Low-lying hadron states in Λ_c^+ decays

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Outline

Introduction

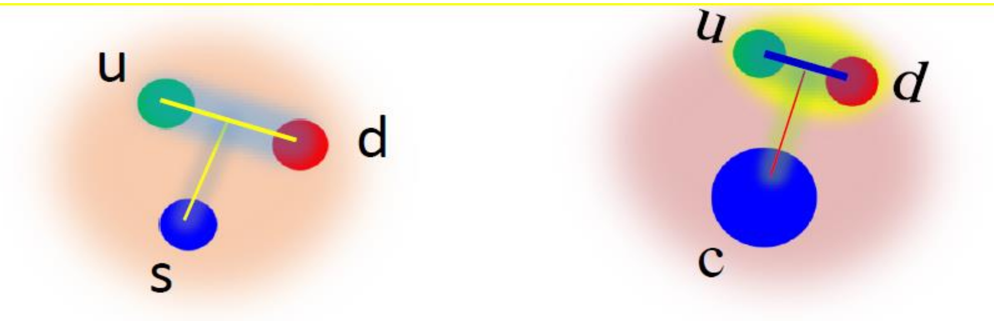
$Possible\ \Sigma^*_{1/2^-}\ state\ in\ \Lambda_c^+ \to \eta\pi^+\Lambda\ decay$

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

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

Summary

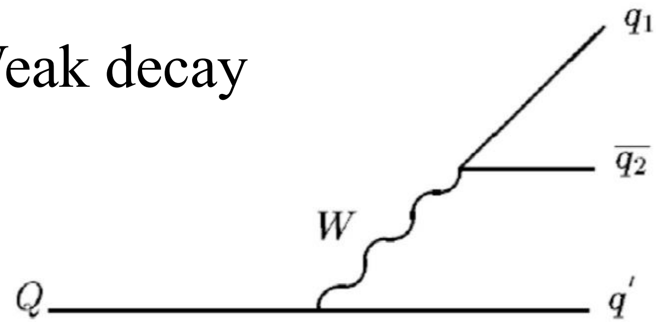
Λ_c^+ The lightest charmed baryon



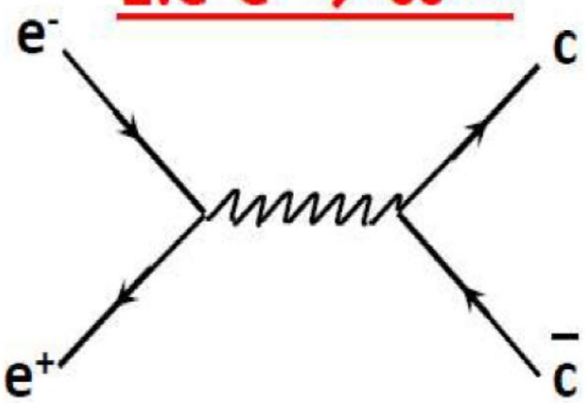
Strange baryons (Λ[uds])
$m_u, m_d \approx m_s$ → (qqq) uniform

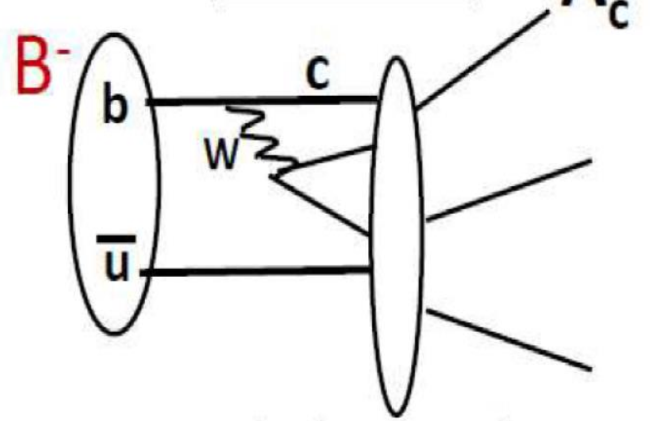
Charmed baryon (Λ_c[udc])
$m_u, m_d \ll m_c$ → diquark + quark
(qq) (Q)

Weak decay



Its production:





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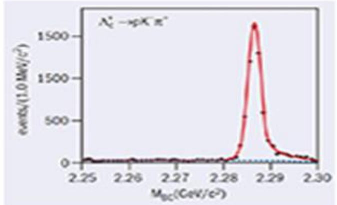
Mar 18, 2016

BESIII makes first direct measurement of the Λ_c at threshold



Beam-constrained mass distribution

The charmed baryon, Λ_c, was first observed at Fermilab in 1976. Now, 40 years later, the Beijing Spectrometer (BESIII) experiment at the Beijing Electron-Positron Collider II (BEPCII) has measured the absolute branching fraction of $\Lambda^+_c \to pK^-\pi^+$ at threshold for the first time.

Because the decays of the Λ^+_c to hadrons proceed only through the weak interaction, their branching fractions are key probes for understanding weak interactions inside of a baryon. In particular, precise measurements of the decays of the Λ^+_c will provide important information on the final-state strong interaction in the charm sector, thereby improving the understanding of quantum chromodynamics in the non-perturbative energy region. In addition, because most of the

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From Prof. Yang-Heng Zheng's PPT

$\Lambda_c^+ \to \pi^+ MB$ three body decays

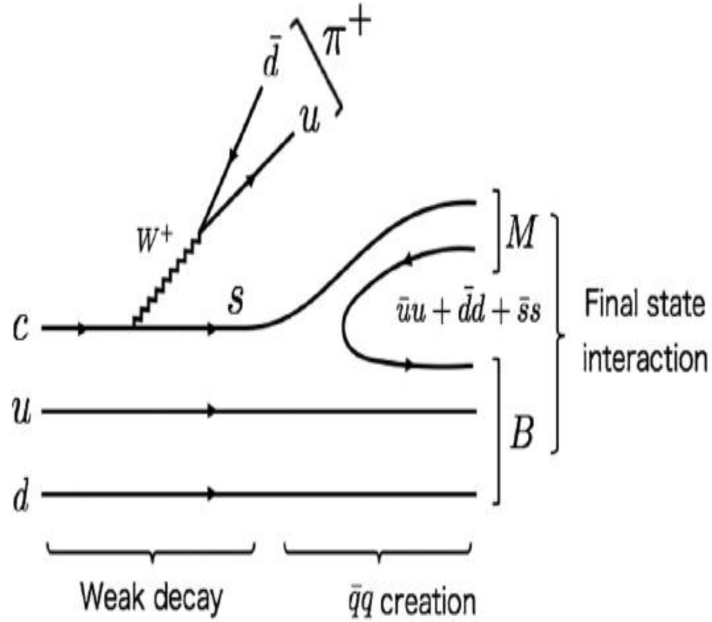
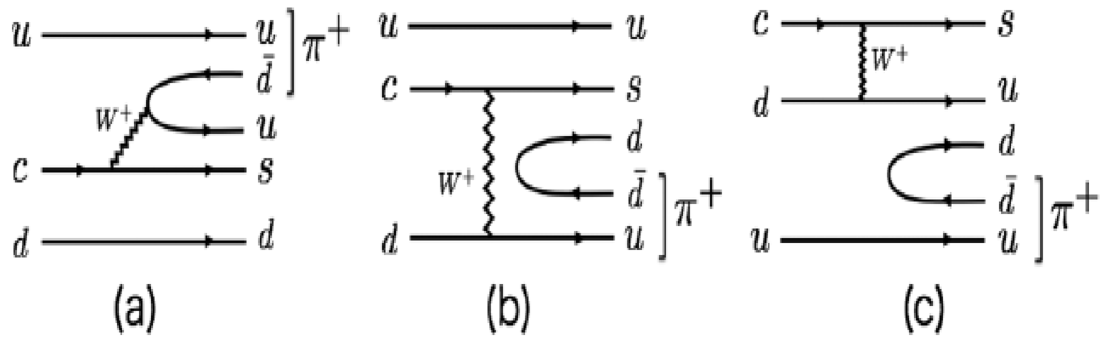
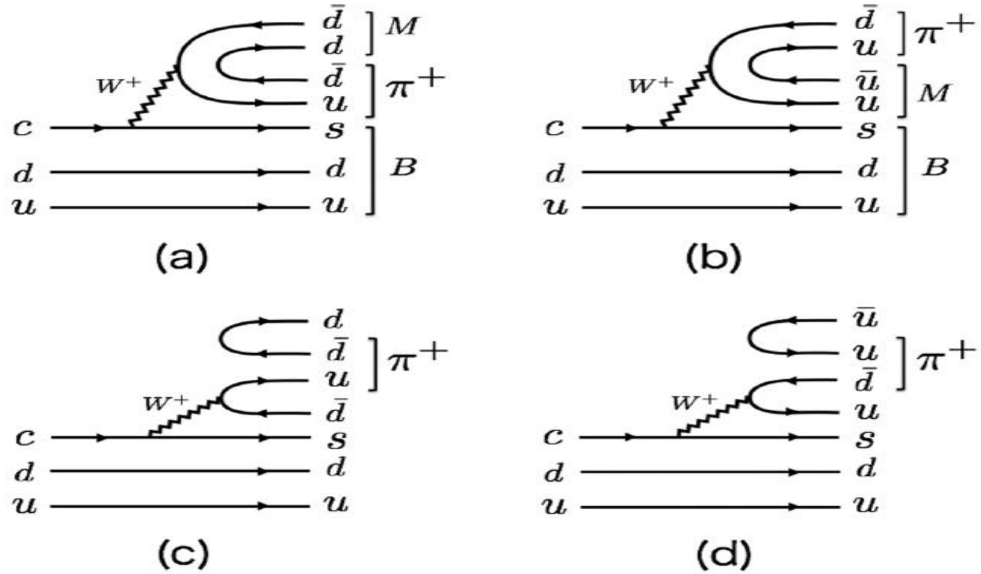


FIG. 1. The dominant diagram for the $\Lambda_c^+ \to \pi^+ MB$ decay. The solid lines and the wiggly line show the quarks and the W boson, respectively.





