ψ(2S) production in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ =5.02 TeV with ALICE

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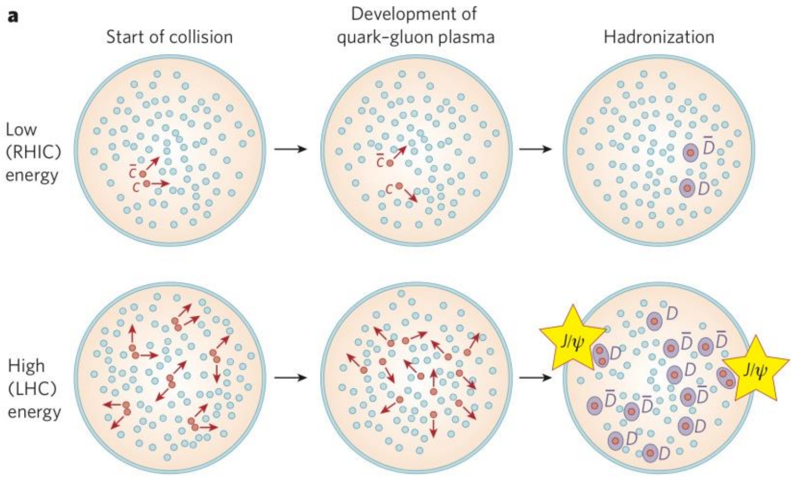
The 10th China LHC Physics Conference

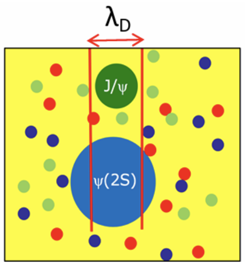
Quarkonium as a probe of QGP in Pb−Pb



Braun-Munzinger, P., Stachel, J. *Nature* **448**, 302–309 (2007).

Phys. Lett.B 178 (1986) 416–422
Phys. Rev. Lett. 92 (2004) 212301
Phys. Lett. B 490 (2000) 196–202
Phys. Rev. D 64 (2001) 094015
Nucl. Phys. A 943 (2015) 147–158
Nature **448**, (2007) 302–309

- Suppression of the direct charmonium due to color screening and dissociation.
- Recombination enhanced the charmonium production close to the transition at LHC energies.



ψ(2S) and J/ψ:

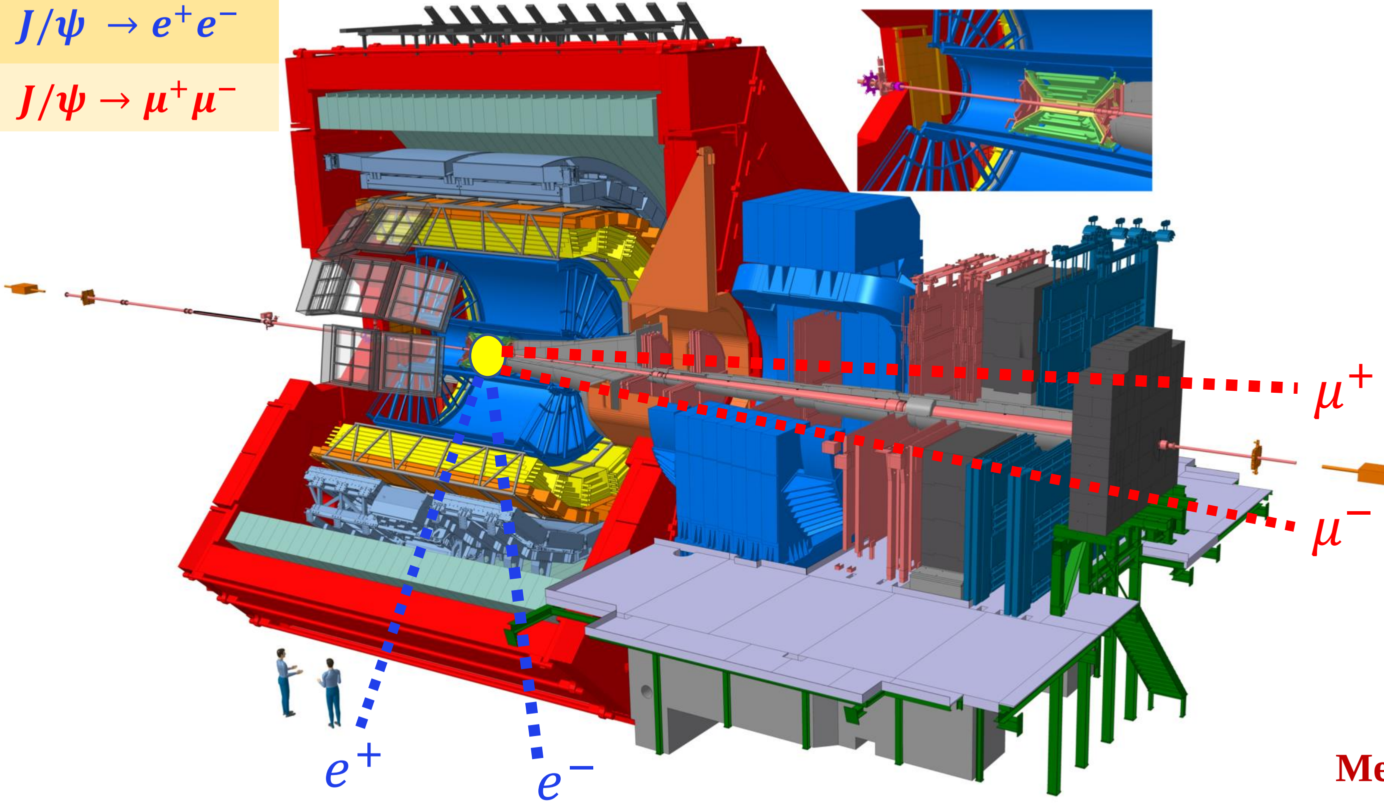
- A factor of 10 differ in binding energy.
- A factor of 2 differ in system size.

