Recent heavy-flavour results from ATLAS

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on behalf of the ATLAS Collaboration

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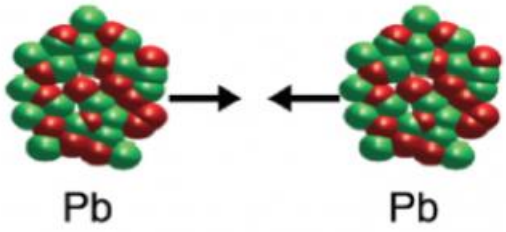
17th International Conference on Strangeness in Quark Matter 2017 Utrecht

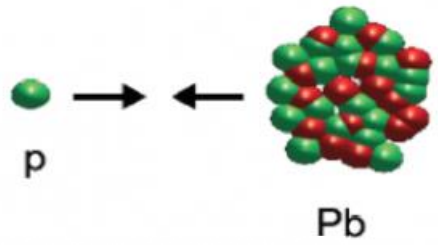
ATLAS EXPERIMENT

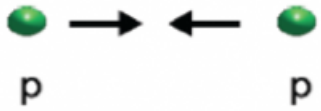
1958 University of Science and Technology of China

Motivations

Colliding systems







Heavy flavor muon
Quarkonia

Hot matter effects

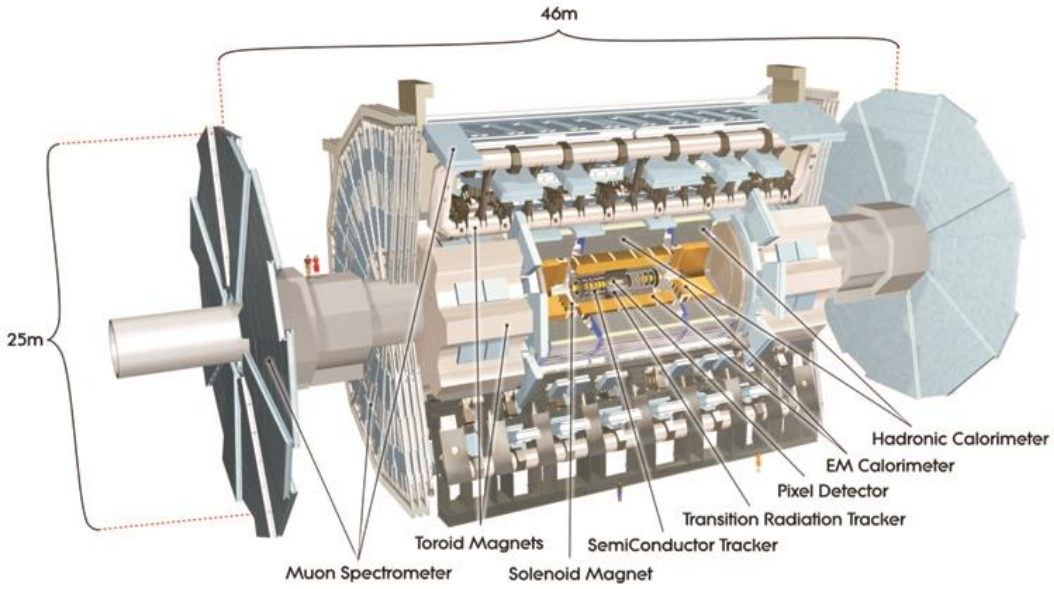
- -Suppression of production (colour screening)
- -Statistical recombination leading to regeneration
- -b-quark energy loss in the medium
- - Anisotropy arise from hydrodynamic expansion of QGP

Cold nuclear matter (CNM) effects

- -Modifications of nPDFs
- -Induced medium energy loss
- -Nuclear absorption
- -An azimuthal anisotropy due to the collective expansion of the mediumor based on saturation of parton distributions(under debate)

Reference

The ATLAS detector



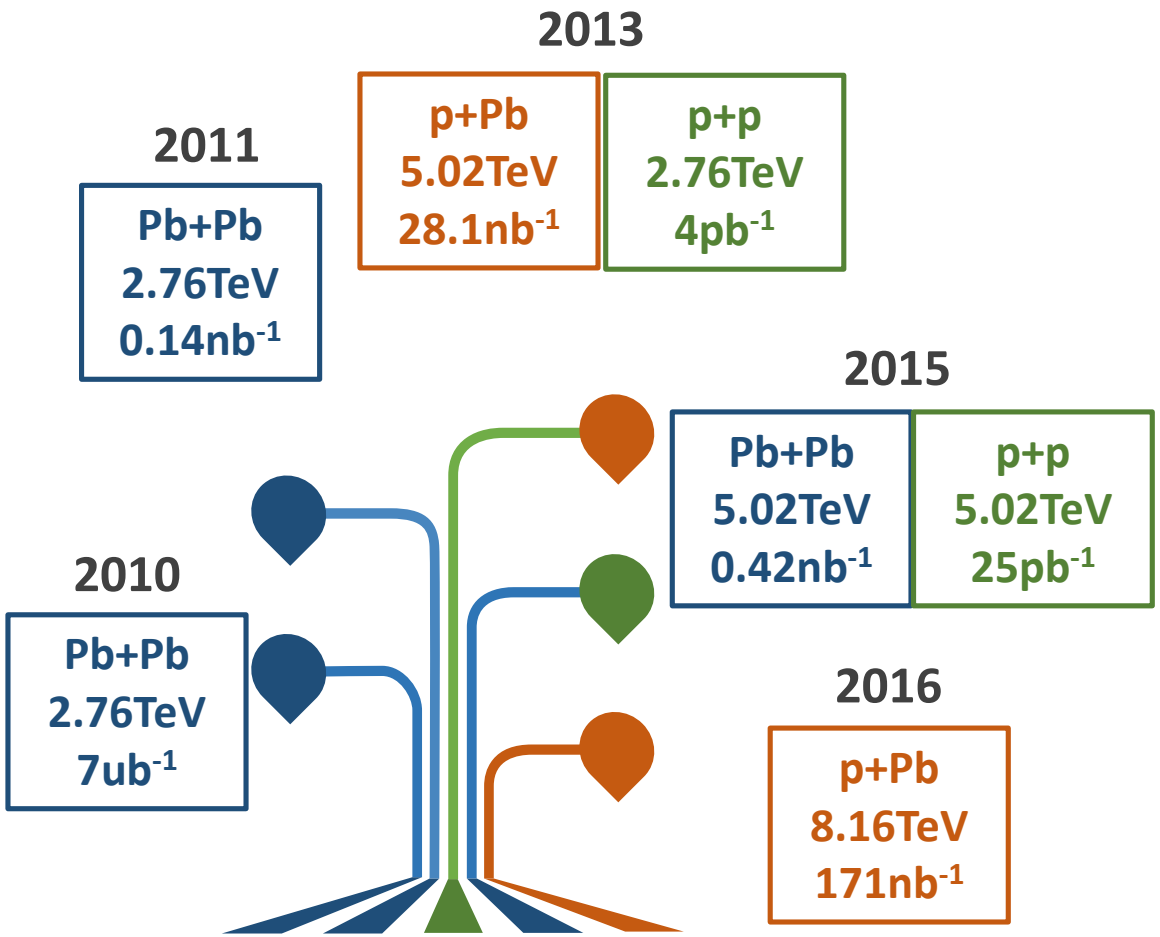
Calorimeters (CALO)
-Pb/LAr accordion structure for EM
-e/γ trigger identification and measurement : $\sigma/E \sim 10\%/\sqrt{E}$
-HAD: trigger and measurement of jets and E_T^{miss}
-Forward calorimeters(FCAL): covers up to $|\eta| < 4.9$

Inner detector (ID)
-$|\eta| < 2.5$
-Si pixels, Si strips, TRT
-Precise tracking and vertexing(in 2014, add Insertable B-layer)
-e/π separation

Muon Spectrometer (MS)
-Triggering $|\eta| < 2.4$
-Precision Tracking $|\eta| < 2.7$
-Magnetic filed produced by toroids
-Muon momentum resolution < 10% up to 1 TeV

Recent results

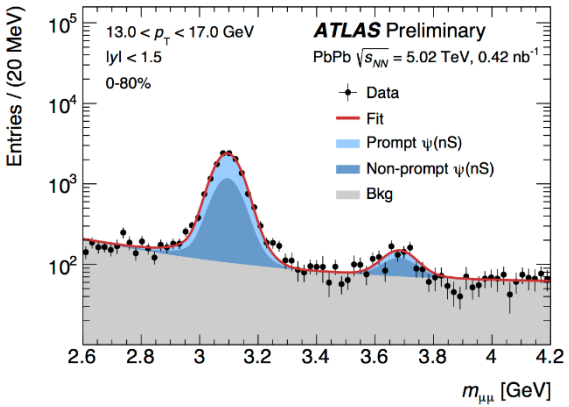
Data samples:

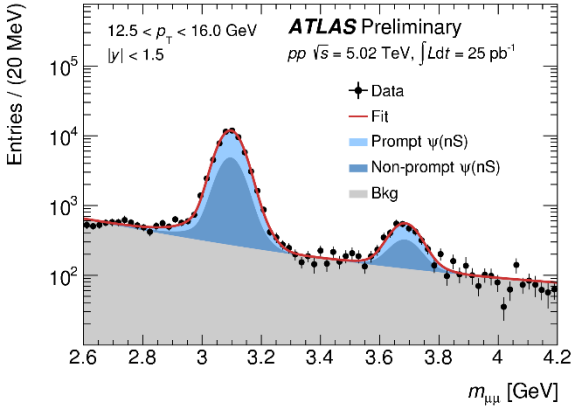


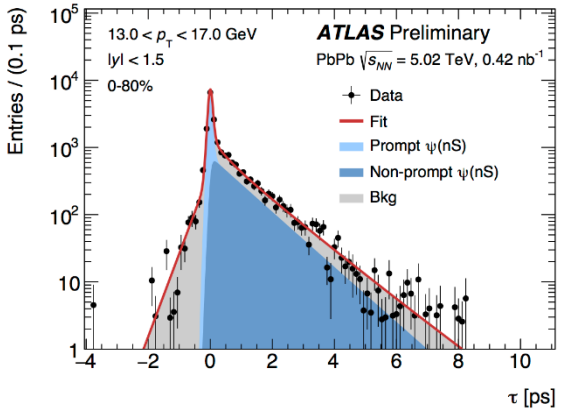
Heavy flavor muon	quarkonia
Muon production and R_{CP} at 2.76 TeV	
J/ψ production and R_{FB} at 5.02TeV	
J/ψ and $\psi(2S)$ production at 5.02TeV in pPb 2.76TeV in pp	
$\Upsilon(nS)$ production at 5.02TeV in pPb 2.76TeV in pp	
The suppression and elliptic anisotropy of heavy flavor muons at 2.76 TeV	
J/ψ and $\psi(2S)$ production at 5.02 TeV	
Azimuthal anisotropy of charged particles and muons at 8.16 TeV	

New results on the way

J/ψ and $\psi(2S)$ candidates







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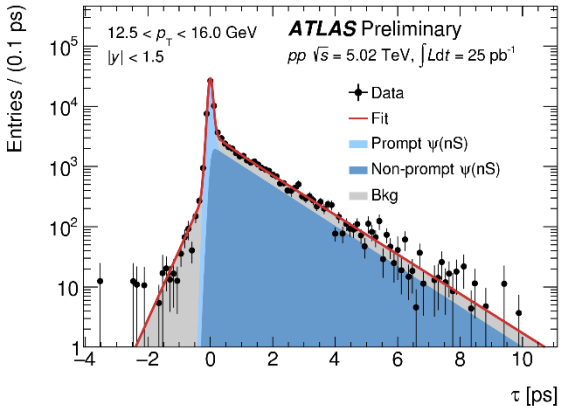
- To distinguish prompt and non-prompt charmonium production:

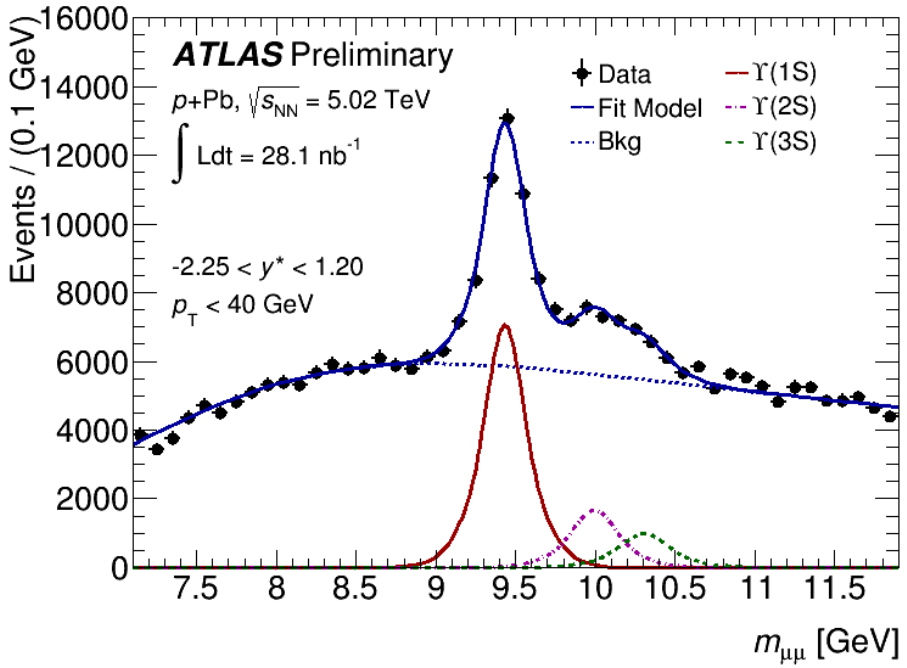
$$\tau = \frac{L_{xy} m_{\mu\mu}}{p_T^{\mu\mu}}$$

L_{xy}:distance between the reconstructed secondary vertex and the primary vertex

- The corrected prompt and non-prompt Charmonium yields are extracted from 2D weighted unbinned maximum likelihood fits performed on $m_{\mu\mu}$ and τ.



