Theoretical study of the low-lying excited baryons

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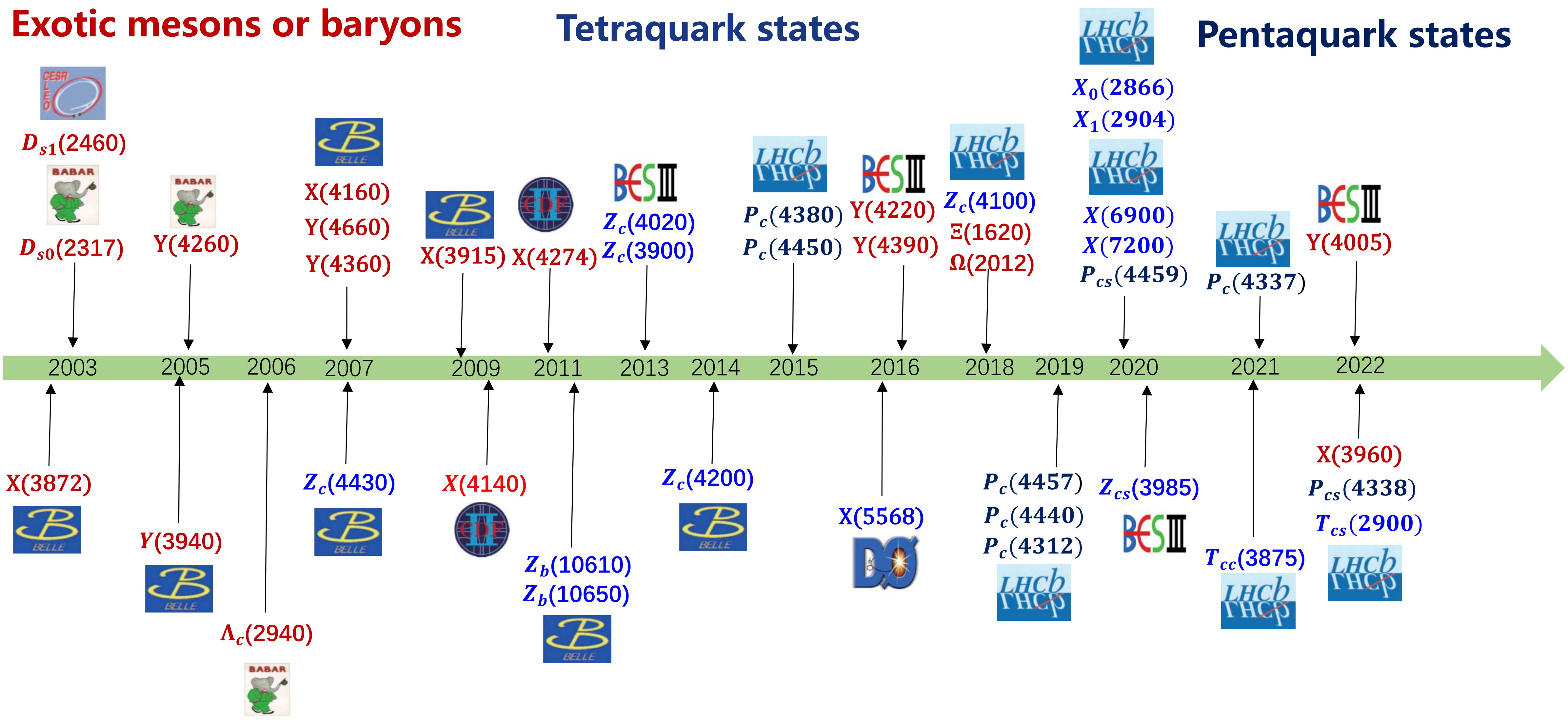
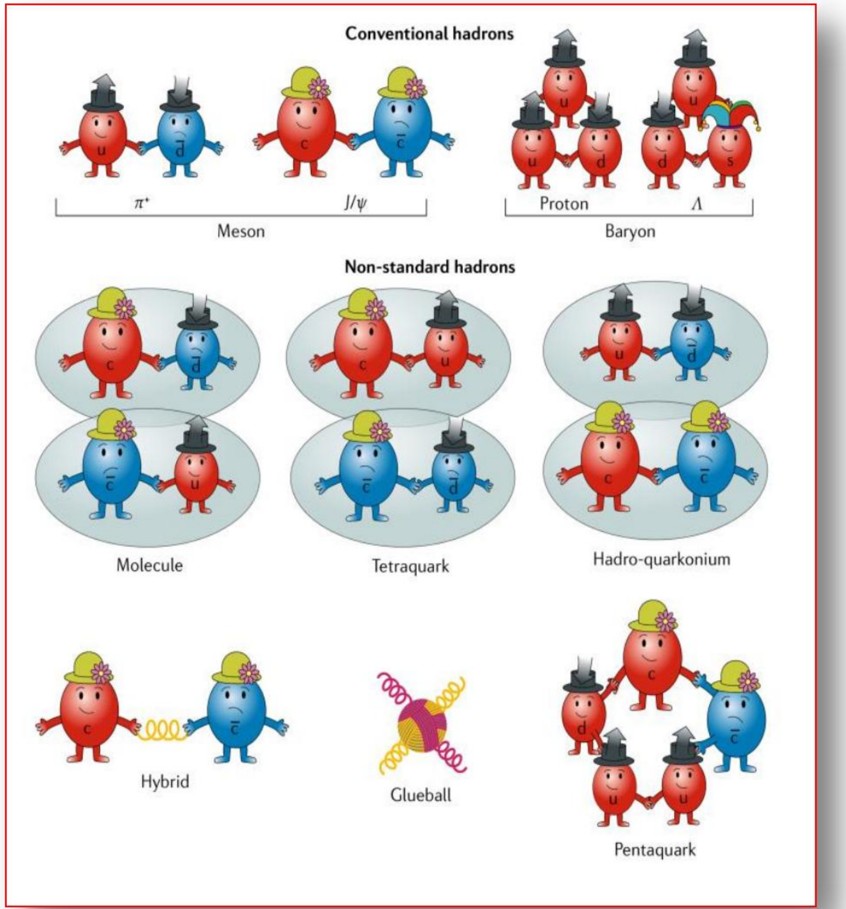
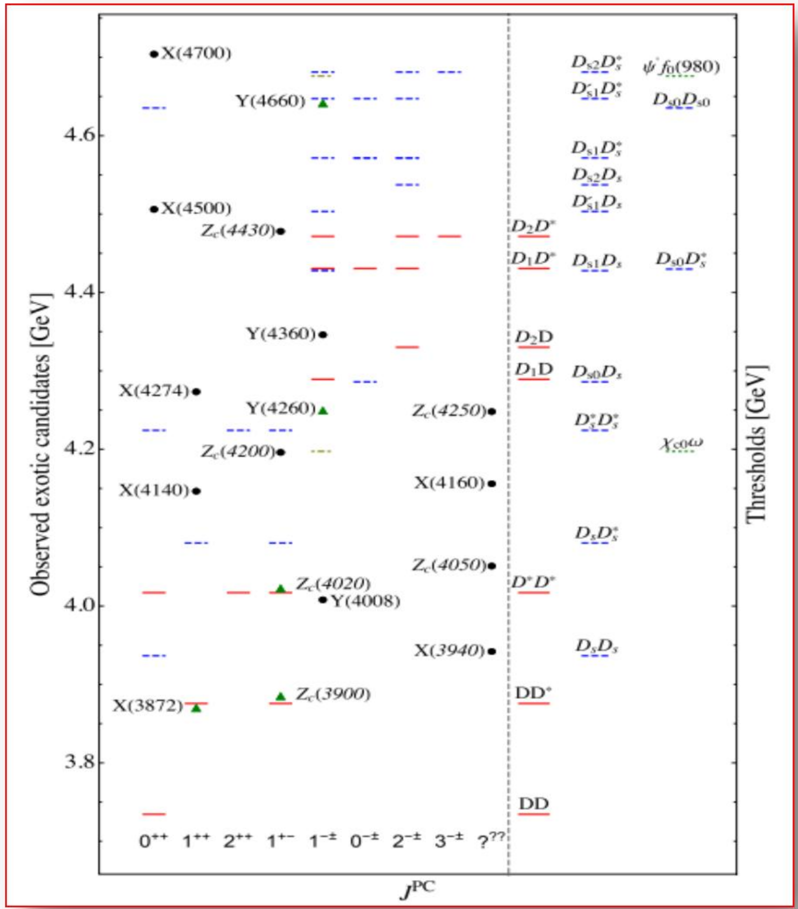
Exotic states

耿立升老师报告



Hadrons



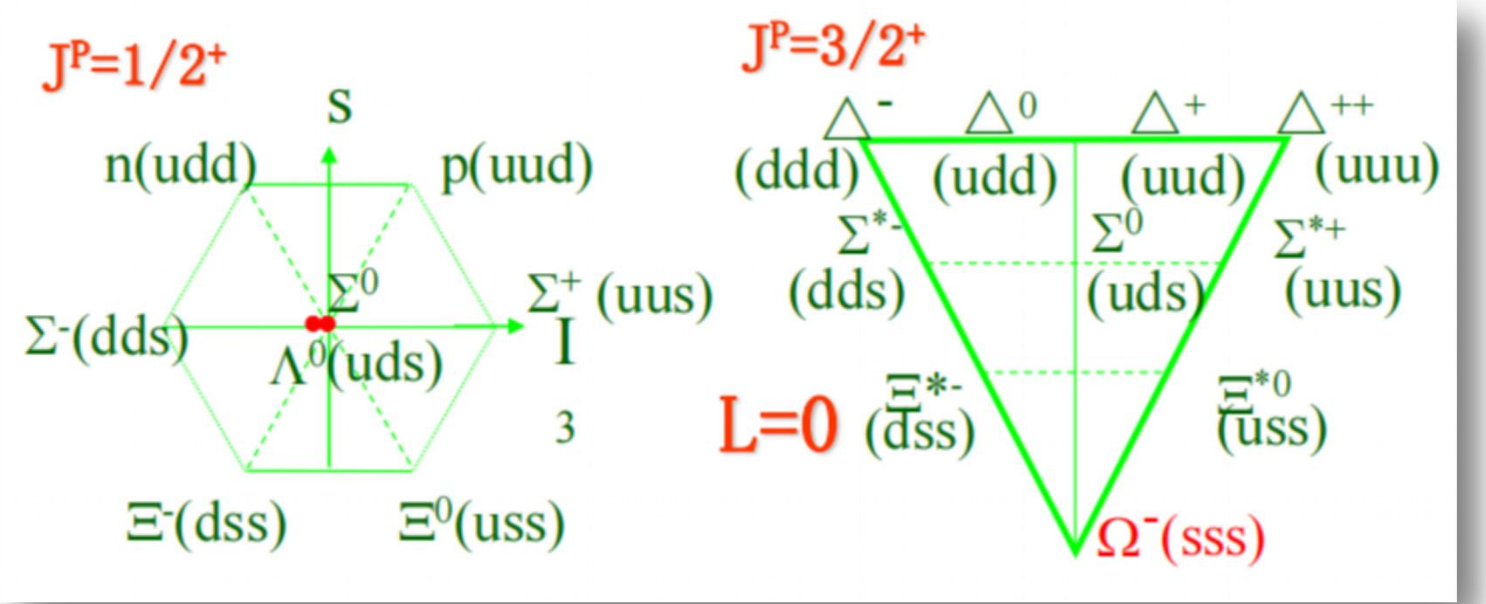


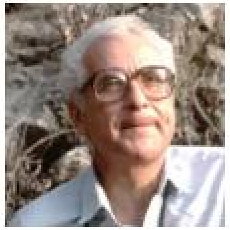
C.Z.Yuan, Nature Rev. Phys. 1 (2019) 480

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 $g_{\Lambda^*\Lambda\eta}$

邹冰松老师报告

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

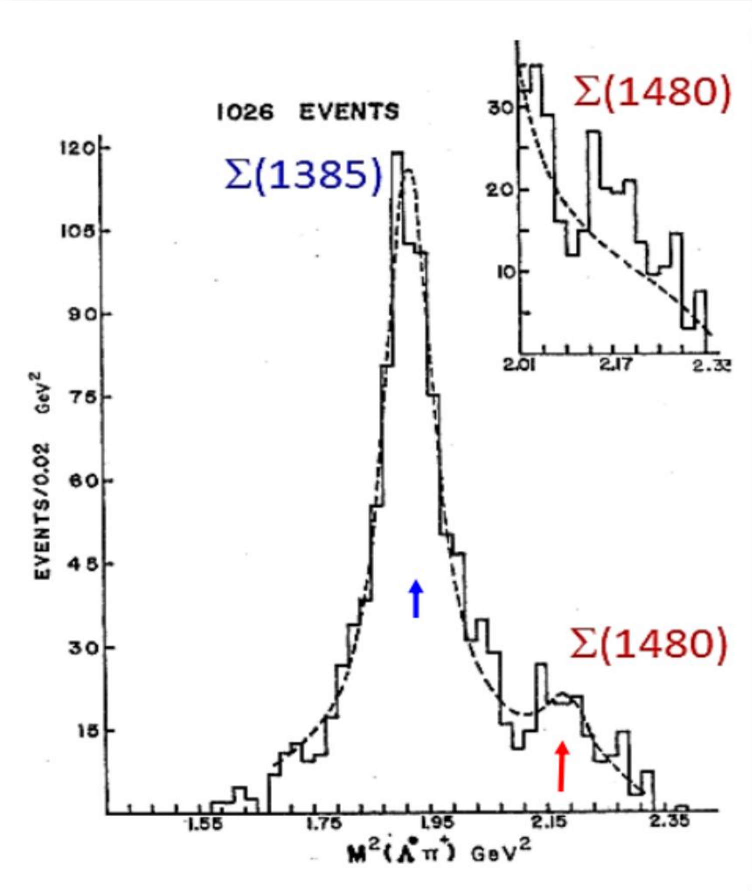
$\Sigma(1480)$ Bumps $\quad I(J^P) = 1(?^?)$ Status: ∗

OMITTED FROM SUMMARY TABLE

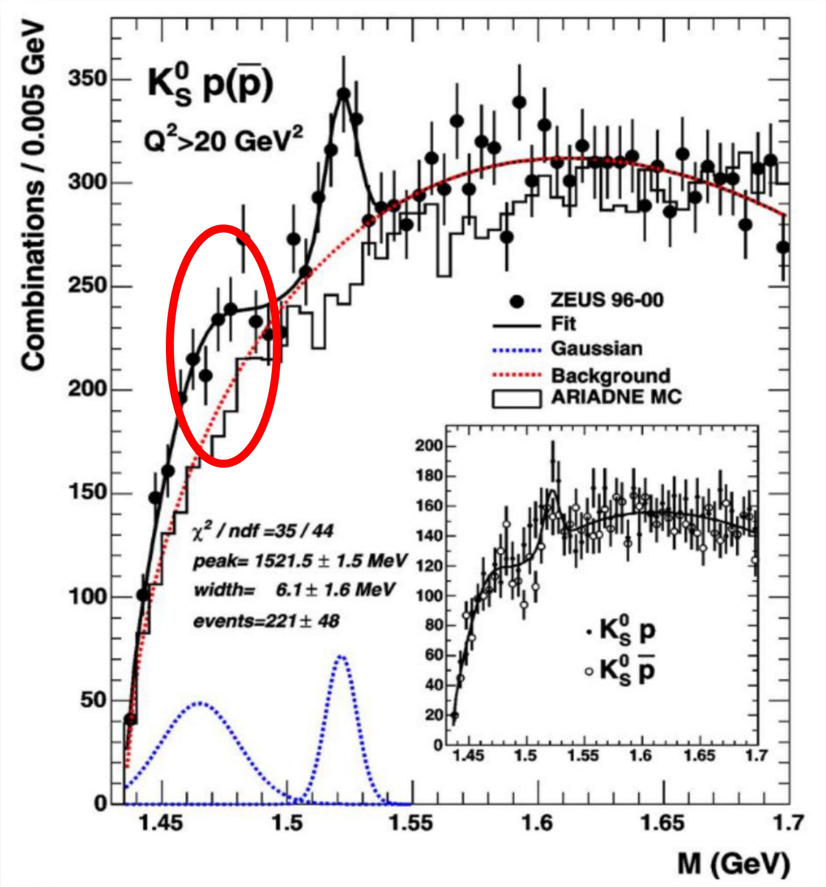
These are peaks seen in $\Lambda\pi$ and $\Sigma\pi$ spectra in the reaction $\pi^+ p \to (Y\pi)K^+$ at 1.7 GeV/c. Also, the Y polarization oscillates in the same region.

Exp. signals of Σ(1480)

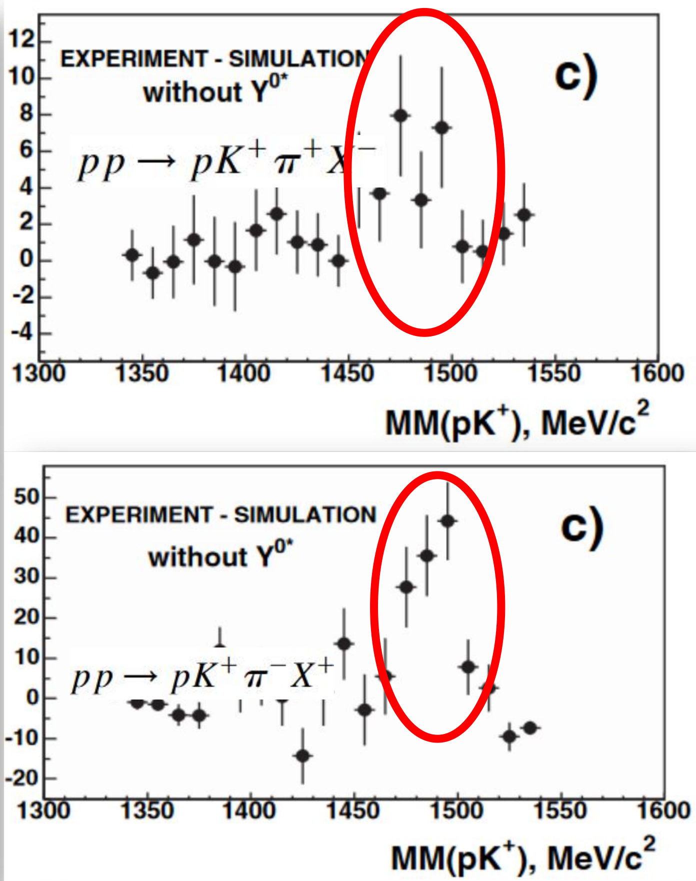
$\pi^+ p \to \pi^+ K^+ \Lambda$
Yu-Li Pan et al, PRD2, 449 (1970)



