Study of the baryon $\Sigma^*(1/2^-)$ in the χ_{c0} decay

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Mini-workshop on Baryonic spectroscopy at e^+e^- colliders

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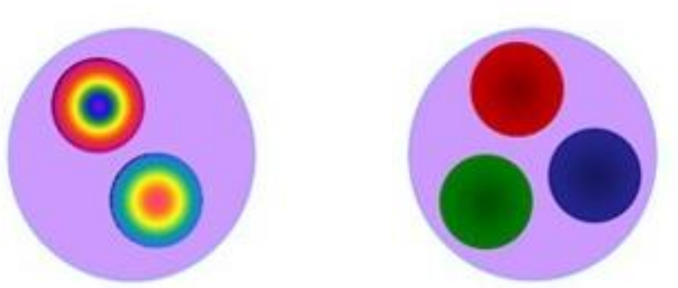
Exotic states

- **Quark model, meson and baryon**



- **Exotic states**
  - **Tetraquark state, pentaquark state, hadronic molecule, hybrid, glueball, dibaryon.**
  - **exotic quantum number, 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+},…**

Baryon resonances

- **Expt: extraction of the baryon resonances from experimental data.**
  - **Pion, photon, kaon beams, e+e-**
  - **BESIII, CDF, CLAS, Belle, LHCb et. al**
- **Theo: The theoretical work and predictions**
  - **Quark models over predict the number baryons - ”the missing resonances”**
  - **Effective theories give rise to some dynamically generated states as a consequence of the interaction of two hadrons - hadronic molecule**

$1/2^-$ baryon nonet with strangeness

- **Quark model assignments for baryons**

J^P	$(D, L^P_N)\, S$	Octet members				Singlets
$1/2^+$	$(56,0^+_0)\; 1/2$	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0^+_2)\; 1/2$	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(1690)^\dagger$	
$1/2^-$	$(70,1^-_1)\; 1/2$	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
				$\Sigma(1560)^\dagger$		

Decuplet members

PDG2017

$3/2^+$	$(56,0^+_0)\; 3/2$	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$
$3/2^+$	$(56,0^+_2)\; 3/2$	$\Delta(1600)$	$\Sigma(1690)^\dagger$	$\Xi(?)$	$\Omega(?)$
$1/2^-$	$(70,1^-_1)\; 1/2$	$\Delta(1620)$	$\Sigma(1750)^\dagger$	$\Xi(?)$	$\Omega(?)$
$3/2^-$	$(70,1^-_1)\; 1/2$	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$

$1/2^-$ baryon nonet with strangeness

- Large 5-quark mixture picture, Zou NPA835(2010)

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

$I(J^P)=1(1/2^-)$ state with $S=-1$

- Mass 1430 MeV
- Predicted with in the coupled-chanel Chiral unitary approach. D. Jido NPA2003, J. Oller, PLB2001。
- A new Σ^* ($J^P=1/2^-$) is necessary to describe the experimental data of $K^- P \to \Lambda \pi^+ \pi^-$. Wu, Dulat, Zou, PRC2010.
- A resonant structure in the I=1 $J^P=1/2^-$ around $\bar{K}N$ threshold is also needed to describe the $\gamma p \to K\pi\Sigma$. Roca, Oset, PRC88(2013).
- We would like to propose a reaction to search this state [$\Sigma^*(1/2^-)$].

Search Σ*(1/2$^-$)

- Σ*(1/2$^-$) is around the KN threshold

  The conventional reactions with $\bar{K}$N in the final states mix I=0 and I=1, which makes it difficult to disentangle the I=1 contribution and extract this state.

- Σ*(1/2$^-$) shows up strongly in the πΣ-> πΣ amplitude.

  Roca. Oset, PRC2013

- $X_{c0}(1P) \to \bar{\Sigma}\Sigma\pi$
  - **Reason 1**: good filter of isospin I=1 for Σπ.
  - **Reason 2**: feasible in present experimental facilities, such BESIII.

$X_{c0}(1P) \to \bar{\Sigma}\Sigma$ is measured by BESIII and CLEO with $Br(X_{c0}(1P) \to \bar{\Sigma}\Sigma)$ ~10-3.

PDG2016

$\chi_{c0}(1P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_{77}	$\Sigma^0\overline{\Sigma}^0$	$(4.4 \pm 0.4) \times 10^{-4}$	
Γ_{78}	$\Sigma^+\overline{\Sigma}^-$	$(3.9 \pm 0.7) \times 10^{-4}$	

- X_{c0}(1P)-> $\bar{\Sigma}\Sigma\pi$
  - Reason 1: good filter of isospin I=1 for $\Sigma\pi$.
  - Reason 2: feasible in present experimental facilities, such BESIII.

X_{c0}(1P)-> $\bar{\Sigma}\Sigma$ is measured by BESIII and CLEO with Br(X_{c0}(1P)-> $\bar{\Sigma}\Sigma$) ~10-3.

Br(X_{c0}(1P)-> $\bar{p}p\pi$) is three times larger than Br(X_{c0}(1P)->pp).

Γ_{56}	$p\bar{p}$	$(2.25\pm0.09)\times10^{-4}$
Γ_{57}	$p\bar{p}\pi^0$	$(6.8\ \pm0.7\ )\times10^{-4}$

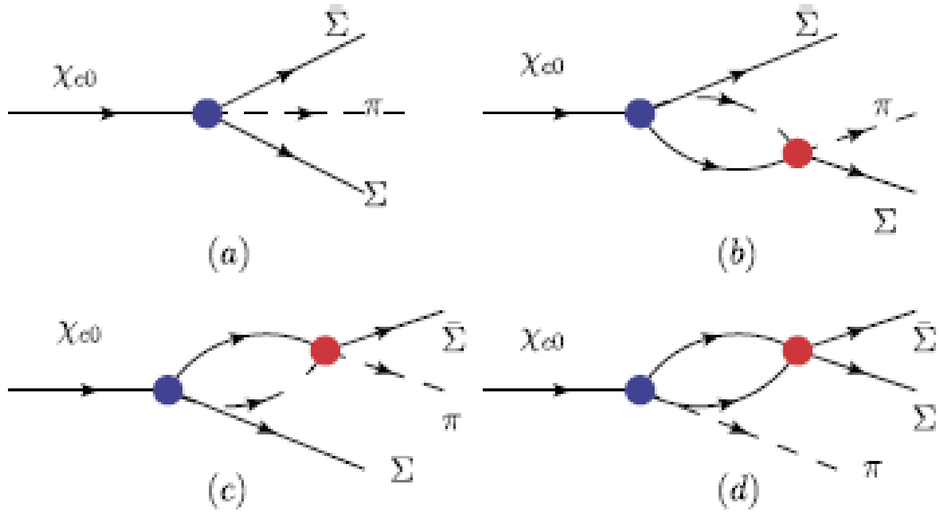
- **$X_{c0}(1P) \to \bar{\Sigma}\Sigma\pi$**
  - **Reason 1: good filter of isospin I=1 for Σπ.**
  - **Reason 2: feasible in present experimental facilities, such BESIII.**

$X_{c0}(1P) \to \bar{\Sigma}\Sigma$ is measured by BESIII and CLEO with $Br(X_{c0}(1P) \to \bar{\Sigma}\Sigma)$ ~10-3.

$Br(X_{c0}(1P) \to \bar{p}p\pi)$ is three times larger than $Br(X_{c0}(1P) \to \bar{p}p)$, without π production.

Thus, the $Br(X_{c0}(1P) \to \bar{\Sigma}\Sigma\pi)$ should be larger than $Br(X_{c0}(1P) \to \bar{\Sigma}\Sigma)$, and easily accessible at BESIII and CLEO.

