On the lineshapes manifested by the molecular candidates of isovector $K^*\bar{K}$

严茂俊

西南大学

合作者：彭方正，安春生，邓成荣，谢聚军

2026 年 8 月 13 日

Axial current

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- $J_\mu = \bar{q}\gamma^\mu\gamma_5 q$ S. Scherer, Adv.Nucl.Phys. 27 (2003)
- Nambu-Goldstone bosons in ChPT S. Scherer, Adv.Nucl.Phys. 27 (2003)
- Coupling to the axial-vector mesons with $J^{PC} = 1^{++}$, J.W. Durso et al, NPA 430 (1984); Ulf Meissner, Phys.Rept. 161 (1988)
- Chiral doublet $\{\rho,\, a_1\}$, L.Ya. Glozman, PLB 587 (2004)

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Axial current and One-Boson-Exchange model

- Pseudoscalar and vector mesons are involved in the classical OBE. M.M. Nagels et al, PRD 17 (1978); R. Machleidt et al, Phys.Rept. 149 (1987); R. Machleidt, Phys.Rev.C 63 (2001)
- Axial-vector meson exchange contributes to the delta-force in OBE MJY et al, PRD 104 (2021); in preparation

More on axial vector meson

- CP violation in $\Lambda_b \to p a_1(1260)$; topics on $g-2$

Low lying axial-vector meson

f_1

- $f_1(1285)$ and $f_1(1420)$ are $^3P_1$ states S. Navas et al, PRD110(2024)[PDG]
- $f_1(1420)$ is a threshold effect. W. H. Liang et al, EP.C 80 (2020)
- $f_1(1420)$ is a mixture of $K^*\bar{K}$ and $[q\bar{q}]$ H.L. Fu et al, arxiv:2606.19040

$K_1(1270)$

- A mixture of $^3P_1$ and $^1P_1$ S. Navas et al, PRD110(2024)[PDG];
- A double-pole state in $\{K^*\pi,\ K\rho\}$ scattering L. Roca et al, PPD 72 (2005)

$a_1(1260)$

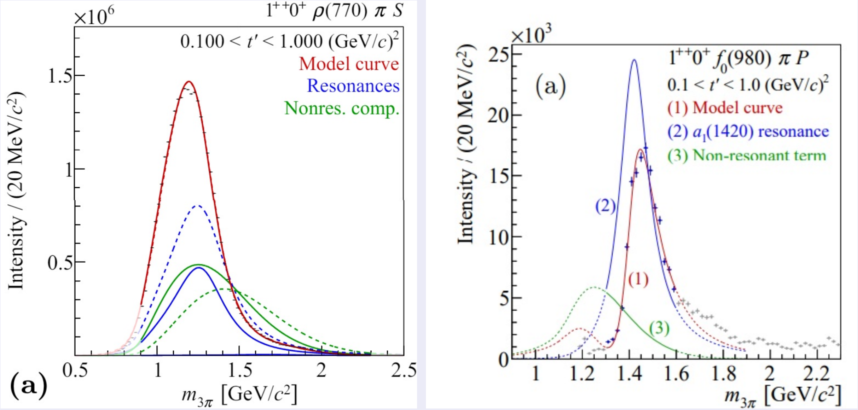
- $^3P_1$ state of $[q\bar{q}]$ S. Godfrey et al, PRD 32, 189 (1985);S. Navas et al, PRD110(2024)[PDG]
- $a_1(1260)$ is a $\rho\pi$ resonance, L. Roca et al,PRD72 (2005); M. Mai et al, PRL. 127 (2021)

b_1

- $b_1(1235)$ is a $^1P_1$ state of $[q\bar{q}]$ S. Navas et al, PRD110(2024)[PDG]

