Photoproduction of Λ^* Resonances at CLAS

CLAS Collaboration Meeting
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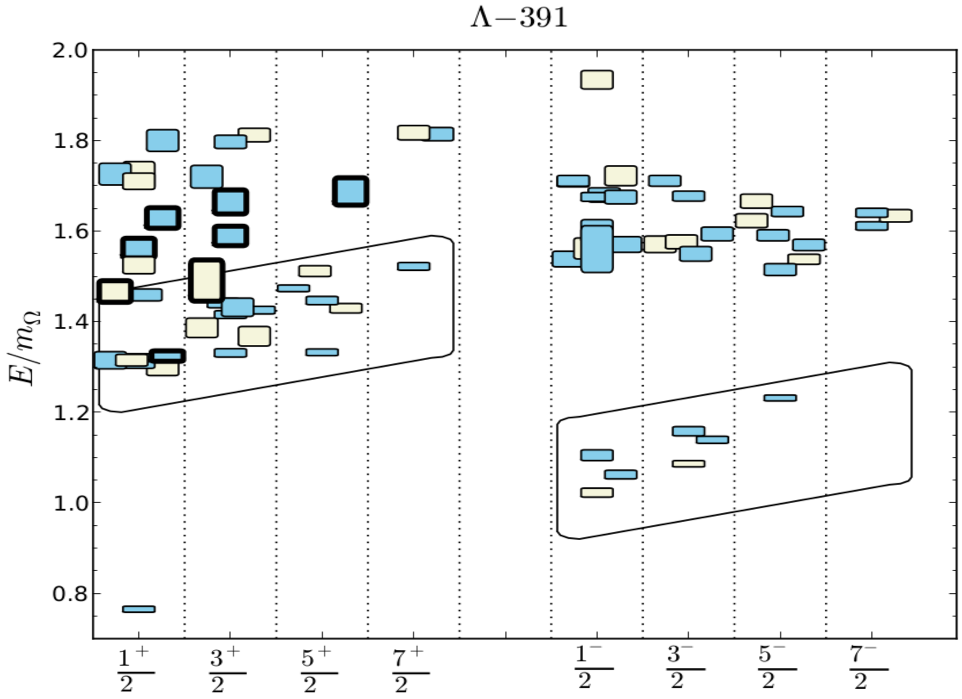
Utsav Shrestha and Ken Hicks
Ohio University

Department of physics + astronomy OHIO UNIVERSITY

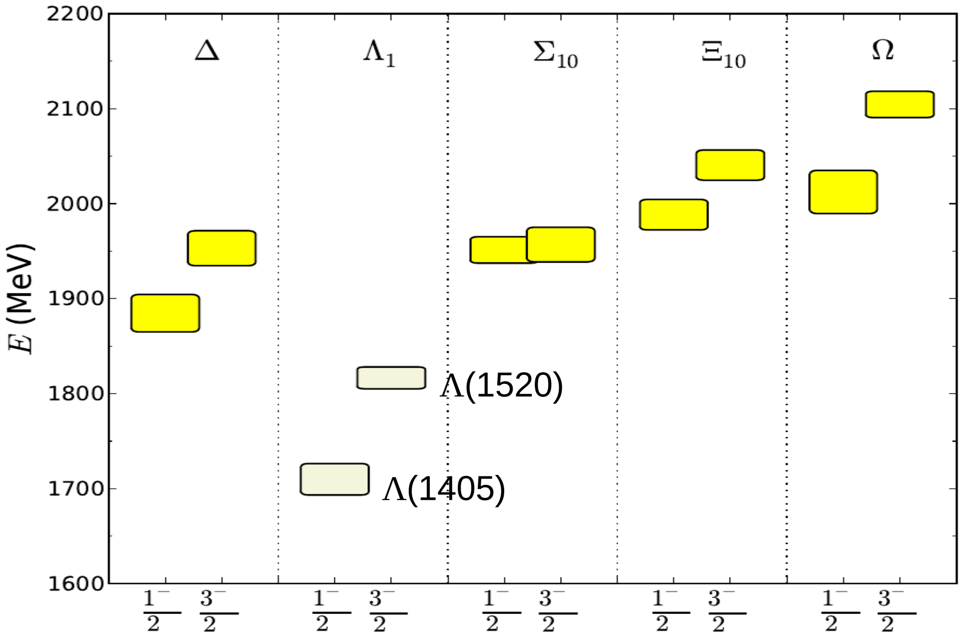
Λ*

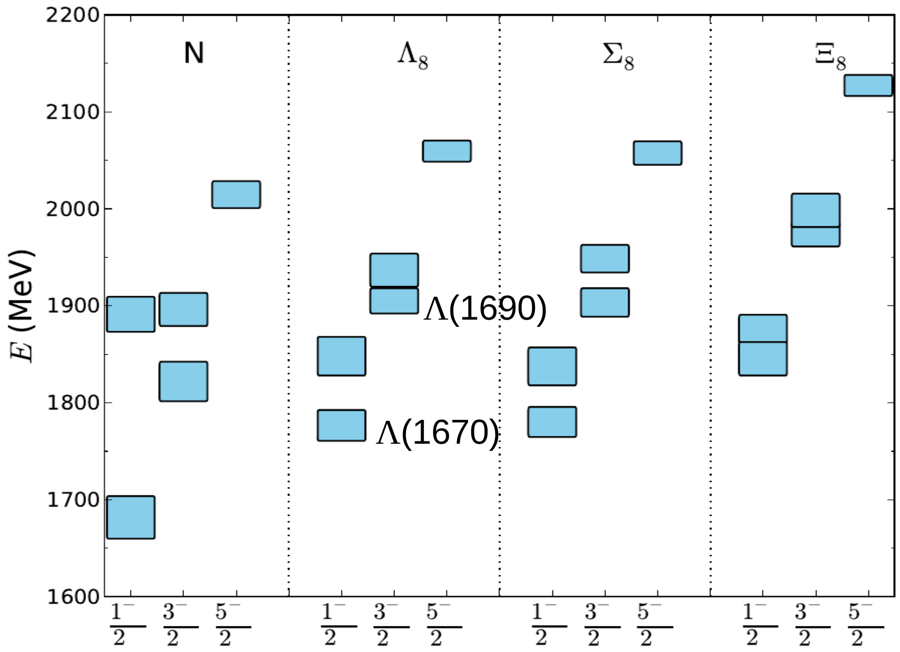
J^P	$(D, L^P_N)\, S$		Octet members				Singlets
$1/2^+$	$(56,0^+_0)$	$1/2$	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0^+_2)$	$1/2$	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(1690)^\dagger$	
$1/2^-$	$(70,1^-_1)$	$1/2$	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
					$\Sigma(1560)^\dagger$		
$3/2^-$	$(70,1^-_1)$	$1/2$	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
$1/2^-$	$(70,1^-_1)$	$3/2$	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$	$\Xi(?)$	
					$\Sigma(1620)^\dagger$		
$3/2^-$	$(70,1^-_1)$	$3/2$	$N(1700)$	$\Lambda(?)$	$\Sigma(1940)^\dagger$	$\Xi(?)$	
$5/2^-$	$(70,1^-_1)$	$3/2$	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(1950)^\dagger$	
$1/2^+$	$(70,0^+_2)$	$1/2$	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(1810)^\dagger$
$3/2^+$	$(56,2^+_2)$	$1/2$	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^+$	$(56,2^+_2)$	$1/2$	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
$7/2^-$	$(70,3^-_3)$	$1/2$	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
$9/2^-$	$(70,3^-_3)$	$3/2$	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$9/2^+$	$(56,4^+_4)$	$1/2$	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	



- Missing baryon resonances play important role to explore the fundamental degrees of freedom inside hadrons.
- Study of quark dynamics to determine properties of hadrons that are responsible for spectrum of hadrons.

Baryon Spectra from Lattice QCD

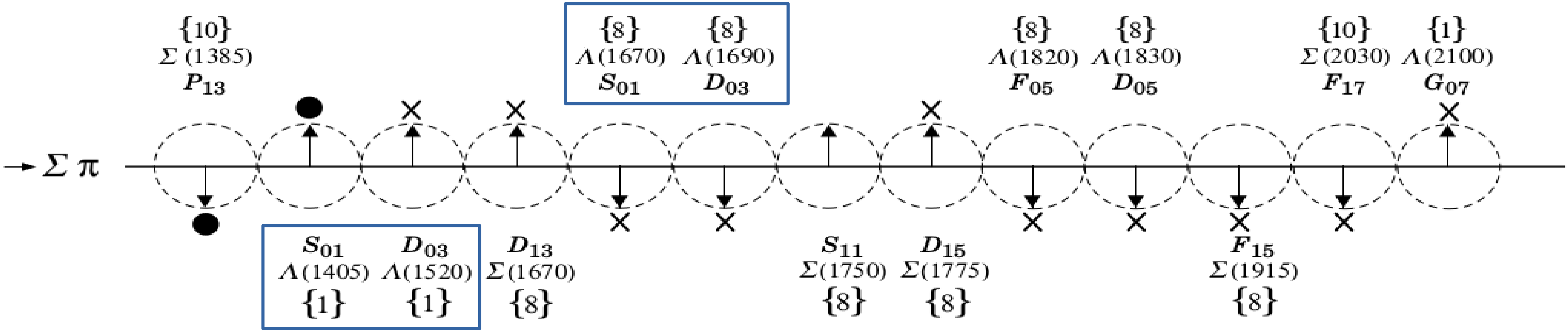




Robert G. Edwards, Nilmani Mathur, David G. Richards, and Stephen J. Wallace. Flavor structure of the excited baryon spectra from lattice qcd. *Phys. Rev. D*, 87:054506, Mar 2013.

- Missing baryon resonances play important role to explore the fundamental degrees of freedom inside hadrons.
- Study of quark dynamics to determine properties of hadrons that are responsible for spectrum of hadrons.

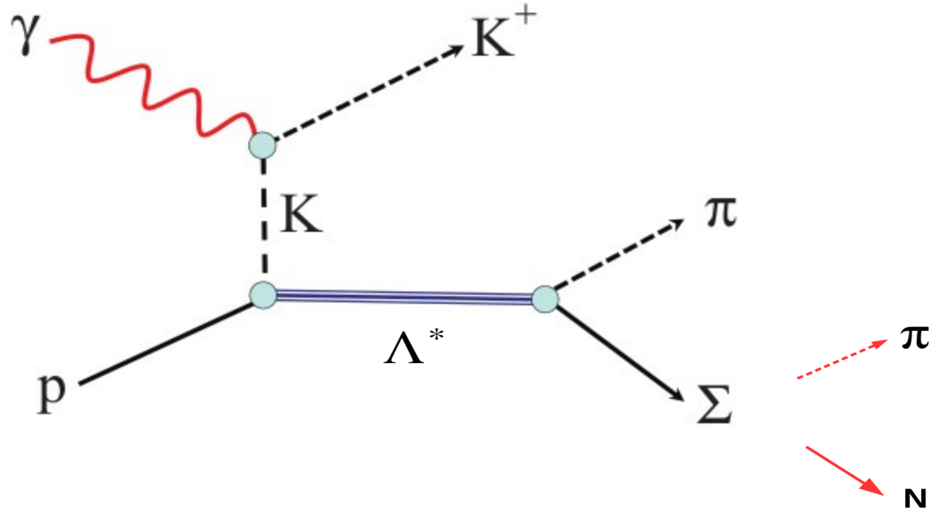
Motivation

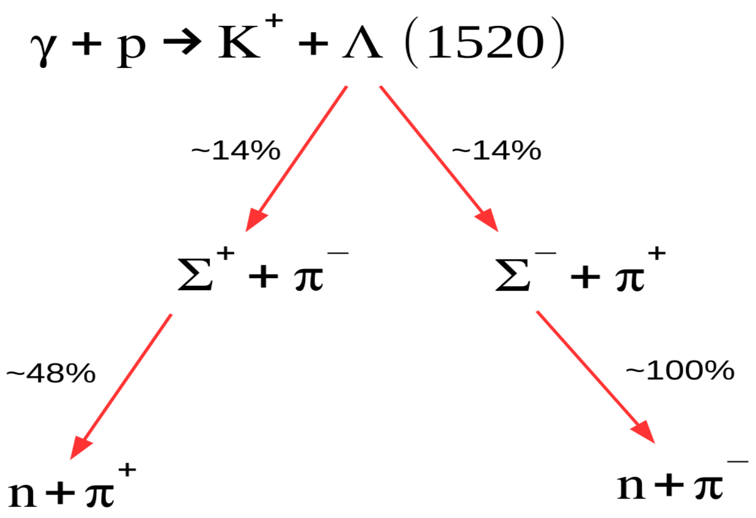


Particle	J^P	Overall status	$N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	$1/2+$	****		F		$N\pi$(weakly)
$\Lambda(1405)$	$1/2-$	****	****	o	****	
$\Lambda(1520)$	$3/2-$	****	****	r	****	$\Lambda\pi\pi, \Lambda\gamma$
$\Lambda(1600)$	$1/2+$	***	***	b	**	
$\Lambda(1670)$	$1/2-$	****	****	i	****	$\Lambda\eta$
$\Lambda(1690)$	$3/2-$	****	****	d	****	$\Lambda\pi\pi, \Sigma\pi\pi$

pdg.lbl.gov

Λ* Photoproduction





$\gamma + p \rightarrow K^{+} + \Lambda^{*}$ $\Lambda^{*} \rightarrow \Sigma^{+} + \pi^{-}$ $\Lambda^{*} \rightarrow \Sigma^{-} + \pi^{+}$

- Photo-prodution off a proton creates a K^{+}-meson and a Λ^{*}.
- Λ^{*} decays by Σπ channel. Σ^{+} gives off a n & π^{+}, Σ- gives off a n & π^{-}.
- The final particles detected are K^{+}, π^{+} & π^{-}.

