第二十届全国中高能核物理大会暨第十四届
全国中高能核物理专题研讨会

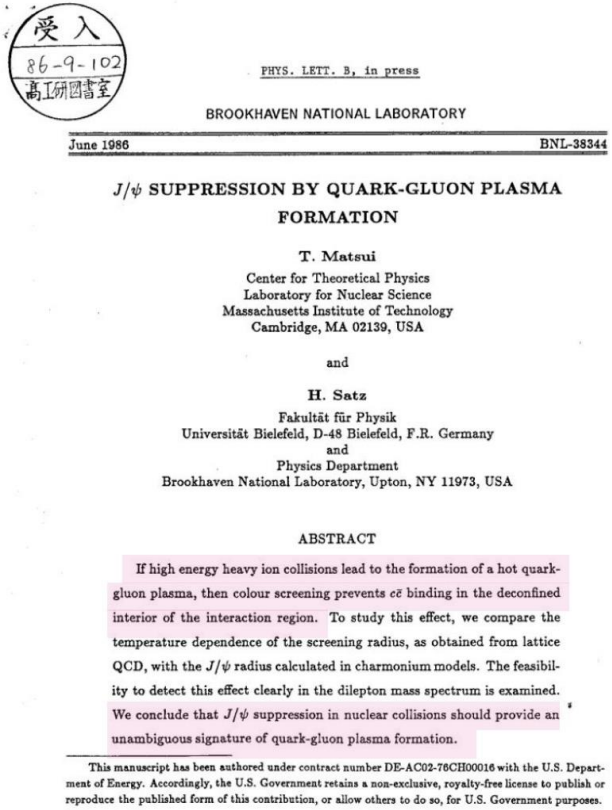
ALICE实验重味夸克偶素的测量

白晓智

中国科学技术大学

上海, 2025.04.27

Quarkonium suppression is the “smoking gun” of QGP



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PHYS. LETT. B, in press

BROOKHAVEN NATIONAL LABORATORY

June 1986 BNL-38344

J/ψ SUPPRESSION BY QUARK-GLUON PLASMA FORMATION

T. Matsui
Center for Theoretical Physics
Laboratory for Nuclear Science
Massachusetts Institute of Technology
Cambridge, MA 02139, USA

and

H. Satz
Fakultät für Physik
Universität Bielefeld, D-48 Bielefeld, F.R. Germany
and
Physics Department
Brookhaven National Laboratory, Upton, NY 11973, USA

ABSTRACT

If high energy heavy ion collisions lead to the formation of a hot quark-gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, we compare the temperature dependence of the screening radius, as obtained from lattice QCD, with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. We conclude that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark-gluon plasma formation.

- Heavy quarks produced in the early collision stages
- Quarkonium production is one of the “smoking guns” of QGP formation
- Quarkonium production suppressed sequentially via colour screening in QGP

T. Matsui, H. Satz, PLB178 (1986) 416

> 5700 citations

Quarkonium suppression is the “smoking gun” of QGP

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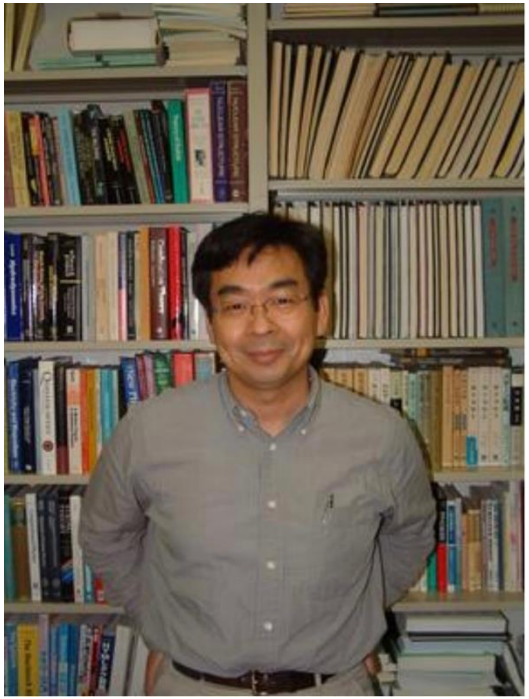
If high energy heavy ion collisions lead to the formation of a hot quark-gluon plasma, then colour screening prevents $c\bar{c}$ binding in the deconfined interior of the interaction region. To study this effect, we compare the temperature dependence of the screening radius, as obtained from lattice QCD, with the J/ψ radius calculated in charmonium models. The feasibility to detect this effect clearly in the dilepton mass spectrum is examined. We conclude that J/ψ suppression in nuclear collisions should provide an unambiguous signature of quark-gluon plasma formation.

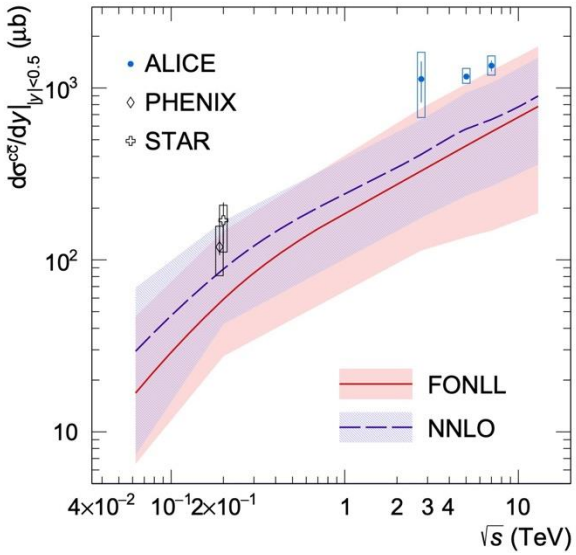


Tetsuo Matsui (1953-2025)

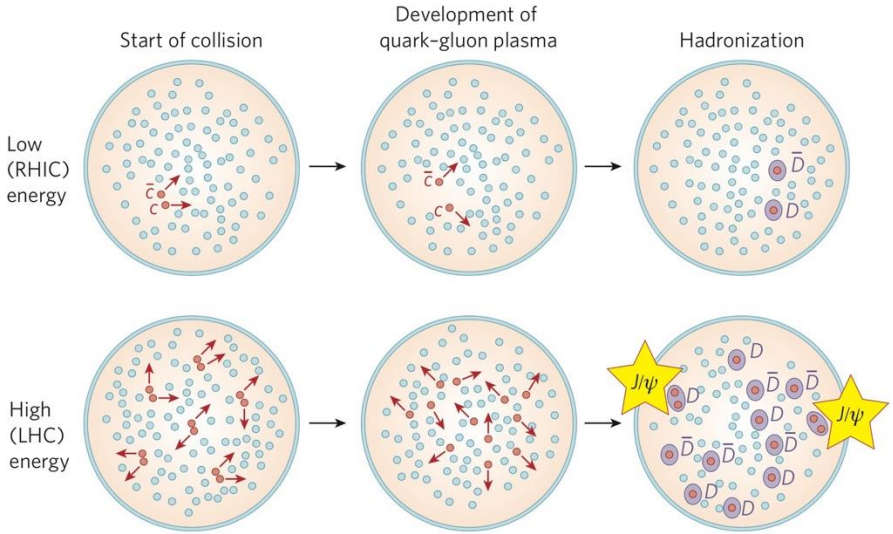
T. Matsui, H. Satz, PLB178 (1986) 416 > 5700 citations

