Anomalous enhancement of isospin-violating $\Lambda(1405)$ production by the decay of Lambda with charm

Lianrong Dai

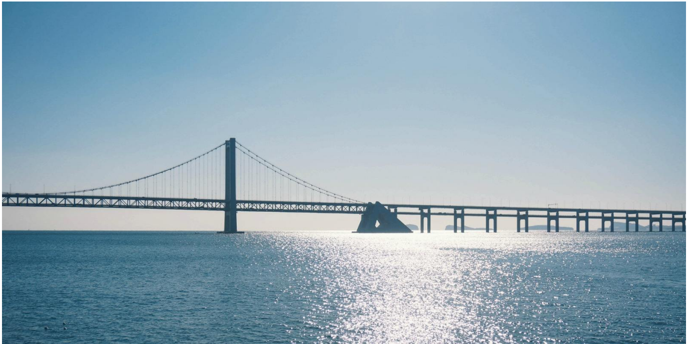
Liaoning Normal University (大连)

第十八届全国中高能核物理大会
Changsha, June 21 −25, 2019

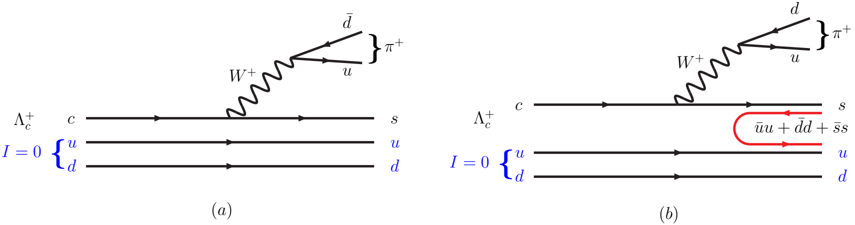
L. R. Dai, R. Pavao, S. Sakai, E. Oset, Phys. Rev. D 97, 116004

$\Lambda_c^+ \to \pi^+ \bar{K}^* N$ **(exp)**
triangle singularities
The dynamical origin of the $\Lambda(1405)$
The $\Lambda_c \to \pi^+\pi^0\pi^0\Sigma^0$ and isospin forbidden $\Lambda(1405)$ production

大连（滨城） 东北，重要的港口城市，位于辽东半岛南端



Weak decay and Hadronization



(a) Quark level diagram for $\Lambda_c^+ \to \pi^+ sud$ (b) Hadronization through $\bar{q}q$ creation with vacuum quantum numbers

$$H = \sum_{i=1}^{3} s\bar{q}_i q_i \frac{1}{\sqrt{2}}(ud-du) = \sum_{i=1}^{3} M_{3i} q_i \frac{1}{\sqrt{2}}(ud-du) \quad (1)$$

$$M = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} \\ d\bar{u} & d\bar{d} & d\bar{s} \\ s\bar{u} & s\bar{d} & s\bar{s} \end{pmatrix}$$

$$M \to V = \begin{pmatrix} \frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & -\frac{\rho^0}{\sqrt{2}} + \frac{\omega}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}$$

$$\rho^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d}),$$

$$\omega = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}),$$

$$\rho^+ = u\bar{d}, \qquad \rho^- = d\bar{u},$$

$$K^{*0} = d\bar{s}, \qquad K^{*-} = s\bar{u},$$

$$K^{*+} = u\bar{s}, \bar{K}^{*0} = s\bar{d}, \qquad \phi = s\bar{s}$$

$$H = K^{*-} u \frac{1}{\sqrt{2}}(ud - du) + \bar{K}^{*0} d \frac{1}{\sqrt{2}}(ud - du) + \phi s \frac{1}{\sqrt{2}}(ud - du) \quad (2)$$

$$p = \frac{1}{\sqrt{2}} u(ud - du) \,, \qquad n = \frac{1}{\sqrt{2}} d(ud - du) \,,$$

