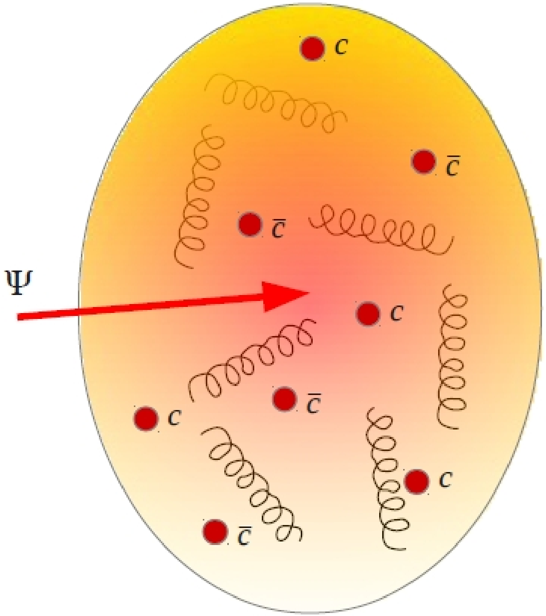
J/ψ production in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV

Ionut-Cristian Arsene
for the ALICE Collaboration

FIAS Frankfurt Institute for Advanced Studies

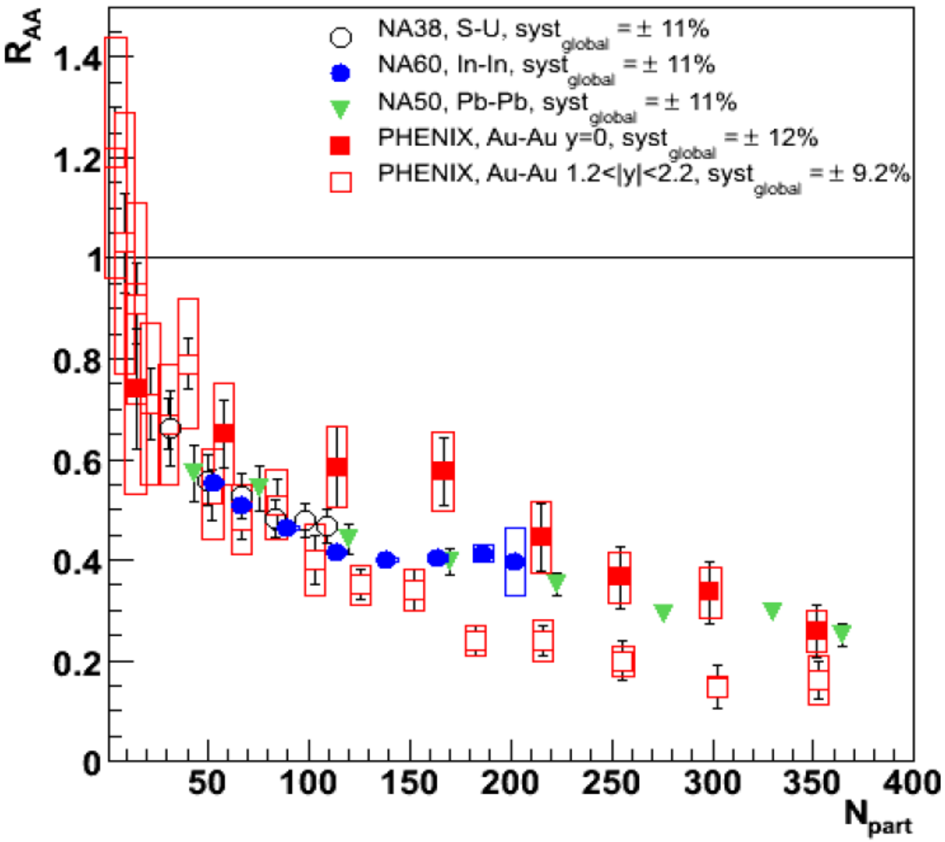
Quarkonia in heavy ion collisions

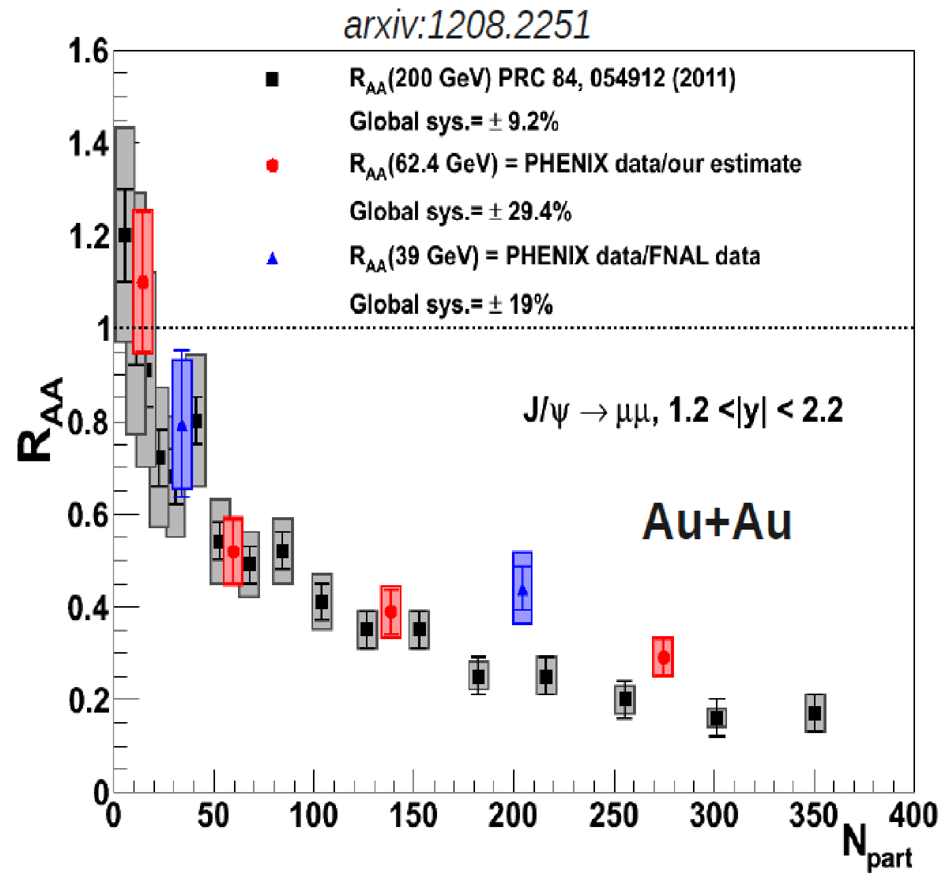
- Created early, during the partonic stage → probes the full history of the collision
- Sensitive to properties of the hot and dense nuclear matter and a probe for a deconfined phase (quark-gluon plasma)
  - T.Matsui and H.Satz, Phys.Lett.B 178 (1986) 416
- Test for deconfinement and hadronization of charm quarks at the phase boundary
  - P.Braun-Munzinger, J.Stachel, Phys.Lett.B490 (2000) 196
  - A.Andronic et al., Nucl.Phys.A789 (2007) 334-356



- Many effects involved in quarkonium production:
  - Nuclear absorption, shadowing, formation time
  - Debye screening,
  - (Re)combination,
  - Feed-down from higher mass states

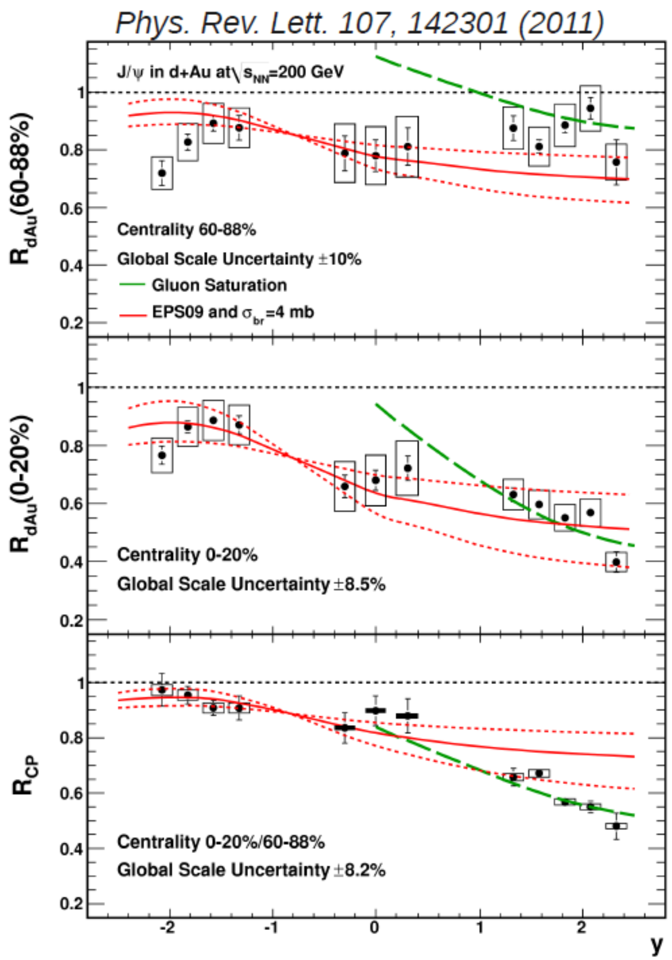
SPS and RHIC measurements

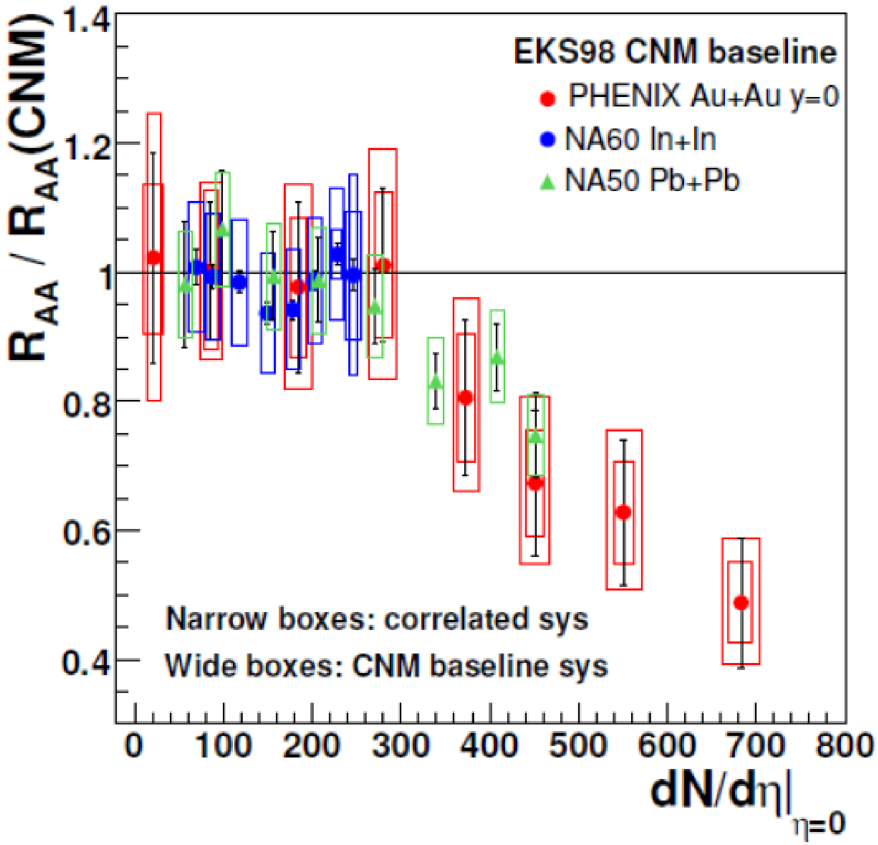




- Strong J/ψ suppression seen at RHIC and at SPS energies
- Competing effects having different dependence on collision energy

