Cascade Production in $\bar{K}$- and Photon-induced Reactions

Collaboration:

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Helmut Haberzettl (GWU)

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K. N. (UGA)

KL2016, Feb. 1-3, 2016

Our Ξ collaboration:

- Theoretical investigation of the reactions:
  - $\bar{K}N \to K\Xi$ [J-PARC]
  - $\gamma N \to KK\Xi$ [JLab]

    $\pi N \to KK\Xi$ [J-PARC]

    $p\bar{p} \to \Xi\bar{\Xi}$ [FAIR]

- Build a reliable model to analyze the cascade spectroscopy data:

  Start learning the production mechanism of the established Ξs. [g.s. $\Xi_{1/2+}(1318)$]

To date:

- $\bar{K}N \to K\Xi$: recent calculations:

  Sharov, Korotkikh and Lanskoy (EPJA47, '11),

  Shyam, Scholten and Thomas (PRC84, '11),

  Feijoo, Magas and Ramos (PRC92, '15), UχPT + high-spin resonances

  Kamano, Nakamura, Lee and Sato (PRC90, '14), DCC approach

  they all point to the importance of the S=-1 hyperons

- $\gamma N \to KK\Xi$: no calculation is available so far, except for:

  Liu and Ko (PRC69, '04), in connection with the Ξ_5 production.

  Our group (PRC74, '06; PRC83, '12), analyzing the CLAS data.

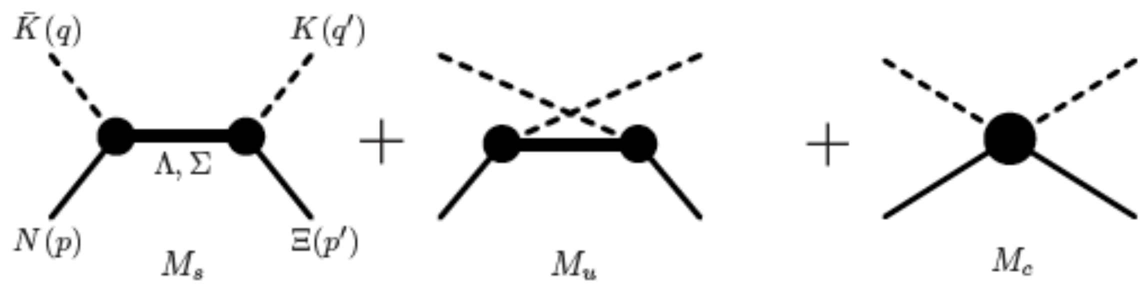
$$\bar{K}N \rightarrow K\Xi$$

$\bar{K}N \rightarrow K\Xi$: *model*

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]

$$T = V + VG_0T = T^P + T^{NP}$$

$$\begin{cases} T^P = \sum_r |F_r\rangle S_r \langle F_r| \rightarrow M_s \\ T^{NP} = V^{NP} + \underbrace{V^{NP}G_0T^{NP}}_{\rightarrow M_c} \rightarrow M_u + M_c \end{cases}$$



$$M_c \begin{cases} M^T_{c++} = M^T_{c--} = \sum_L a_{LT} \left(\frac{p'}{\Lambda_S}\right)^L \exp\left[-\alpha^{LT}\frac{p'^2}{\Lambda_S^2}\right] P_L(\theta) \\ M^T_{c+-} = -M^T_{c-+} = \sum_L b_{LT} \left(\frac{p'}{\Lambda_S}\right)^L \exp\left[-\alpha^{LT}\frac{p'^2}{\Lambda_S^2}\right] P^1_L(\theta) \end{cases}$$

a_{LT}, b_{LT}, α^{LT} = fit parameters

$\Lambda_S \sim 1$ GeV
(scale parameter)

$\bar{K}N \rightarrow K\Xi$: *model*

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]

$\Lambda(1116)$ $\Sigma(1193)$
$\Lambda(1405)$ $\Sigma(1385)$
$\Lambda(1520)$

the model parameters may be fixed from the relevant decay rates(PDG) and/or quark models and SU(3) symmetry considerations.

Λ states				Σ states			
State	J^P	Γ (MeV)		State	J^P	Γ (MeV)	
$\Lambda(1600)$	$1/2^+$	≈ 150	***	$\Sigma(1660)$	$1/2^+$	≈ 100	***
$\Lambda(1670)$	$1/2^-$	≈ 35	****	$\Sigma(1670)$	$3/2^-$	≈ 60	****
$\Lambda(1690)$	$3/2^-$	≈ 60	****	$\Sigma(1750)$	$1/2^-$	≈ 90	***
$\Lambda(1800)$	$1/2^-$	≈ 300	***	$\Sigma(1775)$	$5/2^-$	≈ 120	****
$\Lambda(1810)$	$1/2^+$	≈ 150	***	$\Sigma(1915)$	$5/2^+$	≈ 120	****
$\Lambda(1820)$	$5/2^+$	≈ 80	****	$\Sigma(1940)$	$3/2^-$	≈ 220	***
$\Lambda(1830)$	$5/2^-$	≈ 95	****	$\Sigma(2030)$	$7/2^+$	≈ 180	****
$\Lambda(1890)$	$3/2^+$	≈ 100	****	$\Sigma(2250)$	$?^?$	≈ 100	***
$\Lambda(2100)$	$7/2^-$	≈ 200	****				
$\Lambda(2110)$	$5/2^+$	≈ 200	***				
$\Lambda(2350)$	$9/2^+$	≈ 150	***				

no enough information to fix the parameters of the model.

$\bar{K}N \to K\Xi$: *model*

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]

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→ $\Sigma_{5/2-}(2250) \to M = 2270 \pm 50$ MeV
$\Sigma_{9/2-}(2250) \to M = 2210 \pm 30$ MeV

[A. de Bellefon et al., N. Cim. A7('72)]

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Strategy: consider all the 3- & 4-star hyperon resonances which affects the fit quality significantly ($\delta\chi^2/N > 0.1$).

$\bar{K}N \rightarrow K\Xi(1320)$: model

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]

$\Lambda(1116)$ $\Sigma(1193)$
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no enough information to fix the parameters of the model.

← $W_{thr} \cong$ 1814 MeV

$\Sigma(2250)$ → $\begin{cases} \Sigma_{5/2-}(2250) \rightarrow M = 2270 \pm 50 \text{ MeV} \\ \Sigma_{9/2-}(2250) \rightarrow M = 2210 \pm 30 \text{ MeV} \end{cases}$

[A. de Bellefon et al., N. Cim. A7('72)]

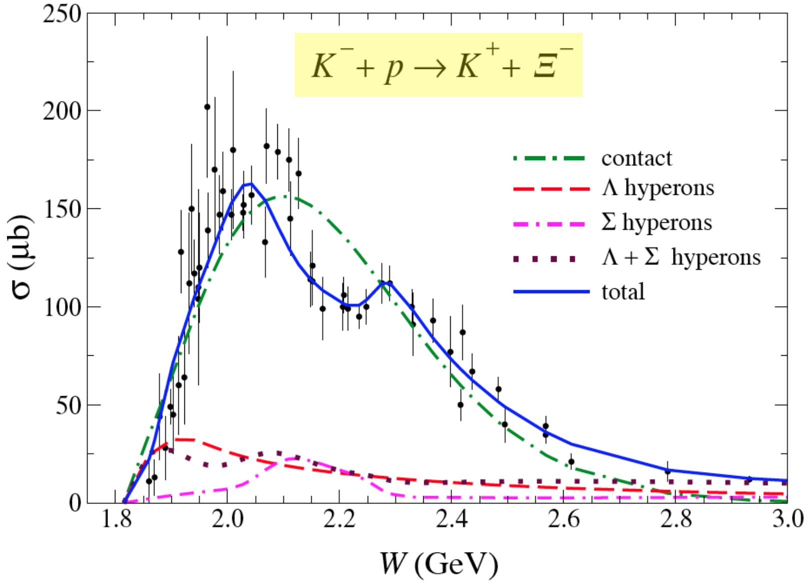
Strategy: consider all the 3- & 4-star hyperon resonances which affects the fit quality significantly ($\delta\chi^2/N > 0.1$).

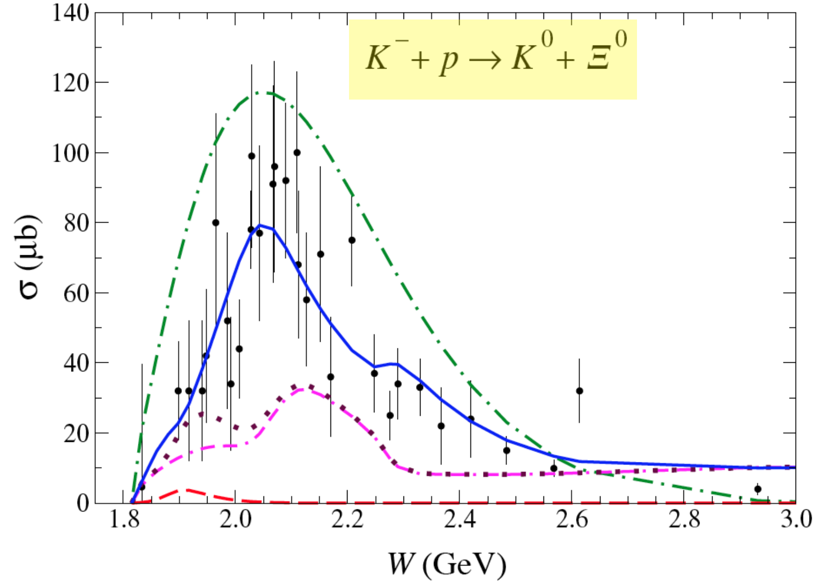
$\Lambda_{3/2+}(1890)$ $\Sigma_{5/2-}(2265)$ $\Sigma_{7/2+}(2030)$
$\Sigma_{3/2+}(1385)$ (g.s. Λ and Σ)

