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

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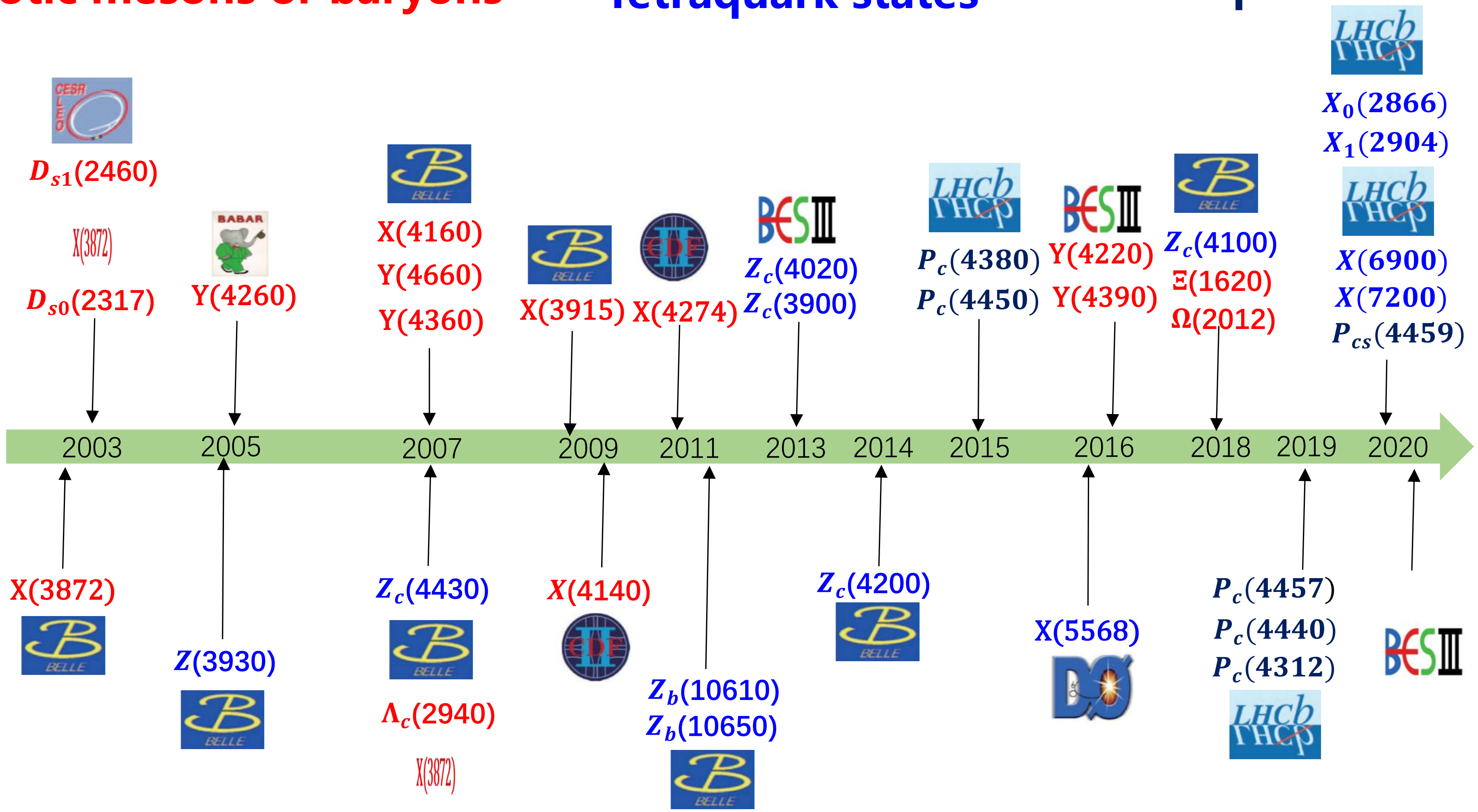
第六届强子谱与强子结构研讨会

2023年8月27-31日

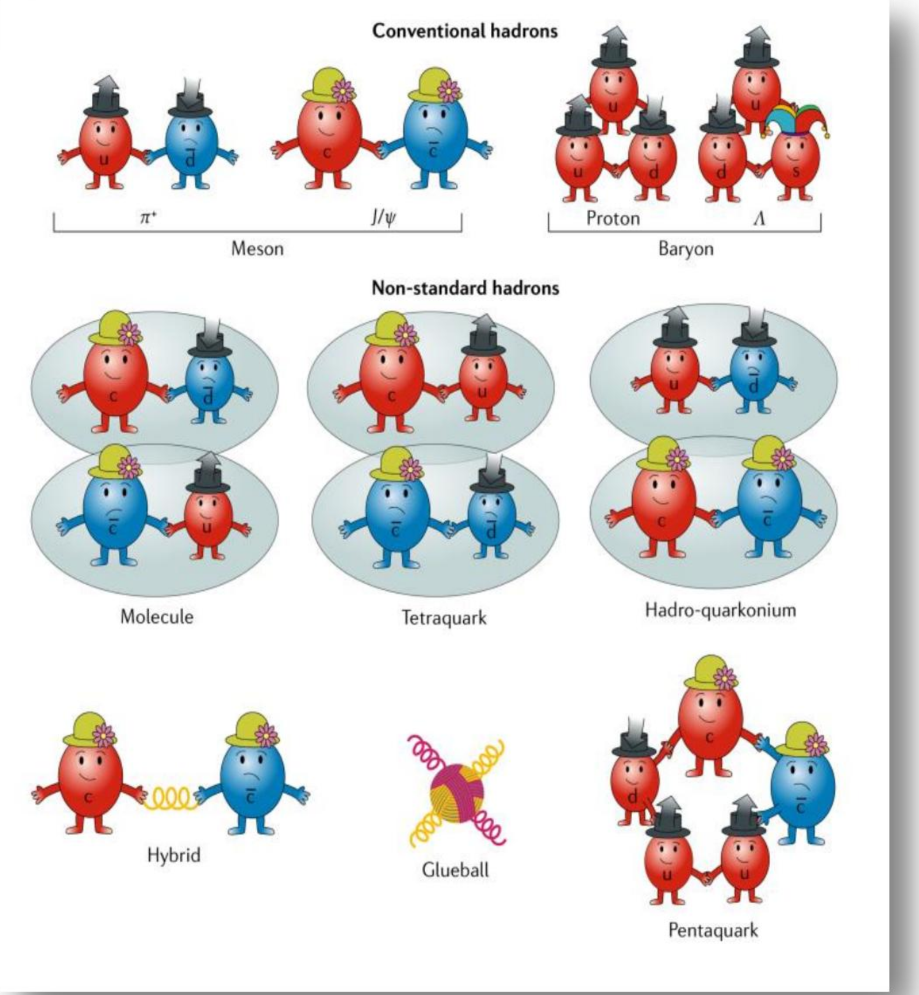
Exotic states

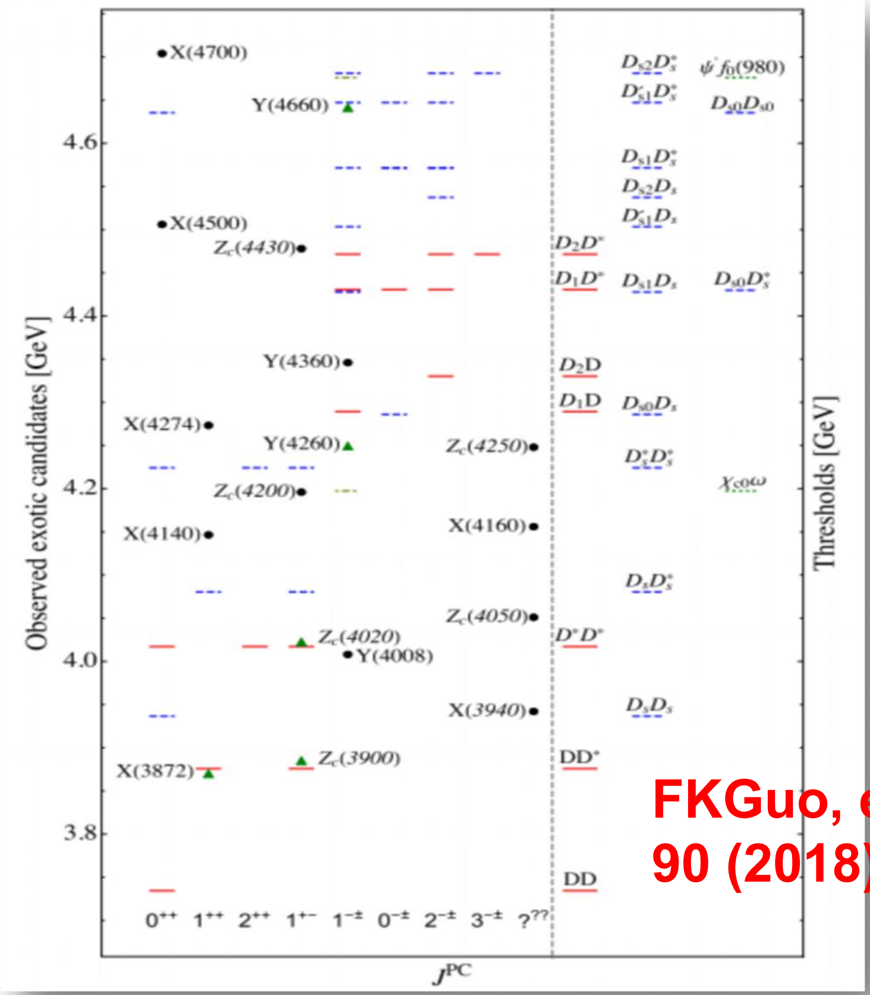
耿立升老师报告

Exotic mesons or baryons **Tetraquark states** **Pentaquark states**



Hadrons





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

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

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

$1/2^-$ 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 $\Lambda^*(1670)$:
  $N^*(1535)$ large couplings $g_{N^*N\eta}$, $g_{N^*K\Lambda}$, $g_{N^*N\eta'}$, $g_{N^*N\phi}$
  $\Lambda^*(1670)$ large coupling $g_{\Lambda^*\Lambda\eta}$

邹老师 报告

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

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

OMITTED FROM SUMMARY TABLE

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

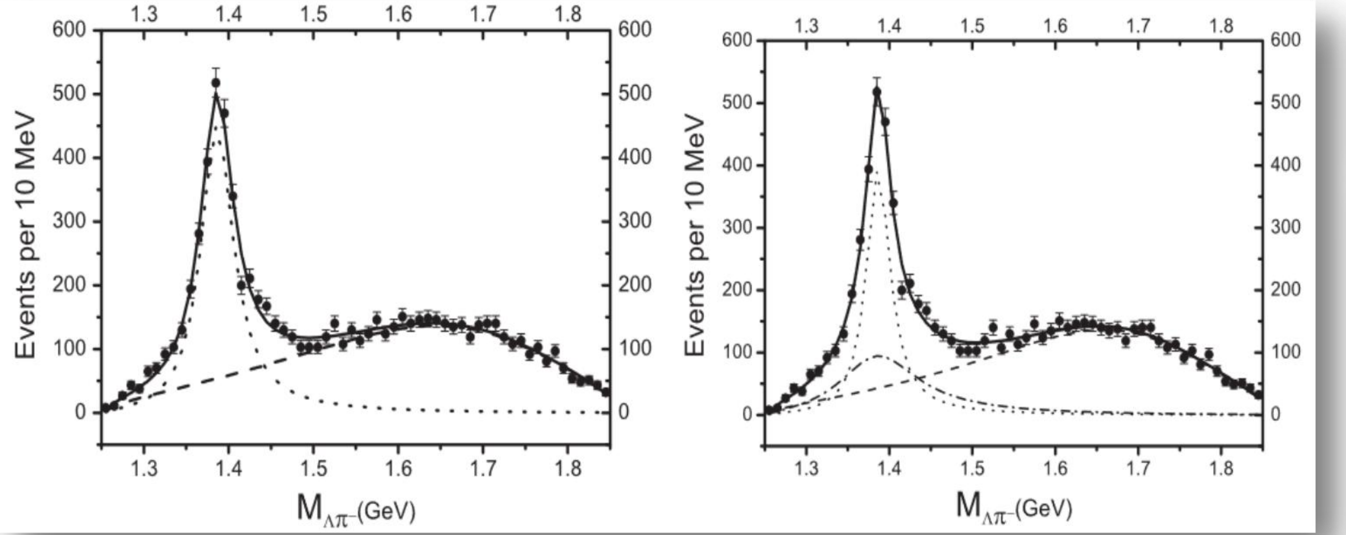
$\Sigma(1480)$ Bumps $I(J^P) = 1(?^?)$ Status: $*$

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.