$$\Lambda = \frac{1}{2\sqrt{3}} [u(ds - sd) + d(su - us) - 2s(ud - du)] \,,$$

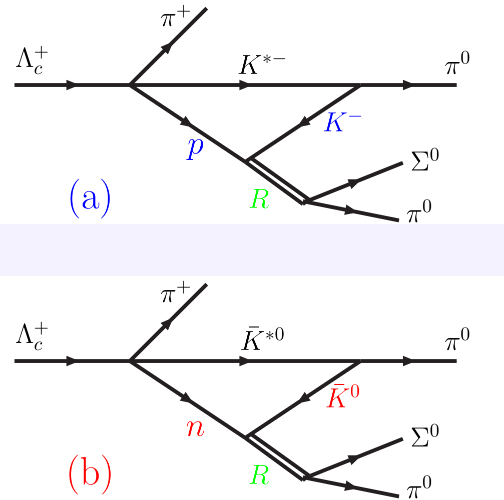
$$\Sigma^0 = \frac{1}{2} [u(ds - sd) - d(su - us)] \,.$$

After the hadronization

$$H = K^{*-} p + \bar{K}^{*0} n - \sqrt{\frac{2}{3}} \phi \Lambda \quad (3)$$

However, we will neglect the $\phi\Lambda$ component since this does not contribute to our triangle singularity mechanism. Note that $s\frac{1}{\sqrt{2}}(ud - du)$ has zero overlap with Σ^0 and thus the $\phi\Sigma^0$ component does not appear, as it should be, since this has $I = 1$.

Triangle mechanism with singularity



STORY!!!

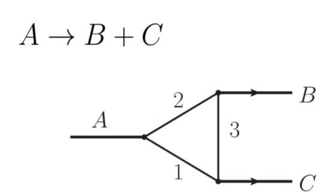
Isospin forbidden

Cancellation of diagrams (a) and (b) if equal masses

The different masses of the Kaons make the cancellation partial and we can see the $\Lambda(1405)$

$\Longrightarrow$ **Dai, Pavao, Sakai, Oset, PRD97,116004 [Anomalous enhancement of the isospin-violating $\Lambda(1405)$ production by a triangle singularity in $\Lambda_c \to \pi^+\pi^0\pi^0\Sigma^0$]**

Triangle Singularity (TS)



L. D. Landau, Nucl. Phys. 13 (1959) 181;

Coleman, Norton, Nuovo Cim. 38 (1965)438;

M. Bayar, F. Aceti, F. K. Guo and E. Oset, Phys. Rev. D 94, 074039 (2016)

All three intermediate particles can go on shell simultaneously and collinear in the rest frame of A, a singularity in the decay amplitude T develops for zero width of the 2, or a peak if the width is considered

Triangle Singularity

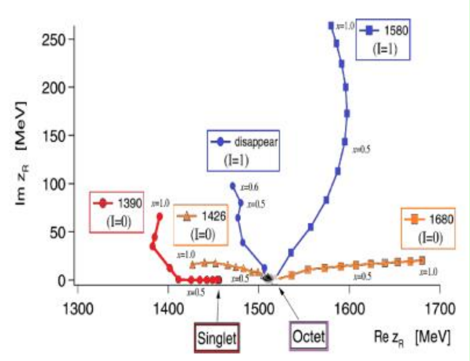
- **simulating a resonance**

requires very special kinematics $\Longrightarrow$ process dependent!
[ex:$a_1(1420)$, Mikhasenko, Ketzer, Sarantsev, PRD91,094015; Aceti,Dai,Oset,PRD94(2016)096015]

- **In some particular modes, the production rate is enhanced by the presence of a TS in the reaction mechanism**

$\bar{K}N$ Interaction and $\Lambda(1405)$ resonance

E. Oset and A. Ramos, Nucl. Phys. A 635 (1998) 99;
D. Jido, J. A. Oller, E. Oset, A. Ramos and U. G. Meissner, Nucl. Phys. A 725 (2003) 181



1	2	3	4	5
K^-p	$\bar{K}^0 n$	$\pi^0\Lambda$	$\pi^0\Sigma^0$	$\eta\Lambda$
6	7	8	9	10
$\eta\Sigma^0$	$\pi^+\Sigma^-$	$\pi^-\Sigma^+$	$K^+\Xi^-$	$K^0\Xi^0$

$$t_3 \equiv t_{\bar{K}N\to\pi^0\Sigma^0}\ ,$$

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

where V_{ij} are obtained from the chiral Lagrangians [NPA635(1999)99]

G is the meson-baryon loop function for the intermediate states

- **Very good reproduction is obtained of scattering data and the threshold parameters**
- **Two $\Lambda(1405)$ are generated from this interaction**

$\Lambda_c^+ \to \pi^+ \bar{K}^* N$ decay Dai,Pavao,Sakai,Oset,PRD97(2018)116004

since the $\Lambda_c^+ \to \pi^+ K^{*-} p$ process can proceed via s-wave, the amplitude

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

where a scalar function is made between the spin and the $\bar{K}^*$ polarization.

