华中师范大学夸克与轻子物理教育部重点实验室暨粒子物理研究所

粒子物理研究所

2025 年度“青年之星”研究生学术论坛

华中師範大學 CENTRAL CHINA NORMAL UNIVERSITY

Investigation of $T_{cs0}^{*}(2870)^{0}$ in pp collisions at $\sqrt{s}$ = 7 TeV with the PACIAE model

Qiang Wang（王强）

Central China Normal University

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in collaboration with

Zhi-Lei She, An-Ke Lei, Dai-Mei Zhou, Wen-Chao Zhang, Hua Zheng, Yu-Liang Yan, Ben-Hao Sa

Mainly based on papers : arXiv: 2506.20145

Outline

- **Introduction of exotic states**
- **Introduction of $T^*_{cs0}(2870)^0$**
- **PACIAE model studying $T^*_{cs0}(2870)^0$**
- **Summary and outlook**

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Introduction of exotic states

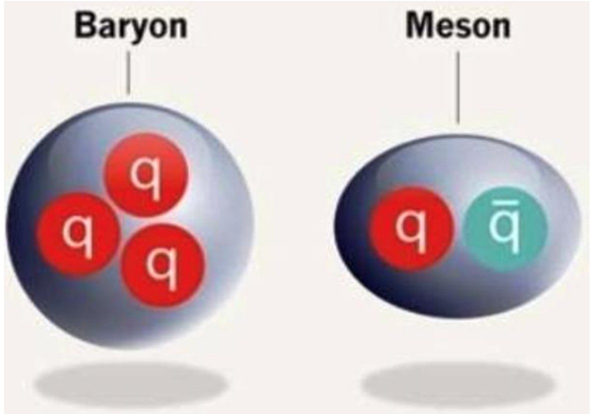
Quark model

M. Gell-Mann

In 1964

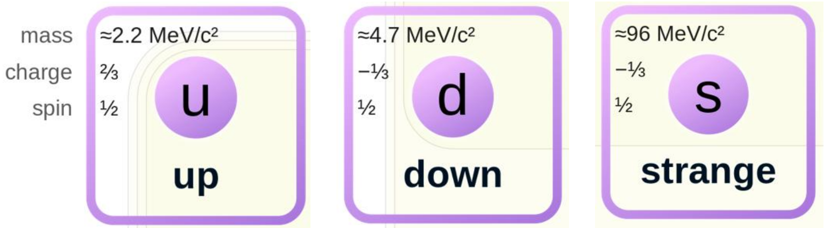
Phys.Lett. 8 (1964) 214-215

10.17181/CERN-TH-412

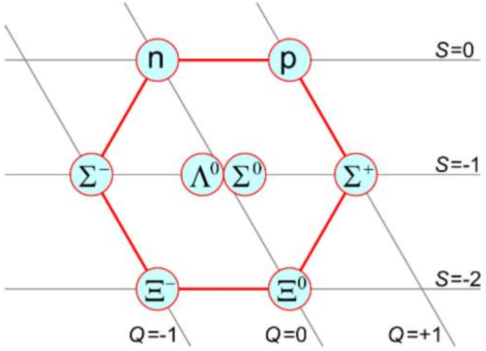


Conventional hadrons

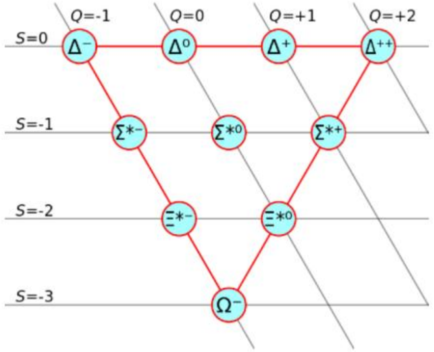
G. Zweig



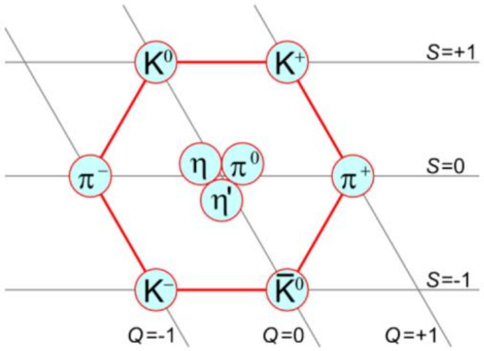
Three light quarks in traditional quark model



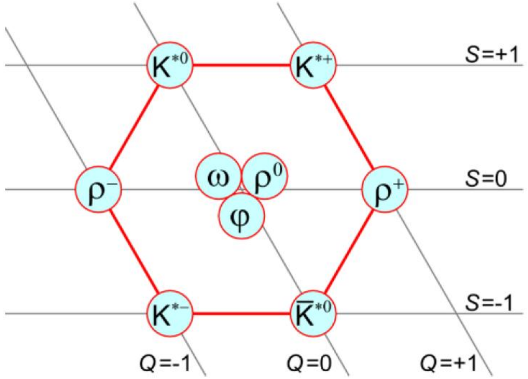
Octet baryons



Decuplet baryons



Pseudoscalar mesons



Vector mesons

Exotic hadrons in quark model

Volume 8, number 3 PHYSICS LETTERS 1 February 1964

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon b if we assign to the triplet t the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{3}$, and baryon number $\frac{1}{3}$. We then refer to the members $u^{\frac{2}{3}}$, $d^{-\frac{1}{3}}$, and $s^{-\frac{1}{3}}$ of the triplet as "quarks" 6) q and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations (qqq), $\boxed{(qqqq\bar{q})}$, etc., while mesons are made out of $(q\bar{q})$, $\boxed{(qq\bar{q}\bar{q})}$, etc. It is assuming that the lowest baryon configuration (qqq) gives just the representations **1**, **8**, and **10** that have been observed, while the lowest meson configuration $(q\bar{q})$ similarly gives just **1** and **8**.

