Vector boson and quarkonia production in p+Pb and Pb+Pb collisions with ATLAS at the LHC

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25th International Workshop on Deep Inelastic Scattering and Related Topics

University of Birmingham

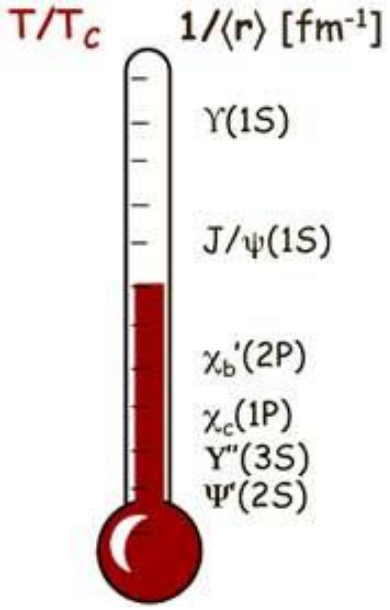
Why measure the Quarkonia and Vector bosons in A+A collisions

Vector bosons

- don´t interact with quark gluon plasma
- provide information on nuclear collision geometry and cold nuclear matter effects

Quarkonia

- bound states of c or b quarks and antiquarks
- interacts strongly with environment
- two types of interactions – cold and hot matter effects



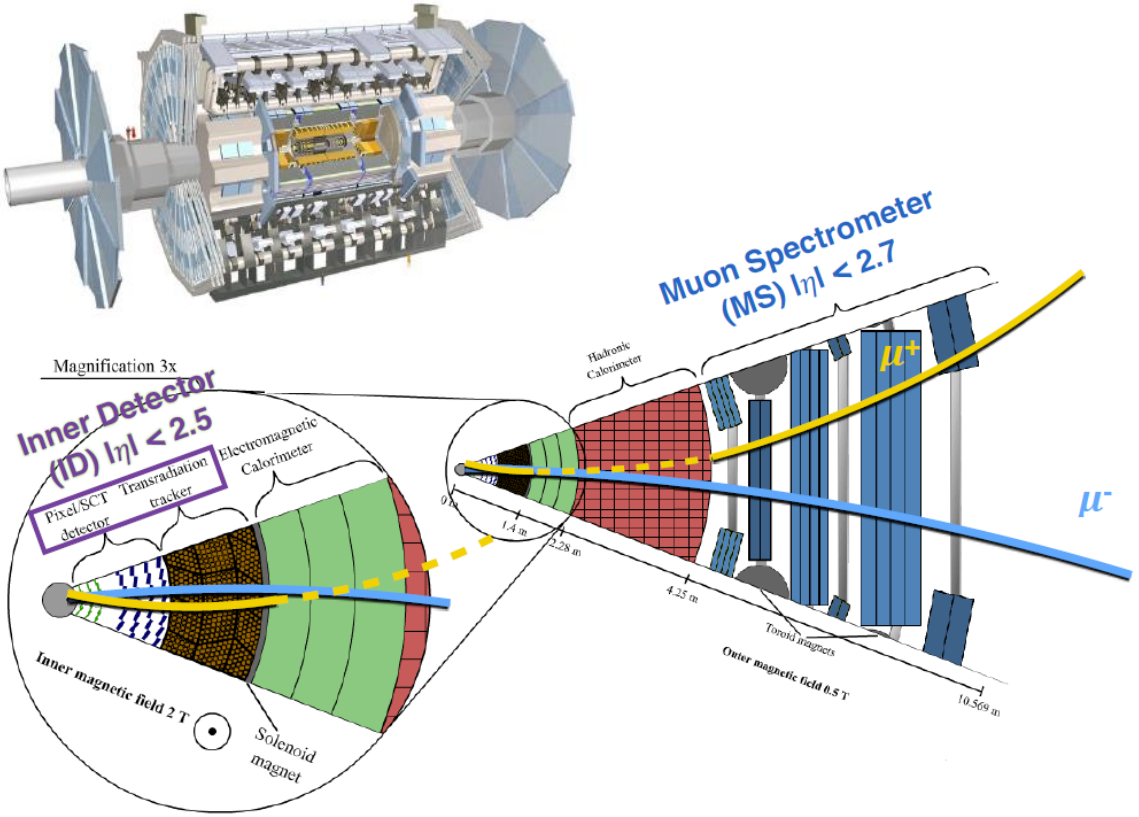
courtesy of A. Mocsy

Nuclear modification factor

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

T_{AA} = nuclear thickness function

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
  - $25.0\ pb^{-1}$

Z boson measurements

Presented new measurements

- February 2017 Z boson production- ATLAS-CONF-2017-010
  - 2015 Pb+Pb $\sqrt{s_{NN}} = 5.02\ TeV$
- September 2016 Z boson production - ATLAS-CONF-2016-107
  - 2015 p+p $\sqrt{s} = 5.02\ TeV$ and 2013 p+Pb $\sqrt{s_{NN}} = 5.02\ TeV$

Method

p+p

Trigger p+p

- one muon MU14 at HLT

Analysis range

- 2 muons, $p_T > 20\ GeV$, $|y| < 2.4$
- $m_{\mu\mu} \in \langle 66; 116 \rangle\ GeV$

Pb+Pb

Event selection

- $|z_0| < 150\ mm$
- no pile-up

Trigger

- one muon MU8 at HLT

Analysis range

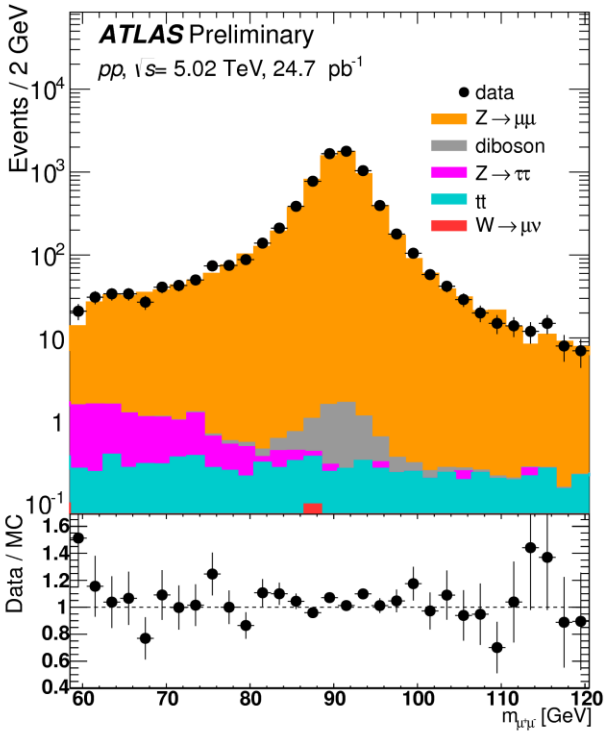
- 2 muons, $|y| < 2.5(2.4)$, $p_T > 20\ GeV$
- $m_{\mu\mu} \in \langle 66; 116 \rangle\ GeV$
- centrality 0−80%

