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Mixing properties of a_1(1260) meson consisting of hadronic composite and quark composite

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H. Nagahiro *et al.*, PRD83(11)111504(R), arXiv:1101.3623 [hep-ph].

Introduction

<u>Exotic hadrons : *not* simple $q\bar{q}$ (or qqq) state</u>

- σ, $f_0(980)$, $a_0(980)$, … , $a_1(1260)$, $K_1(1270)$, …, N*(1535), Λ(1405), … etc…

→ molecule, $qq\bar{q}\bar{q}$ state, *or* ***mixed states among them ?***

<u>Nature of axial vector meson ***a*₁(1260)** : m = 1230 ± 40 MeV, Γ=260 to 600 MeV [PDG]</u>

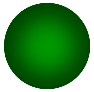
» *elementary* field (or $q\bar{q}$) : chiral partner of ρ meson

[Hidden local sym.] Bando-Kugo-Yamawaki; PR164(88)217; Kaiser-Meissner, NPA519(90)671, …

[$q\bar{q}$-NJL] M.Wakamatsu *et al*,. ZPA311(88)173, A.Hosaka, PLB244(90)363-367 , …

[Lattice QCD] M. Wingate *et al*., PRL74(95)4596, ...

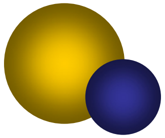
[Holographic QCD] T. Sakai, S. Sugimoto, PTP113 (05) 843; *ibid.*114(05)1083,



» dynamically generated resonance [πρ *composite*]

[coupled-channel BS] Lutz-Kolomeitsev, NPA730(04)392, …

[Chiral Unitary model] Roca-Oset-Singh, PRD72(05)014002, …



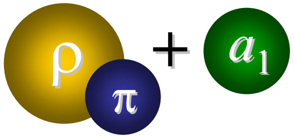
» applications

[τ-decay spectrum] M. Wagner and S. Leupold, PRD78(08)053001, …

[radiative decay width] H. Nagahiro, L. Roca, A. Hosaka , E. Oset, PRD79(09)014015, …

<u>Aim of this study</u>

We study the *"mixing properties"* of exotic hadrons as a quark-core + hadronic composite system

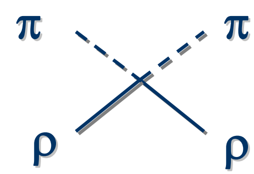


A model for a_1, π and ρ mesons

<u>hidden local sym.</u> or <u>holographic model</u>

Bando-Kugo-Yamawaki, PR164(88)217 Sakai-Sugimoto, PTP113(05)843

$$\mathcal{L}_{\mathrm{WT}} = -\frac{g_4}{4f_\pi^2}\mathrm{tr}\left([\rho^\mu, \partial^\nu \rho_\mu][\pi, \partial_\nu \pi]\right) \Rightarrow$$



⇨ *composite a_1*

$$\mathcal{L}_{a_1\pi\rho} = -g_{a_1\pi\rho}\frac{i\sqrt{2}}{f_\pi}\left\{\mathrm{tr}\left[(\partial_\mu a_{1\nu} - \partial_\nu a_{1\mu})[\partial^\mu \pi, \rho^\nu]\right] + \mathrm{tr}\left[(\partial_\mu \rho_\nu - \partial_\nu \rho_\mu)[\partial^\mu \pi, a_1^\nu]\right]\right\} \Rightarrow$$

*A good model for **composite a_1** and **elementary a_1***

<u>mass of elementary a_1 meson : in holographic model</u>

m_{a1}= **1189 MeV** Sakai-Sugimoto, PTP113(05)843; PTP114(05)1083]

$f_\pi = 92.4\mathrm{MeV}, \ m_\rho = 776\mathrm{MeV}$

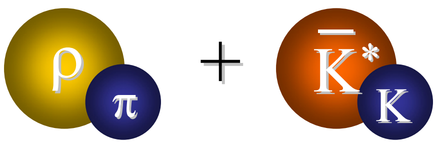
input parameters

✓ this elementary a_1 meson does ***not*** have molecular component [hQCD is constructed in the large Nc limit]

Dynamically generated resonances : **composite a_1 meson**

<u>a_1 meson as a πρ-composite : chiral unitary model</u>

L.Roca, E.Oset and J.Singh, PRD72(05)014002

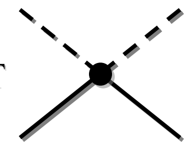


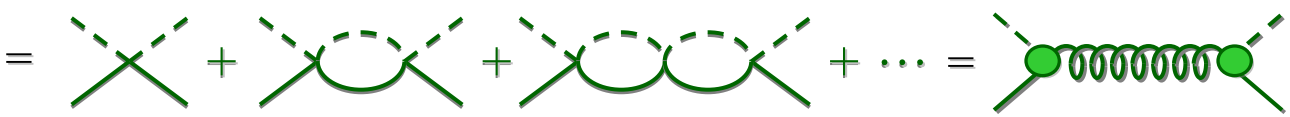
→ a_1 pole as mainly **πρ composite** at 1011-84*i* MeV

[Roca05]

πρ scattering amplitude with coupled-channel calculation

$$T_{\pi\rho\to\pi\rho} = \frac{v_{WT}}{1 - v_{WT}G}\vec{\epsilon}\cdot\vec{\epsilon}\,'$$

v_{WT} 



$$= g_R(s)\frac{1}{s - s_p}g_R(s)$$

<u>regularization constant</u>

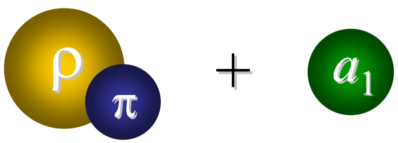
$a(\mu)= -1.85$ (μ=900MeV) [Roca *et al.*] → ***a*(μ) = –0.2 (natural)**

to avoid the double counting.

