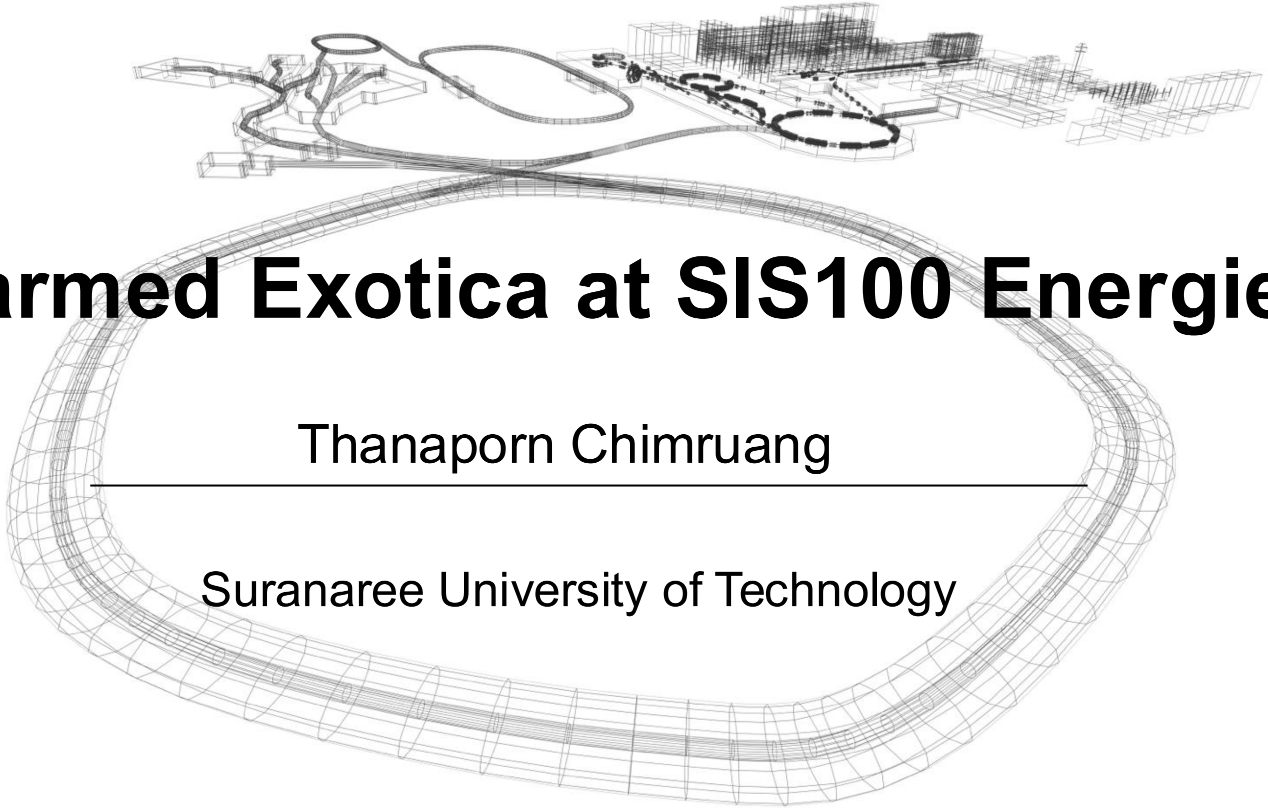
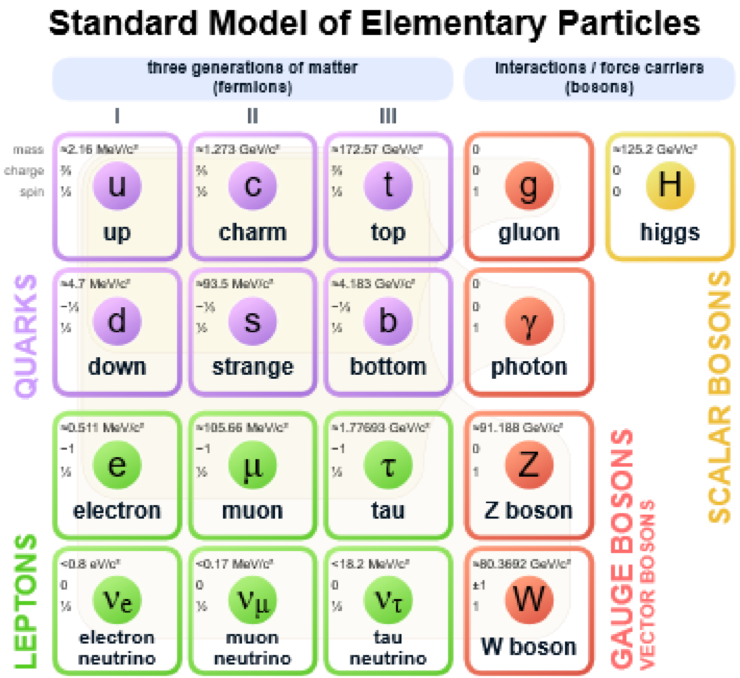


