新学術領域「新ハドロン」
多彩なフレーバーで探る新しいハドロン存在形態の包括的研究
第一回 評価委員会＠名古屋大学, 8月4日(木)

Composite and elementary natures of hadrons
~分子共鳴とクォーク核の状態混合~

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H. Nagahiro *et al.*, Phys. Rev. D83,111504(R) (2011)

本研究の目的

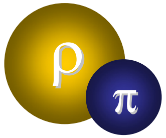
Exotic hadrons : *not* simple $q\bar{q}$ (or qqq) state

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

→ multi-quark system, ハドロン分子共鳴状態, …

$a_1(1260) \rightarrow \pi\gamma$ decay as $\pi\rho$ composite
H. N., L. Roca, A. Hosaka and E. Oset, PR**D79**(09)014015.

$a_1^+ \rightarrow \pi^+\gamma$ … $\Gamma_{\pi\gamma} \sim 130$ keV [実験値 : 640 ± 246 keV]
$b_1^+ \rightarrow \pi^+\gamma$ … $\Gamma_{\pi\gamma} \sim 210$ keV [〃 : 230 + 60 keV]

$|a_1\rangle = C_1 |$ 

$\rangle + C_2 |$ 

$\rangle + \ldots$

physical hadron **hadronic composite** **qq^bar-core**

a_1 に限らず全てのハドロン共鳴は、
多かれ少なかれ、複数の要素の**混合**状態

✓ どのように混ざるか
✓ どの程度混ざっているか

a_1(1260) axial vector meson ⋯ a good example

$a_1(1260)$ $\quad I^G(J^{PC}) = 1^-(1^{++})$ [Particle Data Group, JPG **37**, 075021 (2010)]

	VALUE (MeV)	*EVTS*
MASS	**1230±40 OUR ESTIMATE**	

	VALUE (MeV)	*EVTS*
WIDTH	**250 to 600 OUR ESTIMATE**	

as an **elementary field** (or $q\bar{q}$) : candidate for chiral partner of ρ

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

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

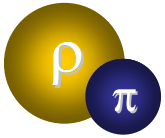
[Hidden local sym.] Bando-Kugo-Yamawaki; PR164(88)217; Harada-Yamawaki, PR381(03)1, Kaiser-Meissner, NPA519(90)671, …

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

as a **dynamically generated resonance** **[as πρ composite particle]**

[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, …

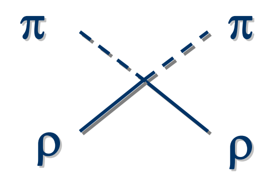
[radiative decay width] H.N, L. Roca, A. Hosaka , E. Oset, PRD79(09)014015, …

A good model for a_1, π and ρ mesons

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

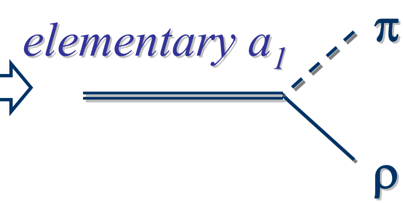
Bando-Kugo-Yamawaki, PR164(88)217 Sakai-Sugimoto, PTP113(05)843

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



⇨ *composite a_1*

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



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

<u>elementary a_1 meson の質量 : in holographic model</u>

m_{a1}= 1189 MeV

Sakai-Sugimoto, PTP113(05)843; PTP114(05)1083]

f_π = 92.4MeV, m_ρ = 776MeV

input parameters

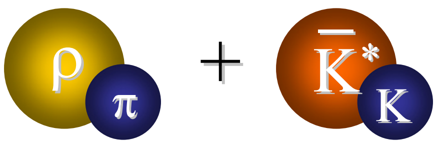
✓ この a_1 meson を qq^{bar} 状態(elementary a_1) と考える。

[hQCD is constructed in the large Nc limit]

Dynamically generated resonances : **composite a_1 meson**

πρ-composite としての a_1 meson : chiral unitary model

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

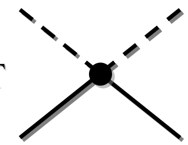


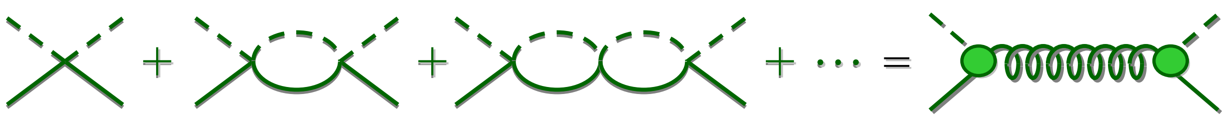
→ a_1 pole as mainly **πρ composite** at 1011-84i MeV

[Roca05]

πρ → πρ 散乱振幅 : coupled-channel 計算

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

v_{WT} 

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

regularization constant

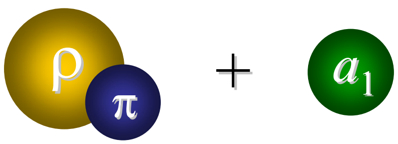
$a(\mu)= -1.85$ (μ=900MeV) [Roca *et al.*] → ***a*(μ) = –0.2 (natural)**

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

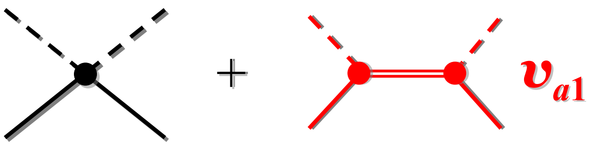


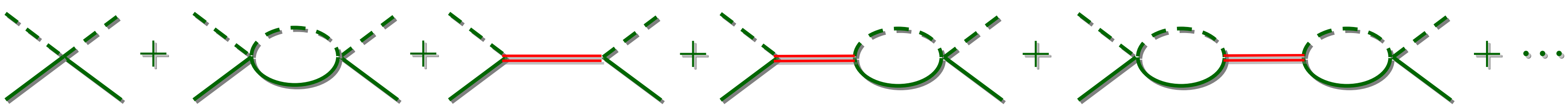
elementary a_1 meson は、additional interaction $\boldsymbol{v}_{a1}$ を通して散乱に寄与