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

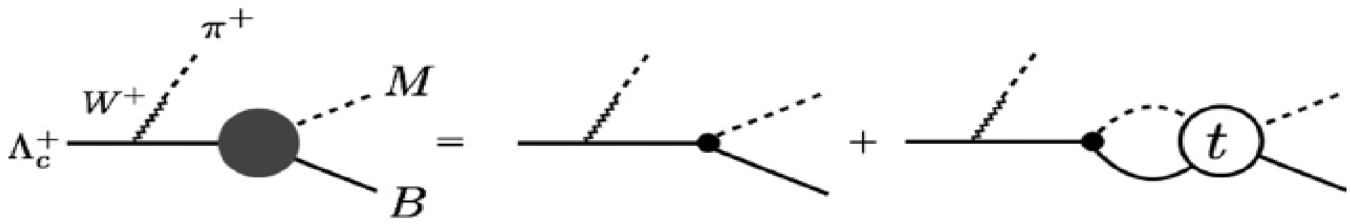
Weak decay of Λ_c^+ for the study of $\Lambda(1405)$ and $\Lambda(1670)$

$$|MB\rangle = \frac{1}{\sqrt{2}}|s(\bar{u}u + \bar{d}d + \bar{s}s)(ud - du)\rangle$$
$$= \frac{1}{\sqrt{2}}\sum_{i=1}^{3}|P_{3i}q_i(ud - du)\rangle,$$

$$q \equiv \begin{pmatrix} u \\ d \\ s \end{pmatrix}, \quad P \equiv q\bar{q} = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} \\ d\bar{u} & d\bar{d} & d\bar{s} \\ s\bar{u} & s\bar{d} & s\bar{s} \end{pmatrix}.$$

$$\begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} & \pi^+ & K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} & K^0 \\ K^- & \bar{K}^0 & -\frac{\eta}{\sqrt{3}} + \frac{2\eta'}{\sqrt{6}} \end{pmatrix}$$

$$|MB\rangle = |K^-p\rangle + |\bar{K}^0 n\rangle - \frac{\sqrt{2}}{3}|\eta\Lambda\rangle.$$



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

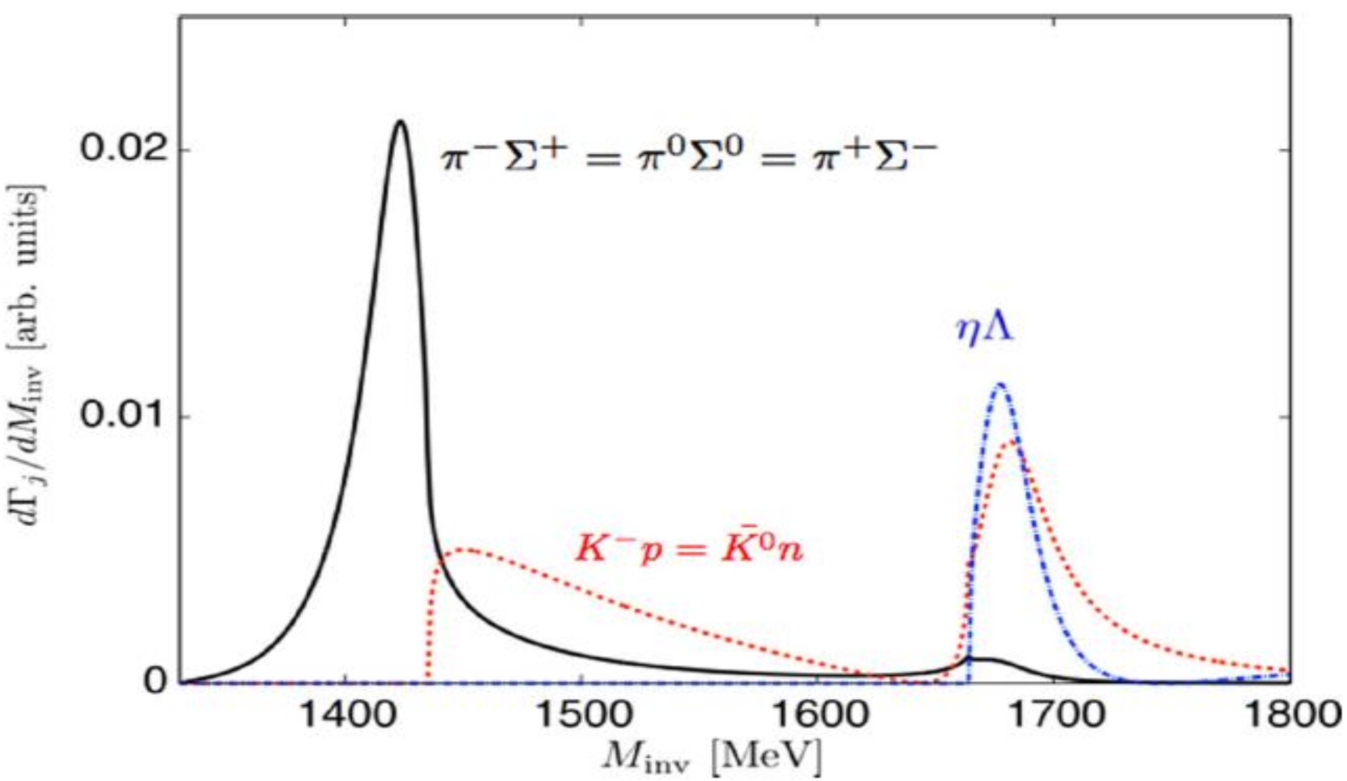
$$\mathcal{M}_j = V_P \left[h_j + \sum_i h_i G_i(M_{\rm inv}) t_{ij}(M_{\rm inv}) \right],$$

$$h_{\pi^0\Sigma^0} = h_{\pi^-\Sigma^+} = h_{\pi^+\Sigma^-} = h_{\pi^0\Lambda} = 0,$$

$$h_{K^-p} = h_{\bar{K}^0 n} = 1, \quad h_{\eta\Lambda} = -\frac{\sqrt{2}}{3},$$

$$h_{\eta\Sigma^0} = h_{K^+\Xi^-} = h_{K^0\Xi^0} = 0,$$

$$\frac{d\Gamma_j}{dM_{\rm inv}} = \frac{1}{(2\pi)^3} \frac{p_{\pi^+} \tilde{p}_j M_{\Lambda_c^+} M_j}{M_{\Lambda_c^+}^2} |\mathcal{M}_j|^2,$$



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

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

Quark Model Predictions

	(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).

Other Model Predictions

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

z_R	$1401 + 40i$	
$(I = 1)$	g_i	$\|g_i\|$
$\pi\Lambda$	$0.60 + 0.47\,i$	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).

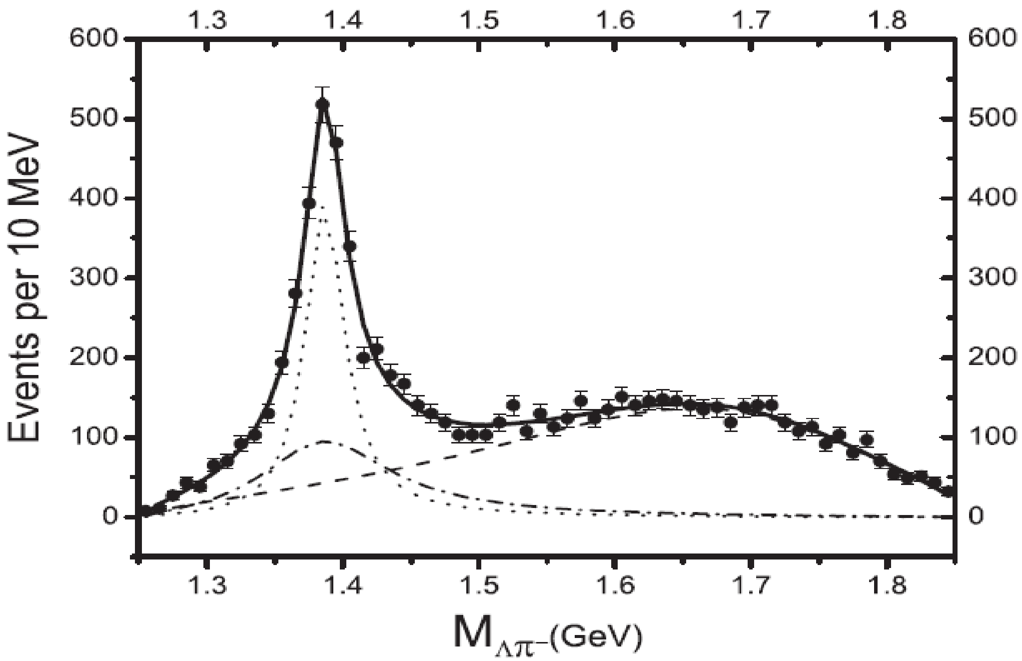
K. P. Khemchandani, A. Martinez Torres, and J. A. Oller, Phys.Rev. C100, 015208 (2019).

