Generation of relative lattice energy spectrum using KK^* operators

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Introduction

LHCb collaboration recently report a doubly charmed tetraquark T_{cc}^{+} in the $D^0D^0\pi^+$ mass spectrum,which is closed to threshold of D^0D^{*+}[1].One explanation for T_{cc}^{+} is a DD^* molecular state. The isospin breaking effect requires a resonance $T_{cc}^{'+}$ between the D^0D^{*+} and D^+D^{*0}mass thresholds [2].The existence of T_{cc}^{+} and $T_{cc}^{'+}$ two states is directly related to the form of DD^* intercation.So we want to check the sign of the intercation of DD^* via the LQCD energy level.Here, due to limitations in data accuracy,we first construct the KK^* operator by dummbell method[3], which is quiet similiar to the DD^* operator, and we obtain different energy levels of different irreducible representations.And this work will be helpful for our latter research of DD^* state.

FORMALISM

Base state for KK^*

$$|\Phi_{\mu R}(\boldsymbol{x})\rangle = |\Phi_{\mu}(R^{-1}\boldsymbol{x})\rangle$$

Representation matrix of the base state

$$\hat{P}_R|\Phi_{\mu R'}(\boldsymbol{x})\rangle = \sum_{\mu' R''} |\Phi_{\mu' R''}(\boldsymbol{x})\rangle \delta_{RR',R''}\Lambda_{\mu'\mu}(R)$$

where $\delta_{RR',R''}$ refers to a regular representation,$\Lambda_{\mu'\mu}$ refers to an irreducible representation T_1^+ of O_h group.So the total representation is the direct product of T_1^+ and the regular representation

Projection to the irreducible representation

$$|\Phi_{\mu R}(\boldsymbol{x})\rangle \Rightarrow |\Phi_{\mu i\Gamma n}(\boldsymbol{x})\rangle \Rightarrow |\Psi_{i\Gamma n}(\boldsymbol{x})\rangle$$

Here $\Phi_{\mu i\Gamma n}$ refers to the direct product of $\Lambda_{\mu'\mu}$ and an irreducible representation of the regular representation, $\Psi_{i\Gamma n}$ refers to an irreducible representation of the direct product of $\Lambda_{\mu'\mu}$ and the regular representation.

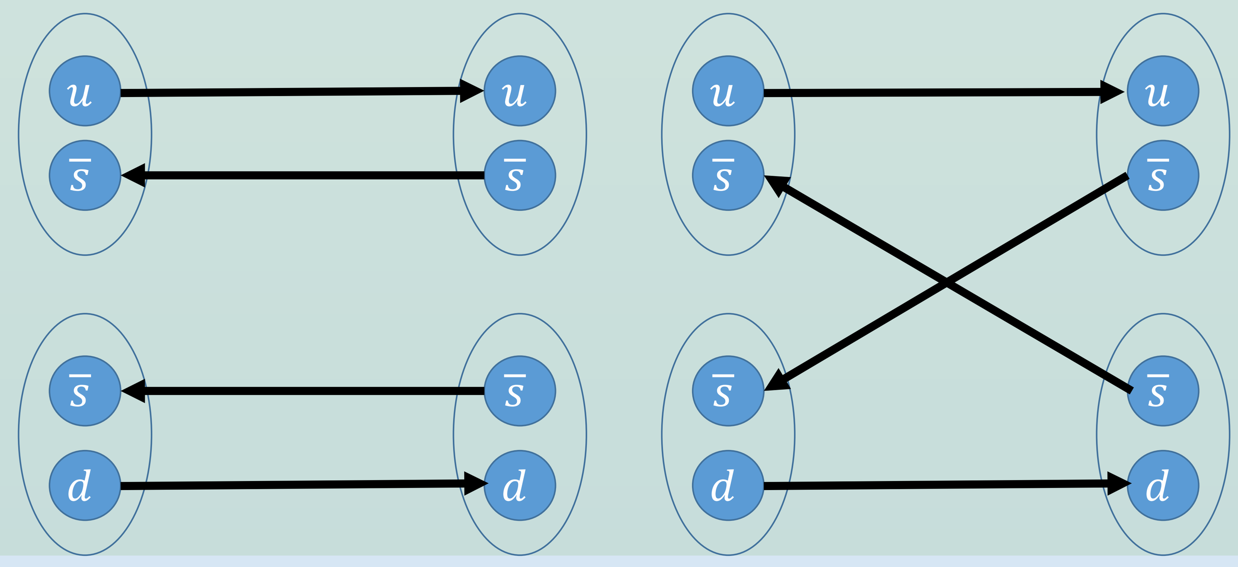
Correlation function of $\Phi_{\mu i\Gamma n}$ and $\Psi_{i\Gamma n}$

$$\sum_i \langle \Phi_{\mu i\Gamma n}(\boldsymbol{y})|\hat{O}|\Phi_{\mu' i\Gamma n'}(\boldsymbol{x})\rangle = \sum_{i\tilde{R}ml\tau\lambda} \bar{\Gamma}^*_{l,m}(\tilde{R})\langle\Phi_{\tau\tilde{R}}|\hat{O}|\Phi_{\lambda I}\rangle \sum_{R'} \Lambda_{\mu\tau}(R')\Lambda_{\mu'\lambda}(R')\bar{\Gamma}^*_{n,l}(R')\bar{\Gamma}_{n',m}(R')$$

