Coherent J/Ψ photoproduction in Pb-Pb collisions with nuclear overlap with ALICE at the LHC

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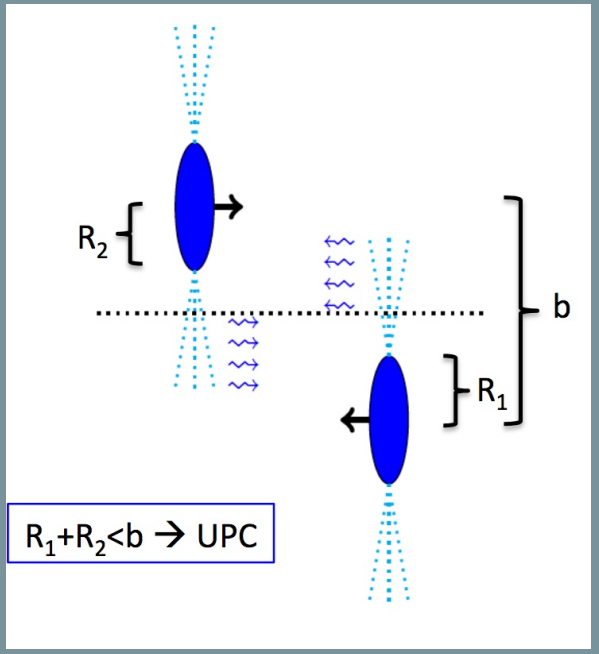
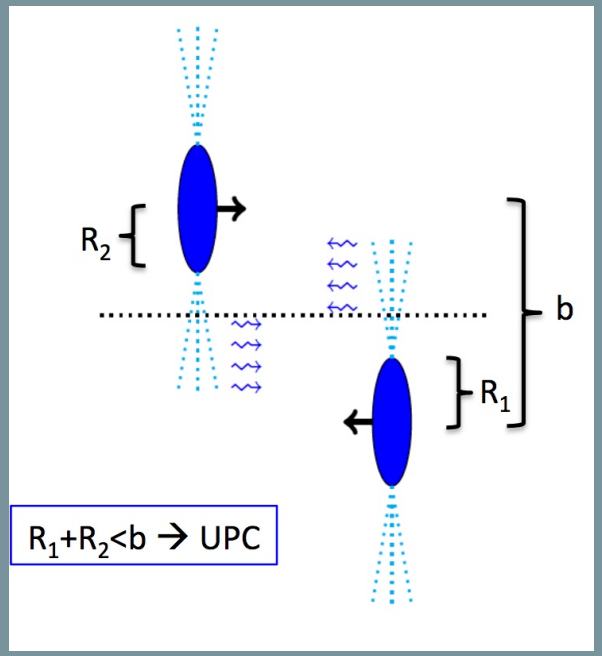
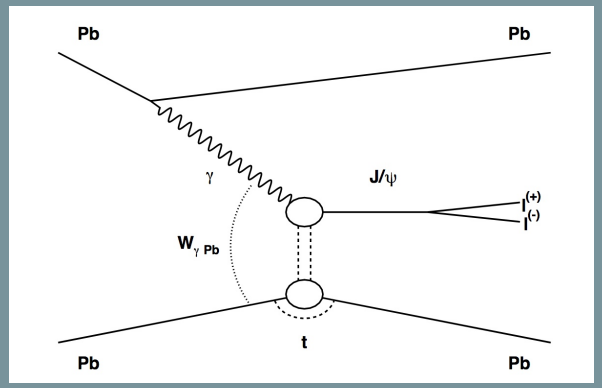
J/Ψ photoproduction and Ultra-Peripheral collisions(UPC)



- The EM field of Pb nuclei can be described as beam of quasi-real photons (number of photons proportional to Z^2)
- UPC : interactions with b larger than the sum radii of the incoming nuclei. Involve at least one photon.
  - Hadronic interaction strongly suppressed
  - Electromagnetic interactions dominant

J/Ψ photoproduction and Ultra-Peripheral collisions(UPC)





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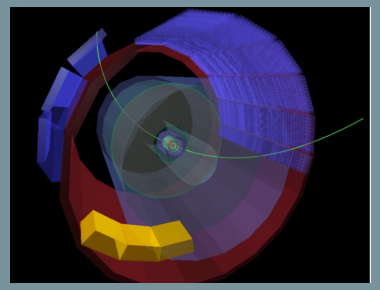
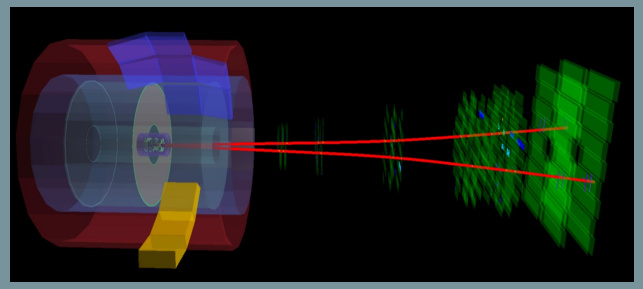
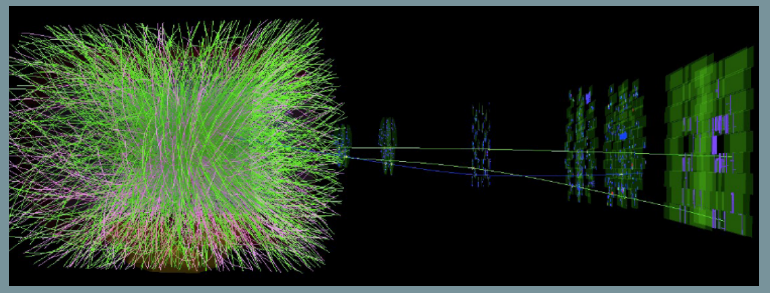
- UPC : interactions with b larger than the sum radii of the incoming nuclei. Involve at least one photon.
  - Hadronic interaction strongly suppressed
  - Electromagnetic interactions dominant
- Photoproduction of vector meson (VM) in UPC has a clean experimental signature:
  - Very low p_T production
  - Large rapidity gaps
- Coherent photoproduction of VM
  - ɣ couples coherently to all nucleons
  - $\langle p_T \rangle^{J/\Psi}$ ~ 50 MeV
  - No breaking of target nucleus
- Incoherent photoproduction of VM
  - ɣ couples to part of nucleus
  - $\langle p_T \rangle^{J/\Psi}$ ~ 500 MeV
  - Usually target nucleus breaks

First observation of a very low p_T J/Ψ excess in peripheral AA collisions



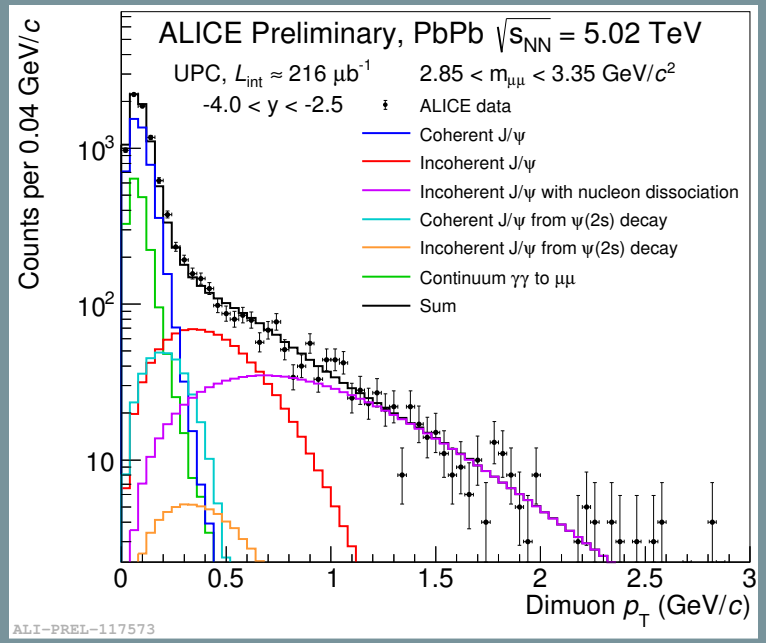


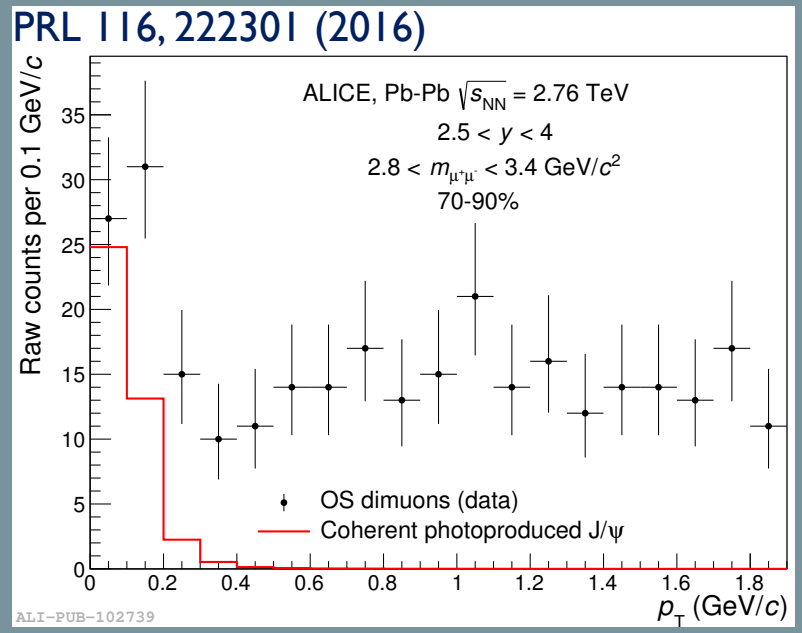
UPC candidate in the central barrel and muon spectrometer



Hadronic interaction with dimuon candidate

- Exclusive event
- Only vector meson decay detected
- VM photoproduction in UPC well-known process used to probe gluon distribution in the nucleus target at low-x





- J/Ψ very low p_T excess observed for the first time in peripheral Pb-Pb collisions (Run-1 data)
- Interpreted as coherent J/Ψ photoproduction for b < 2 x R_{Pb} !

