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Study of the light baryon states in Λ^+_c decays

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2018年4月19日 @中国科学院高能物理研究所

Outline

Introduction

$Possible\ \Sigma_{1/2^-}(1380)\ state\ and\ a\ new\ \Lambda^{*} state\ in\ \Lambda_c^+ \to \eta\pi^+\Lambda\ decay$

$Study\ of\ N^*(1535)\ in\ the\ \Lambda_c^+ \to \bar{K}^0\eta p\ decay$

$Possible\ \phi p\ state\ in\ \Lambda_c^+ \to \pi^0\phi p\ decay$

Summary

A possible Σ(1380) state with spin-parity $J^P = \frac{1}{2}^-$

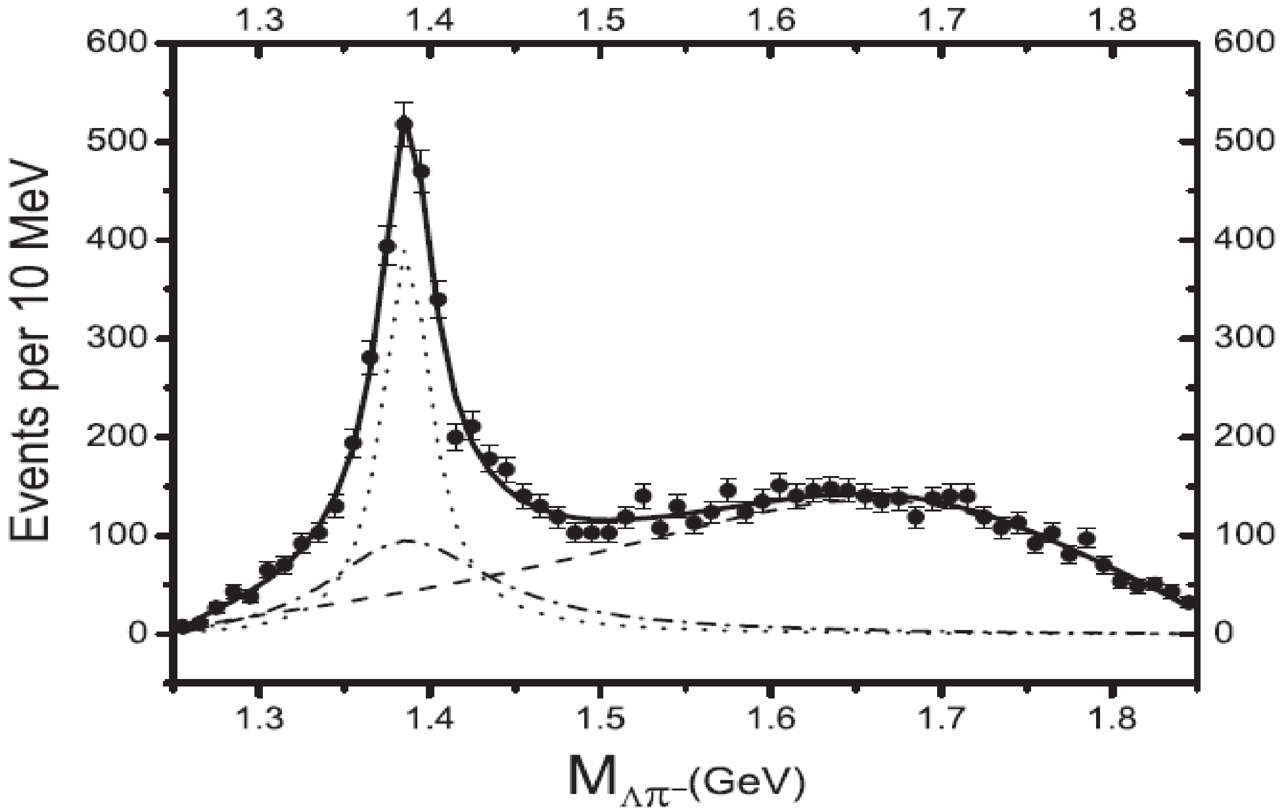
Flavor wave functions and masses of the $\frac{1}{2}^-$ pentaquark octet and singlet.

	(Y, I)	I_3	flavor wave functions	masses (MeV)
Σ_8^+	(0,1)	1	$[su][ud]_-\bar{d}$	1360
Σ_8^0		0	$\frac{1}{\sqrt{2}}([su][ud]_-\bar{u}+[ds][ud]_-\bar{d})$	1360
Σ_8^-		-1	$[ds][ud]_-\bar{u}$	1360

Ao Zhang, Y. R. Liu, P.Z. Huang, W.Z. Deng, X.L. chen and S.L. Zhu,
High Energy Phys. Nucl. Phys. 29, 250 (2005).

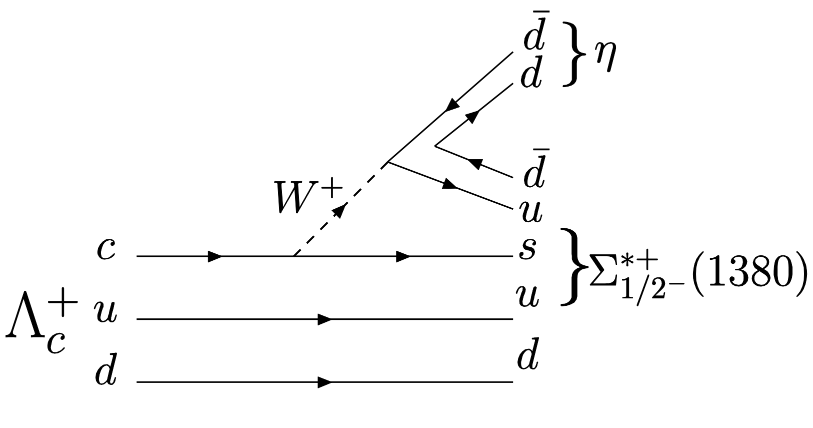
Evidence for a new Σ^* resonance with $J^P = 1/2^-$ in the old data of the $K^- p \to \Lambda \pi^+ \pi^-$ reaction

Jia-Jun Wu,[1] S. Dulat,[2,3] and B. S. Zou[1,3]

