Analysis of anti-Kaon-induced Cascade baryon production

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Outline

- Motivation
- SDM Formalism
- Model Results
- Future Plans

In collaboration with:
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Oh, Yongseok (Kyungpook National Univ.)

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Motivation

- Cascade baryons should be studied as an integral part of any baryon spectroscopy program:
  - JLab: photon-induced productions (data for g.s. Ξ: L. Guo et al., PRC76, '07)
  - J-PARC: pion- & anti-kaon-induced productions (planned)
  - FAIR: anti-nucleon-induced productions
- Multi-strangeness physics has not been well studied
  - Strangeness in the final state is only created in indirect processes unless the initial state has strangeness. Lack of strange beams has been a limiting factor.
  - SU(3) allows as many cascades as the N* and Δ resonances combined (~ 44). However, only 11 cascades have been seen so far:

Particle	$I(J^P)$	Rating	Particle	$I(J^P)$	Rating
Ξ(1318)	$1/2(1/2^+)$	****	Ω(1672)	$0(3/2^+)$	****
Ξ(1530)	$1/2(3/2^+)$	****	Ω(2250)	$0(?^?)$	***
Ξ(1620)	$1/2(?^?)$	*	Ω(2380)	$?(?^?)$	**
Ξ(1690)	$1/2(?^?)$	***	Ω(2470)	$?(?^?)$	**
Ξ(1820)	$1/2(3/2^-)$	***			
Ξ(1950)	$1/2(?^?)$	***			
Ξ(2030)	$1/2(\geq 5/2^?)$	***			
Ξ(2120)	$1/2(?^?)$	*			
Ξ(2250)	$1/2(?^?)$	**			
Ξ(2370)	$1/2(?^?)$	**			
Ξ(2500)	$1/2(?^?)$	*			

Cascade Baryon(s)

$$\Xi^- : |dss\rangle \qquad \Xi^0 : |uss\rangle$$

- Strangeness = -2
- Parity of the ground state has yet to be measured. Expected to be (+).
- Spin observables are very important
  - Basic quantum numbers
  - Production mechanism
    - Is a good place to study hyperon resonances: Λ^*, Σ^*

Spin Observables: $t^{*J}_{L,M}$ or $\rho^{\Xi}_{\lambda,\lambda'}$

- Spin ½ cascades can be produced with vector polarization: $\vec{P}$
- Higher spin resonances can have other forms of polarization (spin 3/2: $\vec{P}$, P^{ij}, P^{ijk})
  - We can describe the polarization of the produced cascade baryons with a Spin Density Matrix.
    - SDM elements, $t^{*J}_{L,M}$ or $\rho^{\Xi}_{\lambda,\lambda'}$, can be measured by analyzing the cascade's decay distribution.

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$$\bar{K} + N \to K + \Xi^*$$

$$J^P = \frac{1}{2}^{\pm}$$

- Mapped out all 8 observables in terms of SDM elements.
  - $\frac{d\sigma}{d\Omega}$, T_y, P_y, K_{yy}, K_{xx}, K_{zz}, K_{xz}, K_{zx}
  - e.g., $K_{yy} = \frac{i\rho^2_{\frac{1}{2},-\frac{1}{2}}}{\rho^0_{\frac{1}{2},\frac{1}{2}}} = \pi_\Xi$

$$(-1)^{\frac{1}{2}-\lambda'} \frac{i\rho^2_{\lambda,-\lambda'}}{\rho^0_{\lambda,\lambda'}} = (-1)^{\frac{1}{2}-\lambda'} \frac{\rho^1_{\lambda,-\lambda'}}{\rho^3_{\lambda,\lambda'}} = \pi_\Xi$$

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$$\bar{K} + N \to K + \Xi^*$$

$$\mathrm{J^P} = \frac{3}{2}^{\pm}$$

- Spin-3/2 observables are more complicated
- There are 16 non-zero observables
  - Again, these are mapped out in terms of SDM elements
- e.g., $K_{yy} = \dfrac{i\left(\rho^2_{\frac{3}{2},-\frac{3}{2}} - \rho^2_{\frac{1}{2},-\frac{1}{2}}\right)}{\rho^0_{\frac{3}{2},\frac{3}{2}} + \rho^0_{\frac{1}{2},\frac{1}{2}}} = \pi_\Xi$

$$(-1)^{\frac{3}{2}-\lambda'}\,\frac{i\rho^2_{\lambda,-\lambda'}}{\rho^0_{\lambda,\lambda'}} = (-1)^{\frac{3}{2}-\lambda'}\,\frac{\rho^1_{\lambda,-\lambda'}}{\rho^3_{\lambda,\lambda'}} = \pi_\Xi$$

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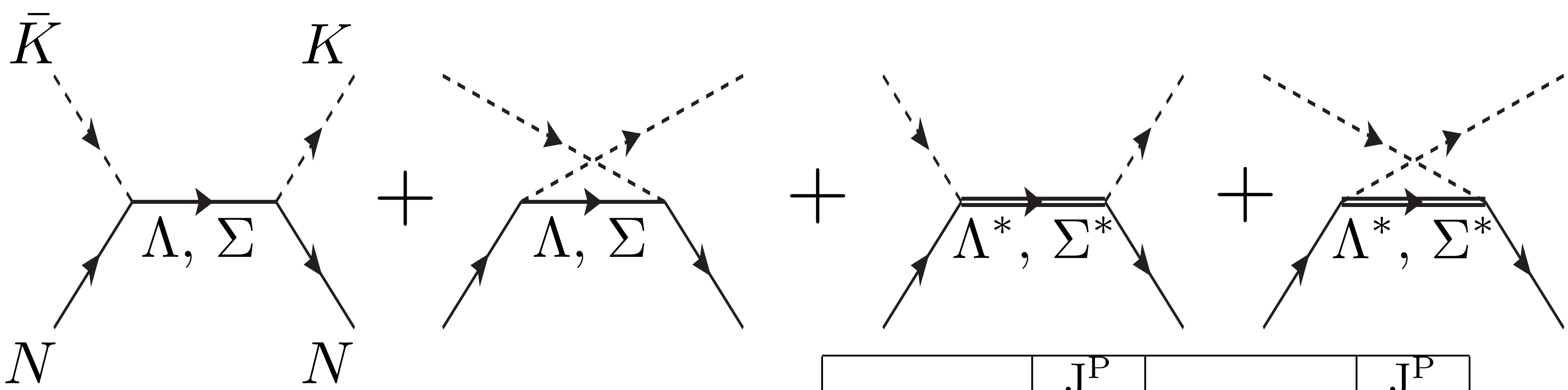
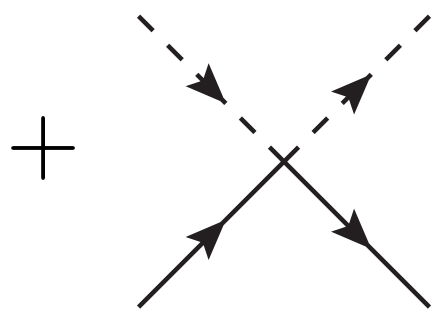
KN→KΞ : model description

- Effective Lagrangian approach
- Includes Λ and Σ resonances
- Tree level calculation
- No t-channel exchange





Contact term (optional)

	J^P		J^P
$\Lambda(1406)$	$\frac{1}{2}^-$	$\Sigma(1385)$	$\frac{3}{2}^+$
$\Lambda(1670)$	$\frac{1}{2}^-$	$\Sigma(1385)$	$\frac{3}{2}^+$
$\Lambda(1520)$	$\frac{3}{2}^-$	$\Sigma(1670)$	$\frac{3}{2}^-$
$\Lambda(1690)$	$\frac{3}{2}^-$	$\Sigma(2250)$	$\frac{3}{2}^+$
$\Lambda(1890)$	$\frac{3}{2}^+$	$\Sigma(1775)$	$\frac{5}{2}^-$
$\Lambda(1820)$	$\frac{5}{2}^+$	$\Sigma(1915)$	$\frac{5}{2}^+$
$\Lambda(1830)$	$\frac{5}{2}^-$	$\Sigma(2030)$	$\frac{7}{2}^+$
$\Lambda(2100)$	$\frac{7}{2}^-$		

KN→KΞ : model description

Form Factors at each vertex:

$$f(s) = \frac{\Lambda^4}{\Lambda^4 + (s - m_Y^2)^2}$$

$$f(u) = \frac{\Lambda^4}{\Lambda^4 + (u - m_Y^2)^2}$$

$$T = V + VGT$$

$$T = T^P + T^{NP}$$
$$V = V^P + V^{NP}$$

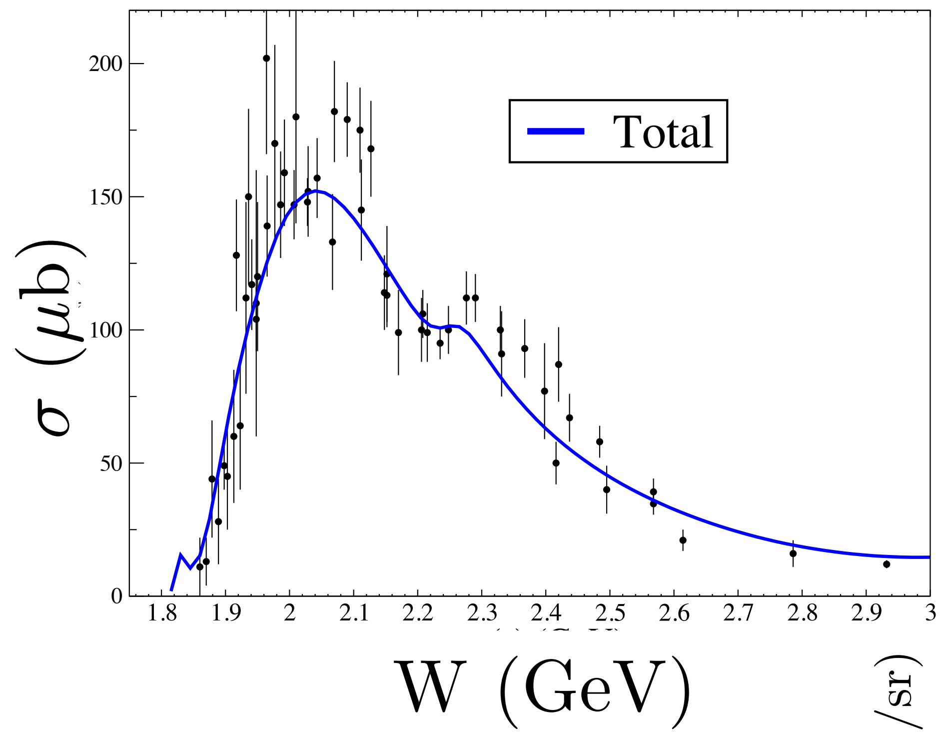
$$T^P \to \sum_r |F_r\rangle\, S_r\, \langle F_r|$$ s – channel

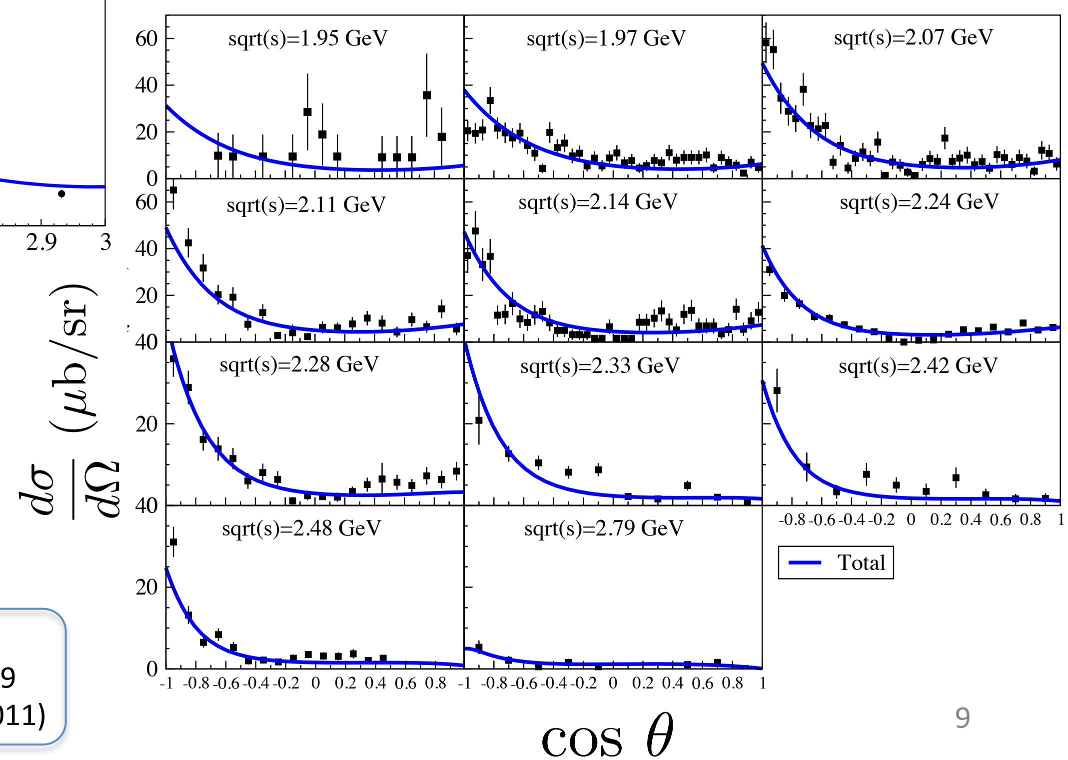
$$T^{NP} = V^{NP} + V^{NP} G T^{NP} \to V^{NP}$$ u – channel

KN→KΞ : model results

$$K^- + p \to K^+ + \Xi^-$$

$$\frac{\chi^2}{N} = 1.84$$

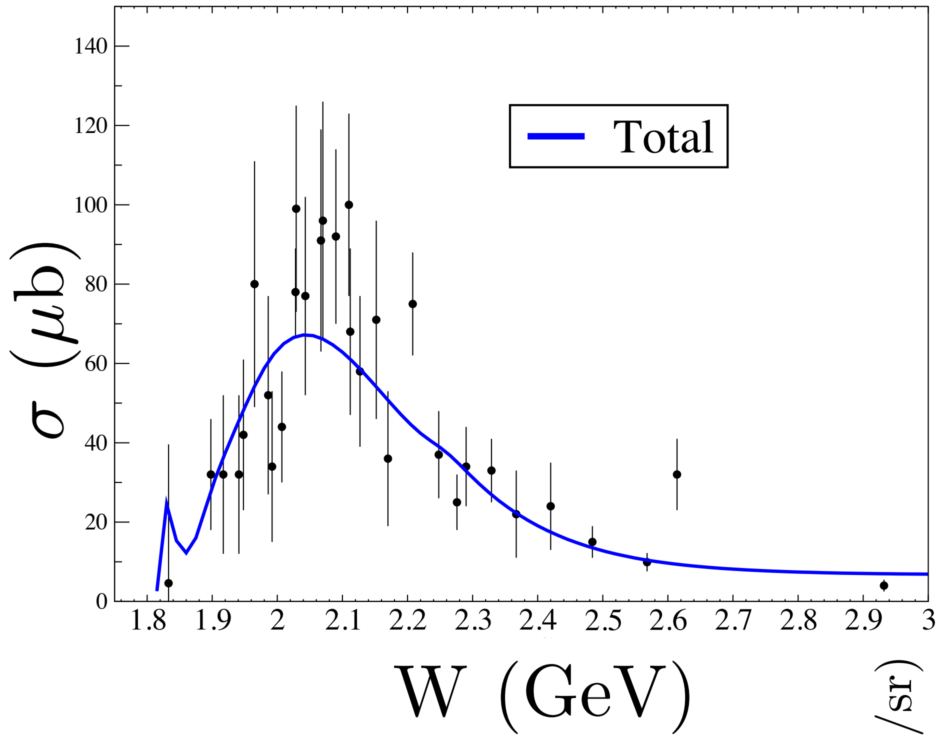




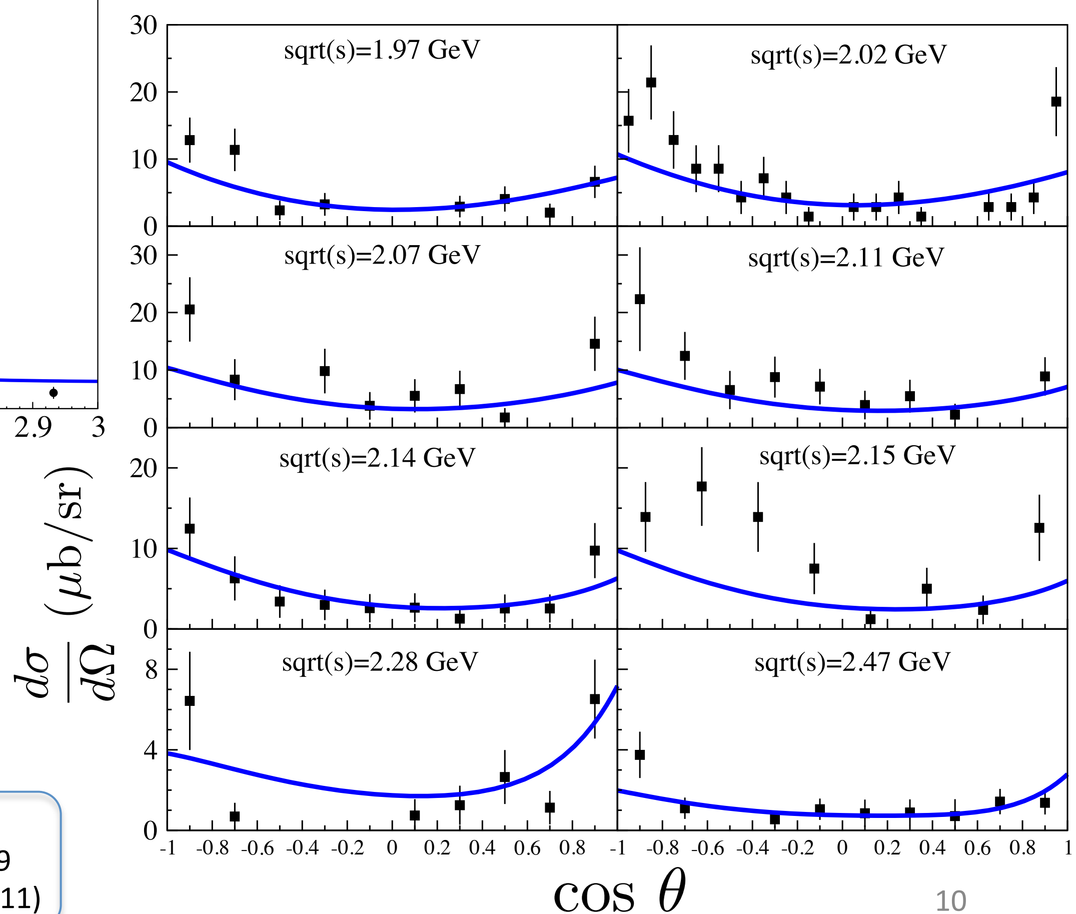
Other analysis done by:
Sharov, Korotkikh and Lanskoy, Eur. Phys. J. A (2011) 47: 109
Shyam, Scholten and Thomas, Phys. Rev. C84 042201(R) (2011)

