

Charmonia in pp and PbPb collisions at 5.02 TeV in CMS

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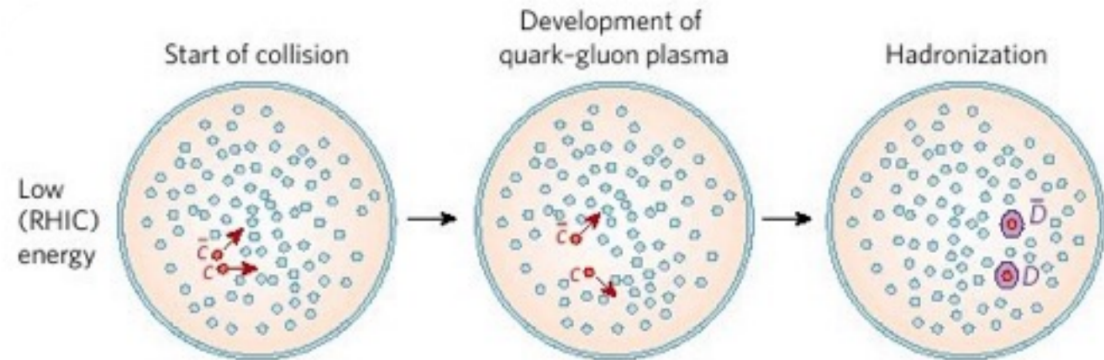
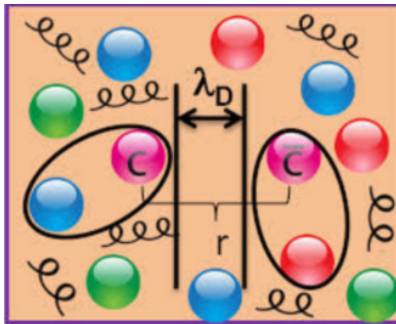
Rencontres QGP-France 2016

Étretat, France

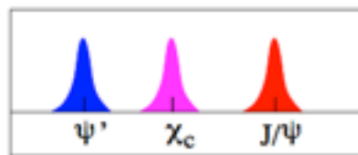
October 10-12, 2016

Motivation: Suppression

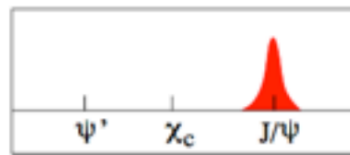
- Charmonia are produced in the **early stage** of the collision.
- Charmonium is expected to be suppressed in the QGP due to **color screening** (Matsui, 1986)



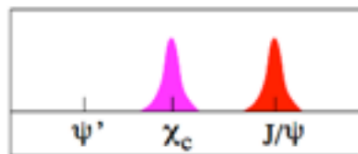
- The binding energy decreases for higher excited states → **Sequential Melting**



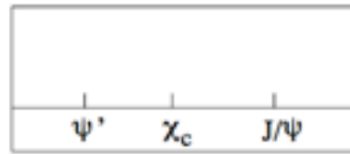
$T < T_c$



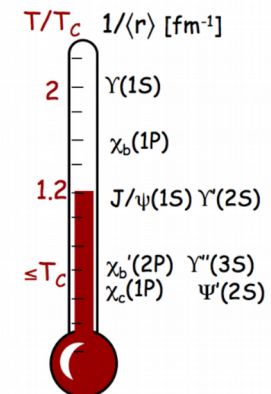
$T_\chi < T < T_\psi$



$T_{\psi'} < T < T_\chi$



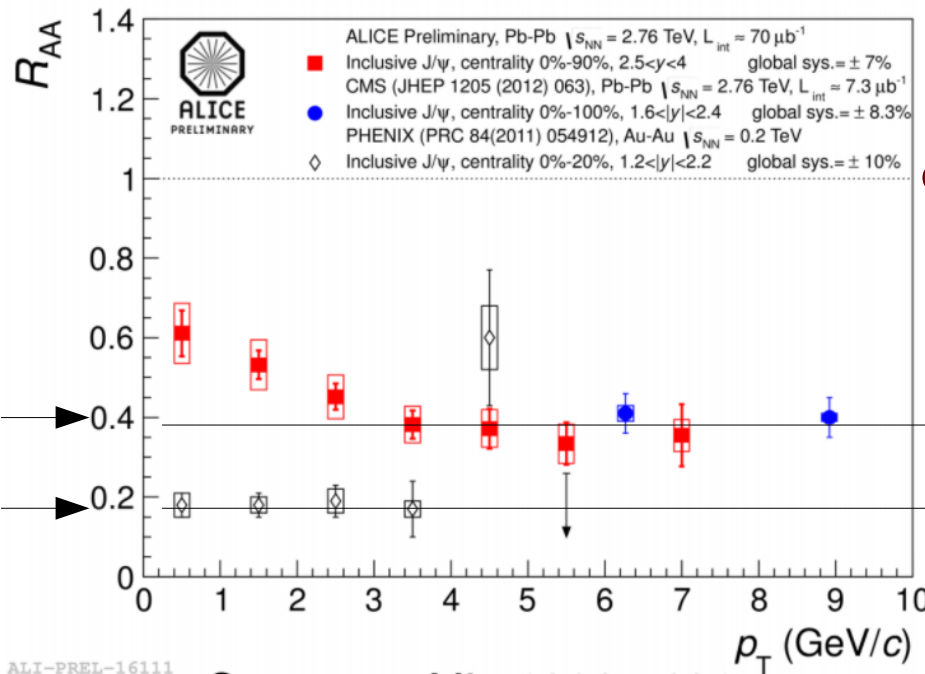
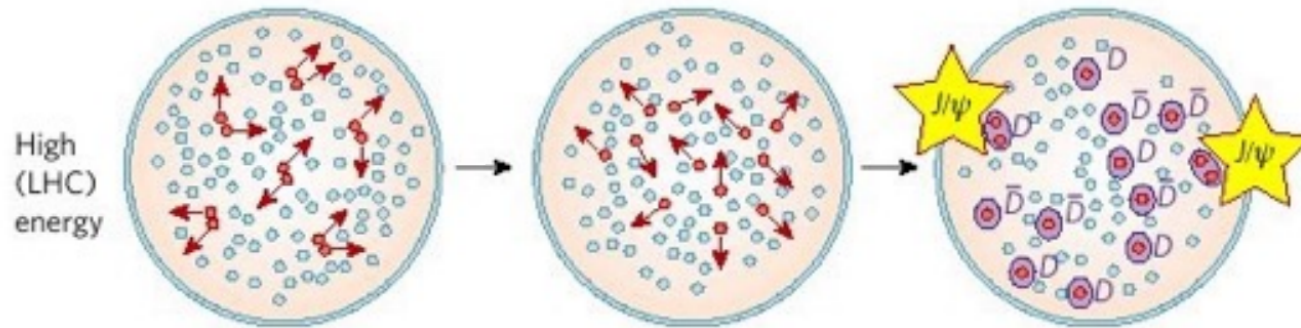
$T > T_\psi$



