Insights into the T_{cc}^{+} tetraquark in a constituent quark model picture

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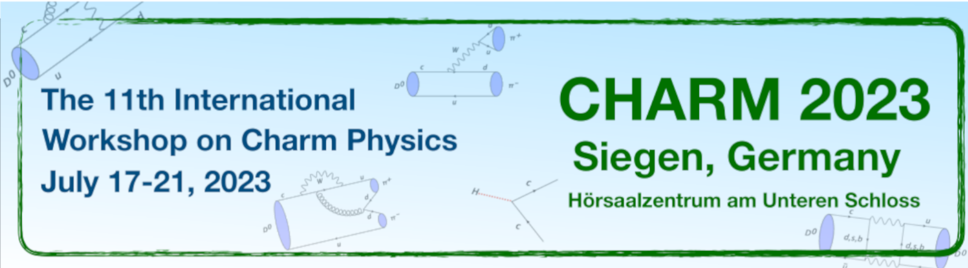
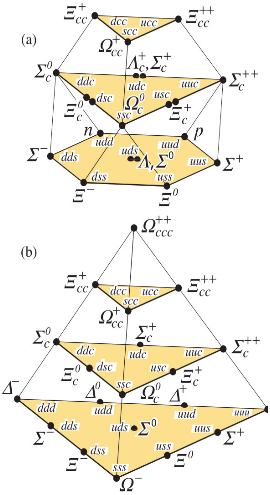
in collaboration with J. Segovia (U. Pablo de Olavide), D.R. Entem and F. Fernández.



The quark model

Successful classification scheme organizing the large number of **conventional hadrons**

Baryons



Mesons

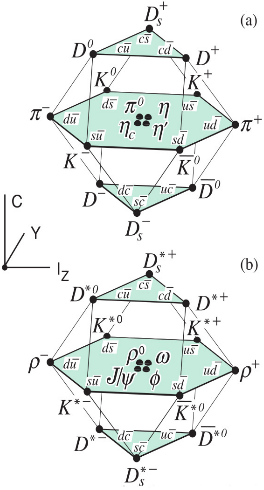
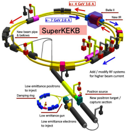
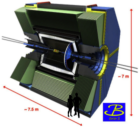


Figure: *

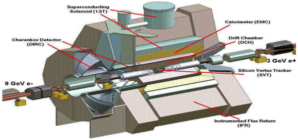
Discoveries at B-factories

BELLE@KEK (Japan)

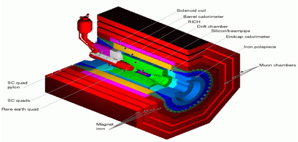




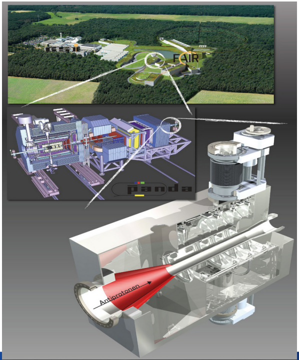
BABAR@SLAC (USA)



CLEO@CORNELL (USA)

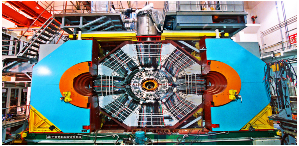


PANDA@GSI (Germany)

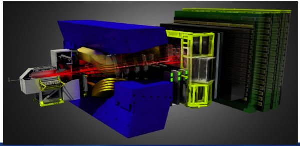


Explosion of related experimental activity:
Signals of exotic structures?
Standard $q\bar{q}$ or qqq?
Threshold cusps?

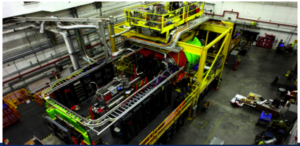
BES@IHEP (China)



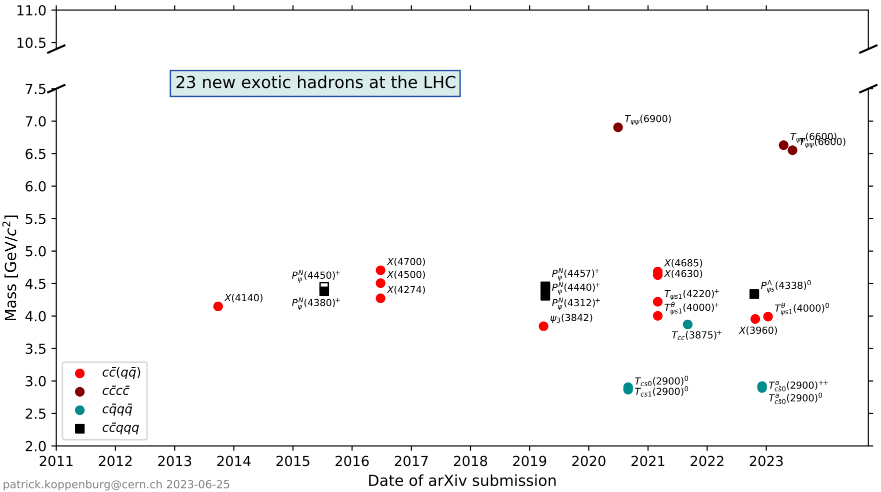
LHCb@CERN (Switzerland)