KN→KΞ : model results

$$K^- + p \rightarrow K^0 + \Xi^0$$



$$\frac{\chi^2}{N} = 1.84$$



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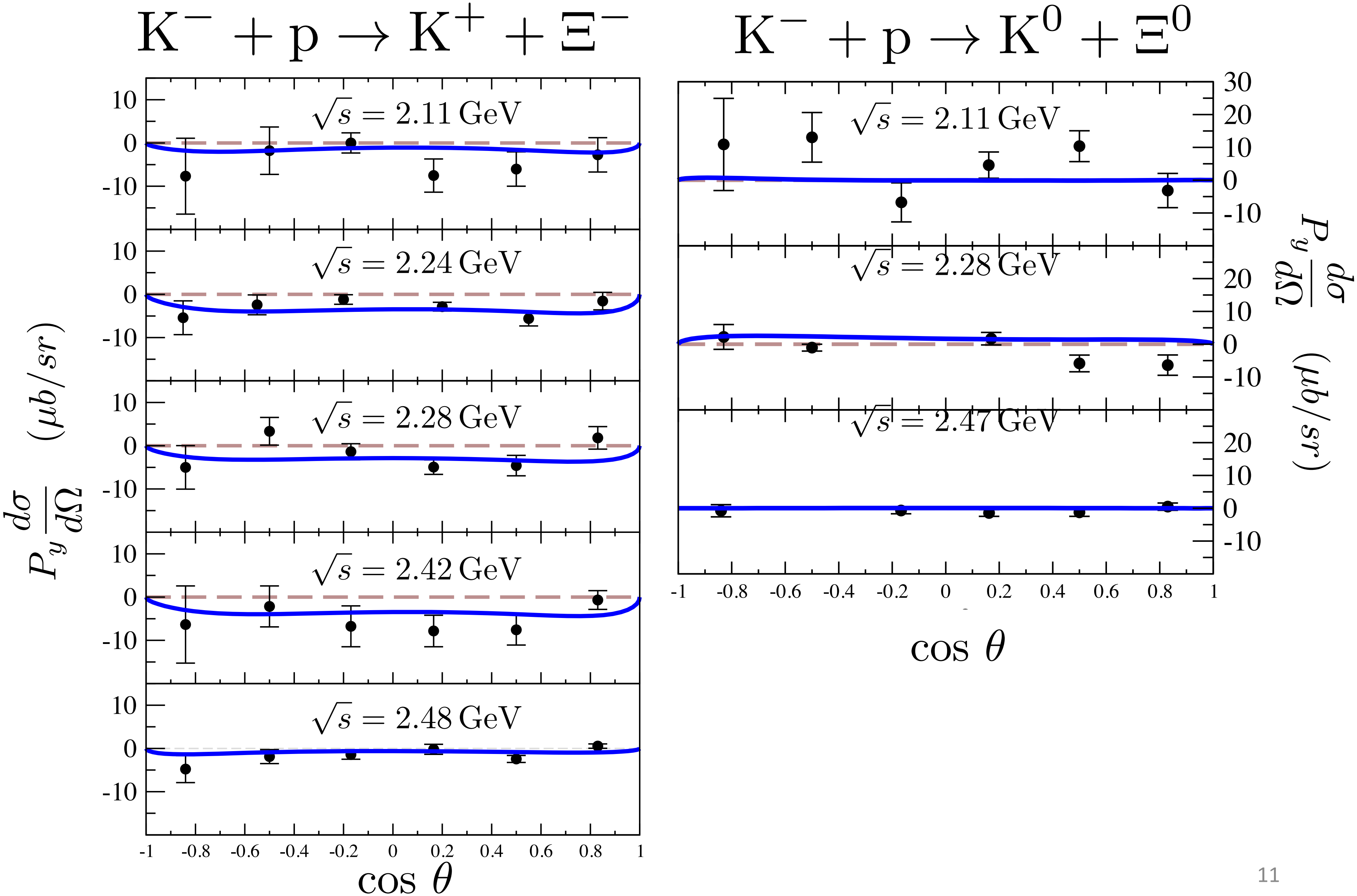
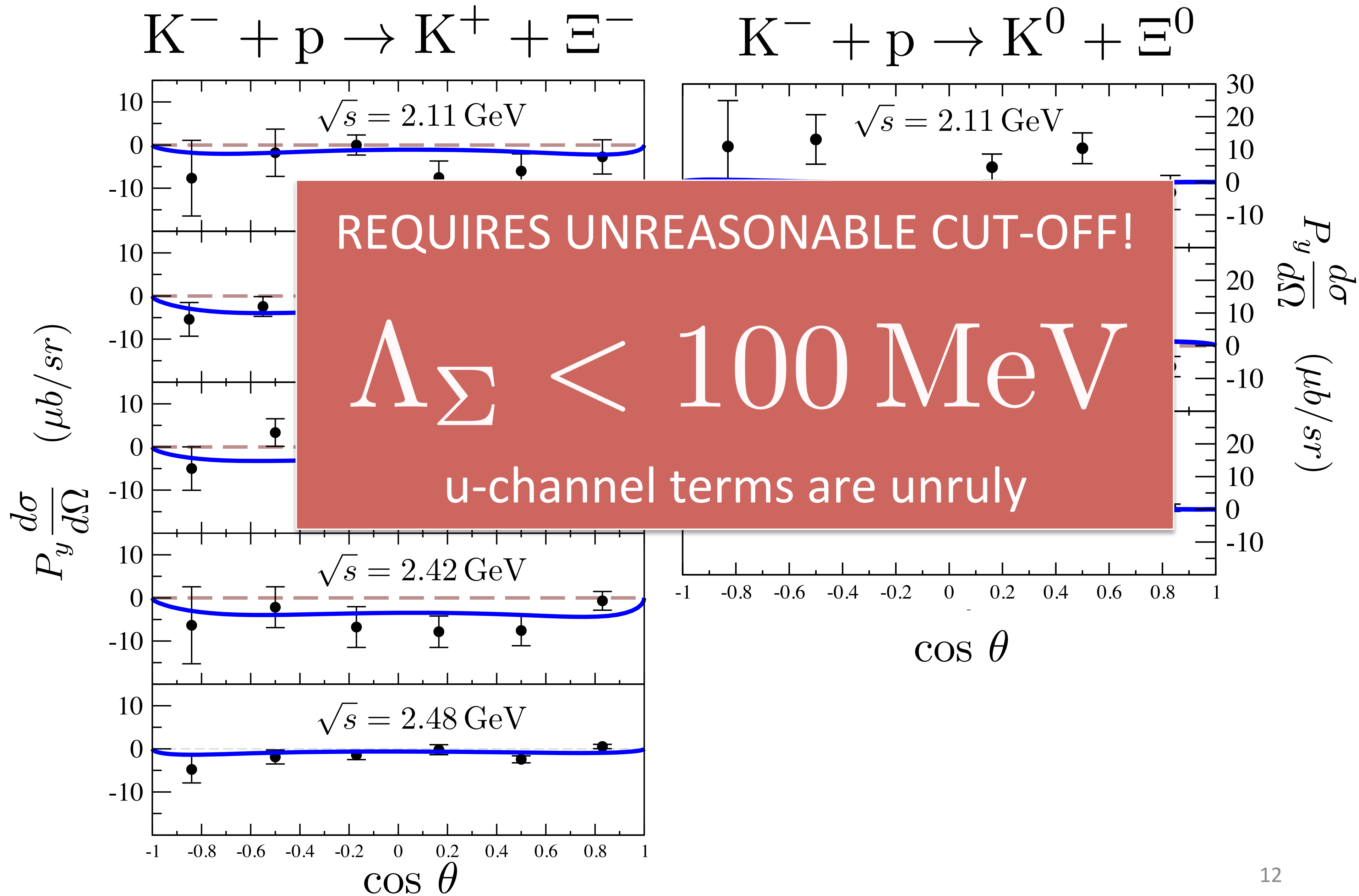


KN→KΞ : model results



REQUIRES UNREASONABLE CUT-OFF!

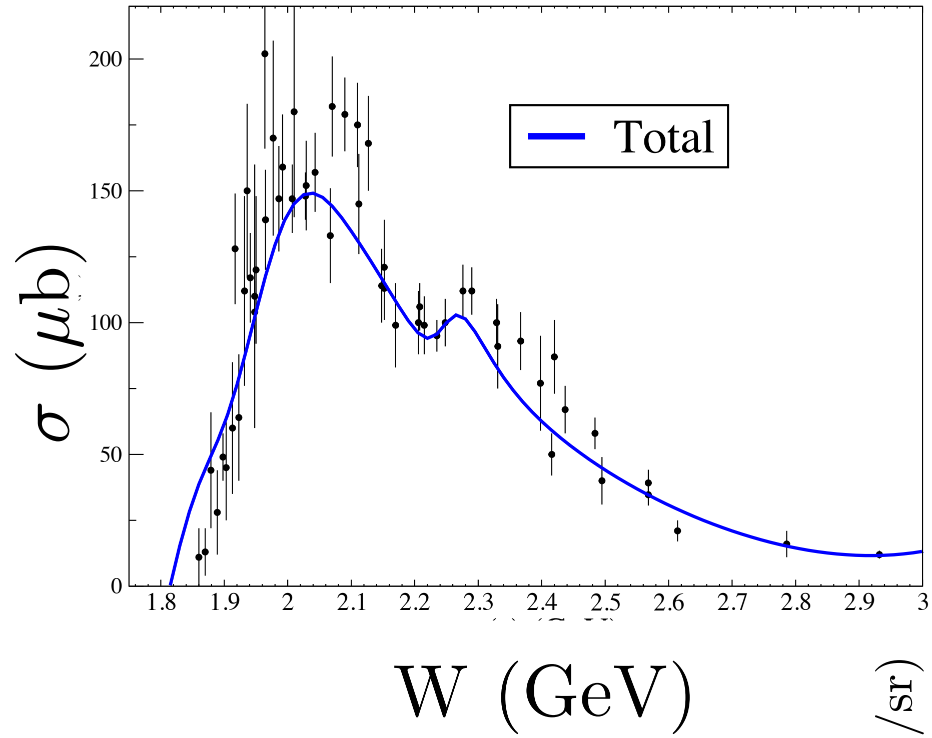
$$\Lambda_\Sigma < 100 \text{ MeV}$$

u-channel terms are unruly

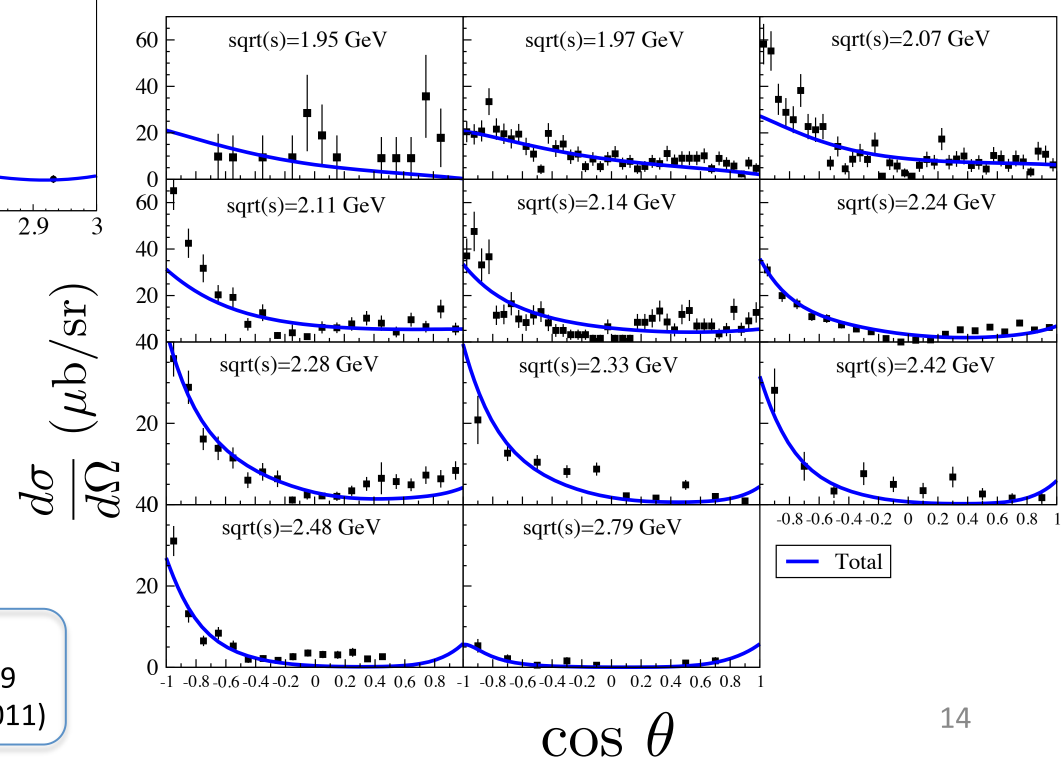
Attempt #2:
Try reasonable values for cut-offs

KN→KΞ : model results

$$K^- + p \rightarrow K^+ + \Xi^-$$



$$\frac{\chi^2}{N} = 2.63$$



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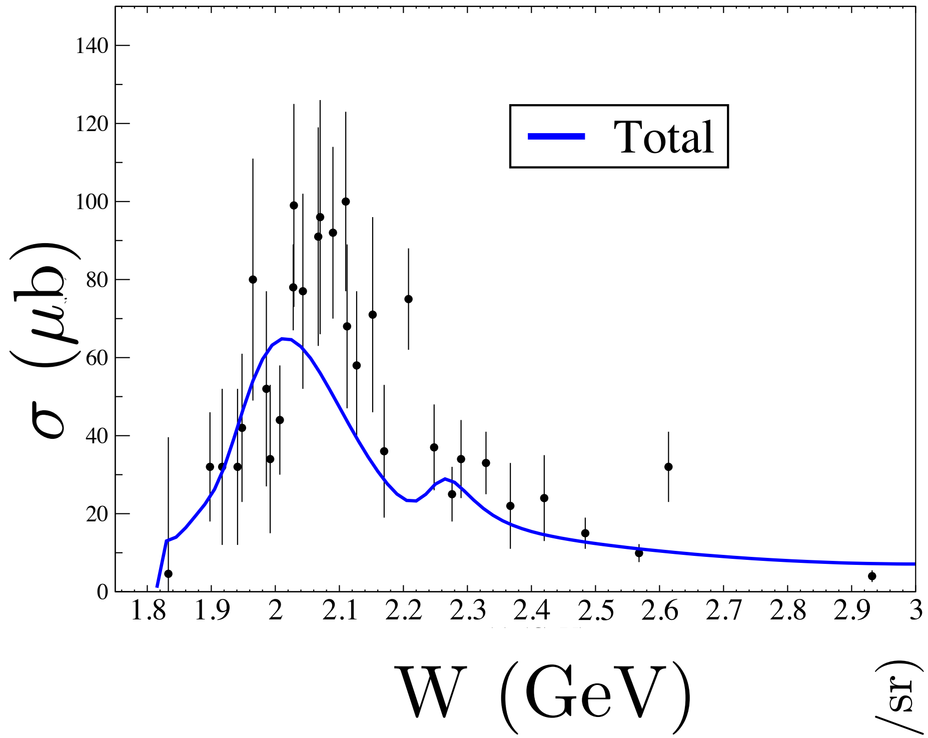
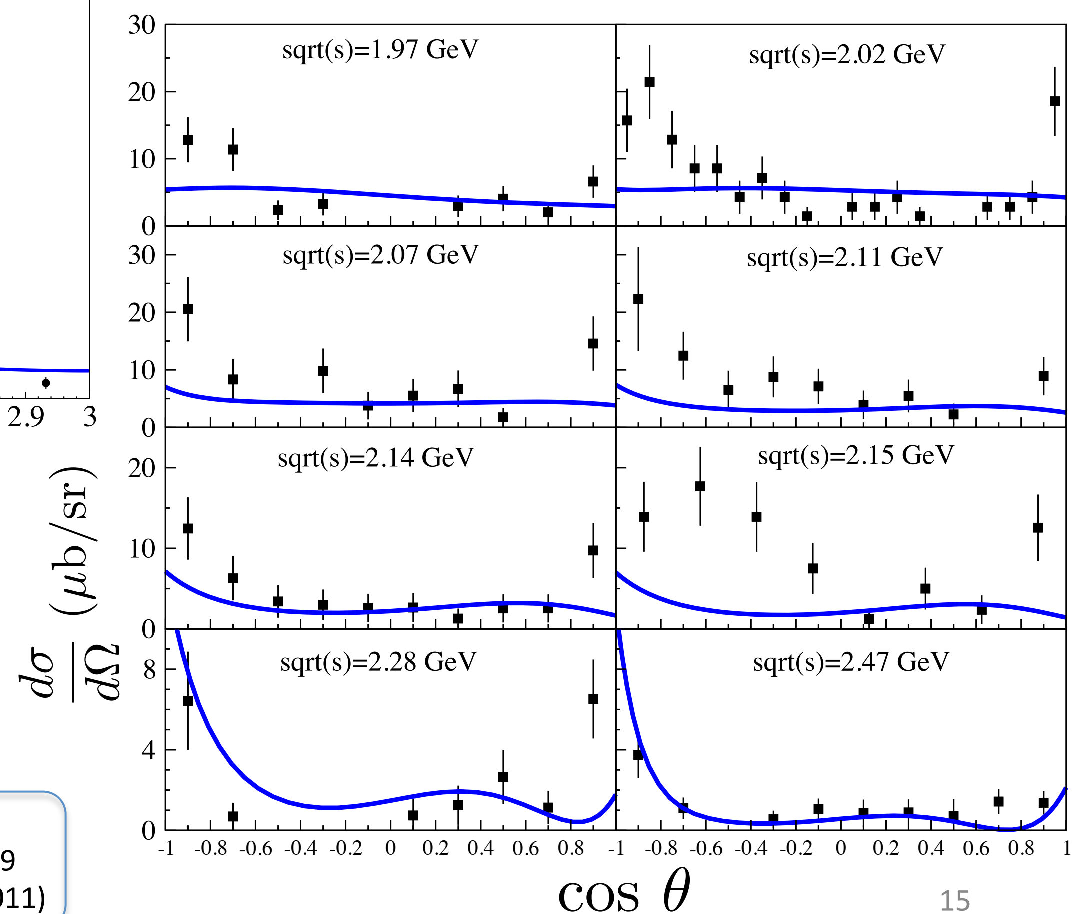
KN→KΞ : model results

