Study of the light baryon states in Λ_c^+ *decays*

Ju-Jun Xie
(谢聚军)

Institute of Modern Physics, Chinese Academy of Sciences
(中国科学院近代物理研究所)

Workshop of the Baryon Production at BESIII
14 Sep. - 16 Sep. 2019 @Anhui Hefei, University of Science and Technology of China

Outline

Introduction

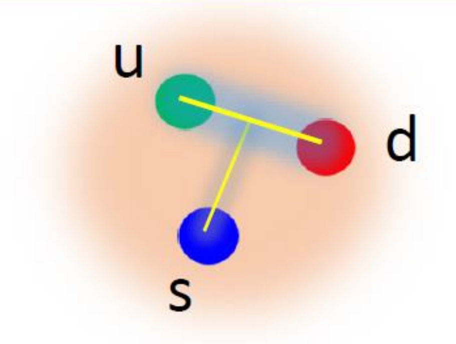
$Possible\ \Sigma^*_{1/2^-}(1380)\ state\ in\ \Lambda_c^+ \to \eta\pi^+\Lambda\ decay$

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

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

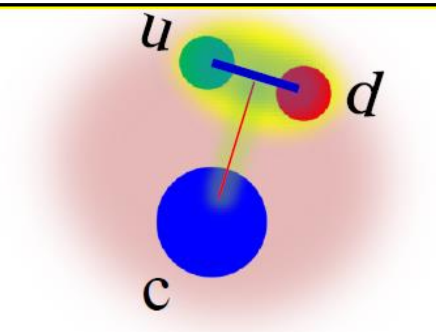
Summary

Λ_c^+ The lightest charmed baryon



<u>Strange baryons</u> (Λ[uds])

$m_u, m_d \approx m_s$ → **(qqq)** uniform

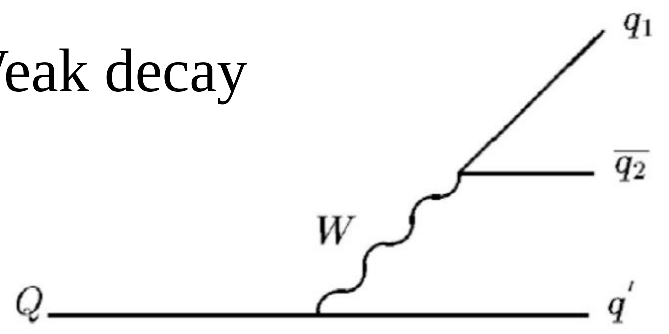


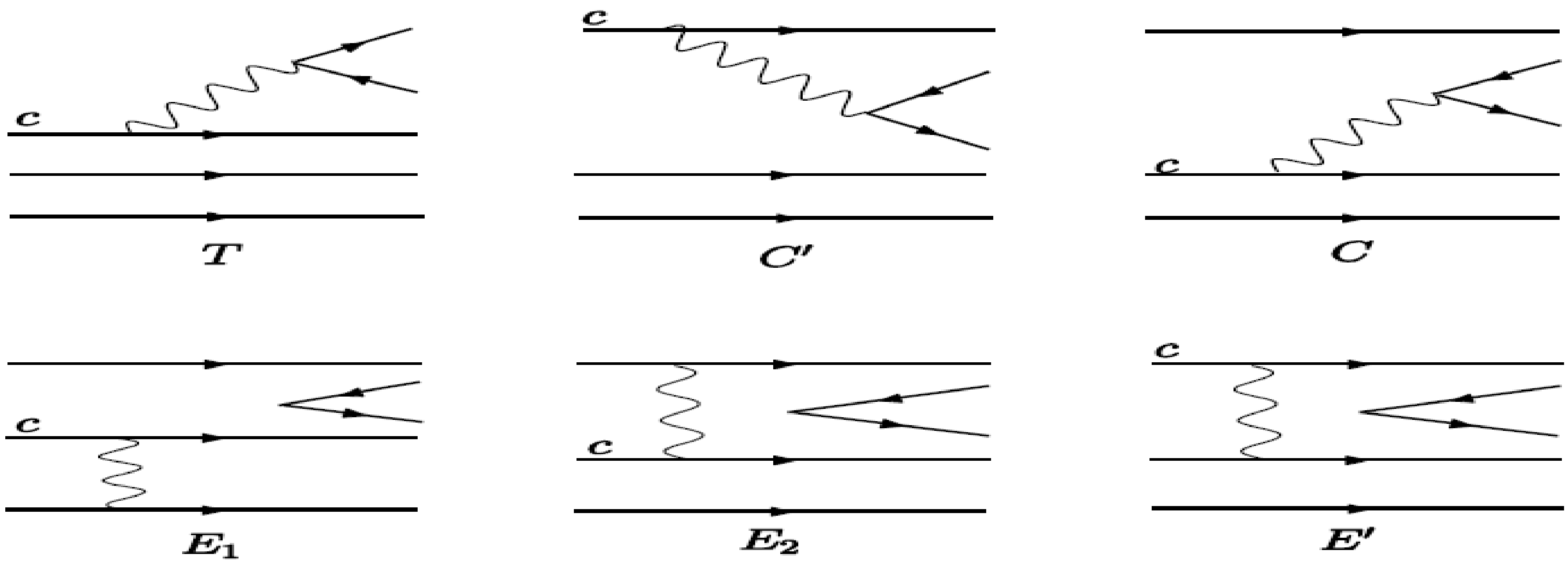
<u>Charmed baryon</u> (Λ_c[udc])

$m_u, m_d \ll m_c$ → **diquark + quark**

(qq) (Q)

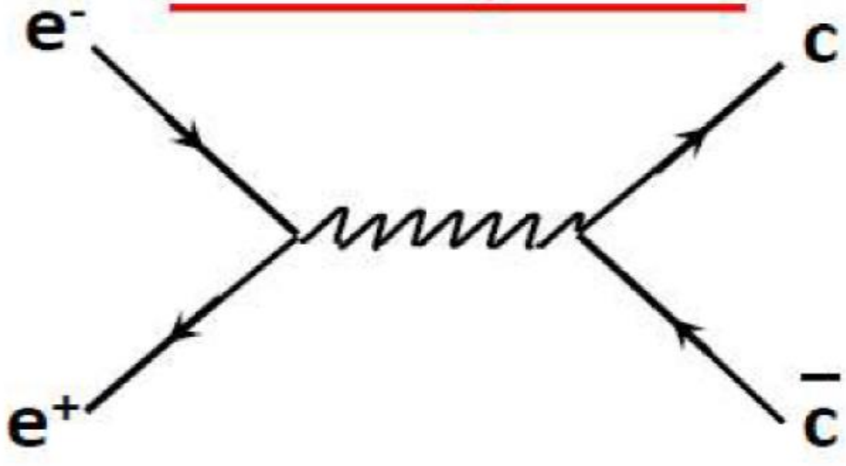
Weak decay



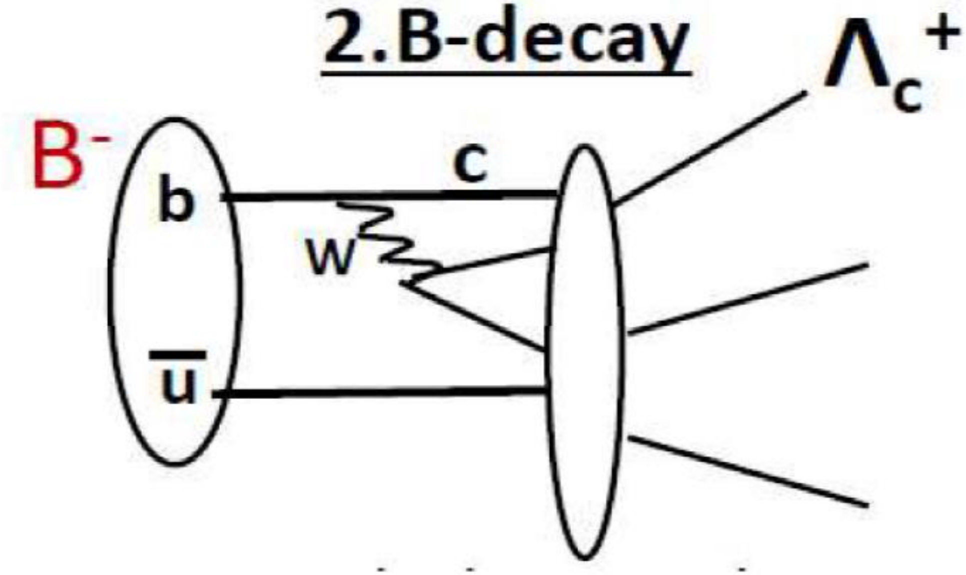


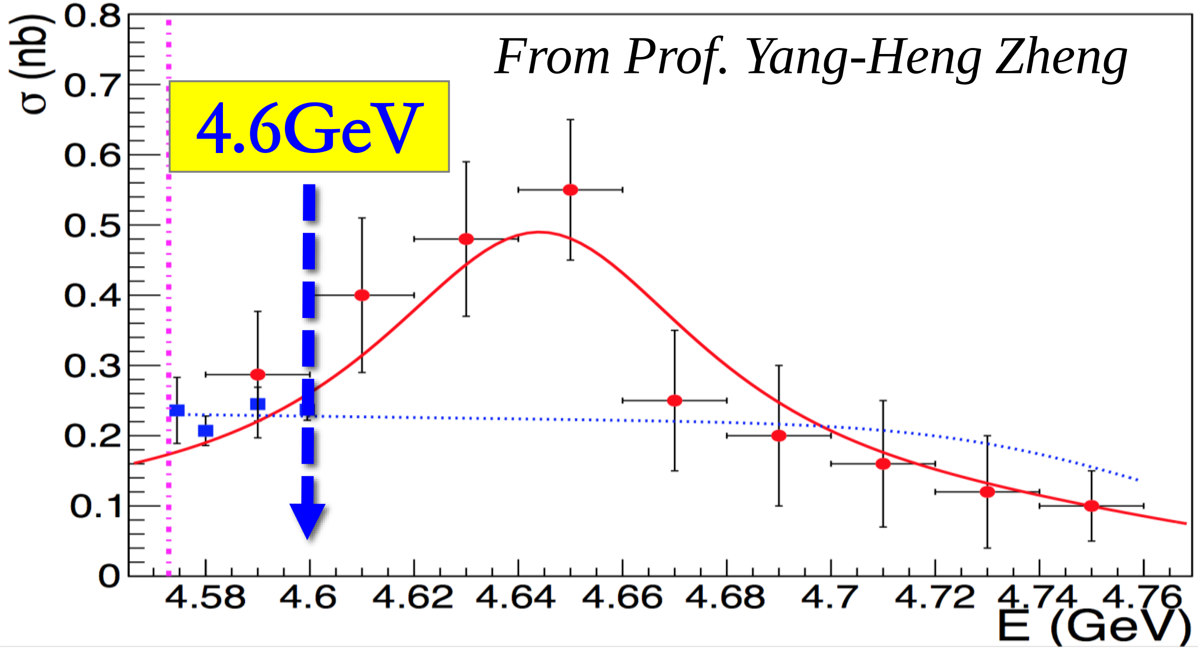
Λ_c^+ : *production*

1.$e^+e^- \rightarrow cc^{bar}$



2.B-decay





BESIII data taking @ $\mathbf{\Lambda_c^+\Lambda_c^-}$ threshold

BF precisions improved significantly

PDG2014

$\Gamma(p\overline{K}^0\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_7/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.66±0.05±0.07	774	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(p\overline{K}^0\eta)/\Gamma(pK^-\pi^+)$ — Γ_8/Γ_2

Unseen decay modes of the η are included.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.25±0.04±0.04	57	AMMAR	95	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(p\overline{K}^0\pi^+\pi^-)/\Gamma(pK^-\pi^+)$ — Γ_9/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.51±0.06 OUR AVERAGE					
0.52±0.04±0.05	985	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$
0.43±0.12±0.04	83	AVERY	91	CLEO	e^+e^- 10.5 GeV
0.98±0.36±0.08	12	BARLAG	90D	NA32	π^- 230 GeV

$\Gamma(pK^-\pi^+\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_{10}/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.67±0.04±0.11	2606	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(pK^*(892)^-\pi^+)/\Gamma(p\overline{K}^0\pi^+\pi^-)$ — Γ_{11}/Γ_9

Unseen decay modes of the $K^*(892)^-$ are included.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.44±0.14	17	ALEEV	94	BIS2	nN 20–70 GeV

$\Gamma(p(K^-\pi^+)_{\text{nonresonant}}\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_{12}/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.73±0.12±0.05	67	BOZEK	93	NA32	π^- Cu 230 GeV

PDG2019

$\Gamma(pK^0_S\pi^0)/\Gamma_{\text{total}}$ — Γ_7/Γ

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
1.96±0.13 OUR FIT	Error includes scale factor of 1.1				
1.87±0.13±0.05	558	ABLIKIM	16	BES3	$e^+e^- \to \Lambda_c\overline{\Lambda}_c$, 4.599 GeV

