ZHENGZHOU UNIVERSITY 郑州大学

Study of $J^P = 1/2^-$ low-lying excited baryons in Λ_c^+ three-body decays

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EPJC 84:1253 (2024) & CPL 43, 050203(2026)

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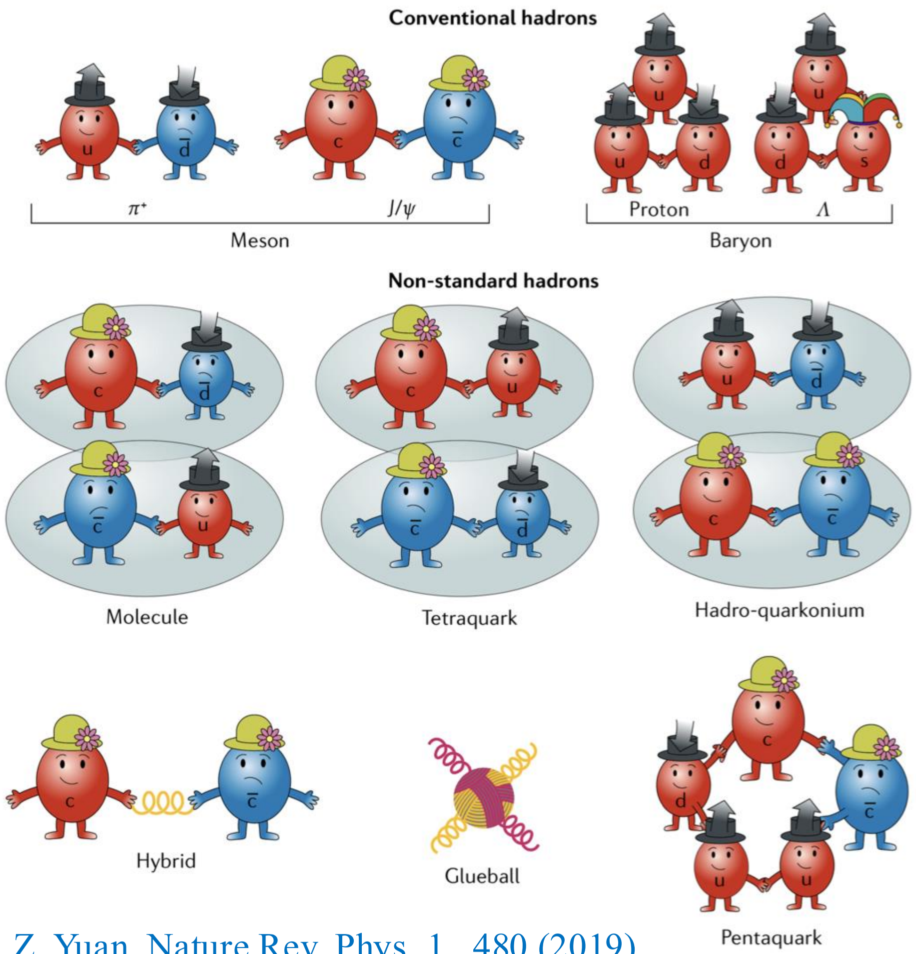
Introduction

- **The decays of Λ_c^+ and meson-baryon interaction**



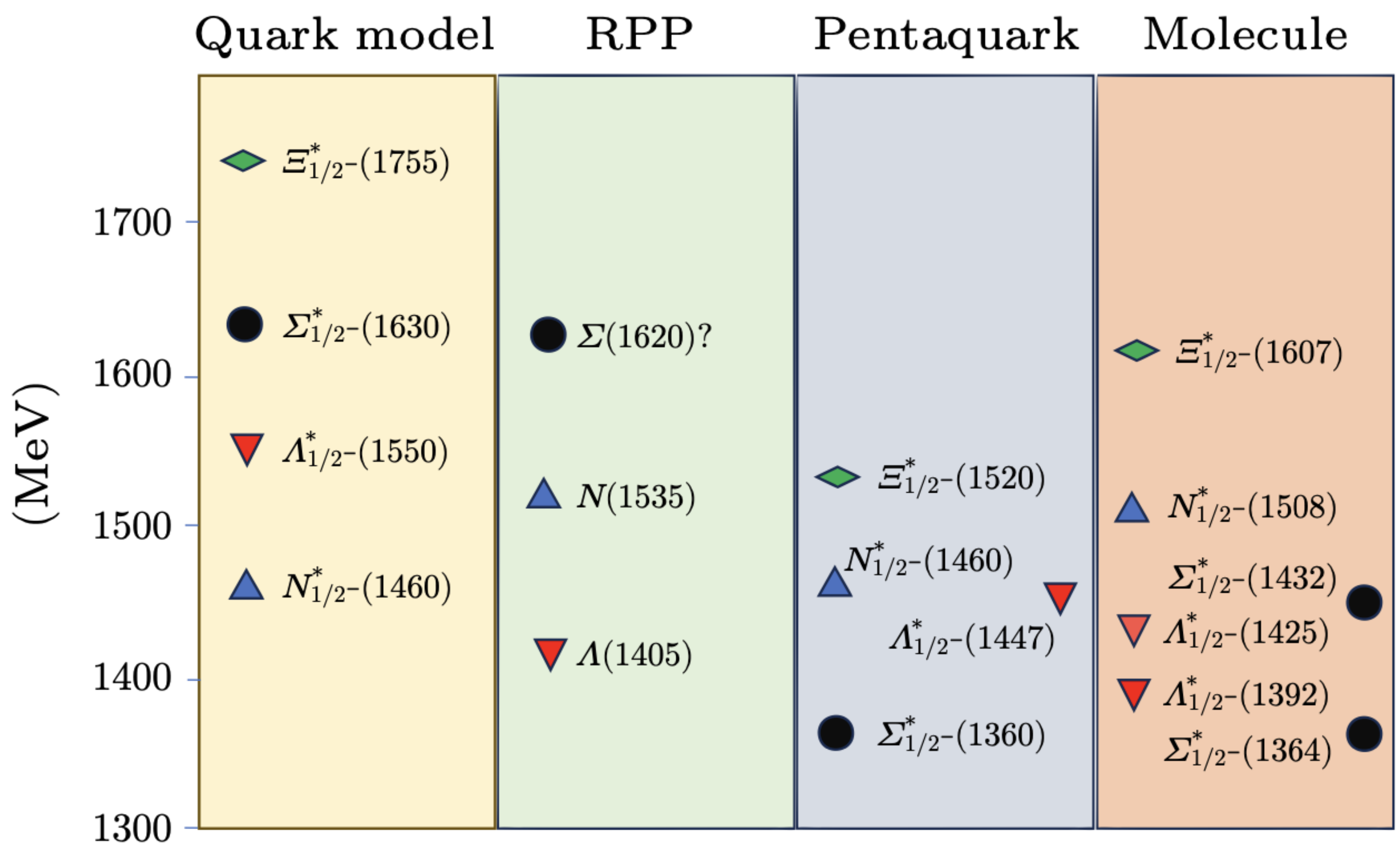
C. Z. Yuan, Nature Rev. Phys. 1 , 480 (2019)

✓ Meson-baryon interaction makes it possible for probing the dynamic structure of the baryon resonance.

✓ The Λ_c^+ , as the first observed charmed baryon, with a large number of decay modes, has been valued by BESIII, Belle, CLEO and LHCb Collaborations.

Introduction

- **Masses of the low-lying excited baryons with $J^P = 1/2^-$**



E. Wang, L. S. Geng, J. J. Wu, J. J. Xie and B. S. Zou,
Chin. Phys. Lett. **41**, no.10, 101401 (2024)

✓ **Mass reverse problem**

$N(1535)\ J^P = 1/2^-\ \ n = 1\ \ L = 1$

$N(1440)\ J^P = 1/2^+\ \ n = 2\ \ L = 0$

- Naive quark model

  $N(1535) < N(1440)$

- Experiment

  $N(1535) > N(1440)$

✓ **The unclear nature of $\Lambda(1670)$**

$\Lambda(1405)\ J^P = 1/2^-\ \ \bar{K}N$

✓ **The missing low-lying $\Sigma^*(1/2^-)$**

$\Sigma^*(1/2^-)$ **unestablished**

$\Sigma(1620)\ J^P = 1/2^-$ **one star** in RPP

Introduction ($\Lambda(1/2^-)$)

$\Lambda(1405)$: two-pole structure

- lower pole: above the $\pi\Sigma$ threshold, also called $\Lambda(1380)$.
- higher pole: below the $\bar{K}N$ threshold, is known as $\Lambda(1405)$, $\bar{K}N$ molecular state.

