Exploring the hadronic phase with momentum and azimuthal distribution of short-lived resonances and understanding the internal structure of exotic resonances

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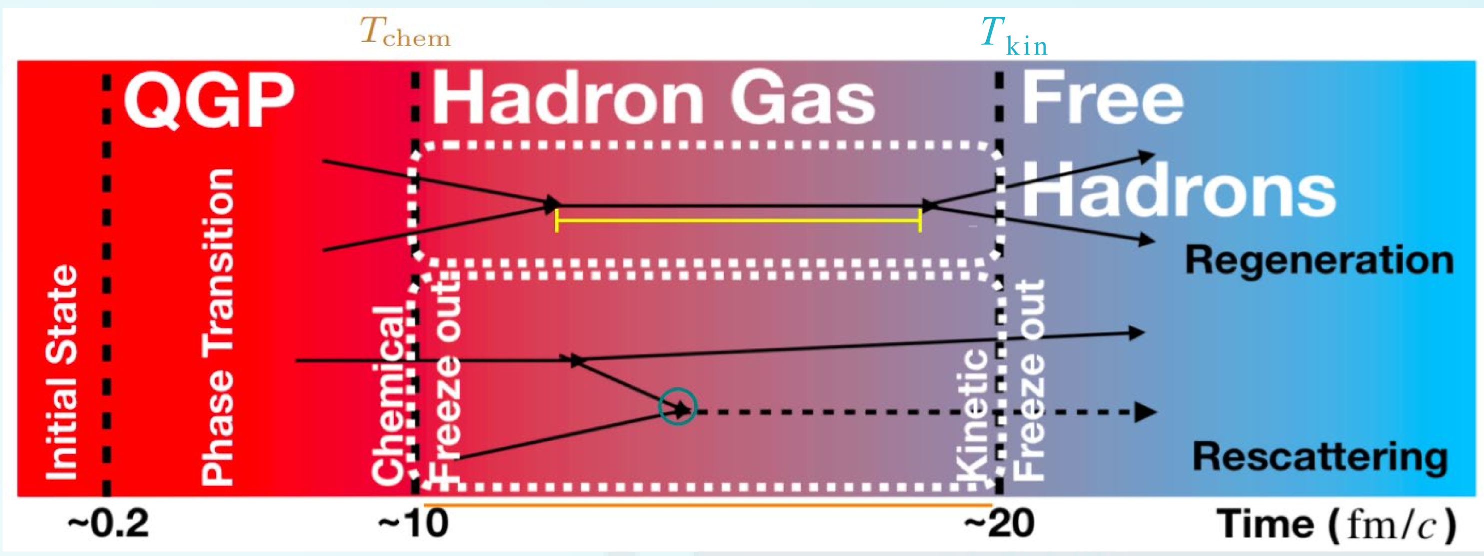
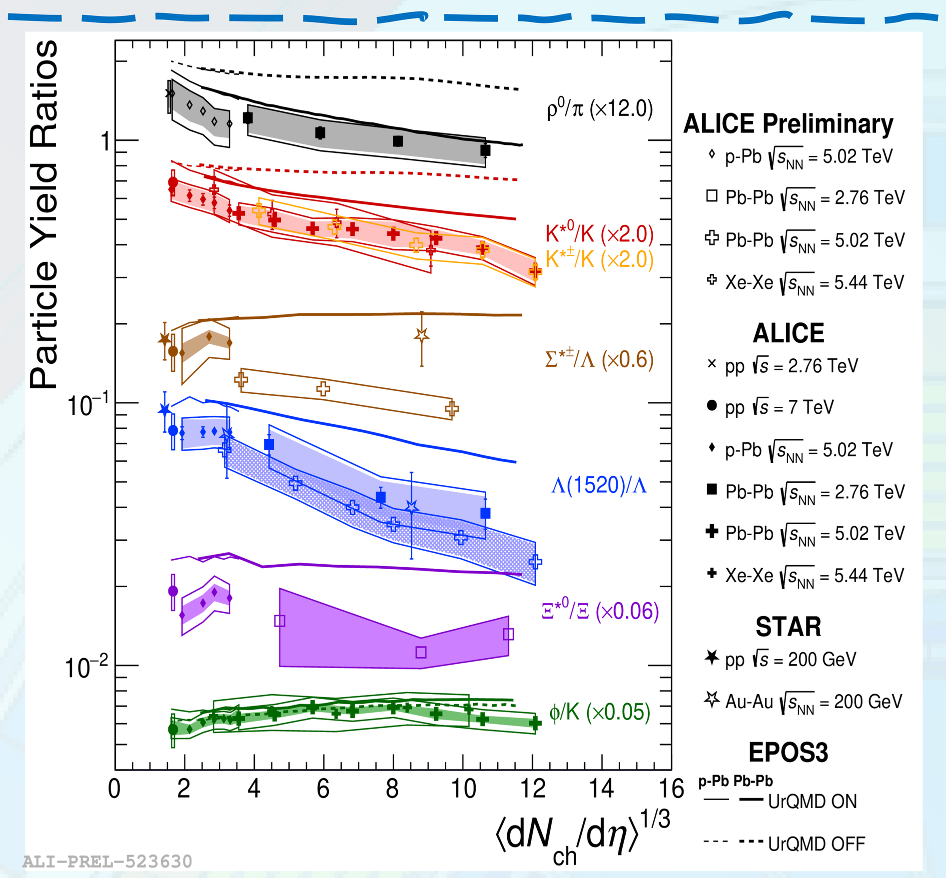
Introduction



