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The hyperon excited states in the Λ^+_c decays

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2020年1月13日 @ 6th workshop on the XYZ particles
2020年1月11—13日，复旦大学，上海

Outline

Introduction

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

$A\ possible\ new\ narrow\ \Lambda^* state\ (cusp)\ in\ \Lambda_c^+ \to \pi^+ K^- p\ decay$

Summary

多夸克“重子态”

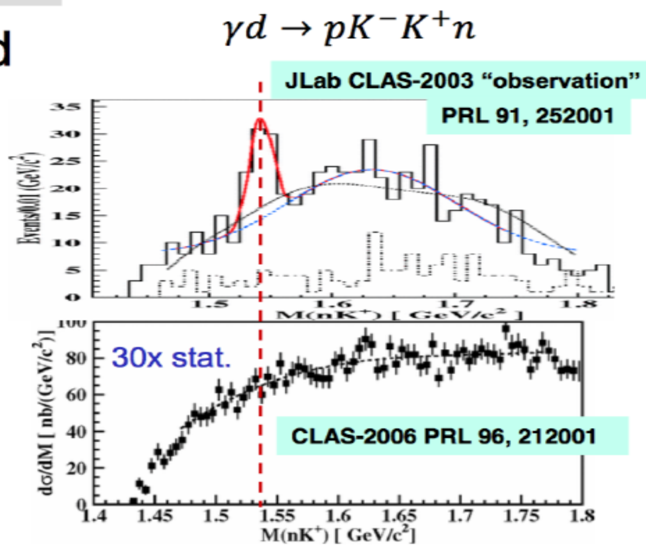
维尔切克的感叹（2005年目睹五夸克态的兴衰）：

对于五夸克态事件折射出我们对 QCD的了解还是多么的贫乏

Curious history of pentaquark Θ^+search

See summary by [K. H. Hicks, Eur. Phys. J. H37 (2012) 1]

- No convincing states 50 years after Gell-mann paper proposing qqqq$\bar{q}$ states
- Prediction: $\Theta^+(uudd\bar{s})$ could exist with m ≈1530 MeV
- In 2003,10 experiments reported seeing narrow peaks of K^0p or K^+n, all >4 σ
- High statistics repeats from JLab showed the original claims were fluctuation
- It was merely a case of “bump hunting”



Taken from Xiang Liu’s talk on Jan. 11.

Borrowed from Li-Ming Zhang’s talk at PhiPsi2015

含多夸克成份的"重子态"

A study of pentaquark Θ state in the chiral $SU(3)$ quark model

F. Huang[a], Z.Y. Zhang[a], Y.W. Yu[a], B.S. Zou[b,a]

Physics Letters B 586 (2004) 69–74

ıark state $uudd\bar{s}$ is studied in the chiral $SU(3)$ quark model as well as in the extended chiral he vector meson exchanges are included. The lowest four configurations of $J^\pi = \frac{1}{2}^-$ and four uster are considered. The results show that the isospin $T = 0$ state is always the lowest one for both $J^\pi = \frac{1}{2}^-$ and $J^\pi = \frac{1}{2}^+$ cases in various models. But the theoretical value of the lowest one is still about 200–300 MeV higher than the experimental mass of Θ. It seems that a dynamical calculation should be done for the further study.

PRL 95, 072001 (2005) PHYSICAL REVIEW LETTERS week ending 12 AUGUST 2005

$s\bar{s}$ Component of the Proton and the Strangeness Magnetic Moment

B. S. Zou*
Institute of High Energy Physics, CAS, P.O. Box 918, Beijing 100049, China

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Helsinki Institute of Physics and Department of Physical Sciences, POB 64, 00014 University of Helsinki, Finland

(Received 25 February 2005; published 11 August 2005)

刘伯超, 邹冰松, Mass and KΛ coupling of N*(1535), PRL 96, 042002 (2006).

安春生, D.O. Riska and B.S. Zou, Strangeness spin, magnetic moment and strangeness configurations of the proton, PRC 73, 035207 (2006).

安春生, Q.B. Li, D.O. Riska and B.S. Zou,The qqqq anti-q components and hidden flavor contributions to the baryon magnetic moments, PRC 74, 055205 (2006); PRC75, 069901 (2007).

安春生, 邹冰松, The Role of the qqqq anti-q components in the electromagnetic transition γ*N --> N(1535), EPJA 195, (2009) .

安春生, 谢聚军, 李刚, Decay patterns of low-lying Nssbar states to the strangeness channels, PRC 98, 045201 (2018).

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

	(Y,I)	I_3	Flavor wave functions	Masses (MeV)
p_8	$(1,\frac{1}{2})$	$\frac{1}{2}$	$[su][ud]_-\bar{s}$	1460
n_8		$-\frac{1}{2}$	$[ds][ud]_-\bar{s}$	1460
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
Λ_8	(0,0)	0	$\frac{[ud][su]_-\bar{u}+[ds][ud]_-\bar{d}-2[su][ds]_-\bar{s}}{\sqrt{6}}$	1533
Ξ_8^0	$(-1,\frac{1}{2})$	$\frac{1}{2}$	$[ds][su]_-\bar{d}$	1520
Ξ_8^-		$-\frac{1}{2}$	$[ds][su]_-\bar{u}$	1520
Λ_1	(0,0)	0	$\frac{[ud][su]_-\bar{u}+[ds][ud]_-\bar{d}+[su][ds]_-\bar{s}}{\sqrt{3}}$	1447

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

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).

Chiral Unitary Model Predictions

A possible Σ^* state

Chiral dynamics in the presence of bound states: kaon–nucleon interactions revisited

J.A. Oller, Ulf-G. Meißner

Physics Letters B 500 (2001) 263–272

Chiral dynamics of the two $\Lambda(1405)$ states

D. Jido [a,c], J.A. Oller [b,*], E. Oset [c], A. Ramos [d], U.-G. Meißner [e]

Nuclear Physics A 725 (2003) 181–200

PHYSICAL REVIEW D **84,** 056017 (2011)

Odd-parity light baryon resonances

D. Gamermann,[1,2,*] C. García-Recio,[3,4,†] J. Nieves,[5,‡] and L. L. Salcedo[3,4,§]

z_R	$1401 + 40i$	
$(I = 1)$	g_i	$\lvert g_i \rvert$
$\pi\Lambda$	$0.60 + 0.47\,i$	0.76
$\pi\Sigma$	$1.27 + 0.71\,i$	1.5
$\bar{K}N$	$-1.24 - 0.73\,i$	1.4
$\eta\Sigma$	$0.56 + 0.41\,i$	0.69
$K\Xi$	$0.12 + 0.05\,i$	0.13

Cusp or "resonance" around the $\bar{K}N$ threshold

J.A. Oller, Eur. Phys. J. A 28, 63–82 (2006). Zhi-Hui Guo and J. A. Oller, PRC 87, 035202 (2013) .

L. Roca and E. Oset, PRC 88, 055206 (2013).

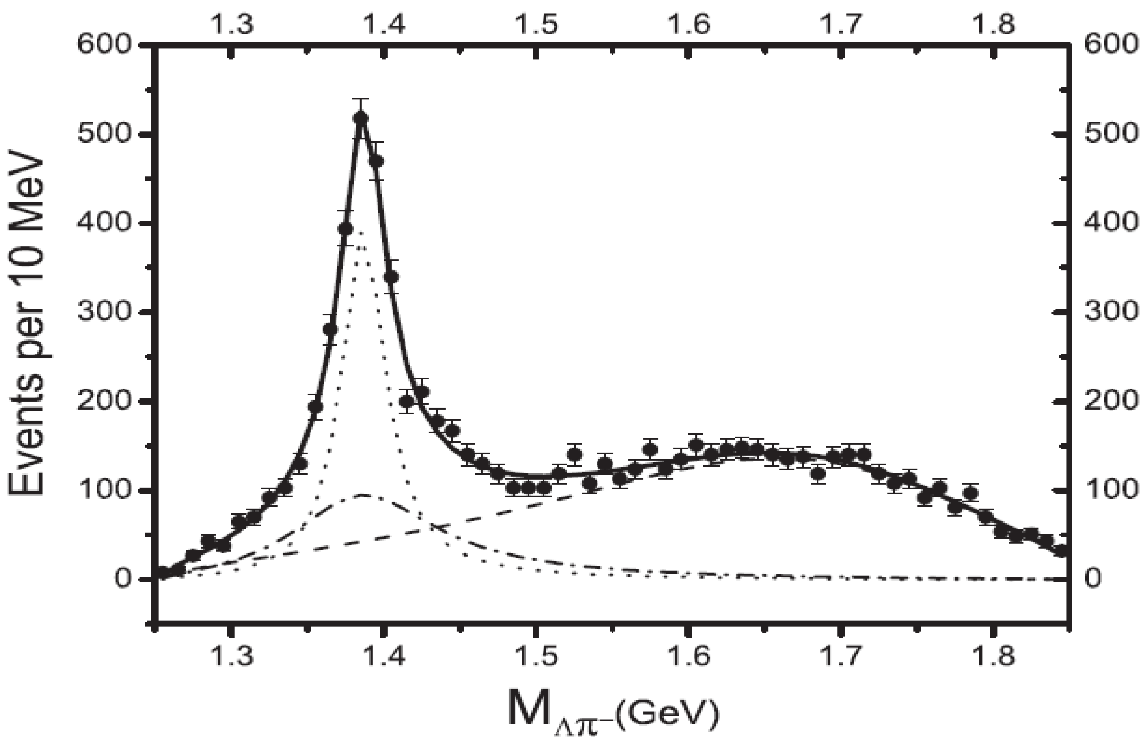
K. P. Khemchandani, A. Martinez Torres, and J. A. Oller, PRC 100, 015208 (2019).