Studying both J/ψ and ψ(2S) can provide insightful information to test the recombination models.

Quarkonium measurements with ALICE detector

$J/\psi \rightarrow e^{+}e^{-}$

$J/\psi \rightarrow \mu^{+}\mu^{-}$



Muon spectrometer
Trigger and tracking for muons
Acceptance : 2.5<y<4.0

Inner Tracking System
Tracking, vertex reconstruction

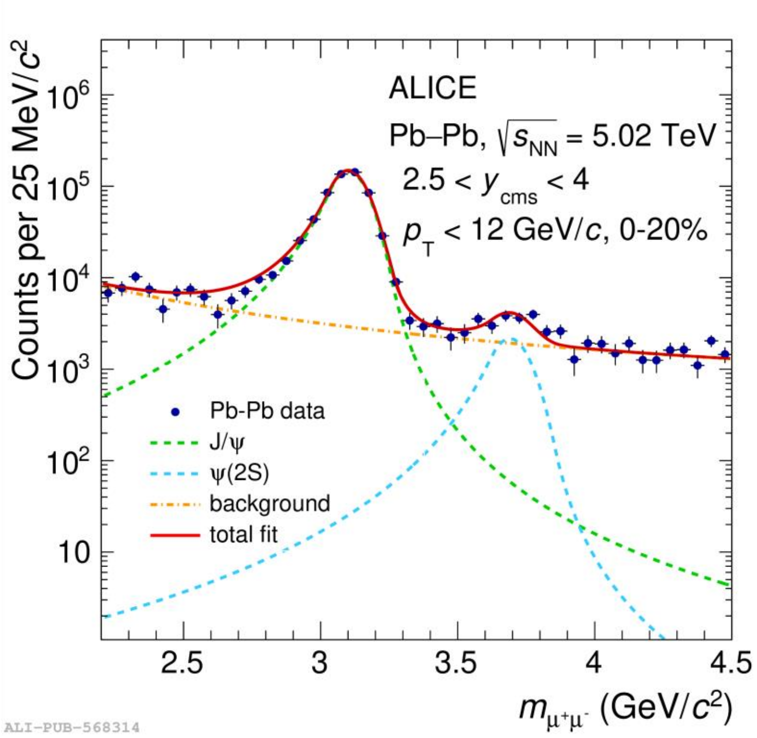
V0 Detector
Centrality determination triggering, and reaction plane measurement

Time Projection Chamber
Tracking, particle identification

Measured p_{T} can be down to 0

Signal extraction procedure of in Pb-Pb

- Data collected in 2015 and 2018, corresponding to an integrated luminosity of $L_{int} \sim 750\ \mu b^{-1}$.
- ψ(2S) and J/ψ yield extracted by least X^2 fits to the opposite sign dimuon invariant mass spectrum.
- In total, $N_{\psi(2S)} \approx 1.3 \times 10^4, N_{J/\psi} \approx 9.2 \times 10^5$.



