$K^- p \to K\,\Xi$ reaction and Λ^* and Σ^* resonances

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1. introduction

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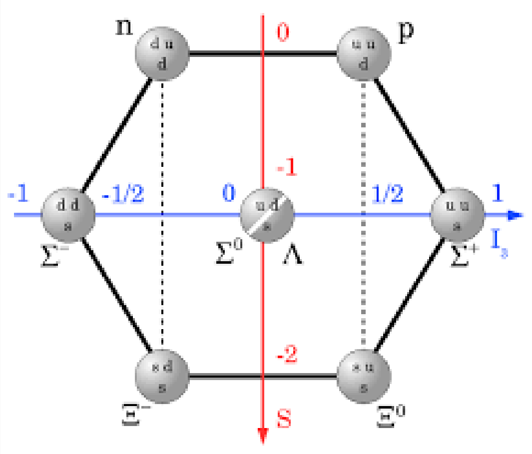
- ❑ SU(3) flavor symmetry allows as many S = -2 baryons, i.e. Ξ, but only 11 Ξ baryons are observed, whereas there are ~ 25 Λ^* or Σ^* resonances (S = -1).



Particle	J^P	Overall status
Ξ(1318)	1/2+	****
Ξ(1530)	3/2+	****
Ξ(1620)		*
Ξ(1690)		***
Ξ(1820)	3/2−	***
Ξ(1950)		***
Ξ(2030)		***
Ξ(2120)		*
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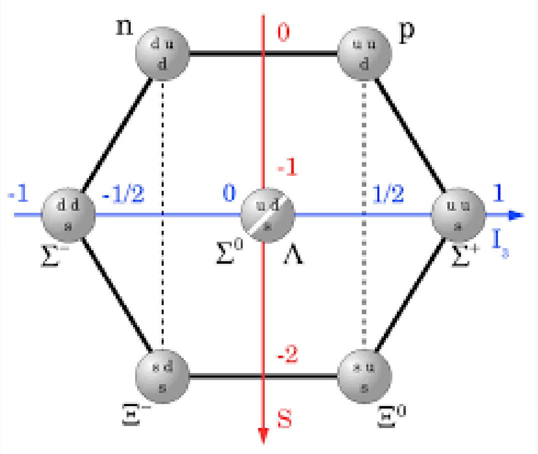

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- This is mainly because multistrangeness hadron production have small cross section rates relatively.
- Recently, the situation becomes better since more precise and abundant data are expected to be produced in the future experiments via various beams:

  a. photoproduction ($\gamma\, p \to K\, K\, \Xi$, $K\, K\, K\, \Omega$) at JLab
  b. $p\bar{p}$ interaction ($p\, \bar{p} \to \Xi\, \bar{\Xi}$, $\Omega\, \bar{\Omega}$) at GSI-FAIR
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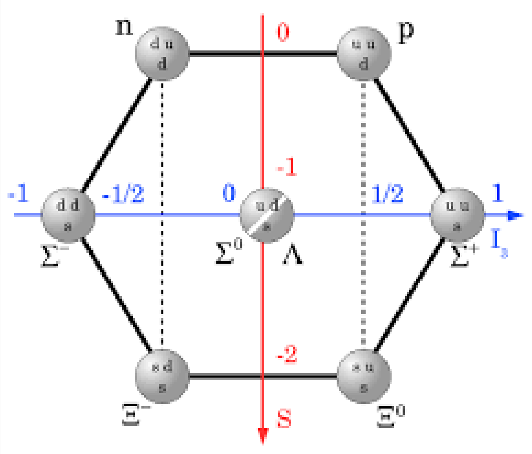

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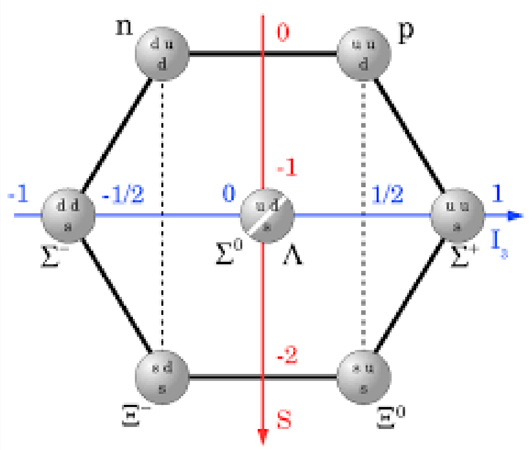

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❑ Multistrangeness production in hadron physics

a. photoproduction ($\gamma\ p \rightarrow K\ K\ \Xi$)

> CLAS & GlueX Collaborations at JLab is producing the data.

> The production mechanism is a two-step process.

> The hadron coupling constants are not well known.

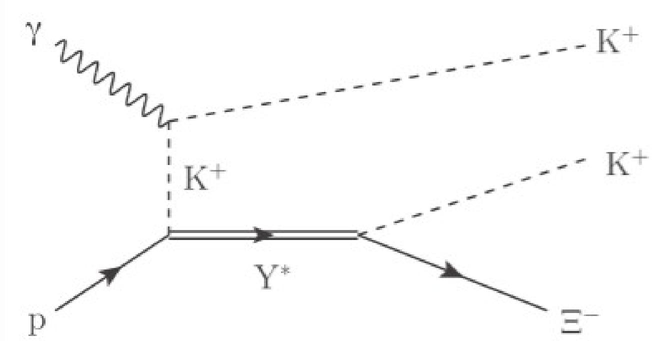
> Theoretical analyses

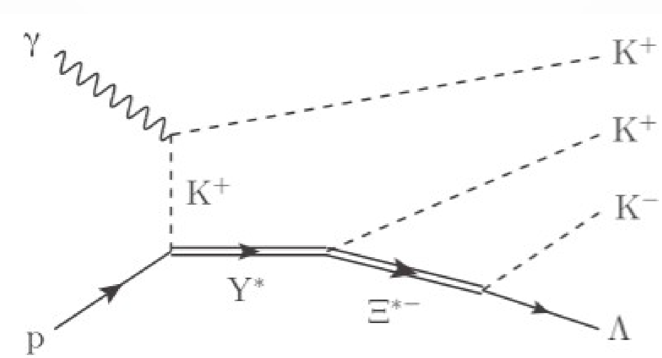
$\gamma\ p \rightarrow K\ K\ \Xi(1318)$

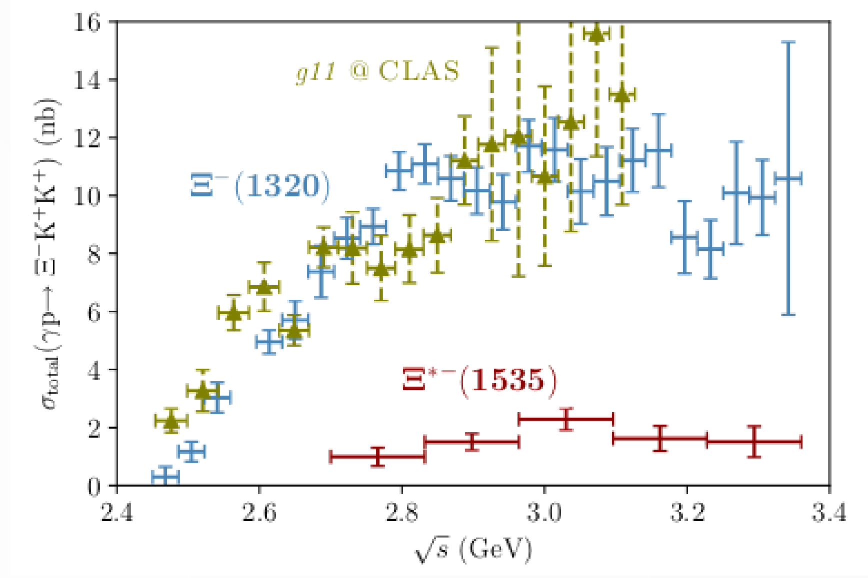
Nakayama et al. PRC.74.035205 (2006)

$\gamma\ p \rightarrow K^+\ K^+\ \Xi^{*-}(1530)$

No analyses yet







Goetz (CLAS) PRC.98.062201(R) (2018)

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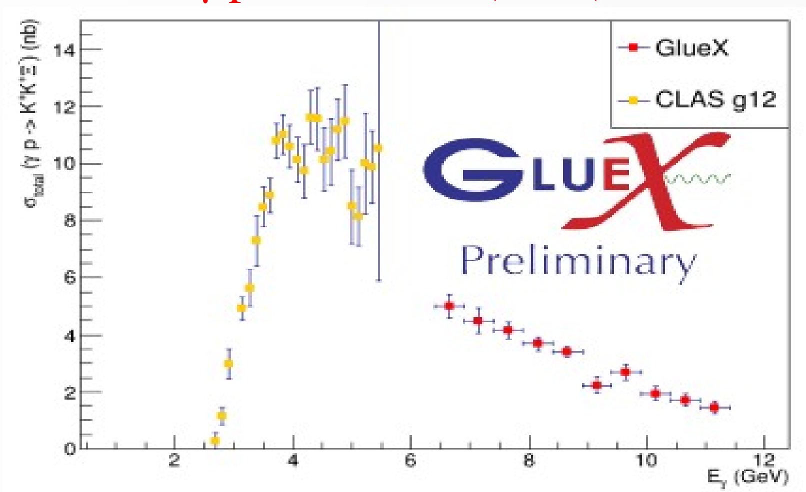

Ernst (GlueX) AIP.CP.2249.030041 (2020)

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No analyses yet

Ξ^0 $\quad I(J^P) = 1/2(1/2^+)$ PDG 2022

The parity has not actually been measured, but $^+$ is of course expected.

Goetz (CLAS) PRC.98.062201(R) (2018)

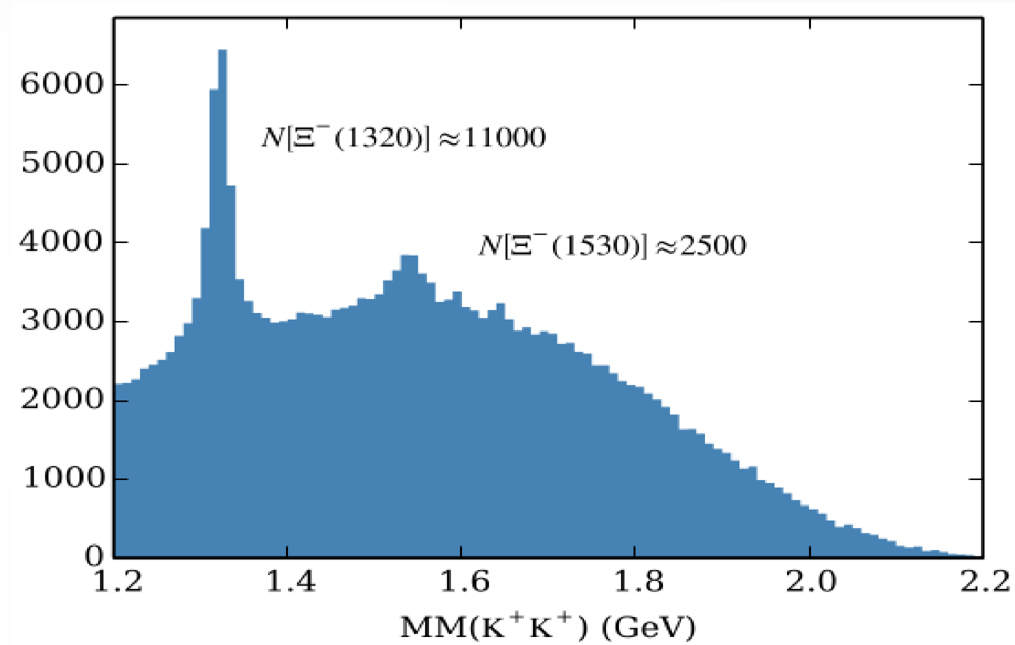

FIG. 2. Missing mass off of (K^+K^+) showing the Ξ spectrum above a smooth background, summed over all angles and all E_γ.

In the missing mass off of K^+K^+ (Fig. 2), the strong peak at 1.32 GeV corresponds to the Ξ ground state $(J^P = \frac{1}{2}^-)$, and the smaller peak at 1.53 GeV is the Ξ^* first excited state $(J^P = \frac{3}{2}^-)$. No other statistically significant structures are seen in this mass spectrum.

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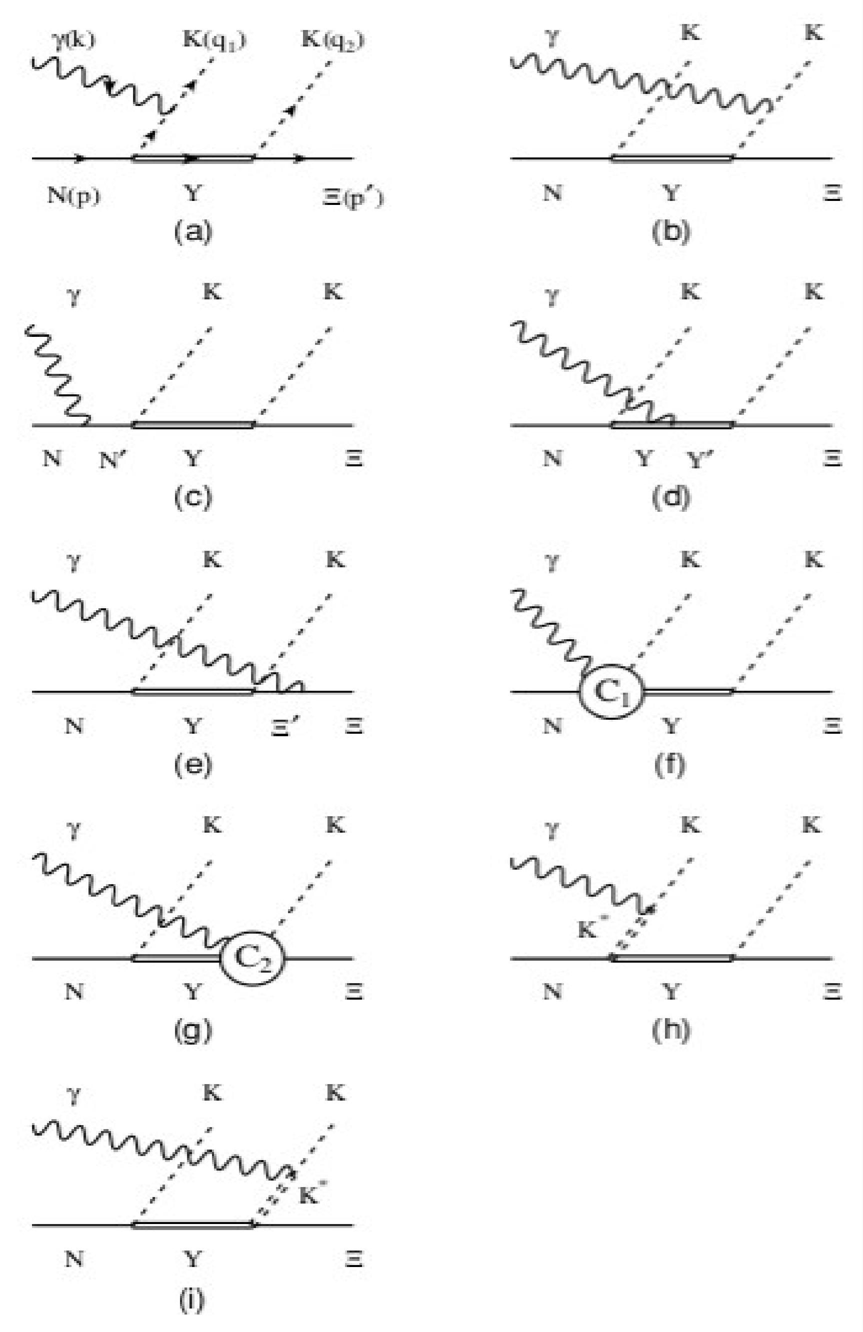

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❑ Multistrangeness production in hadron physics

b. $p\bar{p}$ interaction ($p\,\bar{p} \to \Xi\,\bar{\Xi}$)

> FANDA Collaboration at GSI-FAIR will produce the data.

Lutz et al. 0903.3905 [hep-ex] Physics Performance Report

> The production mechanism is a two-step process.

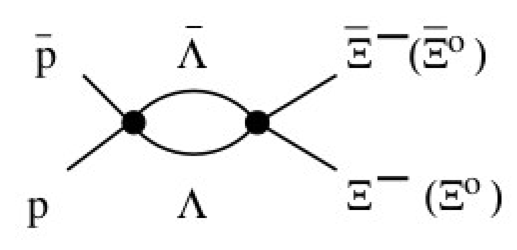
> The amplitudes are described by the loop diagrams within a modified Regge type model.

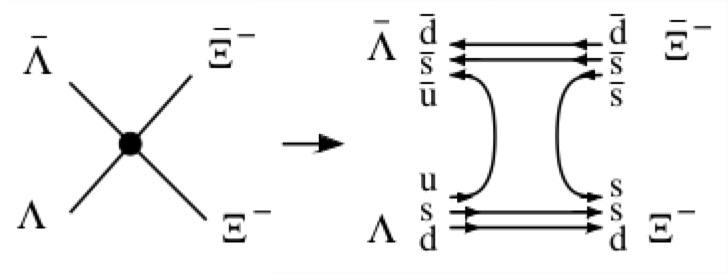
Titov et al. 1105.3847 [hep-ph]

> More rigorous analyses are called for.

Titov et al. 1105.3847 [hep-ph]

❑ Loop diagrams





> K & K^* exchanges are possible.

❑ Scattering amplitude

$$T^{\bar{p}p\to\bar{\Xi}\Xi} \simeq T^{\bar{p}p\to\bar{\Xi}\Xi}_{\rm cut} = i\,\frac{Q_\Lambda}{8\pi\sqrt{s}}\int\frac{d\Omega_\Lambda}{4\pi}\sum_{\text{spins }\bar{\Lambda}\Lambda} T^{\bar{p}p\to\bar{\Lambda}\Lambda}\,T^{\bar{\Lambda}\Lambda\to\bar{\Xi}\Xi}$$

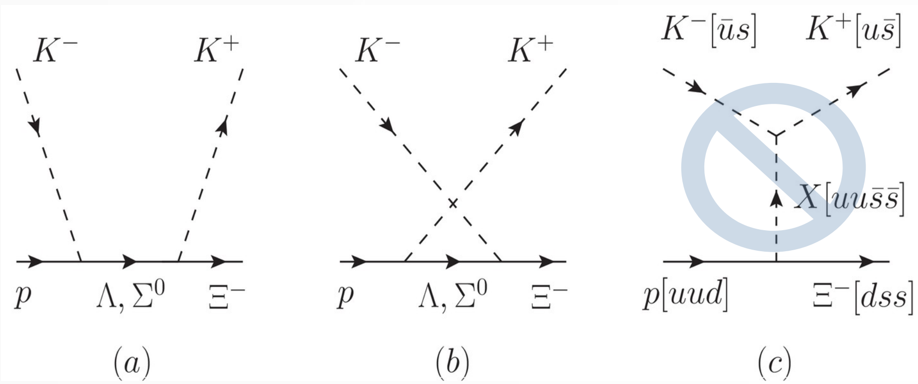
2. $K^- p \to K \Xi$ theoretical framework

❑ Multistrangeness production in hadron physics (**c**. $K^- p \to K \Xi$)

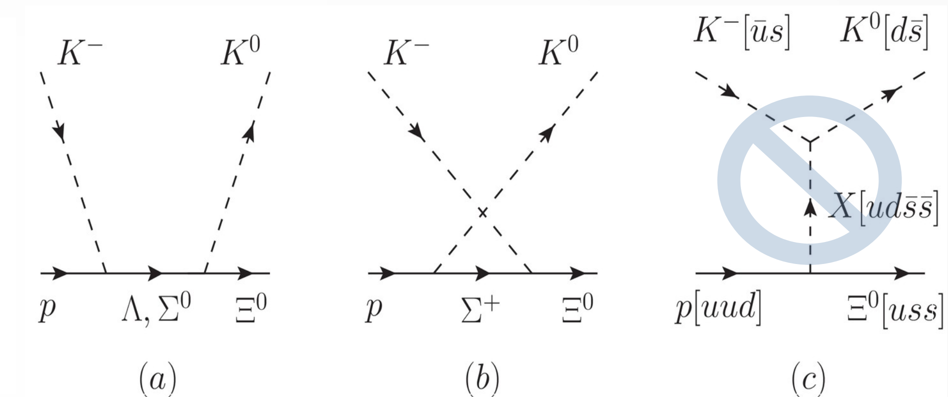
\> Only ($\Lambda^{(*)}$ & $\Sigma^{(*)}$) hyperons mediate in the Born diagrams.

\> *t*-channel meson exchanges are not possible because no meson of strangeness two exists.

(A) $K^- p \to K^+ \Xi^-$



(B) $K^- p \to K^0 \Xi^0$



2. K⁻ p → K Ξ   theoretical framework

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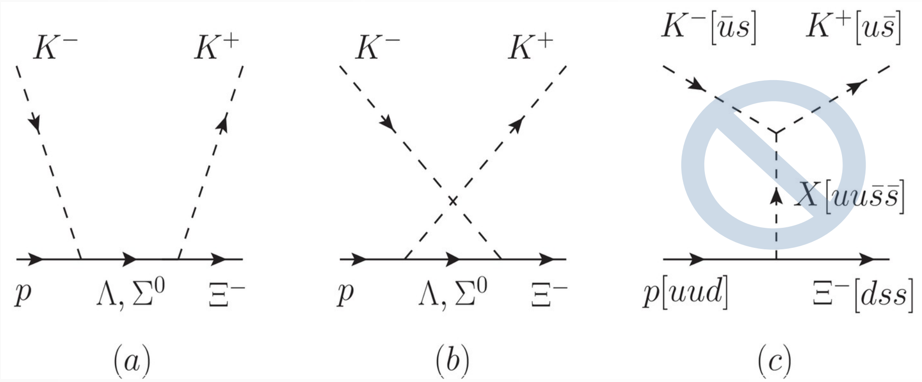

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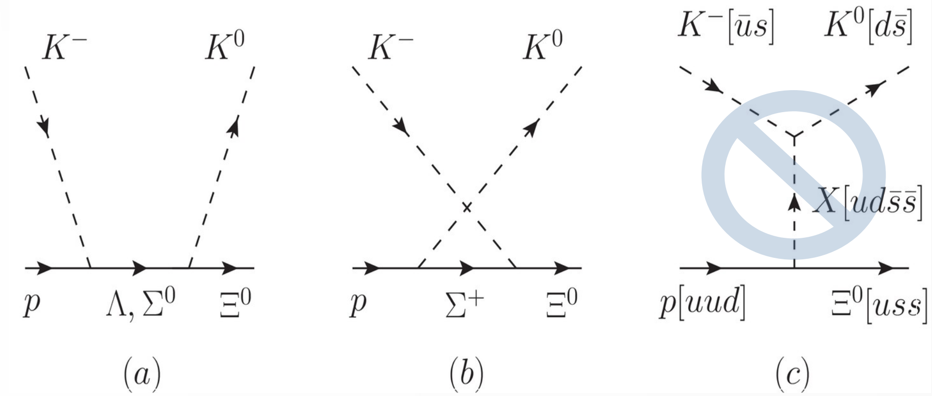

□ tetraquark in **charm sector** [LHCb, Nature Physics (2022)]

> First observation with [$cc\bar{u}\bar{d}$] content, $T_{cc}(3875, 1^+)$, width Γ ~ 410 keV in the mass spectrum of "$D^0 D^0 \pi^+$"

□ tetraquark in **strange sector**

> No meson of strangeness two is known to be exist.

❏ The evidence of the pentaquark in **charm sector**, $P_c^+[uudc\bar{c}]$, is clearer than that in **strange sector**, $P_s^+[uuds\bar{s}]$ & $\theta^+[uudd\bar{s}]$.

