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

Petr Gallus on behalf of the ATLAS Collaboration

25th International Workshop on Deep Inelastic Scattering and Related Topics

University of Birmingham

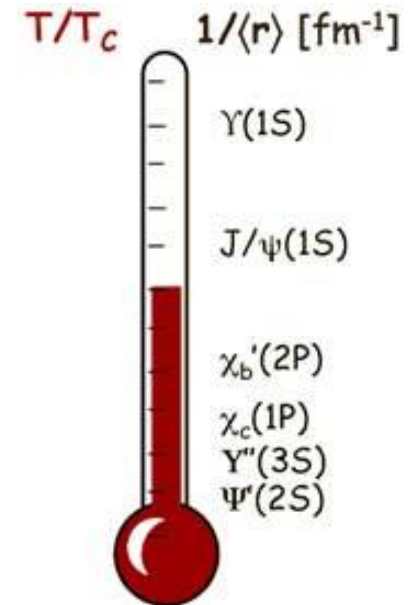
Why measure the Quarkonia and Vector bosons in A+A collisions

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



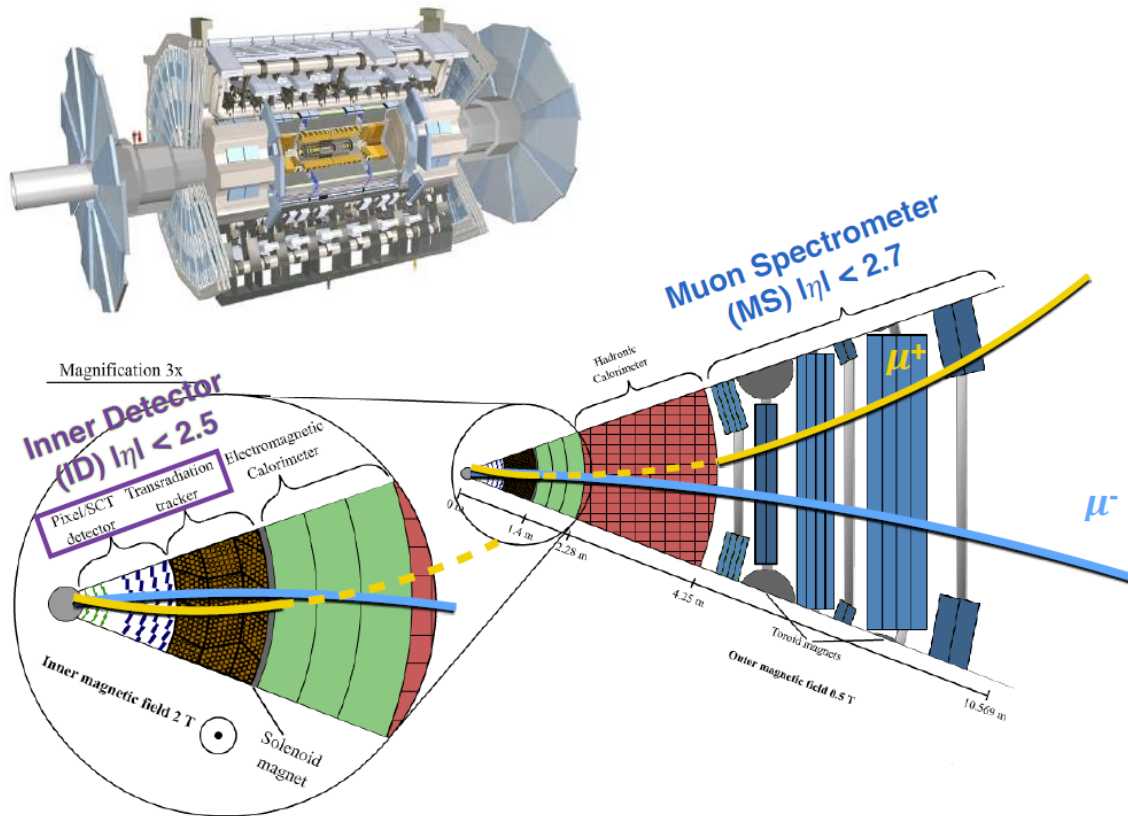
courtesy of A. Mocsy

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

Method

p+p

Trigger p+p

- one muon MU14 at HLT

Analysis range

