RCNP theory group

2 staff members

4 postdocs 4 Chinese

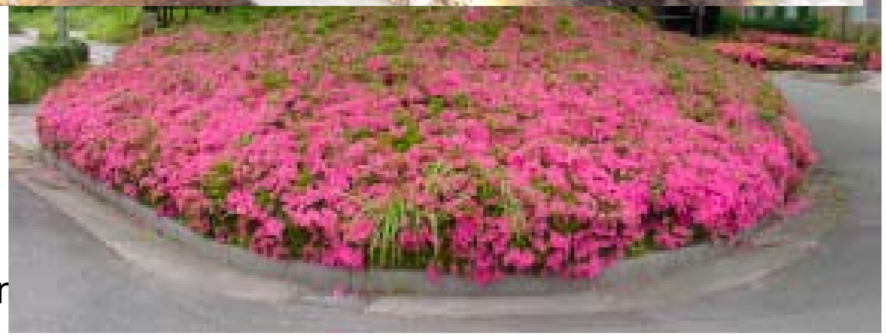
5 visiting researchers

More than 10 students

+ IPC course

http://www.rcnp.osaka-u.ac.jp/~ipc/

RCN
theory



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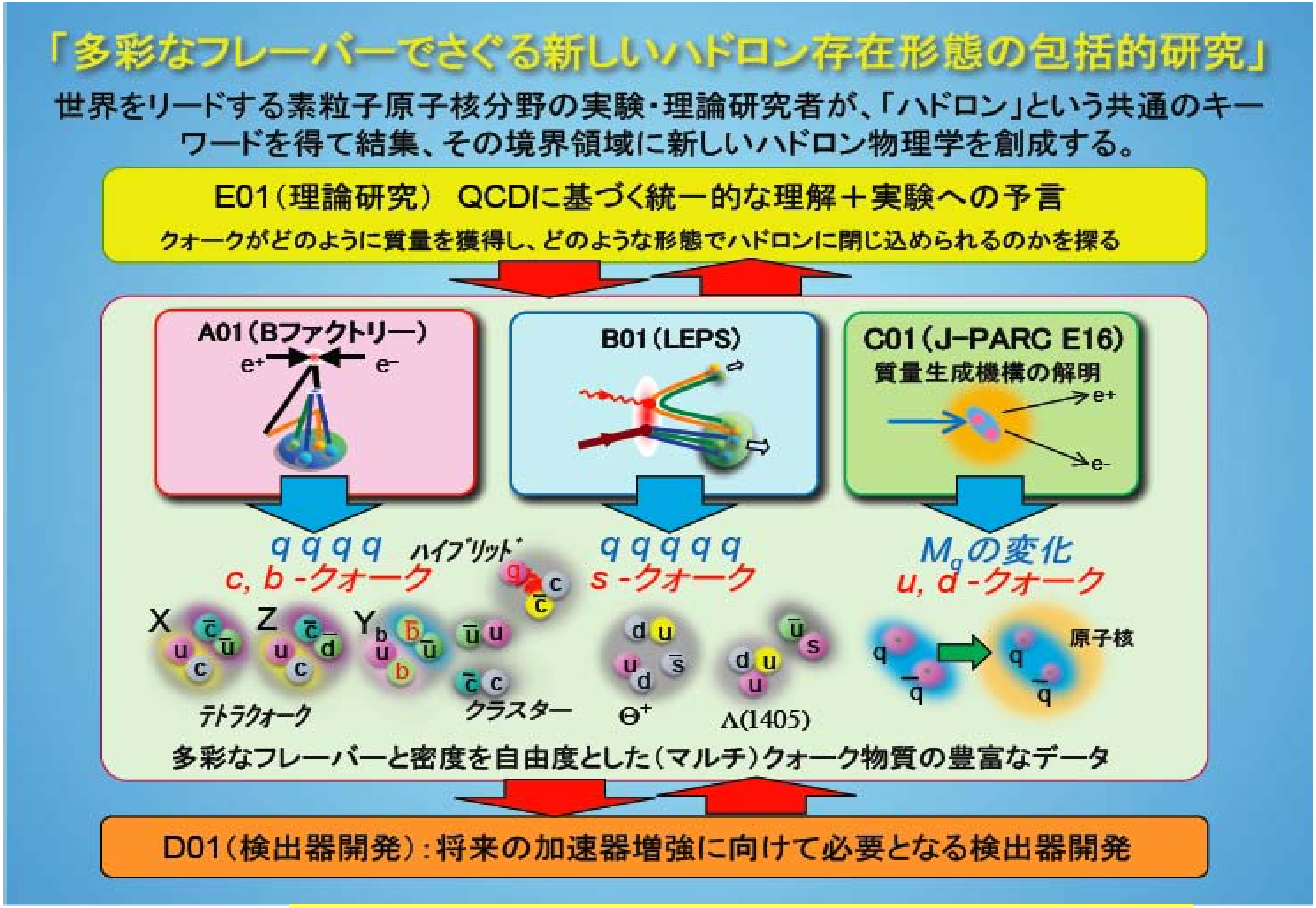
Elucidation of new hadrons with variety of flavors (2009 - 2013)



5 postdocs with Chinese (Yong-Liang Ma) and Indian

Structure of resonances single particle vs collective (cluster)

Atsushi Hosaka 保坂 淳

RCNP, Osaka Univ

Collaborators: T. Hyodo (TITech, Tokyo),
D. Jido (Yukawa Inst. Kyoto),
H. Nagahiro (Nara Women's Univ),
K. Nawa, S. Ozaki (RCNP)

