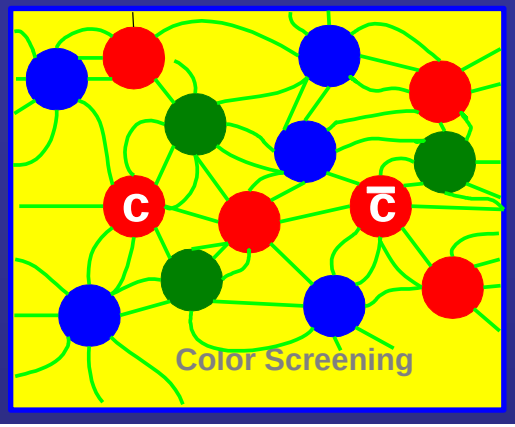
ALICE results on quarkonia

- Introduction
- Selected pp highlights
- NEW → Results from the 2011 Pb-Pb run
  - J/ψ nuclear modification factor(s), v_2, $\langle p_T \rangle$, ψ(2S)
- Prospects and conclusions

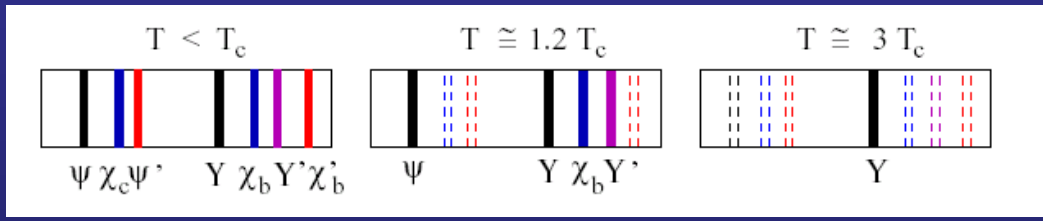
E. Scomparin (INFN Torino)
for the ALICE Collaboration

Introduction (1)

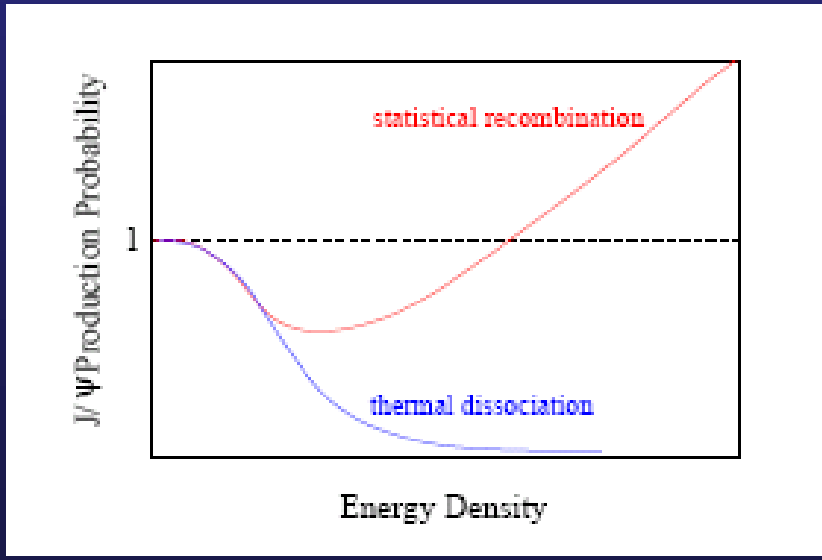
- Quarkonia suppression via colour screening → probe of deconfinement
  (Matsui and Satz, PLB 178 (1986) 416)



- Sequential suppression of the quarkonium states
  (Digal, Petreczky, Satz, PRD 64 (2001) 0940150)

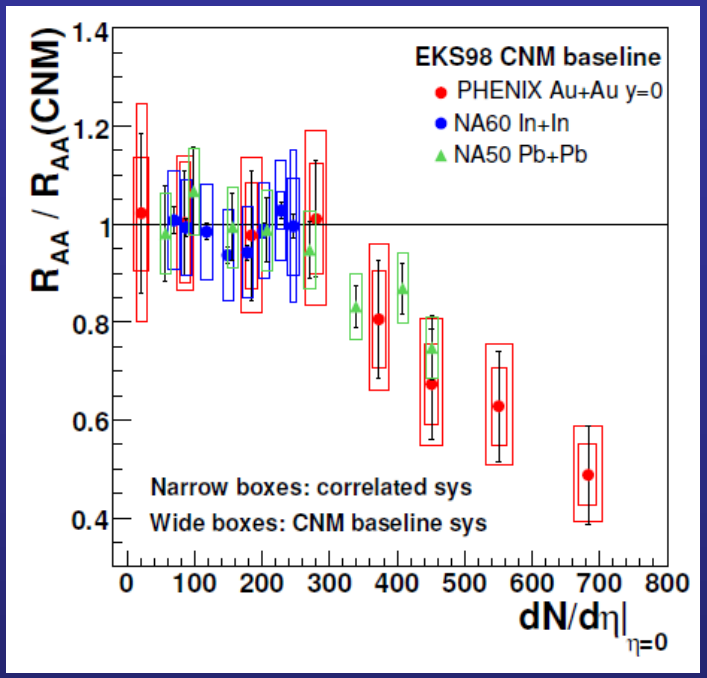


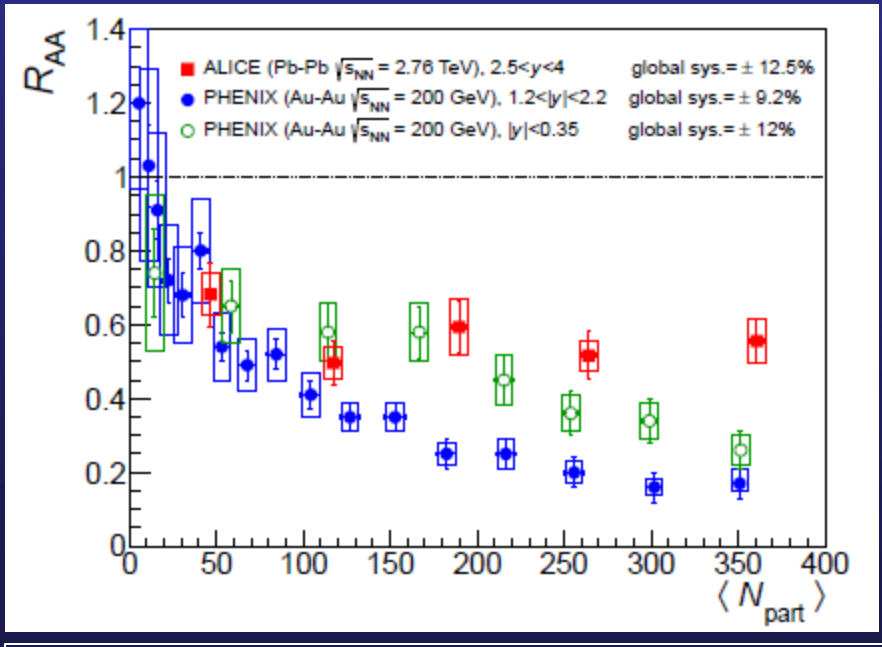
- Enhancement via (re)generation of quarkonia, due to the large heavy-quark multiplicity
  (Andronic, Braun-Munzinger, Redlich, Stachel, PLB 571(2003) 36)



Introduction (2)

- Studies performed at SPS/RHIC energies showed a significant J/ψ suppression in heavy-ion collisions (even after taking into account cold nuclear matter effects)
  (Brambilla et al., EPJ C71(2011) 1534)

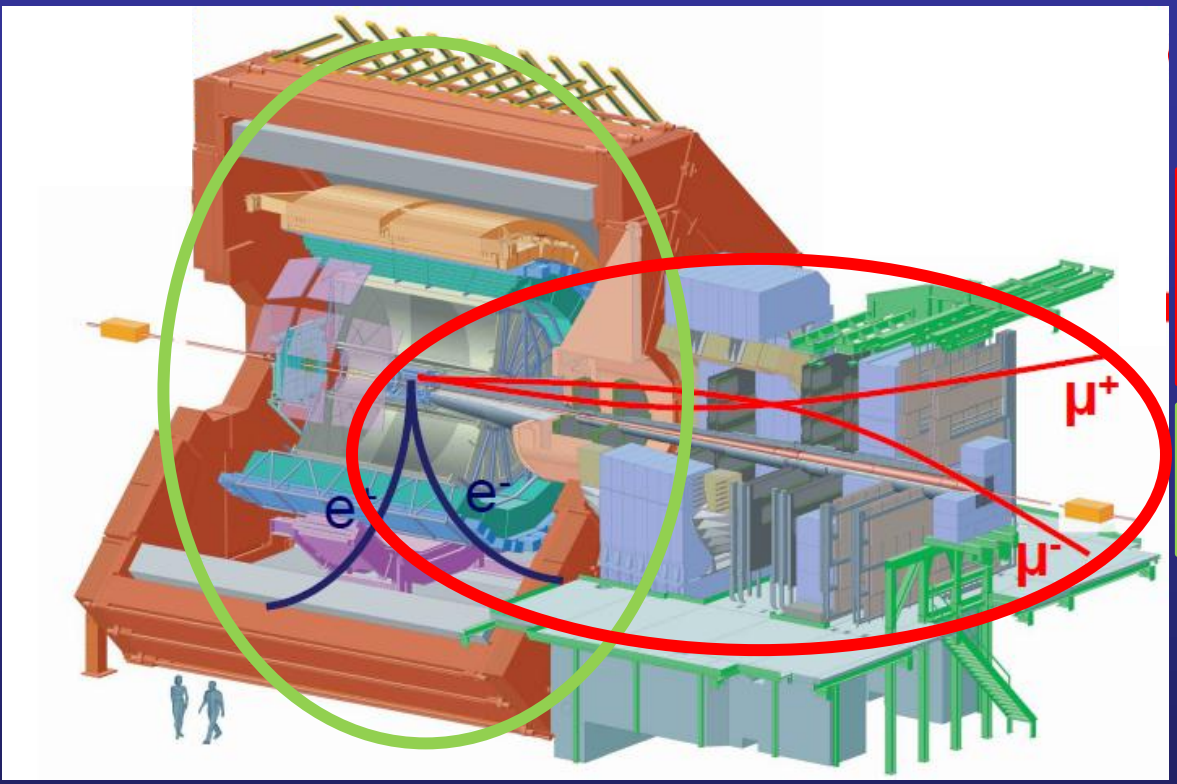




- First results from ALICE (QM2011) have shown a smaller suppression with respect to RHIC, compatible with J/ψ (re)generation
  (ALICE coll., arXiv:1202.1383, accepted by PRL)

Today → deeper understanding thanks to the high-lumi 2011 Pb run

Experiment and data taking



Quarkonia detection

In the forward muon spectrometer ($2.5<y<4$) via $\mu^+\mu^-$ decays

In the central barrel ($|y|<0.9$) via e^+e^- decays

Acceptance extends down to $p_T=0$

- MB trigger based on
  - Forward scintillator arrays (VZERO)
  - Silicon pixel (SPD)
- In addition, trigger on muon (pairs) in the forward spectrometer (p_T ~ 1 GeV/c threshold for Pb-Pb 2011)

Integrated luminosity for quarkonia analysis

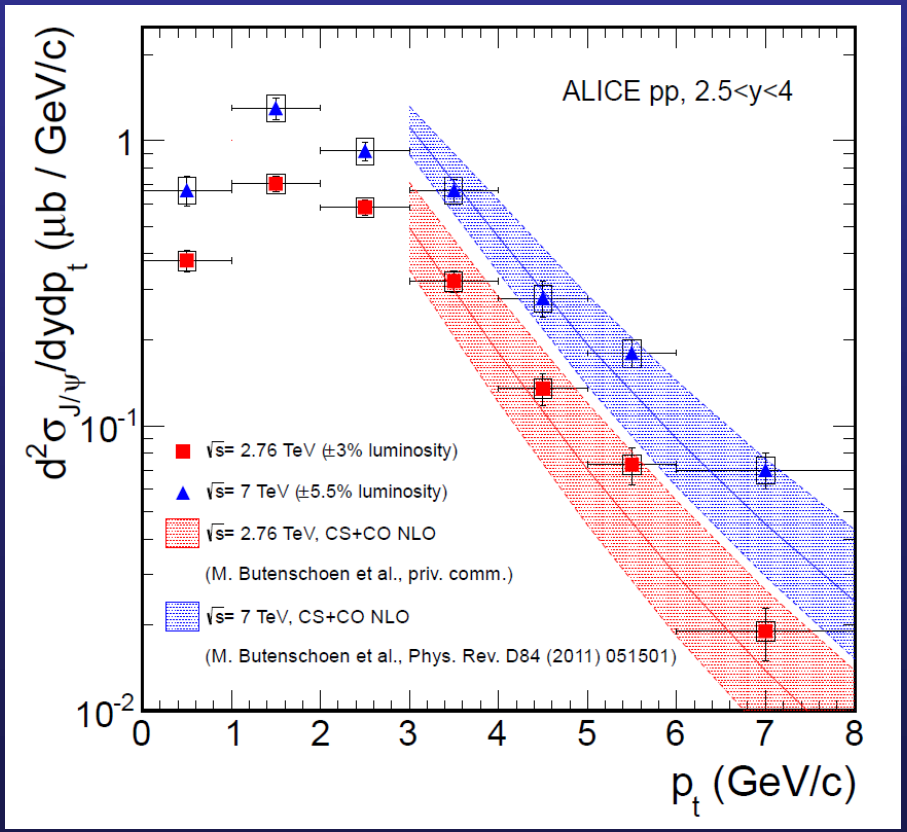
(up to) ~100 nb^{-1} for pp

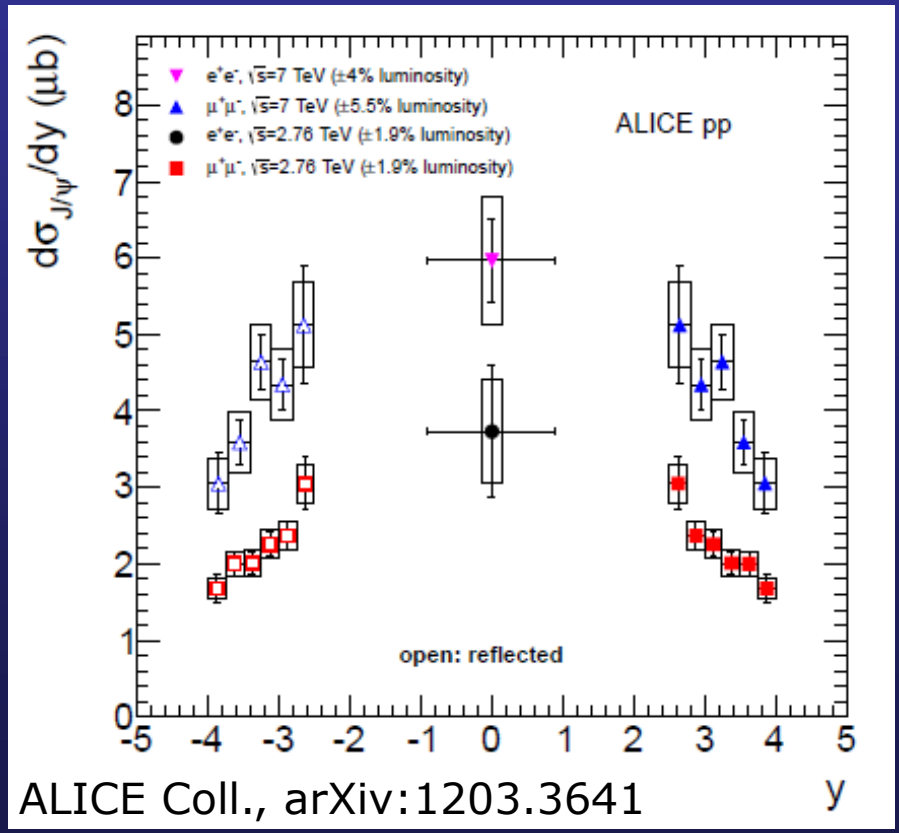
~ 70 μb^{-1} for Pb-Pb

pp: selected results

- Data taking at $\sqrt{s}$=2.76 TeV essential to build the R_{AA} reference, result based on L_{int}^{e}=1.1 nb^{-1} and L_{int}^{μ}=19.9 nb^{-1}

$$\sigma_{J/\psi}(|y|<0.9) = 6.71 \pm 1.54(\text{stat.}) \pm 1.21(\text{syst.}) + 1.01(\lambda_{HE}=1) - 1.41(\lambda_{HE}=-1)\ \mu\text{b and}$$
$$\sigma_{J/\psi}(2.5<y<4) = 3.34 \pm 0.13(\text{stat.}) \pm 0.27(\text{syst.}) + 0.53(\lambda_{CS}=1) - 1.07(\lambda_{CS}=-1)\ \mu\text{b.}$$