full scattering amplitude

a_1 pole term

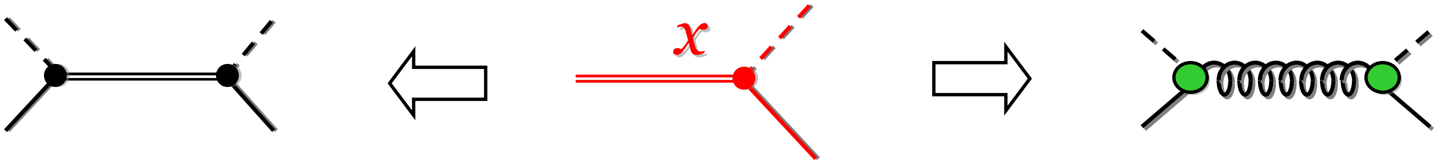
$$T_{\pi\rho\to\pi\rho} = \frac{v_{WT} + v_{a_1}}{1 - (v_{WT} + v_{a_1})G}\vec{\epsilon}\cdot\vec{\epsilon}'$$



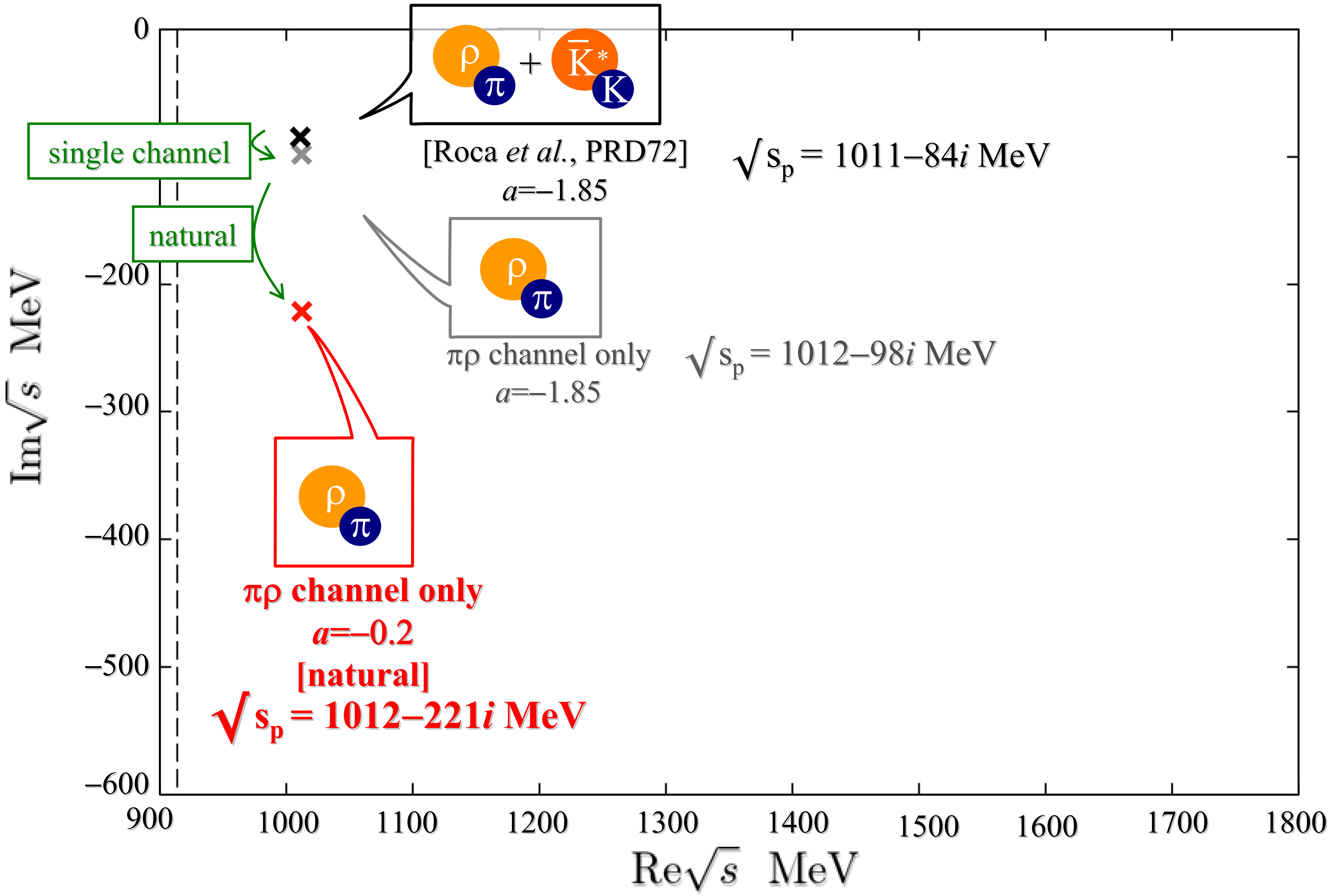


= physical resonant a_1 states