$\Gamma(pK^0_S\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_7/Γ_2

Measurements given as a $\overline{K}^0$ ratio have been divided by 2 to convert to a K^0_S ratio.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.314±0.018 OUR FIT					
0.33 ±0.03 ±0.04	774	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(nK^0_S\pi^+)/\Gamma_{\text{total}}$ — Γ_8/Γ

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
1.82±0.23±0.11	83	ABLIKIM	17H	BES3	e^+e^- at 4.6 GeV

$\Gamma(p\overline{K}^0\eta)/\Gamma(pK^-\pi^+)$ — Γ_9/Γ_2

Unseen decay modes of the η are included.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.25±0.04±0.04	57	AMMAR	95	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(pK^0_S\pi^+\pi^-)/\Gamma_{\text{total}}$ — Γ_{10}/Γ

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
1.59±0.12 OUR FIT	Error includes scale factor of 1.2				
1.53±0.11±0.09	485	ABLIKIM	16	BES3	$e^+e^- \to \Lambda_c\overline{\Lambda}_c$, 4.599 GeV

$\Gamma(pK^0_S\pi^+\pi^-)/\Gamma(pK^-\pi^+)$ — Γ_{10}/Γ_2

Measurements given as a $\overline{K}^0$ ratio have been divided by 2 to convert to a K^0_S ratio.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.255±0.015 OUR FIT	Error includes scale factor of 1.1.				
0.257±0.031 OUR AVERAGE					
0.26 ±0.02 ±0.03	985	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$
0.22 ±0.06 ±0.02	83	AVERY	91	CLEO	e^+e^- 10.5 GeV
0.49 ±0.18 ±0.04	12	BARLAG	90D	NA32	π^- 230 GeV

$\Gamma(pK^-\pi^+\pi^0)/\Gamma_{\text{total}}$ — Γ_{11}/Γ

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
4.42±0.31 OUR FIT	Error includes scale factor of 1.5				
4.53±0.23±0.30	1849	ABLIKIM	16	BES3	$e^+e^- \to \Lambda_c\overline{\Lambda}_c$, 4.599 GeV

$\Gamma(pK^-\pi^+\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_{11}/Γ_2

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT

- BFs of many Λ_c decays: improved significantly
- BF($\Lambda_c^+ \to$pKπ): model dependent ⇒ model independent
- New decay channels observed: i.e. Λ_c^+decay involving the neutron in the final state; more SCS decays

From Prof. Yang-Heng Zheng

Λ_c^+ *two body decays*

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

Physics Letters B 776 (2018) 265–269

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

The branching ratios of the $\Lambda_b \to \mathbf{B}_n M$ decays, where the 2nd column is for our results, where the errors come from the parameters in Eq. (18), while 3, 4, ..., 7 ones correspond to the studies by the heavy quark effective theory (HQET) [24], Sharma and Verma (SV) in Ref. [23], pole model (PM) [11], current algebra (CA) [11] and data [1–3], respectively.

Branching ratios	Our results	HQET [24]	SV [23]	PM [11]	CA [11]	Data [1–3]
$10^2\mathcal{B}(\Lambda_c^+ \to p\bar{K}^0)$	3.3 ± 0.2	1.23	2.67 ± 0.74	1.20	3.46	3.16 ± 0.16
$10^2\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+)$	1.3 ± 0.2	1.17	–	0.84	1.39	1.30 ± 0.07
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^0)$	1.3 ± 0.2	0.69	–	0.68	1.67	1.24 ± 0.10
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+)$	1.3 ± 0.2	0.69	0.87 ± 0.20	0.68	1.67	1.29 ± 0.07
$10^2\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$	0.5 ± 0.1	0.07	–	–	–	0.50 ± 0.12
$10^4\mathcal{B}(\Lambda_c^+ \to p\pi^0)$	5.6 ± 1.5	–	2	–	–	–
$10^4\mathcal{B}(\Lambda_c^+ \to \Lambda K^+)$	4.6 ± 0.9	–	14	–	–	6.1 ± 1.2
$10^4\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+)$	4.0 ± 0.8	–	4	–	–	5.2 ± 0.8
$10^4\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K^0)$	8.0 ± 1.6	–	9	–	–	–
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta)$	0.7 ± 0.4	0.25	0.50 ± 0.17	–	–	0.70 ± 0.23
$10^2\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta')$	$1.0^{+1.6}_{-0.8}$	0.08	0.20 ± 0.08	–	–	–
$10^4\mathcal{B}(\Lambda_c^+ \to p\eta)$	12.4 ± 4.1	–	21	–	–	12.4 ± 3.0
$10^4\mathcal{B}(\Lambda_c^+ \to p\eta')$	$12.2^{+14.3}_{-\ 8.7}$	–	4	–	–	–

[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,‡]

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

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

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

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

Three-body charmed baryon Decays with SU(3) flavor symmetry

C.Q. Geng[1,2,3], Y.K. Hsiao[1], Chia-Wei Liu[2] and Tien-Hsueh Tsai[2]

Phys. Rev. D **99**, 073003 (2019)

$$R(\Delta) \equiv T(\Lambda_c^+ \to n\bar{K}^0\pi^+) - T(\Lambda_c^+ \to pK^-\pi^+) - \sqrt{2}T(\Lambda_c^+ \to p\bar{K}^0\pi^0) = 0\,.$$

$$T(\Lambda_c^+ \to \Sigma^+\pi^0\pi^0) - T(\Lambda_c^+ \to \Sigma^+\pi^+\pi^-) + \frac{1}{2}T(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+) = 0\,,$$

$$T(\Lambda_c^+ \to \Sigma^+K^0\bar{K}^0) - T(\Lambda_c^+ \to \Sigma^+K^+K^-) - \sqrt{2}T(\Lambda_c^+ \to \Sigma^0K^+\bar{K}^0) = 0\,,$$

$$T(\Lambda_c^+ \to \Xi^0\pi^+K^0) - T(\Lambda_c^+ \to \Xi^-\pi^+K^+) - \sqrt{2}T(\Lambda_c^+ \to \Xi^0\pi^0K^+) = 0\,.$$

Λ_c^+ *three body decays*

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

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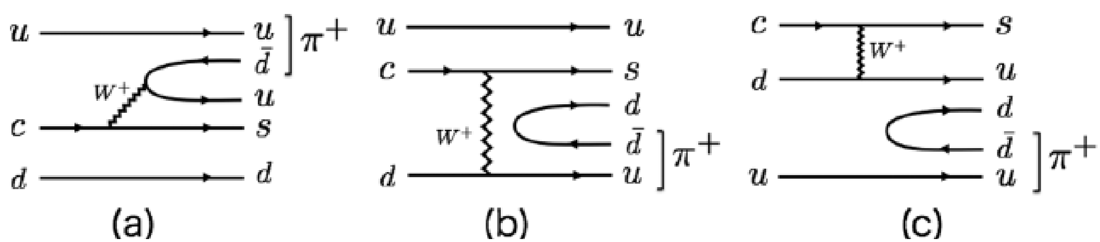
$$\mathcal{A}(\Lambda_c \to n\bar{K}^0\pi^+) = -\frac{1}{2}\mathcal{A}^{(1)} - \frac{1}{\sqrt{2}}\mathcal{A}^{(2)}.$$

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



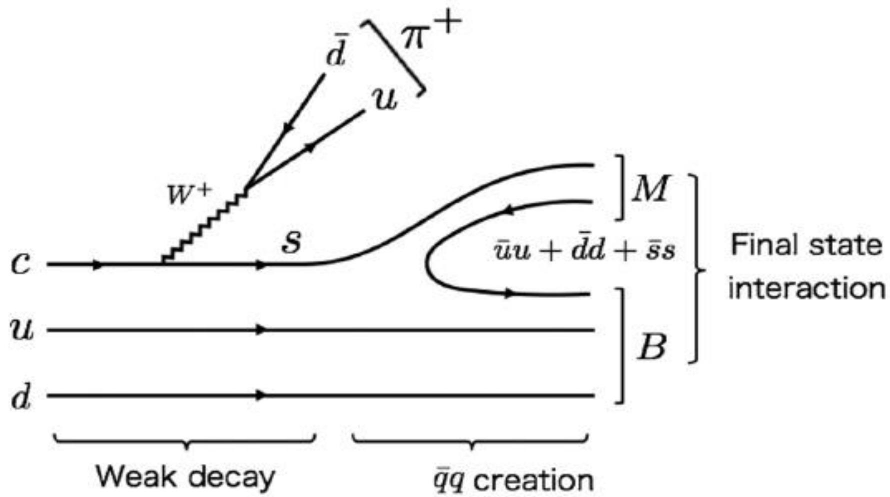
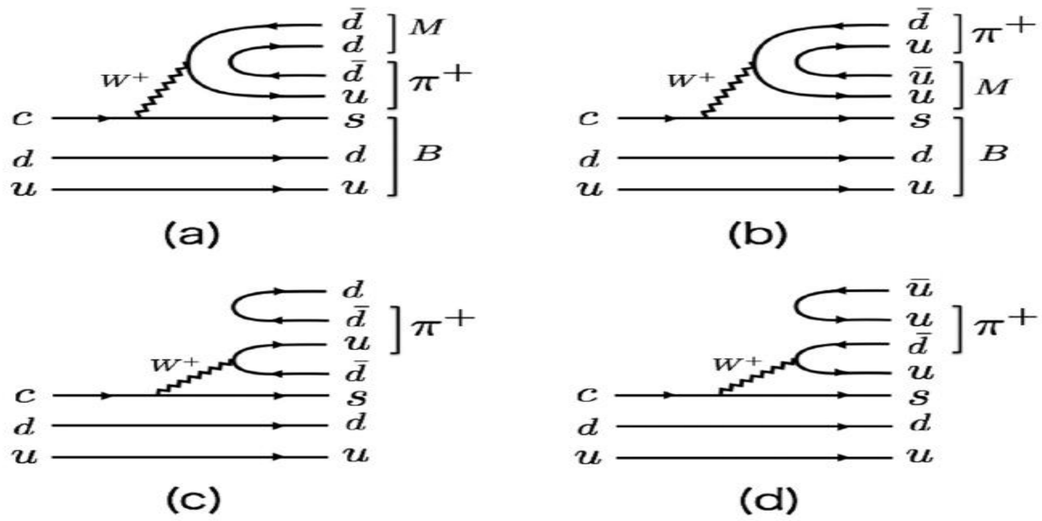


FIG. 1. The dominant diagram for the $\Lambda_c^+ \to \pi^+ MB$ decay. The solid lines and the wiggly line show the quarks and the W boson, respectively.



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 $\Lambda(1670)$

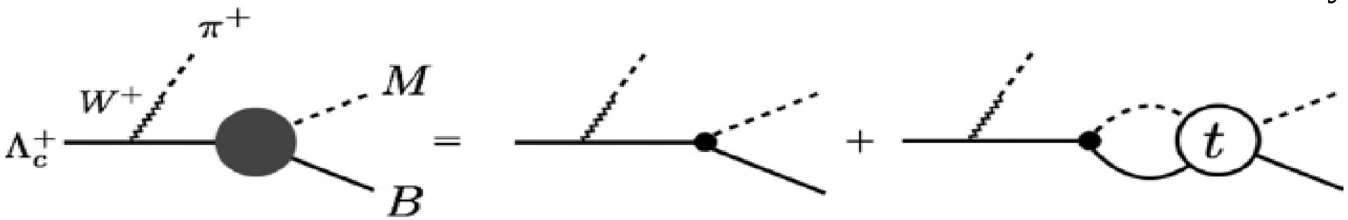
$$|MB\rangle = \frac{1}{\sqrt{2}}|s(\bar{u}u + \bar{d}d + \bar{s}s)(ud - du)\rangle$$
$$= \frac{1}{\sqrt{2}}\sum_{i=1}^{3}|P_{3i}q_i(ud - du)\rangle,$$

