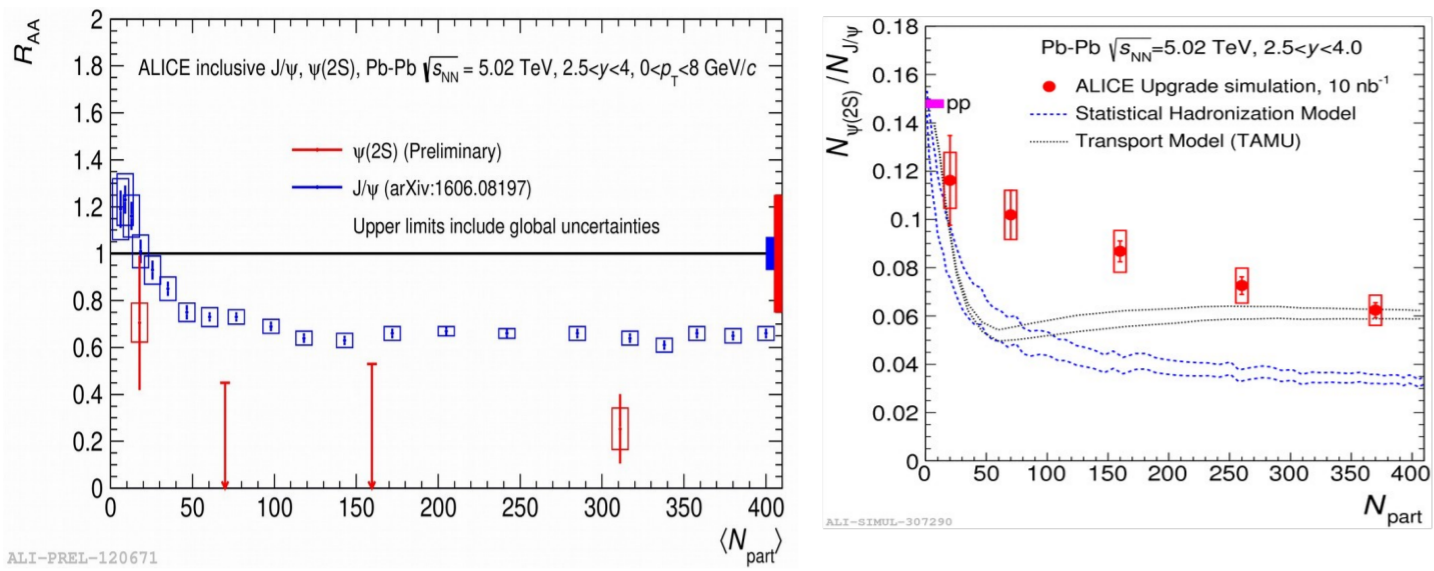


INTRODUCTION



- At high energy density ($\sim 1 \text{ GeV/fm}^3$) nuclear matter undergoes a phase transition from a confined state to a state of deconfined quarks and gluons, called quark-gluon plasma (QGP).
- In the presence of the QGP, quarkonia show suppression due to the Debye screening and dissociation. Hence quarkonia can be used as a probe to study the deconfined medium.
- Sequential dissociation of quarkonia states in medium according to their binding energies leads to stronger suppression of $\psi(2S)$ with respect to J/ψ .
- Recombination of charmonium states at LHC due to large charm quark densities observed for J/ψ at $\sqrt{s_{NN}} = 5.02$ TeV [1].
- $\psi(2S)$ -to- J/ψ ratio measurements weakly dependent on charm production cross section employed as inputs to the models in Pb—Pb collisions \rightarrow **important constraints on models [3,4]**.
- Hint for stronger suppression of $\psi(2S)$ compared to J/ψ observed with ALICE preliminary data using 2015 Pb—Pb statistics; however large uncertainties prevent a strong conclusion.
- New ALICE results available including 2018 Pb—Pb sample (~ 3 times higher statistics), provide more precise results.**

ALICE DETECTOR

V0 detectors (V0A: $2.8 < \eta < 5.1$ & V0C: $-3.7 < \eta < -1.7$)

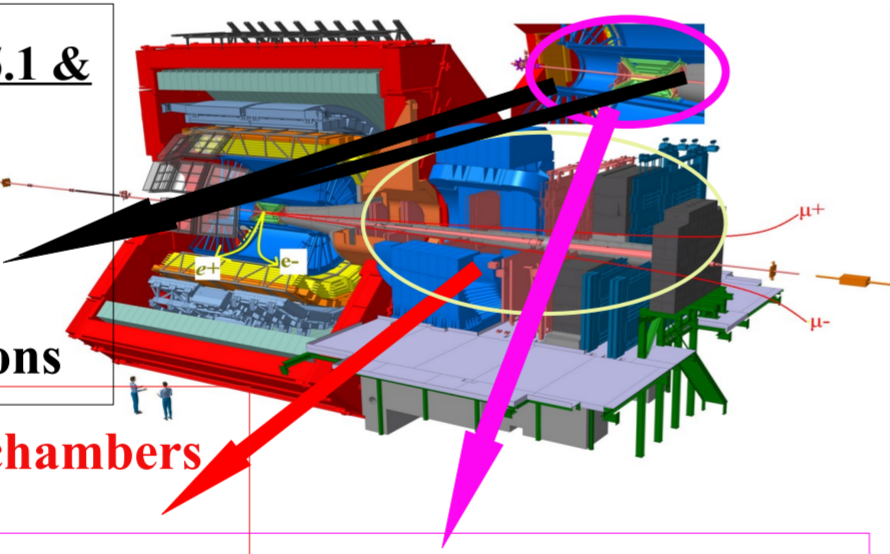
Triggering, background rejection and centrality estimation in Pb—Pb collisions