[T. Hyodo, D.Jido, A.Hosaka, PRC78(08)025203]

Formalism : elementary a_1 field through additional interaction

mixed states of πρ composite a_1 and elementary a_1 mesons

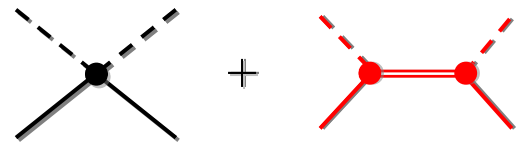


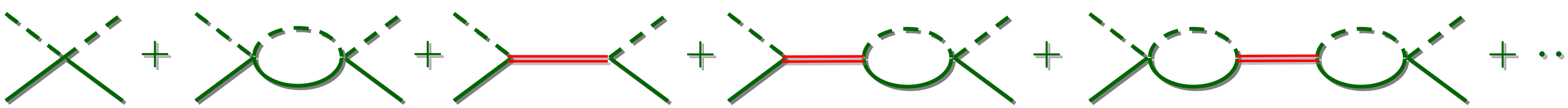
elementary a_1 meson contributes to $T_{\pi\rho}$ through the additional interaction v_{a1}

full scattering amplitude

a_1 pole term

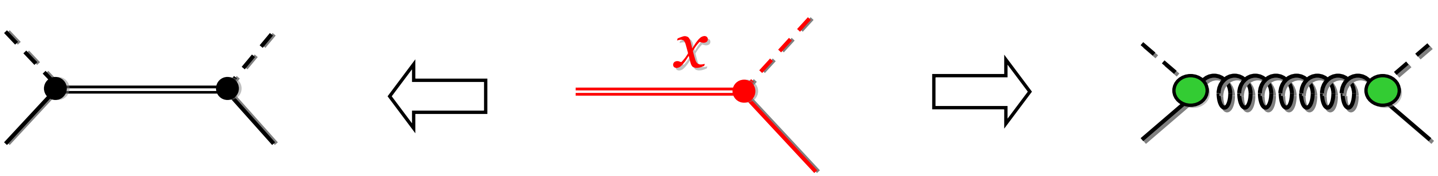
$$T_{\pi\rho\to\pi\rho} = \frac{v_{WT} + v_{a_1}}{1-(v_{WT}+v_{a_1})G}\vec{\epsilon}\cdot\vec{\epsilon}\,'$$