EPJC 61 (2009) 705

Motivation: Regeneration

- The charm-anticharm pair multiplicity increases with energy (large at LHC), which raises the recombination of charmonia at hadronization



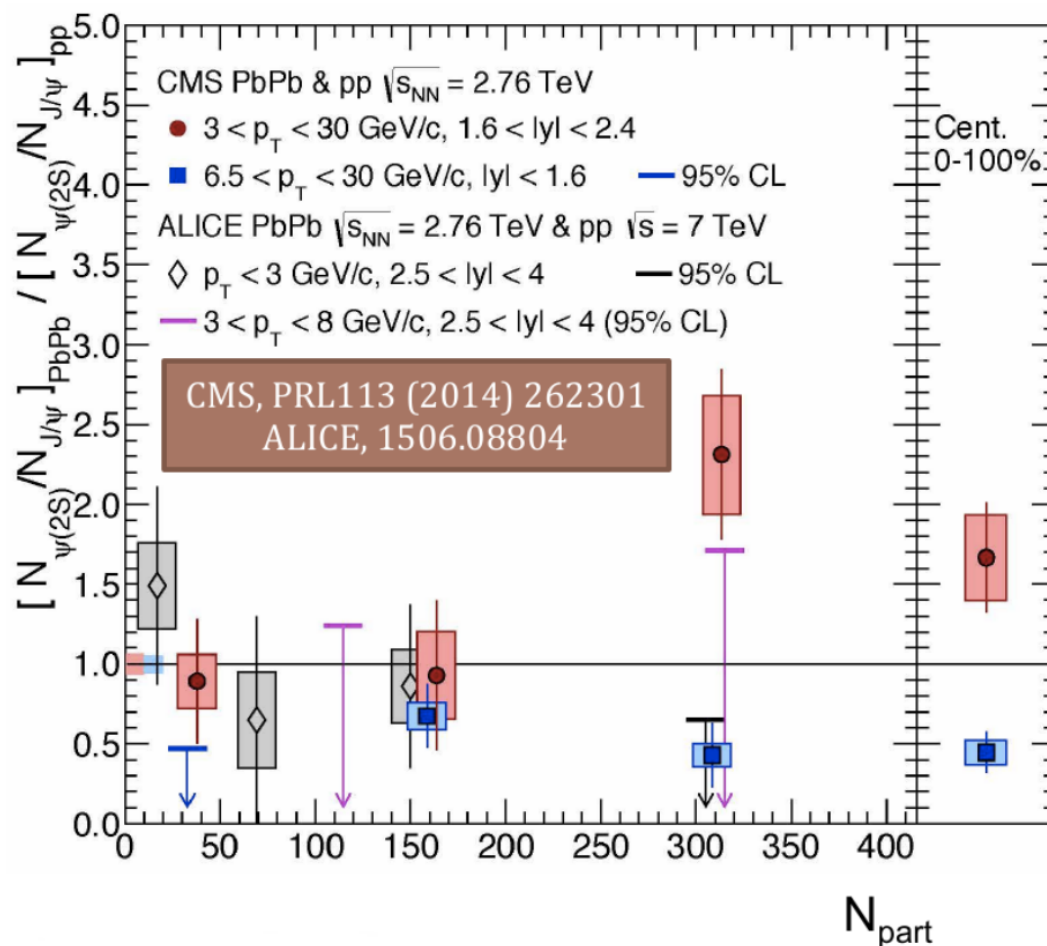
Source: arXiv:1208.5601

- Less suppression at LHC than at RHIC at low p_T !

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{(PbPb)}}{dN_{(pp)}}$$

Motivation: Run 1 Results

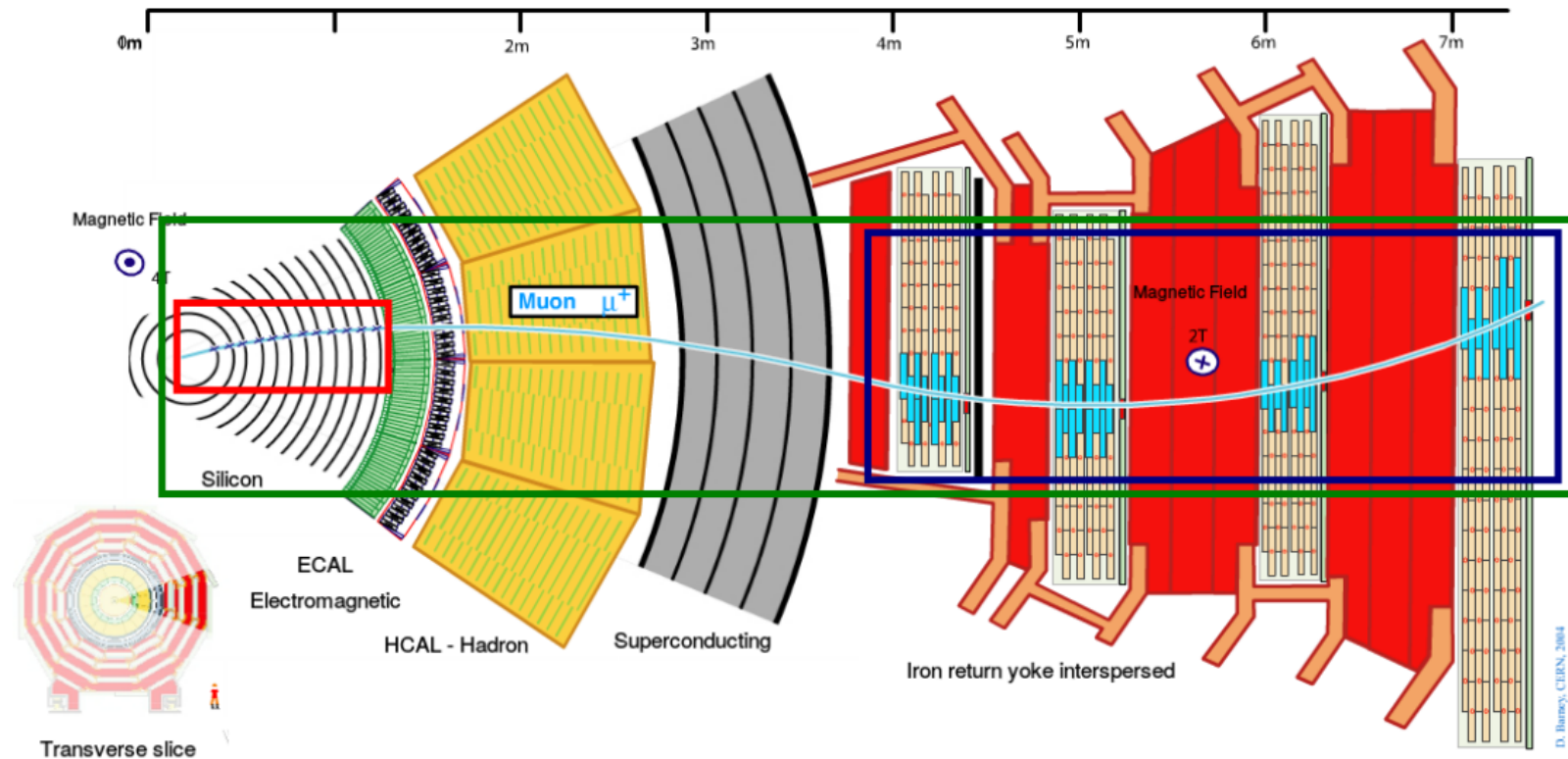
$$\frac{R_{AA}^{\psi(2S)}}{R_{AA}^{\psi(1S)}} \longrightarrow$$



