Photoproduction of Λ^* Resonances at CLAS

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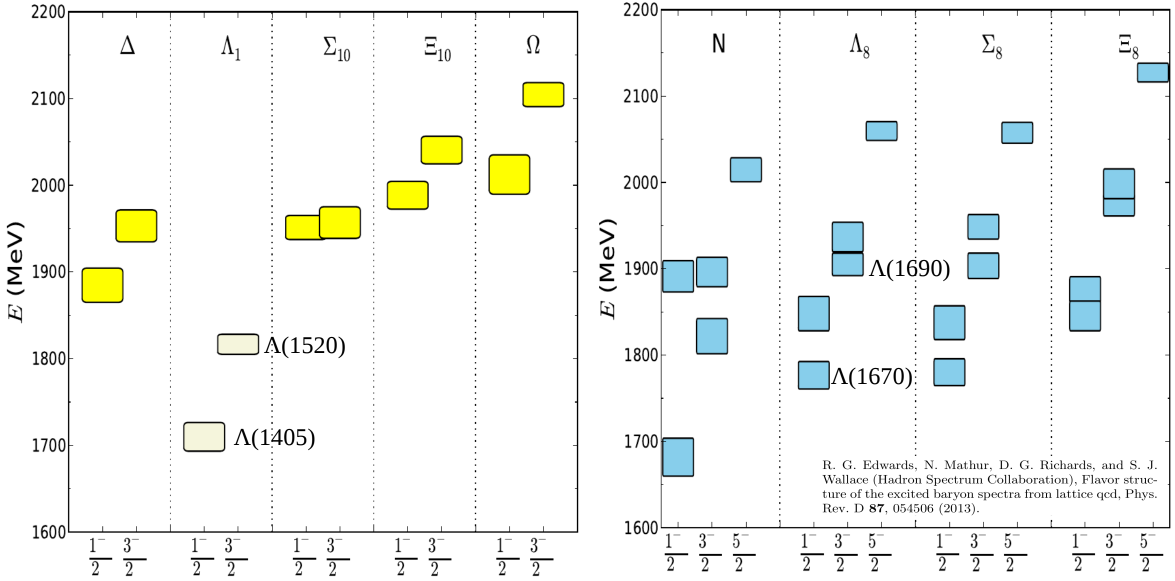
Introduction

The Quark Model

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

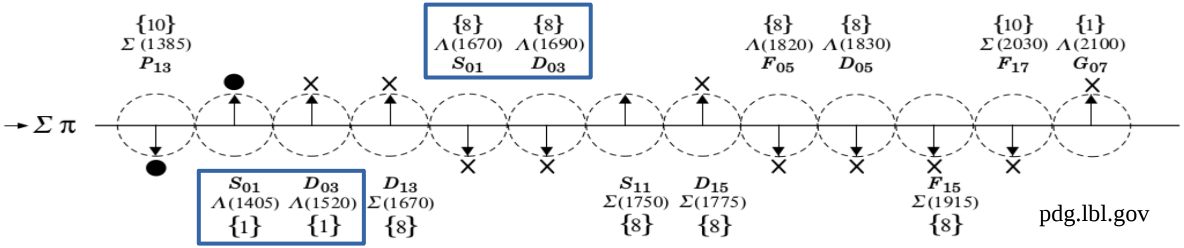
Lattice QCD Calculations



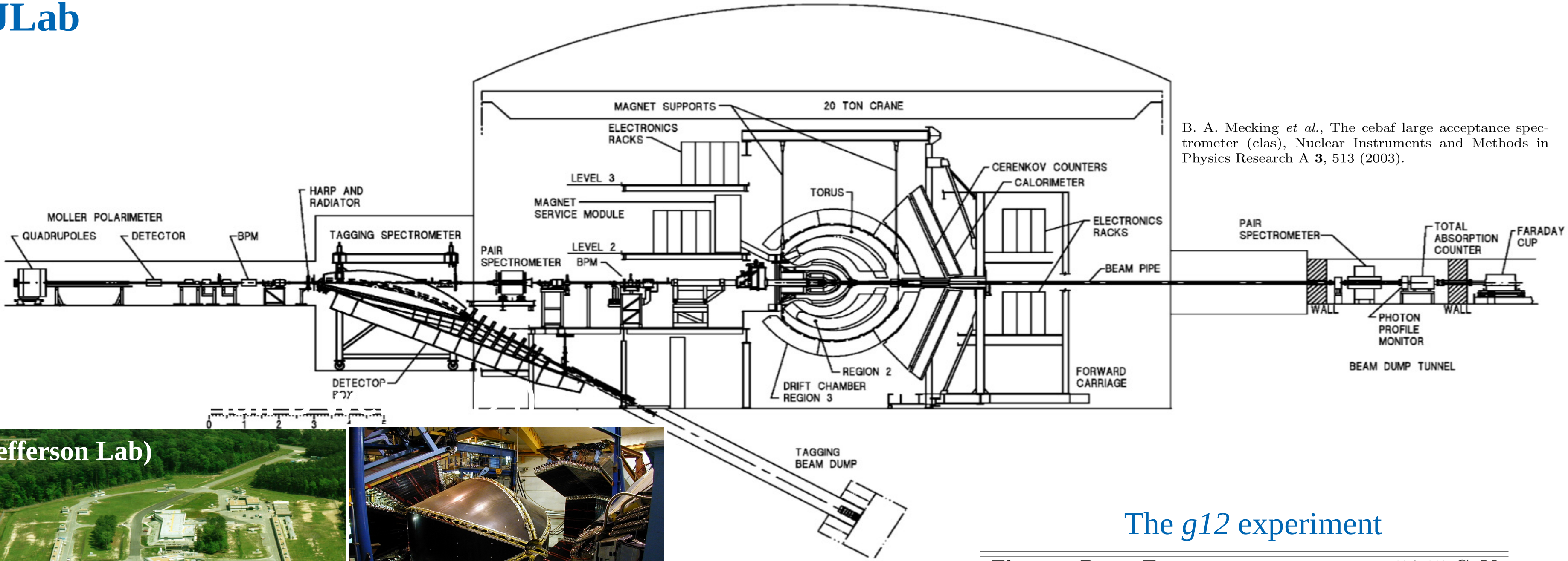
The Particle Data Group Summary

Particle	J^P	PDG rating	$N\overline{K}$	Status as seen in $\Lambda\pi$	$\Sigma\pi$	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	****	$\Lambda\pi\pi$, $\Sigma\pi\pi$

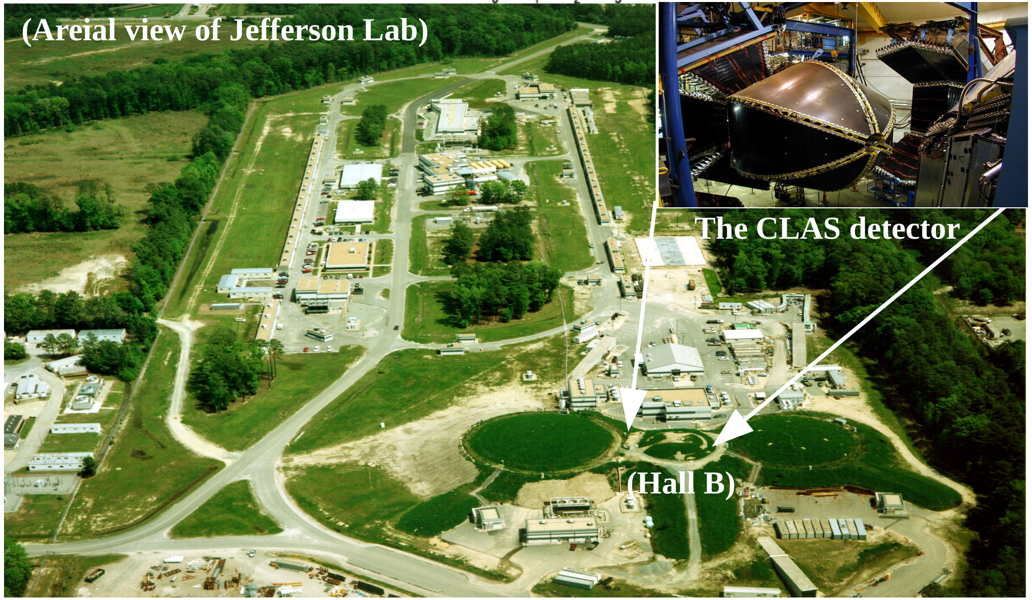
Phase at Resonances in $\Sigma\pi$ Channel