Muon tracking and trigger chambers

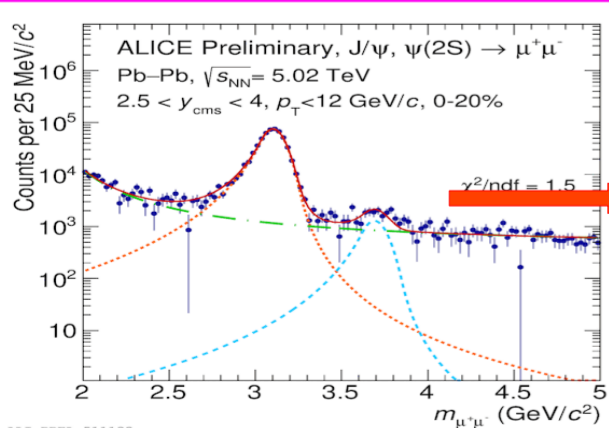
Inclusive $J/\psi, \psi(2S) \rightarrow \mu^+\mu^-$

$-4.0 < \eta < -2.5$

SPD : primary vertex determination



ANALYSIS DETAILS



The $\psi(2S)$ raw yield in Pb-Pb is obtained by fitting the invariant mass spectra after combinatorial background subtraction with mixed-event technique; several functions used for describing signal and residual background shapes.

- Acceptance times efficiency corrections computed through a realistic monte carlo simulation (p_T and y distributions of J/ψ and $\psi(2S)$ tuned on data).
- Reference measurement is obtained from the study of $\psi(2S)$ cross sections in pp collisions at $\sqrt{s} = 5.02$ TeV [2].

REFERENCES

- J. Adam et al., ALICE Collaboration, *Phys. Lett.* **B 766** (2017) 212.
- S. Acharya et al., ALICE Collaboration, **arXiv:2109.15240**.
- X. Du. and R.Rapp, *Nucl. Phys.* **A943** (2015) 147.
- A. Andronic et al., *Nature* **561** no. **7723** (2018) 321.

OBSERVABLES

Nuclear modification factor (R_{AA})

$$R_{AA} = \frac{Y_{AA}^{\psi(2S)}}{\langle T_{AA} \rangle \cdot \sigma_{pp}^{\psi(2S)}}$$

where $Y_{AA}^{\psi(2S)}$ is the $\psi(2S)$ corrected yield in AA, $\sigma^{\psi(2S)}_{pp}$ is the cross section in pp collisions and T_{AA} is the nuclear overlap function.

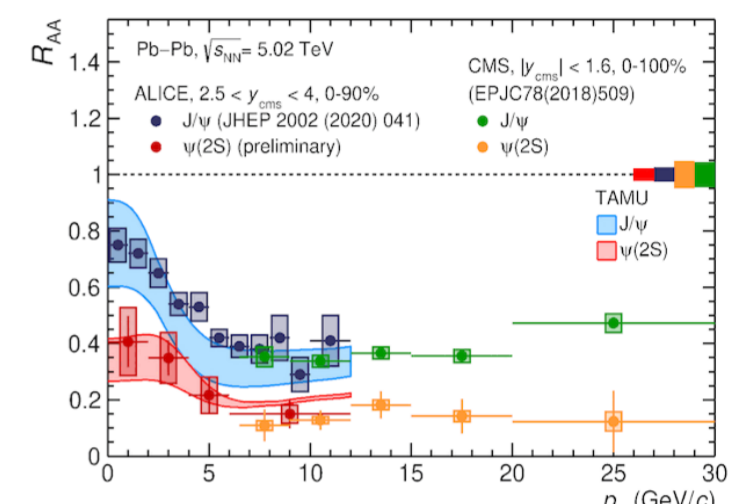
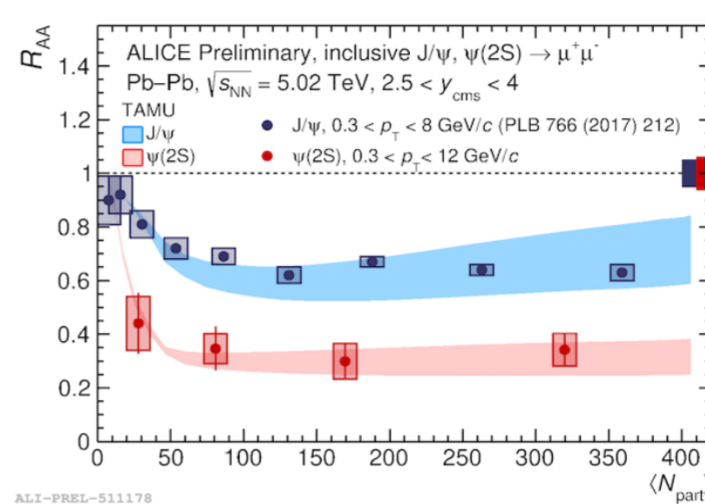
Ratio of $\psi(2S)$ -to- J/ψ

