Hybrid model for the $K^- p \to K \Xi$ reactions

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Contents based on: PRC.107.065202 (2023)

In collaboration with
J.K.Ahn (Korea Univ.), Sh.H.Kim (JAEA), S.i.Nam (PKNU), M.K.Cheoun (Soongsil Univ.)

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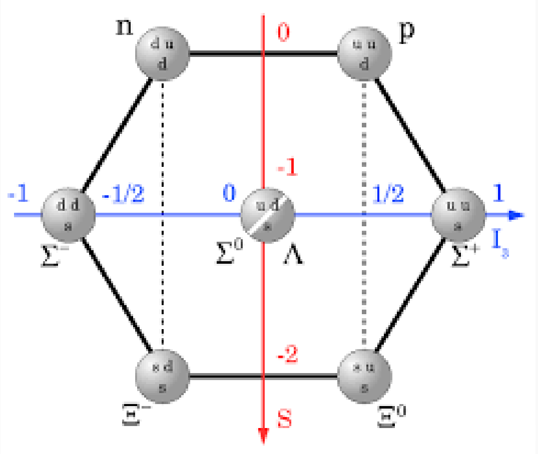

Particle	J^P	Overall status
Ξ(1318)	1/2+	****
Ξ(1530)	3/2+	****
Ξ(1620)		*
Ξ(1690)		***
Ξ(1820)	3/2−	***
Ξ(1950)		***
Ξ(2030)		***
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1. introduction

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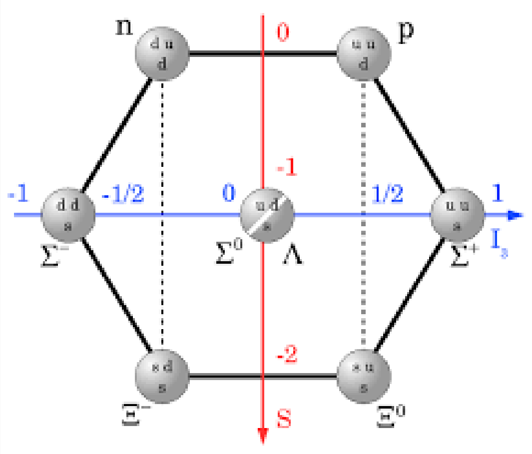

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- This is mainly because multistrangeness hadron production have small cross section rates relatively.
- Recently, the situation becomes better since more precise and abundant data are expected to be produced in the future experiments via various beams:

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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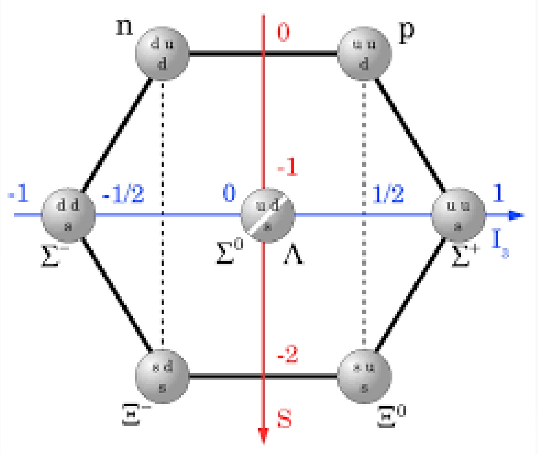

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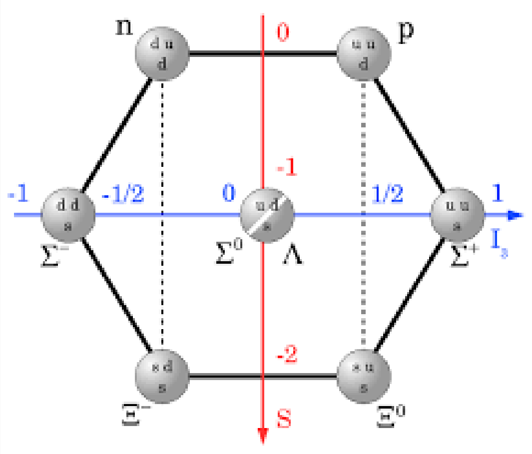

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1. introduction

❏ 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.

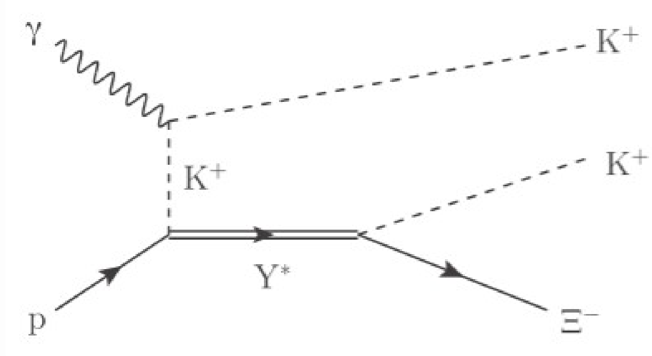
> Theoretical analyses

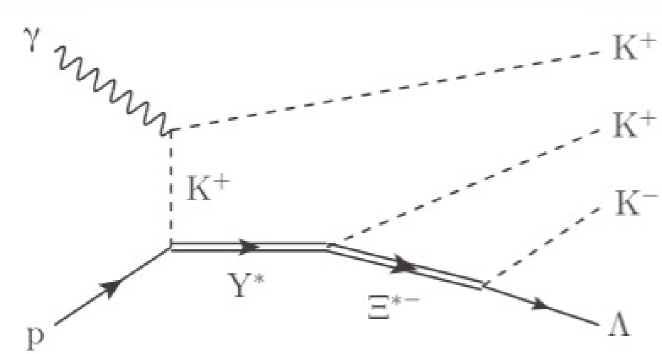
$\gamma\, p \rightarrow K\, K\, \Xi(1318)$

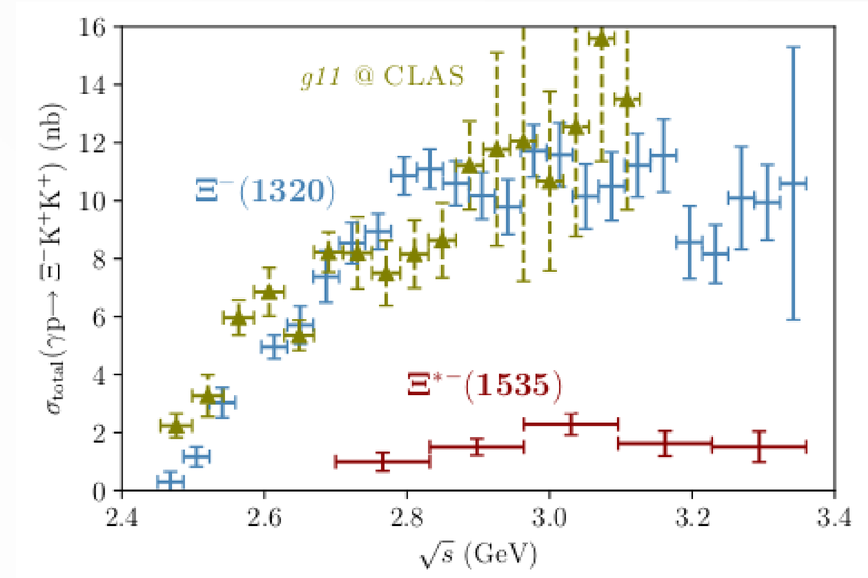
Nakayama et al. PRC.74.035205 (2006)

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

No analyses yet

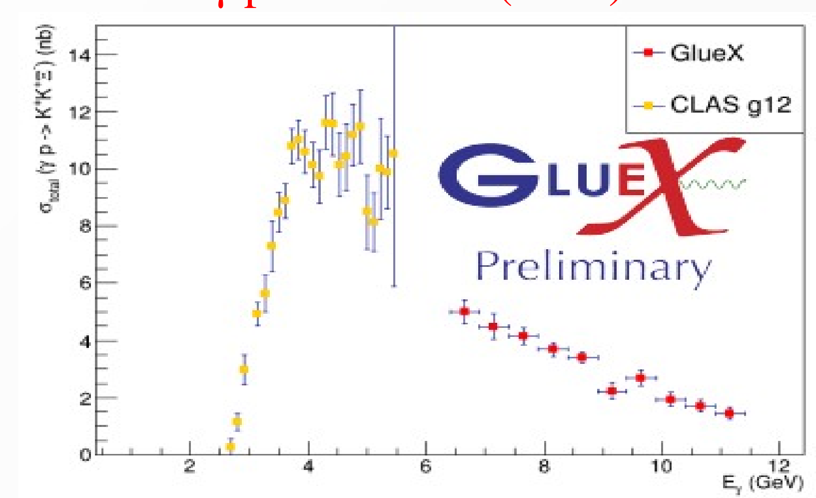






Goetz (CLAS) PRC.98.062201(R) (2018)

$\gamma\, p \rightarrow K^+\, K^+\, \Xi^-(1318)$



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

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

No analyses yet

Ξ^0 $I(J^P) = 1/2(1/2^+)$ PDG 2022

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

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

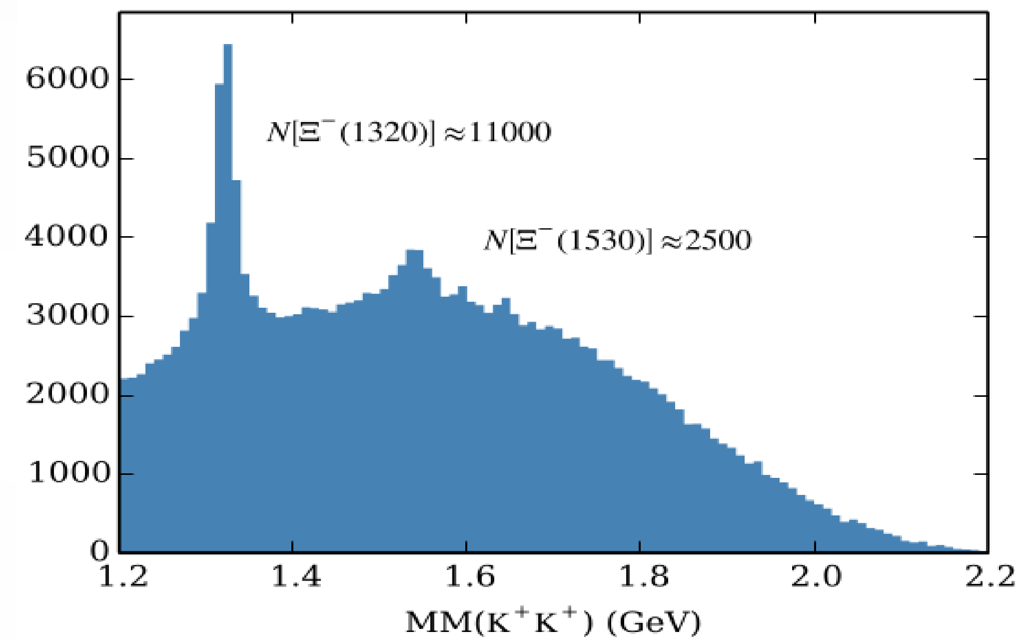

FIG. 2. Missing mass off of (K^+K^+) showing the Ξ spectrum above a smooth background, summed over all angles and all E_γ.

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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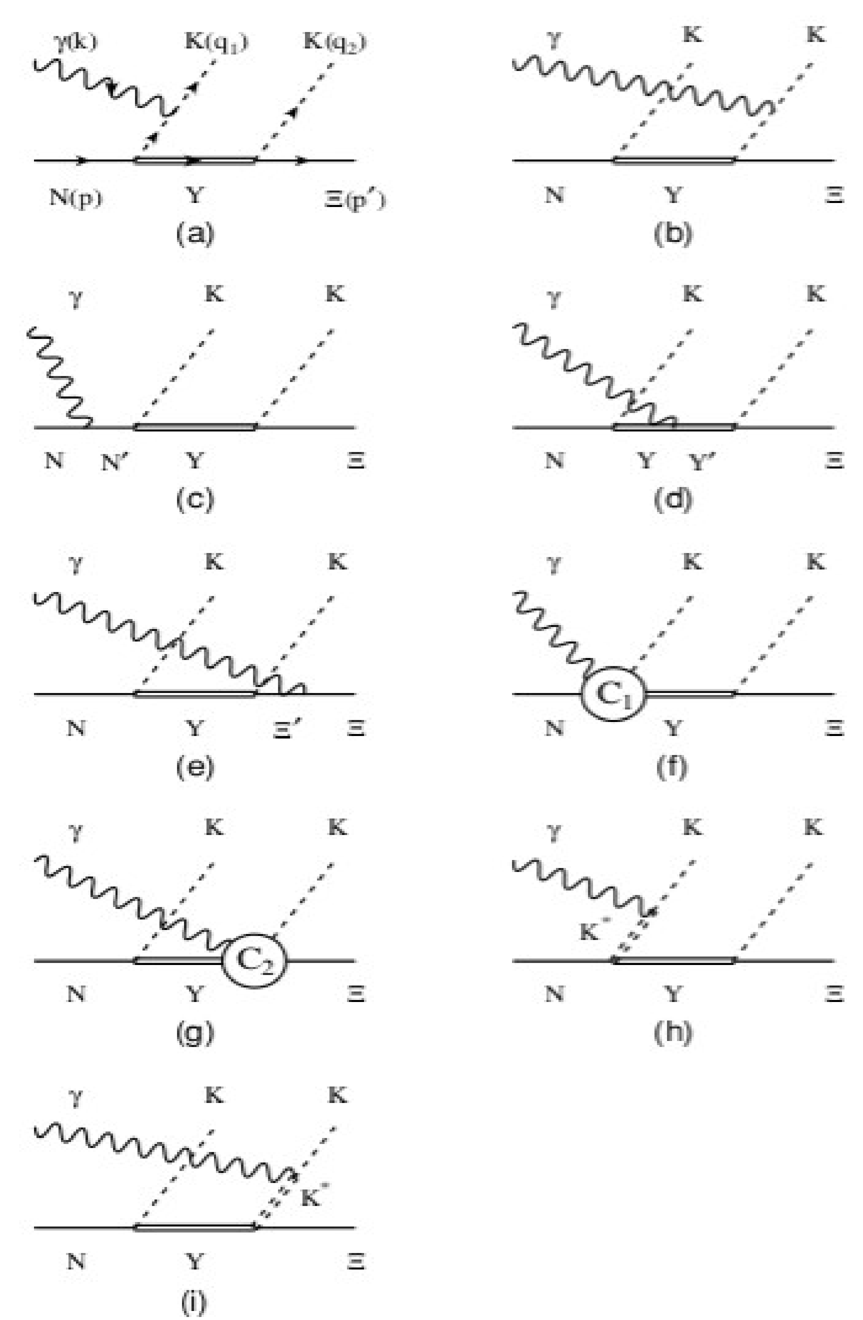


1. introduction

❑ Multistrangeness production in hadron physics

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

> 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.

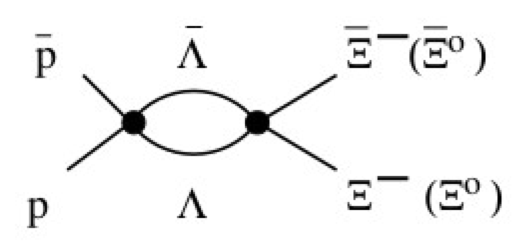
> The amplitudes are described by the loop diagrams within a modified Regge type model.

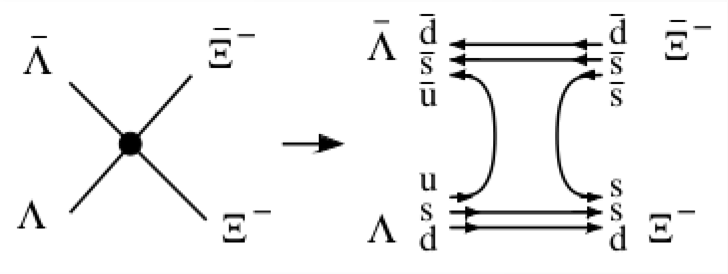
Titov et al. 1105.3847 [hep-ph]

> More rigorous analyses are called for.

Titov et al. 1105.3847 [hep-ph]

❑ Loop diagrams





> K & K* exchanges are possible.

❑ Scattering amplitude

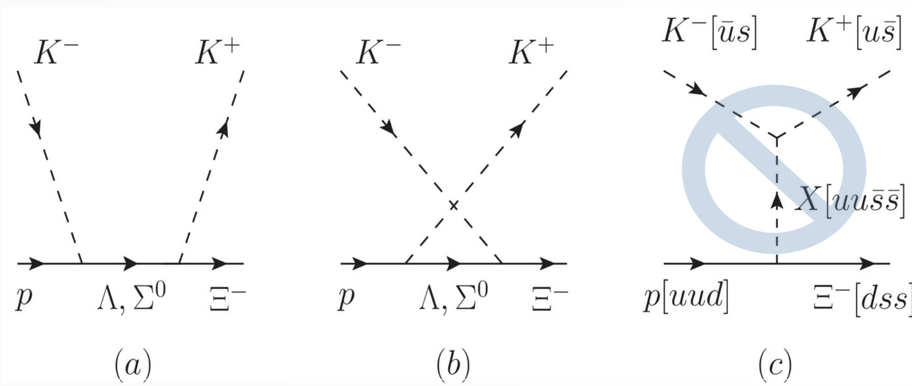
$$T^{\bar{p}p\to\bar{\Xi}\Xi} \simeq T_{\rm cut}^{\bar{p}p\to\bar{\Xi}\Xi}$$
$$= i\,\frac{Q_\Lambda}{8\pi\sqrt{s}}\int\frac{d\Omega_\Lambda}{4\pi}\sum_{\text{spins }\bar{\Lambda}\Lambda} T^{\bar{p}p\to\bar{\Lambda}\Lambda}\,T^{\bar{\Lambda}\Lambda\to\bar{\Xi}\Xi}$$

❑ $K^- p \to K\ \Xi$

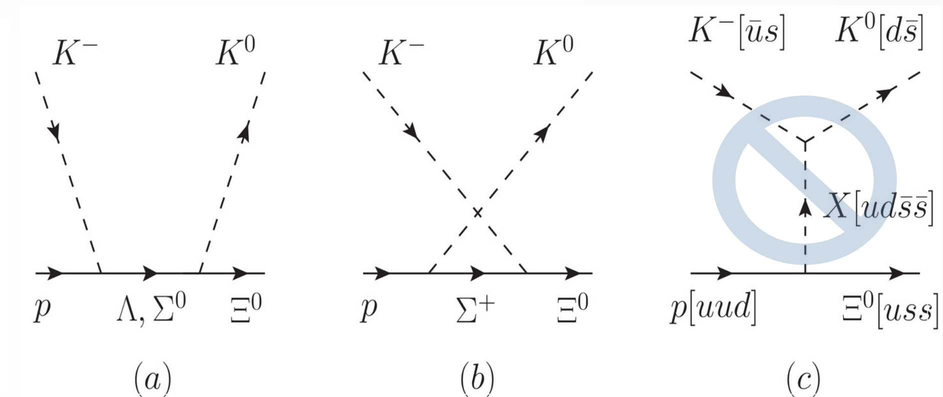
> Only ($\Lambda^{(*)}$ & $\Sigma^{(*)}$) hyperons mediate in the Born diagrams.

