Exotic states in charmed baryon decays

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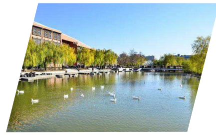
吴佳俊，王冠颖，耿立升，谢聚军

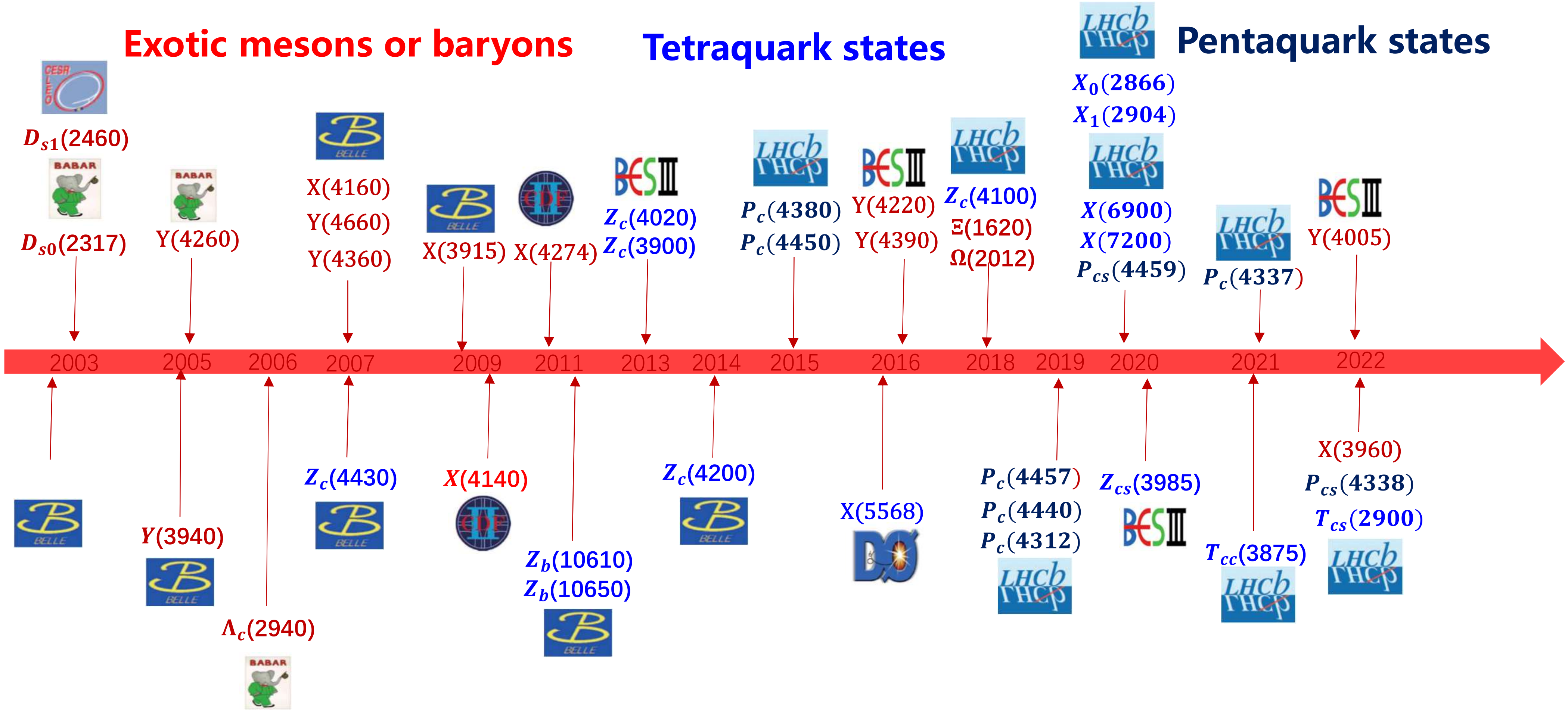
2024年7月7日-7月12日

2024年超级陶粲装置研讨会@兰州

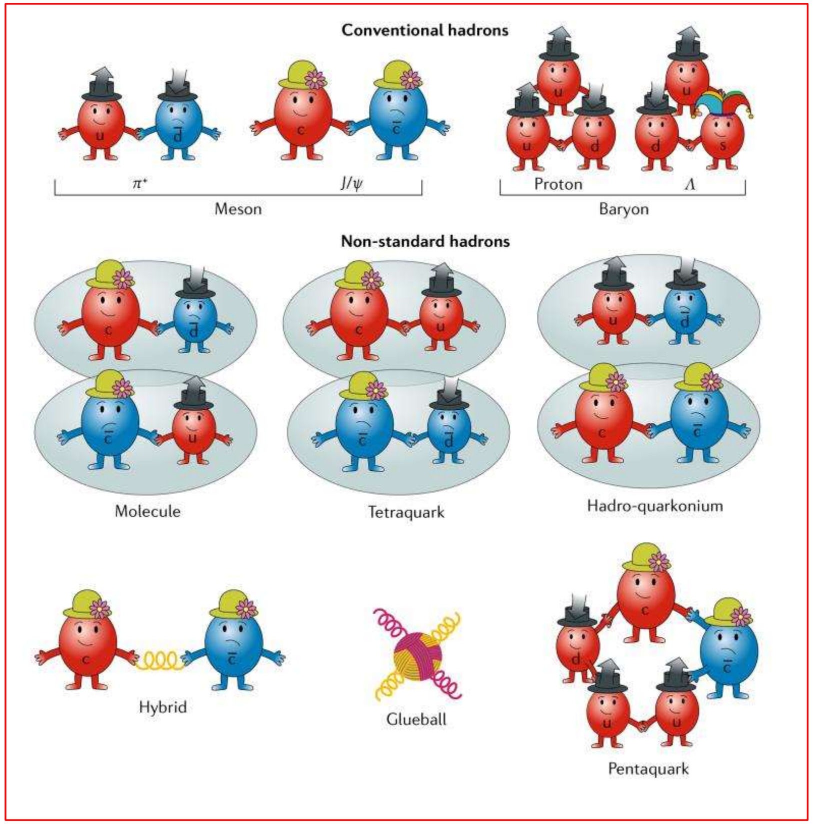


Exotic states

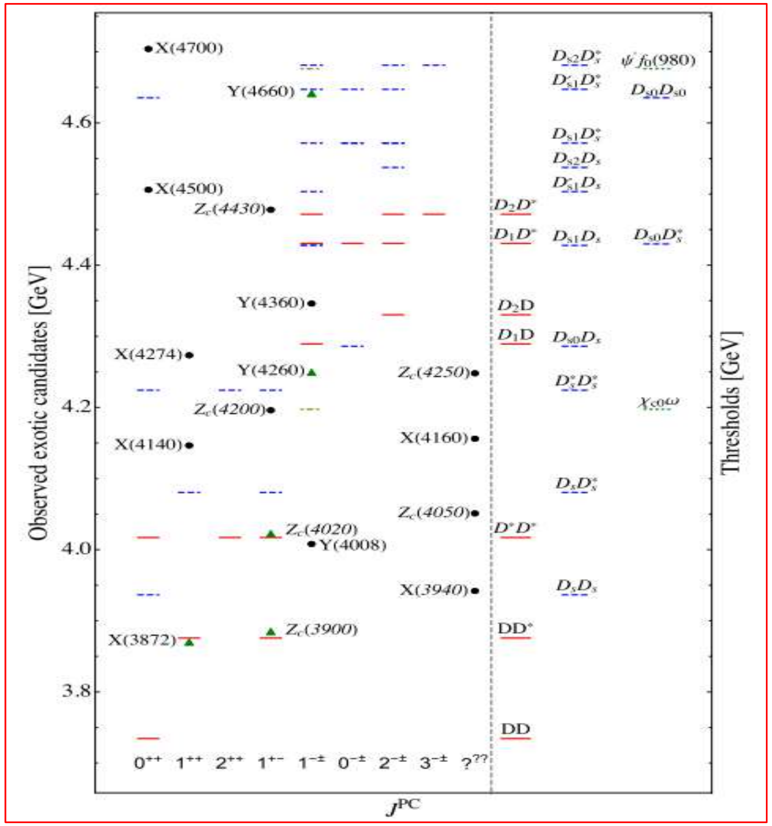
From Li-Sheng Geng



Hadrons



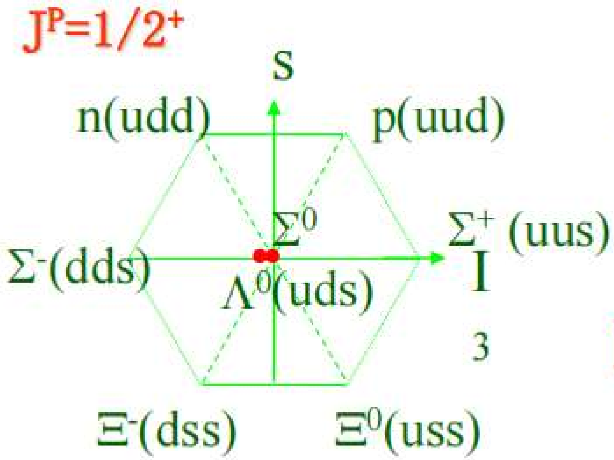
C.Z.Yuan, Nature Rev. Phys. 1 (2019) 480

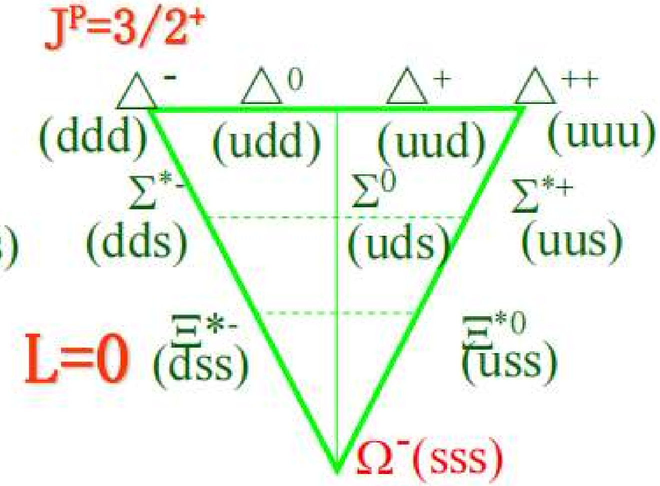


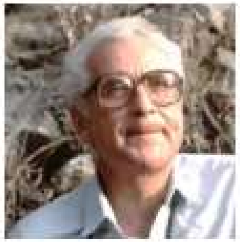
FKGuo, et.al, Mod. Phys. 90 (2018) 015004

Ground light baryons

□Ground baryons








盖尔曼-大久保质量:

$$M = a + bY + c\left[I(I+1) - \frac{1}{4}Y^2\right]$$

质量公式预言 m_Ω=1670 MeV
实验: m_Ω=1672.45±0.29 MeV

Low-lying baryons with $J^P=1/2^-$

$1/2^-$ baryon nonet with strangeness

Zou, EPJA 35 (2008) 325

- Mass pattern : quenched or unquenched ?

  uds (L=1) $1/2^-$ ~ $\Lambda^*(1670)$ ~ [us][ds] $\bar{s}$

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

  uds (L=1) $1/2^-$ ~ $\Lambda^*(1405)$ ~ [ud][su] $\bar{u}$

  uus (L=1) $1/2^-$ ~ $\Sigma^*(1390)$ ~ [us][ud] $\bar{d}$

  Zou et al, NPA835 (2010) 199 ; CLAS, PRC87(2013)035206

- Strange decays of N*(1535) and Λ*(1670) :

  N*(1535) large couplings $g_{N^*N\eta}$, $g_{N^*K\Lambda}$, $g_{N^*N\eta'}$, $g_{N^*N\phi}$

  Λ*(1670) large coupling $g_{\Lambda^*\Lambda\eta}$

Citation: R.L. Workman *et al.* (Particle Data Group), Prog.Theor.Exp.Phys. **2022**, 083C01 (2022)

$\Sigma(1620)\ 1/2^-$ $\quad I(J^P) = 1(\frac{1}{2}^-)$ Status: *

OMITTED FROM SUMMARY TABLE

Citation: M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D **98**, 030001 (2018) and 2019 updat

$\Sigma(1480)$ Bumps $\quad I(J^P) = 1(?^?)$ Status: *

OMITTED FROM SUMMARY TABLE

These are peaks seen in $\Lambda\pi$ and $\Sigma\pi$ spectra in the reaction $\pi^+ p \to (Y\pi)K^+$ at 1.7 GeV/c. Also, the Y polarization oscillates in the same region.

邹冰松老师报告

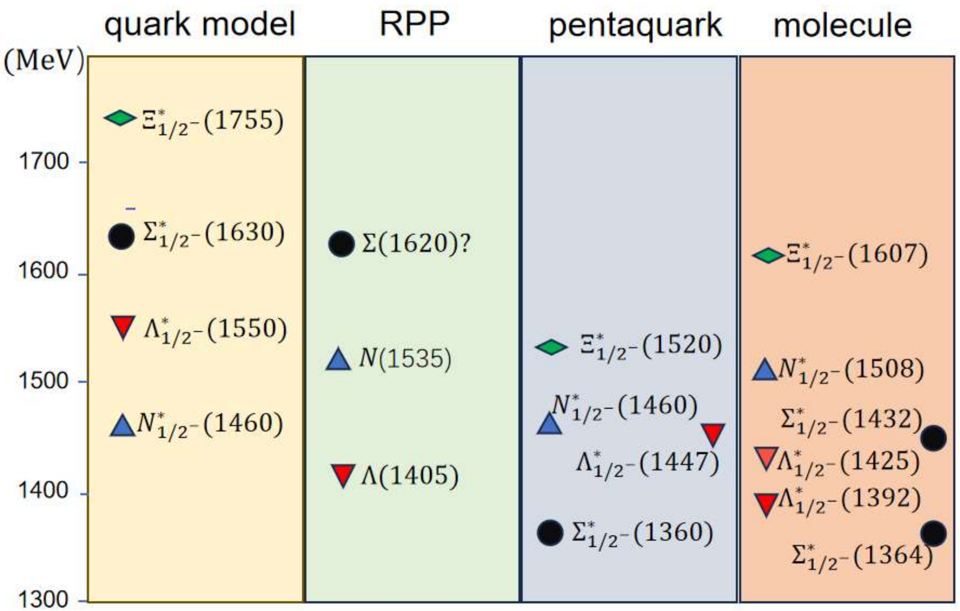
Review about $\Sigma^*(1/2^-)$

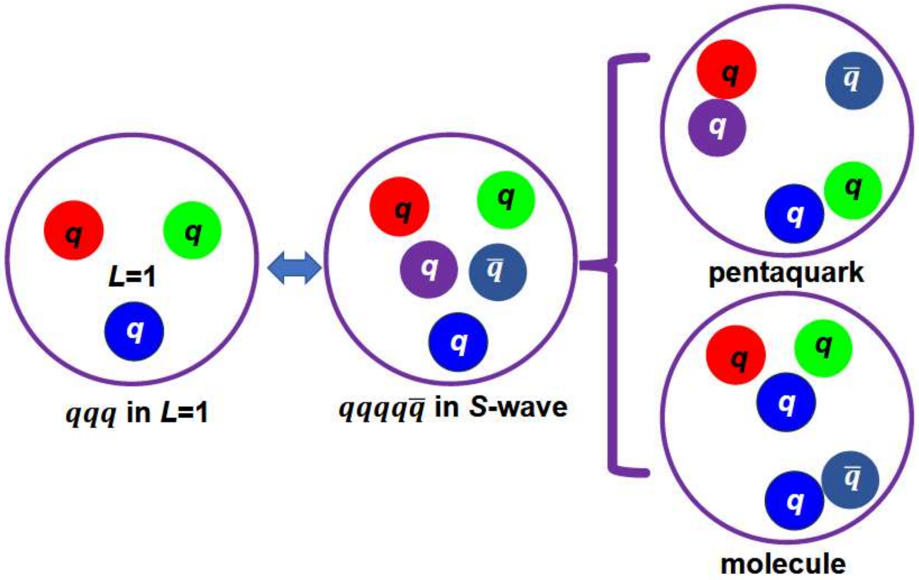
□arxiv: 2406.07839

Review of the low-lying excited baryons $\Sigma^*(1/2^-)$

En Wang,[1,2,*] Li-Sheng Geng,[3,4,5,6,†] Jia-Jun Wu,[7,6,‡] Ju-Jun Xie,[6,8,9,§] and Bing-Song Zou[10,11,7,6,¶]

Strong empirical and phenomenological indications exist for large sea-quark admixtures in the low-lying excited baryons. Investigating the low-lying excited baryon $\Sigma^*(1/2^-)$ is important to determine the nature of the low-lying excited baryons. We review the experimental and theoretical progress on the studies of the $\Sigma^*(1/2^-)$. Although several candidates have received intensive discussions, such as $\Sigma(1620)$ and $\Sigma(1480)$, their existence needs further confirmation. Following the prediction of the unquenched quark models for the $\Sigma^*(1/2^-)$, many theoretical works suggested the existence of these states in various processes. Future experimental measurements could shed light on the existence of the low-lying excited $\Sigma^*(1/2^-)$ state.