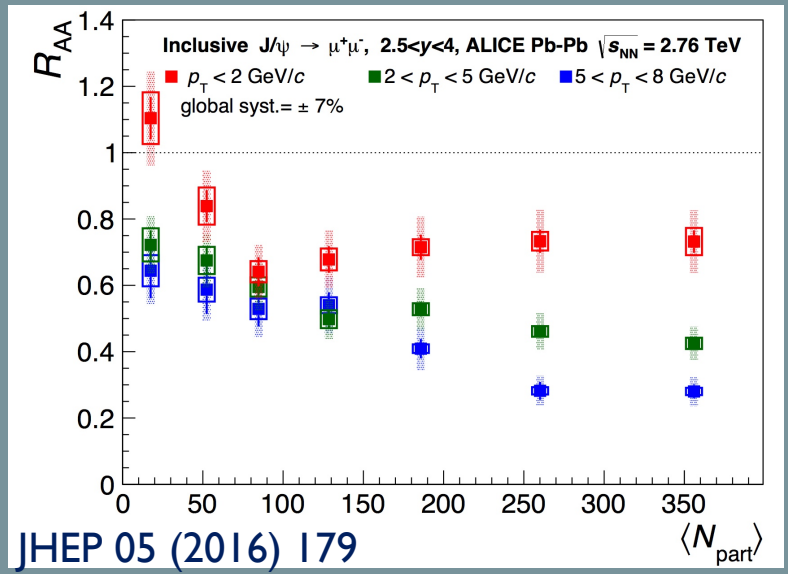
What can we learn from coherent J/Ψ photoproduction in AA collisions with nuclear overlap?

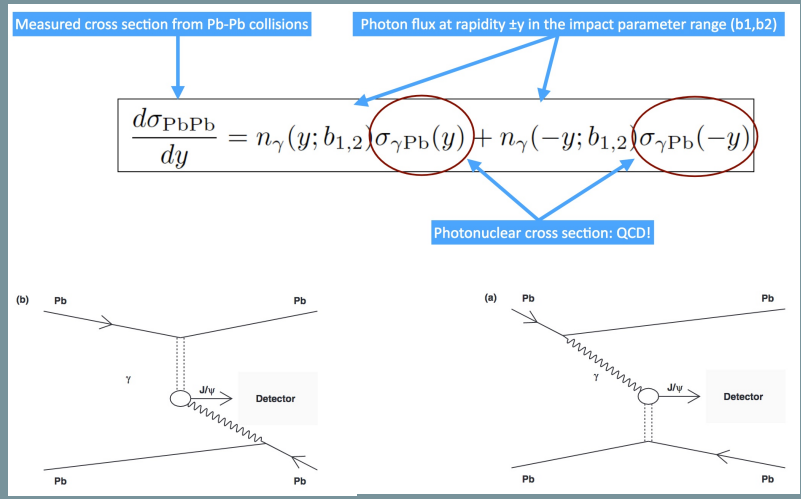
- Affects the J/Ψ R_{AA} measurement at very low p_T and therefore the study of hot nuclear matter effects in Pb-Pb collisions

- Opens new theoretical challenges:
  - How can the coherence condition survive when the nuclei is broken during the hadronic interaction? Do only spectator nucleons participate to the coherence?

- A potential new probe of charmonium color screening in the QGP?
  - Could be formed at the early stages of the collisions
  - Could be dissociated by color screening
  - Recombination of $c\bar{c}$ pairs would not contribute significantly to the very low p_T J/Ψ yield

- A novel way to access $\sigma_{\gamma Pb}$ when combined to UPC measurement
  - See : J.G. Contreras, arXiv:1610.03350



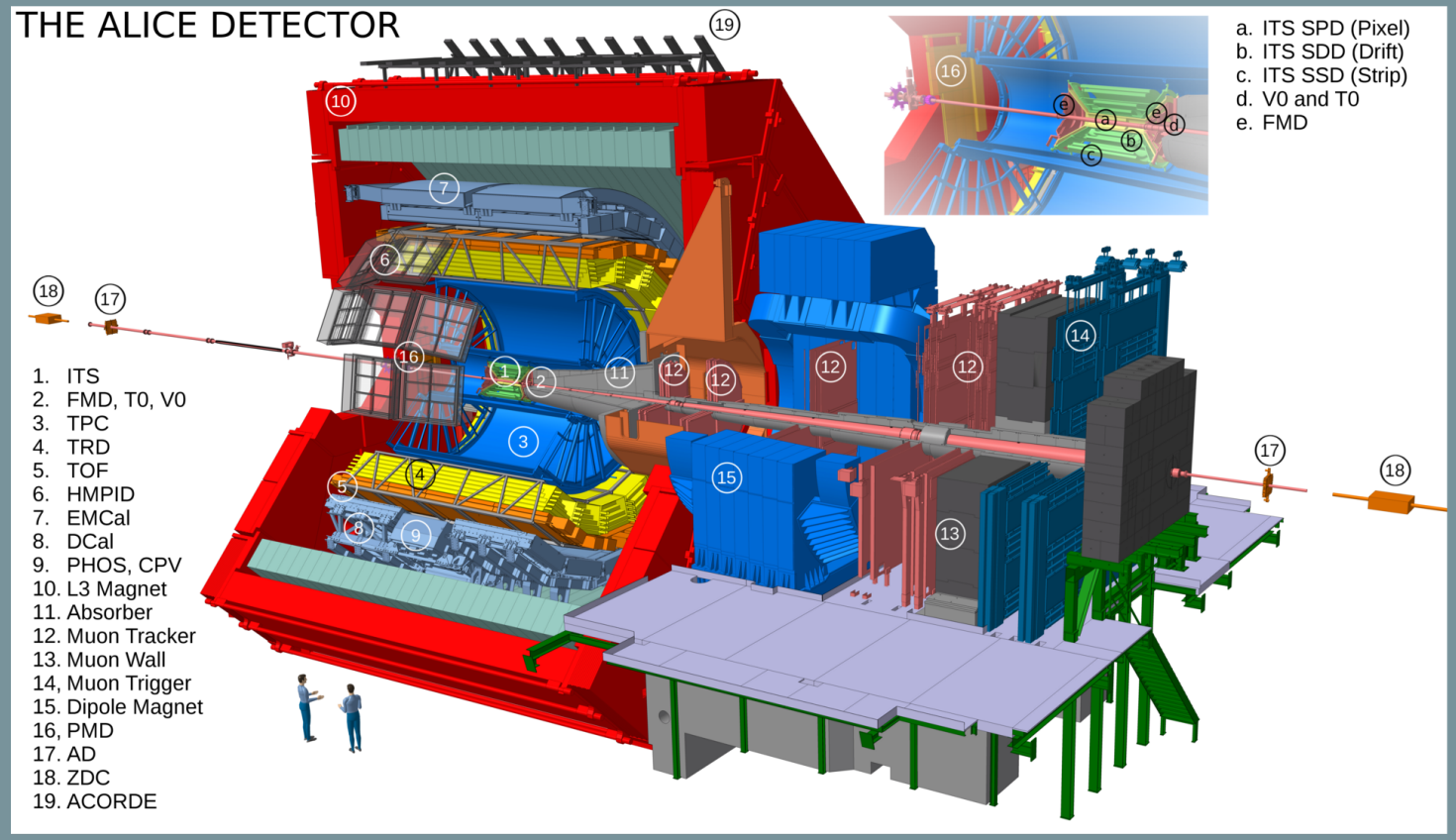


The ALICE apparatus (Run-II)

