

$N_{c\bar{c}} \sim T_A T_B \sigma_{c\bar{c}} \sim o(100)$ a most "charming" system produced in HIC at LHC !

Searching for novel charmed hadrons in HIC at LHC!

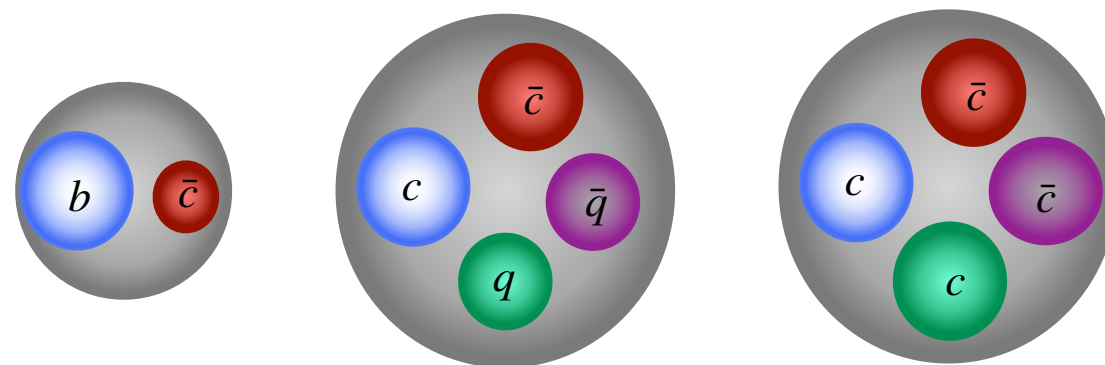
- Yield of B_c , Doubly / Triply charmed baryons, Charmed tetraquarks
- Probe the inner structure of tetraquark states

Jiaxing Zhao (赵佳星)

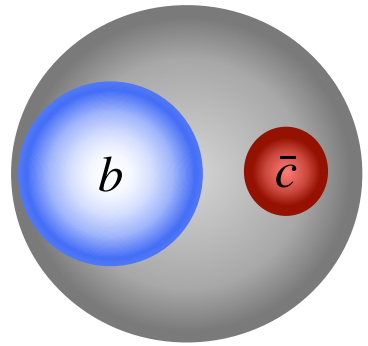
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Many thanks to my collaborators:

Pengfei Zhuang, Baoyi Chen, Shuzhe Shi,



B_c Mesons



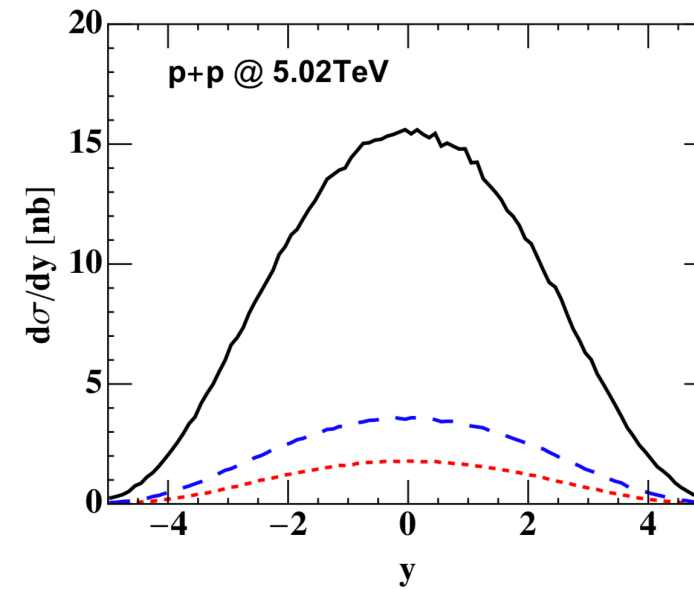
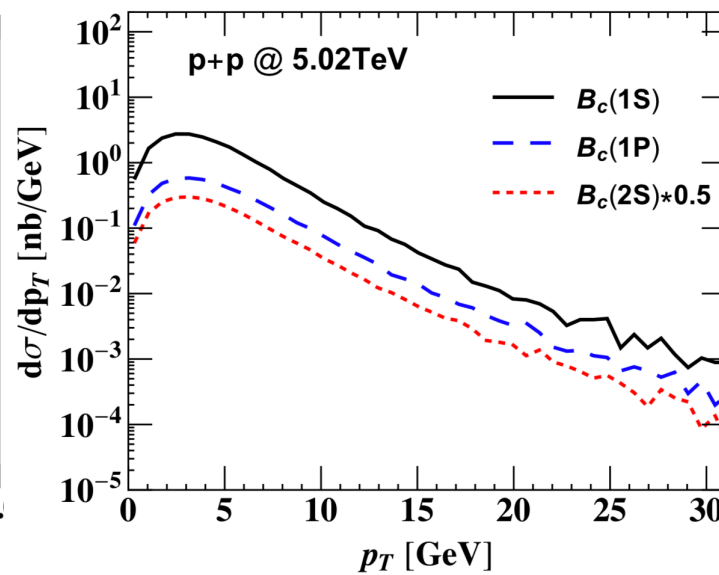
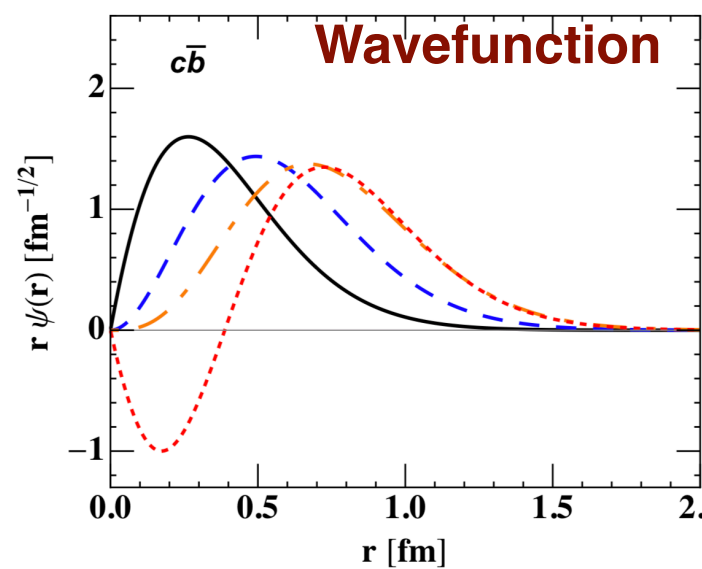
It's hard to produce a pair of $c\bar{c}$ and a pair of $b\bar{b}$ in one event of e^+e^- and pp collisions!