E. Oset and A. Ramos, Nucl. Phys. A **635**, 99-120 (1998)
D. Jido, J. A. Oller, E. Oset, A. Ramos and U. G. Meissner, Nucl. Phys. A **725**, 181-200 (2003)
T. Hyodo and W. Weise, Phys. Rev. C 77, 035204 (2008)
Z. Zhuang, R. Molina, J. X. Lu and L. S. Geng, Sci. Bull. **70**, 1953-1961 (2025)

$\Lambda(1670)$: What is the physical nature?

- traditional three-quark state

X. H. Zhong and Q. Zhao, Phys. Rev. C 79, 045202 (2009)
A. Starostin et al. (Crystal Ball Collaboration), Phys. Rev. C 64, 055205 (2001)

- dynamically generated molecule from coupled-channel interactions like $\bar{K}N$, $\eta\Lambda$, and $\pi\Sigma$

K. Miyahara, T. Hyodo, and E. Oset, Phys. Rev. C 92, 055204 (2015)
J. J. Xie and L. S. Geng, Eur. Phys. J. C 76, 496 (2016)
Z. Y. Wang, S. Q. Luo, Z. F. Sun, C. W. Xiao, and X. Liu, Phys. Rev. D 106, 096026 (2022)

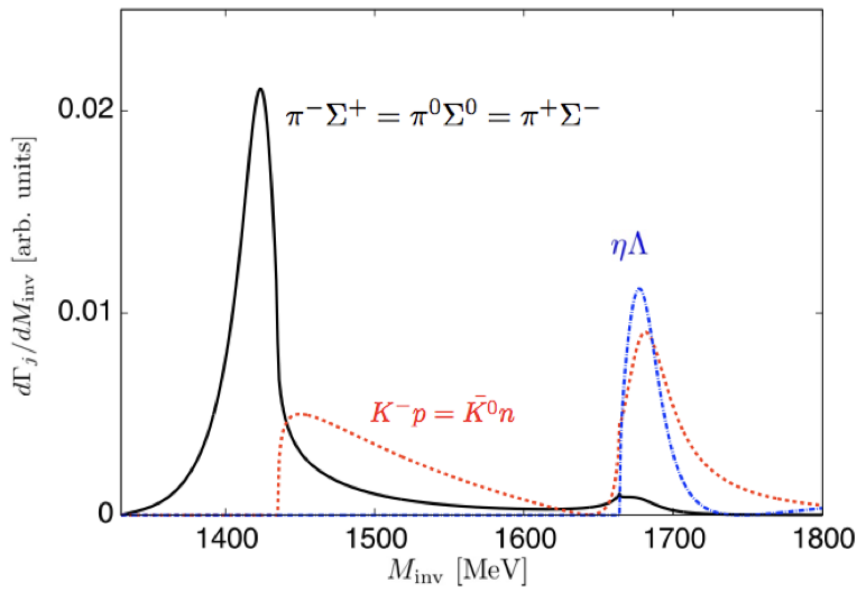
- bare three-quark basis state that mixes with the $\pi\Sigma$, $\bar{K}N$, $\eta\Lambda$, and $K\Xi$ meson-baryon channels

J. J. Liu, Z. W. Liu, K. Chen, D. Guo, D. B. Leinweber, X. Liu, and A. W. Thomas, Phys. Rev. D 109, 054025 (2024)

Introduction ($\Lambda(1/2^-)$)

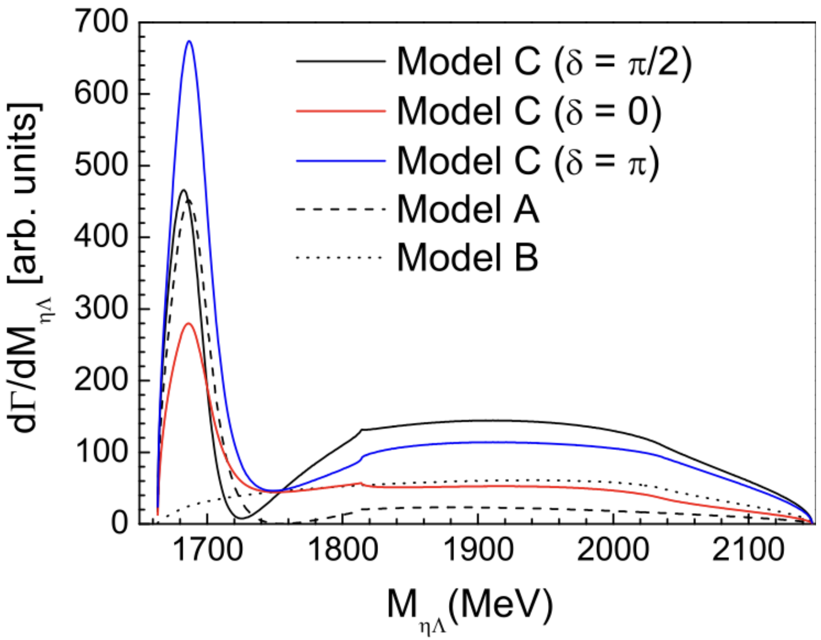
- Invariant mass spectrum predictions for the $\Lambda(1670)$.

$\Lambda_c^+ \to \pi^+ MB$



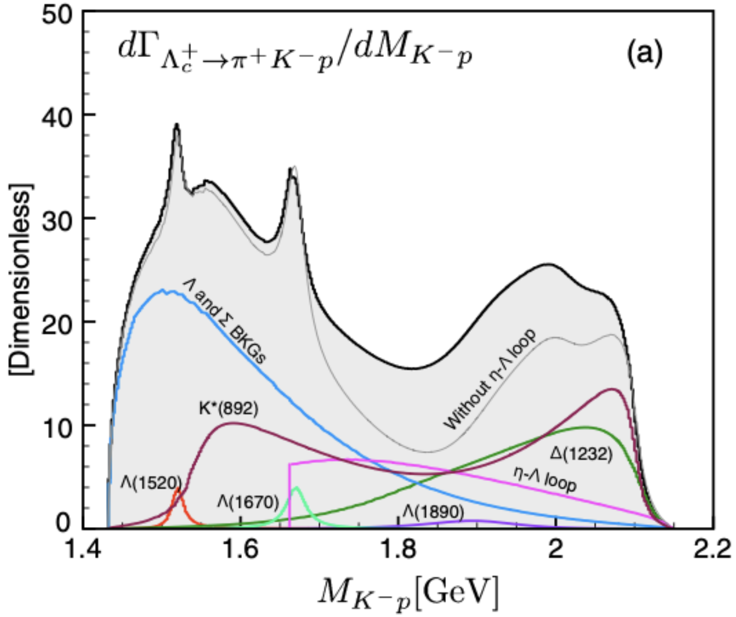
K. Miyahara, T. Hyodo and E. Oset,
Phys. Rev. C 92, 055204(2015)

$\Lambda_c^+ \to \eta\Lambda\pi^+$



J. J. Xie and L. S. Geng,
Eur. Phys. J. C 76, 496 (2016)

$\Lambda_c^+ \to pK^-\pi^+$



J. K. Ahn, S. Yang and S. I. Nam,
Phys. Rev. D 100, 034027 (2019)

Introduction ($\Sigma(1/2^-)$)

$\Sigma(1/2^-)$: remains poorly established

- Predicted theoretically

✓ **The chiral unitary approach**

Theoretical studies predict a $\Sigma^*(1/2^-)$ with a mass near the $\bar{K}N$ threshold, generated from S-wave meson-baryon interactions in the strangeness $S = -1$ sector.

K. P. Khemchandani, A. Martínez Torres and J. A. Oller, Phys. Rev. C **100**, no.1, 015208 (2019)
Y. Kamiya, K. Miyahara, S. Ohnishi, Y. Ikeda, T. Hyodo, E. Oset and W. Weise, Nucl. Phys. A **954**, 41-57 (2016)
J. A. Oller, Eur. Phys. J. A **28**, 63-82 (2006)

✓ **The effective Lagrangian approach**

The $\Sigma^*(1380)(J^P = 1/2^-)$ state plays a role in the $K\Sigma^*$ photoproduction and the $K^-p \to \Lambda\pi^-\pi^+$ reaction.

