Charmonium production measurements in Pb-Pb collisions with ALICE at the LHC

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For the ALICE Collaboration

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Content

Physics motivation

The ALICE detector

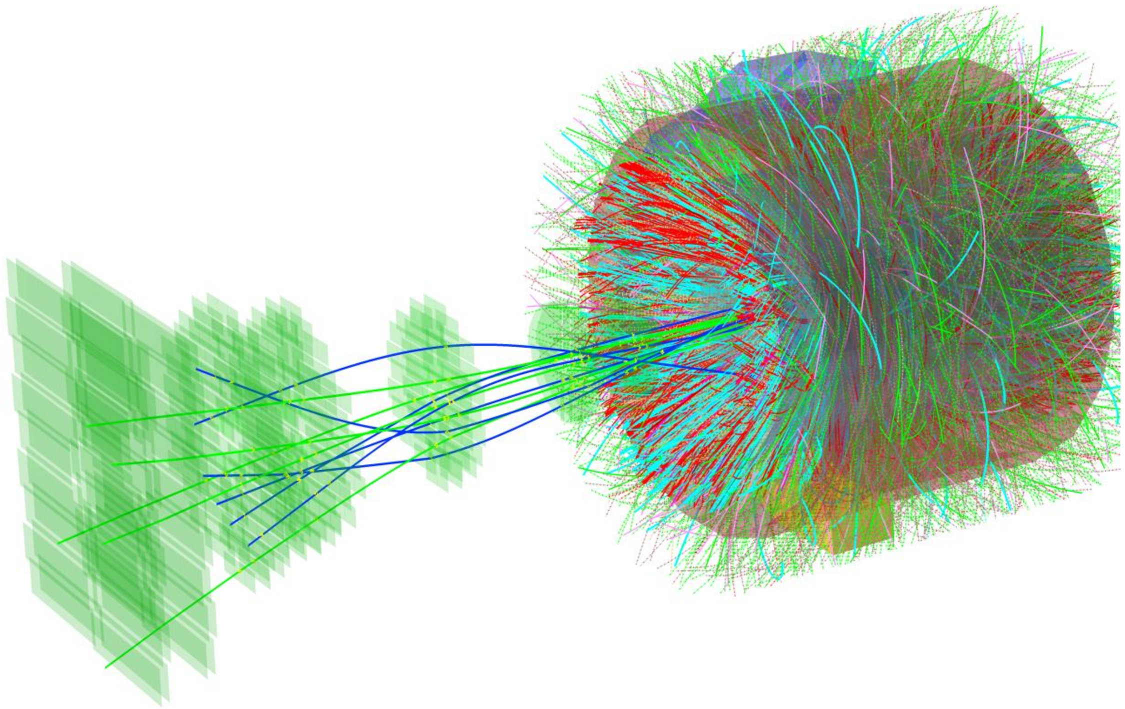
$J/\psi \rightarrow \mu\mu$ $(2.5 < y < 4.0)$:

- ❑ Analysis
- ❑ Results

$\psi(2S) \rightarrow \mu\mu$ $(2.5 < y < 4.0)$:

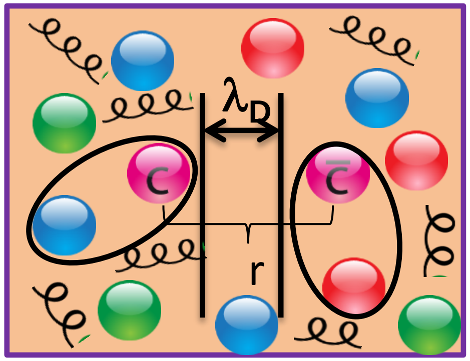
- ❑ Analysis
- ❑ Results

Conclusions



Charmonium in A-A

- Ultrarelativistic heavy-ion collisions → high energy densities.
- Quark-Gluon-Plasma: deconfined state of quarks and gluons.



Charmonium as a probe of deconfinement:

✓ Created in the early stages of the collision.
✓ Suppressed by Debye screening. PLB 178(1986) 416
✓ Different radii & binding energies → sequential suppression. PRD 64(2001) 094015

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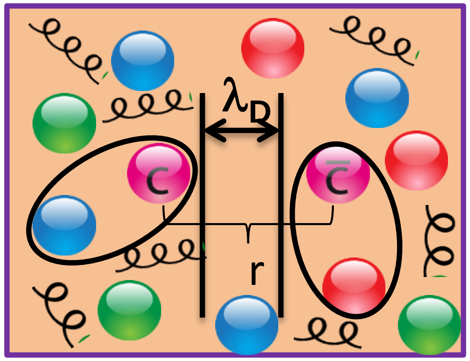

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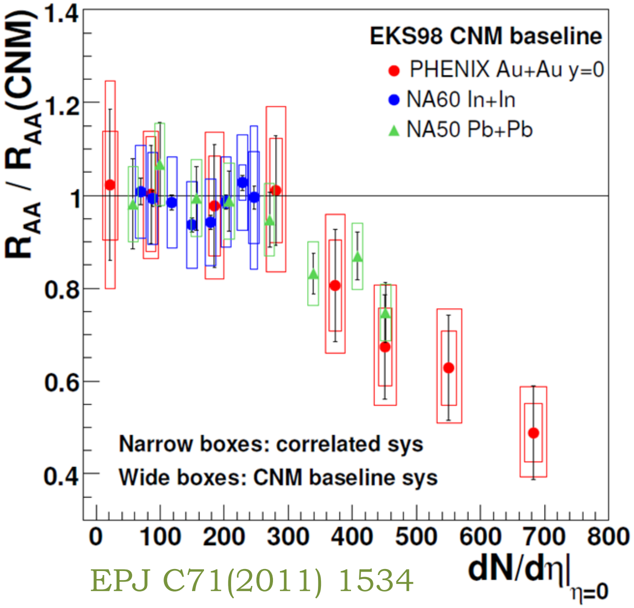
Charmonium production in A-A previously studied by various experiments:

$$R_{AA} = \frac{Y^{J/\psi}_{A-A}}{< N_{Coll} > Y^{J/\psi}_{pp}}$$

- RHIC & SPS: significant J/ψ suppression beyond the Cold Nuclear Matter effects.



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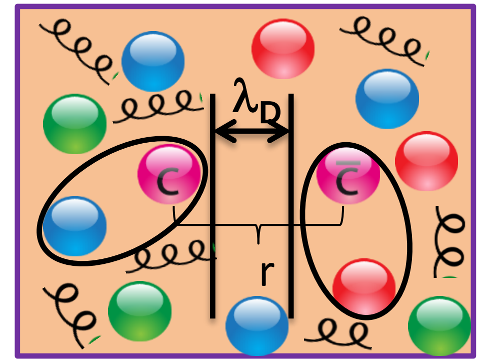

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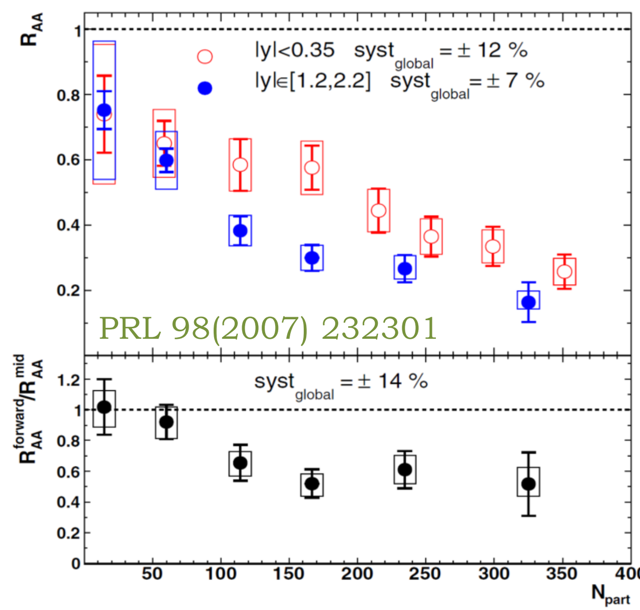

- RHIC & SPS: significant J/ψ suppression beyond the Cold Nuclear Matter effects.

- RHIC: larger suppression at forward than at mid rapidity.

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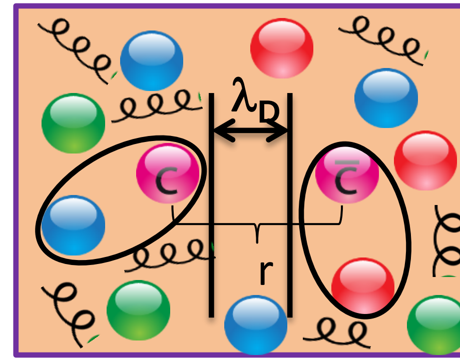

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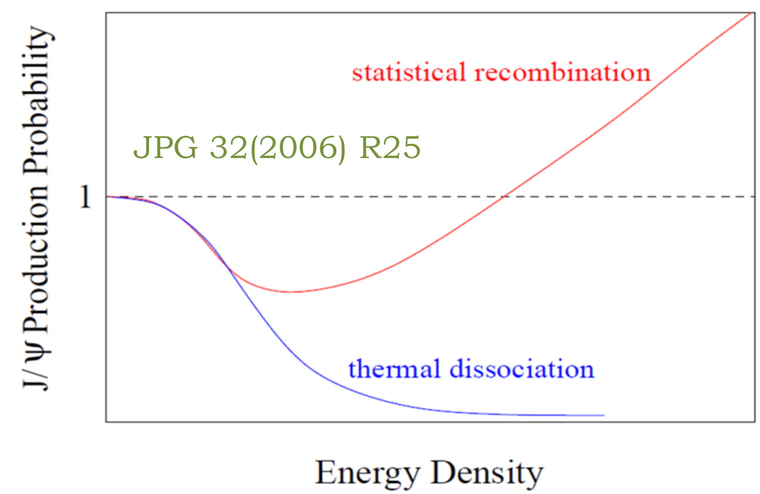
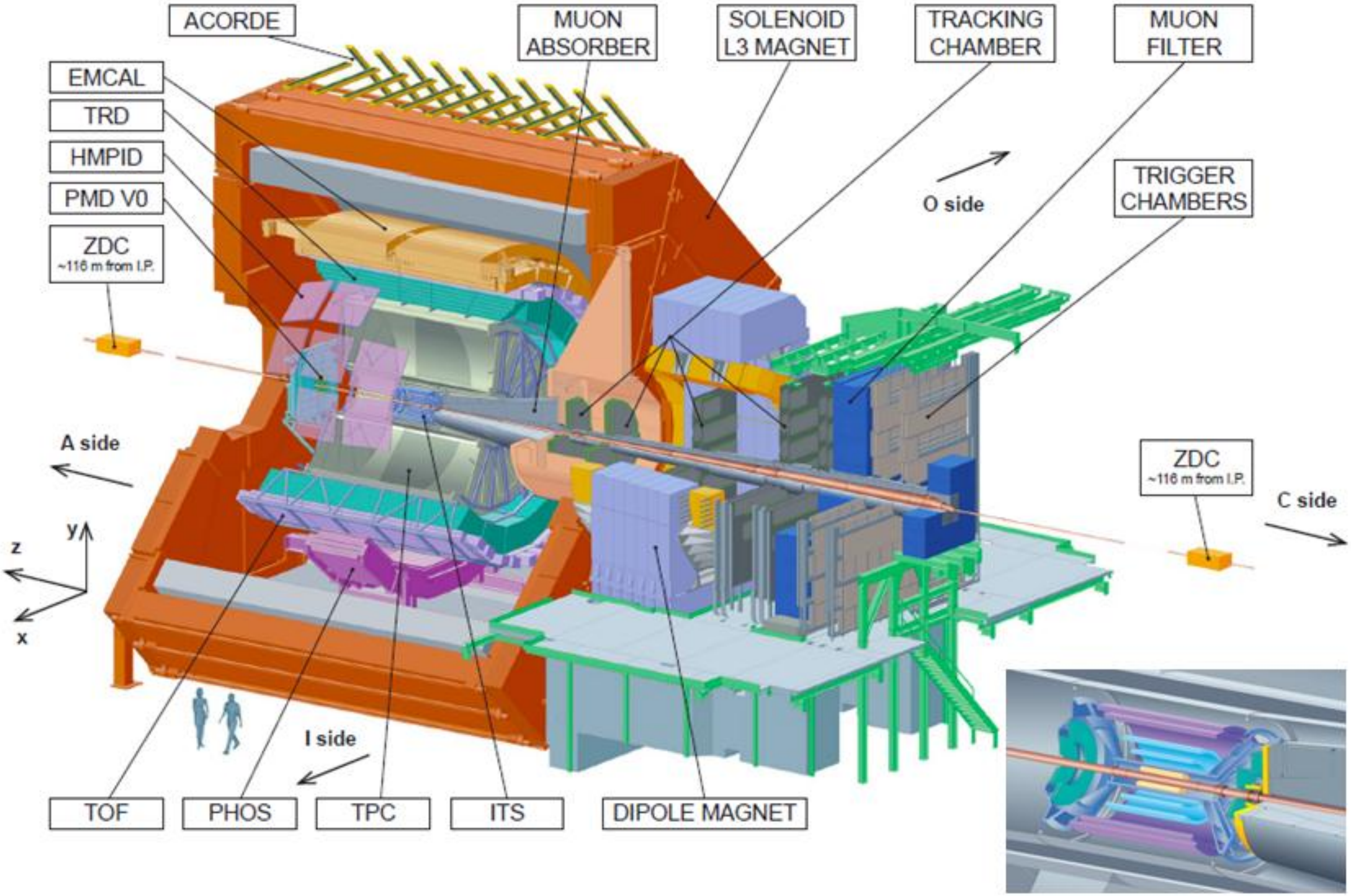
What can we expect at the LHC?