The reaction mechanism



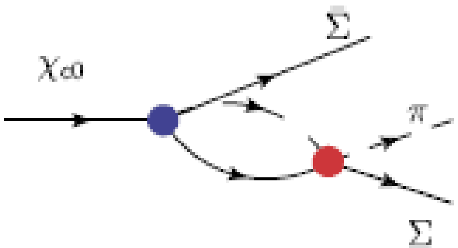
a) the tree diagram, b) final state interaction of Σ π

c) final state interaction of $\bar{\Sigma}$ π

d) final state interaction of $\bar{\Sigma}\Sigma$

- **Σπ final state interaction**
- **The effective lagrangian:**

$$\mathcal{L} \equiv \tilde{D} \left\langle \bar{B} \left\{ \Phi, B \right\} \right\rangle + \tilde{F} \left\langle \bar{B} \left[B, \Phi \right] \right\rangle$$



(b)

$$\Phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix}$$

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}$$

- **The symbol <> stands for the trace of SU(3) matrices.**

Isospin coefficients

- **The isoscalar coefficients are taken from the SU(3) isoscalar factors in the PDG.**

SU(3) isoscalar coefficients for the $\langle\bar{\Sigma}|MB\rangle$ matrix elements.

$\bar{\Sigma}$	$\bar{K}N$	$\pi\Sigma$	$\pi\Lambda$	$\eta\Sigma$	$K\Xi$
$\tilde{D}$	$-\sqrt{\frac{3}{10}}$	0	$\sqrt{\frac{1}{5}}$	$\sqrt{\frac{1}{5}}$	$-\sqrt{\frac{3}{10}}$
$\tilde{F}$	$\sqrt{\frac{1}{6}}$	$\sqrt{\frac{2}{3}}$	0	0	$-\sqrt{\frac{1}{6}}$

$8_1 \rightarrow 8 \otimes$

$$\begin{pmatrix} N \\ \Sigma \\ \Lambda \\ \Xi \end{pmatrix} \begin{pmatrix} N\pi & N\eta & \Sigma K & \Lambda K & \\ N\overline{K} & \Sigma\pi & \Lambda\pi & \Sigma\eta & \Xi K \\ N\overline{K} & \Sigma\pi & \Lambda\eta & \Xi K & \\ \Sigma\overline{K} & \Lambda\overline{K} & \Xi\pi & \Xi\eta & \end{pmatrix} = \frac{1}{\sqrt{20}} \begin{pmatrix} 9 & -1 & -9 & -1 & \\ -6 & 0 & 4 & 4 & -6 \\ 2 & -12 & -4 & -2 & \\ 9 & -1 & -9 & 1 & \end{pmatrix}^{1/2}$$

PDG2016

$8_2 \rightarrow 8 \otimes 8$

$$\begin{pmatrix} N \\ \Sigma \\ \Lambda \\ \Xi \end{pmatrix} \begin{pmatrix} N\pi & N\eta & \Sigma K & \Lambda K & \\ N\overline{K} & \Sigma\pi & \Lambda\pi & \Sigma\eta & \Xi K \\ N\overline{K} & \Sigma\pi & \Lambda\eta & \Xi K & \\ \Sigma\overline{K} & \Lambda\overline{K} & \Xi\pi & \Xi\eta & \end{pmatrix} = \frac{1}{\sqrt{12}} \begin{pmatrix} 3 & 3 & 3 & -3 & \\ 2 & 8 & 0 & 0 & -2 \\ 6 & 0 & 0 & 6 & \\ 3 & 3 & 3 & -3 & \end{pmatrix}^{1/2}$$

Isospin coefficients

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SU(3) isoscalar coefficients for the $\langle\bar{\Sigma}|MB\rangle$ matrix elements.

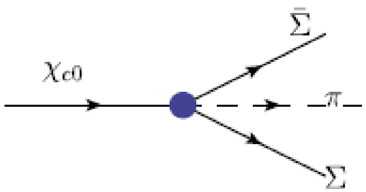
$\bar{\Sigma}$	$\bar{K}N$	$\pi\Sigma$	$\pi\Lambda$	$\eta\Sigma$	$K\Xi$
$\tilde{D}$	$-\sqrt{\frac{3}{10}}$	0	$\sqrt{\frac{1}{5}}$	$\sqrt{\frac{1}{5}}$	$-\sqrt{\frac{3}{10}}$
$\tilde{F}$	$\sqrt{\frac{1}{6}}$	$\sqrt{\frac{2}{3}}$	0	0	$-\sqrt{\frac{1}{6}}$

- The sum of the isoscalar coefficients times D and F gives the weights h_i, which go into the primary production of the meson baryon channel.

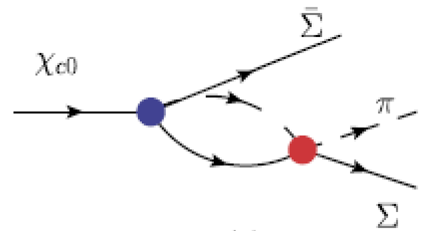
$$h_{\bar{K}N} = -\sqrt{\frac{3}{10}}\tilde{D} + \sqrt{\frac{1}{6}}\tilde{F}, \qquad h_{K\Xi} = -\sqrt{\frac{3}{10}}\tilde{D} - \sqrt{\frac{1}{6}}\tilde{F}$$

$$h_{\pi\Sigma} = \sqrt{\frac{2}{3}}\tilde{F}, \quad h_{\pi\Lambda} = \sqrt{\frac{1}{5}}\tilde{D}, \quad h_{\eta\Sigma} = \sqrt{\frac{1}{5}}\tilde{D}$$

- **The amplitude for the transition is,**



(a)

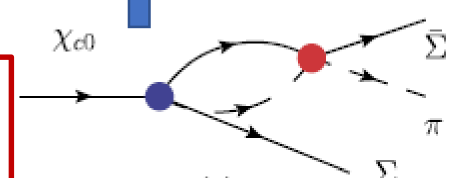


(b)

$$\mathcal{M}(M_{\pi\Sigma}, M_{\pi\bar{\Sigma}}) = V_p \Big(h_{\pi\Sigma} + \sum_i h_i G_i(M_{\pi\Sigma}) t_{i,\pi\Sigma}(M_{\pi\Sigma}) + \sum_i h_i G_i(M_{\pi\bar{\Sigma}}) t_{i,\pi\bar{\Sigma}}(M_{\pi\bar{\Sigma}}) \Big) = V_p (h_{\pi\Sigma} + T_{\pi\Sigma} + T_{\pi\bar{\Sigma}}) \,,$$

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

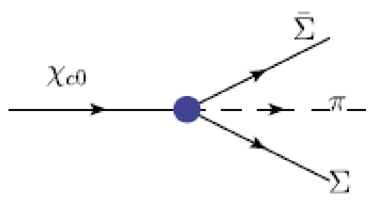
The strength of the amplitude with h=1.



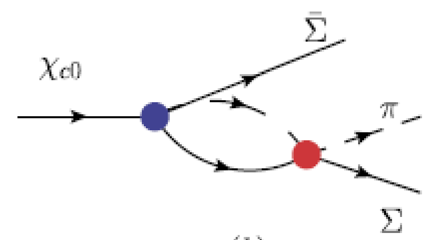
(c)

The poles come from 1-VG=0, and are the same for particle and antiparticle, and combination VG and tG is same for particle and antiparticle, then $T_{\pi\bar{\Sigma}} = T_{\pi\Sigma}$.

- **The amplitude for the transition is,**



(a)



(b)

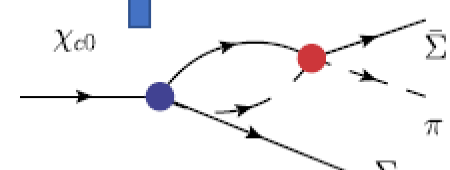
$$\mathcal{M}(M_{\pi\Sigma}, M_{\pi\bar{\Sigma}}) = V_p \Big(h_{\pi\Sigma} + \sum_i h_i G_i(M_{\pi\Sigma}) t_{i,\pi\Sigma}(M_{\pi\Sigma})$$

$$+ \sum_i h_i G_i(M_{\pi\bar{\Sigma}}) t_{i,\pi\bar{\Sigma}}(M_{\pi\bar{\Sigma}}) \Big)$$

$$= V_p (h_{\pi\Sigma} + T_{\pi\Sigma} + T_{\pi\bar{\Sigma}}),$$

$$h_{\bar{K}N} = -\sqrt{\frac{3}{10}}\tilde{D} + \sqrt{\frac{1}{6}}\tilde{F},$$

The strength of the amplitude with h=1.



