

Nature of the D_0^* meson in $D\pi$ scattering with chiral symmetry



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Some history

In 2001, summer...

- first discussion on research
 - chiral symmetry
 - meson-baryon system
 - SU(3) flavor symmetry
 - resummation, pole
- $\Lambda(1405)$, pentaquark Θ^+ , ...

One more thing...

- heavy quark?

→ study of heavy-light meson

T. Sugiura, T. Hyodo, Phys. Rev. C99, 065201 (2019)

Chiral unitary method

Chiral perturbation theory
unitarity
(heavy) quark baryon

(1) Chiral perturbation theory
Strong interaction
Low energy

(2) Meson-Meson vs Quark OK
Meson-Baryon ? Quark ?

(3) Symmetry breaking
SU(3) flavor symmetry
u, d, s

pole

$T = V + V \frac{1}{E - H_0} T$

$V = \frac{1}{1 - V \frac{1}{E - H_0}}$

$= V + V \frac{1}{E - H_0} V + V \frac{1}{E - H_0} V \frac{1}{E - H_0} V + \dots$

Effective Lagrangian

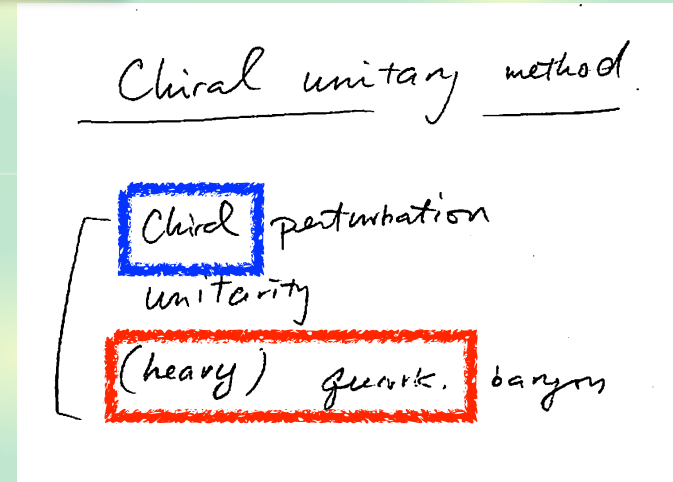
Heavy-light mesons $\sim c\bar{u}/c\bar{d}$

- **chiral** symmetry: **parity** partner

$$D(0^-) \leftrightarrow D_0^*(0^+)$$

- **heavy-quark** symmetry: **spin** partner

$$D(0^-) \leftrightarrow D^*(1^-), \quad D_0^*(0^+) \leftrightarrow D_1(1^+)$$



Effective Lagrangian (linear representation)

M.A. Nowak, M. Rho, I. Zahed, Phys. Rev. D48, 4370 (1993);

W.A. Bardeen, C.T. Hill, Phys. Rev. D49, 409 (1994);

D. Suenaga, S. Yasui, M. Harada, Phys. Rev. C96, 015204 (2017).

$$\mathcal{L} = -\text{Tr} [H_L(i\nu \cdot \partial)\bar{H}_L] - \text{Tr} [H_R(i\nu \cdot \partial)\bar{H}_R] + \dots$$



linear combination of D, D^*, D_0^*, D_1

Decay width of D_0^*

Constraint from chiral symmetry

$$\mathcal{L} = \frac{\Delta_m}{2f_\pi} [2D\sigma D^\dagger - 2D_0^*\sigma D_0^{*\dagger} - 2iD_0^*\pi D^\dagger + 2iD\pi D_0^{*\dagger}] + \dots$$