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]

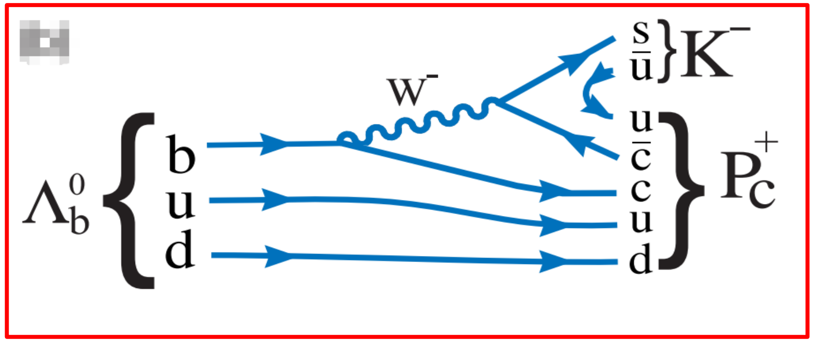
PHYSICAL REVIEW C **81**, 055203 (2010)

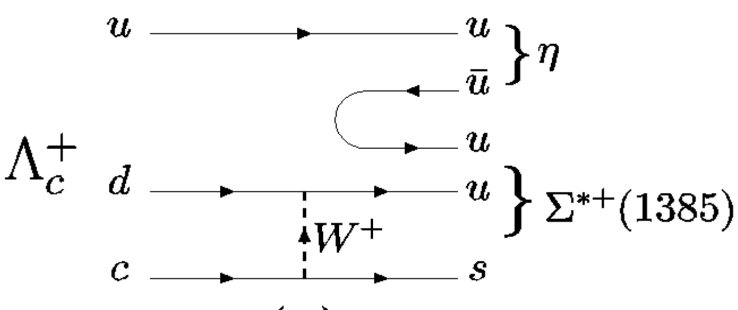
Possible $\Sigma(\frac{1}{2}^-)$ under the $\Sigma^*(1385)$ peak in $K\Sigma^*$ photoproduction

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

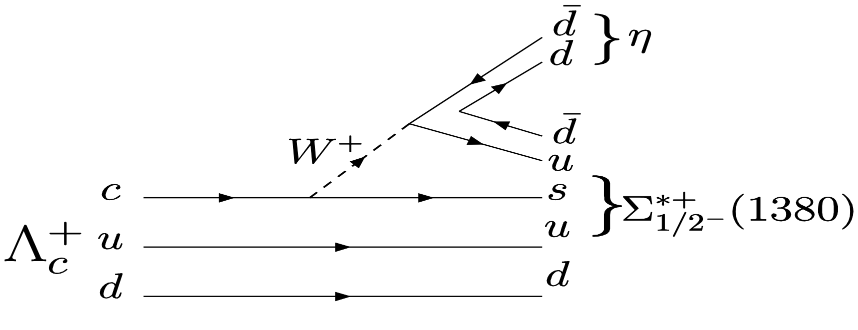
Yun-Hua Chen and B. S. Zou, PRC 88, 024304 (2013).

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

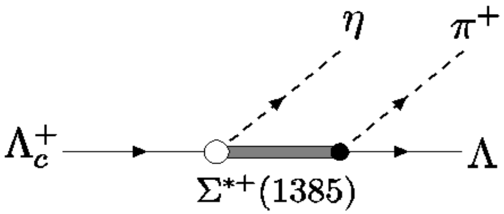




(a)



(a)



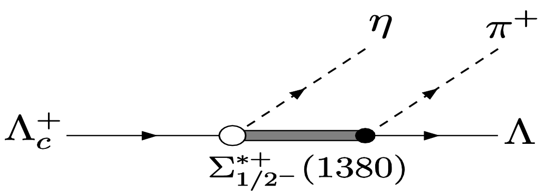
(b)

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

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

with

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



(b)

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

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

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

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

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

PHYSICAL REVIEW D **95,** 074024 (2017)

$\Sigma^*_{1/2^-}(1380)$ in the $\Lambda_c^+ \to \eta\pi^+\Lambda$ decay

Ju-Jun Xie[1] and Li-Sheng Geng[2,*]

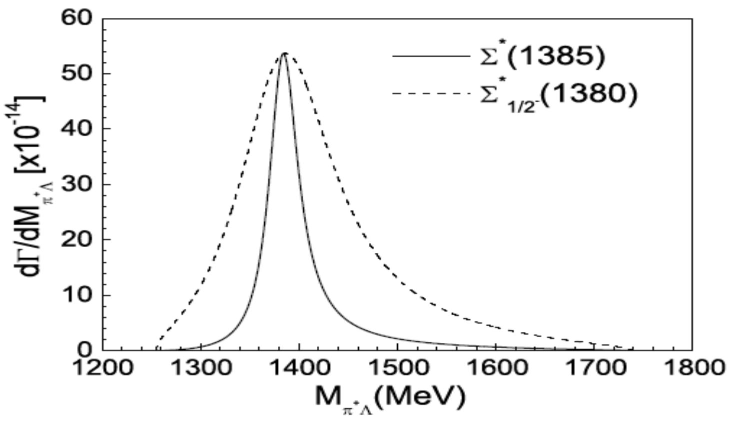


FIG. 5: Invariant mass distributions $d\Gamma/dM_{\pi^+\Lambda}$ as a function of $M_{\pi^+\Lambda}$.

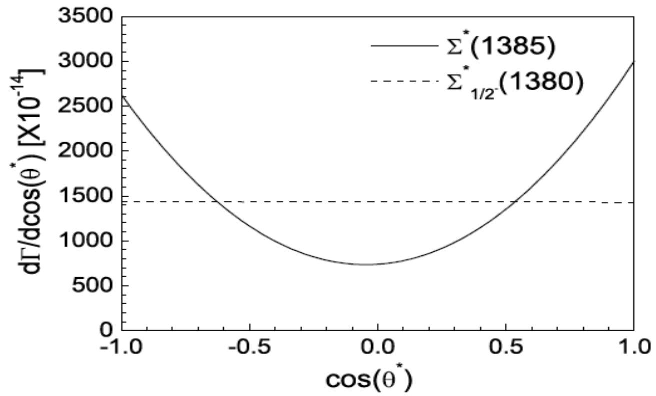


FIG. 6: Angle distributions $d\Gamma/d\cos\theta^*$ in the c.m. frame of $\pi^+\Lambda$ system as a function of $\cos\theta^*$.

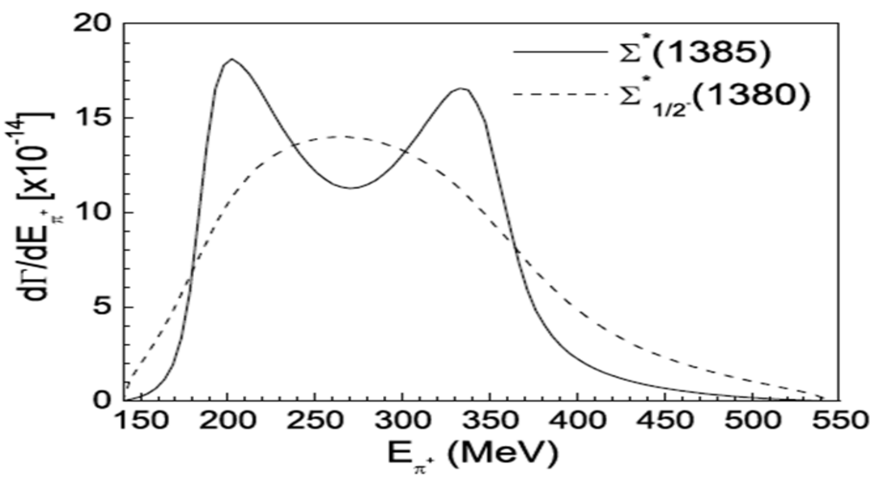
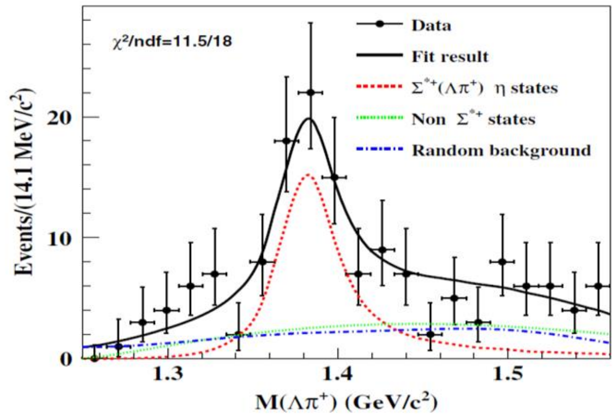
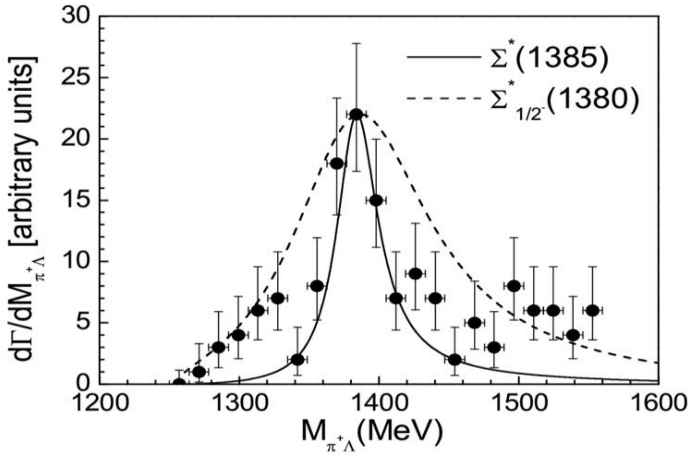