CMS: $\psi(2S)$ was more suppressed than J/ψ at midrapidity and high p_T , but less at forward and medium p_T

ALICE: Different message but statistically compatible

CMS Detector: Muons



- **Muon Reconstruction:** silicon tracker + muon sub-detectors
- **Muon Kinematic Coverage:**
 $p_T > 3.5$ GeV at $|\eta| < 1.6$ and $p_T > 1.8$ GeV at $1.6 < |\eta| < 2.4$
- **“Global Muon”:** Global fit between a track in the tracker and the muon chambers

Event Selection

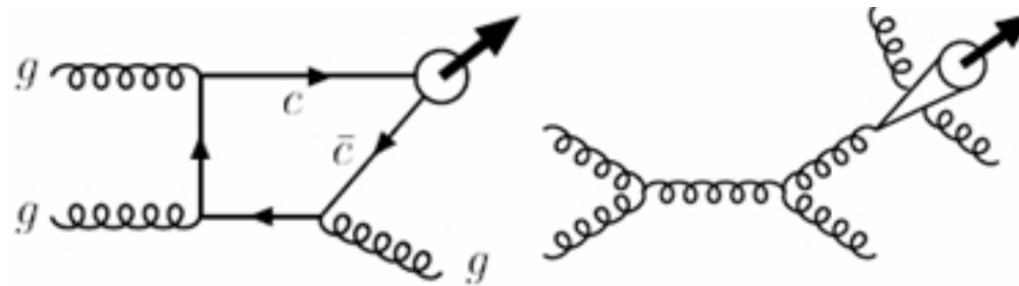
- **Decay Channels:** $\psi(2S) \rightarrow \mu^+\mu^-$ and $J/\psi \rightarrow \mu^+\mu^-$
- **Muon Selection:**
 - Used muon ID cuts to reject fake muons and background events.
 - Applied muon kinematic cuts based on detector coverage

$$\begin{array}{ll} p_T^\mu > 3.5 \text{ GeV}/c & |\eta^\mu| \in [0, 1.2[\\ p_T^\mu > (5.77 - 1.89 \times |\eta^\mu|) \text{ GeV}/c & |\eta^\mu| \in [1.2, 2.1[\\ p_T^\mu > 1.8 \text{ GeV}/c & |\eta^\mu| \in [2.1, 2.4[\end{array}$$

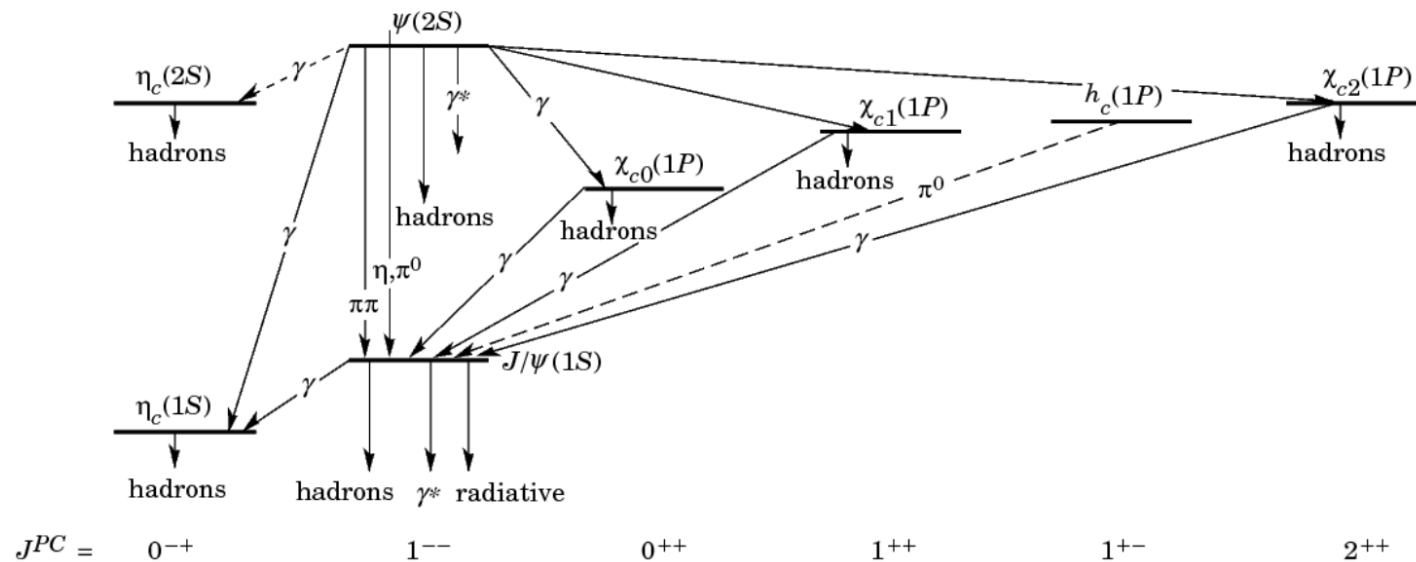
- **Quarkonium Selection:**
 - Global muon pairs with opposite charge and common vertex