1-star state Σ(1620)

□PDG2024

Σ(1620) MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1600 to 1650 (≈ 1620) OUR ESTIMATE				
1681±6	SARANTSEV	19	DPWA	$\overline{K}N$ multichannel
1600±15	ZHANG	13A	DPWA	$\overline{K}N$ multichannel
1600±6	[1] MORRIS	78	DPWA	$K^- n \to \Lambda\pi^-$
1608±5	[2] CARROLL	76	DPWA	Isospin-1 total σ
1630±10	LANGBEIN	72	IPWA	$\overline{K}N$ multichannel
1620	KIM	71	DPWA	K-matrix analysis
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1633±10	[3] CARROLL	76	DPWA	Isospin-1 total σ

Σ(1620) WIDTH

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
40 to 100 (≈ 70) OUR ESTIMATE				
40±12	SARANTSEV	19	DPWA	$\overline{K}N$ multichannel
400±152	ZHANG	13A	DPWA	$\overline{K}N$ multichannel
87±19	[1] MORRIS	78	DPWA	$K^- n \to \Lambda\pi^-$
15	[2] CARROLL	76	DPWA	Isospin-1 total σ
65±20	LANGBEIN	72	IPWA	$\overline{K}N$ multichannel
40	KIM	71	DPWA	K-matrix analysis
• • • We do not use the following data for averages, fits, limits, etc. • • •				
10	[3] CARROLL	76	DPWA	Isospin-1 total σ

Eur. Phys. J. A (2019) **55**: 180
DOI 10.1140/epja/i2019-12880-5

THE EUROPEAN PHYSICAL JOURNAL A

Regular Article – Experimental Physics

Hyperon II: Properties of excited hyperons

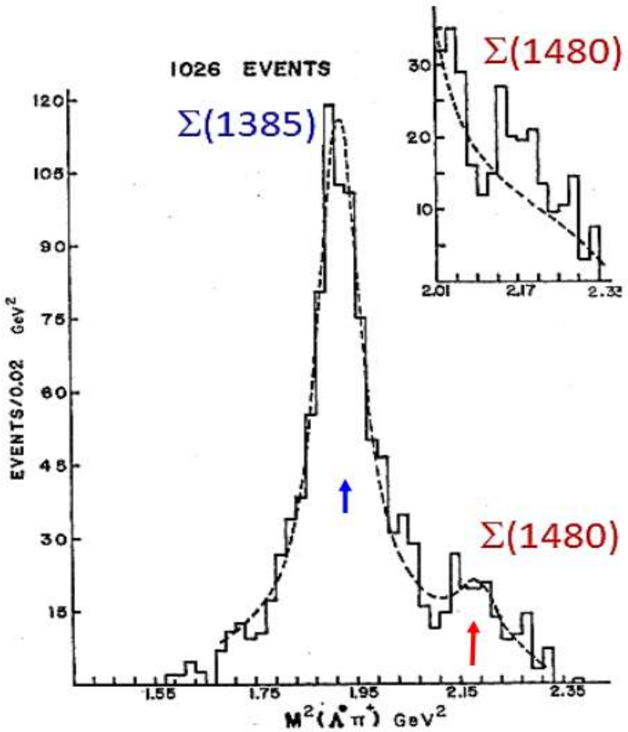
A.V. Sarantsev[1,2], M. Matveev[1,2], V.A. Nikonov[1,2], A.V. Anisovich[1,2], U. Thoma[1], and E. Klempt[1,a]

$\Sigma(1620)1/2^-$ *and* $\Sigma(1750)1/2^-$*:* The $\Sigma(1620)1/2^-$ to $\Sigma(1750)1/2^-$ region is problematic. If we assume no resonance, the fit is unacceptable. A fit with one $1/2^-$ resonance only returns a mass of $M = (1692 \pm 11)$ MeV and $\Gamma = (208 \pm 18)$ MeV. We tentatively identify this resonance with $\Sigma(1750)1/2^-$. The real part of our pole posi-

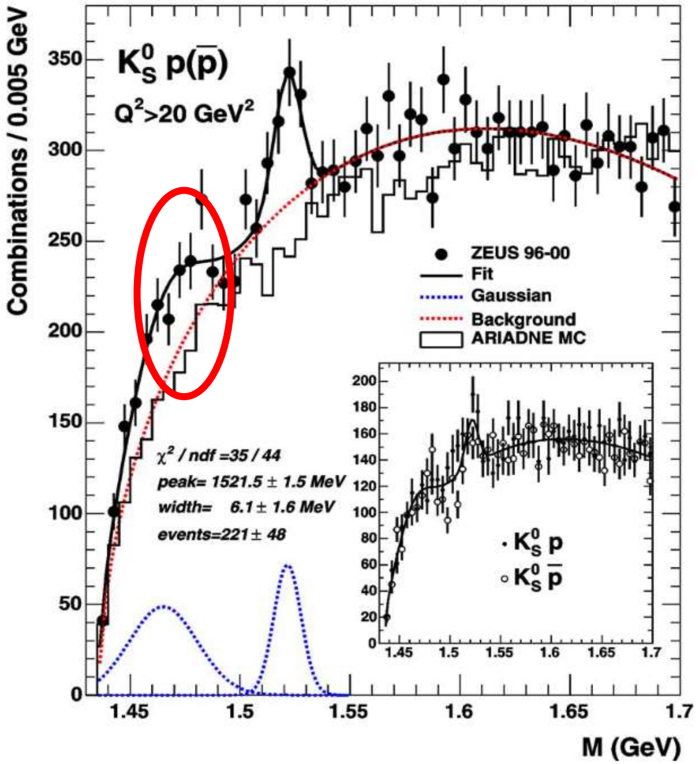
a mass of (1692 ± 11) MeV, which is below $M_\eta + M_\Sigma$. Our BRs add up to $(78\pm11)\%$. A fit with two resonances gives a small but significant improvement for a second narrow resonance, which is found only slightly below $\Sigma(1750)1/2^-$. We list this resonance under $\Sigma(1620)1/2^-$ even though these are likely different objects. We find a sum of branch-

Exp. signals of Σ(1480)

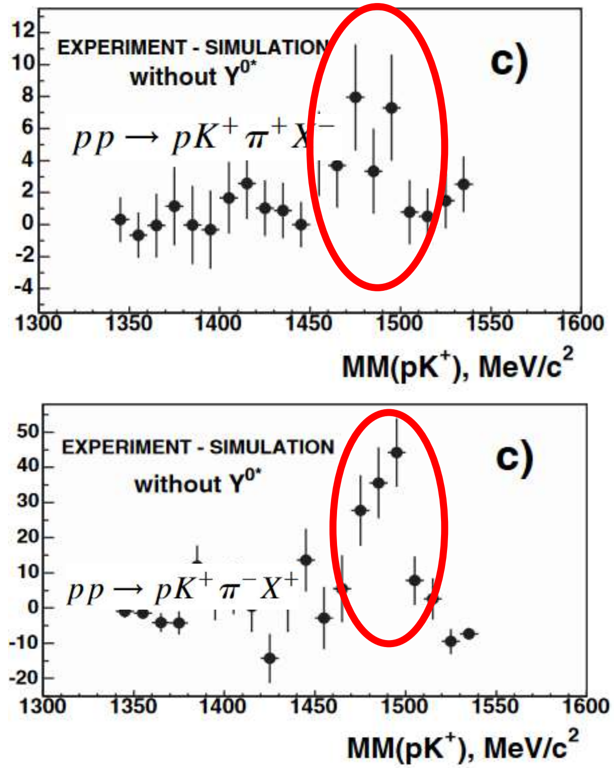
$\pi^+ p \to \pi^+ K^+ \Lambda$
Yu-Li Pan et al, PRD2, 449 (1970)



$e^+ p \to e^+ K^0 \mathrm{pX}$
ZEUS PLB591 (2004) 7–22

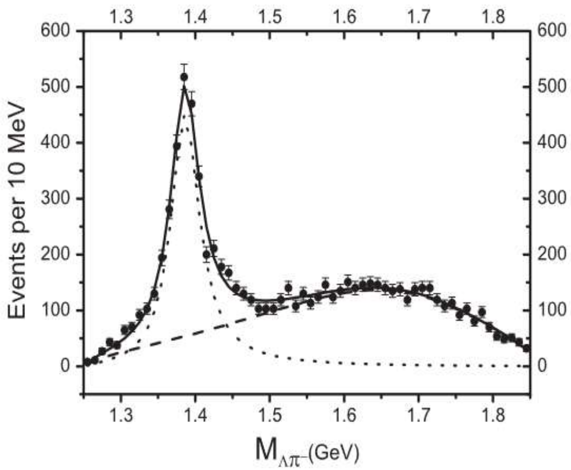


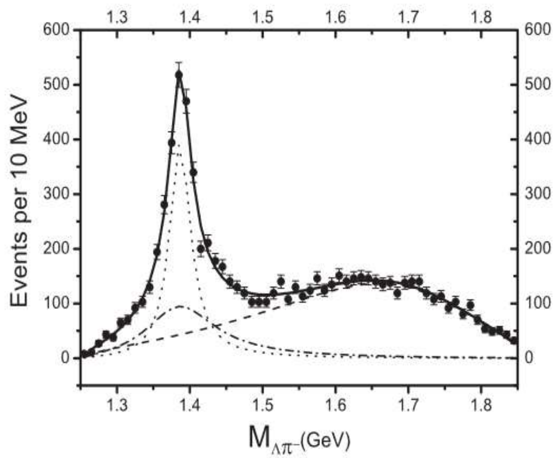
$pp \to pK^+ Y^{0*}$
COSY-Juich PRL 96, 012002 (2006)



Evidence of $\Sigma^*(1/2^-)$

□ $K^- p \to \Lambda\pi^+\pi^-$， Wu-Dulat-Zou, PRD80(2009)017503





$$\frac{dN}{dm_{\Lambda\pi^-}} \propto p_1 \times p_2 \times \sum_{i=1}^{3} \frac{|a_i|}{(m^2_{\Lambda\pi^-} - m_i^2)^2 + m_i^2 \times \Gamma_i^2},$$

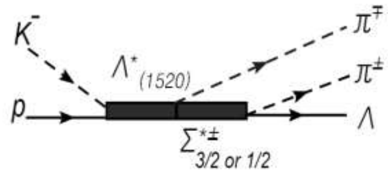
Here we reexamine some old data of the $K^- p \to \Lambda\pi^+\pi^-$ reaction and find that besides the well-established $\Sigma^*(1385)$ with $J^P = 3/2^+$, there is indeed some evidence for the possible existence of a new Σ^* resonance with $J^P = 1/2^-$ around the same mass but with broader decay width. There are also indications for such a possibility in the $J/\psi \to \bar{\Sigma}\Lambda\pi$ and $\gamma n \to K^+\Sigma^{*-}$ reactions. At present, the evidence is not strong. Therefore, high statistics studies

	$M_{\Sigma^*(3/2)}$	$\Gamma_{\Sigma^*(3/2)}$	$M_{\Sigma^*(1/2)}$	$\Gamma_{\Sigma^*(1/2)}$	χ^2/ndf (Fig. 1)	χ^2/ndf (Fig. 2)
Fit1	1385.3 ± 0.7	46.9 ± 2.5			68.5/54	10.1/9
Fit2	$1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	58.0/51	3.2/9

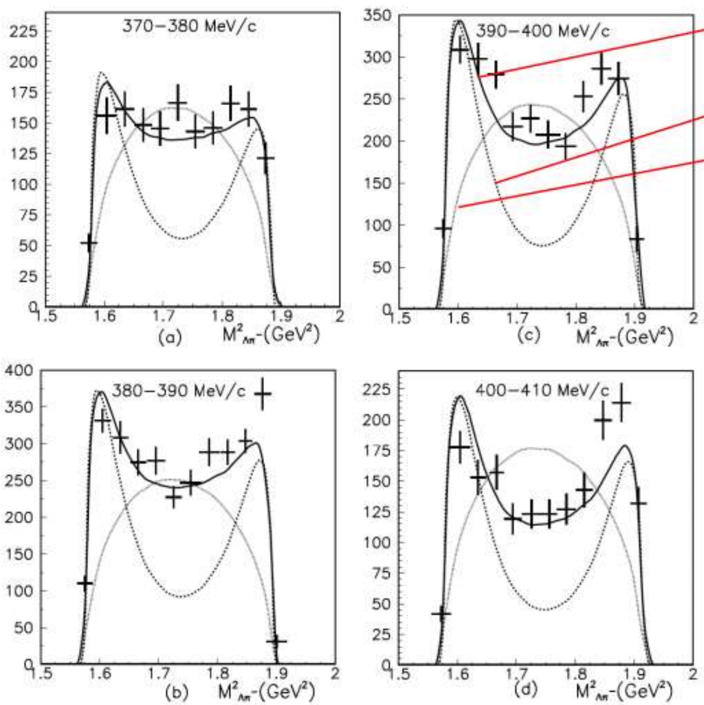
Evidence of $\Sigma^*(1/2^-)$

$K^- p \to \Lambda \pi^+ \pi^-$

J.J.Wu's slide



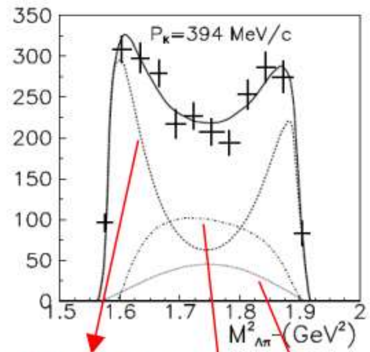
P_K=0.3-0.6 GeV J. J. Wu, S. Dulat and B. S. Zou PRC 81,045210



59% Σ*(3/2⁺)+ 41% Σ*(1/2⁻)

100% Σ*(3/2⁺)

Phase space

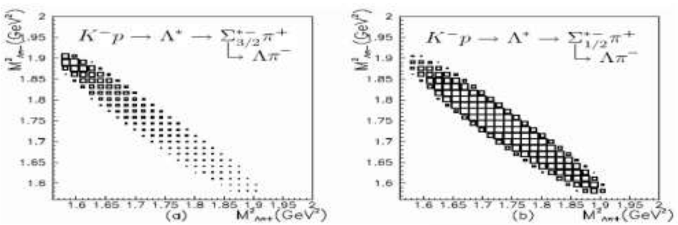


59% Σ*(3/2⁺)

Interference

12.5% Σ*(1/2⁻)

First reason: S-wave between the $\Sigma^{*-}(3/2^+)$ and π^+; but P-wave between the $\Sigma^{*-}(1/2^-)$ and π^+.



Second reason: the width of $\Sigma^{*-}(3/2^+)$ is 35.5MeV; but that of $\Sigma^{*-}(1/2^-)$ is 118.6MeV from fit before.

