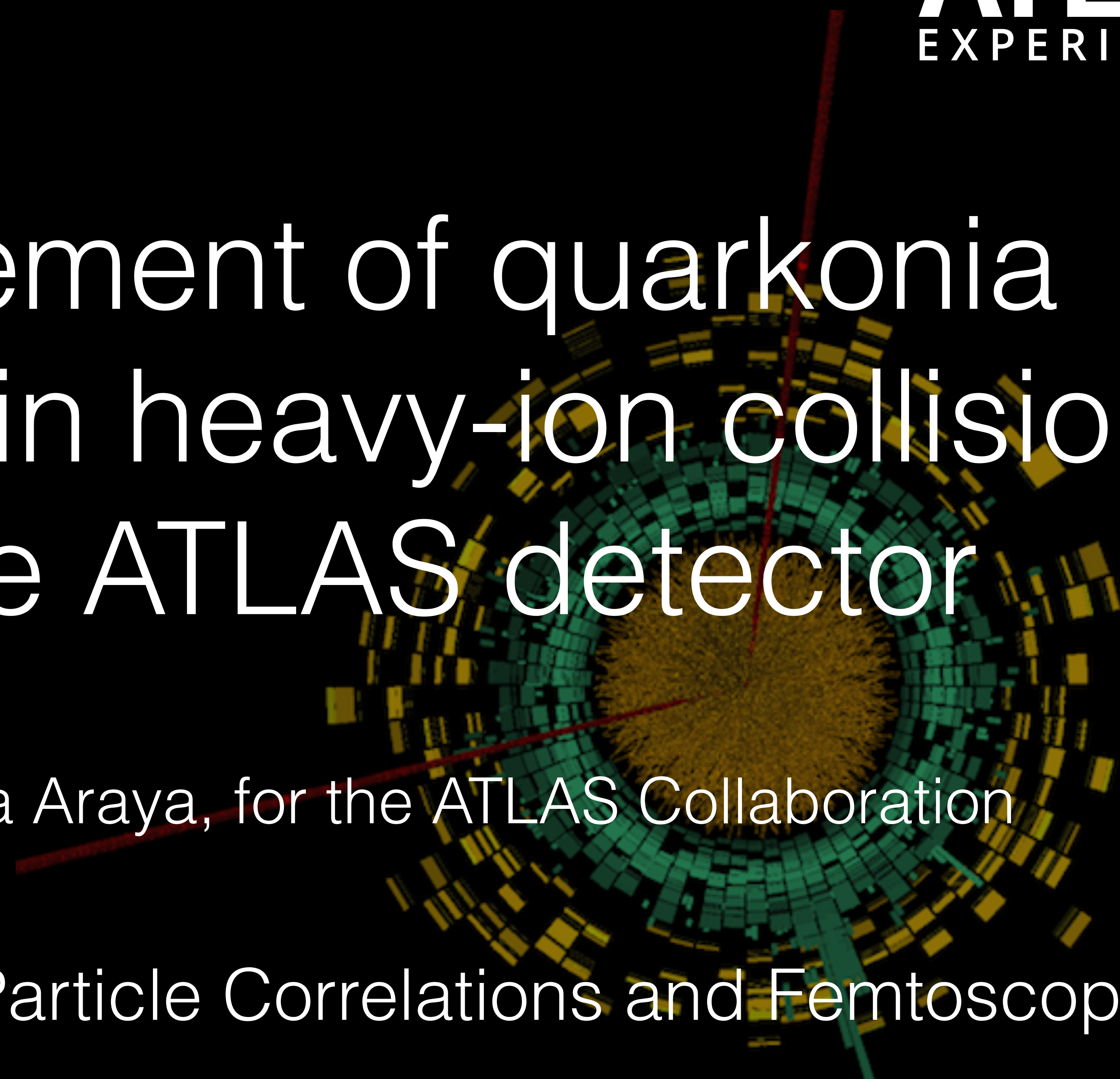
UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

ATLAS EXPERIMENT

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

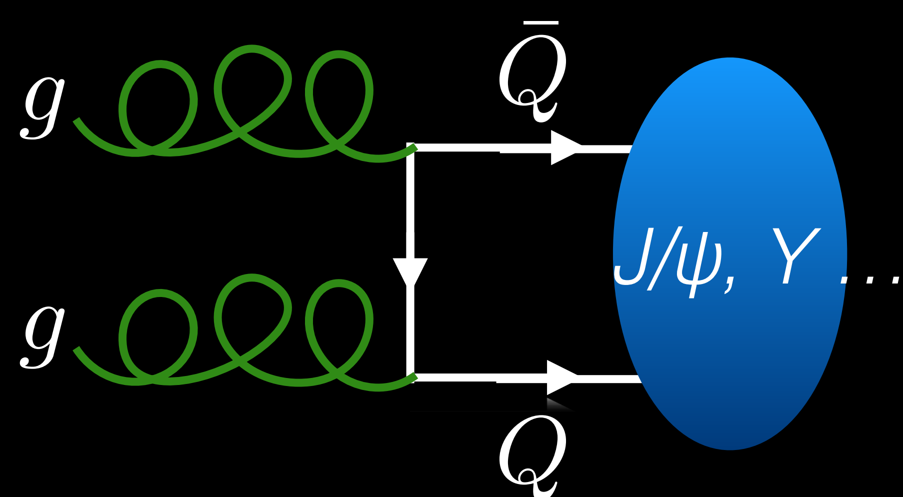


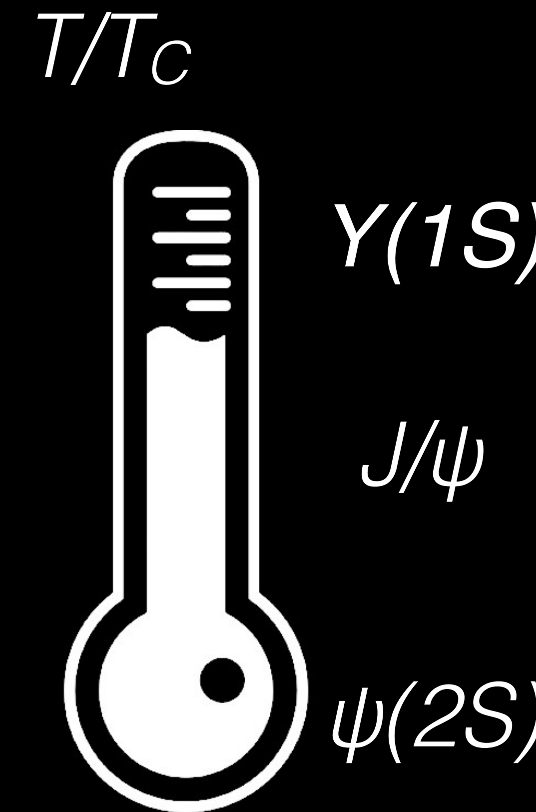
Sebastian Tapia Araya, for the ATLAS Collaboration

XII Workshop on Particle Correlations and Femtoscopy

Why Quarkonia?

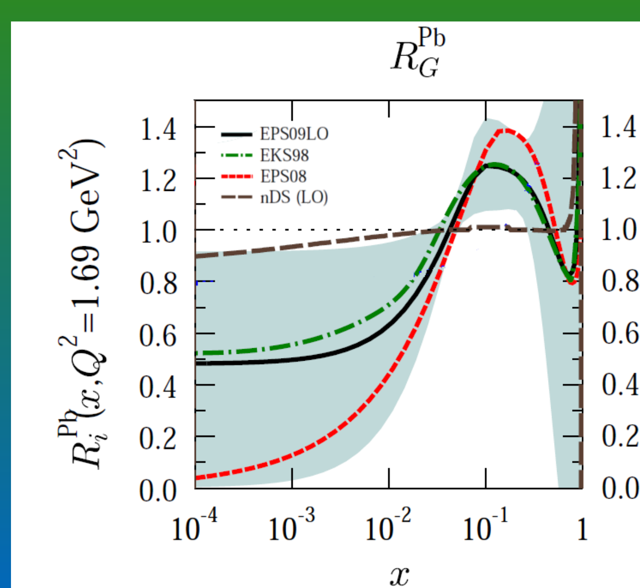
Quarkonia
- Bound states of quark and anti-quark
- Interact strongly with the environment
- Sensitive to hot and cold matter effects