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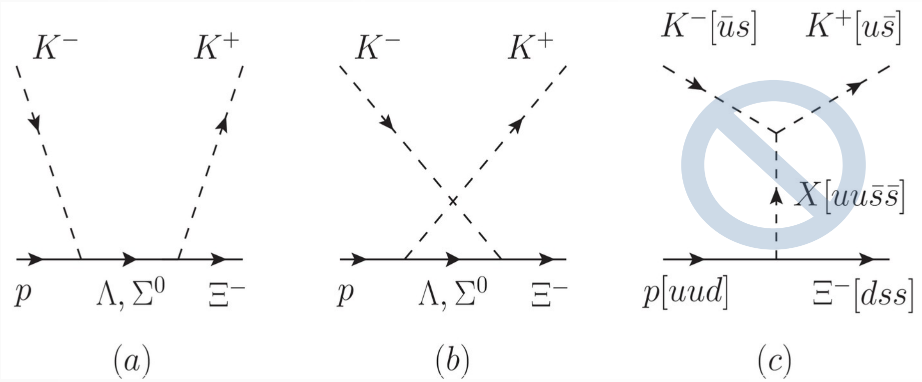

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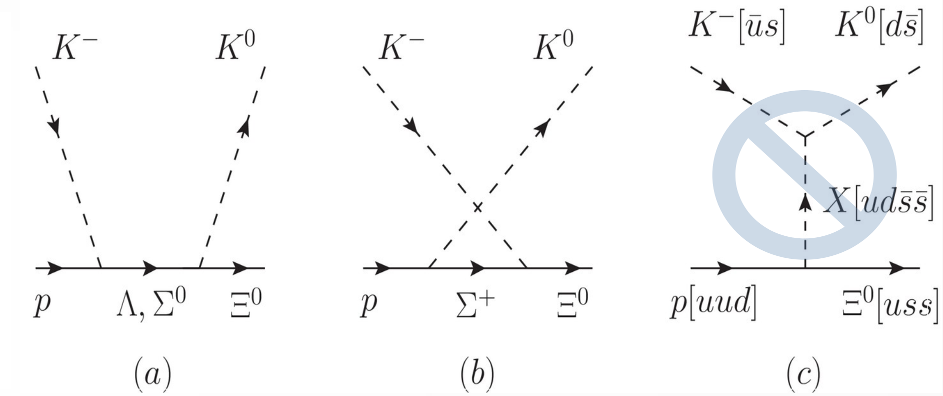
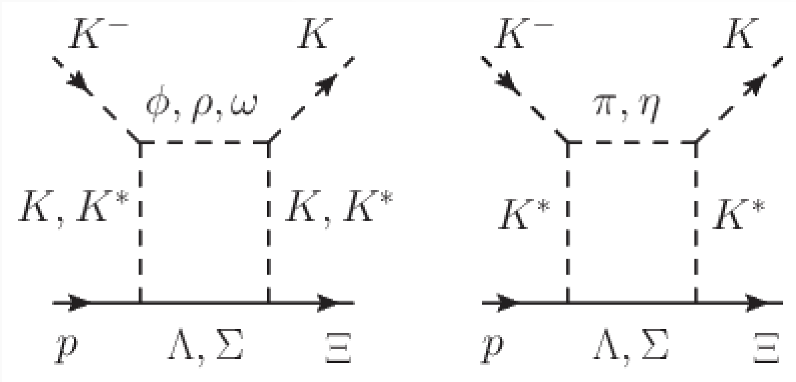


Rescattering effect



$$g_{K^*K\rho} = g_{K^*K\omega} = \frac{1}{\sqrt{2}} g_{K^*K\phi} = \frac{1}{2} g_{\omega\rho\pi}$$

$$g_{KK\rho} = g_{KK\omega} = \frac{1}{2} g_{\pi\pi\rho}$$

‣ Use the dominant decay process: $\varphi \to K^+K^-$, $K^* \to K\pi$, etc

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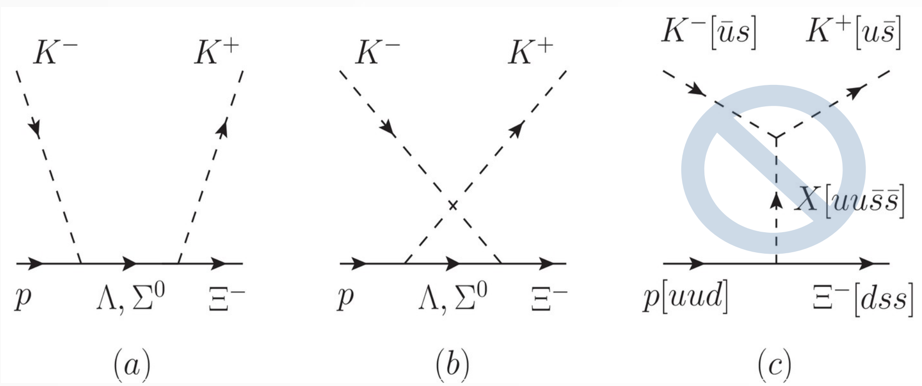

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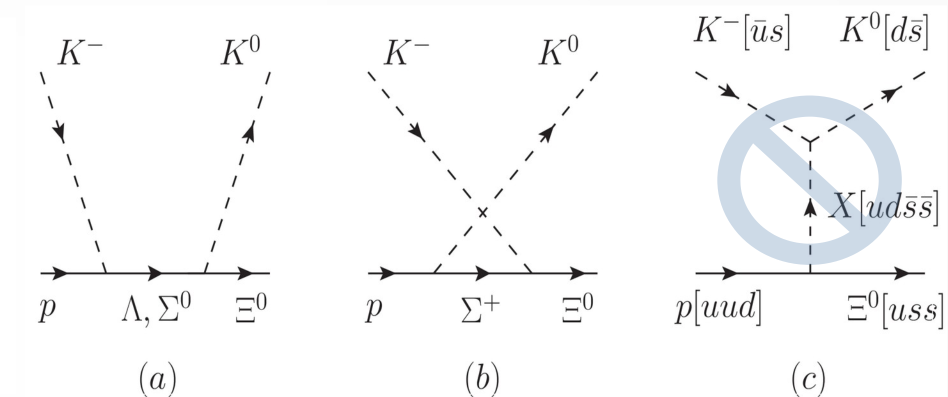

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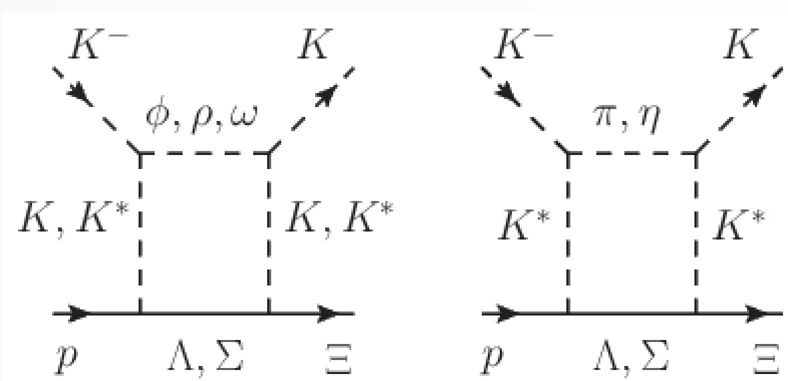

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❑ We employ a “Regge + Resonance + Rescattering” approach.

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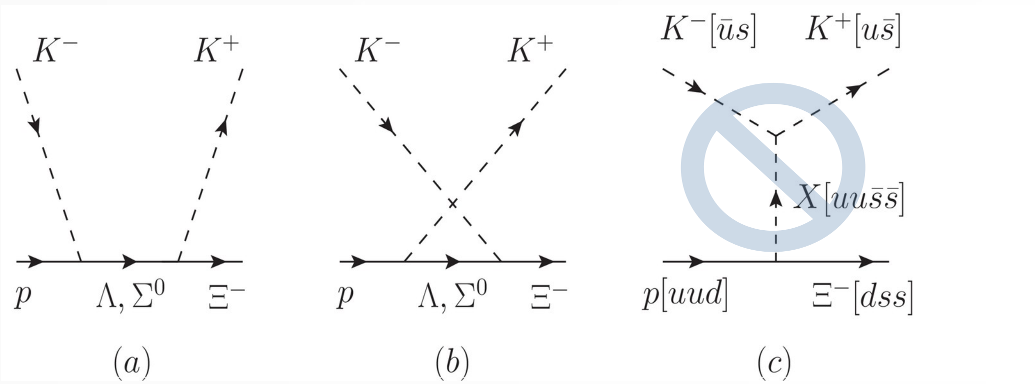

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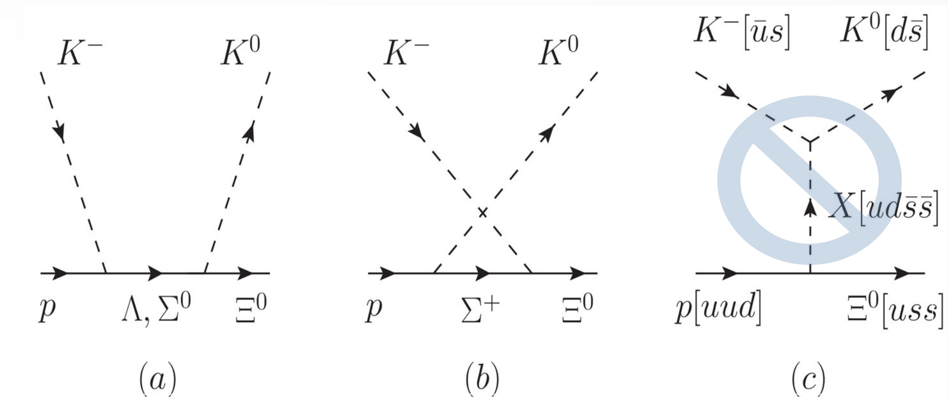

❑ Effective Lagrangians

$$\mathcal{L}^{1/2(\pm)}_{\Lambda NK} \equiv g_{\Lambda NK}\,\bar{\Lambda}\left(D^{1/2(\pm)}_{\Lambda NK}\bar{K}\right)N + \text{H.c.}$$

$$\mathcal{L}^{3/2(\pm)}_{\Lambda NK} = \frac{g_{\Lambda NK}}{m_K}\,\bar{\Lambda}^{\nu}\left(D^{3/2(\pm)}_{\nu}\bar{K}\right)N + \text{H.c.}$$

$$\mathcal{L}^{5/2(\pm)}_{\Lambda NK} = \frac{g_{\Lambda NK}}{m_K^2}\,\bar{\Lambda}^{\mu\nu}\left(D^{5/2(\pm)}_{\mu\nu}\bar{K}\right)N + \text{H.c.}$$

$$\mathcal{L}^{7/2(\pm)}_{\Lambda NK} = \frac{g_{\Lambda NK}}{m_K^3}\,\bar{\Lambda}^{\mu\nu\rho}\left(D^{7/2(\pm)}_{\mu\nu\rho}\bar{K}\right)N + \text{H.c.}$$

$$D^{1/2(\pm)}_{B'BM} \equiv -\Gamma^{(\pm)}\left(\pm i\lambda + \frac{1-\lambda}{m_{B'} \pm m_B}\,\not{\partial}\right),$$

$$D^{3/2(\pm)}_{\nu} \equiv \Gamma^{(\mp)}\partial_\nu\,,$$

$$D^{5/2(\pm)}_{\mu\nu} \equiv -i\,\Gamma^{(\pm)}\partial_\mu\partial_\nu\,,$$

$$D^{7/2(\pm)}_{\mu\nu\rho} \equiv -\Gamma^{(\mp)}\partial_\mu\partial_\nu\partial_\rho\,,$$

($\lambda = 1$) Pseudoscalar (PS) form
($\lambda = 0$) Pseudovector (PV) form

❑ Coupling constants

Y	g_{NYK}	$g_{\Xi YK}$
$\Lambda(1116)\frac{1}{2}^+$	**– 13.24**	**3.52**
$\Sigma(1193)\frac{1}{2}^+$	**3.58**	**– 13.26**

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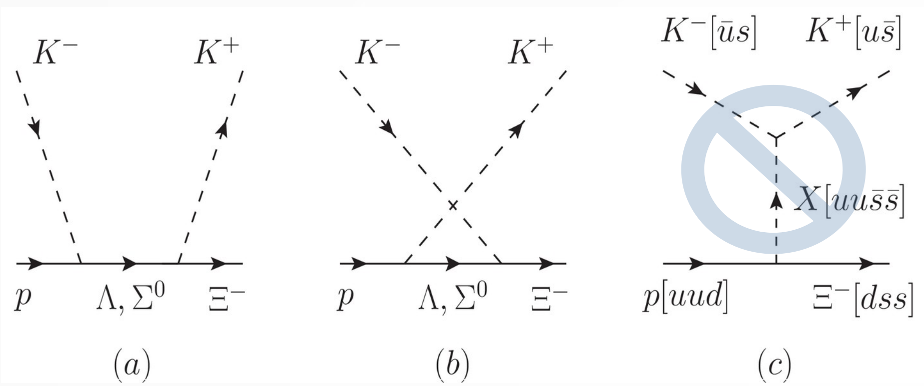

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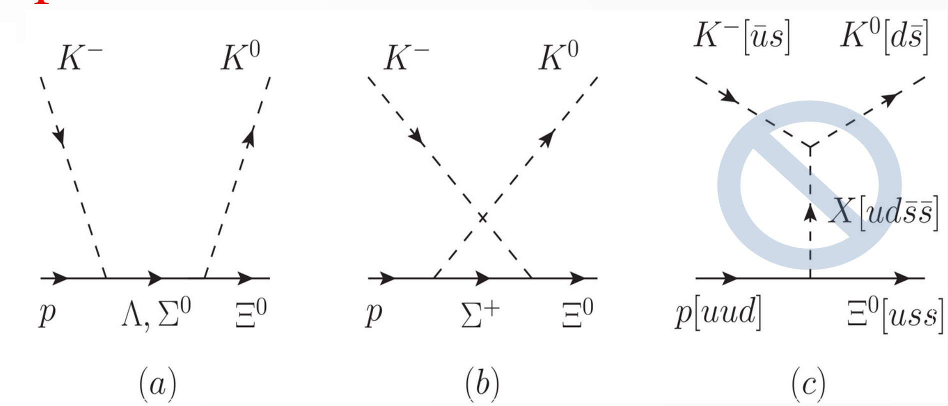

□ (Fig. b) We employ a hybridized Regge model to describe the backward angles in the *u* channel.

"Baryon exchange processes" Storrow, Phys.Rept.103.317 (1984)

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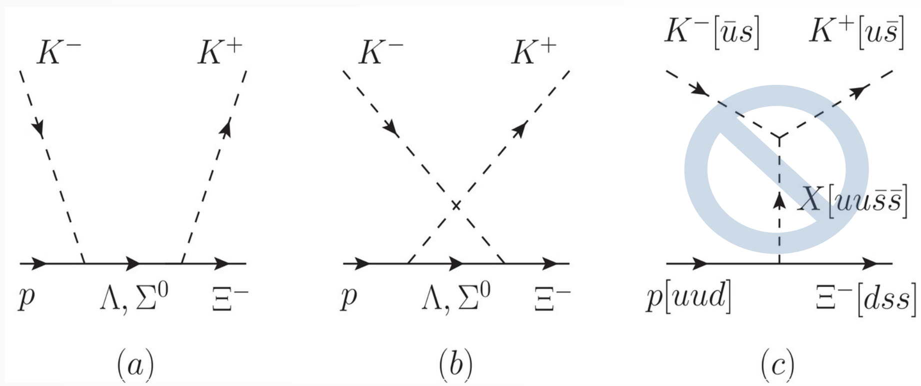

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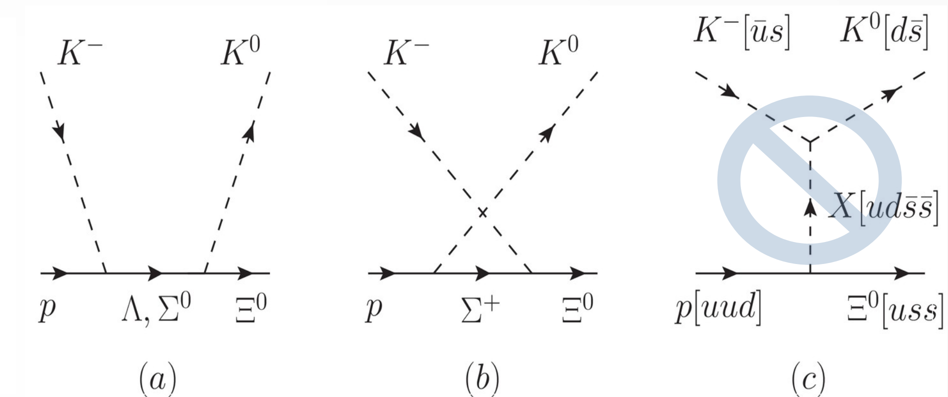

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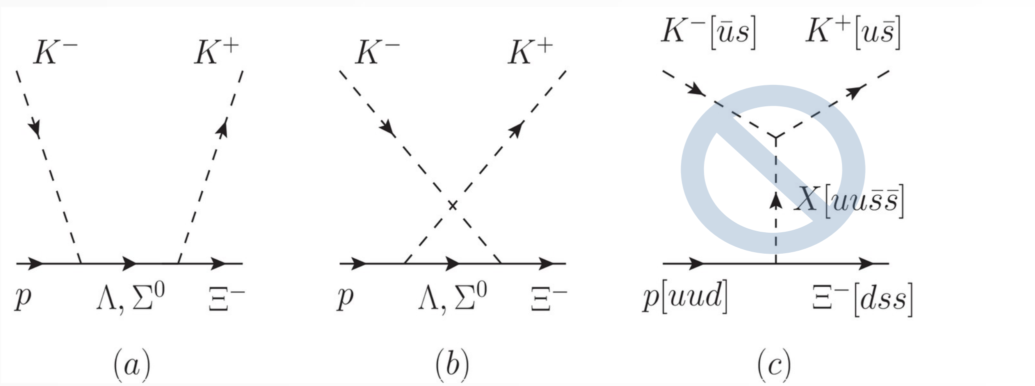

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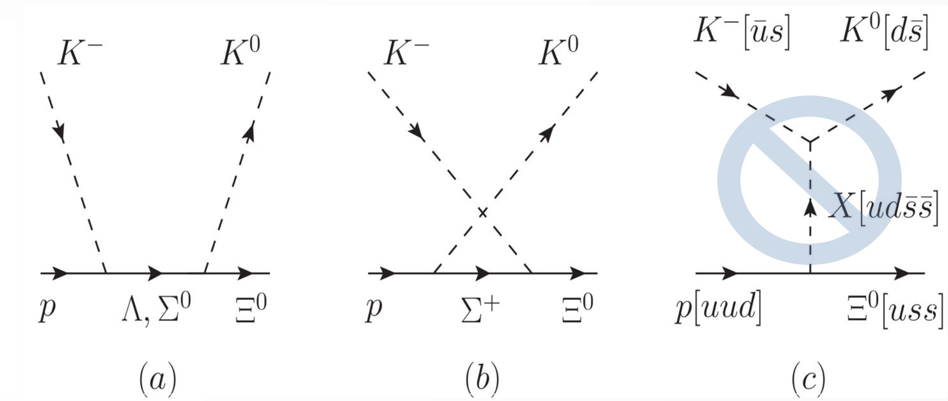

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□ Box diagram is calculated from the 3-dimensional reduction of the Bethe-Salpeter equation.

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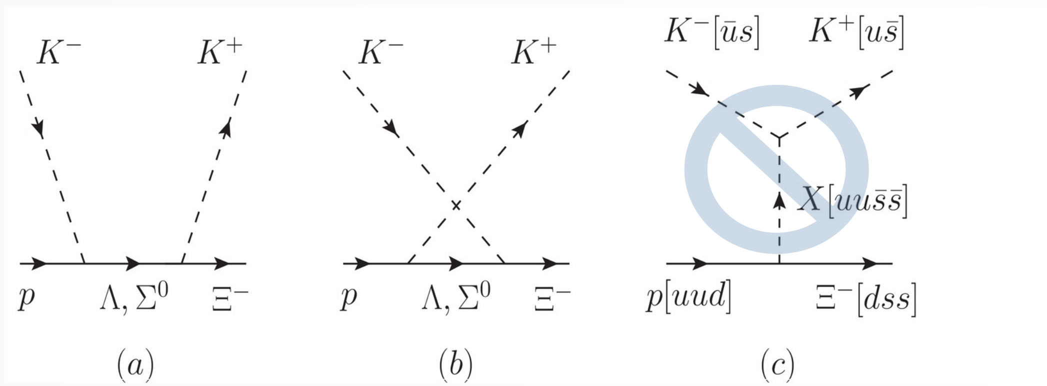
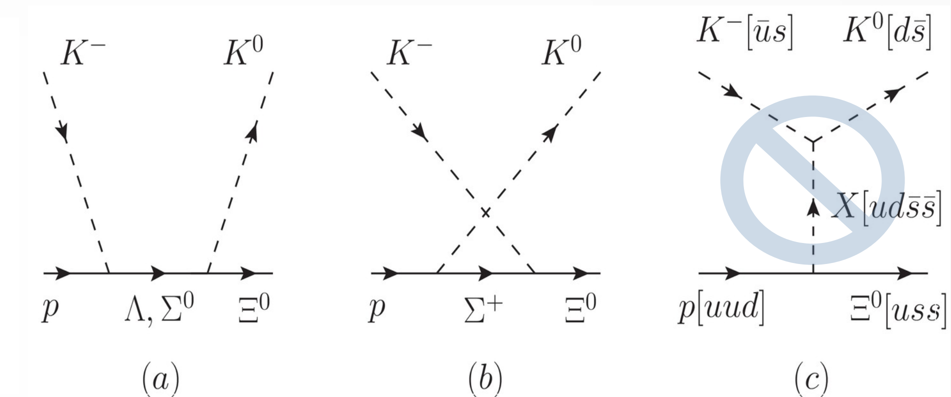


(B) $K^- p \to K^0 \Xi^0$



1(1) -1(1) 1(1) -1(1) [isospin factors] 1(1) 1(1) √2 -√2

□ Isospin factors

Λ exchange: $\begin{pmatrix} \bar{K}^+ & \bar{K}^0 \end{pmatrix} \Lambda \begin{pmatrix} p \\ n \end{pmatrix} = 1\bar{K}^+\Lambda p + 1\bar{K}^0\Lambda n$

Σ exchange: $\begin{pmatrix} \bar{K}^+ & \bar{K}^0 \end{pmatrix} \begin{pmatrix} \Sigma^0 & \sqrt{2}\Sigma^+ \\ \sqrt{2}\Sigma^- & -\Sigma^- \end{pmatrix} \begin{pmatrix} p \\ n \end{pmatrix} = 1\bar{K}^+\Sigma^0 p + \sqrt{2}(\bar{K}^+\Sigma^+ n + \bar{K}^0\Sigma^- p) - 1\bar{K}^0\Sigma^0 n$

□ *u*-channel Σ exchange: σ ($K^- p \to K^+ \Xi^-$) × 4 = σ ($K^- p \to K^0 \Xi^0$)

□ We consider two different isospin channels simultaneously: useful to constrain model parameters.

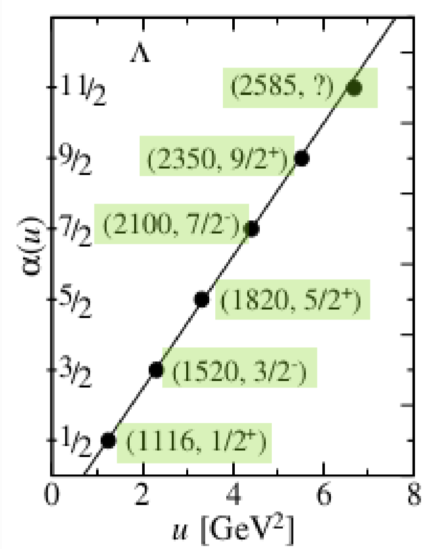
2. K⁻ p → K Ξ theoretical framework

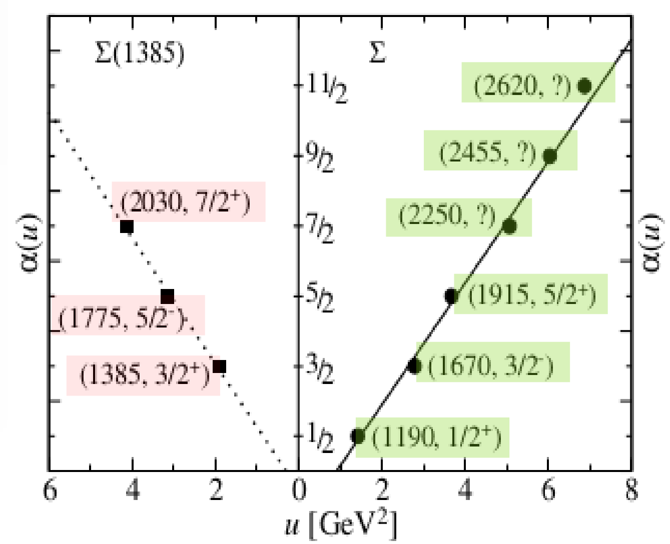
Λ hyperons

	J^P	status
$\Lambda(1116)$	$1/2^+$	****
$\Lambda(1380)$	$1/2^-$	**
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	****
$\Lambda(1670)$	$1/2^-$	****
$\Lambda(1690)$	$3/2^-$	****
$\Lambda(1710)$	$1/2^+$	*
$\Lambda(1800)$	$1/2^-$	***
s_{th}		
$\Lambda(1810)$	$1/2^+$	***
$\Lambda(1820)$	$5/2^+$	****
$\Lambda(1830)$	$5/2^-$	****
$\Lambda(1890)$	$3/2^+$	****
$\Lambda(2000)$	$1/2^-$	*
$\Lambda(2050)$	$3/2^-$	*
$\Lambda(2070)$	$3/2^+$	*
$\Lambda(2080)$	$5/2^-$	*
$\Lambda(2085)$	$7/2^+$	**
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$		*

❑ Hyperon Regge trajectories

Storrow, Phys.Rept.103.317 (1984)





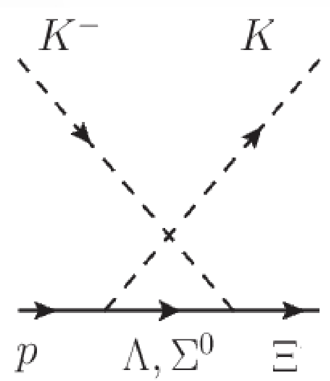
$\Lambda : \alpha(u) = -0.65 + 0.94u$

Λ(1405) : excluded

$\Sigma\ : \alpha(u) = -0.79 + 0.87u$

$\Sigma^* : \alpha(u) = -0.27 + 0.9u$

s_{th} (K⁻ p → K Ξ) = 1.81 GeV



Σ hyperons

	J^P	status
$\Sigma(1193)$	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	*
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1750)$	$1/2^-$	***
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1780)$	$3/2^+$	*
s_{th}		
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(1900)$	$1/2^-$	**
$\Sigma(1910)$	$3/2^-$	***
$\Sigma(1915)$	$5/2^+$	****
$\Sigma(1940)$	$3/2^+$	*
$\Sigma(2010)$	$3/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	*
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2110)$	$1/2^-$	*
$\Sigma(2230)$	$3/2^+$	*
$\Sigma(2250)$		**
$\Sigma(2455)$		*
$\Sigma(2620)$		*
$\Sigma(3000)$		*
$\Sigma(3170)$		*

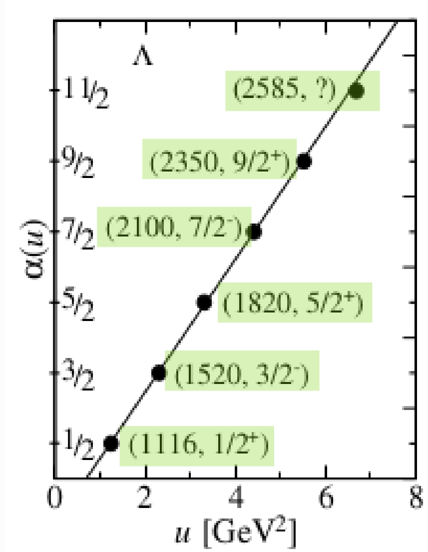
2. $K^- p \to K\,\Xi$ theoretical framework

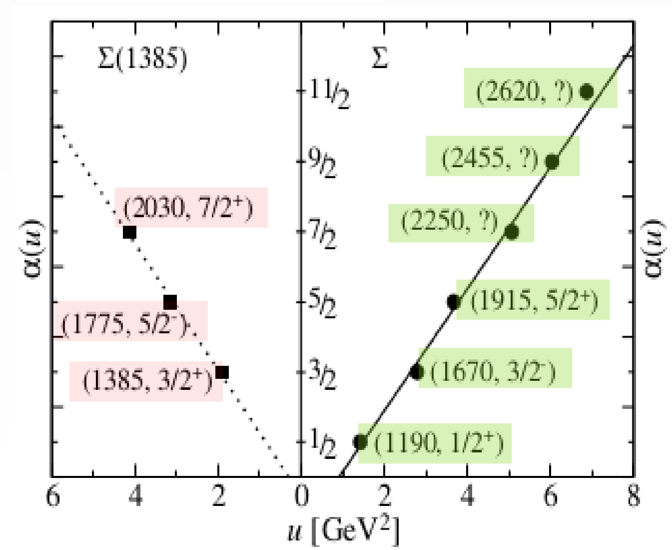
Λ hyperons

	J^P	status
$\Lambda(1116)$	$1/2^+$	****
$\Lambda(1380)$	$1/2^-$	**
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	****
$\Lambda(1670)$	$1/2^-$	****
$\Lambda(1690)$	$3/2^-$	****
$\Lambda(1710)$	$1/2^+$	*
$\Lambda(1800)$	$1/2^-$	***
s_{th}		
$\Lambda(1810)$	$1/2^+$	***
$\Lambda(1820)$	$5/2^+$	****
$\Lambda(1830)$	$5/2^-$	****
$\Lambda(1890)$	$3/2^+$	****
$\Lambda(2000)$	$1/2^-$	*
$\Lambda(2050)$	$3/2^-$	*
$\Lambda(2070)$	$3/2^+$	*
$\Lambda(2080)$	$5/2^-$	*
$\Lambda(2085)$	$7/2^+$	**
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$		*

❑ Hyperon Regge trajectories

Storrow, Phys.Rept.103.317 (1984)





$\Lambda : \alpha(u) = -0.65 + 0.94u$

$\Lambda(1405)$: excluded

$\Sigma : \alpha(u) = -0.79 + 0.87u$

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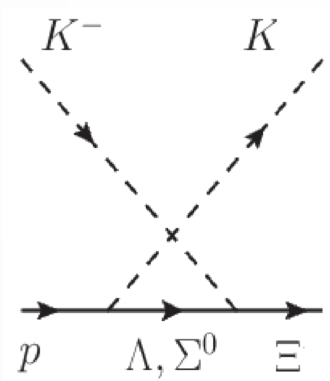
$s_{th}(K^- p \to K\,\Xi) = 1.81$ GeV



Σ hyperons

	J^P	status
$\Sigma(1193)$	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	*
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1750)$	$1/2^-$	***
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1780)$	$3/2^+$	*
s_{th}		
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(1900)$	$1/2^-$	**
$\Sigma(1910)$	$3/2^-$	***
$\Sigma(1915)$	$5/2^+$	****
$\Sigma(1940)$	$3/2^+$	*
$\Sigma(2010)$	$3/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	*
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2110)$	$1/2^-$	*
$\Sigma(2230)$	$3/2^+$	*
$\Sigma(2250)$		**
$\Sigma(2455)$		*
$\Sigma(2620)$		*
$\Sigma(3000)$		*
$\Sigma(3170)$		*

❑ As seen, hyperon Regge trajectories involve many of 3 & 4 star resonances.