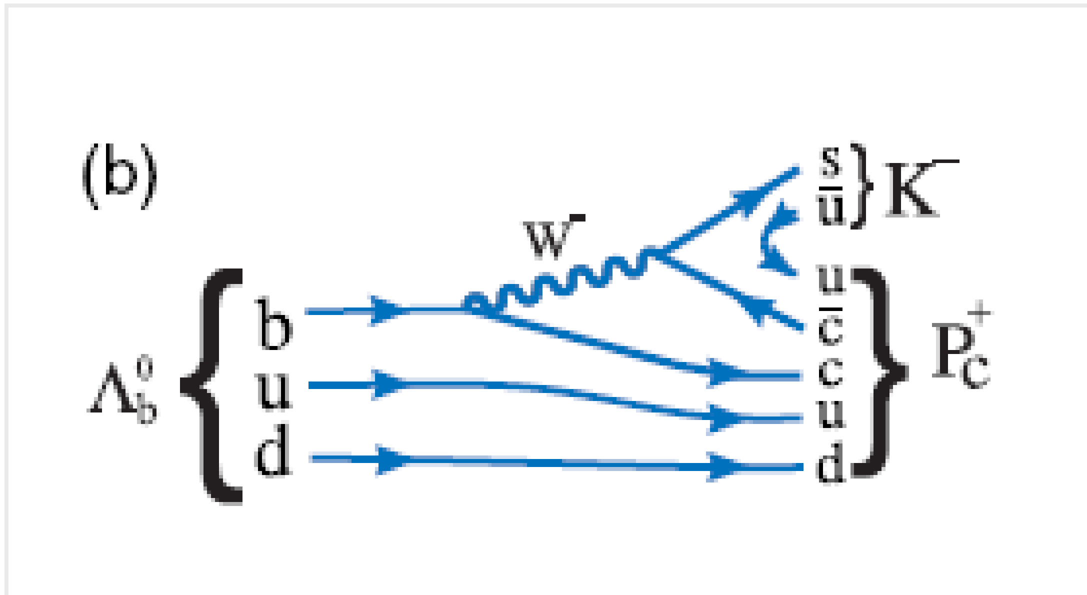


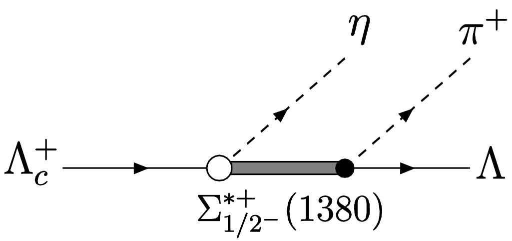
	$M_{\Sigma^*(3/2)}$	$\Gamma_{\Sigma^*(3/2)}$	$M_{\Sigma^*(1/2)}$	$\Gamma_{\Sigma^*(1/2)}$	χ^2/ndf (Fig. 1)
Fit1	1385.3 ± 0.7	46.9 ± 2.5			68.5/54
Fit2	$1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	58.0/51

Σ(1380) in $\Lambda^+_c \to \eta\pi^+\Lambda$ decay



(a)



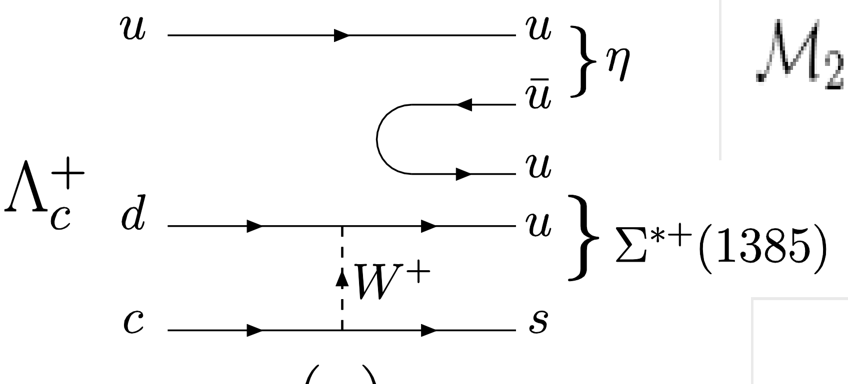


(b)

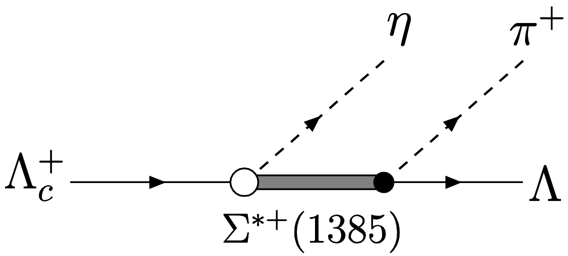
$$\mathcal{M}_1 = i g_{\pi\Lambda\Sigma_1^*} \bar{u}(p_3) G^{\Sigma_1^*}(q)(A_1 + B_1\gamma_5)u(p),$$

$$G^{\Sigma_1^*}(q) = i \frac{\not{q} + M_{\Sigma_1^*}}{q^2 - M^2_{\Sigma_1^*} + i M_{\Sigma_1^*}\Gamma_{\Sigma_1^*}};$$

Σ(1385) in $\Lambda^+_c \to \eta\pi^+\Lambda$ decay



(a)



(b)

$$\mathcal{M}_2 = \frac{i g_{\pi\Lambda\Sigma_2^*}}{m_\eta m_\pi} \bar{u}(p_3) p_2^\mu G_{\mu\nu}^{\Sigma_2^*}(q) p_1^\nu (A_2 + B_2\gamma_5) u(p),$$

$$G_{\mu\nu}^{\Sigma_2^*}(q) = i \frac{\not{q} + M_{\Sigma_2^*}}{q^2 - M_{\Sigma_2^*}^2 + i M_{\Sigma_2^*}\Gamma_{\Sigma_2^*}} P_{\mu\nu},$$

with

$$P^{\mu\nu} = -g^{\mu\nu} + \frac{1}{3}\gamma^\mu\gamma^\nu + \frac{2q^\mu q^\nu}{3M_{\Sigma_2^*}^2} + \frac{\gamma^\mu q^\nu - \gamma^\nu q^\mu}{3M_{\Sigma_2^*}},$$

Invariant mass, decay angle and energy distributions

$$\frac{d\Gamma}{dM_{\pi+\Lambda}} = \frac{m_\Lambda}{32\pi^3 M_{\Lambda_c^+}} \int \sum |\mathcal{M}|^2 |\vec{p}_1||\vec{p}\,^*| d\cos\theta^*$$

$$\frac{d\Gamma}{d\cos\theta^*} = \frac{m_\Lambda}{32\pi^3 M_{\Lambda_c^+}} \int \sum |\mathcal{M}|^2 |\vec{p}_1||\vec{p}\,^*| dM_{\pi+\Lambda}.$$

$$\frac{d\Gamma}{dE_{\pi+}} = \frac{m_\Lambda}{32\pi^3} \int \sum |\mathcal{M}|^2 dE_\Lambda;$$

