有限体積効果による Λ(1405)共鳴の構造

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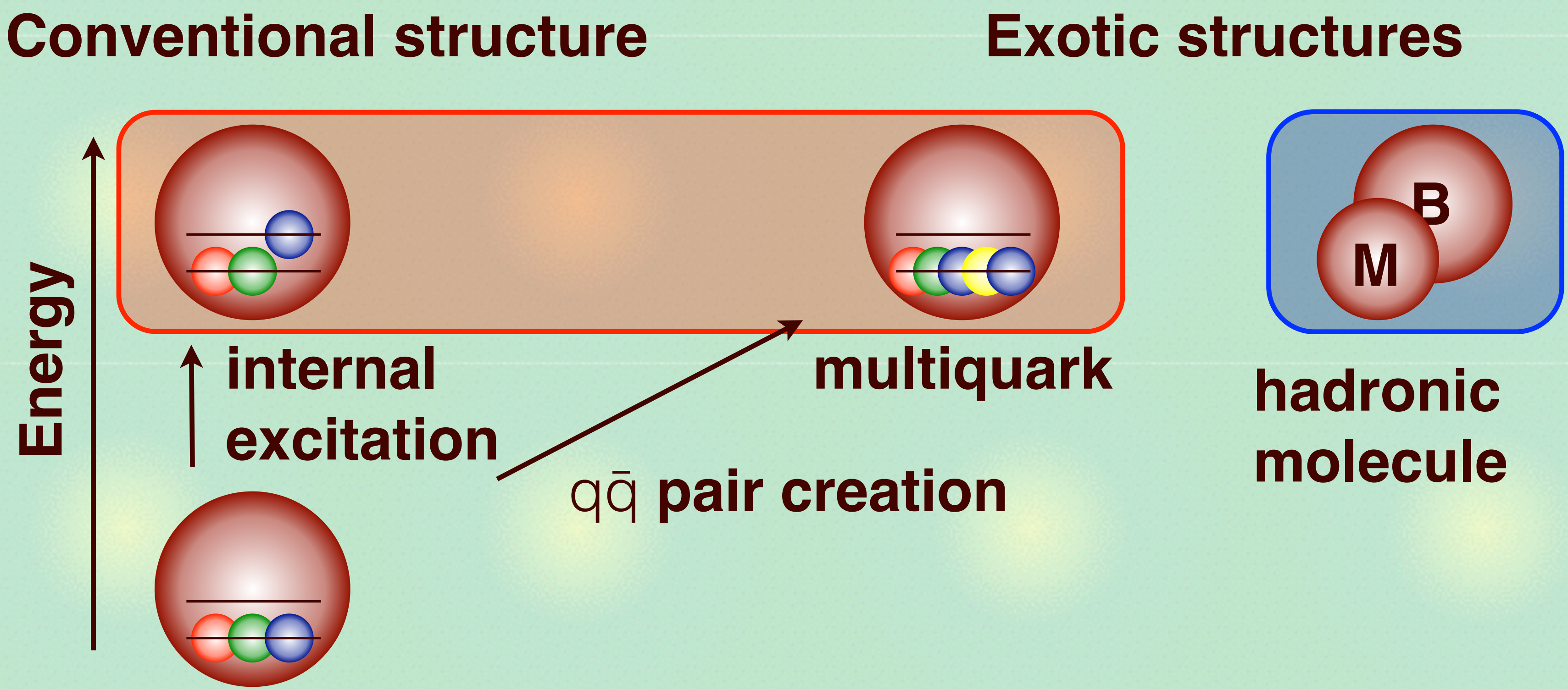
Structure of hadrons

Internal structure of excited hadrons?



- **Compositeness**: measure of the molecular component

S. Weinberg, Phys. Rev. 137, B672 (1965);
T. Hyodo, Int. J. Mod. Phys. A 28, 1330045 (2013)

Compositeness

Compositeness X: projection onto two-body subspace

$$\hat{1} = \hat{P}_{\text{two-body}} + \hat{P}_{\text{others}}, \quad \hat{P}_{\text{two-body}} = \int \frac{d^3\boldsymbol{p}}{(2\pi)^3} | \boldsymbol{p} \rangle \langle \boldsymbol{p} |$$

$$X = \langle B | \hat{P}_{\text{two-body}} | B \rangle$$

Compositeness

$$Z = \langle B | \hat{P}_{\text{others}} | B \rangle$$

“Elementariness”

- **Stable states: real** (X, Z) **are interpreted as probabilities.**
- **Near-threshold states:** (X, Z) **are related to observables.**

