Study the low-lying excited baryons in the decays of charmed hadrons

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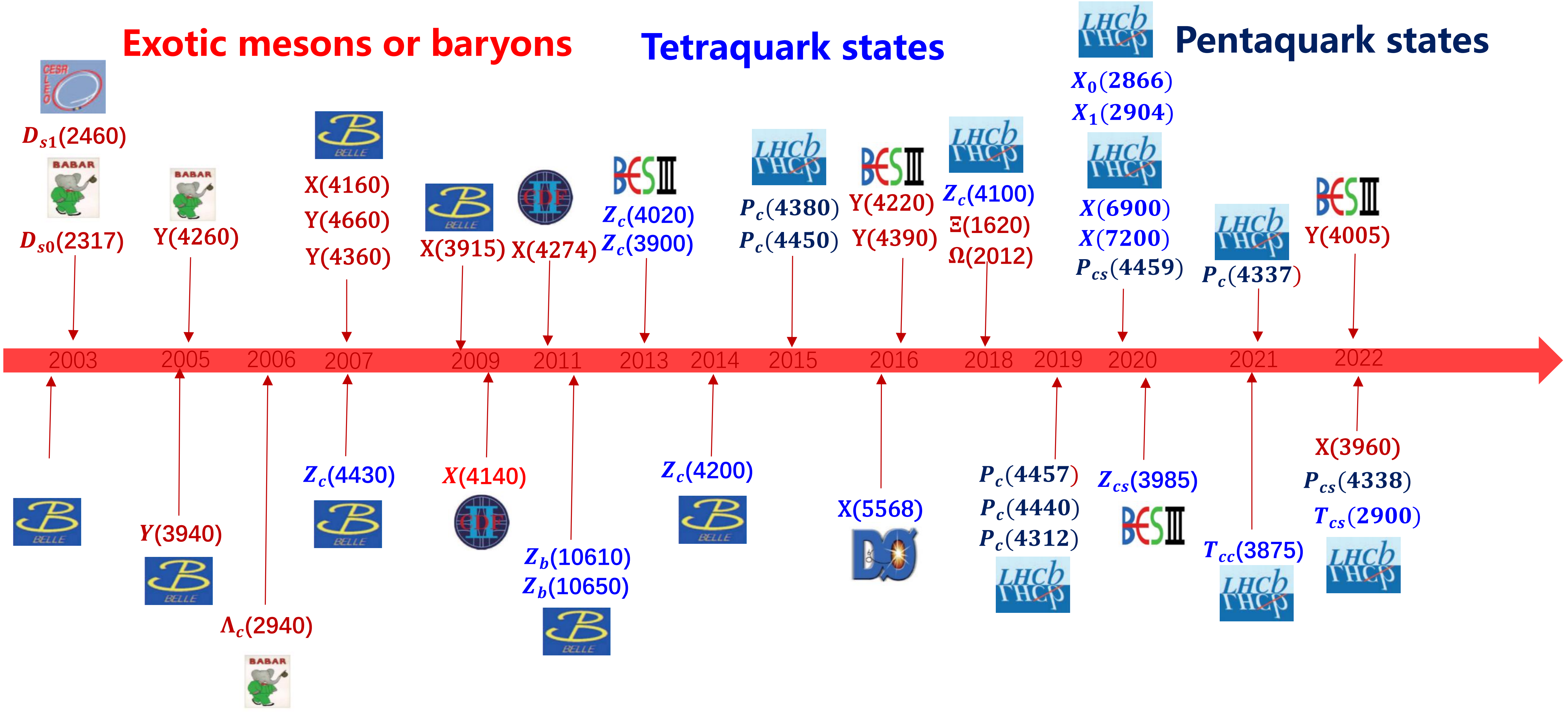
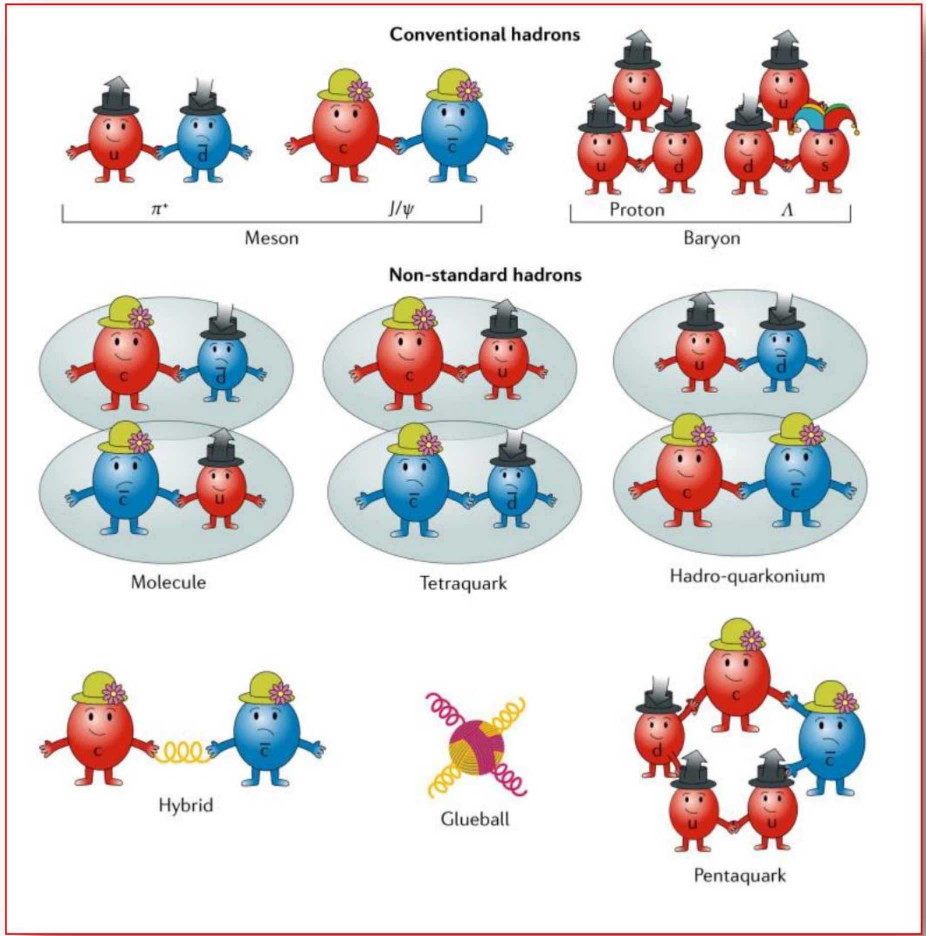
Exotic states

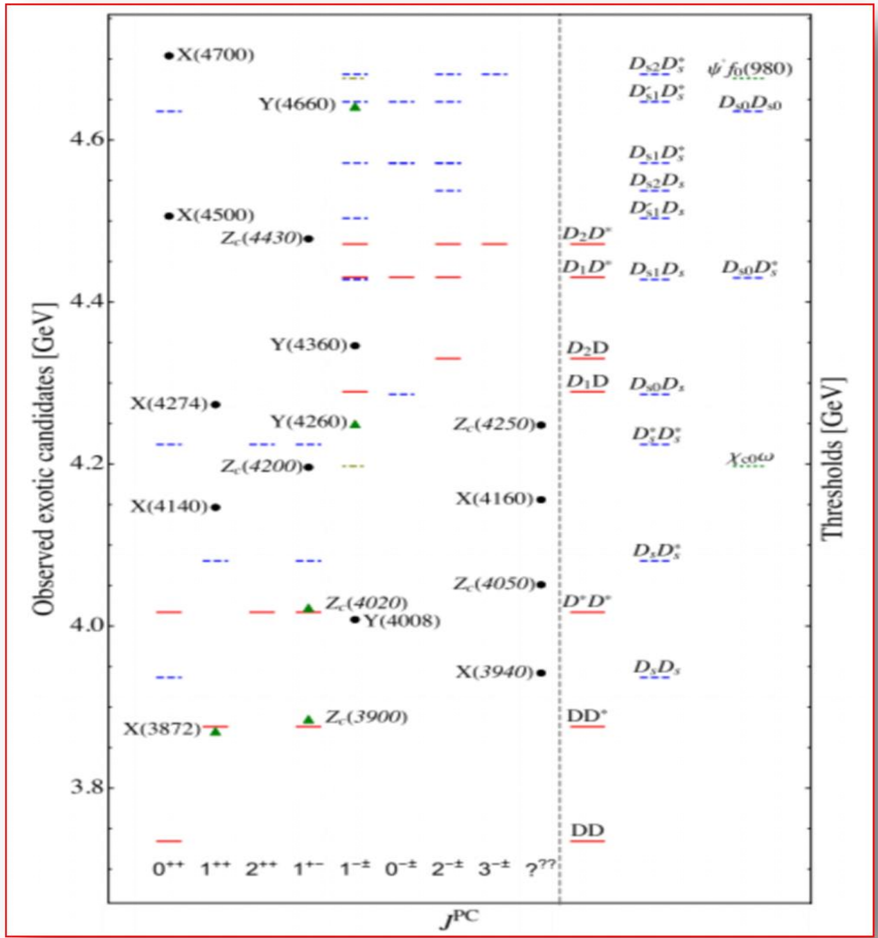
From Li-Sheng Geng



Hadrons



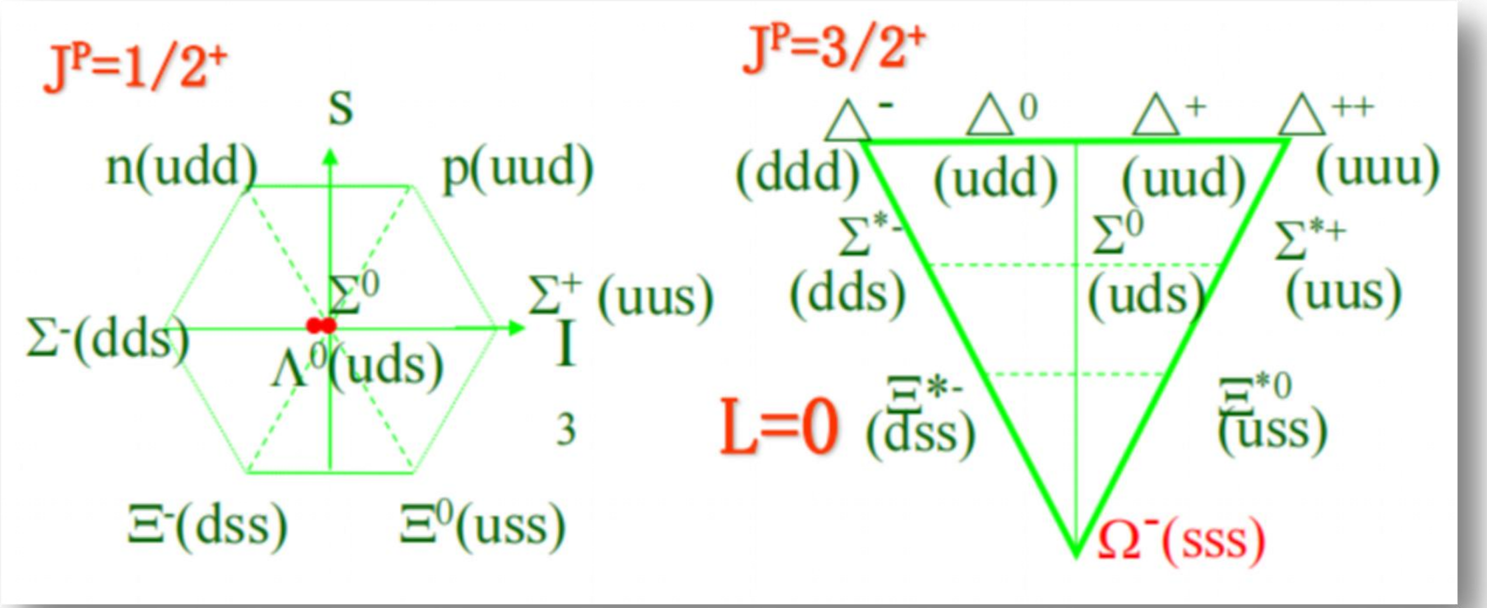
C.Z.Yuan, Nature Rev. Phys. 1 (2019) 480