First observation of B_c mesons in heavy-ion collisions !

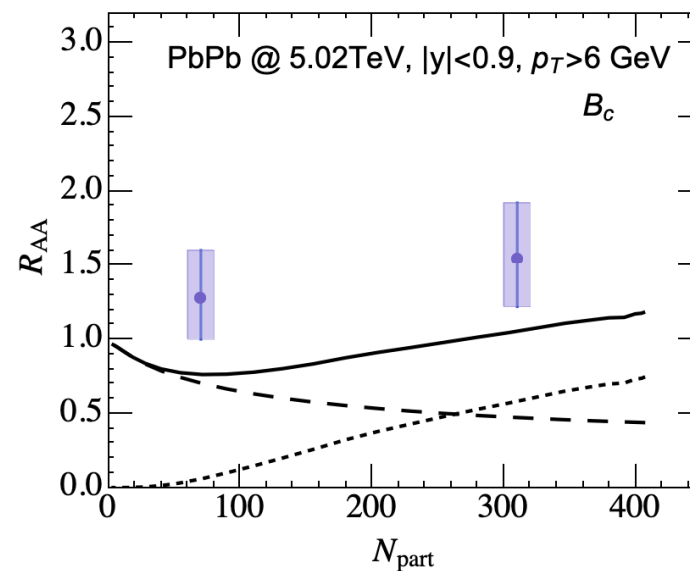
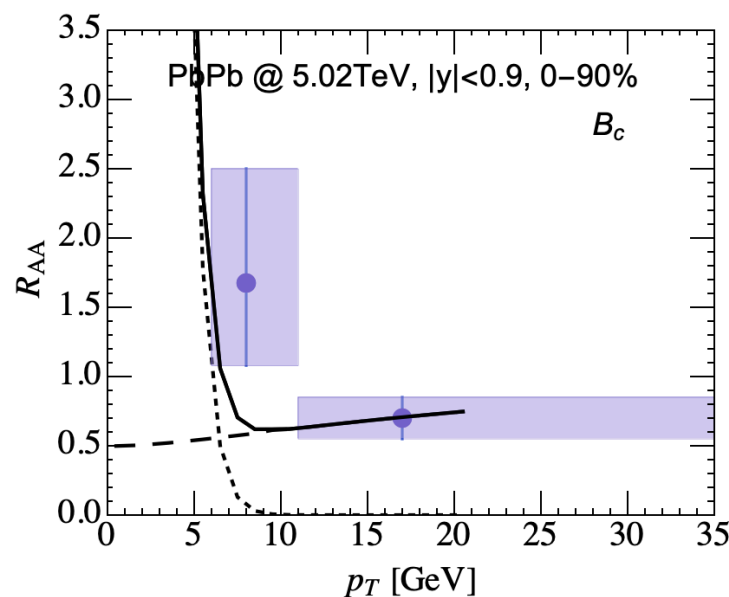
Tue. CMS experiment,
Yongsun Kim's talk.

