Measurement of quarkonia production in heavy-ion collisions with the ATLAS detector

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33rd Winter Workshop on Nuclear Dynamics

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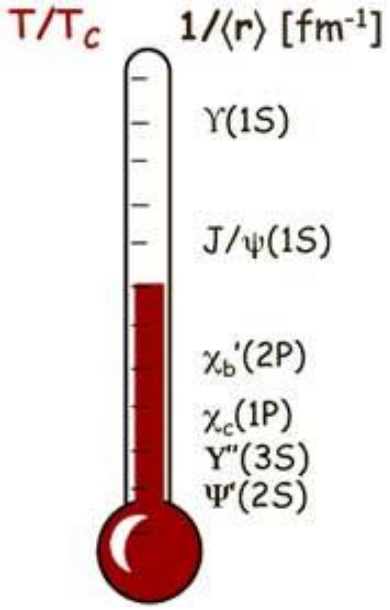
Why to measure the Quarkonia

- bound states of c or b quarks and antiquarks
- unique probe to study the hot, dense system created in nucleus- nucleus (A+A) collisions.

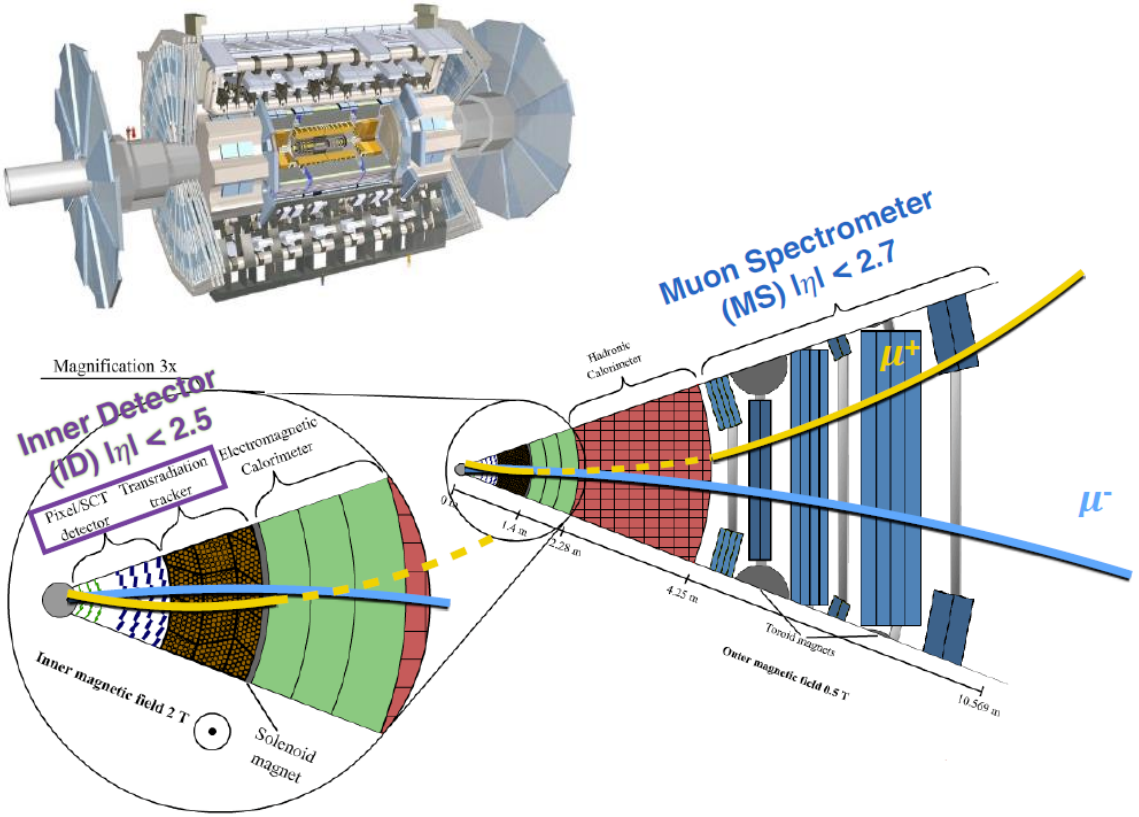
But, the full picture is more complicated, there are also contributions from Cold Matter Effects.

- Color-Screening: melting
- Color-Exchange: absorption
- Regeneration by recombination



courtesy of A. Mocsy

ATLAS detector



- 2013 p+Pb @ 5.02 TeV
  - $28\ nb^{-1}$
- 2013 p+p @ 2.76 TeV
  - $4.0\ pb^{-1}$
- 2015 Pb+Pb @ 5.02 TeV
  - $0.49\ nb^{-1}$
- 2015 p+p @ 5.02 TeV
  - $25.0\ pb^{-1}$

J/ψ and $\psi(2S)$ measurements

- May 2015 J/ψ paper – arXiv: 1505.08141 [hep-ex]
  - 2013 p+Pb $\sqrt{s_{NN}} = 5.02\ TeV$
- June 2015 J/ψ and $\psi(2S)$ - ATLAS-CONF-2015-023
  - 2013 p+Pb $\sqrt{s_{NN}} = 5.02\ TeV$ and p+p $\sqrt{s} = 2.76\ TeV$
- September 2016 J/ψ and $\psi(2S)$ - ATLAS-CONF-2016-109
  - 2015 Pb+Pb $\sqrt{s_{NN}} = 5.02\ TeV$ and p+p $\sqrt{s} = 5.02\ TeV$

Method

Trigger : different for p+Pb and Pb+Pb

- p+Pb: 1+ MU0 at L1, 2 muons, $p_T > 2\ GeV$
- Pb+Pb: 1+ MU4 at L1, 2 muons, $p_T > 4\ GeV$

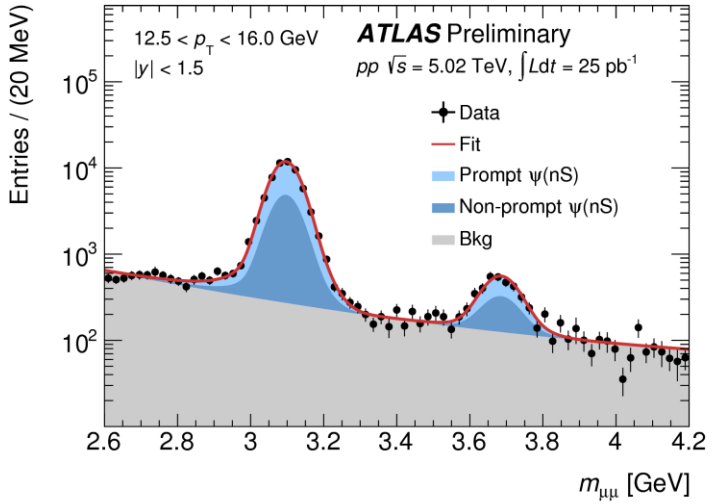
Analysis range

- p+Pb : $p_T \in \langle 8.5; 30 \rangle\ GeV, |y^*| < 1.94\ (1.5)$
- Pb+Pb: $p_T \in \langle 9; 40 \rangle\ GeV, |y| < 2$, centrality 0−80%

Perform weighted 2D unbinned maximum likelihood fit

- dimuon invariant mass and lifetime
- extract fraction of prompt and non-prompt
  - Prompt – direct production, feed-down contribution
  - Non-prompt – decay from B hadrons
- per-Dimuon weight: trigger, reconstruction, acceptance