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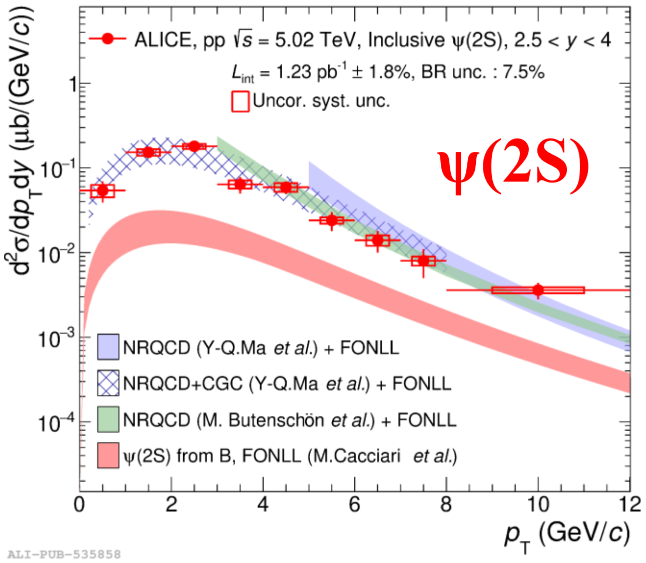
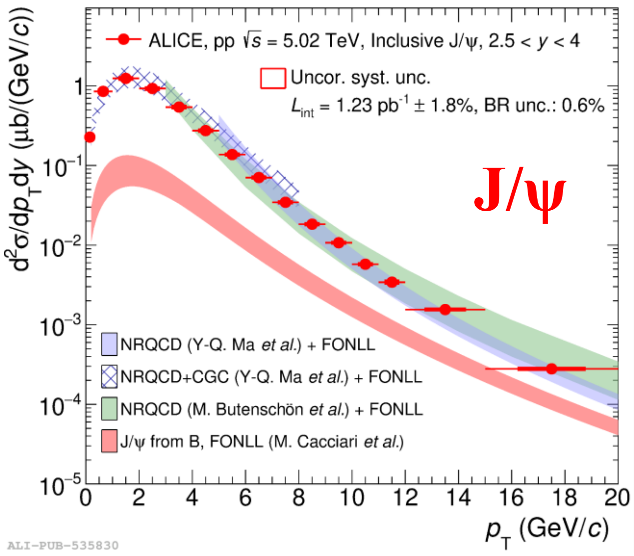
pp reference at $\sqrt{s}$ =5.02 TeV

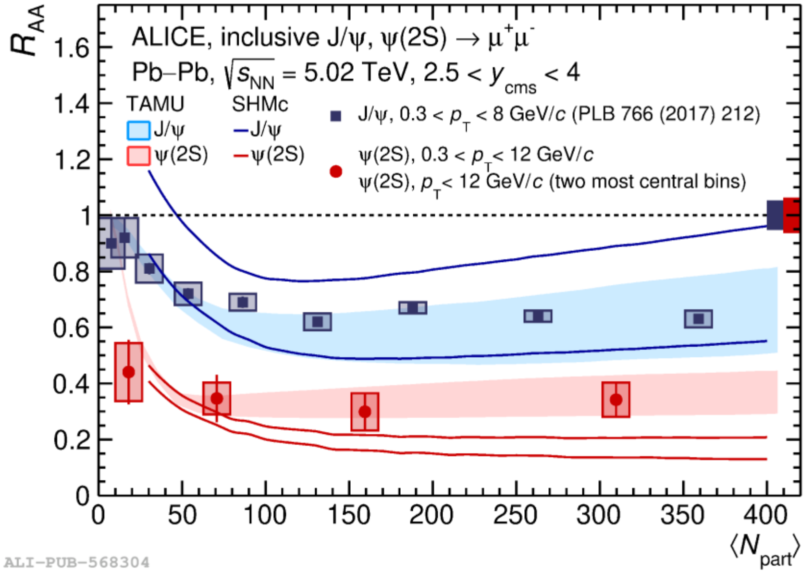




Eur. Phys. J. C 83 (2023) 61

- $\sigma_{J/\psi}$ (p_T<20 GeV/c) = 5.88 ± 0.03 ± 0.34 μb; $\sigma_{\psi(2S)}$ (p_T <12 GeV/c) = 0.87 ± 0.06 ± 0.10 μb.
- Data are well described by models within uncertainties.

Centrality dependence of R_{AA}



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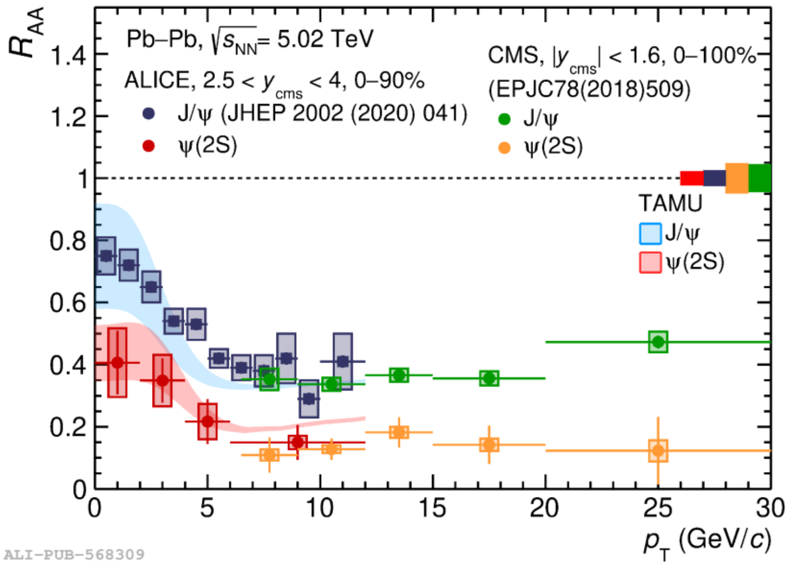
- No centrality dependence is observed for ψ(2S) R_{AA}.
- ψ(2S) is more suppressed.
- Statistical Hadronization Model (SHMc) underestimates ψ(2S) R_{AA} in central collisions, but reproduces J/ψ R_{AA} well.
  (Phys Lett B797 (2019) 134836)
- Transport Model (TAMU) agrees with data well.
  (Nucl. Phys. A 943 (2015) 147-158)

