Forward-rapidity J/ψ production in Pb-Pb collisions with ALICE at the LHC

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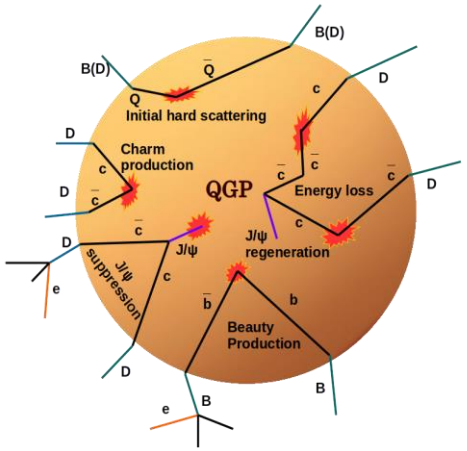
(On behalf of the ALICE Collaboration)

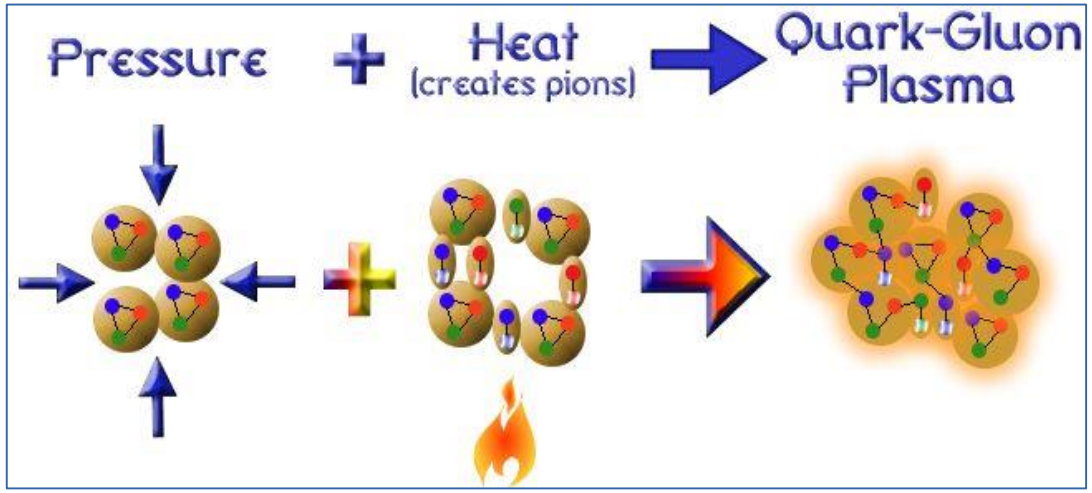
Saha Institute of Nuclear Physics



3rd Heavy Flavor Meet

18th - 20th March, 2019, IIT Indore

Quark-Gluon Plasma and Heavy-ion Collisions



Such conditions exist(ed)

- few micro seconds after the Big-Bang.
- At the core of neutron stars.

Similar conditions can be created in laboratory.

using heavy-ion collisions.

QGP is formed for short time (~10 fm/*c*)

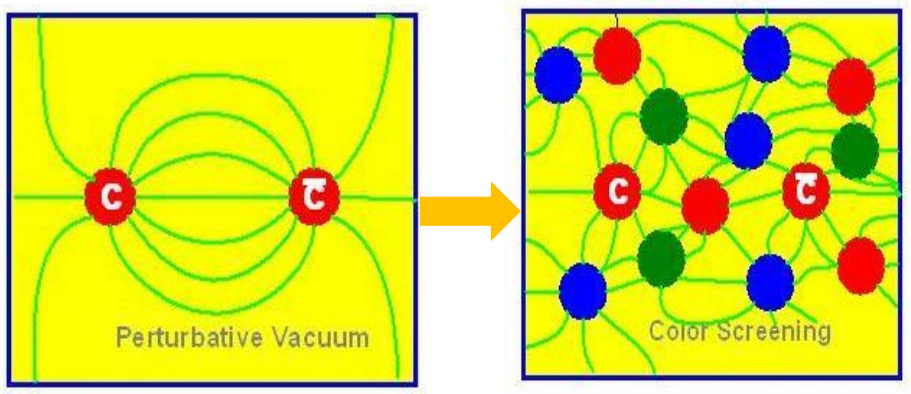
How do we understand the properties of this medium?

By studying specific probes such as Jets, strange particles, dileptons, quarkonium (charmonium and bottonium) etc..

Charmonium as QGP probes

Charmonium is a bound state of charm (c) and anti-charm ($\bar{c}$) quarks.

Charmonium suppression:



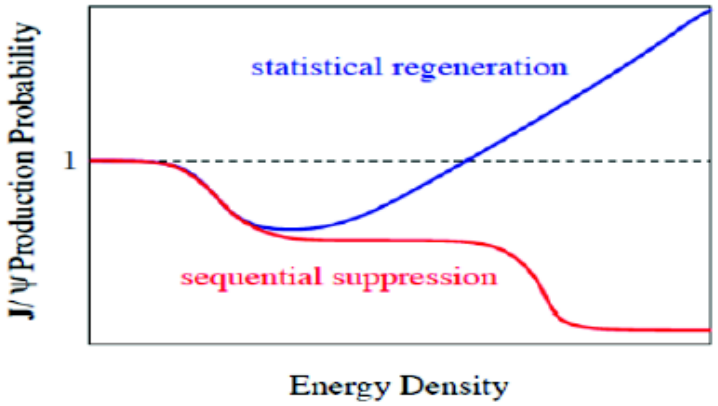
Color screening of the deconfined plasma melts the $c\bar{c}$ pairs.

J/ψ is suppressed.

Matsui and Satz, PLB 178 (1986) 416

Differences in the charmonium binding energies lead to a sequential melting with increasing temperature.

Charmonium regeneration:

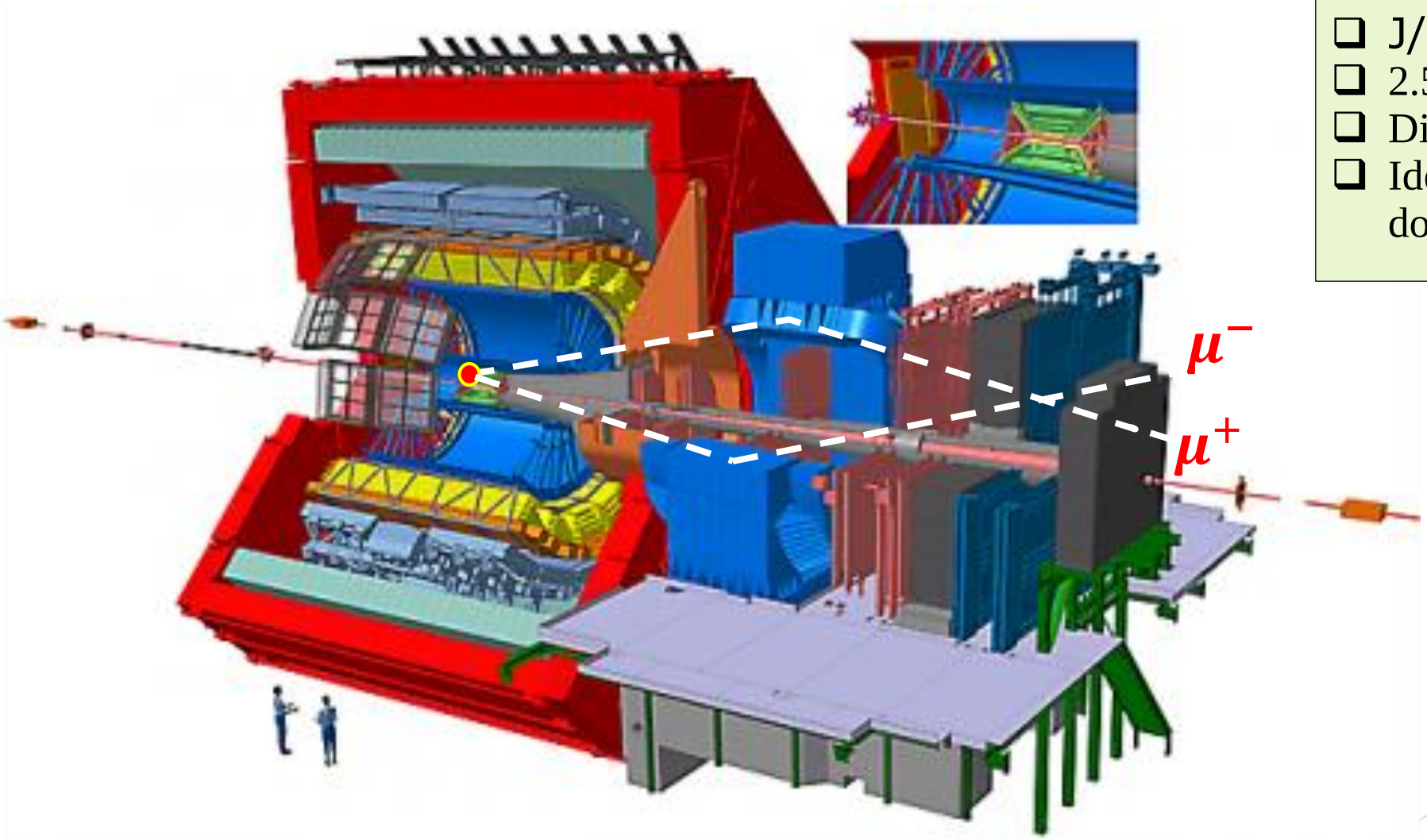


With increasing collision energy, the number of $c\bar{c}$ pairs increases.

An enhancement via (re)combination of $c\bar{c}$ pairs producing quarkonia can take place at hadronization or during QGP stage.

R. Thews et al, PRC 63 (2001) 054905
P. Barun- Muzinger, J. Stachel, PLB 490 (2000) 196

J/ψ measurement with the ALICE detector



Forward Muon Arm

- J/ψ → $\mu^+\mu^-$ (B.R.= 5.93%)
- $2.5 < y_{Lab} < 4.0$
- Di-μ: $p_T > 0$
- Identification and tracking of μ is done in Muon Spectrometer

Event and track selection

General features of event and track selections are :

Event selection

1. Rejection of beam gas and EM interactions (V0 and ZDC)
2. SPD for vertex determination.

Trigger

V0+Dimuon trigger for muon analysis

Centrality of the collisions

V0 and ZDC detector for centrality estimations

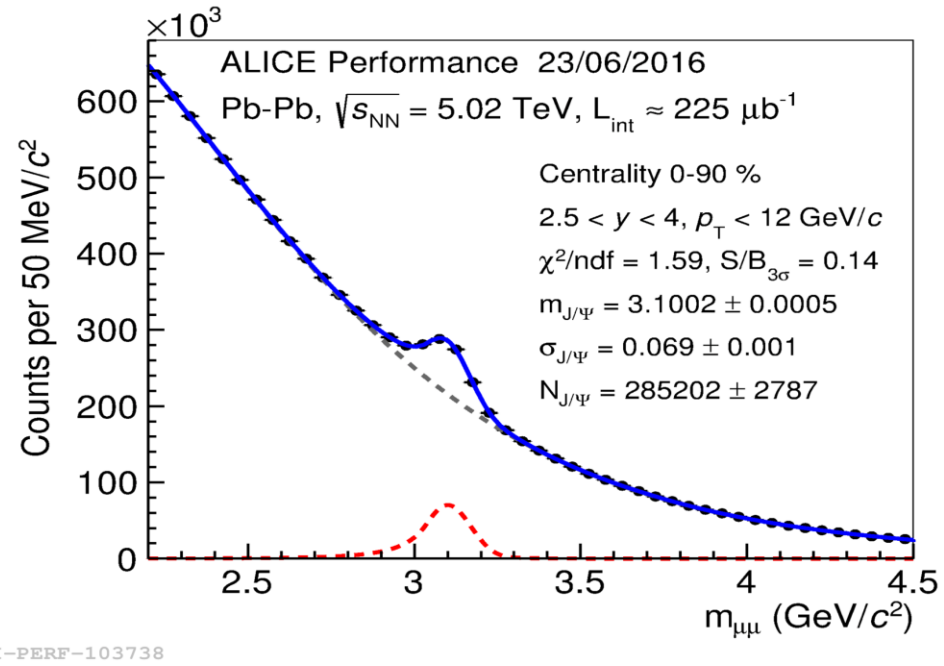
Muon track selection

1. Muon tracking-trigger matching.
2. $-4.0 < \eta_{\mu} < -2.5$
3. $17.6 < R_{abs} < 89$cm (R_{abs}= track radial position at the absorber end)

Muon pair selection

1. $2.5 < y_{Lab}^{\mu\mu} < 4$
2. Opposite sign charges

Analysis steps



- The signal is extracted by fitting the dimuon invariant mass distribution with different background and signal functions.
- The number of J/ψ are further corrected by the detector acceptance and efficiency obtained by MC simulation.
- Realistic embedded MC simulation (in order to have the relevant underlying event and multiplicities in the muon arm) is done using the input shapes of p_T and y distributions tuned on data.
- J/ψ cross-sections measured in pp collisions at the same energy as vacuum reference.

Observables: R_{AA}

Nuclear Modification Factor (R_{AA})

Ratio of the quarkonium yield in AA (Y_{AA}) with respect to pp collisions, scaled by the nuclear overlap function T_{AA} (taken from Glauber model)

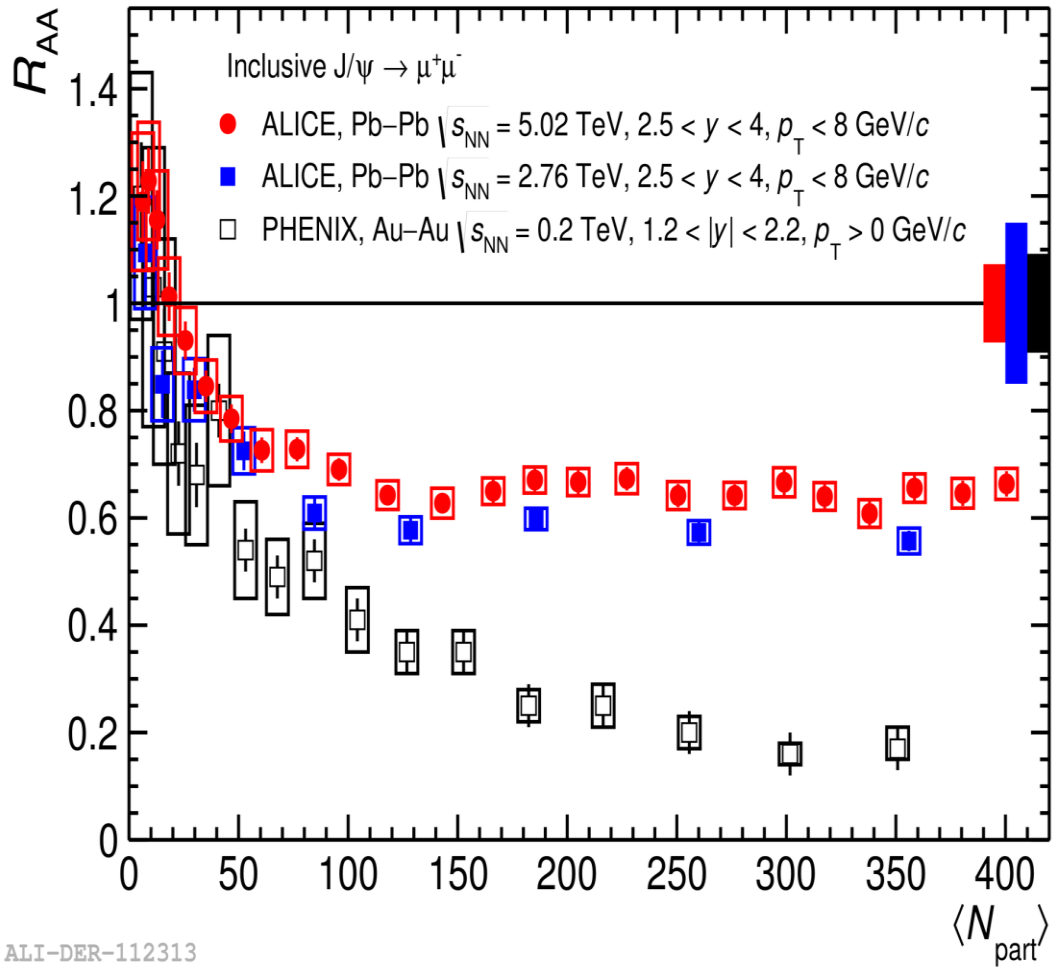
$$R_{AA} = \frac{Y_{AA}^{J/\psi}}{\langle T_{AA} \rangle \sigma_{pp}^{J/\psi}}$$