in the fit. Two type of fits are found as a result. In both cases, the properties of $\Lambda(1405)$ are well reproduced. In addition to this, a Σ state is also found with mass around 1400 MeV. Cross sections,

PHYSICAL REVIEW D **80**, 017503 (2009)

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]



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

PHYSICAL REVIEW C **81**, 045210 (2010)

Possible evidence for the Σ^* resonance with $J^P = 1/2^-$ around 1380 MeV

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

PHYSICAL REVIEW C **81**, 055203 (2010)

Possible $\Sigma(\frac{1}{2}^-)$ under the $\Sigma^*(1385)$ peak in $K\Sigma^*$ photoproduction

Puze Gao, Jia-Jun Wu, and B. S. Zou

Yun-Hua Chen and B. S. Zou, PRC 88, 024304 (2013).

Ju-Jun Xie, Jia-Jun Wu, and Bing-Song Zou, PRC 90, 055204 (2014).

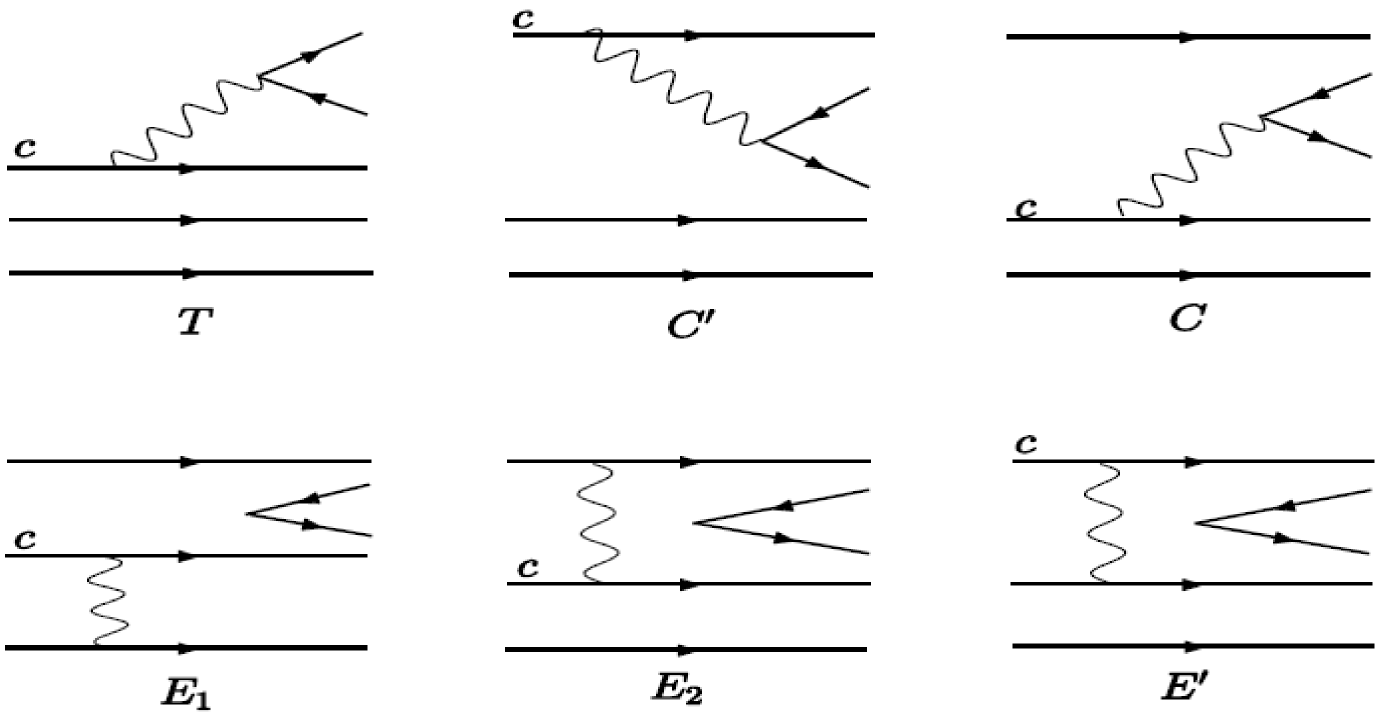
Theory

Λ_c^+ *two body decays*

Non-leptonic two-body weak decays of $\Lambda_c(2286)$

C.Q. Geng [a,b,*], Y.K. Hsiao [a,b], Yu-Heng Lin [b], Liang-Liang Liu [a]

Physics Letters B 776 (2018) 265–269



[11] H.Y. Cheng, B. Tseng, Phys. Rev. D 48 (1993) 4188.
[23] K.K. Sharma, R.C. Verma, Phys. Rev. D 55 (1997) 7067.
[24] K.K. Sharma, R.C. Verma, Eur. Phys. J. C 7 (1999) 217.

Λ_c^+ *three body decays*

PHYSICAL REVIEW D **93,** 056008 (2016)

Test flavor SU(3) symmetry in exclusive Λ_c decays

Cai-Dian Lü,[1,*] Wei Wang,[2,3,†] and Fu-Sheng Yu[4,‡]

$$\mathcal{A}(\Lambda_c \to p\bar{K}^0\pi^0) = \frac{1}{\sqrt{2}}\mathcal{A}^{(1)},$$

$$\mathcal{A}(\Lambda_c \to pK^-\pi^+) = -\frac{1}{2}\mathcal{A}^{(1)} + \frac{1}{\sqrt{2}}\mathcal{A}^{(2)},$$

$$\mathcal{A}(\Lambda_c \to n\bar{K}^0\pi^+) = -\frac{1}{2}\mathcal{A}^{(1)} - \frac{1}{\sqrt{2}}\mathcal{A}^{(2)}.$$

$$\sqrt{2}\mathcal{A}(\Lambda_c \to p\bar{K}^0\pi^0) + \mathcal{A}(\Lambda_c \to pK^-\pi^+) + \mathcal{A}(\Lambda_c \to n\bar{K}^0\pi^+) = 0.$$

