Workshop on extreme nuclear matter frontiers
极端核物质前沿研讨会

Recent highlights of quarkonium measurements with ALICE

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Yichang, Apr. 27 2026

ALICE

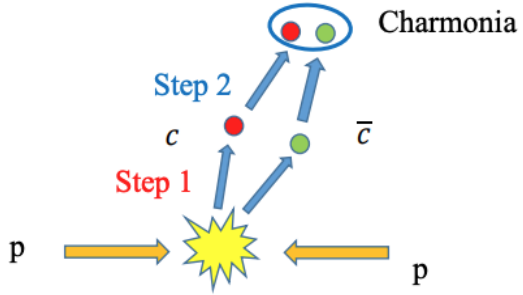
CENTRAL CHINA NORMAL UNIVERSITY

Quarkonium production in pp collisions

- Quarkonia: bound states of heavy quark and heavy anti-quark pairs.

  Charmonia: J/ψ, ψ(2S)…

  Bottomonia: **ϒ**(nS)



- The production mechanism of quarkonia remains as challenge

  (1) Heavy-Quark production (perturbative QCD)

  (2) Formation of the quarkonium states (non-perturbative QCD)

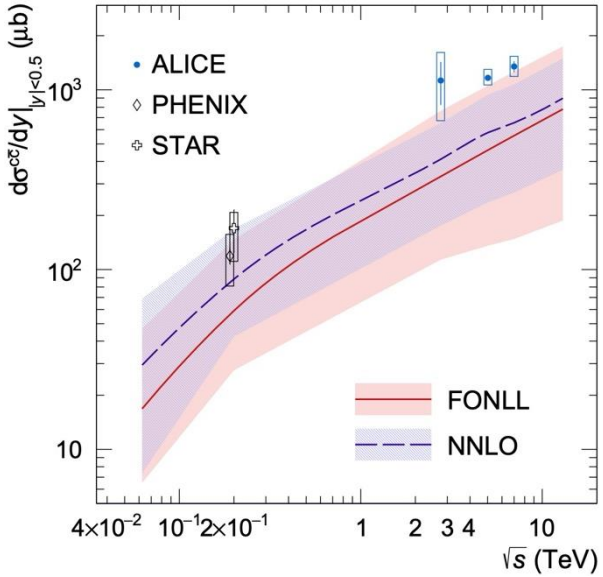
- Non-Relativistic QCD (NRQCD) approach, long-distance effects are described by long distance matrix elements (**LDMEs**) in an effective field theory.

Phys.Rev.D51(1995)1125-1171

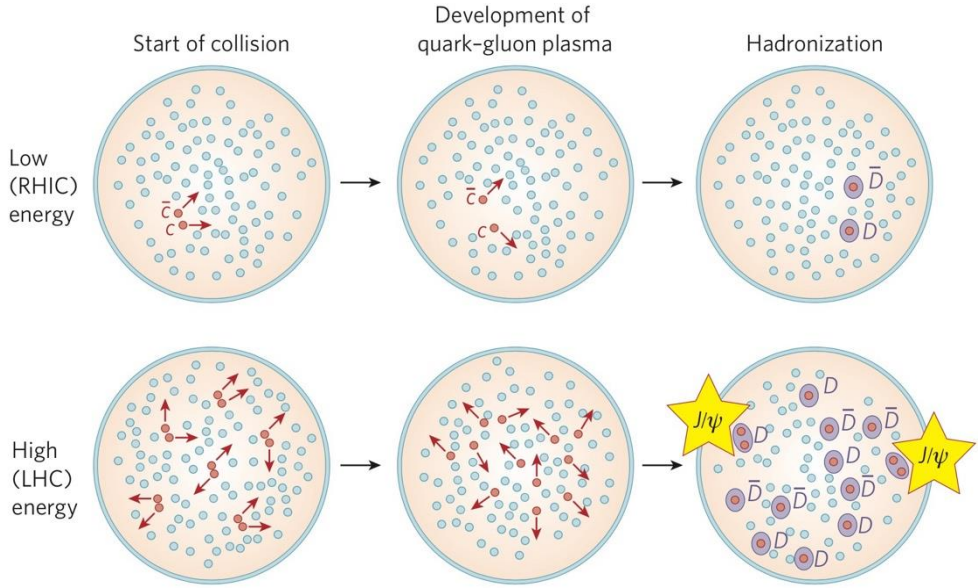
$$(2\pi)^3 2P_H^0 \frac{d\sigma_H}{d^3P_H} = \sum d\hat{\sigma}_n (P_H) \langle \mathcal{O}_n^H \rangle$$

Charmonium production in heavy-ion collisions

ALICE, Phys. Rev. D 105, 011103 (2022)