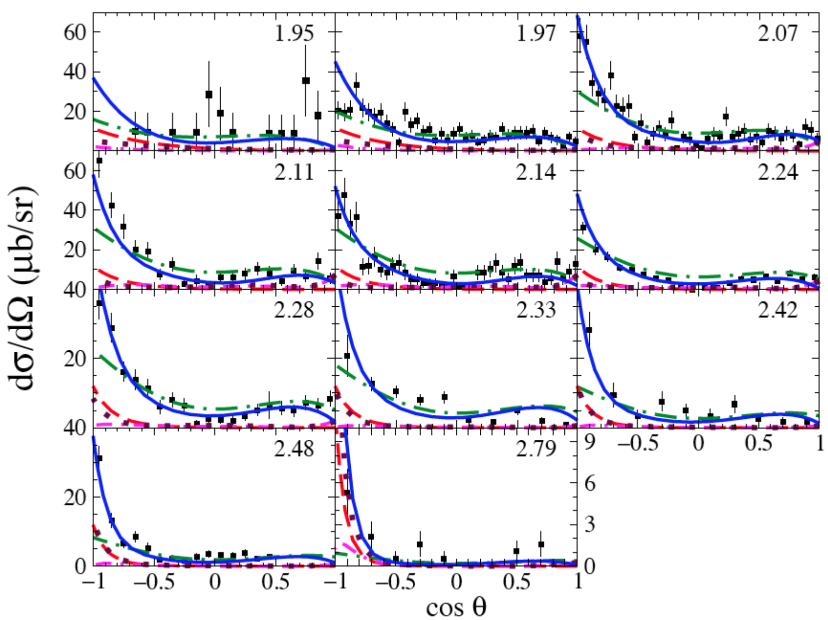
on-shell:
$$M_{1/2\pm}, M_{5/2\pm} \propto (\varepsilon_N \mp m_N)(\varepsilon_\Xi \mp m_\Xi)$$
$$M_{3/2\pm}, M_{7/2\pm} \propto (\varepsilon_N \pm m_N)(\varepsilon_\Xi \pm m_\Xi)$$

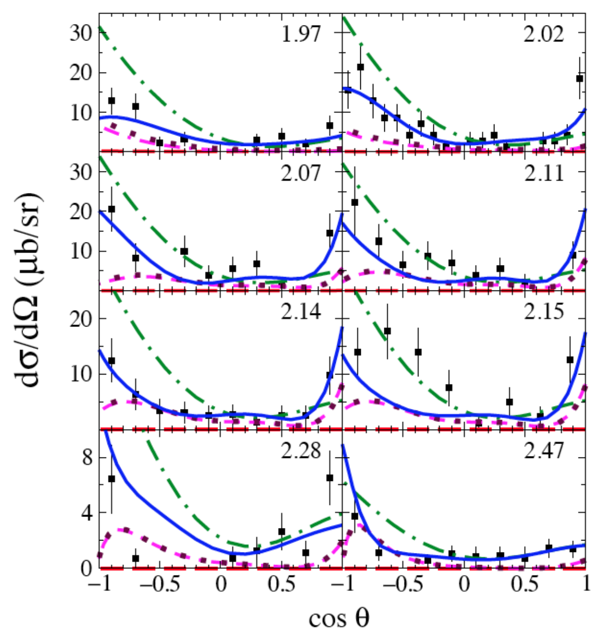
$\bar{K}N \rightarrow K\Xi(1320)$: *model results*

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]



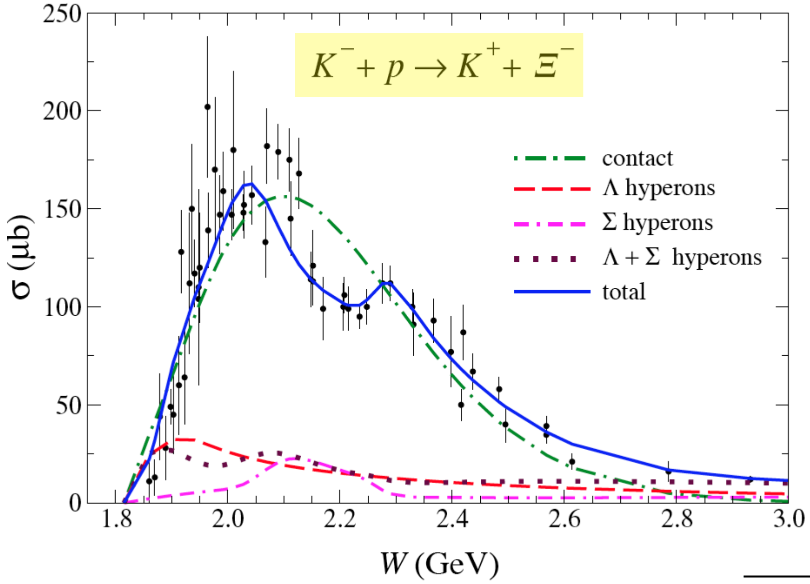


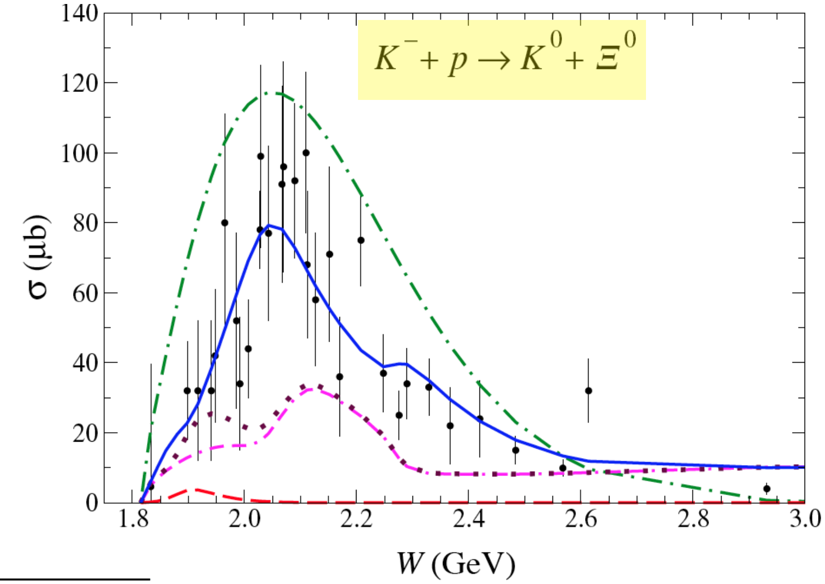


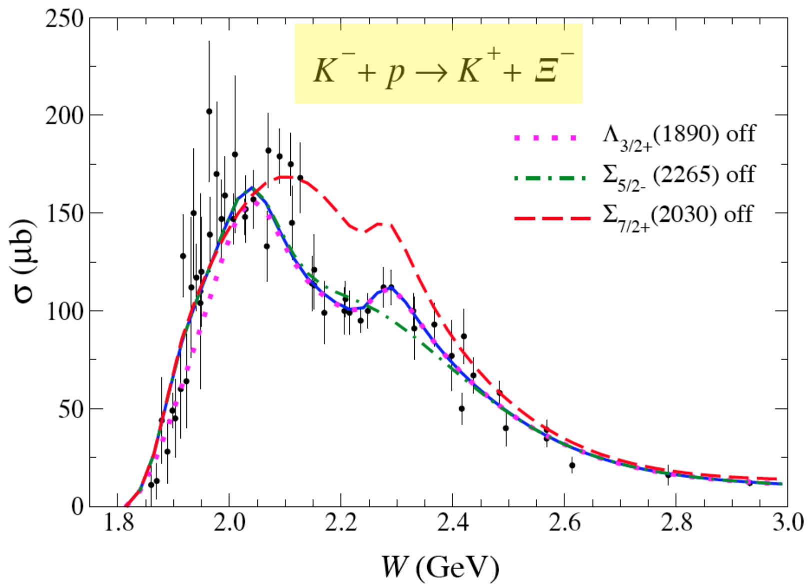


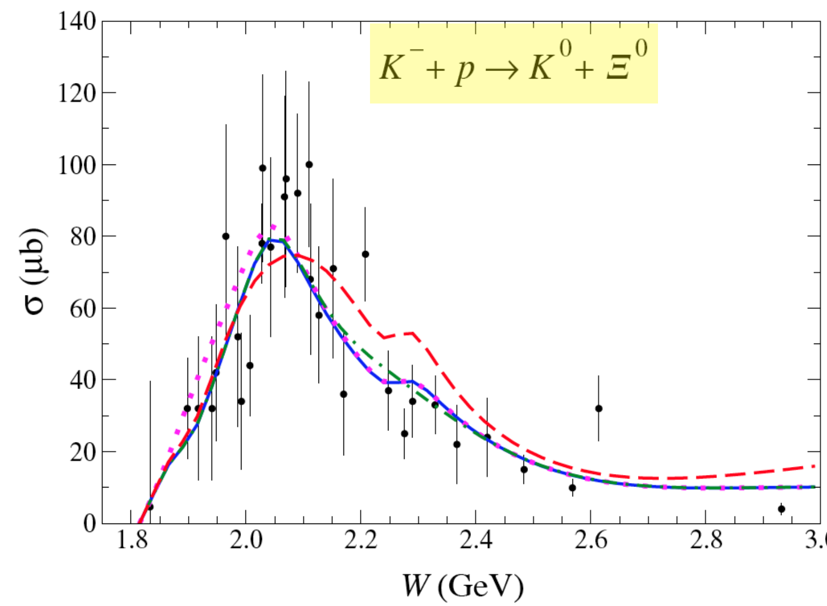
$\bar{K}N \to K\Xi(1320)$: *model results*