Invariant mass distributions

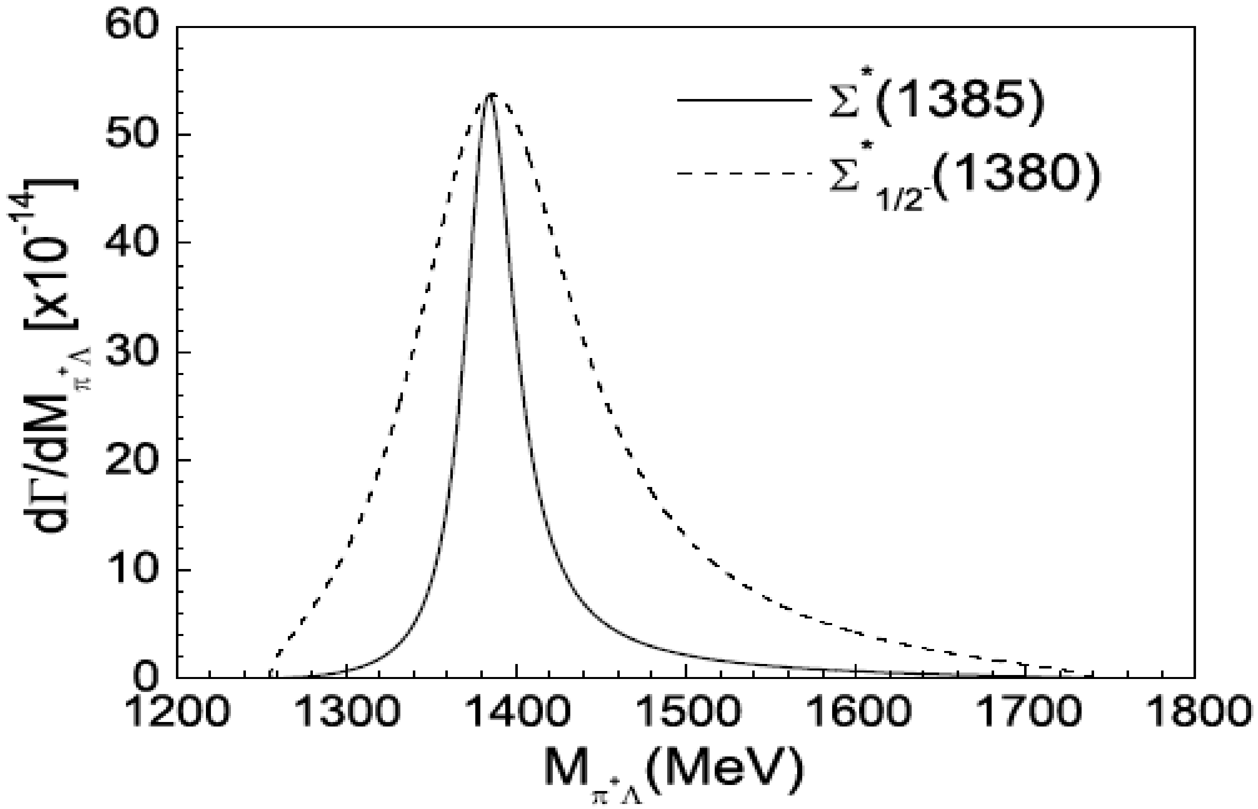


FIG. 5: Invariant mass distributions $d\Gamma/dM_{\pi+\Lambda}$ as a function of $M_{\pi+\Lambda}$.

Ju-Jun Xie and Li-Sheng Geng, PRD 96,054009 (2017).

Decay angle and energy distributions

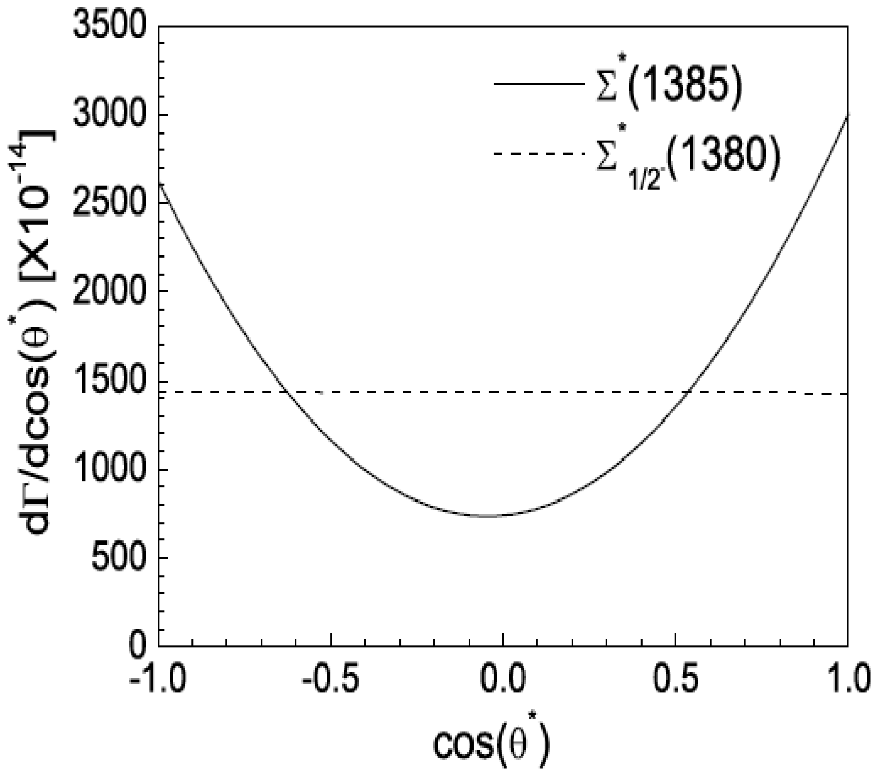


FIG. 6: Angle distributions $d\Gamma/d\cos\theta^*$ in the c.m. frame of $\pi^+\Lambda$ system as a function of $\cos\theta^*$.

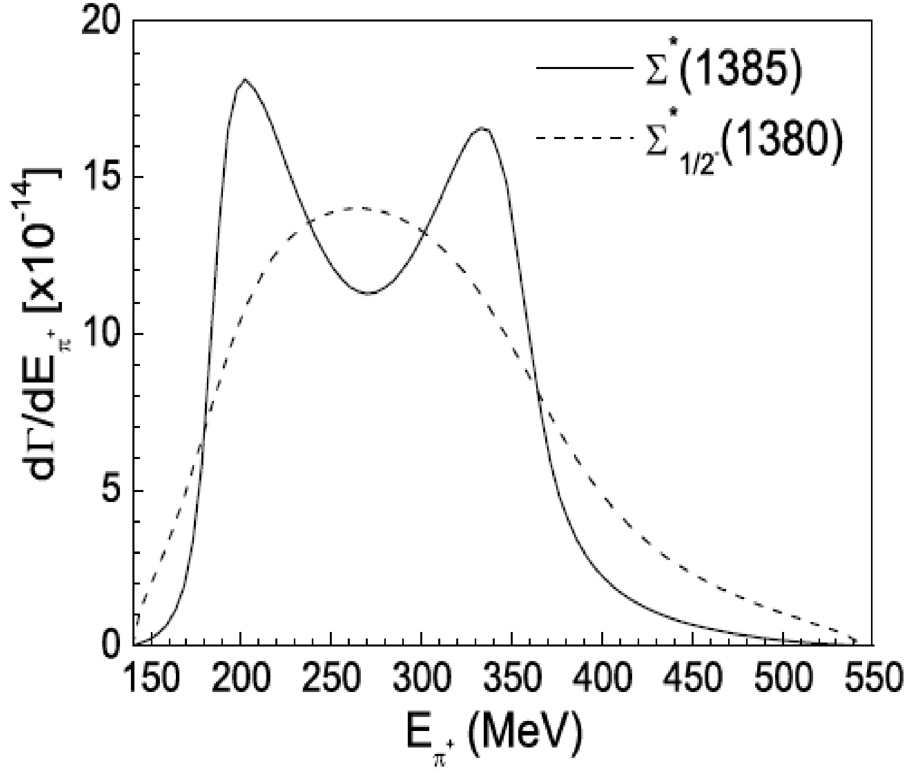
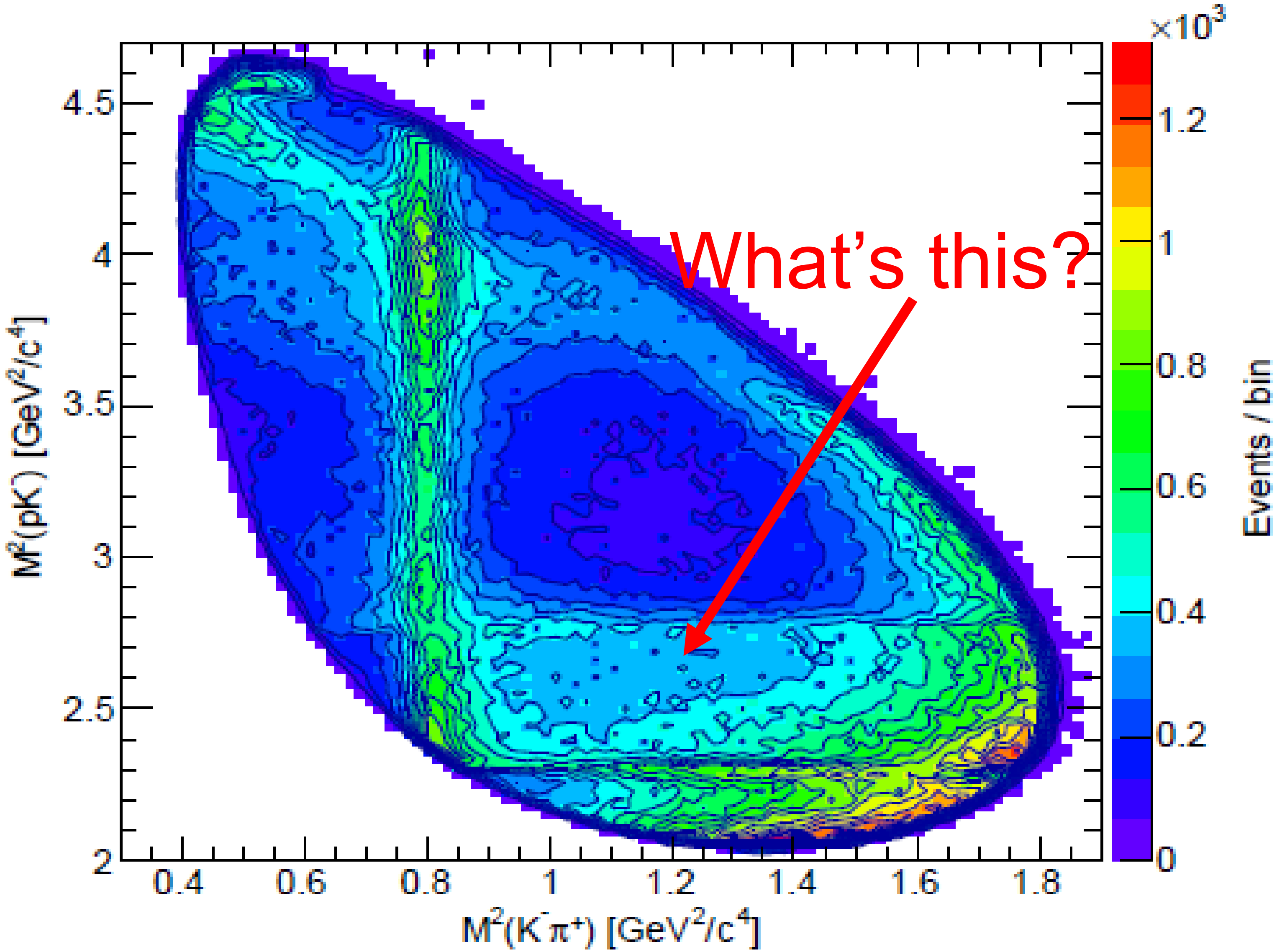