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{d^2 N_{AA}/dy dp_T}{d^2 \sigma_{pp}/dy dp_T}$$

p_T dependence of R_{AA}



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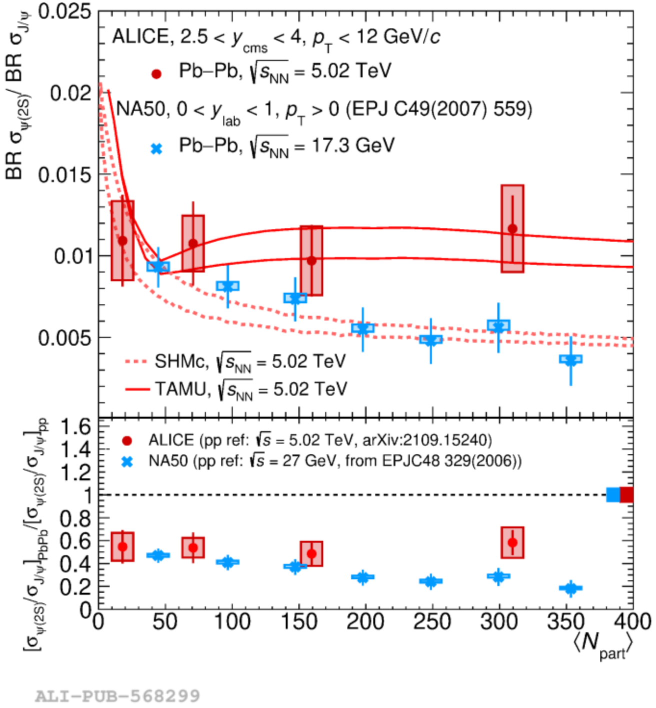
- Measurements agree with CMS measurements at overlapping p_T range.
- ψ(2S) shows a stronger suppression over the full p_T range.
- Smaller suppression at low p_T.
- TAMU model reproduces both centrality and p_T dependence of R_{AA} for both ψ(2S) and J/ψ.

→Hint of regeneration at low p_T.

Centrality dependence of single and double ratio

- Flat centrality dependence for ψ(2S)-to-J/ψ (double) ratio at the LHC.
- SPS results reach smaller ψ(2S)-to-J/ψ single and double ratios values for central events.
- the ψ(2S) suppression in Pb–Pb w.r.t pp is larger than the J/ψ one by a factor ~2
- SHMc underestimates the ψ(2S)-to-J/ψ ratio in central collisions; TAMU agrees with data.



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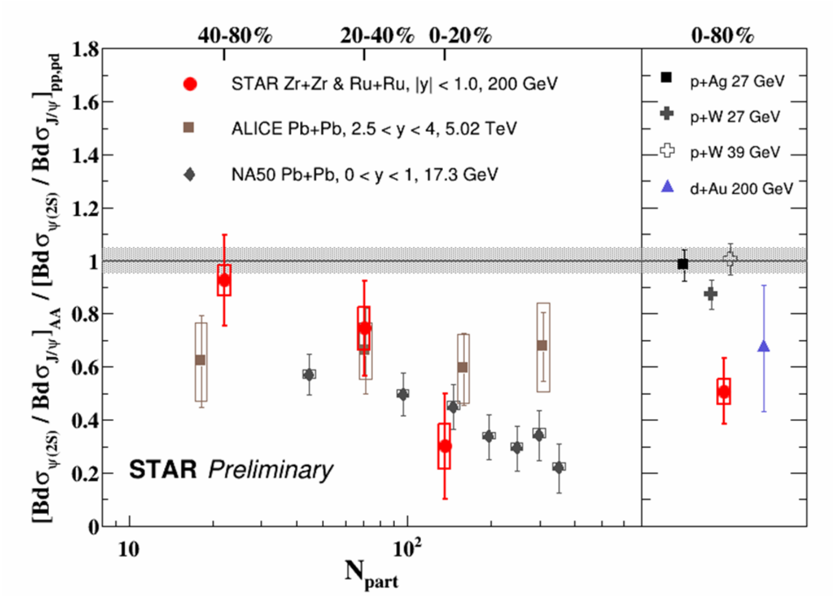
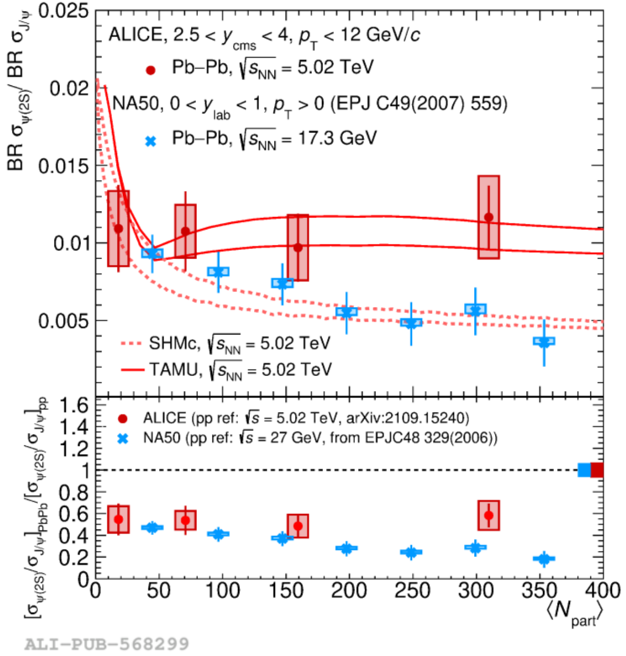
Centrality dependence of single and double ratio