- New collision energy regime
  ➔ larger suppression?
- $N_{c\bar{c}}$/central collision ≈ 10 × RHIC
  ➔ new source of J/ψ production from recombination of $c\bar{c}$ pairs?



The ALICE detector



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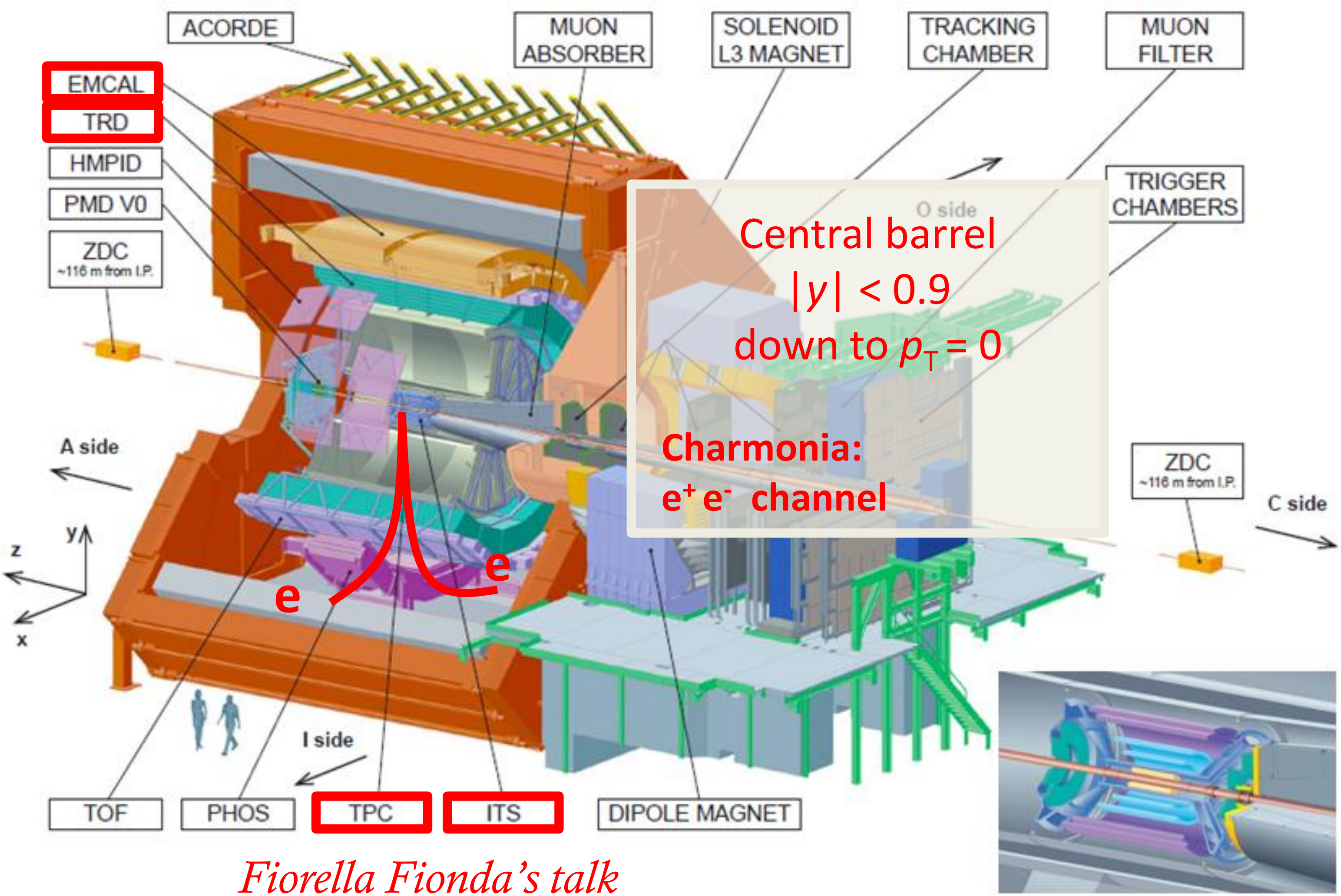
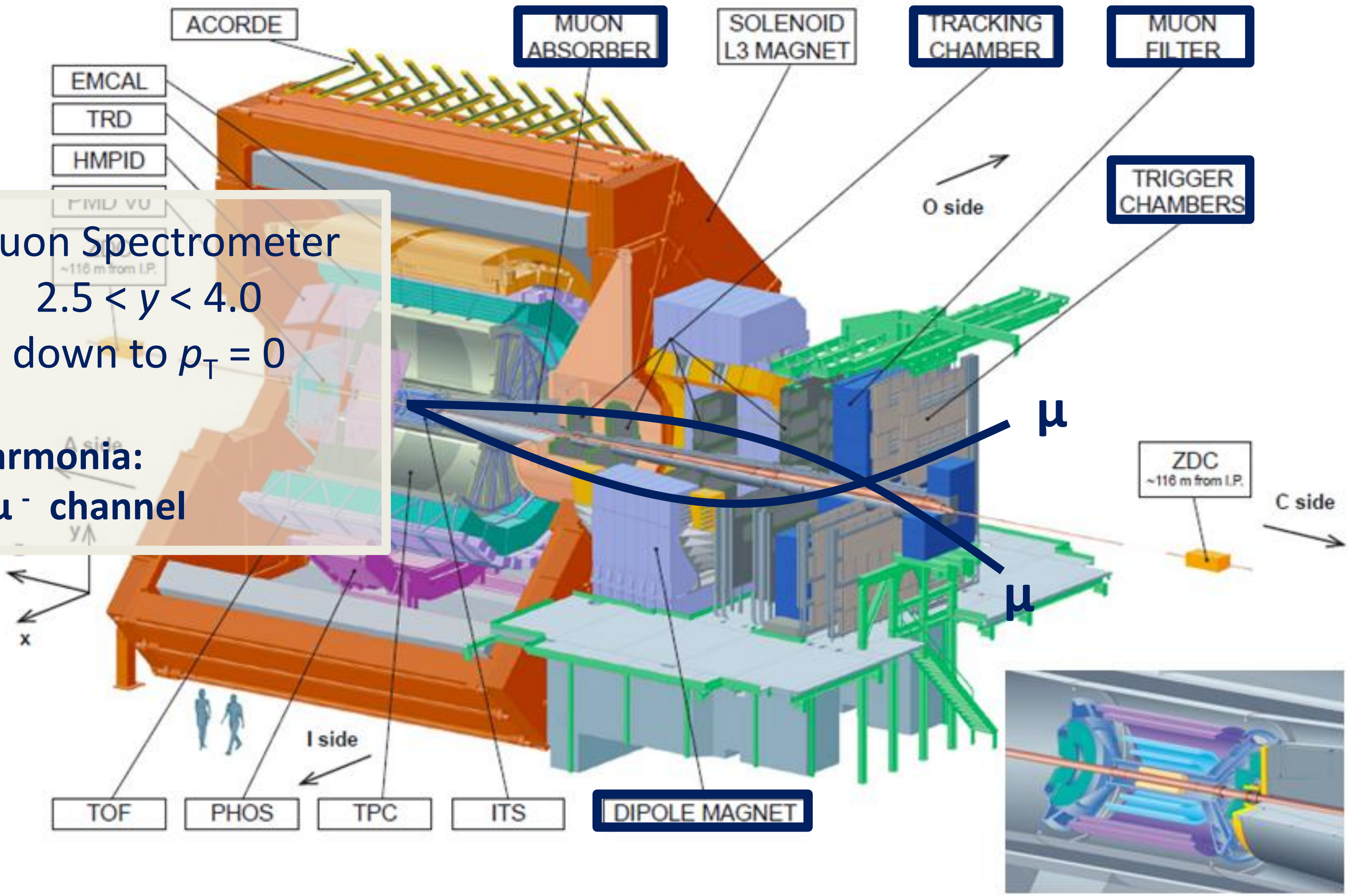


Fiorella Fionda's talk

The ALICE detector

Muon Spectrometer
$2.5 < y < 4.0$
down to $p_T = 0$

Charmonia:
$\mu^+ \mu^-$ channel



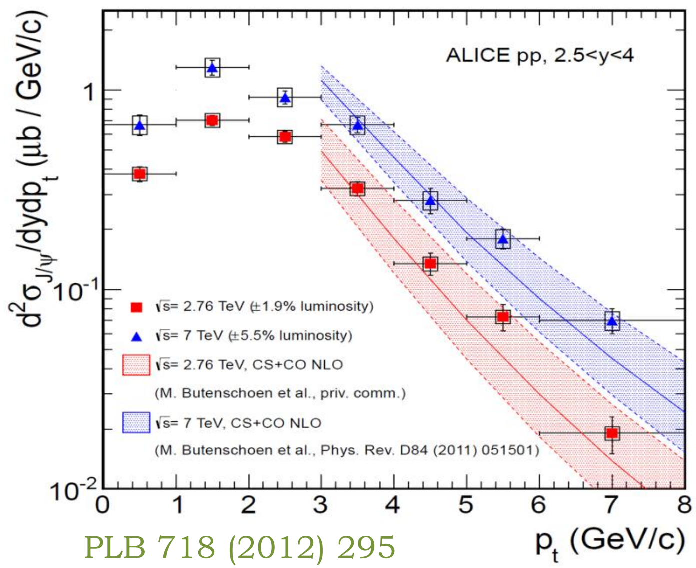
pp reference and Pb-Pb data set

pp collisions: results at $\sqrt{s}$ = 7 and 2.76 TeV.

2.5 < y < 4.0: NRQCD calculations describe the measured $d^2\sigma/dydp_T$ at $\sqrt{s}$ = 7 and 2.76 TeV.

Results at $\sqrt{s}$ = 2.76 TeV (same energy as Pb-Pb collisions) are used as reference.

pp reference is the main source of systematics in the R_{AA}: 9%.