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

Pb+Pb

Event selection

- $|z_0| < 150 \text{ mm}$
- no pile-up

Trigger

- one muon MU8 at HLT

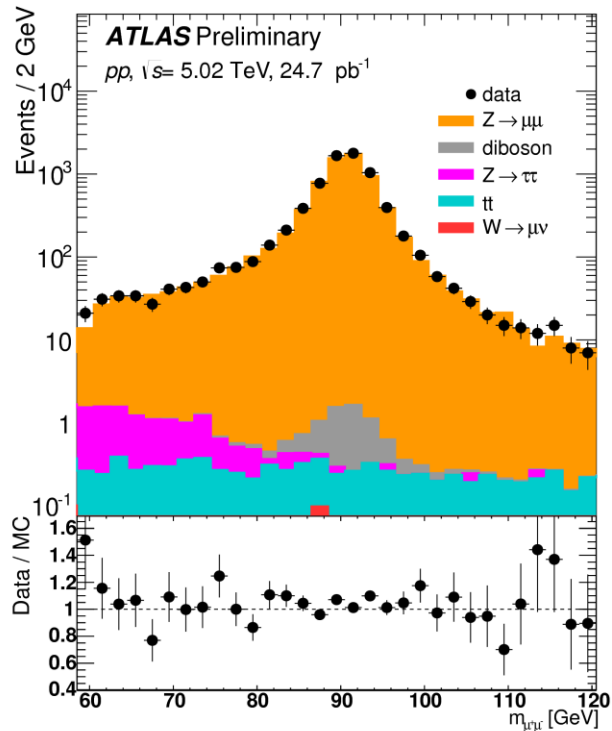
Analysis range

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

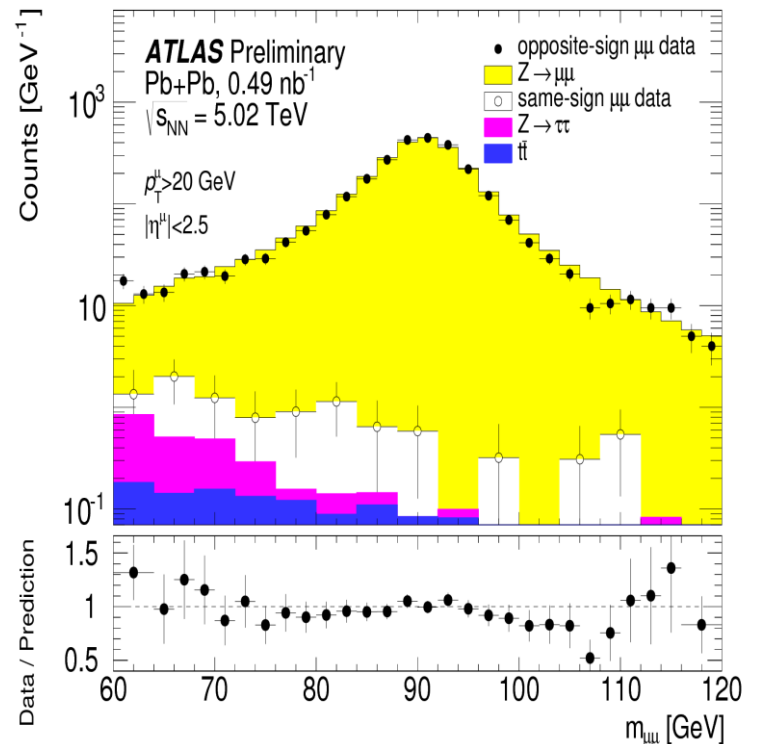
Yields are calculated by

- subtracting the background
- applying the corrections

pp **Data compared to prediction** **Pb+Pb**



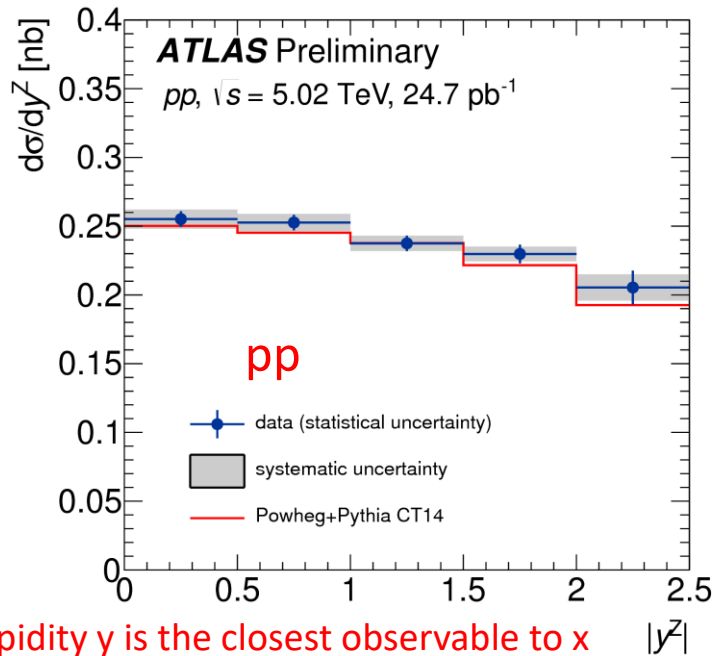
ATLAS-CONF-2016-107



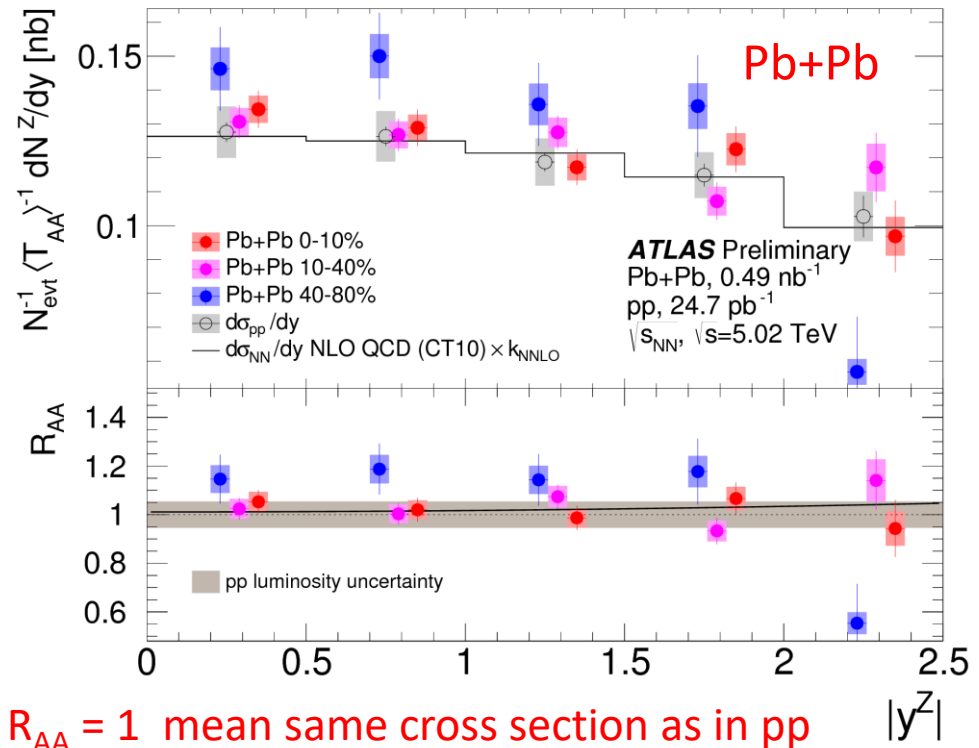