$\Upsilon(nS)$ candidates



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G - single Gaussian function
CB - Crystal Ball function
erf - error function
E - exponential function
P - 2nd order polynomial function
ω - fraction of the Gaussian function in the signal

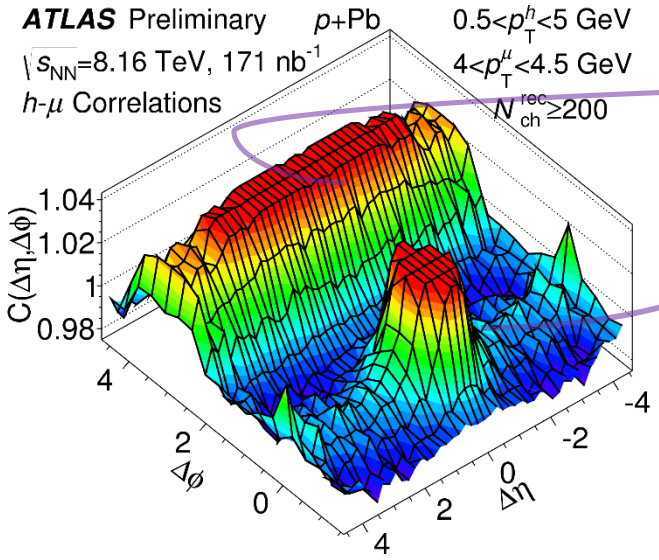
Signal	$f_{\Upsilon(1S)}(m_{\mu\mu})$	$\omega G(m_{\mu\mu}; M_{1S}, \sigma_{1S}) + (1-\omega) CB(m_{\mu\mu}; M_{1S}, 2\sigma_{1S}, \alpha, n)$
	$f_{\Upsilon(2S)}(m_{\mu\mu})$	$\omega G(m_{\mu\mu}; M_{2S}, \sigma_{2S}) + (1-\omega) CB(m_{\mu\mu}; M_{2S}, 2\sigma_{2S}, \alpha, n)$
	$f_{\Upsilon(3S)}(m_{\mu\mu})$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

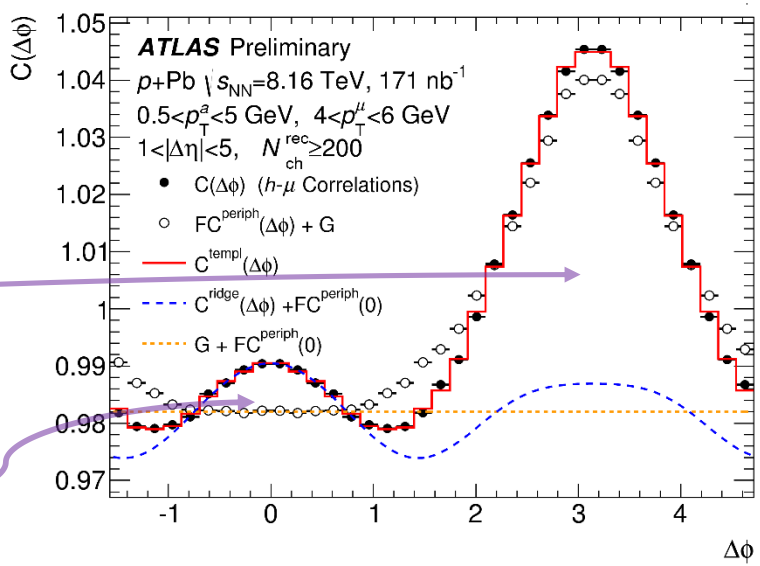
The corrected Υ yields are extracted from binned least square fits performed on $m_{\mu\mu}$.

Heavy flavor muon candidates

ATLAS-CONF-2017-006

Two-particle h–μ correlation functions in 8.16 TeV p+Pb collisions





$$C^{templ}(\Delta\phi) = FC^{periph}(\Delta\phi)+C^{ridge}(\Delta\phi)$$

$$C^{ridge}(\Delta\phi) = G\left(1+\sum_{n=2}^{\infty} 2v_{n,n}cos(n\Delta\phi)\right)$$

$$v_{n,n}(p_T^a, p_T^b) = v_n(p_T^a)v_n(p_T^b)$$

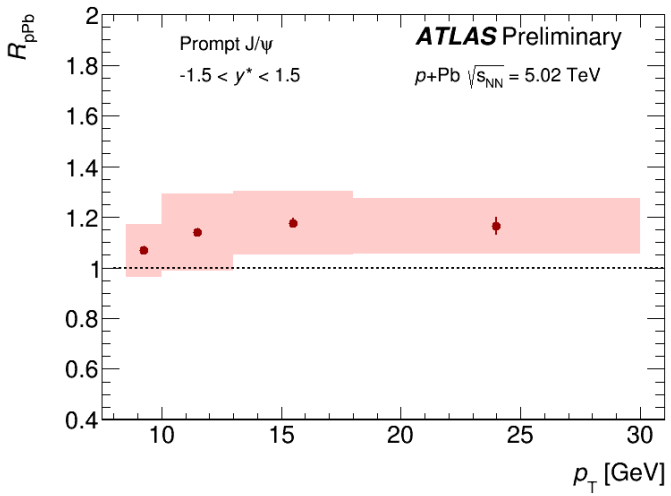
$$v_n(p_T^b) = v_{n,n}(p_T^a, p_T^b)/v_n(p_T^a) = v_{n,n}(p_T^a, p_T^b)/\sqrt{v_{n,n}(p_T^a, p_T^a)}$$

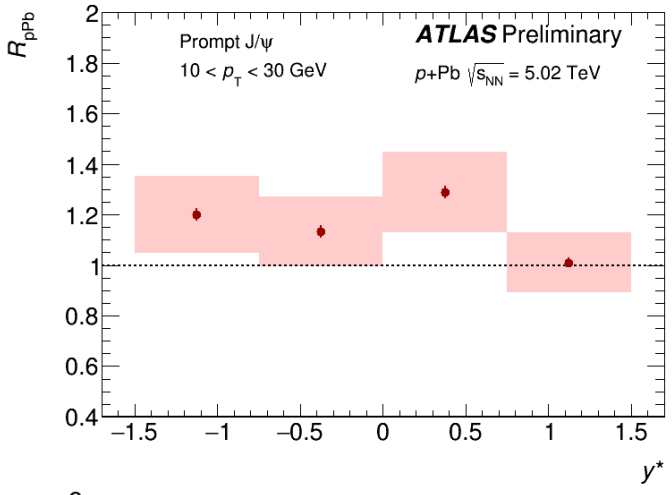
Using **template fit** to estimate signal and background.

Background: pion or kaon decays in flight, muons produced from the decays of particles produced in hadronic showers, and mis-associations of ID and MS tracks.

Cold nuclear matter (CNM) effects p+Pb collisions

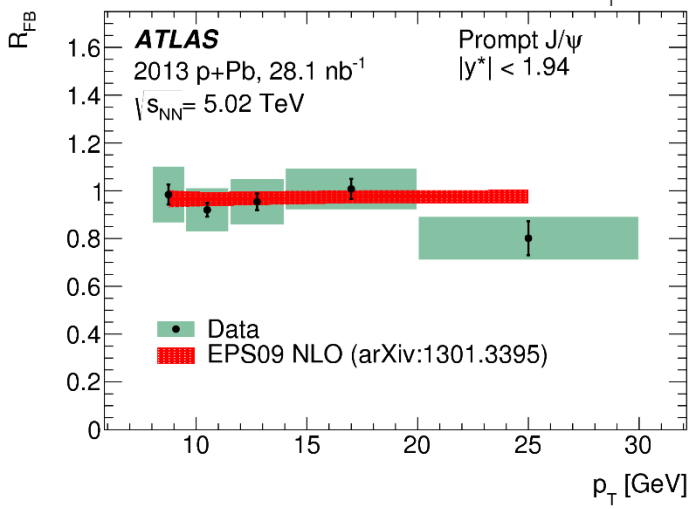
Nuclear modification factor - prompt J/ψ

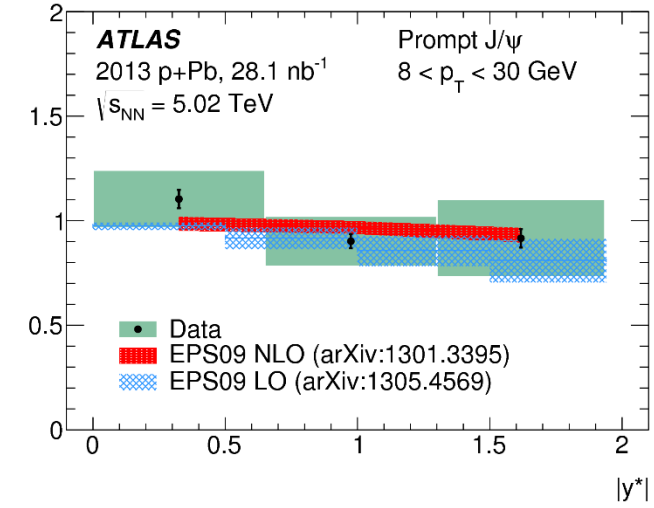




ATLAS-CONF-2015-023

$$R_{p\mathrm{Pb}} = \frac{1}{A^{\mathrm{Pb}}} \frac{d^2\sigma_{\psi}^{p+\mathrm{Pb}}/dy^* dp_{\mathrm{T}}}{d^2\sigma_{\psi}^{pp}/dy dp_{\mathrm{T}}}$$



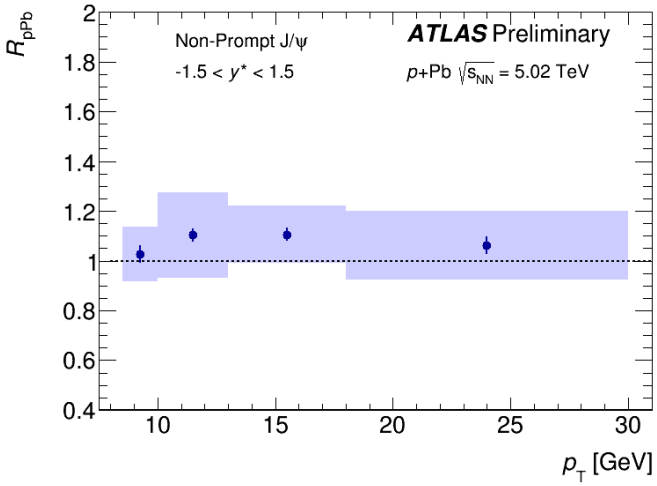


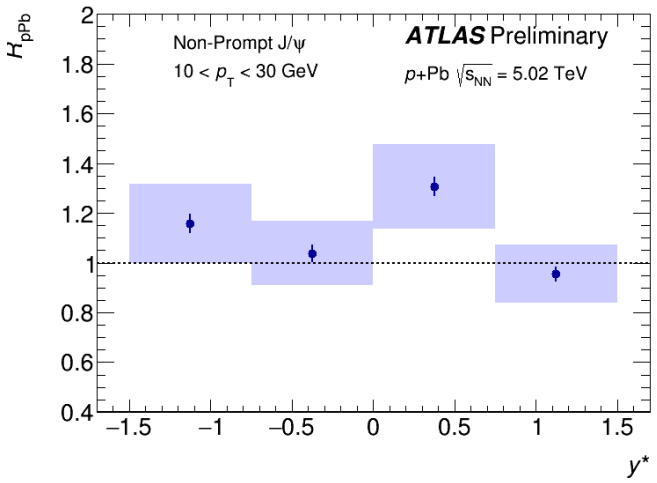
PRC 92(2015)034904

$$R_{\mathrm{FB}}(p_{\mathrm{T}}, y^*) \equiv \frac{d^2\sigma(p_{\mathrm{T}}, y^* > 0)/dp_{\mathrm{T}}dy^*}{d^2\sigma(p_{\mathrm{T}}, y^* < 0)/dp_{\mathrm{T}}dy^*}$$

The prompt J/ψ modification factor no obvious p_T or y^* dependence.

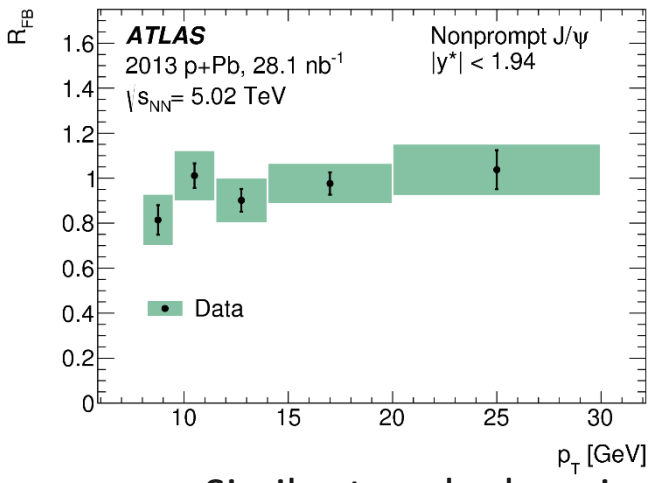
Nuclear modification factor - non-prompt J/ψ

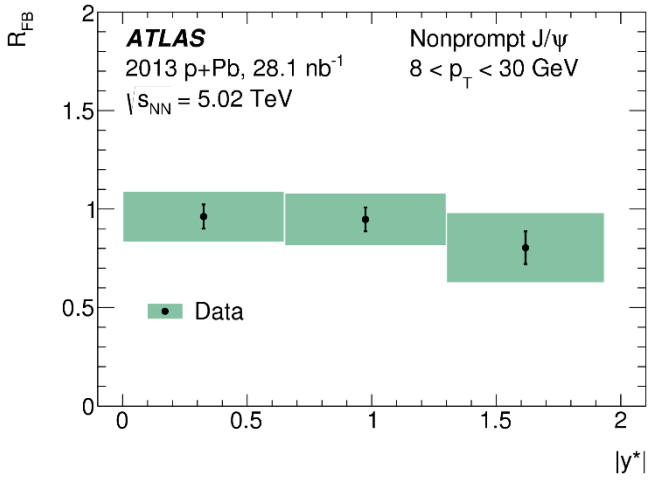




ATLAS-CONF-2015-023

$$R_{p\mathrm{Pb}} = \frac{1}{A^{\mathrm{Pb}}} \frac{d^2\sigma_{\psi}^{p+\mathrm{Pb}}/dy^* dp_{\mathrm{T}}}{d^2\sigma_{\psi}^{pp}/dy dp_{\mathrm{T}}}$$