$$K^- + p \to K^0 + \Xi^0$$



$$\frac{\chi^2}{N} = 2.63$$



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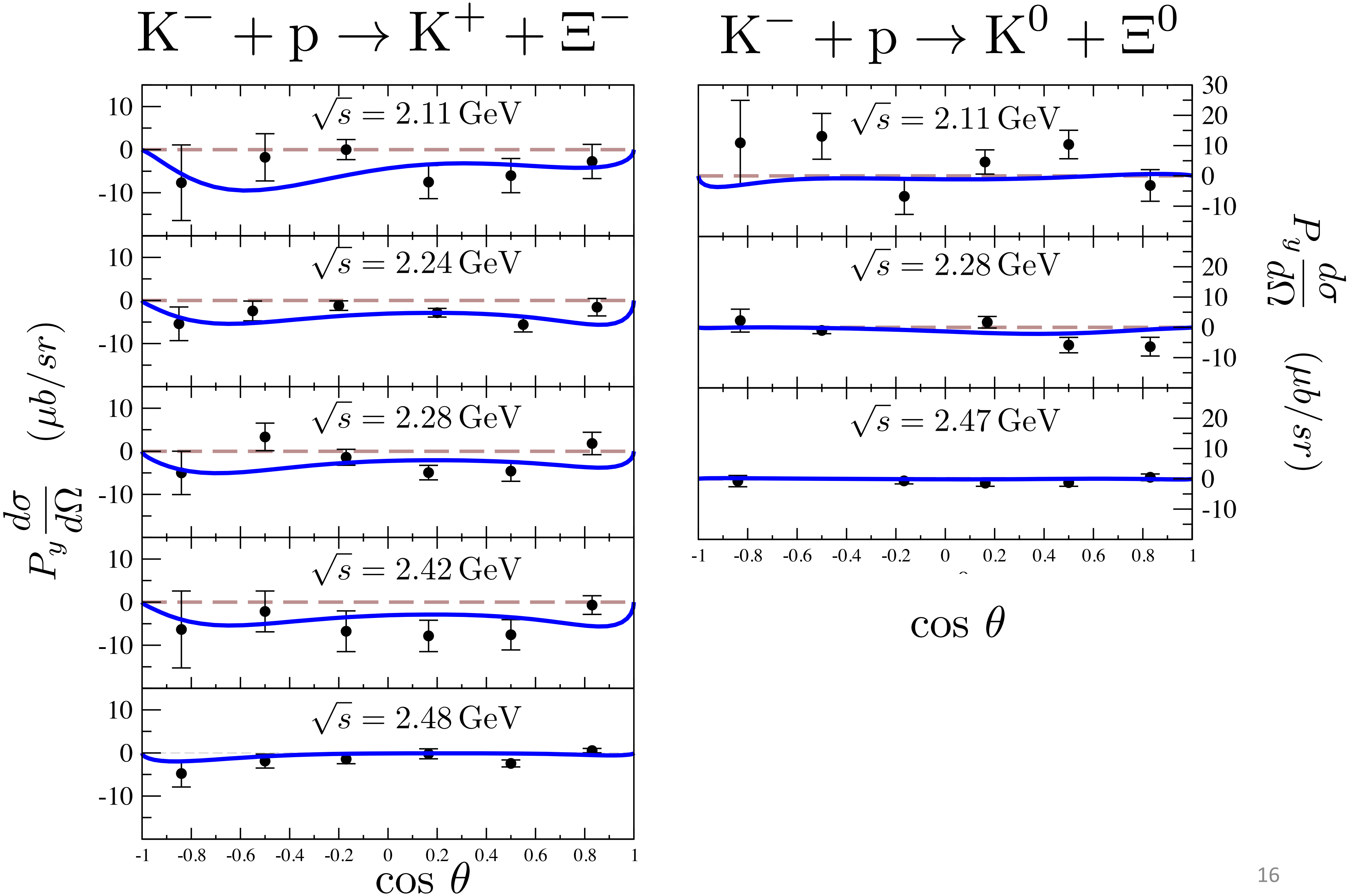
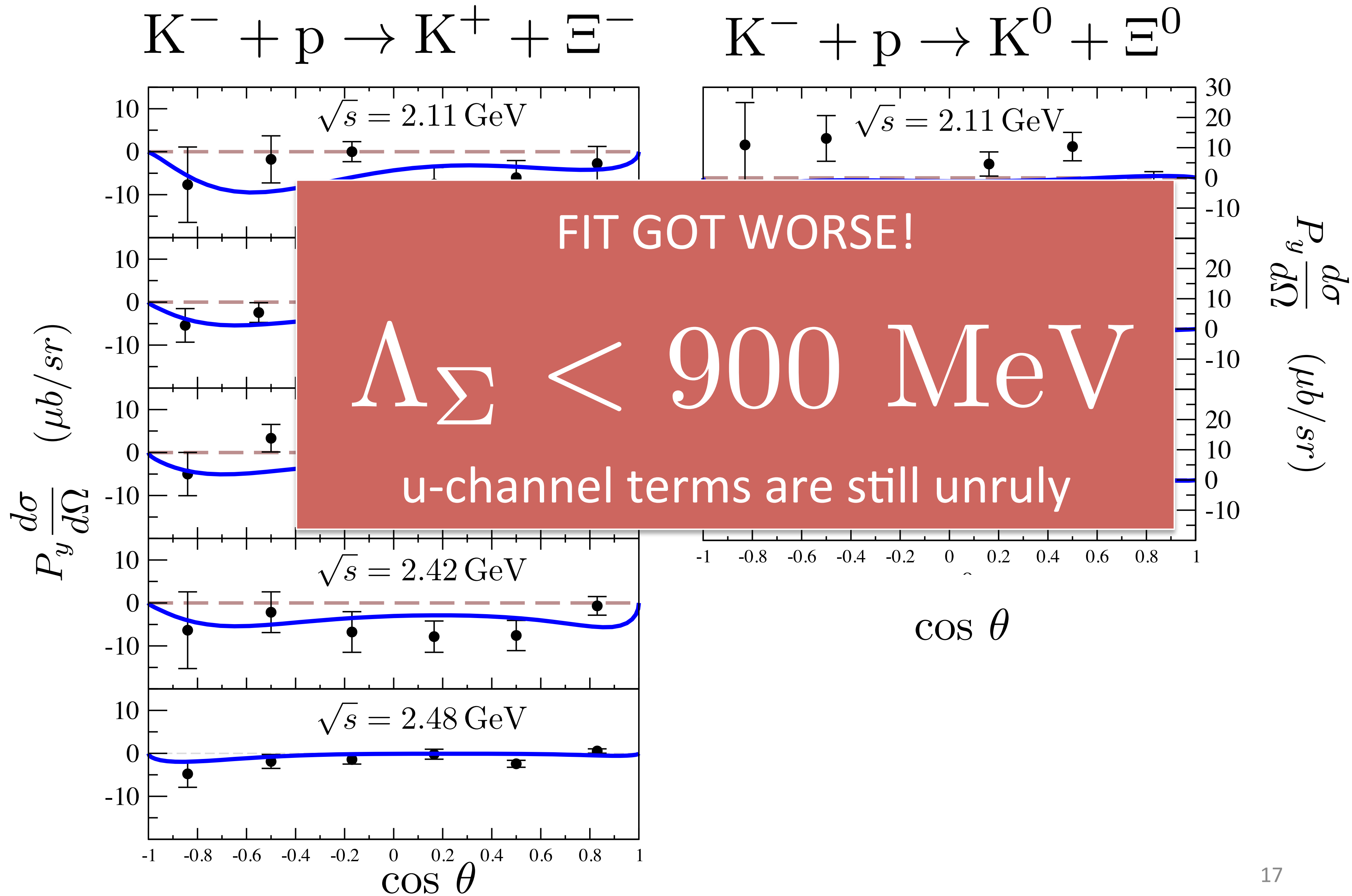


KN→KΞ : model results



FIT GOT WORSE!

$$\Lambda_\Sigma < 900 \text{ MeV}$$

u-channel terms are still unruly

Attempt #3:
Use contact term to help account for background

KN→KΞ : model description

Form Factors at each vertex:

$$f(s) = \frac{\Lambda^4}{\Lambda^4 + (s - m_Y^2)^2}$$

$$f(u) = \frac{\Lambda^4}{\Lambda^4 + (u - m_Y^2)^2}$$

Contact term

$$M_{\uparrow\uparrow} = M_{\downarrow\downarrow} = \sum a_L(s) \mathrm{P}_L(\cos\theta)$$

$$M_{\uparrow\downarrow} = -M_{\downarrow\uparrow} = \sum b_L(s) \mathrm{P}_L^1(\cos\theta)$$

up to L=2

$$T = V + VGT$$

$$T = T^P + T^{NP}$$
$$V = V^P + V^{NP}$$

$$T^P \to \sum_r |F_r\rangle S_r \langle F_r| \qquad \mathrm{s-channel}$$

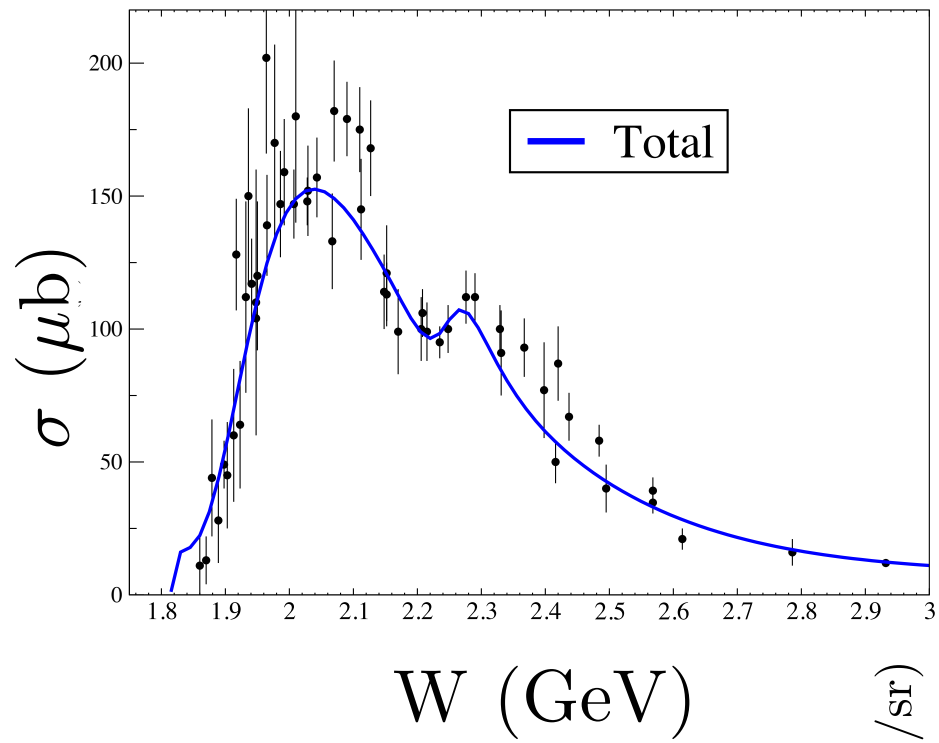
$$T^{NP} = V^{NP} + V^{NP} G T^{NP}$$

u – channel contact

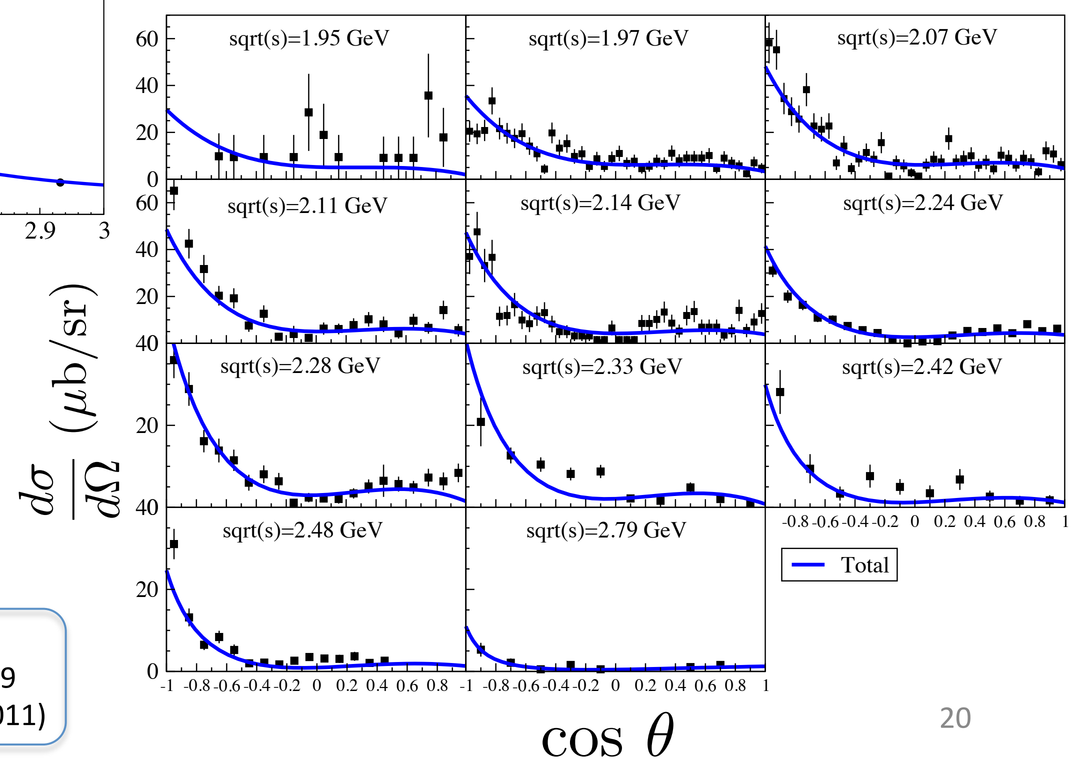
$KN \to K\Xi$: model results

$$K^- + p \to K^+ + \Xi^-$$

$$\frac{\chi^2}{N} = 1.70$$



	J^P		J^P
Λ	$\frac{1}{2}^+$	Σ	$\frac{1}{2}^+$
$\Lambda(1820)$	$\frac{5}{2}^+$	$\Sigma(1385)$	$\frac{3}{2}^+$
		$\Sigma(1750)$	$\frac{1}{2}^-$
		$\Sigma(2250)$	$\frac{3}{2}^+$



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KN→KΞ : model results

$$K^- + p \rightarrow K^+ + \Xi^-$$

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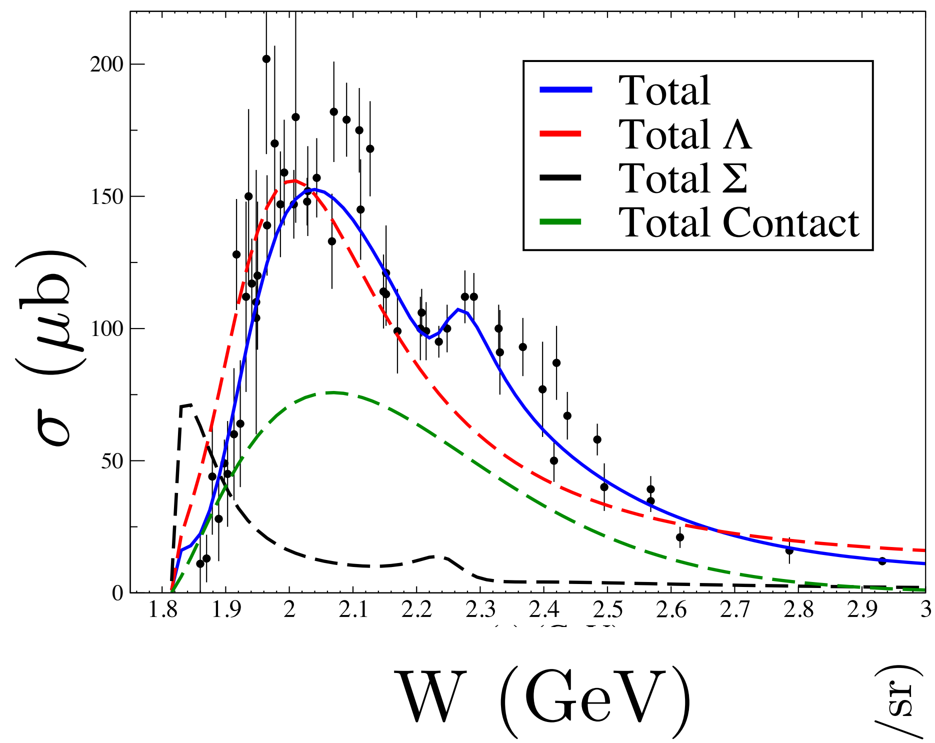

