Inclusive and (non) prompt J/ψ production in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE

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On behalf of the ALICE Collaboration

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ALICE

Inclusive J/ψ production in AA collisions

- **Excellent probe** of the **deconfined** medium, quark-gluon plasma (QGP), produced in high energy nuclear collisions
  - **Dissociation** of charmonium states, such as J/ψ, in the hot nuclear medium

A Rothkopf, *Phys.Rept.* 858 1-117 , T Matsui & H Satz *Phys.Lett.B 178 (1986) 416-422*

  - **Recombination** of charm and anti-charm quarks at the LHC energies

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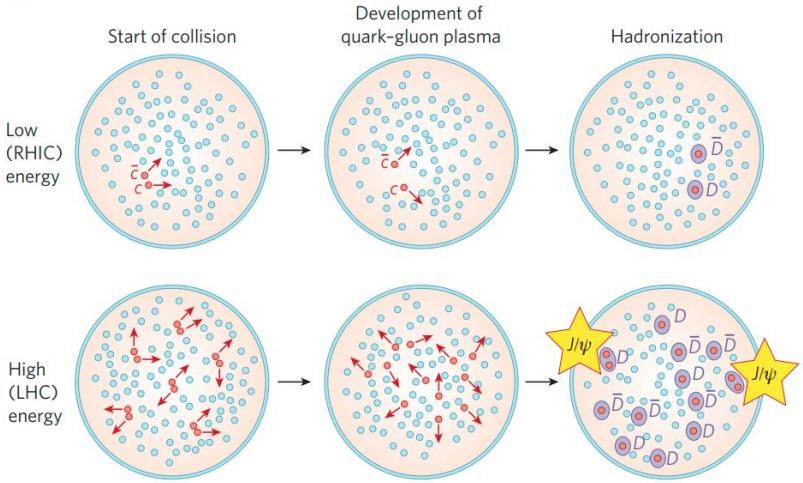

P Braun-Munzinger and J Stachel, *Nature volume 448, pages302–309 (2007)*

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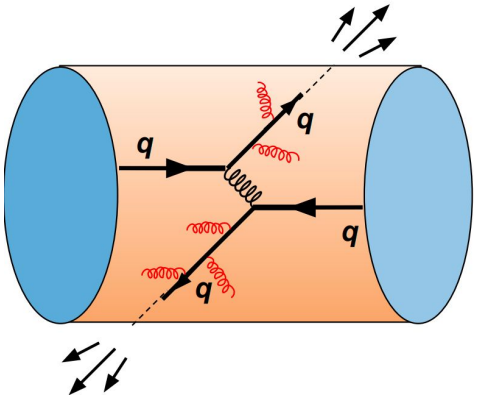
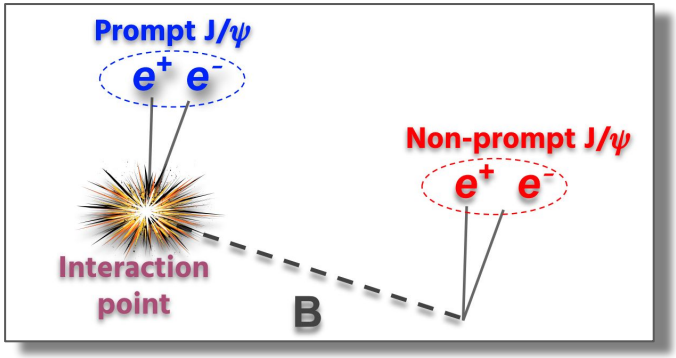
- Parton's mass dependent energy loss within the medium ⇒ transport properties of the QGP

  Non-prompt J/ψ: sensitive to the interaction of b quarks with the medium





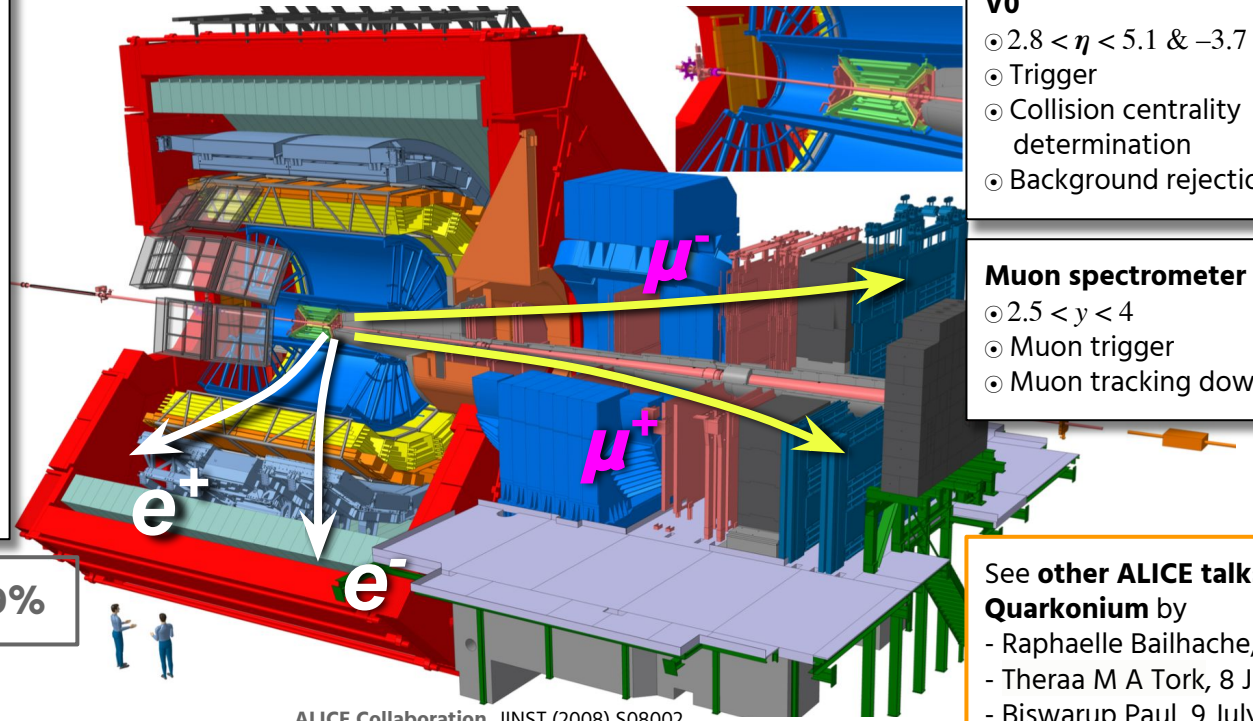
Inclusive J/ψ production in ALICE

Central barrel detectors

1) ITS
- $|\eta| < 0.9$
- Tracking
- Primary and secondary B vertex reconstruction