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

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



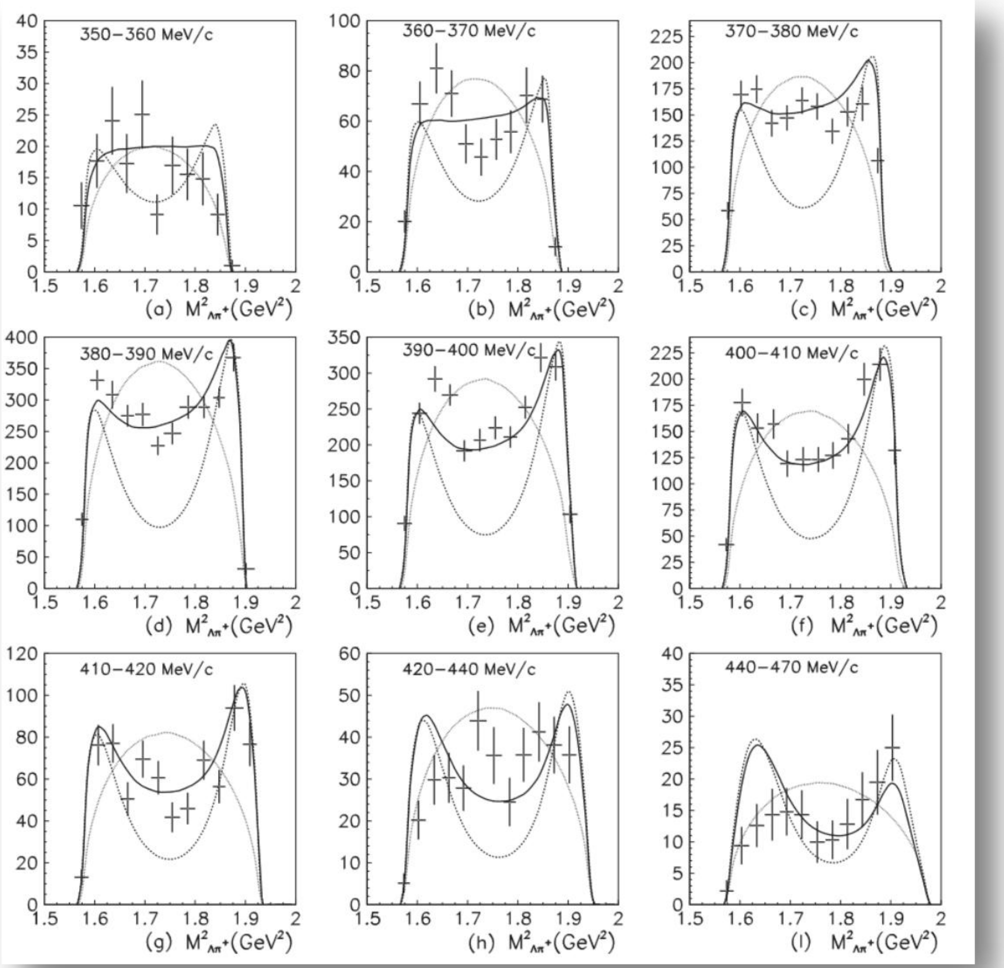
$$\frac{dN}{dm_{\Lambda\pi^-}} \propto p_1 \times p_2 \times \sum_{i=1}^{3} \frac{|a_i|}{(m^2_{\Lambda\pi^-} - m_i^2)^2 + m_i^2 \times \Gamma_i^2},$$

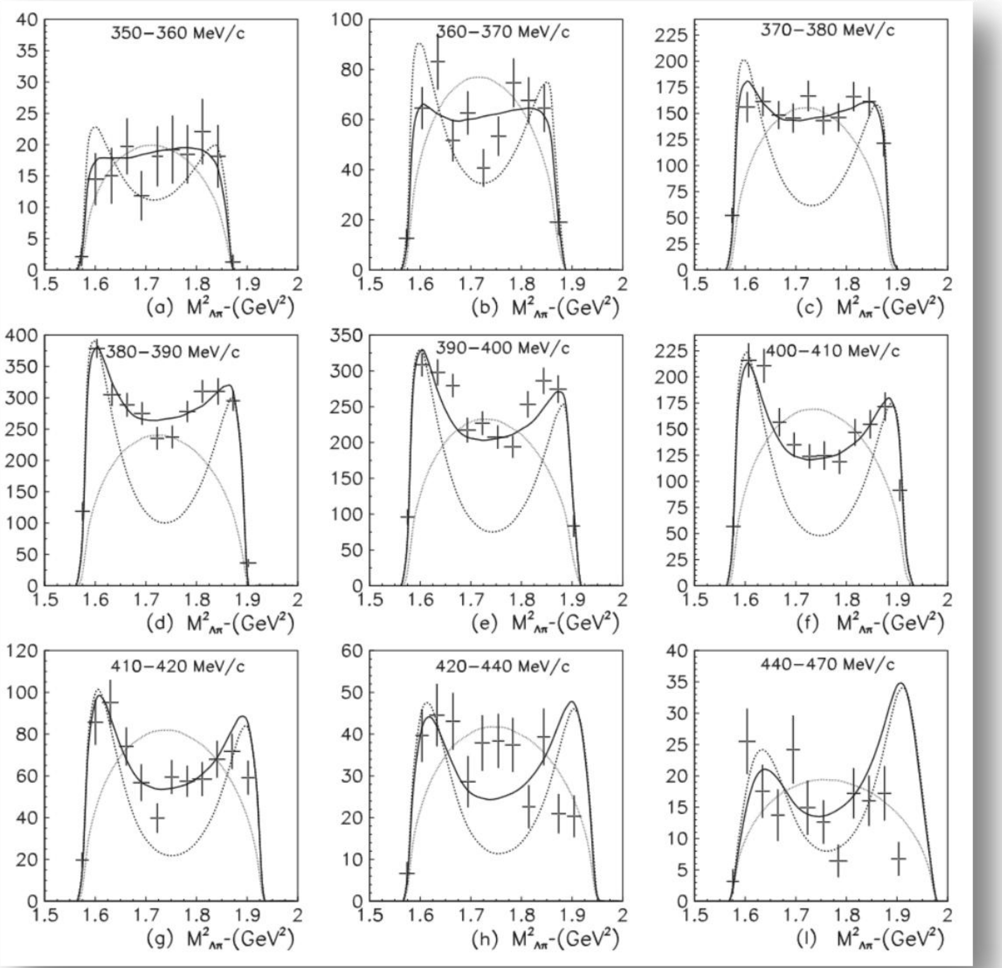
Here we reexamine some old data of the $K^- p \to \Lambda\pi^+\pi^-$ reaction and find that besides the well-established $\Sigma^*(1385)$ with $J^P = 3/2^+$, there is indeed some evidence for the possible existence of a new Σ^* resonance with $J^P = 1/2^-$ around the same mass but with broader decay 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

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

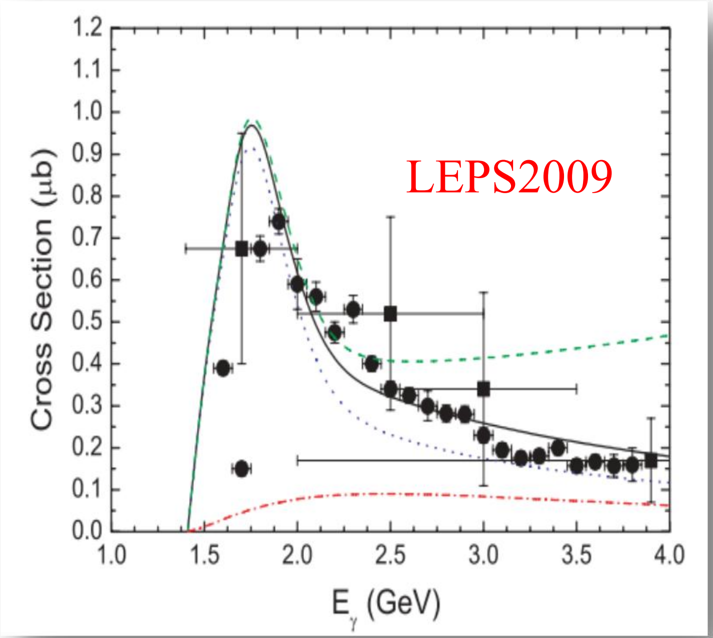
- $K^{-}p \rightarrow \Lambda\pi^{+}\pi^{-}$, Wu-Dulat-Zou, PRC81(2010)045210

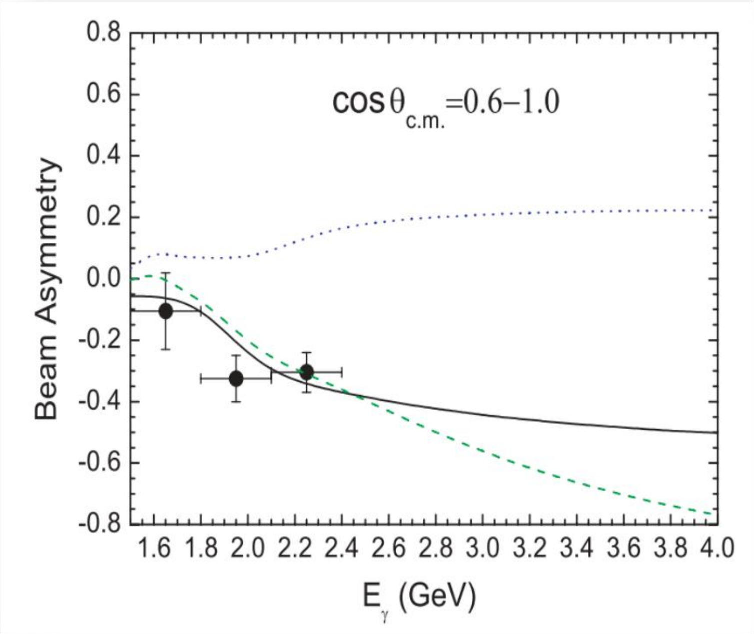


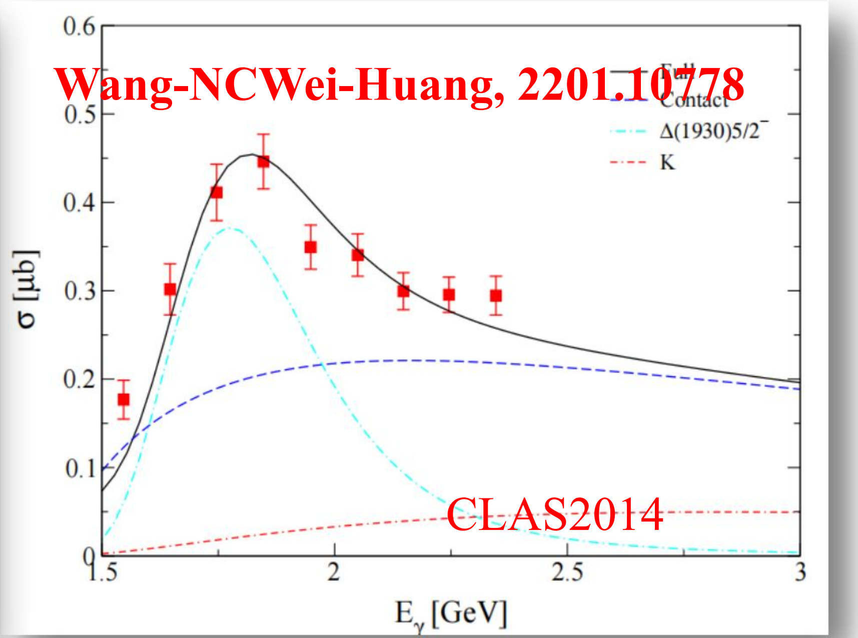


Search for $\Sigma(1/2^-)$

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





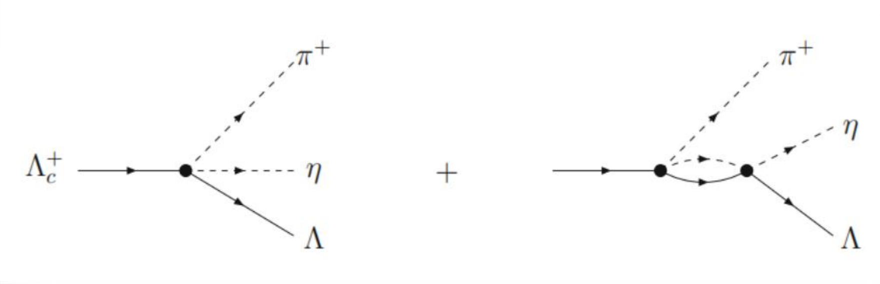


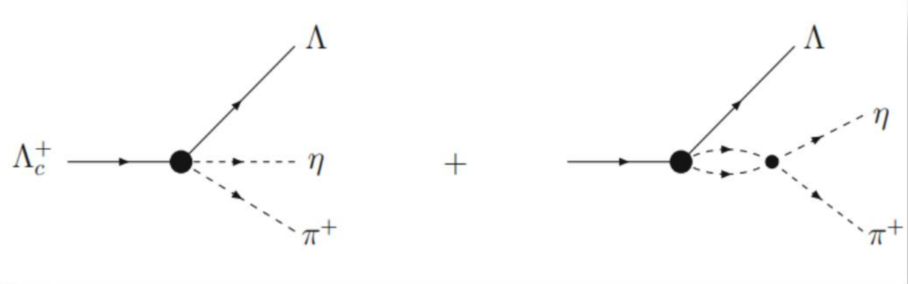
the case that the $\Sigma(\frac{1}{2}^-)$ may contribute to the observables of the $K\Sigma^*(1385)$ photoproduction in our experiments. Our results show that the $\Sigma(\frac{1}{2}^-)$ production can provide a large negative contribution to beam asymmetry, which helps to explain the large negative 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 $\gamma n \to K^+\Sigma^{*-}$

