Charmonia production in large and small systems measured by ATLAS

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Hard Probes 2018 — Aix-Les-Bains

ATLAS EXPERIMENT

HARD PROBES 2018

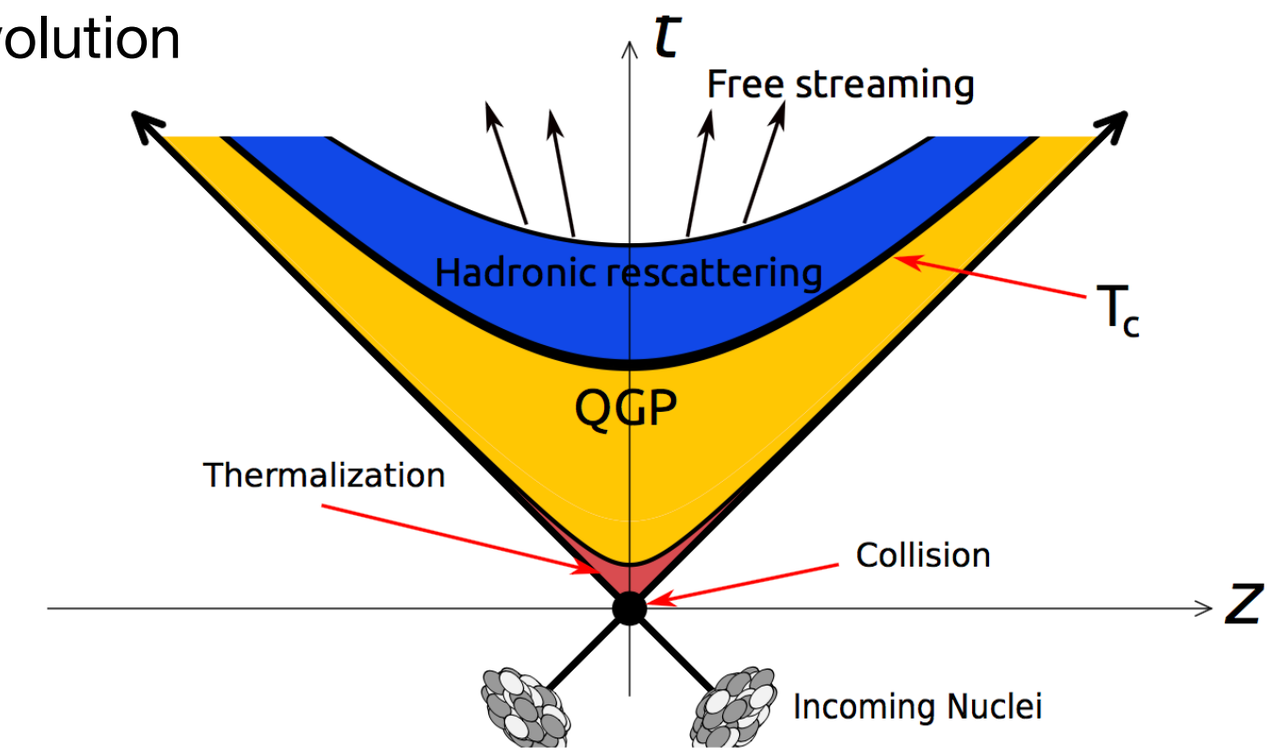
- **Timescales of quarkonia production and Quark Gluon Plasma:**

$$\tau_{\text{formation}}^{Q\bar{Q}} \lesssim \tau_{\text{formation}}^{\text{QGP}} < \tau_{\text{life}}^{\text{QGP}} < \tau_{\text{life}}^{\text{quarkonia}}$$

  - Quark-antiquark systems are the excellent probes of the QGP
  - They experience the complete QGP evolution

- **Main observables:**
  - Nuclear modification factor (R_{pPb}, R_{AA})
  - Elliptic flow (v_2)

- **Different colliding systems**
  - proton–proton (reference)
  - proton–lead (R_{pPb})
  - lead–lead (R_{AA}, v_2)



QGP: hot and dense state of matter created in heavy ions collisions

The ATLAS Experiment

Charmonia analysis:

- Dimuon decay channel
- Per-dimuon correction
- $|y| < 2$, $9 < p_T < 40$ GeV

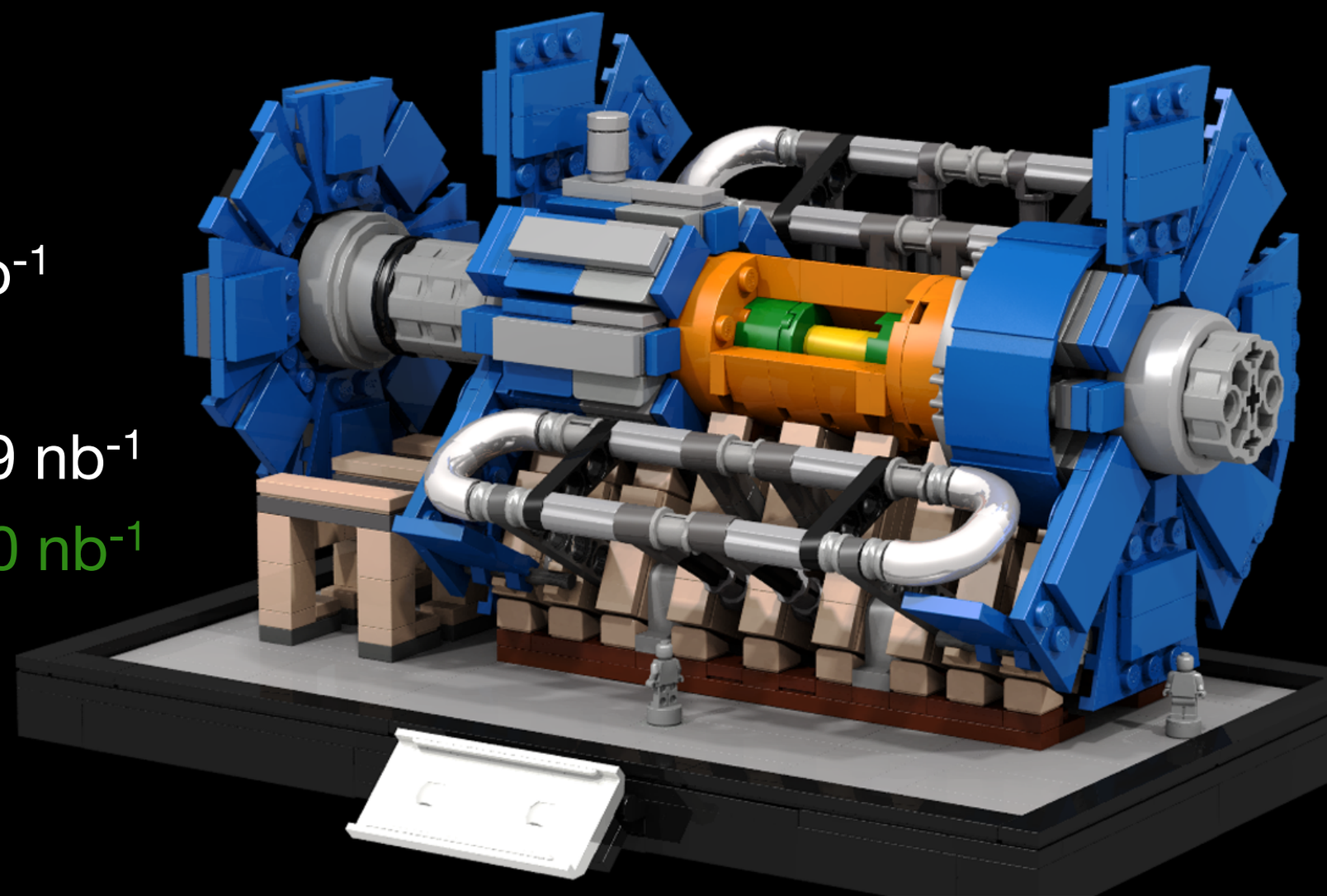
(2013) ***p*+Pb** 5.02 TeV, 28 nb^{-1}

(2015) ***pp*** 5.02 TeV, 25 pb^{-1}

(2015) **Pb+Pb** 5.02 TeV, 0.49 nb^{-1}

(2018) **Pb+Pb** 5.02 TeV, ~2.0 nb^{-1}

Expected 4 times more luminosity than in 2015



Prompt and Non-prompt Charmonia

Inclusive J/ψ

=

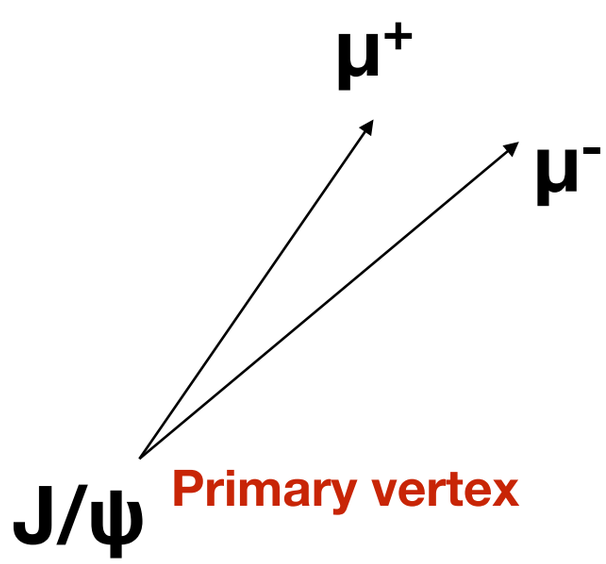
Prompt J/ψ (direct production, feed-down from excited states) → **Modified by color screening and regeneration in the QGP**

And energy loss?

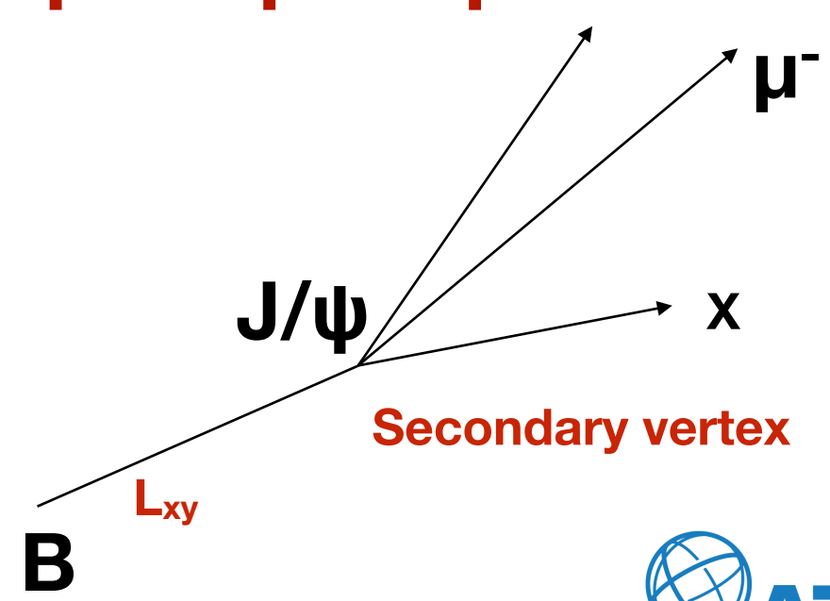
+

Non-Prompt J/ψ (decays from B-hadrons) → **Energy loss of *b*-quarks in the medium**

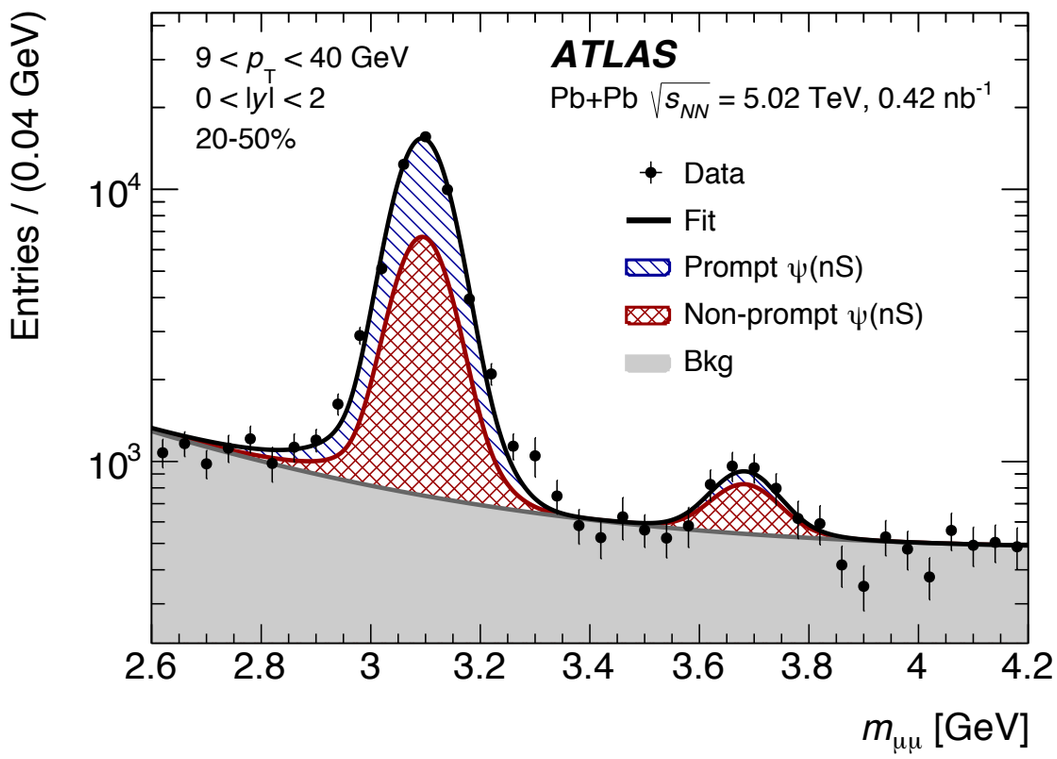
Prompt J/ψ:

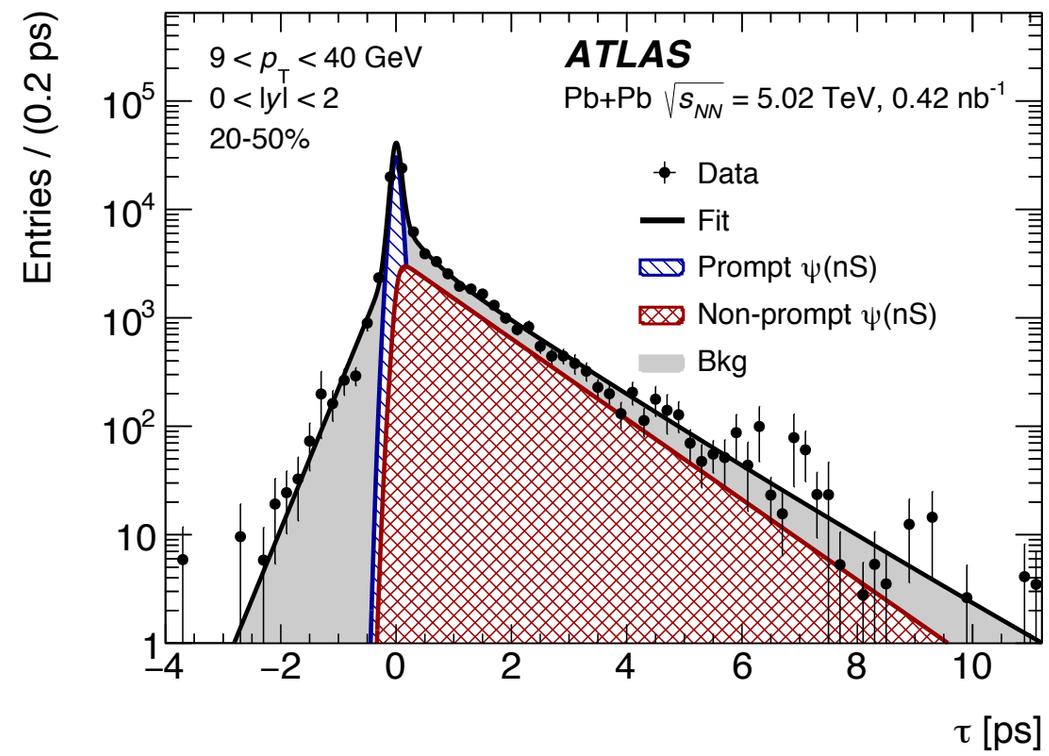


Non-prompt J/ψ: μ^+



Signal extracted from two dimensional fits of dimuon invariant mass and pseudo-proper decay time