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

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

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

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



E. Oset et al., Int.J.Mod.Phys. E25 1630001 (2016).

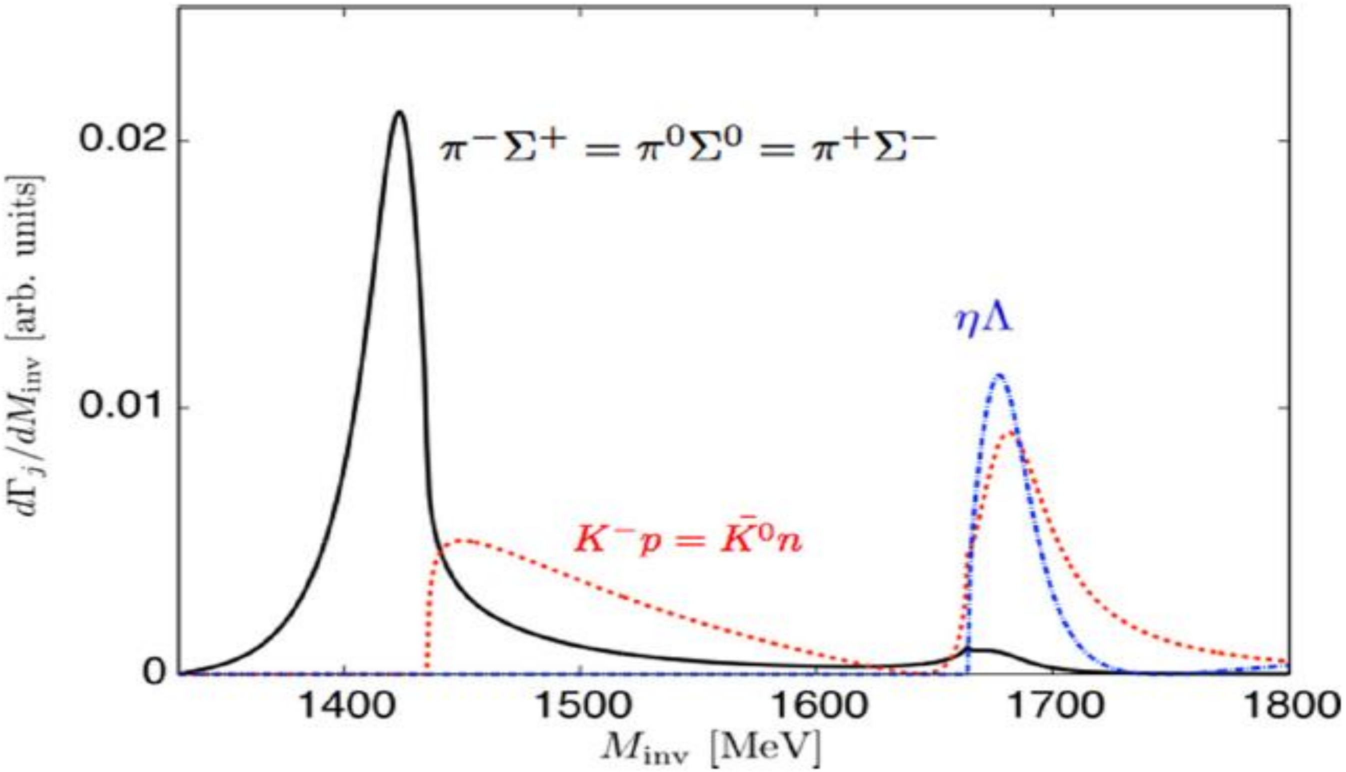
$$\mathscr{M}_j = V_P \left[h_j + \sum_i h_i G_i(M_{\rm inv}) t_{ij}(M_{\rm inv}) \right],$$

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

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

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

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



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

Quark Model Predictions

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).

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

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	$\lvert g_i \rvert$
$\pi\Lambda$	$0.60+0.47i$	0.76
$\pi\Sigma$	$1.27+0.71i$	1.5
$\bar{K}N$	$-1.24-0.73i$	1.4
$\eta\Sigma$	$0.56+0.41i$	0.69
$K\Xi$	$0.12+0.05i$	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).

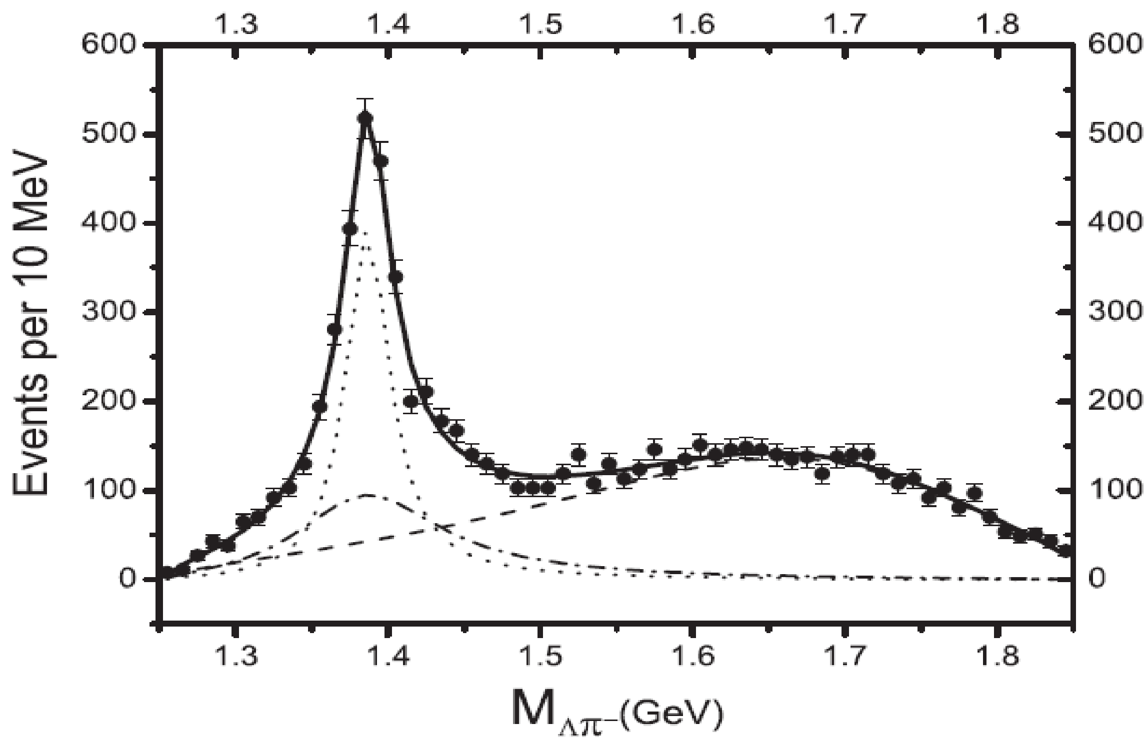
K. P. Khemchandani, A. Martinez Torres, and J. A. Oller, arXiv:1810.09990v1.

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 $K^- p \rightarrow \Lambda\pi^+\pi^-$ 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)

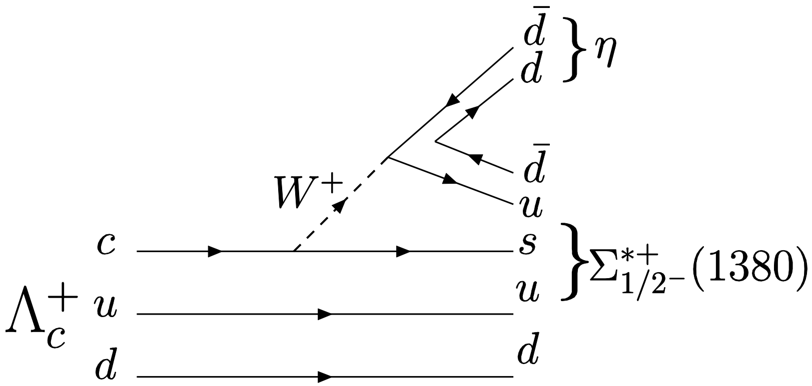
Possible $\Sigma(\frac{1}{2}^-)$ under the $\Sigma^*(1385)$ peak in $K\Sigma^*$ photoproduction

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

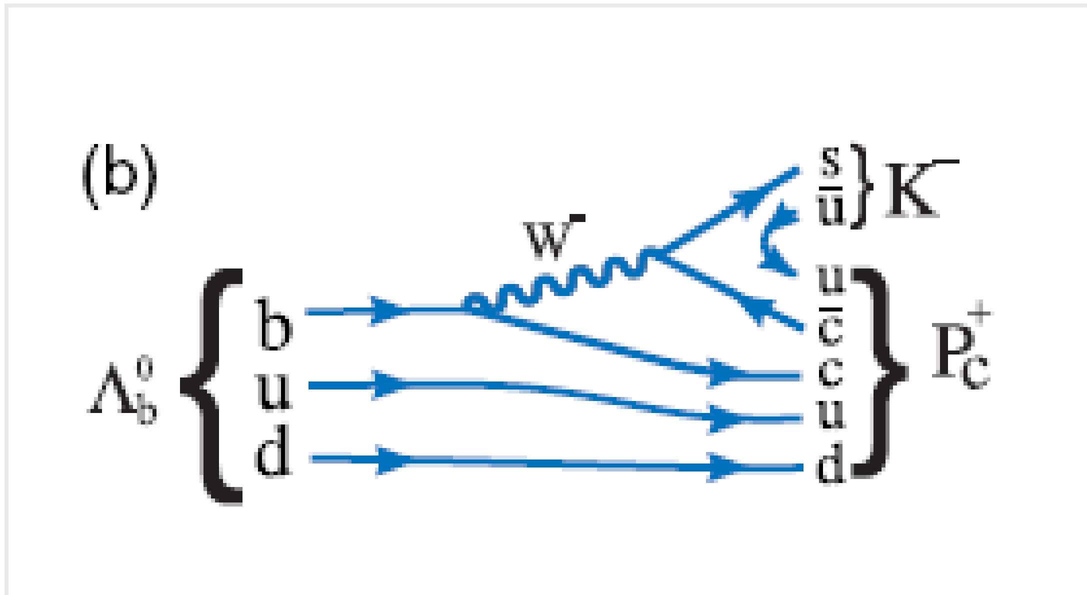
Yun-Hua Chen and B. S. Zou, PRC 88, 024304 (2013).

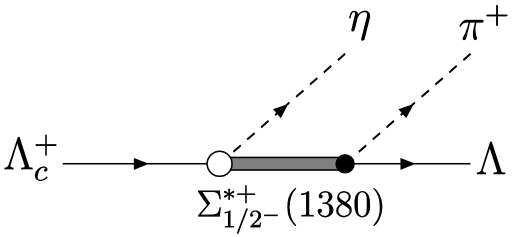
Ju-Jun Xie, Jia-Jun Wu, and Bing-Song Zou, PRC 90, 055204 (2014).

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



(a)



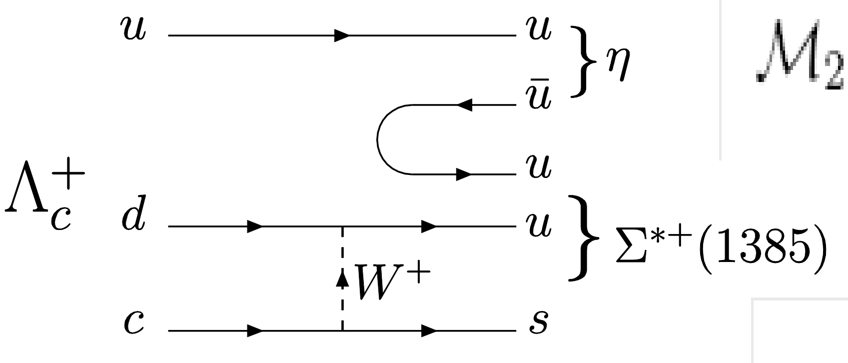


(b)

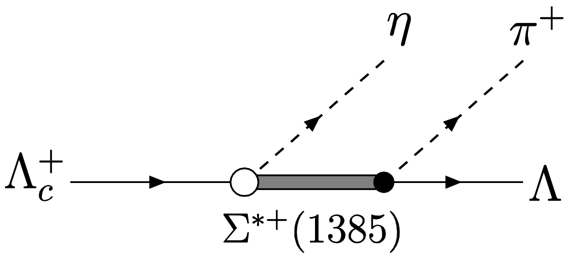
$$\mathcal{M}_1 = i g_{\pi\Lambda\Sigma_1^*} \bar{u}(p_3) G^{\Sigma_1^*}(q)(A_1 + B_1\gamma_5)u(p),$$

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

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 distributions

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

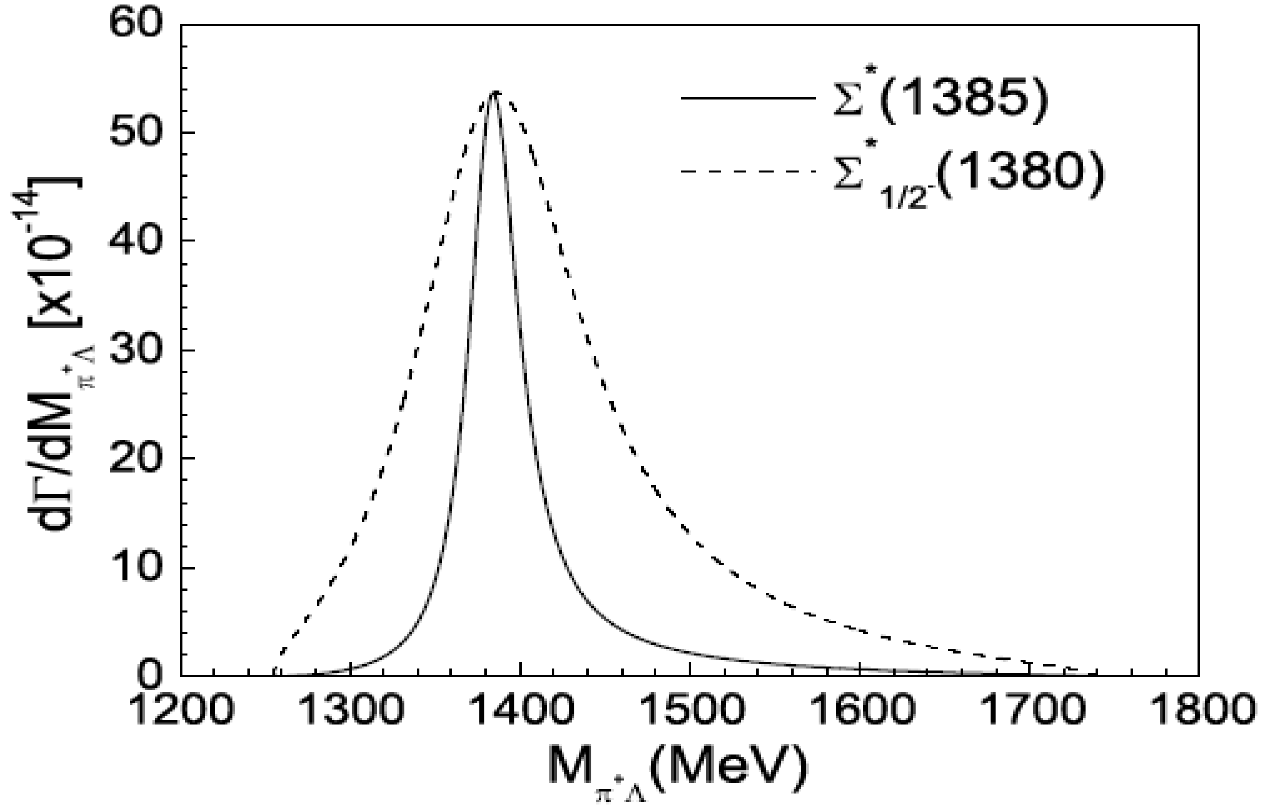


FIG. 5: Invariant mass distributions $d\Gamma/dM_{\pi+\Lambda}$ as a function of $M_{\pi+\Lambda}$.