Search for $\Sigma^*(1/2^-)$

- $\Lambda_c^+ \to \Lambda\eta\pi$, Xie-Geng, PRD95(2017) 074024, JJWu-EW-LSGeng-JJXie, 2405.09226
- $\gamma n \to K\Sigma(1/2^-)$, Lyu-EW-Xie-Wei, CPC47 (2023) 053108
- $\chi_{c0} \to \bar{\Sigma}\Sigma\pi$, EW-Xie-Oset, PLB753(2016)526
- $\chi_{c0} \to \bar{\Lambda}\Sigma\pi$, EW-Xie-Oset, PRD98(2018)114017
- $\Lambda_c \to \Sigma^+\pi^+\pi^0\pi^-$, Xie-Oset, Phys.Lett.B 792 (2019) 450
- $\gamma N \to \Sigma(1/2^-)N$, Kim-Nam-Hosaka, PRD(2021)114017
- $\Lambda_c^+ \to \bar{K}^0\eta p$, YLi-SWLiu-EW-DMLi-LSGeng-JJXie, 2406.01209
- Review of $\Sigma^*(1/2^-)$， EW-JJWu-JJXie-LSGeng-BSZou2406.07839
- …………

Low-lying baryons with $J^P=1/2^-$

□Chiral Lagrangian

$$L_1^{(B)} = \langle \bar{B} i\gamma^\mu \nabla_\mu B\rangle - M_B\langle \bar{B}B\rangle + \tfrac{1}{2}D\langle \bar{B}\gamma^\mu\gamma_5\{u_\mu, B\}\rangle + \tfrac{1}{2}F\langle \bar{B}\gamma^\mu\gamma_5[u_\mu, B]\rangle$$

$$\nabla_\mu B = \partial_\mu B + [\Gamma_\mu, B],$$
$$\Gamma_\mu = \tfrac{1}{2}(u^+\partial_\mu u + u\partial_\mu u^+),$$
$$U = u^2 = \exp(i\sqrt{2}\Phi/f),$$
$$u_\mu = iu^+\partial_\mu U u^+ .$$

Oset Ramos, NPA635(1998)99

$$\Phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix}, \quad B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}$$

At lowest order in momentum

$$L_1^{(B)} = \langle \bar{B} i\gamma^\mu \frac{1}{4f^2}[(\Phi\partial_\mu\Phi - \partial_\mu\Phi\Phi)B - B(\Phi\partial_\mu\Phi - \partial_\mu\Phi\Phi)]\rangle,$$

$$V_{ij} = -C_{ij}\frac{1}{4f^2}\bar{u}(p')\gamma^\mu u(p)(k_\mu + k'_\mu)$$

⬇ Neglect the spatial components at low energies

$$V_{ij} = -C_{ij}\frac{1}{4f^2}(k^0 + k'^0)$$

Low-lying baryons with $J^P=1/2^-$

$$V_{ij} = -C_{ij}\frac{1}{4f^2}(k^0 + k'^0)$$

I=0

	$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$K\Xi$
$\bar{K}N$	3	$-\sqrt{\frac{3}{2}}$	$\frac{3}{\sqrt{2}}$	0
$\pi\Sigma$		4	0	$\sqrt{\frac{3}{2}}$
$\eta\Lambda$			0	$-\frac{3}{\sqrt{2}}$
$K\Xi$				3

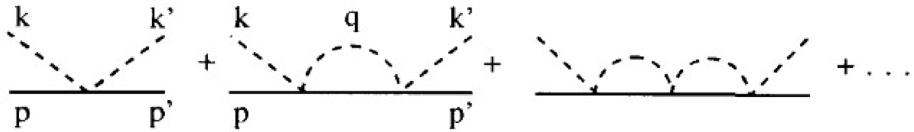
I=1

	$\bar{K}N$	$\pi\Sigma$	$\pi\Lambda$	$\eta\Sigma$	$K\Xi$
$\bar{K}N$	1	-1	$-\sqrt{\frac{3}{2}}$	$-\sqrt{\frac{3}{2}}$	0
$\pi\Sigma$		2	0	0	1
$\pi\Lambda$			0	0	$-\sqrt{\frac{3}{2}}$
$\eta\Sigma$				0	$-\sqrt{\frac{3}{2}}$
$K\Xi$					1

Lippmann-Schwinger equations

$$t_{ij} = V_{ij} + V_{il}G_lT_{lj}\,,$$

$$V_{il}G_lT_{lj} = i\int\frac{d^4q}{(2\pi)^4}\frac{M_l}{E_l(\boldsymbol{q})}\frac{V_{il}(k,q)T_{lj}(q,k')}{k^0+p^0-q^0-E_l(\boldsymbol{q})+i\epsilon}\frac{1}{q^2-m_l^2+i\epsilon}\,.$$



On-shell approximations

$$2iV_{\rm on}\int\frac{d^3q}{(2\pi)^3}\int\frac{dq^0}{2\pi}\frac{M}{E(q)}\frac{q^0-k^0}{k^0-q^0}\frac{1}{q^{02}-\omega(q)^2+i\epsilon}$$

Low-lying baryons with $J^P=1/2^-$

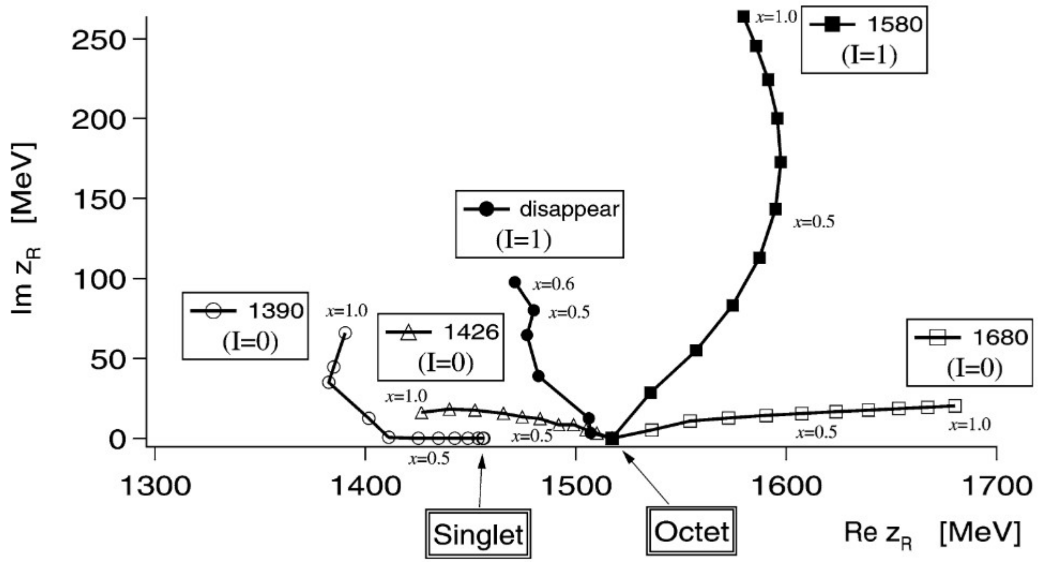
□Bethe-Salpeter Equation

$$T = [1 - VG]^{-1}V$$

$$G_l = i\int \frac{d^4q}{(2\pi)^4}\frac{M_l}{E_l(\boldsymbol{q})}\frac{1}{k^0+p^0-q^0-E_l(\boldsymbol{q})+i\epsilon}\frac{1}{q^2-m_l^2+i\epsilon}$$
$$= \int \frac{d^3q}{(2\pi)^3}\frac{1}{2\omega_l(q)}\frac{M_l}{E_l(\boldsymbol{q})}\frac{1}{p^0+k^0-\omega_l(\boldsymbol{q})-E_l(\boldsymbol{q})+i\epsilon},$$

$$G_l = i2M_l\int\frac{d^4q}{(2\pi)^4}\frac{1}{(P-q)^2-M_l^2+i\epsilon}\frac{1}{q^2-m_l^2+i\epsilon}$$
$$= \frac{2M_l}{16\pi^2}\left\{a_l(\mu)+\ln\frac{M_l^2}{\mu^2}+\frac{m_l^2-M_l^2+s}{2s}\ln\frac{m_l^2}{M_l^2}\right.$$
$$+\frac{q_l}{\sqrt{s}}\left[\ln\left(s-(M_l^2-m_l^2)+2q_l\sqrt{s}\right)+\ln\left(s+(M_l^2-m_l^2)+2q_l\sqrt{s}\right)\right.$$
$$\left.\left.-\ln\left(-s+(M_l^2-m_l^2)+2q_l\sqrt{s}\right)-\ln\left(-s-(M_l^2-m_l^2)+2q_l\sqrt{s}\right)\right]\right\}.$$

Jido Oller Oset Ramos Meissner NPA725 (2003) 181



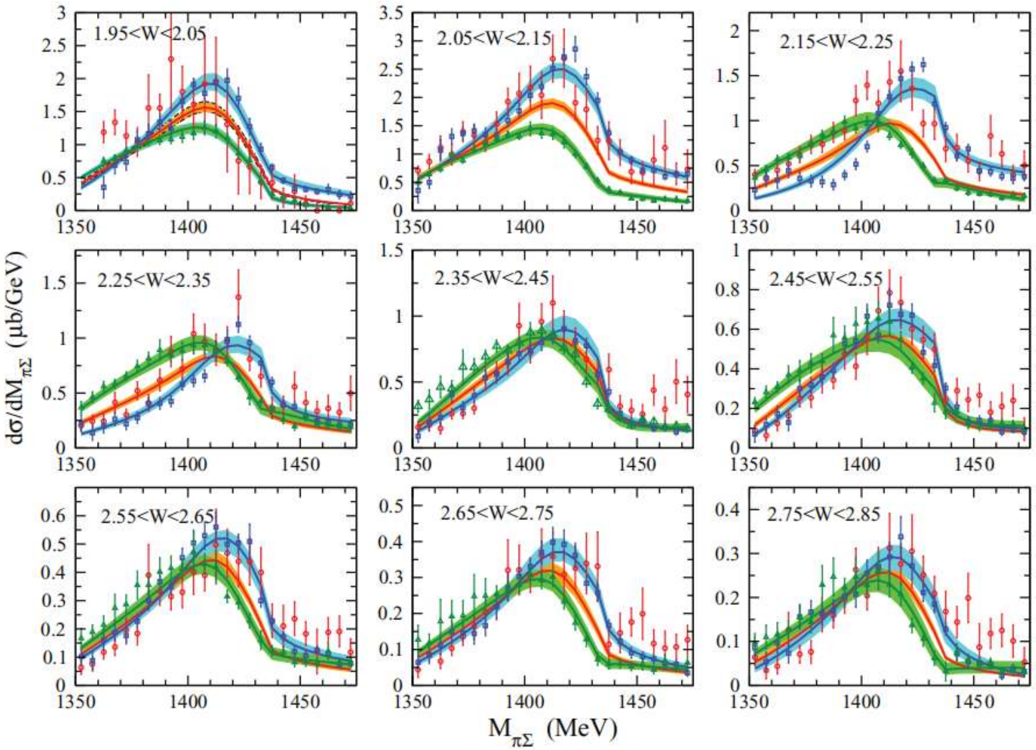
pole positions and couplings

$$T_{ij} = \frac{g_i g_j}{z - z_R}.$$

14

$\Sigma^*(1/2^-)$ in the $\pi\Sigma$ photoproduction

□ $\pi\Sigma$ photoproduction, Roca-Oset, PRC 88, 055206 (2013)



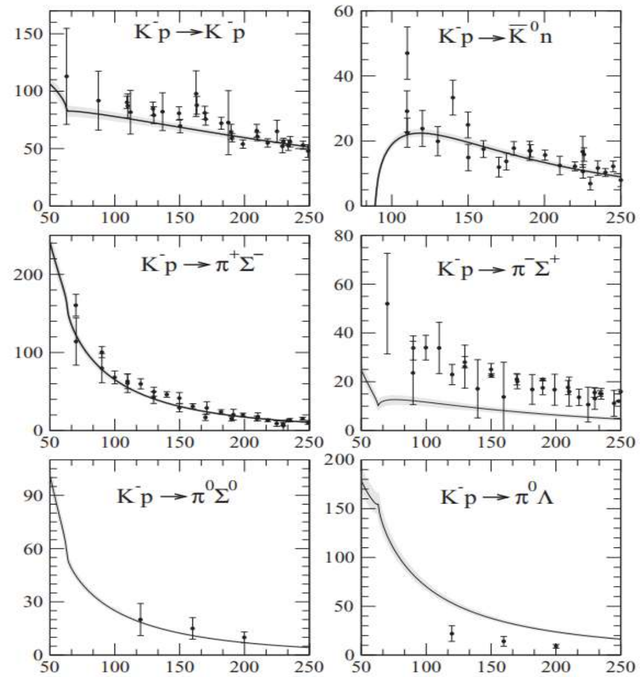
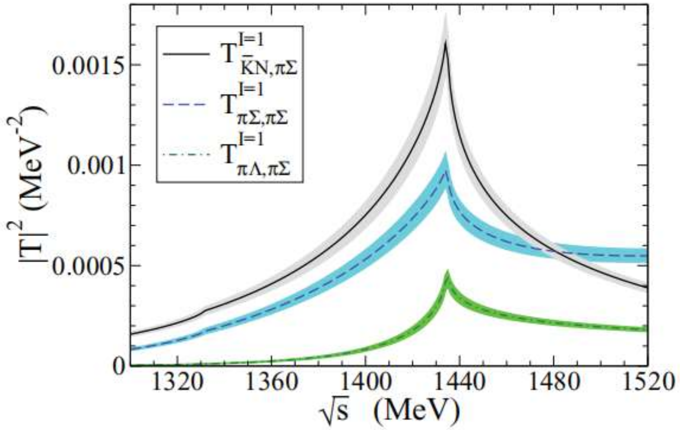


FIG. 6. Predicted K^-p cross sections (in millibarns). Experimental data are from Ref. [46].