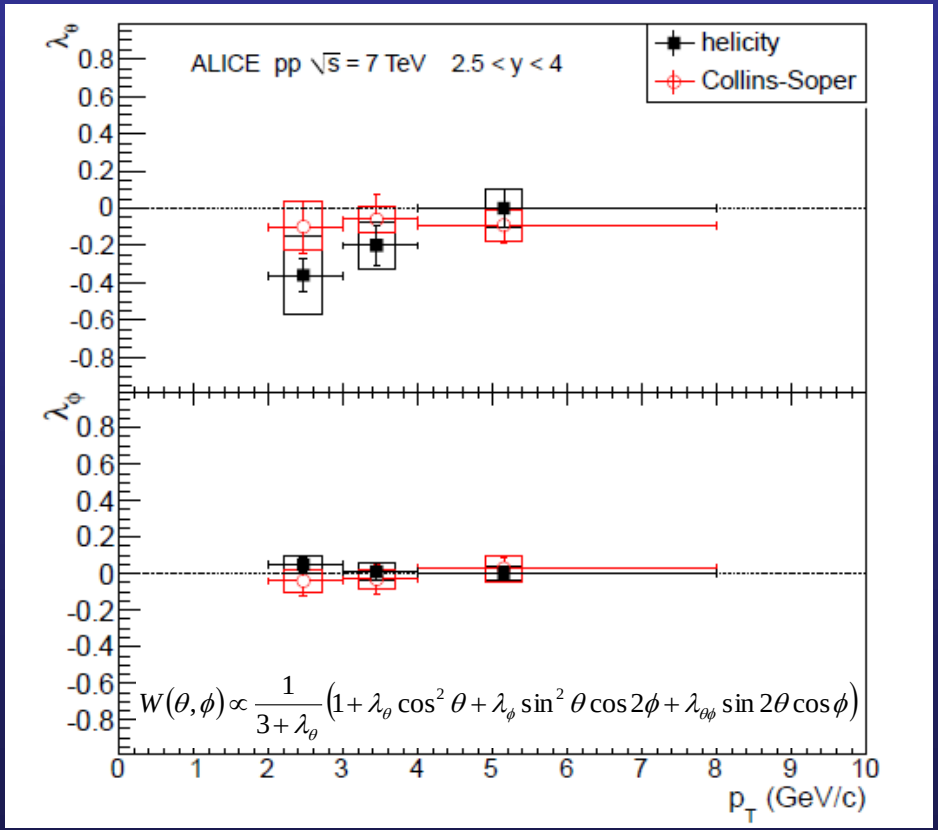


- Results in agreement with NLO NRQCD calculations

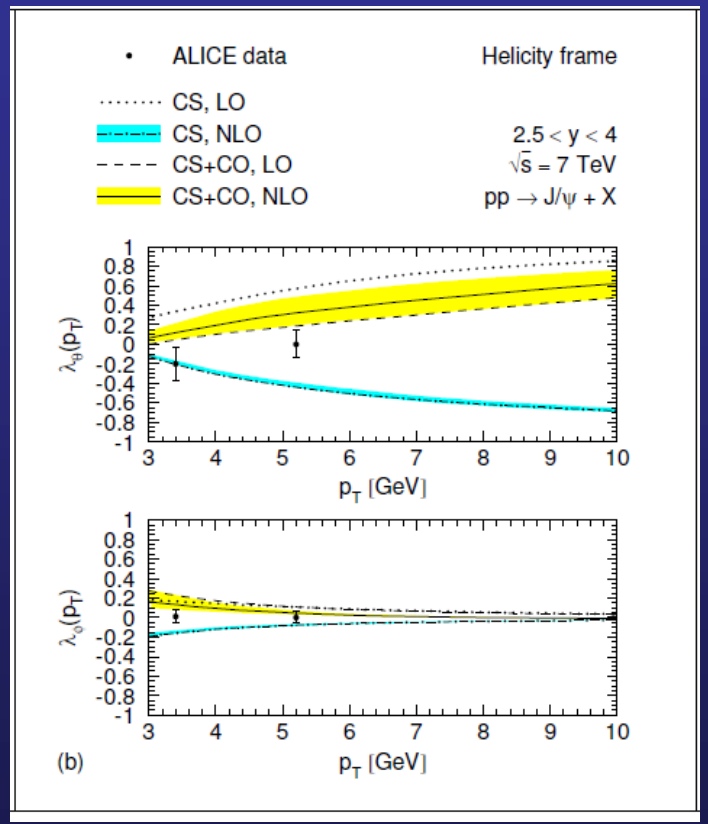
J/ψ polarization results

- Discriminate among the different theoretical models of J/ψ production
- Long-standing puzzle with CDF results

ALICE Coll., PRL 108(2012) 082001



M.Butenschoen, A.Kniehl, arXiv:1201.1872

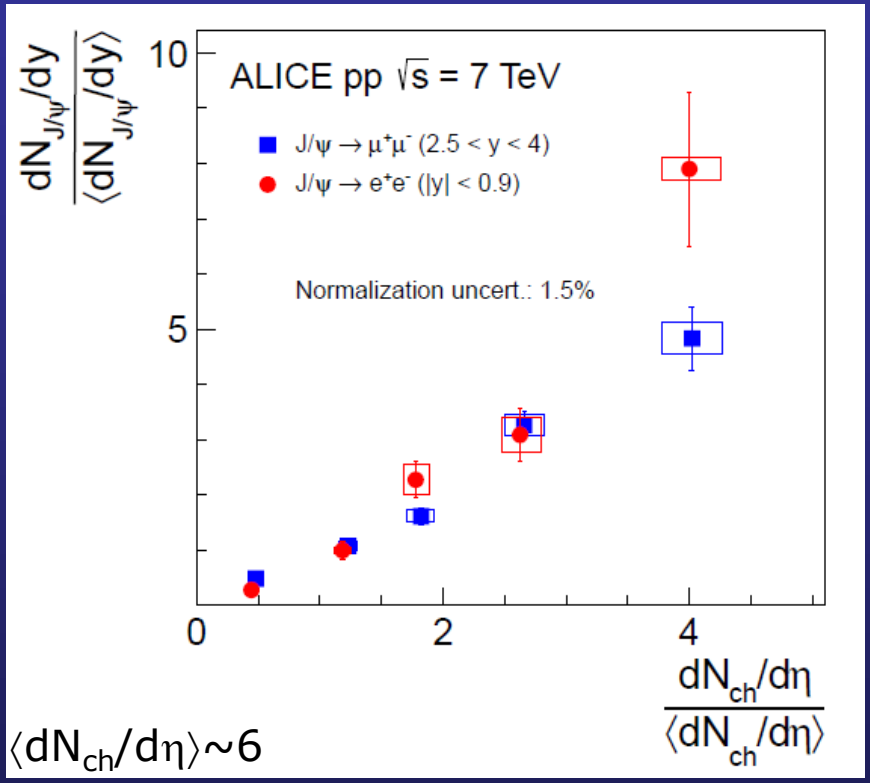


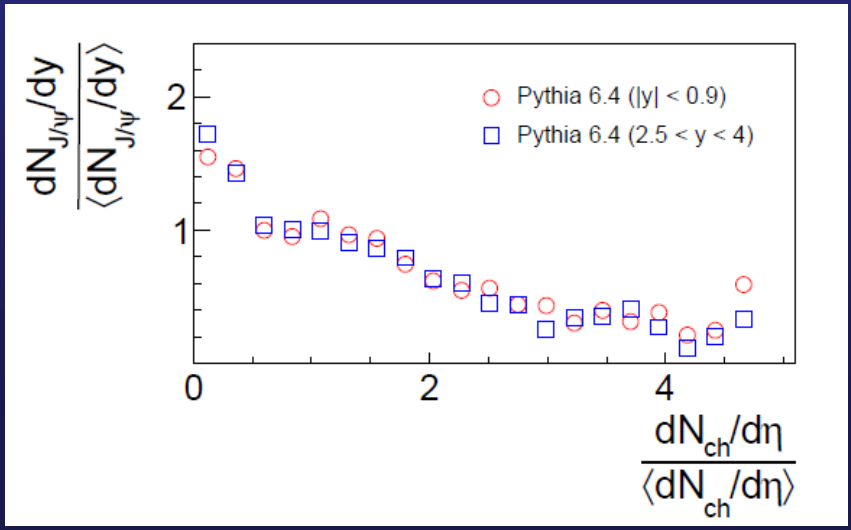
- First result at LHC energy: almost no polarization for the J/ψ
- First theoretical calculation (NLO NRQCD) compared to data: promising result, reasonable agreement with theory

Multiplicity dependence in pp

- Highest charged particle multiplicity ($dN_{ch}/d\eta$ ~30) in this analysis comparable with Cu-Cu collisions (50-55%) at RHIC

- Relative J/ψ yield increases linearly with the relative multiplicity
- Help to understand the interplay between hard and soft interactions in the context of multi-partonic interactions (MPI), and/or underlying event





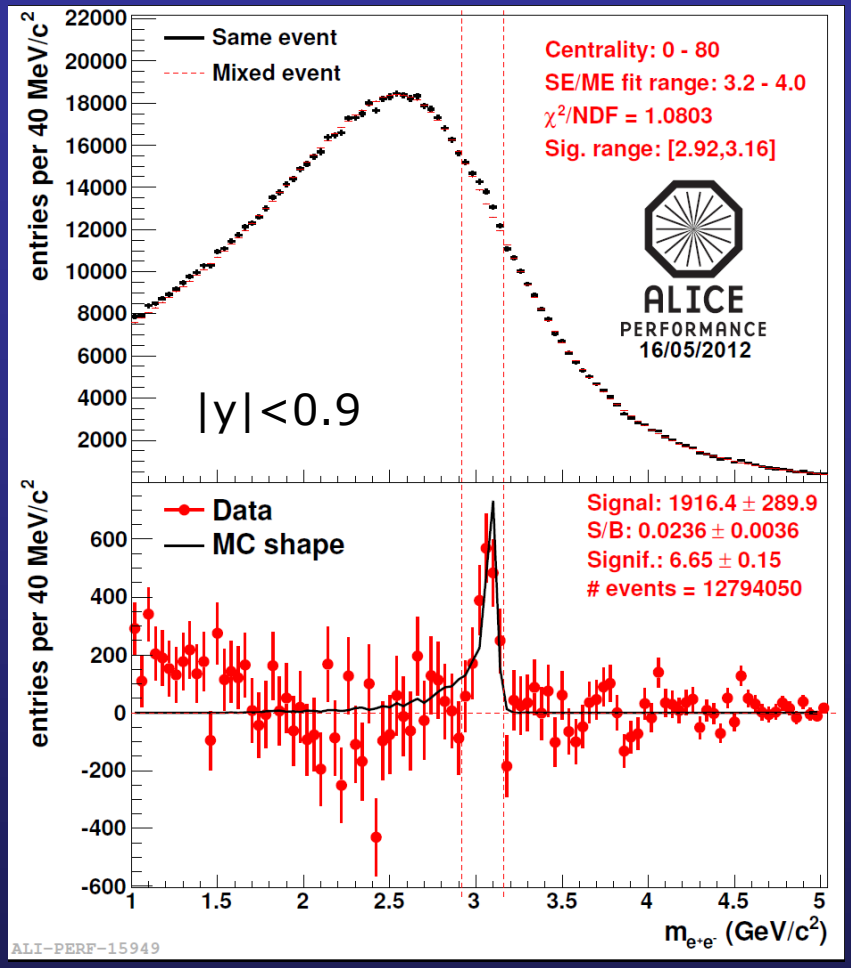
- Model predictions (PYTHIA) do not reproduce data
- Study ongoing with other particles, e.g. D-mesons

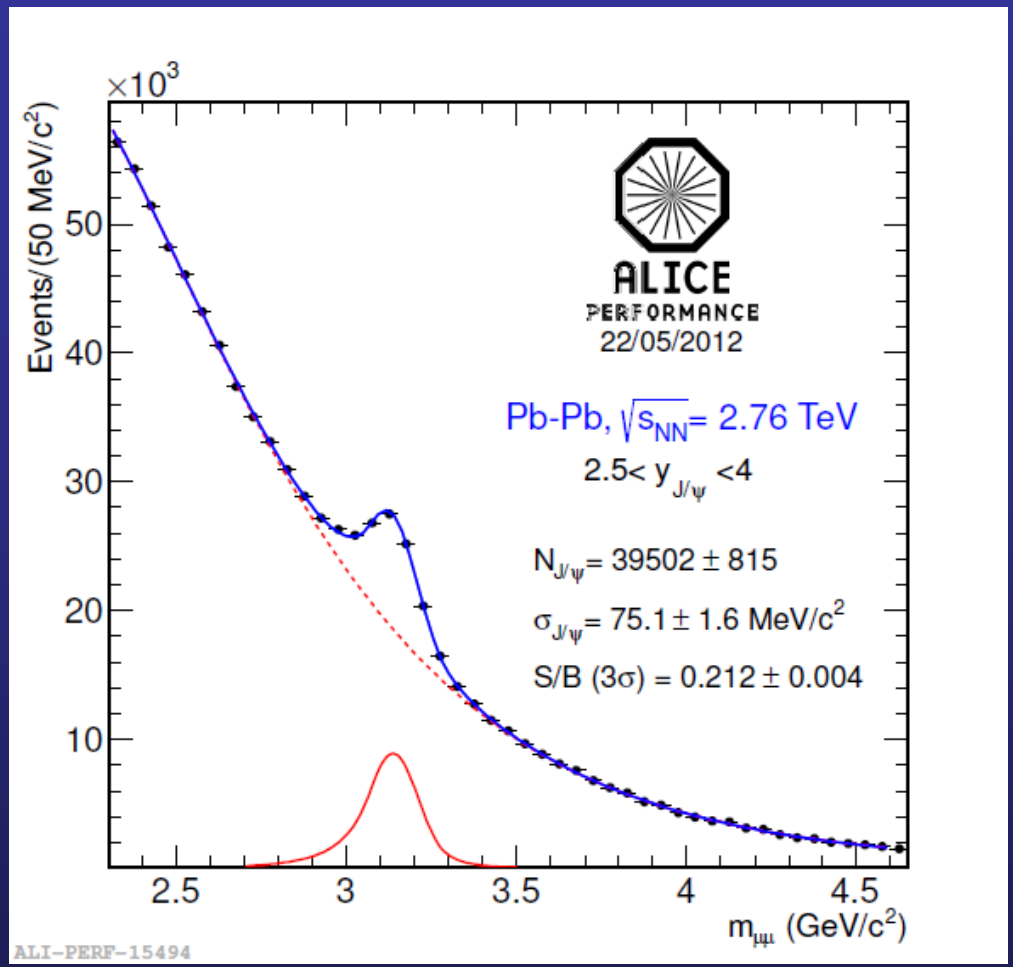
B. Abelev et al., ALICE Coll., Phys. Lett. B712(2012) 165

Pb-Pb collision results

- Today's menu
  - R_{AA} vs $\langle N_{part} \rangle$
    - Forward rapidity (HP '12)
    - Mid-rapidity (NEW!)
    - Forward rapidity in p_T bins (NEW!)
  - R_{AA} vs p_T
    - Forward rapidity (HP '12)
    - Forward rapidity in centrality bins (NEW!)
  - J/ψ $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ (NEW!)
  - R_{AA} vs y (HP '12 + NEW!)
  - J/ψ elliptic flow
    - Intermediate centrality vs p_T (HP '12)
    - v_2 vs centrality (NEW!)
  - ψ(2S)/J/ψ ratio: Pb-Pb vs pp (NEW!)

Charmonia detection (Pb-Pb) in ALICE

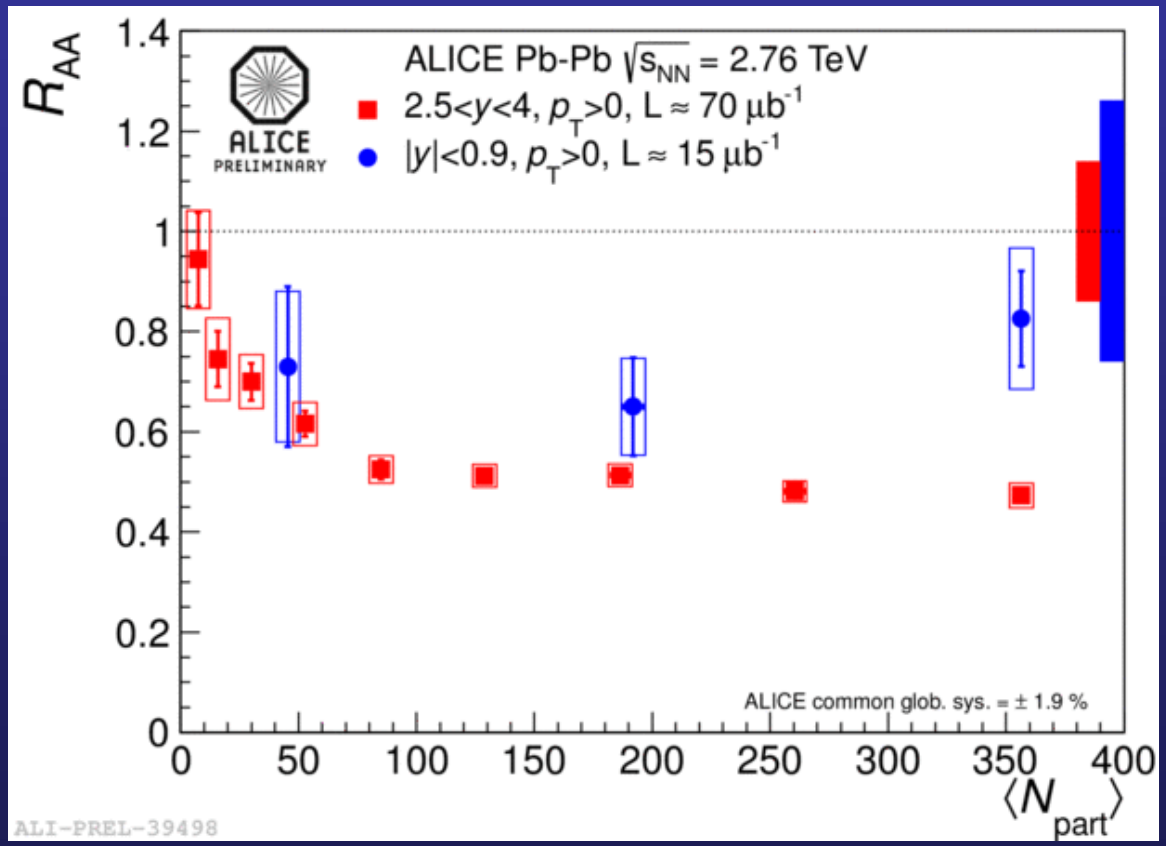




- Electron analysis: background subtracted with event mixing → Signal extraction by event counting
- Muon analysis: fit to the invariant mass spectra → signal extraction by integrating the Crystal Ball line shape

Pb-Pb collisions: R_{AA} vs $\langle N_{part} \rangle$

- Centrality dependence of the nuclear modification factor studied at both central and forward rapidities