Oct. 14-15

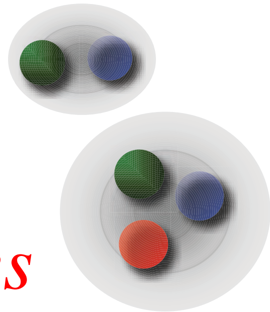
International Symposium on Nuclear Physics in Asia

1. Introduction

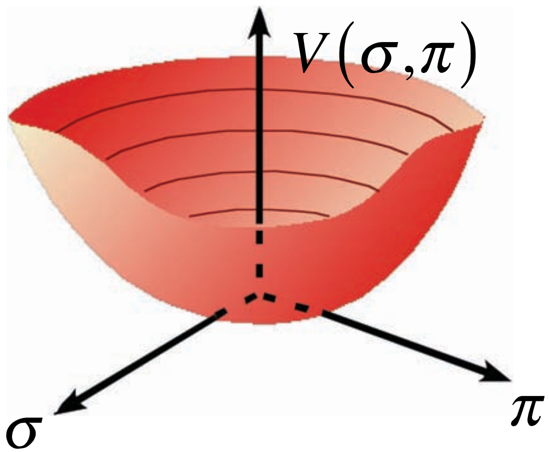
"***Constituent***" quarks

Successful for ***ground states***

$q\bar{q}$ and qqq of *independent particles*

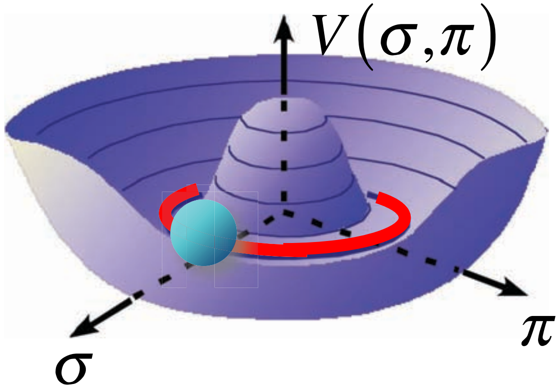


Light flavor



$\langle\sigma\rangle = f_\pi$

Broken symmetry
where we are now



Observation of exotic hadron resonances

Θ^+, $\Lambda(1405)$, …, X(3872), $Z^+(4430)$, etc

Pentaquarks Hadronic molecule Tetraquarks

Quantum nembers
Matrix elements
→
Not easy to explain by
the conventional picture

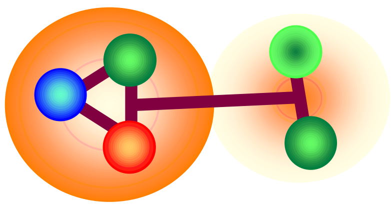
Observation of exotic hadron resonances

Θ^+, $\Lambda(1405)$, …, $X(3872)$, $Z^+(4430)$, etc

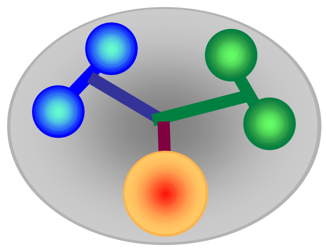
Pentaquarks* *Hadronic molecule* *Tetraquarks

Quantum numbers Matrix elements	⇒	Not easy to explain by the conventional picture

Key question:
What multiquark configurations are possible?