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

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



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



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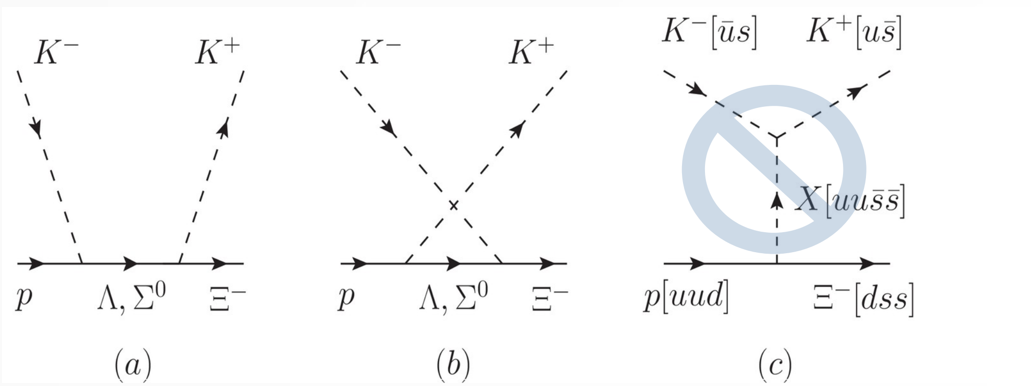

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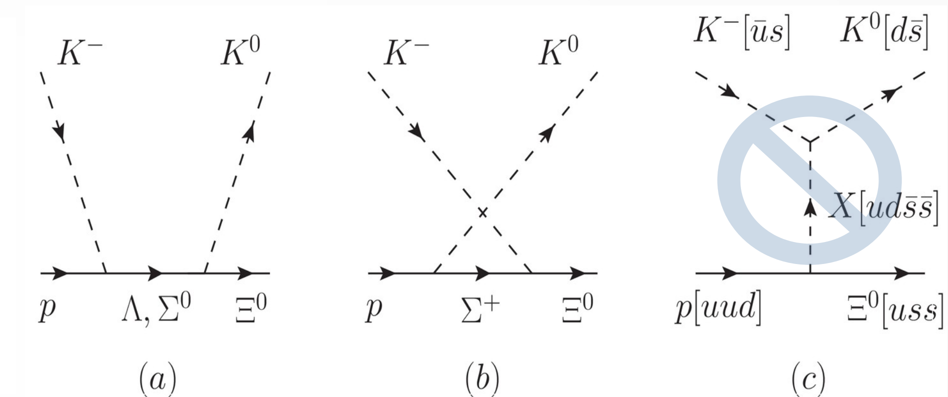


□ tetraquark in **charm sector** [LHCb, Nature Physics 18, 751 (2022)]

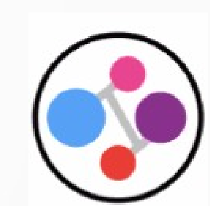
> First observation with [$cc\bar{u}\bar{d}$] content, $T_{cc}(3875, 1^+)$, width $\Gamma \sim 410$ keV in the mass spectrum of "$D^0 D^0 \pi^+$"

□ tetraquark in **strange sector**

> No meson of strangeness two is known to exist.

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

meson



tetraquark

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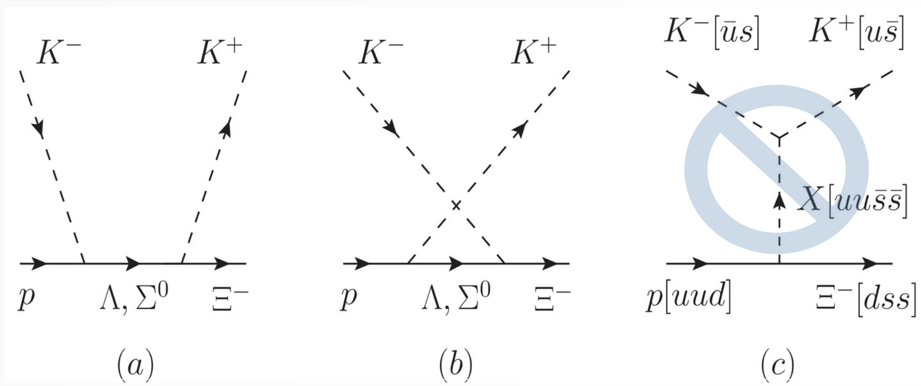

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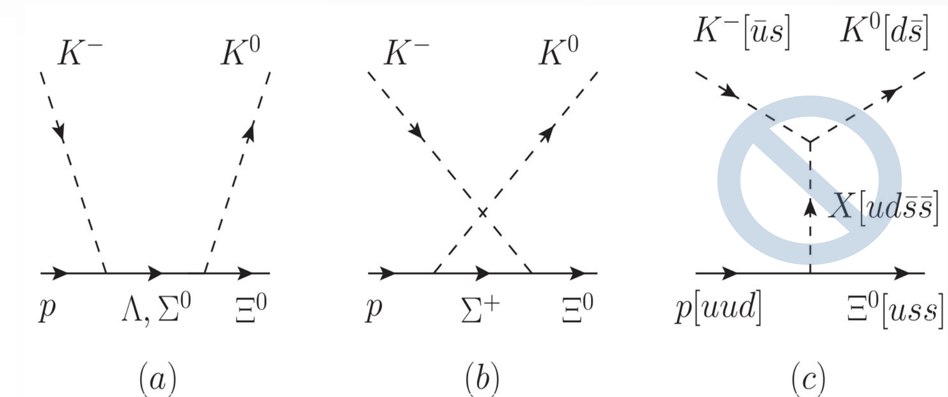
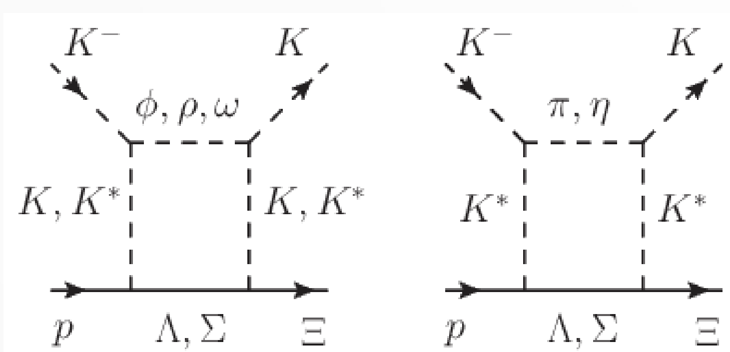


Rescattering digram



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

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

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

2. theoretical framework

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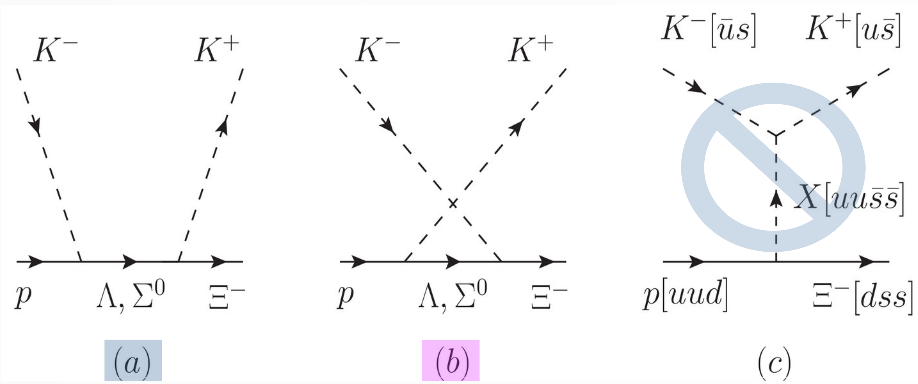

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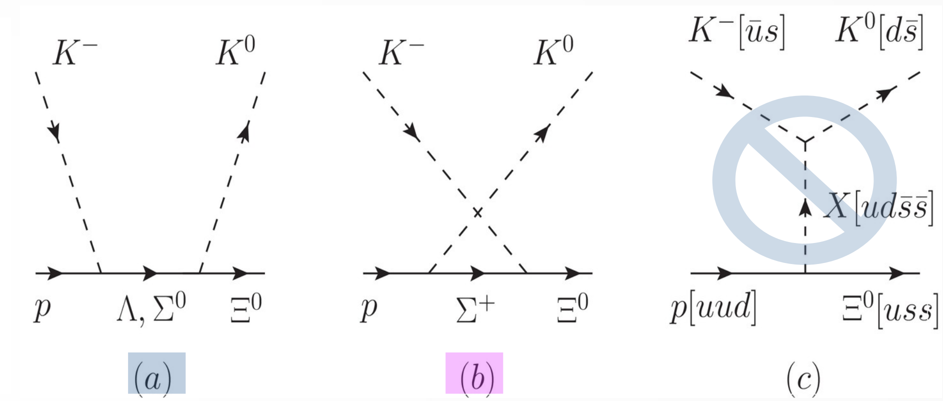

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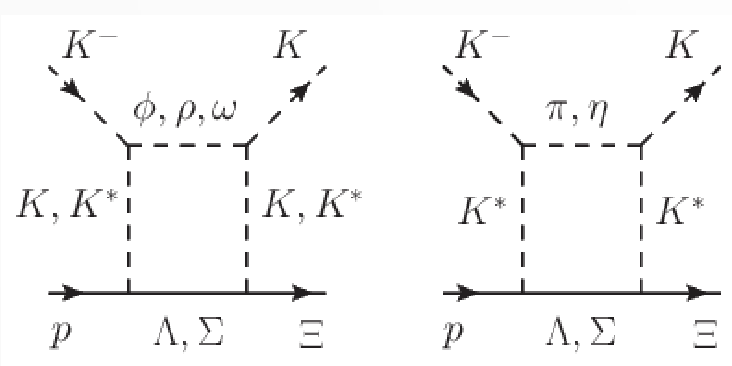

□ (Fig. b) We employ a hybridized Regge model to describe the backward angles in the *u* channel.

□ (Fig. a) Additionally, in the *s* channel, we include (Λ^* & Σ^*) resonances which couple strongly to $\bar{K}N$ & $K\Xi$ channels.

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

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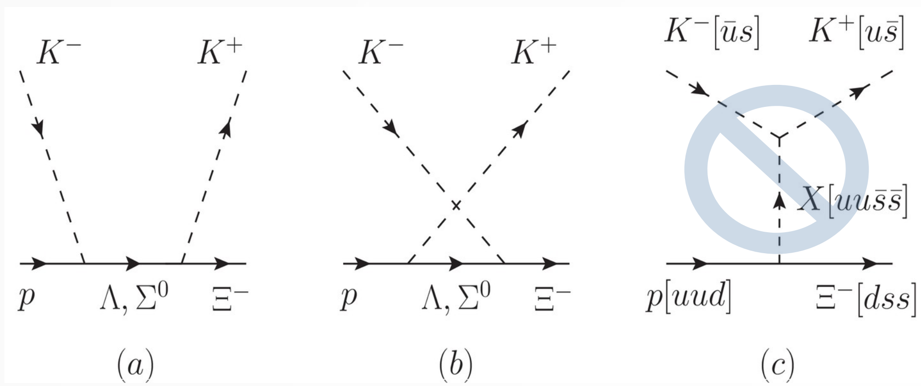

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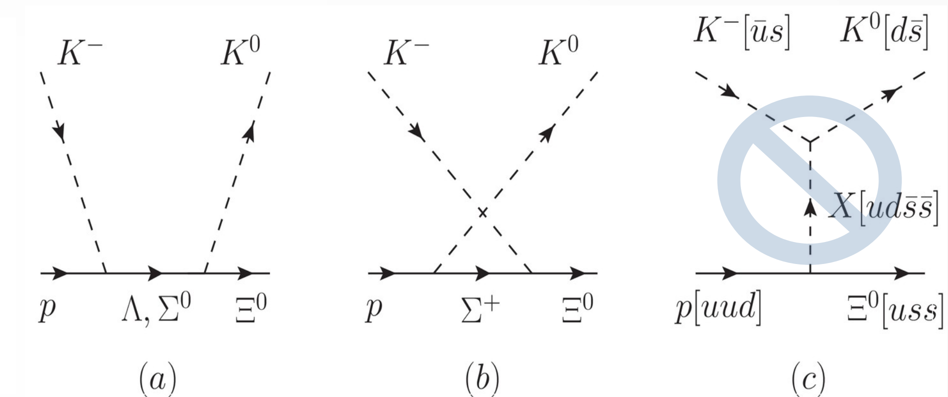

❑ Effective Lagrangians

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

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

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

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

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

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

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

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

($\lambda = 1$) 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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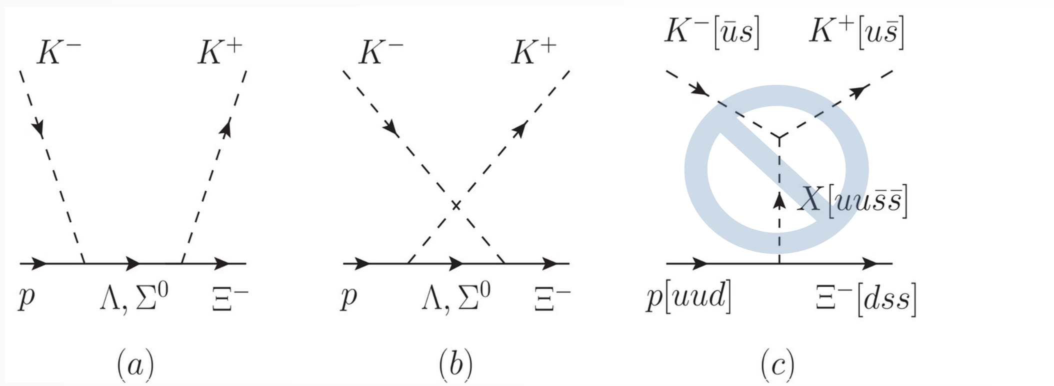

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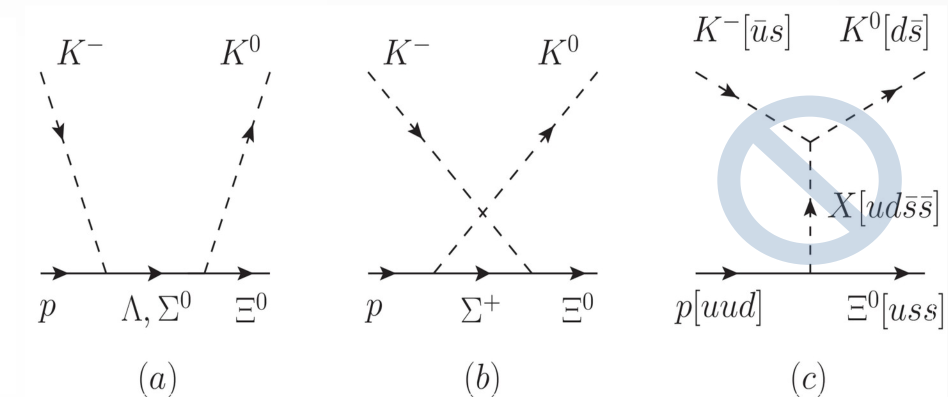


[isospin factors]

(A): 1(1) -1(1) 1(1) -1(1)

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

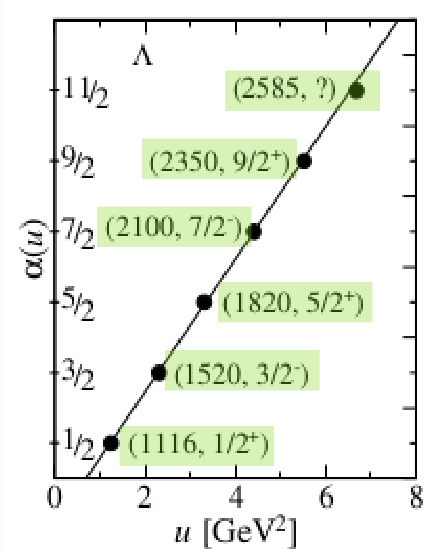
□ We consider two different isospin channels simultaneously: useful to constrain model parameters.

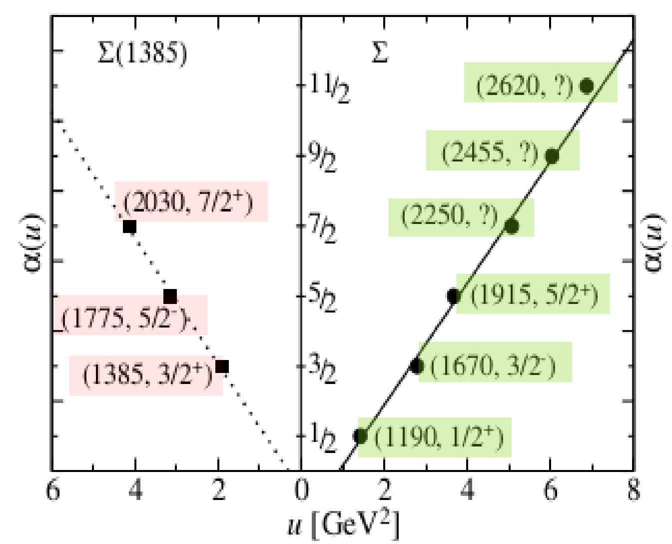
Λ hyperons

	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)





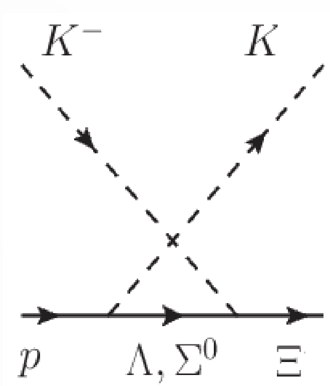
$\Lambda : \alpha(u) = -0.65 + 0.94u$

$\Lambda(1405)$: excluded

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

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

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



Σ hyperons

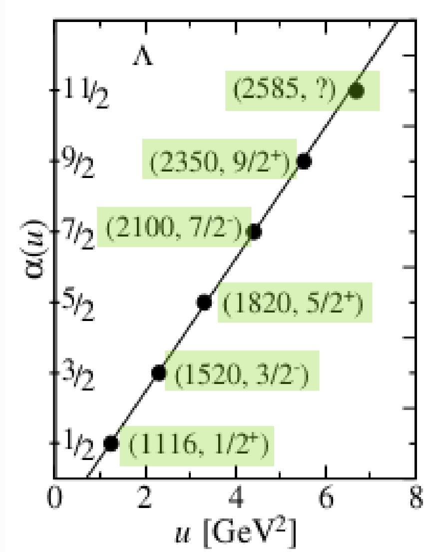
	J^P	status
$\Sigma(1193)$	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	*
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1750)$	$1/2^-$	***
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1780)$	$3/2^+$	*
s_{th}		
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(1900)$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

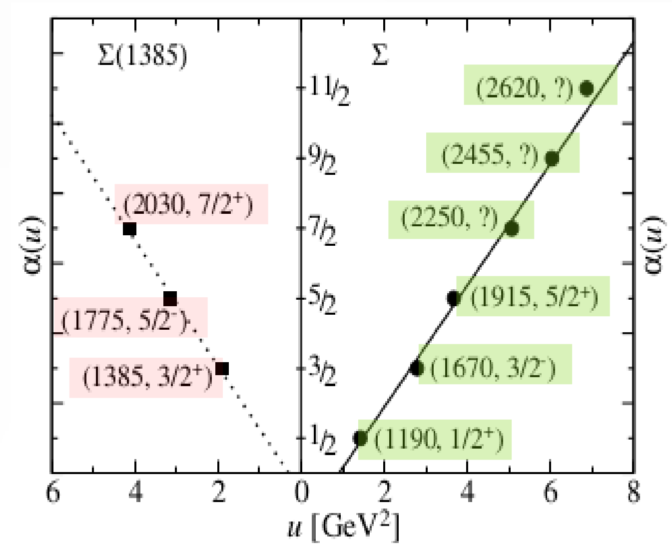
❑ Hyperon Regge trajectories

Storrow, Phys.Rept.103.317 (1984)

Λ hyperons

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





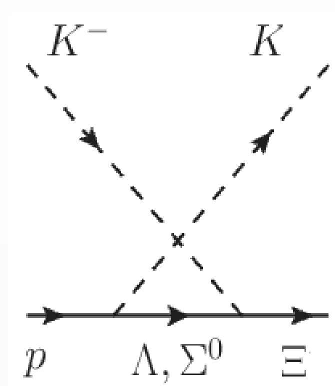
$\Lambda : \alpha(u) = -0.65 + 0.94u$

Λ(1405) : excluded

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

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

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



Σ hyperons

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

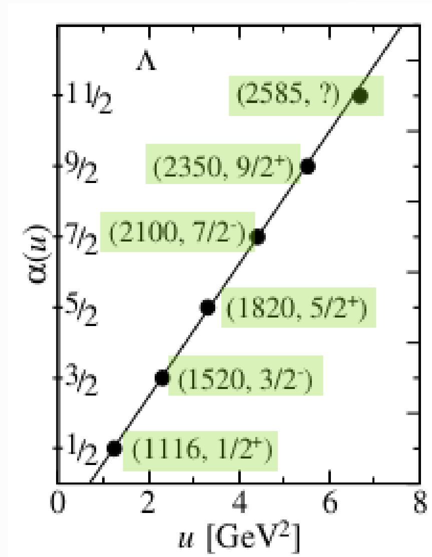
❑ As seen, hyperon Regge trajectories involve many of 3 & 4 star resonances.