Pseudo-proper decay time is the key quantity to separate prompt and non-prompt J/ψ

$$\tau = \frac{L_{xy} m_{\mu\mu}}{p_{\mathrm{T}}^{\mu\mu}}$$

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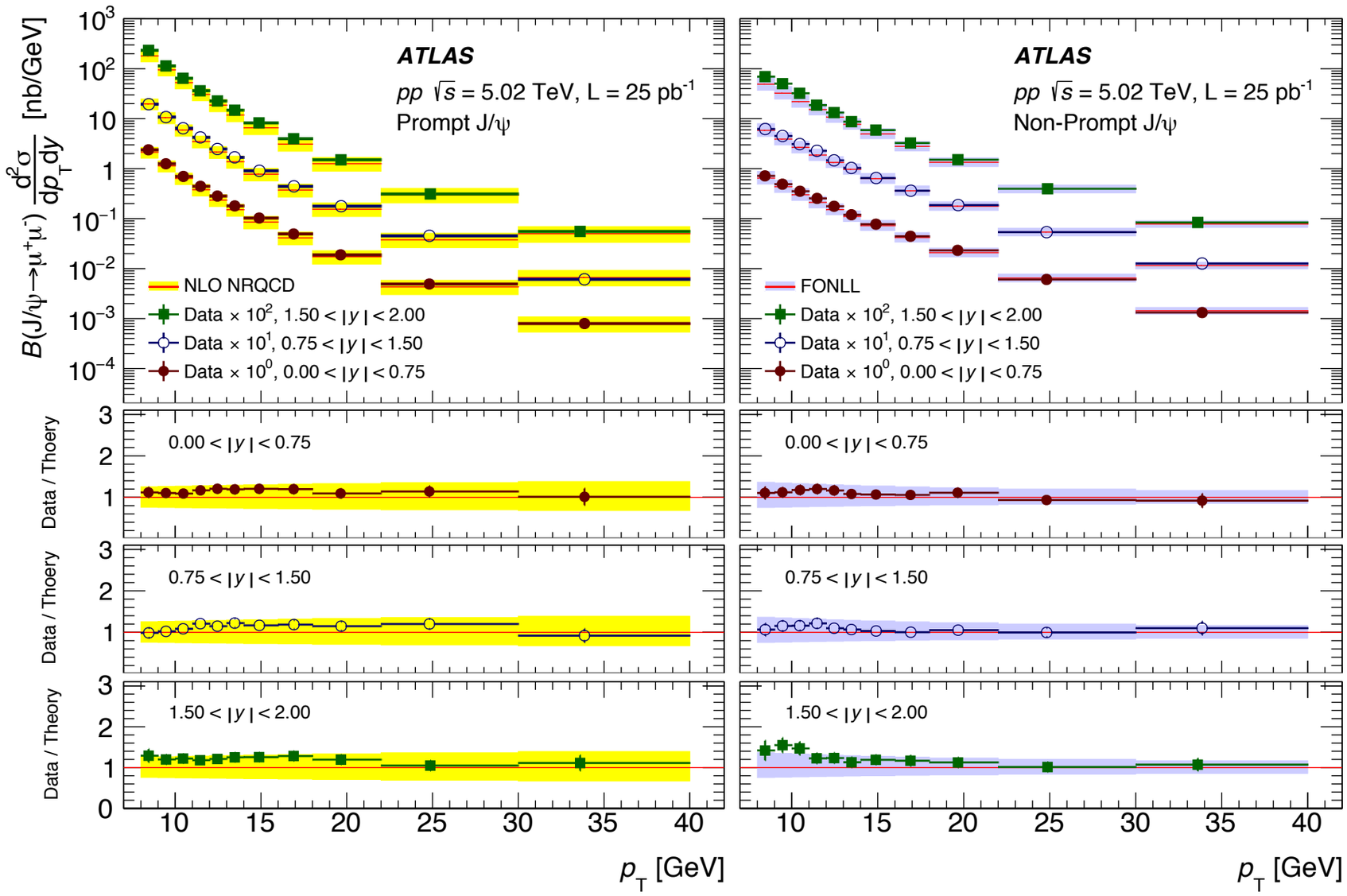
J/ψ pp cross-section



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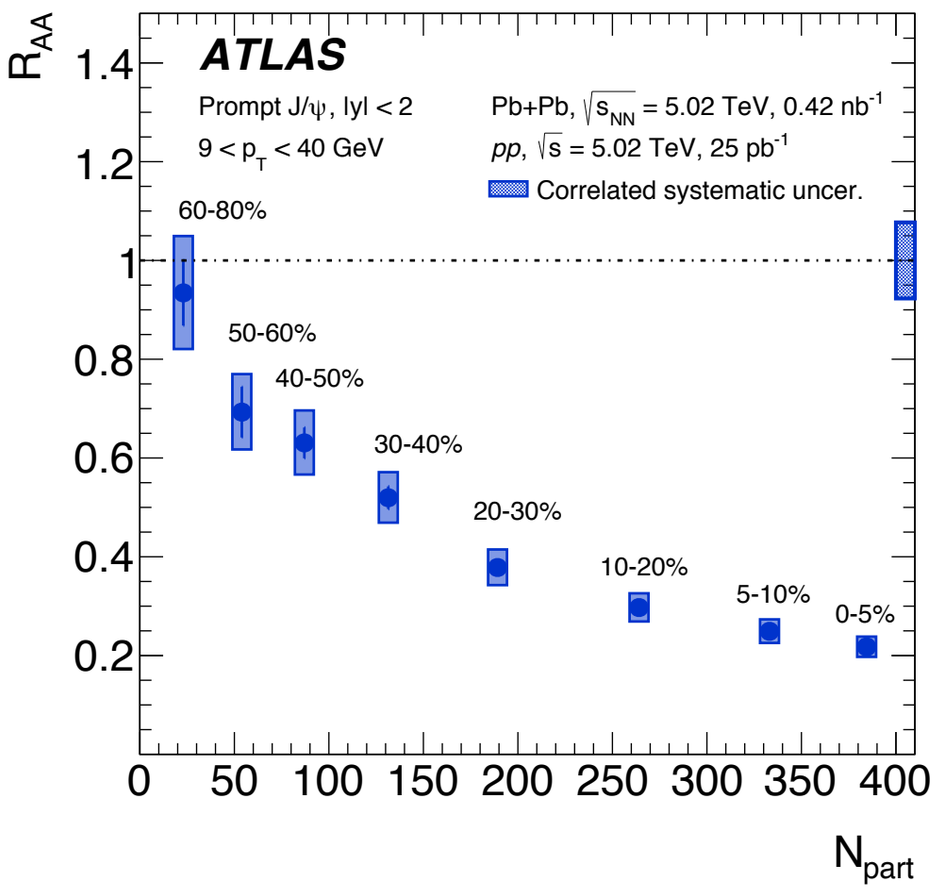
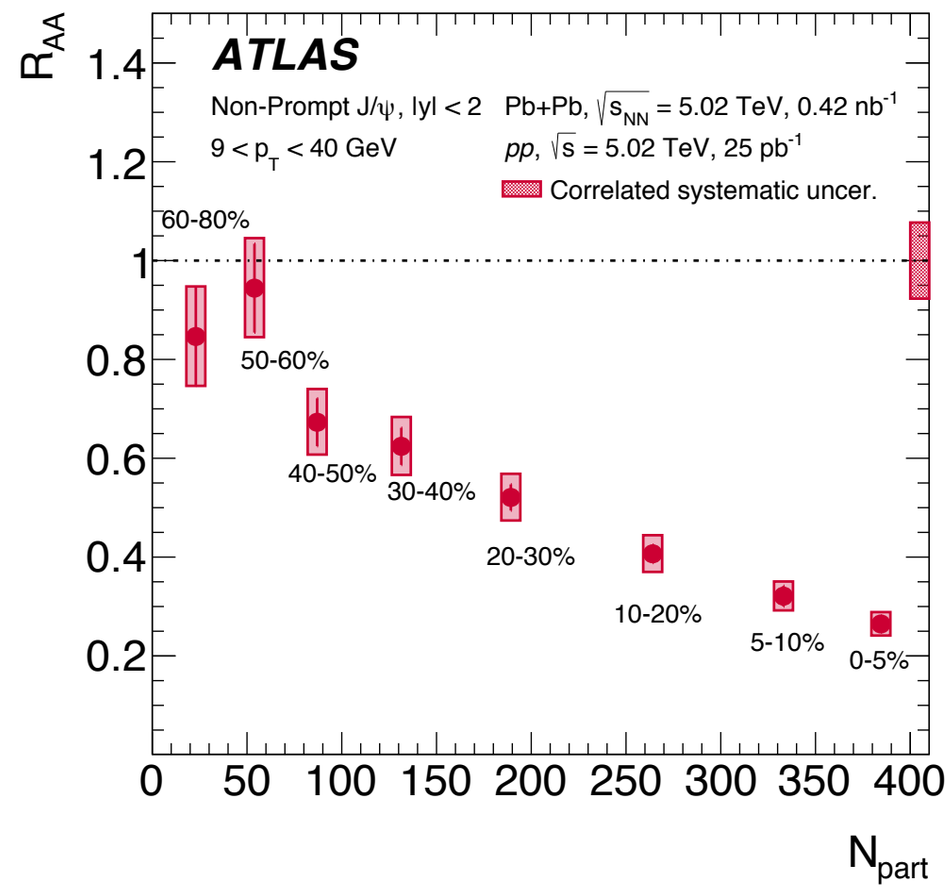
Reference for p+A and A+A collisions

Good agreement between data and predictions

NLO NRQCD (https://arxiv.org/abs/1205.6344) and FONLL (https://arxiv.org/abs/1009.3655)

Nuclear modification factor – R_{AA}





Strong centrality dependence for both **prompt** and **non-prompt** J/ψ with similar suppression for both flavours

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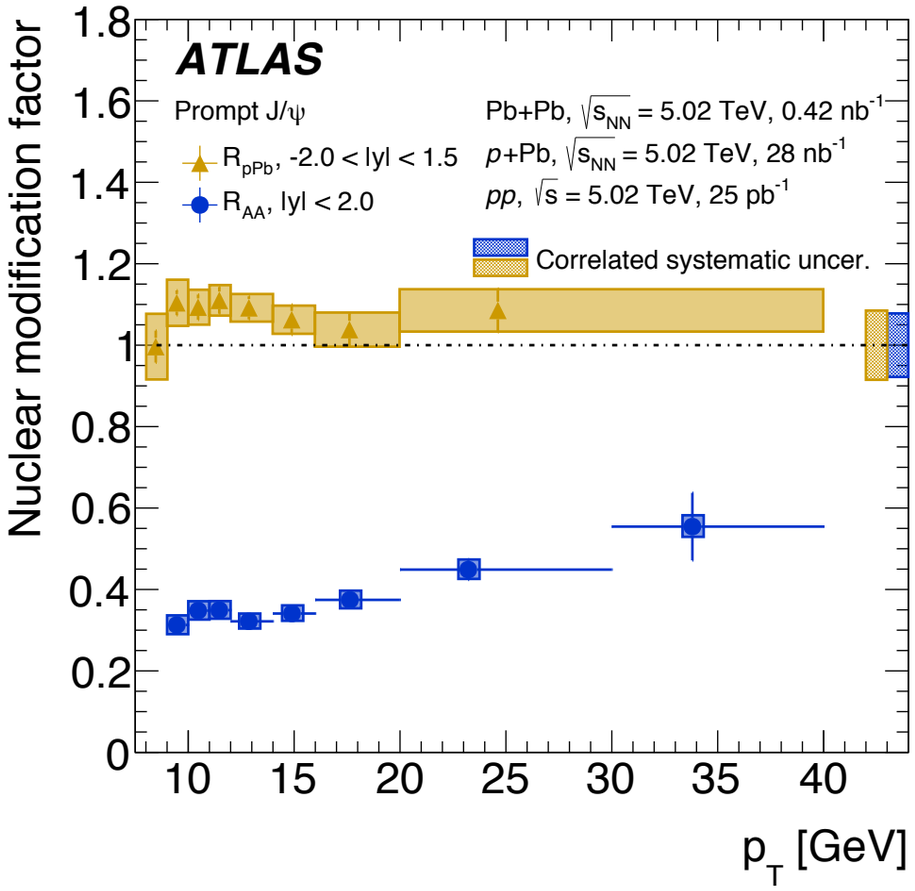
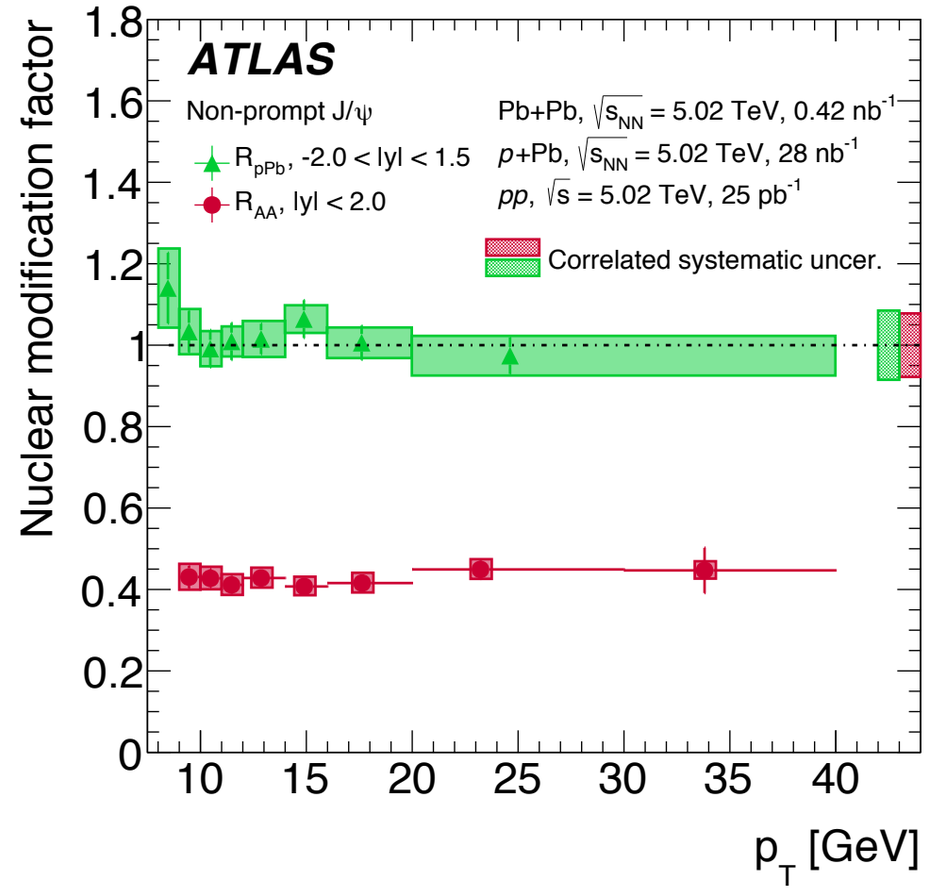
Nuclear Modification Factor – R_{pPb} and $R_{AA}(p_T)$





➜ R_{pPb} is consistent with unity

➜ R_{PbPb} strong suppression

- Suppression (R_{AA}) is mainly coming from QGP effects
- R_{AA} has a different p_T dependence for both prompt and non-prompt J/ψ