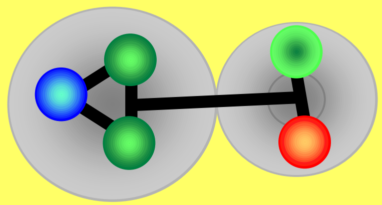


Triquark



Diquark

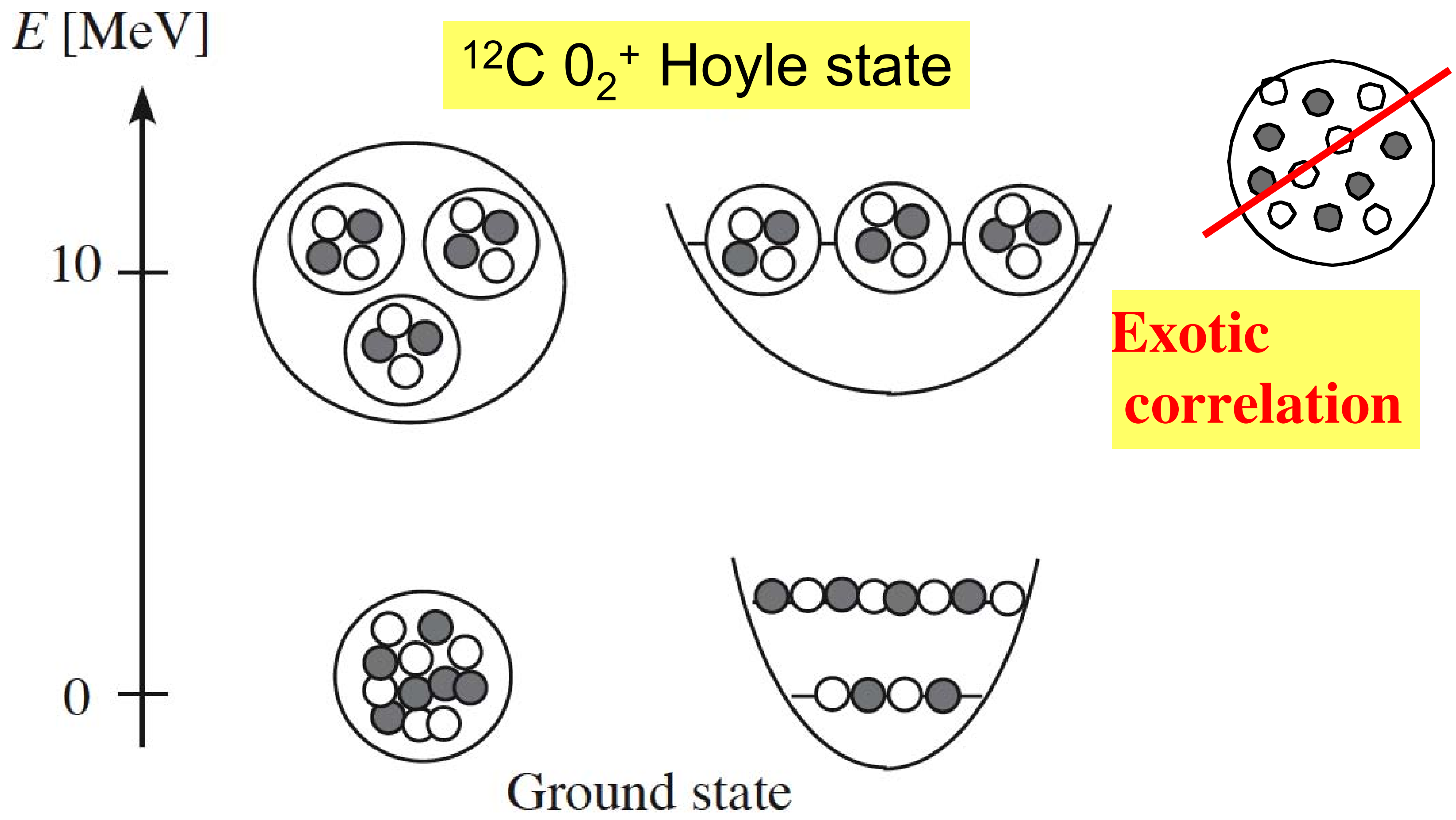
Colored correlation



Meson-baryon composite

Colorless correlation

Example in Nuclear Physics



Single particle like

2. *Coexistence* of different structures

Hideko Nagahiro[1)], Kanabu Nawa[2)],
Sho Ozaki[2)], Daisuke Jido[3)], and Atsushi Hosaka[2)]

[1)] Department of Physics, Nara Women's University,
[2)] RCNP, Osaka University,
[3)] YITP, Kyoto University

Bare $q\bar{q}$ or Hadronic $\pi\rho$ composite for a_1

$$|a_1\rangle_{\text{phys}} = z_1 |a_1\rangle_{\text{bare}} + z_2 |\rho\,\pi\rangle_{\text{composite}} + \dots$$

Reasonably truncated model space

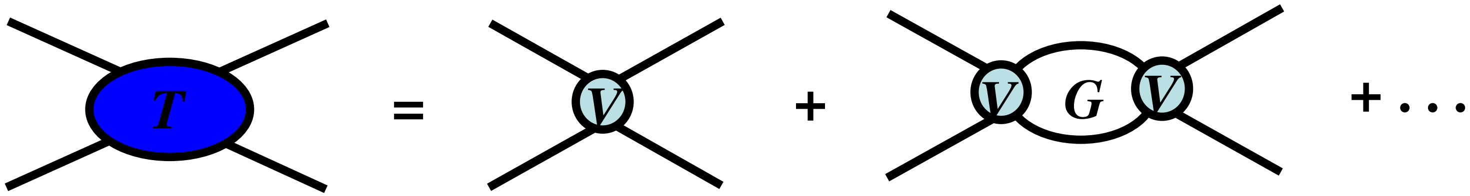
A problem of chiral theory

$$L_{WT} = \frac{1}{4f_\pi^2} \mathrm{tr} \bar{B} i \gamma^\mu [\phi \partial_\mu \phi - \partial_\mu \phi \phi, B] \sim \frac{\sqrt{s} - M}{2f_\pi^2} \bar{B} B \phi \phi$$

A problem of chiral theory

$$L_{WT} = \frac{1}{4f_\pi^2}\mathrm{tr}\bar{B}i\gamma^\mu[\phi\partial_\mu\phi - \partial_\mu\phi\phi, B] \sim \frac{\sqrt{s}-M}{2f_\pi^2}\bar{B}B\phi\phi$$