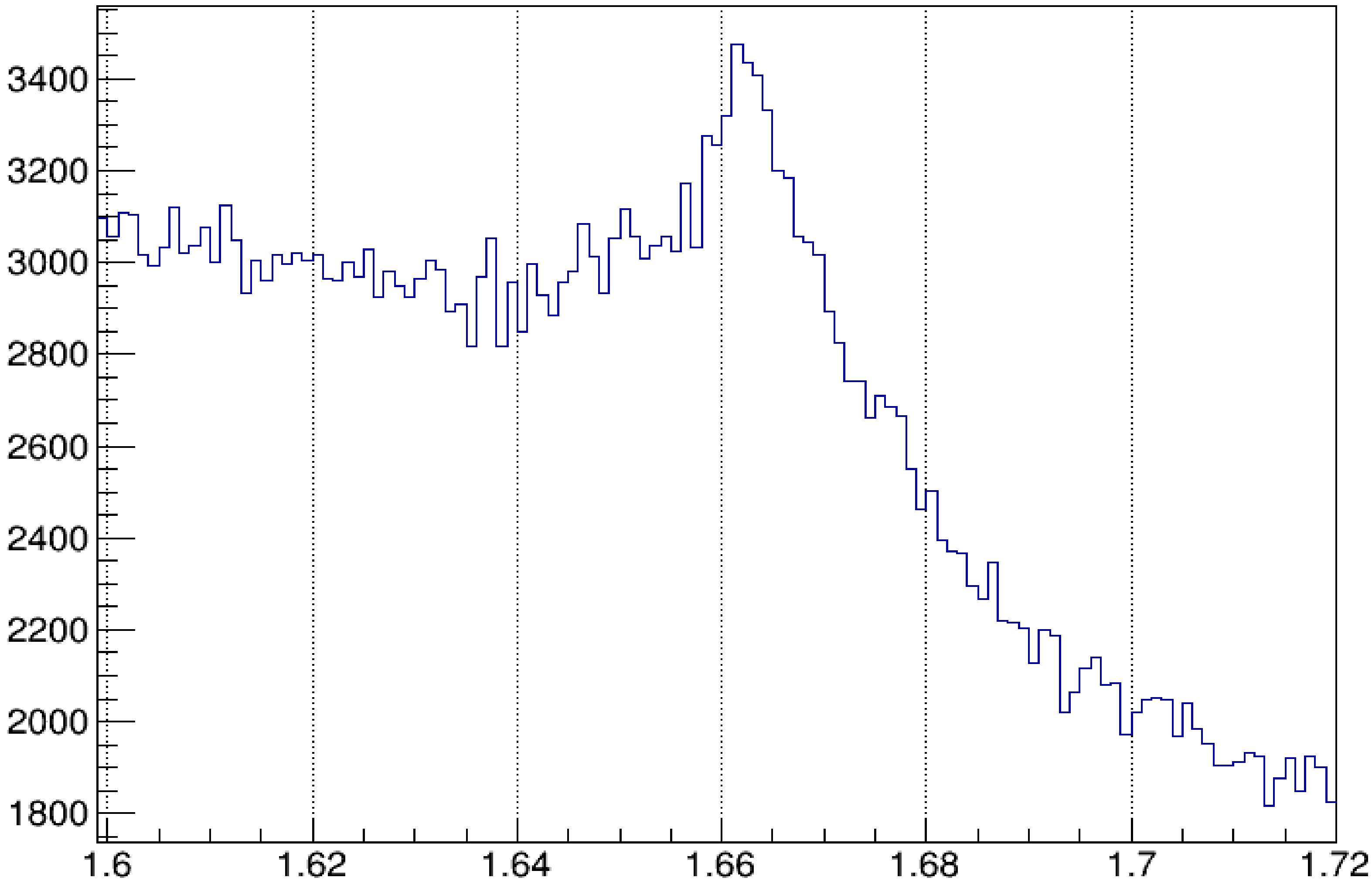
FIG. 7: Energy distributions $d\Gamma/dE_{\pi+}$ in the rest frame of Λ_c^+ as a function of $E_{\pi+}$.

Dalitz Plot: $\Lambda^+_c \to pK^-\pi^+$ decay



Belle Collaboration, PRL 117, 011801 (2016).

■ **1D projection --** $M(pK^{-})$



What's that?