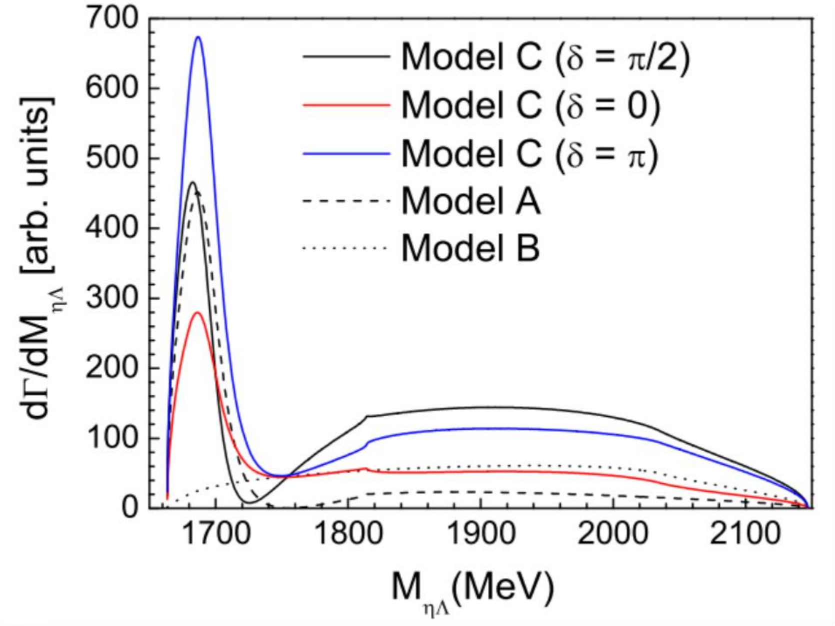
and, in particular, to figure out which one of the $N(1895)1/2^-$, $\Delta(1900)1/2^-$, and $\Delta(1930)5/2^-$ resonances is really capable for a simultaneous description of the data for both $K^+\Sigma^0(1385)$ and $K^+\Sigma^-(1385)$ photoproduction reactions. The results show that the available data 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

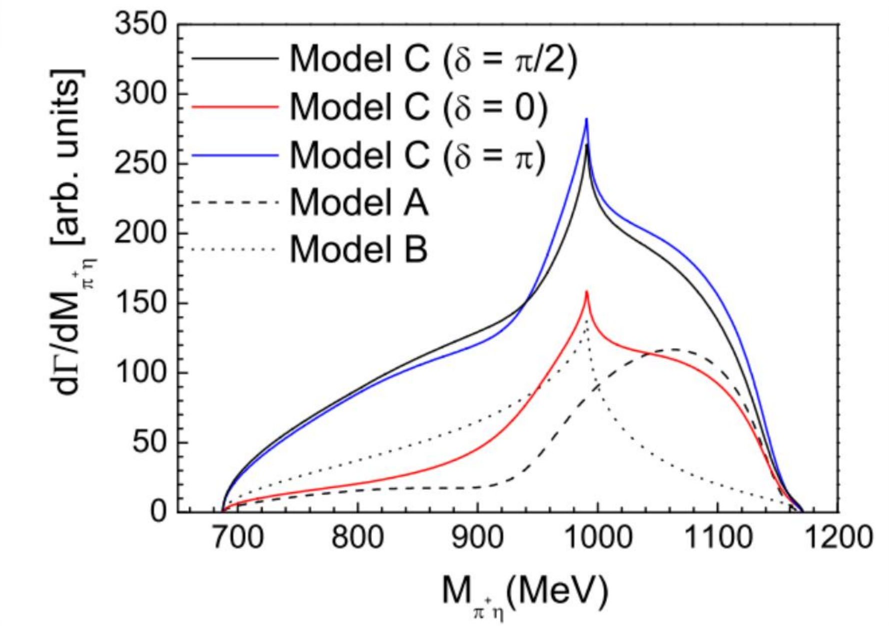
Search for $\Sigma(1/2^-)$

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



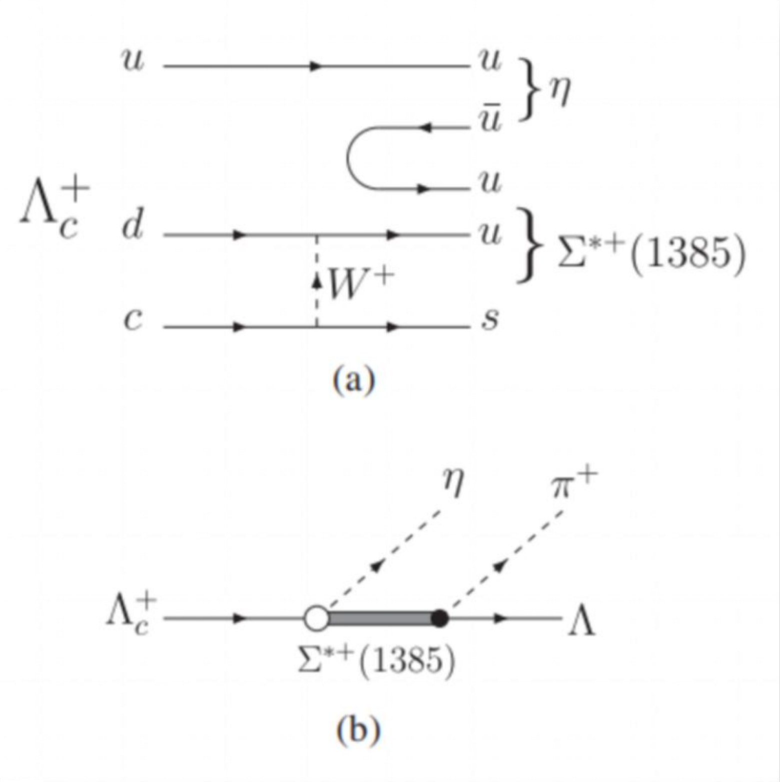


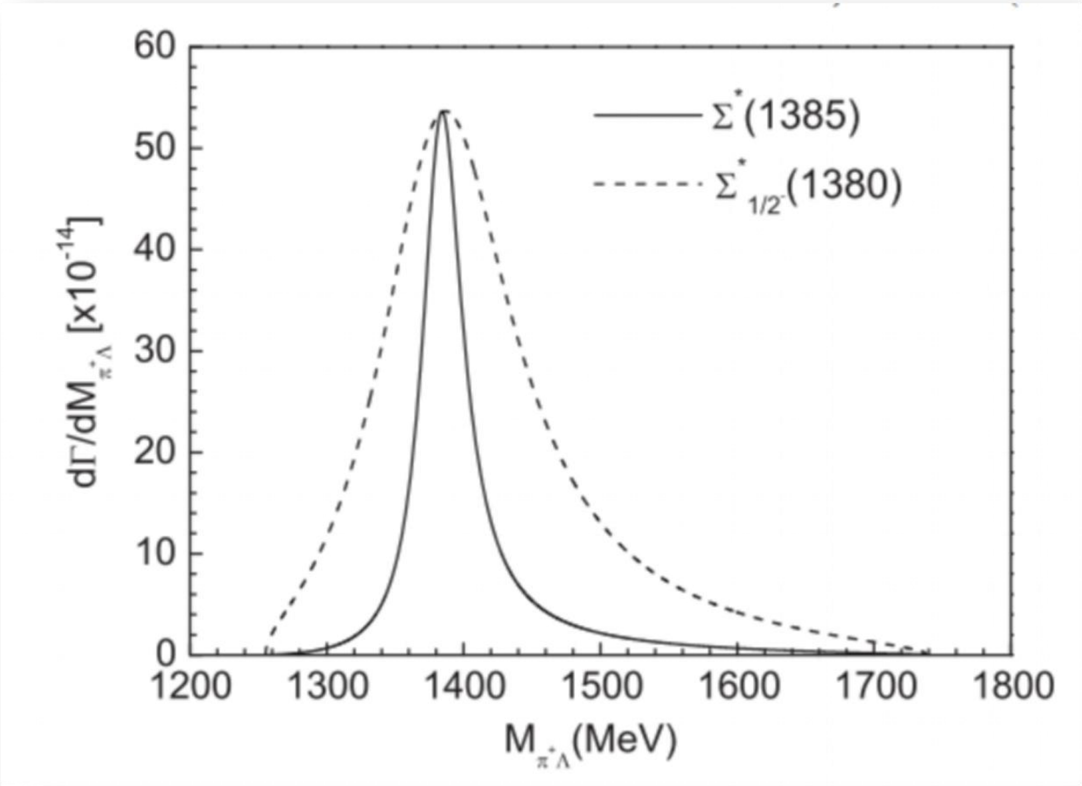




Search for $\Sigma(1/2^-)$

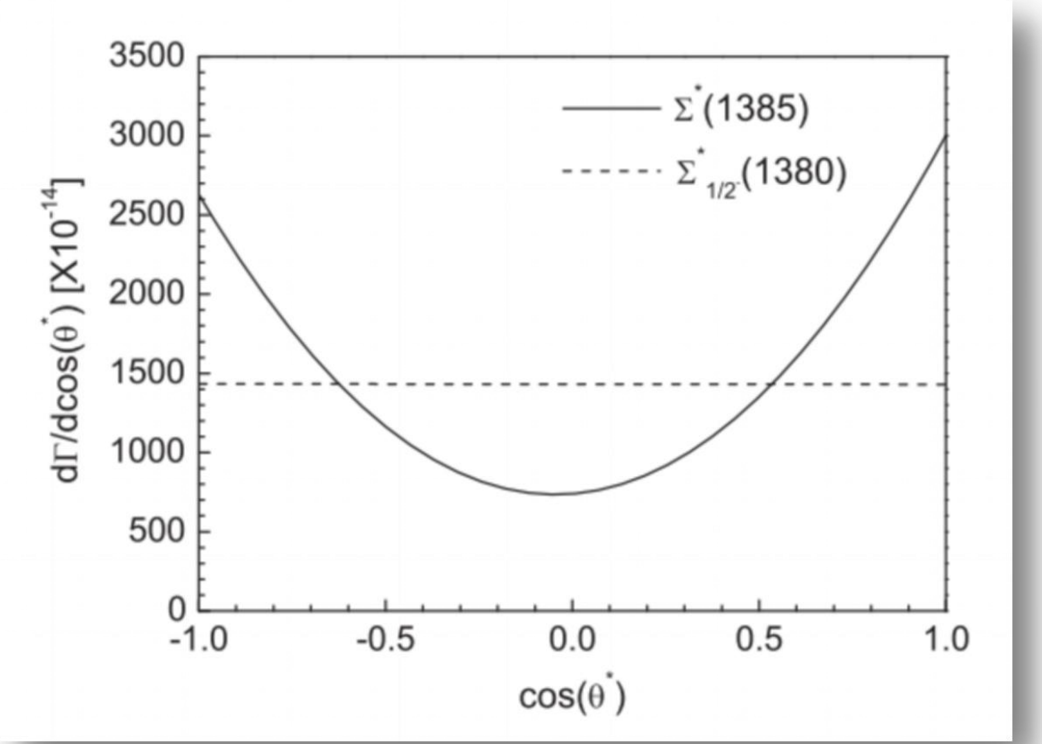
- $\Lambda_c \to \Lambda\eta\pi$, Xie-Geng, PRD95(2017) 074024