Outline (Cuts)

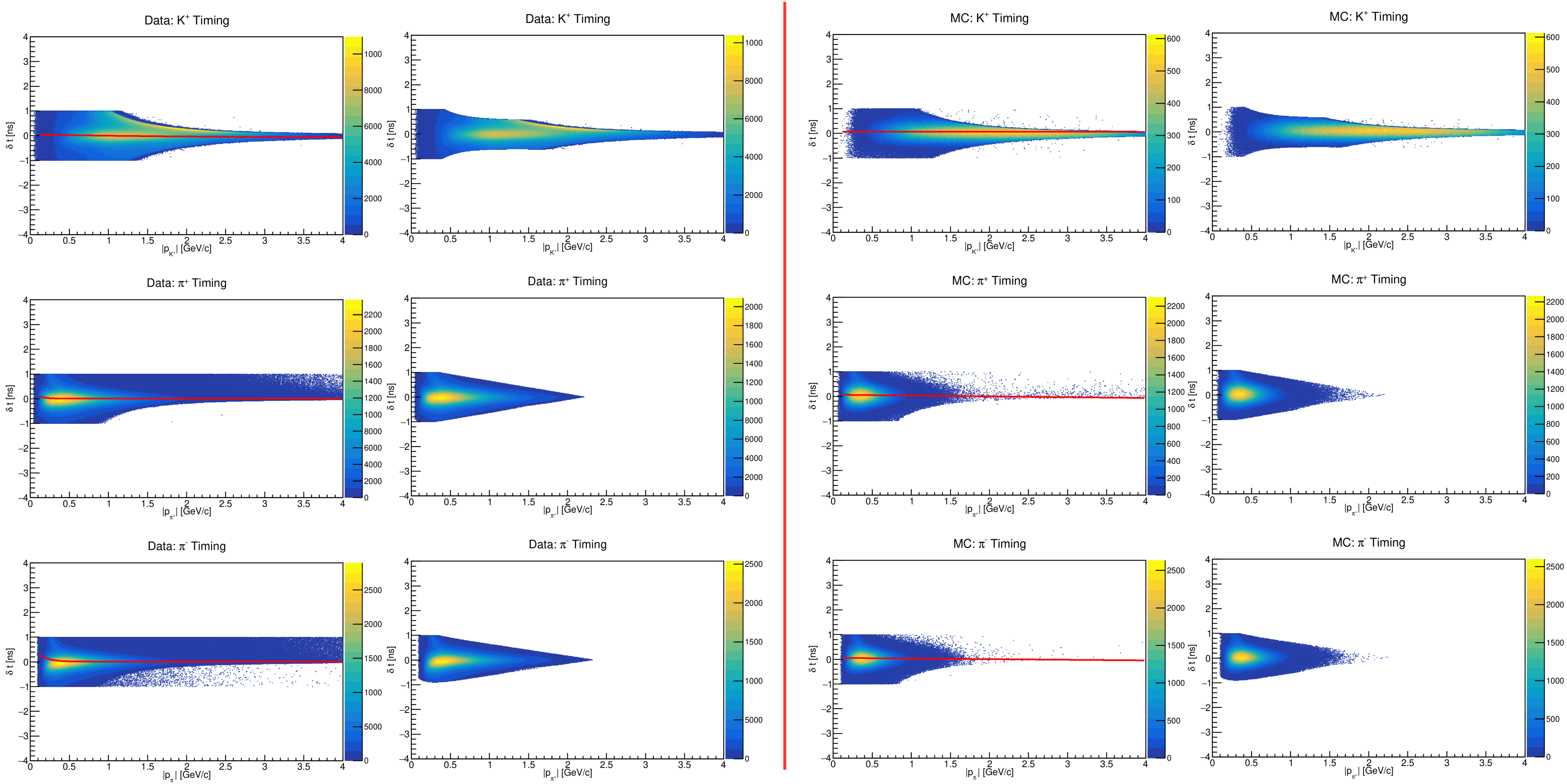
- Photon selection → 1 and 2 photon case (Photon Multiplicity)
- PID → K^+, π^+, π^-. Straight cuts of 1 ns on Momentum vs Timing plots were made for particle identification. A 3σ cut was applied for momentum dependent timing analysis.
- Trigger Correction was applied creating trigger efficiency map using the g12 trigger configuration.
- The g12 standard data analysis procedure was followed for Vertex, Fiducial & Paddle Cuts.
- A series of Missing Mass cut was followed to obtain the nature of Λ* resonances.
- Further analysis includes an appropriate binning and fitting scheme to obtain yield and acceptances for differential cross-section.

Label	Description
C0	Skim
C1	$K^+\pi^+\pi^-$ PID Cut
C2	z-vertex cut
C3	*Nominal* Fiducial Cut
C4	Paddle Cut
C5	Missing Mass Cut
C6	$2.25 < W[\text{GeV}] < 3.25$
C7	$-0.9 < \cos\theta^{c.m.}_{K^+} < 0.9$

$0.9 \le MM(K^+\pi\pi) \le 1.0$	Select neutron events
$0.48 \le IM(\pi^+\pi^-) \le 0.51$	Remove nK^0 channel
$1.15 \le MM(K^+\pi^-) \le 1.25$ $1.15 \le MM(K^+\pi^+) \le 1.25$	Select Σ^+ and Σ^- events for exclusive Σπ channels
$1.44 \le MM(K^+) \le 1.6$ $1.62 \le MM(K^+) \le 1.76$	Fitting Range Λ(1520) Fitting Range Λ(1670) & Λ(1690)
$2.25 \le W \le 3.25$ GeV $-0.9 \le \cos\theta^{K+}_{cm} \le 0.9$	Binning Scheme

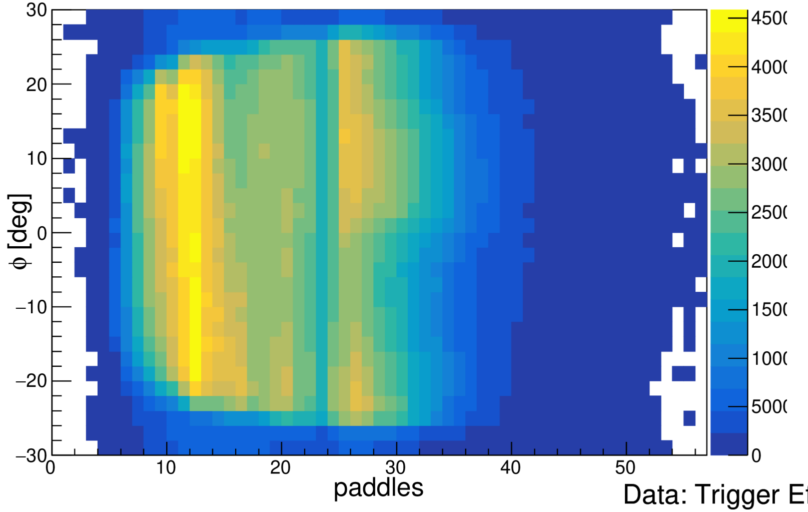
PID Cut

Data: |δt| < 1 ns | Data: 3σ Cut | MC: |δt| < 1 ns | MC: 3σ Cut

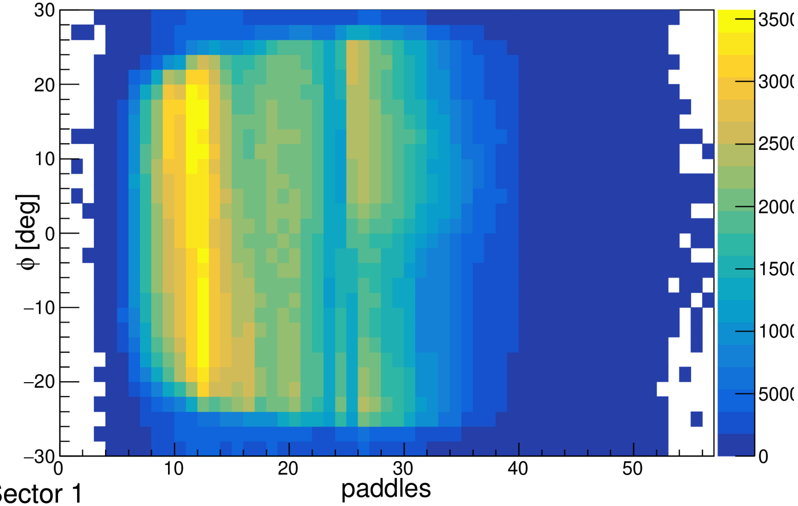


Trigger Correction

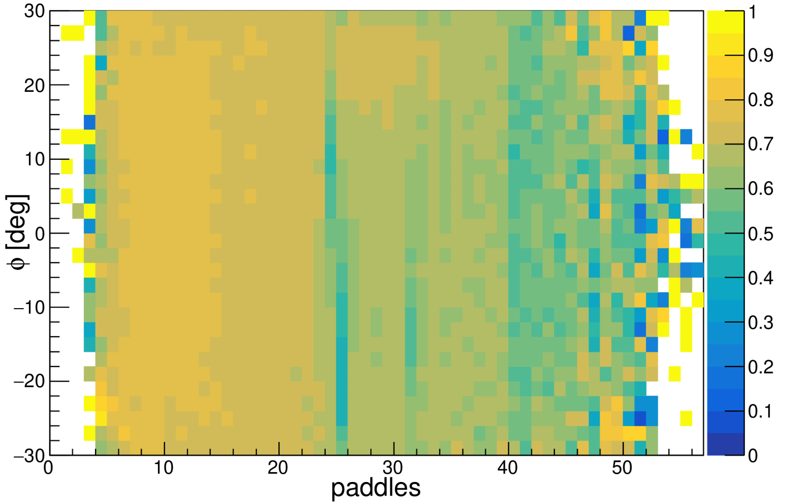
Data: Total (3-sector) events, K^{+} Sector 1



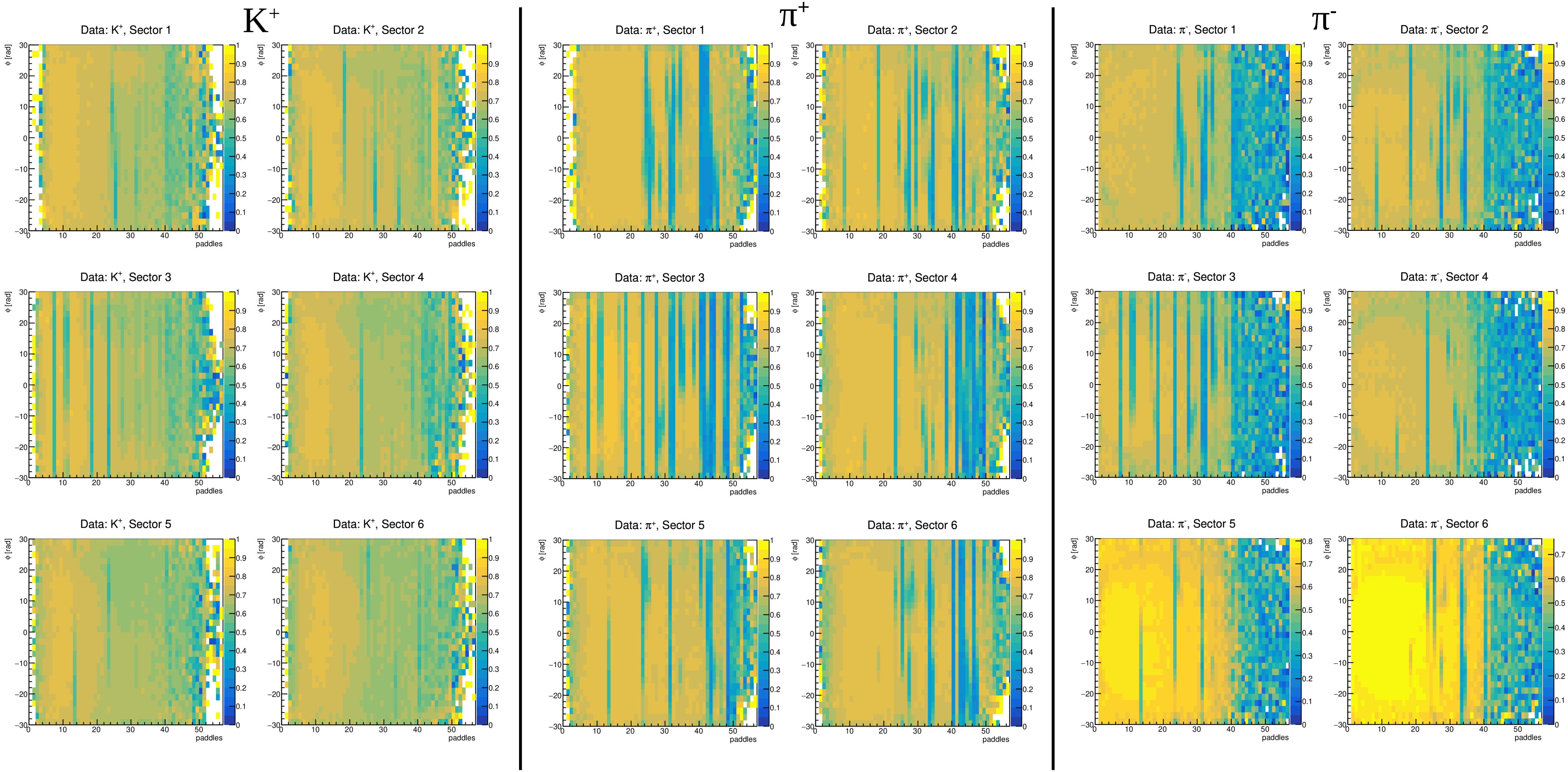
Data: Hit (2-sector) events, K^{+} Sector 1