- ✓ Resonance yield modifications offer insight into the properties of the late hadronic phase.
- ✓ Exotic hadrons, due to their large decay widths, are often interpreted as resonance states.

Final resonance yields are influenced by:
- ✓ Particle composition at chemical freeze-out.
- ✓ Duration of hadronic phase.
- ✓ Lifetimes of resonances.
- ✓ Scattering cross sections of decay products.

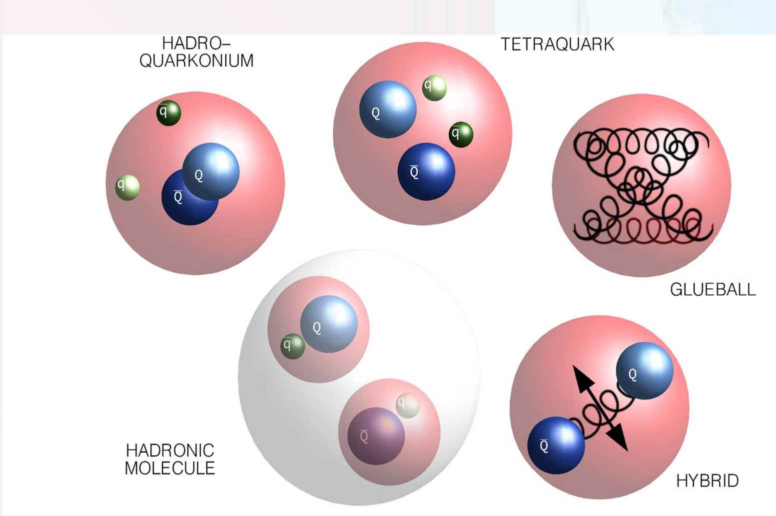
Several short-lived resonances show suppression with increasing event multiplicity
- ✓ continuous from small to large collision systems **for mesons**.
- ✓ **For baryons**: significant in large collision systems.
- ✓ Resonances with longer lifetimes are generally not suppressed.
- ✓ The trend is qualitatively reproduced by EPOS3 with UrQMD afterburner, highlighting the role of hadronic re-scattering.
- ✓ Suppression is neither observed nor expected for $\Sigma^{*\pm}$, $\Lambda(1520)$ in small systems.



	$f_0(980)$	$a_0(980)$	$\kappa(700)$	$f_1(1285)$	$K_1(1270)$	$f_0(1710)$
Mass (MeV/c^2)	990	990	630–730	1,281	1,253	1,730
Width (MeV/c^2)	10-100	60–150	500–700	20	15	150
J^P	0^+	0^+	1^+	0^+	1^+	0^+