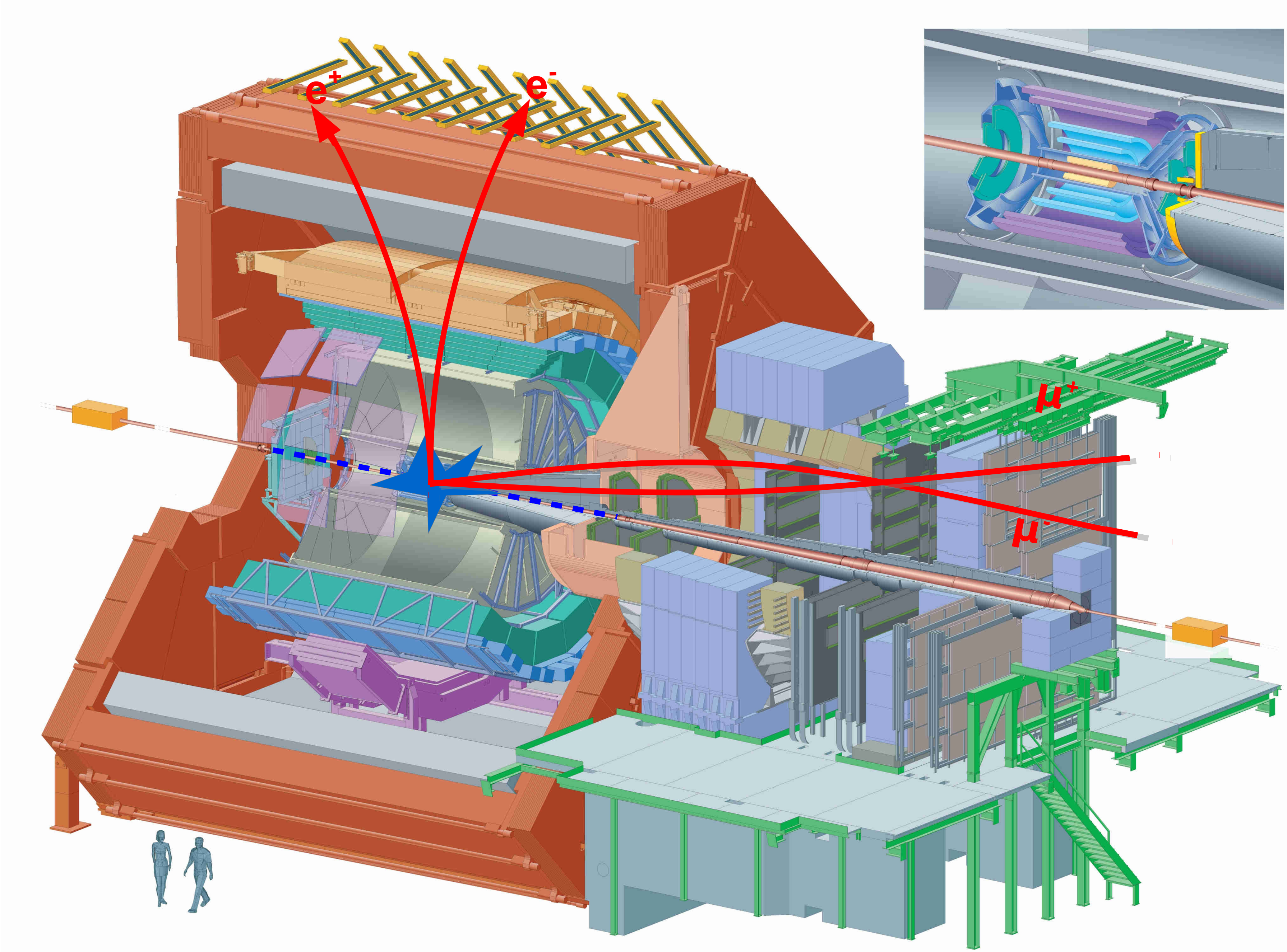
Cold nuclear matter (CNM) effects



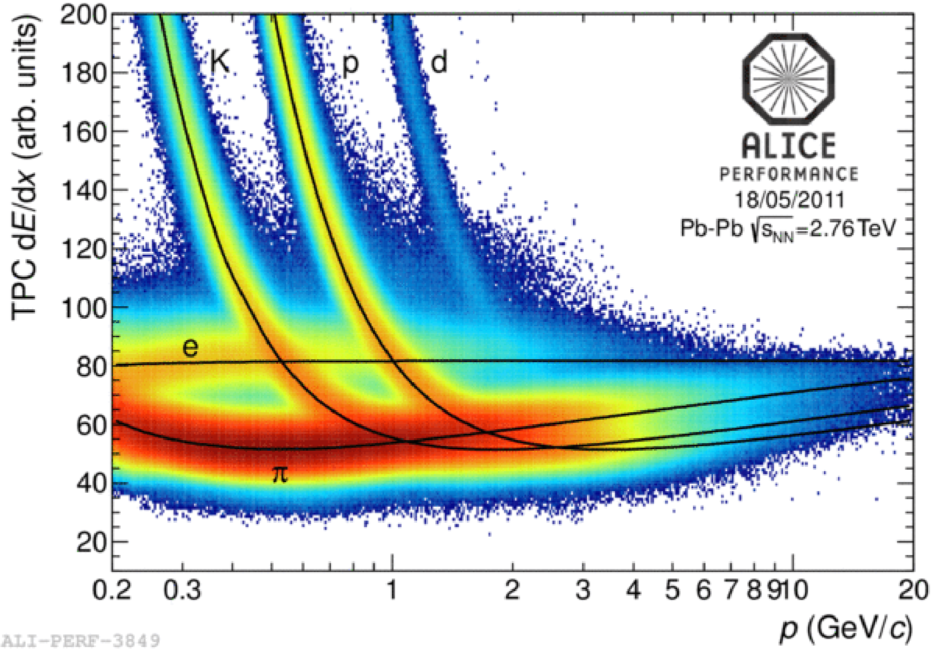


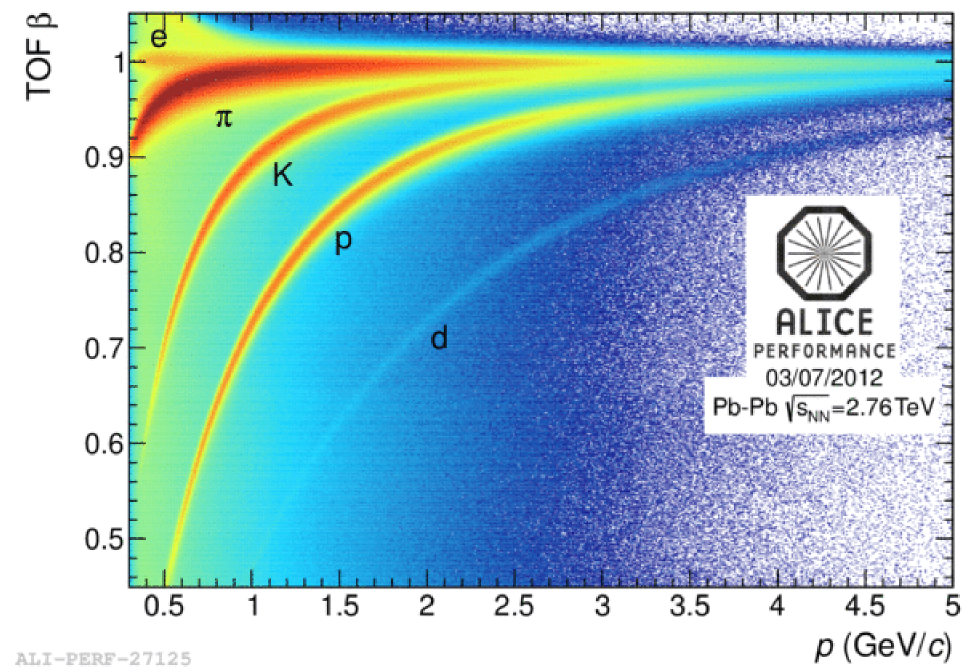
- CNM effects strong at RHIC energies → need to be disentangled in order to understand final state effects
- Strong suppression seen at mid-rapidity after taking into account CNM

J/ψ measurements in ALICE



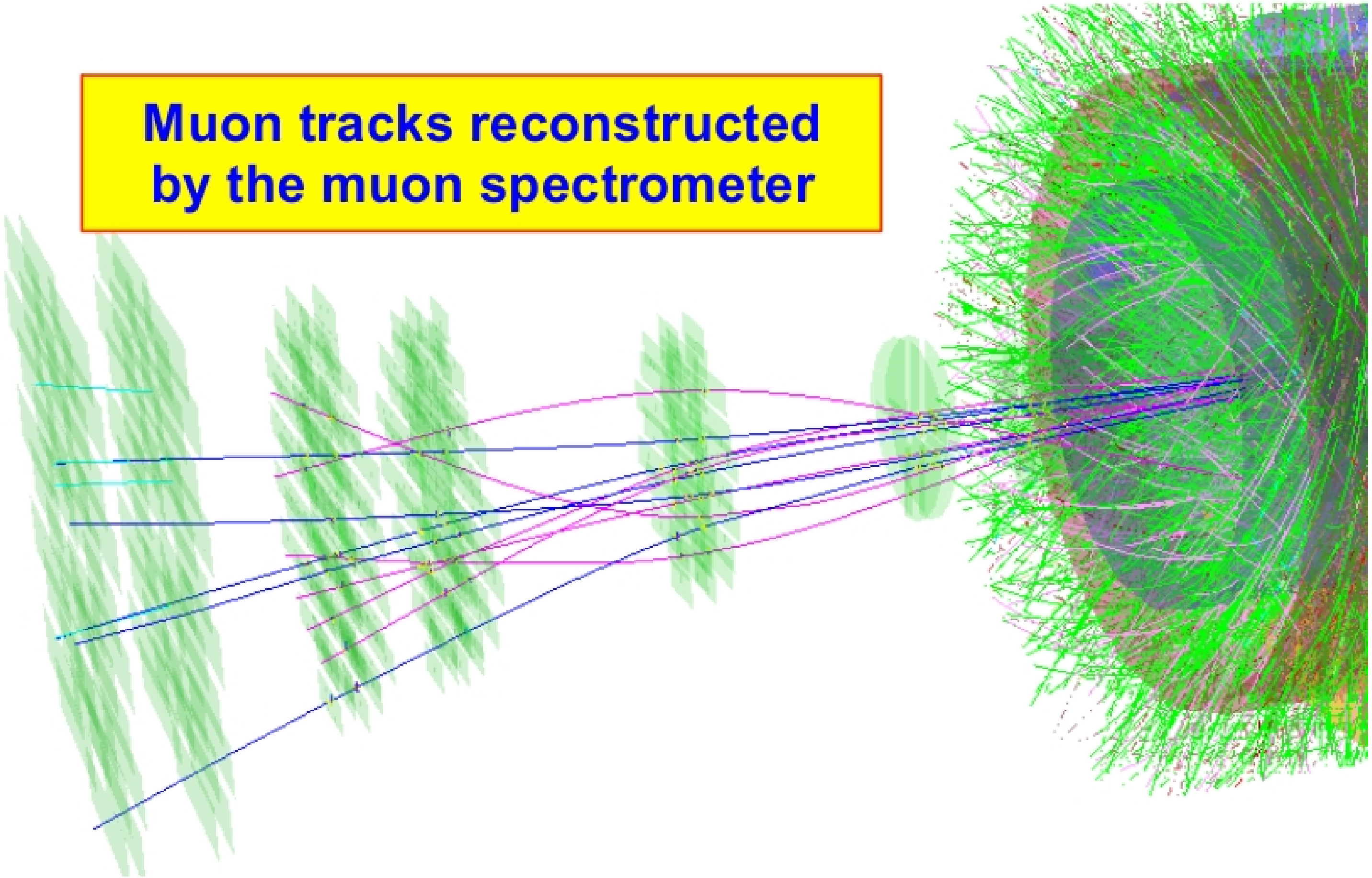
J/ψ→e$^+$e$^-$ reconstruction





- Kinematics
  - $|y^{J/\psi}|<0.9$, $p_T^{J/\psi}>0$ GeV/c
  - $|\eta_e|<0.9$, $p_T^e>0.85$ GeV/c
- Tracking
  - Primary track requirements using ITS and TPC
- Particle identification
  - TPC+TOF
- Conversion electrons rejection
  - ITS cluster requirements on electron candidates
  - Removal of tracks from reconstructed γ-conversion V_0 's

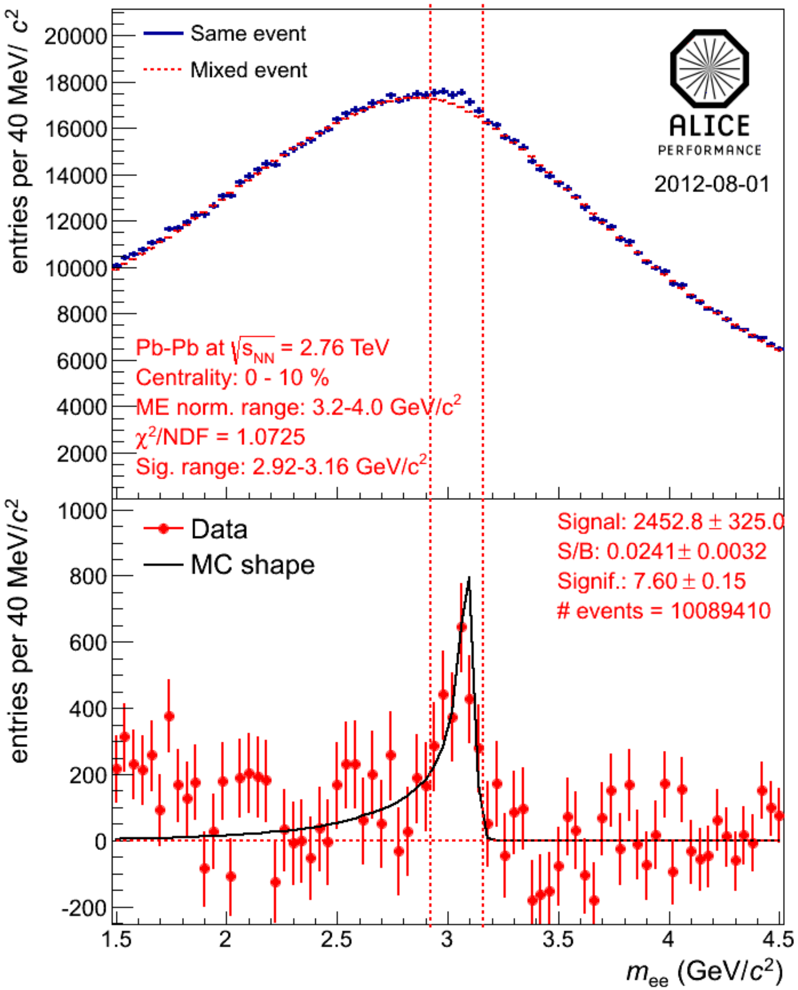
$J/\psi \rightarrow \mu^+\mu^-$ reconstruction

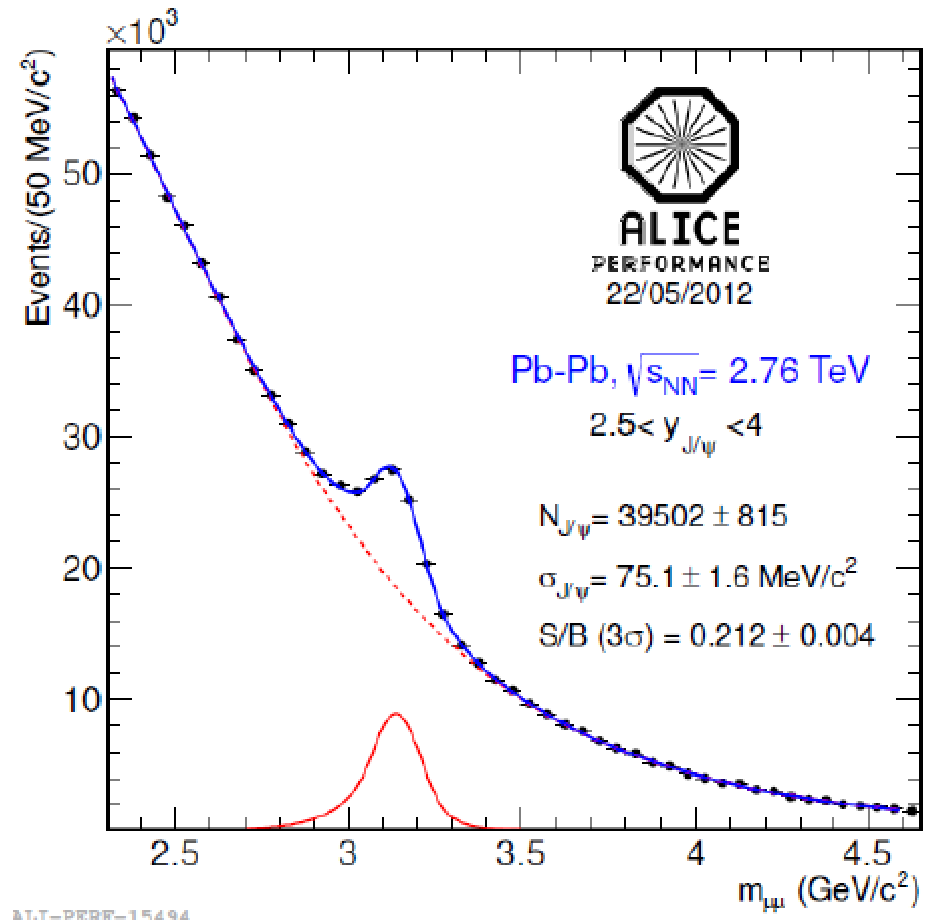


- Muons are reconstructed using tracking chambers placed behind a thick hadron absorber

- Kinematics:
  - Trigger on p_T^{μ}>1 GeV/c
  - 2.5<$y^{J/\psi}$<4
  - $p_T^{J/\psi}$>0 GeV/c

Signal extraction

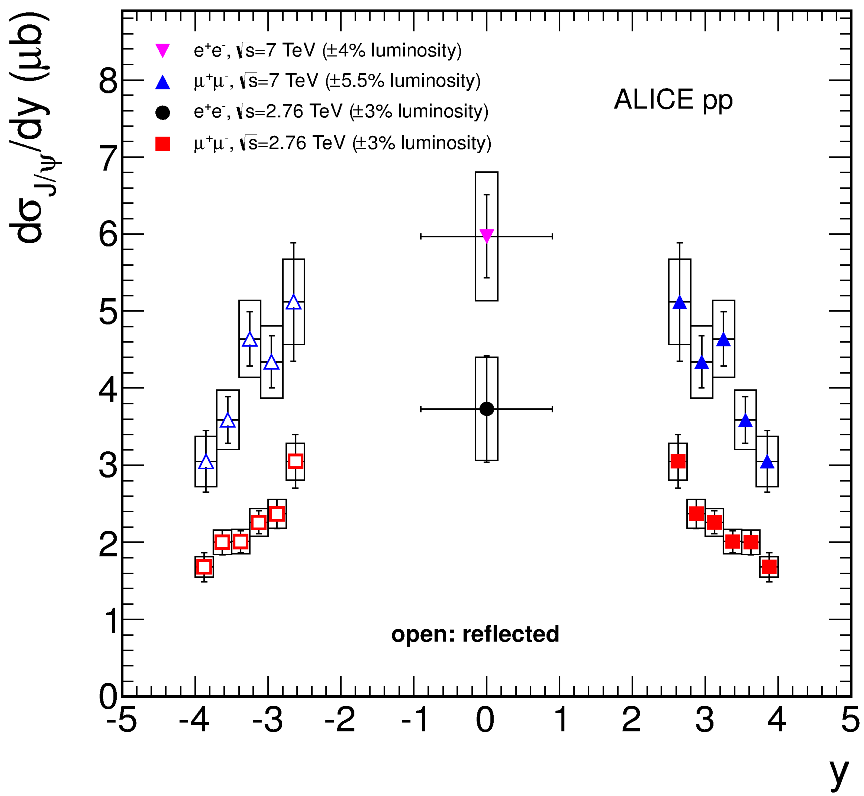


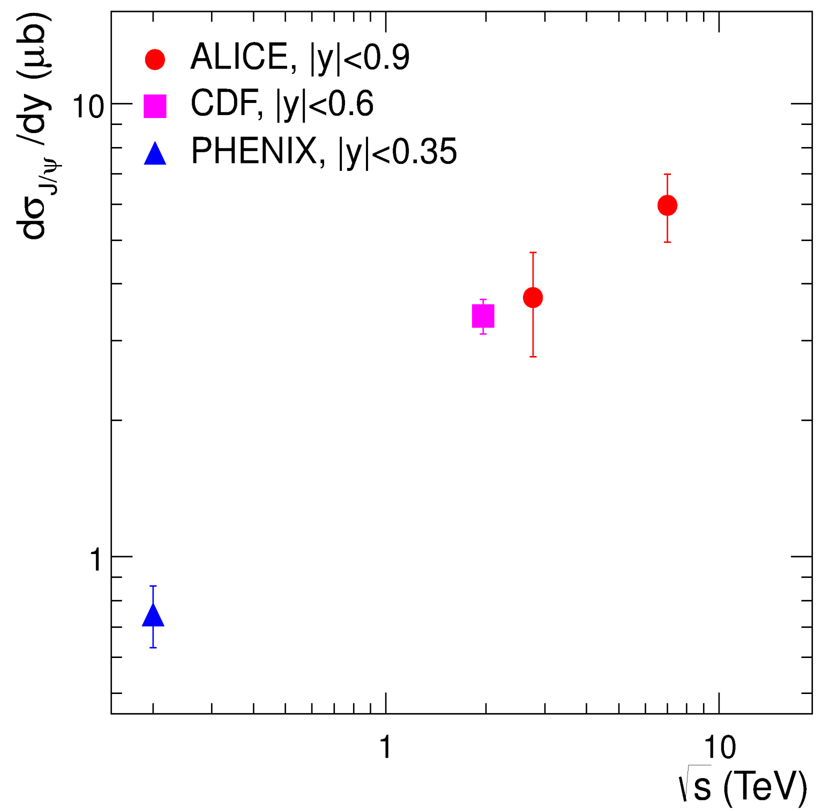


- $J/\psi \rightarrow e^+e^-$: background subtracted using event mixing and signal extracted by bin counting
- $J/\psi \rightarrow \mu^+\mu^-$: invariant mass distribution fitted using a Crystal Ball signal shape