FIG. 7: Energy distributions $d\Gamma/dE_{\pi^+}$ in the rest frame of Λ_c^+ as a function of E_{π^+}.

Measurement of the absolute branching fractions of $\Lambda_c^+ \to \Lambda\eta\pi^+$ and $\Sigma(1385)^+\eta$ (BESIII Collaboration) PRD 99, 032010 (2019).





PHYSICAL REVIEW LETTERS **134**, 021901 (2025)

Observation of $\Lambda_c^+ \to \Lambda a_0(980)^+$ and Evidence for $\Sigma(1380)^+$ in $\Lambda_c^+ \to \Lambda\pi^+\eta$

M. Ablikim *et al.**
(BESIII Collaboration)

(Received 17 July 2024; revised 19 November 2024; accepted 4 December 2024; published 17 January 2025)

Eur. Phys. J. C (2016) 76:496
DOI 10.1140/epjc/s10052-016-4342-z
THE EUROPEAN PHYSICAL JOURNAL C
Regular Article - Theoretical Physics

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]

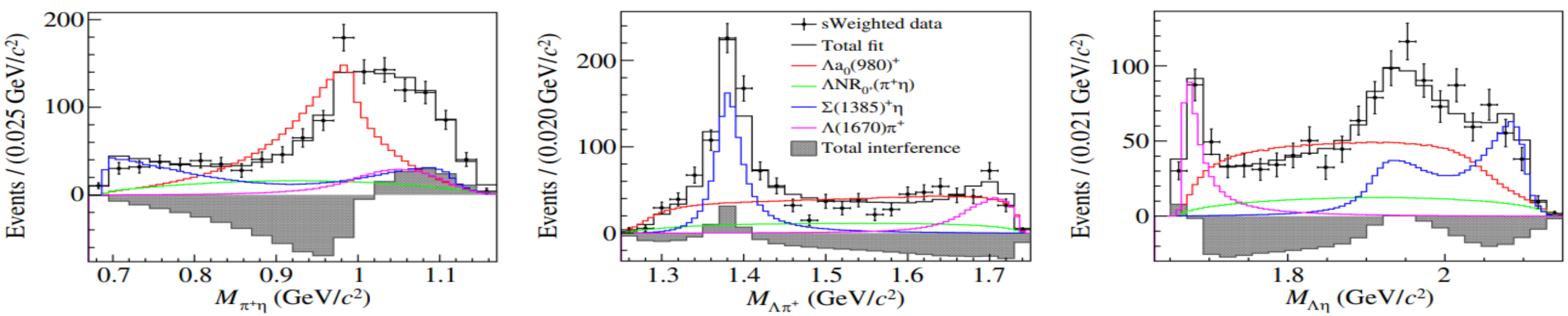


FIG. 2. Projections of the fit results in the $M_{\pi^+\eta}$, $M_{\Lambda\pi^+}$, and $M_{\Lambda\eta}$ spectra. Points with error bars are sWeighted data at all energy points. The curves in different colors are different components.

Chinese Physics Letters **41**, 101401 (2024) **Review**

Review of the Low-Lying Excited Baryons $\Sigma^*(1/2^-)$

En Wang(王恩)[1,2*], Li-Sheng Geng(耿立升)[3,4,5,6], Jia-Jun Wu(吴佳俊)[7,6], Ju-Jun Xie(谢聚军)[6,8,9], and Bing-Song Zou(邹冰松)[10,11,7,6]

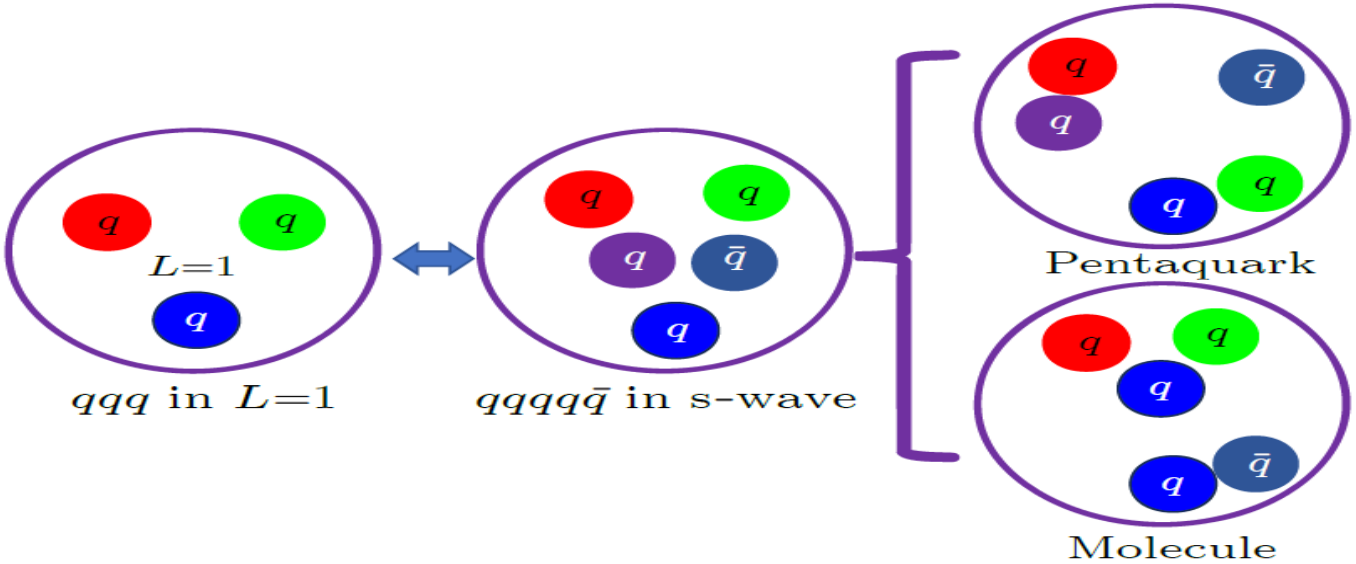


Fig. 2. The qqq and $qqqq\bar{q}$ configurations for the low-lying excited baryons with $J^P = 1/2^-$.

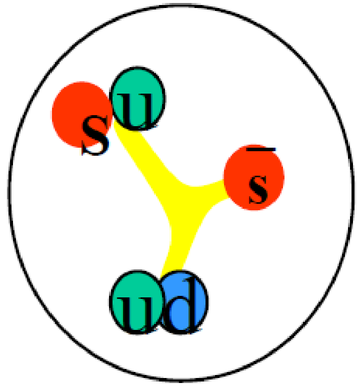
BUT:

Difficult to distinguish them.

$N^*(1535)$: strangeness component

Couples strongly to strangeness channel

uud (L=1) $1/2^-$ ~ N*(1535) ~ [ud][us] $\bar{s}$



	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	32–52 %
Γ_2	$N\eta$	30–55 %

Larger [ud][us] $\bar{s}$ component in N*(1535) makes it coupling strong to Nη & KΛ.