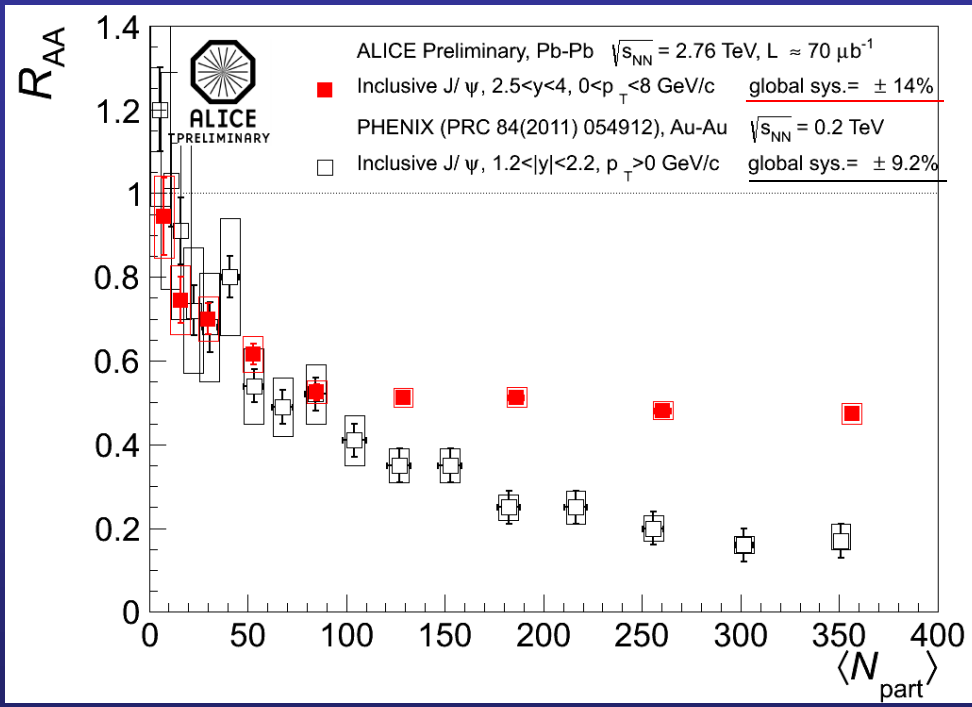


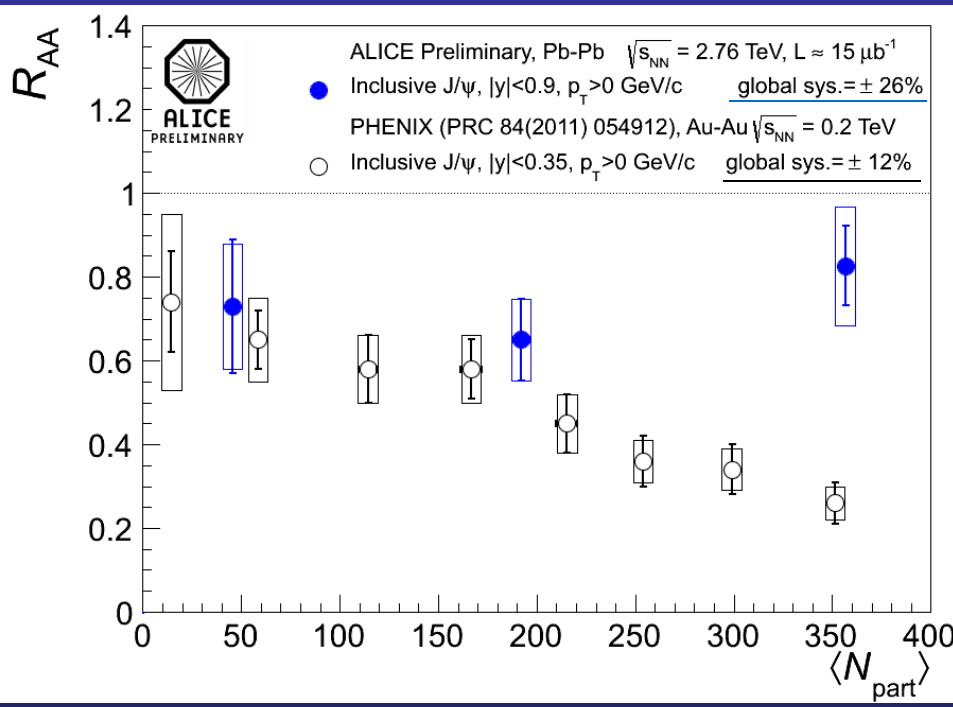
Inclusive J/ψ R_{AA}

Negligible effect of non-prompt contribution on the measured R_{AA}

- At forward y, R_{AA} flattens for $N_{part} \geq 100$
- Large uncertainty on the (midrapidity) pp reference prevents a final conclusion on a different behaviour for central events at mid- and forward rapidity

Pb-Pb collisions: R_{AA} vs $\langle N_{part} \rangle$



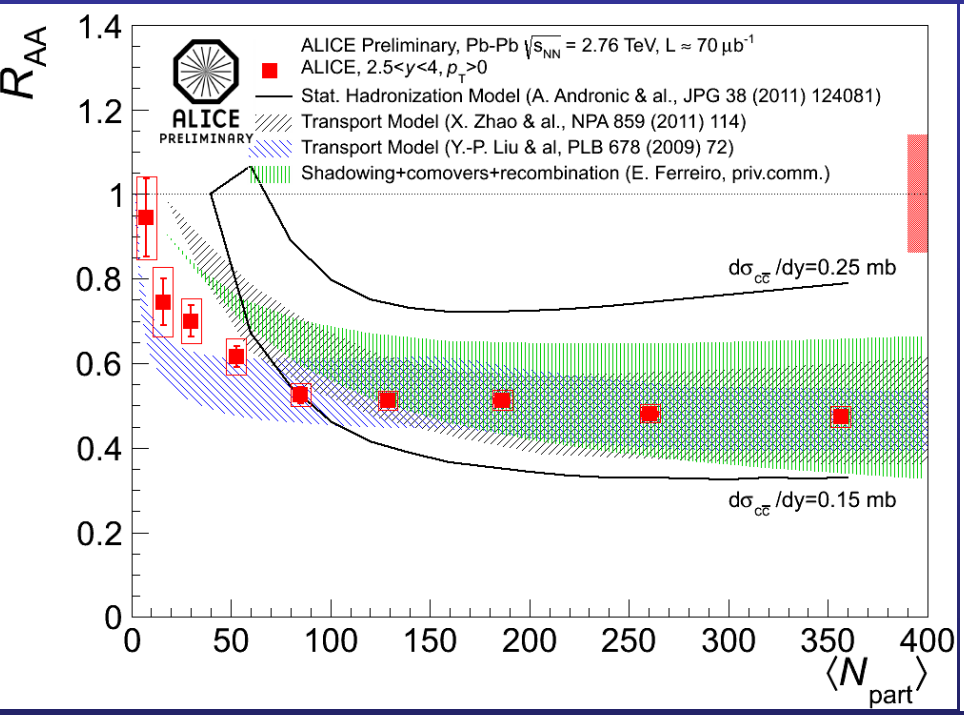


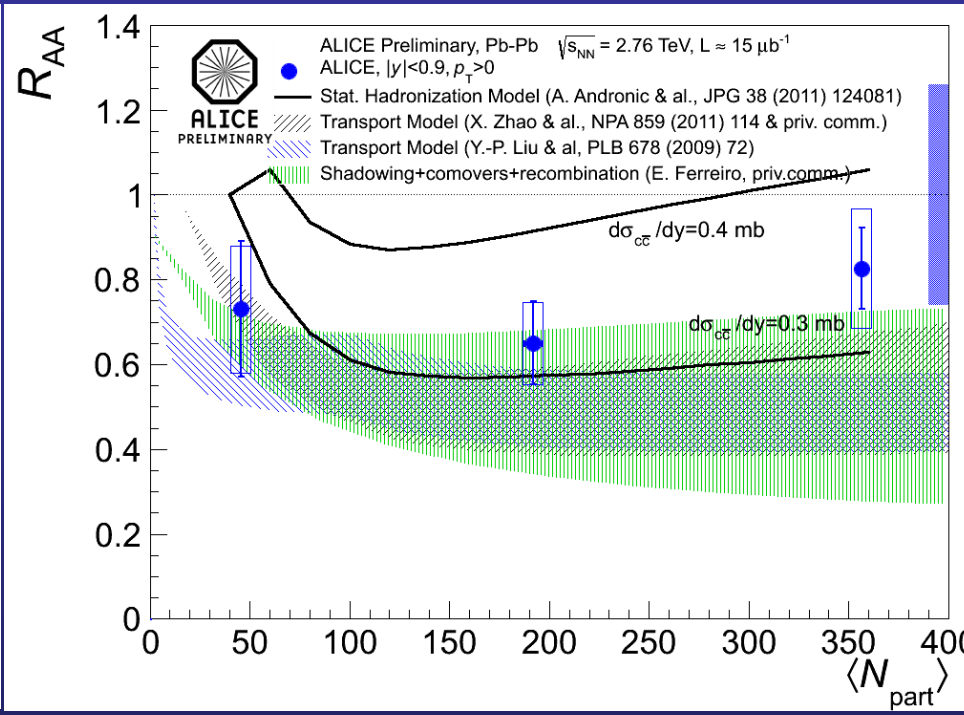
- Comparison with PHENIX

- Stronger centrality dependence at lower energy
- Systematically larger R_{AA} values for central events in ALICE

- Behaviour qualitatively expected in a (re)generation scenario
  → Look at theoretical models

Pb-Pb collisions: R_{AA} vs $\langle N_{part} \rangle$

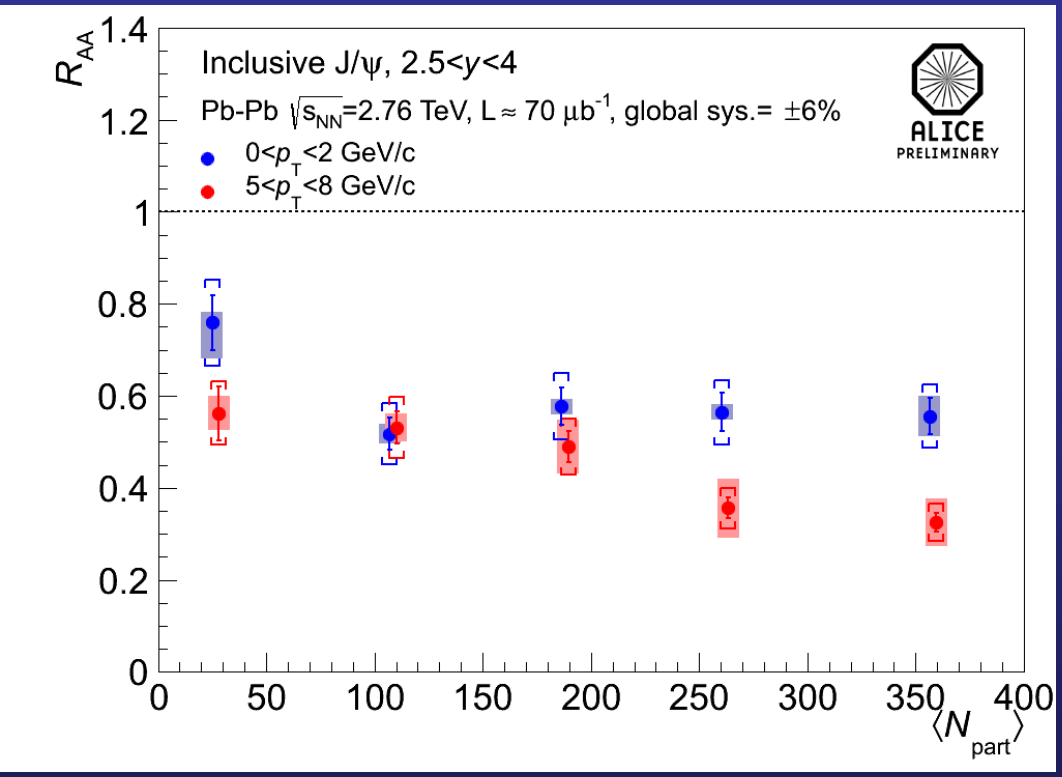




- Comparison with models
  - X.Zhao and R.Rapp, Nucl. Phys. A859(2011) 114
  - Y.Liu, Z. Qiu, N. Xu and P. Zhuang, Phys. Lett. B678(2009) 72
  - A. Capella et al., Eur. Phys. J. C58(2008) 437 and E. Ferreiro, priv. com
- Models including a large fraction (>50% in central collisions) of J/ψ produced from (re)combination or models with all J/ψ produced at hadronization can describe ALICE results for central collisions in both rapidity ranges

R_{AA} vs $\langle N_{part} \rangle$ in p_T bins

- J/ψ production via (re)combination should be more important at low transverse momentum

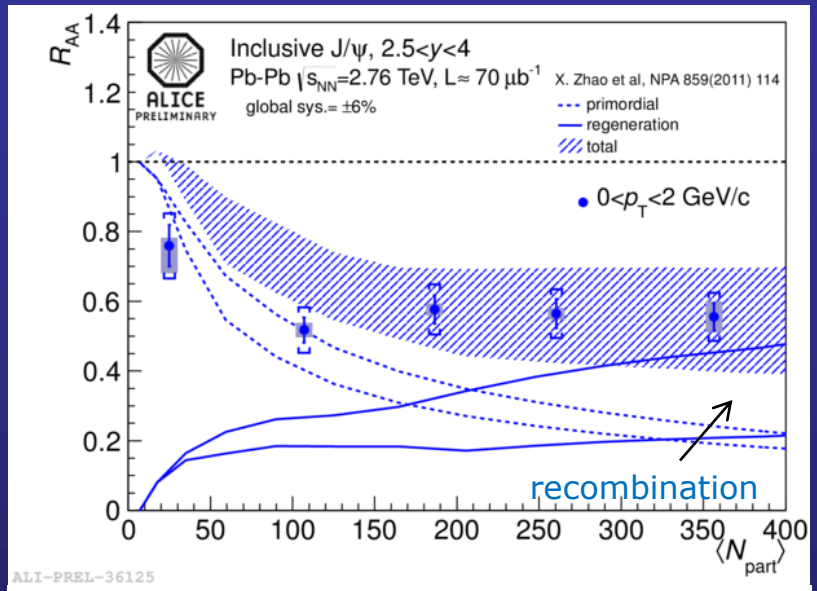


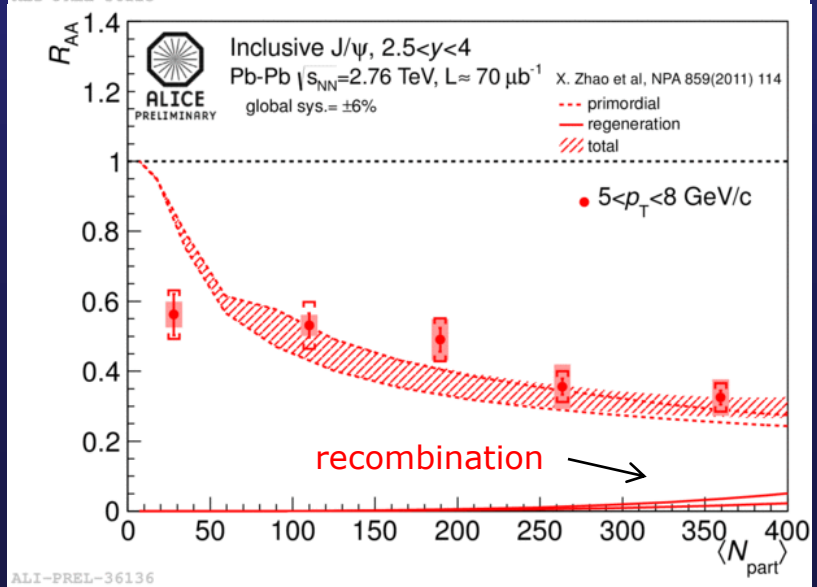
- Compare R_{AA} vs $\langle N_{part} \rangle$ for low-p_T ($0<p_T<2$ GeV/c) and high-p_T ($5<p_T<8$ GeV/c) J/ψ
- Different suppression pattern for low- and high-p_T J/ψ
- Smaller R_{AA} for high p_T J/ψ

Uncertainties
uncorrelated (box around points)
partially correlated within and between sets ([])
100% correlated within a set and between sets (text)

R_{AA} vs $\langle N_{part} \rangle$ in p_T bins

- J/ψ production via (re)combination should be more important at low transverse momentum



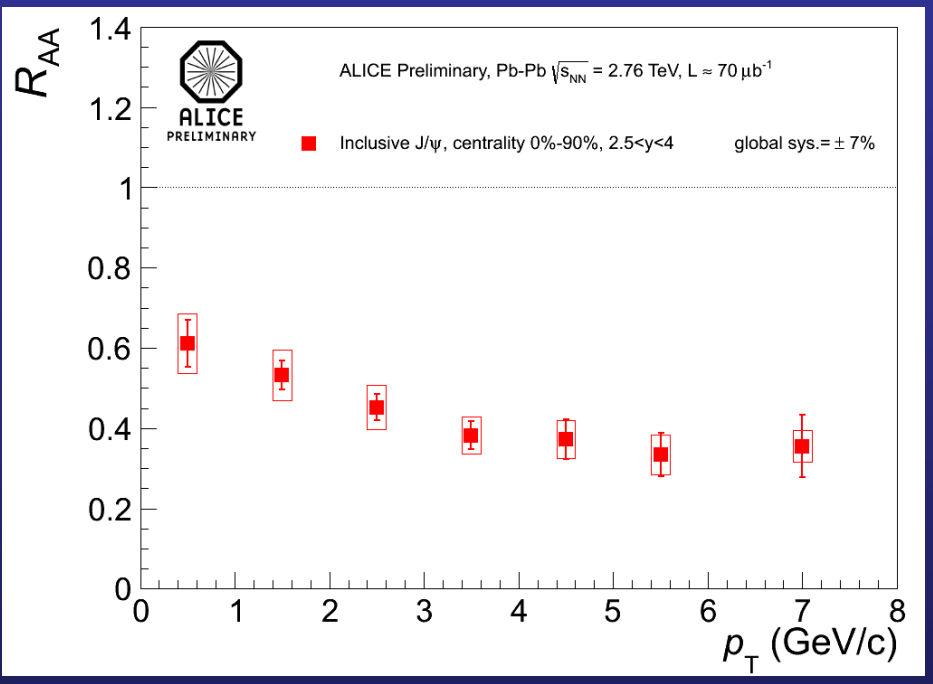


- Compare R_{AA} vs $\langle N_{part} \rangle$ for low-p_T ($0<p_T<2$ GeV/c) and high-p_T ($5<p_T<8$ GeV/c) J/ψ
- Different suppression pattern for low- and high-p_T J/ψ
- Smaller R_{AA} for high p_T J/ψ
- In the models, ~50% of low-p_T J/ψ are produced via (re)combination, while at high p_T the contribution is negligible → fair agreement from N_{part}~100 onwards

