K^-p reactions and hyperon spectroscopes

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Outline:

1. Hyperon spectroscopy

2. Kp reactions in the chiral quark model

3. The role of hyperon resonances in the reaction

4. Summary

1. Hyperon Spectroscopy

Λ* in RPP

Four-star resonances

Λ(1116)1/2+,Λ(1405)1/2-,Λ(1520)3/2- ,
Λ(1670)1/2-,Λ(1690)3/2-, Λ(1820)5/2+,
Λ(1830)5/2-, Λ(1890)3/2+, Λ(2100)7/2-

Three-star resonances

Λ(1600)1/2+, Λ(1800)1/2-, Λ(1810)1/2+,
Λ(2110)5/2+, Λ(2350)?

Two-star resonances

Λ(2585)??,

One-star resonances

Λ(2000)?, Λ(2020)7/2+, Λ(2325)3/2-

Σ^* in RPP

Four-star:

Σ(1193)1/2+, Σ(1385)3/2+, Σ(1670)3/2-, Σ(1775)5/2-, Σ(1915)5/2+, Σ(2030)7/2+

Three-star:

Σ(1660)1/2+, Σ(1750)1/2-, Σ(1940)3/2-, Σ(2250)??,

Two-star:

Σ(1560)??, Σ(1620)1/2-, Σ(1690)??, Σ(1880)1/2+, Σ(2080)3/2+, Σ(2455)??, Σ(2620)??,

One-star :

Σ(1480)??, Σ(1580)3/2-, Σ(1770)1/2+, Σ(1840)3/2+, Σ(2000)1/2-, Σ(2070)5/2+, Σ(2100)7/2-, Σ(3000)??, Σ(3170)??

Ξ^* in RPP

Four-star :

$\Xi(1318)1/2+$, $\Xi(1530)3/2+$

Three-star

$\Xi(1690)?$, $\Xi(1820)3/2-$, $\Xi(1950)?$, $\Xi(2030)?$

Two-star

$\Xi(2250)?$, $\Xi(2370)?$

One-star

$\Xi(1620)?$, $\Xi(2120)?$, $\Xi(2500)?$

- Knowledge about hyperon resonances is still very poor!
- Data from the old experiments of 1970-1990.
- Many states are not well-established!

Λ^*, Σ^* states in the q^3 quark model

$[N_6, {}^{2S+1}N_3, n, \mathrm{L}]$	$l_{I,2J}$	$l_{I,2J}$
$[56, {}^2 8, 0, 0]$ $[56, {}^4 10, 0, 0]$	$P_{01}(1116)$	$P_{11}(1193)$ $P_{13}(1385)$
$[70, {}^2 1, 1, 1]$	$S_{01}(1405)$ $D_{03}(1520)$	
$[70, {}^2 10, 1, 1]$		$S_{11}(?)$ $D_{13}(?)$
$[70, {}^2 8, 1, 1]$	$S_{01}(1670)$ $D_{03}(1690)$	$S_{11}(?)$ $D_{13}(1670)$
$[70, {}^4 8, 1, 1]$	$S_{01}(1800)$ $D_{03}(?)$ $D_{05}(1830)$	$S_{11}(?)$ $D_{13}(?)$ $D_{15}(1775)$
$[56, {}^2 8, 2, 0]$	$P_{01}(1600)$	$P_{11}(1660)$
$[56, {}^2 8, 2, 2]$	$P_{03}(?)$ $F_{05}(?)$	$P_{13}(?)$ $F_{15}(?)$
$[56, {}^4 10, 2, 0]$		$P_{13}(?)$

$[56, {}^4 10, 2, 2]$		$P_{11}(?)$ $P_{13}(?)$ $F_{15}(?)$ $F_{17}(?)$
$[70, {}^2 1, 2, 0]$	$P_{01}(1810?)$	
$[70, {}^2 1, 2, 2]$	$P_{03}(?)$ $F_{05}(?)$	
$[70, {}^2 10, 2, 0]$		$P_{11}(?)$
$[70, {}^2 10, 2, 2]$		$P_{13}(?)$ $F_{15}(?)$
$[70, {}^2 8, 2, 0]$	$P_{01}(?)$	$P_{11}(?)$
$[70, {}^2 8, 2, 2]$	$P_{03}(?)$ $F_{05}(?)$	$P_{13}(?)$ $F_{15}(?)$
$[70, {}^4 8, 2, 0]$	$P_{03}(?)$	$P_{13}(?)$
$[70, {}^4 8, 2, 2]$	$P_{01}(?)$ $P_{03}(?)$ $F_{05}(?)$ $F_{07}(?)$	$P_{11}(?)$ $P_{13}(?)$ $F_{15}(?)$ $F_{17}(?)$

Only a few low-lying states predicted from quark model are found, many of them are missing.

Even the S and D wave Σ^* states are not established!!

Other explanations

- Dynamically generated states:
  Λ(1405,1670)1/2-, Λ(1520)3/2-, Σ(1475),……

  Kaiser, Weise, Oset, Ramos, Oller, Meissner, Hyodo, Jido, Oh……

- multi-quark states:
  Λ(1405)1/2- ,……

  B.S. Zou ……

A review of the hadron Spectroscopy can be seen in the recent report of B. S. Zou.

More theoretical and experimental studies on the hyperons are needed!

2. Kp reactions in the chiral quark model

Λ^*, Σ^* states contribute to the reactions

Nearly all the Λ^*, Σ^* states in RPP are derived from the KN scatterings !!

Models

Chiral quark model Xian-Hui Zhong, Qiang Zhao, Jun He

Chiral Perturbation theory

Kaiser, Weise, Oset, Ramos, Oller, Meissner, Hyodo, Jido, Guo……

K-matrix model A. D. Martin, N. M. Queen, Manley, ……

meson exchange model Buttgen, K. Holinde

Dispersion relations P. M. Gensini, R. Hurtado and G. Violini,

Effective Lagrangian models

B.S. Zou, B.C. Liu, J.J. Xie ……

Recent Partial wave ananlysis

Kent group H. Zhang, J. Tulpan, M. Shrestha, and D. M. Manley, PRC88(13) 035204;035205

Five new states:

Λ(1710)1/2+, Λ(2050)3/2-, Σ(1940)1/2-,
Σ (1730)3/2+, Σ(1940)3/2+,

No evidence of two three-star states:

Σ(1660)1/2+, Σ(1940)3/2-,

Recent Partial wave ananlysis

ANL-Osaka group

H. Kamano, S. X. Nakamura, T.-S. H. Lee, and T. Sato, PRC90(14)065204; PRC92(15)025205

8 states in PDG are confirmed:

Λ(1670)1/2-,Λ(1600)1/2+, Λ(1520)3/2-, Λ(1690)3/2-, Λ(1820)5/2+,

Σ(1670)3/2-,Σ(1775)5/2-, Σ(2030)7/2+

1 exotic state:

Λ(1671)3/2+ with a narrow width of 5 MeV

The chiral quark model

Tree diagrams considered in this work.

