Photoproduction of Λ^* Resonances at CLAS

CLAS Collaboration Meeting
November October 12 – 15, 2019

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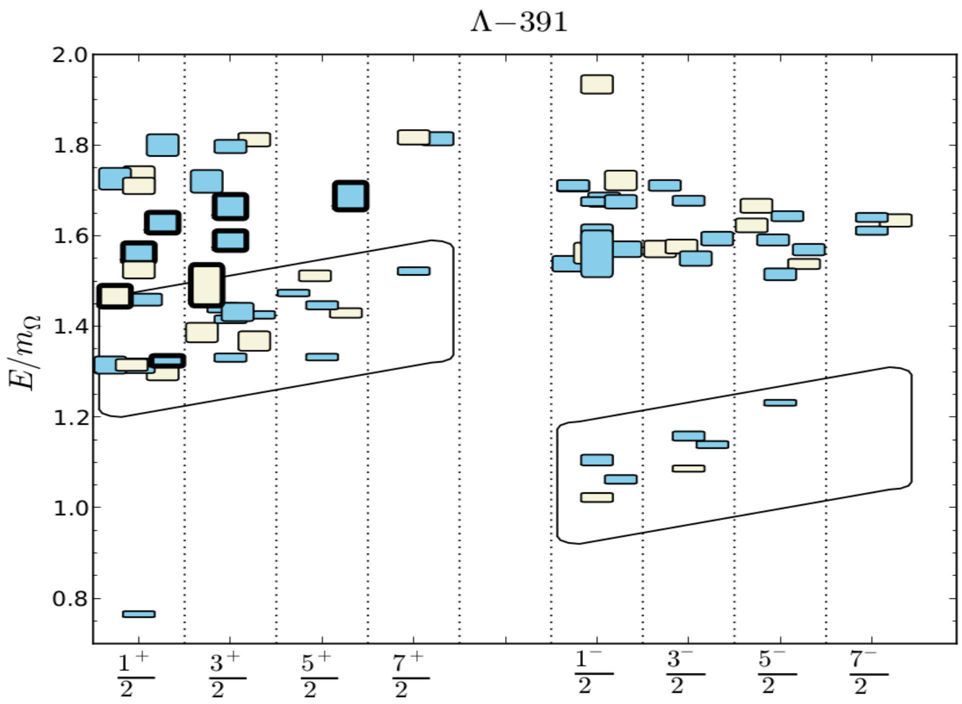
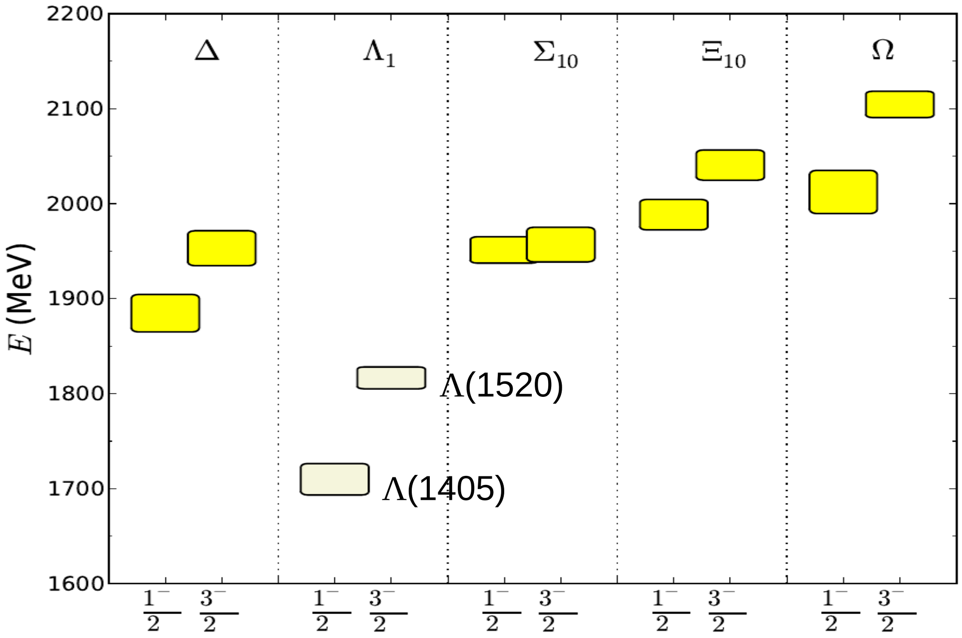
Λ*

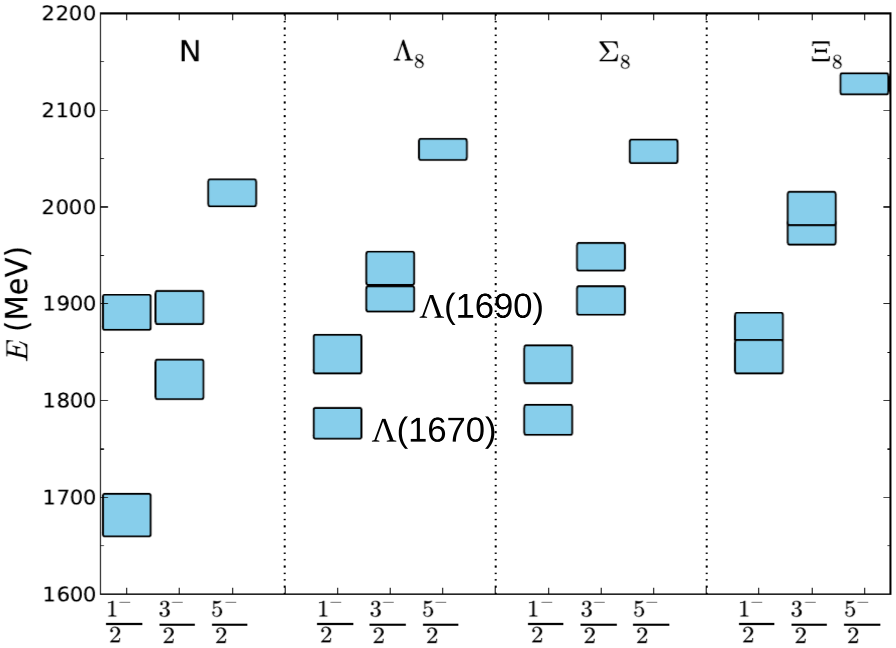
J^P	$(D, L_N^P)\,S$		Octet members			Singlets
$1/2^+$	$(56,0_0^+)$ 1/2	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0_2^+)$ 1/2	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(1690)^\dagger$	
$1/2^-$	$(70,1_1^-)$ 1/2	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
				$\Sigma(1560)^\dagger$		
$3/2^-$	$(70,1_1^-)$ 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

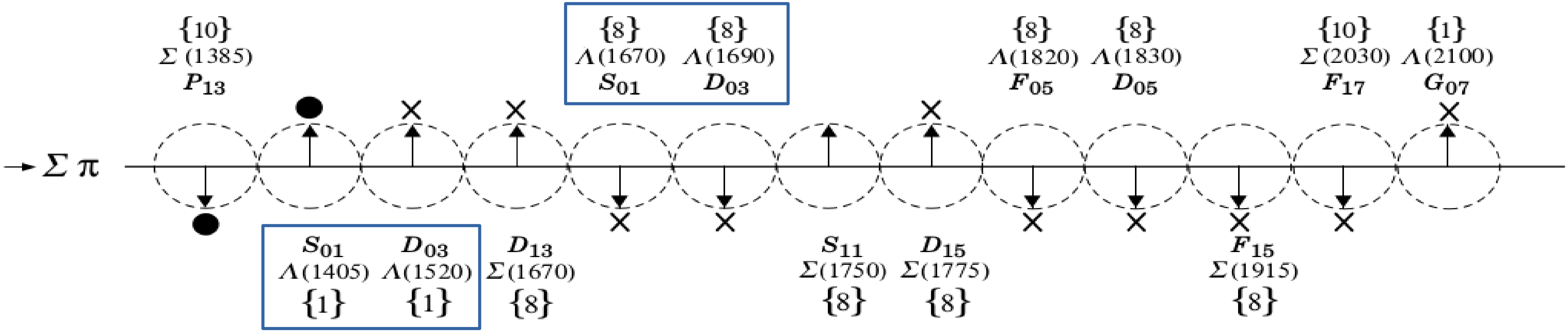




Robert G. Edwards, Nilmani Mathur, David G. Richards, and Stephen J. Wallace. Flavor structure of the excited baryon spectra from lattice qcd. *Phys. Rev. D*, 87:054506, Mar 2013.

- 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.

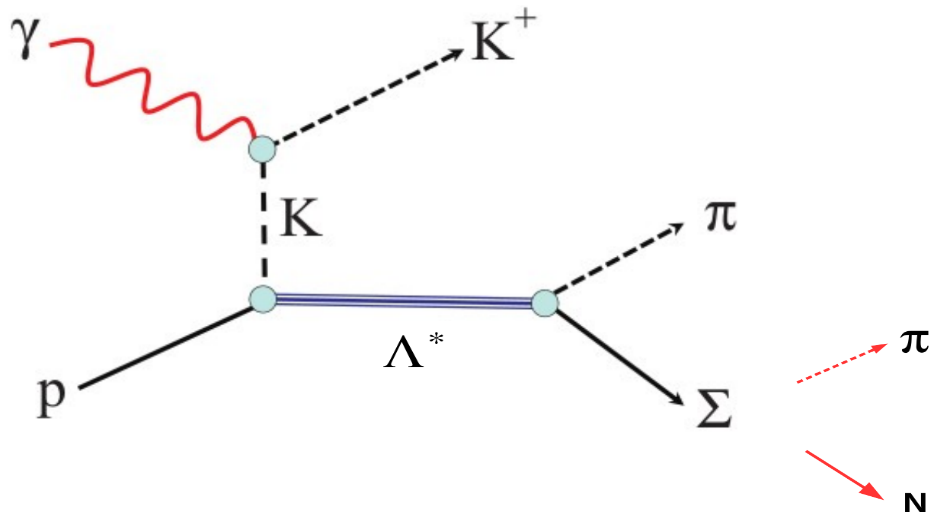
Motivation

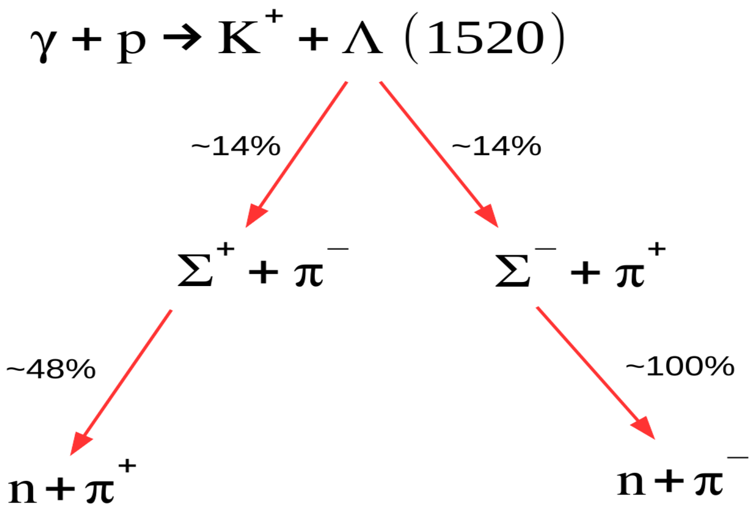


Particle	J^P	Overall status	$N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	1/2+	****		F		$N\pi$(weakly)
$\Lambda(1405)$	1/2−	****	****	o	****	
$\Lambda(1520)$	3/2−	****	****	r	****	$\Lambda\pi\pi, \Lambda\gamma$
$\Lambda(1600)$	1/2+	***	***	b	**	
$\Lambda(1670)$	1/2−	****	****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

pdg.lbl.gov

Λ* Photoproduction





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

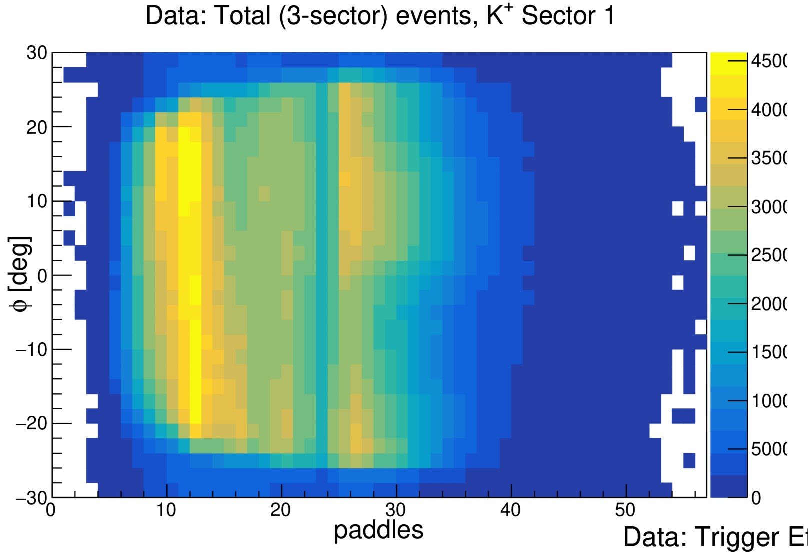
- Photo-prodution off a proton creates a K^{+}-meson and a Λ^{*}.
- Λ^{*} decays by $\Sigma\pi$ channel. Σ^{+} gives off a n & π^{+}, Σ- gives off a n & π^{-}.
- The final particles detected are K^{+}, π^{+} & π^{-}.

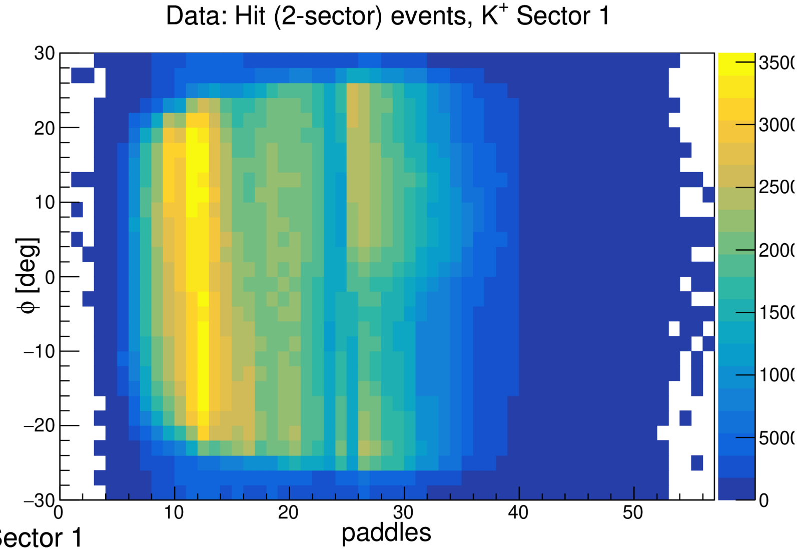
Outline (Cuts)

- 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.
- 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.