QM2023, Yan Wang's talk



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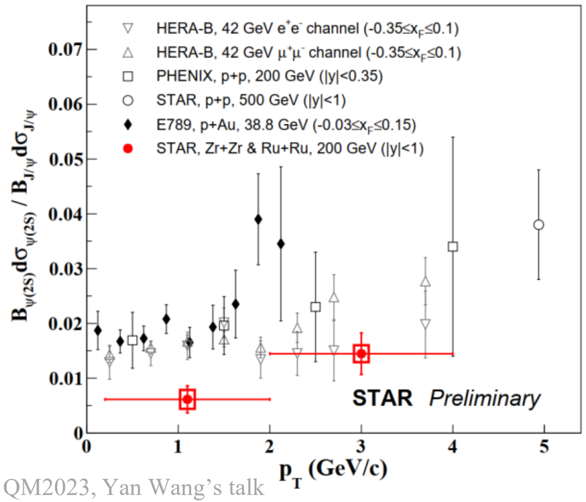
- Flat centrality dependence for (double) ratio at the LHC.
- Decreasing trend from peripheral to central collisions at RHIC and SPS.

→Hint of regeneration at LHC

p_T dependence of single and double ratio



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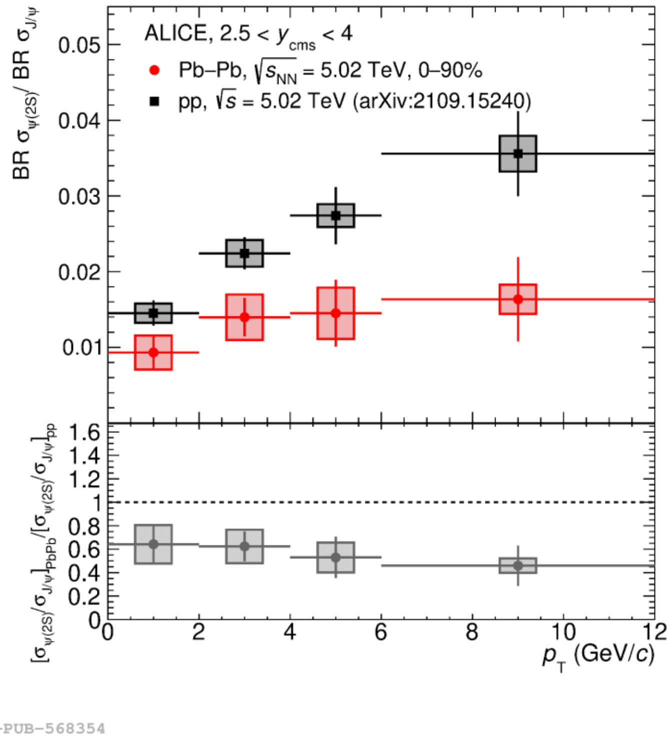