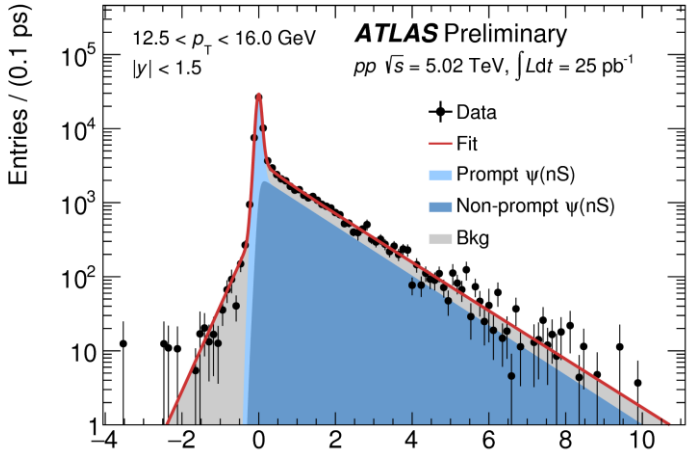
Simultaneous Fit Method



$$PDF(m,\tau) = \sum_{i=1}^{7} k_i f_i(m) \cdot h_i(\tau) * g(\tau)$$

CB: Crystal ball function
G: Gaussian
E: Exponential
g: Double Gaussian

i	Type	Source	$f_i(m)$	$h_i(\tau)$
1	J/ψ S	P	$\omega_i CB_1(m) + (1-\omega_i)G_1(m)$	$\delta(\tau)$
2	J/ψ S	NP	$\omega_i CB_1(m) + (1-\omega_i)G_1(m)$	$E_1(\tau)$
3	$\psi(2S)$ S	P	$\omega_i CB_2(m) + (1-\omega_i)G_2(m)$	$\delta(\tau)$
4	$\psi(2S)$ S	NP	$\omega_i CB_2(m) + (1-\omega_i)G_2(m)$	$E_2(\tau)$
5	Bkg	P	$flat$	$\delta(\tau)$
6	Bkg	NP	$E_3(m)$	$E_4(\tau)$
7	Bkg	NP	$E_5(m)$	$E_6(\|\tau\|)$



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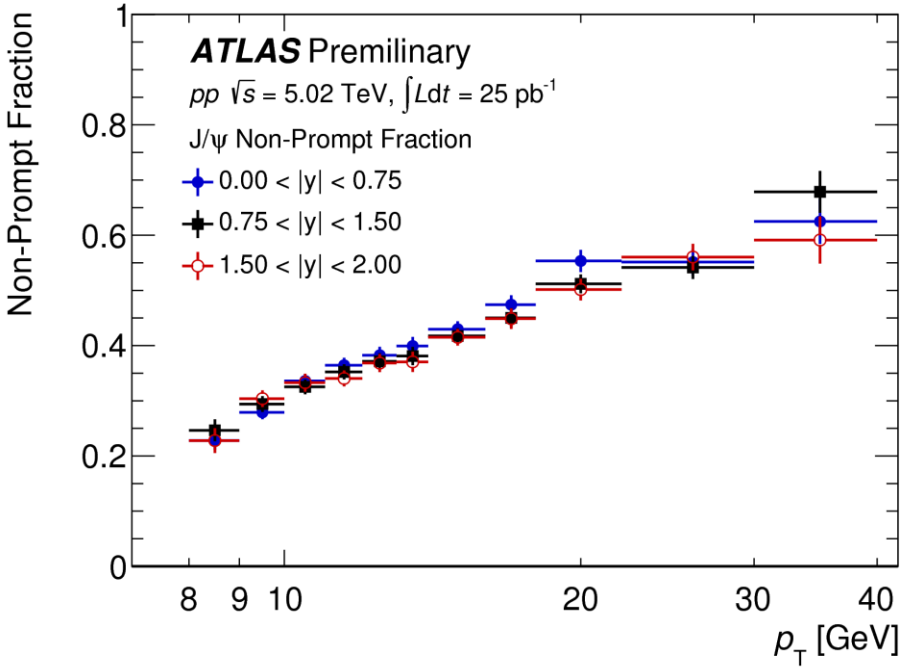
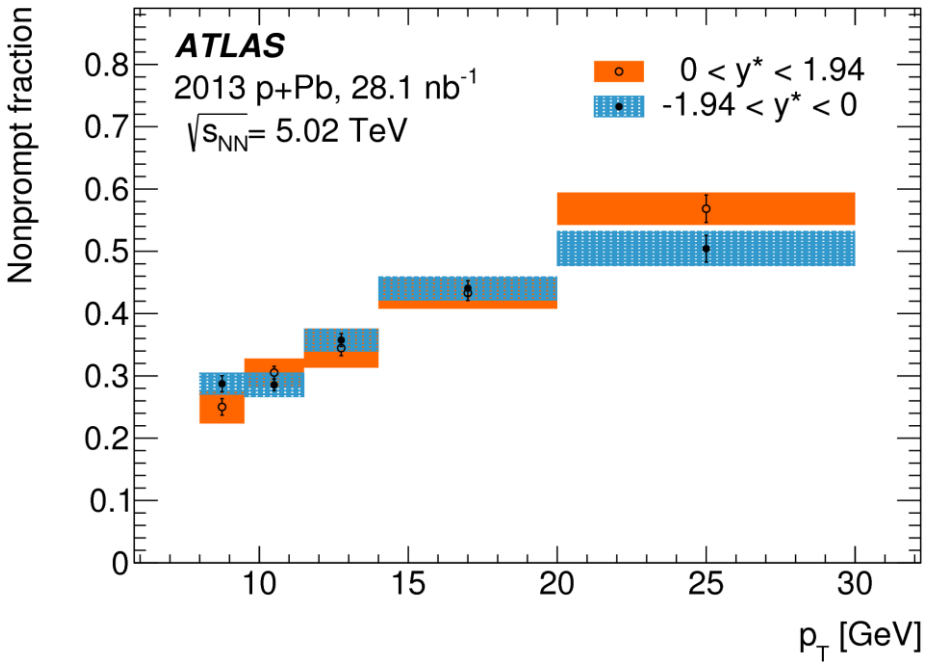
Non-Prompt fraction of J/ψ in p_T

pp



p+Pb



No visible |y| dependence
But significant p_T dependence

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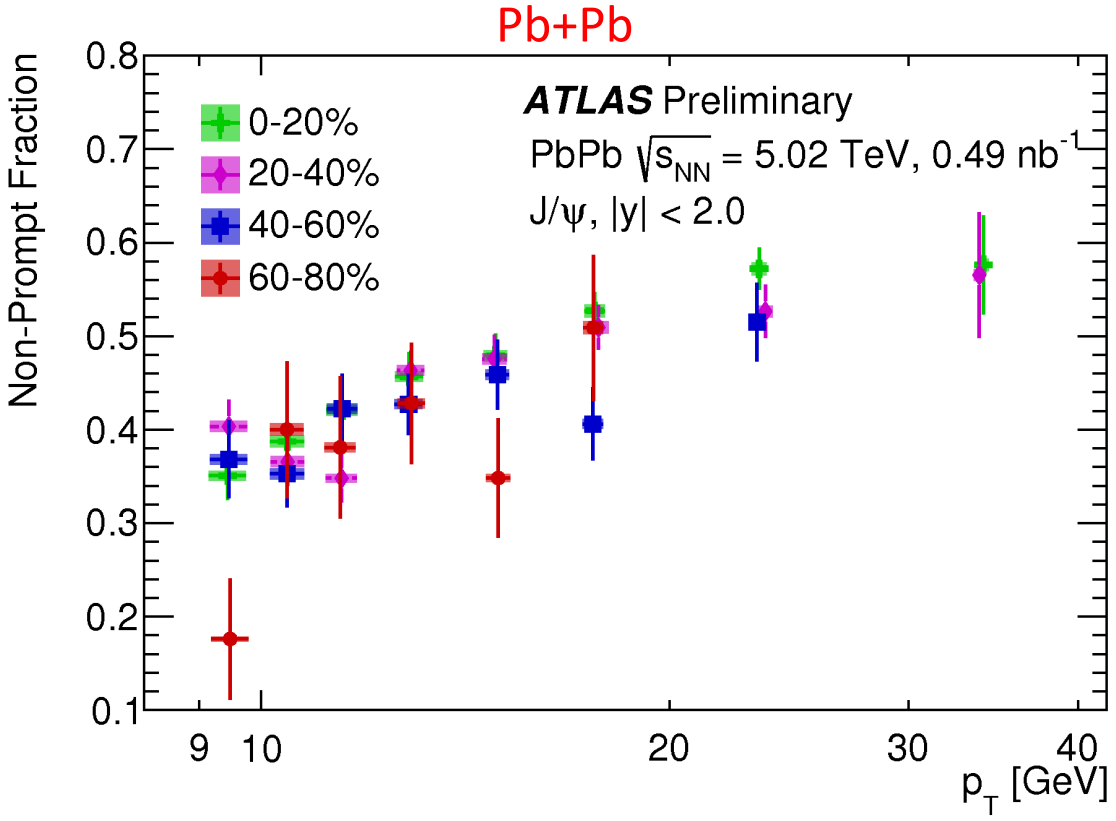
arXiv: 1505.08141 [hep-ex]