GLUEX@JLAB (USA)



Hidden-charm LHCb tetraquarks



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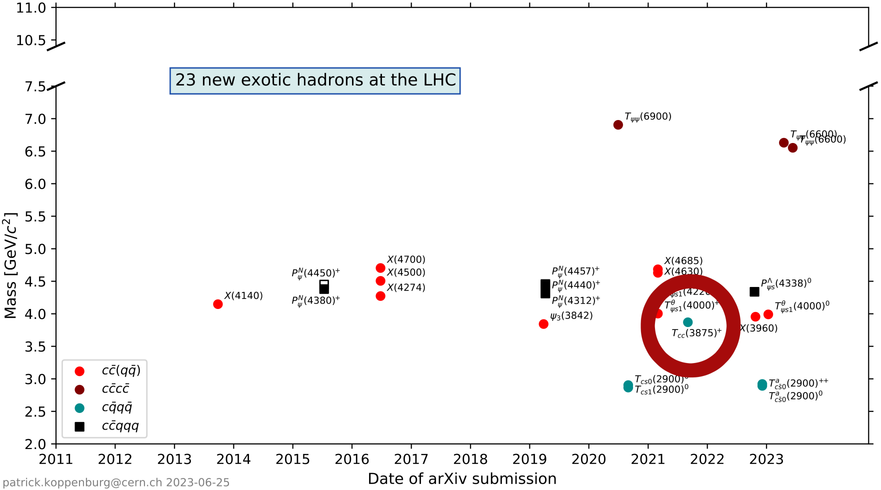
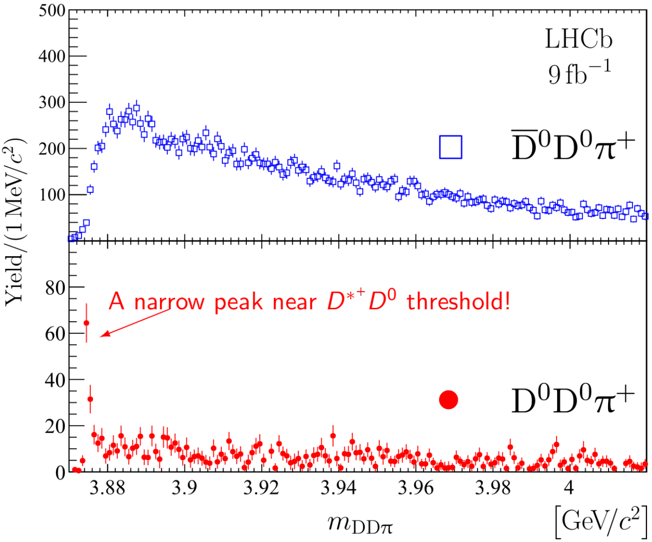


The landmark of 2021: Observation of T_{cc}^{+}

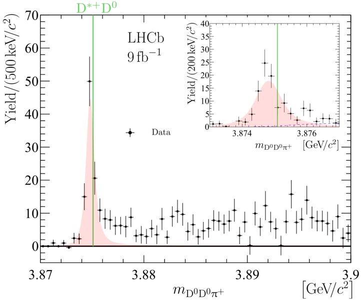


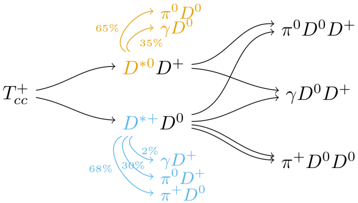
LHCb Coll, *Nature Phys.* **18** (2022), 751; *Nature Commun.*, 13 (2022) 3351.

Analysis using a Breit-Wigner model

- Signal in $D^0 D^0 \pi^+$ from primary pp-vertex.
- BW signal $[(DD)_S \pi$ P-wave$]$ + 2-body phase-space background + polynomial
- Convolution with detector resolution, rms of 400 keV.
- Model assumptions:
  - $J^P = 1^+$ state decaying to DD^* in S-wave
  - Isoscalar T_{cc}^+ due to absence of signal in $D^0 D^+$ and $D^+ D^0 \pi^+$.
  - No isospin violation in couplings to $D^{*+} D^0$ and $D^{*0} D^+$.
- Model results:

Parameter	Value
N	117 ± 16
$\delta m_{\rm BW}$	-273 ± 61 keV/c^2
$\Gamma_{\rm BW}$	410 ± 165 keV





LHCb Coll, *Nature Phys.* **18** (2022), 751; *Nature Commun.*, 13 (2022) 3351.