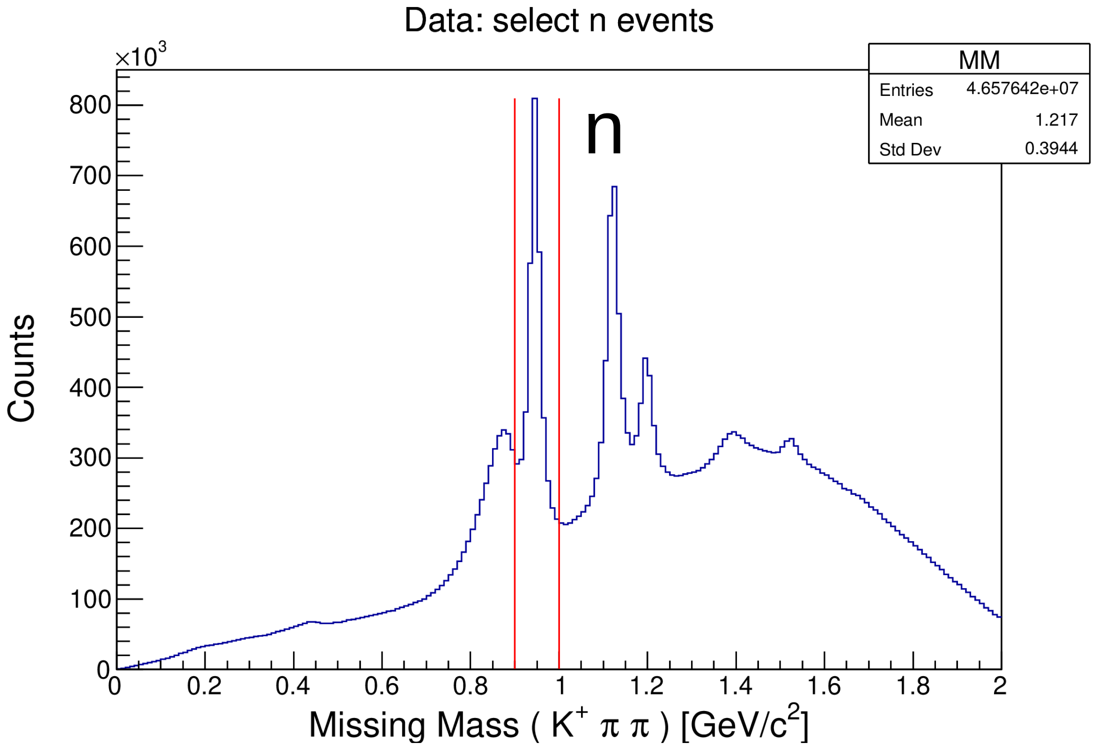
Data: Trigger Efficiency Map, K^{+} Sector 1

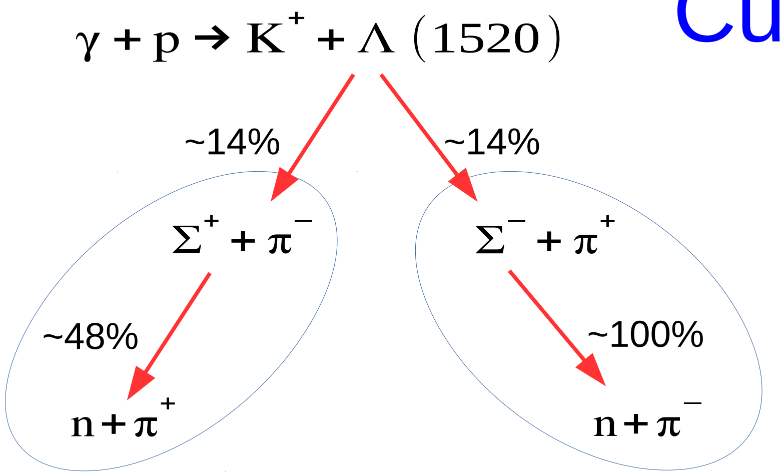


Trigger Efficiency Map

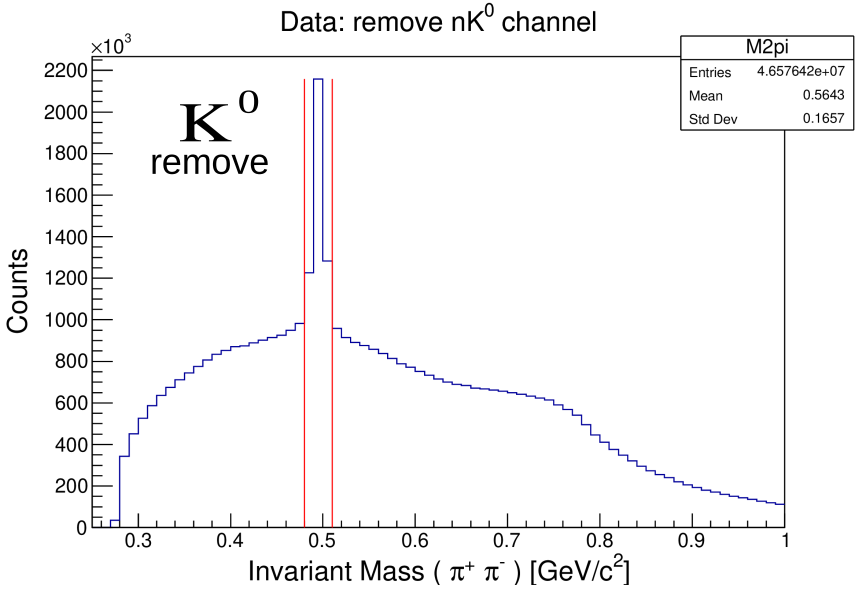


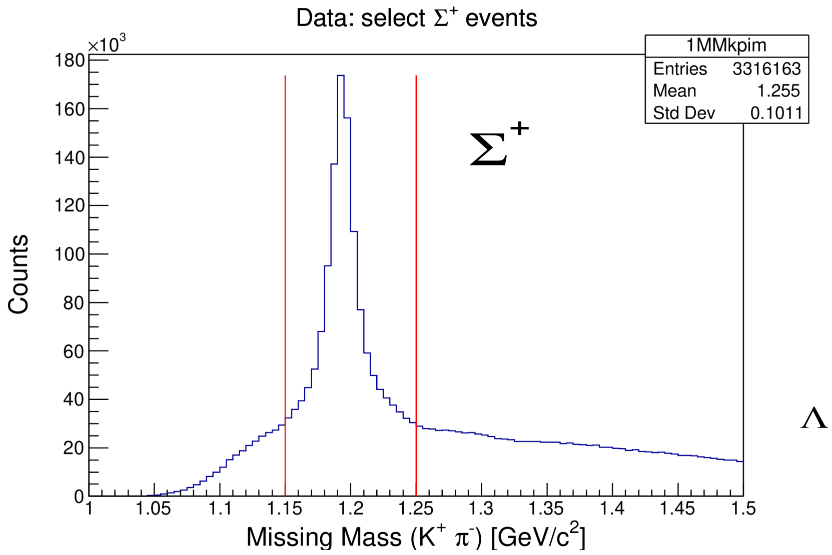
Cuts



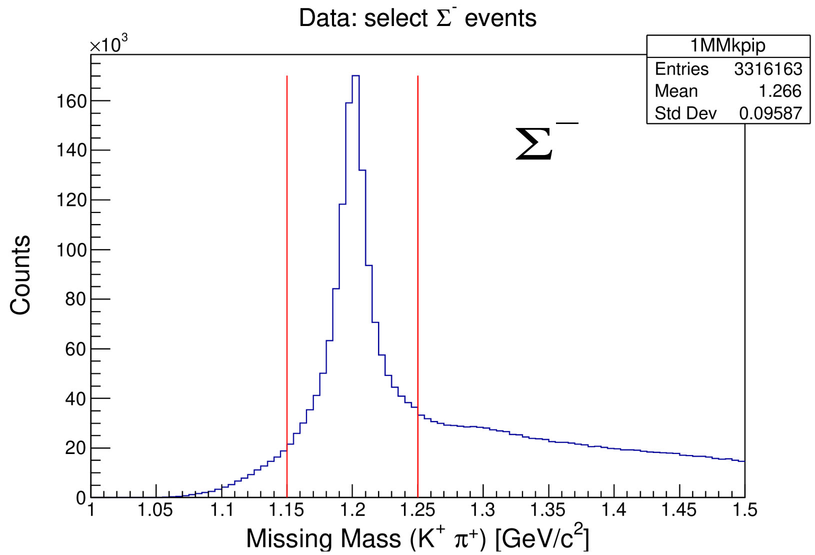


$0.9 < MM(K^{+}\pi\pi) < 1.0$ [GeV]

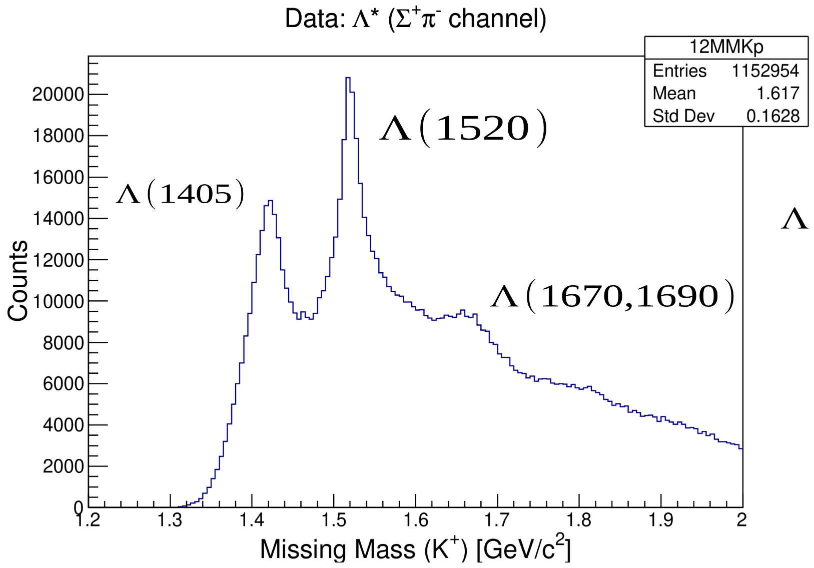




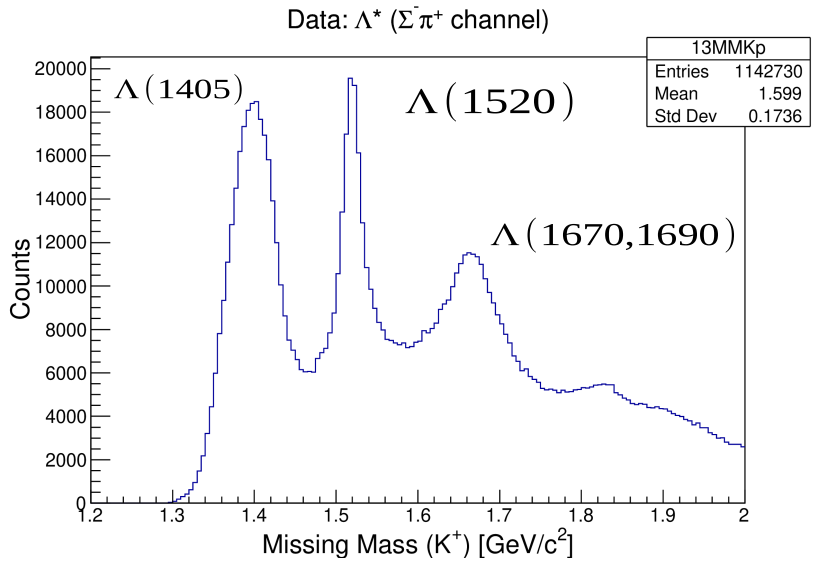
$\Lambda(1520) \rightarrow \Sigma^{+} + \pi^{-}$