The pp reference

ALICE Collaboration, arXiv:1203.3641

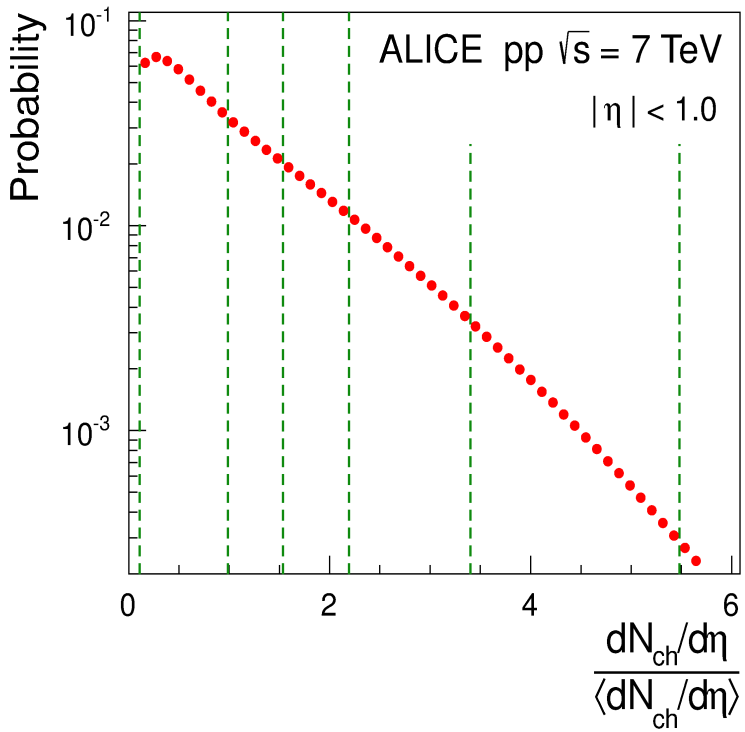




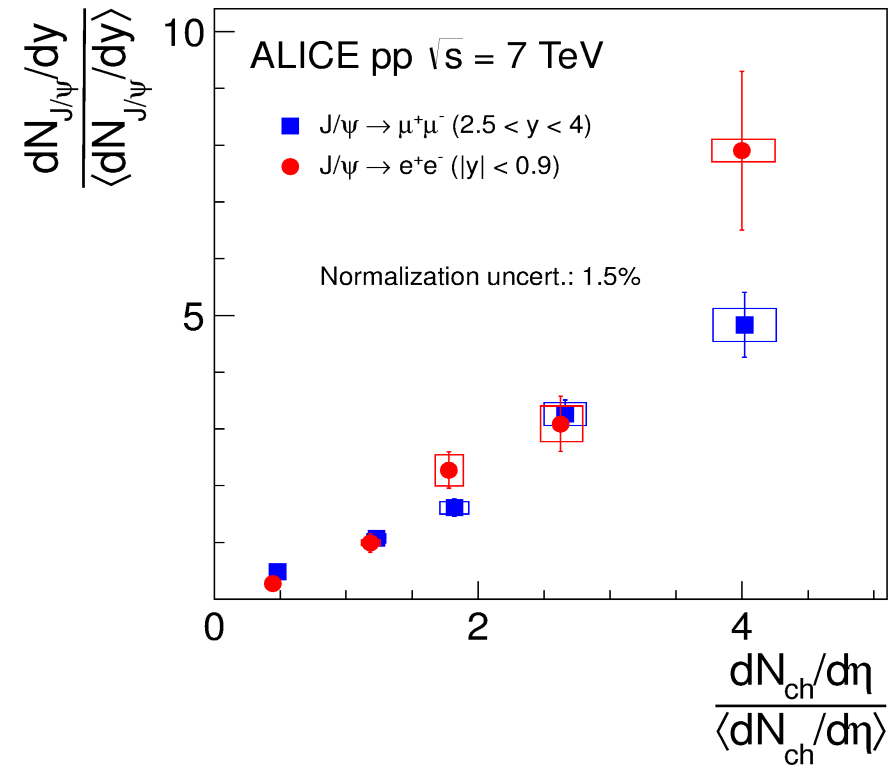
- ALICE measured the J/ψ cross-section in pp at 2.76 TeV
- Combined statistical and systematic error:
  - |y|<0.9 : 26%
  - 2.5<y<4.0 : 8%

$$\sigma_{J/\psi}(|y|<0.9) = 6.71 \pm 1.24\,(stat.) \pm 1.22\,(syst.)\,\mu b$$
$$\sigma_{J/\psi}(2.5<y<4.0) = 3.34 \pm 0.13\,(stat.) \pm 0.27\,(syst.)\,\mu b$$

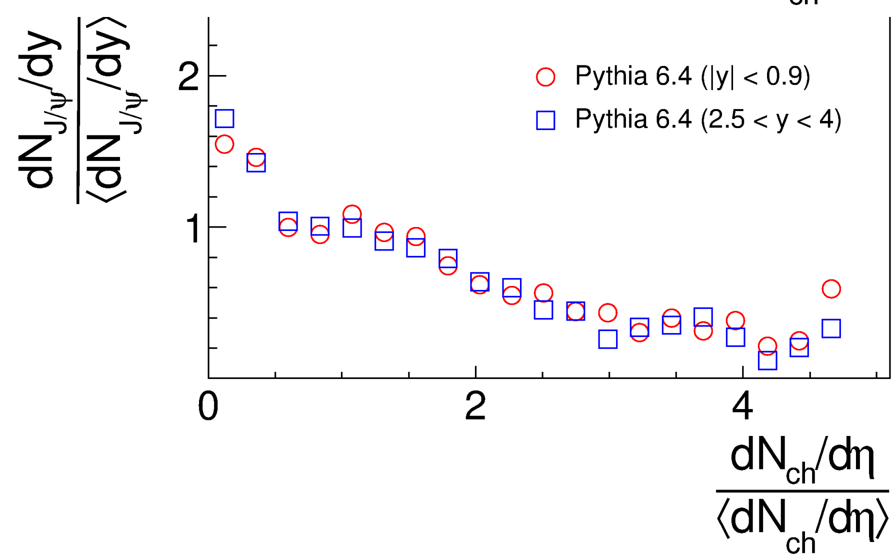
J/ψ vs charged multiplicity in pp collisions



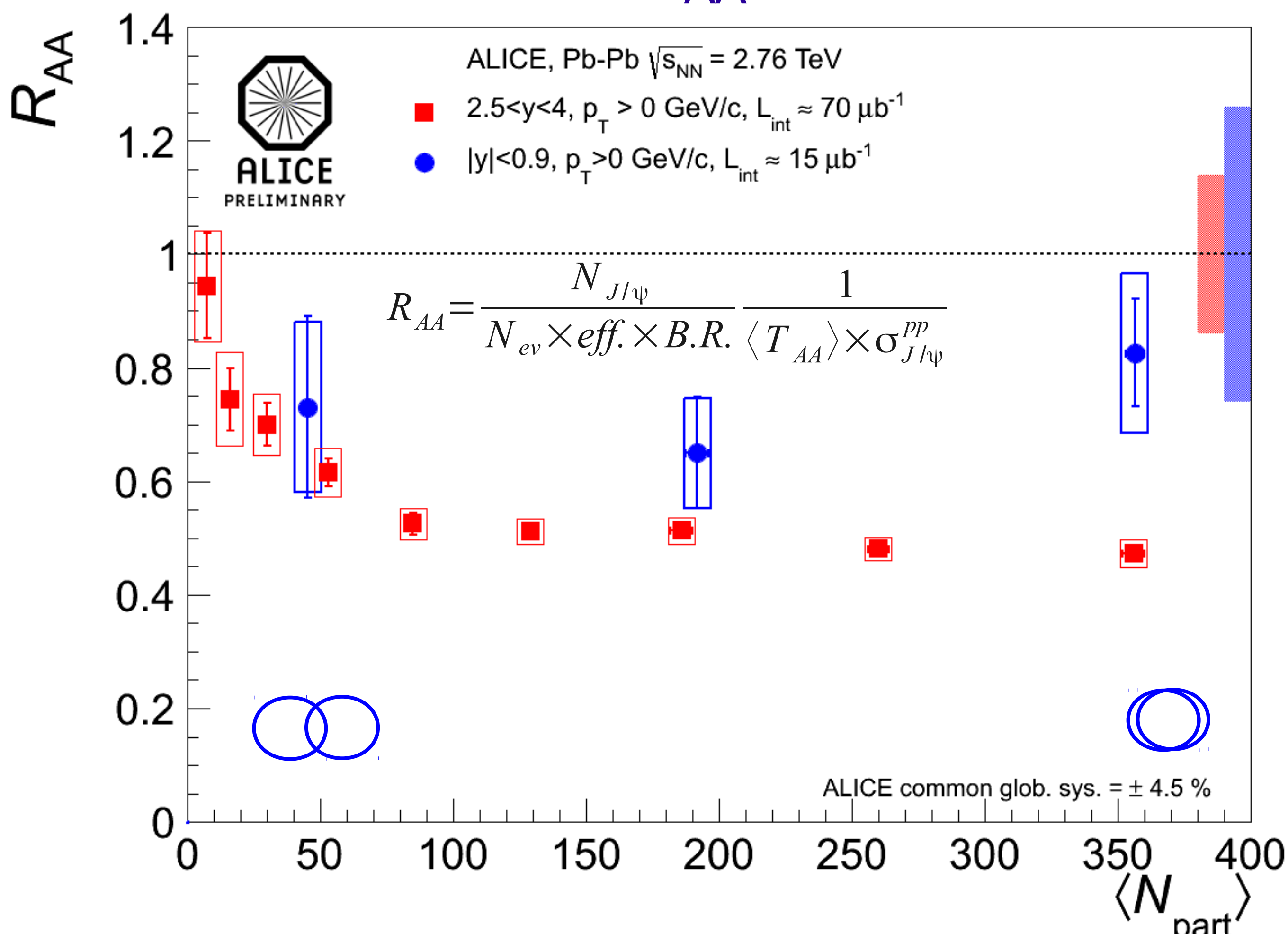
ALICE Collaboration, Phys.Lett.B712 (2012) 165



- Relative J/ψ yield increases linearly with the relative multiplicity
- Model calculations using only hard-processes (e.g. PYTHIA) do not reproduce this data
- Onset of multi-parton interactions?

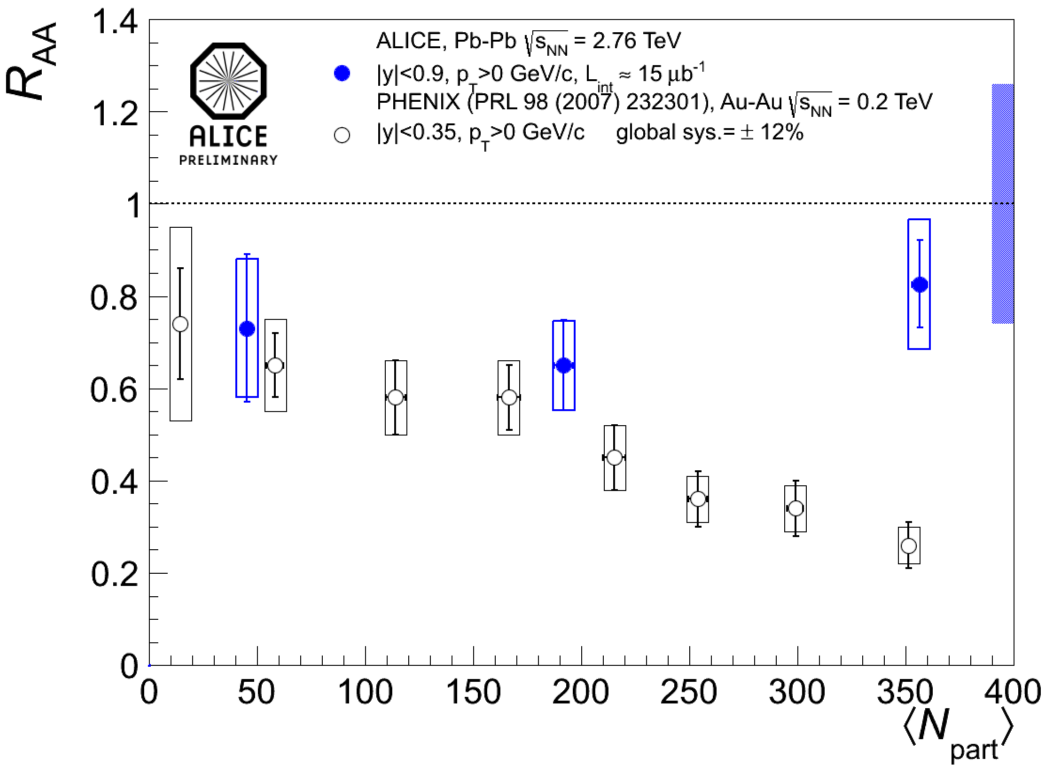


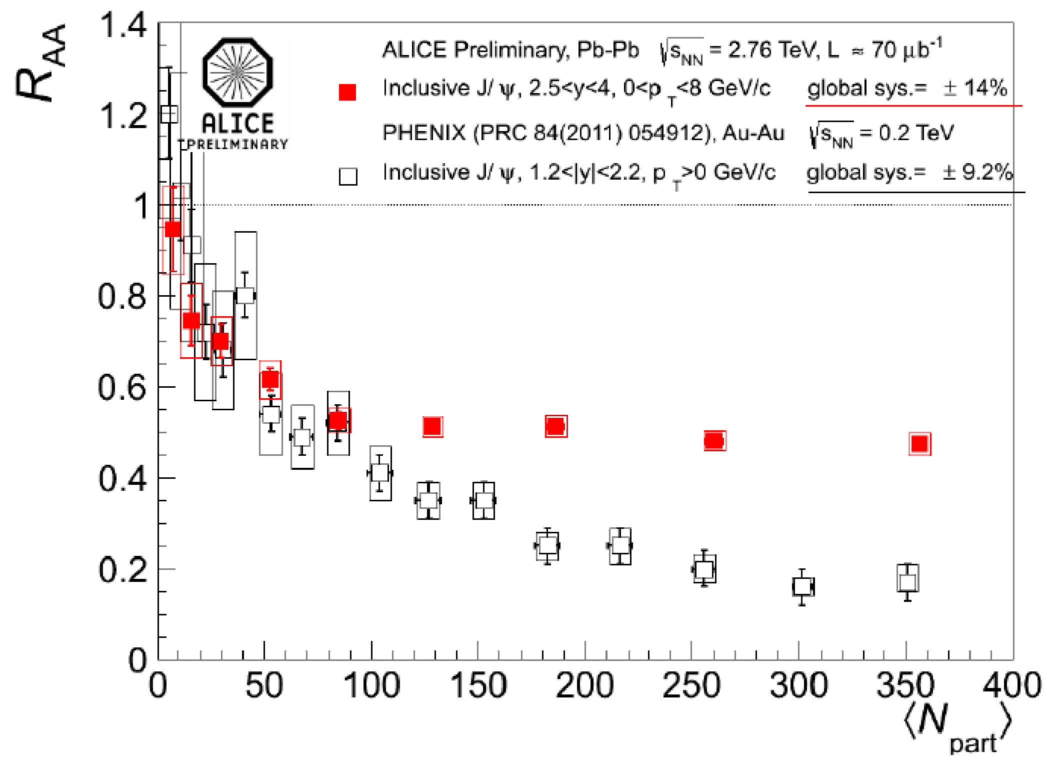
Inclusive J/ψ R_{AA} vs. centrality



- At forward rapidity, R_{AA} is flat for N_{part}>100
- At mid-rapidity, the R_{AA} reaches 0.83 but with large systematic error bars due to the measured pp reference
- Interpolating between results available at RHIC, CDF and top LHC energy will decrease the systematic error on the pp reference