2) TPC
- $|\eta| < 0.9$
- Tracking
- Particle identification

Excellent tracking and PID capabilities down to very low momentum



ALICE Collaboration, JINST (2008) S08002

V0
- $2.8 < \eta < 5.1$ & $-3.7 < \eta < -1.7$
- Trigger
- Collision centrality determination
- Background rejection

Muon spectrometer
- $2.5 < y < 4$
- Muon trigger
- Muon tracking down to very low p_T

BR ($J/\psi \rightarrow \ell^+\ell^-$) ~ 5.9%

See **other ALICE talks** on **Quarkonium** by
- Raphaelle Bailhache, 7 July @ 18:30
- Theraa M A Tork, 8 July @ 18:35
- Biswarup Paul, 9 July @ 9:35
- Maurice Coquet, 9 July @ 11:15
- Yanchun Ding, 9 July @ 10:10

- Inclusive J/ψ measurement down to p_T = 0 GeV/c at mid and forward rapidity
- Prompt and non-prompt J/ψ separation at midrapidity, down to p_T = 1.5 GeV/c in Pb–Pb collisions

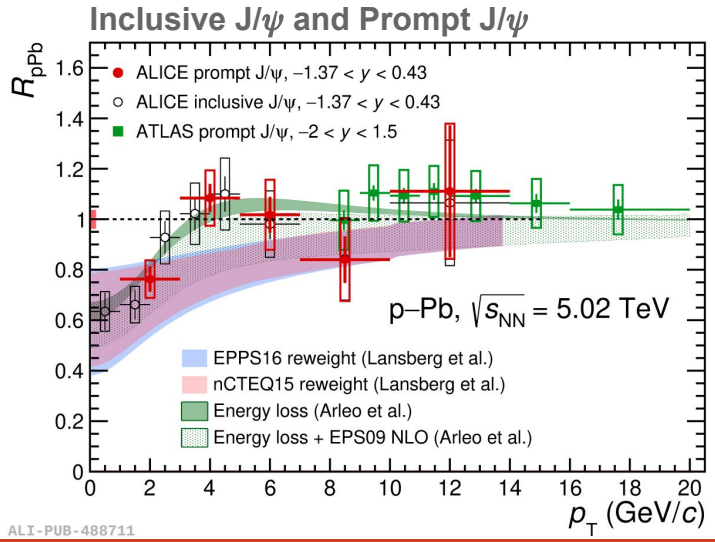
Inclusive J/ψ production in p–Pb collisions

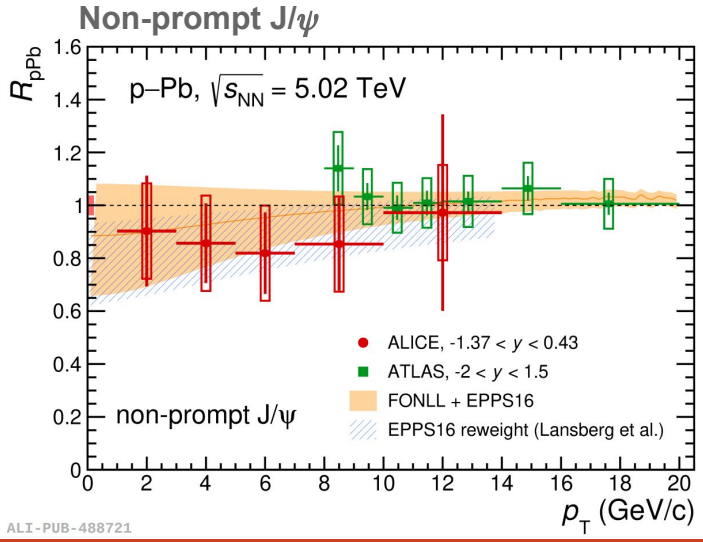
- Quantification of cold nuclear matter (CNM) effects
- Suppression of prompt and inclusive J/ψ production at low p_T
- Hints of larger modifications for prompt J/ψ compared to non-prompt J/ψ at low p_T
- Models including various CNM effects, such as energy loss and nuclear shadowing, describe the data

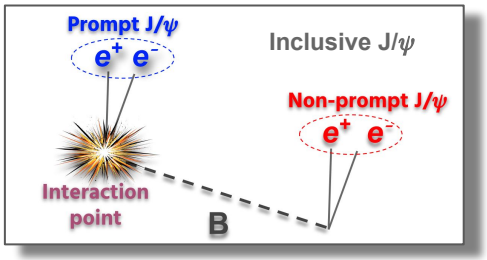
Nuclear Modification factor

$$R_{pA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \cdot \frac{dN_{pA}/dp_T}{dN_{pp}/dp_T}$$

$R_{pA} = 1 \Rightarrow$ pA behaves as scaled pp
$R_{pA} \neq 1 \Rightarrow$ modified production in pA in comparison to pp







ALICE Collaboration: JHEP06(2022)011
ATLAS Collaboration: Eur. Phys. J. C 78 (2018) 171
Arleo et al: Phys.Rev.Lett. 88 (2002) 232303
EPPS16, Eskola et al: Eur. Phys. J. C 77, 163 (2017)
EPPS16-reweight, Lansberg et al: Phys. Rev. Lett. 121, 052004