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]









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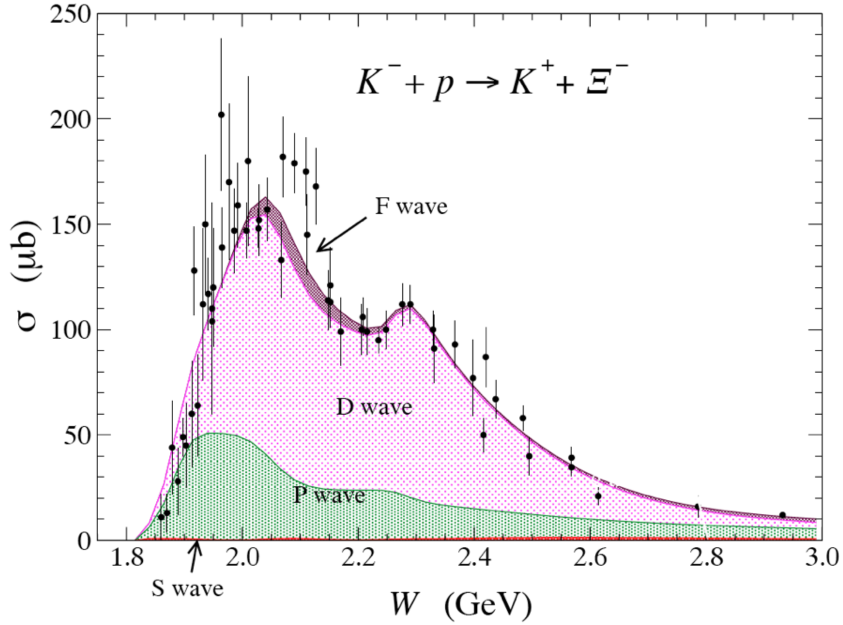

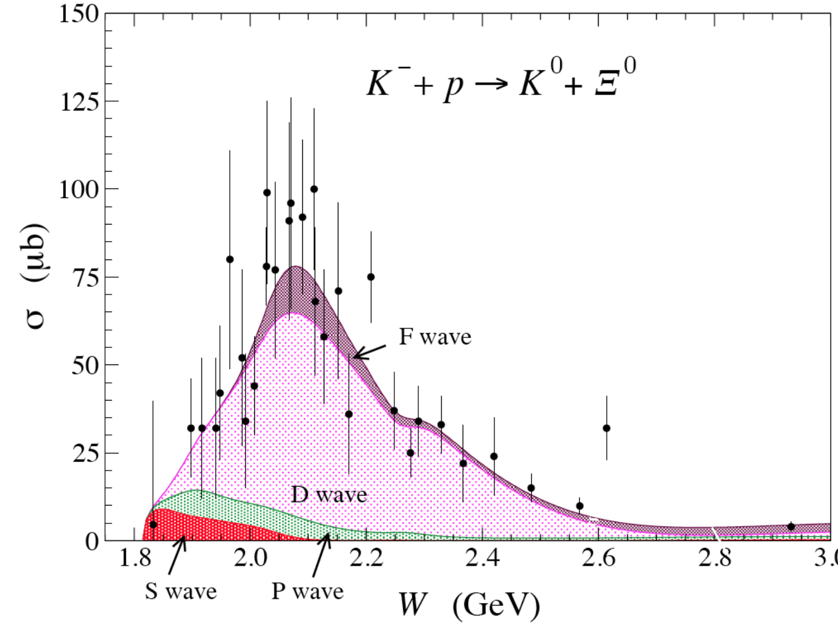

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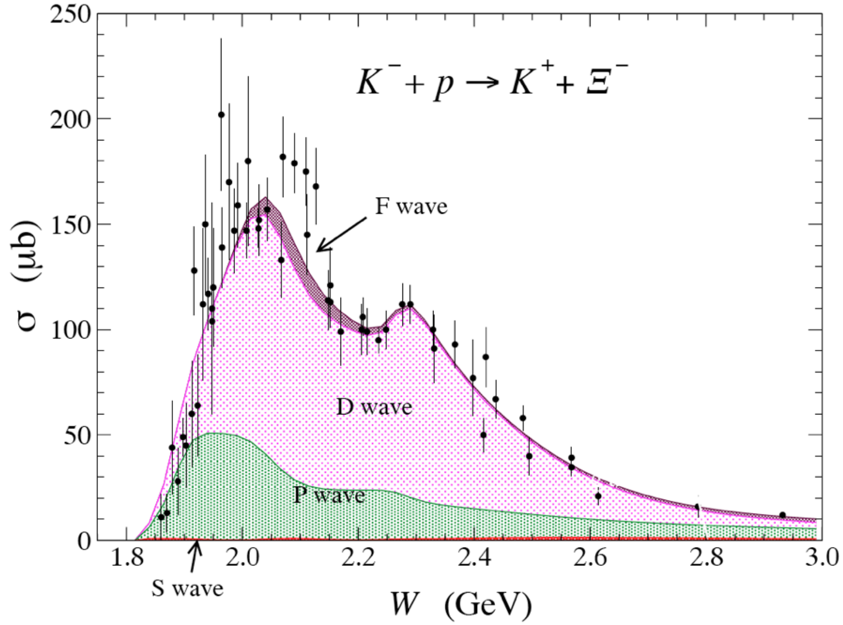
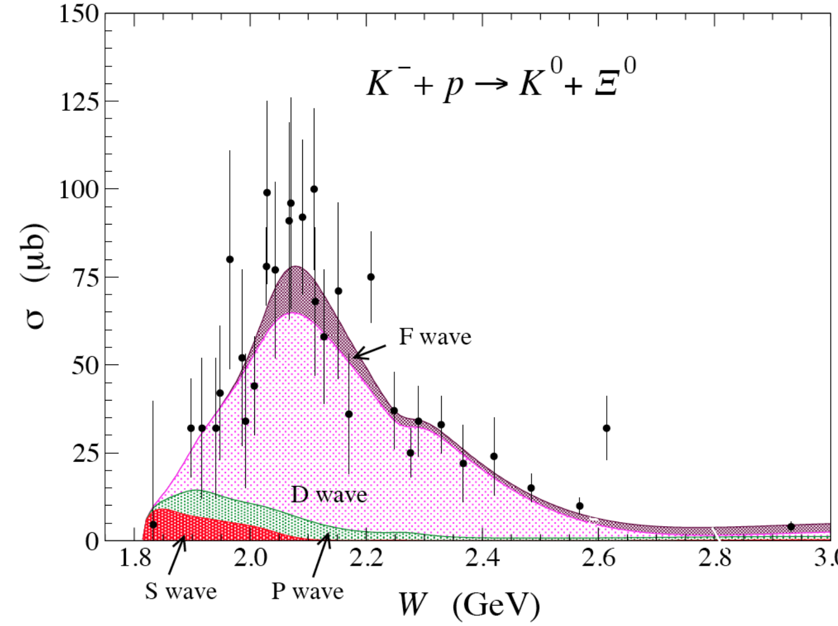
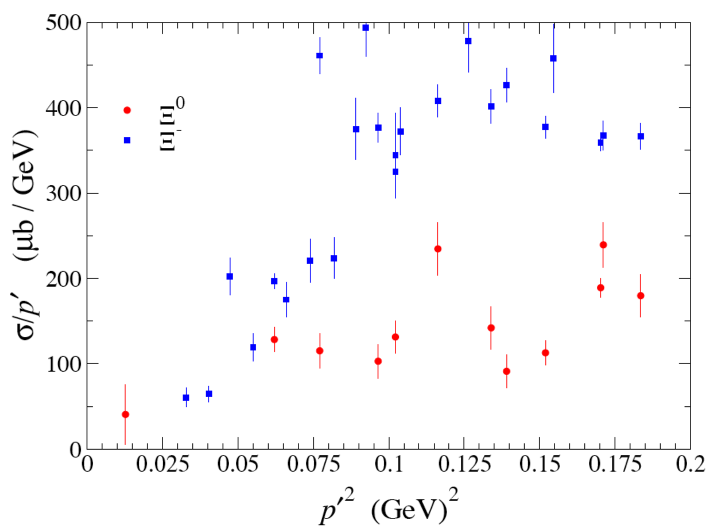




Model-independent result :
(for hard processes)

$$\frac{\sigma}{p'} = c_0 + c_1 p'^2 + c_2 p'^4 + \dots$$

c_L = constant
p' = final state rel. momentum



$\bar{K}N \to K\Xi(1320)$: *model results*

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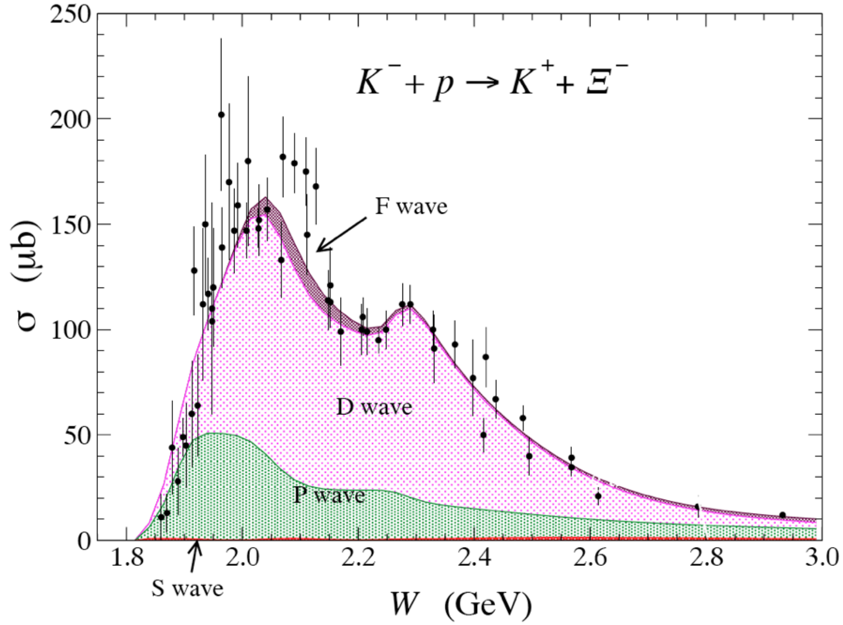