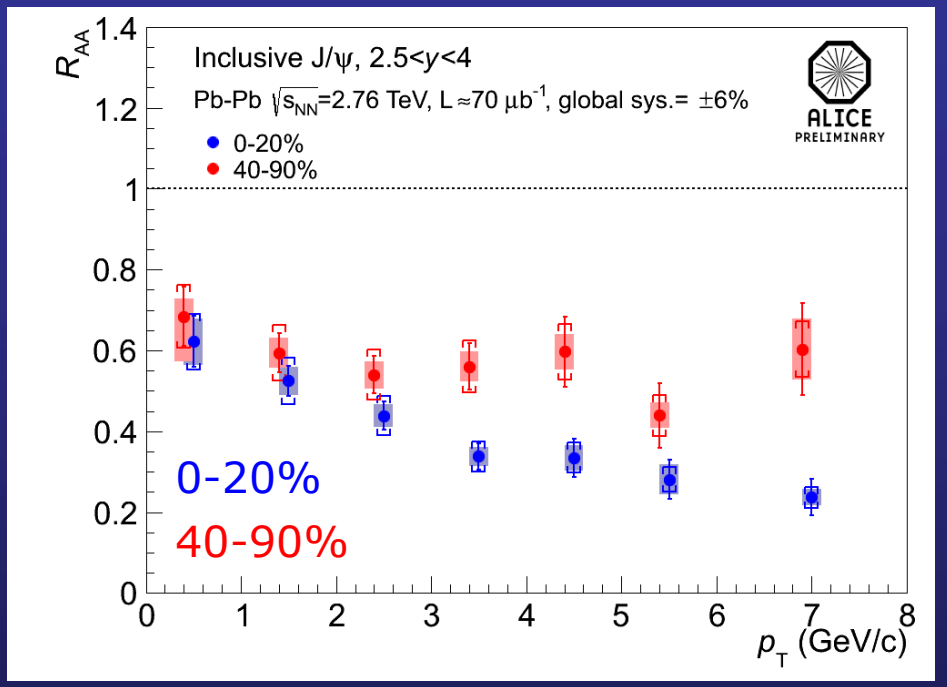
J/ψ R_{AA} vs p_T

- As an alternative view, R_{AA} is shown as a function of the J/ψ p_T for various centrality bins

0-90%



0-20% vs 40-90%

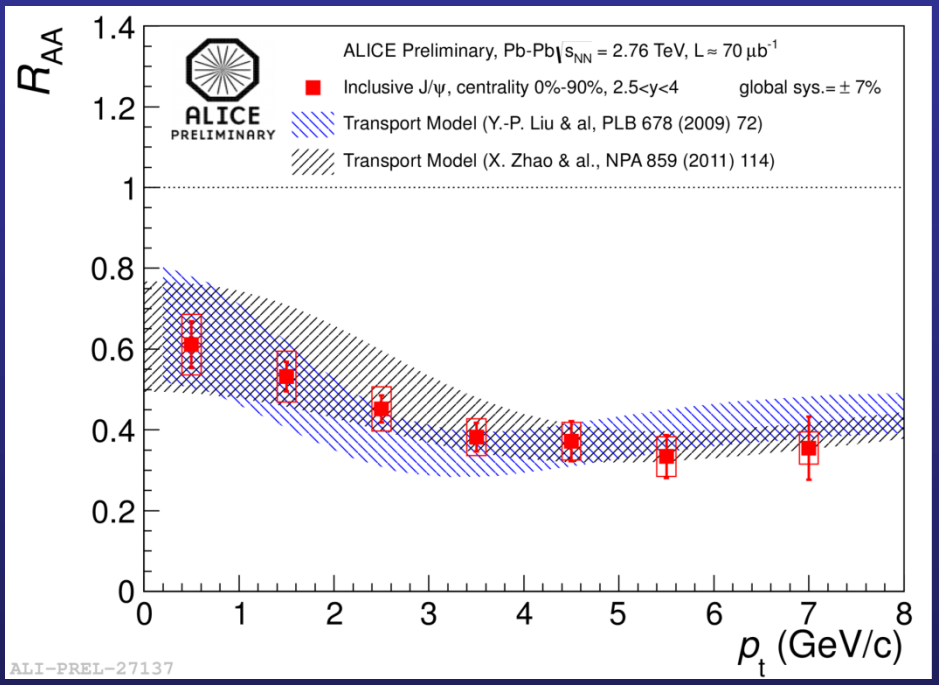


- Suppression is stronger for high-p_T J/ψ (R_{AA}~0.6 at low p_T and ~0.35 at high p_T)
- Splitting in centrality bins we observe that the difference low- vs high-p_T suppression is more important for central collisions

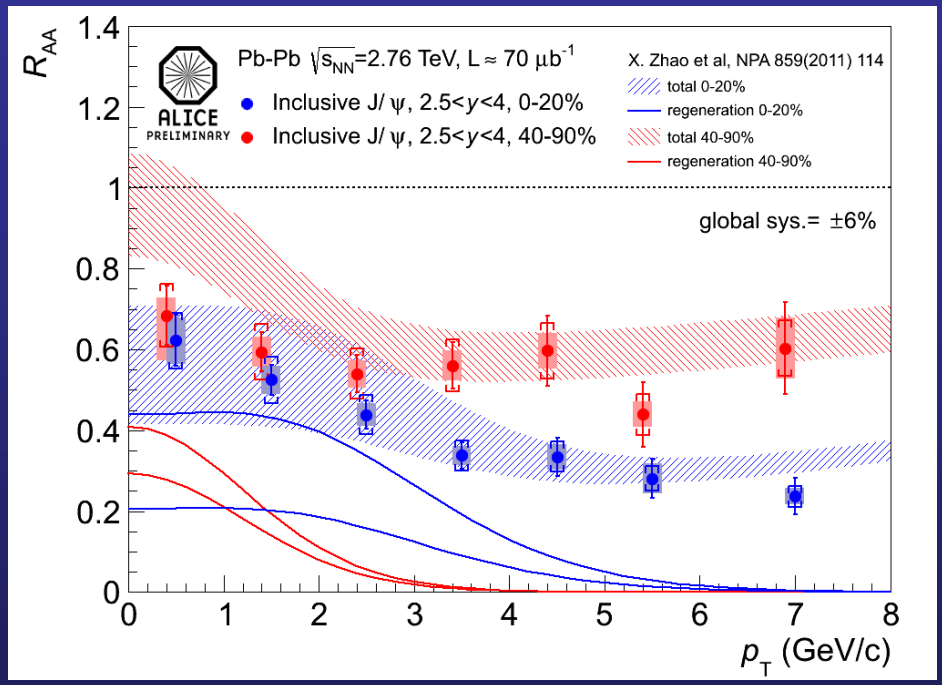
J/ψ R_{AA} vs p_T

- As an alternative view, R_{AA} is shown as a function of the J/ψ p_T for various centrality bins

0-90%

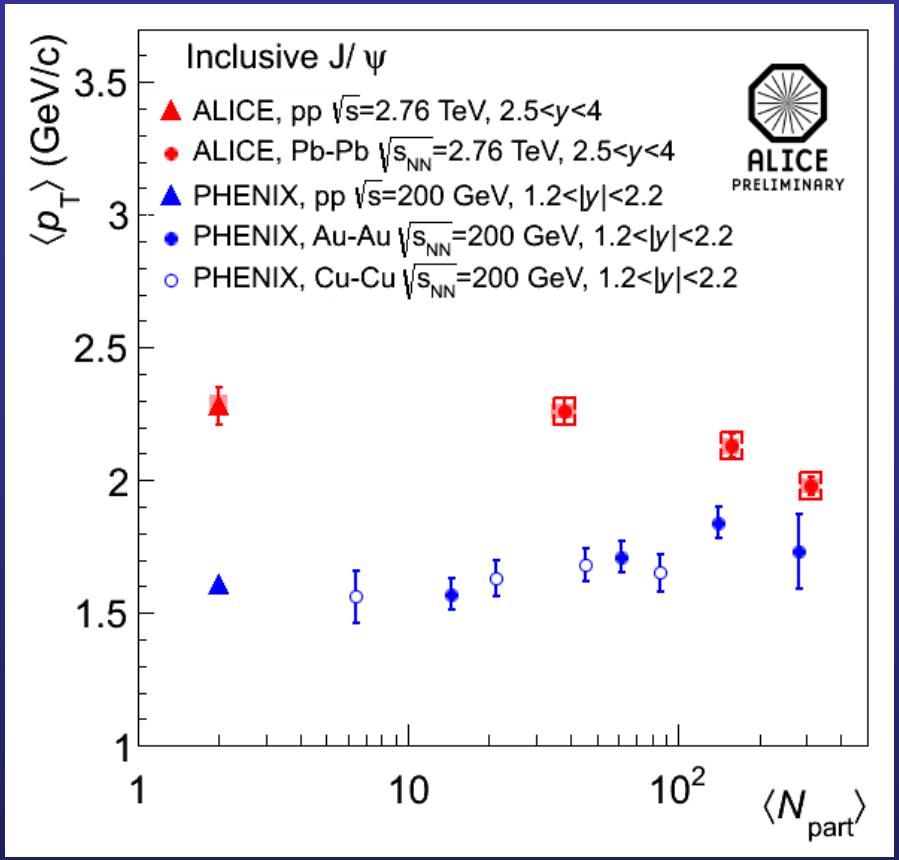


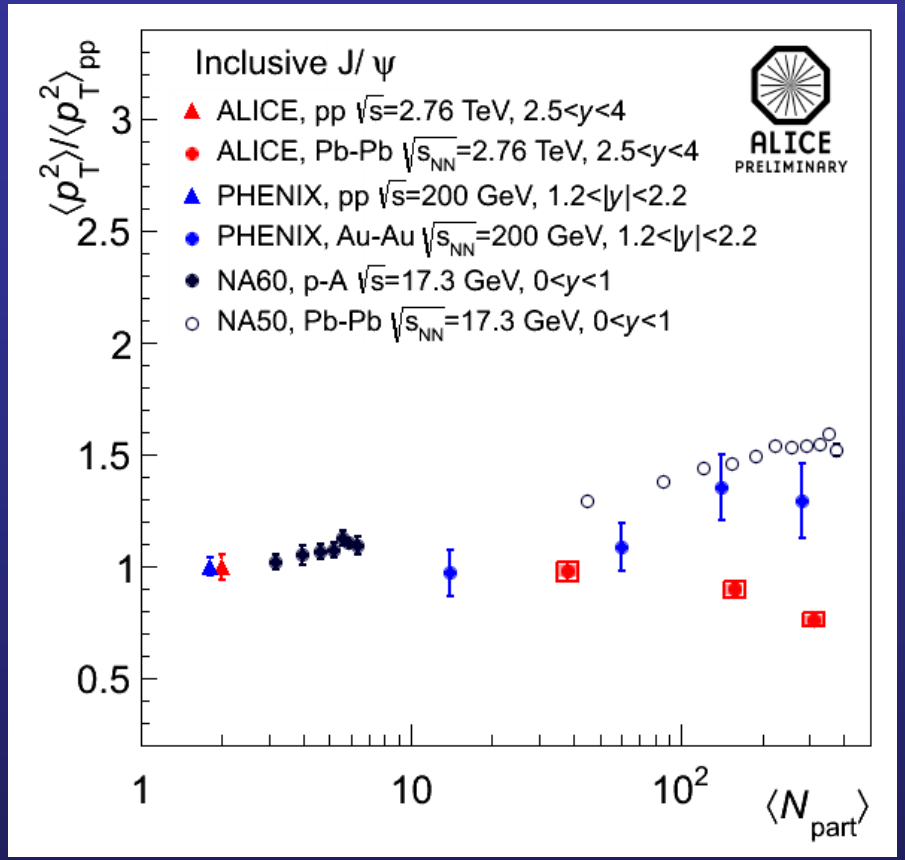
0-20% vs 40-90%



- Suppression is stronger for high-p_T J/ψ (R_{AA}~0.6 at low p_T and ~0.35 at high p_T)
- Splitting in centrality bins we observe that the difference low vs high-p_T suppression is more important for central collisions
- Fair agreement data vs models with large contribution from (re)combination (slightly worse for peripheral events at low p_T)

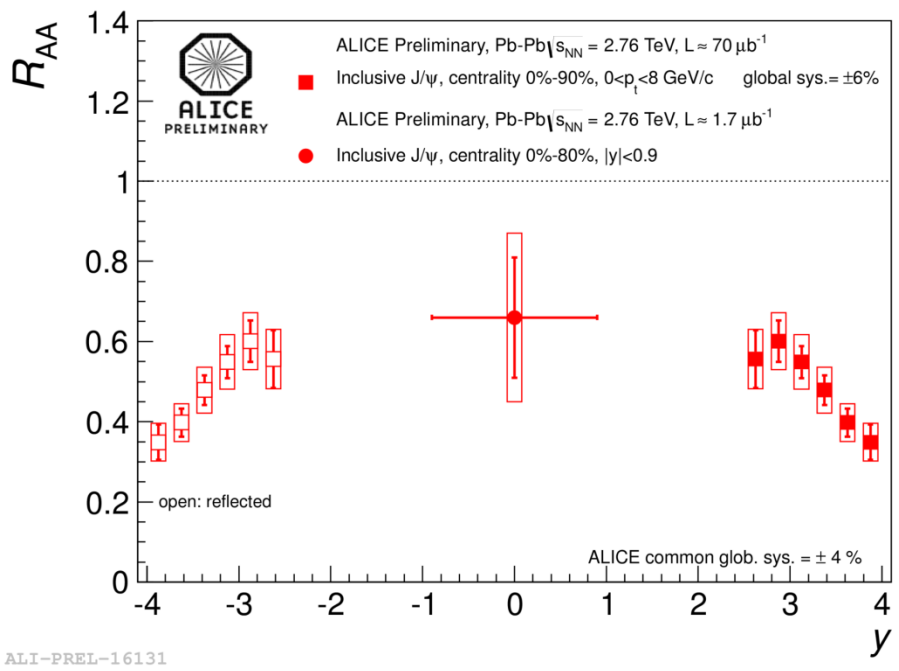
J/ψ $\langle p_T \rangle$ and $\langle p_T^2 \rangle$

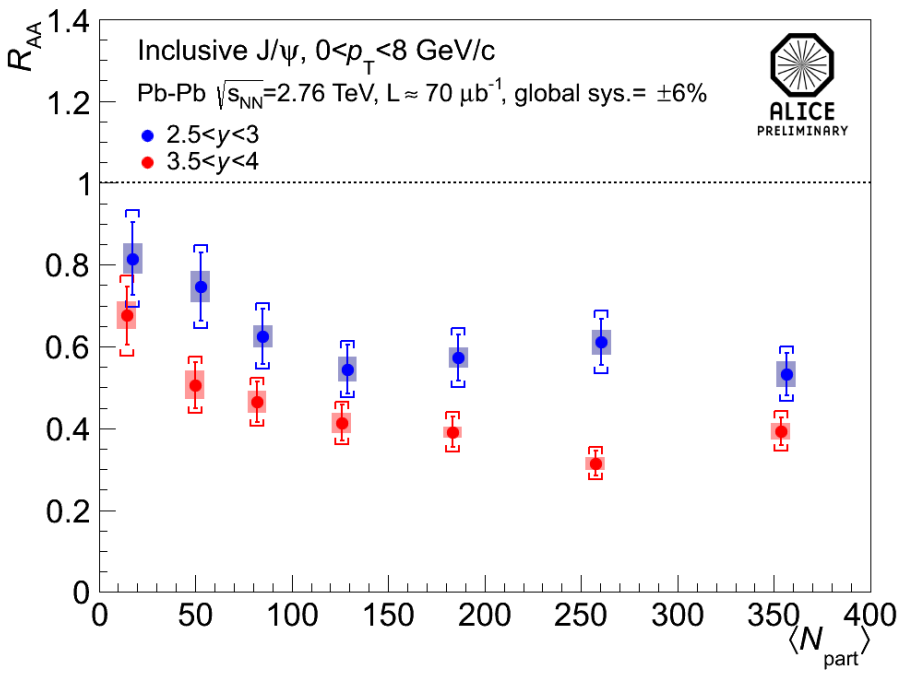




- The J/ψ $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ show a decreasing trend as a function of centrality, confirming the observation that low-p_T J/ψ are less suppressed in central collisions
- The trend is different wrt the one observed at lower energies, where an increase of the $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ with centrality was obtained