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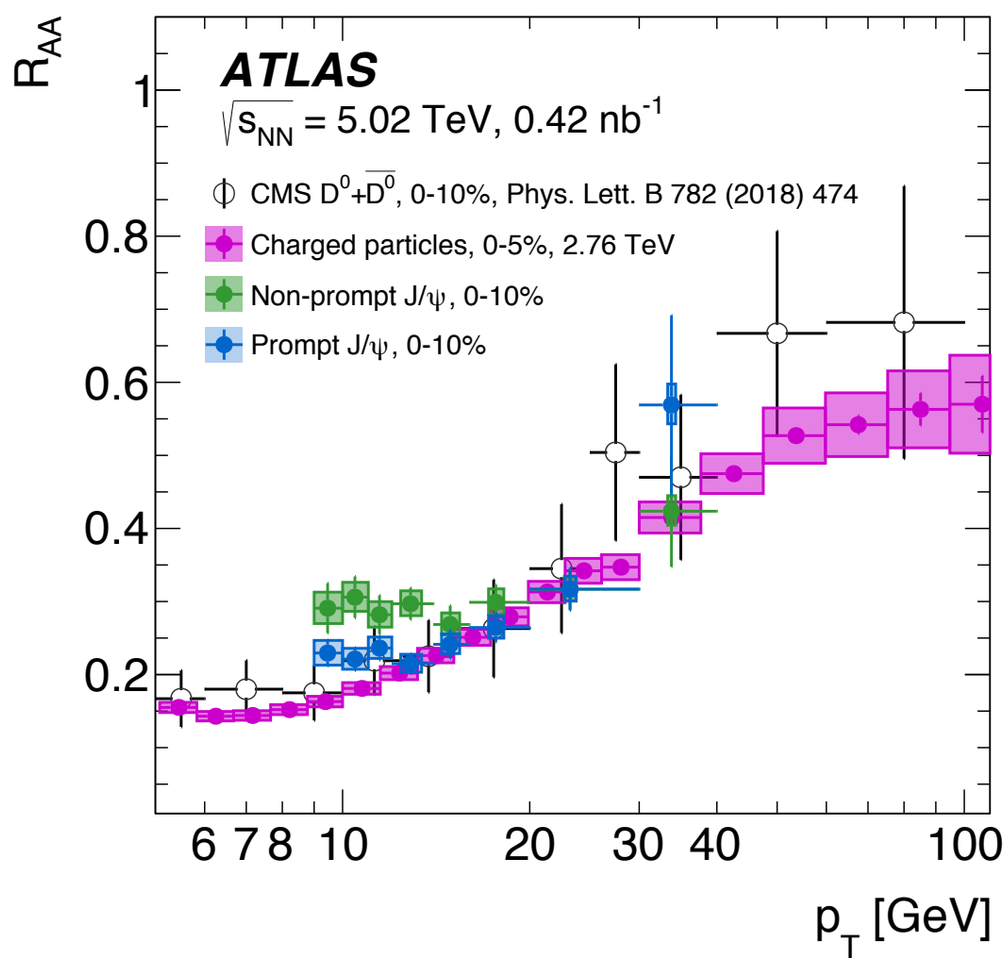
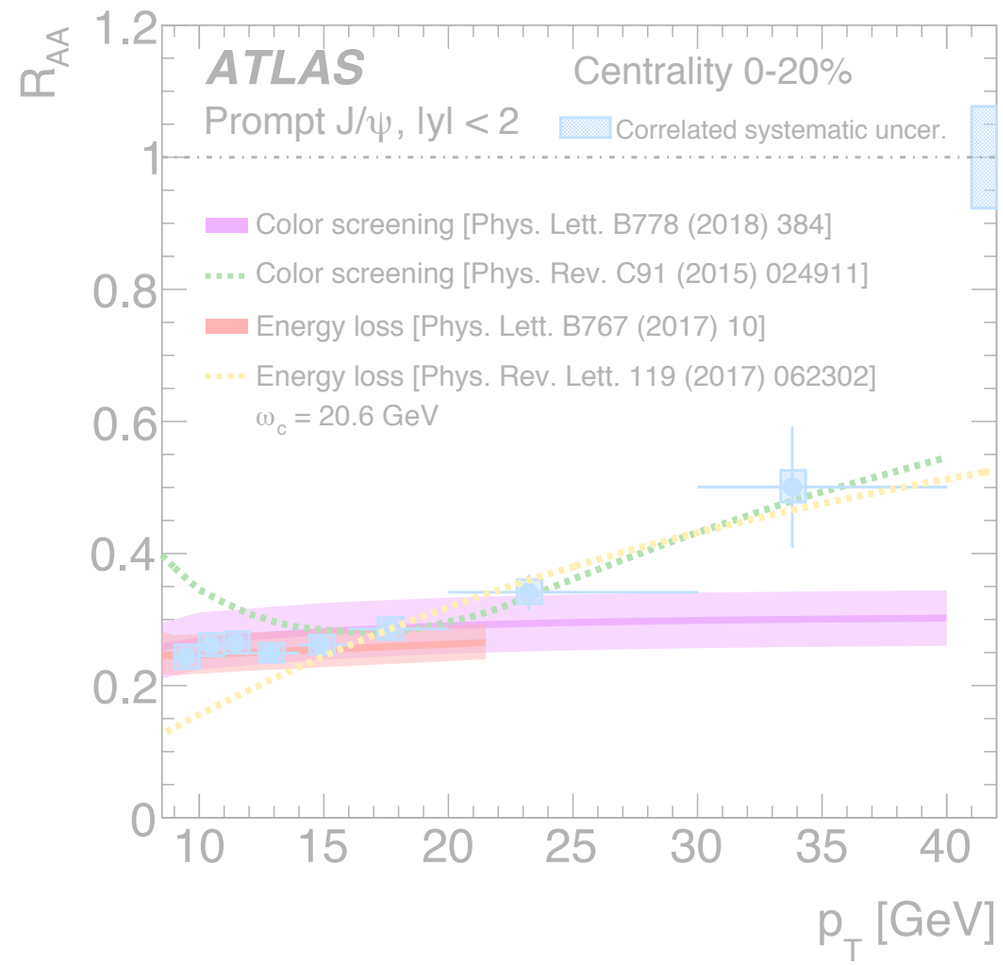
Nuclear Modification Factor – $R_{AA}(p_T)$





Suggestion of high p_T universality from suppression of several different probes

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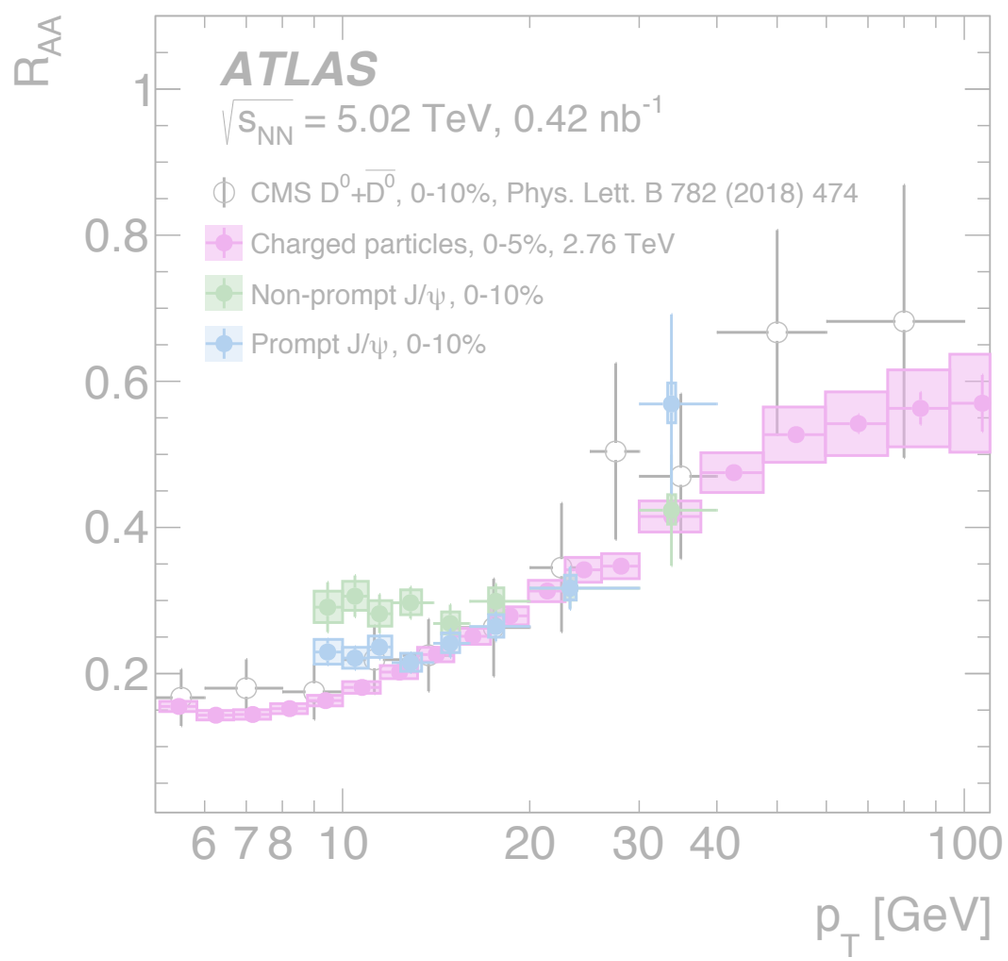
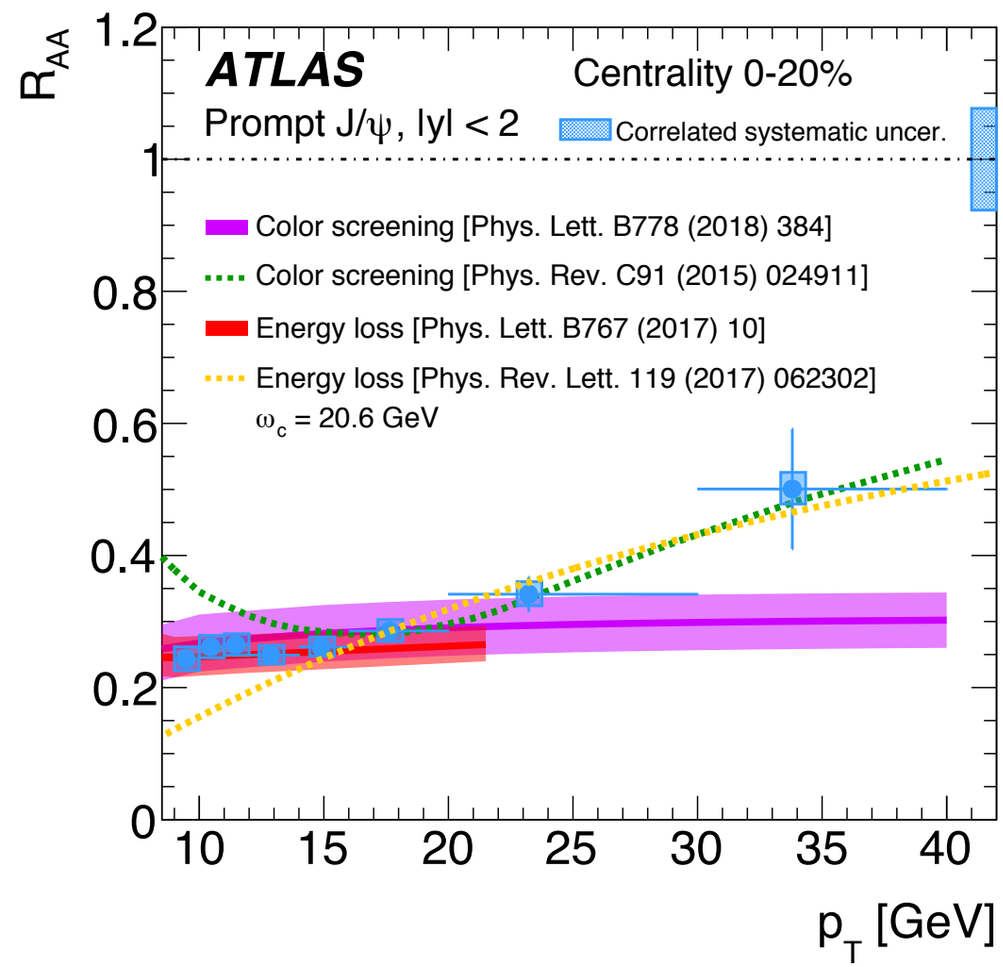
Nuclear Modification Factor – $R_{AA}(p_T)$





Data is described by different models

color screening vs energy loss scenarios

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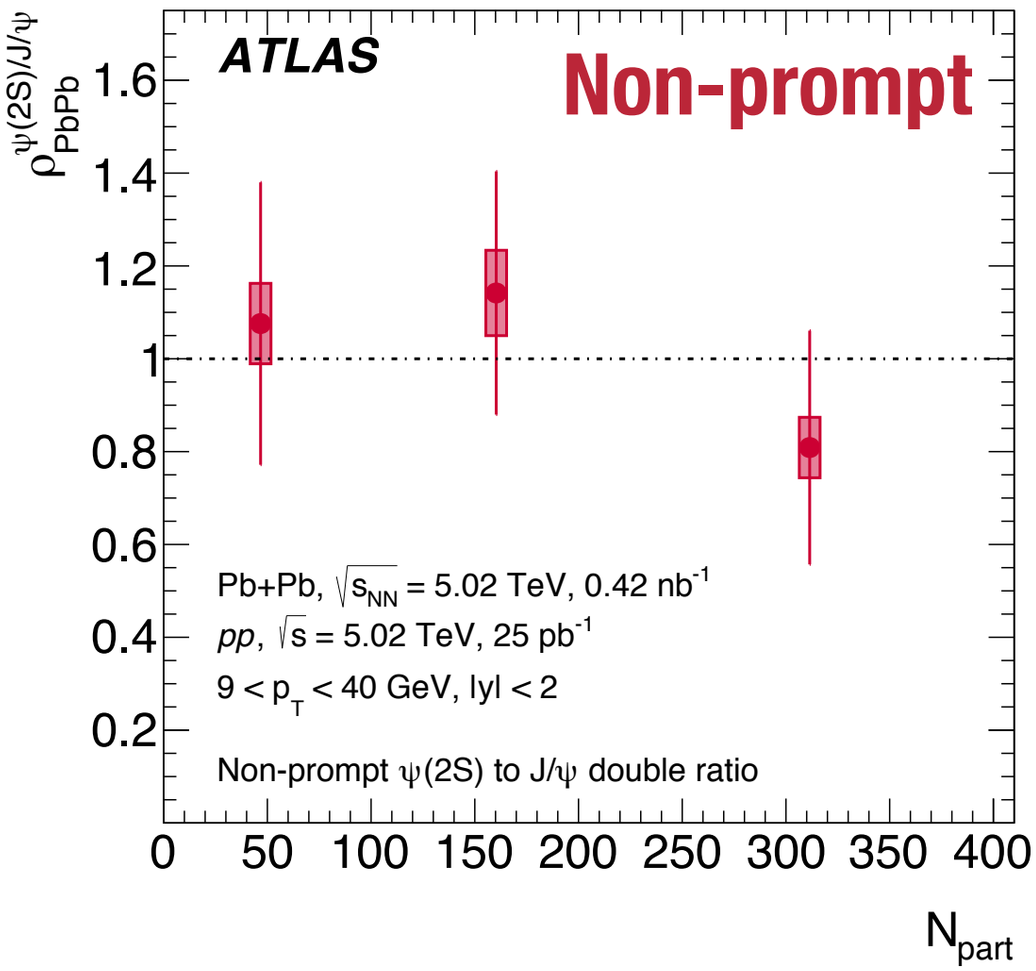
Double Ratios $R_{AA}[\psi(2S)]/R_{AA}[J/\psi]$



Non-prompt double ratio indicates that the suppression of both states is consistent with a decay of the B-hadron outside the medium

$$\rho^{\psi(2S)/J/\psi}_{\mathrm{PbPb}} = R^{\psi(2S)}_{\mathrm{AA}} / R^{J/\psi}_{\mathrm{AA}}$$

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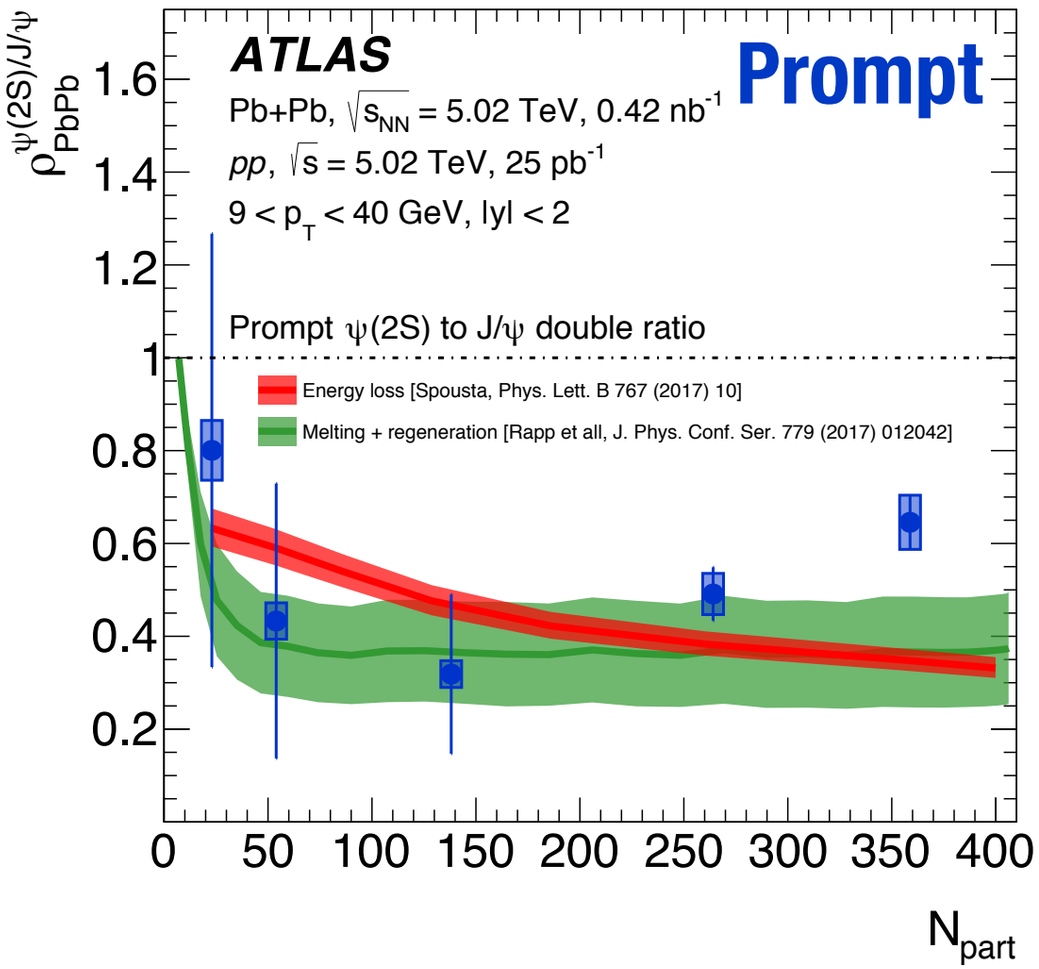
Double Ratios $R_{AA}[\psi(2S)]/R_{AA}[J/\psi]$



Non-trivial behavior for prompt J/ψ:
– data is well described under different scenarios