Charmed Exotica at SIS100 Energies

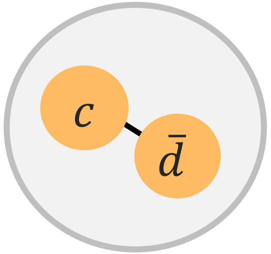
Thanaporn Chimruang

Suranaree University of Technology

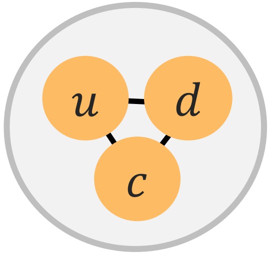
Introduction



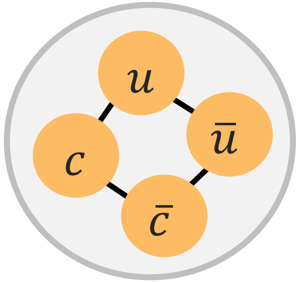
Hobbs (2017)



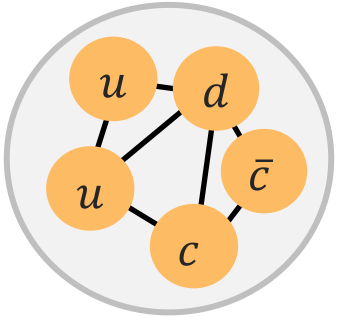
Meson (D^+)



Baryon (Λ_c)

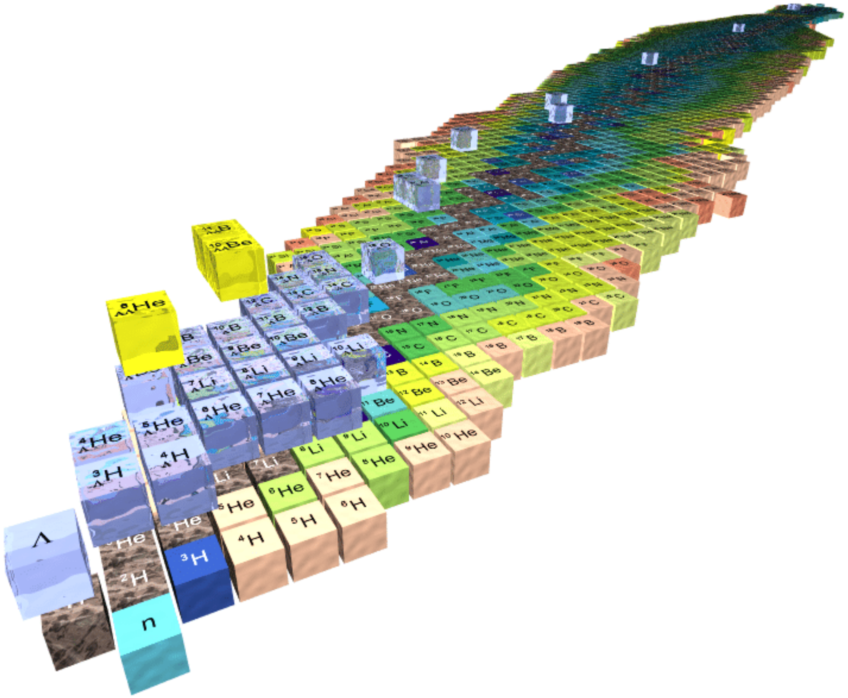


Tetraquark ($X(3872)$)