CLAS @ JLab



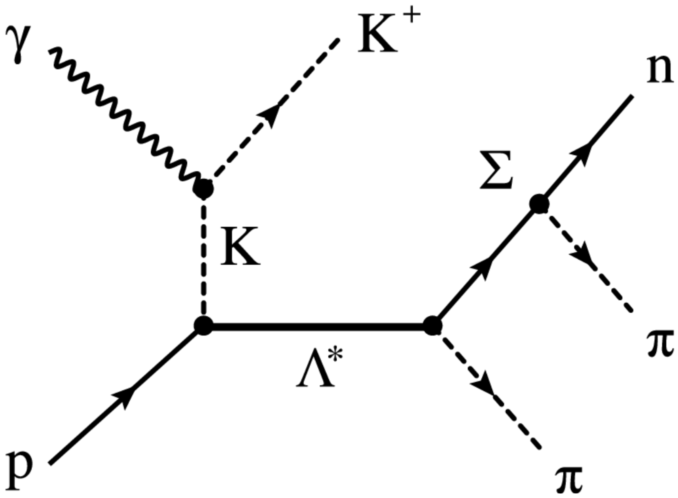
B. A. Mecking *et al.*, The cebaf large acceptance spectrometer (clas), Nuclear Instruments and Methods in Physics Research A **3**, 513 (2003).

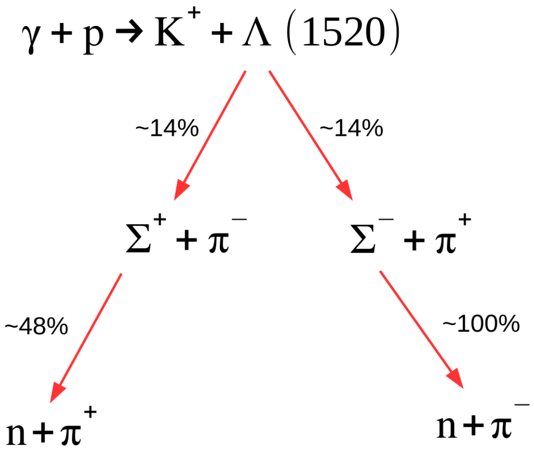


The *g12* experiment

Electron Beam Energy	5.715 GeV
Beam Polarization	Circular
e^- Current	60–65 nA
Tagger Range	20% - 95% of e^- energy
Tagger Trigger Range	3.6 - 5.441 GeV
Torus Magnet	$\frac{1}{2}B_{max}(1930A)$
Target Length	40 cm
Target Center (z location)	-90 cm
Target Material	LH_2
Target Polarization	None
Start Counter Offset	0 cm
Radiator Thickness	10^{-4} radiation lengths
Collimator Radius	6.4 mm

The Reaction

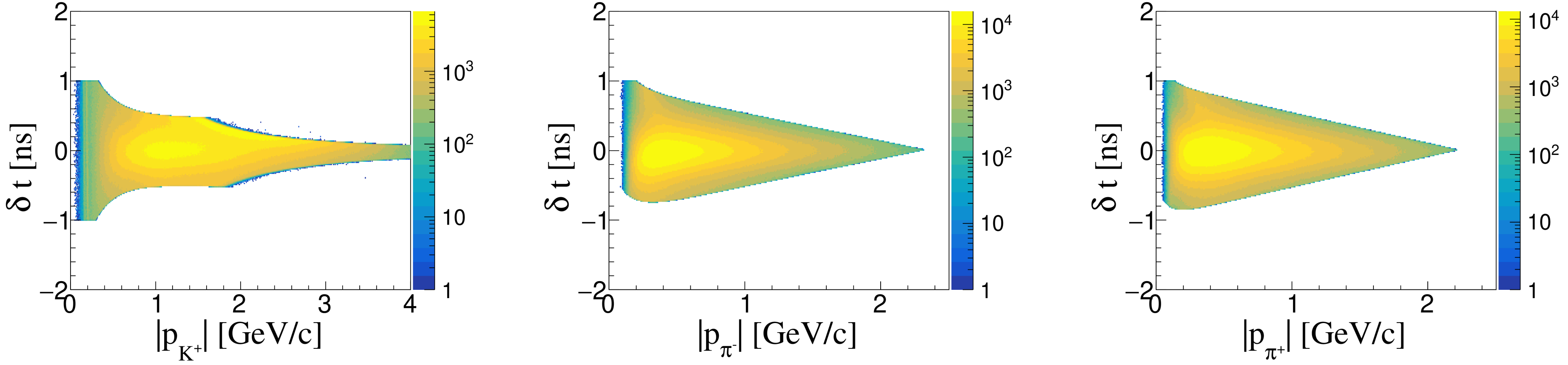




$$\gamma p \rightarrow K^+\Lambda(1520) \rightarrow K^+\Sigma^{\pm}\pi^{\mp}$$

$$\Lambda(1520) \rightarrow \Sigma^{\pm}\pi^{\mp} \rightarrow n\pi^{\pm}\pi^{\mp}$$