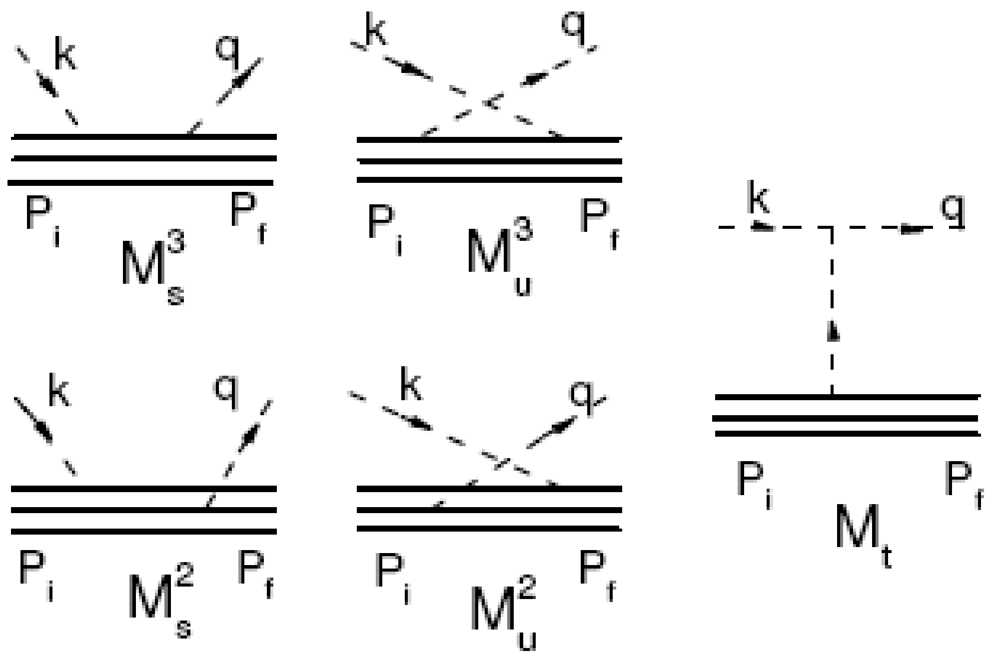


FIG. 1: s, u and t channels are considered in this work. M_s^3 and M_u^3 (M_s^2, M_u^2) correspond to the amplitudes of s and u channels for the incoming and outgoing mesons absorbed and emitted by the same quark (different quarks), respectively.

The effective quark-meson interactions and the s and u channel amplitudes.

$$\mathcal{M}_s = \sum_j \langle N_f | H_m^f | N_j \rangle \langle N_j | \frac{1}{E_i + \omega_i - E_j} H_m^i | N_i \rangle, \qquad (2)$$

$$\mathcal{M}_u = \sum_j \langle N_f | H_m^i \frac{1}{E_i - \omega_f - E_j} | N_j \rangle \langle N_j | H_m^f | N_i \rangle, \qquad (3)$$

where H_m^i and H_m^f stand for the incoming and outgoing meson-quark couplings, which could be described by the effective chiral Lagrangian [86, 87]

$$H_m = \frac{1}{f_m} \bar{\psi}_j \gamma_\mu^j \gamma_5^j \psi_j \vec{\tau} \cdot \partial^\mu \vec{\phi}_m, \qquad (4)$$

Partial Wave amplitudes of the low-lying resonances

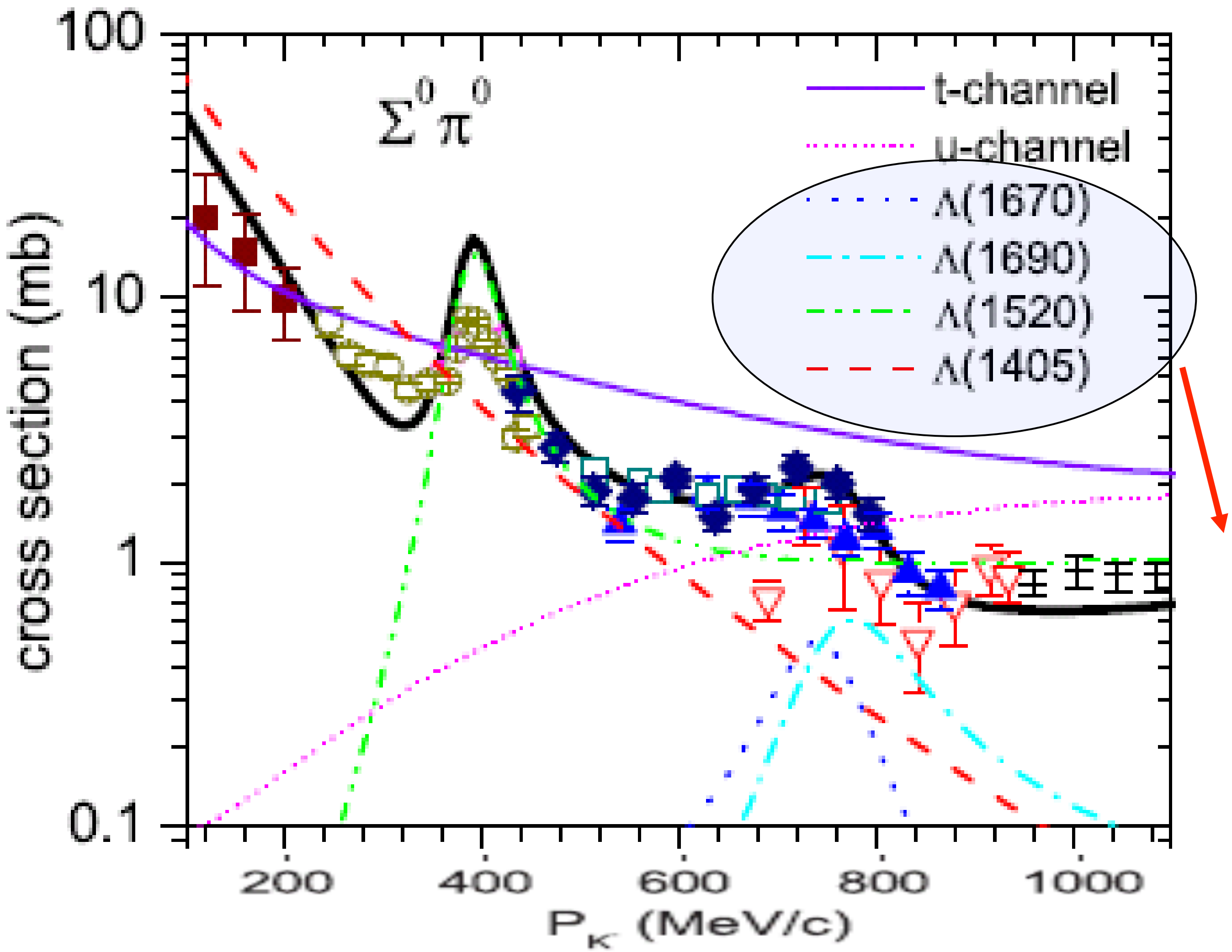
$$\mathcal{O}_0(P) = (g_{s1} + g_{s2})\mathbf{A}_{\text{out}} \cdot \mathbf{A}_{\text{in}} + (g_{v1} + g_{v2}) i\boldsymbol{\sigma} \cdot (\mathbf{A}_{\text{out}} \times \mathbf{A}_{\text{in}}), \quad (39)$$