Inclusive J/ψ production in Pb–Pb collisions

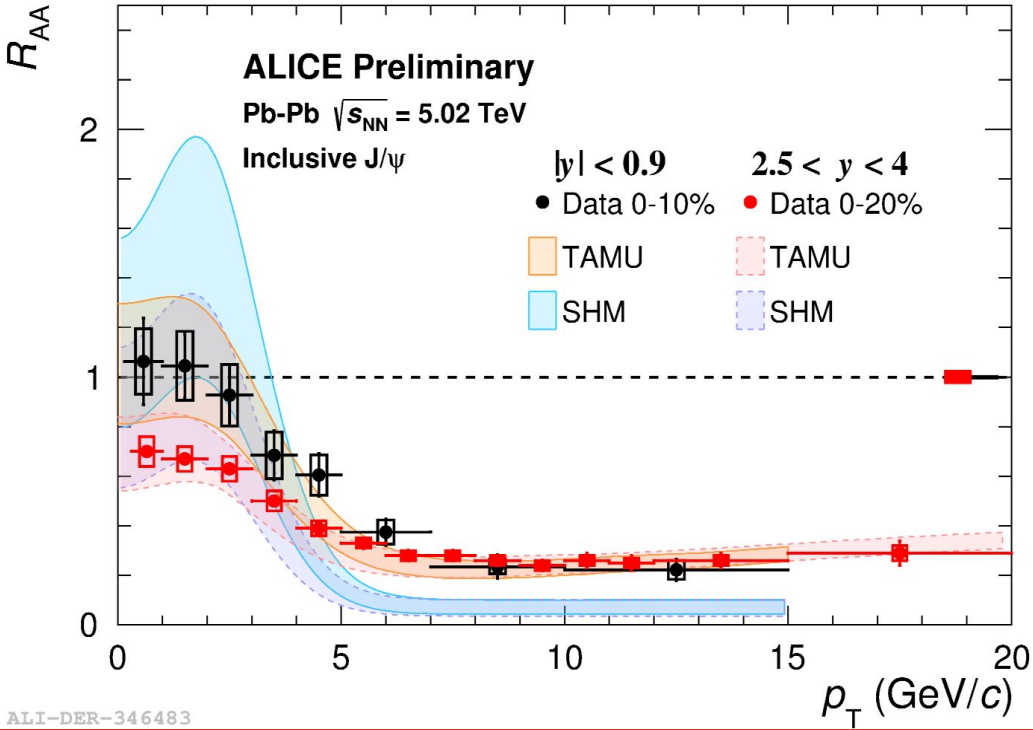
- Modifications observed for inclusive J/ψ production at mid and forward rapidity
- Suppressed production for p_T > 5 GeV/c ⇒ Dissociation and energy loss effects at play
- Lower suppression for p_T < 5 GeV/c, in particular at midrapidity compared to forward rapidity ⇒ consistent with J/ψ regeneration
- Models including J/ψ regeneration throughout the medium evolution (TAMU) or at the phase boundary (SHM), describe the R_{AA} at low p_T

SHM: Andronic et al: Phys. Lett. B797 (2019) 134836
TAMU: Du X and Rapp R: Nucl.Phys.A 943 (2015) 147-158

Nuclear Modification factor

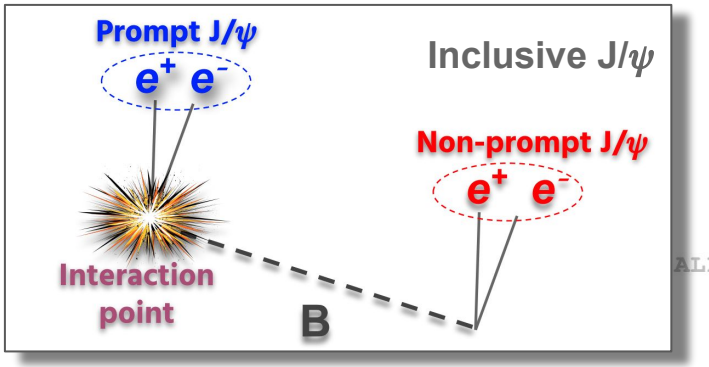
$$R_{AA}(p_T) = \frac{1}{\langle N_{coll} \rangle} \cdot \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

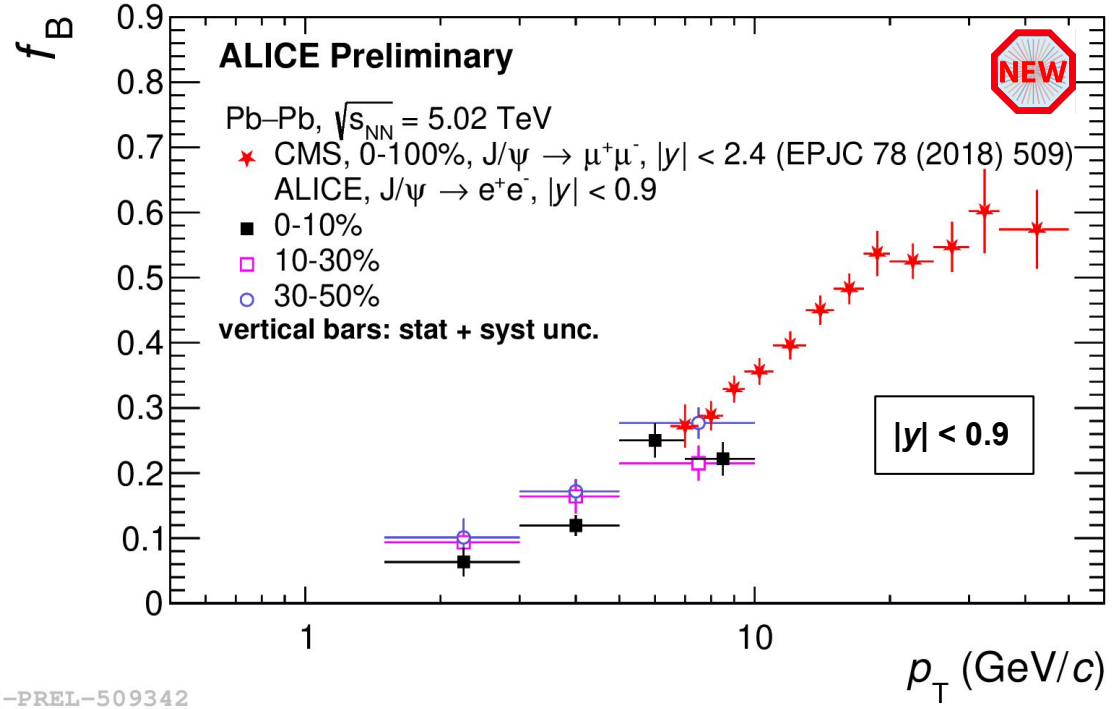
R_{AA} = 1 ⇒ Pb-Pb behaves as scaled pp
R_{AA} ≠ 1 ⇒ modifications of the production in Pb–Pb by medium



Non-prompt J/ψ fractions in Pb–Pb collisions

- Non-prompt J/ψ fractions (f_B) are measured down to very low p_T in central and semi-central collisions at midrapidity
- Larger contribution of non-prompt J/ψ with increasing p_T
- ALICE measurements consistent with CMS measurements in the overlapping p_T region