$R_{AA} \neq 1$ ➡ hot/cold nuclear matter effects

- $R_{AA} < 1$ ➡ J/ψ suppression
- $R_{AA} > 1$ ➡ J/ψ enhancement

J/ψ in Pb-Pb collisions at 5.02 TeV

PLB 766 (2017) 212 (ALICE), PRL 98 (2007) 232301 (PHENIX)



At SPS and RHIC energies

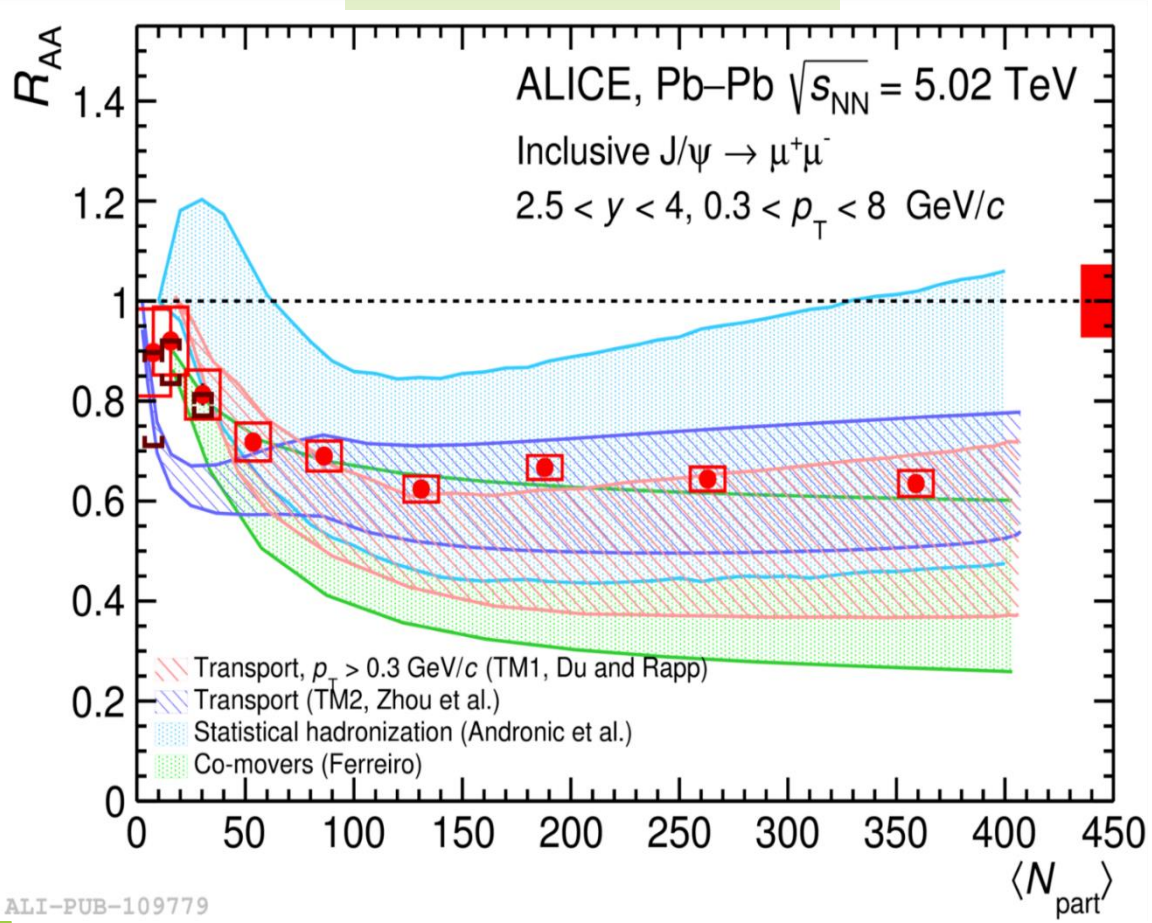
- J/ψ suppression is clearly visible
- Suppression increases with centrality

At LHC energies

- Less suppression is observed
- Interplay between color screening and regeneration mechanism.
- Saturation of R_{AA} as a function of centrality rather than further decrease.

J/ψ vs centrality in Pb-Pb collisions at 5.02 TeV

PLB 766 (2017) 212



- p_T > 0.3 GeV/c to suppress the contribution from photoproduction relevant in (semi)-peripheral collisions.

Statistical Hadronization : [continuous blue shade]
Andronic et al., Nucl. Phys. A 904-905 (2013) 535c

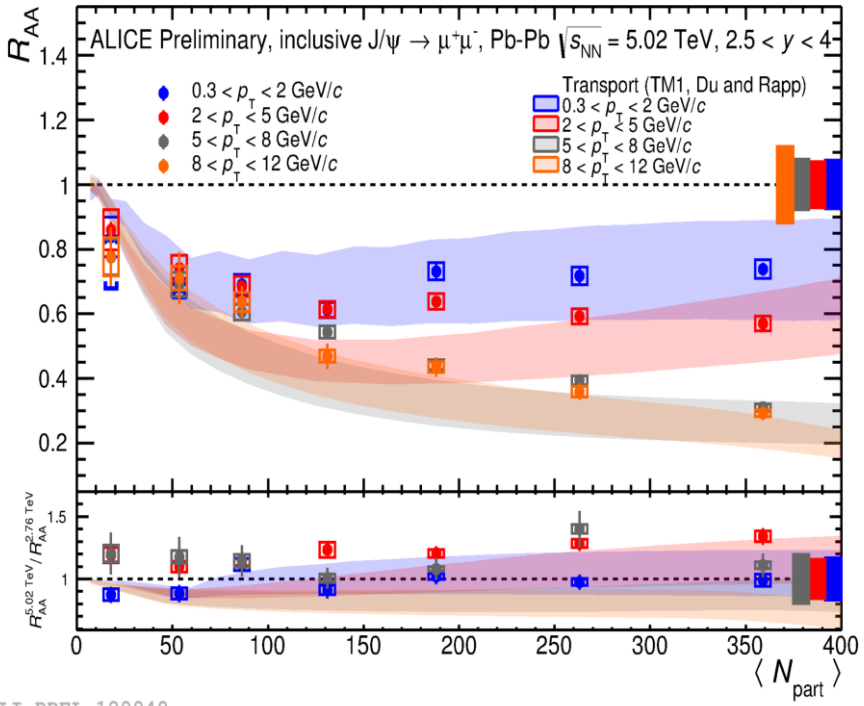
Co-movers interaction model : [continuous green shade]
Ferreiro, Phys. Lett. B 731 (2014) 57