	J^P		J^P
Λ	$\frac{1}{2}^+$	Σ	$\frac{1}{2}^+$
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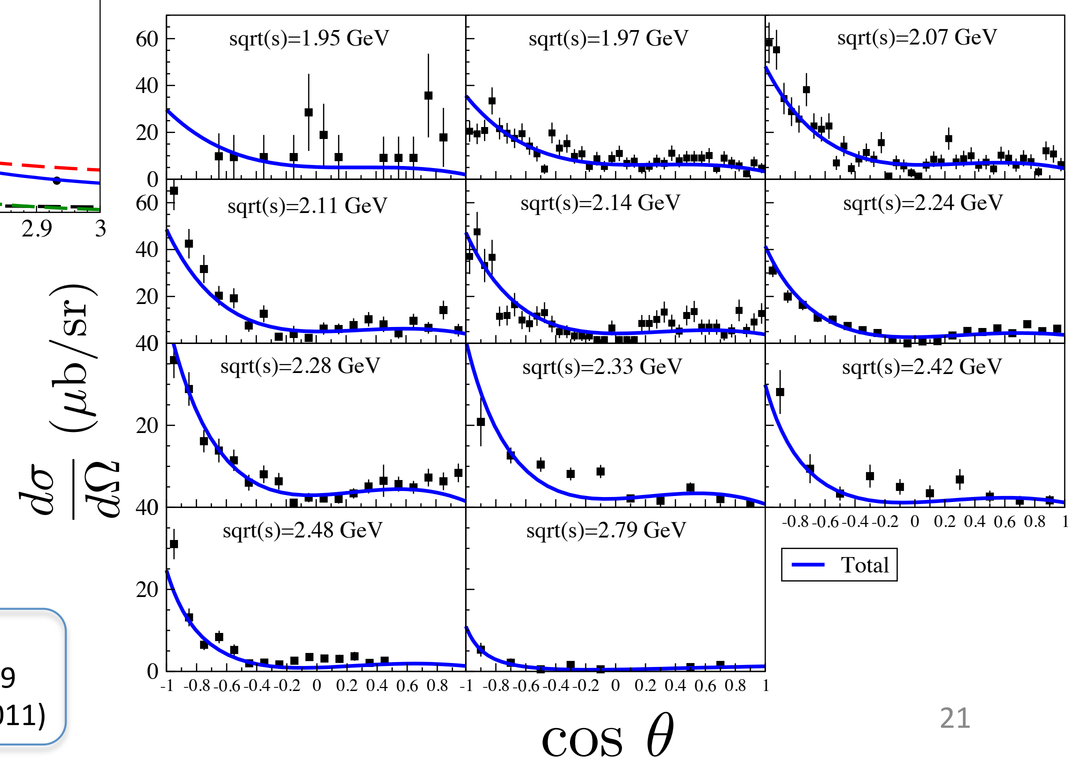

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KN→KΞ : model results

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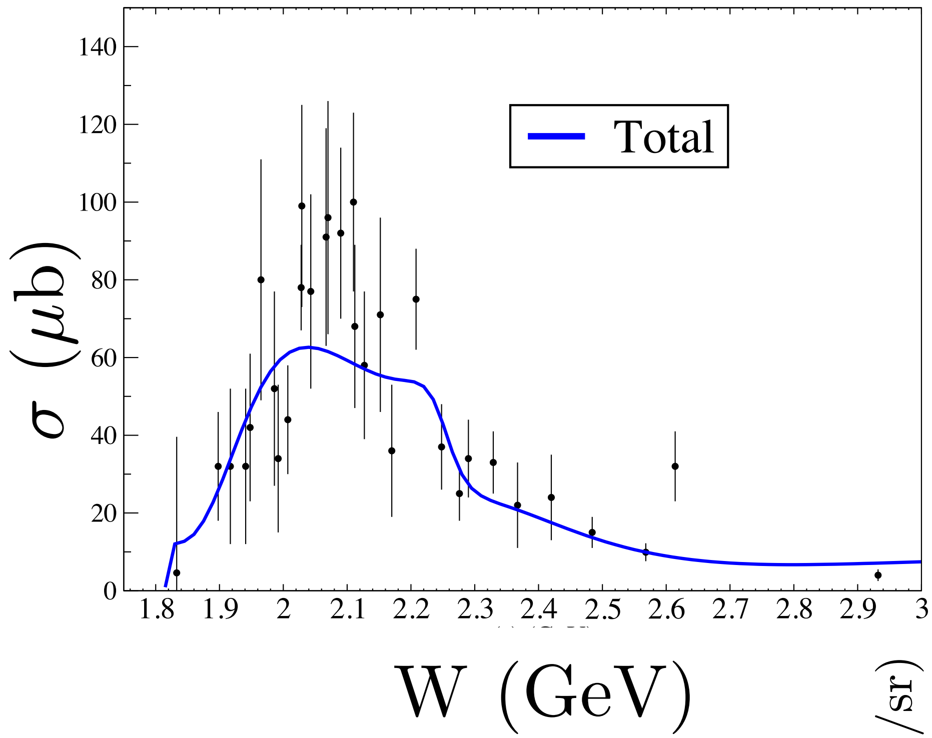
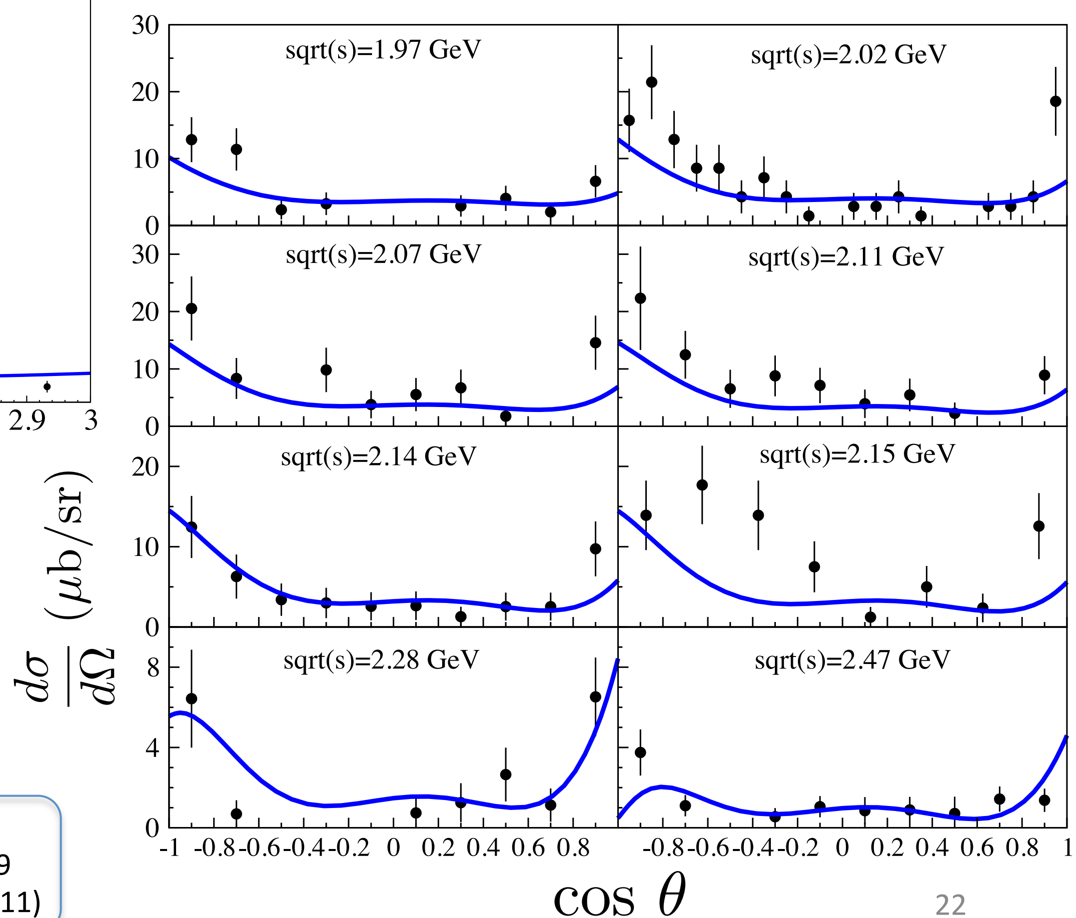
$$K^- + p \rightarrow K^0 + \Xi^0$$





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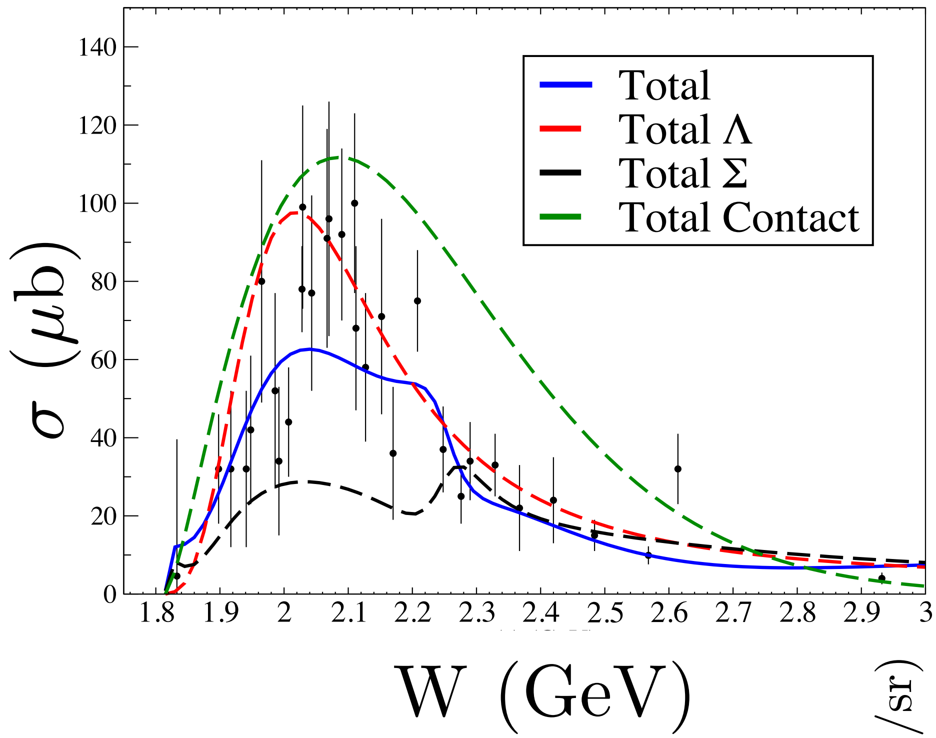

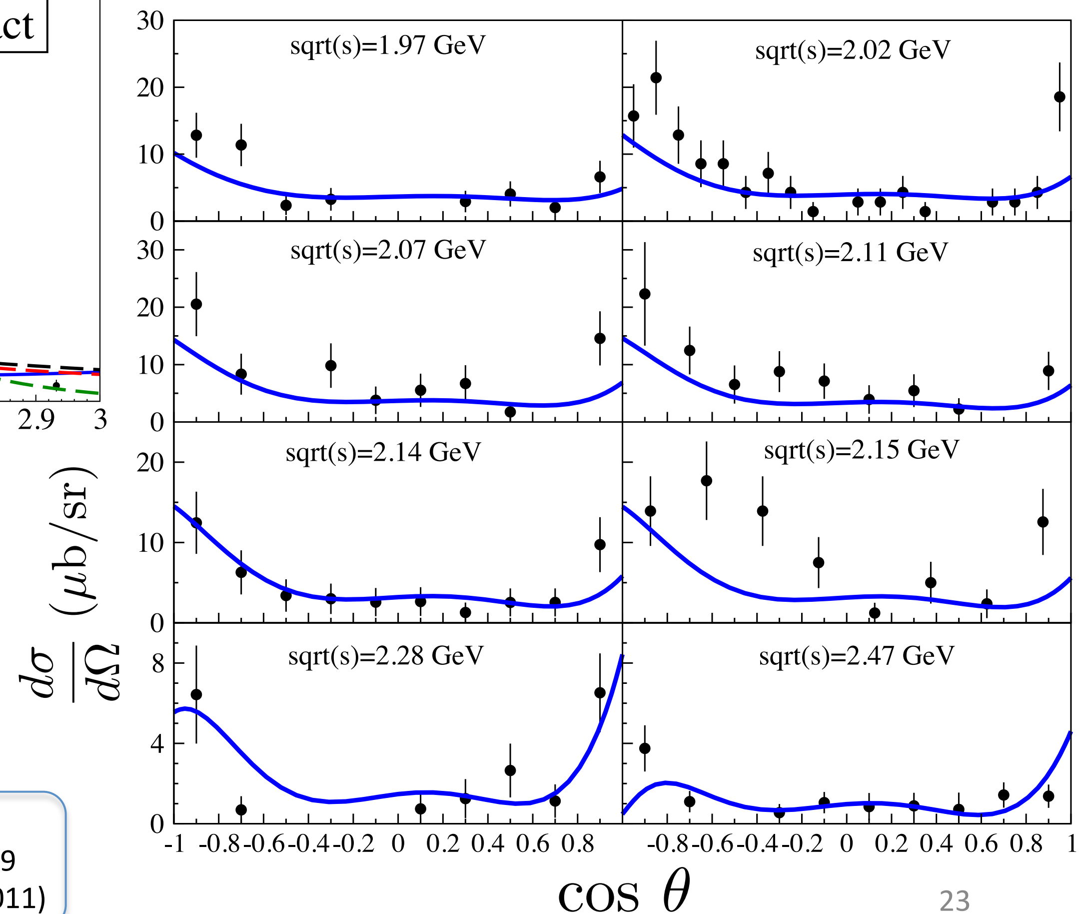

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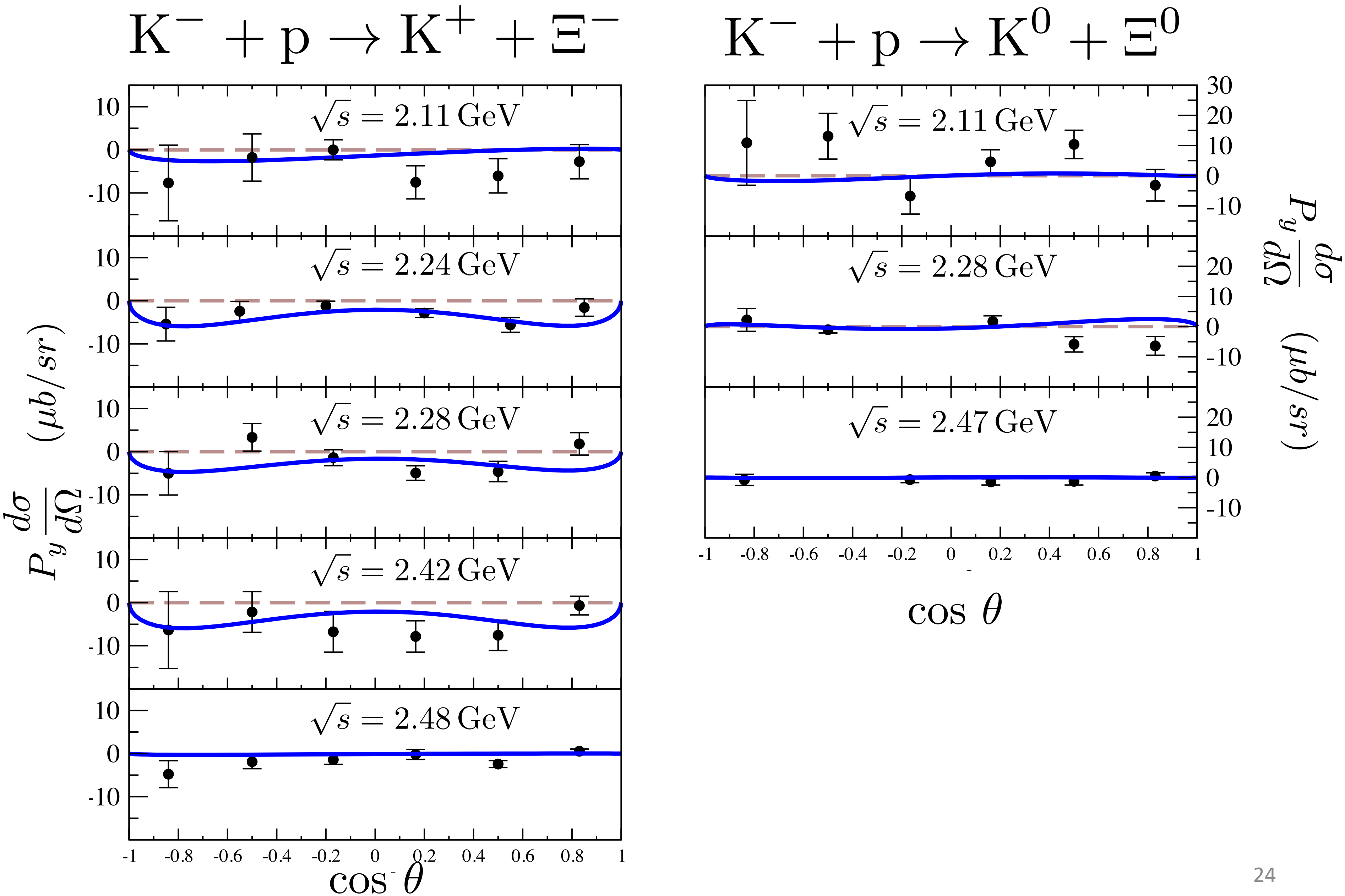