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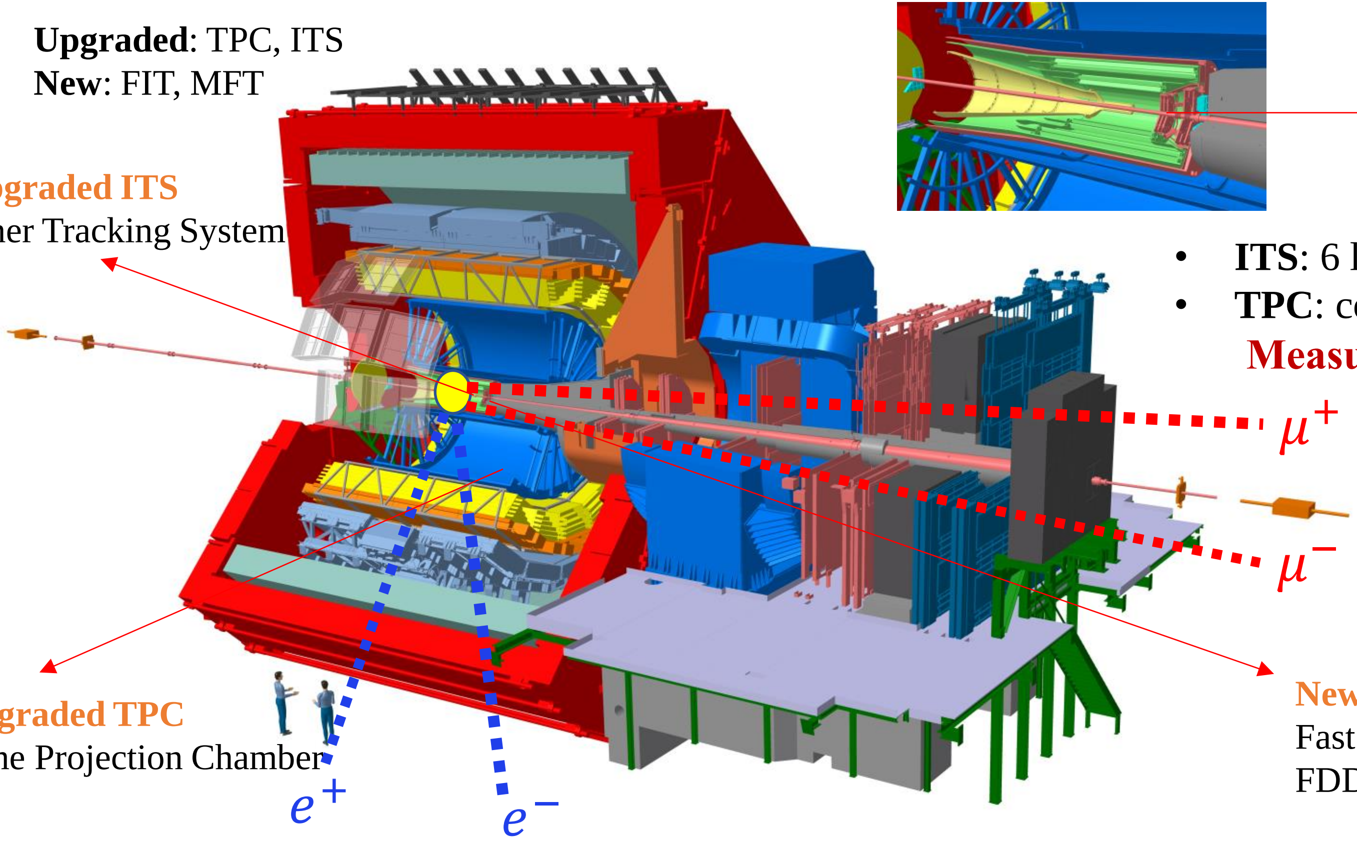
- ψ(2S)-to-J/ψ ratio increase as a function of p_T for both pp and Pb-Pb.
- Pb-Pb ratio tends to show a slower rise.
- The double ratio values tend to decrease with p_T, down to a value of ~0.5, indicating a corresponding possible increase of the relative suppression of the ψ(2S).

Prospective: Run 3 upgrade

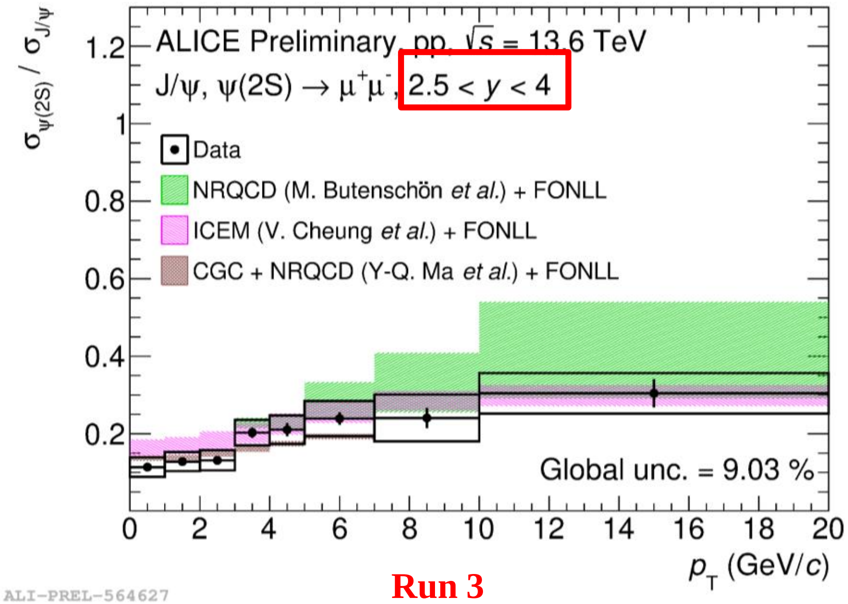
- **Upgraded**: TPC, ITS
- **New**: FIT, MFT