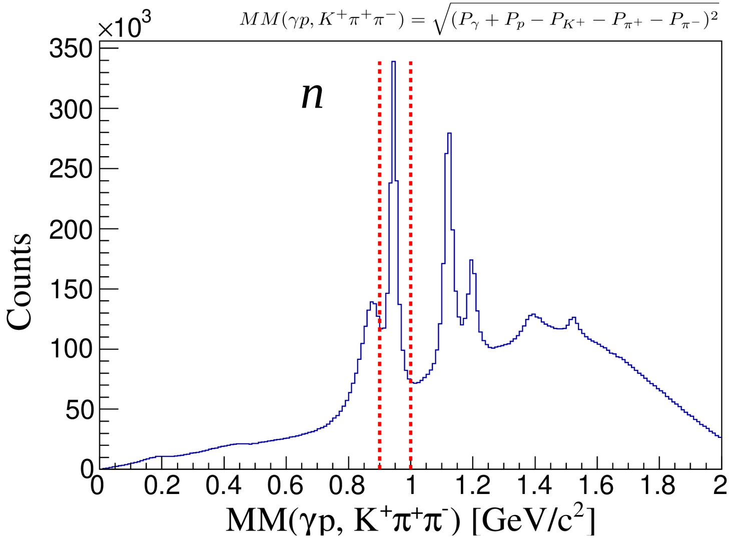
Data Analysis

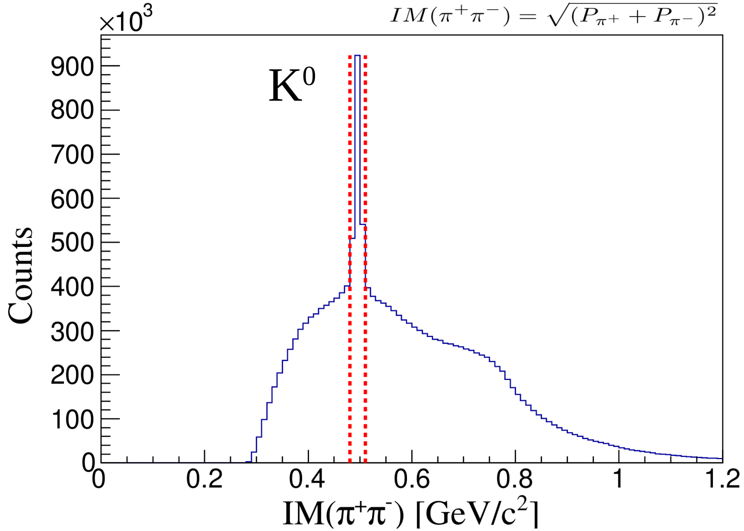


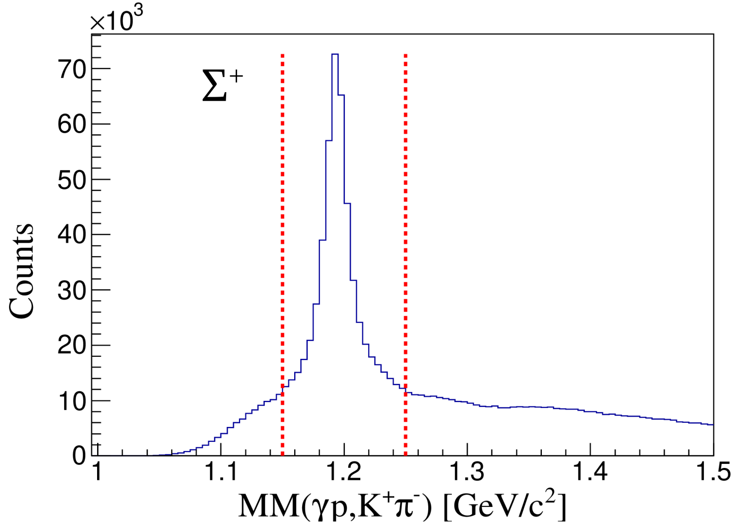
Skim
Photon Selection
$K^+\pi^+\pi^-$ PID Cut
Minimum $|p|$ cut
z-vertex cut
Nominal Fiducial Cut
SC Paddle Cut

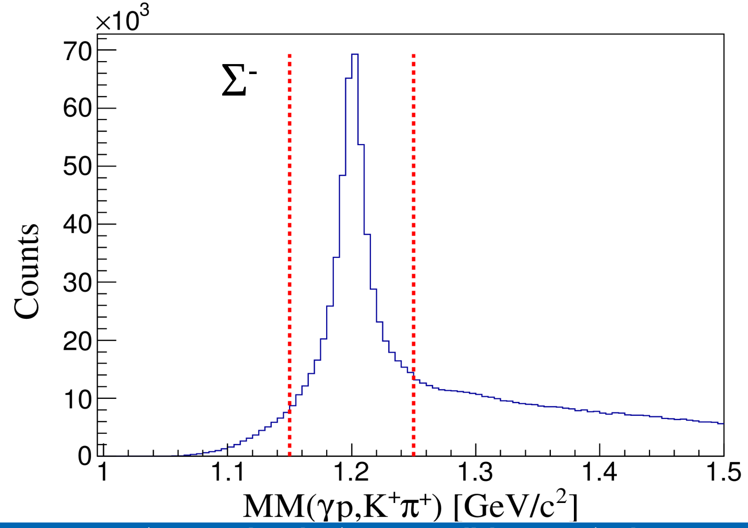
$0.9 \leq MM(K^+\pi\pi) \leq 1.0$	Select neutron events
$0.48 \leq IM(\pi^+\pi^-) \leq 0.51$	Remove nK^0 channel
$1.15 \leq MM(K^+\pi^-) \leq 1.25$ $1.15 \leq MM(K^+\pi^+) \leq 1.25$	Select Σ^+ and Σ^- events for exclusive $\Sigma\pi$ channels
$1.44 \leq MM(K^+) \leq 1.6$	Fitting Range $\Lambda(1520)$
$2.25 \leq W \leq 3.25$ GeV $-0.9 \leq \cos\theta^{K+}_{cm} \leq 0.9$ $-2.7 \leq t \leq -0.3$	Binning Scheme

Data Analysis



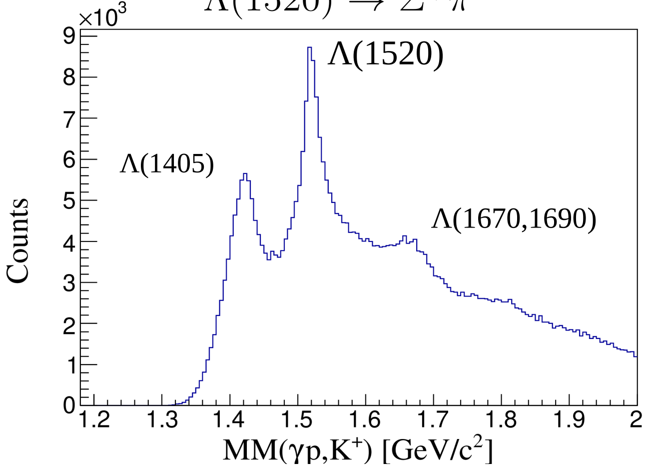




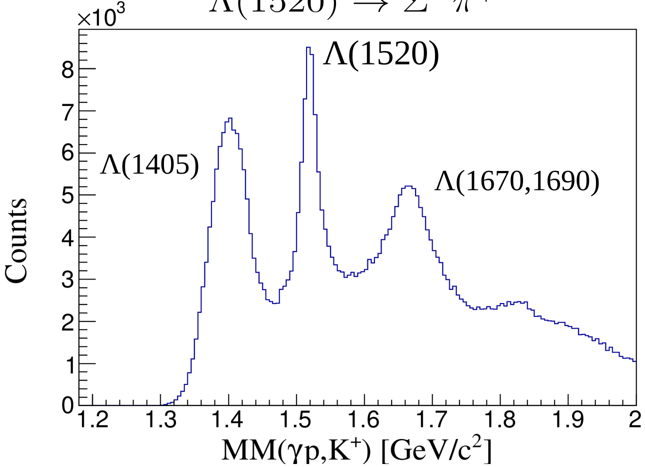


Data Analysis

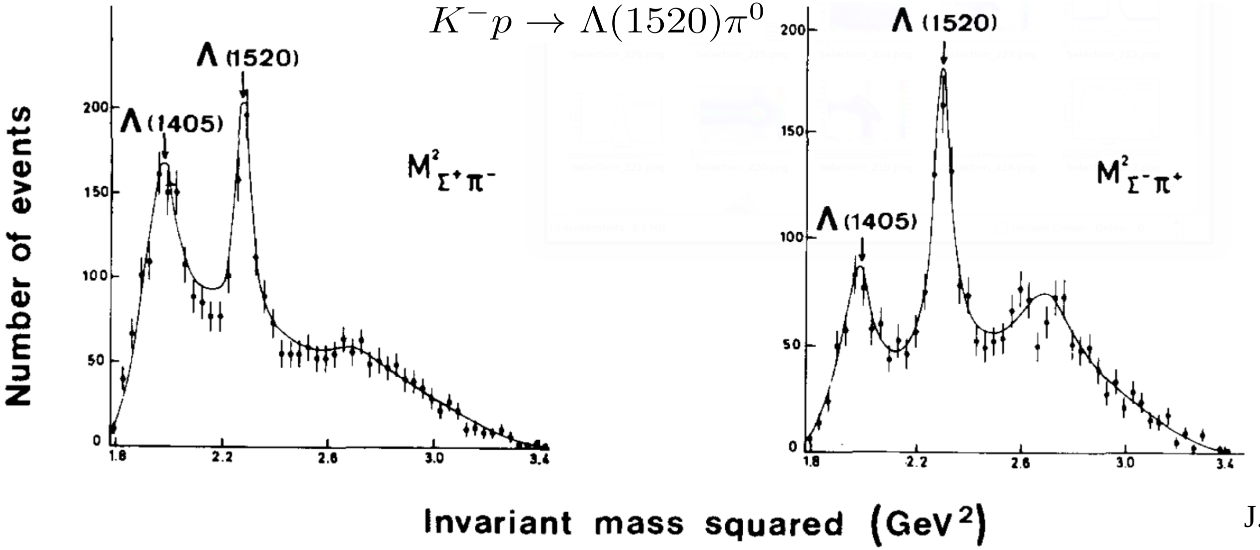
$\Lambda(1520) \rightarrow \Sigma^+\pi^-$



