1^+ T_{cc} -like states from Laplace sum rules and Double ratio of sum rules [1]

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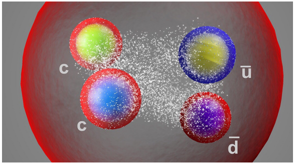
1. R. Albuqueruqe, S. Narison and D. Rabetiarivony, arXiv:2201.13449 [hep-ph] (will be published in Nuclear Physics A)

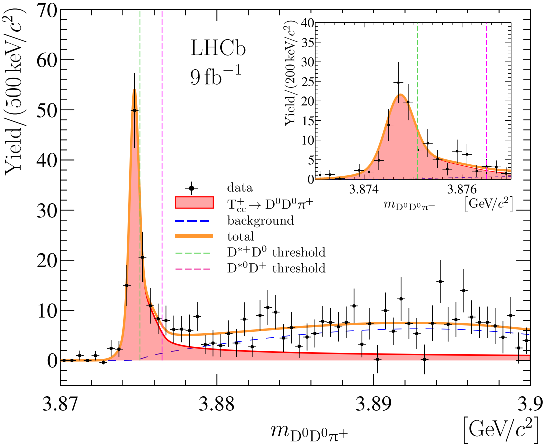
Motivation

arXiv : 2109.01056 [hep-ex]

Observation of doubly charmed tetraquark : T_{cc}^+



Mass around 3875 MeV



Two-point function

Evaluation of two point function $\rightsquigarrow$ Hadron parameters

$$\Pi^{\mu\nu}_{\mathcal{H}}(q^2) = i \int d^4x \; e^{-iqx} \langle 0 | \mathcal{T} \mathcal{O}^{\mu}_{\mathcal{H}}(x) \left(\mathcal{O}^{\nu}_{\mathcal{H}}(0) \right)^{\dagger} | 0 \rangle$$

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Currents

$$\begin{aligned}
\mathcal{O}_{\chi_c(3872)} &= \epsilon_{ijk}\,\epsilon_{mnk}\Big[\left(q_i^T\,C\gamma_5\,c_j\right)\left(\bar{c}_m\,\gamma^\mu C\,\bar{q}_n^T\right) + \left(q_i^T\,C\gamma^\mu\,c_j\right)\left(\bar{c}_m\,\gamma_5 C\,\bar{q}_n^T\right)\Big] \\
\mathcal{O}_{T^{1+}_{cc\bar{u}\bar{d}}} &= \frac{1}{\sqrt{2}}\epsilon_{ijk}\,\epsilon_{mnk}\left(c_i^T\,C\gamma^\mu\,c_j\right)\Big[\left(\bar{u}_m\,\gamma_5 C\,\bar{d}_n^T\right) - \left(\bar{d}_m\,\gamma_5 C\,\bar{u}_n^T\right)\Big] \\
\mathcal{O}_{T^{1+}_{cc\bar{u}\bar{s}}} &= \epsilon_{ijk}\,\epsilon_{mnk}\left(c_i\,C\gamma^\mu c_j^T\right)\left(\bar{u}_m\,\gamma_5 C\bar{s}_n^T\right)
\end{aligned}$$

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♣ QCD side : quark and gluon fields, OPE $\Rightarrow$ Dispertion relation
♣ Phenomenological side : Hadron parameters $\Rightarrow$ Dispertion relation

♣ Quark Hadron duality principle
QCD side $\simeq$ PHEN side

♣ Inverse Laplace Transform

Mass Extraction

Finite Energy Inverse Laplace Transform Sum Rule :

$$\mathcal{L}_n^c|_{\mathcal{H}}(\tau,\mu) = \int_{(2M_c+m_q+m_s)^2}^{t_c} dt\, t^n\, e^{-t\tau}\,\frac{1}{\pi}\mathrm{Im}\,\Pi_{\mathcal{H}}(t,\mu)$$

Ansatz :

$$\frac{1}{\pi}\mathrm{Im}\,\Pi_{\mathcal{H}}(t) = 2f_{\mathcal{H}}^2 M_{\mathcal{H}}^8\,\delta(t-M_{\mathcal{H}}^2)+\frac{1}{\pi}\mathrm{Im}\,\Pi_{\mathcal{H}}^{\mathrm{QCD}}(t)\,\theta(t-t_c)$$

$$M_{\mathcal{H}}^2 = \mathcal{R}_{\mathcal{H}}^c(\tau_0) = \frac{\mathcal{L}_1^c|_{\mathcal{H}}}{\mathcal{L}_0^c|_{\mathcal{H}}};$$

$$r_{\mathcal{H}'/\mathcal{H}}(\tau_0) \equiv \sqrt{\frac{\mathcal{R}_{\mathcal{H}'}^c}{\mathcal{R}_{\mathcal{H}}^c}} = \frac{M_{\mathcal{H}'}}{M_{\mathcal{H}}}$$