Prompt J/ψ

- Directly produced: $g + g \rightarrow J/\psi + g$

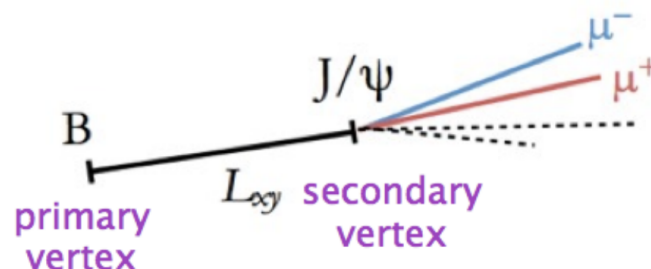
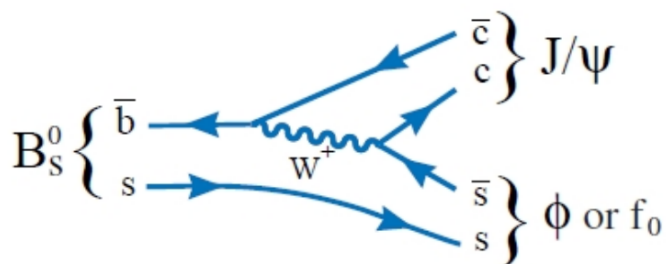


- Feed-down from higher charmonium states



Non-Prompt J/ψ

- Charmonia coming from B-hadrons decays



- Suppressed by cutting over the pseudo-proper decay length

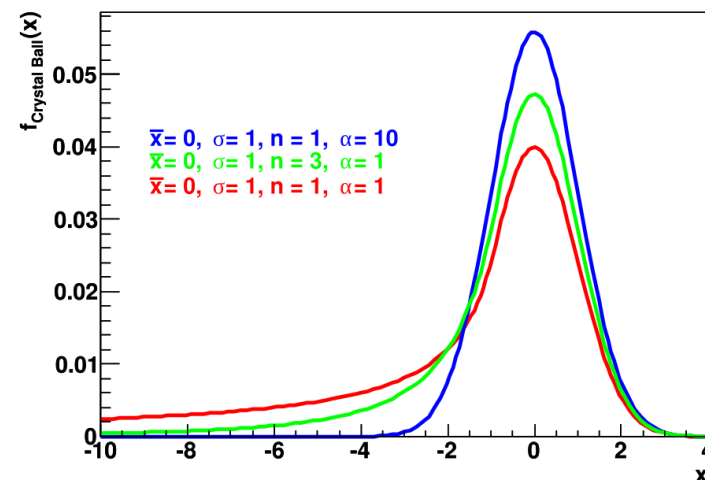
$$\ell_{J/\psi}^{3D} = L_{xyz} \cdot \frac{m_{J/\psi}}{p_{\mu\mu}} \quad \text{with} \quad L_{xyz} = \frac{\hat{u}^T S^{-1} \vec{r}}{\hat{u}^T S^{-1} \hat{u}} \quad \text{where } \hat{u} = \vec{p}/p \text{ and } S \text{ is the sum of the primary and secondary vertex covariance matrices.}$$

- Tune $\ell_{J/\psi}^{3D}$ cut on MC so that the efficiency of keeping prompt J/ψ is 90%.

Signal Extraction

- The J/ψ and $\psi(2S)$ yields are extracted simultaneously by performing an unbinned maximum likelihood fit to the $\mu^+\mu^-$ invariant mass spectrum within the mass interval $[2.2, 4.2] \text{ GeV}/c^2$
- Nominal Signal Model: Sum of 2 Crystal Ball functions per peak.

$$g_{\text{CB}}(m; \alpha, n, \bar{m}, \sigma) = N \cdot \begin{cases} \exp\left(-\frac{(m-\bar{m})^2}{2\sigma^2}\right), & \text{for } \frac{m-\bar{m}}{\sigma} > -\alpha \\ A \cdot \left(B - \frac{m-\bar{m}}{\sigma}\right)^{-n}, & \text{for } \frac{m-\bar{m}}{\sigma} \leq -\alpha \end{cases}$$



- Nominal Background Model: Sum of Chebychev polynomials

The best Chebychev order for each bin is determined from data, using a Log-Likelihood Ratio (LLR) test which picks the lowest order describing correctly the data!

Mass Fits in PbPb

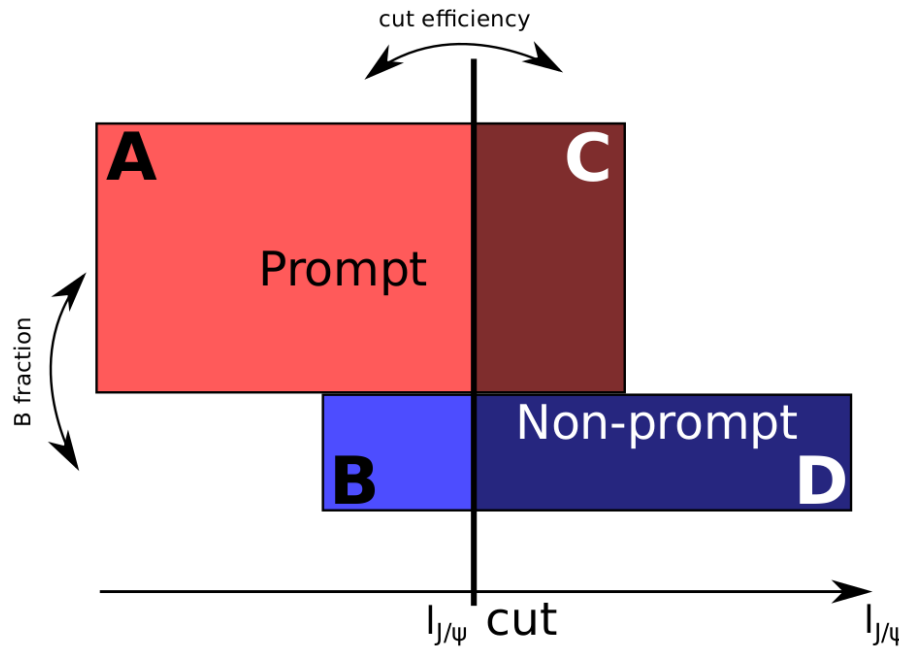
PbPb, $|y| < 1.6$, $9.0 < p_T < 12.0$ GeV/ c