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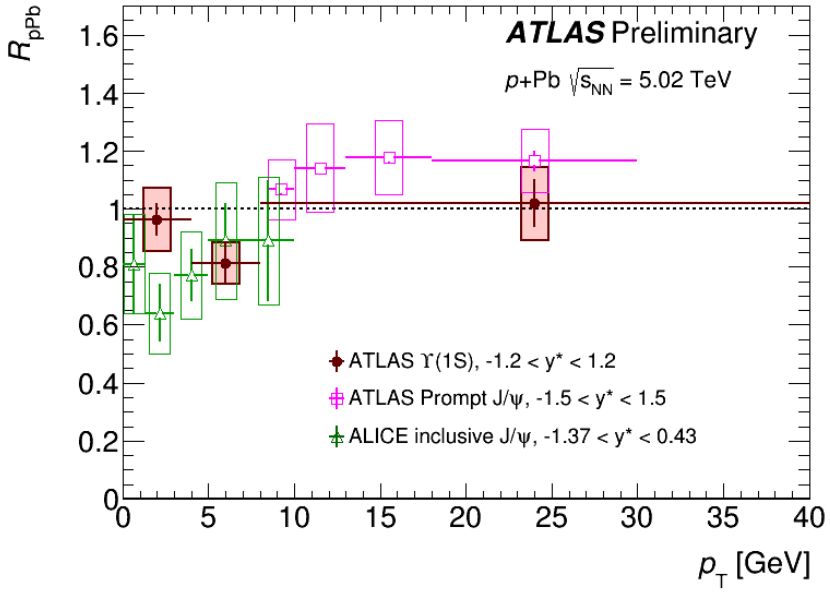
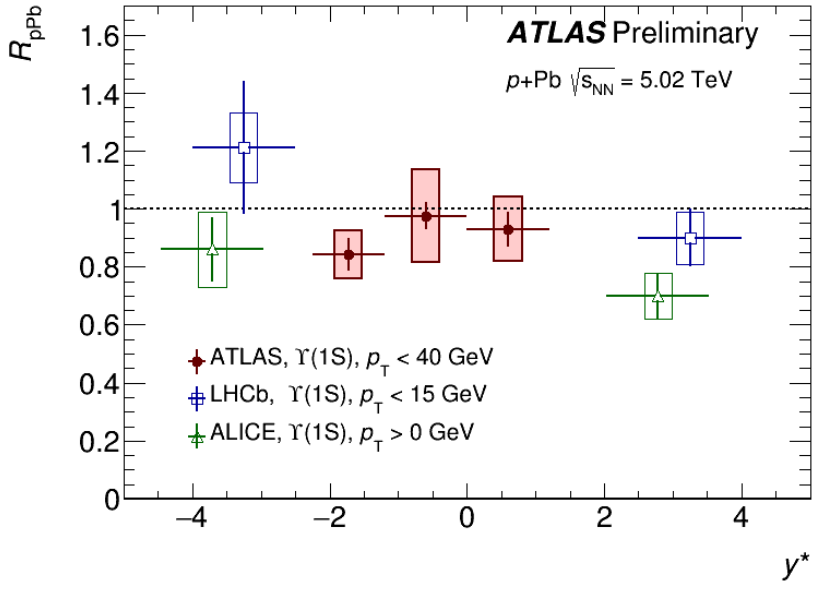
$$R_{\mathrm{FB}}(p_{\mathrm{T}}, y^*) \equiv \frac{d^2\sigma(p_{\mathrm{T}}, y^* > 0)/dp_{\mathrm{T}}dy^*}{d^2\sigma(p_{\mathrm{T}}, y^* < 0)/dp_{\mathrm{T}}dy^*}$$

Similar trends show in non-prompt J/ψ muclear modification factor.

Nuclear modification factor - $\Upsilon(1S)$

ATLAS-CONF-2015-050



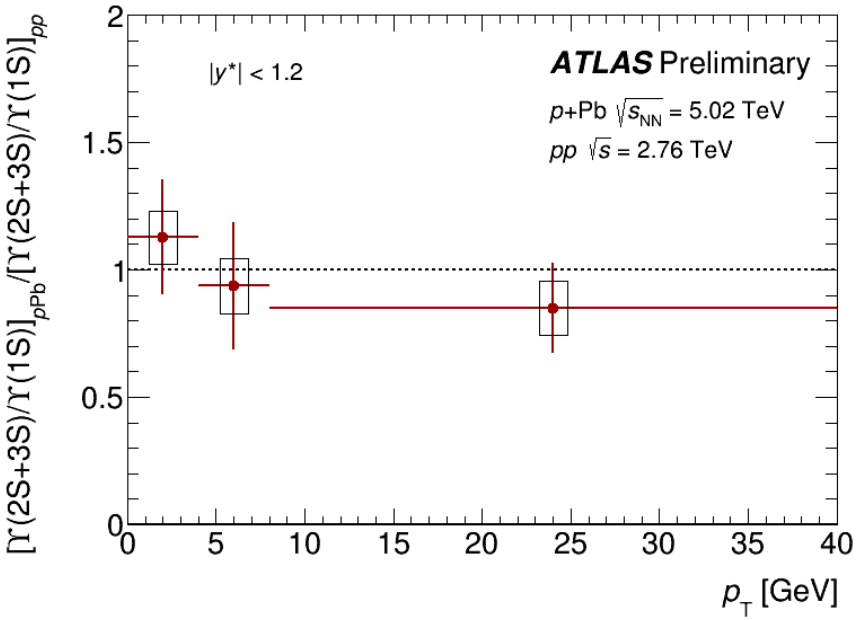


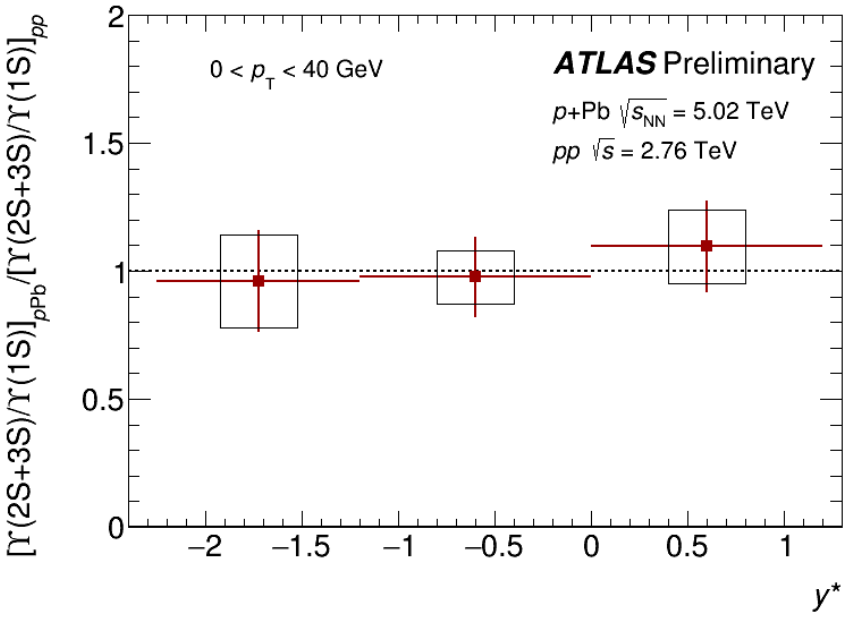
- p_T dependence of Υ(1S) nuclear modification factor is similar between ATLAS and ALICE
- No obvious y dependence of Υ(1S) nuclear modification factor

Y(2S + 3S) to Y(1S) double ratio

p+Pb: 5.02TeV pp: 2.76 TeV

ATLAS-CONF-2015-050



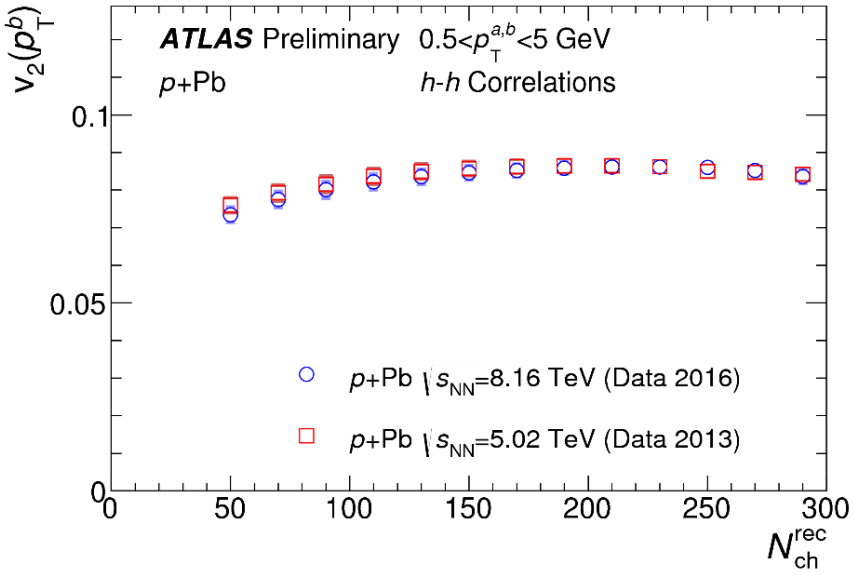


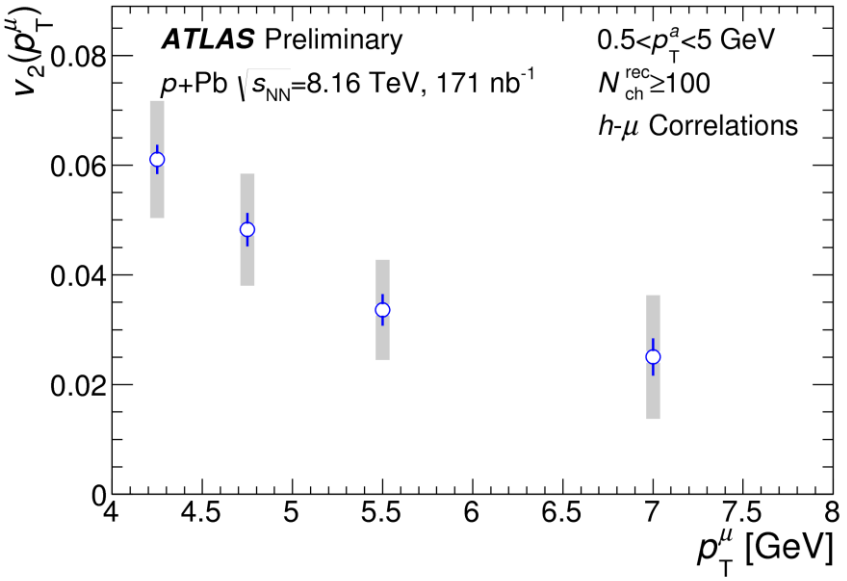
- Provides information on the difference of the CNM effects on states with different binding energy.
- No significant dependence of excited states production with respect to the ground state production.

Azimuthal Anisotropy

ATLAS-CONF-2017-006

h: hadron μ: muon

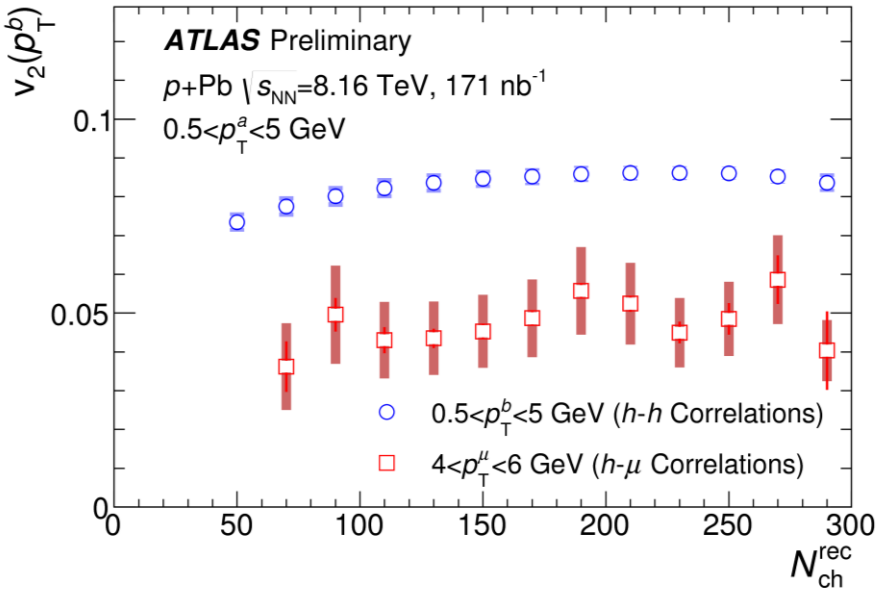


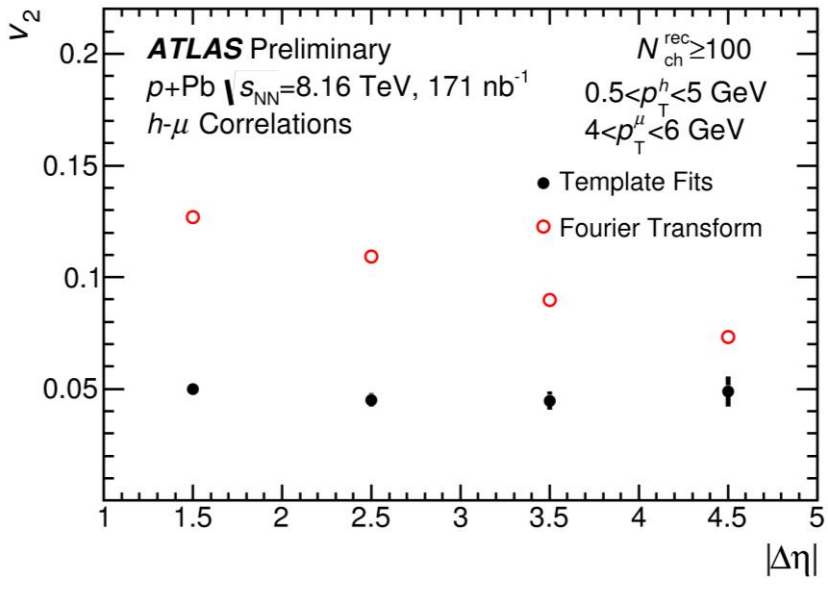


- Anisotropies are measured using the two-particle correlation method
- v_2 at the two collision energies are quite similar and the difference between them is covered by the systematic uncertainties.
- The muon-v_2 values are largest at 4 GeV and decrease with increasing p_T

Azimuthal Anisotropy

ATLAS-CONF-2017-006





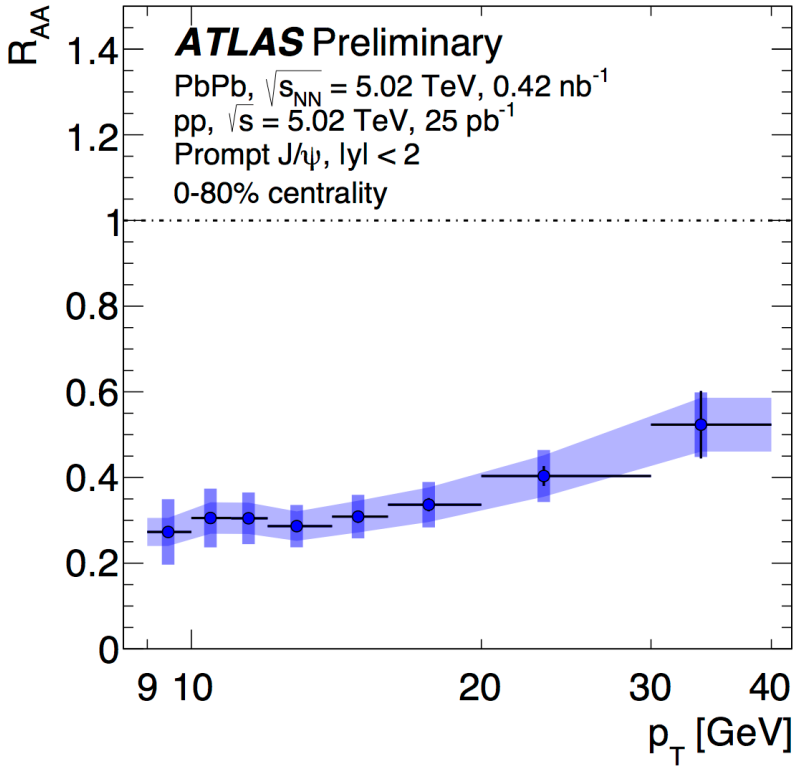
- The v_2 for charged particles increases with N_{ch}^{rec} at low N_{ch}^{rec} and eventually saturates for N_{ch}^{rec}>150. However even at the lowest measured multiplicity, a large v_2 is observed.
- The v_2 for the muons, over this p_T range the measurements are consistent with no N_{ch}^{rec} dependence.
- Here a significant dependence of v_2 on $|\Delta\eta|$ is observed. On the other hand the template v_2 vary by less than 10% over the whole $|\Delta\eta|$ range. (A strong bias in the v_2 values from dijets, which are accounted for and removed in the template fits.)