K. Miyahara, T. Hyodo, and E. Oset, Phys. Rev. C 92, 055204 (2015).

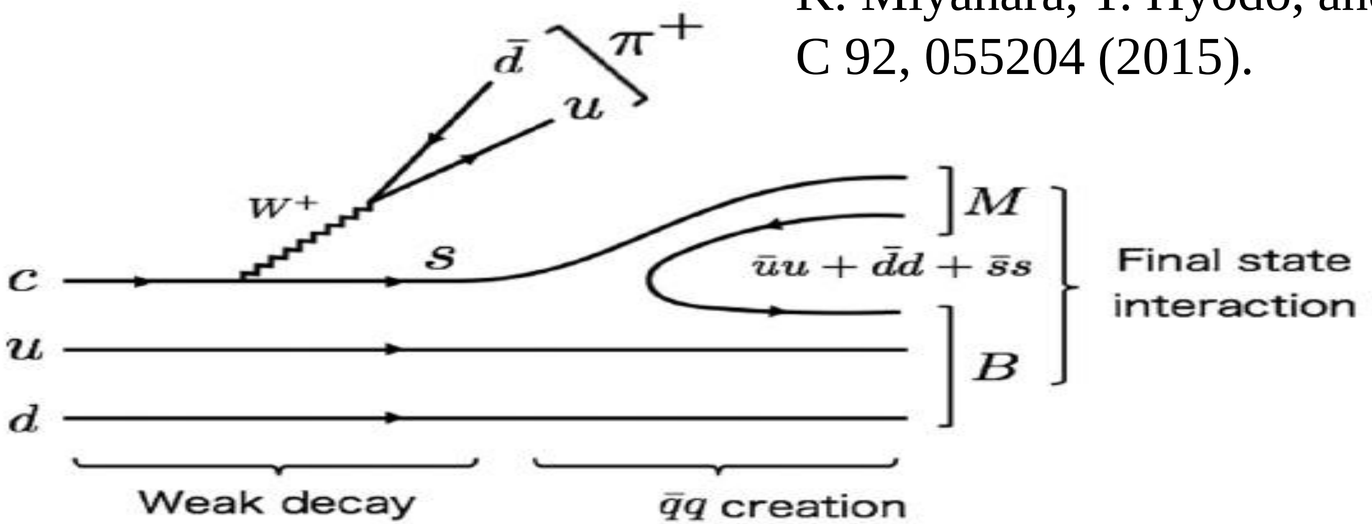
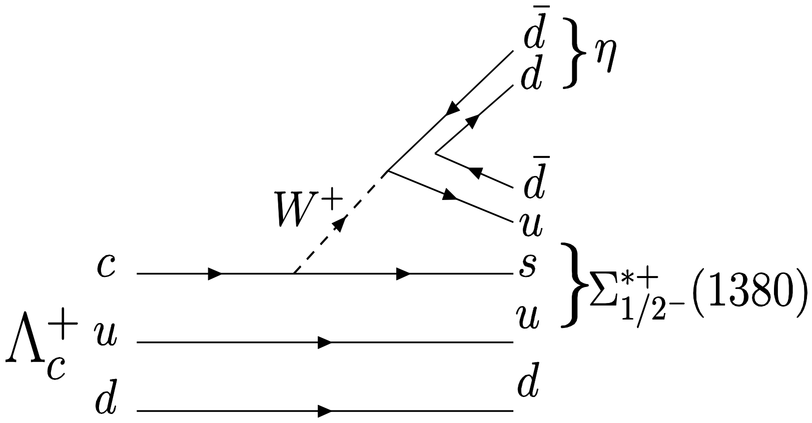
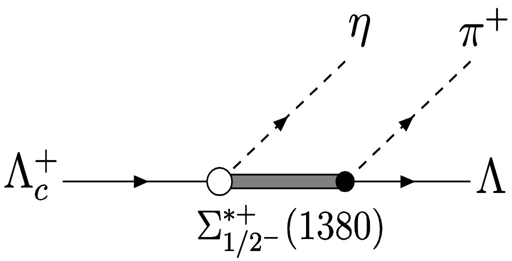


FIG. 1. The dominant diagram for the $\Lambda_c^+ \to \pi^+ MB$ decay. The solid lines and the wiggly line show the quarks and the W boson, respectively.

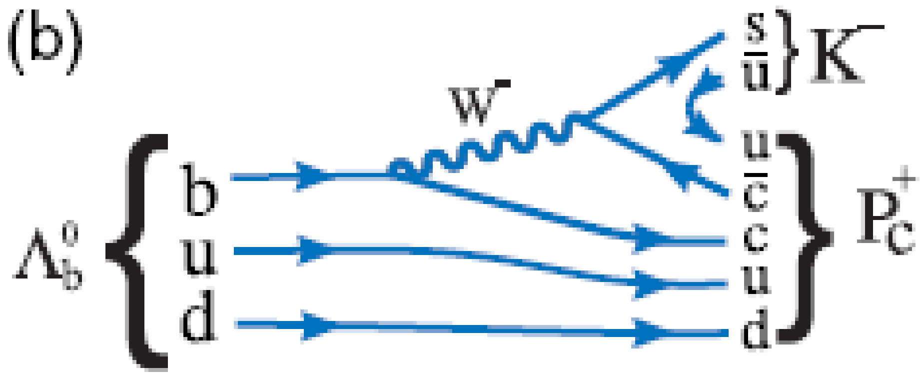
Σ(1380) in $\Lambda^+_c \to \eta\pi^+\Lambda$ decay



(a)



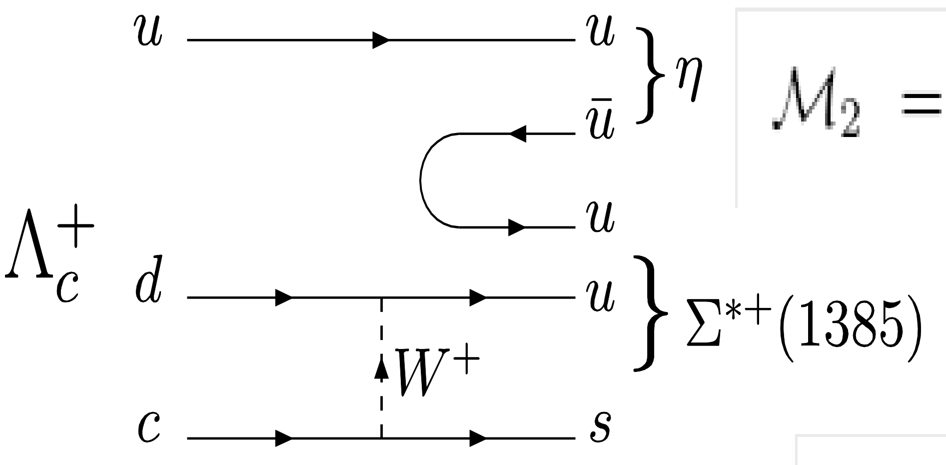
(b)



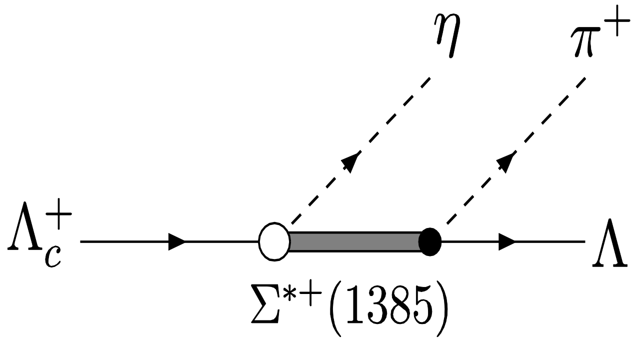
$$\mathcal{M}_1 = i g_{\pi\Lambda\Sigma_1^*} \bar{u}(p_3) G^{\Sigma_1^*}(q)(A_1 + B_1\gamma_5)u(p),$$

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

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



(a)



(b)

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

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

with

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

Invariant mass distributions

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

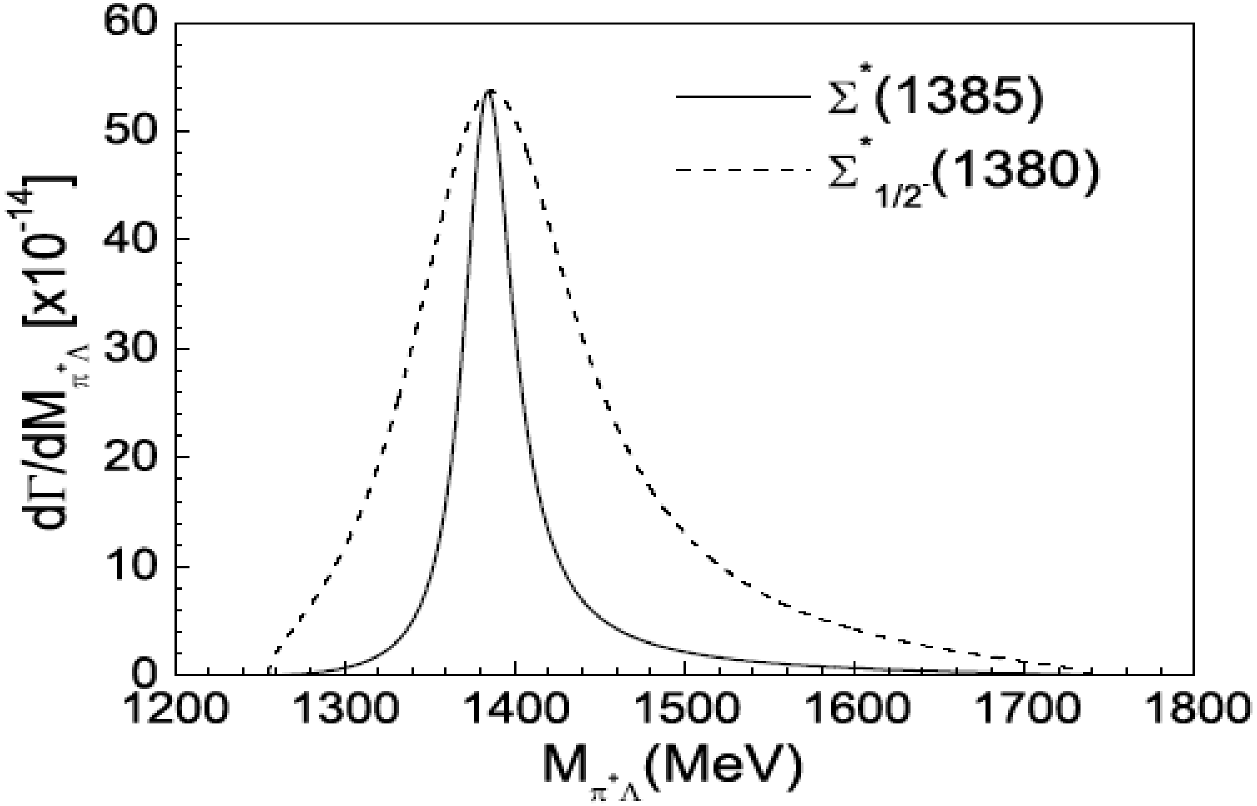


FIG. 5: Invariant mass distributions $d\Gamma/dM_{\pi+\Lambda}$ as a function of $M_{\pi+\Lambda}$.