Yields are calculated by

- subtracting the background
- applying the corrections

Data compared to prediction

pp



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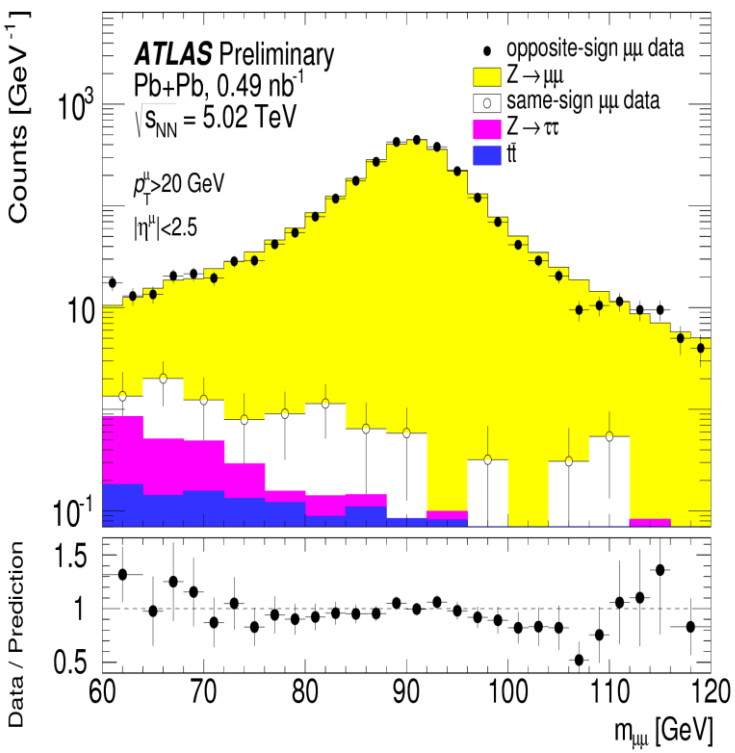
Pb+Pb



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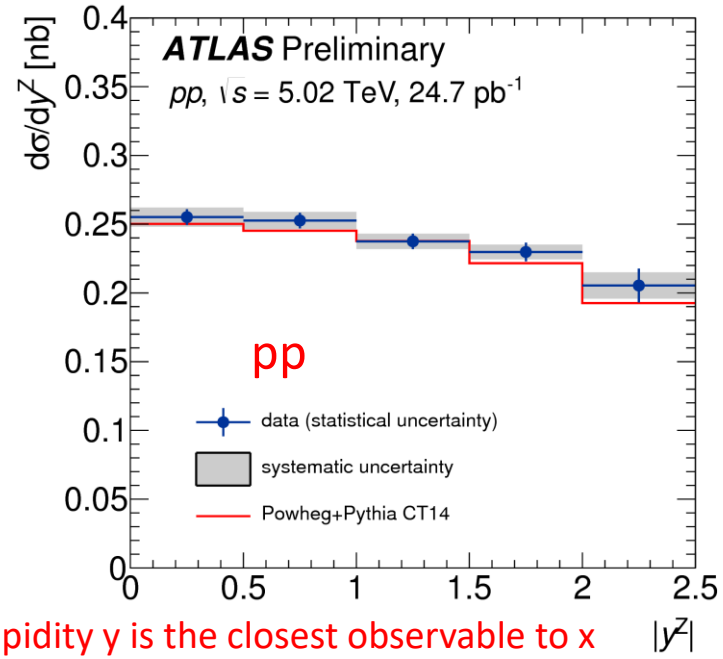
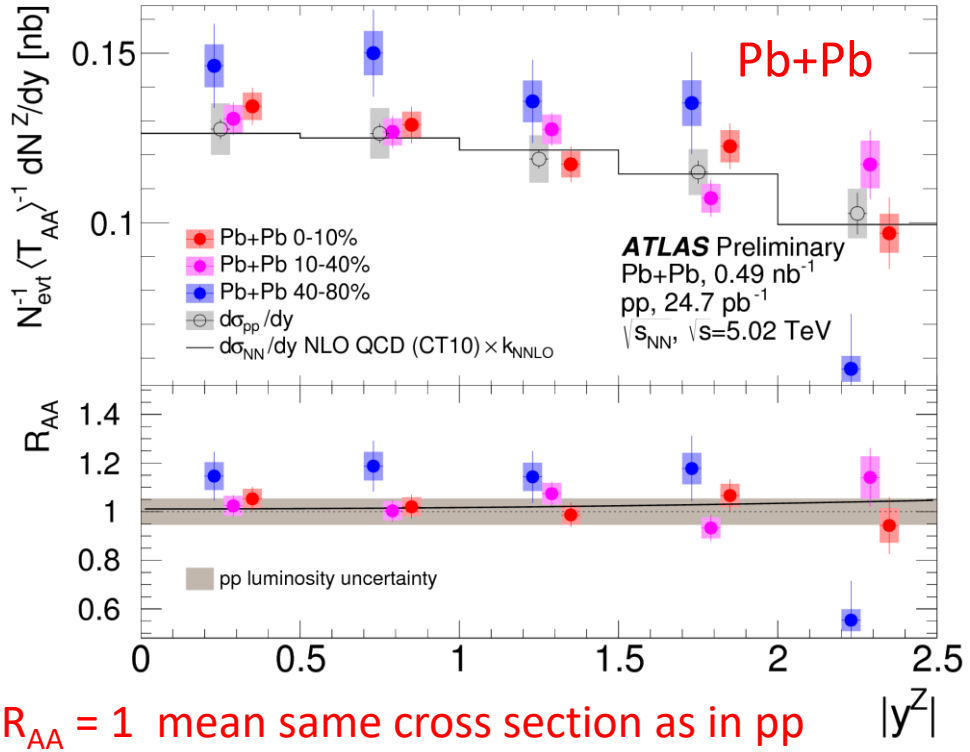
Detector performance of the measurement is well described by simulations

Yields per event scaled by T_{AA} and R_{AA}



rapidity y is the closest observable to x

pp data agree with by pQCD



R_{AA} = 1 mean same cross section as in pp

Pb+Pb measurements are compatible with pp measurement after scaling.