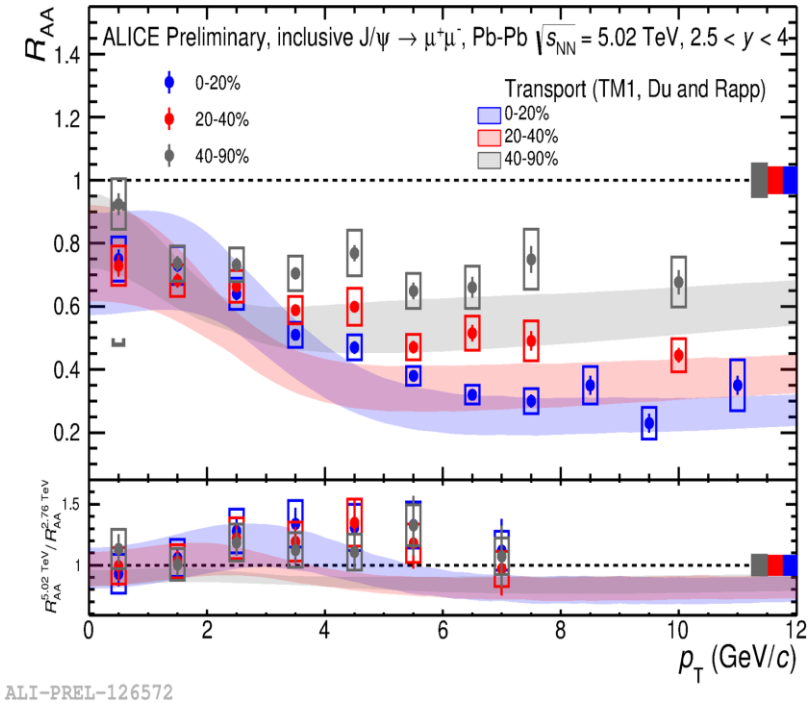
Transport model (TM1) : [slanted red lines]
Du and Rapp, Nucl. Phys. A 859 (2011) 114-125

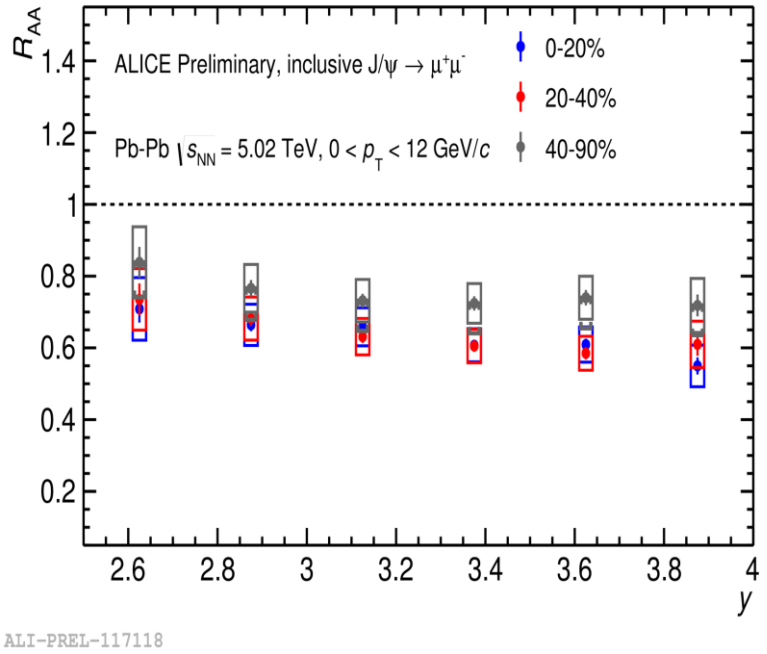
Transport model (TM2) : [slanted blue lines]
Zhou et al., Phys. Rev C 89 no.5, 459 (2014) 054911

- All models can describe the data but with large uncertainties.
- Precise open charm cross section and differential analysis might help to further discriminate between models.

More differential J/ψ R_{AA}: centrality, p_T and rapidity







Centrality (in p_T ranges)

- In central collisions, smaller suppression for lower p_T J/ψ as expected by (re)generation.
- Well reproduced by models which include J/ψ (re)generation (TM1 [Nucl. Phys. A (2011) 114]).
- Stronger centrality dependence at higher p_T .

p_T (in centrality ranges)

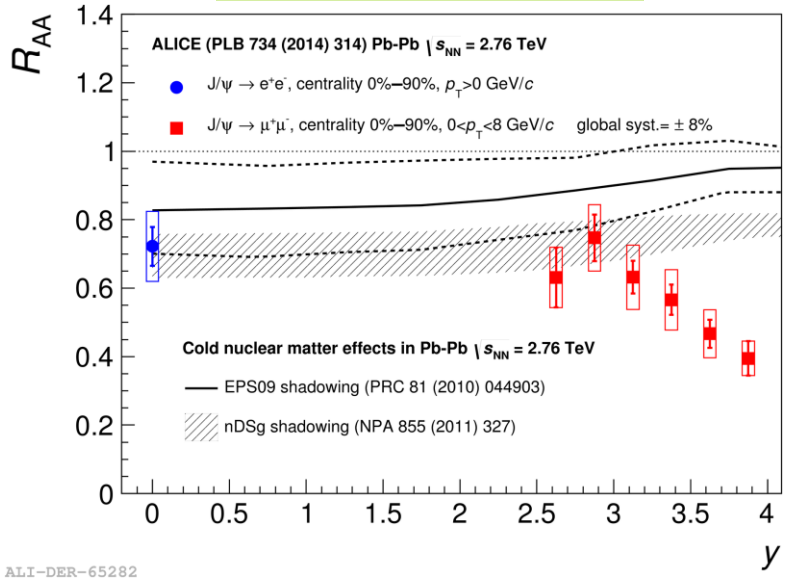
- Suppression is stronger for higher p_T and most central collisions.
- Weak p_T dependence of J/ψ suppression in semi-peripheral collisions .
- Trend is well reproduced by TM1 model within the uncertainties.

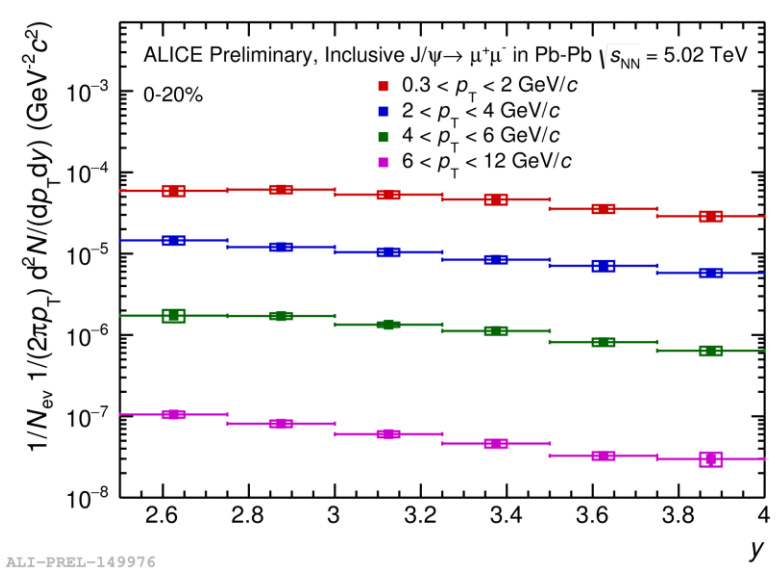
Rapidity (in centrality ranges)

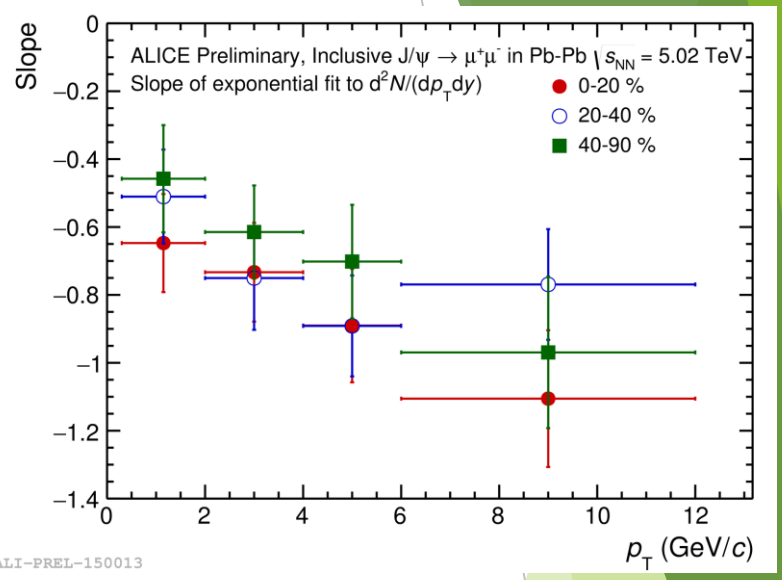
- R_{AA} in various centrality bins shows weak rapidity dependence.