2. $K^- p \to K\,\Xi$ theoretical framework

Λ hyperons

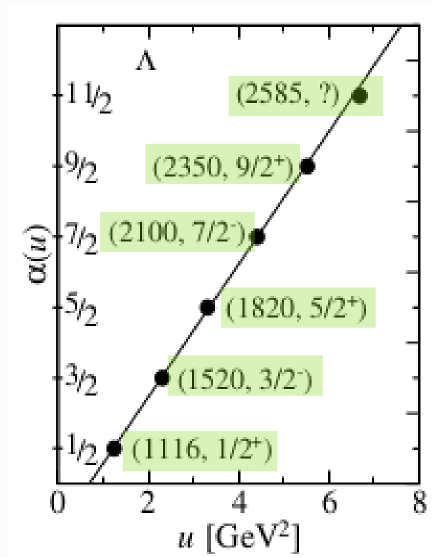
	J^P	status
$\Lambda(1116)$	$1/2^+$	****
$\Lambda(1380)$	$1/2^-$	**
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	****
$\Lambda(1670)$	$1/2^-$	****
$\Lambda(1690)$	$3/2^-$	****
$\Lambda(1710)$	$1/2^+$	*
$\Lambda(1800)$	$1/2^-$	***

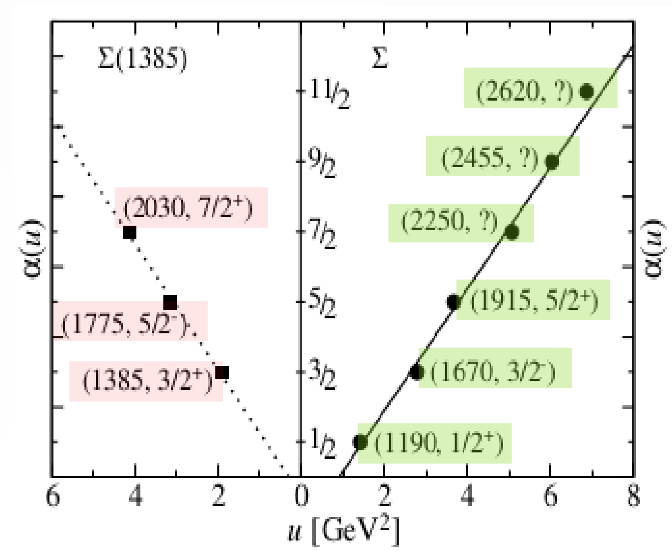
s_{th}

$\Lambda(1810)$	$1/2^+$	***
$\Lambda(1820)$	$5/2^+$	****
$\Lambda(1830)$	$5/2^-$	****
$\Lambda(1890)$	$3/2^+$	****
$\Lambda(2000)$	$1/2^-$	*
$\Lambda(2050)$	$3/2^-$	*
$\Lambda(2070)$	$3/2^+$	*
$\Lambda(2080)$	$5/2^-$	*
$\Lambda(2085)$	$7/2^+$	**
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$	$11/2^-$?	*

❑ Hyperon Regge trajectories

Storrow, Phys.Rept.103.317 (1984)





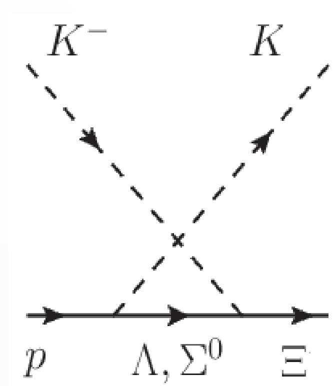
$\Lambda : \alpha(u) = -0.65 + 0.94u$

$\Lambda(1405)$: excluded

$\Sigma : \alpha(u) = -0.79 + 0.87u$

$\Sigma^* : \alpha(u) = -0.27 + 0.9u$

$s_{th}(K^- p \to K\,\Xi) = 1.81$ GeV



Σ hyperons

	J^P	status
$\Sigma(1193)$	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	*
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1750)$	$1/2^-$	***
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1780)$	$3/2^+$	*

s_{th}

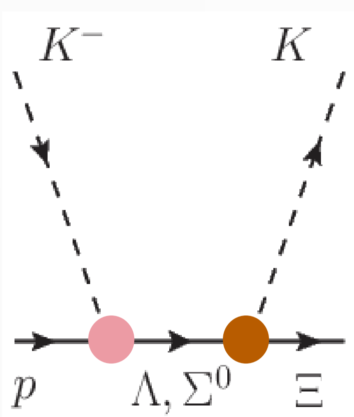
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(1900)$	$1/2^-$	**
$\Sigma(1910)$	$3/2^-$	***
$\Sigma(1915)$	$5/2^+$	****
$\Sigma(1940)$	$3/2^+$	*
$\Sigma(2010)$	$3/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	*
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2110)$	$1/2^-$	*
$\Sigma(2230)$	$3/2^+$	*
$\Sigma(2250)$	$7/2^-$?	**
$\Sigma(2455)$	$9/2^+$?	*
$\Sigma(2620)$	$11/2^-$?	*
$\Sigma(3000)$		*
$\Sigma(3170)$		*

❑ As seen, hyperon Regge trajectories involve many of 3 & 4 star resonances.

2. $K^- p \to K\,\Xi$ theoretical framework

- PDG 2020
- We include (Λ^* & Σ^*) resonances which couple strongly to $\bar{K}N$ & $K\Xi$ channels.
- Partial decay width

$$\Gamma_{Y^*\to\bar{K}N} = \frac{1}{8\pi}\frac{q_K}{M_{Y^*}^2}\frac{1}{2J_{Y^*}+1}|\mathcal{M}_{Y^*\to\bar{K}N}|^2$$



(Λ^*, J^P)	Γ_{Λ^*} [MeV]	status	$\mathrm{Br}_{\Lambda^*\to N\bar{K}}$ [%]	$\lvert g_{KN\Lambda^*}\rvert$	$\mathrm{Br}_{\Lambda^*\to\Xi K}$ [%]	$\lvert g_{K\Xi\Lambda^*}\rvert$
$\Lambda(1820, 5/2^+)$	80	****	$55-65$	8.41	–	–
$\Lambda(1830, 5/2^-)$	90	****	$4-8$		–	–
$\Lambda(1890, 3/2^+)$	120	****	$24-36$	1.19	~ 1	0.75
$\Lambda(2000, 1/2^-)$	190	*	27 ± 6		–	–
$\Lambda(2050, 3/2^-)$	493	*	19 ± 4		–	–
$\Lambda(2070, 3/2^+)$	370	*	12 ± 5	1.01	7 ± 3	1.38
$\Lambda(2080, 5/2^-)$	181	*	11 ± 3	0.71	4 ± 1	1.18
$\Lambda(2085, 7/2^+)$	200	**	–	–	–	–
$\Lambda(2100, 7/2^-)$	200	****	$25-35$	3.40	<3	<8.45
$\Lambda(2110, 5/2^+)$	250	***	$5-25$		–	–
$\Lambda(2325, 3/2^-)$	168	*	–	–	–	–
$\Lambda(2350, 9/2^+)$	150	***	~ 12		–	–
$\Lambda(2585, ?^?)$		**	–	–	–	–

(Σ^*, J^P)	Γ_{Σ^*} [MeV]	status	$\mathrm{Br}_{\Sigma^*\to N\bar{K}}$ [%]	$\lvert g_{KN\Sigma^*}\rvert$	$\mathrm{Br}_{\Sigma^*\to\Xi K}$ [%]	$\lvert g_{K\Xi\Sigma^*}\rvert$
$\Sigma(1880, 1/2^+)$	200	**	$10-30$		–	–
$\Sigma(1900, 1/2^-)$	165	**	$40-70$	0.93	3 ± 2	0.1
$\Sigma(1910, 3/2^-)$	220	***	$1-5$		–	–
$\Sigma(1915, 5/2^+)$	120	****	$5-15$	1.97	–	
$\Sigma(1940, 3/2^+)$	250	*	13 ± 2		–	–
$\Sigma(2010, 3/2^-)$	178	*	7 ± 3	1.26	3 ± 2	3.71
$\Sigma(2030, 7/2^+)$	180	****	$17-23$	0.82	<2	<1.41
$\Sigma(2070, 5/2^+)$	200	*	–	–	–	–
$\Sigma(2080, 3/2^+)$	170	*	–	–	–	–
$\Sigma(2100, 7/2^-)$	260	*	8 ± 2		–	–
$\Sigma(2160, 1/2^-)$	313	*	29 ± 7		–	–
$\Sigma(2230, 3/2^+)$	345	*	6 ± 2	0.41	2 ± 1	0.34
$\Sigma(2250, ?^?)$	100	***	<10	<0.59	–	–
$\Sigma(2455, ?^?)$	120	**	–	–	–	–
$\Sigma(2620, ?^?)$	200	**	–	–	–	–

2. $K^- p \to K\,\Xi$ theoretical framework

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$$\mathcal{L}^{1/2(\pm)}_{\Lambda NK} \equiv g_{\Lambda NK}\,\bar{\Lambda}(D^{1/2(\pm)}_{\Lambda NK}\bar{K})N + \text{H.c.}$$

$$\mathcal{L}^{3/2(\pm)}_{\Lambda NK} = \frac{g_{\Lambda NK}}{m_K}\,\bar{\Lambda}^{\nu}(D^{3/2(\pm)}_{\nu}\bar{K})N + \text{H.c.}$$

$$\mathcal{L}^{5/2(\pm)}_{\Lambda NK} = \frac{g_{\Lambda NK}}{m_K^2}\,\bar{\Lambda}^{\mu\nu}(D^{5/2(\pm)}_{\mu\nu}\bar{K})N + \text{H.c.}$$

$$\mathcal{L}^{7/2(\pm)}_{\Lambda NK} = \frac{g_{\Lambda NK}}{m_K^3}\,\bar{\Lambda}^{\mu\nu\rho}(D^{7/2(\pm)}_{\mu\nu\rho}\bar{K})N + \text{H.c.}$$

(Λ^*, J^P)	Γ_{Λ^*} [MeV]	status	$\mathrm{Br}_{\Lambda^*\to N\bar{K}}$ [%]	$\lvert g_{KN\Lambda^*}\rvert$	$\mathrm{Br}_{\Lambda^*\to\Xi K}$ [%]	$\lvert g_{K\Xi\Lambda^*}\rvert$
$\Lambda(1820, 5/2^+)$	80	****	$55-65$	8.41	–	–
$\Lambda(1830, 5/2^-)$	90	****	$4-8$		–	–
$\Lambda(1890, 3/2^+)$	120	****	$24-36$	1.19	~ 1	0.75
$\Lambda(2000, 1/2^-)$	190	*	27 ± 6		–	–
$\Lambda(2050, 3/2^-)$	493	*	19 ± 4		–	–
$\Lambda(2070, 3/2^+)$	370	*	12 ± 5	1.01	7 ± 3	1.38
$\Lambda(2080, 5/2^-)$	181	*	11 ± 3	0.71	4 ± 1	1.18
$\Lambda(2085, 7/2^+)$	200	**	–	–	–	–
$\Lambda(2100, 7/2^-)$	200	****	$25-35$	3.40	<3	<8.45
$\Lambda(2110, 5/2^+)$	250	***	$5-25$		–	–
$\Lambda(2325, 3/2^-)$	168	*	–	–	–	–
$\Lambda(2350, 9/2^+)$	150	***	~ 12		–	–
$\Lambda(2585, ?^?)$		**	–	–	–	–

(Σ^*, J^P)	Γ_{Σ^*} [MeV]	status	$\mathrm{Br}_{\Sigma^*\to N\bar{K}}$ [%]	$\lvert g_{KN\Sigma^*}\rvert$	$\mathrm{Br}_{\Sigma^*\to\Xi K}$ [%]	$\lvert g_{K\Xi\Sigma^*}\rvert$
$\Sigma(1880, 1/2^+)$	200	**	$10-30$		–	–
$\Sigma(1900, 1/2^-)$	165	**	$40-70$	0.93	3 ± 2	0.1
$\Sigma(1910, 3/2^-)$	220	***	$1-5$		–	–
$\Sigma(1915, 5/2^+)$	120	****	$5-15$	1.97	–	
$\Sigma(1940, 3/2^+)$	250	*	13 ± 2		–	–
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$\Sigma(2030, 7/2^+)$	180	****	$17-23$	0.82	<2	<1.41
$\Sigma(2070, 5/2^+)$	200	*	–	–	–	–
$\Sigma(2080, 3/2^+)$	170	*	–	–	–	–
$\Sigma(2100, 7/2^-)$	260	*	8 ± 2		–	–
$\Sigma(2160, 1/2^-)$	313	*	29 ± 7		–	–
$\Sigma(2230, 3/2^+)$	345	*	6 ± 2	0.41	2 ± 1	0.34
$\Sigma(2250, ?^?)$	100	***	<10	<0.59	–	–
$\Sigma(2455, ?^?)$	120	**	–	–	–	–
$\Sigma(2620, ?^?)$	200	**	–	–	–	–

2. $K^- p \to K\,\Xi$ theoretical framework

- ❑ PDG 2020
- ❑ We include (Λ^* & Σ^*) resonances which couple strongly to $\bar{K}N$ & $K\Xi$ channels.
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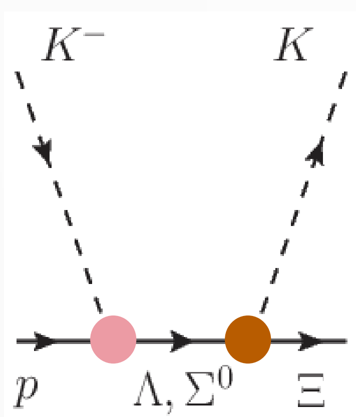
(Λ^*, J^P)	Γ_{Λ^*} [MeV]	status	$\mathrm{Br}_{\Lambda^*\to N\bar{K}}$ [%]	$\lvert g_{KN\Lambda^*}\rvert$	$\mathrm{Br}_{\Lambda^*\to\Xi K}$ [%]	$\lvert g_{K\Xi\Lambda^*}\rvert$
$\Lambda(1820, 5/2^+)$	80	****	$55-65$	8.41	–	–
$\Lambda(1830, 5/2^-)$	90	****	$4-8$		–	–
✓ $\Lambda(1890, 3/2^+)$	120	****	$24-36$	1.19	~ 1	0.75
$\Lambda(2000, 1/2^-)$	190	*	27 ± 6		–	–
$\Lambda(2050, 3/2^-)$	493	*	19 ± 4		–	–
$\Lambda(2070, 3/2^+)$	370	*	12 ± 5	1.01	7 ± 3	1.38
$\Lambda(2080, 5/2^-)$	181	*	11 ± 3	0.71	4 ± 1	1.18
$\Lambda(2085, 7/2^+)$	200	**	–	–	–	–
$\Lambda(2100, 7/2^-)$	200	****	$25-35$	3.40	<3	<8.45
$\Lambda(2110, 5/2^+)$	250	***	$5-25$		–	–
$\Lambda(2325, 3/2^-)$	168	*	–	–	–	–
$\Lambda(2350, 9/2^+)$	150	***	~ 12		–	–
$\Lambda(2585, ?^?)$		**	–	–	–	–



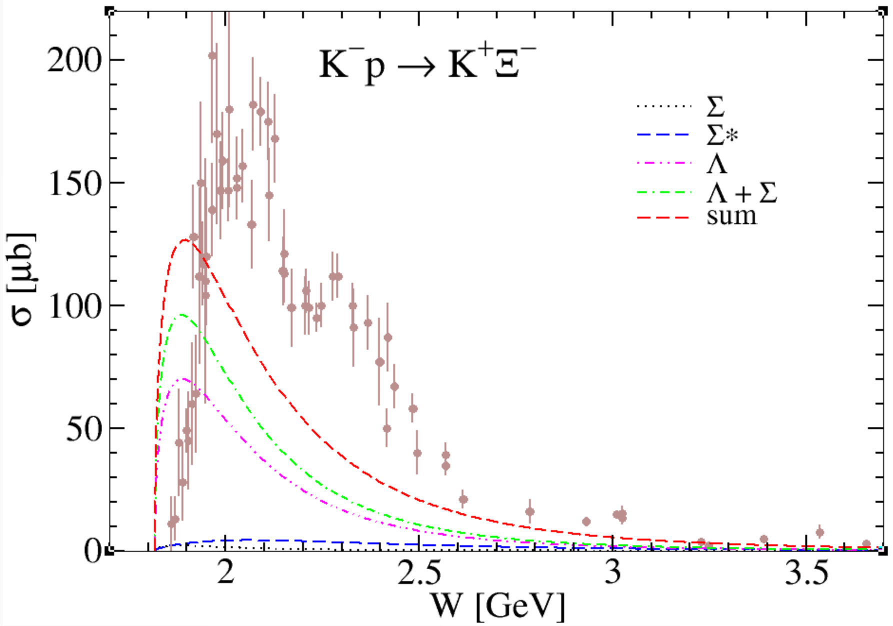
(Σ^*, J^P)	Γ_{Σ^*} [MeV]	status	$\mathrm{Br}_{\Sigma^*\to N\bar{K}}$ [%]	$\lvert g_{KN\Sigma^*}\rvert$	$\mathrm{Br}_{\Sigma^*\to\Xi K}$ [%]	$\lvert g_{K\Xi\Sigma^*}\rvert$
$\Sigma(1880, 1/2^+)$	200	**	$10-30$		–	–
$\Sigma(1900, 1/2^-)$	165	**	$40-70$	0.93	3 ± 2	0.1
$\Sigma(1910, 3/2^-)$	220	***	$1-5$		–	–
$\Sigma(1915, 5/2^+)$	120	****	$5-15$	1.97	–	
$\Sigma(1940, 3/2^+)$	250	*	13 ± 2		–	–
$\Sigma(2010, 3/2^-)$	178	*	7 ± 3	1.26	3 ± 2	3.71
✓ $\Sigma(2030, 7/2^+)$	180	****	$17-23$	0.82	<2	<1.41
$\Sigma(2070, 5/2^+)$	200	*	–	–	–	–
$\Sigma(2080, 3/2^+)$	170	*	–	–	–	–
$\Sigma(2100, 7/2^-)$	260	*	8 ± 2		–	–
$\Sigma(2160, 1/2^-)$	313	*	29 ± 7		–	–
✓ $\Sigma(2230, 3/2^+)$	345	*	6 ± 2	0.41	2 ± 1	0.34
✓ $\Sigma(2250, ?^?)$	100	***	<10	<0.59	–	–
$\Sigma(2455, ?^?)$	120	**	–	–	–	–
$\Sigma(2620, ?^?)$	200	**	–	–	–	–

✓ turn out to be important.