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

Decay angle and energy distributions

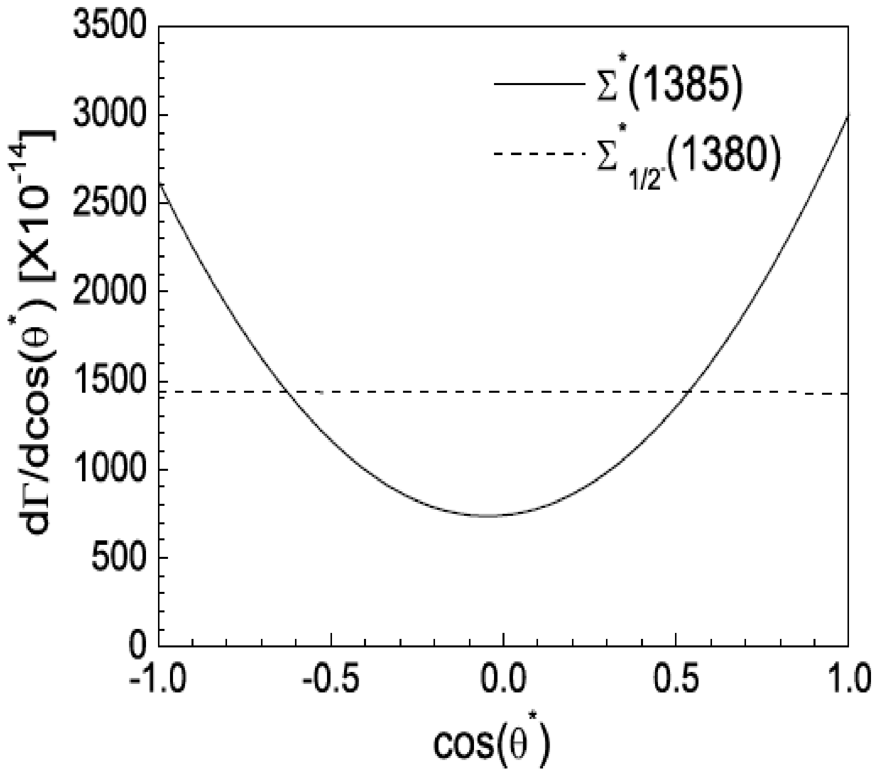


FIG. 6: Angle distributions $d\Gamma/d\cos\theta^*$ in the c.m. frame of $\pi^+\Lambda$ system as a function of $\cos\theta^*$.

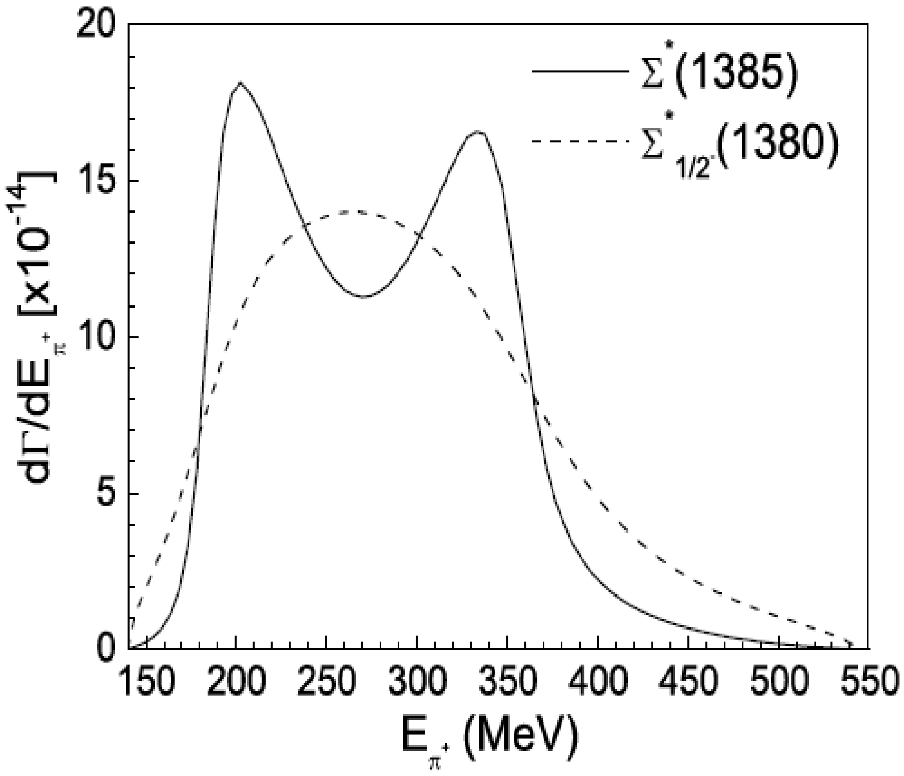
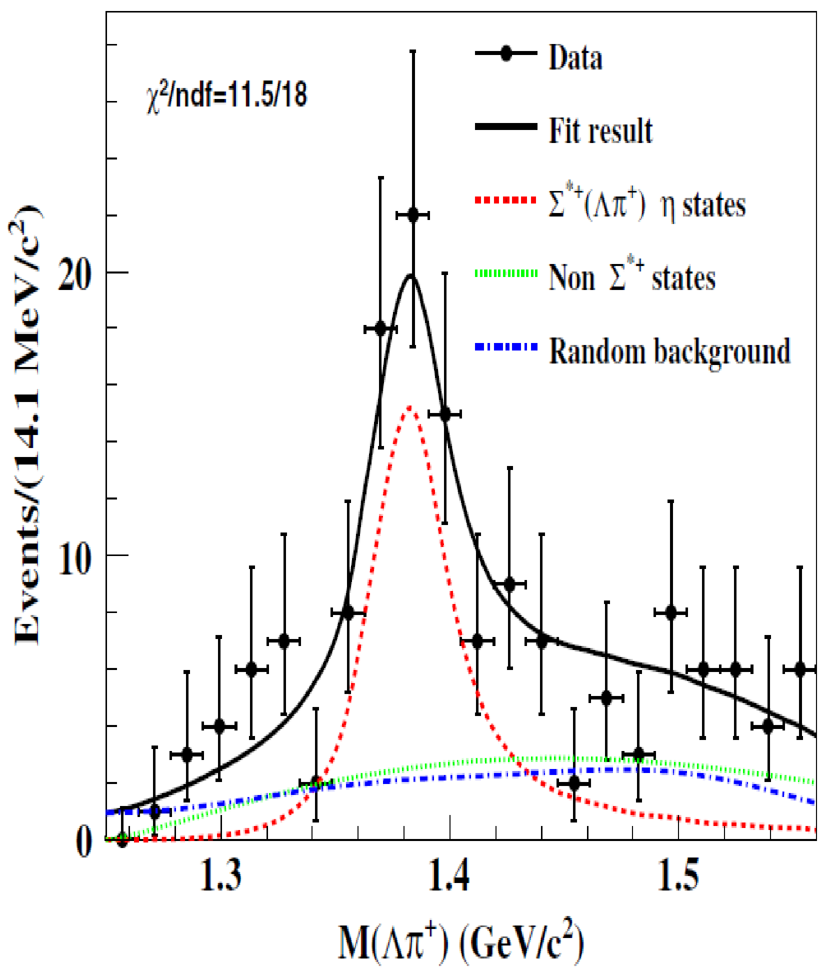
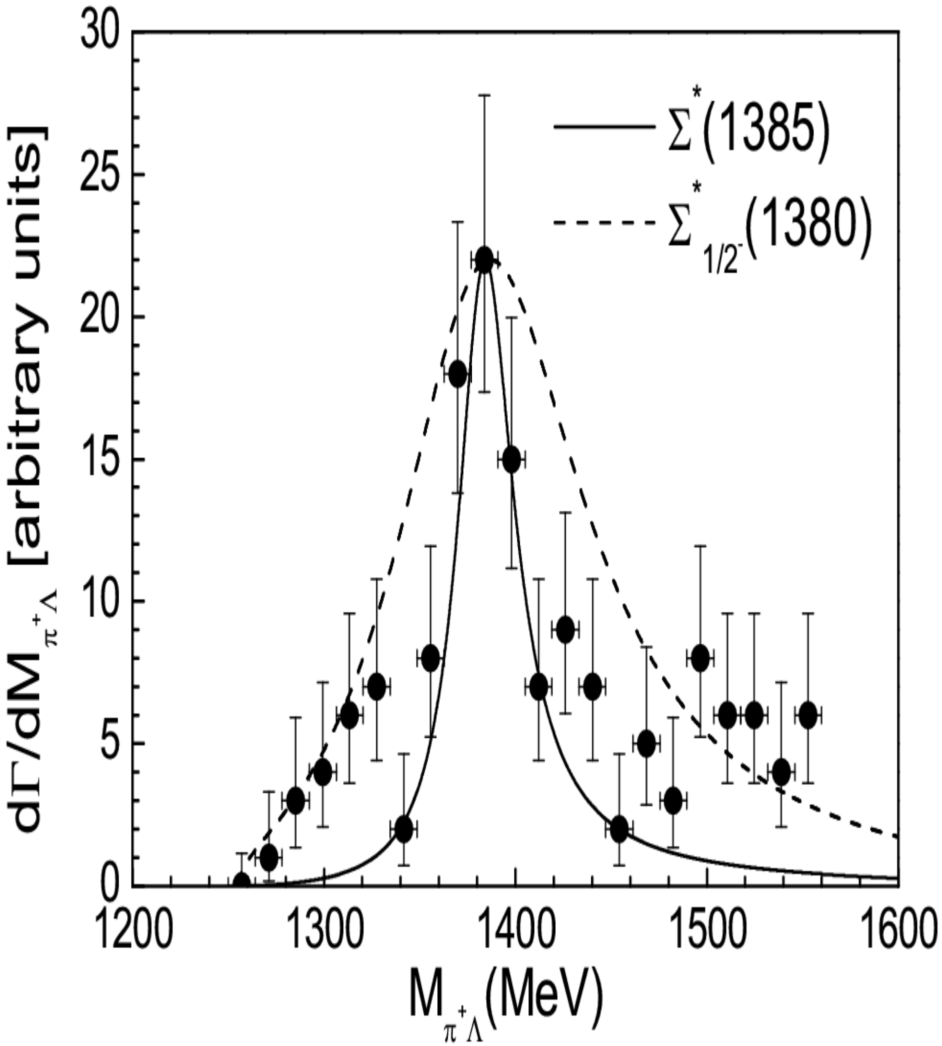