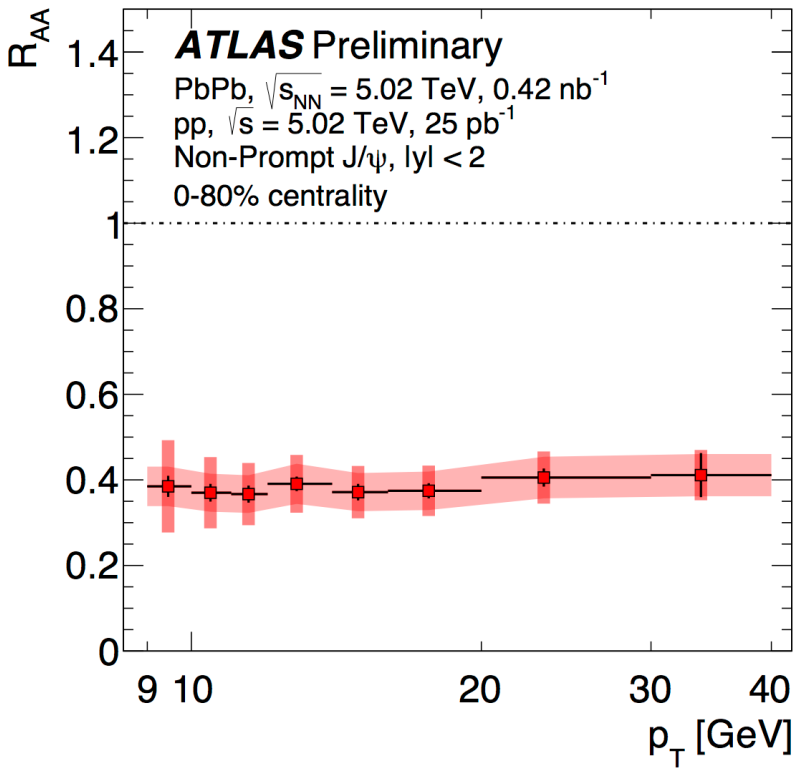
Hot matter effects
Pb+Pb collisions

Nuclear modification factor - J/ψ

p_T, $|y| < 2$, 0 -80% centrality

ATLAS-CONF-2016-109



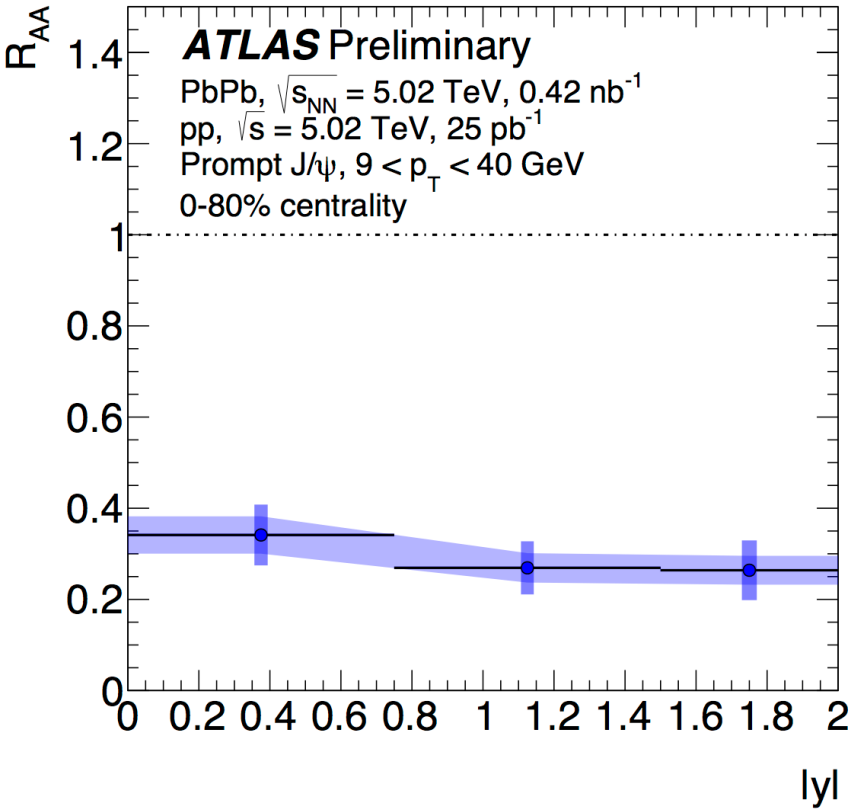


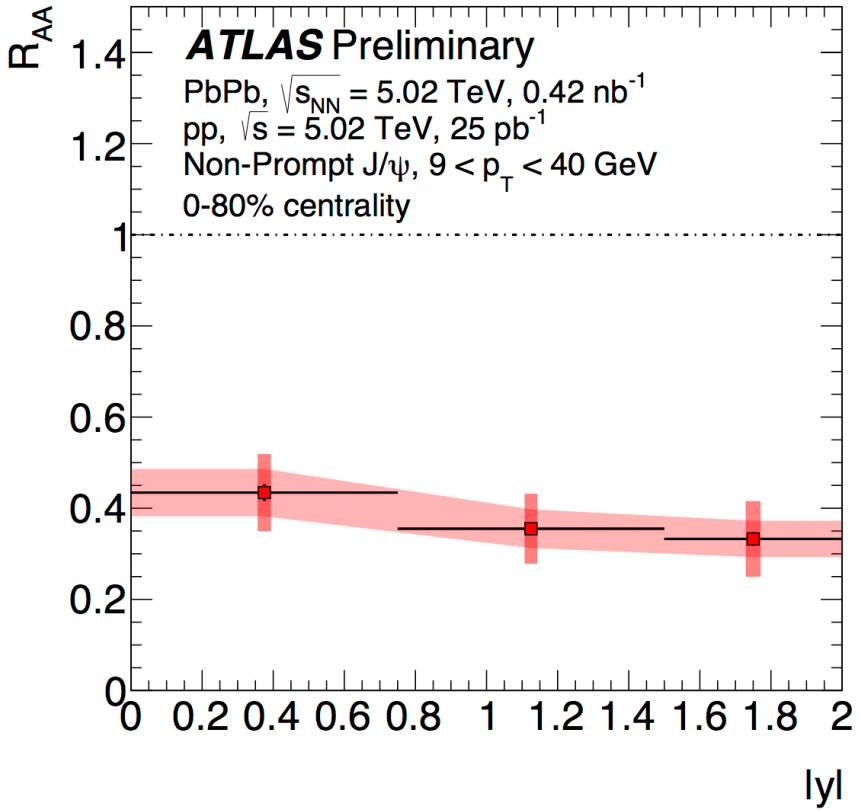
- Prompt J/ψ production: a small increase in R_{AA} with increasing p_T.
- Non-prompt J/ψ production: constant in p_T within the uncertainties.

Nuclear modification factor - J/ψ

y, $9\ \text{GeV} < p_T < 40\ \text{GeV}$, 0 -80% centrality

ATLAS-CONF-2016-109



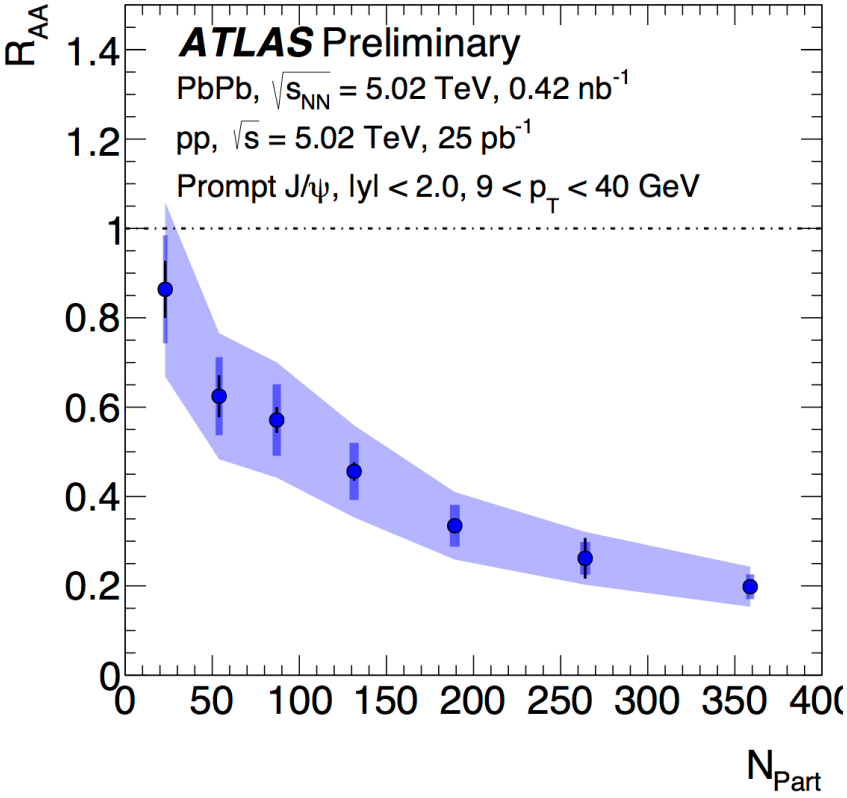


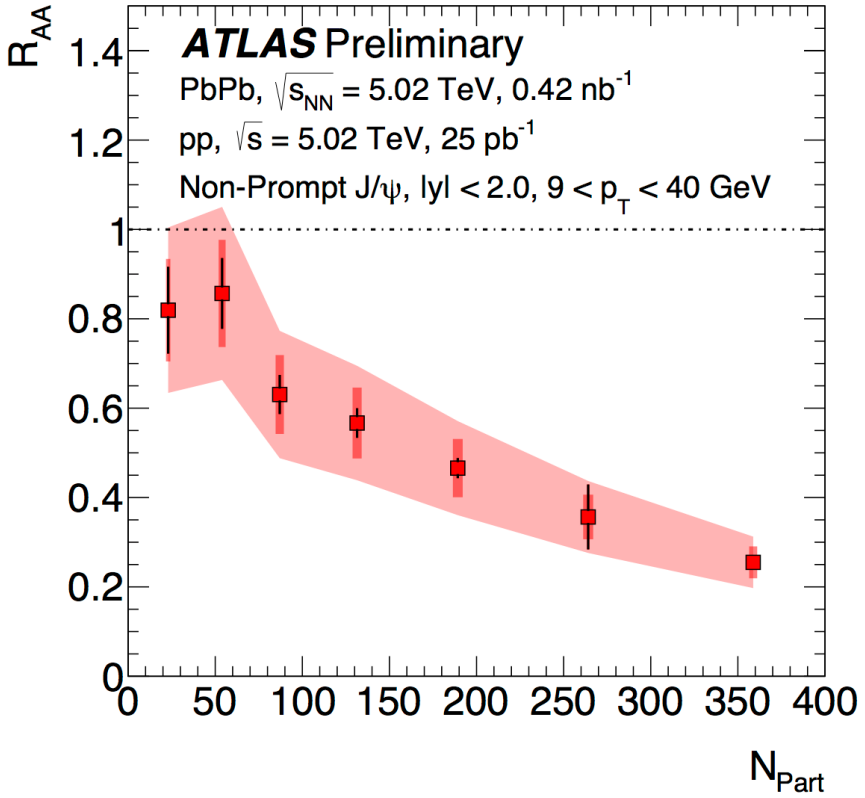
R_{AA} is essentially constant as a function of rapidity within the systematic uncertainties.

