A Large Ion Collider Experiment

Observation of a J/ψ yield enhancement at very low p_T in Pb-Pb collisions at 2.76 TeV

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for the ALICE Collaboration

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Measurement of an excess in the yield of J/ψ at very low pT in Pb-Pb collisions at
$\sqrt{s_{NN}}$ = 2.76 TeV, ALICE Collaboration, CERN-PH-EP-2015-268
Wed Sep 30th 2015 arXiv:1509.08802

J/ψ production in heavy-ion collisions at LHC

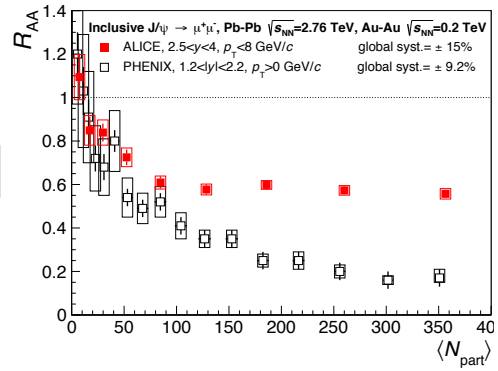
Recombination of charm quarks during the collision evolution, to form charmonia in a latter stage of the QGP evolution :

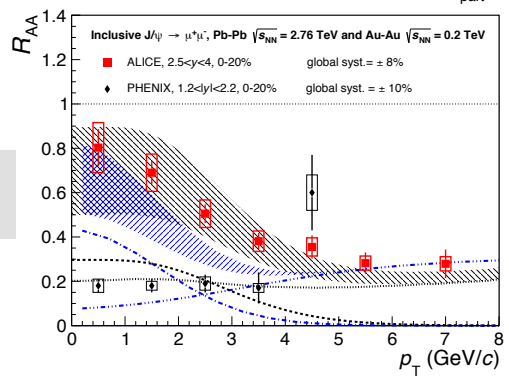
Hugo PEREIRA, Quarkonia II

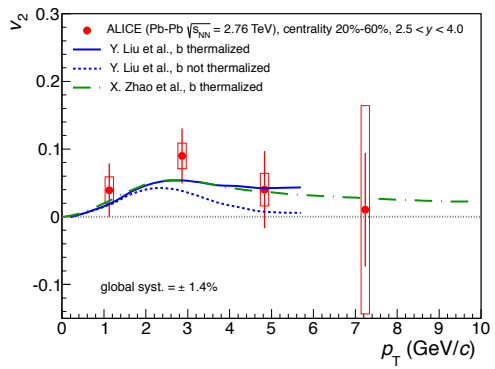
- ✓ Larger R_{AA} than that at RHIC.
- ✓ Larger R_{AA} at low p_T and toward mid-rapidity.
- ✓ Hint of non-zero elliptic flow.
- ✓ Transport models explain the data.
- ✓ J/ψ measurements in p-Pb.

Marco LEONCINO, Quarkonia I
Cynthia HADJIDAKIS, Poster

Direct observation of the deconfined state of matter.