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

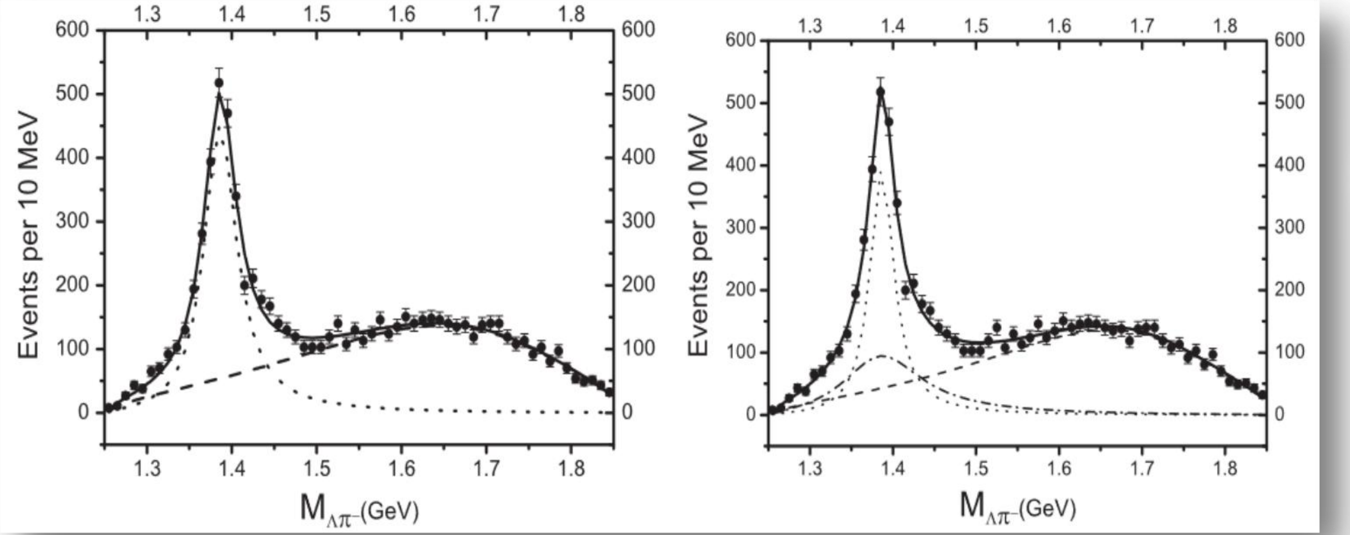


$pp \to pK^+ Y^{0*}$
COSY-Ju;ich PRL 96, 012002 (2006)



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

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



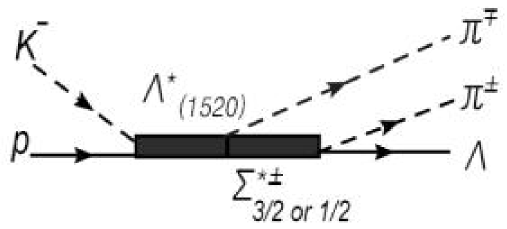
$$\frac{dN}{dm_{\Lambda\pi^-}} \propto p_1 \times p_2 \times \sum_{i=1}^{3} \frac{|a_i|}{(m^2_{\Lambda\pi^-} - m_i^2)^2 + m_i^2 \times \Gamma_i^2},$$

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

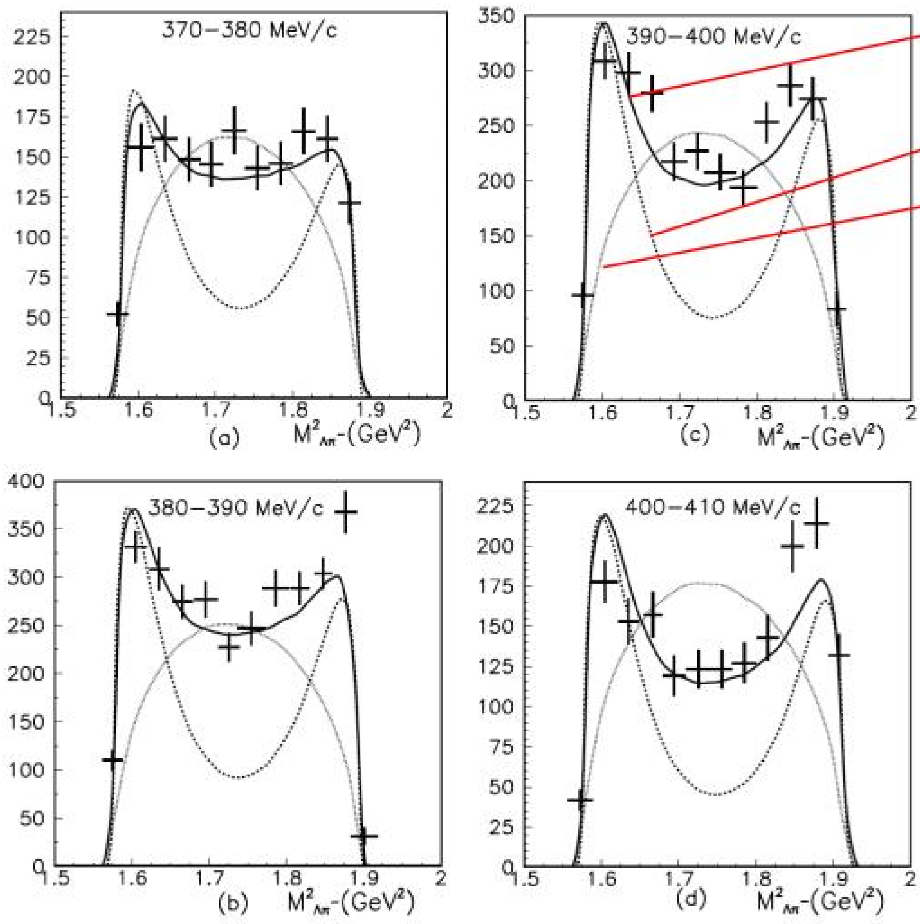
	$M_{\Sigma^*(3/2)}$	$\Gamma_{\Sigma^*(3/2)}$	$M_{\Sigma^*(1/2)}$	$\Gamma_{\Sigma^*(1/2)}$	χ^2/ndf (Fig. 1)	χ^2/ndf (Fig. 2)
Fit1	1385.3 ± 0.7	46.9 ± 2.5			68.5/54	10.1/9
Fit2	$1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	58.0/51	3.2/9

J.J.Wu's slide

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



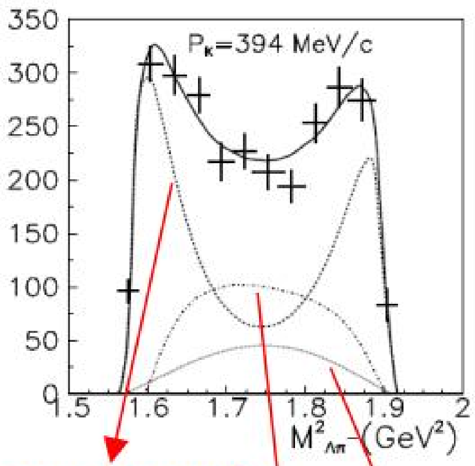
P_K=0.3-0.6 GeV **J. J. Wu, S. Dulat and B. S. Zou PRC 81,045210**



59% $\Sigma^*(3/2^+)$+ 41% $\Sigma^*(1/2^-)$

100% $\Sigma^*(3/2^+)$

Phase space

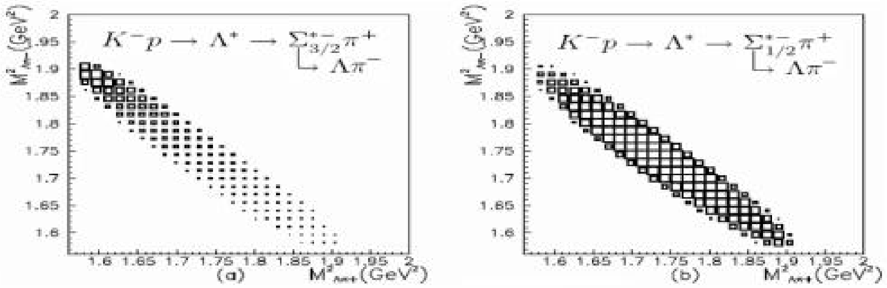


59% $\Sigma^*(3/2^+)$

Interference

12. 5% $\Sigma^*(1/2^-)$

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

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 $J^P=1/2^-$

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

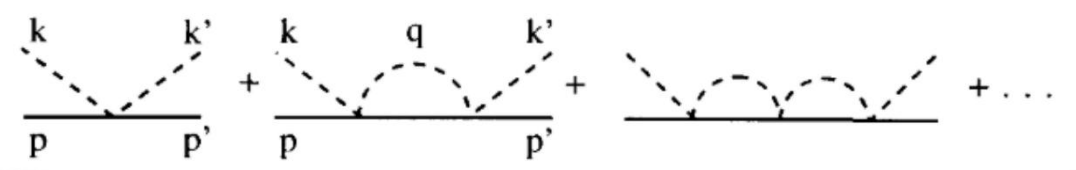
I=0	$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$K\Xi$
$\bar{K}N$	3	$-\sqrt{\frac{3}{2}}$	$\frac{3}{\sqrt{2}}$	0
$\pi\Sigma$		4	0	$\sqrt{\frac{3}{2}}$
$\eta\Lambda$			0	$-\frac{3}{\sqrt{2}}$
$K\Xi$				3

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 $J^P=1/2^-$

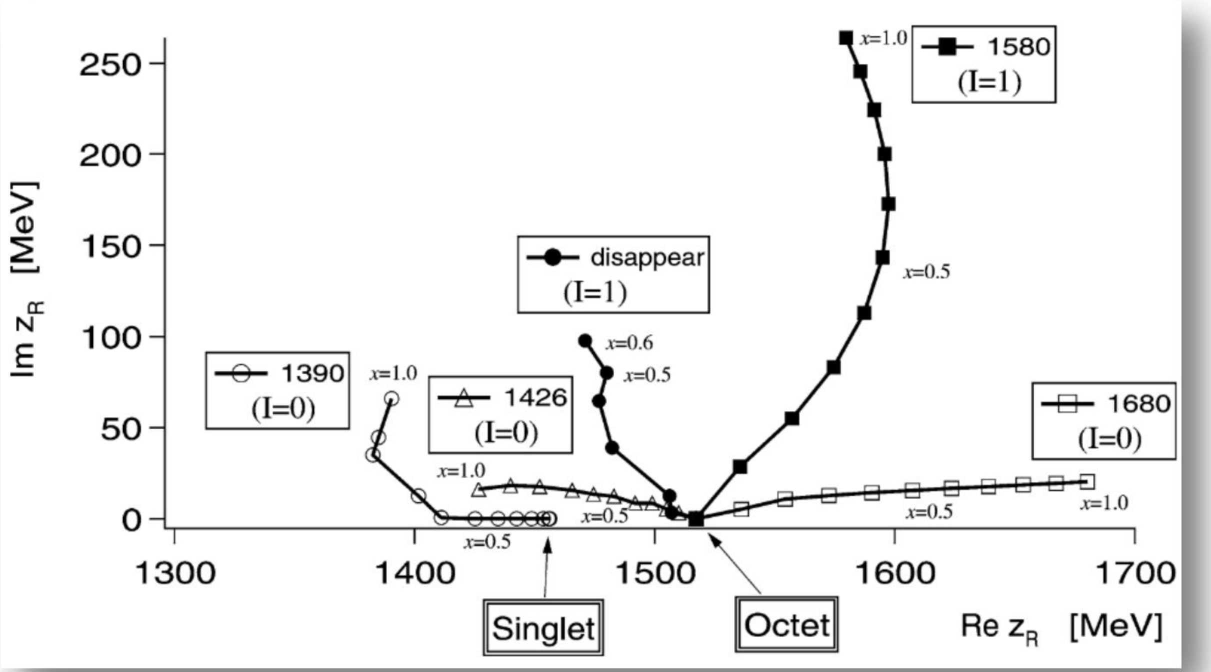
□Bethe-Salpter Equation

Jido Oller Oset Ramos Meissner NPA725 (2003) 181

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

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

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

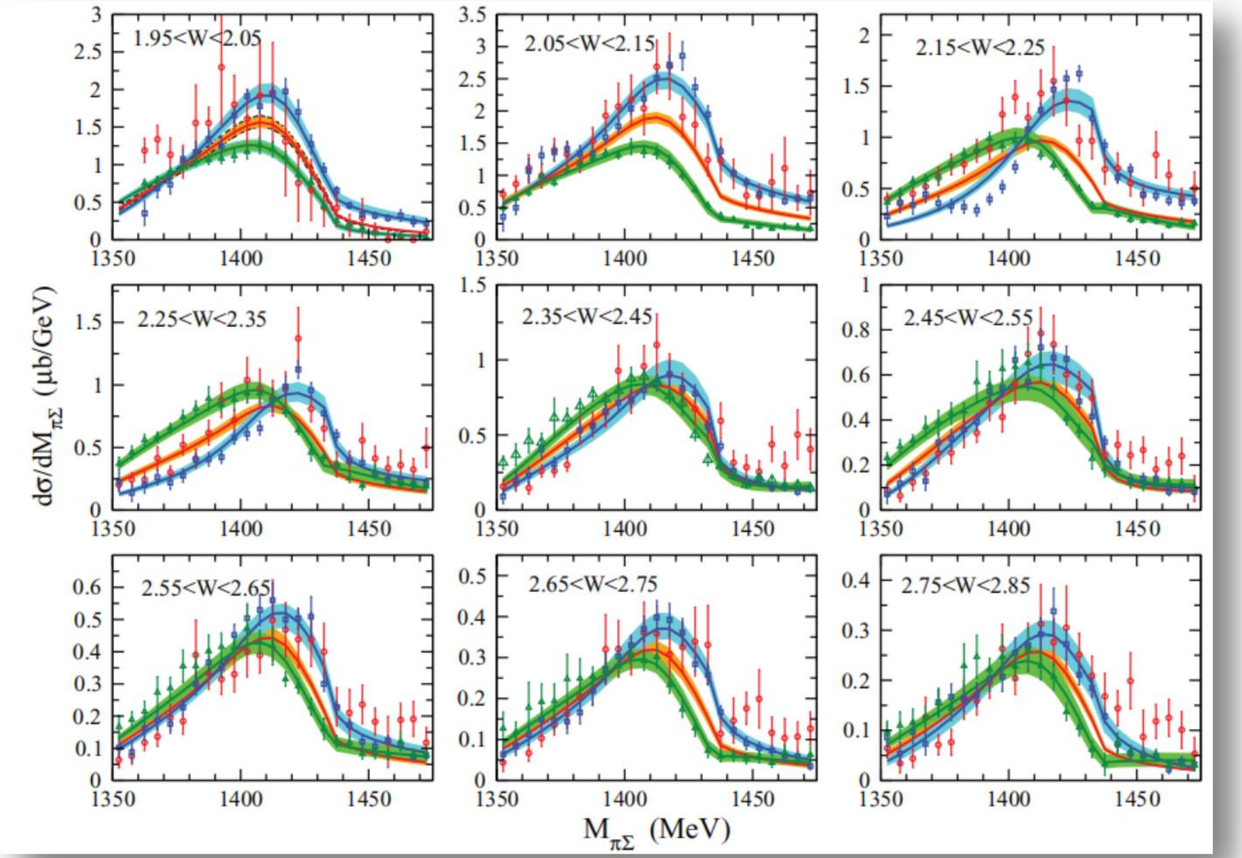


pole positions and couplings

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

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

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



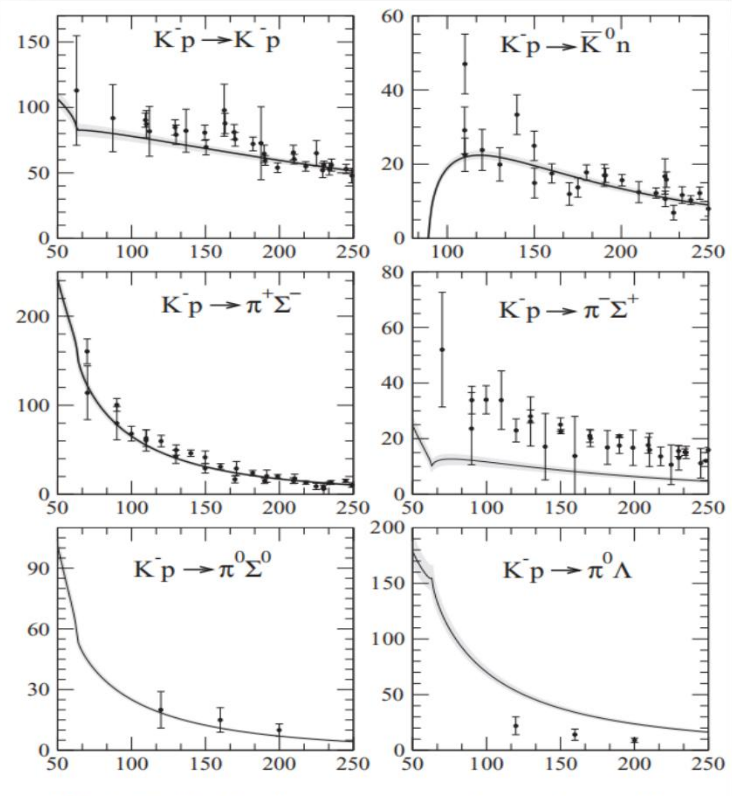
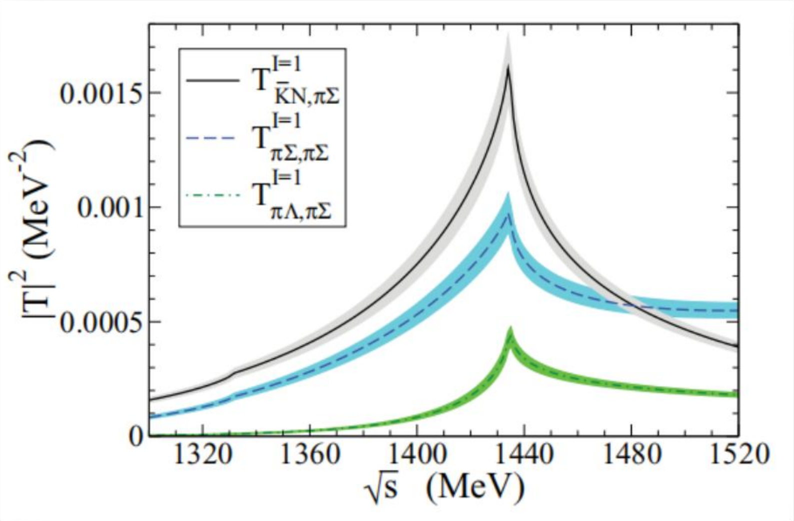


FIG. 6. Predicted K^-p cross sections (in millibarns). Experimental data are from Ref. [46].

