$I=\frac{1}{2}$ $D\pi$ scattering and the D_0^* reasonance from lattice QCD

Haobo Yan (燕浩波)

School of physics, Peking University

ABSTRACT

Using newly generated $N_f=2+1$ Wilson-Clover configurations by the CLQCD collaboration, we examine $D\pi$ scattering in two volume extents ($L^3T = 32^3\times 96$ and $48^3\times 96$) at the same lattice spacing ($a=0.0775$ fm) with a pion mass of $m_\pi \approx 303$ MeV. Employing various operators in both the rest and the moving frame, we determine S and P wave scattering phase shifts from finite-volume spectra and identify a virtual state associated with the D_0^* in these ensembles.

Introduction

- The D_0^* was found in 2004 by Belle collaboration [Belle, PRD, 2004]

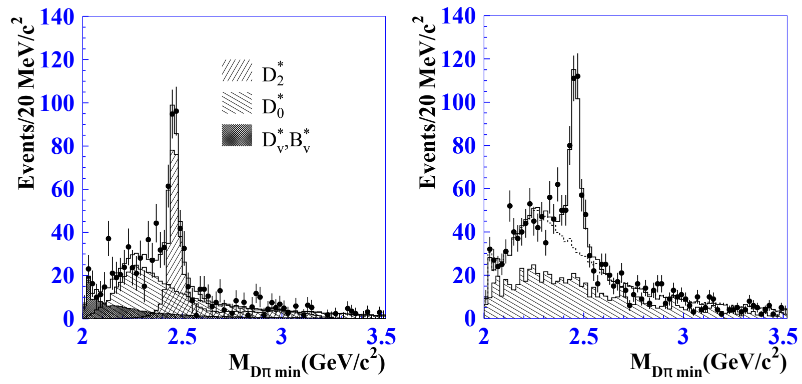
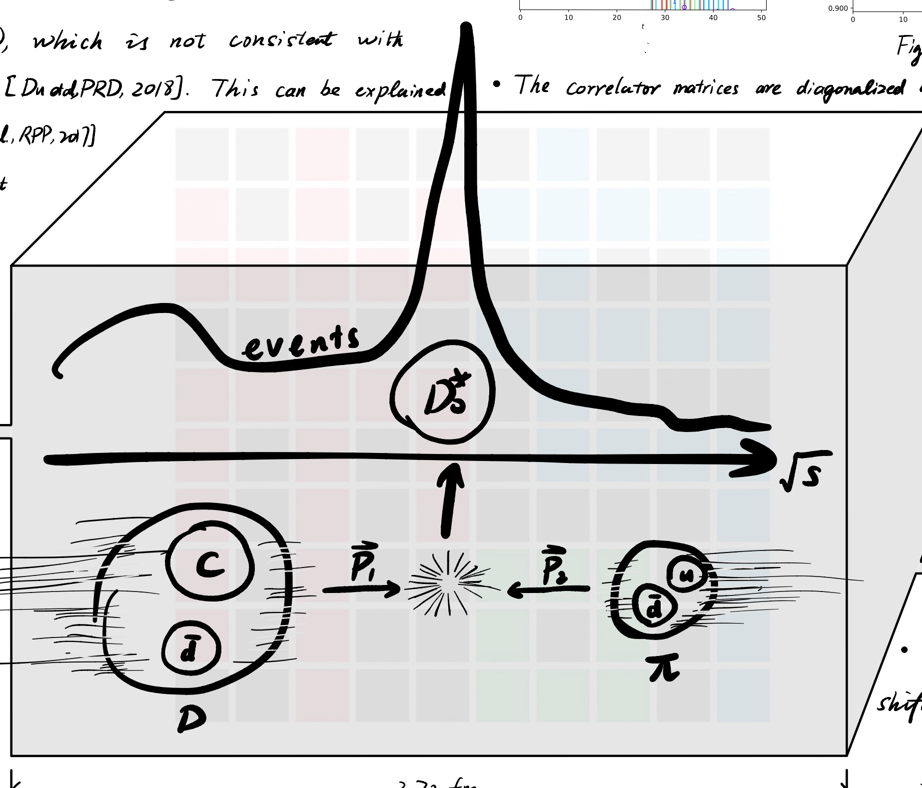