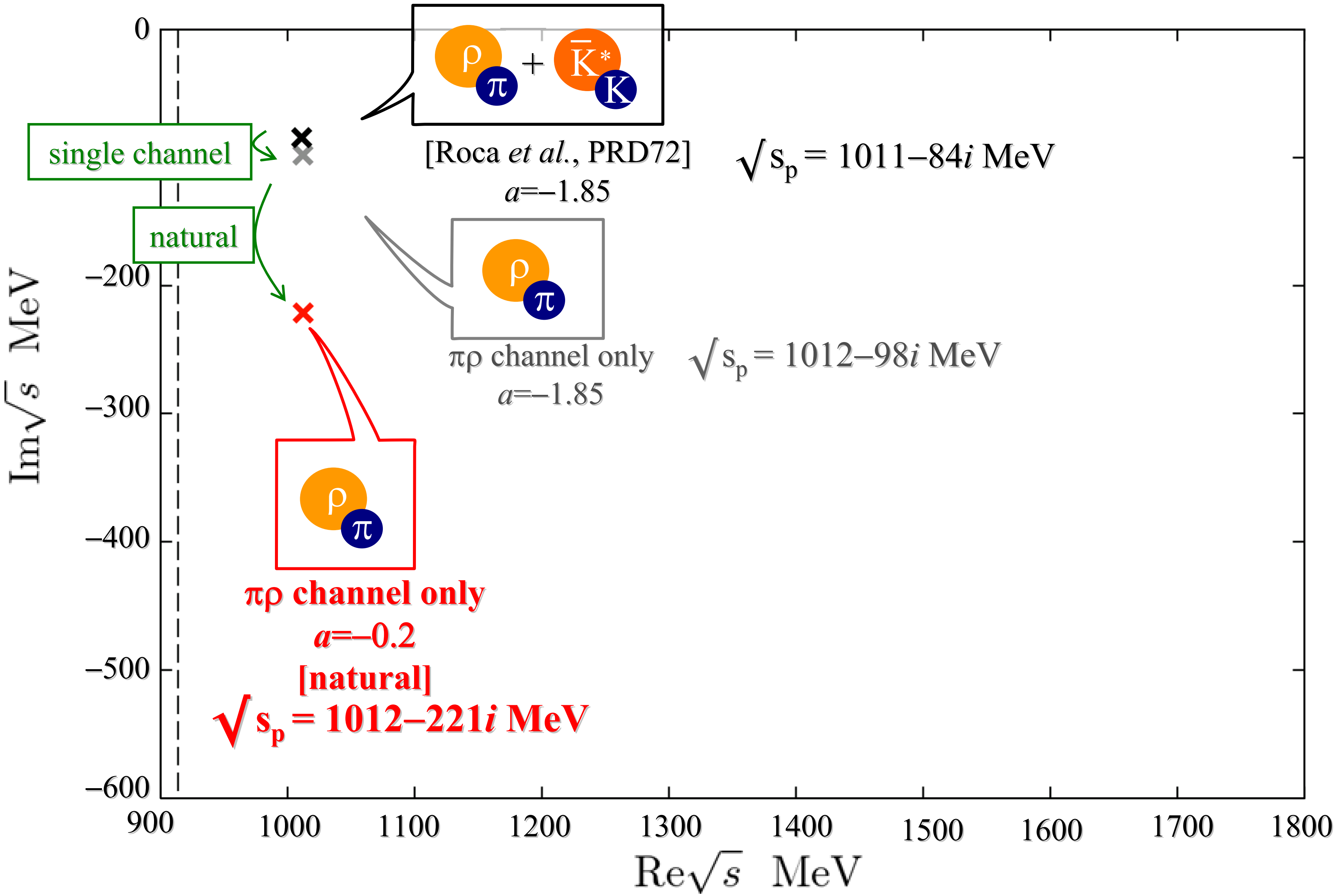


= physical resonant a_1 states

causes the mixing



Numerical result 1 : pole-flow of T-matrix



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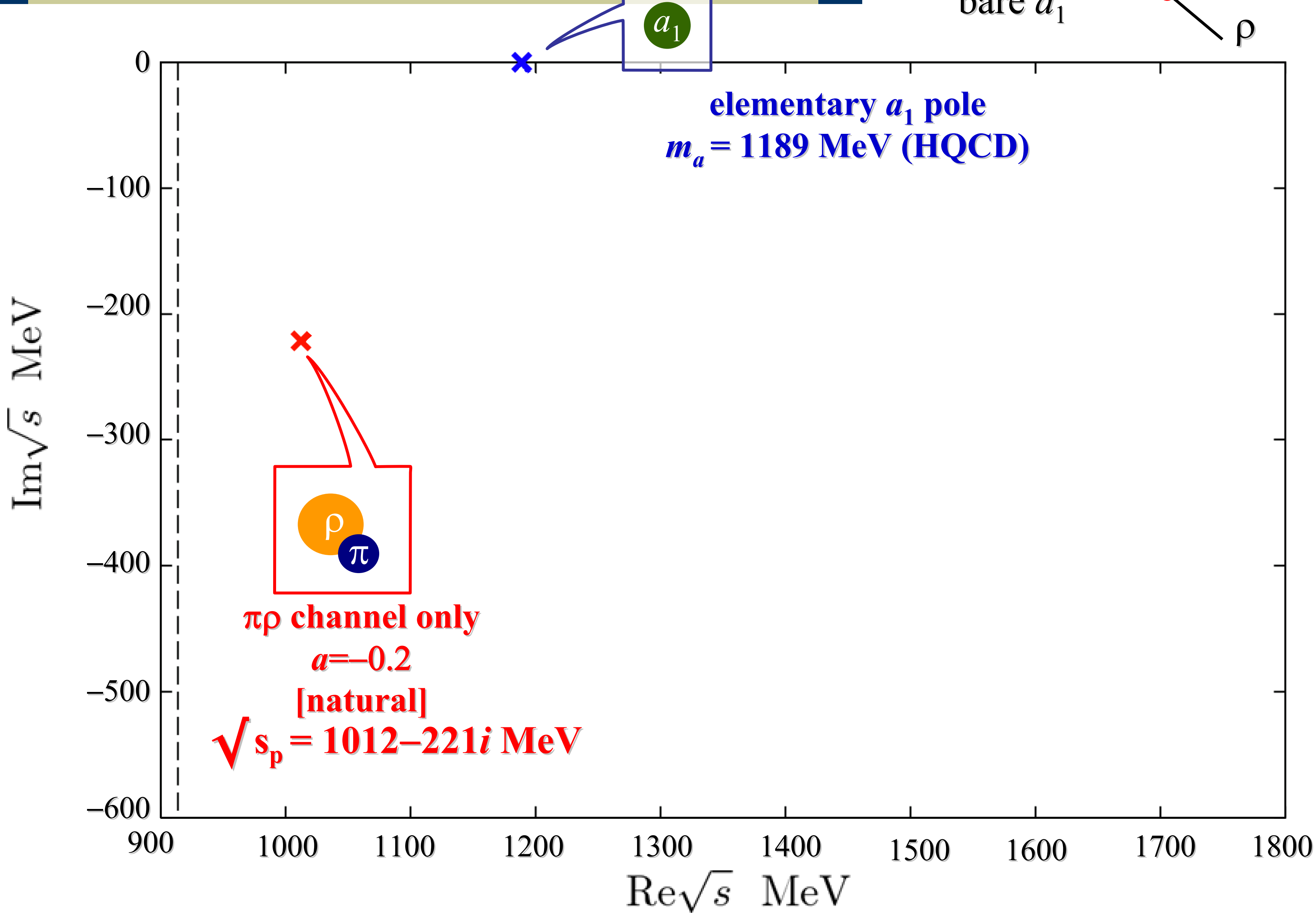