ATLAS-CONF-2017-010

Detector performance of the measurement is well described by simulations

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



pp data agree with by pQCD

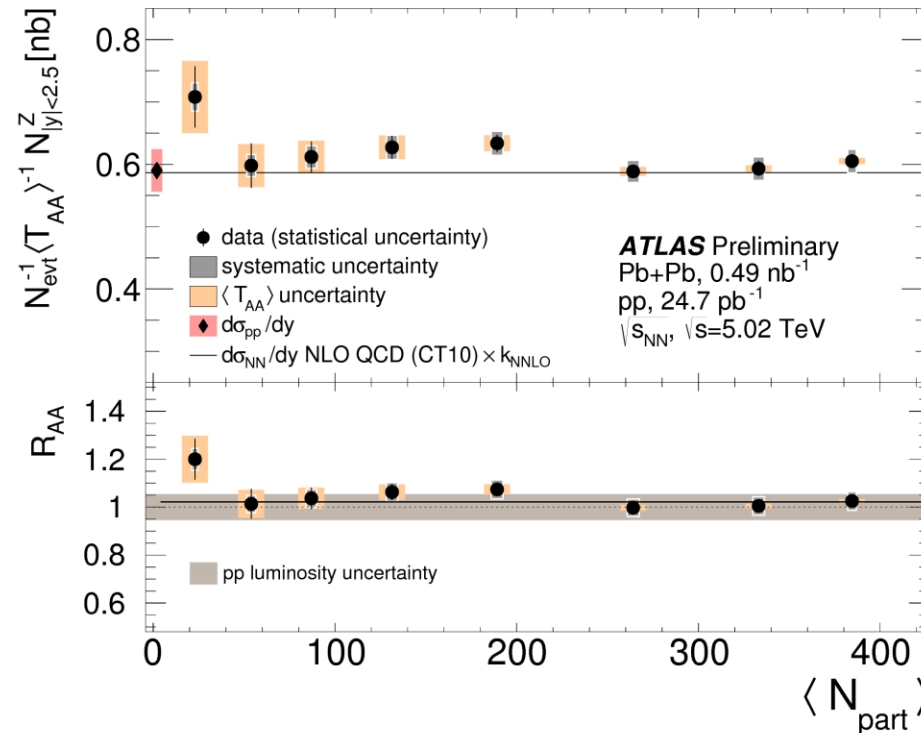


Pb+Pb measurements are compatible with pp measurement after scaling.

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ATLAS-CONF-2017-010

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} .

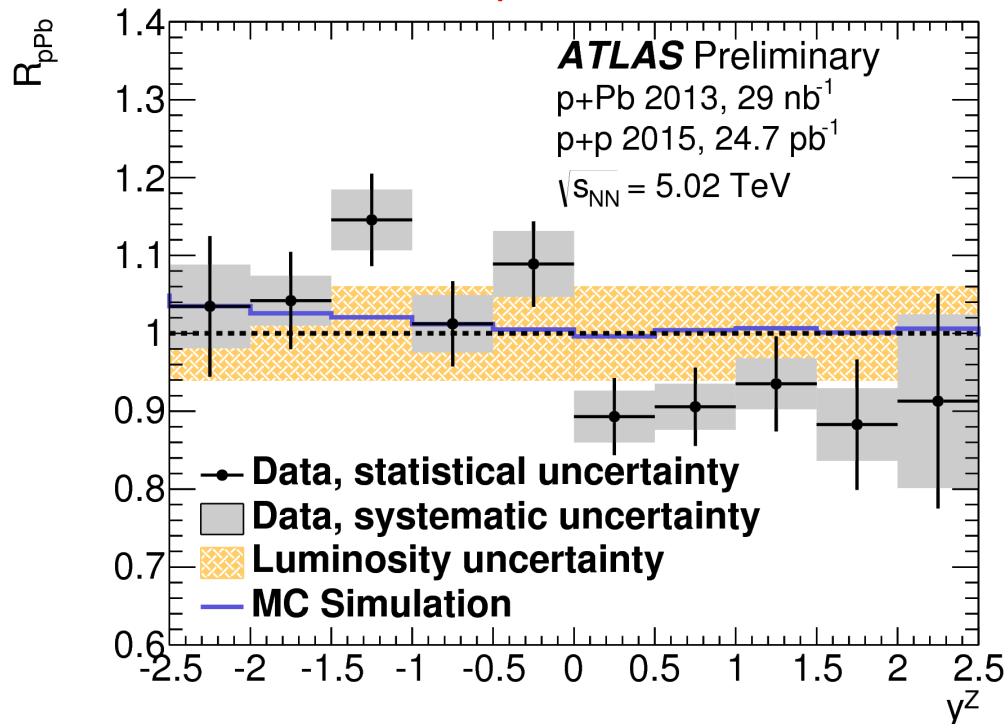
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Nuclear modification function R_{pPb}