➜ Color-screening + Regeneration

➜ Energy Loss

$$\rho^{\psi(2S)/J/\psi}_{PbPb} = R^{\psi(2S)}_{AA} / R^{J/\psi}_{AA}$$

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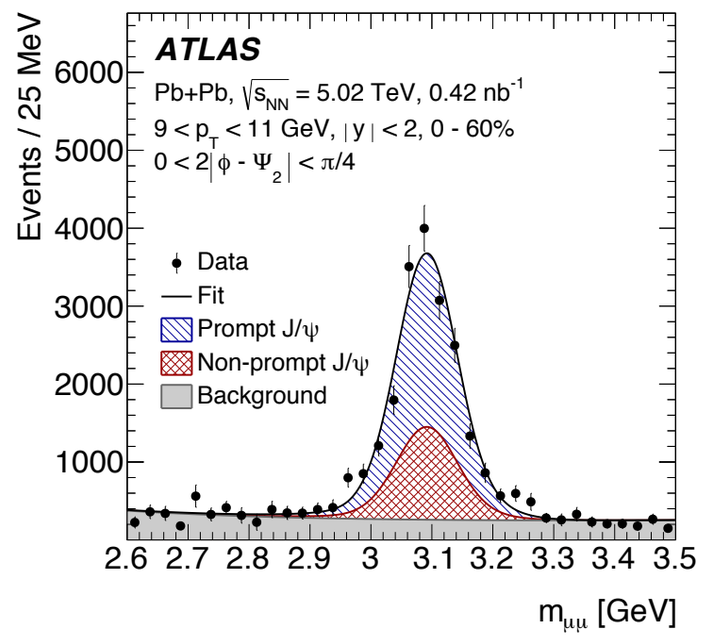
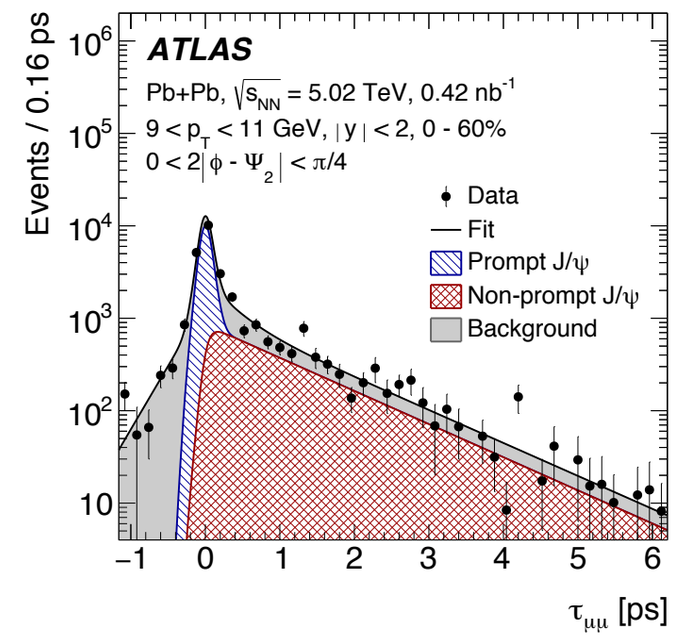
Prompt and Non-prompt J/ψ Elliptic Flow

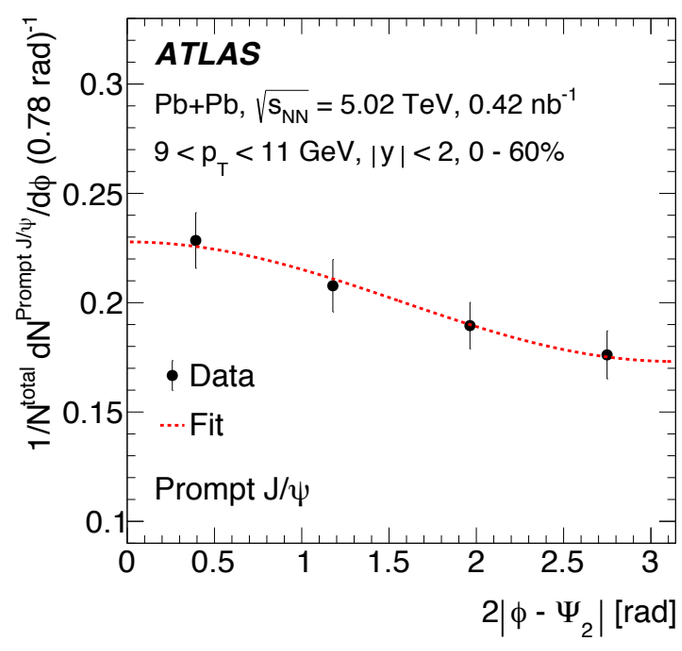
- Reaction plane estimated using the **event plane method**
- Both yields fitted simultaneously to get the elliptic flow coefficient:
  - v_2^{prompt} and $v_2^{non\text{-}prompt}$
  - Correctly accounts for prompt and non-prompt signal correlations.

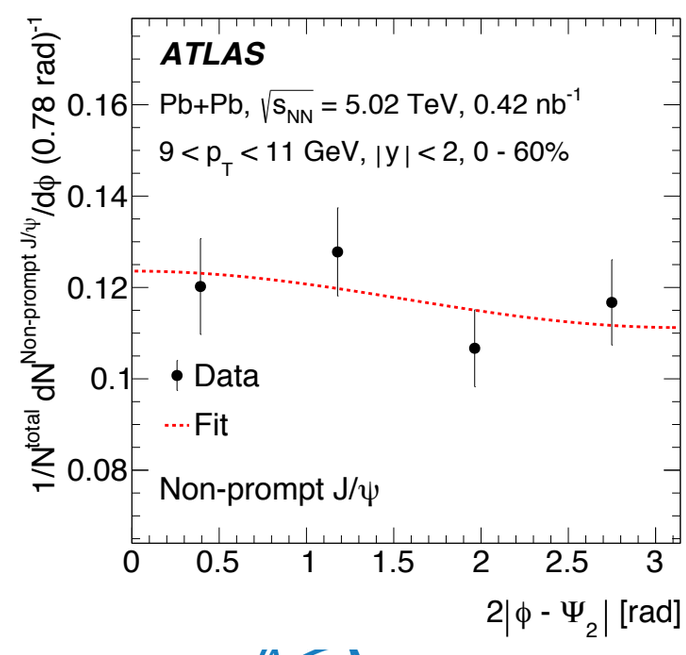
$$\frac{dN}{d\phi} = N_0(1 + 2v_2 \cos[2(\phi - \Psi_2)])$$

$$\chi^2(\boldsymbol{\theta}) = (\boldsymbol{y} - \boldsymbol{\mu}(\boldsymbol{\theta}))^T V^{-1} (\boldsymbol{y} - \boldsymbol{\mu}(\boldsymbol{\theta}))$$









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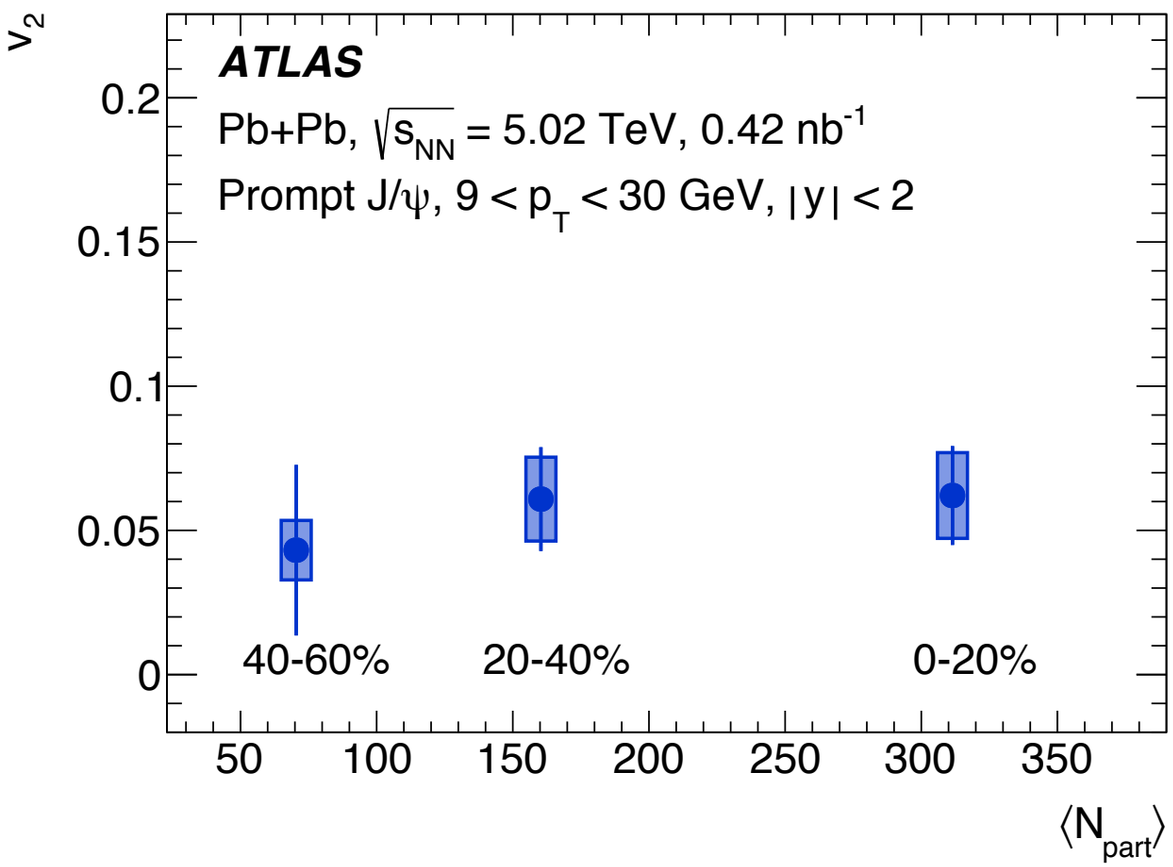
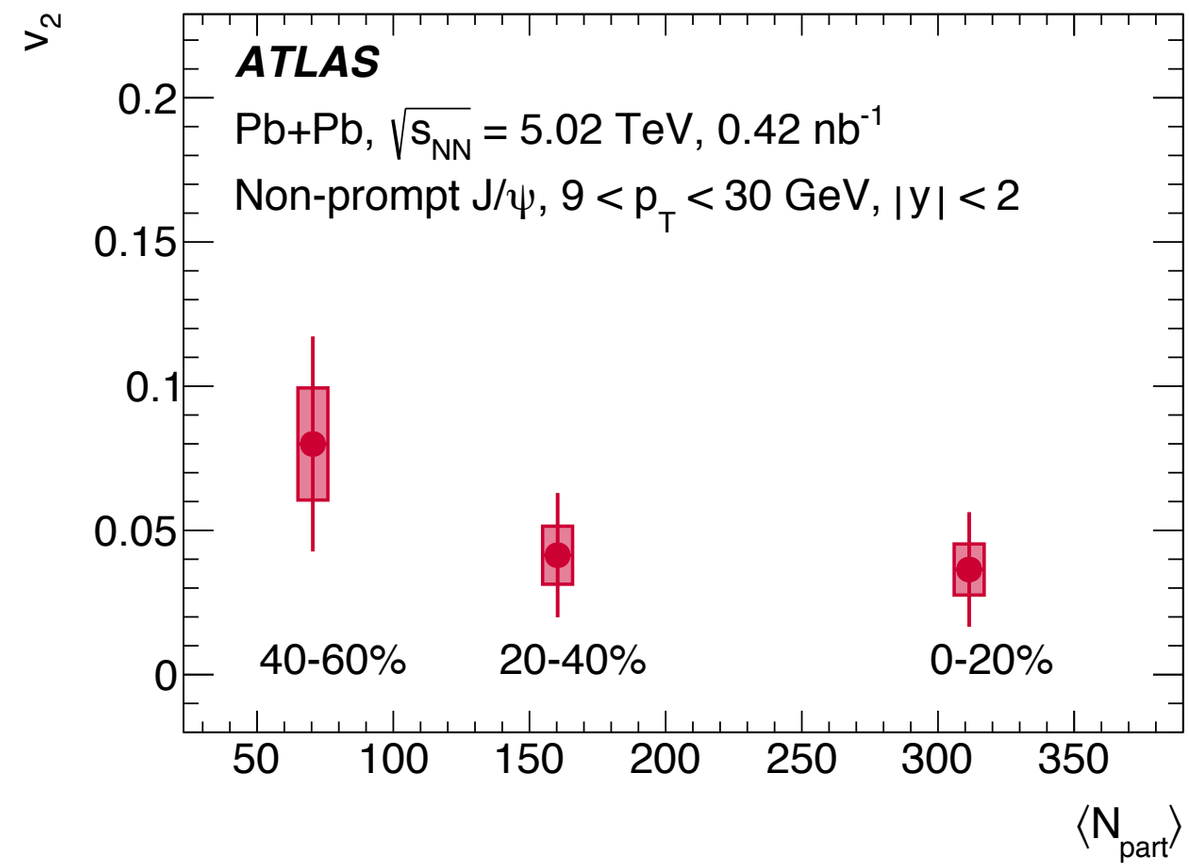
Prompt and Non-prompt J/ψ Elliptic Flow





No hints of centrality dependence

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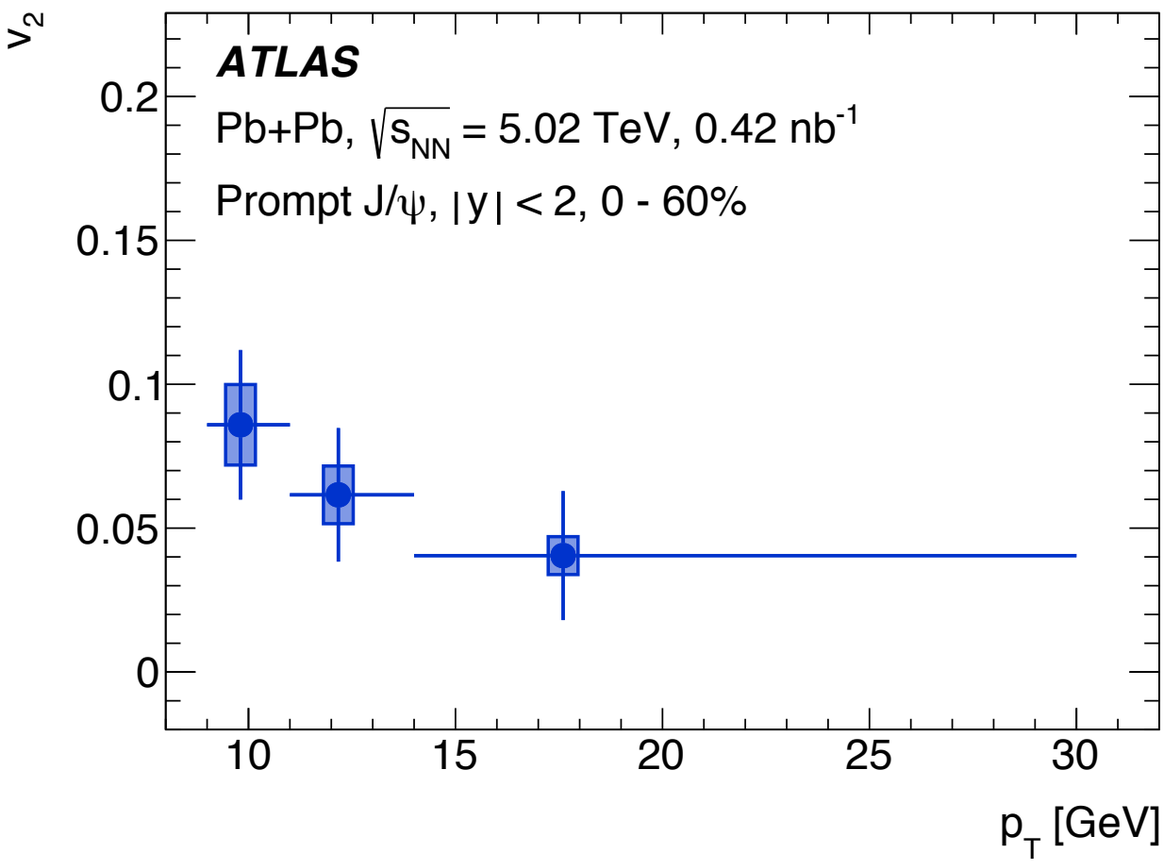
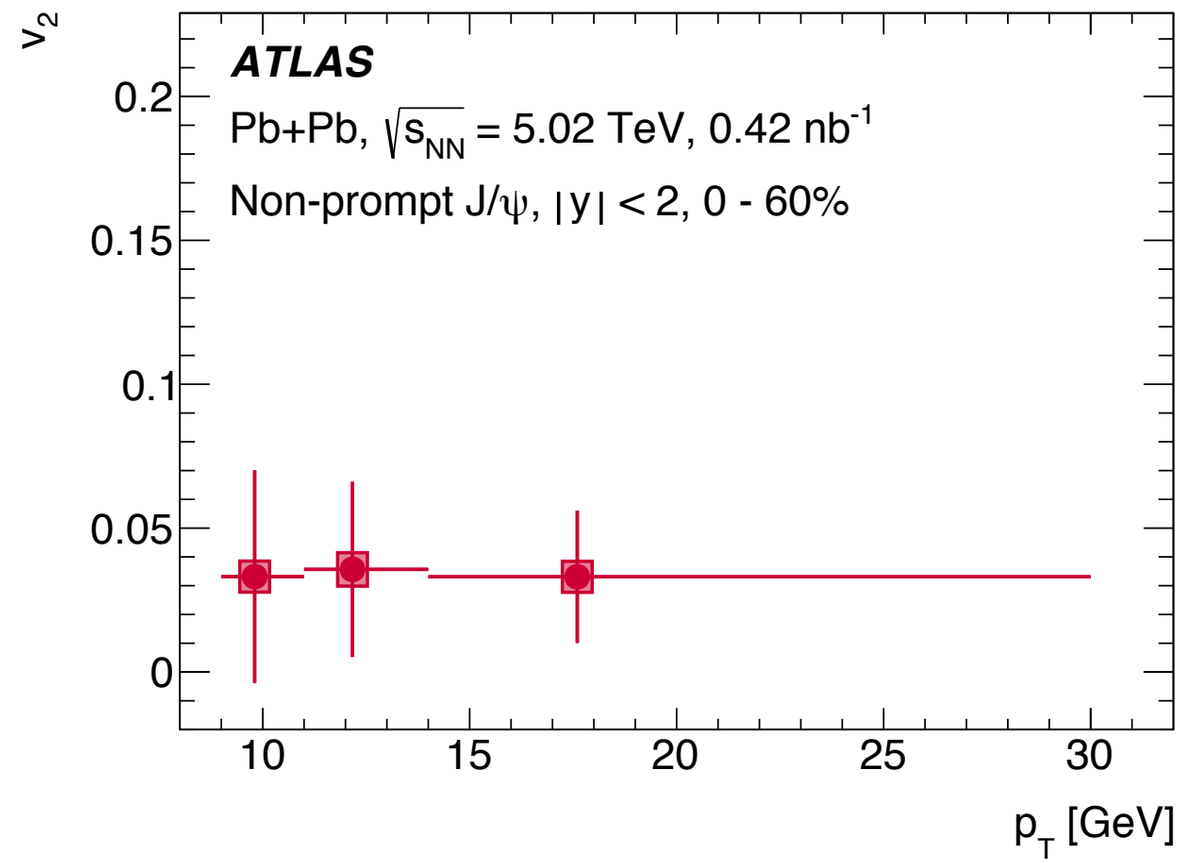
Prompt and Non-prompt J/ψ Elliptic Flow