Nuclear modification factor - J/ψ

$|y| < 2$, 9 GeV $< p_T <$ 40 GeV

ATLAS-CONF-2016-109

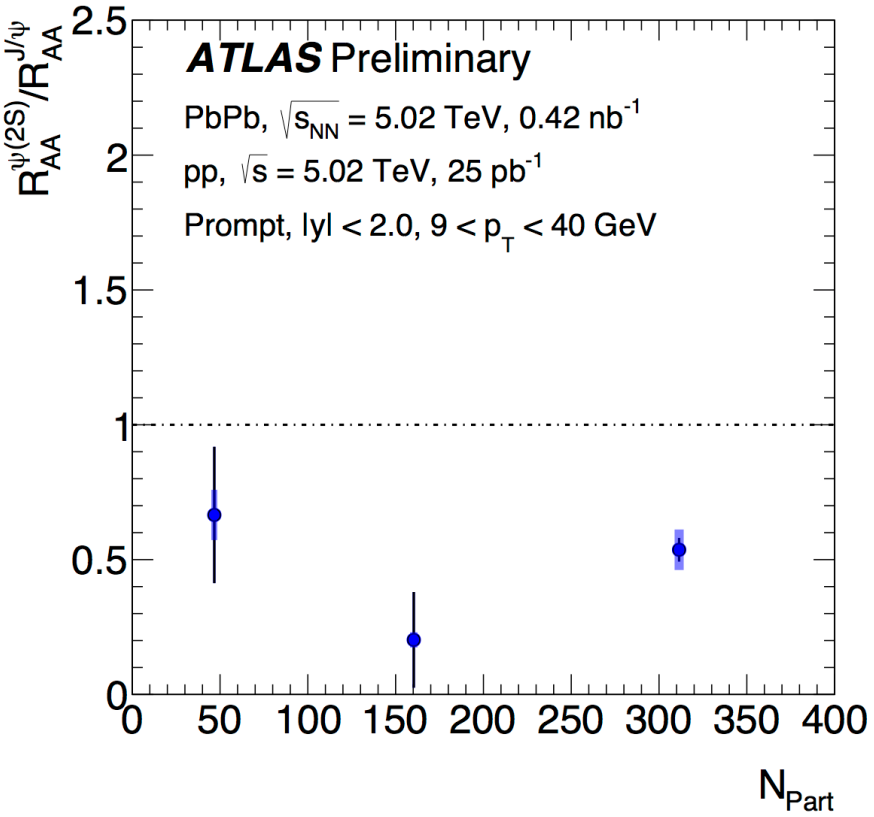


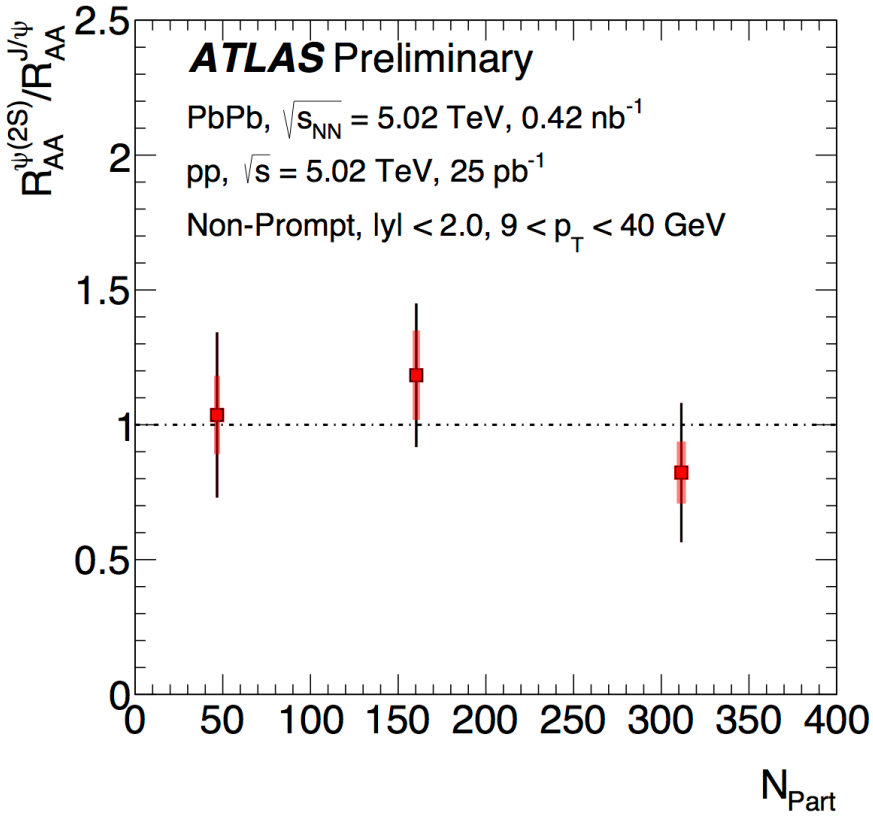


J/ψ production is most strongly suppressed in central collisions, as expected.

$\psi(2S)$ to J/ψ double ratio

ATLAS-CONF-2016-109

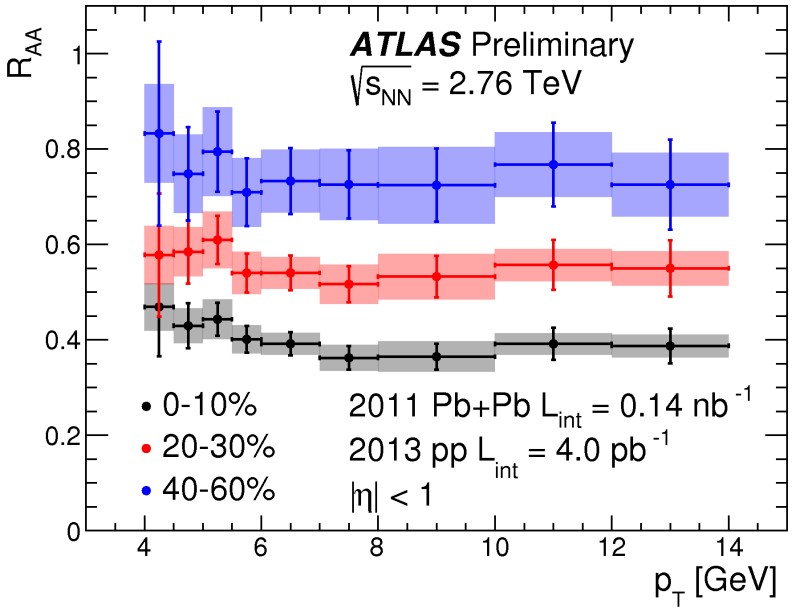




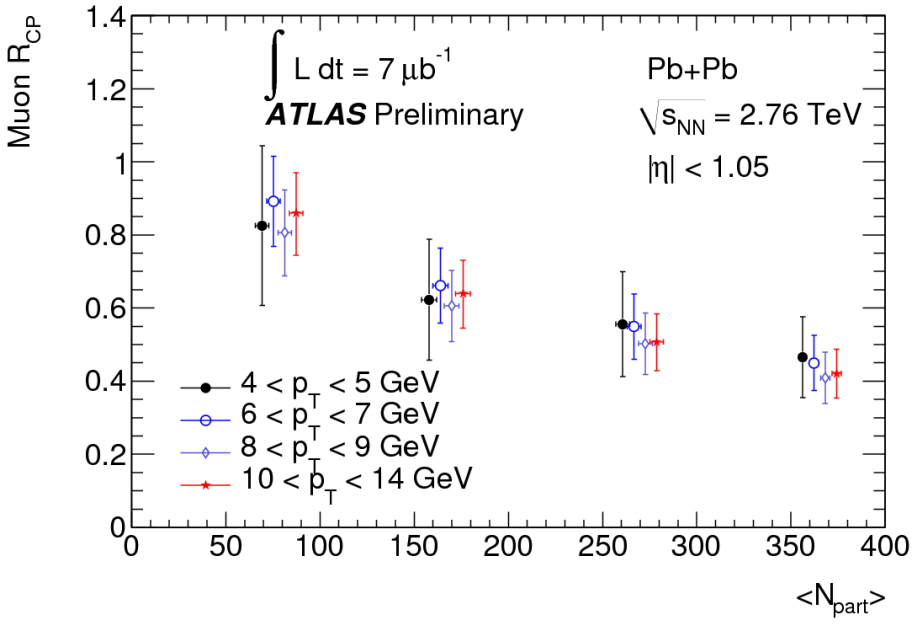
- The suppression of prompt $\psi(2S)$ relative to J/ψ indicate the more tightly bound quarkonium system, the J/ψ , survives the temperature of the hot dense medium with a higher probability than the more loosely bound quarkonium, the $\psi(2S)$.
- Non-prompt mesons(originate from b-quarks) were essentially always formed outside the medium. The unity double ratio was expected.

Nuclear modification factor - HF muon

ATLAS-CONF-2015-053



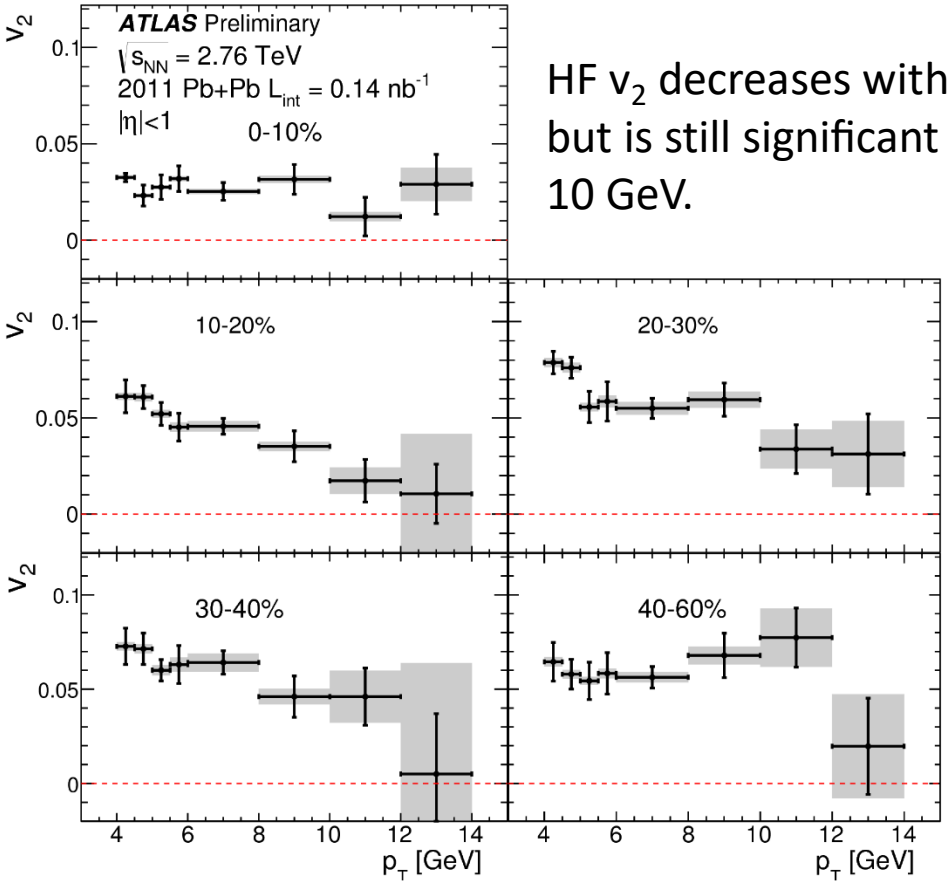
ATLAS-CONF-2012-050



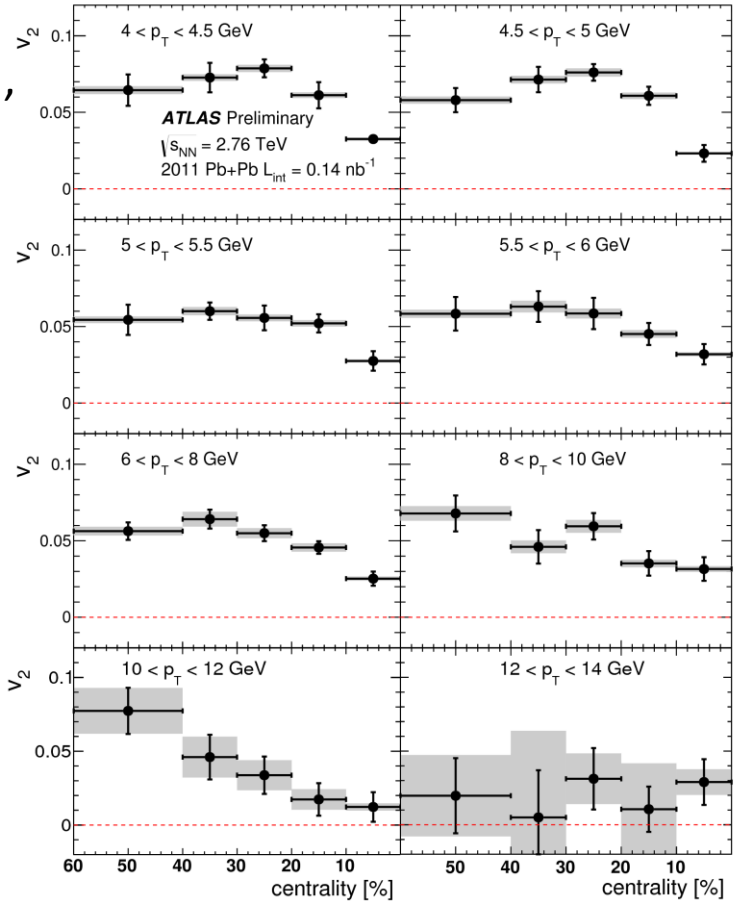
- Independent of p_T
- Centrality-dependent
- Less than unity

  --indicates suppressed production of heavy flavor muons in Pb+Pb collisions

Azimuthal Anisotropy



HF v_2 decreases with p_T, but is still significant at 10 GeV.



$$\frac{dN}{d\phi} = \left\langle \frac{dN}{d\phi} \right\rangle \left(1 + \sum_{n \geq 1} 2 v_n \cos\left(n \left[\phi - \Phi_n \right] \right) \right)$$

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At fixed p_T, the v_2 values show a systematic variation with centrality that is characteristic of elliptic flow measurements.

Summary

Quarkonia

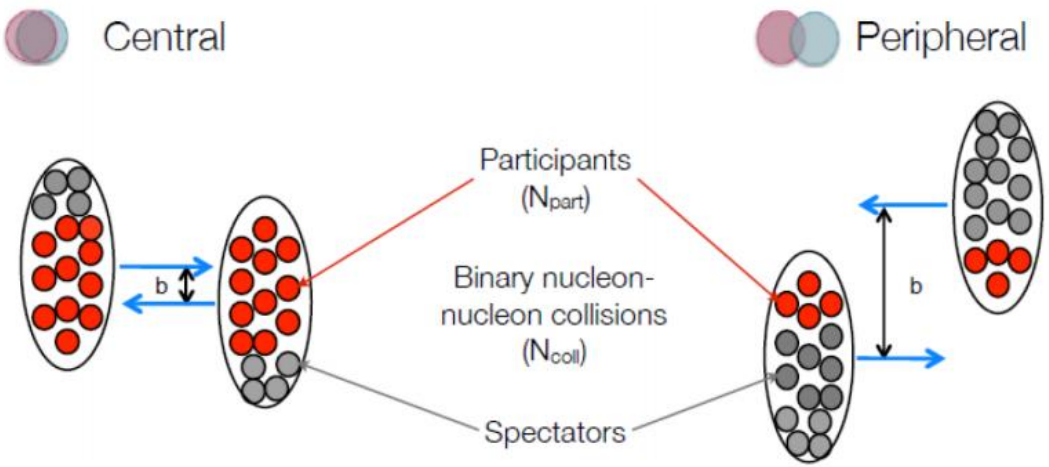
- Measured in p+Pb and Pb+Pb systems.
- The Pb+Pb results in high p_T range show strong suppression with increasing centrality.
- Proton-lead interactions show little modification of the ground charmonium state.
- Upsilons have been studied in p+Pb and found to show only a modest suppression.
- New quarkonia results based on p+Pb at 5TeV and pp at 5TeV will come soon.