(c)

We have two parameters D and F, because Vp is an arbitrary normalization, we can work with **R=F/D**, and include D in the Vp factor. We take R=1.

The meson baryon interaction

- For the coupled channels, $\bar{K}N$, $\pi\Sigma$, $\pi\Lambda$, $\eta\Sigma$, $K\Xi$, the Bethe Salpeter equation,

Take from the lowest order meson baryon chiral lagrangian

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

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

- $f = 1.15 f_\pi$, and f_π=93 MeV. Oset, NPA636 (1998)

Table 3
F_{ij} coefficients of Eq. (9) for $T = 1$. $F_{ji} = F_{ij}$

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

- **The loop function Gi, with $|q_{max}|$=630 MeV**

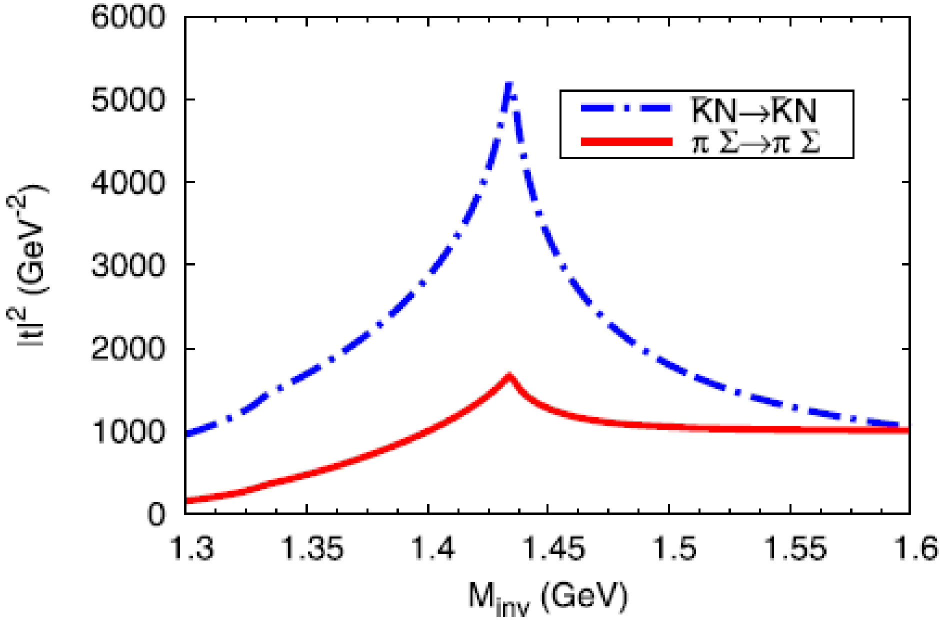
$$G_l = \mathrm{i}\int \frac{d^4q}{(2\pi)^4}\frac{M_l}{E_l(q)}\frac{1}{k^0+p^0-q^0-E_l(q)+\mathrm{i}\epsilon}\times\frac{1}{q^2-m_l^2+\mathrm{i}\epsilon}$$
$$=\int \frac{d^3q}{(2\pi)^3}\frac{M_l}{2\omega_l(q)E_l(q)}\frac{1}{k^0+p^0-q^0-E_l(q)+\mathrm{i}\epsilon}$$

- **And the invariant mass distribution for X_{c0}(1P)-> $\bar{\Sigma}\Sigma\pi$,**

$$\frac{d^2\Gamma}{dM^2_{\pi\Sigma}dM^2_{\pi\bar{\Sigma}}} = \frac{1}{(2\pi)^3}\frac{4M^2_{\Sigma}}{32M^3_{\chi_{c0}}}\left|\mathcal{M}(M_{\pi\Sigma},M_{\pi\bar{\Sigma}})\right|^2$$