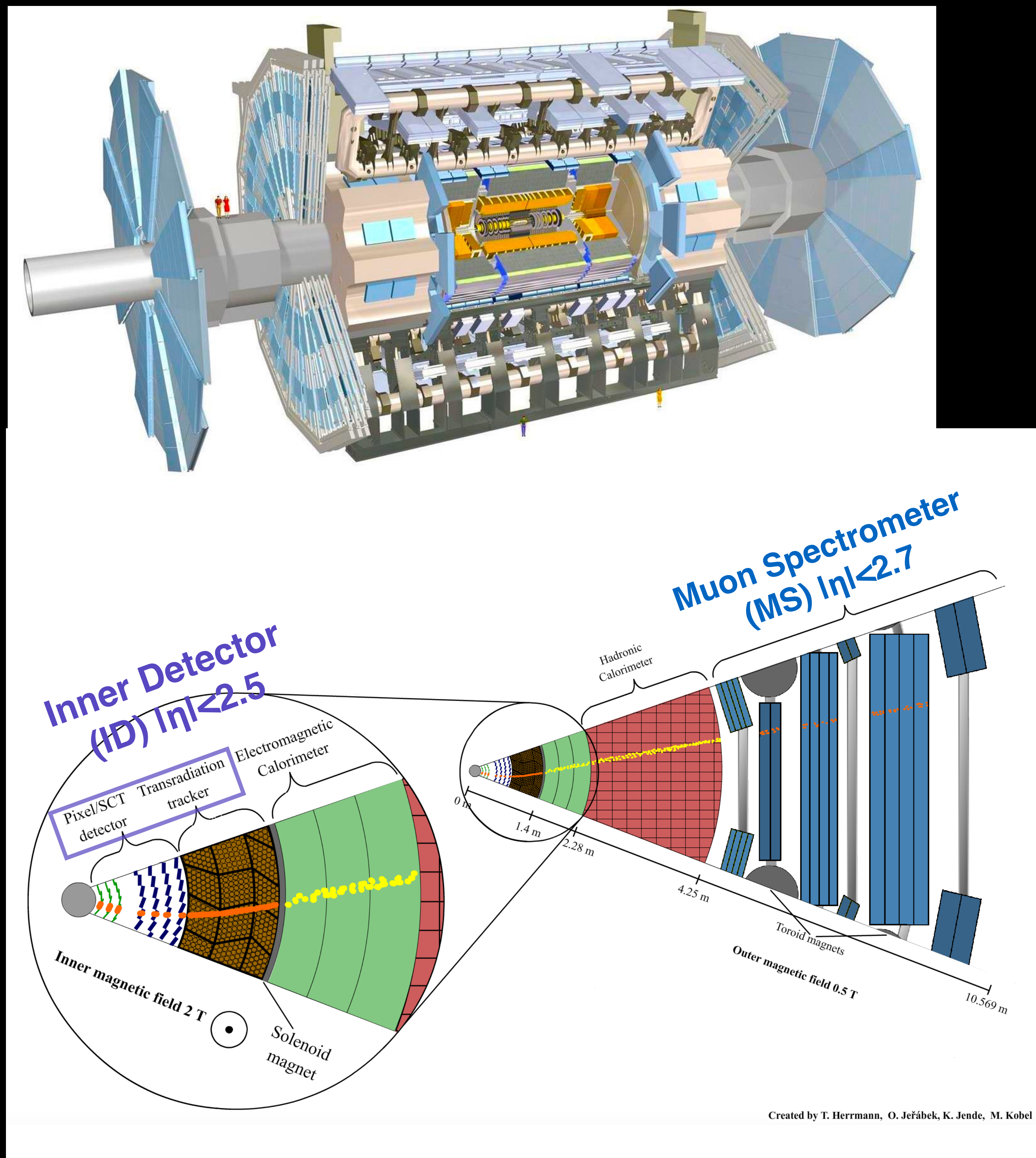
"Quarkonia as QGP thermometer",
T. Matsui and H. Satz PLB 178 (1986) 416

CNM effects
- Nuclear PDFs
- Gluon Saturation
- Parton Energy loss
- Nuclear Absorption
- Comover Breakup



QGP effects
- Debye screening
  - ☆ Sequential melting
- Regeneration
- Energy loss?

ATLAS detector



<u>Muon Trigger System</u>

Barrel, $|\eta| < 1.05$, RPC
Endcaps, $1.05<|\eta|<2.4$, TGC

<u>Muon Tracking System</u>

Barrel, $|\eta| < 2.0$, MDT
Endcaps, $2.0<|\eta|<2.7$, CSC

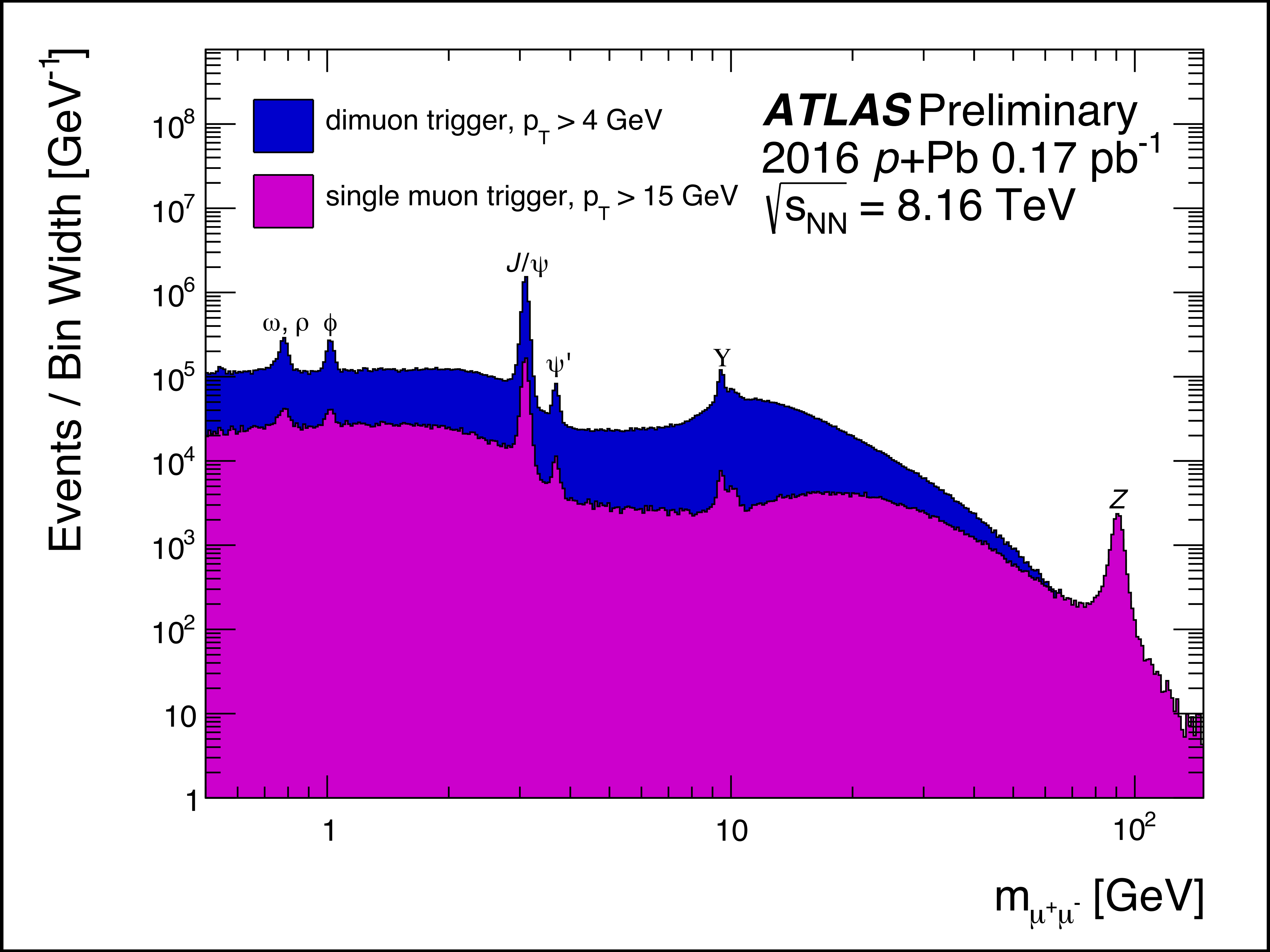
“Muons are reconstructed combining data from the MS and the ID”

<u>Forward Calorimeter, FCal</u>

$3.1<|\eta|<4.9$

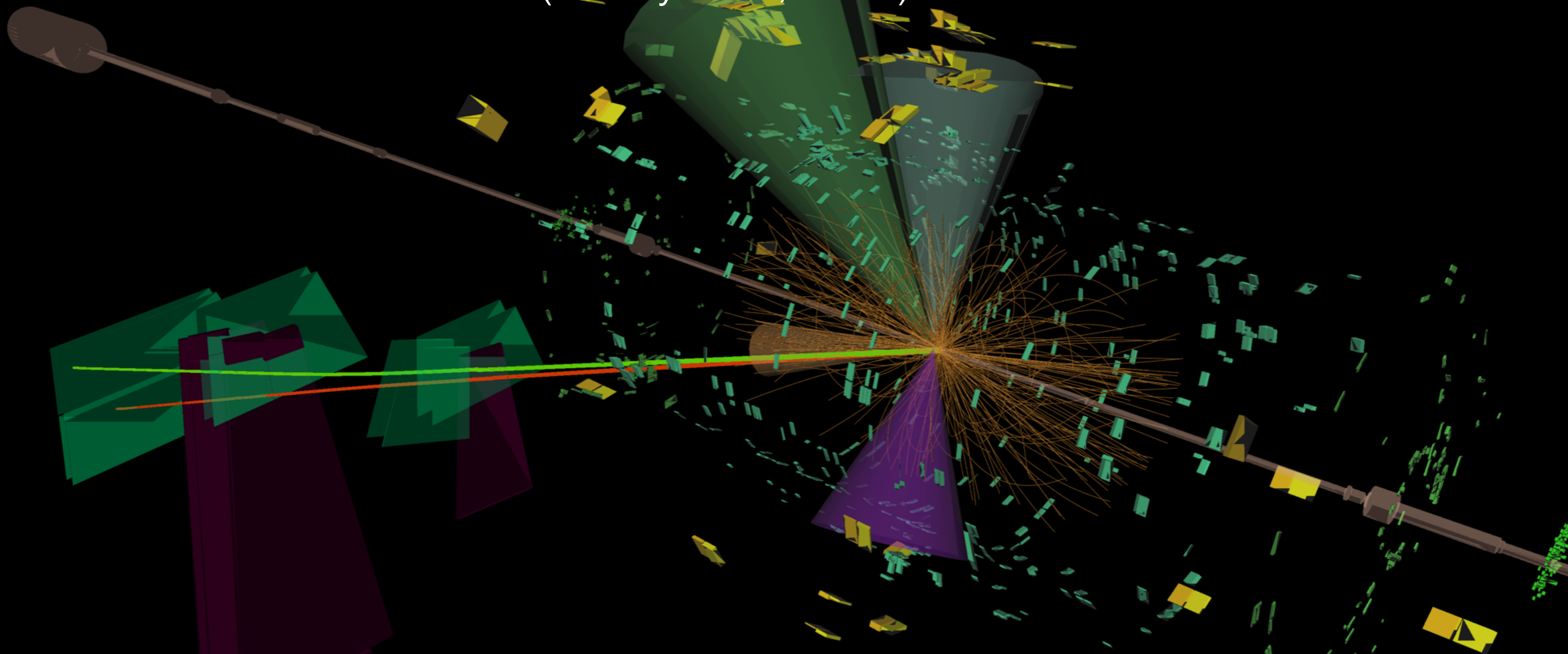
“Centrality of collision is characterized with the sum of transverse energy in both Fcal modules”