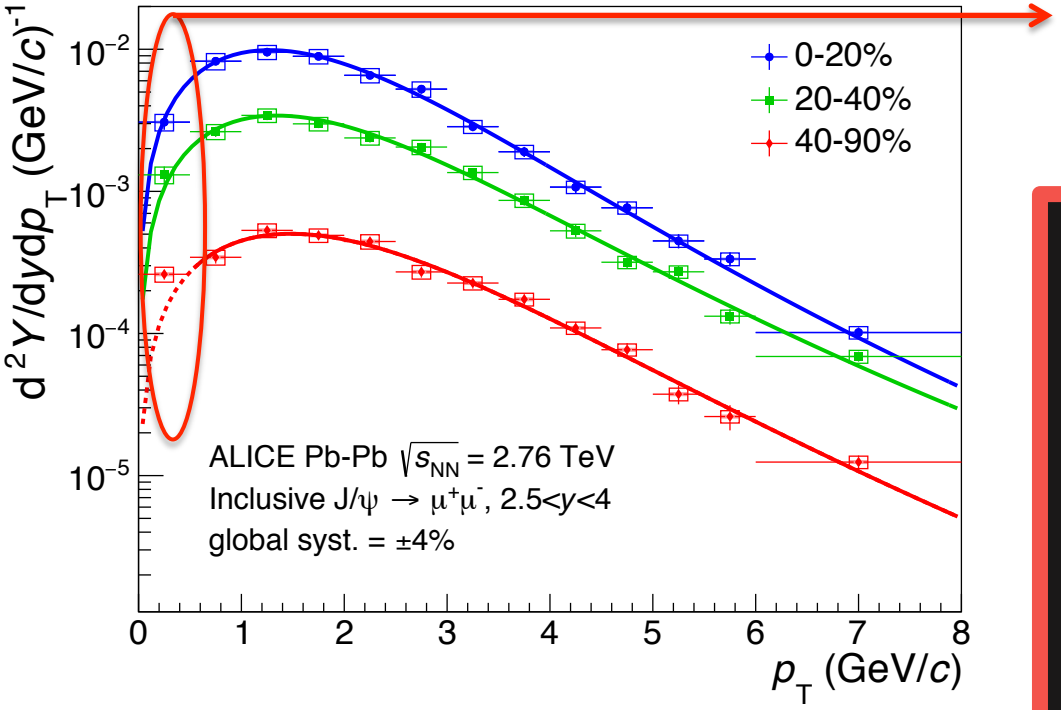


ALICE Collaboration PRL109 072301 (2012) arXiv:1202.1383; PLB734 314 (2014) arXiv:1311.0214; JHEP07 051 (2015) arXiv: 1504.07151; arXiv:1506.08804; PRL111 162301 (2013) arXiv: 1303.5880; JHEP1402 073 (2014) arXiv:1308.6726; JHEP06, 055 (2015) arXiv:1503.07179.
PHENIX Collaboration PRC84 (2011) 054912 arXiv:1103.6269.
X.Zhao et al. NPA859 (2011) 114 arXiv:1102.2194. K.Zhou et al. PRC89 (2014) 054911 arXiv:1401.5845.

See also SaporeGravis I3HP3 report arXiv:1506.03981

Study of J/ψ production at very low p_T

p_T-differential J/ψ yields



ALICE Collaboration, EPJ C74 (2014) 2974
arXiv:1403.3648 and arXiv:1506.08804

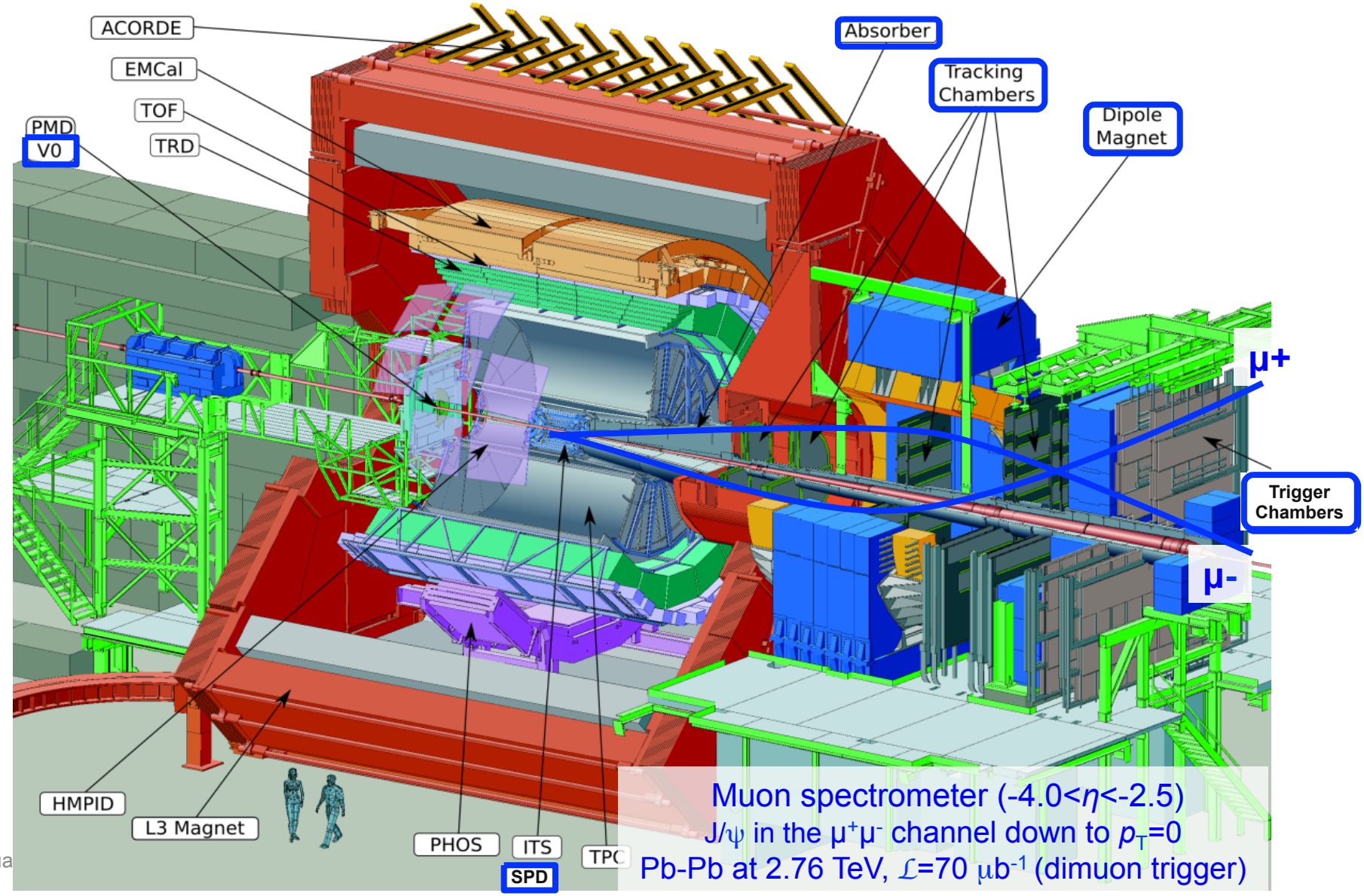
Excess seems to be present at very low p_T (p_T<0.5 GeV/c) in semi-peripheral collisions.

But not seen in pp collisions.