Fig 1. $D\pi$ mass distribution of $B^-\to D^+\pi^-\pi^-$ candidates

- $D_0^*(2300)$ is heavier than $D_{s0}^*(2317)$, which is not consistent with the traditional quark model predictions [Du et al, PRD, 2018]. This can be explained by the strong coupling to DK [Chen et al, RPP, 2017]
- UχPT: $D_0^*(2100)$ should be the lightest charmed scalar meson
- The possible two-pole structure
- Towards the understanding of $\psi_0(4360) \to D^*\bar{D}_1$ (1^{--}) [Ji, PRL, 2022]



Configurations

	volume	a/fm	$m_\pi L$
F32P30	$32^3\times 96$	0.0775	3.81
F48P30	$48^3\times 96$	0.0775	5.72

Tab 1. Lattice details

- Clover fermion with stout smearing
- Symanzik gauge with tadpole improvement
- Same m_π at different volume

Operator construction

There are severe partial-wave mixing problems in $D\pi$ scattering

⇐ SO(3) → O_h or little groups like C_3

⇒ Project the operators into the corresponding irreps. [Prelovsek et al, JHEP 2017]

$$O_{|\vec{p}|,\Gamma,r,n} = \sum_{\tilde{R}\in G} T^{\Gamma}_{r,r}(\tilde{R})\,\tilde{R}\,D(p_1)\pi(p_2)\,\tilde{R}^{-1}$$

irreps of group G; $\bar{d}\gamma_5 c$, $\bar{u}\gamma_5 d$ (Single-hadron operators); Wigner rotation matrices

⇒ Project into other quantum numbers (eg. isospin)

$$I=\frac{1}{2},\ G=Dic_4,\ irrep.=A_1 \begin{cases} O_1 = D_0^*([011]) \\ O_2 = D_y^*([011]) + D_z^*([011]) \\ O_{3,4,5,6,\cdots} = \sum_{\vec{p}}\sum_{i} D_i^*(\vec{p}_D)\,\pi(\vec{P}-\vec{p}_D) \end{cases}$$

O_1, O_2: single-hadron operators; $O_{3,4,5,6,\cdots}$: two-hadron operators; appropriate gamma matrices and momenta

Finite volume spectra

- The correlation function

$$\langle O^{I,I_z}_{D\pi,\Gamma,\vec{p}}(t)\, O^{I,I_z\dagger}_{D\pi,\Gamma,\vec{p}}(0)\rangle = \delta_{\Gamma\Gamma'}\delta_{\vec{p}\vec{p}'}\delta_{II'}\delta_{I_zI_z'}\sum_n |\langle n|O|\Omega\rangle|^2 e^{-E_n t} + \text{thermal pollutions}$$

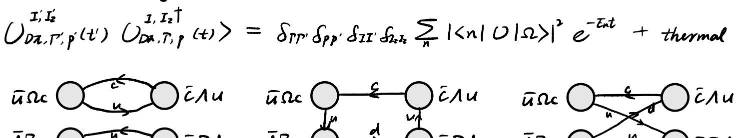


Fig 2. Contraction diagrams

- We apply the distillation method to make the calculation possible [Peardon et al, PRD 2009]

$$\square(t) = V(t)V^\dagger(t) \to \square_{xy}(t) = \sum_{k=1}^{N} v_x^{(k)}(t)\,v_y^{(k)\dagger}(t)$$