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

ATLAS-CONF-2016-107

J/ψ and $\psi(2S)$ measurements

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

Method

Trigger : different for p+Pb and Pb+Pb

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

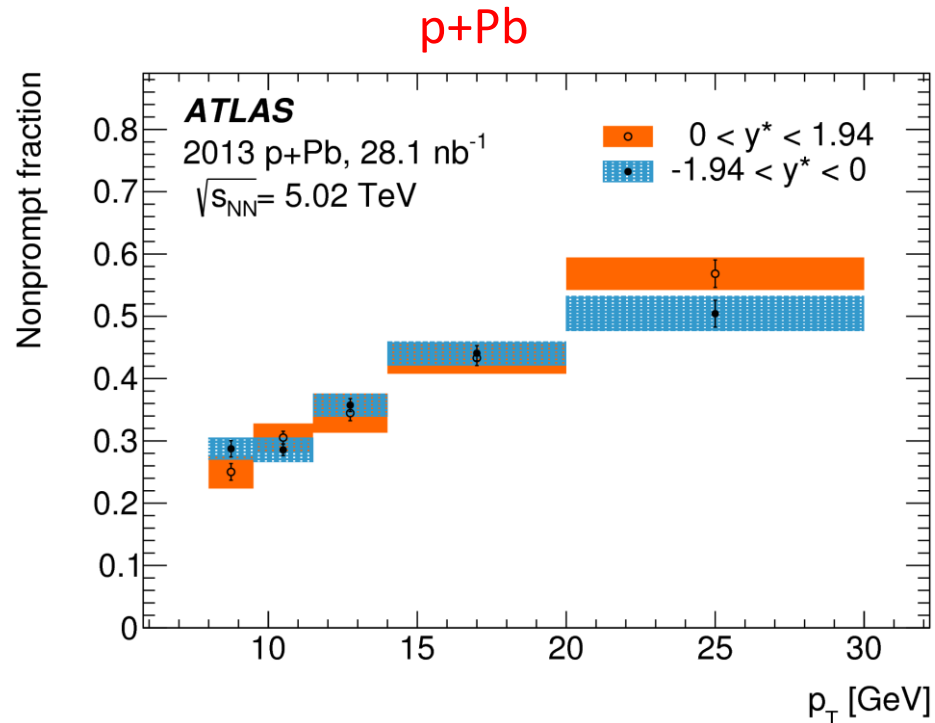
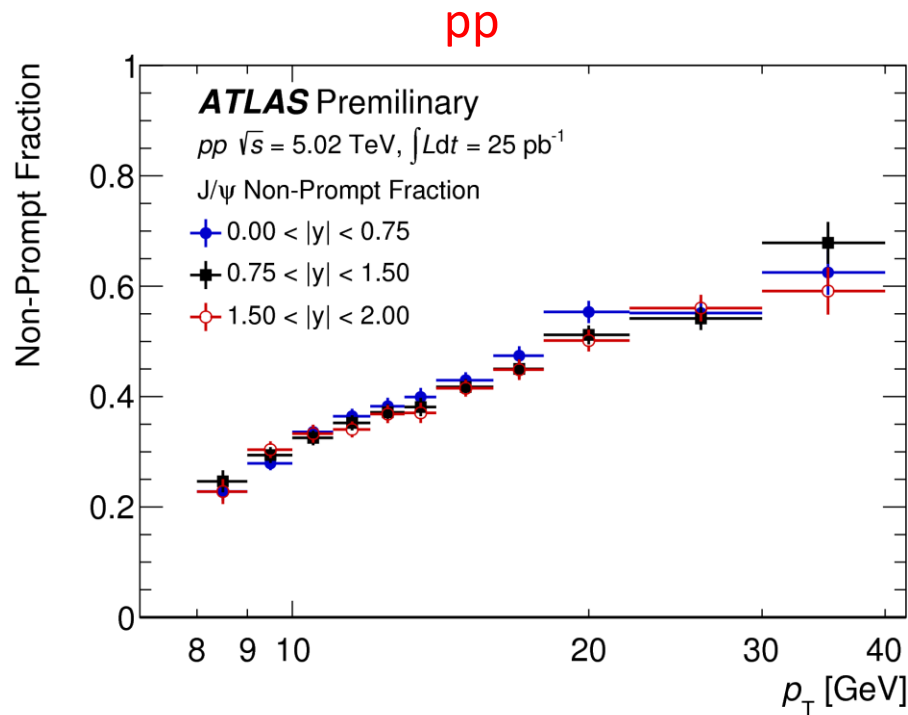
Analysis range

- p+Pb : $p_T \in \langle 8.5; 30 \rangle \text{ GeV}, |y^*| < 1.94$ (1.5)
- Pb+Pb: $p_T \in \langle 9; 40 \rangle \text{ GeV}, |y| < 2$, 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