Σ(1430)

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



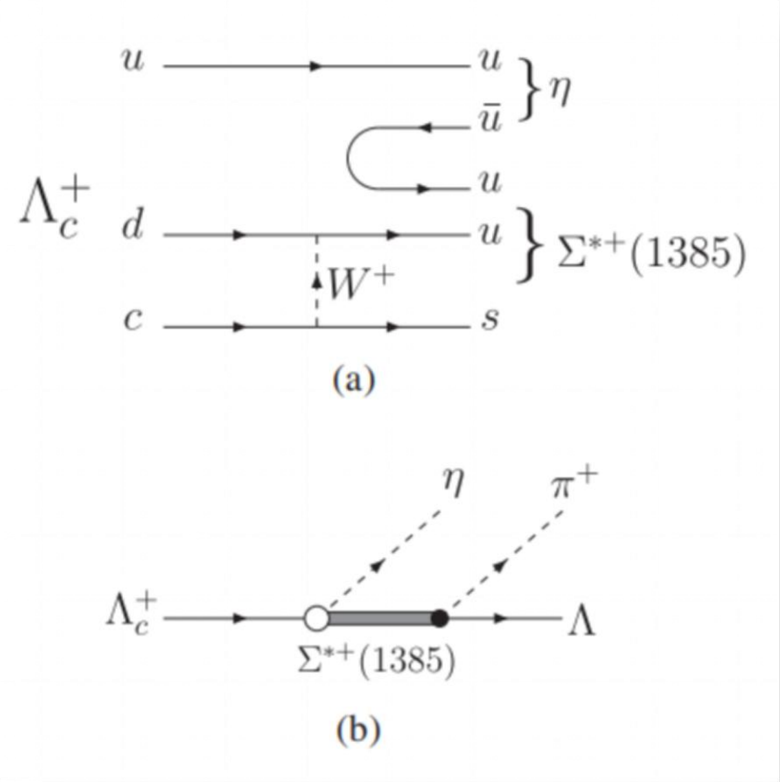
$$V_{ij} = -C_{ij}\frac{1}{4f^2}(k^0 + k'^0) \qquad C^1_{ij} = \begin{pmatrix} \alpha^1_{11} & -\alpha^1_{12} & -\sqrt{\frac{3}{2}}\alpha^1_{13} \\ -\alpha^1_{12} & 2\alpha^1_{22} & 0 \\ -\sqrt{\frac{3}{2}}\alpha^1_{13} & 0 & 0 \end{pmatrix}$$

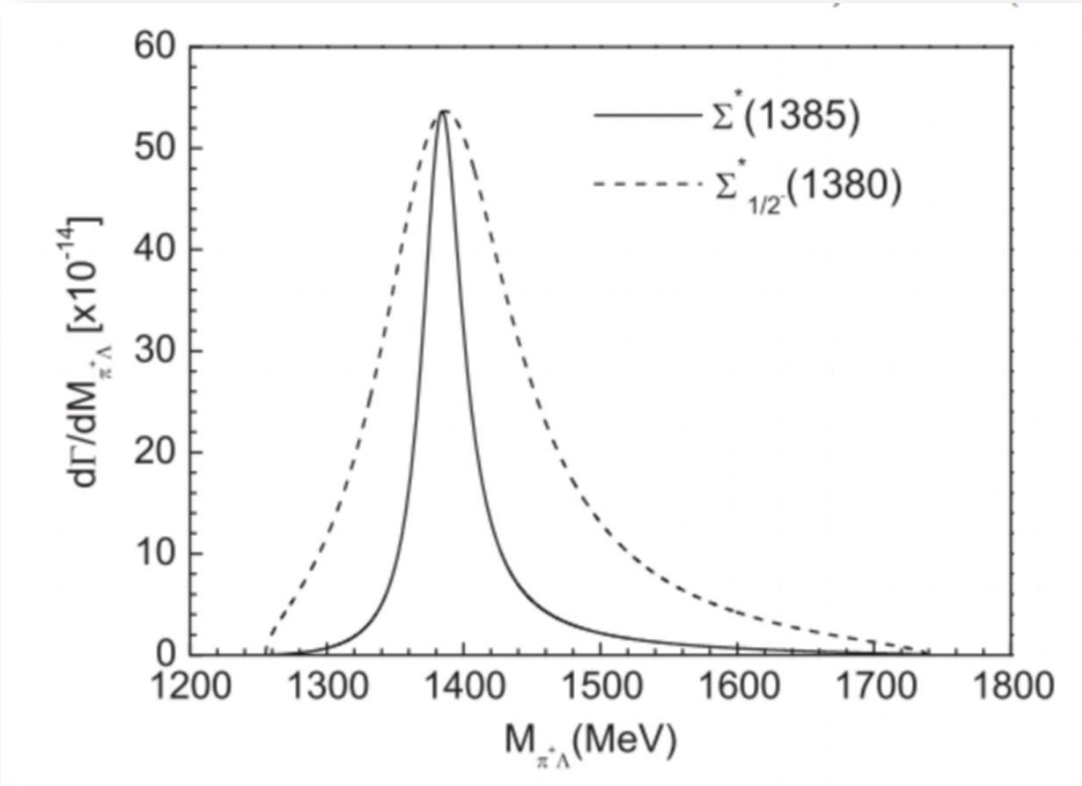
α^0_{11}	α^0_{12}	α^0_{22}	α^1_{11}	α^1_{12}	α^1_{13}	α^1_{22}
1.037	1.466	1.668	0.85	0.93	1.056	0.77

- **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]**

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

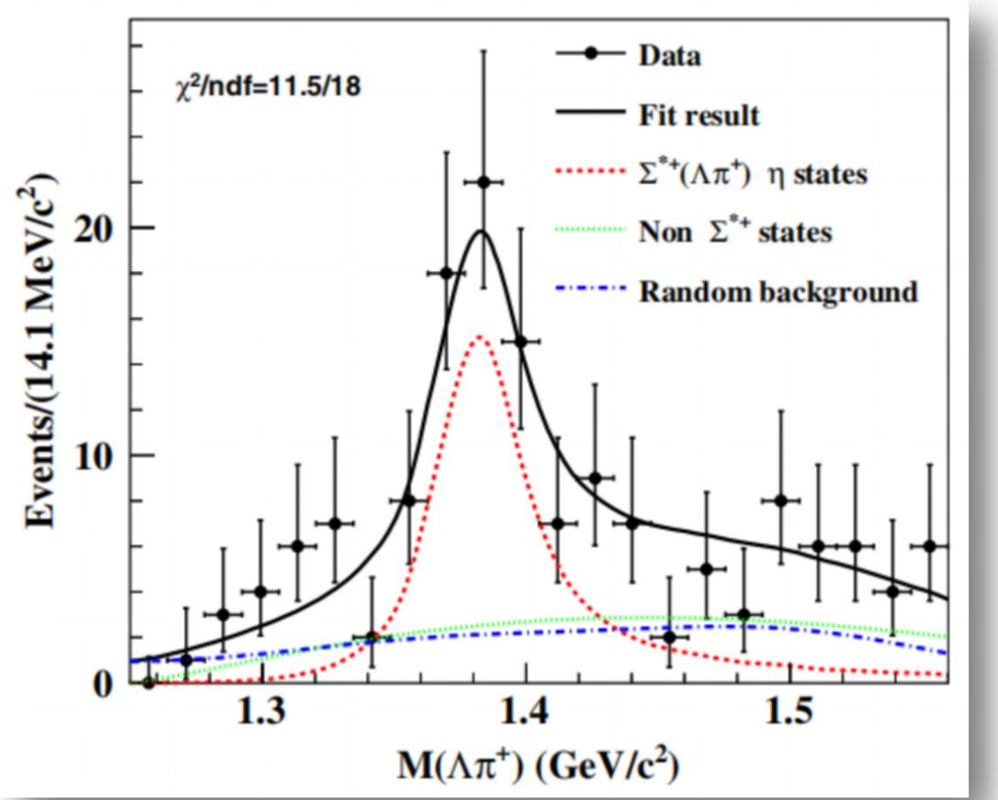
- J.J.Xie, L.S.Geng, EPJC76(2016) 496, PRD95(2017) 074024

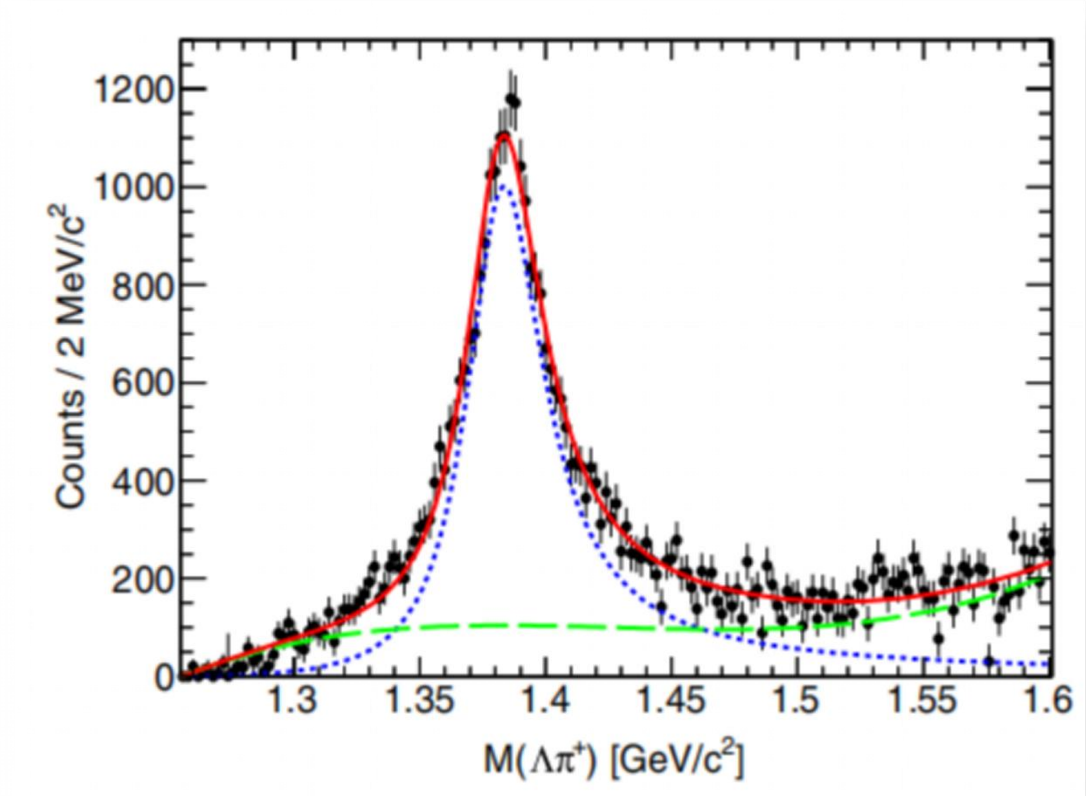




Belle and BESIII measurements

□ $\Lambda_c \to \Lambda\eta\pi$

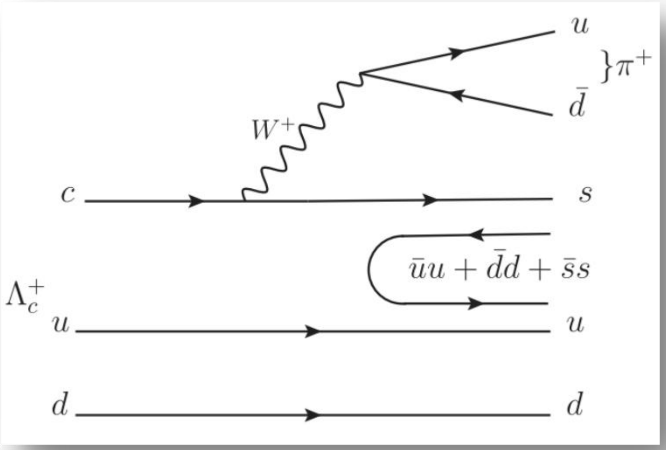


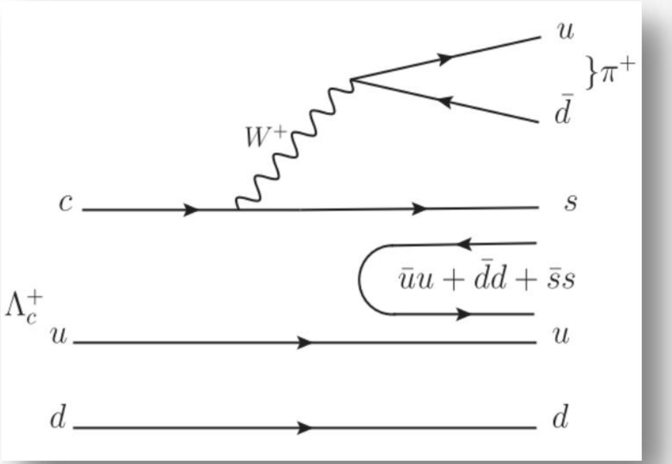


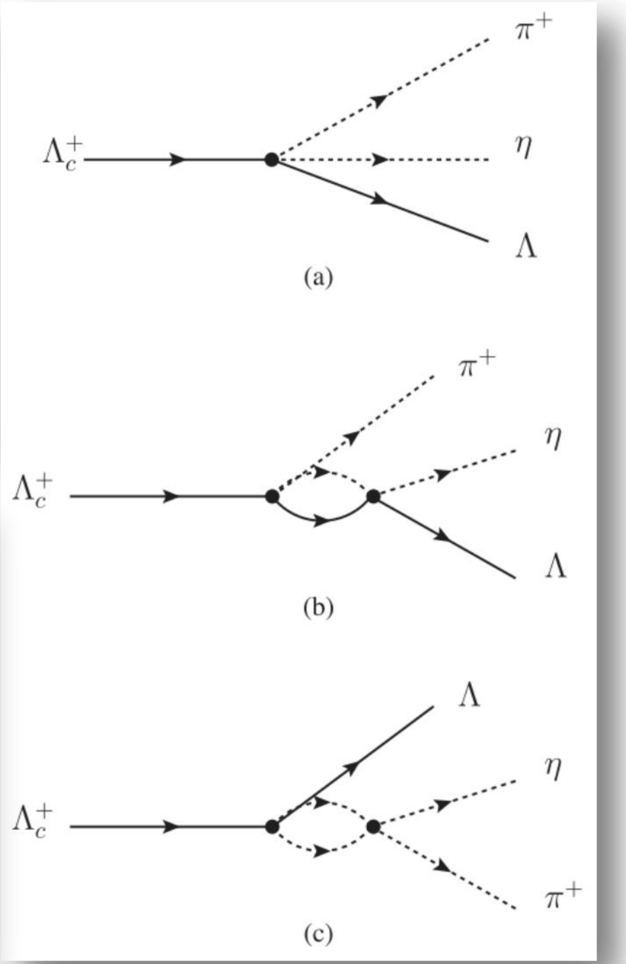
BESIII: PRD99, 032010 (2019)

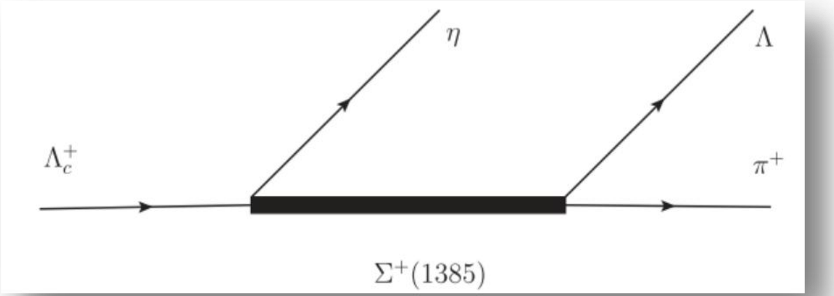
Belle: PRD103(2021)052005

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









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

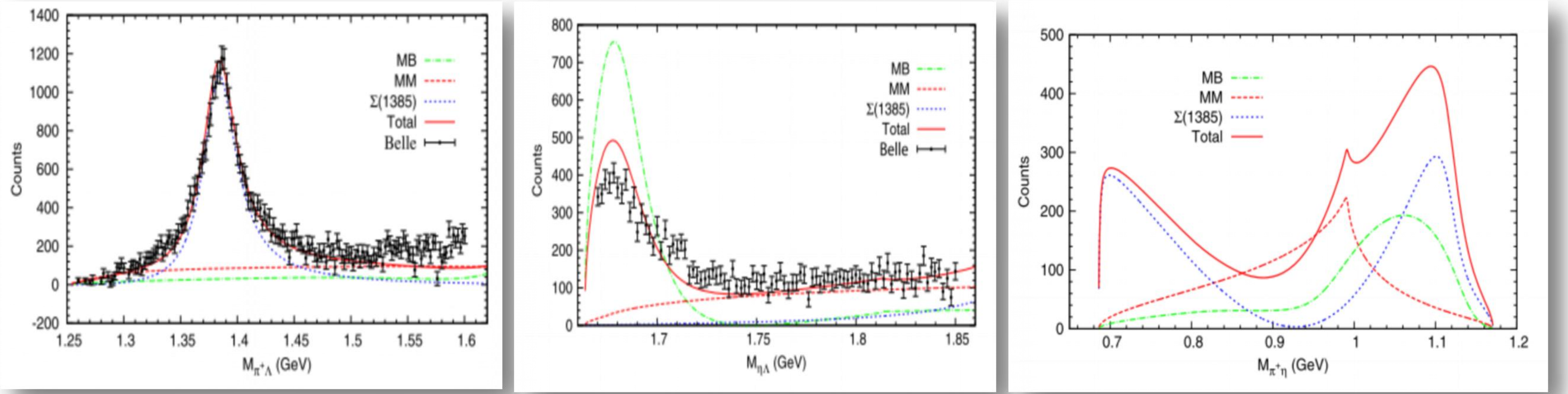
$$\begin{aligned} T^{\mathrm{MB}}(M_{\eta\Lambda}) = V_P \Big\{ & -\frac{\sqrt{2}}{3} + G_{K^-p}(M_{\eta\Lambda}) t_{K^-p\to\eta\Lambda}(M_{\eta\Lambda}) \\ & + G_{\bar{K}^0 n}(M_{\eta\Lambda}) t_{\bar{K}^0 n\to\eta\Lambda}(M_{\eta\Lambda}) \\ & -\frac{\sqrt{2}}{3} G_{\eta\Lambda}(M_{\eta\Lambda}) t_{\eta\Lambda\to\eta\Lambda}(M_{\eta\Lambda})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