causes the mixing



Numerical result 1 : pole-flow of T-matrix



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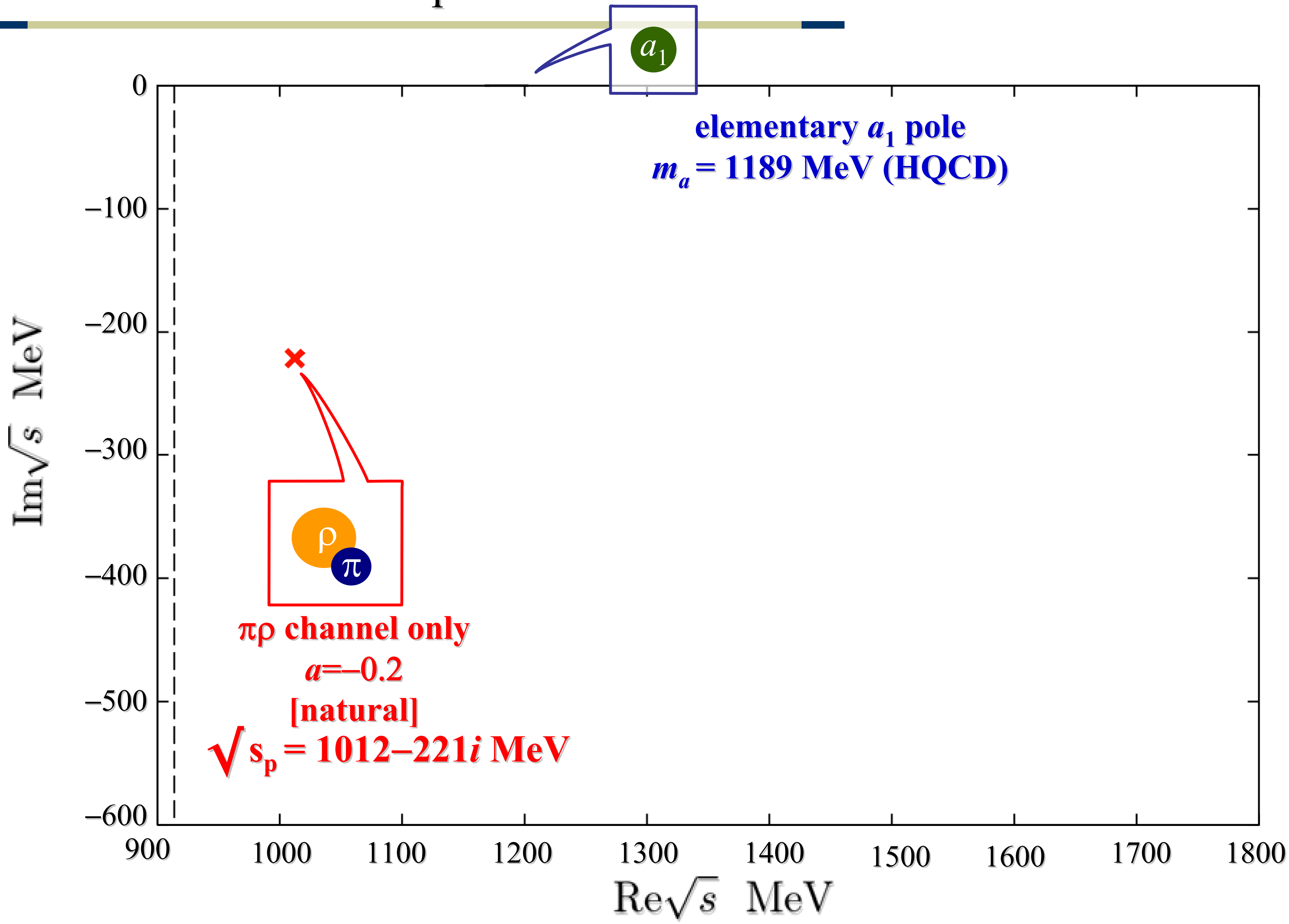

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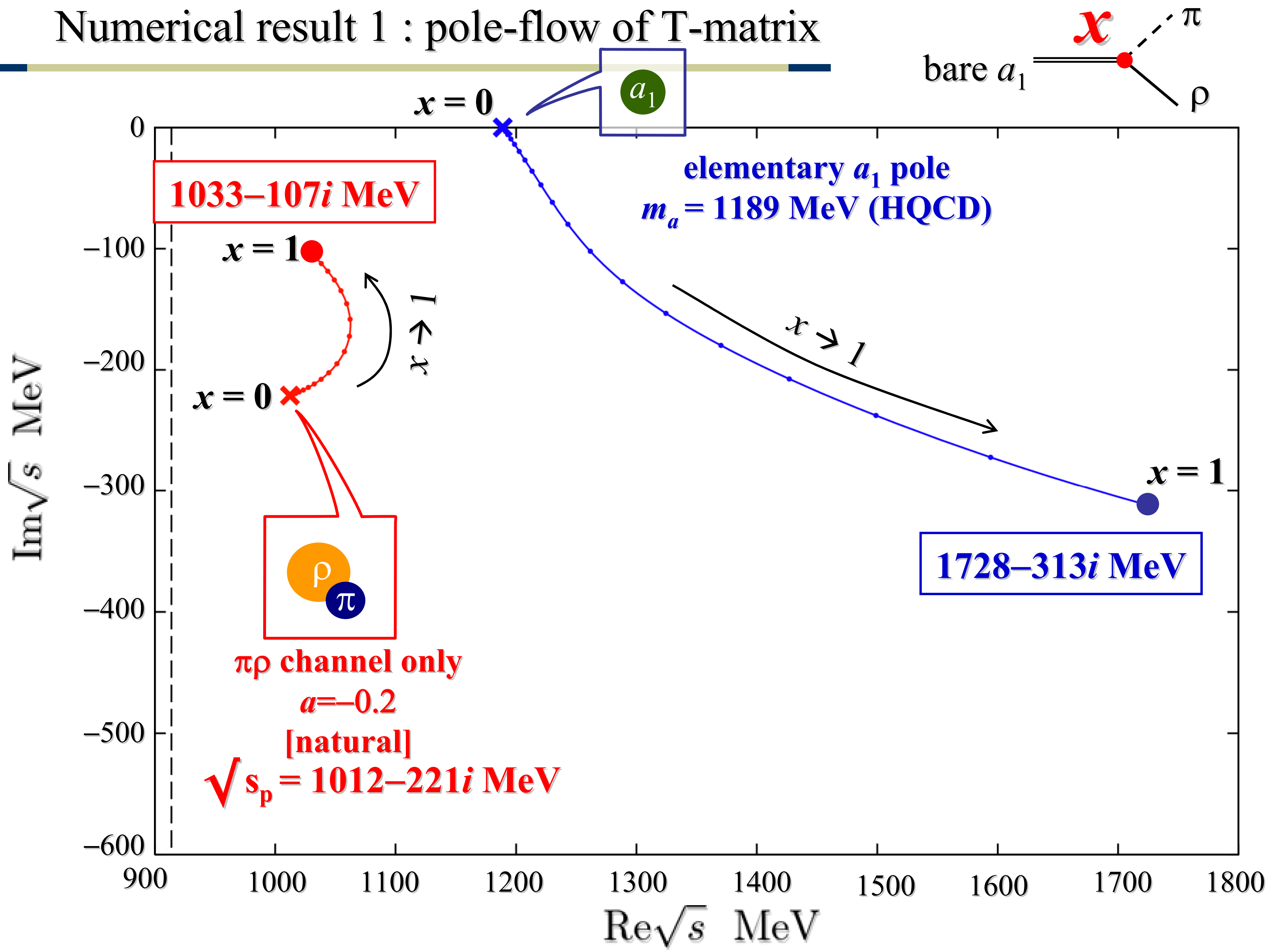