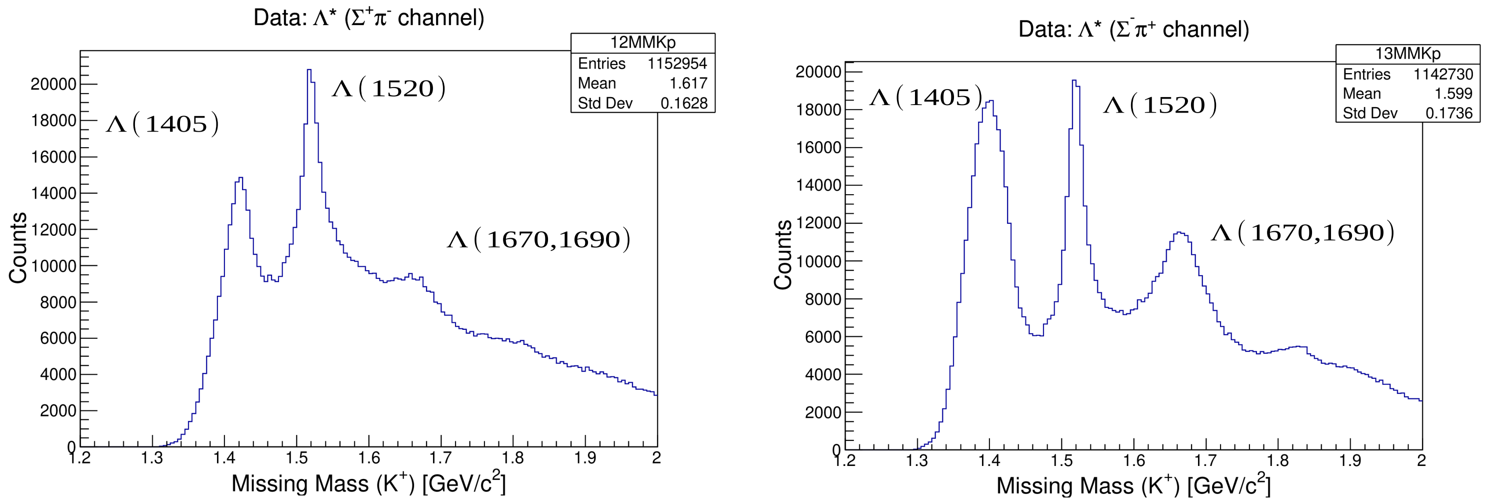


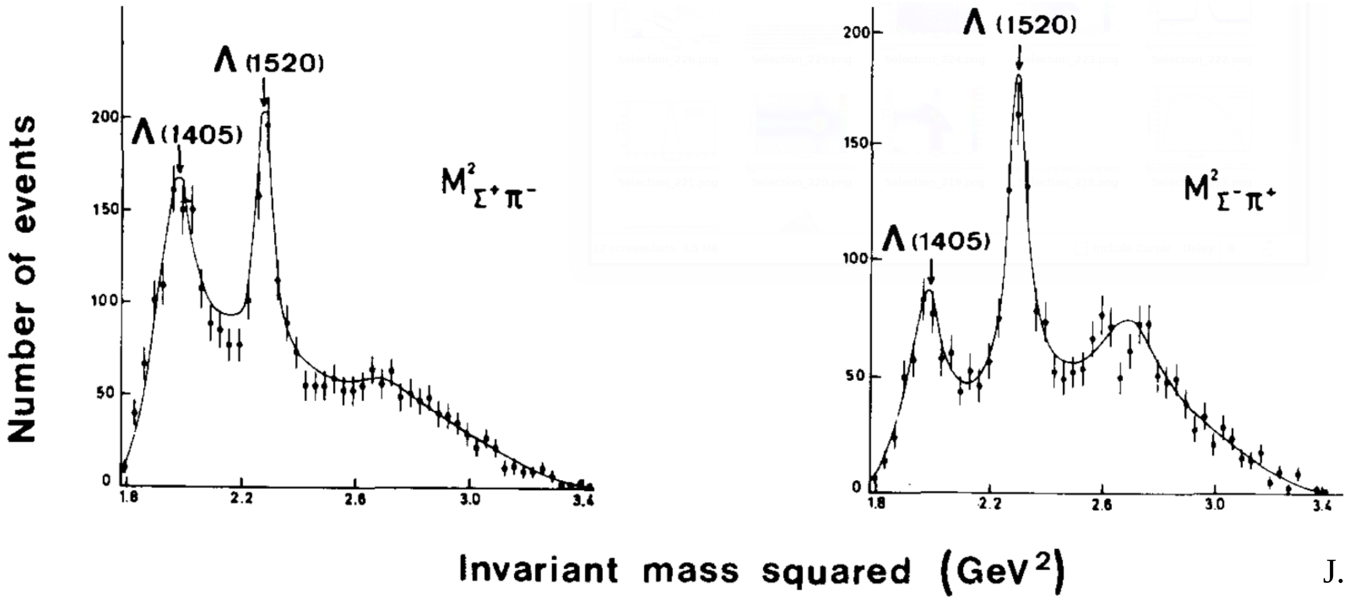
Cuts



$\Lambda(1520) \rightarrow \Sigma^{-} + \pi^{+}$



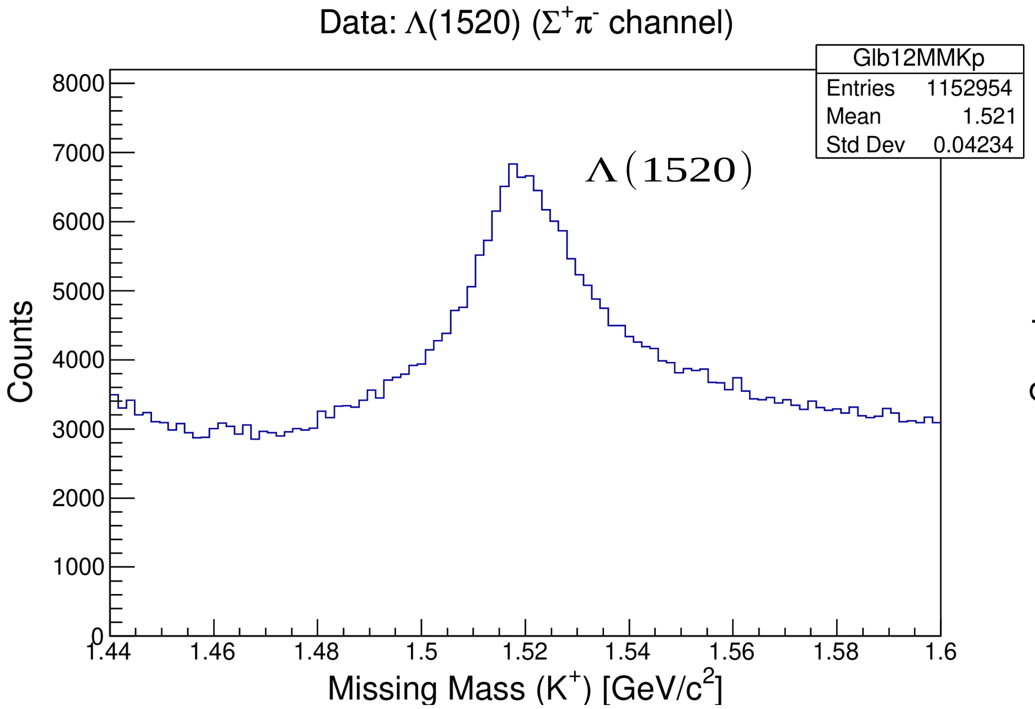




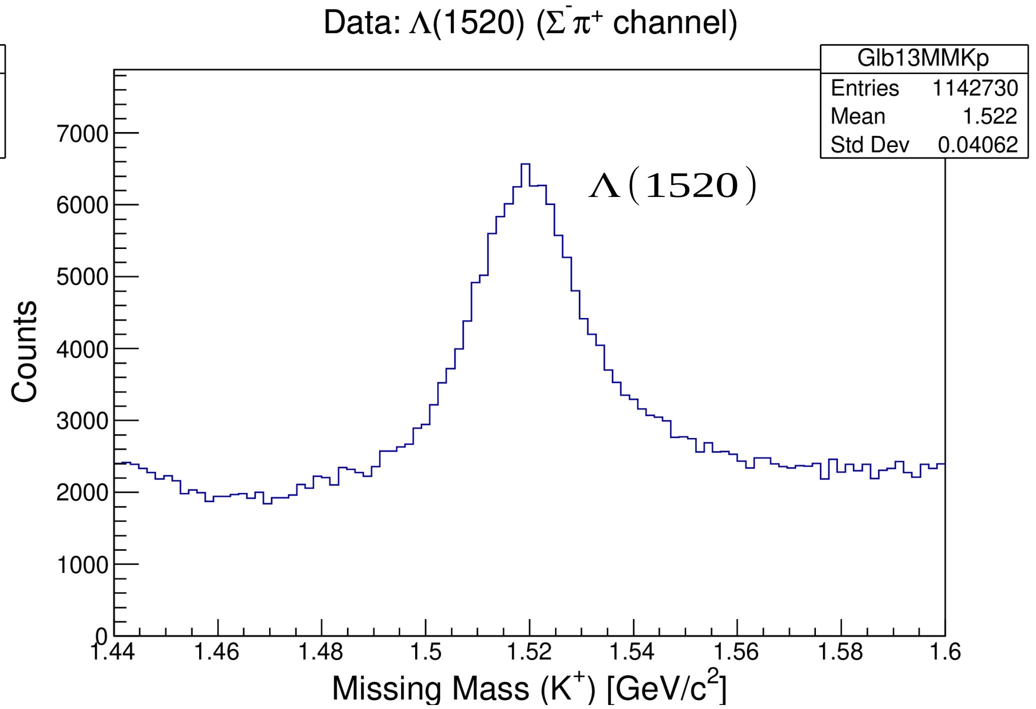
J. Griselin et. al., 1975

Global Spectrum

$\Lambda(1520) \rightarrow \Sigma^{+} + \pi^{-}$



$\Lambda(1520) \rightarrow \Sigma^{-} + \pi^{+}$



Global spectrum integrated over all angles leads towards fitting the $\Lambda(1520)$ peak with a Lorentzian function that rests on a smooth quadratic background.

Differential Cross-section: Λ(1520)

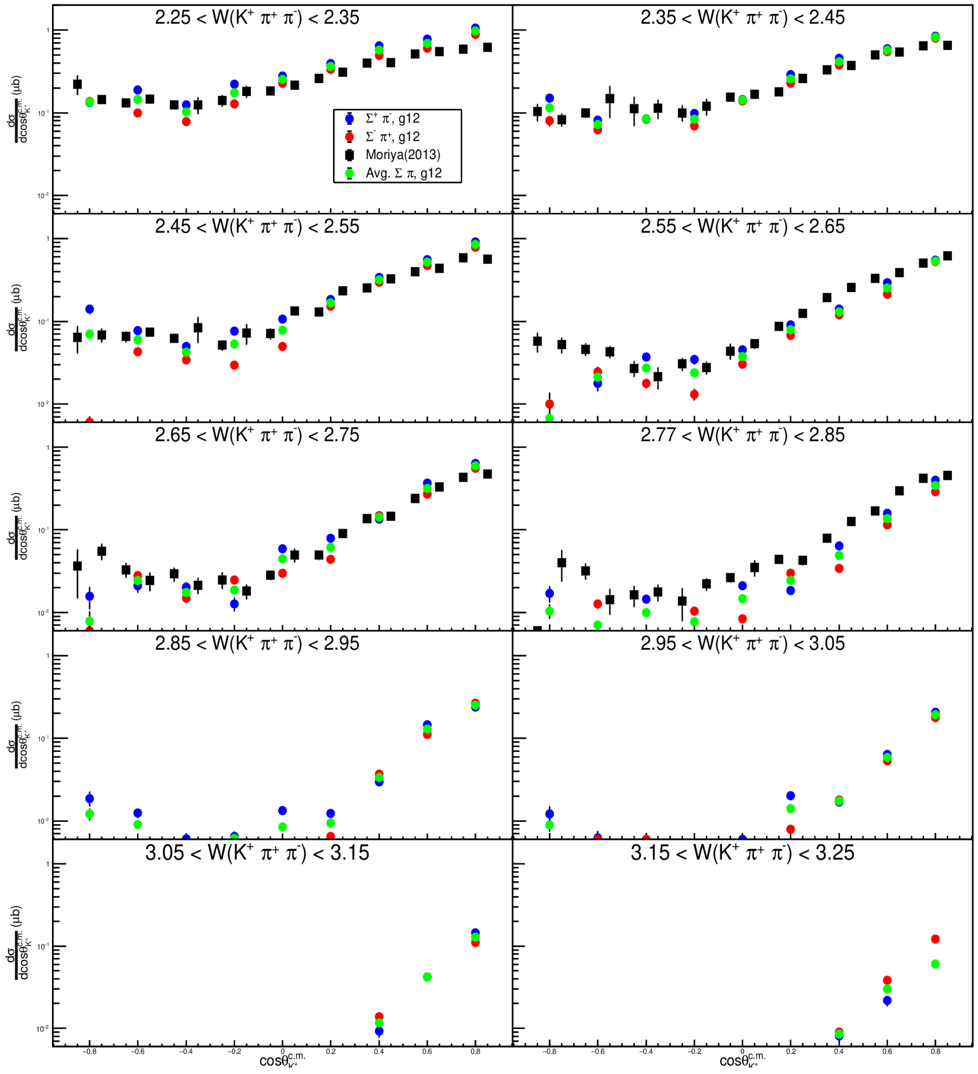
$$\frac{d\sigma}{dCos\theta^{c.m.}_{K^+}} = \frac{Y_d}{\tau\,\Delta\cos\theta^{c.m.}_{K^+}\,A\,L(W)}$$

$\tau = Branching\ ratio$
$Y_d = Signal\ Yield$
$A = Acceptance$
$\Delta\cos\theta^{c.m.}_{K^+} = Width\ of\ cos\theta\ bin$
$L(W) = Luminosity$

$$L(E_W) = \frac{\rho_p N_A l_t}{A_p} N_\gamma(W)$$

$l_t = 40$ cm
$\rho_p = 0.07114\ \mathrm{g/cm^3}$
$A_p = 1.00794$ g/mol
N_A is Avogadro's number

Λ(1520) dcs for $\Sigma^+\pi^-$ & $\Sigma^-\pi^+$ channels with g11 CLAS results



Work in progress!

K. Moriya et al. Differential photoproduction cross sections of the $\Sigma^0(1385)$, Λ(1405), and Λ(1520) *Phys. Rev. C*, 88:045201, Oct 2013.

Sytematics: $\Lambda(1520)$

- Systematic uncertainties are specific to experimental measures, any assumptions made by the experiment, any model used for inferences to observation. Hence, they are errors due to inaccuracy in observation and measurement techniques.