Non-Prompt fraction of J/ψ in p_T



No significant centrality dependence

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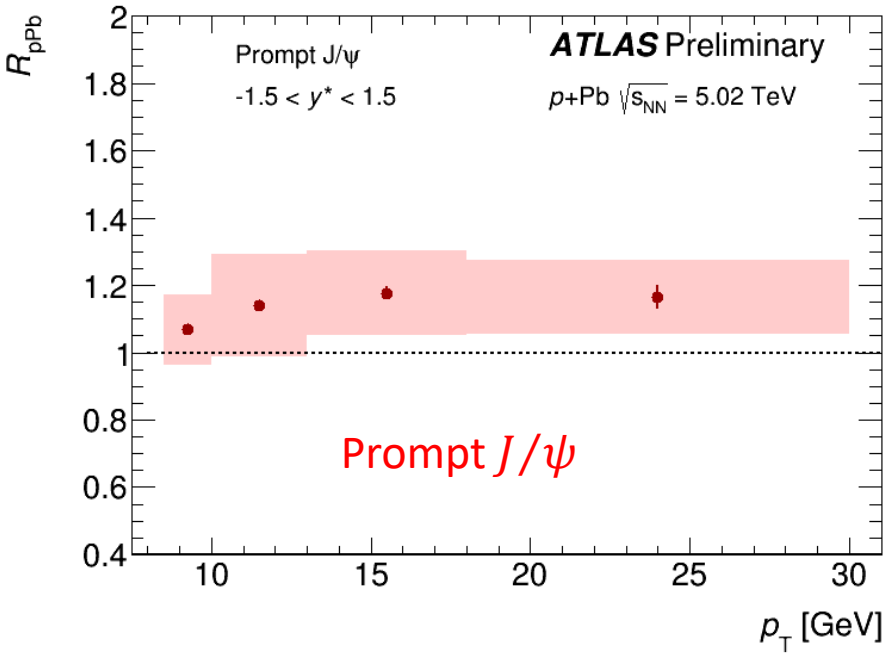
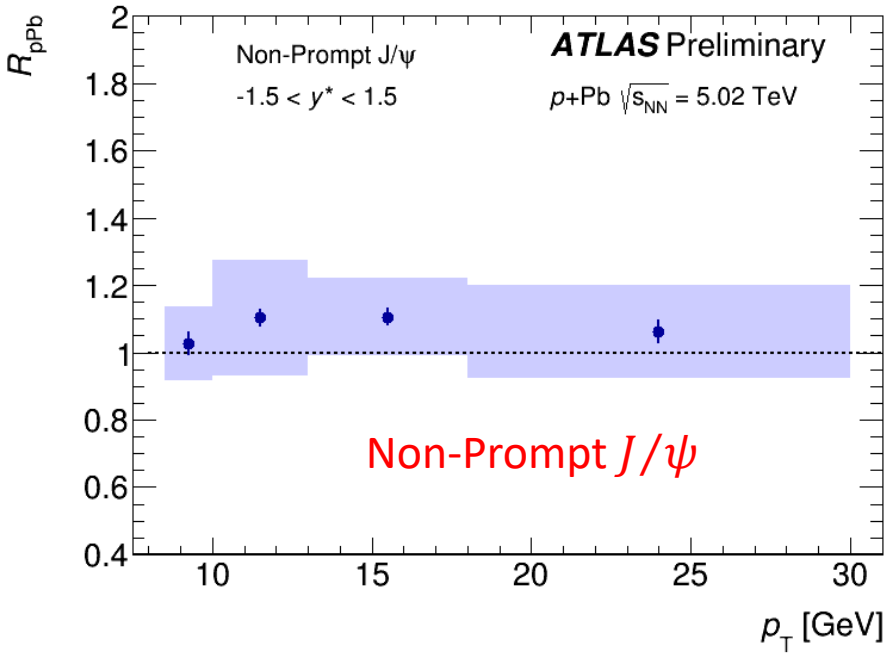
Nuclear modification factor of J/ψ (R_{pPb})





No significant p_T dependence, R_{pPb} is above unity, but within margin of error

pp reference is interpolated from 2.76 TeV, 7 TeV and 8 TeV

pp reference @5.02 TeV is in preparation

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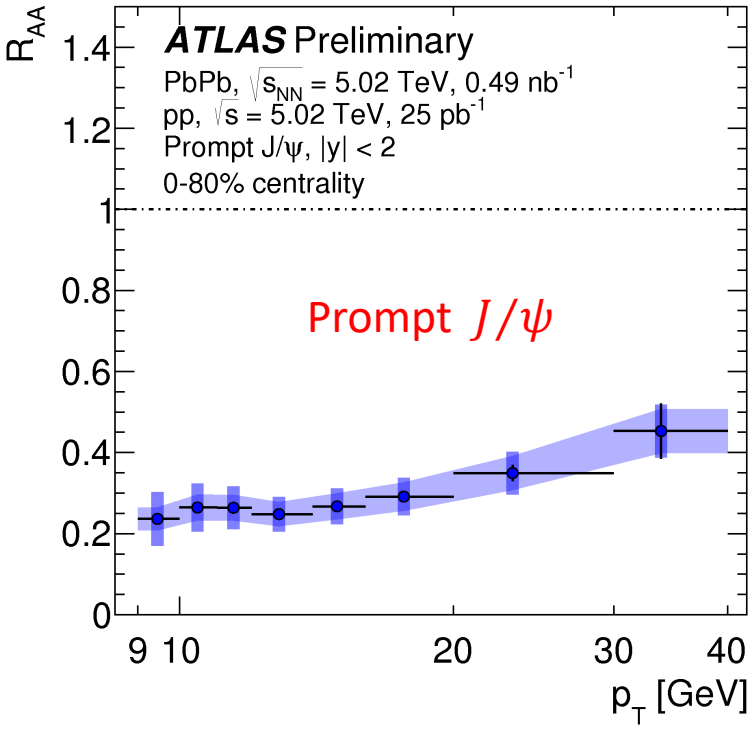
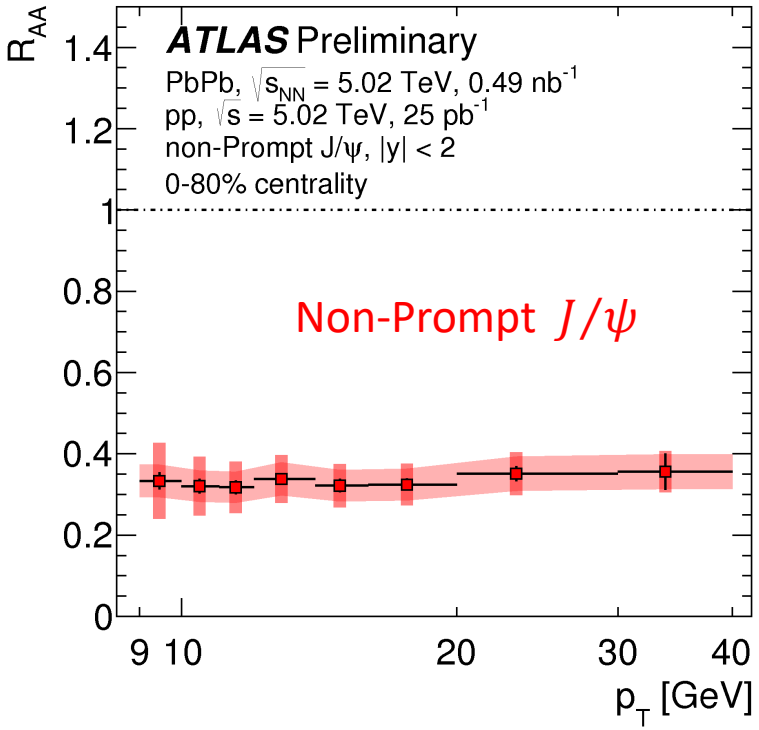
Nuclear modification factor of J/ψ (R_{PbPb})