P. Gao, J. J. Wu and B. S. Zou, Phys. Rev. C **81**, 055203 (2010)
J. J. Wu, S. Dulat and B. S. Zou, Phys. Rev. C **81**, 045210 (2010)

✓ **$\Sigma^*(1/2^-)$ in Λ_c^+ four-body and three-body decays**

The $\Sigma^*(1/2^-)$ makes a significant contribution to the invariant mass spectra of $\pi\Lambda$ and $\pi\Sigma$.

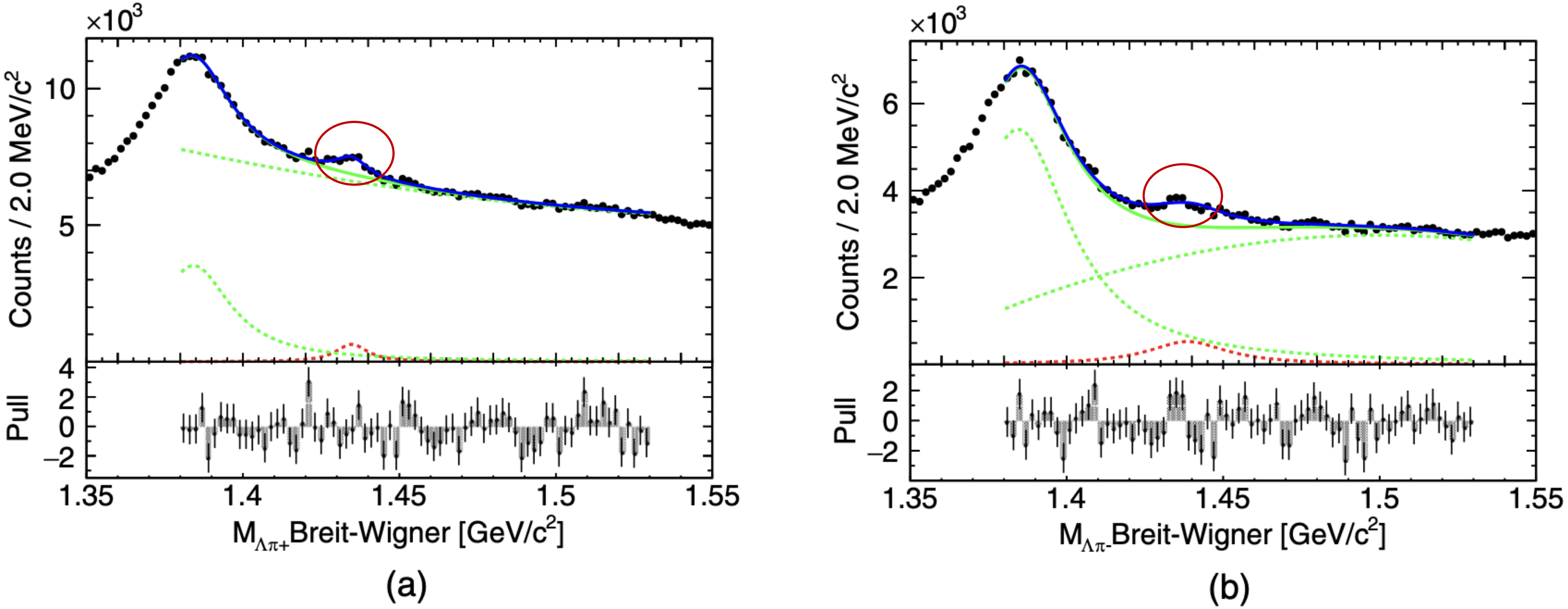
J. J. Xie and E. Oset, Phys. Lett. B **792**, 450-453 (2019)
Y. Y. Li, J. Song, E. Oset, W. H. Liang and R. Molina, Eur. Phys. J. C **85**, no.9, 1086 (2025)
W. T. Lyu, S. C. Zhang, G. Y. Wang, J. J. Wu, E. Wang, L. S. Geng and J. J. Xie, Phys. Rev. D **110**, no.5, 054020 (2024)

Introduction ($\Sigma(1/2^-)$)

- ☐ Observed experimentally
- ✓ $\Sigma^*(1/2^-)$ **in** Λ_c^+ **four-body decays**

Mode	E_{BW} (MeV/c^2)	Γ (MeV/c^2)	χ^2/NDF
$\Lambda\pi^+$	1434.3 ± 0.6	11.5 ± 2.8	74.4/68
$\Lambda\pi^-$	1438.5 ± 0.9	33.0 ± 7.5	92.3/68

$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$



Y. Ma *et al.* [Belle], Phys. Rev. Lett. **130**, no.15, 151903 (2023)

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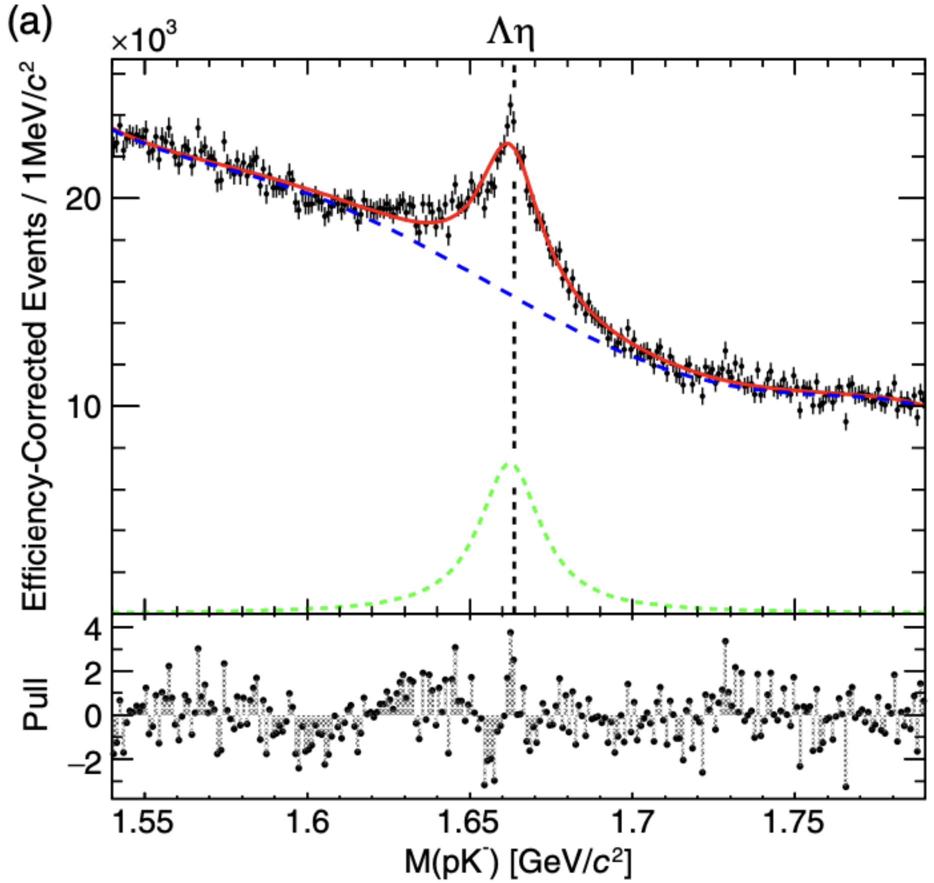
The $\Lambda(1670)$ in $\Lambda_c^+ \to pK^-\pi^+$

- The Belle Collaboration measured the pK^- invariant mass spectrum in $\Lambda_c^+ \to pK^-\pi^+$ decay, revealing a distinct cusp structure at the $\eta\Lambda$ threshold.