$$\mathcal{O}_1(S) = \left(g_{s1} - \frac{1}{2}g_{s2}\right)\left(|\mathbf{A}_{\text{out}}| \cdot |\mathbf{A}_{\text{in}}|\frac{|\mathbf{k}||\mathbf{q}|}{9\alpha^2} + \frac{\omega_i}{6\mu_q}\mathbf{A}_{\text{out}} \cdot \mathbf{q} + \frac{\omega_f}{6\mu_q}\mathbf{A}_{\text{in}} \cdot \mathbf{k} + \frac{\omega_i \omega_f}{4\mu_q \mu_q}\alpha^2\right), \quad (40)$$

$$\mathcal{O}_1(D) = \left(g_{s1} - \frac{1}{2}g_{s2}\right)|\mathbf{A}_{\text{out}}| \cdot |\mathbf{A}_{\text{in}}|(3\cos^2\theta - 1)\frac{|\mathbf{k}||\mathbf{q}|}{9\alpha^2} + \left(g_{v1} - \frac{1}{2}g_{v2}\right) i\boldsymbol{\sigma} \cdot (\mathbf{A}_{\text{out}} \times \mathbf{A}_{\text{in}})\frac{\mathbf{k} \cdot \mathbf{q}}{3\alpha^2}, \quad (41)$$

3. The role of hyperon resonances in the reaction

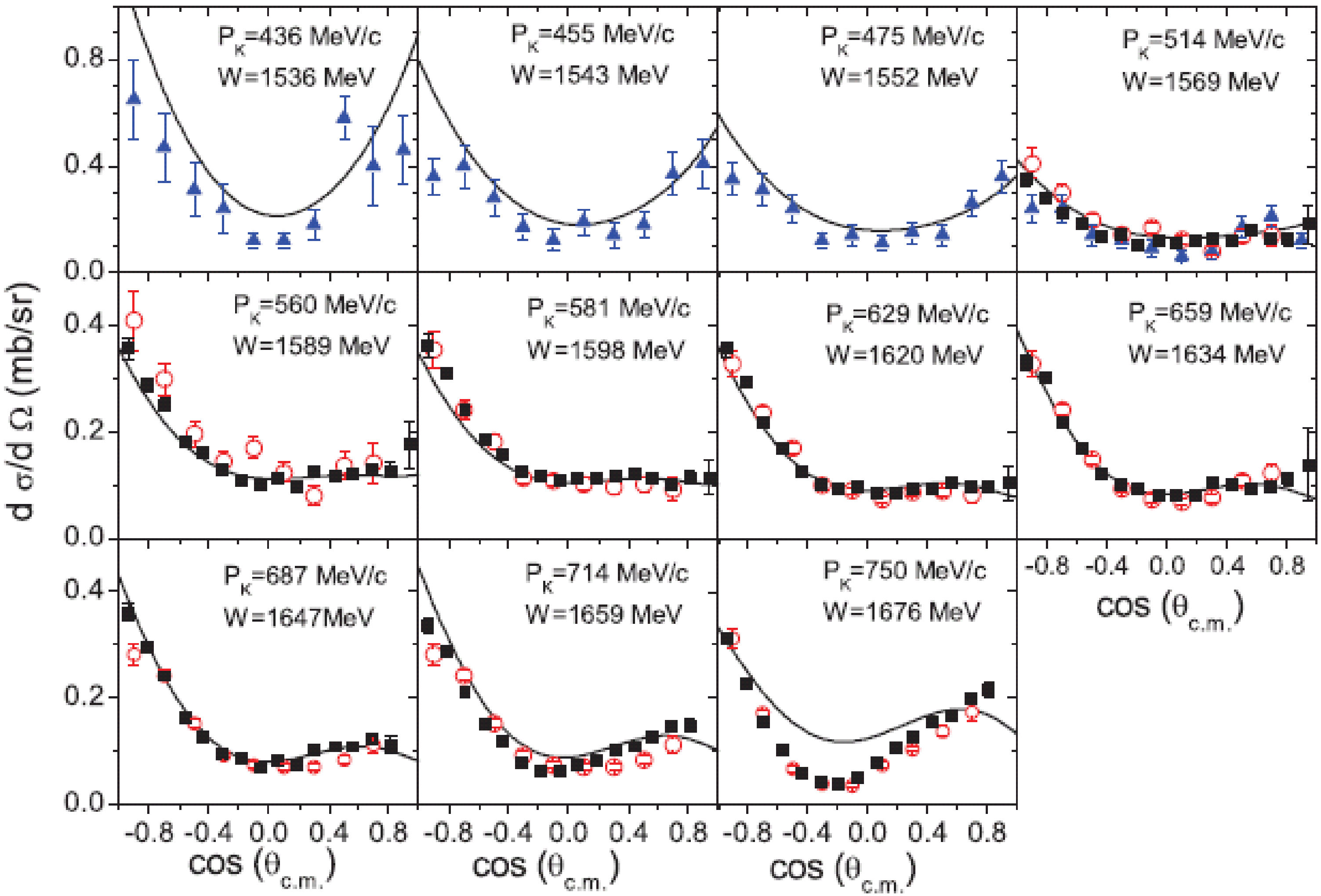
A. Roles of Λ* states in the $K^-p \to \Sigma^0\pi^0$