PLB 718 (2012) 295

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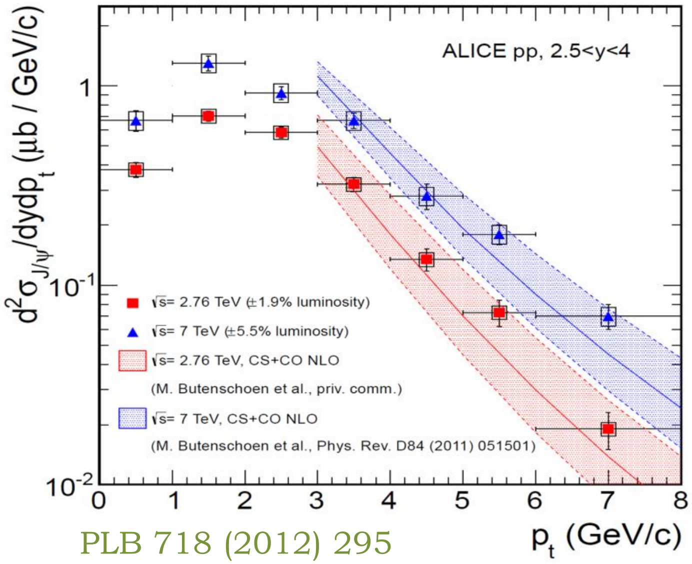
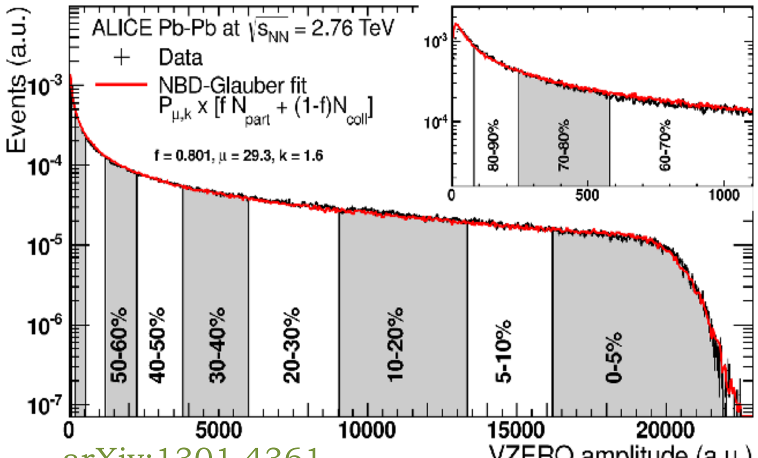


PLB 718 (2012) 295

J/ψ, ψ(2S) → μμ in **Pb-Pb collisions**:

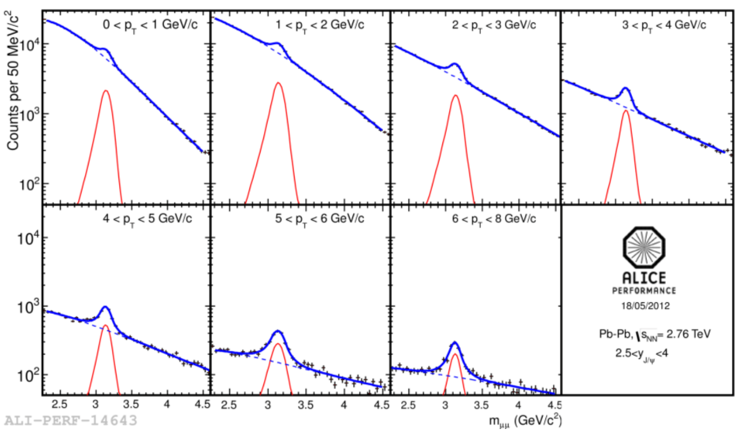
Dimuon events from the muon trigger, $L_{int} \approx 70\ \mu b^{-1}$.

Centrality estimation is based on a Glauber model fit of the V0 amplitude.



arXiv:1301.4361

$J/\psi \rightarrow \mu\mu$ in Pb-Pb: analysis

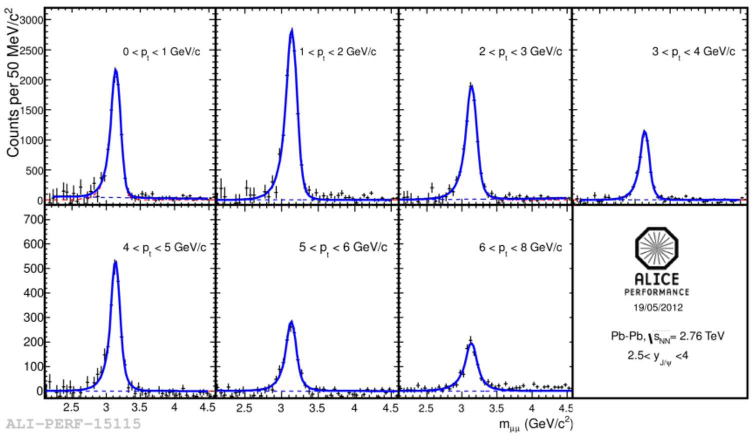


Yield extracted by fitting the invariant mass spectrum of unlike-sign dimuons:

- Signal: modified Crystal Ball with different line shapes.
- Background: different functions with and w/o background subtraction (event mixing technique).

Results are then combined to extract a weighted mean $N_{J/\psi}$ and the systematic uncertainties on signal extraction.

$J/\psi \rightarrow \mu\mu$ in Pb-Pb: analysis



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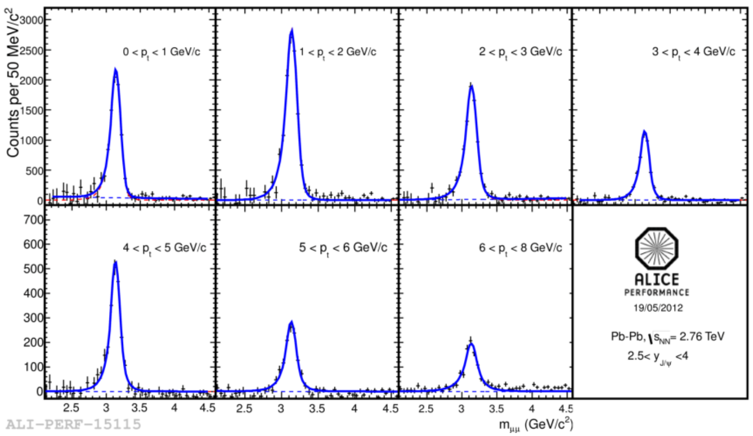

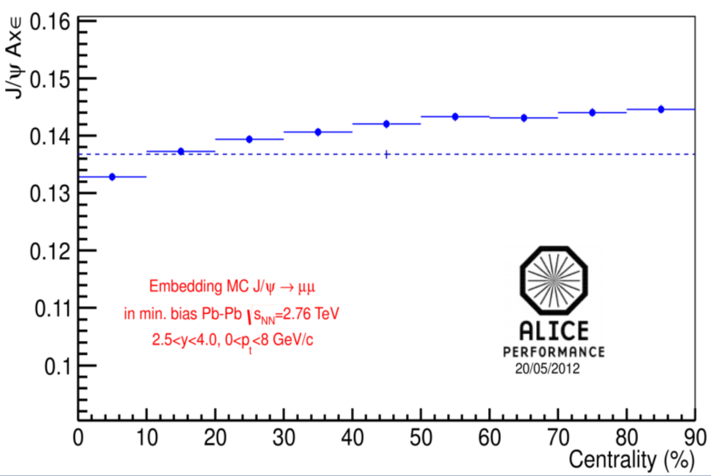

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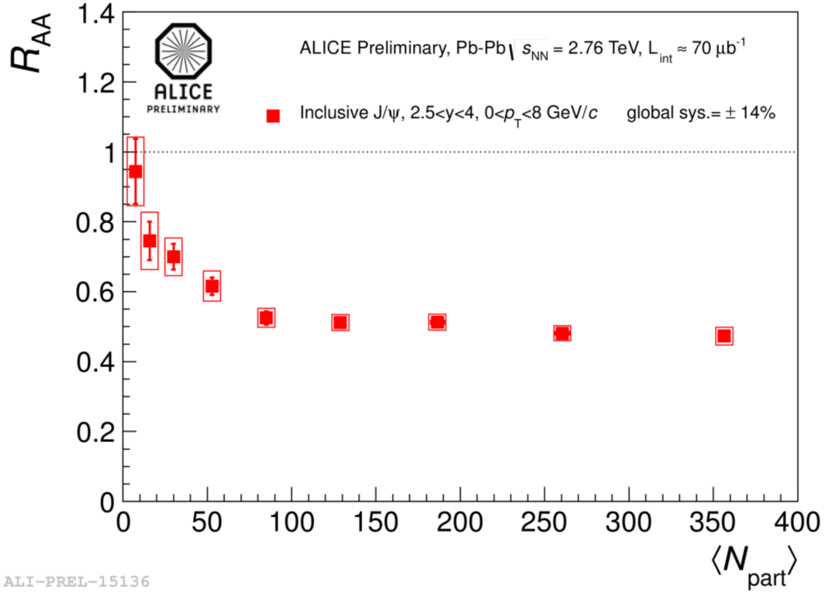
Acceptance x efficiency values are obtained by embedding MC J/ψ into real events.

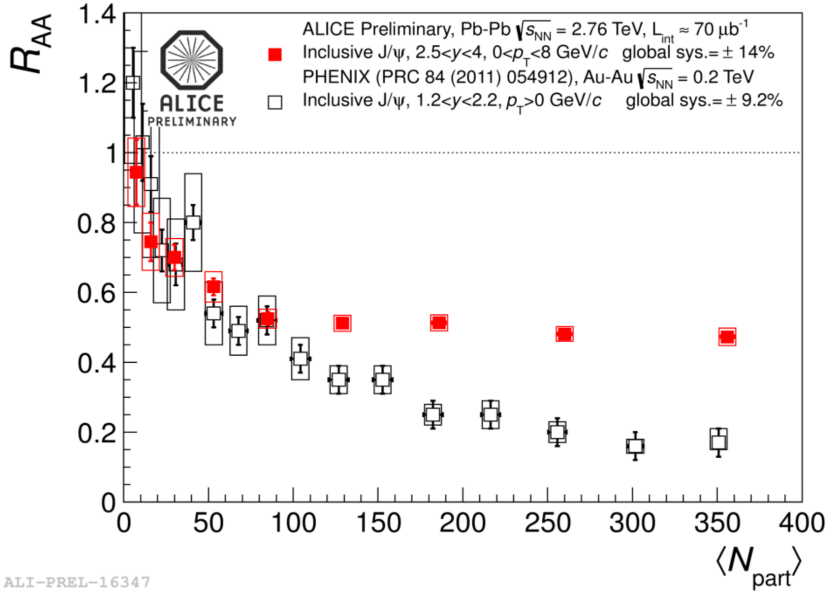
Weak centrality dependence.

Results: J/ψ R_{AA} vs centrality



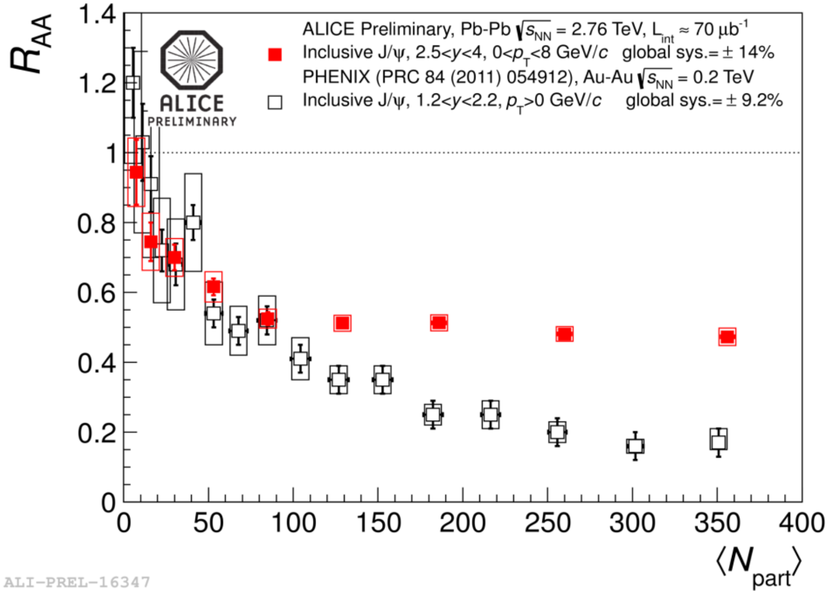
- No significant centrality dependence for N_{part} > 70.