Hideko NAGAHIRO @ hadron 2011, Künstlerhaus, München, 17 June 2011

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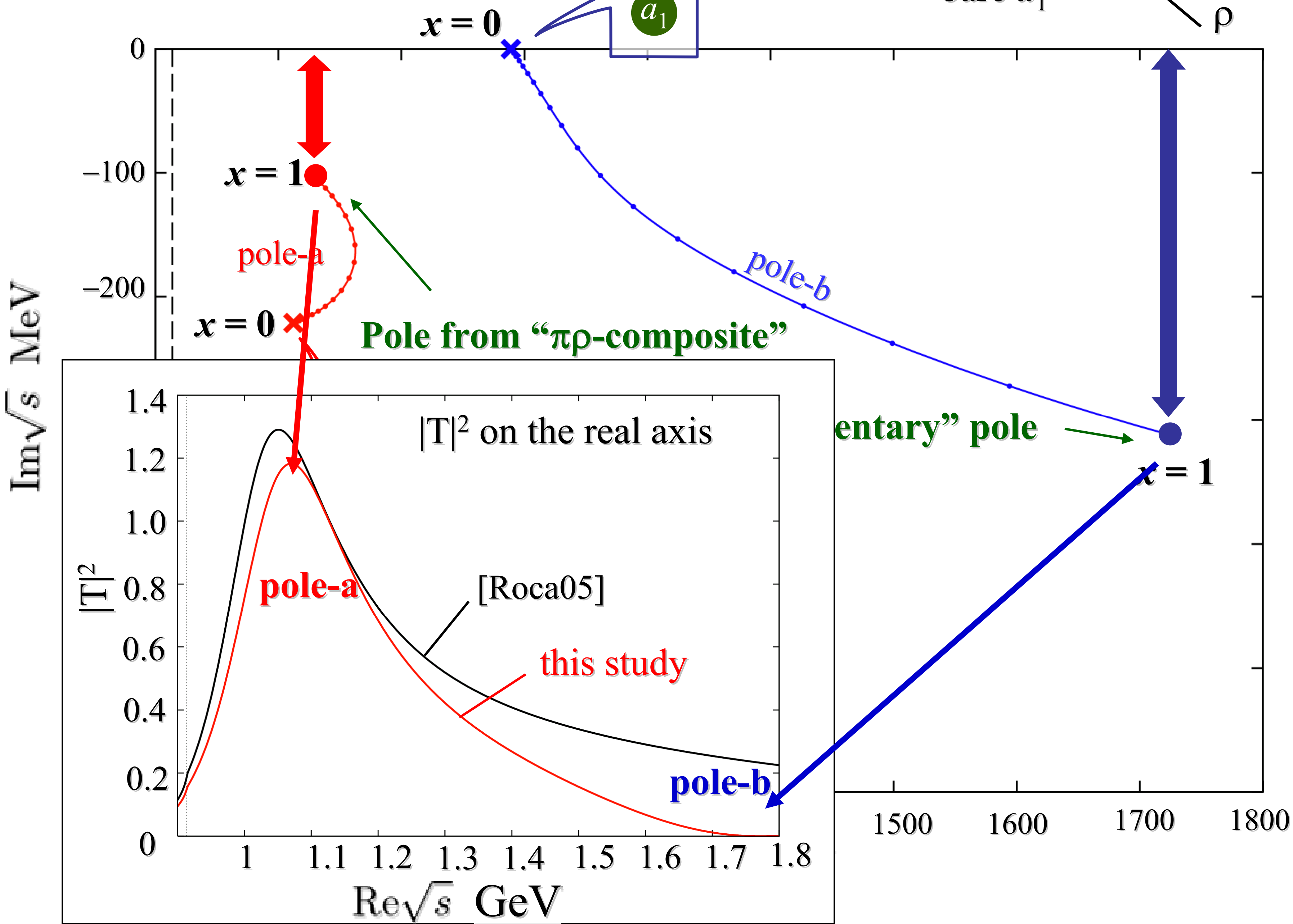