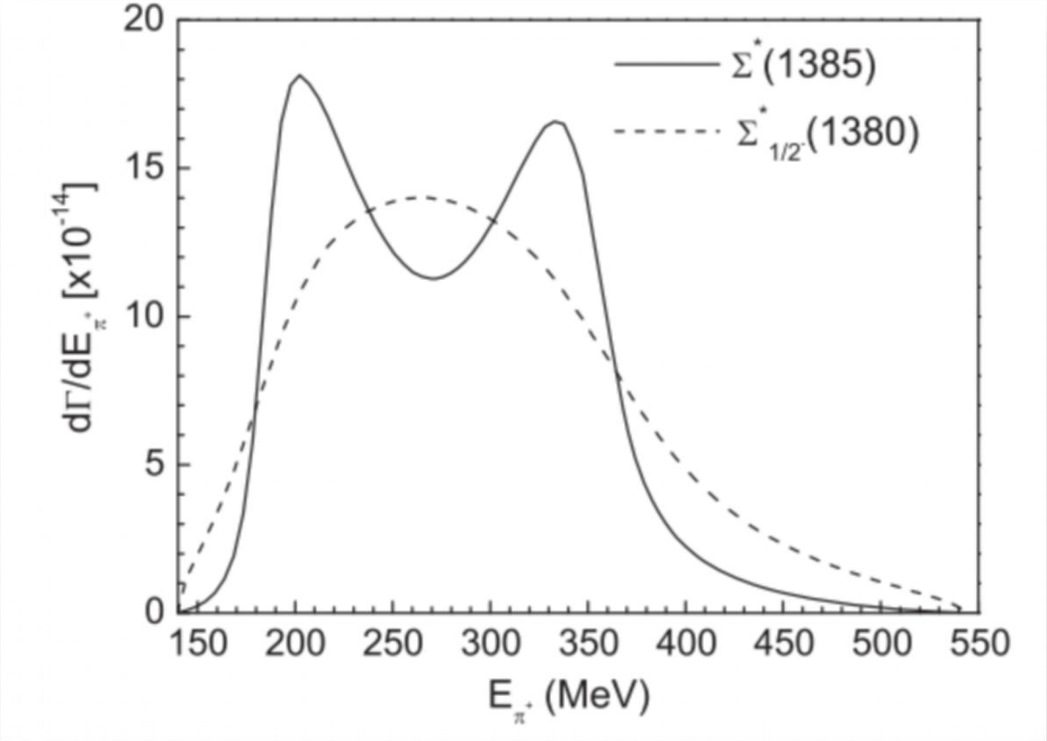




Search for $\Sigma(1/2^-)$

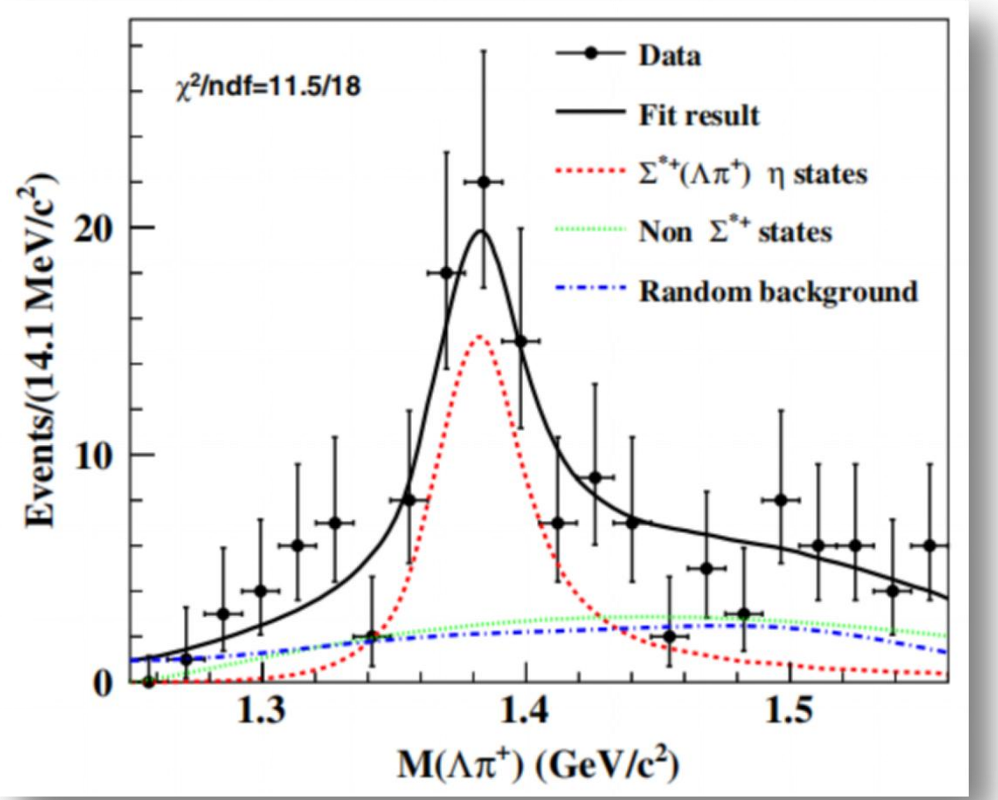
- $\Lambda_c \to \Lambda\eta\pi$, Xie-Geng, PRD95(2017) 074024

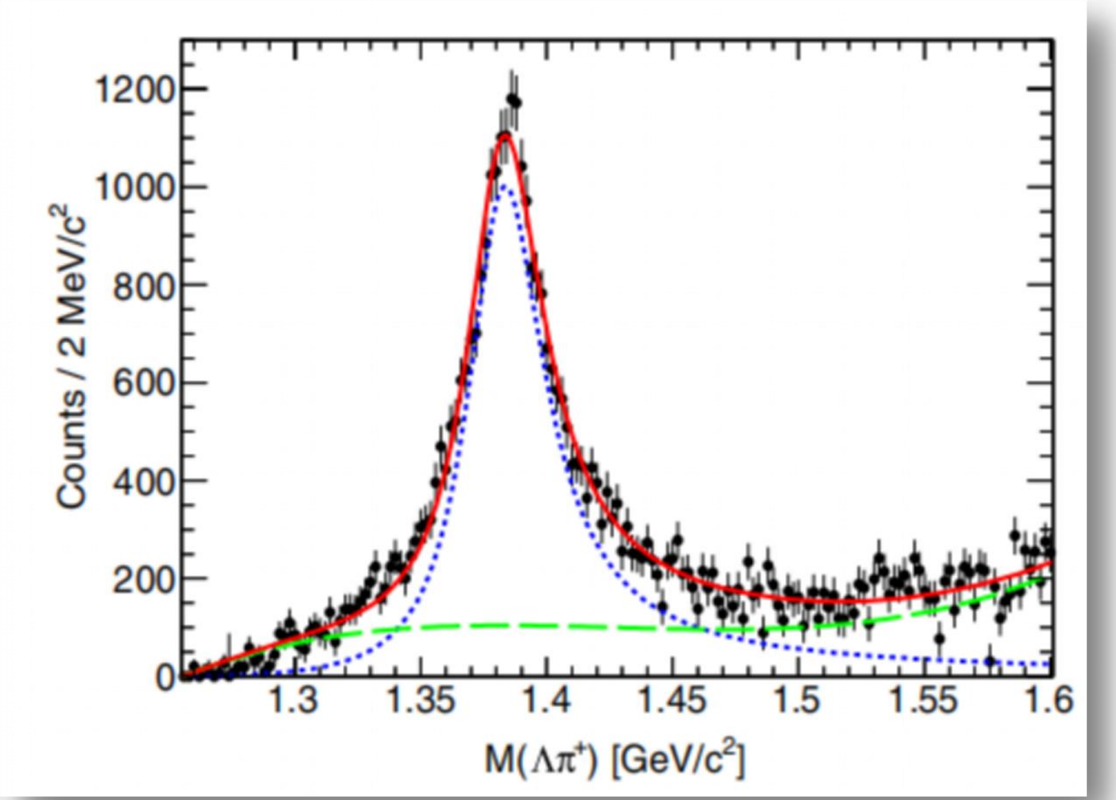




Belle and BESIII measurements

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



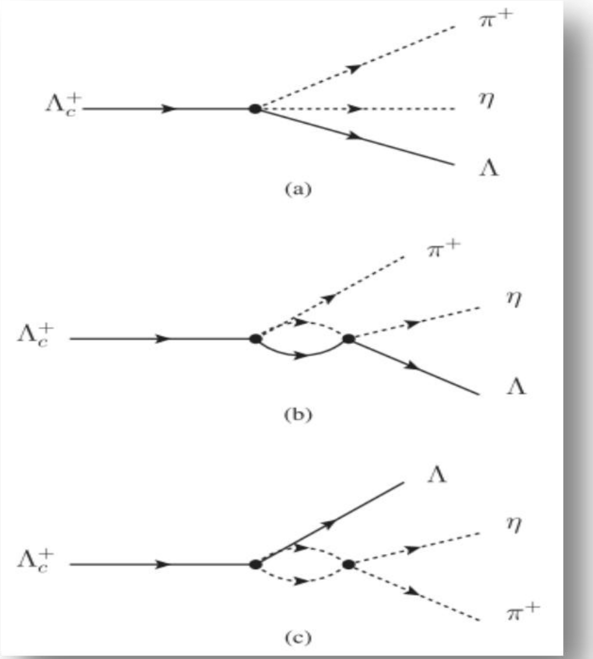


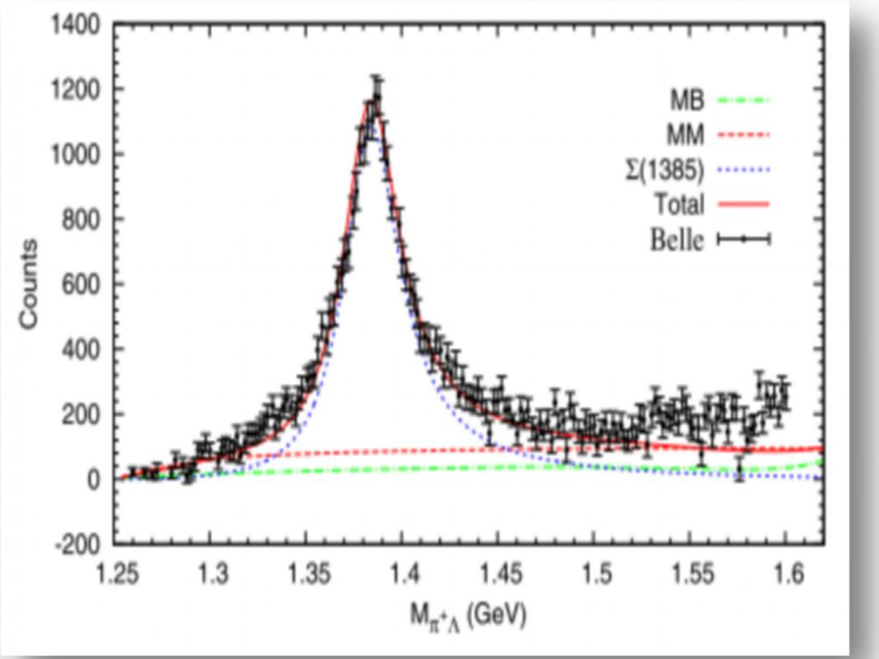
BESIII, PRD99, 032010 (2019)