$J/\psi \to \bar{p}N^* \to \bar{p}(K\Lambda) / \bar{p}(p\eta) \to$ large $g_{N^*K\Lambda}$

Liu&Zou, PRL96 (2006) 042002; Geng,Oset,Zou&Doring, PRC79 (2009) 025203

$\gamma p \to p\eta'$ & $pp \to pp\eta' \to$ large $g_{N^*N\eta'}$

M.Dugger et al., PRL96 (2006) 062001; Cao&Lee, PRC78(2008) 035207

$\pi^- p \to n\phi$ & $pp \to pp\phi$ & $pn \to d\phi \to$ large $g_{N^*N\phi}$

Xie, Zou & Chiang, PRC77(2008)015206; Cao, Xie, Zou & Xu, PRC80(2009)025203

$N^*(1535)$: dynamically generated state

- Pole position

PDG 2024 → $Z_R = [(1500\sim1520) - i(40\sim65)]$ MeV

PHYSICAL REVIEW C, VOLUME 65, 035204

Chiral unitary approach to S-wave meson baryon scattering in the strangeness $S=0$ sector

T. Inoue,* E. Oset, and M. J. Vicente Vacas

Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC, Institutos de Investigación de Paterna, Apartado Correos 22085, E-46071 Valencia, Spain

(Received 31 October 2001; published 14 February 2002)

Chiral dynamics of the $S_{11}(1535)$ and $S_{11}(1650)$ resonances revisited

Peter C. Bruns[a], Maxim Mai[b,*], Ulf-G. Meißner[b,c]

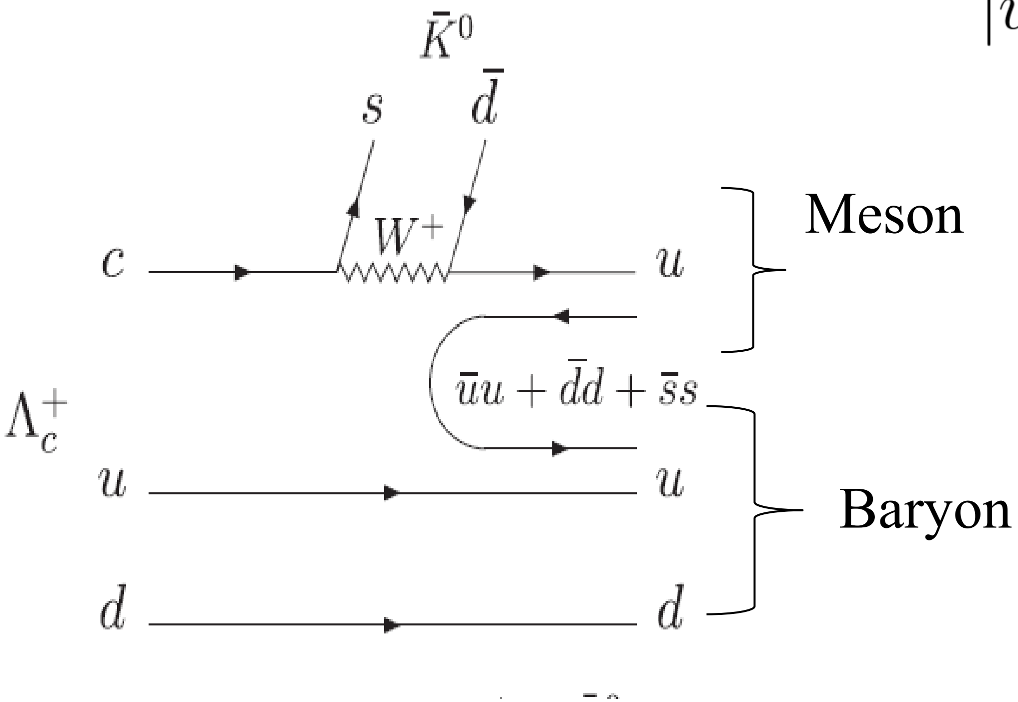
Physics Letters B 697 (2011) 254–259

- Breit-Wigner parameterization

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

↑ PDG 2024

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

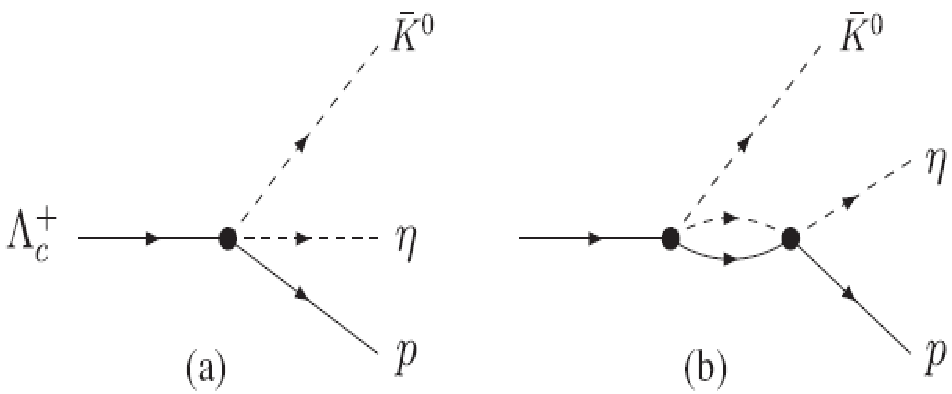


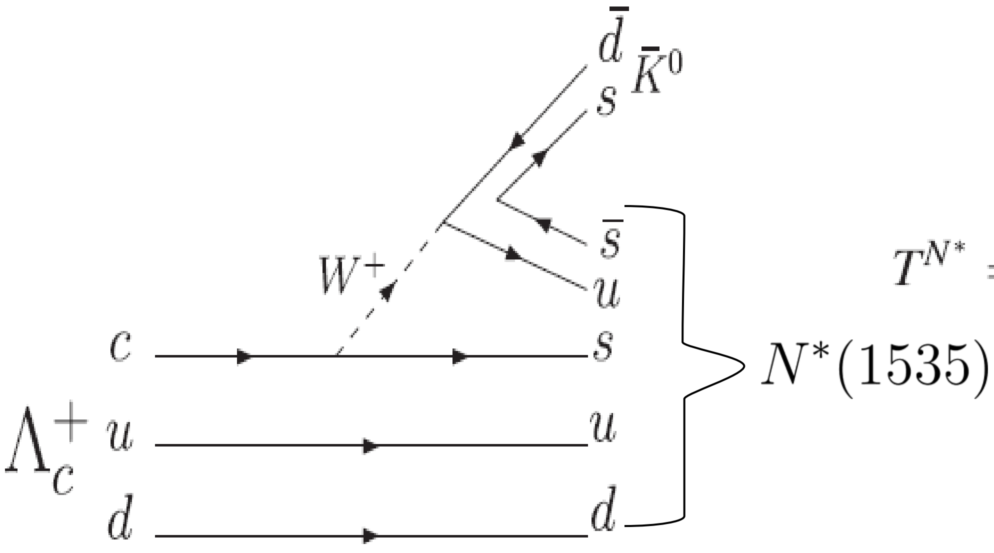
$$|uud> \rightarrow \frac{1}{\sqrt{2}}|u(ud - du)>$$

$$\bar{u}u + \bar{d}d + \bar{s}s$$

$$|MB\rangle = \frac{\sqrt{3}}{3}|\eta p\rangle + \frac{\sqrt{2}}{2}|\pi^0 p\rangle + |\pi^+ n\rangle - \frac{\sqrt{6}}{3}|K^+\Lambda\rangle,$$

$$T^{MB} = V_P\left(\frac{\sqrt{3}}{3} + \frac{\sqrt{3}}{3}G_{\eta p}(M_{\eta p})t_{\eta p\to\eta p}(M_{\eta p})\right.$$
$$+ \frac{\sqrt{2}}{2}G_{\pi^0 p}(M_{\eta p})t_{\pi^0 p\to\eta p}(M_{\eta p})$$
$$+ G_{\pi^+ n}(M_{\eta p})t_{\pi^+ n\to\eta p}(M_{\eta p})$$
$$\left. - \frac{\sqrt{6}}{3}G_{K^+\Lambda}(M_{\eta p})t_{K^+\Lambda\to\eta p}(M_{\eta p})\right),$$





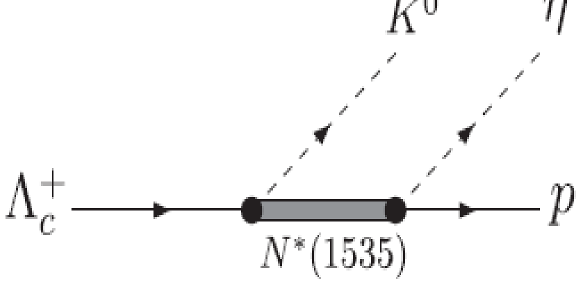
(a)