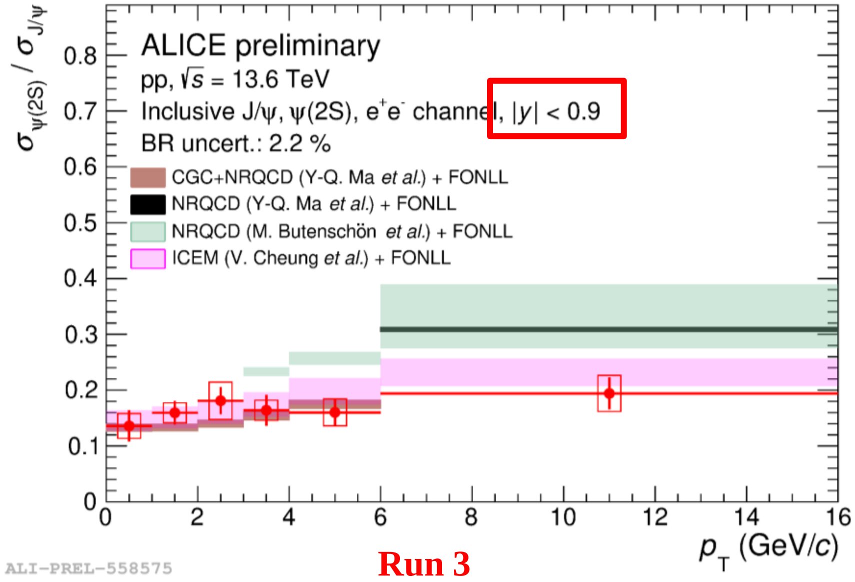
- **ITS**: 6 layers → 7 layers
- **TPC**: continuous read out

Measure ψ(2S) in central barrel

ψ(2S)-to-J/ψ ratio in pp collisions at $\sqrt{s}$ = 13.6 TeV



Run 3



Run 3

See Yuan Zhang's talk

- **First measurement** of ψ(2S) in central barrel in ALICE.
- ψ(2S)-to-J/ψ ratio measurements at midrapidity and forward rapidity.
- Opportunity to measure ratio and double ratio at both midrapidity and forward rapidity, with better precision.

Summary

- **ψ(2S) production in Pb−Pb at $\sqrt{s_{\mathrm{NN}}}$ =5.02 TeV:**
  - No centrality dependence of the ψ(2S) R_{AA} and (double) ratio within uncertainties.
  - An increase of the ψ(2S) suppression at high p_{T} with respect to low p_{T}.
  - ψ(2S) is more suppressed compared to J/ψ, by a factor ~2.
  - TAMU model describes data well; SHMc model agree with data at low p_{T}.
- **Outlook:**
  - Better statistics and tracking performance with ALICE Run 3 upgrades.
  - Opportunity to measure ratio and double ratio at both midrapidity and forward rapidity.

Thanks

Backup

Model

- SHMc:
  - charmonia are assumed to be formed at hadronization according to statistical weights and introducing a charm fugacity factor related to charm conservation and determined by the charm production cross section.
  - In the frame of SHMc it can be more appropriate to use the word “combination” rather than “recombination” as there is no binding of charmonium states in the QGP phase.

- TAMU:
  - dissociation and recombination rates for quarkonium states in the QGP are calculated taking into account a lattice-QCD inspired evaluation of the dependence of their spectral properties on the evolving thermodynamic properties of the medium.

The availability of accurate experimental results for various charmonium states represents a crucial input for the evaluation of the theory approaches and ultimately for the understanding of the existence of bound states of heavy quarks in the QGP.

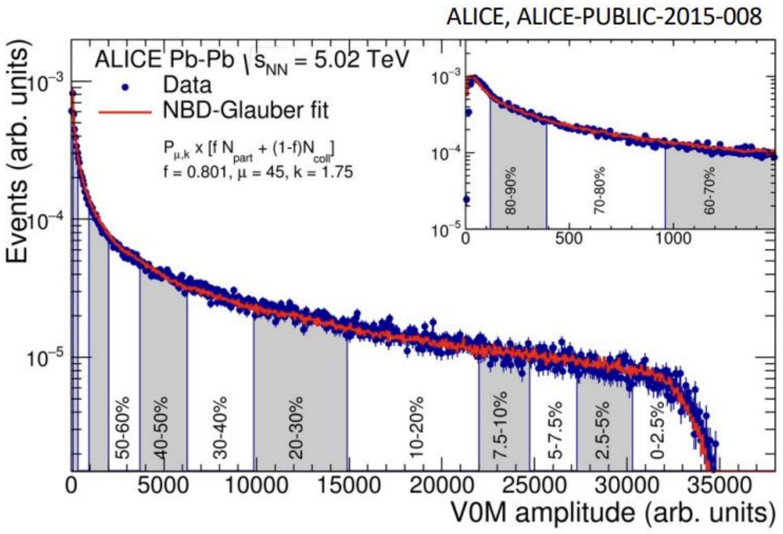
Cent

- Results from Run 2, 2015 + 2018 combined
- Integrated Luminosity ≈ 750 μb−1
- 4*10^8 dimuon triggered, F=13.1

- Muon pair selection:
  - Pseudo rapidity on each muon -4.0<η<-2.5
  - Radial transverse position at the end of the absorber 17.6<Rabs<89.5cm
  - Rapidity of the dimuon 2.5<y<4.0
  - Muons of opposite sign
  - Matching tracks between tracking chambers and trigger

- Event selection:
  - Beam gas and electromagnetic interactions rejected using V0 and ZDC
  - SPD used for vertex determination

- Centrality estimated on a Glauber model fit of the V0 amplitud



Syst.