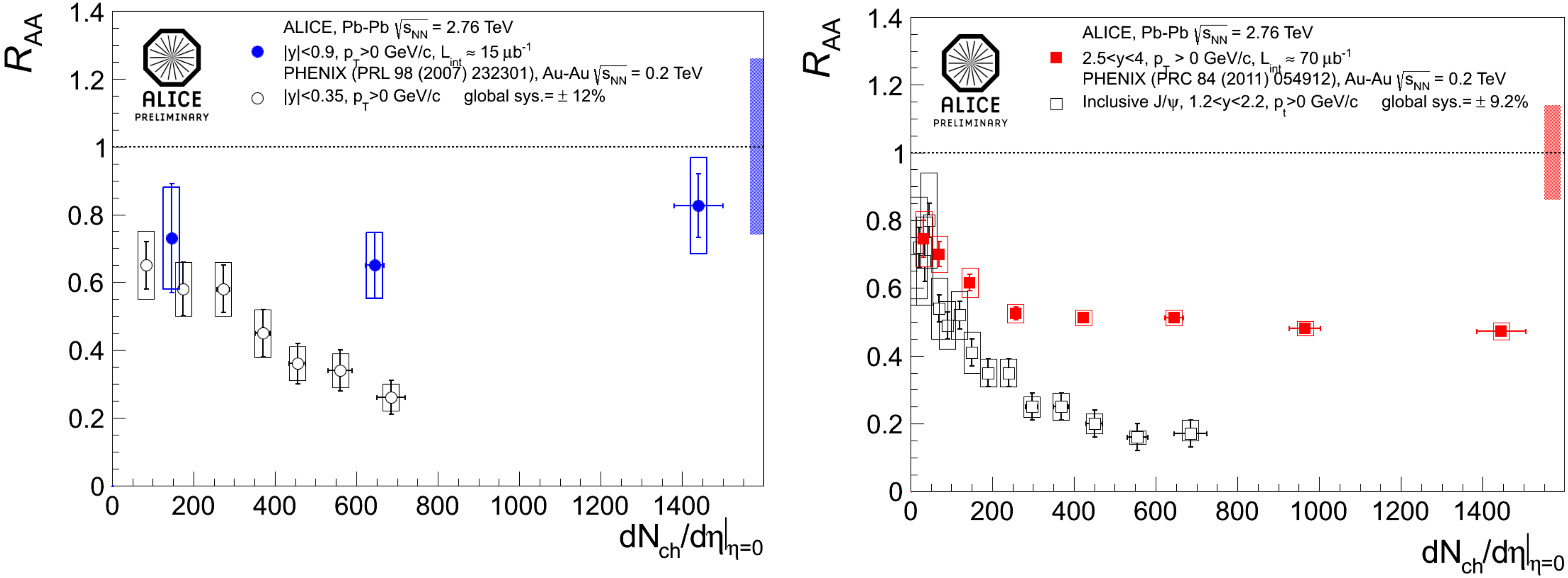
Inclusive J/ψ R_{AA} vs. centrality (comparison to PHENIX)





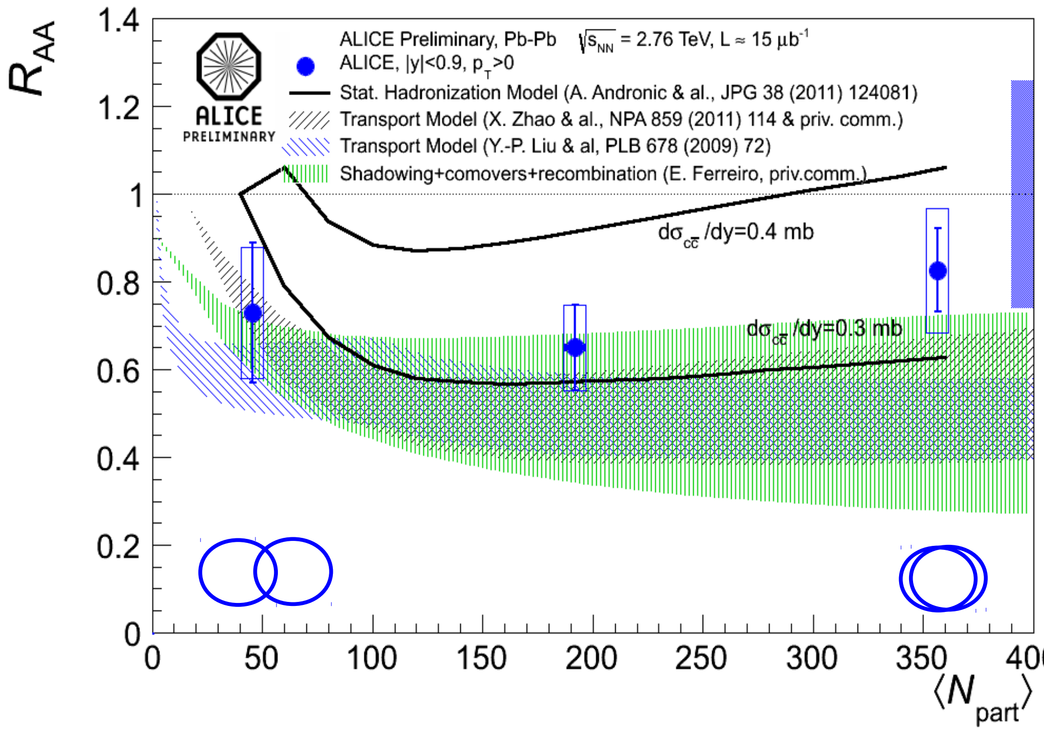
- Higher R_{AA} seen in central collisions by ALICE
- Signature predicted in (re)combination models

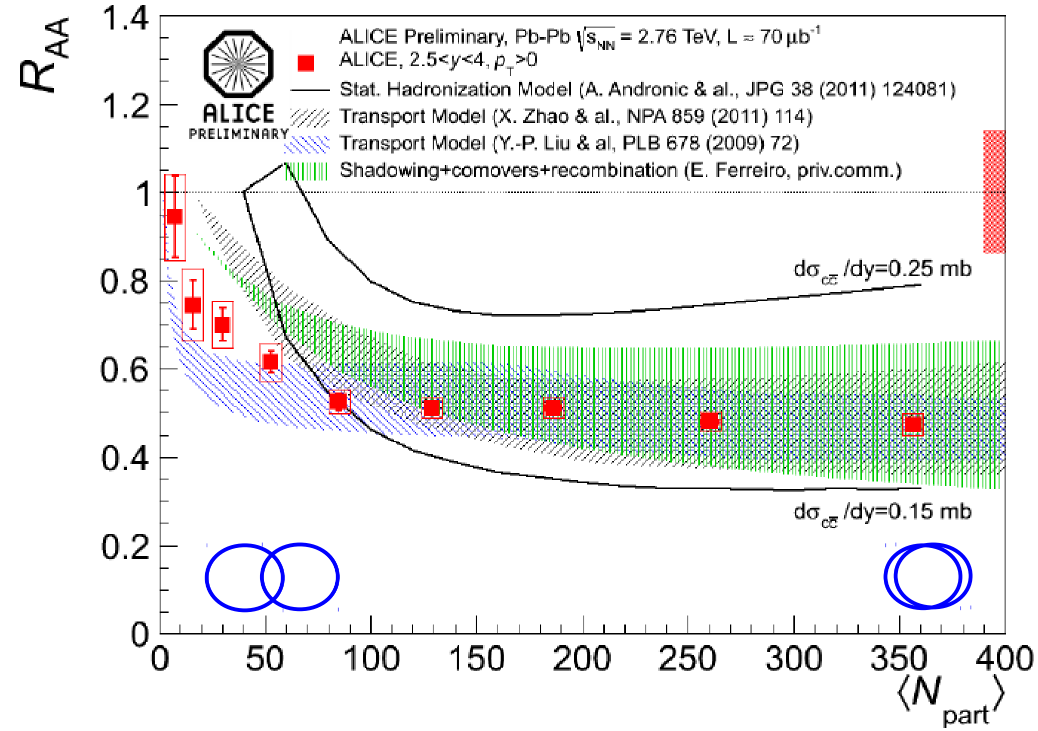
Inclusive J/ψ R_{AA} vs. particle density (comparison to PHENIX)



- R_{AA} at the same charged particle density grows with the collision energy

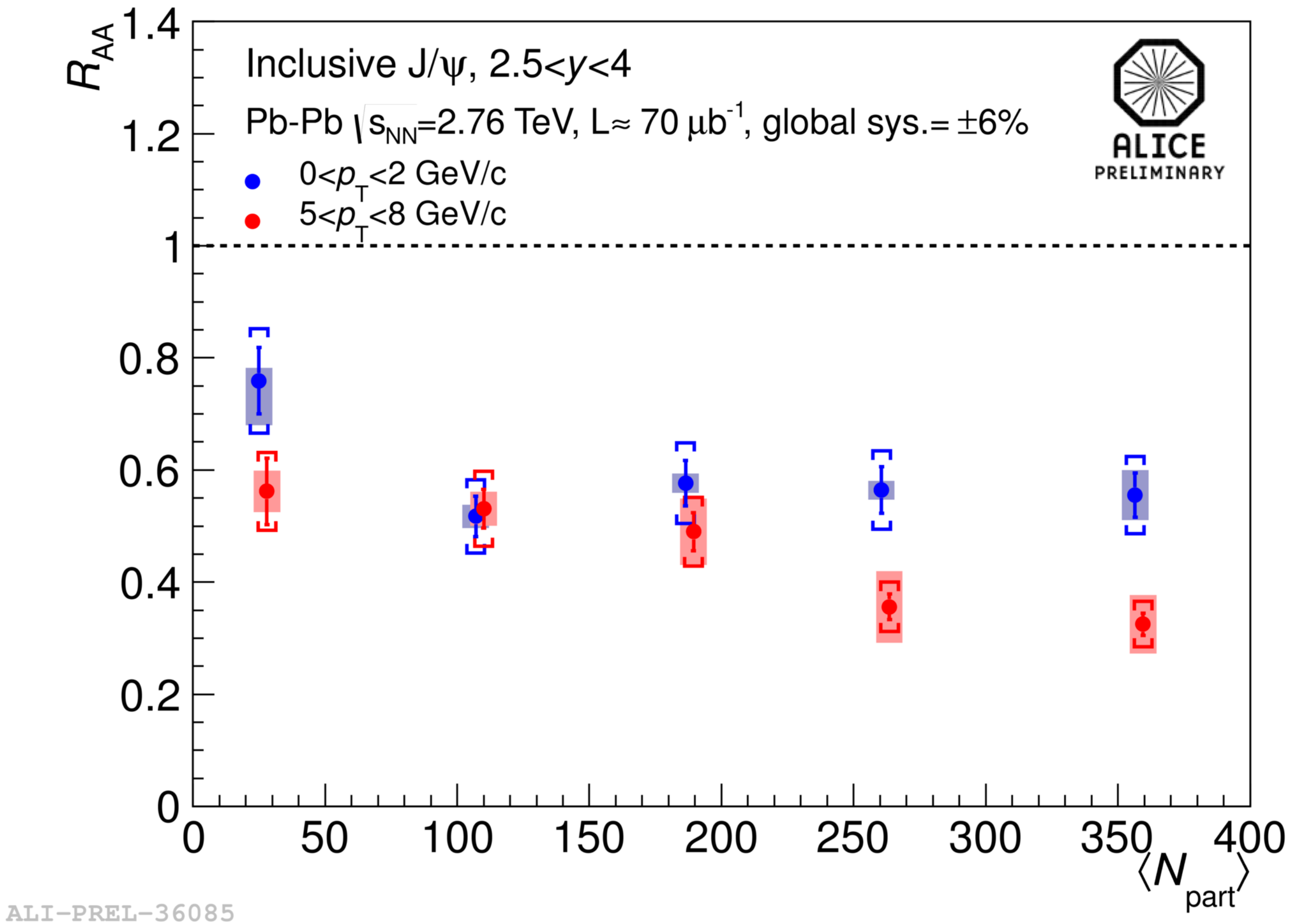
Inclusive J/ψ R_{AA} vs. centrality (models)





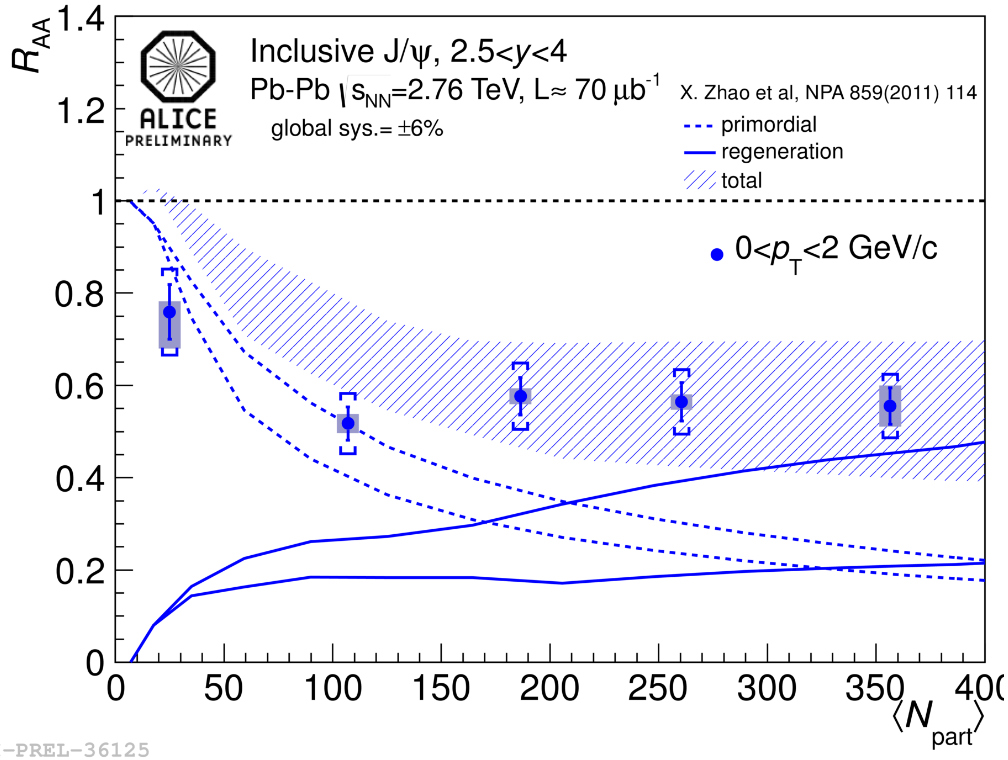
- Models which consider the (re)combination of charm pairs at chemical freeze-out or during QGP lifetime are close to the data.
- Total cc-bar cross-section measurements necessary to constrain the contribution from (re)combination

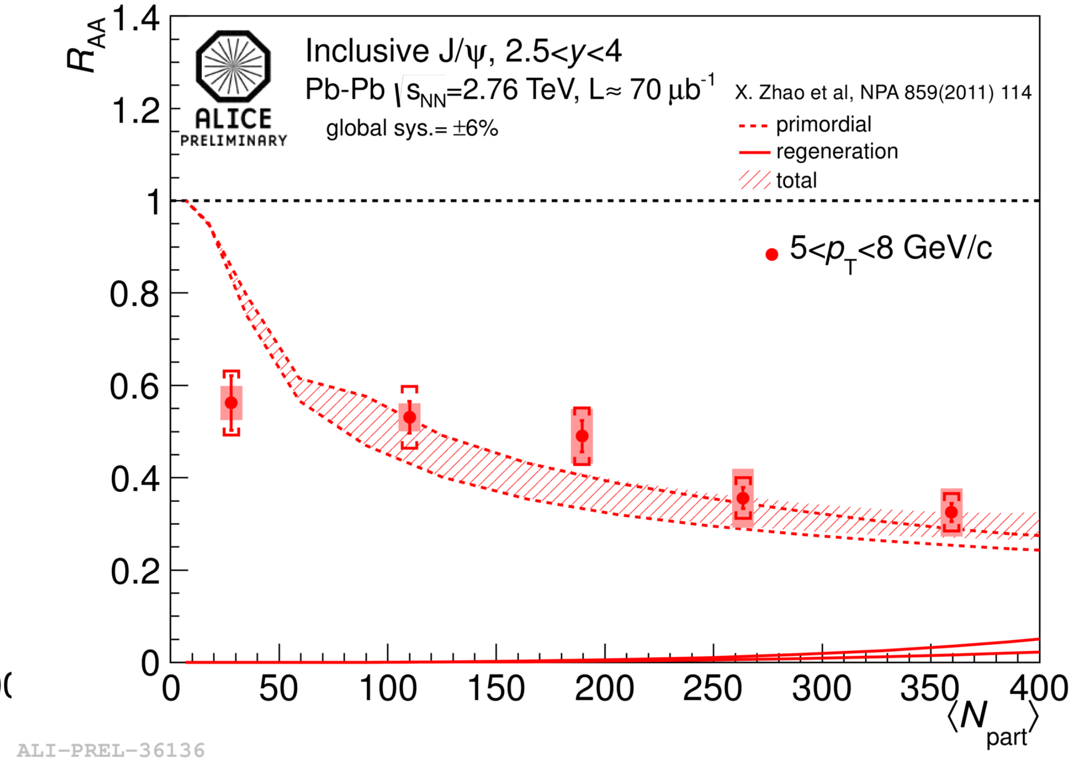
Inclusive J/ψ R_{AA} vs. centrality in p_T bins