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

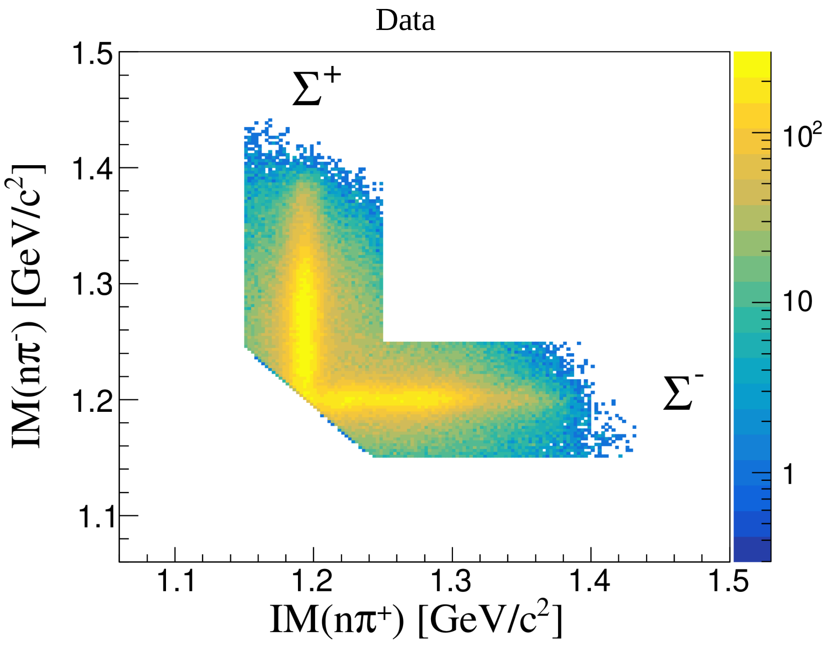


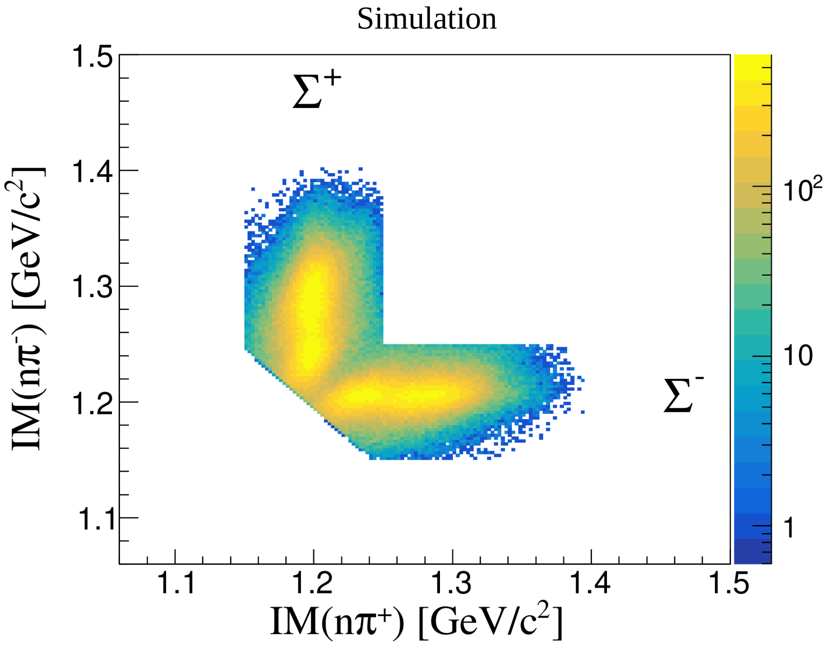
$K^-p \rightarrow \Lambda(1520)\pi^0$



J. Griselin *et. al.*, 1975

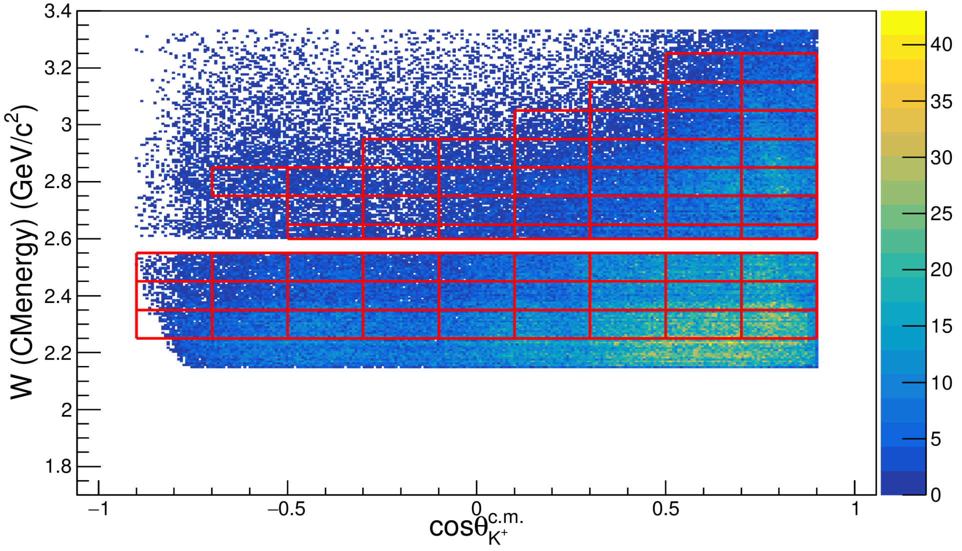
Data Analysis



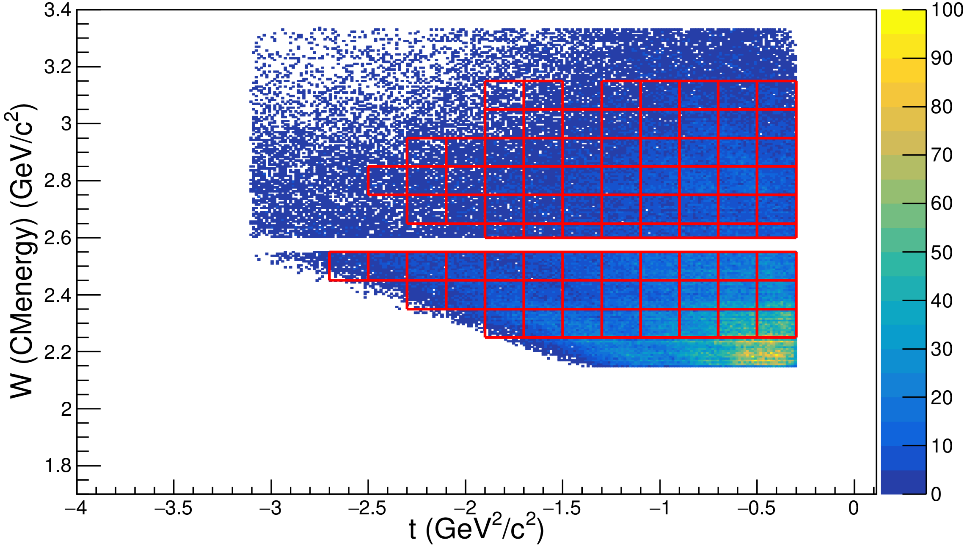


Data Analysis

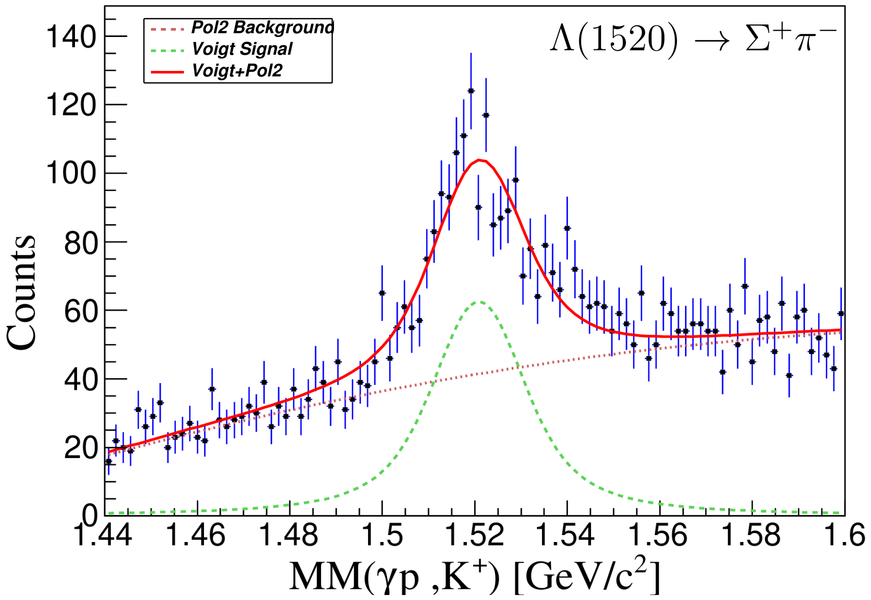
Binning Scheme in W & $cos\theta^{cm}_{K+}$