AN SU_3 MODEL FOR STRONG INTERACTION SYMMETRY AND ITS BREAKING

II *)

G. Zweig **)
CERN---Geneva

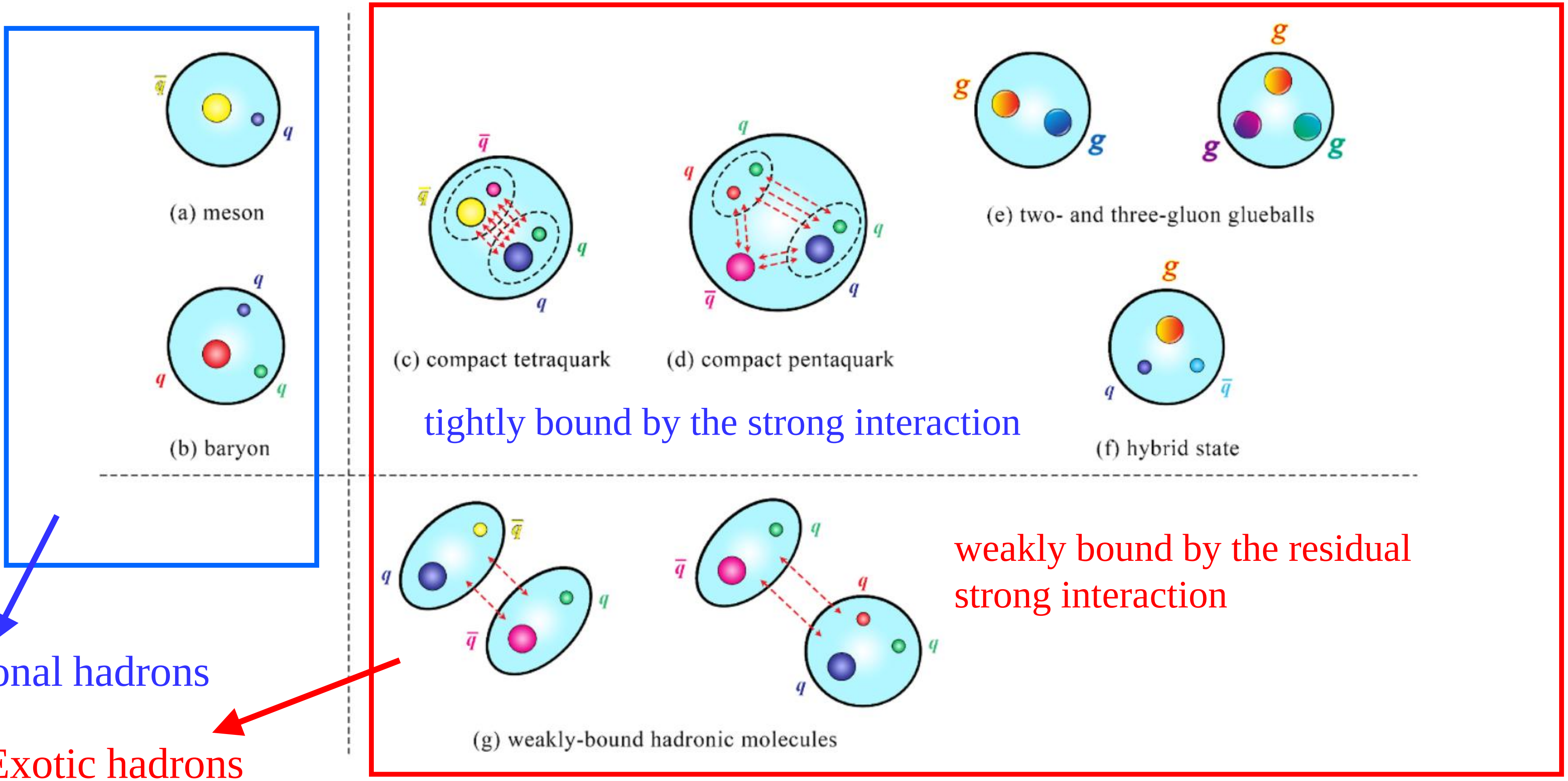
6) In general, we would expect that baryons are built not only from the product of three aces, AAA, but also from $\boxed{\bar{A}AAAA, \bar{A}\bar{A}AAAAA,}$ etc., where $\bar{A}$ denotes an anti-ace. Similarly, mesons could be formed from $\bar{A}A$, $\boxed{\bar{A}\bar{A}AA}$ etc. For the low mass mesons and baryons we will assume the simplest possibilities, $\bar{A}A$ and AAA, that is, "deuces and treys".

Phys.Lett. 8 (1964) 214-215 10.17181/CERN-TH-412

multiquark states: $qq\bar{q}\bar{q}$, $qqq(q\bar{q})$, etc. → **Exotic hadrons**

They are allowed by quark model and QCD.

Exotic hadrons



Conventional hadrons

Exotic hadrons

The picture is taken from Rept.Prog.Phys. 86 (2023) 2, 026201

More review papers:

Phys.Rept. 668 (2017) 1-97, Rev.Mod.Phys. 90 (2018) 1, 015004, Phys.Rept. 873 (2020) 1-154, Phys.Rept. 1001 (2023) 1-66 ...