Outline

1. ALICE detector
2. J/psi R_{AA} at p_T<1 GeV/c for different centrality bins.
3. Estimation of the J/ψ excess.
4. Cross-section evaluation assuming coherent J/ψ photoproduction at the origin of the excess.
5. Conclusions and prospects

The ALICE Detector

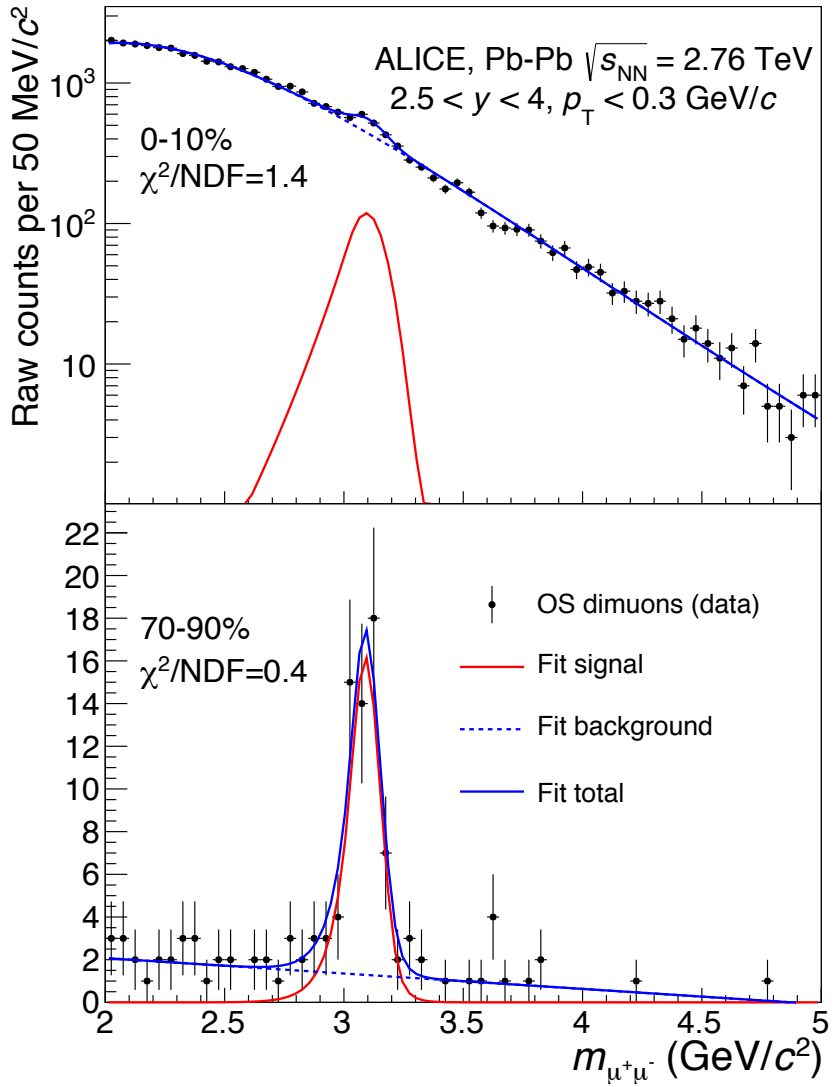


Muon spectrometer ($-4.0<\eta<-2.5$)
J/ψ in the $\mu^+\mu^-$ channel down to $p_T=0$
Pb-Pb at 2.76 TeV, $\mathcal{L}=70\ \mu b^{-1}$ (dimuon trigger)

J/ψ Signal Extraction : $N_{AA}^{J/\psi}$

Invariant mass analysis

- opposite sign dimuon pairs in the dimuon triggered (p_T^{μ}>1 GeV/c) data (17x10^6 events, ~70 μb^{-1}).
- two functions were considered to describe the J/ψ signal shape. Two or three functions for the background.
- Three p_T ranges
  - 0-0.3, 0.3-1.0 and 1-8 GeV/c
- Five centrality bins
  - 0-10%, 10-30% , 30-50%, 50-70% 70-90%
- One y range
  - 2.5<*y*<4.0