$K_1 \rightarrow K^*\pi$

Table: Examples of exotic resonances and their properties



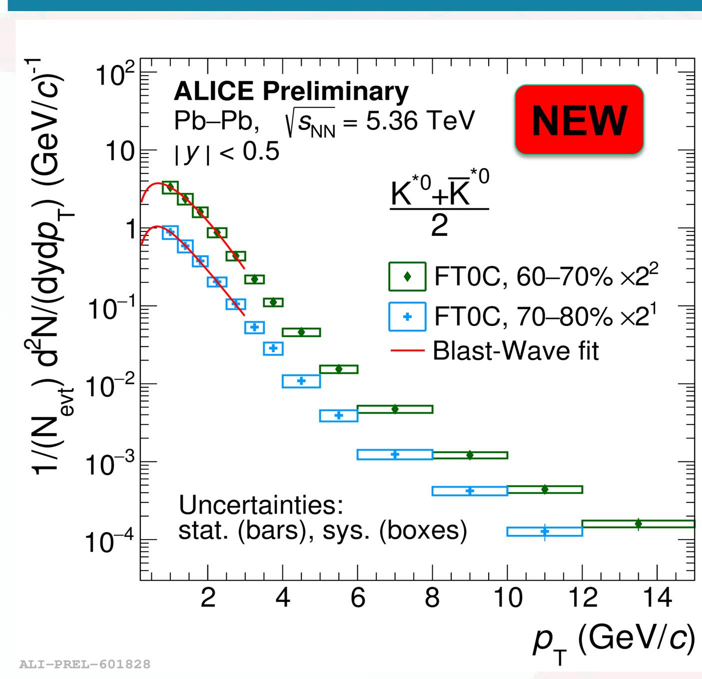
The **internal structure of exotic hadrons** is still under debate. Several interpretations exist:

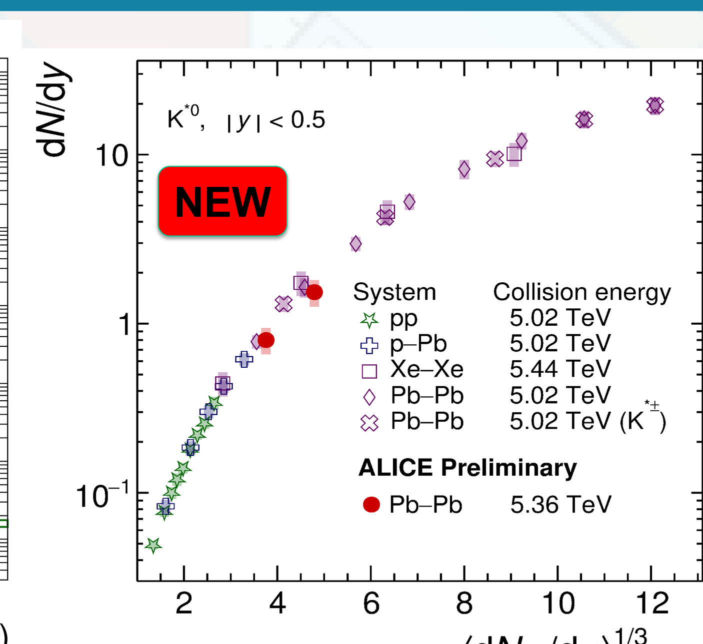
Tetraquark: $(u\bar{u} + d\bar{d})s\bar{s}$ [1]
Molecular state: KK for $f_0(980)$, KK* for $f_1(1285)$ [2]
Conventional meson: $u\bar{u} + d\bar{d}$ [3]

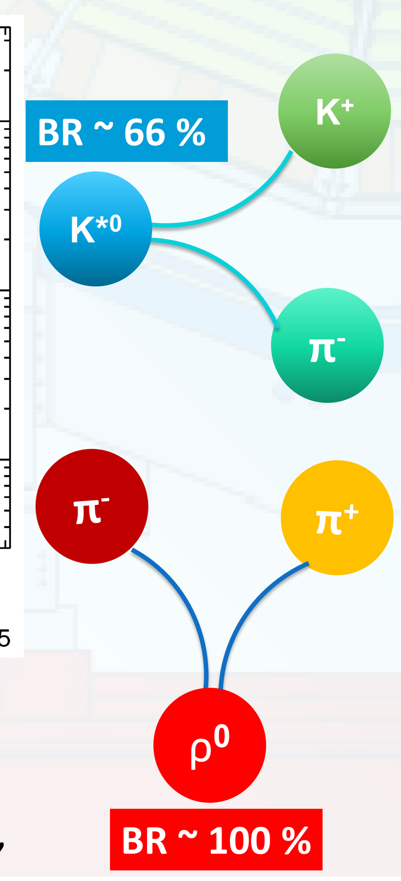
Lattice QCD predicts existence of **glueballs** in the mass range 1 - 5 GeV/c^2 [4].