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

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

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

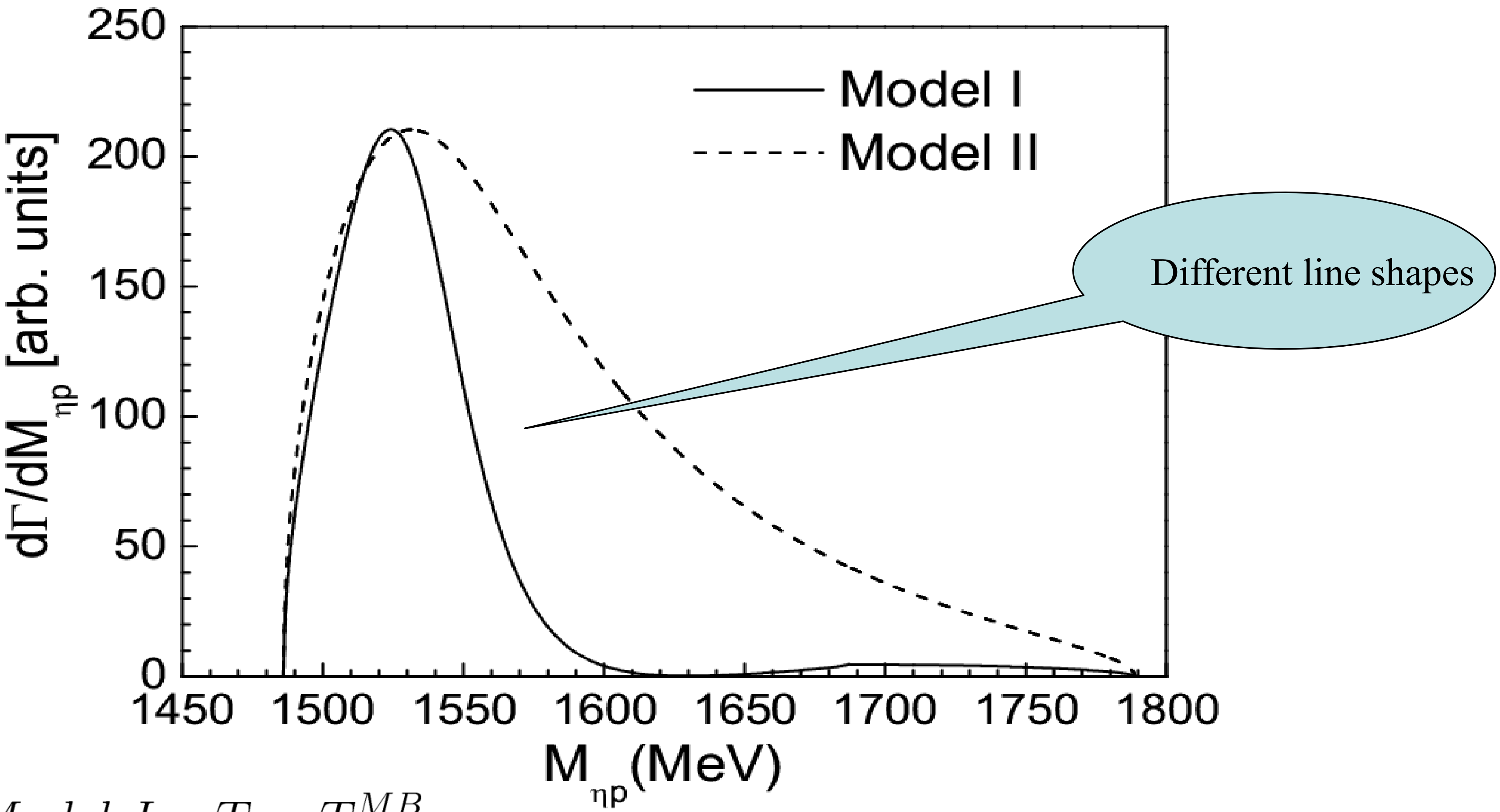
$$\Gamma_0 = 19.5 \text{ MeV} \quad \text{for} \quad \Gamma_{N^*}(\sqrt{q^2} = 1535 \text{ MeV}) = 150 \text{ MeV}.$$



(b)

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

Invariant ηp mass distributions



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

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

Other contributions

$N^*(1650) \to \eta p$

Σ^* $resonances$

$\to \bar{K}^0 p$

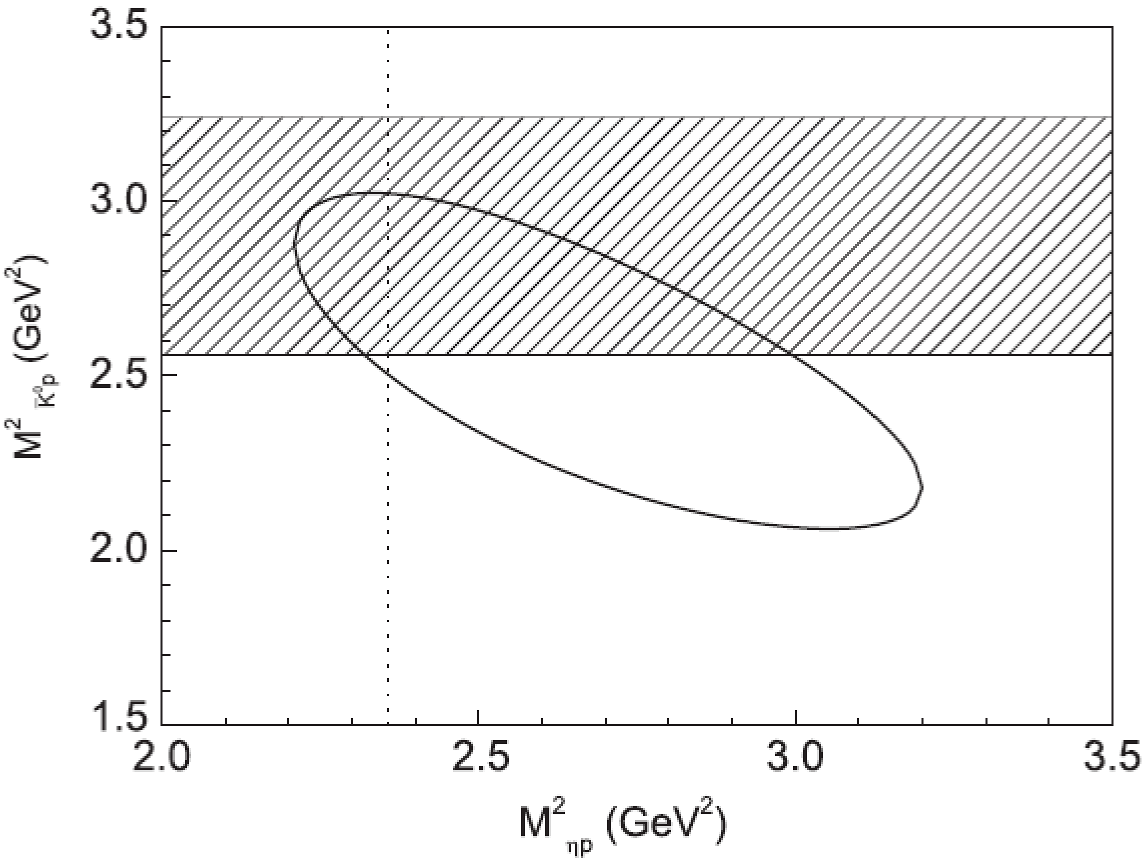


FIG. 7. Dalitz plot for $M^2_{\eta p}$ and $M^2_{\bar{K}^0 p}$ in the $\Lambda_c^+ \to \bar{K}^0 \eta p$ decay. The $N^*(1535)$ energy is shown by the vertical dotted line, and the horizontal band represents the masses of Σ^* states from 1600 to 1800 MeV.

Production of $N^*(1535)$ and $N^*(1650)$ in $\Lambda_c \to \overline{K}^0 \eta p$ (πN) decay

R. Pavao,* S. Sakai, and E. Oset

PRC 98, 015201 (2018).

PHYSICAL REVIEW D **107,** 032004 (2023)

Measurement of branching fractions of $\Lambda_c^+ \to pK_S^0K_S^0$ and $\Lambda_c^+ \to pK_S^0\eta$ at Belle