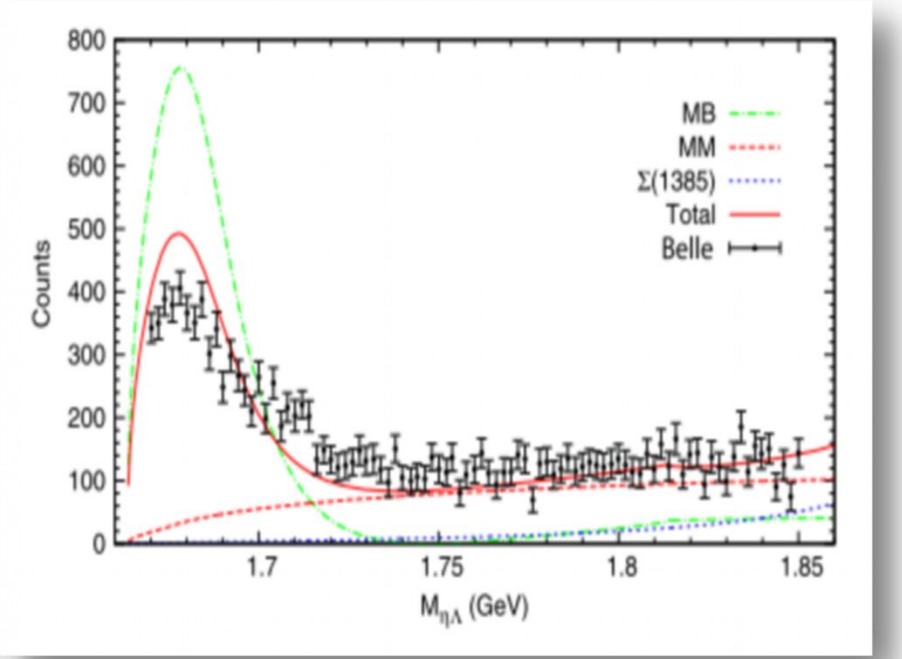
Belle, PRD103(2021)052005

Analysis the Belle data

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

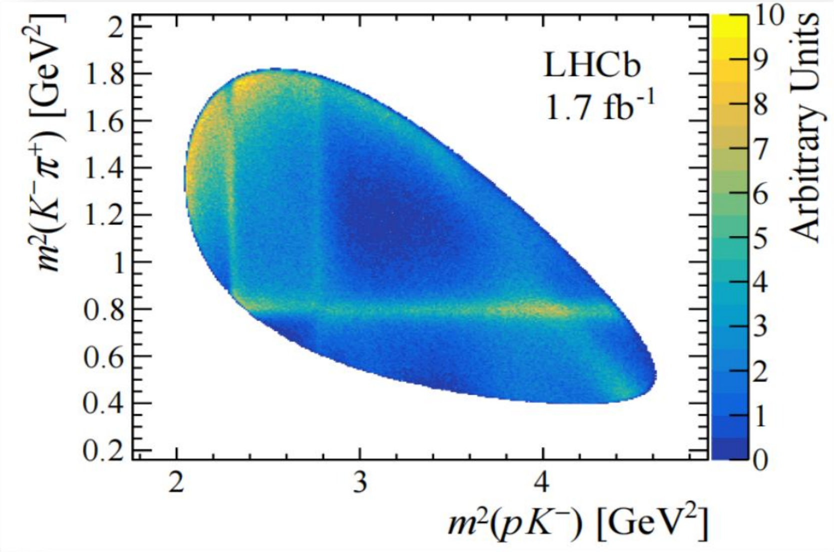


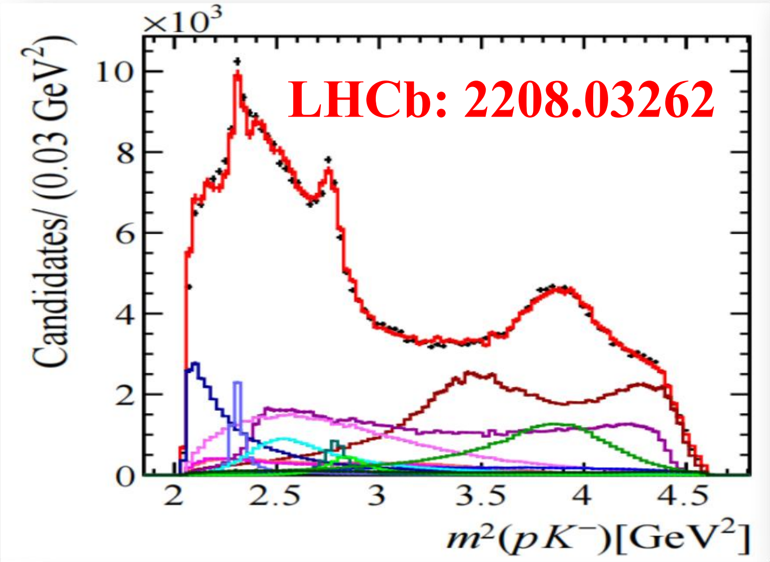


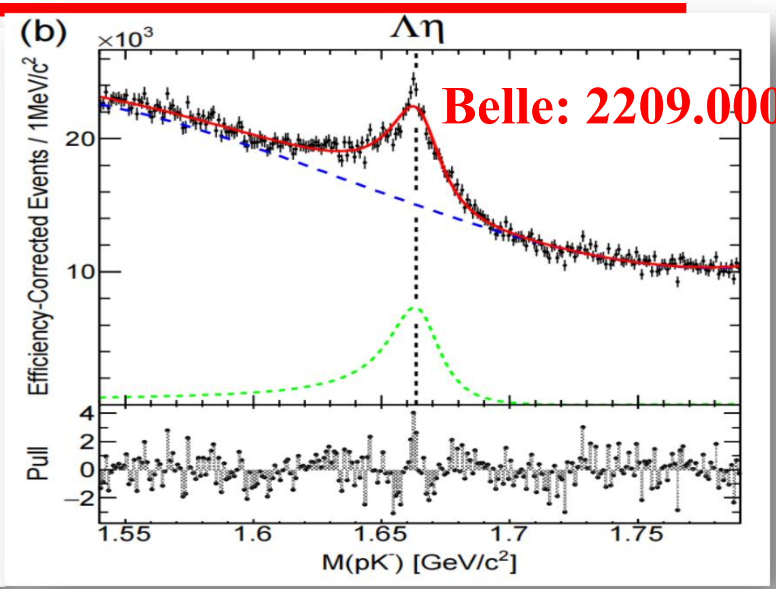


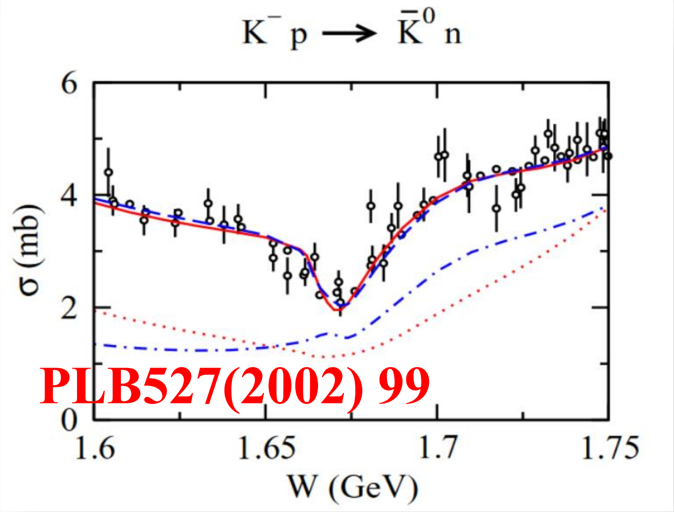
No signal of $\Sigma(1/2^-)$, $\Lambda(1670)$ as the molecular state!

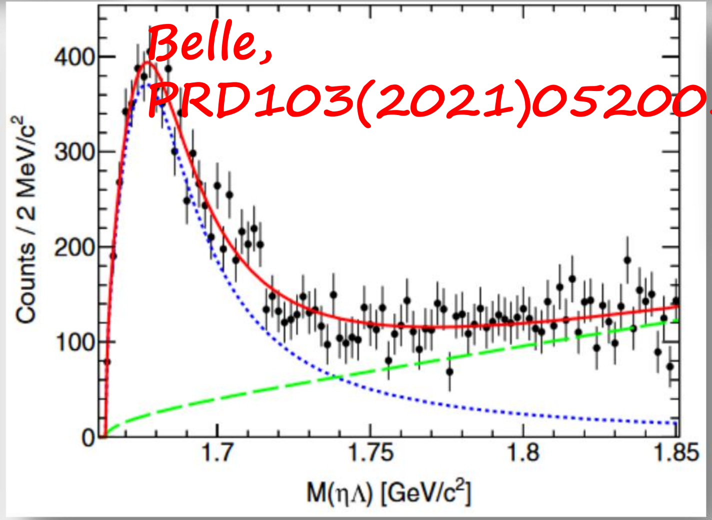
$\Lambda(1670)$ *in* $\Lambda_c \rightarrow pK^-\pi^+$









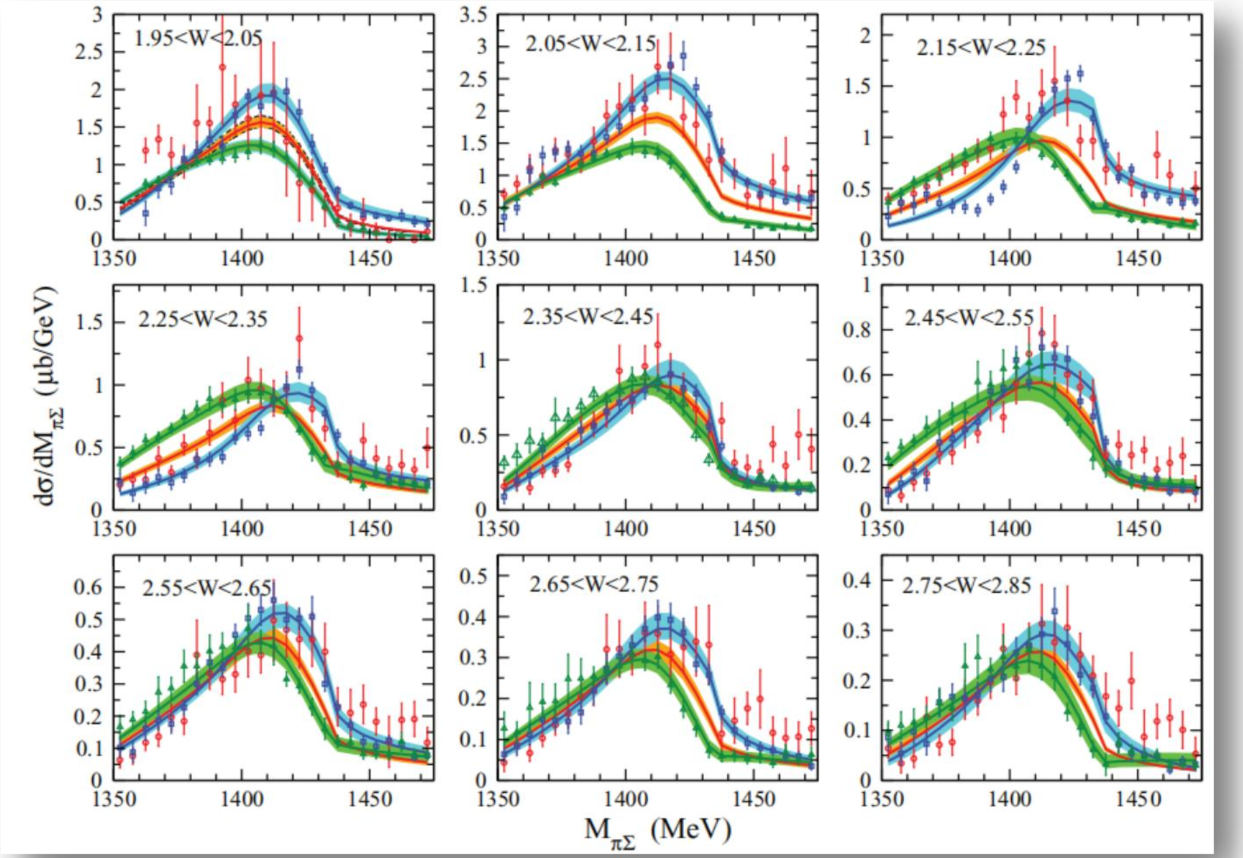


Resonances	Mass [MeV/c^2]	Width [MeV]
$\Lambda(1670)$	$1674.3 \pm 0.8 \pm 4.9$	$36.1 \pm 2.4 \pm 4.8$
$\Sigma(1385)^+$	$1384.8 \pm 0.3 \pm 1.4$	$38.1 \pm 1.5 \pm 2.1$

Λ(1670): cusp? Dip? peak?

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

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



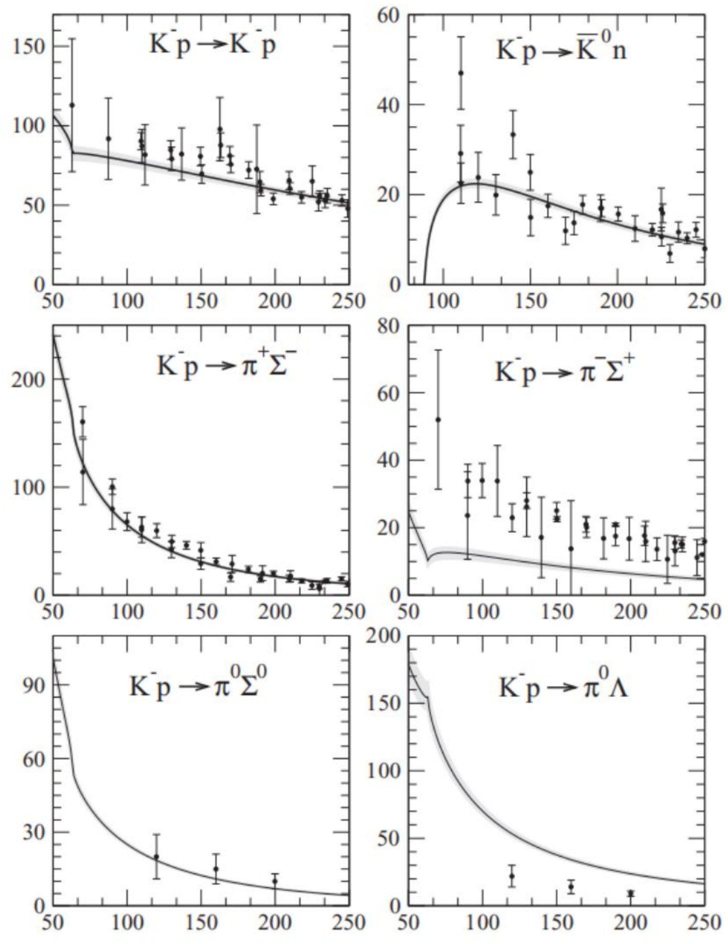
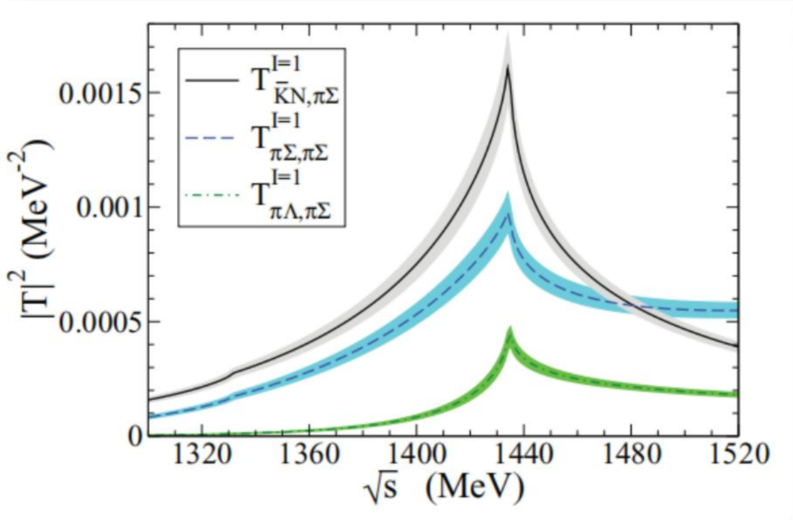


FIG. 6. Predicted K^-p cross sections (in millibarns). Experimental data are from Ref. [46].