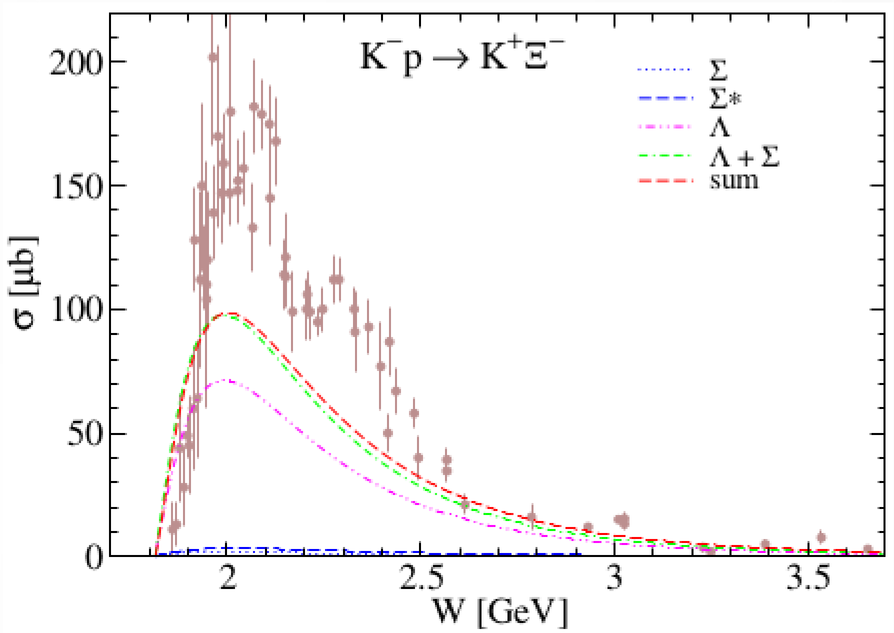
3. K⁻ p → K Ξ results

❑ Total cross section ($K^- p \to K^+ \Xi^-$) [u-channel background]

> pseudoscalar (ps) form (λ=1)

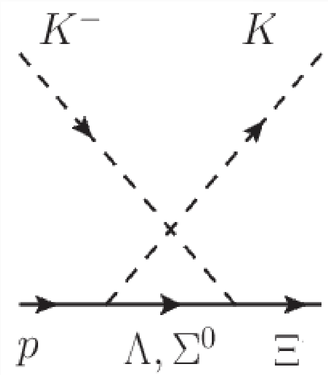


> pseudovector (pv) form (λ=0)



$$\mathcal{L}^{1/2(\pm)}_{\Lambda N K} \equiv g_{\Lambda N K}\, \bar{\Lambda} \left(D^{1/2(\pm)}_{\Lambda N K} \bar{K} \right) N + \text{H.c.}$$

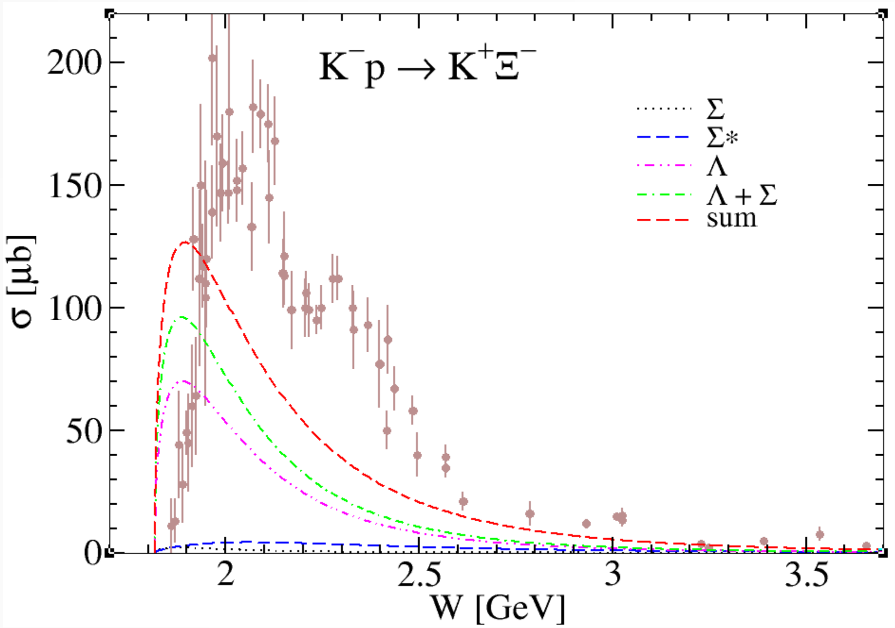
$$D^{1/2(\pm)}_{B' B M} \equiv -\Gamma^{(\pm)} \left(\pm i\lambda + \frac{1-\lambda}{m_{B'} \pm m_B} \partial\!\!\!/ \right)$$



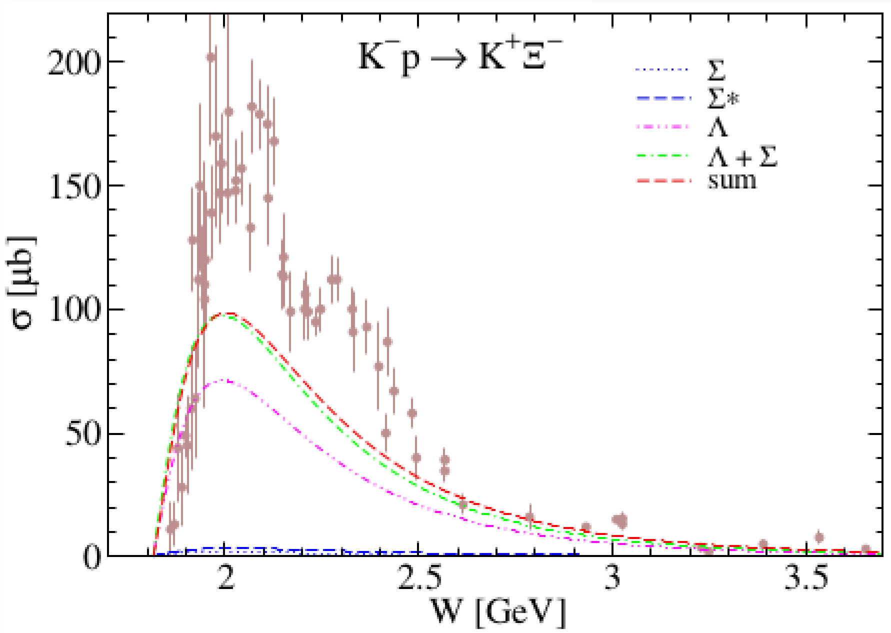
3. K⁻ p → K Ξ results

❑ Total cross section ($K^- p \to K^+ \Xi^-$) [u-channel background]

> pseudoscalar (ps) form (λ=1)



> pseudovector (pv) form (λ=0)

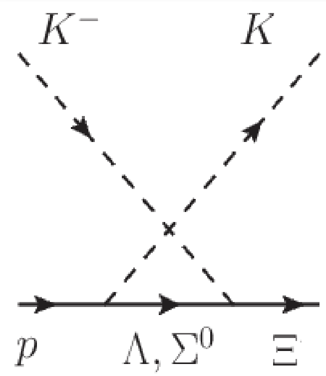


$$\mathcal{L}^{1/2(\pm)}_{\Lambda NK} \equiv g_{\Lambda NK}\,\bar{\Lambda}\left(D^{1/2(\pm)}_{\Lambda NK}\bar{K}\right)N + \text{H.c.}$$

$$D^{1/2(\pm)}_{B'BM} \equiv -\Gamma^{(\pm)}\left(\pm i\lambda + \frac{1-\lambda}{m_{B'} \pm m_B}\,\partial\!\!\!/\right)$$

s_{th} : σ(ps) > σ(pv)

high energy: σ(ps) < σ(pv)

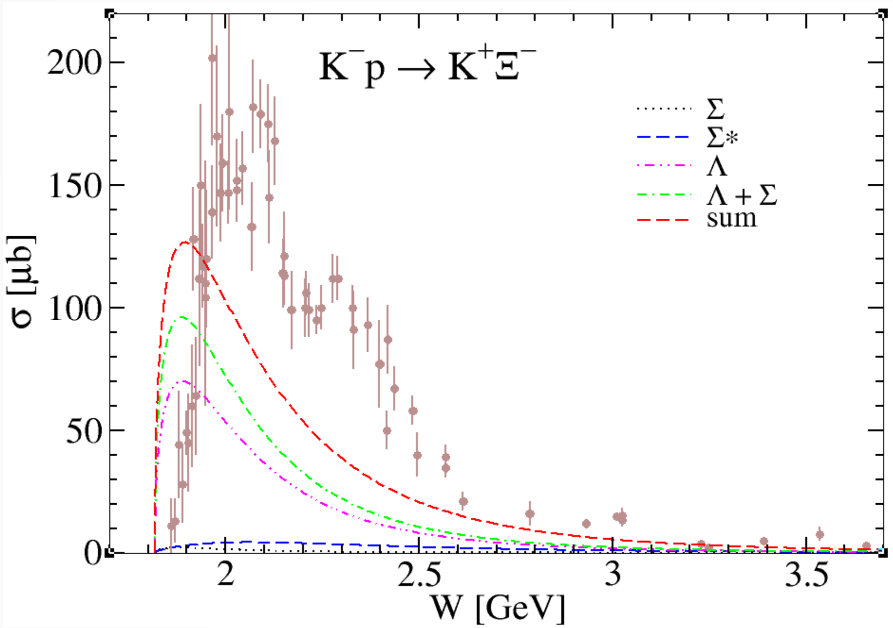


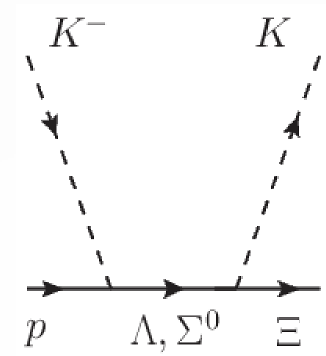
> We adopt the pv scheme rather than the ps scheme.

3. $K^- p \rightarrow K\,\Xi$ results

❑ Total cross section ($K^- p \rightarrow K^+ \Xi^-$) [$u$-channel background]

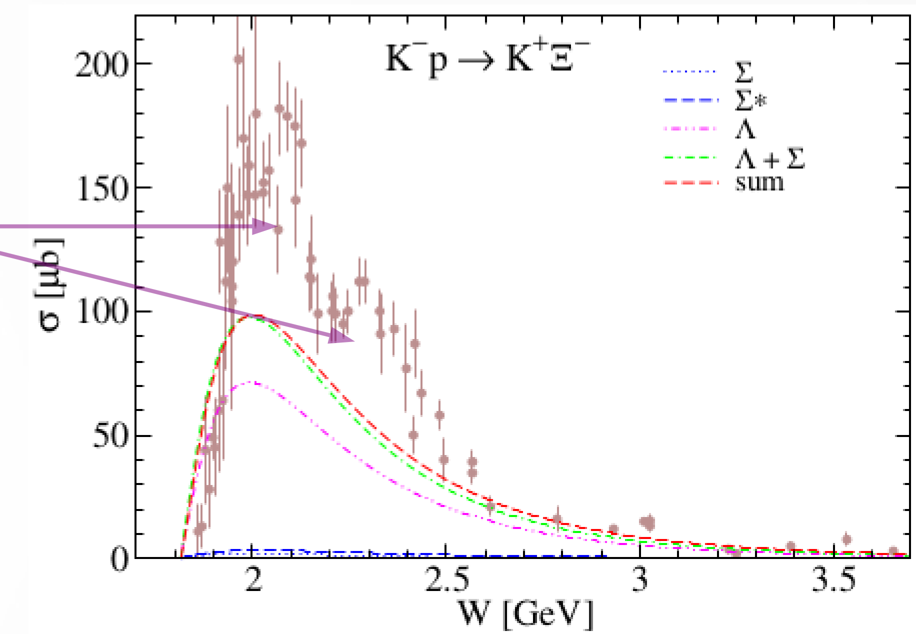
> pseudoscalar (ps) form (λ=1)





[s-channel resonant contribution]

> pseudovector (pv) form (λ=0)



$$\mathcal{L}^{1/2(\pm)}_{\Lambda N K} \equiv g_{\Lambda N K}\, \bar{\Lambda}\left(D^{1/2(\pm)}_{\Lambda N K}\bar{K}\right)N + \mathrm{H.c.}$$

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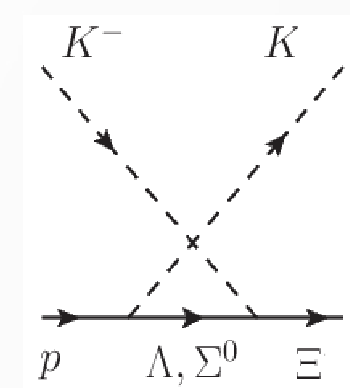
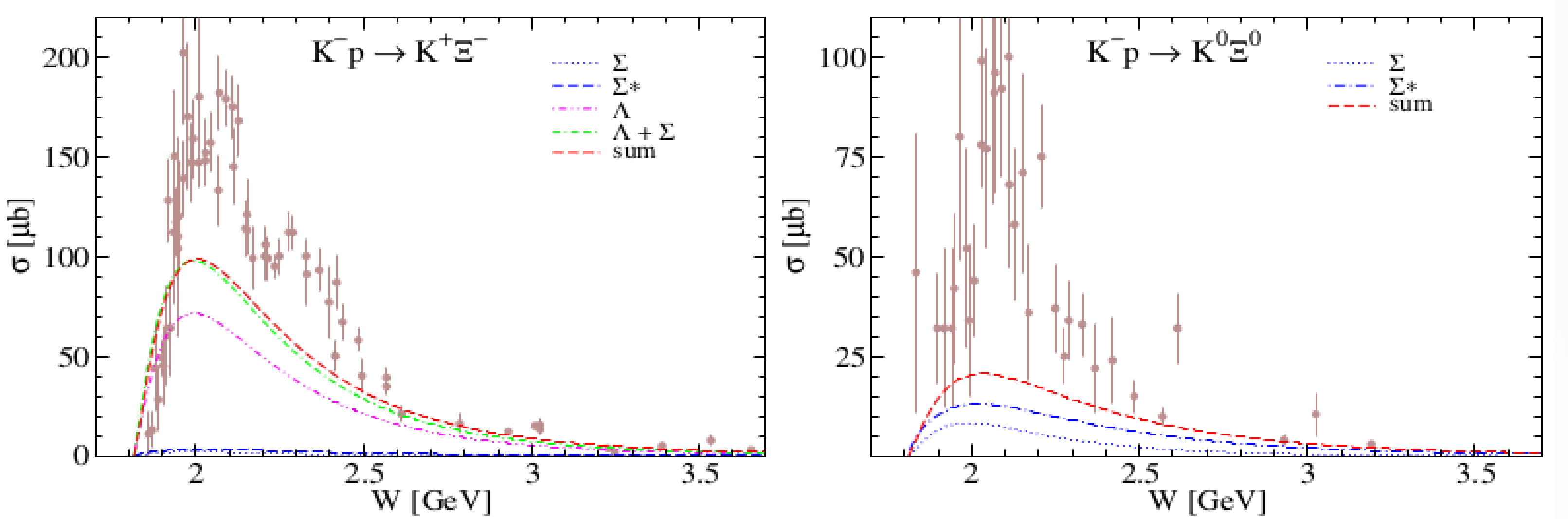


> We adopt the pv scheme rather than the ps scheme.

3. $K^- p \to K\,\Xi$ results

❑ Total cross section ($K^- p \to K^+ \Xi^-$ & $K^0 \Xi^0$) [*u*-channel background, pv form]

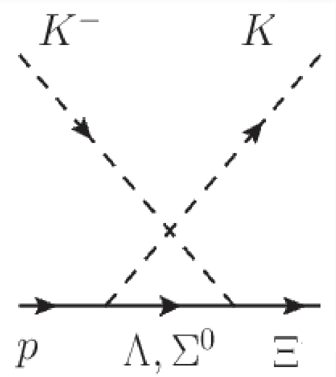


❑ Isospin rule

> *u*-channel Σ & Σ^* exchange

$\sigma\,(K^- p \to K^+ \Xi^-) \times 4$

$= \sigma\,(K^- p \to K^0 \Xi^0)$



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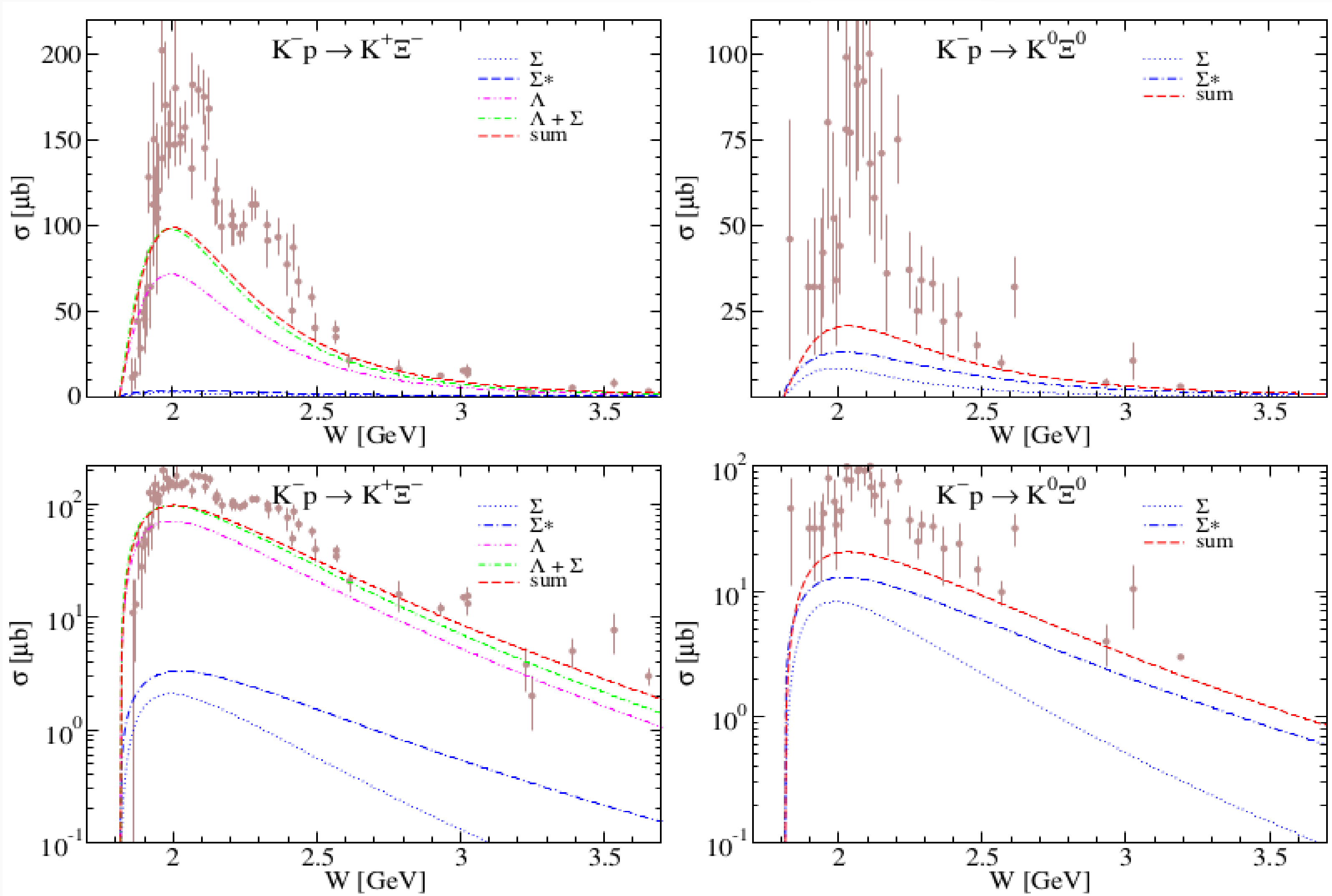
❑ Total cross section ($K^- p \to K^+ \Xi^-$ & $K^0 \Xi^0$) [u-channel background, pv form]

log scale:



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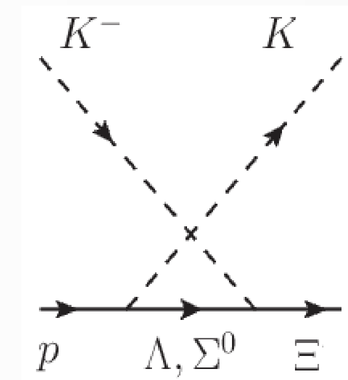


> Analytical behavior:

$$\lim_{s\to\infty} \sum_{s_i, s_f} |\mathcal{M}_\Sigma(s,u)|^2 \propto s$$

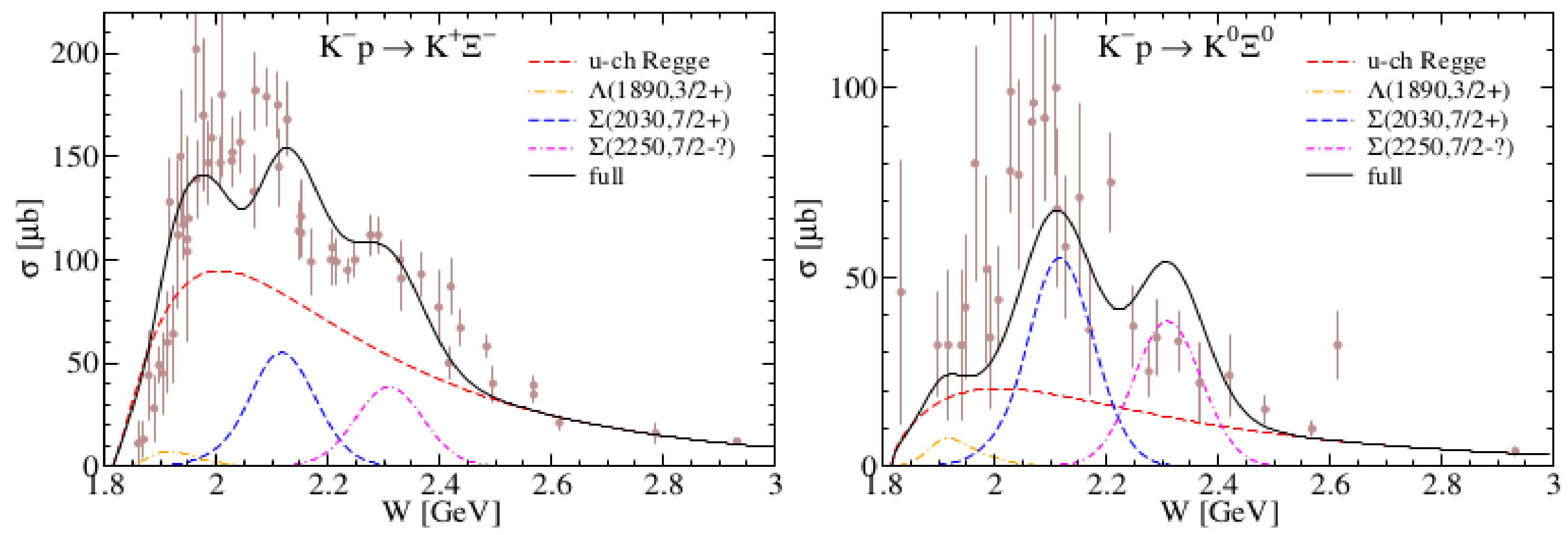
> Asymptotic behavior:

$$\frac{d\sigma}{du}(s \to \infty, u \to 0) \propto s^{2\alpha(u)-2}$$

> u-channel Regge amplitudes describe high energies (W $\gtrsim$ 2.5 GeV) very well.

3. $K^- p \rightarrow K \Xi$ results

❑ Total & Differential cross sections ($K^- p \rightarrow K^+ \Xi^-$ & $K^0 \Xi^0$) [*u*-channel background + *s*-channel Λ^* & Σ^*]



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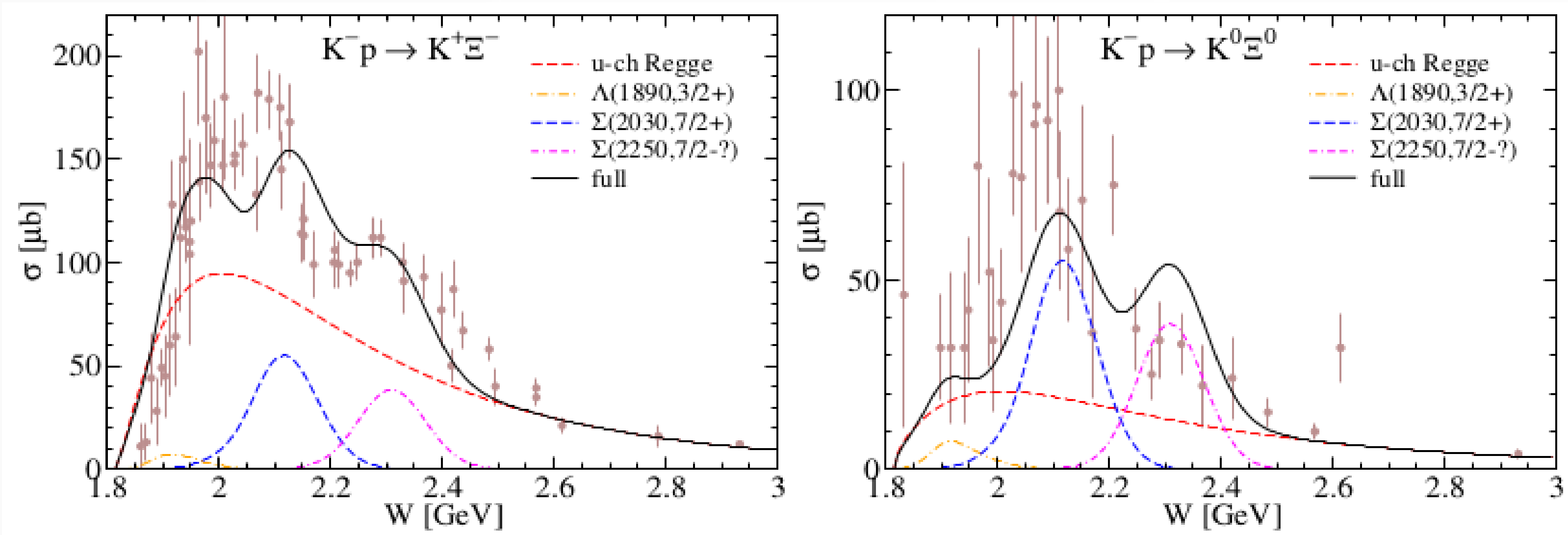