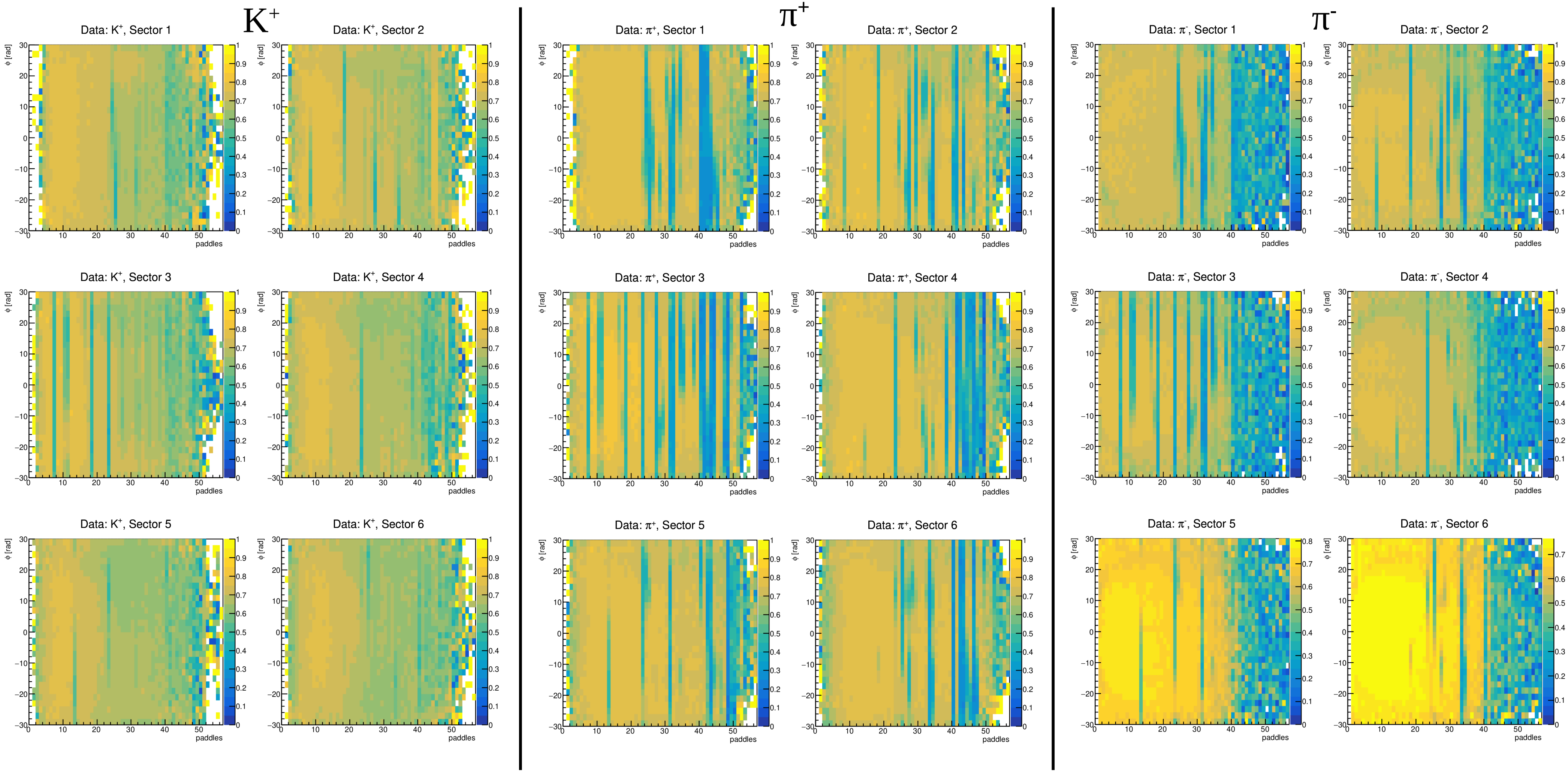
$0.9 \leq MM(K^+\pi\pi) \leq 1$	Select neutron events
$0.48 \leq IM(\pi^+\pi^-) \leq 0.51$	Remove nK^0 channel
$1.15 \leq MM(K^+\pi^-) \leq 1.25$ $1.15 \leq MM(K^+\pi^+) \leq 1.25$	Select Σ^+ and Σ^- events for exclusive $\Sigma\pi$ channels
$1.44 \leq MM(K^+) \leq 1.6$ $1.62 \leq MM(K^+) \leq 1.76$	Fitting Range Λ(1520) Fitting Range Λ(1670) & Λ(1690)
$2.15 \leq W \leq 2.95$ GeV $-0.9 \leq \cos\theta^{K+}_{cm} \leq 0.9$	Kinematic Ranges

Trigger Correction “new”

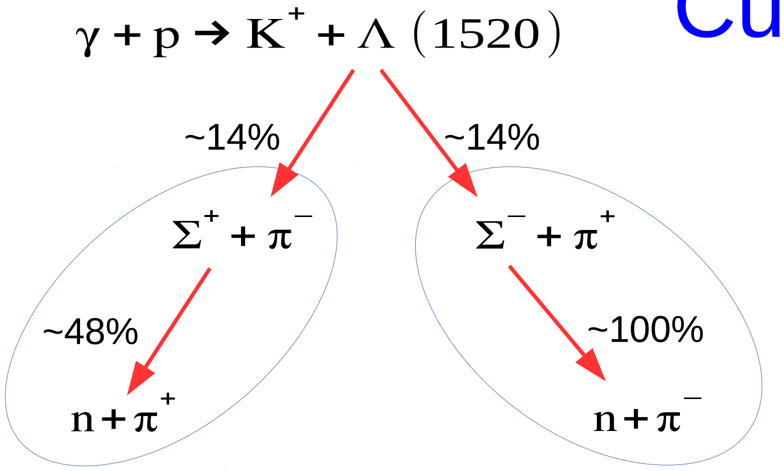


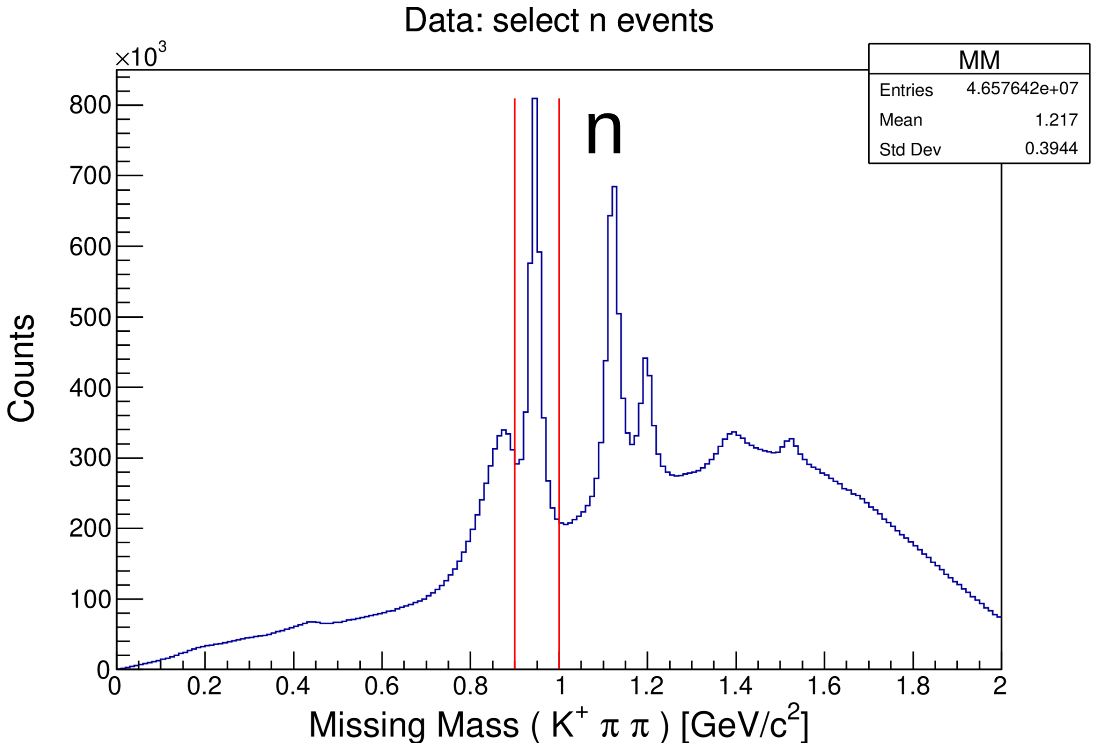


Trigger Efficiency Map

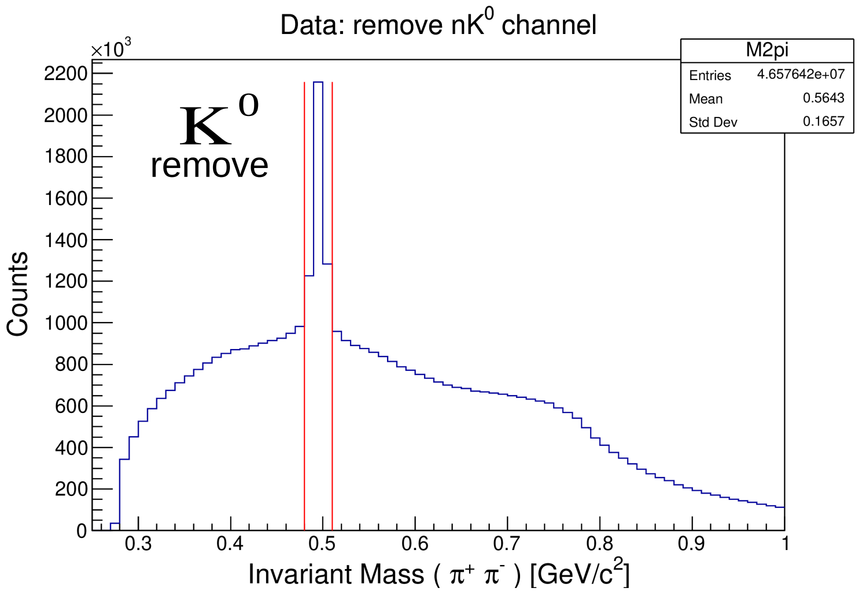


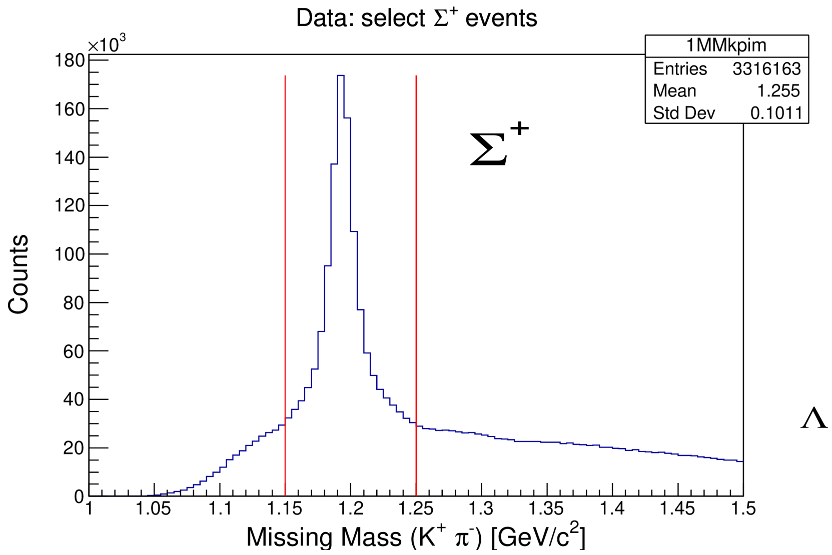
Cuts



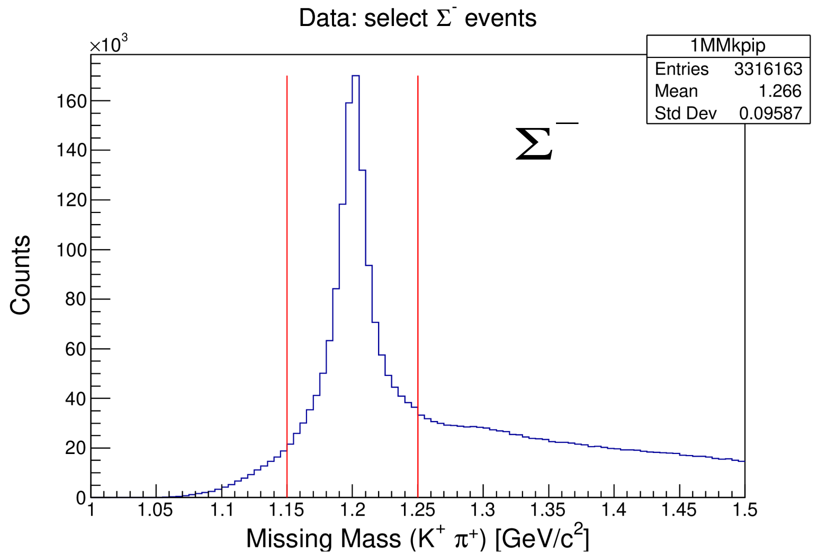


$0.9 < MM(K^{+}\pi\pi) < 1.0$ [GeV]

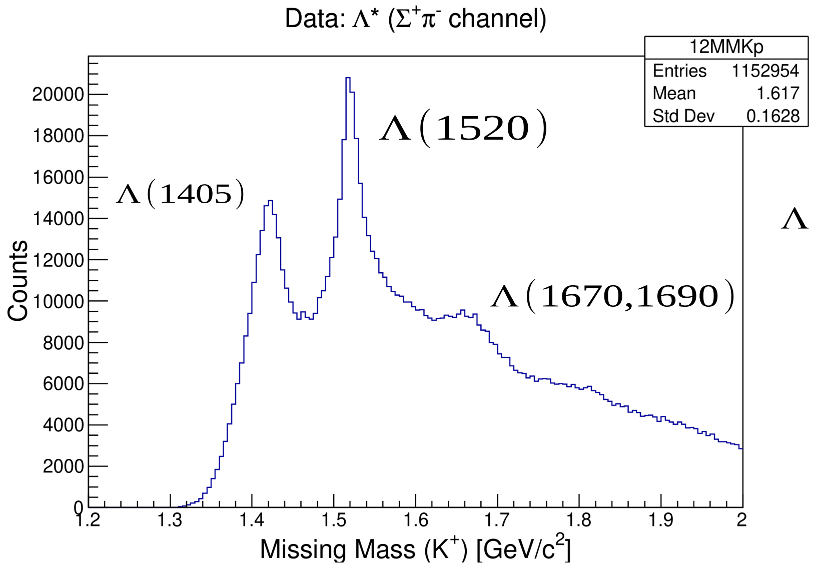




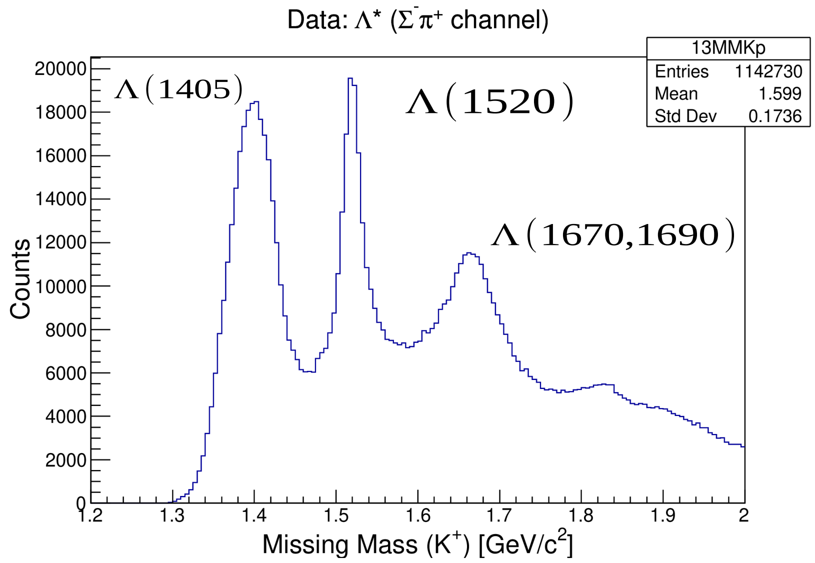
$\Lambda(1520) \rightarrow \Sigma^{+} + \pi^{-}$