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

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

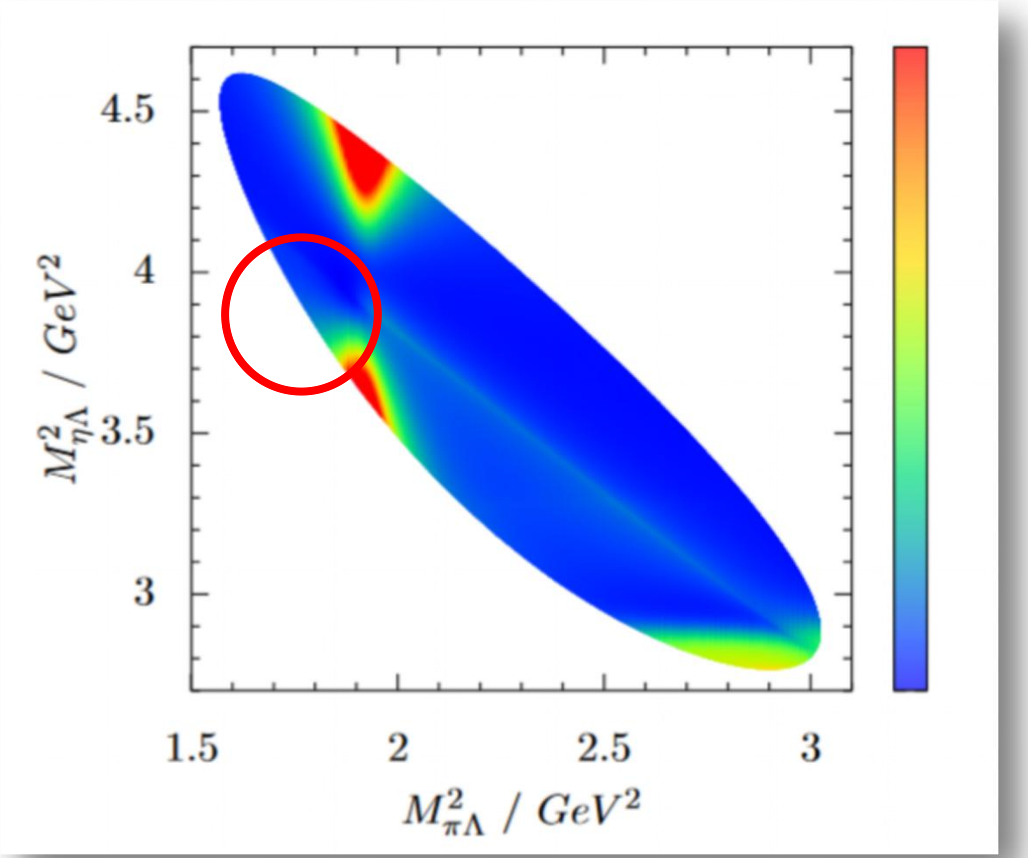
Analysis the Belle data

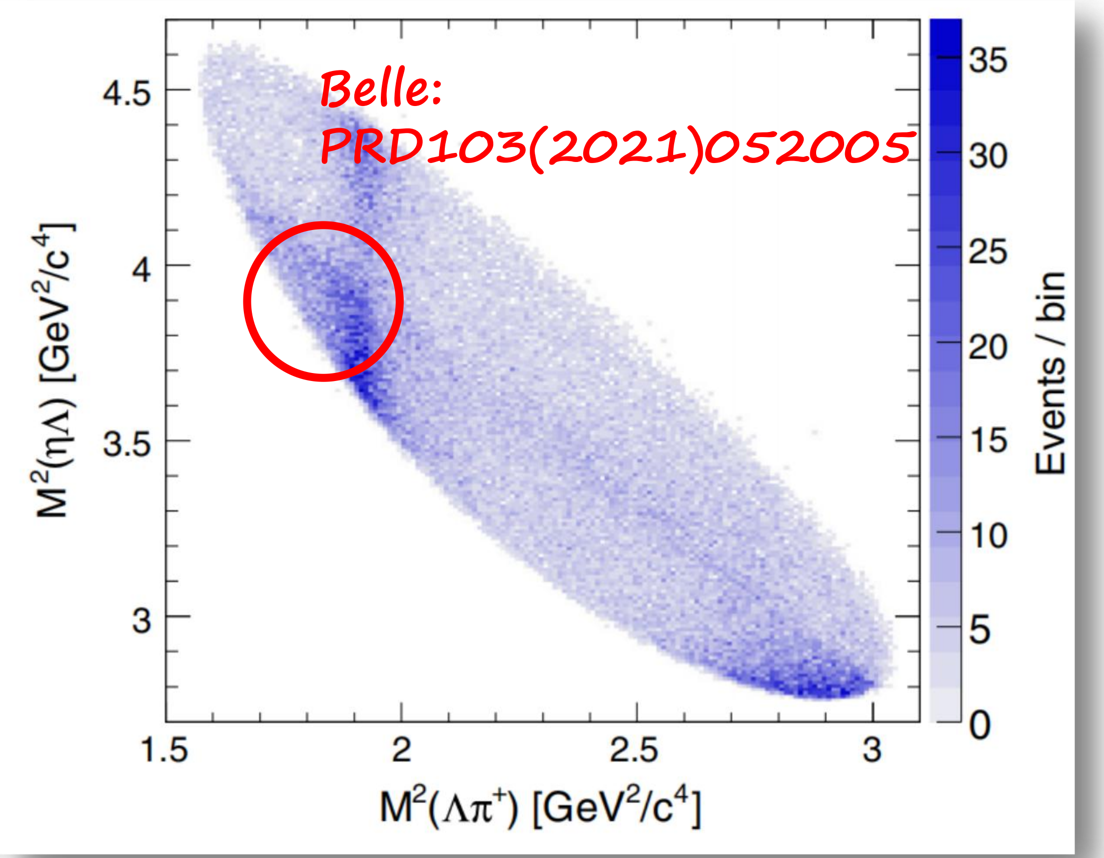
□ $\Lambda_c \to \Lambda\eta\pi$, GYW-EW-Xie-Geng-Wei, PRD 106, 056001 (2022)



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

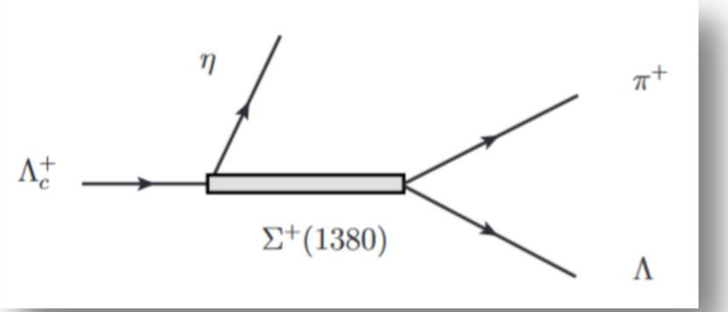
Dalitz plot of $\Lambda_c \to \eta\Lambda\pi$



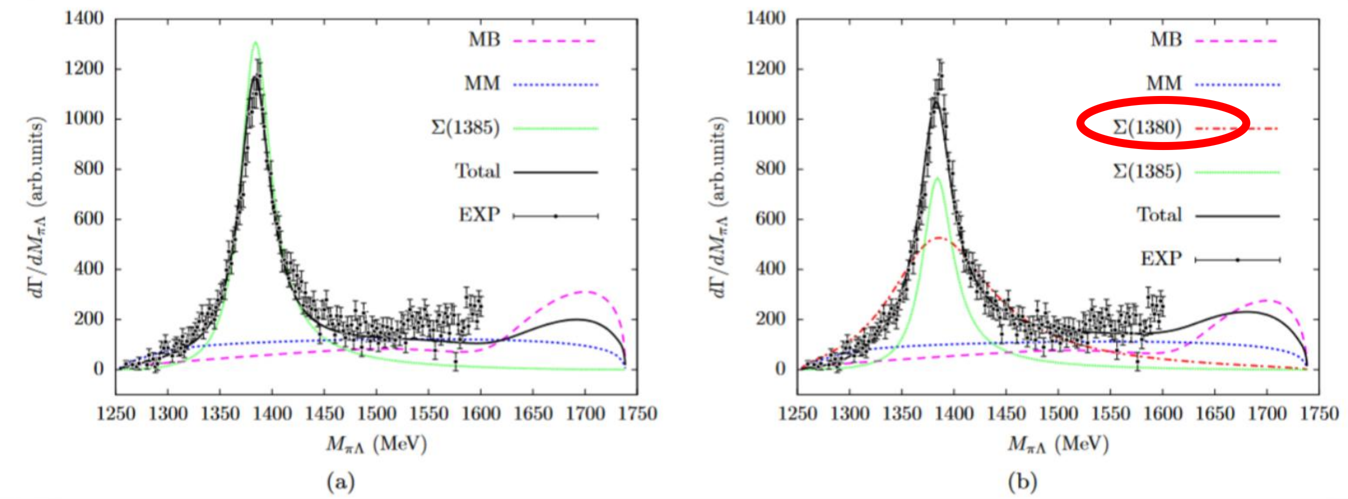


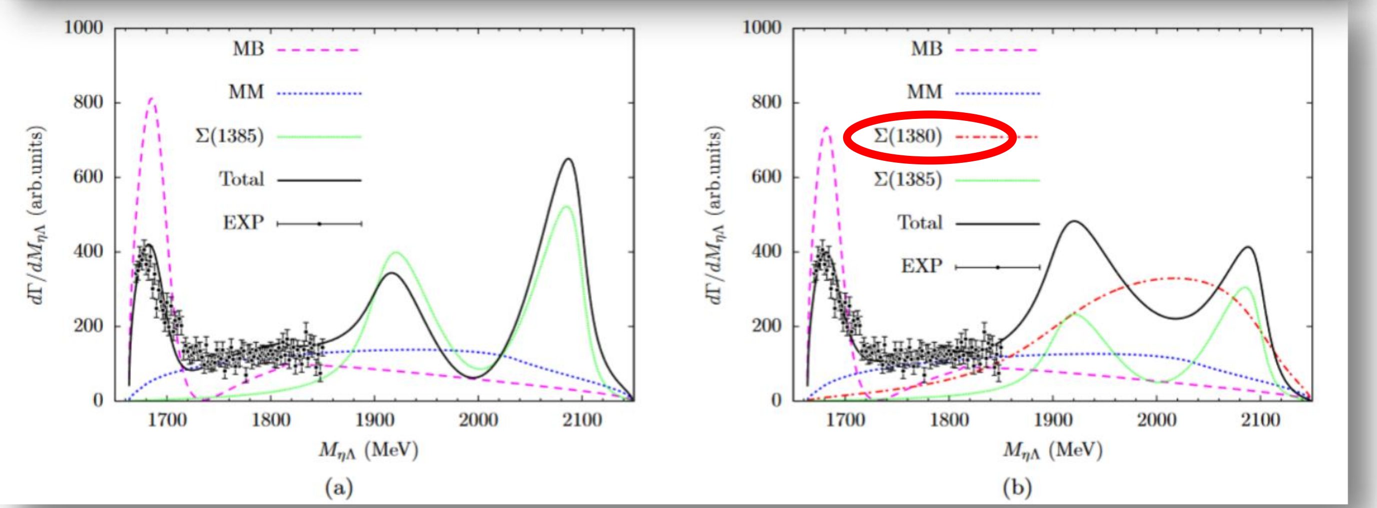
$\Sigma(1/2^-)$ in $\Lambda_c \to \eta\Lambda\pi$

□Intermediate of $\Sigma(1/2^-)$



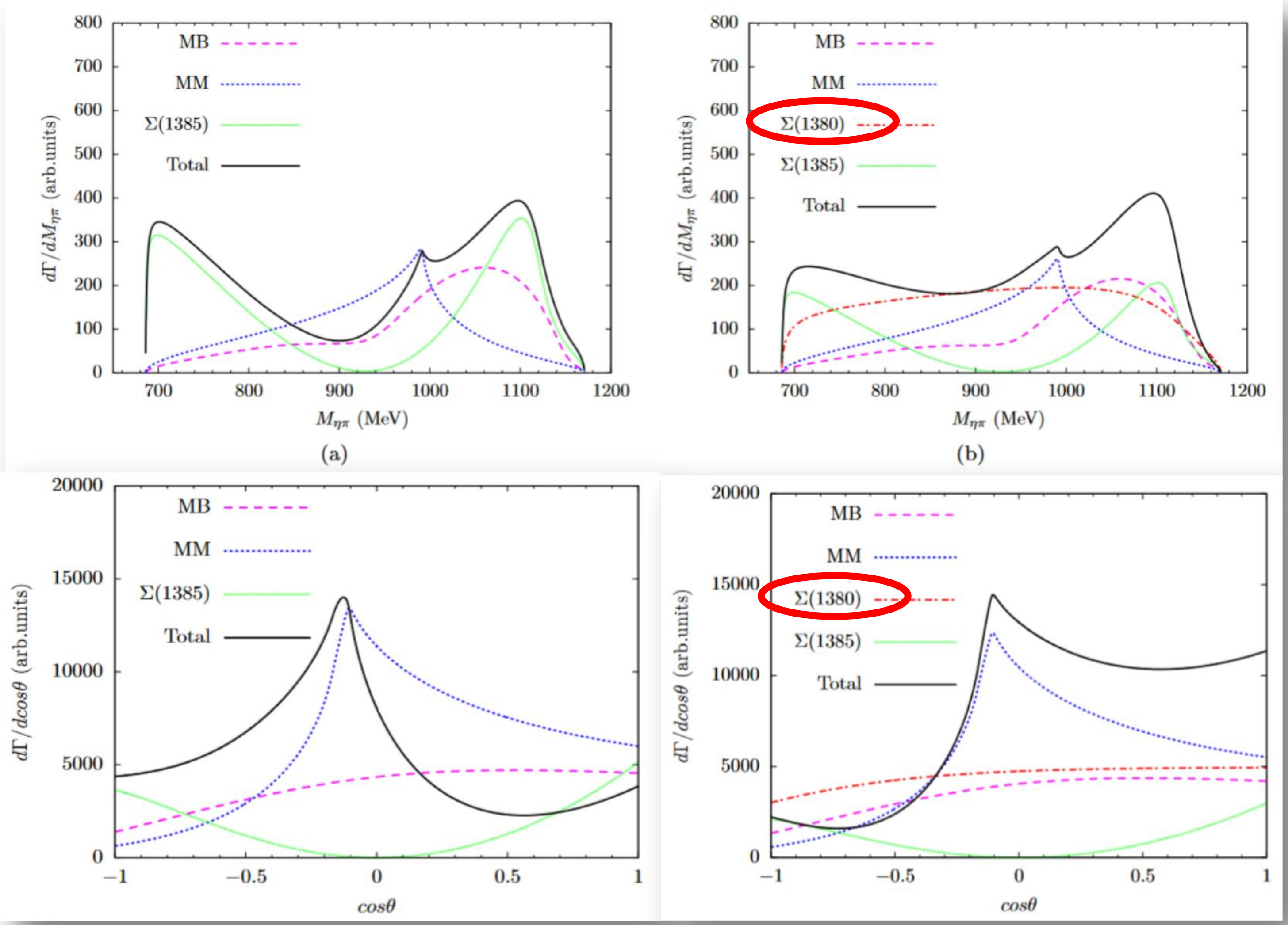
$$\mathcal{T}^{\Sigma(1/2^-)} = \frac{V^{\Sigma(1/2^-)} M_{\Sigma(1/2^-)} \Gamma_{\Sigma(1/2^-)}}{M^2_{\pi^+\Lambda} - M^2_{\Sigma(1/2^-)} + i M_{\Sigma(1/2^-)} \Gamma_{\Sigma(1/2^-)}},$$

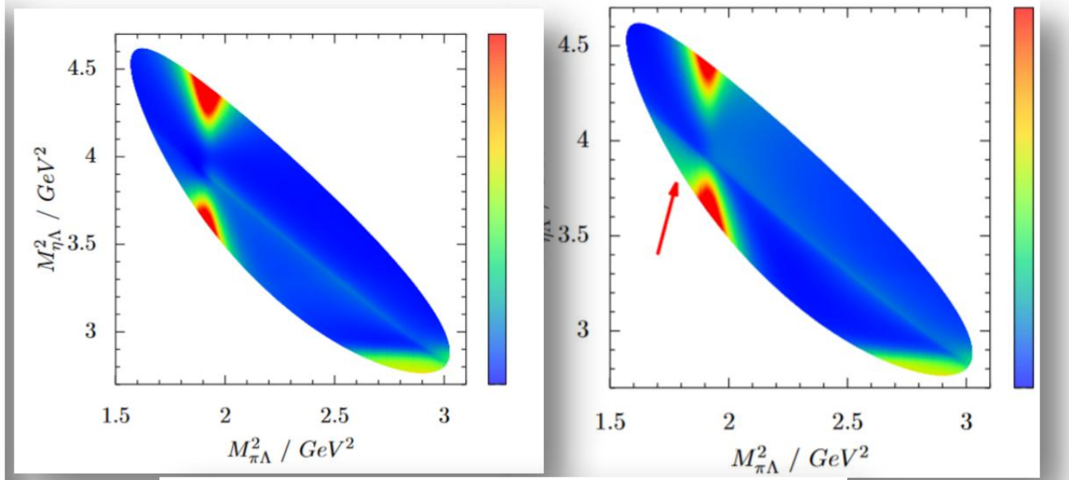


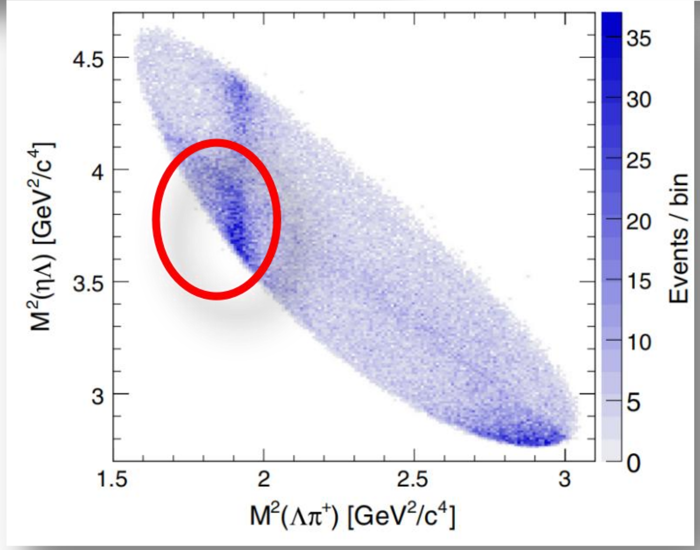


EW, JJWu, to be prepared

The results with/without Σ(1380)





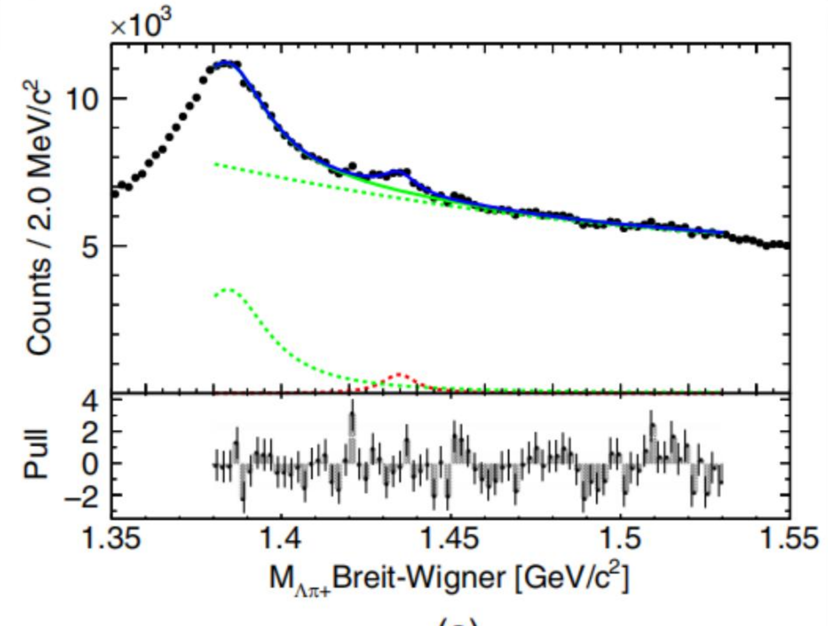


$M_{\pi\Lambda} \geq 1450$ MeV and $M_{\eta\Lambda} \geq 1760$ MeV.