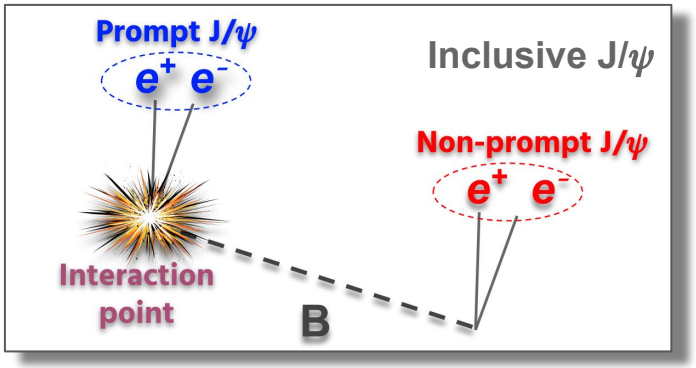


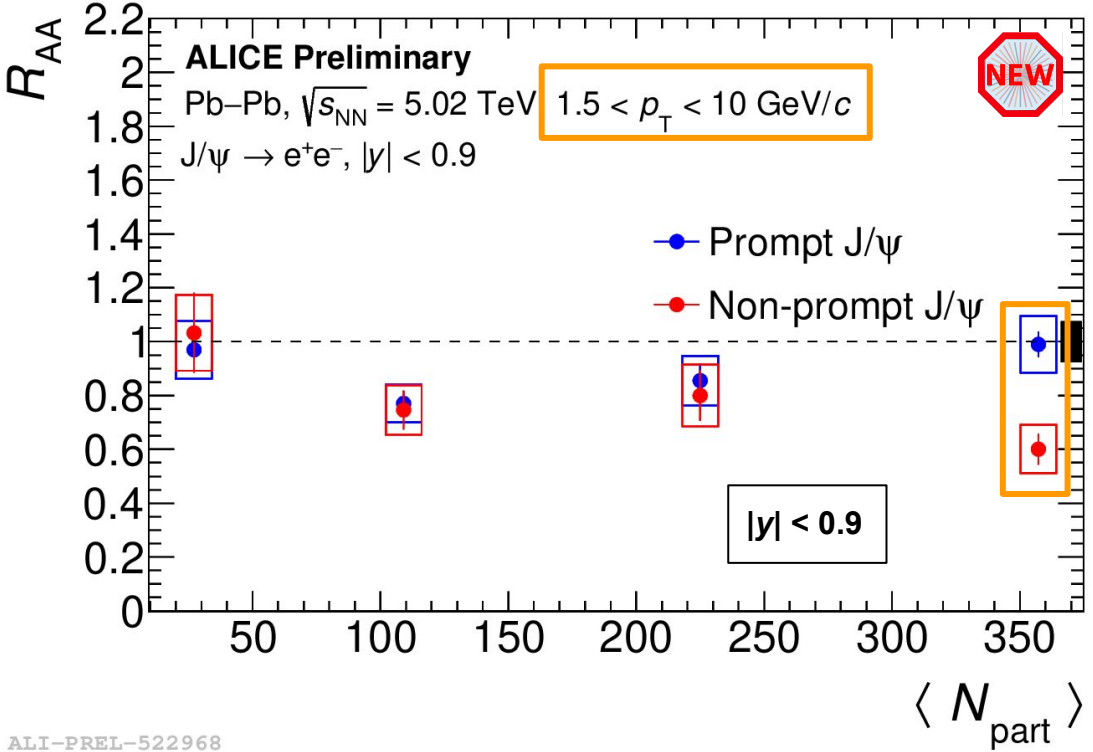
ALI-PREL-509342

(Non) Prompt J/ψ production in Pb–Pb collisions

- In peripheral and semi-central collisions, similar modifications for prompt and non-prompt J/ψ production

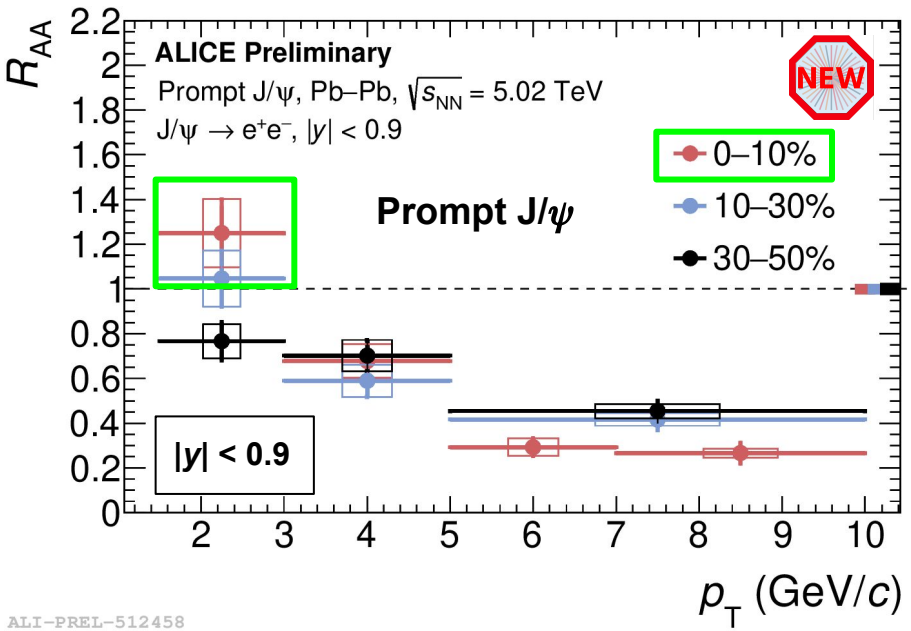
- In the most central collisions, prompt J/ψ production significantly less suppressed in comparison to non-prompt J/ψ