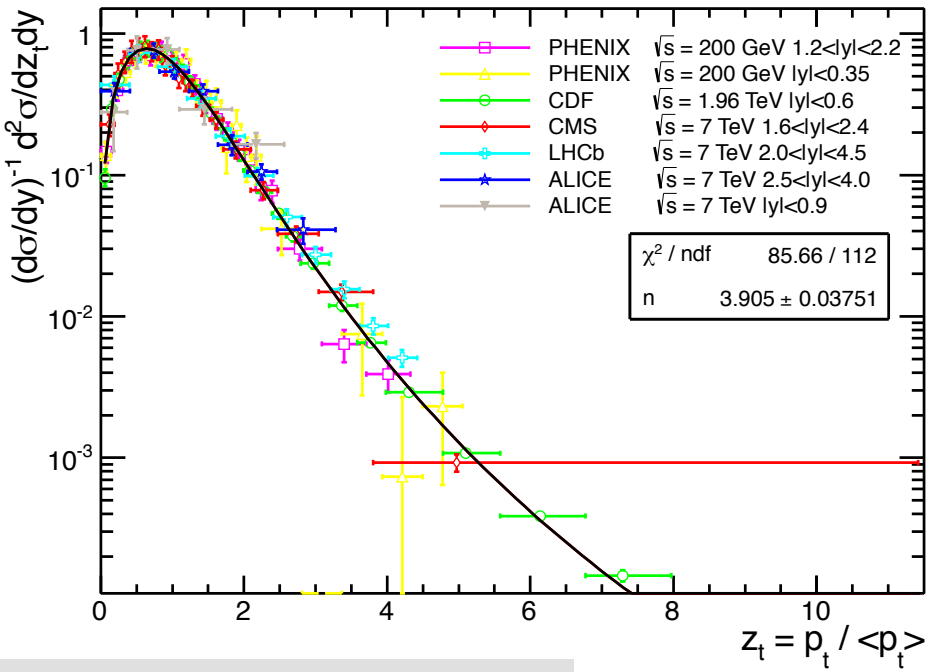


Similar analysis as in arXiv:1506.08804 by the ALICE Collaboration

Proton-proton reference at √s = 2.76 TeV

Not enough statistics at very low p_T in pp collisions at 2.76 TeV to make a direct measurement.

$$\frac{\mathrm{d}^2\sigma_{\mathrm{pp}}^{\mathrm{h\ J/\psi}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} = \frac{c \times \sigma_{\mathrm{J/\psi}}}{1.5 \times \langle p_{\mathrm{T}} \rangle^2} \times \frac{p_{\mathrm{T}}}{\left(1 + a^2 \left(\frac{p_{\mathrm{T}}}{\langle p_{\mathrm{T}} \rangle}\right)^2\right)^n}$$



F. Bossu et al. arXiv:1103.2394

- Reference in the 0-0.3 GeV/c p_T interval was extracted by fitting the experimental data.

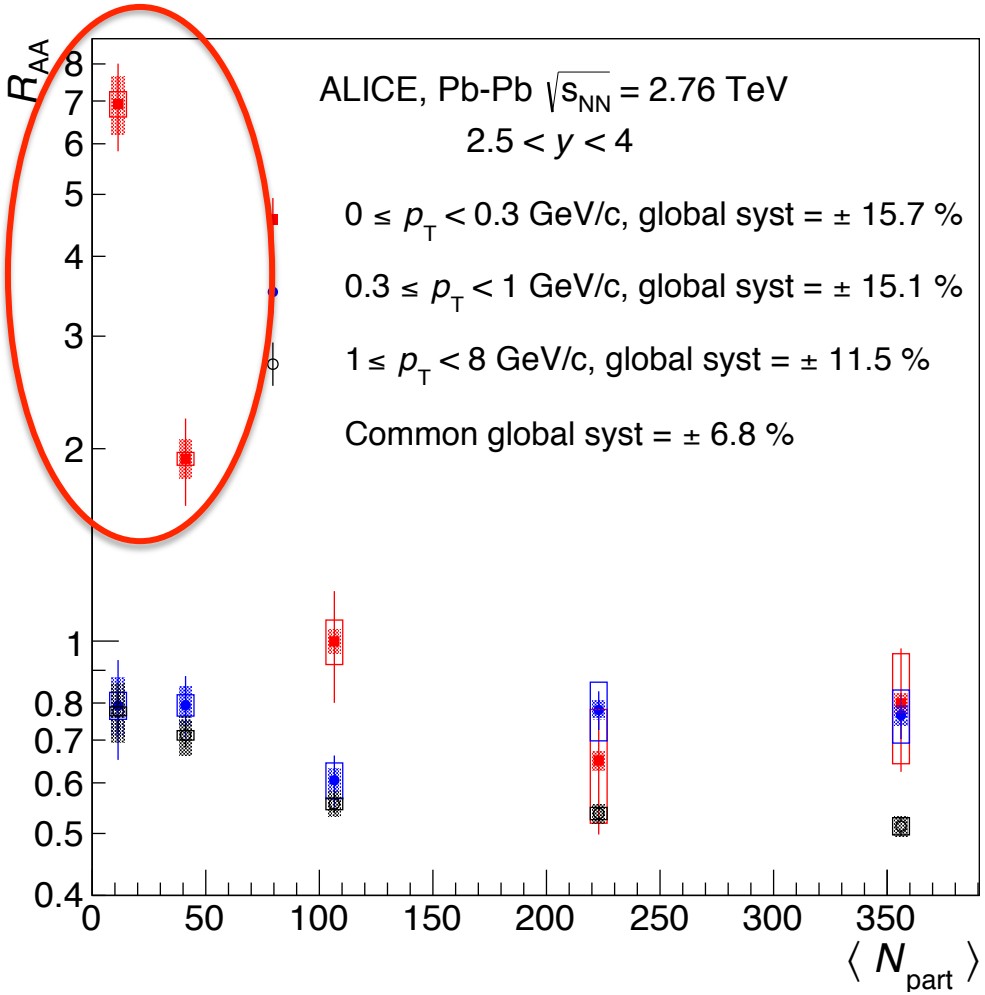
ALICE Collaboration, PLB718 (2012) 295 arXiv:1203.3641

- Levy-Tsallis and UA1 functions also used for determination of the systematics.
- Procedure cross-checked with proton-proton data at 7 TeV.