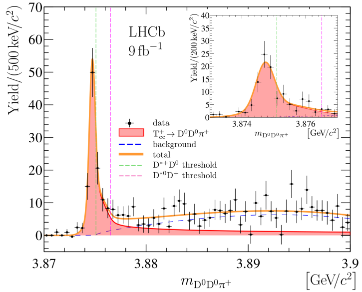
Analysis using an unitarized model

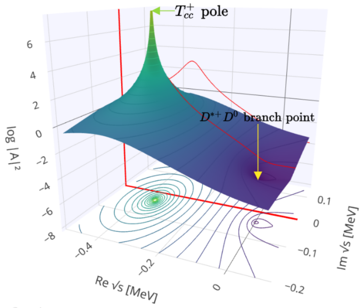
- Dynamic amplitude of $DD^* \to DD^*$ scattering.
- Nearly-isolated resonance below the $D^{*+}D^0$ threshold.
- Most precise peak position wrt threshold.
- Lifetime: $\tau \sim 10^{-20}$ s $\rightarrowtail$ Unprecedently large for exotic hadrons.
- Model parameters:

$$\delta m_{\rm pole} = (-360 \pm 40^{+4}_{-0}) keV,$$

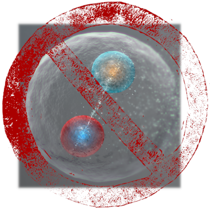
$$\Gamma_{\rm pole} = (48 \pm 2^{+0}_{-14}) keV.$$

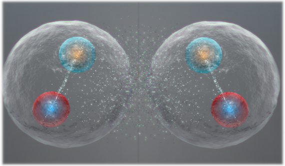
Extremely narrow state, very close to threshold
$\rightarrowtail$ Strong candidate for a pure molecular state.

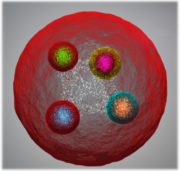




In this talk...







- Analysis of the "molecular" nature of charged T_{cc} state as a DD^* system using a **constituent quark model**.

- Study of bottom partners T_{bb}.

- Reference: P. G. Ortega, J. Segovia, D. R. Entem, F. Fernández, "Nature of the doubly-charmed tetraquark T_{cc}^+ in a constituent quark model", *Phys. Lett. B* **841** (2023), 137918. [arXiv:2211.06118 [hep-ph]].

Constituent quark model (CQM)

- Spontaneous breaking of chiral symmetry
  - Chiral invariant lagrangian

$$\mathcal{L} = \bar{\psi}(i\,\not{\partial} - M(q^2)U^{\gamma_5})\,\psi$$

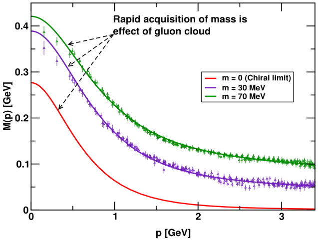
  - Pseudo-Goldstone bosons ($\phi^a = \{\vec{\pi}, K_i, \eta_8\}$).

$$U^{\gamma_5} = e^{i\lambda_a\phi^a\gamma_5/f_\pi}$$

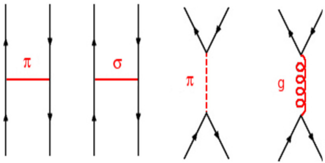
$$\sim 1 + \frac{i}{f_\pi}\gamma_5\lambda_a\phi^a - \frac{1}{2f_\pi^2}\phi_a\phi^a + \ldots$$

  - Constituent quark mass

$$M(q^2) = m_q F(q^2) = m_q\left[\frac{\Lambda^2}{\Lambda^2 + q^2}\right]$$



C.D. Roberts, arXiv:1109.6325v1 [nucl-th]



Constituent quark model (CQM)

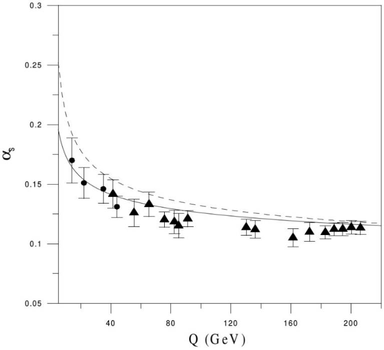
Beyond the chiral symmetry breaking scale $\longrightarrow$ QCD perturbative effects

- Taken into account through the one-gluon-exchange (OGE) potential
- The OGE is a standard color Fermi-Breit interaction from the vertex:

$$\mathcal{L}_{qqg} = i\sqrt{4\pi\alpha_s}\,\bar{\psi}\gamma_\mu G_a^\mu \lambda^a \psi,$$

- $\alpha_s(\mu)$ an effective scale dependent strong coupling constant

$$\alpha_s(\mu) = \alpha_0 \ln^{-1}\left(\frac{\mu^2+\mu_0^2}{\Lambda_0^2}\right)$$



J. Vijande *et al.* J. Phys. G31 (2005) 481.

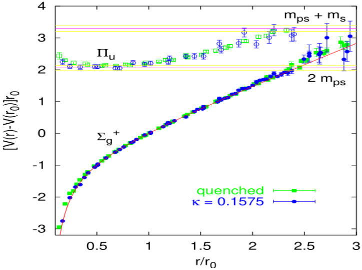
Constituent quark model (CQM)

Beyond the chiral symmetry breaking scale $\longrightarrow$ QCD non-perturbative effects

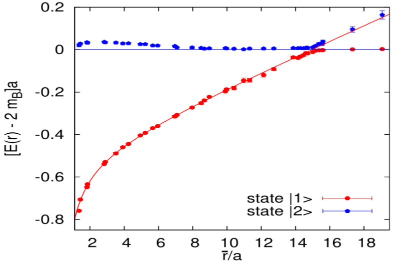
- Linear screened confining potential

$$V_{\mathrm{CON}}(\vec{r}) = \left[-a_c(1-e^{-\mu_c r}) + \Delta\right] (\vec{\lambda}_i^c \cdot \vec{\lambda}_j^c)\,.$$

G.S. Bali *et al.* Phys. Rep. 343 (2001) 1.