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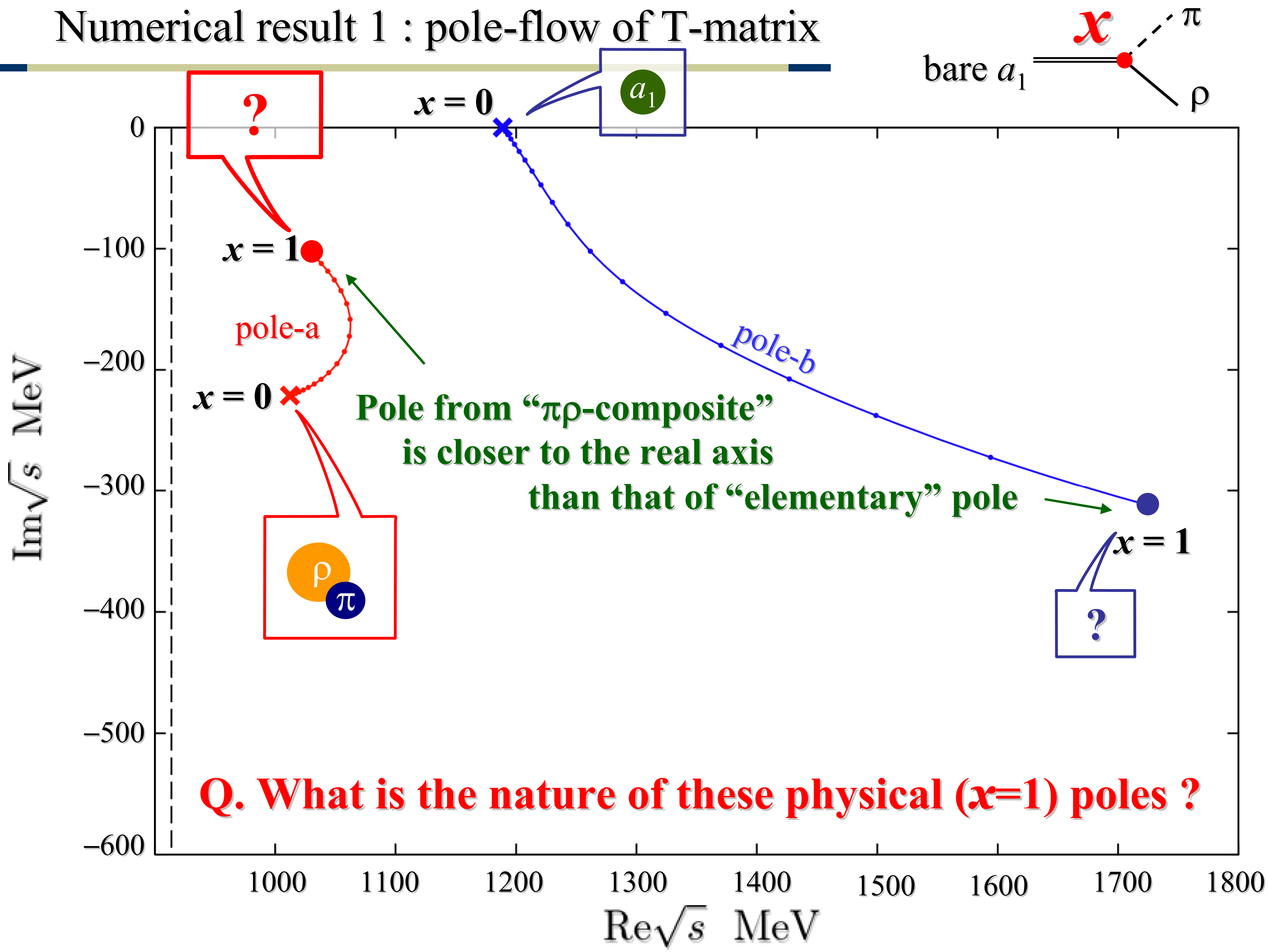
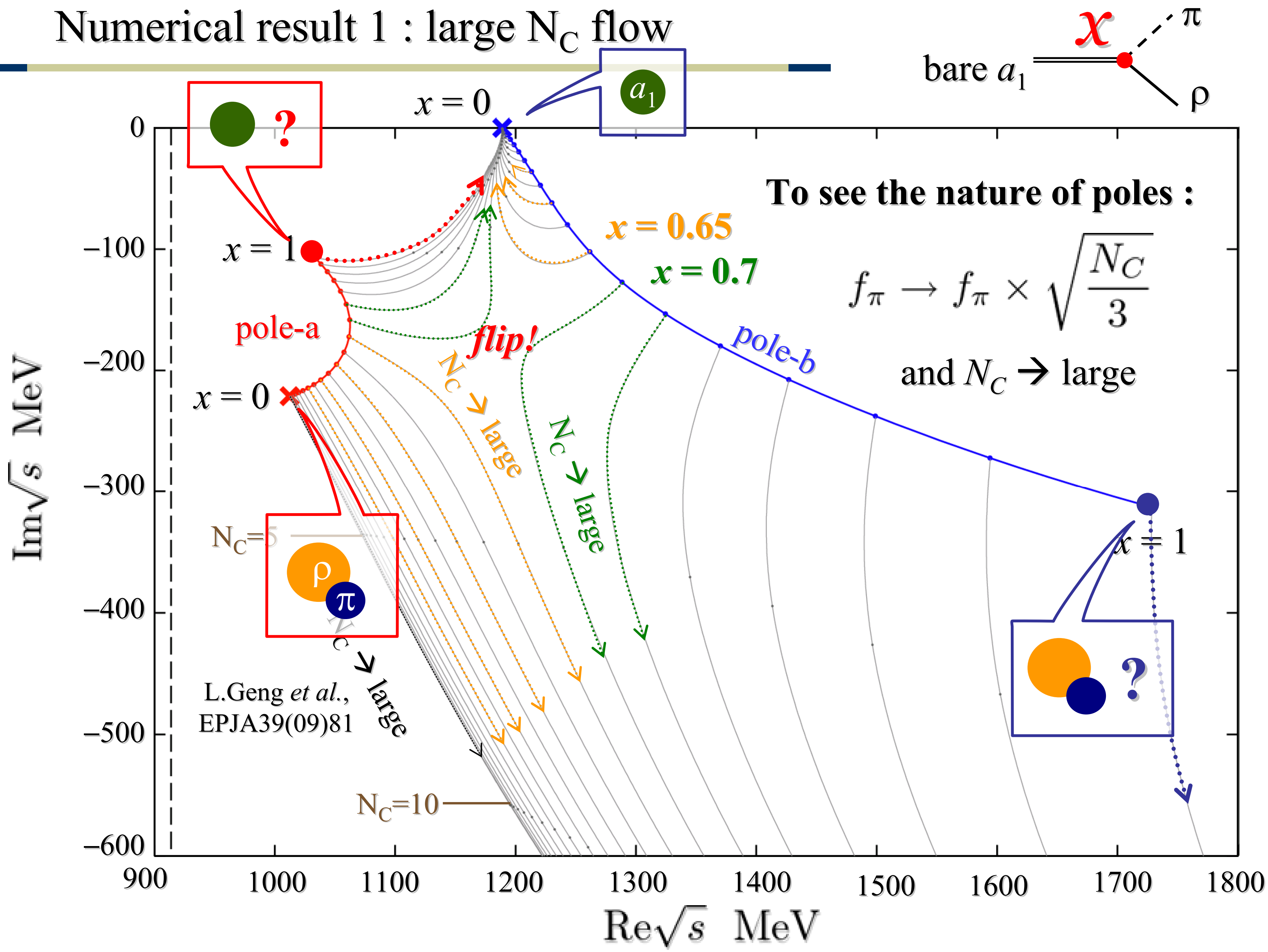
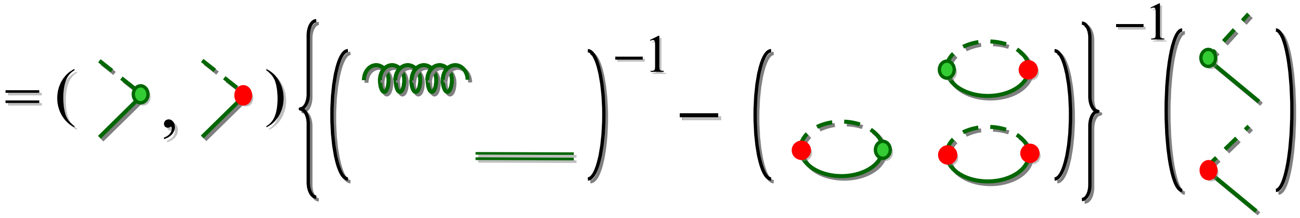