Point like ***δ-function*** attraction => ***Ill defined***



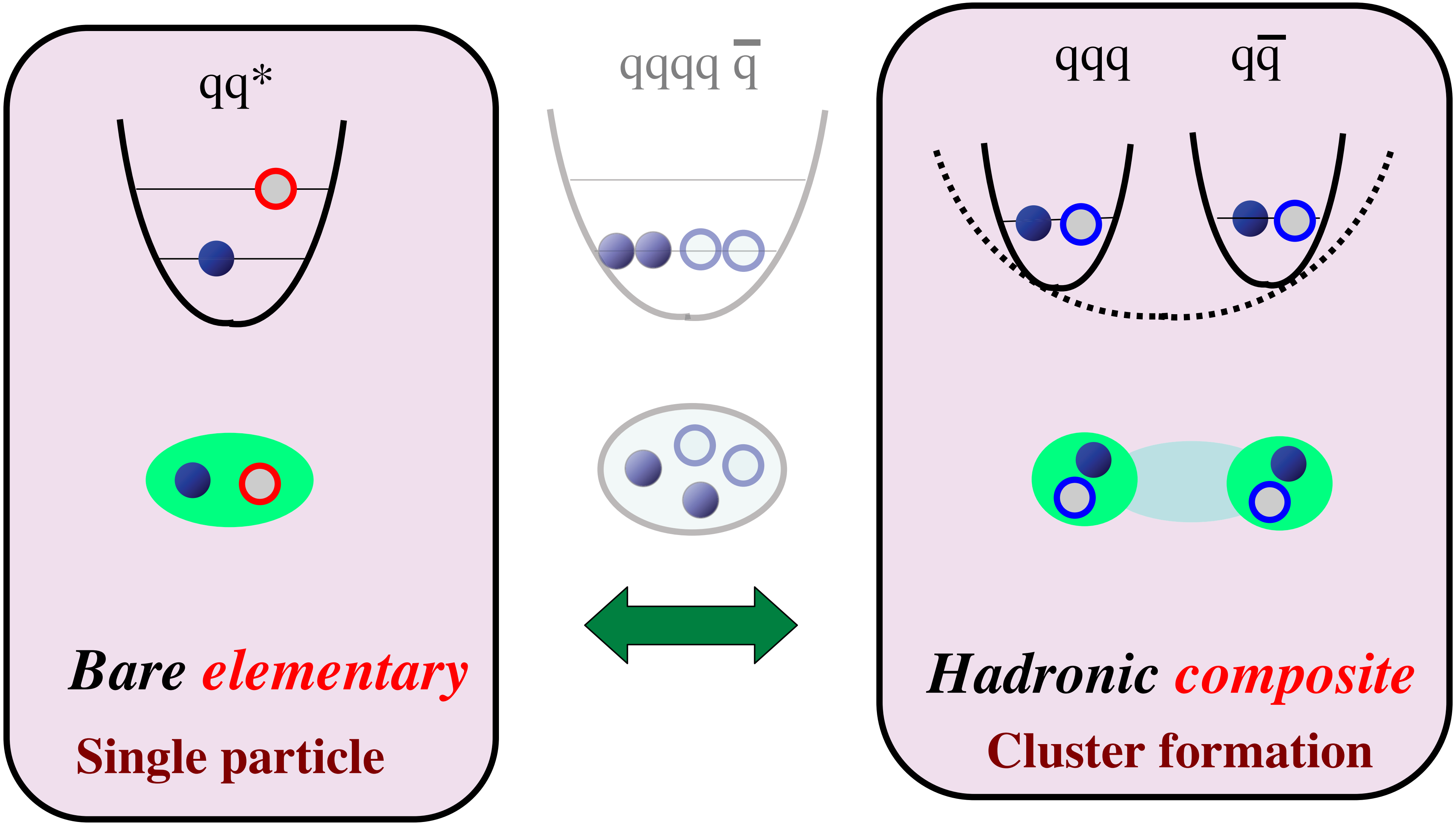
Divergent loop function needs ***regularization***

$\Rightarrow$ We can make a model ***as we want***

Natural scheme for ***compositeness*** condition

Hyodo-Jido-Hosaka, PRC78:025203,2008

Coexistence of different structure



A model for π, ρ and a_1

Hidden Local Symmetry or Holographic model

Bando-Kugo-Yamawaki

Phys. Rept., 164 (1988) 217

Sakai-Sugimono

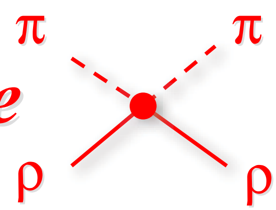
PTP113(05)843; PTP114(05)1083

Nawa, Suganuma, Kojo,

PRD75(07)086003 etc

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

→ ***composite***

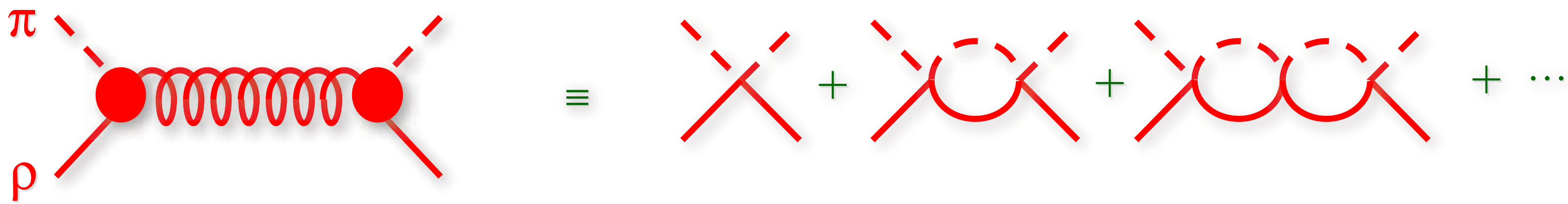


$$\mathcal{L}_{a_1\pi\rho} = -g_{a_1\pi\rho}\frac{\sqrt{2}}{f_\pi}\left\{{\rm tr}\left[(\underline{\partial_\mu a_{1\nu} - \partial_\nu a_{1\mu}})[\partial^\mu \pi, \rho^\nu]\right] + {\rm tr}\left[(\partial_\mu \rho_\nu - \partial_\nu \rho_\mu)[\partial^\mu \pi, \underline{a_1^\nu}]\right]\right\}$$