Light axial-vector meson spectrum: $a_1(1420) \to 3\pi$

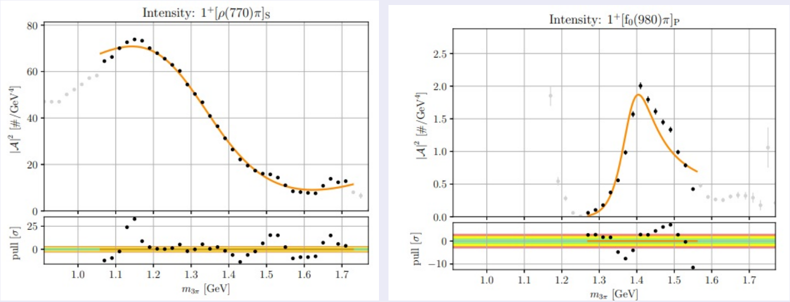
$\pi^- p \to \pi^- \pi^- \pi^+ p$ from COMPASS, C. Adolph et al, PRL. 115 (2015) 8, 082001



- $a_1(1420)$ mainly decays into $f_0(980)\pi$.
- mass (1414^{+15}_{-13}) MeV and width (153^{+8}_{-23}) MeV.

Light axial-vector meson spectrum: $a_1(1420) \to 3\pi$

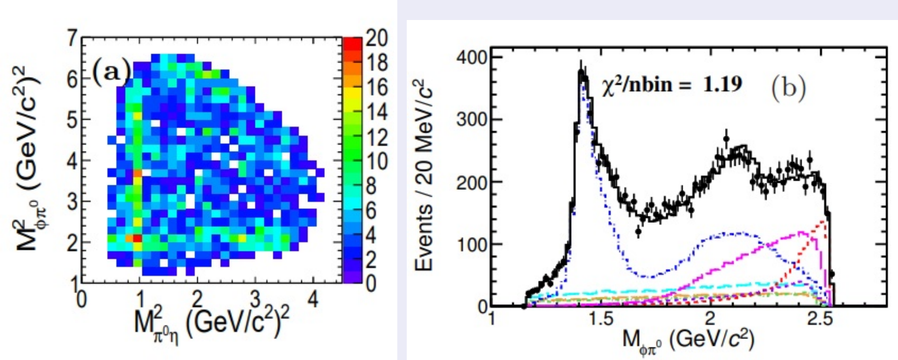
$\tau \to \pi^-\pi^-\pi^+\nu_\tau$ from Belle, Andrei Rabusov et al, HADRON2023



- $a_1(1260)$: (M,Γ) $=(1328.9 \pm 0.1, \quad 388.4 \pm 0.1)$.
- $a_1(1420)$: (M,Γ) $=(1387.8 \pm 0.3, \quad 109.2 \pm 0.6)$.

Hints on $b_1(1400)$ from BESIII in $J/\psi \to \phi\pi^0\eta$

Peak near $K^*\bar{K}$ threshold may couple to Z_s



BESIII,PRL. 121(2018)2,022001, PRD 110 (2024) 11,112014; H.P. Li et al, PRD 113 (2026) 5, 054028

The peak around 1400 MeV is the non-ϕ background.

Models on $a_1(1420)$

- Tetraquark: H.X Chen et al, PRD 91 (2015), T. Gutsche et al, PRD 96 (2017) ;H. Sundu et al, PRD 97 (2018)
- Novelty: one pole generates two peaks in $\rho\pi - f_0(980)\pi$ scattering,Jean-Louis Basdevant et al, PPL. 114 (2015)
- Lattice: $a_1(1260)$ is $q\bar{q}$ and $a_1(1420)$ is not $q\bar{q}$,Y. Murakami et al, 1812.07765; $a_1(1260)$ is a dynamical pole of $\rho\pi$, M. Mai et al, PRL. 127 (2021);

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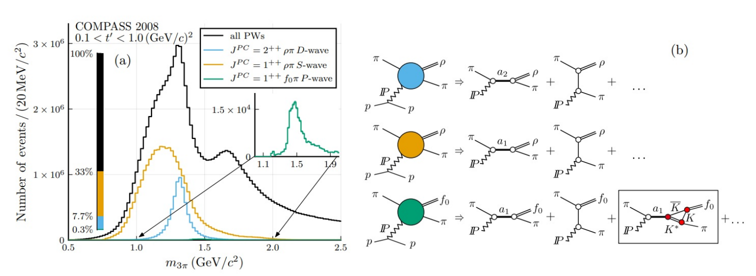
- Triangle singularity: Q. Zhao, HDARON2013; M. Mikhasenko et al, PRD 91 (2015); F. Aceti et al, PRD 94 (2016);G.D. Alexeev et al, PRL. 127 (2021)