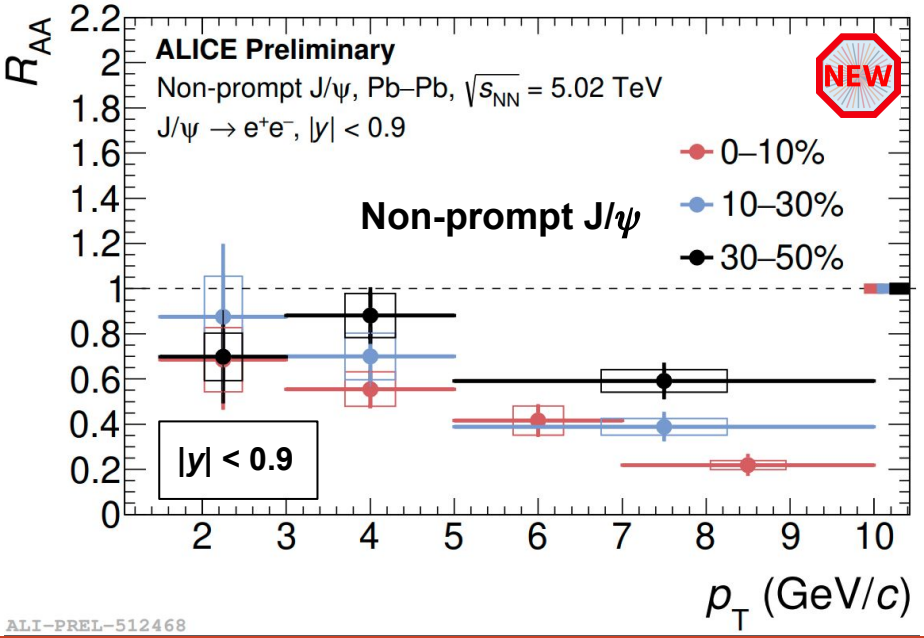




(Non) Prompt J/ψ production in Pb–Pb collisions

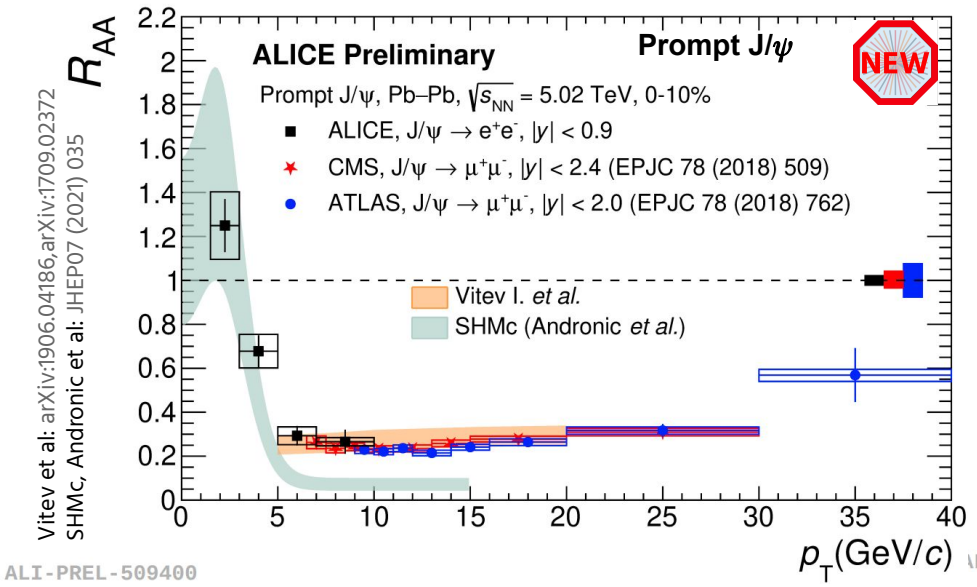
- p_T > 5 GeV/c: Sizable suppression observed for both prompt and non-prompt J/ψ; strongest effects observed in the most central collisions
- p_T < 5 GeV/c: Increasing trend of prompt J/ψ R_{AA} moving towards low p_T ; more evident in central collisions ⇒ consistent with J/ψ regeneration scenario
  - In the most central collisions: hints of $R_{AA}^{\text{prompt J/}\psi} > R_{AA}^{\text{Non-prompt J/}\psi}$ in the lowest p_T interval