G.S. Bali *et al.* Phys. Rev. D71 (2005) 114513.



Constituent quark model (CQM)

Model with a large history $\rightarrowtail$ All parameters constrained from low-lying meson and baryon spectra.

- Summary of interactions for T_{cc}^{+}:

$$V_{q_i q_j} = \begin{cases} qq \Rightarrow V_{\rm CON} + V_{\rm OGE} + V_{\rm Goldstone} \\ Qq \Rightarrow V_{\rm CON} + V_{\rm OGE} \\ QQ \Rightarrow V_{\rm CON} + V_{\rm OGE} \end{cases}$$

- Previous studies:
  - Nucleon-Nucleon interaction:
    Entem:2000mq, Valcarce:1995up, Fernandez:1993hx
  - Baryon spectrum:
    Valcarce:2005rr, Garcilazo:2001ck
  - Meson spectrum:
    Vijande:2004he, Segovia:2008zz, Segovia:2016xqb
  - Meson-meson states:
    Ortega:2009hj, Ortega:2020uvc, Ortega:2023pmr, Ortega:2023azl
  - Baryon-meson states:
    Ortega:2012cx, Ortega:2016syt, Ortega:2014eoa, Ortega:2022uyu

Resonating Group Method (RGM)

- Interaction at quark level $\rightarrowtail$ Interaction between clusters
- 1-Hadron wave function:

$$\phi_A = \phi_A(\vec{p}_A)\sigma_A^{SF}\xi_A^c$$

- 2-Hadron wave function:

$$\Psi = \mathcal{A}\left[\phi_A(\vec{p}_A)\phi_B(\vec{p}_B)\chi(\vec{P})\sigma_{AB}^{SF}\xi_{AB}^c\right]$$

- Dynamics of the bound state governed by the Schrödinger equation:

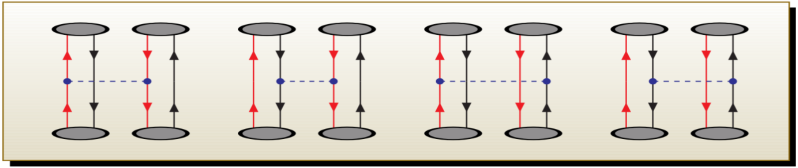
$$(\mathcal{H}-E_T)|\Psi>=0 \Leftrightarrow \mathcal{H}=\sum_{i=1}^{N}\frac{\vec{p}_i^2}{2m_i}+\sum_{i<j}V_{ij}-T_{\rm CM}$$

$$\left(\frac{\vec{P}'^2}{2\mu}-E\right)\chi(\vec{P}')+\int\left({}^{\rm RGM}V_D(\vec{P}',\vec{P}_i)+{}^{\rm RGM}K_E(\vec{P}',\vec{P}_i)\right)\chi(\vec{P}_i)d\vec{P}_i=0$$

- Scattering state dynamics governed by Lippmann-Schwinger equation:

$$T_\beta^{\beta'}(z;p',p)=V_\beta^{\beta'}(p',p)+\sum_{\beta''}\int dp''p''^2V_{\beta''}^{\beta'}(p',p'')\frac{1}{z-E_{\beta''}(p'')}T_\beta^{\beta''}(z;p'',p)$$

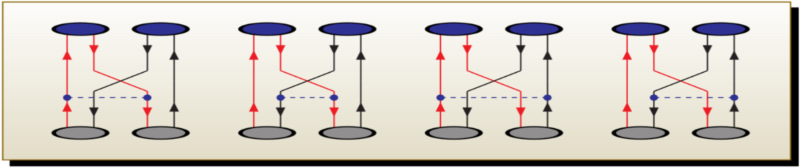
RGM - Direct terms



$$^{\mathrm{RGM}}V_D(\vec{P}',\vec{P}) = \sum_{i\in A, j\in B} \int d\vec{p}'_A d\vec{p}'_B d\vec{p}_A d\vec{p}_B\, \phi^*_{A'}(\vec{p}'_A)\phi^*_{B'}(\vec{p}'_B) V_{ij}(\vec{P}',\vec{P}) \phi_A(\vec{p}_A)\phi_B(\vec{p}_B)$$

- V_{ij} the interaction at quark level given by CQM
- $i(j)$ the indices that run inside the constituentes of $A(B)$ meson.
- $\vec{p}_{A(B)}$ the relative internal momentum of the $A(B)$ meson.
- The wave functions $\phi_{A(B)}$ of the mesons act as natural cut offs for the potentials.