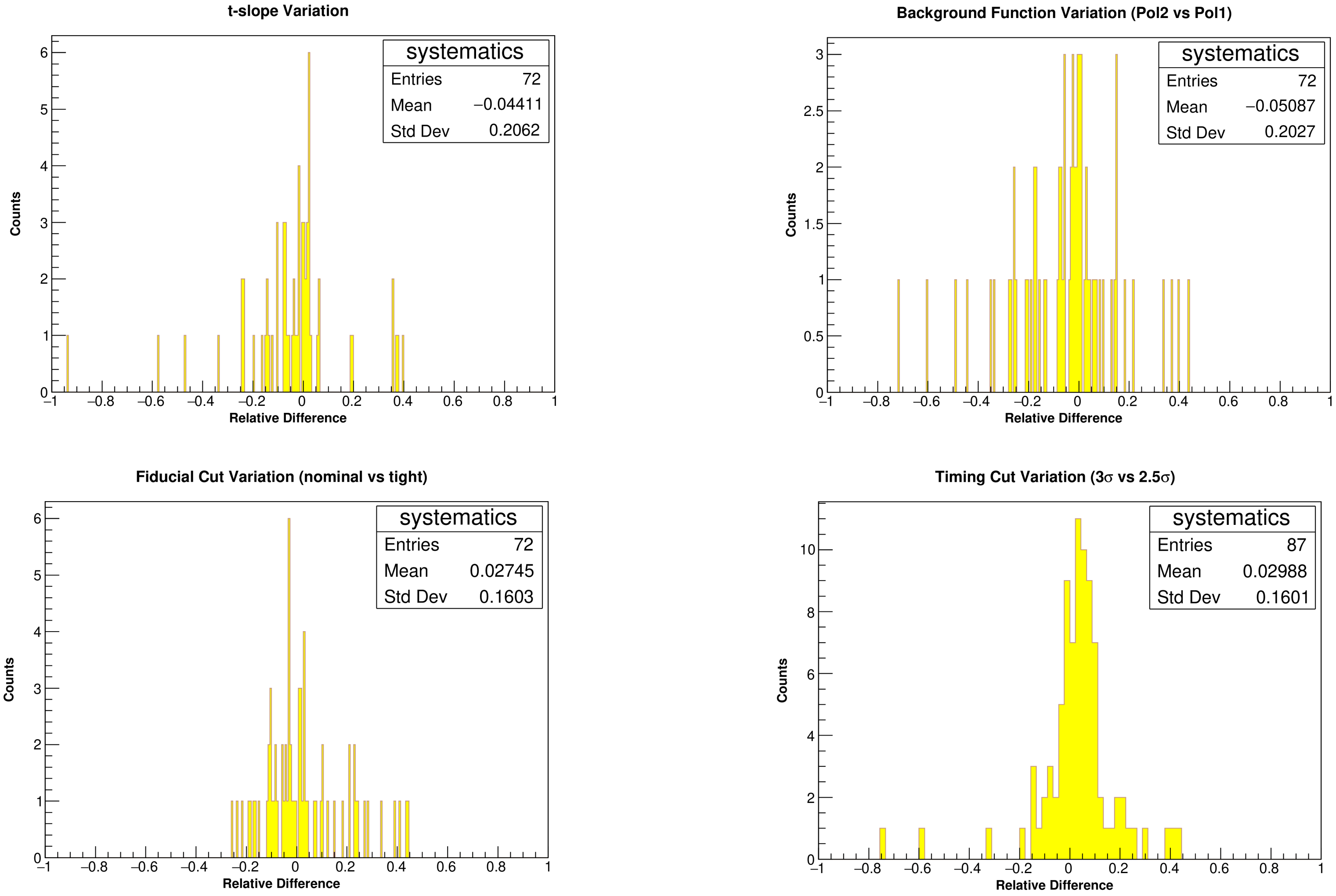
- For this analysis, variations were made on different cuts and procedures, to obtain a variation in the final result.

- For each variation, a relative difference from the nominal result is obtained. A relative difference of zero indicates no change in the result after the variation.

- Systematic uncertainty is recognized as the shift of the average of the relative differences from zero.

$$Relative\ Difference = \frac{dcs_{nom} - dcs_{var}}{dcs_{nom}}$$

Sytematics: Λ(1520)



Sytematics: $\Lambda(1520)$

Source	Description	Uncertainty
t-slope dependence	b = 2.0 vs b = 1.0	4.41%
Timing Cut	3σ vs 2.5σ	2.99%
z-Vertex Cut	$-110 < z < -70$ vs $-108 < z < -72$	0.92%
Fiducial Cut	50%(nominal) vs 100%(tight)	2.75%
Background Function	Pol2 vs Pol1	5.09%
Flux	g12	1.70%
Sector by Sector	g12	5.90%
Target	g12	0.50%
Total Systematic Uncertainty	Added in quadrature	10.03%

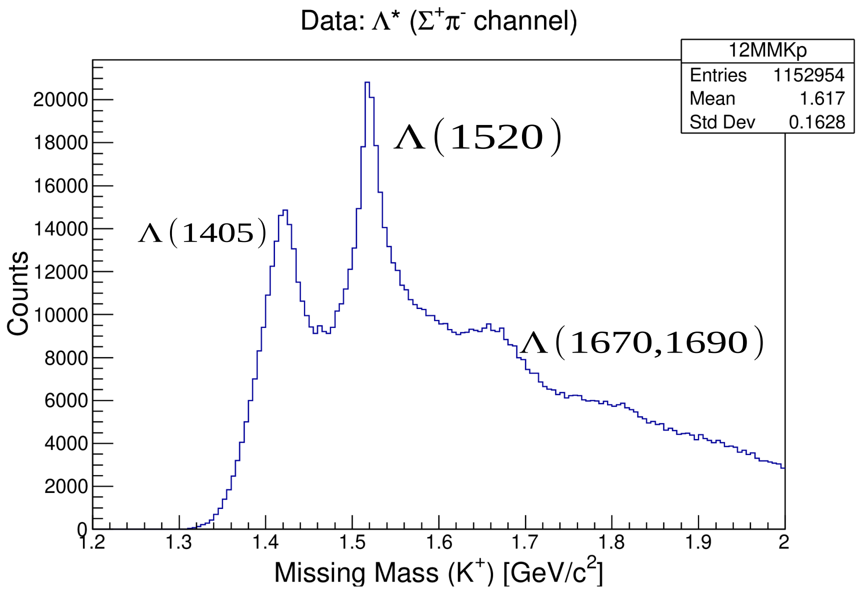
Work in progress!

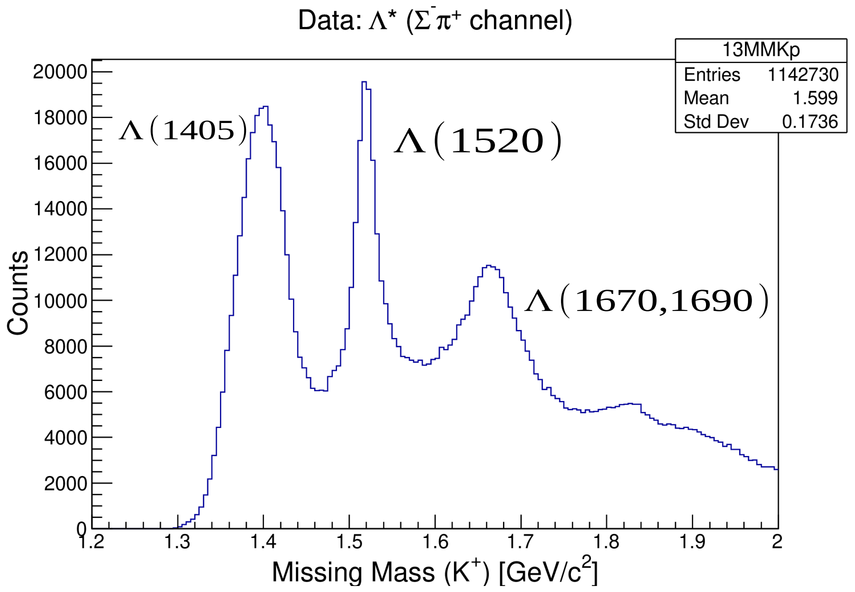
$\Lambda(1670)$ & $\Lambda(1690)$

Particle	J^P	PDG rating	Status as seen in $N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other Channels
$\Lambda(1405)$	1/2-	****	****	Forbidden	****	
$\Lambda(1520)$	3/2-	****	****	Forbidden	****	$\Lambda\pi\pi$, $\Lambda\gamma$
$\Lambda(1670)$	1/2-	****	****	Forbidden	****	$\Lambda\eta$
$\Lambda(1690)$	3/2-	****	****	Forbidden	****	$\Lambda\pi\pi$, $\Sigma\pi\pi$

Not well investigated using photoproduction data.

Same final state particles: K^+, π^+, π^-

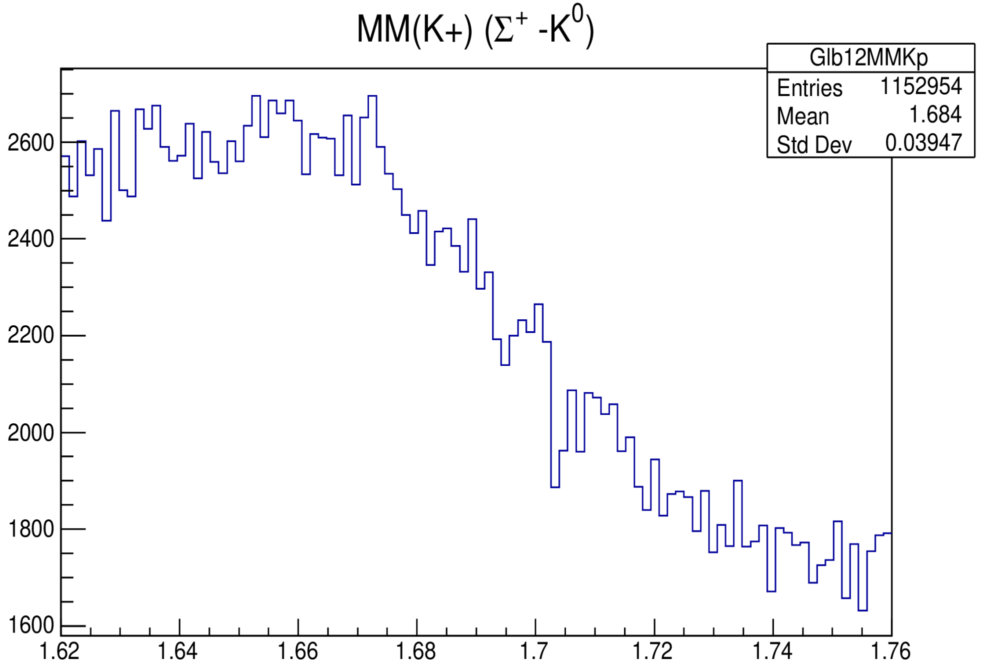


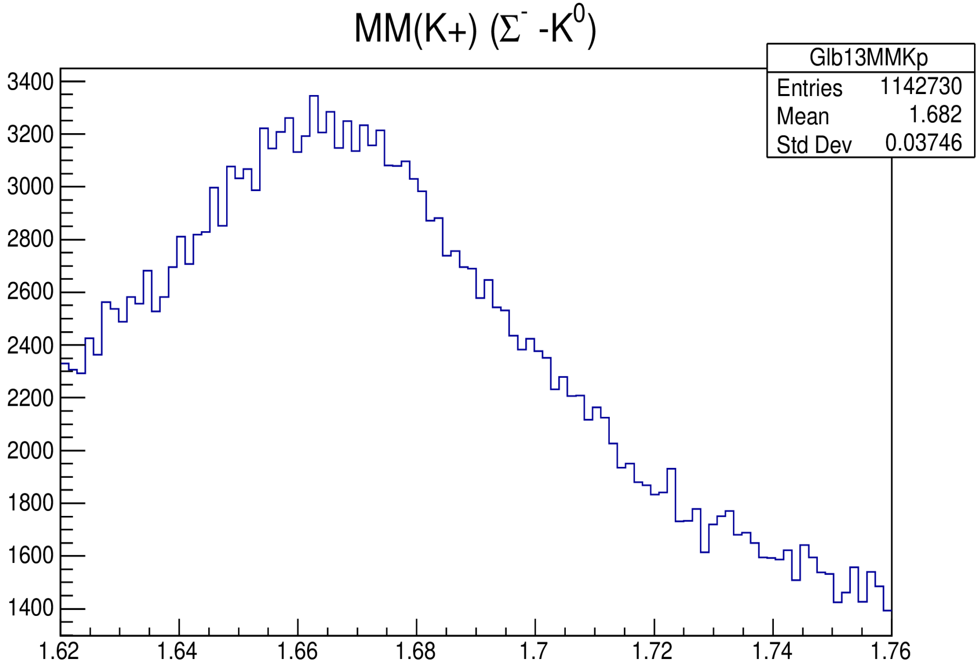


Global Spectrum

$\Lambda(1670,1690) \rightarrow \Sigma^{+} + \pi^{-}$

$\Lambda(1670,1690) \rightarrow \Sigma^{-} + \pi^{+}$





$$\Lambda^* \rightarrow \Sigma^+\pi^- \text{ or } \Sigma^-\pi^+$$

$$<0\ 0\ |\ 1\ {+1}\ 1\ {-1}> = 1/\sqrt{3}$$

$$<0\ 0\ |\ 1\ {-1}\ 1\ {+1}> = 1/\sqrt{3}$$

Σ(1670) 3/2⁻

$I(J^P) = 1(\frac{3}{2}^-)$

Mass m = 1665 to 1685 (≈ 1670) MeV

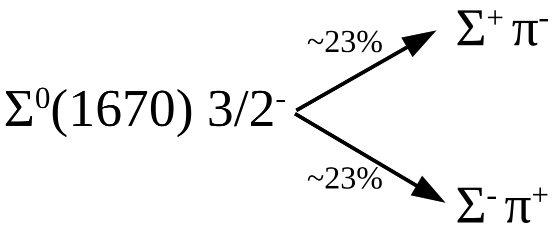
Full width Γ = 40 to 80 (≈ 60) MeV

Σ(1670) DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$N\overline{K}$	7–13 %	414
$\Lambda\pi$	5–15 %	448
$\Sigma\pi$	30–60 %	394