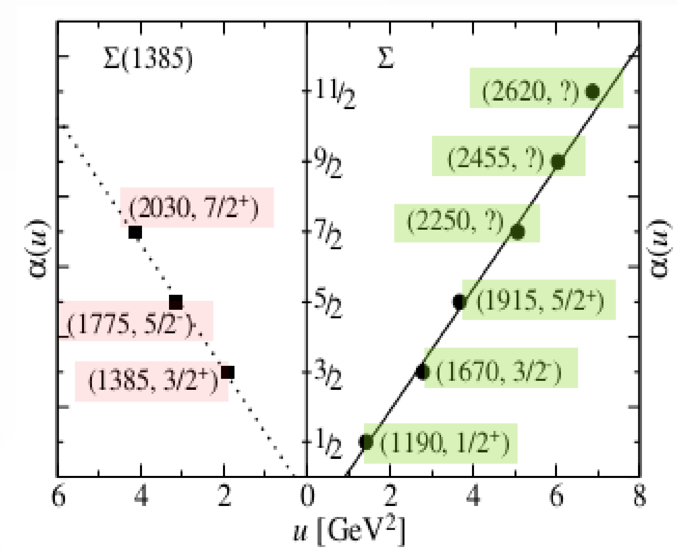
❑ Hyperon Regge trajectories

Storrow, Phys.Rept.103.317 (1984)

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





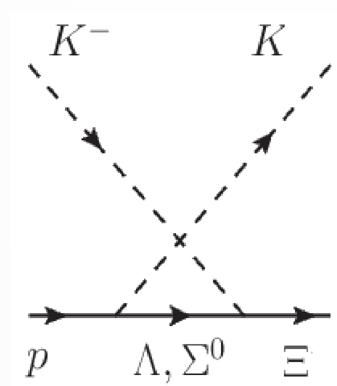
Λ : $\alpha(u) = -0.65 + 0.94u$

$\Lambda(1405)$: excluded

Σ : $\alpha(u) = -0.79 + 0.87u$

Σ^* : $\alpha(u) = -0.27 + 0.9u$

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



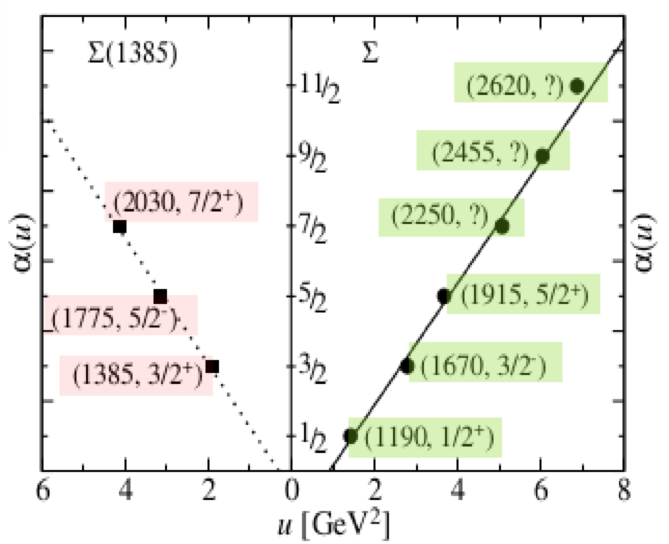
Σ hyperons

	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.

❑ Hyperon Regge trajectories

Storrow, Phys.Rept.103.317 (1984)



$$\Sigma \;:\; \alpha(u) = -0.79 + 0.87u$$
$$\Sigma^* \;:\; \alpha(u) = -0.27 + 0.9u$$

Σ(2250) **

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

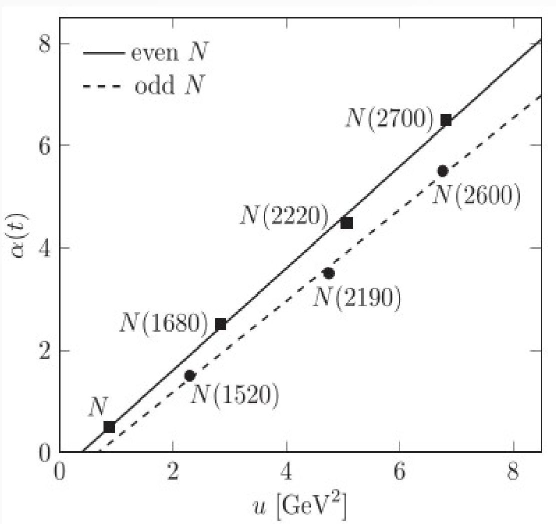
Σ hyperons

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

❑ Baryon Regge trajectories

Storrow, Phys.Rept.103.317 (1984)

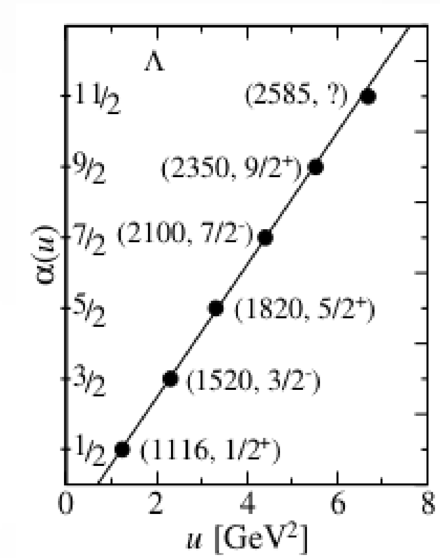
Nucleon



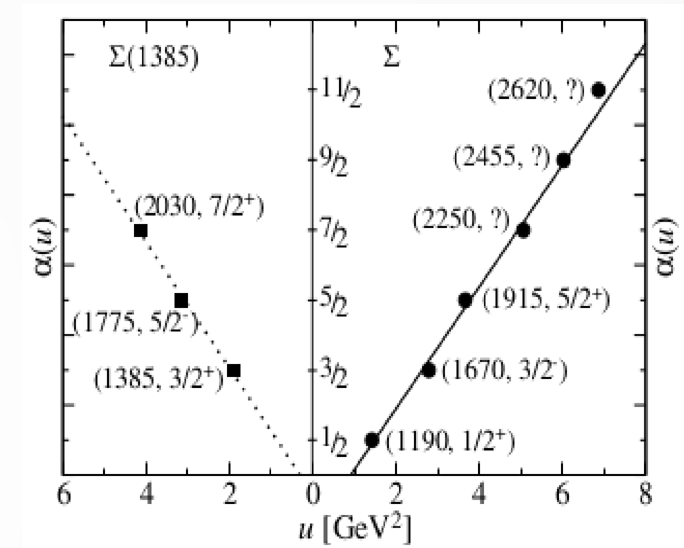
Clymton.
PRD.104.014023 (2021)

N(even) : α(u) = -0.38 + 0.99u

Λ hyperons



Σ hyperons



Feynman (Regge) propagator

$$P_N^F = \frac{1}{u - M_N^2} \implies$$

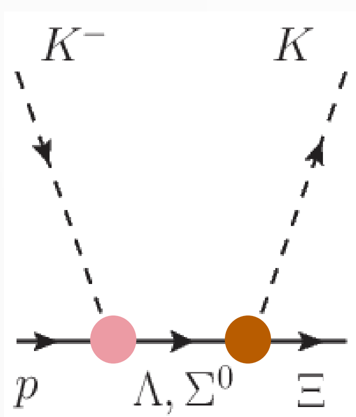
$$P_N^R(s,u) = \frac{1 + \tau \exp(-i\pi\alpha_N(u))}{2} \left(\frac{s}{s_0}\right)^{\alpha_N(u)-\frac{1}{2}} \frac{1}{\cos[\pi\alpha_N(u)]} \frac{\pi\alpha'_N}{\Gamma[\frac{1}{2}+\alpha_N(u)]}$$

$$P_Y^F = \frac{1}{u - M_Y^2} \implies$$

$$P_Y^R(s,u) = \left(\frac{1}{e^{-i\pi\alpha_Y(u)}}\right) \left(\frac{s}{s_0}\right)^{\alpha_Y(u)-\frac{1}{2}} \frac{1}{\cos[\pi\alpha_Y(u)]} \frac{\pi\alpha'_Y}{\Gamma[\frac{1}{2}+\alpha_Y(u)]}$$

- PDG 2022
- 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	**	−	−	−	−

- PDG 2022
- We include (Λ^* & Σ^*) resonances which couple strongly to $\overline{K}N$ & $K\Xi$ channels.
- Partial decay width

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

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

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

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

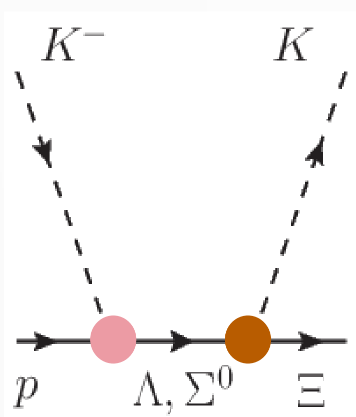
$$\mathcal{L}_{\Lambda NK}^{7/2(\pm)} = \frac{g_{\Lambda NK}}{m_K^3}\,\bar{\Lambda}^{\mu\nu\rho}(D_{\mu\nu\rho}^{7/2(\pm)}\bar{K})N + \text{H.c.}$$

(Λ^*, J^P)	Γ_{Λ^*} [MeV]	status	$\text{Br}_{\Lambda^*\to N\bar{K}}$ [%]	$\lvert g_{KN\Lambda^*}\rvert$	$\text{Br}_{\Lambda^*\to\Xi K}$ [%]	$\lvert g_{K\Xi\Lambda^*}\rvert$
$\Lambda(1820, 5/2^+)$	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	$\text{Br}_{\Sigma^*\to N\bar{K}}$ [%]	$\lvert g_{KN\Sigma^*}\rvert$	$\text{Br}_{\Sigma^*\to\Xi K}$ [%]	$\lvert g_{K\Xi\Sigma^*}\rvert$
$\Sigma(1880, 1/2^+)$	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	**	–	–	–	–

- PDG 2022
- We include (Λ^* & Σ^*) resonances which couple strongly to $\bar{K}N$ & $K\Xi$ channels.
- Partial decay width

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



(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	**	–	–	–	–

✓ turn out to be important.

$\Lambda(2100, 7/2^-)$ ****

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\bar{K} \to \Lambda(2100) \to \Xi K$

VALUE	DOCUMENT ID		TECN	COMMENT
0.035 ±0.018	LITCHFIELD	1971	DPWA	$K^- p \to \Xi K$
• • We do not use the following data for averages, fits, limits, etc. • •				
0.003	MULLER	1969B	DPWA	$K^- p \to \Xi K$
0.05	TRIPP	1967	RVUE	$K^- p \to \Xi K$

References:

LITCHFIELD	1971	NP B30 125	$K^- p$ Elastic and Charge Exchange Scattering in the c.m. Energy Range 1915 –
MULLER	1969B	Thesis UCRL 19372	A Study of the Reaction $K^- n \to \Xi K$ from Threshold to 2.7 GeV/c
TRIPP	1967	NP B3 10	Baryon Resonances in SU(3)

$\Sigma(2030, 7/2^+)$ ****

$\Gamma(\Sigma(2030) \to \Xi K)/\Gamma_{total}$

VALUE	DOCUMENT ID		TECN	COMMENT
< 0.01	SARANTSEV	2019	DPWA	$\bar{K}N$ multichannel
• • We do not use the following data for averages, fits, limits, etc. • •				
0.006	[1] KAMANO	2015	DPWA	$\bar{K}N$ multichannel

[1] From the preferred solution A in KAMANO 2015 .

References:

SARANTSEV	2019	EPJ A55 180	Hyperon II: Properties of excited hyperons
KAMANO	2015	PR C92 025205	Dynamical Coupled-Channels Model of $K^- p$ Reactions. II. Extraction of Λ^*

- ❑ Recent PWA emphasize only the role of $\Sigma(2030, 7/2^+)$ in the $K^- p \to K \Xi$.
- ❑ We have found that $\Lambda(2100, 7/2^-)$ is also essential to describe the $K^- p \to K \Xi$.

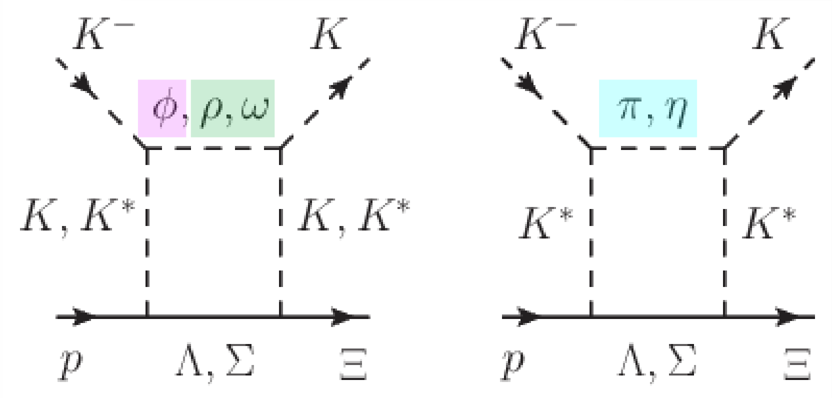
❑ Rescattering amplitude

$$T_{MB}(p,p') = \sum_i \int \frac{d^3\vec{q}}{(2\pi)^3} \frac{m_{B_i}}{E_{B_i}} T_{K^-p\to M_iB_i}(p,q) \frac{1}{s-(E_{M_i}+E_{B_i})^2+i\epsilon} T_{M_iB_i\to K\Xi}(q,p')$$
$$= -i \sum_i \frac{p_{\text{c.m.}}}{16\pi^2} \frac{m_{B_i}}{\sqrt{s}} \int d\Omega \left[T_{K^-p\to M_iB_i}(p,q) T_{M_iB_i\to K\Xi}(q,p')\right] + \mathcal{P}.$$

$M_i = (\varphi, \rho, \omega, \pi, \eta)$

$B_i = (\Lambda, \Sigma)$

$$\frac{1}{s-M^2+i\epsilon} = -i\pi\delta(s-M^2) + P\frac{1}{s-M^2}$$



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

❑ Rescattering amplitude

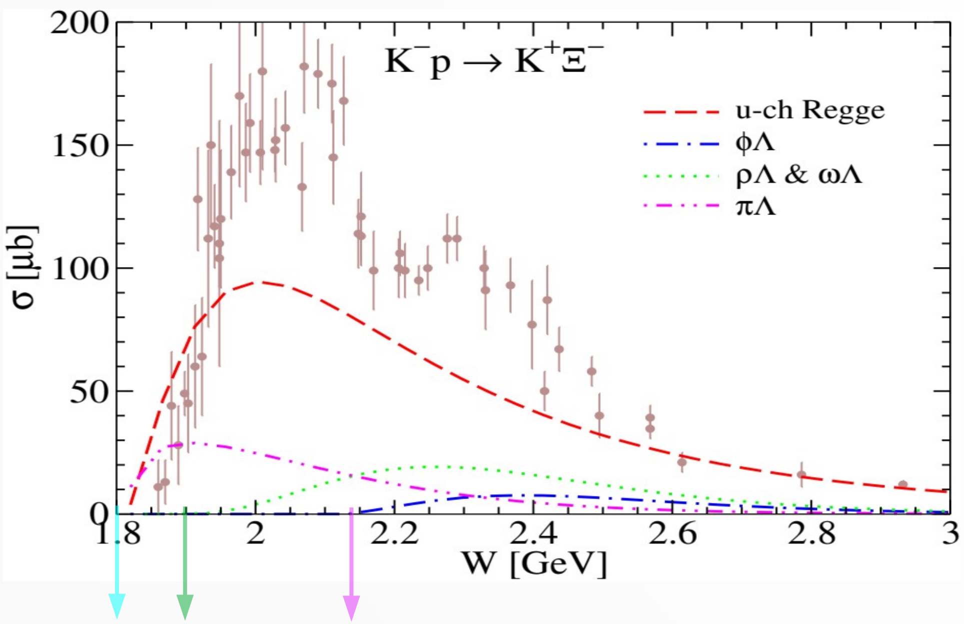
$$T_{MB}(p,p') = \sum_i \int \frac{d^3\vec{q}}{(2\pi)^3}\frac{m_{B_i}}{E_{B_i}} T_{K^-p\to M_iB_i}(p,q)\frac{1}{s-(E_{M_i}+E_{B_i})^2+i\epsilon}T_{M_iB_i\to K\Xi}(q,p')$$

$$= -i\sum_i \frac{p_{\rm c.m.}}{16\pi^2}\frac{m_{B_i}}{\sqrt{s}}\int d\Omega\left[T_{K^-p\to M_iB_i}(p,q)T_{M_iB_i\to K\Xi}(q,p')\right]+\mathcal{P}.$$

$M_i = (\varphi, \rho, \omega, \pi, \eta)$

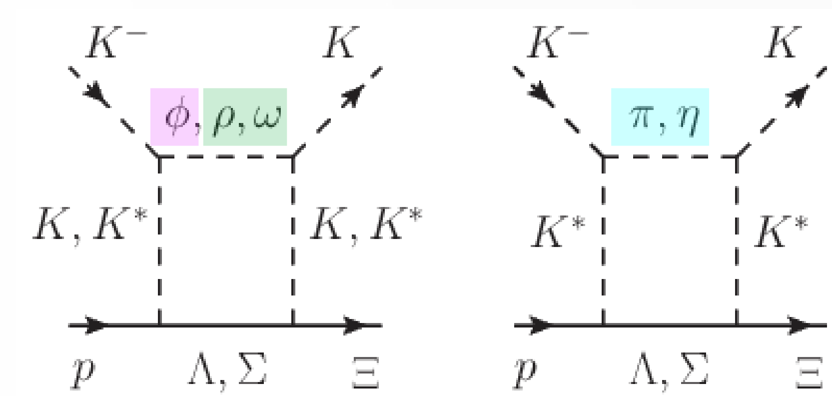
$B_i = (\Lambda, \Sigma)$

□ We **fully** calculate the real and imaginary parts.