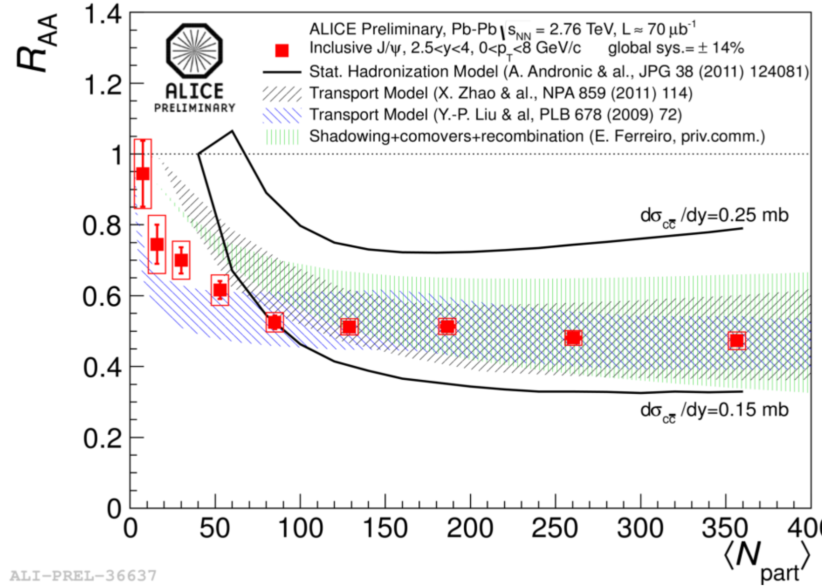
Results: J/ψ R_{AA} vs centrality



- No significant centrality dependence for N_{part} > 70.
- $R_{AA}^{\text{ALICE}} \sim 3 \text{ x } R_{AA}^{\text{PHENIX}}$ for N_{part} > 250.

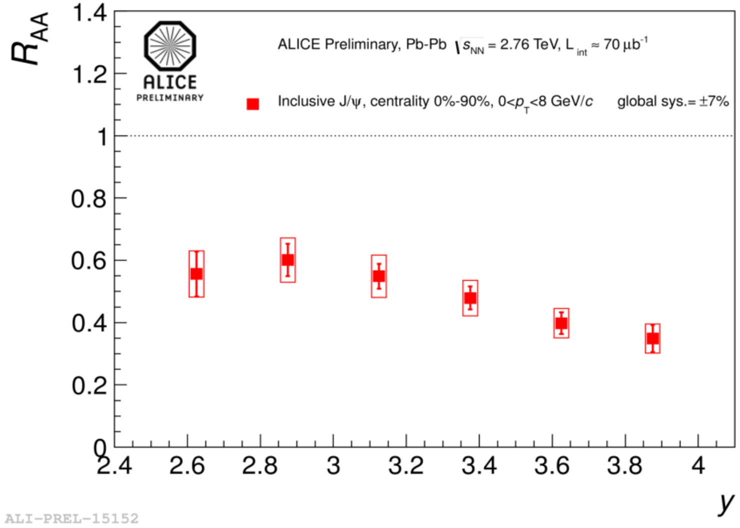
Results: J/ψ R_{AA} vs centrality

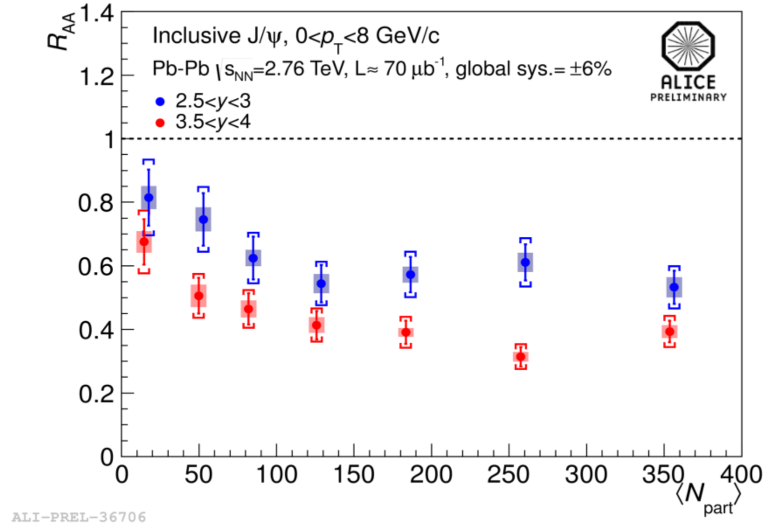




- No significant centrality dependence for N_{part} > 100.
- $R_{AA}^{\text{ALICE}} \sim 3 \text{ x } R_{AA}^{\text{PHENIX}}$ for N_{part} > 250.
- Statistical Hadronisation Model: prediction for two $d\sigma_{c\bar{c}}/dy$ in Pb-Pb.
- Transport Models: different rate equations of J/ψ dissociation and regeneration in QGP.
- Shadowing plus comovers plus recombination model. arXiv:1210.3209
- Need to measure $\sigma_{c\bar{c}}$.

Results: J/ψ R_{AA} vs centrality, *y* bins

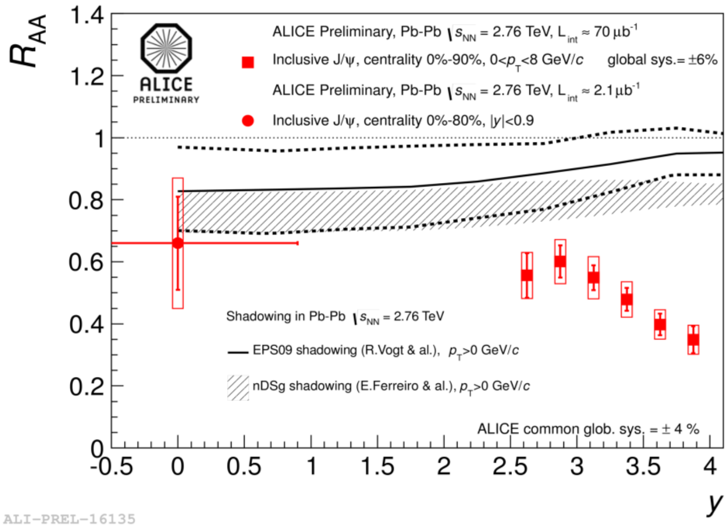


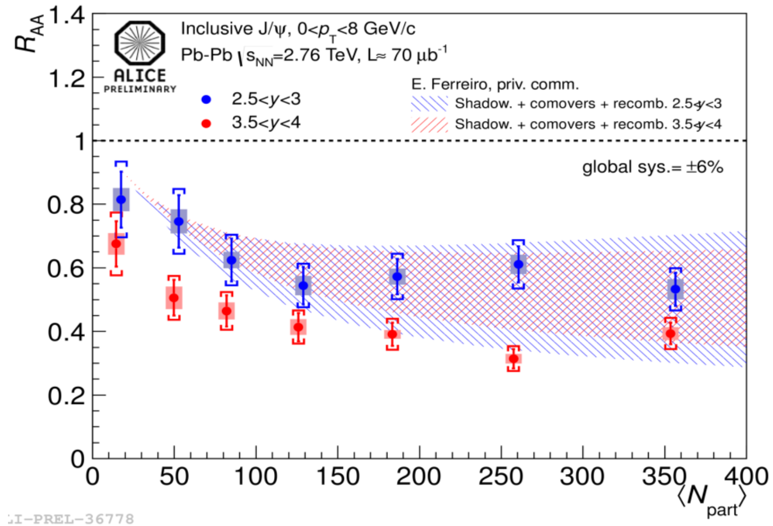


R_{AA} decreases by 40% from y = 2.5 to y = 4.

Similar centrality behavior for different forward rapidity ranges.

Results: J/ψ R_{AA} vs centrality, *y* bins





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Similar centrality behavior for different forward rapidity ranges.

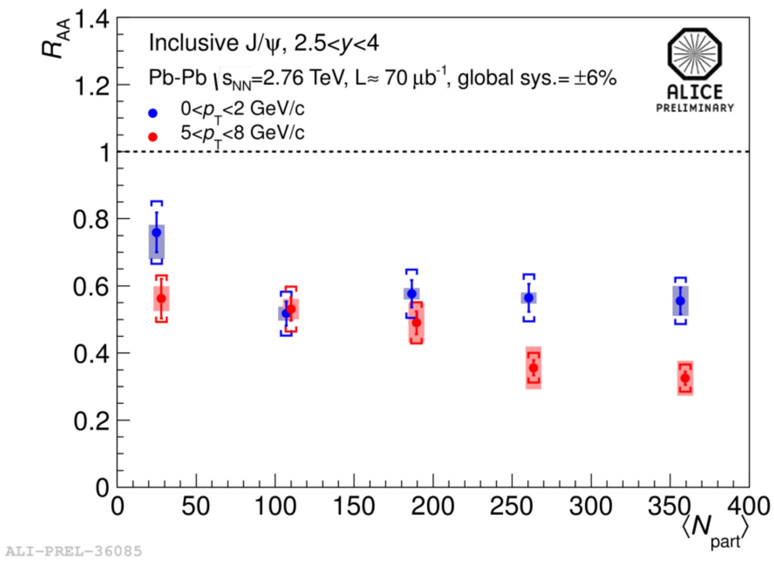
Shadowing accounts for only a fraction of the suppression at forward *y*.

Shadowing + comovers + recombination model does not reproduce the data for 3.5 < *y* < 4.

A measurement of the Cold Nuclear Matter effects is needed!

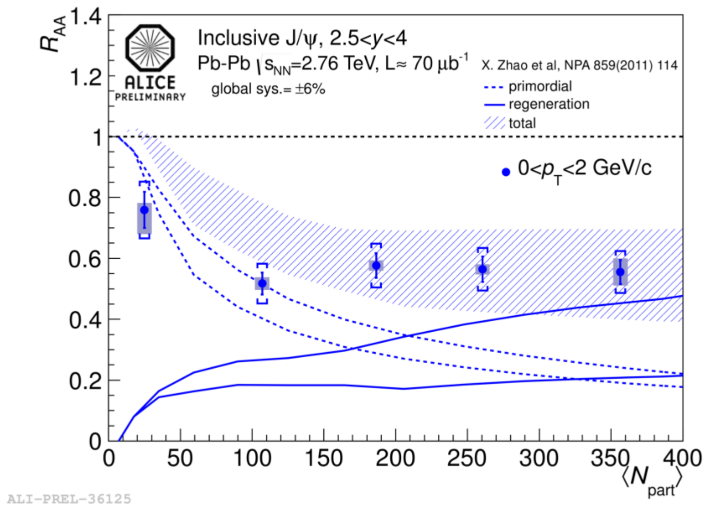
Igor Lakomov's talk

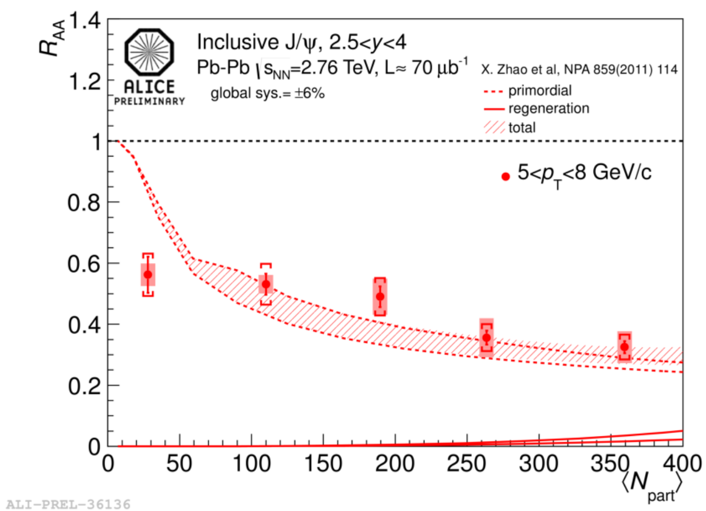
Results: J/ψ R_{AA} vs centrality, p_T bins



- No centrality dependence for low-p_T J/ψ (0 < p_T < 2 GeV/c) when N_{part} > 100.
- Stronger suppression for high-p_T J/ψ (5 < p_T < 8 GeV/c).