Di-muon invariant mass spectrum



J/ψ and ψ(2S) measurements

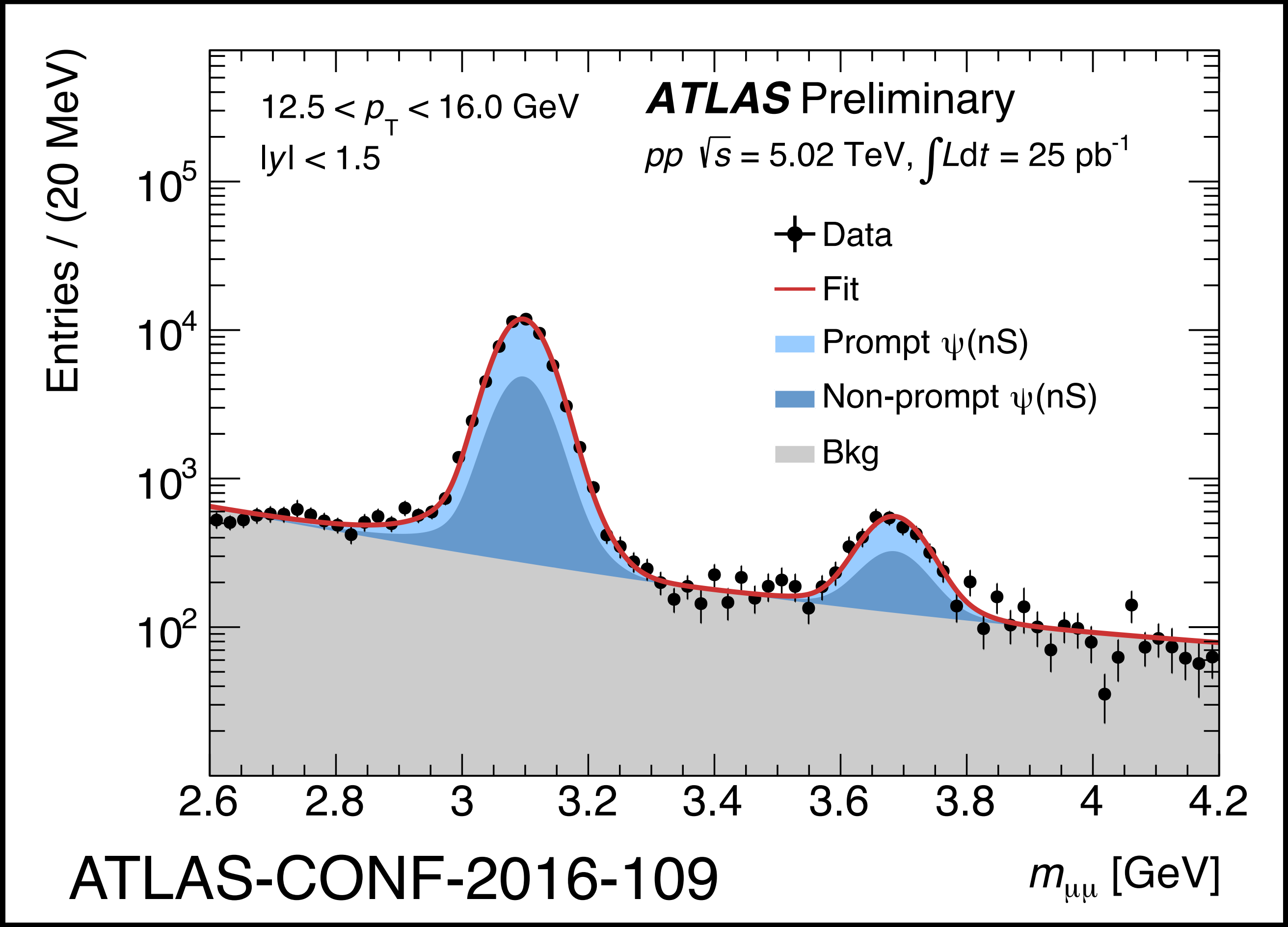
- Di-muon channel, $2.6 < m_{\mu\mu} < 4.2$ GeV
- Di-muon trigger
- Kinematic Range: $8(9) < p_T < 40$ GeV
- Yield extracted with a 2D (decay time,mass) likelihood fit.



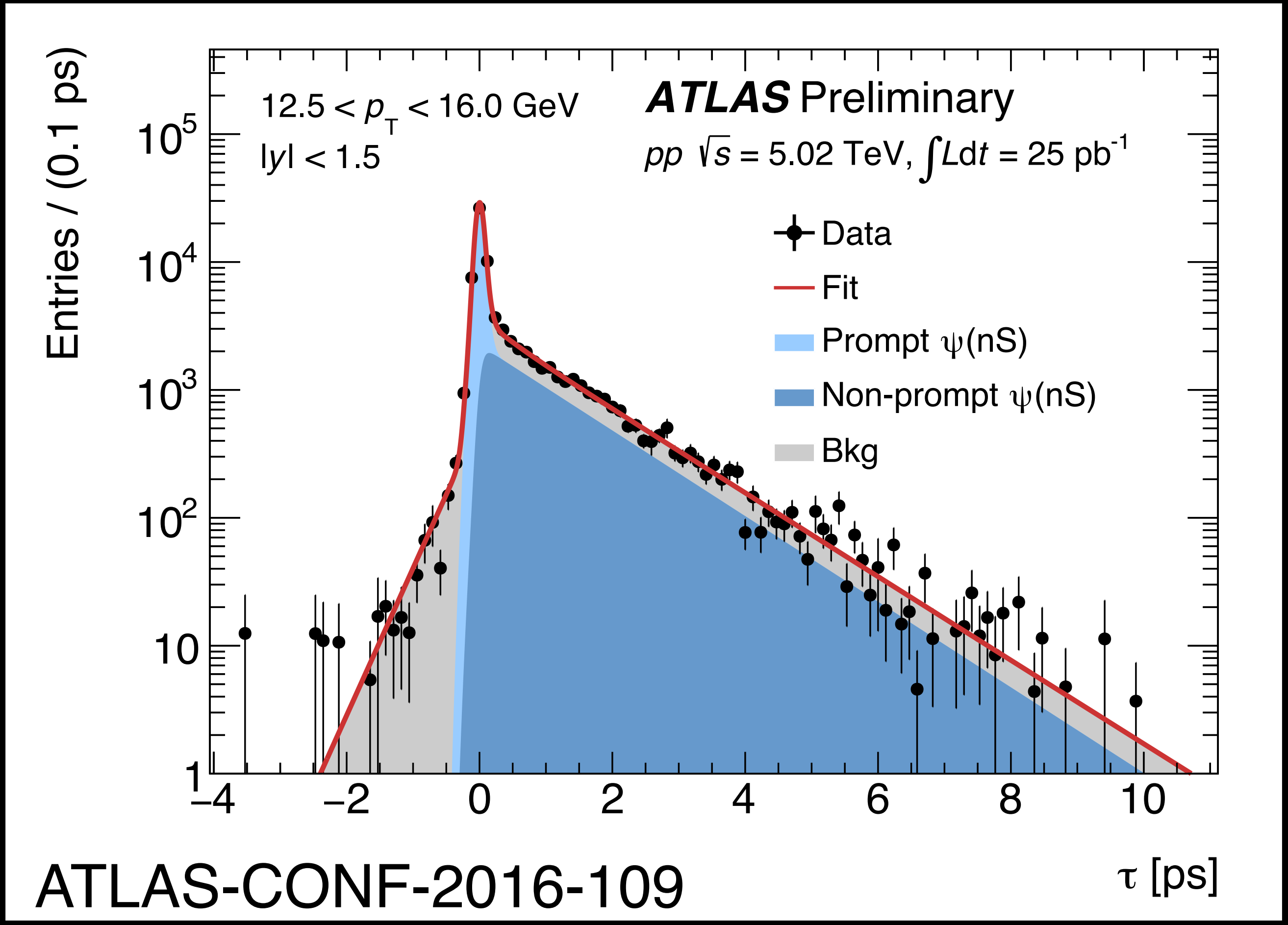
- Phys. Rev. C 92, 034904 (2015), 2013 p+Pb @ 5.02 TeV
- ATLAS-CONF-2015-023, 2013 p+Pb @ 5.02 TeV and p+p @ 2.76 TeV
- ATLAS-CONF-2016-109, 2015 Pb+Pb @ 5.02 TeV and p+p @ 5.02 TeV