Central barrel :
$J/\Psi \rightarrow e^+e^-$
$|y| < 0.9$

2015 Pb-Pb (Run-II)
$\sqrt{s_{NN}} = 5.02$ TeV
$L_{int} \sim 10\ \mu b^{-1}$

ITS : tracking
TPC : tracking, PID



Muon spectrometer :
$J/\Psi \rightarrow \mu^+\mu^-$
$2.5 < y < 4$

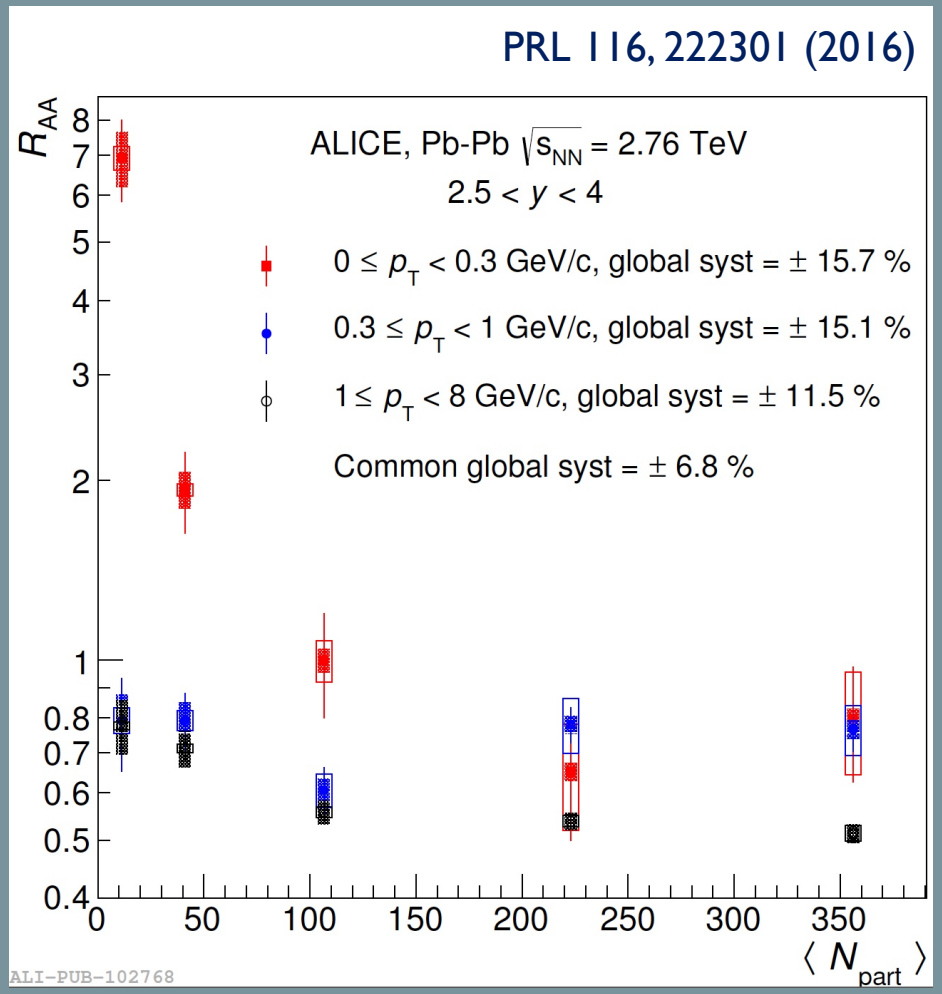
2011 Pb-Pb (Run-I)
$\sqrt{s_{NN}} = 2.76$ TeV
$L_{int} \sim 70\ \mu b^{-1}$
2015 Pb-Pb (Run-II)
$\sqrt{s_{NN}} = 5.02$ TeV
$L_{int} \sim 200\ \mu b^{-1}$

Muon tracker : tracking
Muon trigger : triggering

ITS : vertex reconstruction
ZDC : background rejection
V0 scintillators : triggering, centrality determination, background rejection

Coherent J/Ψ photoproduction at forward rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

PRL 116, 222301 (2016)



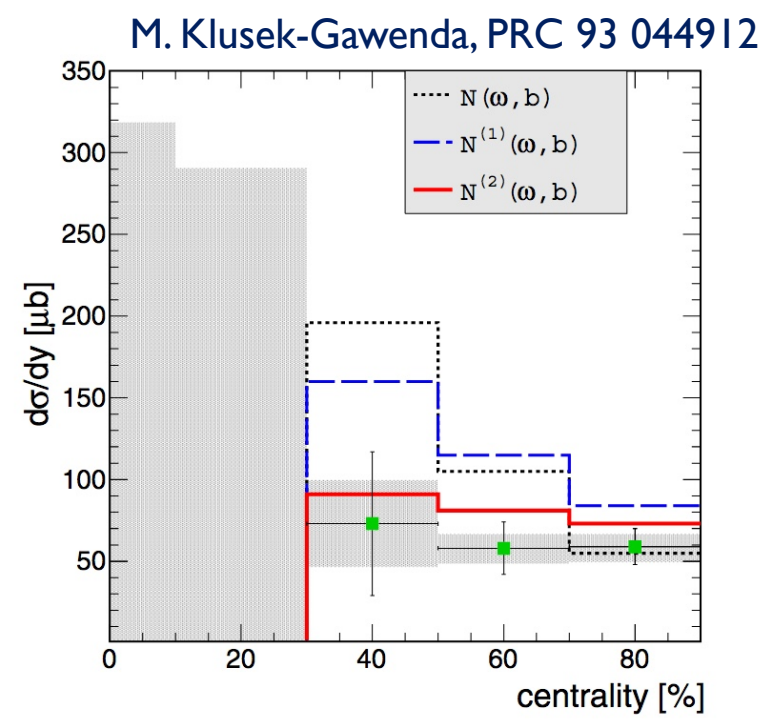
- Effect of the observed very low p_T J/ψ excess on the hadronic R_{AA}
  - For p_T < 0.3 GeV/c, J/ψ R_{AA} as large as 7
  - None of the recombination models predict such a pattern at LHC energies
  - Model with photoproduction + hadroproduction with QGP effects can reproduce the R_{AA} (W. Shi, PLB 777 (2018) 399-405)

- Measured coherent cross section

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

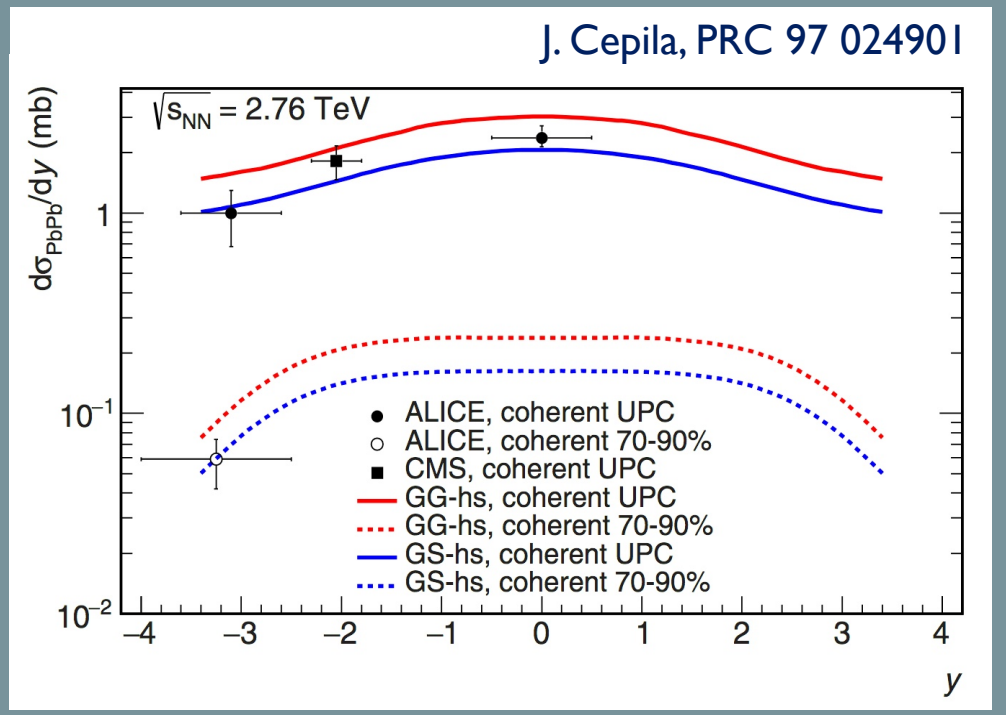
- Significance of the excess yield :
  - In centrality 70-90% : 5.4σ
  - In centrality 50-70% : 3.4σ
  - In centrality 30-50% : 1.4σ

Coherent J/Ψ photoproduction at forward rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV and model comparisons



- Vector dominance model
  - Standard photon flux (UPC)
  - Effective photon flux (considering nuclear overlap) / upper limit
  - Effective photon flux (considering spectator nucleons only) / lower limit
  - ALICE data
  - ALICE exp uncertainties