ALICE Collaboration, EPJ C74 (2014) 2974 arXiv:1403.3648

J/ψ nuclear modification factor at very low p_T

Strong enhancement in the p_T interval 0-0.3 GeV/c



- ✓ Systematics:
  - Open box : uncorrelated in p_T and centrality.
  - Shaded area: correlated in p_T and uncorrelated in centrality.
- ✓ **R_{AA} ~7 (2) for the 70-90% (50-70%) centrality classes.**
- ✓ None of the transport models predict such a pattern.

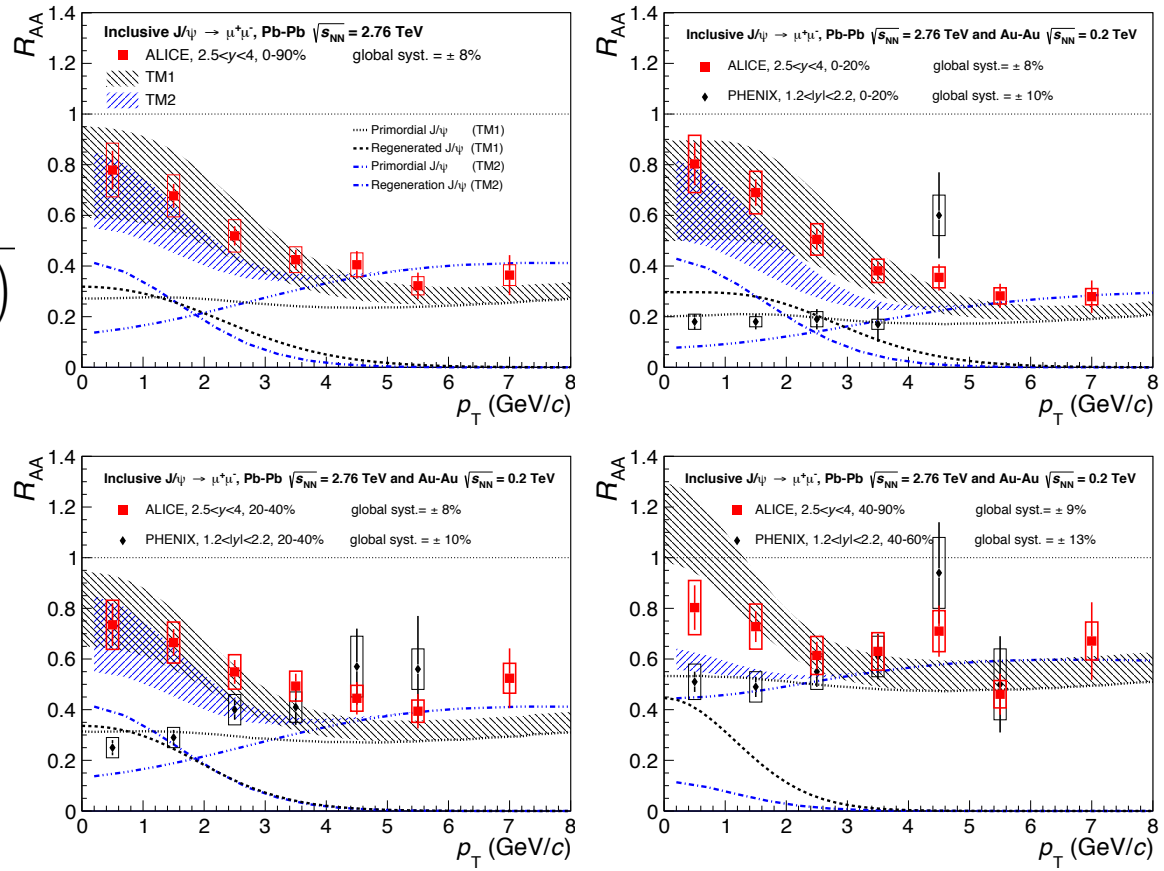
Evaluation of hadroproduced J/ψ at very low p_T

$$\frac{dN_{AA}^{h\ J/\psi}}{dp_T} = \mathcal{N} \times \frac{d\sigma_{pp}^{h\ J/\psi}}{dp_T} \times R_{AA}^{h\ J/\psi} \times (\mathcal{A} \times \varepsilon)_{AA}^{h\ J/\psi}$$

- Smooth R_{AA} evolution down to zero p_T.

$$R_{AA}^{h\ J/\psi}(p_T) = R_{AA}^{0} + \frac{\Delta_{R_{AA}}}{1+\exp\left(\frac{p_T - p_T^0}{\sigma_{p_T}}\right)}$$

- Two fits, fixed and free p_T^0 parameter.
- Also 1st order polynomial and a constant to R_{AA} for the most peripheral bin.
- Two fitting intervals 0-8 and 1-8 GeV/c.