Simultaneous Fit Method

Fit projections



Prompt:
produced in the direct collision
Non-prompt:
Decays from B-hadron



Pseudo-proper decay time

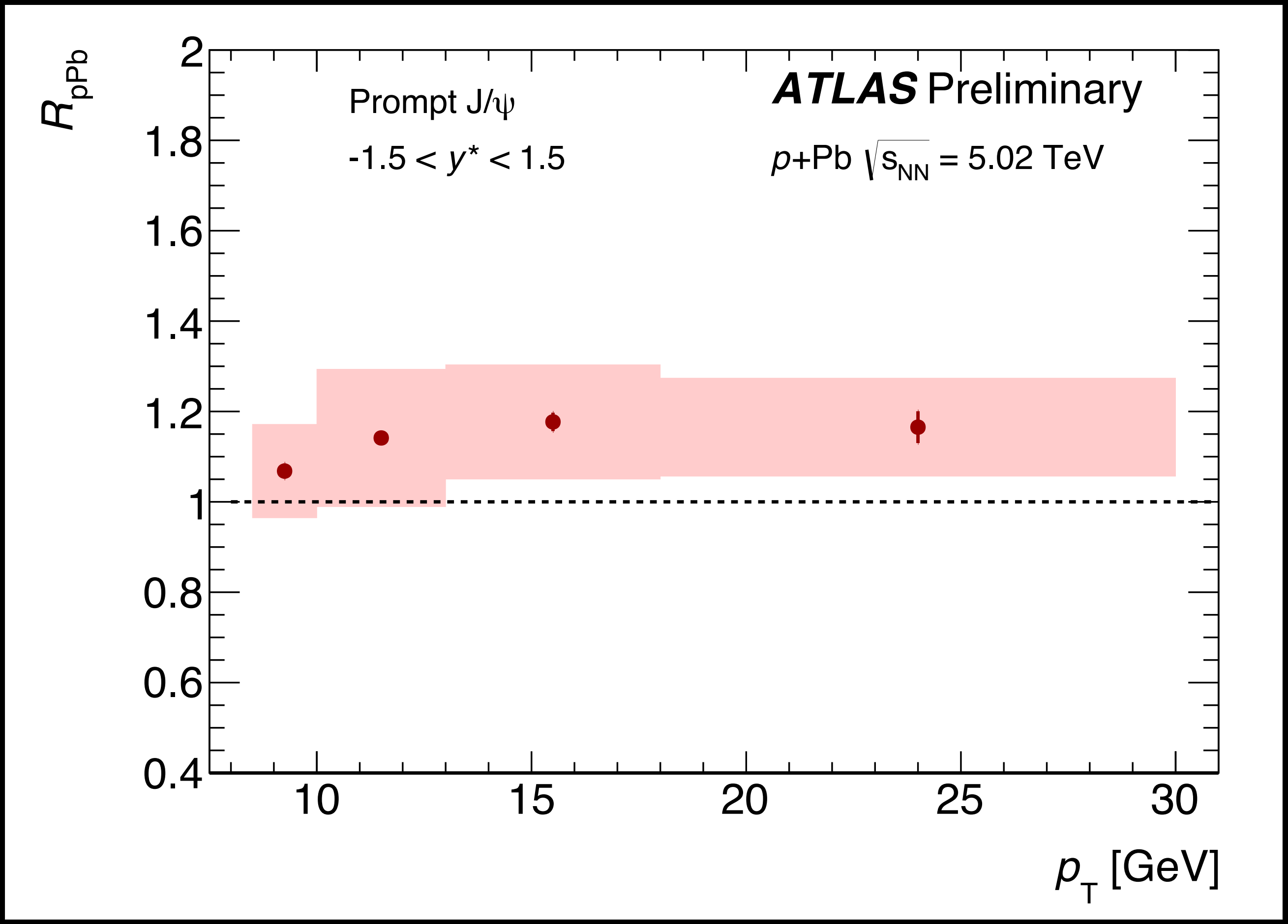
$$\tau = \frac{L_{xy} m_{\mu\mu}}{p_T^{\mu\mu}}$$

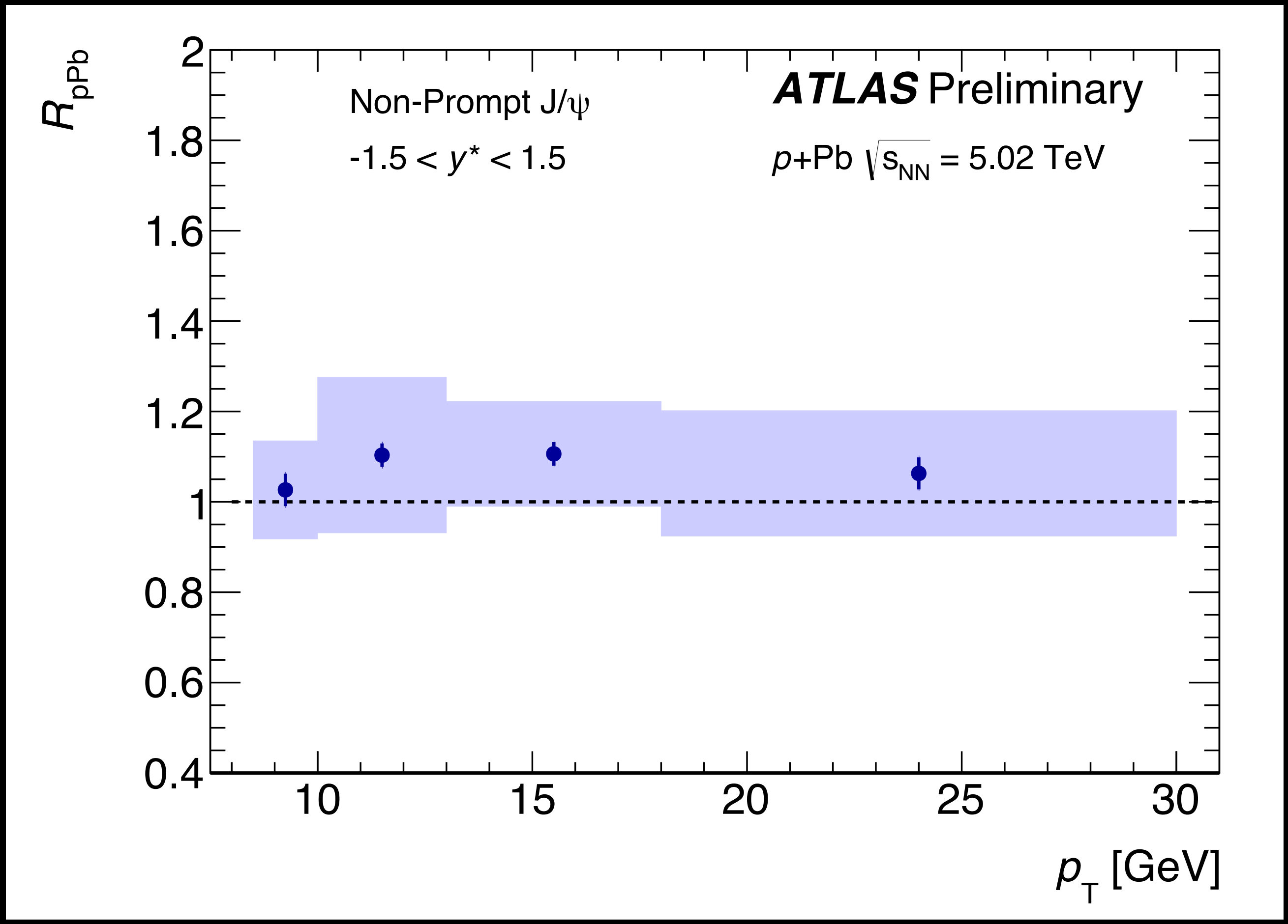
L_{XY} = projection of decay length on the transverse plane