→ Best agreement with « lower limit » photon flux

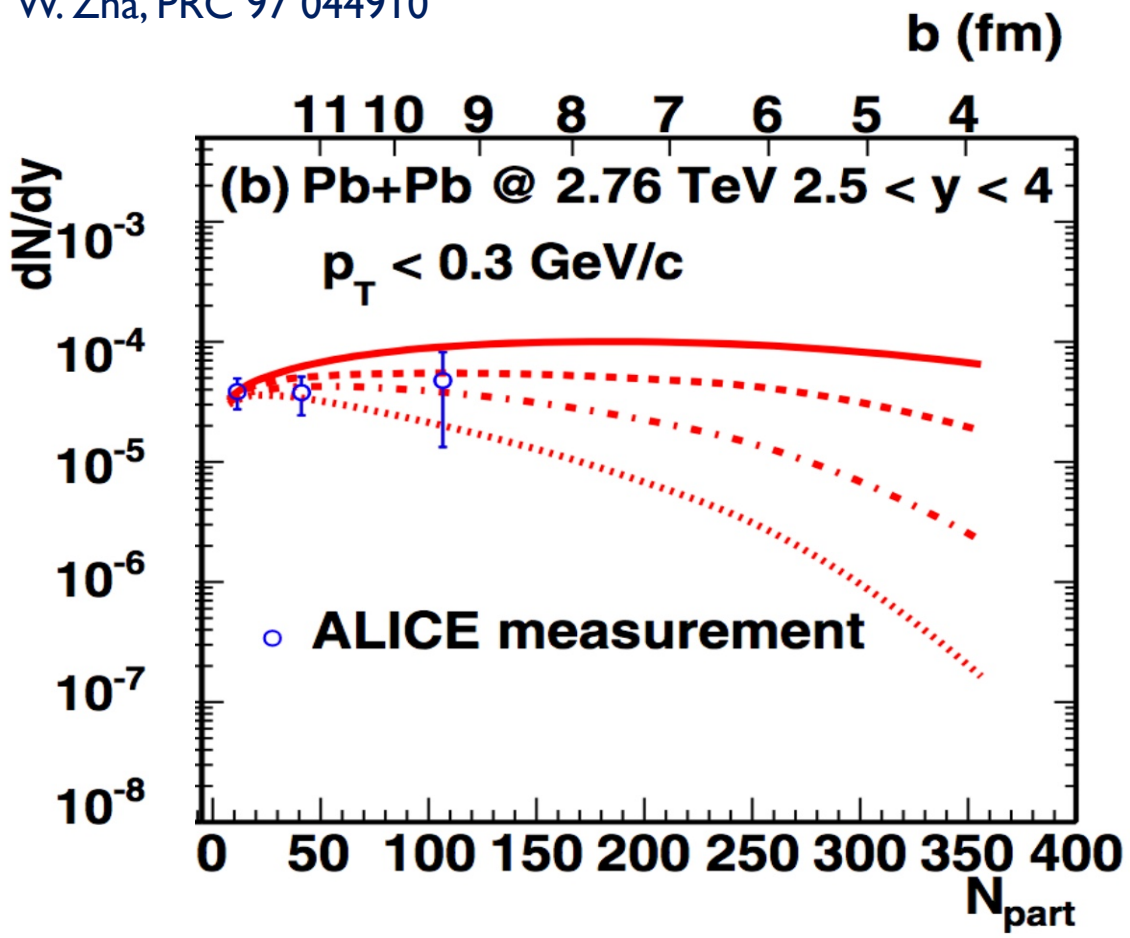


- Energy dependent hot-spot model calculations
- Extrapolation of γp to γPb interactions with:
  - Gribov-Glauber calculation (GG)
  - Geometric Scaling (GS)

→ Model describes both UPC and peripheral data (better agreement with GS calculation)

Coherent J/Ψ photoproduction at forward rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV and model comparisons

W. Zha, PRC 97 044910



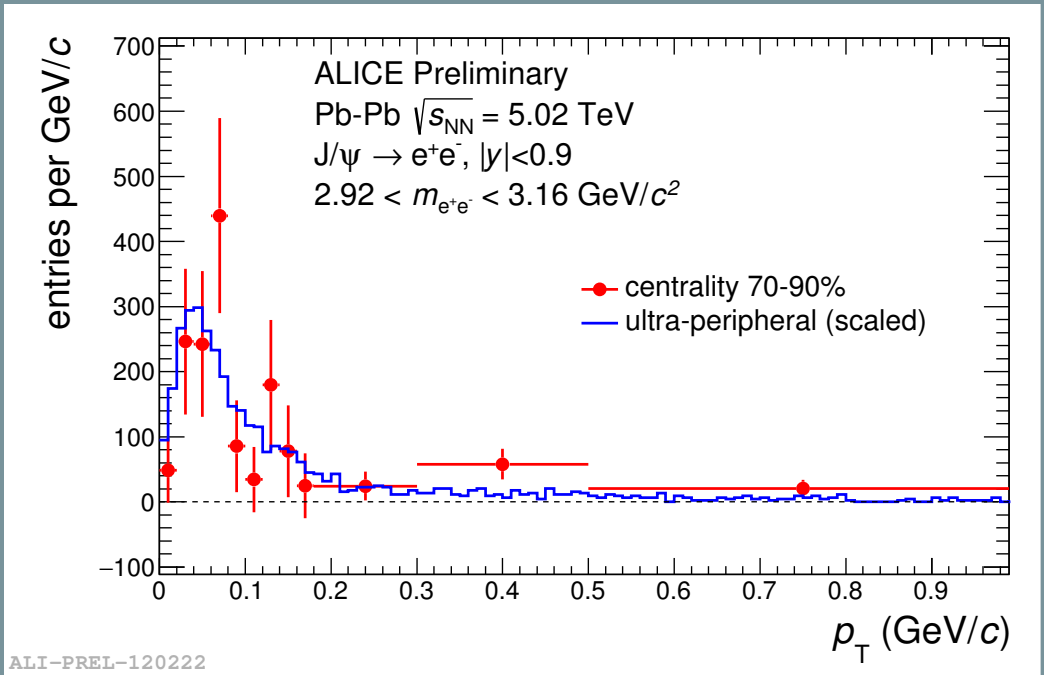
- Strong interactions in the overlapping region of incoming nuclei may disturb the coherent production, leaving room for different coupling assumptions:

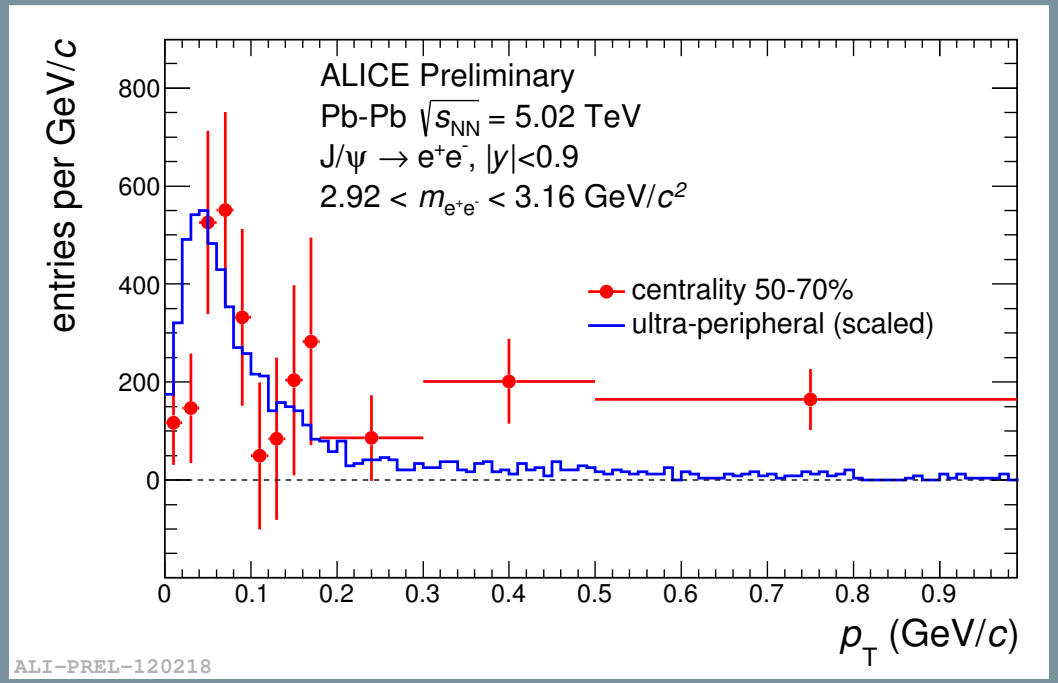
N + N	nucleus – nucleus (no hadronic interaction)
N + S	nucleus – spectator
S + N	spectator – nucleus
S + S	spectator - spectator

- ALICE Run-I data consistent with all 4 scenarios within uncertainties
- Need more precise data and measurement towards most central collisions (challenging!) to be able to disentangle the different scenarios

Coherent J/Ψ photoproduction at mid rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

- Very low p_T J/Ψ yield excess also observed at mid-rapidity in the dielectron channel, in peripheral collisions
- Good resolution at mid-rapidity allows for the excess p_T distribution measurement