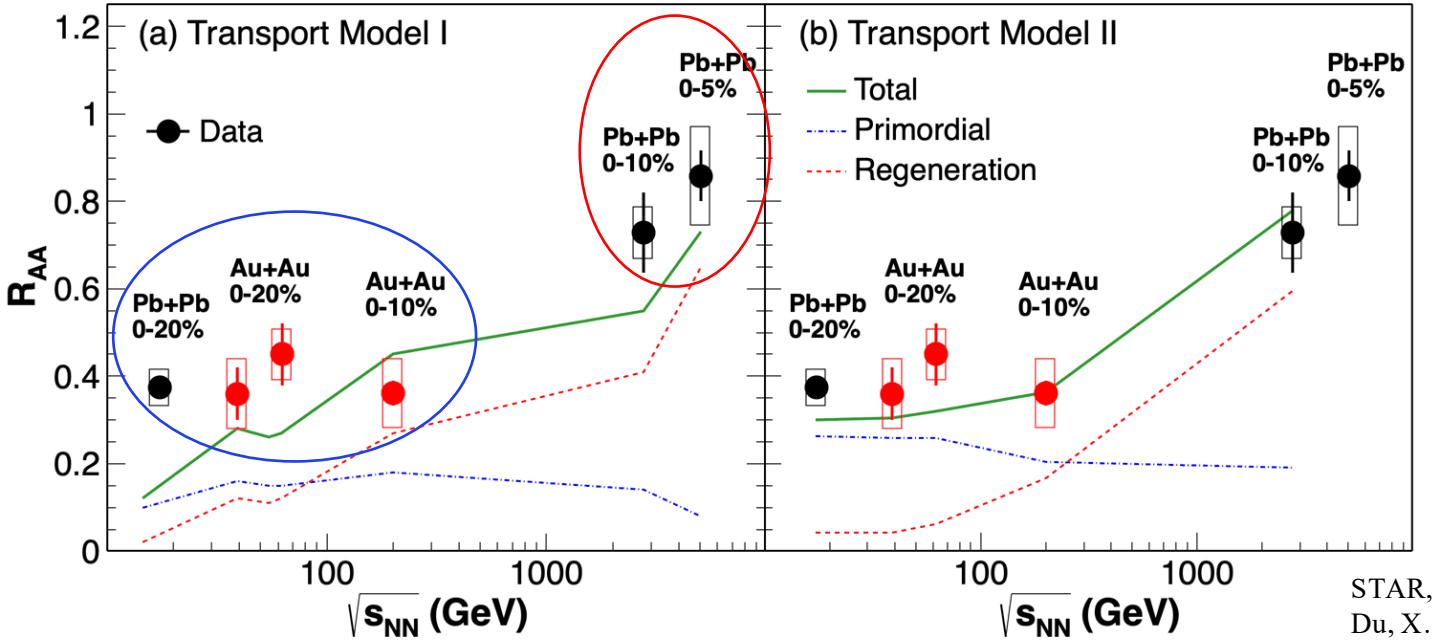


P. Braun-Munzinger, J. Stachel, Nature 448 (2007) 302



- Charm quark production cross section at the LHC is much larger compared to RHIC energies
- The (re-)generation contribution to J/ψ production is dominant at LHC energies

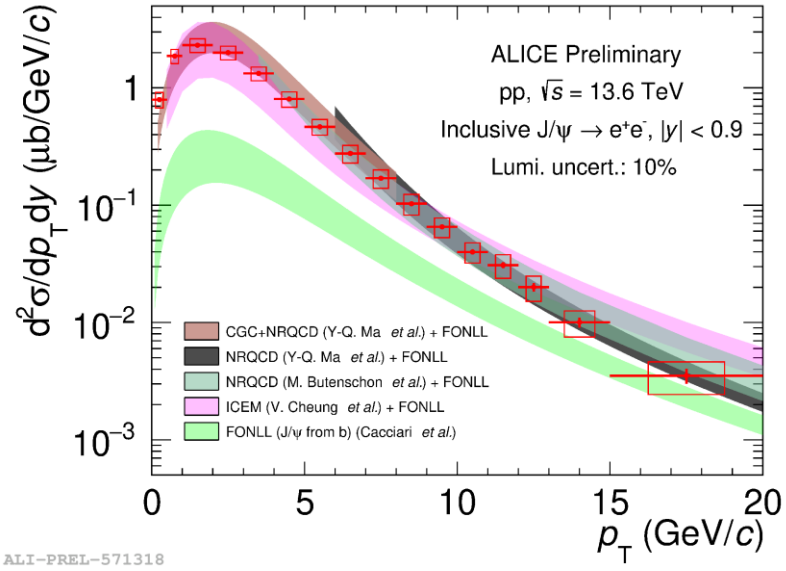
Charmonium production in RHIC and LHC

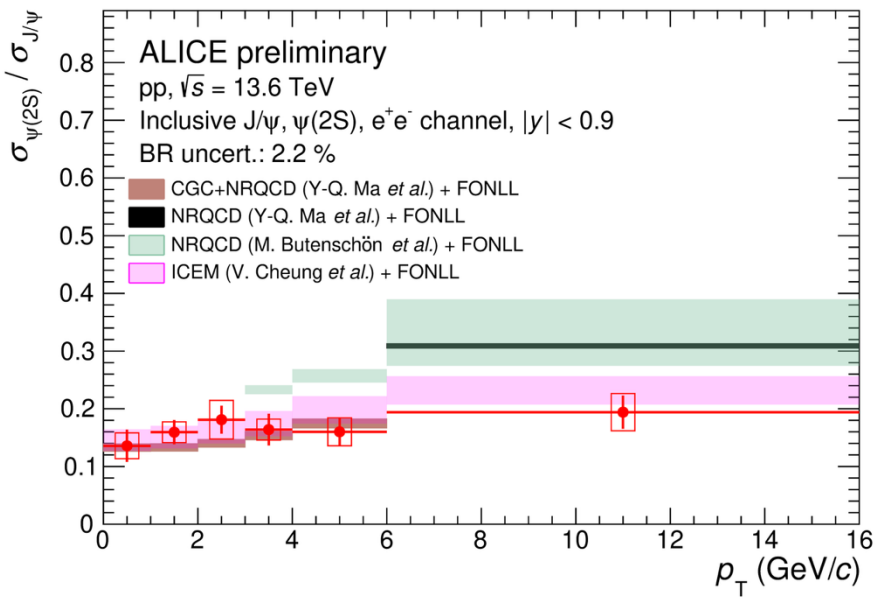


STAR, PLB 877 (2026) 140405
Du, X. et al., NPA 943, 147–158 (2015)
Zhou, K., et al., PRC 89, 054911 (2014)

- Suppression of the charmonia due to colour screening and the dynamic dissociation
- The **(re-)generation** contribution to the J/ψ is significantly higher than at RHIC

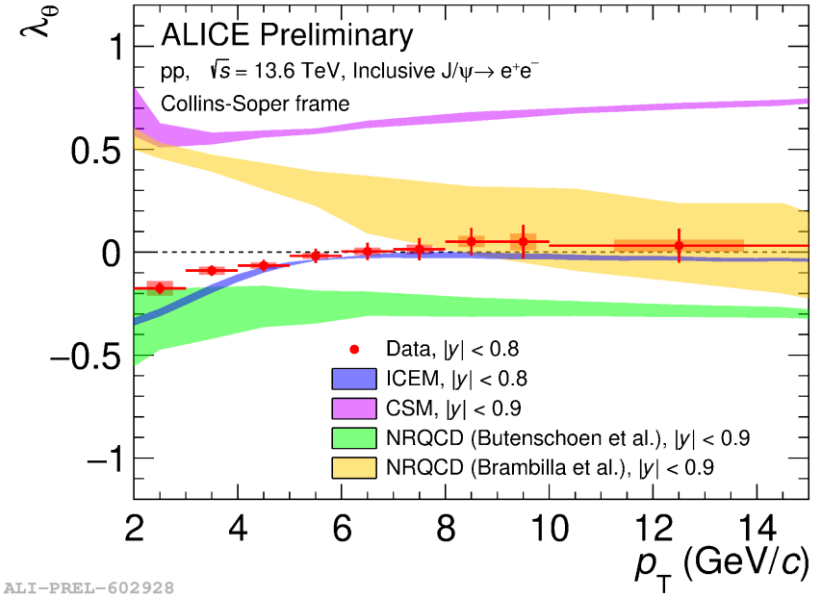
Charmonia in pp collisions at $\sqrt{s}$ = 13.6 TeV