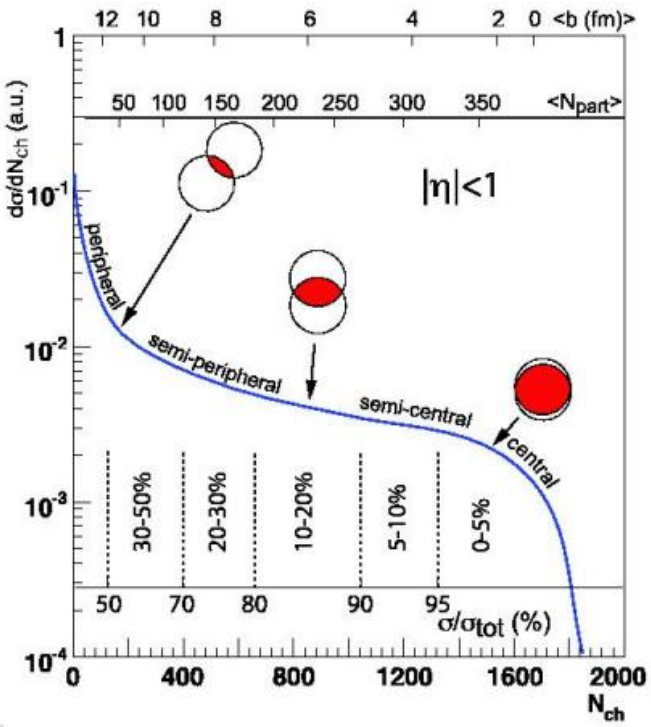
Heavy flavor muons

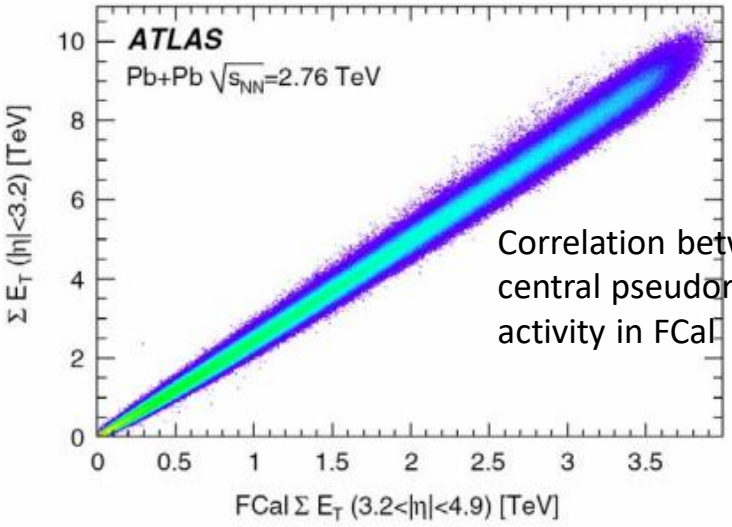
- Measured in Pb+Pb and p+Pb collisions.
- Fourier coefficients associated with the azimuthal modulation ($v2$) has been measured.
- $\mu-h$ correlations have been studied in the 2016 8 TeV data.
- These results provide improved insight on the propagation of heavy quarks in QGP.

backup

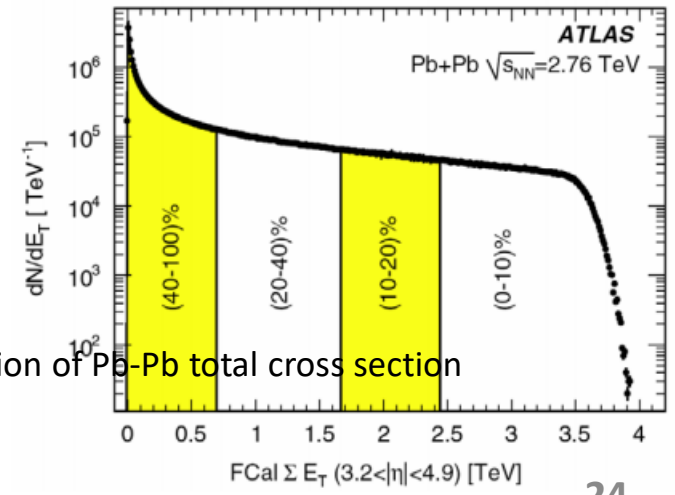
Collision centrality







Correlation between activity in central pseudorapidity region, and activity in FCal



Bins in fraction of Pb-Pb total cross section

J/ψ and $\psi(2S)$ candidates

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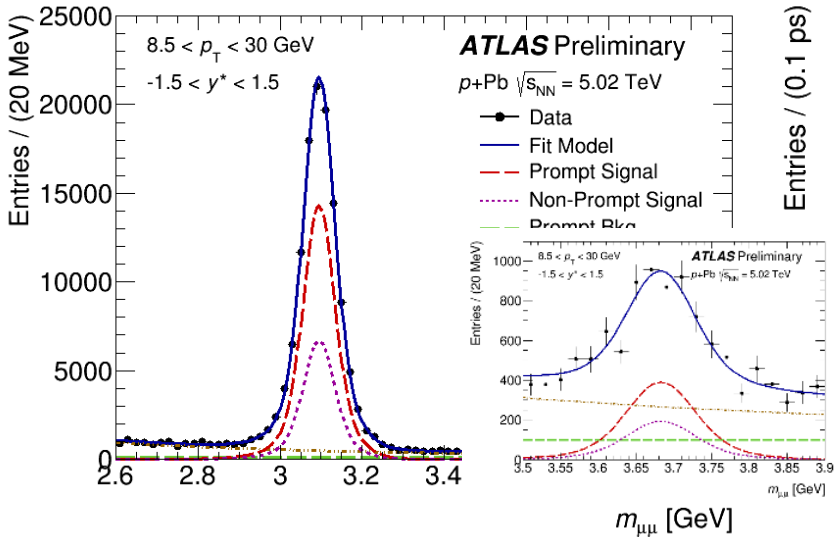
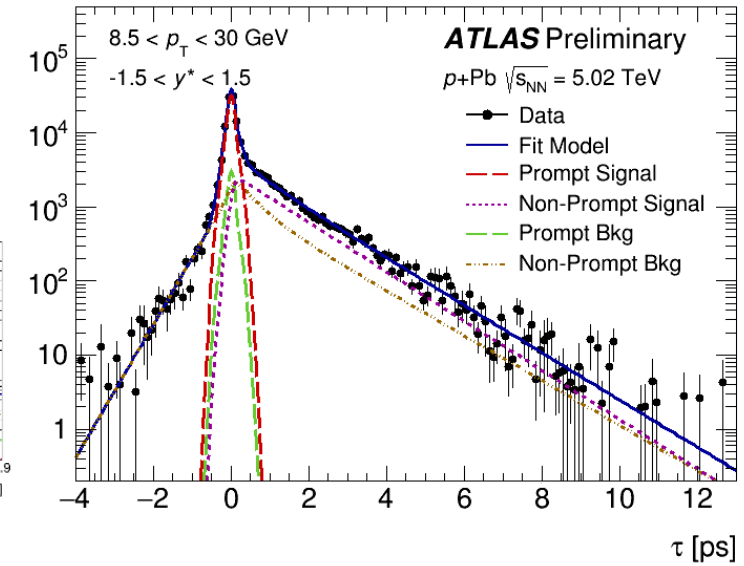
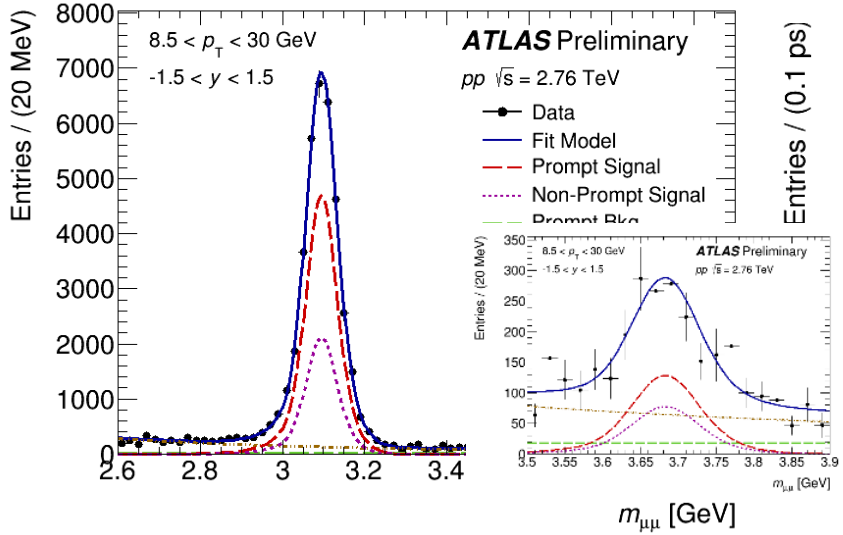
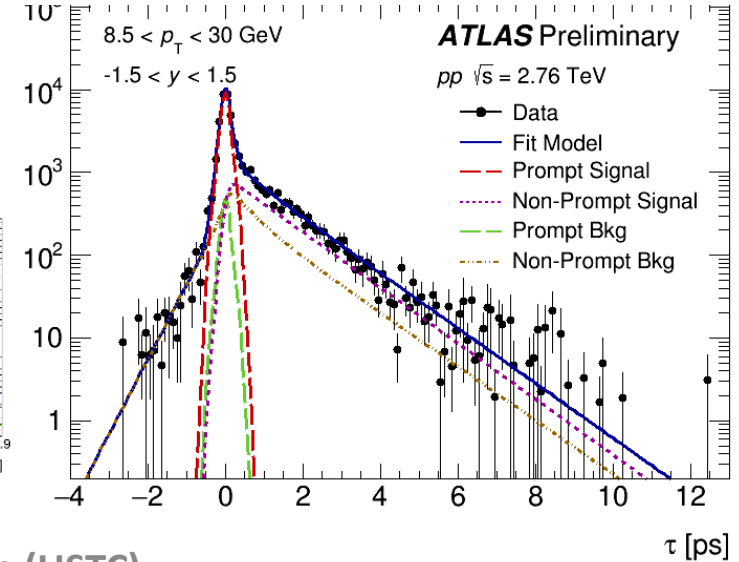
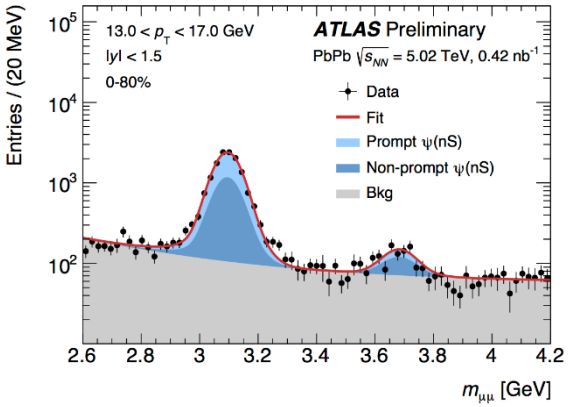


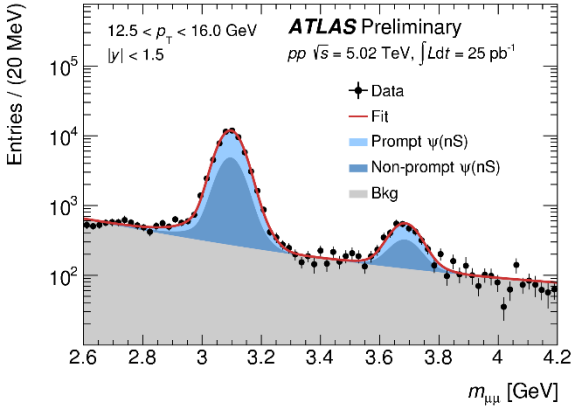


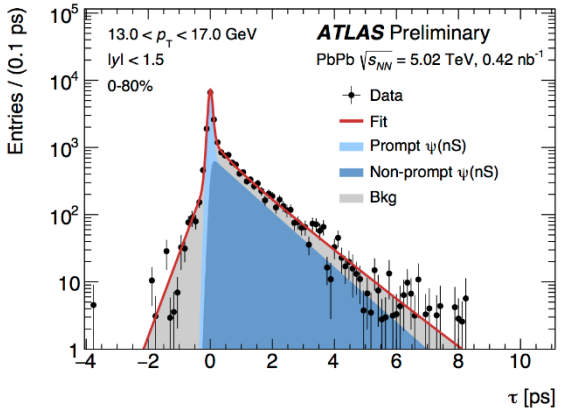




Charmonium fits







$\psi(2S)$ and J/ψ fit model:

i	Type	Source	$f_i(m)$	$h_i(\tau)$
1	J/ψ	P	$\omega_i \mathrm{CB}_1(m) + (1-\omega_i)\mathrm{G}_1(m)$	$\delta(\tau)$
2	J/ψ	NP	$\omega_i \mathrm{CB}_1(m) + (1-\omega_i)\mathrm{G}_1(m)$	$\mathrm{E}_1(\tau)$
3	$\psi(2S)$	P	$\omega_i \mathrm{CB}_2(m) + (1-\omega_i)\mathrm{G}_2(m)$	$\delta(\tau)$
4	$\psi(2S)$	NP	$\omega_i \mathrm{CB}_2(m) + (1-\omega_i)\mathrm{G}_2(m)$	$\mathrm{E}_2(\tau)$
5	Bkg	P	flat	$\delta(\tau)$
6	Bkg	NP	$\mathrm{E}_3(m)$	$\mathrm{E}_4(\tau)$
7	Bkg	NP	$\mathrm{E}_5(m)$	$\mathrm{E}_6(\|\tau\|)$

CB: Crystal Ball function
G: Gaussian

E: exponential
$\delta(\tau)$: Dirac delta function

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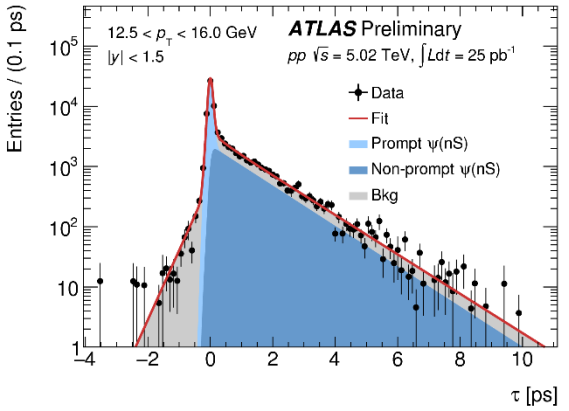

Non-prompt fraction

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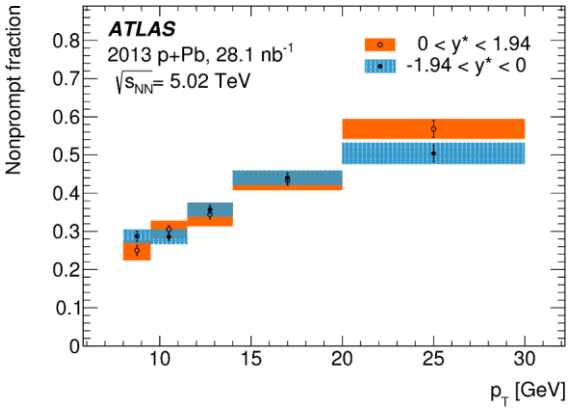