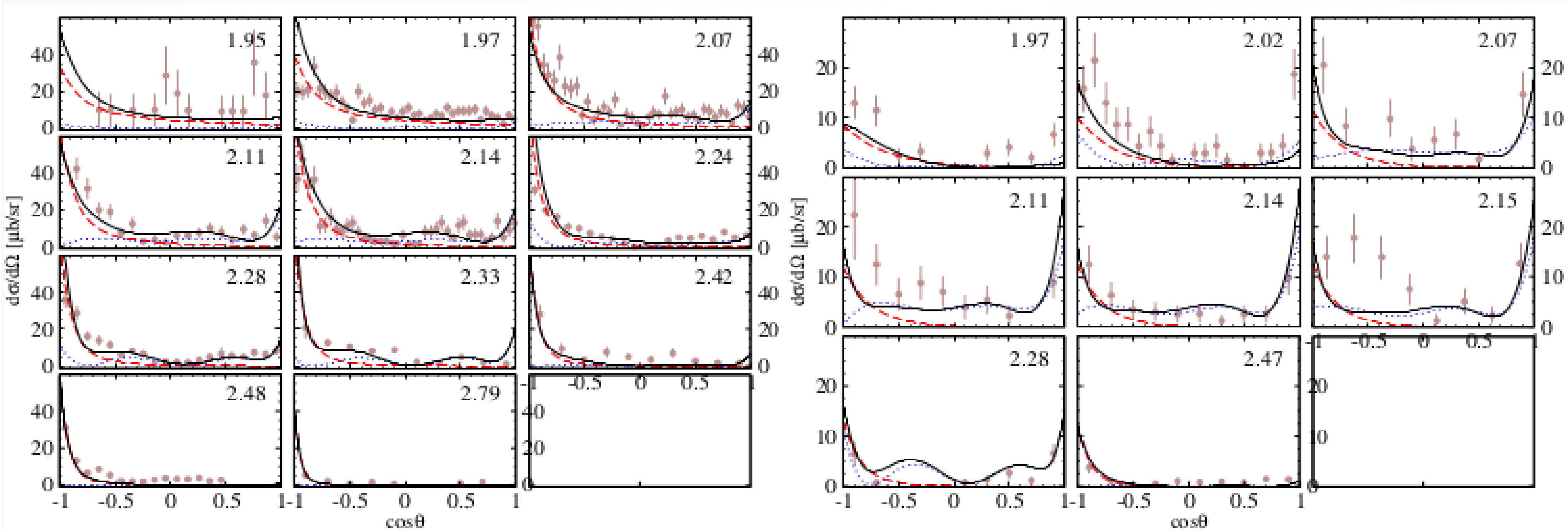

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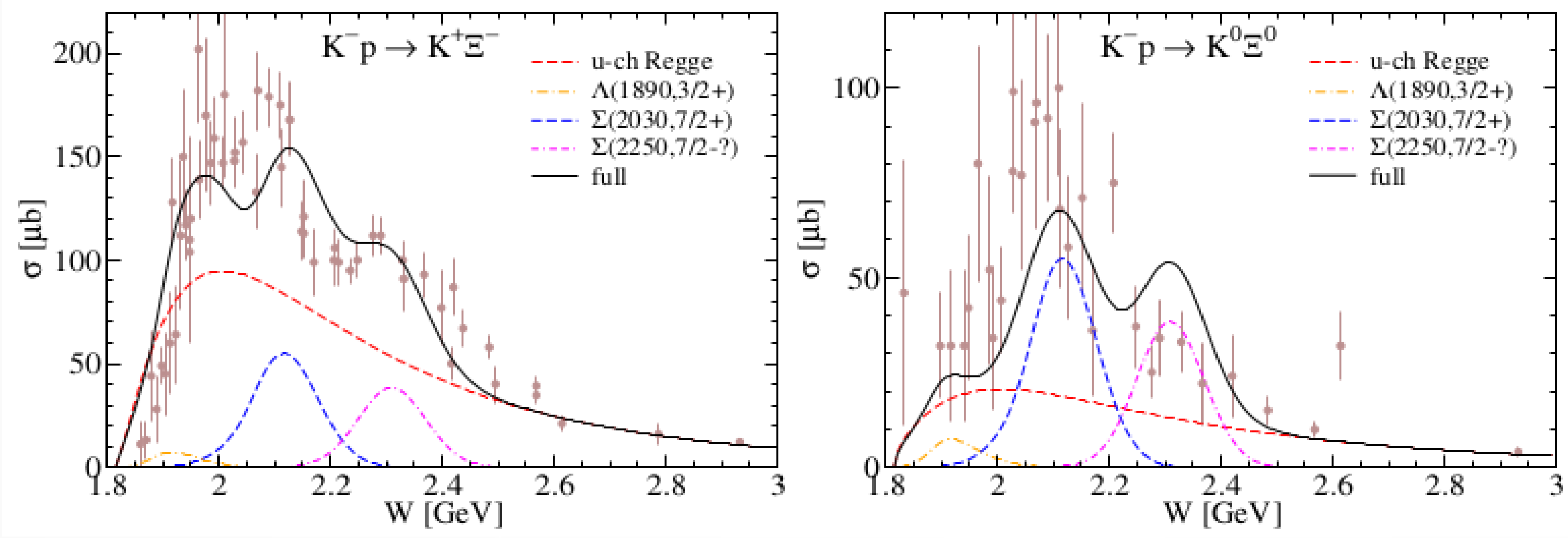
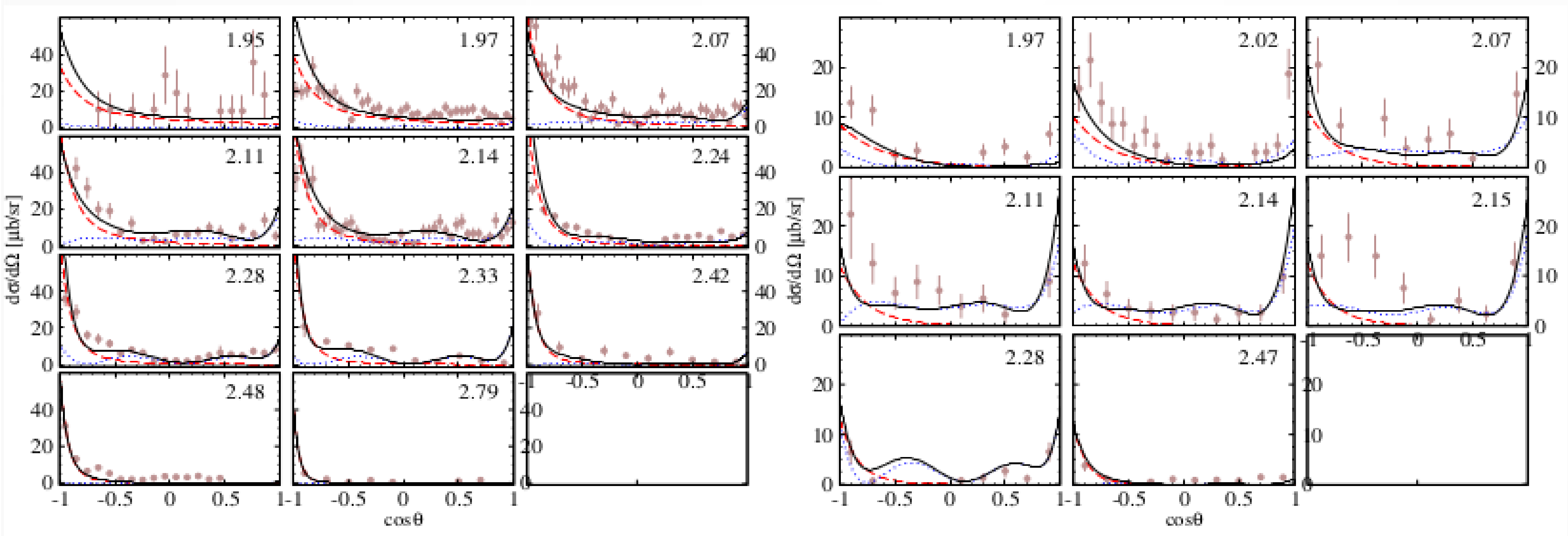


> Backward peaks due to a *u*-channel background contribution are clearly verified.
> Inclusion of various *s*-channel Λ^* & Σ^* resonances provides good agreement with the data.



3. $K^- p \to K \Xi$ results

- We used old experimental data taken in 1960s and 1970s.

3. $K^- p \rightarrow K\,\Xi$ results

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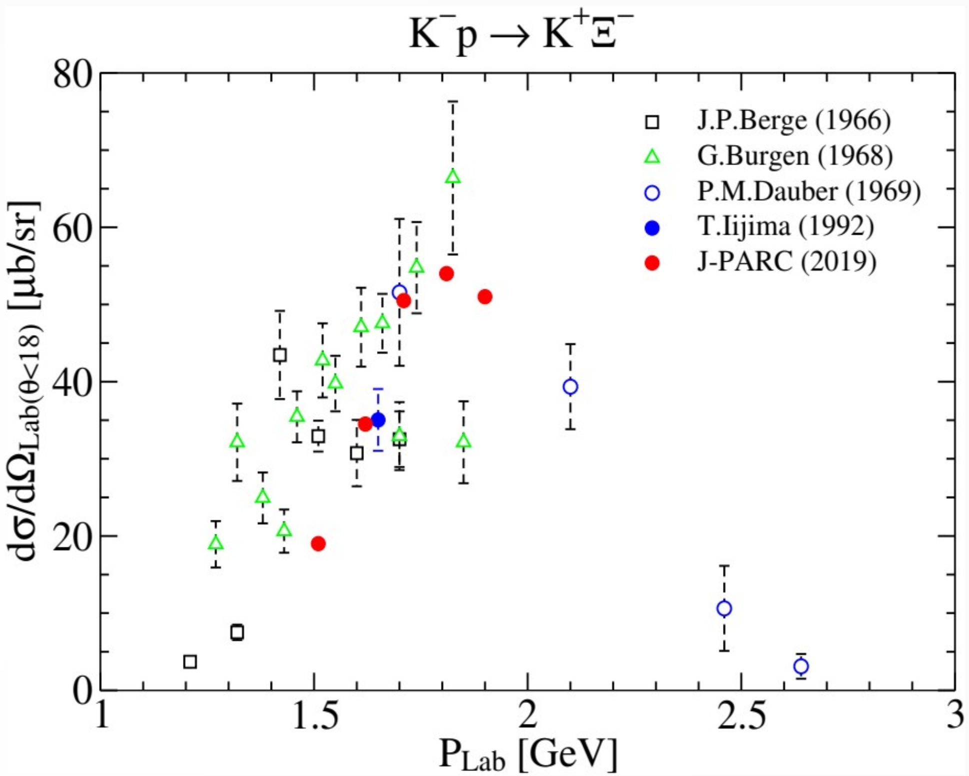
- Recently, the J-PARC E05 experiment measured the cross section at forward angles ($\theta_{Lab} < 18°$).

> Nagae et al. AIP Conf. Proc. 2130, 020015 (2019)
>
> Observation of a Ξ bound state in the $^{12}C(K^-, K^+)$ reaction at 1.8 GeV/c



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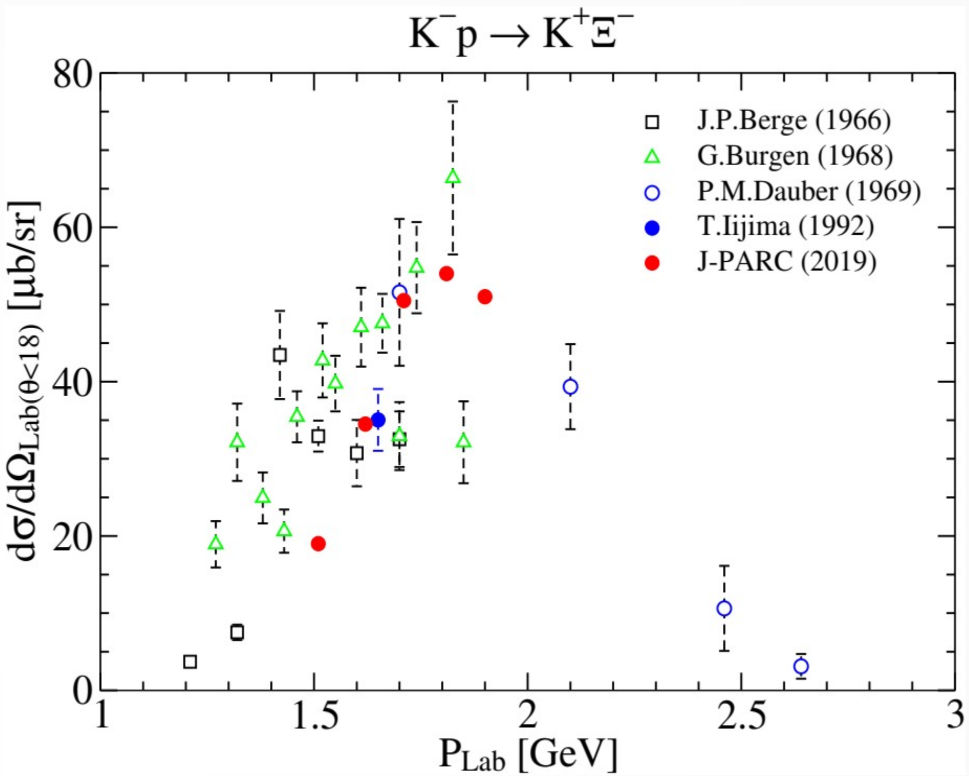
- Relations between c.m. and Lab frames:

$$\cos\theta_{\mathrm{lab}} = (\varepsilon_{K-L}\varepsilon_{K+L} - \varepsilon_{K^-}\varepsilon_{K^+} + p p_{K^+}\cos\theta_{\mathrm{c.m.}})/p_{\mathrm{lab}}\, p_{K+L}$$

$$\frac{(d\sigma/d\Omega)_L}{(d\sigma/d\Omega)_{\mathrm{c.m.}}} = \frac{m_N p_{\mathrm{lab}} p_{K+L}}{p p_{K^+}}(\varepsilon_{K-L} + m_N - p_{\mathrm{lab}}\varepsilon_{K+L}\cos\theta_{\mathrm{lab}}/p_{K+L})^{-1}$$

$$\boxed{\left\langle \frac{d\sigma}{d\Omega_L}\right\rangle_{AV} = \int_0^{\theta_{\max}} d(\cos\theta_L)\, d\sigma/d\Omega_L \Big/ \int_0^{\theta_{\max}} d(\cos\theta_L)}$$



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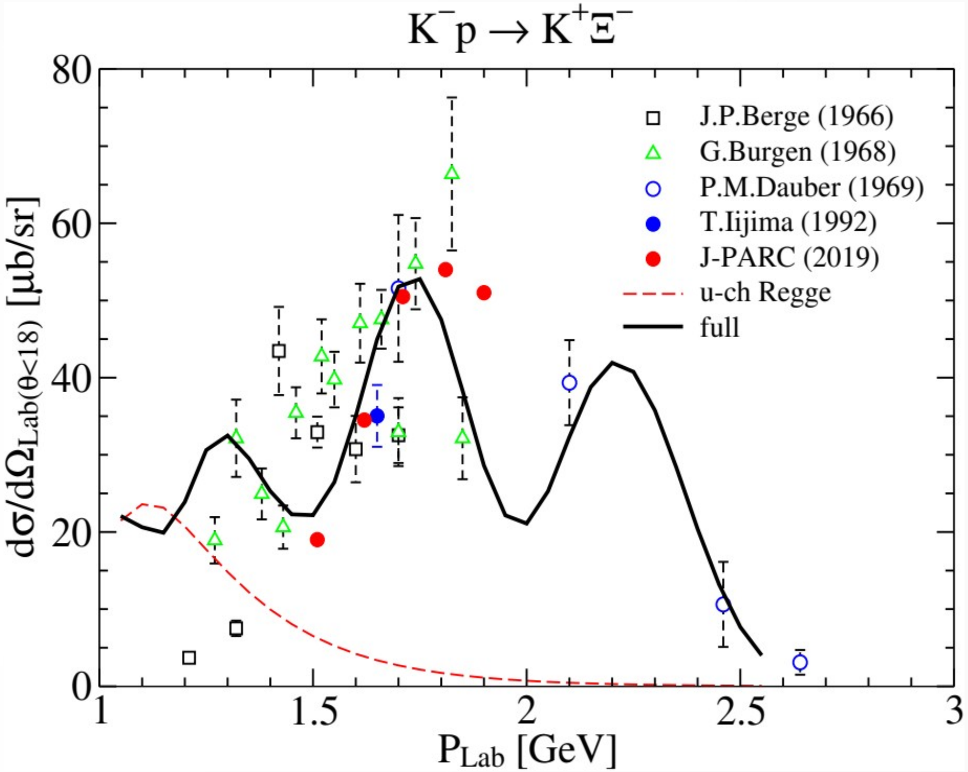

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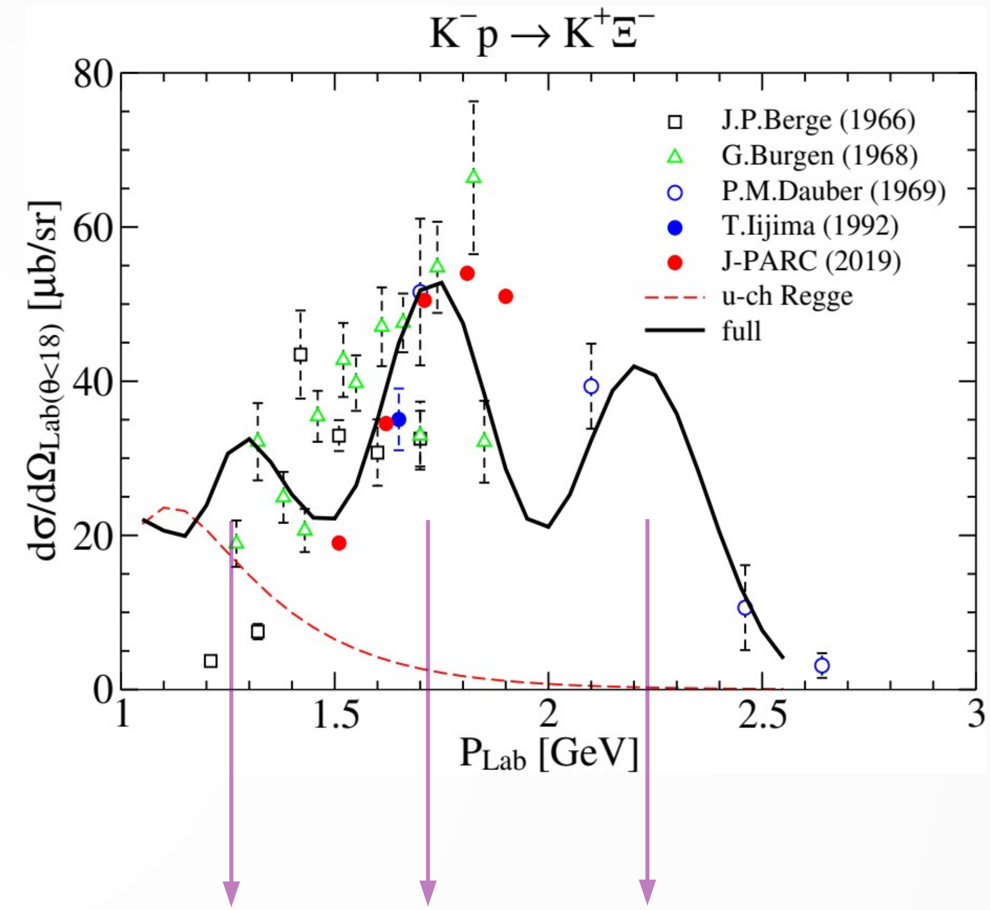
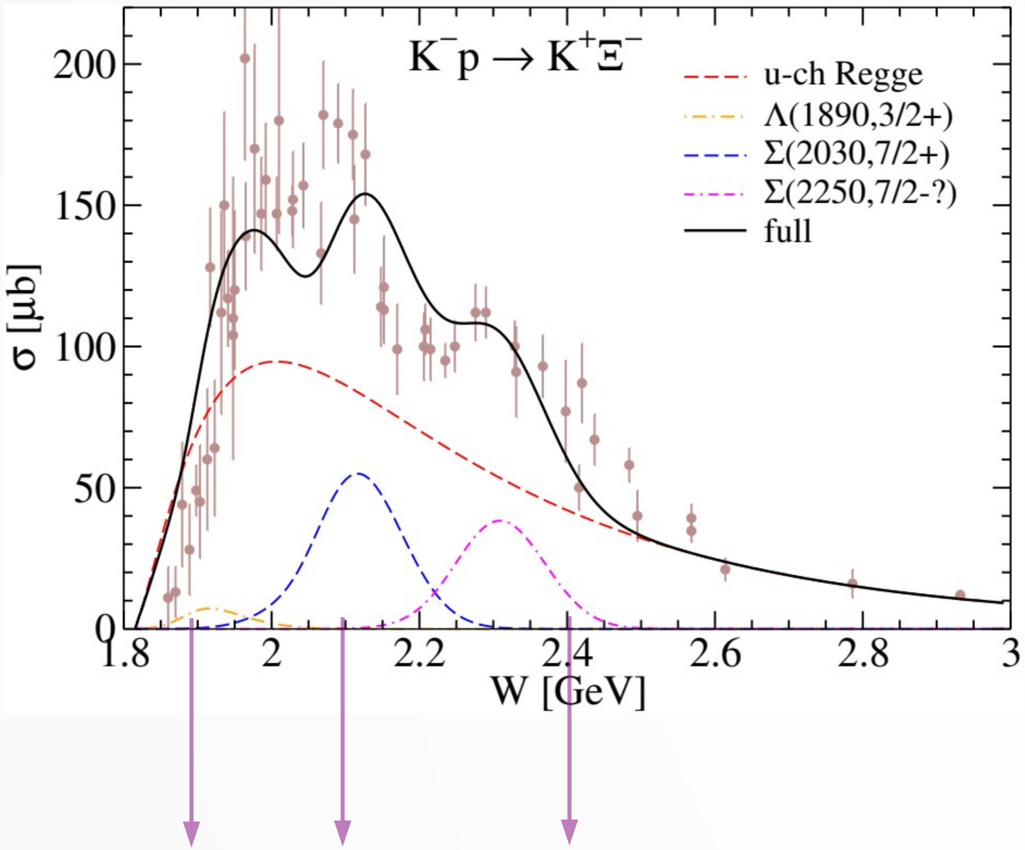


Λ(1890,3/2⁺) Σ(2030,7/2⁺) Σ(2250,7/2⁻ ?)

- ❑ The evidence of these three Y^* resonances looks very convincing.

- ❑ More data from the J-PARC E05 experiment are strongly called for.

3. $K^- p \rightarrow K\,\Xi$ results



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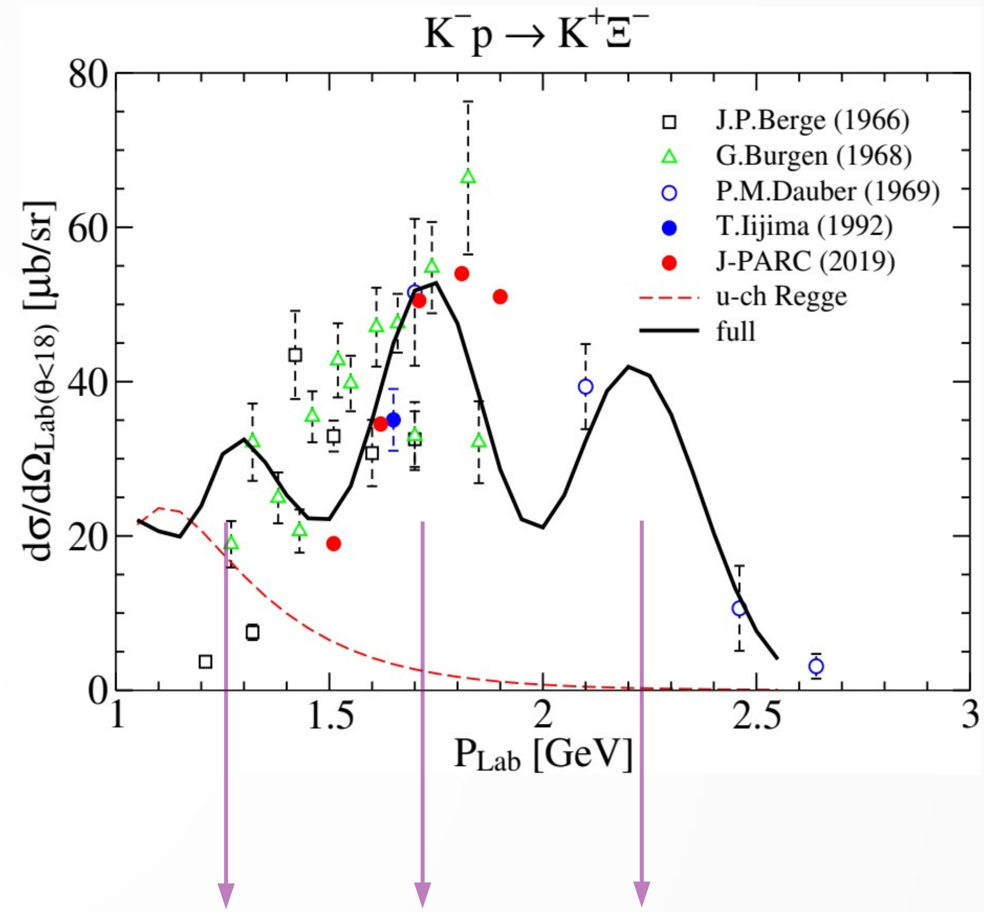

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Previous works

Sharov et al. EPJA.47.109 (2011)
Shyam et al. PRC.84.042201 (2011)
> Effective Lagrangian approach

Kamano et al. PRC.90.065204 (2014)
> Dynamical coupled-channel approach to $\overline{K}$ induced reactions

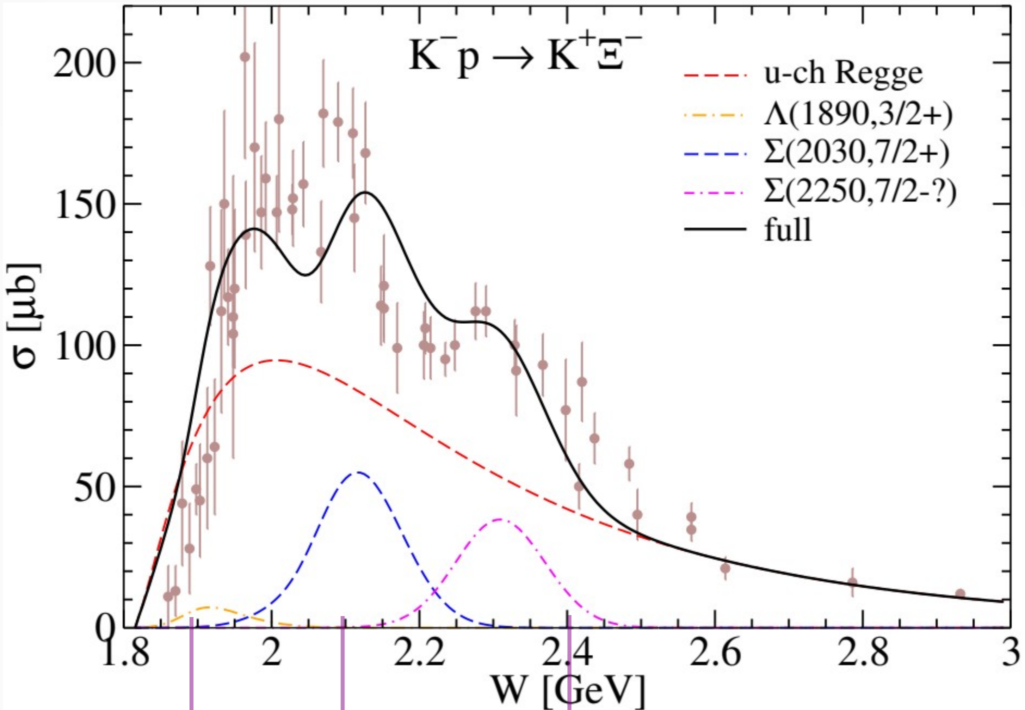
Feijoo et al. PRC.92.015206 (2015)
> Coupled-channel unitarized chiral perturbation approach

Nakayama et al. PRC.85.042201 (2012)
Jackson et al. PRC.89.025206 (2014)
> Model independent aspects

Jackson et al. PRC.91.065208 (2015)
> Effective Lagrangian approach in which "the rescattering contribution" is accounted for by "a phenomenological contact amplitude"