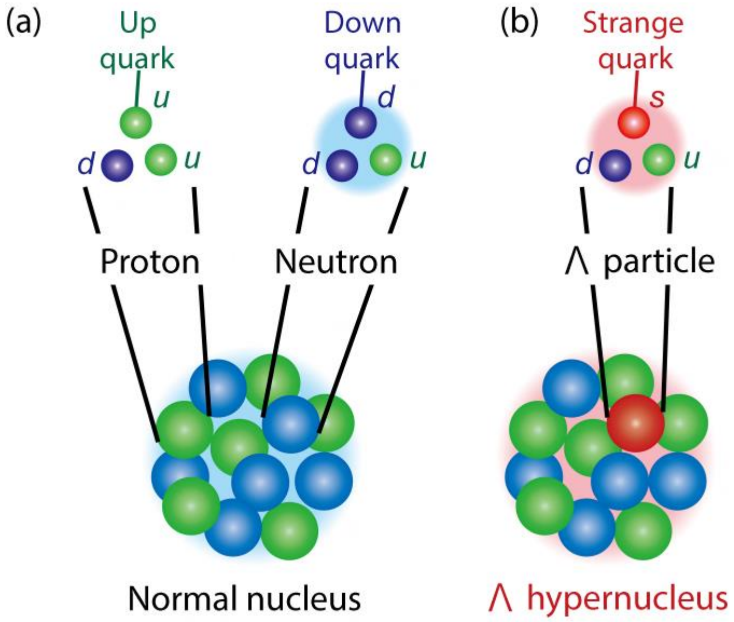


Pentaquark (P_c^+)