Numerical result 1 : large N_C flow



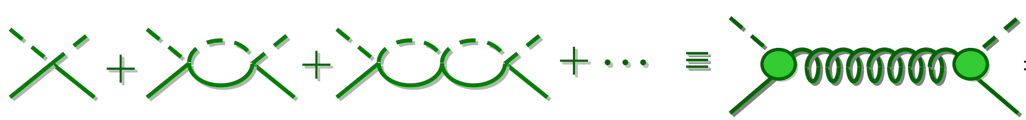
Alternative expression for the *full* πρ scattering amplitude T

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



<u>πρ-composite a_1 pole</u>

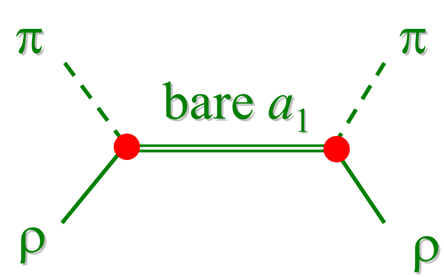
$$T_{WT} = \frac{v_{WT}}{1 - v_{WT} G}$$



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

<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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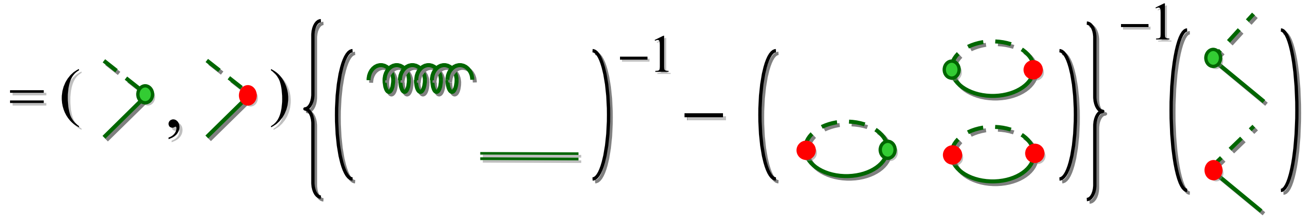
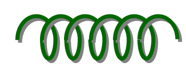
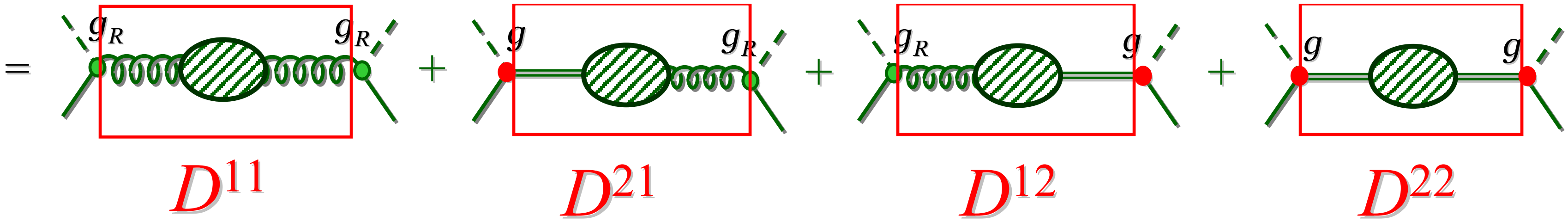
$\hat{D}$



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

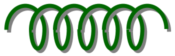


full propagator D の性質

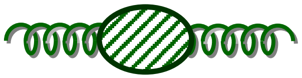
- ✓ それぞれの propagator は T_{full} と同じ所に pole を持つ。
- ✓ その residues z_a^{ii} は、mixing rate の意味を持つ。