Results: J/ψ R_{AA} vs centrality, p_T bins





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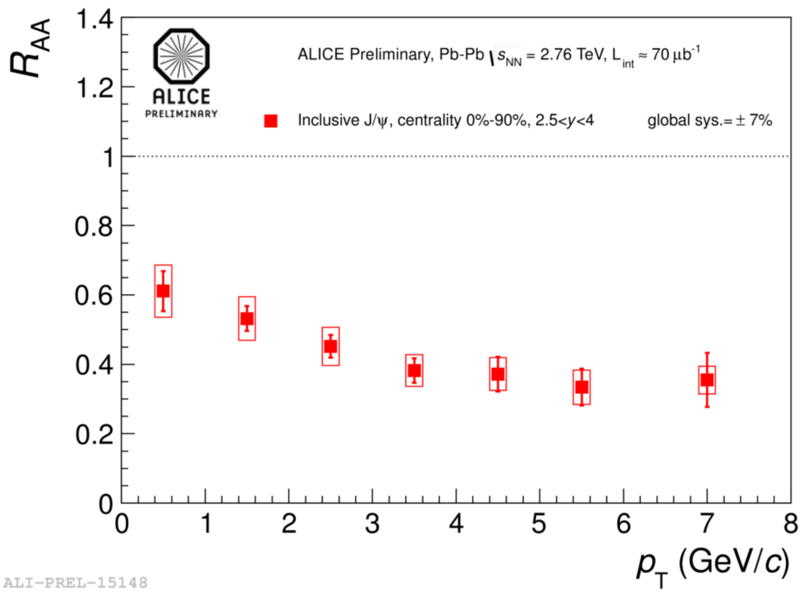
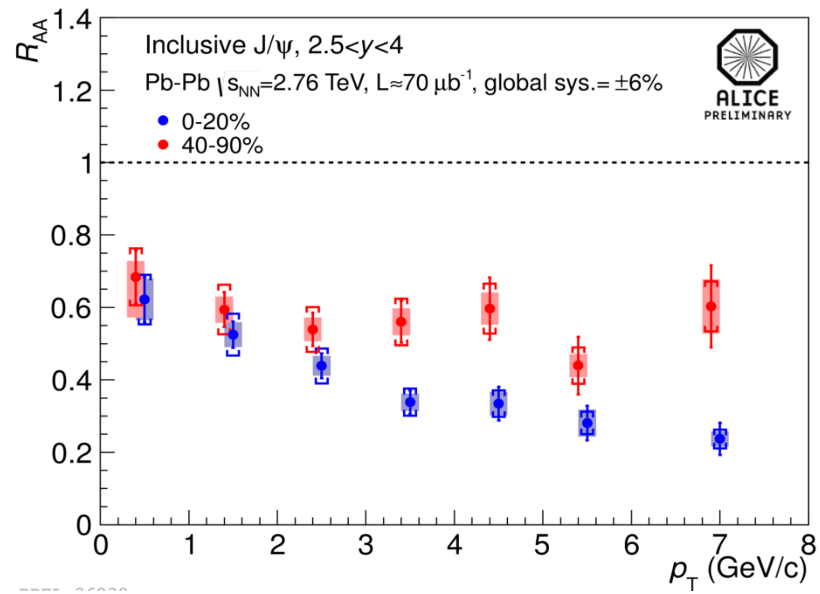
- Stronger suppression for high-p_T J/ψ ($5 < p_T < 8$ GeV/c).
- Transport Models predictions in good agreement with the data:
  - Around 50% of the low-p_T J/ψ in the most central collisions are produced by regeneration.
  - For high-p_T J/ψ, contribution from regeneration is very small.

Results: J/ψ R_{AA} vs p_T, centrality bins

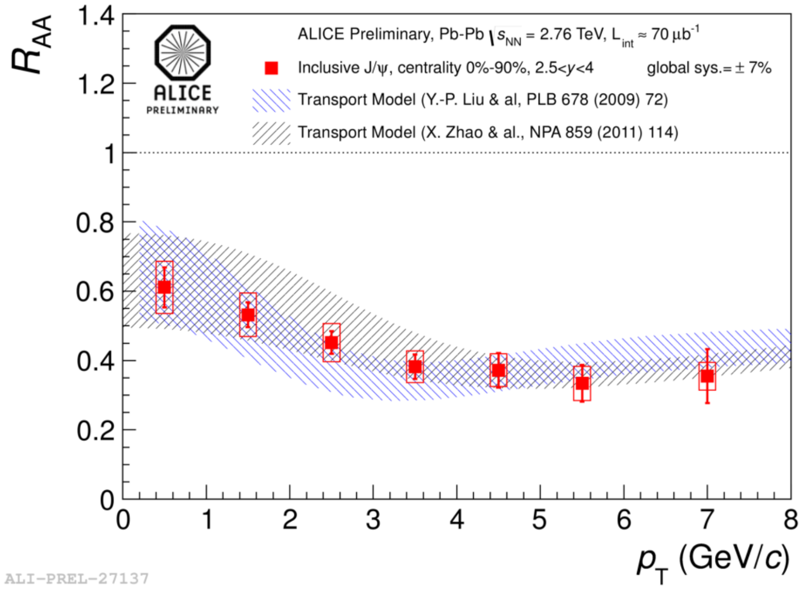


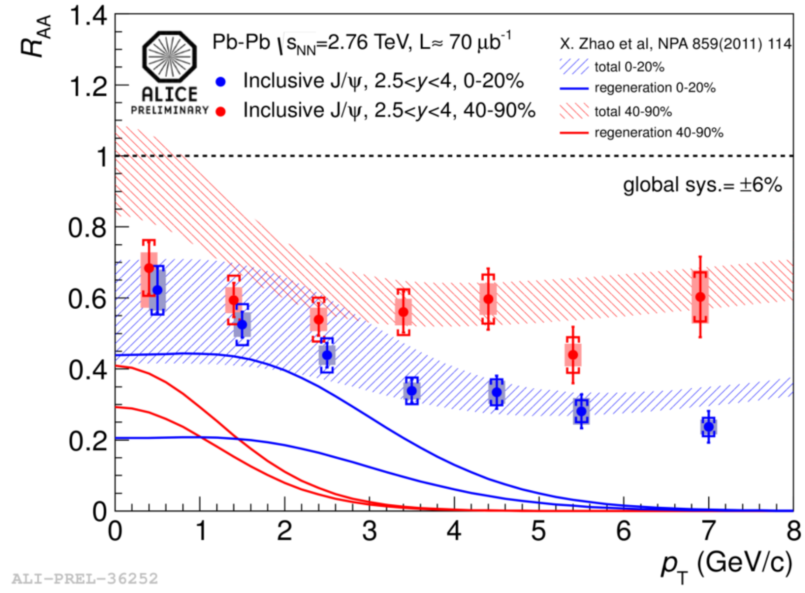
Stronger suppression for high-p_T J/ψ.



Stronger p_T dependence for central collisions (0-20%).

Results: J/ψ R_{AA} vs p_T, centrality bins





Stronger suppression for high-p_T J/ψ.

Stronger p_T dependence for central collisions (0-20%).

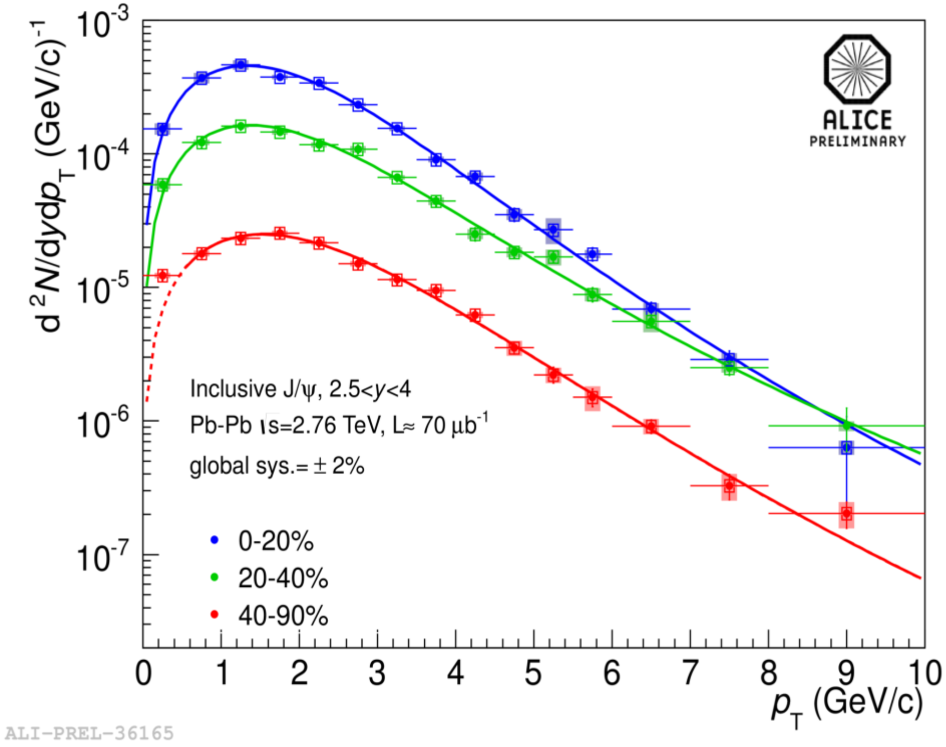
Very good agreement with Transport Models.

Discrepancy between model and data at low-p_T in peripheral collisions (40-90%).

According to Transport Models: regeneration at work in the low-p_T regime.

Results: J/ψ $< p_T >$

$< p_T >$ values were obtained by fitting $$\frac{d^2N}{dydp_T} \propto \frac{p_T}{\left[1+(p_T/p_0)^2\right]^n}$$ in three different centrality bins.



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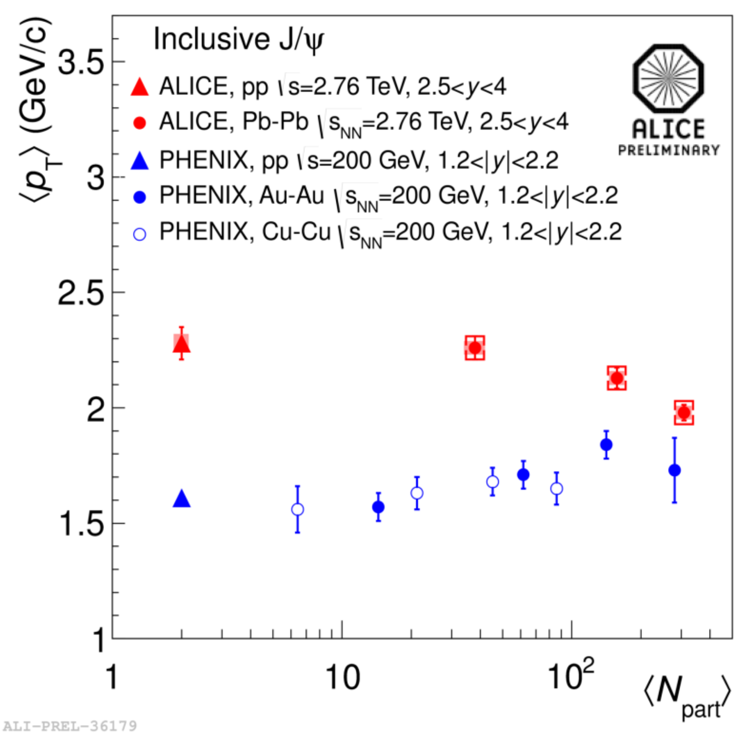


ALICE: clear decrease of $< p_T >$ with increasing N_{part}.