ATLAS-CONF-2016-109

R_{pPb} vs. p_T

$$R_{\mathrm{pPb}} = \frac{N_{\mathrm{pPb}}}{A * \sigma_{pp}}$$





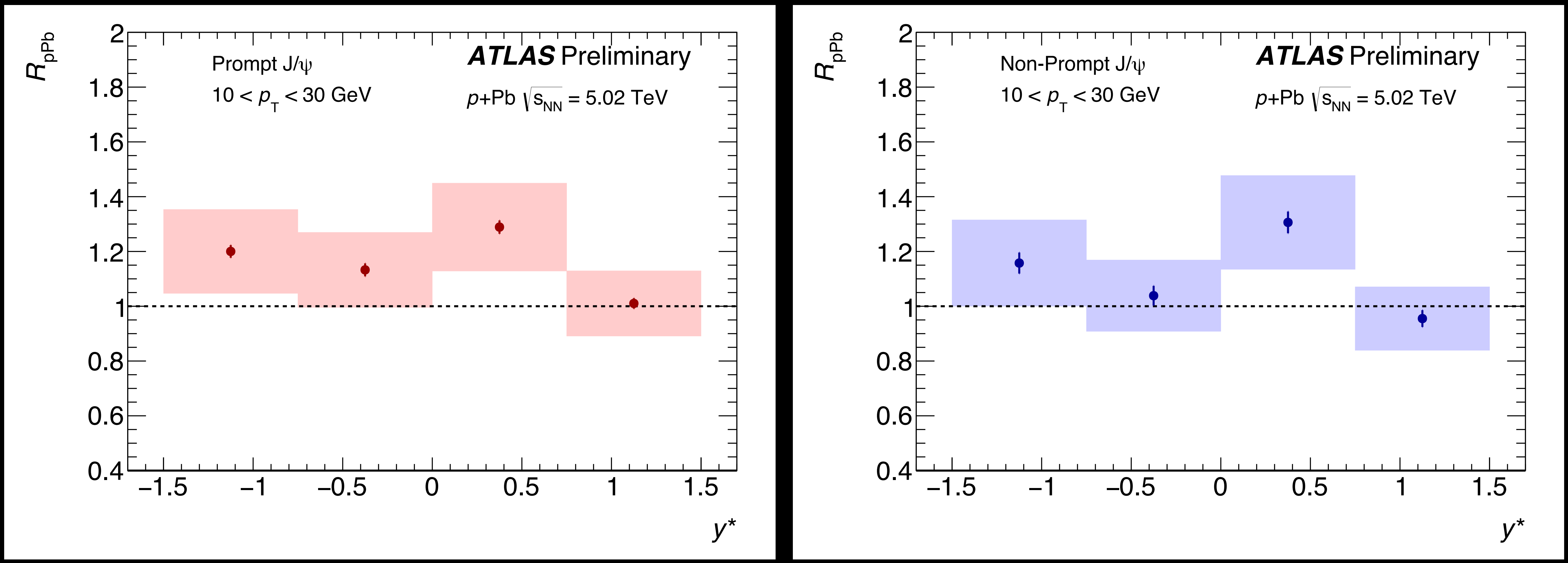
No strong modification of prompt and non-prompt production

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

ATLAS-CONF-2015-023

R_{pPb} vs. y*

$$R_{\mathrm{pPb}} = \frac{N_{\mathrm{pPb}}}{A * \sigma_{pp}}$$



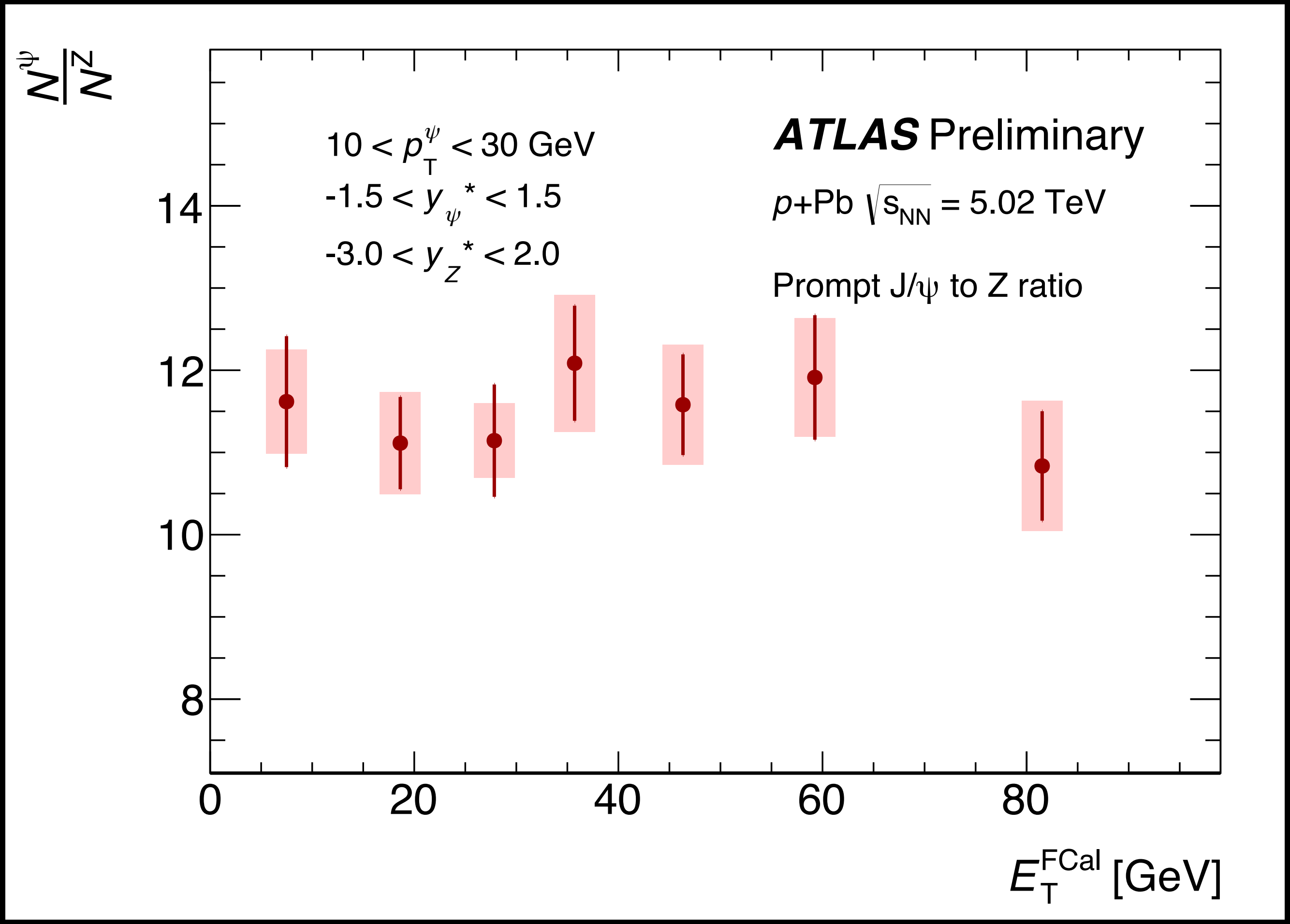
Prompt and non-prompt nuclear modification factor consistent with unity, no clear evidence of nPDF effects

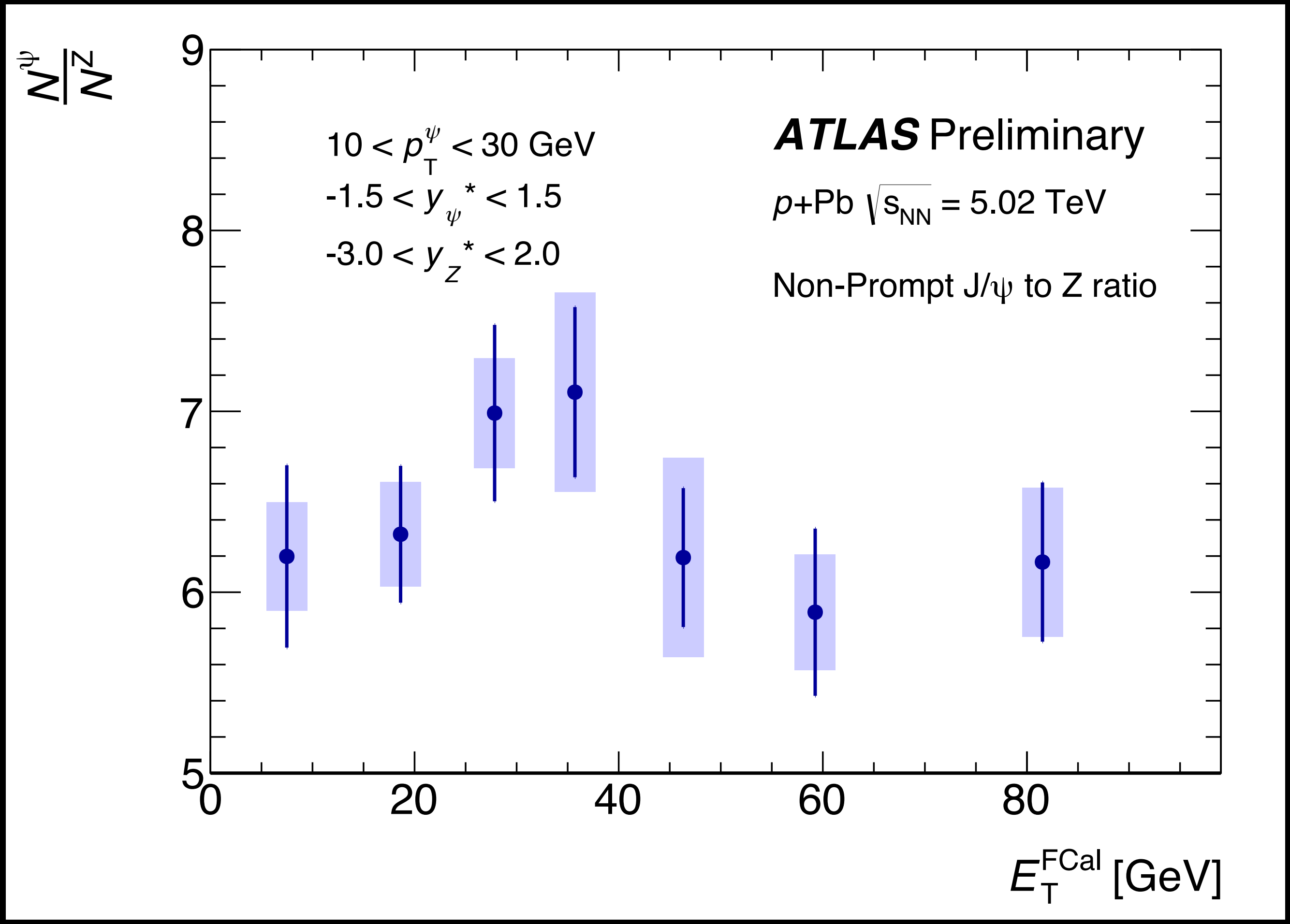
pp reference is interpolated from 2.76 TeV, 7 TeV and 8 TeV