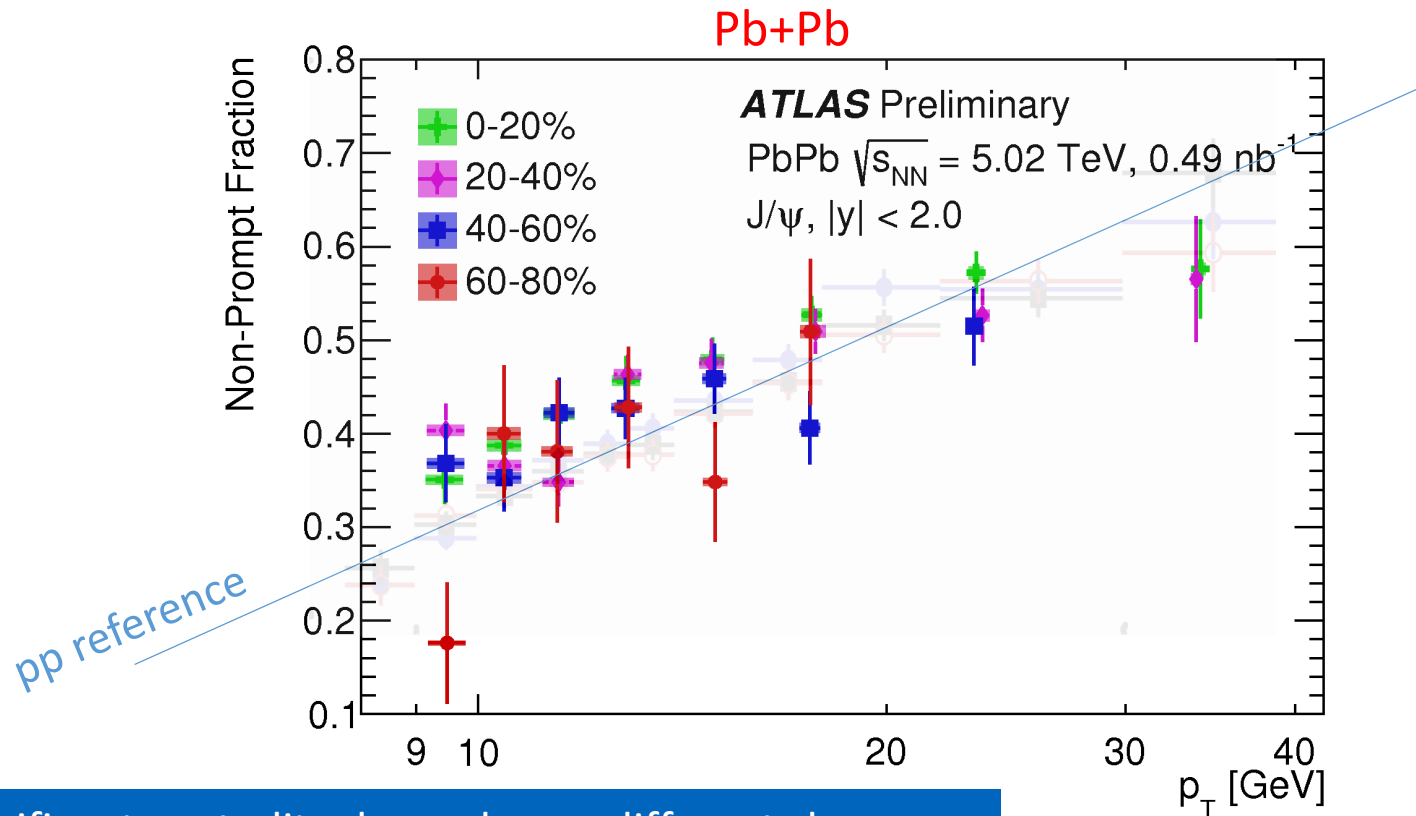


No visible $|y|$ dependence, but significant p_T dependence, both distributions are comparable.

ATLAS-CONF-2016-109

arXiv: 1505.08141 [hep-ex]

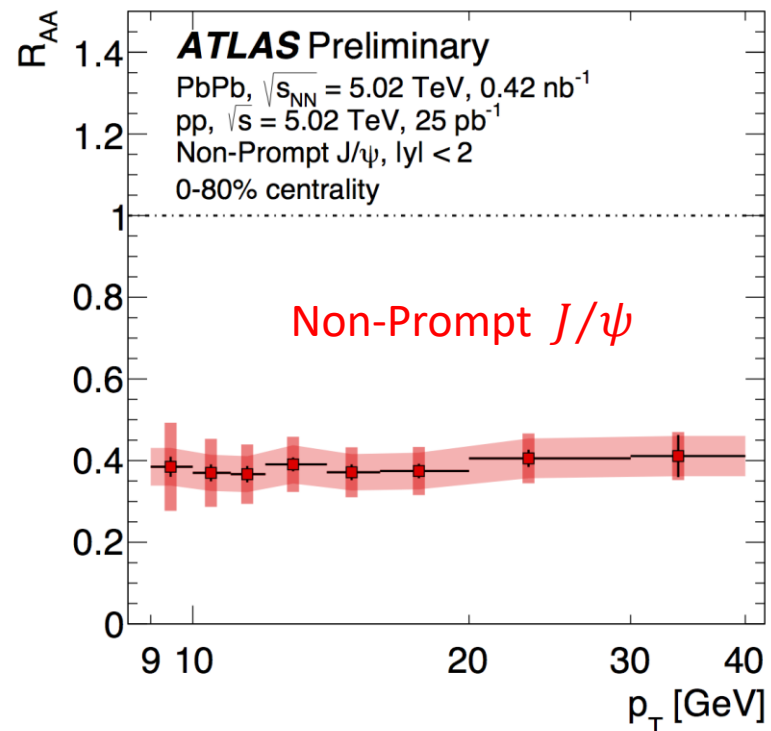
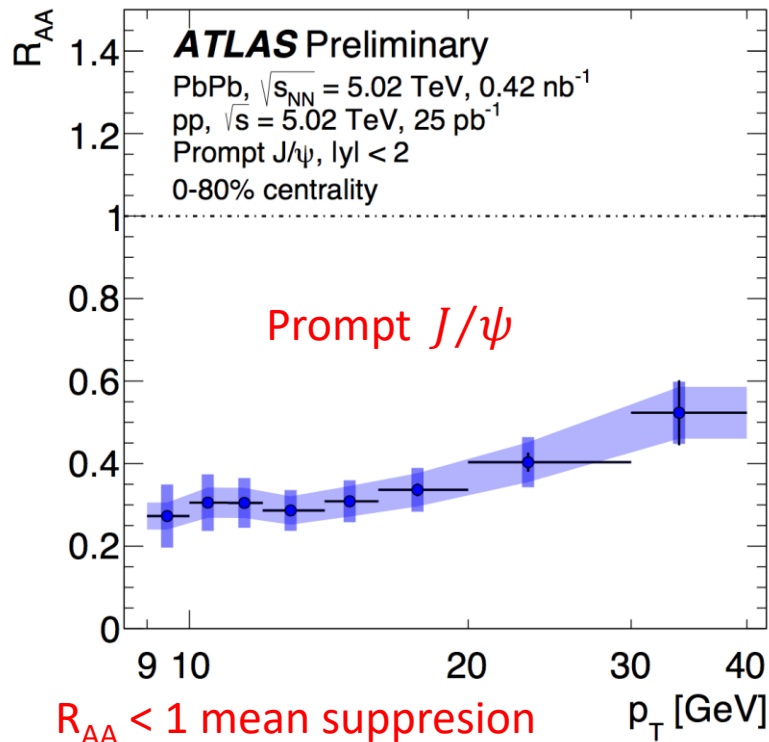
Non-Prompt fraction of J/ψ as a function of p_T