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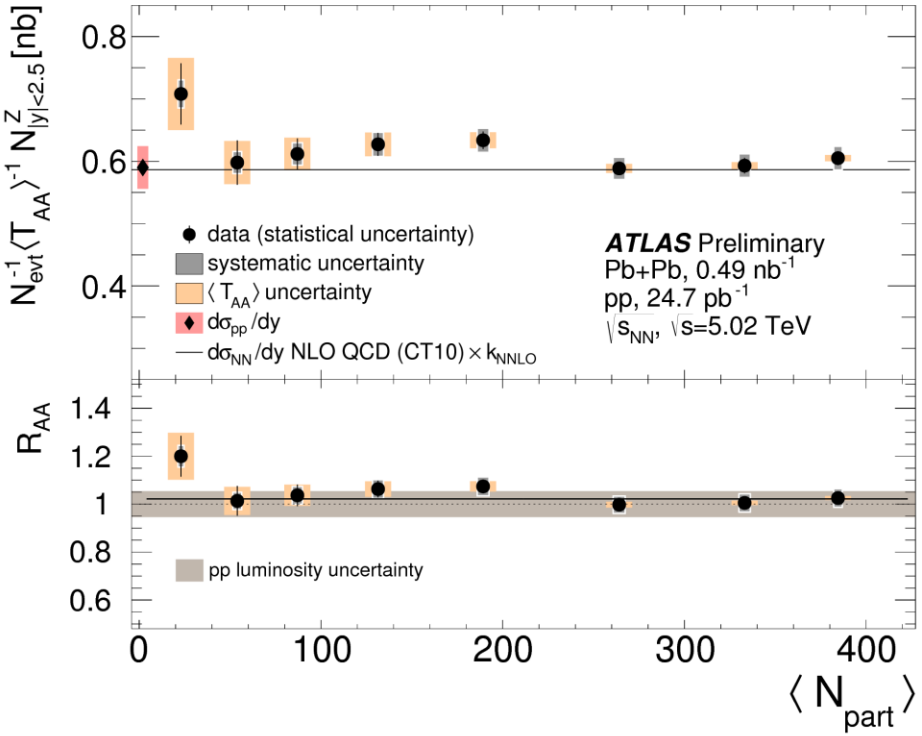
Yields in centrality scaled by T_{AA}



Yield scales well with T_{AA} in all centrality bins, in some bins yield has smaller uncertainty than T_{AA}.

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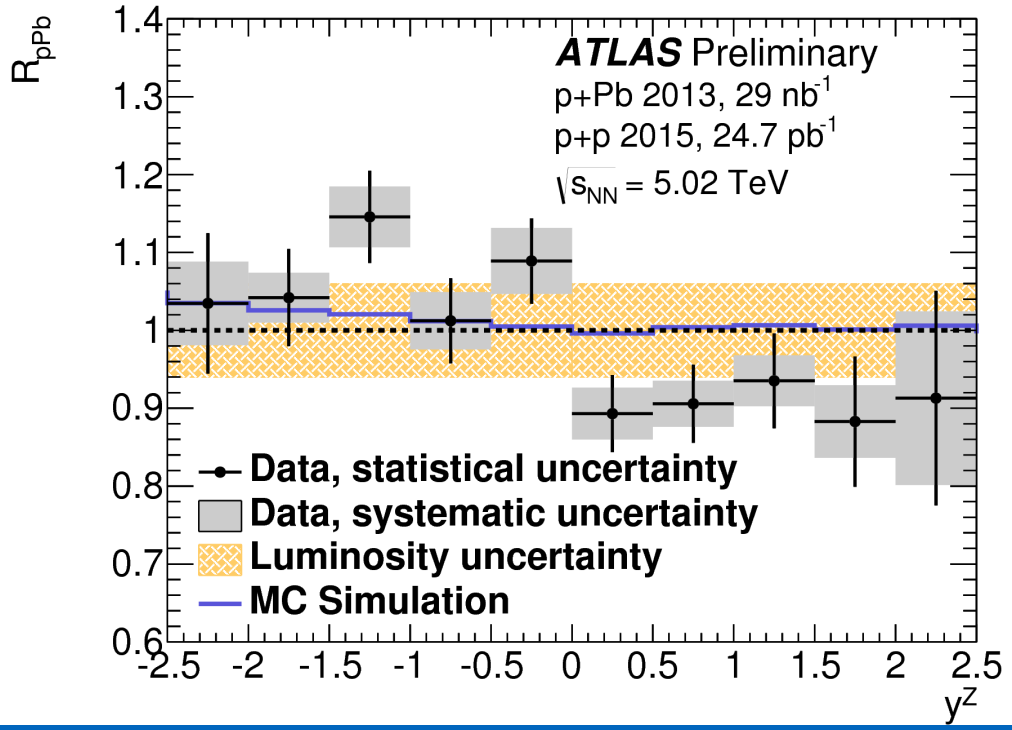
Nuclear modification function R_{pPb}

p+Pb

p ->



<- Pb

We observe suppression in forward rapidity in events corresponding to low x on nucleus, measurement is sensitive to nuclear shadowing which is not simulated in our MC

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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: at least one muon at L1 (MU0),
  2 muons with $p_T > 2\ GeV$ at HLT
- Pb+Pb: at least one muon at L1 (MU4),
  2 muons with $p_T > 4\ GeV$ at HLT