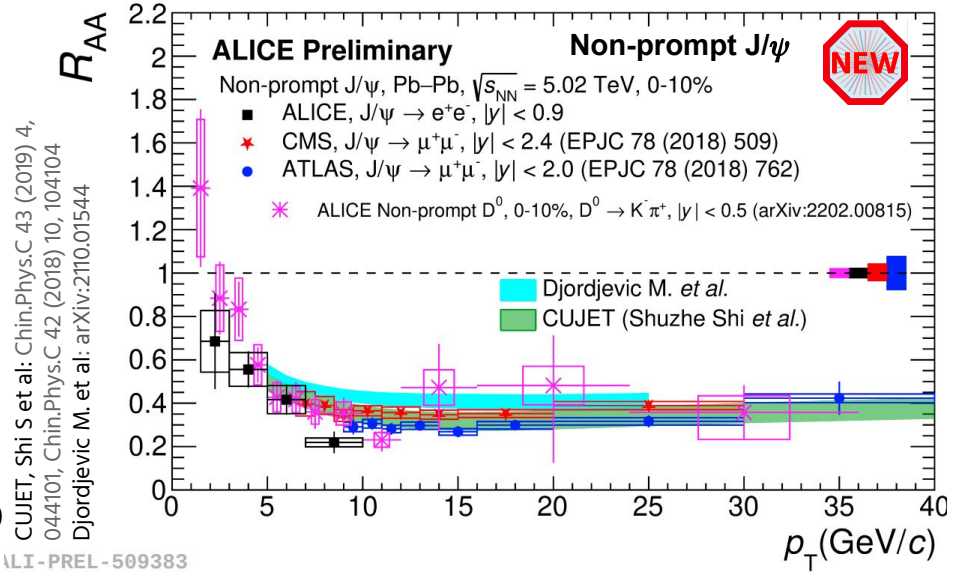




(Non) Prompt J/ψ production in Pb–Pb collisions

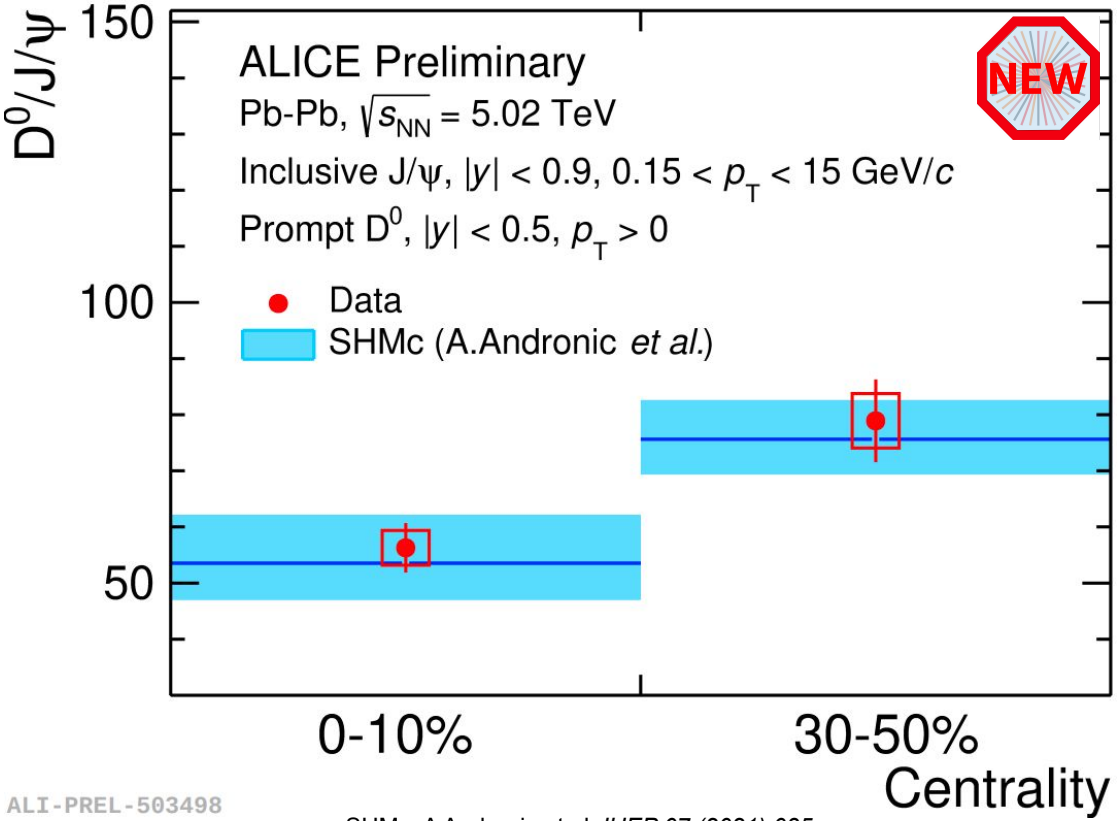
- Prompt & non-prompt J/ψ R_{AA} in agreement with ATLAS and CMS measurements in the overlapping p_T ranges
- Similar R_{AA} values for non-prompt J/ψ and non-prompt D^0
- Prompt J/ψ R_{AA} described by models including quarkonium dissociation (regeneration at the phase boundary) at high (low) p_T
- Non-prompt J/ψ R_{AA} consistent with models implementing collisional + radiative energy loss for p_T > 5 GeV/c





D^0-to-J/ψ ratio in Pb–Pb collisions

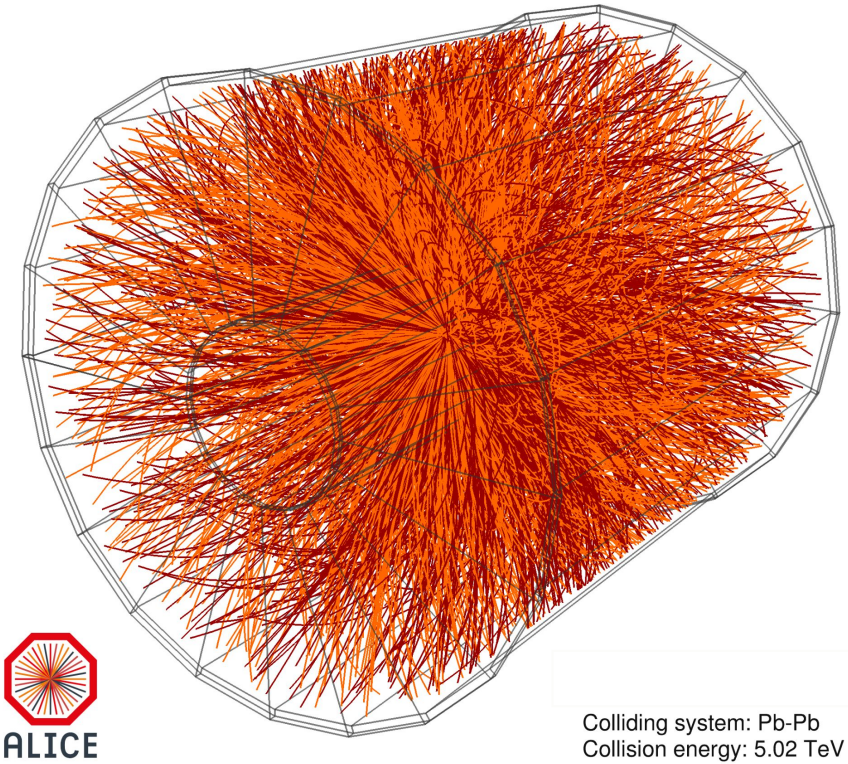
- Sensitive to hadronization mechanism for open and hidden charm production
- Centrality dependence of the ratio is explained by larger charm fugacity in most central collisions according to SHMc predictions



SHMc: A Andronic et al *JHEP 07 (2021) 035*

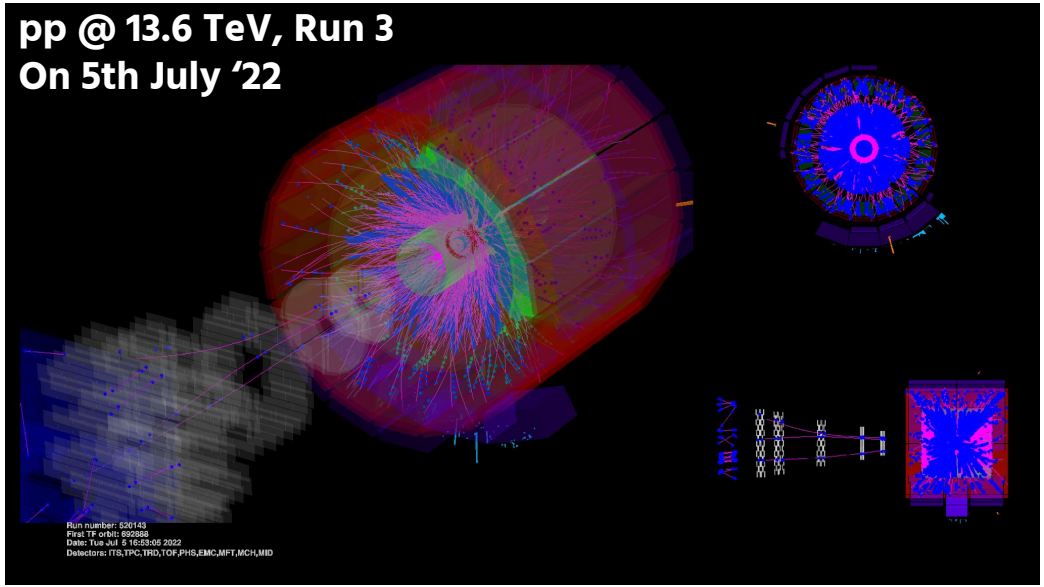
Summary

- R_{AA} of inclusive and (non) prompt J/ψ measured in Pb–Pb collisions using full statistics collected during LHC Run 2
- Prompt J/ψ: R_{AA} measurements are compatible with an interplay between dissociation and regeneration mechanism, stronger effects in central collisions:
  - J/ψ regeneration dominant at low p_T , dissociation effects at high p_T
- Non-prompt J/ψ: Consistent with b-quark energy loss at high p_T