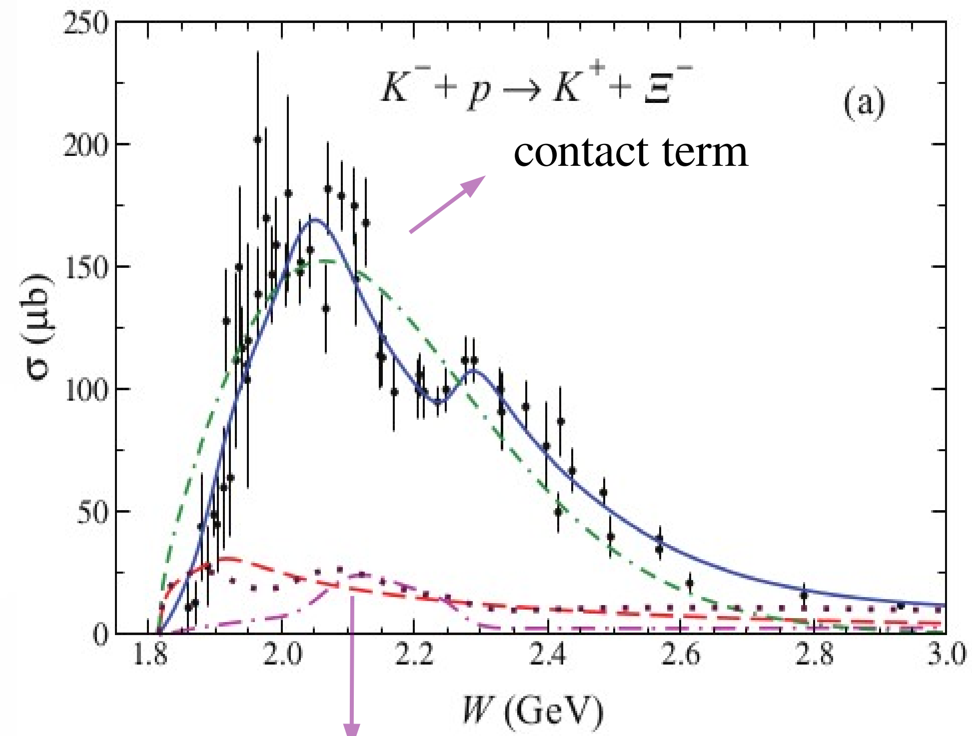
3. K⁻ p → K Ξ results

Comparison with other works



Λ(1890,3/2⁺) Σ(2030,7/2⁺) $\boxed{\Sigma(2250,7/2^-\,?)}$

Jackson et al. PRC.91.065208 (2015)

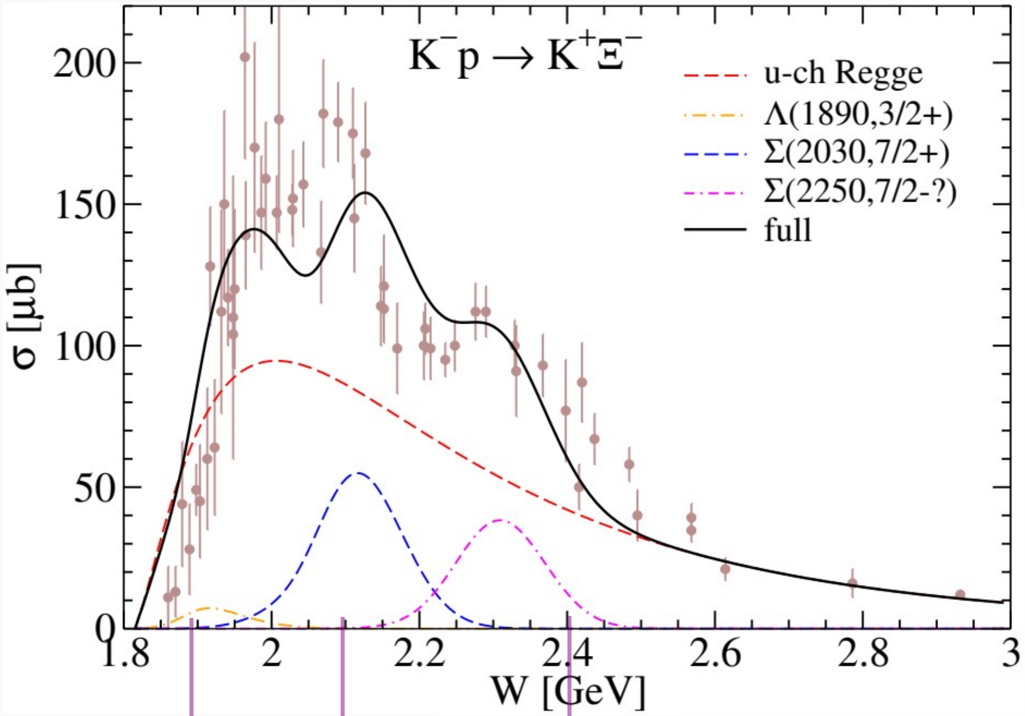


Λ(1890,3/2⁺)
Σ(2030,7/2⁺)
$\boxed{\Sigma(2250,5/2^-\,?)}$

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
2210 to 2280 (≈ 2250)	**OUR ESTIMATE**			
2270 ±50	DEBELLEFON	1978	DPWA	D_5wave
2210 ±30	DEBELLEFON	1978	DPWA	G_9wave

3. $K^- p \rightarrow K\,\Xi$ results

Comparison with other works



Λ(1890,3/2⁺) Σ(2030,7/2⁺) Σ(2250,7/2⁻ ?)

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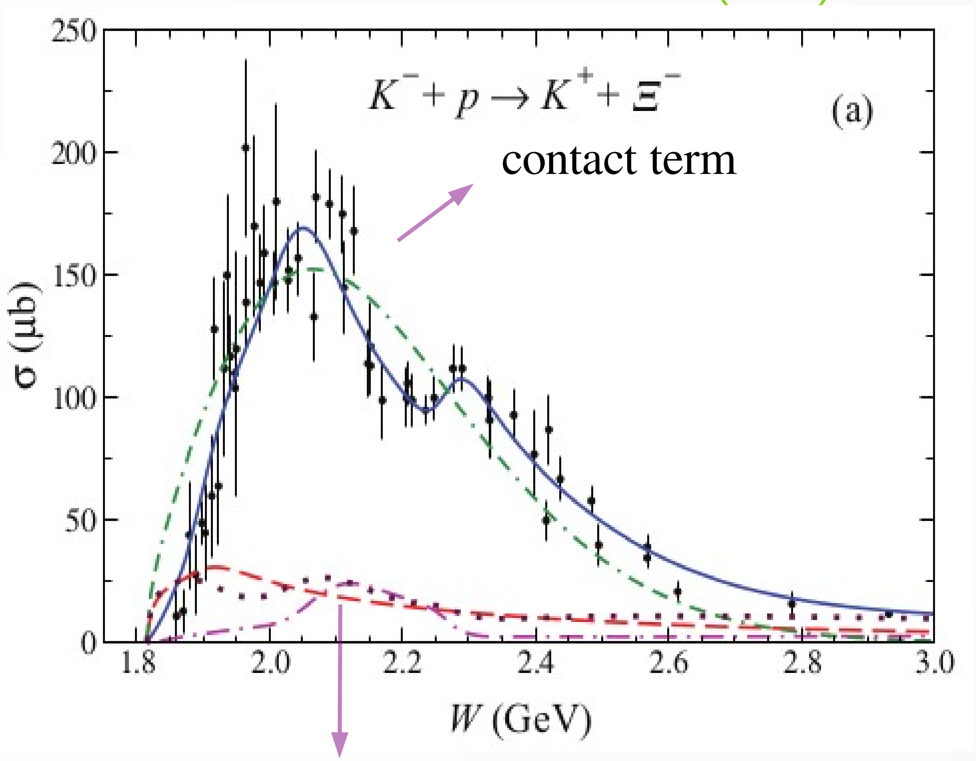


Λ(1890,3/2⁺)
Σ(2030,7/2⁺)
Σ(2250,5/2⁻ ?)

- The structure at W ≈ 2.2 GeV are explained by a destructive effect between “contact term” and “resonant amplitudes”.

3. $K^- p \rightarrow K \Xi$ results

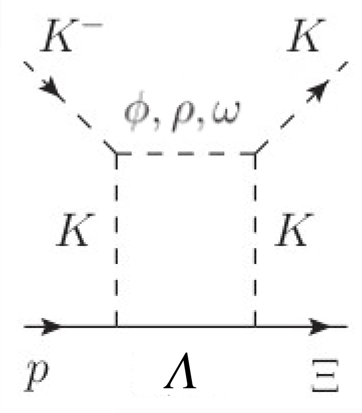
❑ Rescattering amplitude

$$T_{V\Lambda} = \int \frac{d^3\vec{p}}{(2\pi)^3} \frac{M_\Lambda}{E_\Lambda} \frac{1}{p_V^2 - M_V^2 + i\epsilon} T_{K^- p \to V\Lambda} T_{V\Lambda \to K\Xi}$$

$$T_{V\Lambda} = -i \frac{p_{c.m.}}{16\pi^2} \frac{M_\Lambda}{\sqrt{s}} \int d\Omega \left[T_{K^- p \to V\Lambda}(t_K)\, T_{V\Lambda \to K\Xi}(t_K)\right] + \mathcal{P}$$

$V = (\varphi, \rho, \omega)$

$$\int d\Omega = \int d\cos\theta' d\phi'$$



$$K^- p \to \begin{Bmatrix} \rho & \Lambda \\ \omega & \Lambda \\ \phi & \Lambda \end{Bmatrix} \to \Xi^- K^+$$

3. $K^- p \to K \Xi$ results

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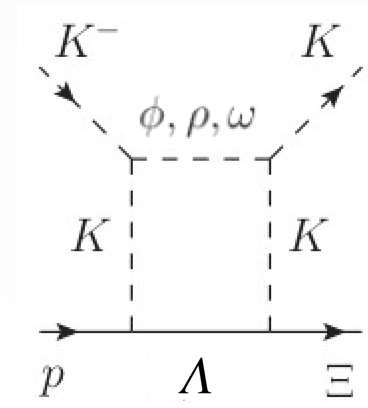
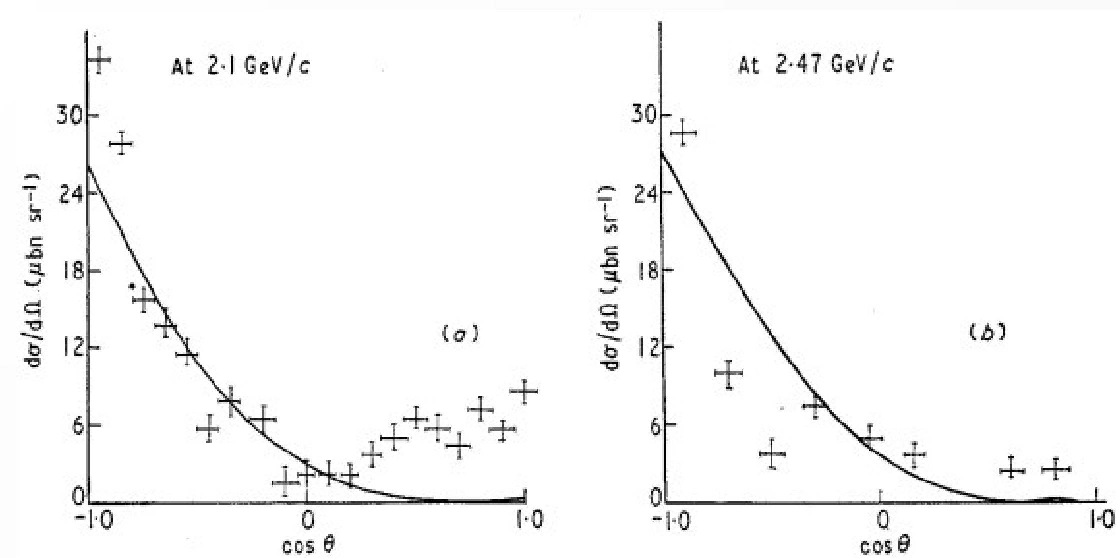


$$K^- p \to \begin{Bmatrix} \rho & \Lambda \\ \omega & \Lambda \\ \phi & \Lambda \end{Bmatrix} \to \Xi^- K^+$$

$K^-p \to K^+\Xi^-$ process in the two-meson-exchange peripheral model

To cite this article: B K Agarwal *et al* 1971 *J. Phys. A: Gen. Phys.* **4** L52



□ Naive calculation by assuming forward production of φ: $\cos\theta' = \hat{q}_{K^-}\cdot\hat{q}_\phi \to 1$

□ Except for "P = $1/(t_1-M_K^2)(t_2-M_K^2)$", which is a rapidly varying function of cosθ′, therefore essentially determines the angular distribution.

3. K⁻ p → K Ξ results

❑ Rescattering amplitude

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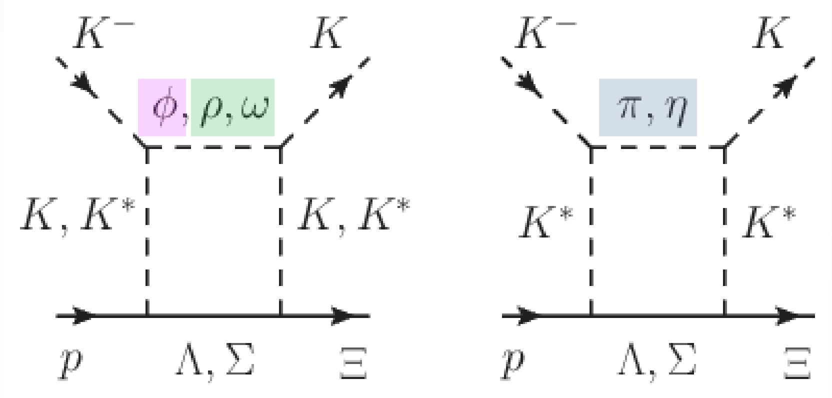
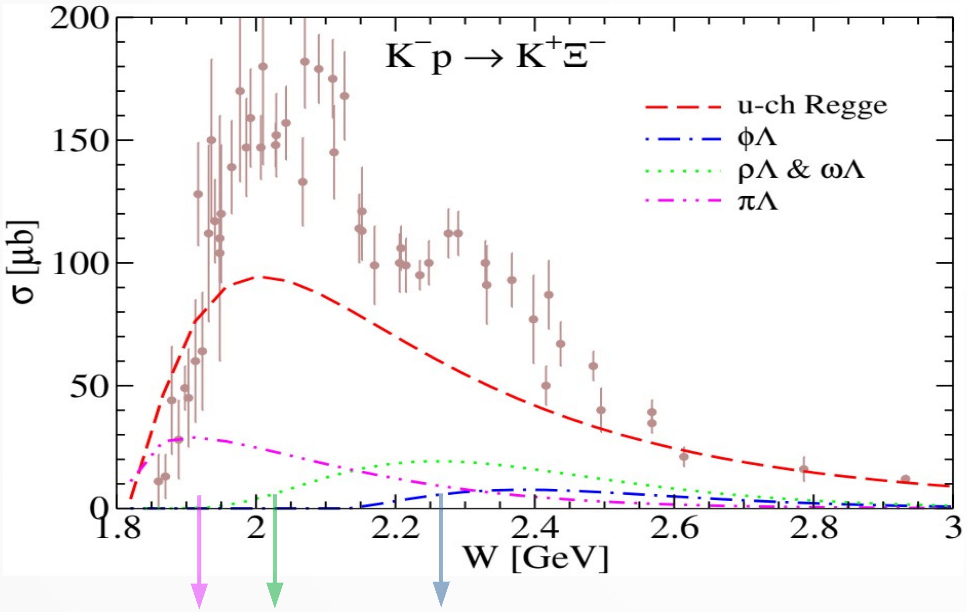
V = (φ, ρ, ω)



$$g_{K^*K\rho} = g_{K^*K\omega} = \frac{1}{\sqrt{2}} g_{K^*K\phi} = \frac{1}{2} g_{\omega\rho\pi}$$

$$g_{KK\rho} = g_{KK\omega} = \frac{1}{2} g_{\pi\pi\rho}$$

□ We **fully** calculate the singular part.



πΛ (ρΛ,ωΛ) φΛ

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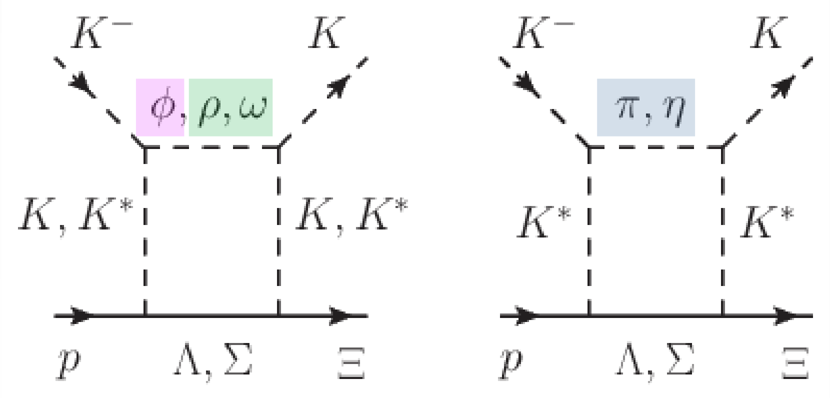

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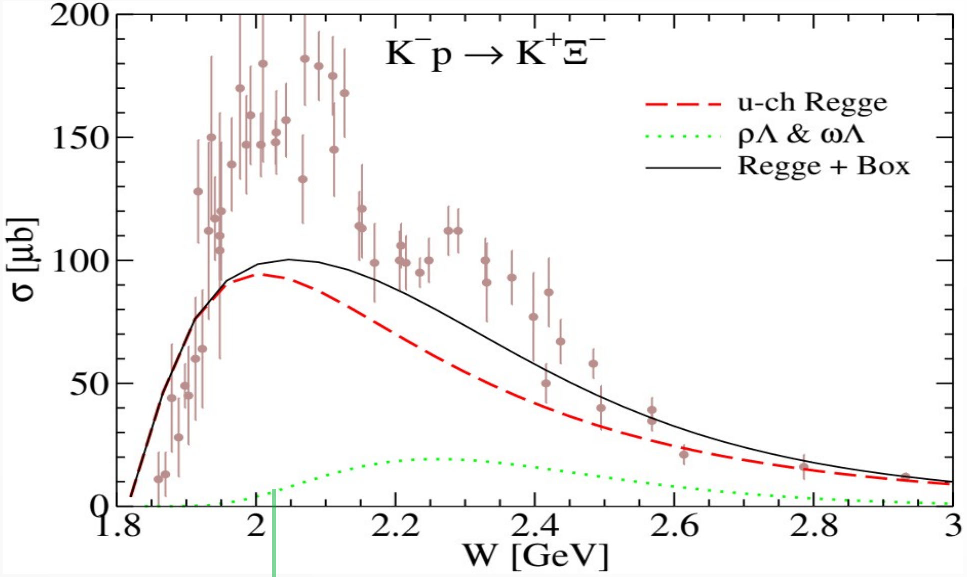
$$g_{KK\rho} = g_{KK\omega} = \frac{1}{2} g_{\pi\pi\rho}$$

□ We **fully** calculate the singular part.



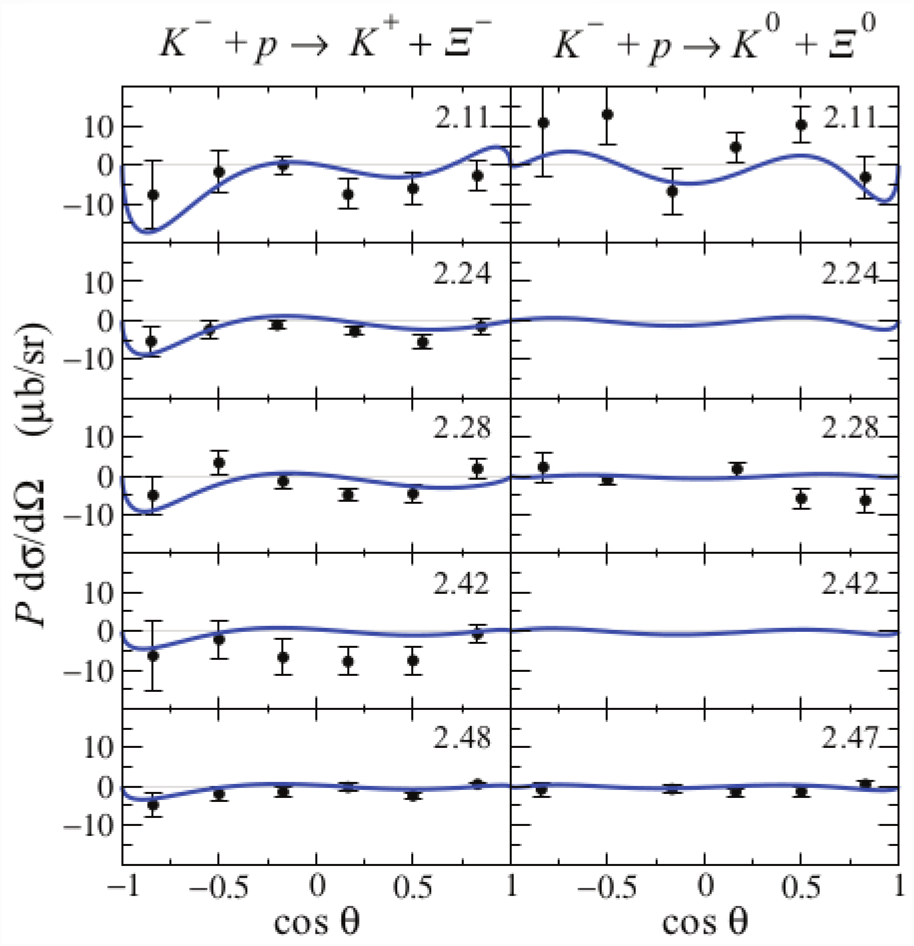
(ρΛ,ωΛ)

> It is difficult to clarify the role of the box diagrams with only the TCS data.

3. K⁻ p → K Ξ results

- We can polarize "the incoming nucleon" or "the outgoing Ξ baryon": Target (*T*), Recoil (*P*), Target-recoil (*K*) asymmetries

Recoil asymmetries

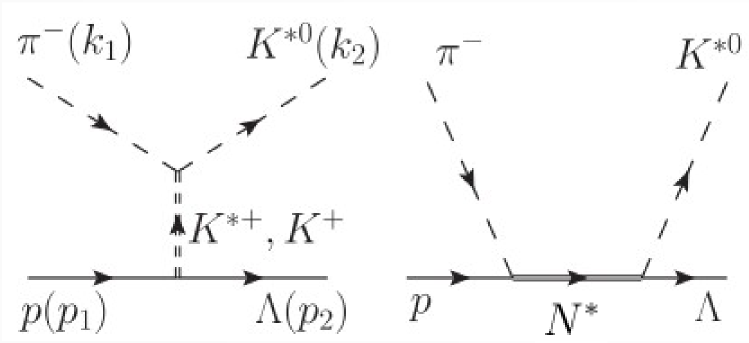


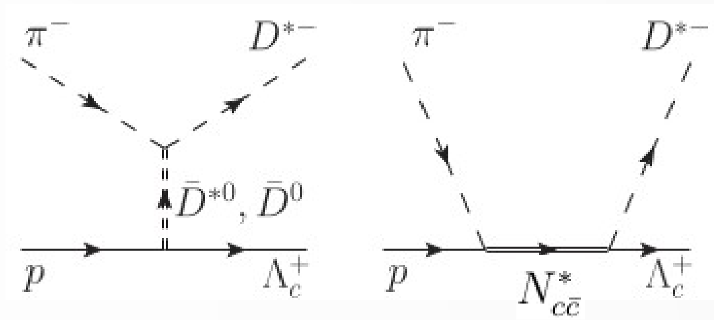
Theory: Jackson et al. PRC.91.065208 (2015)

4. Application

(a) "open" strange (charm) production

$\pi^- p \rightarrow K^{*0} \Lambda$ [Regge + Resonance] $\pi^- p \rightarrow D^{*-} \Lambda_c^+$





4. Application

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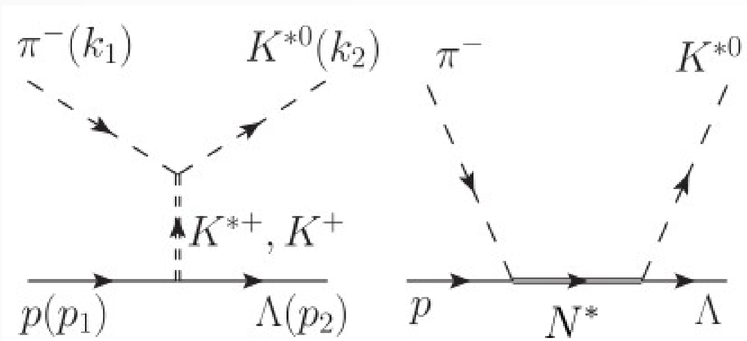
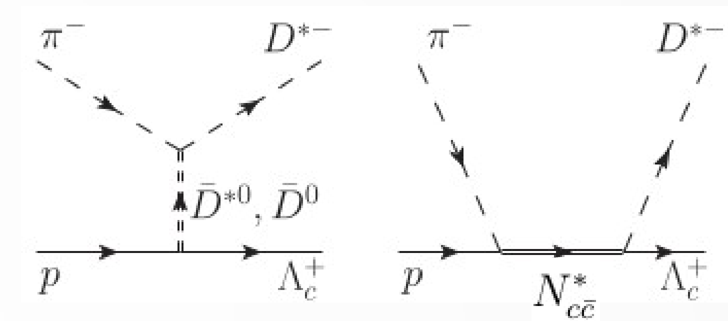
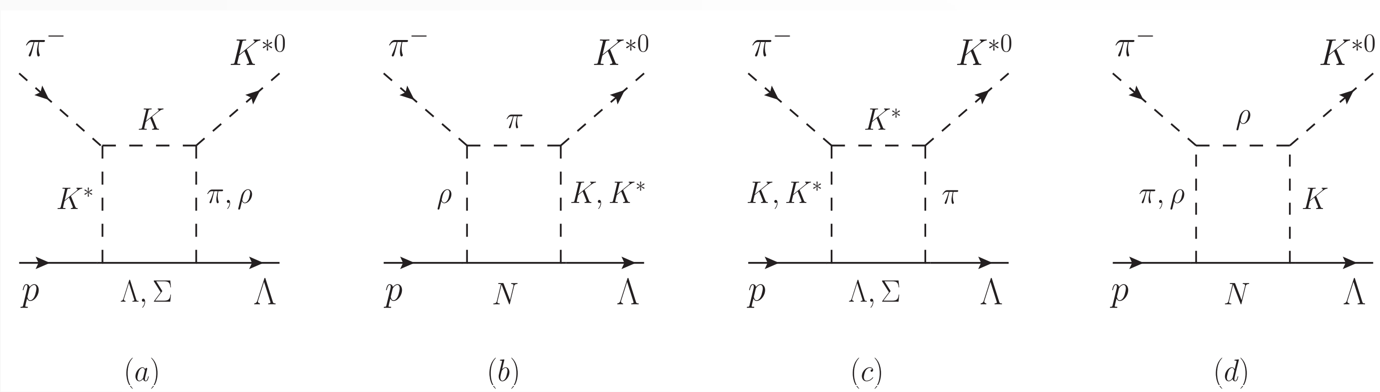
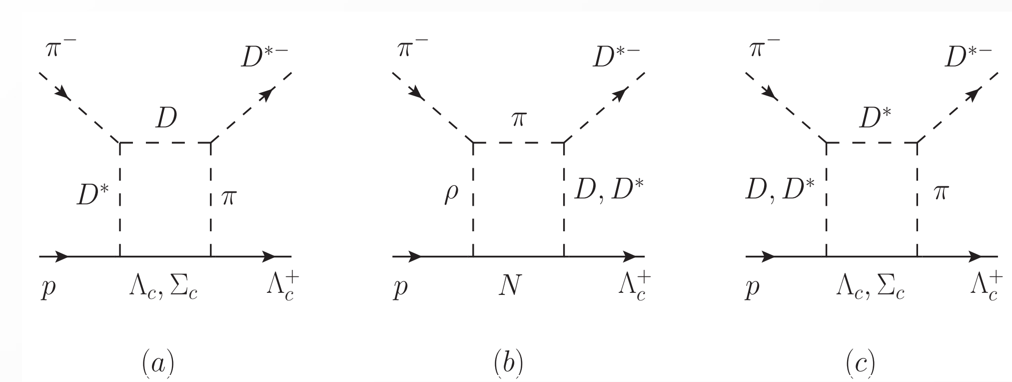
$\pi^- p \to K^{*0} \Lambda$ [Regge + Resonance] $\pi^- p \to D^{*-} \Lambda_c^+$