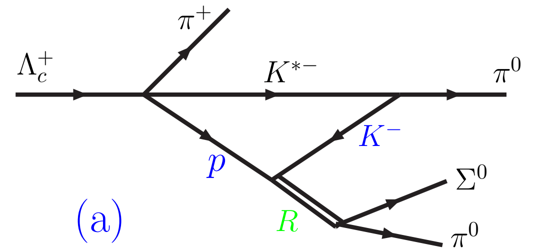
The $K^{*-} p$ invariant mass distribution

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

where p_{π^+} is the momentum of π^+ in the Λ_c^+ rest frame, and $\widetilde{p}_{K^{*-}}$ is the momentum of K^{*-} in the $K^{*-} p$ rest frame.

By calculating the width of this decay, using the experimental branching ratio of this decay $Br(\Lambda_c^+ \to \pi^+ K^{*-} p) = (1.5 \pm 0.5) \times 10^{-2}$ [PRD98(2018)030001], we can determine the value of the constant $|A|$.

For the first diagram



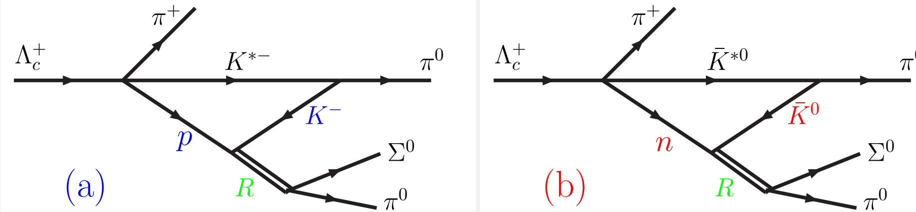
$$t_{\Lambda_c^+ \to \pi^+ \pi^0 \pi^0 \Sigma^0} = -A \, \frac{1}{\sqrt{2}} \, g \, \vec{\sigma} \cdot \vec{k} \; t_{K^- p \to \pi^0 \Sigma^0} \; t_T \, ,$$

where $t_T \equiv t_T(m_{K^{*-}}, M_p, m_{K^-})$ **for the triangle loop function for the decay**

$$t_T = i \int \frac{d^4 q}{(2\pi)^4} \frac{2M_p}{q^2 - M_p^2 + i\epsilon} \frac{(2 + \frac{\vec{q} \cdot \vec{k}}{\vec{k}^2})}{(P-q)^2 - m_{K^{*-}}^2 + i\epsilon} \frac{1}{(P-q-k)^2 - m_{K^-}^2 + i\epsilon} \, .$$

Include the two diagrams

$\Longrightarrow$ the isospin-breaking effect



The final differential distributions

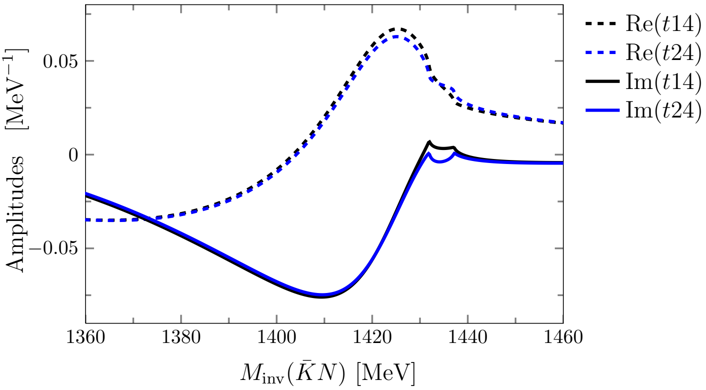
$$\frac{1}{\Gamma_{\Lambda_c^+}}\frac{d^2\Gamma}{dM_{\mathbf{inv}}(\pi^0\Lambda(1405))dM_{\mathbf{inv}}(\pi^0\Sigma^0)} = \frac{1}{(2\pi)^5}\frac{M_{\Sigma^0}}{M_{\Lambda_c^+}}\widetilde{p}_{\pi^+}\widetilde{q}_{\Sigma^0}\frac{1}{2}g^2\frac{A^2}{\Gamma_{\Lambda_c^+}}|\vec{k}|^3$$
$$\times\left|t_T(m_{K^{*-}}, M_p, m_{K^-})t_{K^-p\to\pi^0\Sigma^0} - t_T(m_{\bar{K}^{*0}}, M_n, m_{\bar{K}^0})t_{\bar{K}^0 n\to\pi^0\Sigma^0}\right|^2 .$$