→ ***bare***

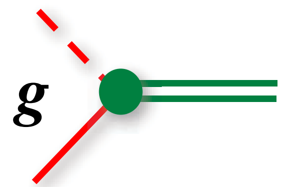
Solving the problem

(a) Composite, dynamically generated



(b) Bare, $\bar{q}q$

mixing with
the strength x

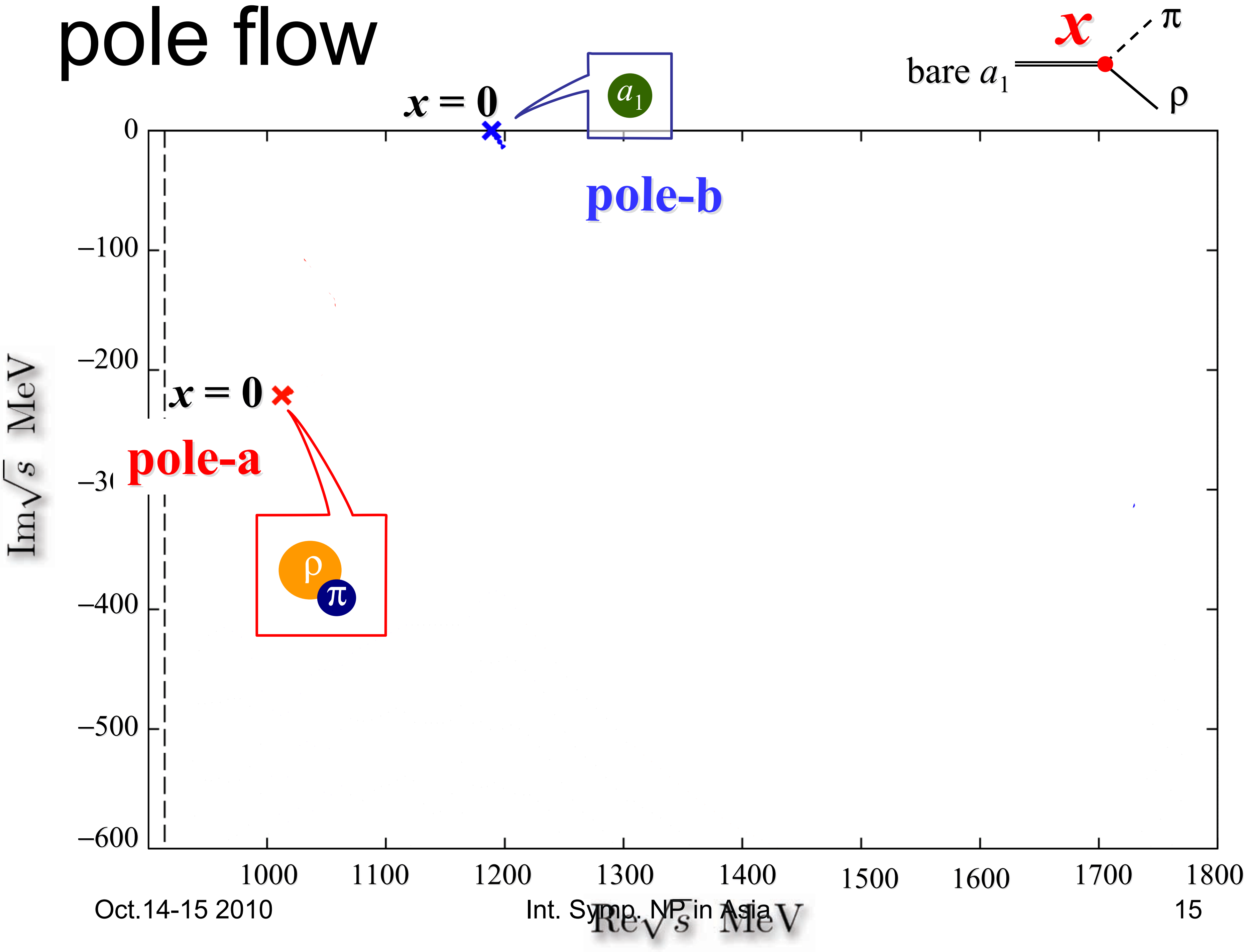


Hamiltonian

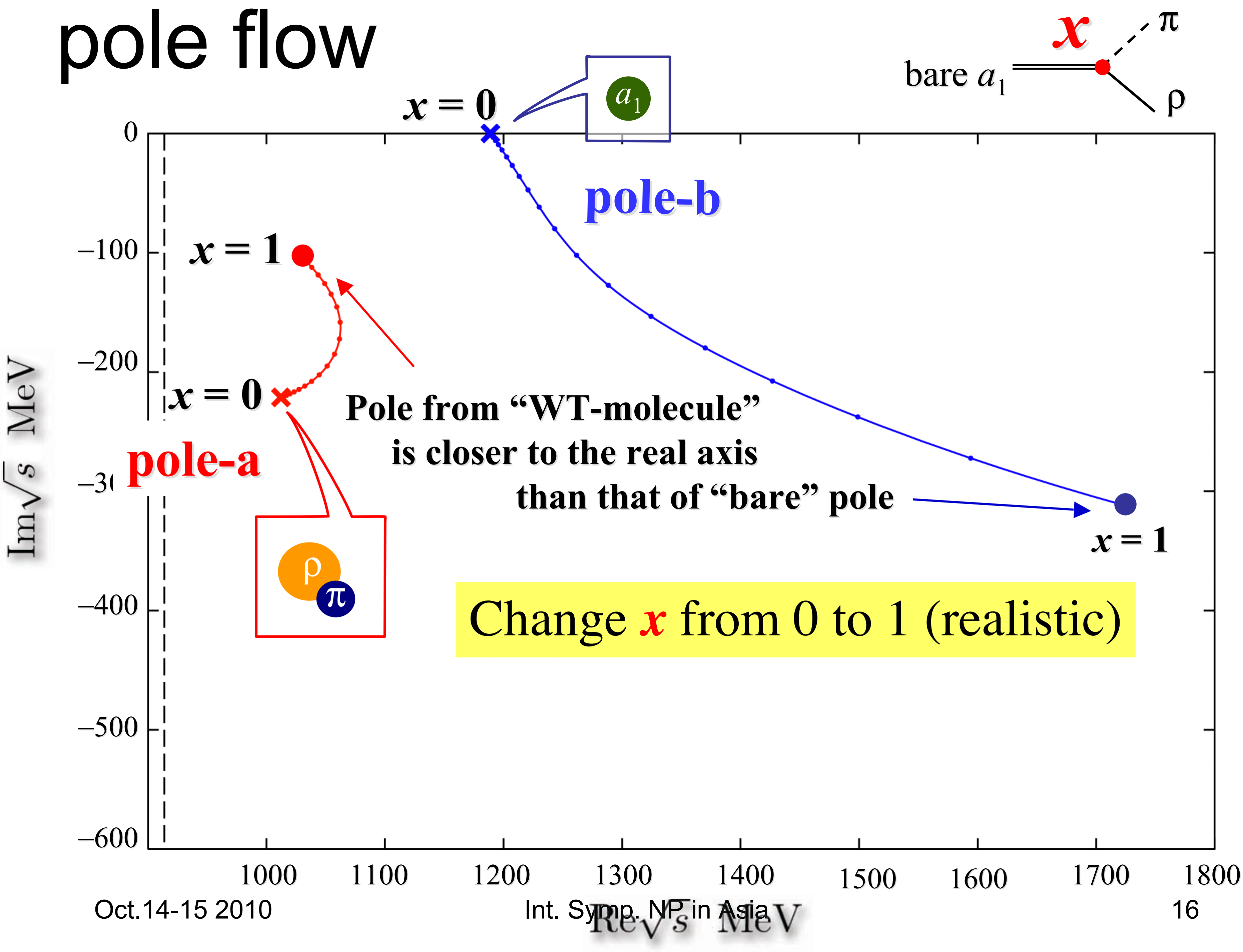
T-matrix

$$H = \begin{pmatrix} H_{\pi\rho} + v_{WT} & g \\ g & H_{a_1} \end{pmatrix} \xrightarrow{\textit{LS-equation}} T = \begin{pmatrix} T_{\pi\rho\to\pi\rho} & T_{\pi\rho\to a_1} \\ T_{a_1\to\pi\rho} & T_{a_1\to a_1} \end{pmatrix}$$

pole flow


bare a_1
x
π
ρ
x = 0
a_1
0
−100
−200
−3(
−400
−500
−600
pole-b
x = 0
pole-a
ρ
π
1000
1100
1200
1300