S. Weinberg, Phys. Rev. 137, B672 (1965)

- **Unstable states: complex, interpretation?**

$$X = \langle \tilde{R} | \hat{P}_{\text{two-body}} | R \rangle \in \mathbb{C}$$

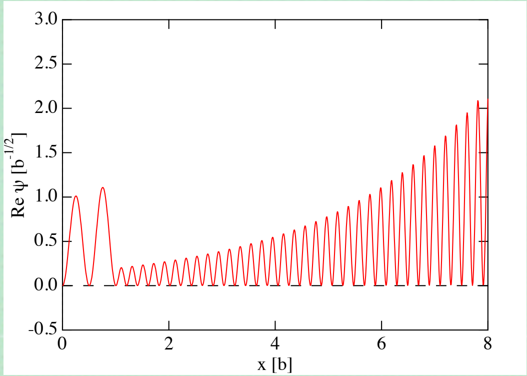
T. Hyodo, Phys. Rev. Lett. 111, 132002 (2013),
Z.H. Guo, J.A. Oller, Phys. Rev. D93, 096001 (2016),
Y. Kamiya, T. Hyodo, Phys. Rev. C 93, 035203 (2016); PTEP 023D02 (2017)

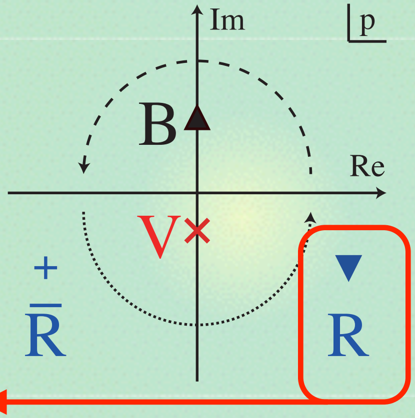
Use of finite volume eigenstates?

Wavefunction of resonance

- **outgoing boundary condition (c.f.** exp{-κr}**)**

$$\psi(r) \sim \exp[ipr] \\ = \exp\{i[\mathrm{Re}\ p]r\}\exp\{-[\mathrm{Im}\ p]r\}$$



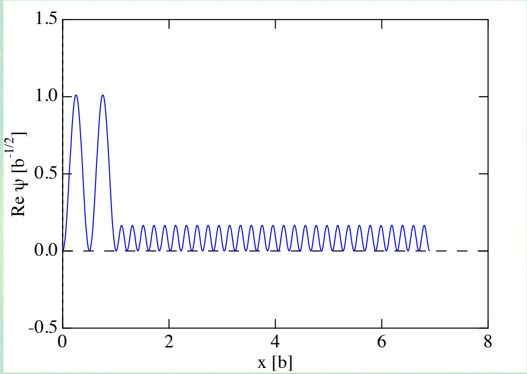


- **If** Im p < 0, ψ **is not square integrable.**
- **complex eigenvalues (energy,** X**)**

Finite-volume system with size L

- ψ **is square integrable on** $[0,L]^3$.
- **real eigenvalues (energy,** X**)**

—> Probabilistic interpretation!



Compositeness in finite volume

Effective field theory in finite box of size L

- **discrete real eigenenergies in finite volume (FV)**

$$H|\Psi^{(m)}\rangle = E^{(m)}|\Psi^{(m)}\rangle, \quad E^{(m+1)} > E^{(m)}, \quad \langle\Psi^{(m)}|\Psi^{(l)}\rangle = \delta_{ml}$$

- **Compositeness**

$$X^{(m)} = \langle\Psi^{(m)}|\hat{P}_{\text{two-body}}|\Psi^{(m)}\rangle, \quad \hat{P}_{\text{two-body}} = \frac{1}{L^3}\sum_{\boldsymbol{n}} |\boldsymbol{p_n}\rangle\langle\boldsymbol{p_n}|$$

$$= \frac{I'_{\text{FV}}(E^{(m)})}{I'_{\text{FV}}(E^{(m)}) - [1/v(E^{(m)})]'}, \quad 1 - I_{\text{FV}}(E^{(m)})v(E^{(m)}) = 0$$

c.f.) infinite volume: $I_{FV}(E;L)$ **—>** $G(E)$

Y. Kamiya, T. Hyodo, Phys. Rev. C 93, 035203 (2016); PTEP 023D02 (2017).

- **Compositeness** $X^{(m)}$ **is defined for each FV eigenstate.**
- $X^{(m)}$ **can be interpreted as a probability.**
- $X^{(m)}$ **has** L **dependence through** I_{FV} **and** $E^{(m)}$**.**