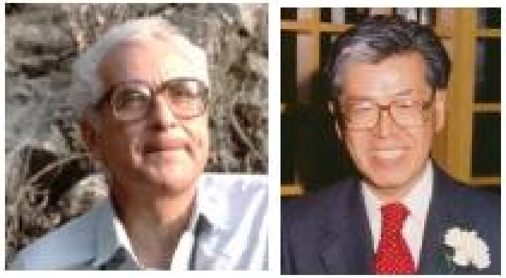


FKGuo, et.al, Mod. Phys. 90 (2018) 015004

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

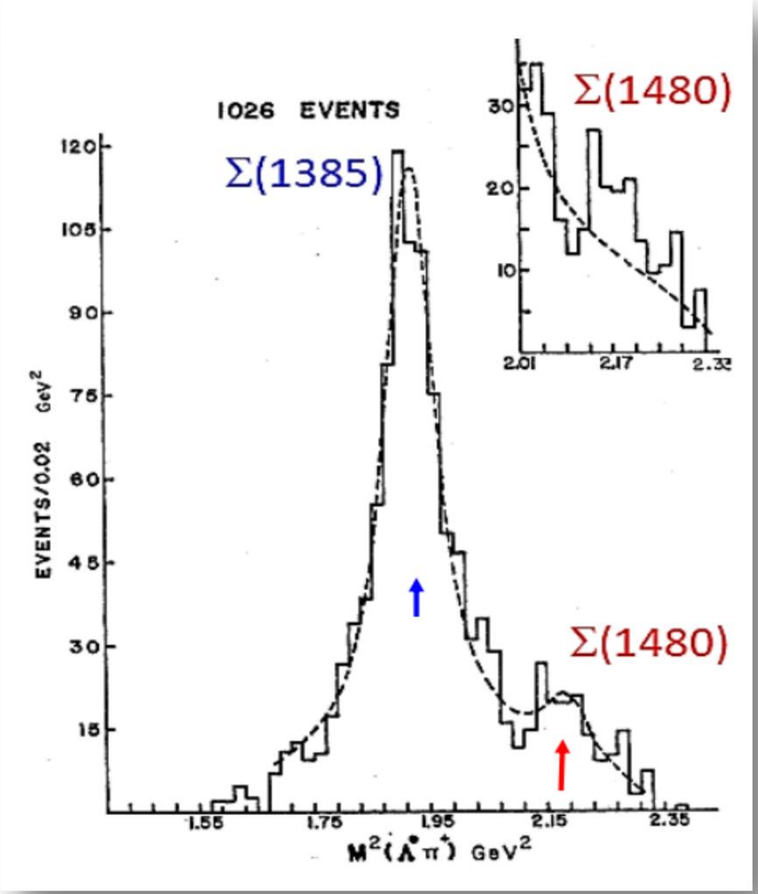
These are peaks seen in $\Lambda\pi$ and $\Sigma\pi$ spectra in the reaction $\pi^+ p \to (Y\pi)K^+$ at 1.7 GeV/c. Also, the Y polarization oscillates in the same region.

邹冰松老师报告

Exp. signals of Σ(1480)

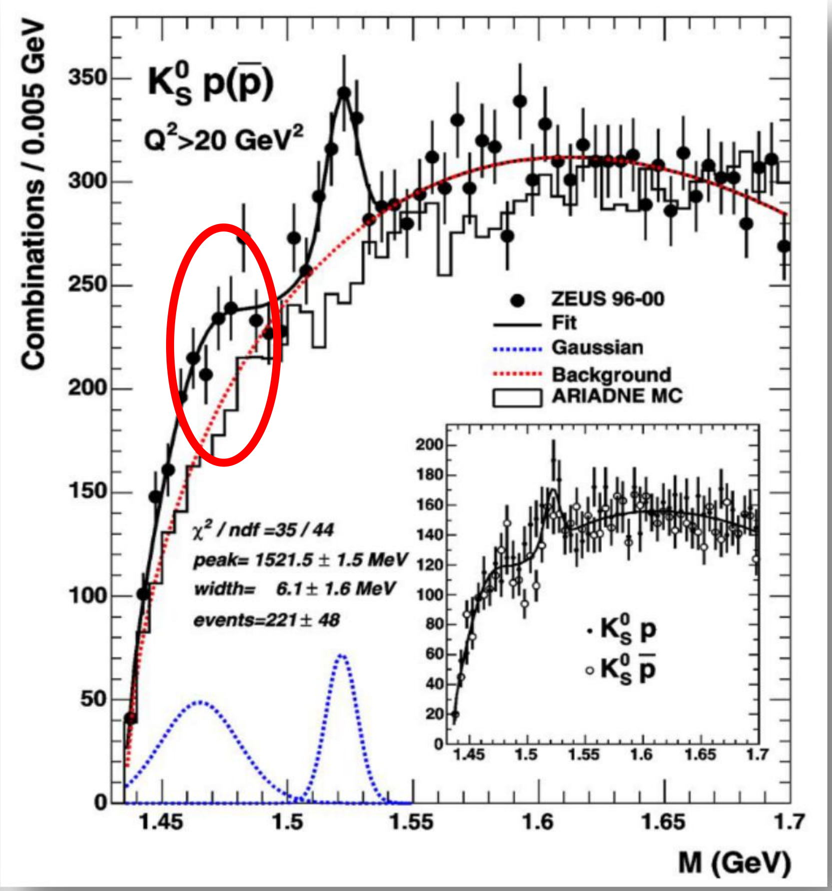
$\pi^+ p \to \pi^+ K^+ \Lambda$

Yu-Li Pan et al, PRD2, 449 (1970)



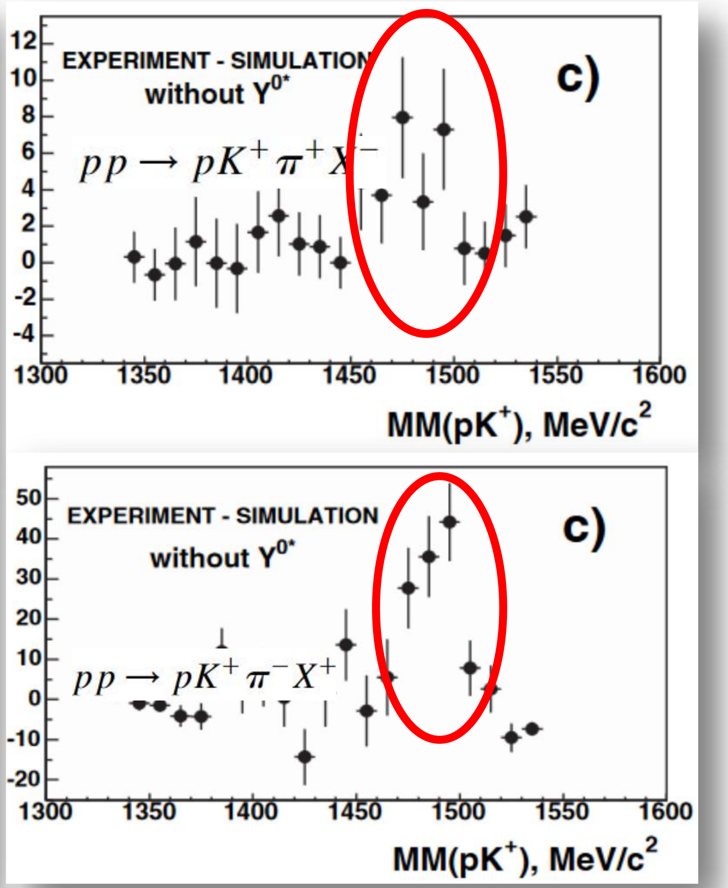
$e^+ p \to e^+ K^0 \mathrm{pX}$

ZEUS PLB591 (2004) 7–22



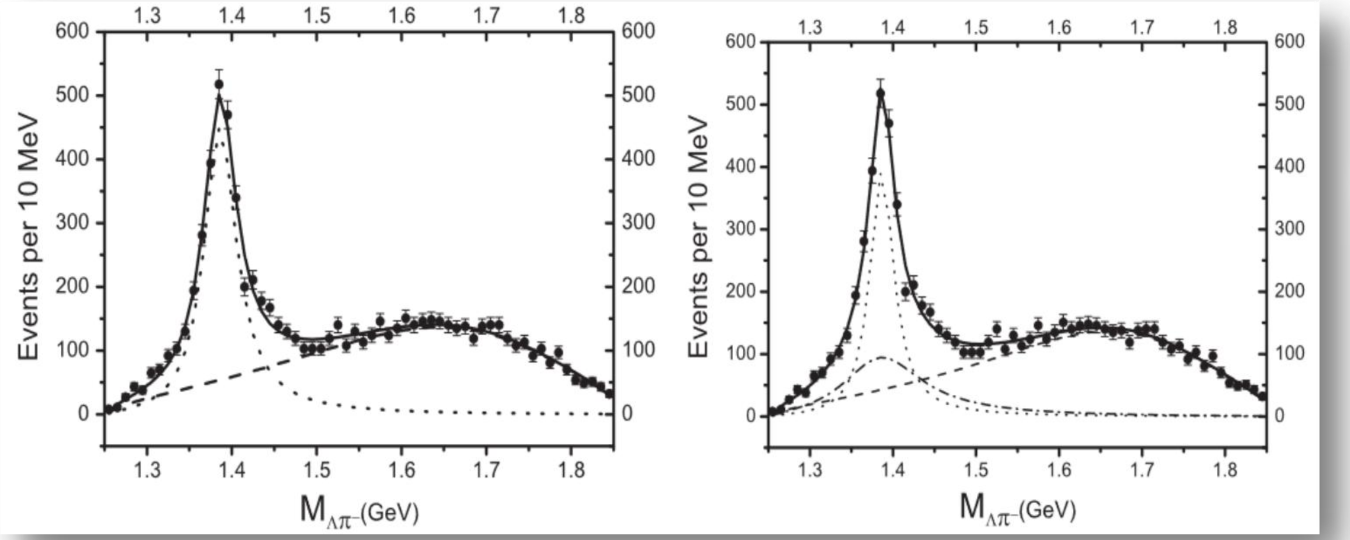
$pp \to pK^+ Y^{0*}$

COSY-Juich PRL 96, 012002 (2006)



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

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



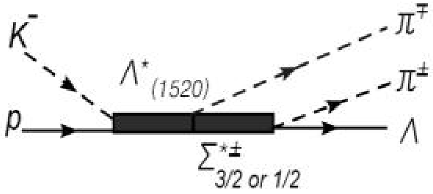
$$\frac{dN}{dm_{\Lambda\pi^-}} \propto p_1 \times p_2 \times \sum_{i=1}^{3} \frac{|a_i|}{(m_{\Lambda\pi^-}^2 - m_i^2)^2 + m_i^2 \times \Gamma_i^2},$$

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

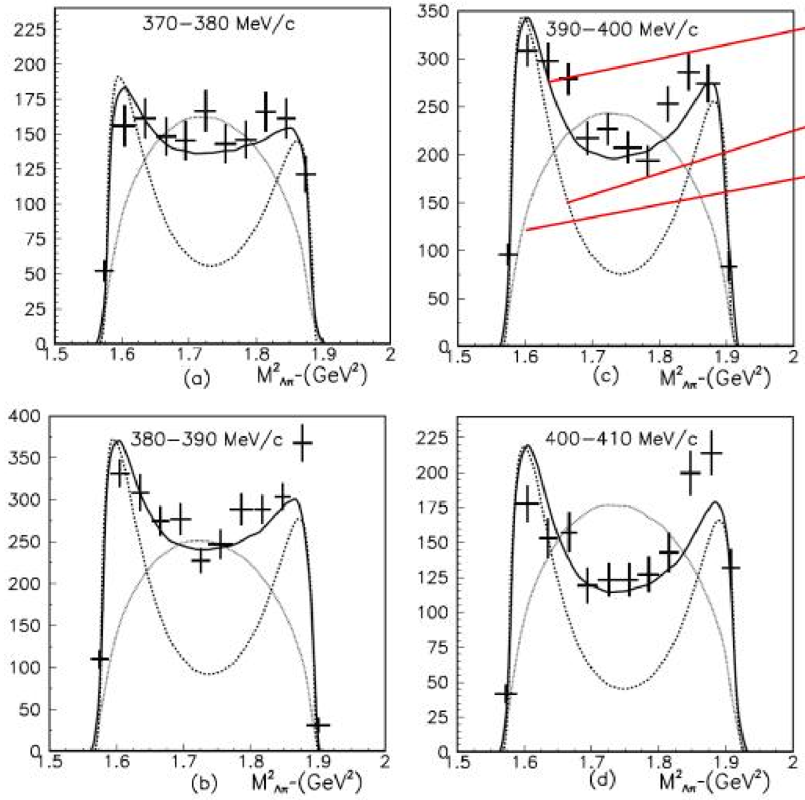
Evidence of $\Sigma(1/2^-)$

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



J.J.Wu's slide

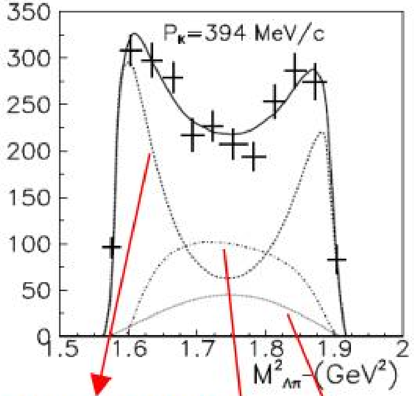
P_K=0.3-0.6 GeV **J. J. Wu, S. Dulat and B. S. Zou PRC 81,045210**