For prompt R_{PbPb} is a function of p_T, for non-prompt no significant dependence

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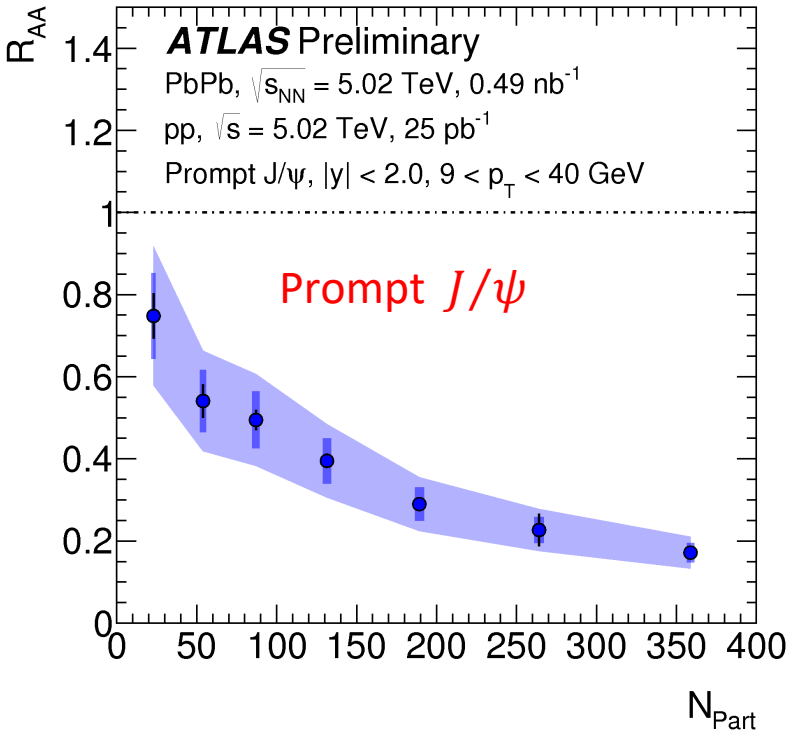
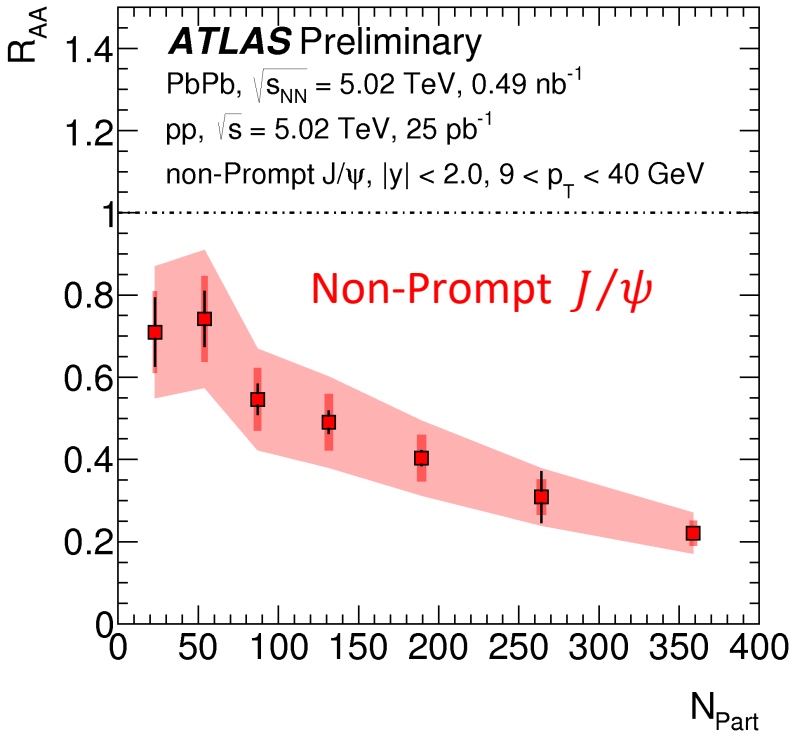
Nuclear modification factor of J/ψ (R_{PbPb})





Suppression is strongly centrality dependent, independently on production mechanism

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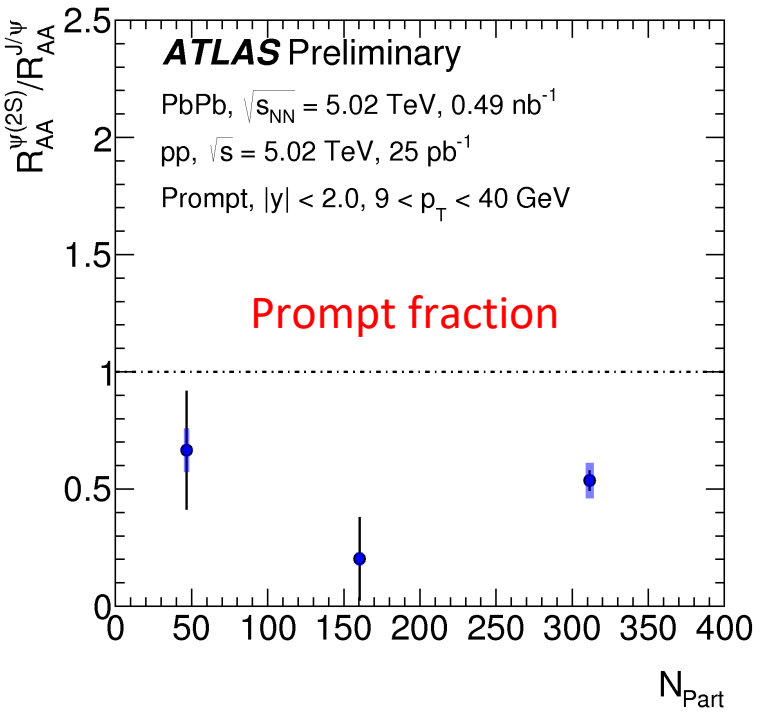
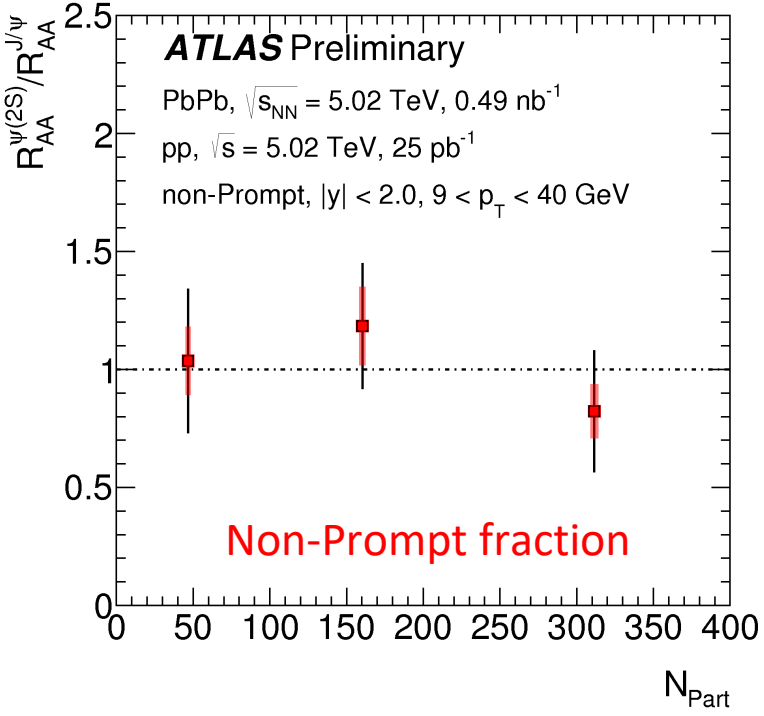
Double Ratio of $R_{PbPb}^{\psi(nS)}$ for J/ψ and $\psi(2S)$ in PbPb for both fractions





Strong suppression of Prompt $\psi(2S)$ compared to J/ψ, no significant difference in suppression for non-Prompt.