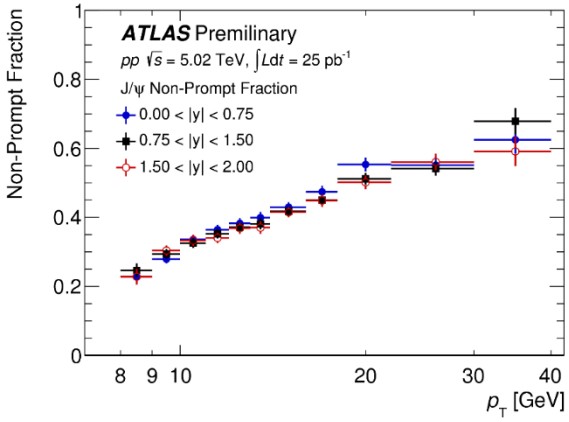

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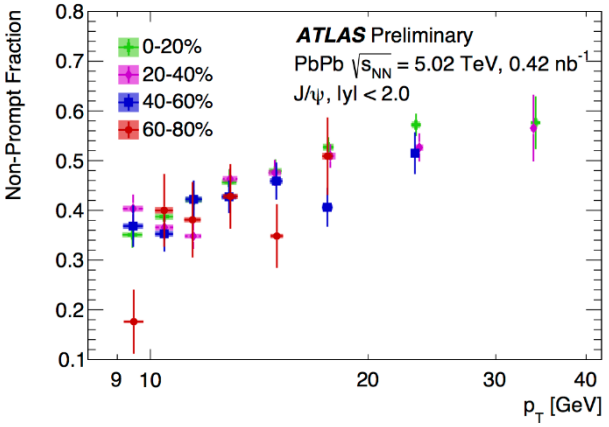
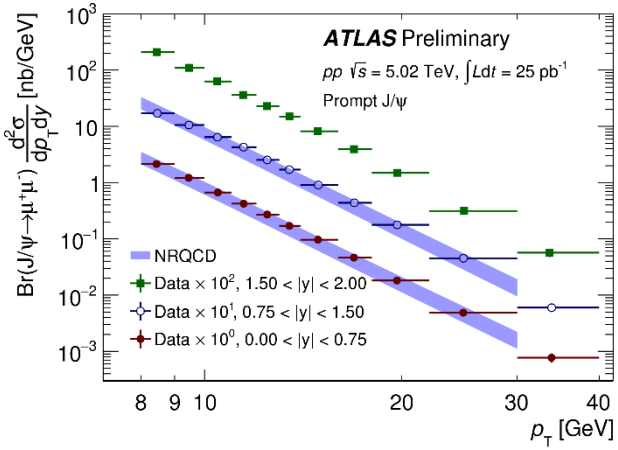
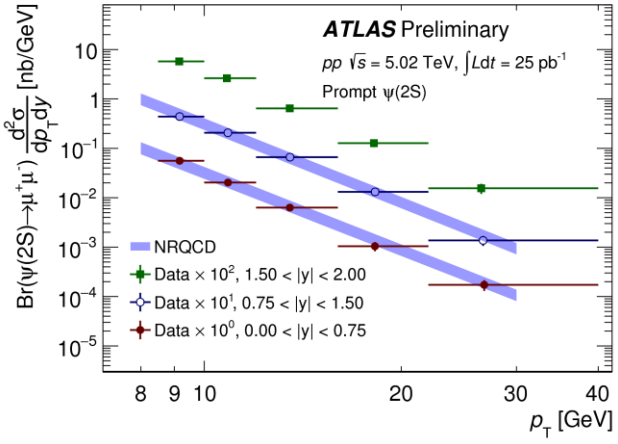


$$f_{NP}^{\psi} = \frac{N_{\psi}^{np,corr}}{N_{\psi}^{np,corr} + N_{\psi}^{p,corr}}$$

- f_{NP}^{ψ} of J/ψ production is found to depend strongly on p_T. No significant rapidity dependence is observed.
- In pp and pPb collisions, this trend consistent with each other.
- f_{NP}^{ψ} measured in Pb+Pb collisions as a function of p_T does not depend on the collision centrality class.

Double differential cross section





The measured prompt J/ψ and $\psi(2S)$ cross sections show good agreement with NRQCD predictions.

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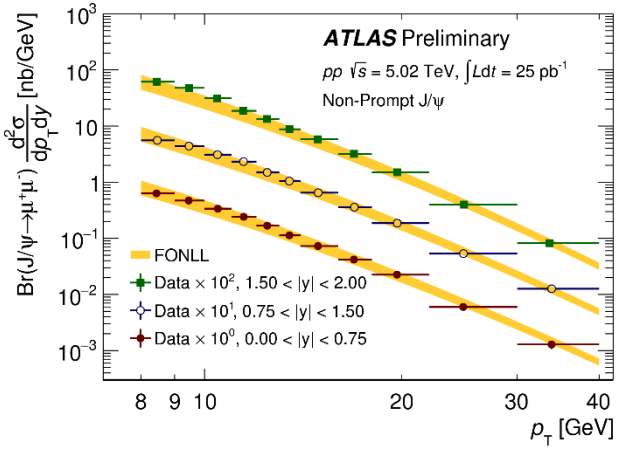

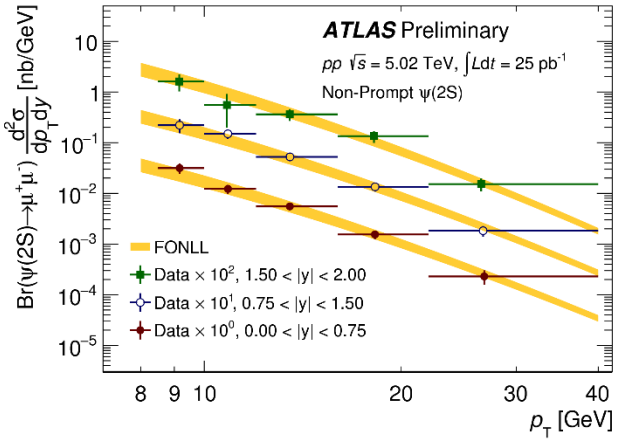

The measured non-prompt J/ψ and $\psi(2S)$ cross sections show good agreement with FONLL predictions.

$\psi(2S)$ to J/ψ double ratio

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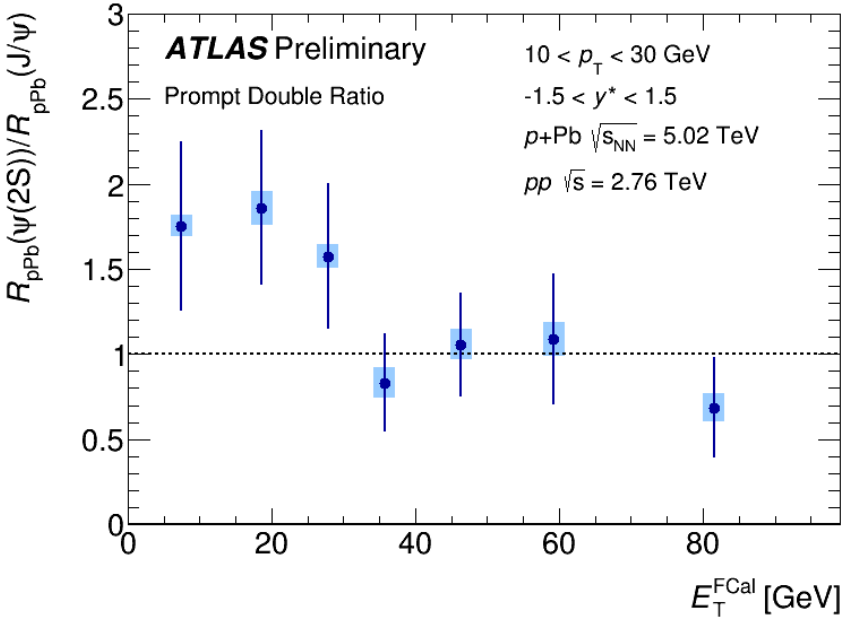
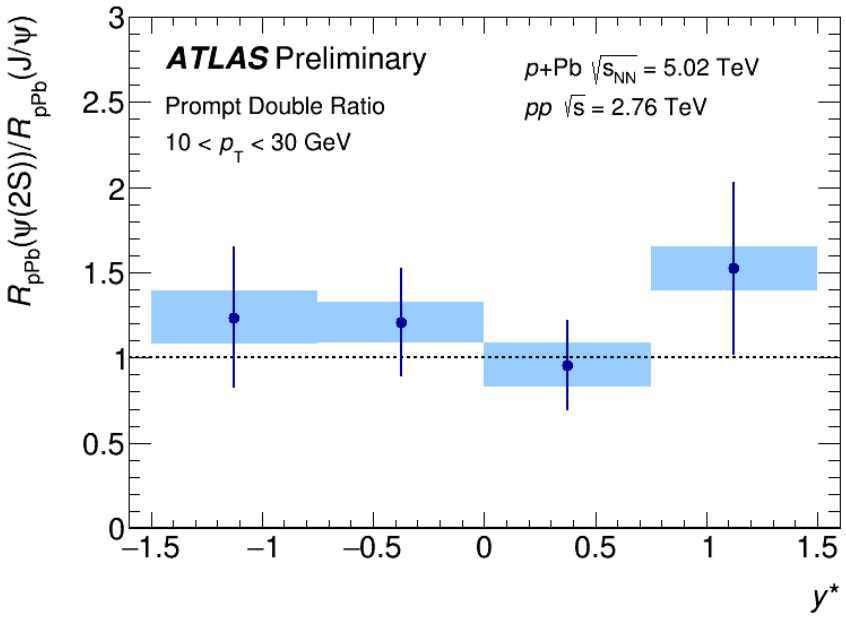
pp cross section at $\sqrt{s}$ = 5.02 TeV absence

interpolation

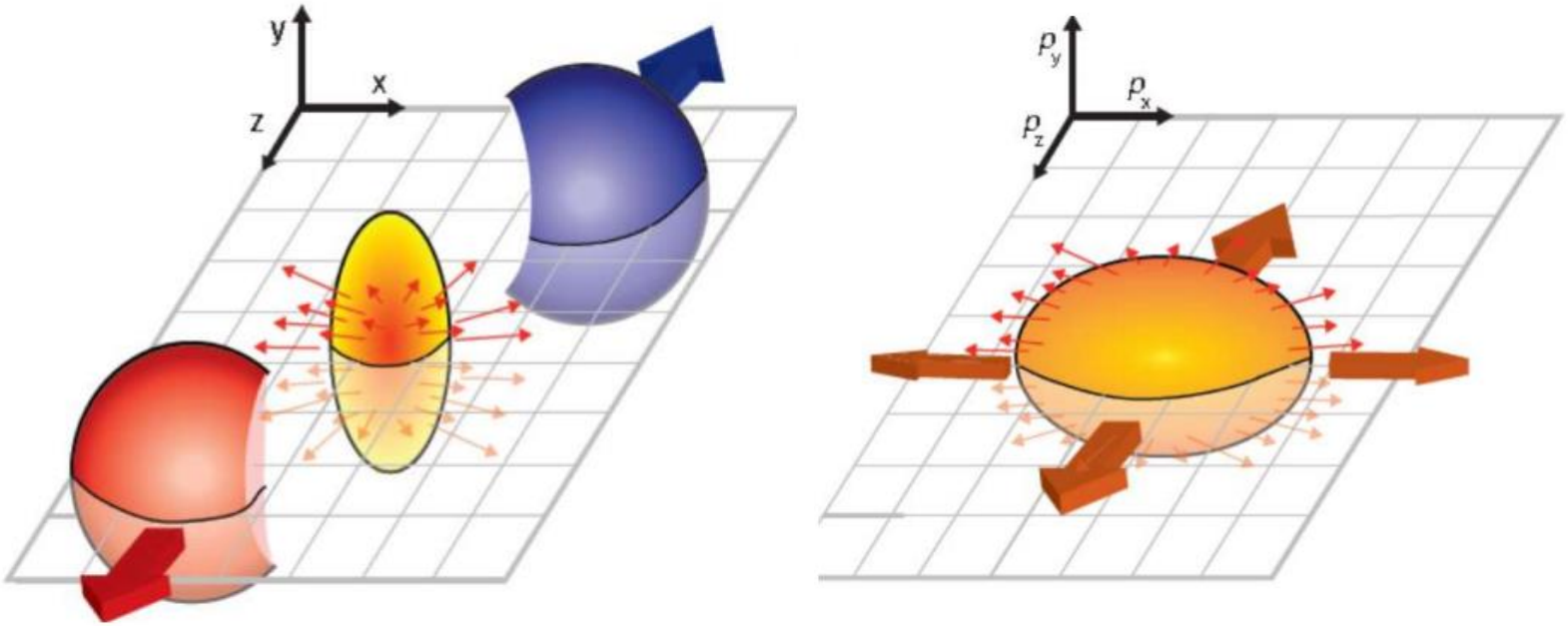
$\sqrt{s}$ = 2.67 TeV , 7TeV, 8TeV pp cross section





The prompt $\psi(2S)$ to J/ψ double ratio show no obvious rapidity dependence, but a decreasing trend as the event activity increases.

Elliptic flow of HF muons



HF muon candidates

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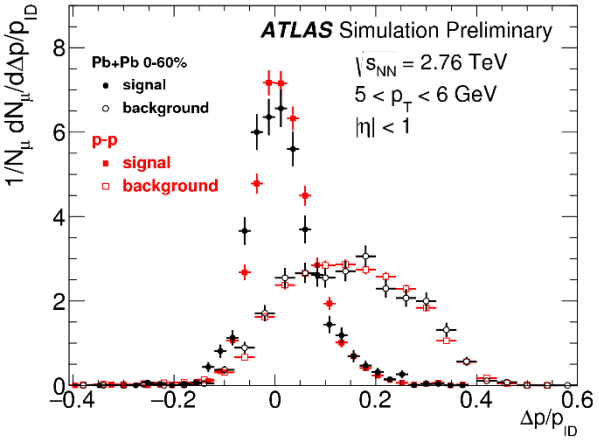
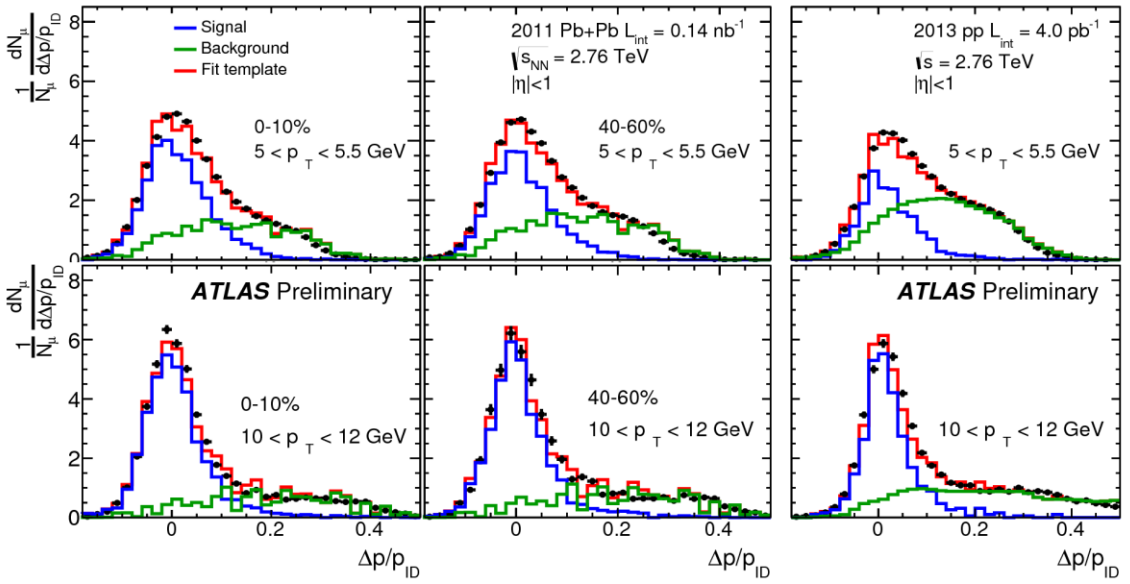


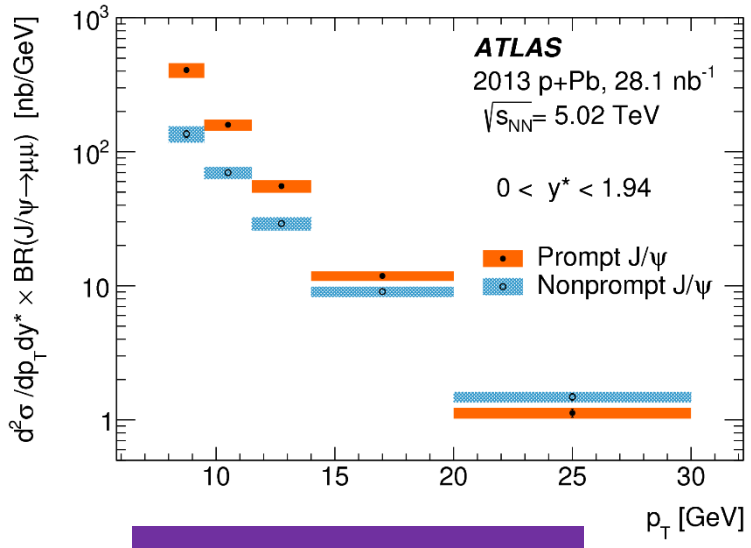


$$\frac{\Delta p}{p_{ID}} = \frac{p_{ID} - p_{MS} - p_{calo}}{p_{ID}}$$

Background: pion decays in flight, kaon decays in flight, muons produced by secondary interactions of prompt particles, and misassociations.