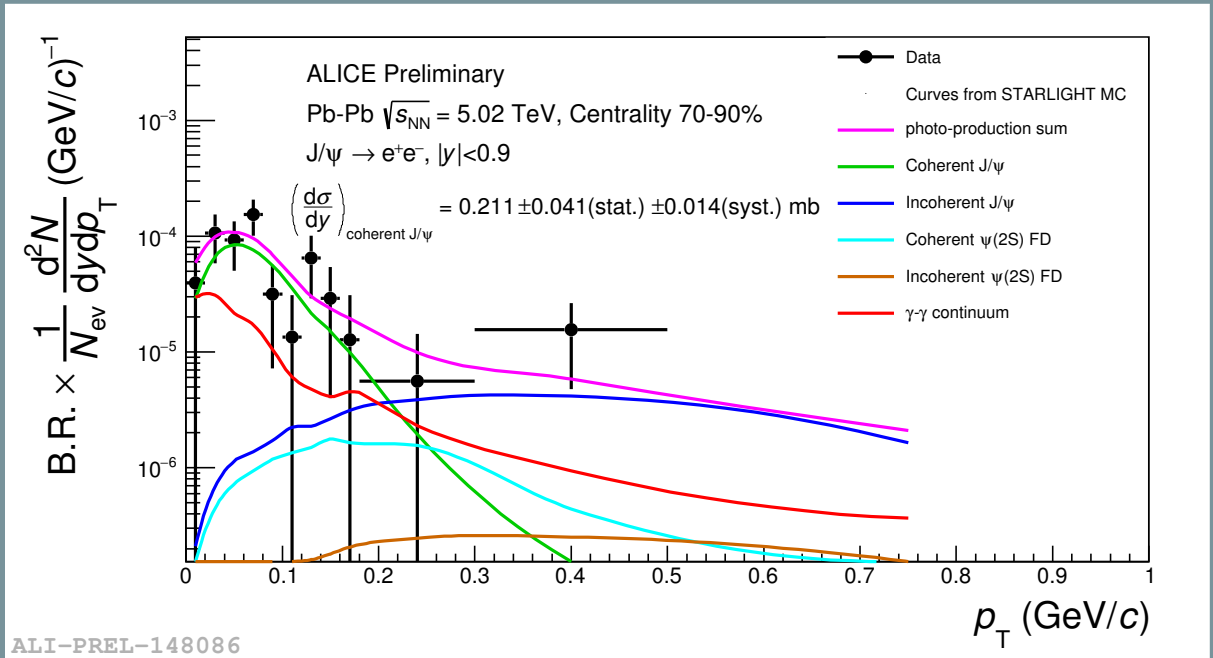
- Uncorrected dielectron p_T distribution in the J/Ψ mass range : same trend as coherent photoproduction UPC

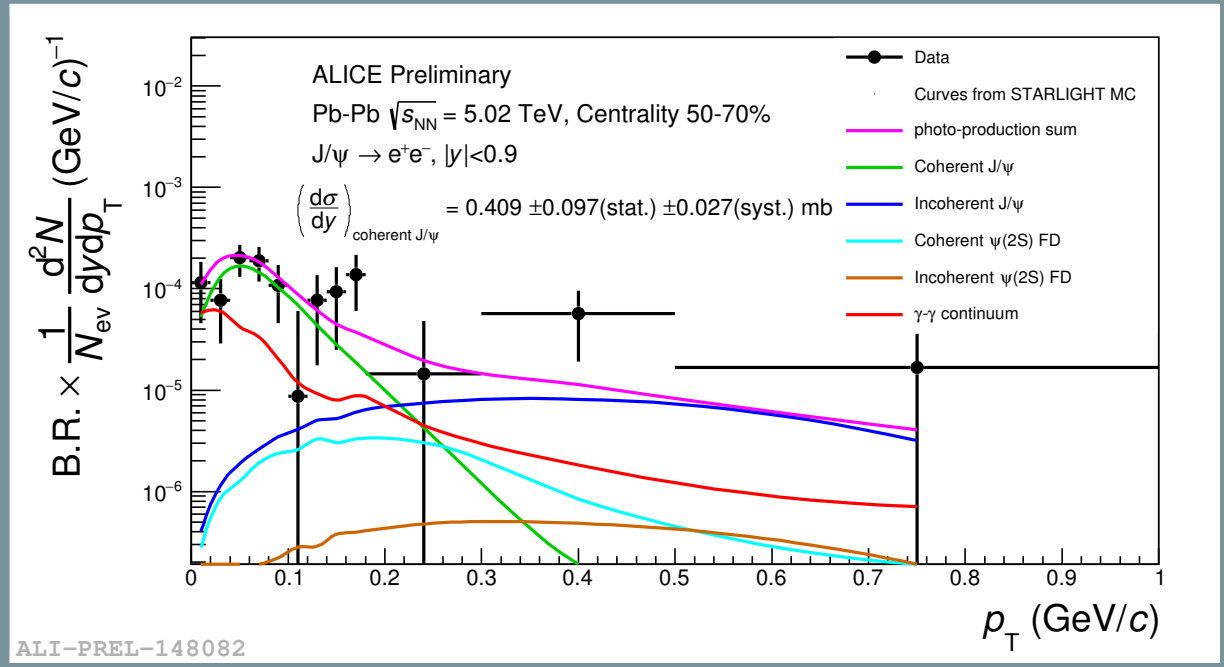
→ Strengthens the hypothesis that the excess origin is coherent photoproduction

- Differences can be seen at high p_T since contribution from hadronic J/Ψ is not subtracted

Coherent J/Ψ photoproduction at mid rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

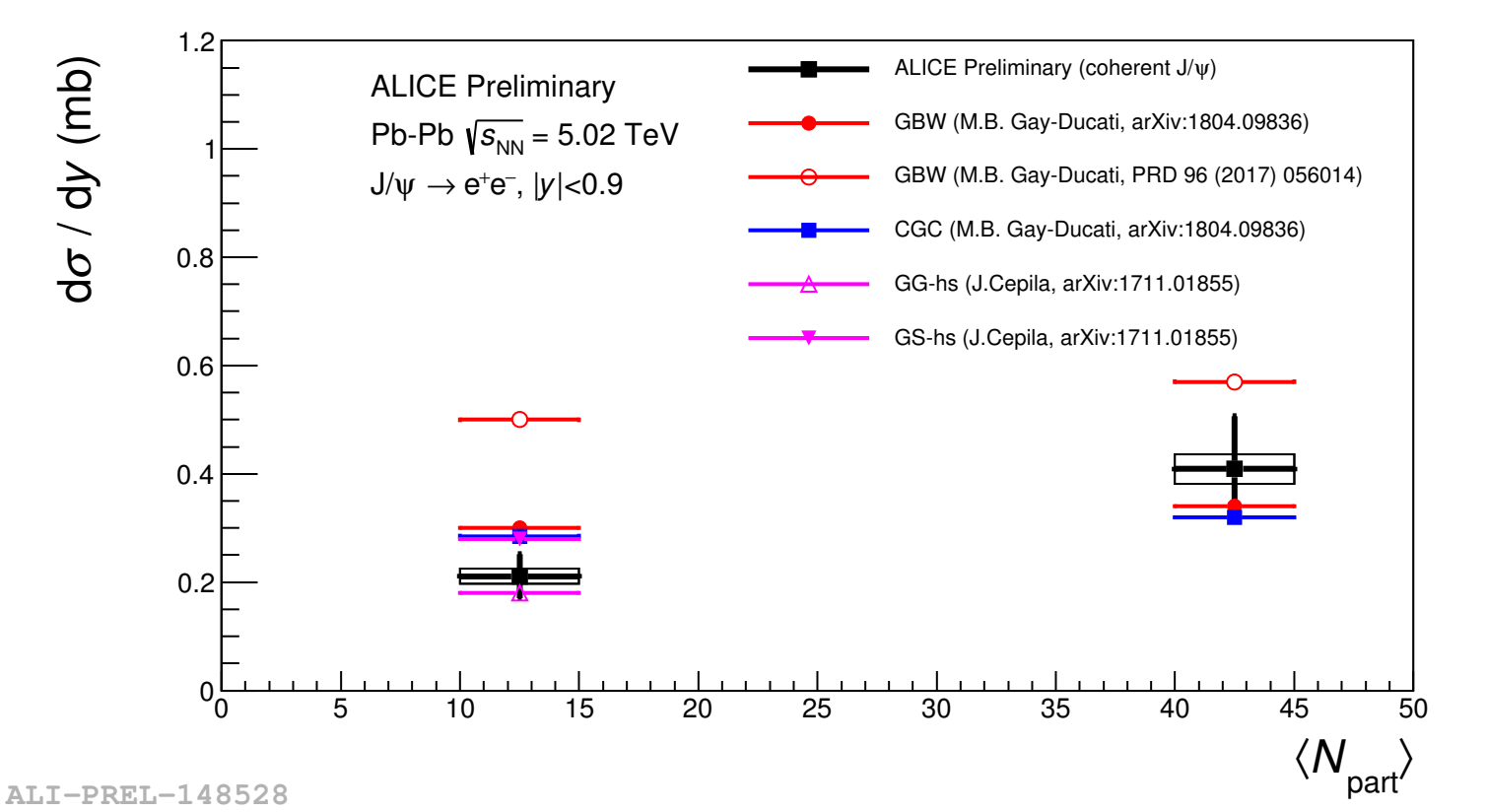
- Coherent J/Ψ photoproduction cross section has been extracted from a template fit (STARLIGHT + HIJING MC) of the corrected J/Ψ yield p_T distribution
- Relative contributions of the various processes are fixed to the UPC measurement values (overall scale is free)





Coherent J/Ψ photoproduction at mid rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

