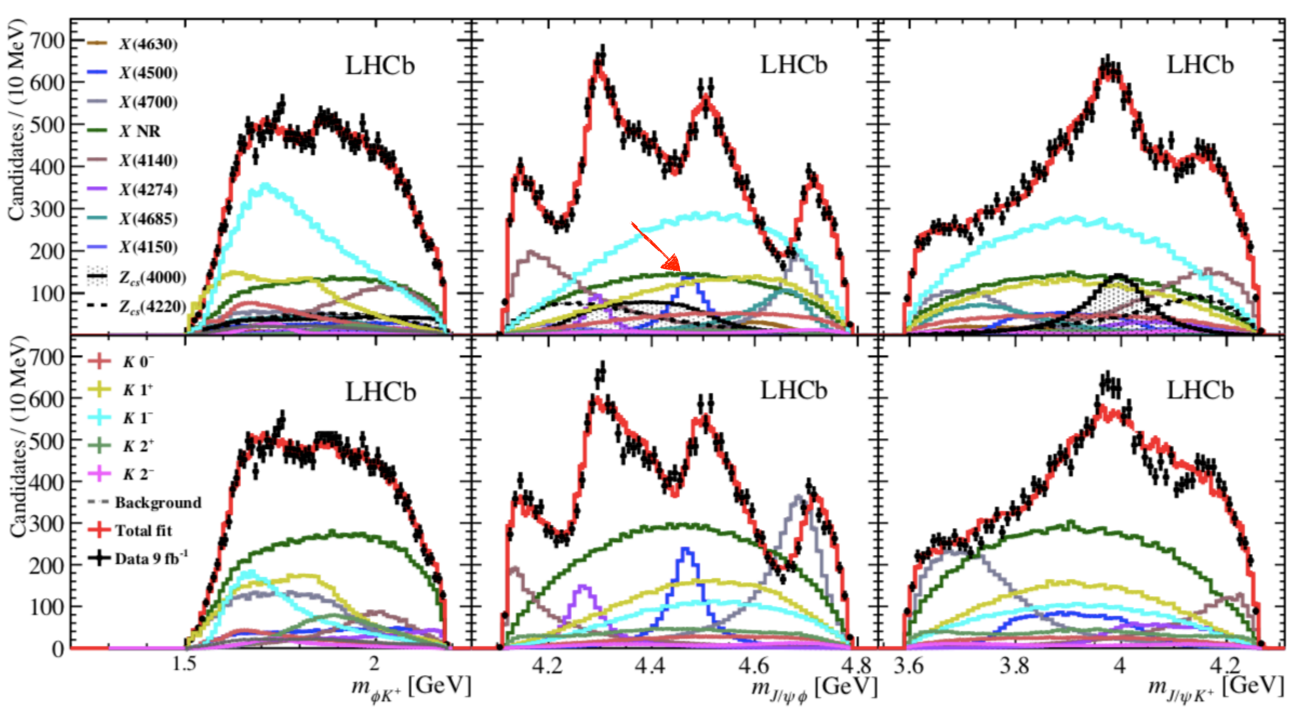
中山大學 SUN YAT-SEN UNIVERSITY 物理学院 SCHOOL OF PHYSICS

中国物理学会高能物理分会第十一届全国会员代表大会暨学术年会海报展览

D-wave excited $cs\bar{c}\bar{s}$ tetraquark states with $J^P = 1^{++}$ and 1^{+-}

[arXiv: 2206.06051]

Introduction

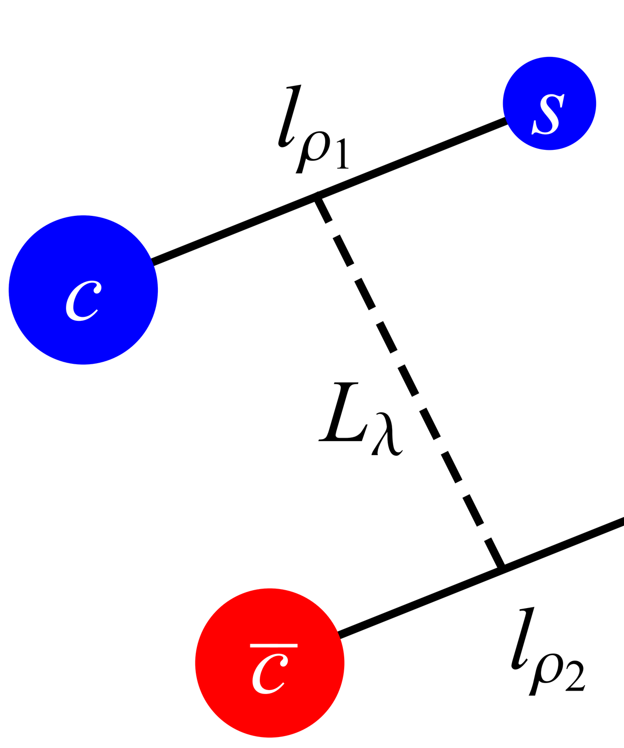


Observation of new resonances decaying to $J/\psi\phi$

[LHCb, PRL. 127, 082001 (2021)]