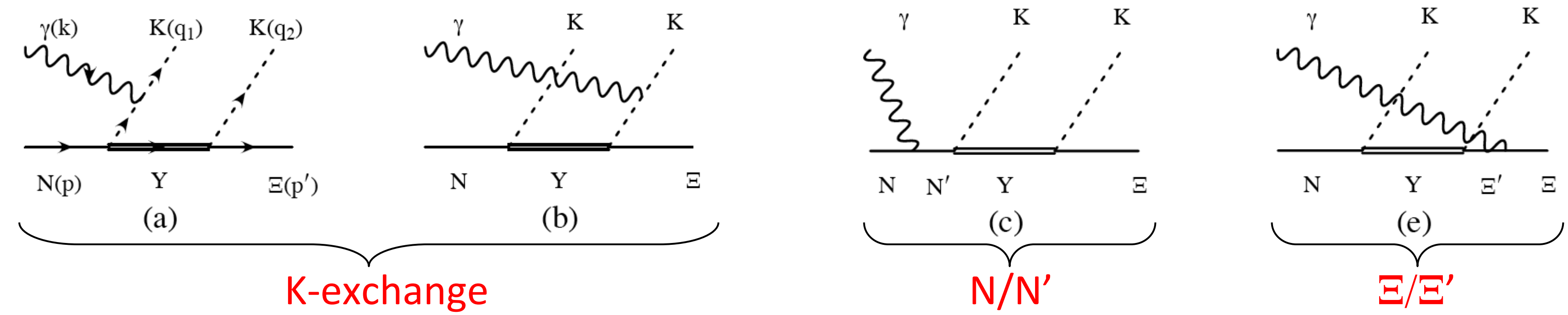
KN→KΞ : summary

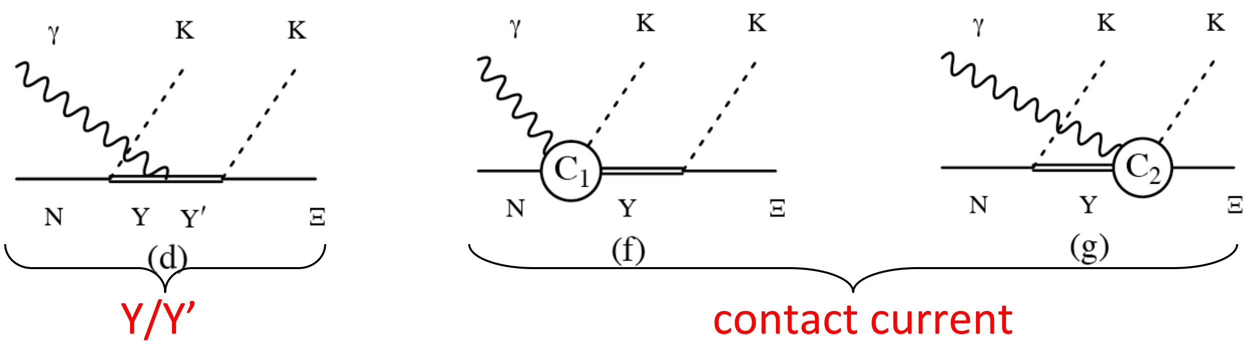
# of Y^*	χ^2/N	Result
up to 15	>1.84	UNREASONABLE CUTOFFS
up to 15	>2.63	POOR FIT CUTOFFS STILL NOT ACCEPTABLE
4	1.70	BEST FIT, EFFICIENT

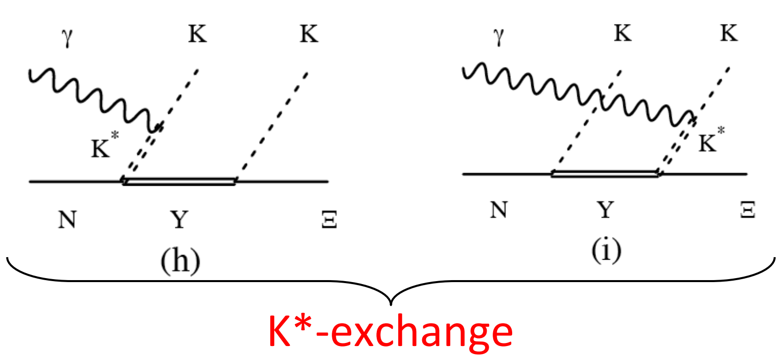
- Using a contact term is a SIMPLE, EFFICIENT, and EFFECTIVE way of modeling these background processes
- $\Sigma(2250)$ is very important

$\gamma N \rightarrow KK\Xi$: model

Nakayama, Oh and Haberzettl (PRC74, ’06)
Man, Oh and Nakayama (PRC83, ‘12)







+ ($K_1(q_1) \leftrightarrow K_2(q_2)$)

$\gamma N \rightarrow K K \Xi$: results

- Fit cross sections
- High spin resonances necessary
- SDM analysis for this reaction channel is in the works
- Will be studied in a combined analysis with
  K-bar reaction

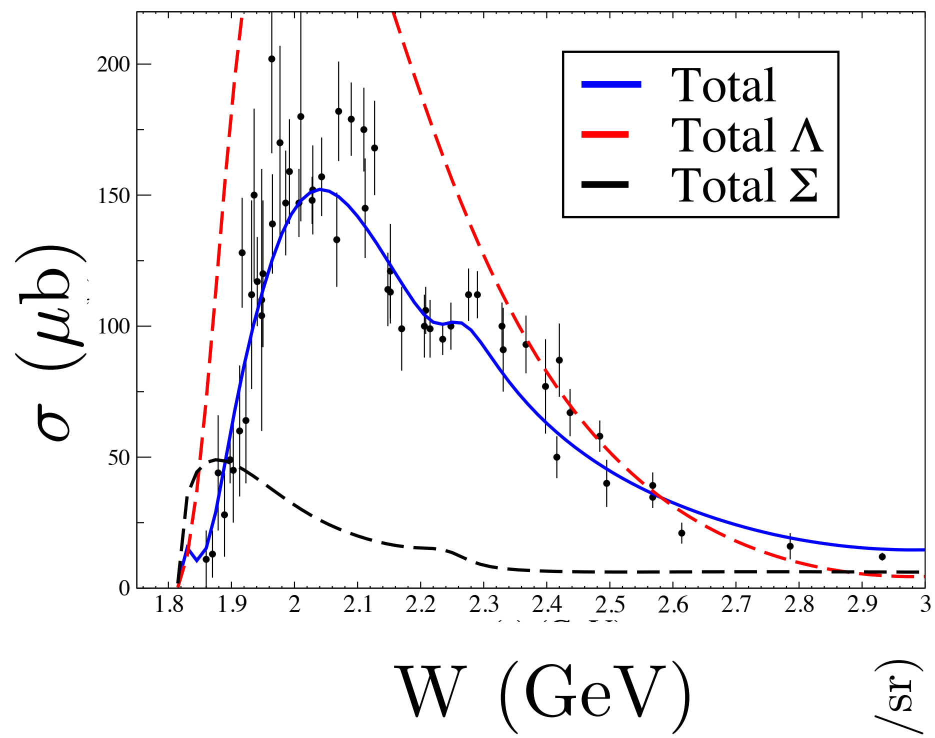
Conclusions and Future Studies

- Ξ Baryon physics is NOT well studied
  - upcoming experiments will be studying Ξ production in different reactions
- Effective Lagrangian model reproduced the existing differential cross section and polarization data
  - Trouble with cut-offs in form factors, introduction of a contact term is a more efficient means of accounting for 'background' processes
- Will be doing a consistent analysis of existing data using this approach
  - photo-production, pion-induced, pp reactions

THANK YOU!

KN→KΞ : model results

$$K^- + p \rightarrow K^+ + \Xi^-$$

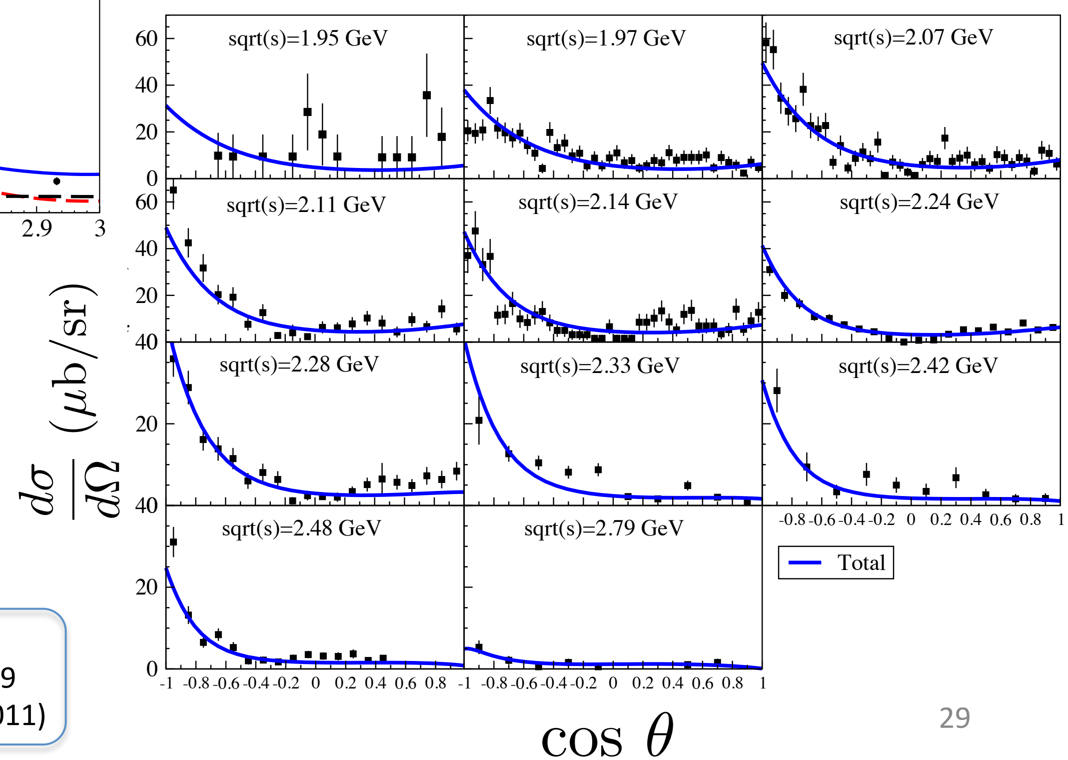


HYPERON RESONANCES

HERE IS DIFF CUT_OFFS

Here show channel contributions

Which resonances are contributing?



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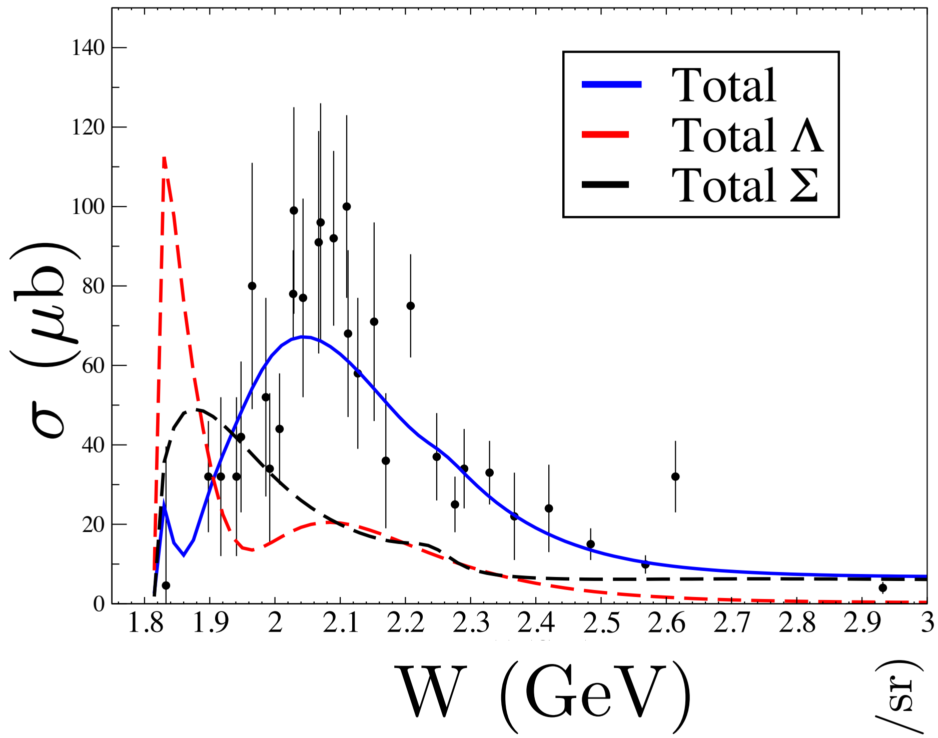
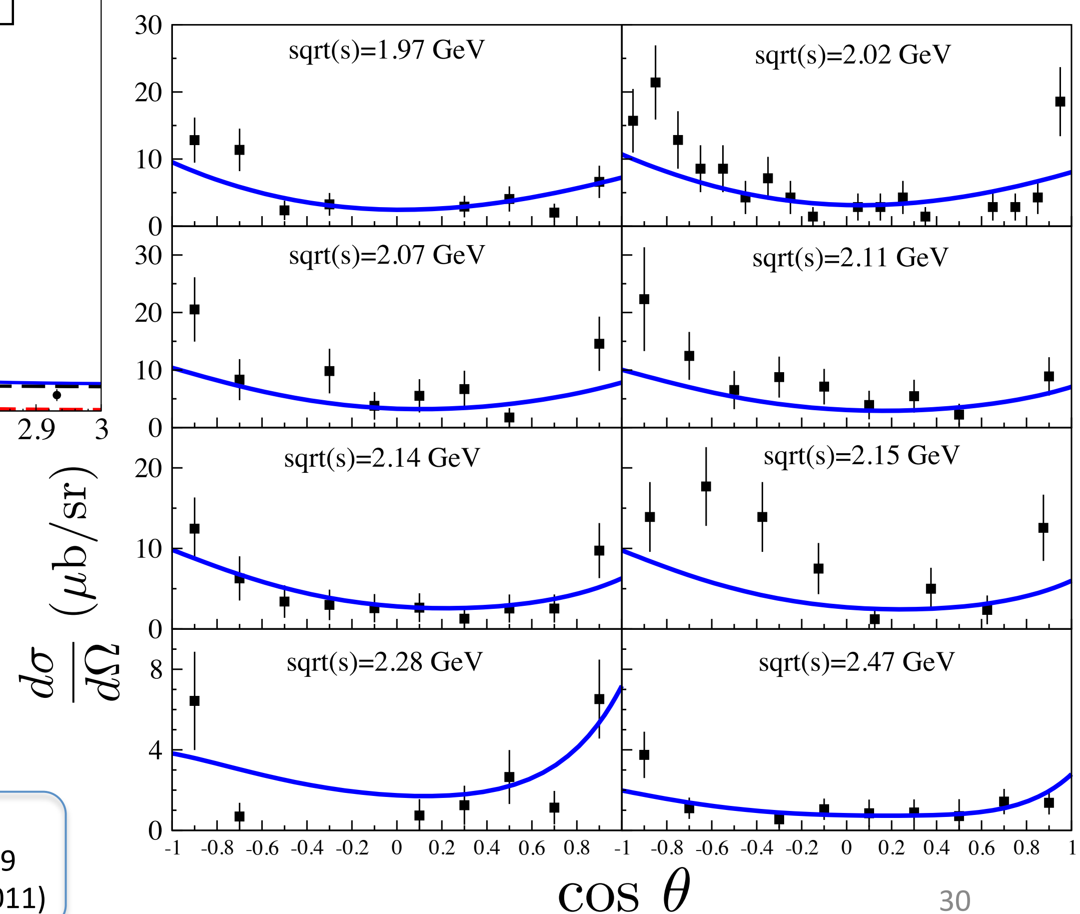


HYPERON RESONANCES

HERE IS DIFF CUT_OFFS

Neutral production



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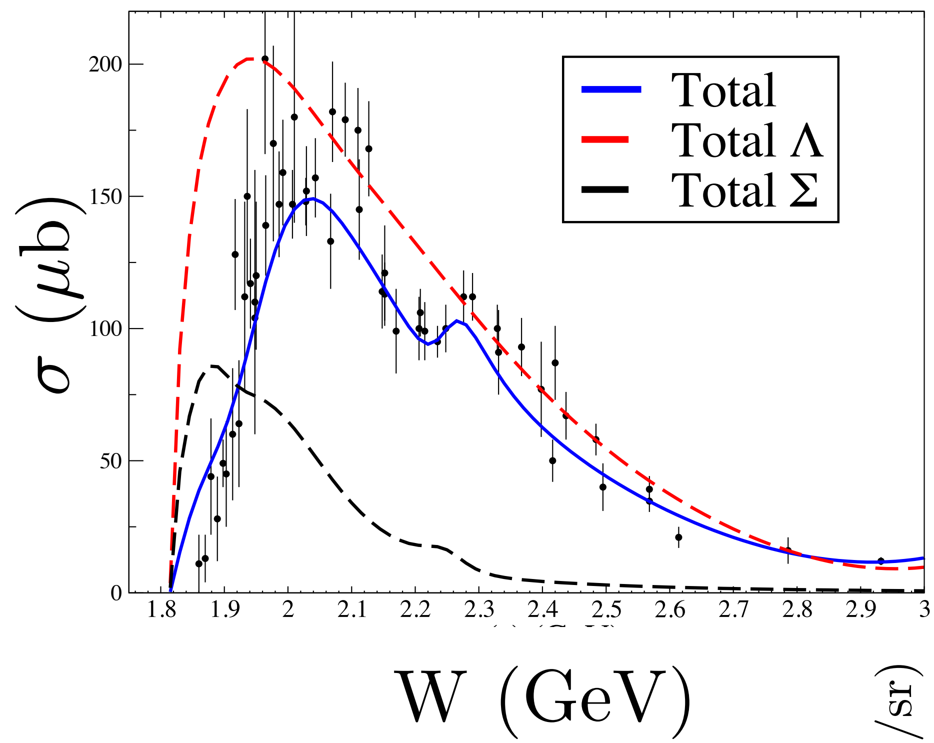
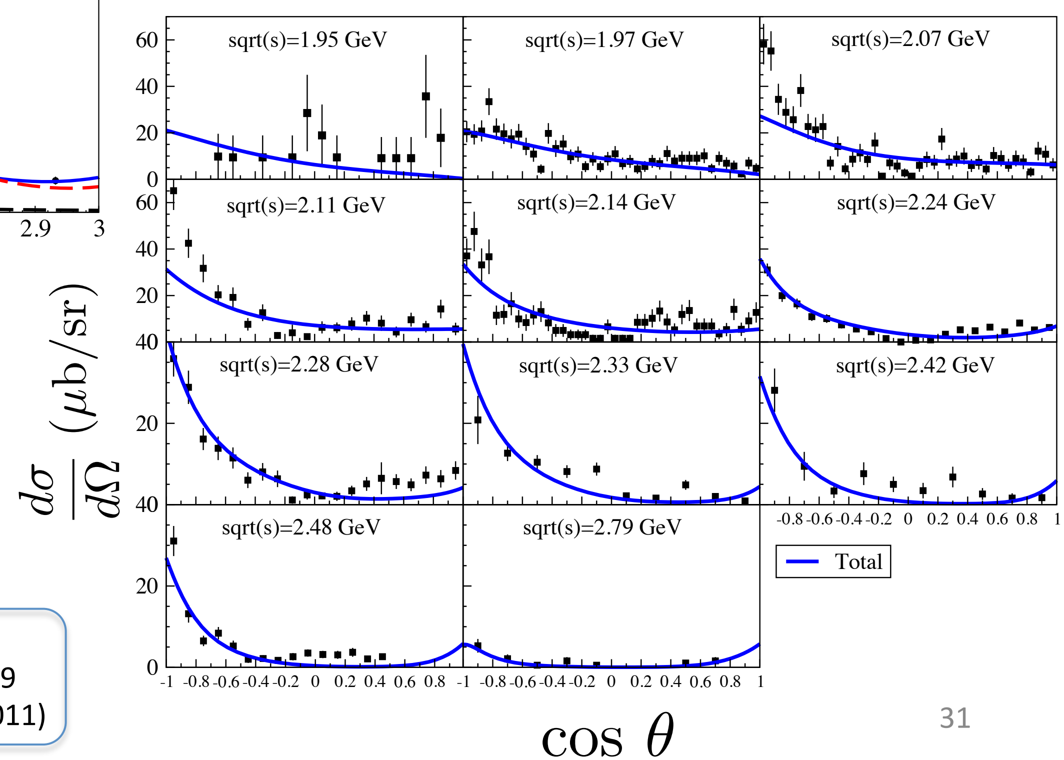


HYPERON RESONANCES

HERE IS SAME CUT_OFFS

Here show channel contributions

Which resonances are contributing?