FIG. 7: Energy distributions $d\Gamma/dE_{\pi+}$ in the rest frame of Λ_c^+ as a function of $E_{\pi+}$.

$\pi^+\Lambda$ *invariant mass distributions at low energies*





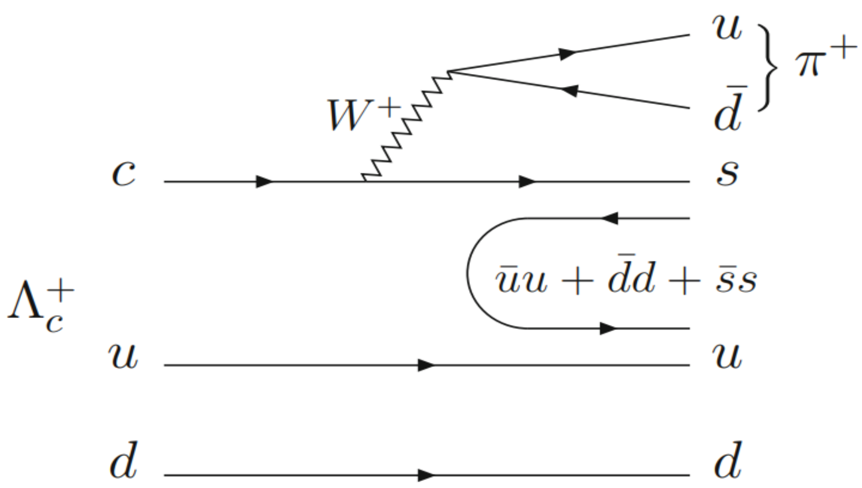
BESIII Collaboration, PRD 99, 032010 (2019).

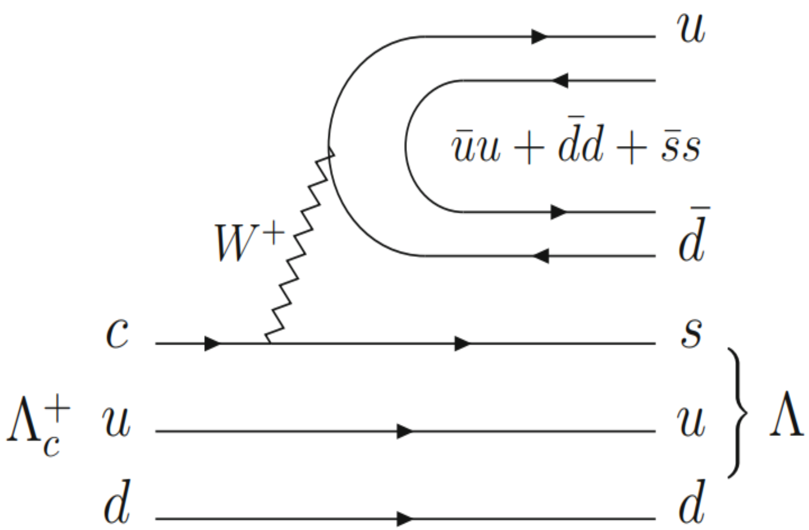
Other contributions

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

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

Σ^* *resonances*, $\to \pi^+\Lambda$ $\qquad$ $a_0(980)$, $\to \pi^+\eta$





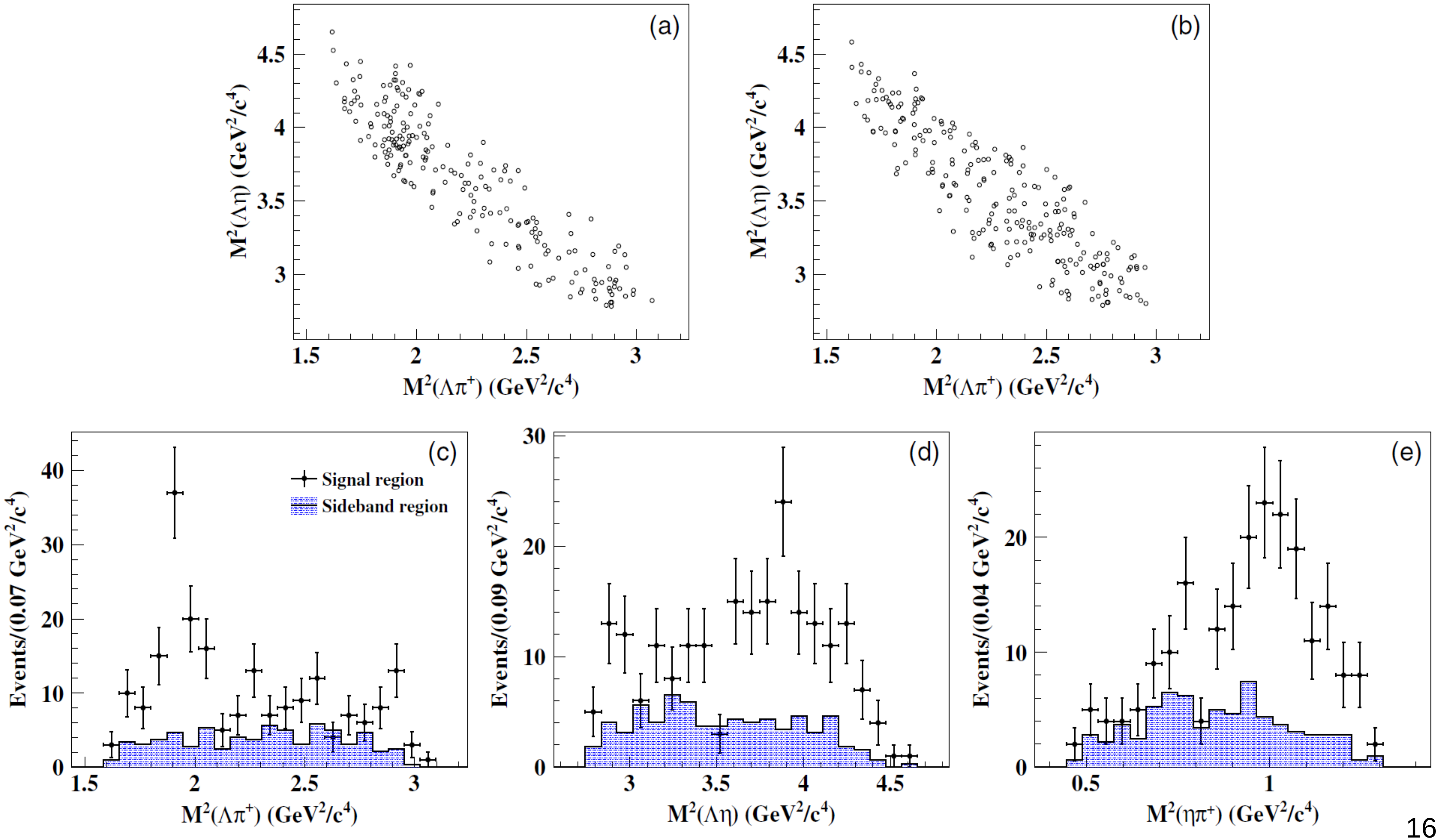
The $a_0(980)$ and $\Lambda(1670)$ in the $\Lambda_c^+ \to \pi^+\eta\Lambda$ decay