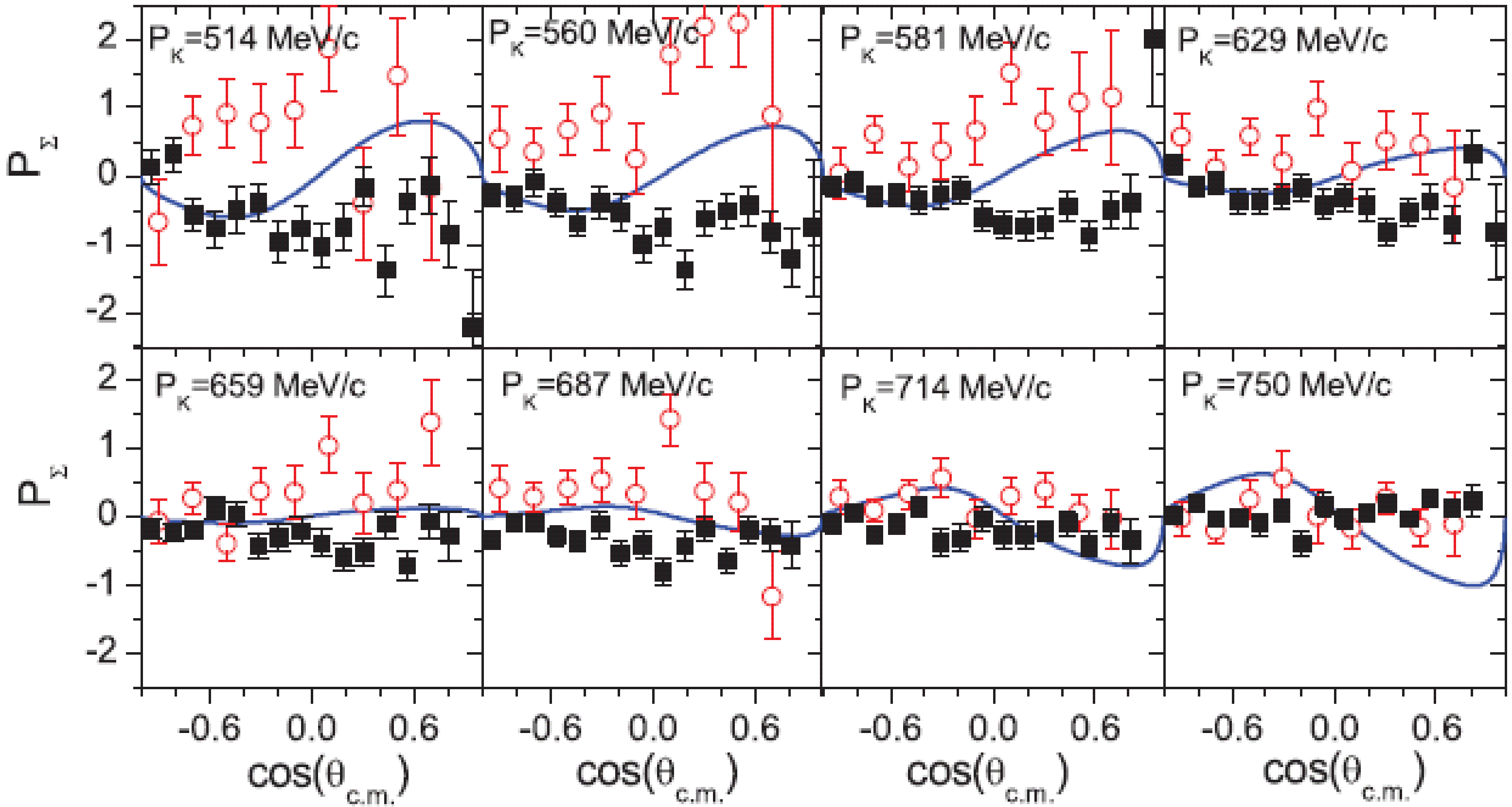
Obvious roles of the negative parity states: Λ(1405), Λ(1670), Λ(1520), Λ(1690), are found.

Backgrounds are also important!