$$\Sigma^0 \rightarrow \Sigma^+\pi^- \text{ or } \Sigma^-\pi^+$$

$$<1\ 0\ |\ 1\ {+1}\ 1\ {-1}> = 1/\sqrt{2}$$

$$<1\ 0\ |\ 1\ {-1}\ 1\ {+1}> = -1/\sqrt{2}$$



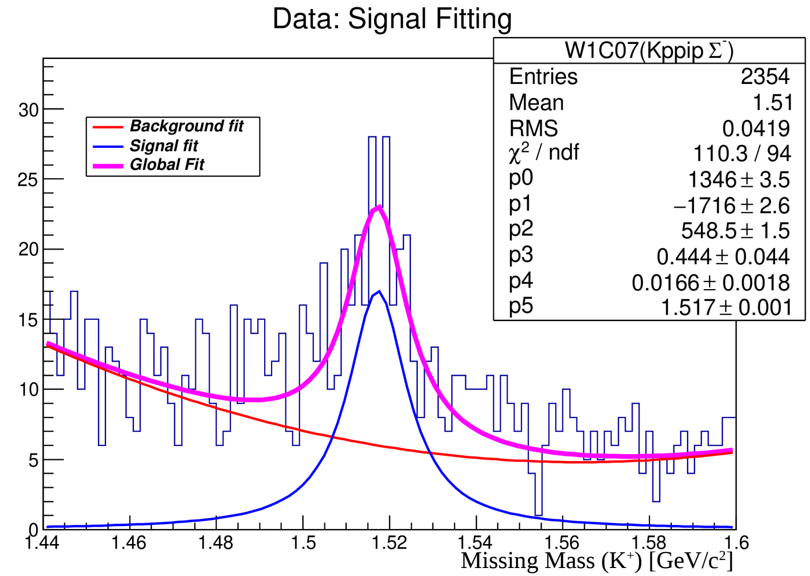
Next

- The Λ(1520) peak will be fit with Voigtian function.
- Systematic studies for Λ(1520) cross sections will be detailed.
- Λ(1520) CLAS note is in progress and will be submitted soon.
- Partial Wave Analysis is the next step to isolate Λ(1670) & Λ(1690) peaks from $\Sigma^0(1670)\ 3/2^-$.

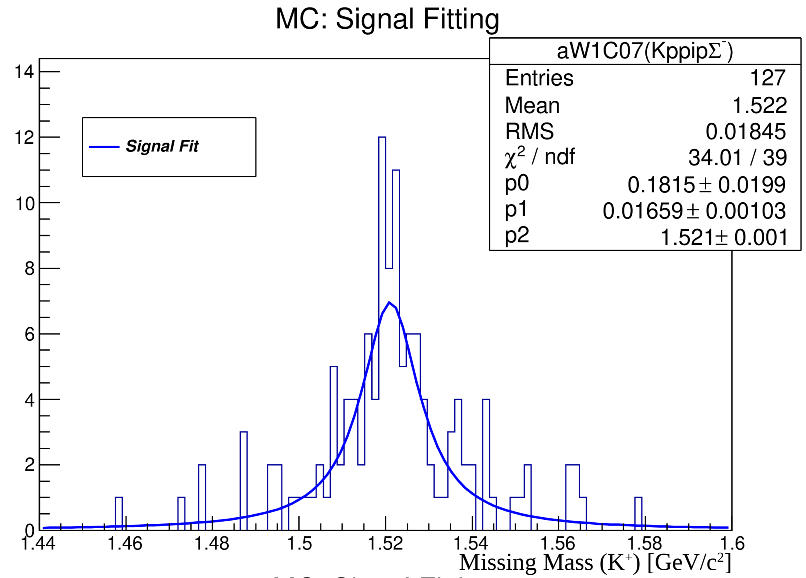
Thank You!

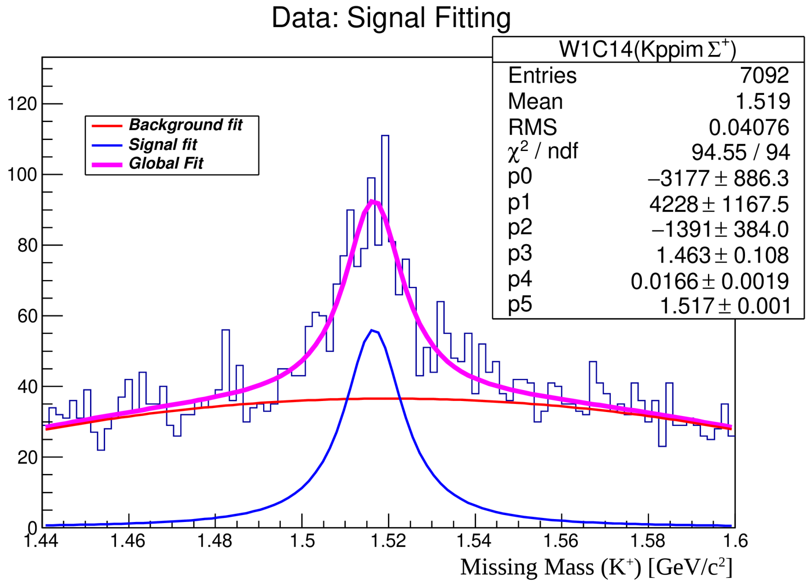
Extras

Λ(1520): Yield & Acceptance

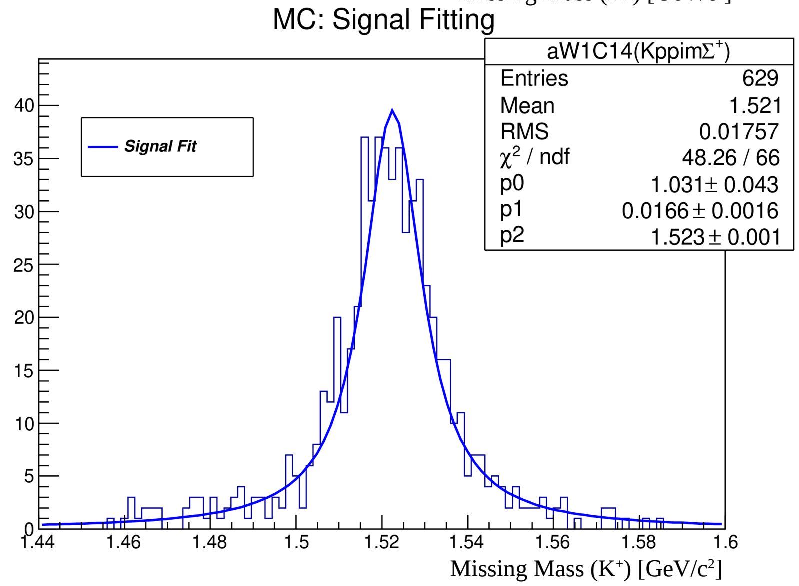


$$\Lambda(1520) \rightarrow \Sigma^- + \pi^+$$





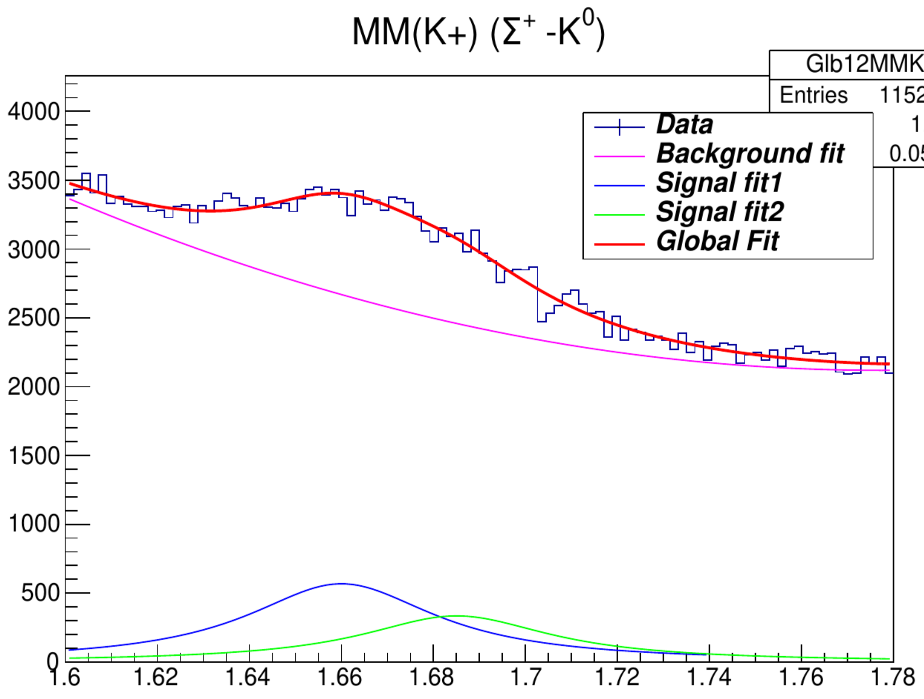
$$\Lambda(1520) \rightarrow \Sigma^+ + \pi^-$$

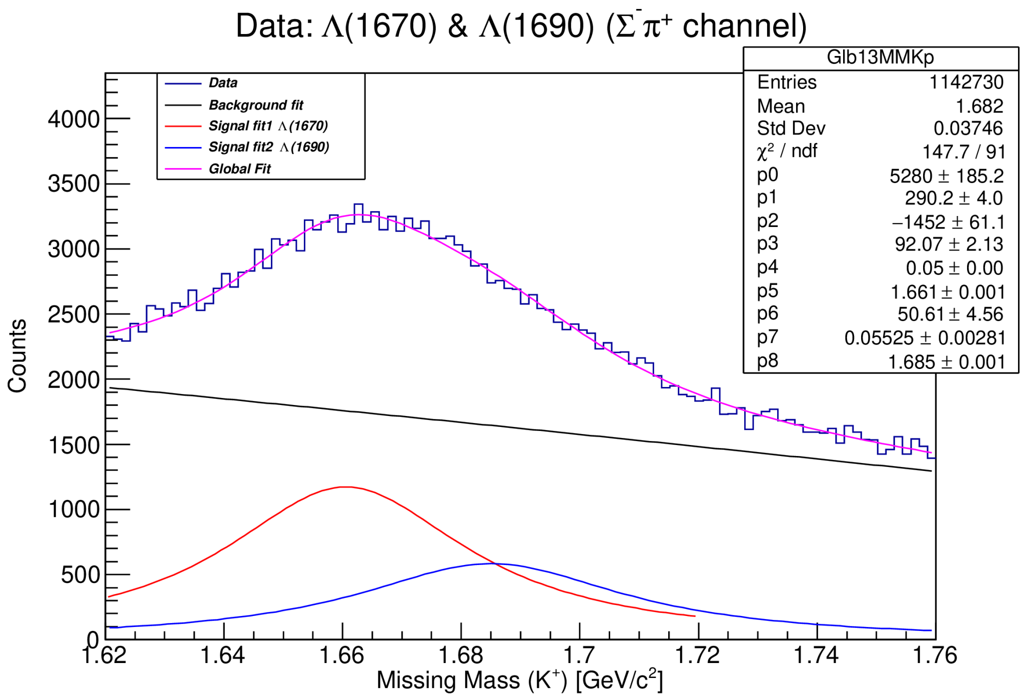


Global Spectrum

$\Lambda\,(1670,1690) \rightarrow \Sigma^{+} + \pi^{-}$

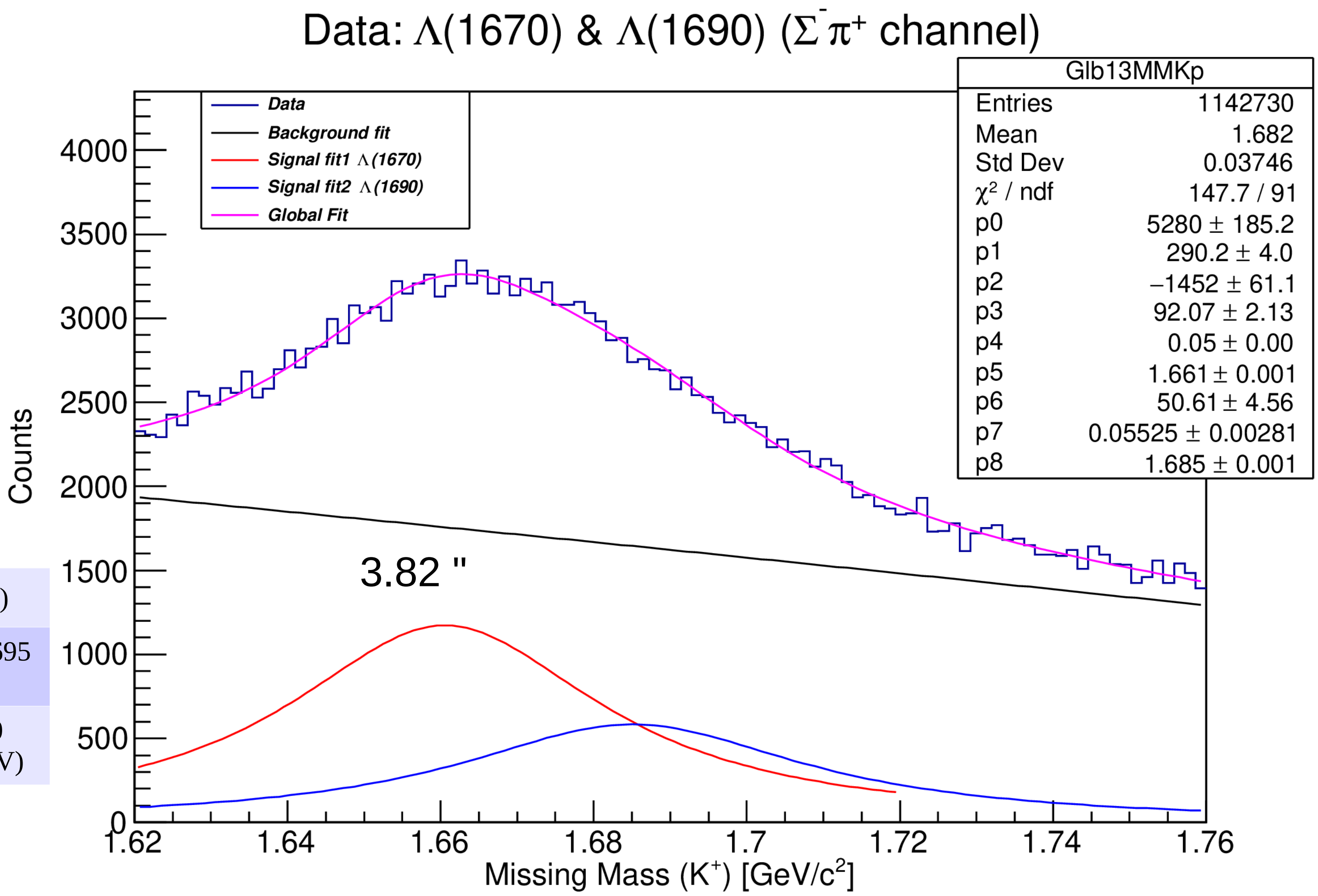
$\Lambda\,(1670,1690) \rightarrow \Sigma^{-} + \pi^{+}$