CMS Collaboration, arXiv: 2201.02659.

B_c in proton-proton collisions is essential ! (two-body Schrodinger equation + B_c generator: BCVEGPY)



B_c in heavy ion collisions (Initial + regeneration)

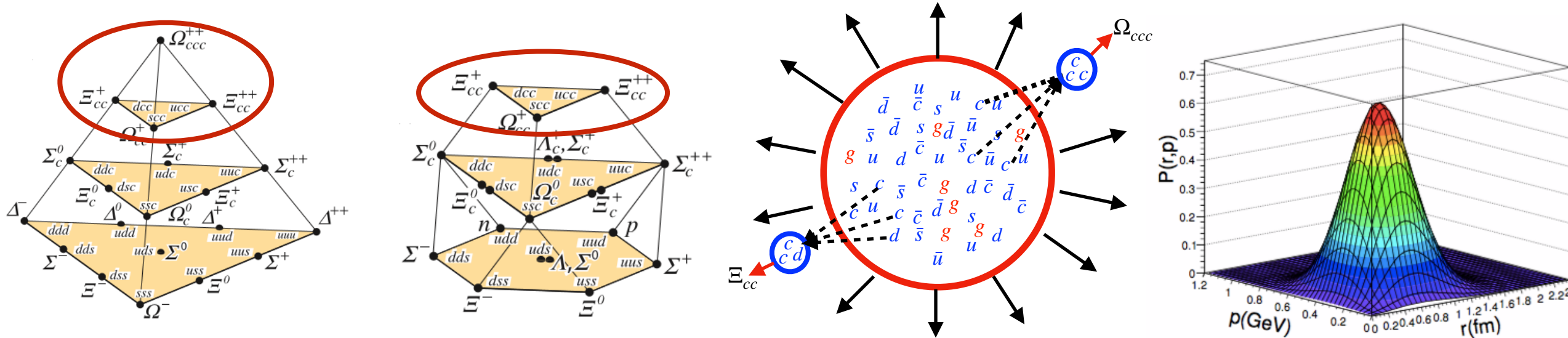


J. Zhao, P. Zhuang. In progressing...

- $R_{AA} > 1$ indicate the production of B_c is largely enhanced in heavy-ion collisions!

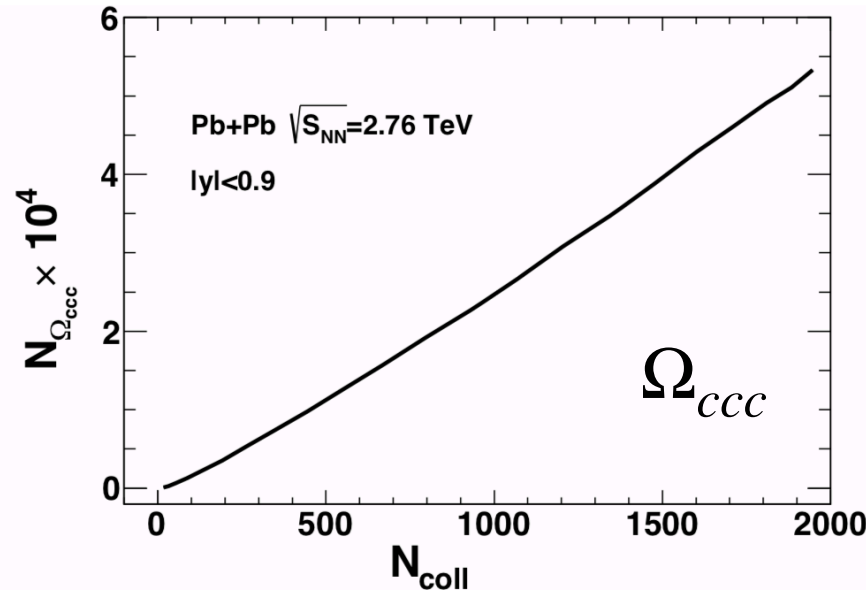
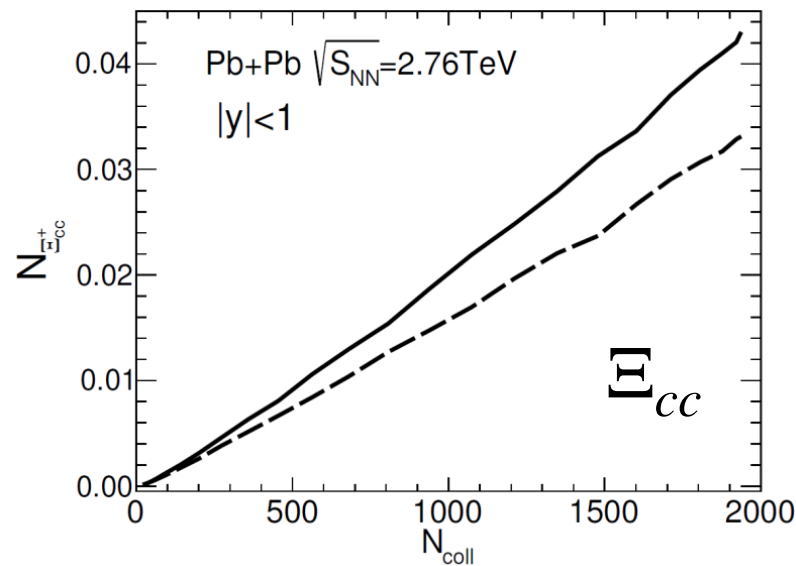
Multi-charmed baryons (Ω_{ccc} , Ξ_{cc})