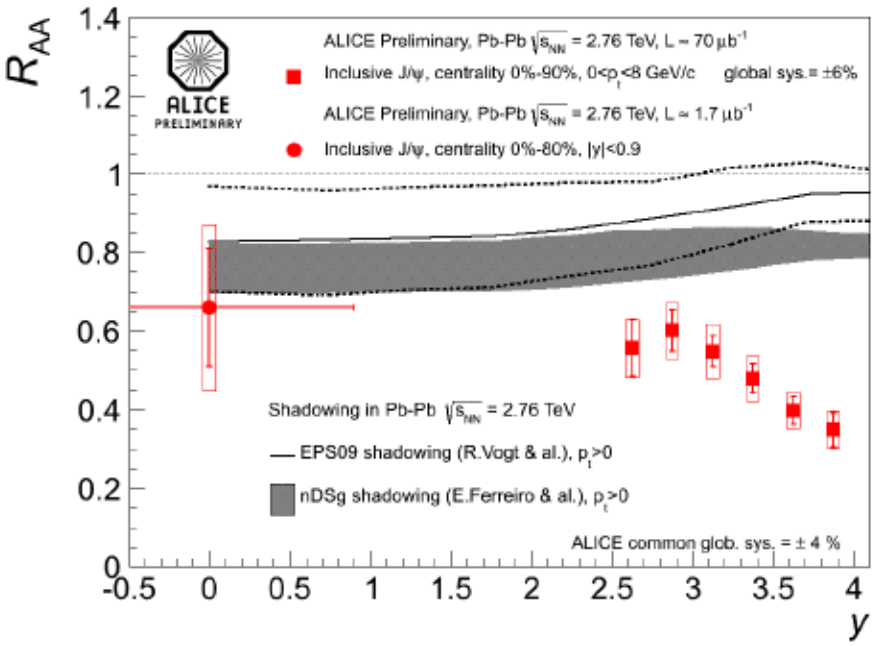
J/ψ R_{AA} vs rapidity

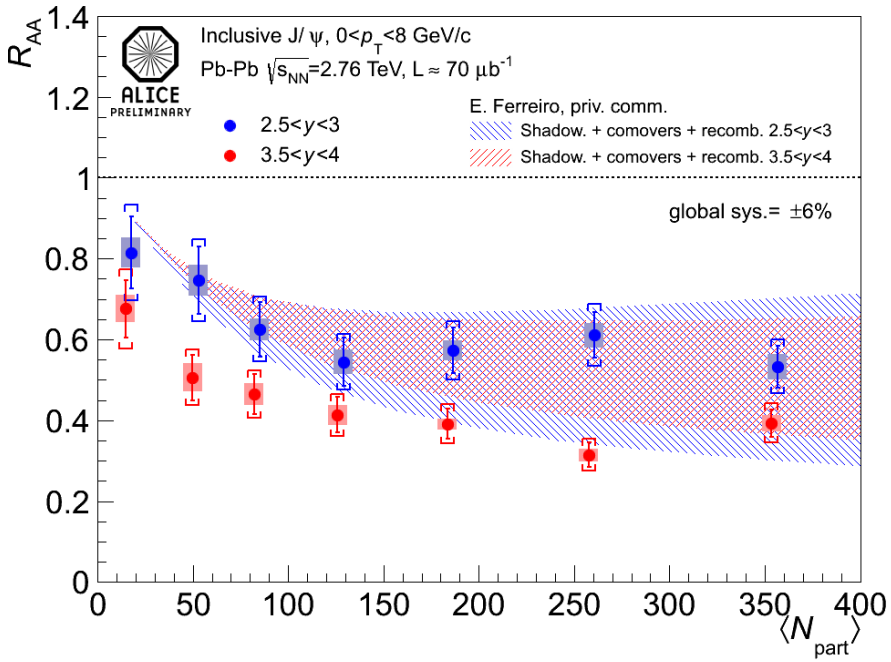




- Inclusive J/ψ measured also as a function of rapidity: R_{AA} decreases by 40% from y=2.5 to y=4
- Suppression increases with centrality and it is stronger in the most forward region

J/ψ R_{AA} vs rapidity





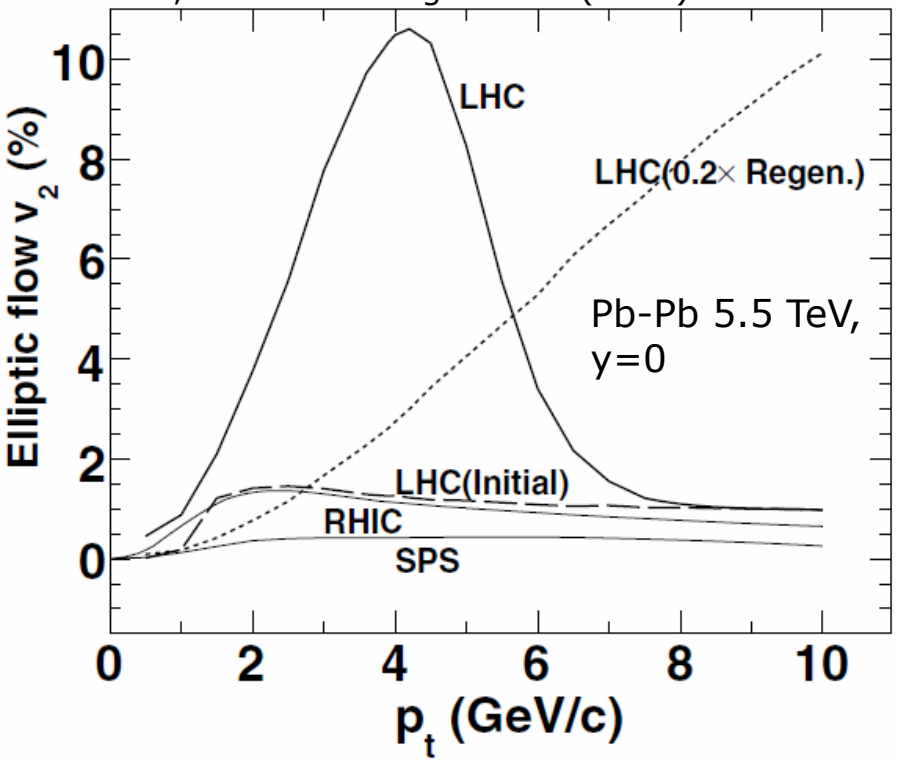
- Inclusive J/ψ measured also as a function of rapidity: R_{AA} decreases by 40% from y=2.5 to y=4
- Suppression beyond the current shadowing estimates. Important to measure cold nuclear matter effects (incoming pA data taking)

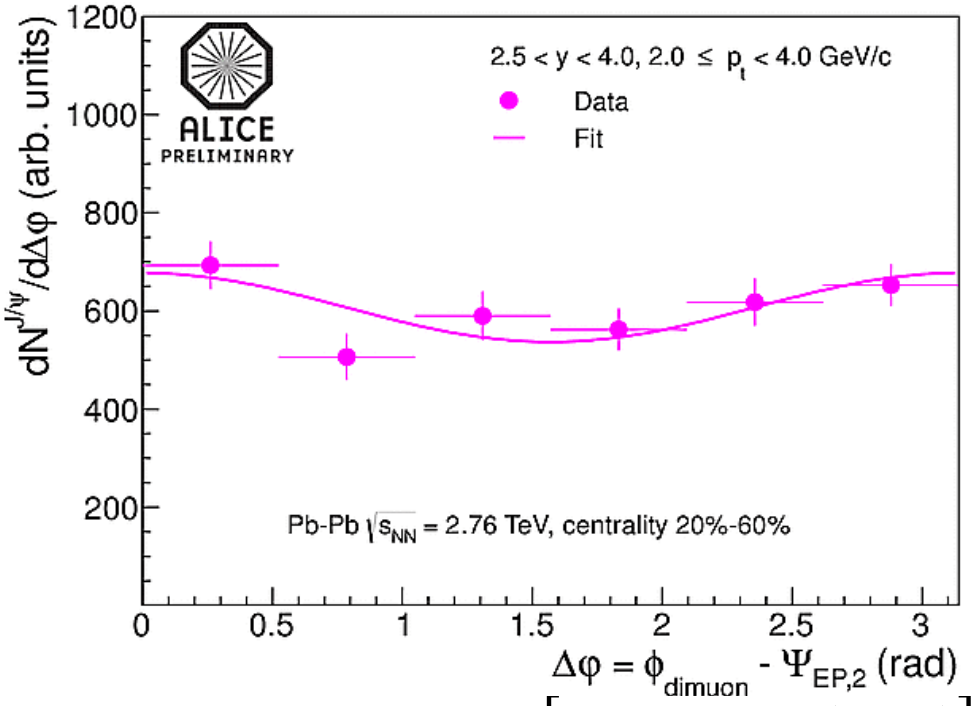
- Suppression increases with centrality and it is stronger in the most forward region
- Comover+regeneration model seems to predict a weaker rapidity dependence

J/ψ elliptic flow

- The contribution of J/ψ from (re)combination should lead to a significant elliptic flow signal at LHC energy

Liu, Xu and Zhuang NPA834(2010) 317c

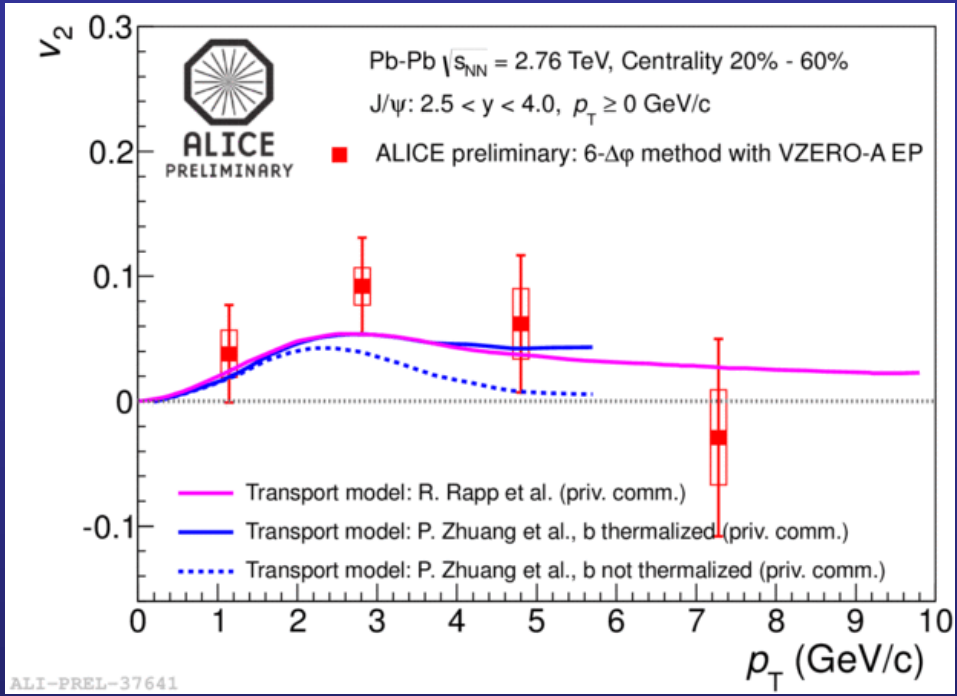


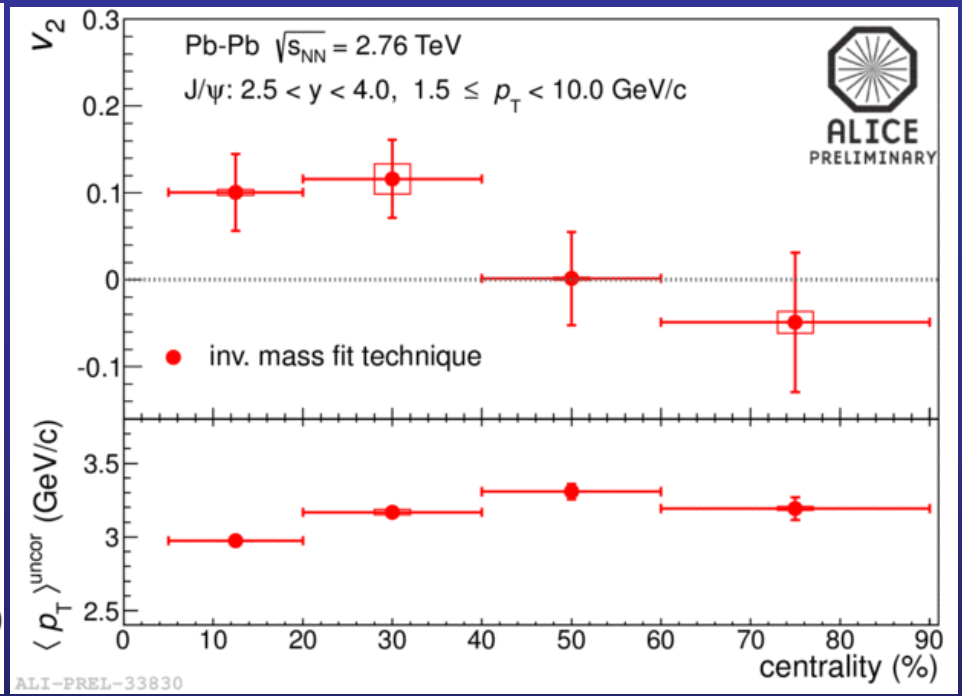


$$dN_{J/\psi}/d\Delta\varphi = A\times\left[1+2v_2^{obs}\cos(2\Delta\varphi)\right]$$

- Analysis performed with the EP approach (using VZERO-A)
- Correct v_2^{obs} by the event plane resolution, $v_2=v_2^{obs}/\sigma_{EP}$ (σ_{EP} measured by 3 sub-events method)
- Checks with alternative methods performed

Non-zero J/ψ elliptic flow at the LHC



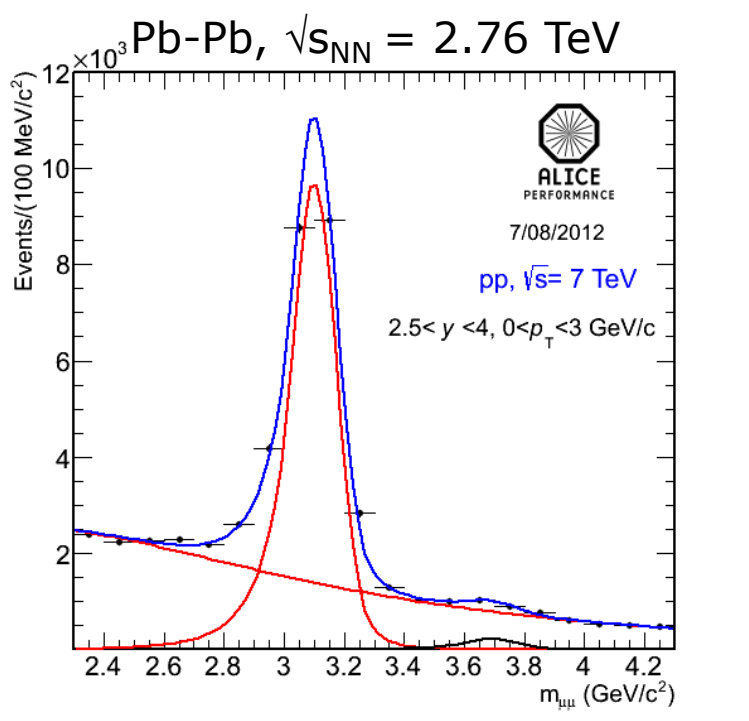


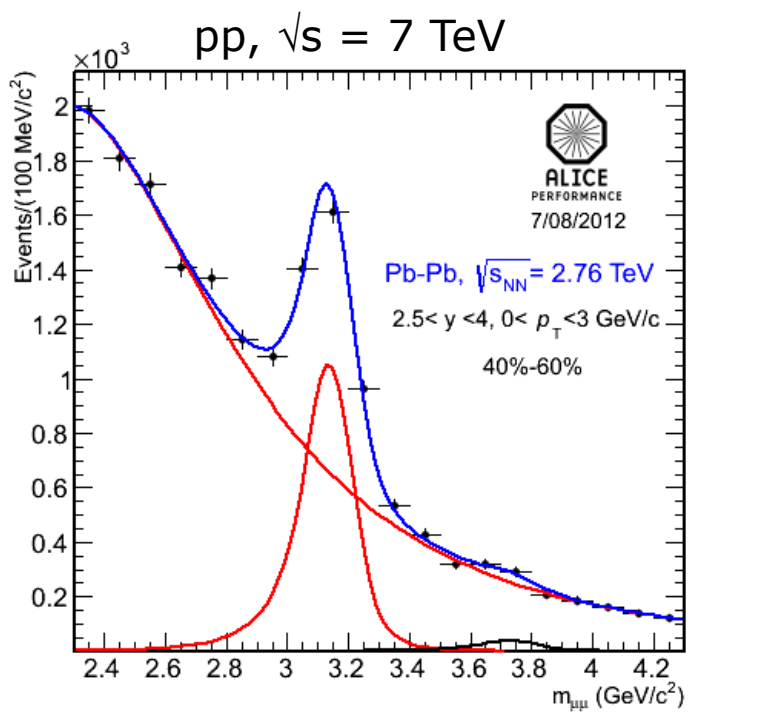
- STAR: v_2 compatible with zero everywhere
- ALICE: hint for non-zero v_2 in both
  - 20-60% central events in $2<p_T<4$ GeV/c
  - 5-20% and 20-40% central events for $1.5<p_T<10$ GeV/c
- Significance up to 3.5 σ for chosen kinematic/centrality selections

- Qualitative agreement with transport models including regeneration
- Complements indications obtained from R_{AA} studies

ψ(2S)

- Study the ψ(2S) yield normalized to the J/ψ one in Pb-Pb and in pp
- Charmonia yields are extracted fitting the invariant mass spectra in two p_T bins: $0<p_T<3$ and $3<p_T<8$ GeV/c and, for Pb-Pb, also as a function of centrality