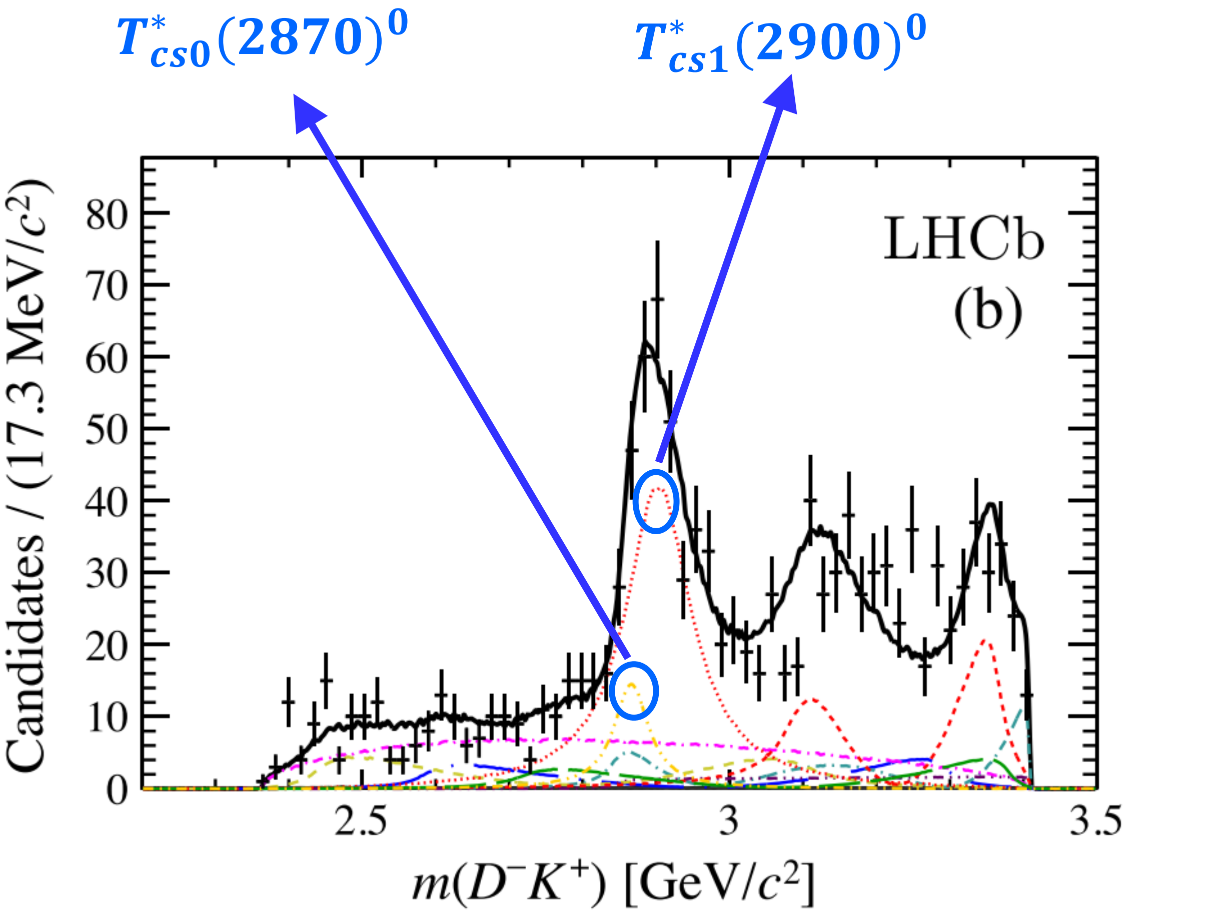
Introduction of $T^{*}_{cs0}(2870)^{0}$

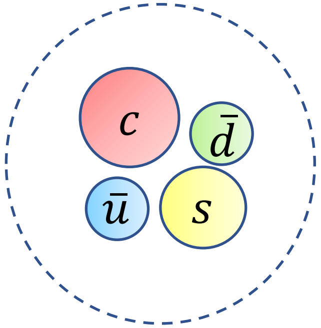
The first observation of $T^*_{cs0}(2870)^0$

pp collision

$B^+ \to D^+ D^- K^+$

LHCb





Phys.Rev.D 102 (2020) 112003

Phys.Rev.Lett. 125 (2020) 242001

The first observation of manifestly exotic candidates with a single charm quark !

open-charm tetraquark candidate

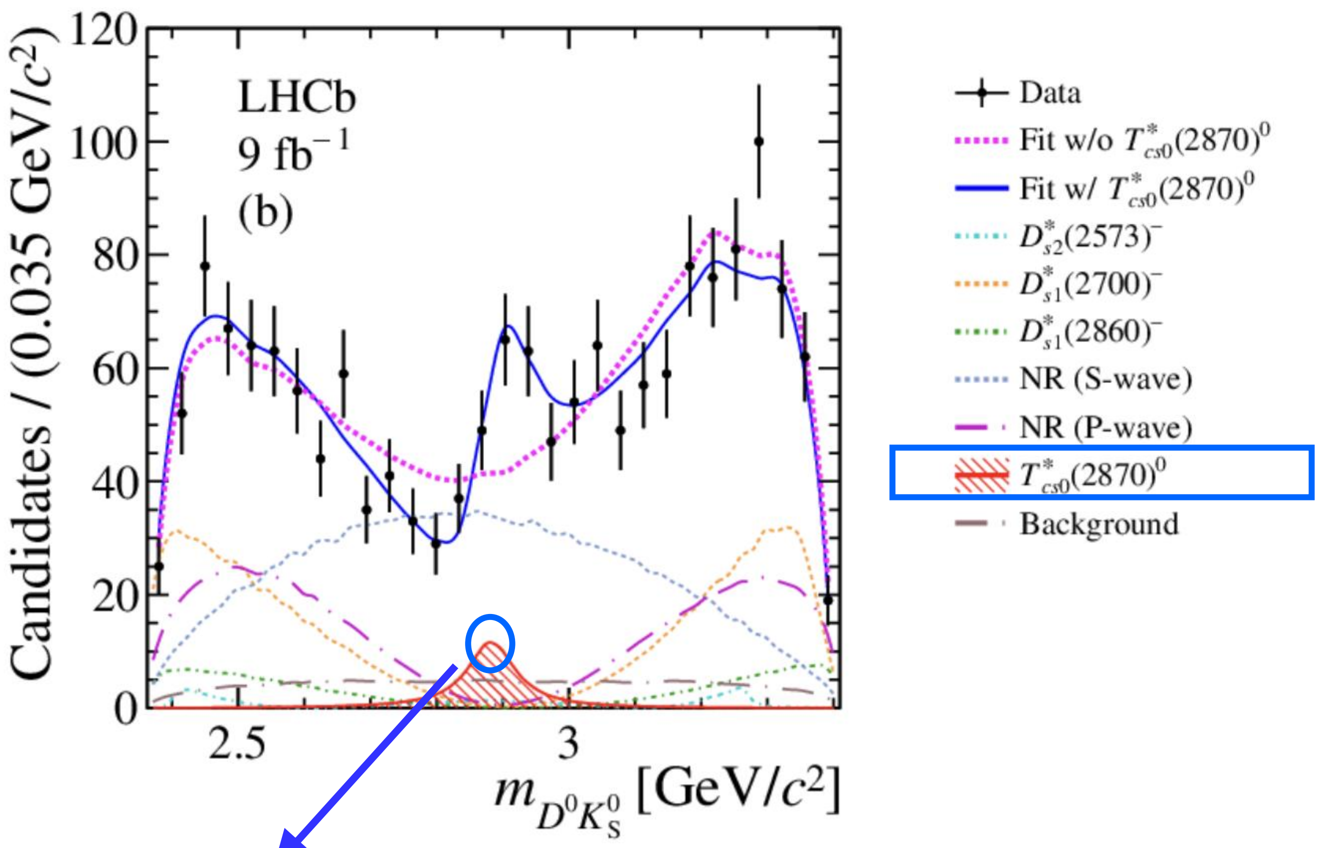
The observation of $T^{*}_{cs0}(2870)^{0}$