RGM - Exchange terms



- Identical quarks in T_{cc}^{+}: $c\bar{q} - c\bar{q}'$ $\rightarrowtail$ Exchange terms needed:

$$\mathcal{A} = (1 - P_q)(1 - P_c) \rightarrowtail \Psi = (1 - P_q)\left[(\phi_A\phi_B + (-1)^{L+S-s_A-s_B+I-1}\phi_B\phi_A)\chi_L \sigma_{AB}^{SF}\xi_{AB}^{c}\right]$$

- ${}^{\rm RGM}K_E(\vec{P}', \vec{P})$ is a non-local energy-dependent exchange kernel.

$$K_E(\vec{P}', \vec{P}) = V_E(\vec{P}', \vec{P}) - E_T\, {}^{\rm RGM}N_E(\vec{P}', \vec{P})$$

- It can be separated in a potential term and a normalization term.

$${}^{\rm RGM}V_E(\vec{P}', \vec{P}_i) = \int d\vec{p}_A'd\vec{p}_B'd\vec{p}_A d\vec{p}_B d\vec{P}\, \phi_{A'}^{*}(\vec{p}_A')\phi_{B'}^{*}(\vec{p}_B')\mathcal{H}(\vec{P}', \vec{P})P_q\left[\phi_A(\vec{p}_A)\phi_B(\vec{p}_B)\delta^{(3)}(\vec{P} - \vec{P}_i)\right],$$

$${}^{\rm RGM}N_E(\vec{P}', \vec{P}_i) = \int d\vec{p}_A'd\vec{p}_B'd\vec{p}_A d\vec{p}_B d\vec{P}\, \phi_{A'}^{*}(\vec{p}_A')\phi_{B'}^{*}(\vec{p}_B')P_q\left[\phi_A(\vec{p}_A)\phi_B(\vec{p}_B)\delta^{(3)}(\vec{P} - \vec{P}_i)\right],$$

- E_T is the total energy of the system, $\mathcal{H}$ hamiltonian from CQM.

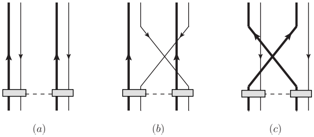
Details of the calculation

Aim $\rightarrowtail$ Evaluate the molecular nature of the T_{cc}^{+}

- Coupled-channels calculation of the $J^P = 1^+$ $cc\bar{q}\bar{q}'$ sector
- Meson-meson thresholds: $D^0 D^{*+}$ (3875.10), $D^+ D^{*0}$ (3876.51) and $D^{*0} D^{*+}$ (4017.11).
- Meson-meson pairs can be in relative $^3S_1$ and $^3D_1$ partial waves.
- Energy difference between $D^0 D^{*+}$ and $D^+ D^{*0}$ is ∼1.4 MeV $\rightarrowtail$ Isospin breaking effects via calculation in charged basis:

$$|D^{*0} D^+\rangle = -\frac{1}{\sqrt{2}} \left(|D^* D, I = 1\rangle - |D^* D, I = 0\rangle\right) ,$$
$$|D^{*+} D^0\rangle = -\frac{1}{\sqrt{2}} \left(|D^* D, I = 1\rangle + |D^* D, I = 0\rangle\right) .$$

- Recalls the $X(3872)$ case studied in Ortega:2009hj:
  - Same $J^P = 1^+$
  - Similar system $D\bar{D}^*$ (X) vs DD^* (T_{cc}).
  - Same direct interaction for $I = 0$.
  - X can couple to $c\bar{c}$, T_{cc} cannot.
  - T_{cc} has exchange diagrams, X does not.



Results

- We find one bound state below the lower D^0D^{*+} threshold $\rightarrowtail$ Binding energy of $M_{D^0D^{*+}} - M_{\rm pole} = 387$ keV.

- Most of the attraction is due to π and σ exchanges, but unbound unless the exchange kernel is considered.

- The state is basically a D^0D^{*+} molecule, with $\sim 87\%$ probability due to its proximity to threshold. The remaining 13% corresponds to the D^+D^{*0} channel.

- Essentially an isoscalar ($\sim 81\%$) state $\rightarrowtail$ Sizable isospin breaking ($\sim 19\%$ of $I=1$) due to the mass difference between D^0D^{*+} and D^+D^{*0} channels.

- Pole mass and partial widths:

E_B (keV)	$M - i\frac{\Gamma}{2}$ (MeV)	$\Gamma_{D^0D^0\pi^+}$ (keV)	$\Gamma_{D^0D^+\pi^0}$ (keV)	$\Gamma_{D^0D^+\gamma}$ (keV)	Γ (keV)
387	$3874.713 - i\,0$	49	26	6	84

- State sensitive to three-body effects $\rightarrowtail$ If a D^* energy-dependent self-energy is taken for the D^* meson the pole moves to 278 keV binding energy and its width drops to 42 keV.

Additional T_{cc} state in $J^P = 1^+$

- Besides the T_{cc}^+ below $D^0 D^{*+}$, we also find a molecular candidate slightly below the $D^+ D^{*0}$ threshold in the $J^P = 1^+$ $cc\bar{q}\bar{q}'$ sector

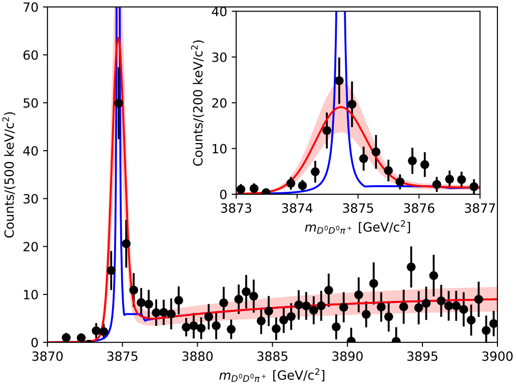
- Probabilities of each chanel:

State	$\mathcal{P}_{D^0 D^{*+}}$	$\mathcal{P}_{D^+ D^{*0}}$	$\mathcal{P}_{D^{*+} D^{*0}}$	$\mathcal{P}_{I=0}$	$\mathcal{P}_{I=1}$
T_{cc}	86.8	13.1	0.1	81.3	18.7
T'_{cc}	16.9	83.1	0.01	57.7	42.3

- Properties of bound states (in %):

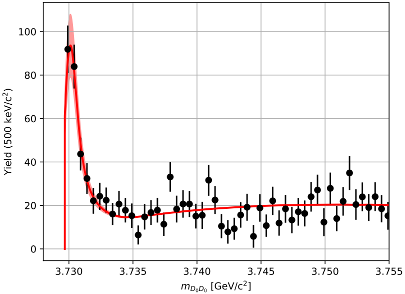
State	E_B	$M - i\frac{\Gamma}{2}$	$\Gamma_{D^0 D^0 \pi^+}$	$\Gamma_{D^0 D^+ \pi^0}$	$\Gamma_{D^0 D^+ \gamma}$
T_{cc}	387	3874.713	49	26	6
T'_{cc}	3	$3876.507 - i\,0.129$	175	140	40

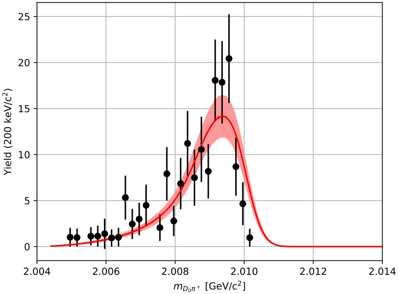
Experimental line shape description



- Good description of the experimental line shape of $D^0D^0\pi^+$.
- Theoretical line convoluted with the detector resolution (rms of 400 keV).
- T_{cc} peak clearly visible.
- T'_{cc} peak appears as a small bump smeared by the resolution.
- The normalization via χ^2-minimization procedure.

Experimental line shape description (II)





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- Theoretical line convoluted with the detector resolution (rms of 400 keV).
- T_{cc} peak clearly visible.
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- The normalization via χ^2-minimization procedure.

Scattering lengths and effective ranges

Channel	$a_{\rm sc}$ [fm]	$r_{\rm eff}$ [fm]	g [GeV$^{-1/2}$]
$D^0 D^{*+}$	-7.14	-0.49	0.12
$D^+ D^{*0}$	$-8.98 + 8.57\,i$	$0.82 + 0.48\,i$	0.07
$D^{*0} D^{*+}$	$0.20 + 0.02\,i$	$-6.09 - 6.23\,i$	< 0.01

- Scattering length of the lower threshold $D^0 D^{*+}$ fully compatible with the experimental estimation ($a_{\rm sc}^{\rm LHCb} = -7.15(51)$ fm).
- The LHCb only gives an upper limit of $r_{\rm exp} > -11.9(16.9)$ fm at 90(95)% CL $\rightarrowtail$ Compatible with our $r_{\rm eff} = -0.49$ fm.
- The scattering length and effective ranges for $D^+ D^{*0}$ and $D^{*0} D^{*+}$ channels are complex $\rightarrowtail$ Indicates the existence of inelastic channels.
- The real part of the $D^+ D^{*0}$ scattering length is large and negative $\rightarrowtail$ Compatible with the $T_{cc}'(3876)$ bound state.

T_{cc}^+ partners and the bottom sector (I)

J^P	I	Mass	Width	E_B	$\mathcal{P}_{D^*D^*}$	Type
0^+	0	4018.0	8.15	0.9	95.6%	Resonance
	1	4016.9	0.6	-0.2	98.8%	Virtual
1^+	–	4014.0	0	-3.1	38.5%	Virtual

- We searched for T_{cc}^+ partners in alternative J^P sectors and thresholds $\rightarrowtail$ E.g. DD in $J^P = 0^+$ or D^*D^* in $J^P = 0^+$, 1^+ and 2^+.
- No bound state was found. However, we find a virtual and resonance in $J^P = 0^+$ in isospin 1 and 0, respectively, just below the D^*D^* threshold.
- Additionaly, in $J^P = 1^+$, below the D^*D^* threshold, a faint virtual state is found just below the D^*D^* threshold.

T_{cc}^+ partners and the bottom sector (II)

- In the bottom sector we analyzed the 1^+ $\bar{b}\bar{b}qq'$ sector.
- Coupled-channels calculation analog to that of the $T_{cc}^+ \rightarrowtail B^0B^{*+}$, B^+B^{*0} and $B^{*+}B^{*0}$ thresholds.
- Two T_{bb} bound states found below the B^0B^{*+} threshold:

Mass	E_B	$\mathcal{P}_{B^0B^{*+}}$	$\mathcal{P}_{B^+B^{*0}}$	$\mathcal{P}_{B^{*+}B^{*0}}$	$\mathcal{P}_{I=0}$	$\mathcal{P}_{I=1}$
10582.2	21.9	47.8	50.0	2.2	99.99	0.01
10593.5	10.5	51.0	48.6	0.4	0.02	99.98

- We searched for further T_{bb} states in $J^P = 0^+$ and 2^+, including all meson-meson channels in a relative S-wave $\rightarrowtail BB + B^*B^*$ for 0^+ and B^*B^* for 2^+.
- We find five candidates:

J^P	I	Mass	Width	E_B	$\mathcal{P}_{BB}$	$\mathcal{P}_{B^*B^*}$	Γ_{BB}	$\Gamma_{B^*B^*}$
0^+	0	10553.0	0	6.0	92%	8%	0	0
		10640.7	2.8	8.7	76%	24%	2.8	0
	1	10545.9	0	13.1	93%	7%	0	0
		10672.6	72.0	−23.2	39%	61%	30.7	41.3
2^+	1	10642.3	0	7.1	-	100%	-	0

These results show a populated spectroscopy in the bottom sector, which can be detected in future searches.