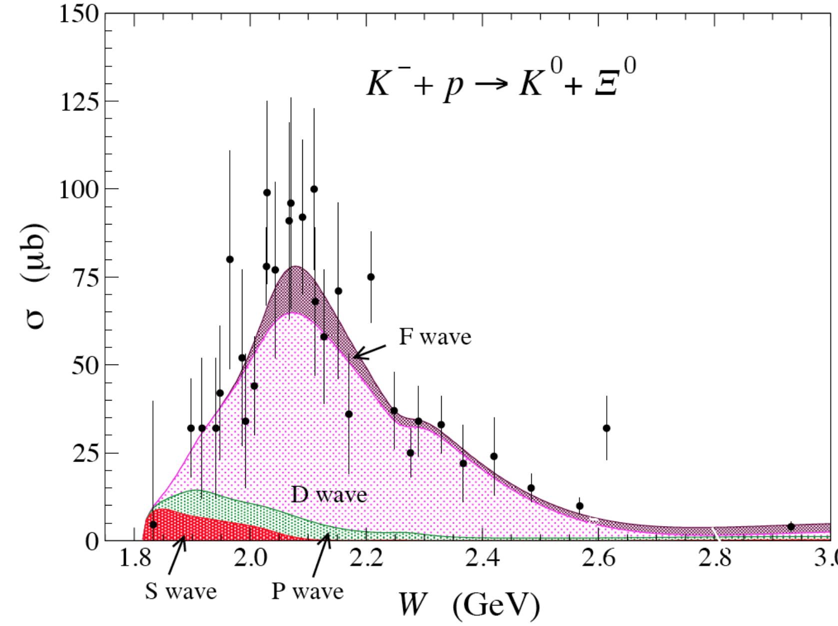

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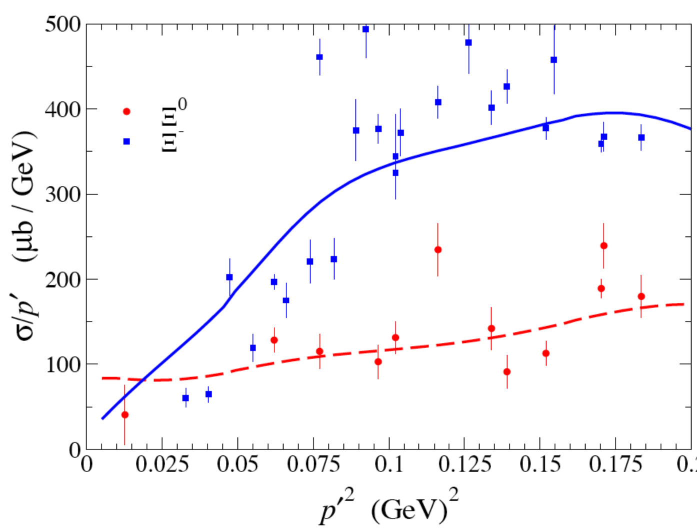
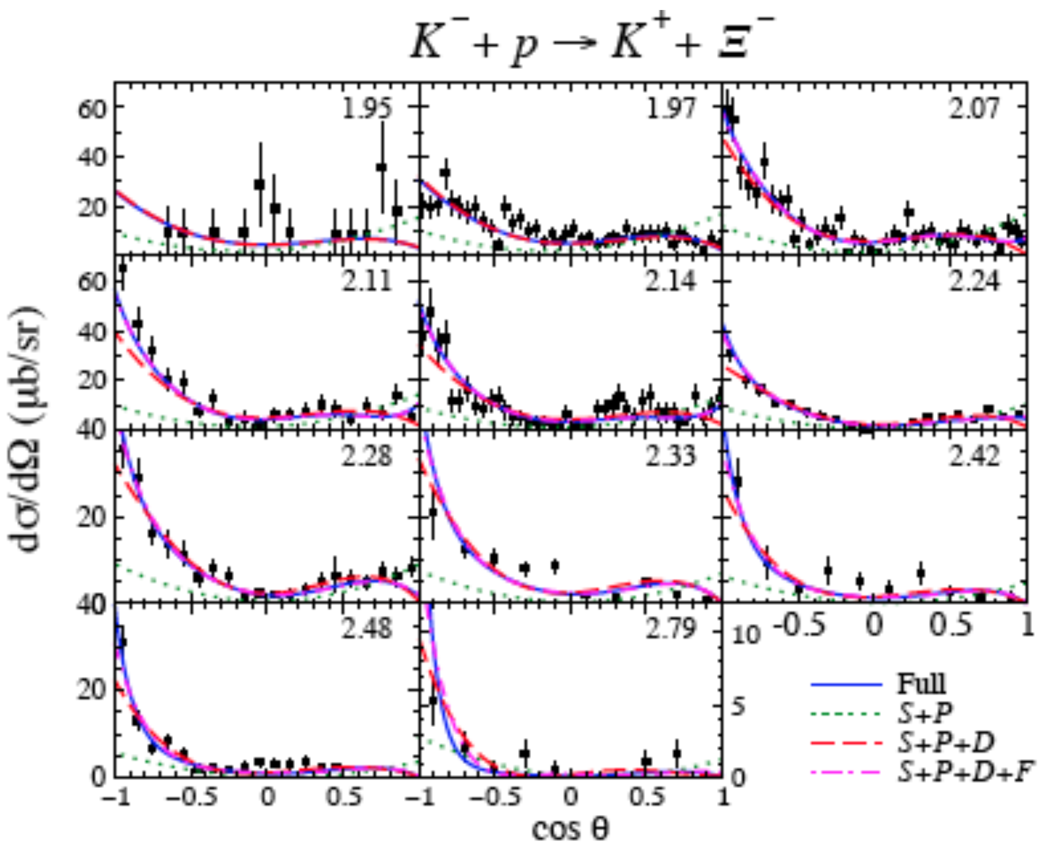
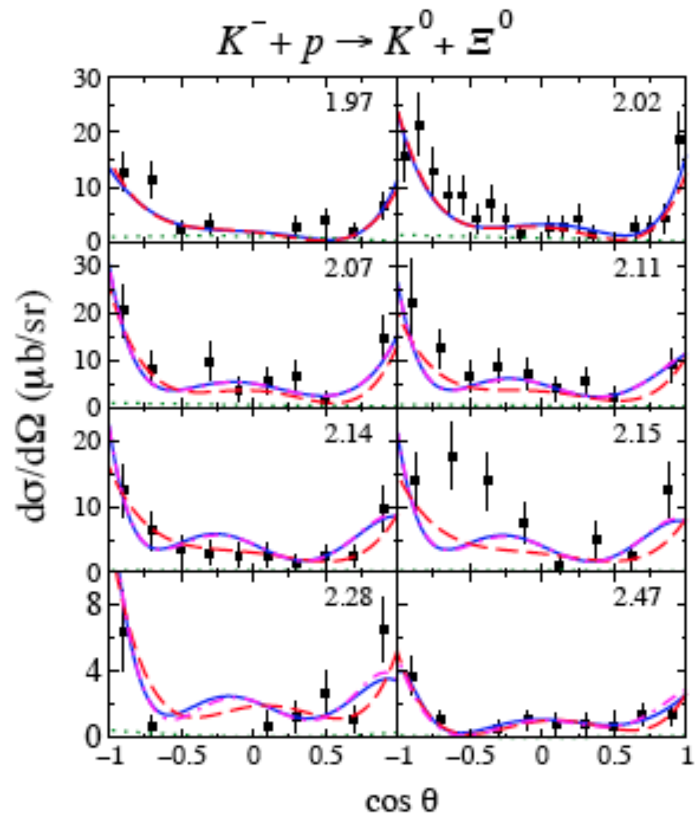


$\bar{K}N \rightarrow K\Xi(1320)$: *model results*

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]





(efficient P-D destructive interference at low energies)

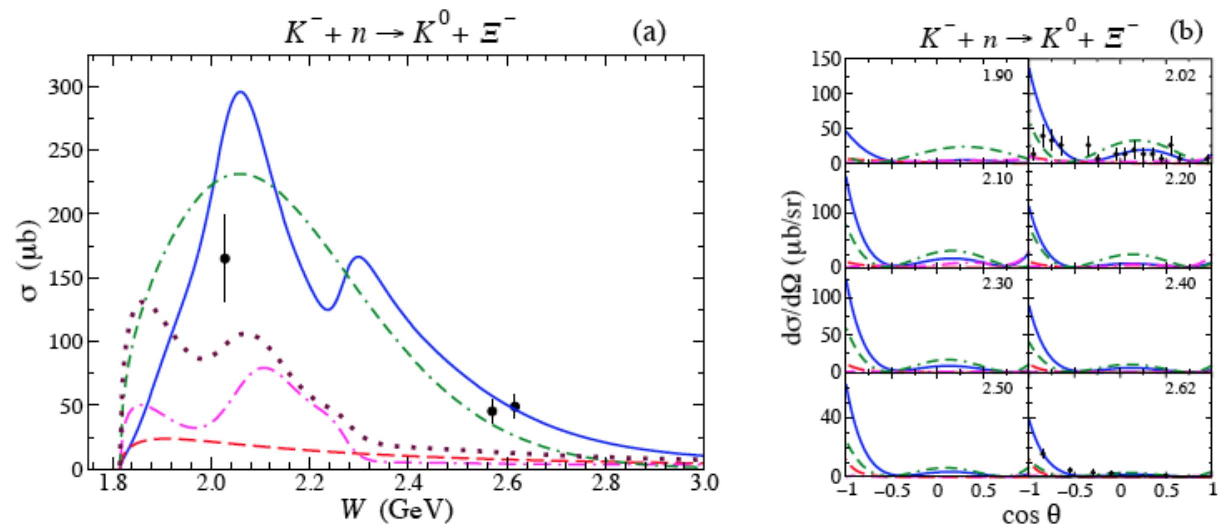
(P-wave supressed)