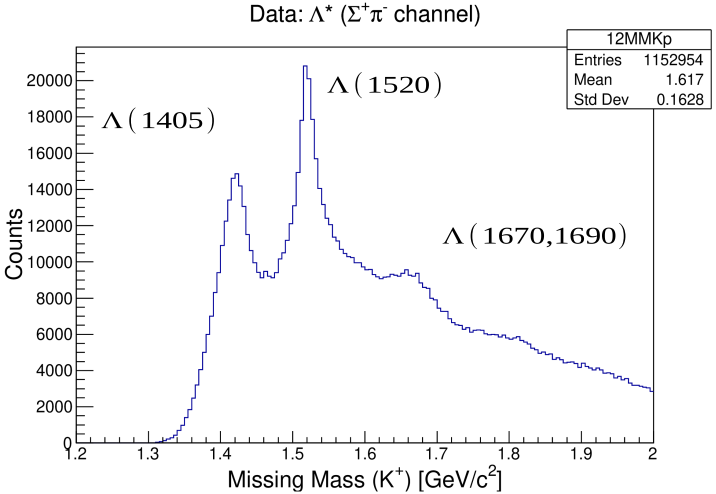


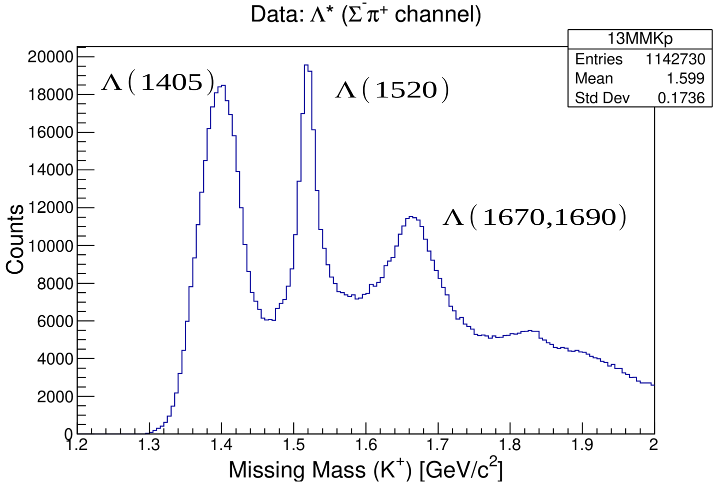
Cuts

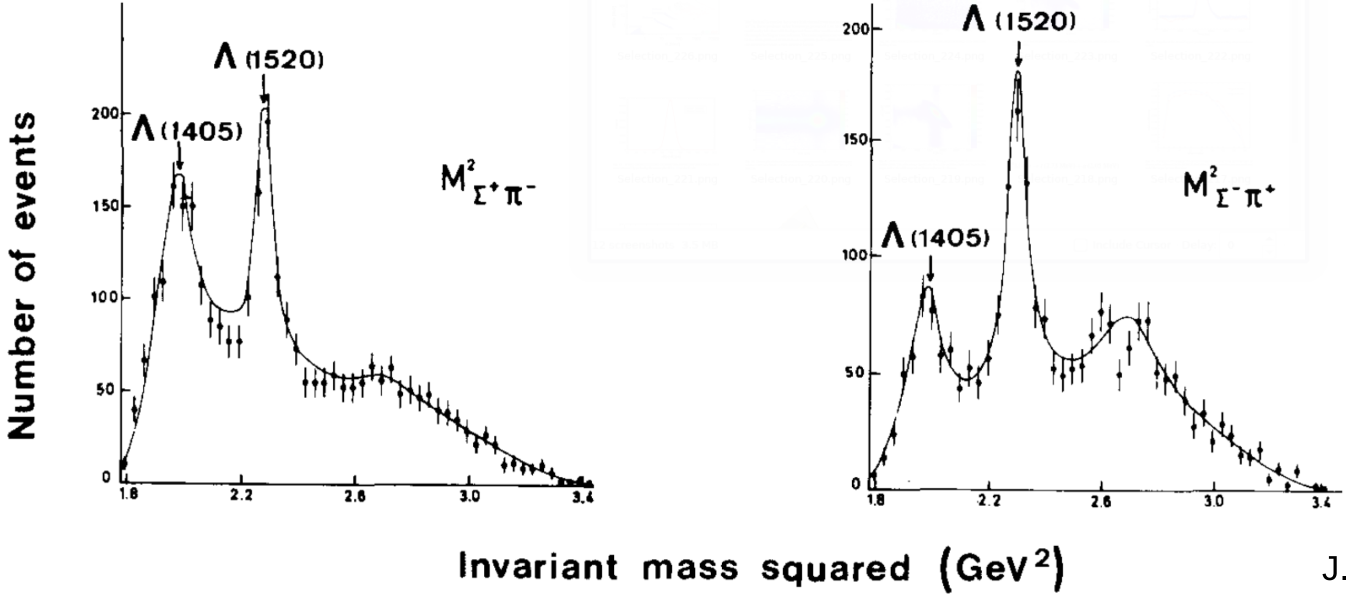


$\Lambda(1520) \rightarrow \Sigma^{-} + \pi^{+}$



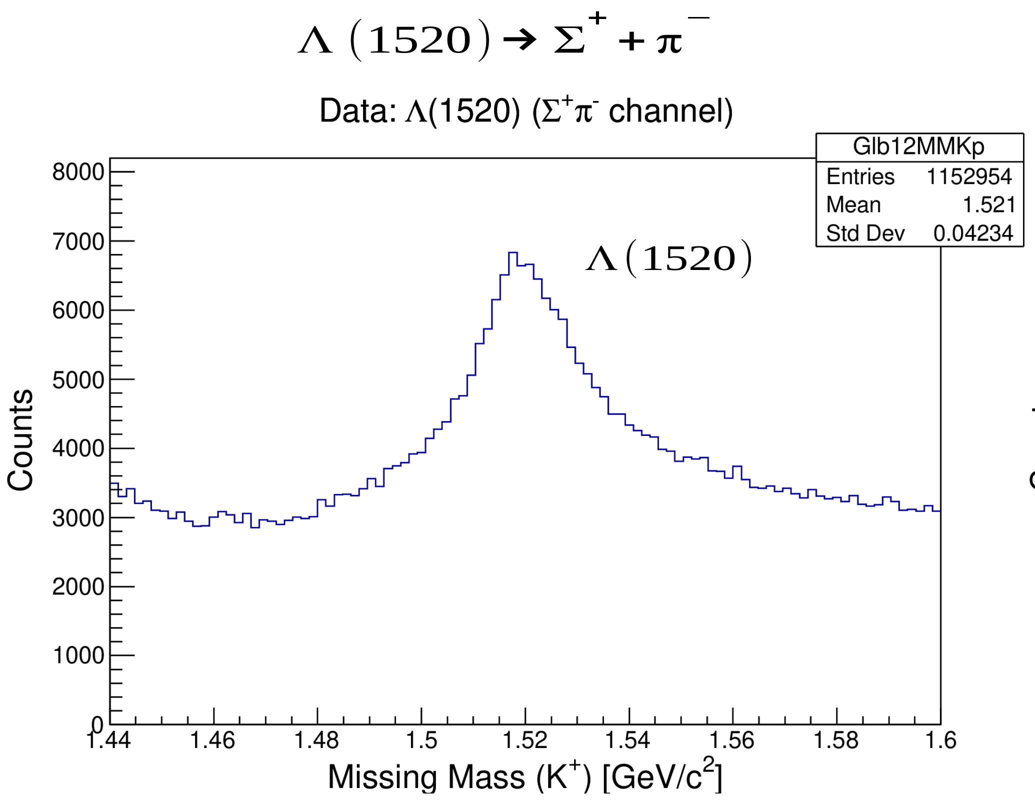


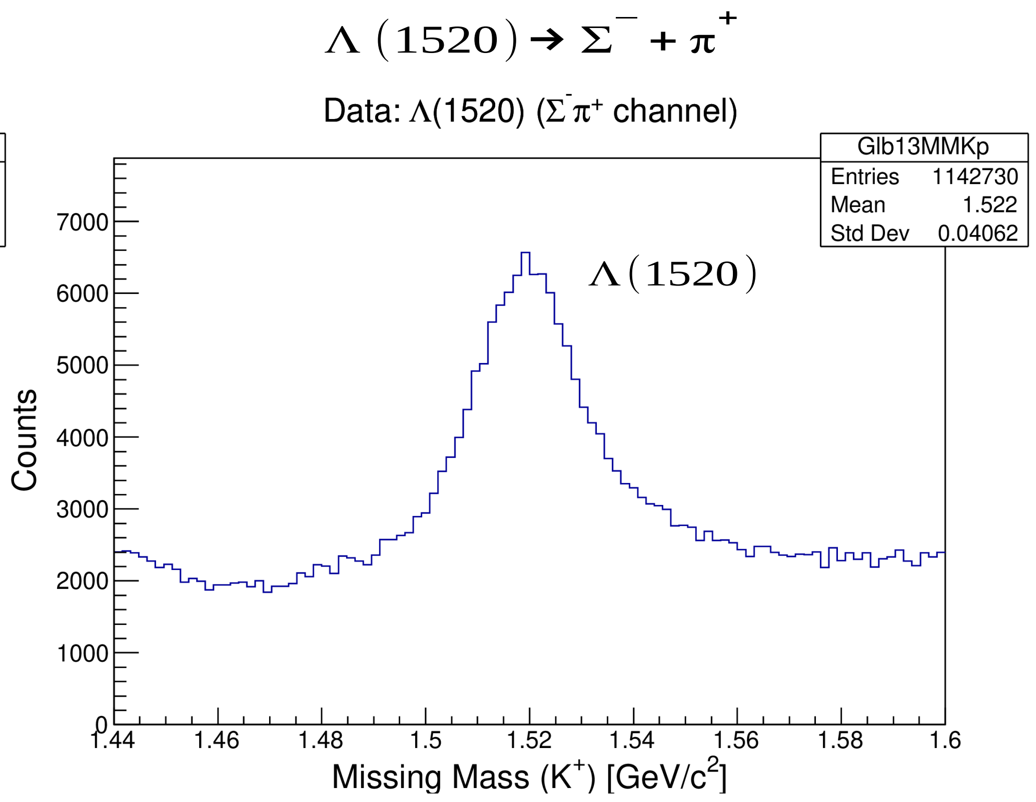




J. Griselin et. al., 1975

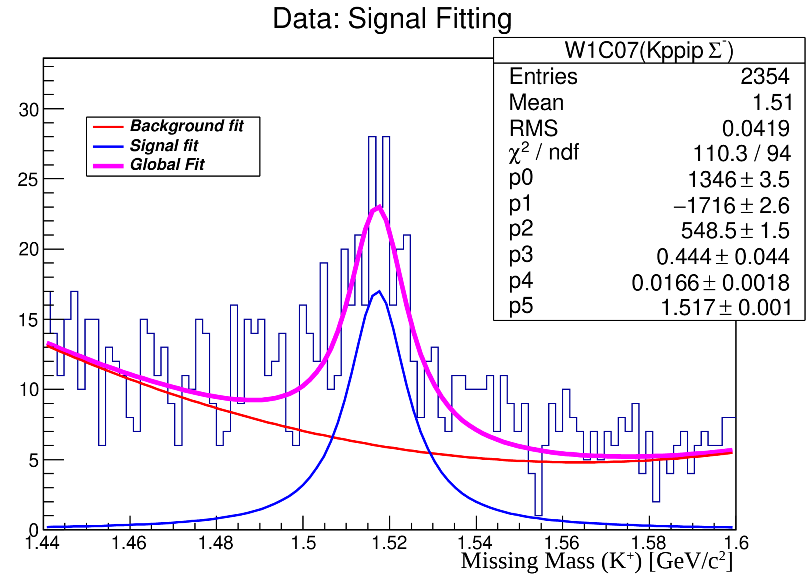
Global Spectrum



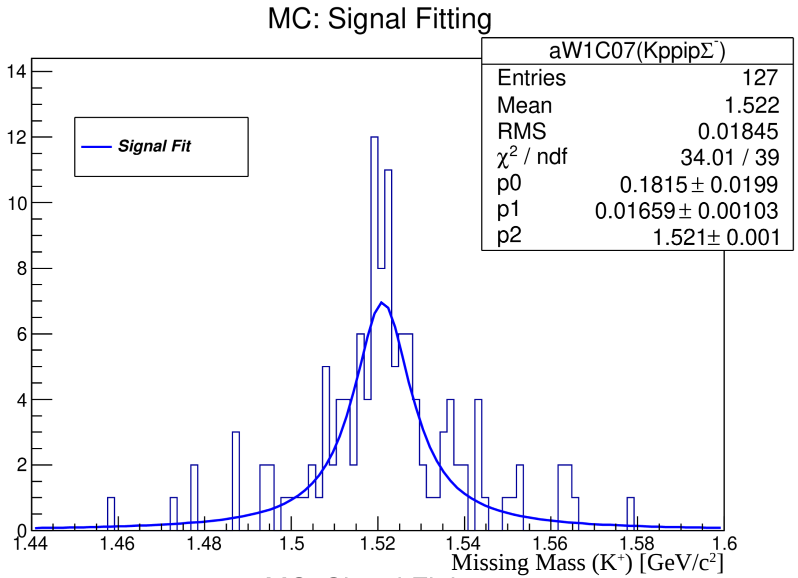


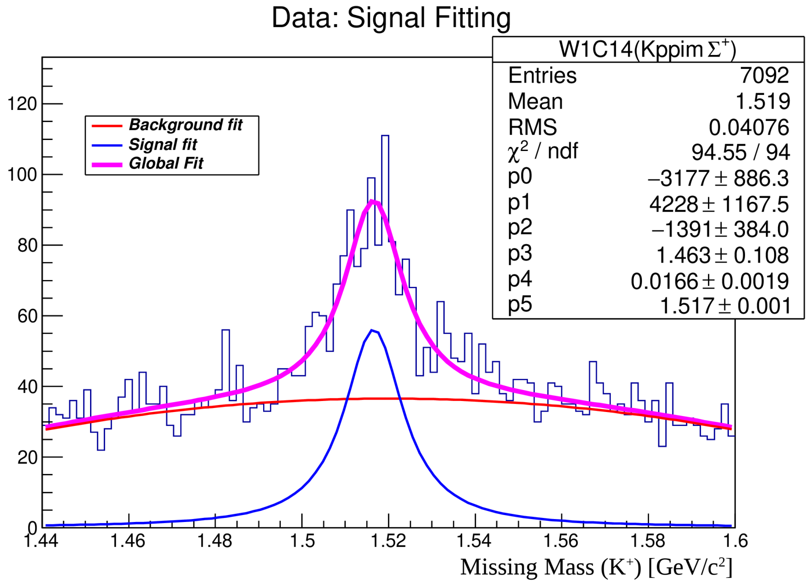
Global spectrum integrated over all angles leads towards fitting the Λ(1520) peak with a Lorentzian function that rests on a smooth quadratic background.

$\Lambda(1520)$: Yield & Acceptance

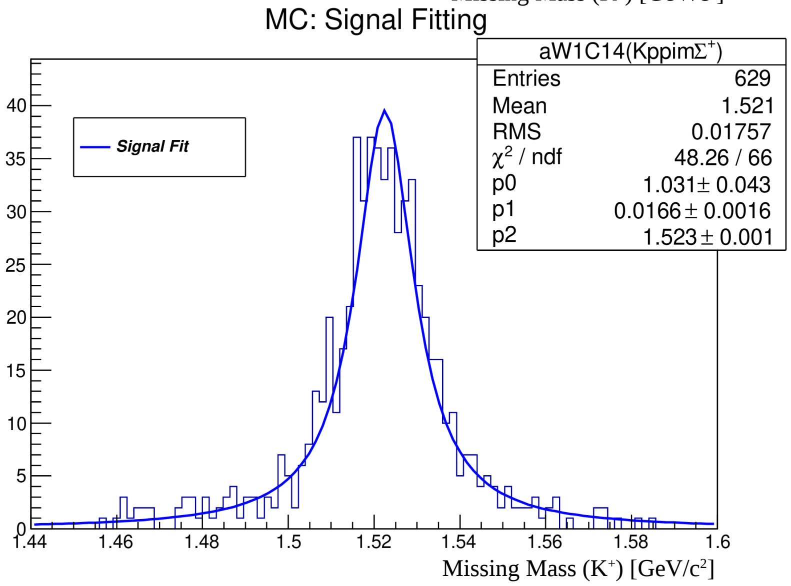


$\Lambda(1520) \rightarrow \Sigma^- + \pi^+$





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



Differential Cross-section: Λ(1520)

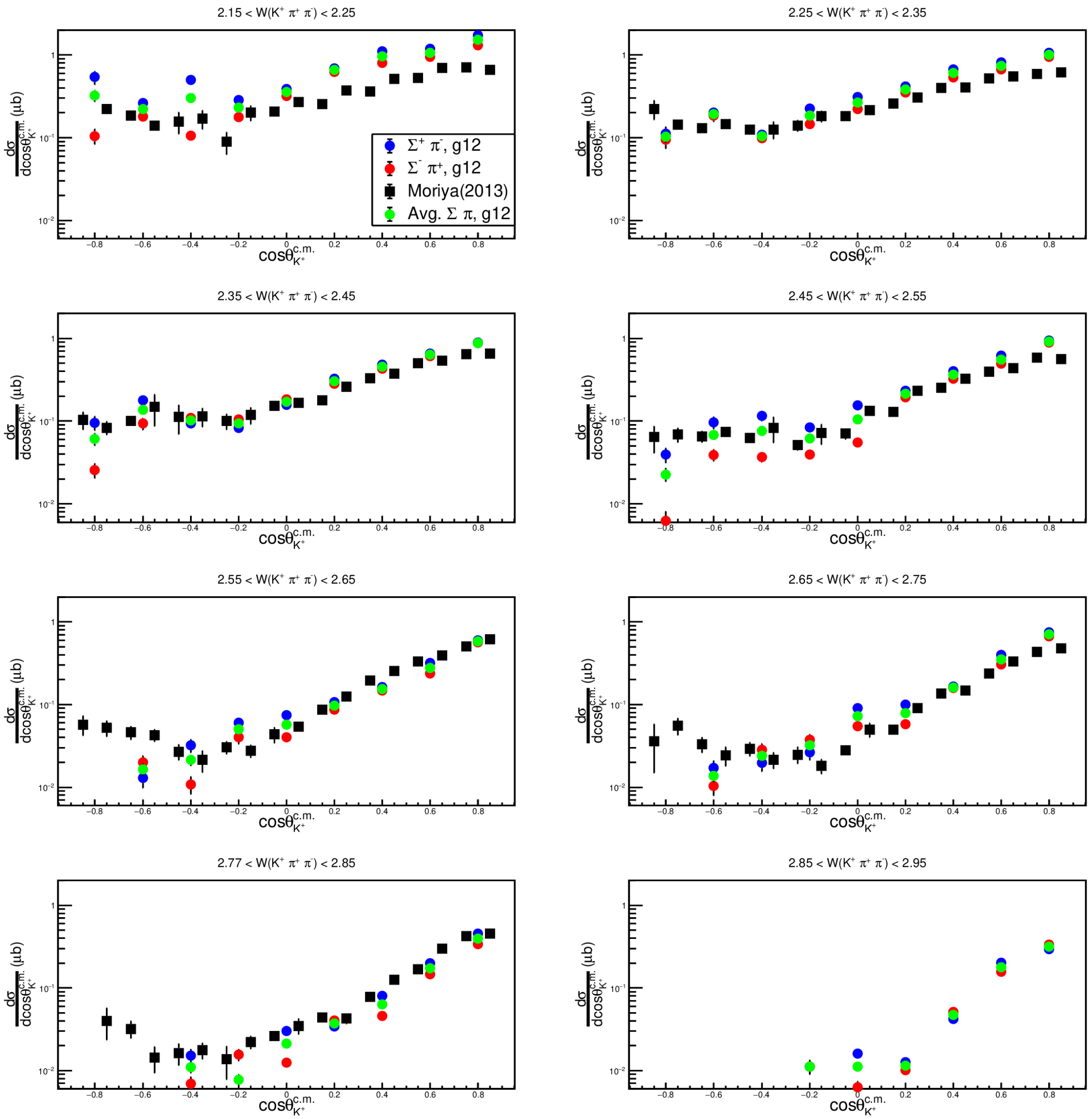
$$\frac{d\sigma}{dCos\theta^{c.m.}_{K^+}} = \frac{Y_d}{\tau\,\Delta\,cos\theta^{c.m.}_{K^+}\,A\,L(W)}$$

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

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

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

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



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.