Striking difference with respect to lower energy results (PHENIX)!

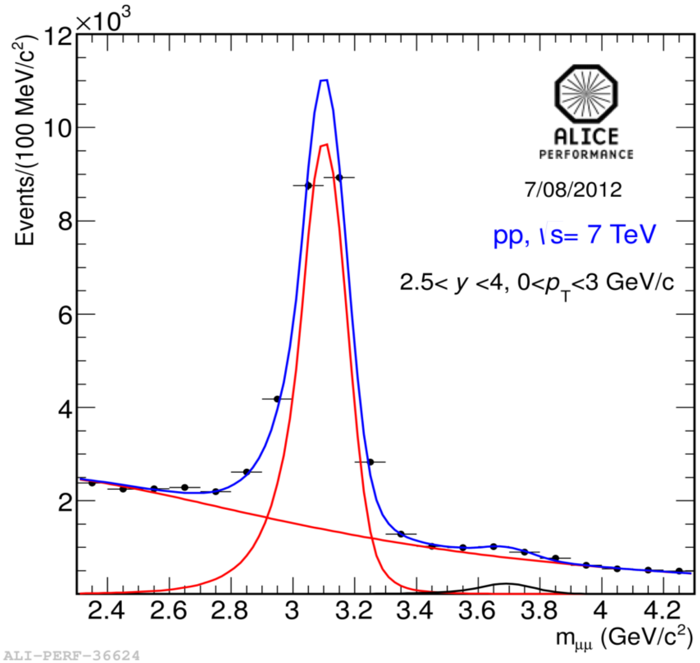
ψ(2S) → μμ

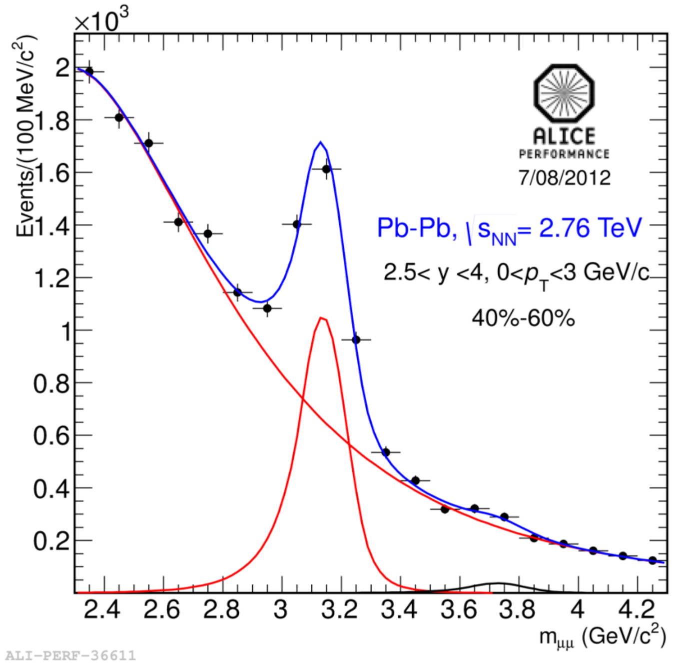
ψ(2S) analysis suffers from low statistics, both in pp and Pb-Pb.

Signal extraction only possible in 2 p_T bins:

- $0 < p_T < 3$ GeV/c: 20-40%, 40-60% and 60-90%.
- $3 < p_T < 8$ GeV/c : 0-20% and 20-60%.

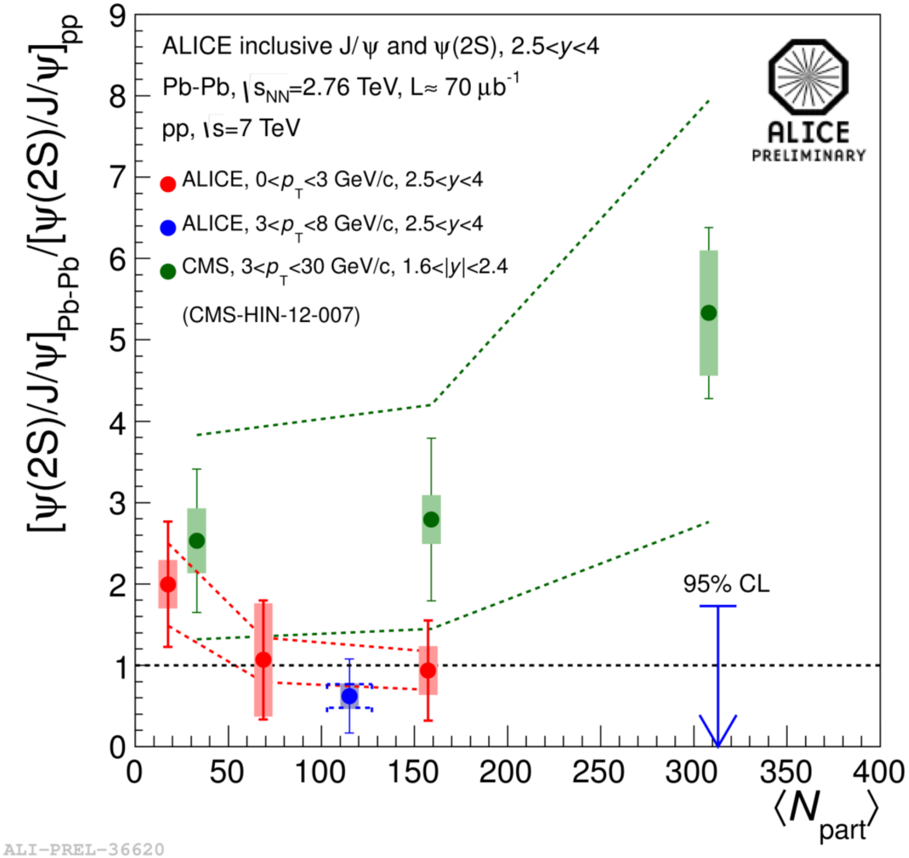
S/B in Pb-Pb: between 0.01 and 0.3 from 20-40% to 60-90% centrality.





$\psi(2S) \rightarrow \mu\mu$

ALICE used pp at $\sqrt{s}$ = 7 TeV as reference: small $\sqrt{s}$ and y dependence from $[\psi(2S) / J/\psi]_{pp}$ results by CDF, LHCb and CMS taken into account in the systematic uncertainty (~ 15%).



Dashed lines show the error on the pp reference: CMS used pp at $\sqrt{s}$ = 2.76 TeV.

Signal extraction and MC inputs for Acceptance x Efficiency corrections are the main source of systematics (some others vanish in the double ratio).

No decisive conclusion on the $\psi(2S)$ enhancement/suppression vs N_{part} due to large statistical and systematic uncertainties.

ALICE excludes large enhancement in the most central collisions.

Conclusions

- ALICE Pb-Pb results vs N_{part} show a different behavior relative to RHIC energies:
  - ❑ Flat centrality dependence (N_{part} > 70).
  - ❑ $R_{\mathrm{AA}}^{\mathrm{ALICE}} \sim 3 \mathrm{~x} R_{\mathrm{AA}}^{\mathrm{PHENIX}}$ for the most central collisions.
- Stronger suppression for high-p_{T} J/ψ relative to the low-p_{T} ones.
- $< p_{\mathrm{T}} >$ decreases with increasing collision centrality, opposite behavior compared to lower energy results (PHENIX).
- Comparisons to models and RHIC results point to (re)generation.
- Important to measure Cold Nuclear Matter effects and $\sigma_{c\bar{c}}$.
- ψ(2S): No firm conclusion on enhancement/suppression with respect to J/ψ, but a strong enhancement in central Pb-Pb collisions seems unlikely.

BACKUP

The ALICE Muon Spectrometer

Located in the forward rapidity region and with a full azimuthal coverage, it is composed by:

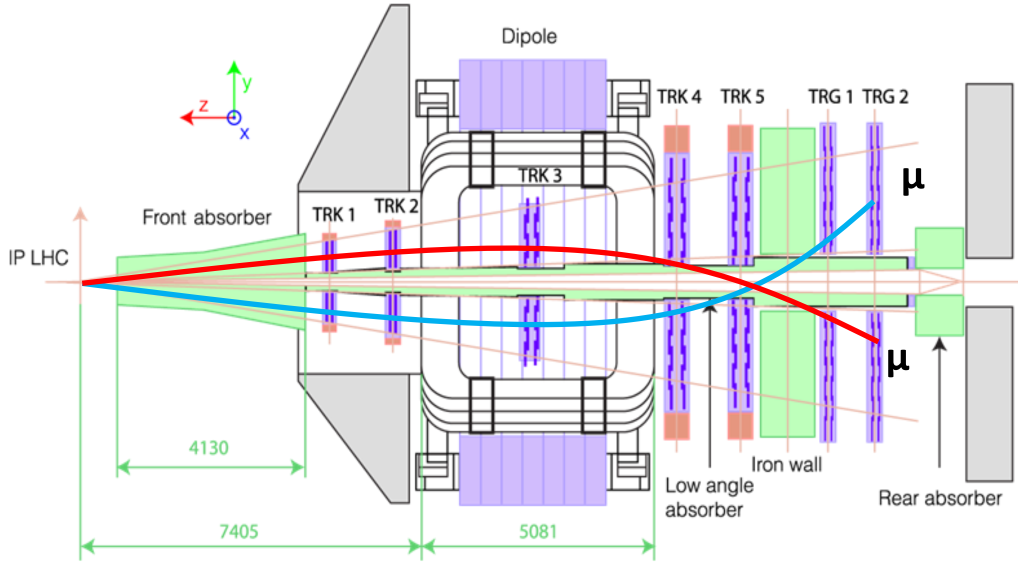
- Absorbers:

  a) Front absorber.- Absorbs hadrons, photons and electrons.

  b) Beam shield.- Protects from particles produced at large *y*.

  c) Iron wall.- Absorbs hadrons that punch-through the frontal absorber.

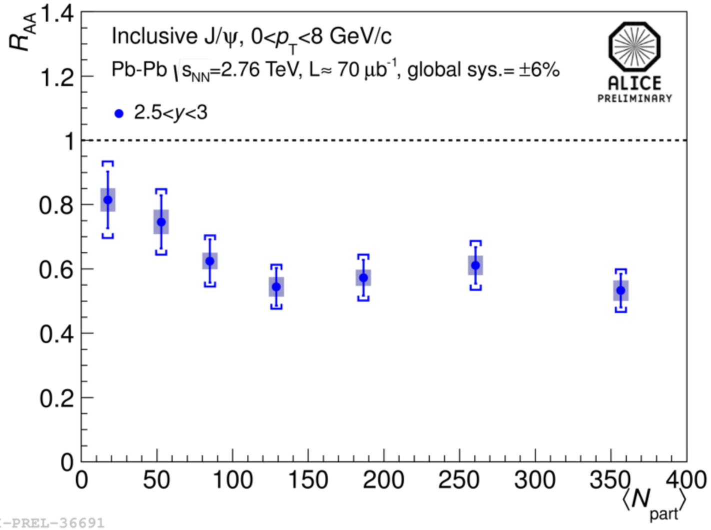
- Magnetic dipole.- 3 T·m integrated magnetic field, bends charged particles allowing to extract the sign of their electric charge and momentum.