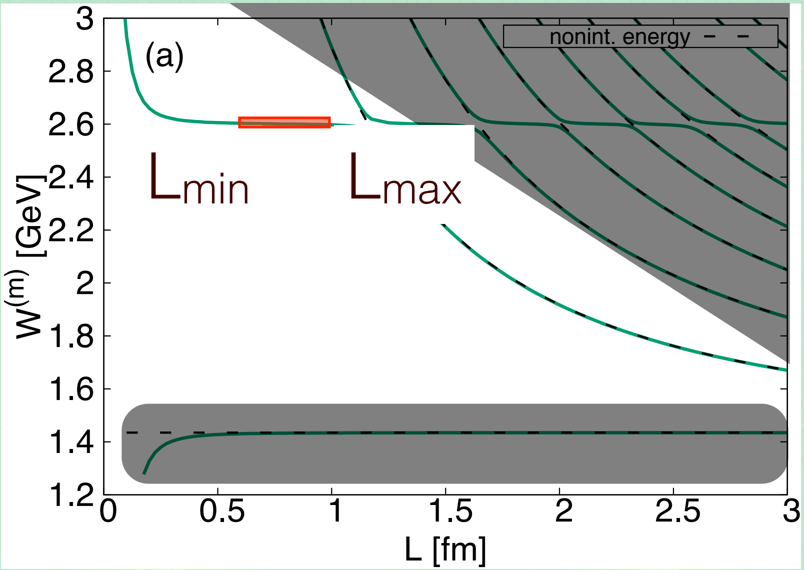
Compositeness of resonances

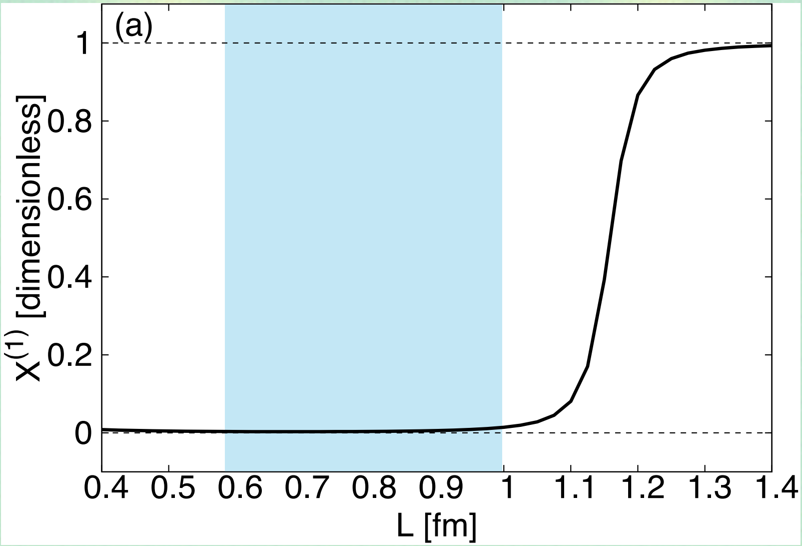
Which is the eigenstate representing the resonance?

- choose first excited state $E^{(1)}(L)$
- energy region —> (L_{min}, L_{max})

$$E_{\rm min} \leq E^{(1)}(L) \leq E_{\rm max}$$

- L_{min}: finite-volume effect on wavefunction
- L_{max}: mixing of scattering state





Compositeness of resonance

$$X_{\rm res} = \frac{1}{L_{\rm max} - L_{\rm min}} \int_{L_{\rm min}}^{L_{\rm max}} X^{(1)}(L) dL$$

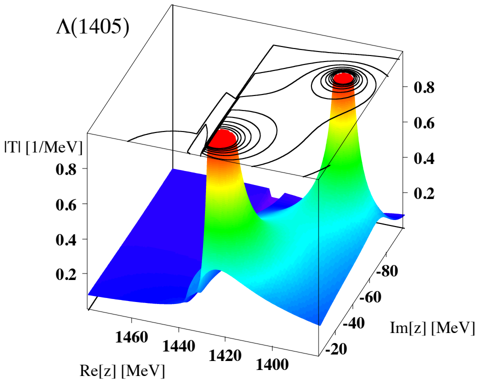
- interpreted as a probability

Eigenenergies of Λ(1405)