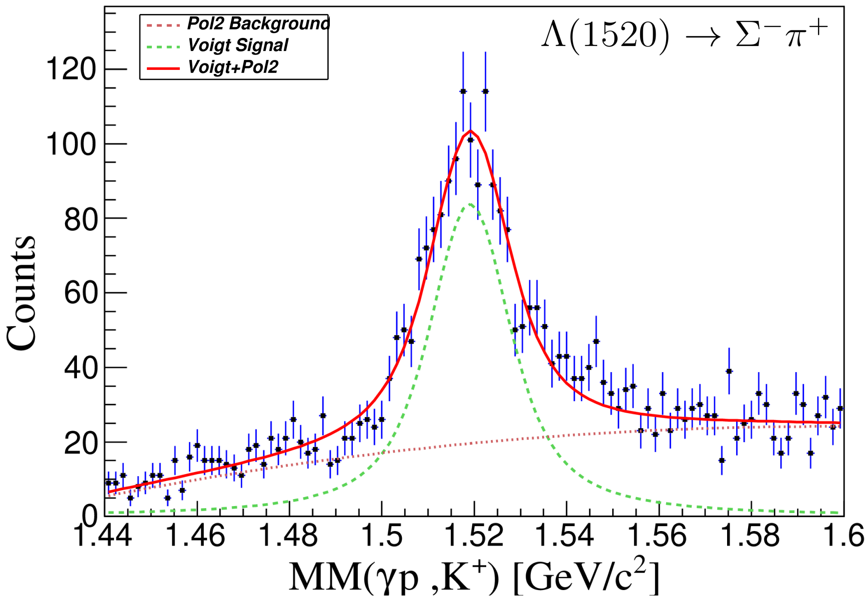


Binning Scheme in W & t



Data Analysis

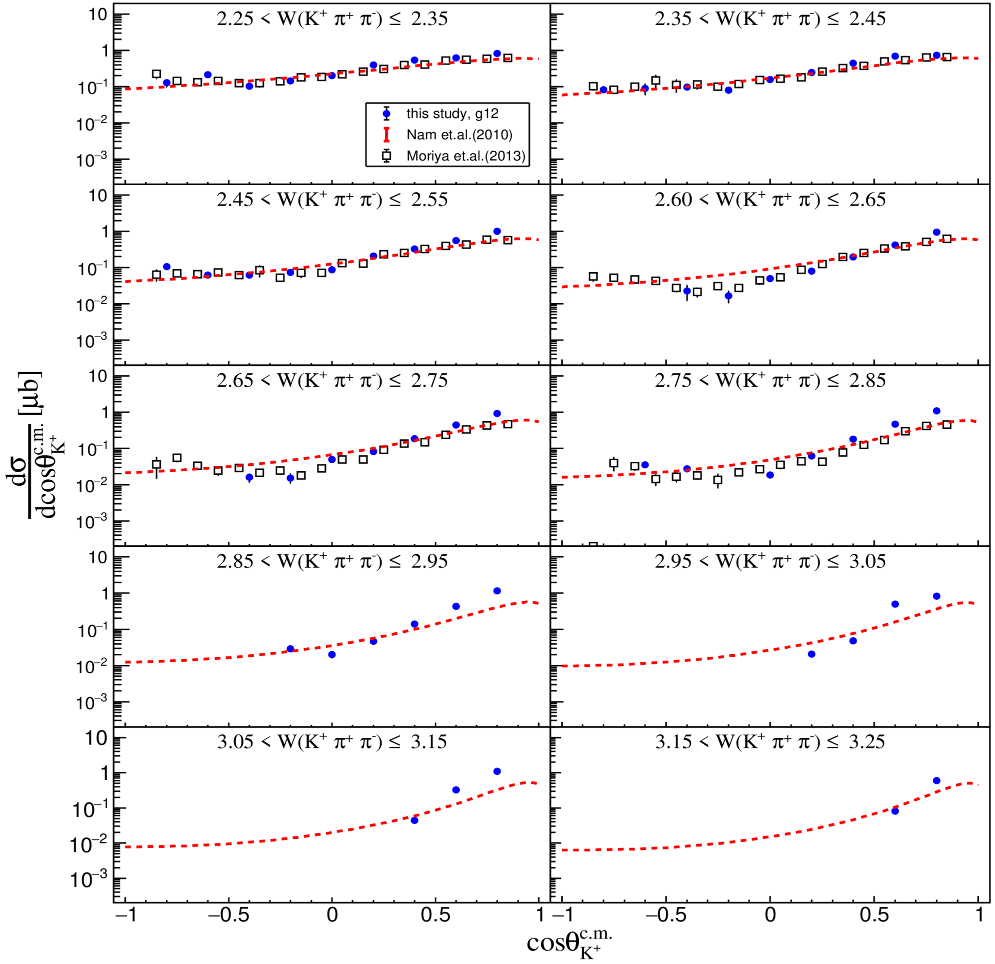


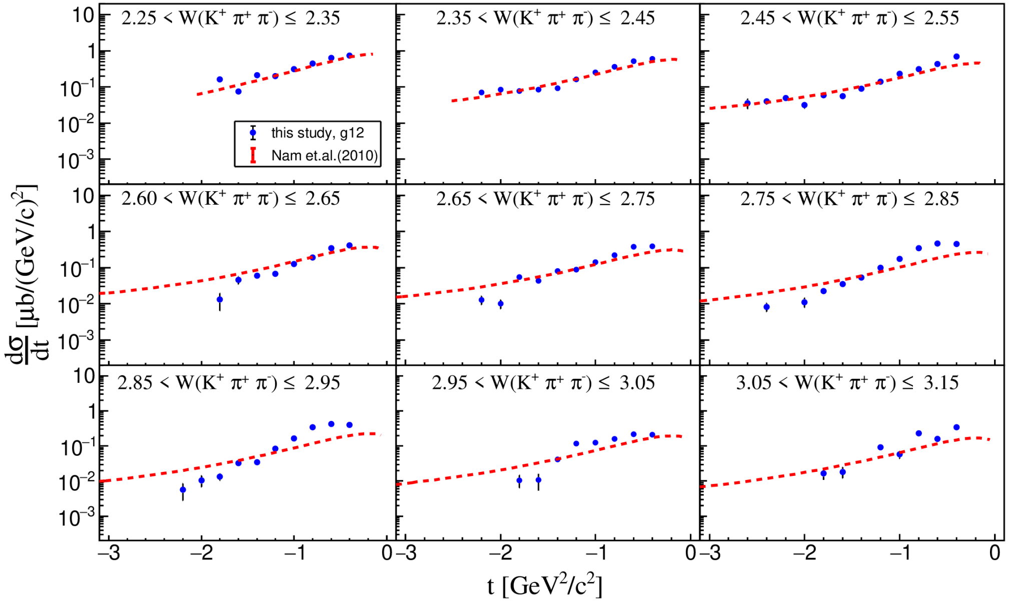


Differential Cross-sections

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

$$\frac{d\sigma}{dt} = \frac{Y(W,t)}{\tau\Delta t A(W,t)L(W)}$$





- The $\Lambda(1520)$ differential cross sections are shown as a function of CM angle and invariant 4-momentum transfer *t*, and extented for higher *W*.
- The *g12* results are in good agreement with previous CLAS measurements.
- The model calculations by Nam *et. al.* (2010), shown as dashed curves, reproduce the data very well.
- Some deviations at forward angles for $W > 2.7$ GeV may need more sophisticated theoretical approaches.

Systematic Uncertainties

Source	Description	Uncertainty
t-slope dependence	b = 2.0 *vs.* b = 1.0	0.78%
Timing Cut	3σ *vs.* 2.5σ	4.11%
Minimum $\|p\|$ cut	Minimum $\|p\|$ *vs.* no cut	0.20%
z-Vertex Cut	$-110 < z < -70$ *vs.* $-108 < z < -72$	1.28%
Fiducial Cut	50%(nominal) *vs.* 100%(tight)	3.13%
Background Function	*Pol2 vs. Pol1*	2.07%
Signal Integration Range	3.0σ *vs.* 3.5σ	0.43%
Flux Consistency/Luminosity	*g12*	1.70%
Sector by Sector	*g12*	5.90%
Target	*g12*	0.50%