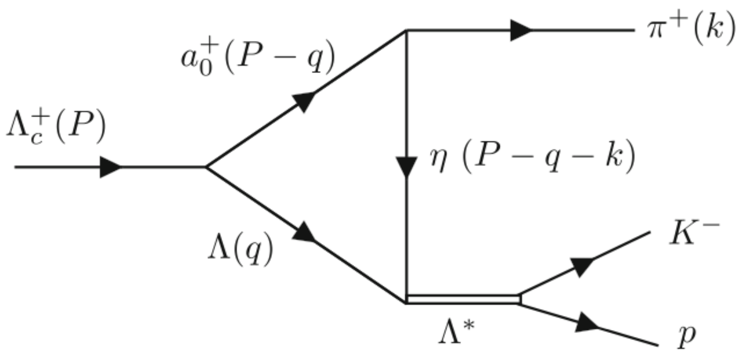
S. B. Yang et al. [Belle], Phys. Rev. D **108**, L031104 (2023)

The $\Lambda(1670)$ in $\Lambda_c^+ \to pK^-\pi^+$

- We consider the triangle diagram contribution of the process $\Lambda_c^+ \to pK^-\pi^+$ via the intermediate process $\Lambda_c^+ \to a_0(980)^+\Lambda$, with the vertex amplitude given by

$$t_{\Lambda_c^+ \to a_0(980)^+\Lambda} = g_{\Lambda_c^+ a_0 \Lambda}$$

$$t_{a_0(980)^+ \to \eta\pi^+} = g_{a_0 \eta\pi^+}$$



- The total amplitude via the triangle mechanism

$$\mathcal{T}^{TS} = \mathcal{Q} t^{TS} \times t_{\Lambda\eta \to pK^-}$$

where $\mathcal{Q} = g_{\Lambda_c^+ a_0 \Lambda} g_{a_0 \eta\pi^+}$ is a constant, t^{TS} is the triangle amplitude, and $t_{\Lambda\eta \to pK^-}$ is the interaction transition amplitude for the S-wave $\eta\Lambda \to pK^-$.

The $\Lambda(1670)$ in $\Lambda_c^+ \to pK^-\pi^+$

- The transition amplitude for the S-wave $\eta\Lambda \to pK^-$
- The Bethe-Salpeter equation: $T = [1 - VG]^{-1}V$
- The potential: $V_{ij} = -C_{ij}\frac{1}{4f^2}(2\sqrt{s} - M_i - M_j) \times \left(\frac{M_i+E_i}{2M_i}\right)^{1/2}\left(\frac{M_j+E_j}{2M_j}\right)^{1/2}$
- The meson-baryon loop function: $G_l(\sqrt{s}) = \frac{1}{16\pi^2}\Big\{a_l(\mu) + ln\frac{M_l^2}{\mu^2} + \frac{m_l^2-M_l^2+s}{2s}ln\frac{m_l^2}{M_l^2} + \frac{\bar{q}_l}{\sqrt{s}}[\ln\big(s - (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s}\big) + \ln\big(s + (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s}\big) - \ln(-s + (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s} - \ln\big(-s - (M_l^2 - m_l^2) + 2\bar{q}_l\sqrt{s}\big)]\Big\}$

Table 1
C_{ij} coefficients of Eq. (7). $C_{ji} = C_{ij}$ E. Oset and A. Ramos, Nucl. Phys. A 635, 99 (1998)

	K^-p	$\bar{K}^0n$	$\pi^0\Lambda$	$\pi^0\Sigma^0$	$\eta\Lambda$	$\eta\Sigma^0$	$\pi^+\Sigma^-$	$\pi^-\Sigma^+$	$K^+\Xi^-$	$K^0\Xi^0$
K^-p	2	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$\frac{\sqrt{3}}{2}$	0	1	0	0
$\bar{K}^0n$		2	$-\frac{\sqrt{3}}{2}$	$\frac{1}{2}$	$\frac{3}{2}$	$-\frac{\sqrt{3}}{2}$	1	0	0	0
$\pi^0\Lambda$			0	0	0	0	0	0	$\frac{\sqrt{3}}{2}$	$-\frac{\sqrt{3}}{2}$
$\pi^0\Sigma^0$				0	0	0	2	2	$\frac{1}{2}$	$\frac{1}{2}$
$\eta\Lambda$					0	0	0	0	$\frac{3}{2}$	$\frac{3}{2}$
$\eta\Sigma^0$						0	0	0	$\frac{\sqrt{3}}{2}$	$-\frac{\sqrt{3}}{2}$
$\pi^+\Sigma^-$							2	0	1	0
$\pi^-\Sigma^+$								2	0	1
$K^+\Xi^-$									2	1
$K^0\Xi^0$										2

- The subtraction constant: $a_{\bar{K}N} = -1.84$， $a_{\pi\Sigma} = -2.00$， $a_{\eta\Lambda} = -2.25$ and we take $a_{K\Xi}$ to be a free parameter

The $\Lambda(1670)$ in $\Lambda_c^+ \to pK^-\pi^+$

- The triangle amplitude

$$t^{TS} = \int \frac{d^3q}{(2\pi)^3} \frac{2m_\Lambda}{8\omega_\Lambda\omega_{a_0}\omega_\eta} \frac{1}{k^0-\omega_{a_0}-\omega_\eta+i\frac{\Gamma_{a_0}}{2}} \times \frac{1}{P^0+\omega_\Lambda+\omega_\eta-k^0}$$

$$\times \frac{2P^0\omega_\Lambda + 2k^0\omega_\eta - 2(\omega_\Lambda+\omega_\eta)(\omega_\Lambda+\omega_\eta+\omega_\Lambda+\omega_{a_0})}{P^0-\omega_{a_0}-\omega_\Lambda+i\frac{\Gamma_{a_0}}{2}} \times \frac{1}{P^0-\omega_\Lambda-\omega_\eta-k^0+i\varepsilon}$$

- The pK^- invariant mass distribution for the process $\Lambda_c^+ \to pK^-\pi^+$:

$$\frac{d\Gamma}{dM_{pK^-}} = \frac{1}{(2\pi)^3} \frac{M_p M_{\Lambda_c} p_{\pi^+} \tilde{p}_{K^-}}{4M_{\Lambda_c^+}^2} |\mathcal{T}^{TS}|^2$$

where $p_{\pi^+} = \frac{\lambda^{1/2}(M_{\Lambda_c^+}^2, M_{\pi^+}^2, M_{pK^-}^2)}{2M_{\Lambda_c^+}}$ and $\tilde{p}_{K^-} = \frac{\lambda^{1/2}(M_{pK^-}^2, m_{K^-}^2, m_p^2)}{2M_{pK^-}}$.

- The background: $f(M_{pK^-}) = a_0 + a_1 M_{pK^-} + a_2 M_{pK^-}^2 + a_3 M_{pK^-}^3$

The $\Lambda(1670)$ in $\Lambda_c^+ \to pK^-\pi^+$

- 6 free parameters: normalization factor $Q^{'}$;

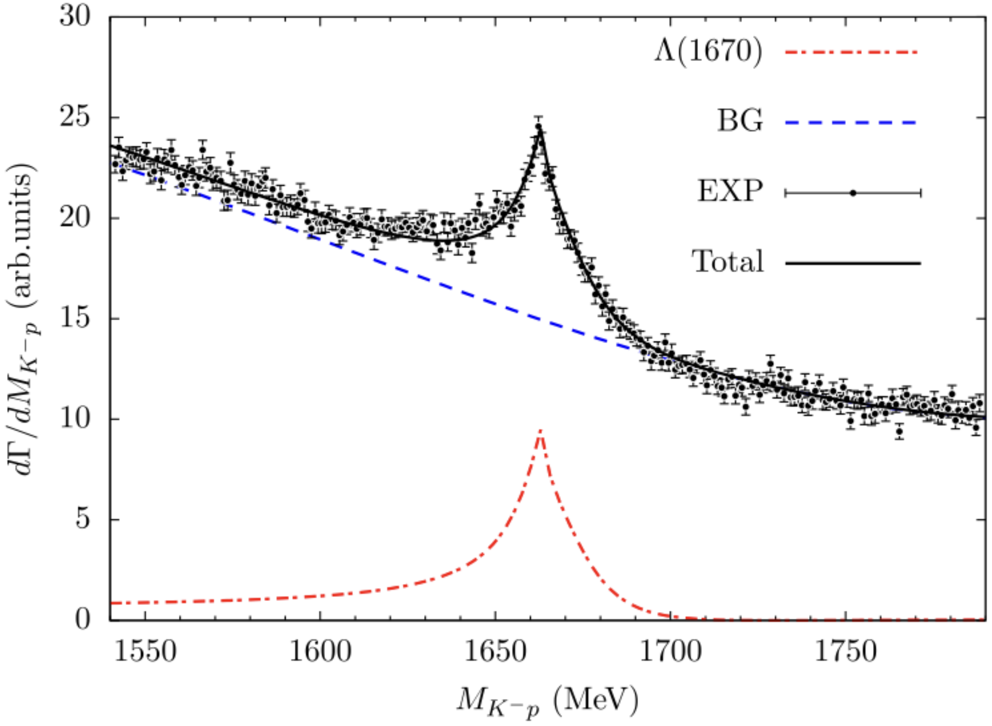
  subtraction constant $a_{K\Xi}$;

  background parameters a_0, a_1, a_2, a_3.