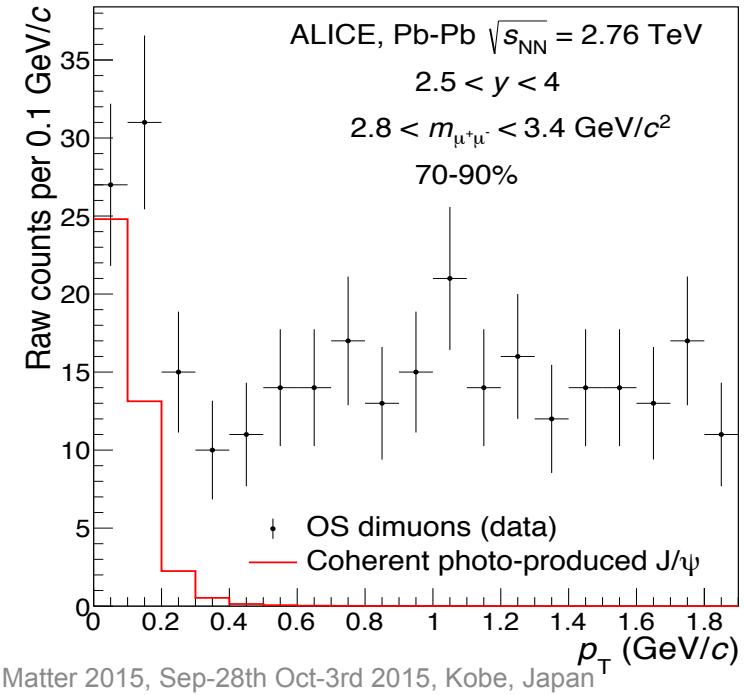


ALICE Collaboration arXiv:1506.08804

Evaluation of the J/ψ excess at very low p_T

Cent. (%)	$N_{AA}^{J/\psi}$	$N_{AA}^{h\ J/\psi}$	$N_{AA}^{excess\ J/\psi}$
0–10	$339 \pm 85 \pm 78$	$406 \pm 14 \pm 55$	< 251
10–30	$373 \pm 87 \pm 75$	$397 \pm 10 \pm 61$	< 237
30–50	$187 \pm 37 \pm 15$	$126 \pm 4 \pm 15$	$62 \pm 37 \pm 21$
50–70	$89 \pm 13 \pm 2$	$39 \pm 2 \pm 5$	$50 \pm 14 \pm 5$
70–90	$59 \pm 9 \pm 3$	$8 \pm 1 \pm 1$	$51 \pm 9 \pm 3$

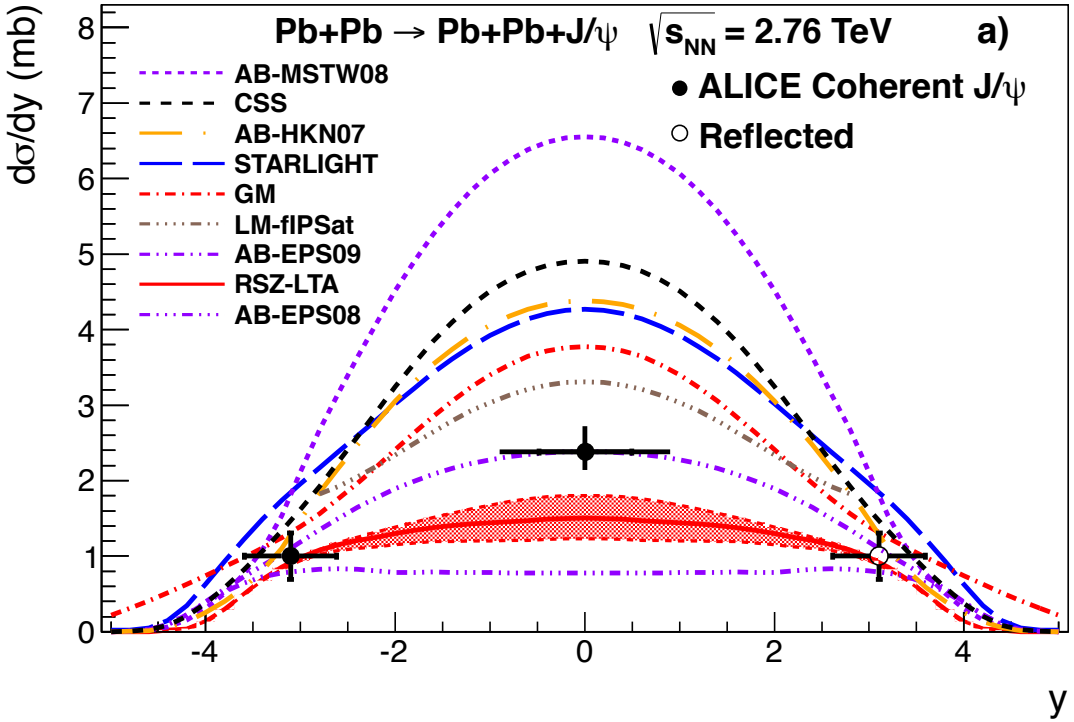
- 5.4 (3.4)σ significance in 70-90% (50-70%) centrality bins.
- 1.4σ in 30-50%.