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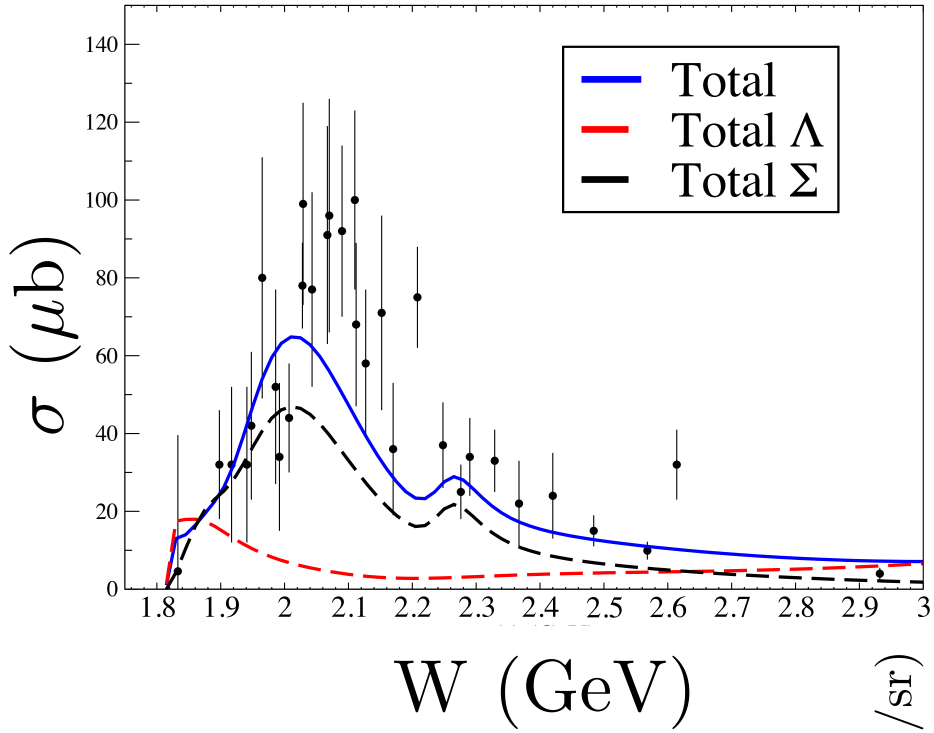
KN→KΞ : model results

$$K^- + p \rightarrow K^0 + \Xi^0$$



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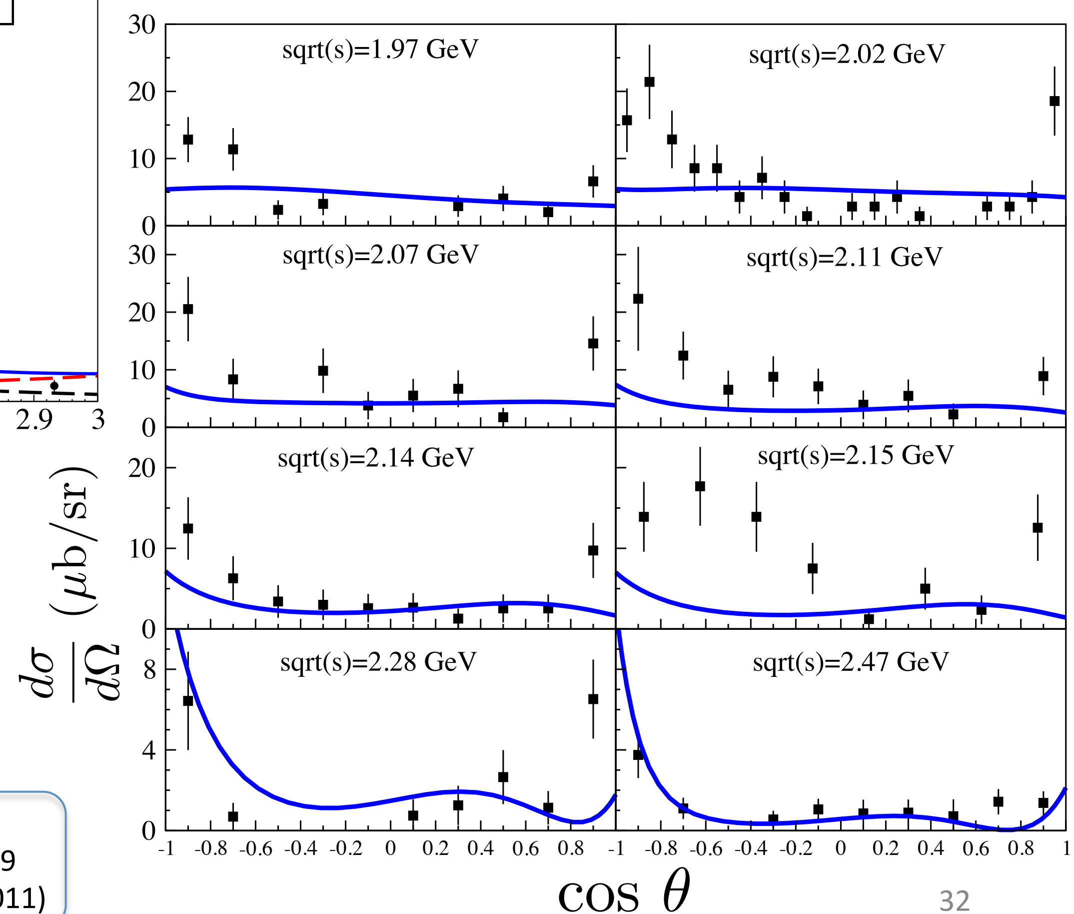
Neutral production



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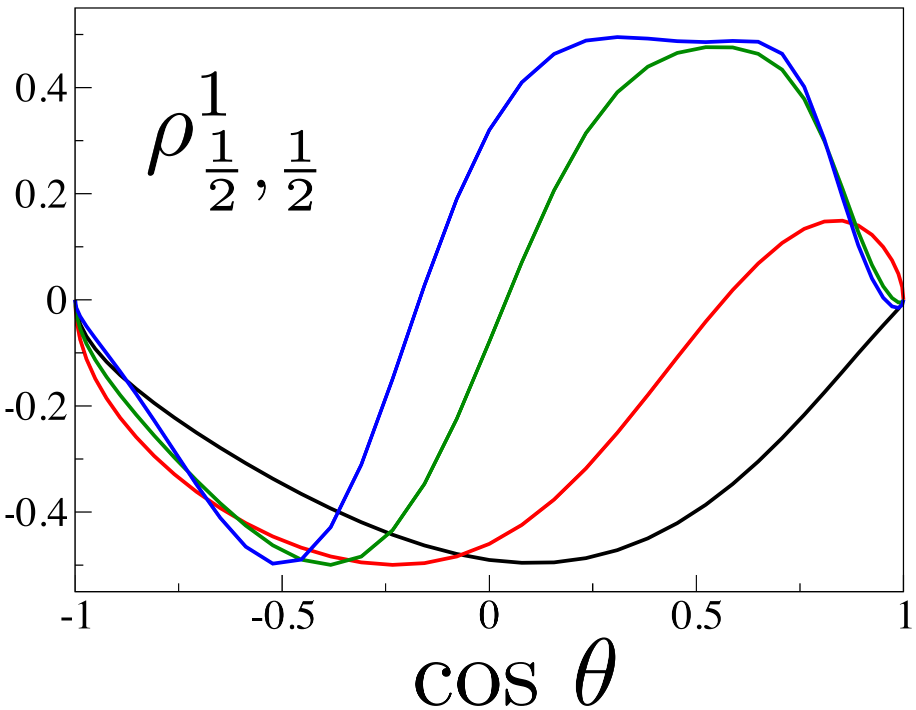
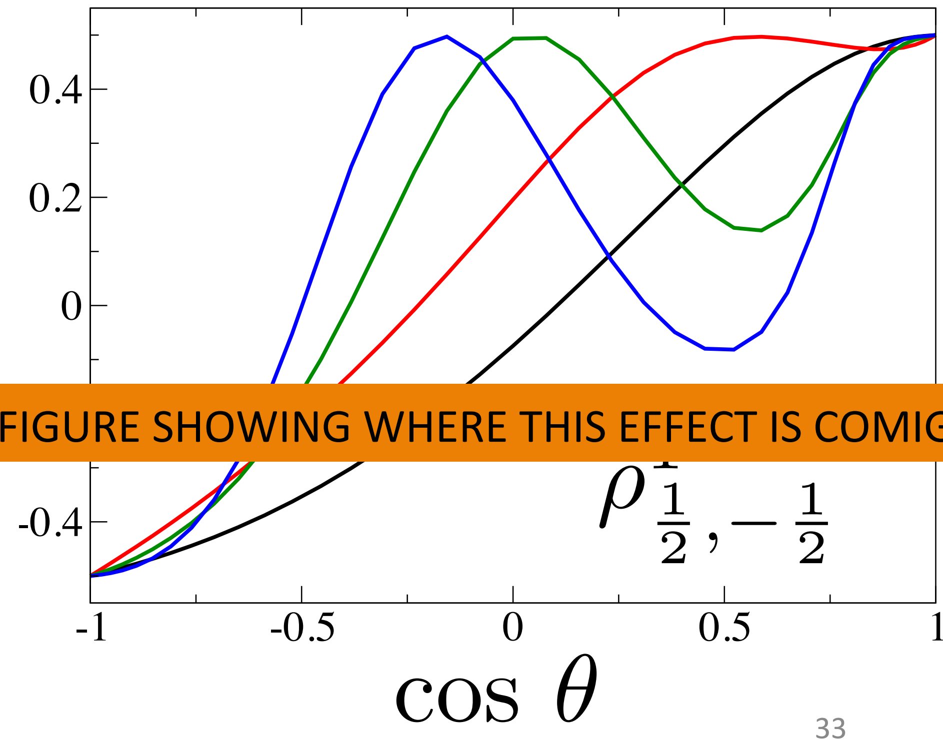
KN→KΞ : model results

$\sqrt{s} = 2.0$ GeV
$\sqrt{s} = 2.1$ GeV
$\sqrt{s} = 2.2$ GeV
$\sqrt{s} = 2.3$ GeV





IF I USE SOEMTHIGN LIKE THIS, HAVE ANOTHER FIGURE SHOWING WHERE THIS EFFECT IS COMIGI

Multistrangeness physics!!!!

Motivation

- Cascade baryons should be studied as an integral part of the baryon spectroscopy program:
  - JLab: photon-induced productions (data for g.s. Ξ: L. Guo et al., PRC76, '07)
  - J-PARC: pion- & anti-kaon-induced productions
  - FAIR: anti-nucleon-induced productions

References here

- Cascade physics has been studied only very little:
  - SU(3) allows as many cascades as the N* and Δ resonances combined (~ 44). However, only 11 cascades have been seen so far:

Particle	$I(J^P)$	Rating	Particle	$I(J^P)$	Rating
Ξ(1318)	$1/2(1/2^+)$	****	Ω(1672)	$0(3/2^+)$	****
Ξ(1530)	$1/2(3/2^+)$	****	Ω(2250)	$0(?^?)$	***
Ξ(1620)	$1/2(?^?)$	*	Ω(2380)	$?(?^?)$	**
Ξ(1690)	$1/2(?^?)$	***	Ω(2470)	$?(?^?)$	**
Ξ(1820)	$1/2(3/2^-)$	***			
Ξ(1950)	$1/2(?^?)$	***			
Ξ(2030)	$1/2(\geq 5/2^?)$	***			
Ξ(2120)	$1/2(?^?)$	*			
Ξ(2250)	$1/2(?^?)$	**			
Ξ(2370)	$1/2(?^?)$	**			
Ξ(2500)	$1/2(?^?)$	*			

$$\bar{K} + N \to K + \Xi^*$$

$$\mathrm{J^P} = \frac{3}{2}^{\pm}$$

$$\rho^0_{\frac{3}{2},\frac{3}{2}} = |\mathcal{H}_2|^2 + |\mathcal{H}_1|^2 \qquad \rho^0_{\frac{1}{2},\frac{1}{2}} = |\mathcal{H}_4|^2 + |\mathcal{H}_3|^2$$

$$\rho^3_{\frac{3}{2},\frac{3}{2}} = -|\mathcal{H}_2|^2 + |\mathcal{H}_1|^2 \qquad \rho^3_{\frac{1}{2},\frac{1}{2}} = -|\mathcal{H}_4|^2 + |\mathcal{H}_3|^2$$

$$\rho^1_{\frac{3}{2},\frac{1}{2}} = \mathcal{H}_1\mathcal{H}_4^* + \mathcal{H}_2\mathcal{H}_3^*$$

$$\rho^3_{\frac{3}{2},\frac{1}{2}} = -\mathcal{H}_2\mathcal{H}_4^* + \mathcal{H}_1\mathcal{H}_3^* \qquad \rho^0_{\frac{3}{2},\frac{1}{2}} = \mathcal{H}_2\mathcal{H}_4^* + \mathcal{H}_1\mathcal{H}_3^*$$

$$(-1)^{\frac{3}{2}-\lambda'}\,\frac{i\rho^2_{\lambda,-\lambda'}}{\rho^0_{\lambda,\lambda'}} = (-1)^{\frac{3}{2}-\lambda'}\,\frac{\rho^1_{\lambda,-\lambda'}}{\rho^3_{\lambda,\lambda'}} = \pi_\Xi$$

Benjamin C. Jackson, Yongseok Oh, H. Haberzettl, and K. Nakayama Phys. Rev. C 89, 025206

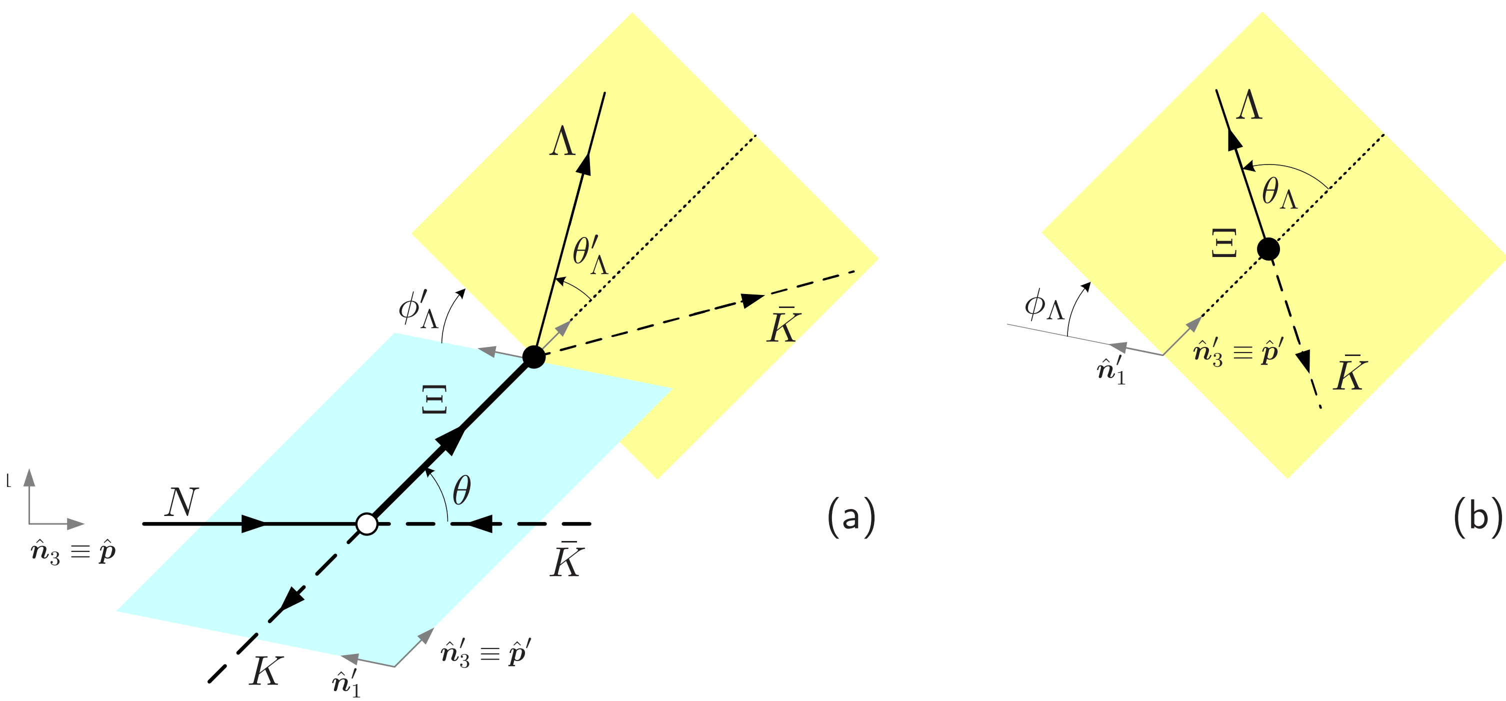
Conclusions and Future Studies

- SDM formalism is very useful for analysis of production of higher spin Baryons
- We can extract more information than just $\mathrm{J^P}$ from the decay distribution.
  - Tells us a lot about production amplitude
- SDM formalism is a universal way to study Ξ, Ξ^* production
  - Wish to apply this analysis to other production techniques (photo-production)

$H(l, m, L, M)$

$$H(l,m,L,M) \equiv \int I(\Omega_\Lambda, \Omega_p) \mathrm{D}^L_{M,m}(\Omega_\Lambda) D^l_{m,0}(\Omega_p) d\Omega_\Lambda d\Omega_p$$

Decay distribution of Ξ and Λ .
Ω_Λ : direction of Λ in Ξ rest frame.
Ω_p : direction of p in Λ rest frame.