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

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

Phase space

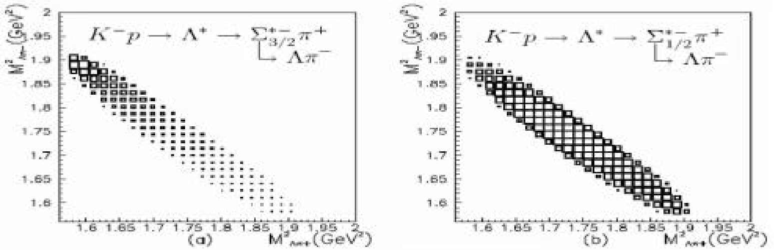


59% $\Sigma^*(3/2^+)$

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

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

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

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

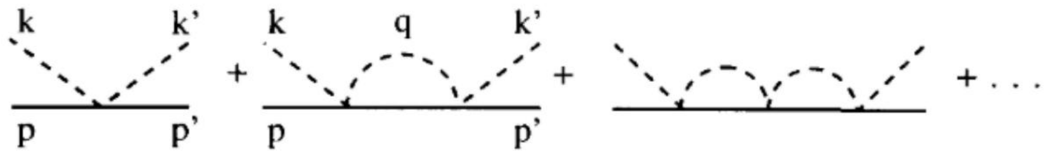
I=1

	$\bar{K}N$	$\pi\Sigma$	$\pi\Lambda$	$\eta\Sigma$	$K\Xi$
$\bar{K}N$	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

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

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

□Bethe-Salpter Equation

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

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

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

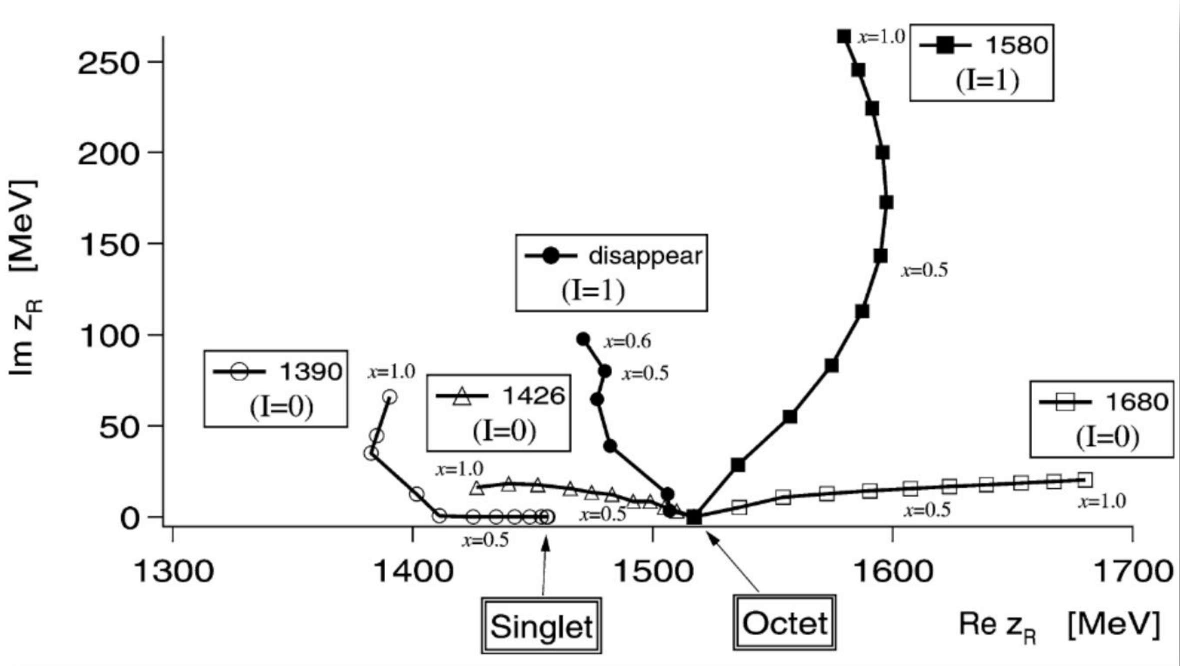
$$G_l = i2M_l \int \frac{d^4 q}{(2\pi)^4} \frac{1}{(P-q)^2 - M_l^2 + i\epsilon} \frac{1}{q^2 - m_l^2 + i\epsilon}$$

$$= \frac{2M_l}{16\pi^2} \Big\{ a_l(\mu) + \ln\frac{M_l^2}{\mu^2} + \frac{m_l^2 - M_l^2 + s}{2s} \ln\frac{m_l^2}{M_l^2}$$

$$+ \frac{q_l}{\sqrt{s}} [\ln(s - (M_l^2 - m_l^2) + 2q_l\sqrt{s}) + \ln(s + (M_l^2 - m_l^2) + 2q_l\sqrt{s})$$

$$- \ln(-s + (M_l^2 - m_l^2) + 2q_l\sqrt{s}) - \ln(-s - (M_l^2 - m_l^2) + 2q_l\sqrt{s})] \Big\}.$$

Jido Oller Oset Ramos Meissner NPA725 (2003) 181

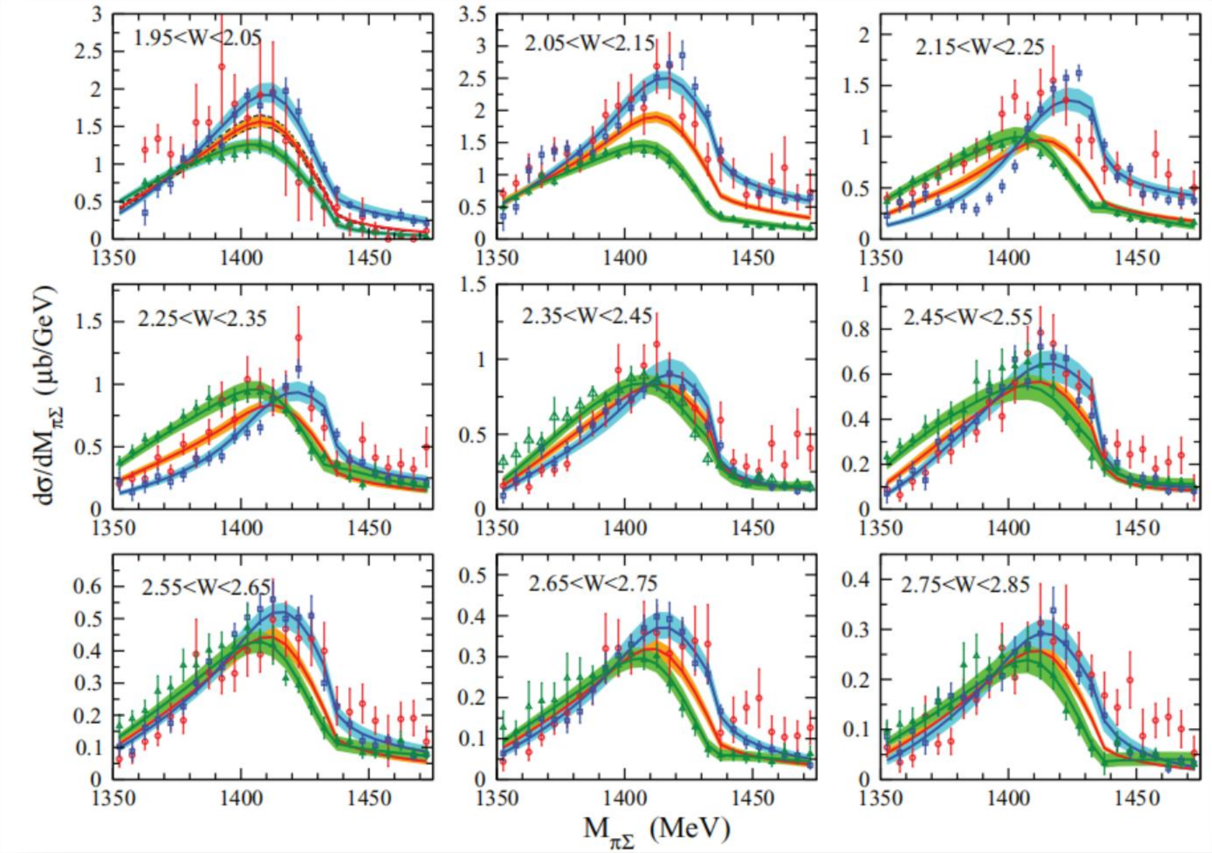


pole positions and couplings

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

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

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



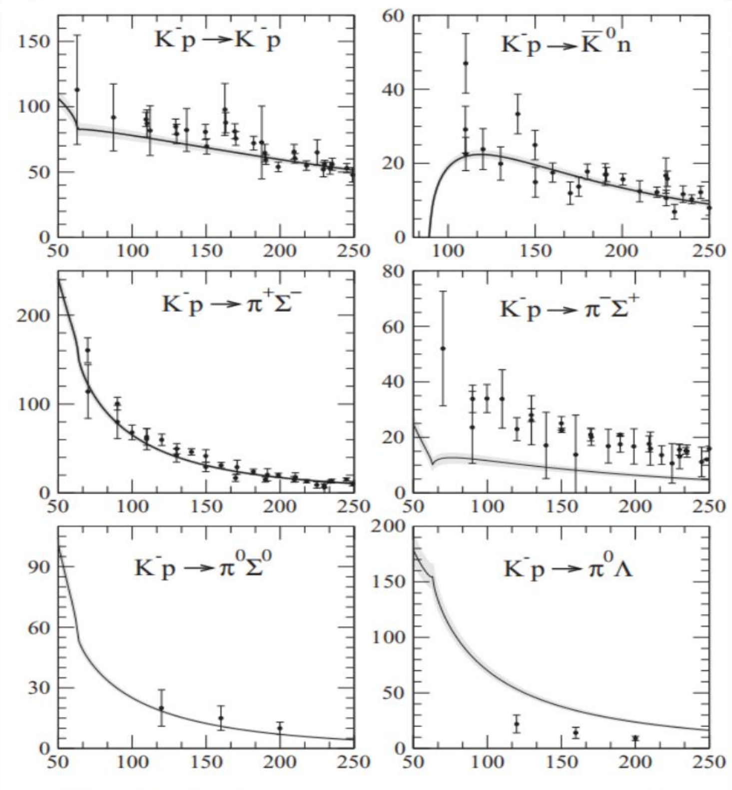
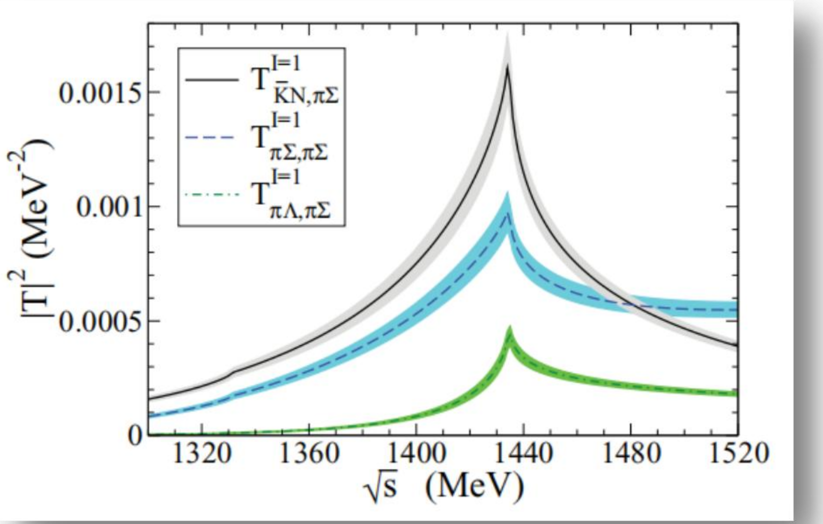


FIG. 6. Predicted K^-p cross sections (in millibarns). Experimental data are from Ref. [46].