- The peak position is ~1663 MeV, near the $\eta\Lambda$ threshold (1663.5 MeV)

- Width is ~10 MeV, significantly narrower than Λ^* resonances in this region

  $\Lambda(1670)$: 25-50 MeV

  $\Lambda(1690)$: ~60 MeV

- Maybe due to interference with BG amplitude?

A new narrow Λ^* resonance

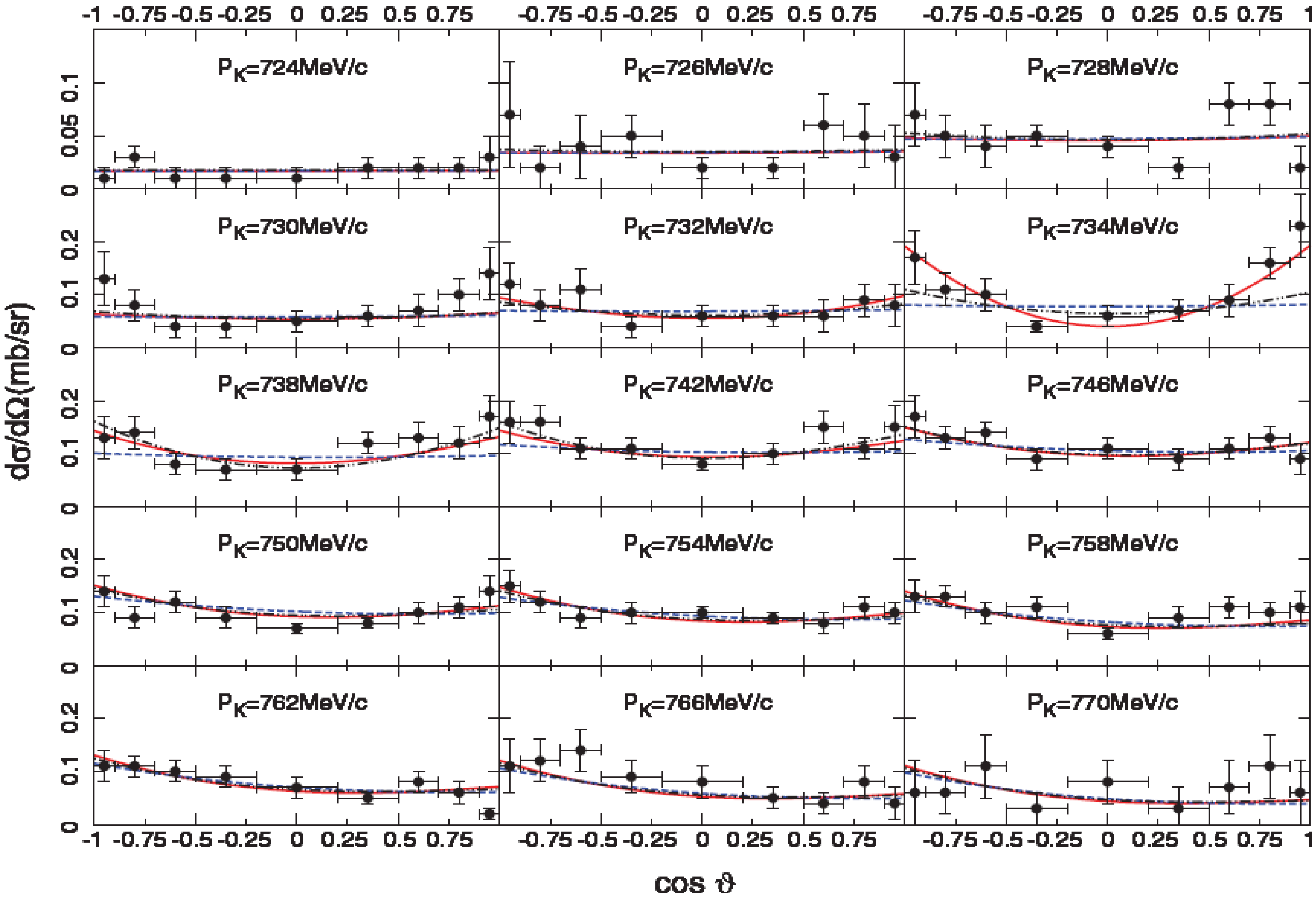
- Predictions before: a new narrow Λ^* resonance at this energy with J=3/2

  – Kamano et al. [PRC 90, 065204 (2014); PRC 92, 025205 (2015)]
  $J^P=3/2^+$ (P_{03}), $M=1671^{+2}_{-8}$ MeV, $\Gamma=10^{+22}_{-4}$ MeV

  – 刘伯超 & 谢聚军 [PRC 85, 038201 (2012); PRC 86, 055202 (2012)]
  $J^P=3/2^-$ (D_{03}), $M=1668.5\pm0.5$ MeV, $\Gamma=1.5\pm0.5$ MeV

  Couples strongly to $\Lambda\eta$ channel

Angular distributions for $K^-p \rightarrow \eta\Lambda$ reaction



Other contributions

$$\Lambda^*(1670),\ J^P = 1/2^-, (M,\Gamma) = (1670, 35)\mathrm{MeV} \quad \to \Lambda\eta \sim 10 - 25\%$$

$$\Lambda^*(1690),\ J^P = 3/2^-, (M,\Gamma) = (1690, 60)\mathrm{MeV} \quad \to \Lambda\eta \quad ??$$

$$\Sigma^*\ resonances, \quad \to \pi^+\Lambda$$

......

$$a_0(980), \quad \to \pi^+\eta$$

$N^*(1535)$

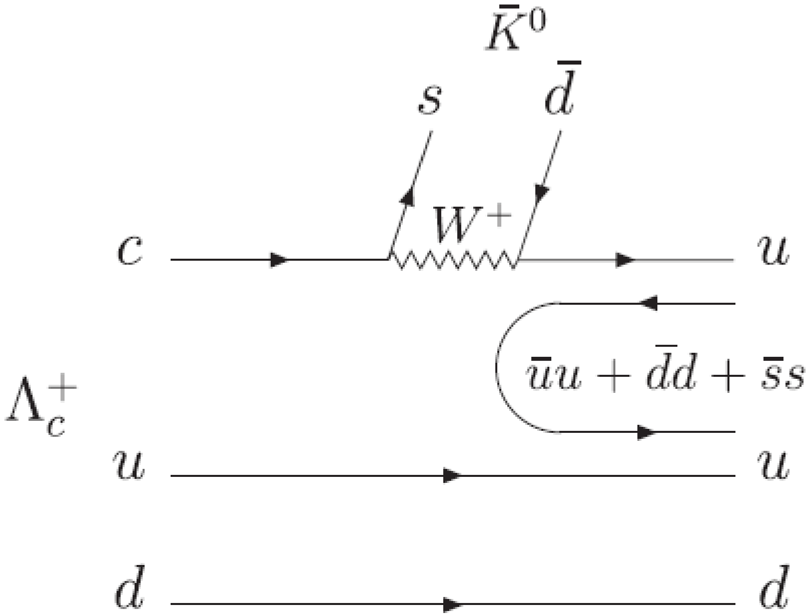
- Couples strongly to $N\eta$ channel
- Pole position $z_R = [(1490 \sim 1530) - i(45 \sim 125)]\mathrm{MeV}$