- Low p_T J/ψ less suppressed in central collisions

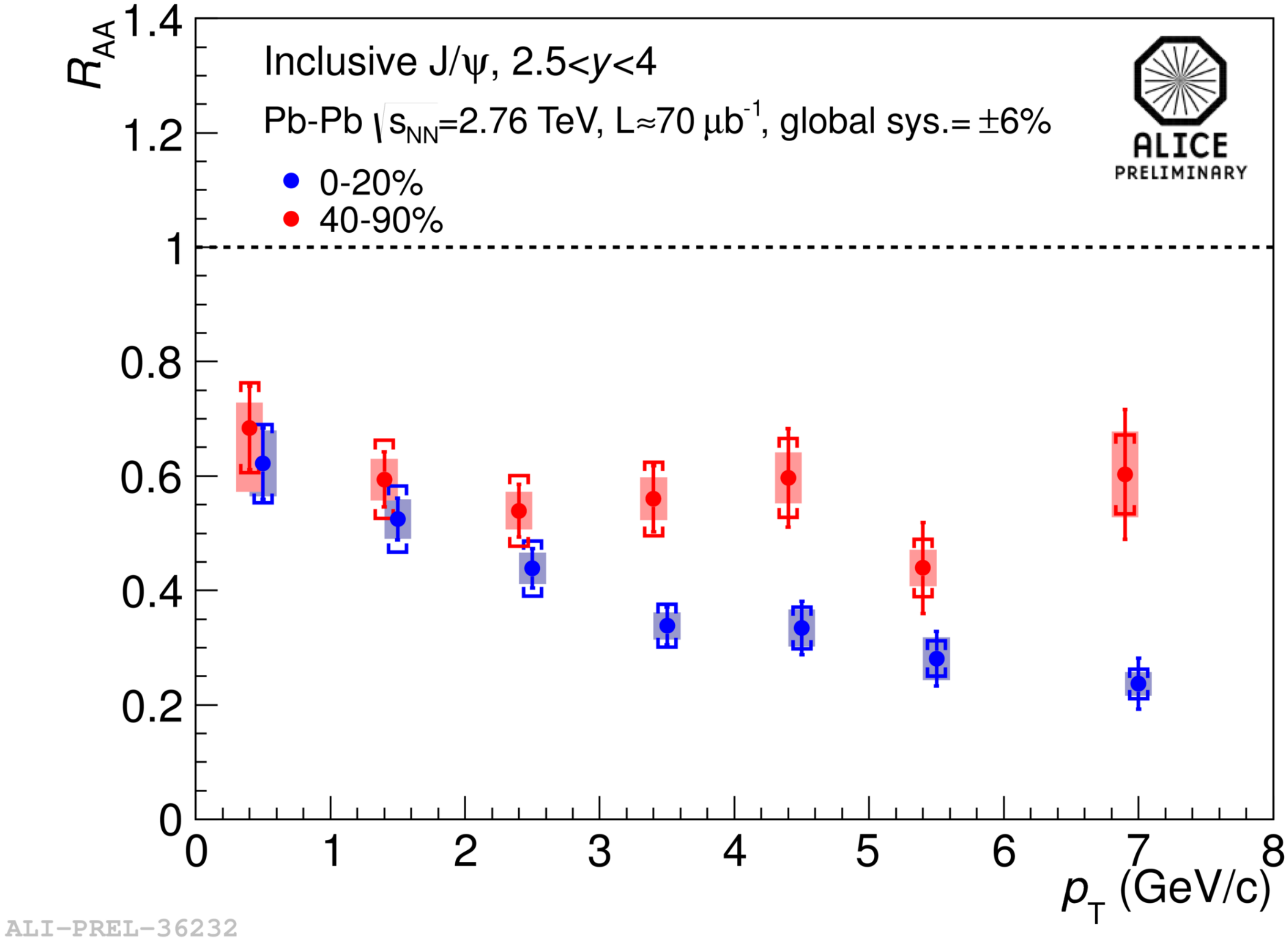
Inclusive J/ψ R_{AA} vs. centrality in p_T bins





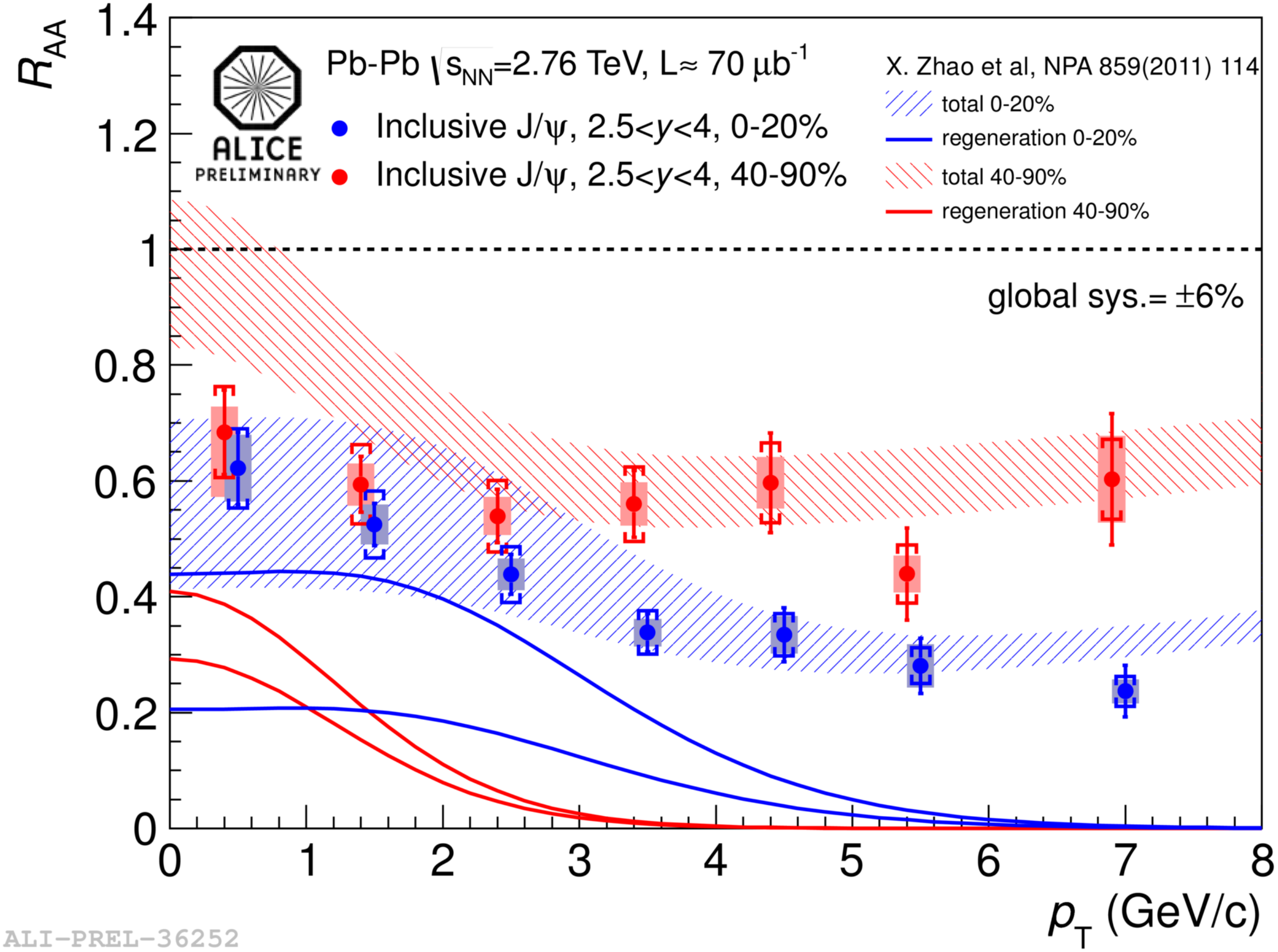
- Transport models (e.g. *Zhao et. al*) suggest that ~50% of the J/ψ yield at low p_T is produced via (re)combination of charm quarks

Inclusive J/ψ R_{AA} vs. p_T



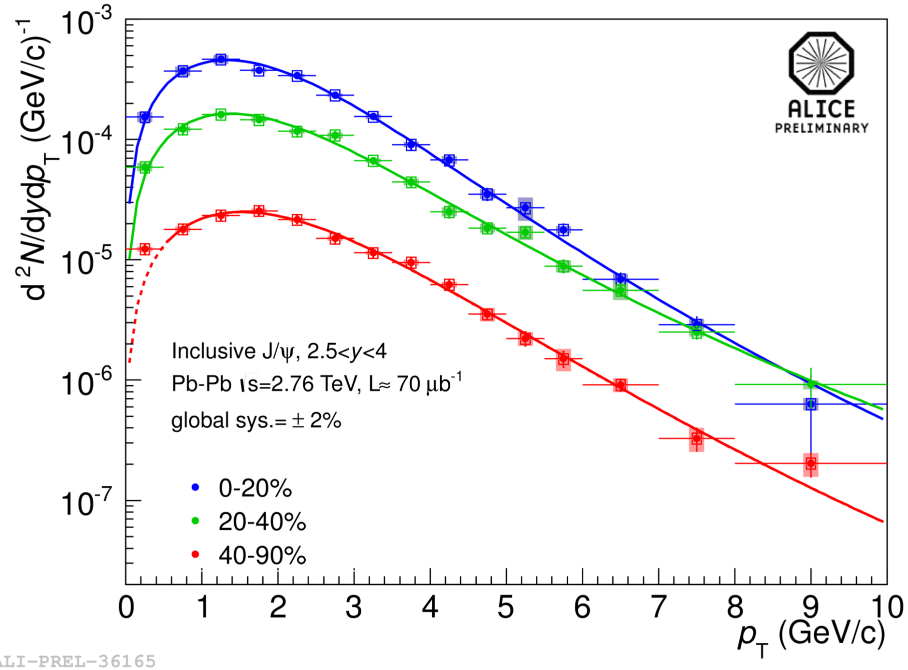
- More suppression seen with increasing p_T in central collisions

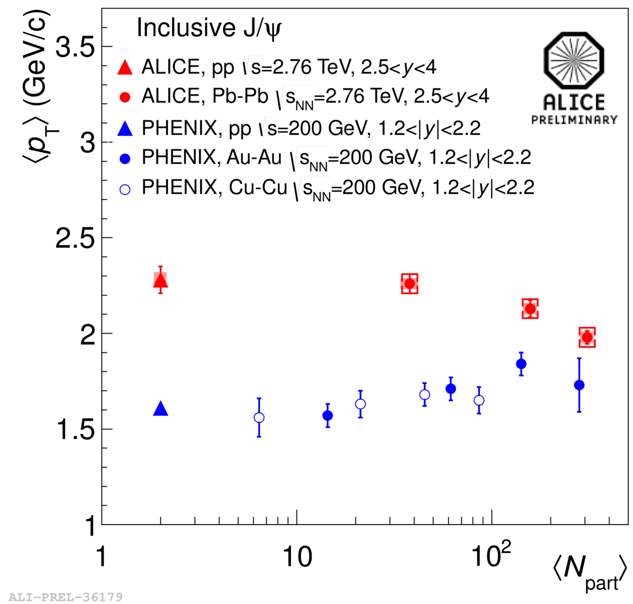
Inclusive J/ψ R_{AA} vs. p_T

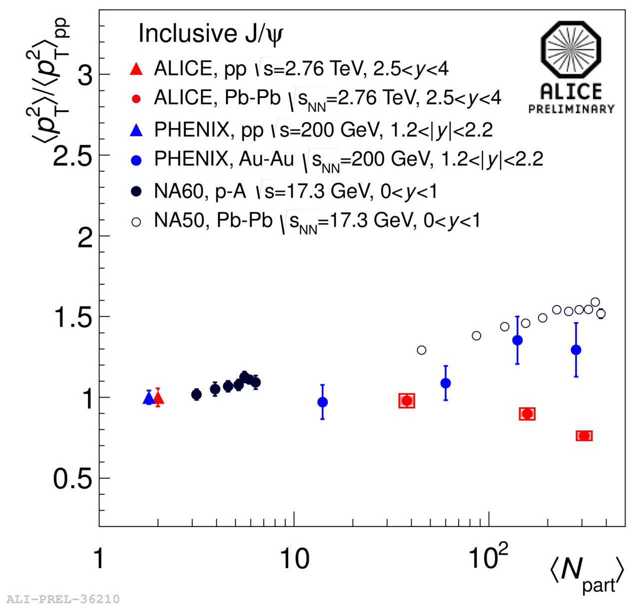


- More suppression seen with increasing p_T in central collisions
- Calculations from *Zhao et al.* in agreement with data in central collisions but overestimate the yield at low p_T in peripheral collisions.

J/ψ $<p_T>$ and $<p_T^2>$

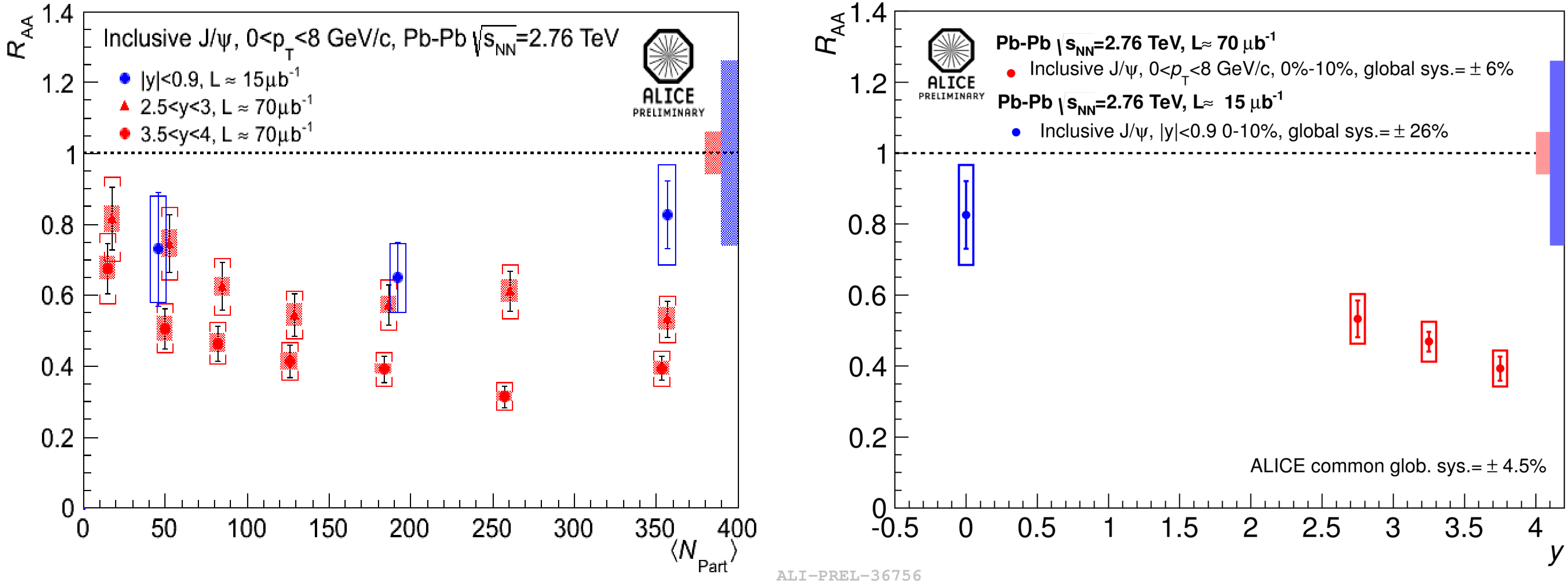






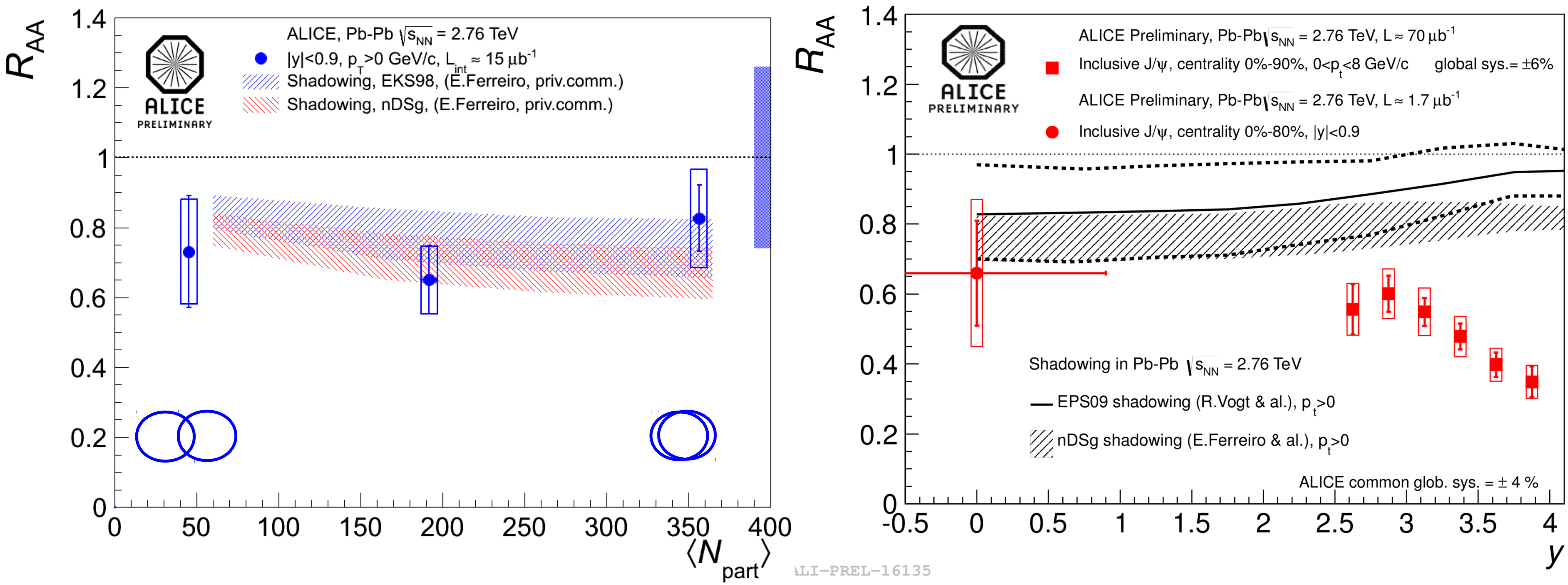
- Look at the J/ψ spectral shapes
- J/ψ $<p_T>$ in Pb-Pb at LHC is softer than in pp at all centralities. The opposite behaviour is observed at lower energies