- Cross section comparison with models



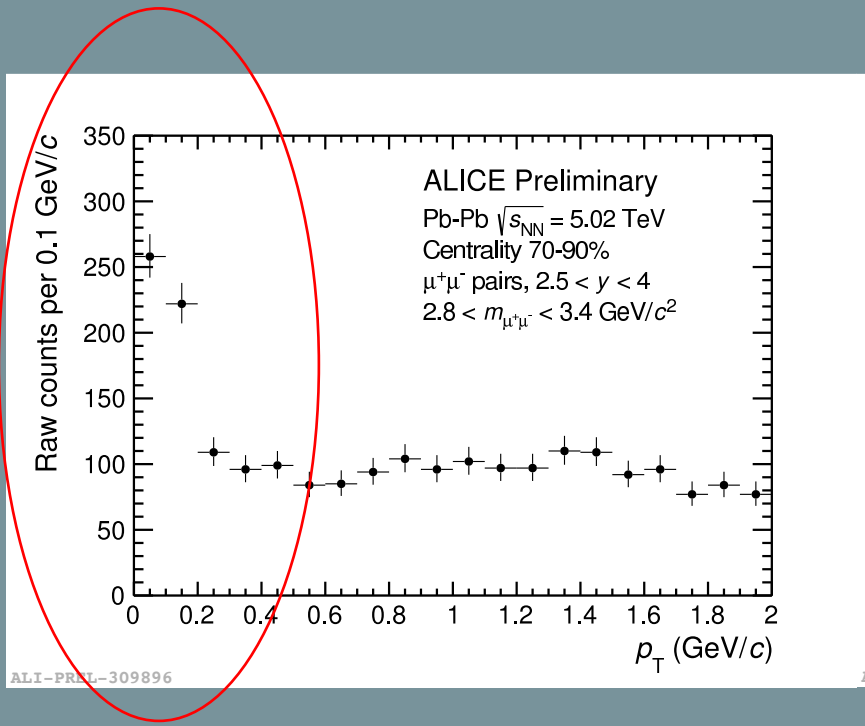
- Energy dependent hot-spot model
  - Gribov-Glauber calculation (GG)
  - Geometric Scaling (GS)
- Color Glass Condensate model
- GBW dipole model
  - modification of photon flux (2017)
  - modification of photon flux + photonuclear cross section (2018)

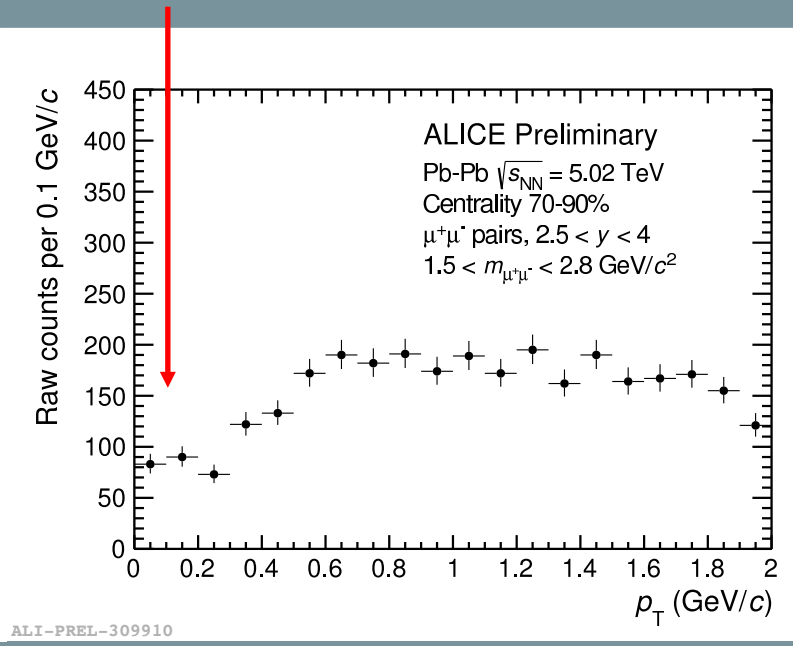
- Qualitative agreement is found with all models (apart the first version of GBW (2017) in which the modification of the photonuclear cross section was not accounted for)

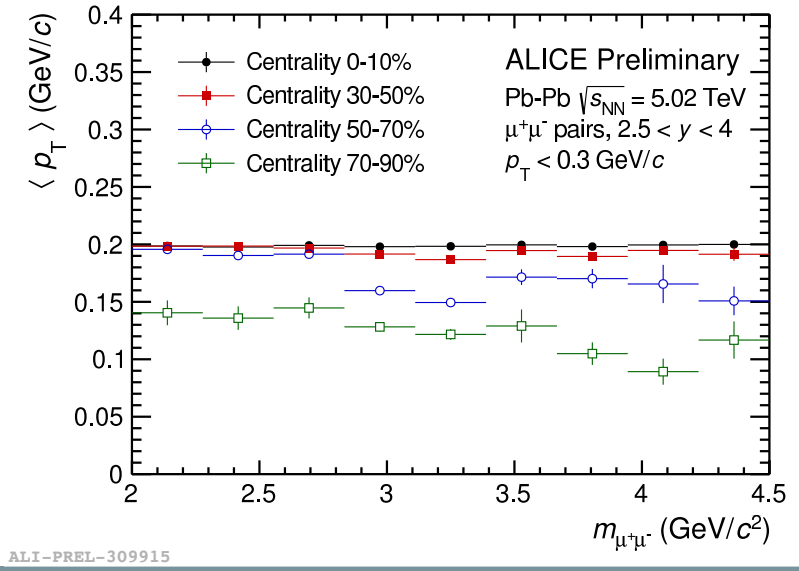
Coherent J/Ψ photoproduction at forward rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

NEW

- Very low p_T J/ψ excess also observed at forward rapidity at $\sqrt{s_{NN}}$ = 5.02 TeV in peripheral events
- A decrease of the dimuon $\langle p_T \rangle$ at the J/ψ mass is clearly seen at very low p_T in the centrality ranges 50-70%, 70-90% (hint in 30-50%) with respect to the centrality range 0-10%
- The decrease of the background $\langle p_T \rangle$ in the centrality range 70-90% could be an indication of the presence of γγ → μ+μ-

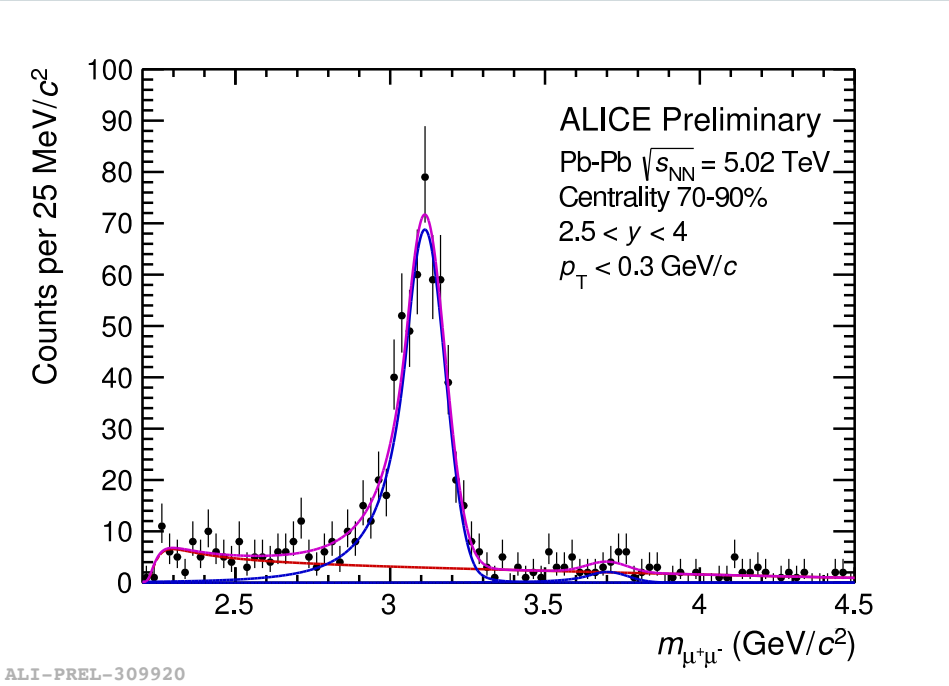






Coherent J/Ψ photoproduction at forward rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