πΛ (ρΛ,ωΛ) φΛ : Im part starts from here.

→ Re part starts from the reaction threshold.



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

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$M_i = (\varphi, \rho, \omega, \pi, \eta)$
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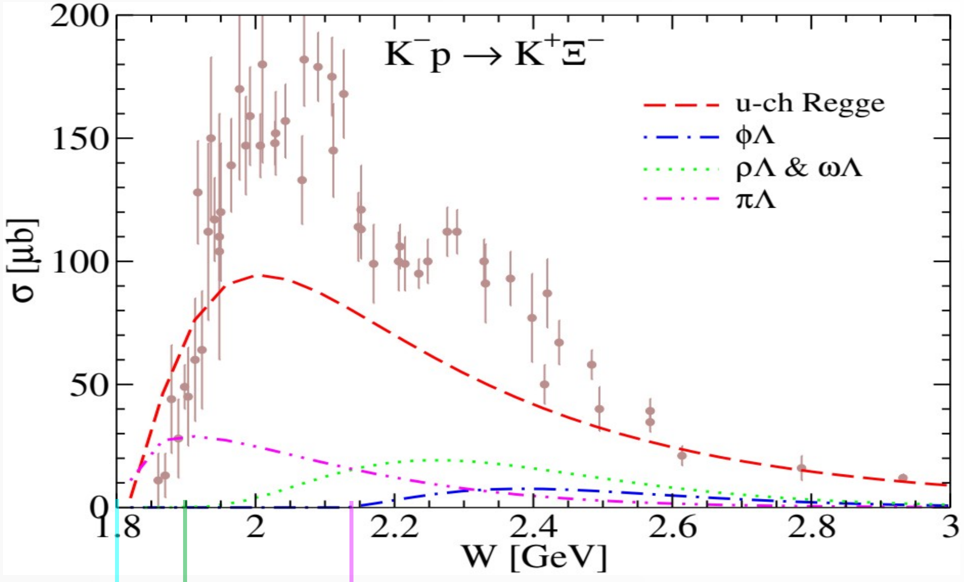
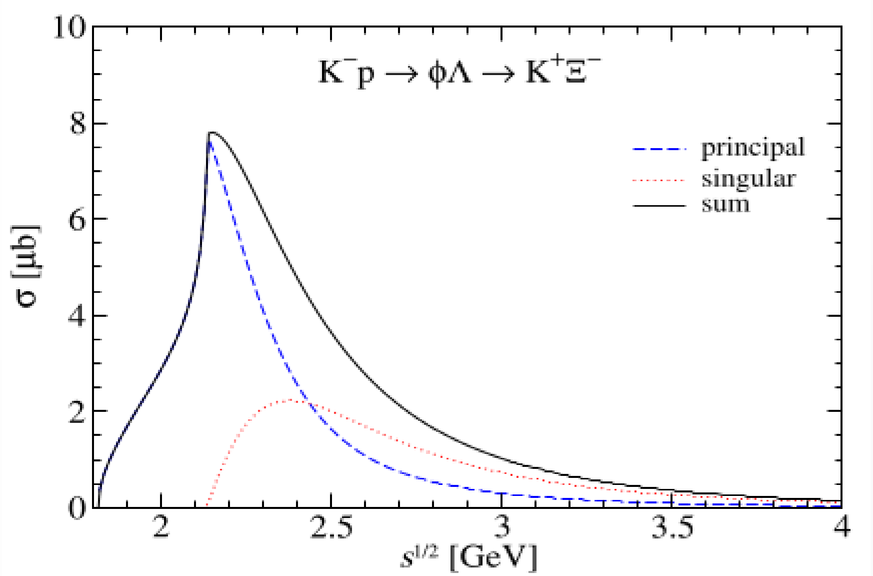


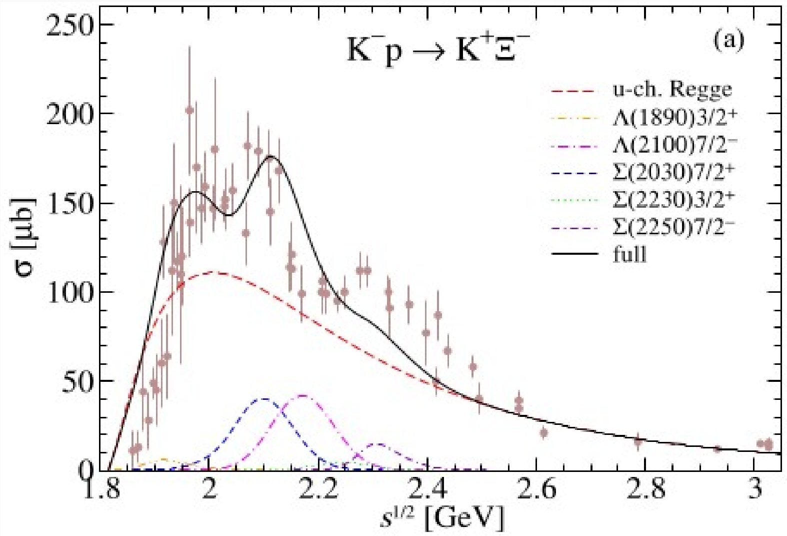
πΛ (ρΛ,ωΛ) φΛ : Im part starts from here.

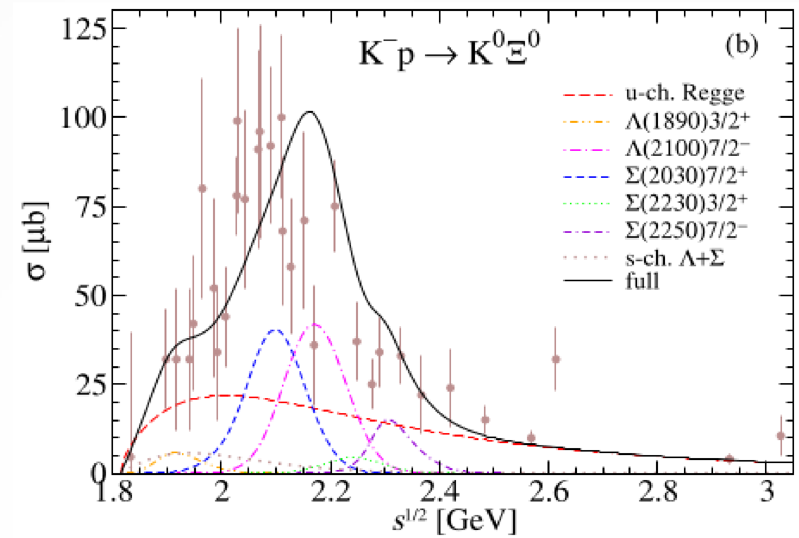
→ Re part starts from the reaction threshold.



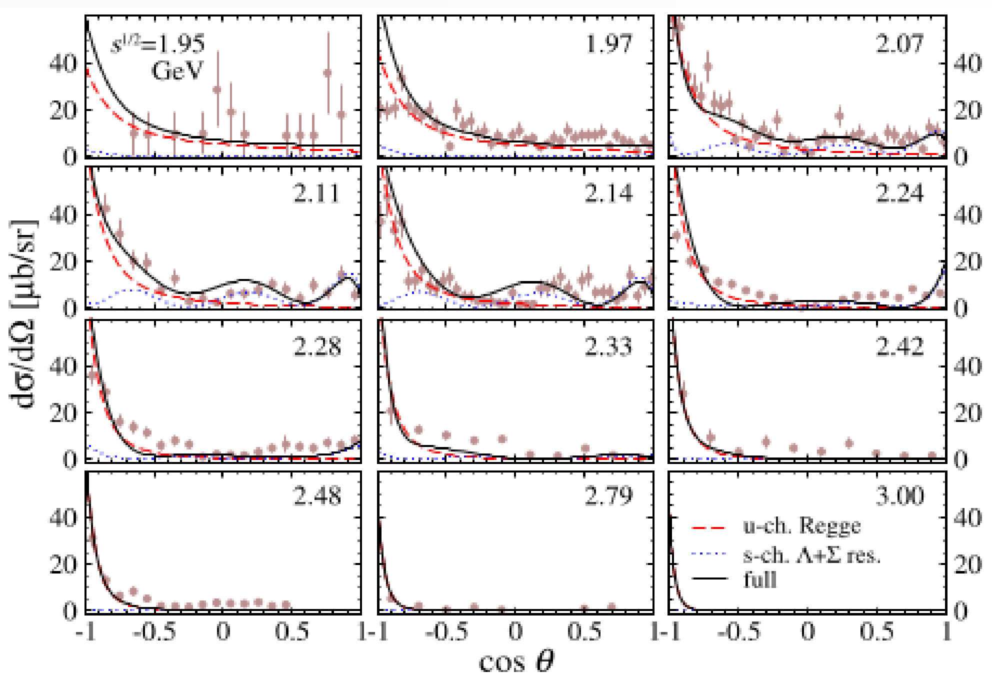
> The Real (Imaginary) part is crucial in the low (high) energy region.

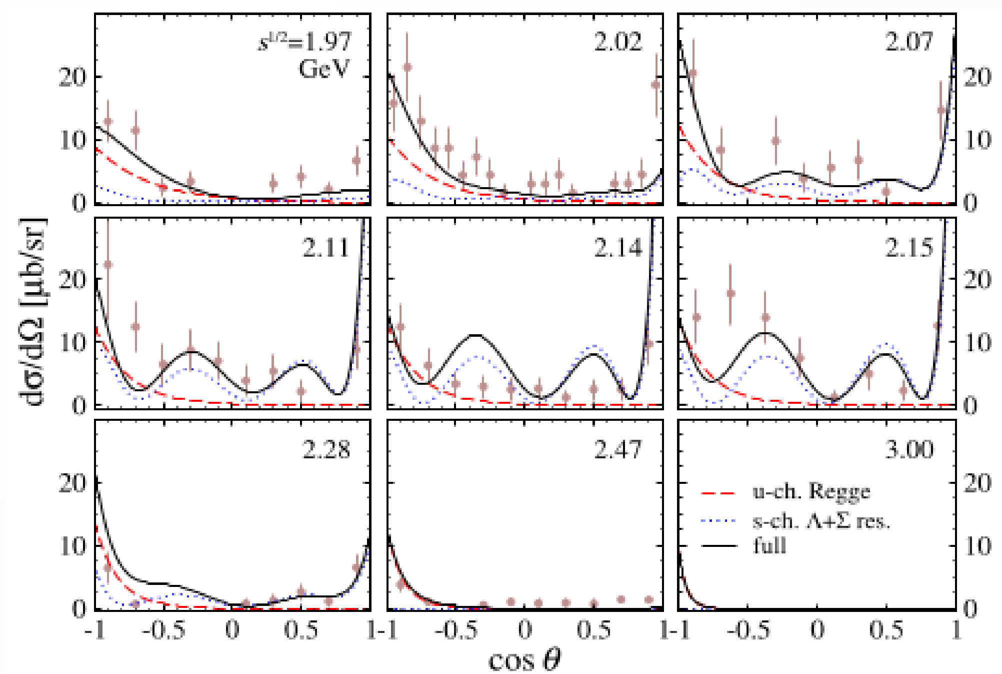
❑ Total & Differential cross sections ($K^- p \rightarrow K^+ \Xi^-$ & $K^0 \Xi^0$) [*u*-channel background + *s*-channel Λ^* & Σ^*]





> 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. numerical results

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

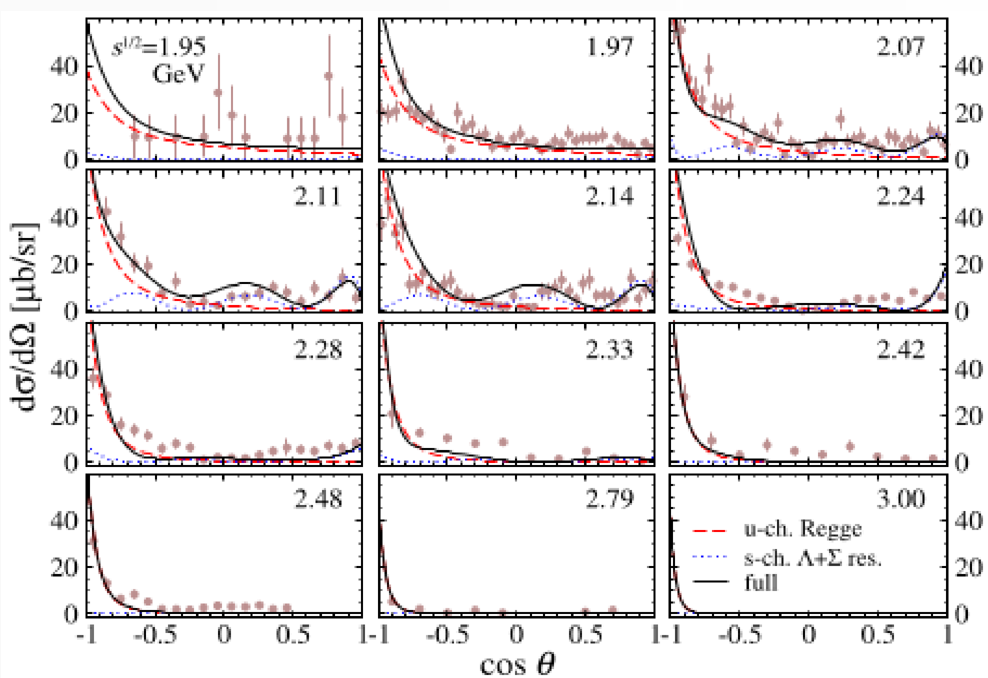
$K^- p \to K^+ \Xi^-$

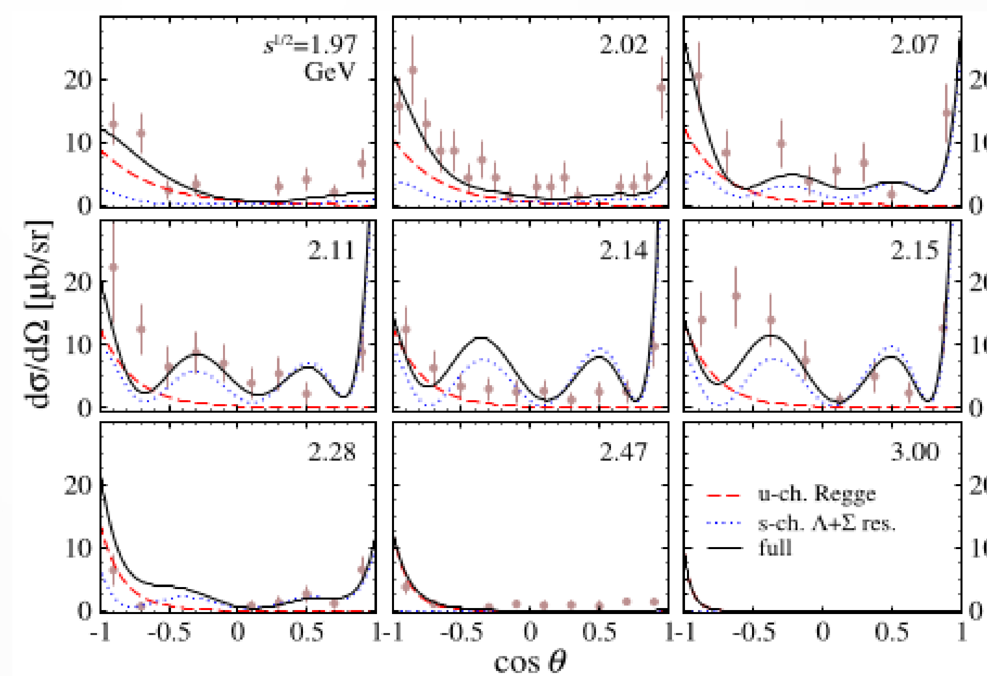
> The sharp decreasing at the forward angle

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

> The sharp forward peak

> Explained by the interference between *s*-channel (Λ^*, Σ^*) resonances of different isospins.





3. numerical results

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

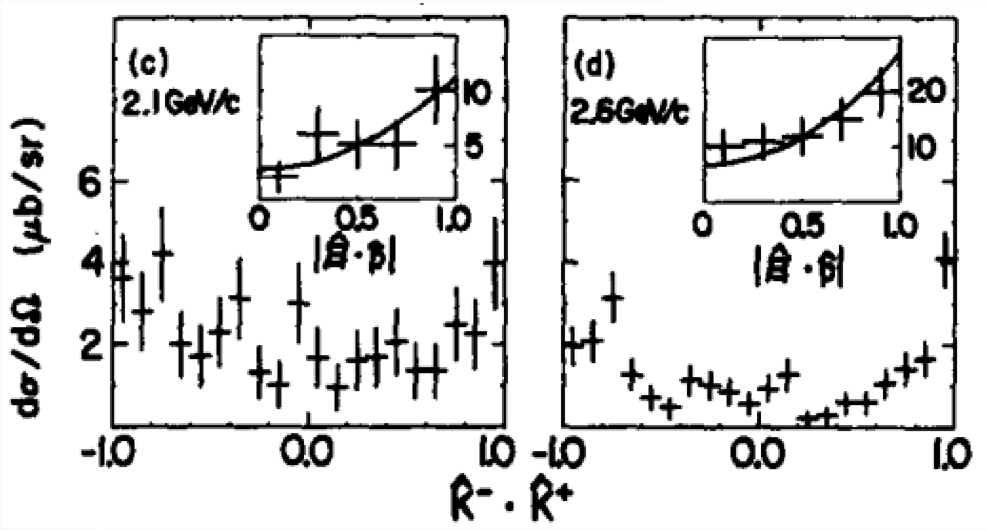
$K^- p \rightarrow K^+ \Xi^{*-}$

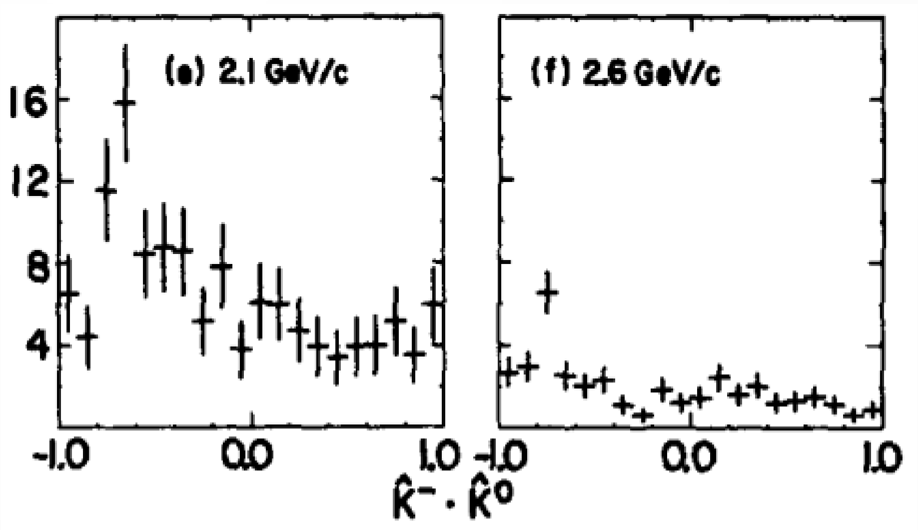
> The presence of
a forward peak

$K^- p \rightarrow K^0 \Xi^{*0}$

> The absence of
a forward peak

> Explained by the interference between *s*-channel (Λ^*, Σ^*) resonances of different isospins.