Outlook for LHC Run 3

- Increase by a factor of 10 compared to Run 2 for the **integrated luminosity** in Pb–Pb collisions
- **Upgraded ITS**: Improved impact parameter resolution by factor of 3 (5) in transverse (longitudinal) direction, improved vertexing and tracking precision
- **Muon Forward Tracker** will enable prompt/non-prompt charmonia separation at forward rapidity ($-3.6 < \eta < -2.5$) in the dimuon decay channel
- More ALICE talks on LHC Run 3:
  - Robert Munzer, 7 July @ 9:00
  - Aimeric Landou, 8 July @ 9:18



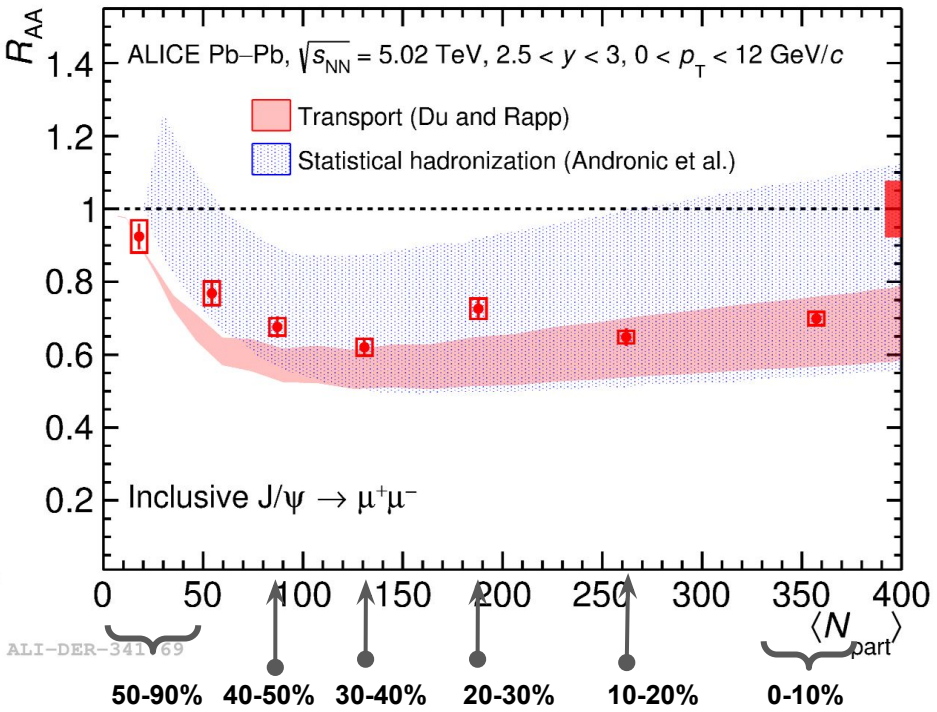
ALICE is ready for the LHC Run 3, with an exciting physics program rich in many new quarkonium measurements... stay tuned!