Summary

- The T_{cc}^+ found as a D^0D^{*+} molecule (87%) $\rightarrowtail E_B = 387$ keV/c^2 and $\Gamma = 81$ keV, in agreement with the experimental measurements.
- The quark content of the state forces the inclusion of exchange diagrams to treat indistinguishable quarks between the D mesons, which are found to be essential to bind the molecule.
- The $D^0D^0\pi^+$ line shape, scattering lengths and effective ranges of the molecule are also analyzed, which are found to be in agreement with the LHCb analysis.
- We search for further partners of the T_{cc}^+ in other charm and bottom sectors, finding different candidates. In particular, in the charm sector we found a shallow $J^P = 1^+$ D^+D^{*0} molecule (83%), dubbed T'_{cc}, just 1.8 MeV above the T_{cc}^+ state.
- In the bottom sector, an isoscalar and an isovector $J^P = 1^+$ bottom partners were identified as BB^* molecules lying 21.9 MeV/c^2 ($I = 0$) and 10.5 MeV/c^2 ($I = 1$), respectively, below the B^0B^{*+} threshold.

Thanks for your attention.

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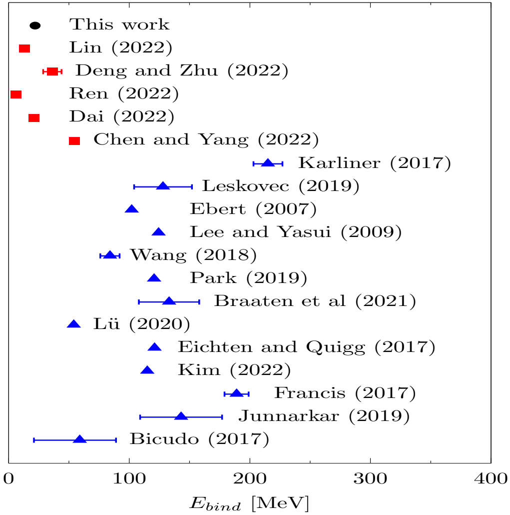
- Reference:
  - *Nature of the doubly-charmed tetraquark T_{cc}^{+} in a constituent quark model*, *Phys. Lett. B* **841** (2023), 137918. [arXiv:2211.06118 [hep-ph]].
- Recent related studies:
  - *Unraveling the nature of the novel T_{cs} and $T_{c\bar{s}}$ tetraquark candidates* – Arxiv: 2305.14430
  - *Exploring $T_{\psi\psi}$ tetraquark candidates in a coupled-channels formalism* – Arxiv: 2307.00532

Backslides

T_{cc}^{+} partners and the bottom sector (III)



Comparison of our isoscalar T_{bb} candidate with the predictions from other theoretical studies.

Weinberg's compositeness criterion

- Following Weinberg's analysis:

$$a_{\rm sc} = -\frac{2(1-Z)}{2-Z}R + \mathcal{O}(m_\pi^{-1}),$$
$$r_{\rm eff} = -\frac{Z}{1-Z}R + \mathcal{O}(m_\pi^{-1}),$$

with $R = (2mB)^{-1}$ and B the binding energy.

- Taking our values $a_{\rm sc} = -7.15$ fm and $r_{\rm eff} = -0.49$ fm we obtain

$$Z = 1 - \frac{1}{\sqrt{1 + 2\left|\frac{r_{\rm eff}}{a_{\rm sc}}\right|}} \sim 0.06$$

- $Z = 0.06 \rightarrowtail$ Mostly composite!

Antisymmetry and OPE sign

$X(3872)$

- $J^{PC} = 1^{+\pm}$ State:

$$|\Psi^{\pm}_{D\bar{D}^*}\rangle = \frac{1}{\sqrt{2}}\left(|D\bar{D}^*\rangle \mp |D^*\bar{D}\rangle\right)$$

- Quark ordering: $c\bar{q} - q'\bar{c}$
- Central part of OPE between $q\bar{q}$:

$$V_{23}(q) = V(q)(\vec{\sigma}_2\cdot\vec{\sigma}_3)(\vec{\tau}_2\cdot\vec{\tau}_3)$$

with $\langle\vec{\tau}_2\cdot\vec{\tau}_3\rangle = 2I(I+1)-3$. Hence,

$$\langle\Psi^{\pm}_{D\bar{D}^*}|V_{23}|\Psi^{\pm}_{D\bar{D}^*}\rangle \propto \pm(2I(I+1)-3)V(Q)$$

- Sign for $(I)J^{PC} = (0)1^{++}$, $D\bar{D}^*$+h.c.:

$$\langle\Psi^{+}_{D\bar{D}^*}|V_{23}|\Psi^{+}_{D\bar{D}^*}\rangle \propto -3V(Q)$$