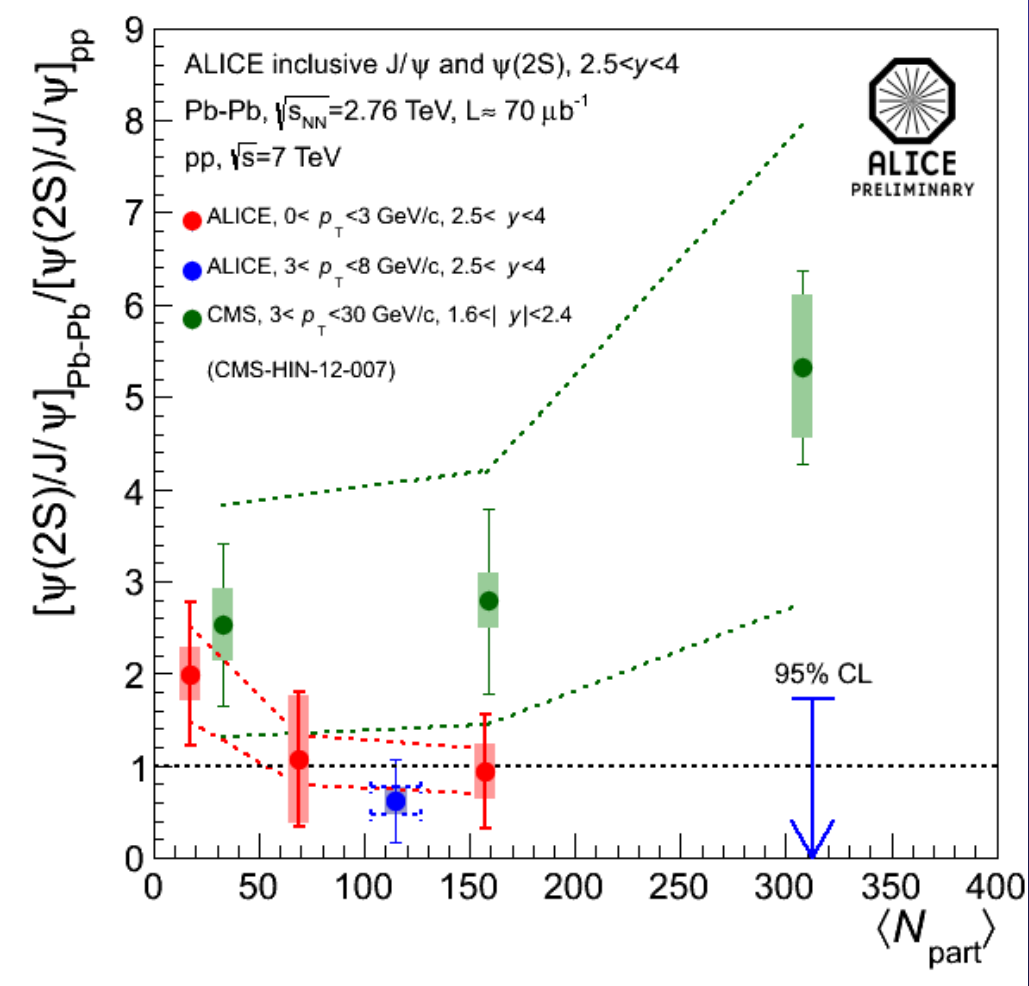




- Pb-Pb: S/B (at 3 σ around the ψ(2S)) varies between 0.01 and 0.3 from central to peripheral collisions

ψ(2S)/J/ψ double ratio

- $[\psi(2S)/J/\psi]_{Pb\text{-}Pb}$ / $[\psi(2S)/J/\psi]_{pp}$
  - Use $\sqrt{s}$ = 7 TeV pp data as a reference (small $\sqrt{s}$- and *y*-dependence → accounted for in the systematic uncertainty)



- Main systematic uncertainties (some sources cancel)
  - Signal extraction
  - MC inputs for acceptance calculation
- Large statistics and systematic errors prevent a firm conclusion on the ψ(2S) enhancement or suppression versus centrality
- Exclude large enhancement in central collisions

(uncertainty on the reference shown as colored dashed lines in the plot)

Conclusions

- ALICE has studied J/ψ production in Pb-Pb collisions down to zero p_T
- Centrality, p_T and y dependence of R_{AA}
  - R_{AA} exhibits a weak centrality dependence at all y and is larger than at RHIC
  - Less suppression at low p_T with respect to high p_T , with stronger p_T dependence for central events
  - Lower energy experiments show an opposite behaviour (see $\langle p_T \rangle$ vs $\langle N_{part} \rangle$)
  - Stronger suppression when rapidity increases
- First measurement of J/ψ elliptic flow at the LHC, indications of non-zero v_2
- Models including J/ψ production via (re)combination describe ALICE results on R_{AA} and v_2
- First look at low-p_T ψ(2S) in Pb-Pb at the LHC
- Next step: quantitative evaluation of cold nuclear matter effects in the p-Pb run at the beginning of 2013

Please find **more details** on all the topics covered in this talks in the following

Talks

R. Arnaldi (session 1D)
"J/ψ and ψ(2S) production in Pb-Pb collisions with the ALICE Muon spectrometer at the LHC"

I. Arsene (session 2D)
"J/ψ production at mid-rapidity in Pb-Pb collisions at 2.76 TeV"

H. Yang (session 7A)
"Elliptic flow of J/ψ at forward rapidity in Pb-Pb collisions at 2.76 TeV with the ALICE experiment"

Posters

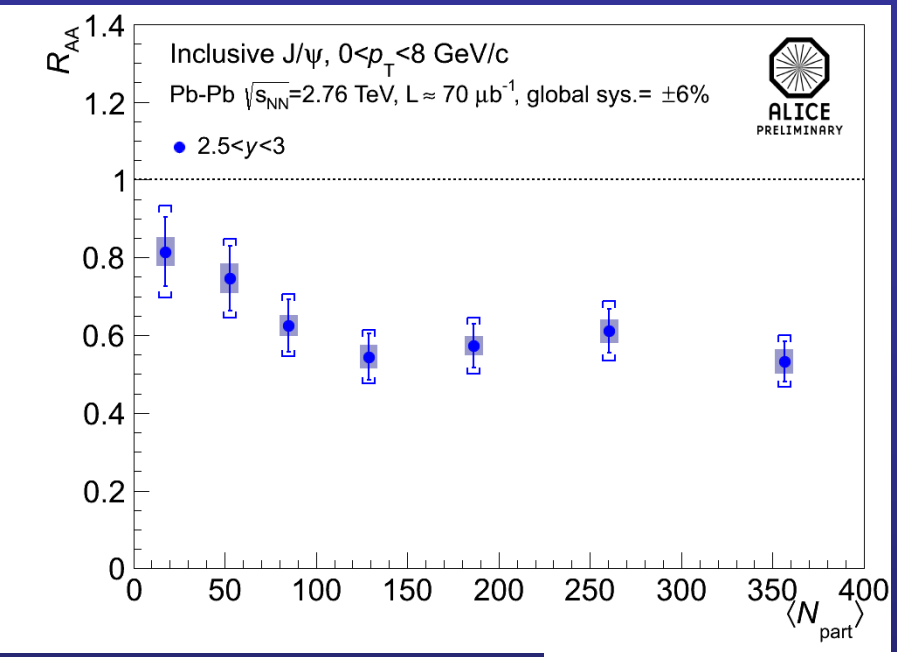
M. Figueredo
"J/ψ measurements at ALICE using EMCal-triggered events"

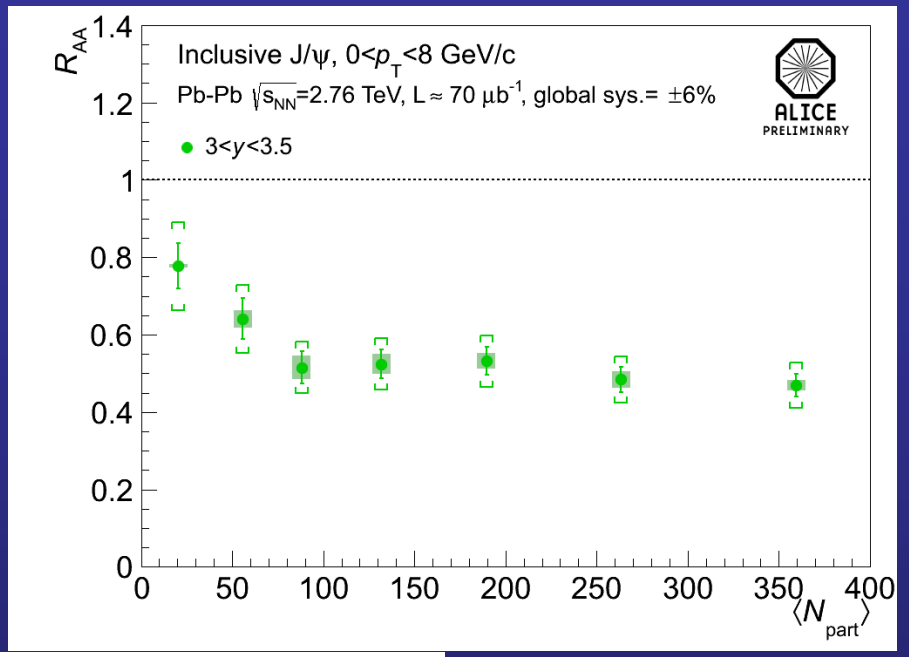
F. Fionda
"Charmonium production in pp collisions measured with the ALICE experiment at LHC"

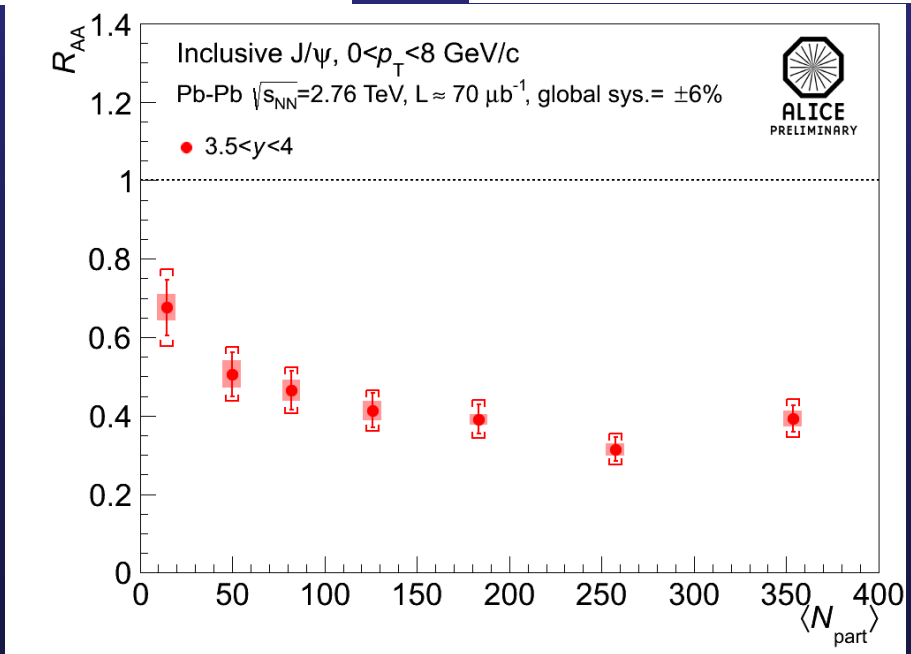
T. Sarkar-Sinha
"Study of single muon and J/ψ production in pp collisions at √s=2.76 TeV as a function of multiplicity with ALICE"