- CDF, CMS, D0, BARBAR: X(4140), X(4274) in $B^+ \to J/\psi\phi K^+$ [PRL. 102,242002; Mod.Phys.Lett.A 32 (2017) 26, 1750139; PLB. 734, 261; PRD. 89, 012004; PRD. 91,012003]
- LHCb: X(4140), X(4274), X(4500), X(4700) in $B^+ \to J/\psi\phi K^+$.[PRD. 95,012002; PRL. 118, 022003]
- Inspired by these structures observed in the $J/\psi\phi$ invariant mass spectrum, X(4140), X(4274) are considered to be assigned as $cs\bar{c}\bar{s}$ tetraquark ground states while X(4500) and X(4700) were interpreted as $cs\bar{c}\bar{s}$ tetraquark excited states in various theoretical methods. [W.Chen, F.Stancu, H-X. Chen, D.Ebert, Q-F. Lv, J.Wu, C. Deng, X. Liu, Z-G. Wang etc.]
- X(4685) may be interpreted as D-wave $cs\bar{c}\bar{s}$ tetraquark excited state with $J^{PC} = 1^{++}$.
- D-wave $cs\bar{c}\bar{s}$ tetraquark excited states were studied in various method:
  - Relativistic quark model, the masses for λ-mode excitation are around 4.8 GeV.[D. Ebert, etc.]
  - Color flux-tube model, the masses for λ-mode excitation are around 4.9 GeV and 5.2 GeV for antisymmetric and symmetric color structures, respectively. [C.Deng, etc.]
  - Relativistic quark model, the masses for ρ-mode excitation are around 4.6-4.7 GeV, much lower than λ-mode excitation. [Q-F. Lv, etc.]
- Other interpretation: S-wave $cs\bar{c}\bar{s}$ tetraquark [A. Turkan, etc.], 2S radial excited $cs\bar{c}\bar{s}$ tetraquark [Z-G. Wang]

D-wave $cs\bar{c}\bar{s}$ excited tetraquark



$$(L_\lambda, L_\rho\{l_{\rho_1}, l_{\rho_2}\}) = (2,0\{0,0\}), (1,1\{1,0\}), (1,1\{0,1\}), (0,2\{1,1\}), (0,2\{2,0\}), (0,2\{0,2\}).$$

QCD Sum Rule

The two-point correlation function for the tensor currents:

$$\Pi_{\mu\nu,\rho\sigma}(q^2) = i\int d^4x e^{iq\cdot x}\langle 0|T[J_{\mu\nu}(x)J^\dagger_{\rho\sigma}(0)]|0\rangle$$

Hadron Level

Dispersion relation: $\Pi(q^2) = \frac{1}{\pi}\int_{s_<}^{\infty} ds \frac{\mathrm{Im}\Pi(s)}{s - q^2 - i\epsilon}$

The imaginary part of the correlation function is defined as the spectral function, with narrow resonance approximation: $\rho(s) = \frac{1}{\pi}\mathrm{Im}\Pi(s) = f_X^2\delta(q^2 - m_X^2) + \text{continuum}$

$$\mathcal{L}_k(s_0, M_B^2) = f_X^2 m_X^{2k} e^{-m_X^2/M_B^2} = \int_{4m_c^2}^{s_0} ds\, e^{-s/M_B^2}\rho(s)s^k$$

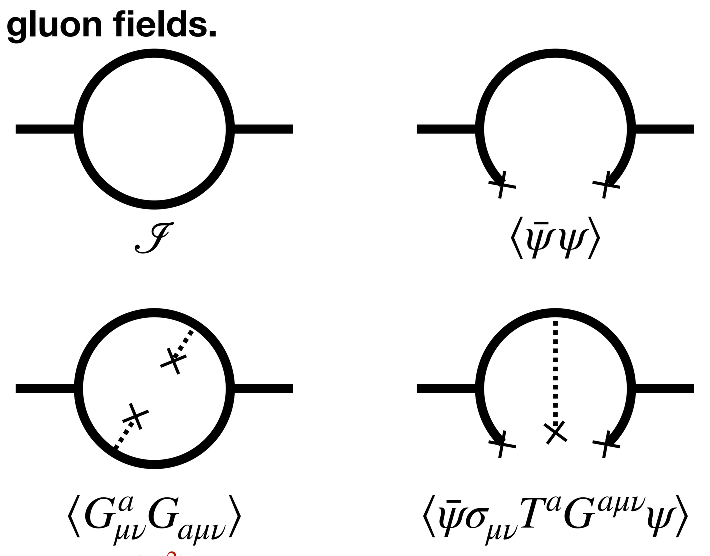
$$m_X(s_0, M_B^2) = \sqrt{\frac{\mathcal{L}_1(s_0, M_B^2)}{\mathcal{L}_0(s_0, M_B^2)}}$$