Multi-differential J/ψ measurement in Pb-Pb collisions at 5.02 TeV

PLB 734 (2014) 314





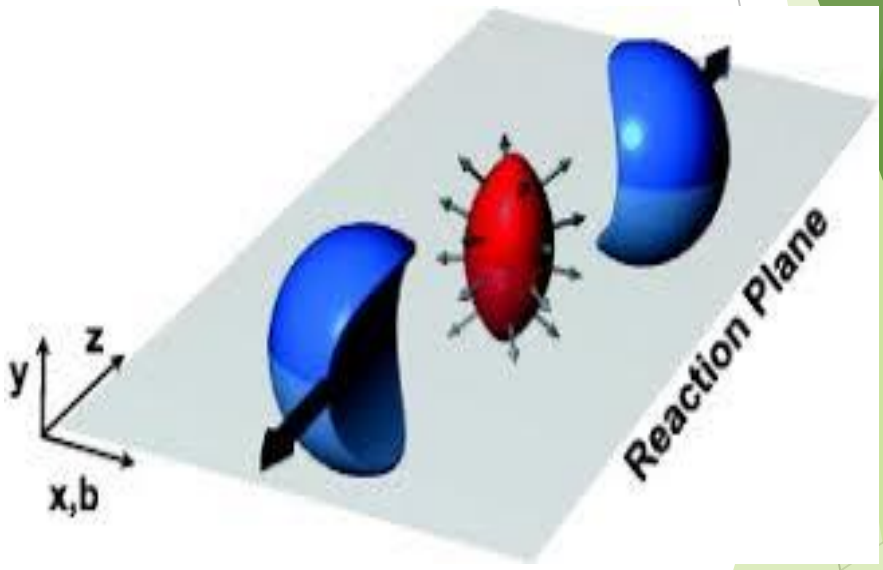


- A strong rapidity dependence is measured for J/ψ R_{AA} at $\sqrt{s_{NN}}$ = 2.76 TeV which shows a trend opposite to that of shadowing predictions.
- The multi-differential measurement of J/ψ R_{AA} as a function of centrality, p_T, and rapidity is ongoing and will provide more insight into the interplay between suppression and (re)generation in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

Observables: J/ψ flow

- Non central AA collisions result in an azimuthally anisotropic distribution of particles in coordinate space.
- Pressure gradients and the interactions between the particles lead to momentum anisotropy.
- This anisotropy is quantified by the 2nd order coefficient (v_2) of the Fourier expansion with respect to the reaction plane

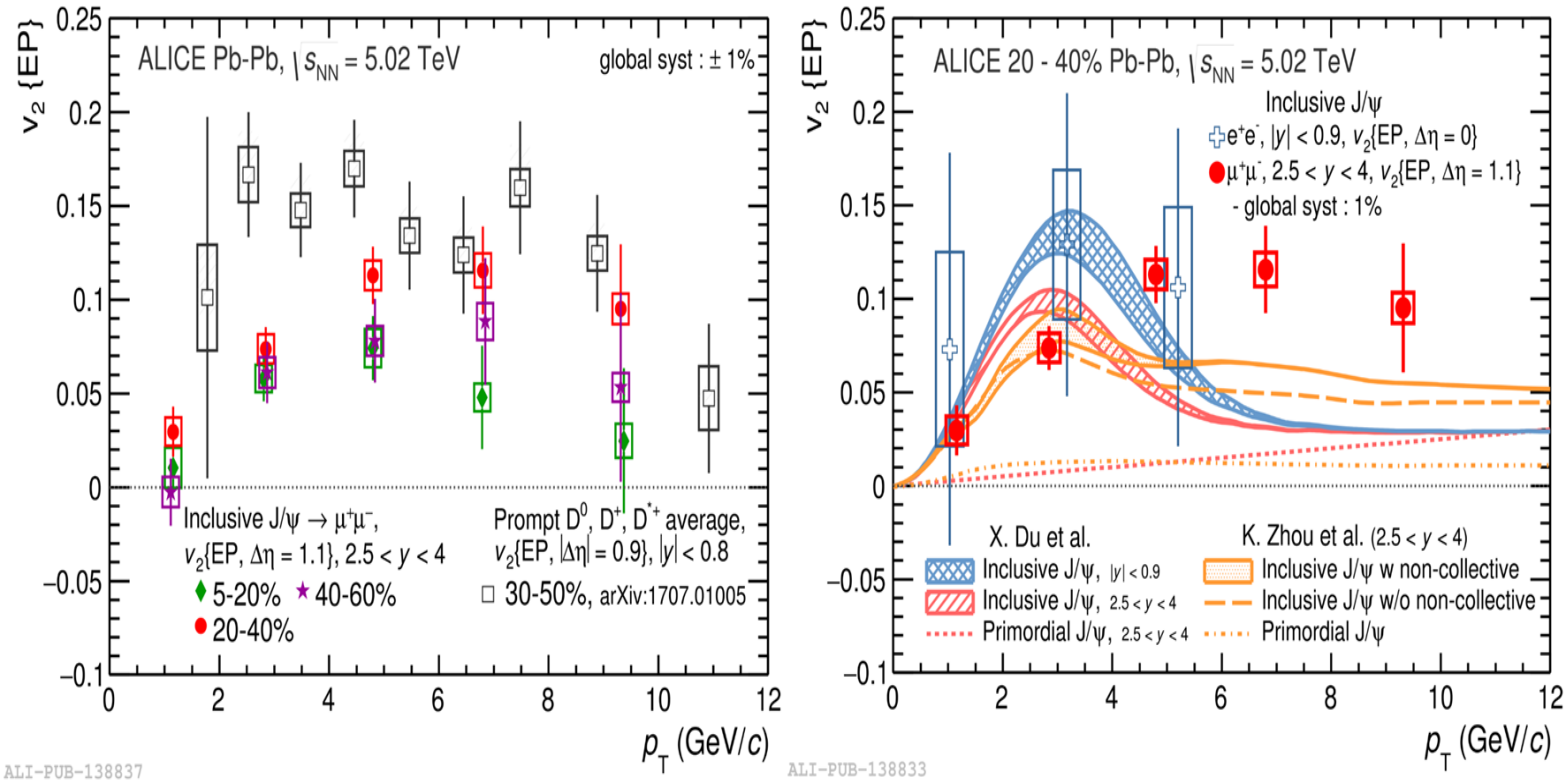
$$v_2 = \langle \cos 2(\phi_{\mu\mu} - \psi_{EP}) \rangle$$



- J/ψ produced through (re)generation should inherit the charm-quark flow in QGP medium.