$$(M_R, \Gamma_R) = (\simeq 1510, \simeq 170)\mathrm{MeV}$$

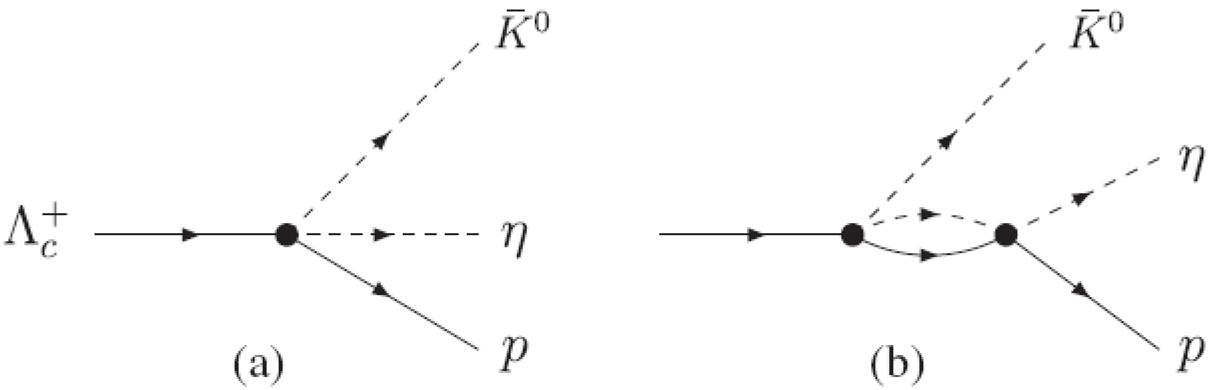
- Breit-Wigner parameterization

$$(M_R, \Gamma_R) = (1525 \sim 1545, 125 \sim 175)\mathrm{MeV} = (\simeq 1535, \simeq 150)\mathrm{MeV}$$

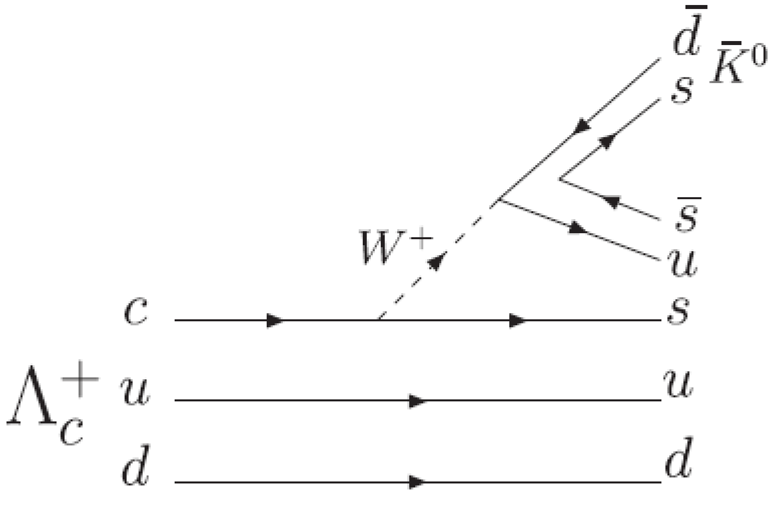
The $N^*(1535)$ as a dynamically generated state



$$
\begin{aligned}
T^{MB} = V_P \Big(& \frac{\sqrt{3}}{3} + \frac{\sqrt{3}}{3} G_{\eta p}(M_{\eta p}) t_{\eta p \to \eta p}(M_{\eta p}) \\
& + \frac{\sqrt{2}}{2} G_{\pi^0 p}(M_{\eta p}) t_{\pi^0 p \to \eta p}(M_{\eta p}) \\
& + G_{\pi^+ n}(M_{\eta p}) t_{\pi^+ n \to \eta p}(M_{\eta p}) \\
& - \frac{\sqrt{6}}{3} G_{K^+ \Lambda}(M_{\eta p}) t_{K^+ \Lambda \to \eta p}(M_{\eta p}) \Big),
\end{aligned}
$$



Effective Lagrangian approach and the N*(1535) resonance as a Breit-Wigner resonance



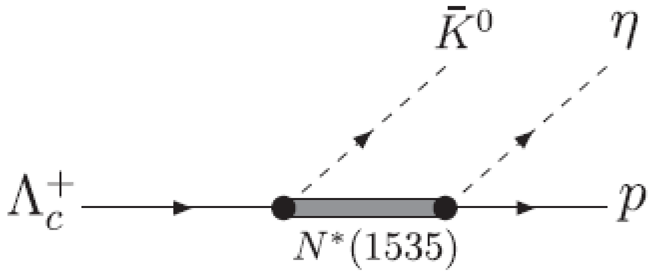
(a)

$$T^{N^*} = i g_{N^* N \eta} \bar{u}(p_3, s_p) G_{N^*}(q)(A + B\gamma_5) u(p, s_{\Lambda_c^+}),$$

$$G_{N^*}(q) = i \frac{\not{q} + M_{N^*}}{q^2 - M_{N^*}^2 + i M_{N^*} \Gamma_{N^*}(q^2)},$$

$$\Gamma_{N^*}(q^2) = \Gamma_{N^* \to \pi N}(q^2) + \Gamma_{N^* \to \eta N}(q^2) + \Gamma_0,$$

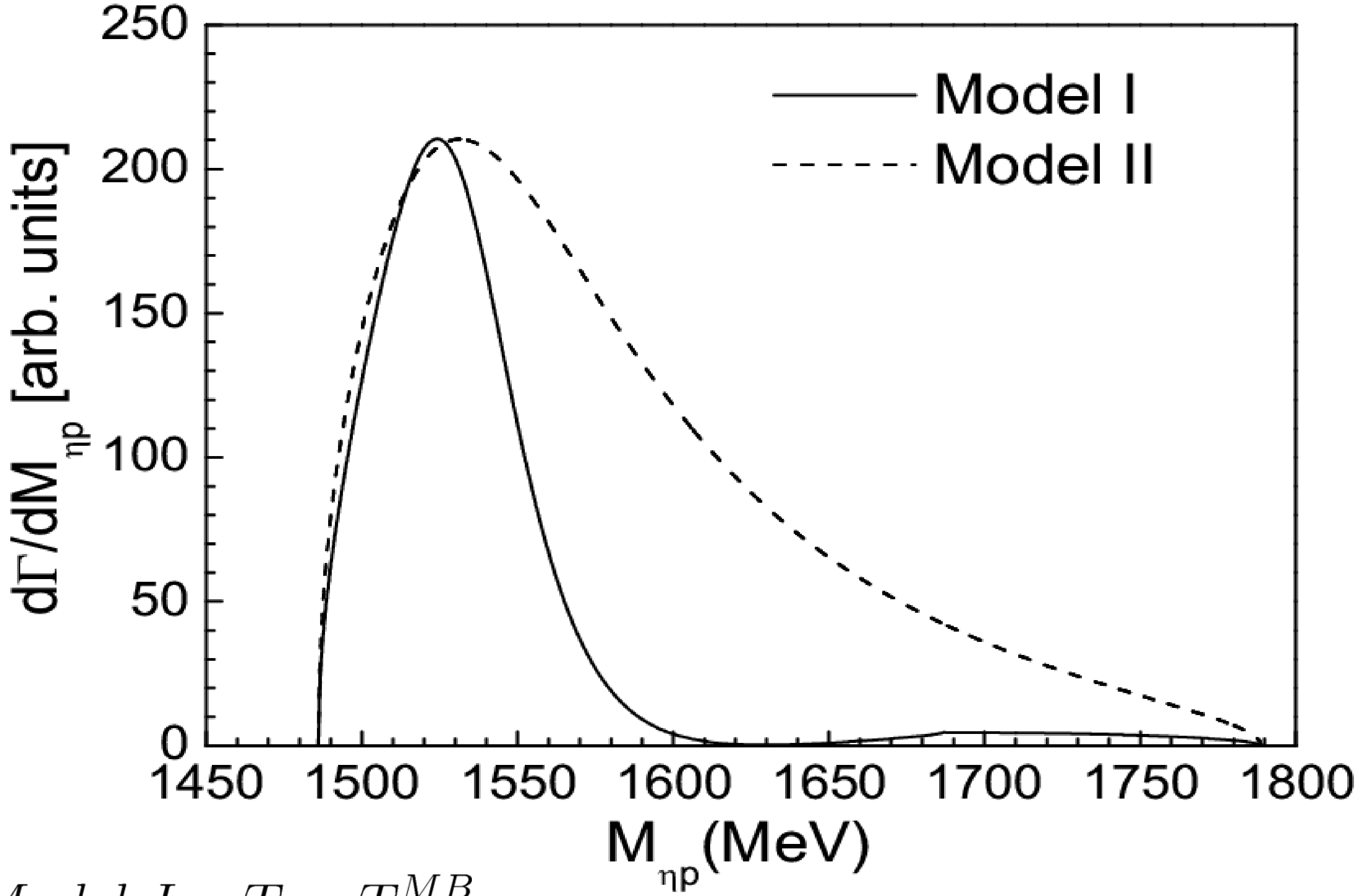
$$\Gamma_0 = 19.5 \text{ MeV} \quad \text{for} \quad \Gamma_{N^*}(\sqrt{q^2} = 1535 \text{ MeV}) = 150 \text{ MeV}.$$