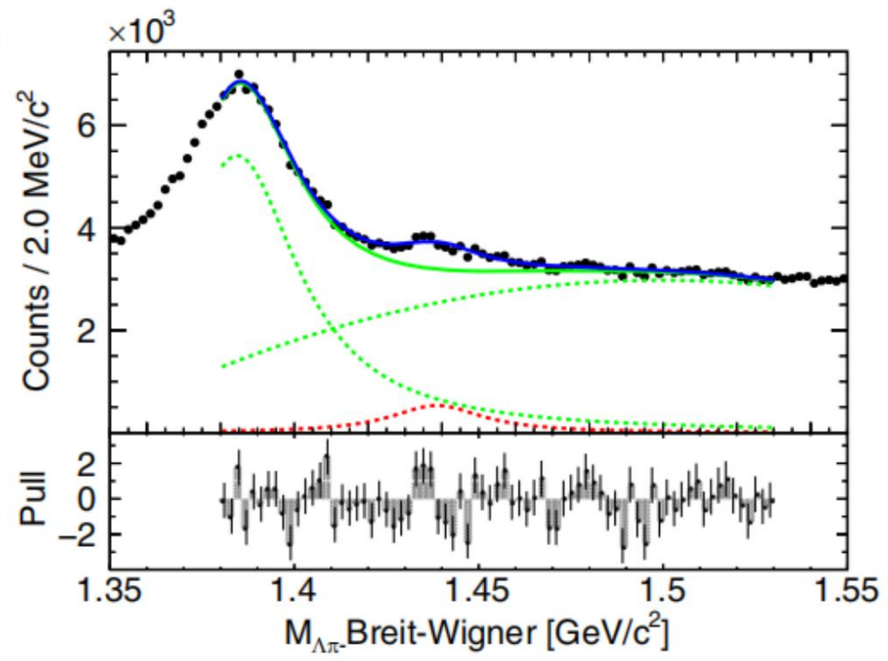
EW, JJWu, to be prepared

Belle measurements

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



(a)

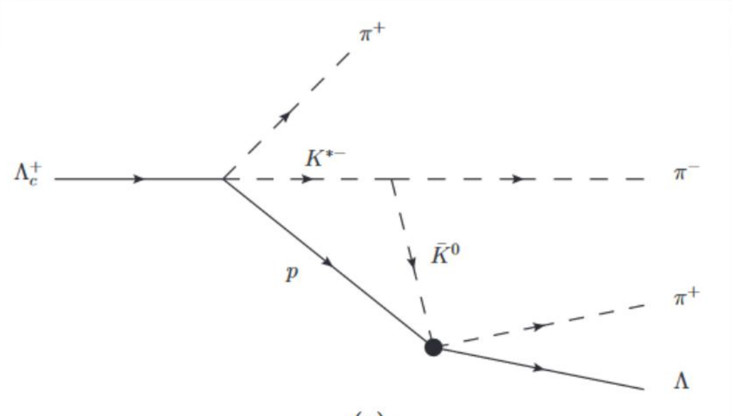


Mode	E_{BW} (MeV/c^2)	Γ (MeV/c^2)	χ^2/NDF
$\Lambda\pi^+$	1434.3 ± 0.6	11.5 ± 2.8	74.4/68
$\Lambda\pi^-$	1438.5 ± 0.9	33.0 ± 7.5	92.3/68

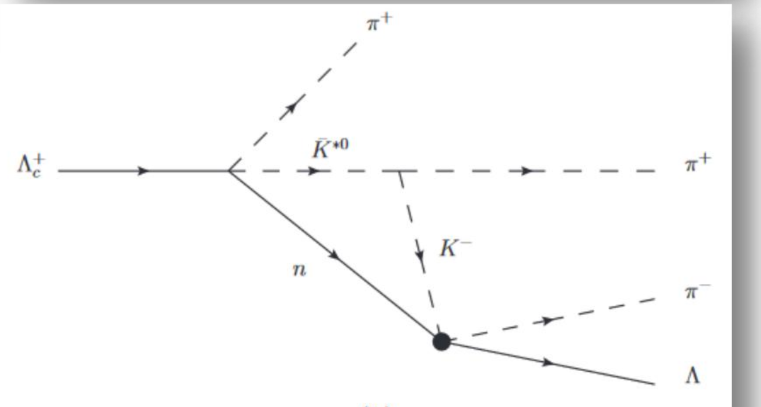
Evidence of $\Sigma(1430)$

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

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



(a)



(b)

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

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

$$\mathcal{B}(\Lambda_c^+ \to \pi^+ K^{*-} p) = (1.4 \pm 0.5) \times 10^{-2}$$

$$|A|^2 = (3.9 \pm 1.4) \times 10^{-16}\ \text{MeV}^{-2}$$

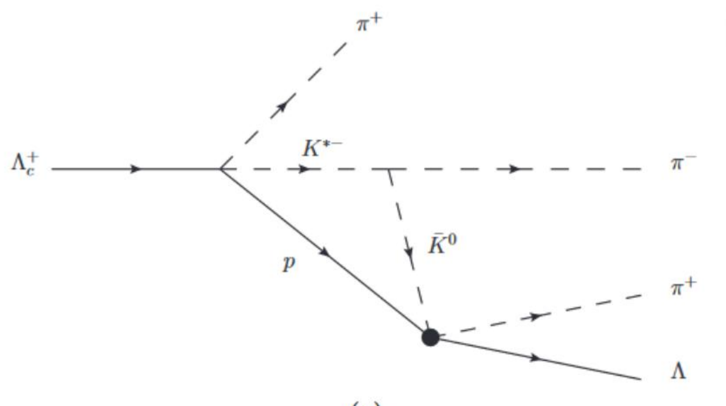
$$\mathcal{L}_{VPP} = -ig < V^\mu [P, \partial P] >$$

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

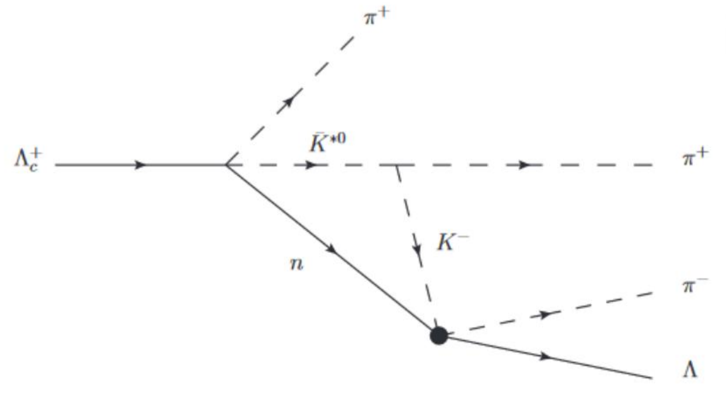
Evidence of $\Sigma(1430)$

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

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



(a)

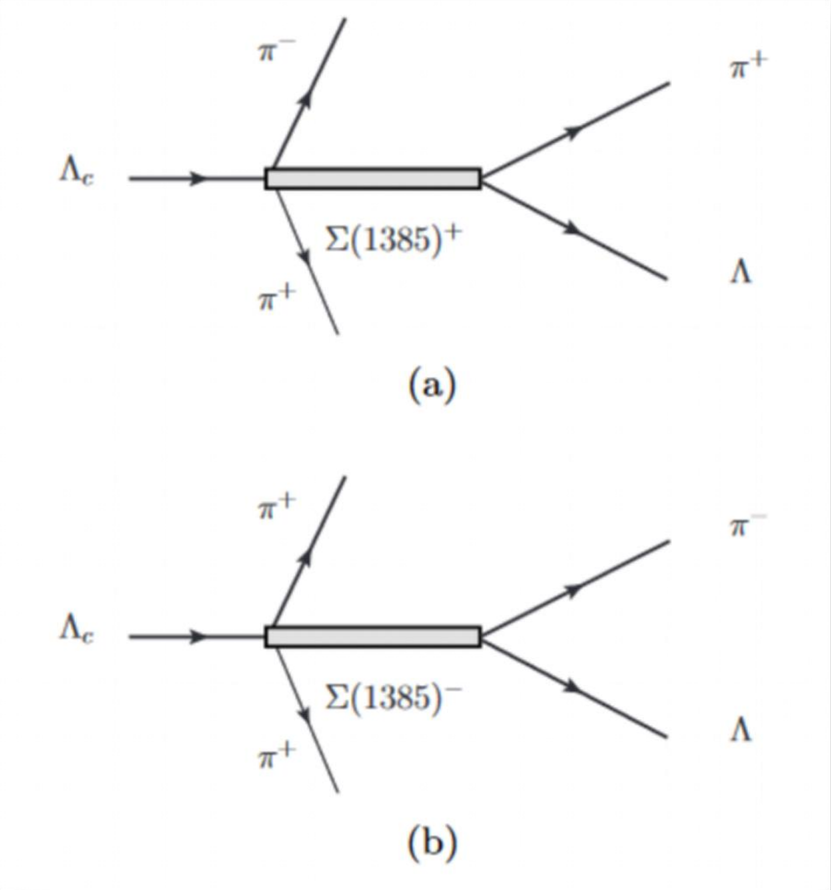


(b)

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

Evidence of $\Sigma(1430)$

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



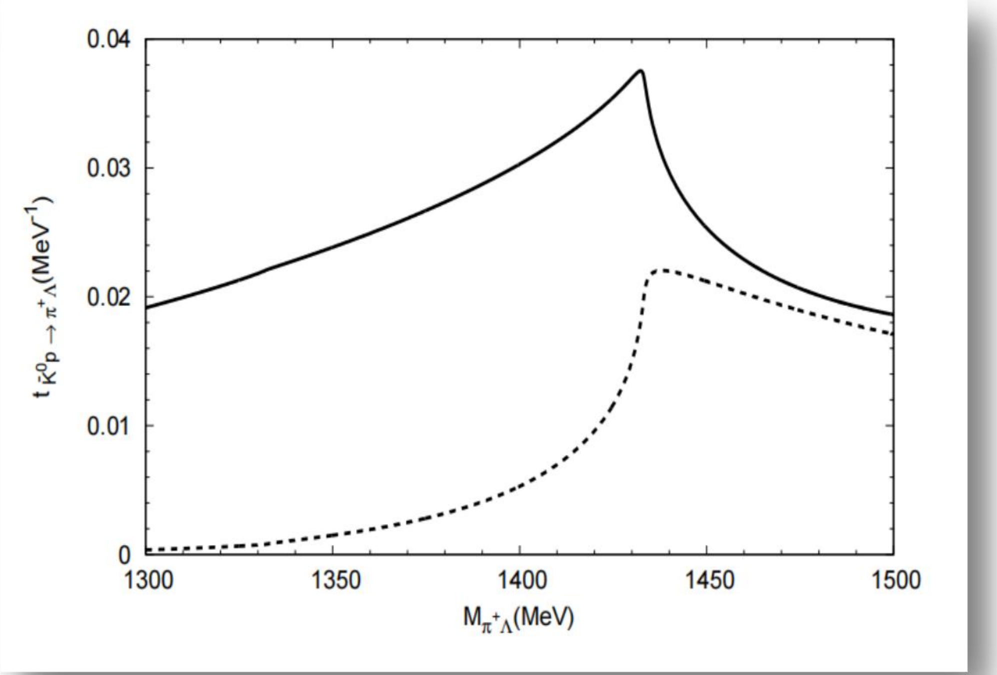
$$T^{\Sigma^{*+}(1385)} = \frac{V_p|p_{\pi^+}|}{M_{\pi^+\Lambda} - M_{\Sigma^{*+}} + i\frac{\Gamma_{\Sigma^{*+}}}{2}},$$

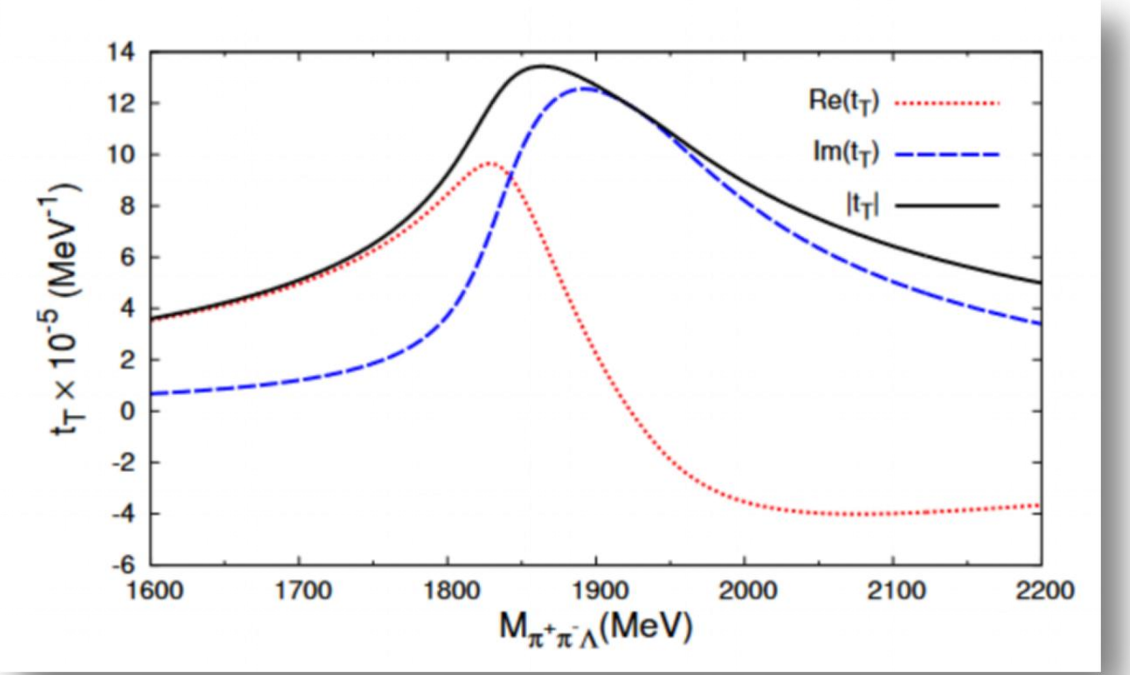
$$T^{\Sigma^{*-}(1385)} = \frac{V_p|p_{\pi^-}|}{M_{\pi^-\Lambda} - M_{\Sigma^{*-}} + i\frac{\Gamma_{\Sigma^{*-}}}{2}},$$

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

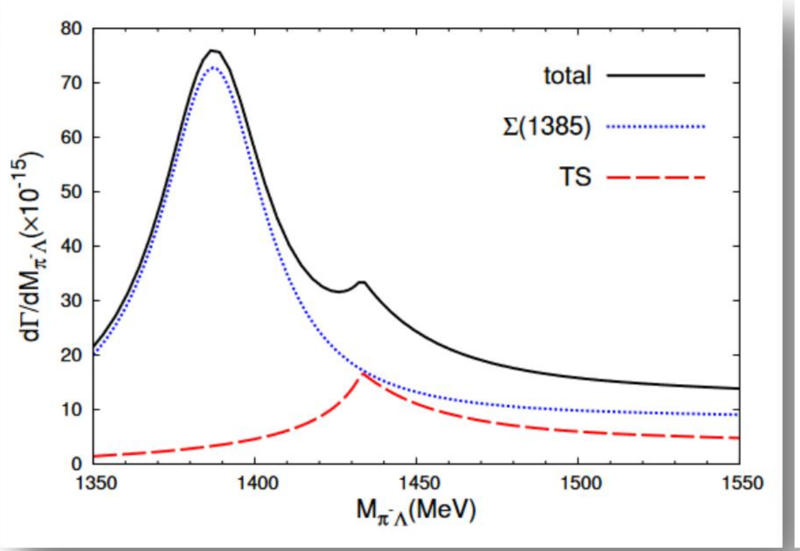
Evidence of $\Sigma(1430)$

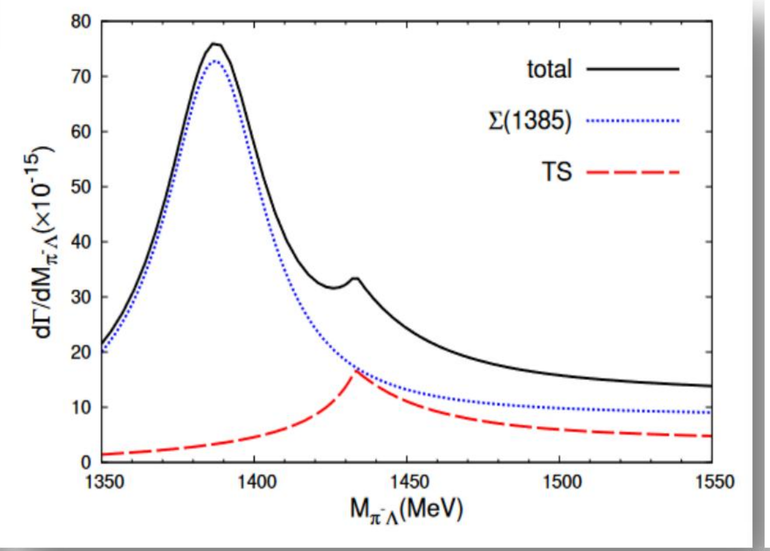
- $\Lambda_c \to \Lambda\pi^+\pi^+\pi^-$, Lyu-GYW-EW-Xie-Geng, to prepare

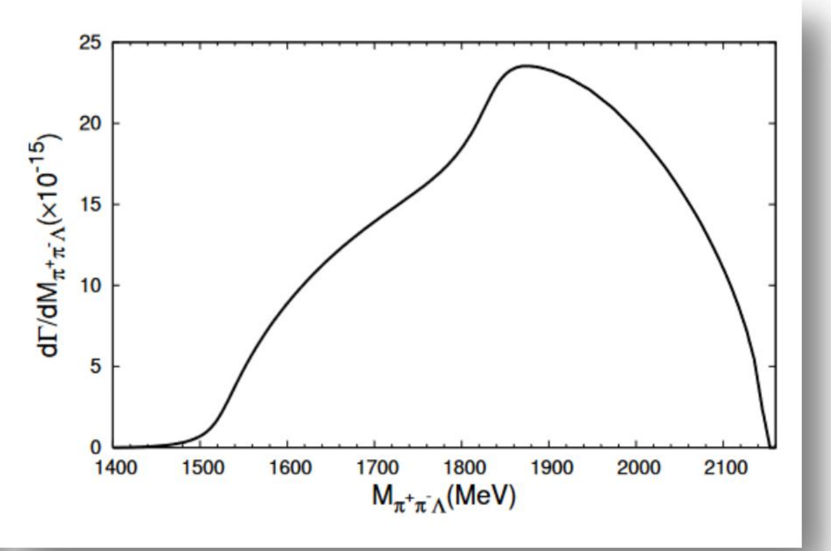




Results of $\Lambda_c \to \Lambda\pi^+\pi^+\pi^-$

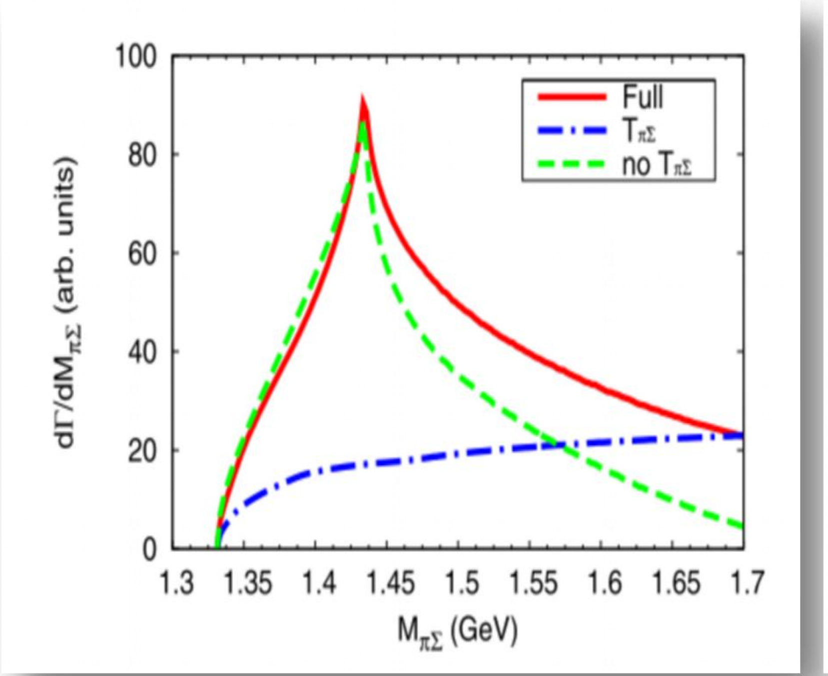






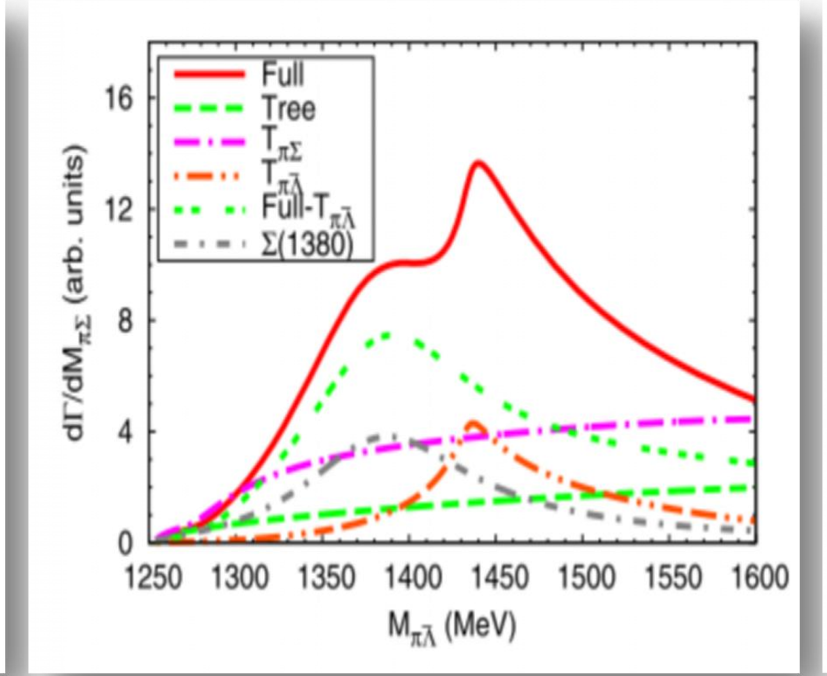
Cusp signal of $\Sigma(1/2^-)$ around $\bar{K}N$ threshold!