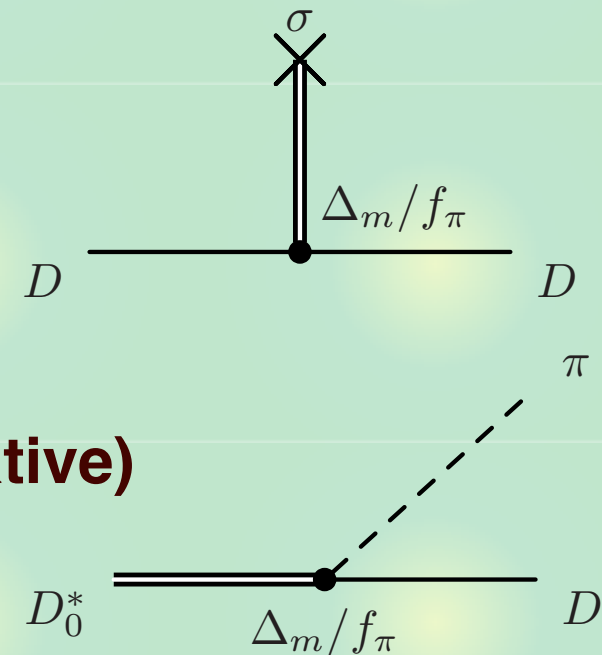
- chiral condensate $\langle \sigma \rangle = f_\pi$: mass splitting of D and D_0^*

$$M_D = m - \frac{\Delta_m}{2}, \quad M_{D_0^*} = m + \frac{\Delta_m}{2}$$

- $D_0^* D \pi$ coupling: same Δ_m/f_π

- $M_{D_0^*} \rightarrow$ **decay width** of $D_0^* \rightarrow D\pi$ (perturbative)

$$\Gamma_{\text{th}} \sim 1000 \text{ MeV} \gg \Gamma_{\text{exp}} \sim 250 \text{ MeV}$$



Pure chiral partner D_0^* is **not** consistent with data.

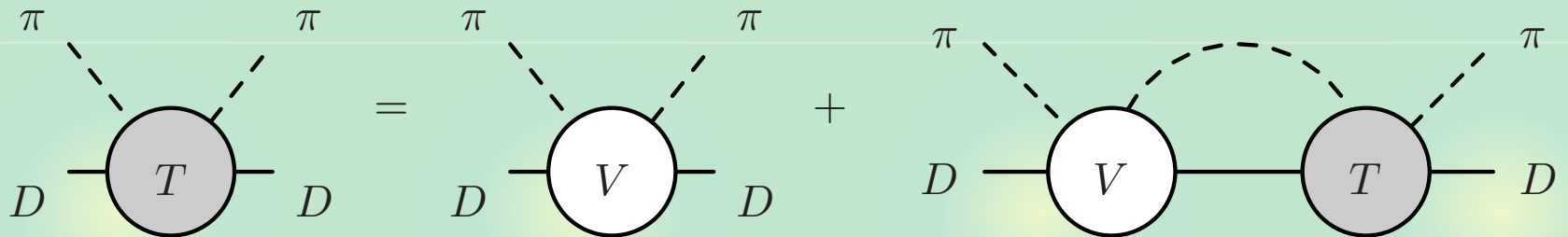
$D\pi$ scattering

What is missing?

- D_0^* is a resonance.
- Search for pole!

Handwritten notes showing the Lippmann-Schwinger equation: $T = V + V \frac{1}{E - H_0} T$. To the right, the potential V is given as $V = \frac{1}{1 - V \frac{1}{E - H_0} V}$. Below this, a series expansion is shown: $V + V \frac{1}{E - H_0} V + V \frac{1}{E - H_0} V \frac{1}{E - H_0} V + \dots$. On the left, a complex plane diagram shows the real axis $\text{Re } E$ and imaginary axis $\text{Im } E$. A pole is marked at $E = E_0 + i \frac{\Gamma}{2}$ in the upper half-plane. A dashed line represents the branch cut along the real axis starting from E_0 .