Parameters	Values
Q'	$(6.092 \pm 0.068) \times 10^4$
$a_{K\Xi}$	-2.776 ± 0.003
a_0	-1969.30 ± 0.23
a_1	3.860 ± 0.001
a_2	$(-2.455 \pm 0.001) \times 10^{-3}$
a_3	$(5.118 \pm 0.001) \times 10^{-7}$
χ^2	301.76
$\chi^2/d.o.f.$	1.25

The $\Lambda(1670)$ in $\Lambda_c^+ \to pK^-\pi^+$

- The pK^- invariant mass distribution for $\Lambda_c^+ \to pK^-\pi^+$ decay



- The fitted subtraction constant $a_{K\Xi} = -2.776$ corresponds to the pole position $(1669.0 - i20.3)$ MeV for the $\Lambda(1670)$.

$\Lambda(1670)1/2^-$

Pole parameters	
M=1676±2	Γ=33±4

A. V. Sarantsev, M. Matveev, V. A. Nikonov, A. V. Anisovich, U. Thoma and E. Klempt, Eur. Phys. J. A 55, 180 (2019)

	$J^P(l_{I2J})$	Model A
Λ baryons	$1/2^-(S_{01})$	$(1669^{+3}_{-8}, 9^{+9}_{-1})$

H. Kamano, S. X. Nakamura, T. S. H. Lee and T. Sato, Phys. Rev. C 92, 025205 (2015)

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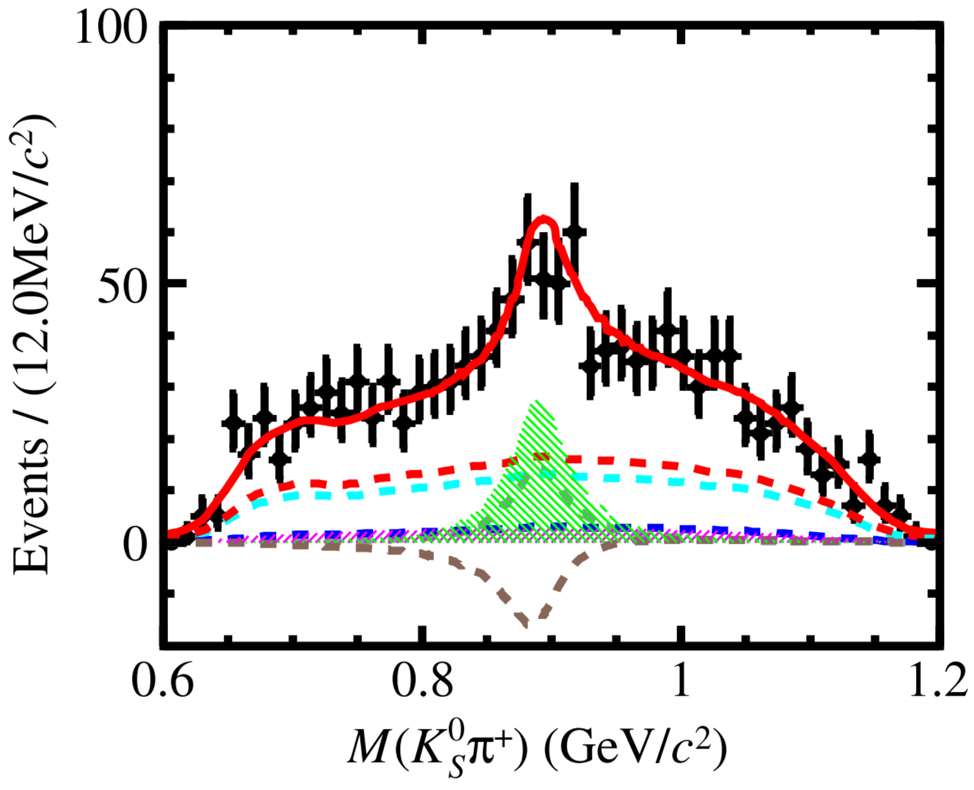
The $\Sigma^*(1/2^-)$ in $\Lambda_c^+ \to \Lambda K^0 \pi^+$

$\Lambda_c^+ \to \Lambda K^0 \pi^+$

- $\mathcal{B}(\Lambda_c^+ \to \Lambda K_S^0 \pi^+) = (1.73 \pm 0.26 \pm 0.01) \times 10^{-3}$
- From the BESIII data, we can determine the relevant parameters and predict the invariant mass distributions of ΛK^0 and $\Lambda\pi^+$ in the $\Lambda_c^+ \to \Lambda K^0 \pi^+$ process.
- According to the predictions for the $\Lambda\pi$ channel, we search for the $\Sigma^*(1/2^-)$ in the $\Lambda\pi$ invariant mass distribution.

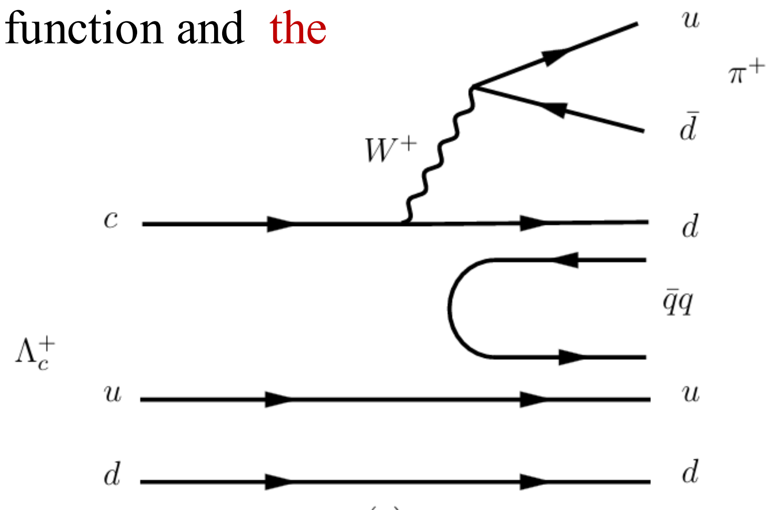


M. Ablikim *et al.* [BESIII],
Phys. Rev. D **111**, no.1, 012014 (2025)

The $\Sigma^*(1/2^-)$ in $\Lambda_c^+ \to \Lambda K^0 \pi^+$

- For **the external emission mechanism**, at the quark level, using the Λ_c wave function and the wave functions of the octet of baryon, we have

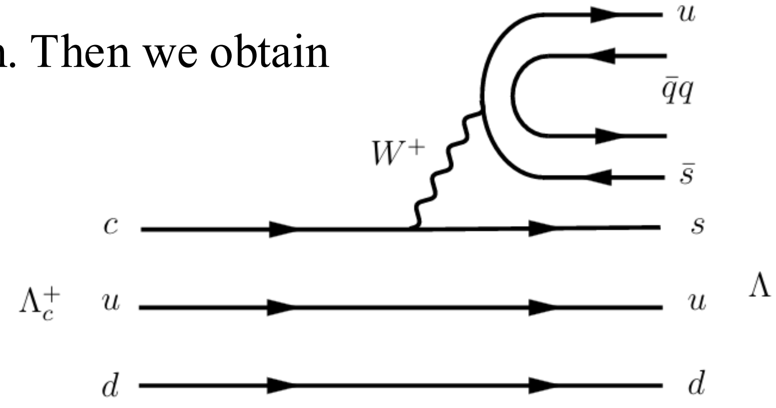
$$\Lambda_c^+ \Rightarrow \frac{1}{\sqrt{2}} c(ud-du)\chi_{MA} \Rightarrow \frac{1}{\sqrt{2}} u\bar{d}d(q\bar{q})(ud-du)\chi_{MA}$$
$$\Rightarrow \frac{1}{\sqrt{2}}\pi^+ \sum M_{2i}q_i\,(ud-du)\chi_{MA}$$
$$\Rightarrow \pi^+\left(\frac{1}{\sqrt{2}}\pi^- p + \frac{1}{2}\pi^0 n + \frac{1}{\sqrt{6}}\eta n + \frac{1}{\sqrt{3}}K^+\Lambda\right)$$



(a)