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



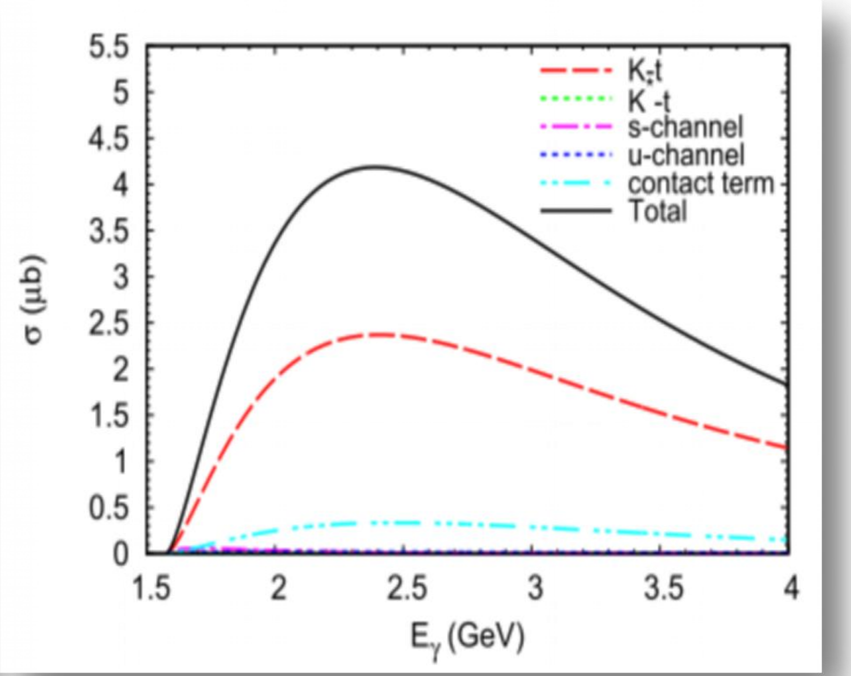
$\chi_{c0} \to \bar{\Sigma}\Sigma\pi$

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

Jun-Xu Lu,[1,2] Li-Sheng Geng,[3,2,4,5,*] Michael Doering,[6,7] and Maxim Mai[8,6]
[1]*School of Space and Environment, Beijing 102206, China*
[2]*School of Physics, Beihang University, Beijing 102206, China*

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 measurements of $\Lambda_c \to \eta\Lambda\pi$ show some hints of the $\Sigma(1/2^-)$, and the more precise measurements could be used to test the existence of $\Sigma(1/2^-)$.
- 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 $\chi_{c0} \to \bar{\Sigma}\Sigma\pi$, $\chi_{c0} \to \bar{\Lambda}\Sigma\pi$, $\gamma n \to K\Sigma(1/2^-)$.

Thank you very much!

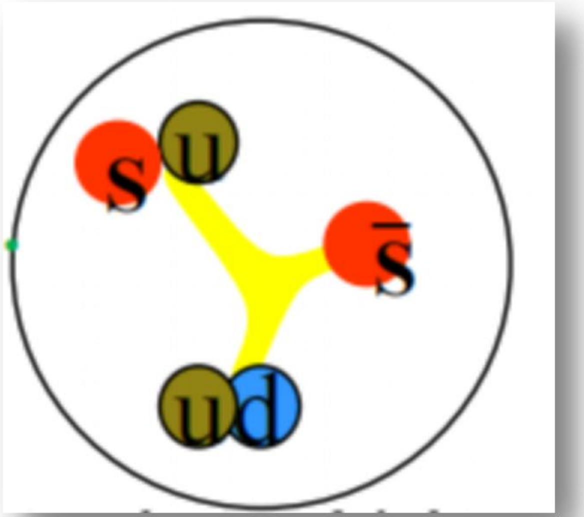
Backup

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

- **Pentaquark**, S. L. Zhu, etc. High Energy Phys. Nucl. Phys. 29, 250(2005).

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

	(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	$\frac{[ud][su]_-\bar{u}+[ds][ud]_-d+[su][ds]_-\bar{s}}{\sqrt{3}}$	1447



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

- **Pentaquark,** C. Helminen and D. O. Riska, NPA699, 624(2002).

PDG2001

$[4]_X[1111]_{CFS}[211]_C$ $[f]_{FS}[f]_F[f]_S$	Energy (MeV)	J^P	Λ (emp.)	Σ (emp.)
$[31]_{FS}[211]_F[22]_S$	1509	$\frac{1}{2}^-$	$\Lambda(1405)$	$\Sigma(1560)(**)$
$[31]_{FS}[211]_F[31]_S$	1565	$\frac{1}{2}^-$		$\Sigma(1560)(**)$, $\Sigma(1620)(**)$
		$\frac{3}{2}^-$	$\Lambda(1520)$	$\Sigma(1580)(**)$

unknown. If indeed the $\Lambda(1405)$ is partly a 5-quark state, it would be natural to expect the $\Sigma(1560)$ to be the analog of the $\Lambda(1405)$, and thus that it has $J^P = \frac{1}{2}^-$. This is indeed what the structure of the $qqqq\bar{q}$ spectrum shown in Table 7 indicates. This would also explain why the usual quark-model description of the baryons as 3-quark states cannot predict sufficiently low energies for the $\Lambda(1405)$ and $\Sigma(1560)$ [4]. The $\Sigma(1480)(*)$

$\Sigma(1560)$ Bumps $I(J^P) = 1(?^?)$ Status: $**$

OMITTED FROM SUMMARY TABLE

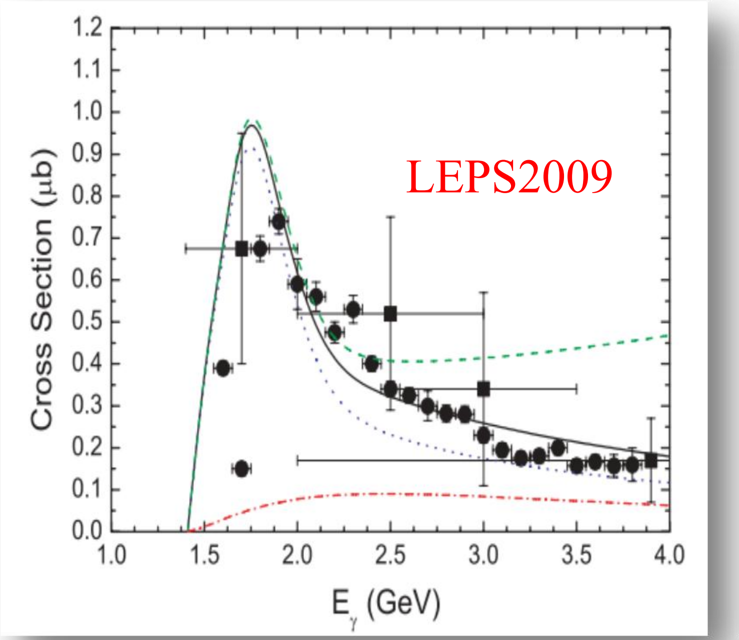
This entry lists peaks reported in mass spectra around 1560 MeV without implying that they are necessarily related.

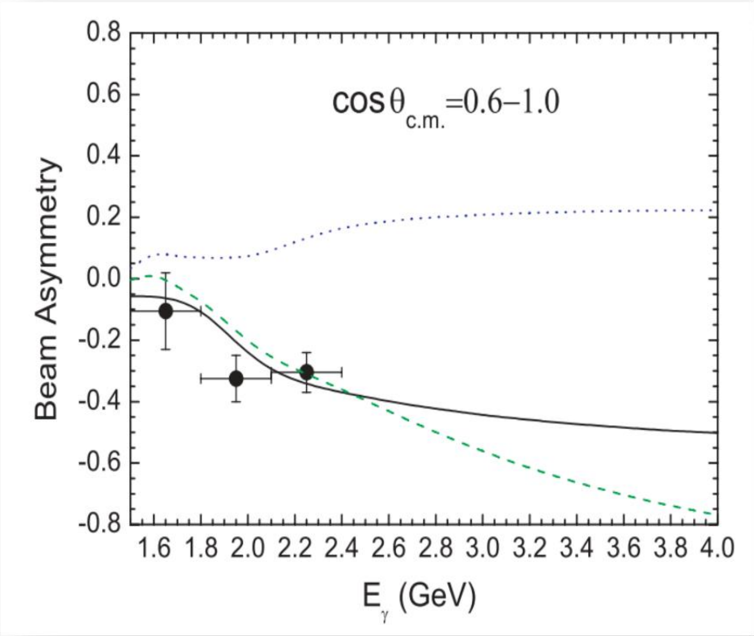
VALUE (MeV)	*EVTS*
≈ 1560 OUR ESTIMATE	
1553±7	121
1572±4	40

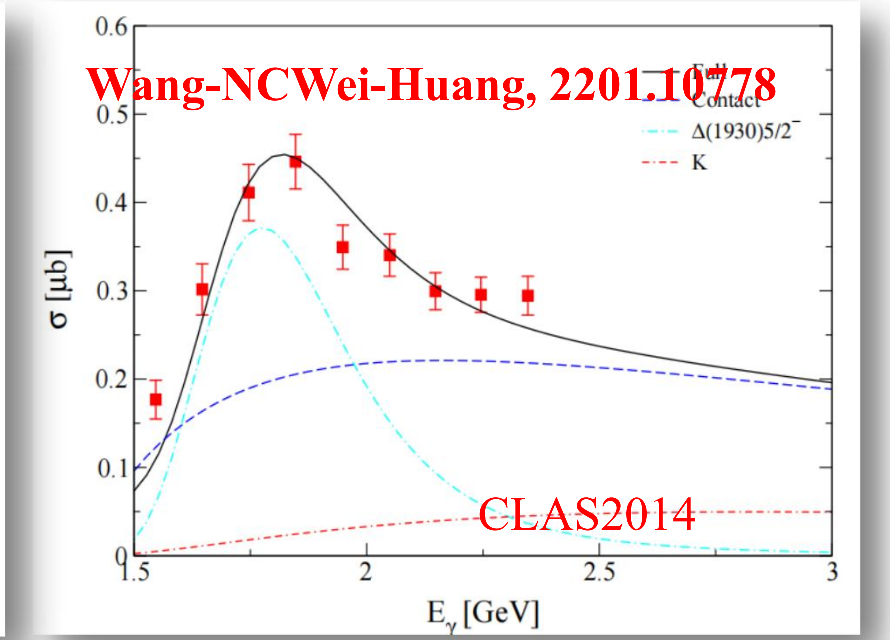
VALUE (MeV)
79±30
15± 6

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

- $\gamma N \to K\Sigma(1385)$, Gao-Wu-Zou, PRC 81(2010) 055203





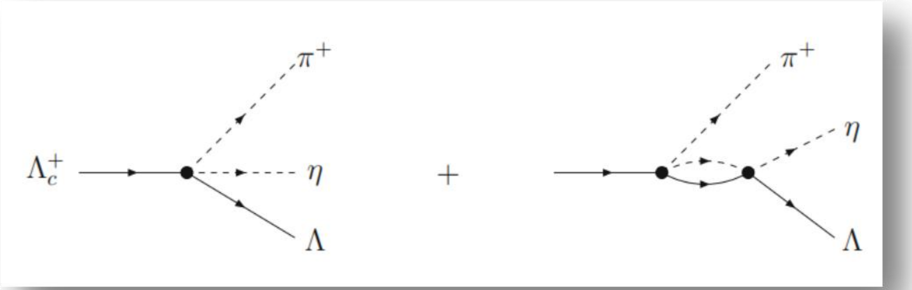


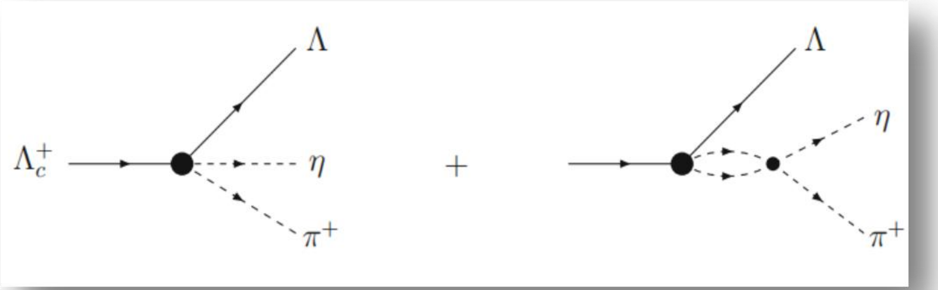
the case that the $\Sigma(\frac{1}{2}^-)$ may contribute to the observables of the $K\Sigma^*(1385)$ photoproduction in our experiments. Our results show that the $\Sigma(\frac{1}{2}^-)$ production can provide a large negative contribution to beam asymmetry, which helps to explain the large negative linear beam asymmetry observed by the LEPS experiment. With a portion of the $\Sigma(\frac{1}{2}^-)$, the same set of parameters can reproduce both the data for $\gamma n \to K^+\Sigma^{*-}$

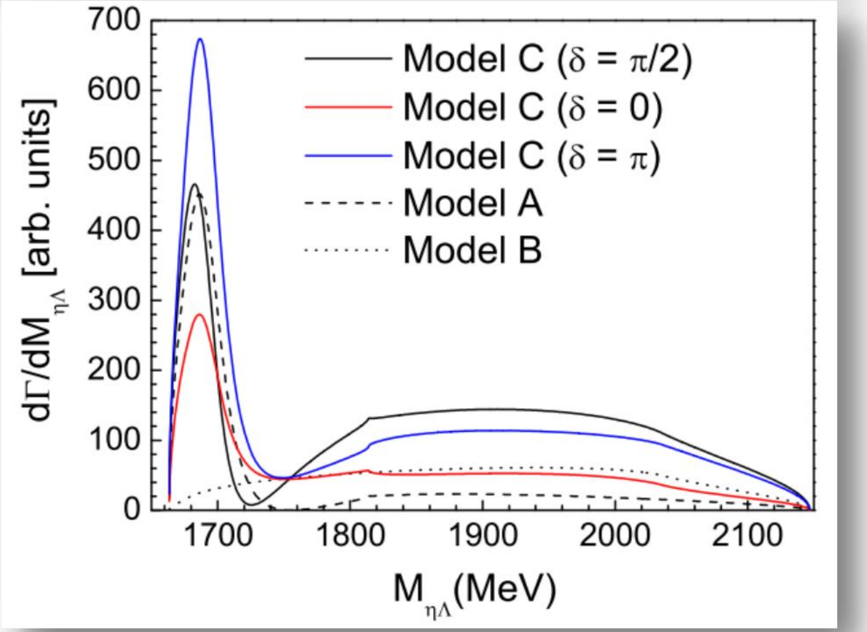
and, in particular, to figure out which one of the $N(1895)1/2^-$, $\Delta(1900)1/2^-$, and $\Delta(1930)5/2^-$ resonances is really capable for a simultaneous description of the data for both $K^+\Sigma^0(1385)$ and $K^+\Sigma^-(1385)$ photoproduction reactions. The results show that the available data on differential and total cross sections and photo-beam asymmetries for $\gamma n \to K^+\Sigma^-(1385)$ can be reproduced only with the inclusion of the $\Delta(1930)5/2^-$ resonance rather than the other two. The generalized