Quark-Gluon Level

Operation Production Expansion(OPE): $\Pi(q^2) = C_0\mathcal{I} + \sum_n C_n(q)\mathcal{O}_n$

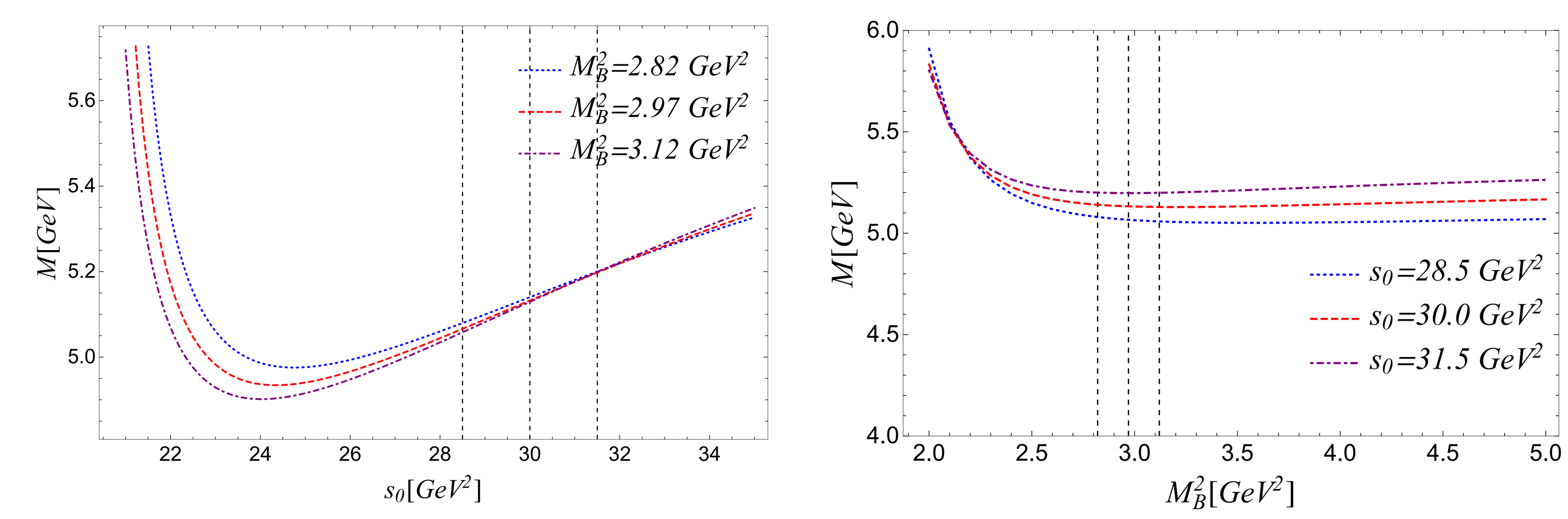
$C_n(q)$ are Wilson coefficient, which can be calculated perturbatively, and $\mathcal{O}_n$ are local gauge invariant operator constructed from quark and gluon fields.