Different $v_2(p_T)$ coefficient for prompt and non-prompt J/ψ

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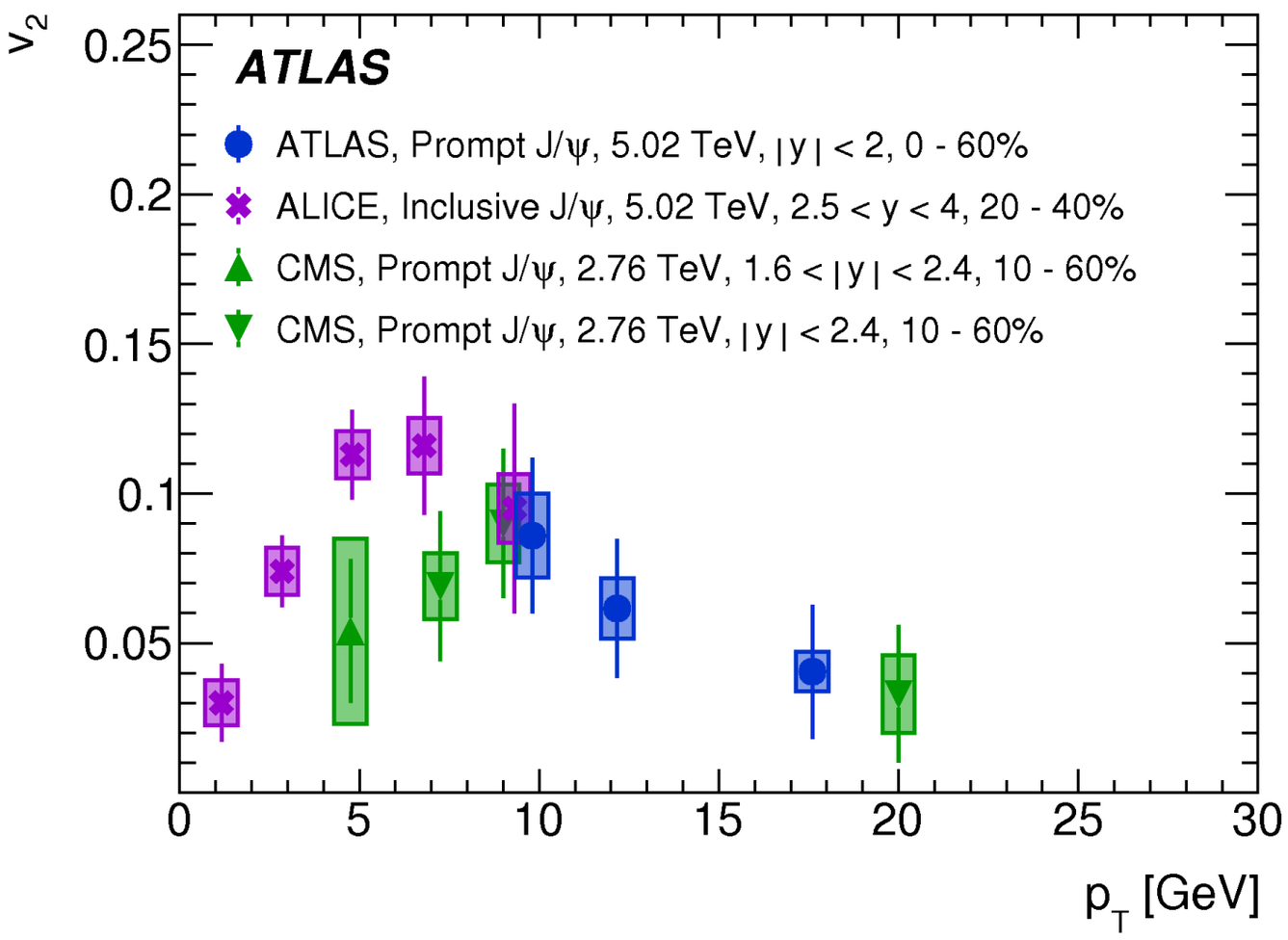
ATLAS EXPERIMENT

Prompt J/ψ Elliptic Flow



- Despite different rapidity selections and collision energy
- Good agreement at p_T~9 GeV between ATLAS, CMS and ALICE measurements
- Non-prompt fraction at low p_T is very small allowing to compare inclusive and prompt J/ψ production

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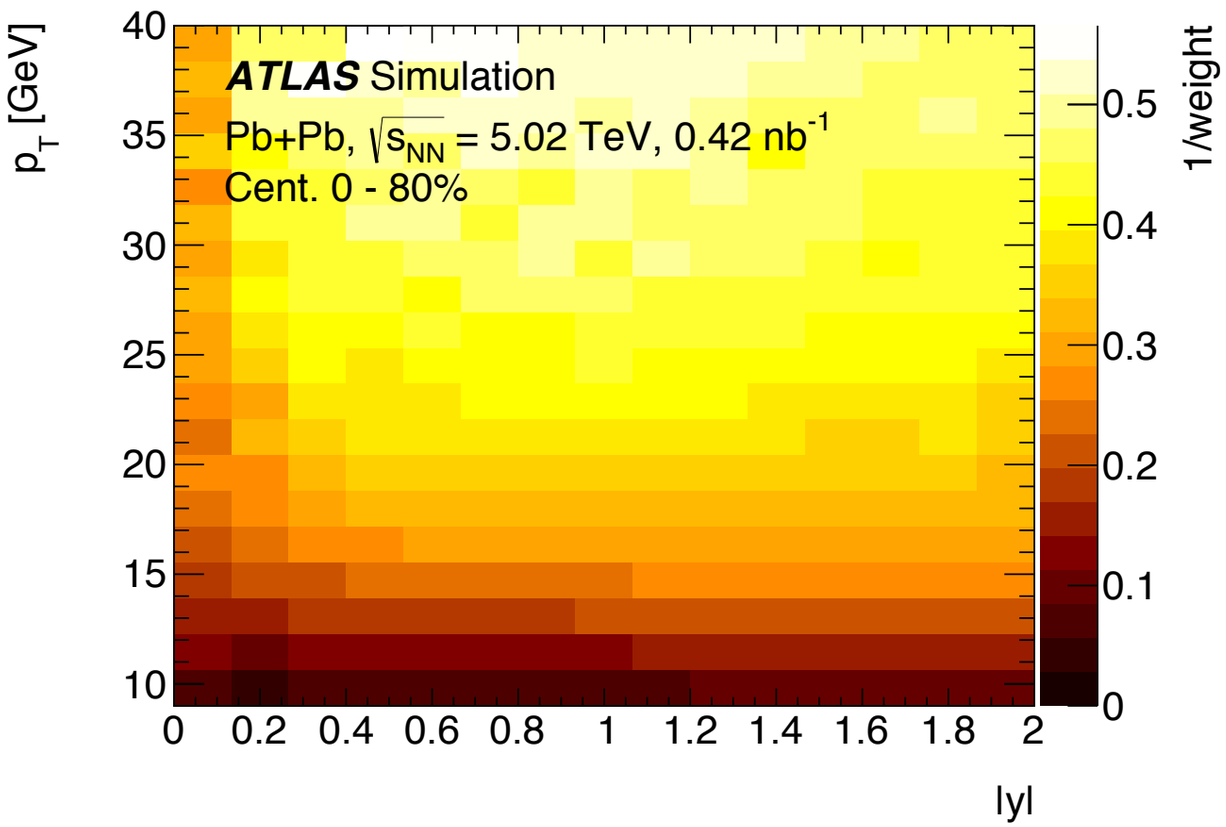
ATLAS EXPERIMENT

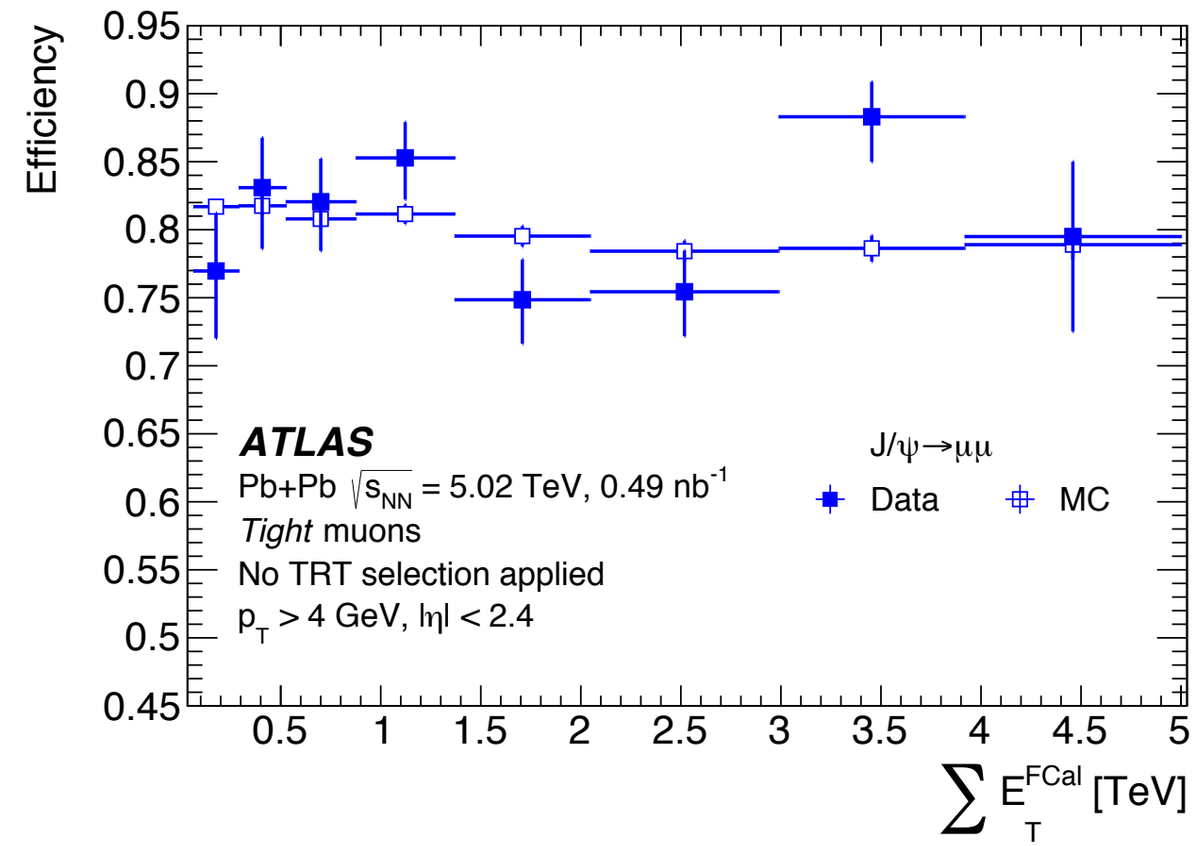
SUMMARY

- Results for proton–lead:
  - Weak cold nuclear matter effect in the studied kinematics
  - Clean window for the study of hot matter effects
- Results for lead–lead:
  - Suppression of charmonia production strongly dependent on centrality
  - Different transverse momentum dependence for prompt and non-prompt J/ψ
  - Elliptic flow of prompt J/ψ suggests regeneration of charm quarks at high p_T
  - Different flow scenario for charm and bottom quarks

Additional Slides

Per-dimuon corrections



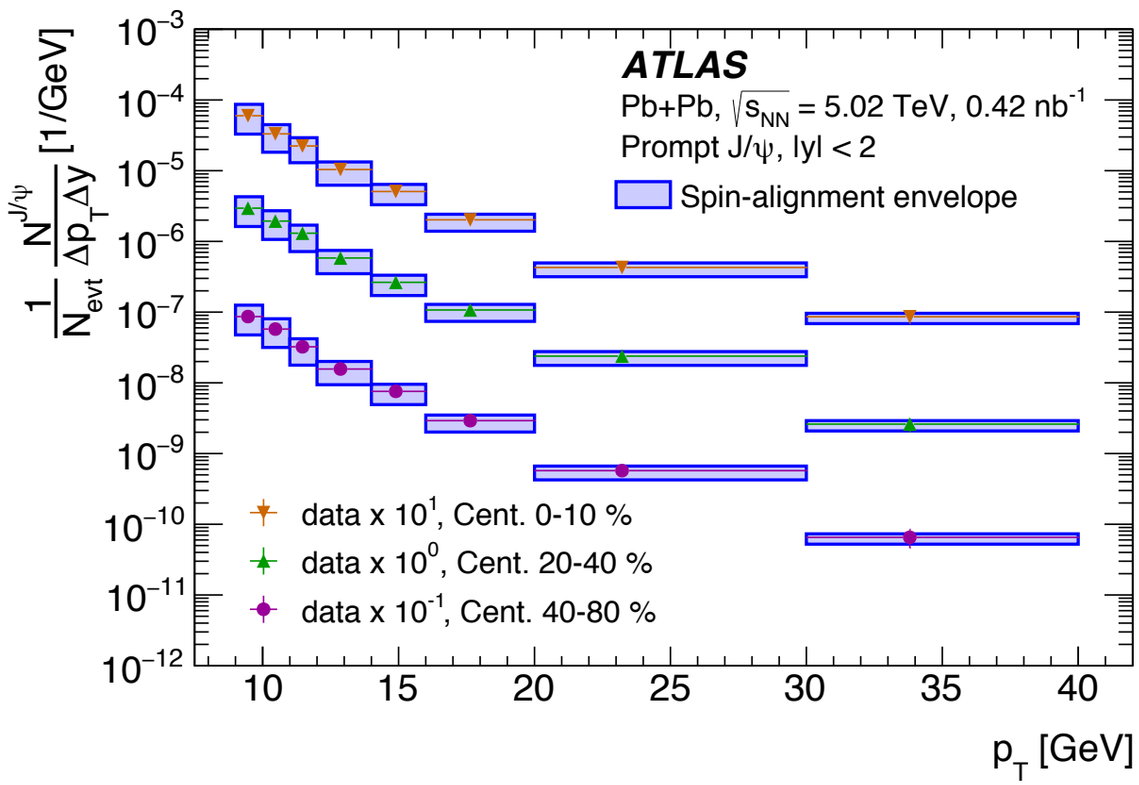


$$w^{-1} = \epsilon_{trig} * \epsilon_{reco} * Acc$$

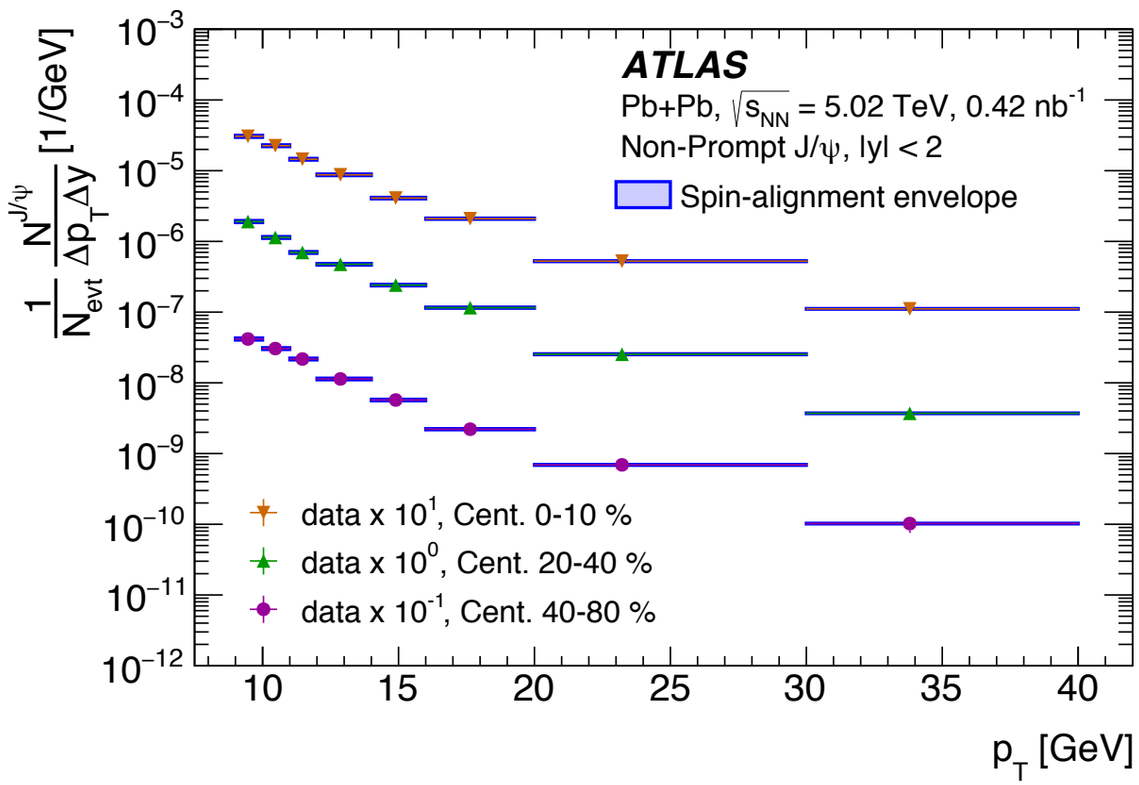
Centrality dependence of the muon reconstructions