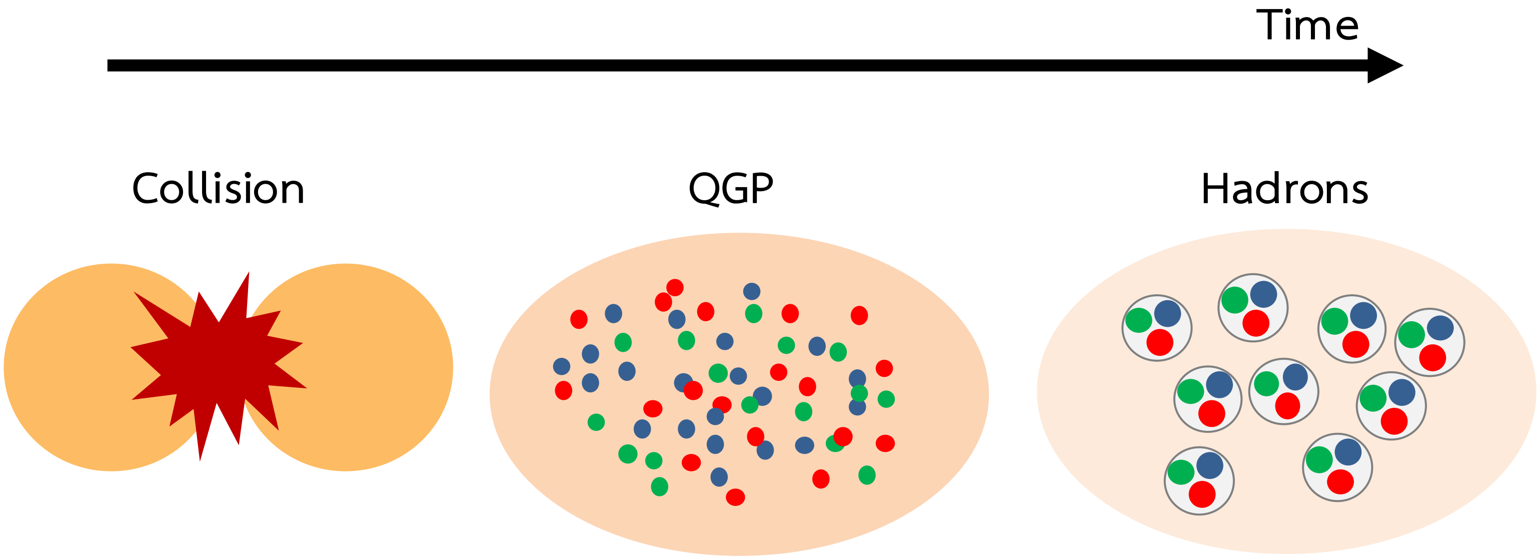
Introduction



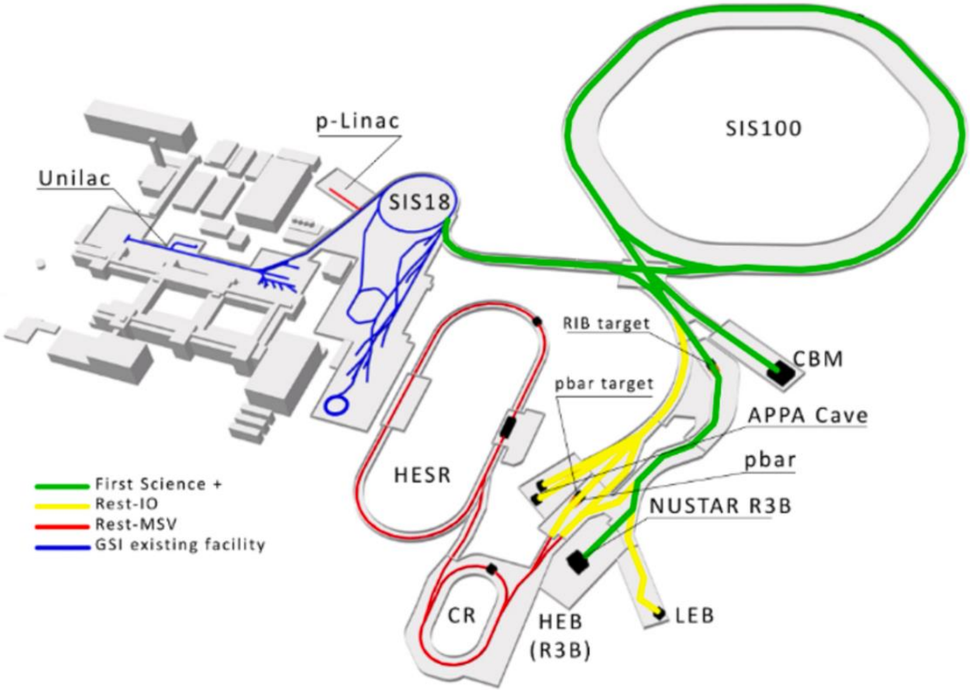
Shyam (2008)



Background



Objective



Reimann et al. (2025)

The goal of this work

To predict the production of charmed states and charmed nuclei in heavy ion and proton-ion reactions

at the **CBM** experiment.

CM Energies	2.4, 3.0, 3.5, 4.0, 4.5, 5.0	GeV

With no current plans for **PANDA, the CBM experiment** becomes our primary focus.

Related theories

The Canonical Partition Function for a hadron resonance gas with conserved quantum number is given by:

$$\mathcal{Z}(B,Q,S,C) = \int_{-\pi}^{\pi} \frac{d\phi_B}{2\pi} \int_{-\pi}^{\pi} \frac{d\phi_Q}{2\pi} \int_{-\pi}^{\pi} \frac{d\phi_S}{2\pi} \int_{-\pi}^{\pi} \frac{d\phi_C}{2\pi} \times e^{-i\,(B\phi_B + Q\phi_Q + S\phi_S + C\phi_C)} \times e^{\left[\sum_j \sum_{n=1}^{\infty} z_{j,n}\, e^{i\,n\,(B_j\phi_B + Q_j\phi_Q + S_j\phi_S + C_j\phi_C)}\right]}. \qquad (1)$$

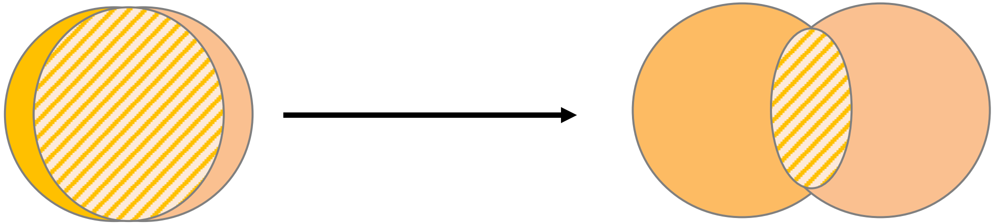
The single-particle partition function for a hadron species j and its n excited state is defined as:

$$z_{j,n} = (\mp 1)^{n+1} \gamma_q^{|q_i|} \gamma_S^{|S_i|} \gamma_C^{|C_i|} \frac{d_j V_c}{2\pi^2} \frac{T m^2}{n^2} K_2\left(n \frac{m}{T}\right) \qquad (2)$$

Chimruang et al.(2026)

Methodology

Hadron multiplicities from **UrQMD** simulation of Au+Au collisions



0-10% 10-20% 20-30% 30-40%

Central collisions — Peripheral collisions

$\pi^+, \pi^-, K^+, K^-, p, \bar{p}, \Lambda, \bar{\Lambda}, \Xi^-, \Omega, K_S^0, J/\psi$, and Λ_c

Energies	2.4, 3.0, 3.5, 4.0, 4.5, 5.0	GeV

Get parameters T, mu, gamma, R and Hadron multiplicities from **UrQMD**

↓

Input these into Thermal model/FIST

↓

Compare UrQMD and FIST multiplicities.