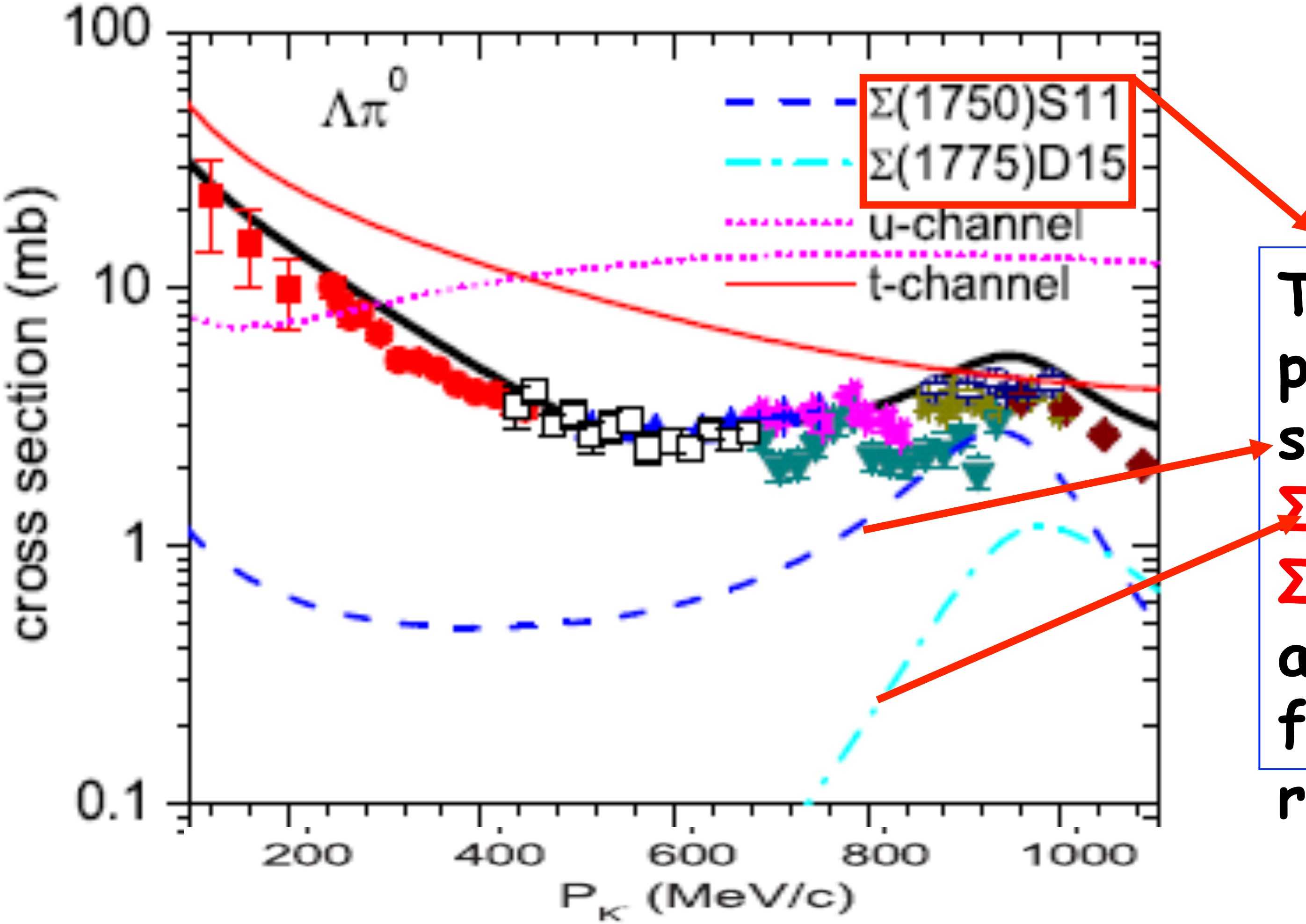
Differential cross section



Polarization



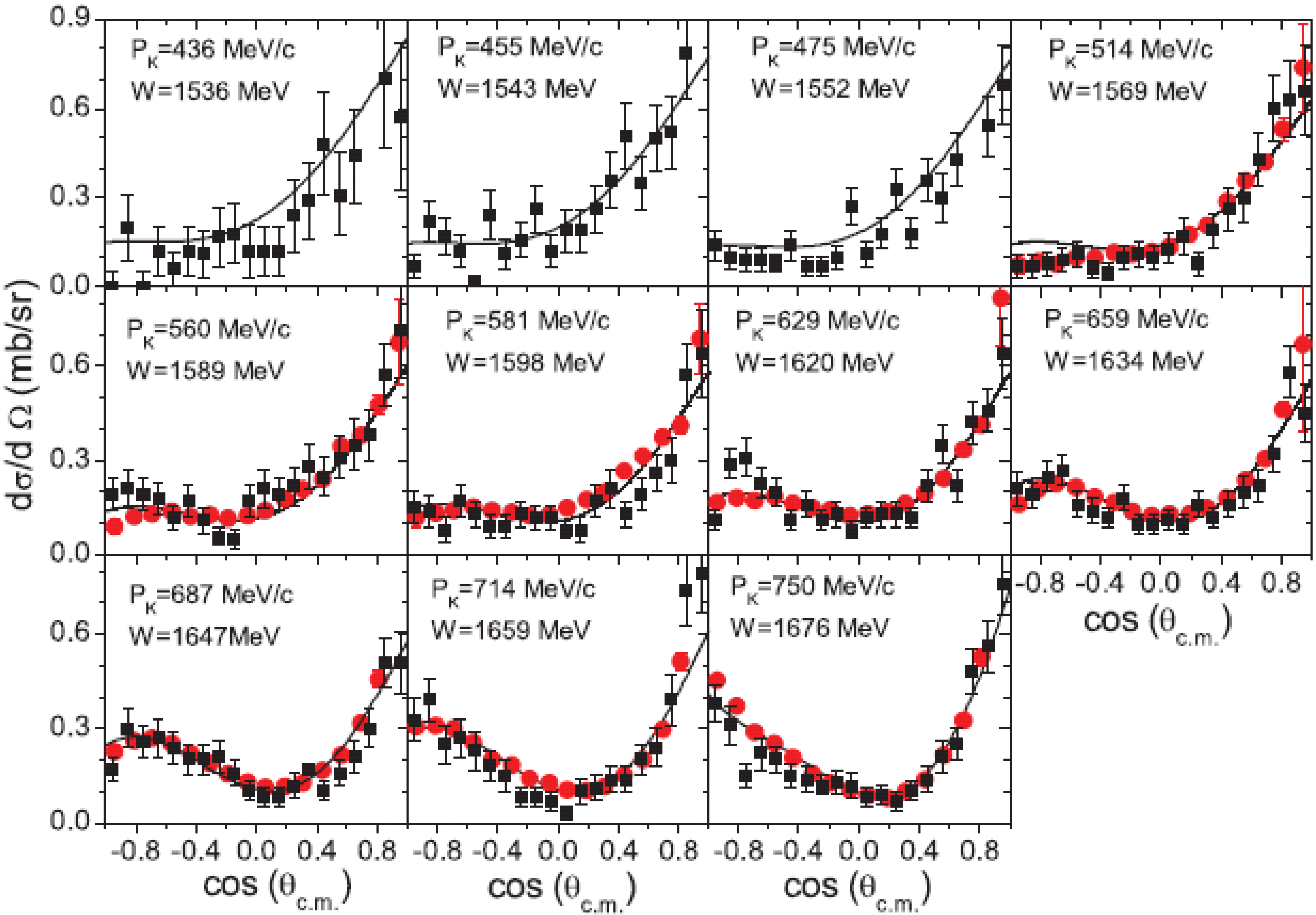
B. Roles of Σ* states in the $K^-p \to \Lambda\pi^0$