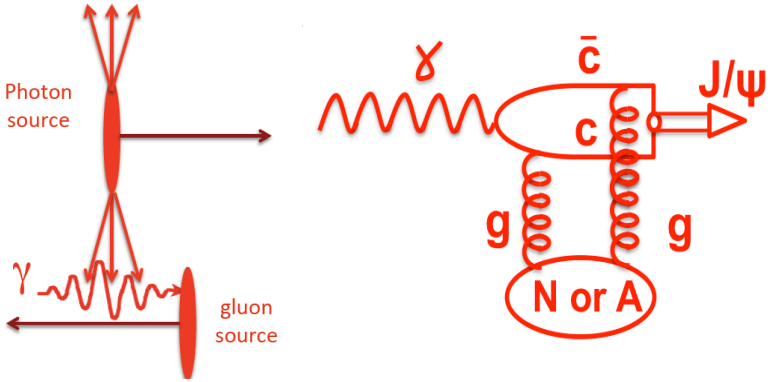


Hypothesis on the underlying mechanism

- Coherent photoproduction of J/ψ in Pb-Pb collisions.
- $\langle p_T \rangle$~60 MeV/c (~100 MeV/c after muon spectrometer response function).
- Shape of STARLIGHT calculation in ultra-peripheral collisions (UPC) in good qualitative agreement.

Photoproduction in Pb-Pb UPC at 2.76 TeV





- Photon from the Pb EM field interacts with the Pb nucleus (coherent) or with a nucleon (incoherent).
- Measured in Pb-Pb ultra peripheral collisions (b>2 R_{Pb}).
- Sensitive to gluon nPDF.

ALICE Collaboration, PLB718 (2013) 1273 arXiv:1209.3715 and EPJ73 (2013) 11 arXiv:1305.1467

Coherent photoproduction cross-section

$N_{AA}^{excess\ J/\psi} / (1+f_D+f_I) \rightarrow d\sigma^{coh}_{J/\psi}/dy$

ALICE Collaboration, PLB718 (2013) 1273 arXiv:1209.3715

- Correction by the fraction of incoherent contribution, f_I.
- Correction by the feed-down of coherently photoproduced $\psi(2S)$, f_D.
- $(Ax\varepsilon)_{AA}^{J/\psi}$ assuming coherent photoproduction (transverse polarized J/ψ) from STARTLIGHT.

Cent. (%)	$N_{AA}^{J/\psi}$	$N_{AA}^{excess\ J/\psi}$	$d\sigma^{coh}_{J/\psi}/dy$ (μb)
0–10	$339 \pm 85 \pm 78$	< 251	< 318
10–30	$373 \pm 87 \pm 75$	< 237	< 290
30–50	$187 \pm 37 \pm 15$	$62 \pm 37 \pm 21$	$73 \pm 44\ ^{+26}_{-27} \pm 10$
50–70	$89 \pm 13 \pm 2$	$50 \pm 14 \pm 5$	$58 \pm 16\ ^{+8}_{-10} \pm 8$
70–90	$59 \pm 9 \pm 3$	$51 \pm 9 \pm 3$	$59 \pm 11\ ^{+7}_{-10} \pm 8$

Uncorrelated systematics as a function of centrality:

- Measured excess,
- Incoherent J/ψ and coherent $\psi(2S)$ contributions,
- Centrality selection, occupancy, trigger, tracking.

Correlated systematic 14%

- Luminosity, MC input, trigger and tracking efficiencies, and matching.

Comparison with theoretical expectations

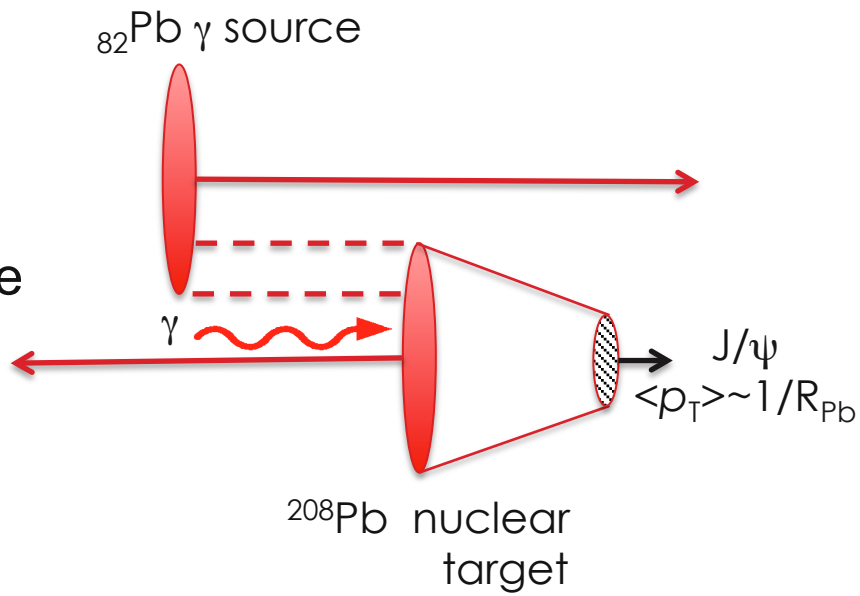
No model is available for a complete description of coherent photoproduction in Pb-Pb nuclear collisions.

$$\sigma_{\mathrm{AA}\to J/\psi\mathrm{AA}} = \sum_{\mathrm{i}=\gamma A, A\gamma} \sigma_{\mathrm{i}}(w_\gamma) \otimes \int_{\mathrm{R}} \frac{dN_\gamma(w_\gamma, b)}{dS} dS$$