Description of $D\pi$ scattering



$$T = V + VGT$$

$$= V + VGV + VGVG + \dots$$

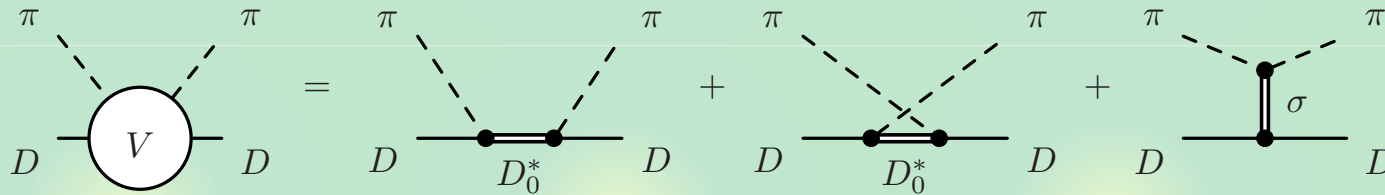
↑
effective Lagrangian

- nonperturbative resummation

D_0^* can appear as a pole in scattering amplitude T

Low-energy theorem

Tree-level amplitude



- low-energy expansion

$$V^{1/2} = \frac{3}{4} \frac{M_{D_0^*}^2 - M_D^2}{\bar{\sigma}^2} \left[-1 - \frac{2}{M_D^2} \dots \right]$$

- chiral symmetry: \mathcal{O}

- Weinberg-Tomozawa th

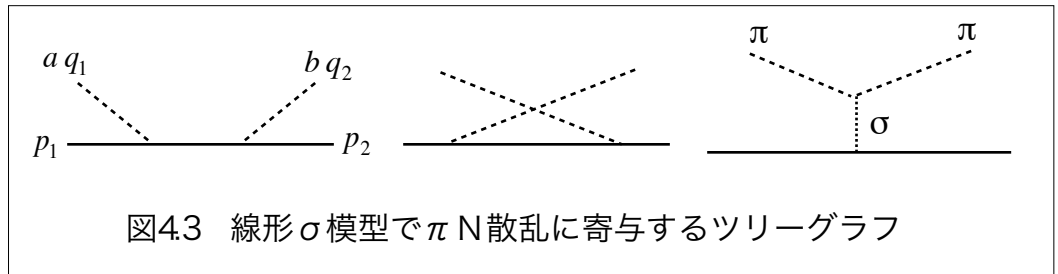
$$= -\frac{2M_D\omega}{\bar{\sigma}^2} + \mathcal{O}(Q^2),$$