Σ(1430)

- **πΣ photoproduction,** Roca-Oset, PRC 88, 055206 (2013)



$$T = [1 - VG]^{-1} V$$

$$V_{ij} = -C_{ij}\frac{1}{4f^2}(k^0 + k'^0)$$

$$C^1_{ij} = \begin{pmatrix} \alpha^1_{11} & -\alpha^1_{12} & -\sqrt{\frac{3}{2}}\alpha^1_{13} \\ -\alpha^1_{12} & 2\alpha^1_{22} & 0 \\ -\sqrt{\frac{3}{2}}\alpha^1_{13} & 0 & 0 \end{pmatrix}$$

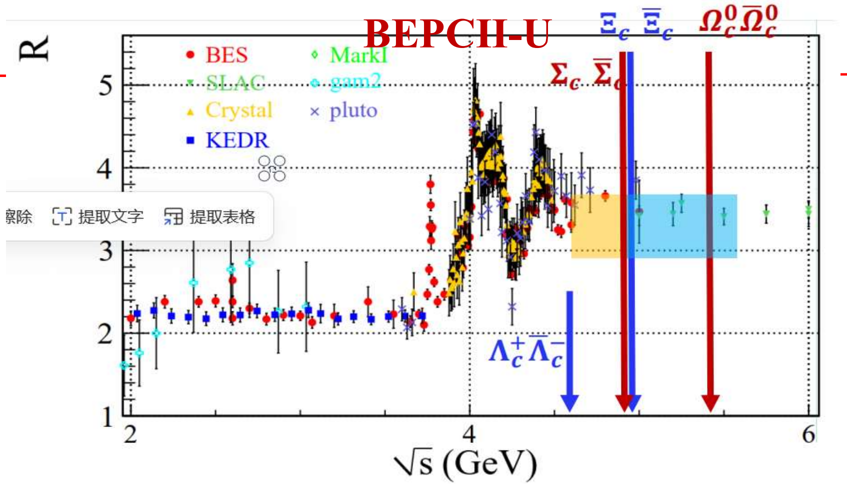
α^0_{11}	α^0_{12}	α^0_{22}	α^1_{11}	α^1_{12}	α^1_{13}	α^1_{22}
1.037	1.466	1.668	0.85	0.93	1.056	0.77

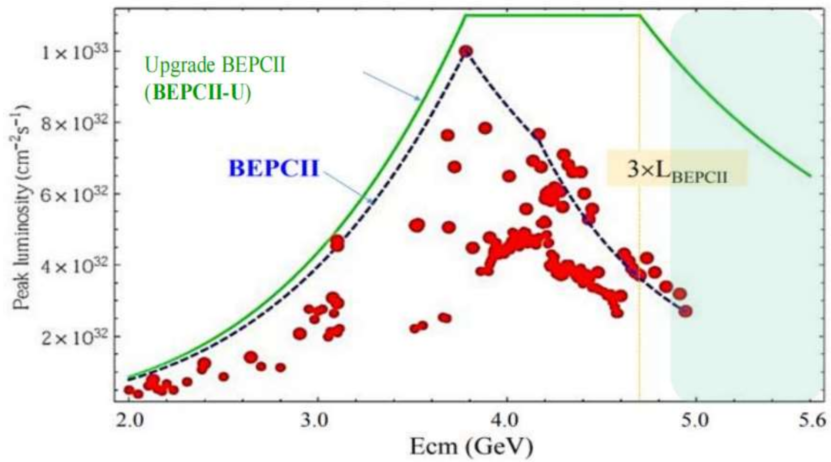
- **Oset-Ramos, NPA635 (1998) 99 [nucl-th/9711022].**
- **PB,VB, Hosaka, PRD 85, 114020 (2012)**
- **Oller-Meißner, Phys. Lett. B 500 (2001) 263 [hep-ph/0011146]**

Λ_c^+ at BESIII

Hadronic decays	
$\Lambda_c \to pK\pi$ + 11 CF modes	PRL 116, 052001 (2016)
$\Lambda_c \to pK^+K^-, p\pi^+\pi^-$	PRL 117, 232002 (2016)
$\Lambda_c \to nK_s\pi$	PRL 118, 112001 (2017)
$\Lambda_c \to p\eta, p\pi^0$	PRD 95, 111102(R) (2017)
$\Lambda_c \to \Sigma\pi^+\pi^-\pi^0$	PLB 772, 338 (2017)
$\Lambda_c \to \Xi^{0(*)}K$	PLB 783, 200 (2018)
$\Lambda_c \to \Lambda\eta\pi$	PRD 99, 032010 (2019)
$\Lambda_c \to pK_s\eta$	PLB 817 (2021) 136327

耿聪老师报告





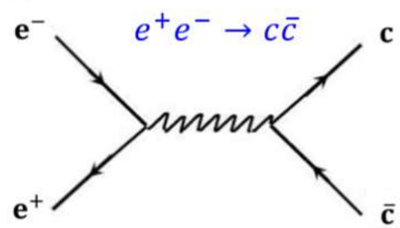
郑阳恒老师报告

Charm hadrons at Belle II/LHCb

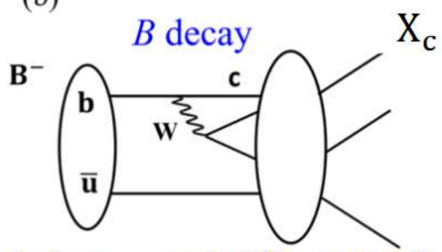
复旦大学 李阳报告

Experiment	Machine	Operation	C.M.	Luminosity	N_{prod}	Efficiency	Characters
BESIII	BEPC-II (e^+e^-)	2010-2011 (2021-) 2016-2019 2014+2020	3.77 GeV 4.18-4.23 GeV 4.6-4.7 GeV	2.9 (8 → 20) fb^{-1} 7.3 fb^{-1} 4.5 fb^{-1}	$D^{0,+}$: $10^7 (\to 10^8)$ D_s^+: 5×10^6 Λ_c^+: 0.8×10^6 ★☆	~ 10-30% ★★★	☺ extremely clean environment ☺ quantum coherence ☺ pure D-beam, almost no background ☹ no CM boost, no time-dept analyses
Belle II	SuperKEKB (e^+e^-)	2019-	10.58 GeV	0.4 (→ 50) ab^{-1}	D^0: 6×10^8 ($\to 10^{11}$) $D_{(s)}^+$: 10^8 ($\to 10^{10}$) Λ_c^+: 10^7 ($\to 10^9$)	$\mathcal{O}$(1-10%)	☺ clear event environment ☺ high trigger efficiency ☺ good-efficiency detection of neutrals ☺ time-dependent analysis ☹ smaller cross-section than LHCb
Belle	KEKB (e^+e^-)	1999-2010	10.58 GeV	1 ab^{-1}	D: 10^9 Λ_c^+: 10^8 ★★☆	★★	

Two ways to produce charm samples at Belle (II)



$\sigma(e^+e^- \to c\bar{c}) \sim 1.33\text{nb}$
$@\sqrt{s} = 10.58$ GeV

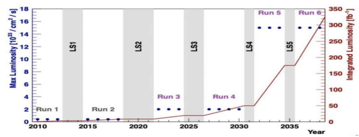


$\sigma(e^+e^- \to \Upsilon(4S)) \sim 1.05\text{nb}$
$\mathcal{B}(\Upsilon(4S) \to B\bar{B}) \sim 96\%$

Future opportunity at LHCb

- RUN1&2: 9 fb^{-1}
- RUN3&4: 50 fb^{-1}

➔ x10 more statistics



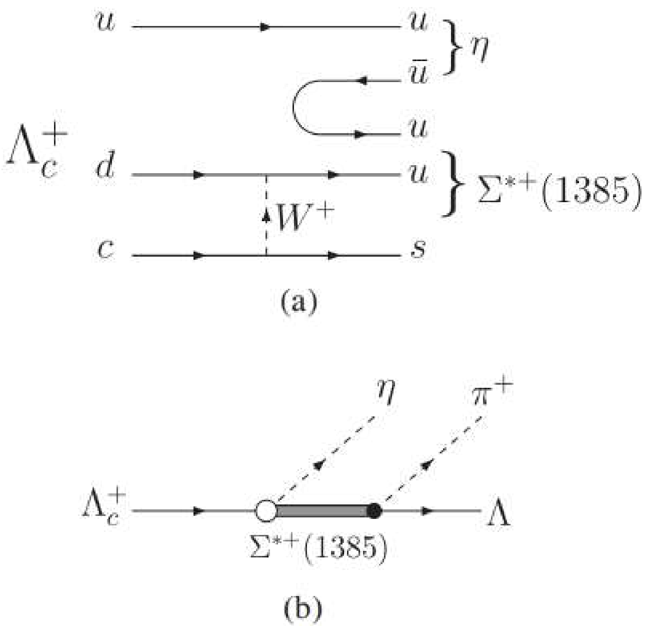
➢ Further improvement on mass and lifetime measurement
➢ SCS and DCS hadronic decays
  ○ e.g. $\Xi_c^0 \to pK^-$、$\Xi_c^+ \to pK_S$、$\Omega_c^0 \to \Lambda K_S$、$pK^-$

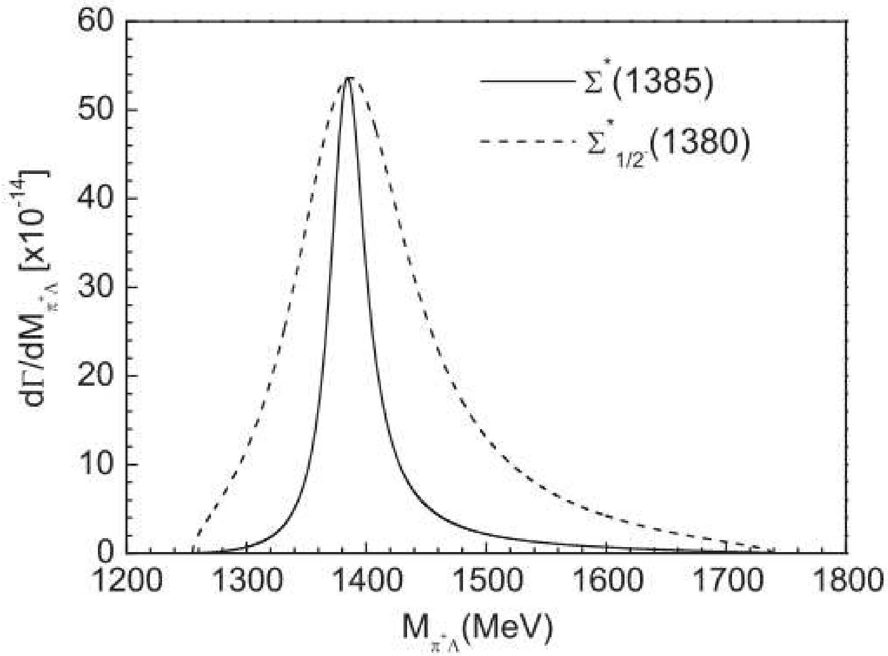
- ➢ Further improvement on mass and lifetime measurement
- ➢ SCS and DCS hadronic decays
  - ○ e.g. $\Xi_c^0 \to pK^-$、$\Xi_c^+ \to pK_S$、$\Omega_c^0 \to \Lambda K_S$、$pK^-$
- ➢ Semi-leptonic decays via b-baryon four-body decays
  - ○ e.g. $\Lambda_c^+ \to pK^-\mu^+\nu, p\pi^-\mu^+\nu$; $\Xi_c^0 \to \Xi^-\mu^+\nu$; $\Xi_c^+ \to \Lambda\mu^+\nu$; $\Omega_c^0 \to \Omega^-\mu^+\nu$
- ➢ Decay asymmetries and CPV search via prompt production or b-baryon decays
  - ○ e.g. $\Lambda_c^+ \to pK_S$, $\Lambda\pi^+$, ΛK^+; $\Xi_c^0 \to \Lambda K_S$, $\Xi^-\pi^+$, Ξ^-K^+; $\Omega_c^0 \to \Omega^-\pi^+, \Omega^-K^+$, $\Xi^-\pi^+$
- ➢ Amplitude analysis of multi-body hadronic decays

郑阳恒老师报告

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

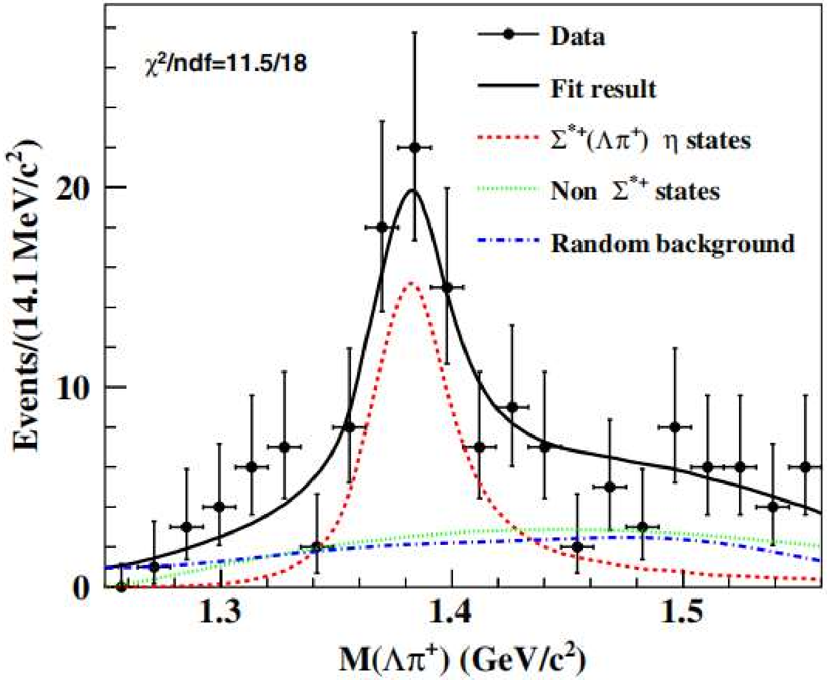
- J.J.Xie, L.S.Geng, EPJC76(2016) 496, PRD95(2017) 074024

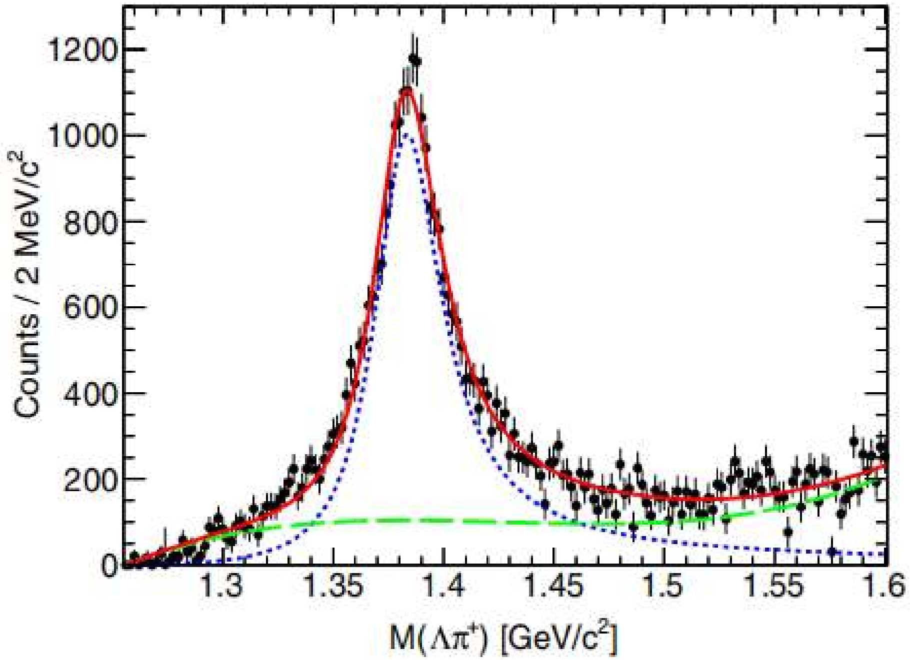




Belle and BESIII measurements

- $\Lambda_c^+ \rightarrow \Lambda\eta\pi$



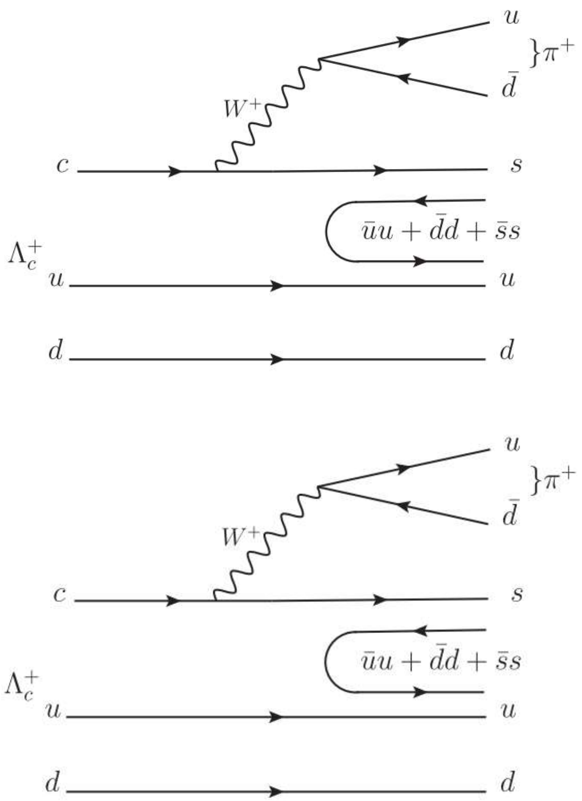


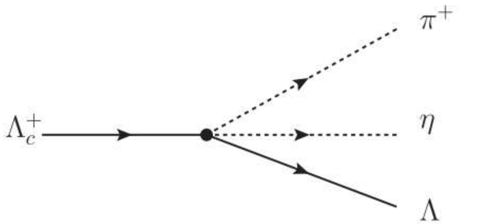
BESIII: PRD99, 032010 (2019)

Belle: PRD103(2021)052005

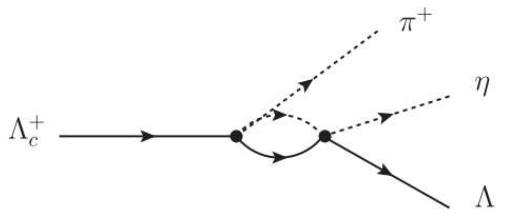
Mechanism of $\Lambda_c^+ \to \eta\Lambda\pi$