Analysis range

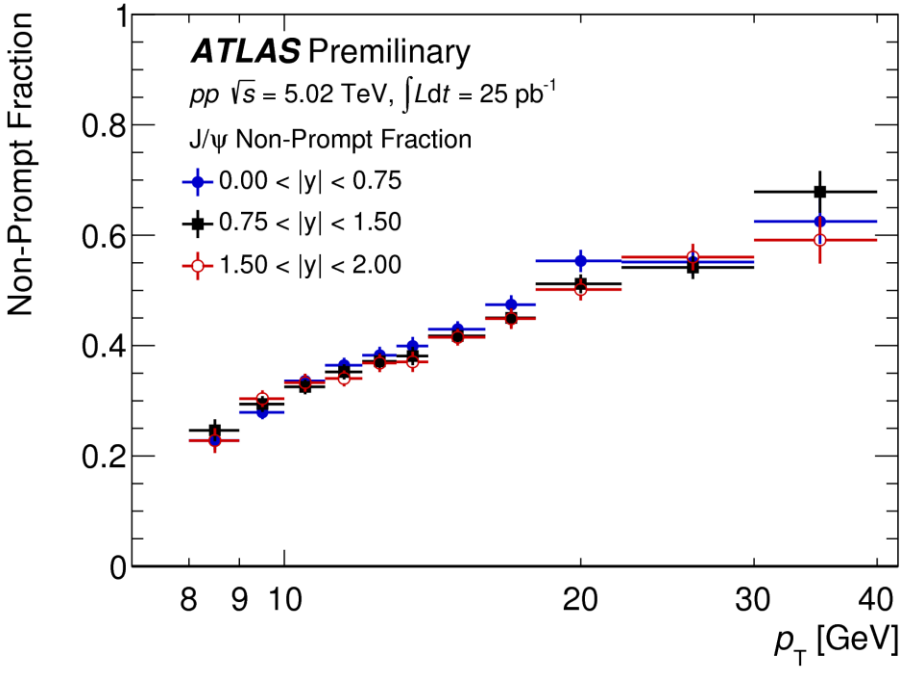
- p+Pb : $p_T \in \langle 8.5; 30 \rangle\ GeV, |y^*| < 1.94\ (1.5)$
- Pb+Pb: $p_T \in \langle 9; 40 \rangle\ GeV, |y| < 2$, centrality 0−80%

Perform weighted 2D unbinned maximum likelihood fit

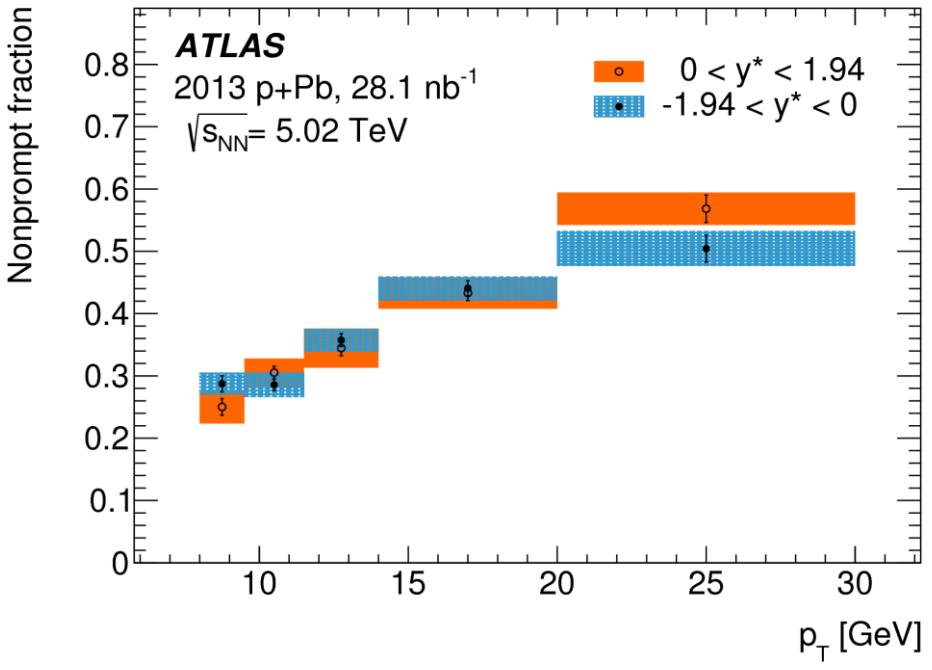
- dimuon invariant mass and lifetime
- extract fraction of prompt and non-prompt
  - Prompt – direct production, feed-down contribution
  - Non-prompt – decay from B hadrons
- per-Dimuon weight: trigger, reconstruction, acceptance

Non-Prompt fraction of J/ψ as a function of p_T

pp



p+Pb



No visible |y| dependence, but significant p_T dependence, both distributions are comparable.