$\pi^- p \to M_i B_i \to K^{*0} \Lambda$ [Rescattering] $\pi^- p \to M_i B_i \to D^{*-} \Lambda_c^+$





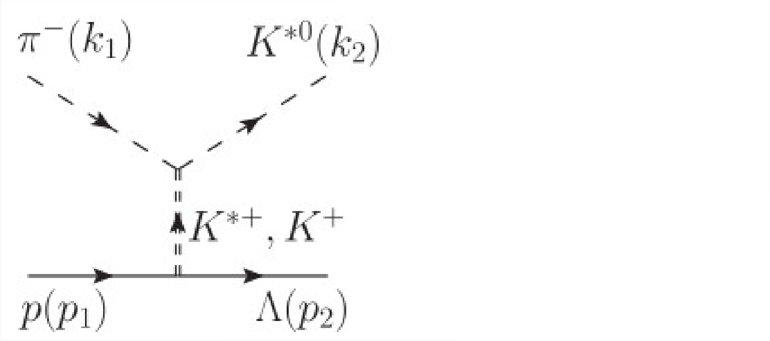
- Use the dominant decay process: $K^* \to K\pi$, $\rho \to \pi\pi$ $D^* \to D\pi$, $\rho \to \pi\pi$

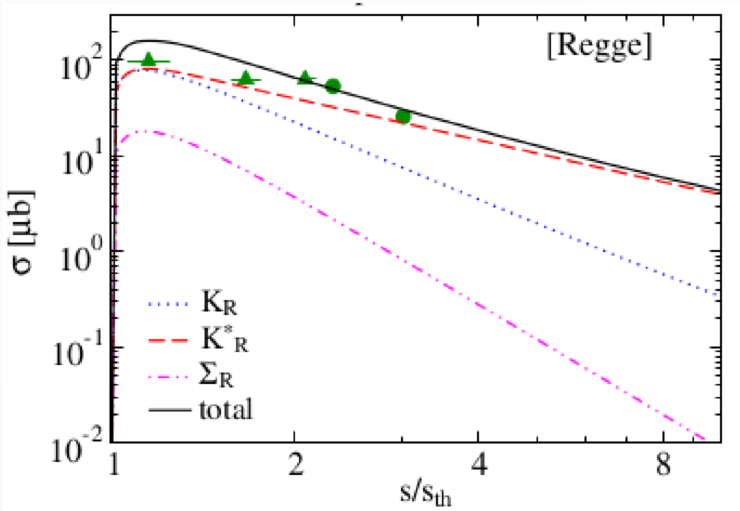
4. Application

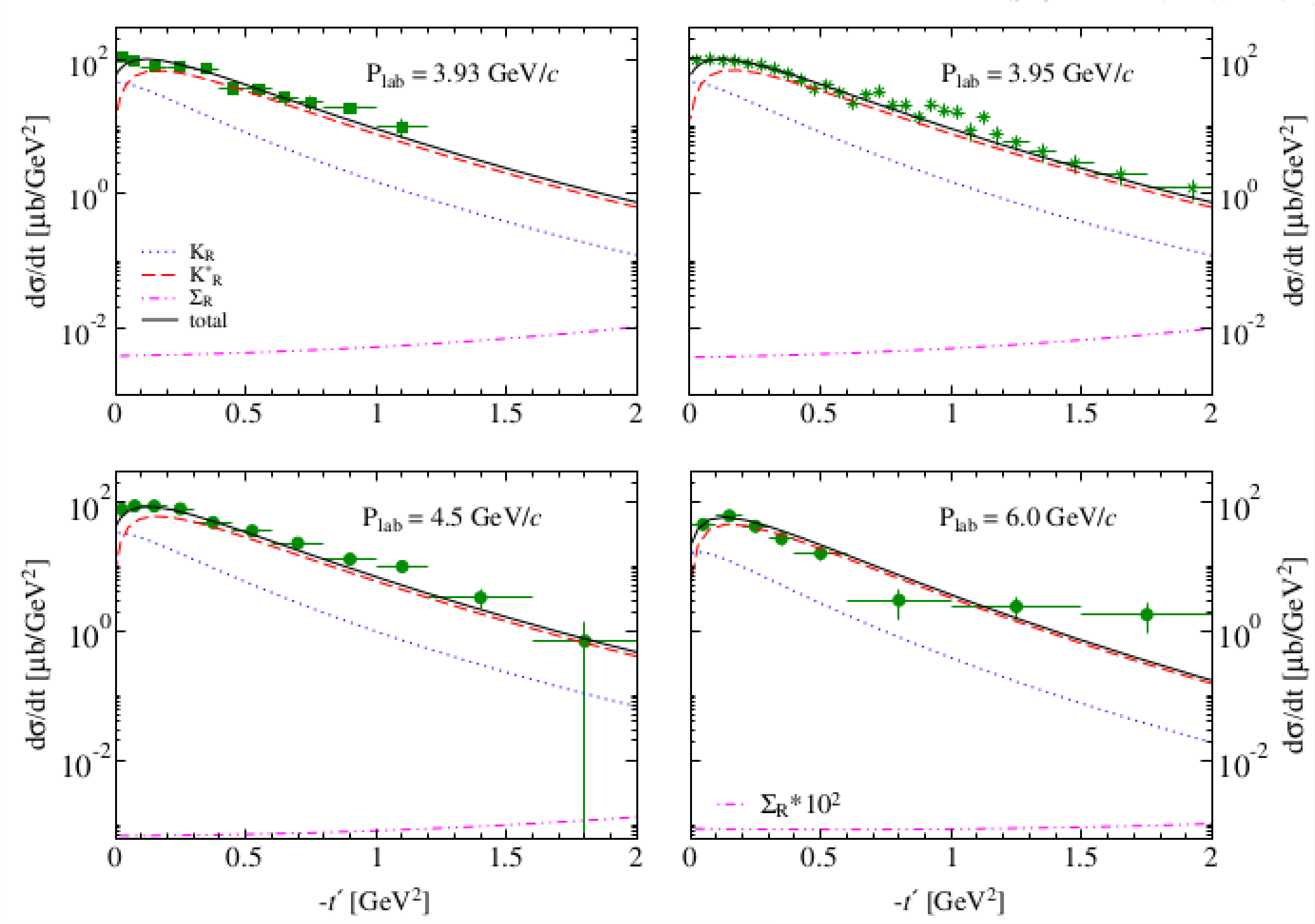
(a) "open" strange (charm) production

S.H.Kim et al.
PRD.92.094021 (2015)

$\pi^- p \rightarrow K^{*0} \Lambda$







> K exchange governs dσ/dt near $-t' \approx 0$, whereas K^* exchange becomes dominant as $-t'$ increases.

4. Application

(a) “open” strange (charm) production   [$\pi^- p \to K^{*0}\, \Lambda$ ($D^{*-}\, \Lambda_c^+$)]

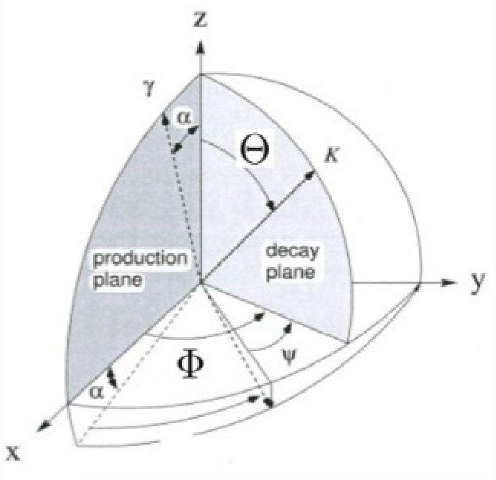
How to describe the 3-body decay process

$\pi^- + p \to V + Y \to (P + \pi) + Y$

in the rest frame of the vector-meson?

▢ Differential cross section

$$\frac{d\sigma}{dt\, d\Omega_f} = \frac{d\sigma}{dt} W(\Omega_f)$$



Θ: polar angle

Φ: azimuthal angle

▢ Decay angular distributions

$$W(\Omega_f) = \sum_{m_i, m_f, \lambda_V, \lambda'_V} \mathcal{M}_{m_f, \lambda_V; m_i} \mathcal{M}^*_{m_f, \lambda'_V; m_i} \times Y_{1\lambda_V}(\Omega_f) Y^*_{1\lambda'_V}(\Omega_f),$$

with $\mathcal{M}_{m_f, \lambda_V; m_i} = \frac{1}{\mathcal{N}} S_{m_f, \lambda_V; m_i}$

▢ Normalization factor

$$\mathcal{N}^2 = \sum_{m_f, m_i, \lambda_V} \left| S_{m_f, \lambda_V; m_i} \right|^2$$

▢ Spin factor

$$S = \varepsilon^*_\mu \bar{u}_\Lambda S^\mu u_N$$

$$S^\mu_K = I_K i g_{\pi K K^*} \frac{g_{KN\Lambda}}{M_N + M_\Lambda} \gamma^\nu \gamma_5 k_1^\mu (k_2 - k_1)_\nu,$$

$$S^\mu_{K^*} = I_{K^*} g_{\pi K^* K^*} g_{K^* N\Lambda} \epsilon^{\mu\nu\alpha\beta} \left[\gamma_\nu - \frac{i\kappa_{K^* N\Lambda}}{M_N + M_\Lambda} \sigma_{\nu\lambda} (k_2 - k_1)^\lambda \right] k_{2\alpha} k_{1\beta}$$

4. Application

(a) "open" strange (charm) production [$\pi^- p \to K^{*0} \Lambda$ ($D^{*-} \Lambda_c^+$)]

1. spin-density matrices ($\rho_{\lambda\lambda'}$)

(1) Unpolarized case

$$\rho^0_{\lambda\lambda'} = \sum_{m_i=\pm\frac{1}{2},\, m_f=\pm\frac{1}{2}} \mathcal{M}_{m_f,\lambda;\, m_i} \mathcal{M}^*_{m_f,\lambda';\, m_i}$$

(2) Polarized Y hyperon

$$\rho^\pm_{\lambda\lambda'} = \sum_{m_i=\pm\frac{1}{2}} \mathcal{M}_{m_f,\lambda;m_i} \mathcal{M}^*_{m_f,\lambda';m_i}$$

λ, λ': helicity states of the vector meson

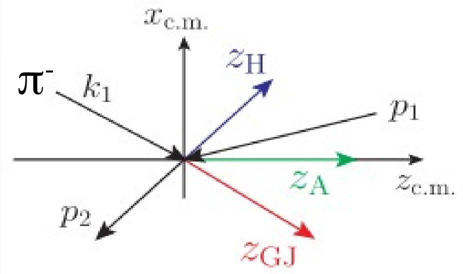
2. decay angular distributions (W)

(1) Unpolarized case

$$W^0(\Omega_f) = \frac{3}{4\pi}\Big[\rho^0_{00}\cos^2\Theta + \rho^0_{11}\sin^2\Theta - \rho^0_{1-1}\sin^2\Theta\cos 2\Phi - \sqrt{2}\,\mathrm{Re}(\rho^0_{10})\sin 2\Theta\cos\Phi\Big],$$

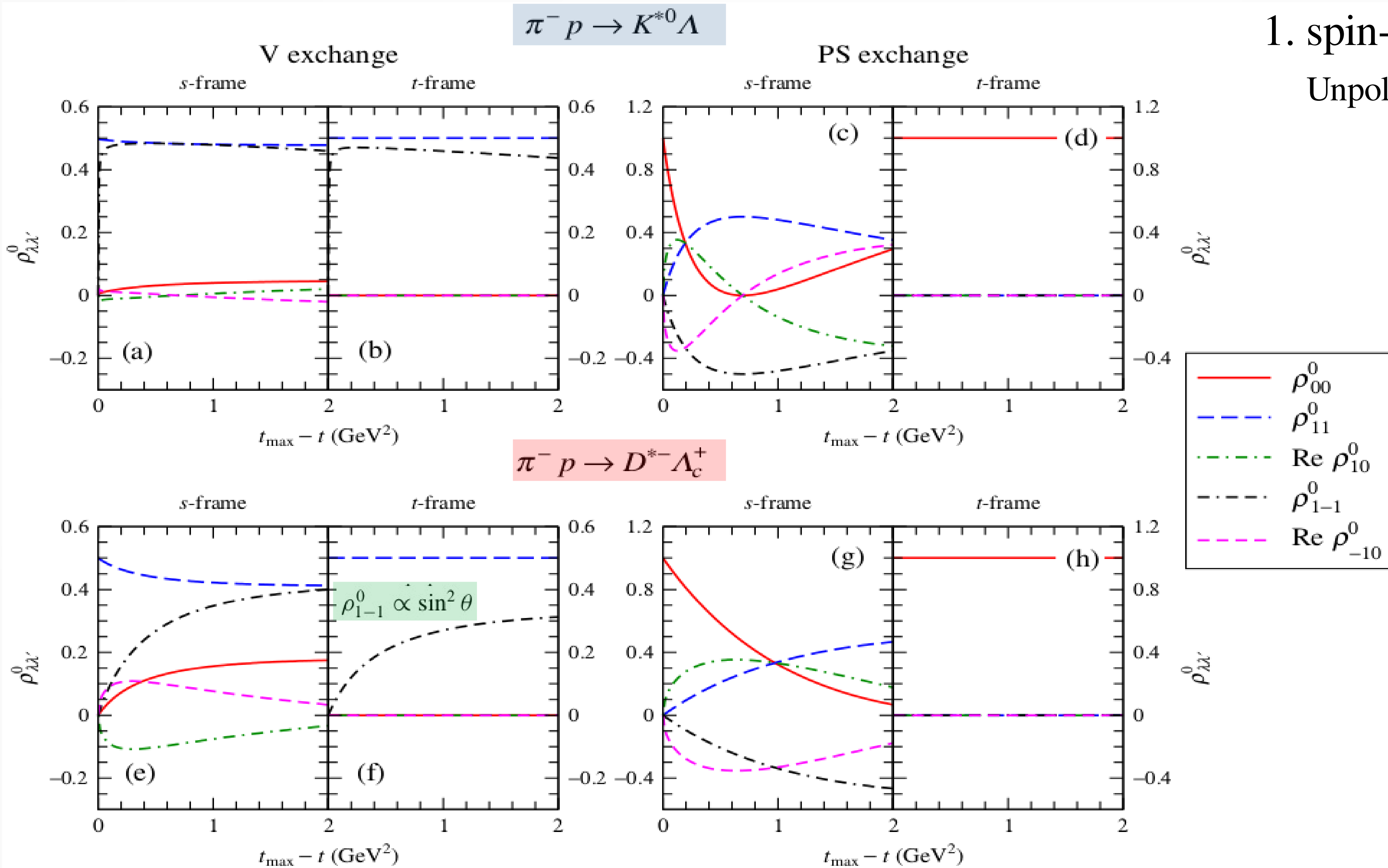
(2) Polarized Y hyperon

$$W^\pm(\Omega_f) = \frac{3}{4\pi}\Big[\rho^\pm_{00}\cos^2\Theta + \frac{1}{2}\left(\rho^\pm_{11} + \rho^\pm_{-1-1}\right)\sin^2\Theta - \rho^\pm_{1-1}\sin^2\Theta\cos 2\Phi - \frac{1}{\sqrt{2}}\mathrm{Re}\left(\rho^\pm_{10} - \rho^\pm_{-10}\right)\sin 2\Theta\cos\Phi\Big],$$



- ❑ Quantization axis in the rest frame of the V-meson
  - "s"-frame (helicity frame) : anti-parallel to the outgoing Y
  - "t"-frame (Gottfried-Jackson frame): parallel to the incoming π

4. Application



1. spin-density matrices ($\rho_{\lambda\lambda'}$)

Unpolarized case

$p_\pi = 6$ and 15 GeV$/c$

S.H.Kim, Y,Oh, A.I.Titov, PRC.95.055206 (2017)

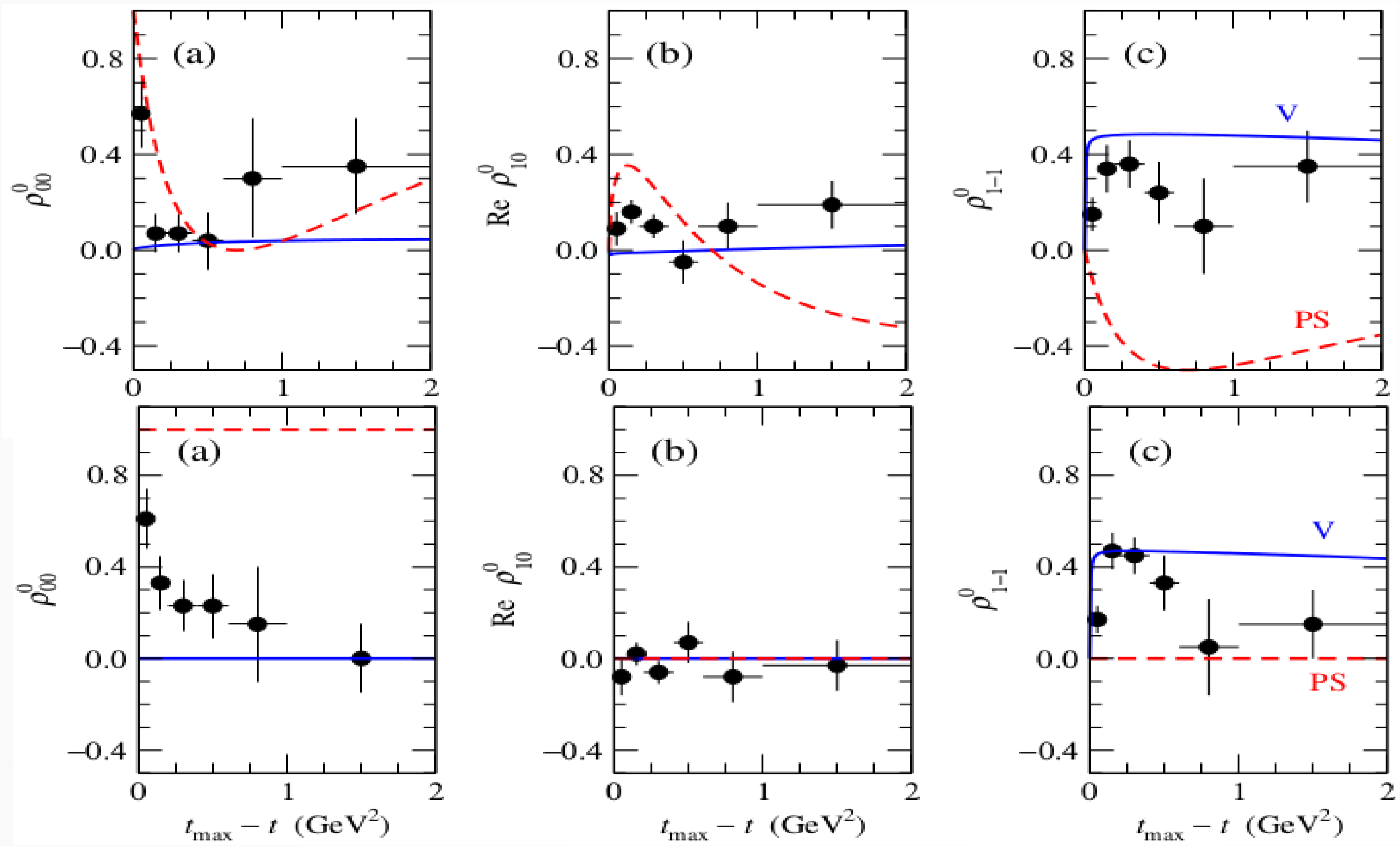
enhancement of $\rho^0_{\lvert\lambda\rvert=1,\,\lvert\lambda'\rvert=1}$	enhancement of ρ^0_{00}
$\epsilon^{\mu\nu\alpha\beta} q_\mu p_{V\alpha} \varepsilon^*_\beta$ $\quad \varepsilon^* \times \mathbf{p}_\pi \simeq i\lambda_V \varepsilon^* \lvert\mathbf{p}_\pi\rvert$	$\varepsilon^* \cdot \mathbf{p}_\pi$

4. Application

(a) "open" strange (charm) production

1. spin-density matrices ($\rho_{\lambda\lambda'}$) Unpolarized case

$\pi^- p \to K^{*0}\,\Lambda$



s-frame

t-frame

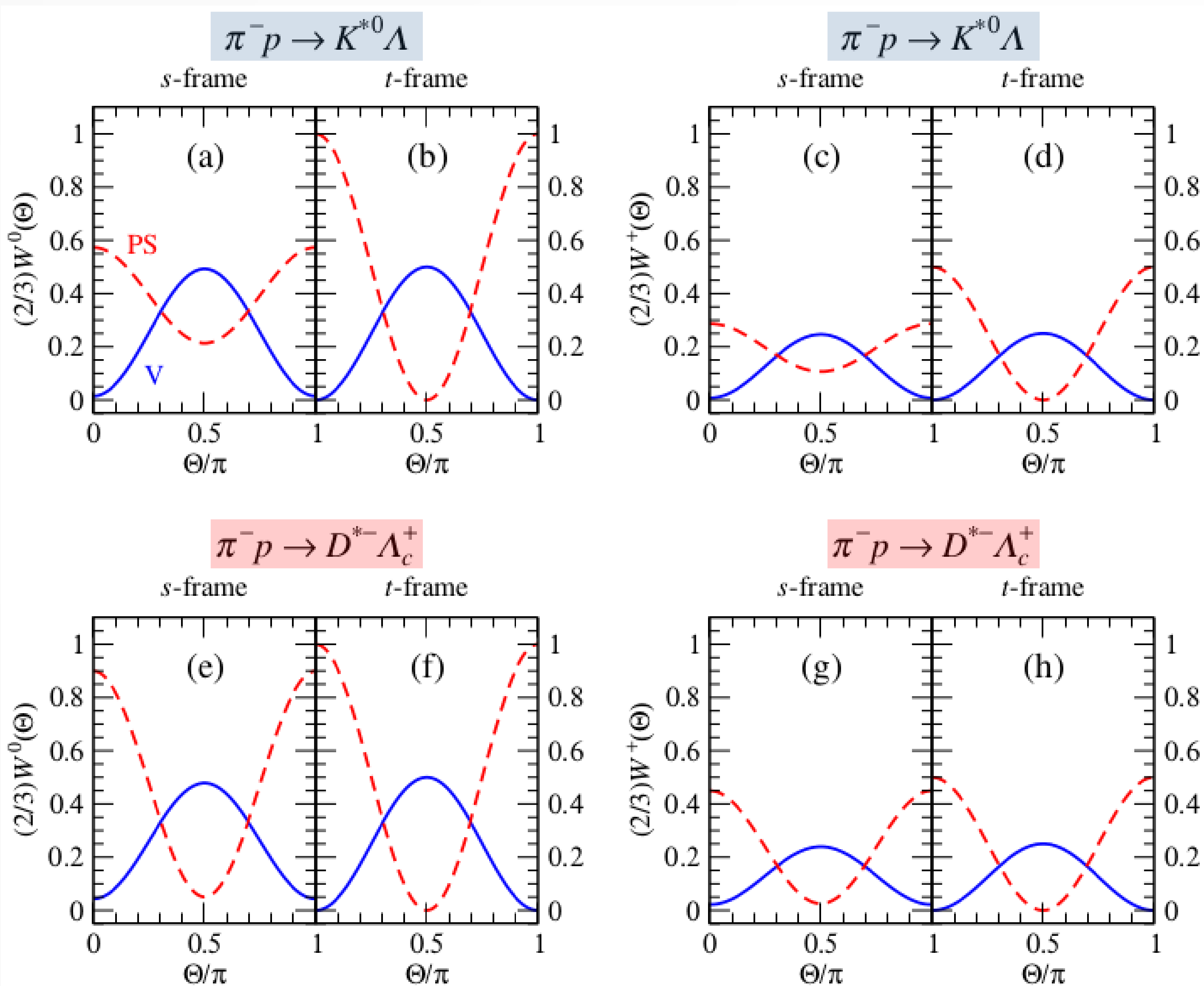
S.H.Kim, Y,Oh, A.I.Titov, PRC.95.055206 (2017)

Exp.: Crennell et al, PRD.6.1220 (1972)

enhancement of $\rho^0_{\lvert\lambda\rvert=1,\,\lvert\lambda'\rvert=1}$		enhancement of
$\epsilon^{\mu\nu\alpha\beta} q_\mu p_{V\alpha} \varepsilon^*_\beta$	$\varepsilon^* \times \mathbf{p}_\pi \simeq i\lambda_V \varepsilon^* \lvert\mathbf{p}_\pi\rvert$	$\varepsilon^* \cdot \mathbf{p}_\pi$

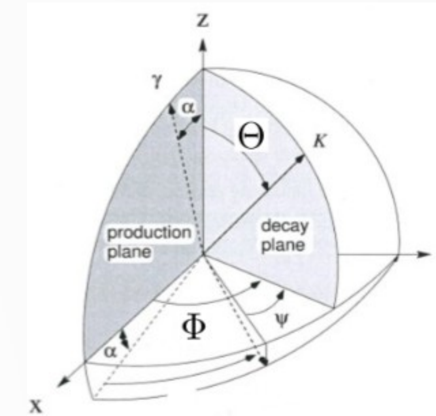
(a) "open" strange (charm) production

(1) Unpolarized case (2) Polarized Y hyperon



2. decay angular distributions (W)

S.H.Kim, Y,Oh, A.I.Titov, PRC.95.055206 (2017)



Θ: polar angle
Φ: azimuthal angle

(1) $\frac{2}{3} W^0(\Theta) = \rho^0_{00} \cos^2\Theta + \rho^0_{11} \sin^2\Theta,$

(2) $\frac{2}{3} W^\pm(\Theta) = \rho^\pm_{00} \cos^2\Theta + \frac{1}{2}\left(\rho^\pm_{11} + \rho^\pm_{1-1}\right) \sin^2\Theta$

❑ V- and PS-meson exchanges exhibit totally different shapes.