Inclusive J/ψ R_{AA} vs. rapidity



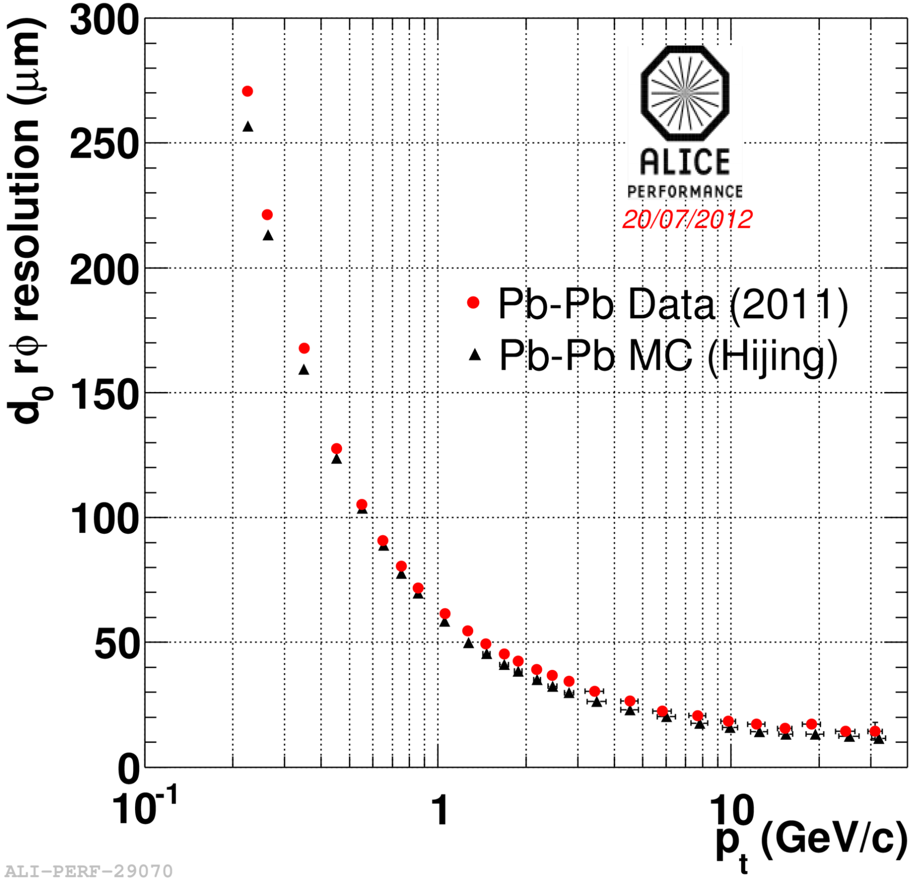
- Suppression increases with increasing rapidity

Inclusive J/ψ R_{AA} (shadowing corrections)

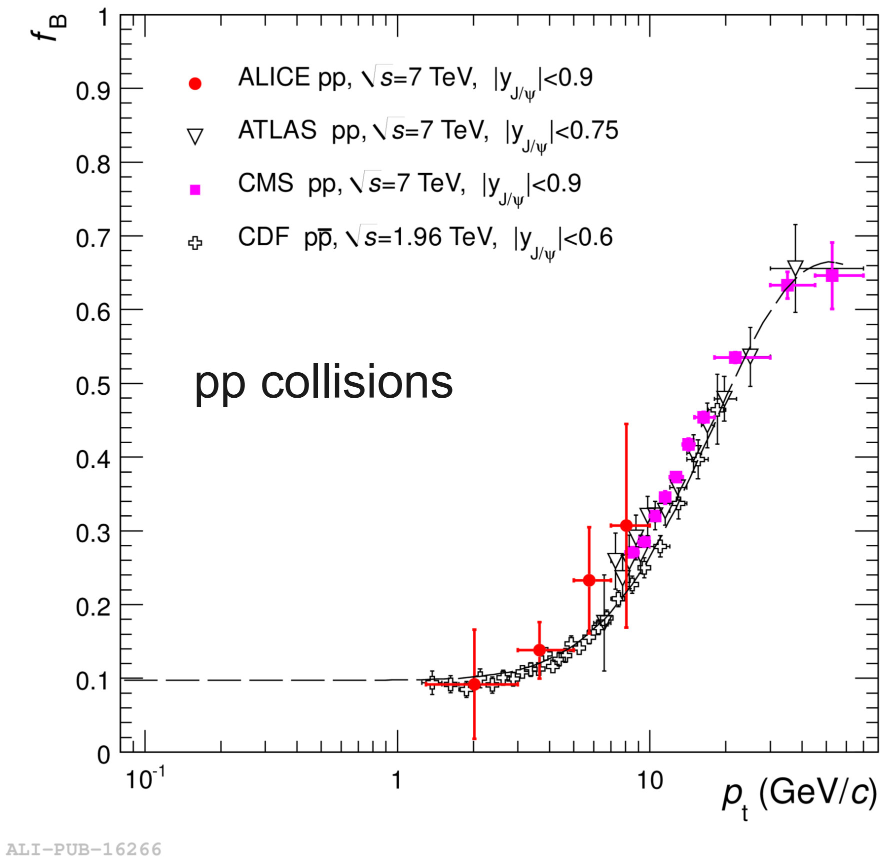


- J/ψ at mid-rapidity even less suppressed when considering current theoretical shadowing calculations.
- Cold nuclear matter effects will be investigated in the p-Pb run in 2013

Outlook: Prompt vs. non-prompt J/ψ suppression

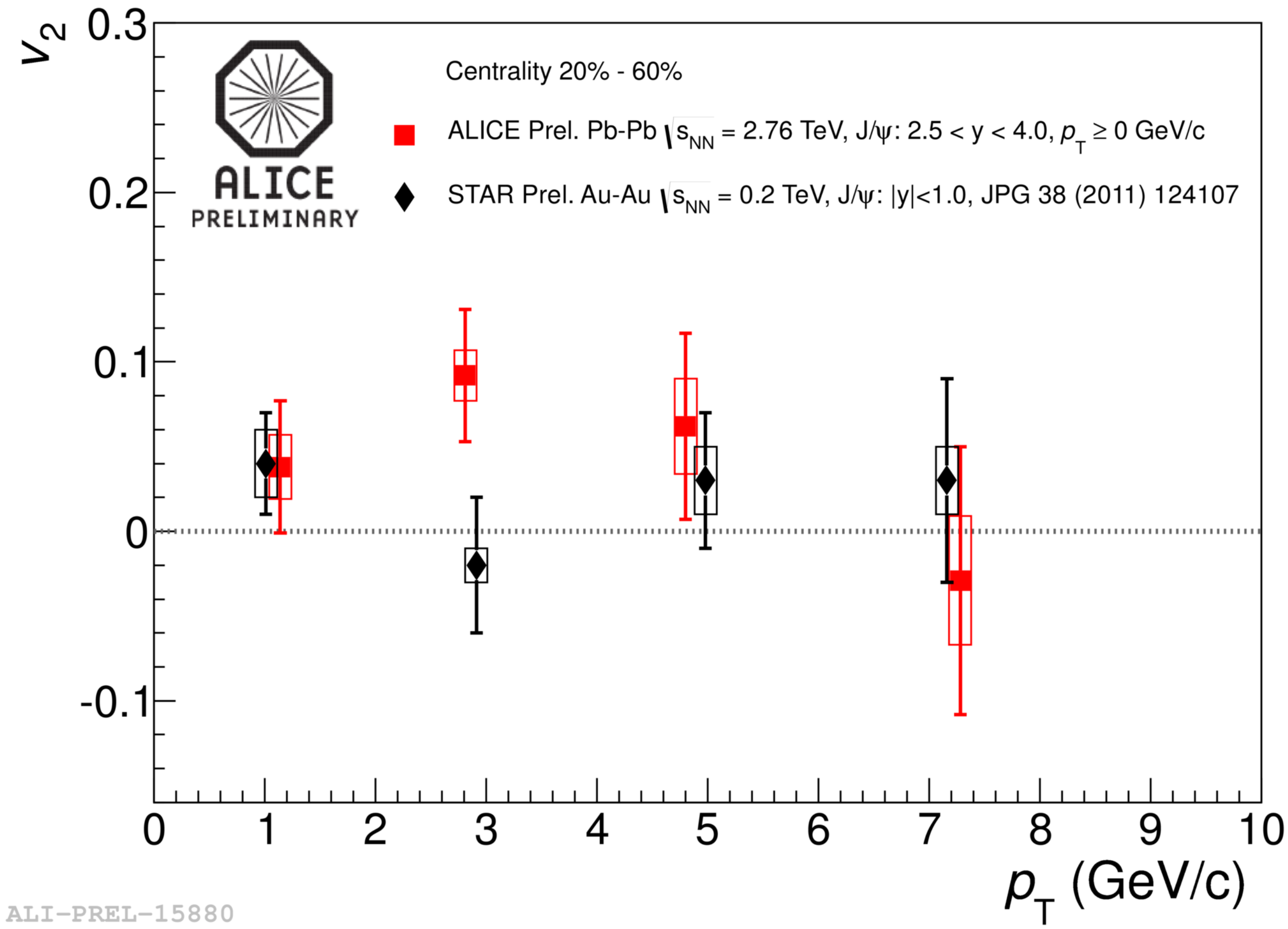


ALICE Collaboration, arXiv:1205.5880



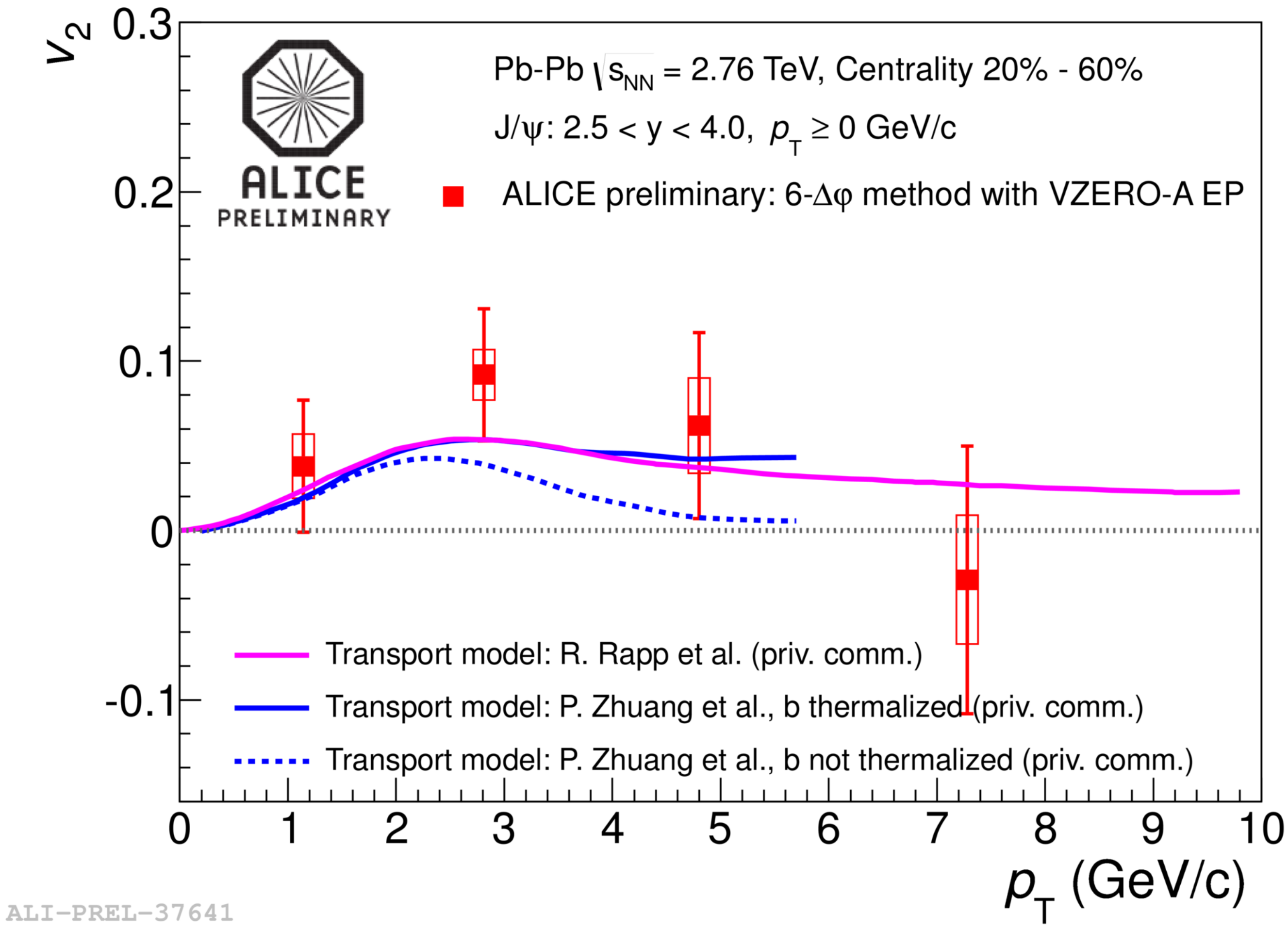
- The spatial resolution for tracks with p_T>1 GeV/*c* is better than 50 μm
  - Non-prompt J/ψ fraction from beauty decays can be extracted at mid-rapidity
  - Analysis already performed for pp collisions
- The R_{AA} for beauty hadrons can be obtained via the secondary vertex analysis
- No significant impact on the prompt J/ψ R_{AA}