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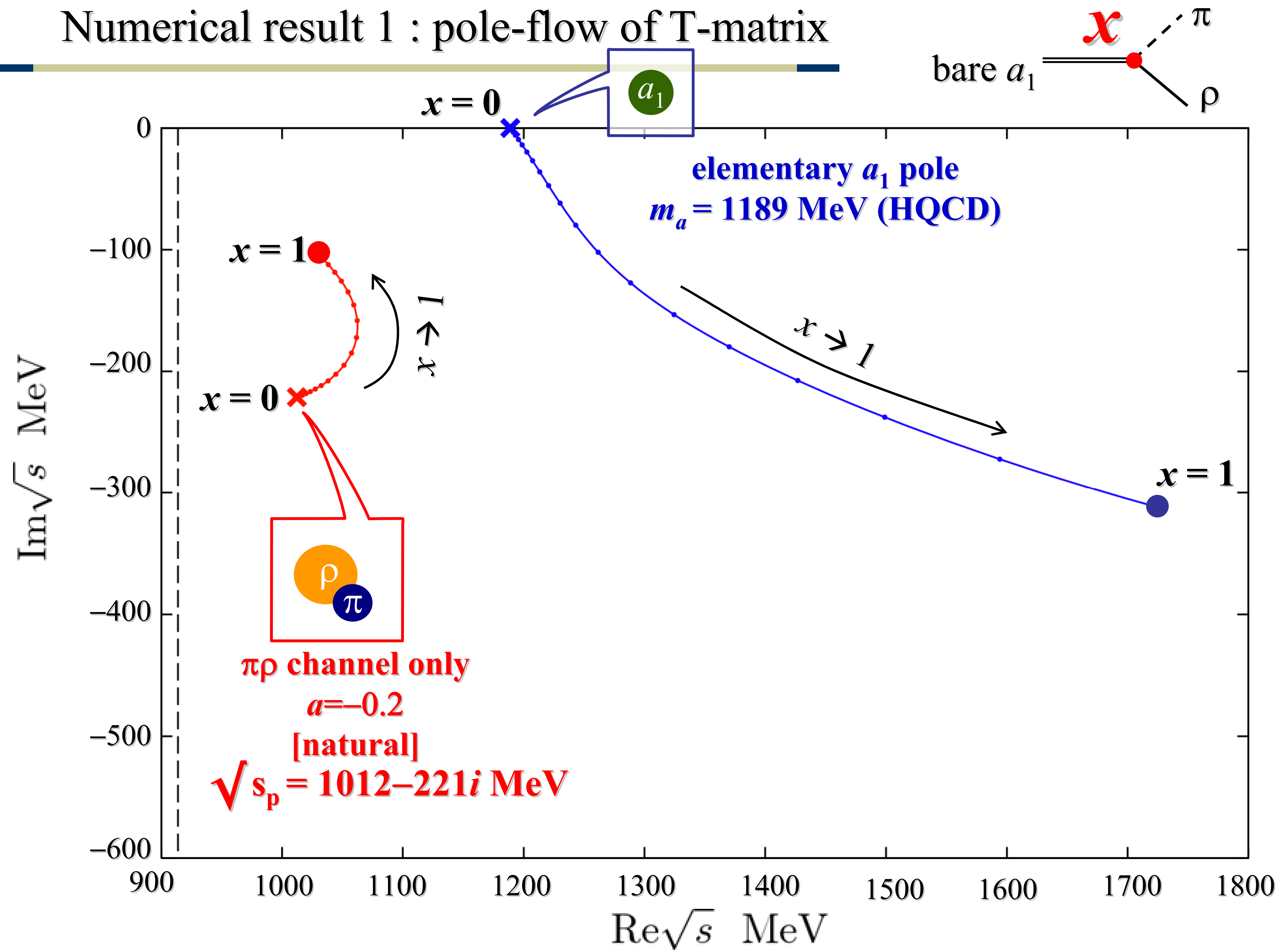
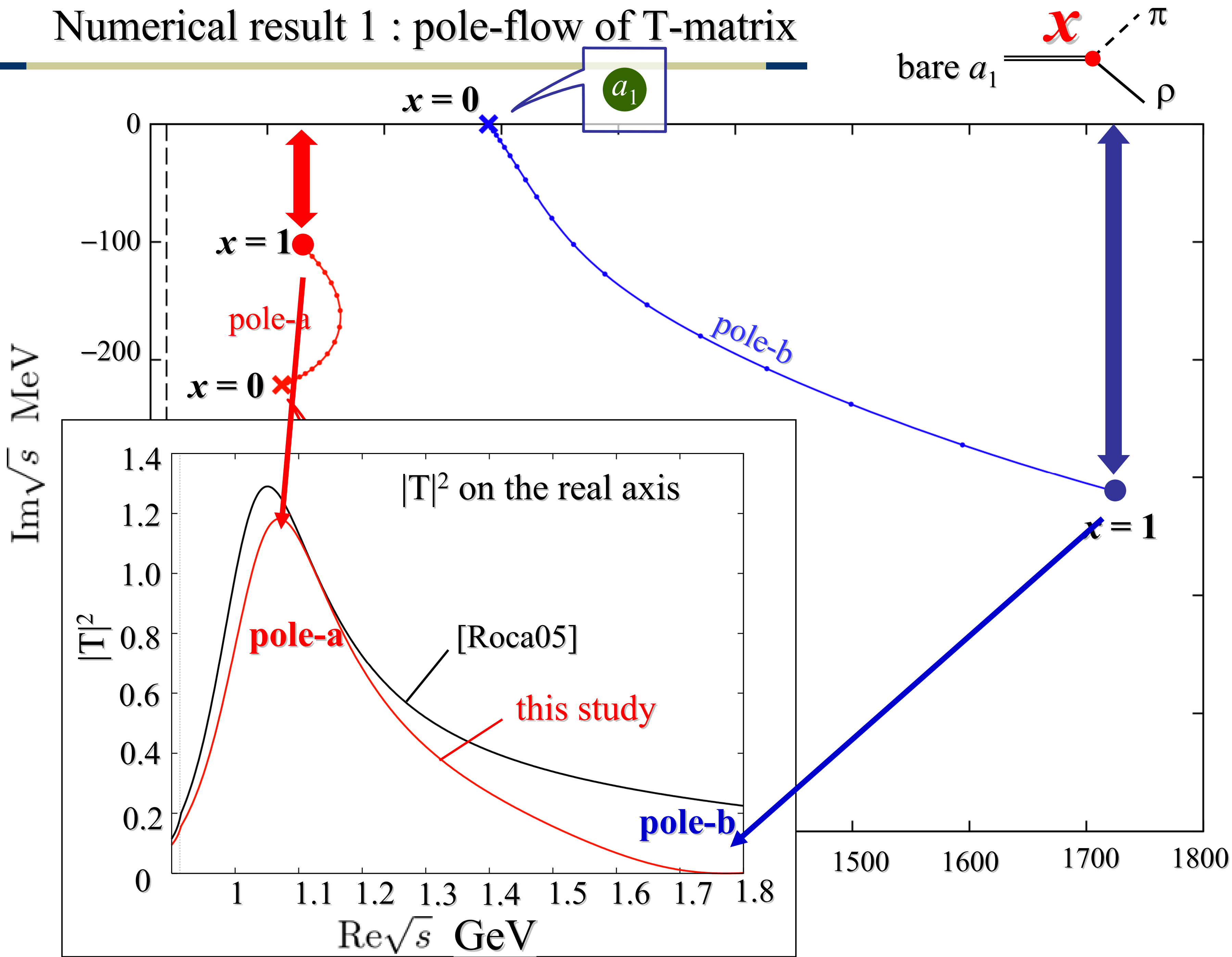
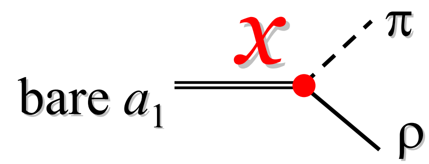
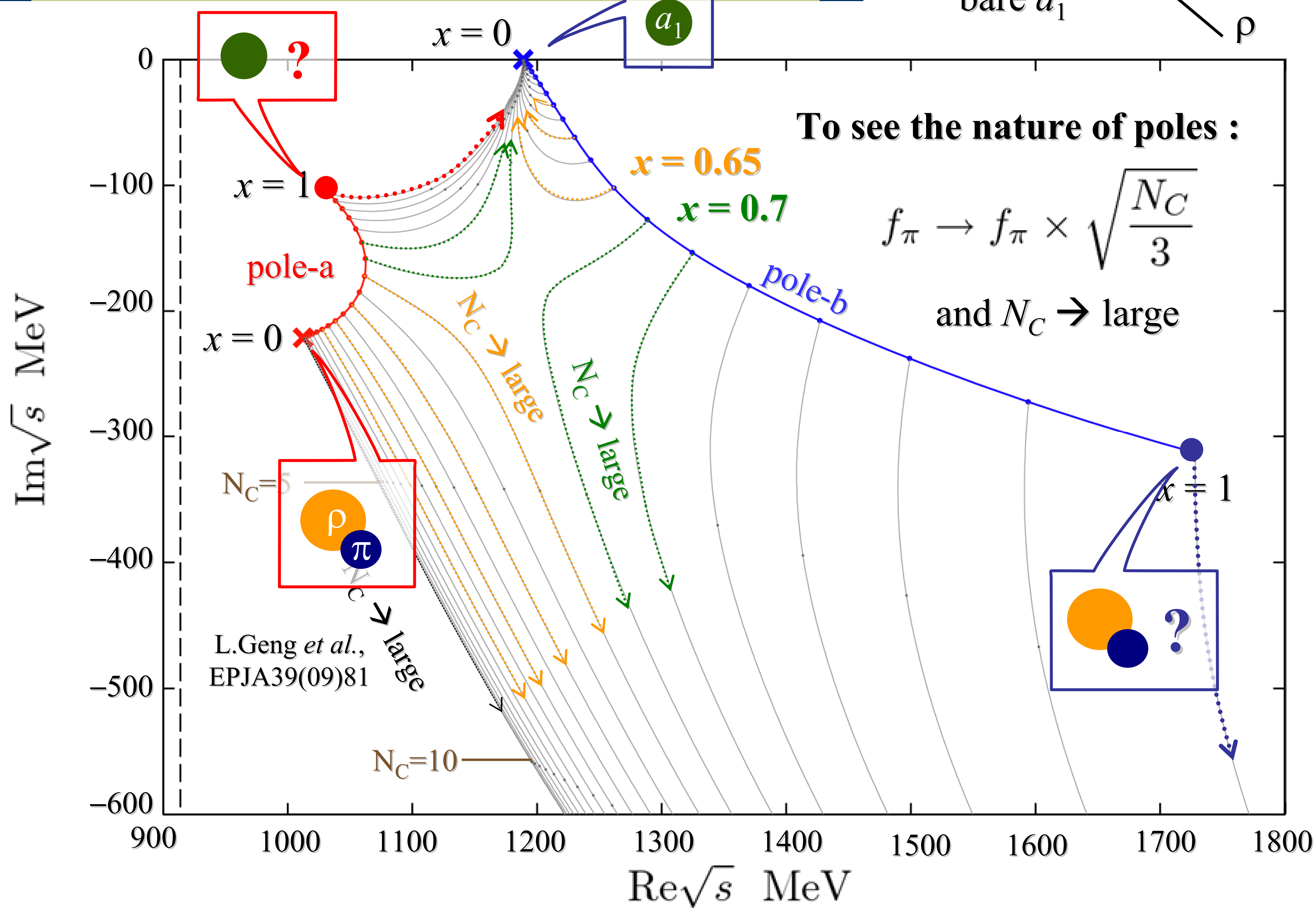