Σ(1430)

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



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

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

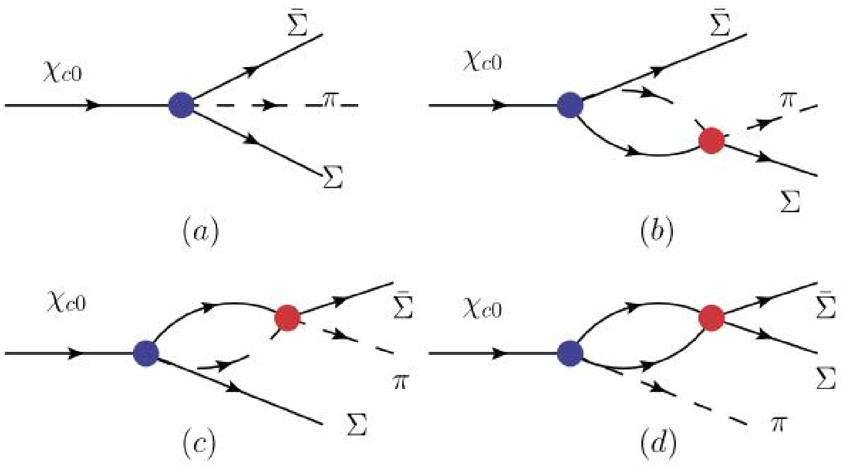
$$G_i = i\int\frac{d^4q}{(2\pi)^4}\frac{M_i}{E_i(\vec{q}\,)} \times \frac{1}{k^0 + p^0 - q^0 - E_i(\vec{q}\,) + i\epsilon}\frac{1}{q^2 - m_i^2 + i\epsilon}.$$

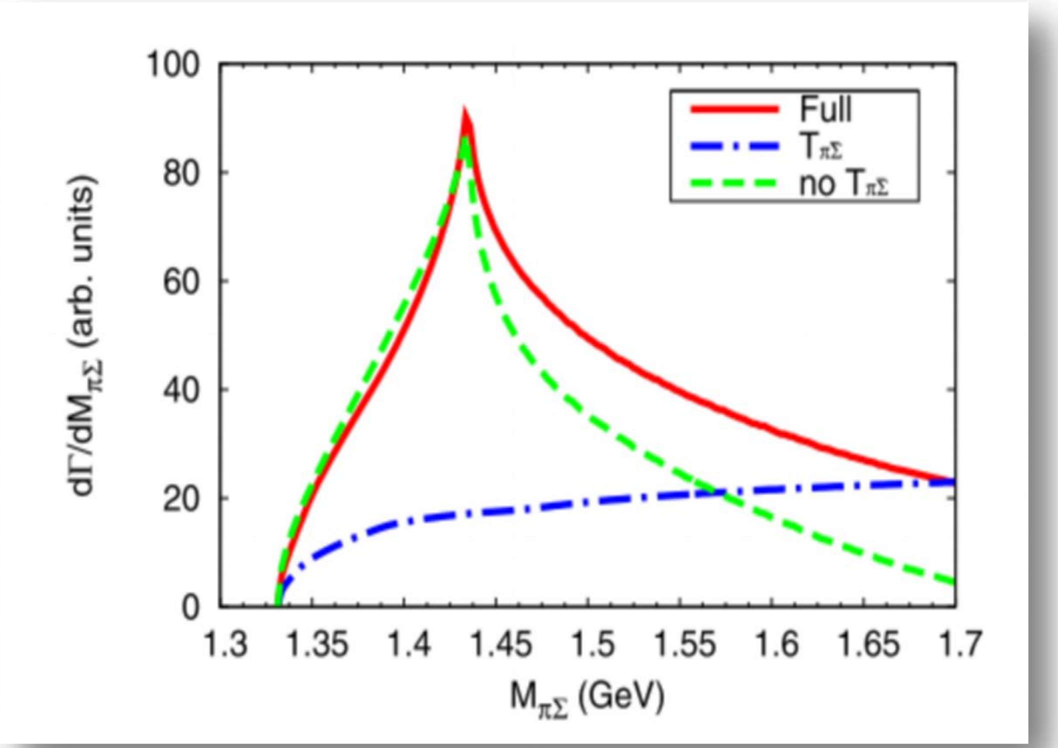
$$T_{ij}(\sqrt{s}) = \frac{g_i\, g_j}{\sqrt{s} - \sqrt{s_{\rm pole}}},$$

- **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]**

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

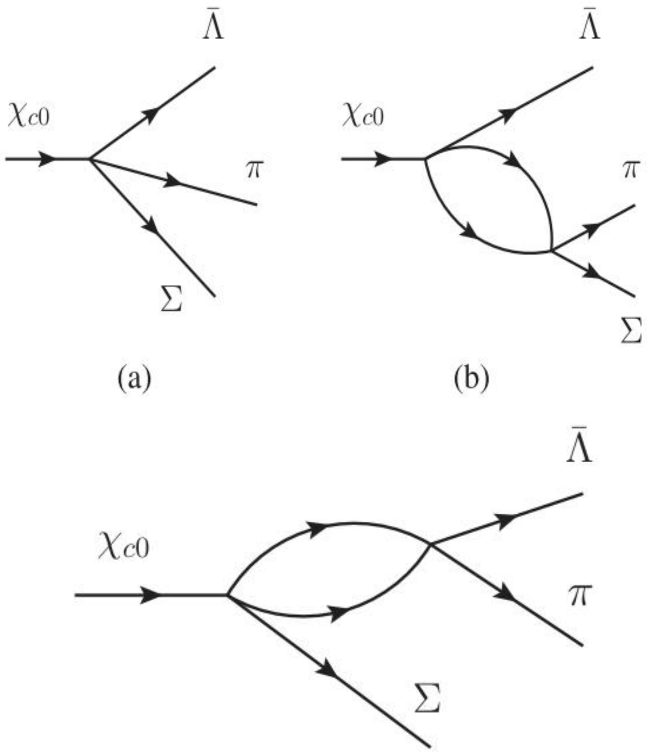
- $\chi_{c0} \to \bar{\Sigma}\Sigma\pi$, $\bar{\Lambda}\Sigma\pi$, EW-Xie-Oset, PLB753(2016)526, PRD98(2018)114017

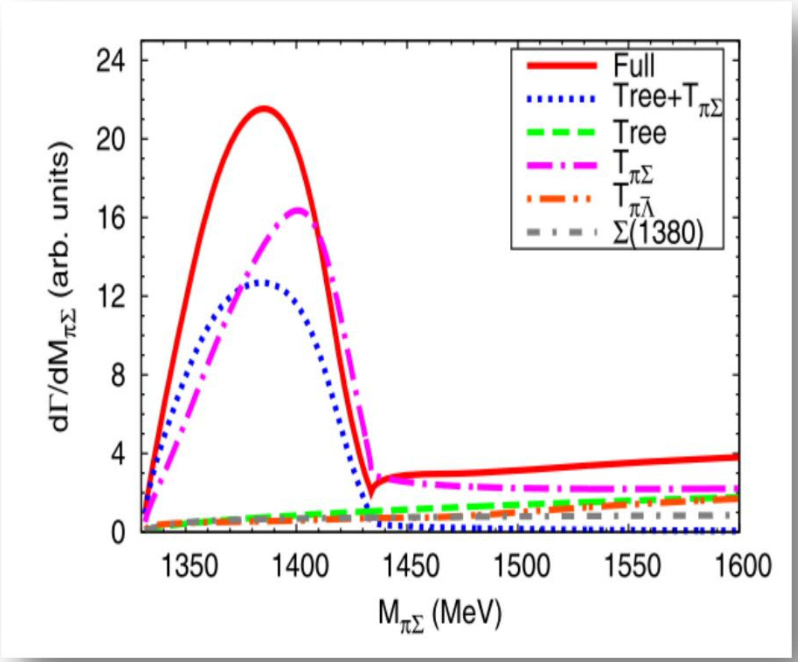


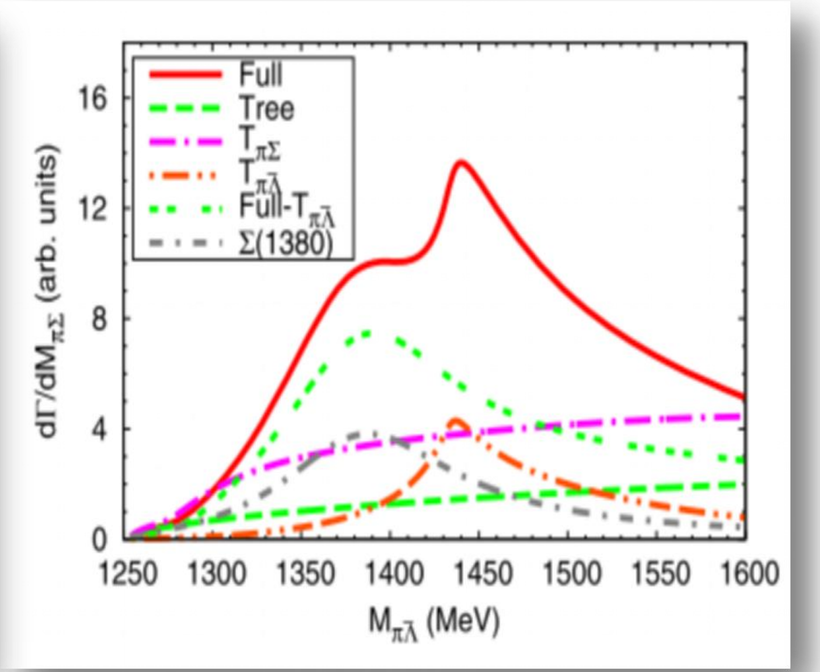


Search for $\Sigma(1/2^-)$

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

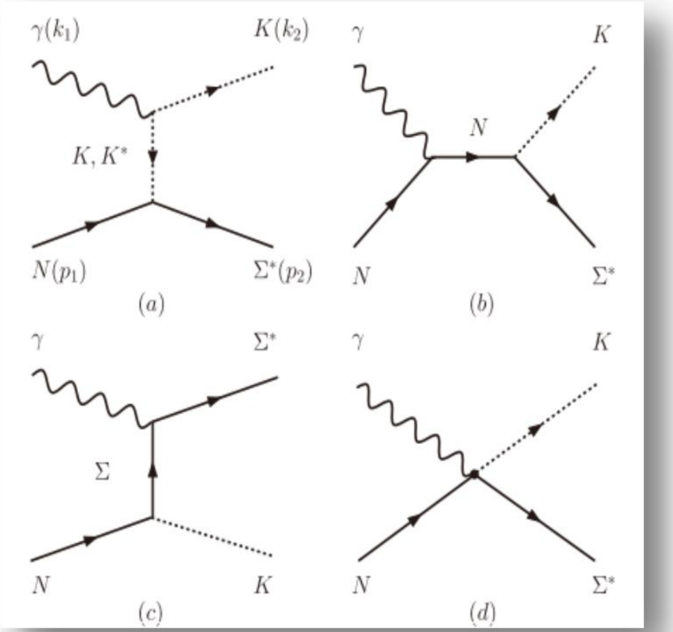






Search for $\Sigma(1/2^-)$

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



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

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

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

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

$$M^\mu_{K^-} = -2\mathrm{i}\frac{e g_{KN\Sigma^*}}{t-M^2_K}k^\mu_2,$$

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

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

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

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

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

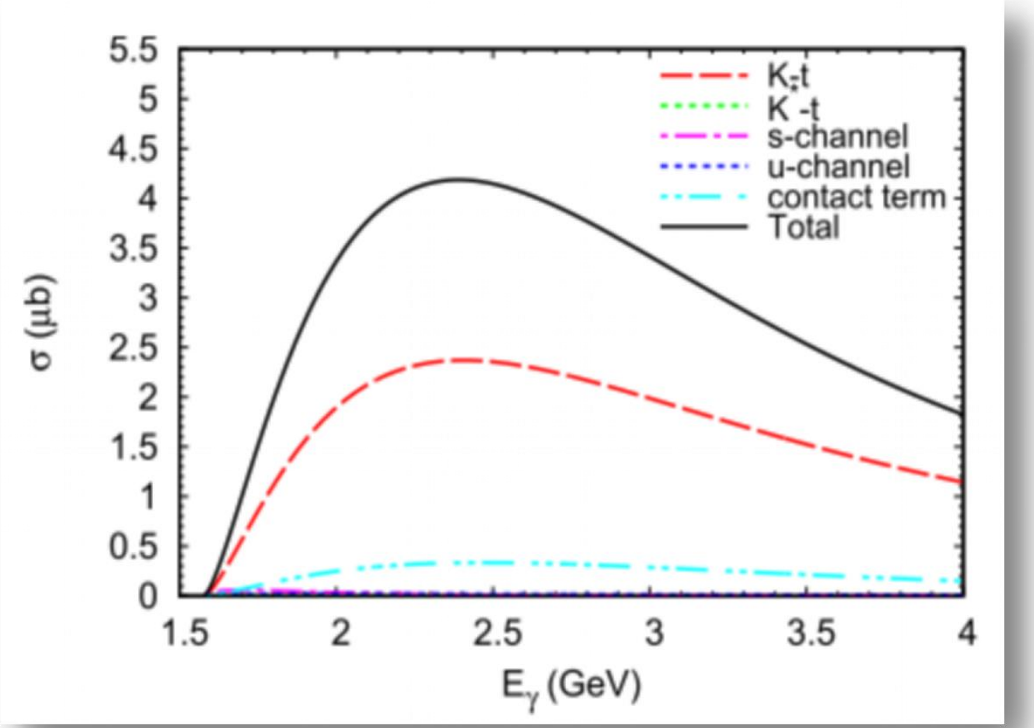
$$\mathcal{L}_{KN\Sigma^*} = g_{KN\Sigma^*}\bar{K}\bar{\Sigma}^* N + \text{h.c.},$$