pp collision

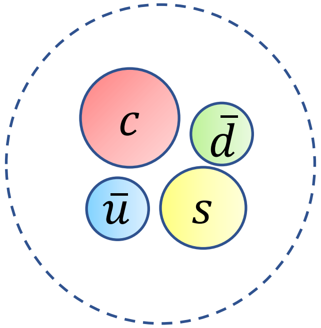
$B^{-} \rightarrow D^{-}D^{0}K_{S}^{0}$

LHCb

Phys.Rev.Lett. 134 (2025) 10, 101901



$T^{*}_{cs0}(2870)^{0}$

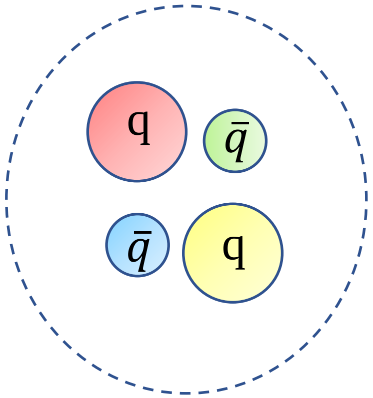


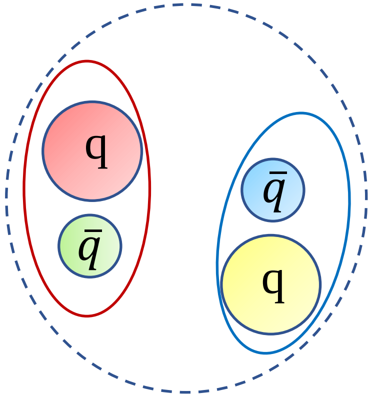
open-charm tetraquark candidate

Only $T^{*}_{cs0}(2870)^{0}$

No evidence for $T^{*}_{cs1}(2900)^{0}$

Explanations of $T^{*}_{cs0}(2870)^0$





Tetraquark:

Phys.Rev.D 102 (2020) 9, 094016

Eur.Phys.J.C 80 (2020) 11, 1026

Phys.Rev.D 105 (2022) 5, 054018

Hadronic molecular:

Phys.Rev.D 102 (2020) 9, 091502

Phys.Rev.D 104 (2021) 9, 094012

Chin.Phys.C 45 (2021) 2, 021003

……

The nature of exotic state $T^{*}_{cs0}(2870)^0$ is controversial.

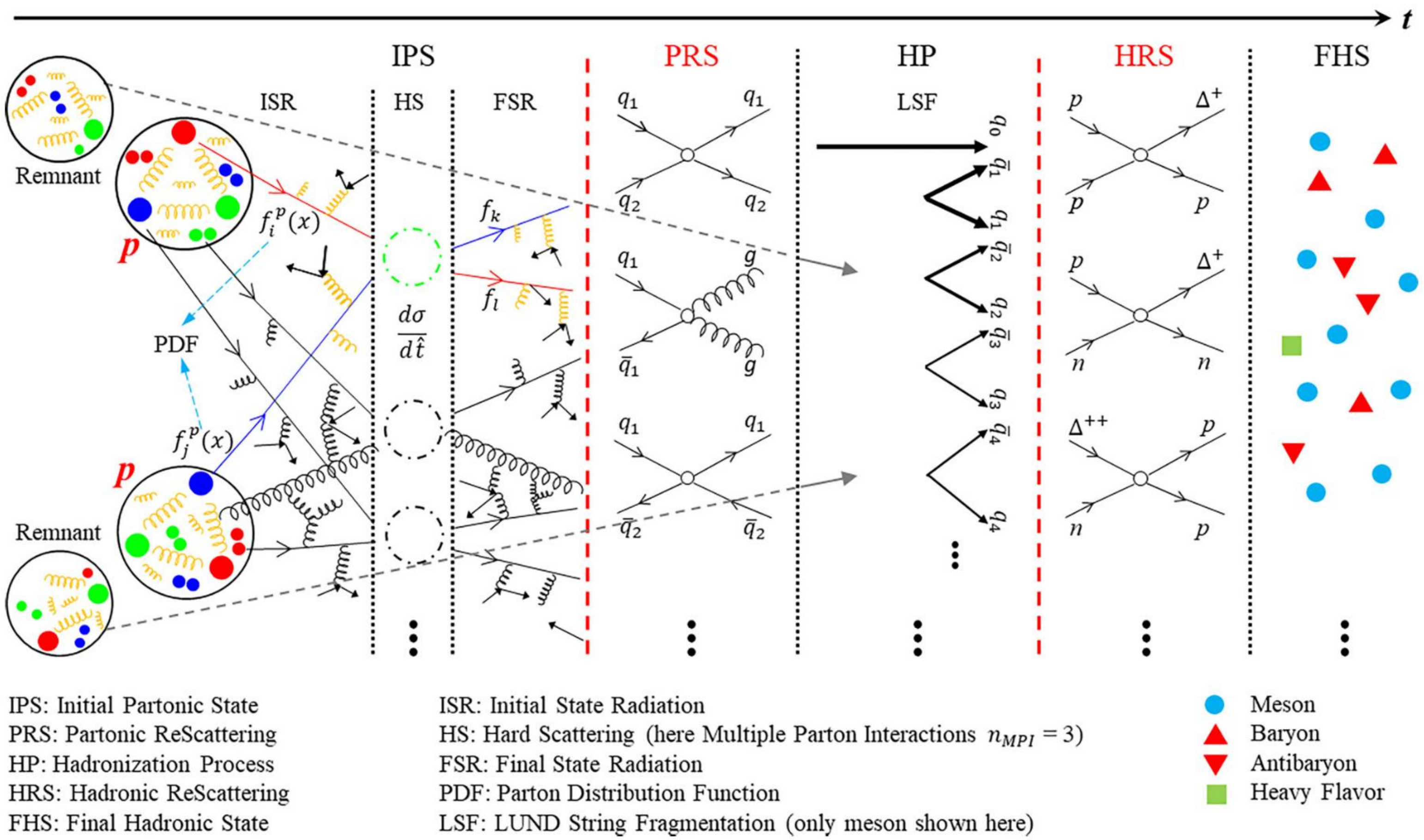
We will focus on the explanation of **hadronic molecular state** for $T^{*}_{cs0}(2870)^0$.

Phys.Rev.D 108 (2023) 1, 014015

PACIAE model studying $T^{*}_{cs0}(2870)^{0}$

The PACIAE model

Phys.Rev.C 108 (2023) 6, 064909



Sketch for the physical routines in a high-energy pp simulation

PACIAE： **P**arton **A**nd-hadron **CIAE** (the parton and hadron cascade model)

The model is based on the **PYTHIA** model , can be used to describe elementary particle collisions and heavy-ion collisions.