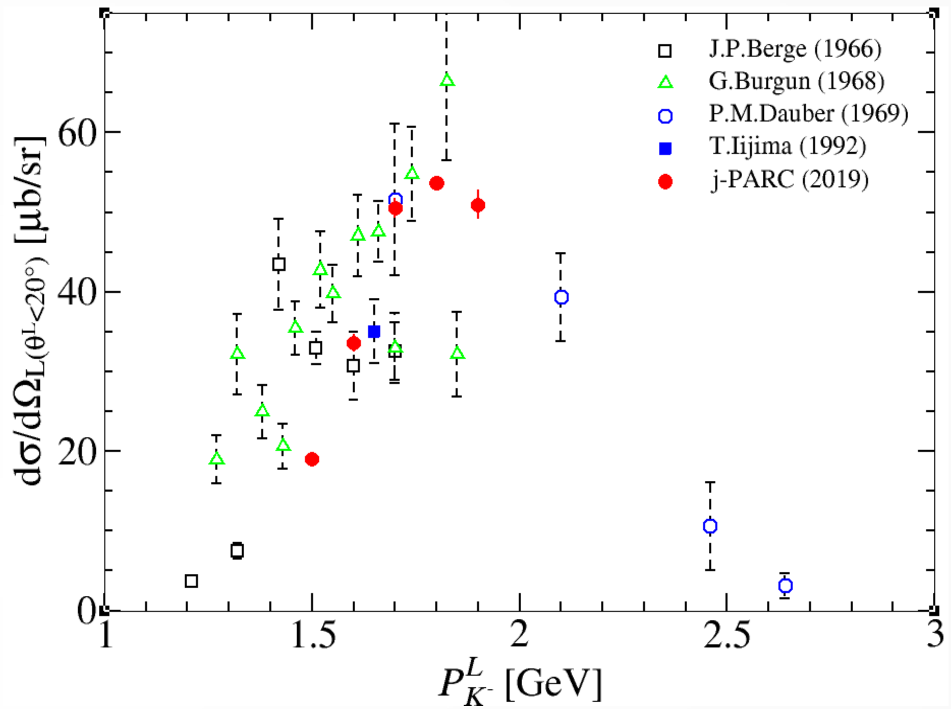


Dauber, PLB.29.609 (1969)

> The data indicate that
the reaction mechanism of $K^- p \rightarrow K \Xi^*$ will be totally different from that of $K^- p \rightarrow K \Xi$.

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

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

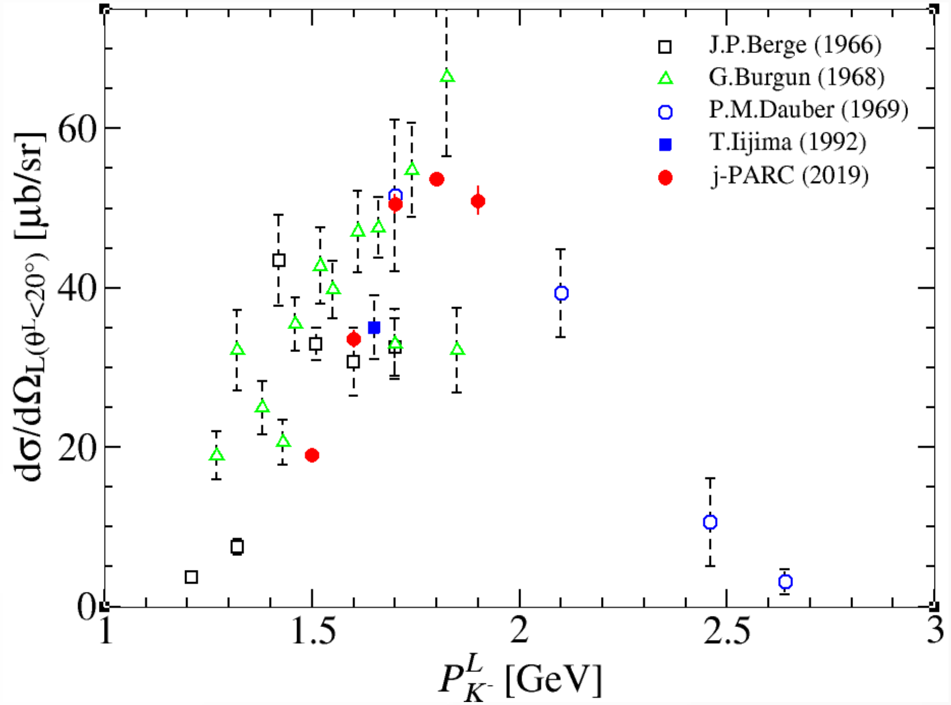


- We used old experimental data taken in 1960s and 1970s.

- Recently, the J-PARC E05 experiment measured the cross section at forward angles ($\theta_{Lab} < 20°$).

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

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



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Nagae, AIP Conf. Proc. 2130, 020015 (2019)

Observation of a Ξ bound state in the $^{12}C(K^-, K^+)$ reaction at 1.8 GeV/*c*

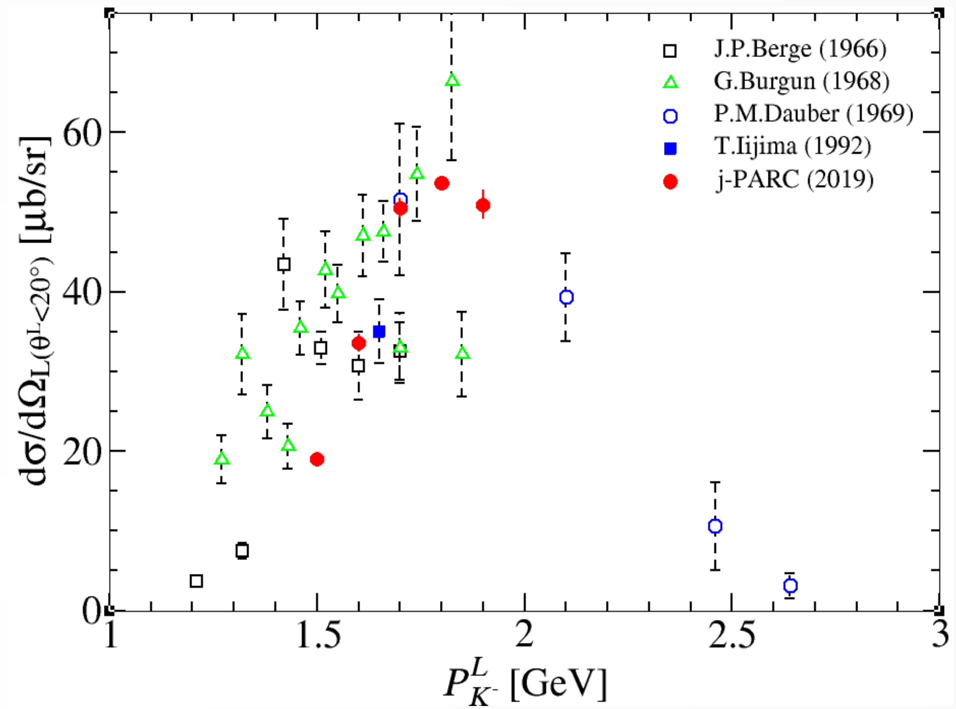
- Relations between c.m. and Lab frames:

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

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

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

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



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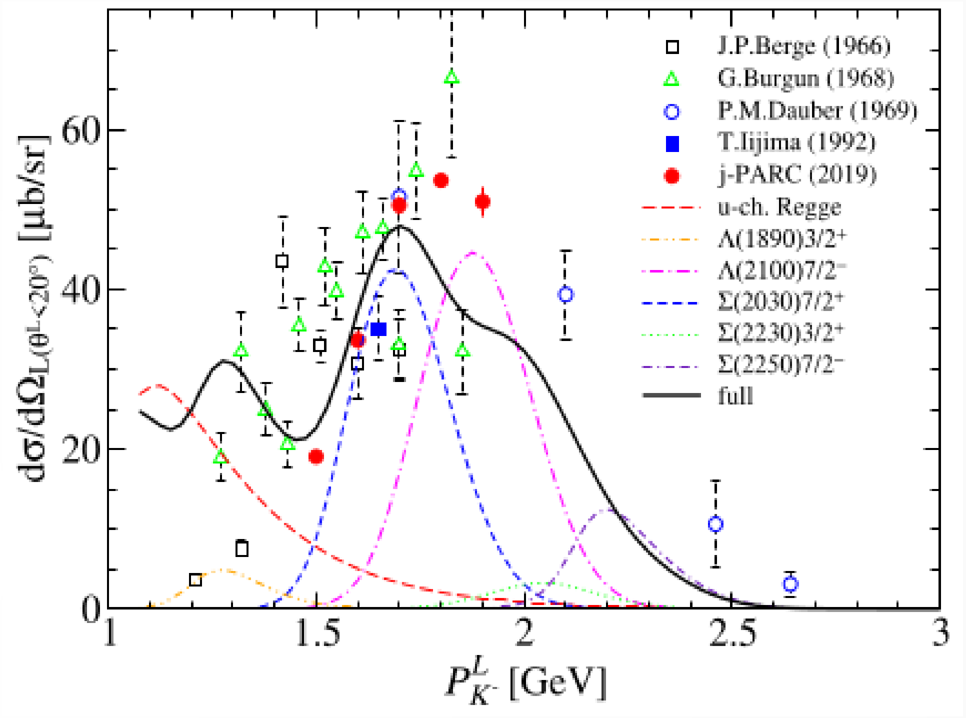
$K^- p \rightarrow K^+ \Xi^-$



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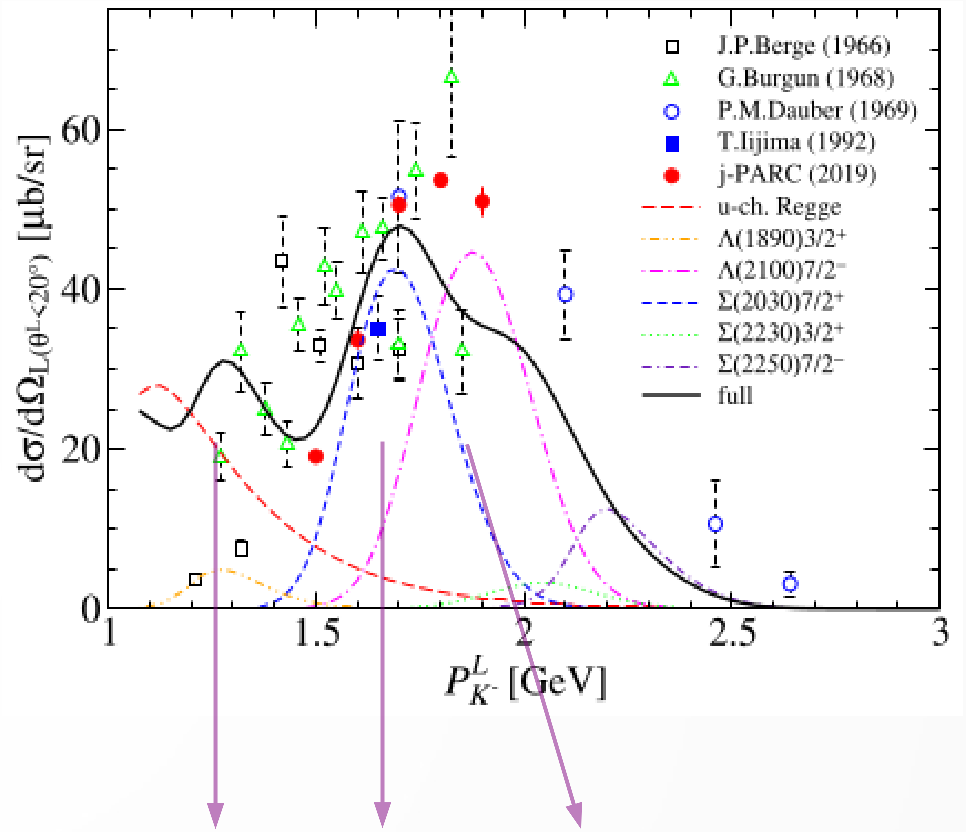
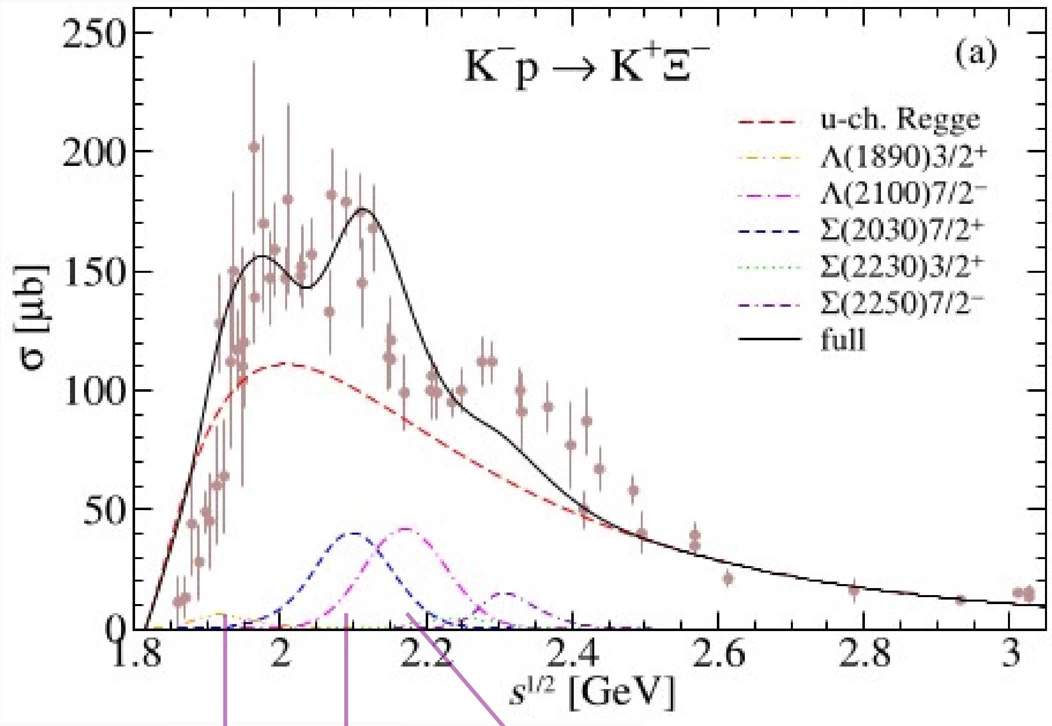
$K^- p \to K^+ \Xi^-$



$\Lambda(1890, 3/2^+)$ $\Sigma(2030, 7/2^+)$ $\Lambda(2100, 7/2^-)$

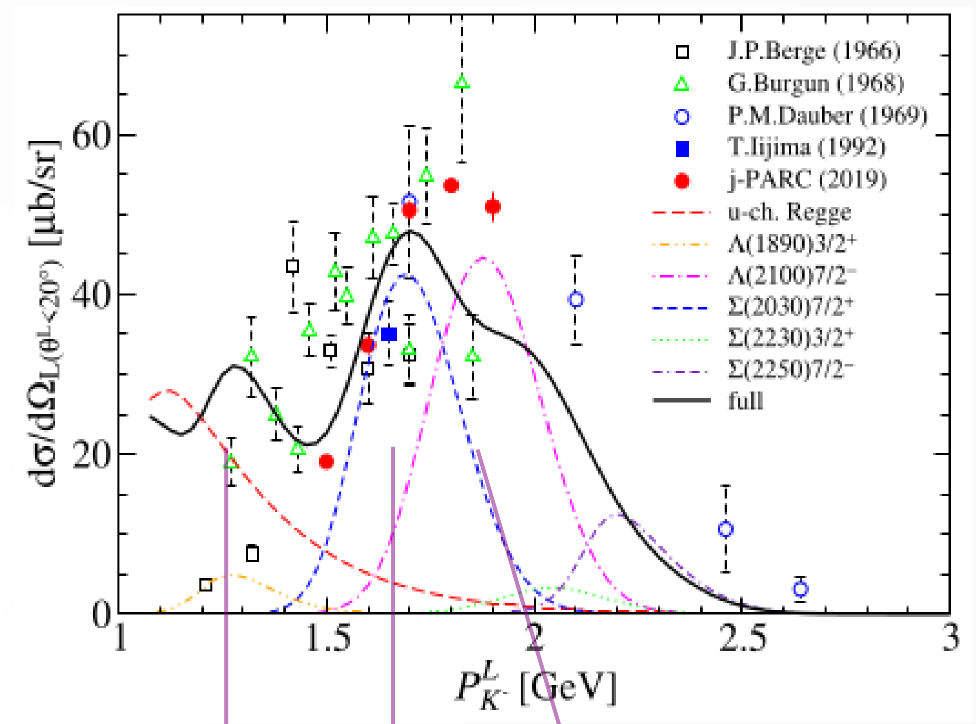
- The evidence of these three Y^* resonances looks very convincing.