NEW

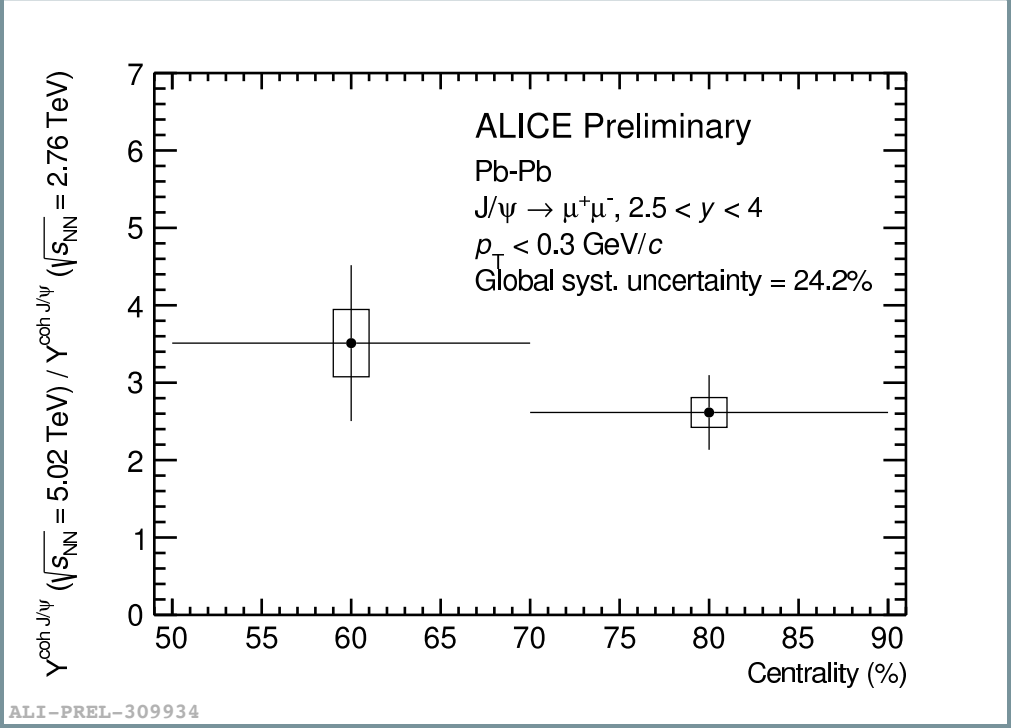


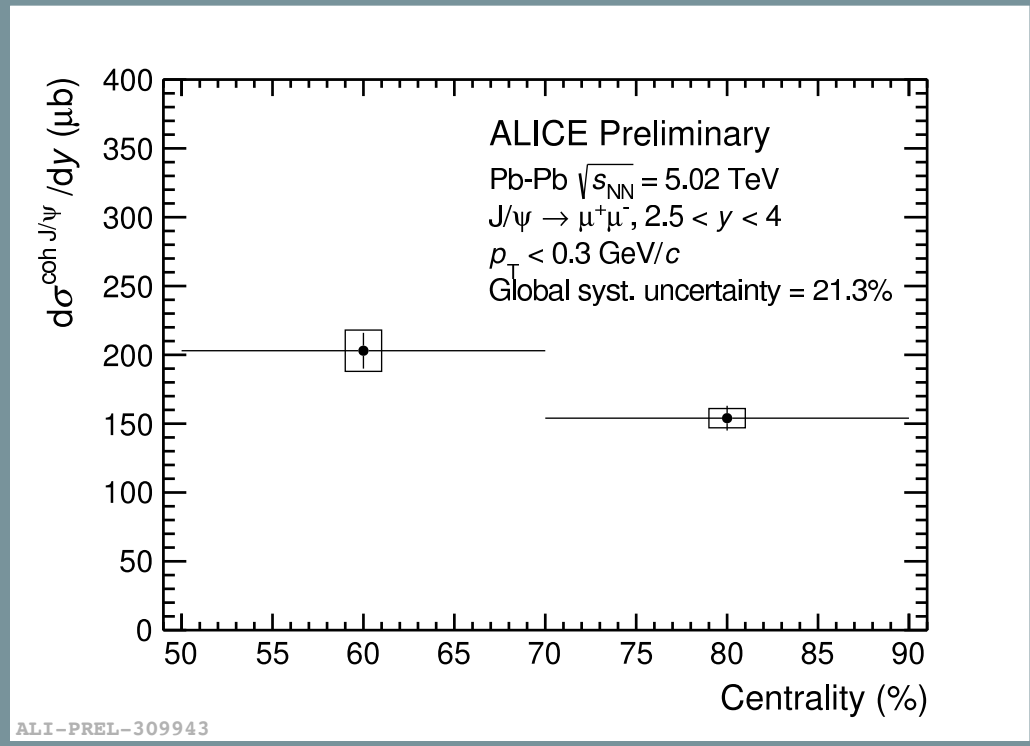
- Large J/Ψ signal almost background free in the centrality range 70-90% and for p_T ($\mu^+\mu^-$) < 0.3 GeV/c
- Increase of statistics ~ factor 10 with respect to Run-I analysis
- Hadronic J/Ψ background subtracted thanks to a modelization which uses as input the J/Ψ p_T distribution measurement in pp collisions at 5.02 TeV, the J/Ψ R_{AA} measurement in Pb-Pb at 5.02 TeV, and the Axε of hadronic J/Ψ from MC
- Significance of the raw excess : 14σ (centrality 70-90%), 10σ (centrality 50-70%)

Centrality	Raw $N_{J/\psi}$ excess
50-70%	628 ± 39 (stat) ± 46 (syst)
70-90%	477 ± 26 (stat) ± 21 (syst)

Coherent J/Ψ photoproduction at forward rapidity in peripheral Pb-Pb : comparison 2.76 TeV versus 5 TeV

NEW

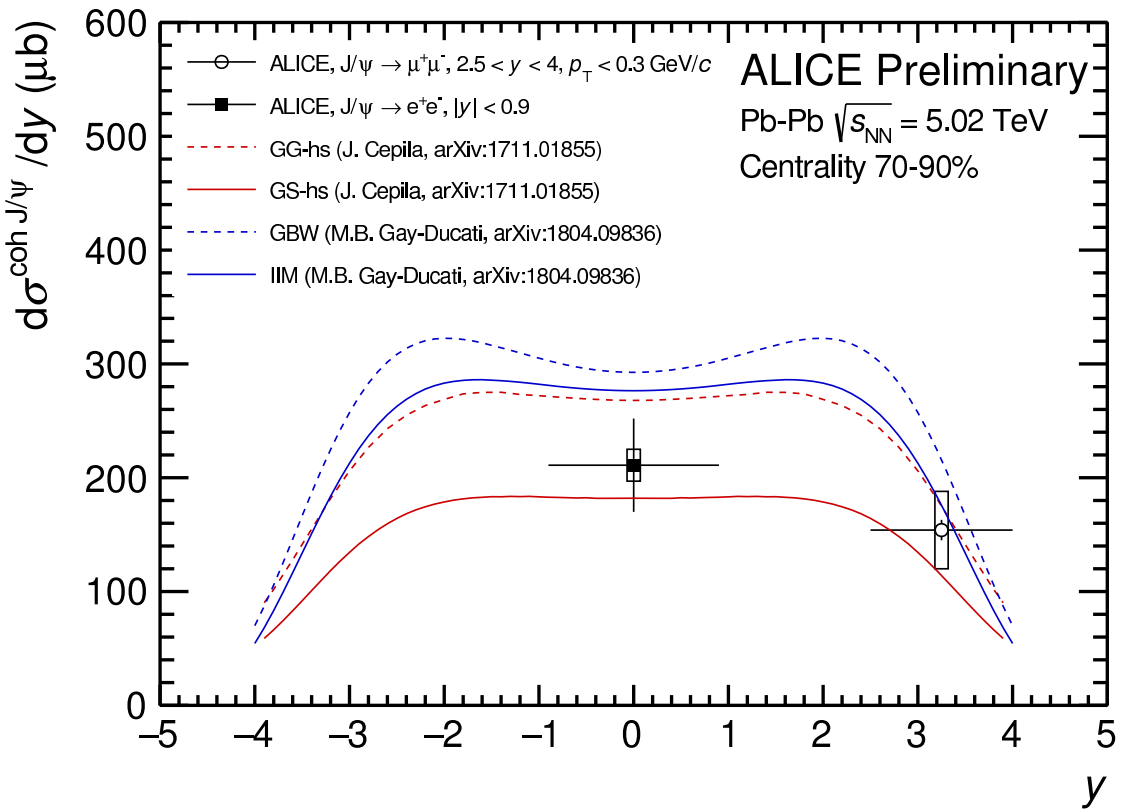




- Coherent J/ψ yield increases by ~ factor 2.5 in centrality range 70-90% between the two energies
- No strong centrality dependence is observed within uncertainties between 50-70% and 70-90% centrality ranges
- Coherent J/ψ cross section at 5.02 TeV is extracted from the yield ratio and cross section measurement at 2.76 TeV
- Cross section increases by ~ a factor 2.5 in the centrality range 70-90% with respect to 2.76 TeV
- Dominant uncertainty from unknown energy dependence of the fraction of incoherent J/ψ and J/ψ from coherent ψ(2S) decay → will improve thanks to new UPC measurement

Coherent J/Ψ photoproduction at forward rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV and comparison with models *NEW*