Σ(1430)

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



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

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

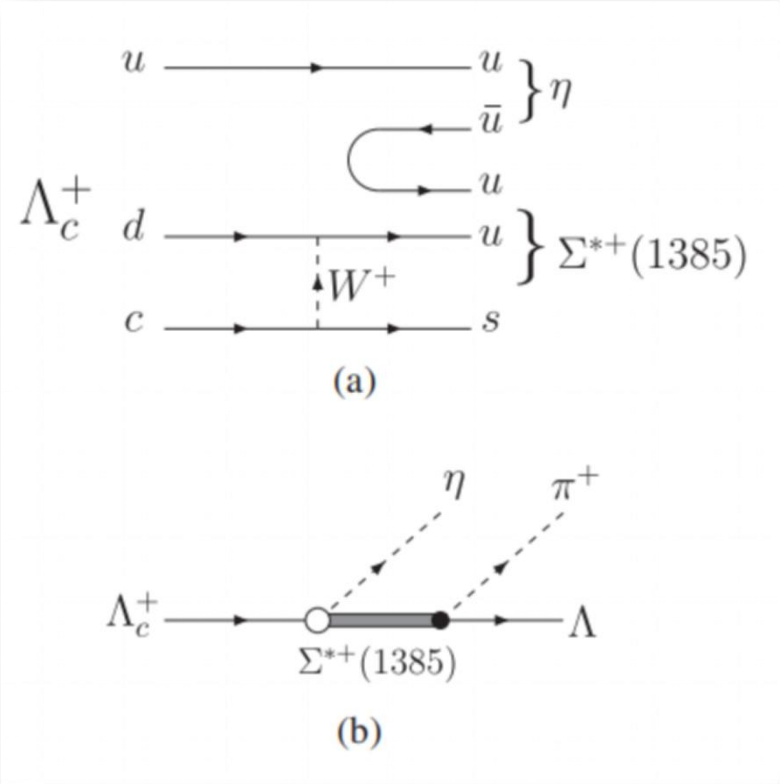
$$C^1_{ij} = \begin{pmatrix} \alpha^1_{11} & -\alpha^1_{12} & -\sqrt{\frac{3}{2}}\alpha^1_{13} \\ -\alpha^1_{12} & 2\alpha^1_{22} & 0 \\ -\sqrt{\frac{3}{2}}\alpha^1_{13} & 0 & 0 \end{pmatrix}$$

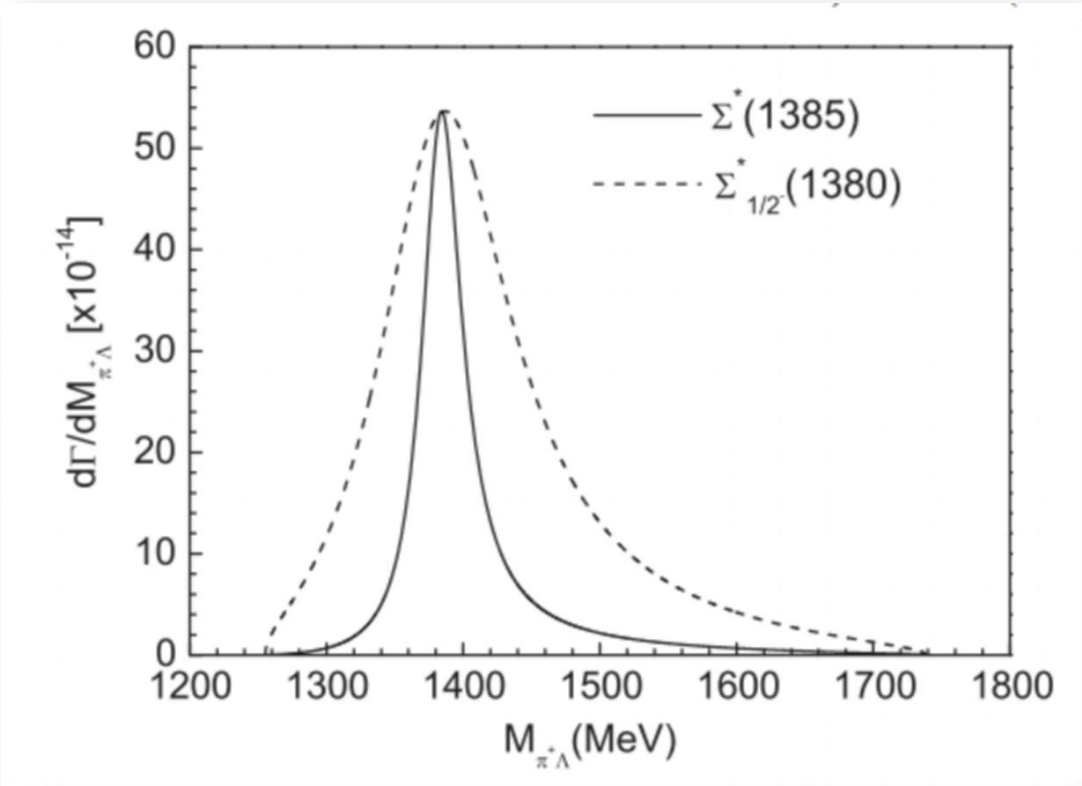
α^0_{11}	α^0_{12}	α^0_{22}	α^1_{11}	α^1_{12}	α^1_{13}	α^1_{22}
1.037	1.466	1.668	0.85	0.93	1.056	0.77

- ☐ **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]**

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

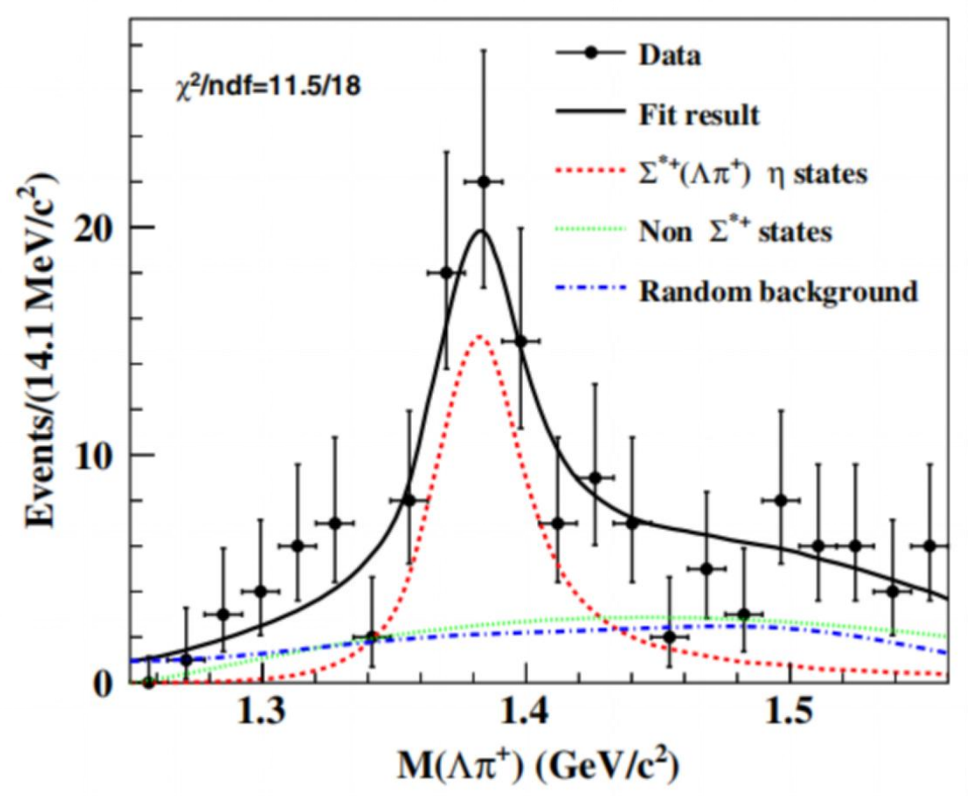
- J.J.Xie, L.S.Geng, EPJC76(2016) 496, PRD95(2017) 074024

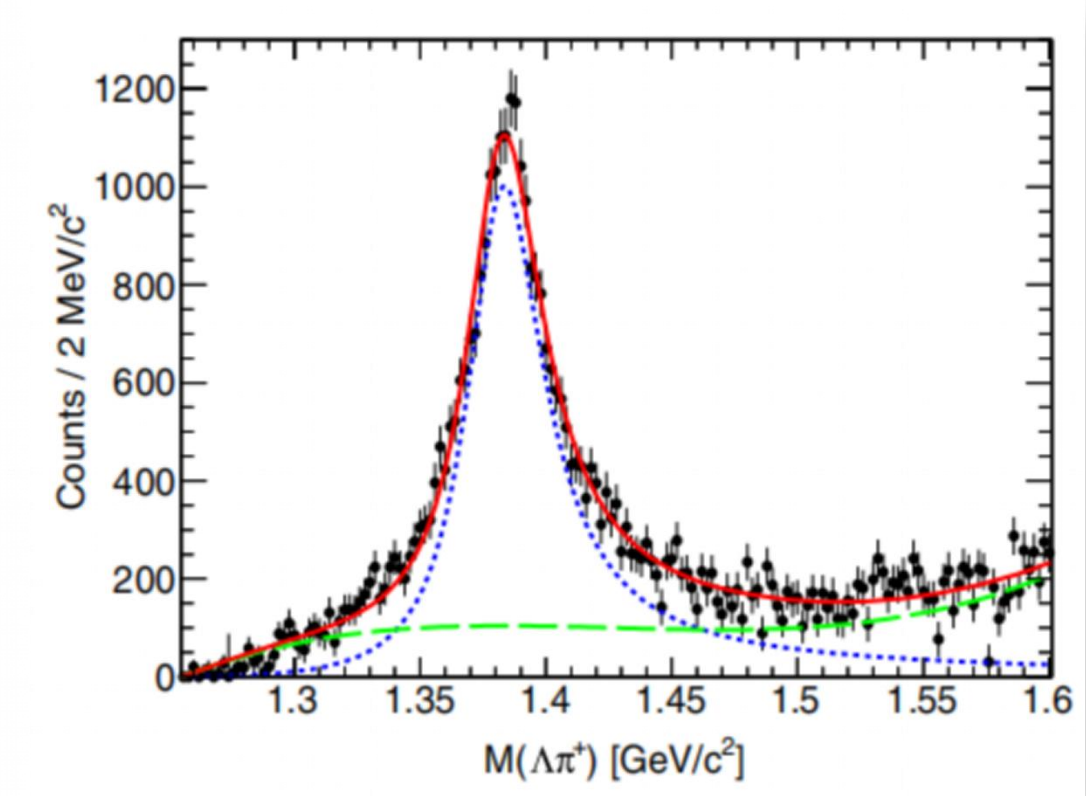




Belle and BESIII measurements

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



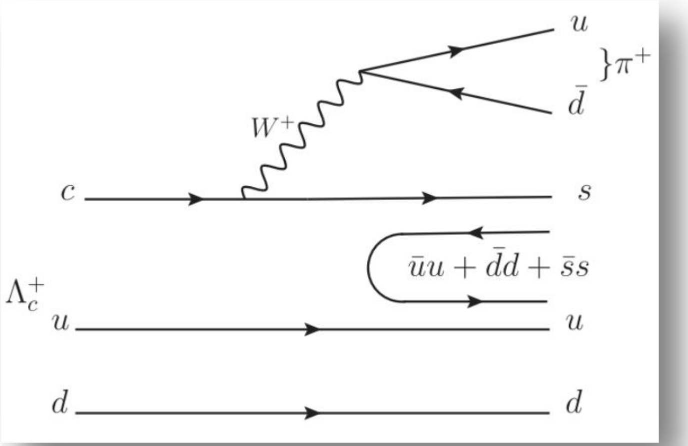


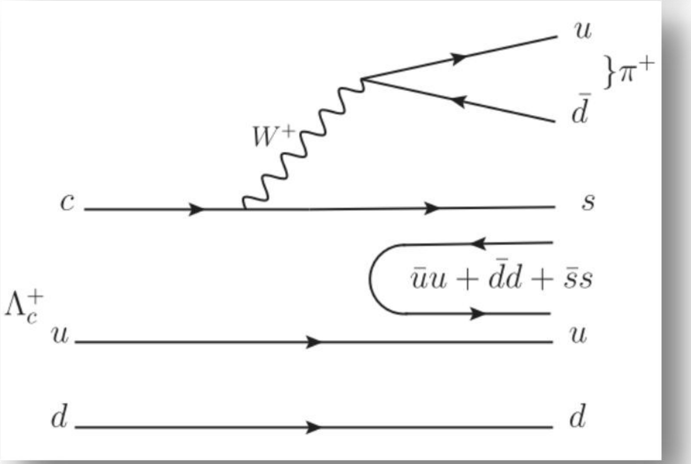
BESIII: PRD99, 032010 (2019)

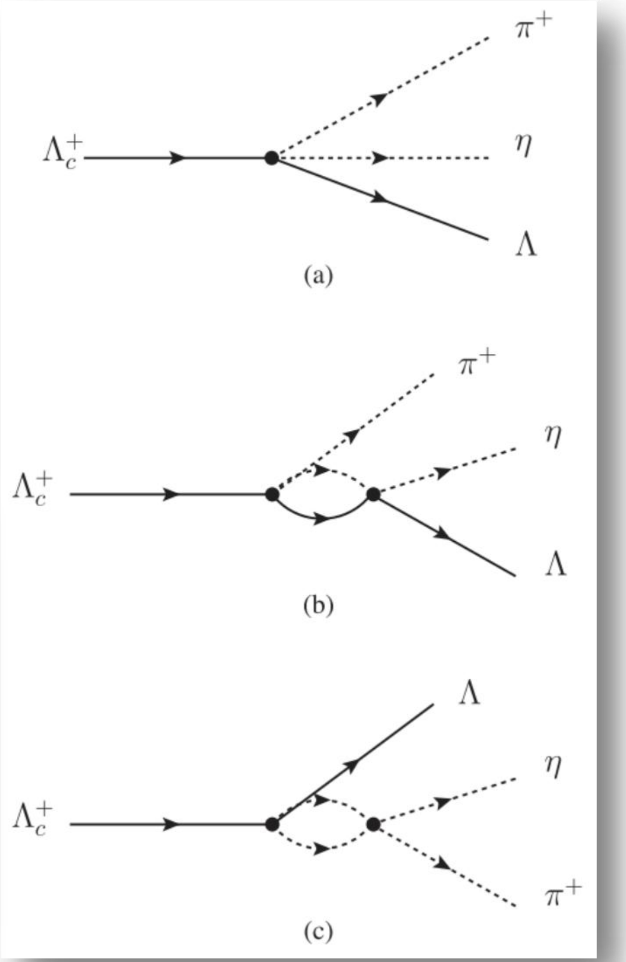
Belle: PRD103(2021)052005

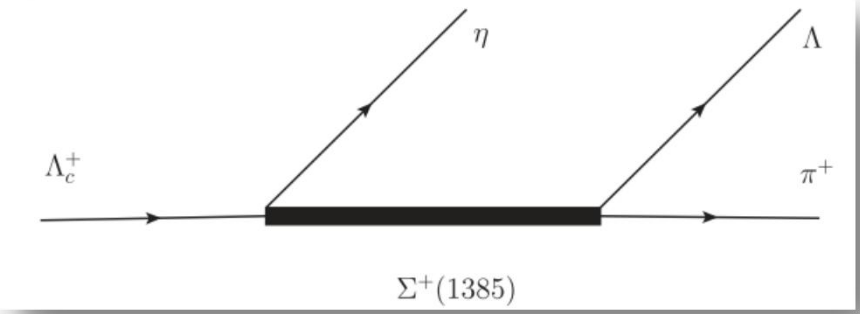
Mechanism of $\Lambda_c \to \eta\Lambda\pi$

