Production of doubly charmed exotic hadrons in heavy ion collisions

张辉　**(Hui Zhang)**

Institute of Quantum Matter, South China Normal University, Guangzhou, China

Collaborators: Yuanyuan Hu, Jinfeng Liao, Enke Wang, Qian Wang, Hongxi Xing
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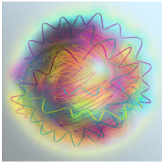
Exotic State XYZ

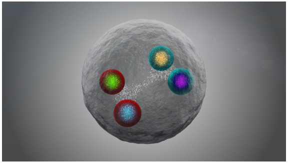
Hadrons are mostly found in two modes:

- Mesons ($q\bar{q}$)
- Baryons (qqq)

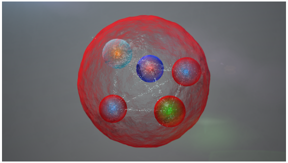
Many other types of color singlet compound hadrons, the so-called exotics, could exist



Glueball



Tetraquark



Pentaquark

Charmed hadrons

- Charmed mesons: D, D_s ...
- Singly charmed baryons: Λ_c, Σ_c, Ξ_c, Ω_c ...
- Doubly and triply charmed hardons: Ξ_{cc}, Ω_{ccc} ...

Multiquark state

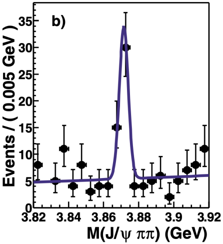
Table: Tetra- & pentaquark candidates Nature Commun. 13 (2022) 1, 3351

States
$X_0(2900)$, $X_1(2900)$ $\chi_{c1}(3872)$ $Z_c(3900)$, $Z_c(4020)$, $Z_c(4050)$, $X(4100)$, $Z_c(4200)$, $Z_c(4430)$, $R_{c0}(4240)$ $Z_{cs}(3985)$, $Z_{cs}(4000)$, $Z_{cs}(4220)$ $\chi_{c1}(4140)$, $\chi_{c1}(4274)$, $\chi_{c0}(4500)$, $\chi_{c0}(4700)$, $X(4630)$, $X(4685)$, $X(4740)$ $X(6900)$ $Z_b(10610)$, $Z_b(10650)$
$P_c(4312)$, $P_c(4380)$, $P_c(4440)$, $P_c(4457)$, $P_c(4357)$ $P_{cs}(4459)$

Introduction

$X(3872) \quad J^{PC} = 1^{++} \quad (c\bar{c}q\bar{q})$

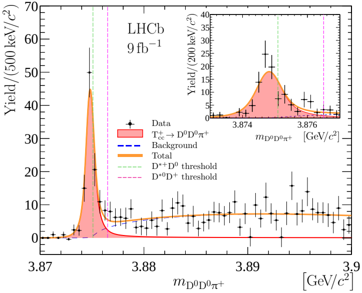
- Belle collaboration (2003) $B \to J/\psi\pi^+\pi^- K$
- $M_X = 3871.69 \pm 0.17 MeV$
- Decay pattern: $J/\psi\rho(\pi^+\pi^-)$, $J/\psi\omega(\pi^+\pi^-\pi^0)$, $D^0\bar{D}^{*0}/\bar{D}^0 D^{*0}/D\bar{D}\pi$, $J/\psi\gamma$



Belle, PRL91(2003)262001

$T_{cc} \quad J^{PC} = 1^{+} \quad (cc\bar{q}\bar{q})$

- LHCb collaboration (2019) $T_{cc}^+ \to D^0 D^0 \pi^+$
- $M_{T_{cc}^+} = 3875 \pm 0.41 MeV$



LHCb, Nature Commun. 13 (2022) 1, 3351; Nature Phys. (2022)

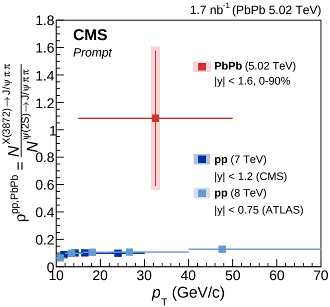
Estimated yields of $X(3872)$ and T_{cc}

	RHIC				LHC			
	$2q/3q/6q$	$4q/5q/8q$	Mol.	Stat.	$2q/3q/6q$	$4q/5q/8q$	Mol.	Stat.
T_{cc}^{1} [a]	—	4.0×10^{-5}	2.4×10^{-5}	4.3×10^{-4}	—	6.6×10^{-4}	4.1×10^{-4}	7.1×10^{-3}
$X(3872)$	1.0×10^{-4}	4.0×10^{-5}	7.8×10^{-4}	2.9×10^{-4}	1.7×10^{-3}	6.6×10^{-4}	1.3×10^{-2}	4.7×10^{-3}

[a] Particles that are newly predicted by theoretical model.