$H(l, m, L, M)$

$$\frac{H(1, \pm 1, L, M)}{H(1, 0, L, M)} = \pi_{\Xi}(-)^{\mathrm{J}+\frac{1}{2}} \frac{2\mathrm{J}+1}{\sqrt{2L(L+1)}}$$

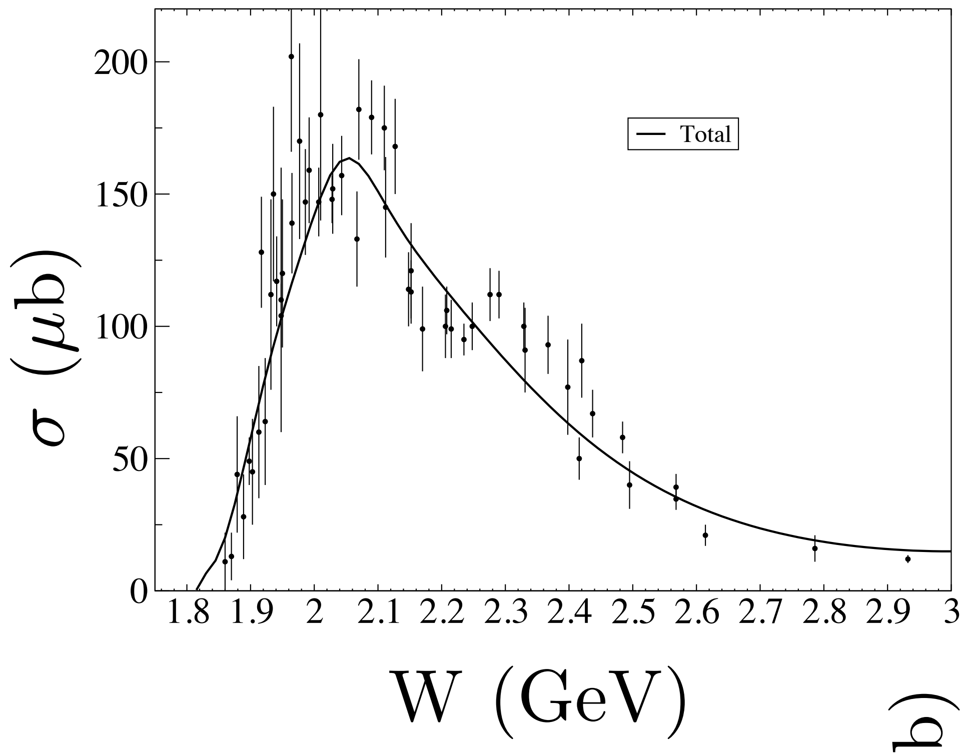
S.F. Biagi, et al, Z. Phys. C34, 175 (1987)

$$\frac{H(0, 0, L, M)}{H(0, 0, 0, 0)} \sim \frac{t^*_{L,M}}{t^*_{0,0}} \qquad \text{for even } L$$

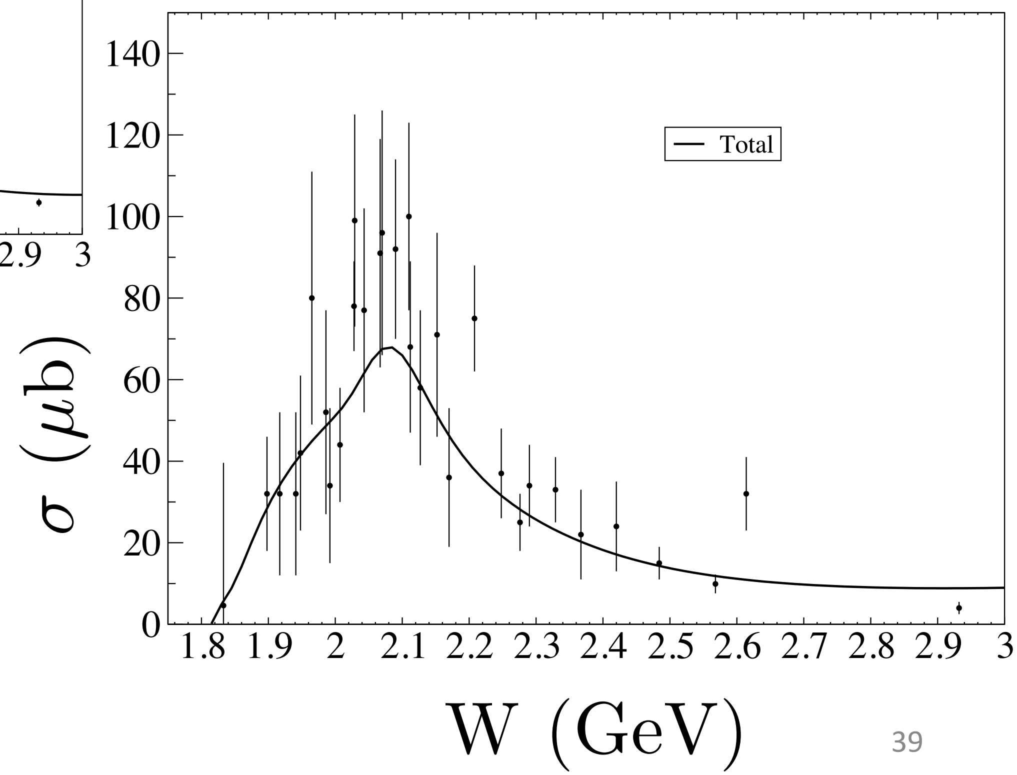
$$\frac{H(1, 0, L, M)}{H(0, 0, 0, 0)} \sim \alpha_{\Lambda} \frac{t^*_{L,M}}{t^*_{0,0}} \qquad \text{for odd } L$$

$KN \rightarrow K\Xi$: model results with contact term

$K^- + p \rightarrow K^+ + \Xi^-$

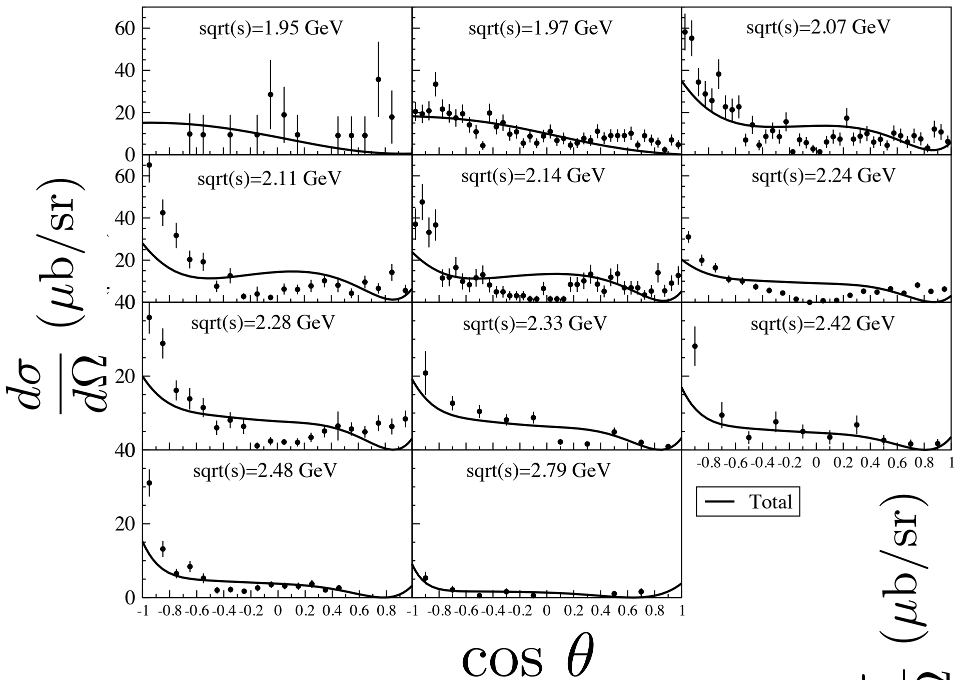


$K^- + p \rightarrow K^0 + \Xi^0$

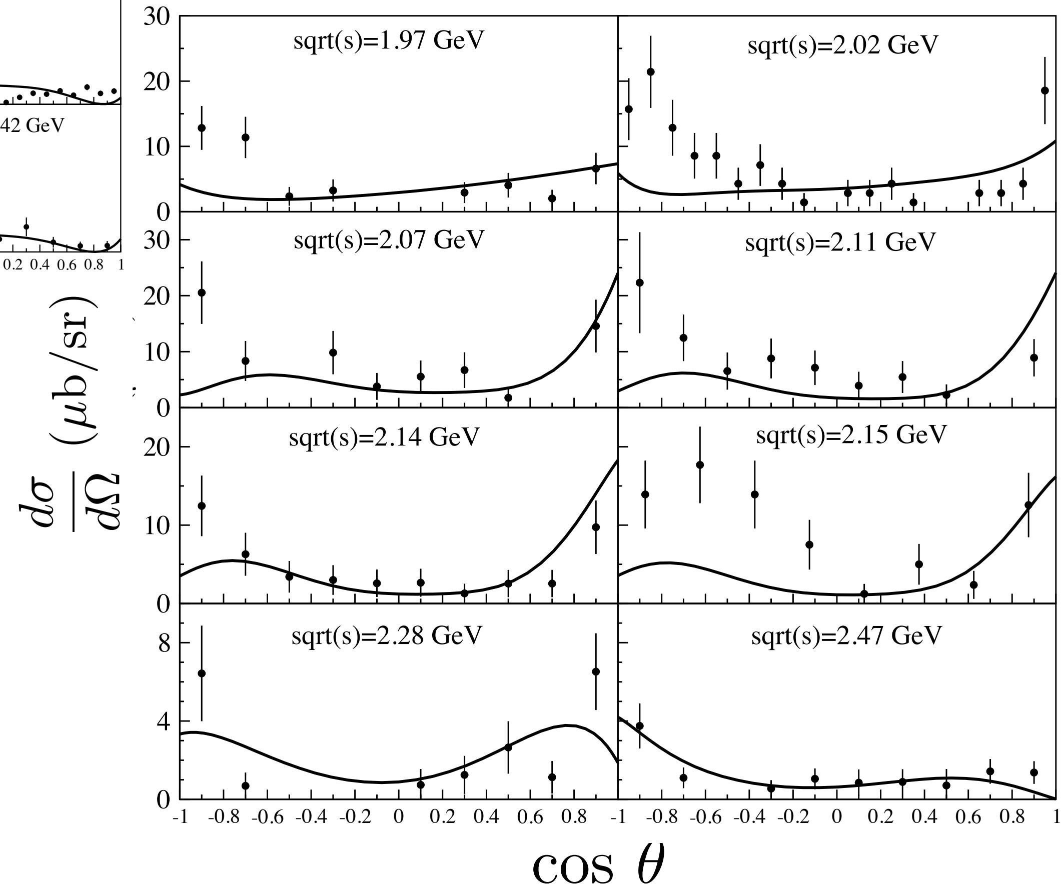


KN→KΞ : model results with contact term

$K^- + p \to K^+ + \Xi^-$



$K^- + p \to K^0 + \Xi^0$



How to determine $\mathrm{J^P}$?

- One method is observing a double decay sequence (strong decay, followed by a weak decay)
  - Examples:
    - $\Xi^* \rightarrow \Xi + \pi$
      then $\Xi \rightarrow \Lambda + \pi$
    - $\Xi^* \rightarrow \Lambda + \bar{K}$
      then $\Lambda \rightarrow p + \pi^-$

$H(l, m, L, M)$

$$H(l,m,L,M) \equiv \int I(\Omega_\Lambda, \Omega_p) \mathrm{D}^L_{M,m}(\Omega_\Lambda) D^l_{m,0}(\Omega_p) d\Omega_\Lambda d\Omega_p$$

$$= t^{*\mathrm{J}}_{L,M} \sum_{\lambda_\Lambda, \lambda'_\Lambda} g^{\Xi}_{\lambda_\Lambda, \lambda'_\Lambda} (\mathrm{J}\lambda'_\Lambda Lm|\mathrm{J}\lambda_\Lambda)(\frac{1}{2}\lambda'_\Lambda lm|\frac{1}{2}\lambda_\Lambda)$$

$$\times \sum_{\lambda_p} g^{\Lambda}_{\lambda_p} (\frac{1}{2}\lambda_p l0|\frac{1}{2}\lambda_p)$$

$$g^{\Xi}_{--} = g^{\Xi}_{++}$$

$$g^{\Xi}_{+-} = g^{\Xi}_{-+} = \pi_{\Xi}(-)^{\mathrm{J}+\frac{1}{2}} g^{\Xi}_{++}$$

$$\frac{g^{\Lambda}_{+} - g^{\Lambda}_{-}}{g^{\Lambda}_{+} + g^{\Lambda}_{-}} = \alpha_\Lambda$$

$$\bar{K} + N \to K + \Xi^*$$

$$\mathrm{J^P} = \frac{1}{2}^{\pm}$$

- There are 4 possible (complex) spin amplitudes
  - $M_{\uparrow\uparrow}, M_{\uparrow\downarrow}, M_{\downarrow\uparrow}, M_{\downarrow\downarrow}$
  - Reflection symmetry reduces these to 2 independent amplitudes:

As long as quantization axis is in the production plane

$$M_{\uparrow\uparrow} = \pi_\Xi M_{\downarrow\downarrow} \text{ and } M_{\uparrow\downarrow} = -\pi_\Xi M_{\downarrow\uparrow}$$

$$M_{\uparrow_y\downarrow_y} = M_{\downarrow_y\uparrow_y} = 0$$

$$\pi_\Xi = +1$$

$$M_{\uparrow_y\uparrow_y} = M_{\downarrow_y\downarrow_y} = 0$$

$$\pi_\Xi = -1$$

A. Bohr, Nucl. Phys. 10, 486 (1959)

$$\bar{K} + N \to K + \Xi^*$$

$$\mathrm{J^P} = \frac{1}{2}^{\pm}$$

$$t^{*\frac{1}{2}}_{0,0} = \frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}^{\mathrm{unpol}} [1 + \mathrm{P}_y \mathrm{T}_y]$$

$$\sqrt{3} t^{*\frac{1}{2}}_{1,0} = \frac{d\sigma}{d\Omega}^{\mathrm{unpol}} [\mathrm{P}_x \mathrm{K}_{\lambda x} + \mathrm{P}_z \mathrm{K}_{\lambda z}]$$

$$\sqrt{\frac{3}{2}} \left(-t^{*\frac{1}{2}}_{1,1} + t^{*\frac{1}{2}}_{1,-1} \right) = \frac{d\sigma}{d\Omega}^{\mathrm{unpol}} [\mathrm{P}_x \mathrm{K}_{\perp x} + \mathrm{P}_z \mathrm{K}_{\perp z}]$$

$$-i\sqrt{\frac{3}{2}} \left(t^{*\frac{1}{2}}_{1,1} + t^{*\frac{1}{2}}_{1,-1} \right) = \frac{d\sigma}{d\Omega}^{\mathrm{unpol}} [\mathrm{R}_y + \mathrm{P}_y \mathrm{K}_{yy}]$$

$$\bar{K} + N \to K + \Xi^*$$

$$J^P = \frac{1}{2}^{\pm}$$

$$t^{*\frac{1}{2}}_{0,0} = \frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}^{\text{unpol}} [1 + P_y T_y]$$

$$\sqrt{3} t^{*\frac{1}{2}}_{1,0} = \frac{d\sigma}{d\Omega}^{\text{unpol}} [P_x K_{\lambda x} + P_z K_{\lambda z}]$$

$$\sqrt{\frac{3}{2}} \left(-t^{*\frac{1}{2}}_{1,1} + t^{*\frac{1}{2}}_{1,-1} \right) = \frac{d\sigma}{d\Omega}^{\text{unpol}} [P_x K_{\perp x} + P_z K_{\perp z}]$$

$$-i\sqrt{\frac{3}{2}} \left(t^{*\frac{1}{2}}_{1,1} + t^{*\frac{1}{2}}_{1,-1} \right) = \frac{d\sigma}{d\Omega}^{\text{unpol}} [R_y + P_y K_{yy}]$$

$$\bar{K} + N \to K + \Xi^*$$

$$\mathrm{J^P} = \frac{1}{2}^{\pm}$$

$$t^{*\frac{1}{2}}_{0,0} = \frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}^{\mathrm{unpol}} [1 + \mathrm{P}_y \mathrm{T}_y]$$

$$\sqrt{3} t^{*\frac{1}{2}}_{1,0} = \frac{d\sigma}{d\Omega}^{\mathrm{unpol}} [\mathrm{P}_x \mathrm{K}_{\lambda x} + \mathrm{P}_z \mathrm{K}_{\lambda z}]$$

$$\sqrt{\frac{3}{2}} \left(-t^{*\frac{1}{2}}_{1,1} + t^{*\frac{1}{2}}_{1,-1} \right) = \frac{d\sigma}{d\Omega}^{\mathrm{unpol}} [\mathrm{P}_x \mathrm{K}_{\perp x} + \mathrm{P}_z \mathrm{K}_{\perp z}]$$

$$-i\sqrt{\frac{3}{2}} \left(t^{*\frac{1}{2}}_{1,1} + t^{*\frac{1}{2}}_{1,-1} \right) = \frac{d\sigma}{d\Omega}^{\mathrm{unpol}} [\mathrm{R}_y + \mathrm{P}_y \mathrm{K}_{yy}]$$

$$T_y = \pi_\Xi R_y \qquad K_{yy} = \pi_\Xi$$

$$K_{xz} = -\pi_\Xi K_{zx} \qquad K_{xx} = \pi_\Xi K_{zz}$$

$$\bar{K} + N \to K + \Xi^*$$

$$\mathrm{J^P} = \frac{3}{2}^{\pm}$$

- In spin 3/2 there are 4 independent complex spin amplitudes to determine (after considering mirror symmetry).
- Many more observables: 16 $t^{*\frac{3}{2}}_{L,M}$