Open source : https://github.com/ArcsaberHep/PACIAE

The DCPC model

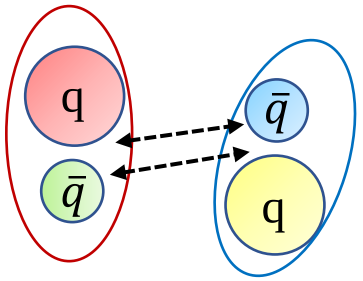
DCPC：**D**ynamically **C**onstrained **P**hase-space **C**oalescence model

- The cluster yield containing *N* particles is: $$Y_N = \int \ldots \int_{E_a \leq H \leq E_b} \frac{\mathrm{d}\vec{r}_1 \mathrm{d}\vec{p}_1 \ldots \mathrm{d}\vec{r}_N \mathrm{d}\vec{p}_N}{h^{3N}},$$

  E_a and E_b : the lower and upper energy thresholds

- The yield of hadronic molecular state $T^*_{cs0}(2870)^0$ can be written:

$$Y_{T^*_{cs0}(2870)^0} = \int \ldots \int \delta_{12} \frac{\mathrm{d}\vec{r}_1 \mathrm{d}\vec{p}_1 \mathrm{d}\vec{r}_2 \mathrm{d}\vec{p}_2}{h^6},$$



hadronic molecular state

- Where

$$\delta_{12} = \begin{cases} 1 & \text{if} \quad 1 \equiv \mathrm{D}, 2 \equiv \mathrm{K}, \\ & m_0 - \Delta m \leq m_{\mathrm{inv}} \leq m_0 + \Delta m, \\ & r_{i0} \leq R_0, (i = 1, 2) \\ 0 & \text{otherwise.} \end{cases}$$

Component constraint

Momentum constraint

Spatial coordinate constraint

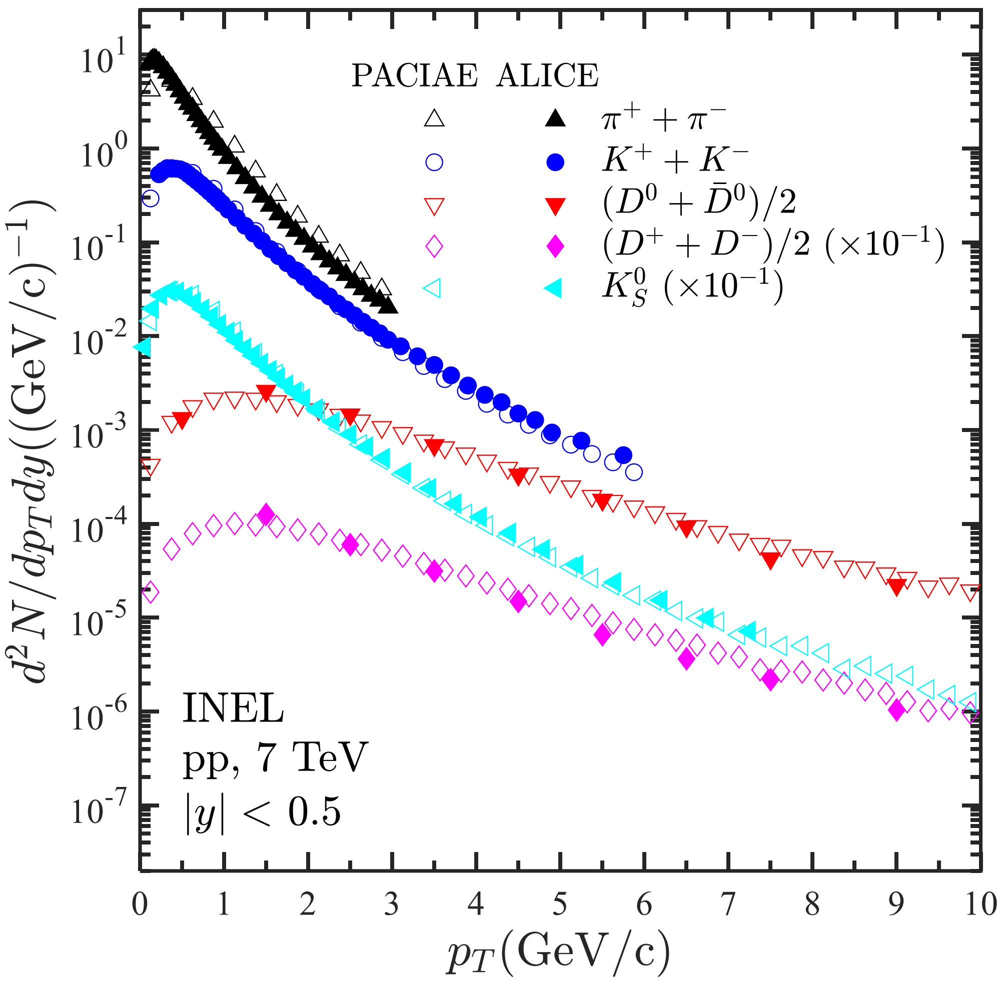
- The invariant mass of cluster can be calculated:

$$m_{inv} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}.$$

$D^0 K^0_S$, $D^+ K^-$, $D^{*+} K^{*-}$, and $D^{*0} \bar{K}^{*0}$

Phys.Rev.C 85 (2012) 024907

p_T spectra of component mesons



ALICE data:

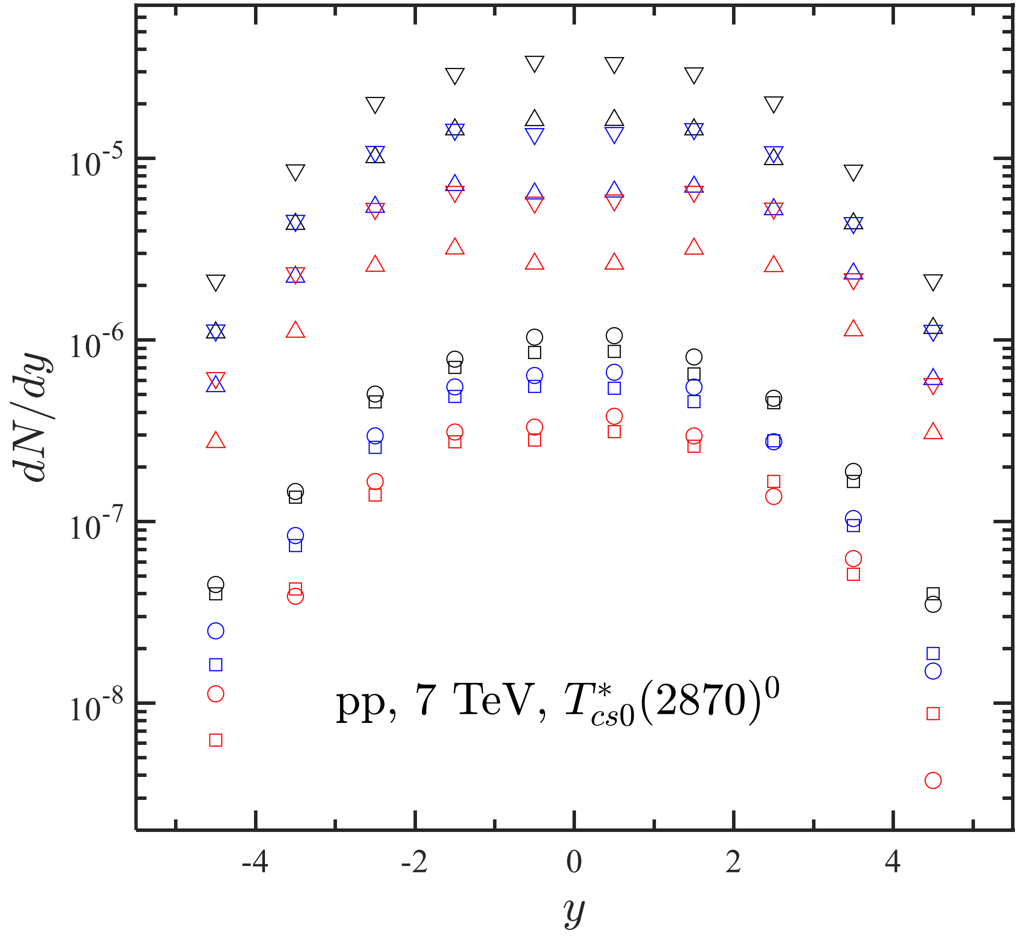
Eur.Phys.J.C 75 (2015) 5, 226

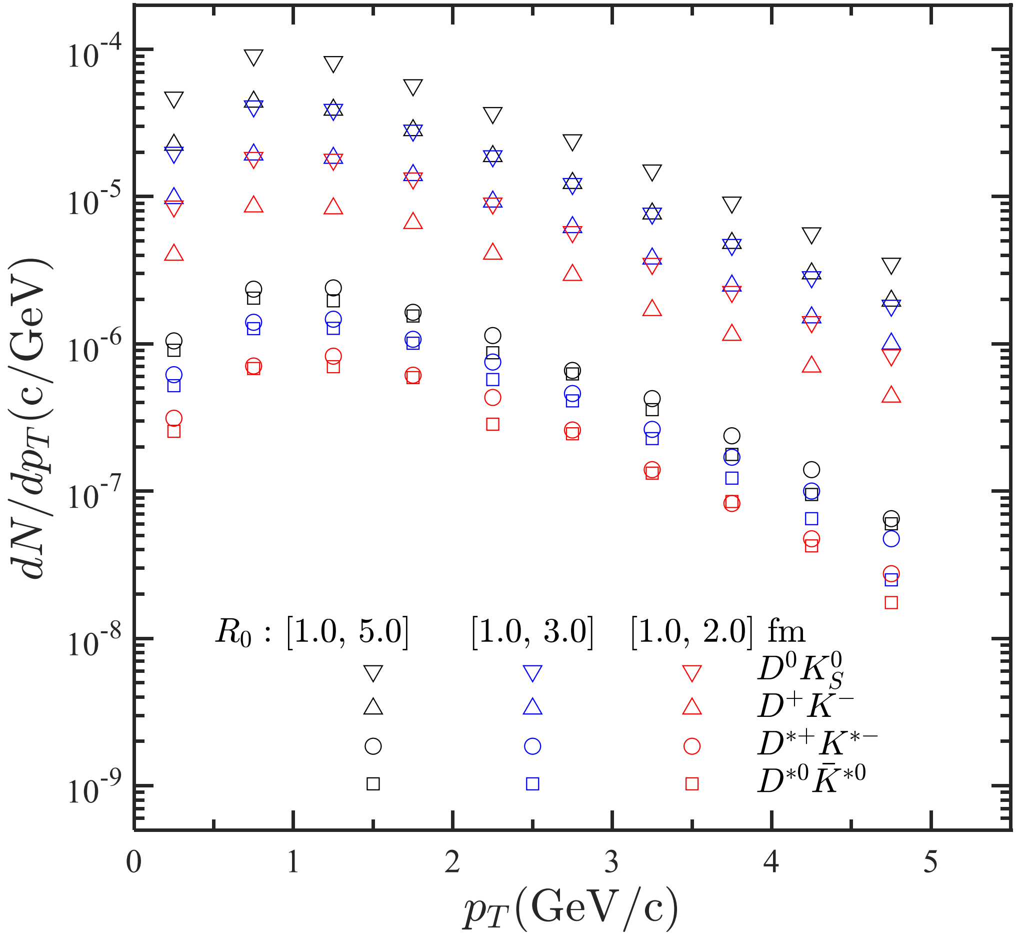
Eur.Phys.J.C 77 (2017) 8, 550

Eur.Phys.J.C 81 (2021) 3, 256

arXiv: 2506.20145

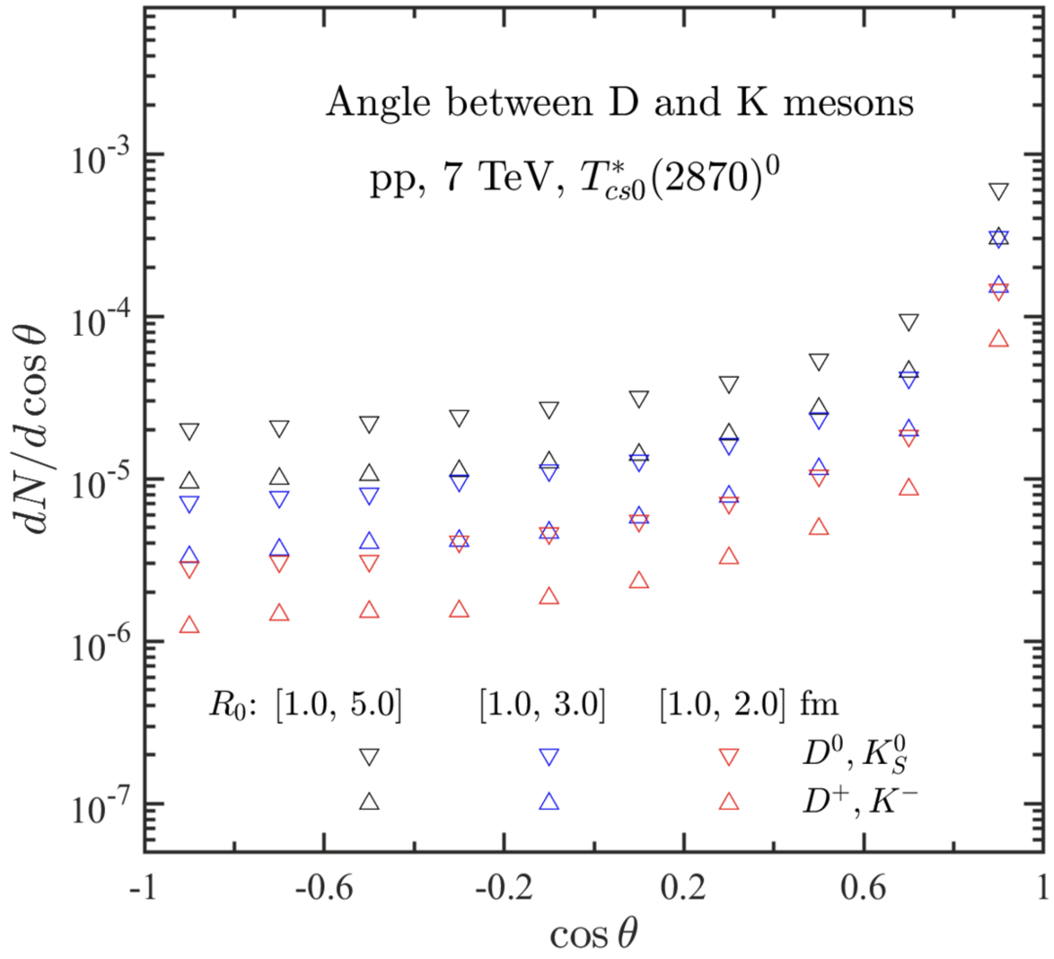
y and p_T distributions of $T^*_{cs0}(2870)^0$