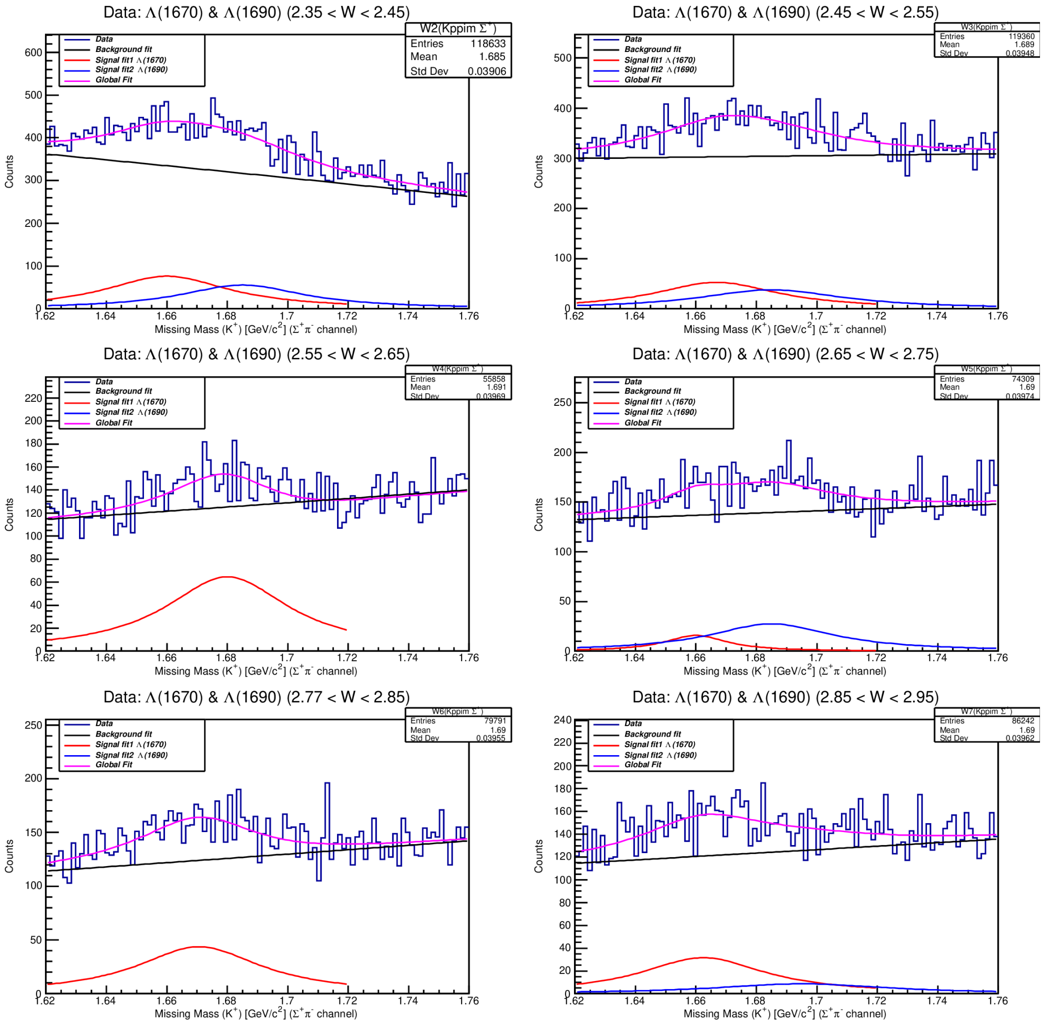
Signal Fitting: Λ(1670) & Λ(1690)

Parameter	Λ(1670)	Λ(1690)
Peak	1660 – 1680 (MeV)	1685 – 1695 (MeV)
Width	25 – 50 (~35 MeV)	50 – 70 (~60 MeV)

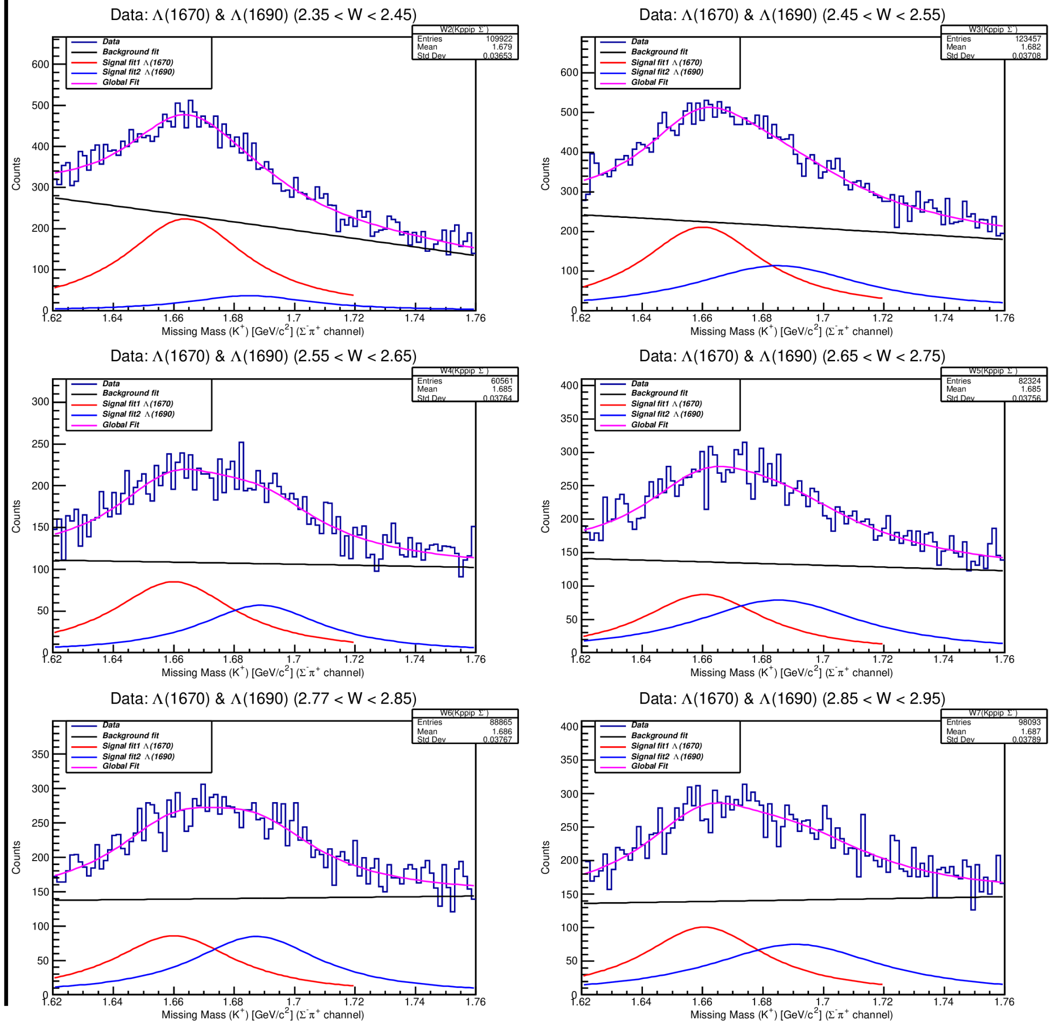


Signal Fitting: Λ(1670) & Λ(1690) (W bins)

$\Sigma^+\pi^-$



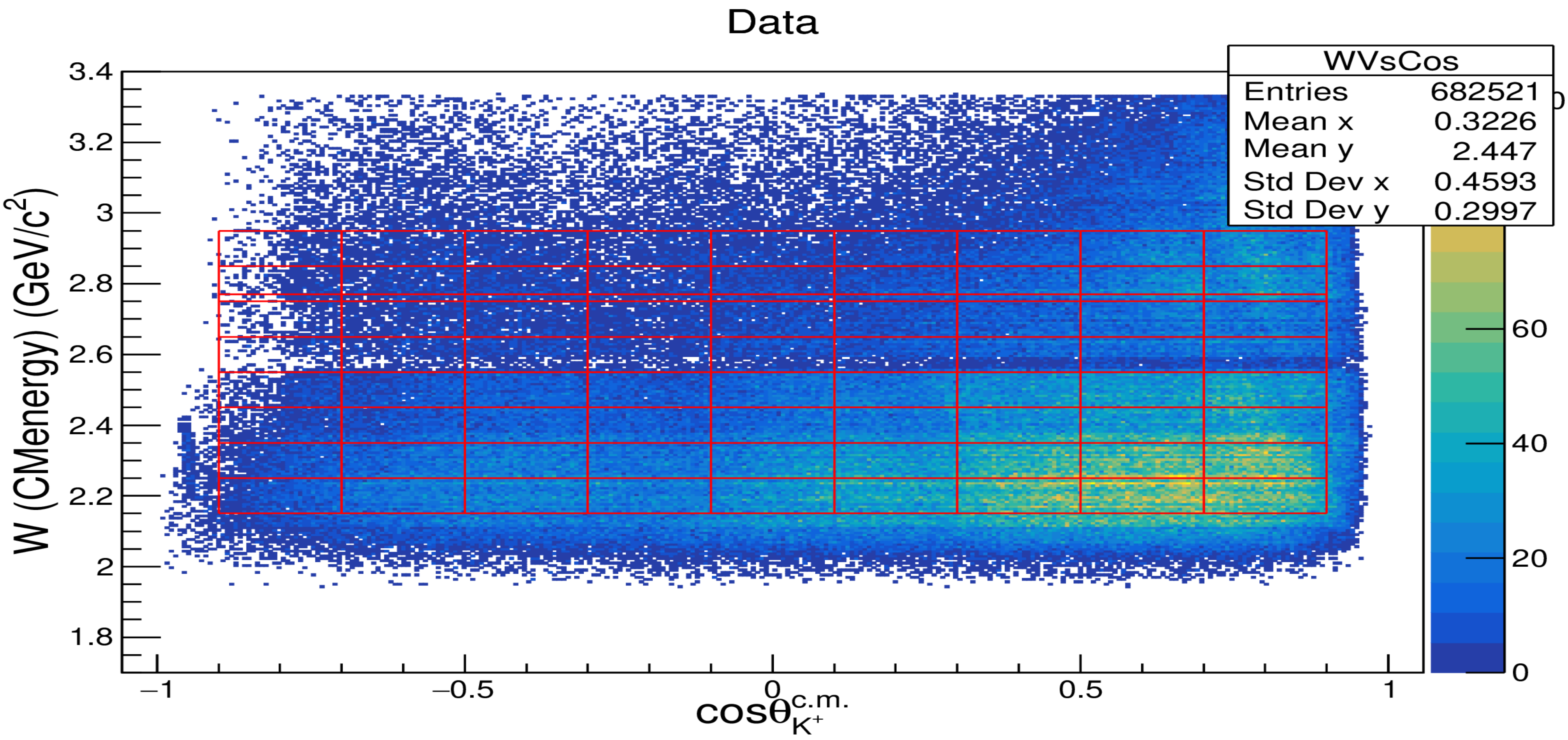
$\Sigma^-\pi^+$



Preliminary!!!

Used PART bank reconstruction for the analysis. EVNT was NOT used	N/A ☐ Yes ☐ No ☐
Momentum corrections as described in the g12 note	N/A ☐ Yes ☐ No ☐
Beam energy correction as described in the g12 note	N/A ☐ Yes ☐ No ☐
Inclusive Good run list as described in table 7. Individual analysis may use a subset of it	N/A ☐ Yes ☐ No ☐
Target density and its uncertainty as described in the g12 note	N/A ☐ Yes ☐ No ☐
Photon flux calculation procedure as described in the g12 note	N/A ☐ Yes ☐ No ☐
Lower limit for the systematic uncertainty of normalized yield is 5.7%	N/A ☐ Yes ☐ No ☐
Photon polarization calculation procedure as described in the g12 note	N/A ☐ Yes ☐ No ☐
Systematic uncertainty of the photon polarization as described in the g12 note	N/A ☐ Yes ☐ No ☐
gsim parameters	N/A ☐ Yes ☐ No ☐
gpp smearing parameters	N/A ☐ Yes ☐ No ☐
DC efficiency map	N/A ☐ Yes ☐ No ☐
EC knockout	N/A ☐ Yes ☐ No ☐

Bin Scheme



Data
WVsCos
Entries 682521
Mean x 0.3226
Mean y 2.447
Std Dev x 0.4593
Std Dev y 0.2997
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
W (CMenergy) (GeV/c^2)
−1
−0.5
0
0.5
1
$\cos\theta_{K^+}^{c.m.}$
60
40
20
0

Trigger Correction

Trigger Efficiency : Data

- First, the efficiency of the trigger as a function of particle type, momentum, and detector position was obtained using a ratio of two-sector hit events to total (two & three sector) hit events in the form of Trigger Efficiency Map.