Charmonium (re)generation production

Phys. Rev. D 105, 011103 (2022)



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

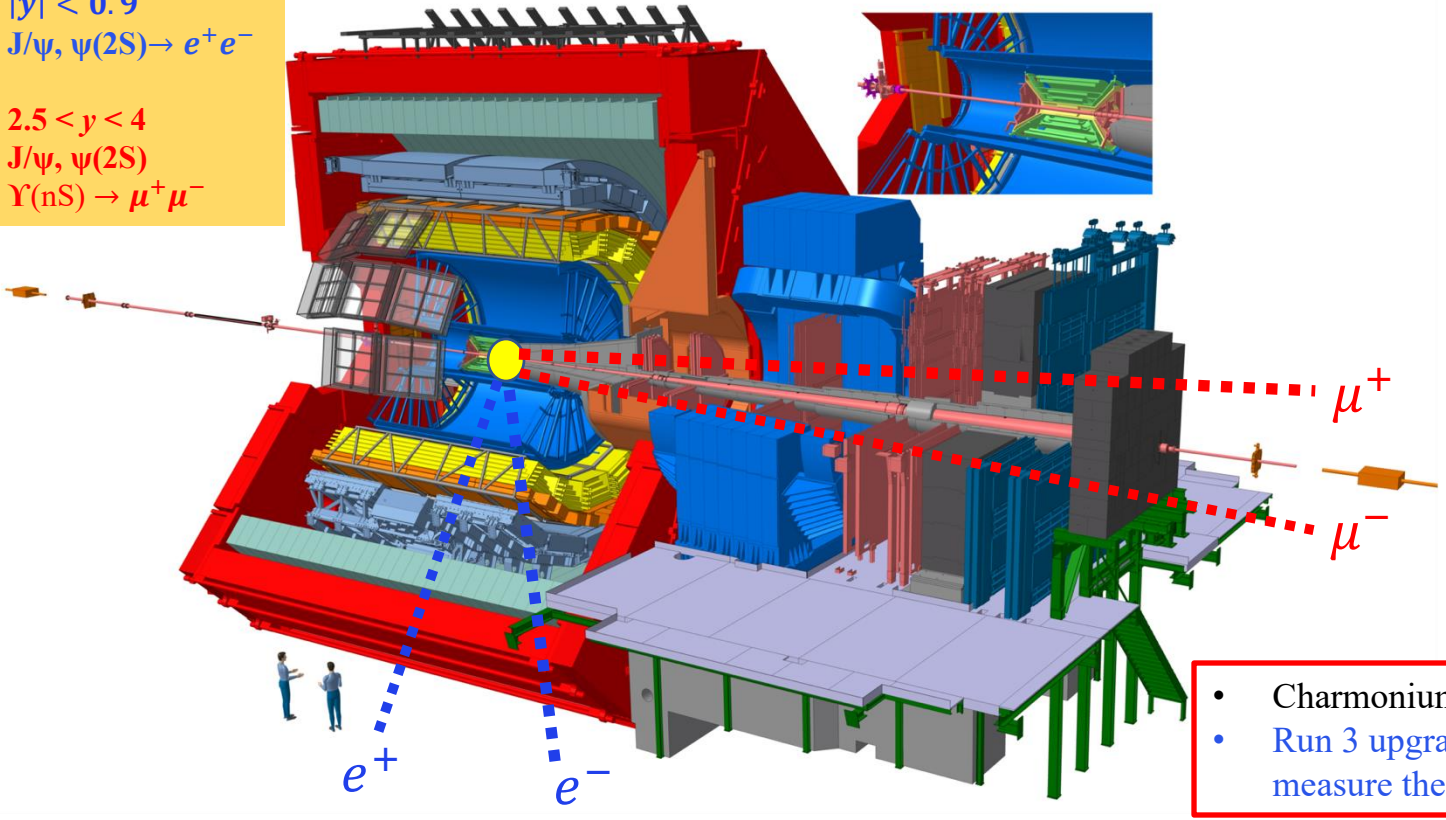


- Suppression of the charmonia due to colour screening and the dynamic dissociation
- Charm quark production cross section at the LHC is much larger compared to RHIC energies, and the **(re)generation** contribution to the J/ψ is significantly higher than at RHIC

Quarkonium measurements with the ALICE

$|y| < 0.9$
$J/\psi, \psi(2S) \rightarrow e^+e^-$

$2.5 < y < 4$
$J/\psi, \psi(2S)$
$\Upsilon(nS) \rightarrow \mu^+\mu^-$



Time Projection Chamber
Tracking, particle identification

Inner Tracking System
Tracking, vertex reconstruction, Event plane determination

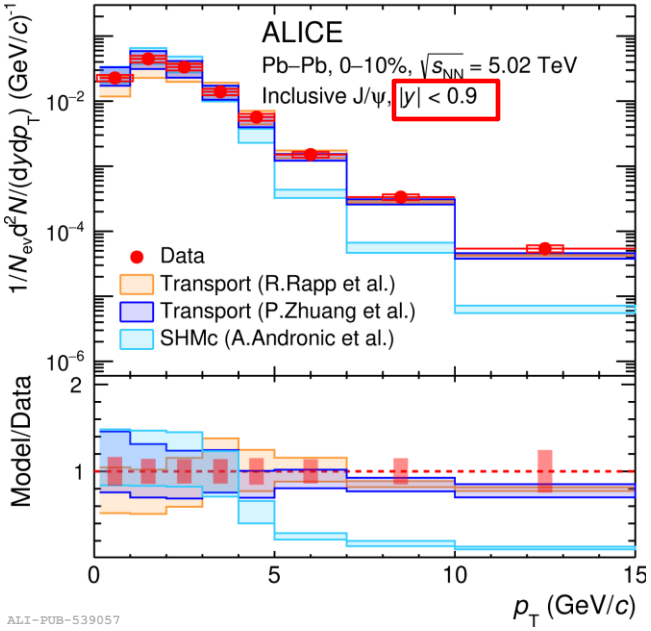
V0 Detector
Centrality determination, triggering, event plane determination, and background rejection