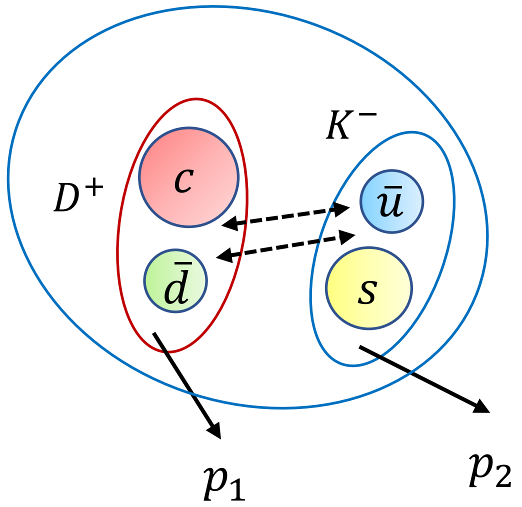




arXiv: 2506.20145

Angular distributions

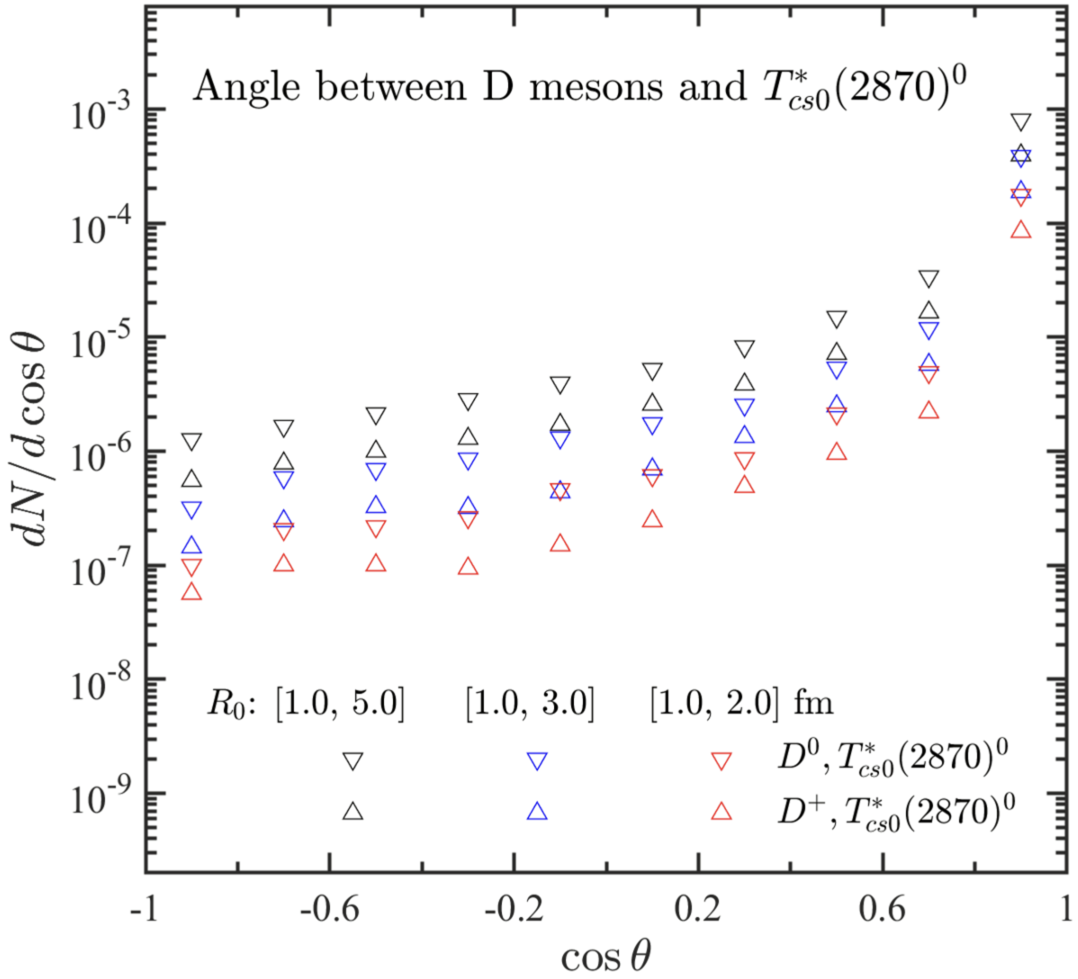


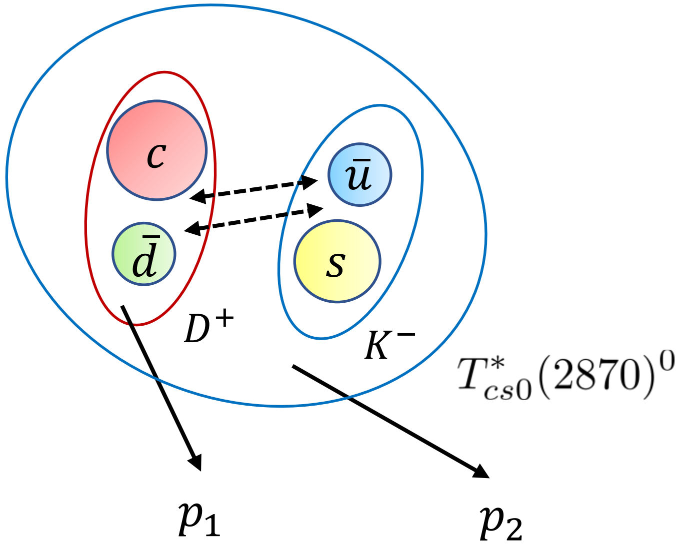


$$\cos\theta = \frac{\vec{p}_1 . \vec{p}_2}{|\vec{p}_1||\vec{p}_2|}$$

arXiv: 2506.20145

Angular distributions





$$\cos\theta = \frac{\vec{p}_1 \cdot \vec{p}_2}{|\vec{p}_1||\vec{p}_2|}$$

arXiv: 2506.20145

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Summary and outlook

Summary and outlook

- We recombined four sets of $T_{cs0}^{*}(2870)^{0}$ molecular state candidates based on the PACIAE model simulated final hadronic state in pp collisions at $\sqrt{s}$ = 7 TeV.