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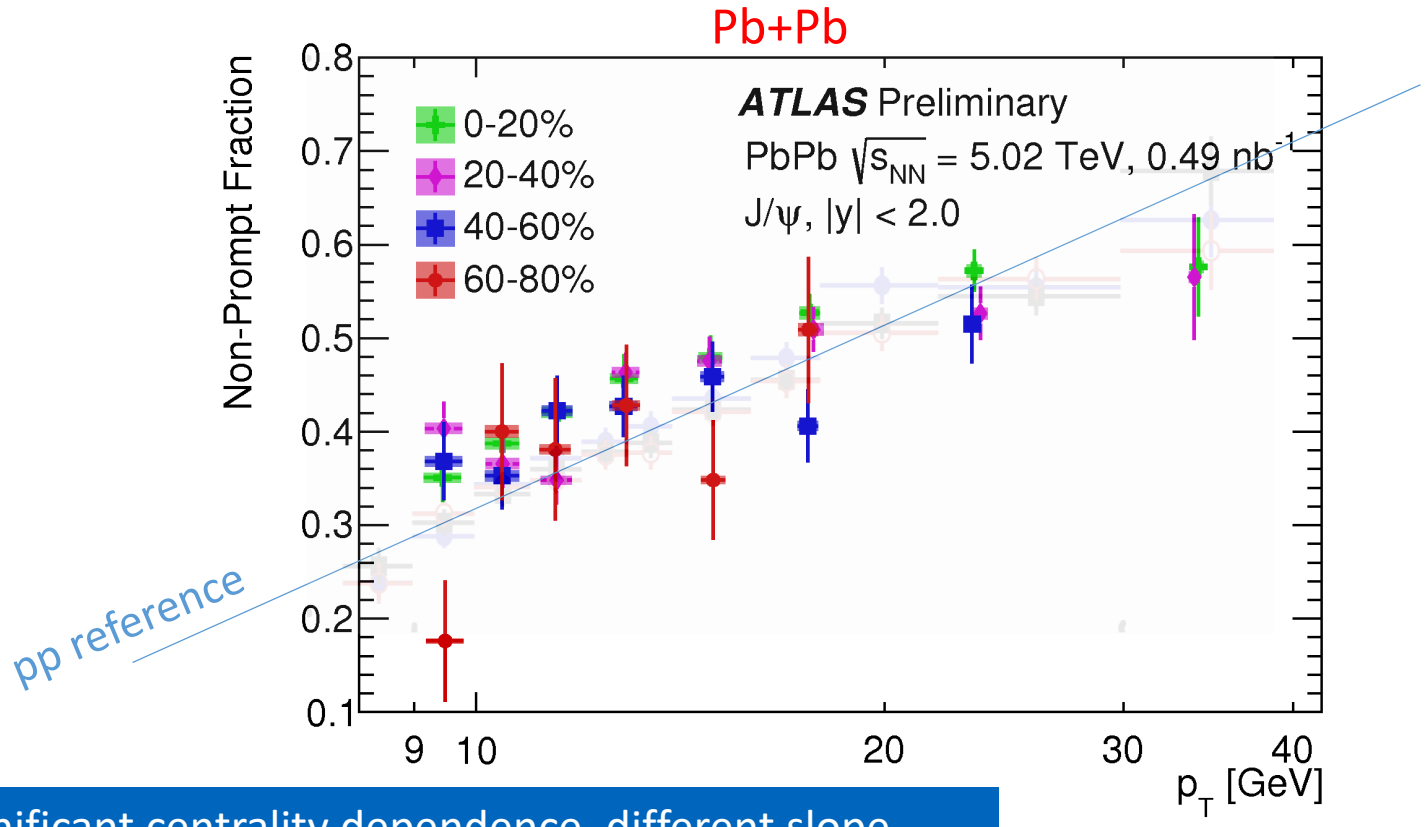
arXiv: 1505.08141 [hep-ex]

Non-Prompt fraction of J/ψ as a function of p_T



No significant centrality dependence, different slope than pp due to different suppression of fractions

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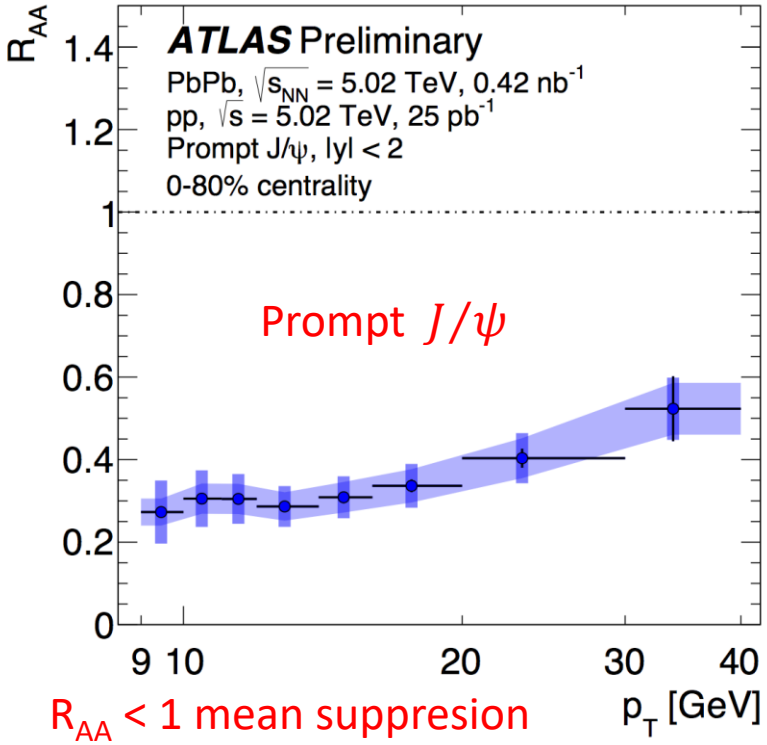
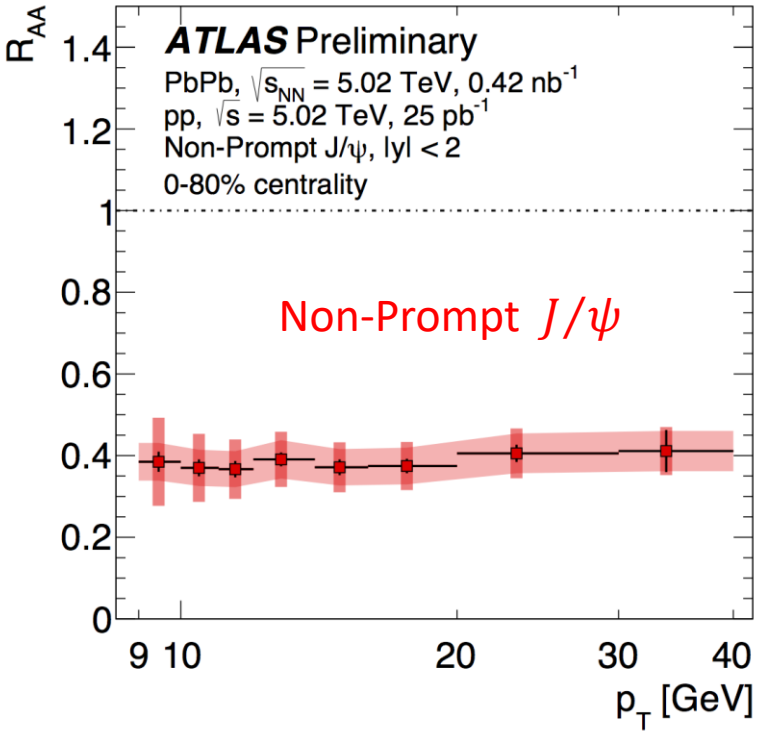
Nuclear modification factor of J/ψ (R_{PbPb})