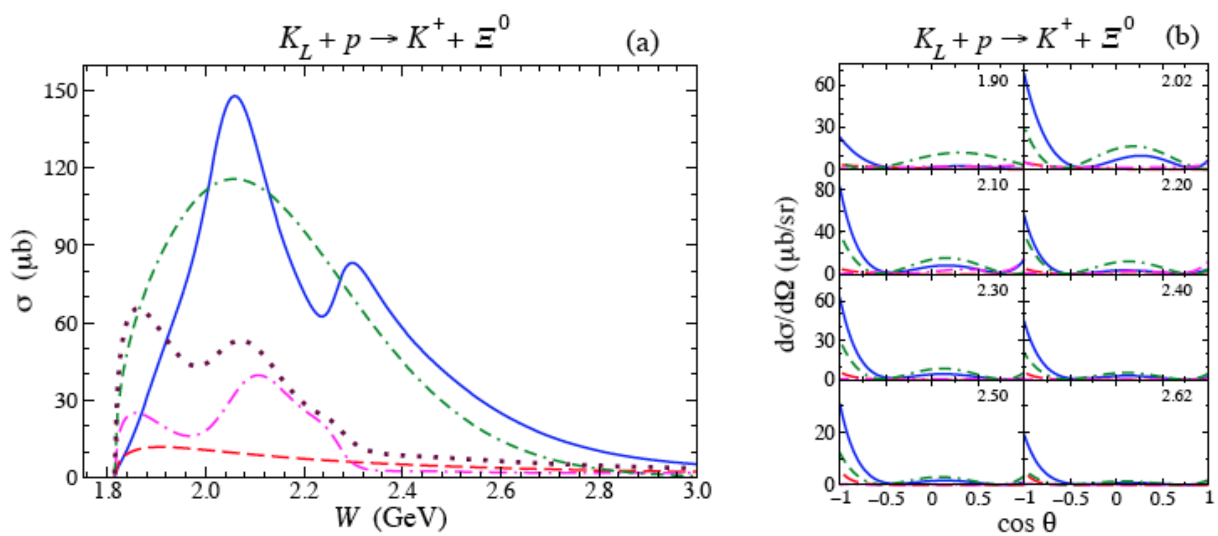
$$
\begin{aligned}
\frac{d\sigma}{d\Omega} = &\left|\alpha_{02}\right|^2 + \left[\left|\alpha_1\right|^2 + 2\,\mathrm{Re}\left(\alpha_{02}\tilde{\alpha}_2^*\right)\right]\cos^2\theta \\
&+ \left|\tilde{\alpha}_2\right|^2\cos^4\theta + \left(\left|\beta_1\right|^2 + |\tilde{\beta}_2|^2\cos^2\theta\right)\sin^2\theta \\
&+ 2\,\mathrm{Re}\left[\alpha_{02}\alpha_1^* + \alpha_1\tilde{\alpha}_2^*\cos^2\theta + \beta_1\tilde{\beta}_2^*\sin^2\theta\right]\cos\theta
\end{aligned}
$$

α_L = spin-non-flip partial-wave m.e.
β_L = spin-flip partial-wave m.e.

$\bar{K}N \rightarrow K\Xi(1320)$: *model results* *(prediction)*

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]

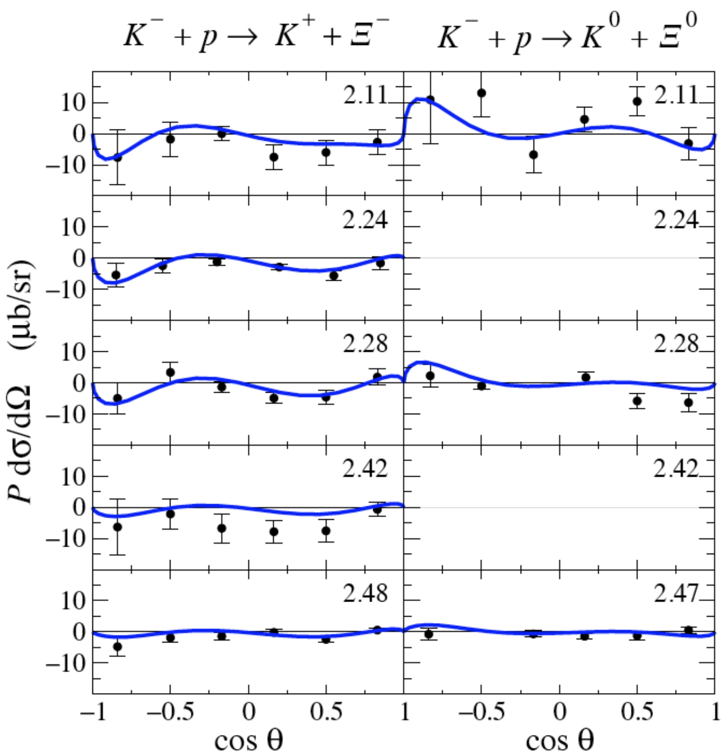




$\bar{K}N \to K\Xi(1320)$: *model results*

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]

recoil polarization *P*



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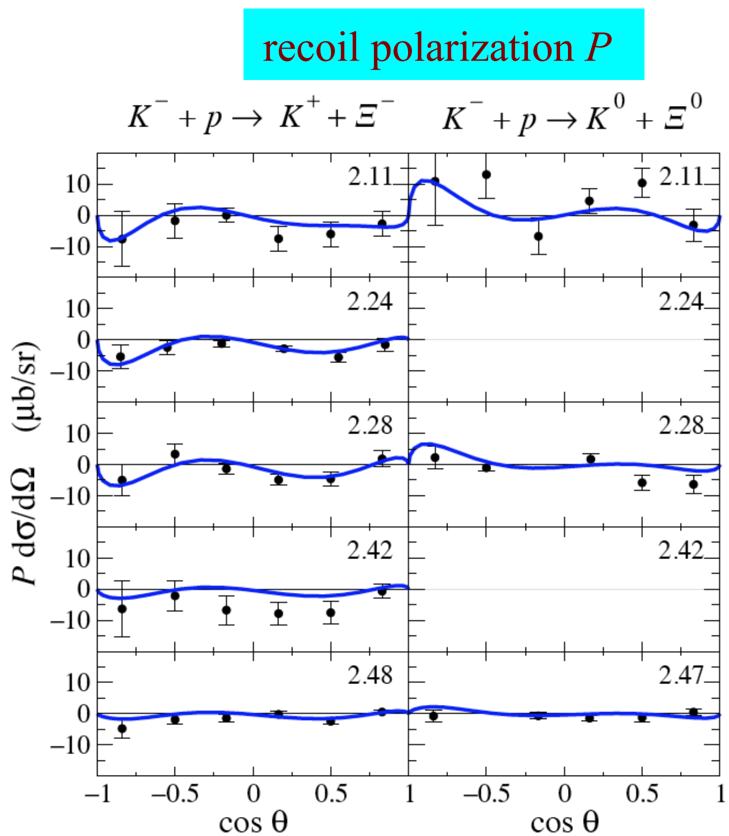


an opportunity to measure the parity of the g.s. Ξ

parity has never been measured

[A. Bohr, NPA10, 486(1959)]

[K.N., Oh, Haberzettl, PRC89'14]

based on Bohr's theorem $[\pi_{fi} = (-)^{(M_f - M_i)}]$:

π_{fi} = product of the intrinsic parities of all the particles in the final and initial state

$M_f(M_i)$ = sum of the spin projections of the particles in the final (initial) state along the direction perpendicular to the reaction plane

$$K_{yy} = \pi_\Xi$$

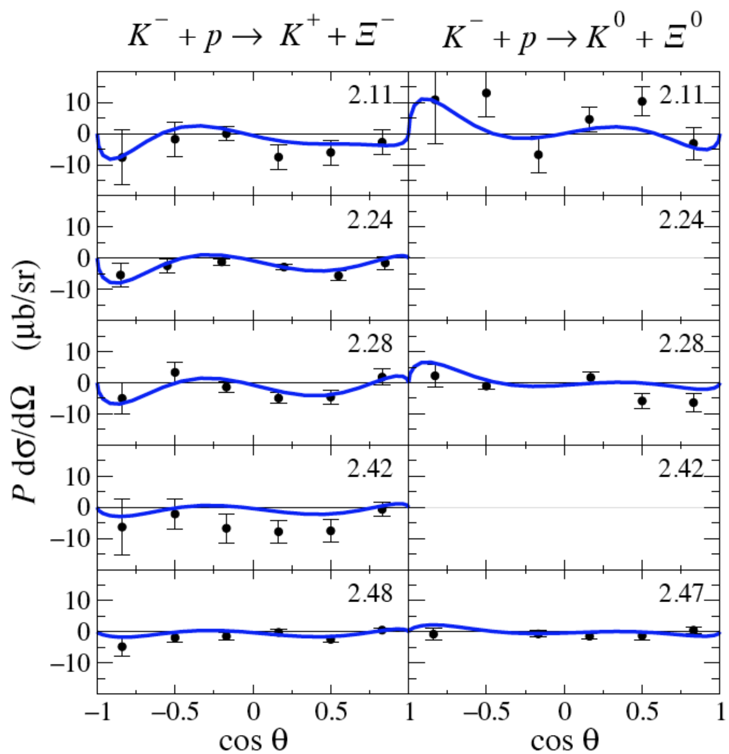
K_{yy} = target-recoil asymmetry (spin transfer coefficient)