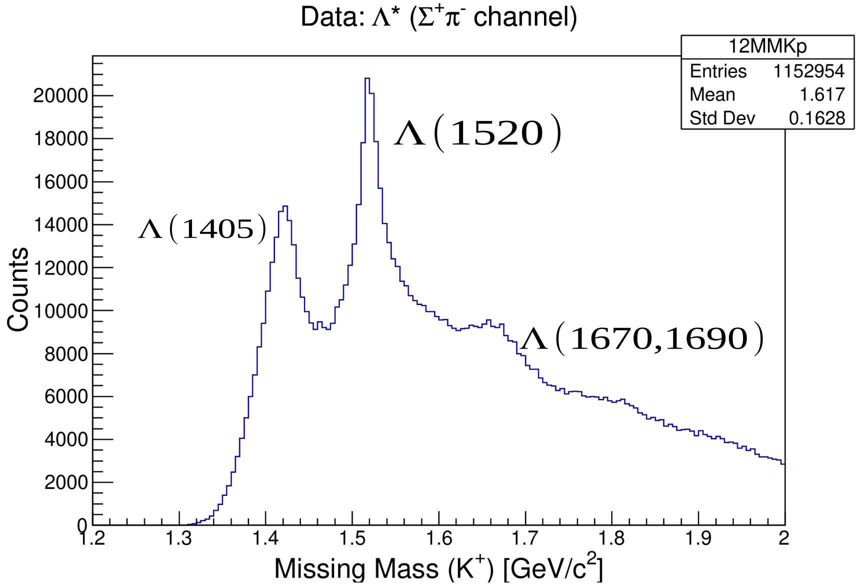
$\Lambda(1670)$ & $\Lambda(1690)$

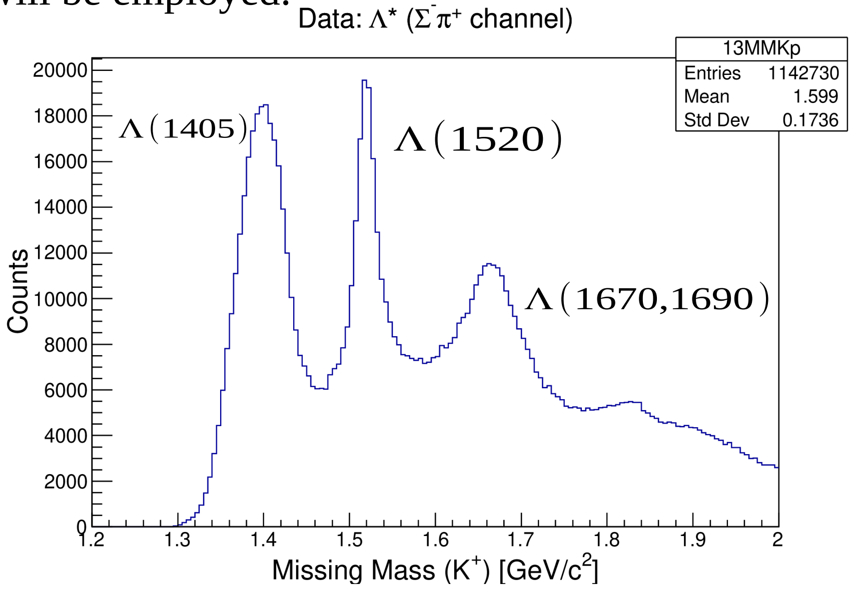
Particle	J^P	PDG rating	Status as seen in $N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other Channels
$\Lambda(1405)$	1/2-	****	****	Forbidden	****	
$\Lambda(1520)$	3/2-	****	****		****	$\Lambda\pi\pi$, $\Lambda\gamma$
$\Lambda(1670)$	1/2-	****	****		****	$\Lambda\eta$
$\Lambda(1690)$	3/2-	****	****		****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

Not well investigated using photoproduction data.

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

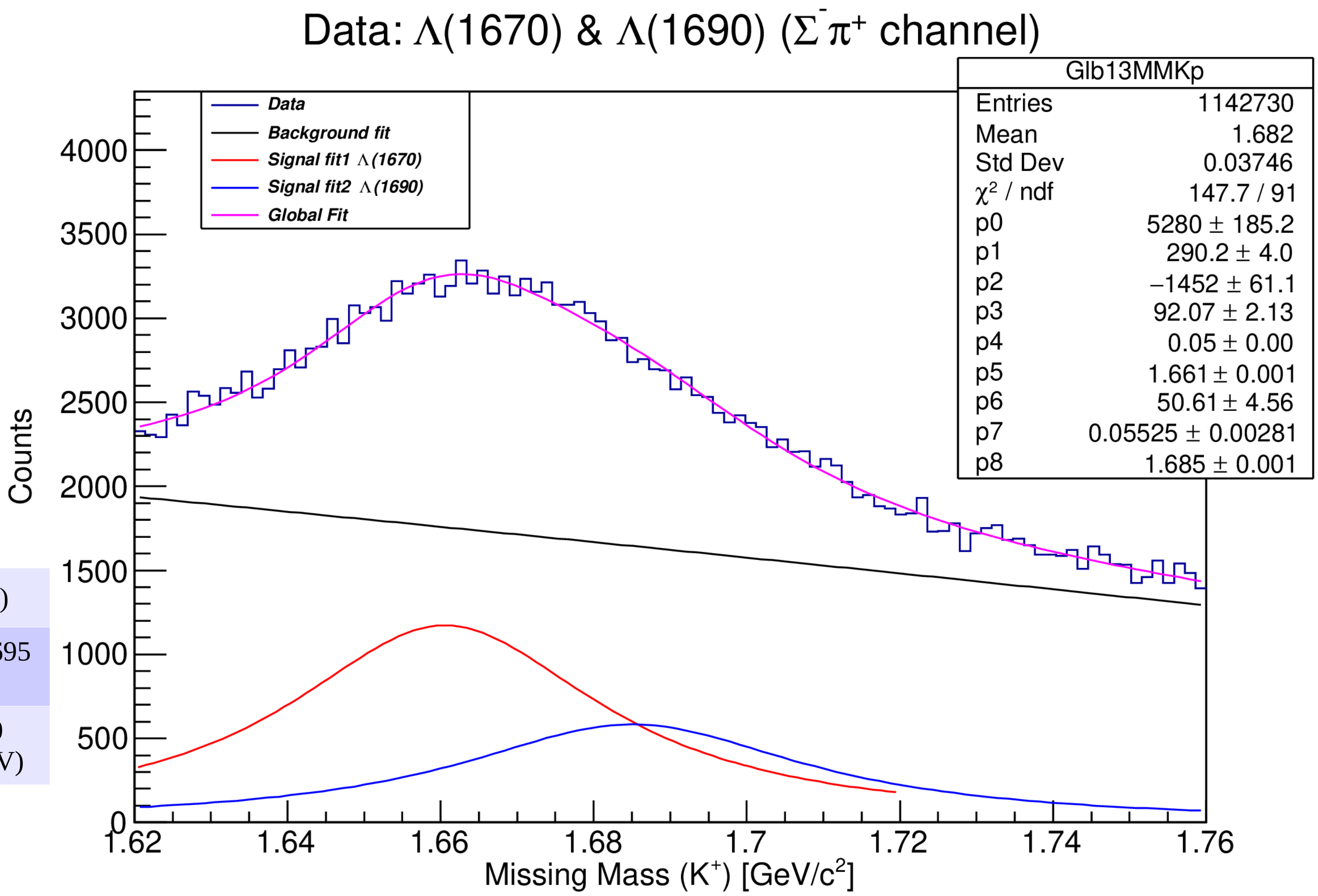
Partial Wave Analysis will be employed.





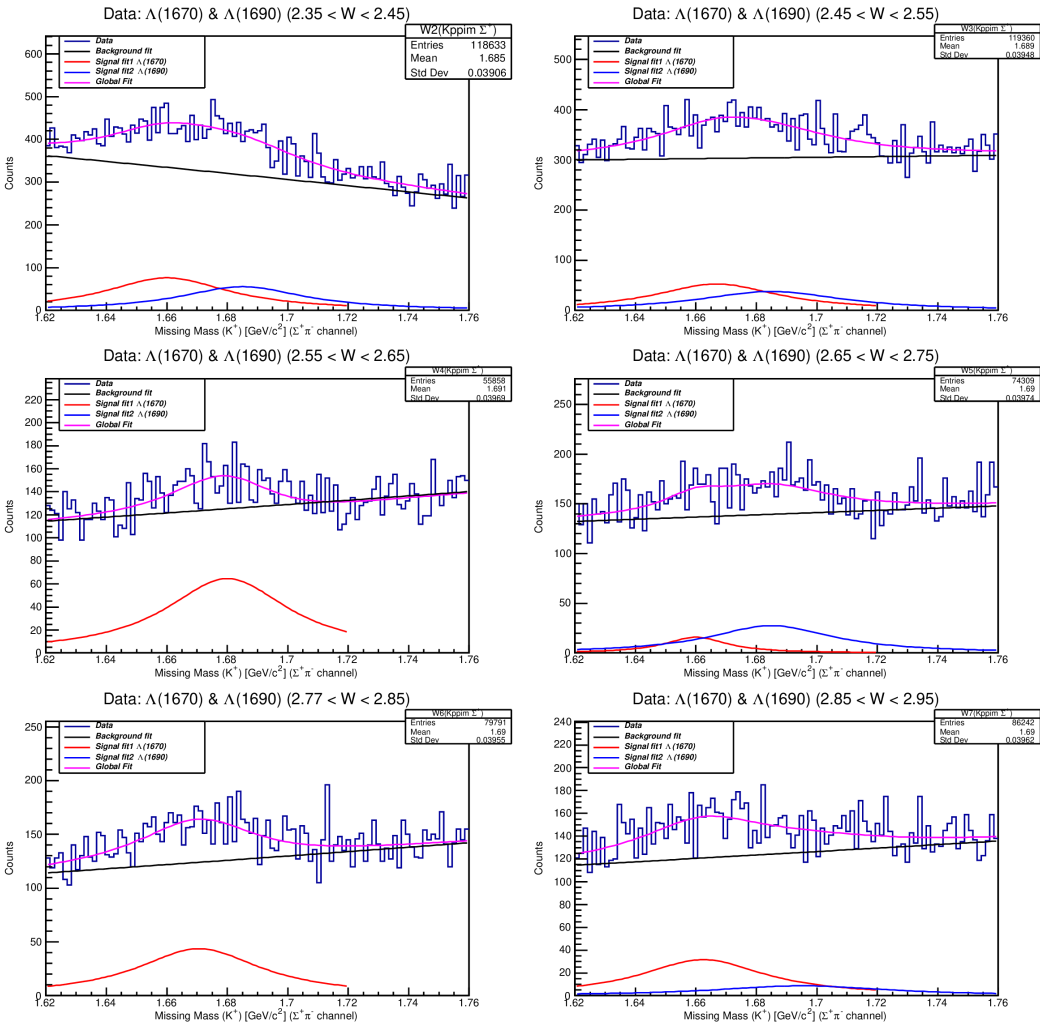
Signal Fitting: Λ(1670) & Λ(1690)

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

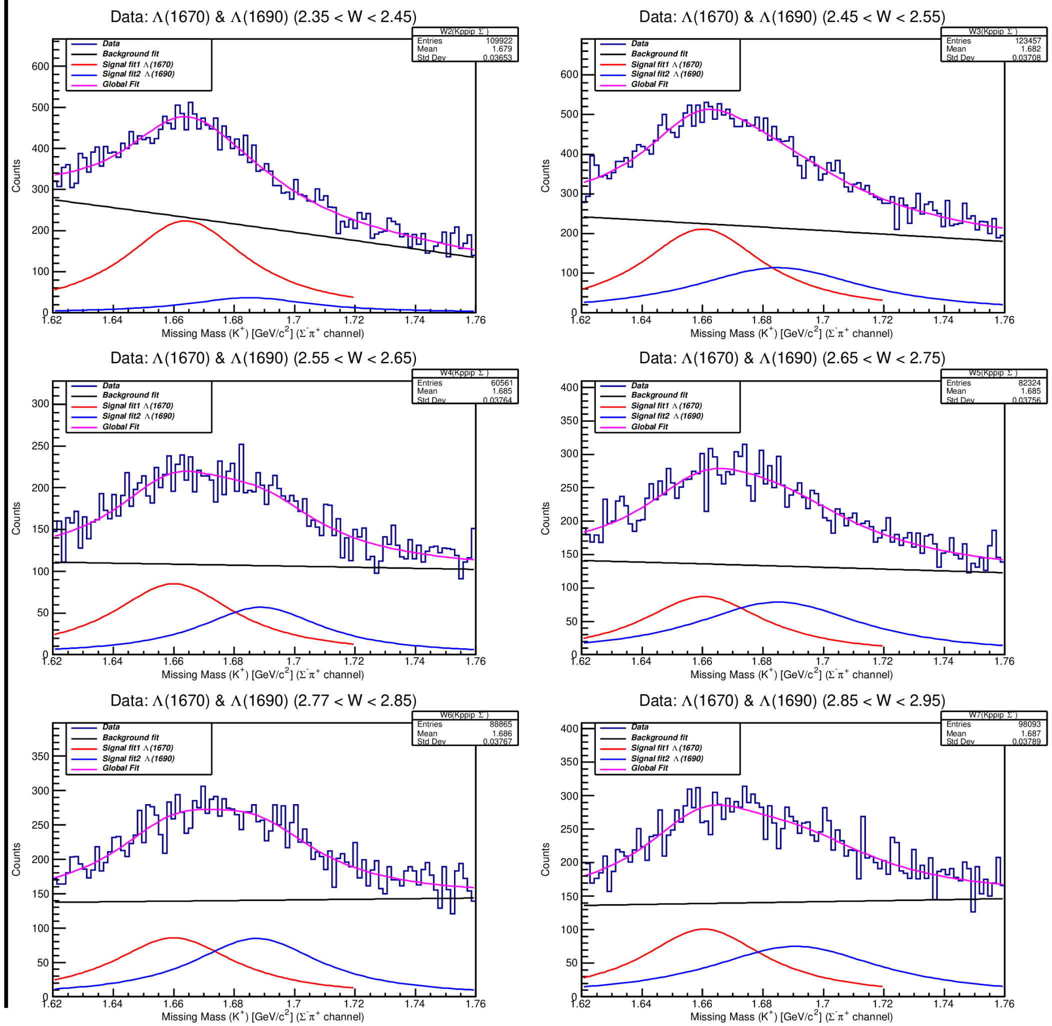


Signal Fitting: Λ(1670) & Λ(1690) (W bins)

$\Sigma^+ \pi^-$



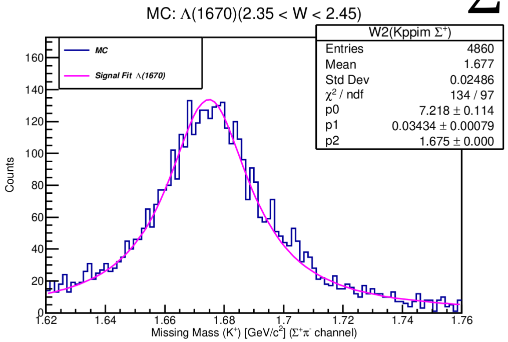
$\Sigma^- \pi^+$

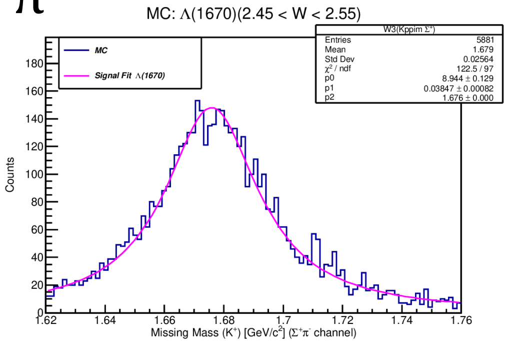


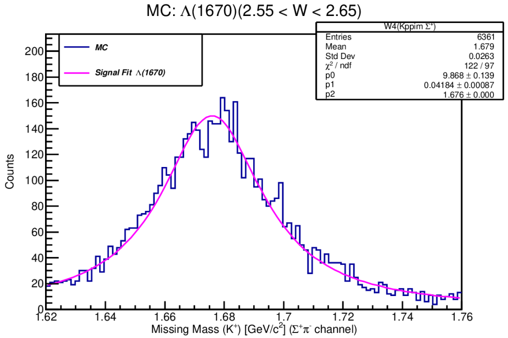
Preliminary!!!