Glueballs: Particles composed entirely of gluons.
$f_0(1710)$ in $K_S^0K_S^0$ decay channel could be a glueball candidate [5].

Short-lived resonances

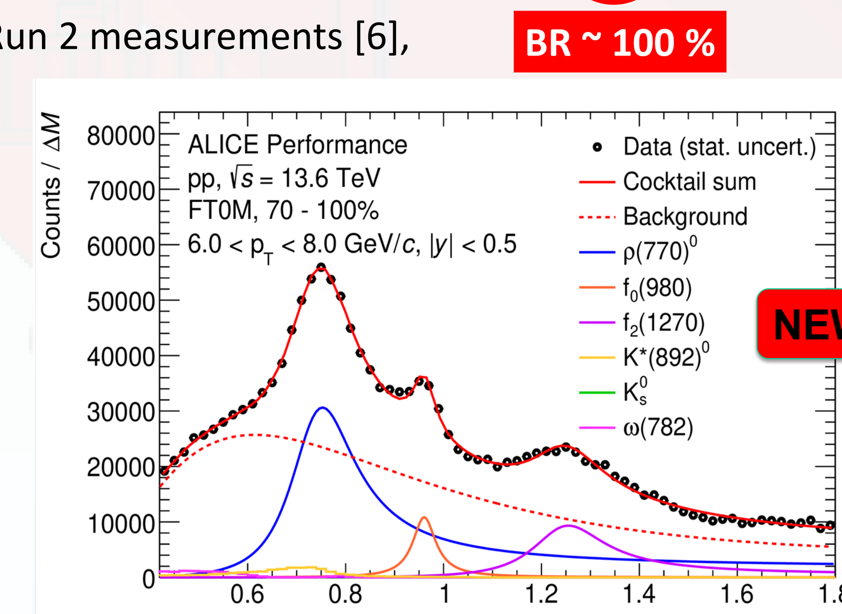




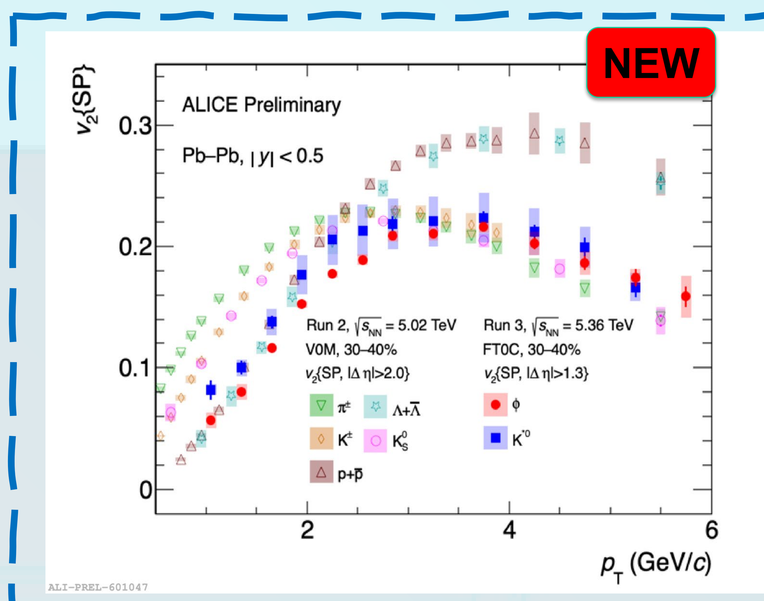


K*0(892):
- ➢ The Blast-Wave model provides a good description of transverse momentum (p_T) distributions at low p_T.
- ➢ p_T–integrated yield in Run 3 are consistent with Run 2 measurements [6], validating analysis techniques and trends.

ρ0(770):
- ➢ Invariant-mass distribution with like-sign background subtraction reveal clear peaks from various hadronic decays, enabling precise resonance identification.
- ➢ The increased statistics from Run 3 will facilitate multiplicity-dependent studies of ρ0 production.