π_Ξ = parity of Ξ

$\bar{K}N \to K\Xi(1320)$: *model results*

[Jackson, Oh, Haberzettl, K.N., PRC91(2015)065208]

recoil polarization P



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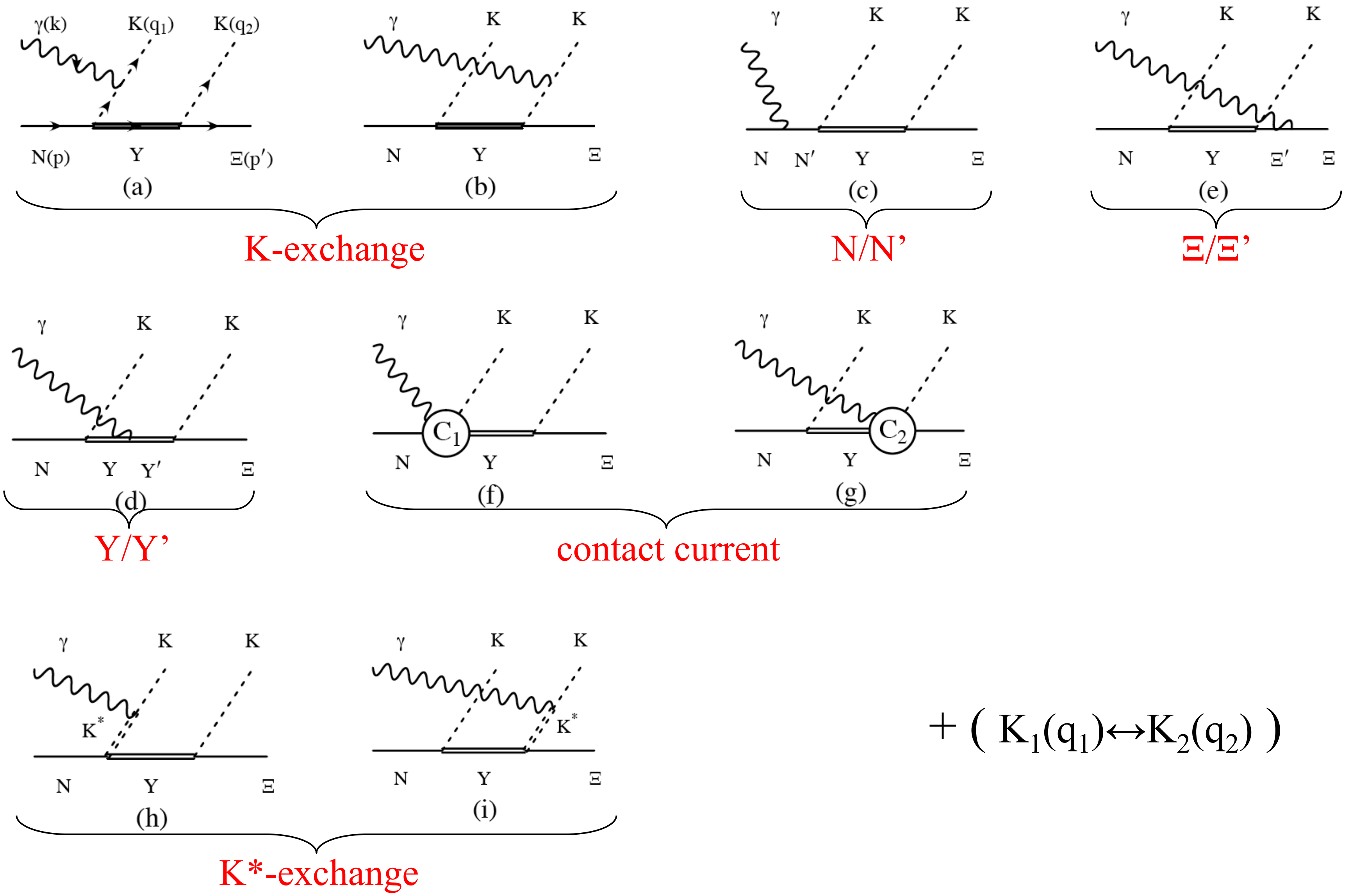
$$T = \pi_\Xi P$$

measure T and P

$\gamma N \rightarrow K K \Xi$

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

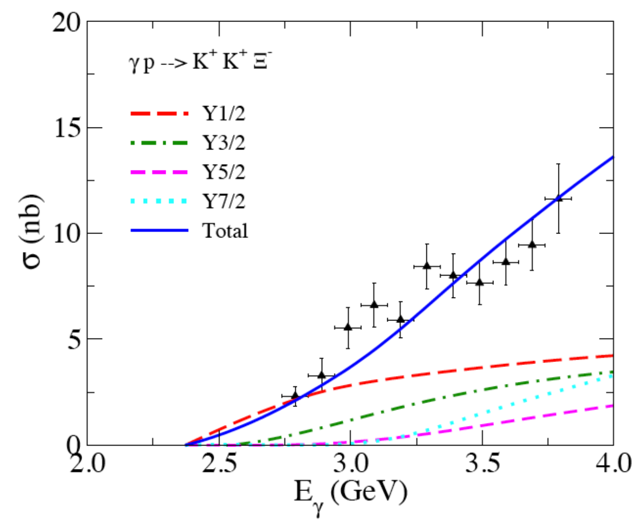
Nakayama, Oh and Haberzettl (PRC74, '06)
Man, Oh and Nakayama (PRC83, '12)

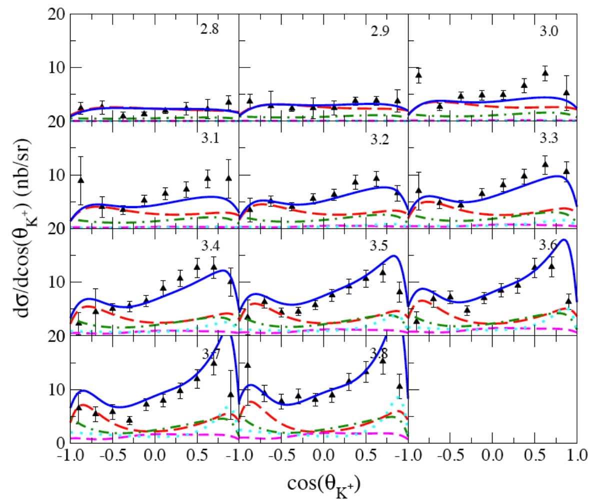


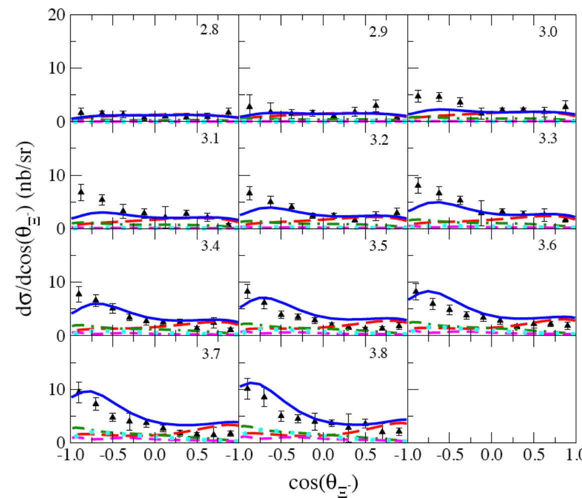
$+ \left(K_1(q_1) \leftrightarrow K_2(q_2) \right)$

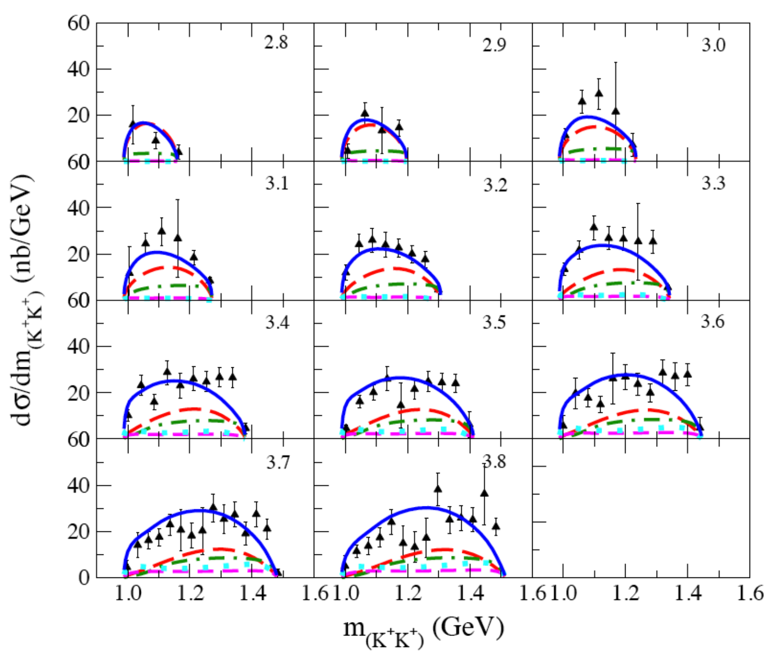
$\gamma N \rightarrow KK\Xi(1320)$: *(improved) model results*