VP scattering in ChUA

Bethe-Salpeter equation

$$T = \left[1 + V\hat{G}\right]^{-1}(-V)\,\vec{\epsilon}\cdot\vec{\epsilon}',$$

with

$$\begin{aligned} V_{ij}(s) &= -\frac{\epsilon\cdot\epsilon'}{8f_\pi^2}C_{ij}\left[3s - \left(M^2 + m^2 + M'^2 + m'^2\right)\right. \\ &\left. -\frac{1}{s}\left(M^2 - m^2\right)\left(M'^2 - m'^2\right)\right]. \end{aligned}$$

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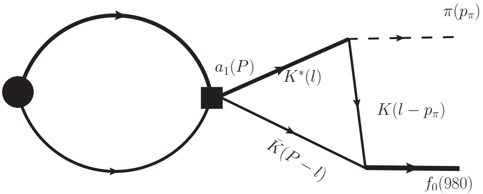
with

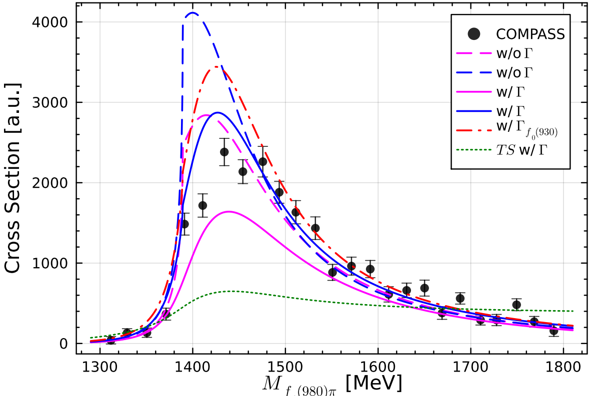
$$V_{ij}(s) = -\frac{\epsilon\cdot\epsilon'}{8f_\pi^2}C_{ij}\left[3s - \left(M^2 + m^2 + M'^2 + m'^2\right) - \frac{1}{s}\left(M^2 - m^2\right)\left(M'^2 - m'^2\right)\right].$$

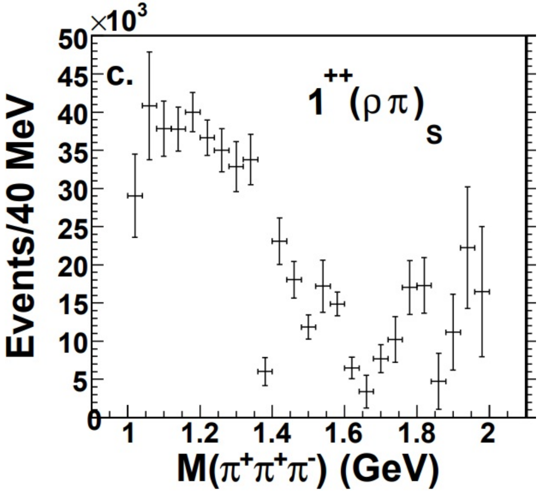
$C_{11} = -2,\ C_{12} = -\sqrt{2},\ C_{22} = -1$

- $det = (1 - V_{11}G_{11})(1 - V_{22}G_{22}) - V_{12}^2 G_{11}G_{22}$
- $V_{11}V_{22} \simeq V_{12}^2$: $det \simeq 1 - V_{11}G_{11} - V_{22}G_{22}$
- One pole is presented L. Roca et al, PPD 72 (2005)