As long as quantization axis is in the production plane

$$M_{\frac{3}{2},\frac{1}{2}} = \pi_\Xi M_{-\frac{3}{2},-\frac{1}{2}} \qquad M_{\frac{1}{2},\frac{1}{2}} = -\pi_\Xi M_{-\frac{1}{2},-\frac{1}{2}}$$

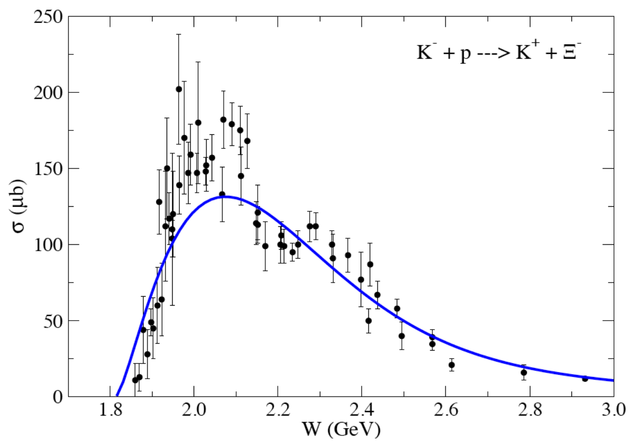
$$M_{\frac{3}{2},-\frac{1}{2}} = -\pi_\Xi M_{-\frac{3}{2},\frac{1}{2}} \qquad M_{\frac{1}{2},-\frac{1}{2}} = \pi_\Xi M_{-\frac{1}{2},\frac{1}{2}}$$

$$M_{\frac{3}{2}y,\frac{1}{2}y} = M_{\frac{1}{2}y,-\frac{1}{2}y} = M_{-\frac{1}{2}y,\frac{1}{2}y} = M_{-\frac{3}{2}y,-\frac{1}{2}y} = 0 \qquad \pi_\Xi = +1$$

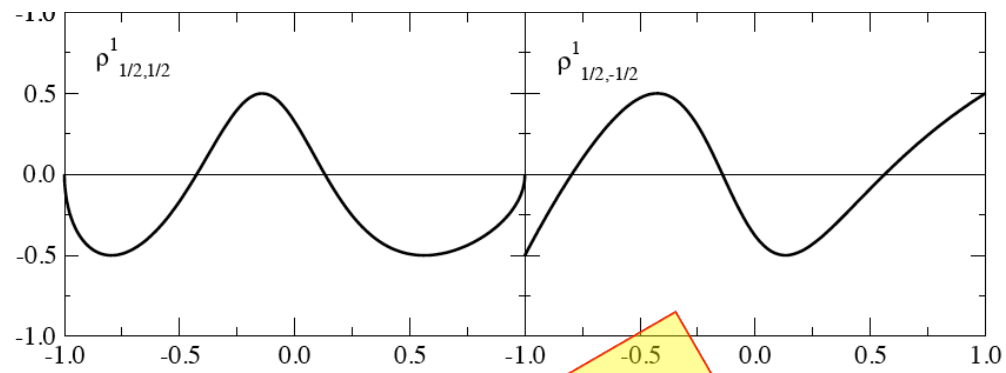
$$M_{\frac{1}{2}y,\frac{1}{2}y} = M_{\frac{3}{2}y,-\frac{1}{2}y} = M_{-\frac{3}{2}y,\frac{1}{2}y} = M_{-\frac{1}{2}y,-\frac{1}{2}y} = 0 \qquad \pi_\Xi = -1$$

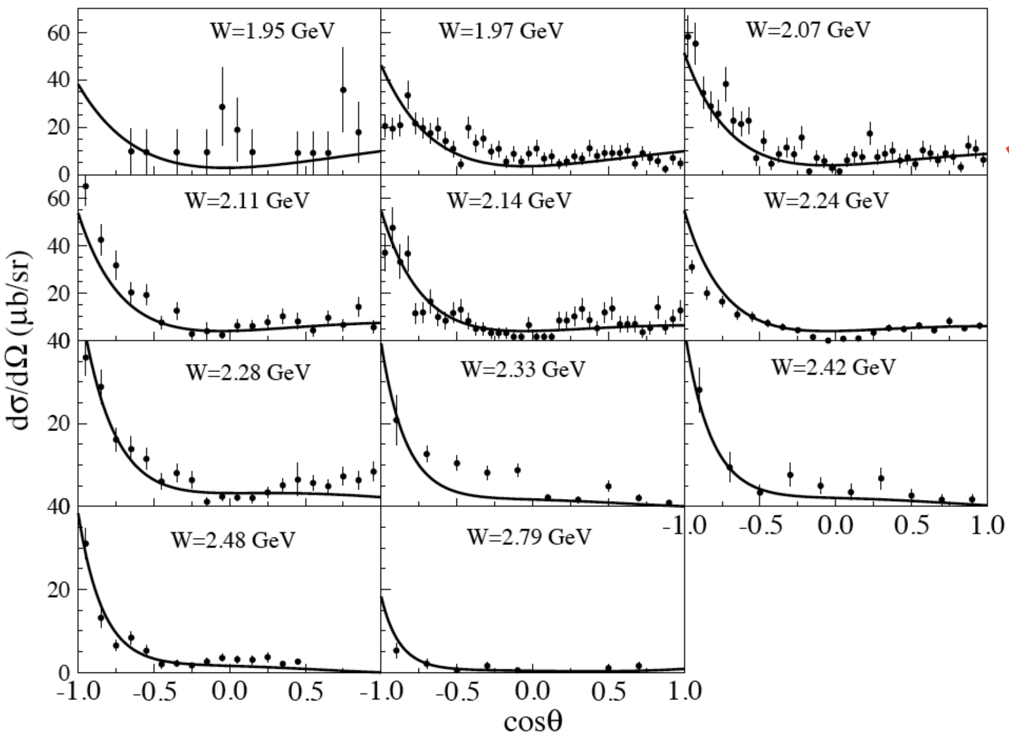
A. Bohr, Nucl. Phys. 10, 486 (1959)

KN→KΞ : model results

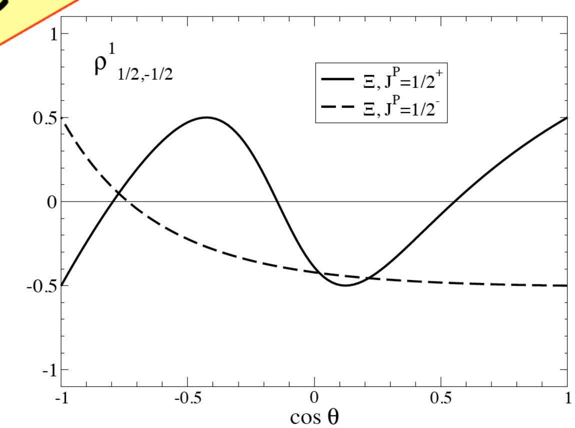


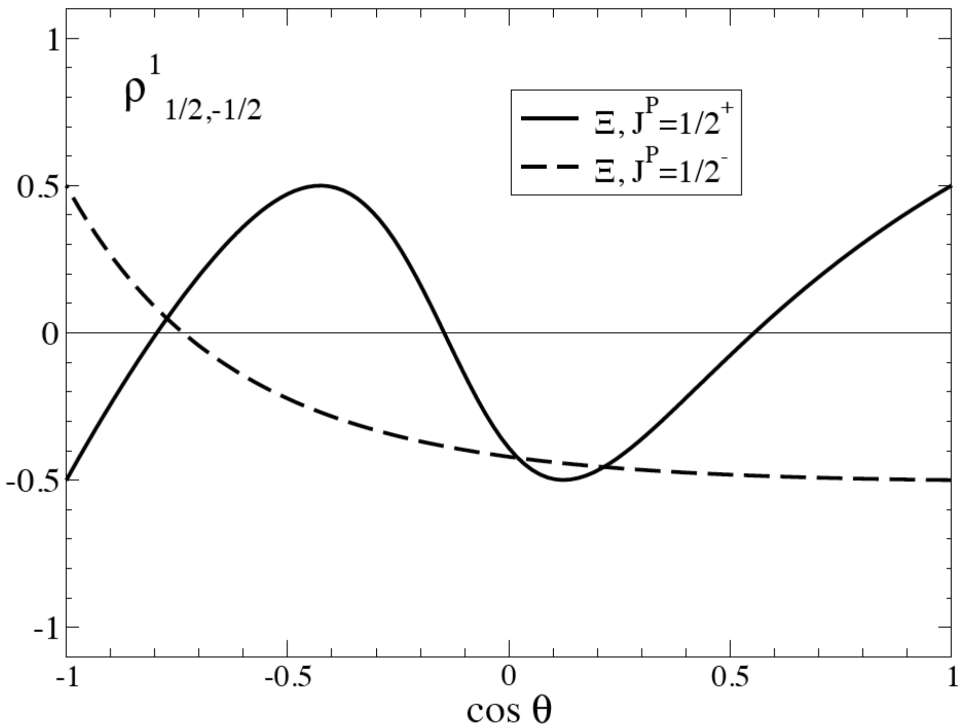
W=1.95 GeV





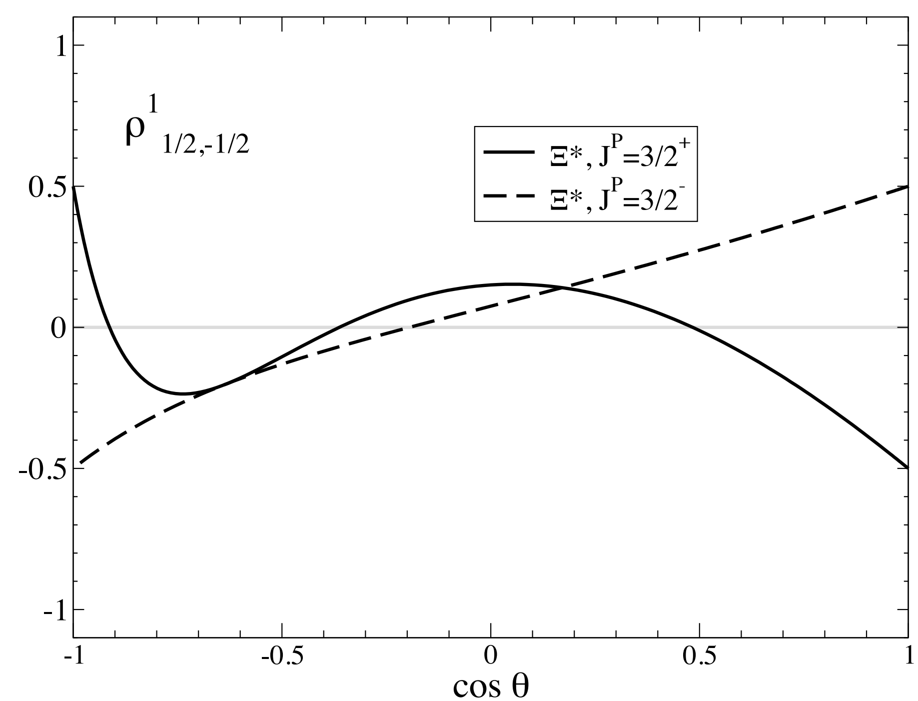
preliminary

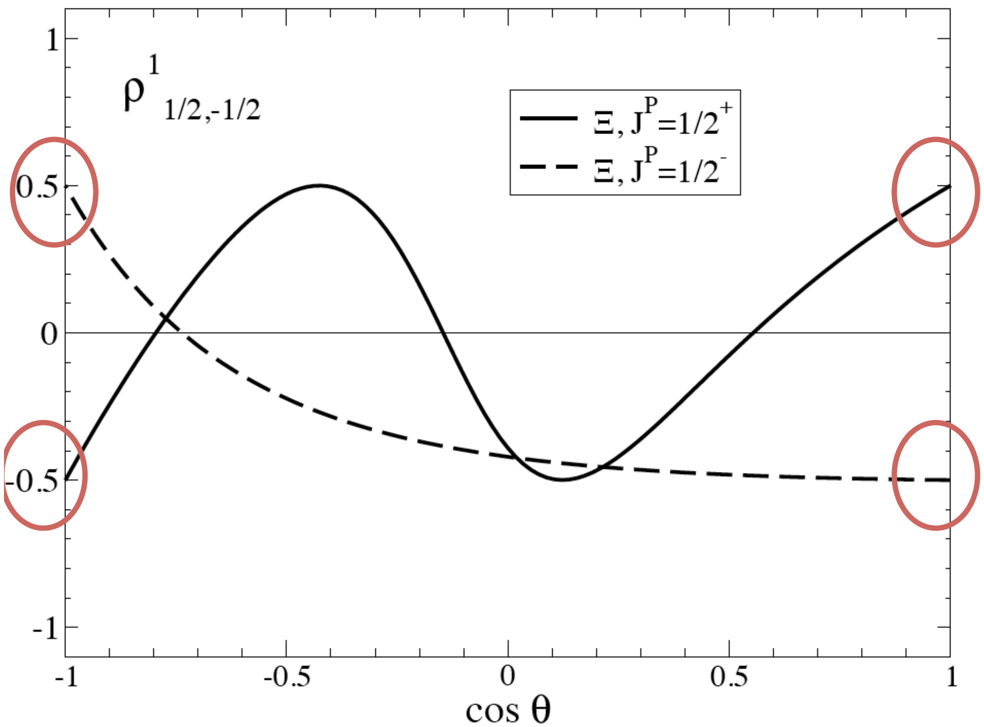




$$\rho^{1}_{\frac{1}{2},-\frac{1}{2}} \sim \rho^{3}_{\frac{1}{2},\frac{1}{2}}$$

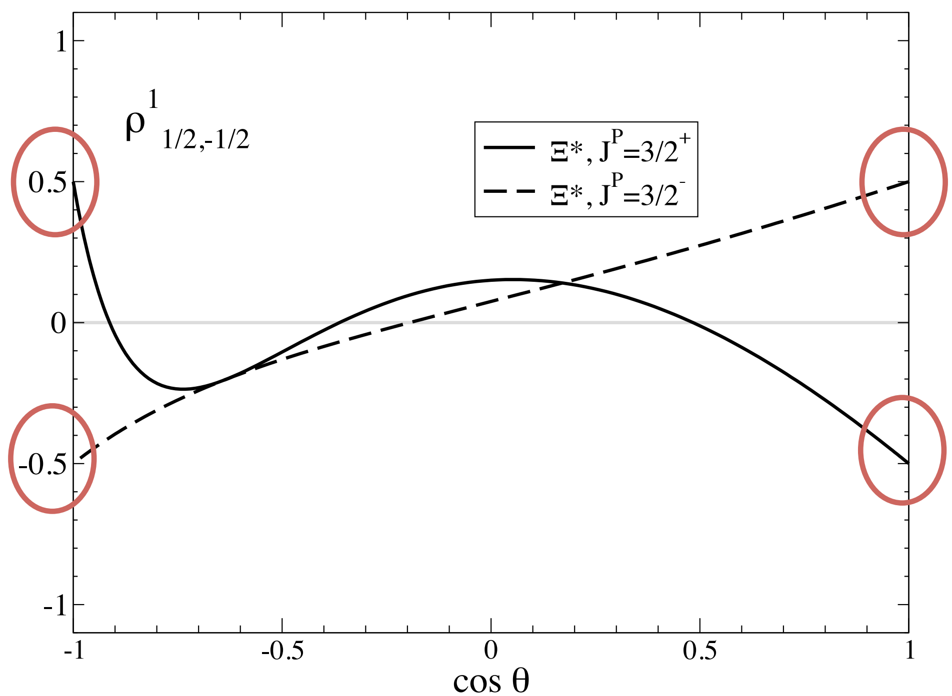
Measurement of a certain SDM element at forward or backward scattering angles is an unambiguous measurement of parity





$$\rho^1_{\frac{1}{2},-\frac{1}{2}} \sim \rho^3_{\frac{1}{2},\frac{1}{2}}$$

Measurement of a certain SDM element at forward or backward scattering angles is an unambiguous measurement of parity



Cascade Baryon(s)

- Uss Xi0, dss Xi-
- Parity of the ground state has yet to be measured, some work on determining JP of some resonances has been done over 20 years ago, JP still unclear.
- Xi(1530), Xi(1820), Xi(1950), Xi(2030) are all listed in the PDG
  - {The Cascade decay can tell us a lot (everything?) about the production mechanism. Not here…}

H(l,m,L,M)

- Define H(l,m,L,M)= int(I(omega1,omega2) * D....)
- Ratios of H(l,m,L,M)'s are equal to .... Allowing us to directly measure J and P
- While other ratios can be used to give us tJ_LM/tj_00
  - Dependent on production amplitude!

$$\frac{H(0,0}{H(0,}$$

$$\frac{H(1,0}{H(0,}$$

for

for o

Model, KbarN -> KXi

- Effective field theory model with hadronic degr of freedom
  - S and u channel hyperon (lambda, sigma) exchanges

Model, gammaN-> KKXi

- Gauge invariant effective field theory
  - Needed higher spin resonances to fit dsig/dM data
  - What affect should we see on the tLM?

Spin-Density Matrices

- (Psi_Xi)(Psi_Xi)^dagger is an operator that contains all the information about the spin-state of the produced cascades.
  - Spin ½ Xi's can be polarized in a certain direction (vector polarization)
  - Spin 3/2 Xi's can be polarized in more ways (vector, rank 2 tensor, rank 3 tensor)

- For Spin-1/2 Xi
  - T00=…
  - T10=…
  - T11=…
  - T1-1=…

The decay

- Define H(l,m,L,M)=…….
- Measuring certain ratios of different H's can tell us the spin-parity of the resonance.
- Measuring the other ratios will allow us to resolve tJLM=….
  - These are directly related to the production reaction.
  - For spin ½ Xi, the only non-zero tJLM's are 0,0 and 1,M. (4 in total!)
  - For spin 3/2 Xi, the only non-zero tJLM's are 0,0 & 1,M & 2,M & 3,M

Spin-1/2 Cascade

- In Kbar+N -> K+Xi, there are 2 complex spin-transition amplitudes.
- In Kbar+N -> K+Xi, originally, there are 8 total (non-zero) observables: sig, Ty, Ry, Kxx,Kyy,Kzz,Kxz,Kzx. Reflection symmetry in the reaction plane says that Ty=pmRy, Kxx=pmKzz, Kyy=pm1, Kxz=pmKzx, so we are left with 4 observables to determine the amplitudes.