arXiv:1805.04077

J/ψ Pb+Pb per-event yield



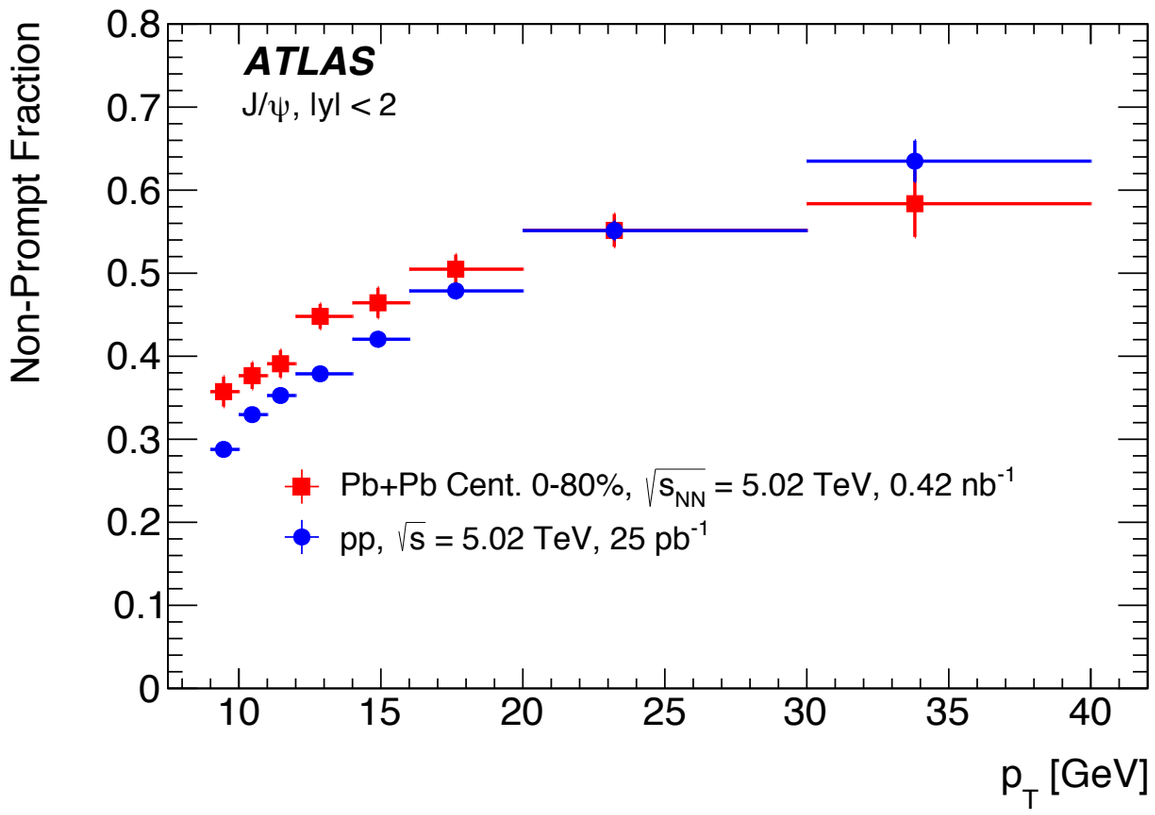
Prompt

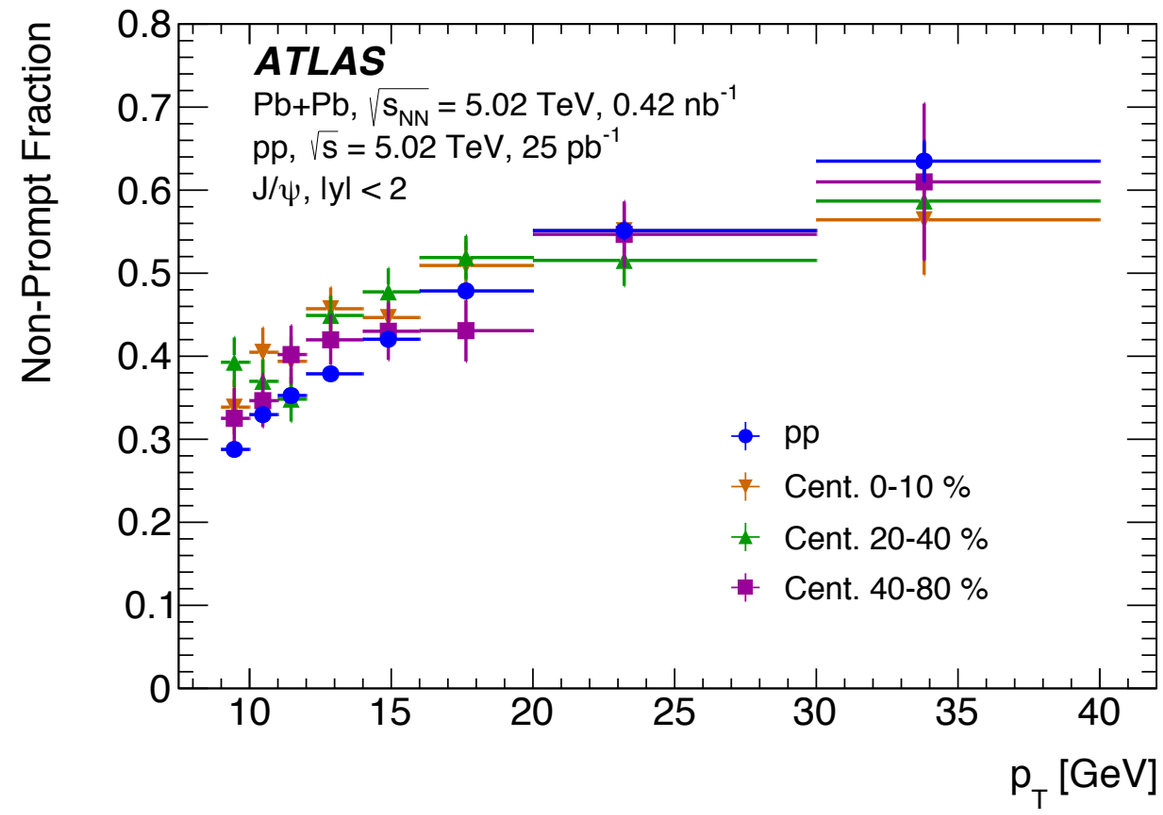


Non-prompt

arXiv:1805.04077

J/ψ Non-prompt fraction $f_{NP}(p_T)$





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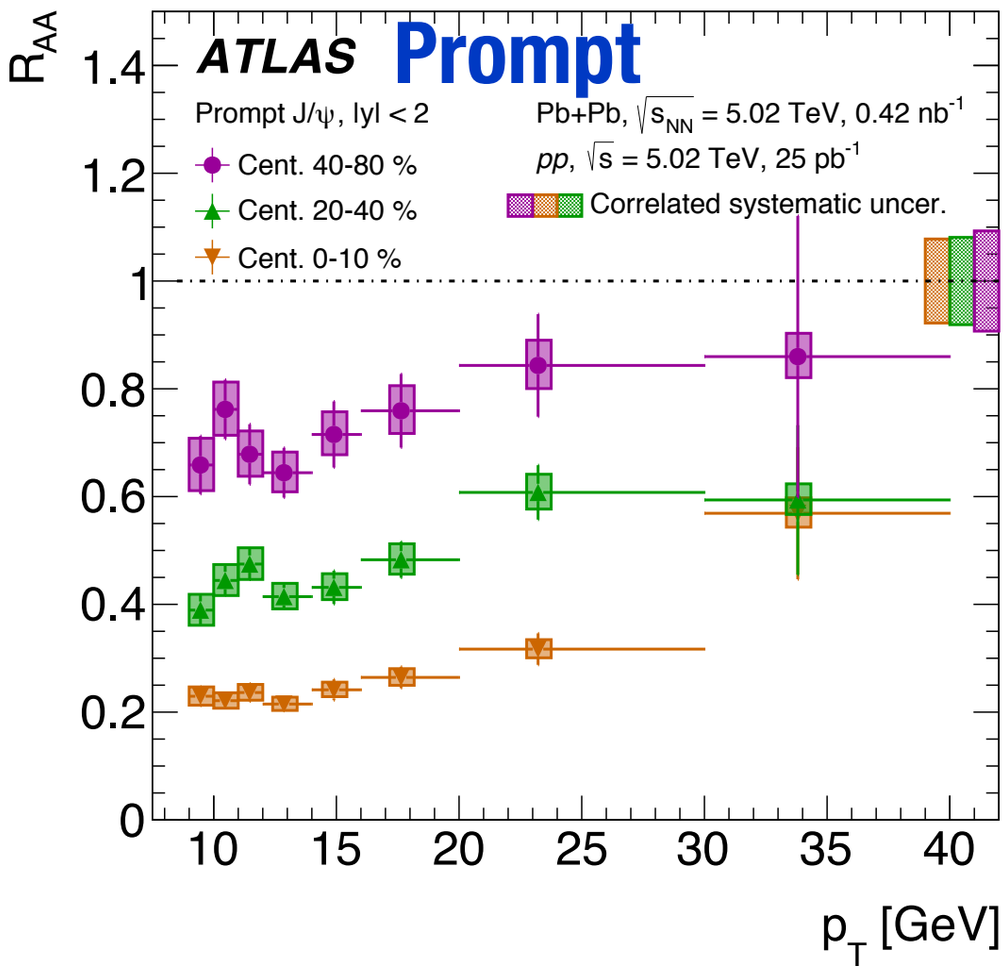
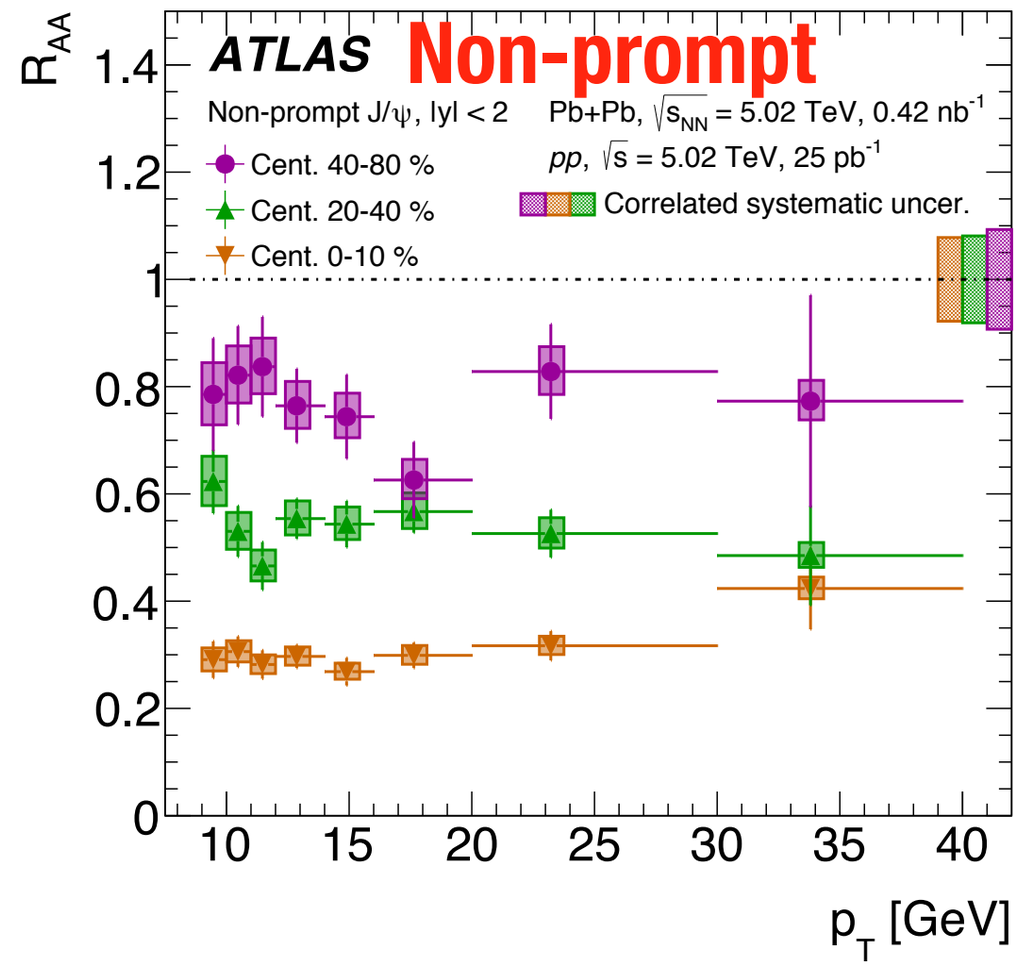
Nuclear Modification Factor – $R_{AA}(p_T)$





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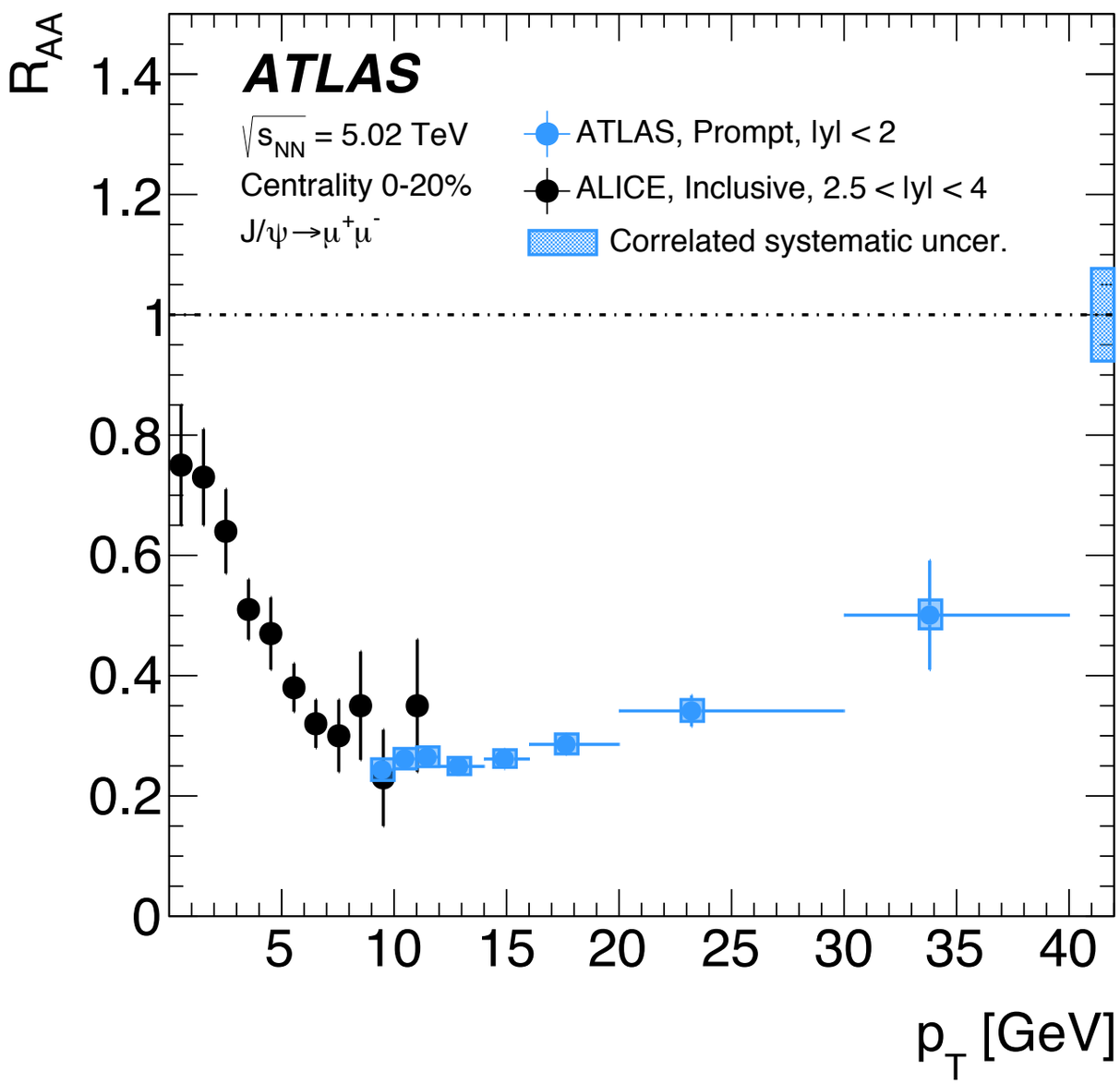