Backup

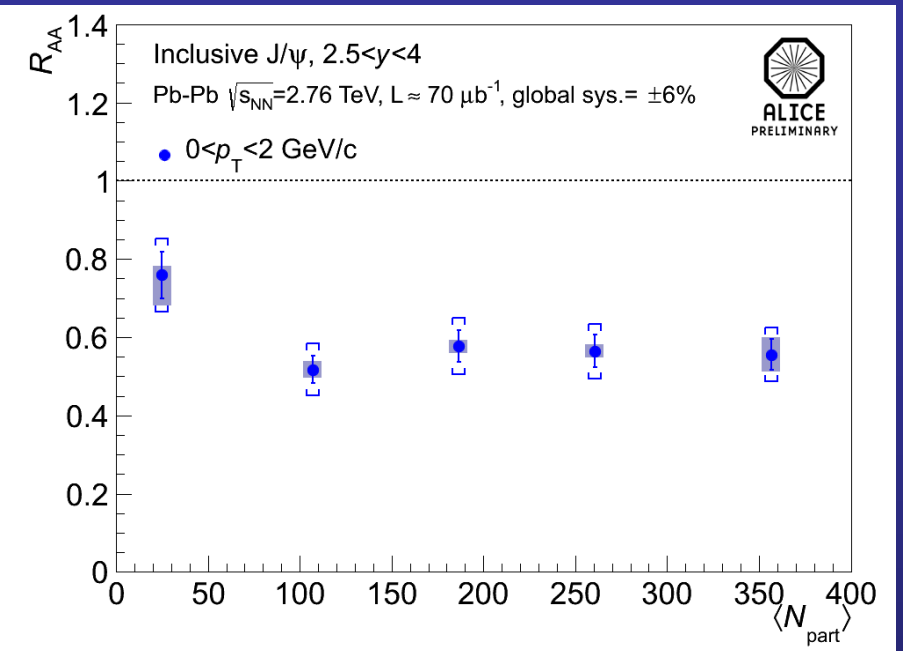
R_{AA} vs centrality, *y*-bins

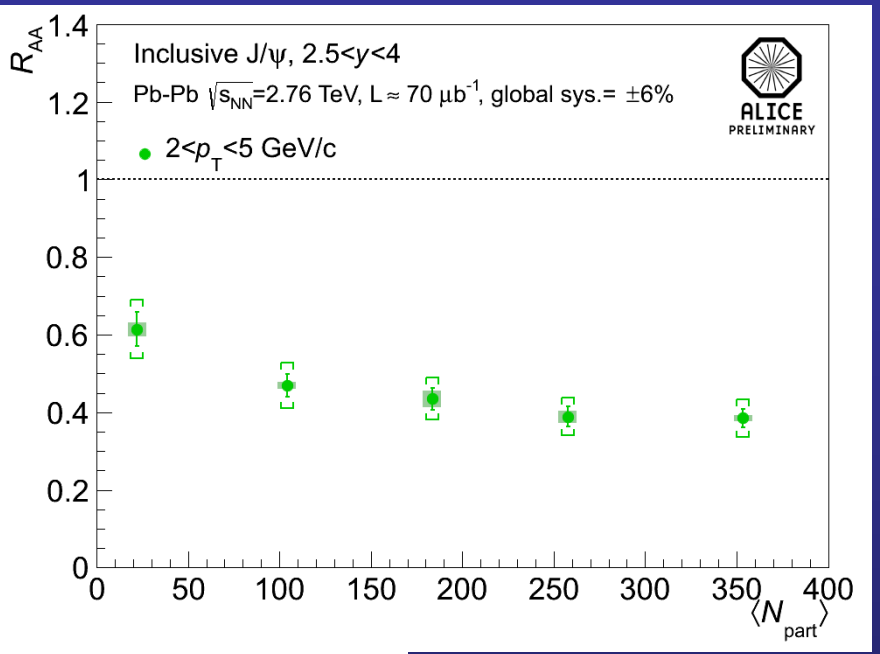


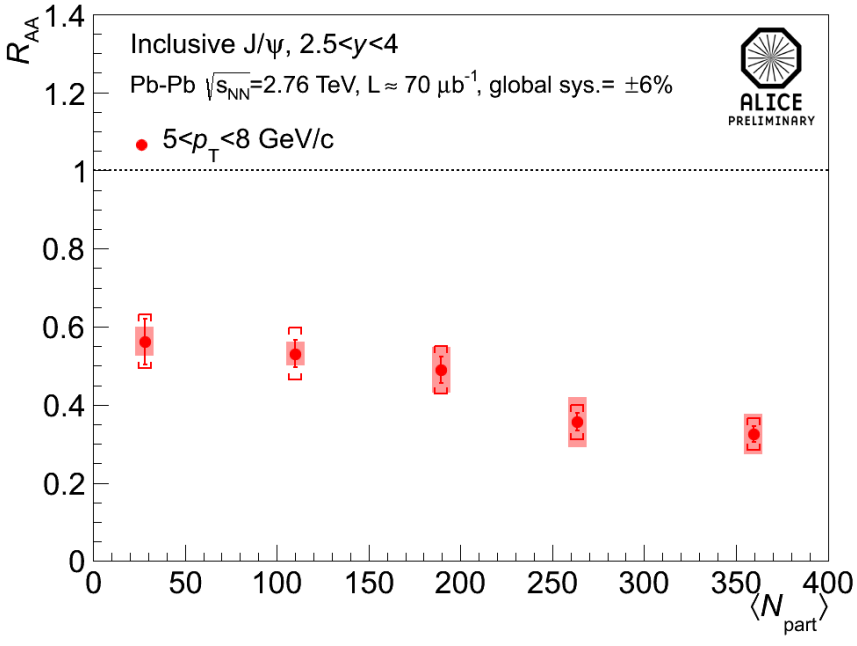




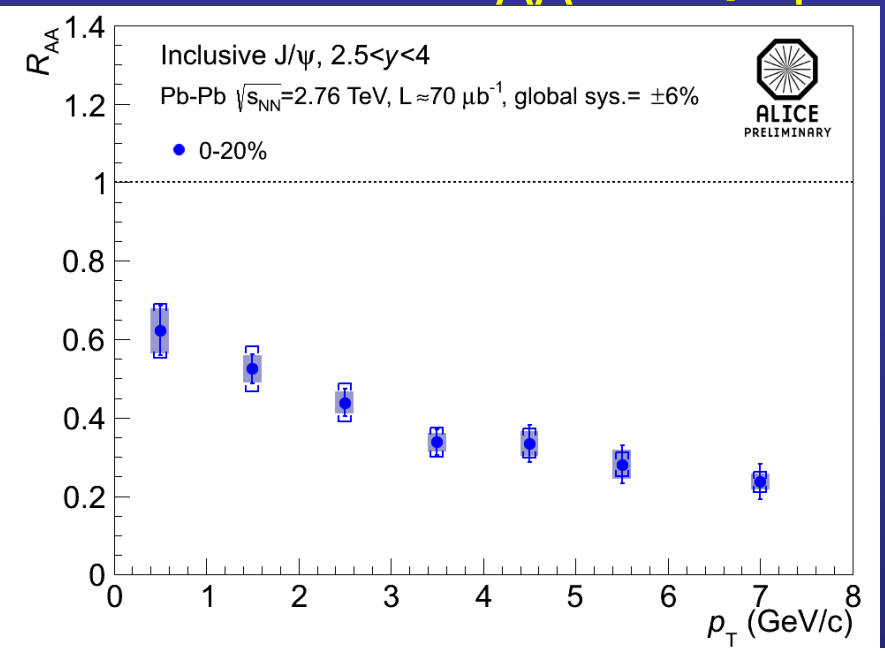
R_{AA} vs centrality, p_T bins

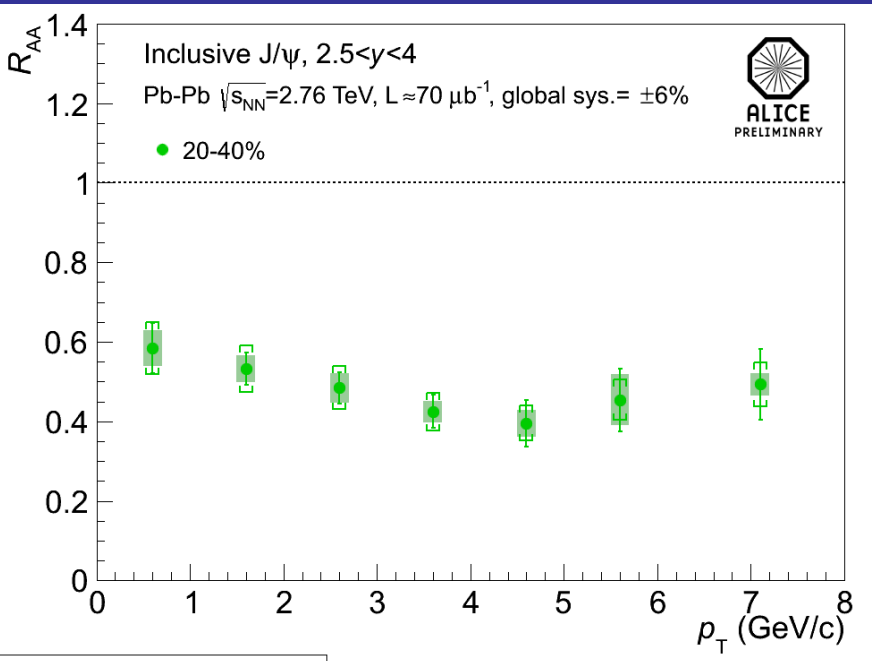


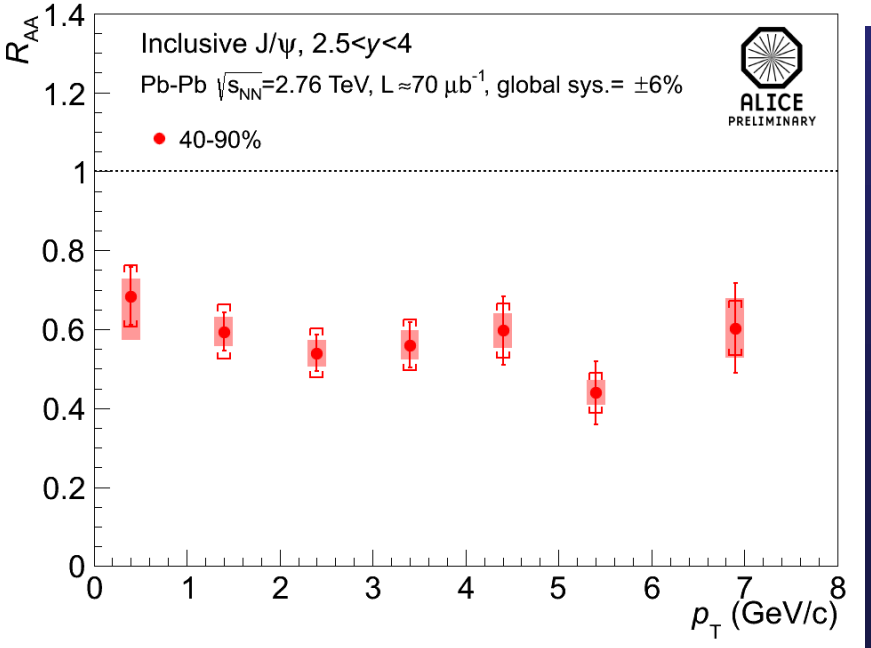




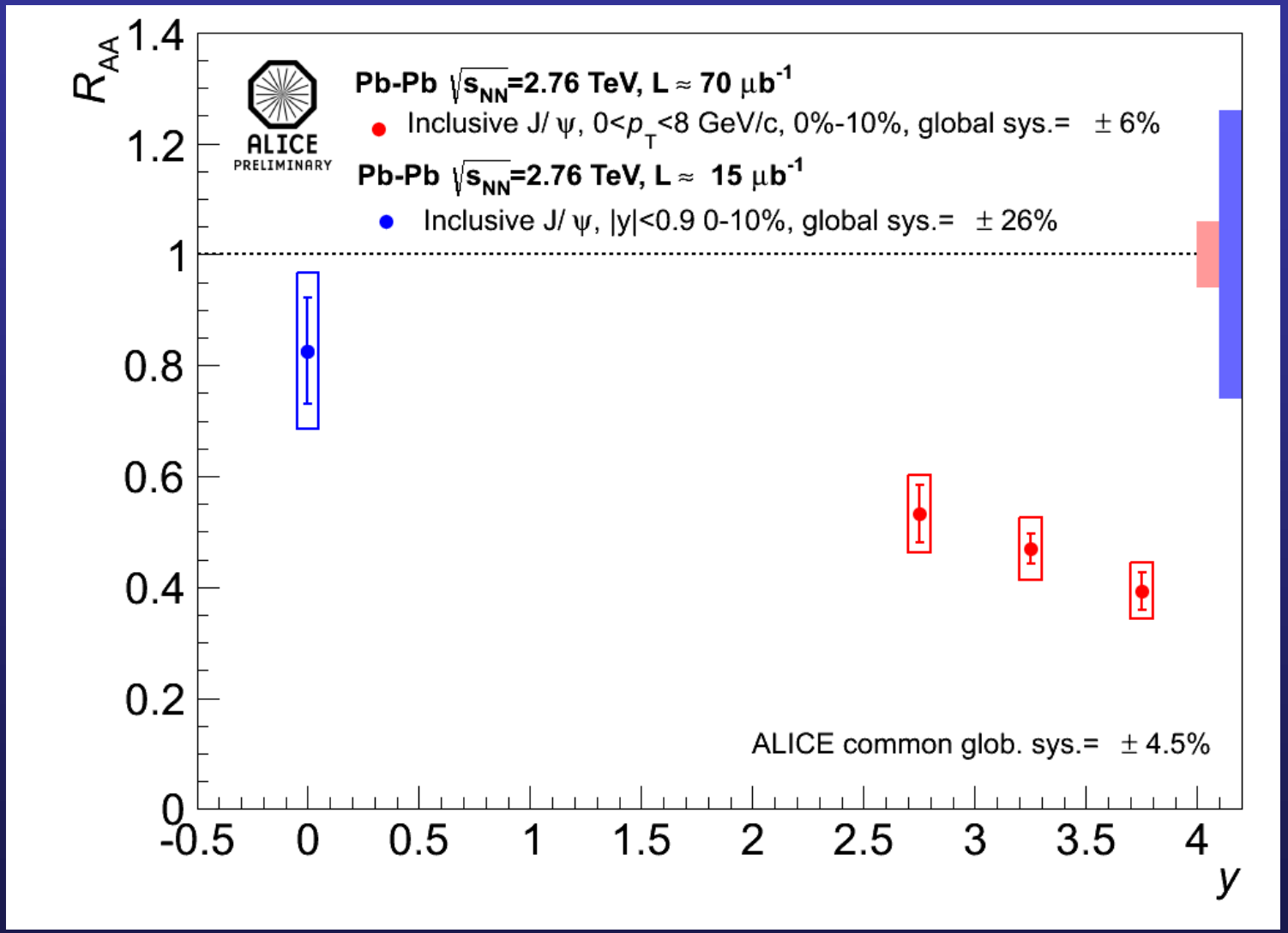
R_{AA} vs p_T, centrality bins



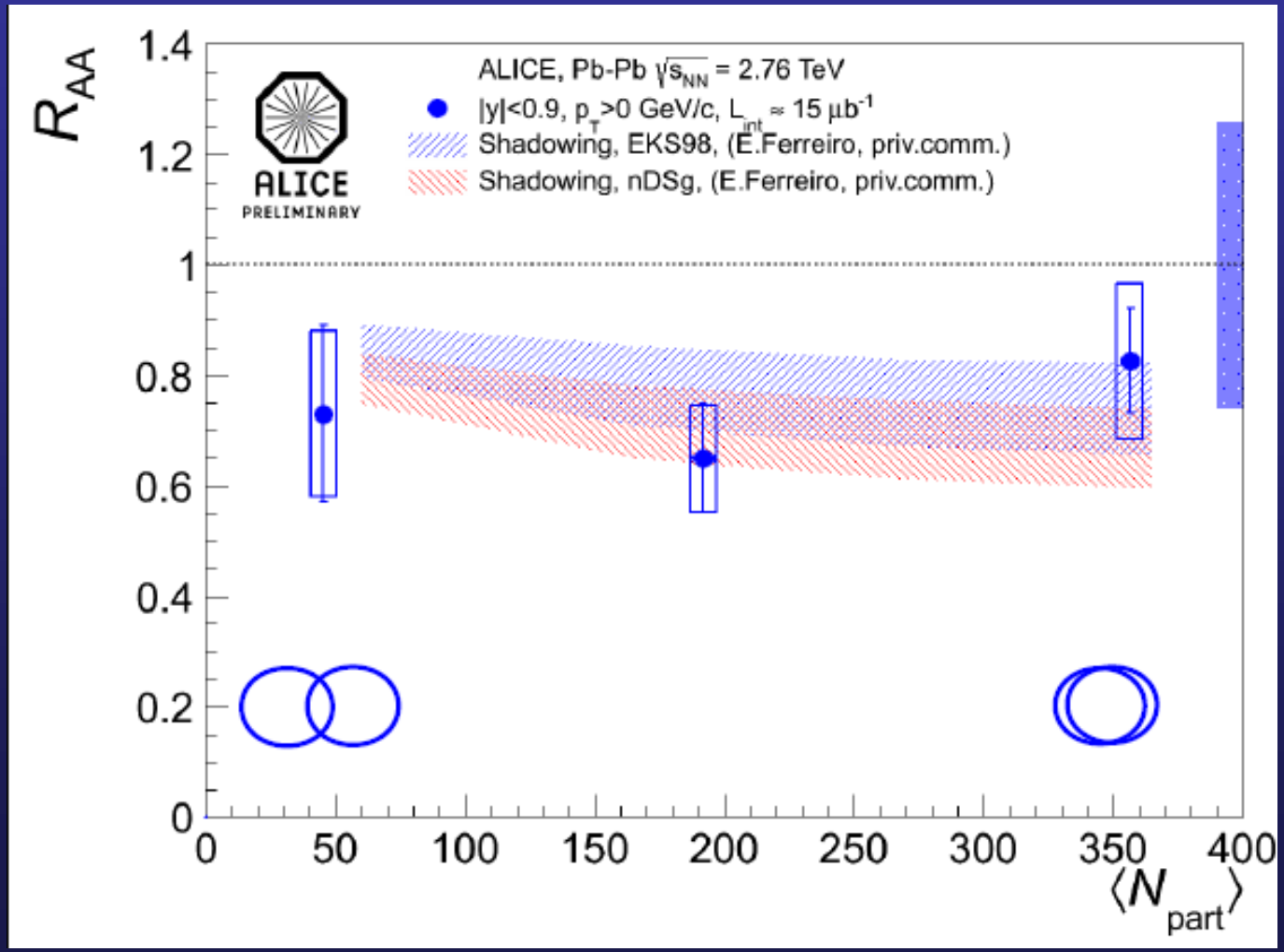




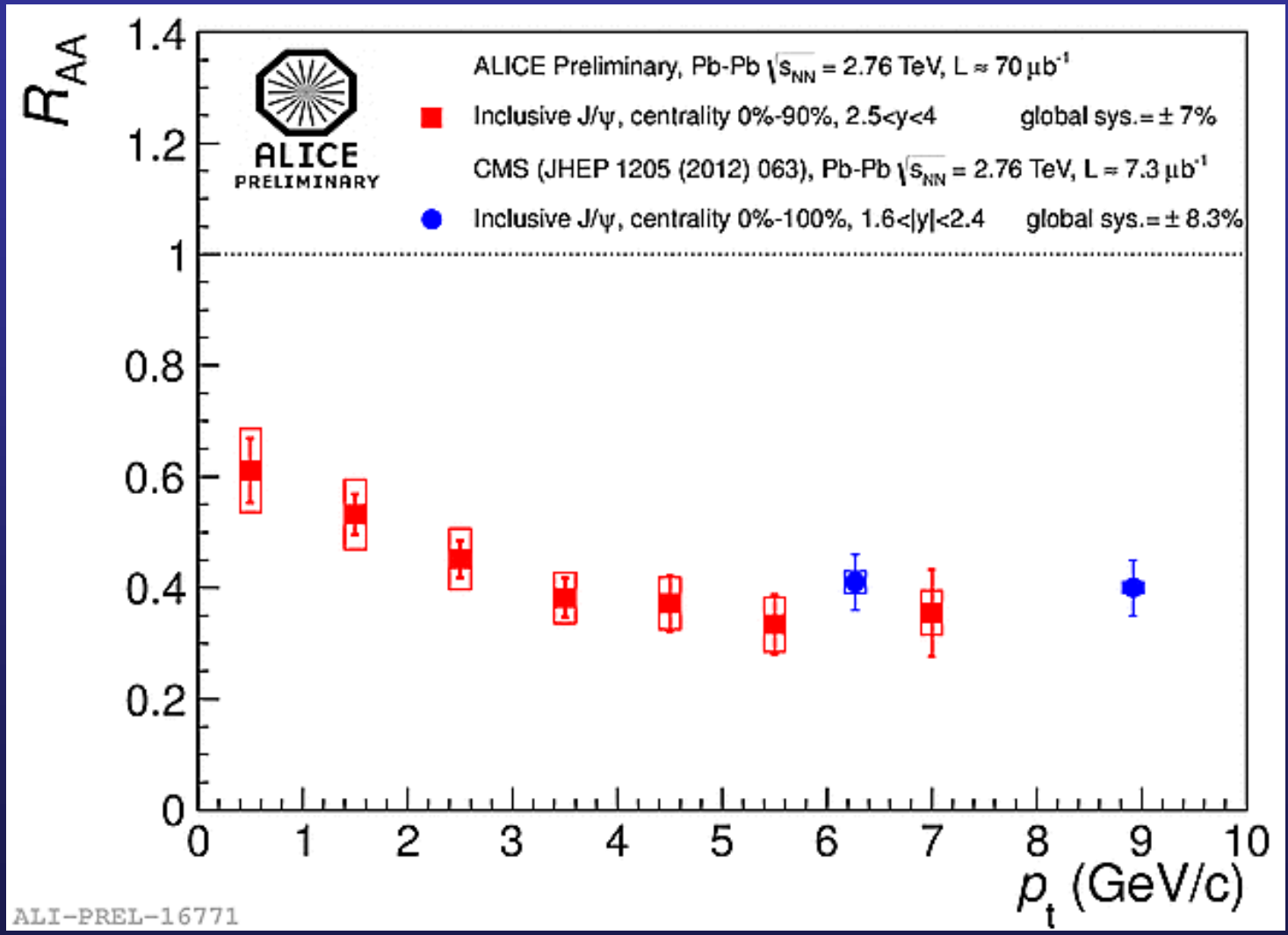
R_{AA} vs rapidity, central events



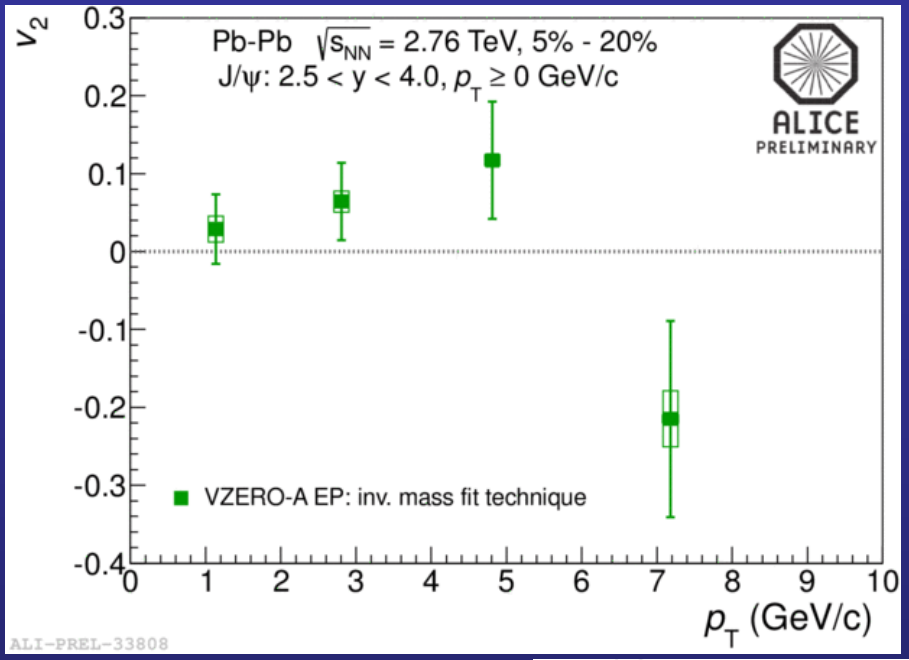
Mid-rapidity R_{AA} and shadowing

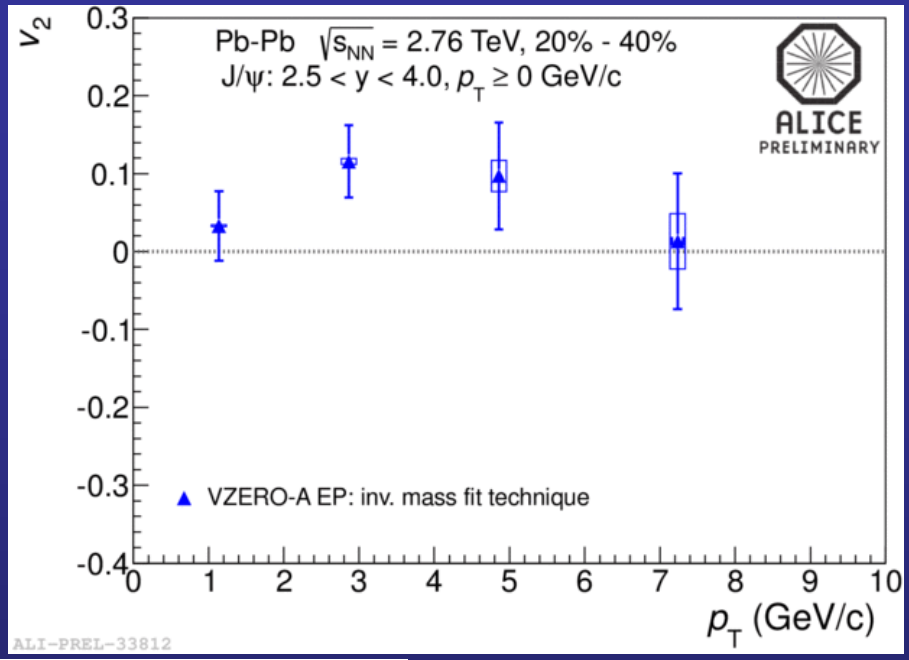


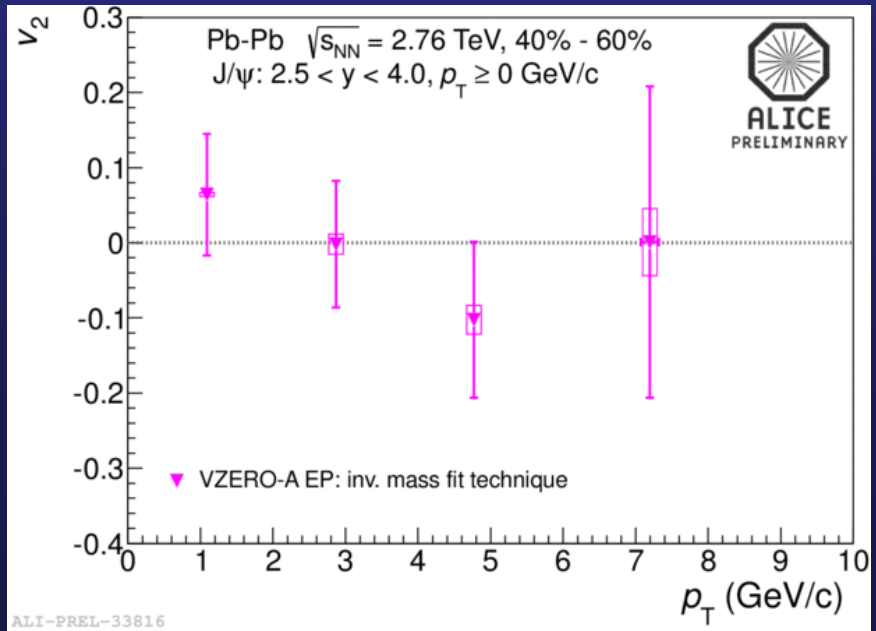
R_{AA}: comparison with CMS



v_2 – centrality scan



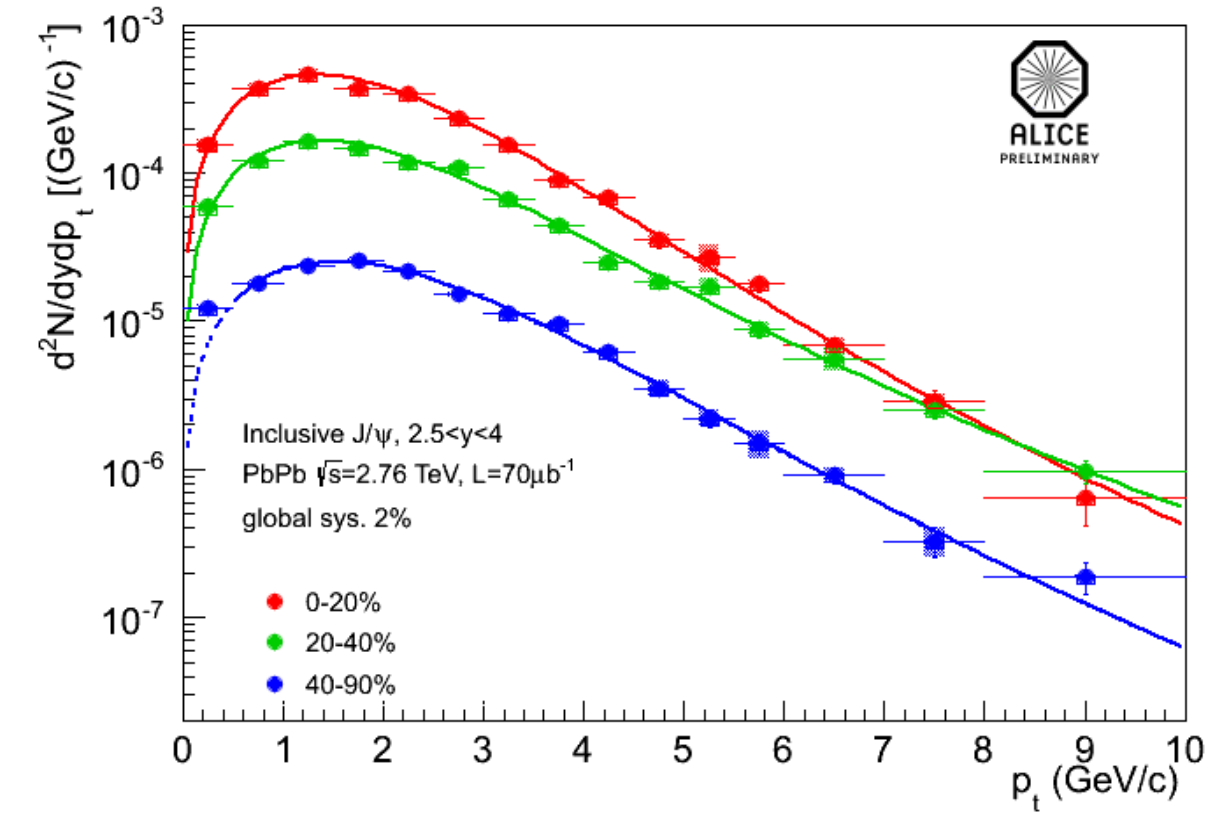




J/ψ p_T spectra

- Comparison with lower energy results can be carried out by studying $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ vs centrality
- J/ψ $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ values are extracted from fits to $d^2N/dydp_T$

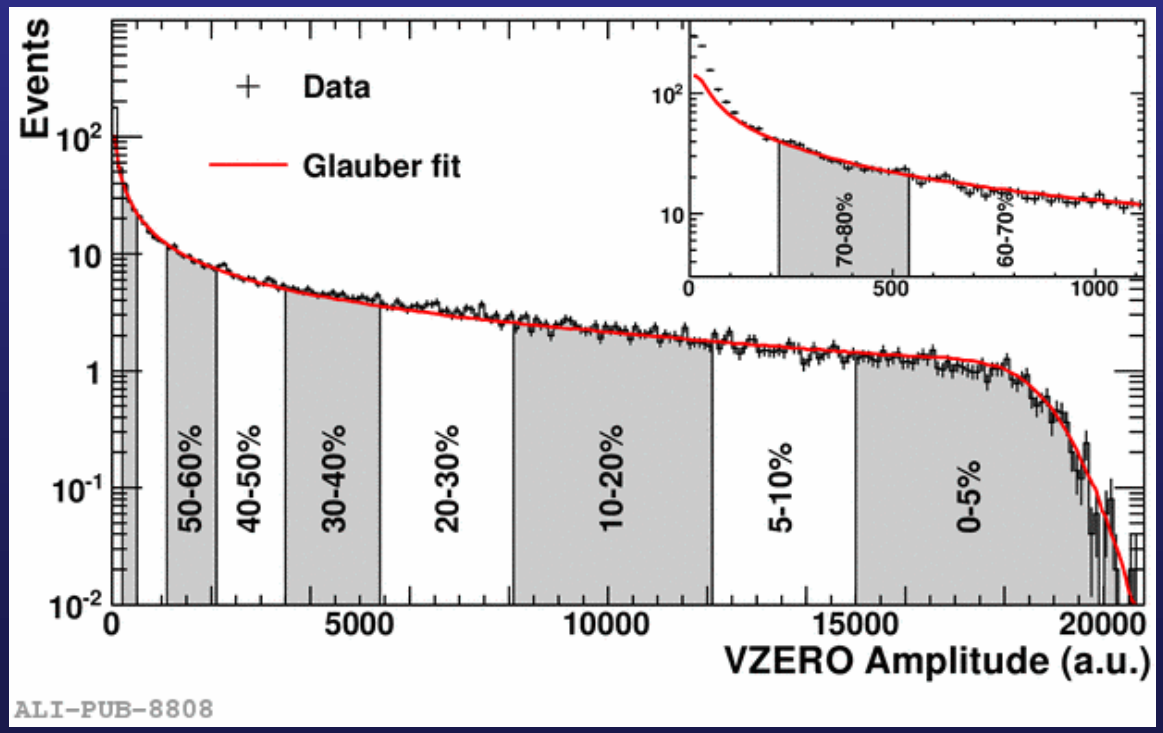
$$\frac{d^2N}{dydp_T} \propto \frac{p_T}{\left(1+\left(\frac{p_T}{p_0}\right)^2\right)^x}$$



- Relative shapes of spectra strictly related to R_{AA}
- Finer binning than in R_{AA} studies possible (not limited by pp statistics)