- Similarly, we consider that the c quark in Λ_c decays into a W^+ boson and an s quark, while the $u\bar{s}$ pair from the W^+ boson decay interacts with the $\bar{q}q$ pair created from the vacuum. Then we obtain

$$\Lambda_c^+ \Rightarrow \frac{1}{\sqrt{2}} c(ud-du)\chi_{MA} \Rightarrow \frac{1}{\sqrt{2}} u(\bar{q}q)\bar{s}s(ud-du)\chi_{MA}$$
$$\Rightarrow \sum M_{1i}M_{i3}\frac{1}{\sqrt{2}} s(ud-du)\chi_{MA}$$
$$\Rightarrow \left(\frac{1}{\sqrt{6}}\pi^0 K^+ + \frac{1}{\sqrt{3}}\pi^+ K^0\right)\Lambda$$

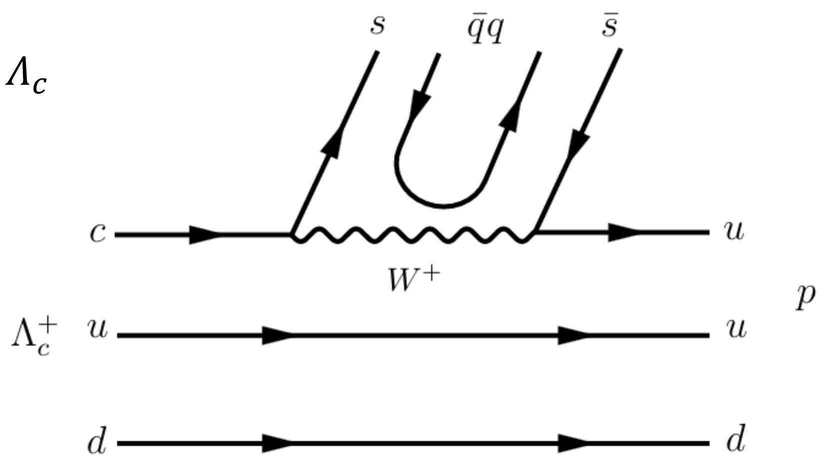


(b)

The $\Sigma^*(1/2^-)$ in $\Lambda_c^+ \to \Lambda K^0 \pi^+$

- For **the internal emission mechanism**, at the quark level and using the Λ_c wave function, we have

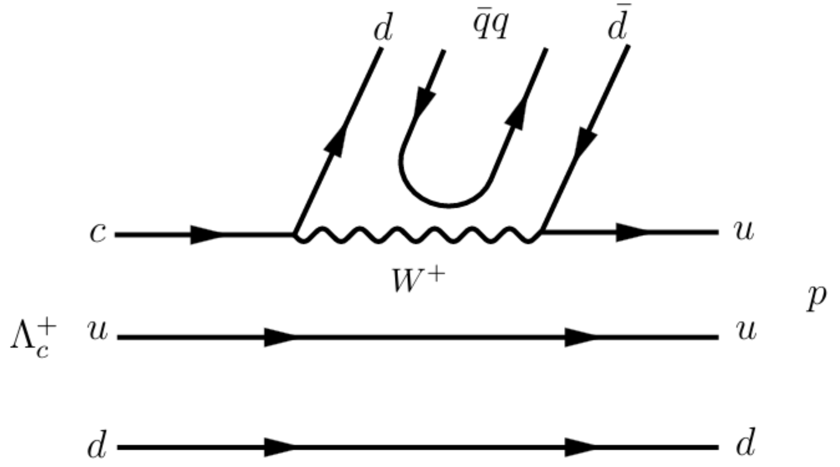
$$\Lambda_c^+ \Rightarrow \frac{1}{\sqrt{2}} c(ud-du)\chi_{MA} \Rightarrow \frac{1}{\sqrt{2}} s(\bar{q}q)\bar{s}u(ud-du)\chi_{MA}$$
$$\Rightarrow \sum M_{3i}M_{i3}\frac{1}{\sqrt{2}}u(ud-du)\chi_{MA}$$
$$\Rightarrow \left(\frac{1}{\sqrt{2}}K^-K^+ + \frac{1}{\sqrt{2}}\bar{K}^0K^0 + \frac{1}{3\sqrt{2}}\eta\eta\right)p$$



(c)

- Similarly, we can obtain

$$\Lambda_c^+ \Rightarrow \frac{1}{\sqrt{2}} c(ud-du)\chi_{MA} \Rightarrow \frac{1}{\sqrt{2}} d(\bar{q}q)\bar{d}u(ud-du)\chi_{MA}$$
$$\Rightarrow \sum M_{2i}M_{i2}\frac{1}{\sqrt{2}}u(ud-du)\chi_{MA}$$
$$\Rightarrow \left(\frac{1}{\sqrt{2}}\pi^-\pi^+ + \frac{1}{3\sqrt{2}}\eta\eta - \frac{1}{\sqrt{3}}\eta\pi^0 + \frac{1}{2\sqrt{2}}\pi^0\pi^0 + \frac{1}{\sqrt{2}}\bar{K}^0K^0\right)p$$



(d)

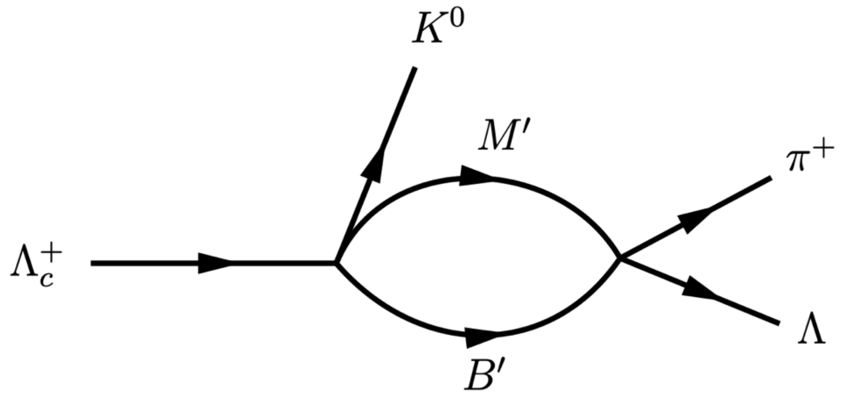
The $\Sigma^*(1/2^-)$ in $\Lambda_c^+ \to \Lambda K^0 \pi^+$

- The scattering matrix for the mechanism of $\Lambda_c^+ \to K^0 M' B' \to K^0 \pi^+ \Lambda$ is given by

$$\mathcal{T}^{\Sigma^*(1/2^-)} = V_P[h_{K^0\Lambda} G_{\pi^+\Lambda}(M_{\rm inv}) t_{\pi^+\Lambda\to\pi^+\Lambda}(M_{\rm inv})$$
$$+h_{\pi^+K^0} G_{\pi^+\Lambda}(M_{\rm inv}) t_{\pi^+\Lambda\to\pi^+\Lambda}(M_{\rm inv})$$
$$+\frac{2}{C} h_{\bar{K}^0K^0} G_{\bar{K}^0p}(M_{\rm inv}) t_{\bar{K}^0p\to\pi^+\Lambda}(M_{\rm inv})\Big]$$

$$h_{K^0\Lambda} = h_{\pi^+K^0} = \frac{1}{\sqrt{3}}, h_{\bar{K}^0K^0} = \frac{1}{\sqrt{2}}$$

- 3 coupled channels: $\bar{K}N, \pi\Sigma, \pi\Lambda$.



✓ The Bethe-Salpeter equation: $T = [1 - VG]^{-1}V$

$$V_{ij} = -C_{ij}\frac{1}{4f^2}(2\sqrt{s} - M_i - M_j) \times \left(\frac{M_i + E_i}{2M_i}\right)^{1/2}\left(\frac{M_j + E_j}{2M_j}\right)^{1/2}$$

✓ The loop function:

$$G_l(\sqrt{s}) = \frac{2M_l}{16\pi^2}\Bigg(a_l(\mu) + ln\frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s} ln\frac{m_l^2}{M_l^2}$$
$$+\frac{|\vec{q}|}{\sqrt{s}}[\ln(s - (M_l^2 - m_l^2) + 2|\vec{q}|\sqrt{s})$$
$$+\ln(s + (M_l^2 - m_l^2) + 2|\vec{q}|\sqrt{s}) - \ln(-s + (M_l^2 - m_l^2)$$
$$+2|\vec{q}|\sqrt{s} - \ln(-s - (M_l^2 - m_l^2) + 2|\vec{q}|\sqrt{s})]\,\Bigg)$$