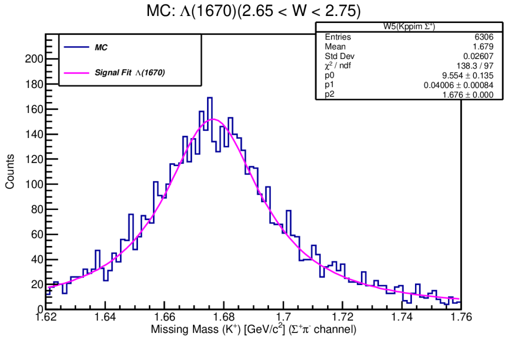
MC Signal Fitting: Λ(1670) (W bins)

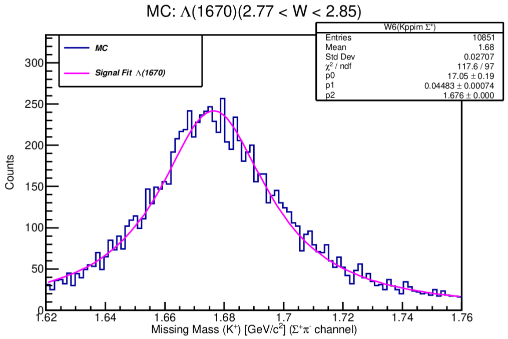
$\Sigma^+ \pi^-$

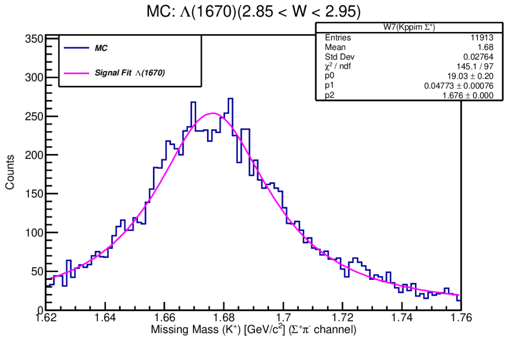




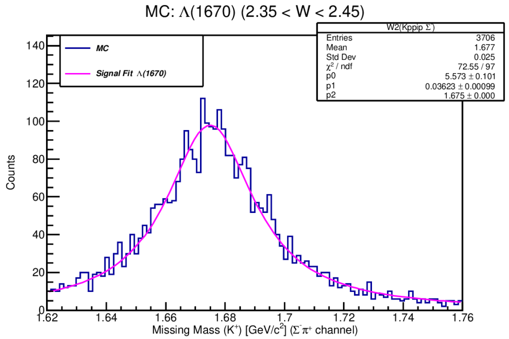


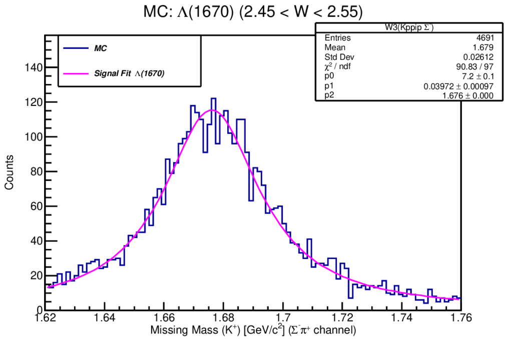


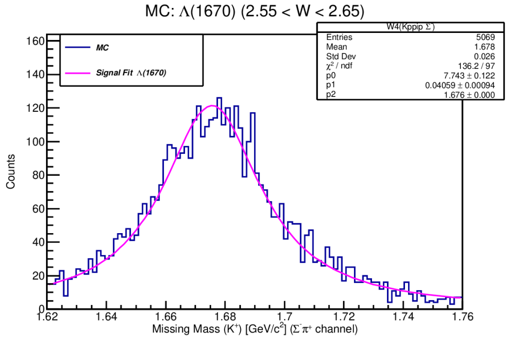


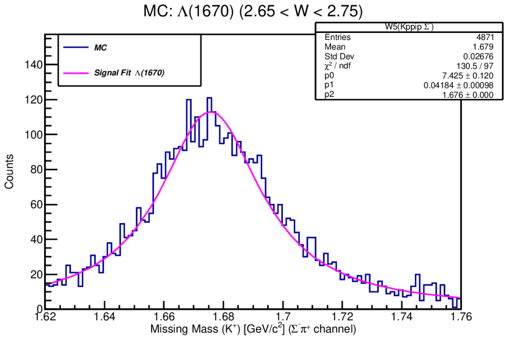


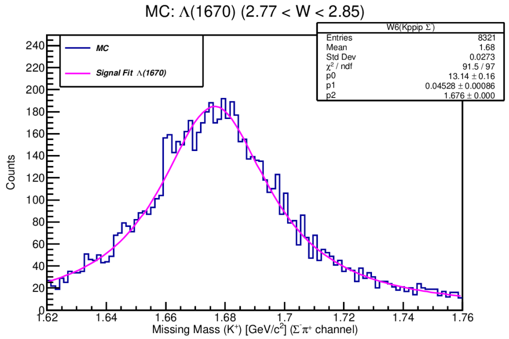
$\Sigma^- \pi^+$

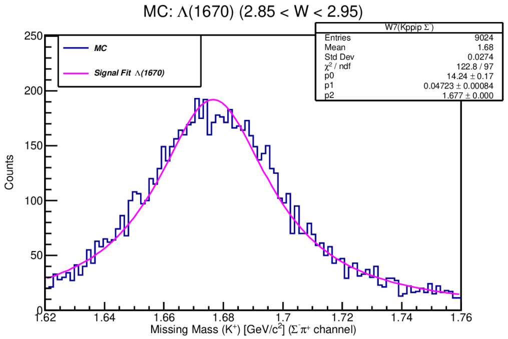






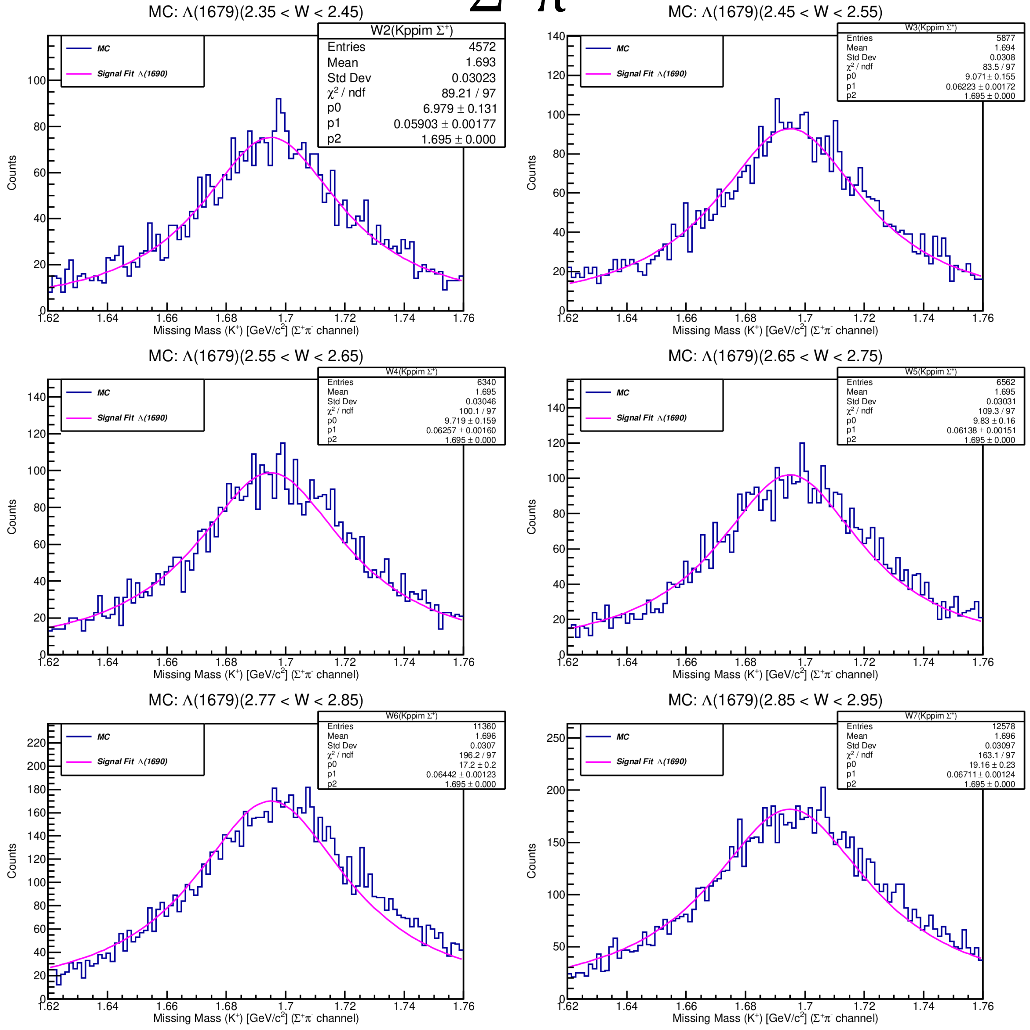




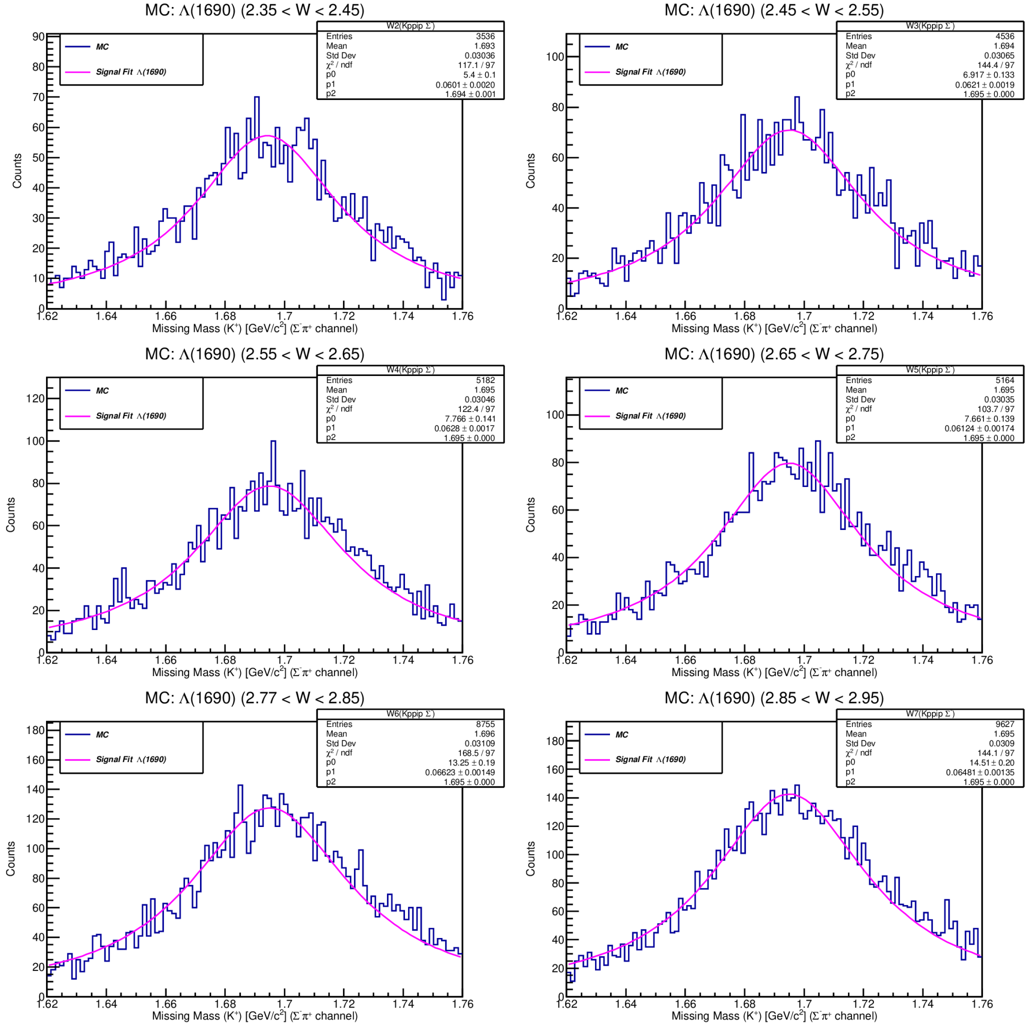


MC Signal Fitting: Λ(1690) (W bins)