Jpsi: 49554 in PbPb and 6988 in pp

PbPb, $1.6 < |y| < 2.4$, $3 < p_T < 30$ GeV/ c

Jpsi: 18382 in PbPb and 153499 in pp

Correction for B-hadron contamination



- A: **prompt** ψ **passing** the $\ell_{J/\psi}^{3D}$ cut
- B: **non-prompt** ψ **passing** the $\ell_{J/\psi}^{3D}$ cut
- C: **prompt** ψ **failing** the $\ell_{J/\psi}^{3D}$ cut
- D: **non-prompt** ψ **failing** the $\ell_{J/\psi}^{3D}$ cut

- Even after the $\ell_{J/\psi}^{3D}$ cuts, a non-prompt contamination is left in our sample
- Accounted for by using a sideband in $\ell_{J/\psi}^{3D}$ (reverted the $\ell_{J/\psi}^{3D}$ cut)

- Passing fraction:
$$f_{\text{pass}} = \frac{N_{\text{pass}}}{N_{\text{pass}} + N_{\text{fail}}} = \frac{N_{\text{pass}}}{N_{\text{tot}}} = \frac{A + B}{A + B + C + D}$$

- Prompt fraction:
$$f_P = \frac{f_{\text{pass}} - \epsilon_{NP}}{\epsilon_P - \epsilon_{NP}} = \frac{N_P}{N_{\text{tot}}} = \frac{A + C}{A + B + C + D}$$

f_{pass} measured in **data**, ϵ_P and ϵ_{NP} estimated from **MC**

Correction for B-hadron contamination: Cross-check

J/ψ

$\psi(2S)$

CMS: JHEP02(2012)011

CMS: JHEP02(2012)011

**Good agreement between NP fractions
using different methods!**

Systematic Uncertainties

- **Systematic uncertainty on Fitting Procedure**

Determined by using **different signal and background models for pp and PbPb, changing fit parameters, and varying the fitting range**

pp: 0.001 – 0.015 and PbPb: 0.08-0.1

- **Systematic uncertainty on Cancellation of Efficiencies**

Three main sources: **Statistical uncertainty of MC, deviation from unity of the double ratio of efficiencies, and spread of the double ratio of efficiencies** when varying the MC p_T spectra allowed by the data

Eff: 0.012 – 0.096

- **Systematic uncertainty on B-hadron contamination**

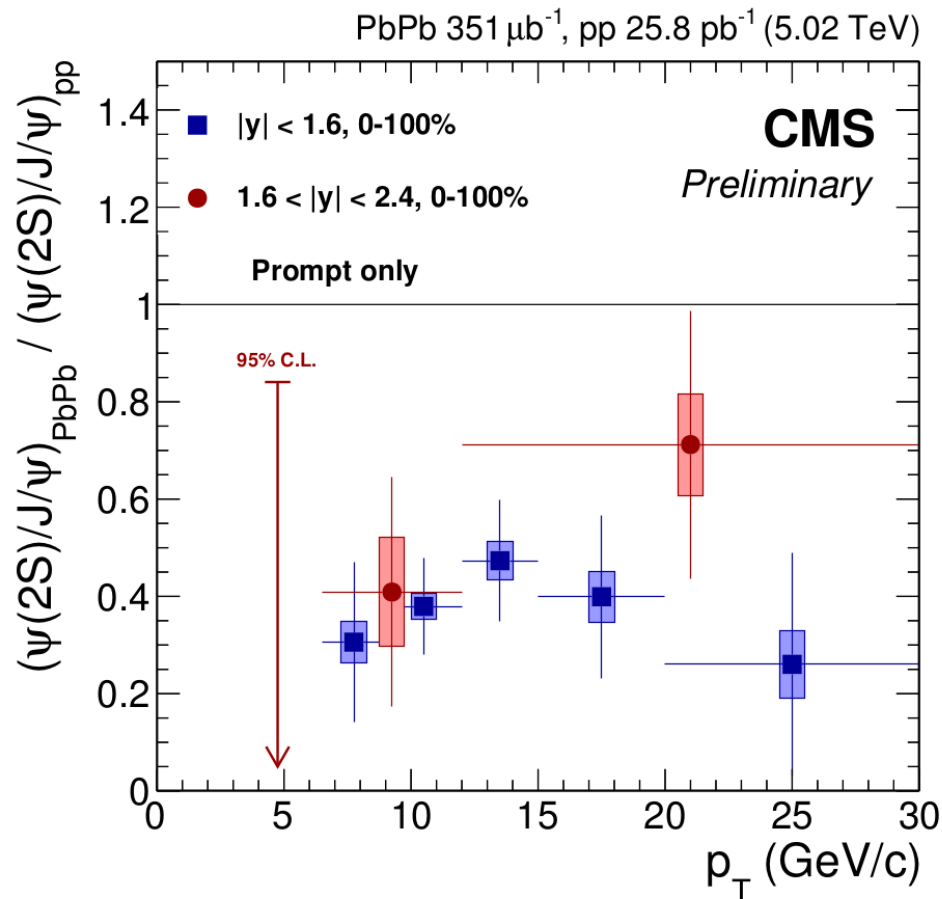
Determined from the **difference in B fractions** between 2D mass-lifetime fits and the $\ell_{J/\psi}^{3D}$ sideband method

NP subtraction: 0.006 – 0.09

Systematic Uncertainties

Statistical uncertainties largely dominate!