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

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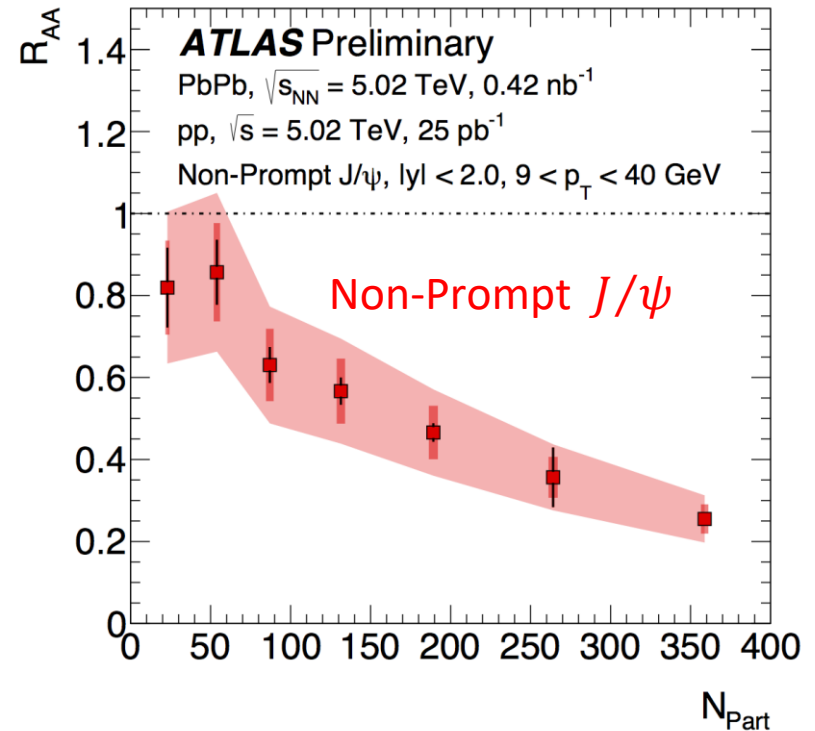
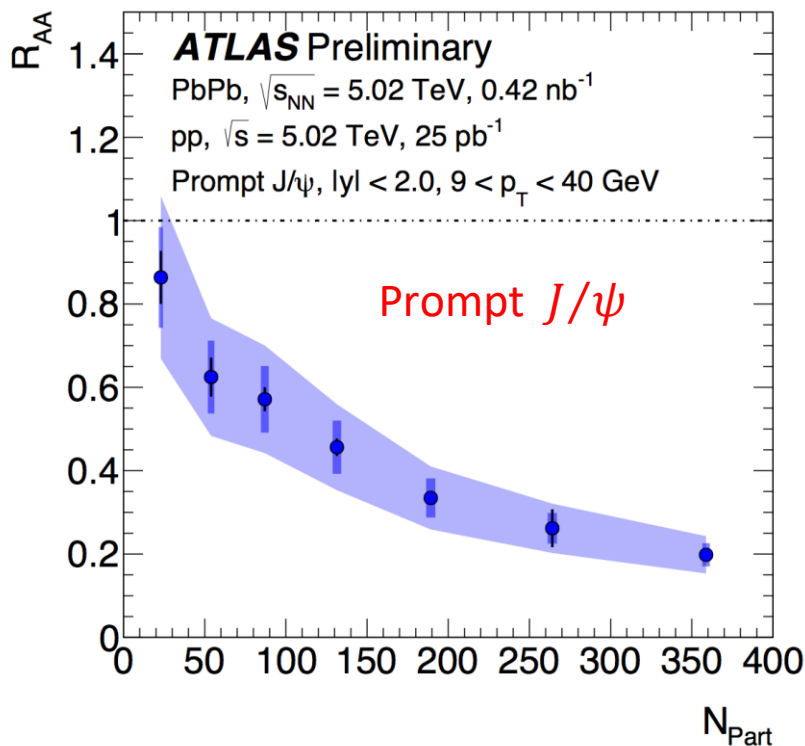
Nuclear modification factor of J/ψ (R_{PbPb})



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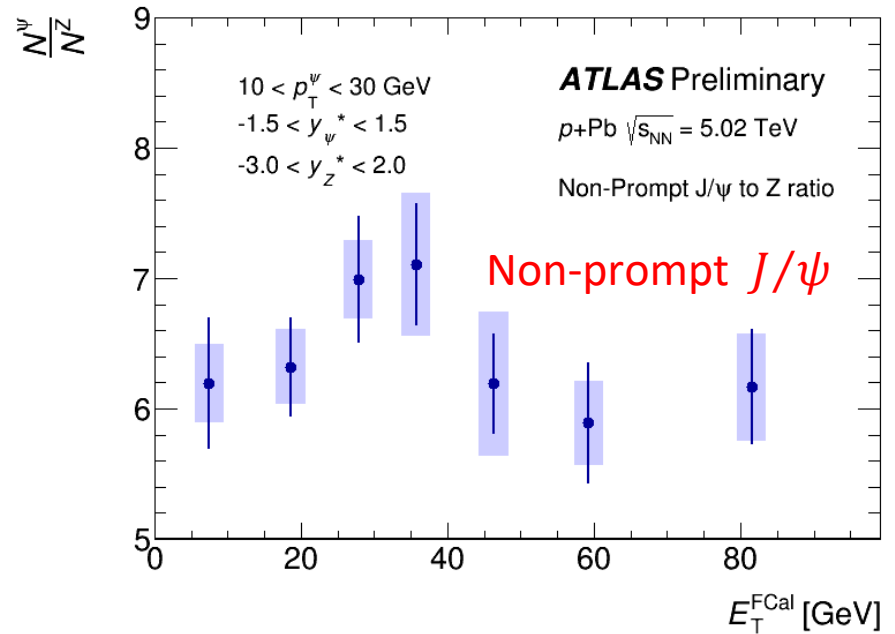
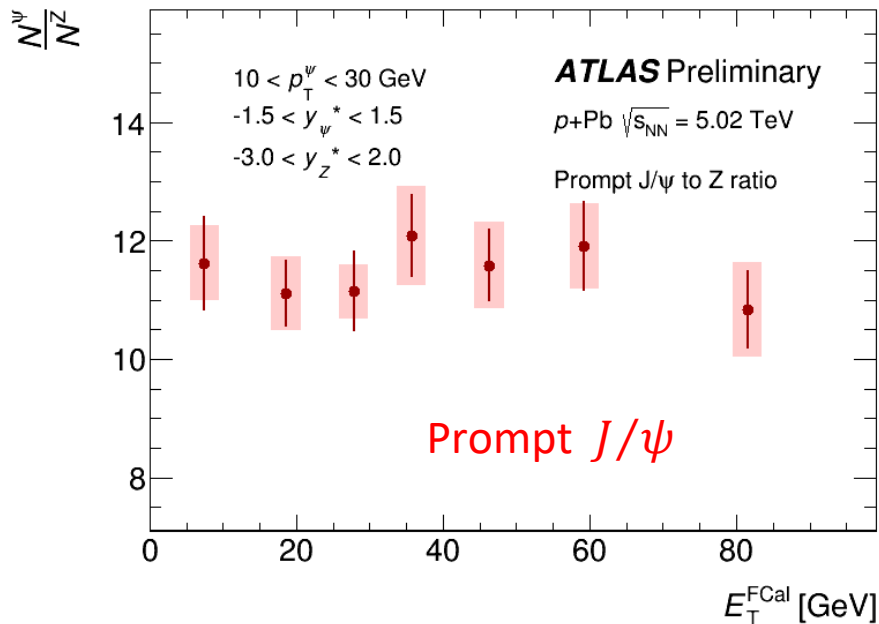
Nuclear modification factor of J/ψ (R_{PbPb})