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

Decay angle and energy distributions

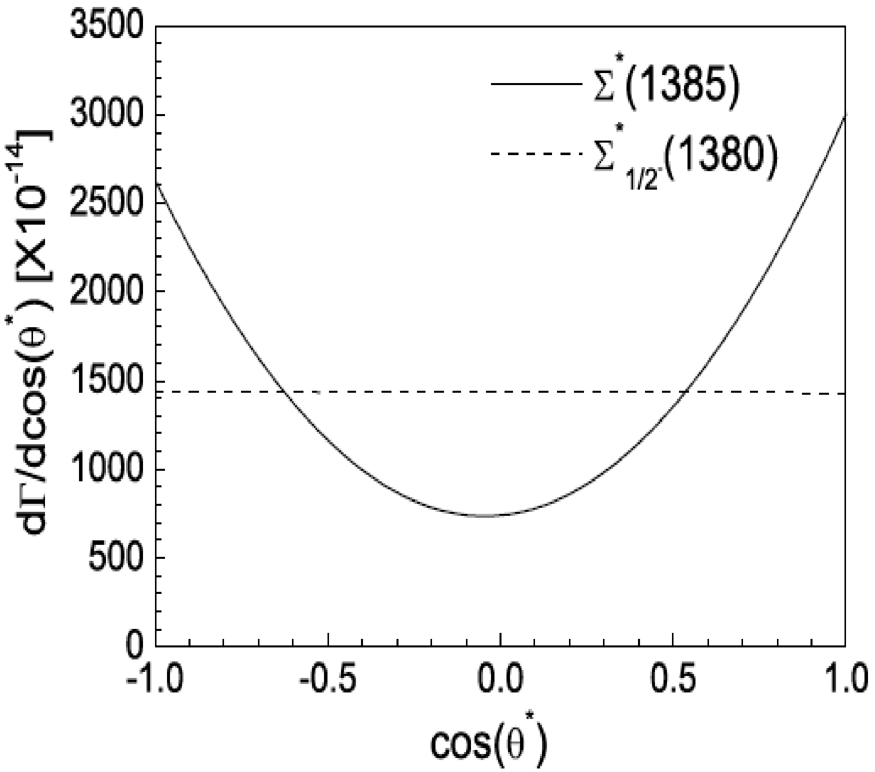


FIG. 6: Angle distributions $d\Gamma/d\cos\theta^*$ in the c.m. frame of $\pi^+\Lambda$ system as a function of $\cos\theta^*$.

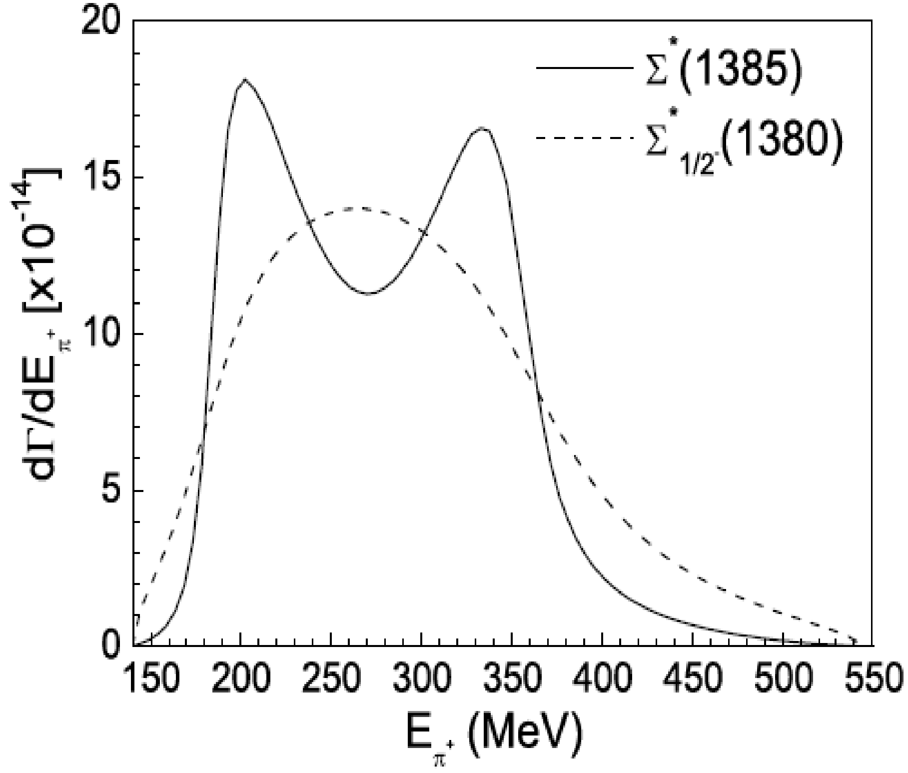
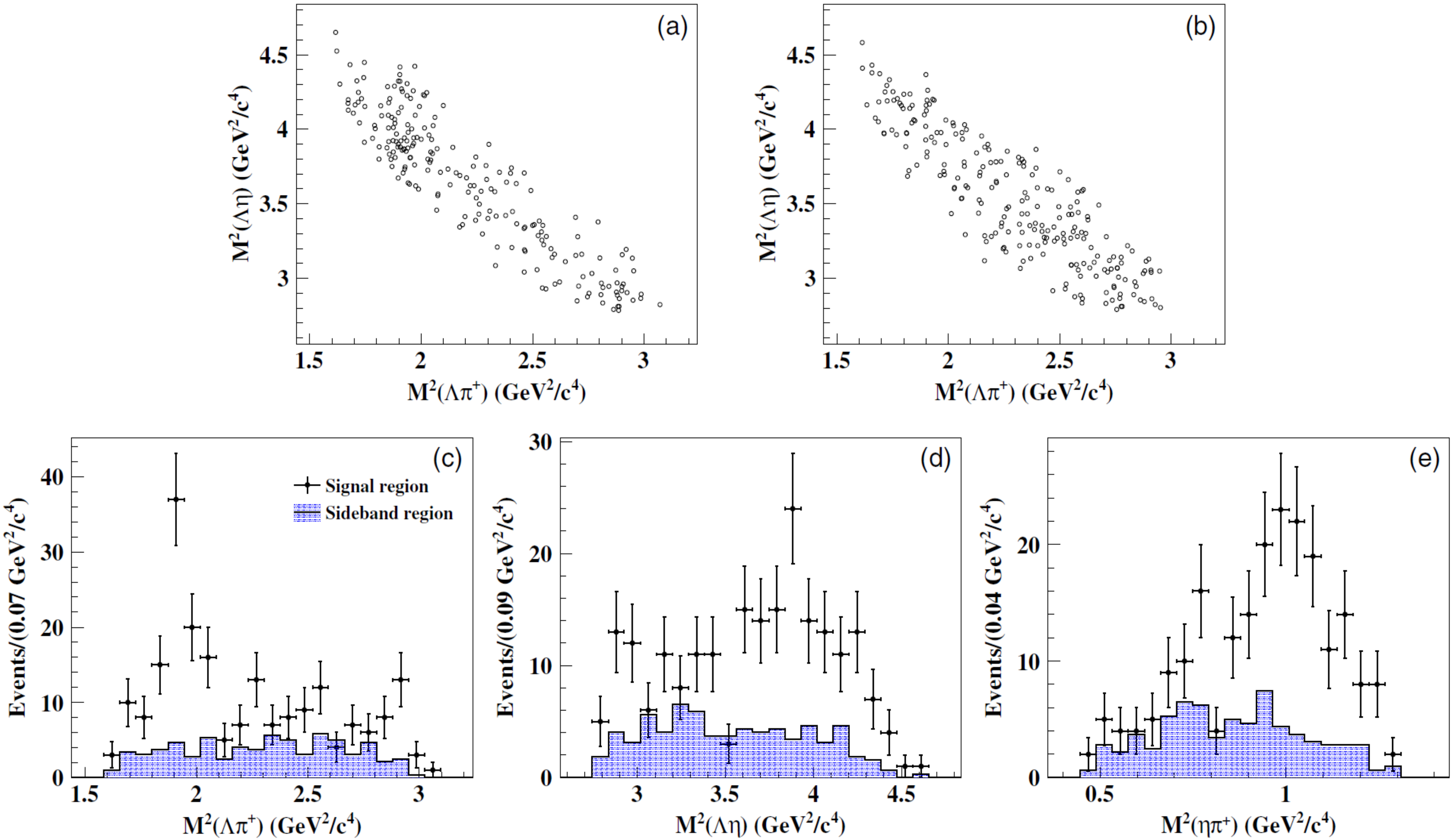


FIG. 7: Energy distributions $d\Gamma/dE_{\pi+}$ in the rest frame of Λ_c^+ as a function of $E_{\pi+}$.

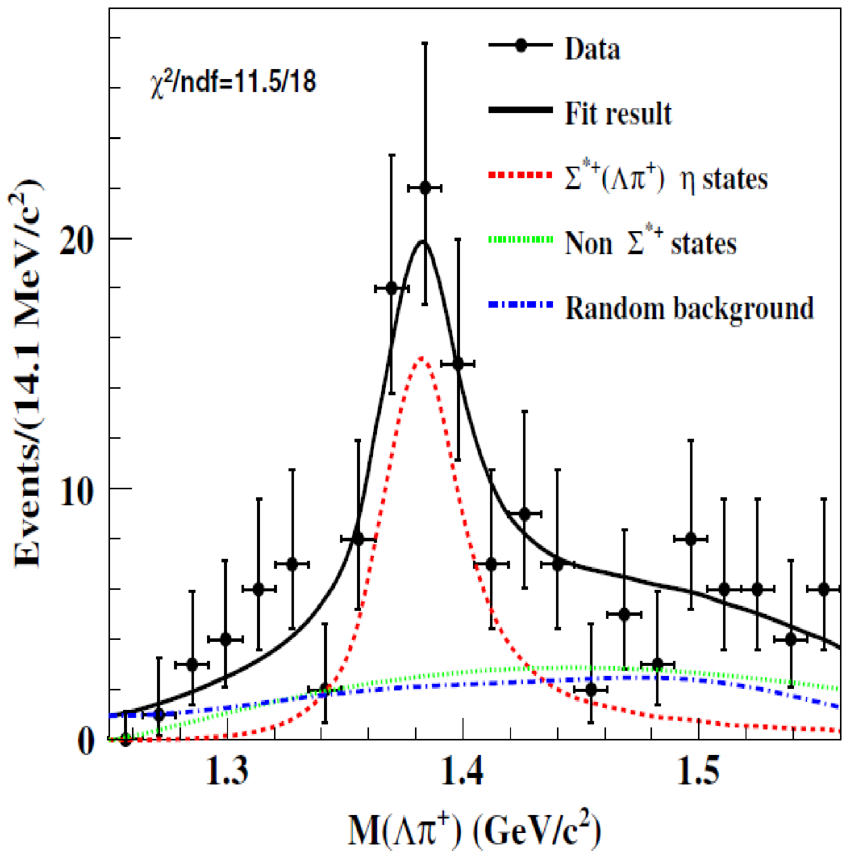
Measurement of the absolute branching fractions of $\Lambda_c^+ \to \Lambda\eta\pi^+$ and $\Sigma(1385)^+\eta$