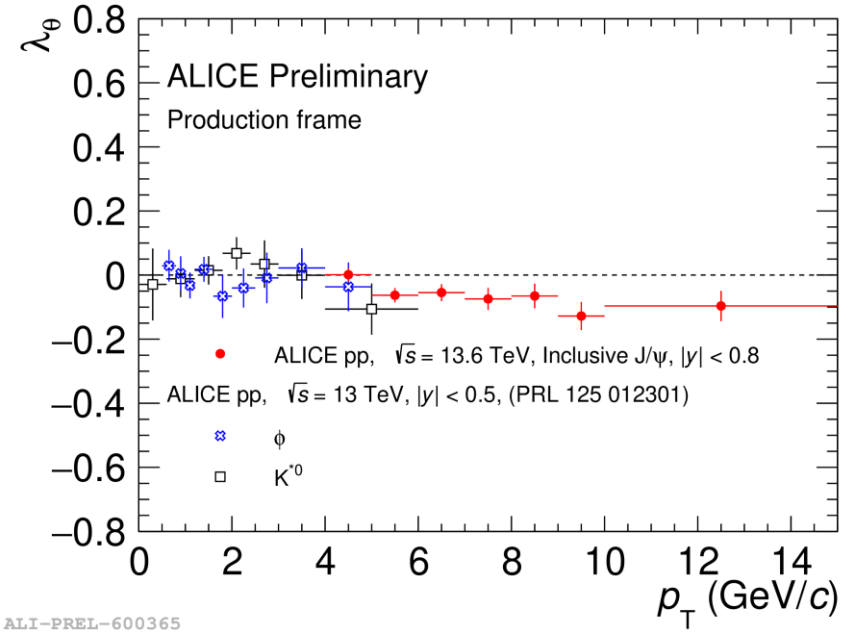




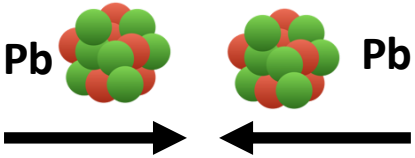
- The new J/ψ cross section is described by ICEM and NRQCD based models, the CGC + NRQCD and ICEM can describe the data at low p_T
- FONLL to account for the non-prompt J/ψ contribution

Charmonia polarization in pp collisions



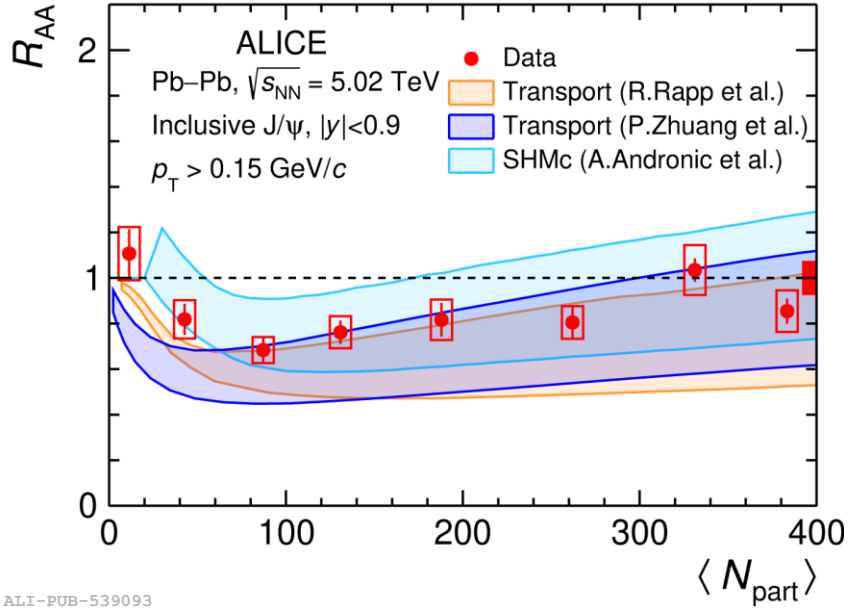


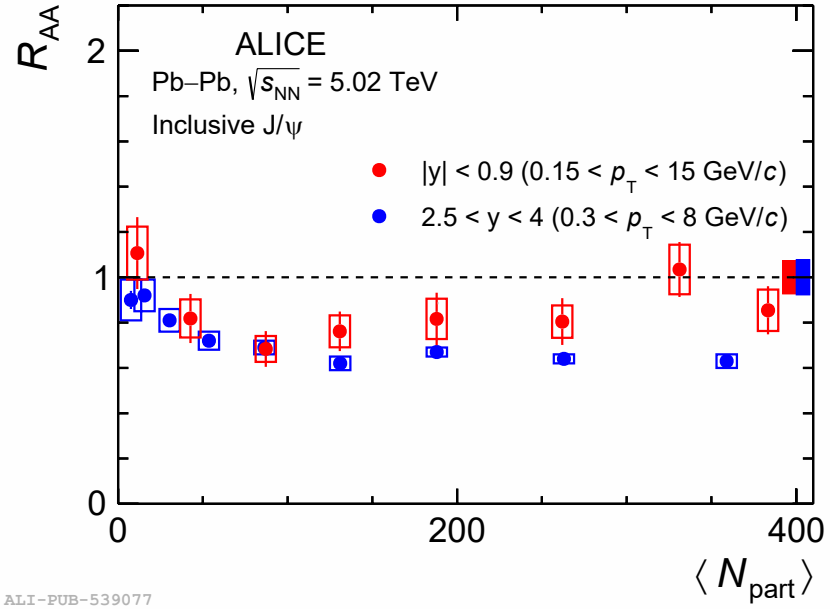
- The measurement of J/ψ polarization in pp collisions at midrapidity. The measurements in Pb–Pb collisions is ongoing
- The data can be described by the ICEM calculations.