Suppression is strongly centrality dependent, regardless of on production mechanism

ATLAS-CONF-2016-109

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

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}

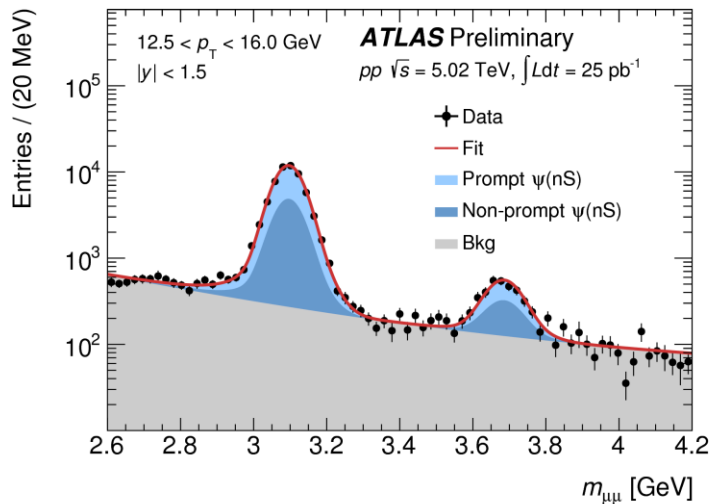
$$R_{AA} = \frac{N^{AA}}{\langle T_{AA} \rangle \times \sigma^{pp}}$$

- 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

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

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

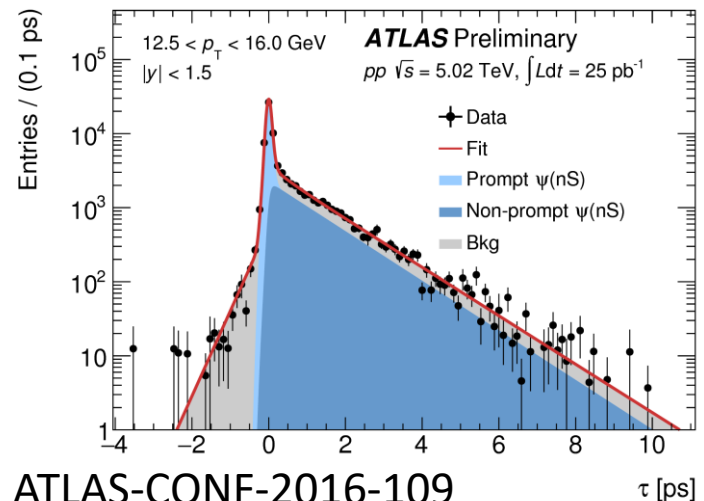
Simultaneous Fit Method



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	$E_5(m)$	$E_6(\tau)$

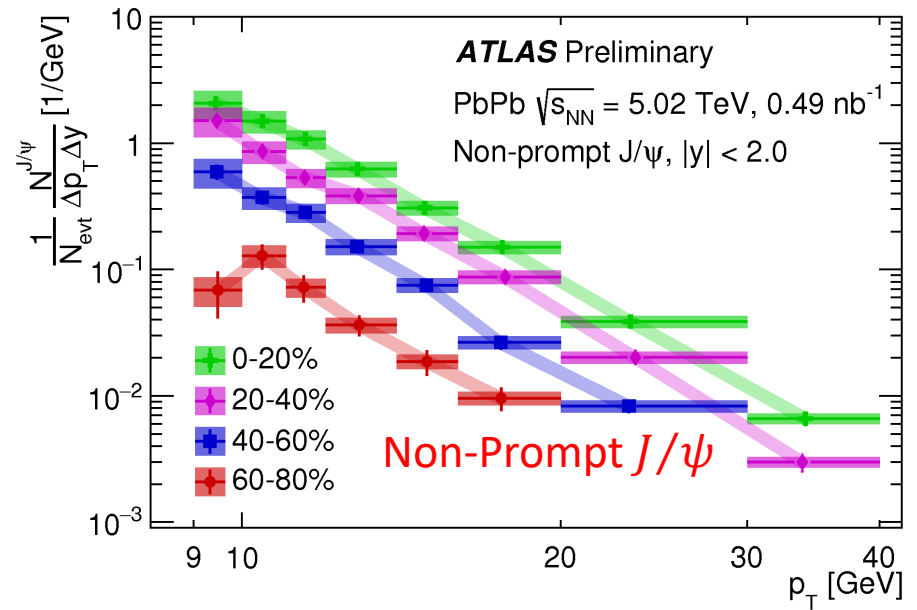
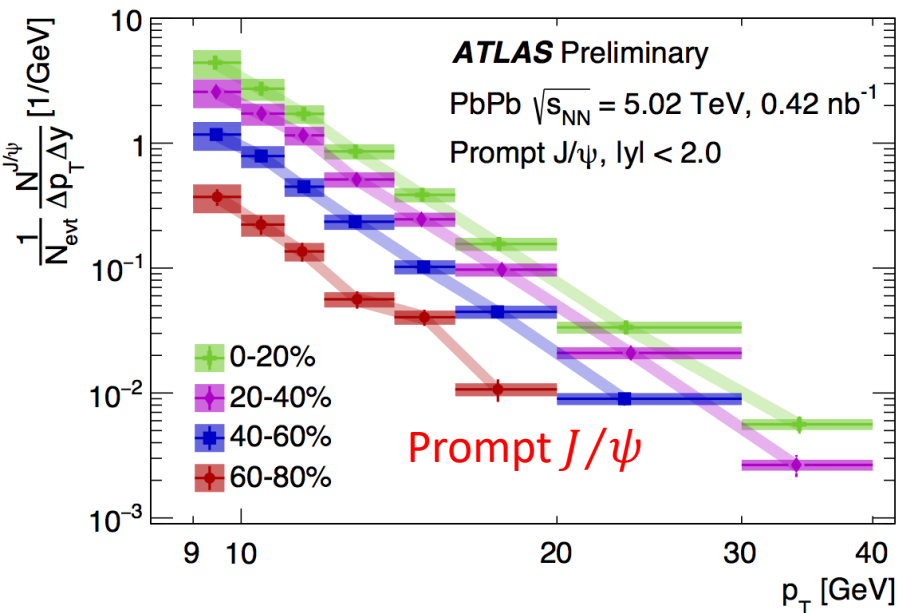
$$PDF(m, \tau) = \sum_{i=1}^7 k_i f_i(m) \cdot h_i(\tau) * g(\tau)$$