J/ψ flow in Pb-Pb at 5.02 TeV: elliptic flow (v_2)

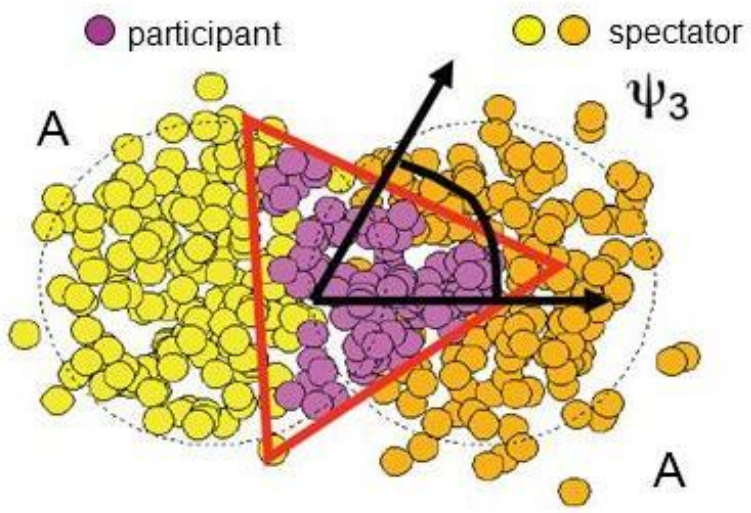
PRL 119(2017) 242301



- Both the bound state charmonium and prompt open-charm mesons show non-zero elliptic flow.
- Transport models have difficulties in reproducing J/ψ v_2 in the high-p_T region (p_T > 7 GeV/c).

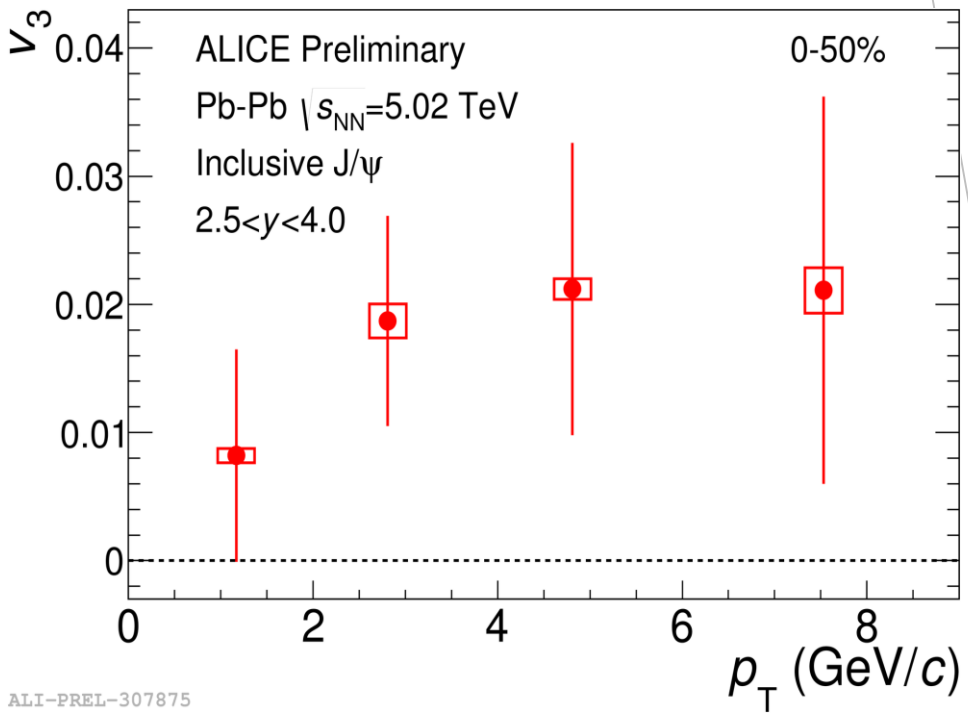
J/ψ flow in Pb-Pb at 5.02 TeV: triangular flow (v_3)

PRC 81 (2010) 054905



$$v_3 = \langle \cos 3(\phi_{\mu\mu} - \psi_{EP}) \rangle$$

JHEP 1902 (2019) 012

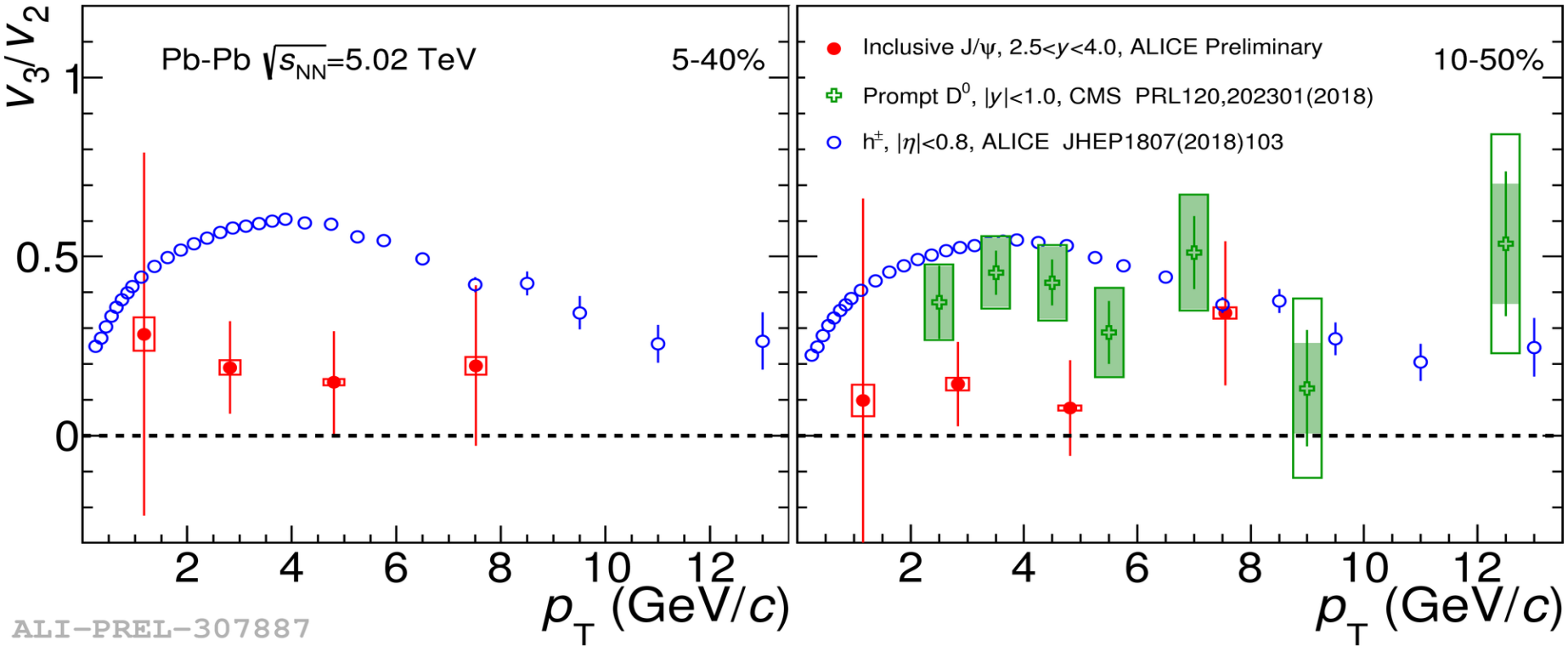


➡ A non-zero v_3 flow of J/ψ (3.7σ significance) has been measured.

➡ v_3 is created by event-by-event fluctuations of the collision geometry.