R_{AA} < 1 mean suppresion



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

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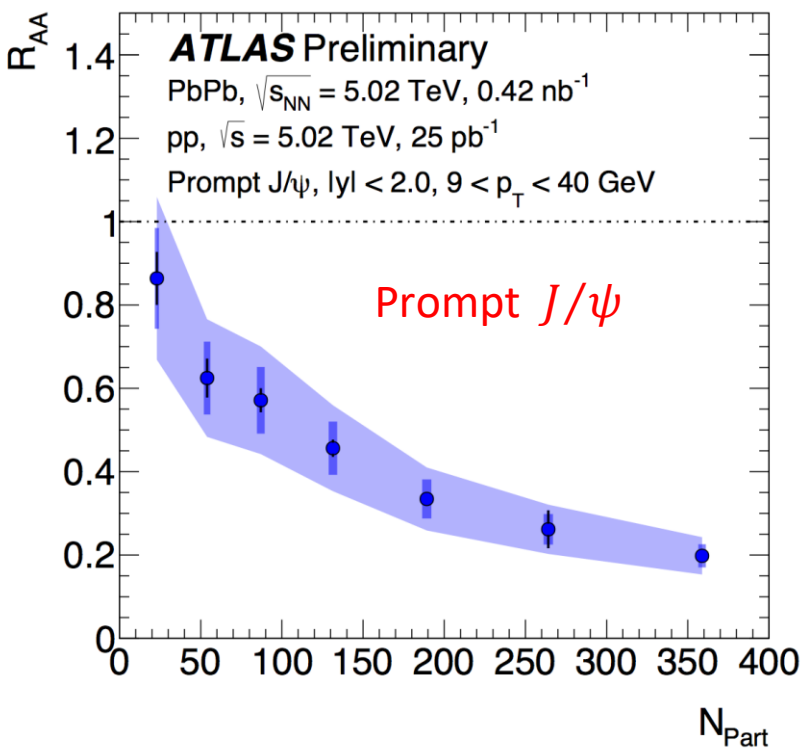
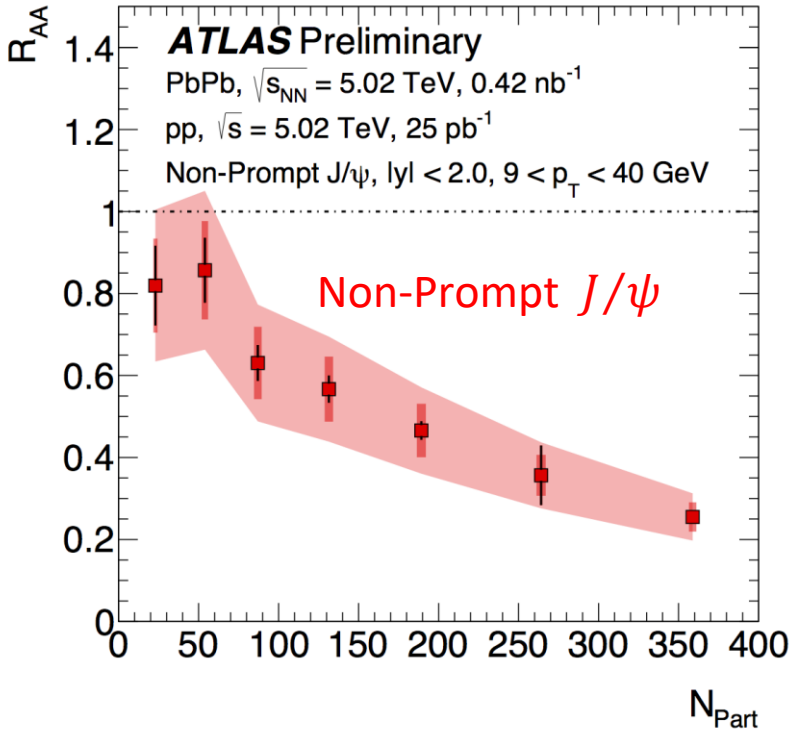
Nuclear modification factor of J/ψ (R_{PbPb})





Suppression is strongly centrality dependent, regardless of on production mechanism

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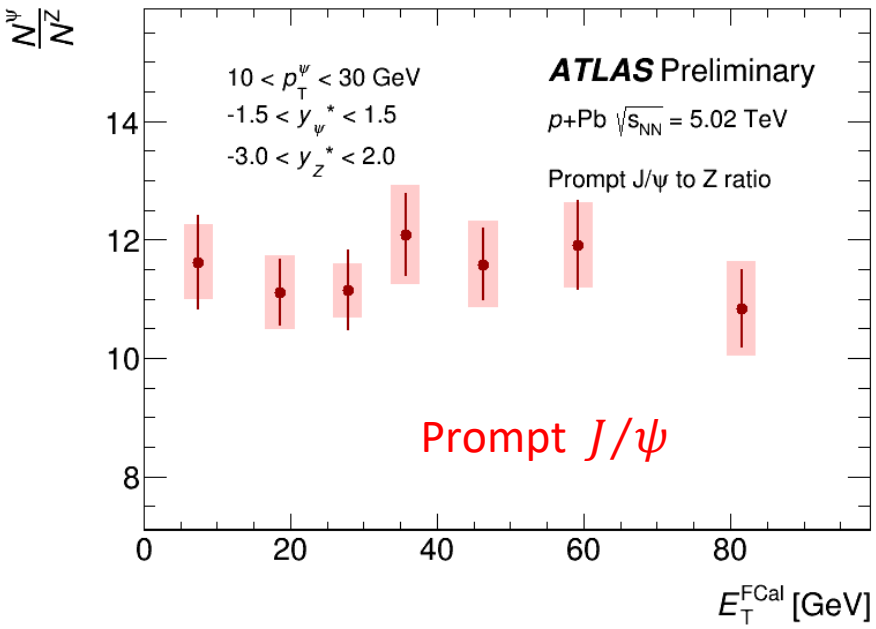
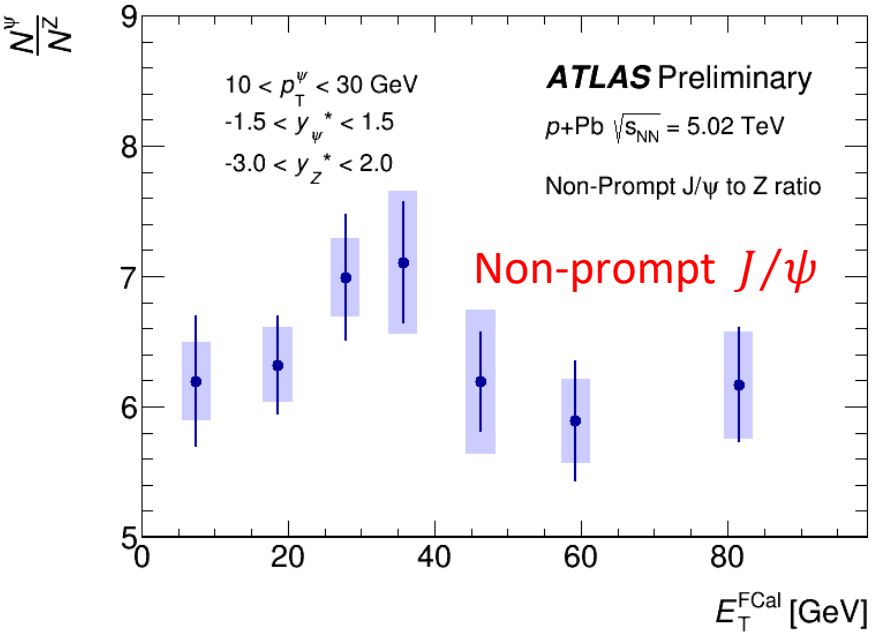
Comparison of Z boson and J/ψ yields in p+Pb collisions