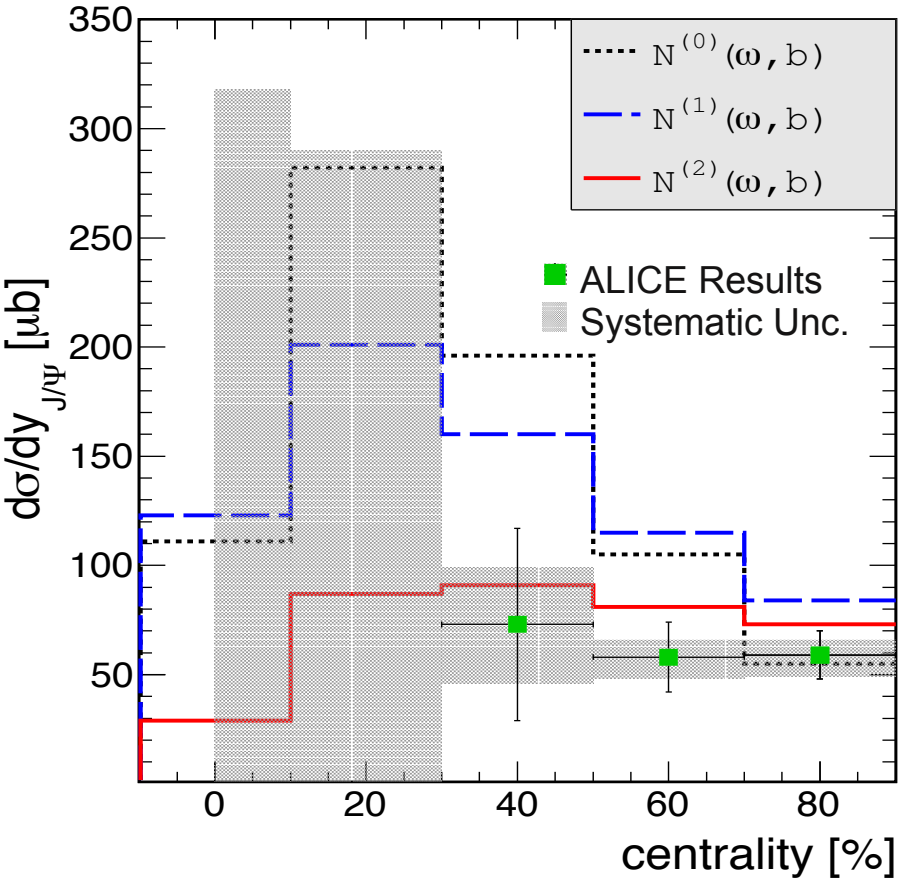
$E_\gamma = \hbar w_\gamma$

N_γ photon flux

- Part of the nuclei interacts.
- Photon flux of a charge distribution of the nucleus for $b<2R_{Pb}$.
- An extrapolation of measured J/ψ in UPC ($b_1=2R_{Pb}, b_2=\infty$) to 70-90% (N_{part}~11) centrality class ($b_1^{70\text{-}90\%}, b_2^{70\text{-}90\%}$), provides a cross section of ~40 μb. Good qualitative agreement with the measured value 59±16 μb.
- Two extreme cases for the photon flux:
  - full nucleus
  - spectator region



Model M.Klusek-Gawenda & A. Szczurek



(0) UPC γ flux approximation.
(1) γ flux in the whole nuclear target.
(2) γ flux in the spectator nuclear target.

- "Calculation of coherent photoproduction for $b<2R_A$ is not clear."
- Different ways to treat the overlap region.
- Reasonable good agreement with our preliminary results.
- Experimental data favour the scenario where only the spectator region contributes to the coherent photoproduction.

M. Klusek-Gawenda and A. Szczurek arXiv:1509.03173v1 and
L. Massacrier for ALICE Collab., EDS2015, Corsica, France

Conclusion

- ALICE Collaboration has observed a J/ψ yield enhancement at very low p_T (0-0.3 GeV/c) in Pb-Pb collisions at 2.76 TeV.
- The nuclear modification factor R_{AA} reaches 7 (2) in the centrality bin 70-90% (50-70%).
- J/ψ excess in the 0-0.3 GeV/c p_T range is extracted. The significance of this excess is 5.4 (3.4)σ in 70-90% (50-70%) and 1.4σ in 30-50%.
- It could result from the coherent photoproduction of J/ψ in nuclear Pb-Pb collisions. Good qualitative agreement between the extracted cross-section and the expectation from UPC calculations is found.
- Model by M.Klusek-Gawenda & A. Szczurek favours the scenario where only the spectator region contributes to photoproduction.
- This measurement is a challenge for theoretical studies since the implementation of coherent photoproduction in nuclear collisions is far to be trivial.

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Prospects

- Theoretical model addressing all the aspects is needed. Ideally to provide a reference to this observable in the absence of QGP.
- Measurement of the excess in central and semi-central collisions at forward and mid-rapidity will be explored during Run2 and Run3 at the LHC.
- Measurements of the mean p_T are also needed to study the size of the region contributing to the coherent photoproduction ($<p_T>\sim 1/R_A$): wider p_T distribution in semi-central collisions?
- The measurement of the J/ψ polarisation is a golden channel to confirm the coherent photo-production hypothesis.
- Photon-photon contribution should be there and it is not affected by QGP. However it is an experimental challenge.
- Whether this new probe can be used to study the QGP, is an open question.

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