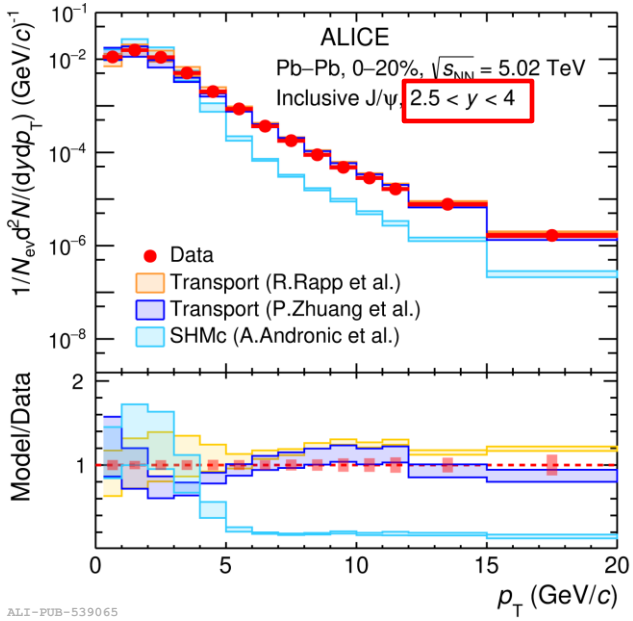
Muon spectrometer
Trigger and tracking for muons

- Charmonium measurement down to $p_T = 0$
- Run 3 upgraded detectors allow to measure the **$\psi(2S)$, $\Upsilon(nS)$** at midrapidty

Inclusive J/ψ yield

ALICE, PLB 849 (2024) 138451



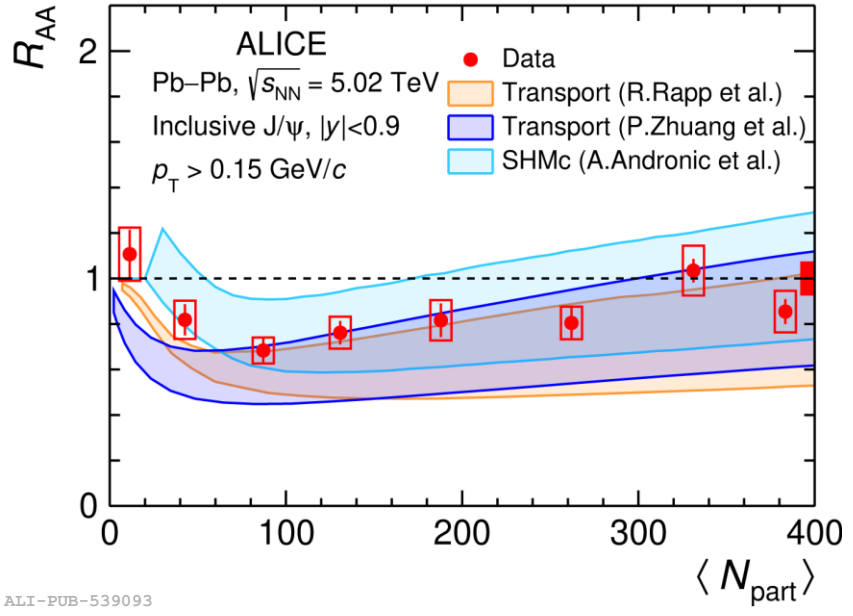


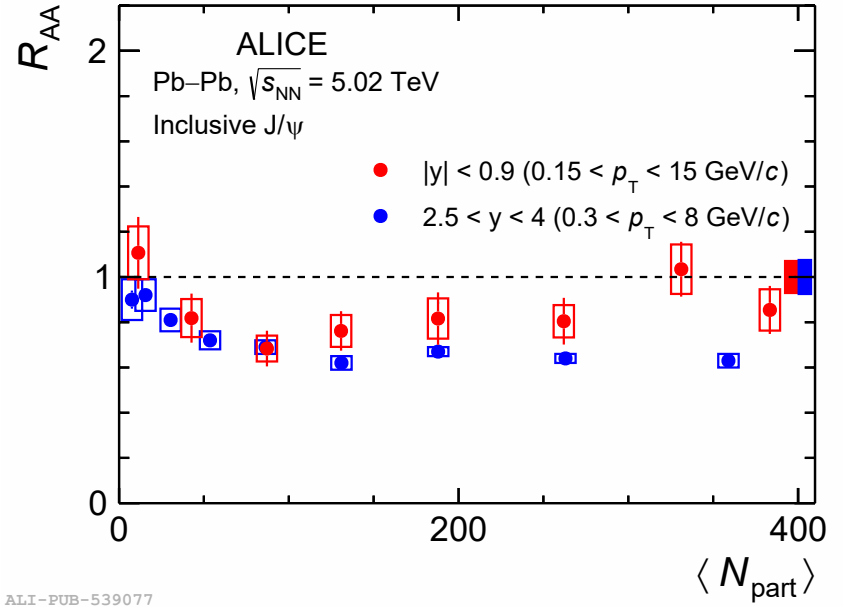
- Inclusive J/ψ yields are shown as a function of p_T at **mid- (left) and forward (right)** rapidity in central collisions
- Two transport models describe the data within uncertainties
- SHMc agrees with data at low p_T, and underestimates the measurement at high p_T