□Theometical model

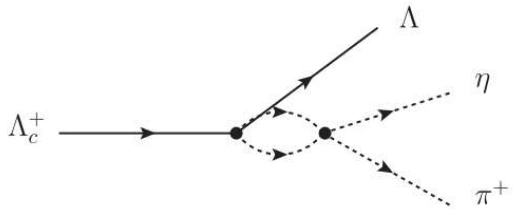




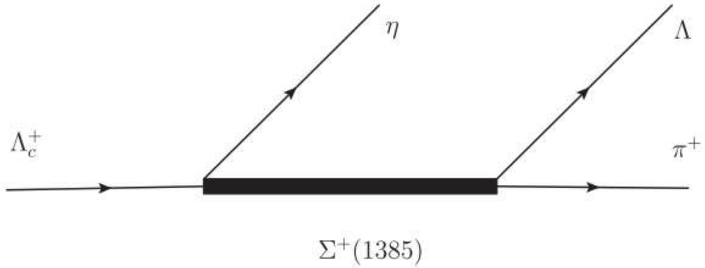
(a)



(b)



(c)



$$T^{\Sigma^*}(M_{\pi^+\Lambda}) = V_P'' \frac{|\vec{p}_\pi| \cdot |\vec{p}_\eta| \cdot \cos\theta}{M_{\pi^+\Lambda} - M_{\Sigma^*} + i\frac{\Gamma_{\Sigma^*}}{2}},$$

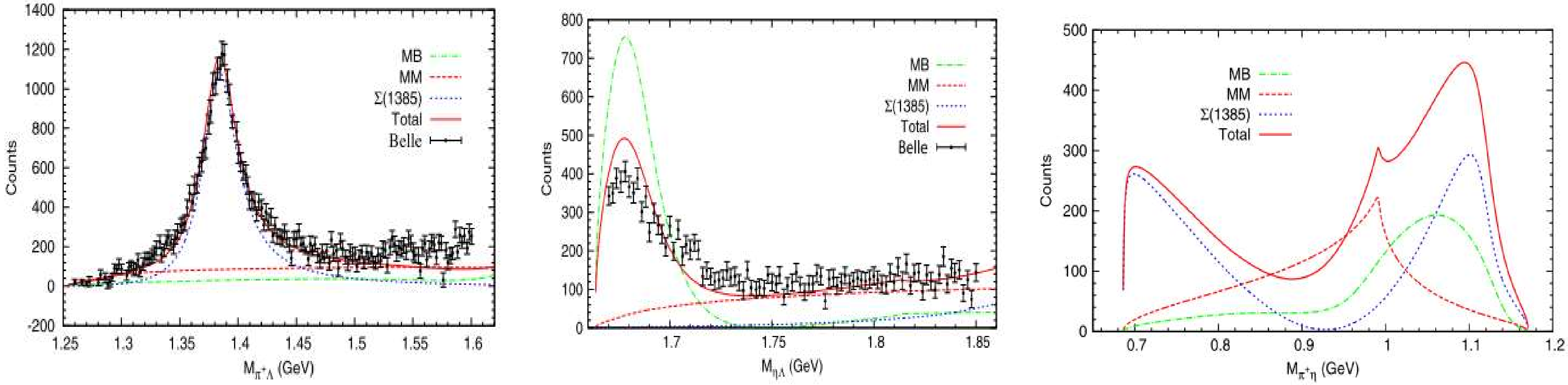
$$T^{\rm MB}(M_{\eta\Lambda}) = V_P\Big\{-\frac{\sqrt{2}}{3} + G_{K^-p}(M_{\eta\Lambda})t_{K^-p\to\eta\Lambda}(M_{\eta\Lambda}) + G_{\bar{K}^0n}(M_{\eta\Lambda})t_{\bar{K}^0n\to\eta\Lambda}(M_{\eta\Lambda}) - \frac{\sqrt{2}}{3}G_{\eta\Lambda}(M_{\eta\Lambda})t_{\eta\Lambda\to\eta\Lambda}(M_{\eta\Lambda})\Big\},$$

$$T^{\rm MM}(M_{\pi^+\eta}) = V_P'\frac{2\sqrt{2}}{3}\Big\{1 + G_{\pi^+\eta}(M_{\pi^+\eta})t_{\pi^+\eta\to\pi^+\eta}(M_{\pi^+\eta}) + \frac{\sqrt{3}}{2}G_{K^+\bar{K}^0}(M_{\pi^+\eta})t_{K^+\bar{K}^0\to\pi^+\eta}(M_{\pi^+\eta})\Big\}, \quad ($$

GYW-EW-Xie-Geng-Wei, PRD 106, 056001 (2022)

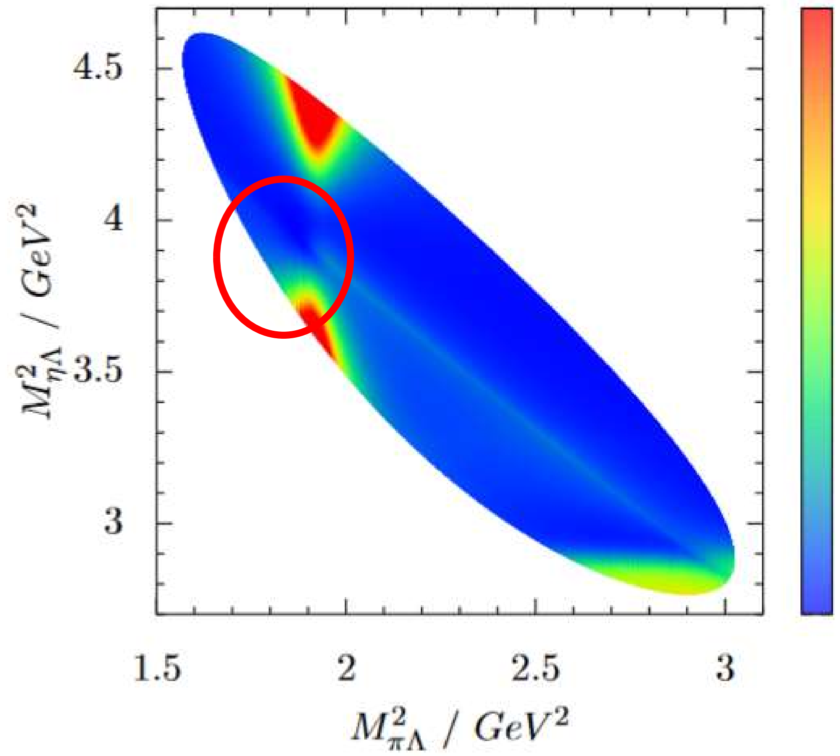
Analysis the Belle data

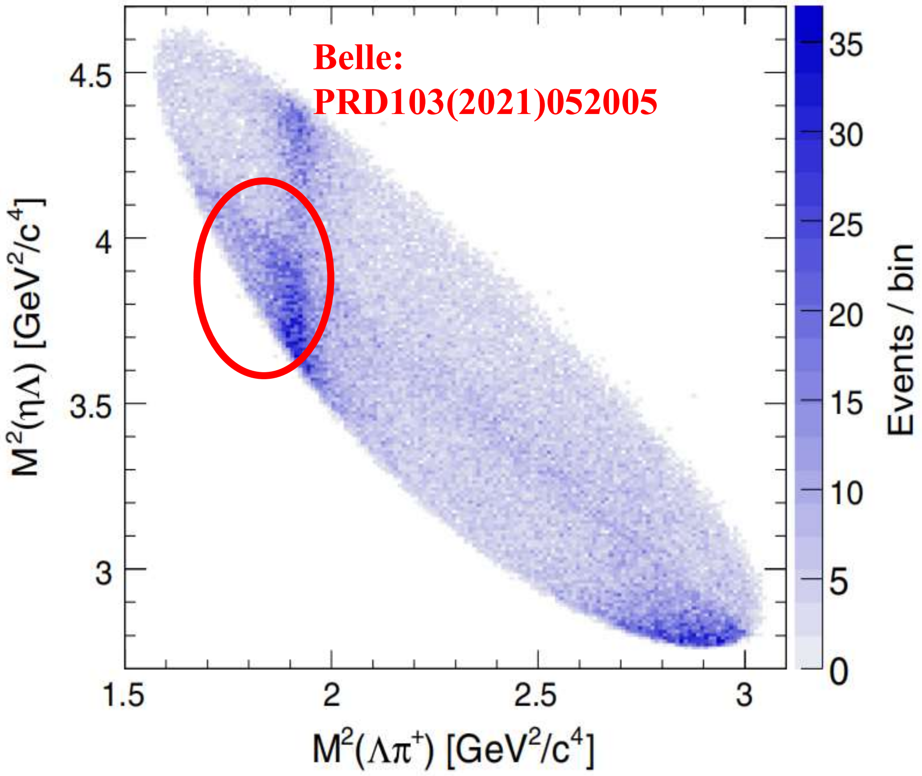
- $\Lambda_c^+ \to \Lambda\eta\pi$, GYW-EW-Xie-Geng-Wei, PRD 106, 056001 (2022)



By regarding the $\Lambda(1670)$ as the molecule, we could well reproduce the Belle data of the mass distributions.

Dalitz plot of $\Lambda_c^+ \to \eta\Lambda\pi$

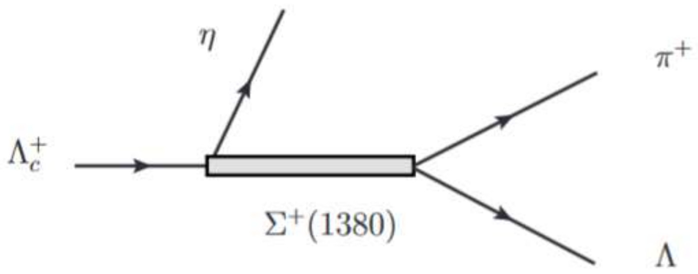




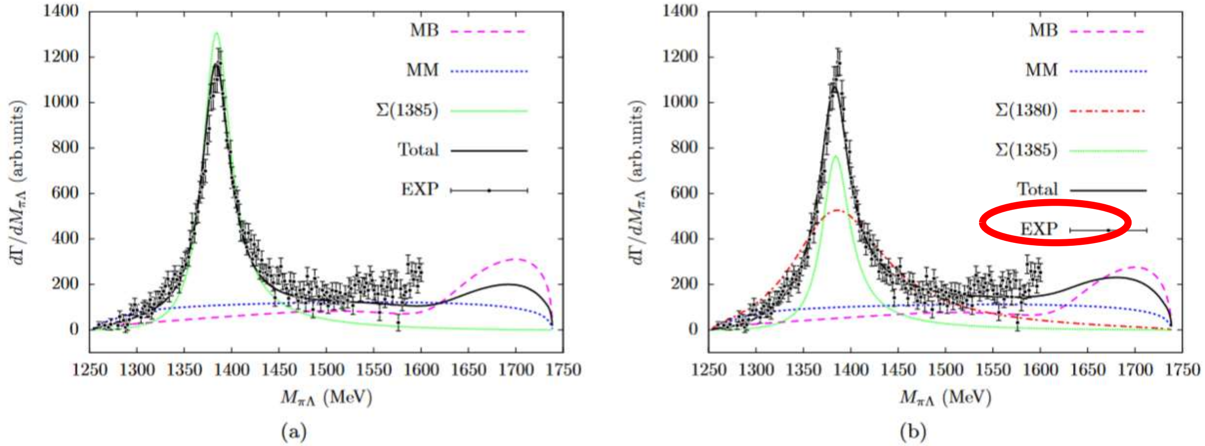
$\Sigma(1/2^-)$ in $\Lambda_c^+ \to \eta\Lambda\pi$

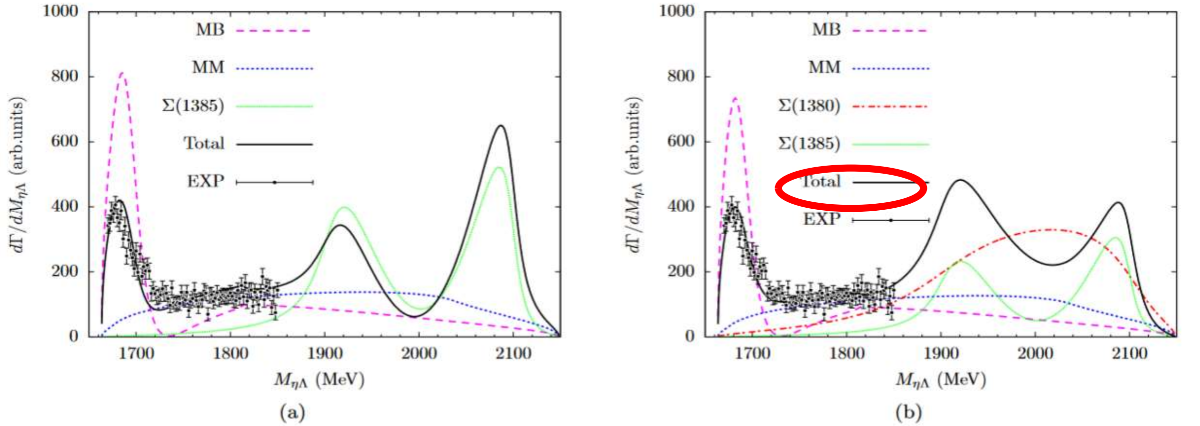
arXiv:2405.09226

□Intermediate of $\Sigma(1/2^-)$

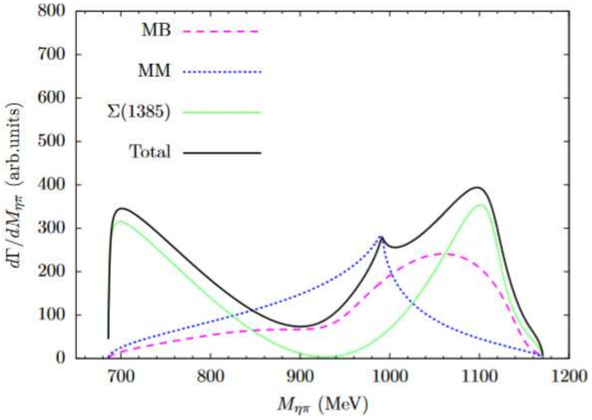


$$\mathcal{T}^{\Sigma(1/2^-)} = \frac{V^{\Sigma(1/2^-)} M_{\Sigma(1/2^-)} \Gamma_{\Sigma(1/2^-)}}{M_{\pi^+\Lambda}^2 - M_{\Sigma(1/2^-)}^2 + i M_{\Sigma(1/2^-)} \Gamma_{\Sigma(1/2^-)}},$$

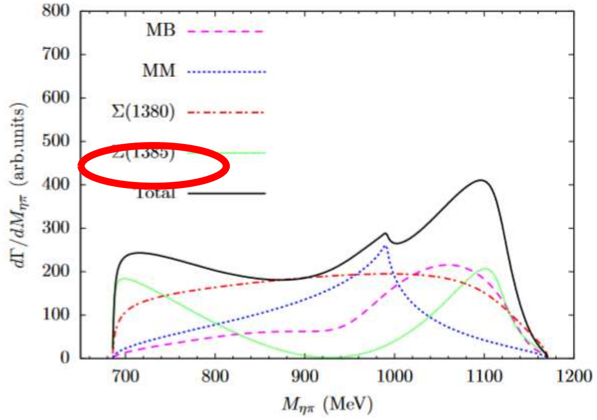




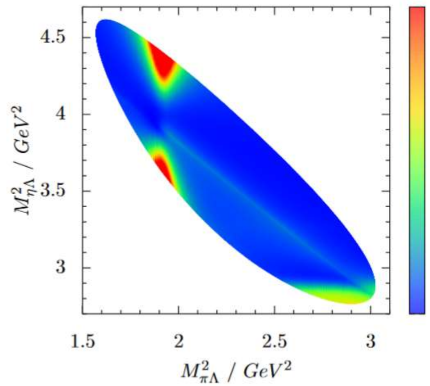
The results with/without Σ(1380)