Centrality 70-90%

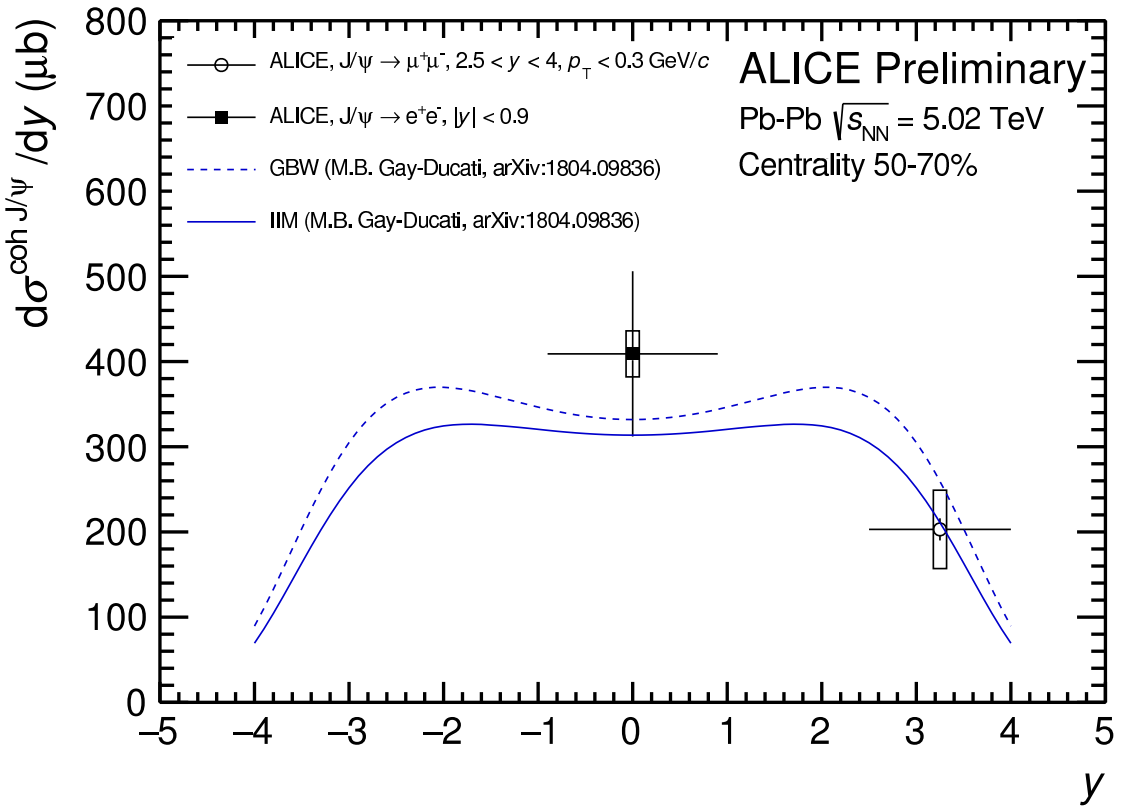


- Energy dependent hot-spot model calculations:
  - Gribov-Glauber calculation (GG)
  - Geometric Scaling (GS)
- GBW dipole model (2018)
- IIM model (CGC)

- As at $\sqrt{s_{NN}}$ = 2.76 TeV, the peripheral coherent J/ψ cross section at $\sqrt{s_{NN}}$ = 5 .02 TeV agrees qualitatively with the same models in all centrality ranges
- Dominant uncertainty from unknown energy dependence of the fraction of incoherent J/ψ and J/ψ from coherent ψ(2S) decay → will improve thanks to new UPC measurement

Coherent J/Ψ photoproduction at forward rapidity in peripheral Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV and comparison with models *NEW*

Centrality 50-70%



- GBW dipole model (2018)
- IIM model (CGC)

- As at $\sqrt{s_{NN}}$ = 2.76 TeV, the peripheral coherent J/ψ cross section at $\sqrt{s_{NN}}$ = 5 .02 TeV agrees qualitatively with the same models in all centrality ranges

- Dominant uncertainty from unknown energy dependence of the fraction of incoherent J/ψ (f_I) and J/ψ from coherent ψ(2S) decay (f_D)

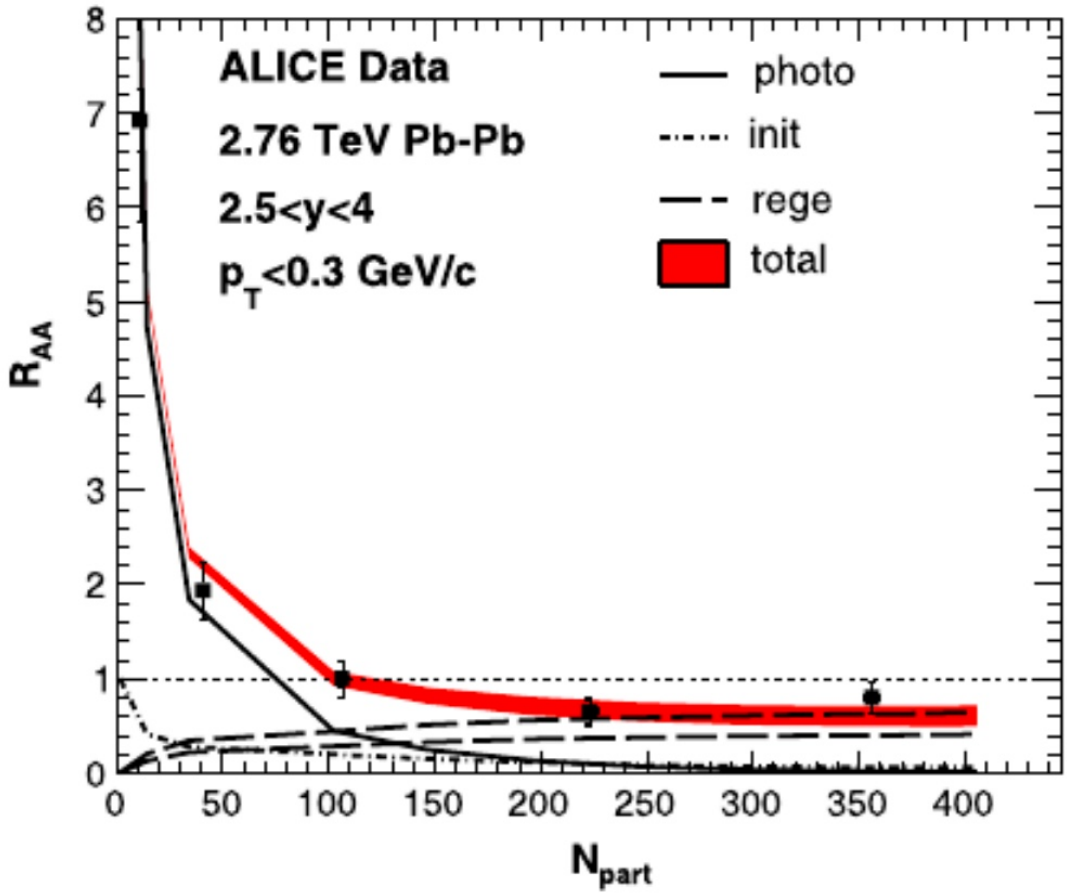
→ will improve thanks to new UPC measurement

Conclusion

- Excess in the yield of J/ψ at very low p_T observed in peripheral Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV confirmed both at mid and forward rapidity at $\sqrt{s_{NN}}$ = 5.02 TeV
- J/Ψ coherent photoproduction mechanism seems supported by the measured shape of the excess p_T distribution at mid-rapidity
- Results from new forward analysis! → will be extended towards more central events (stay tuned!)
- Models used to describe UPC data and modified to account for nuclear overlap region qualitatively reproduce the data
- Future 2018 Pb-Pb run opens new experimental perspectives:
  - The centrality dependence of the J/Ψ excess p_T distribution at mid-rapidity
  - Forward rapidity cross section measurement in most central collisions
  - Excess polarization
  - Other vector mesons
  - Combine UPC and peripheral measurements to extract $\sigma_{\gamma Pb}(y)$ and $\sigma_{\gamma Pb}(-y)$

Back up

W. Shi et al., PLB 777 (2018) 399-405



- Charmonium coherent photoproduction and hadroproduction treated consistently with modifications from both cold and hot nuclear matter effects

Coherent J/Ψ photoproduction at forward rapidity in peripheral Pb-Pb : systematic uncertainties *NEW*

ALICE

❑ Systematic uncertainties on the yield ratio

Source	2.76 TeV	5.02 TeV
Signal extraction	5.9-10%	4.4-7.3%
Centrality dependence of efficiency loss	0-0.5%	0-0.5%
MC input	3%	3%
Tracking efficiency	11%	3%
Trigger efficiency	3.6 %	2.8%
Matching efficiency	1%	1%
Normalisation	3.6%	0.5%
Uncertainty on the energy dependence of the fraction of incoherent J/ψ (f_I) and J/ψ from coherent ψ(2S) decay (f_D)	20%	

❑ Systematic uncertainties on the cross section

Source	5.02 TeV
Signal extraction	4.4-7.3%
Centrality dependence of efficiency loss	0-0.5%
MC input	3%
Tracking efficiency	3%
Trigger efficiency	2.8%
Matching efficiency	1%
Normalisation	0.5%
Uncertainty on the energy dependence of the fraction of incoherent J/ψ (f_I) and J/ψ from coherent ψ(2S) decay (f_D)	20%
BR	1%
σ_{PbPb}	XX %

❑ Dominant uncertainty from unknown energy dependence of f_I+ f_D → will improve thanks to new UPC measurement