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 centrality

ALICE, PLB 849 (2024) 138451



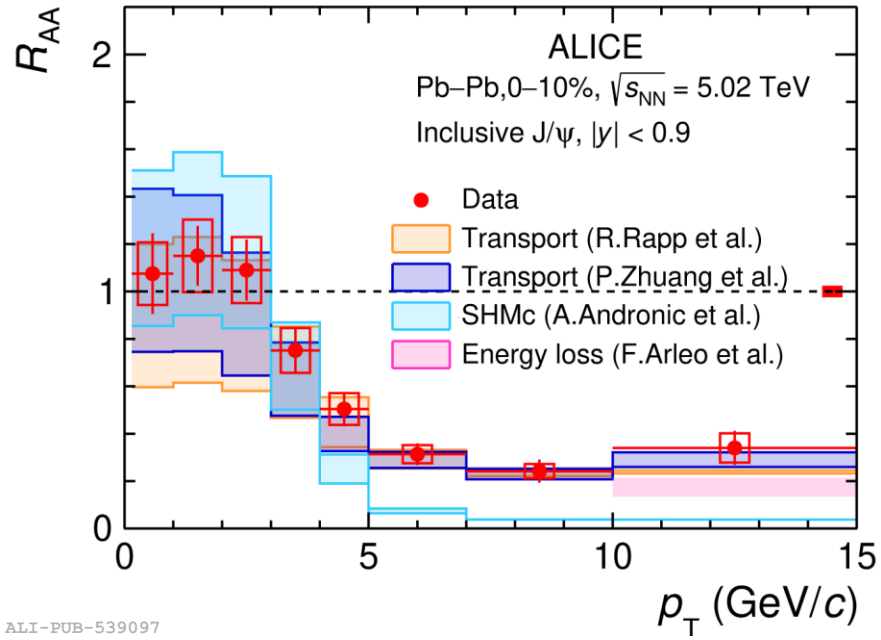


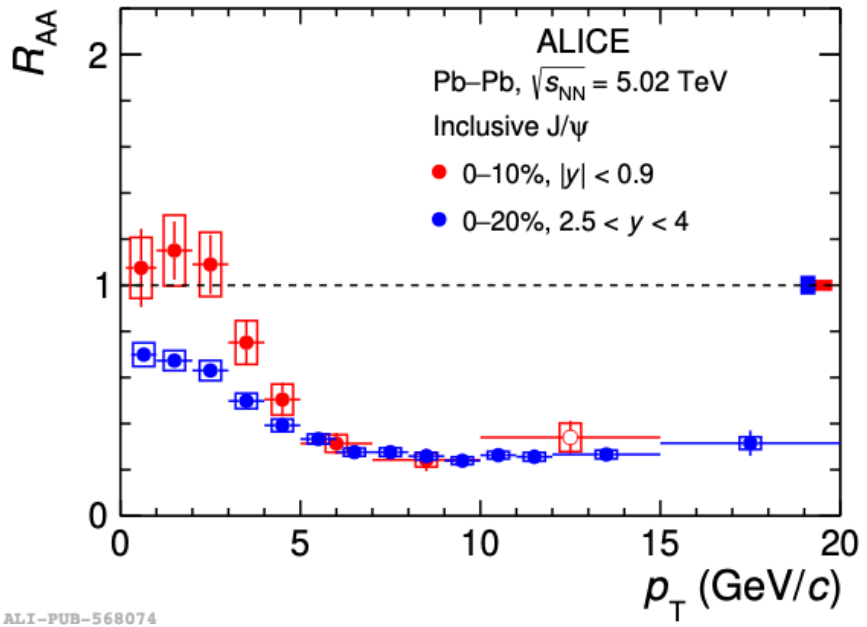
- **Evidence for J/ψ (re-)generation in central collisions, with a larger contribution at midrapidity compared to forward rapidity**
- All models can describe the data but suffer from large uncertainties related to inputs used in calculations (eg. charm cross section, shadowing).

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



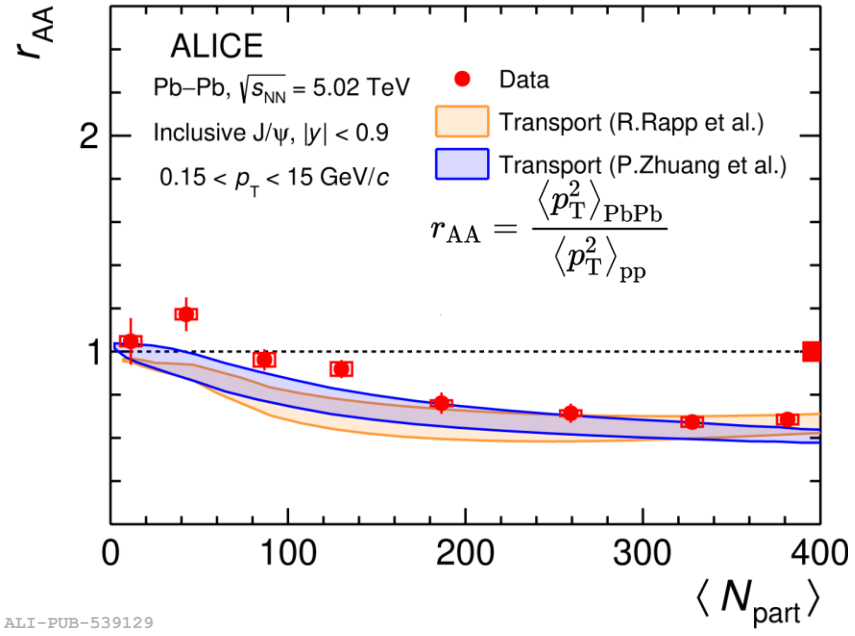


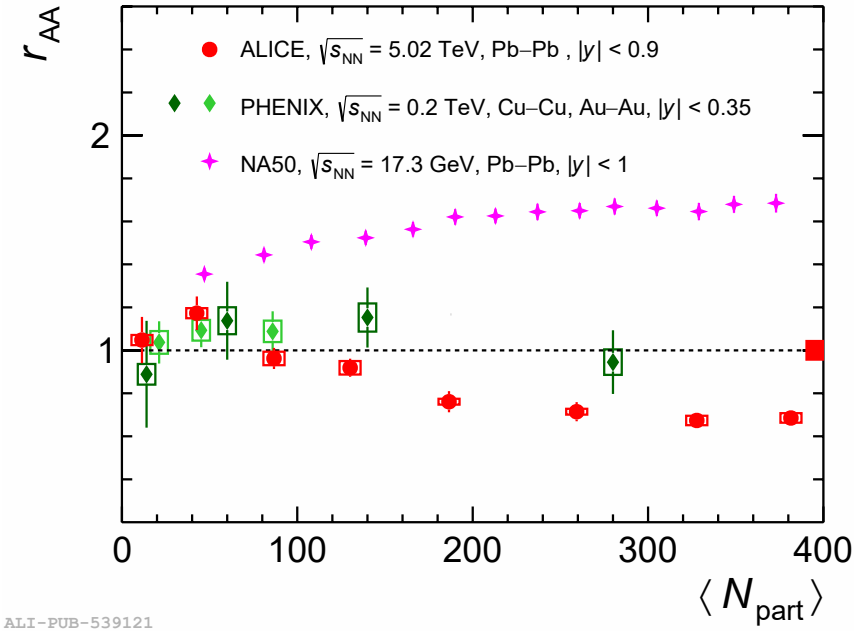
- Transport and SHMc models describe data at low p_T, while SHMc underestimates the measurement at high p_T, the energy loss model agrees with data at high p_T
- **Evidence for the (re)generation and demonstration of deconfinement at LHC**

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)
Arleo. F, PRL119, 062302 (2017)