Chiral Symmetry in Hadron Physics

Methods and ideas of chiral symmetry

ハドロン物理におけるカイラル対称性ー基本的な考え方と方法

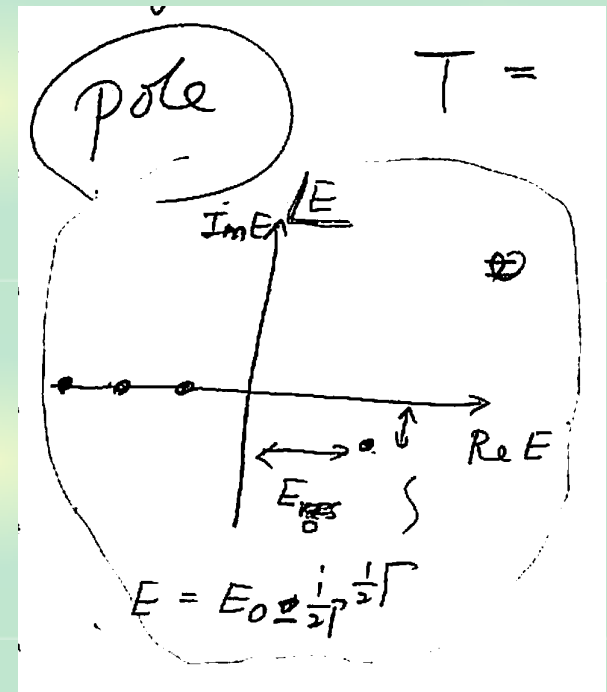
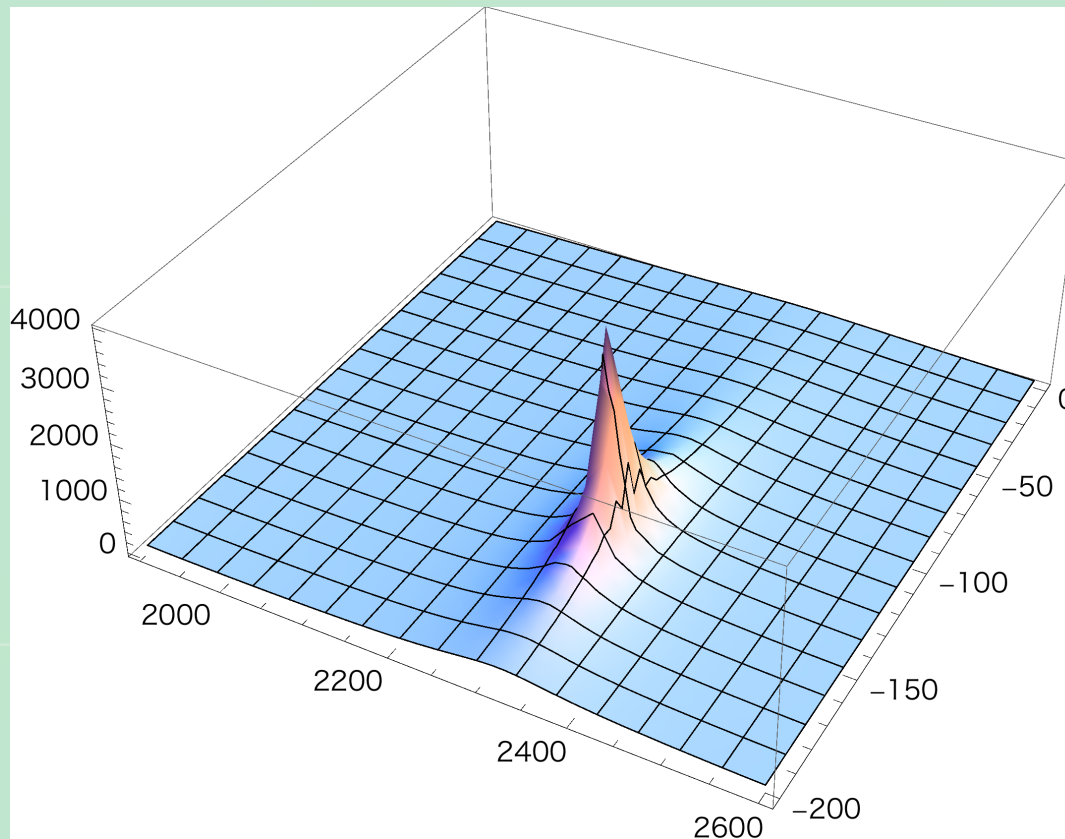
原子核三者若手夏の学校2002
保坂 淳 (阪大、RCNP)



Low-energy theorem ← Inclusion of all possible diagrams

D_0^* pole**Scattering amplitude in the complex energy plane**

- pole at $\sqrt{s} = 2318 - i135$ MeV : mass and width



PDG $2318 \pm 29 - i(134 \pm 20)$ MeV can be reproduced.

Nature of D_0^*

What is the nature of D_0^* ?

1) pure chiral partner

- perturbative calculation with linear sigma model
- **too large decay width:** $\Gamma_{\text{th}} \sim 1000 \text{ MeV} \gg \Gamma_{\text{exp}} \sim 250 \text{ MeV}$

2) pure dynamically generated molecule

- pole with nonlinear sigma model (no bare D_0^*)




M. Altenbuchinger, L.S. Geng, W. Weise, *Phys. Rev. D* **89**, 014026 (2014)

- **too small mass:** $M_{\text{th}} \sim 2100 \text{ MeV} < M_{\text{exp}} \sim 2320 \text{ MeV}$

3) chiral partner dressed by the $D\pi$ cloud

- PDG value is reproduced: OK

Summary

-  Heavy-light mesons serve as a testing ground for chiral and heavy-quark symmetries.
-  Chiral low-energy theorem is guaranteed when all possible contributions are included.
-  D_0^* can be interpreted as a chiral partner of D coupled with the $D\pi$ scattering states.

[T. Sugiura, T. Hyodo, Phys. Rev. C99, 065201 \(2019\)](#)

-  **Follow advices from the supervisor.**