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

→ pole-a に, composite a_1 を見いだす確率

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

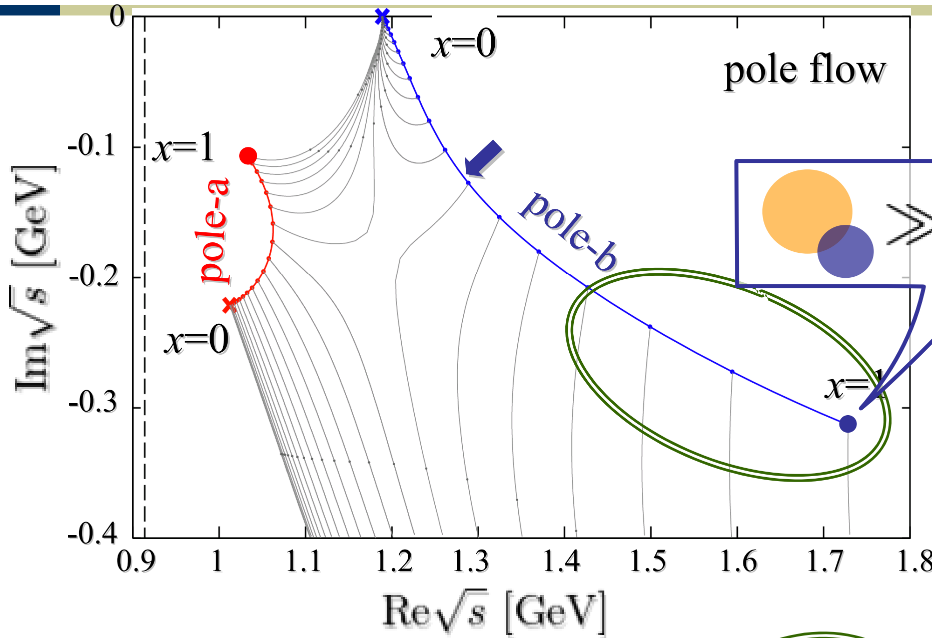
composite a_1 elementary a_1



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

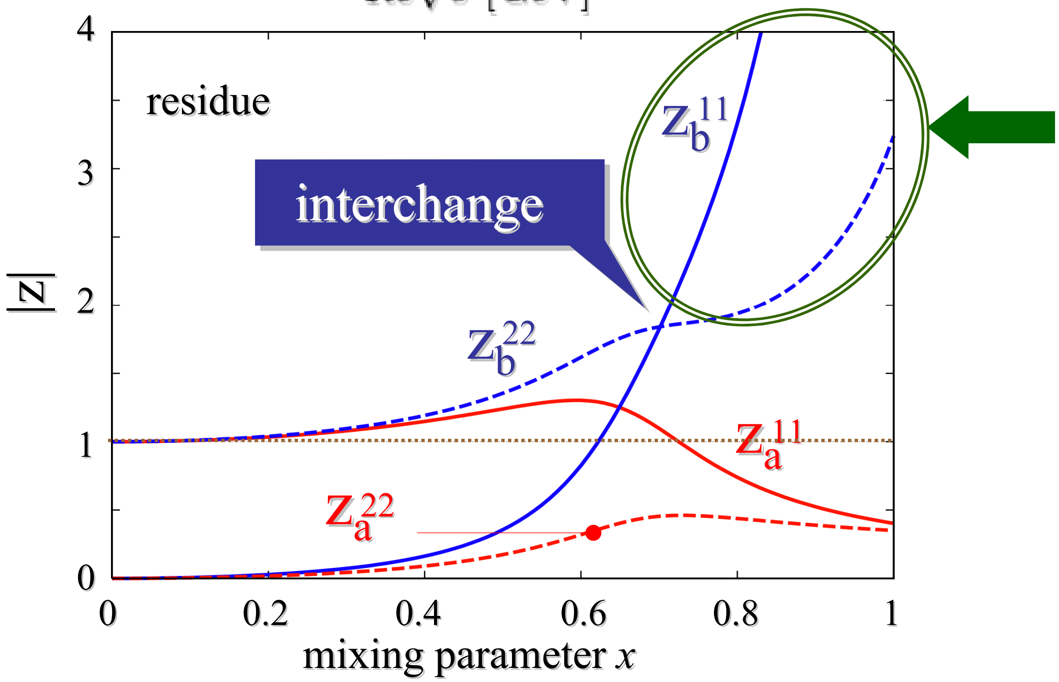


$$[\hat{D}_{\rm full}]^{11} = \frac{z_a^{11}}{E - E_a} + \frac{z_b^{11}}{E - E_b} + \text{(regular)}$$

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

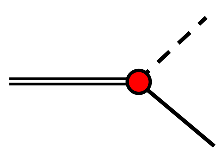
$$|a\rangle = \sqrt{z_a^{11}}\,|\quad\rangle + \sqrt{z_a^{22}}\,|\quad\rangle$$