Methodology

Plot predicted multiplicities with energies into three categories:

Normal hadrons: $\pi^+, K^+, K^-, p, \bar{p}, \Lambda, \Xi^-, d, t$ and Ω

Charmed hadrons: $J/\psi, \Lambda_c, D_0$ and $\overline{D}_0$

$X(3872), D_s, \eta_c, \chi_{c0}(1P), \chi_{c1}(1P), \Sigma_c^+(2455), \Sigma_c^{++}(2455)$

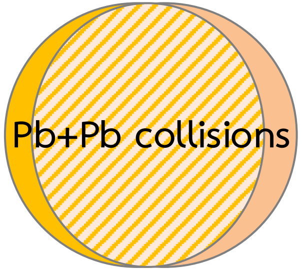
Nuclei: $\{pn\Lambda_c\}, \{n\Lambda_c\}, \{pnn\Lambda_c\}, \{\alpha D^-\}$

Tab.1 List of charmed hadrons and nuclei that have been introduced to thermal-FIST with their masses and quantum numbers.

Particle	Mass[GeV]	Q	B	S	C	$\lvert C\rvert$	d_J
$\{pn\Lambda_c\}$	4.163	2	3	0	1	1	2
$\{n\Lambda_c\}$	3.225	1	2	0	1	1	3
$\{pnn\Lambda_c\}$	5.102	2	4	0	1	1	1
$\{\alpha D^-\}$	5.596	1	4	0	-1	1	3
X(3872)	3.872	0	0	0	0	2	3
D_s^+	1.968	1	0	1	1	1	1
$\eta_c(1S)$	2.984	0	0	0	0	2	1
$\chi_{c0}(1P)$	3.414	0	0	0	0	2	1
$\chi_{c1}(1P)$	3.510	0	0	0	0	2	3
Σ_c^{++}	2.454	2	1	0	1	1	2
Σ_c^+	2.453	1	1	0	1	1	2

Methodology

Hadron multiplicities from **ALICE** data



Central collisions

$$J/\psi,\ \Lambda_c, \bar{\Lambda}_c, D^+,\ D^-,$$
$$D^{*+}, D^{*-}, D_0, \bar{D}_0, D_s, and\ \bar{D}_s$$

Energy	5.02	TeV

Get parameters T, mu, gamma, R and Hadron multiplicities from **The available data**

↓

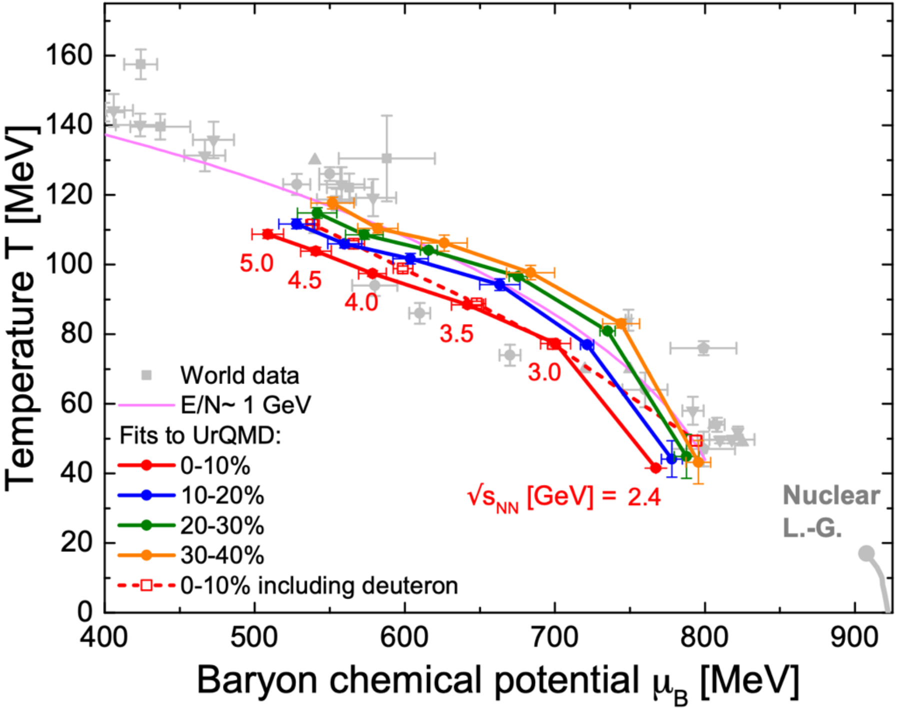
Applying Thermal Model to predict charm nuclei.

↓

Compare multiplicities for Au+Au and Pb+Pb collisions

Results

Fig.1 Freeze out points from fits to UrQMD, in the $T - \mu_B$ phase diagram.



Different centralities are shown as filled symbols with solid lines compared to world data (grey symbols) [1, 2–8] and a parametrization of the freeze out line from [8]. The dashed line shows the fit for central collisions when the deuteron is included in the list of fitted particles.