□Theometical model









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

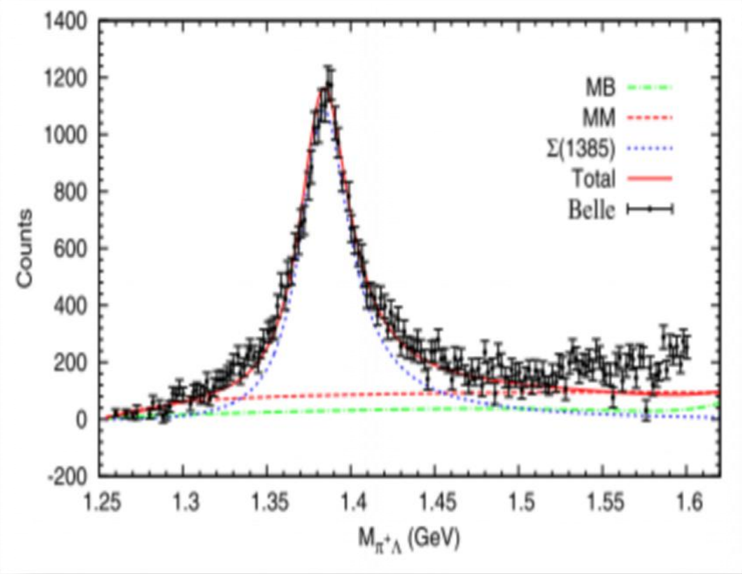
$$T^{\rm MB}(M_{\eta\Lambda}) = V_P\Big\{-\frac{\sqrt{2}}{3} + G_{K^-p}(M_{\eta\Lambda})t_{K^-p\to\eta\Lambda}(M_{\eta\Lambda}) + G_{\bar{K}^0 n}(M_{\eta\Lambda})t_{\bar{K}^0 n\to\eta\Lambda}(M_{\eta\Lambda}) - \frac{\sqrt{2}}{3}G_{\eta\Lambda}(M_{\eta\Lambda})t_{\eta\Lambda\to\eta\Lambda}(M_{\eta\Lambda})\Big\},$$

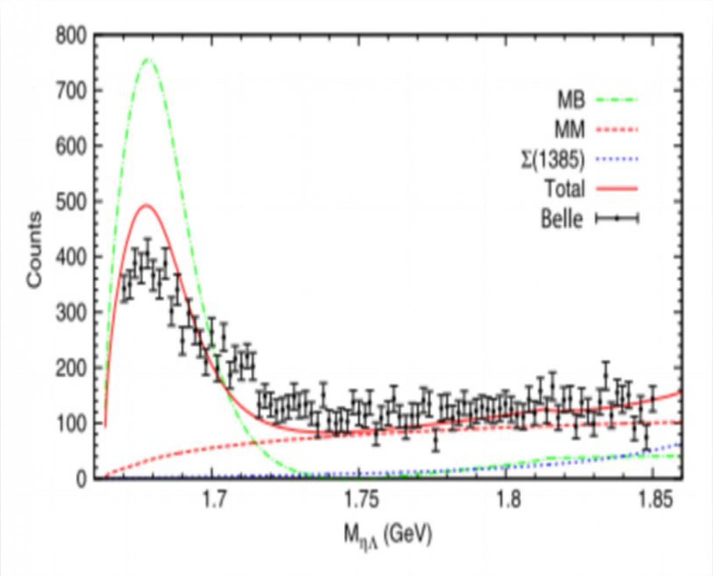
$$T^{\rm MM}(M_{\pi^+\eta}) = V_P'\frac{2\sqrt{2}}{3}\Big\{1 + G_{\pi^+\eta}(M_{\pi^+\eta})t_{\pi^+\eta\to\pi^+\eta}(M_{\pi^+\eta}) + \frac{\sqrt{3}}{2}G_{K^+\bar{K}^0}(M_{\pi^+\eta})t_{K^+\bar{K}^0\to\pi^+\eta}(M_{\pi^+\eta})\Big\}, \quad ($$

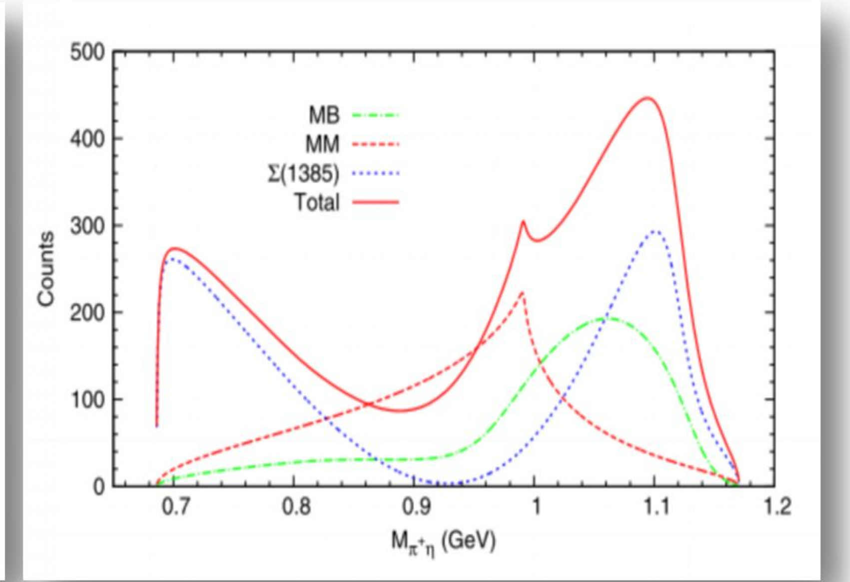
GYW-EW-Xie-Geng-Wei, PRD 106, 056001 (2022)

Analysis the Belle data

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

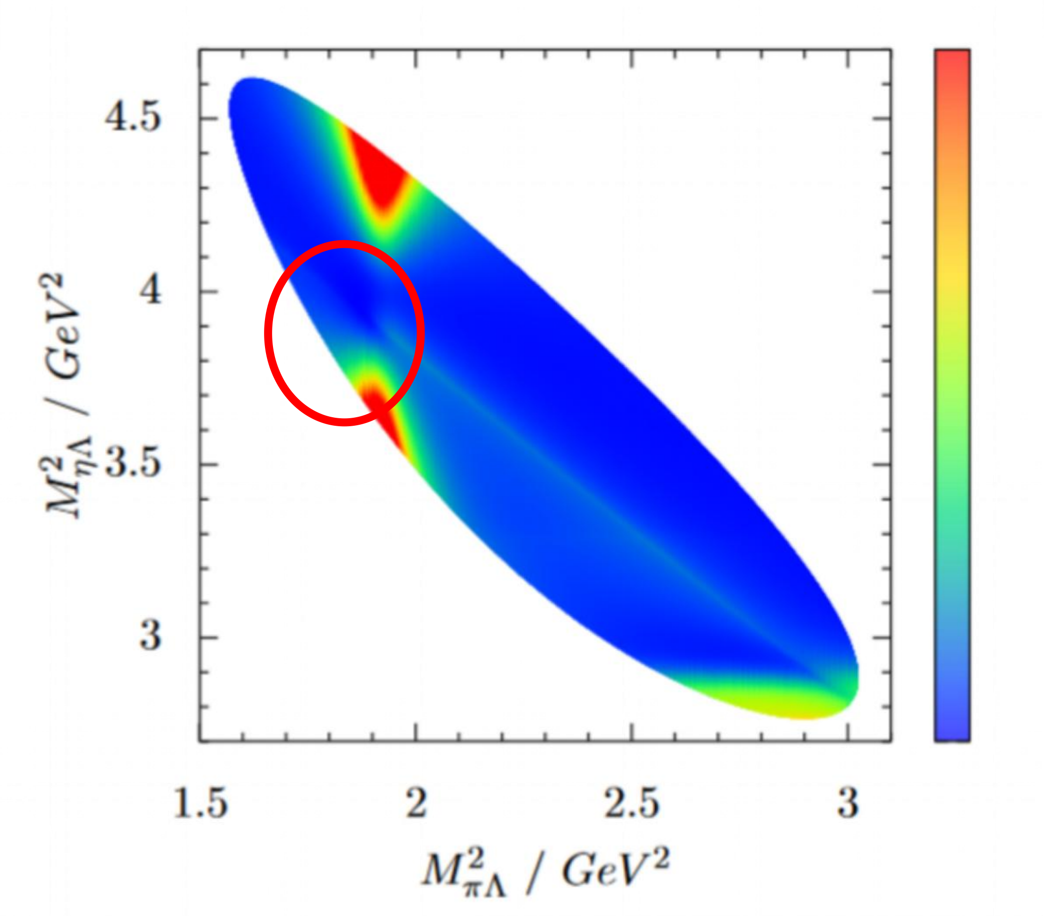


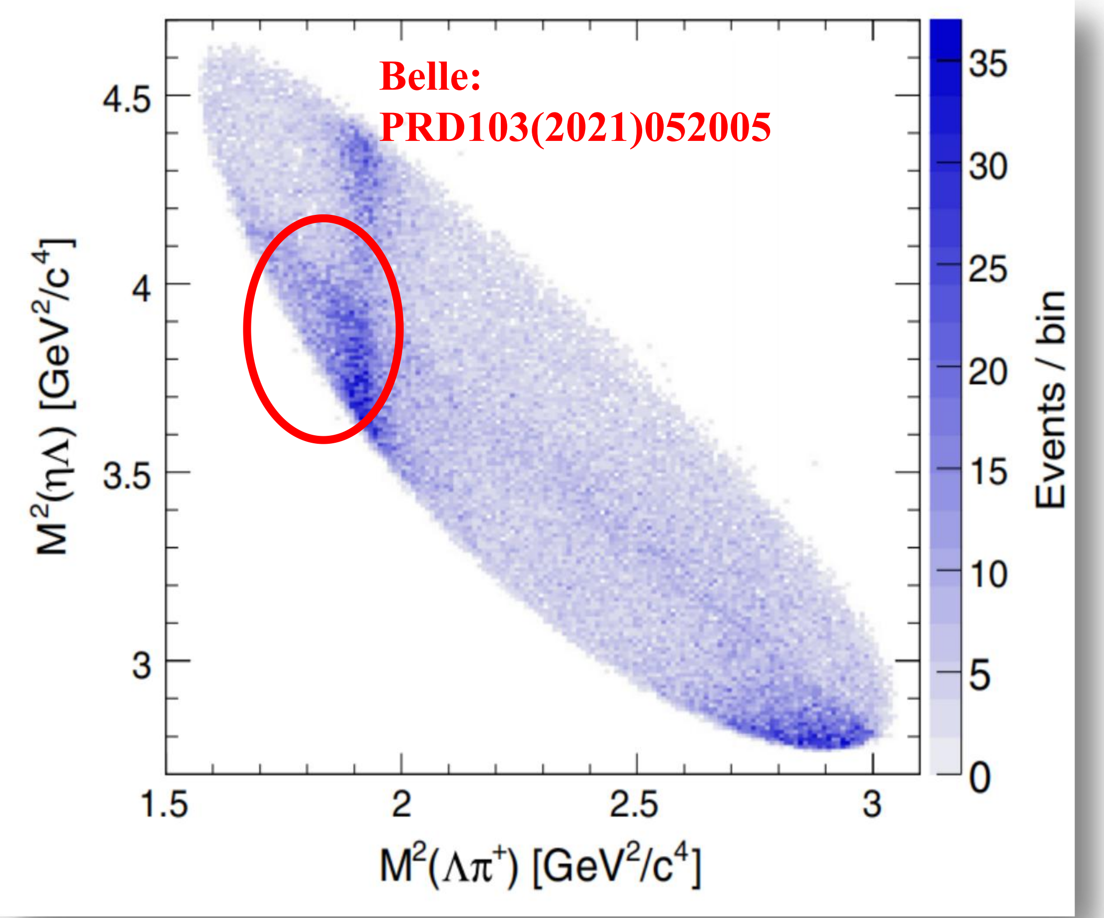




By regarding the $\Lambda(1670)$ as the molecule, we could well reproduce the Belle data of the mass distributions.