S. Cho et al. (EXHIC Coll.), PRC84(2011)064910

Recent measurements



CMS, PRL128(2022)032001

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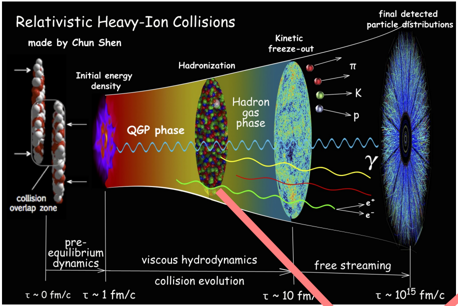
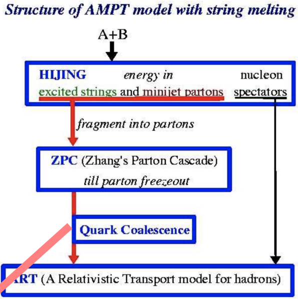
A "realistic" simulation by AMPT

U. W. Heinz, J.Phys.Conf.Ser455(2013)012044



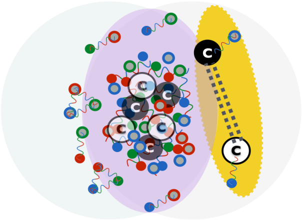
Z. W. Lin .., PRC72(2005)064901



Coalescence

	$X(3872)$	T_{cc}
Molecule:	$D + \bar{D}^*$	$D + D^*$

molecule state:



- Coalescence of D mesons
- The relative distance between D meson pairs: $R \sim 5 - 7 fm$
- Mass: $2M_D < M < 2M_{D^*}$

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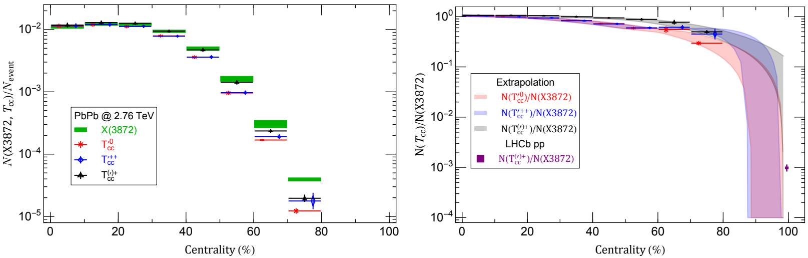
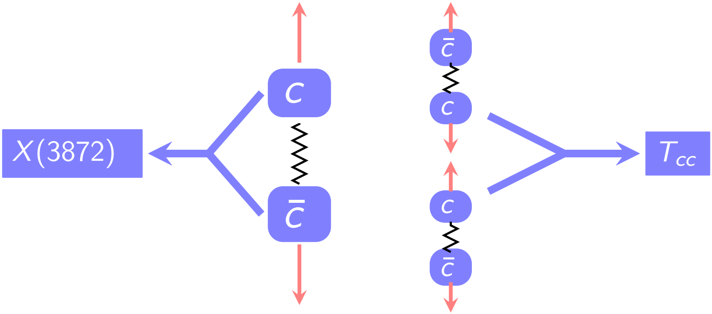
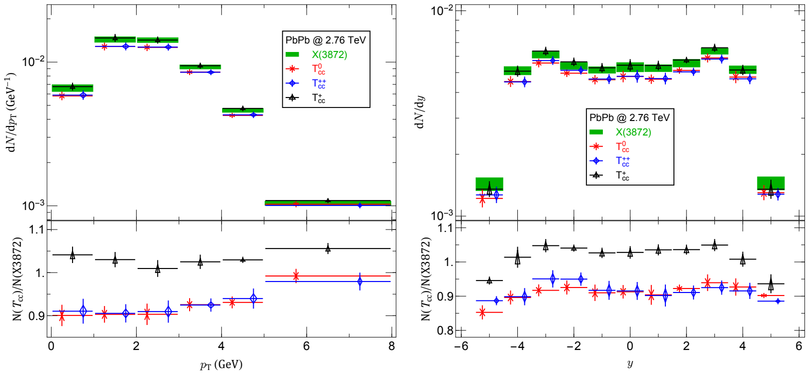
production of doubly charmed exotic hadrons



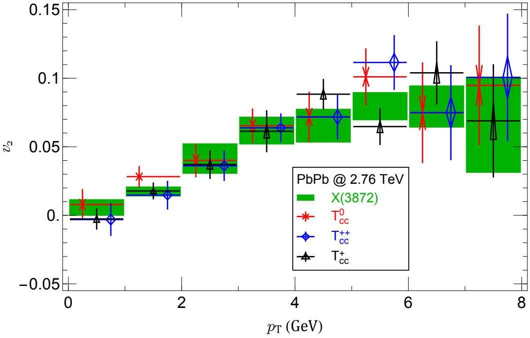


p_T & y dependence



production of doubly charmed exotic hadrons

Elliptic flow



- Elliptic flow is the key observable for collective property of bulk medium
- This study showed the first estimation of elliptic flow for exotic states

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Summary and Outlook

Summary

- HIC provides an extremely charm-rich enviroment.
- Yields of T_{cc}^+ as well as its potential isospin partners are computed within the molecular picture for Pb-Pb collisions.
- We find three-order-of-magnitude enhancement in the production of T_{cc}^+ in $Pb - Pb$ collisions as compared with the yield in $p - p$ collisions.

Outlook

- Compact state
- Hadron Gas Phase: Interact with other hadrons: production + absorption

Thank you for your attention!