Results and discussion

- **Module squared of $t_{KN,KN}$, and $T_{\pi\Sigma,\pi\Sigma}$,**

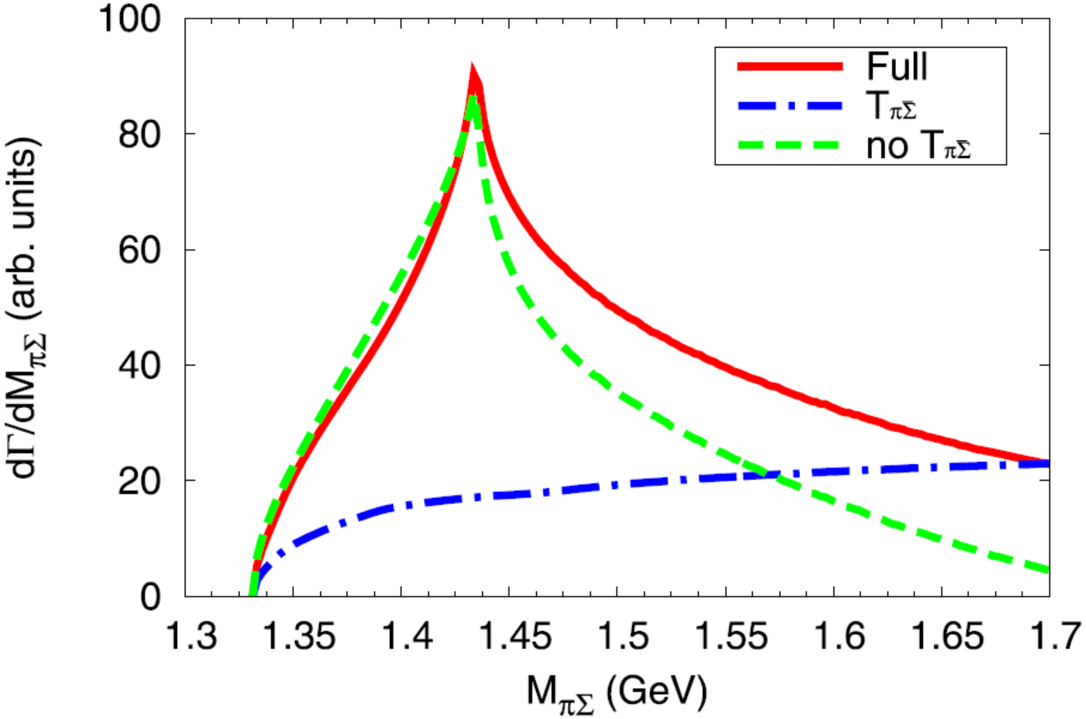


$$t = [1 - VG]^{-1} V$$

- **A cusp is found around $\bar{K}N$ threshold.**

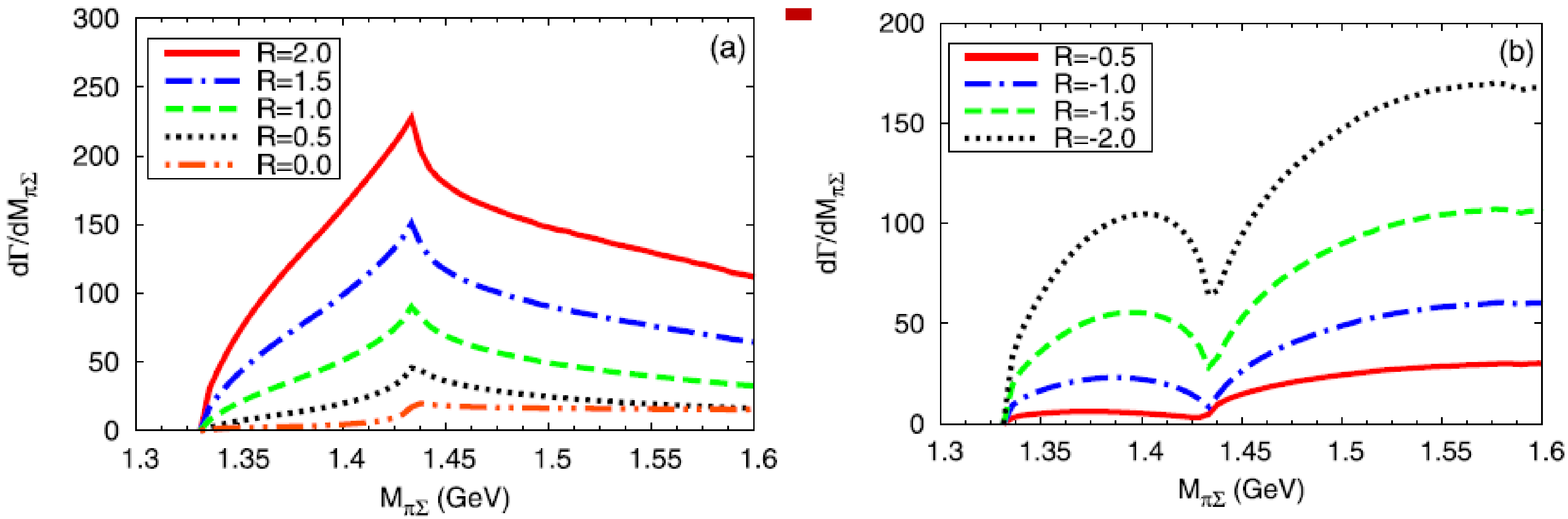
Results and discussion

- **πΣ invariant mass distribution**



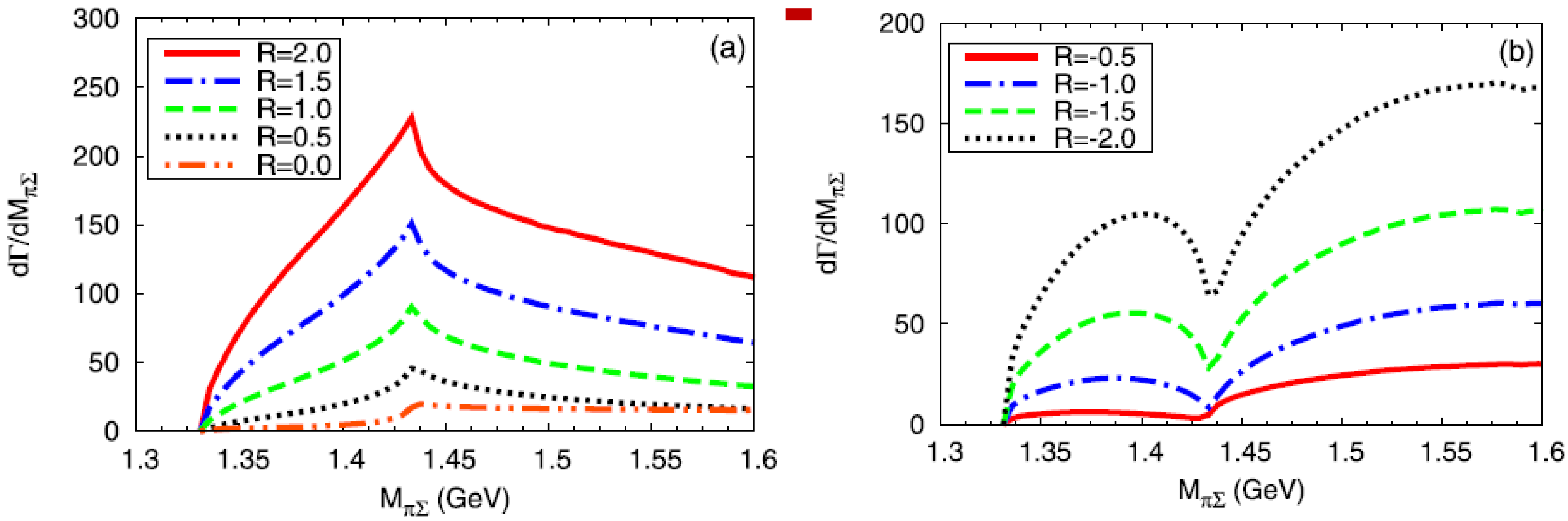
$$\mathcal{M}(M_{\pi\Sigma}, M_{\pi\bar{\Sigma}}) = V_p \left(h_{\pi\Sigma} + T_{\pi\Sigma} + T_{\pi\bar{\Sigma}}\right)$$

Different value of R



- **R=F/D**
- **For positive R, we have a strong cusp structure around KN threshold, but for negative R, the cusp is inverted.**

Different value of R

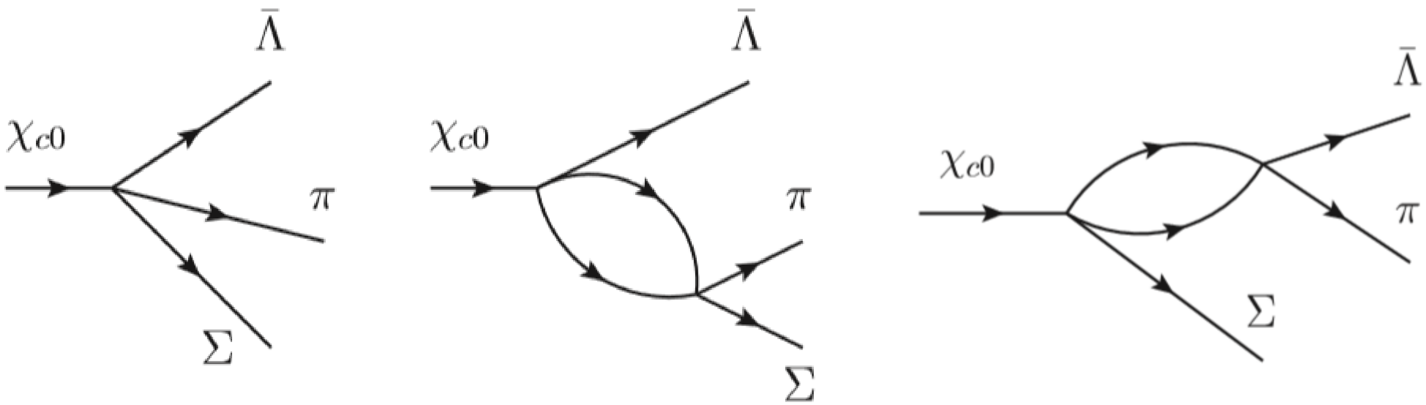


$$\mathcal{M}(M_{\pi\Sigma}, M_{\pi\bar{\Sigma}}) = V_p\left(h_{\pi\Sigma} + \sum_i h_i G_i(M_{\pi\Sigma}) t_{i,\pi\Sigma}(M_{\pi\Sigma}) + \sum_i h_i G_i(M_{\pi\bar{\Sigma}}) t_{i,\pi\bar{\Sigma}}(M_{\pi\bar{\Sigma}})\right) = V_p\left(h_{\pi\Sigma} + T_{\pi\Sigma} + T_{\pi\bar{\Sigma}}\right),$$