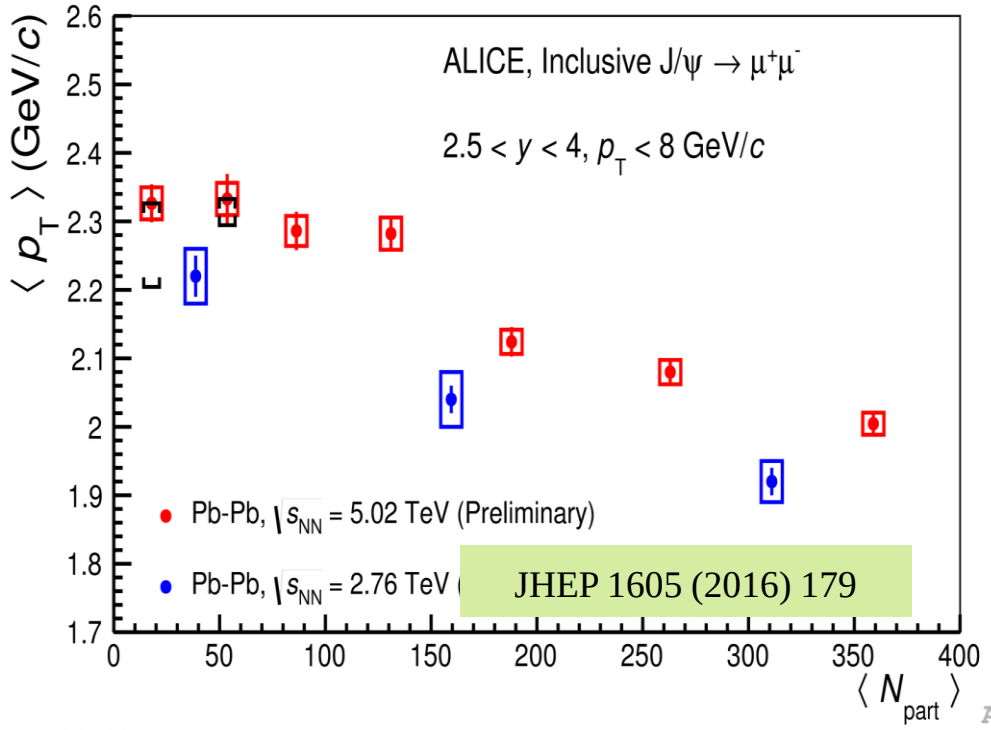
J/ψ flow in Pb-Pb at 5.02 TeV

JHEP 1902 (2019) 012



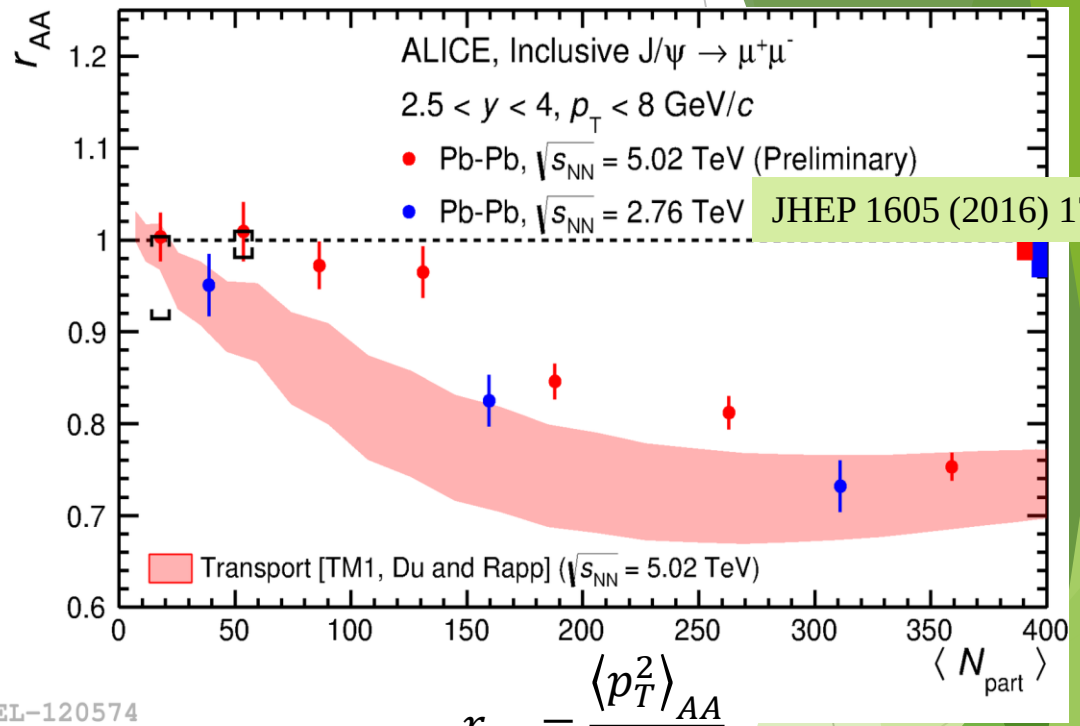
- Ratio of v_3/v_2 as function of p_T for different centrality bins.
- J/ψ v_3/v_2 is significantly lower (4.6σ) with respect to that of charged particles.

J/ψ mean $\langle p_T \rangle$ in Pb-Pb at 5.02 TeV



JHEP 1605 (2016) 179

ALI-PREL-120593



JHEP 1605 (2016) 179

ALI-PREL-120574

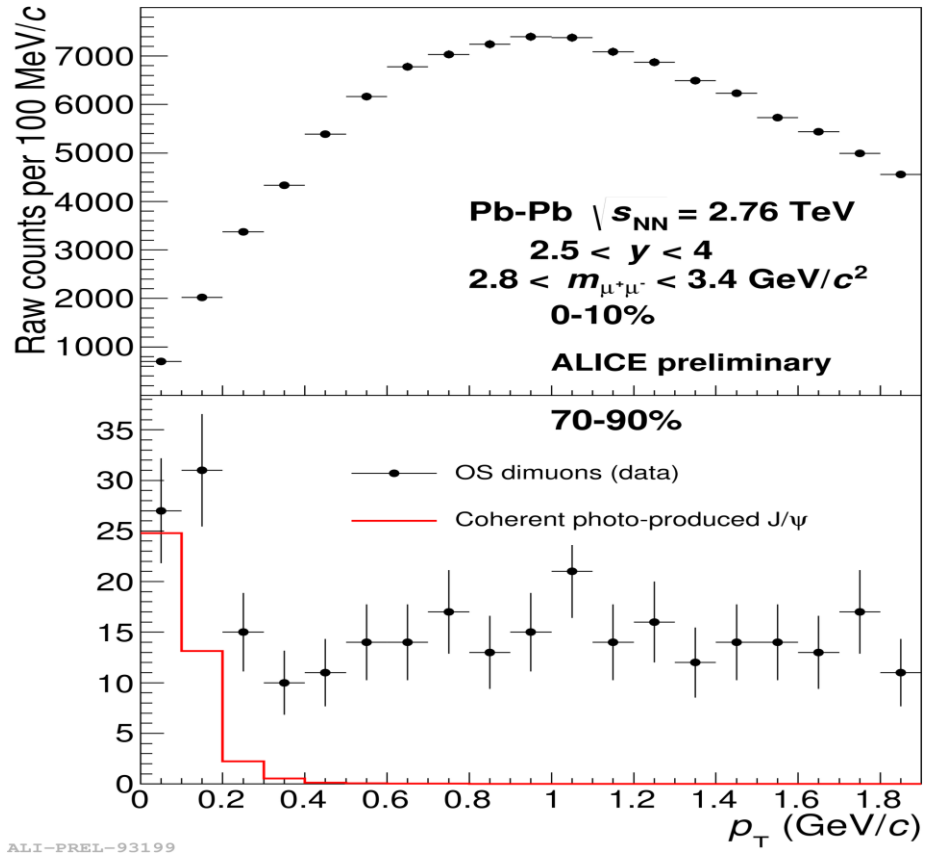
$$r_{AA} = \frac{\langle p_T^2 \rangle_{AA}}{\langle p_T^2 \rangle_{pp}}$$