- The yields of four $T_{cs0}^{*}(2870)^{0}$ candidates follow the magnitude order of $D^{0}K_{S}^{0} > D^{+}K^{-} > D^{*+}K^{*-} \sim D^{*0}\bar{K}^{*0}$.

Next studies:

- The extended studies for the pp collisions at $\sqrt{s}$ = 8 and 13 TeV and for the $p-$Pb and/or the Pb $-$ Pb collisions at LHC energies are required..
- Other observables, such as elliptic flow, etc. are also worthy to be investigated.

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谢 谢 观 看

T H A N K Y O U F O R W A T C H I N G

Spectroscopy at LHC

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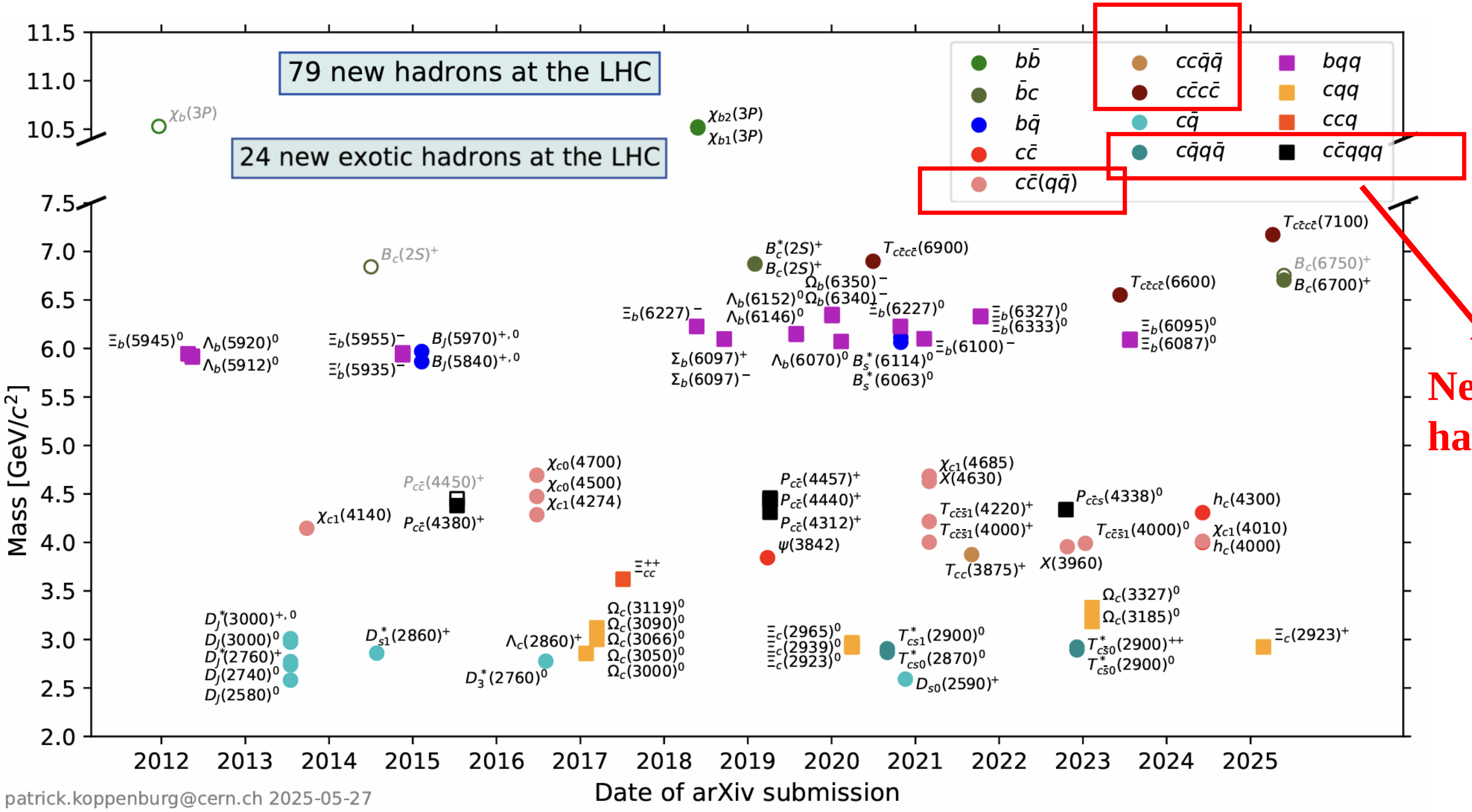

New exotic hadrons

https://www.koppenburg.ch/particles.html