Numerical result 1 : pole-flow of T-matrix



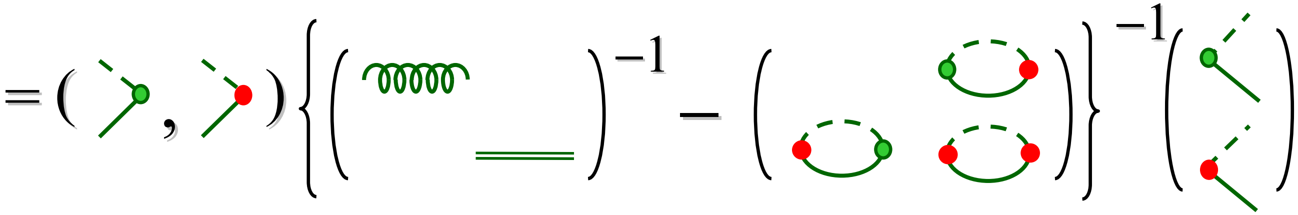
Numerical result 1 : large N_C flow





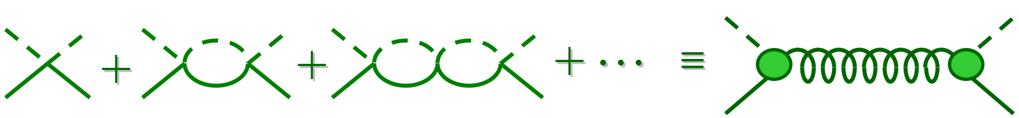
Alternative expression for the *full* πρ scattering amplitude T

$$T = \frac{v_{WT} + v_{a_1}}{1-(v_{WT}+v_{a_1})G} = (g_R, g)\left\{\begin{pmatrix} s-s_p & \\ & s-m_{a1}^2 \end{pmatrix} - \begin{pmatrix} & g_R G g \\ g G g_R & g G g \end{pmatrix}\right\}^{-1}\begin{pmatrix} g_R \\ g \end{pmatrix}$$