ATLAS-CONF-2015-023

J/ψ to Z ratio

$$N^{J/\psi}/N^{Z}$$





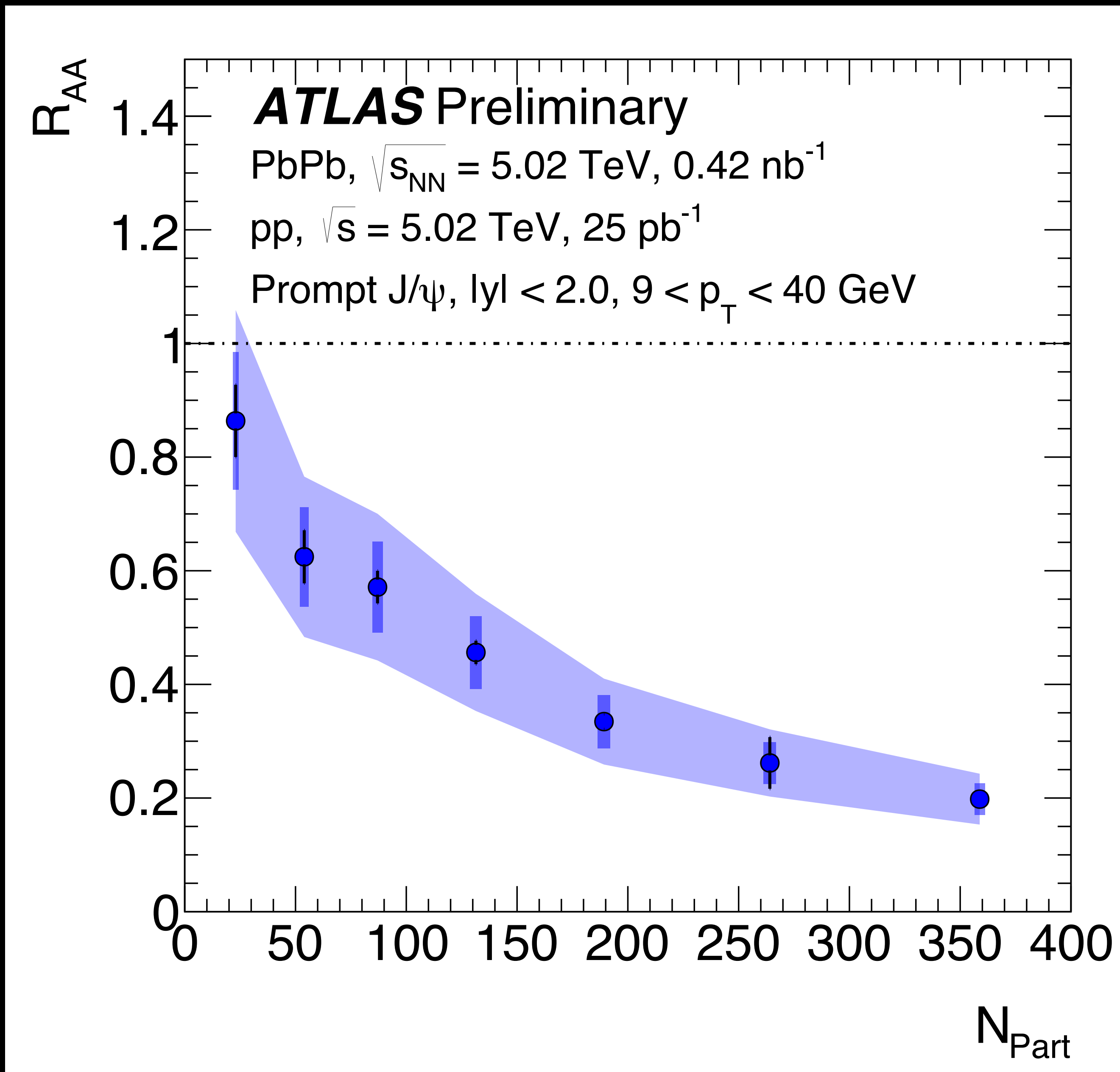
Ratios of the yields are independent on event activity, number of Z and J/psi production rates scale with the number of interaction