(b)

Ju-Jun Xie and Li-Sheng Geng, PRD 96, 054009 (2017).

Invariant ηp mass distributions



$$Model\ I:\ T = T^{MB}$$

$$Model\ II:\ T = T^{N^*},\ M_{N^*} = 1535\ \mathrm{MeV},\ \Gamma_{N^*} = \Gamma_{N^*}(q^2)$$

Other contributions

$$N^*(1650)$$

$$\Sigma^* \; resonances$$

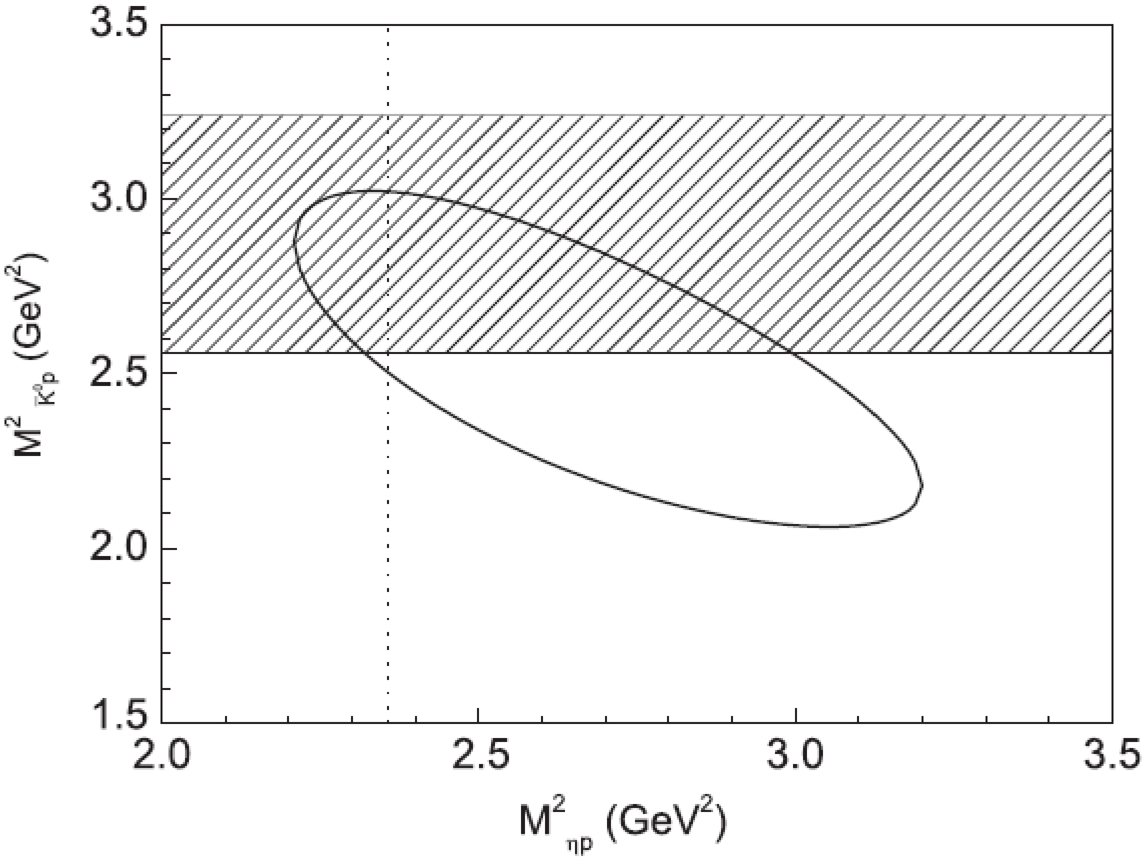


FIG. 7. Dalitz plot for $M^2_{\eta p}$ and $M^2_{\bar{K}^0 p}$ in the $\Lambda_c^+ \to \bar{K}^0 \eta p$ decay. The $N^*(1535)$ energy is shown by the vertical dotted line, and the horizontal band represents the masses of Σ^* states from 1600 to 1800 MeV.

Possible ϕp state in $\Lambda^+_c \to \pi^0 p\phi$ decay

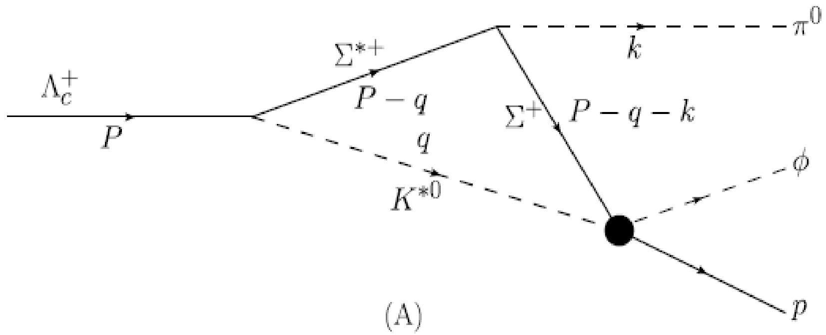


Fig. 1. Triangle diagrams for the $\Lambda_c^+ \to \pi^0 p\phi$ decay. (A): Σ^+-exchange. (B): Λ-exchange. The definitions of the kinematical variables (P, q, k) are also shown.