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



$\Lambda(1890,3/2^+)$ $\Sigma(2030,7/2^+)$ $\Lambda(2100,7/2^-)$

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



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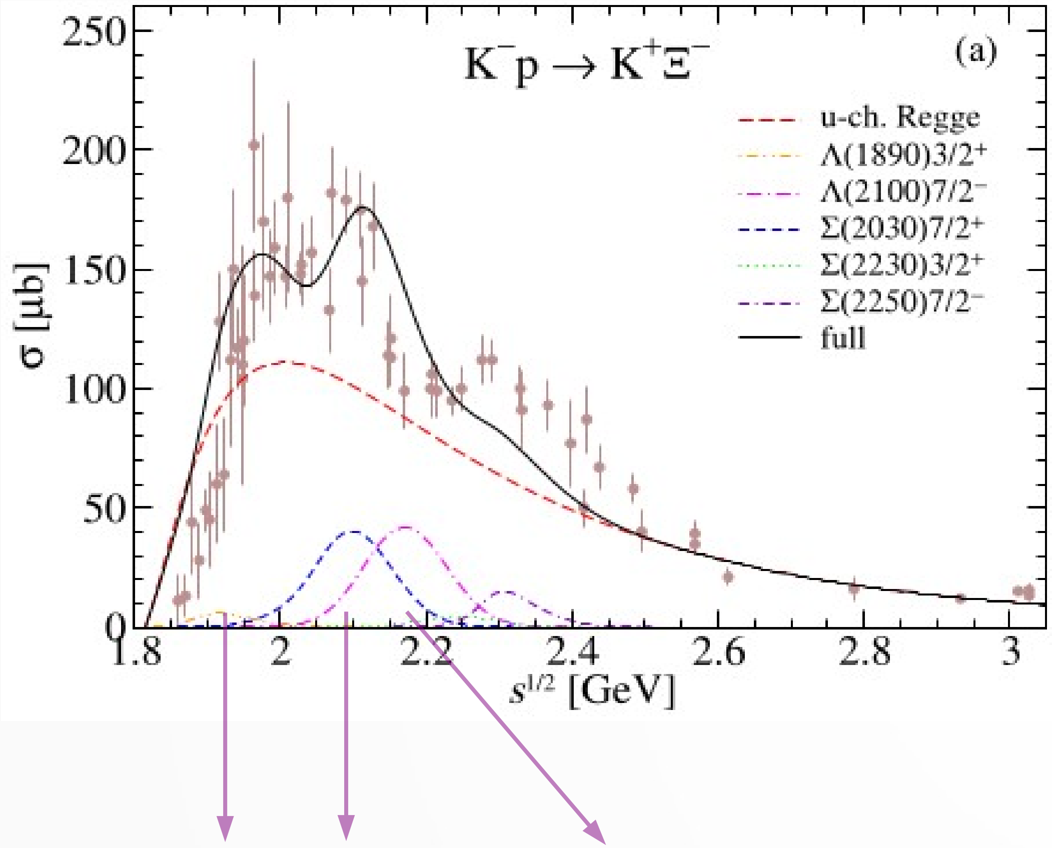
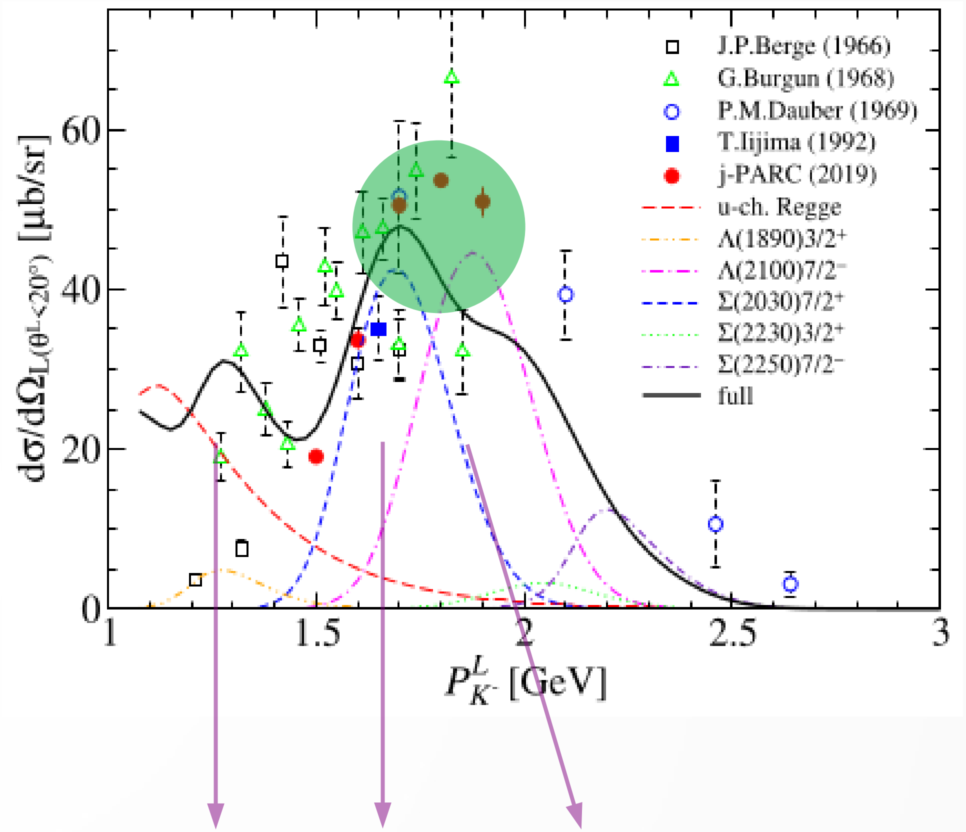


Λ(1890,3/2⁺) Σ(2030,7/2⁺) Λ(2100,7/2⁻)

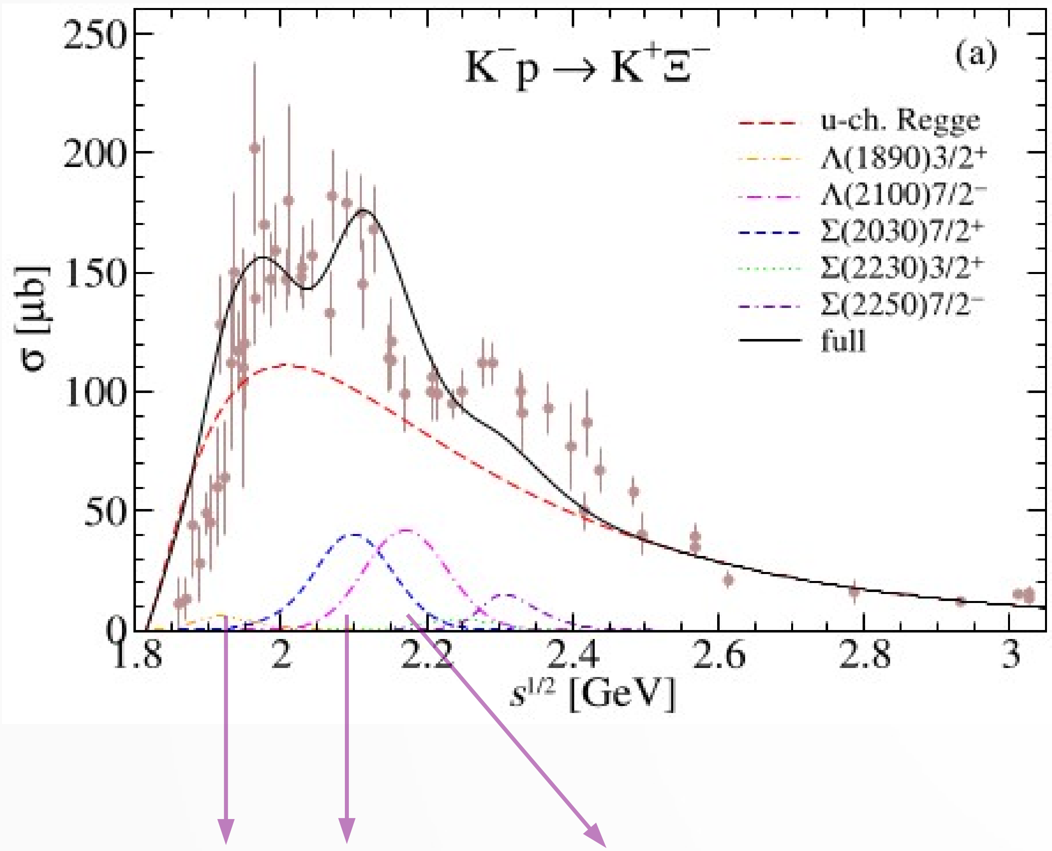
$K^- p \rightarrow K^+ \Xi^-$



Λ(1890,3/2⁺) Σ(2030,7/2⁺) Λ(2100,7/2⁻)

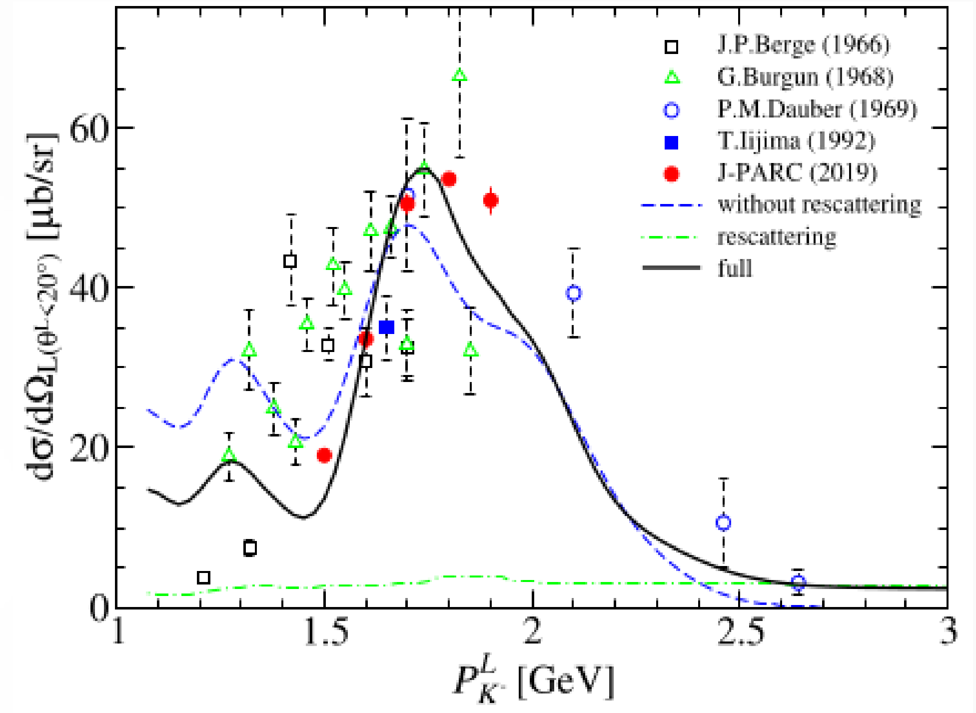
- The evidence of these three Y^* resonances looks very convincing.
- More data from the J-PARC E05 experiment are strongly called for.

3. numerical results



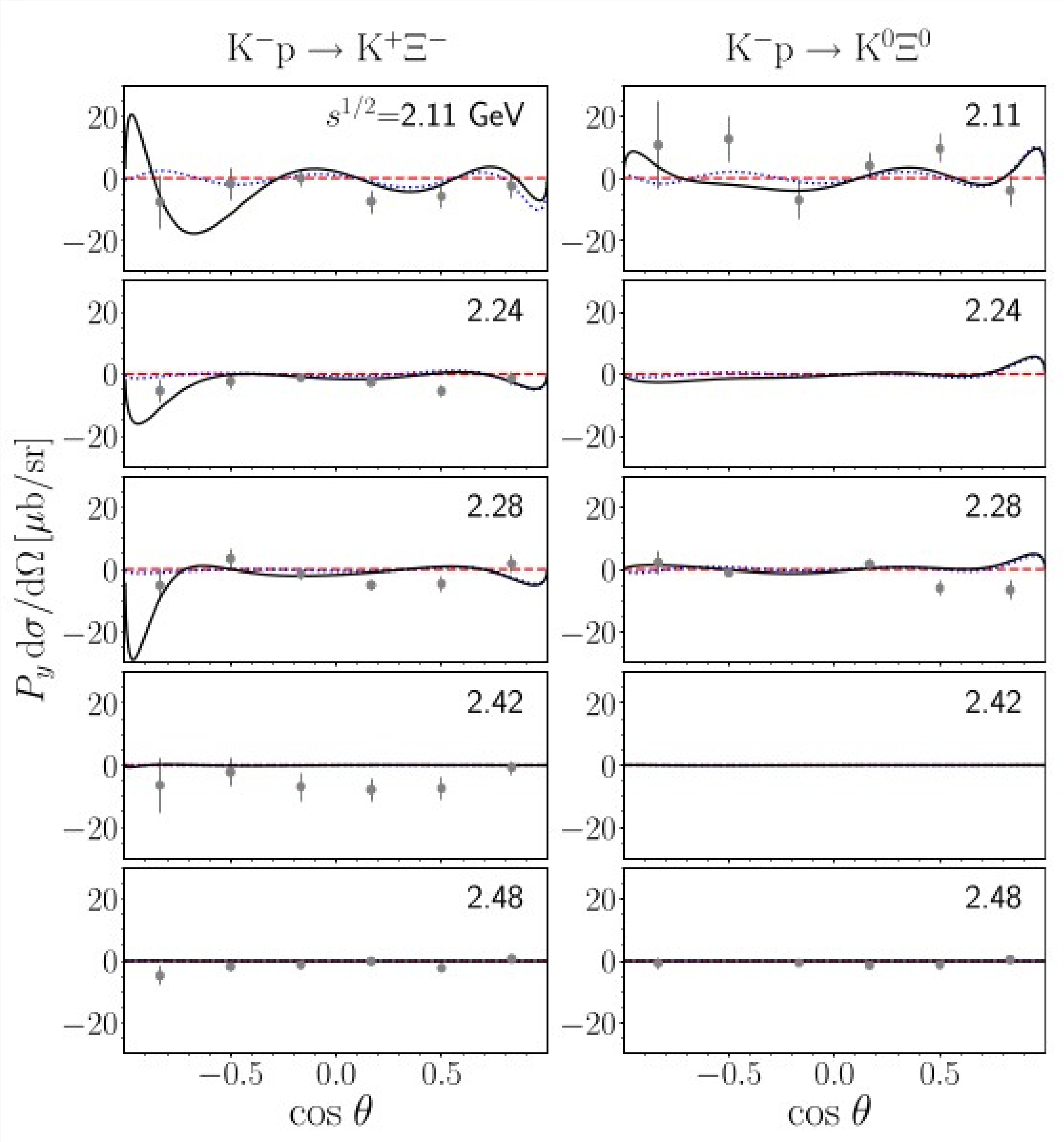
Λ(1890,3/2⁺) Σ(2030,7/2⁺) Λ(2100,7/2⁻)

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



❑ The inclusion of the rescattering diagrams improves the recent J-PARC data.

❑ Recoil asymmetries multiplied by differential cross sections



The backward angles are significantly affected by the inclusion of the s-channel (Λ^*, Σ^*) resonances for $K^- p \to K^+ \Xi^-$.

Changes in the forward angles were relatively mild in both channels.

By definition, Py = Ty.

Previous works

Sharov, EPJA.47.109 (2011)   Shyam, PRC.84.042201 (2011)

> Effective Lagrangian approach

Kamano, PRC.90.065204 (2014)

> Dynamical coupled-channel approach to $\overline{\mathrm{K}}$ induced reactions

Feijoo, PRC.92.015206 (2015)

> Coupled-channel unitarized chiral perturbation approach

Nakayama, PRC.85.042201 (2012)   Jackson, PRC.89.025206 (2014)

> Model independent aspects

Jackson, PRC.91.065208 (2015)

> Effective Lagrangian approach in which “the rescattering contribution” is accounted for by “a phenomenological contact amplitude”

Landay, PRD.99.016001 (2019)

> Least absolute shrinkage and selection operator (LASSO)

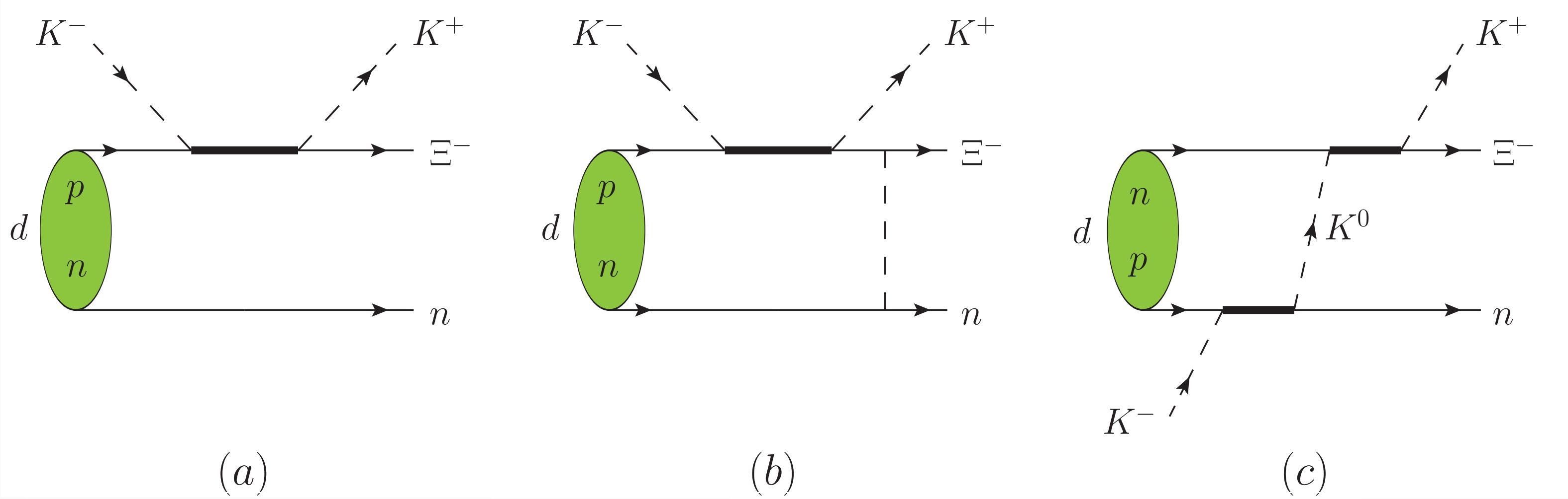
Matveev, EPJA 55.179 (2019)

> BnGa partial wave analysis

◇ K induced reactions off nucleon ⇨ K induced reactions off nuclei

$K^- p \rightarrow K^+ \Xi^-$ ⇨ $K^- d \rightarrow K^+ \Xi^- n$

plane- or distorted-wave impulse approximation



S.H.Kim,
T.-S.H. Lee,
in process

◇ K induced reactions off nucleon ⟹ K induced reactions off nuclei

$K^- p \rightarrow K^+ \Xi^-$ ⇨ $K^- d \rightarrow K^+ \Xi^- n$

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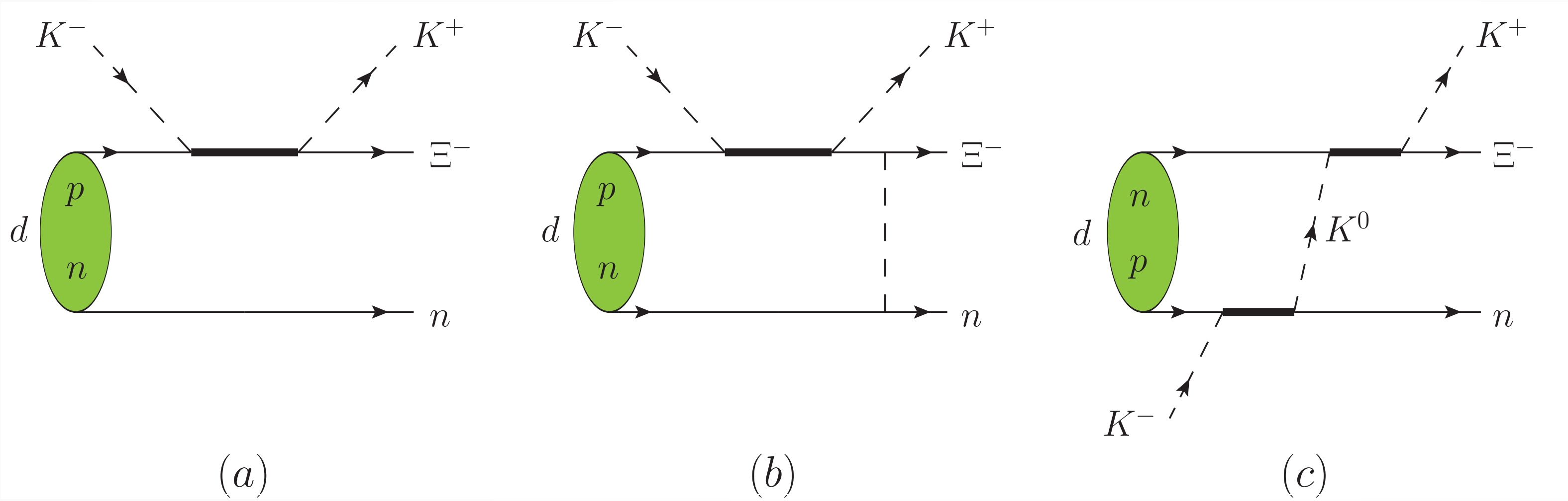