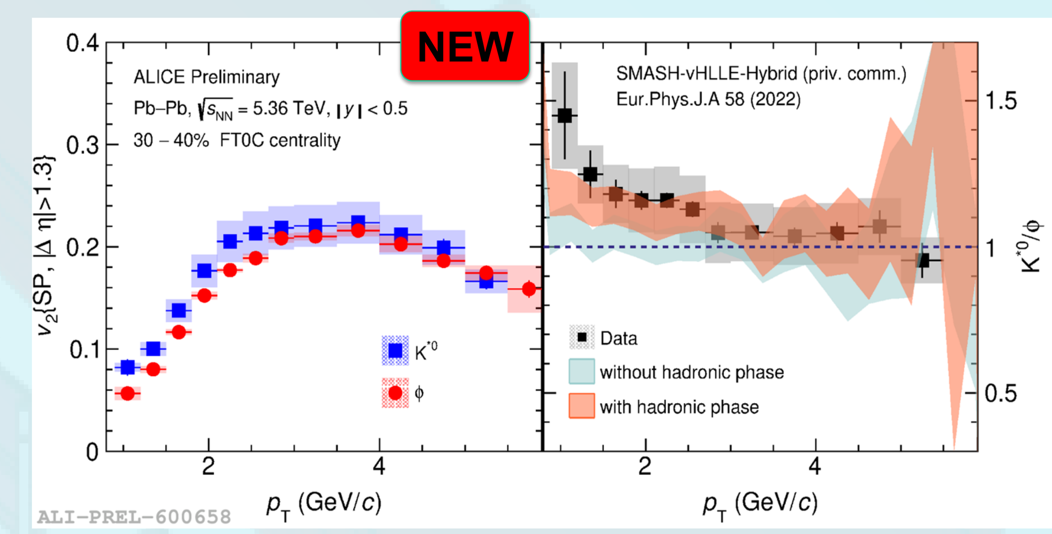


Resonance Flow: A Probe of the Hadronic Phase

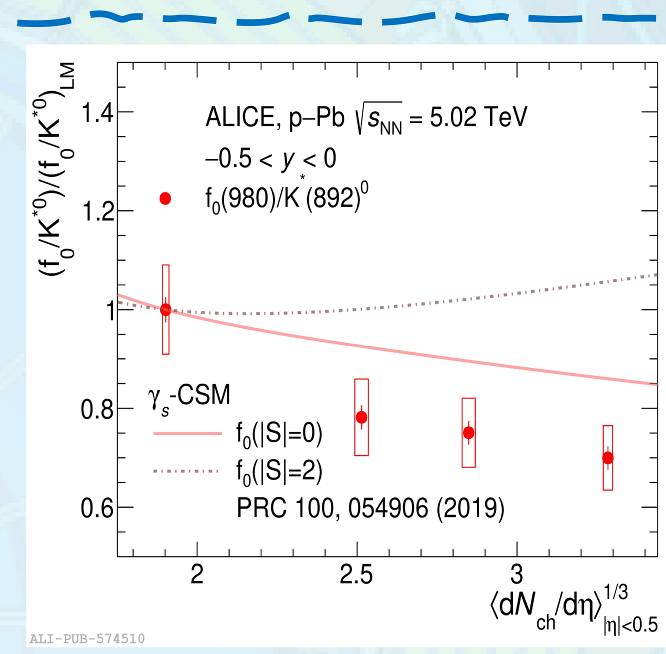


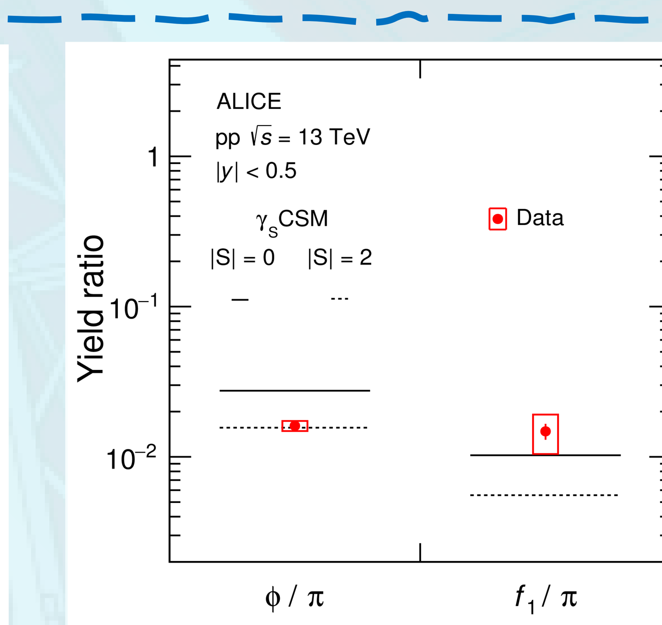
Anisotropic flow of K*0(892) and ϕ mesons in Run 3:
- ✓ K*0(892) and ϕ meson exhibit clear meson–baryon flow splitting at intermediate p_T, consistent with previous observations.
- ✓ Both resonances follow the trend of other mesons ⟹ presence of partonic collectivity prior to hadronization.