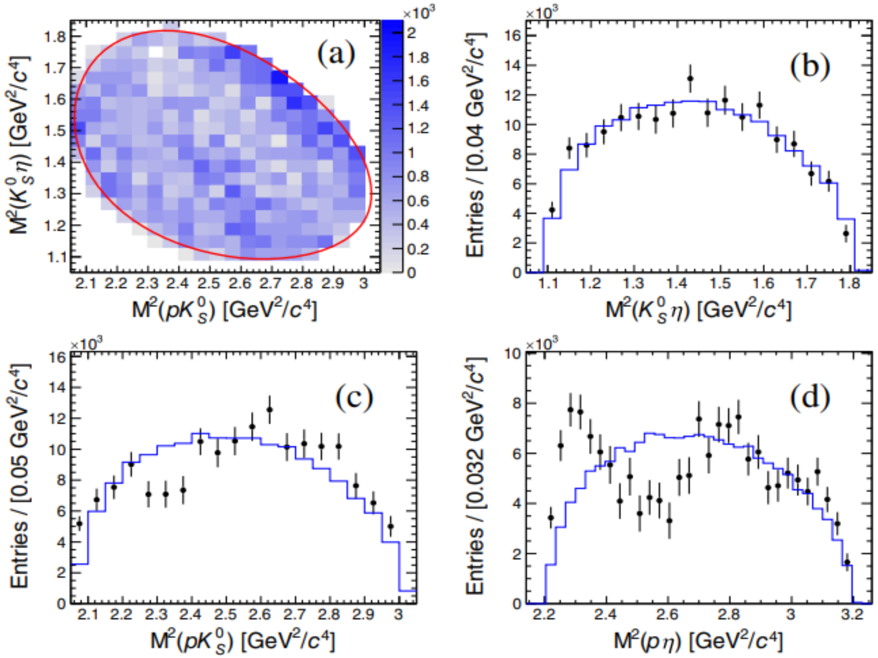
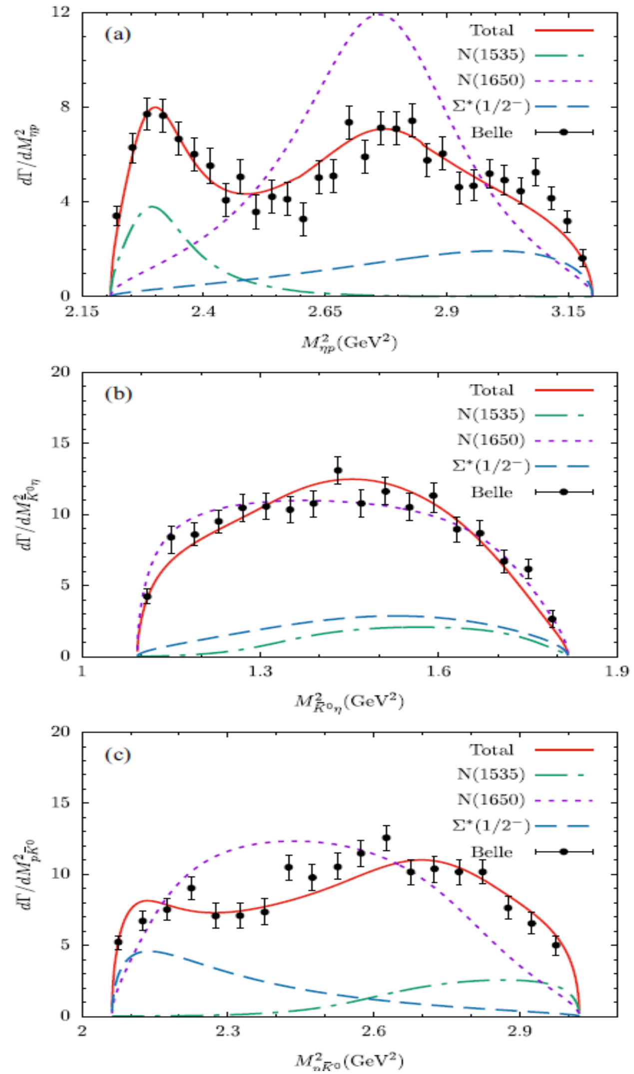


FIG. 4. For $\Lambda_c^+ \to pK_S^0\eta$, the Dalitz plot after background subtraction and efficiency correction bin-by-bin and its projections superimposing with signal MC produced by phase space mode (blue histograms). A significant structure of $N^*(1535)$ near the $p\eta$ threshold is found.

PHYSICAL REVIEW D **110,** 074010 (2024)

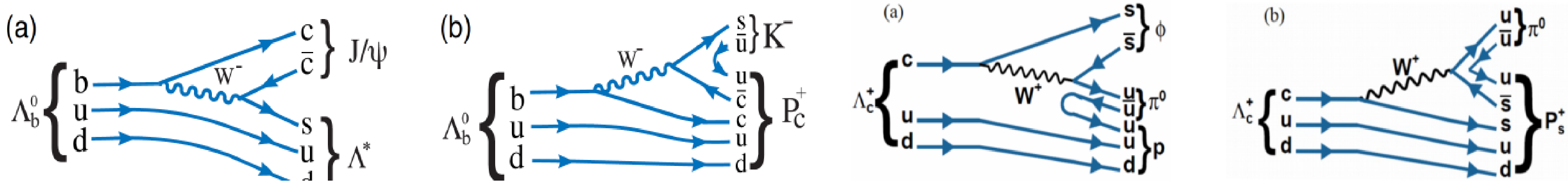
Theoretical study of $N(1535)$ and $\Sigma^*(1/2^-)$ in the Cabibbo-favored process $\Lambda_c^+ \to p\bar{K}^0\eta$

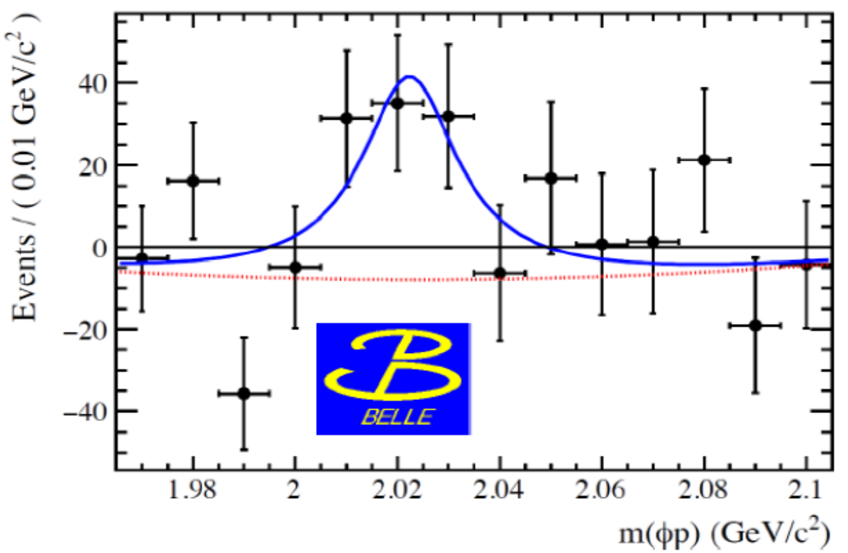
Ying Li,[1] Si-Wei Liu,[2,3] En Wang,[1,4,*] De-Min Li,[1,†] Li-Sheng Geng,[5,6,7,8,‡] and Ju-Jun Xie[2,3,8,§]



Possible ϕp state in $\Lambda^{+}_{c}\text{->}\pi^{0}p\phi$ decay

R. Lebed, PRD92(2015)114030





$\Sigma^{+}\rightarrow p\pi^{0}$ vetoed

From Cheng-Ping Shen

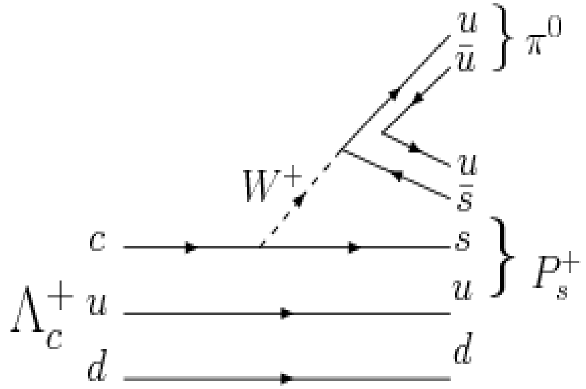
- **No significant Ps signal**
- **Best fit yields a peak at M=(2025±5) MeV/c² and Γ=(22±12) MeV**

PRD96, 051102(R) (2017); 915fb^{-1}

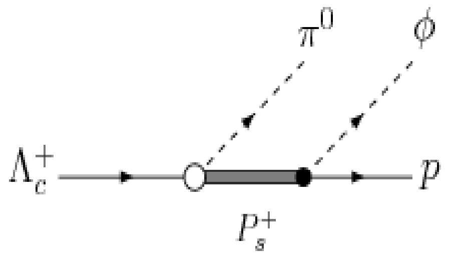
Number of candidate $\Lambda_c\rightarrow P_s\pi^0\rightarrow\phi p\pi^0$ events: 77.6±28.1

$B(\Lambda_c\rightarrow P_s\pi^0)\text{x}B(P_s\rightarrow\phi p)<8.3\text{x}10^{-5}$ @90% C.L.