[1] A. Andronic (2006), [2] J. Cleymans (1998), [3] F. Becattini (2001), [4] J. Cleymans (2006), [5] G. Agakishiev (2011), [6] M. Lorenz (2014), [7] F. Becattini (2017), [8] A. Lysenko (2025)

Results

Fig.2 Input (symbols) and fitted (lines) light hadron multiplicities from the UrQMD simulations of Au+Au collisions at different centrality selections.

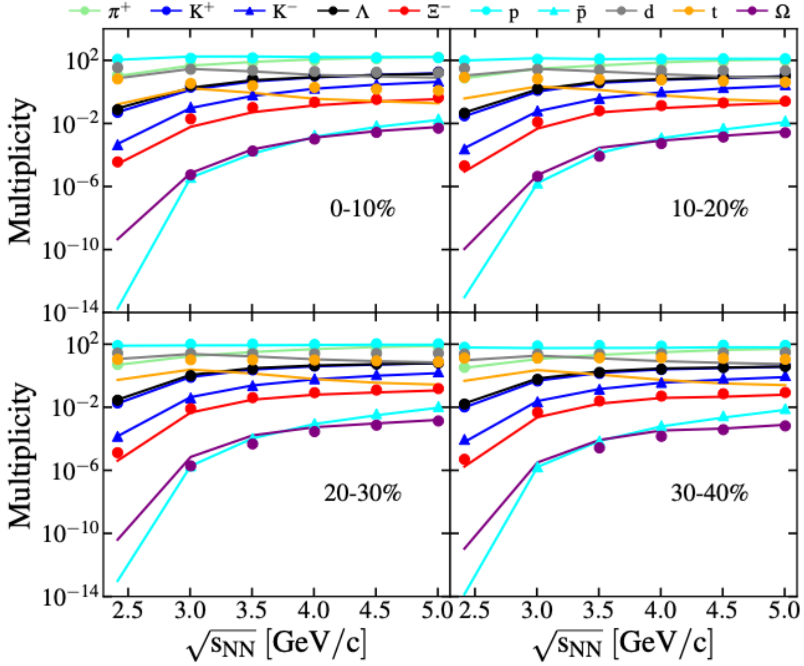
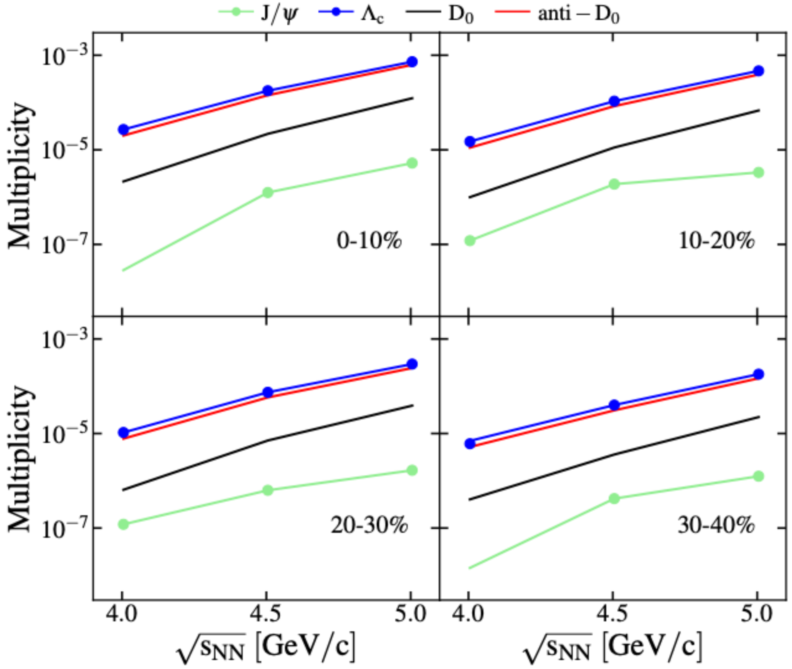


Fig.3 Input (symbols) and predicted charm hadron multiplicities in Au+Au collisions at different centralities as function of the beam energy.



Results

Fig.4 Predicted (lines) charmed hadron multiplicities in Au+Au collisions at different centralities as function of the beam energy.