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



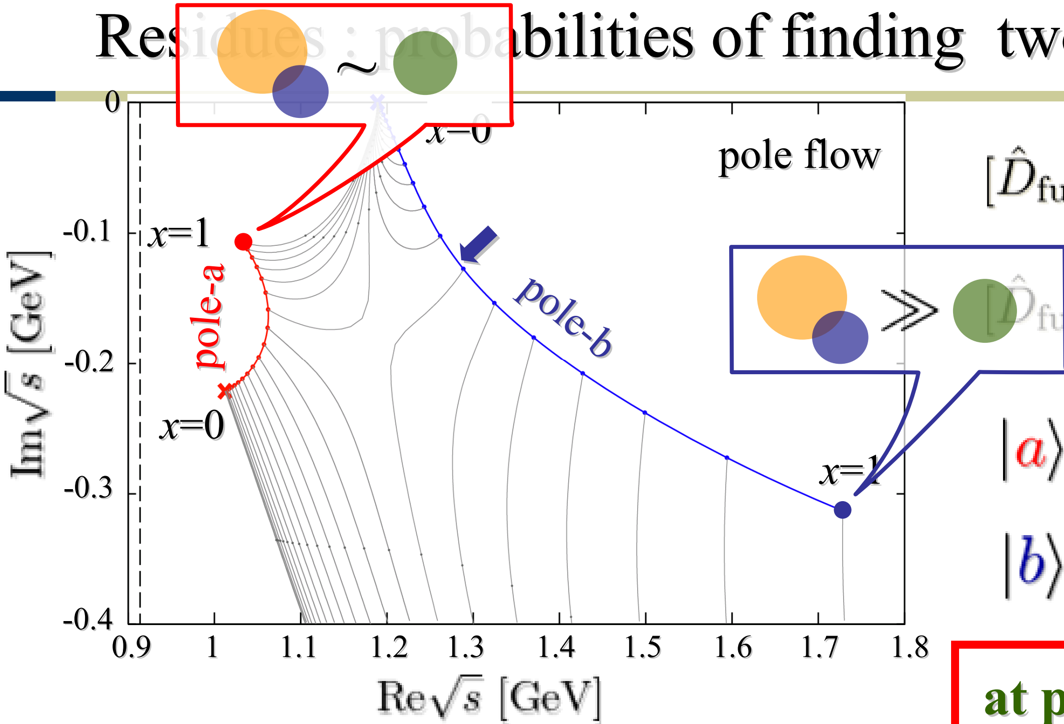
Large residue

→ 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

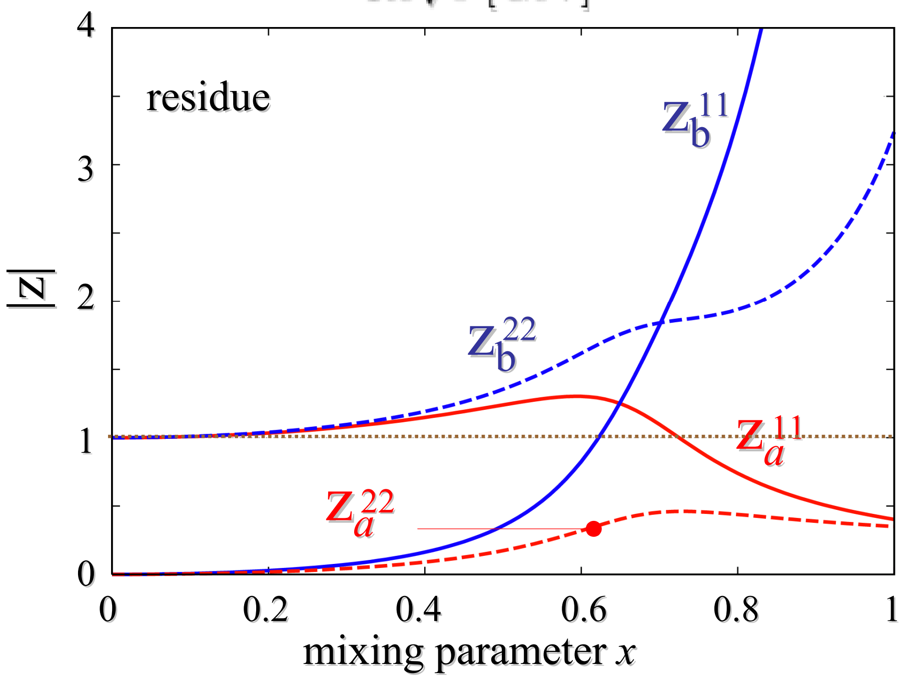


$$[\hat{D}_{\rm full}]^{11} = \frac{z_a^{11}}{E - E_a} + \frac{z_b^{11}}{E - E_b} + \text{(regular)}$$

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

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

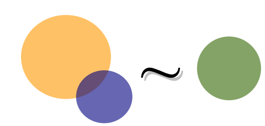
$$|b\rangle = \sqrt{z_b^{11}}\,|\quad\rangle + \sqrt{z_b^{22}}\,|\quad\rangle$$



at physical point (x=1)

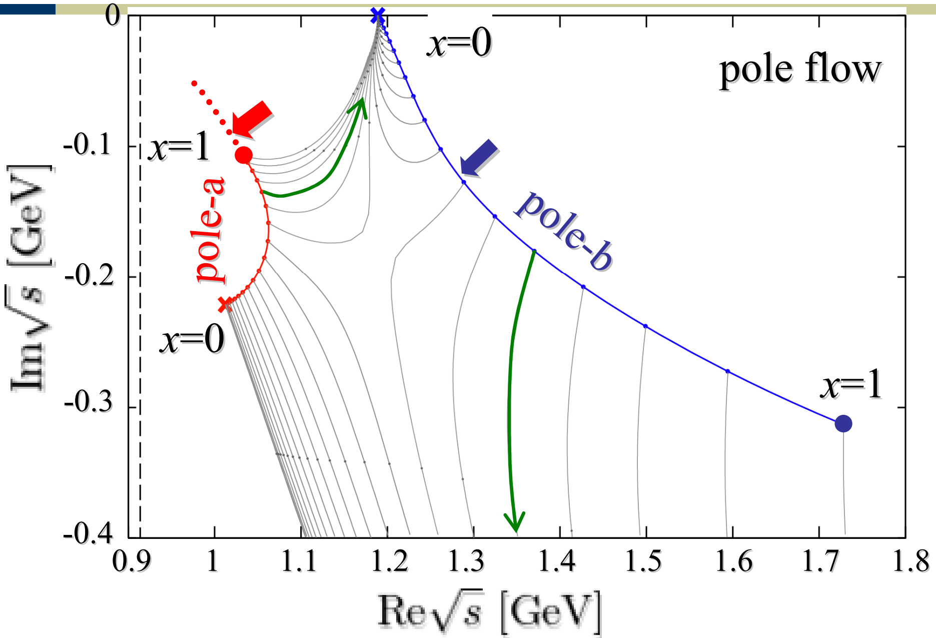
- pole-a has a component of the elementary a_1 meson ***comparable to*** that of composite a_1.

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



non-zero comp. of

Last question : large N_C limit vs. nature of poles

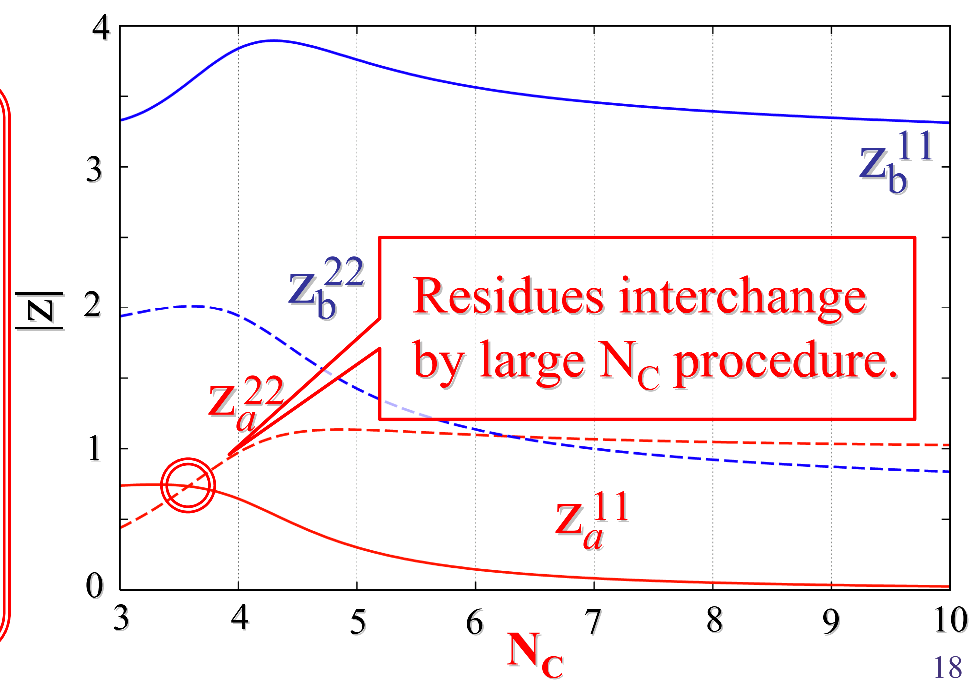


- for pole-b, large N_C flip point ~ residue-interchange
- for pole-a, large N_C flip point ≪ residue-interchange

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

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

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



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Conclusions

» **We analyzed the nature of the hadronic resonance by residues**

» a_1(1260) meson : πρ分子共鳴 + elementary a_1

› bare a_1 … doesn't have molecule nature

› πρ molecule … "natural" regularization

Important to avoid the double-counting

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

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

Future works

phenomenological interests

» τ-decay spectrum with our model parameter

» radiative decay width, etc…

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

theoretical interests

» application to other systems, σ, N^*(1535), etc…