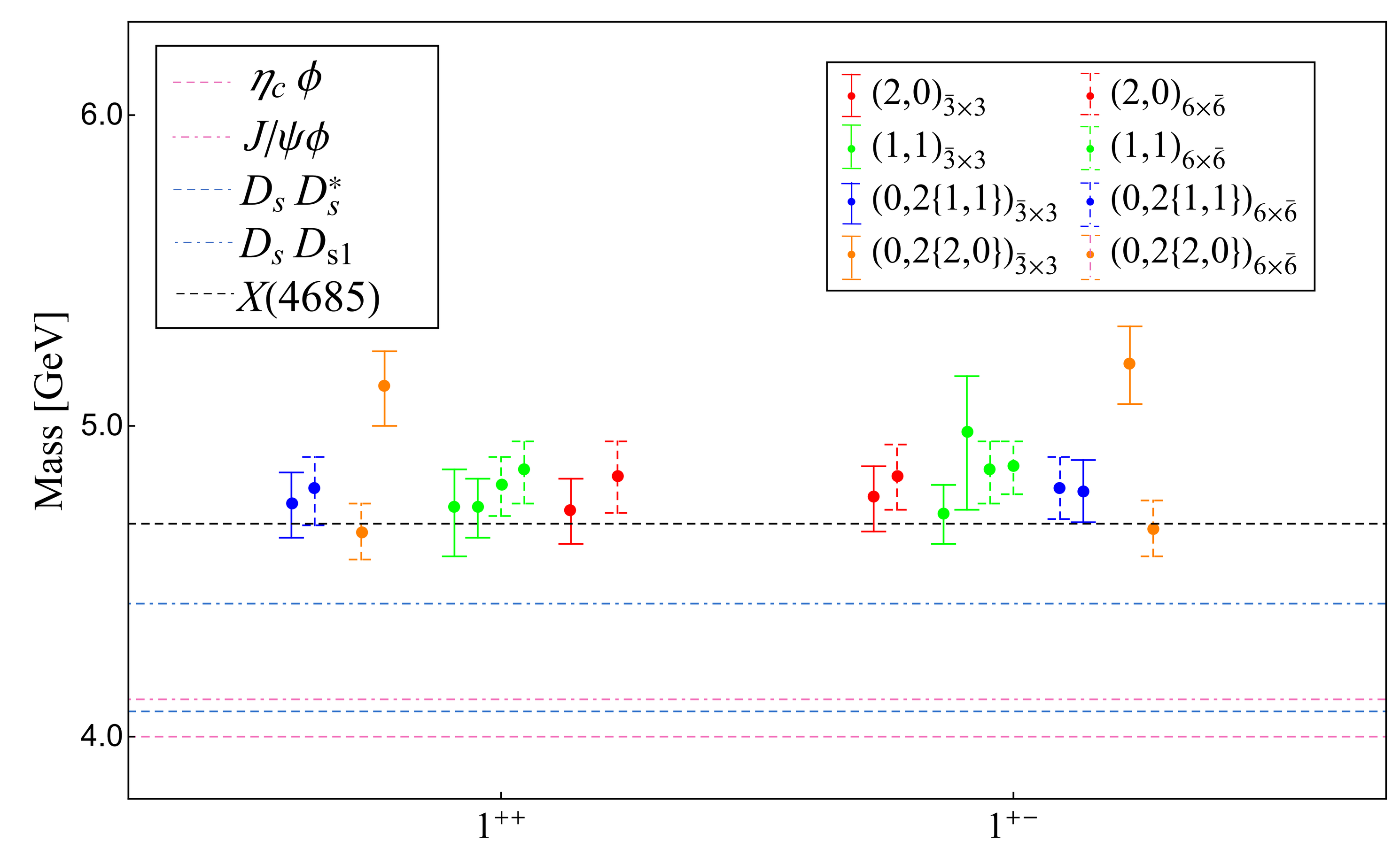
$\mathcal{I}$	$d = 0$
$\bar{\psi}\psi$	$d = 3$
$G^a_{\mu\nu}G_{a\mu\nu}$	$d = 4$
$\bar{\psi}\sigma_{\mu\nu}T^aG^{a\mu\nu}\psi$	$d = 5$
…	



OPE: $\Pi(s) = \Pi^{pert}(s) + \Pi^{\langle q\bar{q}\rangle}(s) + \Pi^{\langle G^2\rangle}(s) + \cdots$

Numerical Analysis





Discussion and conclusion

- Our results support to interpret the recent observed X(4685) resonance as a D-wave $cs\bar{c}\bar{s}$ tetraquark state with $J^{PC} = 1^{++}$ in the (0,2{2,0}) excitation mode, although some other possible excitation structures cannot be excluded exhaustively within theoretical errors.
- By using the color antisymmetric current, the mass of the $cs\bar{c}\bar{s}$ tetraquark with $J^{PC} = 1^{++}$ and 1^{+-} in the (2, 0{0, 0}) excitation mode is predicted to be around 4.73 GeV and 4.77 GeV respectively, which is consistent with the calculations of the relativistic quark model [1, 2].
- in Ref. [2]. Their masses were predicted about 4.7 GeV $(P - \bar{P})$ and 4.6 GeV $(D - \bar{S})$, which are in agreement with our calculations.
- Our results provide a mass relation $6_{\rho\rho} < 3_{\lambda\lambda} < 3_{\lambda\rho} < 3_{\rho\rho}$ and $6_{\rho\rho} < 3_{\lambda\lambda} < 6_{\lambda\lambda} < 3_{\rho\rho}$ for the C-positive and negative D-wave $cs\bar{c}\bar{s}$ tetraquarks, respectively.

Reference:

[1] D. Ebert, R. N. Faustov, and V. O. Galkin, Eur. Phys. J. C 58, 399 (2008)
[2] Q.-F. Lü and Y.-B. Dong, Phys. Rev. D 94, 074007 (2016)

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