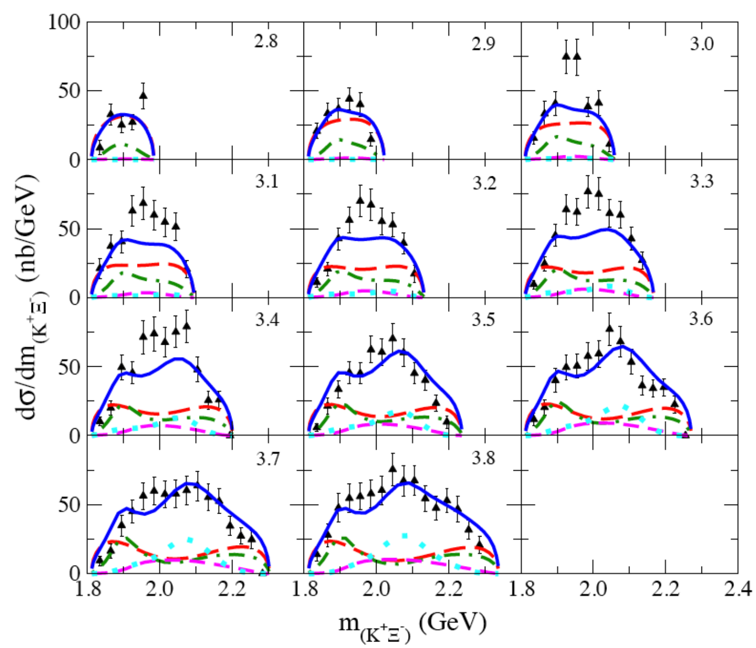
Man, Oh and Nakayama (PRC83, '12)





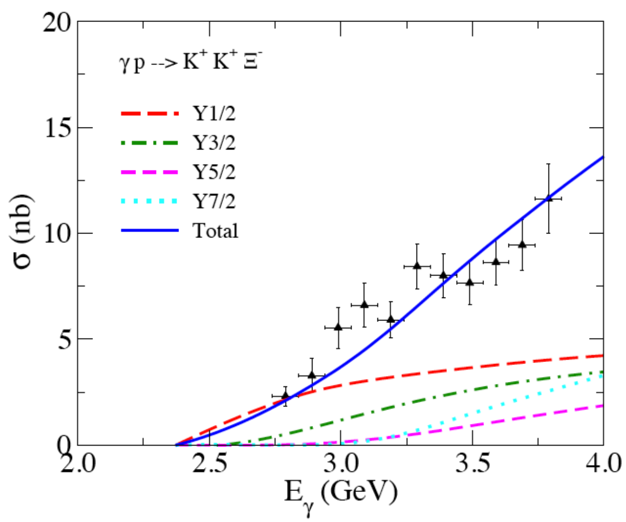


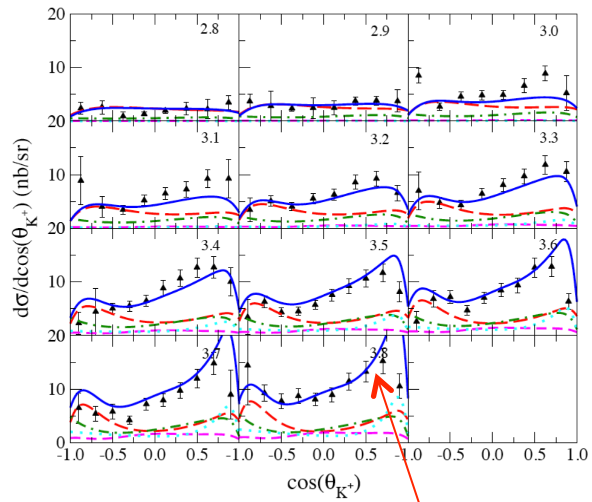


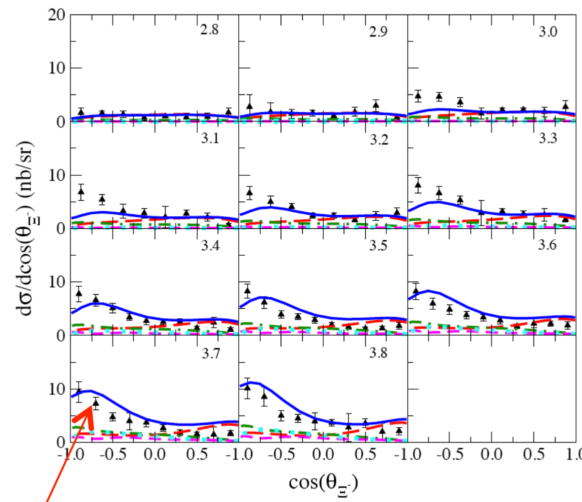


γN→KKΞ(1320) : (improved) model results

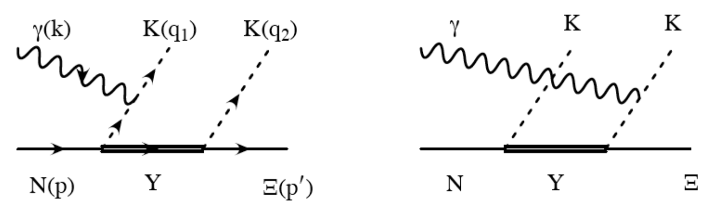
Man, Oh and Nakayama (PRC83, '12)







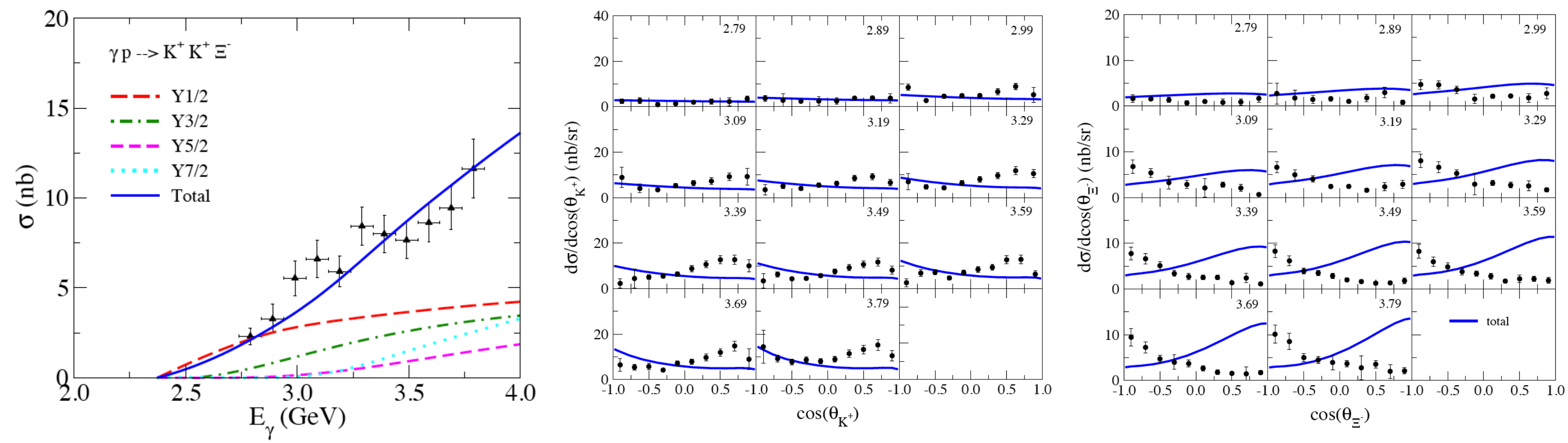
Kaon-exchange: responsible for the forward (backward) angle peaking of the K+ (X-) distribution



S=-1 resonances needed

$\gamma N \rightarrow KK\Xi(1320)$: *(improved) model results*

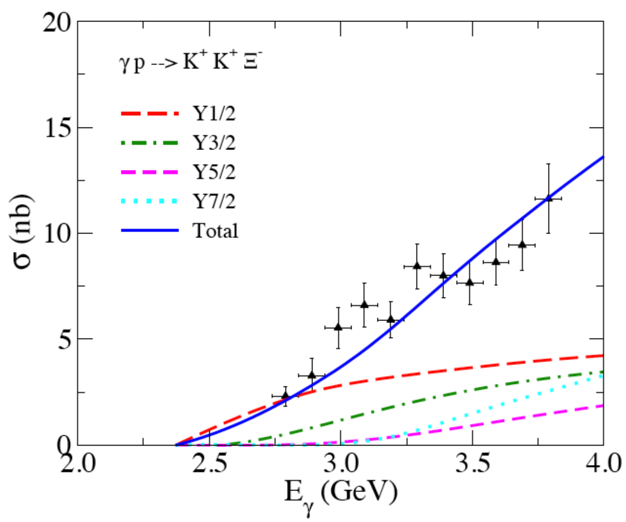
Man, Oh and Nakayama (PRC83, '12)