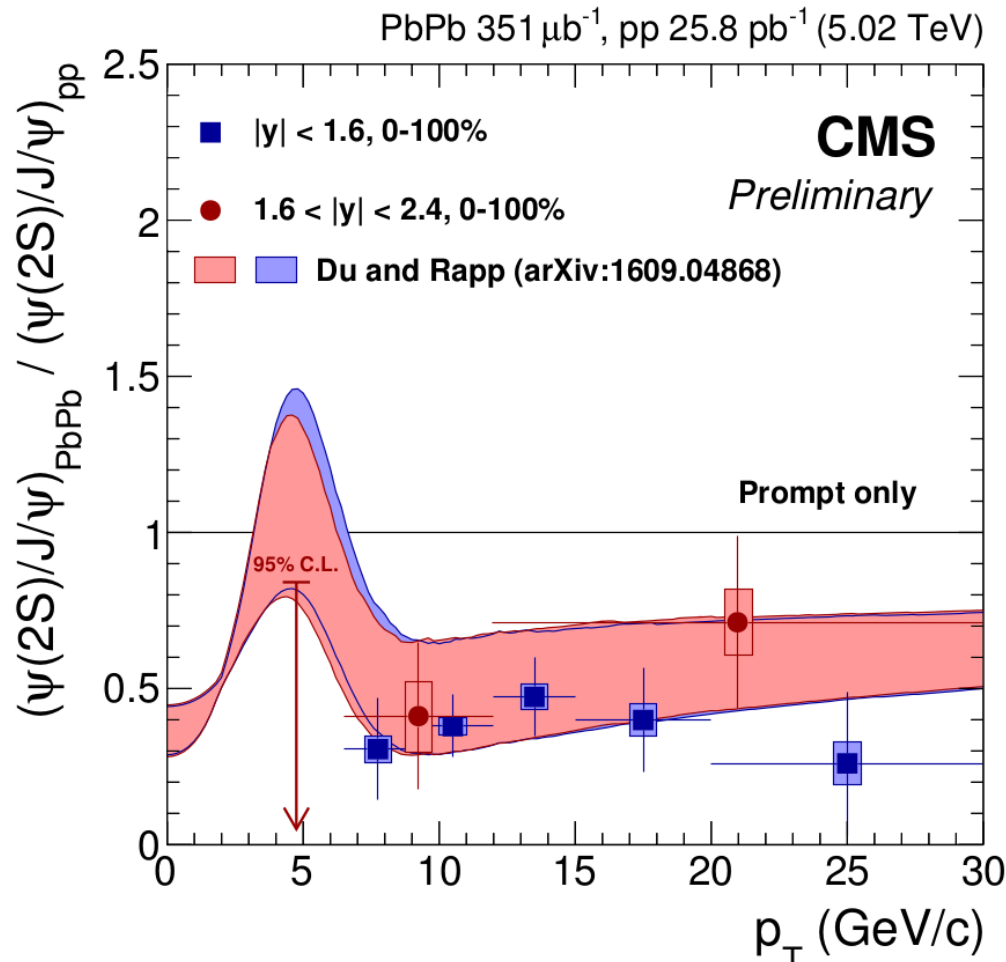
ψ double ratio @ 5.02 TeV: p_T dependence



CMS-PAS-HIN-16-004

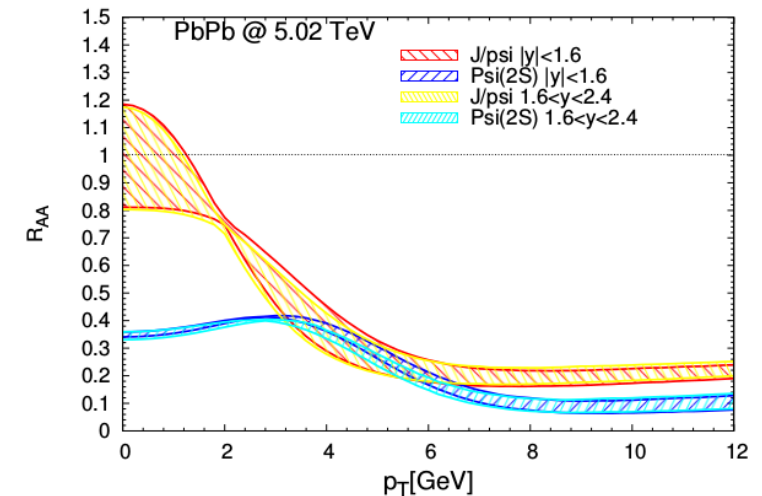
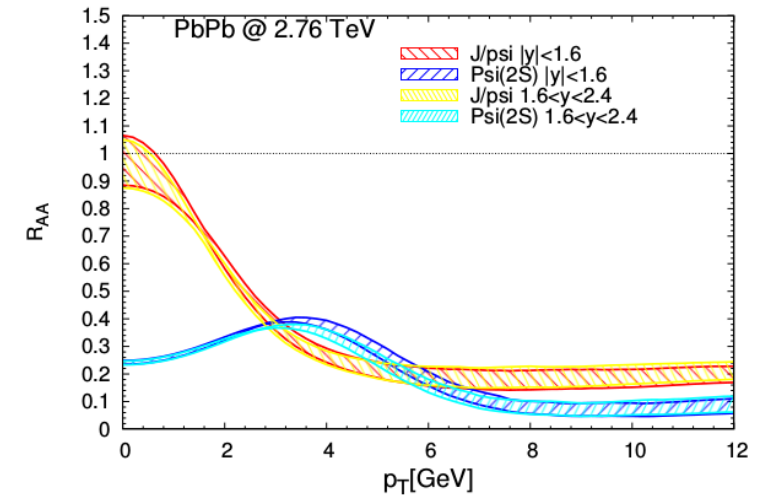
- ✎ Double ratio < 1 in all bins: **$\psi(2S)$ more suppressed than J/ψ**
95% C.L. upper limits when no significant $\psi(2S)$ in PbPb
- ✎ No significant p_T dependence