$$\text{Single Ratio} = \frac{BR \sigma_{\psi(2S)}}{BR \sigma_{J/\psi}}$$

$$\text{Double Ratio} = \frac{[\sigma_{\psi(2S)}/\sigma_{J/\psi}]_{PbPb}}{[\sigma_{\psi(2S)}/\sigma_{J/\psi}]_{pp}}$$

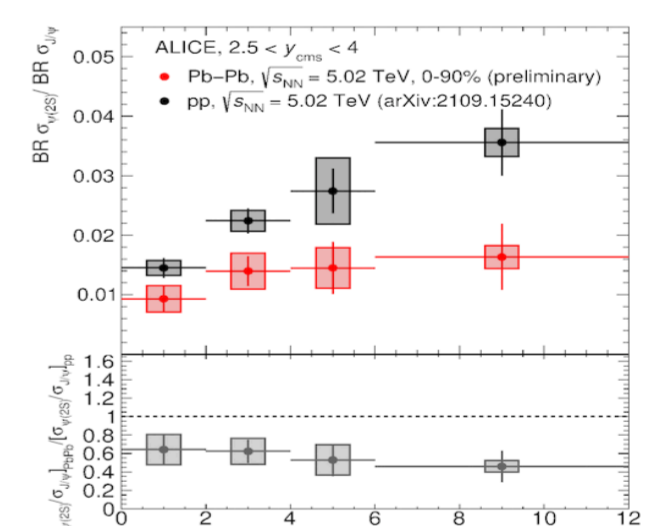
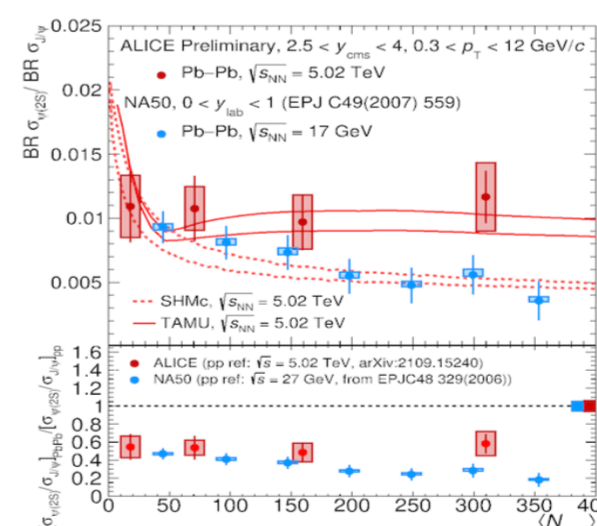
BR is the branching ratio of $J/\psi, \psi(2S) \rightarrow \mu^+\mu^-$
 $\sigma_{J/\psi}$ & $\sigma_{\psi(2S)}$ represent the cross section of both states.

R_{AA} VS p_T & CENTRALITY



- $\psi(2S)$ significantly suppressed as a function of p_T and centrality, and shows stronger suppression than the J/ψ .
- Increasing trend of R_{AA} towards low p_T and suppression at high- p_T observed for both charmonium states..
- TAMU model [3], which includes charmonium regeneration, reproduces the centrality and p_T dependence of R_{AA} for both J/ψ and $\psi(2S)$.
- Good agreement between CMS and ALICE data in common p_T range, in spite of different rapidity coverage.

DOUBLE & SINGLE RATIOS VS p_T & CENTRALITY



- Significant suppression of $\psi(2S)$ -to- J/ψ ratio in Pb-Pb with respect to pp
- No significant centrality or p_T dependence is observed.
- TAMU model [3] reproduces the cross section ratios over centrality, while SHM [4] tends to underestimate the data in central Pb—Pb collision.

CONCLUSIONS

- No significant p_T or centrality dependence of the $\psi(2S)$ - to- J/ψ double ratio observed within the uncertainties.
- The $\psi(2S)$ R_{AA} shows a significant decrease as a function of p_T as expected from the contribution of charm quark regeneration at low p_T .
- Comparison of J/ψ and $\psi(2S)$ R_{AA} with transport and statistical hadronisation models shows a fair agreement within uncertainties.
- Transport model, that includes recombination of charm quarks in the QGP phase, better reproduces the $\psi(2S)$ -to- J/ψ ratio for central events.