Ju-Jun Xie[1,3], Li-Sheng Geng[2,3,a] Eur. Phys. J. C (2016) 76:496

Measurement of the absolute branching fractions of $\Lambda_c^+ \to \Lambda\eta\pi^+$ and $\Sigma(1385)^+\eta$

(BESIII Collaboration)

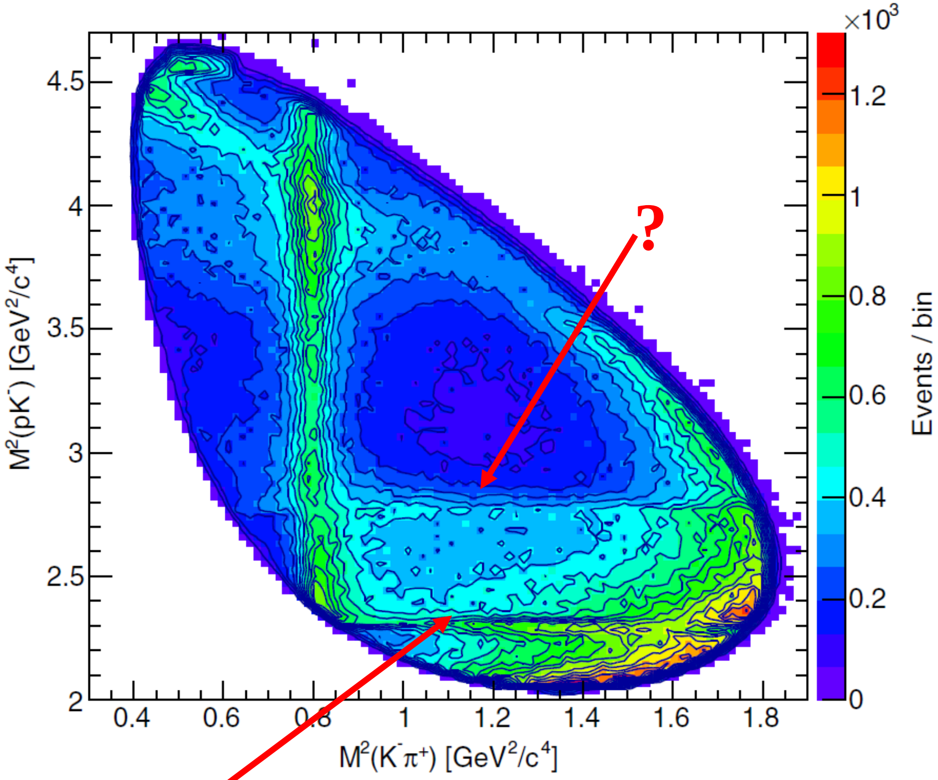
PRD 99, 032010 (2019).



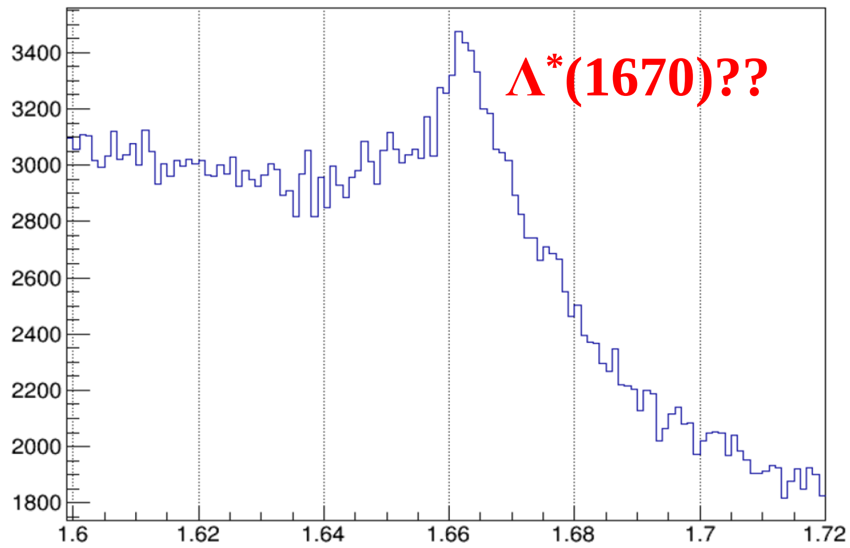
Observation of "Λ(1663)"

Dalitz plot for $\Lambda^+_c \to \pi^+ p K^-$

Belle, PRL117,011801(2016)
1.452 $\times 10^6$ events



■ 1D projection -- $M(pK^-)$



✓ **Bin width: 1 MeV**

✓ **M≈1663 MeV**

✓ **Γ ≈10 MeV**

Λ(1670): 25-50 MeV
Λ(1690): ~60 MeV

✓ **$\Lambda\eta$ threshold: 1663.545 MeV**

From C.P. Shen's talk, no published result concerning "Λ(1663)"

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)]

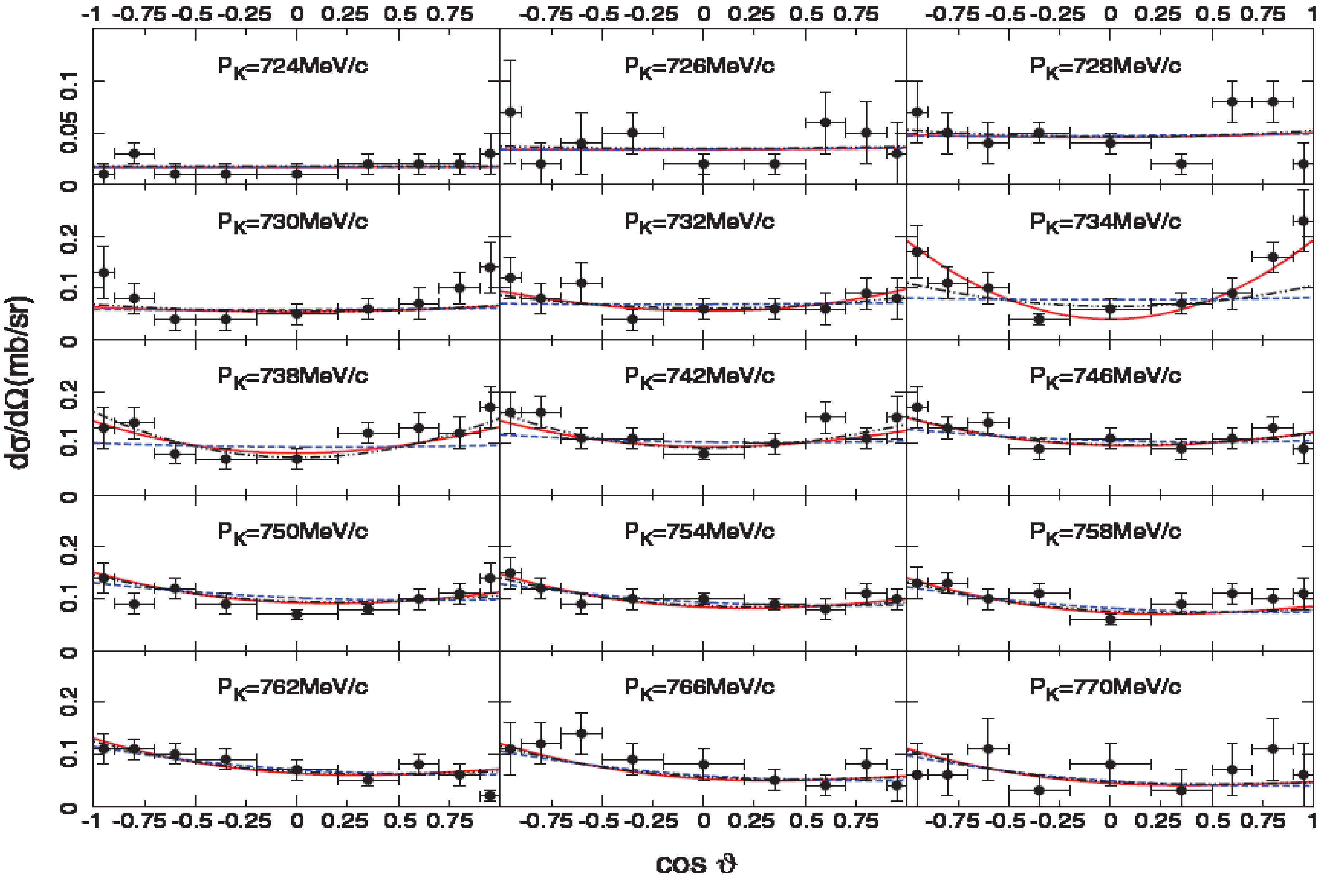
    $J^P=3/2^+$ (P_{03}), $M=1671^{+2}_{-8}$ MeV, $\Gamma=10^{+22}_{-4}$ MeV