<u>πρ-composite a_1 pole</u>

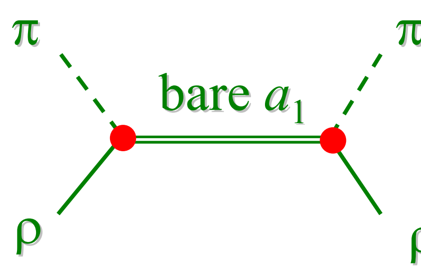
$$T_{WT} = \frac{v_{WT}}{1-v_{WT}G}$$



$$= g_R(s)\frac{1}{s-s_p}g_R(s)$$

<u>a_1 pole term</u>

$$V_{a_1} = g(s)\frac{\vec{\epsilon}\cdot\vec{\epsilon}\,'}{s-m_a^2}g(s)$$



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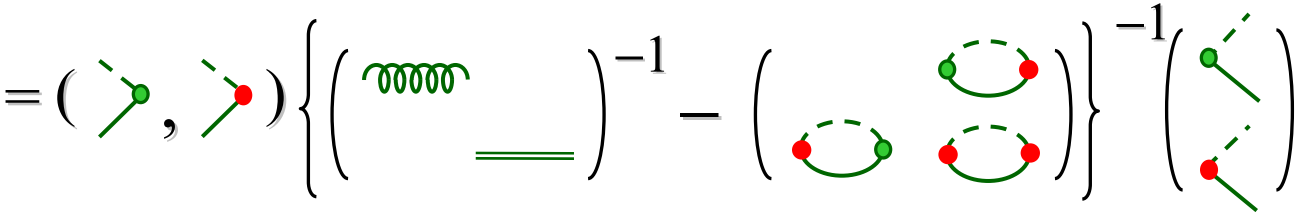
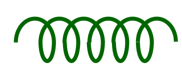
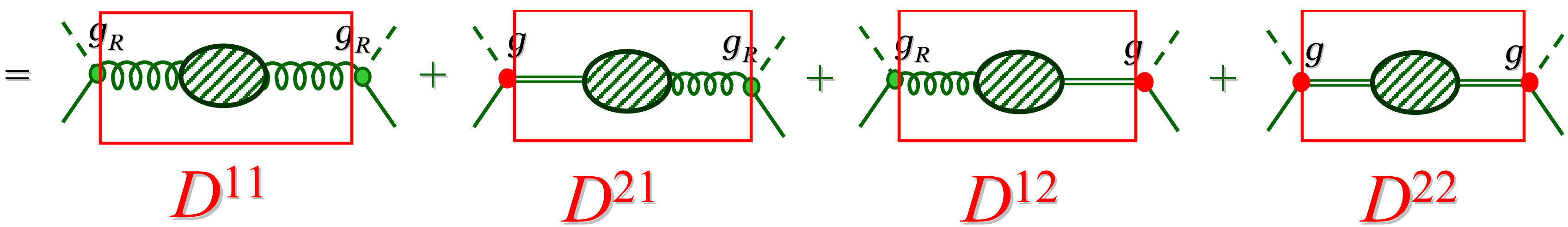


In this form, we can analyze the mixing nature of the physical a_1 in terms of the **original two bases**:  and

composite a_1 elementary a_1

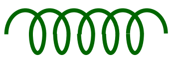


Features of the full propagators

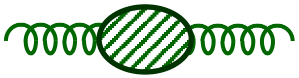
- ✓ The propagators have two poles exactly at the same position as T_{full}
- ✓ the residues z_a^{ii} have the information on the mixing rate

$$z_a^{11} = |\langle 1|a\rangle|^2 = |\langle$$  $$|\text{pole-a}\rangle|^2$$

→ ***Probability of finding the original composite a_1 in pole-a***

In this form, we can analyze the mixing nature of the physical a_1 in terms of the **original two bases**:  and 

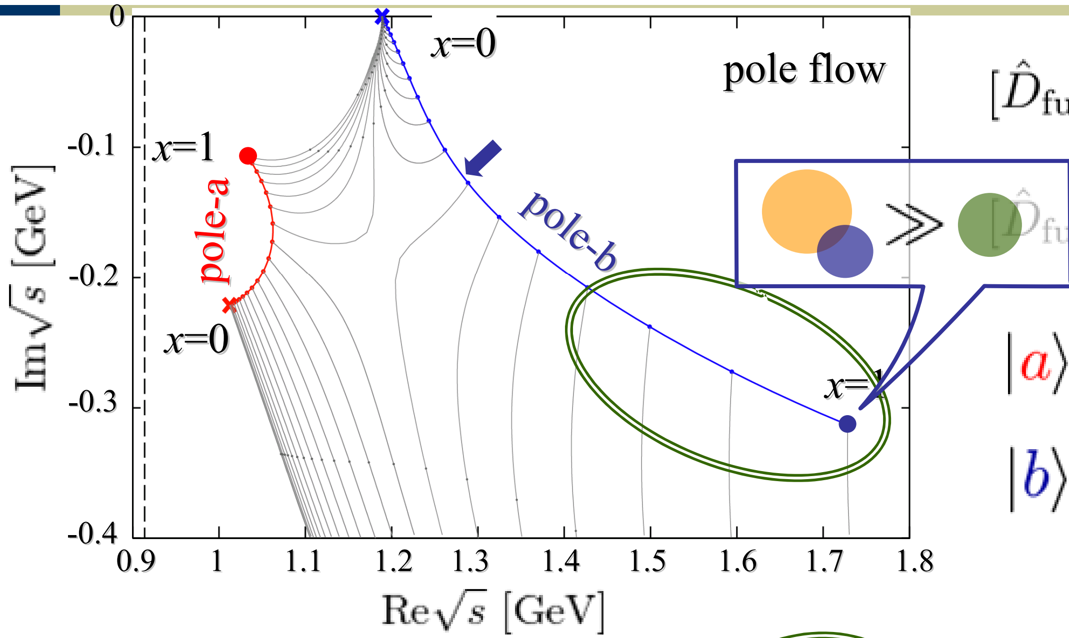
composite a_1 elementary a_1



D^{11}

$$D^{11} = \frac{z_a^{11}}{s - M_a^2} + \frac{z_b^{11}}{s - M_b^2} + \text{regular term}$$

Residues : probabilities of finding two a_1's in pole-a and -b

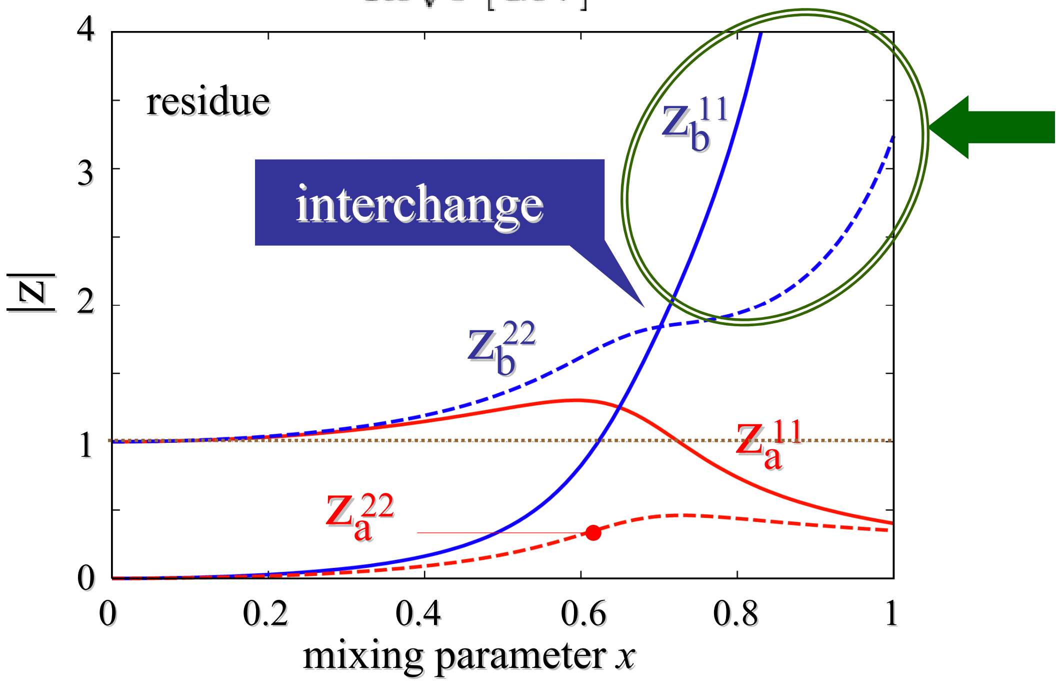


$$[\hat{D}_{\rm full}]^{11} = \frac{z_a^{11}}{E - E_a} + \frac{z_b^{11}}{E - E_b} + \text{(regular)}$$

$$[\hat{D}_{\rm full}]^{22} = \frac{z_a^{22}}{E - E_a} + \frac{z_b^{22}}{E - E_b} + \text{(regular)}$$