ψ double ratio @ 5.02 TeV: Model comparison



CMS-PAS-HIN-16-004

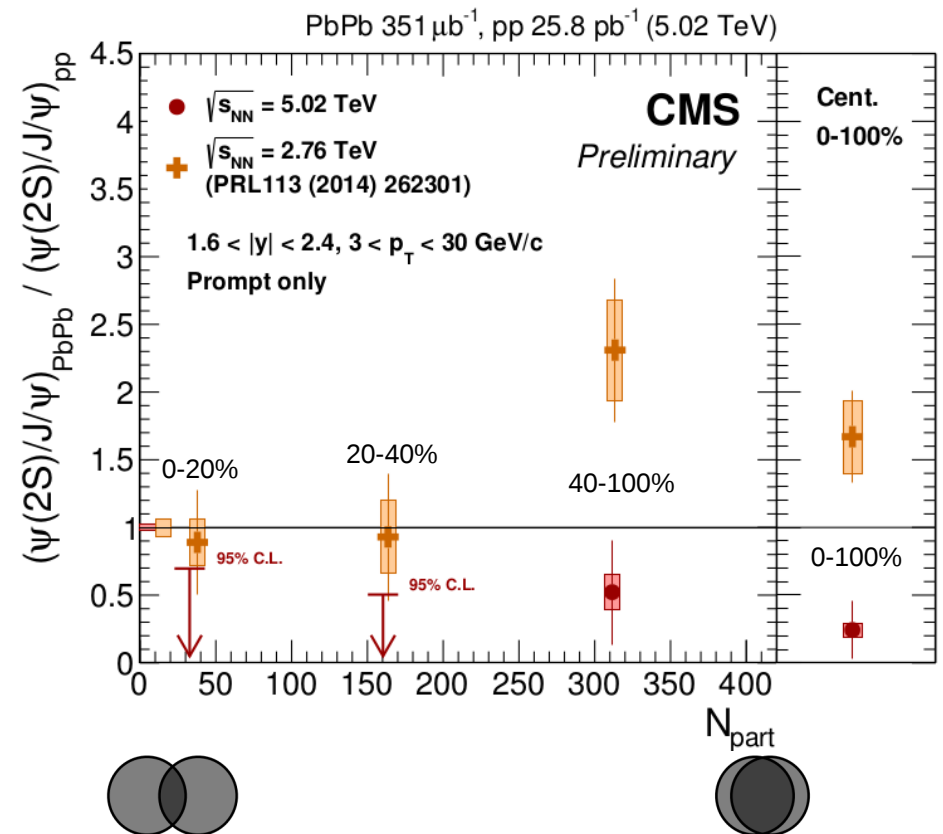
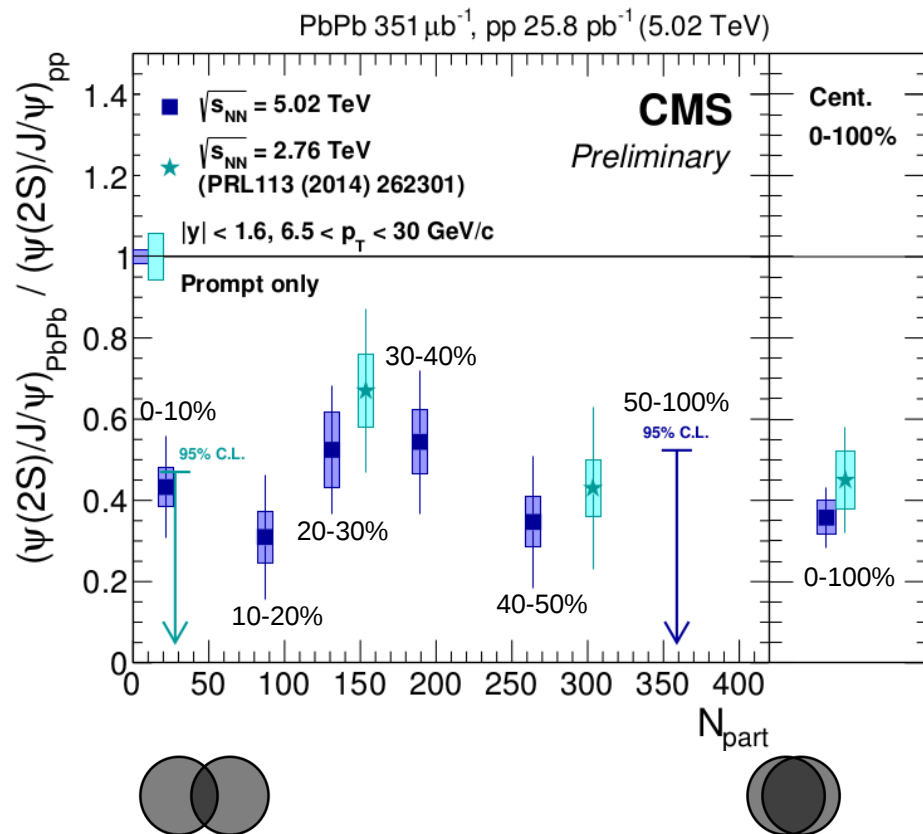
Nucl. Phys. A **943**, 147, 1609.04868