Pb
Pb

Inclusive J/ψ R_{AA} vs centrality

ALICE, PLB 849 (2024) 138451



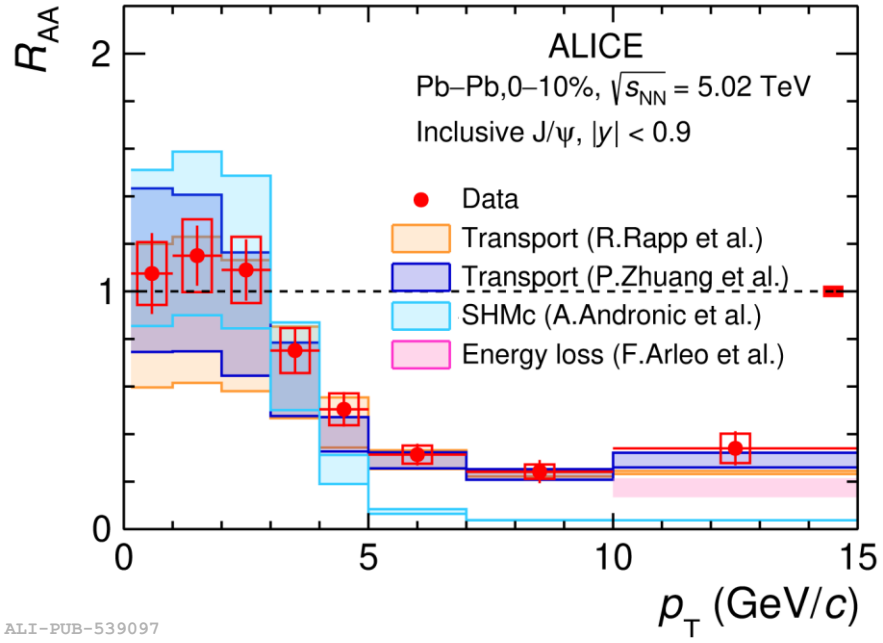


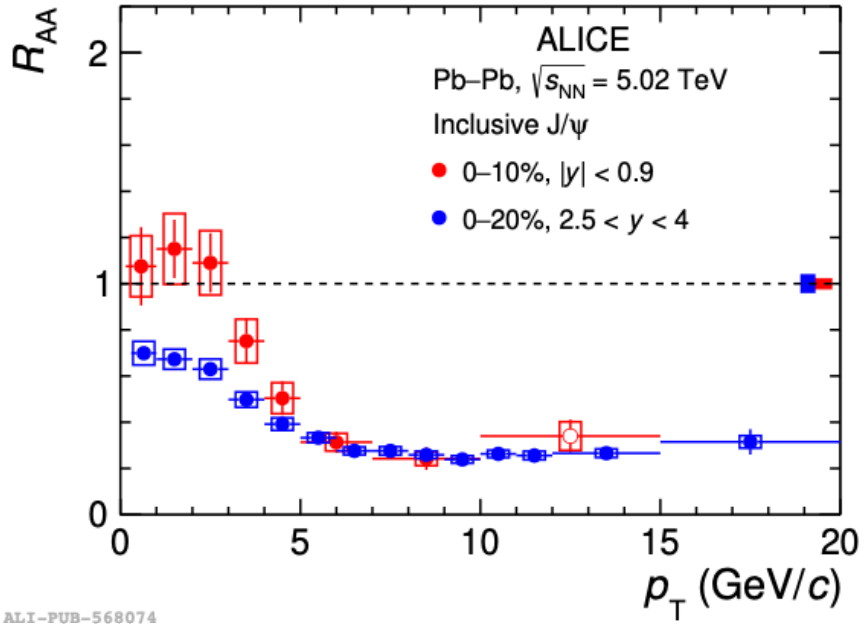
- **Evidence for J/ψ (re-)generation in central collisions, with a larger contribution at midrapidity compared to forward rapidity**
- All models can describe the data but suffer from large uncertainties related to inputs used in calculations (eg. charm cross section, shadowing)

Du, X. et al., NPA 943, 147–158 (2015)
Zhou, K., et al., PRC 89, 054911 (2014)
Andronic, A, et al, PLB 797, 134836 (2019)

Inclusive J/ψ R_{AA} vs p_T

ALICE, PLB 849 (2024) 138451



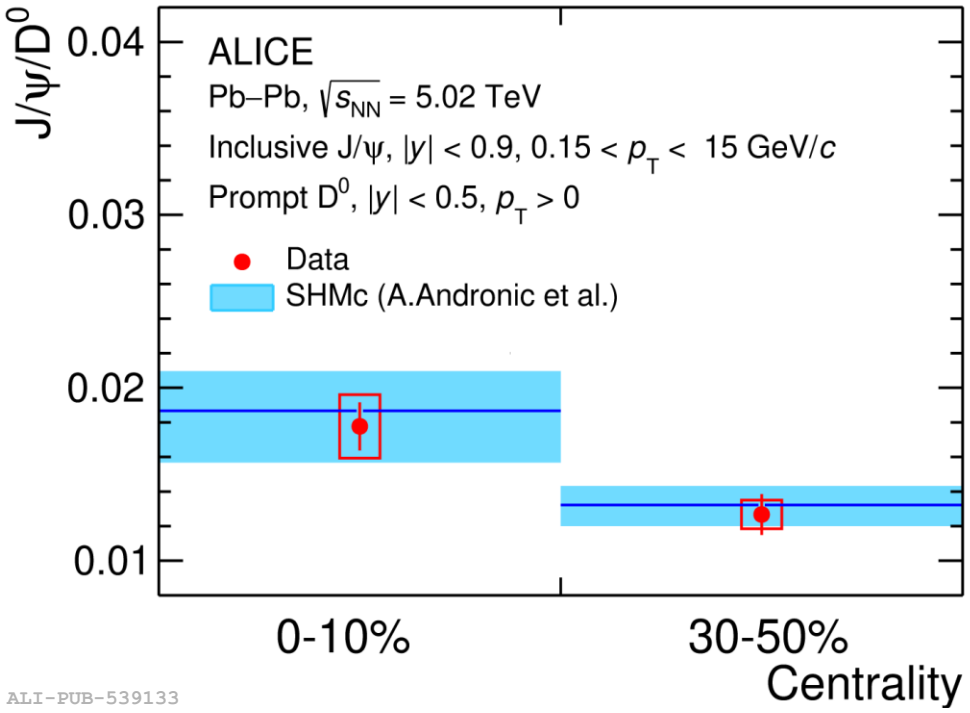


- Transport and SHMc models describe data at low p_T, while SHMc underestimates the measurement at high p_T, the energy loss model agrees with data at high p_T
- **Evidence for the (re-)generation and demonstration of deconfinement at LHC**

Du, X. et al., NPA 943, 147–158 (2015)
Zhou, K., et al., PRC 89, 054911 (2014)
Andronic, A, et al, PLB 797, 134836 (2019)