$K^*\bar{K} - f_0(980)\pi$ scattering in $I^G J^{PC} = 1^- 1^{++}$ sector



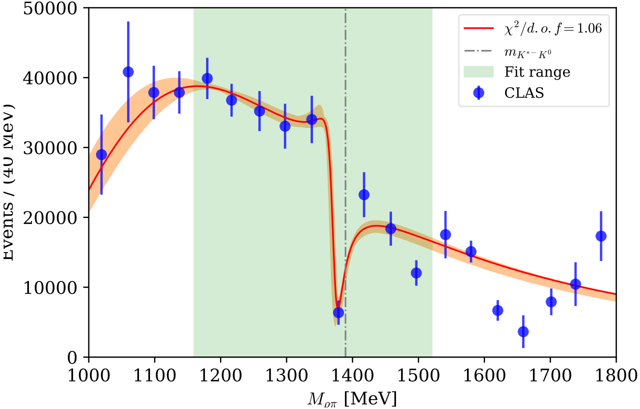




$a_1(1260)$ is concerned M. Nozar et al, CLAS, PRL 102 (2009)

NO TS around $1.4\mathrm{GeV}$ in $\rho\pi$ invariant mass distribution.

$\gamma p \to n\pi^+\pi^+\pi^-$: 2 BWs

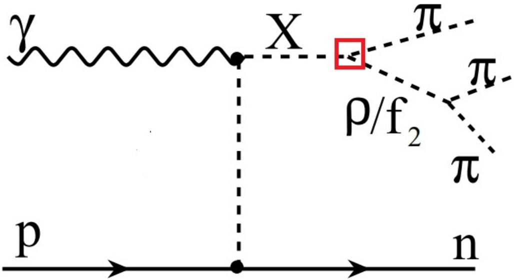


$$\mathcal{M} = \frac{g_1}{w - m_1 + i\frac{\Gamma_1}{2}} + \frac{g_2}{w - m_2 + i\frac{\Gamma_2}{2}},\ \frac{dN}{dM} = |\mathcal{M}|^2 p.s.$$

$$g_1 = (6.06 \pm 0.30)e^5,\ m_1 = (1.07 \pm 0.04)e^3\,\mathrm{MeV}, \Gamma_1 = 600 \pm 70\,\mathrm{MeV}$$

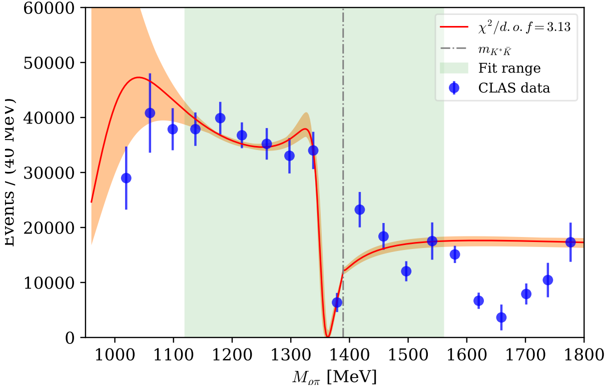
$$g_2 = -(8.6 \pm 1.3)e^3,\ m_2 = (1.372 \pm 0.005)e^3\,\mathrm{MeV}, \Gamma_2 = 20 \pm 4\,\mathrm{MeV}$$

$\gamma p \to n\pi^+\pi^+\pi^-$: $\{\rho\pi, K^*\bar{K}\}$



$\{\rho\pi, K^*\bar{K}\}$ coupled channel scattering in the rectangle

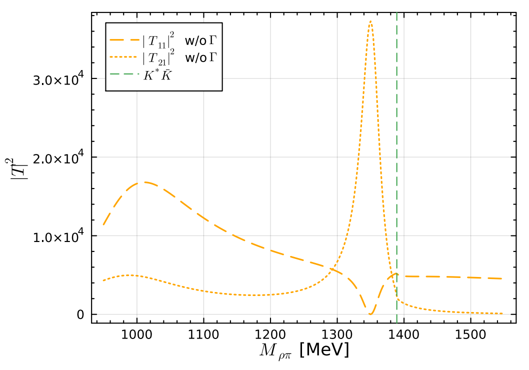
- WT: V_{11}, V_{22}
- V_{12} is a constant; dim. regularized G
- the production rates P_i and loop connected to the production vertex are approximated by constants: $\lambda_i = P_i \tilde{G}_i$ and λ_2 is a constant