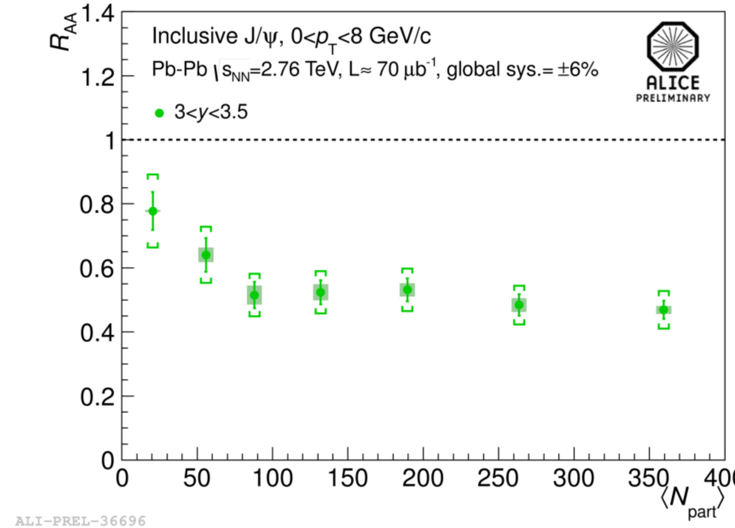


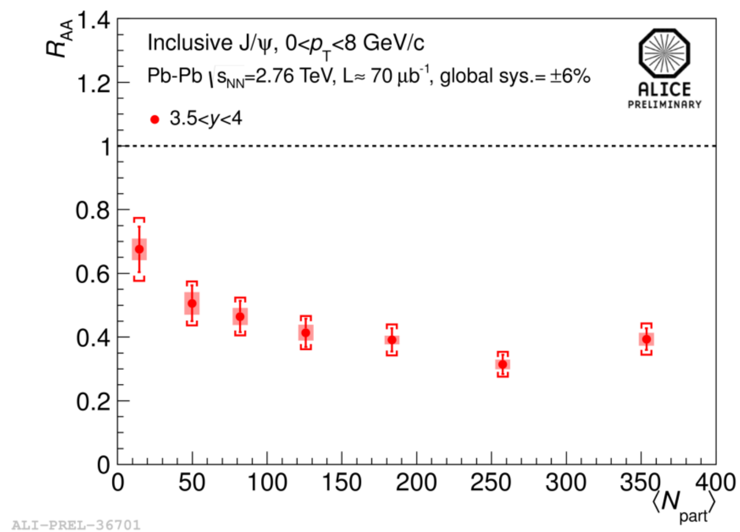
- Tracking chambers.- Spatial resolution, in bending coordinate, better than 100 μm in order to identify and disentangle the ϒ family (100 MeV resolution).

- Trigger chambers.- Timing resolution of 1-2 ns and latency of 700 ns (LØ trigger), can trigger likesign and unlikesign events.

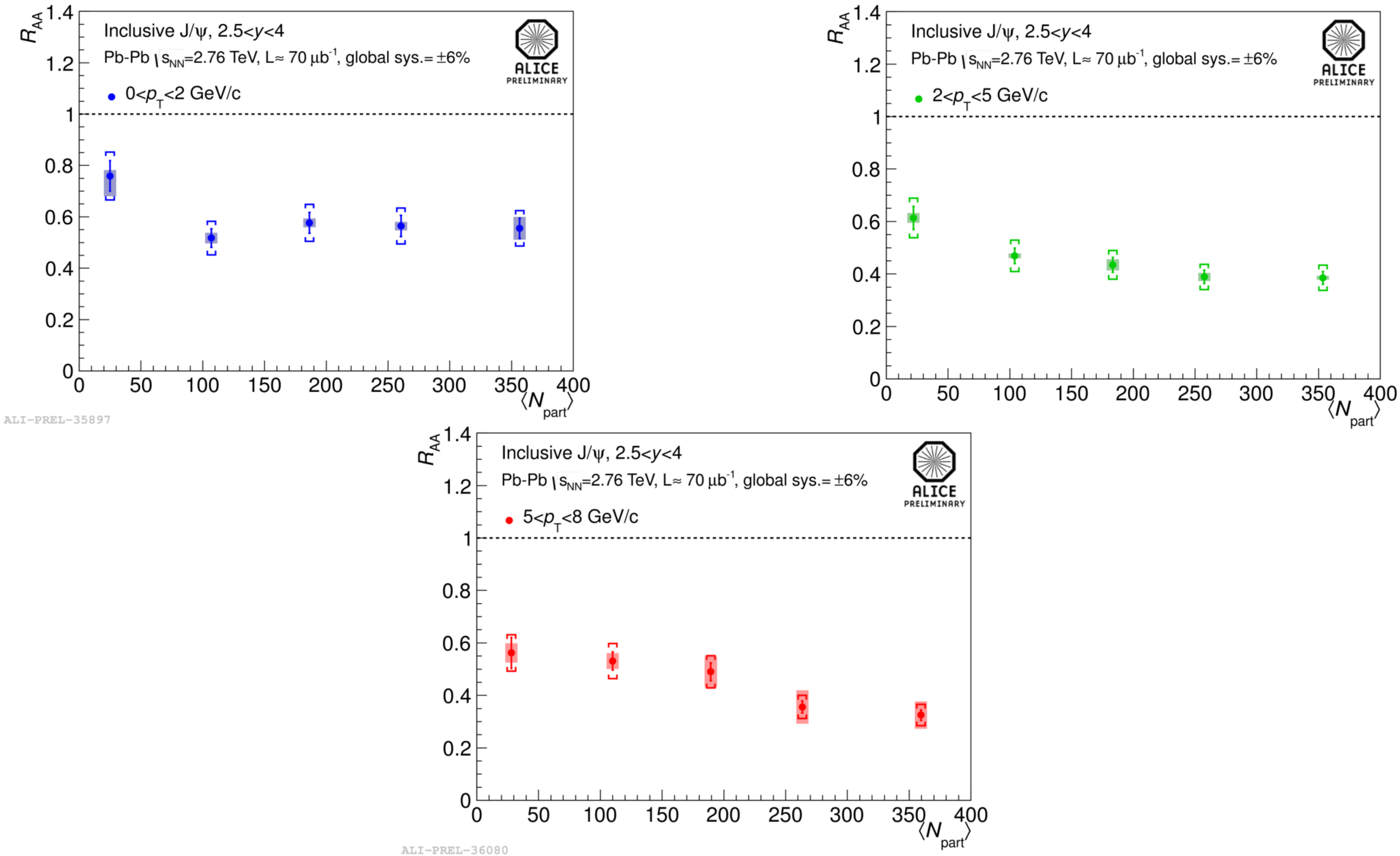
R_{AA} vs Centrality, *y* bins



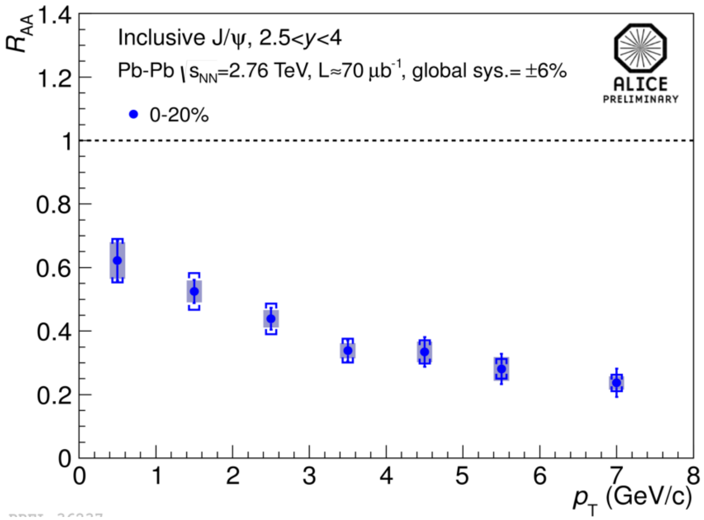


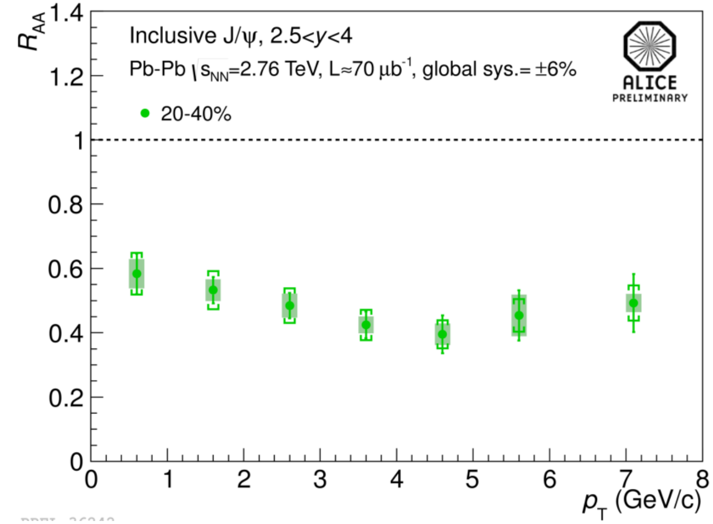


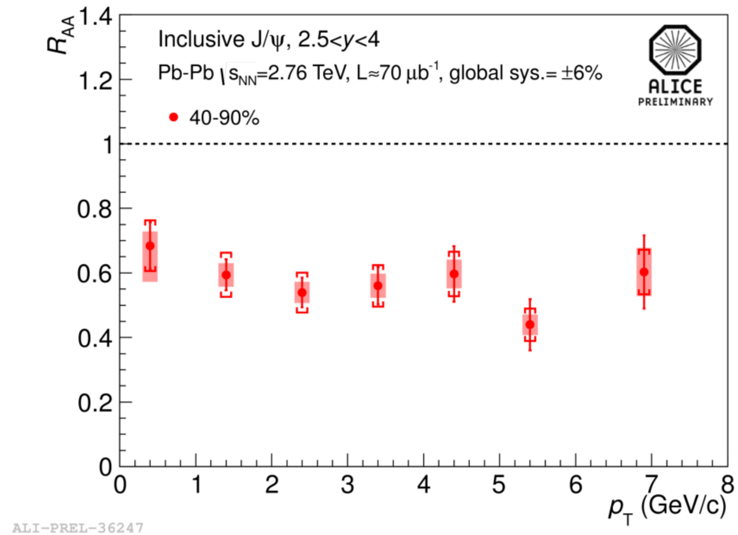
R_{AA} vs Centrality, p_T bins



R_{AA} vs p_T, centrality bins







Systematic uncertainties

Concept	Value (%)
Luminosity pp	1.9
R factor pp	3.0
Normalization (MUL $\rightarrow$ MB)	2.1
Trigger	6.4
Tracking	6.0
Matching	2.0
MC input	5.0

Systematic uncertainties

Corr. systematics: MC input + Matching + Tracking + Trigger + Normalization + J/ψ pp + pp Lumi.

Unc. systematics: n J/ψ + T_{AA} + Tracking + Trigger.

Statistics: n J/ψ.

} vs centrality

Corr. systematics: Normalization + pp Lumi + T_{AA} + corr. J/ψ pp.

Unc. Systematics: n J/ψ + nMB + Tracking + Trigger + MC input + Matching + non corr. J/ψ pp.

Statistics: n J/ψ + J/ψ pp .

} vs p_T /*y*

In the plots:
Statistics: vertical line at each point.
Unc. systematics: shaded area at each point.
Corr. Systematics: written at the top.

Systematic uncertainties

Unc. systematics: n J/ψ.

P.C. systematics: MC input + Matching + Tracking + Trigger + TAA + unc. J/ψ pp.

} vs centrality

Unc. systematics: n J/ψ + unc. J/ψ pp.

P.C. systematics: MC input + Matching + Tracking + Trigger + TAA.