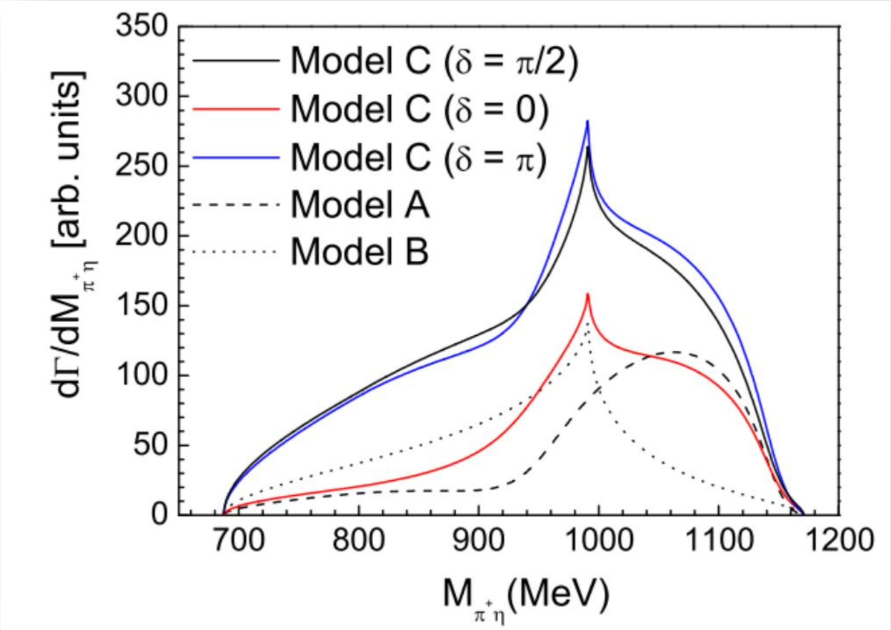
Search for $\Sigma(1/2^-)$

- $\Lambda_c \to \Lambda\eta\pi$, Xie-Geng, *EPJC(2016) 76:496*



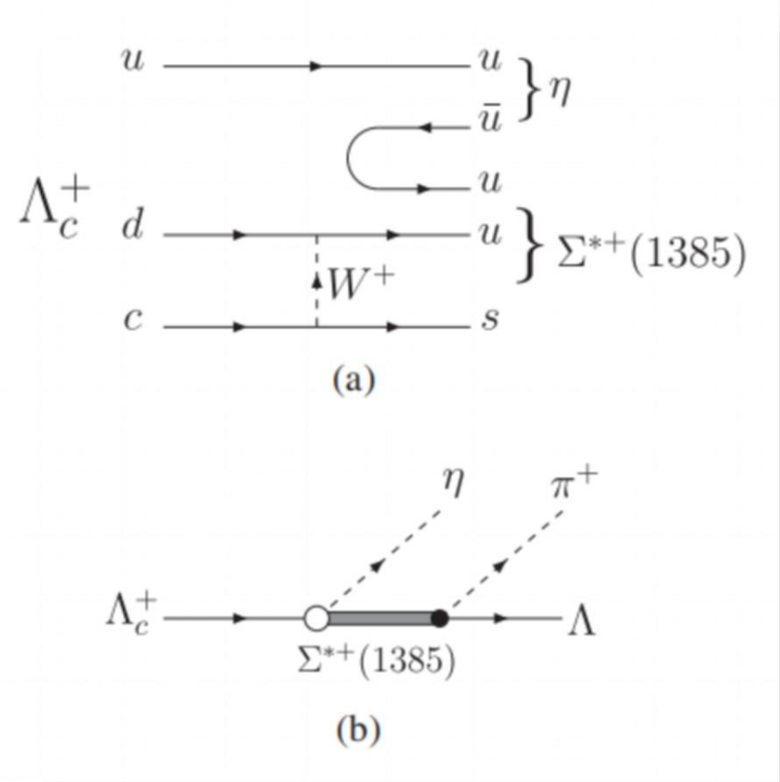


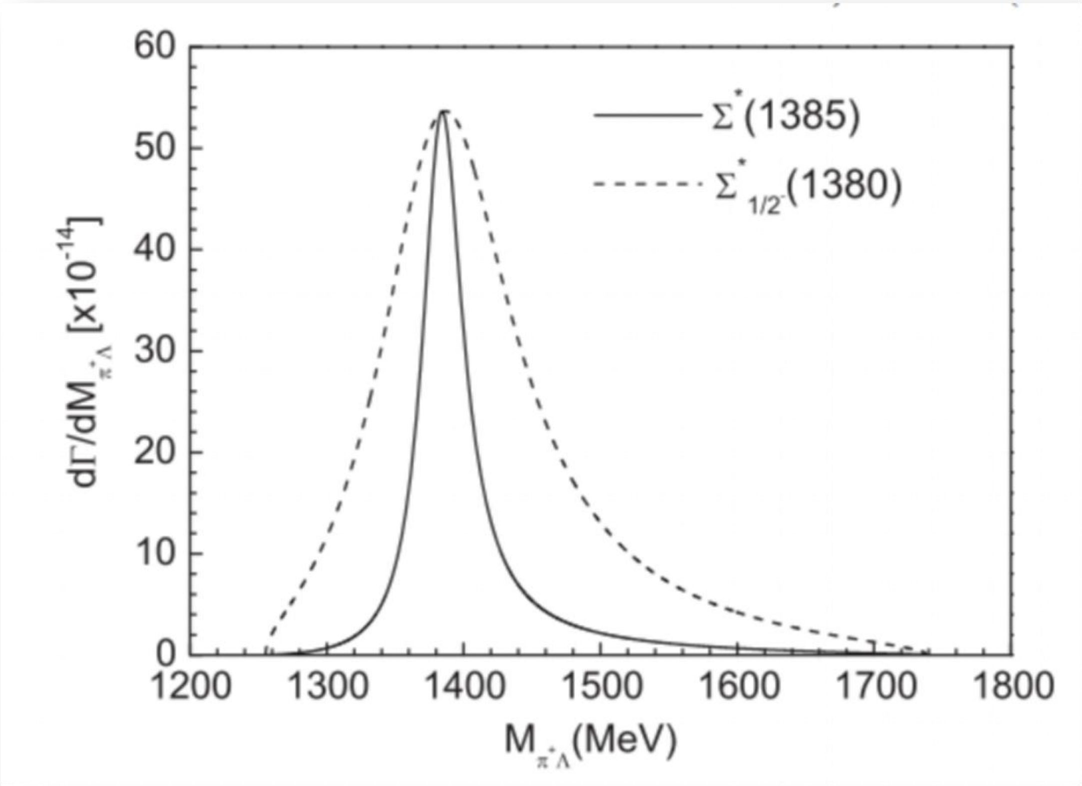




Search for $\Sigma(1/2^-)$

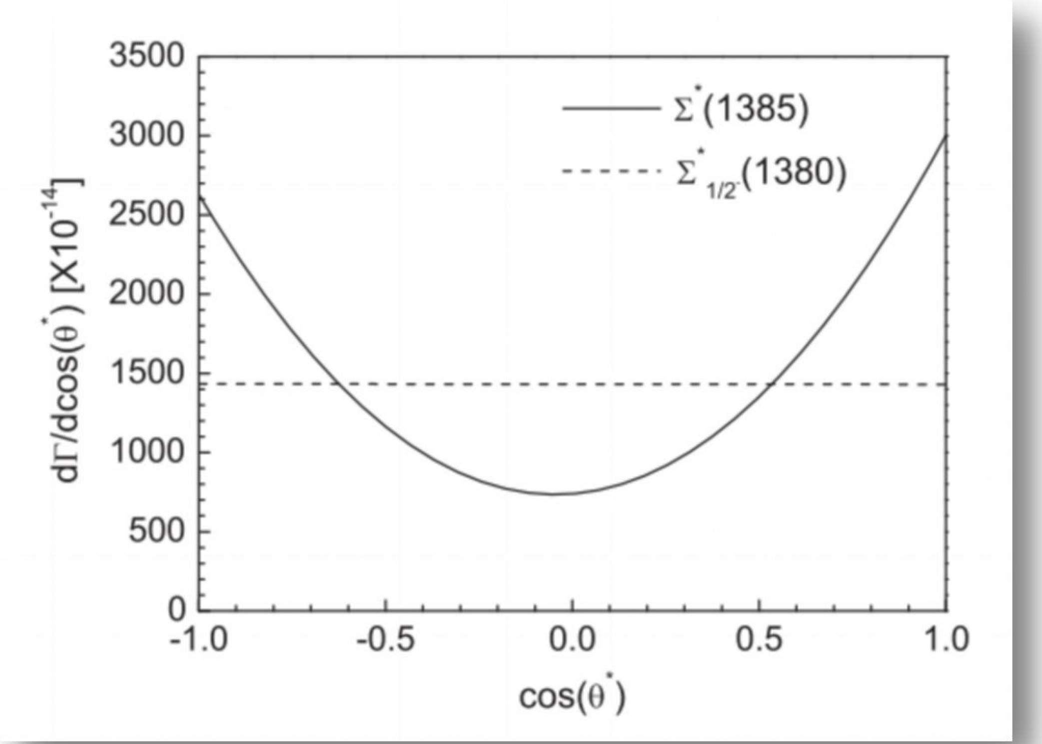
- $\Lambda_c \to \Lambda\eta\pi$, Xie-Geng, PRD95(2017) 074024

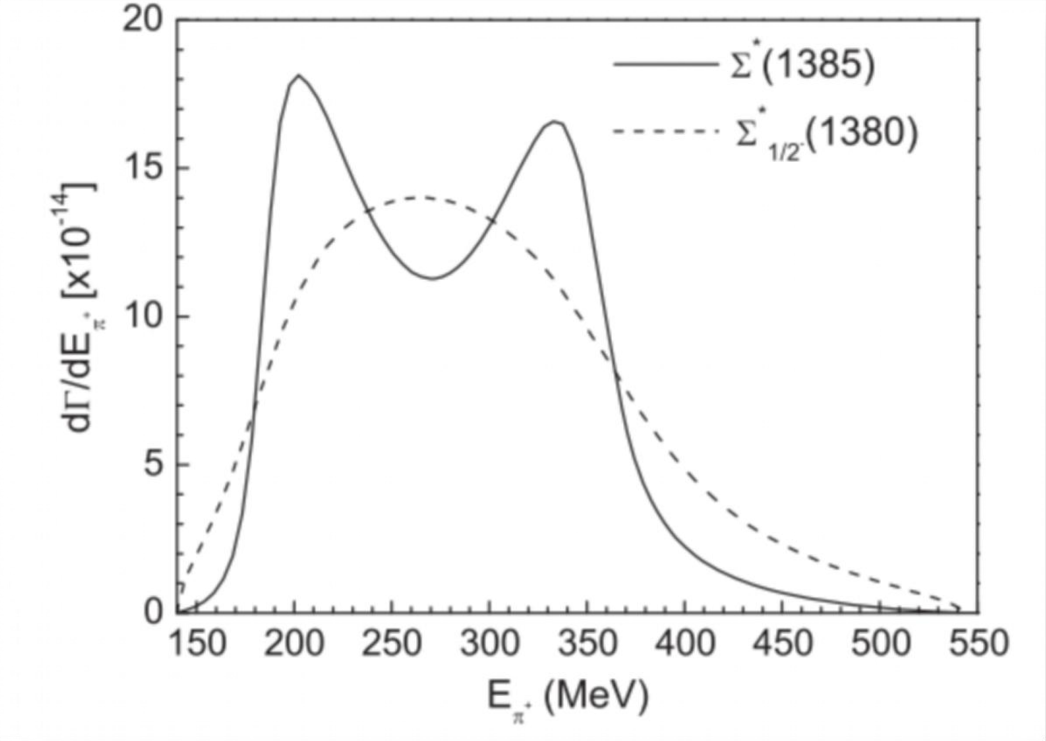




Search for $\Sigma(1/2^-)$

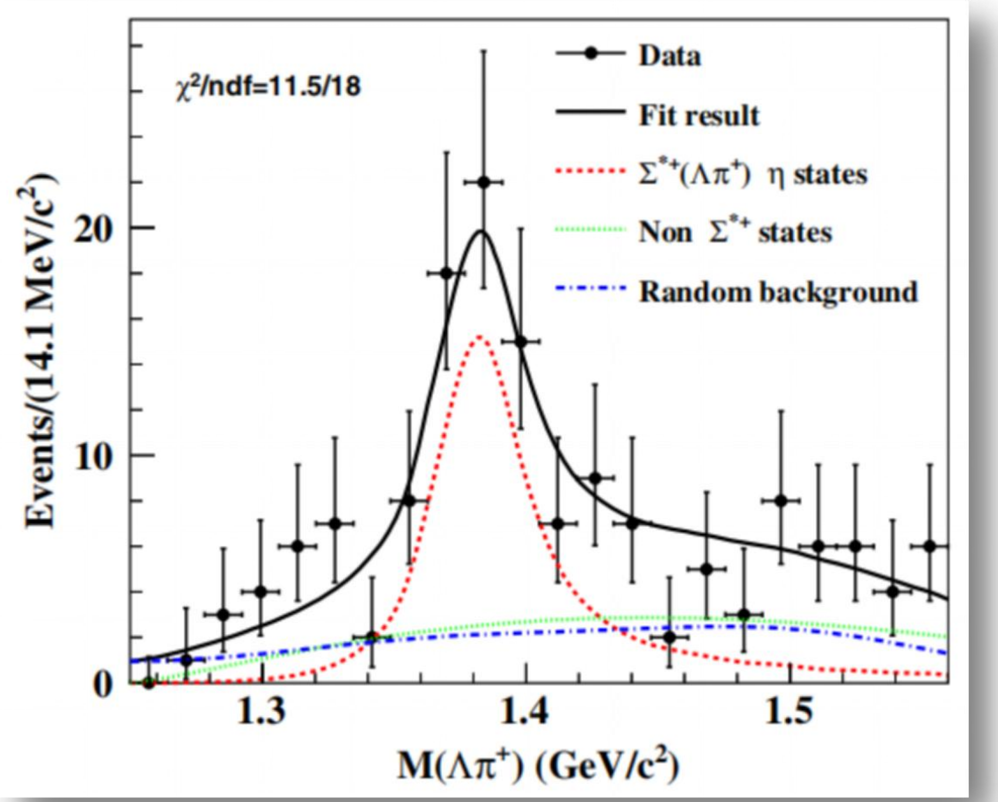
- $\Lambda_c \to \Lambda\eta\pi$, Xie-Geng, PRD95(2017) 074024



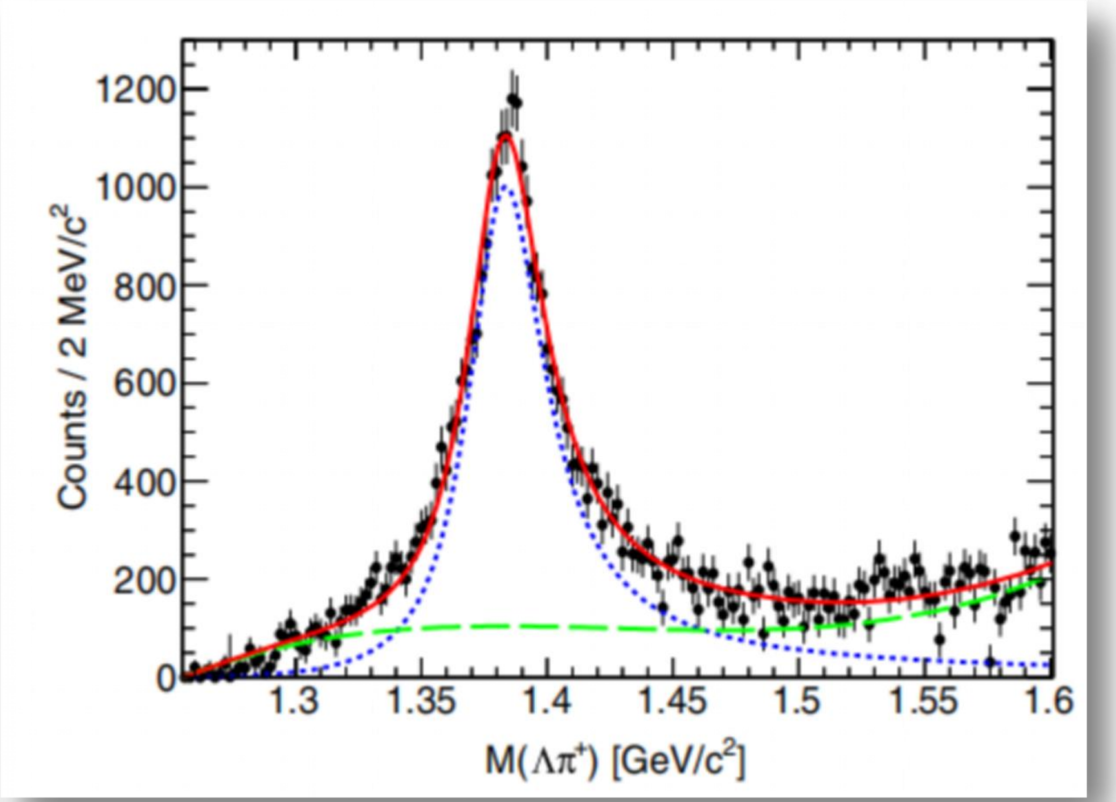


Belle and BESIII measurements

- $\Lambda_c \to \Lambda\eta\pi$



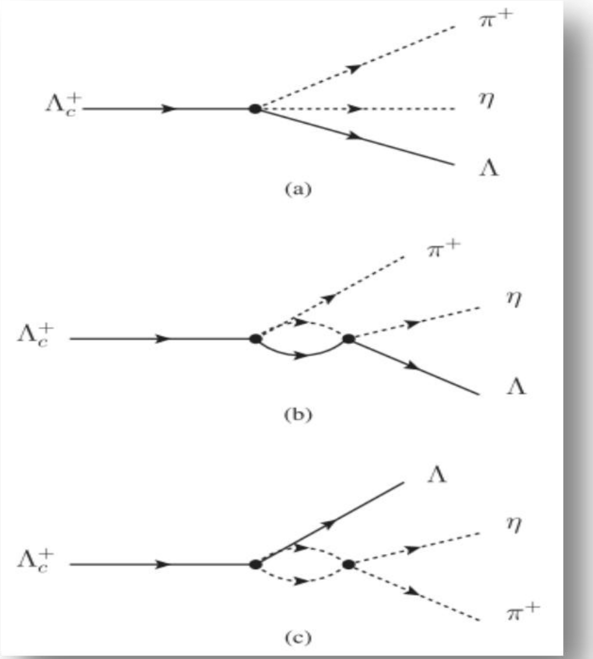
BESIII, PRD99, 032010 (2019)