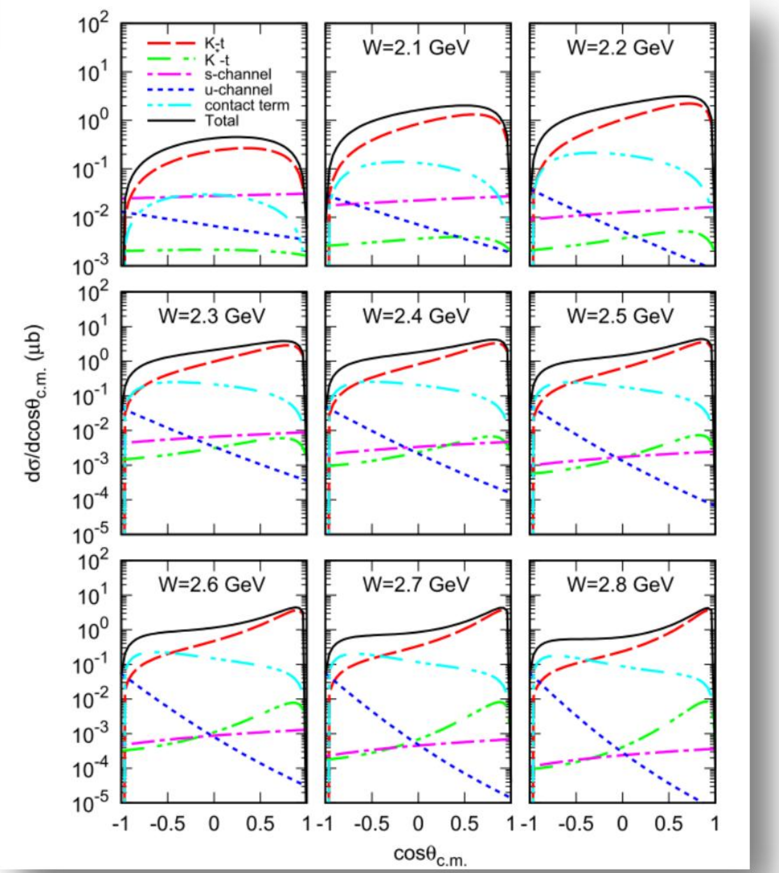
$$\mathcal{M}^\mu = \left(\mathcal{M}^\mu_{K^-} + \mathcal{M}^\mu_c\right)\left(t - M^2_K\right)\mathcal{F}^{\text{Regge}}_K + \mathcal{M}^\mu_{\Sigma^-}f_u + \mathcal{M}^\mu_{K^*}\left(t - M^2_{K^*}\right)\mathcal{F}^{\text{Regge}}_{K^*} + \mathcal{M}^\mu_n f_s,$$

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

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

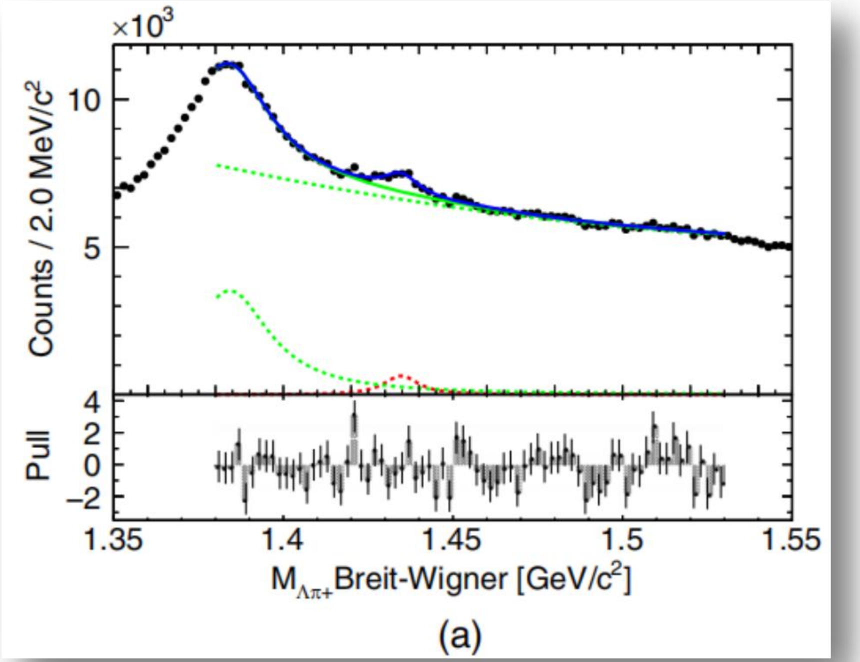
- $\gamma n \to K\Sigma(1/2^-)$, Lyu-EW-Xie-Wei, CPC47 (2023) 053108

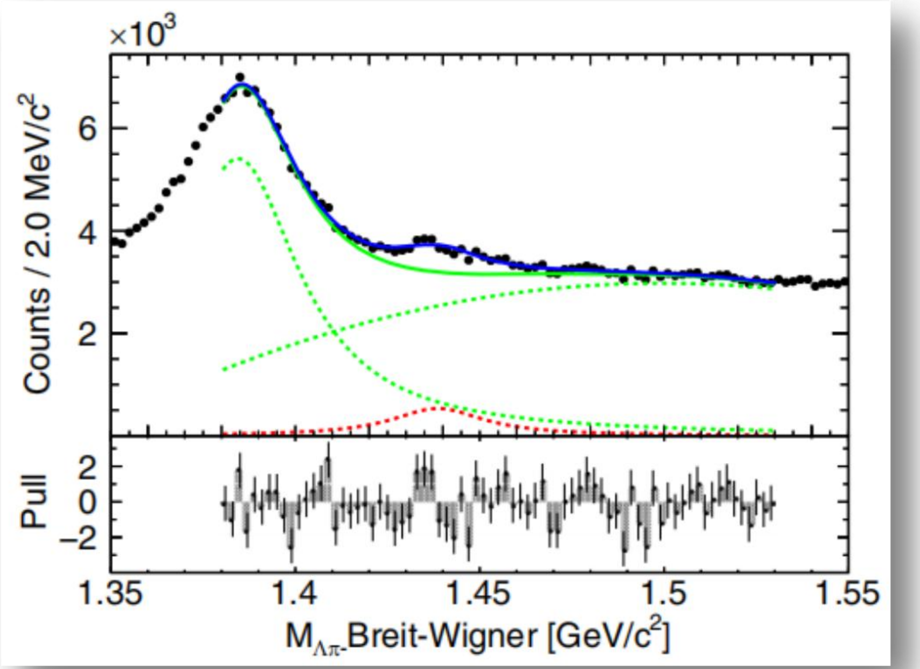




Belle measurements

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



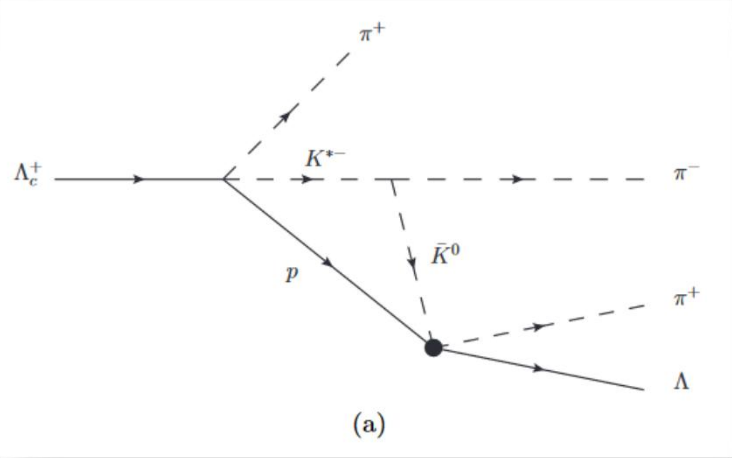


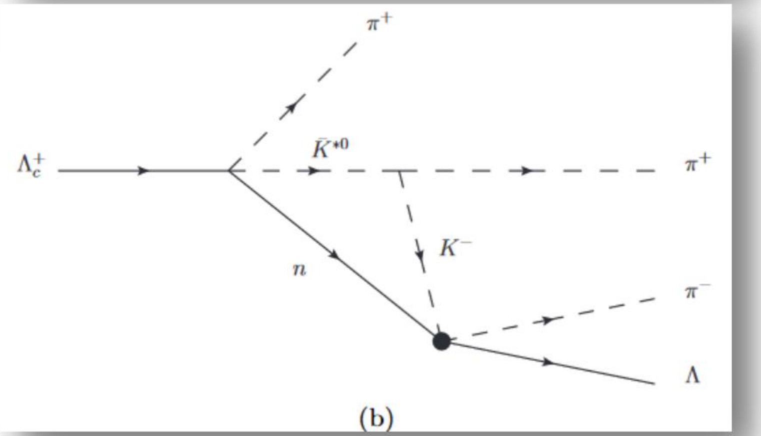
Mode	E_{BW} (MeV/c^2)	Γ (MeV/c^2)	χ^2/NDF
$\Lambda\pi^+$	1434.3 ± 0.6	11.5 ± 2.8	74.4/68
$\Lambda\pi^-$	1438.5 ± 0.9	33.0 ± 7.5	92.3/68

Evidence of Σ(1430)

- $\Lambda_c \to \Lambda\pi^+\pi^+\pi^-$, **TS**

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





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

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

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

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

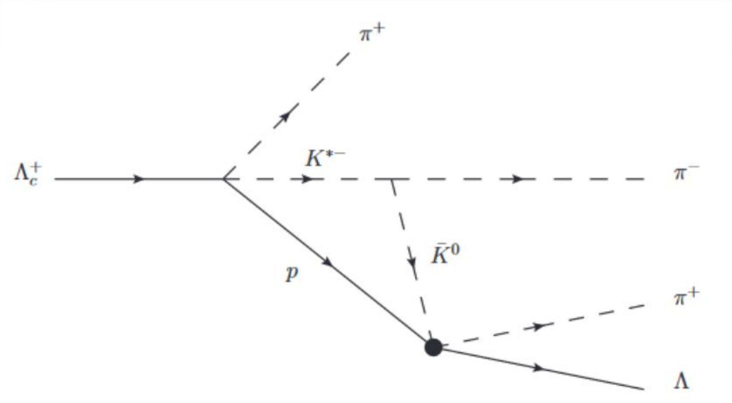
$$\mathcal{L}_{VPP} = -ig < V^\mu[P,\partial P] >$$

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

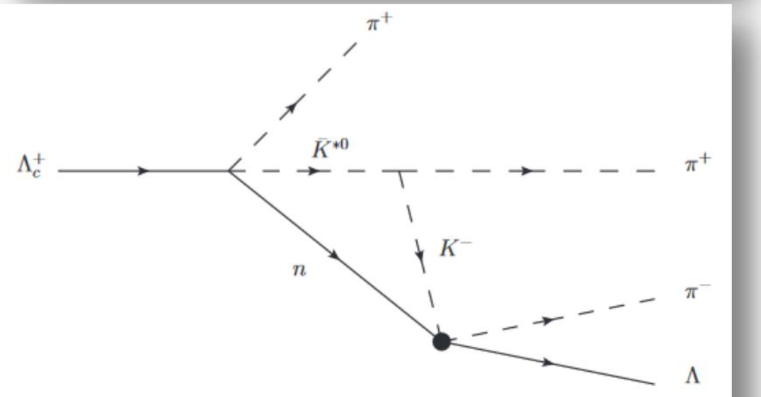
Evidence of Σ(1430)

- $\Lambda_c \to \Lambda\pi^+\pi^+\pi^-$, **TS**

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



(a)

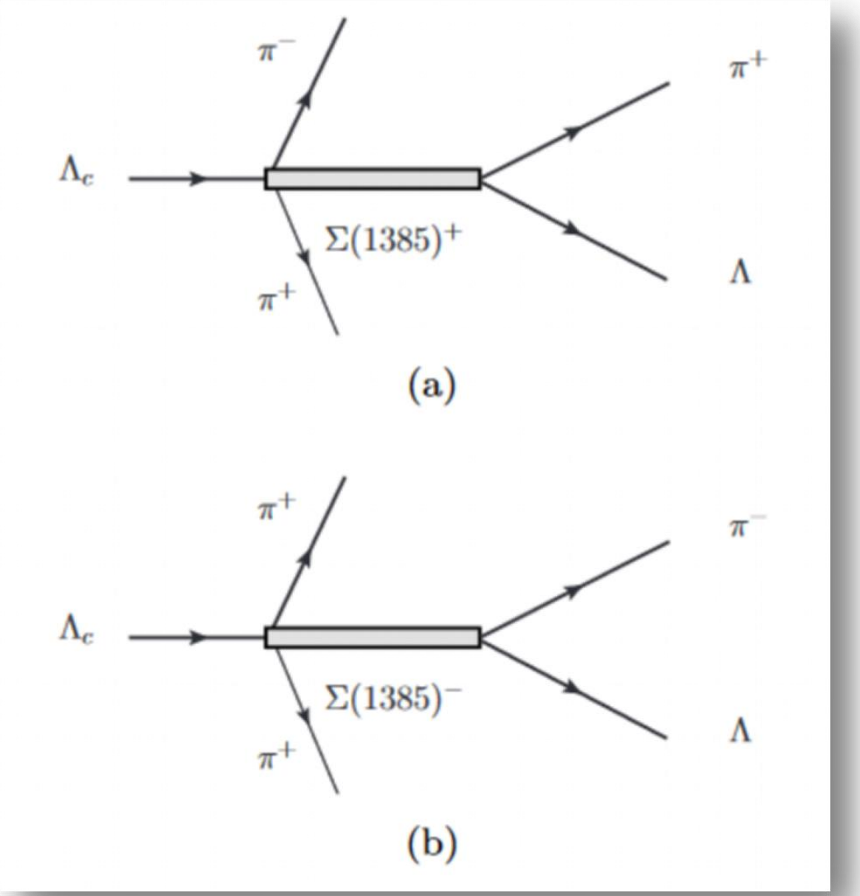


(b)