$$t = \frac{g_{\Lambda_c \Sigma^* K^*}\, g}{m_\pi} \vec{\epsilon}_\phi \cdot \vec{k} \sum_{i=\Sigma,\Lambda} \mathcal{C}_i \int \frac{d^4 q}{(2\pi)^4}$$
$$\times \frac{i2m_{\Sigma^*}}{(P-q)^2 - m_{\Sigma^*}^2 + i m_{\Sigma^*}\Gamma_{\Sigma^*}} \frac{i}{q^2 - m_{K^*}^2 + i m_{K^*}\Gamma_{K^*}}$$
$$\times \frac{i2m_i}{(P-q-k)^2 - m_i^2 + i\epsilon}, \qquad (4)$$

where we have defined $\mathcal{C}_\Sigma = \frac{\sqrt{6}}{3} t_{K^{*0}\Sigma^+ \to \phi p}$ and $\mathcal{C}_\Lambda = -t_{K^{*+}\Lambda \to \phi p}$,

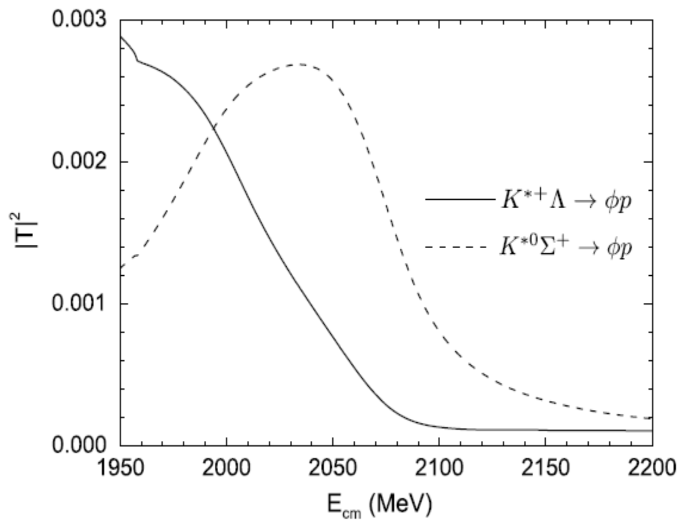
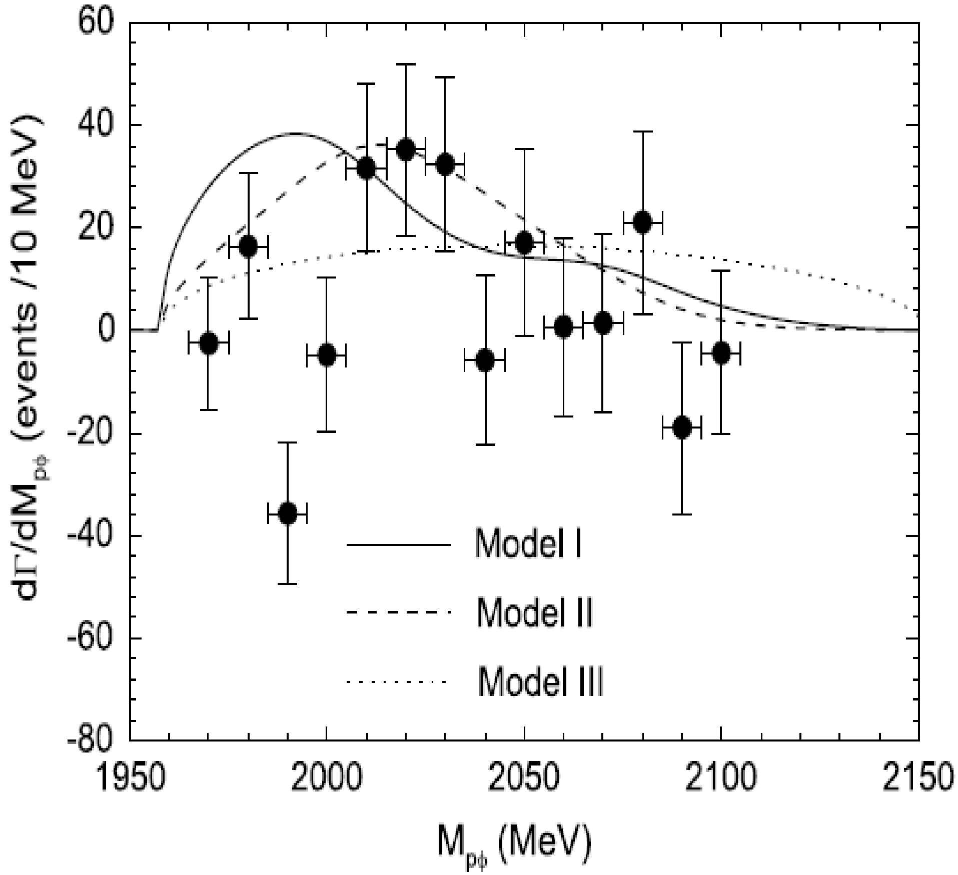


Fig. 3. The squared norm of the T-matrix elements for $K^{*+}\Lambda \to \phi p$ and $K^{*0}\Sigma^+ \to \phi p$ as a function of the meson–baryon invariant mass E_{cm} in the model of Ref. [72].



$$t_{\rm I} = t,$$

$$t_{\rm II} = t, \text{ but with } t_{K^{*+}\Lambda\to\phi p} = \frac{\sqrt{6}}{2} t_{K^{*0}\Sigma^+\to\phi p}$$

$$= c_1 \frac{\sqrt{6}}{2} \frac{E_{K^*} + E_\phi}{4F_\pi^2},$$

$$t_{\rm III} = c_2,$$

Fig. 2. Invariant mass distribution of the $\Lambda_c^+ \to \pi^0 p\phi$ decay. The experimental data are taken from Ref. [47].

[47] B. Pal, et al., Belle Collaboration, arXiv:1707.00089 [hep-ex].

J.-J. Xie, F.-K. Guo / Physics Letters B 774 (2017) 108–113

Summary

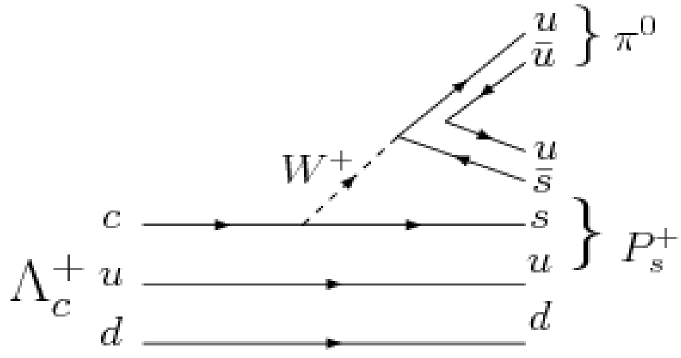
$The\ \Lambda_c^+ \to \eta\pi^+\Lambda\ decay\ can\ be\ used\ to\ study\ the\ \Sigma^*\ and\ \Lambda^* resonances$

$The\ \Lambda_c^+ \to \bar{K}^0\eta p\ decay\ can\ be\ used\ to\ study\ the\ N^*(1535)\ resonance$

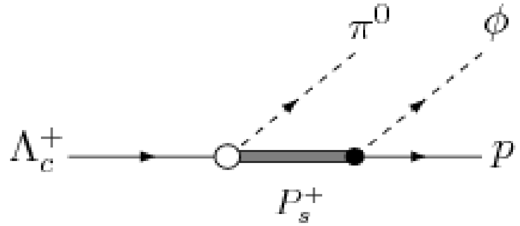
$Possible\ \phi p\ state,\ P_s,\ in\ the\ \Lambda_c^+ \to \pi^0\phi p\ decay$

But,
We need more efforts, both on theoretical and experimental sides.

Thank you very much for your attention!



(a)



(b)