The flavor $SU(4)$ quark model predicts 22 charmed baryons, but some of them are *not yet discovered* !



Need at least two pairs of charm quarks in an event of elementary collisions (e^+e^- , pp) !

Plenty of off-diagonal charm quarks in QGP + Coalescence at QCD phase transition boundary



$$\sigma_{AA}^{eff} \equiv \frac{N_{AA}}{N_{coll} \Delta\eta} \sigma_{pp}^{inel}$$

$$\frac{\sigma_{AA}^{eff}(\Omega_{ccc})}{\sigma_{pp}(\Omega_{ccc})} : \frac{\sigma_{AA}^{eff}(\Xi_{cc})}{\sigma_{pp}(\Xi_{cc})} : \frac{\sigma_{AA}^{eff}(J/\psi)}{\sigma_{pp}(J/\psi)} \approx 10^2 : 10^1 : 10^0$$

J. Zhao, H. He, Y. Liu, P. Zhuang. *PLB* 746 (2015);
PLB 771 (2017) 349-353;
Few Body Syst. 58 (2017) 2, 100.

- Due to the combination of uncorrelated charm quarks in the hot medium, the multi-charmed baryon yield are **largely enhanced** in HIC comparing with pp collisions!

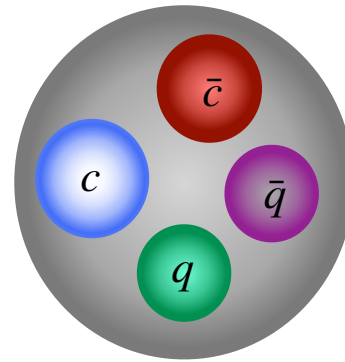
X(3872)

$$\chi_{c1}(3872)$$

$$I^G(J^{PC}) = 0^+(1^{++})$$

also known as X(3872)

This state shows properties different from a conventional $q\bar{q}$ state.
A candidate for an exotic structure. See the review on non- $q\bar{q}$ states.