Ratio of the yields is independent on event activity, number of Z and J/ψ particles scale with the number of interactions

ATLAS-CONF-2015-023

Summary

- Charmonia and Z boson production in p+Pb and Pb+Pb collisions are presented.
- Z boson
  - After scaling by T_{AA}, yields are described by pQCD
  - Nuclear modification factor R_{PbPb} is consistent with unity in centrality and rapidity
- 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.
- Ratio N_ψ / N_Z in p+Pb is independent on event activity and could be used as a benchmark for T_{AA} and N_{coll}.
- 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

1/20/17

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

1/20/17

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

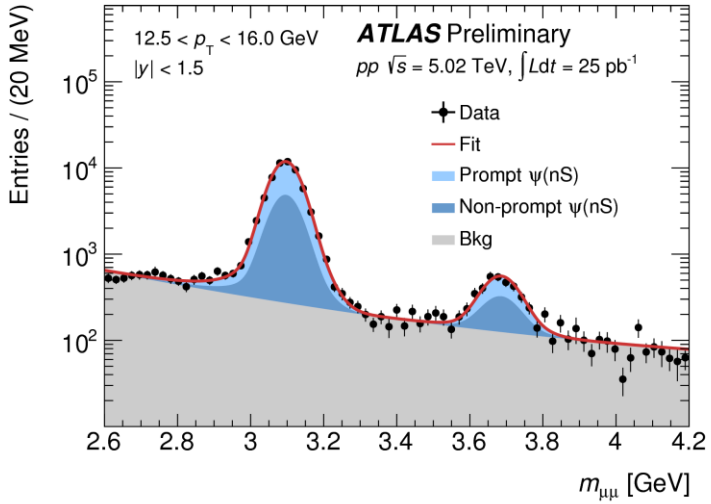
$$R_{AA} = \frac{N^{AA}}{\langle T_{AA} \rangle \times \sigma^{pp}}$$