Possible ϕp state in Λ^+_c->$\pi^0 p\phi$ decay

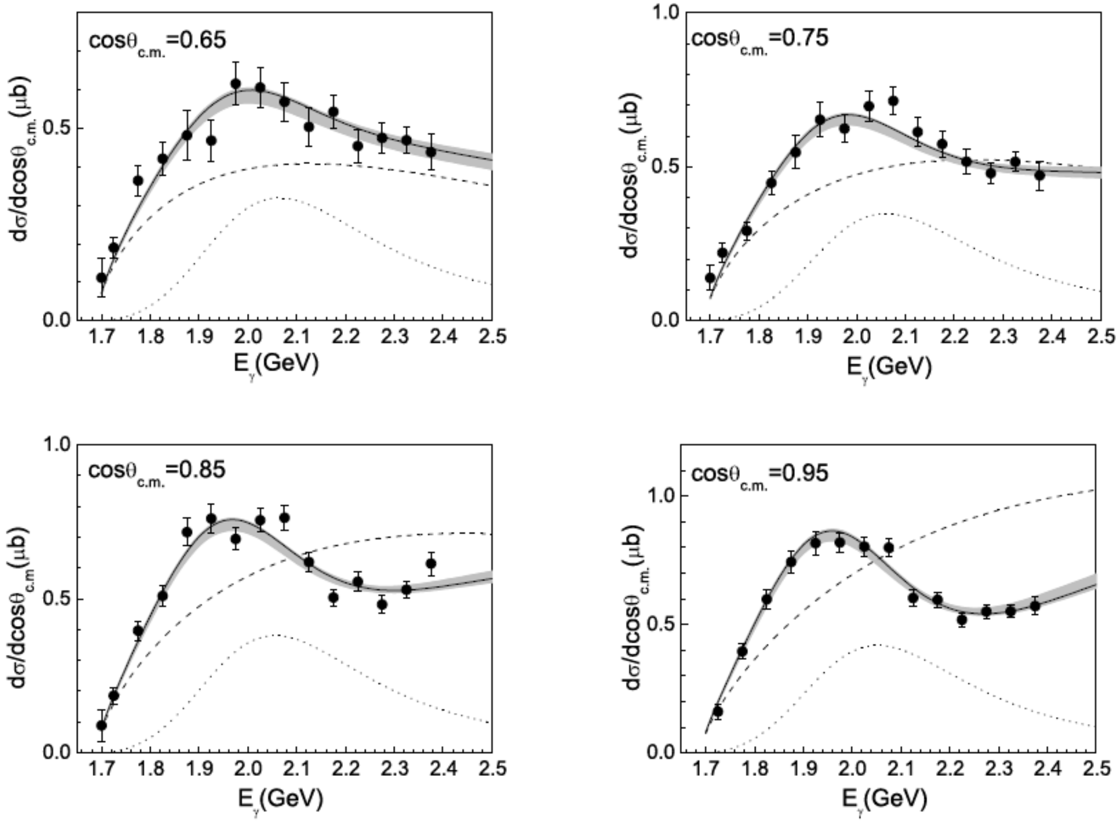


(a)



(b)

N*(2120) in γp->ϕp and γp->$K^+\Lambda(1520)$ reactions



Alvin Kiswandhi, Ju-Jun Xie, Shin Nan Yang, Phys. Lett. B, 691, 214 (2010).
Ju-Jun Xie, and Juan Nieves, Phys. Rev. C 82, 045205 (2010).

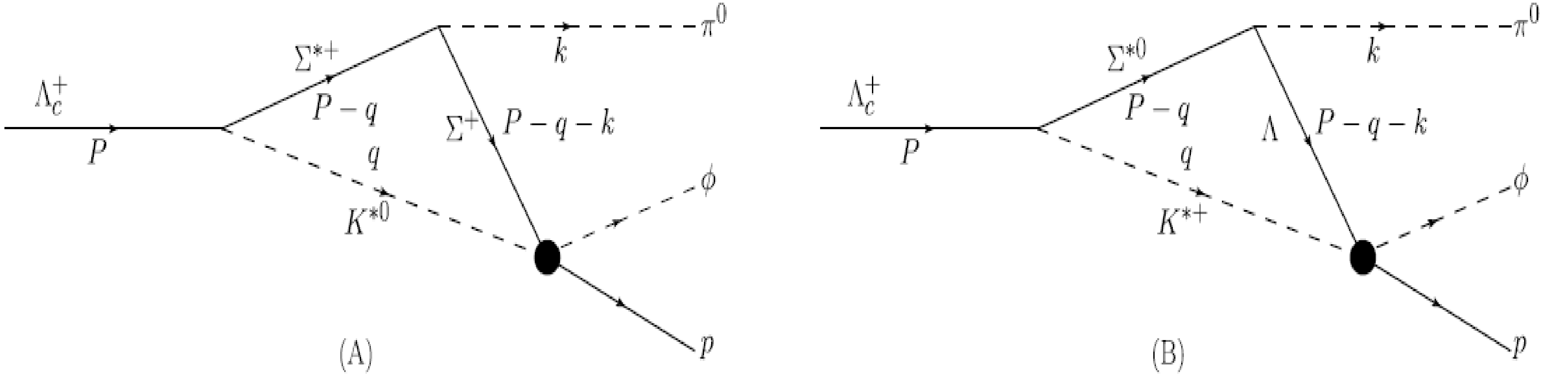


Fig. 1. Triangle diagrams for the $\Lambda_c^+ \to \pi^0 p\phi$ decay. (A): Σ^+-exchange. (B): Λ-exchange. The definitions of the kinematical variables (P, q, k) are also shown.

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

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

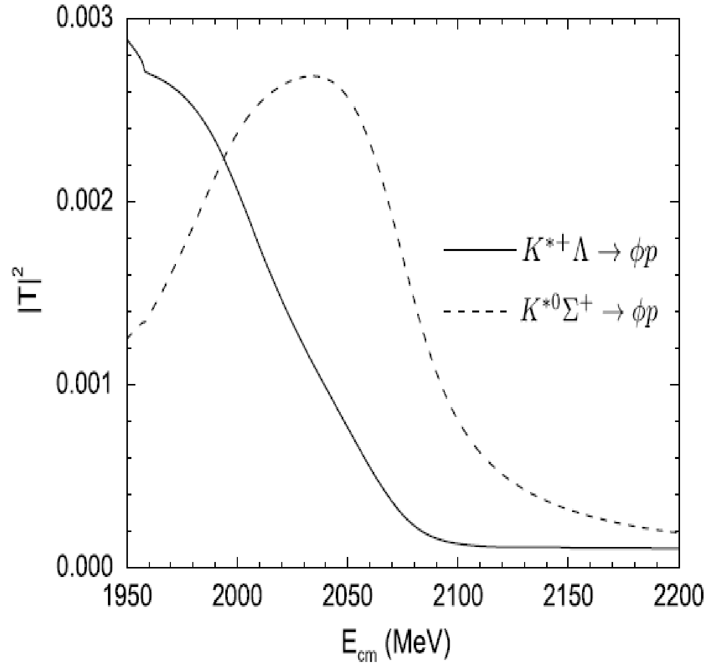
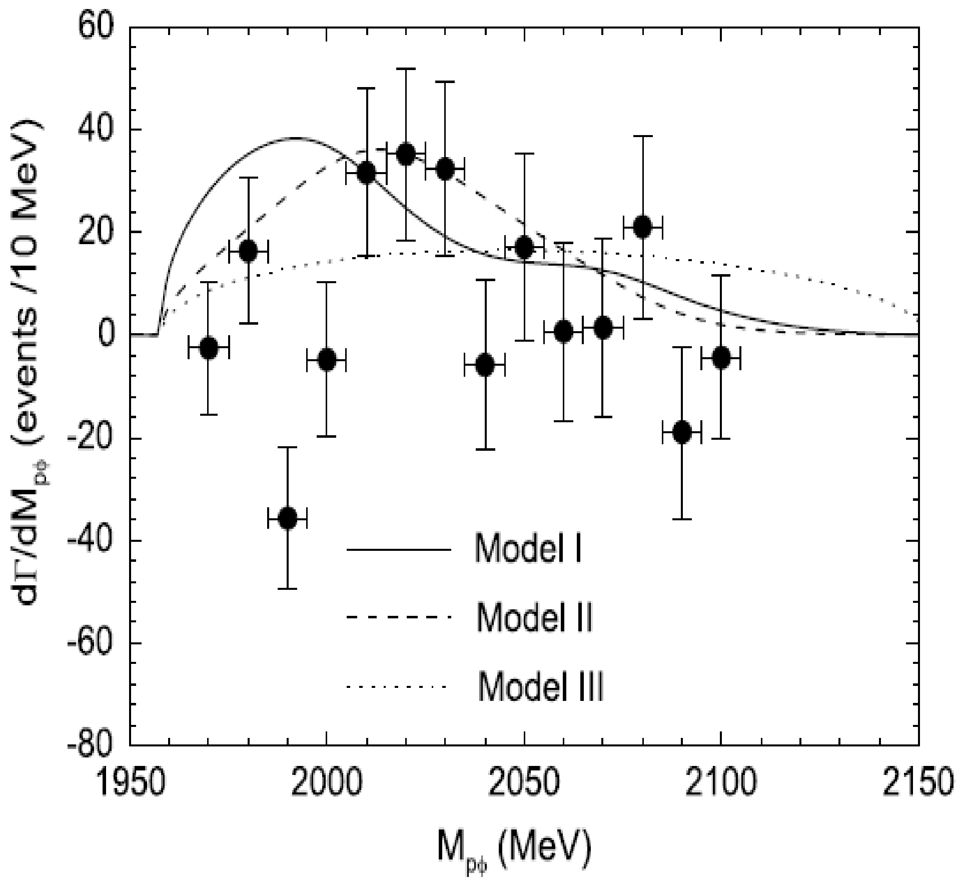


Fig. 3. The squared norm of the T-matrix elements for $K^{*+}\Lambda \to \phi p$ and $K^{*0}\Sigma^+ \to \phi p$ as a function of the meson–baryon invariant mass E_{cm} in the model of Ref. [72].



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

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

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

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

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

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

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

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

TS produces a bump at around 2.02 GeV

Ps, if exists, could distort the line shape, but difficult to be distinguished from TS in this process

Hence, we need more efforts, both on theoretical and experimental sides.

Thank you very much for your attention!