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



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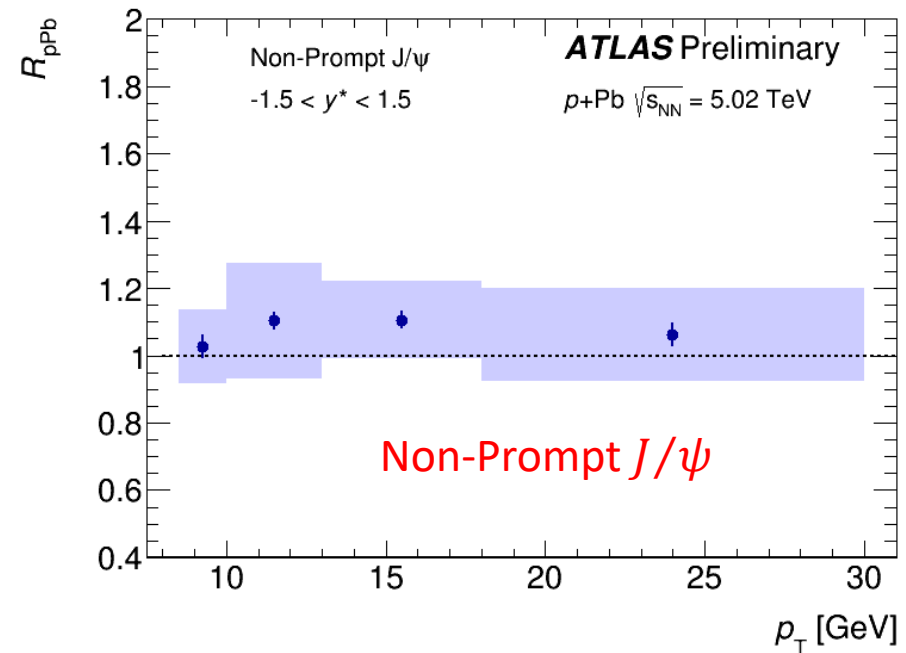
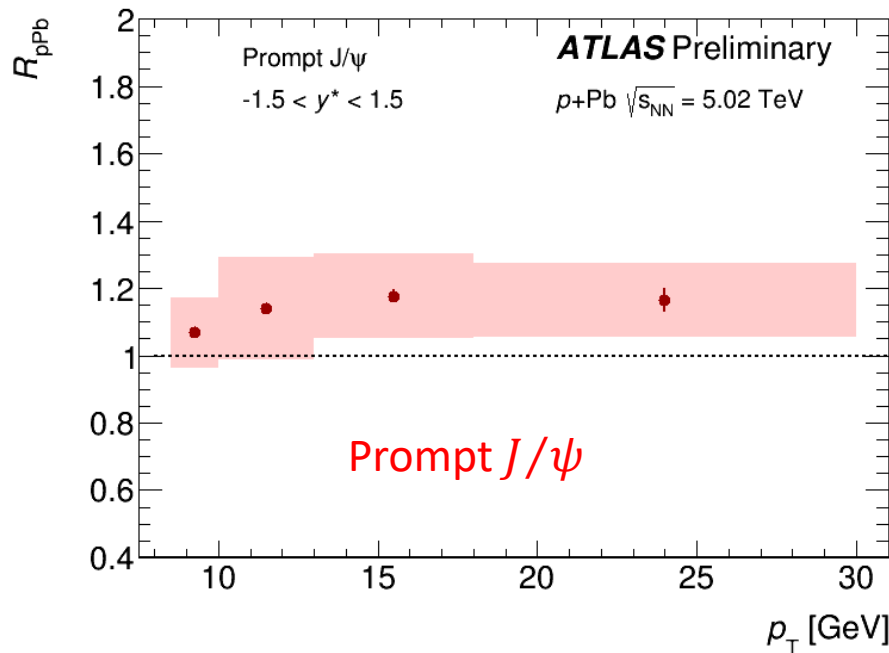
Pb+Pb per-event yields



Yields are centrality and p_T dependent

ATLAS-CONF-2016-109

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



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

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

pp reference @5.02 TeV is in preparation

ATLAS-CONF-2015-023