- Not same rapidity coverage over detectors
- Non-prompt fraction at low p_T is very small allowing to compare inclusive and prompt J/ψ production
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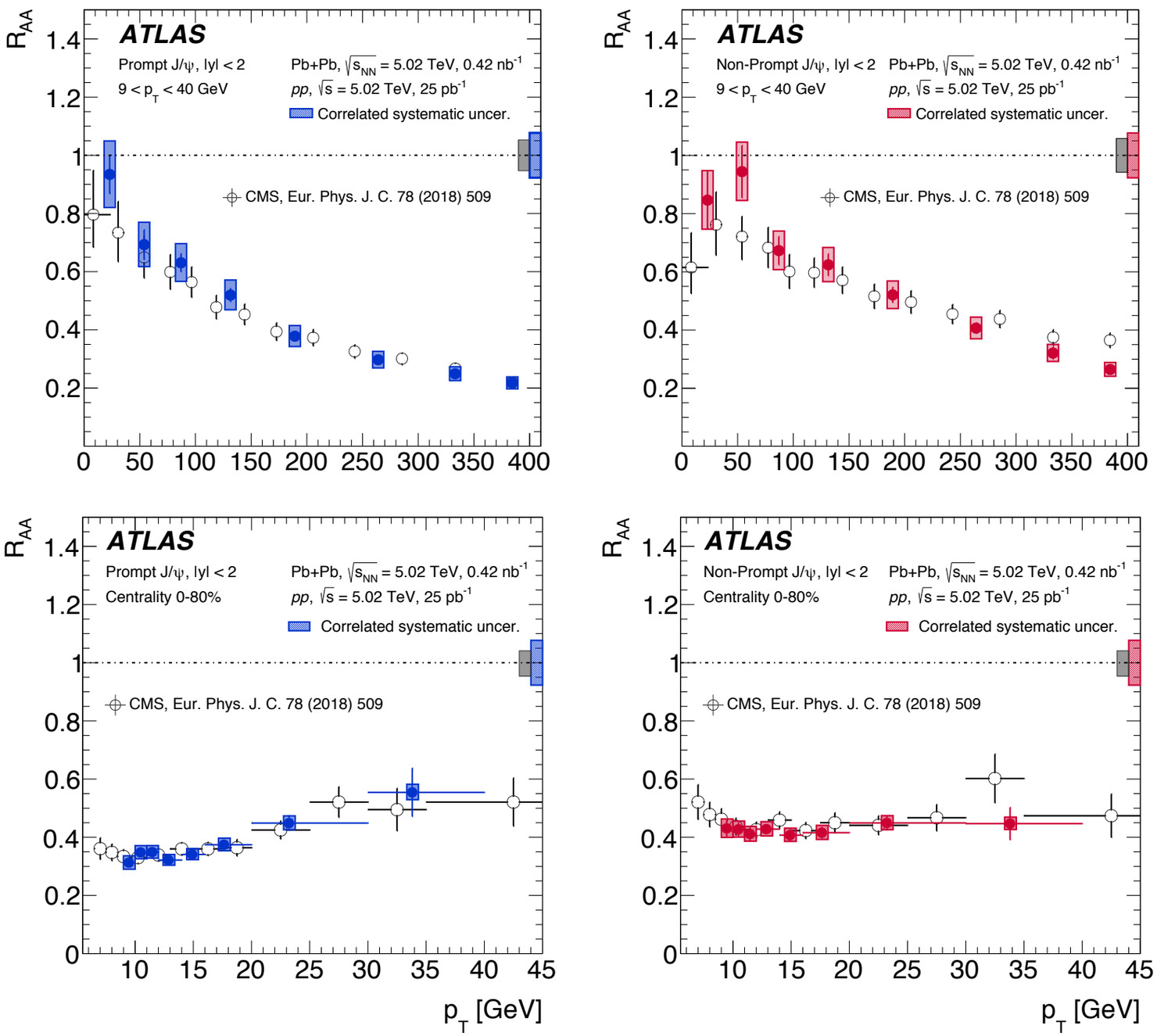
arXiv:1805.04077

Nuclear Modification Factor – $R_{AA}(p_T)$



- Same rapidity coverage over detectors
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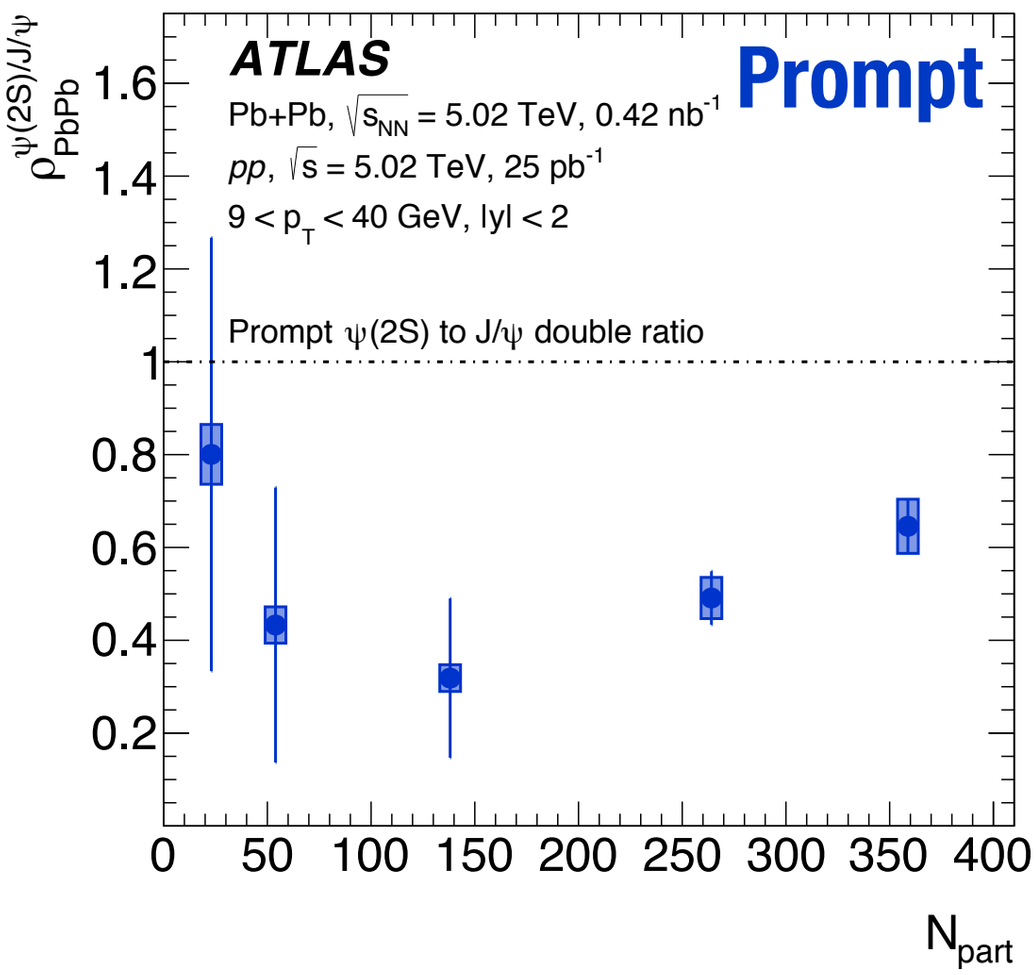
arXiv:1805.04077

Double Ratios $R_{AA}[\psi(2S)]/R_{AA}[J/\psi]$



Non-trivial behavior for **prompt** J/ψ:

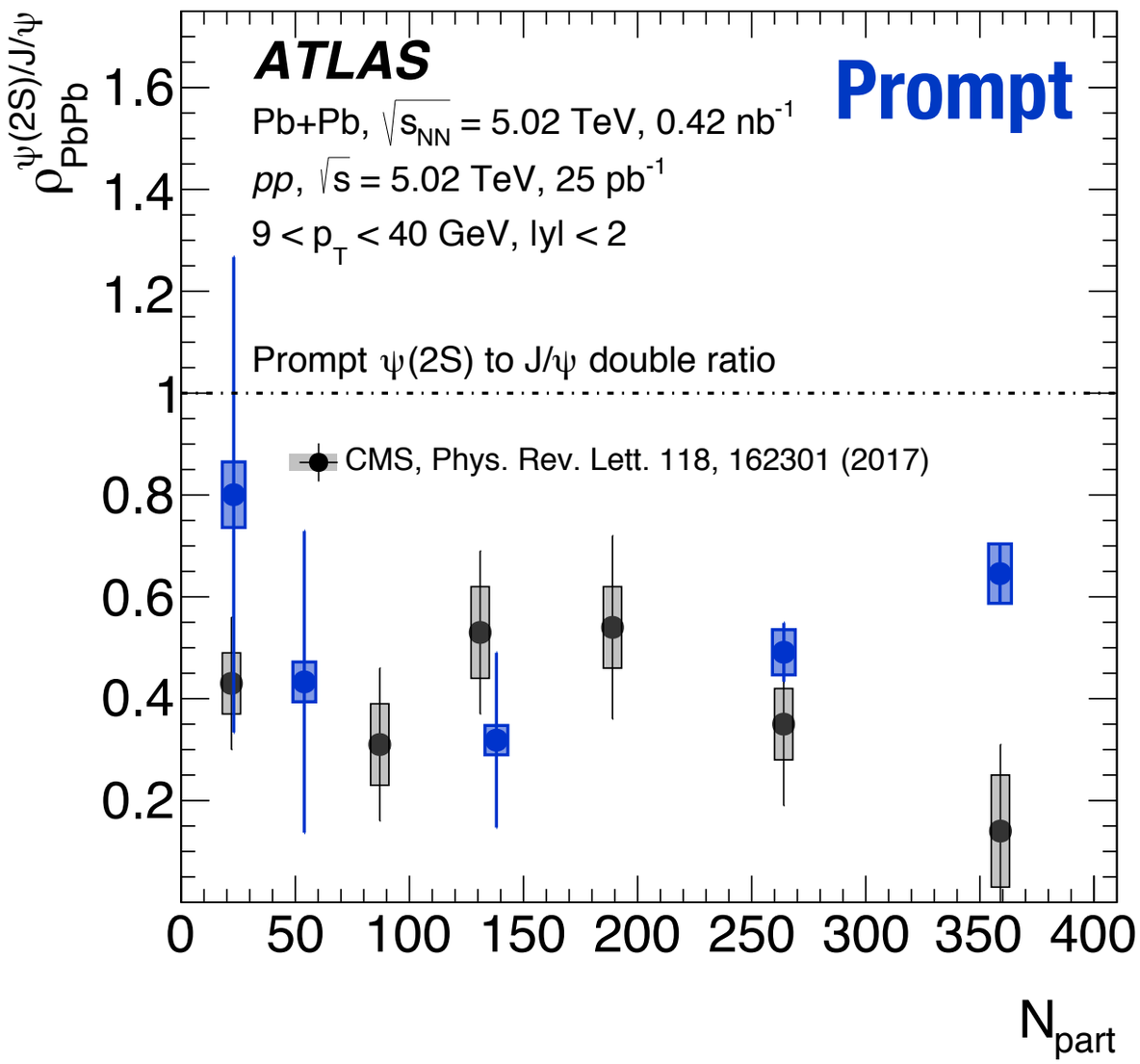
- Good test for the sensitivity of QGP effects and difference of binding energy.
- Sequential melting $R_{AA}[\psi(2S)] > R_{AA}[J/\psi]$.

$$\rho^{\psi(2S)/J\psi}_{PbPb} = R^{\psi(2S)}_{AA} / R^{J\psi}_{AA}$$

arXiv:1805.04077

ATLAS EXPERIMENT

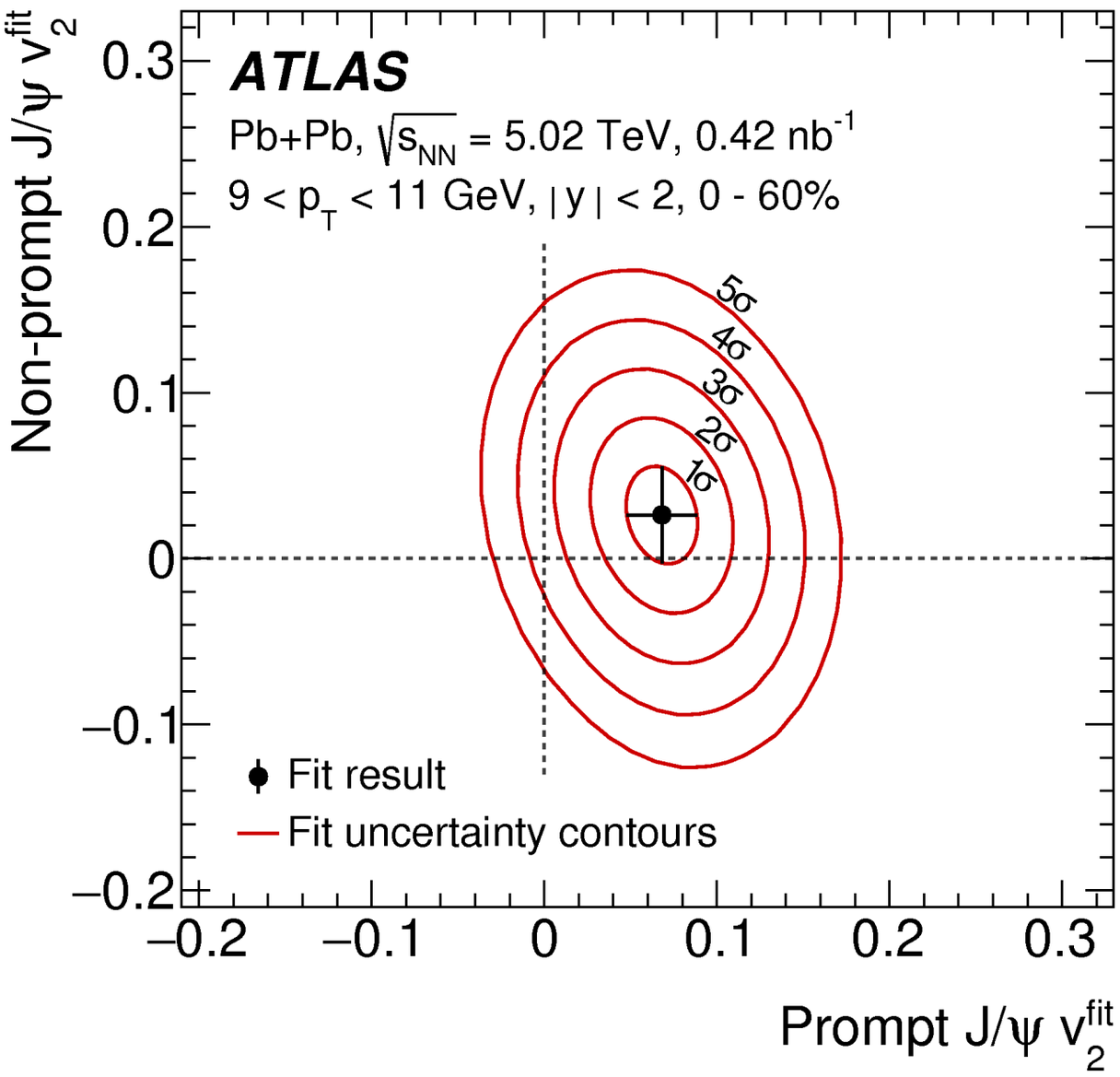
Double Ratios $R_{AA}[\psi(2S)]/R_{AA}[J/\psi]$



$$\rho_{\mathrm{PbPb}}^{\psi(2\mathrm{S})/J/\psi} = R_{\mathrm{AA}}^{\psi(2\mathrm{S})}/R_{\mathrm{AA}}^{J/\psi}$$