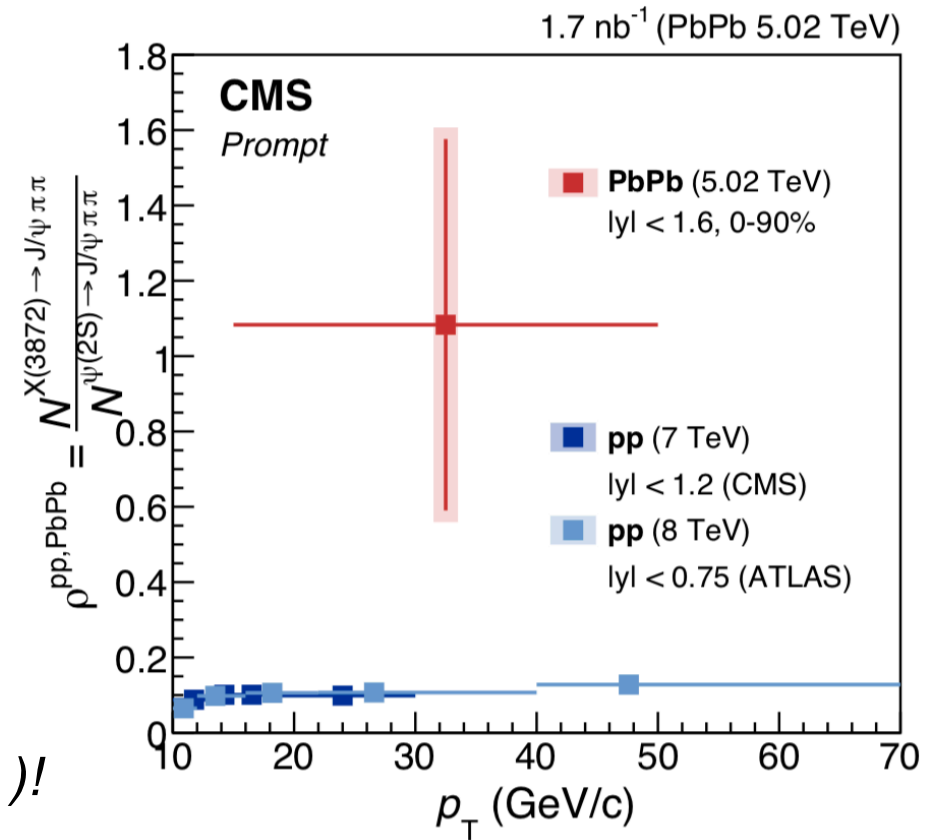
First observed by Belle collaboration (2003)

$$m_X = 3871.69 \pm 0.17 \text{ MeV}$$

$$m_X - (m_{D^0} + m_{\bar{D}^{*0}}) = 0.01 \pm 0.27 \text{ MeV}$$

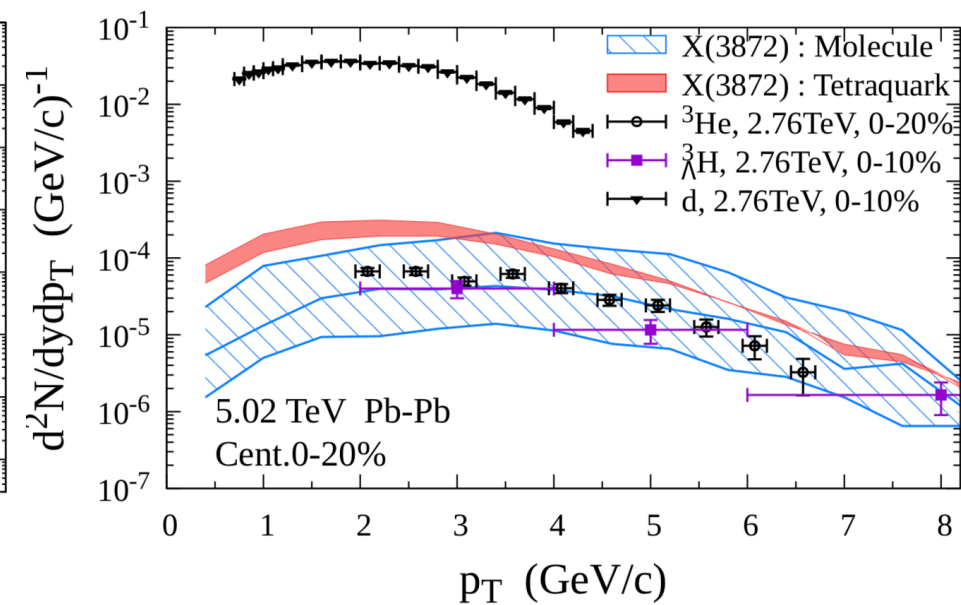
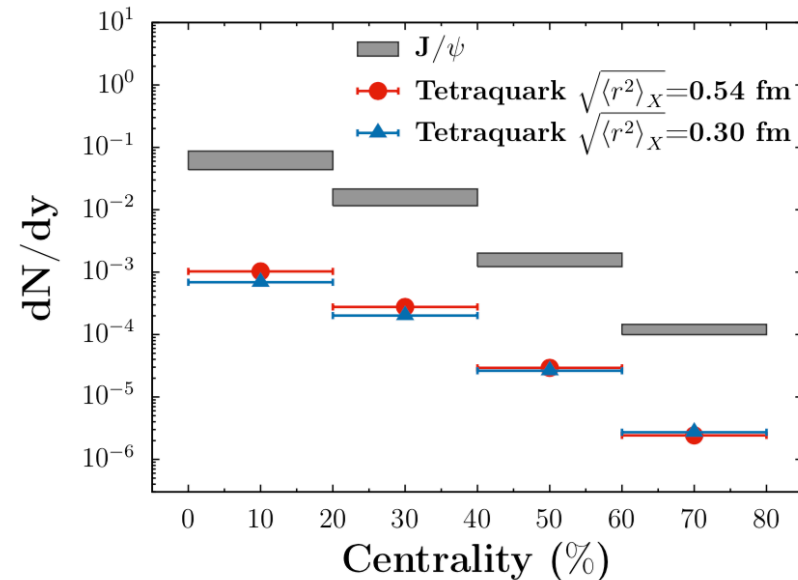
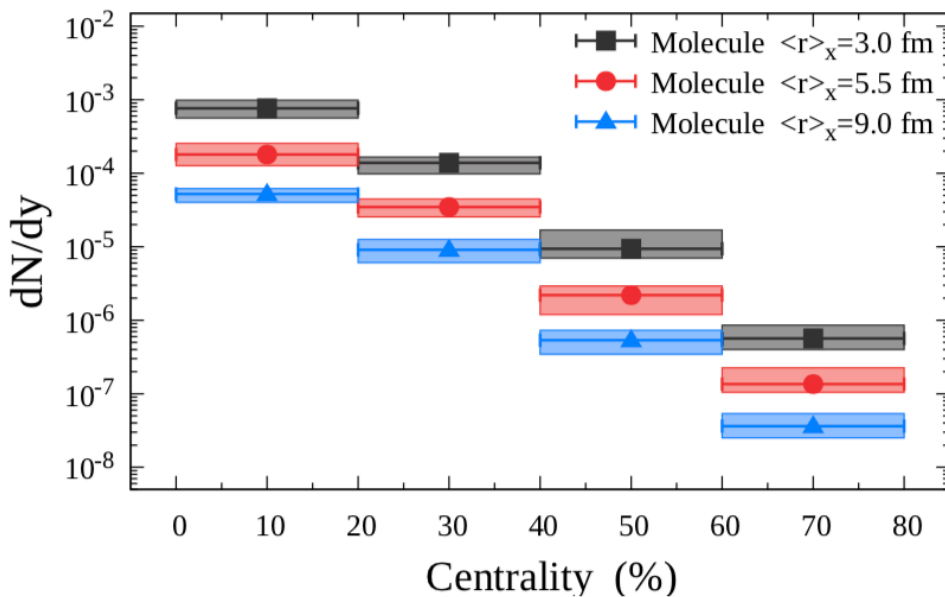
More than 20 XYZ mesons are observed in the Exp. (e^+e^- , pp , ...)!