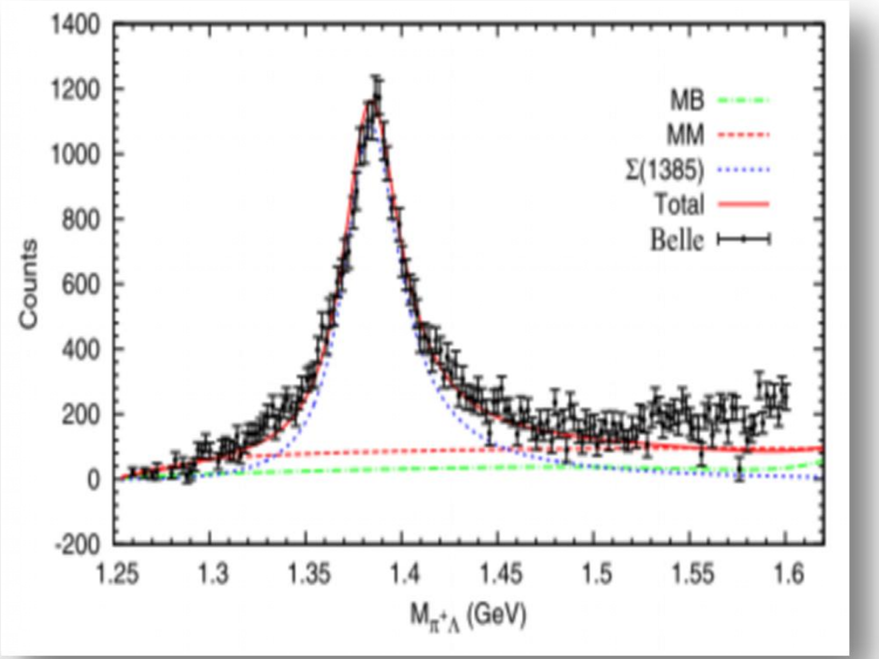


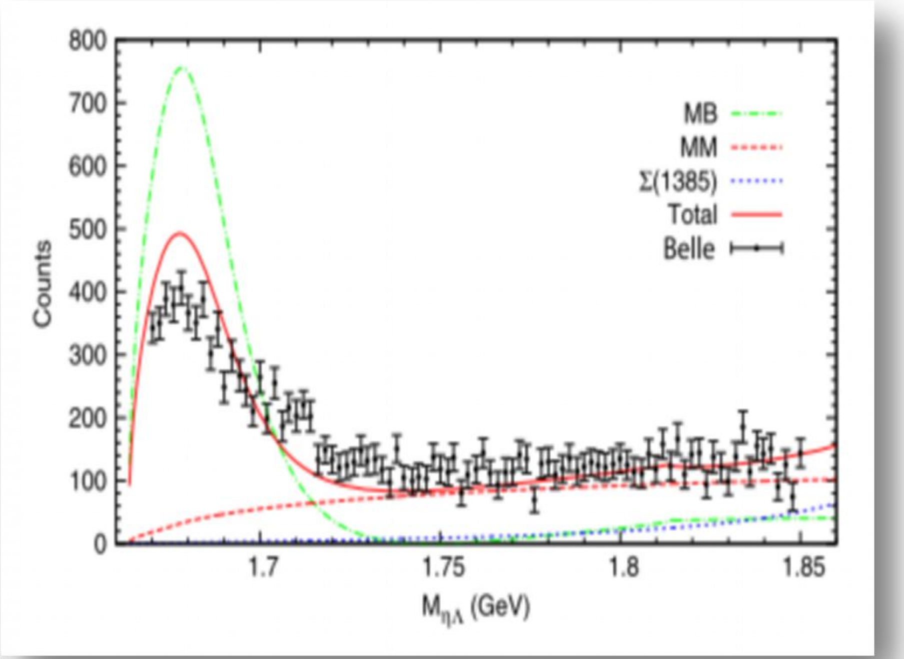
Belle, PRD103(2021)052005

Analysis the Belle data

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



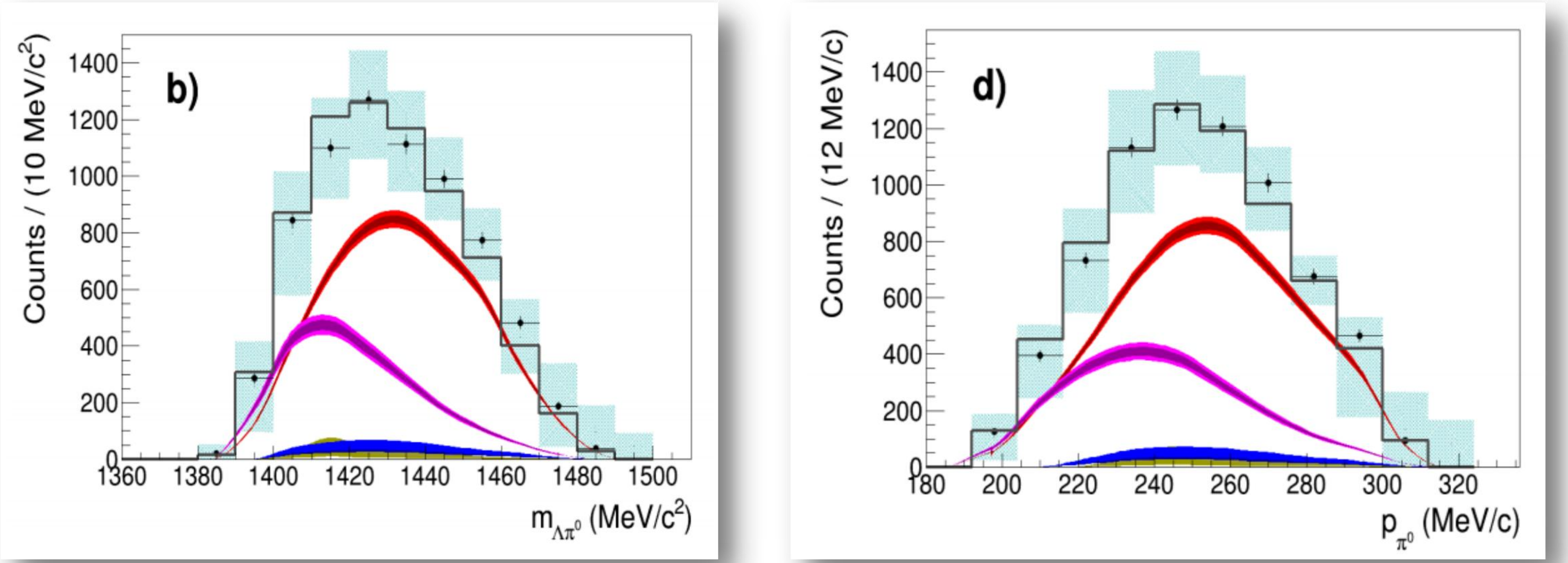




No signal of $\Sigma(1/2^-)$, $\Lambda(1670)$ as the molecular state!

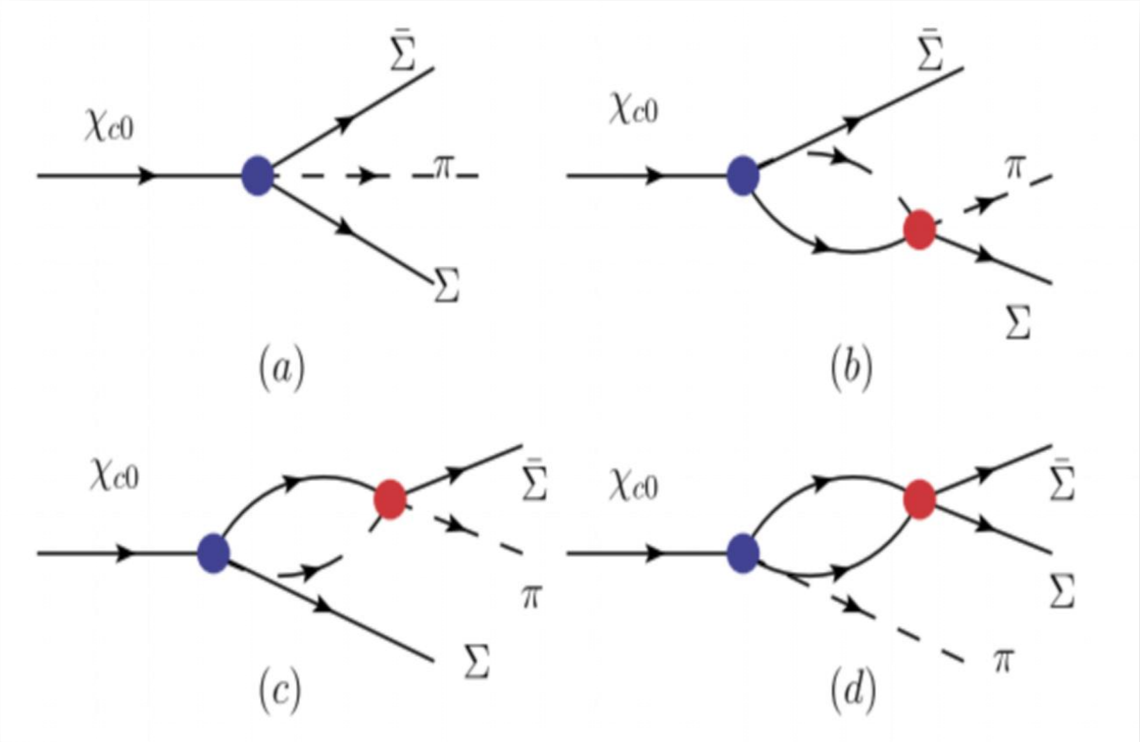
Other evidence of $\Sigma(1430)$

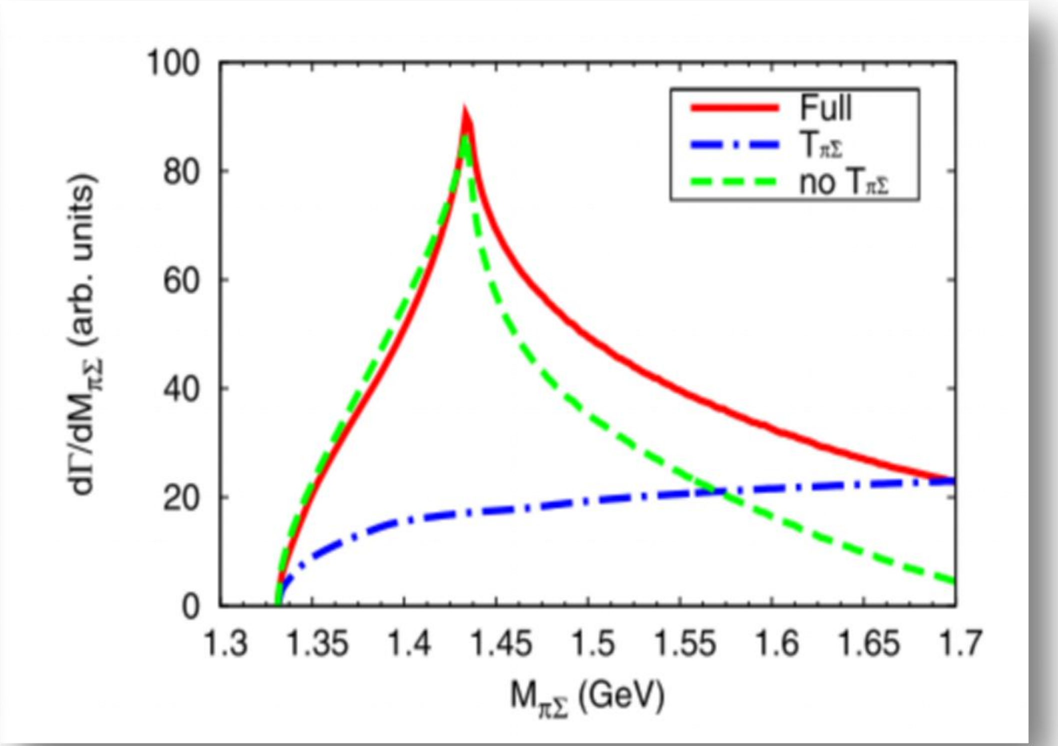
- $K^- p \to \Lambda\pi^0$, 2210.10342, corresponding to 2004/2005 KLOE data



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

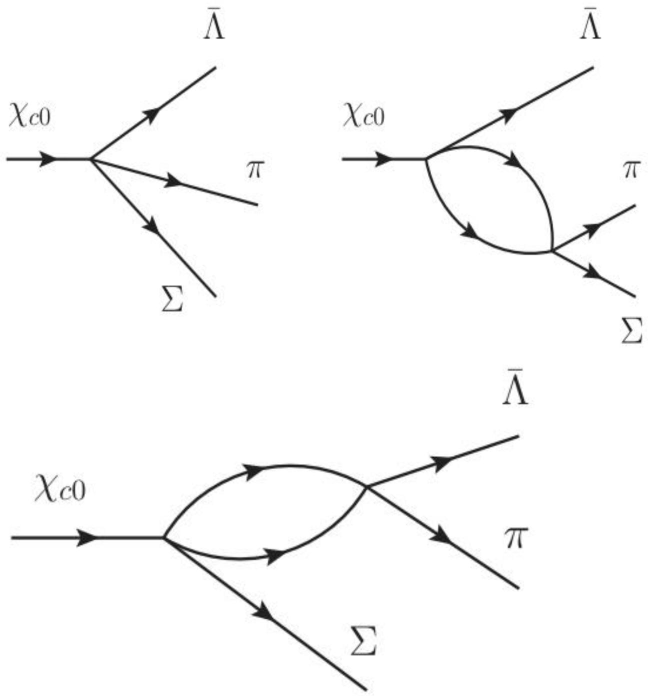
- $\chi_{c0} \to \bar{\Sigma}\Sigma\pi,\ \bar{\Lambda}\Sigma\pi,$ EW-Xie-Oset, PLB753(2016)526, PRD98(2018)114017

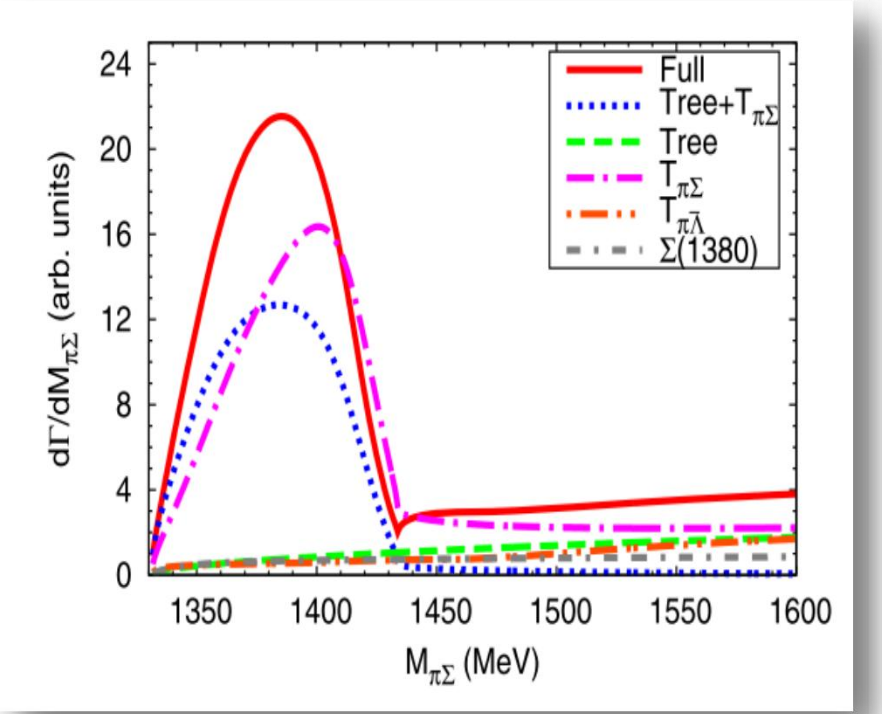


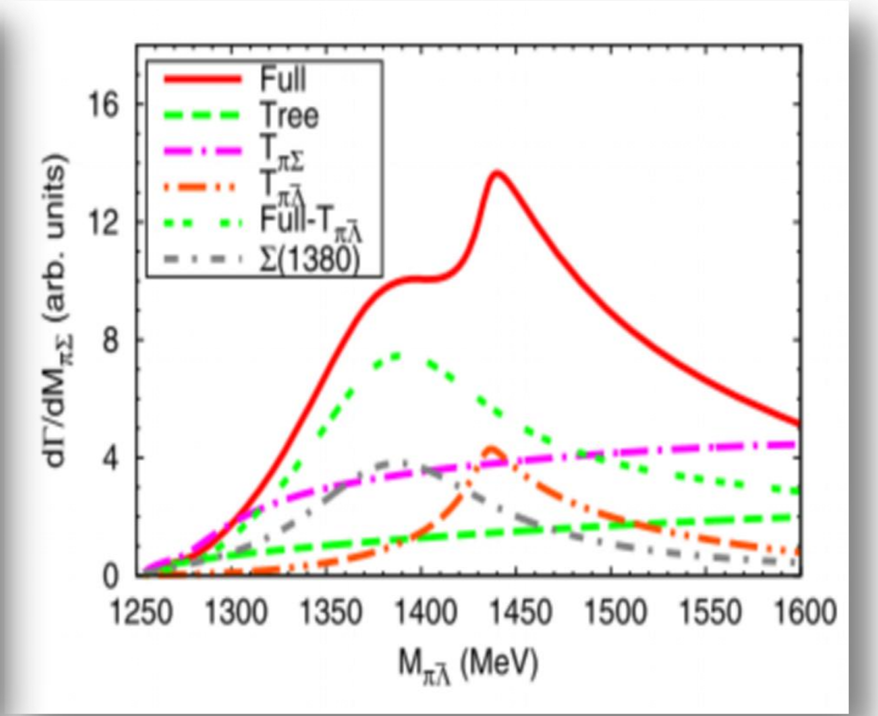


Search for $\Sigma(1/2^-)$

- $\chi_{c0} \to \bar{\Sigma}\Sigma\pi$, $\bar{\Lambda}\Sigma\pi$, EW-Xie-Oset, PLB753(2016)526, PRD98(2018)114017

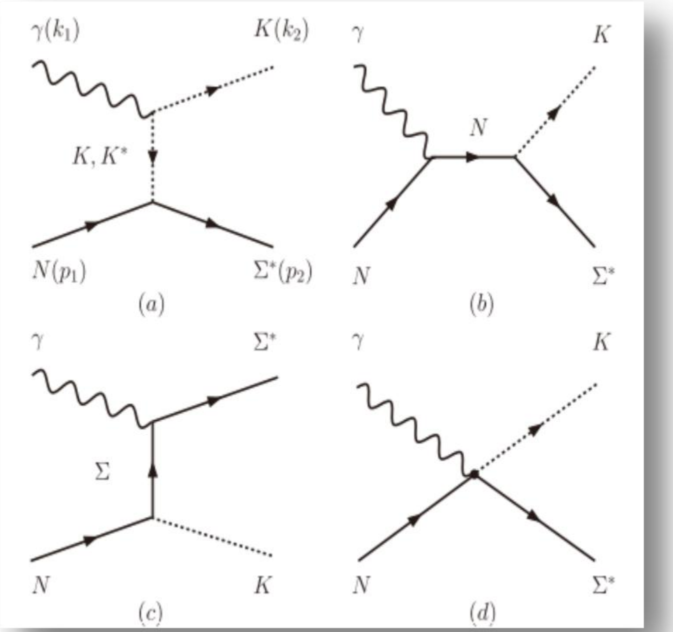






Search for $\Sigma(1/2^-)$

- $\gamma n \to K\Sigma(1/2^-)$, **Lyu-EW-Xie-Wei, CPC47 (2023) 053108**



$$\mathcal{L}_{\gamma KK} = -ie\left[K^\dagger\left(\partial_\mu K\right) - \left(\partial_\mu K^\dagger\right)K\right]A^\mu,$$

$$\mathcal{L}_{\gamma KK^*} = g_{\gamma KK^*}\epsilon^{\mu\nu\alpha\beta}\partial_\mu A_\nu \partial_\alpha K^*_\beta K,$$

$$\mathcal{L}_{\gamma NN} = -e\bar{N}\left[\gamma_\mu \hat{e} - \frac{\hat{\kappa}_N}{2M_N}\sigma_{\mu\nu}\partial^\nu\right]A^\mu N,$$

$$\mathcal{L}_{\gamma\Sigma\Sigma^*} = \frac{e\mu_{\Sigma\Sigma^*}}{2M_N}\bar{\Sigma}\gamma_5\sigma_{\mu\nu}\partial^\nu A^\mu \Sigma^* + \text{h.c.},$$

$$\mathcal{L}_{KN\Sigma} = -\mathrm{i}g_{KN\Sigma}\bar{N}\gamma_5\Sigma K + \text{h.c.},$$

$$\mathcal{L}_{K^*N\Sigma^*} = \mathrm{i}\frac{g_{K^*N\Sigma^*}}{\sqrt{3}}\bar{K}^{*\mu}\bar{\Sigma}^*\gamma_\mu\gamma_5 N + \text{h.c.},$$

$$\mathcal{L}_{KN\Sigma^*} = g_{KN\Sigma^*}\bar{K}\bar{\Sigma}^* N + \text{h.c.},$$

$$\mathcal{M}^\mu_{K^*} = \frac{g_{\gamma KK^*}g_{K^*N\Sigma^*}}{\sqrt{3}(t-M^2_{K^*})}\epsilon^{\alpha\beta\mu\nu}k_{1\alpha}k_{2\beta}\gamma_\nu\gamma_5,$$

$$\mathcal{M}^\mu_{K^-} = -2\mathrm{i}\frac{eg_{KN\Sigma^*}}{t-M_K^2}k_2^\mu,$$

$$\mathcal{M}^\mu_{\Sigma^-} = -\mathrm{i}\frac{e\mu_{\Sigma\Sigma^*}g_{KN\Sigma}}{2M_n(u-M_\Sigma^2)}(\not{q}_u - M_\Sigma)\sigma^{\mu\nu}k_{1\nu},$$

$$\mathcal{M}^\mu_n = \frac{\kappa_n g_{KN\Sigma^*}}{2M_n(s-M_n^2)}\sigma^{\mu\nu}k_{1\nu}(\not{q}_s + M_n).$$

$$\mathcal{M}^\mu = \left(\mathcal{M}^\mu_{K^-} + \mathcal{M}^\mu_c\right)\left(t-M_K^2\right)\mathcal{F}_K^{\text{Regge}} + \mathcal{M}^\mu_{\Sigma^-}f_u + \mathcal{M}^\mu_{K^*}\left(t-M^2_{K^*}\right)\mathcal{F}^{\text{Regge}}_{K^*} + \mathcal{M}^\mu_n f_s,$$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{M_N M_{\Sigma^*}|\vec{k}_1^{\text{c.m.}}||\vec{k}_2^{\text{c.m.}}|}{8\pi^2(s-M_N^2)^2}\sum_{\lambda,s_p,s_{\Sigma^*}}|\mathcal{M}|^2,$$

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

- $\gamma n \to K\Sigma(1/2^-)$, Lyu-EW-Xie-Wei, CPC47 (2023) 053108