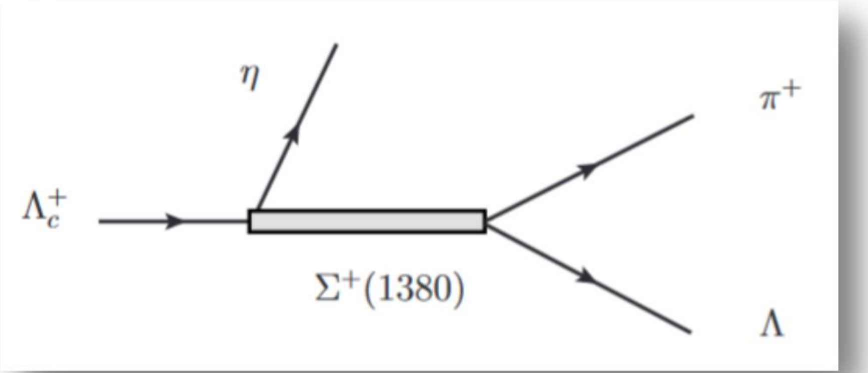
Dalitz plot of $\Lambda_c \to \eta\Lambda\pi$

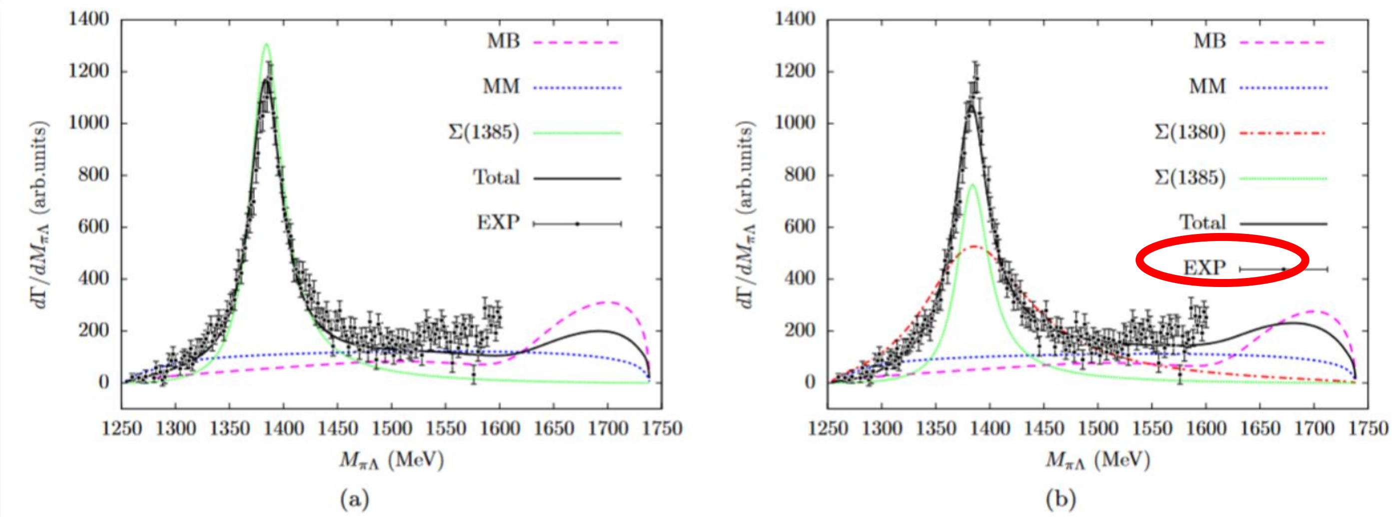




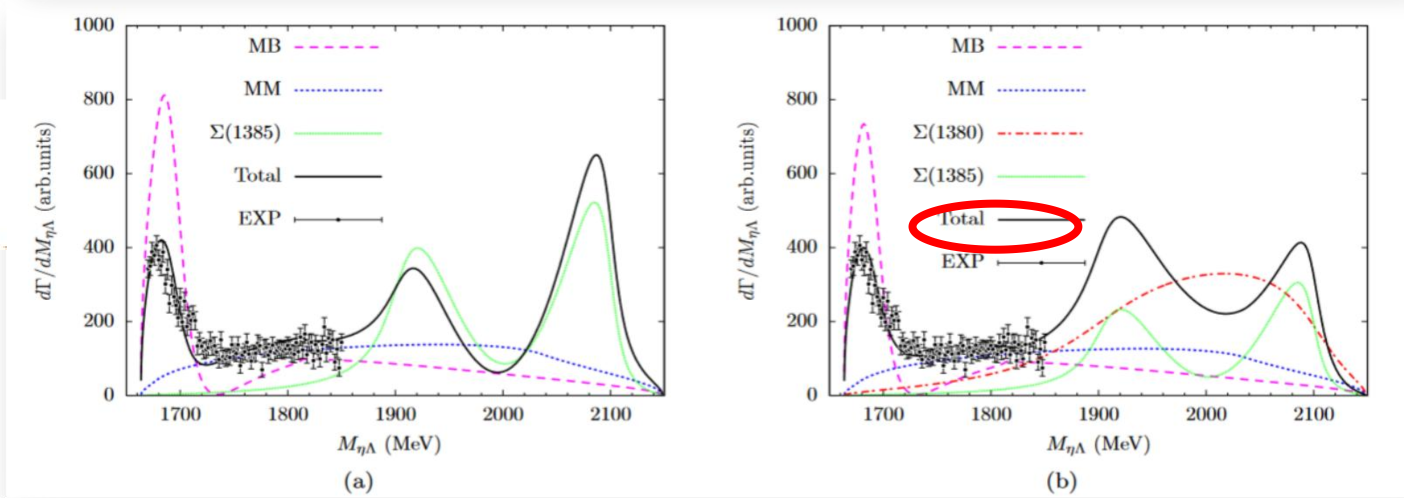
$\Sigma(1/2^-)$ in $\Lambda_c \to \eta\Lambda\pi$

□Intermediate of $\Sigma(1/2^-)$

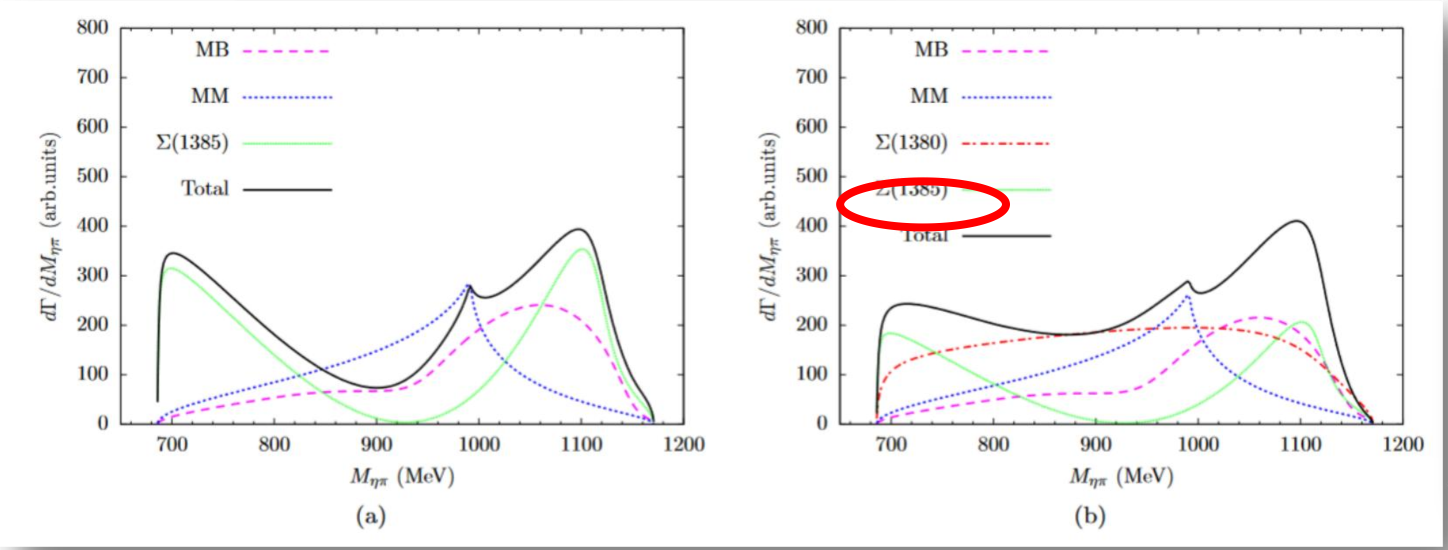


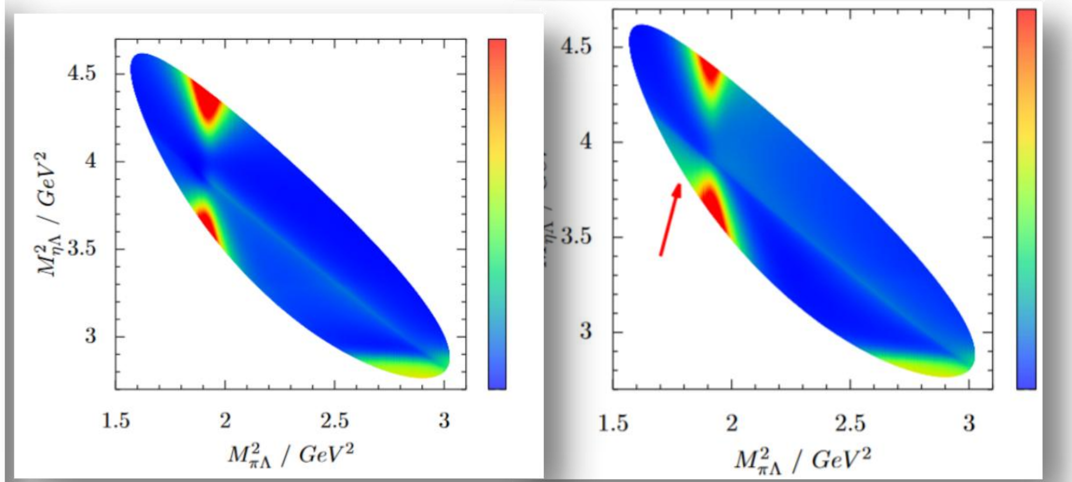


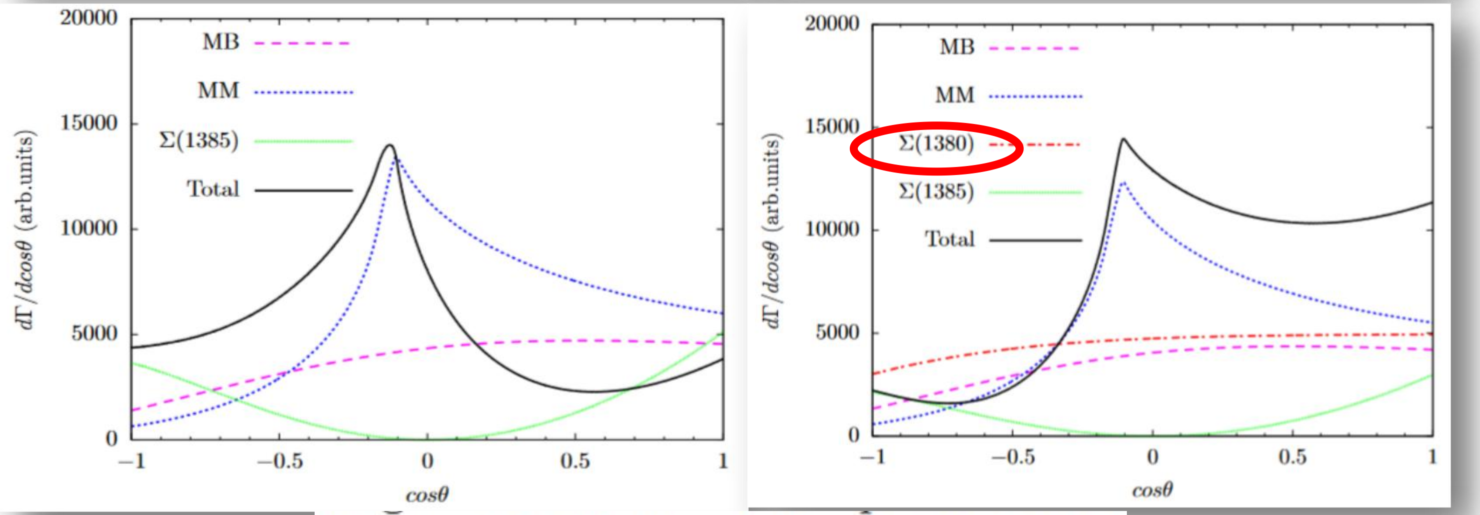
$$\mathcal{T}^{\Sigma(1/2^-)} = \frac{V^{\Sigma(1/2^-)} M_{\Sigma(1/2^-)} \Gamma_{\Sigma(1/2^-)}}{M^2_{\pi^+\Lambda} - M^2_{\Sigma(1/2^-)} + iM_{\Sigma(1/2^-)}\Gamma_{\Sigma(1/2^-)}},$$