The results

PRD97 (2018) 116004

$\bar{K}N$ Interaction [real and imaginary parts]

Dai, Pavao, Sakai, Oset, PRD97(2018)116004

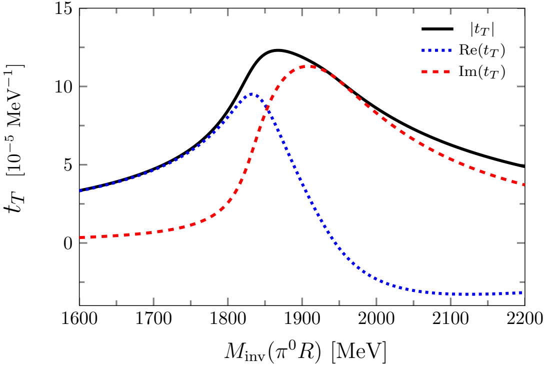


$$\begin{cases} t_{14} & t_{K^- p \to \pi^0 \Sigma^0} \\ t_{24} & t_{\bar{K}^0 n \to \pi^0 \Sigma^0} \end{cases}$$

1	2	3	4	5	6	7	8	9	10
$K^- p$	$\bar{K}^0 n$	$\pi^0 \Lambda$	$\pi^0 \Sigma^0$	$\eta \Lambda$	$\eta \Sigma^0$	$\pi^+ \Sigma^-$	$\pi^- \Sigma^+$	$K^+ \Xi^-$	$K^0 \Xi^0$

Triangle amplitude real and imaginary absolute value

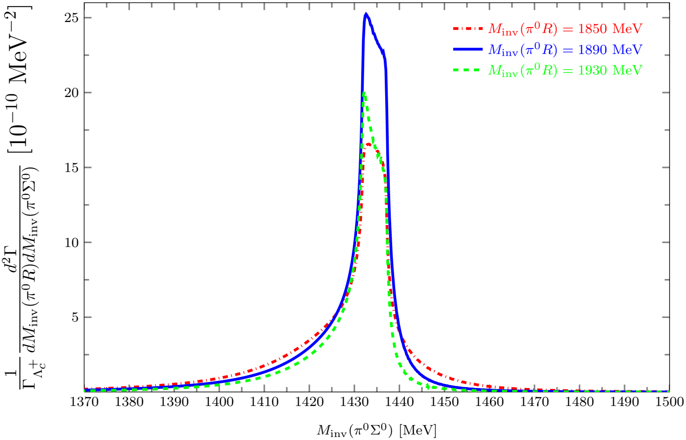
$t_T(m_{K^{*-}}, M_p, m_{K^-})$ $M_{\rm inv}(R) \equiv M_{\rm inv}(\pi^0\Sigma^0)$ **fixed at 1420 MeV**



Re(t_T) **has a peak around 1838 MeV,** Im(t_T) **a peak around 1908 MeV,** $|t_T|$ **a peak around 1868 MeV**

The peak of the real part is related to the $K^{*-}p$ threshold while the peak of the imaginary part, dominating for the larger invariant masses for $\pi^0 R$, is due to the triangle singularity