1400
1500
1600
1700
1800
Im√s MeV
Re√s MeV

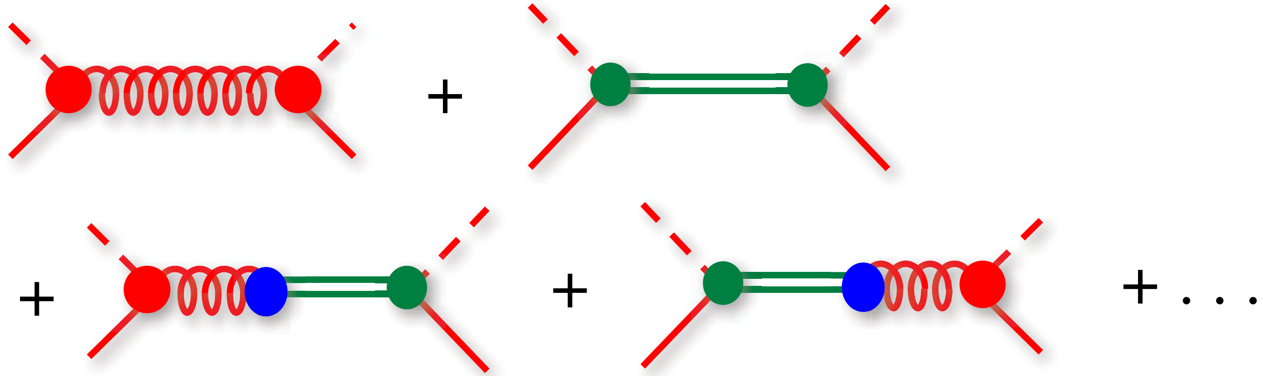
pole flow


x
bare a_1
π
ρ
x = 0
a_1
pole-b
x = 1
x = 0
pole-a
ρ
π
Pole from "WT-molecule"
is closer to the real axis
than that of "bare" pole
x = 1
Change x from 0 to 1 (realistic)
0
−100
−200
−300
−400
−500
−600
1000
1100
1200
1300
1400
1500
1600
1700
1800
Im√s MeV
Re√s MeV

To know better the nature of the poles

Extract two one-particle propagators in the T matrix

$T_{\pi\rho\to\pi\rho} =$

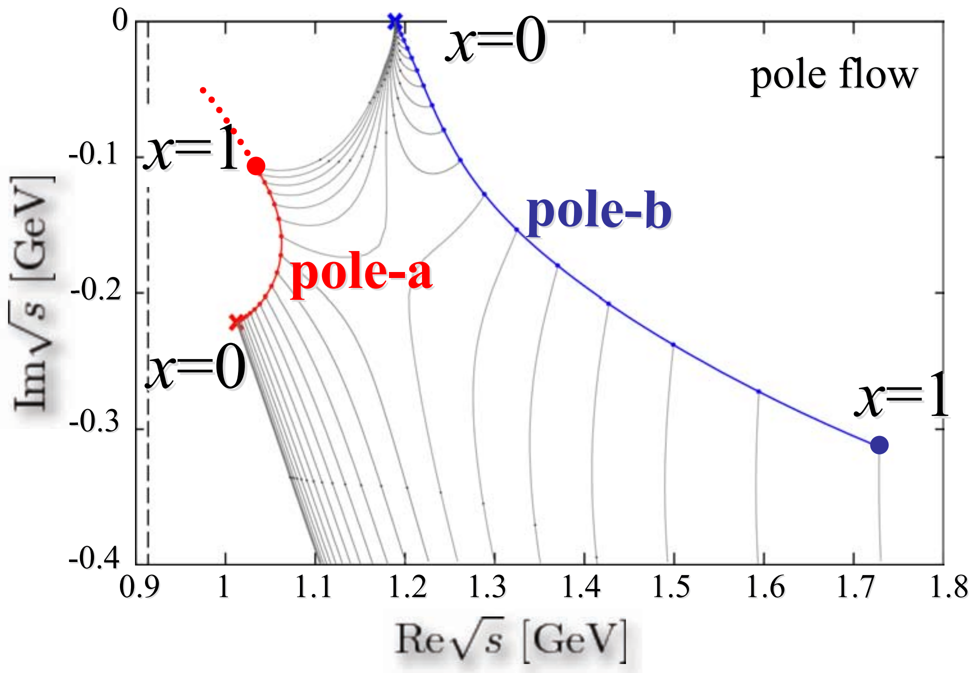


$$[\hat{G}_{\text{full}}]^{11} = \frac{z_a^{11}}{E - E_a} + \frac{z_b^{11}}{E - E_b}$$