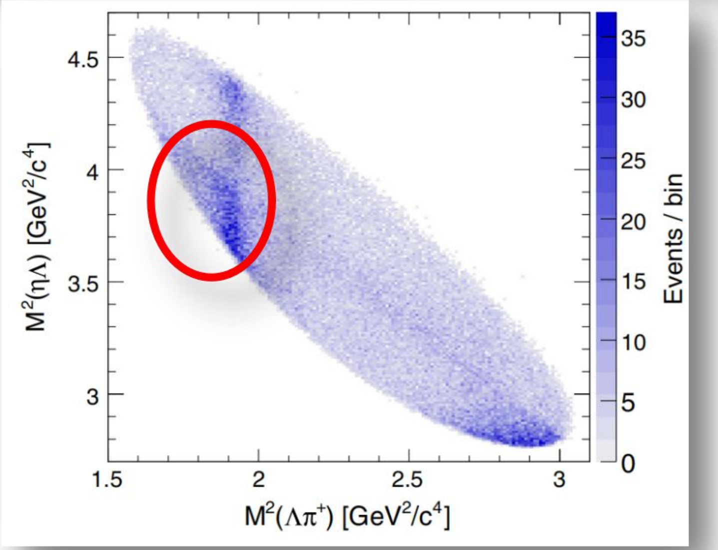
The results with/without Σ(1380)







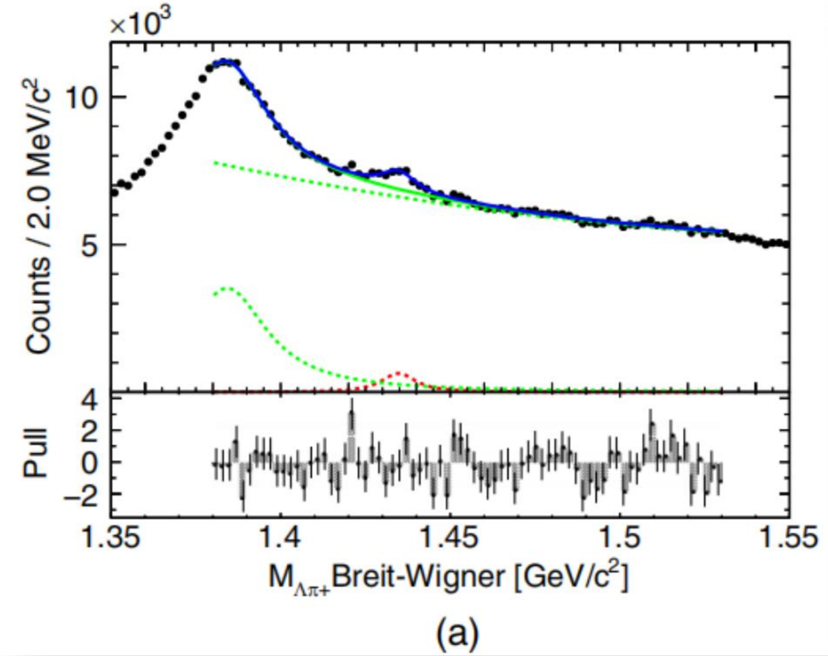
$M_{\pi\Lambda} \geq 1450$ MeV and $M_{\eta\Lambda} \geq 1760$ MeV.

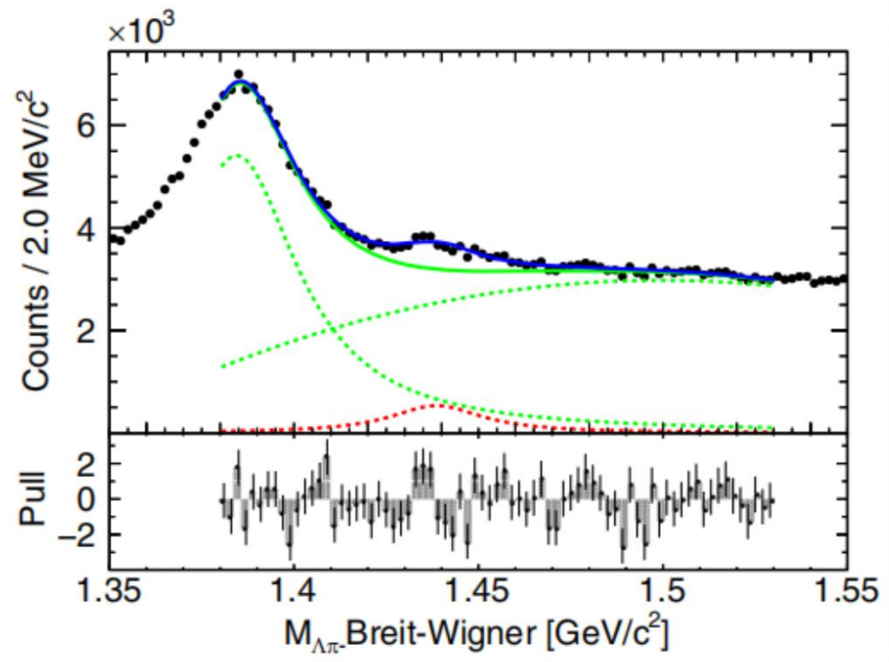


to be prepared

Belle measurements

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

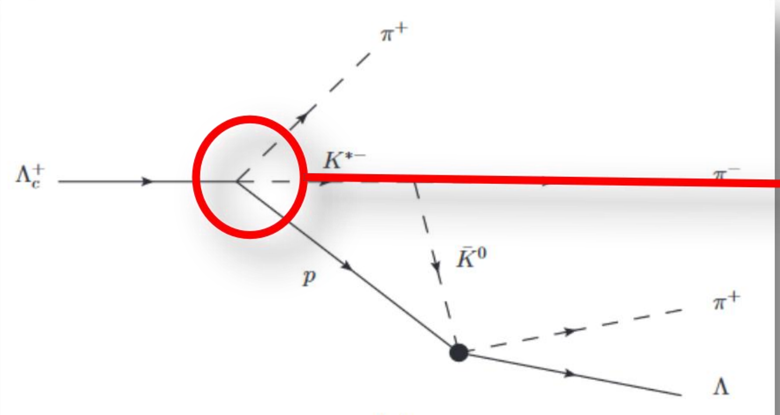




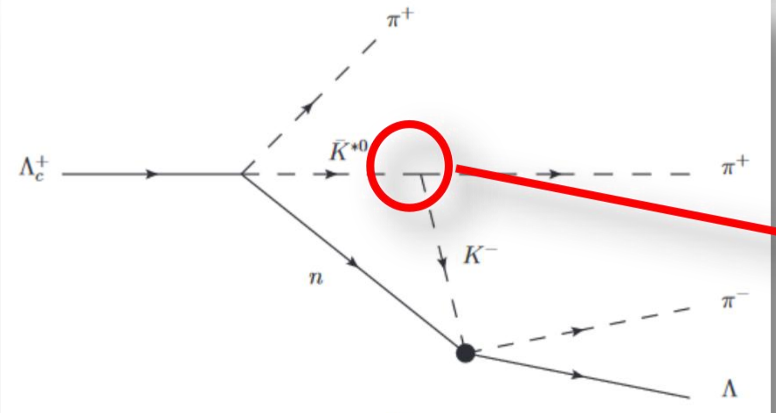
Mode	E_{BW} (MeV/c^2)	Γ (MeV/c^2)	χ^2/NDF
$\Lambda\pi^+$	1434.3 ± 0.6	11.5 ± 2.8	74.4/68
$\Lambda\pi^-$	1438.5 ± 0.9	33.0 ± 7.5	92.3/68

Evidence of Σ(1430)

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



(a)



(b)

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

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

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

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

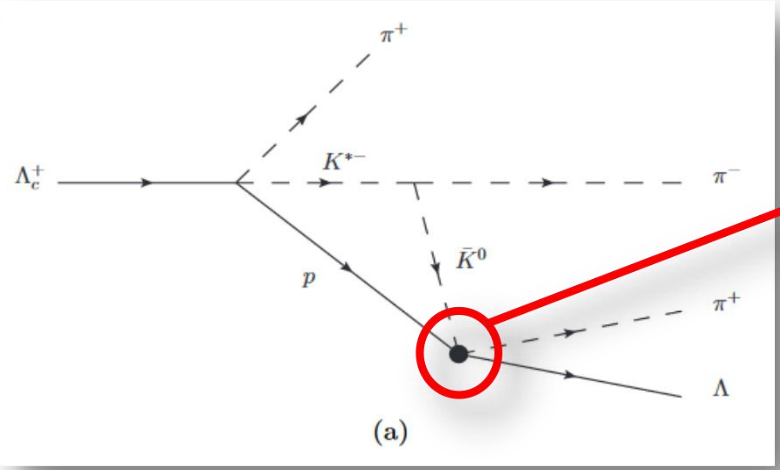
$$|A|^2 = (3.9\pm1.4)\times10^{-16}\ \mathrm{MeV}^{-2}.$$

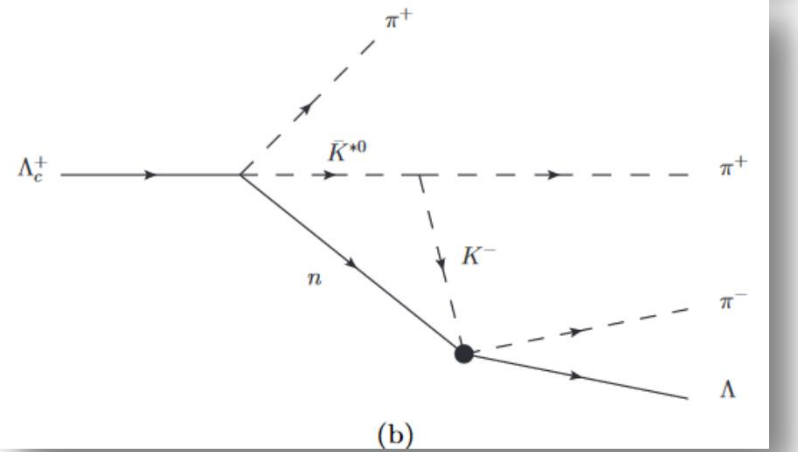
$$\mathcal{L}_{VPP} = -ig < V^\mu[P,\partial P] >$$

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

Evidence of Σ(1430)

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





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

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

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

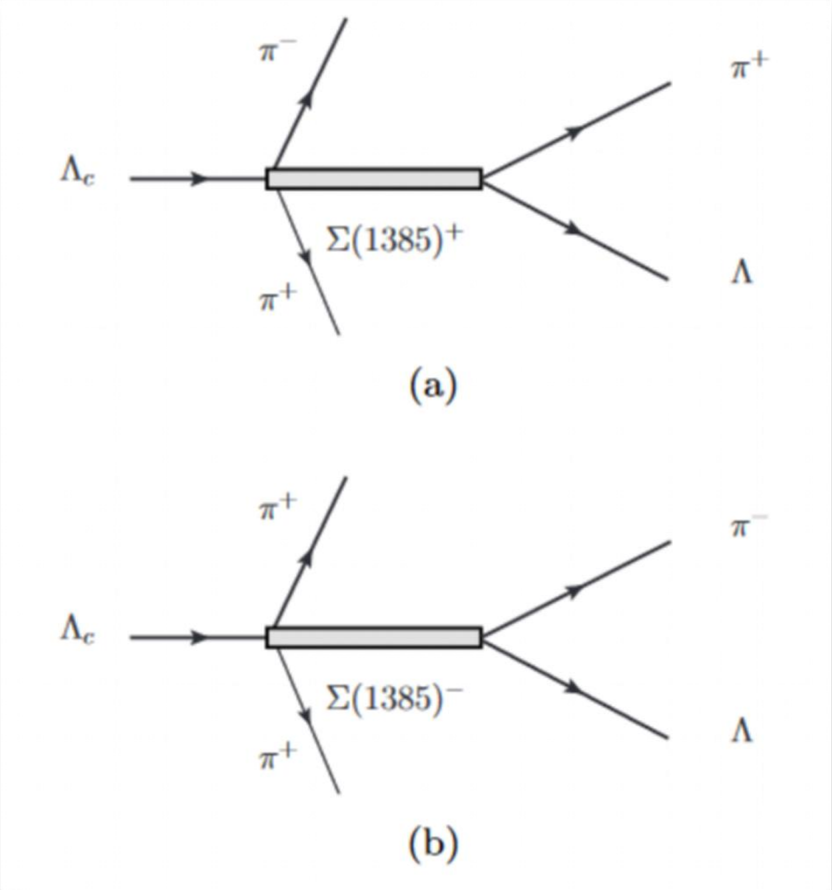
$$T = [1 - VG]^{-1}V,$$

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

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

Evidence of Σ(1430)