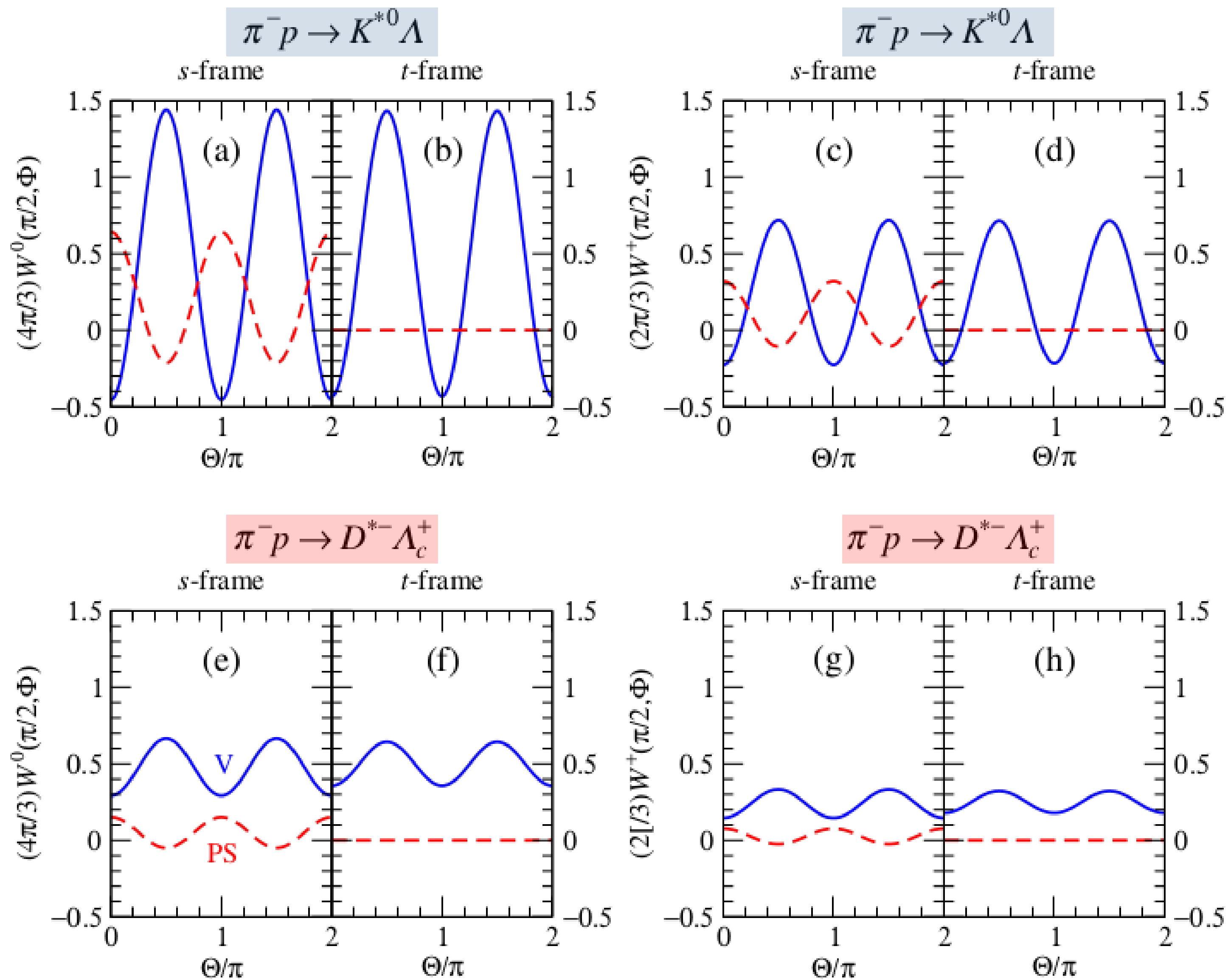
4. Application

(a) "open" strange (charm) production

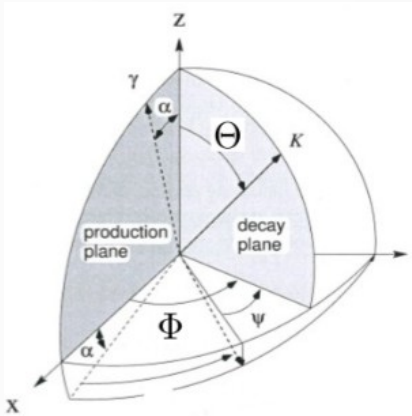
2. decay angular distributions (W)

(1) Unpolarized case

(2) Polarized Y hyperon



S.H.Kim, Y,Oh, A.I.Titov, PRC.95.055206 (2017)



Θ: polar angle

Φ: azimuthal angle

$$(1)\quad \frac{4\pi}{3}W^0\left(\Theta=\frac{\pi}{2},\Phi\right)=\rho^0_{11}-\rho^0_{1-1}\cos 2\Phi\ ,$$

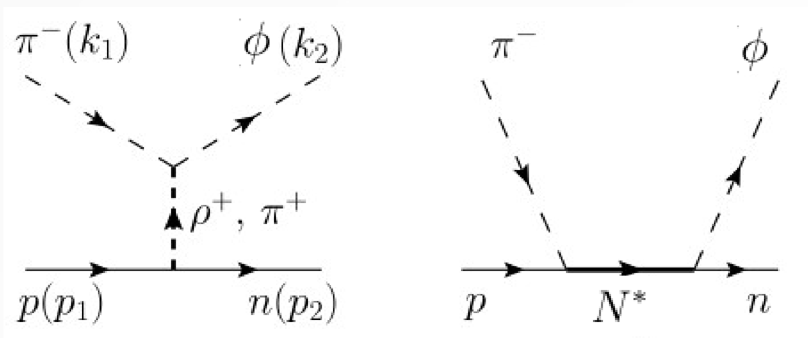
$$(2)\quad \frac{4\pi}{3}W^{\pm}\left(\Theta=\frac{\pi}{2},\Phi\right)=\frac{1}{2}\left(\rho^{\pm}_{11}+\rho^{\pm}_{-1-1}\right)-\rho^{\pm}_{1-1}\cos 2\Phi$$

- V- and PS-meson exchanges exhibit totally different shapes.

4. Application

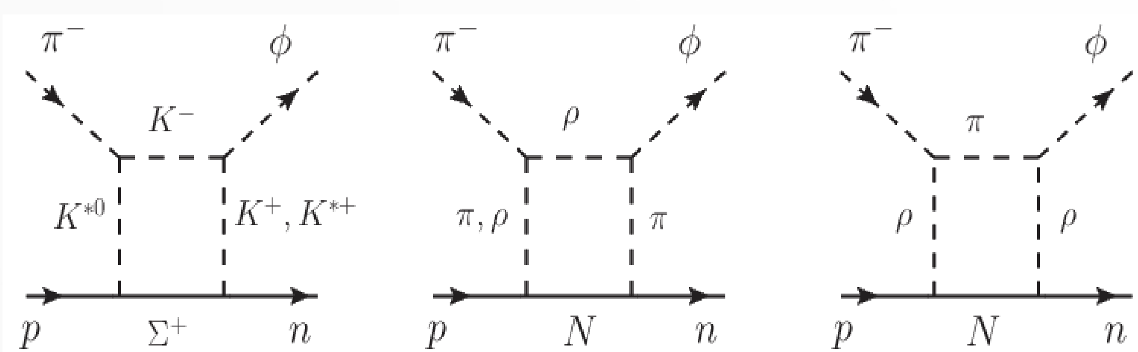
(b) “hidden” strange (charm) production

$\pi^- p \to \varphi\, n$ [Regge + Resonance]



$P_s^0[uuds\bar{s}]$

$\pi^- p \to M_i\, B_i \to \varphi\, n$ [Rescattering]

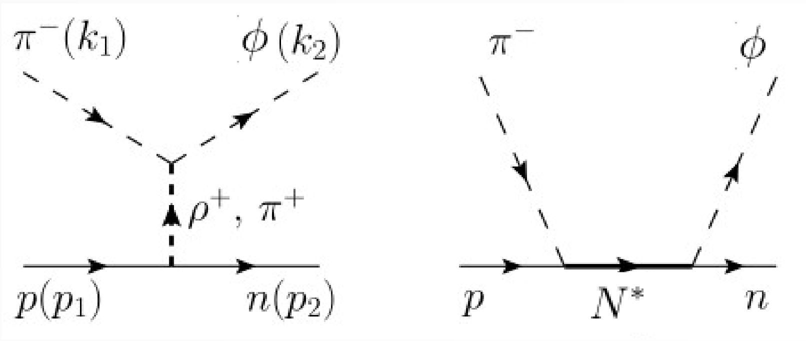


- Use the dominant decay process: $\varphi \to K^+K^-$, $\rho\pi$, $K^* \to K\pi$, $\rho \to \pi\pi$

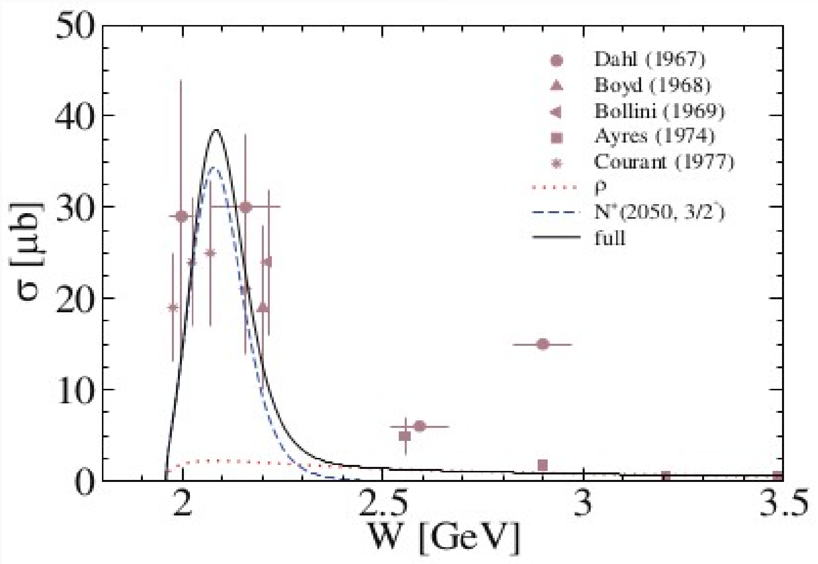
4. Application

(b) “hidden” strange (charm) production

$\pi^- \, p \rightarrow \varphi \, n$ [Regge + Resonance]

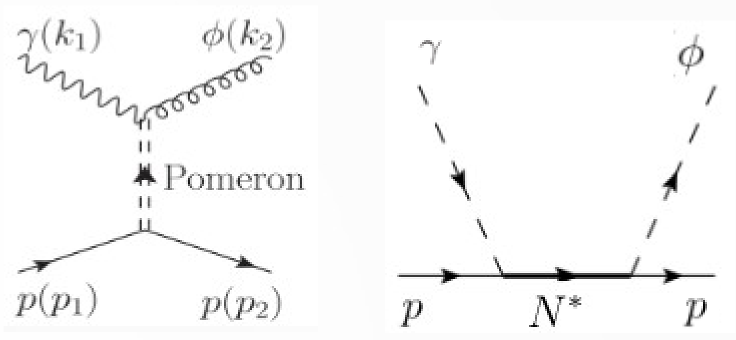


$P_s^0[uuds\bar{s}]$

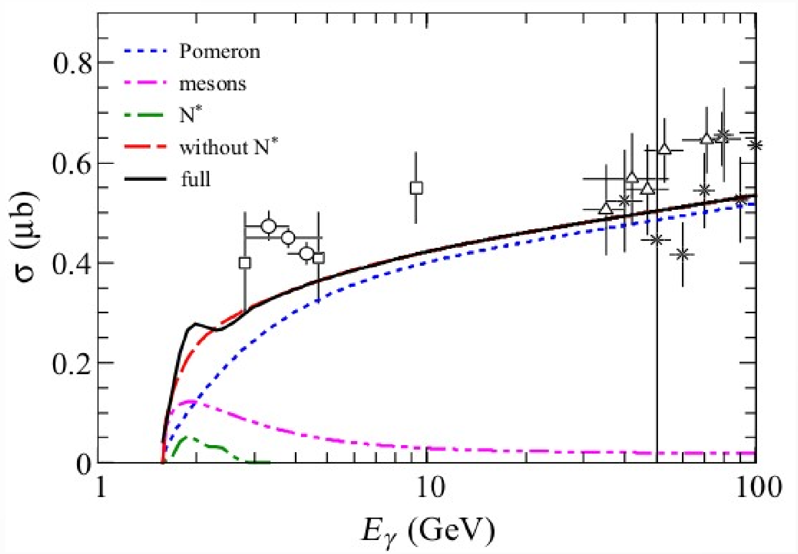


[T.Ishikawa et al. Proposal submitted using the J-PARC E16 spectrometer (2022)]

$\gamma \, p \rightarrow \varphi \, p$ [Pomeron + Resonance]



$P_s^+[uuds\bar{s}]$



[S.H.Kim, T.S.H.Lee, S.i.Nam, Y. Oh, PRC.104.045202 (2021)]

5. Summary & Future work

- ◇ Multistrangeness production, $K^- p \to K \Xi$, is investigated in a hybridized Regge model for two different isospin channels ($K^- p \to K^+ \Xi^-$ & $K^0 \Xi^0$).
- ◇ As for a background contribution, (Λ & Σ & Σ^*) hyperon Regge trajectories are considered in the u channel to describe the backward angles.
- ◇ We employ a "pseudovector" scheme for the KNY & KΞY vertices rather than a "pseudoscalar" scheme.
- ◇ For $K^- p \to K^0 \Xi^0$, only (Σ & Σ^*) Regge trajectories are possible and their relative contributions are well constrained.
- ◇ For $K^- p \to K^+ \Xi^-$, Λ Regge trajectory is more dominant than (Σ & Σ^*) ones.
- ◇ $\Lambda(1890, 3/2^+)$, $\Sigma(2030, 7/2^+)$, and $\Sigma(2250, 7/2^-\,?)$ play a crucial role in explaining the bump structures.
- ◇ The box diagrams may play an important role.

5. Summary & Future work

◇ Production of multistrangeness ($S < -1$) baryons

$K^- p \rightarrow K^- p$ ➪ $K^- \, {}^{12}C \rightarrow K^- \, {}^{12}C$

$K^- p \rightarrow K^+ \Xi$ ➪ $K^- \, {}^{12}C \rightarrow K^+ \, {}^{12}_{\Xi}Be$

> A distorted-wave impulse approximation within the multiple scattering formulation

> Ξ hypernuclei is important to study multistrangeness systems and strange neutron stars in astrophysics.

◇ Relevant experiments to date at J-PARC:

[P05] Spectroscopic Study of Ξ-Hypernucleus, ${}^{12}_{\Xi}Be$, via the ${}^{12}C(K^-,K^+)$ Reaction

[P50] Charmed Baryon Spectroscopy via the (π^-,D^{*-}) reaction

[P85] Spectroscopy of Omega Baryons

[LoI] Study of Σ-N interaction using light Σ-nuclear system

[LoI] Ξ Baryon Spectroscopy High-momentum Secondary Beam

◇ Rescattering effects could be important for the meson induced production:

$K^- p \rightarrow K^+ \Xi$, $\pi^- p \rightarrow \varphi n$

$K^- p \rightarrow \varphi (\Lambda,\Sigma)$, $\pi^- p \rightarrow D^{(*)} (\Lambda_c,\Sigma_c)$

> The systematic analyses should be carried out.

5. Summary & Future work

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$K^- p \rightarrow \varphi\, (\Lambda,\Sigma)$, $\pi^- p \rightarrow D^{(*)}\, (\Lambda_c,\Sigma_c)$

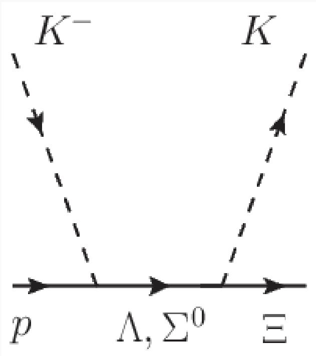
> The systematic analyses should be carried out.

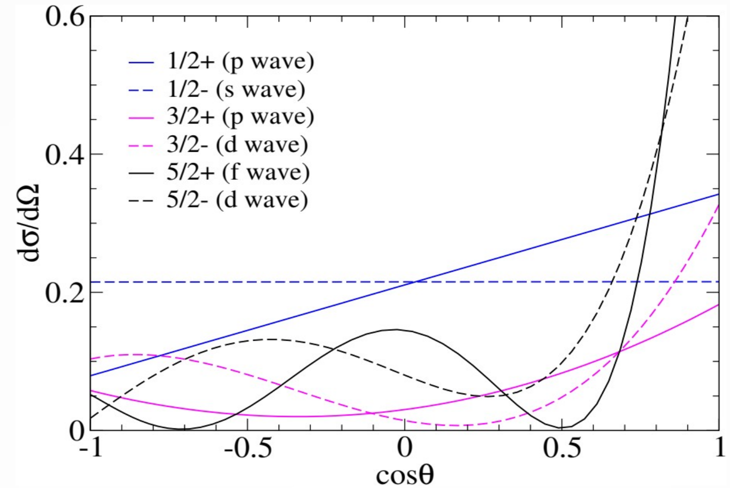
Thank you very much for your attention

Back Up

3. $K^- p \rightarrow K\,\Xi$ results

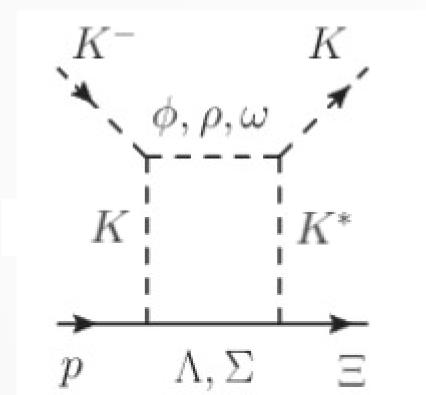
❑ Resonant amplitude

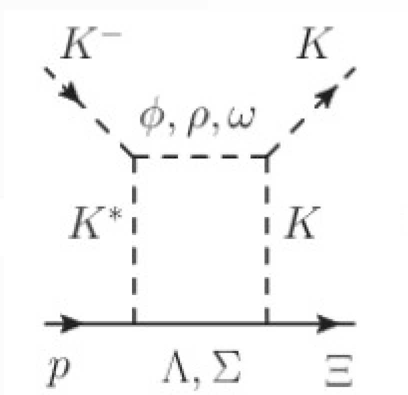


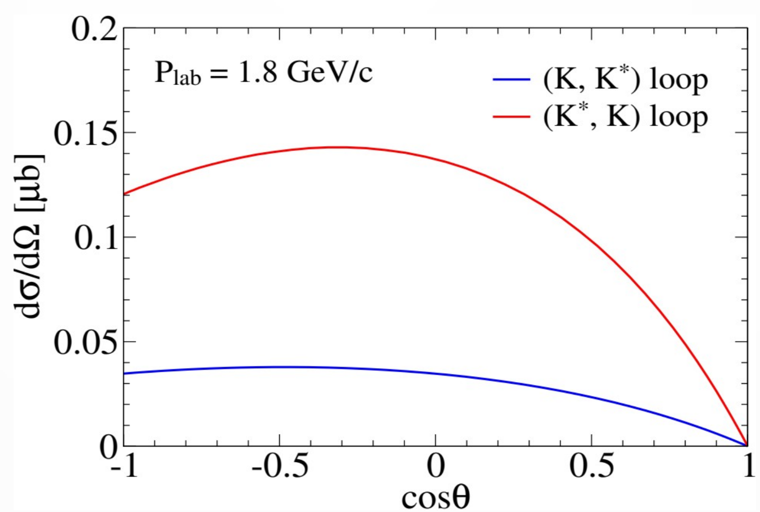


> It becomes a forward peak as J increases.

❑ Rescattering amplitude



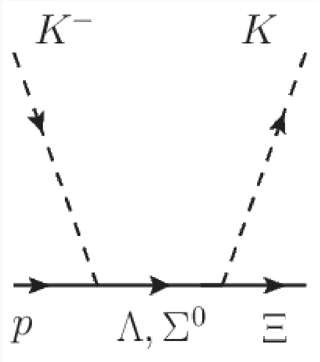


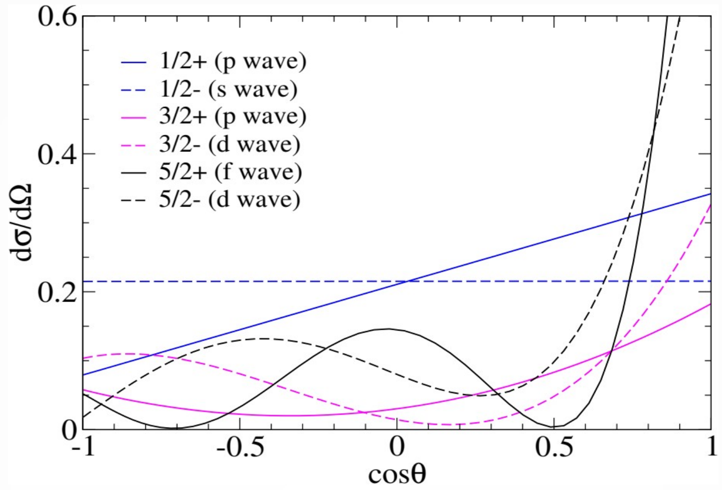


> It is the only channel which provides decreasing behavior at forward angles.

3. $K^- p \to K\,\Xi$ results

❑ Resonant amplitude





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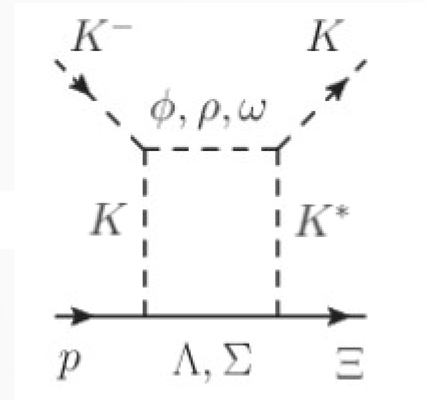
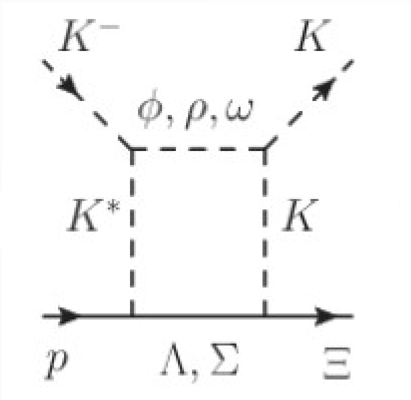
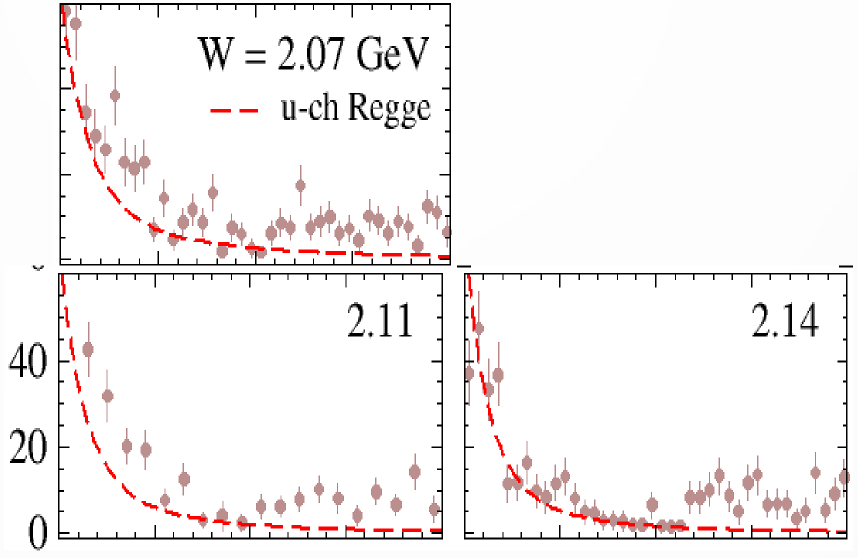
❑ Rescattering amplitude







> It is the only channel which provides decreasing behavior at forward angles.

> More accurate data are called for from the J-PARC.