Thank you

Backup

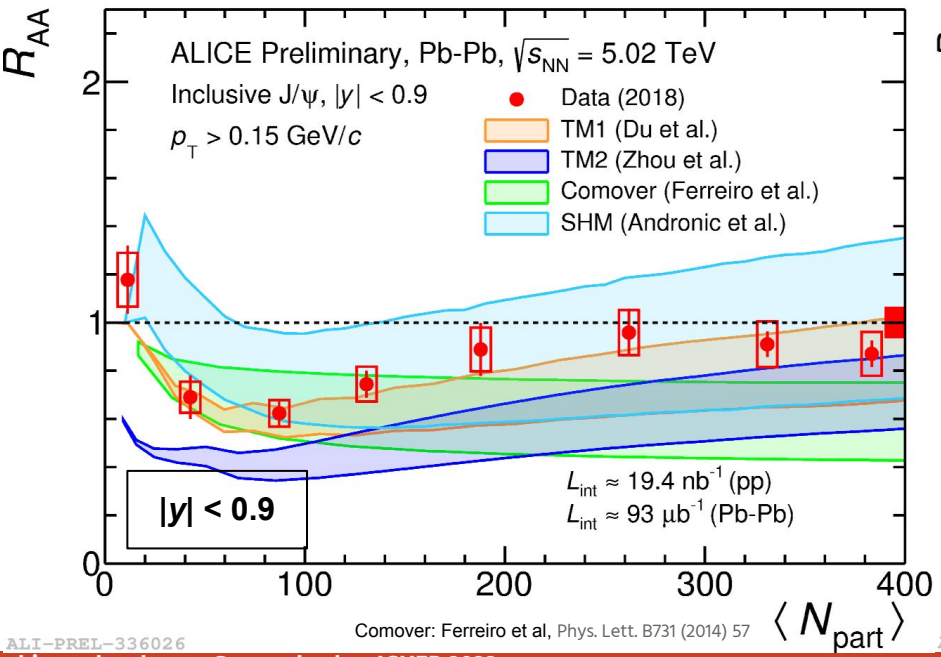
<Npart> and centrality in Pb-Pb

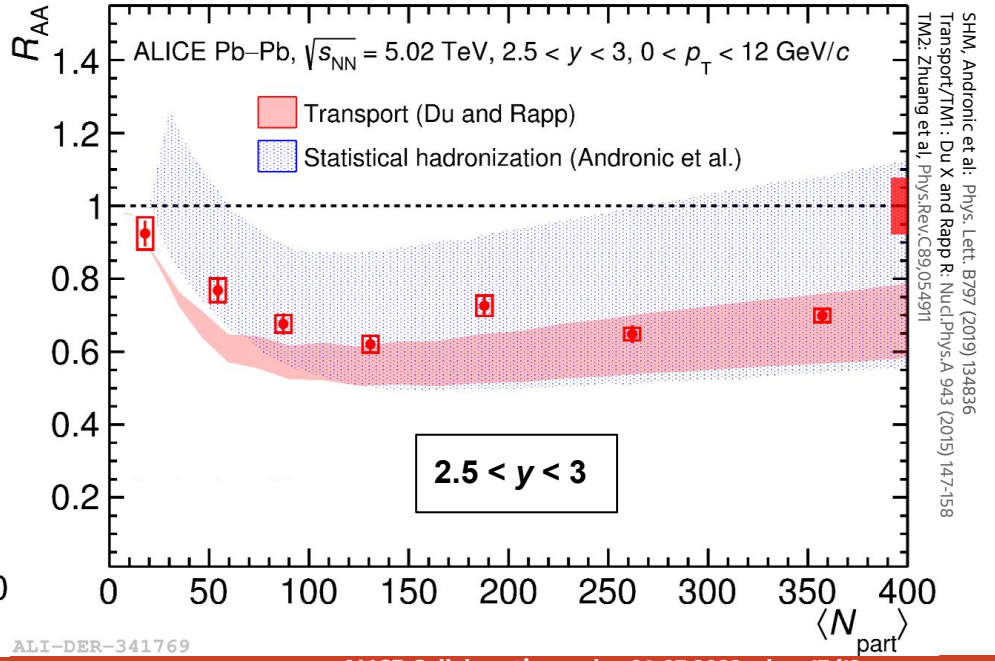
Centrality	$\langle T_{AA} \rangle (\mathrm{mb}^{-1})$	$\langle N_{\mathrm{part}} \rangle$
0-5%	26.08 ±0.18	383.40 ±0.57
0-10%	20.44 ±0.17	331.20 ±1.03
10-20%	14.4 ±0.13	262.00 ±1.15
20-30%	8.77 ±0.10	187.90 ±1.34
30-40%	5.09 ±0.08	130.80 ±1.33
40-50%	2.75 ±0.05	87.14 ±0.93
50-70%	0.98 ±0.02	42.65 ±0.63
70-90%	0.016 ±0.001	11.34 ±0.13



Inclusive J/ψ production in Pb-Pb collisions

- Modifications observed with respect to pp, at central and forward rapidity
- R_{AA} increases from peripheral to the most central collisions at midrapidity, described by the models including J/ψ dissociation and regeneration mechanism
- R_{AA} exhibits a flat behaviour at forward rapidity

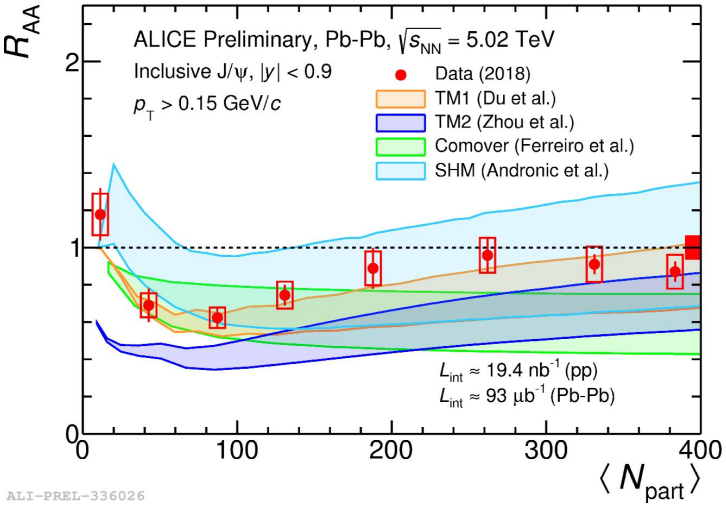




Charmonium Models in Pb-Pb

Comover model
- J/ψ suppression and dissociation via co-moving
- Partonic/hadronic interaction of J/ψ with medium
- Dissociation Π density of comovers
- Regeneration Π c quark cross section

Π = "depends on"



Transport models
- Boltzmann equation
- With dissociation and regeneration effects
- Idea hydrodynamics

TM1 (Rapp et al)
- Dissociation rate Π LQCD inspired binding energy of charmonia
- Regeneration, c quarks reach stat equilibrium after relaxation time of few fm/c

TM2 (Zhou et al)
- Dissociation rate Π $r^2_{charmonia}$
- Regenration, same cross section as dissociation, thermalized distribution of c quarks

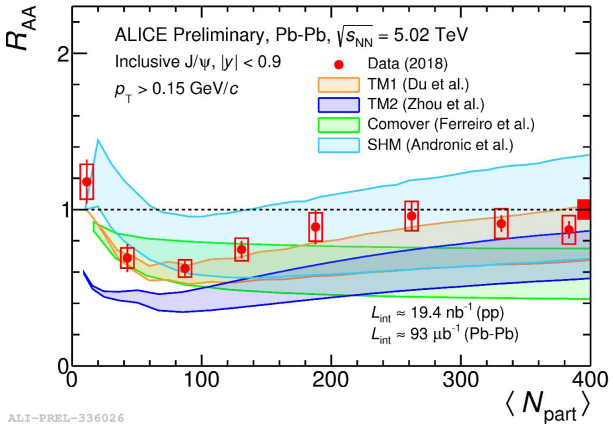
Charmonium Models in Pb-Pb

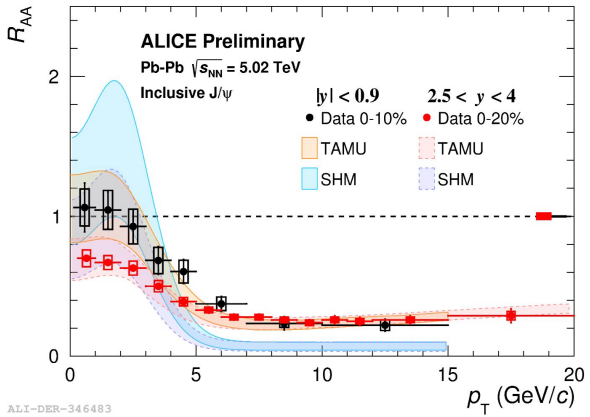
SHM

- HQ produced via hard parton scatterings initially
- All J/ψ melt in medium
- Form bound states at the phase boundary according to thermal weights of the bound state
- Core-corona model, core - high density medium (QGP), corona - < 10% density of core, pp like conditions

At higher p_T, lack of description might be related to:

- Underestimate the survived primary J/ψ yield during QGP phase
- Hydro inspired freezeout hypersurface underestimate the radial flow of c quarks





Charmonium Models in p-Pb

- Coherent energy loss with and without including nuclear shadowing according to EPPS09 nPDF
- EPPS16 and nCTEQ are set of nPDFs
- Bayesian re-weighting approach employing J/ψ measurements from LHCb to constraint the calculations
- For non-prompt J/ψ, FONLL calculations included with nuclear shadowing effects according to EPPS16 nPDFs