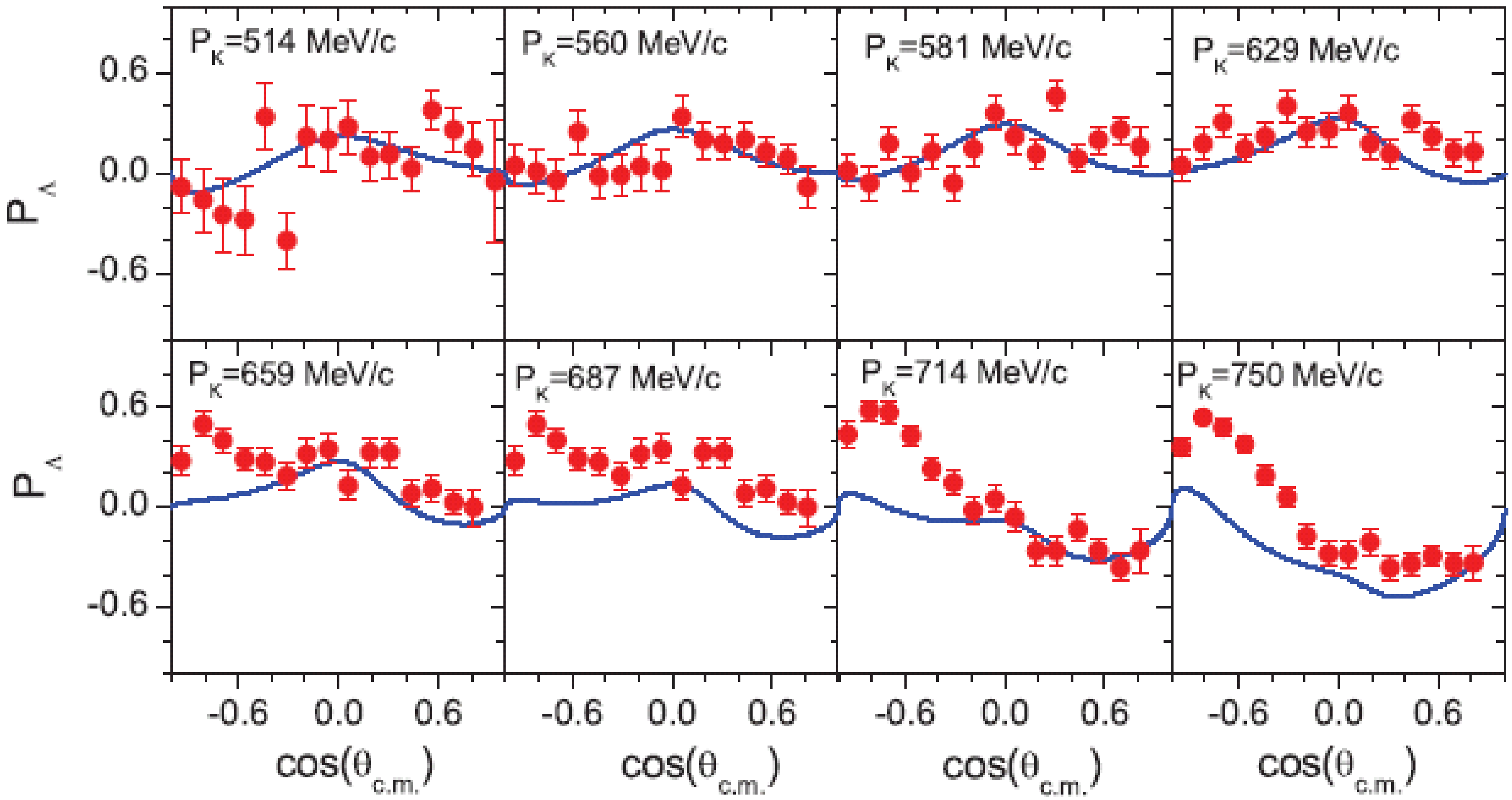
Two negative parity states: **Σ(1750)1/2-, Σ(1775)5/2-** are obviously found in the reaction.

Backgrounds are also important!