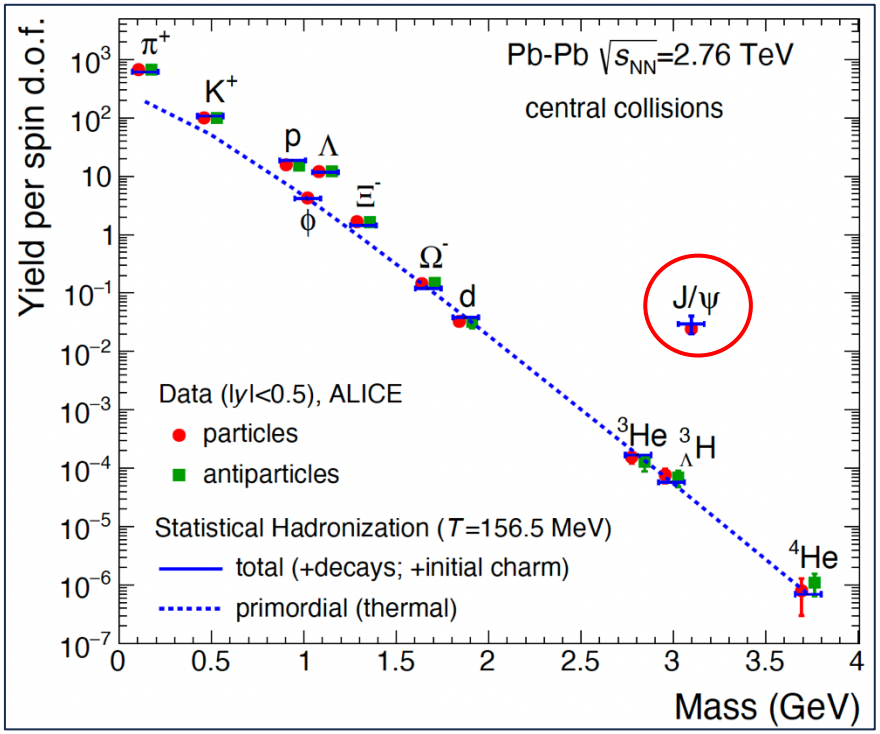
J/ψ-to-D^0 ratio in Pb–Pb collisions

ALICE, PLB 849 (2024) 138451



- Sensitive to hadronization mechanisms for open and hidden charm hadrons
- The centrality-dependent trend of the D^0 to J/ψ ratio can be explained by the increase of charm fugacity towards most central collisions
- **Evidence of charm deconfinement at LHC**

Charm thermalization at LHC



A. Andronic, Nature 561 (2018) 7723, 321-330

The only additional parameters are constrained by data.

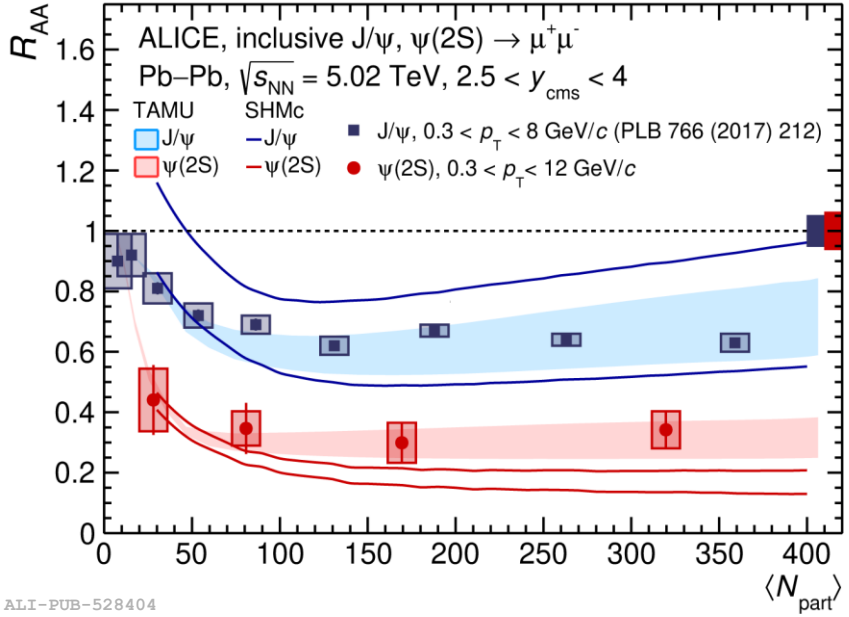
$$N_{c\bar{c}} = 13.8 \rightarrow g_c = 31.5; N_{J/\psi} \sim g_c^2$$

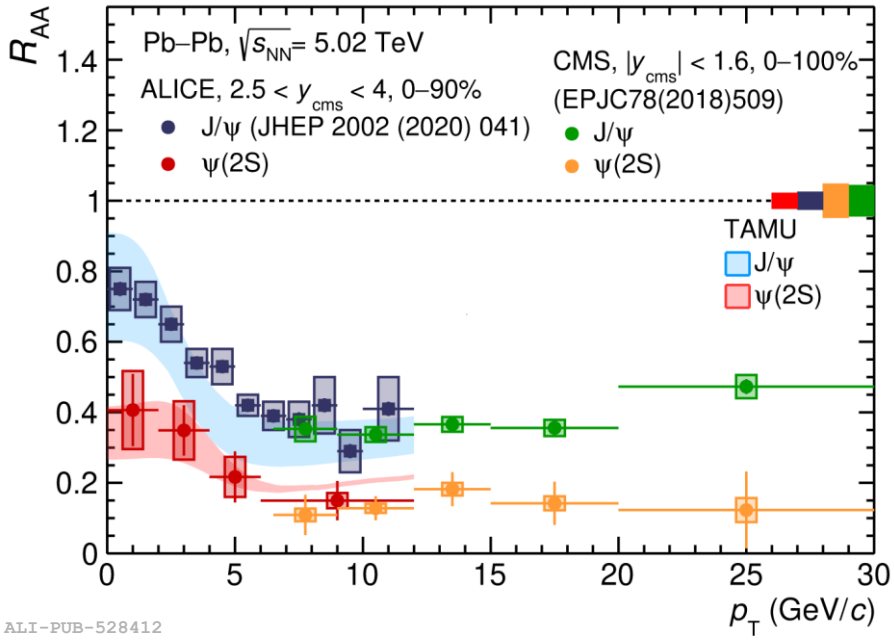
Assumptions:

- **Full thermalization** of charm quarks ("mobility" in V ~ 4000 fm³)
- Full color screening, and without the primordial produced J/ψ (Matsui–Satz)

ψ(2S) R_{AA} in Pb−Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

ALICE, PRL **132**, 042301(2024)

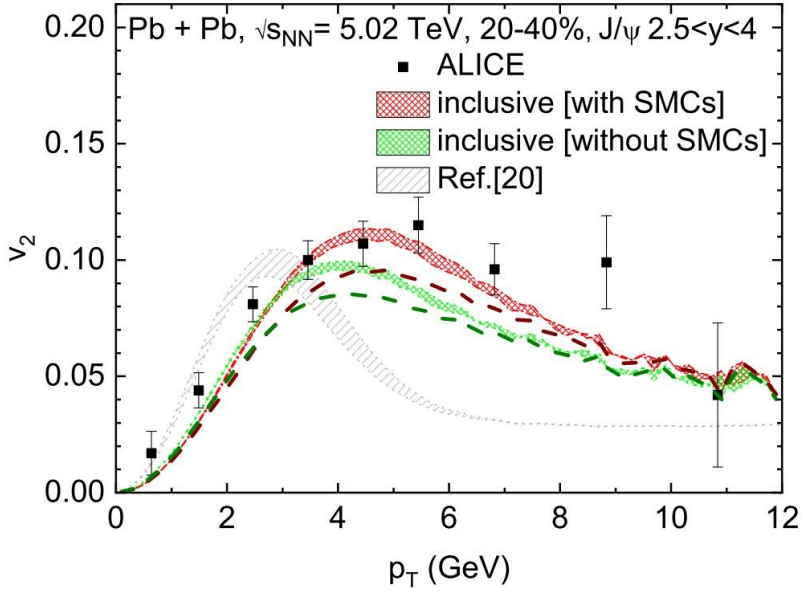


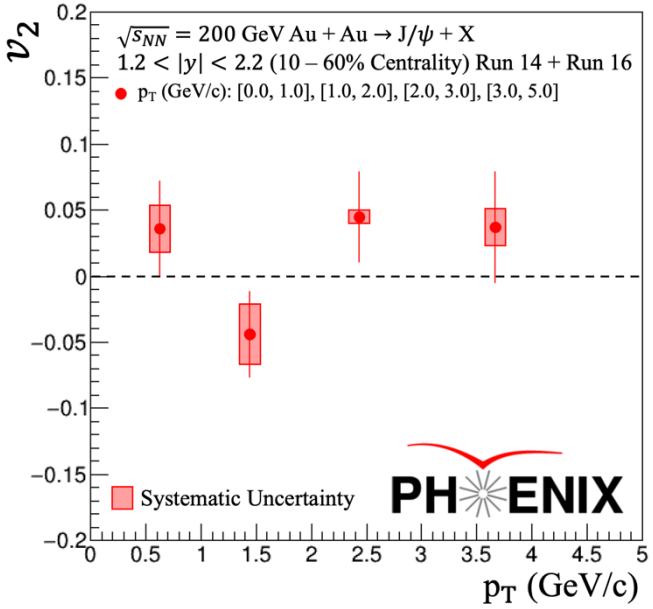


- A **larger suppression** of the ψ(2S) w.r.t the J/ψ is observed
- The ψ(2S) R_{AA} increases at low p_T , which is a hint of ψ(2S) regeneration
- The TAMU model describes data better than SHMc in central collisions

(TAMU) X. Du, et al.,NPA943,147-158(2015)
(SHMc) A. Andronic, et al.,PLB797,134836(2019)

Charmonium elliptic flow in Pb–Pb collisions



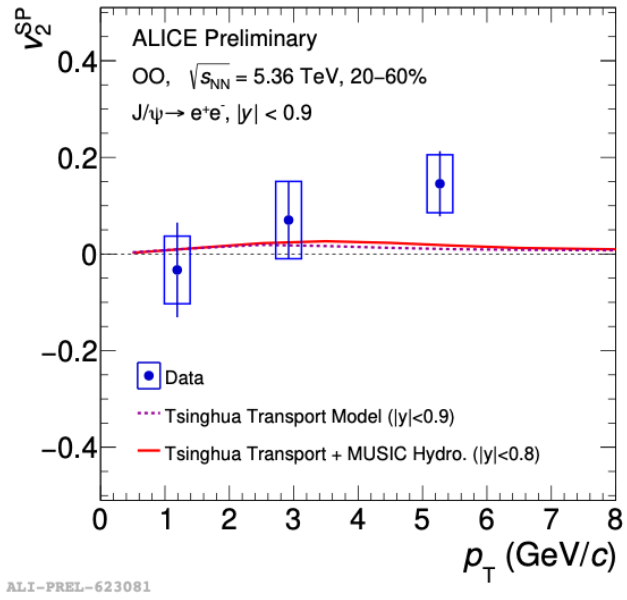


M. He, et al., PRL.128, 162301 (2022)

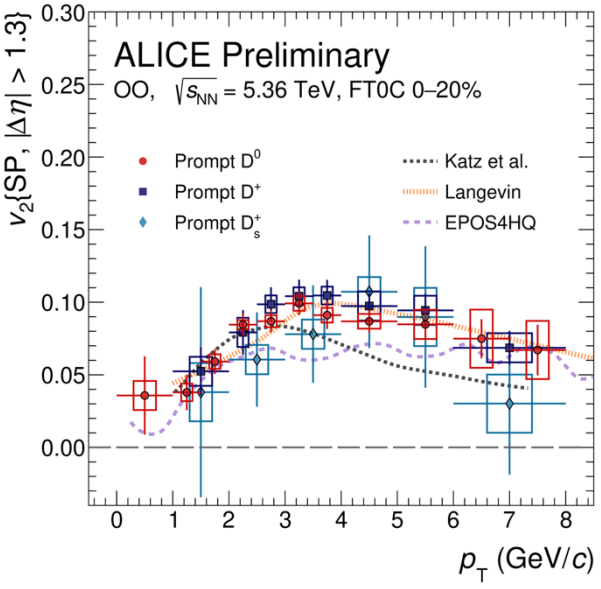
- A significant J/ψ v_2 is observed at LHC energy, while it consistent with 0 at RHIC energy
- Suggest the charm quark thermalization