Inclusive J/ψ mean p_T

ALICE, PLB 849 (2024) 138451



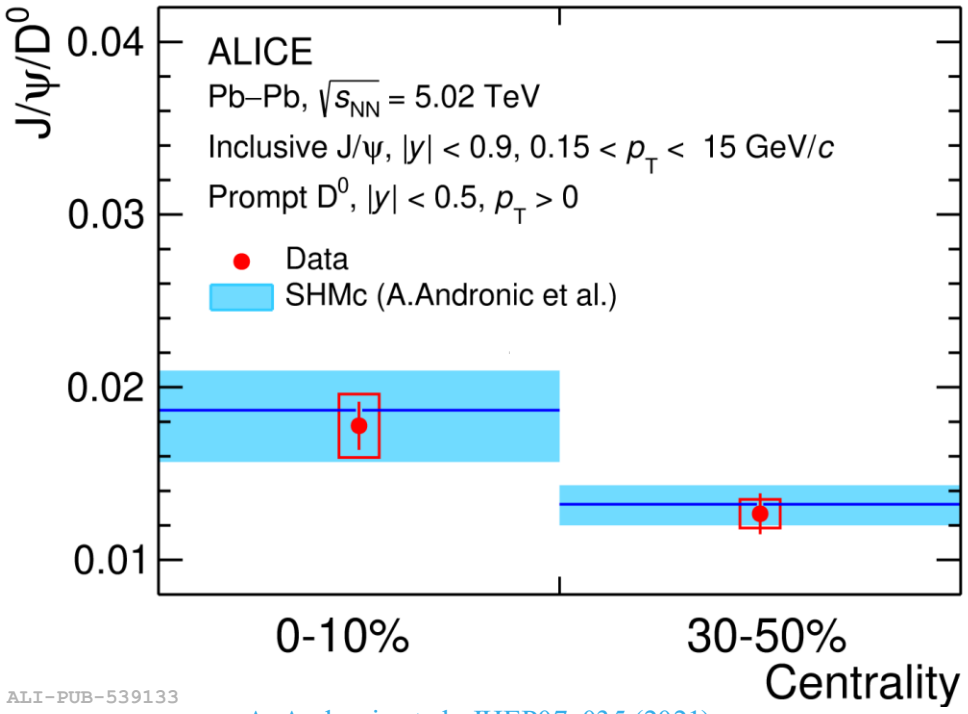


- Decreasing trend for r_{AA} from semicentral toward central collisions
- r_{AA} below unity indicates a softening of the J/ψ p_T shape in Pb−Pb collisions compared to pp collisions, the behavior is different from the lower center-of-mass energies

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

J/ψ-to-D^0 ratio in Pb–Pb collisions

ALICE, PLB 849 (2024) 138451

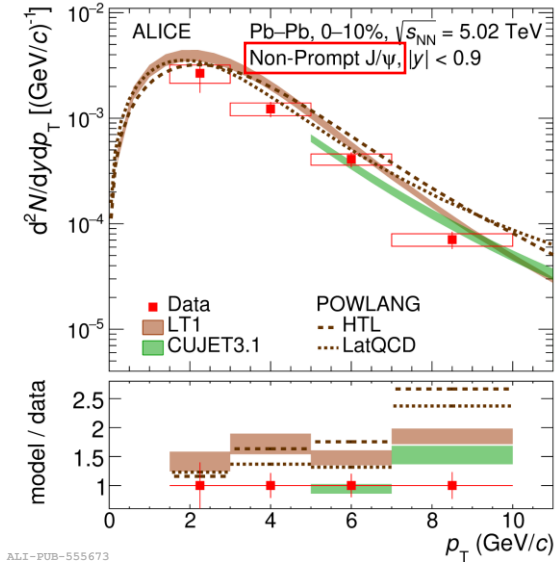


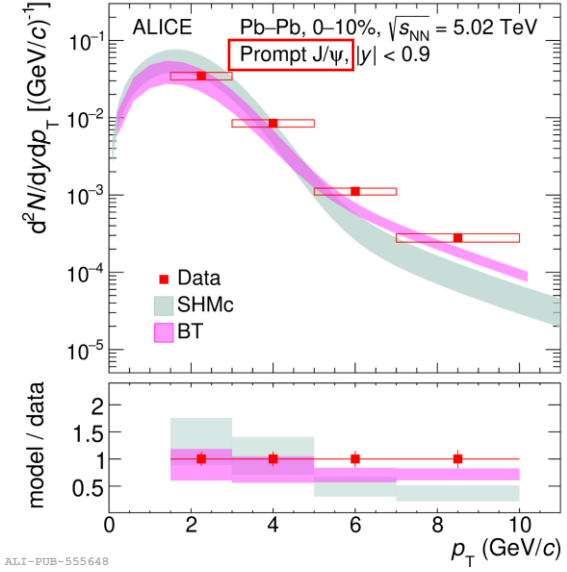
A. Andronic et al., JHEP07, 035 (2021)

- 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 according to SHMc prediction

Non-prompt and prompt J/ψ p_T spectrum

ALICE, JHEP 02 (2024) 066



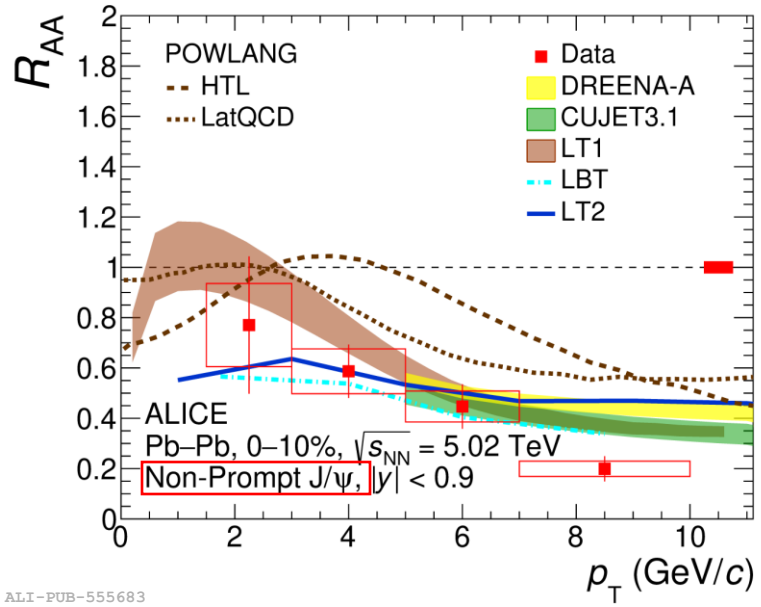


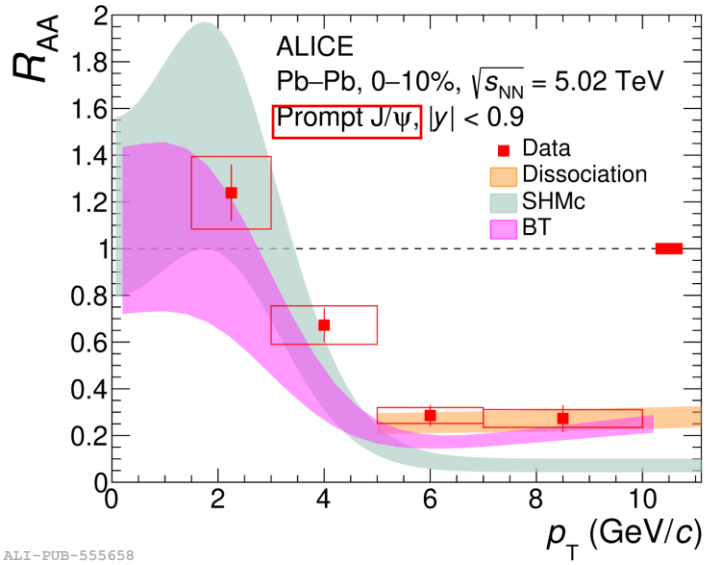
LT1: PRC107, 054917(2023)
POWLANG:
JHEP 05 (2021) 279,
EPJC 75 (2015) 121
CUJJET3.1: CPC 43 (2019) 044101
SHMc: PLB 797 (2019) 134836
BT: CPC43 (2019) 124101