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



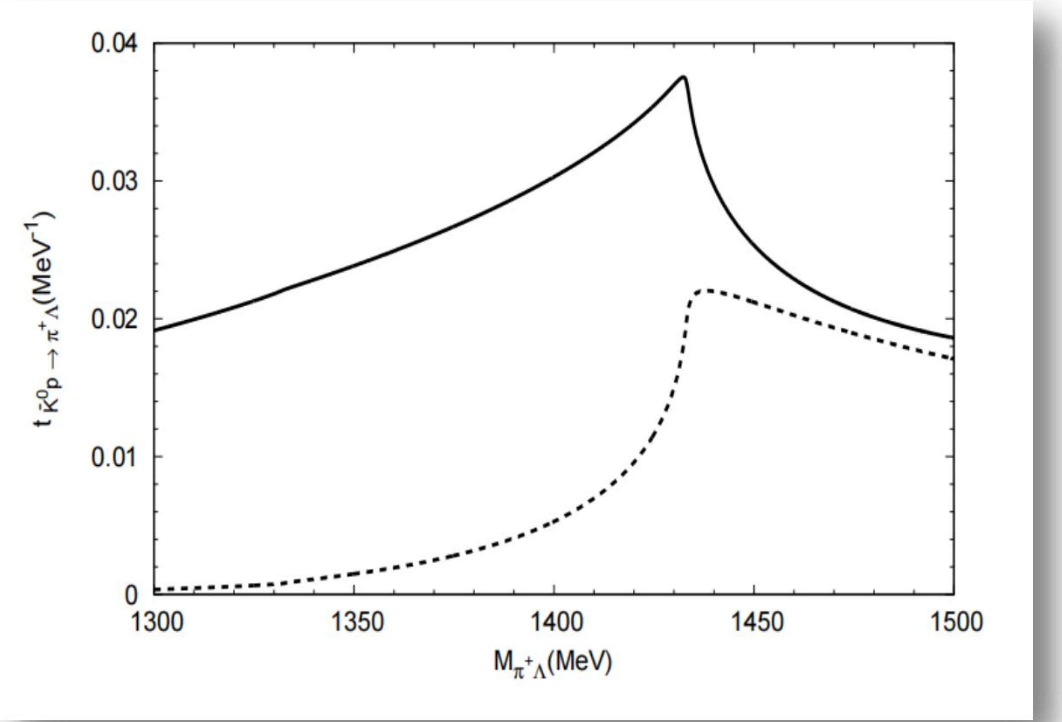
$$T^{\Sigma^{*+}(1385)} = \frac{V_p |p_{\pi^+}|}{M_{\pi^+\Lambda} - M_{\Sigma^{*+}} + i\frac{\Gamma_{\Sigma^{*+}}}{2}},$$

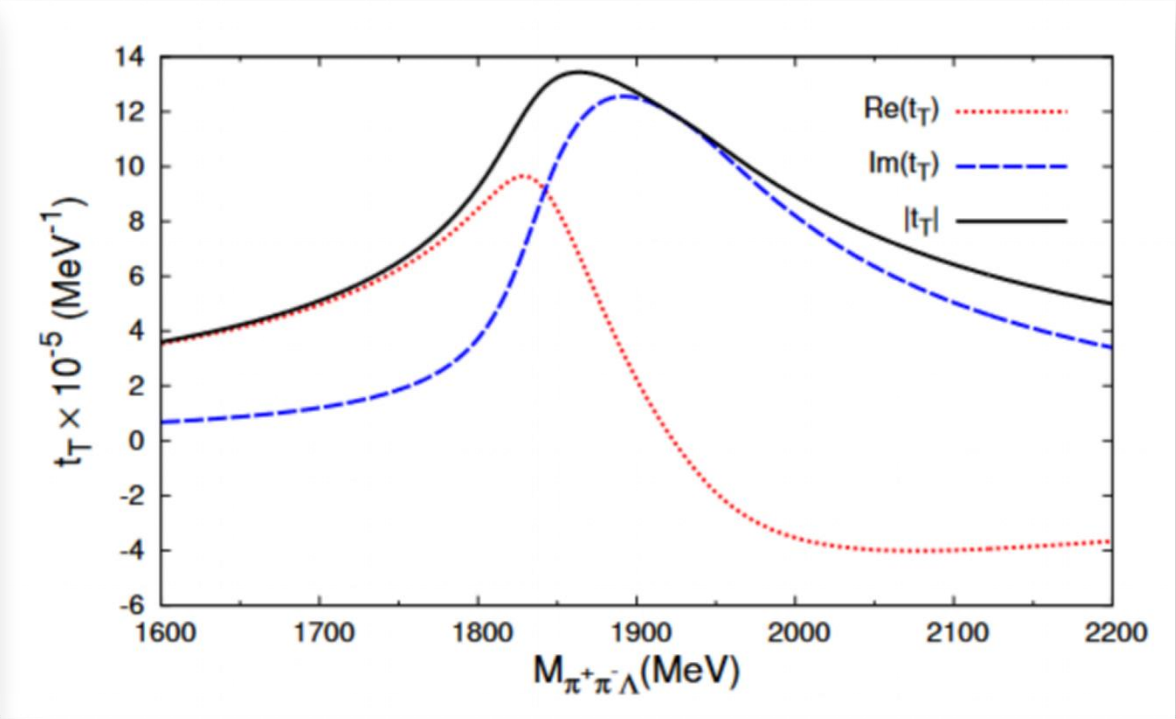
$$T^{\Sigma^{*-}(1385)} = \frac{V_p |p_{\pi^-}|}{M_{\pi^-\Lambda} - M_{\Sigma^{*-}} + i\frac{\Gamma_{\Sigma^{*-}}}{2}},$$

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

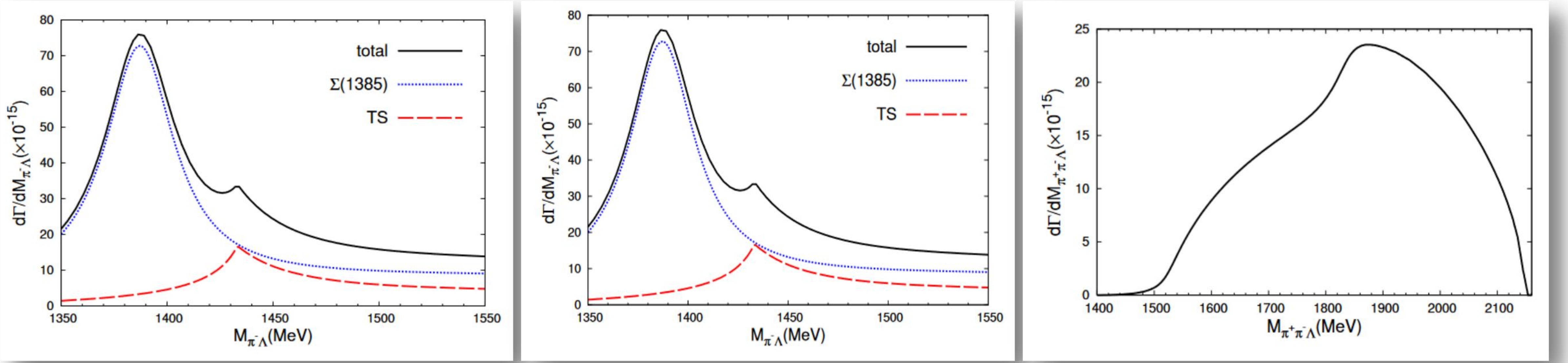
Evidence of $\Sigma(1430)$

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



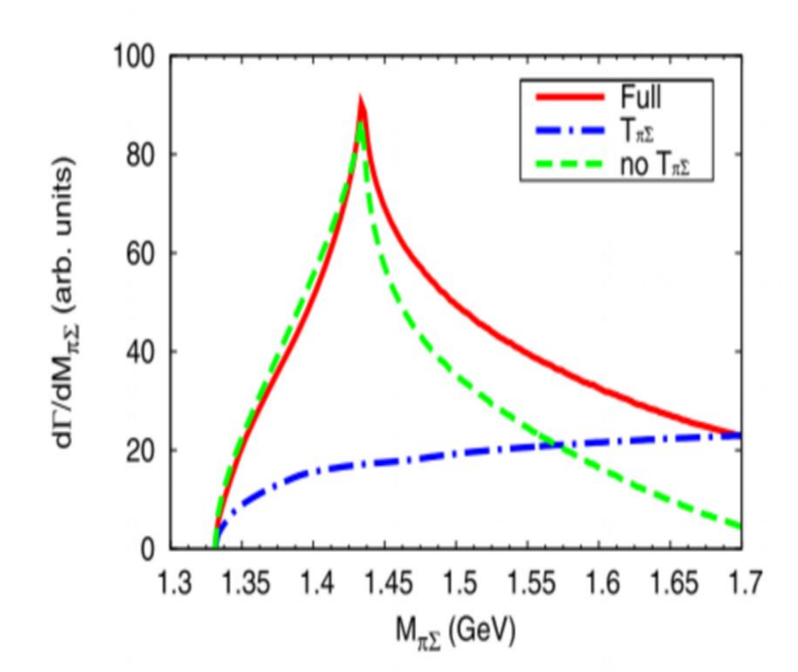


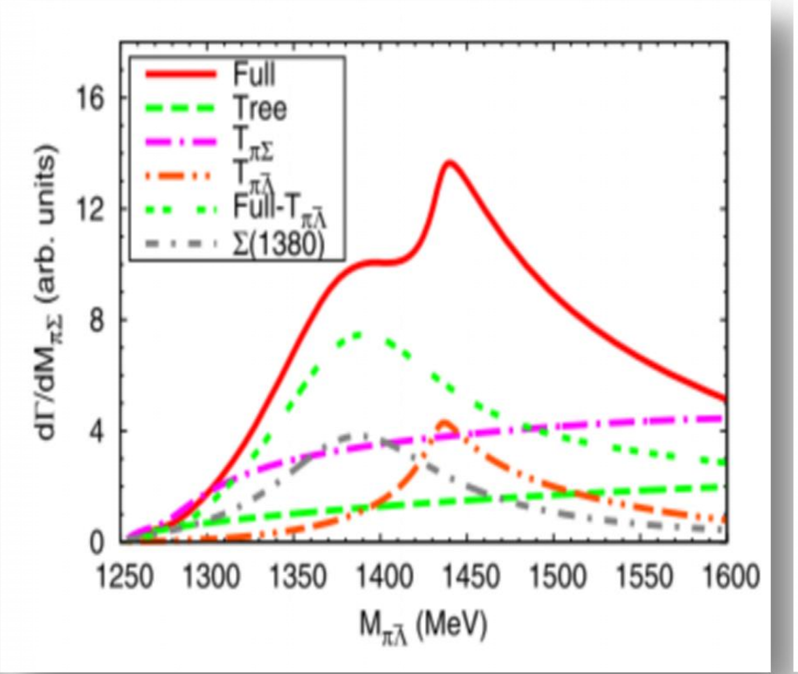
Results of $\Lambda_c \to \Lambda\pi^+\pi^+\pi^-$

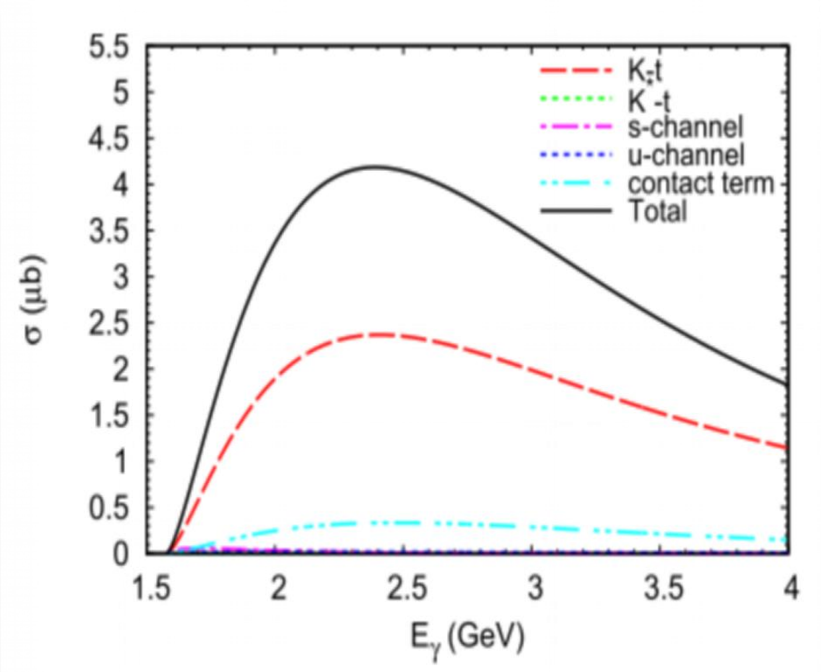


Cusp signal of $\Sigma(1/2^-)$ around $\bar{K}N$ threshold!

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

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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 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!