The remarkable observation of a peak



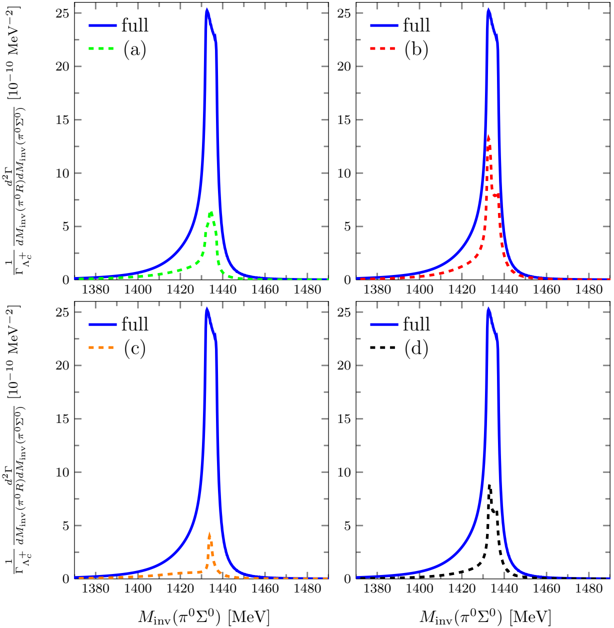
FIRST TIME!!!

7 MeV!!!
Unusual narrow width

The remarkable observation of a peak tied to the $\Lambda(1405)$ state close to the $\bar{K}N$ threshold of 1432 MeV.

It is also remarkably narrow and is tied to the difference of masses, **mostly from the K^- and $\bar{K}^0$ mass difference.**

discussion on separate the effects



Dai, Pavao, Sakai, Oset, PRD 97 (2018) 116004

mostly from the K^- and $\bar{K}^0$ mass difference

Isospin forbidden reactions

History!!!

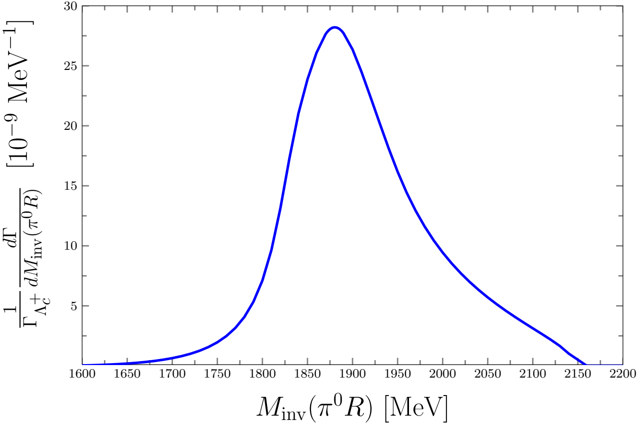
The apperance of a narrow resonance in the isospin forbidden reactions due to different Kaon masses also appears in the $f_0(980)$ or $a_0(980)$ isospin forbidden production in

"Investigation of a0-f0 mixing" C. Hanhart, B. Kubis and J. R. Pelaez, Phys. Rev. D 76 (2007) 074028

"Isospin violation in $J/\Psi \to \phi\pi^0\eta$ decay and the $f_0 - a_0$ mixing" L. Roca, Phys. Rev. D 88 (2013) 014045

"Isospin breaking and $f_0(980)$-$a_0(980)$ mixing in the $\eta(1405) \to \pi^0 f_0(980)$ reaction" F. Aceti, W. H. Liang, E. Oset, J. J. Wu and B. S. Zou, Phys. Rev. D 86 (2012) 114007

Differential distribution and branching ratio



a clear peak

triangle singularity!!!

$$Br(\Lambda_c^+ \to \pi^+\pi^0\Lambda(1405);\ \ \Lambda(1405) \to \pi^0\Sigma^0) = (4.17 \pm 1.39) \times 10^{-6},$$

$\Longrightarrow$ **this number** is within **a measurable range**

The errors come from the experimental errors in the branching ratio of $Br(\Lambda_c^+ \to \pi^+ K^{*-} p)$

Conclusions

Triangle singularities show a great potential to enhance suppressed processes.

In the present case we showed how the $\Lambda(1405)$ could be produced in an isospin forbidden mode.

Resulting from cancellation of diagrams involving the $\bar{K}N \to \pi\Sigma$ amplitudes, it stresses the nature of this resonance as dynamically generated from the meson-baryon interaction.

One signal of this is the narrow shape of the resonance, which would not be justified if the resonance was a genuine state.

The Triangle singularity also enhances the production of resonances that appear around the singular point.

THE ENDING!!!

Another similar work Xie, Oset, PLB792(2019) to produce a $\Sigma^*(1430)$ state predicted by the chiral unitary approach, filtering the spin channel and enhancing the production due to the triangle singularity.