$$h_{\pi\Sigma} = \sqrt{\frac{2}{3}}\tilde{F},$$

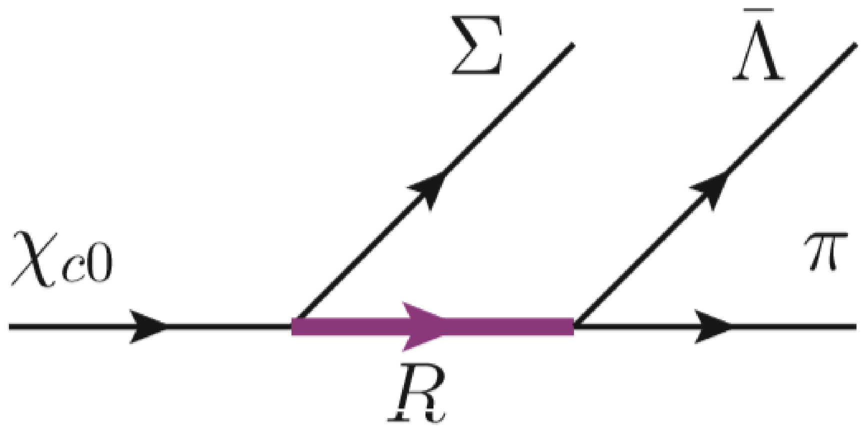
$$R = \tilde{F}/\tilde{D}$$

$\chi_{c0}(1P) \to \bar{\Lambda}\Sigma\pi$



$$
\begin{aligned}
\mathcal{M} &= V_p \left[h_{\pi\Sigma} + \sum_i h_i G_i(M_{\pi\Sigma}) t_{i,\pi\Sigma}(M_{\pi\Sigma}) \right] \\
&\quad + \tilde{V}_p \sum_j \tilde{h}_j \tilde{G}_j(M_{\pi\bar{\Lambda}}) \tilde{t}_{j,\pi\bar{\Lambda}}(M_{\pi\bar{\Lambda}}) \\
&= \mathcal{M}_{\text{tree}} + \mathcal{M}_{\pi\Sigma} + \mathcal{M}_{\pi\bar{\Lambda}}
\end{aligned}
$$

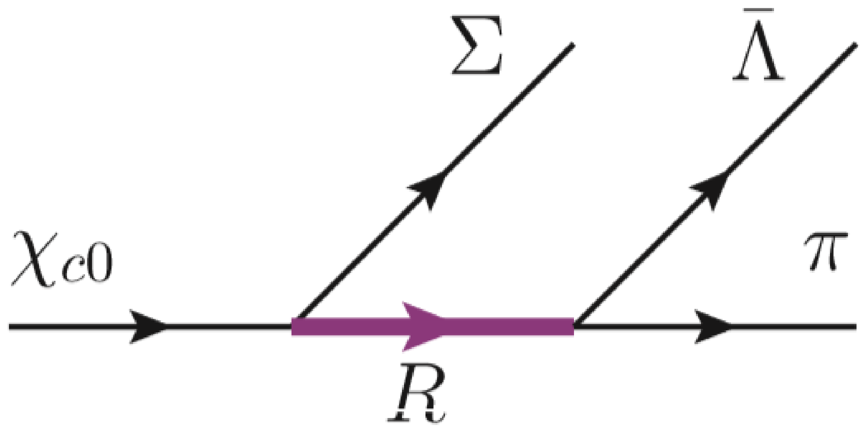
- **Sigma(1380)，M=1380MeV, Width=120MeV**



$$\mathcal{M} = V_p \left(h_{\pi\Sigma} + T_{\pi\Sigma} + T_{\pi\bar{\Lambda}} + T_{\pi\bar{\Lambda}} \right),$$

$$T_{\pi\bar{\Lambda}} = \frac{\alpha M_{\Sigma(1380)}}{M_{\pi\bar{\Lambda}} - M_{\Sigma(1380)} + i\Gamma_{\Sigma(1380)}/2}$$

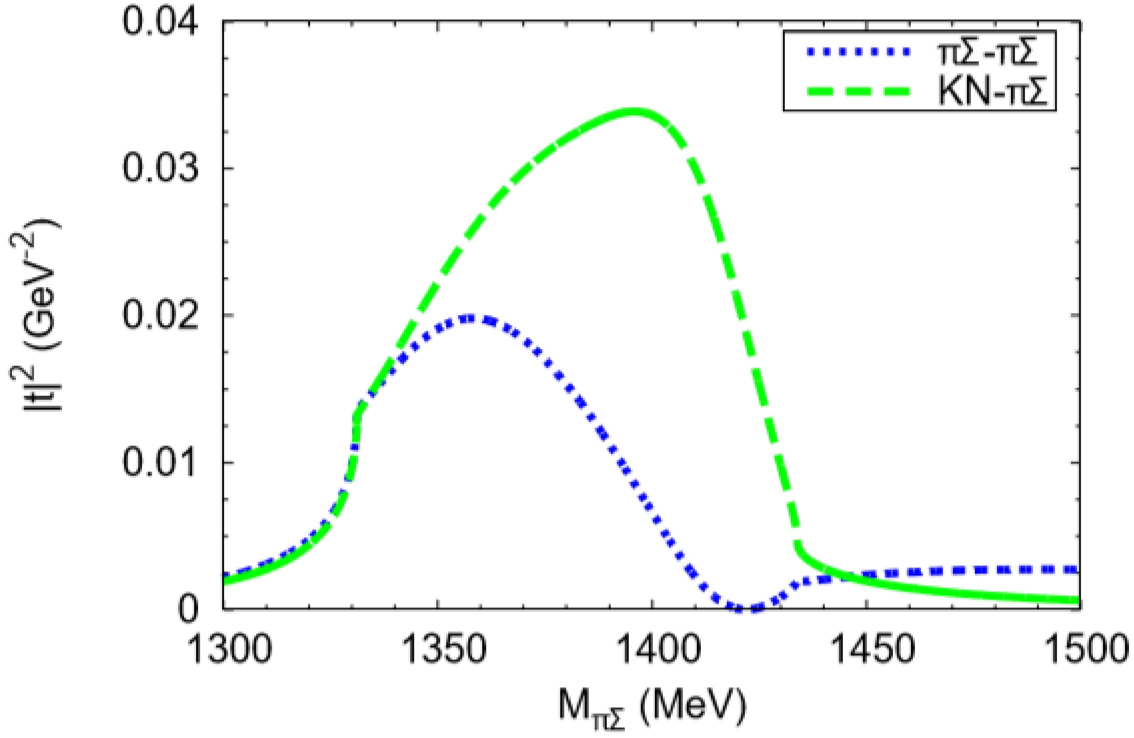
- **Sigma(1385)??**



$3/2^+$	$(56,0_0^+)$	$3/2$	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$
$3/2^+$	$(56,0_2^+)$	$3/2$	$\Delta(1600)$	$\Sigma(1690)^\dagger$	$\Xi(?)$	$\Omega(?)$
$1/2^-$	$(70,1_1^-)$	$1/2$	$\Delta(1620)$	$\Sigma(1750)^\dagger$	$\Xi(?)$	$\Omega(?)$
$3/2^-$	$(70,1_1^-)$	$1/2$	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$