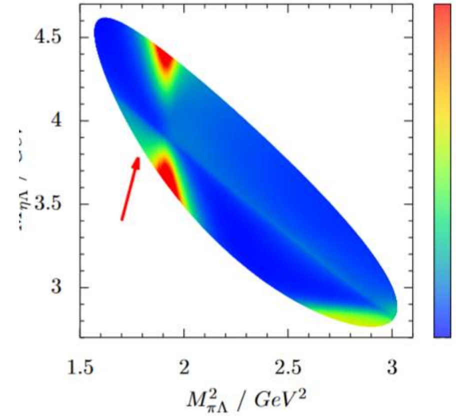


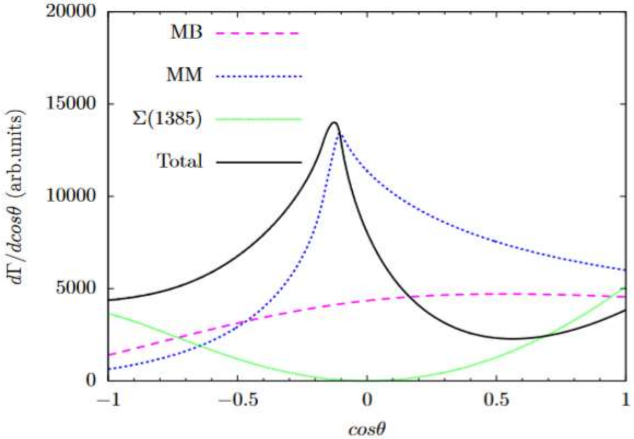
(a)

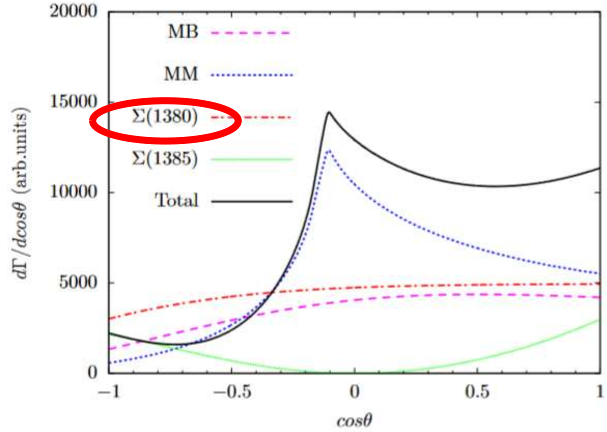


(b)

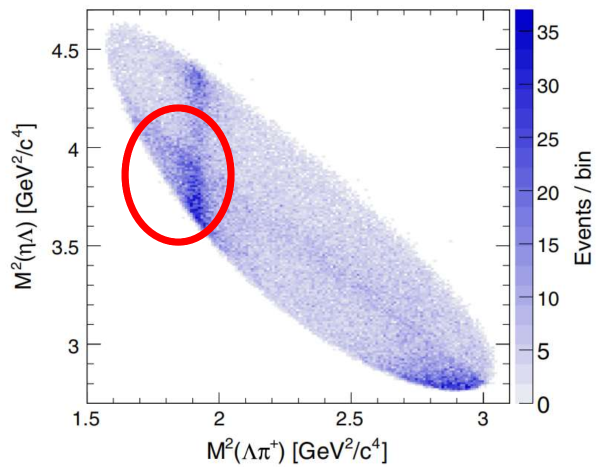






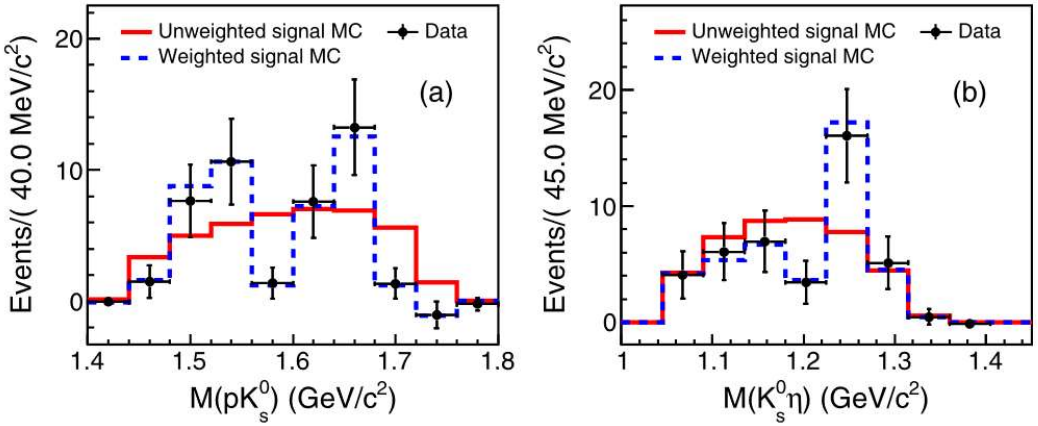


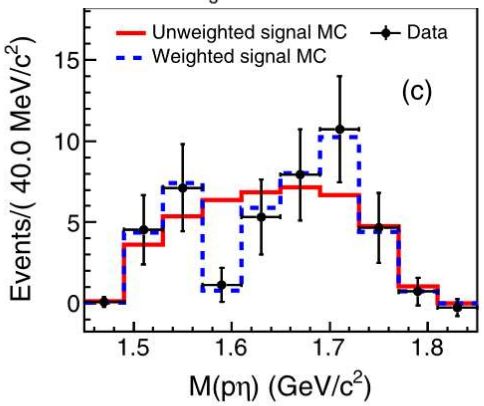
$M_{\pi\Lambda} \geq 1450$ MeV and $M_{\eta\Lambda} \geq 1760$ MeV.



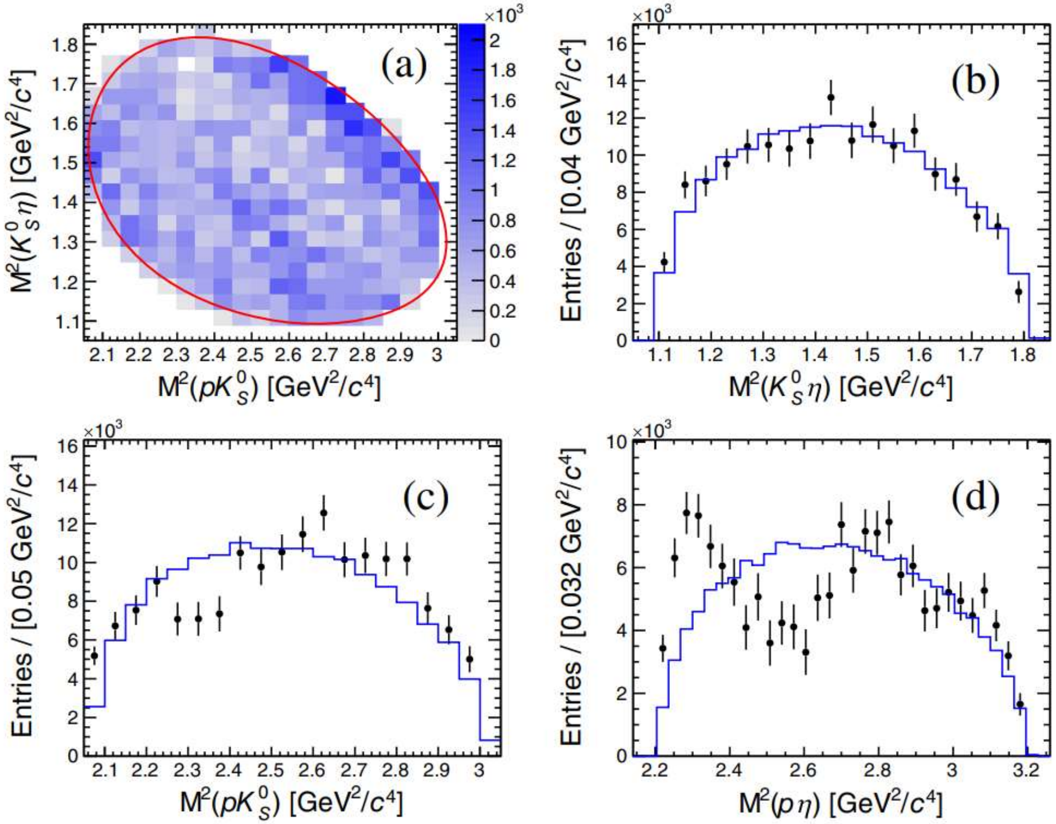
to be prepared

Exp of $\Lambda_c^+ \to \bar{K}^0 \eta p$





Belle: PRD107 (2023) 032004



BESIII: PLB817 (2021) 136327

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

Ju-Jun Xie (Lanzhou, Inst. Modern Phys.), Li-Sheng Geng (BeiH

Phys.Rev.D 96 (2017) 5, 054009 • e-Print: 1704.05714 • DOI: 10.

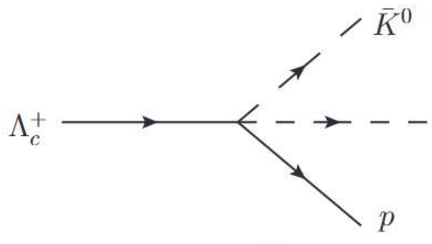
Production of $N^*(1535)$ and $N^*(1650)$ in $\Lambda_c \to \bar{K}^0\eta p$ (πN) decay

R. Pavao (Valencia U. and Valencia U., IFIC), S. Sakai (Valencia U. and Valencia U., IFIC), E. Oset

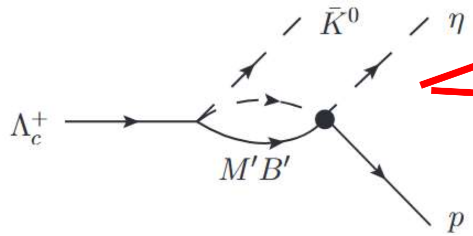
Phys.Rev.C 98 (2018) 1, 015201 • e-Print: 1802.07882 • DOI: 10.1103/PhysRevC.98.015201

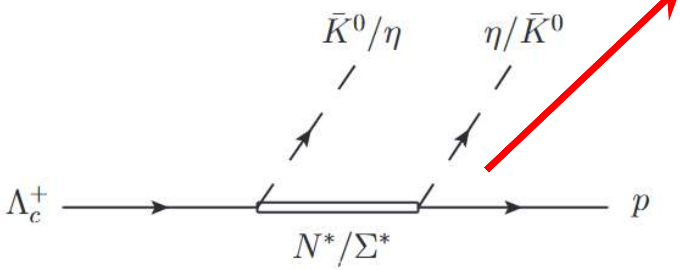
$\Sigma(1/2^-)$ in $\Lambda_c^+ \to \bar{K}^0 \eta p$

arXiv:2406.01209



(a)





$$\mathcal{T}^{N(1535)} = V_1 (h_{\eta N} + h_{\eta N} G_{\eta N} t_{\eta N\to\eta N} + h_{\pi N} G_{\pi N} t_{\pi N\to\eta N} + h_{K\Lambda} G_{K\Lambda} t_{K\Lambda\to\eta N})$$

$$h_{\eta N} = \frac{1}{\sqrt{3}},\ h_{\pi N} = -\frac{\sqrt{6}}{2},\ h_{K\Lambda} = -\frac{\sqrt{6}}{3},$$

$$T = [1 - VG]^{-1} V,$$

PhysRevC.65.035204

$$\tilde{\mathcal{T}}^{N(1535)} = \frac{\tilde{V}_1 M_{N(1535)} \Gamma_{N(1535)}}{M_{\eta p}^2 - M_{N(1535)}^2 + i M_{N(1535)} \Gamma_{N(1535)}},$$

$$\mathcal{T}^{N(1650)} = \frac{V_2 M_{N^*} \Gamma_{N^*}}{M_{\eta p}^2 - M_{N^*}^2 + i M_{N^*} \Gamma_{N^*}},$$

$$\mathcal{T}^{\Sigma^*(1/2^-)} = \frac{V_3 M_{\Sigma^*} \Gamma_{\Sigma^*}}{M_{p\bar{K}^0}^2 - M_{\Sigma^*}^2 + i M_{\Sigma^*} \Gamma_{\Sigma^*}},$$

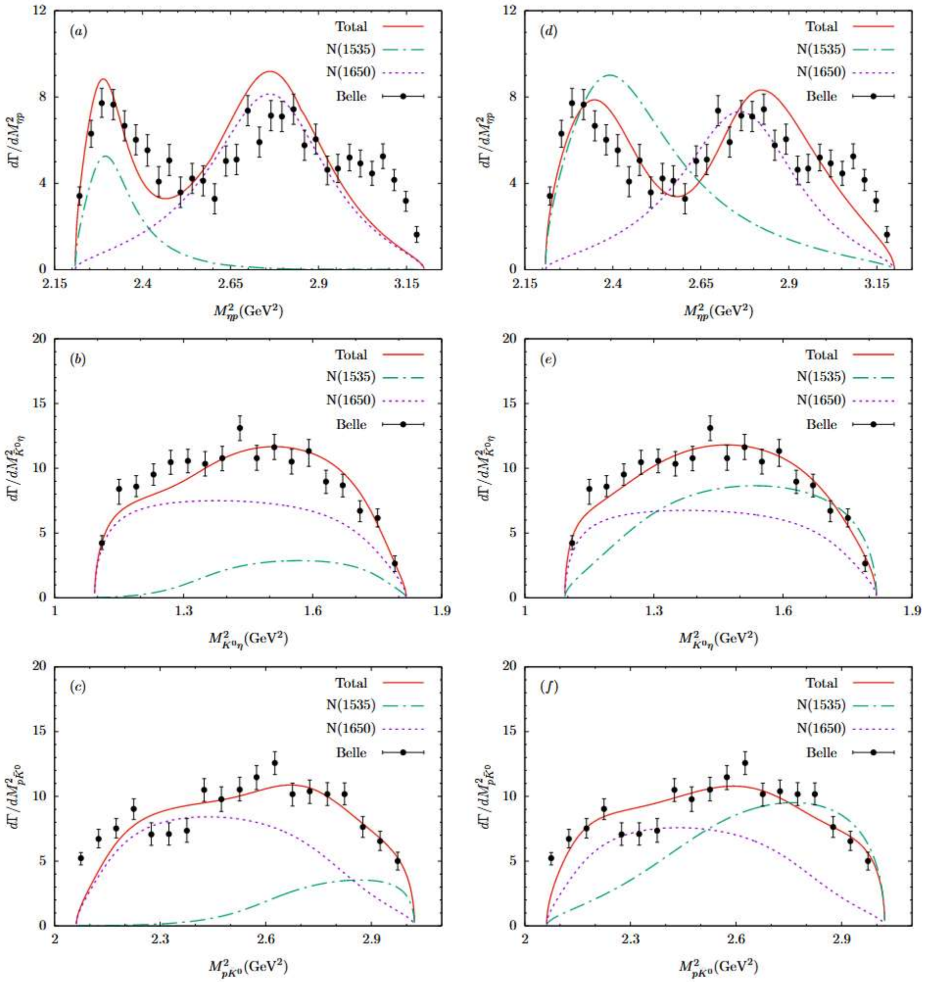
$$|\mathcal{T}^{\rm A}|^2 = |\mathcal{T}^{N(1535)} + \mathcal{T}^{N(1650)} e^{i\phi}|^2,$$