arXiv:1805.04077

Prompt and Non-prompt J/ψ Elliptic Flow



- Correlation originated by signal extraction method

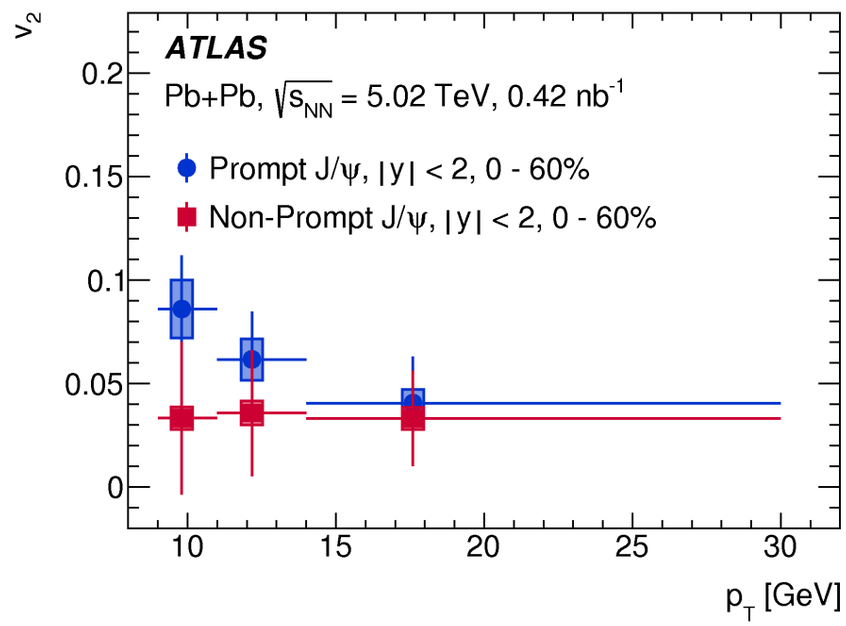
$N_{Prompt} = N_{Total}*(1-f_{NP})$

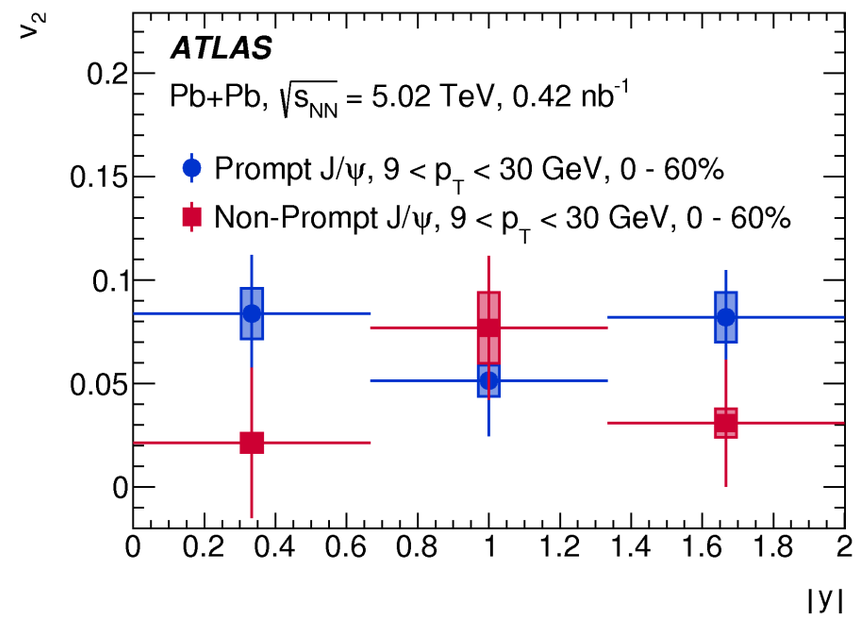
$N_{Non\text{-}Prompt} = N_{Total}*f_{NP}$

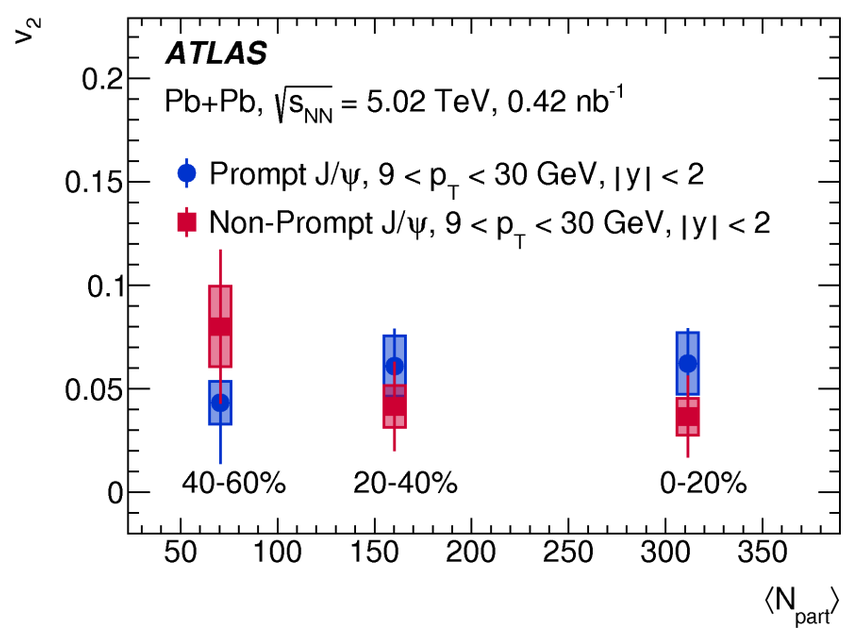
arXiv:1807.05198

ATLAS EXPERIMENT

Prompt and Non-prompt J/ψ Elliptic Flow





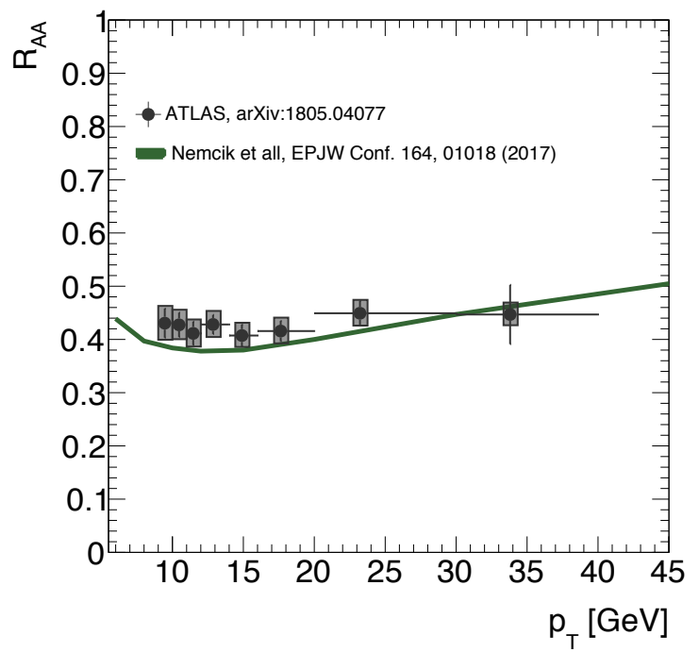


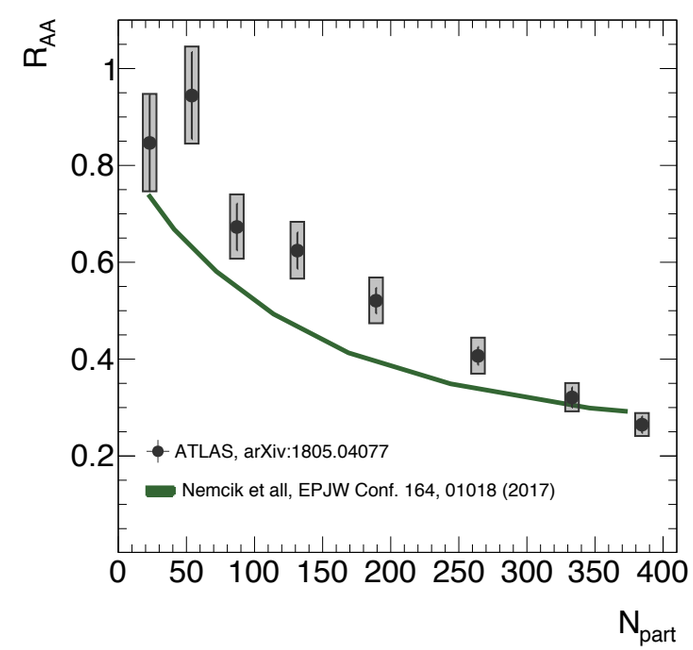
arXiv:1807.05198

ATLAS EXPERIMENT

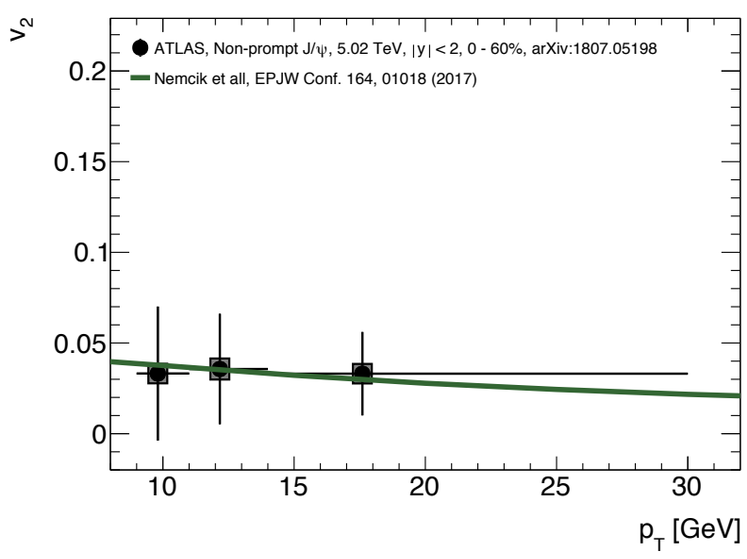
Non-prompt J/ψ Elliptic Flow and suppression simultaneous description

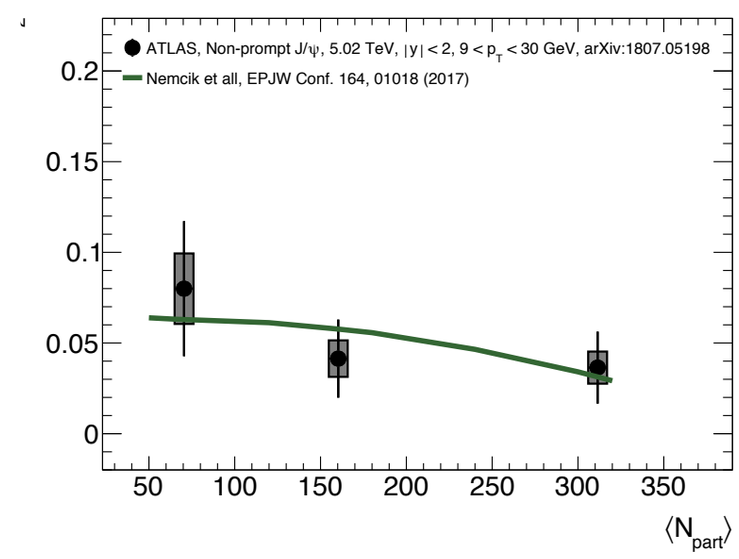
R_{AA}





v_2

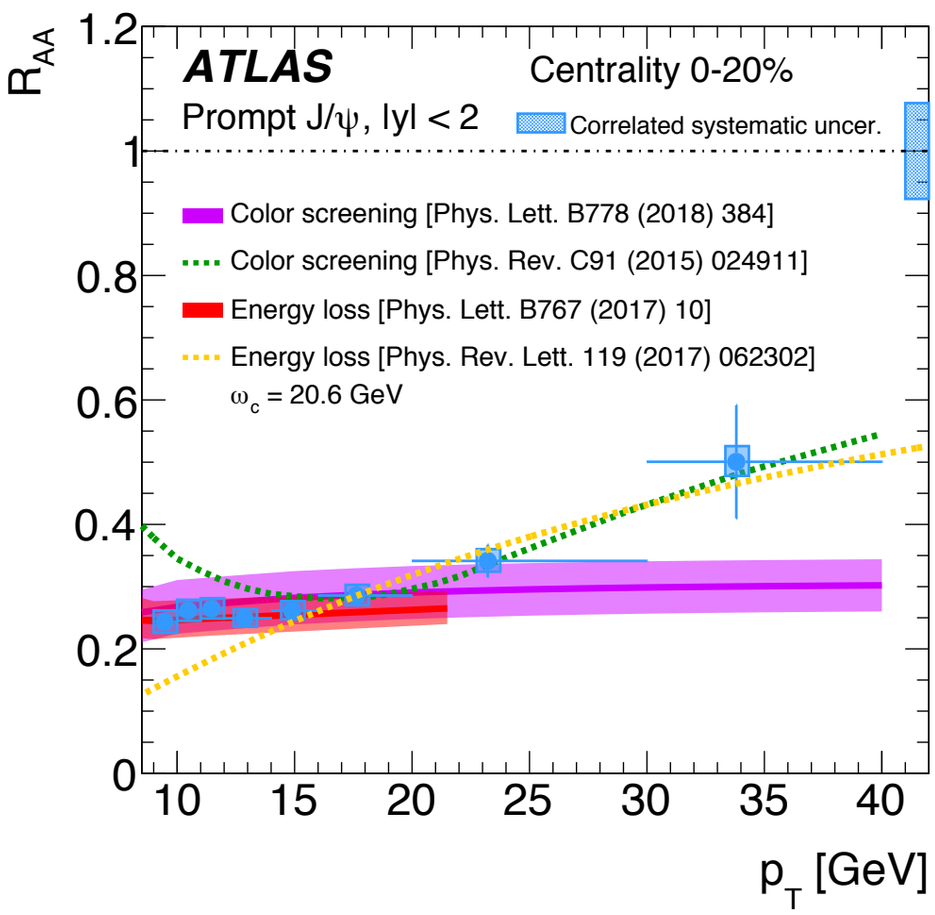
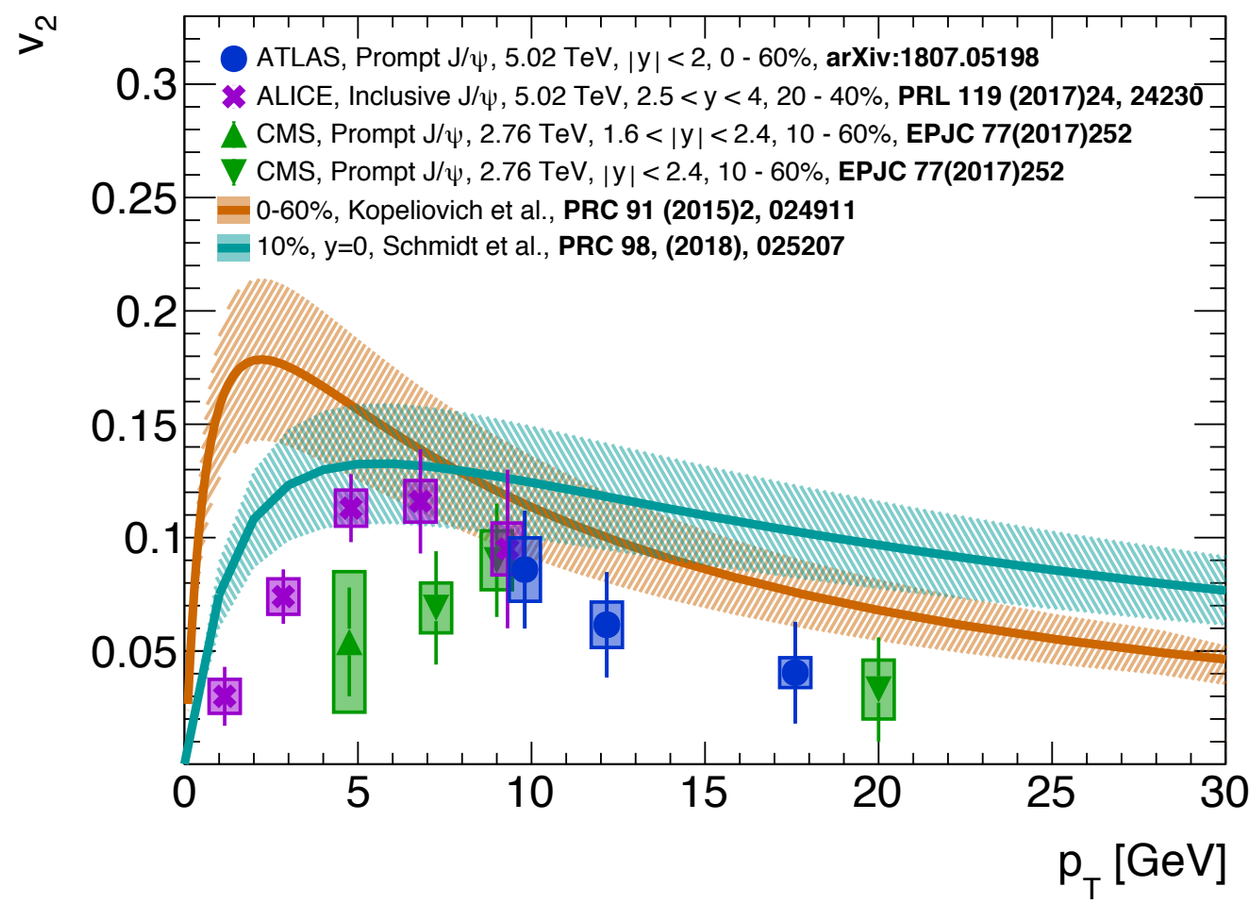




ATLAS EXPERIMENT

Prompt J/ψ Elliptic Flow and suppression simultaneous description

R_{AA}



v_2