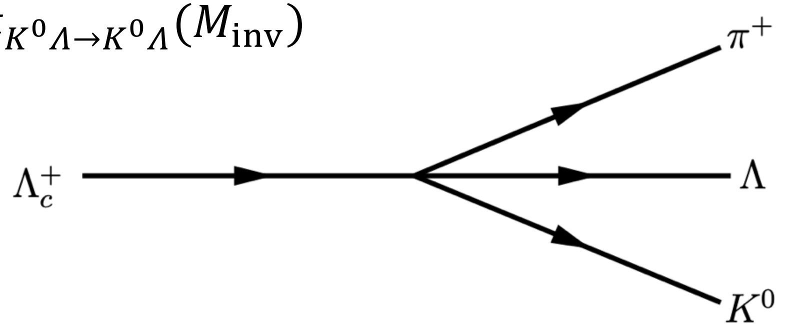
L. Roca and E. Oset, Phys. Rev. C **88**, no.5, 055206 (2013)

The $\Sigma^*(1/2^-)$ in $\Lambda_c^+ \to \Lambda K^0 \pi^+$

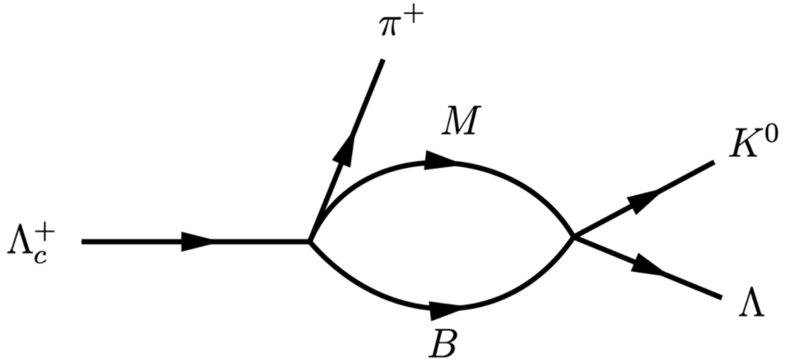
- The scattering matrix for the mechanism of $\Lambda_c^+ \to \pi^+ MB \to \pi^+ K^0 \Lambda$ is given by

$$\mathcal{T}^{Tree} = V_P(h_{K^0\Lambda} + h_{\pi^+K^0})$$

$$\mathcal{T}^{N(1535)} = V_P\left[\sum_i h_i\,\tilde{G}_i(M_{\rm inv})t_{i\to K^0\Lambda}(M_{\rm inv}) + h_{\pi^+K^0}\tilde{G}_{K^0\Lambda}(M_{\rm inv})t_{K^0\Lambda\to K^0\Lambda}(M_{\rm inv}) + \frac{1}{C}h_{\pi^-\pi^+}\tilde{G}_{\pi^-p}(M_{\rm inv})t_{\pi^-p\to K^0\Lambda}(M_{\rm inv})\right]$$



$$h_{\pi^-p} = h_{\pi^-\pi^+} = \frac{1}{\sqrt{2}}, h_{\pi^0n} = -\frac{1}{2},$$
$$h_{\eta n} = \frac{1}{\sqrt{6}}, h_{K^0\Lambda} = h_{\pi^+K^0} = \frac{1}{\sqrt{3}}$$



- 6 coupled channels: $K^+\Sigma^-, K^0\Sigma^0, K^0\Lambda, \pi^-p, \pi^0n, \eta n$.

✓ The loop function: $\tilde{G}_l = \int_0^{q_{max}} \frac{2M_l}{(2\pi)^2} \frac{|\vec{q}|^2(\omega_1+\omega_2)dq}{\omega_1\omega_2[s-(\omega_1+\omega_2)^2]}$

J. X. Lu, E. Wang, J. J. Xie, L. S. Geng and E. Oset, Phys. Rev. D **93**, 094009 (2016)

The $\Sigma^*(1/2^-)$ in $\Lambda_c^+ \to \Lambda K^0 \pi^+$

- The decay amplitude for the mechanism of $\Lambda_c^+ \to \Lambda K^*(892) \to \Lambda K^0 \pi^+$ is given by

$$\mathcal{T}^{K^*} = V_P' \frac{|\vec{p}_{\pi^+}||\vec{p}_\Lambda| cos\theta}{M_{\pi^+ K^0}^2 - M_{K^*}^2 + iM_{K^*}\Gamma_{K^*}}$$

$$|\vec{p}_{\pi^+}| = \frac{\lambda^{1/2}(M_{\pi^+K^0}^2, m_{\pi^+}^2, m_{K^0}^2)}{2M_{\pi^+K^0}}$$

$$|\vec{p}_\Lambda| = \frac{\lambda^{1/2}\left(M_{\Lambda_c^+}^2, m_\Lambda^2, M_{\pi^+K^0}^2\right)}{2M_{\pi^+K^0}}$$

$$cos\theta = \frac{M_{\Lambda K^0}^2 - M_{\Lambda_c^+}^2 - m_{\pi^+}^2 + 2P_{\Lambda_c^+}^0 P_{\pi^+}^0}{2|\vec{p}_{\pi^+}||\vec{p}_\Lambda|}$$

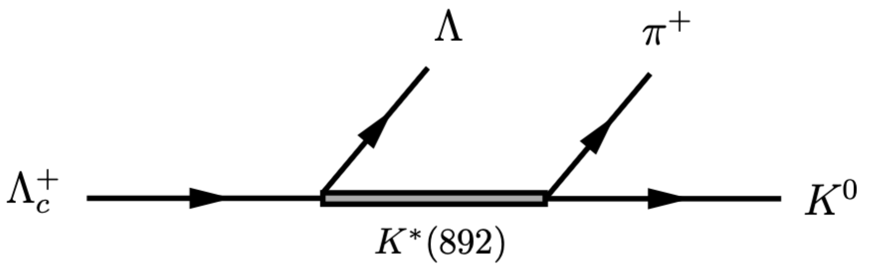


FIG. 3: Mechanisms for the $\Lambda_c^+ \to \Lambda K^0 \pi^+$ decay via the intermediate $K^*(892)$.

- V_P and V_P' are obtainable from the branching ratios of intermediate processes

Parameters	V_P (MeV^{-1})	V_P' (MeV^{-1})
Values	1.60×10^{-8}	3.07×10^{-9}

The $\Sigma^*(1/2^-)$ in $\Lambda_c^+ \to \Lambda K^0 \pi^+$

- **The total decay amplitude:**

$$|\mathcal{T}|^2 = \left|\mathcal{T}^{Tree} + \mathcal{T}^{N(1535)} + \mathcal{T}^{\Sigma^*(1/2^-)} e^{i\phi} + \mathcal{T}^{K^*} e^{i\phi'}\right|^2$$

- Then the double differential width:

$$\frac{d^2\Gamma}{dM_{K^0\Lambda} dM_{\pi^+\Lambda}} = \frac{1}{(2\pi)^3} \frac{M_\Lambda M_{K^0\Lambda} M_{\pi^+\Lambda}}{2M_{\Lambda_c^+}^2} |\mathcal{T}|^2$$

- In total we have 3 free parameters:

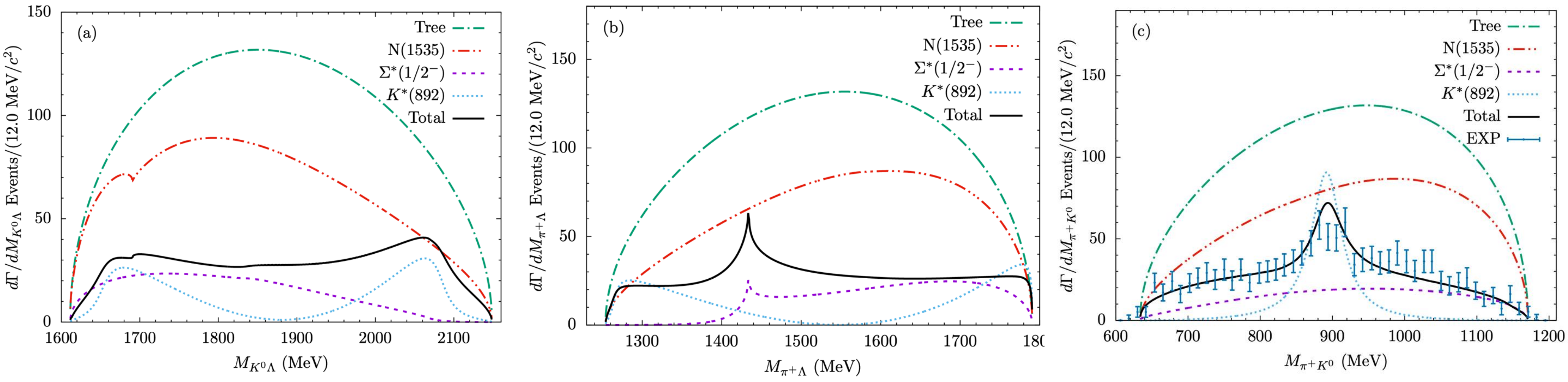
the phase angles: $\phi = (1.73 \pm 0.11)\pi$, $\phi' = (1.57 \pm 0.06)\pi$;

a normalization constant $(1.22 \pm 0.26) \times 10^{15}$.