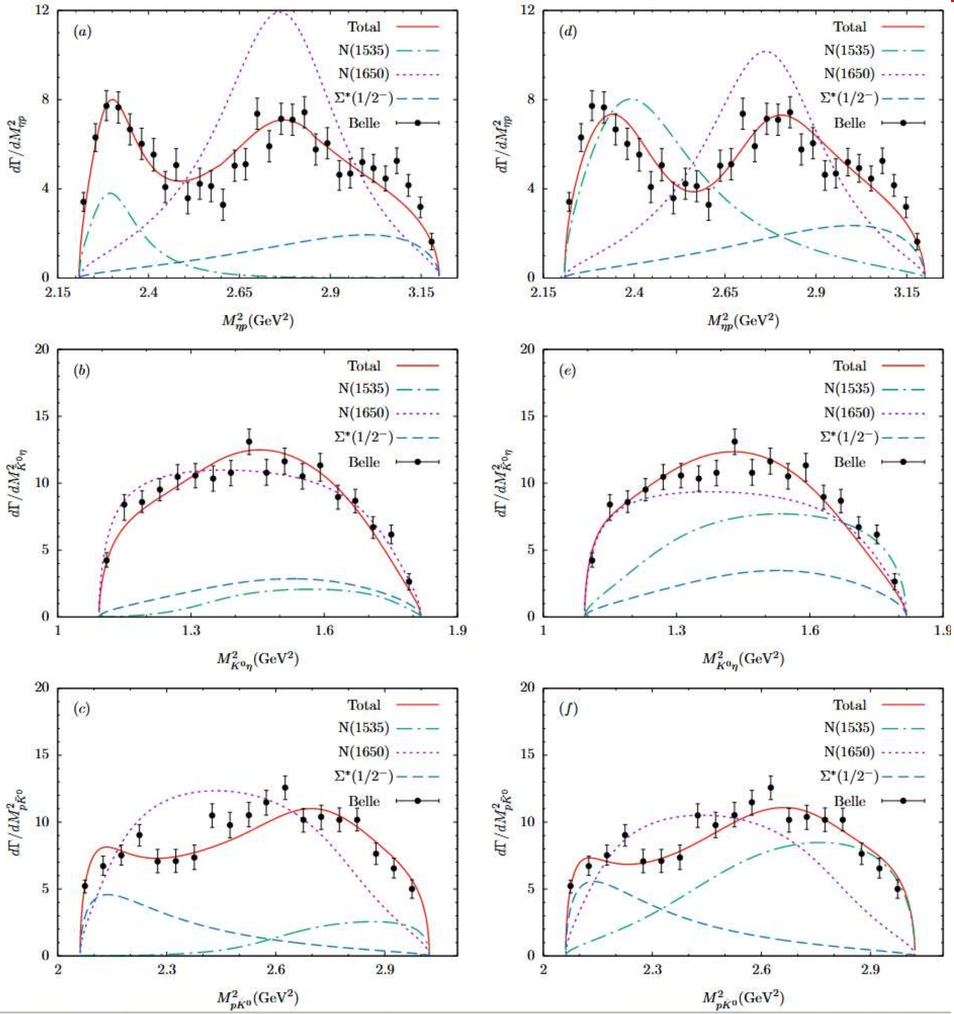
$$|\mathcal{T}^{\rm B}|^2 = |\tilde{\mathcal{T}}^{N(1535)} + \mathcal{T}^{N(1650)} e^{i\phi}|^2,$$

$$|\mathcal{T}^{\rm C}|^2 = |\mathcal{T}^{N(1535)} + \mathcal{T}^{N(1650)} e^{i\phi} + \mathcal{T}^{\Sigma^*(1/2^-)} e^{i\phi'}|^2,$$

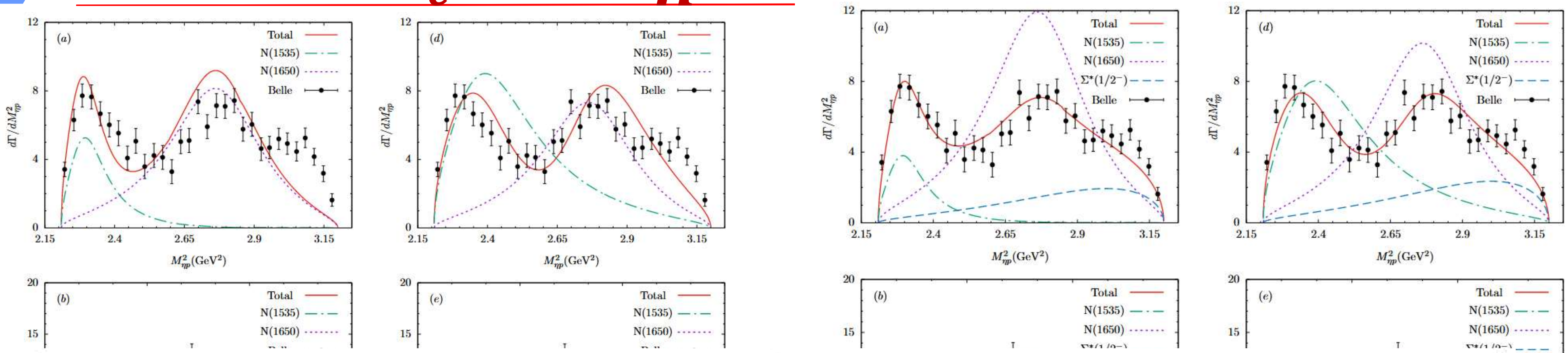
$$|\mathcal{T}^{\rm D}|^2 = |\tilde{\mathcal{T}}^{N(1535)} + \mathcal{T}^{N(1650)} e^{i\phi} + \mathcal{T}^{\Sigma^*(1/2^-)} e^{i\phi'}|^2,$$

Results of $\Lambda_c^+ \to \bar{K}^0 \eta p$

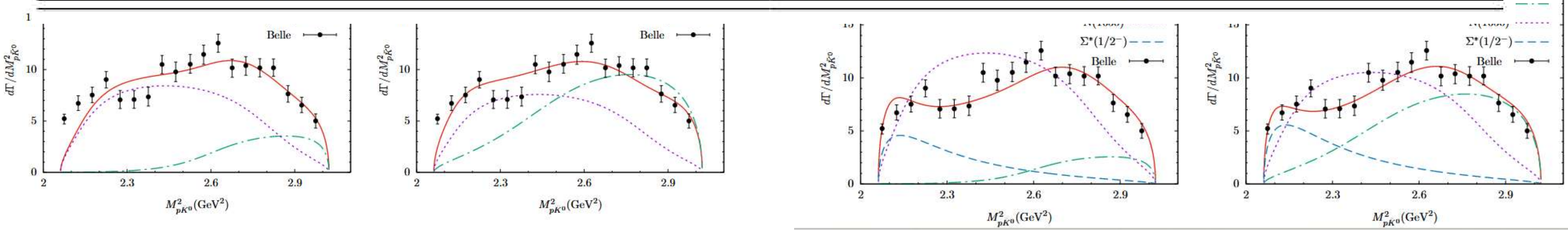




Results of $\Lambda_c^+ \to \bar{K}^0 \eta p$

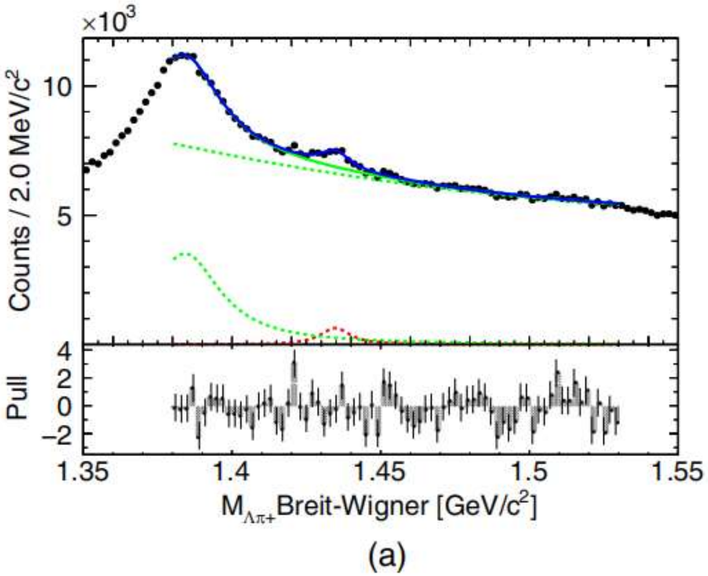


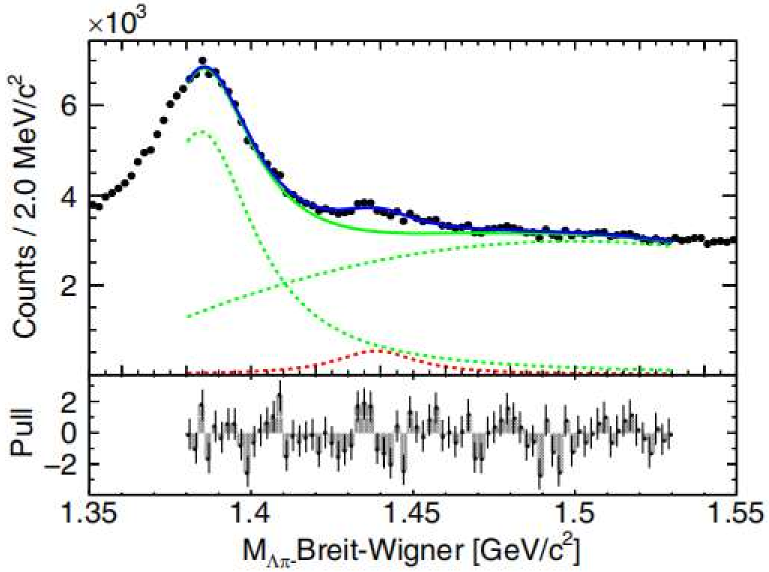
Parameters	$V_1(\tilde{V}_1)$	V_2	V_3	ϕ	ϕ'	$\chi^2/d.o.f.$
Model A	13939 ± 895	43369 ± 3227	—	$(0.98 \pm 0.21)\pi$	—	5.67
Model B	50151 ± 3730	41144 ± 3059	—	$(1.77 \pm 0.14)\pi$	—	3.20
Model C	11848 ± 813	52495 ± 3938	56230 ± 4019	$(1.35 \pm 0.43)\pi$	$(1.83 \pm 0.35)\pi$	1.55
Model D	47337 ± 2868	48454 ± 2457	61947 ± 4506	$(1.94 \pm 0.21)\pi$	$(0.62 \pm 0.16)\pi$	1.69



Belle measurements

□ $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$, Belle, PRL130, 151903 (2023)



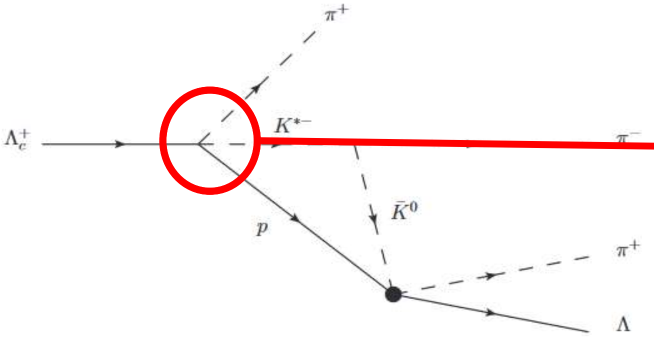


Mode	$E_{\rm BW}$ (MeV/c^2)	Γ (MeV/c^2)	χ^2/NDF
$\Lambda\pi^+$	1434.3 ± 0.6	11.5 ± 2.8	74.4/68
$\Lambda\pi^-$	1438.5 ± 0.9	33.0 ± 7.5	92.3/68

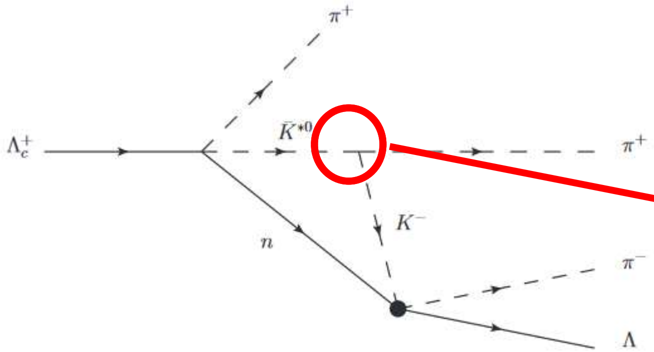
Evidence of Σ(1430)

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

Dai-Pavao-Sakai-Oset, PRD 97, 116004 (2018)
Xie-Oset, PLB 792, 450-453 (2019)



(a)



(b)

$$t_{\Lambda_c^+\to\pi^+K^{*-}p} = A\vec{\sigma}\cdot\vec{\epsilon},$$

$$\frac{d\Gamma_{\Lambda_c^+\to\pi^+K^{*-}p}}{dM_{\rm inv}(K^{*-}p)} = \frac{1}{(2\pi)^3}\frac{2M_{\Lambda_c^+}2M_p}{4M_{\Lambda_c^+}^2}p_{\pi^+}\tilde{p}_{K^{*-}} \times \bar{\sum}\sum|t_{\Lambda_c^+\to\pi^+K^{*-}p}|^2,$$

$$\mathcal{B}(\Lambda_c^+\to\pi^+K^{*-}p) = (1.4\pm0.5)\times10^{-2}$$

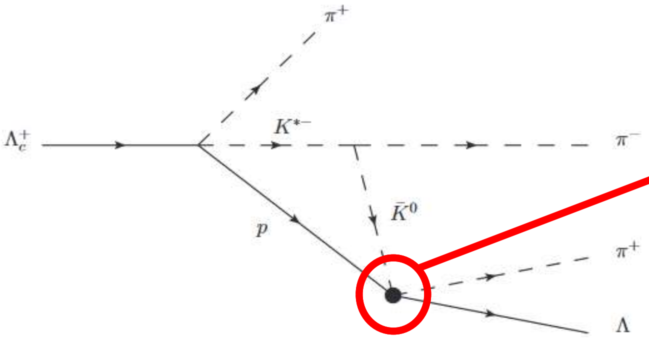
$$|A|^2 = (3.9\pm1.4)\times10^{-16}\ {\rm MeV}^{-2}.$$

$$\mathcal{L}_{VPP} = -ig < V^\mu[P,\partial P] >$$

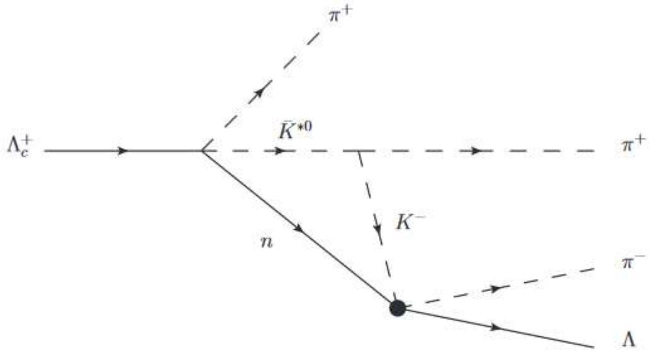
$$\mathcal{L}_{\bar{K}^*\to\pi\bar{K}} = -ig\,(K^{*-})^\mu\,(\pi^-\partial_\mu\bar{K}^0 - \partial_\mu\pi^-\bar{K}^0).$$

Evidence of Σ(1430)

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



(a)



(b)

$$\mathcal{T}^{\mathrm{TS}} = -Ag(\vec{\sigma}\cdot\vec{k}_a t_T^a \mathcal{M}^a + \vec{\sigma}\cdot\vec{k}_b t_T^b \mathcal{M}^b),$$

$$\mathcal{M}^a = t_{K^-n\to\pi^-\Lambda}$$

$$T = [1 - VG]^{-1}V,$$

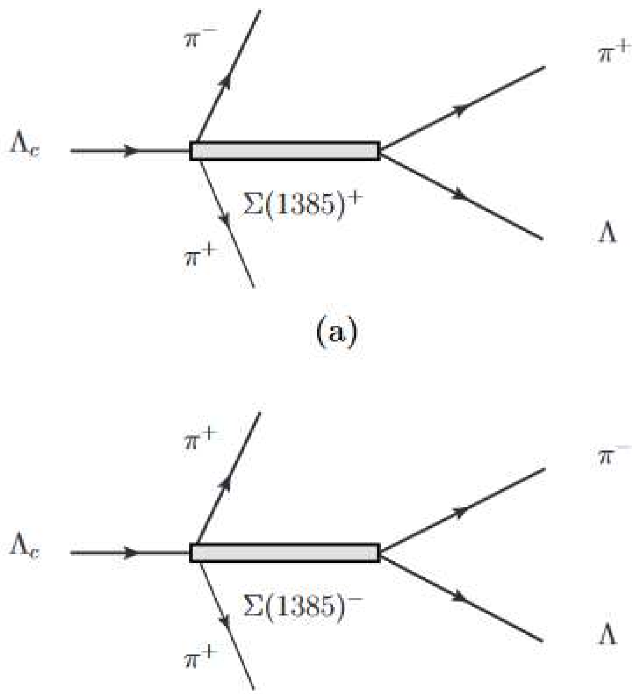
$$\mathcal{M}^b = t_{\bar{K}^0 p\to\pi^+\Lambda}$$