First evidence of X(3872) production in heavy-ion collisions!



CMS Collaboration, arXiv: 2102.13048.

Langevin evolution + Coalescence model

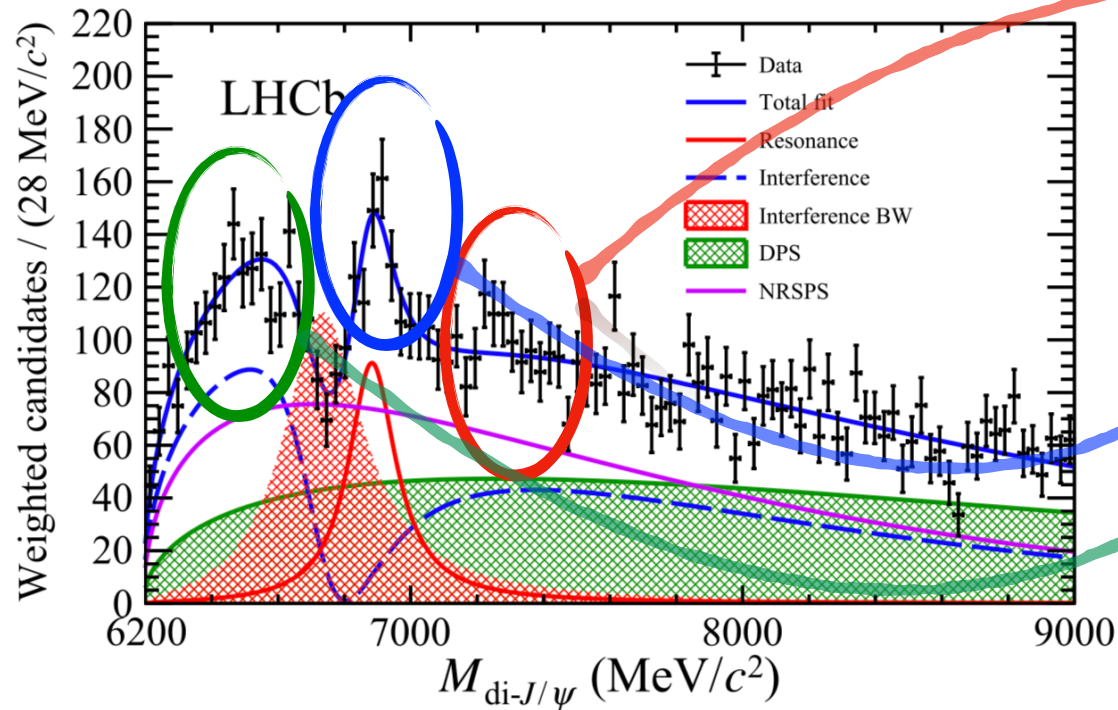
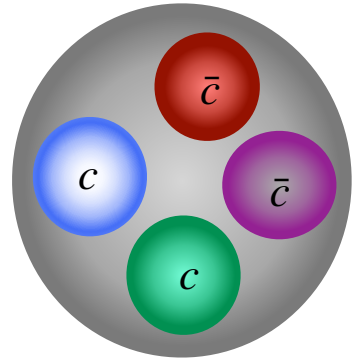