Total Systematic Uncertainty	Added in quadrature	8.45%

Discussion and Conclusion

- The theory calculations are the numerical results without the N^* contribution, and conserve gauge invariance.
- Theoretical study has concluded that the K^*-N-$\Lambda(1520)$ coupling must be very small to explain the data.
- Calculations with N^* show very small contribution, just above threshold, and is limited to the first W bin. Such calculations include only N^* resonances with mass below 2.2 GeV.
- The simplest theoretical model with a pseudoscalar K-meson exchange, assuming t-channel dominance, is sufficient to explain our data, without other processes like Regge, K^* and hyperon resonances.
- This theoretical model can be used to study higher N^* resonances as well.

Extras

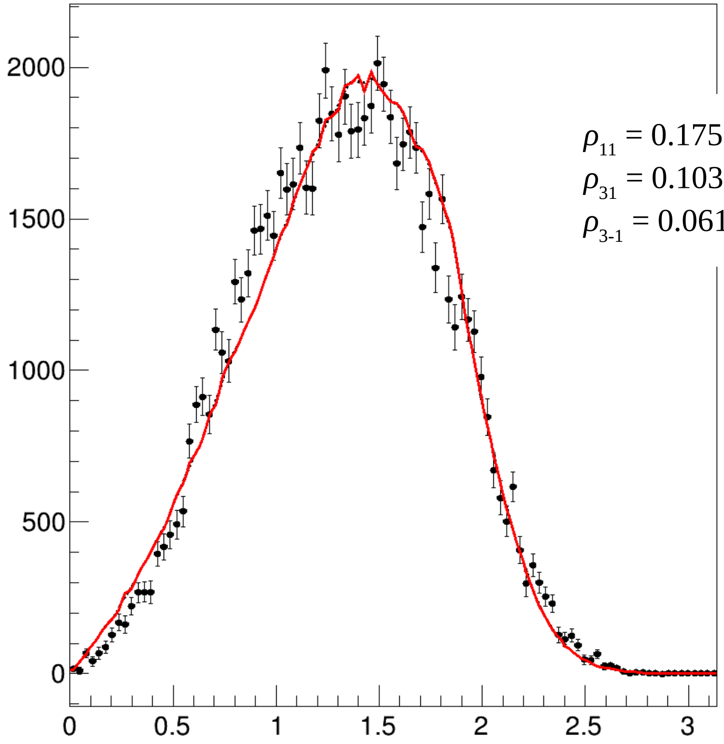
Λ(1520) SDME

Barber *et. al.*, (1980)

$\Lambda(1520) \rightarrow \Sigma\,\pi$

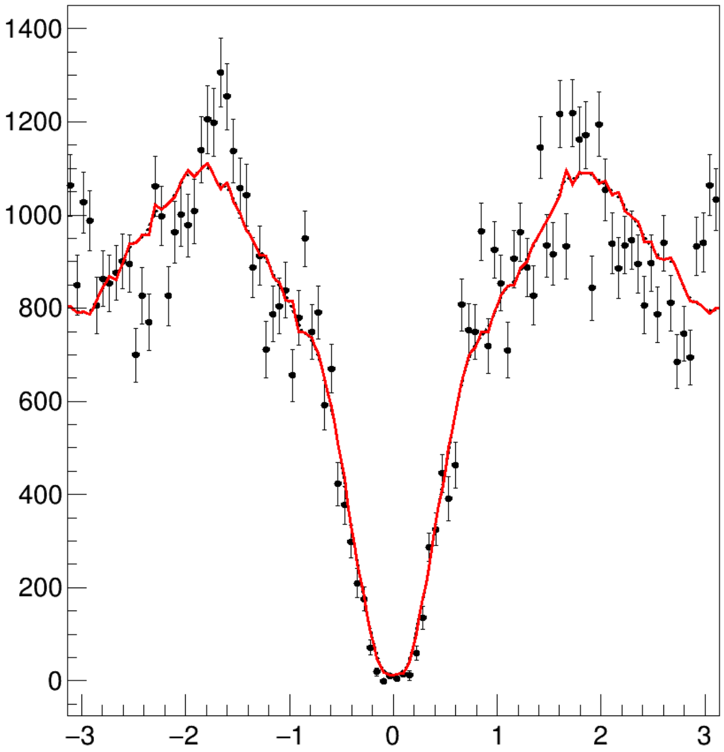
$3/2^- \rightarrow 1/2^+\,0^-$

$$I(\cos\theta,\phi) = \frac{3}{4\pi}\left\{\varrho_{33}\sin^2\theta + \varrho_{11}\left(\tfrac{1}{3}+\cos^2\theta\right) - \frac{2}{\sqrt{3}}\mathrm{Re}\,\varrho_{31}\sin 2\theta\cos\phi - \frac{2}{\sqrt{3}}\mathrm{Re}\,\varrho_{3-1}\sin^2\theta\cos 2\phi\right\}$$