Pb-Pb:centrality selection

- Centrality estimate: standard approach
- Glauber model fits
- Define classes corresponding to fractions of the inelastic Pb-Pb cross section



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Systematic uncertainties on R_{AA}

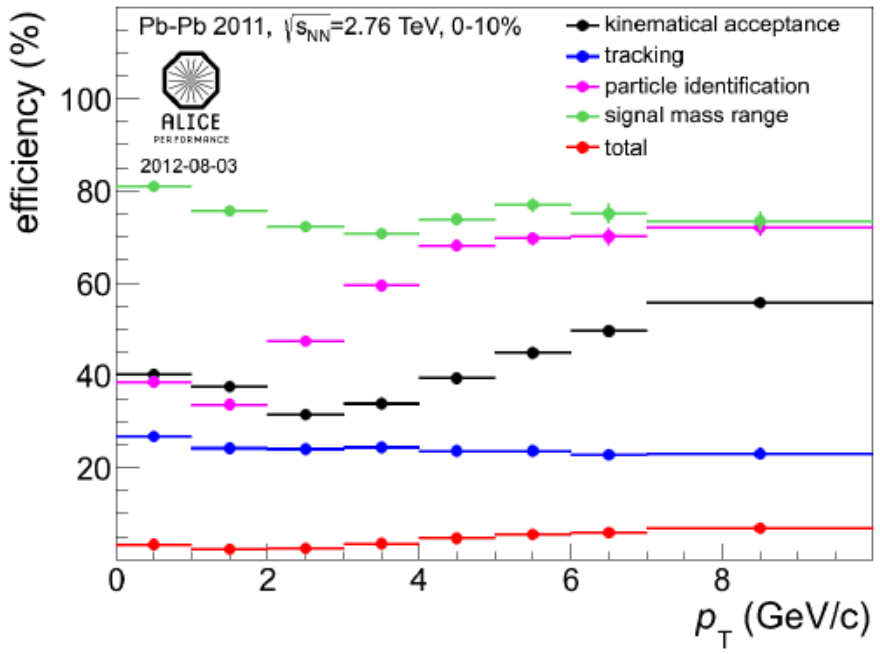
Source	
pp reference	9% (for y,p_t integrated)
MC inputs	5%
Tracking	6%
Trigger	6.4%
Matching	2%
T_{AA}	3.8% (for 0-90%)
Normalization	2%

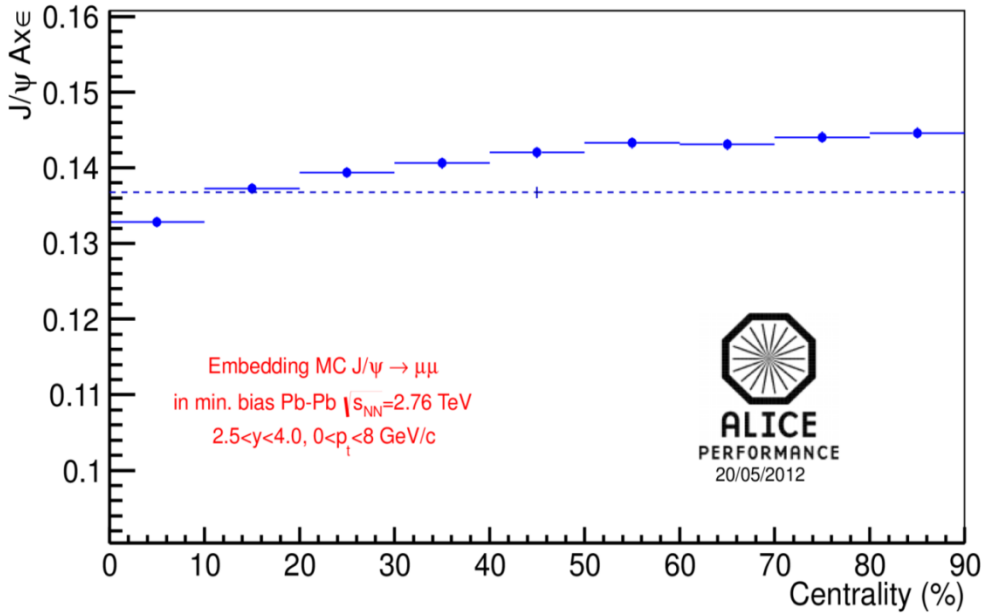
- Type A:
  uncorrelated
  (shown as filled box around points)
- Type B:
  partially correlated within and between sets (shown as [] around points)
- Type C:
  100% correlated within a set and between sets (global quantity for all sets)

For the R_{AA} versus centrality:

- Type A:
  signal extraction
- Type B:
  uncorr. syst on pp, MC inputs, trigger, tracking, matching, T_{AA}
- Type C:
  normalization, corr. syst on pp

A × ε





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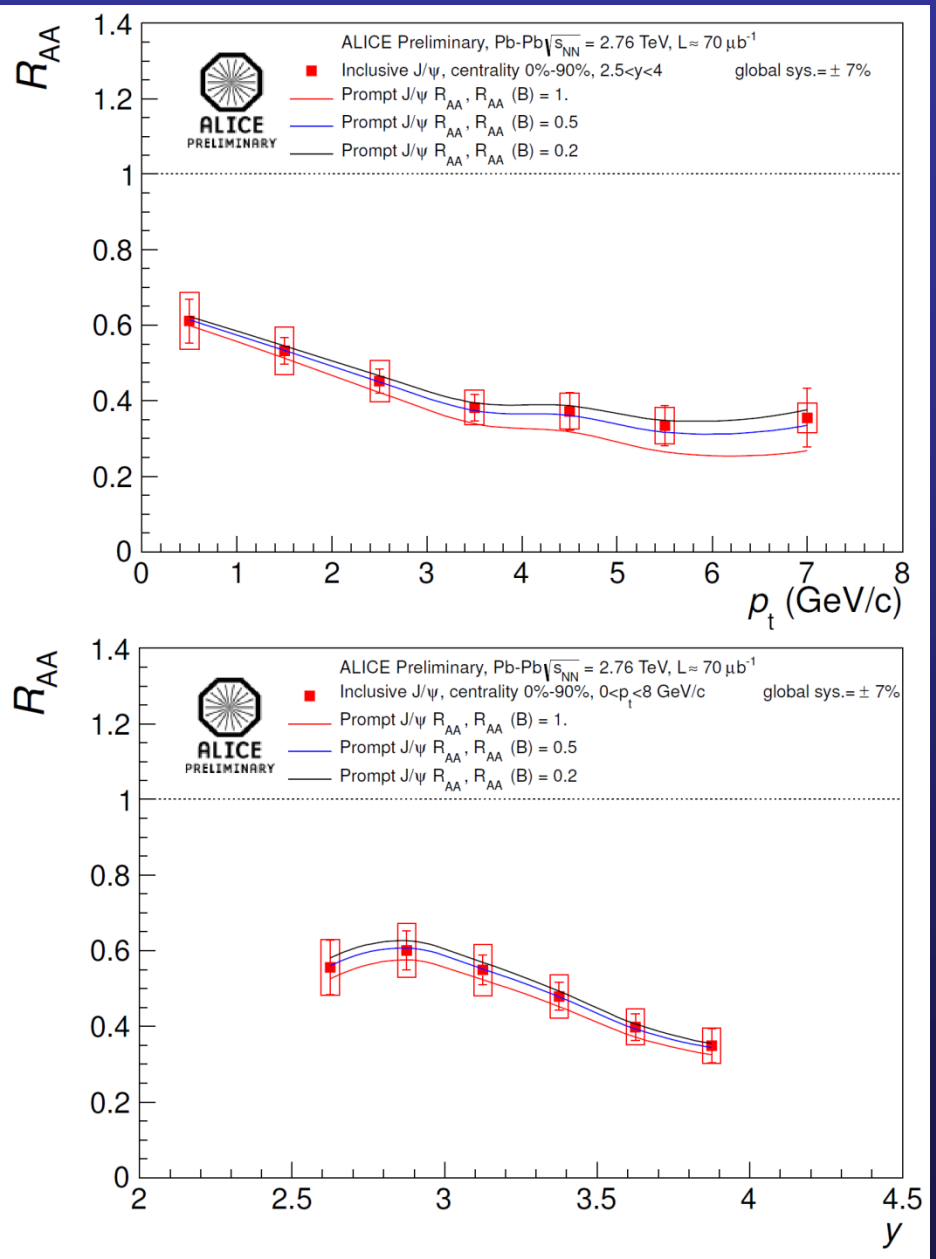
Electrons

Muons

Effect of non-prompt J/ψ



Inclusive J/ψ measured in ALICE

Estimate of prompt J/ψ RAA using:

- b-fraction measured by CDF, CMS and LHCb
- Interpolation at √s= 2.76 TeV
- Different b-quenching hypothesis from R_{AA}(B)=0.2 to R_{AA}(B)=1

J/ψ from b-hadrons decays have a negligible influence on our measurements