S.H.Kim, T.-S.H. Lee, in process

$$< \vec{k}_+, \vec{p}_y m_y, \vec{p}_n m_n | T^{res-yn}(E) | \vec{k}_- \Phi_{m_d m_{T_d}} >$$

$$= \sum_{m_{s_1}, m_{\tau_1}} \sum_{m_{s_2}, m_{\tau_2}} \sum_{m'_y} \int d\vec{p} \{ \Phi_{m_d m_{T_d}}(\vec{p}, m_{s_1}, m_{\tau_1}, m_{s_2}, m_{\tau_2}) < \vec{\kappa}, m_y m_n | t_{\Xi^- n, \Xi^- n}(W) | \vec{\kappa}', m'_y m_{s_2} >$$

$$\times \frac{1}{E - E_K(k_+) - E_y(\vec{p}_y') - E_N(-\vec{p}) + i\epsilon} < \vec{k}_+, \vec{p}_y' m'_y | t_{K^+\Xi^-, K^- p} | \vec{k}_-, \vec{p} m_{s_1} > \delta_{m_{\tau_1}, 1/2} \delta_{m_{\tau_2}, -1/2} \} \}$$

◇ K induced reactions off nucleon ⇨ K induced reactions off nuclei

$K^- p \rightarrow \pi \Sigma$ ⇨ $K^- d \rightarrow \pi \Sigma n$

Spectroscopic study of hyperon resonances below $\bar{K}N$ threshold via the (K^-,n) reaction on Deuteron

S. Ajimura, S. Enomoto, H. Noumi (*Spokesperson/Contact Person)
Research Center for Nuclear Physics (RCNP), Osaka University, Japan

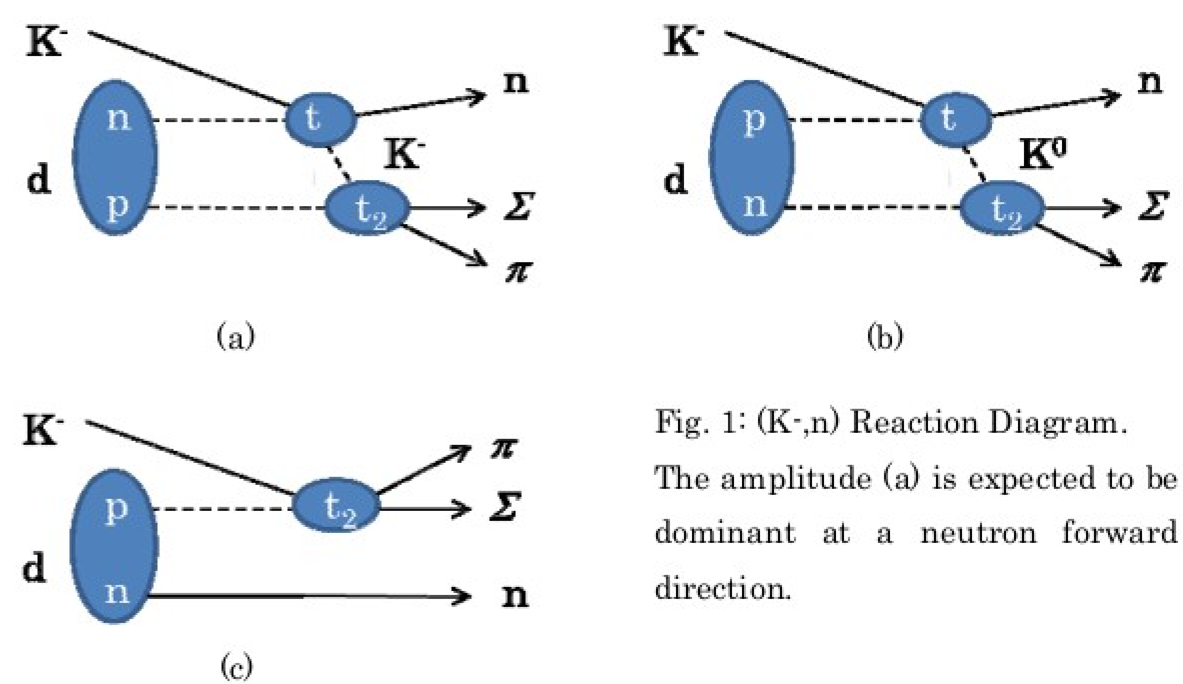

Fig. 1: (K^-,n) Reaction Diagram. The amplitude (a) is expected to be dominant at a neutron forward direction.

◇ π induced reactions off nucleon ⇨ π induced reactions off nuclei

$\pi^- p \rightarrow K^+ \Sigma^-$ ⇨ $\pi^- p \rightarrow K^+ (^{28}Si, ^{209}Bi, ^{6}Li, ...)\ X$

◇ K induced reactions off nucleon ⇨ K induced reactions off nuclei

$K^- p \rightarrow K^- p$ ⇨ $K^-\ ^{12}C \rightarrow K^-\ ^{12}C$

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

plane- or distorted-wave impulse approximation

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

◇ π induced reactions off nucleon ⇨ π induced reactions off nuclei

$\pi^- p \to K^+ \Sigma^-$ ⇨ $\pi^- p \to K^+ (^{28}Si, ^{209}Bi, ^{6}Li, \ldots)\ X$

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plane- or distorted-wave impulse approximation

> 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

[P95] Pion-induced phi-meson production on the proton, $(\pi^- p \to \varphi n)$

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

[LoI] Ξ Baryon Spectroscopy High-momentum Secondary Beam

5. Summary

◇ Multistrangeness production, $K^- p \rightarrow K \Xi$, is investigated in a hybridized Regge model for two different isospin channels ($K^- p \rightarrow K^+ \Xi^-$ & $K^0 \Xi^0$).

◇ As for a background contribution, (Λ & Σ & $\Sigma^*(1385)$) 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 $K^- p \rightarrow K^0 \Xi^0$, only ($\Sigma$ & $\Sigma^*(1385)$) Regge trajectories are possible and their relative contributions are well constrained.

◇ For $K^- p \rightarrow K^+ \Xi^-$, Λ Regge trajectory is more dominant than (Σ & $\Sigma^*(1385)$) ones.

◇ $\Lambda(1890, 3/2^+)$, $\Sigma(2030, 7/2^+)$, and $\Lambda(2100, 7/2^-)$ play a crucial role in explaining the bump structures.

◇ The rescattering diagrams are essential to improve the recent J-PARC data.

5. Summary

◇ This study is the first step toward developing reasonable reaction theories of meson-induced reactions.

The extension of our hybrid model to other π- or K-induced reactions is essential for understanding the relevant reaction mechanisms more systematically, and will significantly contribute to the development of baryon spectroscopy;

Relevant research is currently in progress.

5. Summary

◇ This study is the first step toward developing reasonable reaction theories of meson-induced reactions.

The extension of our hybrid model to other π- or K-induced reactions is essential for understanding the relevant reaction mechanisms more systematically, and will significantly contribute to the development of baryon spectroscopy;

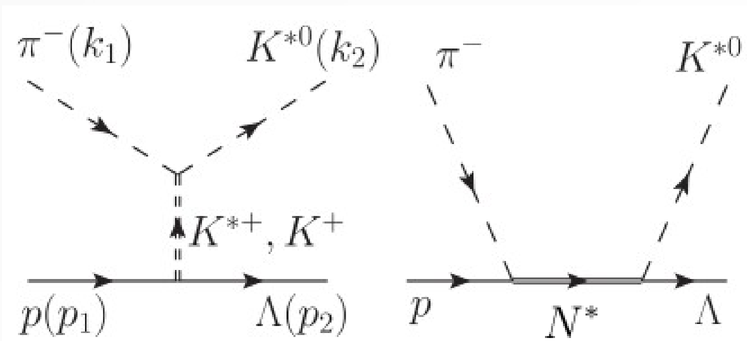
Relevant research is currently in progress.

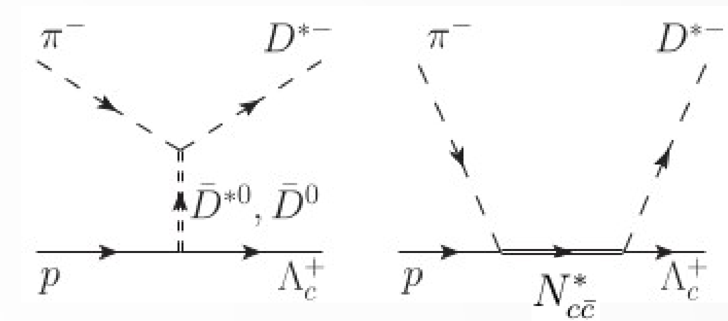
Thank you very much for your attention

Back Up

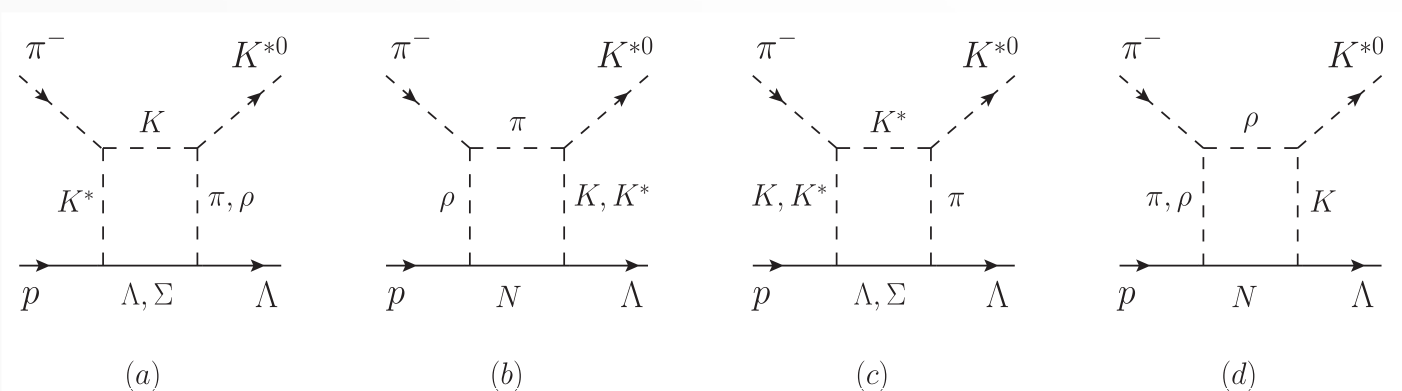
(a) “open” strange (charm) production

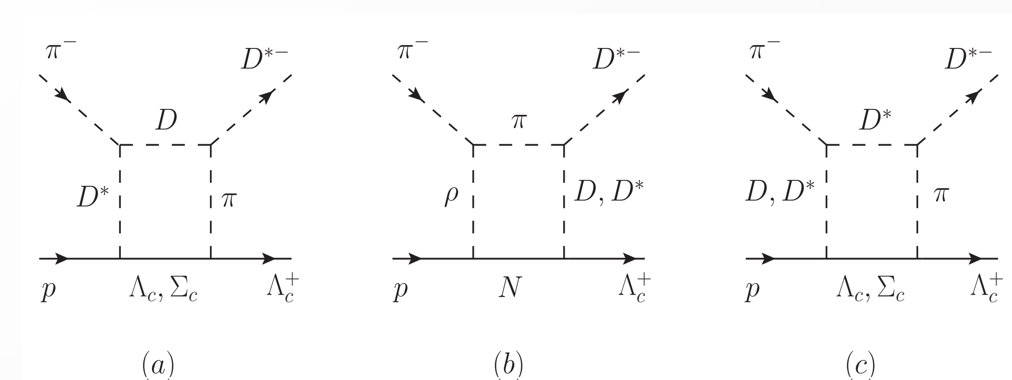
$\pi^- p \to K^{*0} \Lambda$ [Regge + Resonance] $\pi^- p \to D^{*-} \Lambda_c^+$





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



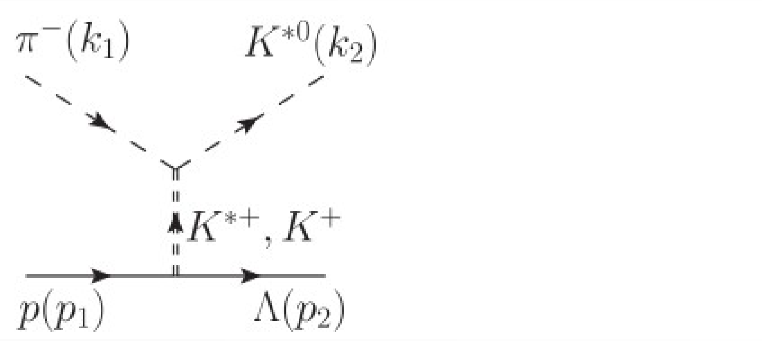


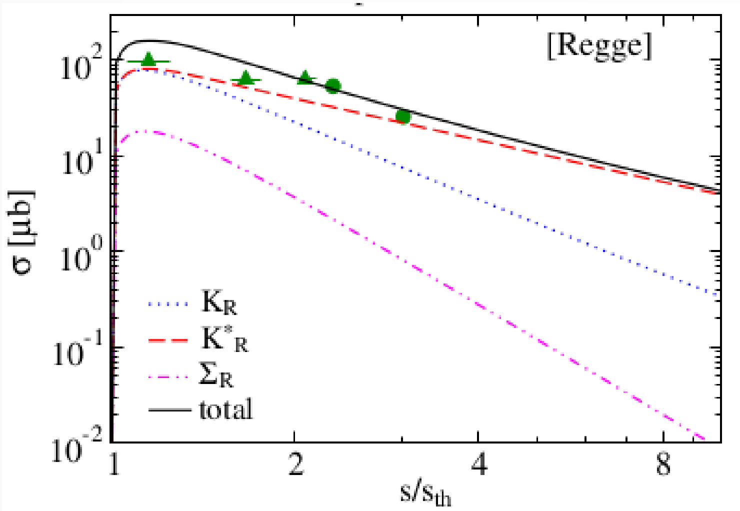
- Use the dominant decay process: $K^* \to K\pi$, $\rho \to \pi\pi$ $D^* \to D\pi$, $\rho \to \pi\pi$

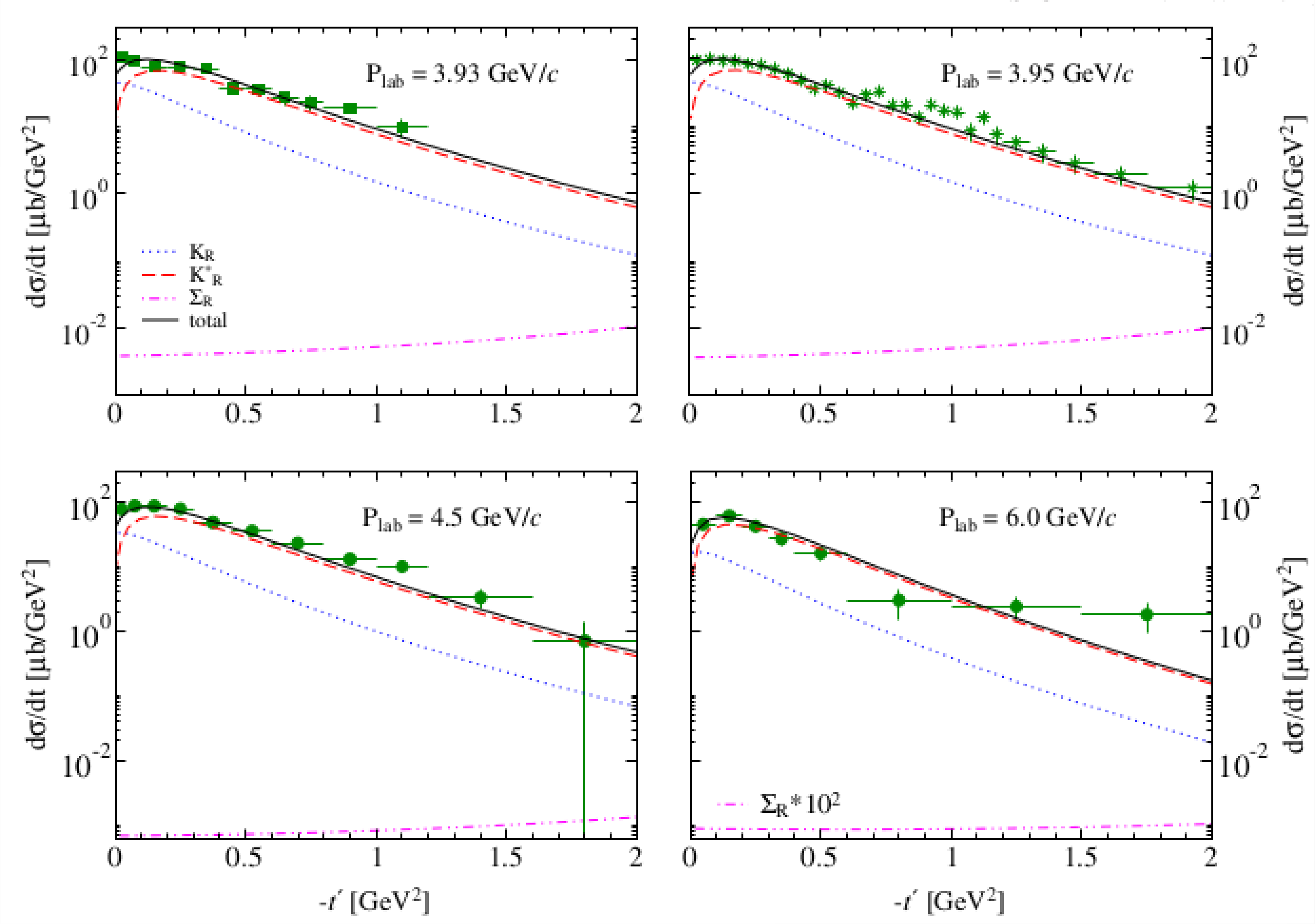
(a) “open” strange production

S.H.Kim,
PRD.92.094021 (2015)

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



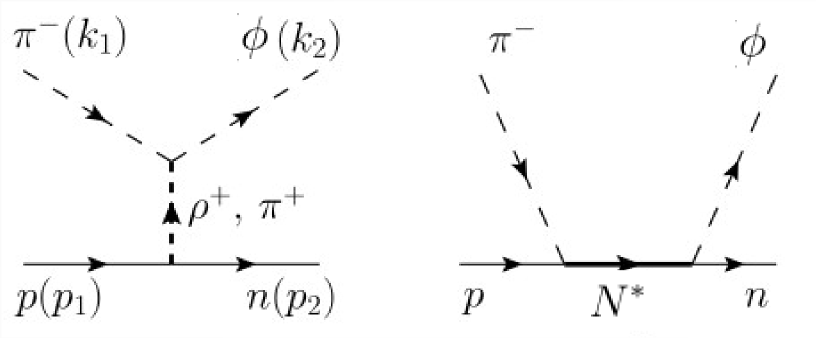




> K exchange governs dσ/dt near $-t' \approx 0$, whereas K^* exchange becomes dominant as $-t'$ increases.