$\theta_\pi^{\mathrm{G.J.}}$

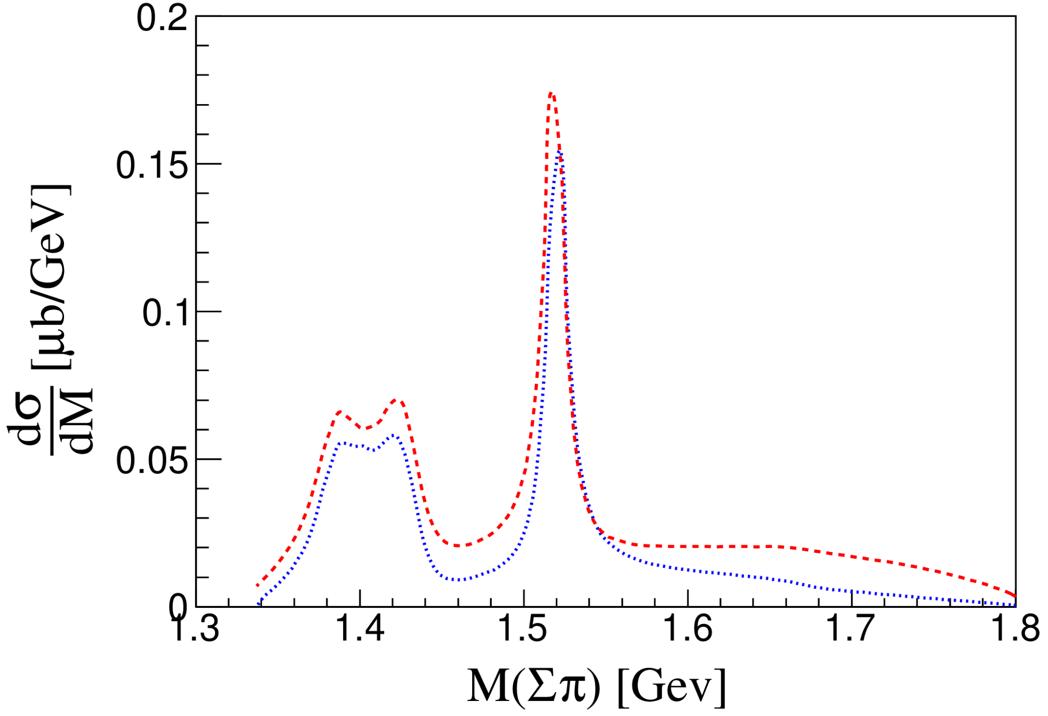
ρ_{11} = 0.1755 ± 0.0050
ρ_{31} = 0.10321 ± 0.0045
$\rho_{3\text{-}1}$ = 0.0615 ± 0.0043



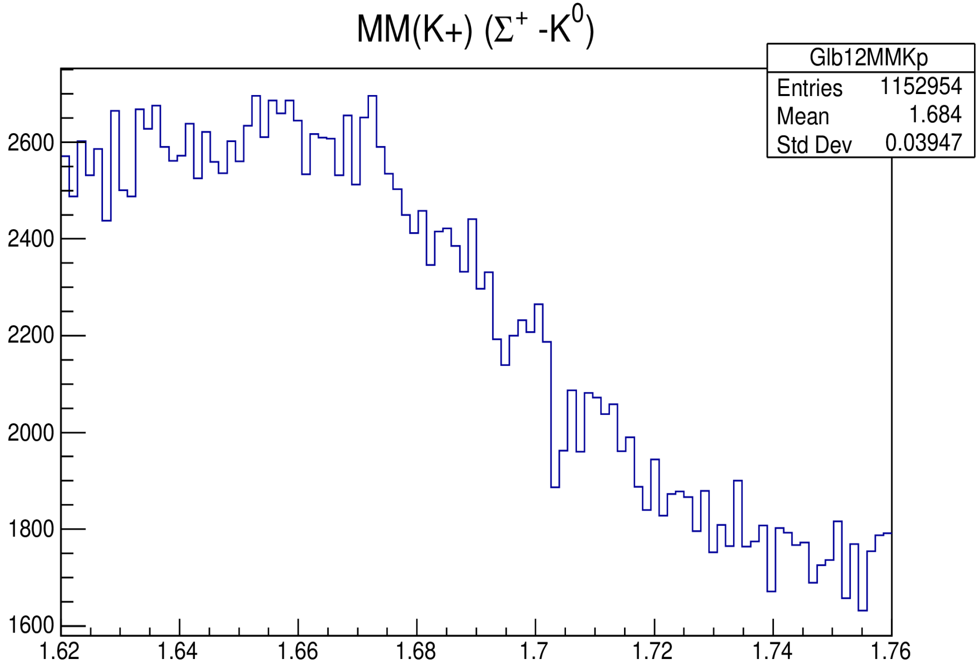
$\varphi_\pi^{\mathrm{G.J.}}$

$K^{*0} \rightarrow K^{+}\pi^{-}$ Backgound

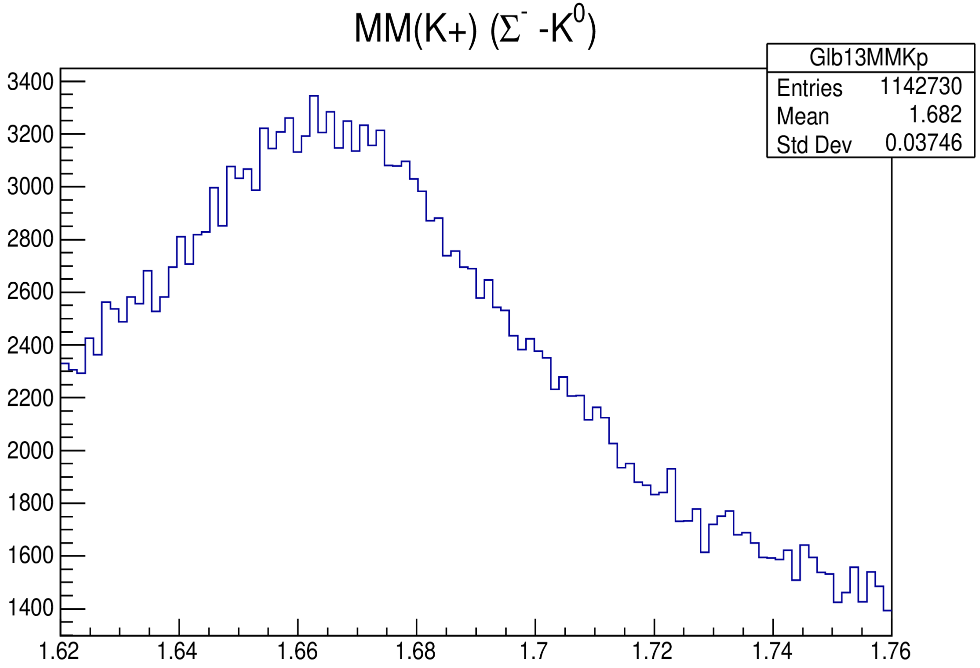
Model prediction showing the difference in K^{*0} background contributions to the decay of Λ^* into two channels $\Sigma^{+}\pi^{-}$ (red) and $\Sigma^{-}\pi^{+}$ (blue).



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



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



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

$$\langle 0\ 0 \mid 1\ {+1}\ 1\ {-1}\rangle = 1/\sqrt{3}$$

$$\langle 0\ 0 \mid 1\ {-1}\ 1\ {+1}\rangle = 1/\sqrt{3}$$

Σ(1670) 3/2⁻ $\qquad I(J^P) = 1(\tfrac{3}{2}^-)$

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

Σ^0 coupling to the decay of $\Sigma^+\pi^-$ $\Sigma^-\pi^+$

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

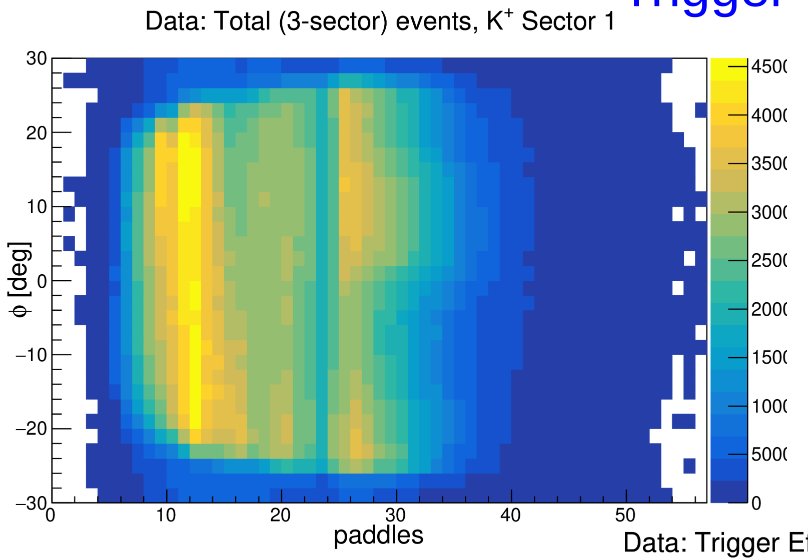
$$\langle 1\ 0 \mid 1\ {+1}\ 1\ {-1}\rangle = 1/\sqrt{2}$$