T^{+}_{cc}

- $J^{PC} = 1^{+}$ State:

$$|\Psi_{DD^*}\rangle = \frac{1}{\sqrt{2}}\left(|DD^*\rangle + (-1)^{I-1}|D^*D\rangle\right)$$

- Quark ordering: $c\bar{q} - c\bar{q}'$
- Central part of OPE between $\bar{q}\bar{q}$:

$$V_{24}(q) = -V(q)(\vec{\sigma}_2\cdot\vec{\sigma}_4)(\vec{\tau}_2\cdot\vec{\tau}_4)$$

with $\langle\vec{\tau}_2\cdot\vec{\tau}_4\rangle = 2I(I+1)-3$. Hence,

$$\langle\Psi_{DD^*}|V_{24}|\Psi_{DD^*}\rangle \propto (-1)^{I}(2I(I+1)-3)V(Q)$$

- Sign for $(I)J^{P} = (0)1^{+}$, DD^*:

$$\langle\Psi_{DD^*}|V_{24}|\Psi_{DD^*}\rangle \propto -3V(Q)$$

with Q the transferred momentum between mesons and $V(q) = \frac{1}{(2\pi)^3}\frac{g_{ch}^2}{4m_q^2}\frac{1}{3}\frac{\Lambda^2}{\Lambda^2+q^2}\frac{q^2}{q^2+m^2}$.

Calculation of partial decay widths

- The T_{cc}^{+} only decays strongly if the D^* inside the DD^* disintegrates.
- As the D^* width is small, the decay can be calculated perturbatively considering the D^* as unstable into $D\pi$ or $D\gamma$. E.g.:

$$\Gamma_{D^0 D^0 \pi^+} = \Gamma_{D^{*+}\to D^0\pi^+} \int_0^{k_{\max}} k^2 dk |\chi_{D^0 D^{*+}}(k)|^2 \frac{(M_T - E_{D^0} - E_{D^{*+}})^2}{(M_T - E_{D^0} - E_{D^{*+}})^2 + \frac{\Gamma_{D^*}^2}{4}} ,$$

where

- $\Gamma_{D^{*+}\to D^0\pi^+}$ is the D^{*+} experimental partial width to $D^0\pi^+$.
- $\chi_{D^0 D^{*+}}(k)$ is the wave function of the channel $D^0 D^{*+}$
- E_D are the total energies of the mesons involved in the reaction.
- $k_{\max}$ is the maximum on-shell momentum of the $D^0 D^0 \pi^+$ system:

$$k_{\max} = \frac{1}{2M_T}\sqrt{[M_T^2 - (2m_{D^0} + m_{\pi^+})^2]\left[M_T^2 - m_{\pi^+}^2\right]} ,$$

where M_T is the mass of the T_{cc}^{+}.

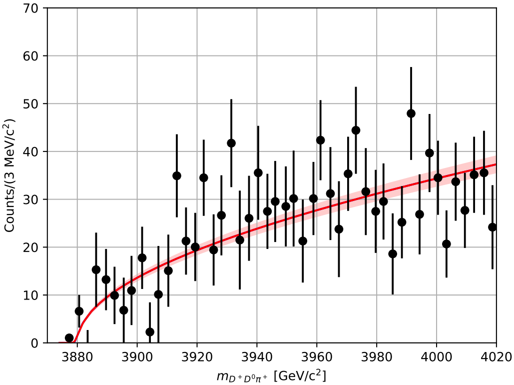
- The $D^0 D^0 \pi^+$ threshold is located at about 3869 MeV, *i.e.* there is not much phase space available, which explains the small partial width obtained.

Scattering lengths and effective ranges

Table: $D^0 D^{*+}$ pole position and S-wave scattering lengths for coupled-channels calculation with an unstable D^* meson, considering different D^{*0} and D^{*+} widths. We distinguish between the scattering length evaluated at the real $M_{D^0 D^{*+}} = m_{D^0} + m_{D^{*+}}$ (third column) or at the complex $E_{D^0 D^{*+}} = m_{D^0} + m_{D^{*+}} - i\Gamma_{D^{*+}}/2$ (forth column).

Case	$E_R - i\,\Gamma_R/2$	$-\pi\mu T(M_{D^0 D^{*+}})$	$a_{\mathrm{sc,D^0 D^{*+}}}$
$\Gamma_{D^{*0}} = \Gamma_{D^{*+}} = 0$	$3874.713 - i\,0$	$-7.14 + 0.00\,i$	$-7.14 + 0.00\,i$
$\Gamma_{D^{*0}} = 0$, $\Gamma_{D^{*+}} = 83.4$ keV	$3874.713 - i\,0.036$	$-8.64 + 2.32\,i$	$-7.14 - 0.08\,i$
$\Gamma_{D^{*0}} = \Gamma_{D^{*+}} = 83.4$ keV	$3874.713 - i\,0.042$	$-8.58 + 2.43\,i$	$-7.14 + 0.001\,i$

Experimental line shape of $D^+D^0\pi^+$



- Good description of the experimental line shape of $D^+D^0\pi^+$.
- T'_{cc} not visible $\rightarrowtail$ No bound state in D^+D^{*+} system.