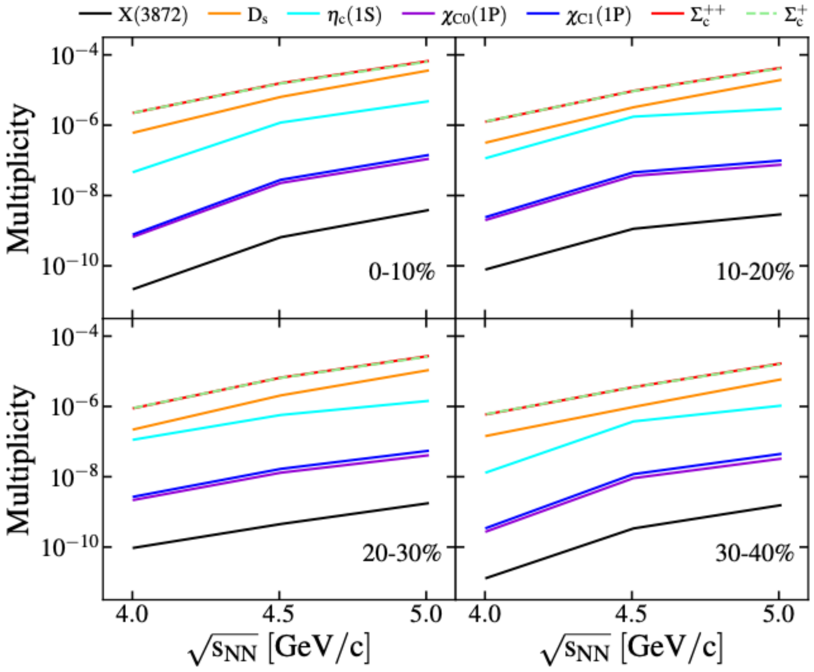
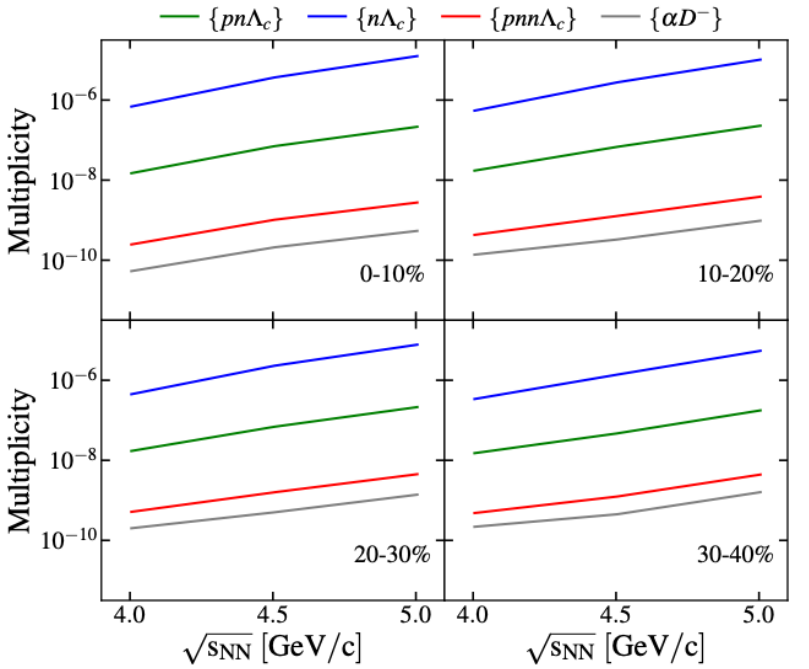
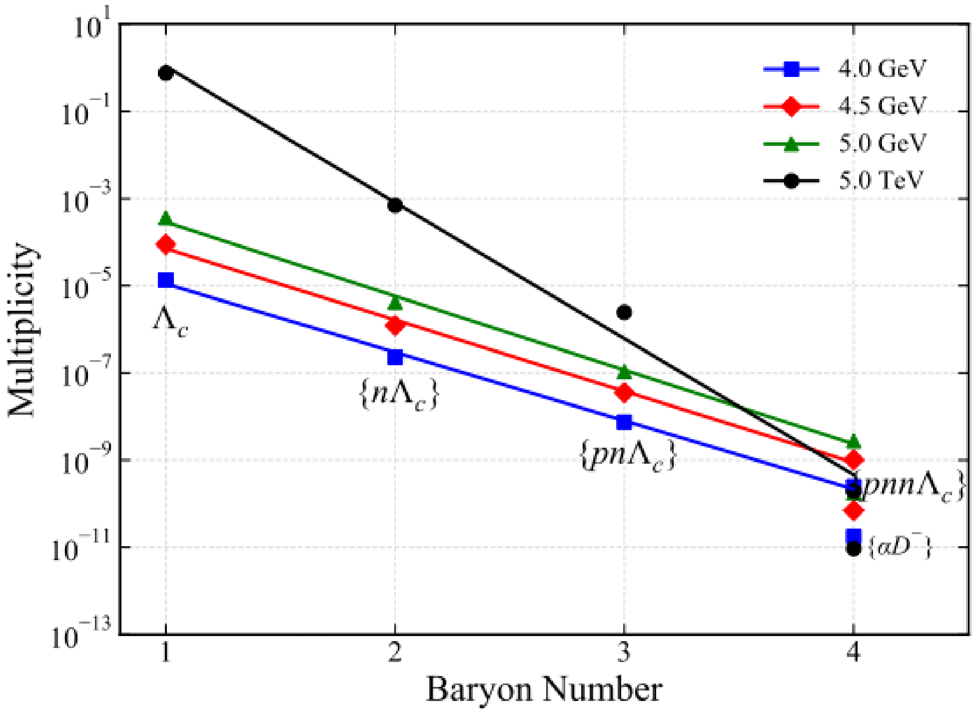