ATLAS-CONF-2015-023

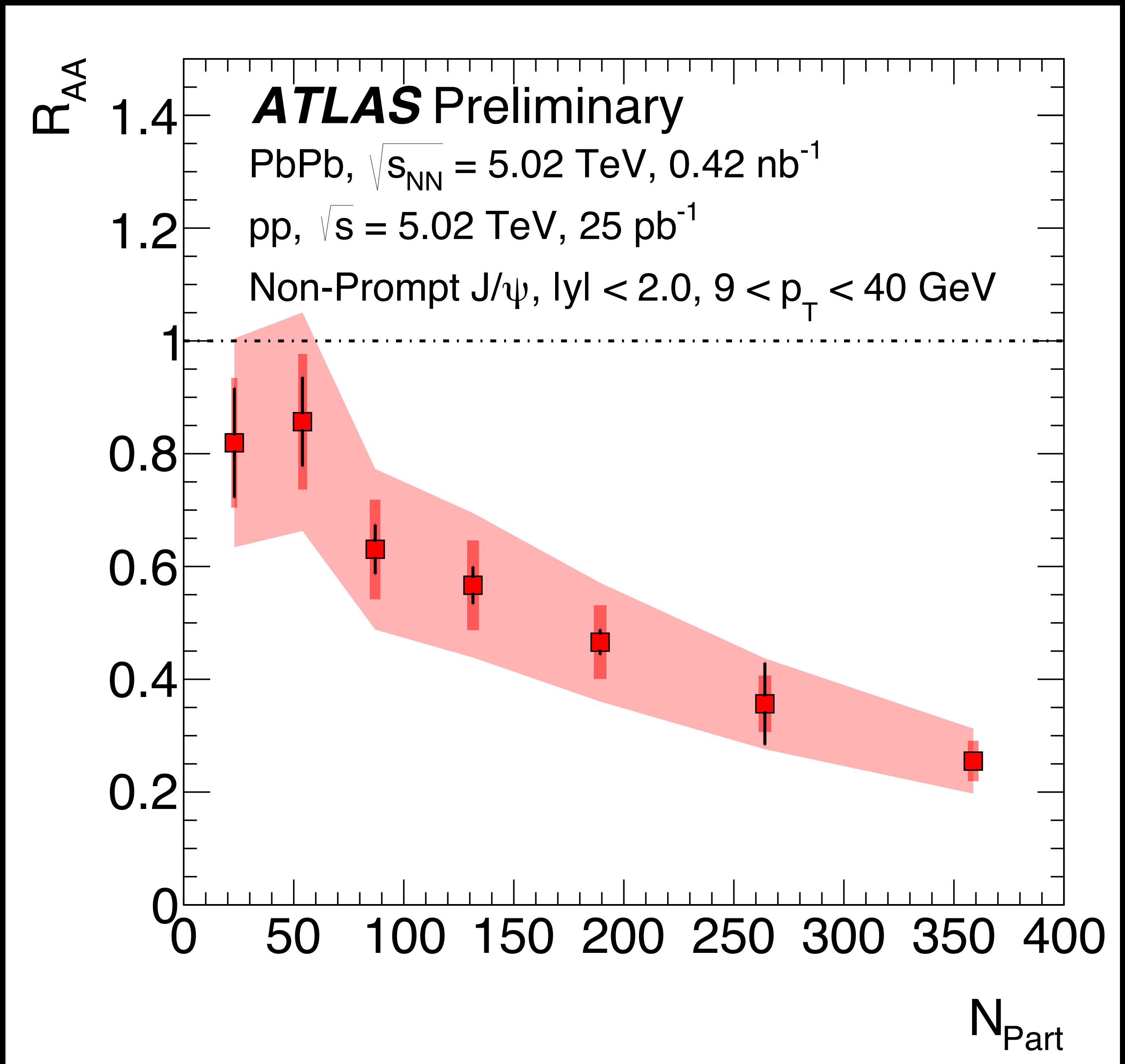
R_{AA} vs. N_{part}

N_{part}: mean number of participants

Prompt



Non-Prompt



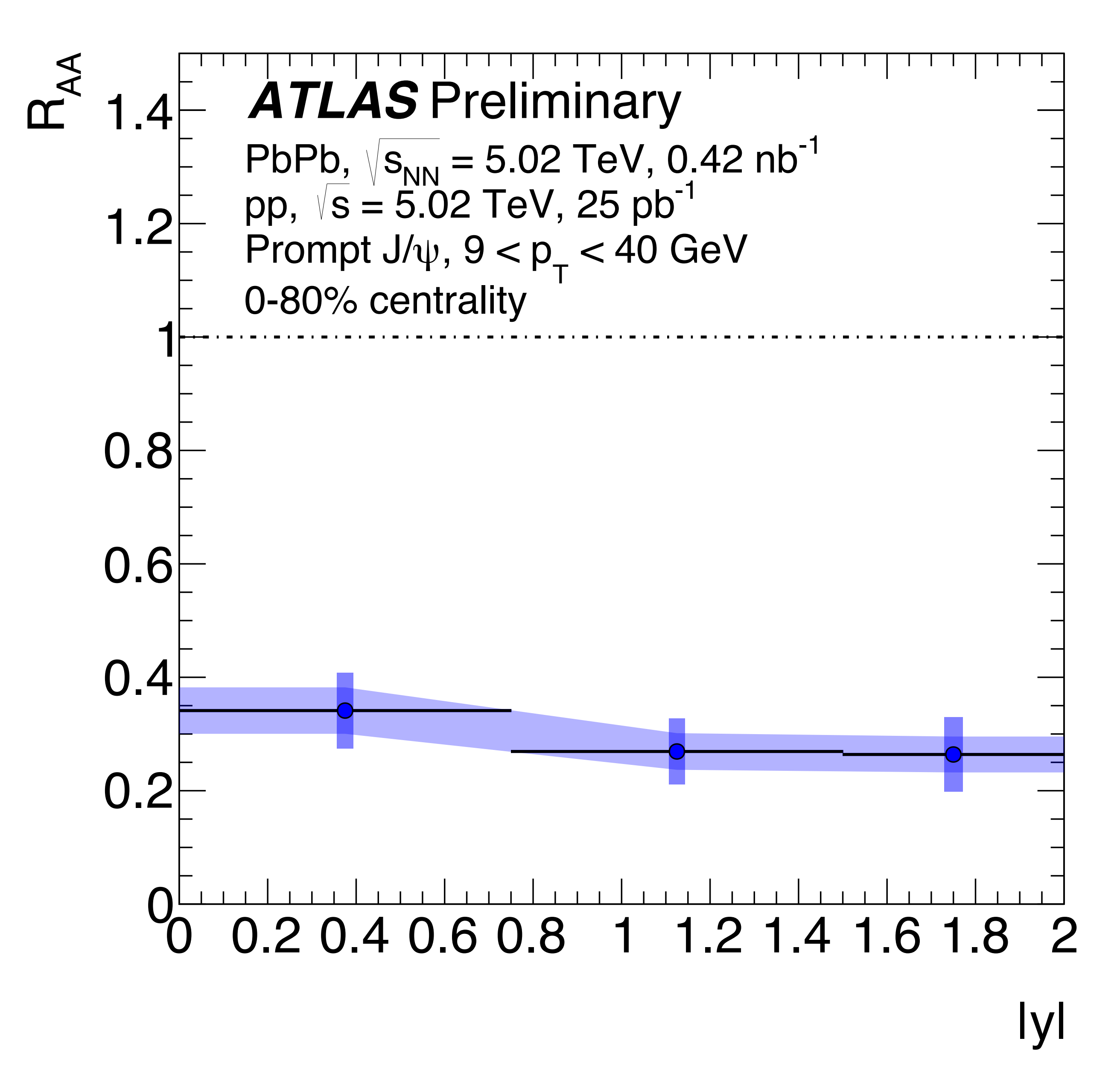
- J/ψ is strongly suppressed in most central collisions
- Prompt and non-prompt shows a similar pattern