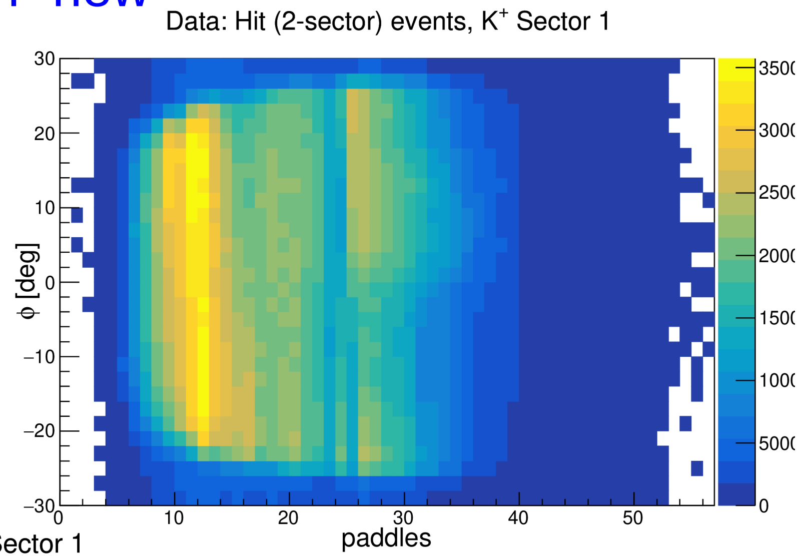
$$\langle 1\ 0 \mid 1\ {-1}\ 1\ {+1}\rangle = -1/\sqrt{2}$$

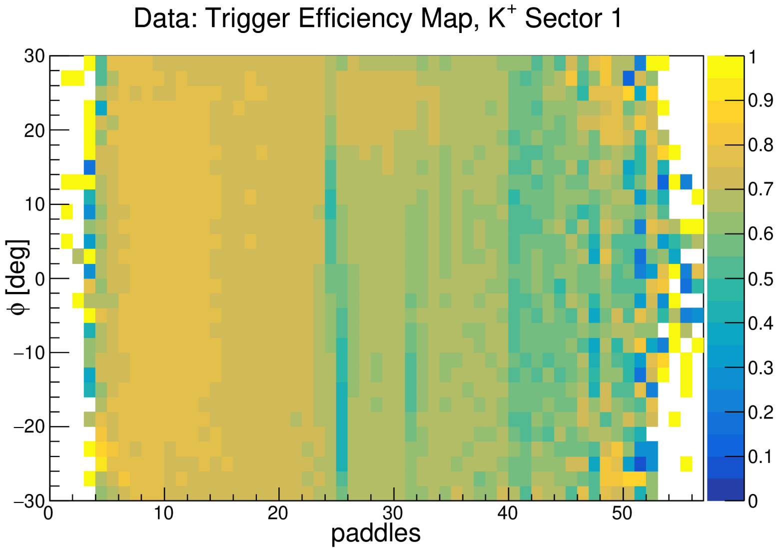
$$\Sigma^0(1670)\ 3/2^- \xrightarrow{\sim 23\%} \Sigma^+\pi^-$$

$$\Sigma^0(1670)\ 3/2^- \xrightarrow{\sim 23\%} \Sigma^-\pi^+$$

Trigger Correction “new”

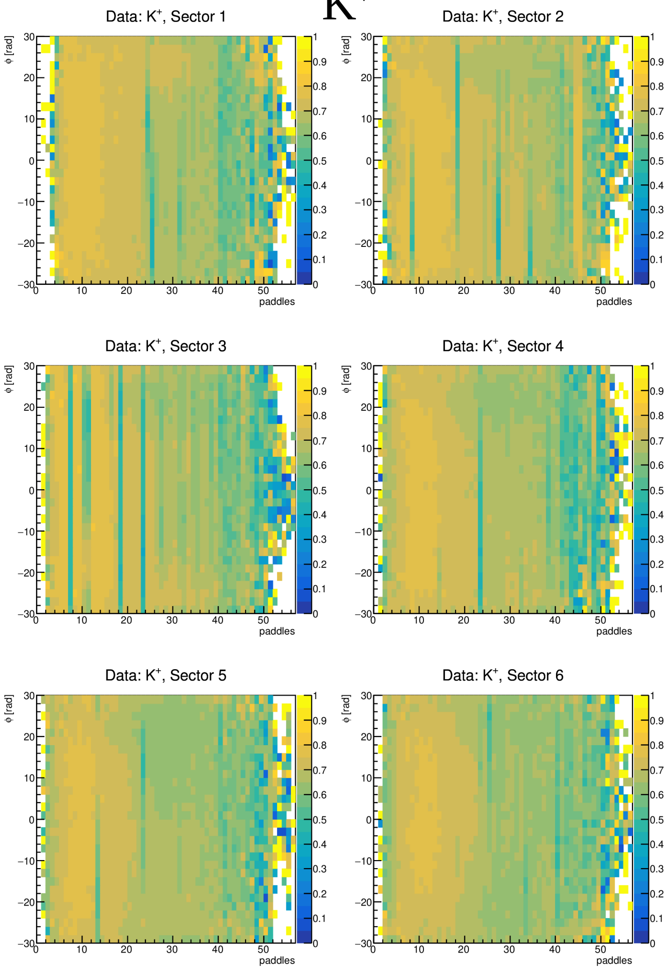




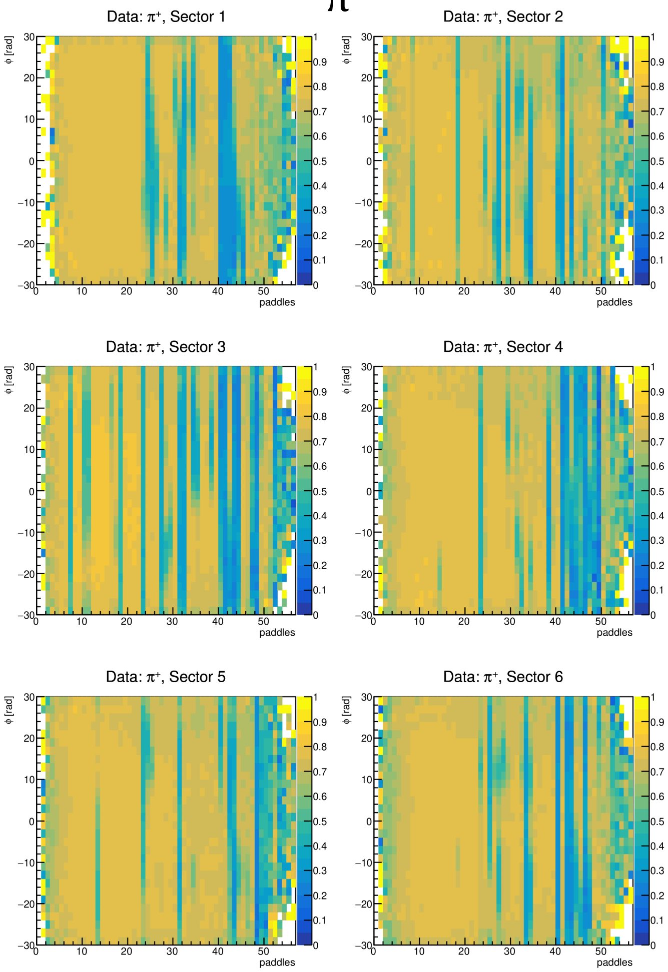


Trigger Efficiency Map

K^+



π^+



π^-