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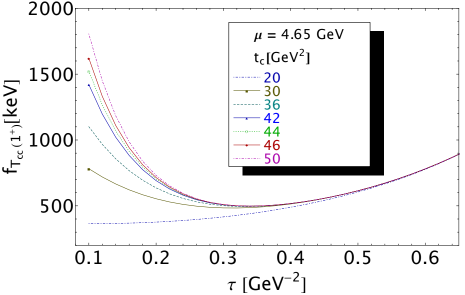
⊛ We use **stability criteria** with respect to (τ, t_c, μ) to extract the lowest ground state mass and coupling of hadron $\mathcal{H}$ **[S. Narison : QCD21]**

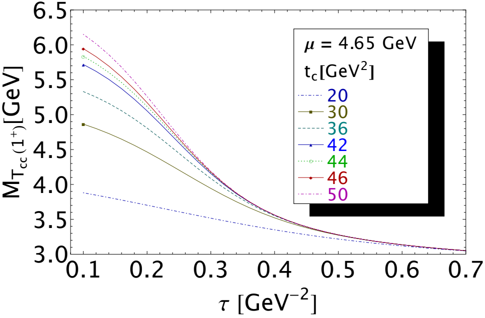
⊛ **OPE convergence** obtained for condensates up to $d \leq 6$

⊛ To prevent the **violation of factorization** the inclusion of higher dimension condensates is not suggested

⊛ Inclusion of **NLO PT correction** to justify the use of MS running mass for heavy quark

$J^P = 1^+$ $T_{cc\bar{u}\bar{d}}$ and $T_{cc\bar{u}\bar{s}}$ states





♣ Beginning of τ-stability for : $(\tau,\, t_c) = (0.31,\, 30)$ (GeV^{-2}, GeV^2)

♣ t_c-stability reached for : $(\tau,\, t_c) = (0.34,\, 46)$ (GeV^{-2}, GeV^2)

$\Rightarrow f_{T_{cc}}(1^+) = 491(48)$ keV ; $M_{T_{cc}}(1^+) = 3885(123)$ MeV

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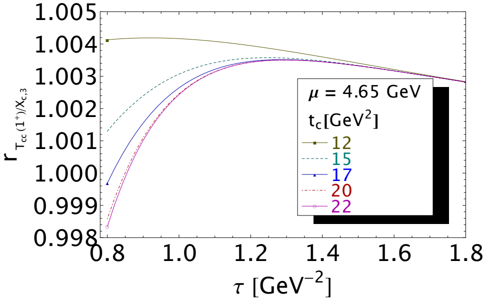

♣ Stability region :

$(\tau,\, t_c) = (1.24,\, 15) \sim (1.30,\, 20)$

⊙ $r_{T_{cc}^{1+}/\chi_c} = 1.0035(10)$

$\Rightarrow M_{T_{cc}}(1^+) = 3886(4)$ MeV

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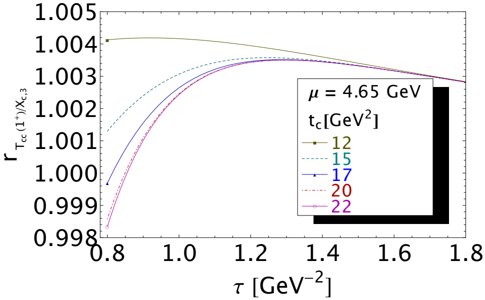

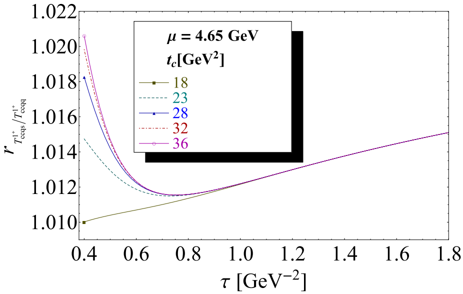

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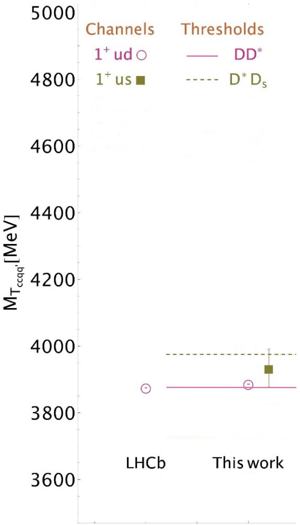
♣ Stability region :

$(\tau,\, t_c) = (0.72,\ 23) \sim (0.74,\ 32)$

⊙ $r_{T_{cc\bar{s}\bar{u}}/T_{cc}(1^+)} = 1.0115(13)$

$\Rightarrow M_{T_{cc\bar{s}\bar{u}}}(1^+) = 3931(7)$ MeV

Summary



⊛ We have systematically evaluated the masses and couplings of $I(J^P) = 0(1^+)$ $(cc)(\bar{u}\bar{d})$ and $I(J^P) = \frac{1}{2}(1^+)$ $(cc)(\bar{u}\bar{s})$ tetraquark states using QCD Laplace sum rules to study the recent data from LHCb.

⊛ We have included the NLO PT corrections to justify the use of the running heavy quark mass and to improve the LO results in literature.

⊛ Our predictions are grouped around the physical threshold.

⊛ The mass shift due to SU3 breaking is tiny.