- Second, the probability for two-sector events of having at least one photon with $E_\gamma > 3.6$ GeV was obtained by analyzing the ratio of energy-dependent intensity distributions of two-sector and three-sector events.

Trigger Simulation : MC

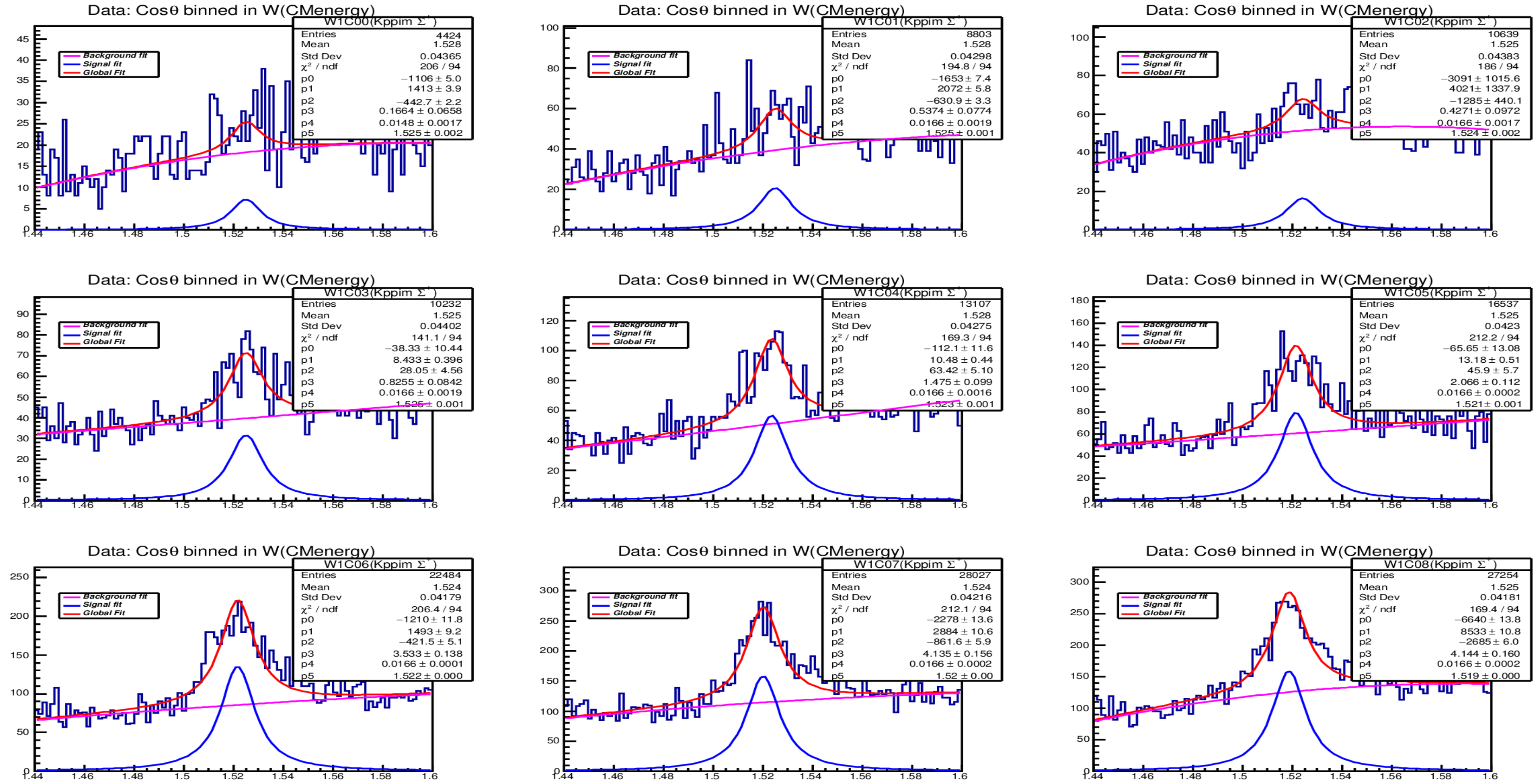
- Events with two particles in the same sector are cut out both for data and MC.

- MC events with all particles firing the trigger (three-sector events) go through.

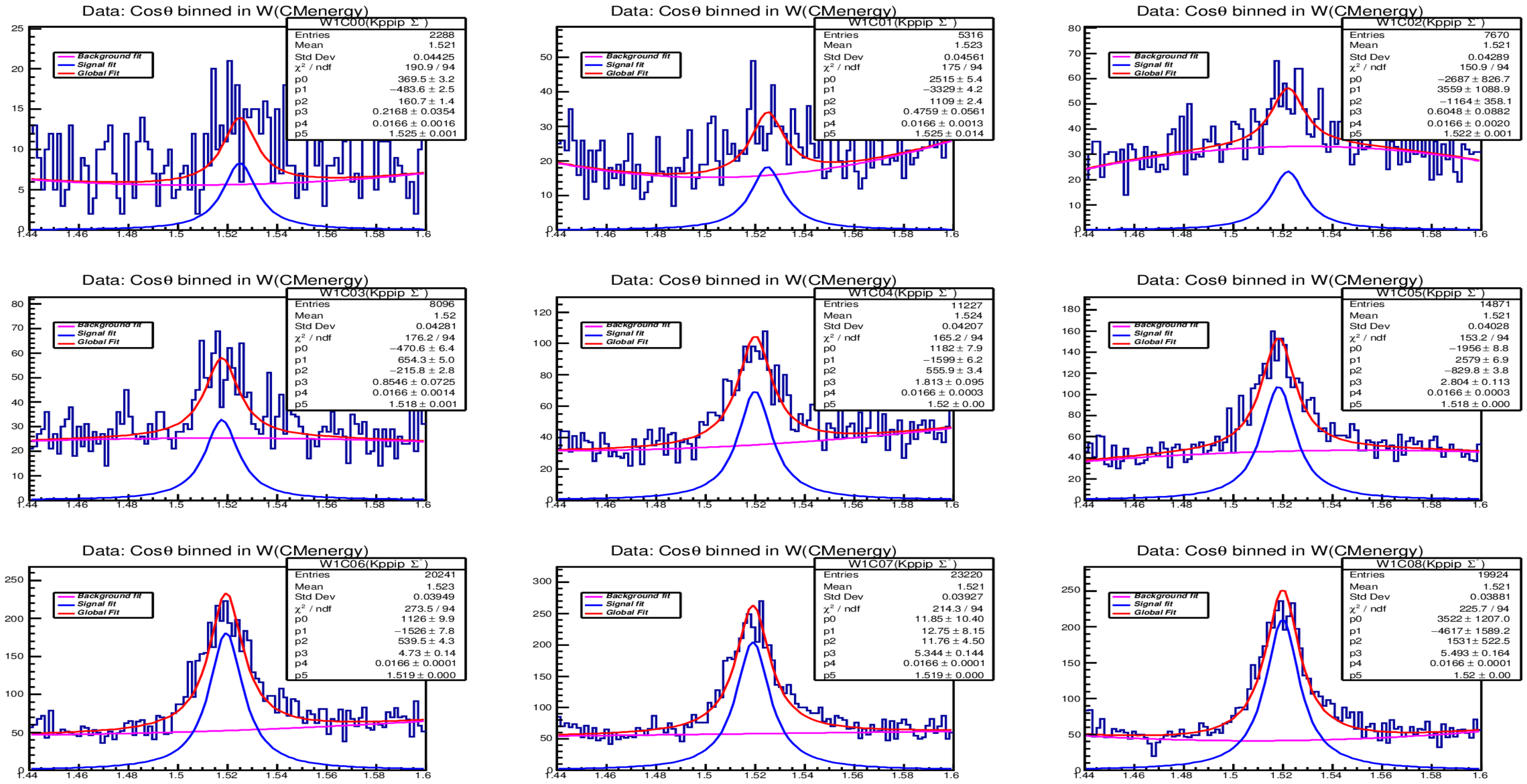
- MC events with only two particles firing the trigger and the photon energy above 3.6 GeV go through.

- MC events with only two particles firing the trigger and the photon energy below 3.6 GeV go through if any randomly generated probability is less than the probability for having at least one photon with $E_\gamma > 3.6$ GeV.

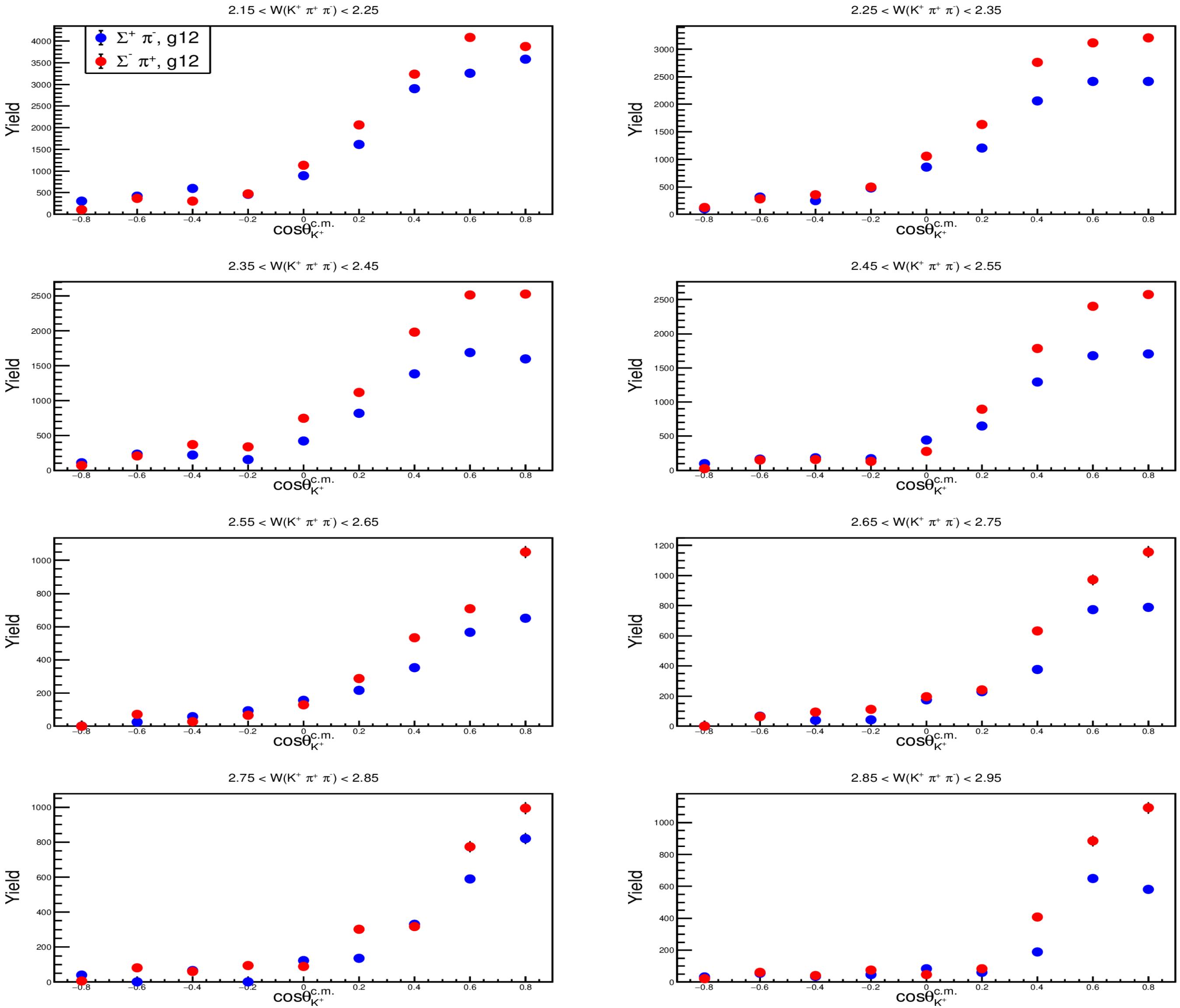
Signal Fitting: Λ(1520) (2.15 < W < 2.25) $\Sigma^+\pi^-$ channel



Signal Fitting: Λ(1520) (2.15 < W < 2.25) $\Sigma^{-}\pi^{+}$ channel



Yield: Λ(1520)



Σ+ π-, g12
Σ- π+, g12
2.15 < W(K+ π+ π-) < 2.25
2.25 < W(K+ π+ π-) < 2.35
2.35 < W(K+ π+ π-) < 2.45
2.45 < W(K+ π+ π-) < 2.55
2.55 < W(K+ π+ π-) < 2.65
2.65 < W(K+ π+ π-) < 2.75
2.75 < W(K+ π+ π-) < 2.85
2.85 < W(K+ π+ π-) < 2.95
Yield
cosθ c.m. K+

Acceptance: $\Lambda(1520)$

$$Acceptance = \frac{Accepted\ Events}{Generated\ Event}$$

GEANT Based MC Simul