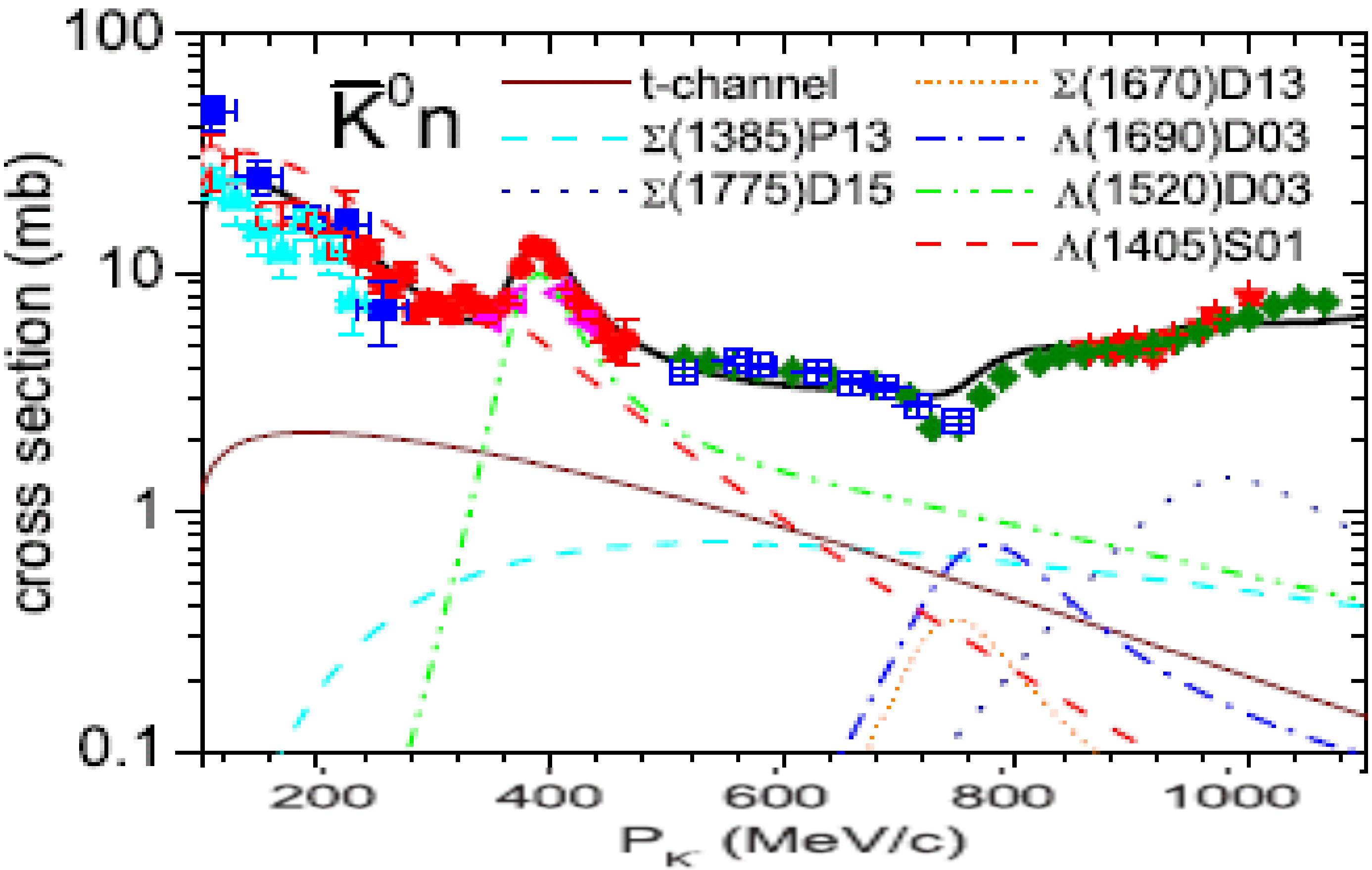
Differential cross section



Polarization

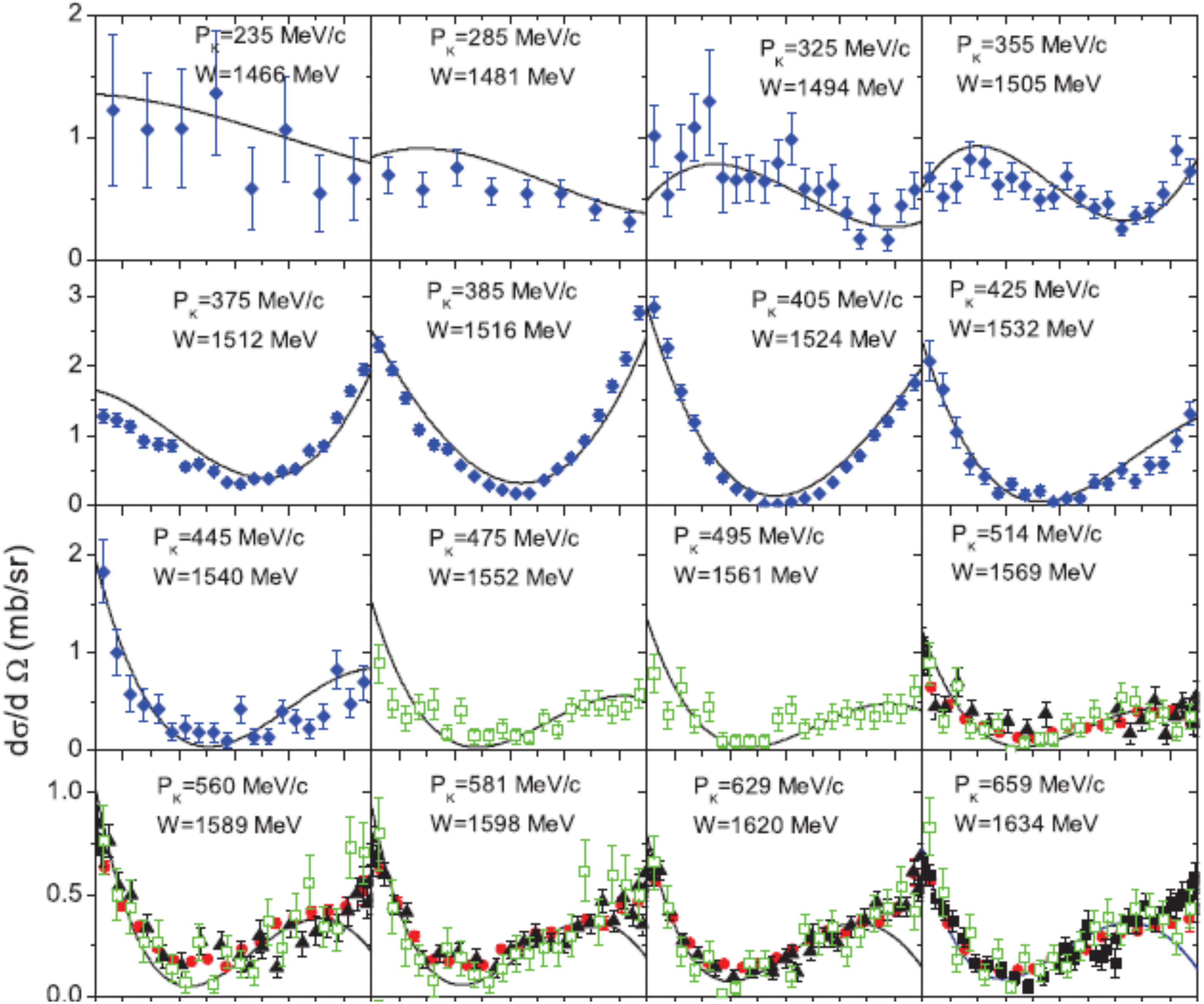


C. Roles of Λ* ,Σ* states in the $K^- p \rightarrow \underline{K} n$

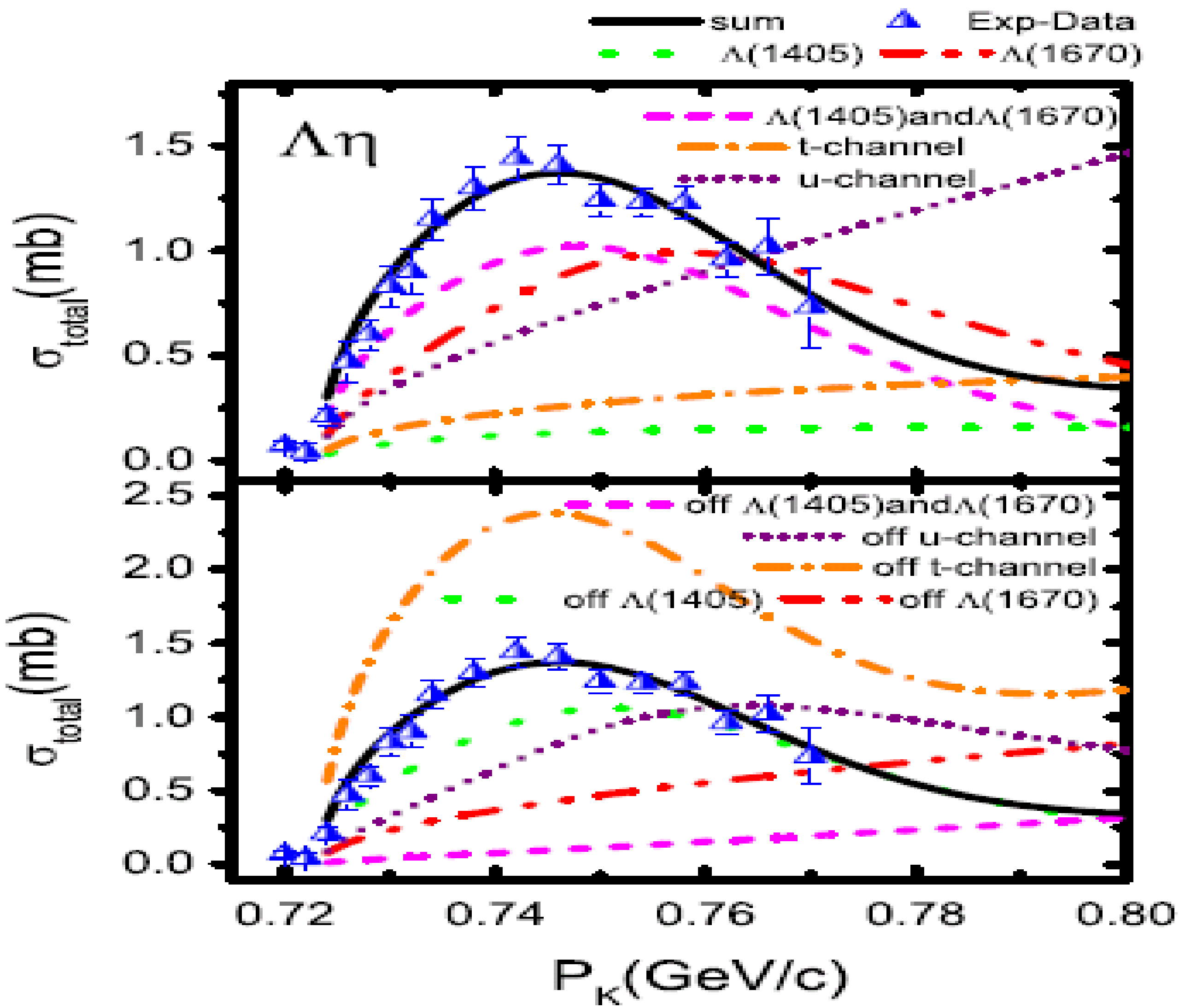


The negative parity states: Σ(1775)5/2-, Σ(1670)3/2-,Λ(1520,1690)3/2-, Λ(1405)1/2- are obviously found in the reaction.

Differential cross section



D. Roles of Λ* states in the K-p→ηΛ



Λ (1670) and background dominate the reaction

Briet-Wigner masses of resonances

TABLE IV: Breit-Wigner masses M_R (MeV) and widths Γ_R (MeV) for the resonances.

$[N_6, {}^{2S+1}N_3, n, \mathbf{L}]$	$l_{I,2J}$	M_R	Γ_R	M_R (PDG)	Γ_R (PDG)
$[\mathbf{70}, {}^2 1, 1, \mathbf{1}]$	S_{01}	1410	80	1406 ± 4	50 ± 2
	D_{03}	1519	19	1520 ± 1	16 ± 1
$[\mathbf{70}, {}^2 10, 1, \mathbf{1}]$	S_{11}	1810	200	...	...
	D_{13}	1780	150	...	...
$[\mathbf{70}, {}^2 8, 1, \mathbf{1}]$	S_{01}	1674	50	1670 ± 10	$25 \sim 50$
	D_{03}	1685	62	1690 ± 5	60 ± 10
	S_{11}	1631	102	1620	$10 \sim 110$
	D_{13}	1674	52	1675 ± 10	60 ± 20
$[\mathbf{70}, {}^4 8, 1, \mathbf{1}]$	S_{11}	1770	90	1765 ± 35	$60 \sim 160$
	D_{13}	1740	80	...	...
	D_{15}	1775	105	1775 ± 5	120 ± 15
$[\mathbf{56}, {}^2 8, 2, \mathbf{0}]$	P_{01}	1600	150	1630 ± 70	150 ± 100
	P_{11}	1660	160	1660 ± 30	$40 \sim 200$

The un-established S wave **Σ^* states** might be established in the **$K^- p \to \Lambda \pi^0$**.

Configuration mixing is important!

For example: No configuration mixing, the couplings of Lambda(1670) to KN is too strong, however, to ηΛ is too weak!

Without configuration mixing :

TABLE VII: The predicted total and partial decay widths(MeV) and partial decay width ratios of $\Lambda(1670)$ as a pure state of $|70,^2 8,1,1,\frac{1}{2}^-\rangle$. Taking the $\delta = 0.654$, $\phi_P = 35^0$, Γ^{th} denotes the theory data, Γ^{exp} denotes the experiment data from PDG.