Fig.5 Predicted (lines) charmed nuclei multiplicities in Au+Au collisions at different centralities as function of the beam energy.



Results

Fig.6 Particle multiplicities as a function of Baryon Number for Au+Au and Pb+Pb collisions.



Tab.2 Predicted particle multiplicities for central collisions of Au+Au and Pb+Pb.

System	Au+Au	Pb+Pb
$\sqrt{s_{NN}}$	5 GeV	5.02 TeV
$\{pn\Lambda_c\}$	2.15×10^{-7}	4.91×10^{-6}
$\{n\Lambda_c\}$	1.25×10^{-5}	0.002
$\{pnn\Lambda_c\}$	2.76×10^{-9}	1.93×10^{-10}
$\{\alpha D^-\}$	5.40×10^{-10}	2.8×10^{-11}
X(3872)	5.71×10^{-9}	0.0015
D_s^+	3.57×10^{-5}	2.91
$\eta_c(1S)$	4.76×10^{-6}	0.132
$\chi_{c0}(1P)$	1.09×10^{-7}	0.010
$\chi_{c1}(1P)$	1.40×10^{-7}	0.016
Σ_c^{++}	6.66×10^{-5}	0.159
Σ_c^{+}	6.39×10^{-5}	0.134

Conclusion

Thermal Model → To predict the production of charmed hadrons nuclei.

The multiplicity of exotic states **exhibits an exponential suppression** with **increasing baryon number** which is stronger for the highest beam energies.

The CBM has excellent potential to study these **high-baryon number** states, also because of a higher collision rate compared to the LHC (**3 orders of magnitude**). So even the ones with **lower multiplicities** at CBM **can be produced** in the same or higher numbers over the **same amount of time.**

Tab.3 Predicted charmed nuclei multiplicities for central collisions of Au+Au and Pb+Pb.

Experiment	CBM	LHCb
System	Au+Au	Pb+Pb
$\sqrt{s_{NN}}$	5 GeV	5.02 TeV
$\{pn\Lambda_c\}$	2.15×10^{-7}	4.91×10^{-6}
$\{n\Lambda_c\}$	1.25×10^{-5}	0.002
$\{pnn\Lambda_c\}$	2.76×10^{-9}	1.93×10^{-10}
$\{\alpha D^-\}$	5.40×10^{-10}	2.8×10^{-11}

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High Energy Physics – Phenomenology

[Submitted on 26 Feb 2026]

Charmed nuclei and exotic charmed meson production at CBM@FAIR and ALICE@LHC

Thanaporn Chimruang, Christoph Herold, Ayut Limphirat, Yupeng Yan, Jan Steinheimer, Benjamin Dönigus, Tom Reichert, Volodymyr Vovchenko, Marcus Bleicher

We make predictions for the expected multiplicities of exotic charmed hadrons and charmed nuclei in Au+Au collisions at SIS100 and LHC beam energies, using input on light hadron and charm production from the UrQMD transport model, and applying the Thermal-FIST model. We demonstrate that the CBM experiment has the capability to explore these states with production rates of one per 3 seconds for $\chi_{c0}(1P)$ and $\chi_{c1}(1P)$, and one every 3 minutes for $X(3872)$ at the expected data taking rates. Due to the higher baryon density at CBM compared to the LHC, charmed nuclei, if they exist, will be equally abundant at CBM as at the LHC, even though the total charm production at CBM is much lower.

Comments:	8 pages, 7 figures
Subjects:	**High Energy Physics – Phenomenology (hep-ph)**; High Energy Physics – Theory (hep-th)
Report number:	CERN-TH-2026-026
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	(or arXiv:2602.22676v1 **[hep-ph]** for this version)
	https://doi.org/10.48550/arXiv.2602.22676

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