X. Du and R. Rapp: $\psi(2S)$ regenerated later than J/ψ in the fireball evolution

ψ double ratio @ 5.02 TeV: centrality dependence

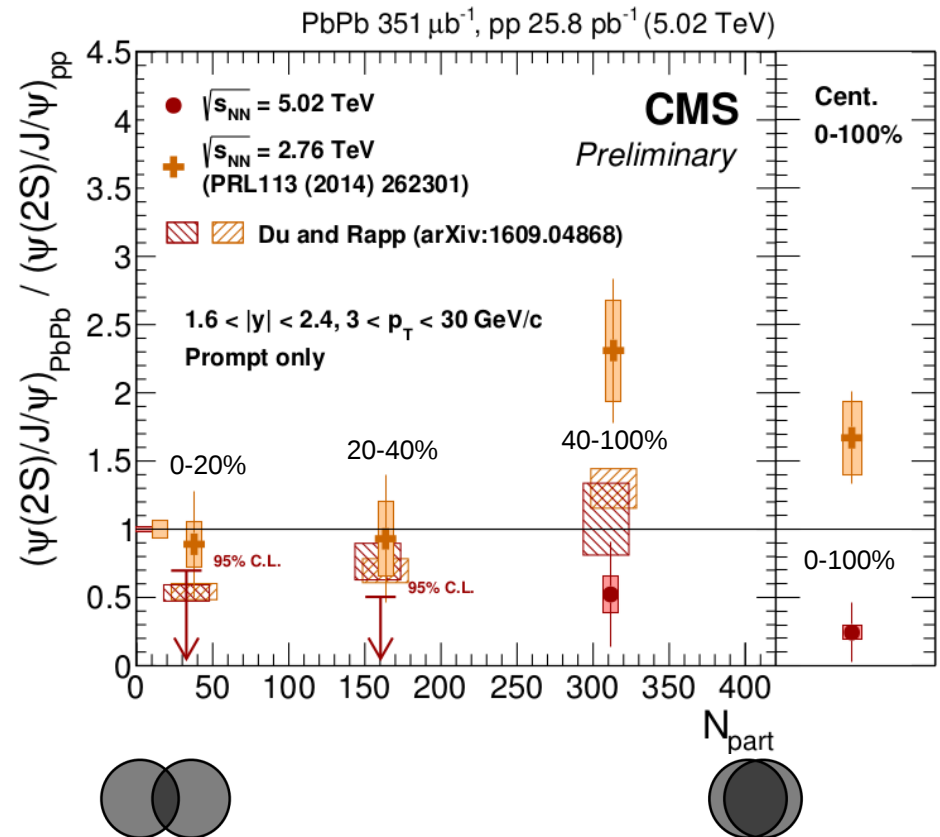
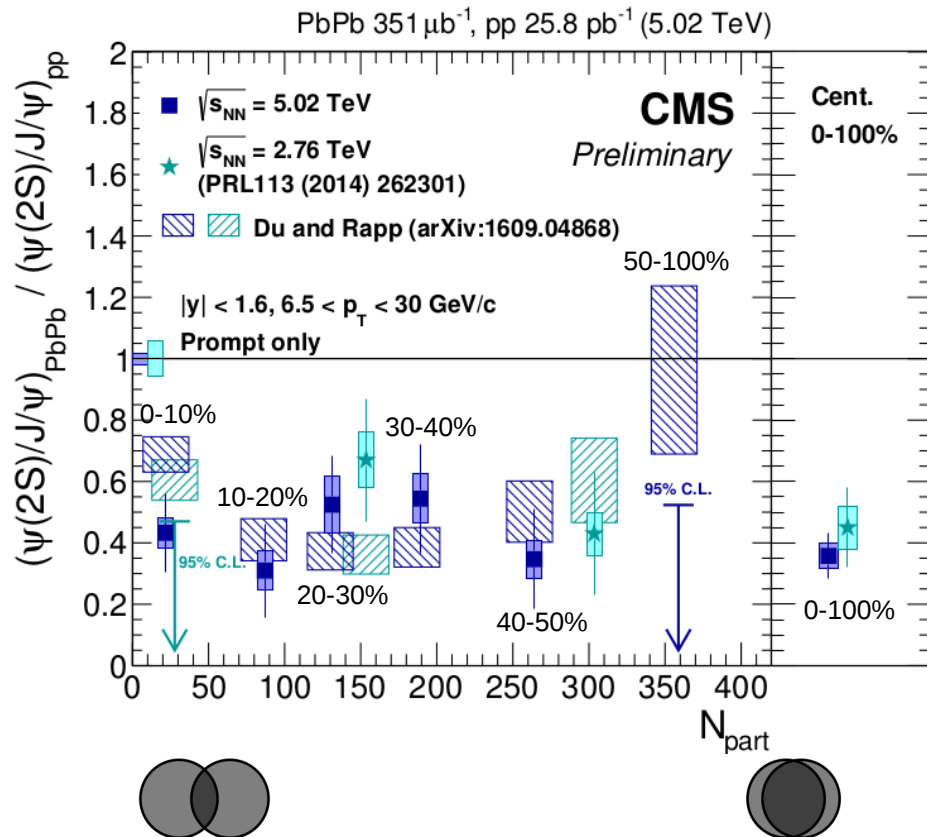
CMS-PAS-HIN-16-004



- ✂ No strong N_{part} dependence at 5.02 TeV
- ✂ Good agreement with 2.76 TeV for most bins
- ✂ Some difference (~ 3 s.d.) only for central events at forward rap.

ψ double ratio @ 5.02 TeV: model comparison

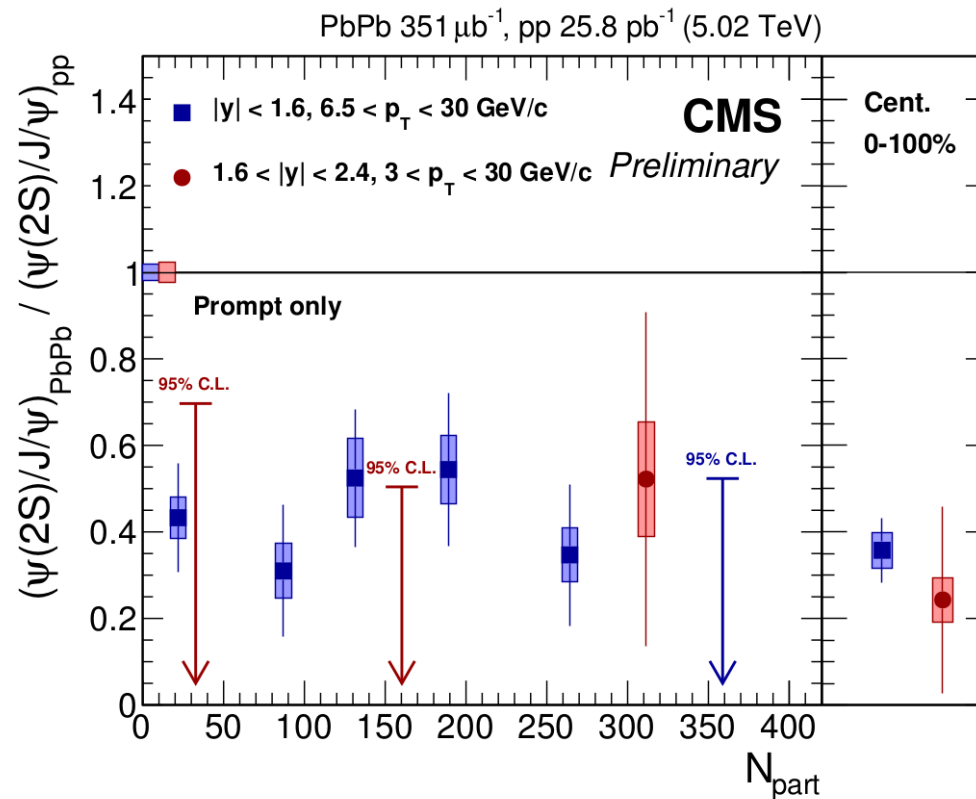
CMS-PAS-HIN-16-004



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Summary

CMS-PAS-HIN-16-004



- $\psi(2S)$ **more suppressed** than J/ψ in all bins @ 5.02 TeV
- Good agreement between 5.02 TeV and 2.76 TeV in most bins except in central events at forward rap (~ 3 s.d.).

J/ψ R_{AA} @ 5.02 TeV results coming early 2017!

BACKUP