$$[\hat{G}_{\text{full}}]^{22} = \frac{z_a^{22}}{E - E_a} + \frac{z_b^{22}}{E - E_b}$$

Full solution -> Two level problem

mixing properties



$$[\hat{G}_{\mathrm{full}}]^{11} = \frac{z_a^{11}}{E - E_a} + \frac{z_b^{11}}{E - E_b}$$

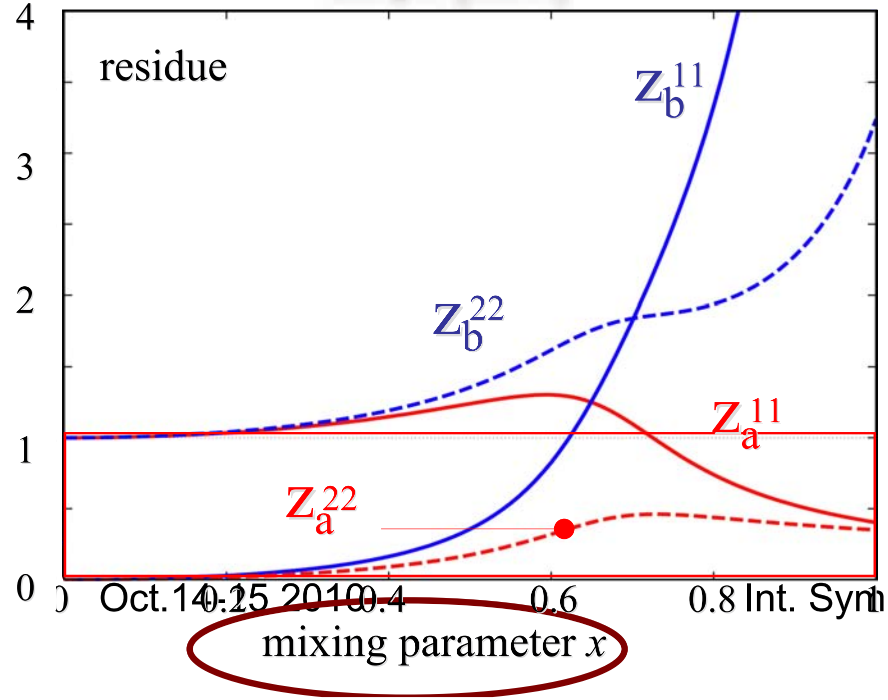
$$[\hat{G}_{\mathrm{full}}]^{22} = \frac{z_a^{22}}{E - E_a} + \frac{z_b^{22}}{E - E_b}$$