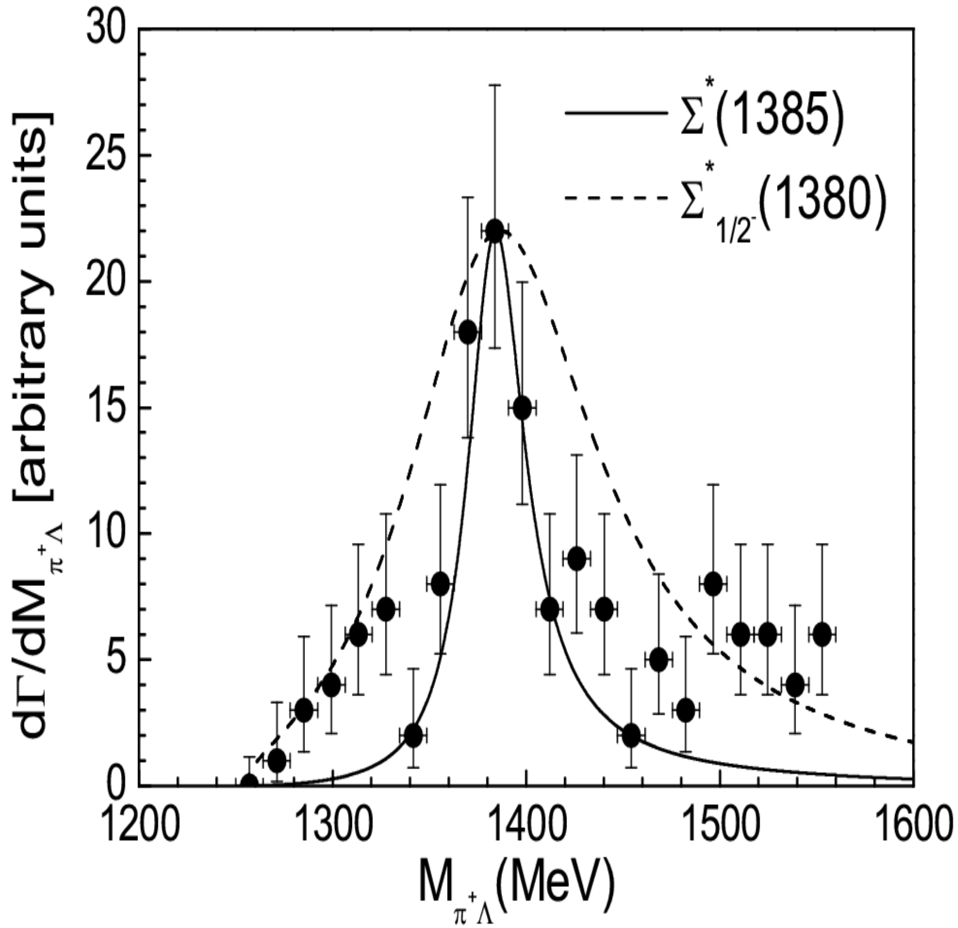
(BESIII Collaboration)

PRD 99, 032010 (2019).



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

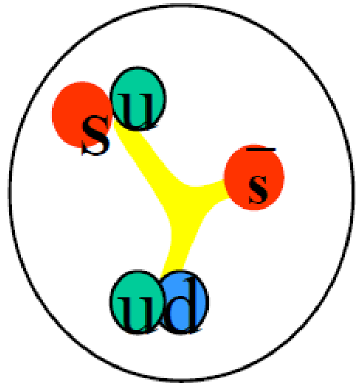




$N^*(1535)$: strangeness component

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/ψ → $\bar{p}$N* → $\bar{p}$ (KΛ) / $\bar{p}$ (pη) → large $g_{N^*K\Lambda}$

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

γp → pη' & pp→ppη' → large $g_{N^*N\eta'}$

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

π^- p → nϕ & pp → ppϕ & pn → dϕ → 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 $z_R = [(1490 \sim 1530) - i(45 \sim 125)]\mathrm{MeV}$

PDG 2018 → $(M_R, \Gamma_R) = (\simeq 1510, \simeq 170)\mathrm{MeV}$

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

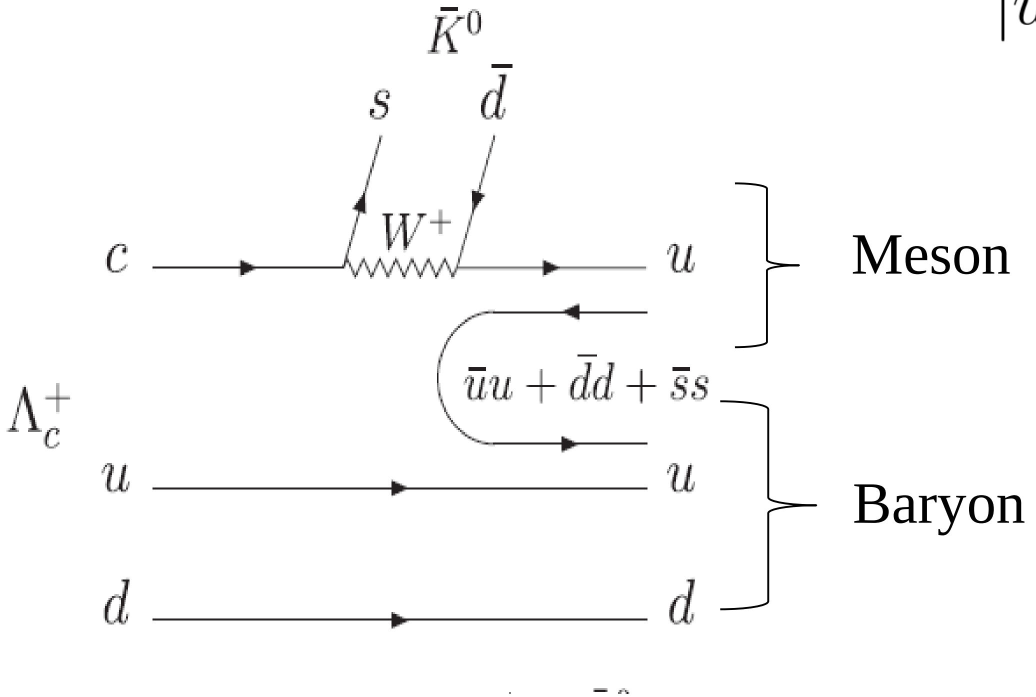
- Breit-Wigner parameterization

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

↑

PDG 2018

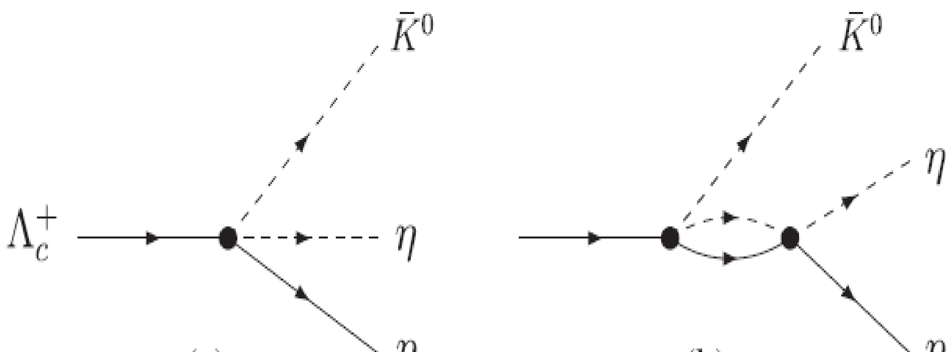
The $N^*(1535)$ as a dynamically generated state



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

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

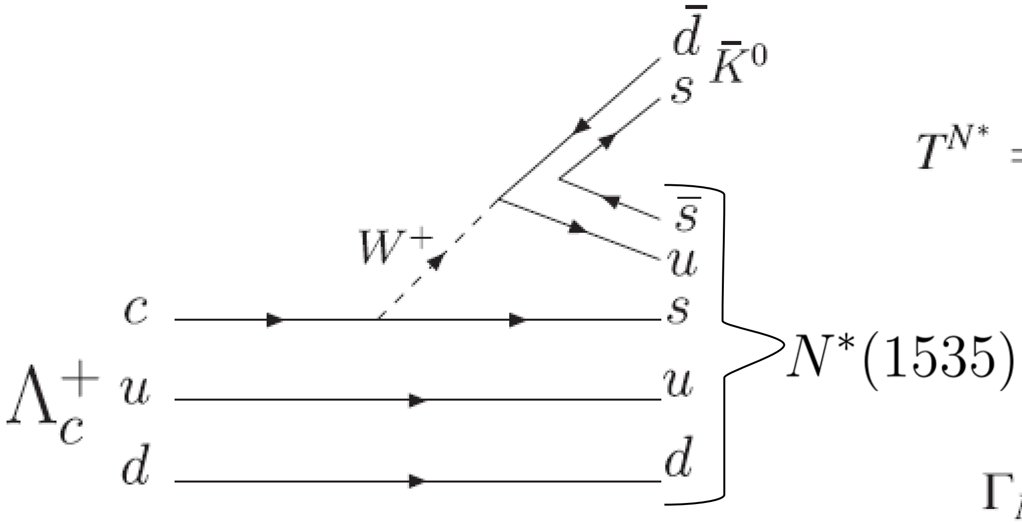
$$|MB\rangle = \frac{\sqrt{3}}{3}|\eta p\rangle + \frac{\sqrt{2}}{2}|\pi^0 p\rangle + |\pi^+ n\rangle - \frac{\sqrt{6}}{3}|K^+\Lambda\rangle,$$



(a) (b)

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

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



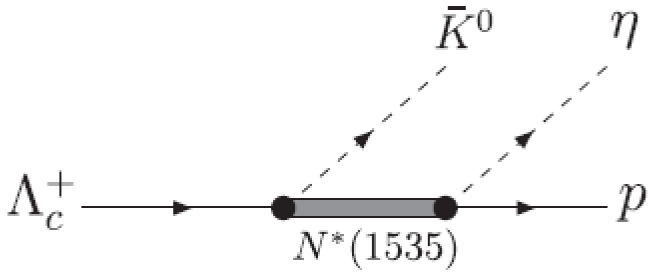
(a)

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

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

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

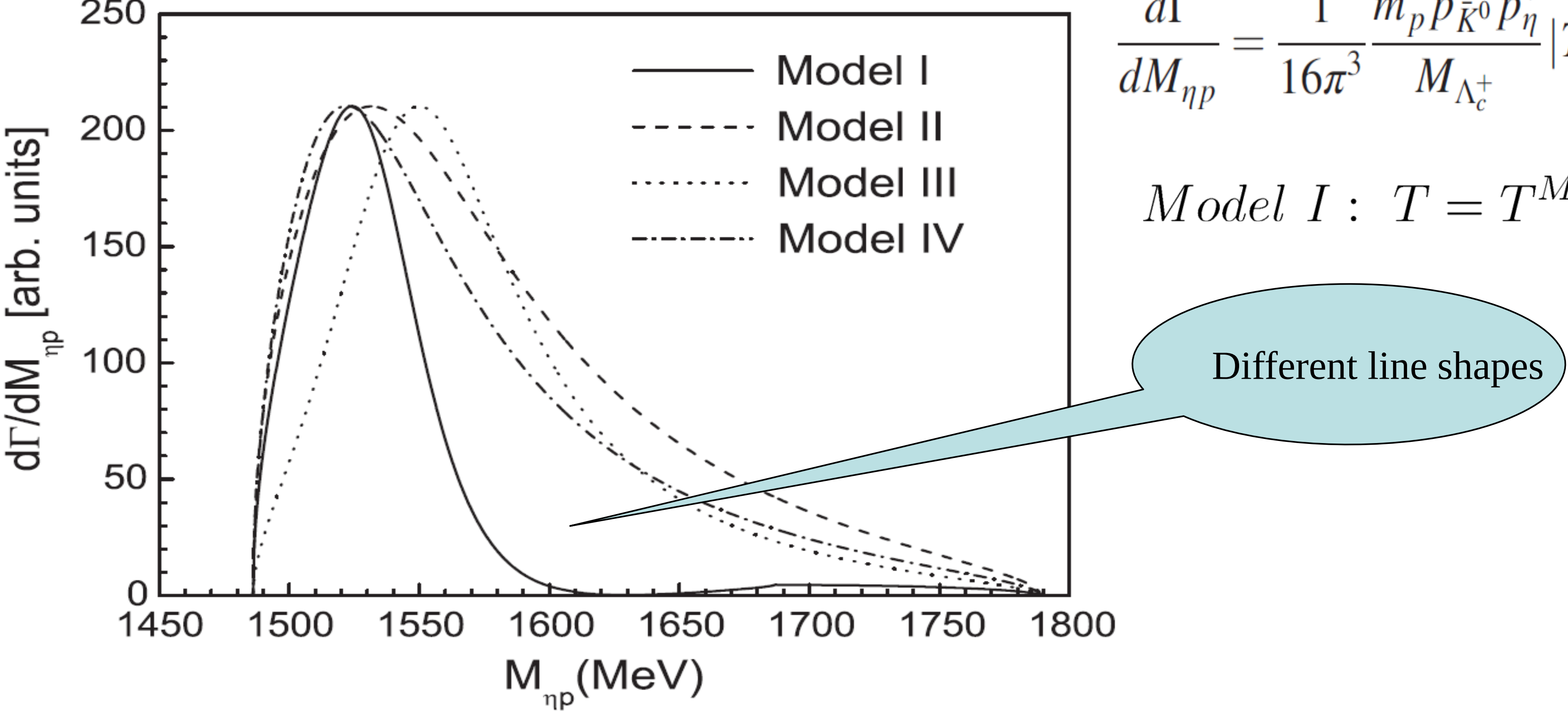
$$\Gamma_0 = 19.5 \text{ MeV} \quad \text{for} \quad \Gamma_{N^*}(\sqrt{q^2} = 1535 \text{ MeV}) = 150 \text{ MeV}.$$