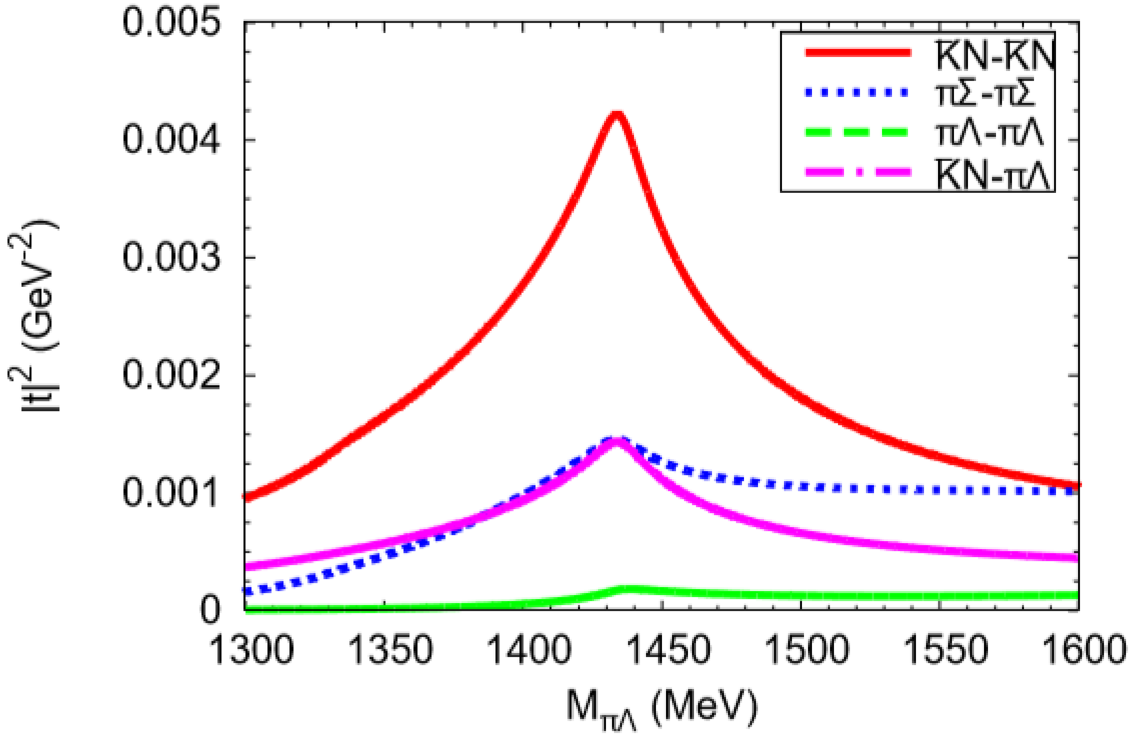
Results

- **Two poles of Lambda(1405)**

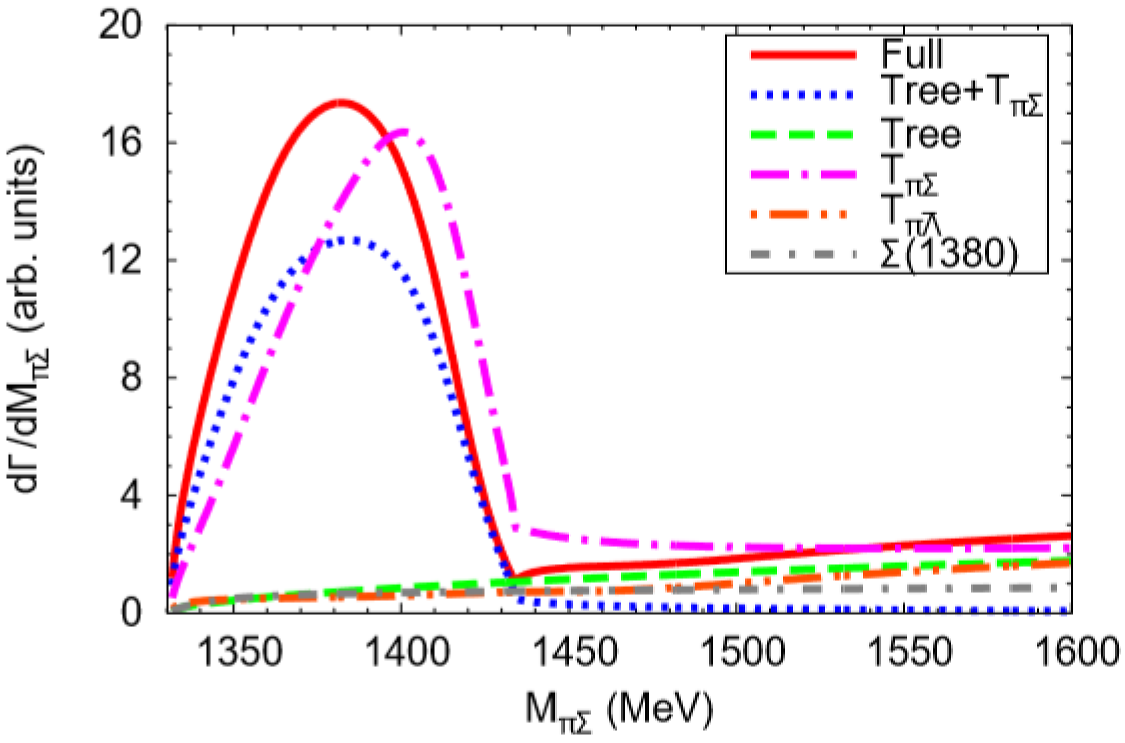


Results

- **Sigma*, with ½-**

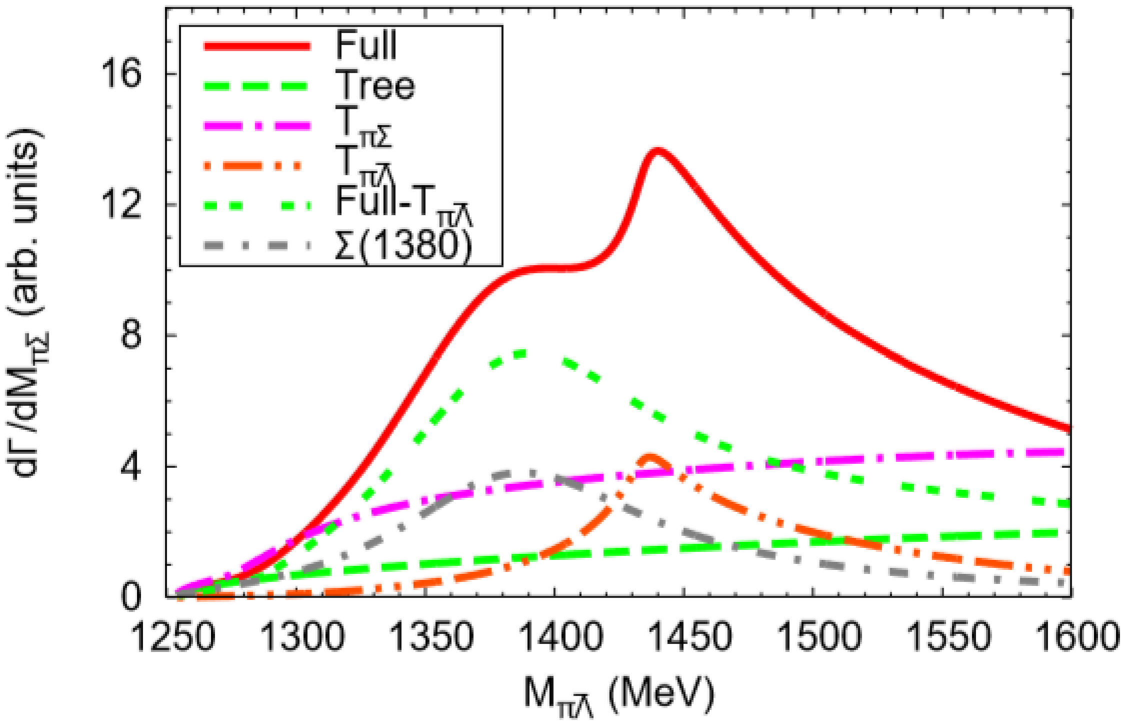


Results



Full
Tree+$T_{\pi\Sigma}$
Tree
$T_{\pi\Sigma}$
$T_{\pi\Lambda}$
Σ(1380)
20
16
12
8
4
0
1350
1400
1450
1500
1550
1600
$d\Gamma/dM_{\pi\Sigma}$ (arb. units)
$M_{\pi\Sigma}$ (MeV)