B. Chen, L. Jiang, X. Liu, Y. Liu, J. Zhao. arXiv: 2107.00969

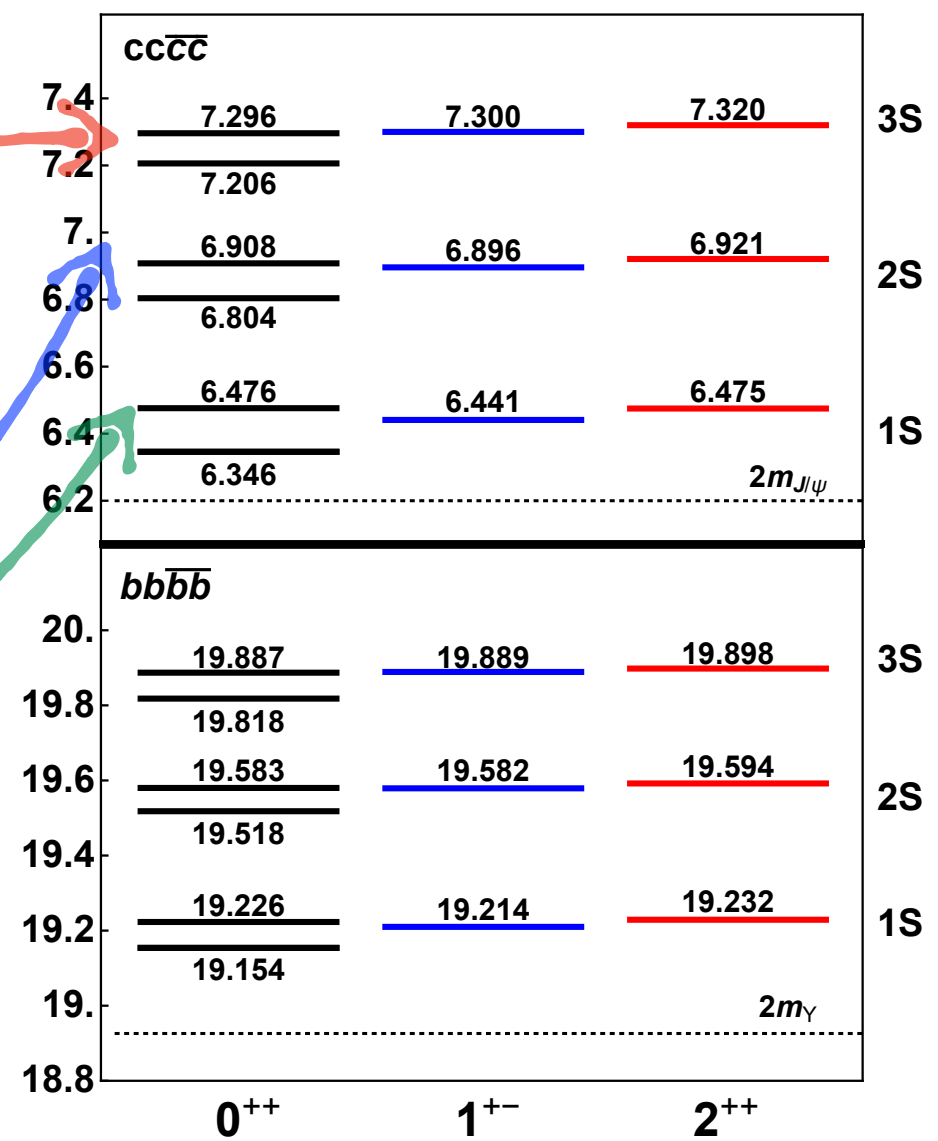
● Production in heavy-ion collisions: Reveal the inner structure of X(3872)

● $R_{AA} > 1$ for tightly bound tetra quarks while $R_{AA} < 1$ for loosely bound molecule states.