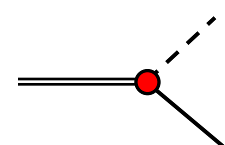
$$|a\rangle = \sqrt{z_a^{11}}|\quad\rangle + \sqrt{z_a^{22}}|\quad\rangle$$

$$|b\rangle = \sqrt{z_b^{11}}|\quad\rangle + \sqrt{z_b^{22}}|\quad\rangle$$



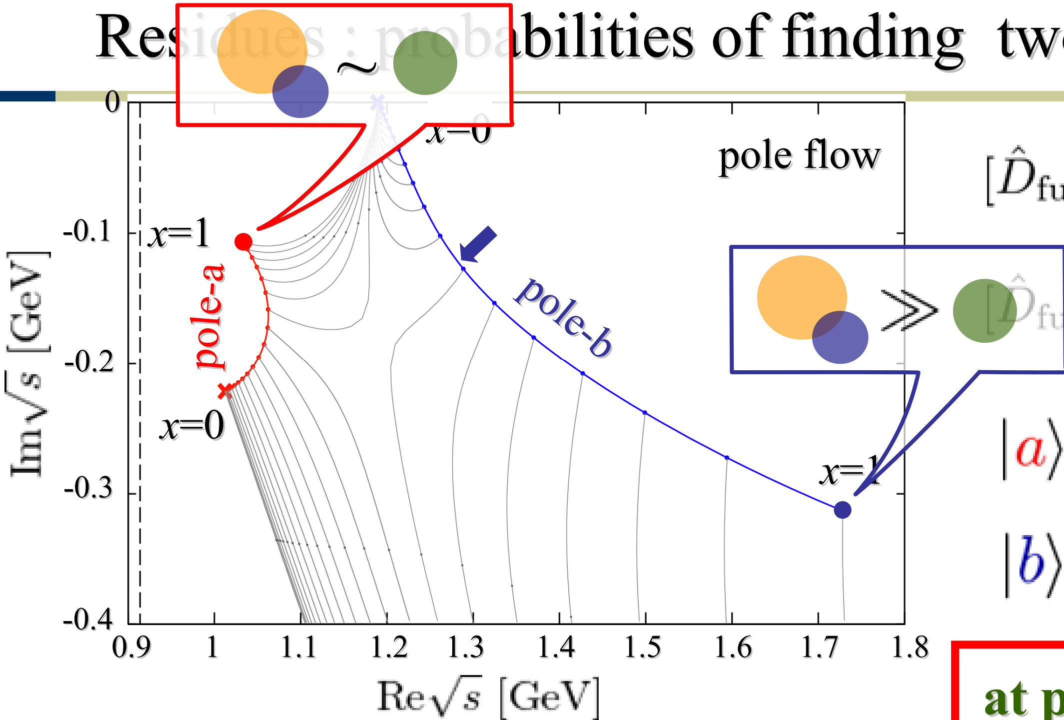
Large residue

→ due to the ene-dep.



$$g(s) = \frac{2\sqrt{2}}{f_\pi} g_{a_1\pi\rho}(s - M_\rho^2)$$

Residues : probabilities of finding two a_1's in pole-a and -b

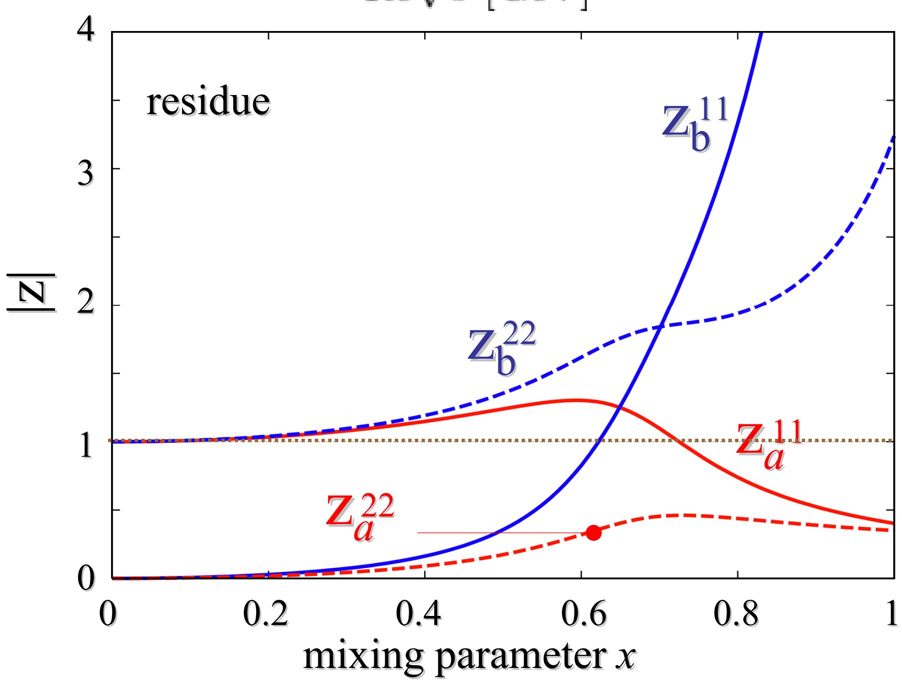


$$[\hat{D}_{\rm full}]^{11} = \frac{z_a^{11}}{E - E_a} + \frac{z_b^{11}}{E - E_b} + \text{(regular)}$$

$$[\hat{D}_{\rm full}]^{22} = \frac{z_a^{22}}{E - E_a} + \frac{z_b^{22}}{E - E_b} + \text{(regular)}$$

$$|a\rangle = \sqrt{z_a^{11}}|\ \bullet\!\bullet\ \rangle + \sqrt{z_a^{22}}|\ \bullet\ \rangle$$