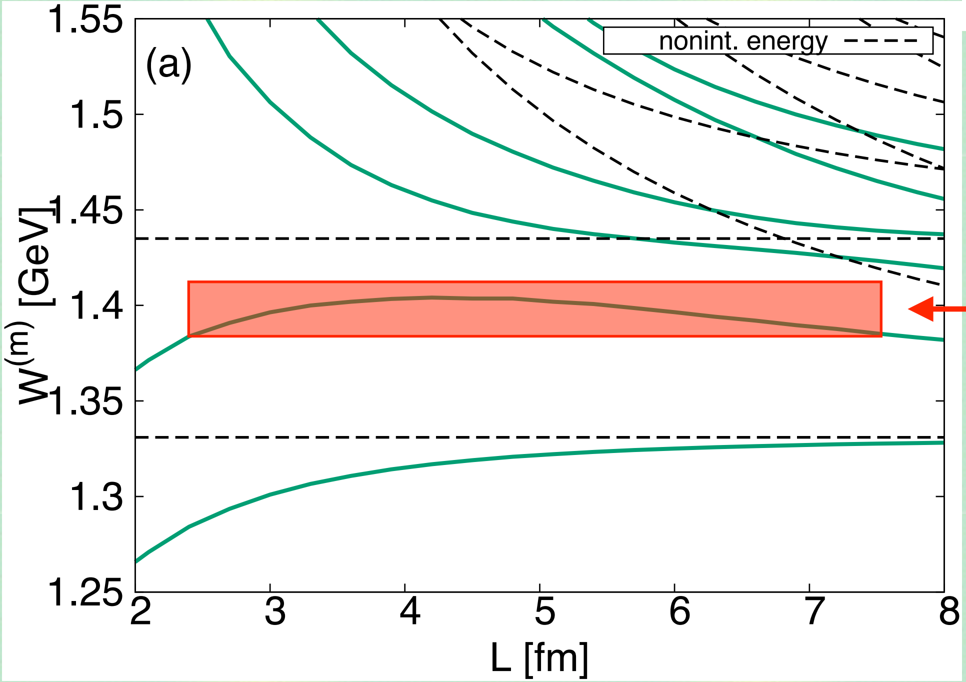
ETW model ($\bar{K}N$-$\pi\Sigma$ 2channel, WT interaction)

Y. Ikeda, T. Hyodo, W. Weise, Nucl. Phys. A881, 98 (2012)

- two poles, consistent with SIDDHARTA



Finite volume eigenenergies



$\bar{K}N$ threshold

Λ(1405)

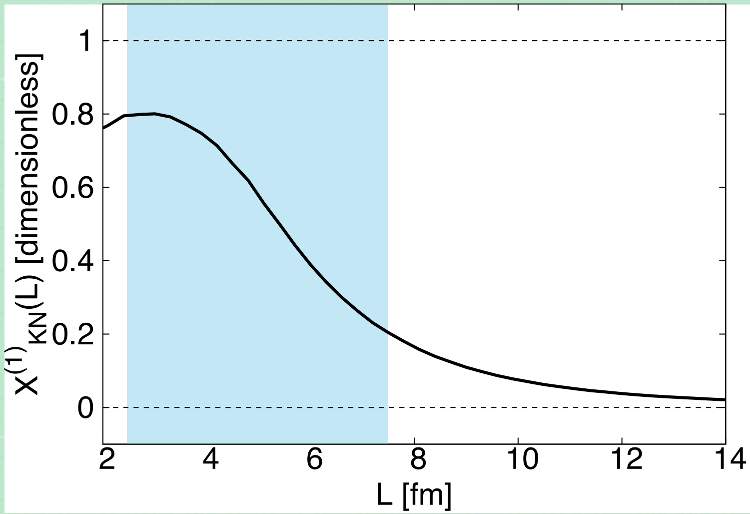
$\pi\Sigma$ threshold

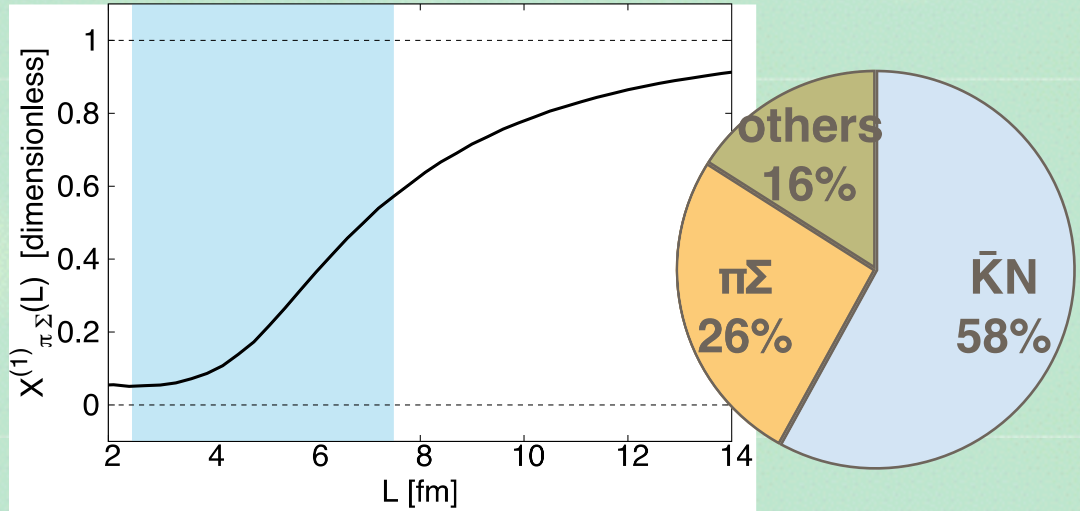
Λ(1405) **is represented by a single FV eigenstate.**