	Vs centrality (%)	Vs p_T (%)
Signal extraction	16-22	12-25
Tracking efficiency	3*	3
Trigger efficiency	1.6*	1.5-2
Matching efficiency	1*	1
MC input	2*	2
Normalization factor	0.7*	0.7*
$\langle T_{AA} \rangle$	0.7-2.3	1*
Centrality estimation	0-7	0.3*
pp reference	4.7*	7.9-11.1

Detector

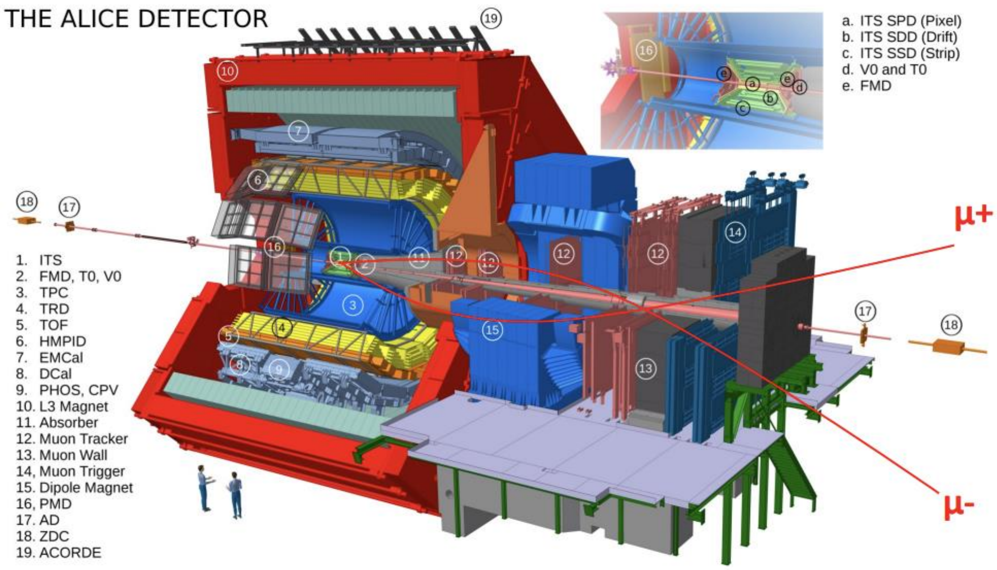


Illustration of ALICE Detector during Run 2

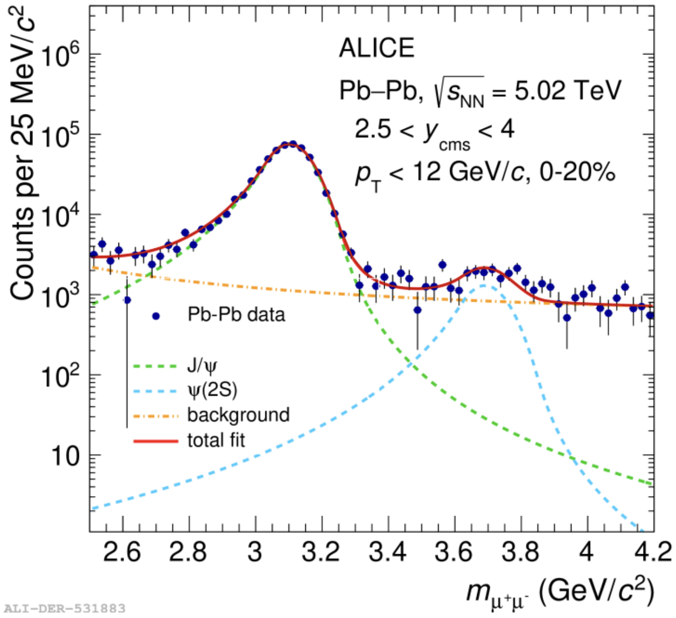
- Muon Arm : J/ψ, ψ(2S), **Υ**(nS) → $\mu^+\mu^-$
- Acceptance : 2.5<y<4.0
- Down to $p_T = 0$
- Inclusive charmonia only

- 5 stations of tracking chambers
- 2 stations of trigger chambers
- Dipole Magnet
- Absorbers

- ITS used for vertex determination
- V0 hodoscopes used as trigger (in coincidence with Muon Trigger)
- V0 also used for centrality determination
- V0 and ZDC used for background rejection

Extraction

- ψ(2S) yield extracted by χ^2 minimization fits the opposite sign dimuon invariant mass spectrum using :
  - 2 signal functions
  - Several line shapes are used for the signal functions
  - Combinatorial Background substracted with mixed-event technique
  - Remaining background fitted with several empirical functions
  - The mass of the ψ(2S) is fixed to the one of the J/ψ via the mass difference of the two resonances as provided by the Particle Data Group
  - Several fit ranges



- For the whole dataset, $N_{\psi(2S)} \approx 1.3 .10^4$ and $N_{J/\psi} \approx 9.2 .10^5$

Central<12GeV/c; peripheral0.3-12: remove photoproduction at low pt