Flow of J/ψ



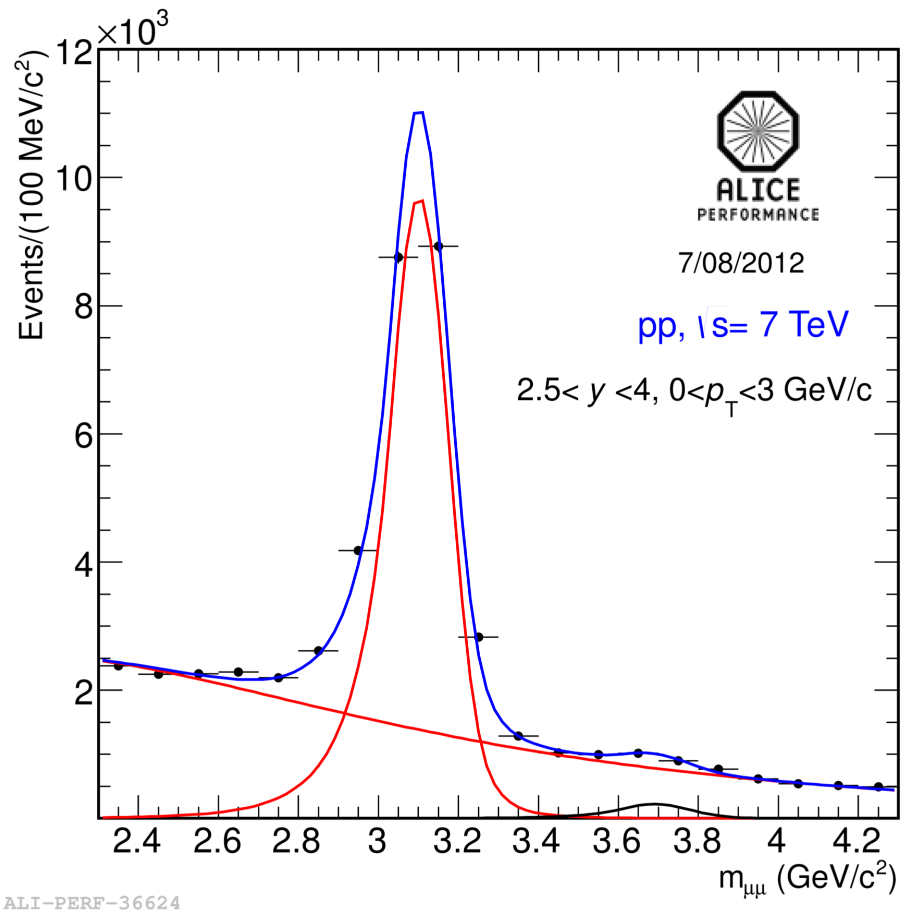
- Hint of non-zero v_2 in the intermediate p_T region seen in ALICE
- STAR results are consistent with zero flow

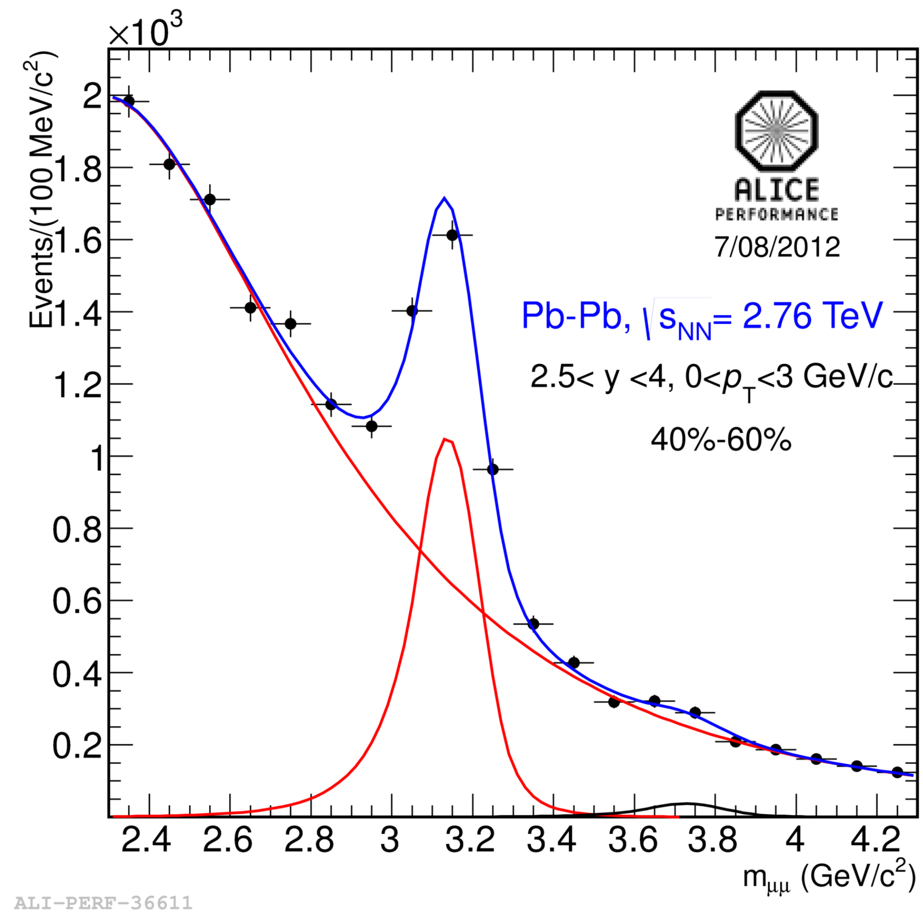
Flow of J/ψ



- Hint of non-zero v_2 in the intermediate p_T region seen in ALICE
- Transport models with (re)combination in qualitative agreement with data.

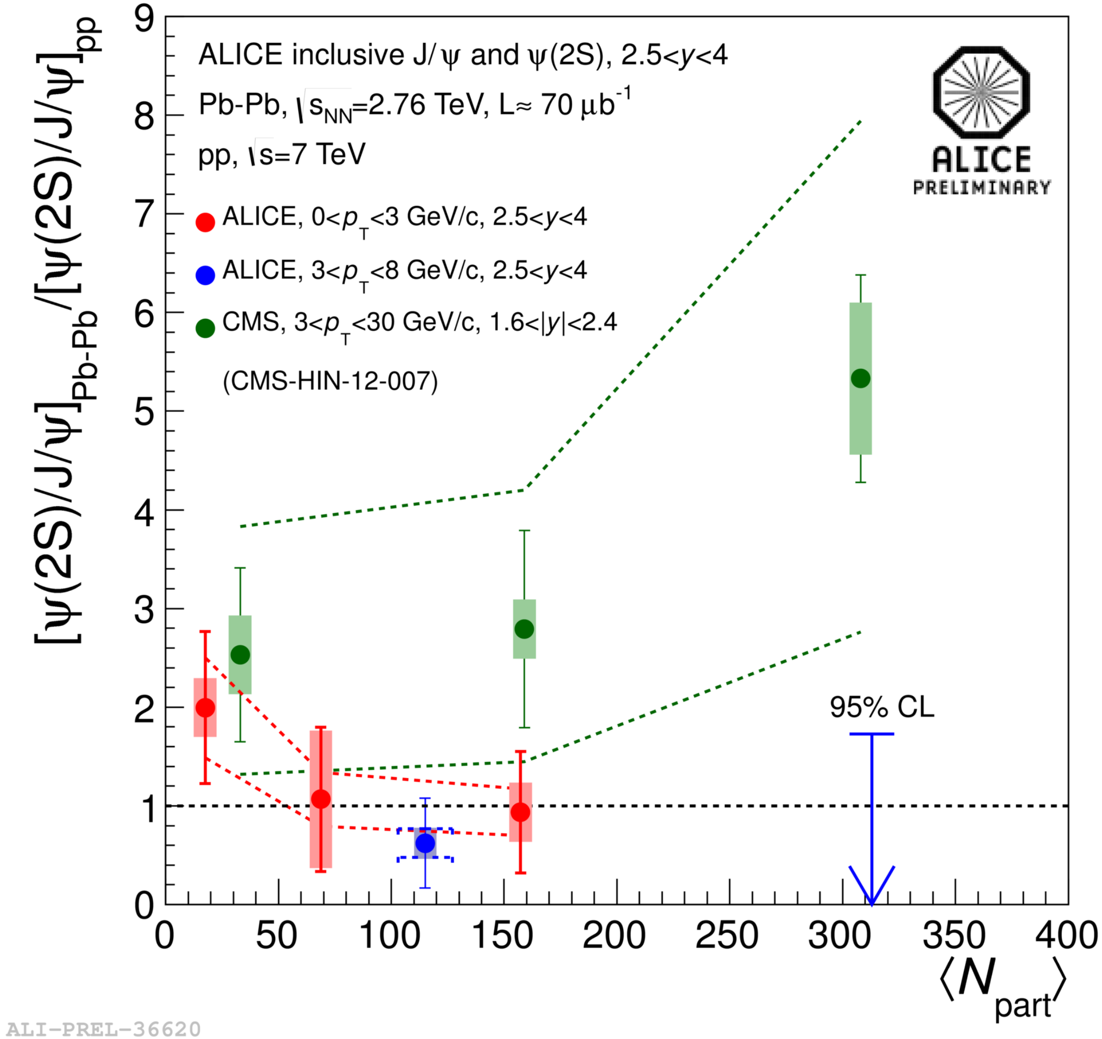
ψ(2S)





- ψ(2S) yields obtained in a few centrality and p_T intervals.
- In Pb-Pb the S/B for ψ(2S) varies between 0.01 and 0.3

ψ(2S)/ψ(1S)



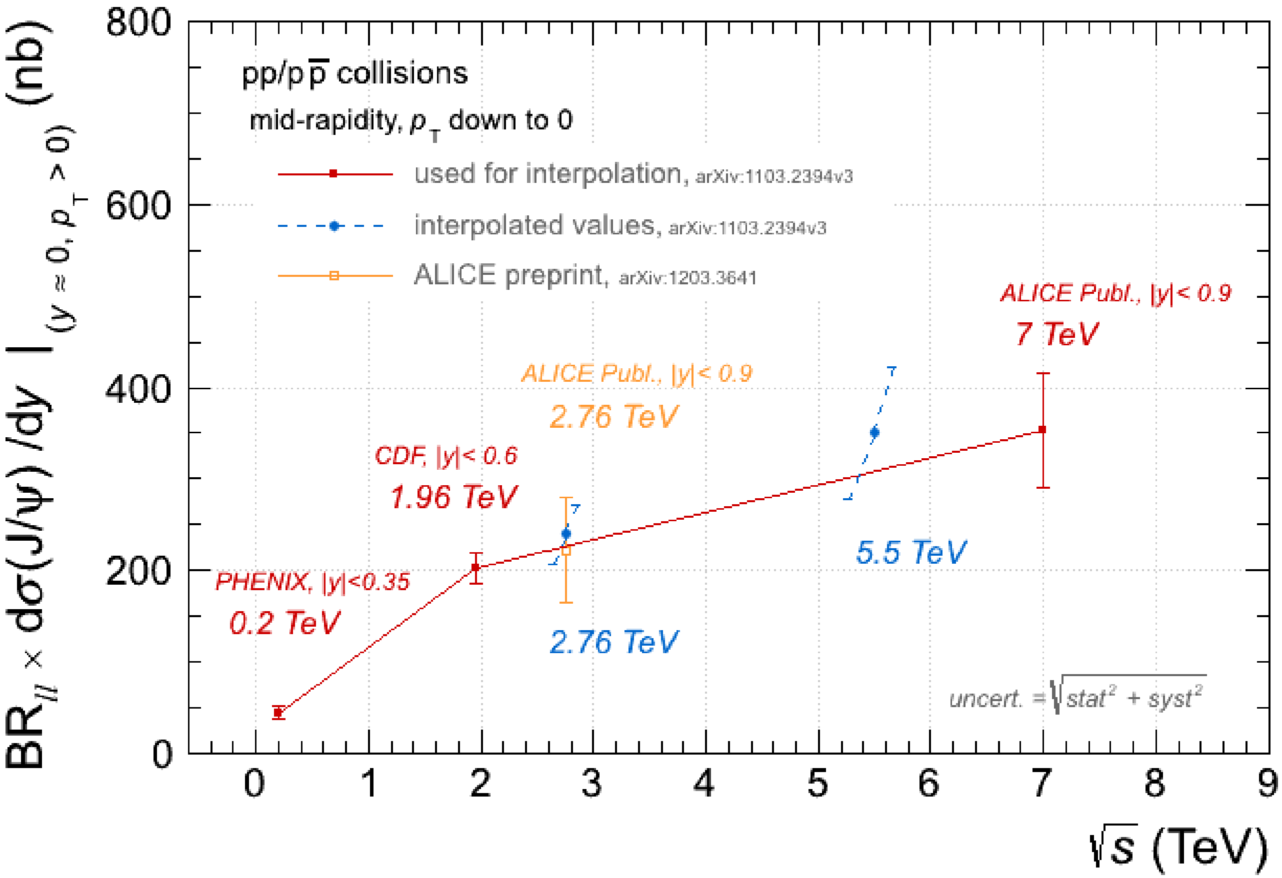
- ALICE uses the pp reference measured at √s=7 TeV
- CMS had measured pp reference at √s=2.76 TeV
- No final conclusion yet due to large uncertainties but a large ψ(2S) enhancement seem to be excluded in central collisions

Summary

- The nuclear modification factor for inclusive J/ψ in Pb-Pb collisions
  - R_{AA} seen by ALICE is significantly higher than the one measured at RHIC both at mid- and forward-rapidity.
  - The low p_T J/ψ are less suppressed than high p_T J/ψ
  - R_{AA} drops with increasing rapidity
  - Calculations from models which include the mechanism of (re)combination during the system lifetime or at freeze-out are consistent with the data.
  - CNM effects will be measured in the p-Pb run in 2013
- Hint of non-zero J/ψ v_2 at forward-rapidity in the intermediate p_T region
- The ψ(2S)/ψ(1S) ratio is measured at mid-rapidity. The large error bars prevent a firm conclusion but a large ψ(2S) enhancement in central collisions is unlikely.

Backup slides

pp reference for R_{AA} : interpolation

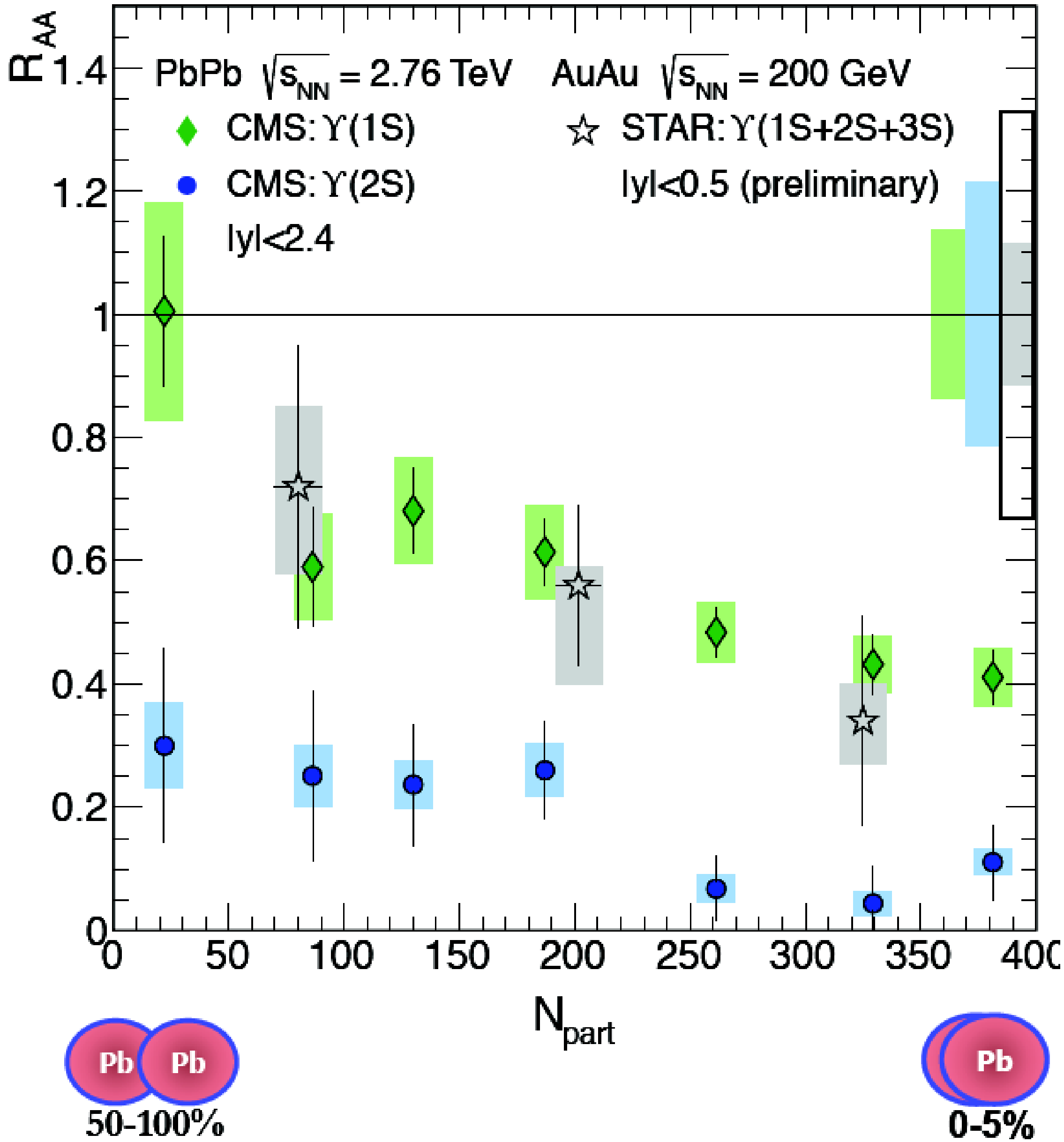


- Interpolation of *dσ/dy* in pp collisions at √*s* = 2.76 TeV at *y* ≈ 0 using:
  - **PHENIX** data at √*s* = 0.2 TeV
  - **CDF** data at √*s* = 1.96 TeV
  - **ALICE** data at √*s* = 7 TeV
- 3 interpolation strategies :
  - *ad hoc* functional form
  - FONLL based approach
  - LO CEM based approach