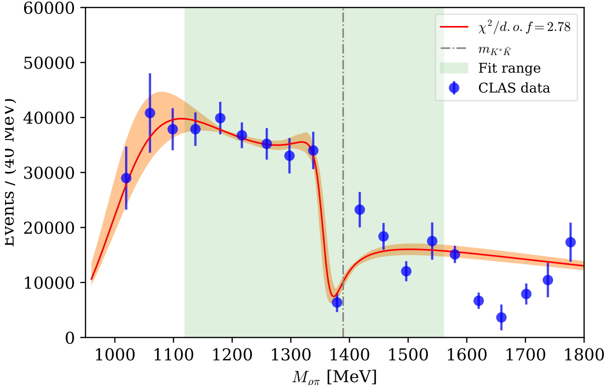
- $\mathcal{M} = \lambda_1 t_{11} + \lambda_2 t_{21}$,w/ $\lambda_i = P_i \tilde{G}_i$, $\frac{dN}{dM} = |\mathcal{M}|^2 p.s.$
- $V_{12} = 25.7 \pm 1.7,\ \lambda_1 = -16.9 \pm 0.5,\ \lambda_2 = -5.7 \pm 1.7,\ |\lambda_1/\lambda_2| > 1$
- $a_{\mu 1} = -1.2 \pm 0.4,\ a_{\mu 2} = -3.77 \pm 0.11$, v.s. $a_{\mu i} \in [-1.6, -1.2]$

$\gamma p \to n\pi^+\pi^+\pi^-$: $\{\rho\pi,\, K^*\bar{K}\}$

- $V_{12} = 25.7 \pm 1.7 < V_{12}^{WT} = 82@th_2$
- $Num = \lambda_1 V_{11} V_{22}\left[\frac{1}{V_{22}} + \frac{\lambda_2}{\lambda_1}\frac{V_{12}}{V_{11}V_{22}} + G_{22}\left(1 - \frac{V_{12}^2}{V_{11}V_{22}}\right)\right]$
- The $V_{22}^{eff.}$ leads to a large au_2.
- Poles $972 - i\,98\,\mathrm{MeV}$ and $1349 - i\,17\,\mathrm{MeV}$ on RS_{-+} :a_1 states



$\gamma p \to n\pi^+\pi^+\pi^-$: $\{\rho\pi, K^*\bar{K}\}$ w/ widths of mesons



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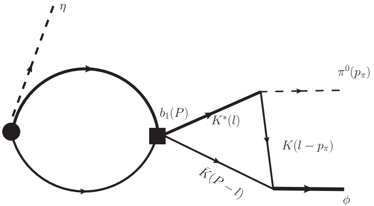
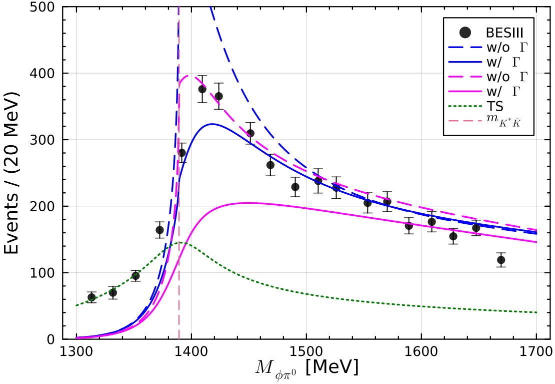
- $V_{12} = 10.0 \pm 1.7,\ \lambda_1 = -18.9 \pm 1.5,\ \lambda_2 = -10.4 \pm 1.7,\ |\lambda_1/\lambda_2| > 1$
- $au_1 = -2.1 \pm 0.5,\ au_2 = -4.30 \pm 0.04$

$b_1(1400)$



η
$\pi^0(p_\pi)$
$b_1(P)$
$K^*(l)$
$K(l-p_\pi)$
$\bar{K}(P-l)$
ϕ



500
400
300
200
100
0
1300
1400
1500
1600
1700
Events / (20 MeV)
$M_{\phi\pi^0}$ [MeV]
BESIII
w/o Γ
w/ Γ
w/o Γ
w/ Γ
TS
$m_{K^*\bar{K}}$

Summary

Pole and TS

- The pole and TS contribute to the lineshape ***simultaneously***.
- The dip is a "TS" filter.