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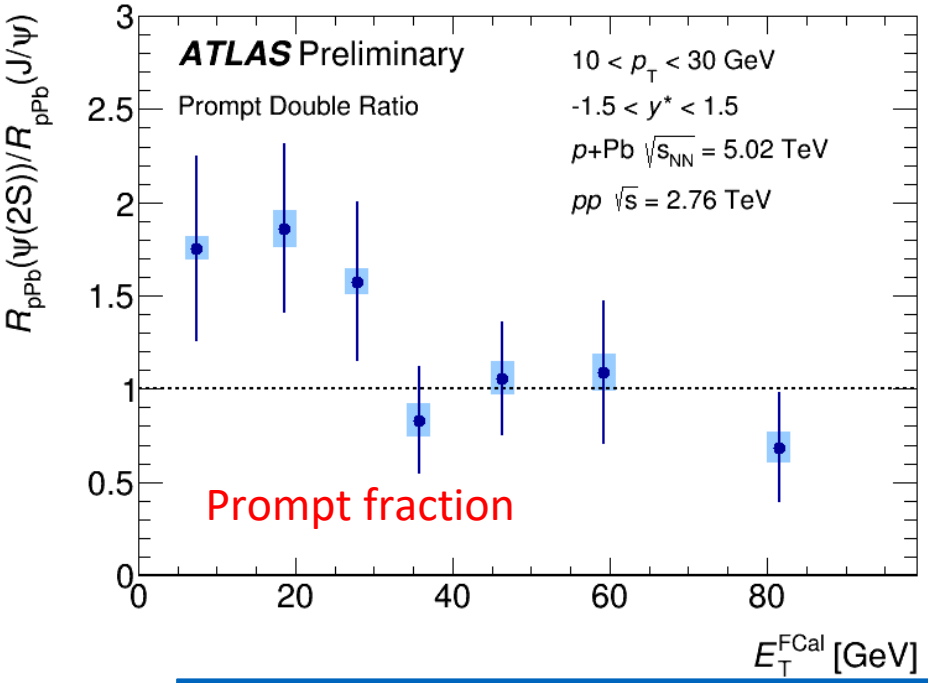
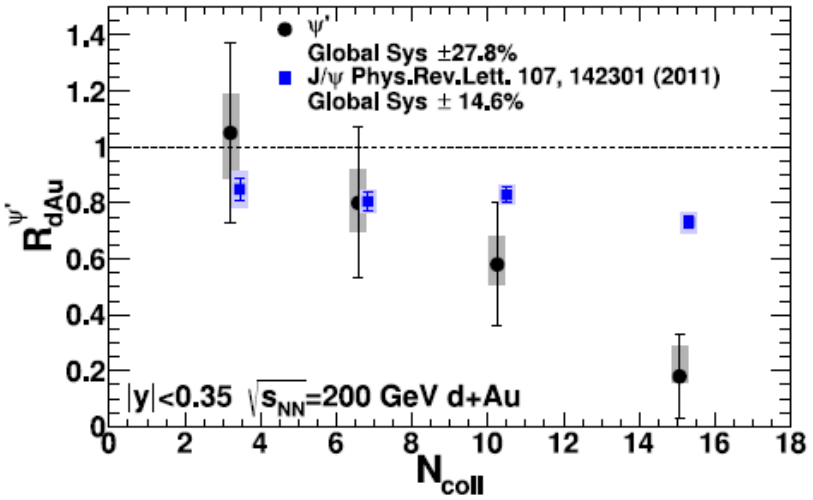
Double Ratio $R_{pPb}^{\psi(nS)}$ for p+Pb Prompt fraction





Suppresion has decrese trend in centrality, similar with PHENIX result

pp reference @2.76 TeV

PHENIX result from d+Au @200 GeV

ATLAS-CONF-2015-023

arXiv:1305.5516v1 [nucl-ex]

$\Upsilon(nS)$ measurement in p+Pb

- September 2015 $\Upsilon(nS)$ - ATLAS-CONF-2015-050
  - 2013 p+Pb $\sqrt{s_{NN}} = 5.02\ TeV$ and p+p $\sqrt{s} = 2.76\ TeV$

Method

Trigger:

- 1+ MU0 at L1, 2 muons, $p_T > 2\ GeV$

Kinematics range:

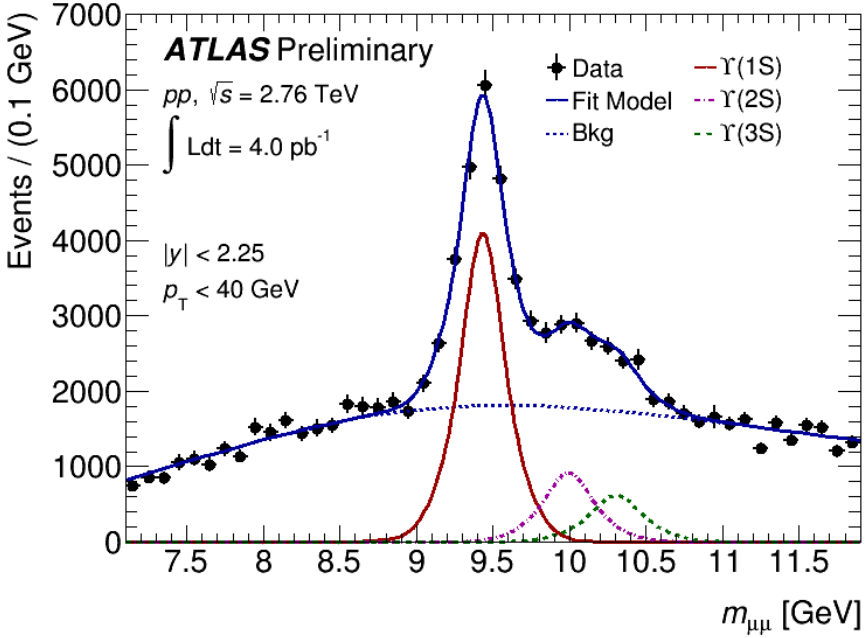
- $m_{\mu\mu} \in \langle 7; 12 \rangle\ GeV$ and $p_T^{\mu\mu} < 40\ GeV$
- $-2.25 < y^* < 1.2$ for p+Pb and $|y| < 2.25$ for p+p

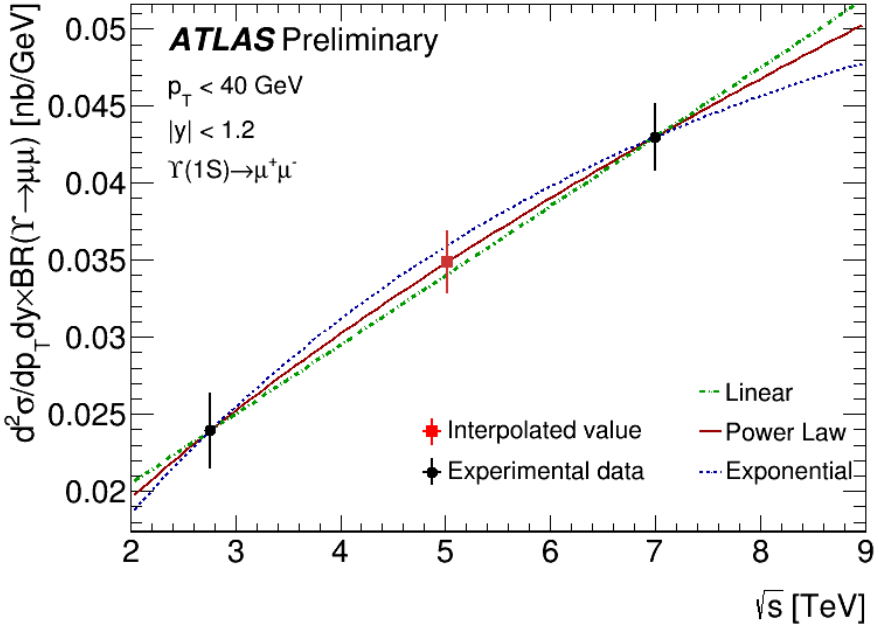
Fit model

- Binned least square fit
- Background is p_T dependent
  - Low p_T - $p_T < 8\ GeV$ or integrated over p_T range
  - High p_T - $p_T > 8\ GeV$