  - 刘伯超 & 谢聚军 [PRC 85, 038201 (2012); PRC 86, 055202 (2012)]
  -

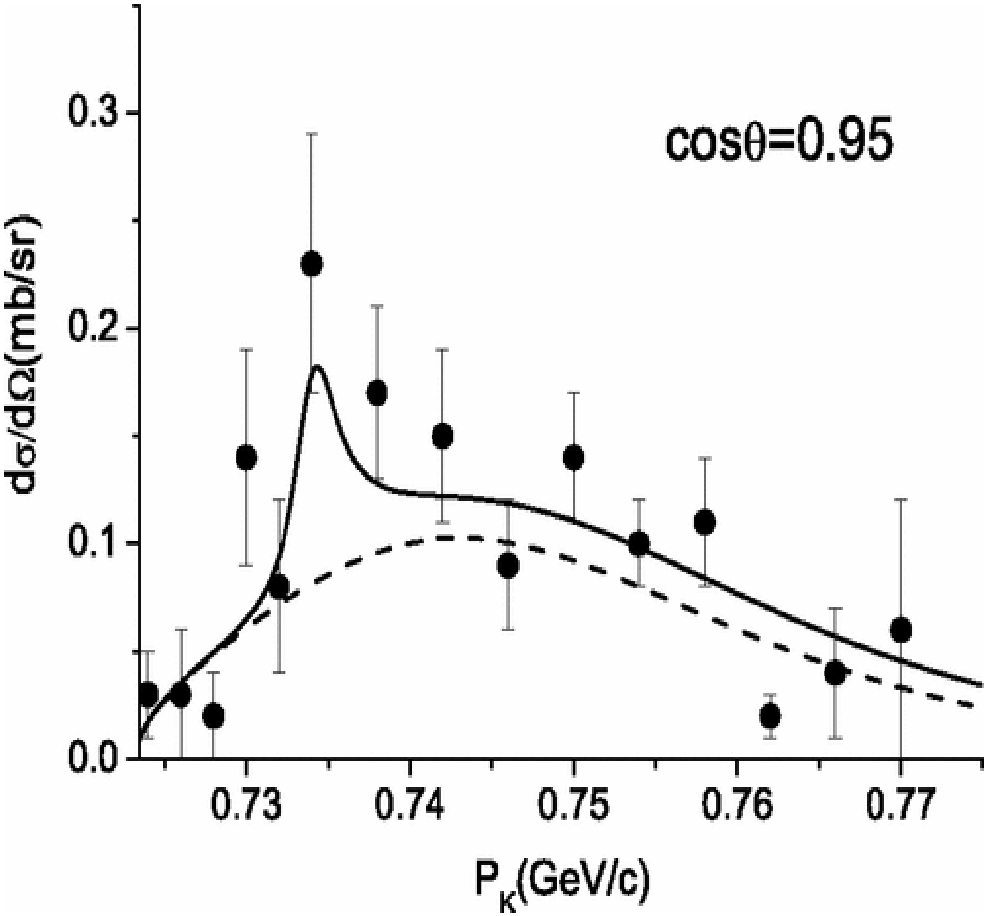
    $J^P=3/2^-$ (D_{03}), $M=1668.5\pm0.5$ MeV, $\Gamma=1.5\pm0.5$ MeV

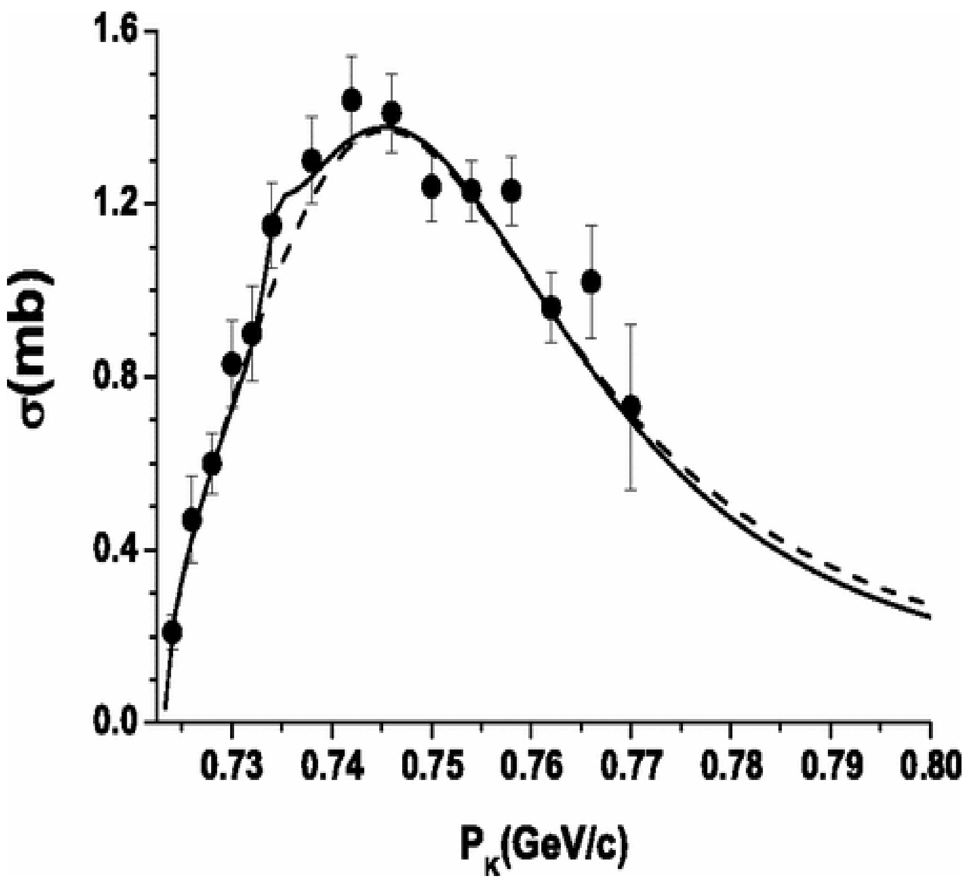
    Couples strongly to $\Lambda\eta$ channel

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



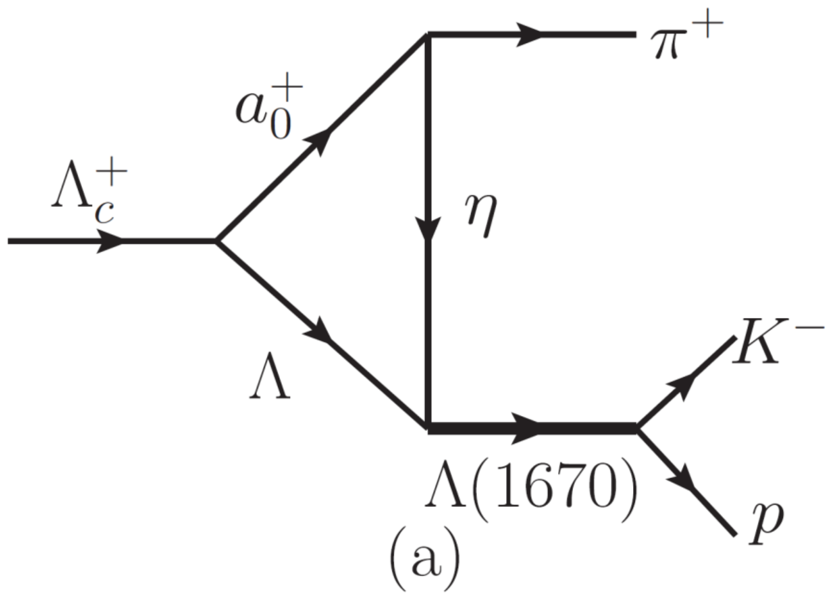
Total cross sections for $K^- p \to \eta\Lambda$ reaction





Bo-Chao Liu and Ju-Jun Xie, Phys. Rev. C **86**, 055202 (2012).