Light axial-vector meson

- Signals of $a_1(1260)$ and $a_1(1420)$ are displayed in $\gamma p \to n 3\pi$
- $a_1(1260)$ is broad and strongly couples to $\rho\pi$ in S wave.
- $K^*\bar{K}$ is essential to understand the dip around $1.4\,\mathrm{GeV}$ in $\rho\pi$ invariant mass distribution, is a flavor partner of $W_{c1}(3880)$.

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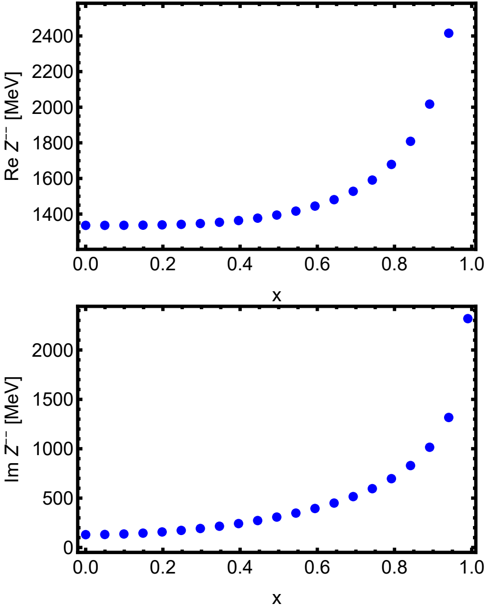
Thanks !

Backup: Pole trajectory w/ $q_{max} = 800\,\mathrm{MeV}$



Backup

$$G_\ell^{\mathrm{DR}}(s) = \frac{1}{16\pi^2}\left[\alpha_\ell(\mu) + \log\frac{M_\ell^2}{\mu^2} + \frac{m_\ell^2 - M_\ell^2 + s}{2s}\log\frac{m_\ell^2}{M_\ell^2}\right.$$
$$\left. + \frac{p_\ell}{\sqrt{s}}\left(\log\frac{s - m_\ell^2 + M_\ell^2 + 2p_\ell\sqrt{s}}{-s + m_\ell^2 - M_\ell^2 + 2p_\ell\sqrt{s}} + \log\frac{s + m_\ell^2 - M_\ell^2 + 2p_\ell\sqrt{s}}{-s - m_\ell^2 + M_\ell^2 + 2p_\ell\sqrt{s}}\right)\right],$$

$$\mathcal{L}_{K^*K\pi} = g_1 K^{*,\mu}\left(K\partial_\mu\pi - \partial_\mu K\pi\right), \mathcal{L}_{f_0K\bar{K}} = g_2 f_0 K\bar{K},$$

$$\mathcal{M}_{a_1}^{tri.} = \int\frac{d^4l}{(2\pi)^4}\frac{g_1 g_2 \epsilon_i \delta^{ij}\left(\vec{p}_\pi - \vec{l}\right)_i}{\left(q^2 - m_{K^*}^2\right)\left[(P-q)^2 - m_{\bar{K}}^2\right]\left(l^2 - m_K^2\right)},$$

$$\mathcal{M}_{b_1}^{tri.} = \int\frac{d^4l}{(2\pi)^4}\frac{g_1 \tilde{g}_2 \epsilon_i \delta^{ij}\left(p_\pi - l\right)_i (l - P + q)^m \epsilon(\phi)_m}{\left(q^2 - m_{K^*}^2\right)\left[(P-q)^2 - m_{\bar{K}}^2\right]\left(l^2 - m_K^2\right)}$$