Signal	$f_{\Upsilon(1S)}(m_{\mu\mu})$	$\omega G(m_{\mu\mu}; M_{1S}, \sigma_{1S}) + (1-\omega) CB(m_{\mu\mu}; M_{1S}, 2\sigma_{1S}, \alpha, n)$
	$f_{\Upsilon(2S)}(m_{\mu\mu})$	$\omega G(m_{\mu\mu}; M_{2S}, \sigma_{2S}) + (1-\omega) CB(m_{\mu\mu}; M_{2S}, 2\sigma_{2S}, \alpha, n)$
	$f_{\Upsilon(3S)}(m_{\mu\mu})$	$\omega G(m_{\mu\mu}; M_{3S}, \sigma_{3S}) + (1-\omega) CB(m_{\mu\mu}; M_{3S}, 2\sigma_{3S}, \alpha, n)$
Background	low p_T $f_{bkg}(m_{\mu\mu})$	$erf(m_{\mu\mu}) \times E(m_{\mu\mu})$
	high p_T $f_{bkg}(m_{\mu\mu})$	$P(m_{\mu\mu})$

Fit method





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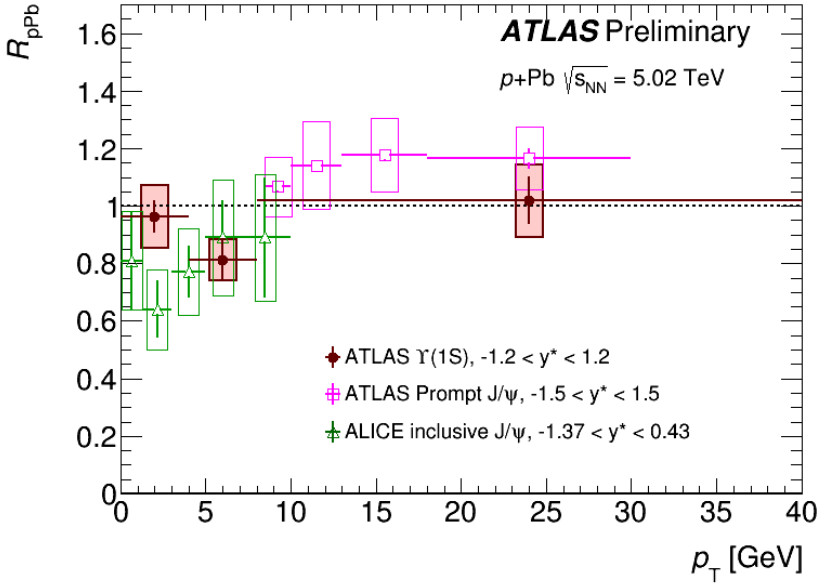
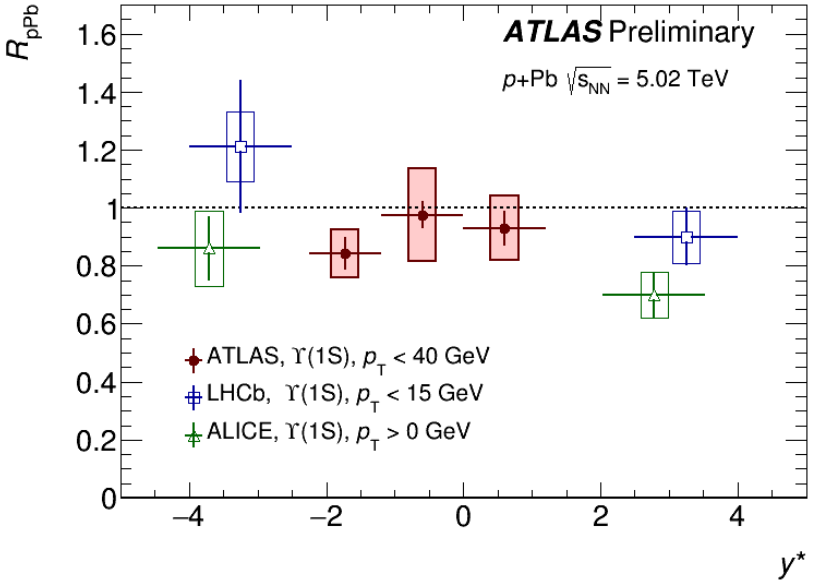
Nuclear modification factor R_{pPb}





Compatible with results of J/ψ R_{pPb} from ALICE and ATLAS

Comparison with $\Upsilon(1S)$ in different rapidity from other experiments

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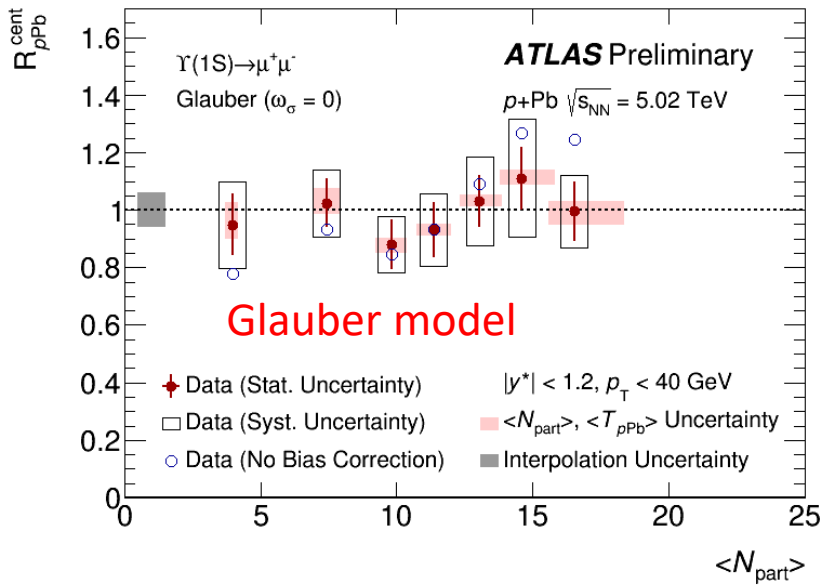
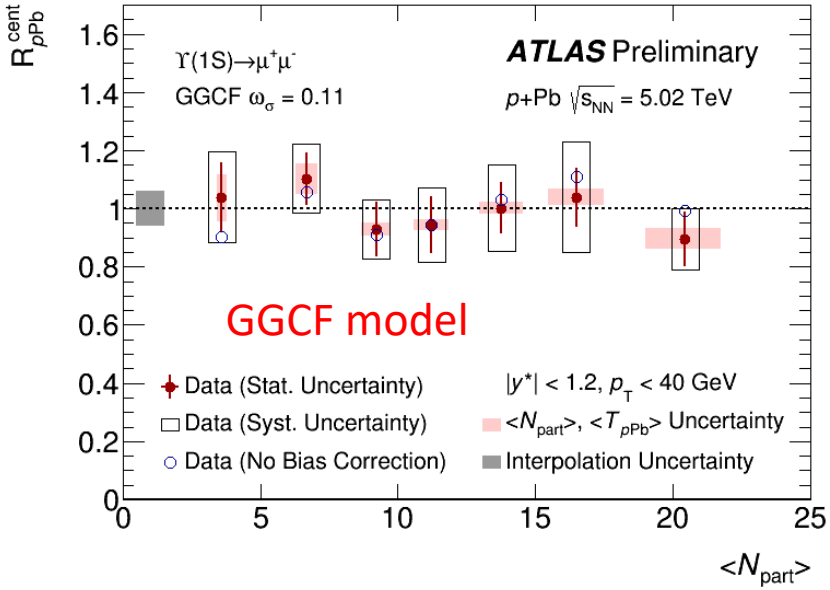
Nuclear modification factor R_{pPb}^{cent} in centrality