The $\Sigma^*(1/2^-)$ in $\Lambda_c^+ \to \Lambda K^0 \pi^+$

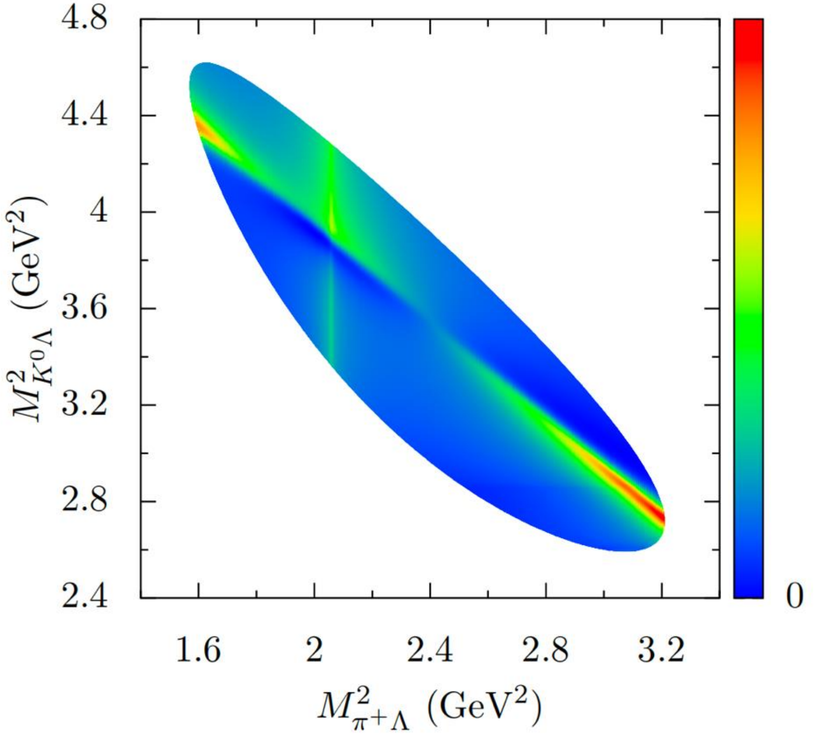
- The invariant mass distributions with phase interference

$$|\mathcal{T}|^2 = \left|\mathcal{T}^{Tree} + \mathcal{T}^{N(1535)} + \mathcal{T}^{\Sigma^*(1/2^-)} e^{i\phi} + \mathcal{T}^{K^*} e^{i\phi'}\right|^2$$

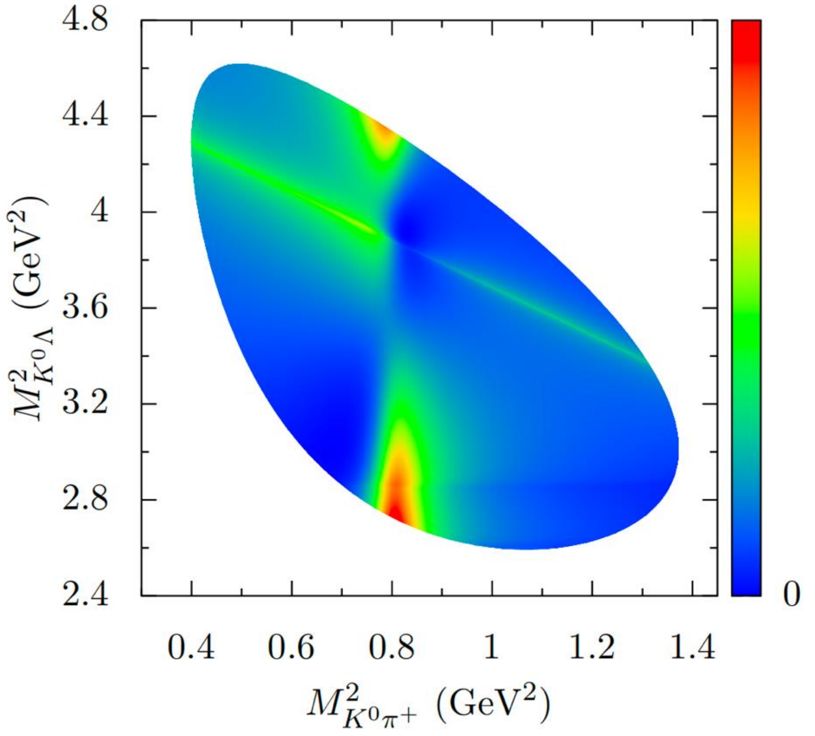


The $\Sigma^*(1/2^-)$ in $\Lambda_c^+ \to \Lambda K^0 \pi^+$

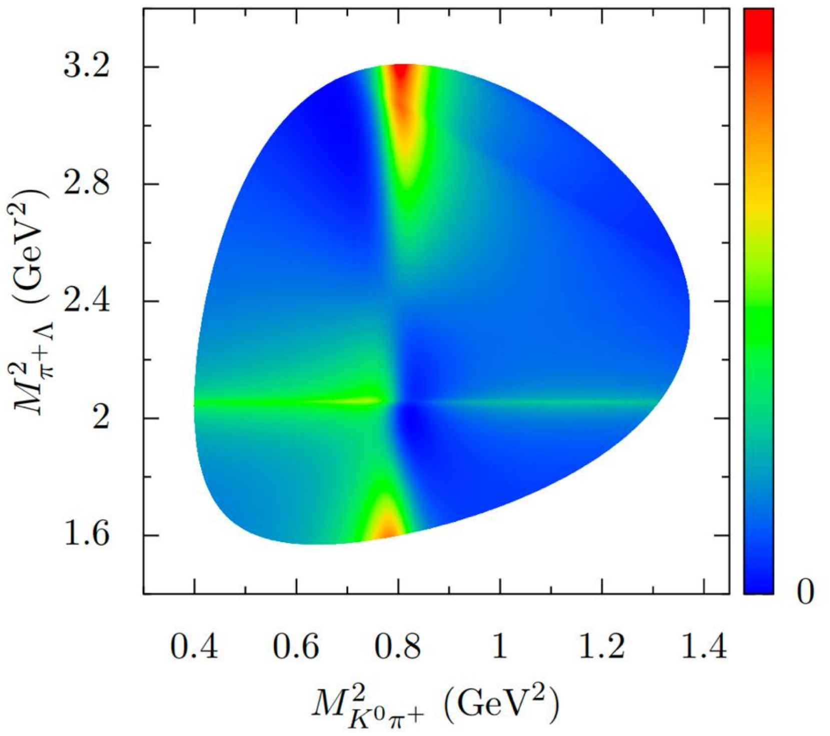
- The Dalitz plots



$M^2_{\pi^+\Lambda}$ vs $M^2_{K^0\Lambda}$



$M^2_{K^0\pi^+}$ vs $M^2_{K^0\Lambda}$



$M^2_{K^0\pi^+}$ vs $M^2_{\pi^+\Lambda}$

CONTENTS

Summary

- For the $\Lambda(1670)$ clearly confirmed by the PDG, we fit the experimental data from Belle and show that **the cusp structure near the $\eta\Lambda$ threshold in the pK^- invariant mass distribution** of the $\Lambda_c^+ \to pK^-\pi^+$ decay is closely related to **the molecular state nature of $\Lambda(1670)$**.

- For the $\Sigma^*(1/2^-)$ not yet established by the PDG, verifying and confirming its existence through more decay processes is crucial for improving the baryon spectrum. By considering **the S-wave meson-baryon interaction** and the contribution of **the vector meson $K^*(892)$** , we studied the $\Lambda_c^+ \to \Lambda K^0\pi^+$ decay process, and **observed a distinct cusp structure around 1430 MeV in the $\Lambda\pi^+$ invariant mass distribution**, which is associated with the predicted $\Sigma^*(1/2^-)$.

- Future precise measurements will deepen our understanding of the nature of $J^P = 1/2^-$ low-lying excited baryons.

Thank you for attention !