Here, we project the $\Phi_{\mu R}$ to the $\Phi_{\mu i\Gamma n}$,then by using the transition matrix we can obtain the correlation function of $\Psi_{i\Gamma n}$.

$$\langle \Psi_{\tilde{\Gamma}'m'}(\boldsymbol{y})|\hat{O}|\Psi_{\tilde{\Gamma}m}(\boldsymbol{x})\rangle = \sum_{\mu' n'}\sum_{\mu i\Gamma n} S_{\mu\Gamma n',\tilde{\Gamma}'m'}\langle\Phi_{\mu' i\Gamma n'}(\boldsymbol{y})|\hat{O}|\Phi_{\mu i\Gamma n}(\boldsymbol{x})\rangle S_{\mu\Gamma n,\tilde{\Gamma}m}$$

Wick contraction

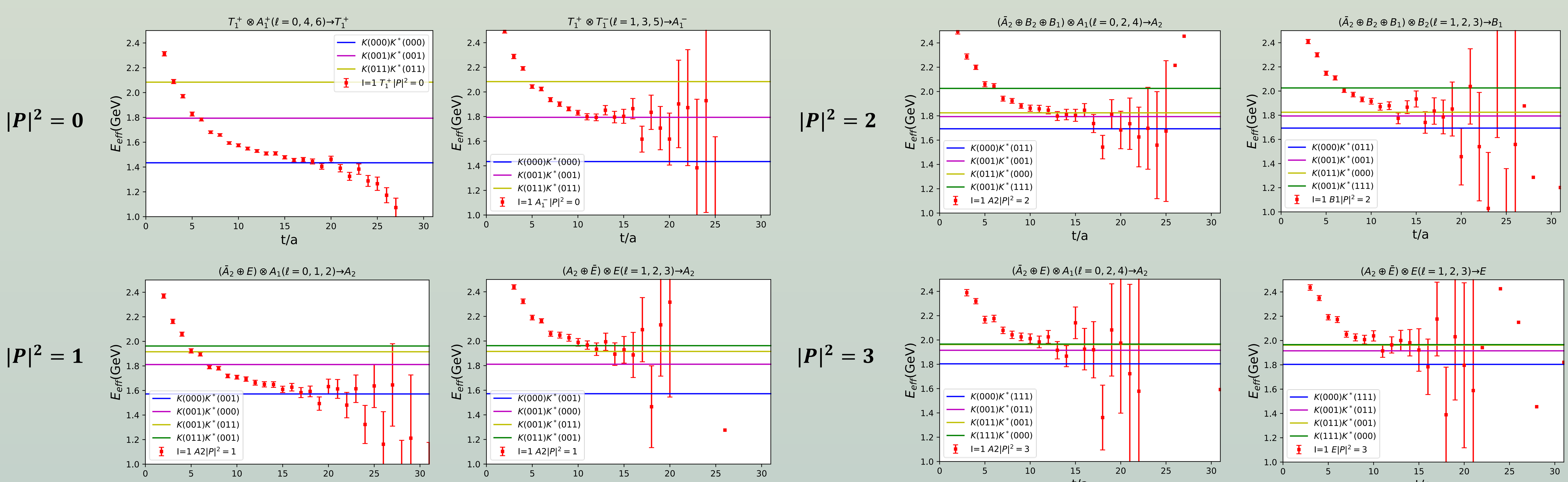


Main Result

Lattice setup

$L^3 \times$T	a(fm)	κ(u,d)	κ(s)	N_{cfg}	m_π(MeV)	m_K(MeV)	m_{K^*} (MeV)	$N_{t_{src}}$
$32^3 \times 64$	0.074	0.12104	0.12062	700	362.1(0.5)	506.6(1.6)	928(11)	16

Spectra



Summary

- The energy levels of distinct irreducible representation are separated clearly.
- As excepted, the results belonging to the irreducible representation A_1^+ of the regular representation are generally cleaner statistically, nevertheless the signal quality degrades for the irreducible representation corresponding to the resolution of higher-spin partial waves.

Reference: [1] R. Aaij et al. (LHCb), Nature Phys. 18, 751 (2022),arXiv:2109.01038 [hep-ex].
[2] Chen, Rui and Huang, Qi and Liu, Xiang and Zhu, Shi-Lin, Phys. Rev. D 104, 114042[arXiv:2108.01911[hep-ph]]
[3] Wu, Jia-Jun and Kamleh, Waseem and Leinweber, Derek B. and Li, Yan and Schierholz, Gerrit and Young, Ross D. and Zanotti, James M,Phys.Rev.D 105.074506[arXiv:2109.01557[hep-lat]]

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