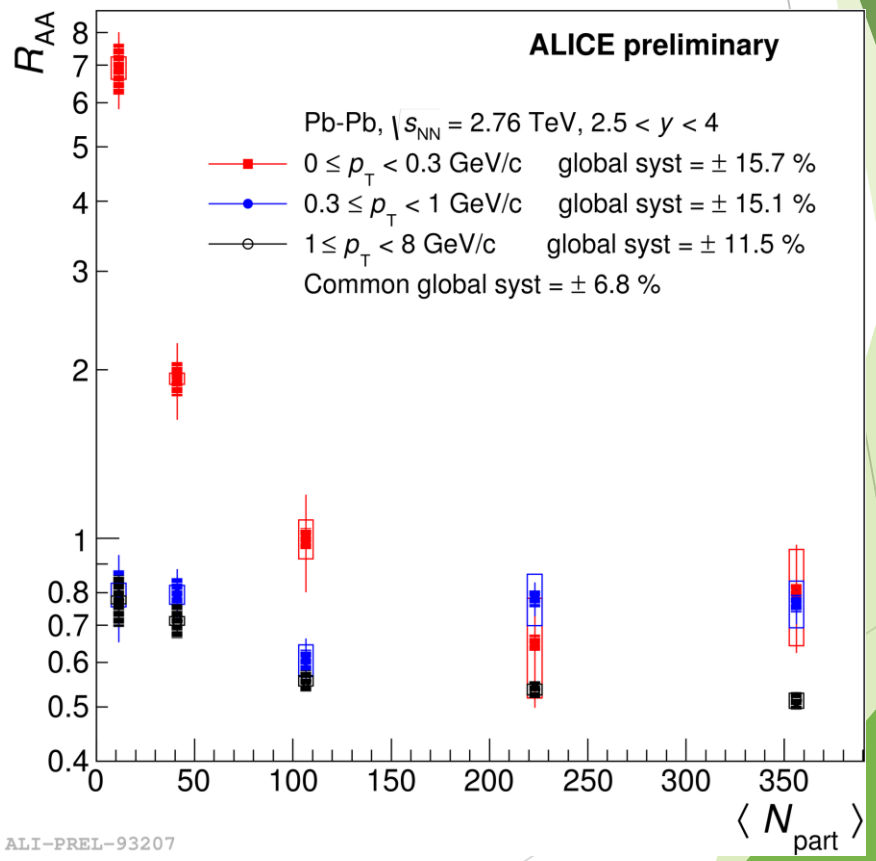
- ✓ The J/ψ $\langle p_T \rangle$ smaller in central events than in peripheral collisions indicates the (re)generation for central collisions.
- ✓ The results of r_{AA} at 5.02 TeV and 2.76 TeV are compatible within uncertainties.
- ✓ The transport model does not reproduce the r_{AA} at intermediate centralities.

Coherent photoproduction

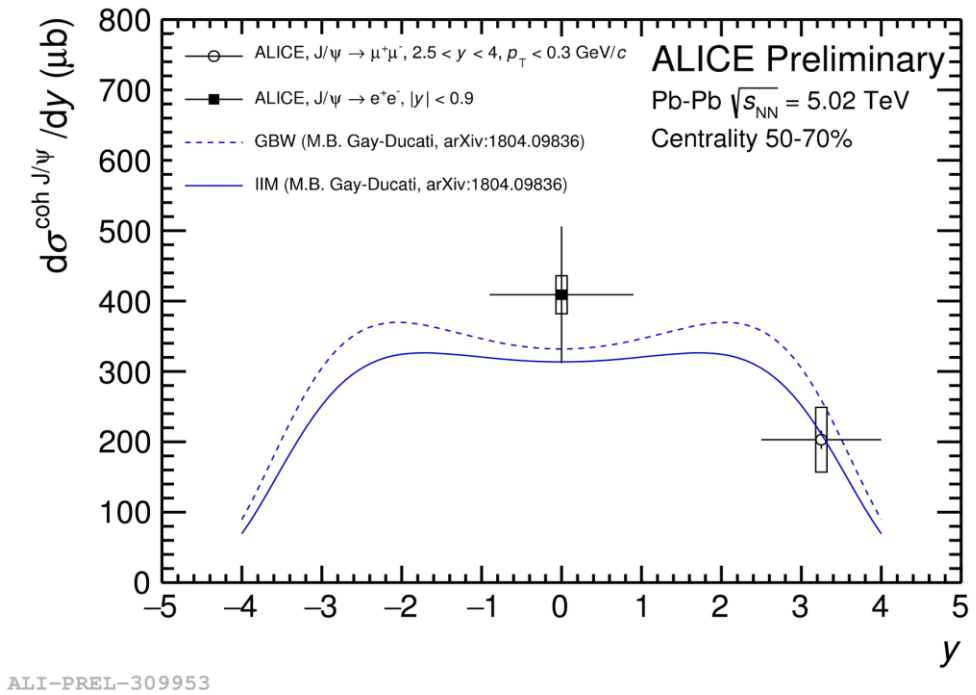
First observation of an excess in the yield of J/ψ at very low p_T (< 0.3 GeV/c) in peripheral Pb-Pb hadronic collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. This excess is attributed to coherent photoproduction of J/ψ.

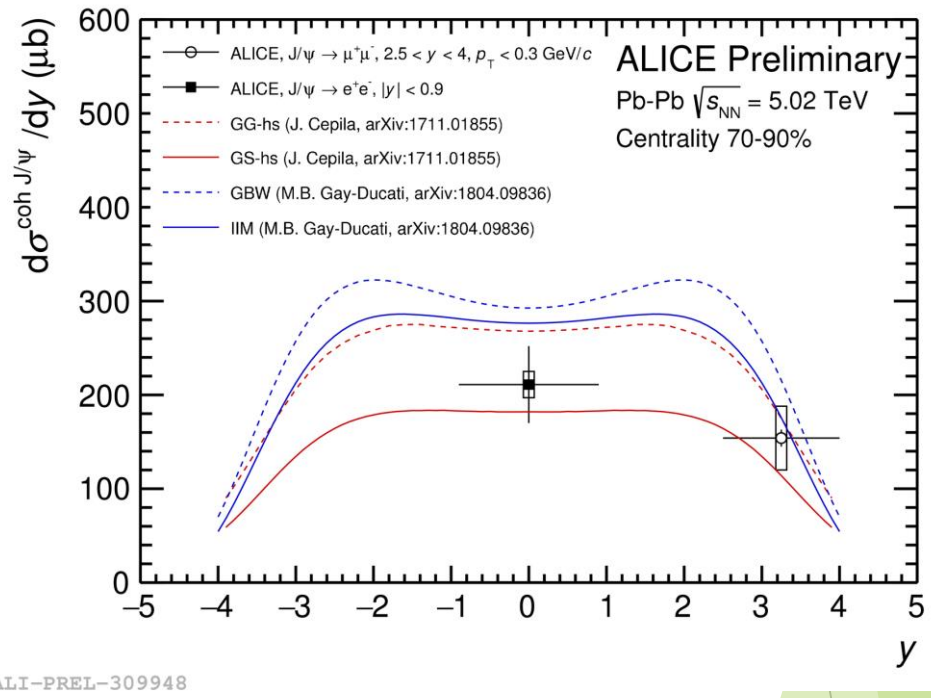
PRL 116 (2016) 222301





J/ψ photoproduction in peripheral Pb-Pb collisions at 5.02 TeV





- ✓ The coherently photo-produced J/ψ cross section is compared with the theoretical models.
- ✓ The challenge for models of J/ψ photoproduction is to calculate the photo-flux when the nucleus breaks during the collisions.

Summary

- ✓ R_{AA} measurement at low p_T provides evidence for a competition between suppression and (re)generation for charmonium.
- ✓ At high p_T the suppression effect is dominant.
- ✓ Differential R_{AA} analyses should be able to put constraints on the model.
- ✓ A significant non-zero v_2 has been observed and for $p_T > 7$ GeV/c models significantly undershoot the data at forward rapidity.
- ✓ First observation of a non-zero v_3 for J/ψ has been shown.
- ✓ J/ψ mean $\langle p_T \rangle$ and r_{AA} results has been shown and compared with the model predictions.
- ✓ Coherent J/ψ photoproduction cross-sections in peripheral Pb-Pb collisions are reasonably well reproduced by models.


Thank
You