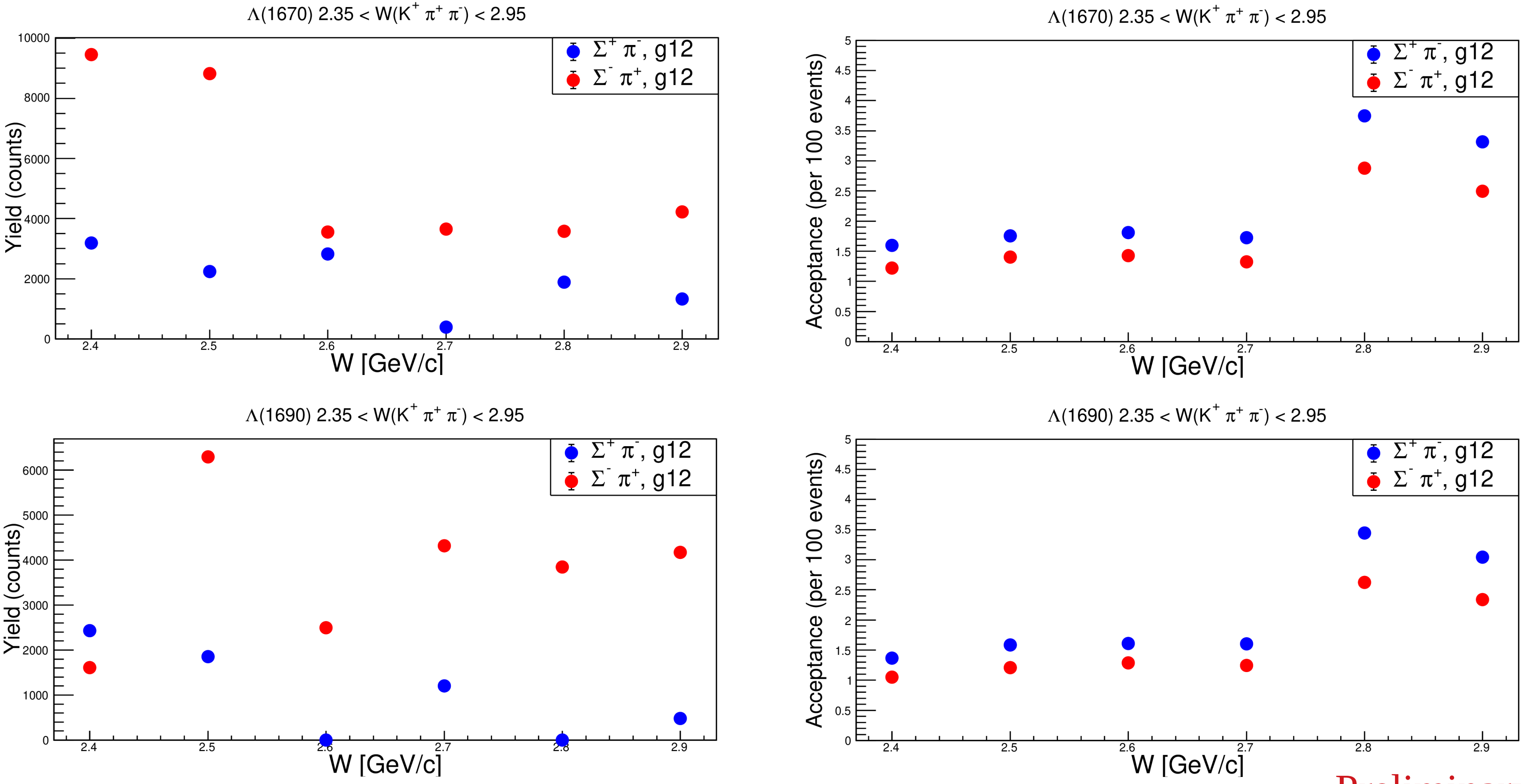
$\Sigma^+ \pi^-$



$\Sigma^- \pi^+$

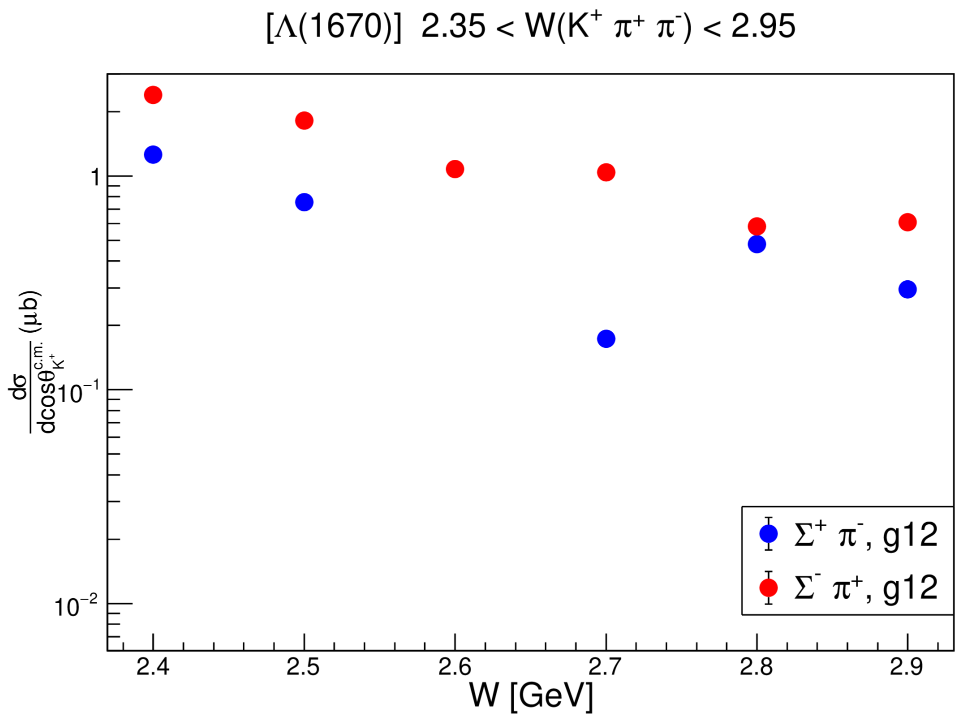


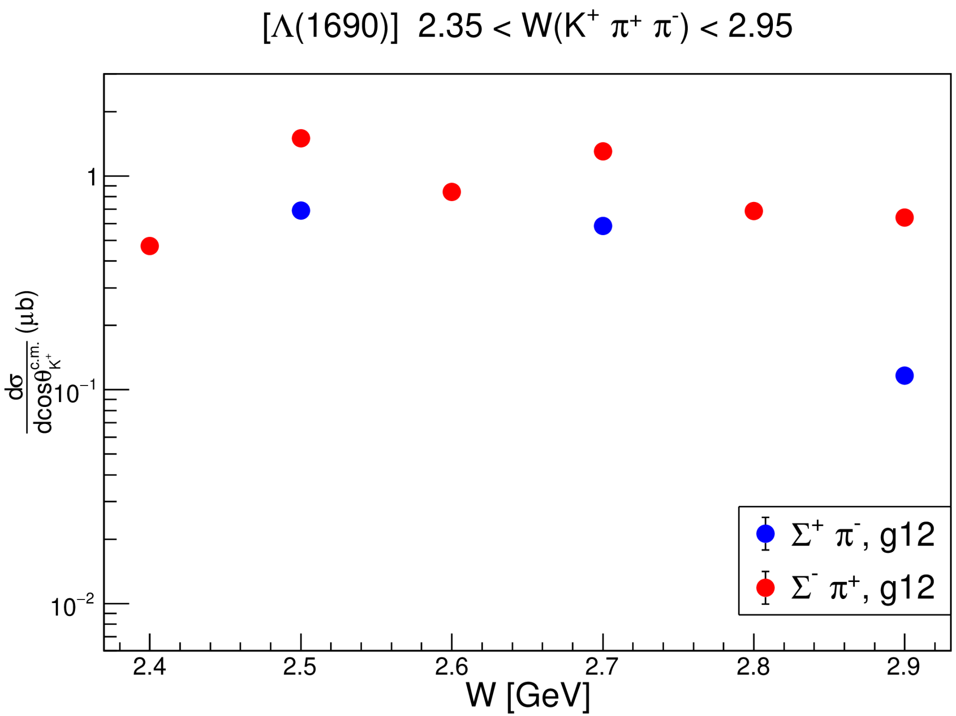
Yield & Acceptance: Λ(1670) & Λ(1690) (W bins)



Preliminary!!!

Differential Cross-section: Λ(1670) & Λ(1690) (W bins)

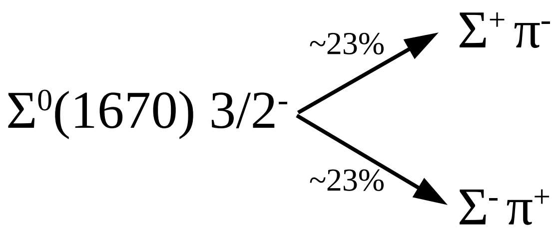




Preliminary!!!

Next

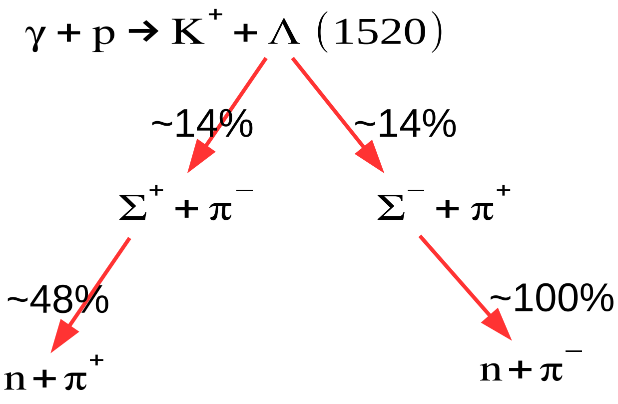
- The Λ(1520) cross section matches with the CLAS g11 data.
- Λ(1520) cross sections for higher W value will be obtained.
- First attempt at Λ(1670) & Λ(1690) peaks are shown.
- We believe that there is an asymmetry to the branching ratio of the two channels due to some interference of other resonances.



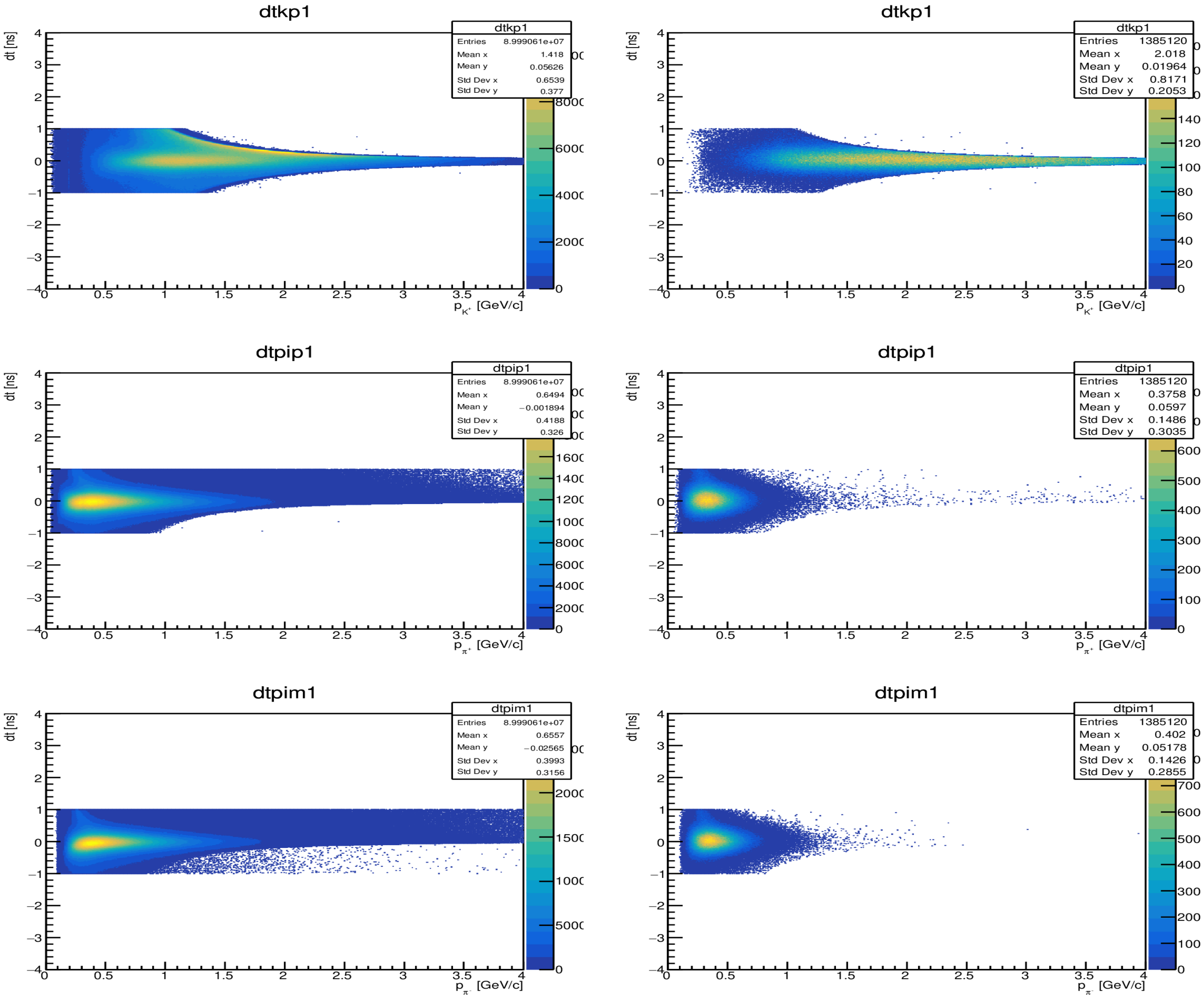
Extras

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 ☐

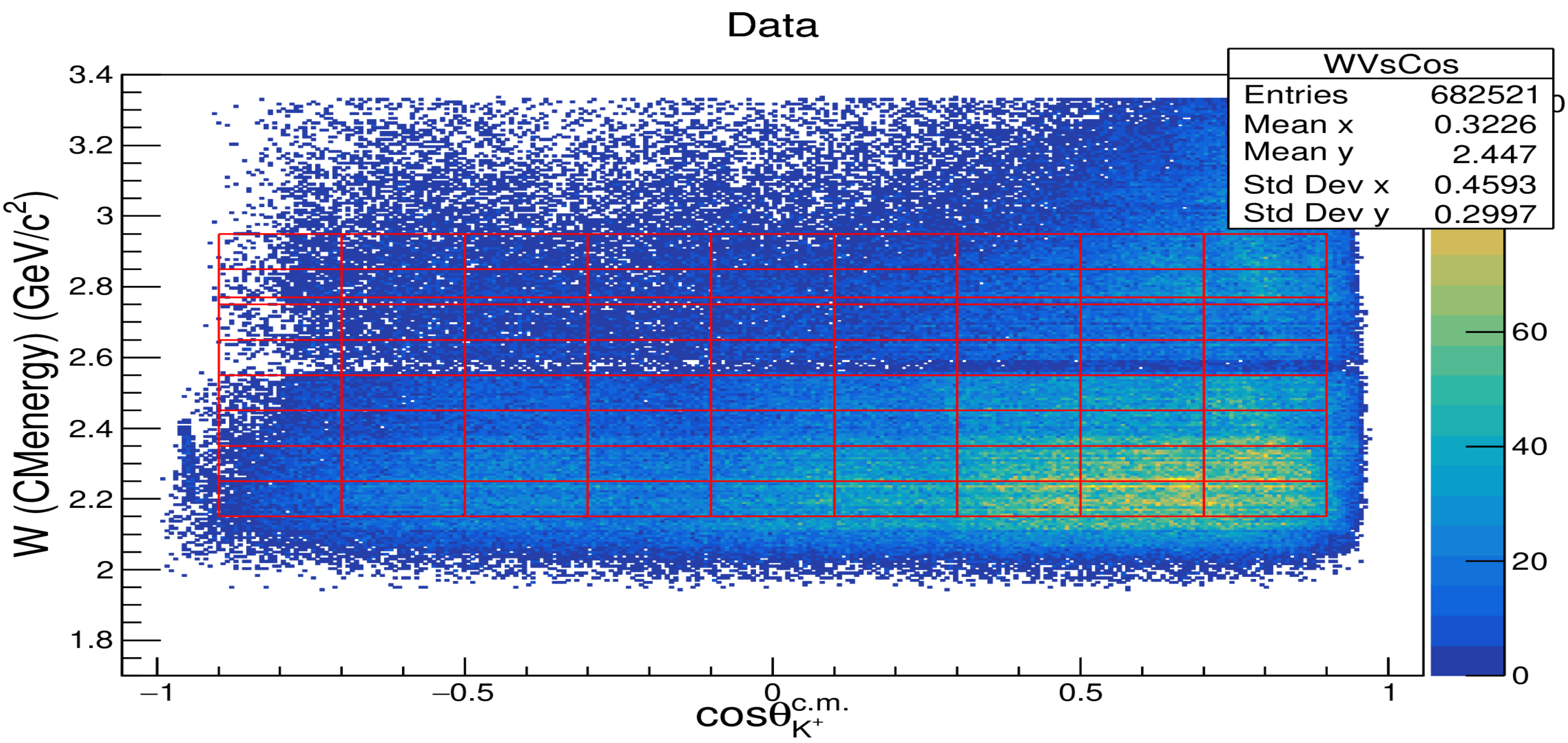
PID



$$\delta t = t_{meas} - t_{calc}$$
$$t_{meas} = t_{SC} - t_{\gamma}$$
$$t_{calc} = \frac{d_{path}}{c}\frac{E_i}{p_i}$$



Bin Scheme



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

Trigger Correction

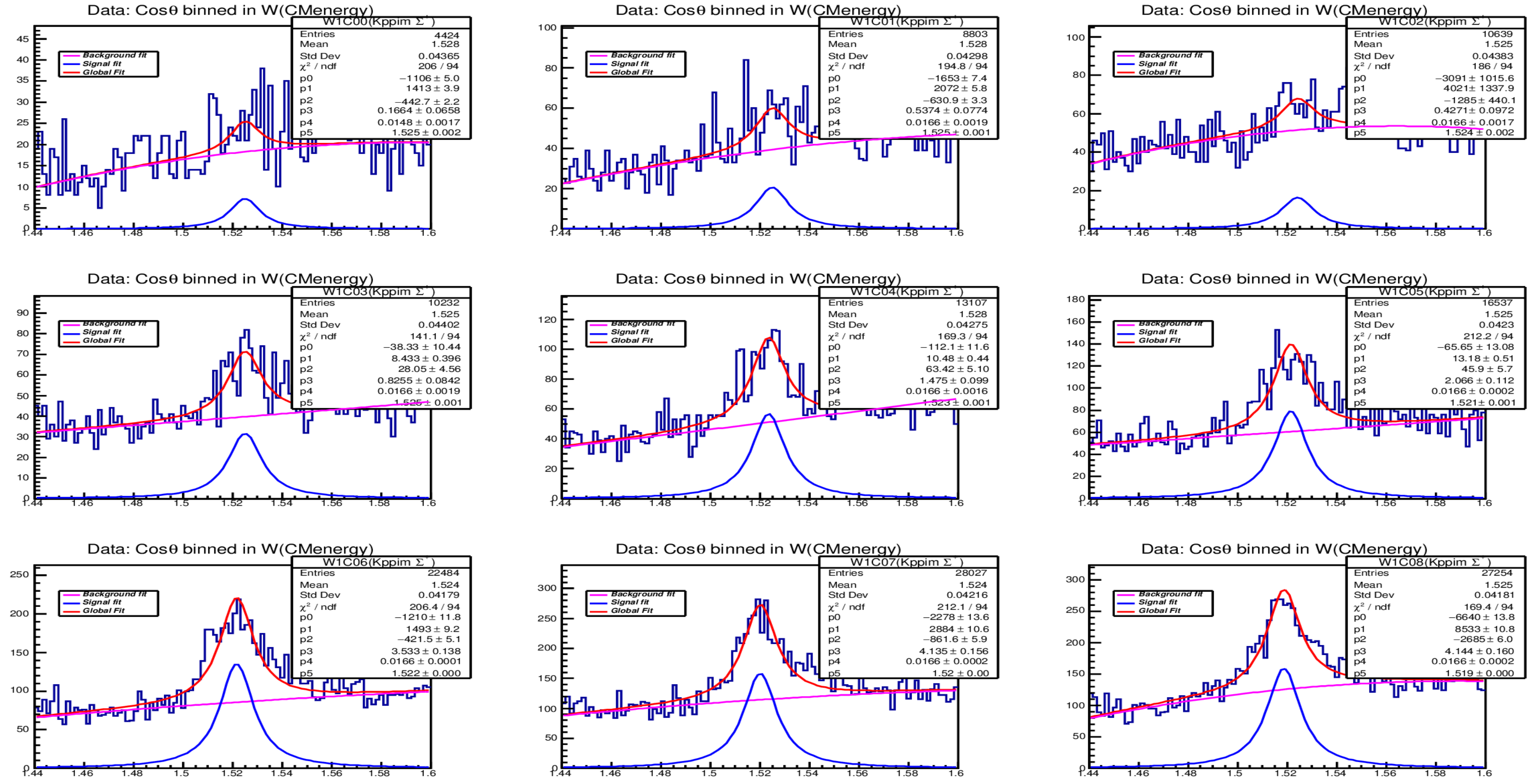
Trigger Efficiency : Data

- 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.