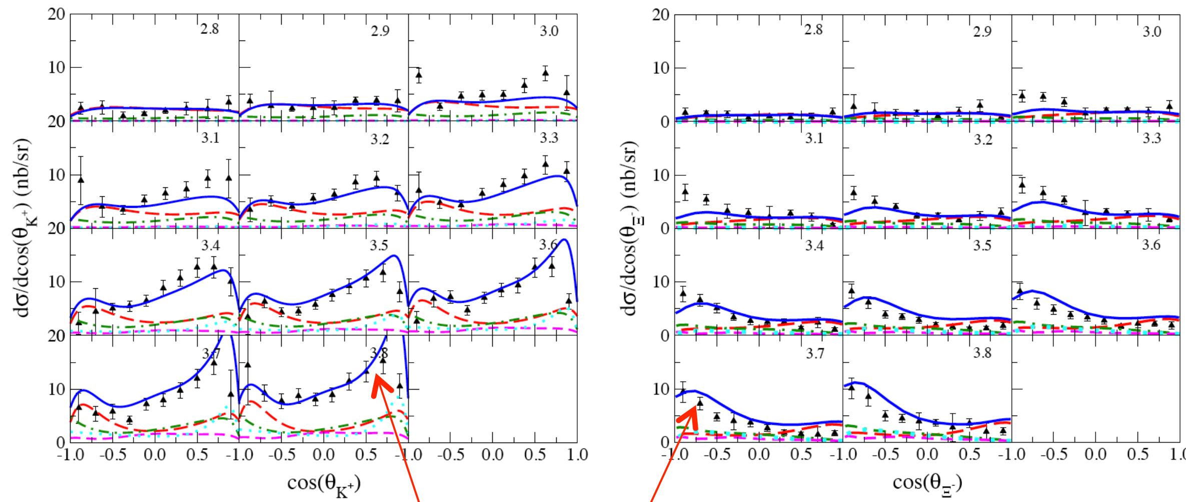


above threshold resonances off

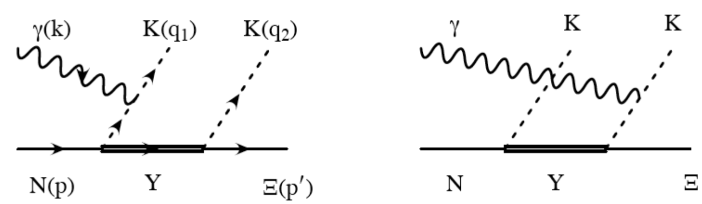
$\gamma N \rightarrow KK\Xi(1320)$: *(improved) model results*

Man, Oh and Nakayama (PRC83, '12)





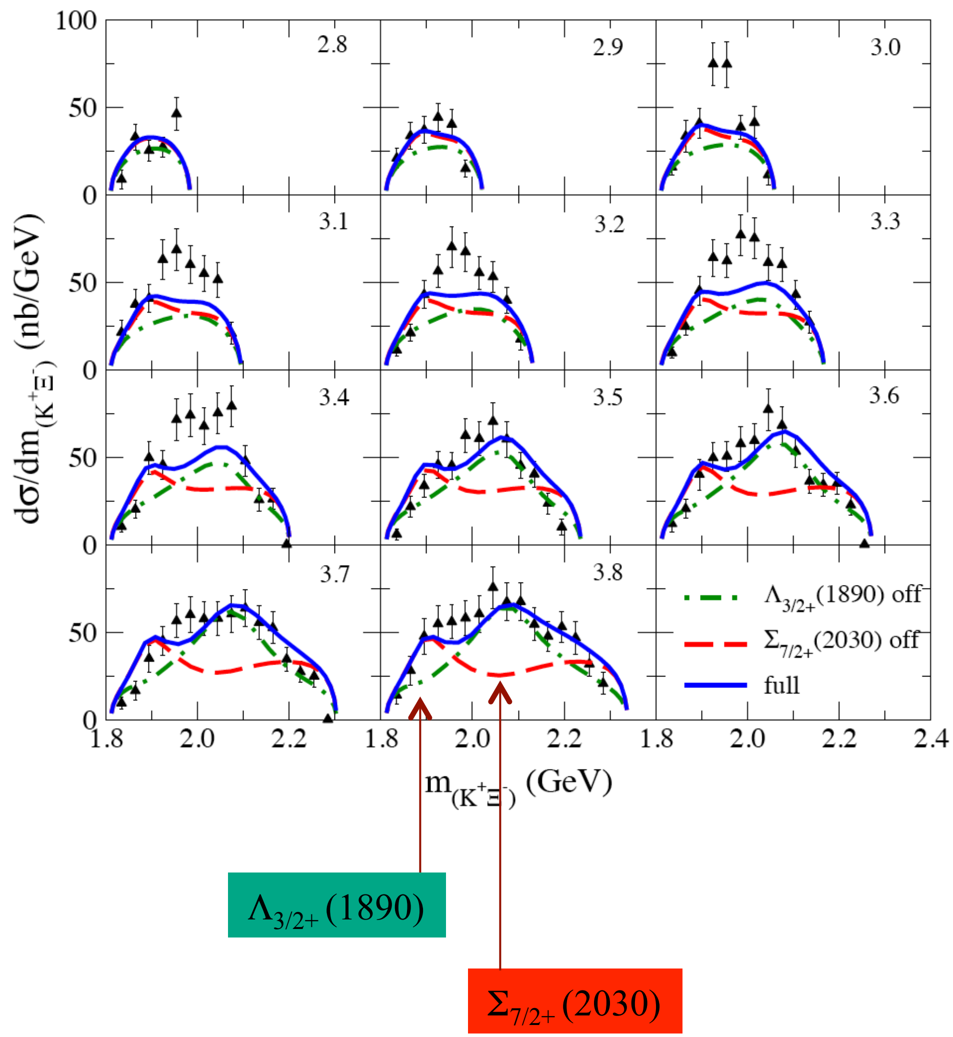
Kaon-exchange: responsible for the forward (backward) angle peaking of the K+ (X-) distribution



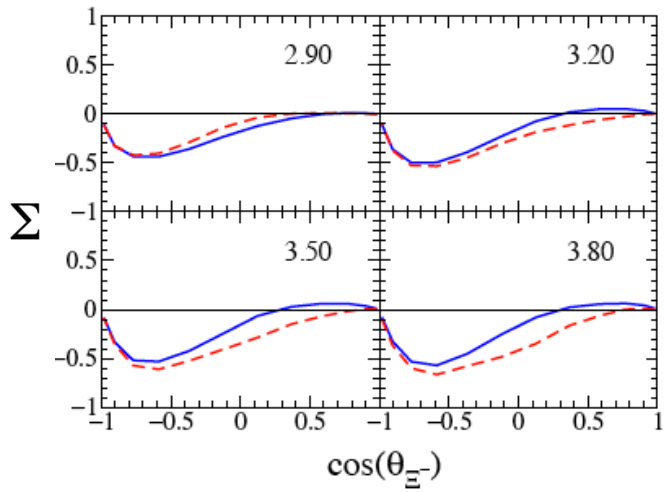
above threshold S=-1 resonances needed

$\gamma N \to K K \Xi(1320)$: *(improved) model results*

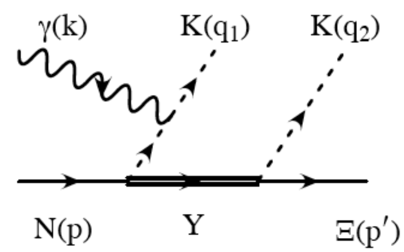
Man, Oh and Nakayama (PRC83, '12)

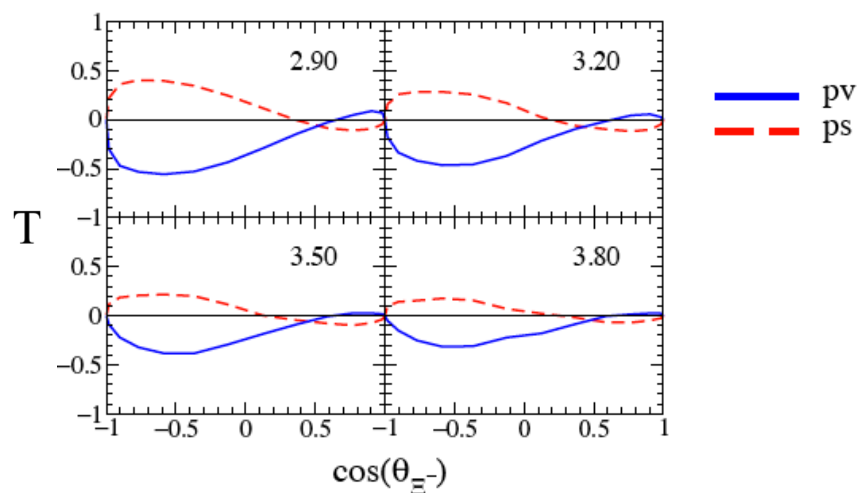


$\gamma N \rightarrow KK\Xi$: *beam and target asymmetries*



t-channel Kaon exchange: $\Sigma = -1$





NYK vertex

Summary :

- $\bar{K}N \rightarrow K\Xi(1320)$:

  a) overall, existing data are described well.

  b) suited for learning about S=-1 hyperon resonances in the 2 GeV mass region:

  - Hints for the coupling to $\Sigma_{7/2+}(2030)$, $\Sigma_{5/2-}(2265)$, $\Lambda_{3/2+}(1890)$: more accurate data required for a definite confirmation and more complete model.

  c) P-wave dominance even close to threshold in $K^- + p \rightarrow K^+ + \Xi^-$.

  total and differential cross section data are consistent with each other.

  d) for further detailed analysis : more accurate data required.

- $\gamma p \rightarrow KK\Xi(1320)$:

  a) basic features of $\gamma p \rightarrow K^+K^+\Xi^-(1318)$ understood:

  K-exchange currents : essential for describing the $d\sigma/d\Omega$ data.

  (above the threshold S=-1 resonances needed)

  b) suited for learning about S=-1 hyperon resonances in the 2 GeV mass region:

  - Hints for the coupling to $\Lambda_{3/2+}(1890)$, $\Sigma_{7/2+}(2030)$: required to describe $m_{K\Xi}$ data.

  c) more data needed, especially, the spin observables:

  beam-asymmetry : sensitive to the K-exchange currents (Σ =-1).

  target-asymmetry : sensitive to the ps-pv mixing in the KNY couplings.

The End