(b)

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

Invariant ηp mass distributions



$$\frac{d\Gamma}{dM_{\eta p}} = \frac{1}{16\pi^3}\frac{m_p p_{\bar{K}^0} p_\eta^*}{M_{\Lambda_c^+}}|T|^2,$$

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

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

$$Model\ III:\ T = T^{N^*},\ M_{N^*} = 1543\ \mathrm{MeV},\ \Gamma_{N^*} = 92\ \mathrm{MeV}$$

$$Model\ IV:\ T = T^{N^*},\ M_{N^*} = 1500\ \mathrm{MeV},\ \Gamma_{N^*} = 110\ \mathrm{MeV}$$

Other contributions

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

$$\Sigma^* \; resonances$$

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

$$\Sigma^*(1660)1/2^+ : \; p - wave$$

$$\Sigma^*(1670)3/2^- : \; d - wave$$

$$\Sigma^*(1750)1/2^- : s - wave, \; but,$$

$$very \; small \; phase \; space$$

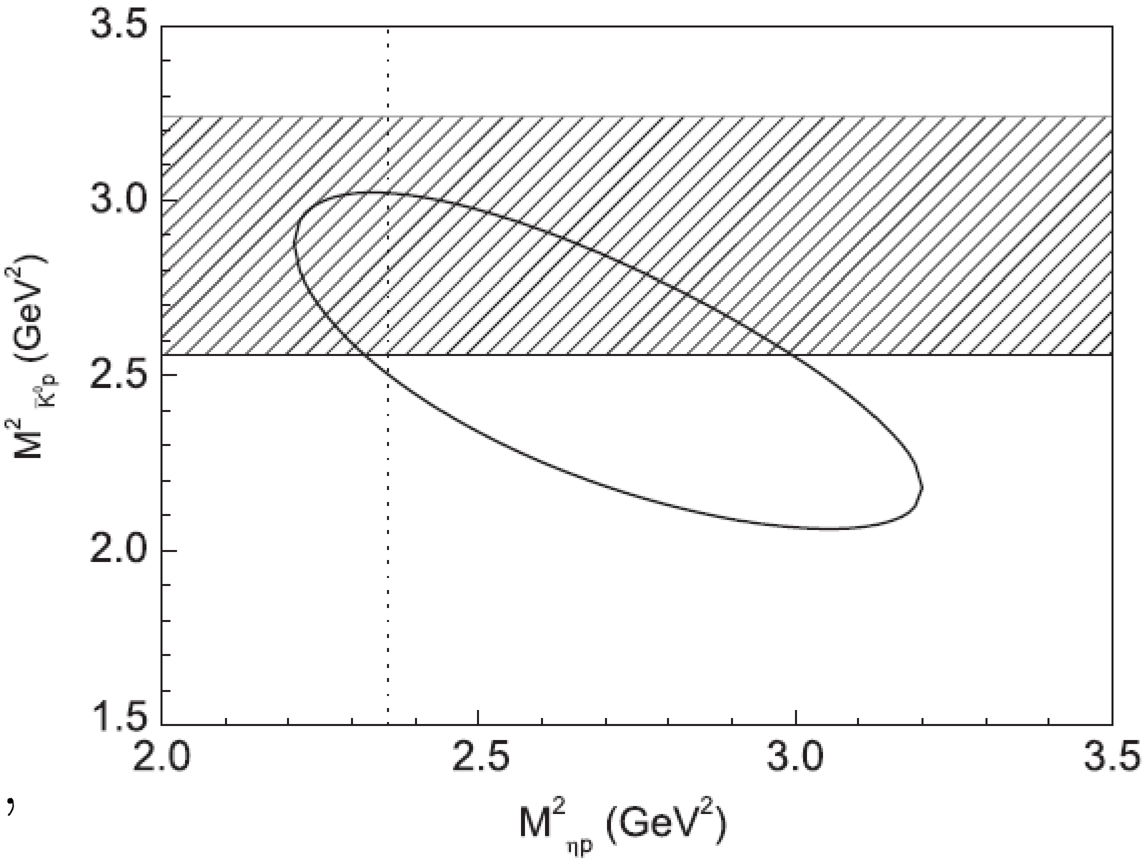


FIG. 7. Dalitz plot for $M^2_{\eta p}$ and $M^2_{\bar{K}^0 p}$ in the $\Lambda_c^+ \to \bar{K}^0 \eta p$ decay. The $N^*(1535)$ energy is shown by the vertical dotted line, and the horizontal band represents the masses of Σ^* states from 1600 to 1800 MeV.

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).

ϕN bound state

PHYSICAL REVIEW C, VOLUME 63, 022201(R)

ϕ-N bound state

H. Gao,[1] T.-S. H. Lee,[2] and V. Marinov[1]

PHYSICAL REVIEW C 73, 025207 (2006)

$N\phi$ states in a chiral quark model

F. Huang,[1,2,3] Z. Y. Zhang,[2] and Y. W. Yu[2]

PHYSICAL REVIEW C 95, 055202 (2017)

Search for a hidden strange baryon-meson bound state from ϕ production in a nuclear medium

Haiyan Gao,[1,2] Hongxia Huang,[1,3,*] Tianbo Liu,[1,2,†] Jialun Ping,[3] Fan Wang,[4] and Zhiwen Zhao[1]

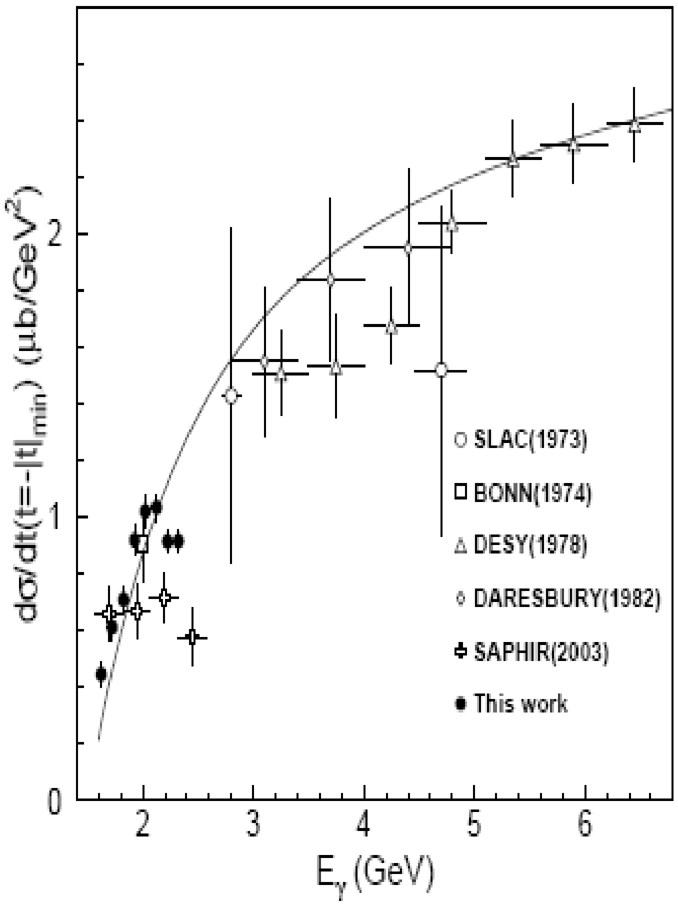
We investigate the hidden strange light baryon-meson system. With the resonating-group method, two bound states, $\eta' - N$ and $\phi - N$, are found in the quark delocalization color screening model. Focusing on the $\phi - N$ bound state around 1950 MeV, we obtain the total decay width of about 4 MeV by calculating the phase shifts in

Decay patterns of low-lying $N_{s\bar{s}}$ states via strangeness channels

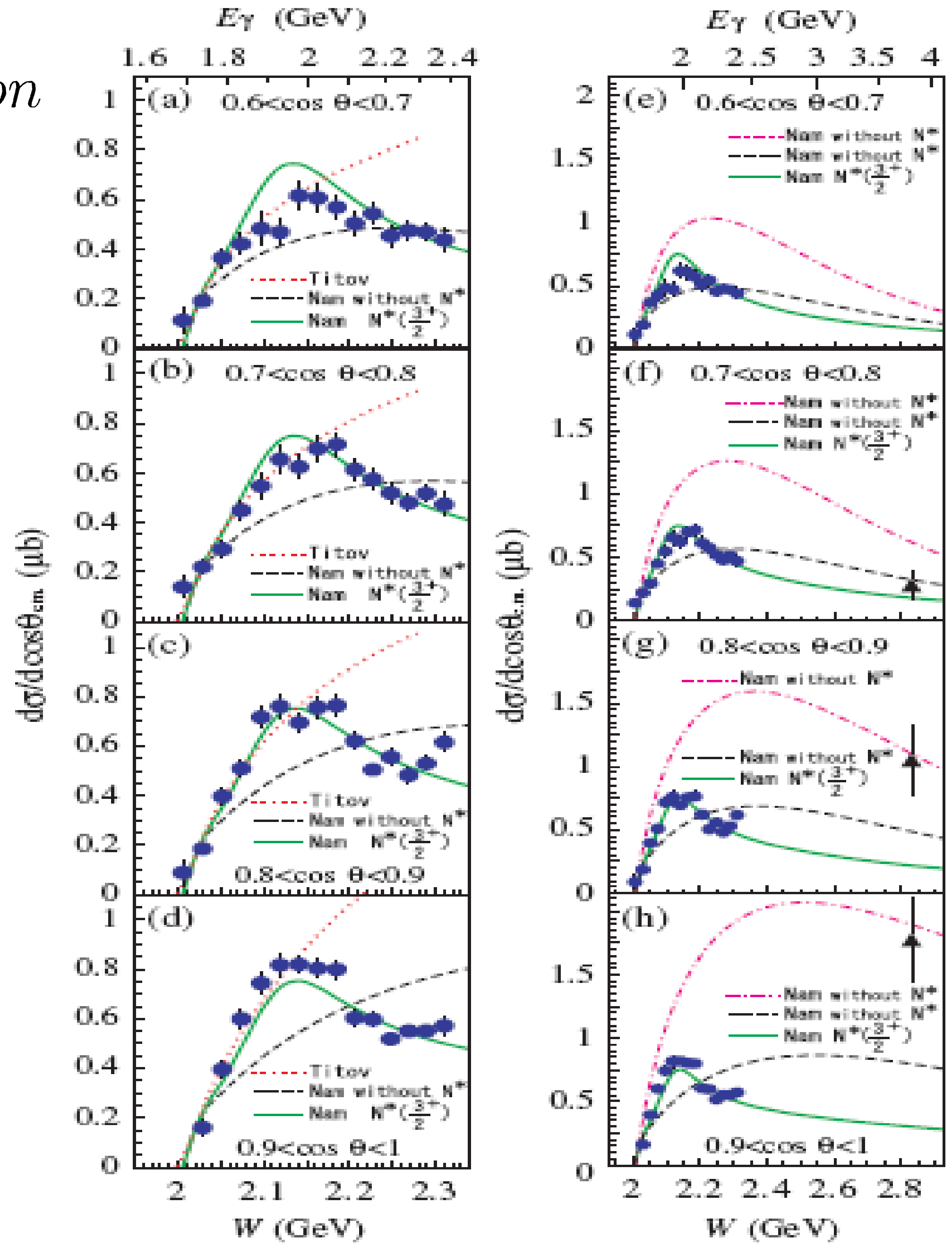
Chun-Sheng An,[1] Ju-Jun Xie,[2] and Gang Li[3,*]

PHYSICAL REVIEW C 98, 045201 (2018)

$\gamma p \rightarrow K^+\Lambda(1520)$ *reaction*



$\gamma p \rightarrow p\phi$ *reaction*



PRL, 95, 182001 (2005); PRL,104, 172001 (2010), LEPS Collaboration.