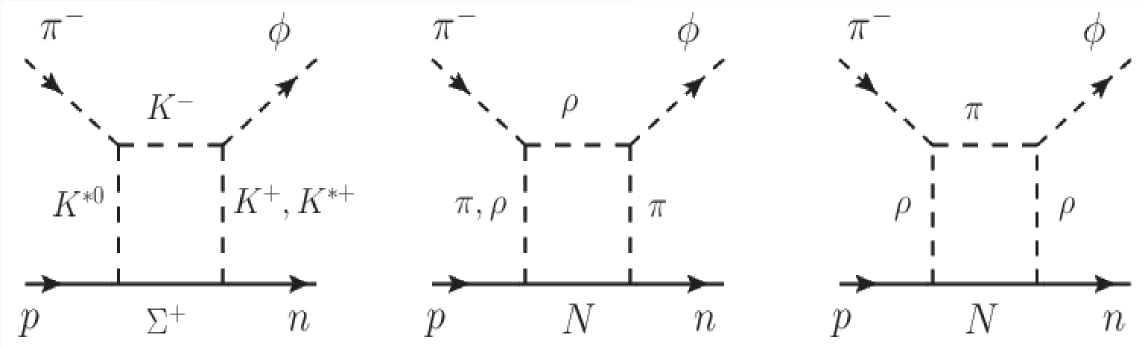
(b) "hidden" strange production

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



P_s^0[uddss̄]

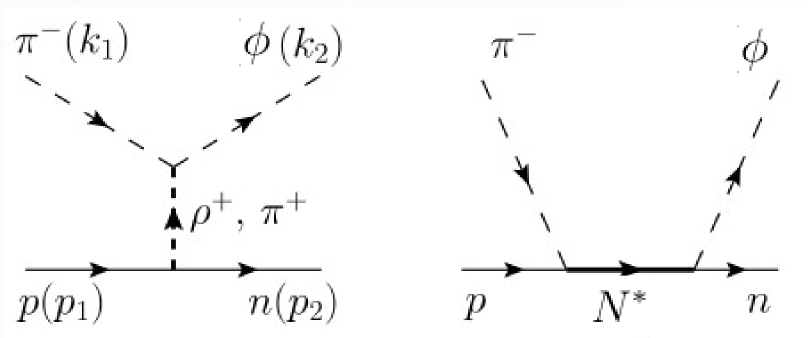
$\pi^- p \to M_i B_i \to \varphi n$ [Rescattering]



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

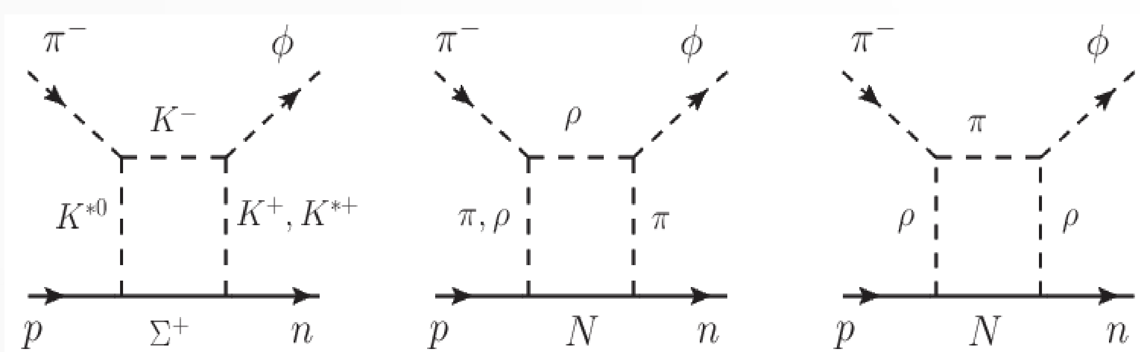
(b) "hidden" strange production

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



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

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



[P95: T.Ishikawa, Proposal submitted using the J-PARC E16 spectrometer (2022)]

Proposal for the J-PARC 30-GeV Proton Synchrotron

Pion-induced phi-meson production on the proton (addendum)

Takatsugu Ishikawa,[*] Atsushi Hosaka, Tomoaki Hotta, Hiroyuki Noumi, Sun Young Ryu, Kotaro Shirotori, and Yorihito Sugaya

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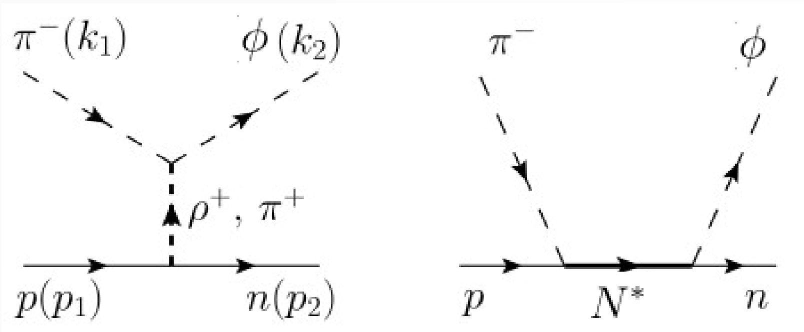
Asia Pacific Center for Theoretical Physics (APCTP), Pohang 37673, Korea

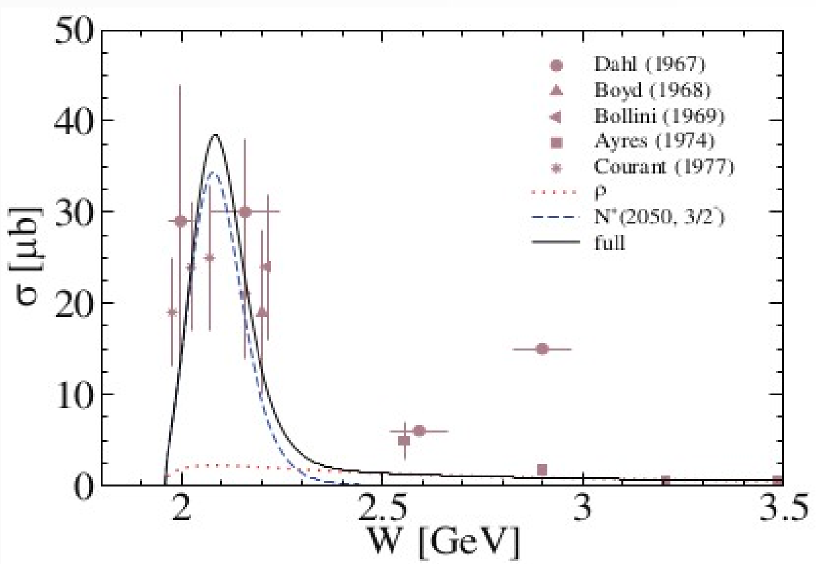
- Use the dominant decay process: $\varphi \rightarrow K^+K^-, \rho\pi$, $K^* \rightarrow K\pi$, $\rho \rightarrow \pi\pi$

(b) "hidden" strange production

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

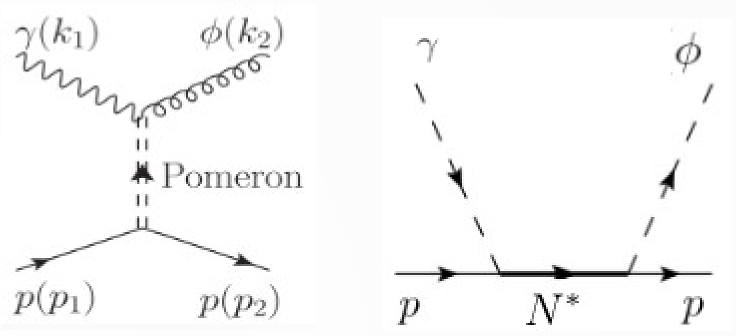


$P_s^0[udds\bar{s}]$

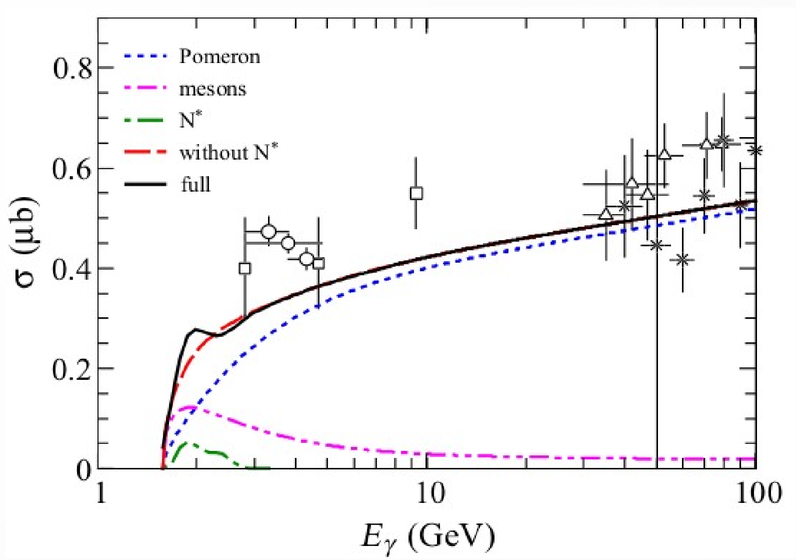


[T.Ishikawa, Proposal submitted using the J-PARC E16 spectrometer (2022)]

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



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



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

□ The contribution from the impulse term for spin J=0 nuclei:

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

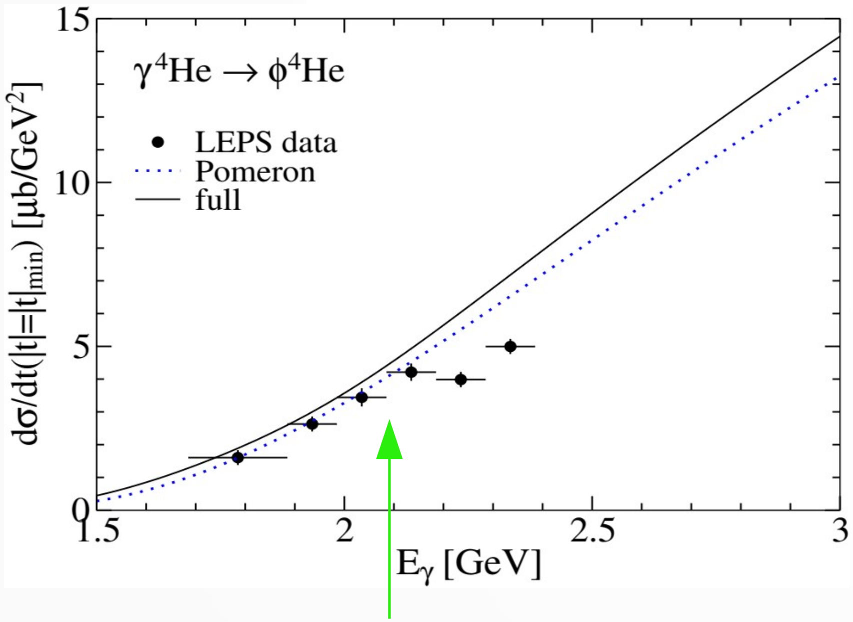
$$\frac{d\sigma^{\mathrm{IMP}}}{d\Omega_{\mathrm{Lab}}} = \frac{(2\pi)^4 |\mathbf{k}|^2 E_V(\mathbf{k}) E_A(\mathbf{q}-\mathbf{k})}{|E_A(\mathbf{q}-\mathbf{k})|\mathbf{k}| + E_V(\mathbf{k})(|\mathbf{k}| - |\mathbf{q}|\cos\theta_{\mathrm{Lab}})|} |A F_T(t)\bar{t}(\mathbf{k},\mathbf{q})|^2$$

$$F_c(q^2) = F_N(q^2) F_T(q^2 = t)$$

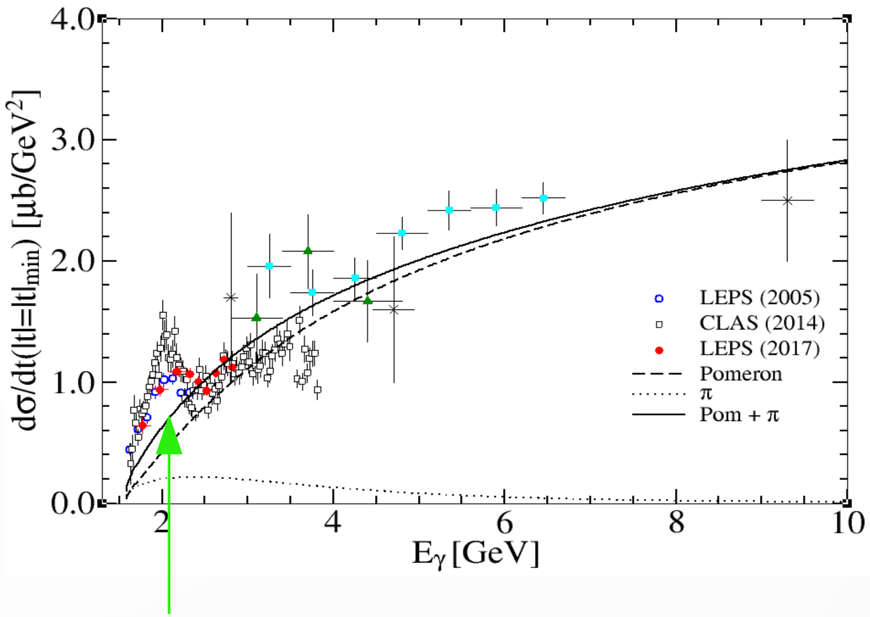
F_c (F_N) :
nuclear (nucleon) charge FF

$\gamma\ {}^4\mathrm{He} \to \varphi\ {}^4\mathrm{He}$ $\gamma\ p \to \varphi\ p$

$\gamma\ {}^4\mathrm{He} \to \varphi\ {}^4\mathrm{He}$



$\gamma\ p \to \varphi\ p$



□ The peak position is similar to each other. Any relation between them?

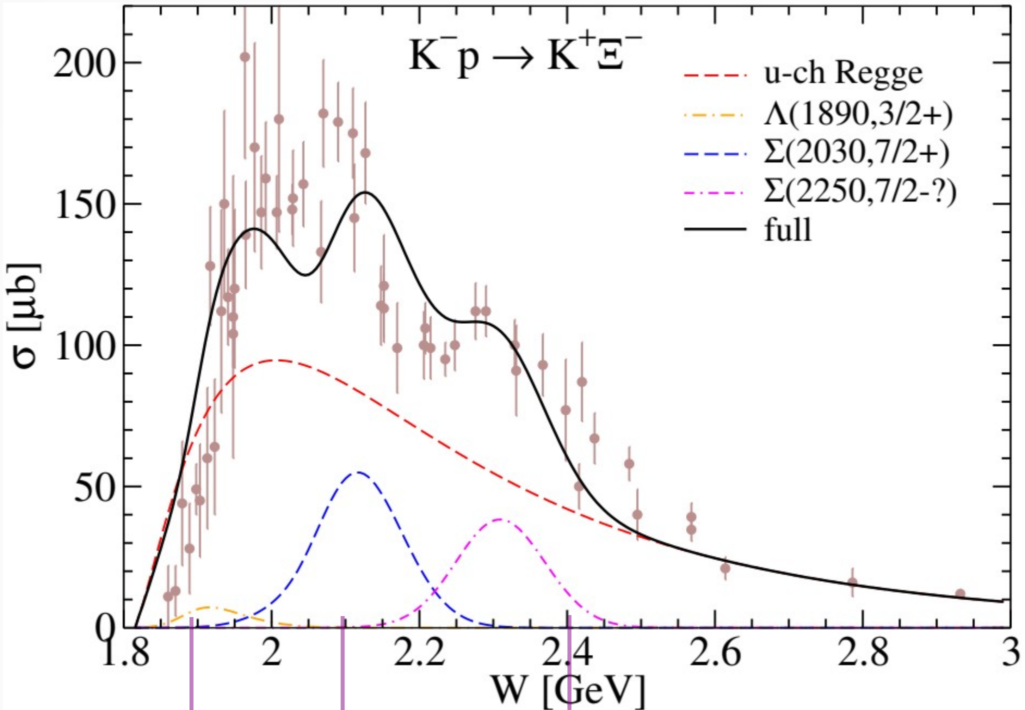
1. Introduction

□ Our purpose is to extend the Regge plus Resonance (R + R) model
to the meson-induced reactions off nucleon targets.
[e.g., $\pi^- p \to K^{*0} \Lambda$ ($D^{*-} \Lambda_c^+$), φn ($J/\psi\, n$), ...]

□ Additionally, the Rescattering effects are considered from
the 3-dimensional reduction of the Bethe-Salpeter equation.

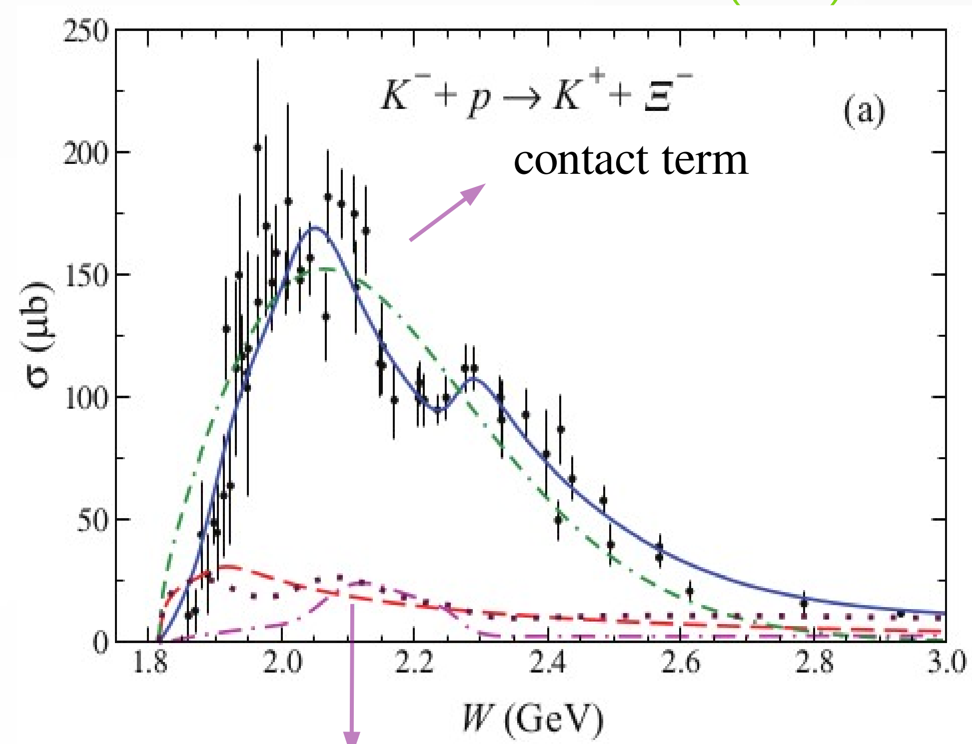
⇨ We employ the Regge plus Resonance plus Rescattering effect (R + R + R) model
to the $K^- p \to K \Xi$ reaction.

Comparison with other works



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

Jackson et al. PRC.91.065208 (2015)



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”.

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

	Λ(1890)	Λ(2100)	Σ(2030)	Σ(2230)	Σ(2250)
g_{KNY^*}	0.84	2.41	0.82	0.41	0.59
$g_{K\Xi Y^*}$	−0.26	2.95	−0.93	0.34	0.88
$\mathcal{B}(Y^* \to K\Xi)[\%]$	0.23	0.73	0.88	2.0	1.0