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

Evidence of $\Sigma(1430)$

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



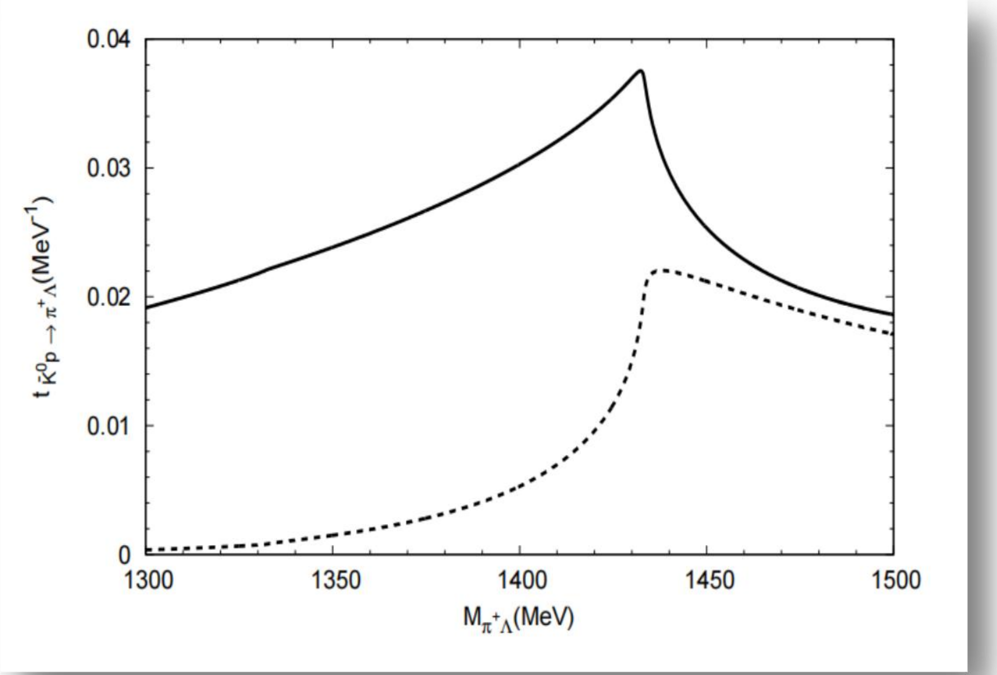
$$T^{\Sigma^{*+}(1385)} = \frac{V_p|p_{\pi^+}|}{M_{\pi^+\Lambda} - M_{\Sigma^{*+}} + i\frac{\Gamma_{\Sigma^{*+}}}{2}},$$

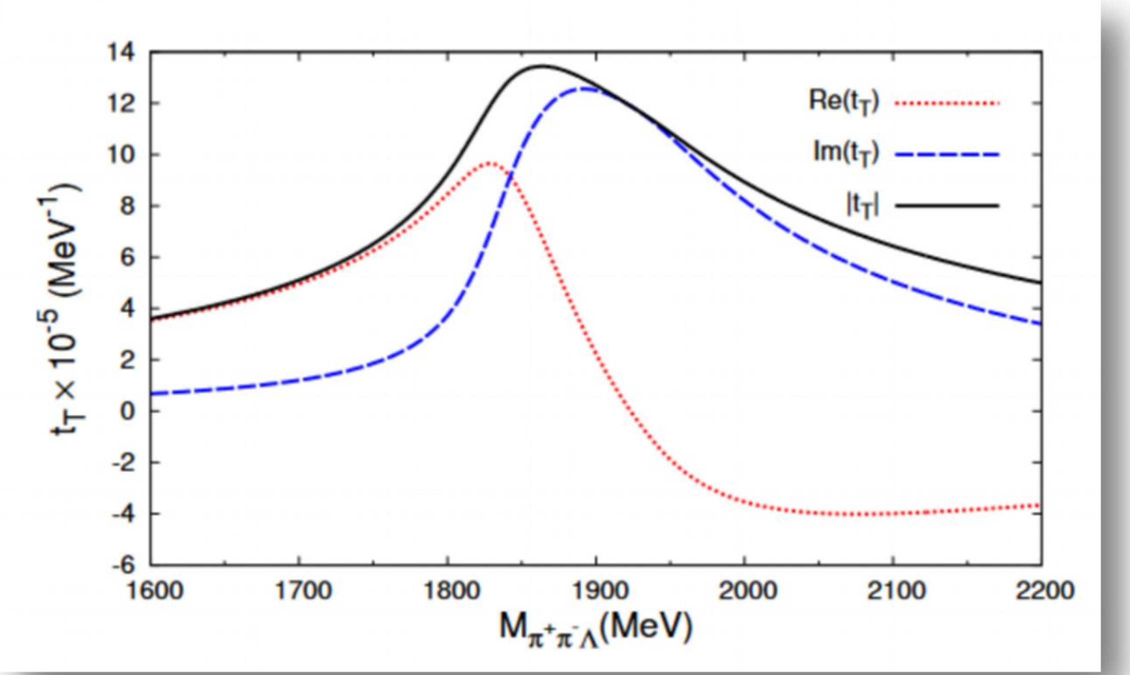
$$T^{\Sigma^{*-}(1385)} = \frac{V_p|p_{\pi^-}|}{M_{\pi^-\Lambda} - M_{\Sigma^{*-}} + i\frac{\Gamma_{\Sigma^{*-}}}{2}},$$

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

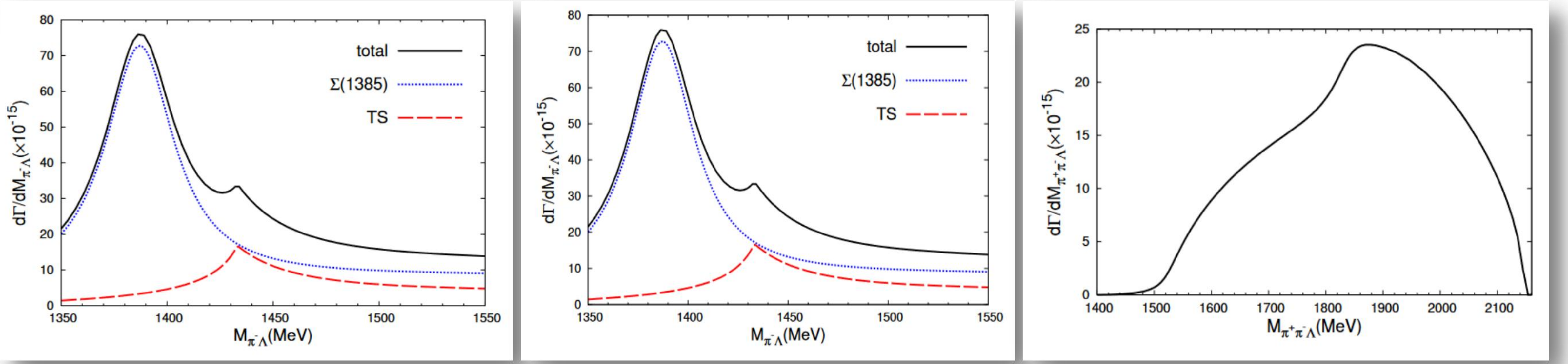
Evidence of $\Sigma(1430)$

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





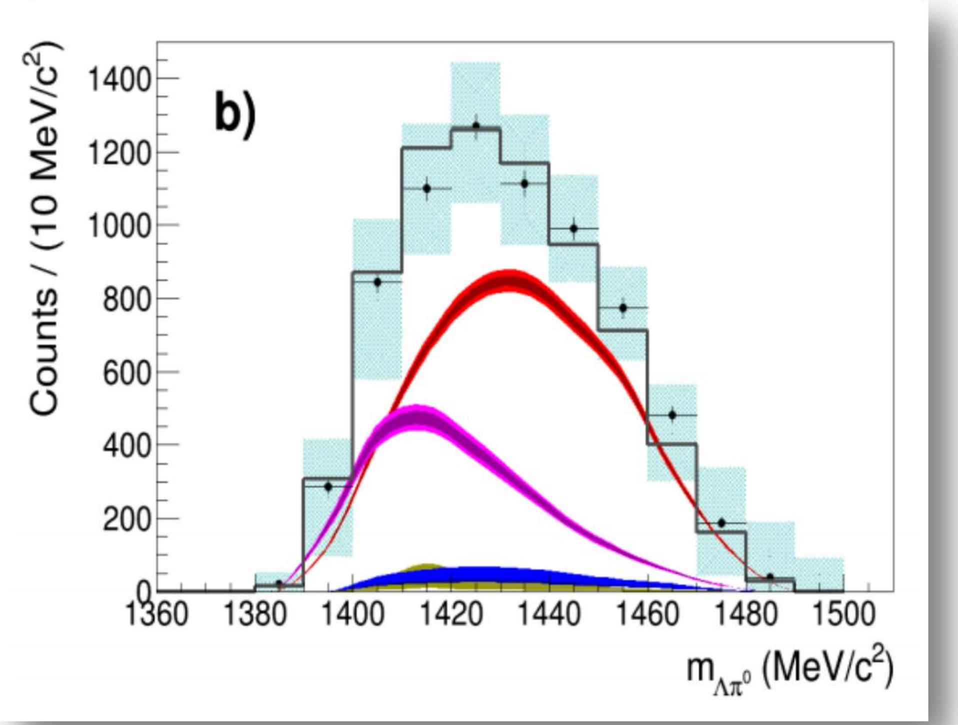
Results of $\Lambda_c \to \Lambda\pi^+\pi^+\pi^-$

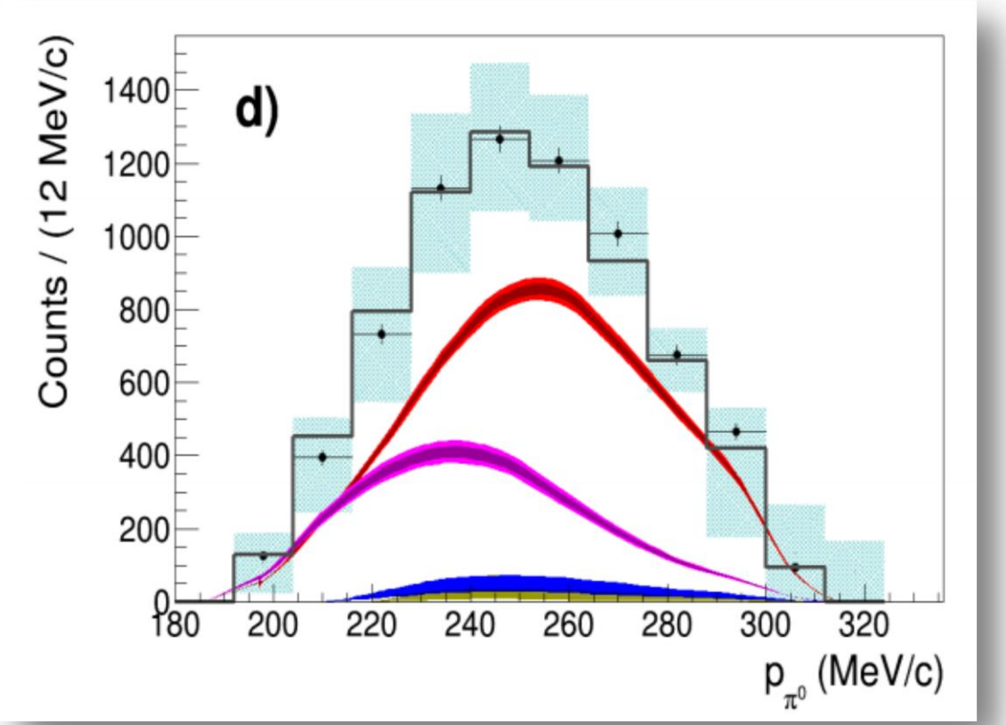


Cusp signal of $\Sigma(1/2^-)$ around $\bar{K}N$ threshold!

Other evidence of $\Sigma(1430)$

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





Summary

- There are many evidences/hints of $\Sigma\left(\frac{1}{2}^-\right)$
- Some modes: $J/\psi(\chi_{c0}) \to \bar{\Lambda}\Sigma\pi,\ \bar{\Sigma}\Sigma\pi$
- The cusp structure around 1430 MeV observed in $\Lambda_c \to \Lambda\pi\pi\pi$ should be associated with the $\Sigma(1430)$.
- The cusp structure is enhanced by the TS effects.

Thank you very much!

第八届手征有效场论研讨会

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- 9月20日前注册：https://indico.ihep.ac.cn/event/20010/