} vs p_T

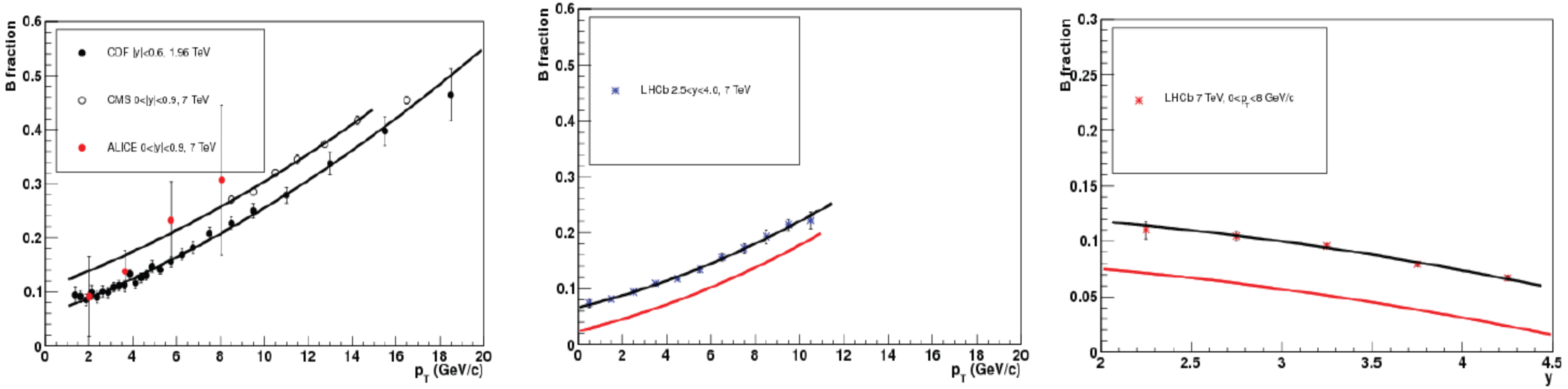
Corr. systematics: Normalization + corr. J/ψ pp.

Statistics: n J/ψ + J/ψ pp .

} vs centrality/ p_T

In the plots:
Statistics: vertical line.
Unc. systematics: shaded area at each point.
P.C. systematics: boxes at each point,
Corr. Systematics: written at the top.

Effect of non-prompt J/ψ on R_{AA}



Non-prompt fraction of the inclusive J/ψ yield in pp at mid rapidity (f_B):
CDF vs CMS: increase of 5% and p_T independent.

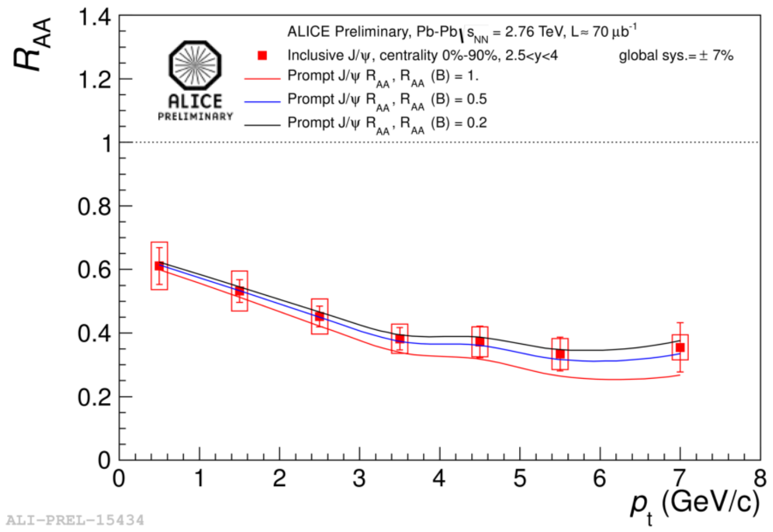
Assume:

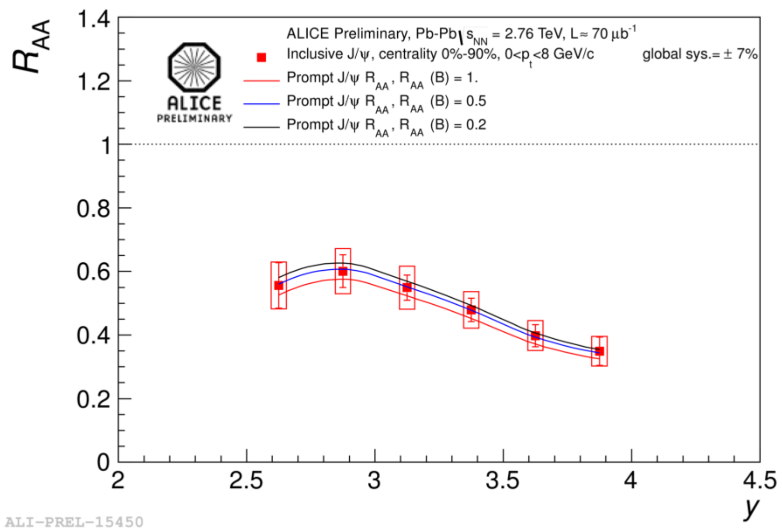
1. Linear increase of $f_B(\sqrt{s})$.
2. It does not depend on the *y* region.

} $f_B(p_T)$ for $\sqrt{s}$ = 2.76 TeV

b-hadron suppression factor in Pb-Pb (*q*)? $R^D_{AA} \approx 0.3$ for $2 < p_T < 16$ GeV/c
➔ 'Dead cone effect': $R^B_{AA} > R^D_{AA}$.
$0.2 < q < 1$ is used

Effect of non-prompt J/ψ on R_{AA}





$$R_{AA}^{prompt}(p_T) = \frac{R_{AA}^{incl} - f_B q}{1 - f_B}$$

➔ small effect on the inclusive J/ψ R_{AA} results.

Similar study can be carried out for R_{AA} vs y: LHCb shows $f_B(y)$ decreases with increasing rapidity.

➔ Difference between inclusive and prompt R_{AA} well within errors.

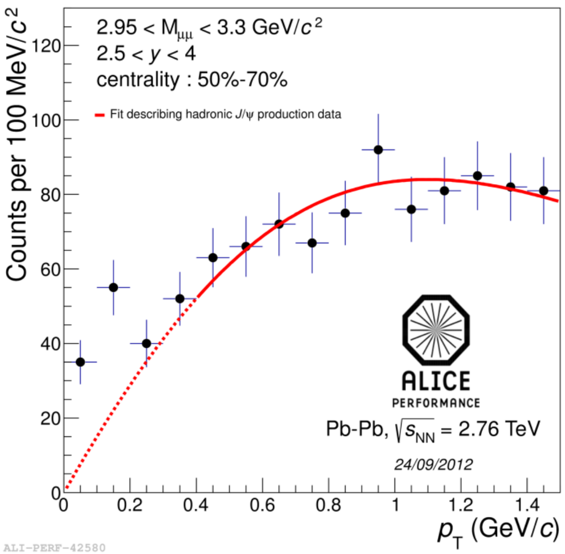
Theoretical models

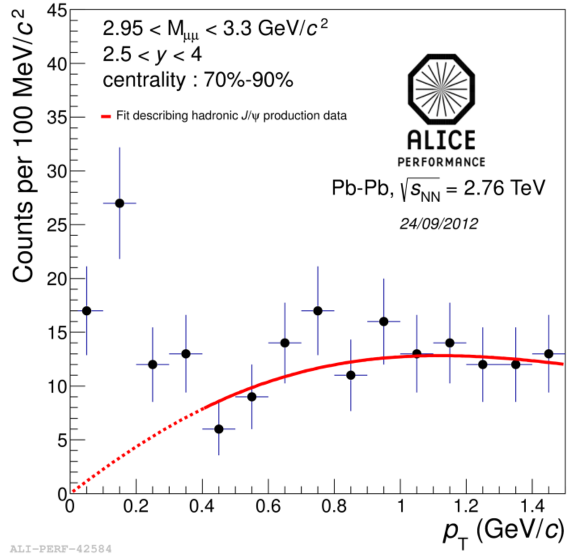
Statistical hadronization
Thermal model with T=164 MeV, μ = 1 MeV (from particle ratio fits).
All charm produced in the initial hard-scatterings.
Charmonium production at phase boundary.

Transport Model by Rapp & Zhao
Boltzman transport equation for the J/ψ.
V_{FB} adjusted to measured $dN_{ch}/d\eta$.
$\sigma_{c\bar{c}}|_{y=3.25} \approx 0.5$ mb.
Shadowing: 30% suppression in the most central collisions.
No Croning effect and σ_{Abs} = 0.
10% of J/ψ ← B and no quenching.

Transport Model by Liu *et al*.
Boltzman transport equation for the J/ψ.
$\sigma_{c\bar{c}}|_{y=3.25} \approx 0.38$ mb.
EKS98 shadowing and σ_{Abs} = 0.
10% of J/ψ ← B and R_{AA} (b) = 0.4 for all p_T range.

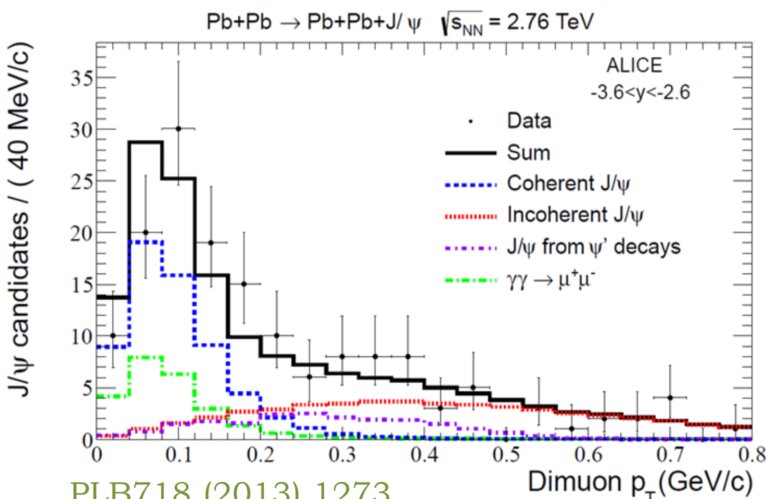
J/ψ photo-production





Clear deviation, at low- p_T for semi and peripheral collisions, to the expected J/ψ hadro-production.

J/ψ photo-production could be responsible of this excess.



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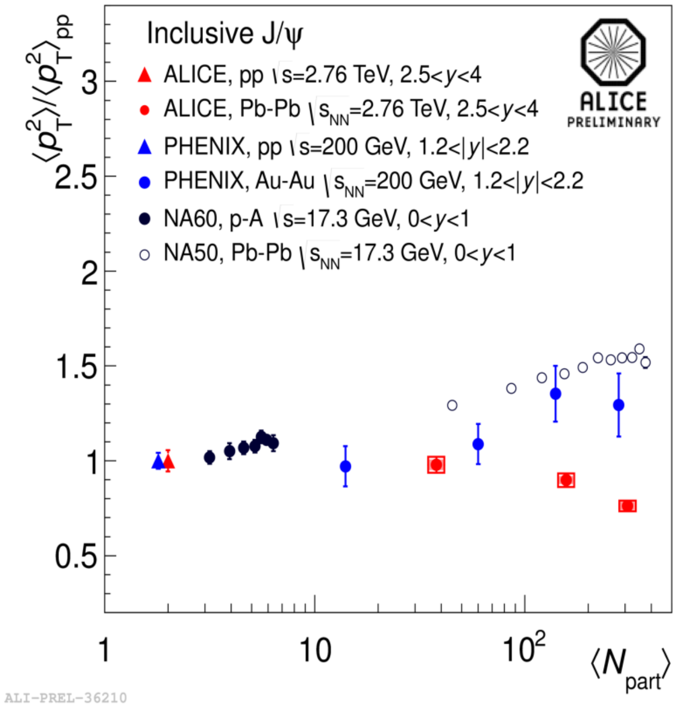
More than 50% of the J/ψ from photo-production have a p_T in the 0-200 MeV/c range.

Only ~ 1% of the J/ψ from hadro-production have a p_T < 200 MeV.

$J/\psi < p_T^2 >$


Inclusive J/ψ
ALICE, pp √s=2.76 TeV, 2.5<y<4
ALICE, Pb-Pb √sNN=2.76 TeV, 2.5<y<4
PHENIX, pp √s=200 GeV, 1.2<|y|<2.2
PHENIX, Au-Au √sNN=200 GeV, 1.2<|y|<2.2
NA60, p-A √s=17.3 GeV, 0<y<1
NA50, Pb-Pb √sNN=17.3 GeV, 0<y<1
ALICE PRELIMINARY
⟨p_T^2⟩/⟨p_T^2⟩_pp
⟨N_part⟩
ALI-PREL-36210