Channel	Γ_i^{th}	Γ_{total}^{th}	Γ_{total}^{exp}	$\frac{\Gamma_i}{\Gamma_{total}}\|_{th}$	$\frac{\Gamma_i}{\Gamma_{total}}\|_{exp}$
$\Sigma\pi$	15.4	123.4	25 to 50($\approx$ 35)	0.12	$0.25 \sim 0.55$
NK	103.1			0.84	$0.20 \sim 0.30$
$\Lambda\eta$	0.28			0.002	$0.10 \sim 0.25$
$\Sigma(1385)\pi$	4.7			0.04	$\cdots$

With configuration mixing :

$$\begin{pmatrix} |\Lambda(1800)\frac{1}{2}^-\rangle \\ |\Lambda(1670)\frac{1}{2}^-\rangle \\ |\Lambda(1405)\frac{1}{2}^-\rangle \end{pmatrix} = \begin{pmatrix} 0.17 & 0.62 & 0.77 \\ 0.42 & -0.76 & 0.43 \\ 0.90 & 0.21 & -0.37 \end{pmatrix} \begin{pmatrix} |70,^2 1\rangle \\ |70,^2 8\rangle \\ |70,^4 8\rangle \end{pmatrix} \quad (45)$$

TABLE VIII: The predicted total and partial decay widths(MeV) and partial decay width ratios of $\Lambda(1670) \equiv |\Lambda\frac{1}{2}^-\rangle_2$ compared with the experiment data from PRD. The mixing angles are $\theta_{12} = 75^0$, $\theta = 50^0$ and $\theta_{23} = 125^0$.

Channel	Γ_i^{th}	Γ_{total}^{th}	Γ_{total}^{exp}	$\frac{\Gamma_i}{\Gamma_{total}}\vert_{th}$	$\frac{\Gamma_i}{\Gamma_{total}}\vert_{exp}$
$\Sigma\pi$	11.8	44.7	25 to 50($\approx$ 35)	0.26	$0.25 \sim 0.55$
NK	13.6			0.30	$0.20 \sim 0.30$
$\Lambda\eta$	18.2			0.41	$0.10 \sim 0.25$
$\Sigma(1385)\pi$	1.1			0.02	...

With configuration mixing, the couplings of Lambda(1670) to KN is weaker, to ηΛ is stronger!

In agreement with the data!

3. Summary

- Within the chiral quark model the Kp scatterings can be reasonably understood.
- Some well-established resonances are further confirmed in the reactions.
- Some evidence of the S wave un-established Σ states, Σ(1620,1750)1/2-, is found.
- **Configuration mixing might be important!**
- Backgrounds play important role in the reactions, thus, it is difficult to distinguish the resonances in the reactions.
- The experiments in BESIII and J-PARC will help us to know more knowledge of hyperon resonances.

Thanks !