Contributions from re-scattering processes



- ✓ **Cabibbo-favored process**
- ✓ **Strong couplings**
- ✓ **Exp. value:** $Br(\Lambda_c \to \Lambda\eta\pi^+) \sim (2.2 \pm 0.5)\%$

$$Br(\Lambda_c \to \Sigma(1385)\ \eta \to \Lambda\eta\pi^+) \sim (1.06 \pm 0.32)\%$$

Xiao-Hai Liu, Gang Li, Ju-Jun Xie, and Qiang Zhao, Phys. Rev. D **100**, 054006 (2019).

Kinematic region of triangle singularity (TS)

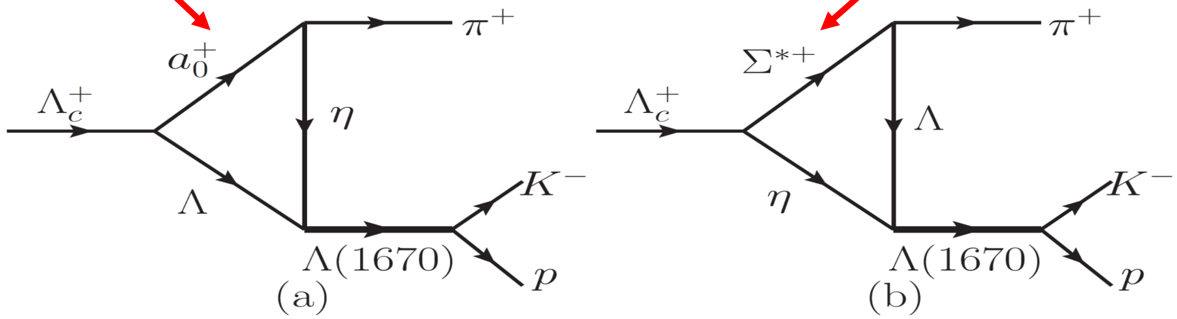
$$\frac{m_1 m_{\pi^+}^2 + m_3 M_{\Lambda_c^+}^2}{m_1 + m_3} - m_1 m_3 \le m_2^2 \le (M_{\Lambda_c^+} - m_1)^2$$

$$(m_1 + m_3)^2 \le s^- \le (m_1 + m_3)^2 + \frac{m_1[(m_2 - m_3)^2 - m_{\pi^+}^2]}{m_2}$$

Liu, Oka, Zhao, PLB753,297 (2016).

$1.06 \le m_2 \le 1.17$ GeV

$1.70 \le m_2 \le 1.74$ GeV



F.K. Guo, X.H. Liu and S. Sakai, **Threshold cusps and triangle singularities in hadronic reactions**, arXiv:1912.07030 [hep-ph].

Re-scattering Amplitude

$$\mathcal{T} = \frac{1}{s - M^2_{\Lambda(1670)} + iM_{\Lambda(1670)}\Gamma_{\Lambda(1670)}}$$

$$\times \int \frac{d^4 q_1}{(2\pi)^4} \frac{\mathcal{A}}{(q_1^2 - m_1^2)(q_2^2 - m_2^2)(q_3^2 - m_3^2)},$$

with $\mathcal{A} = \mathcal{M}(\Lambda_c^+ \to \Lambda a_0^+)\mathcal{M}(a_0^+ \to \eta\pi^+)\mathcal{M}(\eta\Lambda \to \Lambda(1670))\mathcal{M}(\Lambda(1670) \to K^- p)$ and $\mathcal{A} = \mathcal{M}(\Lambda_c^+ \to \eta\Sigma^{*+})\mathcal{M}(\Sigma^{*+} \to \Lambda\pi^+)\mathcal{M}(\eta\Lambda \to \Lambda(1670))\mathcal{M}(\Lambda(1670) \to K^- p)$ for a_0-loop and Σ^*-loop

$$\mathcal{M}(\Lambda_c^+ \to \Lambda a_0^+/\eta\Sigma^{*+}) = g_A \bar{u}_f u_i + i g_B \bar{u}_f \gamma_5 u_i$$

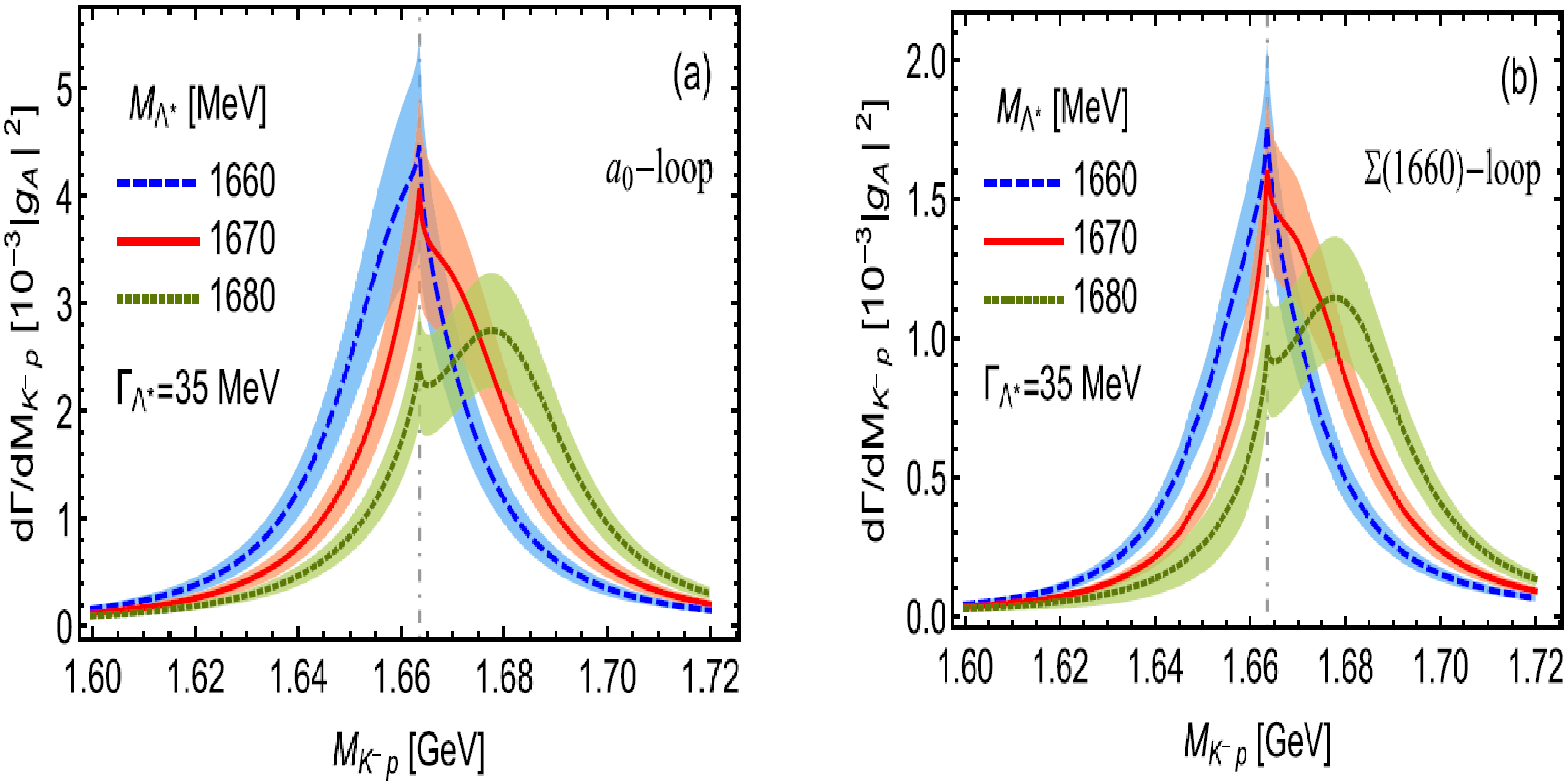
Estimation:

$R \equiv |g_B|/|g_A|$ **~1**

$|g_A|^2_{\max} \approx 0.32\ \mathrm{GeV}^{-1}/\tau_{\Lambda_c}$ for Λa_0^+ channel

$|g_A|^2_{\max} \approx 3.14\ \mathrm{GeV}^{-1}/\tau_{\Lambda_c}$ for $\Sigma(1660)\eta$ channel

Numerical results



Xiao-Hai Liu, Gang Li, Ju-Jun Xie, and Qiang Zhao, Phys. Rev. D **100**, 054006 (2019).

Summary

The Λ_c^+ decays can be used to study the light baryon resonances.

However

一切都是刚刚起步！！！

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

Thank you very much for your attention!