J/ψ elliptic Elliptic flow measurements in OO

J/ψ elliptic flow

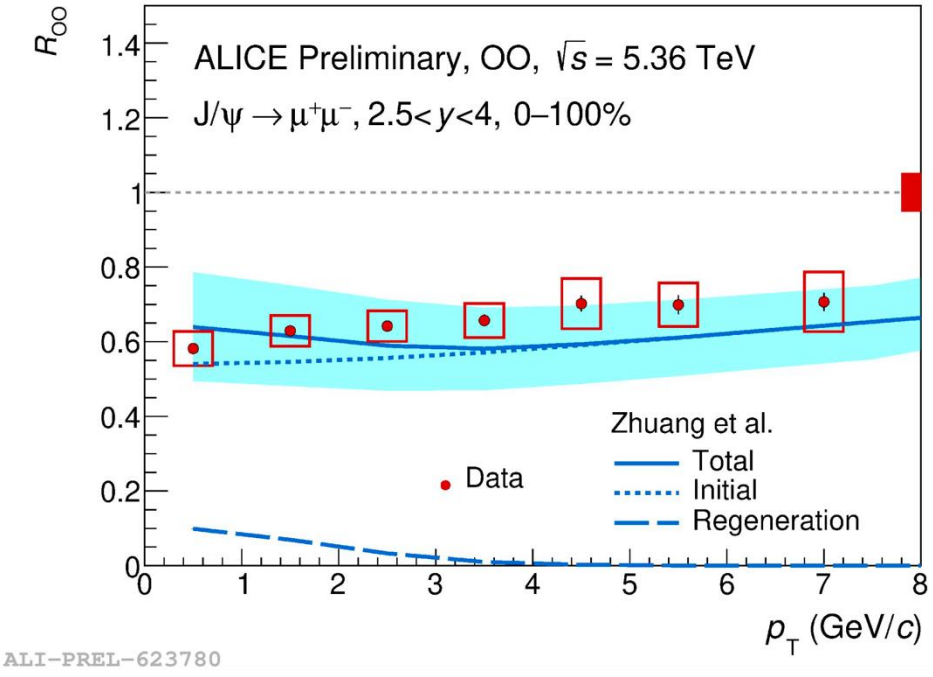


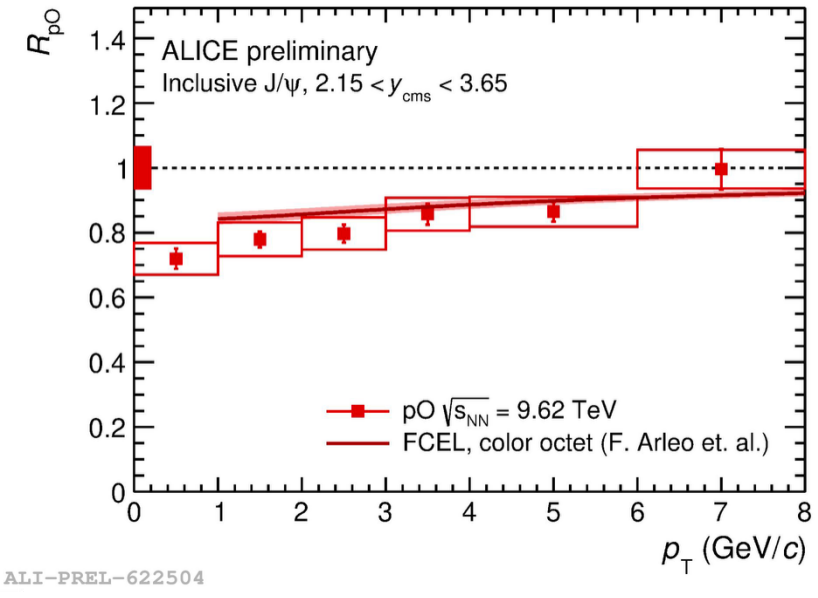
D-mesons elliptic flow



- First observation of positive D-meson elliptic flow in central OO collisions
- J/ψ elliptic flow is suggested from (re-)generation of the thermalized charm quarks

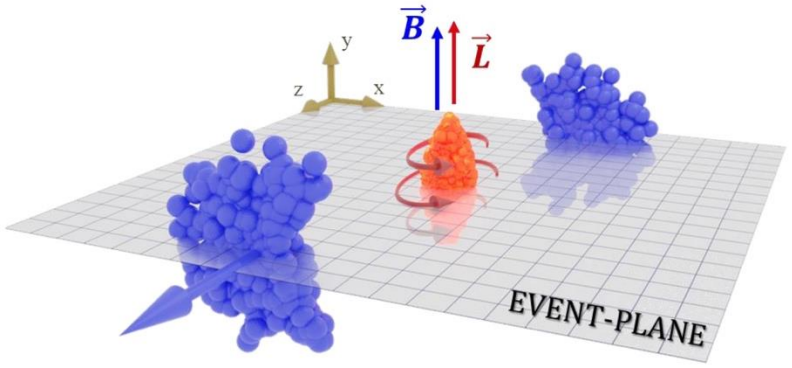
J/ψ production in OO collisions

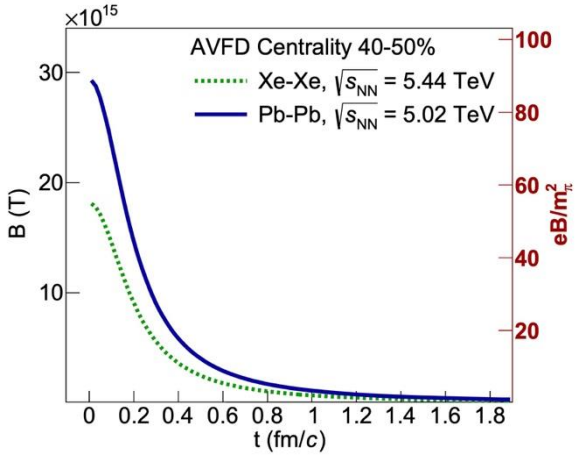




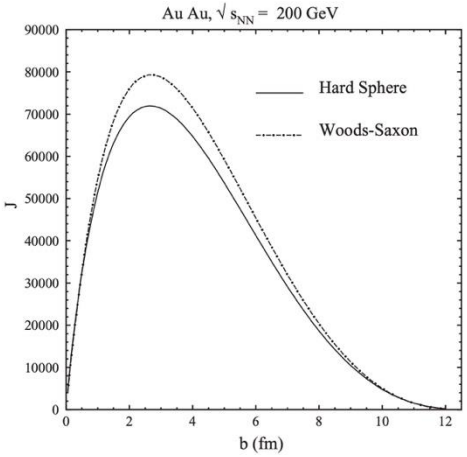
- J/ψ production is measured in OO（right） and pO（left） collisions at 5.36 TeV, a strong suppression is observed
- The J/ψ regeneration contribution is negligible in OO collisions