Using **template fit** to estimate signal and background.

Double differential cross section



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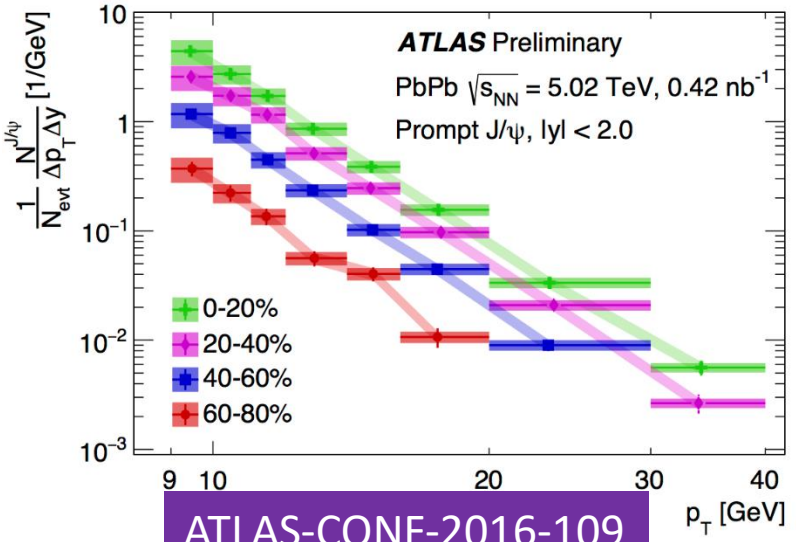

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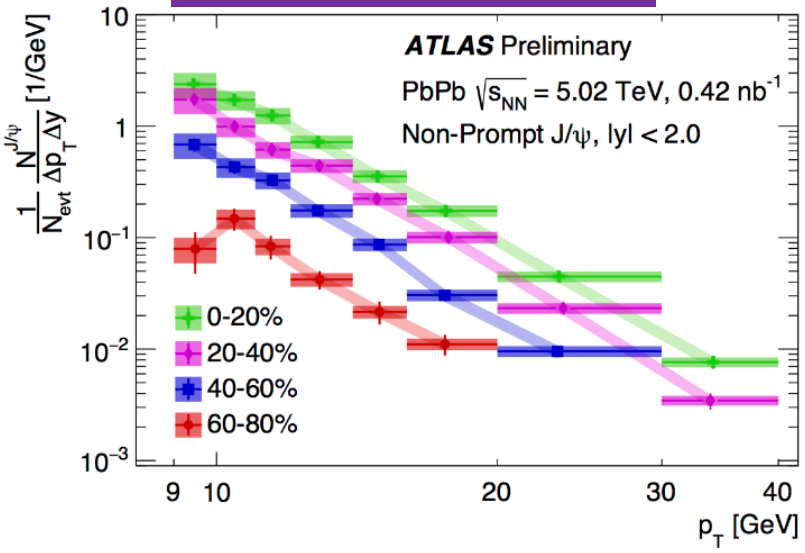

Double differential cross sections (or per-event yields) are also measured in p+Pb and Pb+Pb collisions.

$\Upsilon(nS)$ cross section

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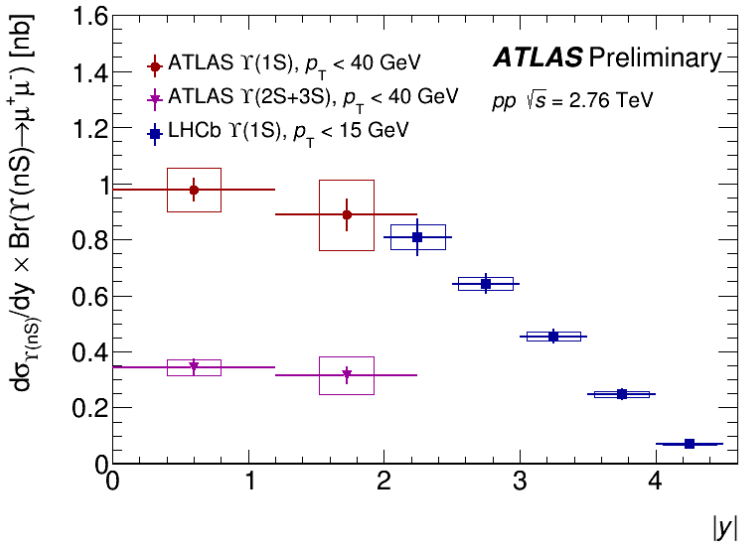
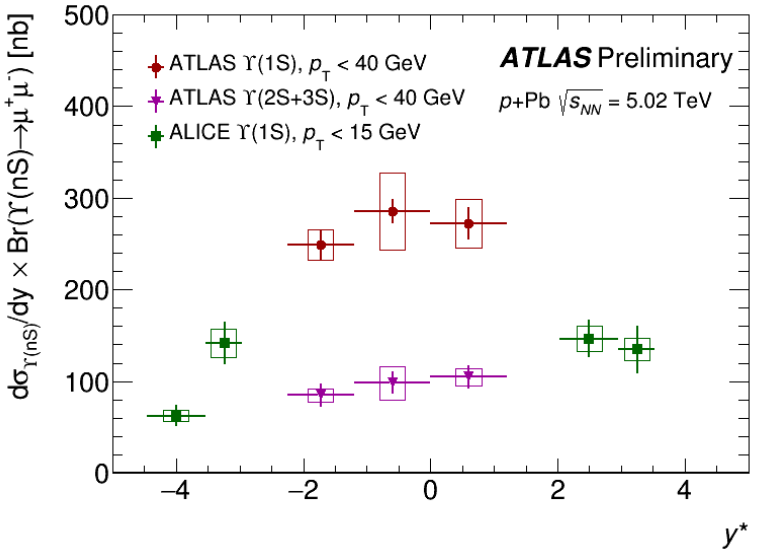
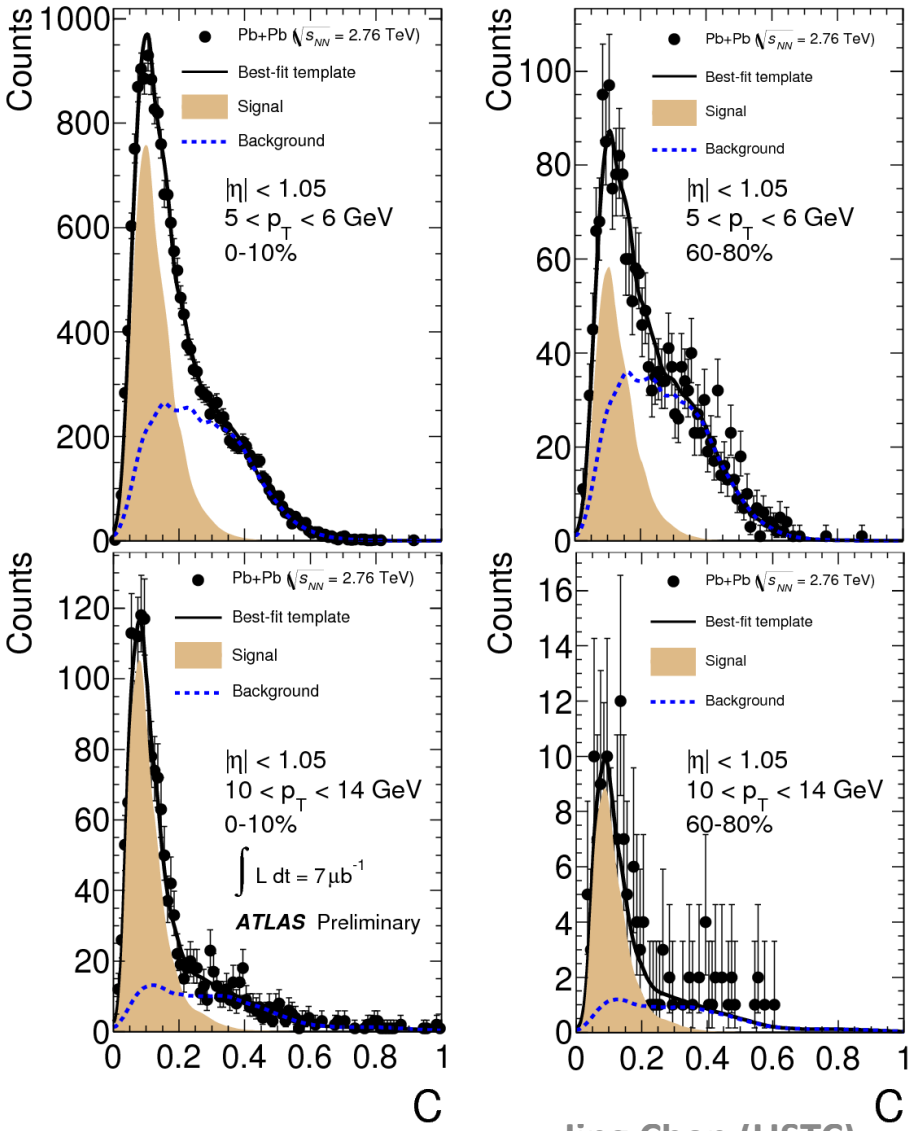




- $\Upsilon(2S)$ and $\Upsilon(3S)$ are combined as $\Upsilon(2S+3S)$
- The differential cross sections are compared to the results measured by LHCb and ALICE

Two-particle correlations



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Heavy flavor muon R_{AA}

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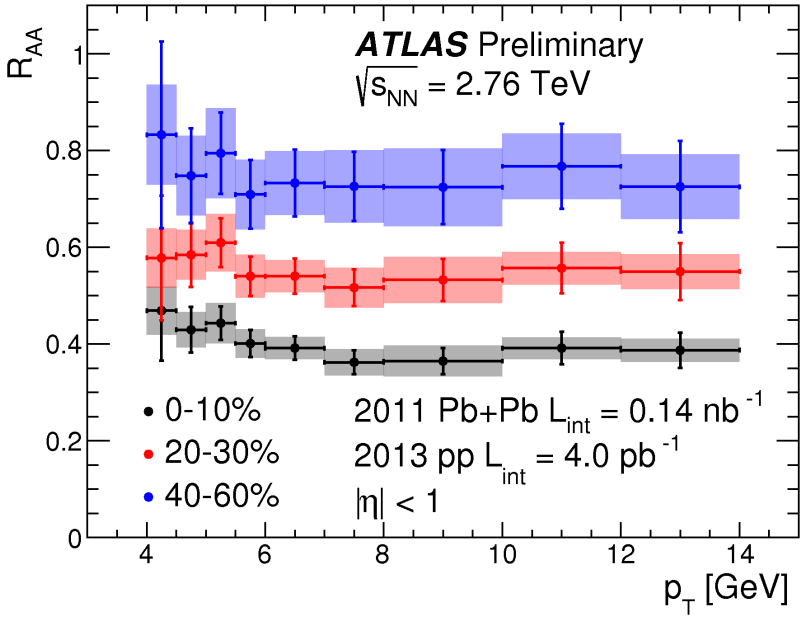

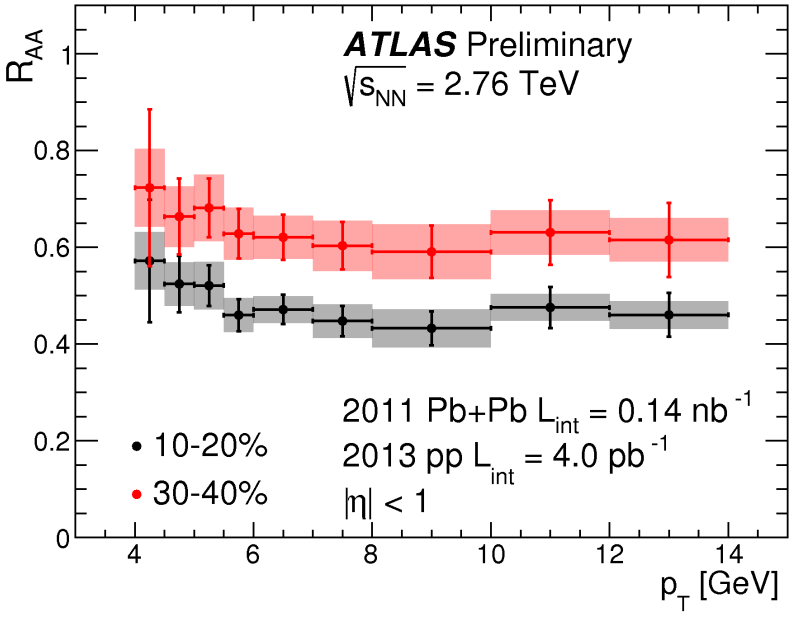

R_{AA} shows a centrality-dependent suppression that is p_T-independent within uncertainties.