- ✓ K*0(892) exhibits a higher flow (v_2) than the ϕ meson, particularly at low p_T.
- ✓ At intermediate p_T, the flow values of both resonances become consistent.
- ✓ This behavior is well-described by models incorporating a hadronic phase.
- ✓ A similar suppression trend in particle yield ratios ⟹ indication of hadronic phase effect on K*0(892) flow.



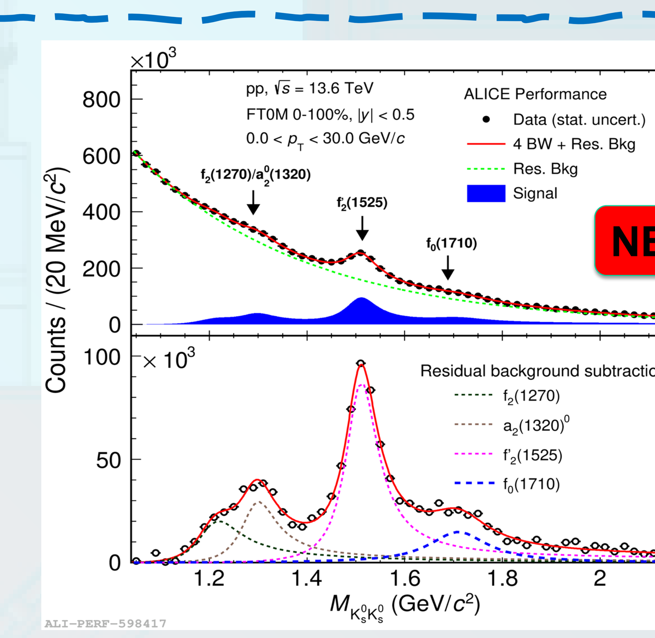
Exotic Resonances





- ▪ A decreasing f_0/K*0 yield ratio is observed [7], consistent with the |S|=0 scenario.
- ▪ Particle yield ratio for $f_1(1285)$ aligns with expectations for hadrons containing no (anti-strange) quarks [8].
- ▪ These observations suggest that both are **likely conventional mesons rather than exotic states.**

Precision Measurements Enabled by Run 3 Statistics:
- ▪ Promising signals of glueball candidates in ALICE.
- ▪ High-statistics data from Run 3 allows for signal identification with excellent significance, even for rare and broad resonances.



Conclusion and Outlook

- ✓ Multi-dimensional resonance measurements serve as powerful tools to probe the hadronic phase between chemical and kinetic freeze-out stages.
- ✓ Resonance yield modifications, influenced by factors such as lifetime and interaction cross sections, provide indirect access to hadron gas properties.
- ✓ The flow of short-lived K0*(892) and ϕ resonances in Pb–Pb collisions offers insights into late-stage hadronic interactions.
- ✓ Yield measurements of exotic candidates like $f_0(980)$ and $f_1(1285)$ are consistent with the "**no strange quark**" hypothesis, suggesting a conventional meson structure.

- ❑ The ALICE experiment continues the search for exotic states, including glueball candidates, to explore the QCD spectrum beyond conventional hadrons.
- ❑ Future measurements of additional exotic resonances and differential observables (e.g., v_2, R_{AA}) will help further unravel the role and dynamics of the hadronic phase.

References

[1] **N. N. Achasov et al.**, Phys. Rev. D 103, 014010 (2021)
[2] **H. A. Ahmed and C. W. Xiao**, Phys. Rev. D 101, 094034 (2020)
[3] **C. Chen**, Phys. Rev. D 67, 094011 (2003)
[4] **Y. Chen et al.**, Phys. Rev. D 73, 014516 (2006)
[5] **S. Chekanov et al.**, Phys. Lett. B 578, 33-44 (2004)
[6] **S. Acharya et al.**, Phys. Rev. C 109, 014911 (2024)
[7] **S. Acharya et al.**, Phys. Lett. B 853, 138665 (2024)
[8] **S. Acharya et al.**, Phys. Lett. B 866, 139562 (2025)

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