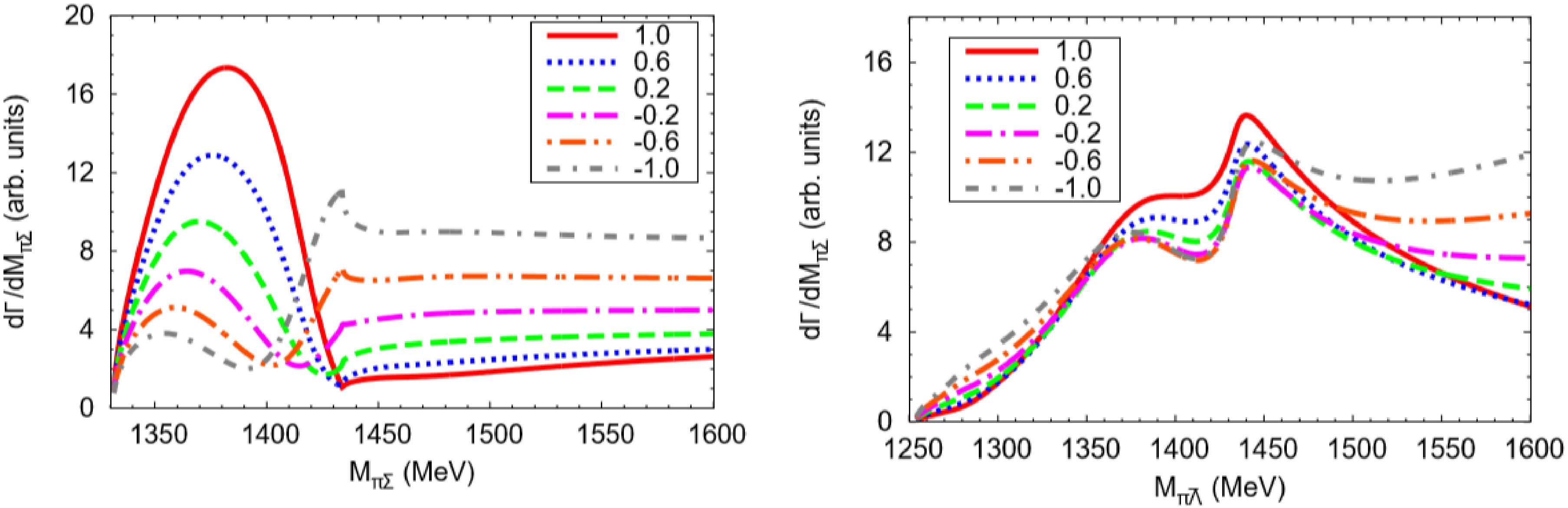
Results



Full
Tree
$T_{\pi\Sigma}$
$T_{\pi\Lambda}$
Full-$T_{\pi\Lambda}$
Σ(1380)
16
12
8
4
0
1250
1300
1350
1400
1450
1500
1550
1600
$d\Gamma/dM_{\pi\Sigma}$ (arb. units)
$M_{\pi\Lambda}$ (MeV)

Results

- **R dependence**



Summary

- We propose that the reaction $X_{c0}(1P) \to \bar{\Sigma}\Sigma\pi$ can be used to test/search I=1, S=-1, $J^P=1/2^-$ resonance (Σ^*) close to the KN threshold. This state appears in the theoretical work using the chiral unitary approach, and is necessary to describe the experimental data.
- The results depend on the ratio of R=F/D. For a positive R, we predict a strong cusp structure, and for a negative R, the cusp is inverted, and a strong dip is found.
- The reaction of $X_{c0}(1P) \to \bar{\Sigma}\Sigma\pi$ is easier to be used to test/search this state than $J/\psi \to \bar{\Sigma}\Sigma\pi$.
- **Our suggestion is easily accessible at BESIII.**

Summary

- **We also suggest that X_{c0}(1P)-> $\bar{\Lambda}\Sigma\pi$ can be used to search/distinguish the Σ*(1/2-) 1430 MeV and 1380 MeV, and also to check the role of Λ(1405) in the mass distribution.**

会议通知

- 5th workshop on XYZ particles
- 时间：2018年10月中下旬
- 地点：河南 郑州大学
- 主办单位：中科院高能所，北京大学，北京航空航天大学，郑州大学
- 联系人：苑长征，朱世琳
- 沈成平：shencp@buaa.edu.cn
- 王 恩：wangen@zzu.edu.cn
- 第一届：2013年5月在北京
- 第二届：2013年11月20-22日在安徽
- 第三届：2015年4月1-3日在高能所
- 第四届：2016年11月23-25日在北京航空航天大学

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郑州大学强子物理简介

- 物理学一级博士学位点
- 目前人员：

    理论：李德民，王恩

    实验：杜书先，刘海东

- 拟引进博士，博士后

    方向：强子物理理论，实验

    1.优秀博士，安家费20万，科研启动费20万

    2.校拔尖人才，安家费30万，科研启动费50万，年薪20-30万

    3.优青，青年，年薪40-60万，面议

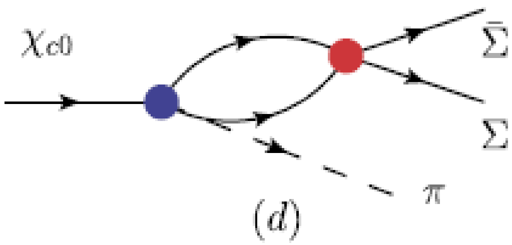
- 热烈欢迎大家到郑州大学指导工作！

- 学科网站：**http://www5.zzu.edu.cn/particle/**

Thanks for your attentions!

Backup

More discussion - $\bar{\Sigma}\Sigma$



- In addition to the above contributions, we also consider the effect of $\bar{\Sigma}\Sigma$ to $\bar{p}p$.
- The $\bar{p}p$ has an enhancement close to the threshold that is attributed to the resonance X(1835), which is seen in the decays of J/ψ->$p\bar{p}\gamma$. BESIII, PRL2012.
- The $\bar{\Sigma}\Sigma$ will couple to $\bar{p}p$ in the couple channels, so any pole in the $\bar{p}p$ -> $\bar{p}p$ will be also presented in the $\bar{p}p$-> $\bar{\Sigma}\Sigma$ amplitude.

$$\mathcal{M}(M_{\pi\Sigma}, M_{\pi\bar{\Sigma}}) = V_p\left(h_{\pi\Sigma}+T_{\pi\Sigma}+T_{\pi\bar{\Sigma}}+T_{p\bar{p}}\right),$$

$$T_{p\bar{p}} = \frac{a}{M_{\Sigma\bar{\Sigma}} - M_X + i\frac{\Gamma_X}{2}}$$

M=1835 MeV
Γ=100 MeV

More discussion

- In addition to the X(1835) intermediate, the ΣΣ interaction could have some sharp structure at threshold, bound state or cusp structure.
- the amplitude for ΣΣ scattering,

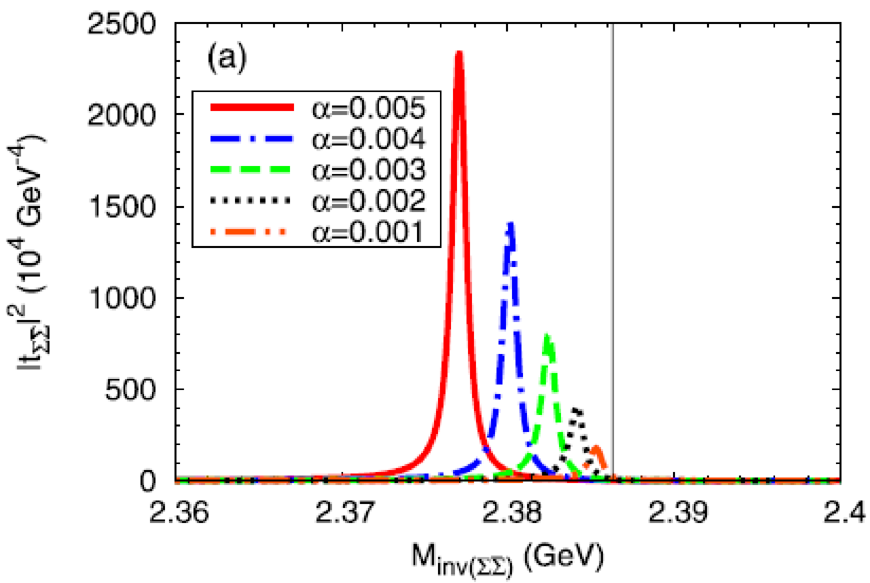
$$t_{\Sigma\bar{\Sigma}} = \frac{1}{V^{-1}_{\Sigma\bar{\Sigma}} - G_{\Sigma\bar{\Sigma}}(M_{\Sigma\bar{\Sigma}})}, \qquad T_{\Sigma\bar{\Sigma}} = h_{\pi\Sigma} G_{\Sigma\bar{\Sigma}}(M_{\Sigma\bar{\Sigma}}) t_{\Sigma\bar{\Sigma}}(M_{\Sigma\bar{\Sigma}}),$$