No significant centrality dependence, independent on model

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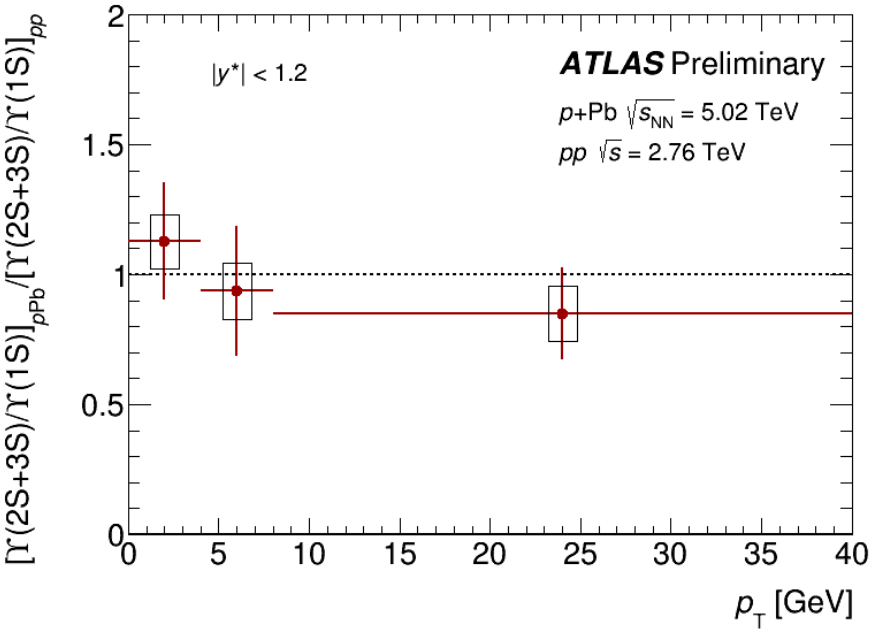
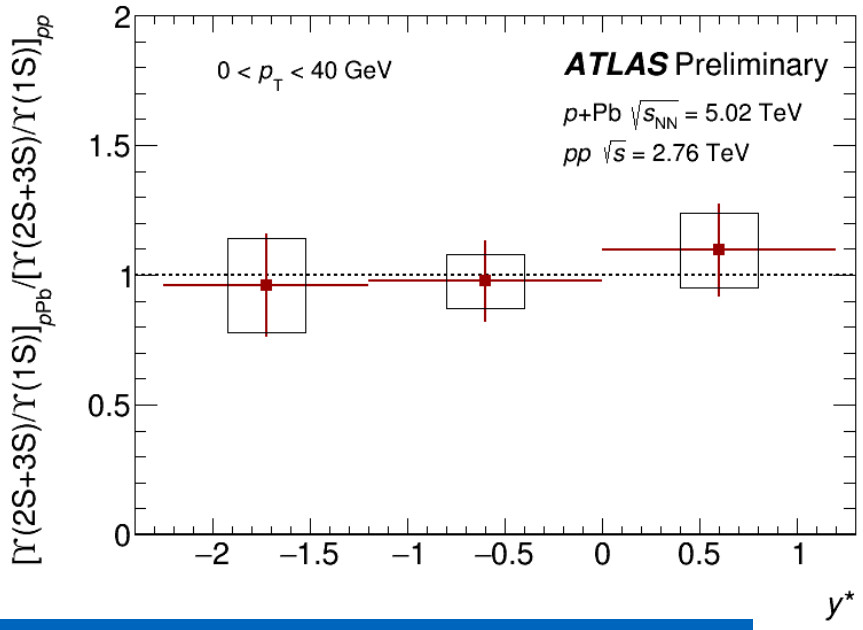
Double Ratio





$$\frac{[\Upsilon(2S+3S)/\Upsilon(1S)]_{pPb}}{[\Upsilon(2S+3S)/\Upsilon(1S)]_{pp}}$$

→ pp @ 2.76 TeV

No significant difference in production, no suppression of higher states

ATLAS-CONF-2015-050

Summary

- Charmonia and bottomonia production in p+Pb and Pb+Pb collisions are presented.
- Charmonia (J/ψ and $\psi(2S)$):
  - Charmonium R_{pPb} shows no obvious p_T and rapidity dependence.
  - Charmonium R_{PbPb} shows different behavior for prompt and non-prompt J/ψ in p_T dependence.
  - Charmonium R_{PbPb} shows strong centrality dependence.
  - $\psi(2S)$ shows suppression of prompt fraction in PbPb collisions
- Bottomonia ($\Upsilon(1S)$ and $\Upsilon(2S+3S)$) :
  - $\Upsilon(1S)$ R_{pPb} is compatible with prompt J/ψ R_{pPb}.
  - $\Upsilon(1S)$ R_{pPb} shows no centrality dependence.
- ATLAS HI Public Results

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Additional slides

Pseudo-proper decay time

$$\tau = \frac{L_{xy} m_{\mu\mu}}{p_T^{\mu\mu}}$$

L_{xy} = projection of decay length on the transverse plane

Definition of y*

$$y^* = y_{lab} - 0.465$$
$$y^* = -(y_{lab} + 0.465)$$

due to shift of center of mass

y* is defined as positive in proton beam direction

Nuclear modification factor R_{AA} and R_{pA}

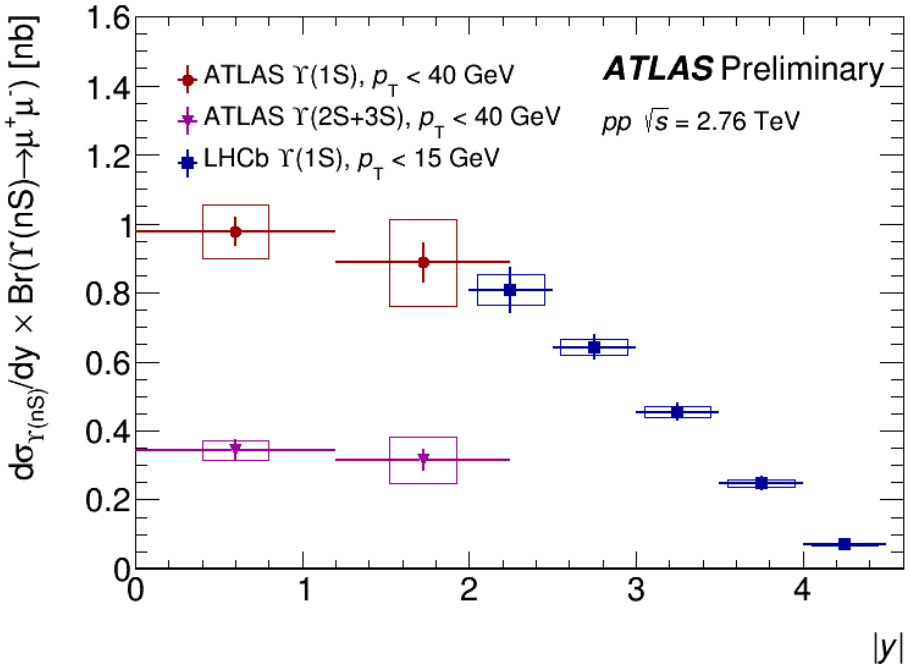
$$R_{AA} = \frac{N^{AA}}{\langle T_{AA} \rangle \times \sigma^{pp}}$$