- Non-prompt (left) and prompt (right) J/ψ p_T spectrum are compared with several different models.
- All the models seem to over estimate measured data of non-prompt J/ψ, the SHMc and BT agree with data within uncertainties for the prompt J/ψ at low p_T

Non-prompt and prompt J/ψ R_{AA}

ALICE, JHEP 02 (2024) 066



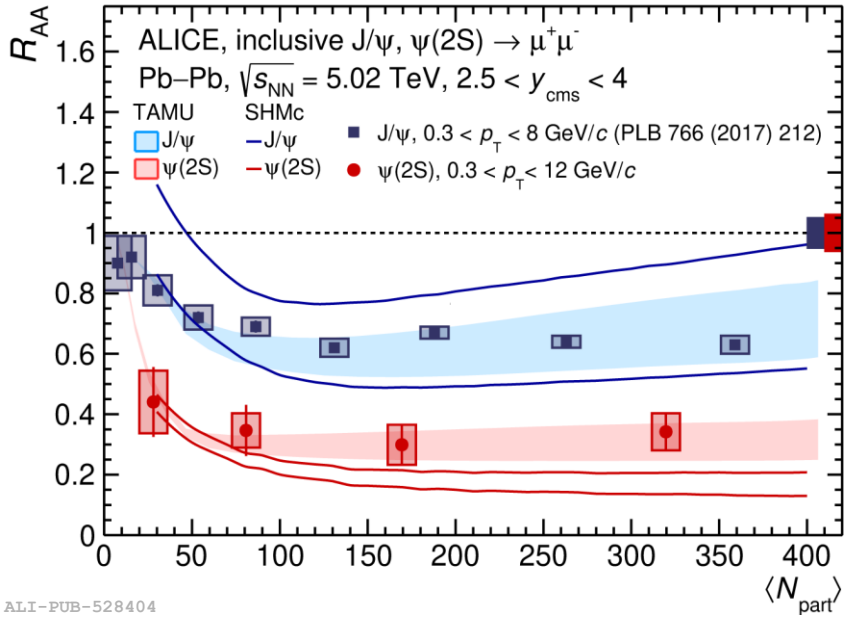


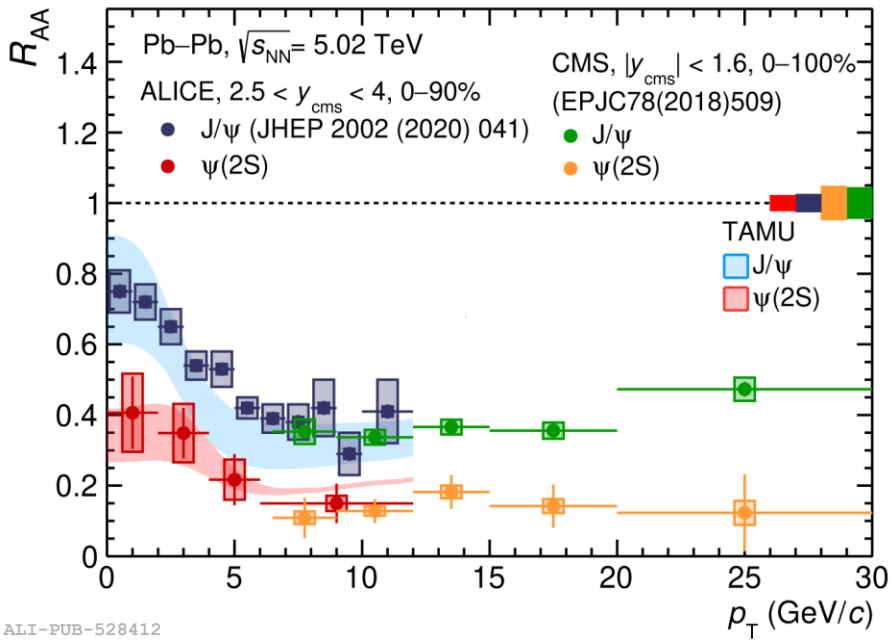
DREENA-A: Front. Phys. 10:957019 (2022), Phys. Rev. C 105, L021901
CUJJET3.1: CPC 43 (2019) 044101
LT1: PRC107, 054917(2023)
LBT: PLB838(2023) 137733
LBT2: EPJC 81 848 (2021) 1035
Dissociation: PLB 778 (2018) 384-391
SHMc: PLB 797 (2019) 134836
BT: CPC43 (2019) 124101

- The SHMc model and transport microscopic calculations that include a contribution from **regeneration** are compatible with the measured **prompt J/ψ R_{AA} at low p_T**
- **Non-prompt J/ψ R_{AA}** is described within uncertainties by models implementing **collisional and radiative energy loss** contributions
- POWLANG calculations, which include only collisional contributions, overestimate the R_{AA} at intermediate and high p_T

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

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

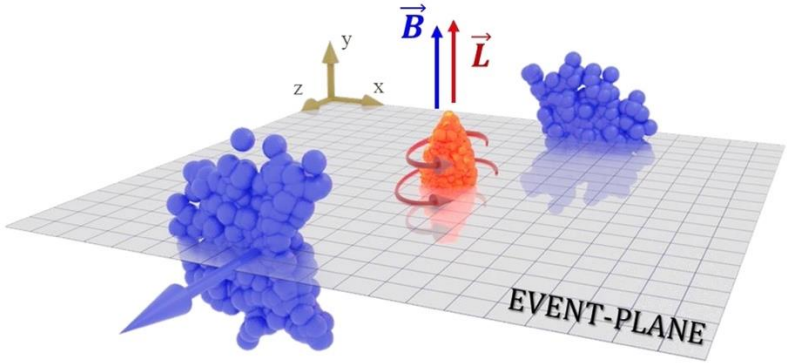


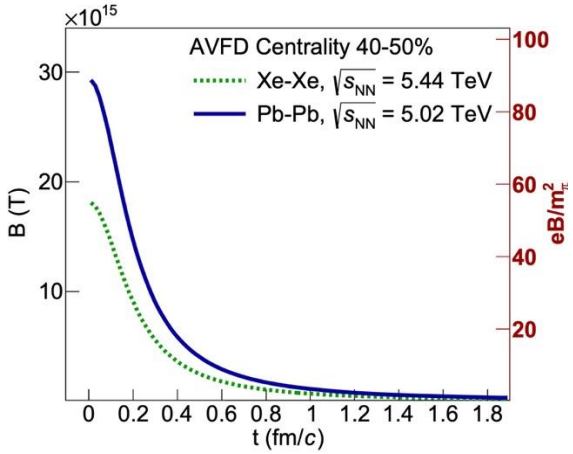


- A larger suppression of the ψ(2S) w.r.t the J/ψ is observed
- The ψ(2S) R_{AA} increases at low p_T , which is a hint of ψ(2S) regeneration
- The TAMU model describes data better than SHMc in central collisions