E. Oset, A. Ramos, NPA 635, 99

$$\begin{aligned} t_T^a = \int \frac{d^3q}{(2\pi)^3}\frac{2M_p}{8\omega_p\omega_{K^{*-}}\omega_{\bar{K}^0}}\frac{1}{k_a^0-\omega_{K^{*-}}-\omega_{\bar{K}^0}+i\frac{\Gamma_{K^{*-}}}{2}} \\ \times \frac{1}{P^0+\omega_p+\omega_{\bar{K}^0}-k_a^0}\left(2+\frac{\vec{q}\cdot\vec{k}}{|\vec{k}|^2}\right) \\ \times \frac{2P^0\omega_p+2k_a^0\omega_{\bar{K}^0}-2(\omega_p+\omega_{\bar{K}^0})(\omega_p+\omega_{\bar{K}^0}+\omega_{K^{*-}})}{P^0-\omega_{K^{*-}}-\omega_p+i\frac{\Gamma_{K^{*-}}}{2}} \\ \times \frac{1}{P^0-\omega_p-\omega_{\bar{K}^0}-k_a^0+i\varepsilon}, \qquad (19) \end{aligned}$$

Evidence of Σ(1430)

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



(a)

(b)

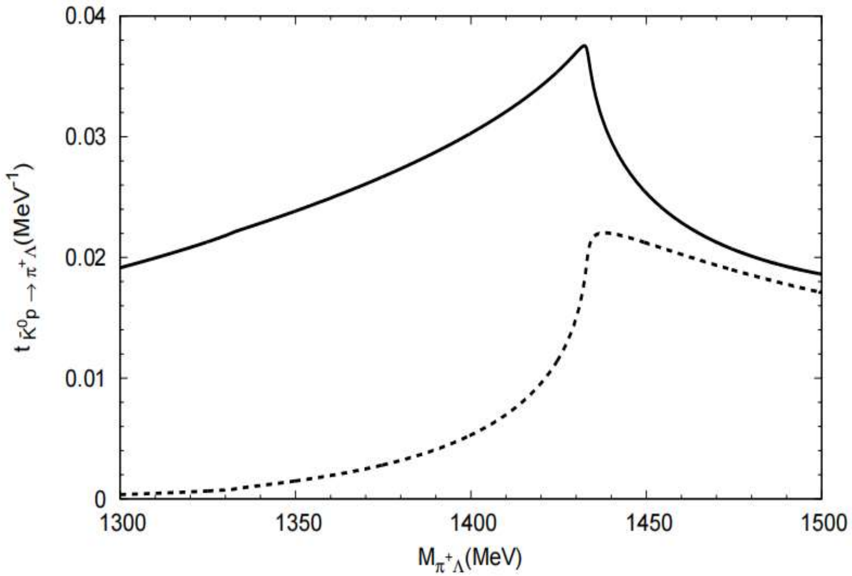
$$T^{\Sigma^{*+}(1385)} = \frac{V_p|p_{\pi^+}|}{M_{\pi^+\Lambda} - M_{\Sigma^{*+}} + i\frac{\Gamma_{\Sigma^{*+}}}{2}},$$

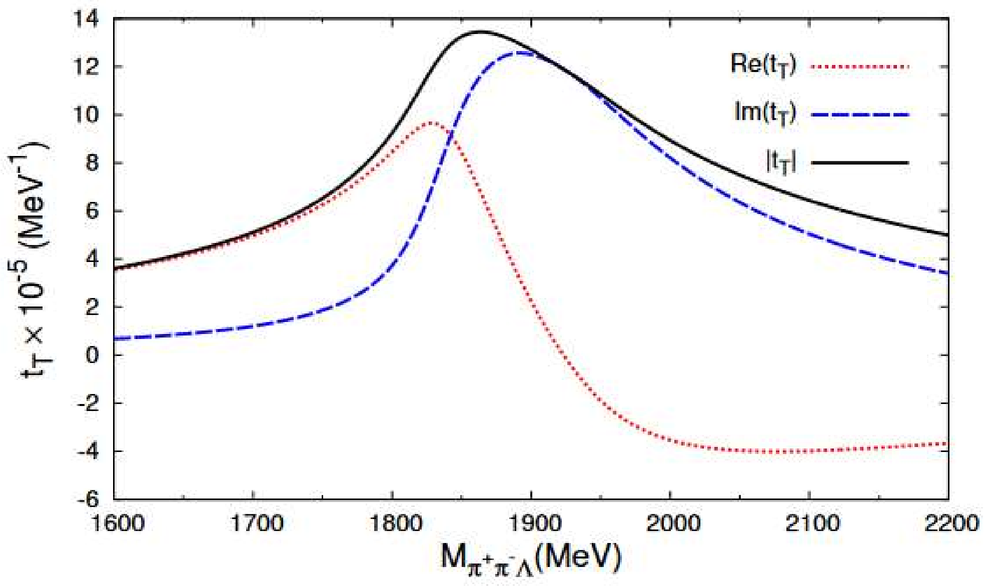
$$T^{\Sigma^{*-}(1385)} = \frac{V_p|p_{\pi^-}|}{M_{\pi^-\Lambda} - M_{\Sigma^{*-}} + i\frac{\Gamma_{\Sigma^{*-}}}{2}},$$

$$\frac{d^3\Gamma}{dM_{\pi^+\pi^-\Lambda}dM_{\pi^+\Lambda}dM_{\pi^-\Lambda}} = \frac{g^2|A|^2}{64\pi^5}\frac{M_\Lambda}{M_{\Lambda_c^+}}\tilde{p}_{\pi^+}\frac{M_{\pi^+\Lambda}M_{\pi^-\Lambda}}{M_{\pi^+\pi^-\Lambda}}$$
$$\Big\{|\vec{k}_a|^2|t_T^a\mathcal{M}^a|^2 + |\vec{k}_b|^2|t_T^b\mathcal{M}^b|^2 + 2\mathrm{Re}[t_T^a\mathcal{M}^a(t_T^b\mathcal{M}^b)^*]$$
$$\times\vec{k}_a\cdot\vec{k}_b + |T^{\Sigma^{*+}(1385)}|^2 + |T^{\Sigma^{*-}(1385)}|^2\Big\}, \quad (29)$$

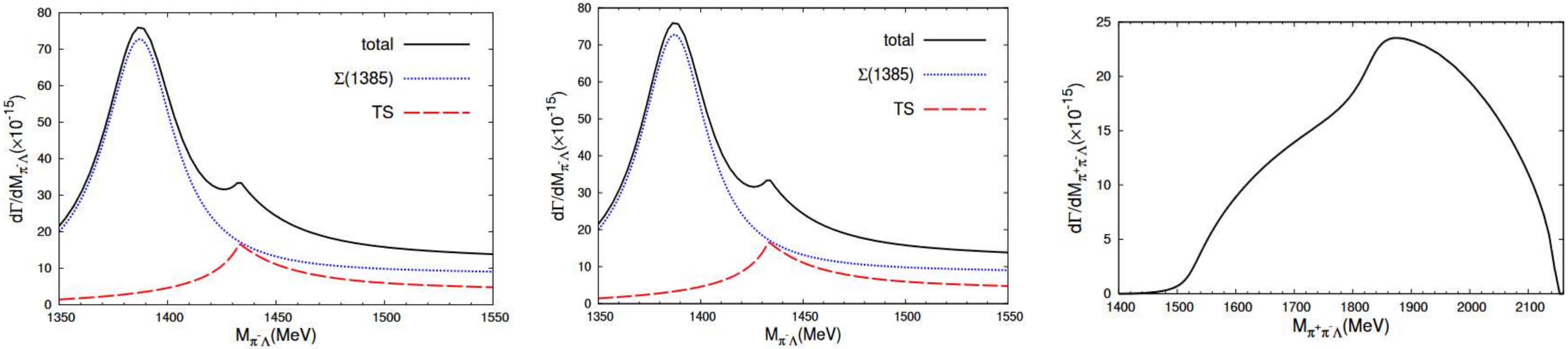
Evidence of Σ(1430)

□ $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$, Lyu-GYW-EW-Xie-Geng, to prepare



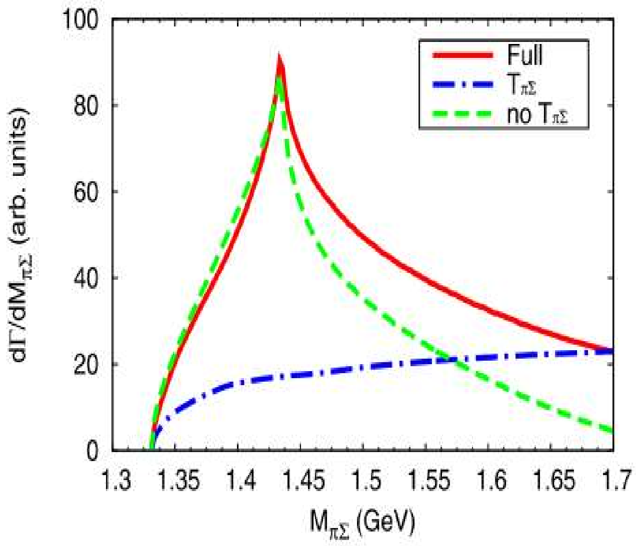


Results of $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$



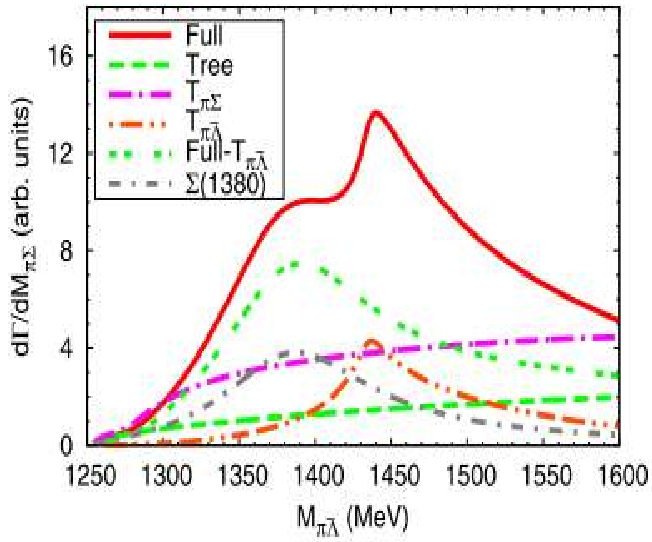
Cusp signal of $\Sigma(1/2^-)$ around $\bar{K}N$ threshold!

Search for $\Sigma^*(1/2^-)$ in other processes



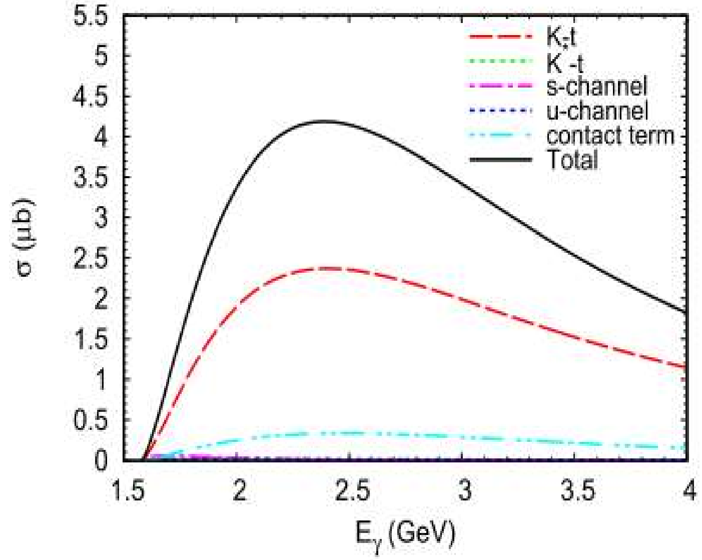
$\chi_{c0} \to \bar{\Sigma}\Sigma\pi$

PLB753(2016)526



$\chi_{c0} \to \bar{\Lambda}\Sigma\pi$

PRD98(2018)114017



$\gamma n \to K\Sigma(1/2^-)$

CPC47 (2023) 053108

Two poles of $\Sigma^*(1/2^-)$

PHYSICAL REVIEW LETTERS **130,** 071902 (2023)

Cross-Channel Constraints on Resonant Antikaon-Nucleon Scattering

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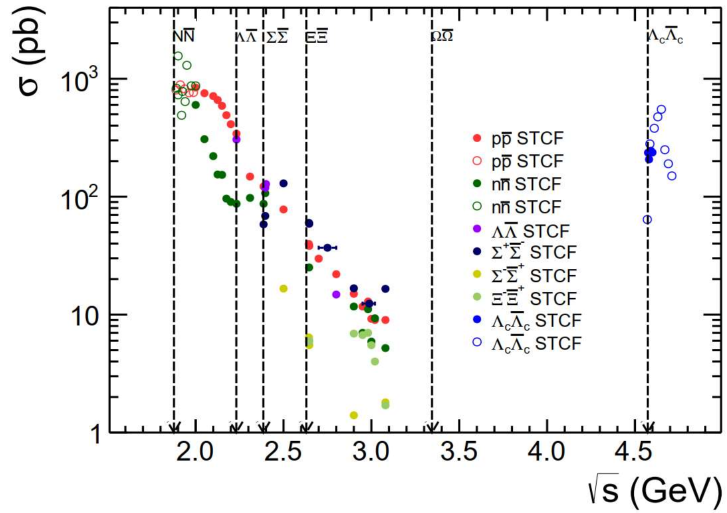
It is interesting to note that in our NNLO fit there exist two $I = 1$ states around the $\bar{K}N$ threshold located at $(1435, -39)$ MeV and $(1440, -135)$ MeV on the $(--++++)$ sheet, the order of which corresponds to $\pi\Lambda, \pi\Sigma, \bar{K}N, \eta\Lambda, \eta\Sigma, K\Xi$ respectively. Both states are well above the K^-p threshold and appear as cusps on the real axis. In the Fit "NNLO*" in which the constraints from baryon masses are omitted, the two $I = 1$ states are located at $(1364, -110)$ MeV and $(1432, -18)$ MeV also on the $(--++++)$ sheet. In this case, the narrower state still shows up as a cusp but the broader one becomes a broad enhancement on the $I = 1$ amplitude on the real axis. We note that the existence of a $\Sigma^*(\frac{1}{2}^-)$ state has been predicted in a number of UChPT

Are there two poles of $\Sigma(1/2^-)$?

Summary

- Belle/BESIII measurements of $\Lambda_c^+ \to \eta\Lambda\pi/\bar{K}^0\eta p$ show some hints of the $\Sigma^*(1/2^-)$.
- The cusp structure around 1430 MeV in $\Lambda_c^+ \to \Lambda\pi\pi\pi$ could be associated with the $\Sigma(1430)$.
- Some processes could be used to search for $\Sigma^*(1/2^-)$, such as $\chi_{c0} \to \bar{\Sigma}\Sigma\pi$, $\chi_{c0} \to \bar{\Lambda}\Sigma\pi$, $\gamma n \to K\Sigma(1/2^-)$.
- **Charmed hadrons at STCF**



Thank you very much!