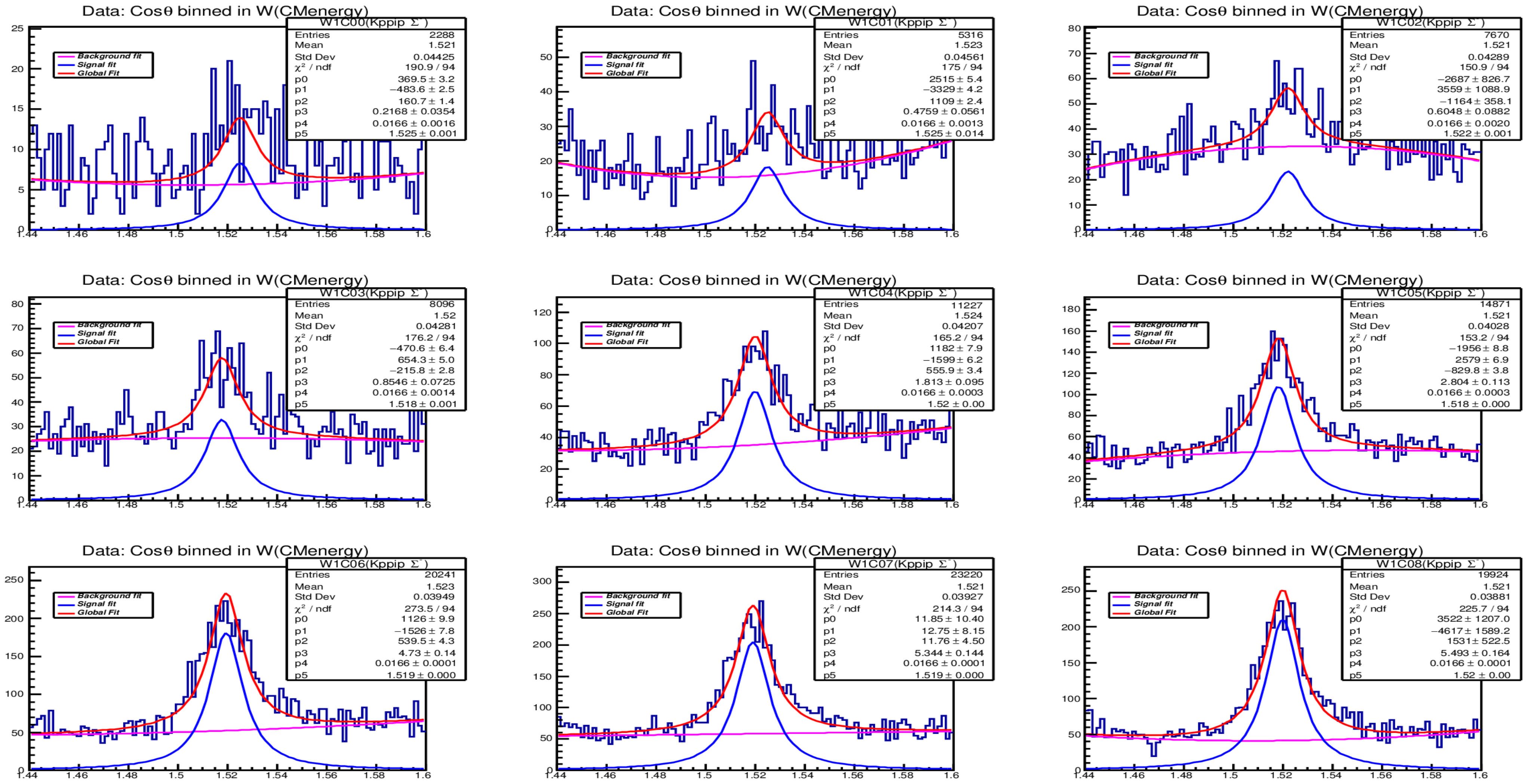
Trigger Simulation : MC

- 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.

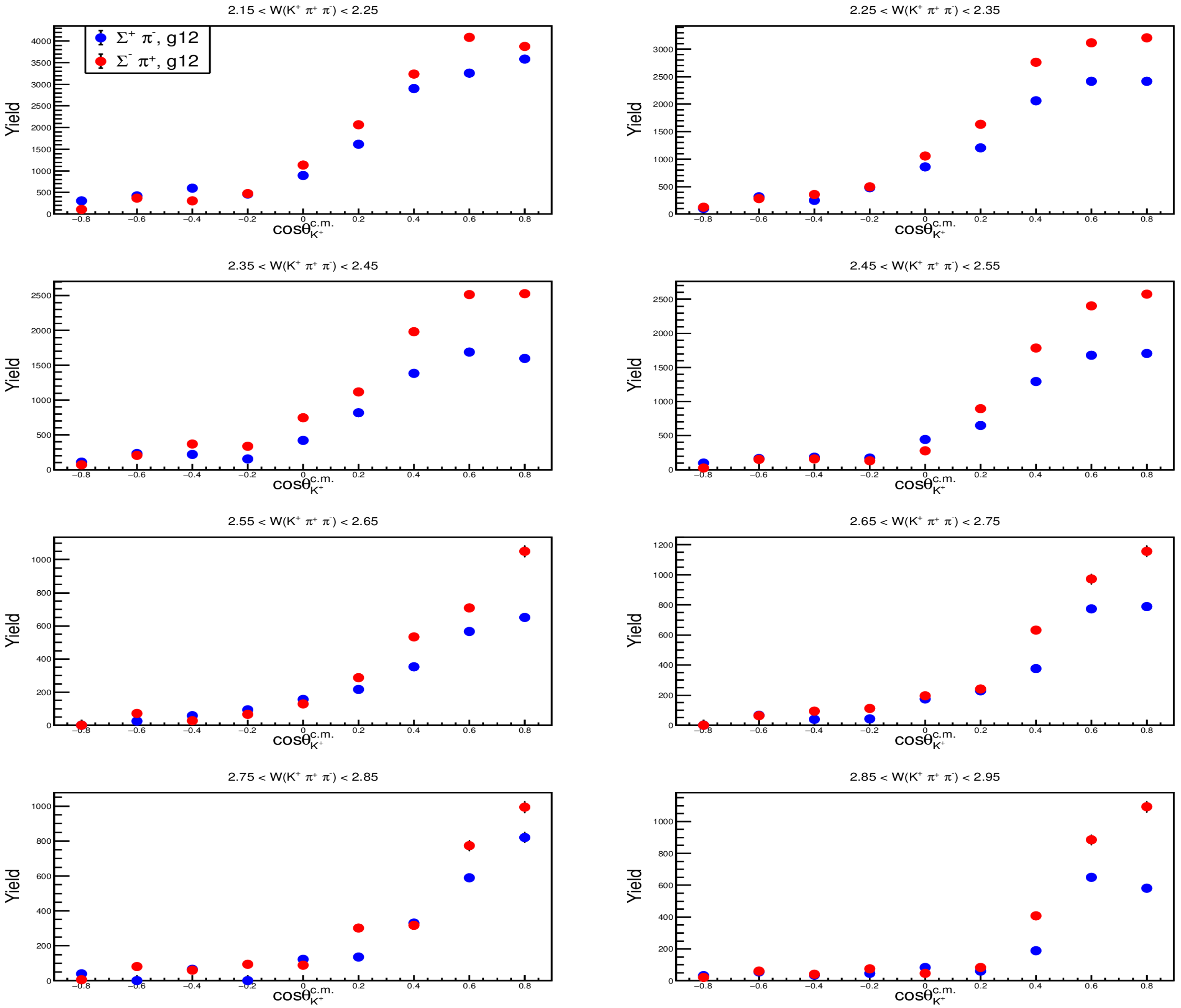
Signal Fitting: Λ(1520) (2.15 < W < 2.25) $\Sigma^+\pi^-$ channel



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



Yield: Λ(1520)

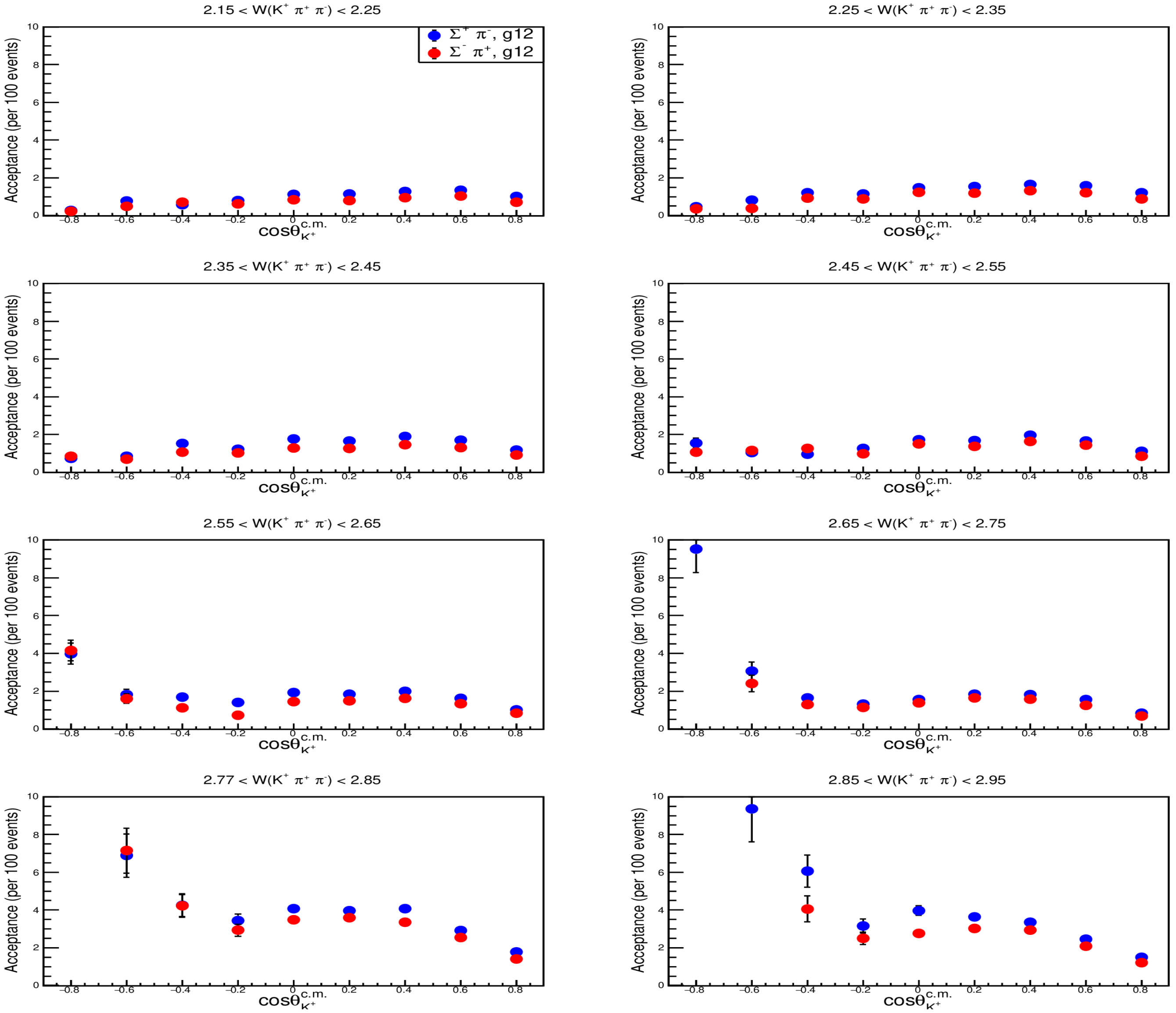


2.15 < W(K⁺ π⁺ π⁻) < 2.25
2.25 < W(K⁺ π⁺ π⁻) < 2.35
2.35 < W(K⁺ π⁺ π⁻) < 2.45
2.45 < W(K⁺ π⁺ π⁻) < 2.55
2.55 < W(K⁺ π⁺ π⁻) < 2.65
2.65 < W(K⁺ π⁺ π⁻) < 2.75
2.75 < W(K⁺ π⁺ π⁻) < 2.85
2.85 < W(K⁺ π⁺ π⁻) < 2.95
Σ⁺ π⁻, g12
Σ⁻ π⁺, g12
Yield
cosθ K⁺ c.m.

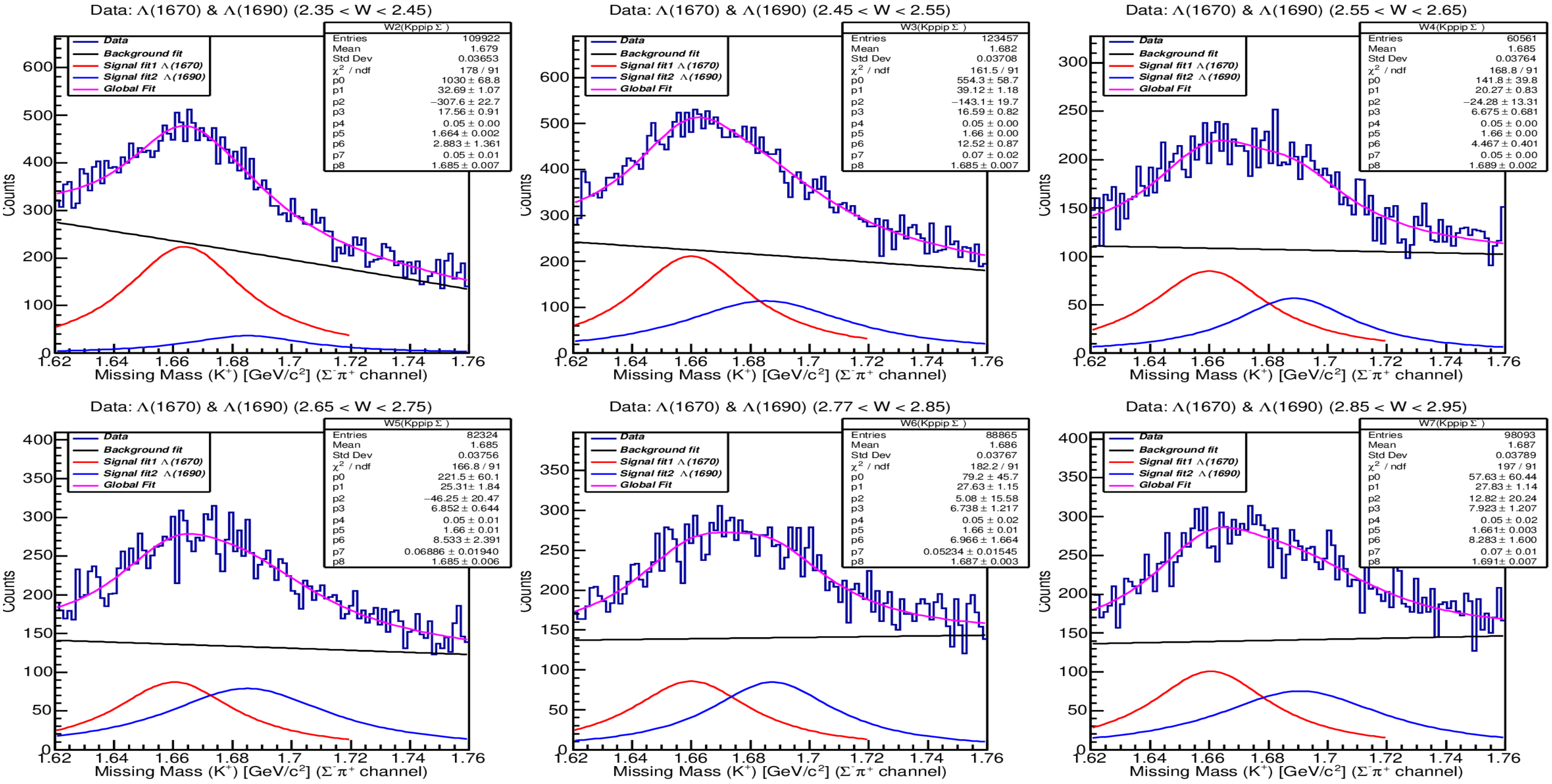
Acceptance: Λ(1520)