▲ Single particle dispersion check

$$E(\vec{p}) = \sqrt{m_H^2 + Z\vec{p}^{\,2}}\,(1+O(ap))$$

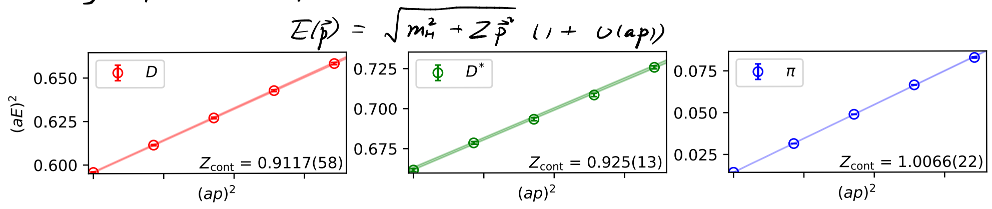


Fig 3. Dispersion relations

▲ $D\pi$-system spectra

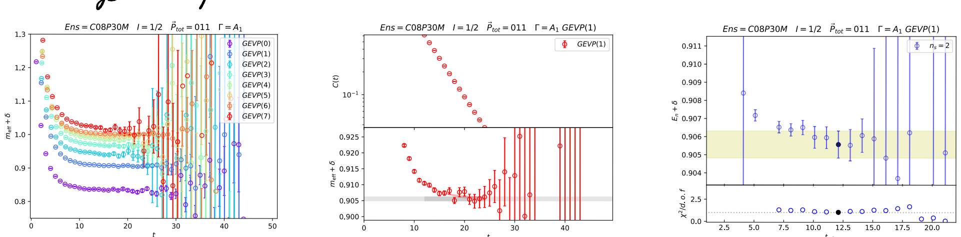


Fig 4. GEVP example

- The correlator matrices are diagonalized by the GEVP method: $C(t)v_n(t) = \lambda_n(t)C(t_0)v_n(t)$
- The eigenvalues are sorted by many methods and the spectra is observed to be stable

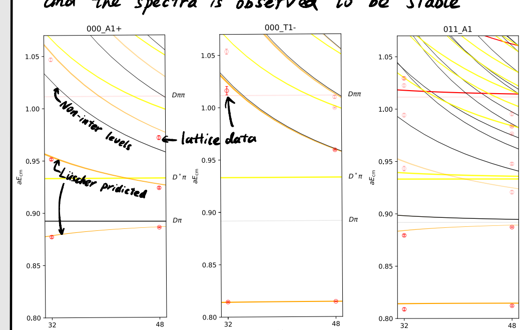


Fig 5. The full spectra and fit

Scattering analysis

- The spectra are related to the phase shifts in infinite volume by the Lüscher's equation

$$\det[F^{-1}(E;\vec{P};L) + \mathcal{M}(E)] = 0$$

Effective range expansion ⇐ under constrained problem

$$k^{2l+1}\cot\delta_l = \frac{1}{a_l} + \frac{1}{2}r_l k^2 + O(k^4)$$

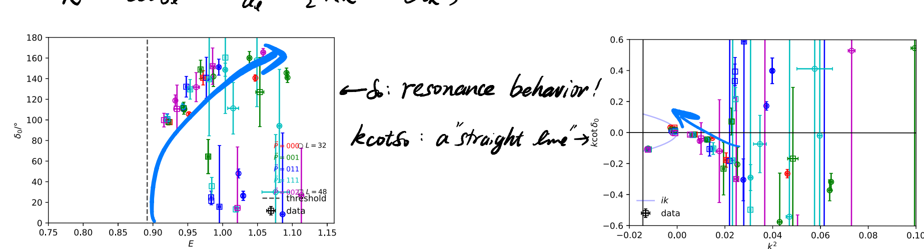


Fig 6. δ_0 and $k\cot\delta_0$, ignoring pollutions from higher partial waves

- The S and P wave phase shifts are extracted

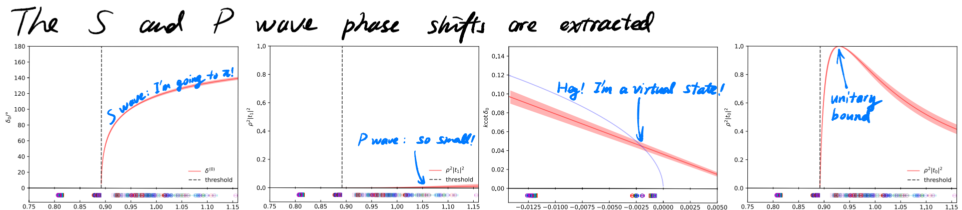


Fig 7. Fitted S and P wave phase shifts

- The pole position and residue

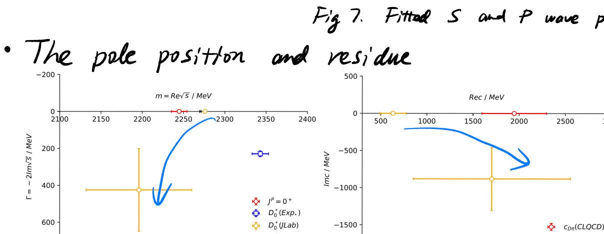


Fig 8. Pole and residue of D_0^*

▲ Pole on the second Riemann sheet

▲ Consistent with the JLab results in the sense of pion mass dependence

Conclusions

▲ There has been a renaissance in hadron specotroscopy

▲ The finite volume spectra was reliably extracted with a large number of operators

▲ Found the D_0^* virtual state on our ensembles