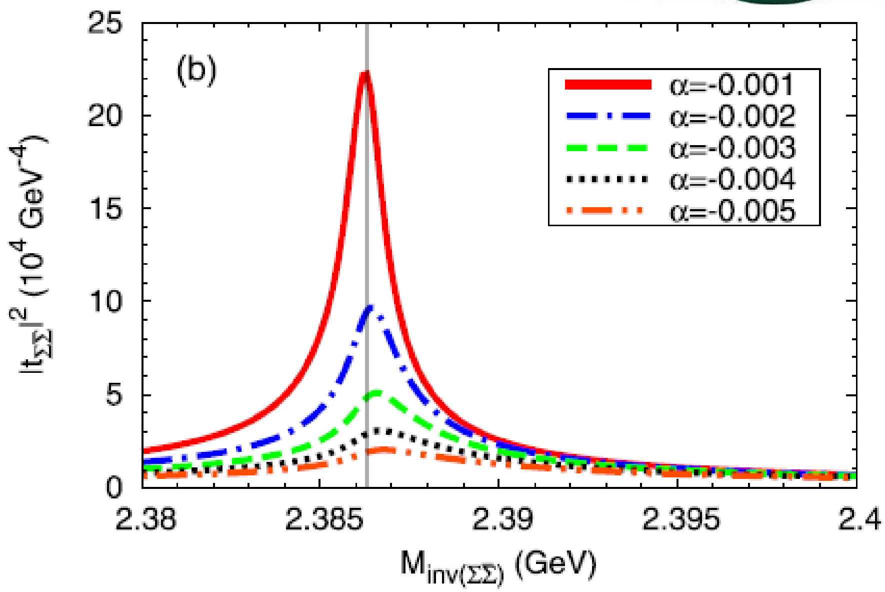
$$\mathcal{M}(M_{\pi\Sigma}, M_{\pi\bar{\Sigma}}) = V_p \left(h_{\pi\Sigma} + T_{\pi\Sigma} + T_{\pi\bar{\Sigma}} + T_{p\bar{p}} + T_{\Sigma\bar{\Sigma}}\right).$$

$$G_{\Sigma\bar{\Sigma}}(M_{\Sigma\bar{\Sigma}}) = \int \frac{d^3q}{(2\pi)^3} \frac{M^2_{\Sigma}}{E^2(q)} \frac{1}{M_{\Sigma\bar{\Sigma}} - 2E(q) + i\epsilon}, \qquad |\vec{q}_{\max}| = 600\ \text{MeV}$$

- A pole at threshold require $V_{\Sigma\Sigma}=G_{\Sigma\Sigma}(M_{\Sigma\Sigma})$, then we take,

$$V^{-1}_{\Sigma\bar{\Sigma}} = G_{\Sigma\bar{\Sigma}}(2M_{\Sigma}) + \alpha M^2_{\Sigma},$$



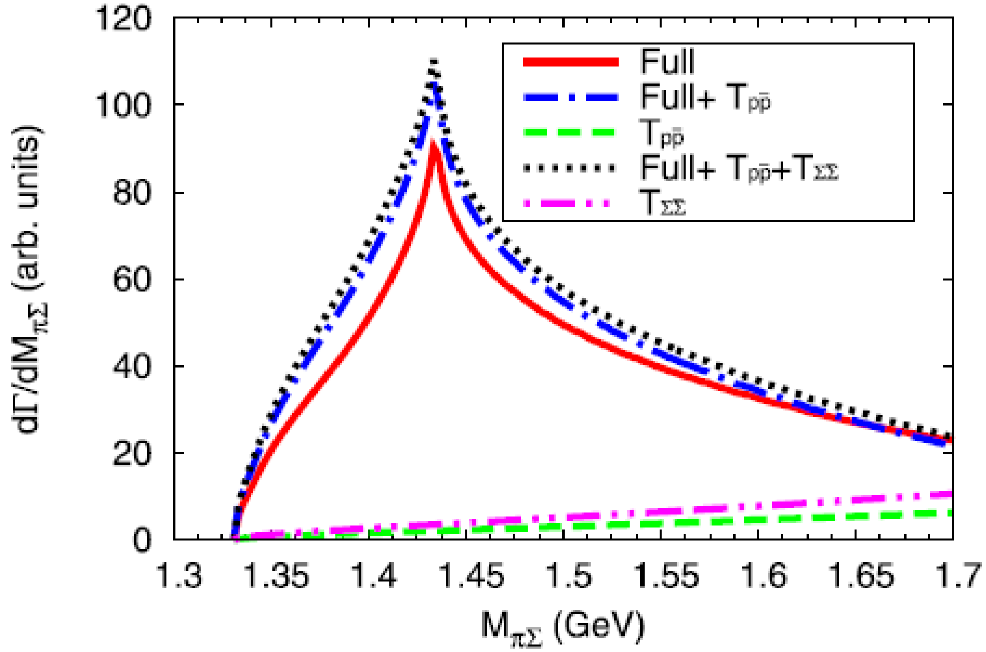


For $\alpha>0$, we get a bound state.

For $\alpha<0$, we get a cusp structure.

We take $\alpha=0.001$ in the following calculation, but the same conclusions are obtained for different value of α.

πΣ invariant mass distribution



$$\mathcal{M}(M_{\pi\Sigma}, M_{\pi\bar{\Sigma}}) = V_p \left(h_{\pi\Sigma} + T_{\pi\Sigma} + T_{\pi\bar{\Sigma}} + T_{p\bar{p}} + T_{\Sigma\bar{\Sigma}}\right)$$

Full

There is a small effect in the πΣ invariant mass distribution.

X_{c0} and J/ψ decay process

$$\chi_{c0}(1P)\left(0^+\right)\rightarrow\bar{\Sigma}\left(1/2^-\right)\Sigma\left(1/2^+\right)\pi\left(0^-\right)$$

L=0

$1/2^-$

0^+

$$\chi_{c0}(1P)\left(0^+\right)\rightarrow\bar{\Sigma}\Sigma$$

L=1

$$\rightarrow\bar{p}p$$

PDG2016

Γ_{56}	$p\overline{p}$	$(2.25\pm0.09)\times10^{-4}$
Γ_{57}	$p\overline{p}\pi^0$	$(6.8\ \pm0.7\ )\times10^{-4}$

$$J/\psi\left(1^-\right)\rightarrow\bar{\Sigma}\left(1/2^-\right)\Sigma\left(1/2^+\right)\pi\left(0^-\right)$$

L=1

$1/2^-$

0^+

$$J/\psi\left(1^-\right)\rightarrow\bar{\Sigma}\Sigma$$

L=0

$$\rightarrow\bar{p}p$$

Γ_{120}	$\Sigma^+\overline{\Sigma}^-$	$(\ 1.50\ \pm0.24\ )\times10^{-3}$
Γ_{121}	$\Sigma^0\overline{\Sigma}^0$	$(\ 1.29\ \pm0.09\ )\times10^{-3}$

PDG2016

Γ_{108}	$p\overline{p}$	$(\ 2.120\pm0.029)\times10^{-3}$
Γ_{109}	$p\overline{p}\pi^0$	$(\ 1.19\ \pm0.08\ )\times10^{-3}$