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

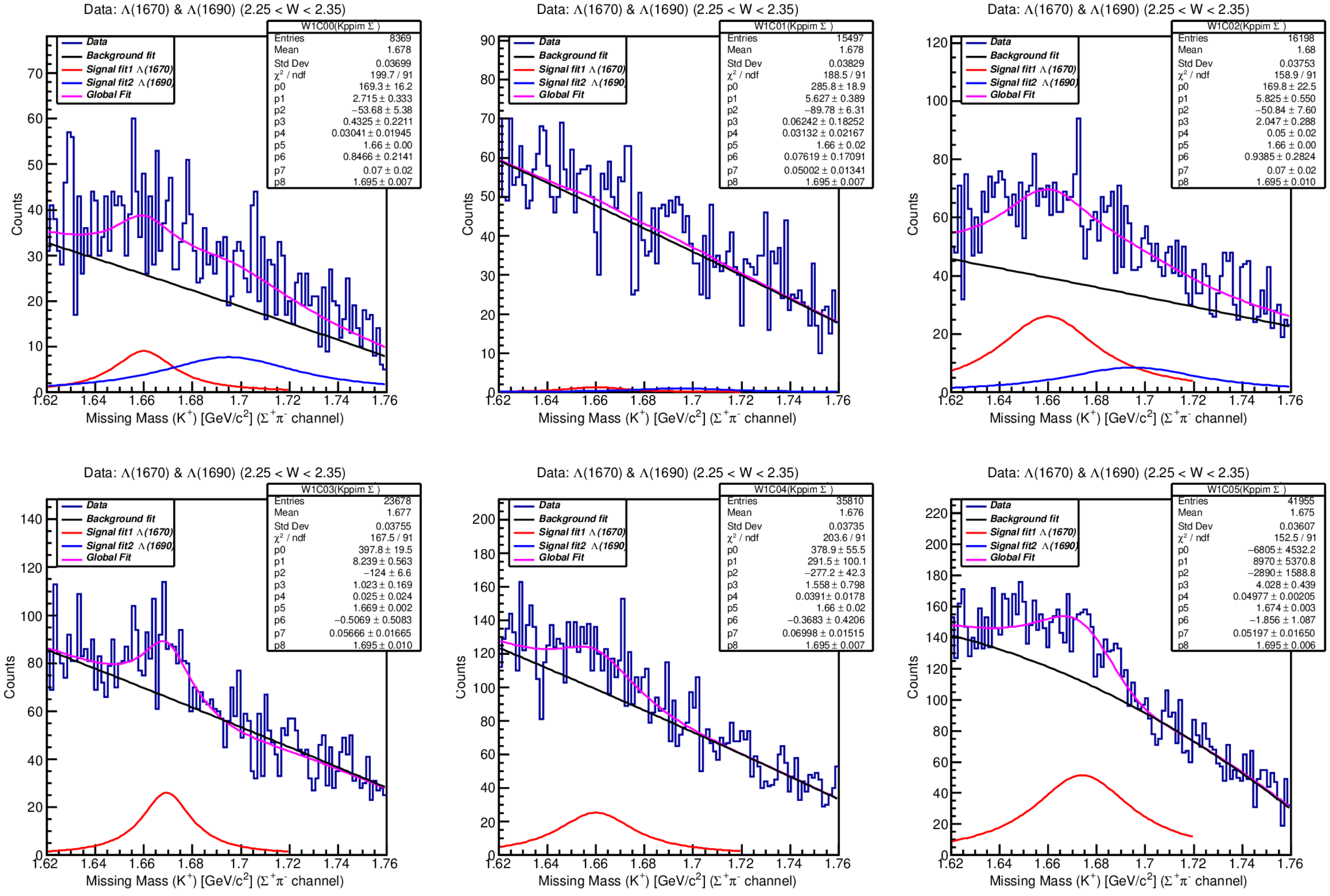
GEANT Based MC Simul



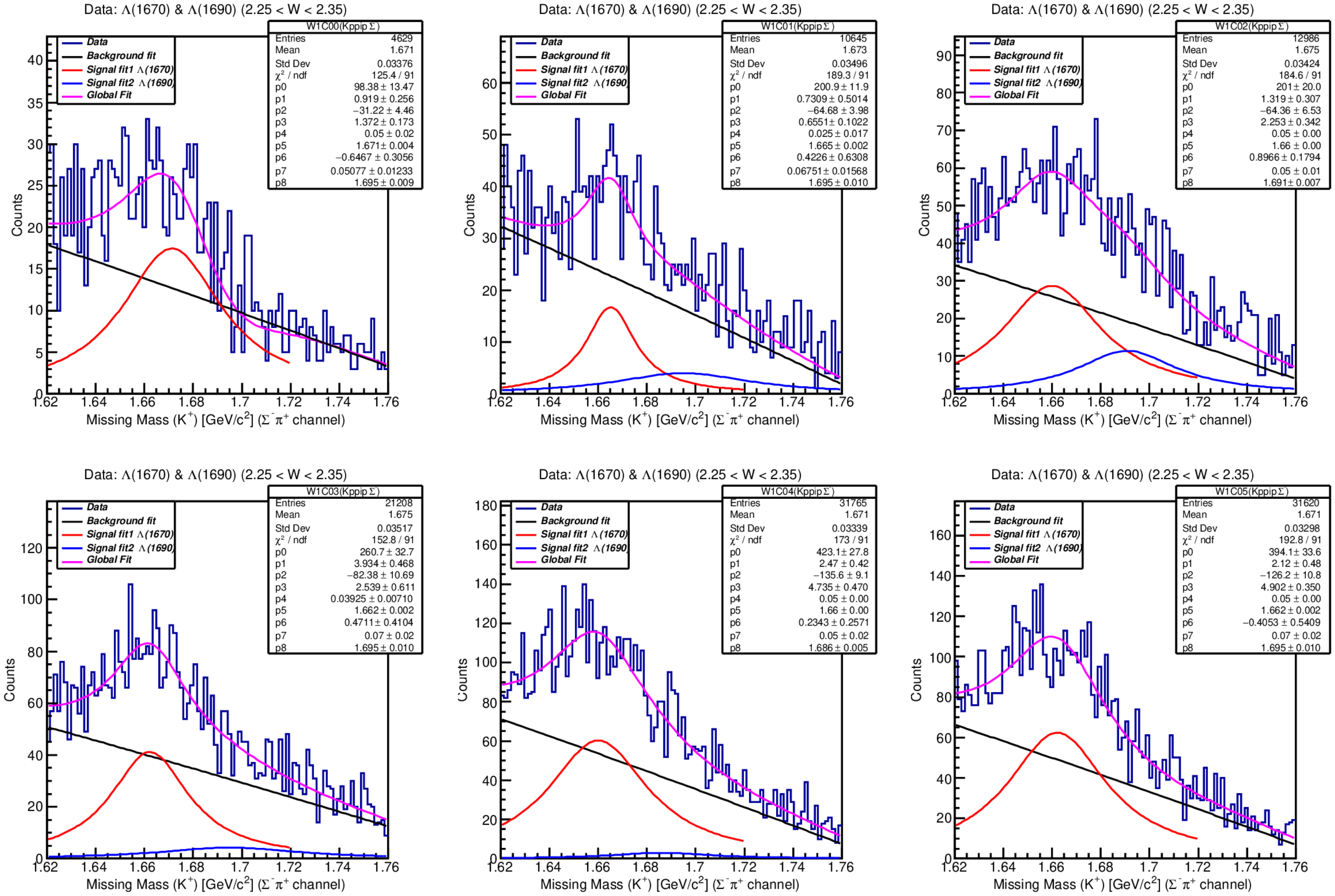
Signal Fitting: Λ(1670) & Λ(1670) $\Sigma^-\pi^+$ channel (W bins)



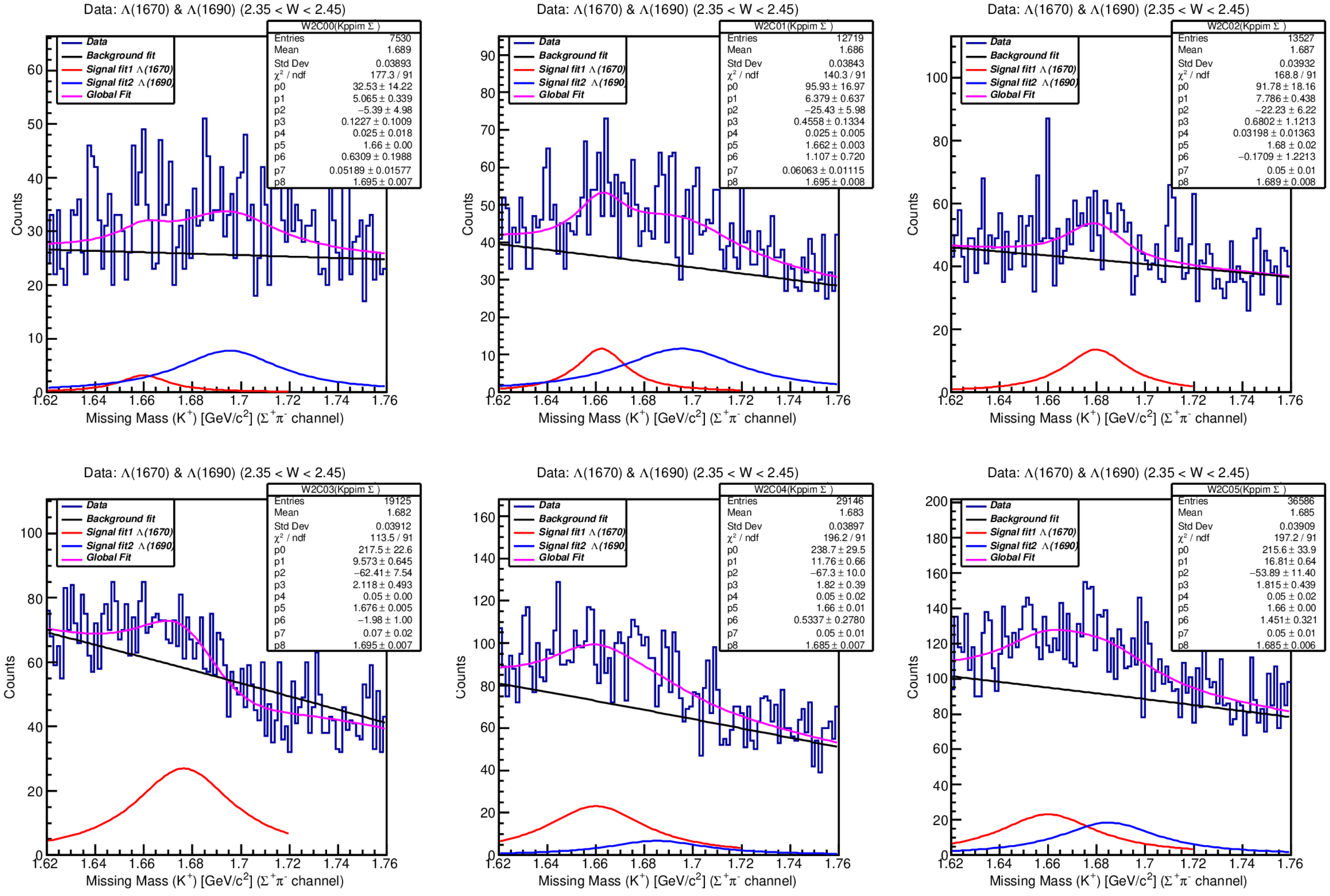
Signal Fitting: Λ(1670) & Λ(1670) $\Sigma^-\pi^+$ channel (W bins)



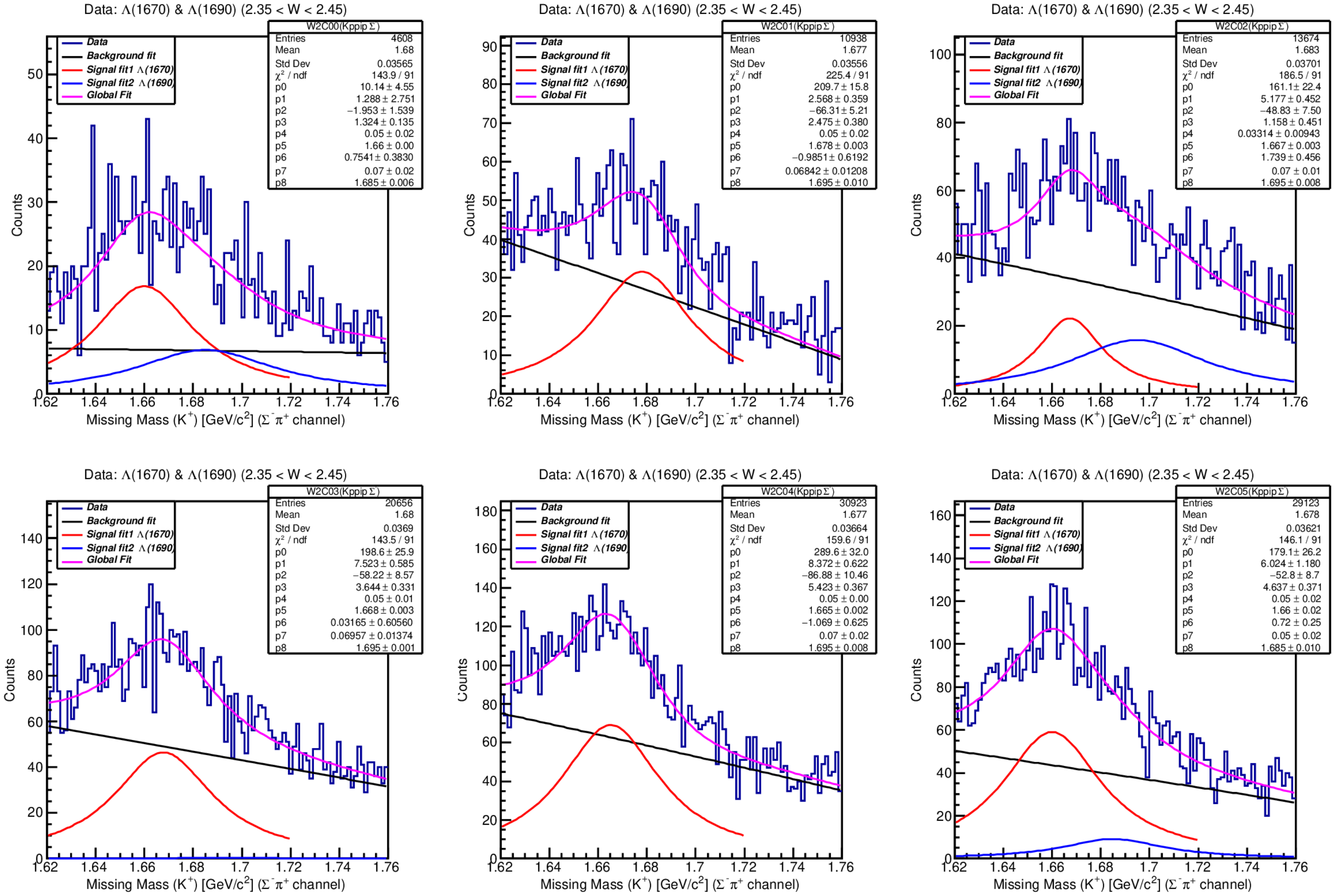
Signal Fitting: Λ(1670) & Λ(1670) $\Sigma^{-}\pi^{+}$ channel (W bins)



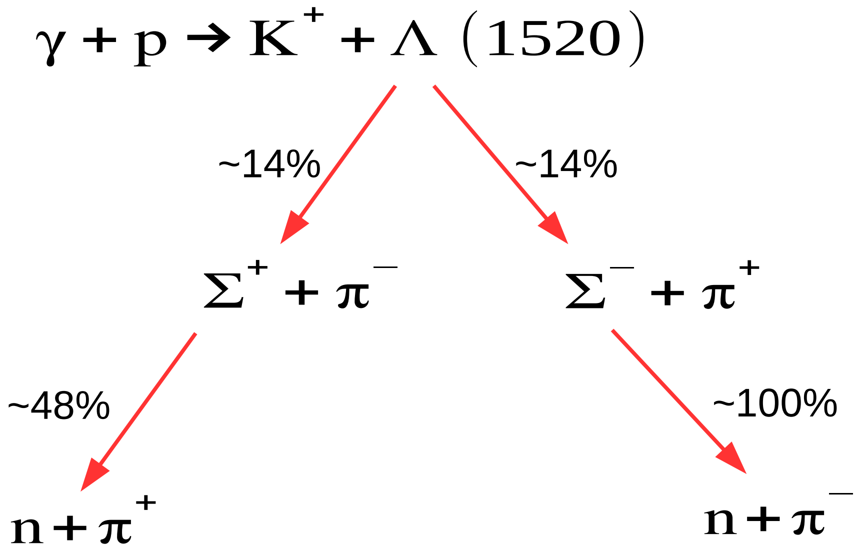
Signal Fitting: Λ(1670) & Λ(1670) $\Sigma^-\pi^+$ channel (W bins)



Signal Fitting: Λ(1670) & Λ(1670) $\Sigma^-\pi^+$ channel (W bins)



Differential Cross-section



Differential Cross-section

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

$\tau = Branching\ ratio$

$Y_d = Signal\ Yield$

$A = Acceptance$

$\Delta\cos\theta_{K^+}^{c.m.} = Width\ of\ \cos\theta\ bin$

$L(W) = Luminosity$