- 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

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

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

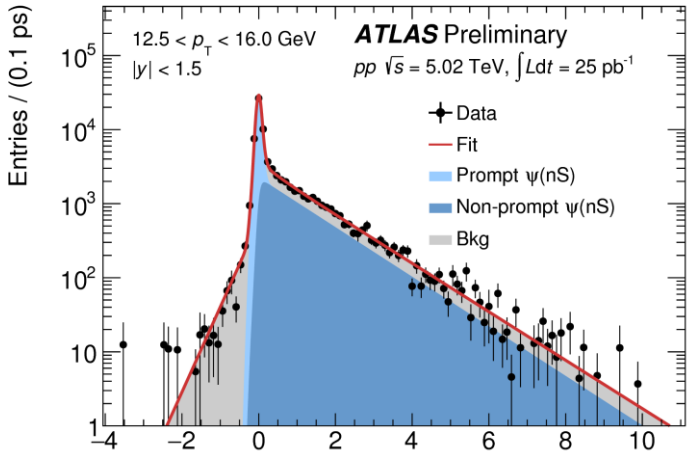
Simultaneous Fit Method



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

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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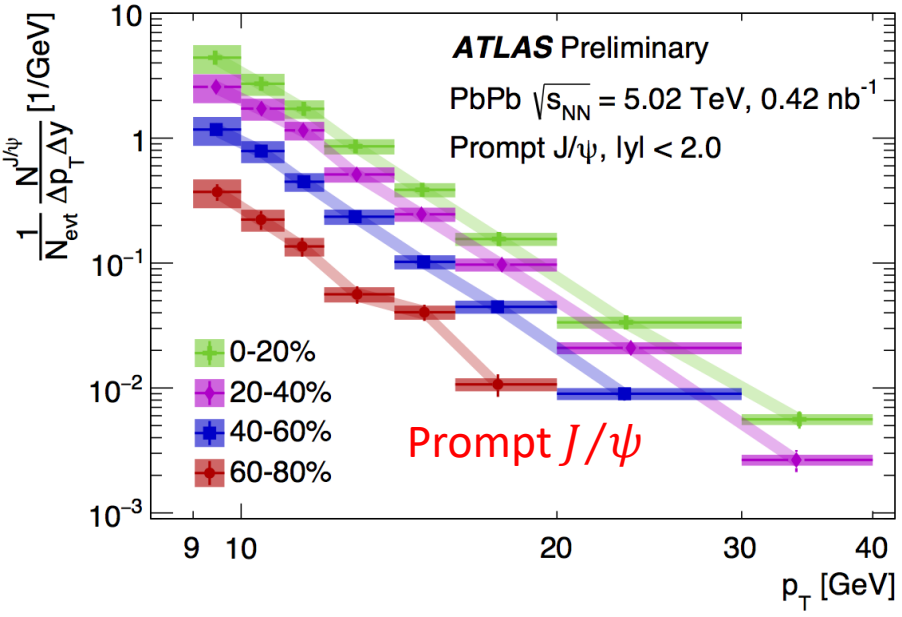
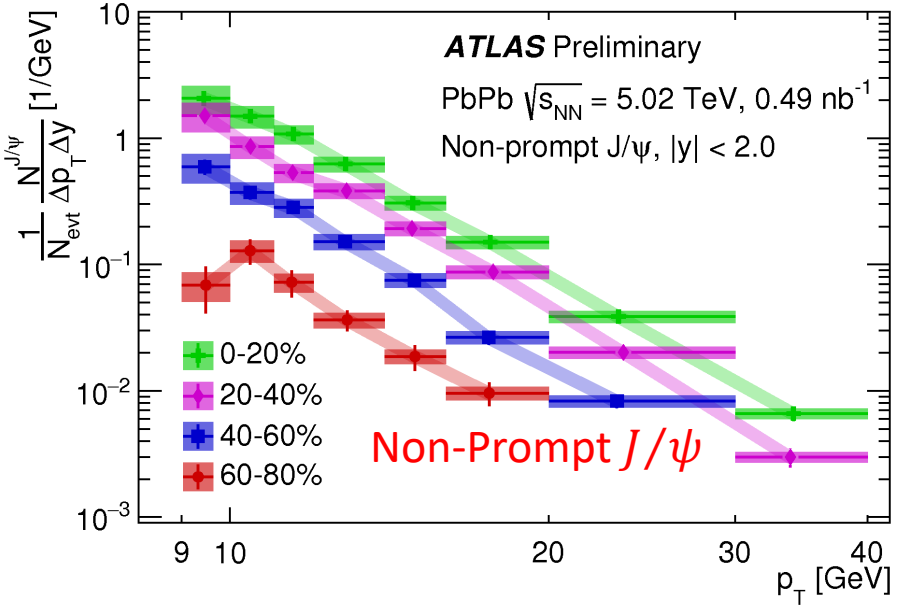
Pb+Pb per-event yields





Yields are centrality and p_T dependent

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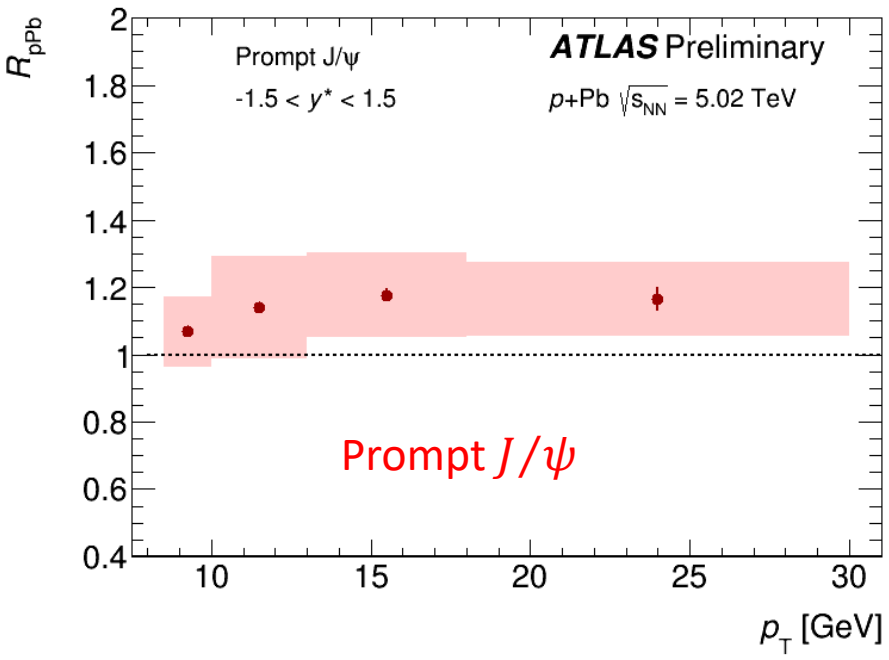
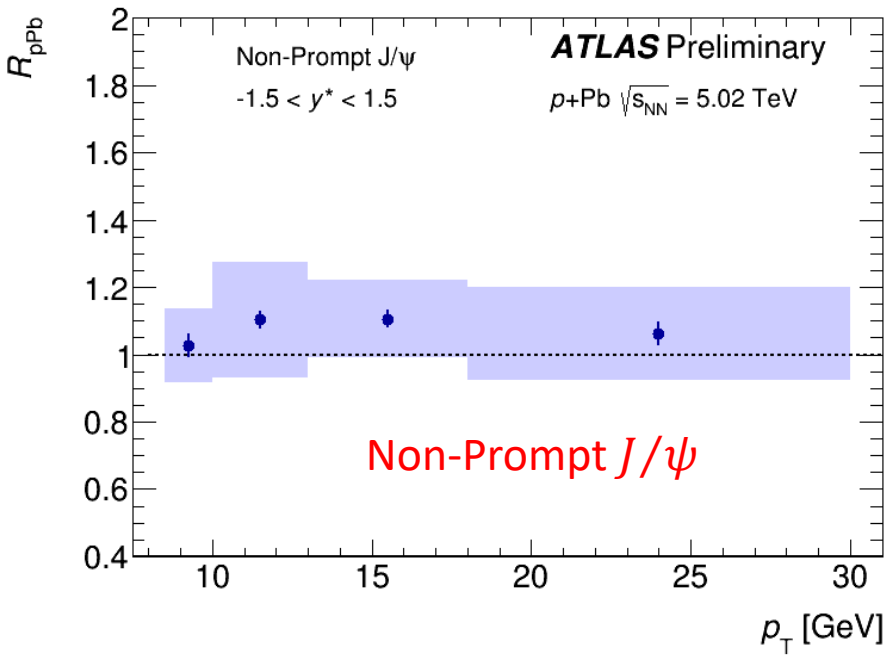
Nuclear modification factor of J/ψ (R_{pPb})





No significant p_T dependence, R_{pPb} is above unity, but within systematics uncertainties

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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