Ghent
Kaon-MAID
BOGA



T_z for $K^+\Lambda$

Data:
CLAS g9b

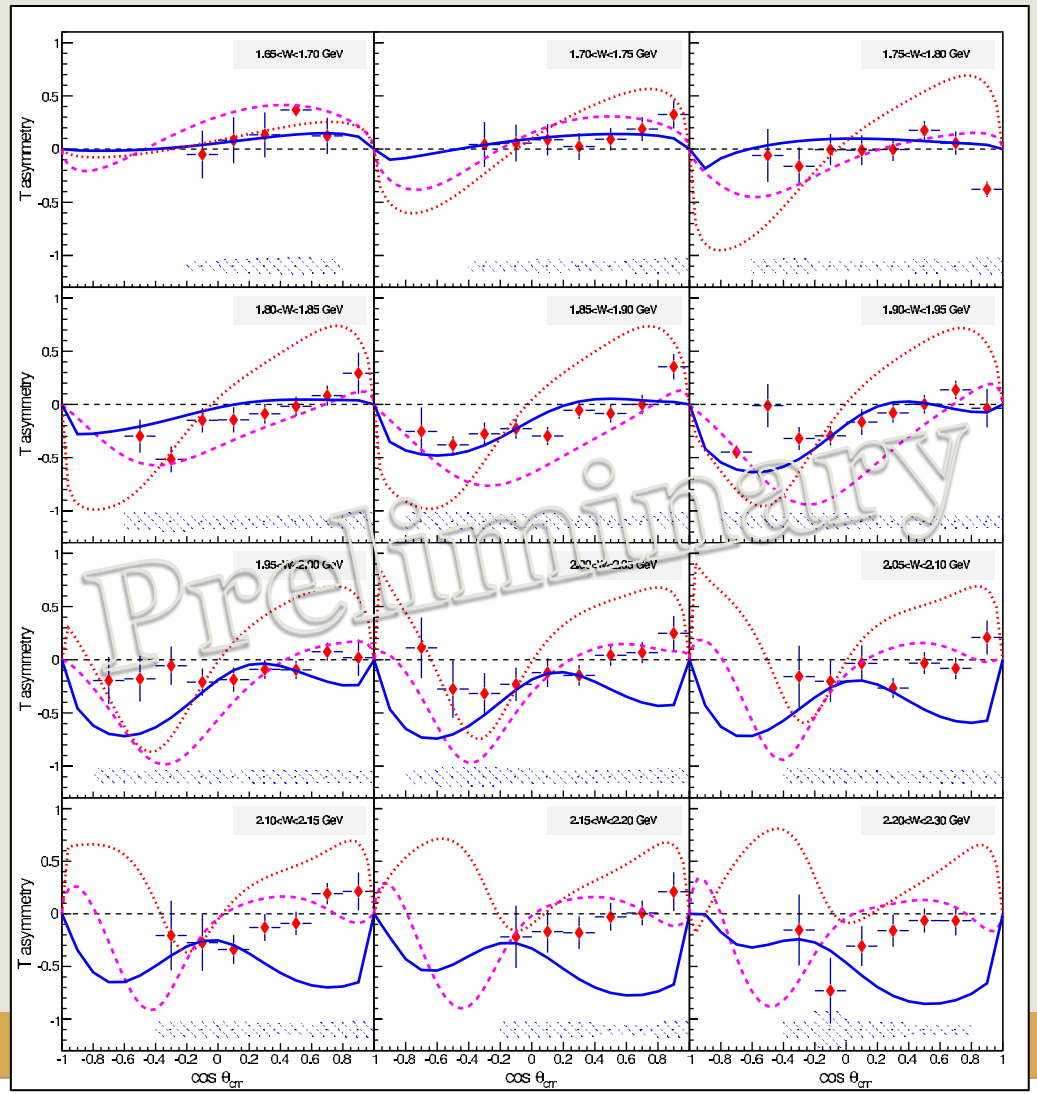
Models:
RPR-Ghent
Kaon-MAID
BOGA



F for $K^+\Lambda$

Data:
CLAS g9b

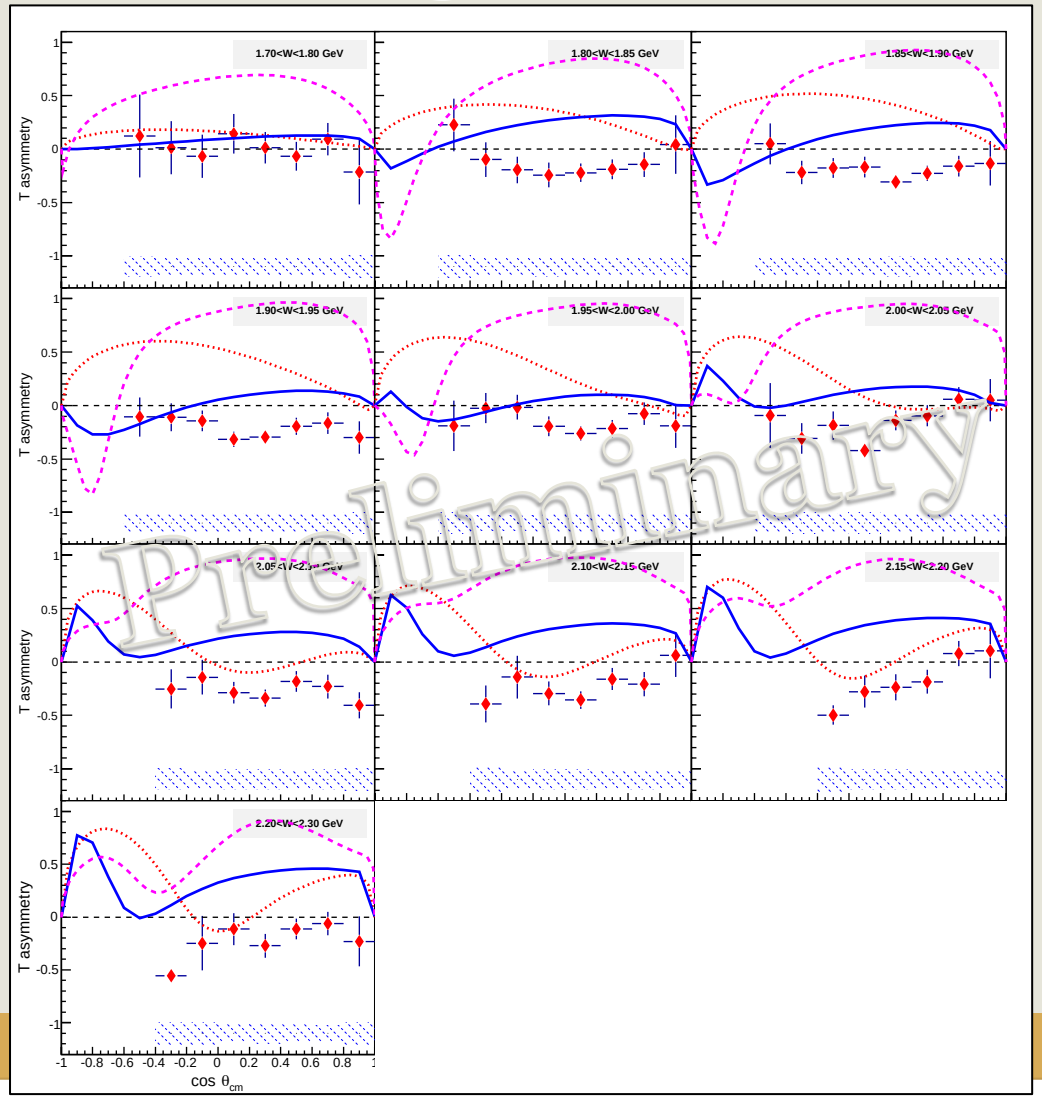
Models:
RPR-Ghent
Kaon-MAID
BOGA



F for $K^+\Sigma^0$

Data:
CLAS g9b

Models:
RPR-Ghent
Kaon-MAID
BOGA



Conclusion

- Kaon photoproduction data is necessary to help solve missing resonance problem
- First results for many of the observables for $K^+\Lambda$ and $K^+\Sigma^0$
- Working on publishing results now
- Models and PWA results are only partially consistent with data: can expect that resonance parameters with greatly improve with this data