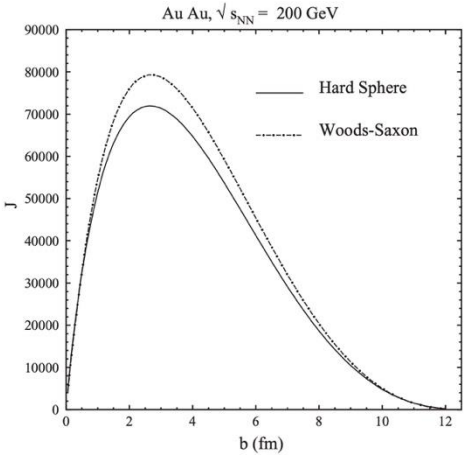
(TAMU) X. Du, et al.,NPA943,147-158(2015)
(SHMc) A. Andronic, et al.,PLB797,134836(2019)

Charmonium polarization





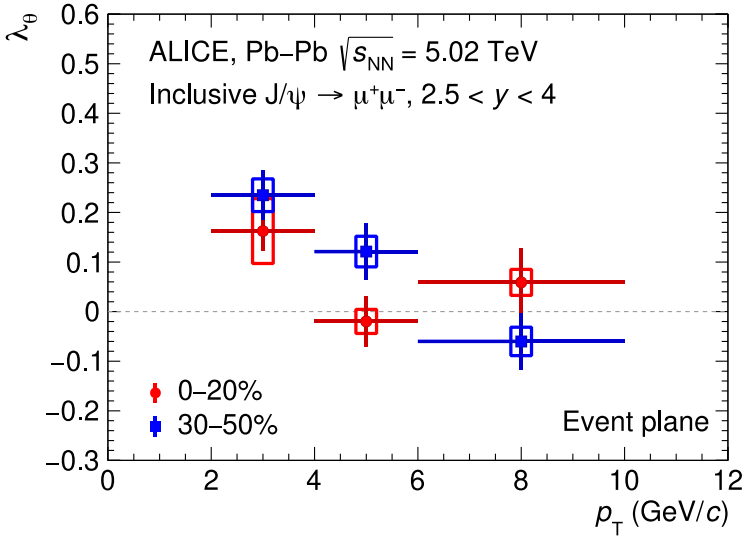
Christakoglu et al., EPJC (2021) **81**: 717

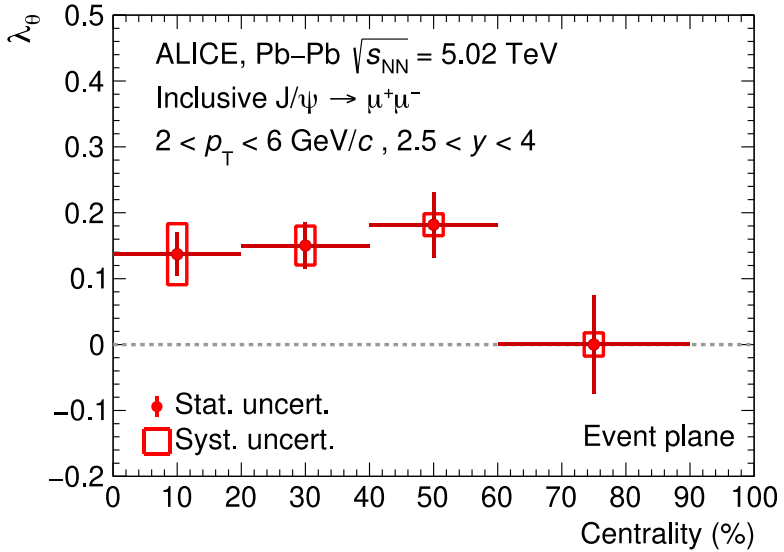


F. Becattini et al., PRC 77 (2008)

Heavy-quark pairs 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.

Charmonium polarization w.r.t event plane





- The λ_θ deviation reaches ~**3.9σ** at low p_T ($2 < p_T < 4$ GeV/c) in 30-50%
- Significant polarization (~**3.5σ**) observed in semicentral collisions (40-60%) in $2 < p_T < 6$ GeV/c
- In LHC Run 3 ALICE will be able to study polarization at midrapidity via the dielectron channel

ALICE, PRL 131 (2023) 4, 042303

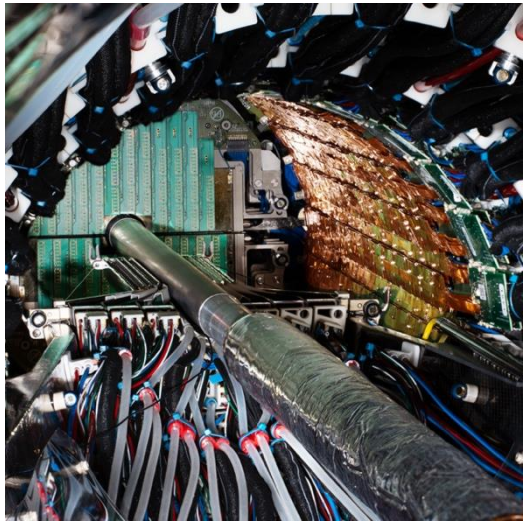
ALICE detector upgrades in Run 3

TPC upgrades

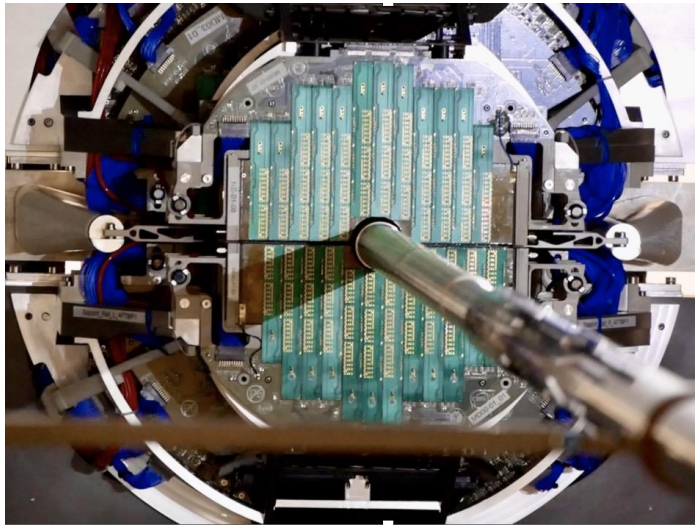
Time Projection Chamber -> **GEM, continuous readout**