(# of FV eigenstates <—> # of π/2 crossings of phase shift)

Compositeness of $\Lambda(1405)$

Compositeness $X_{res,\bar{K}N}$, $X_{res,\pi\Sigma}$



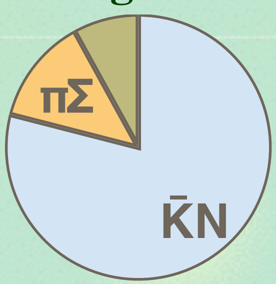


Complex compositeness at each pole —> real-valued

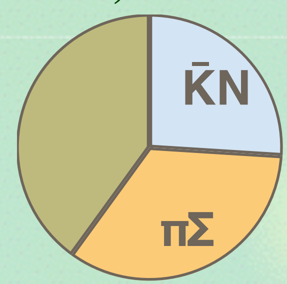
Y. Kamiya, T. Hyodo, Phys. Rev. C 93, 035203 (2016); PTEP 023D02 (2017),

T. Sekihara, T. Arai, J. Yamagata-Sekihara, S. Yasui, Phys. Rev. C 93, 035204 (2016)

- higher pole



- lower pole



X_{res} **represents the contributions from both poles**

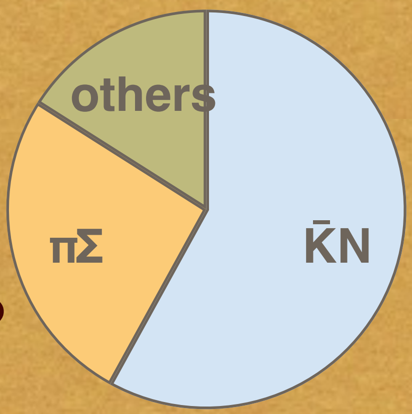
Summary

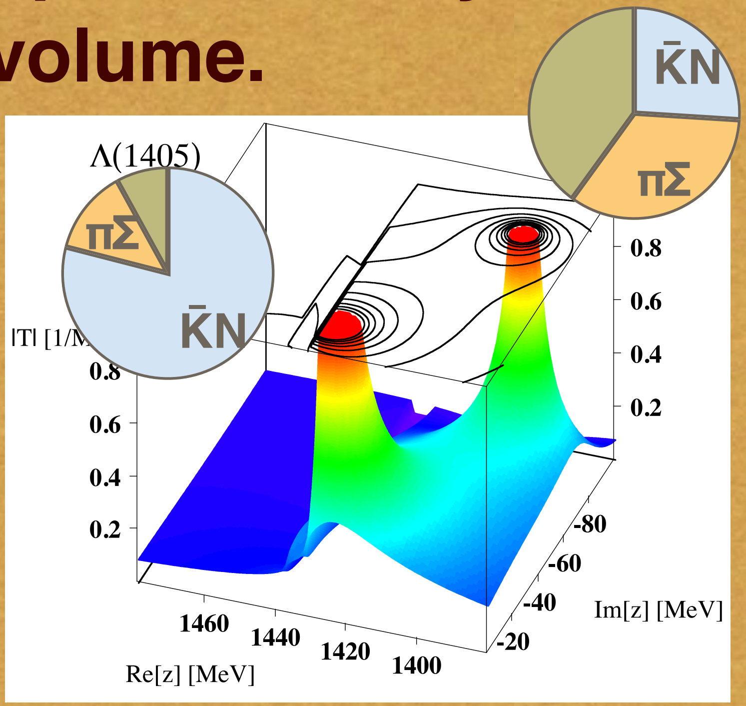
- We propose a new definition of compositeness of resonances using finite-volume eigenstates.

- Two poles of $\Lambda(1405)$ are represented by **a single eigenstate** in finite volume.

- Structure of $\Lambda(1405)$:

  - $\bar{K}N$: 58%
  - $\pi\Sigma$: 26%
  - others: 16%





Y. Tsuchida, T. Hyodo, arXiv:1703.02675 [nucl-th]