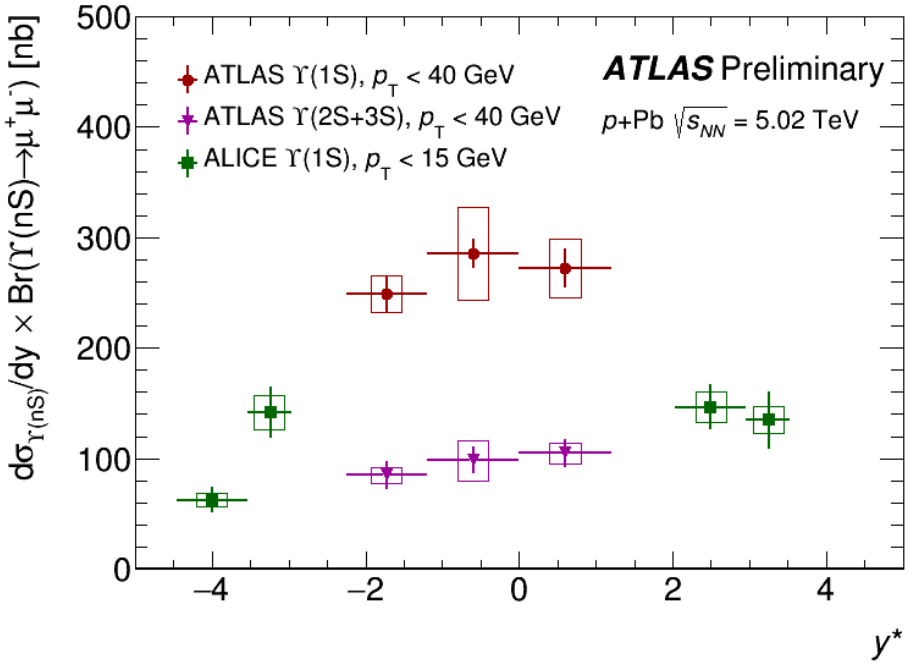
- N^{AA} - per-event yield of quarkonia states in A+A collisions
- $\langle T_{AA} \rangle$ - mean nuclear function ψ
- σ^{pp} - cross section in pp collisions

$$R_{pA} = \frac{1}{A^{Pb}} \frac{d^2\sigma_{\psi}^{p+Pb}/dy * dp_T}{d^2\sigma_{\psi}^{p+p}/dy * dp_T}$$

$$R_{pA}^{cent} = \frac{\langle 1/N_{evt}^{cent} \rangle \; d^2N^{p+Pb}/dydp_T|_{cent}}{\langle T_{pPb} \rangle_{cent} \, d^2\sigma^{pp}/dydp_T}$$

Cross section of $\Upsilon(nS)$





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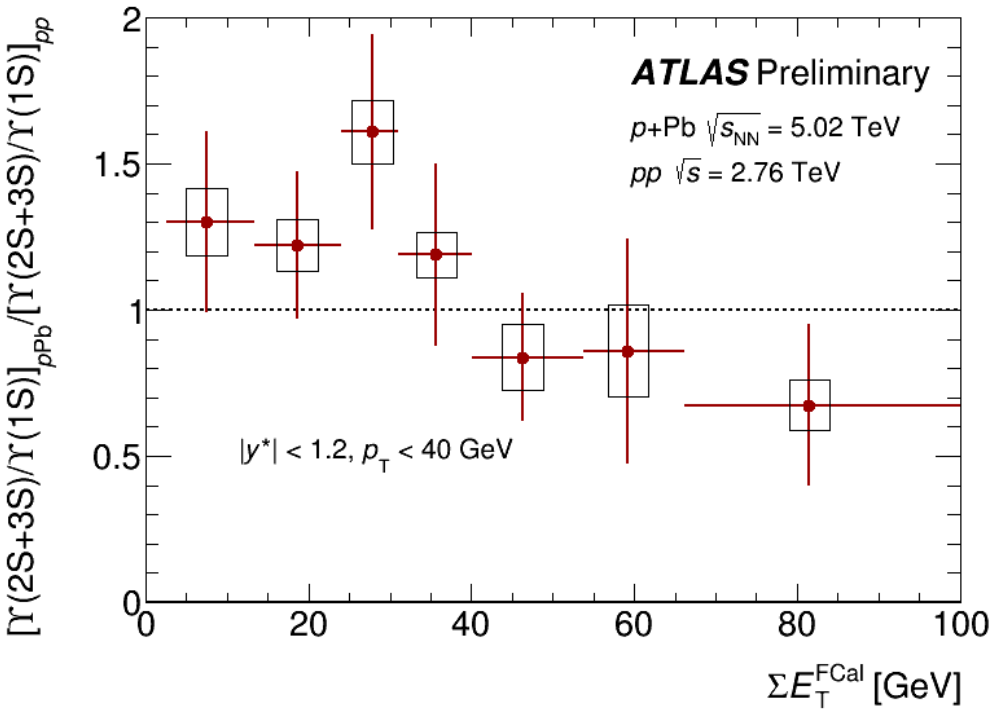
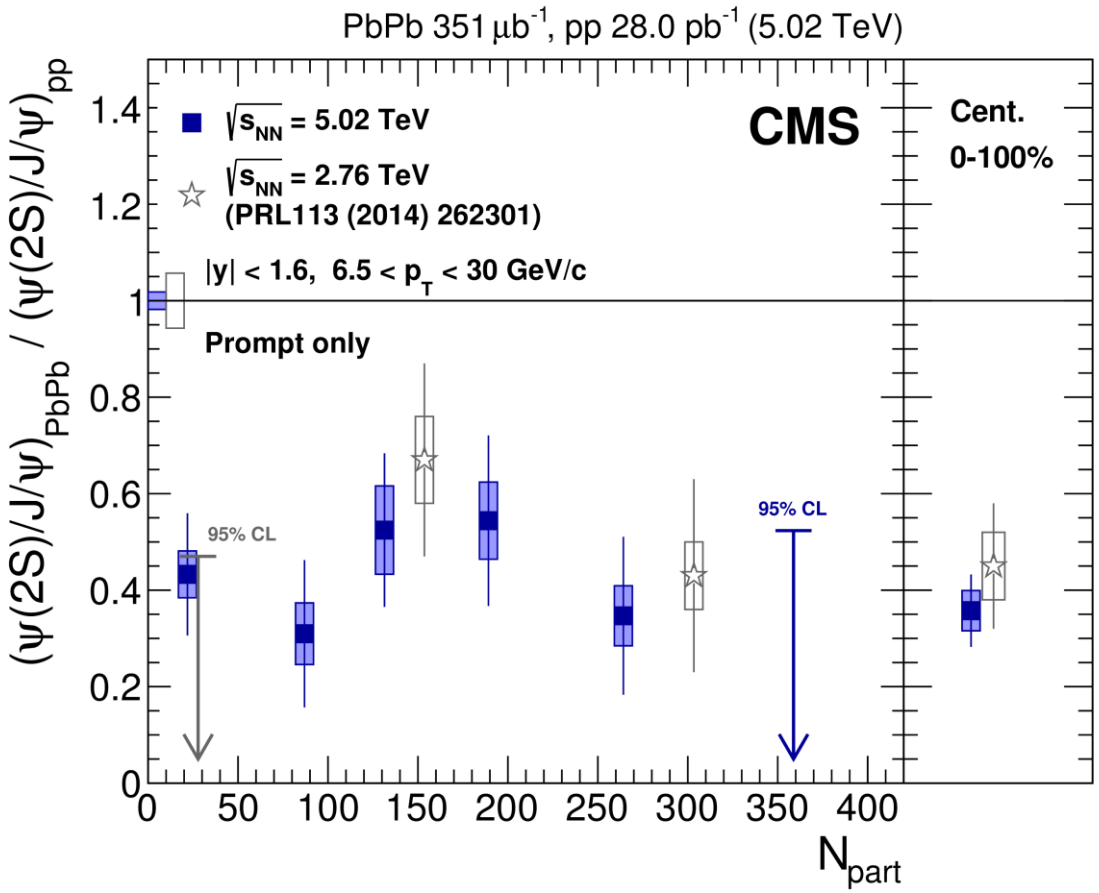
Double Ratio in centrality



Same trend as for J/ψ to $\psi(2S)$ ratio, less significant ATLAS-CONF-2015-050

CMS results – Double Ratio J/Psi to Psi(2S)



Prompt fraction

CMS-HIN-16-004