- pp data taking at 500 kHz
- Pb-Pb data taking at 50 kHz

ITS upgrades

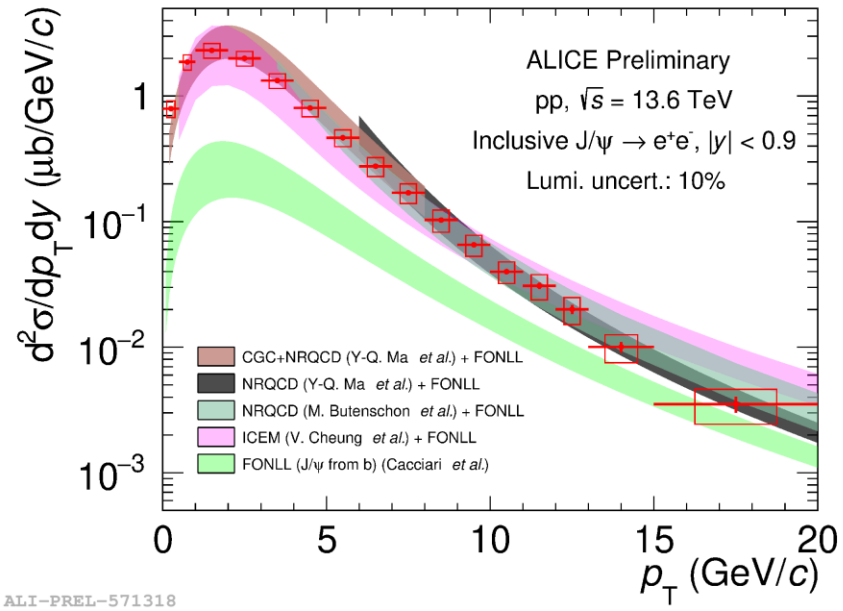


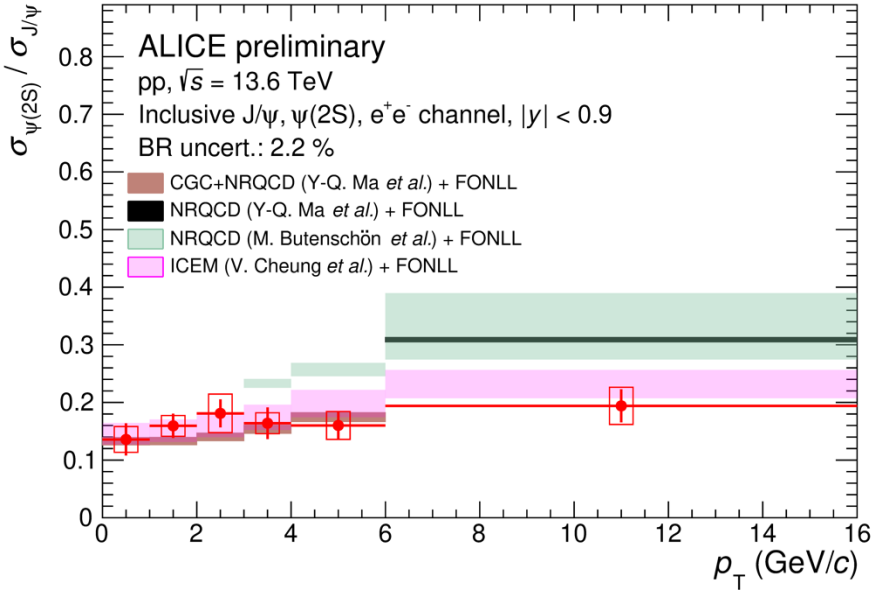
Newly installed MFT



- Improved pointing resolution **at midrapidity**
- Secondary vertex reconstruction enabled **at forward rapidity**

Charmonia in pp collisions at √s = 13.6 TeV

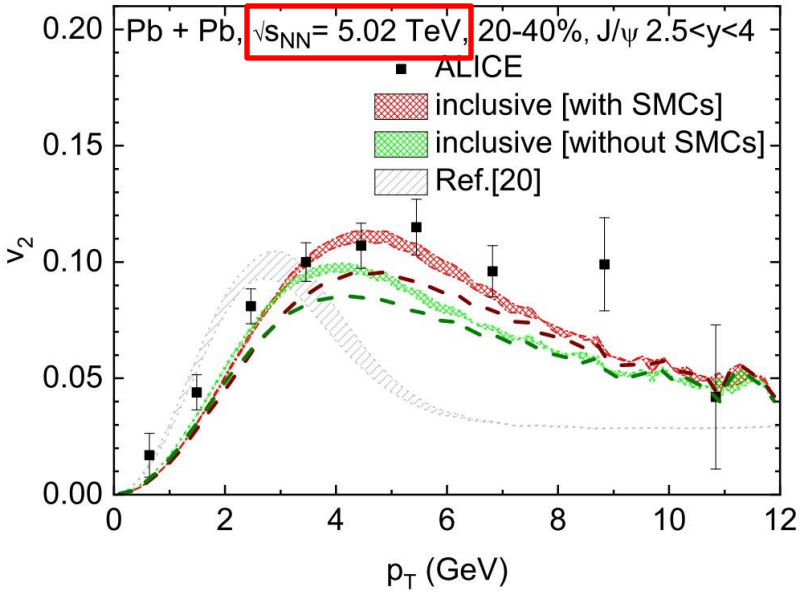


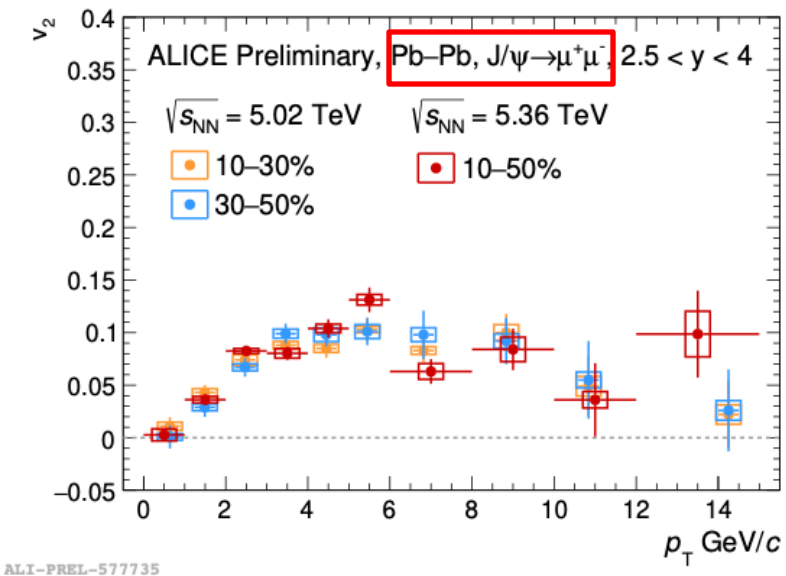


- With the significantly increased statistics allow to reconstruct ψ(2S) via dielectron decays
- The CGC + NRQCD and ICEM can describe the data at low p_T

Charmonium elliptic flow

New Preliminary





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

- The new result is consistent with Run 2, with statistical precision improved at low p_T at forward rapidity
- A significant J/ψ v_2 is observed at forward rapidity, consistent with the charm quark thermalization

Summary and outlook

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

  Evidence of the deconfinement at LHC

- A larger suppression of the ψ(2S) with respect to the J/ψ is observed
- Significant non-zero J/ψ polarization observed w.r.t event plane
- A significant J/ψ v_2 is observed, consistent with the charm quark thermalization

Thanks