The γp->φp reaction

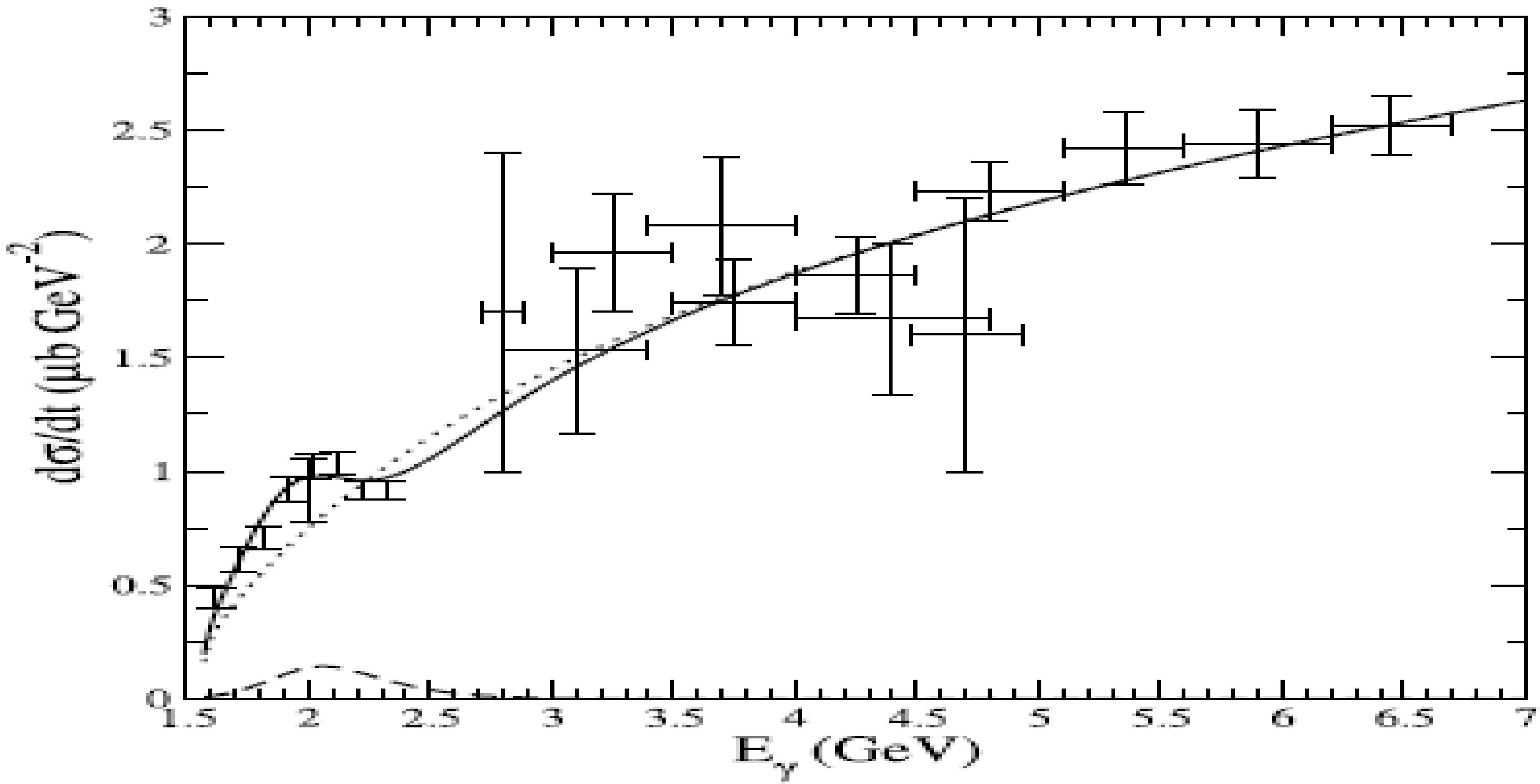
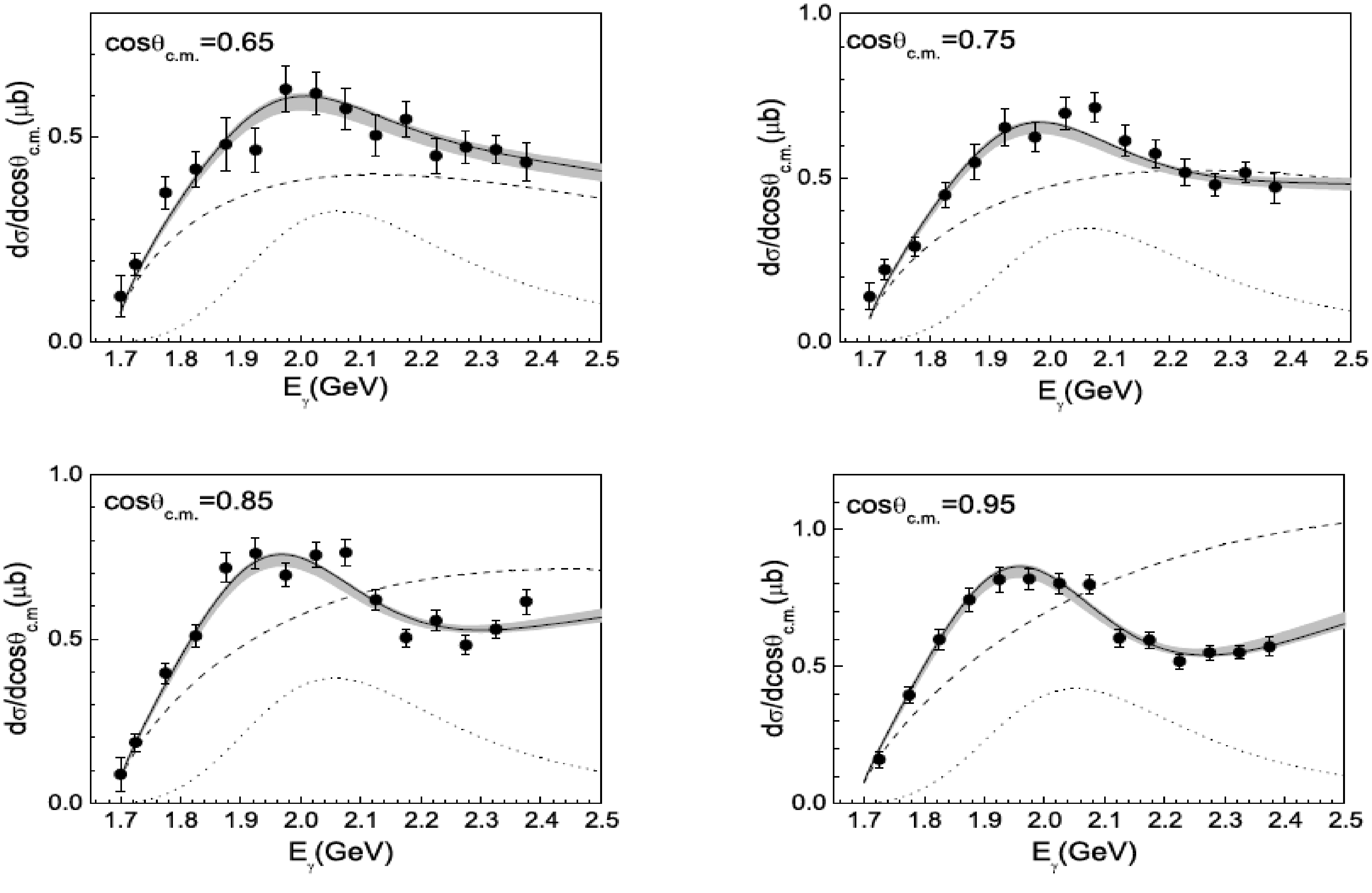


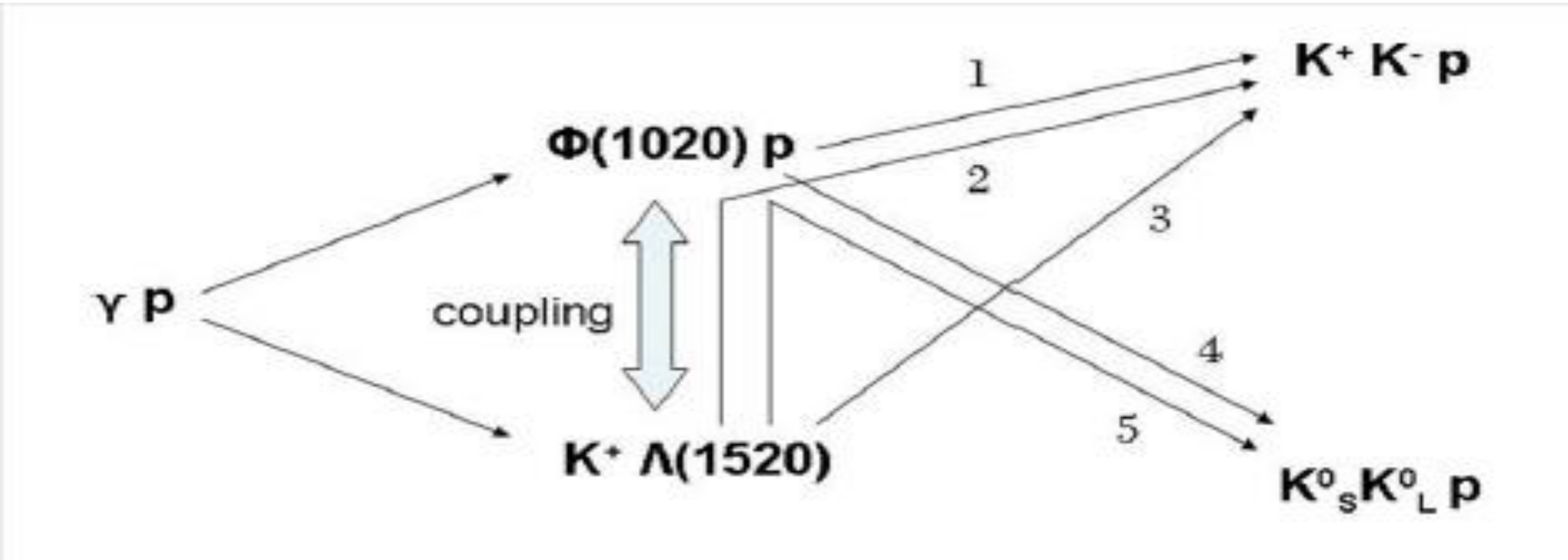
Fig. 2. Differential cross section of $\gamma p \to \phi p$ at forward direction as a function of photon energy E_γ. The dotted, dashed, and solid lines denote contributions from nonresonant, resonance with $J^P = 3/2^-$, and their sum, respectively. Data are from Refs. [10,17].

Alvin Kiswandhi, Ju-Jun Xie, Shin Nan Yang, PLB, 691, 214 (2010).

The γp->K⁺Λ(1520) reaction



Ju-Jun Xie, and Juan Nieves, Phys. Rev. C 82, 045205 (2010).



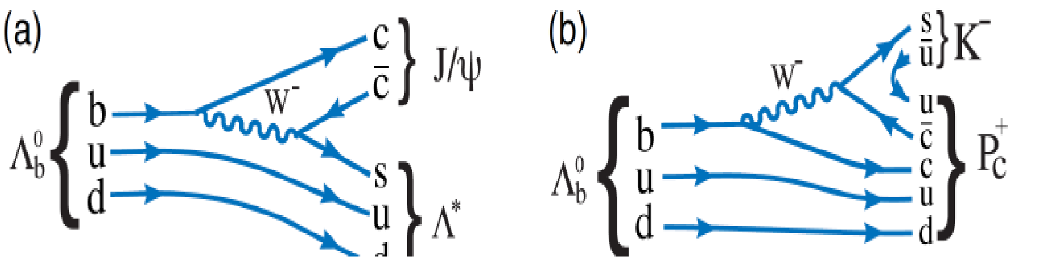
The γp->pϕ and γp-> $K^+\Lambda(1520)$ reactions should be studied together.

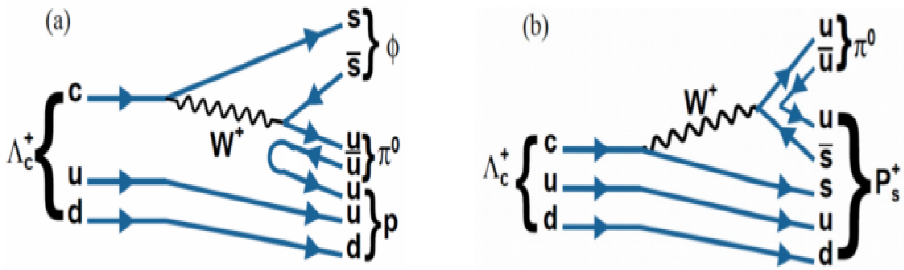
PRL **116**, 232001 (2016) PHYSICAL REVIEW LETTERS week ending 10 JUNE 2016

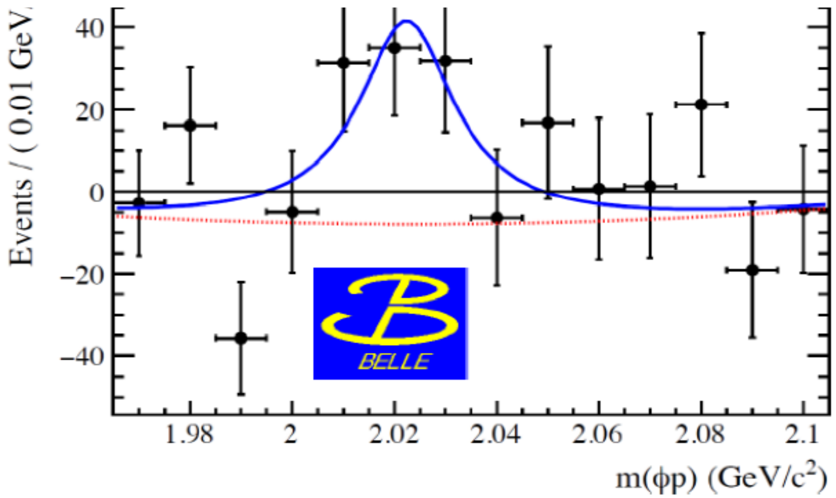
Interference Effect between ϕ and $\Lambda(1520)$ Production Channels in the $\gamma p \rightarrow K^+K^-p$ Reaction near Threshold

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

R. Lebed, PRD92(2015)114030







From Cheng-Ping Shen

$\Sigma^+ \to p\pi^0$ vetoed

- **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 $\Lambda_c \to P_s\pi^0 \to \phi p \pi^0$ events: 77.6±28.1

$B(\Lambda_c \to P_s\pi^0) x B(P_s \to \phi p) < 8.3x10^{-5}$ @90% C.L.