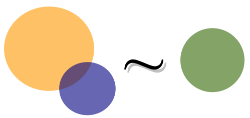
$$|b\rangle = \sqrt{z_b^{11}}|\ \bullet\!\bullet\ \rangle + \sqrt{z_b^{22}}|\ \bullet\ \rangle$$



at physical point (x=1)

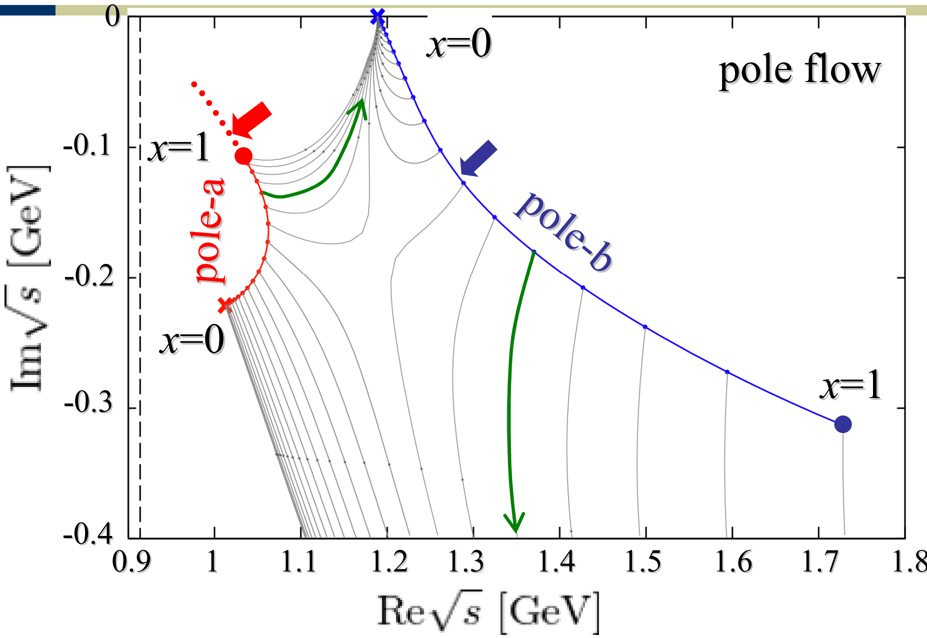
- pole-a has a component of the elementary a_1 meson ***comparable to*** that of composite a_1.

  (pole-a at x=1 is possibly observed one)



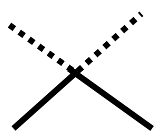
non-zero comp. of

Last question : large N_C limit vs. nature of poles

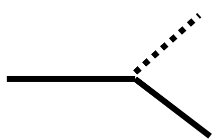


- for pole-b,
large N_C flip point ~ residue-interchange

- for pole-a,
large N_C flip point ≪ residue-interchange



$\propto 1/N_C$

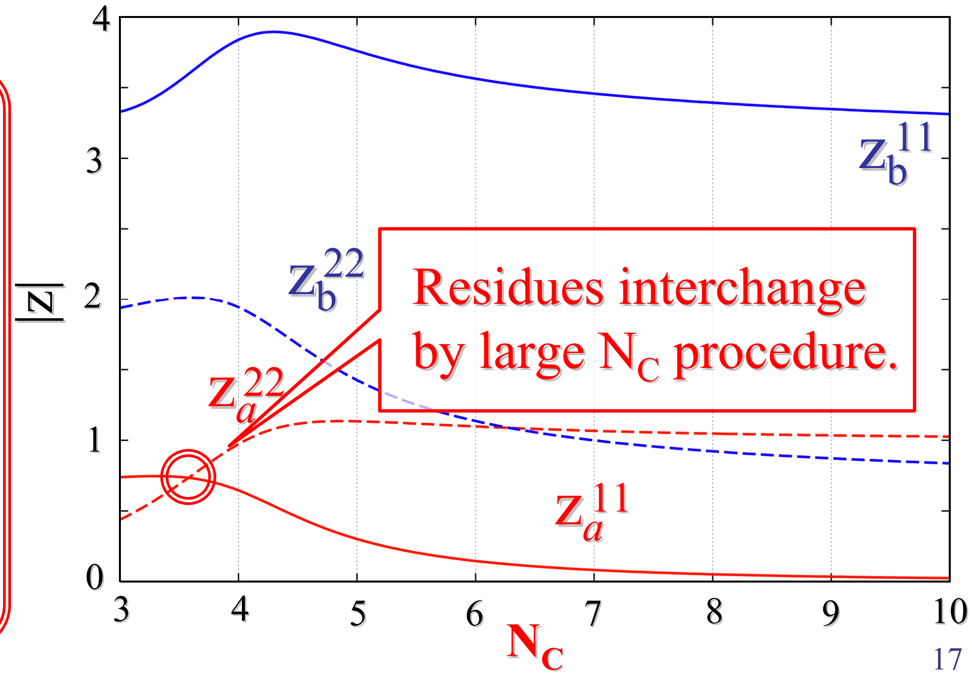


$\propto \mathbf{1/\sqrt{N_C}}$

mixing nature ***changes*** as N_C is increased

Large N_C limit doesn't always reflect the world at N_C=3.

x=0.8



Conclusions

» We discussed the mixing properties of $a_1(1260)$ meson as the superposition of the hadronic πρ composite and elementary a_1 based on the holographic QCD Lagrangian.

- › bare a_1 … doesn't have molecule nature
- › πρ molecule … "natural" regularization

Important to avoid the double-counting

» **We analyzed the pole nature by residues**

✓ the pole expected to be observed is *pole-a*: having finite  comp.

✓ Non-trivial N_C dependence pole-nature ← ? → large N_C limit

<u>Future works</u>

<u>phenomenological interests</u>

» τ-decay spectrum with our model parameter

[Wagner and Leupold, PRD78(08)053001, …]

» radiative decay width

[H. Nagahiro, L. Roca, A. Hosaka , E. Oset, PRD79(09)014015, …]

» etc…

to see how the nature of poles affects ***observables***