Z_a^{11} … molecular

Z_a^{22} … bare

Z_b^{11} … molecular

Z_b^{22} … bare

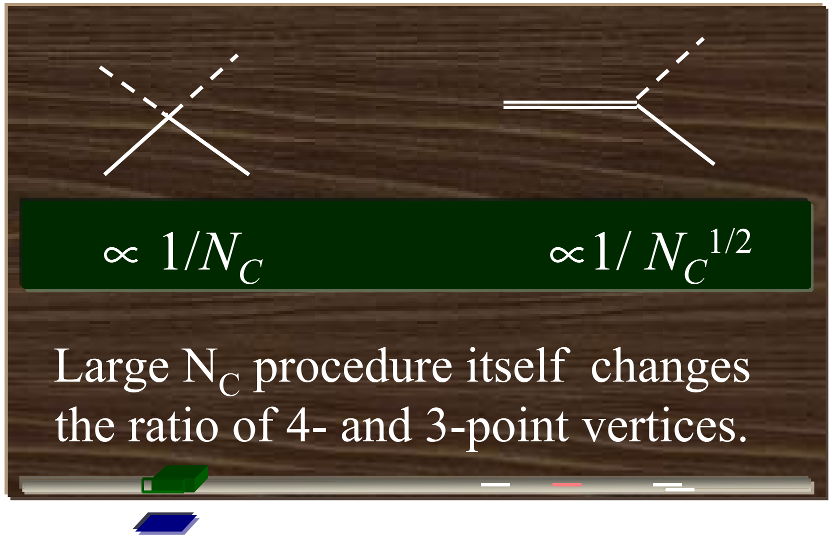


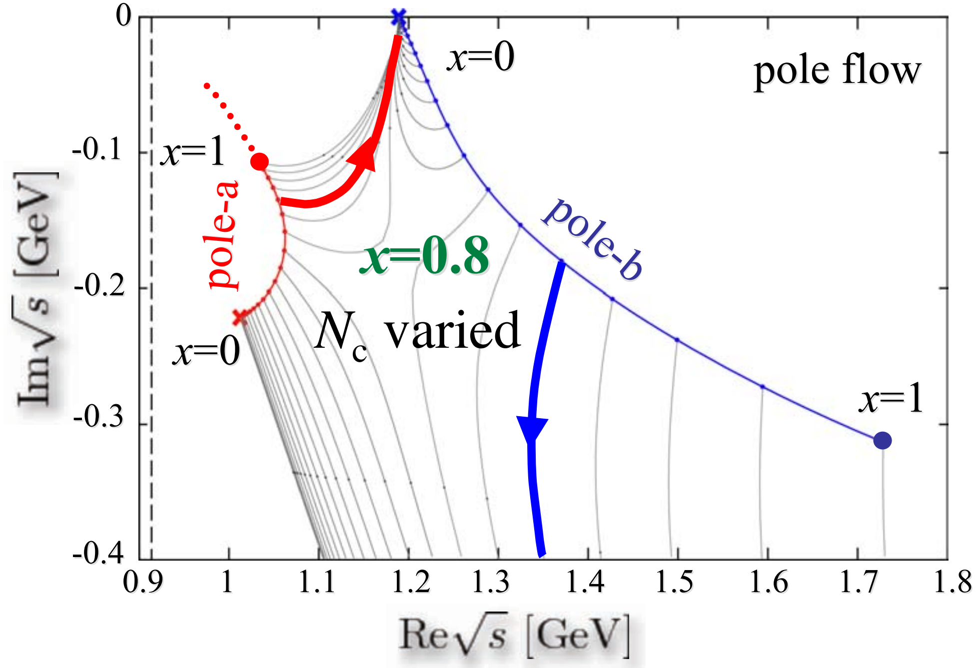
at physical point (*x*=1)

- pole-a remains as a "*molecule*"
  (bare comp. δ molecule comp.)
- pole-b changes into a "*molecule*"
  → **both poles have molecule comp.**

will exchange at $x > 1$

large N_C



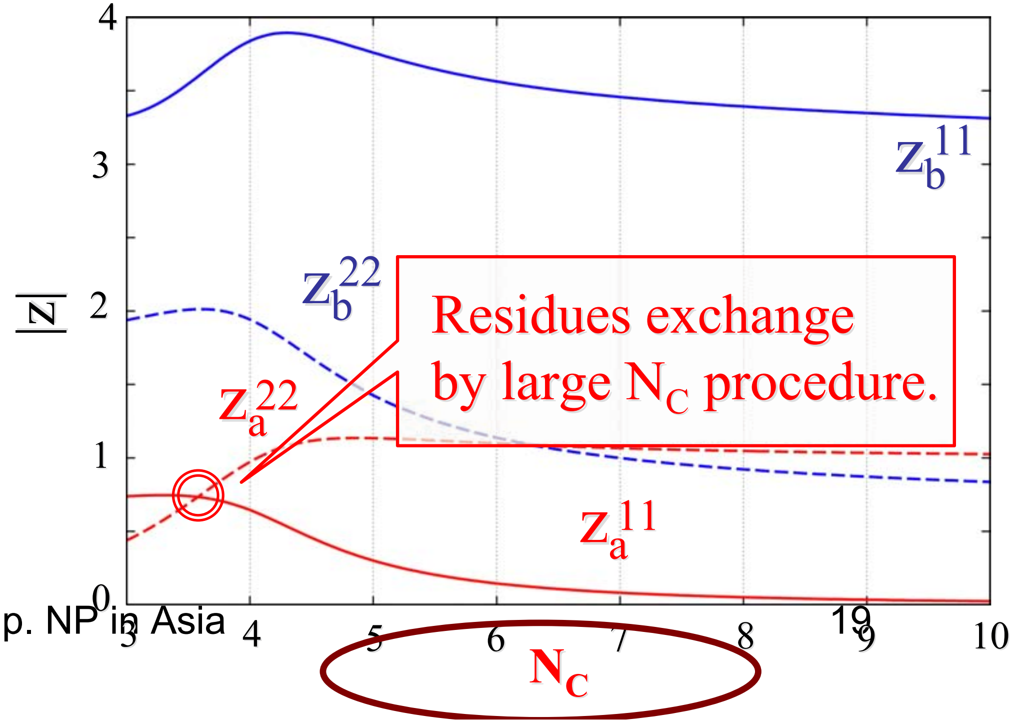


For realistic mixing

pole-b stays similar

pole-a changes its nature

molecule-> bare



Summary for dynamical generation

- Exotics may have *correlations*

  $q\bar{q}$, qq, qqq

  Question; how are they realized and observed

- For hadronic composite, a_{natural} has been defined
  Difference a_{pheno} - a_{natural} is interpreted as ***bare*** states

- We have studied a system of ***composite + bare a₁***

$$|\mathbf{a}_1\rangle_{\mathbf{phys}} = z_1 | a \rangle_{\mathbf{bare}} + z_2 | \rho\,\pi \rangle_{\mathbf{composite}} + \cdots$$

Two channel treatment is now being completed
Large-Nc behavior is well studied.

International conference on the structure of baryons

BARYONS'10

Dec. 7-11, 2010, Osaka, Japan

http://www.rcnp.osaka-u.ac.jp/~baryons

baryons@rcnp.osaka-u.ac.jp

2. Topics

- **Spectroscopy**

 Light/heavy flavor hadrons, Resonances, Exotics, Pentaquarks, Tetraquarks, Hadronic molecules, etc

- **Hadron Interactions**

 Meson-meson, meson-baryon and baryon-baryon interactions, Anti-proton interactions, etc

- **Electromagnetic and weak interactions**

 Photo and electro productions of hadrons, P and CP-violating processes in nucleons and nuclei, etc

- **Hadrons at finite density and temperature**

 The QCD vacuum, Chiral symmetry, Hadron properties, QGP, Heavy ion collisions, etc

- **Structure of hadrons**

 Form Factors, Structure Functions, Generalized Parton Distributions, Fragmentation functions, etc

- **Recent Approaches to non-perturbative QCD**

 AdS/CFT correspondence, Lattice gauge theory, Effective field theories, etc

- **New Facilities**
- **Other related topics**