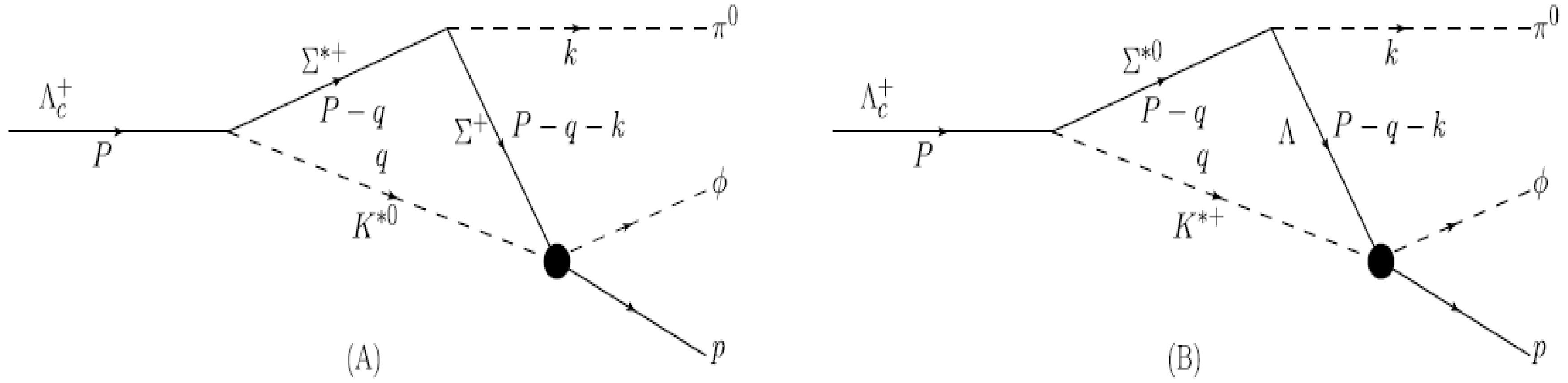


Fig. 1. Triangle diagrams for the $\Lambda_c^+ \to \pi^0 p\phi$ decay. (A): Σ^+-exchange. (B): Λ-exchange. The definitions of the kinematical variables (P, q, k) are also shown.

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

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

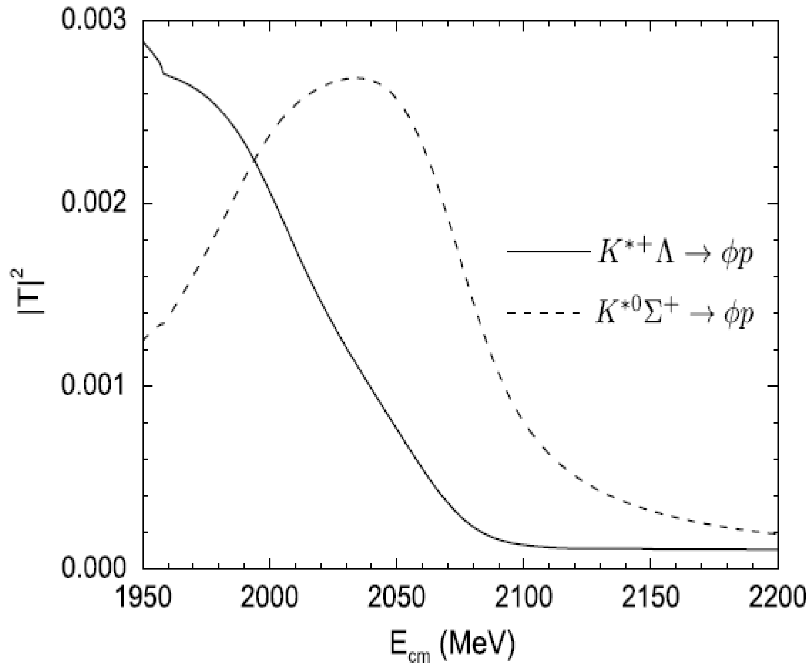


Fig. 3. The squared norm of the T-matrix elements for $K^{*+}\Lambda \to \phi p$ and $K^{*0}\Sigma^+ \to \phi p$ as a function of the meson–baryon invariant mass E_{cm} in the model of Ref. [72].

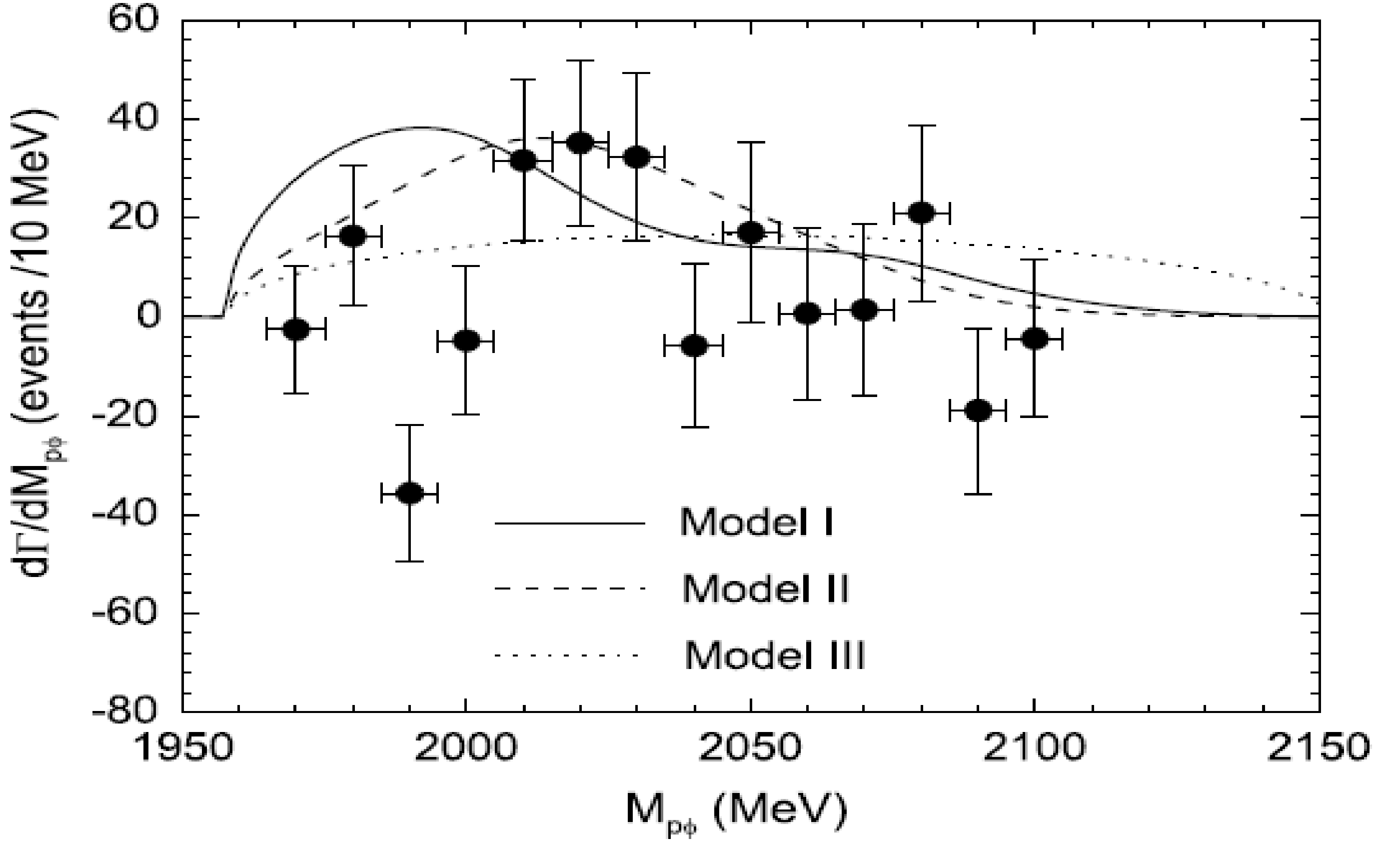


Fig. 2. Invariant mass distribution of the $\Lambda_c^+ \to \pi^0 p\phi$ decay. The experimental data are taken from Ref. [47].

Model I: the BV interaction model (P_s generated) of A. Ramos, E. Oset, PLB727(2013)287;

Model II: no resonance, constant interaction; Model III: phase space

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

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

Thank you very much for your attention!

$$\frac{d\Gamma}{dM_{\eta p}} = f_1 A^2 + f_2 B^2.$$

$$R = \frac{f_2 B^2}{f_1 A^2} = \frac{f_2}{f_1}.$$

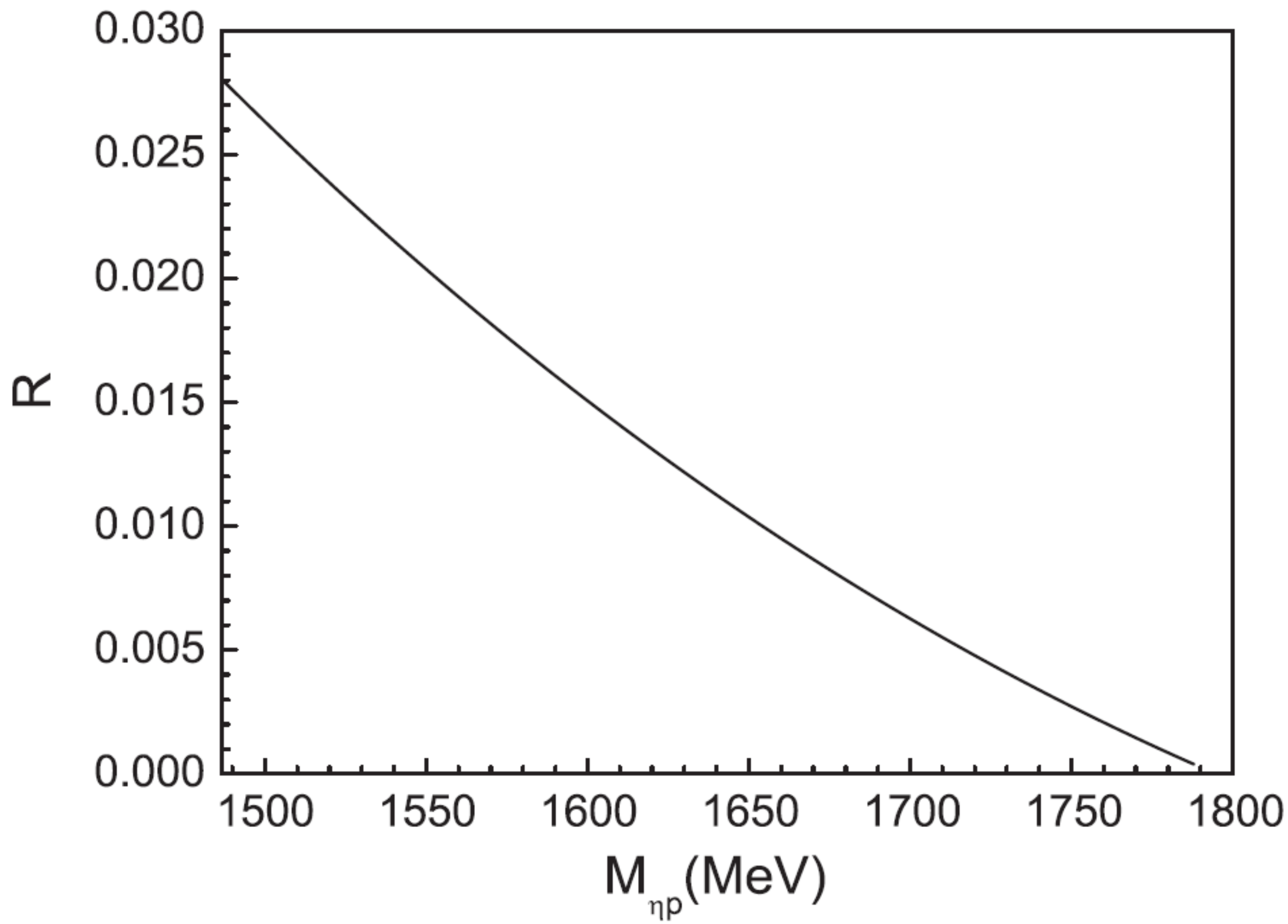


FIG. 6. Ratio R of the B and A terms as a function of the ηp invariant mass.