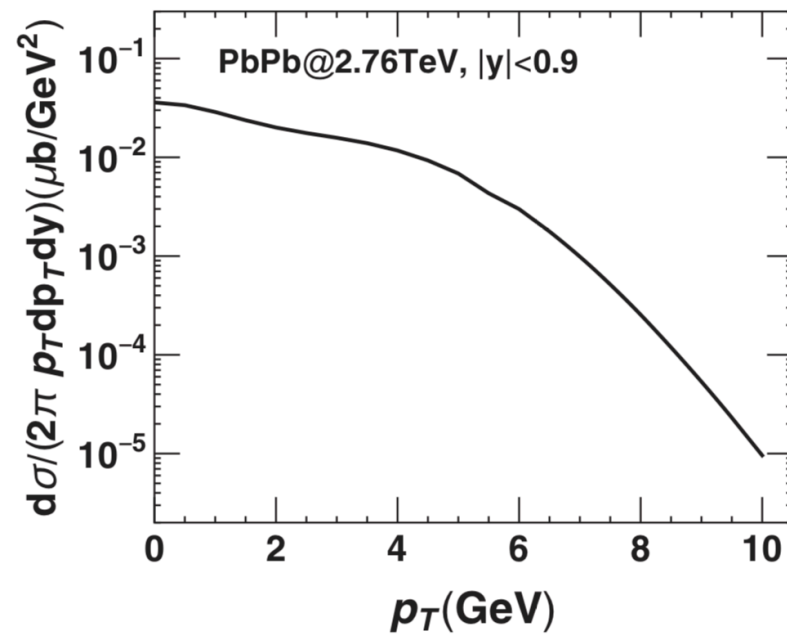
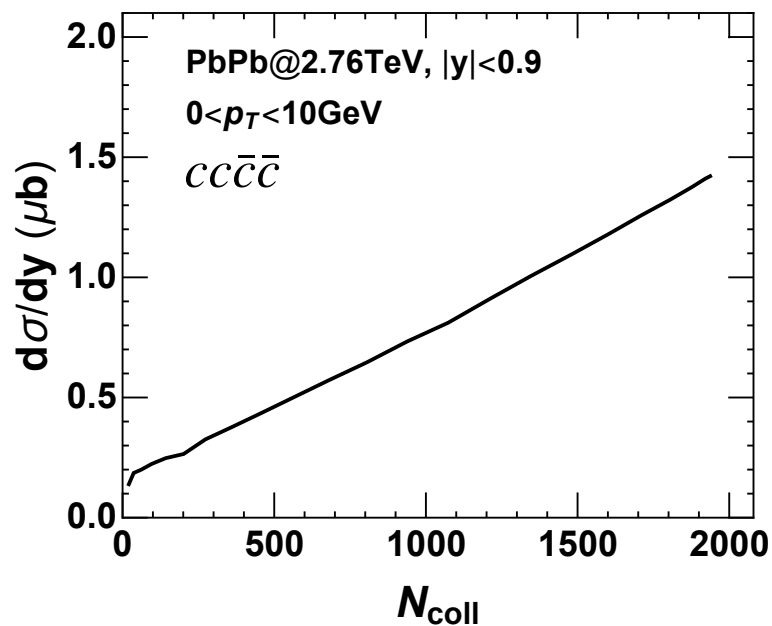
Fully-heavy Tetraquark $X_{cc\bar{c}\bar{c}}$



LHCb Collaboration, Science Bulletin, 2020, 65(23)1983-1993



Four-body Schrödinger equation + Coalescence model



J. Zhao, S. Shi, and P. Zhuang, Phys.Rev.D 102 (2020) 11, 114001

● $\left. \frac{d\sigma}{N_{coll} dy} \right|_{AA} \approx 770 pb$ in AA at 5.02TeV is much larger than $\left. \frac{d\sigma}{dy} \right|_{pp} = 78 pb$ in pp at 7TeV

● The four-lepton decay ($X(cc\bar{c}\bar{c}) \rightarrow l_1^+ l_2^- l_3^+ l_4^-$), well separated from the bulk back ground !