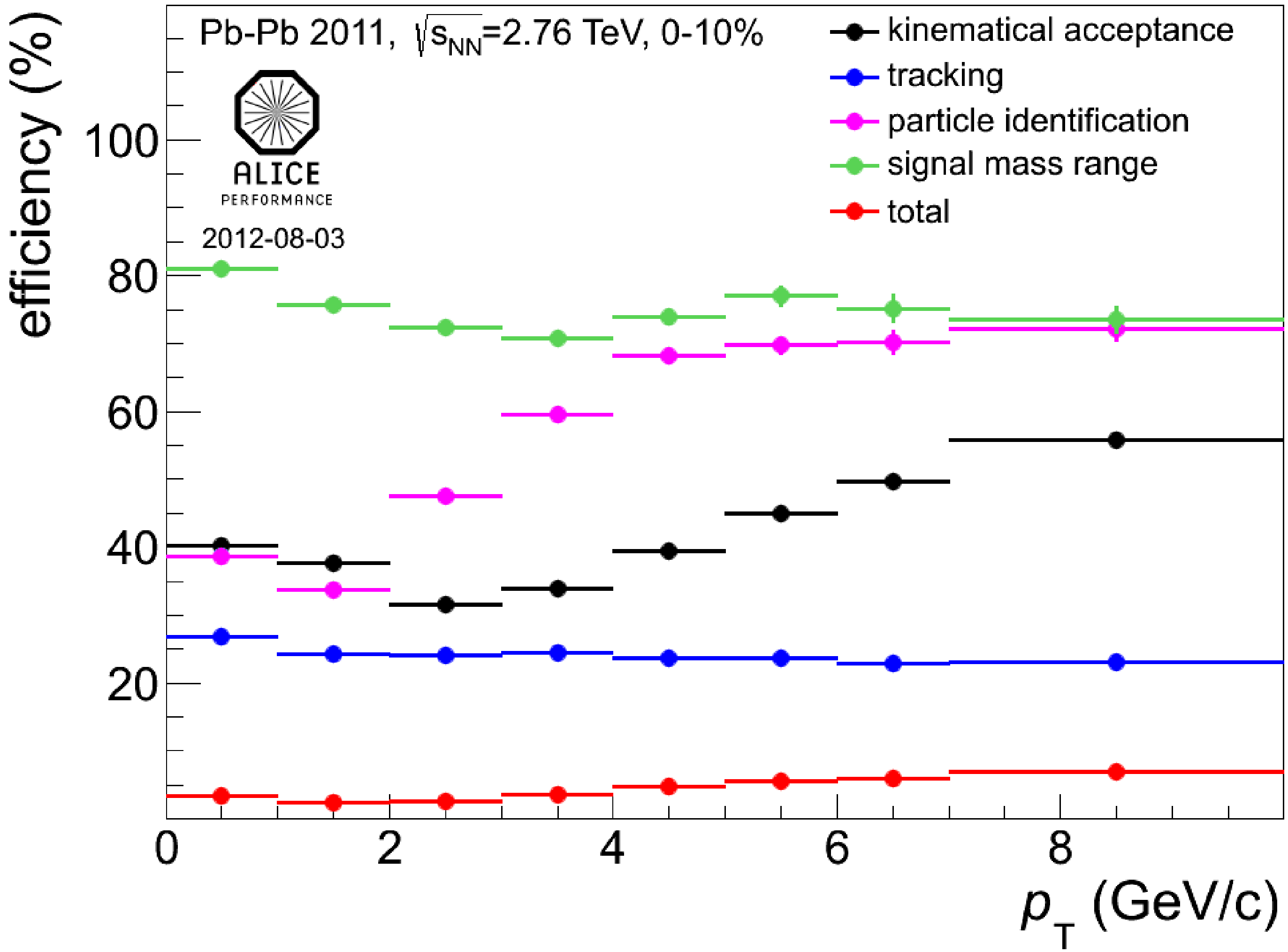
→ See arXiv:1103.2394v3

- Overall uncertainty of interpolated value approximately **2 times lower** than for the measured one

Upsilon nuclear suppression

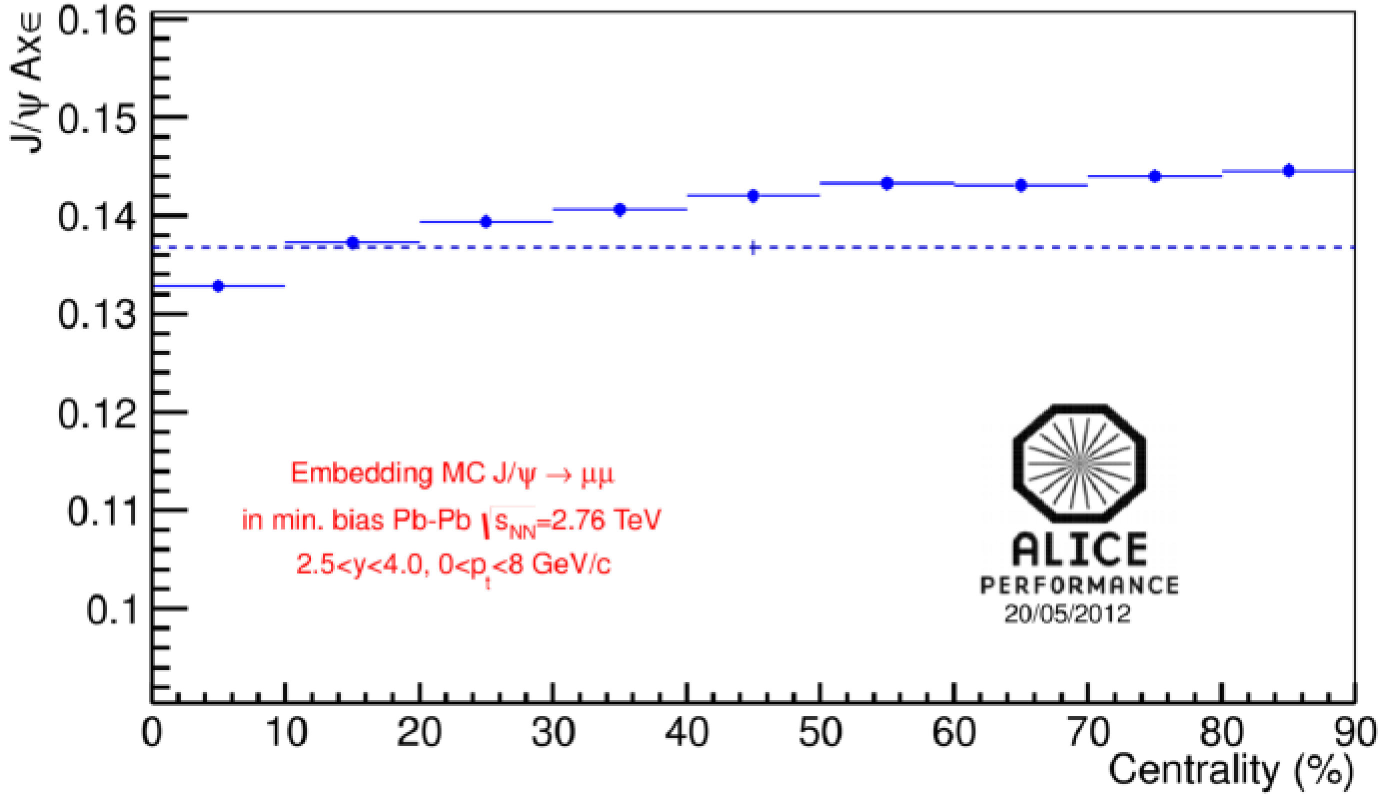


J/ψ reconstruction efficiency for the dielectron channel



- Efficiencies calculated using MC Pb-Pb events enriched with J/ψ particles.
- The generated particles are transported through the ALICE setup simulated in GEANT 3.21.

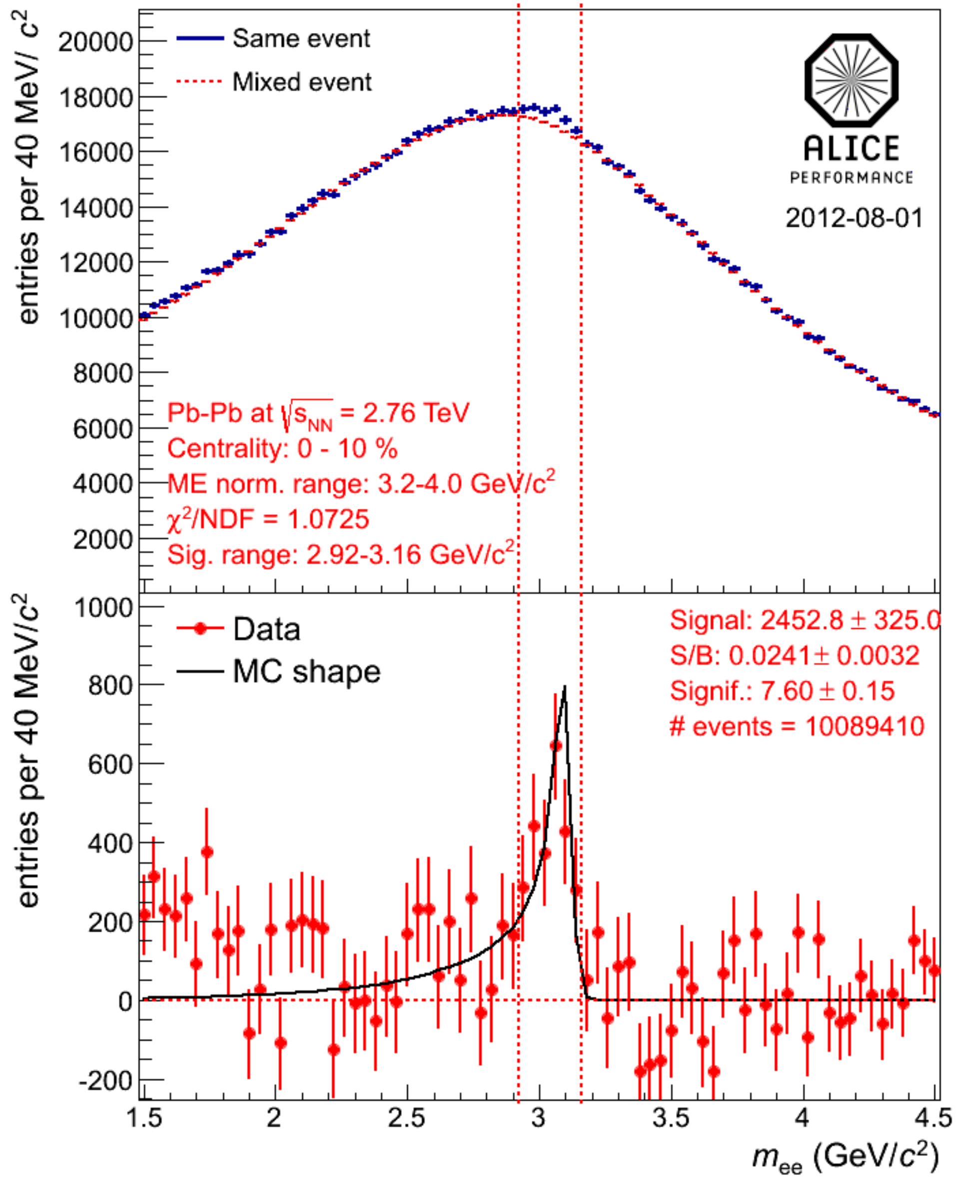
J/ψ reconstruction efficiency for the dimuon channel



Efficiencies calculated using Monte-Carlo J/ψ embedded in real Pb-Pb events

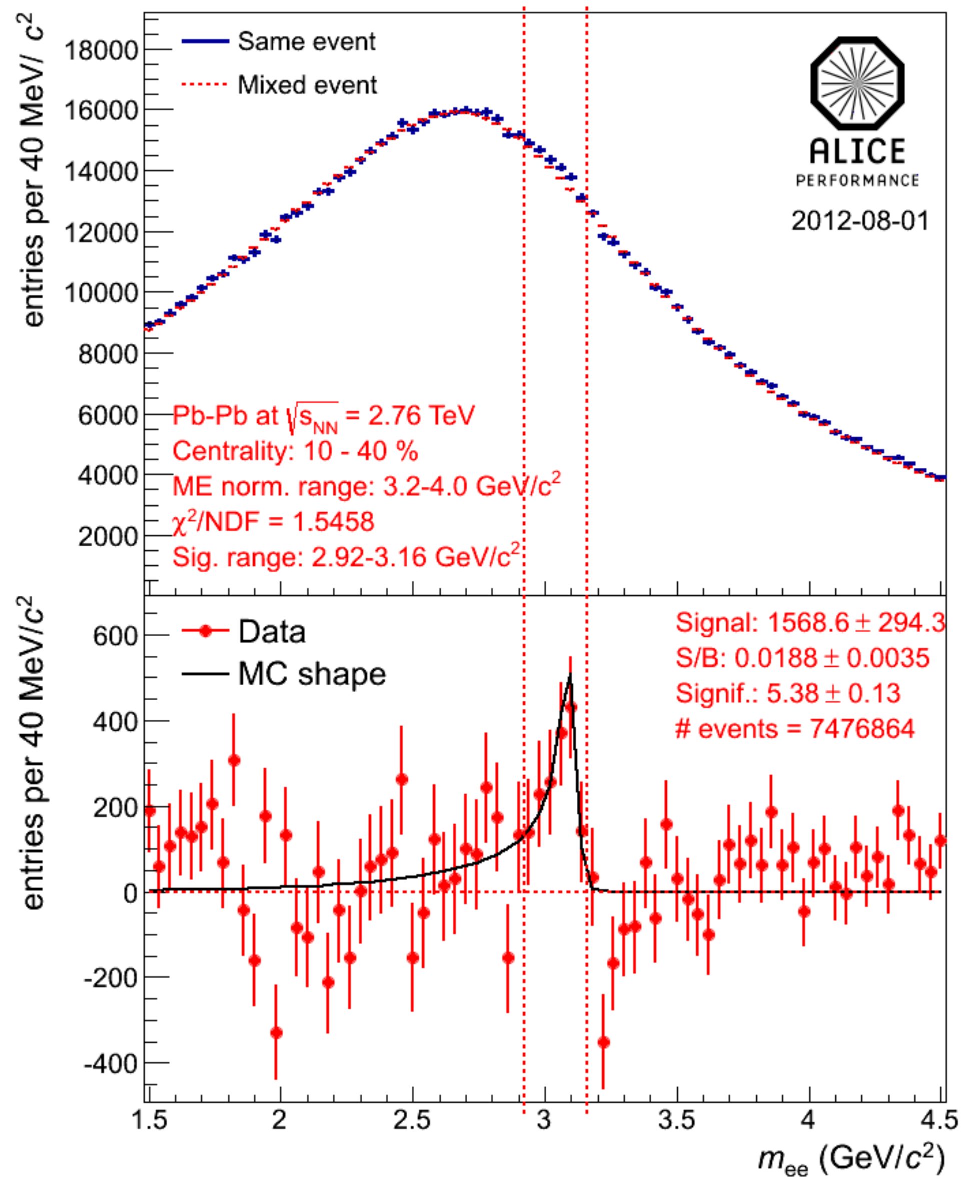
Signal extraction (centrality 0-10%)

- J/ψ yield obtained by subtracting the mixed event background from the opposite sign dielectron invariant mass spectrum
- Mixed event background is normalized to the same event distribution in the mass region 3.2-4.0 GeV/c^2
- Good matching between the data and the Monte-Carlo signal shape is obtained.
- The MC signal shape includes the bremsstrahlung of the electrons in the detector material and the radiative decay channel $e^+e^-\gamma$ (internal bremsstrahlung)



Signal extraction (centrality 10-40%)

- J/ψ yield obtained by subtracting the mixed event background from the opposite sign dielectron invariant mass spectrum
- Mixed event background is normalized to the same event distribution in the mass region 3.2-4.0 GeV/c^2
- Good matching between the data and the Monte-Carlo signal shape is obtained.
- The MC signal shape includes the bremsstrahlung of the electrons in the detector material and the radiative decay channel $e^+e^-\gamma$ (internal bremsstrahlung)



Signal extraction (centrality 40-80%)

- J/ψ yield obtained by subtracting the mixed event background from the opposite sign dielectron invariant mass spectrum
- Mixed event background is normalized to the same event distribution in the mass region 3.2-4.0 GeV/c^2
- Good matching between the data and the Monte-Carlo signal shape is obtained.
- The MC signal shape includes the bremsstrahlung of the electrons in the detector material and the radiative decay channel $e^+e^-\gamma$ (internal bremsstrahlung)