Charmonium polarization





Christakoglu et al., EPJC (2021) **81**: 717

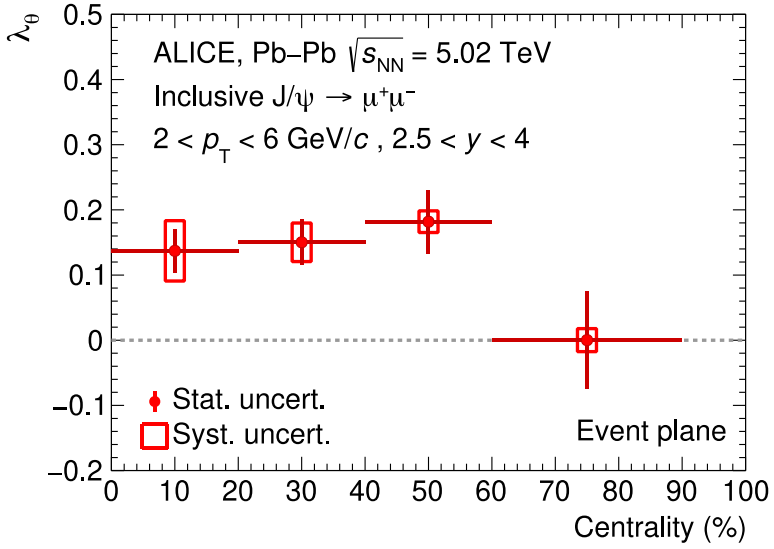


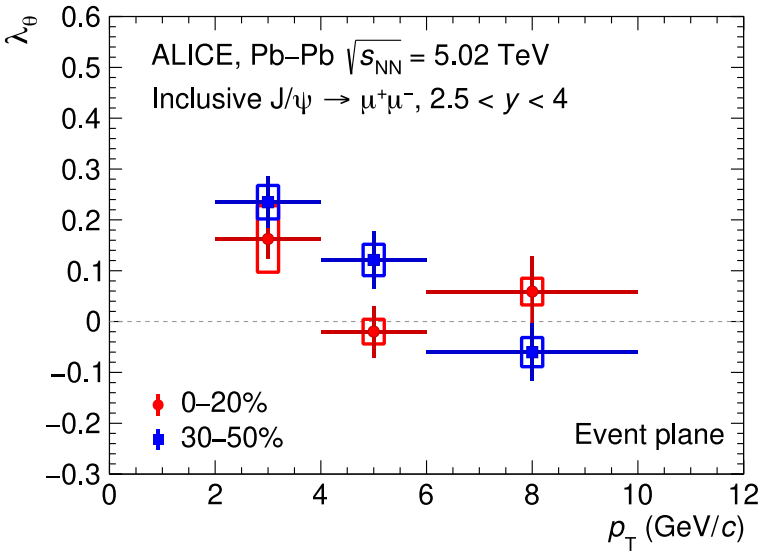
F. Becattini et al., PRC 77 (2008)

Heavy-quark are produced in the early stage of AA collision and can experience both the **short living *B* and the *L* of the rotating medium**, polarization w.r.t. an axis orthogonal to the event plane can be affected.

J/ψ polarization w.r.t the event plane

ALICE, PRL 131 (2024) 4, 042303





- First measurement of quarkonium polarization **w.r.t the event plane**
- **Significant polarization (~3.5σ)** observed in semicentral collisions (40-60%) in 2 < p_T < 6 GeV/c
- The significance of the polarization reaches **~3.9σ** at low p_T (2 < p_T < 4 GeV/c) in 30-50%
- Interpretation of results requires inputs from theoretical models

Summary

- Dominant contribution from (re-)generation in central collisions and low p_T for J/ψ in Pb-Pb collisions

  Evidence of the charm deconfinement at LHC

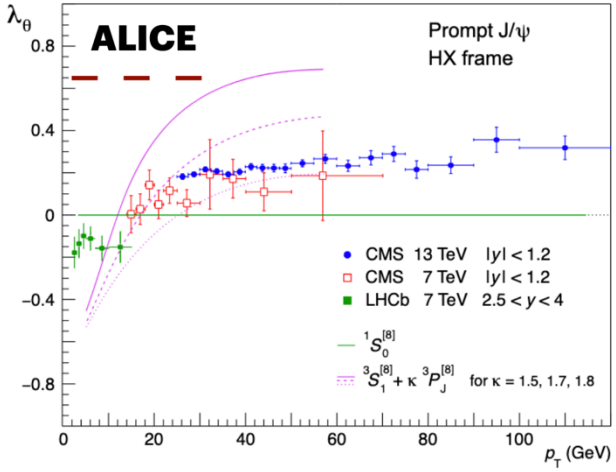
- Significant non-zero polarization and v_2 are observed in Pb-Pb collisions

  Charm quarks thermalized at LHC energies (?)

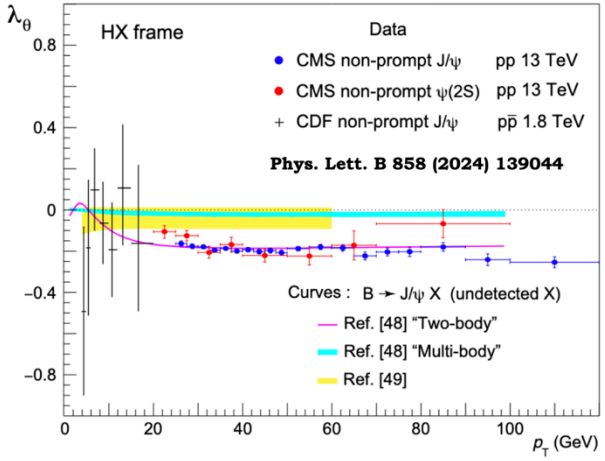
Thanks

Motivation

Prompt



Non-prompt



Prompt J/ψ : model fails to describe the measurement
At high p_T (e.g., 30 GeV/c ~ 30× m(J/ψ)),
λ_θ asymptotically reaches = +0.3, excluding strong transverse polarization by NRQCD

Non-prompt J/ψ is well-modeled by B-hadron decay dynamics, both measurement and model calculations are consistent within each other