ATLAS-CONF-2016-109

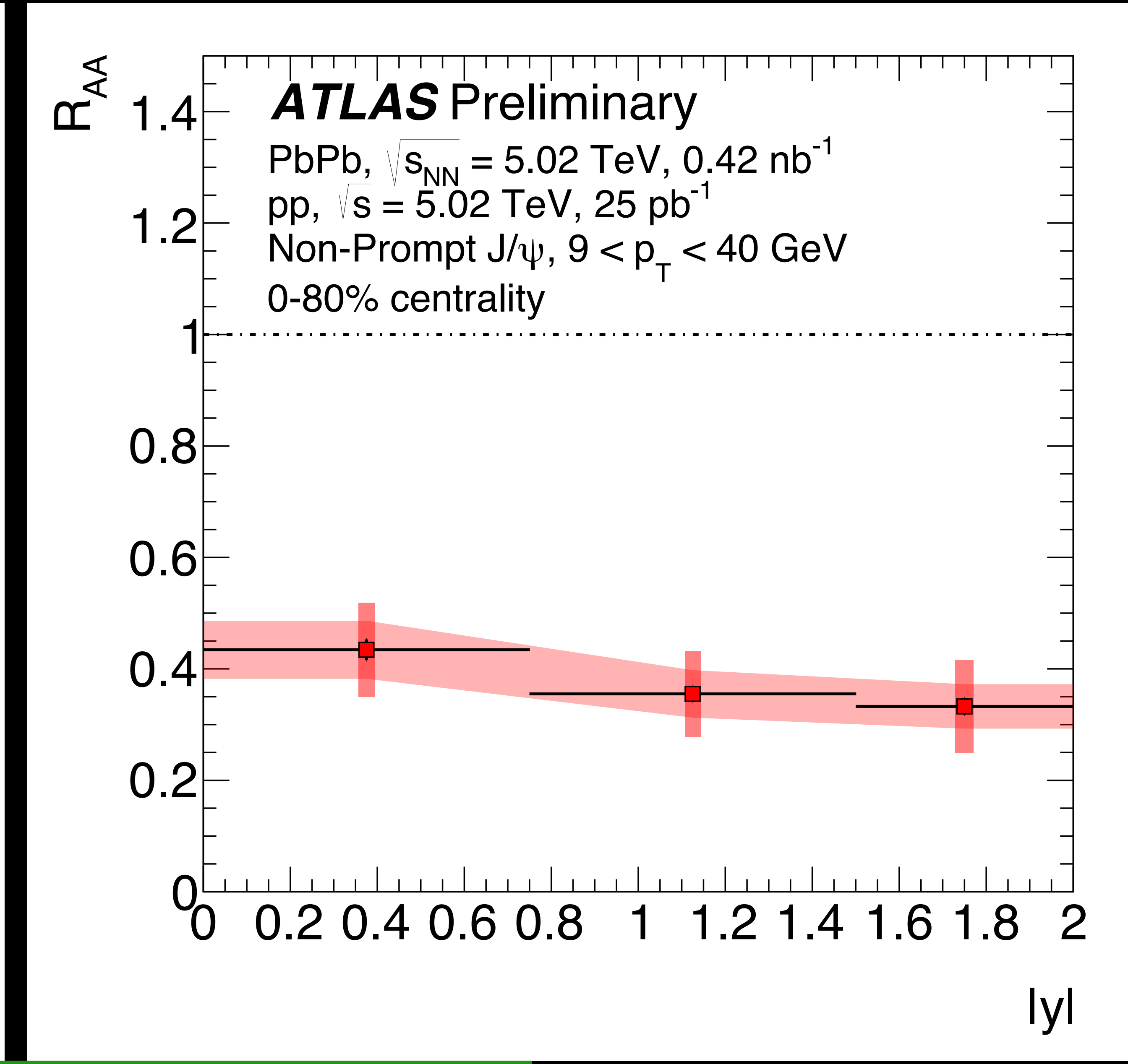
R_{AA} vs. |y|

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

Prompt



Non-Prompt



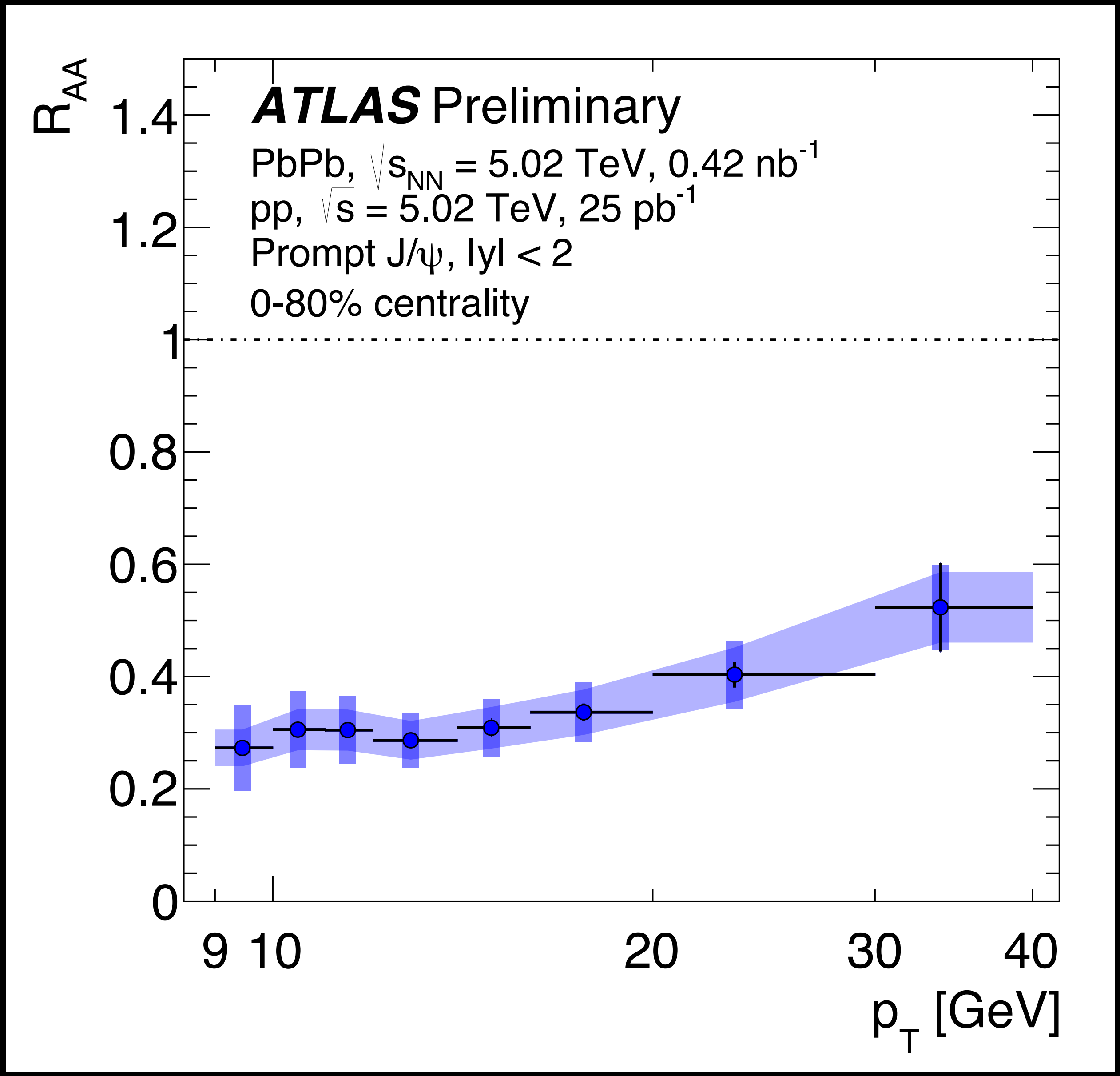
No significant |y| dependence

ATLAS-CONF-2016-109

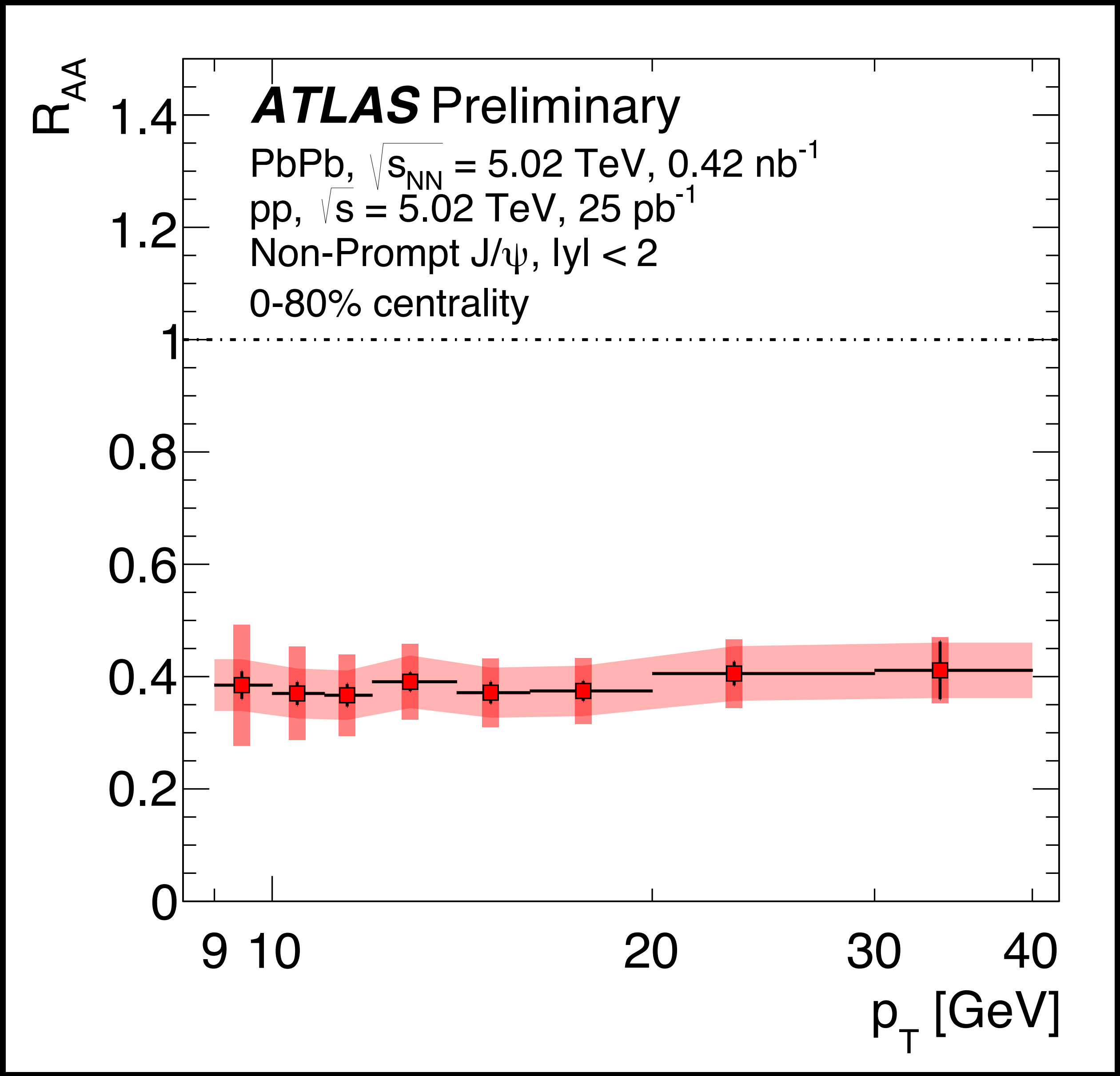
R_{AA} vs. p_T

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

Prompt



Non-prompt



- R_{AA} increases for $p_T > 20$ GeV
- Related to energy loss effects, rather than dissociation?

Flat in the measured p_T range

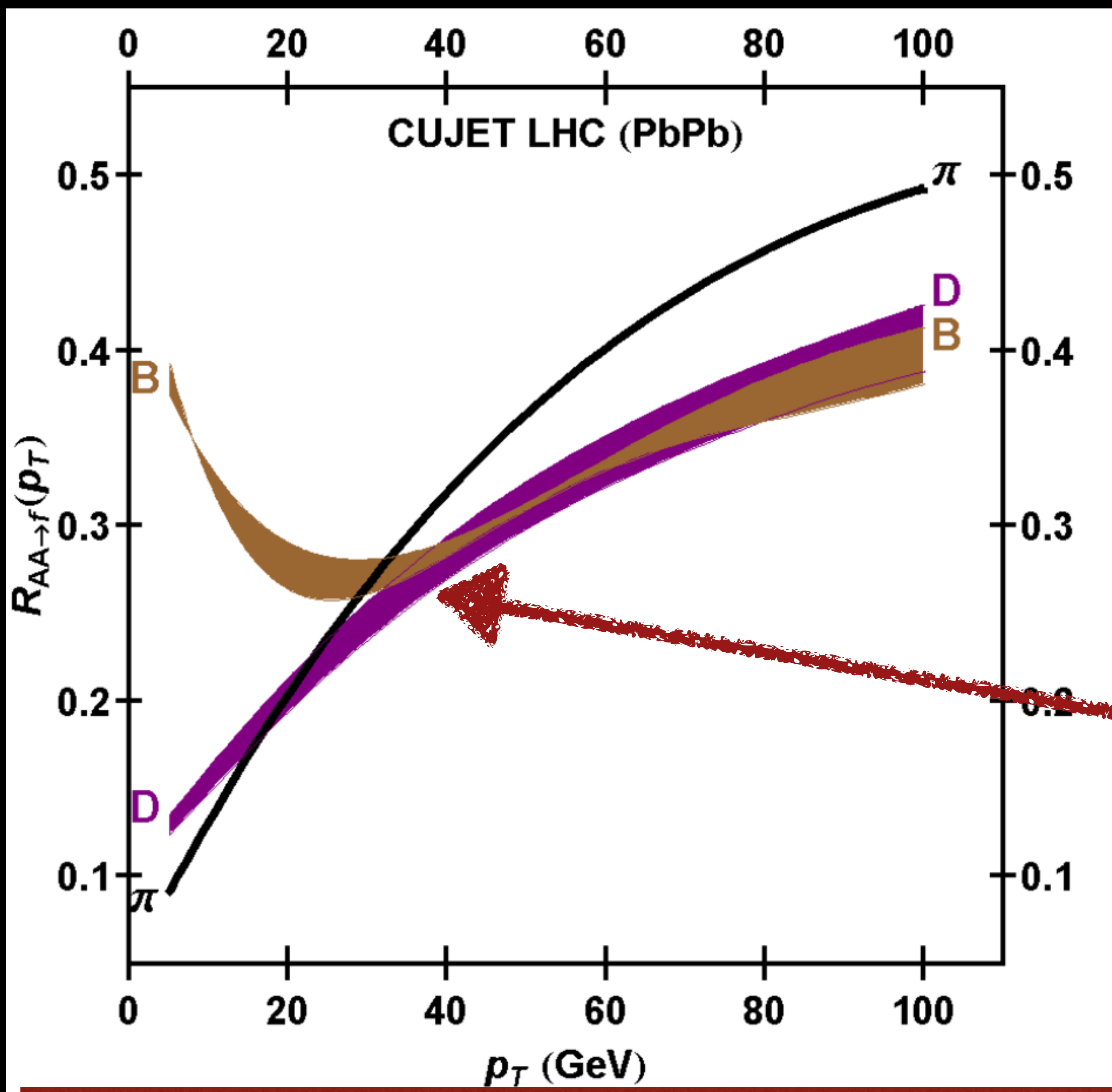
ATLAS-CONF-2016-109

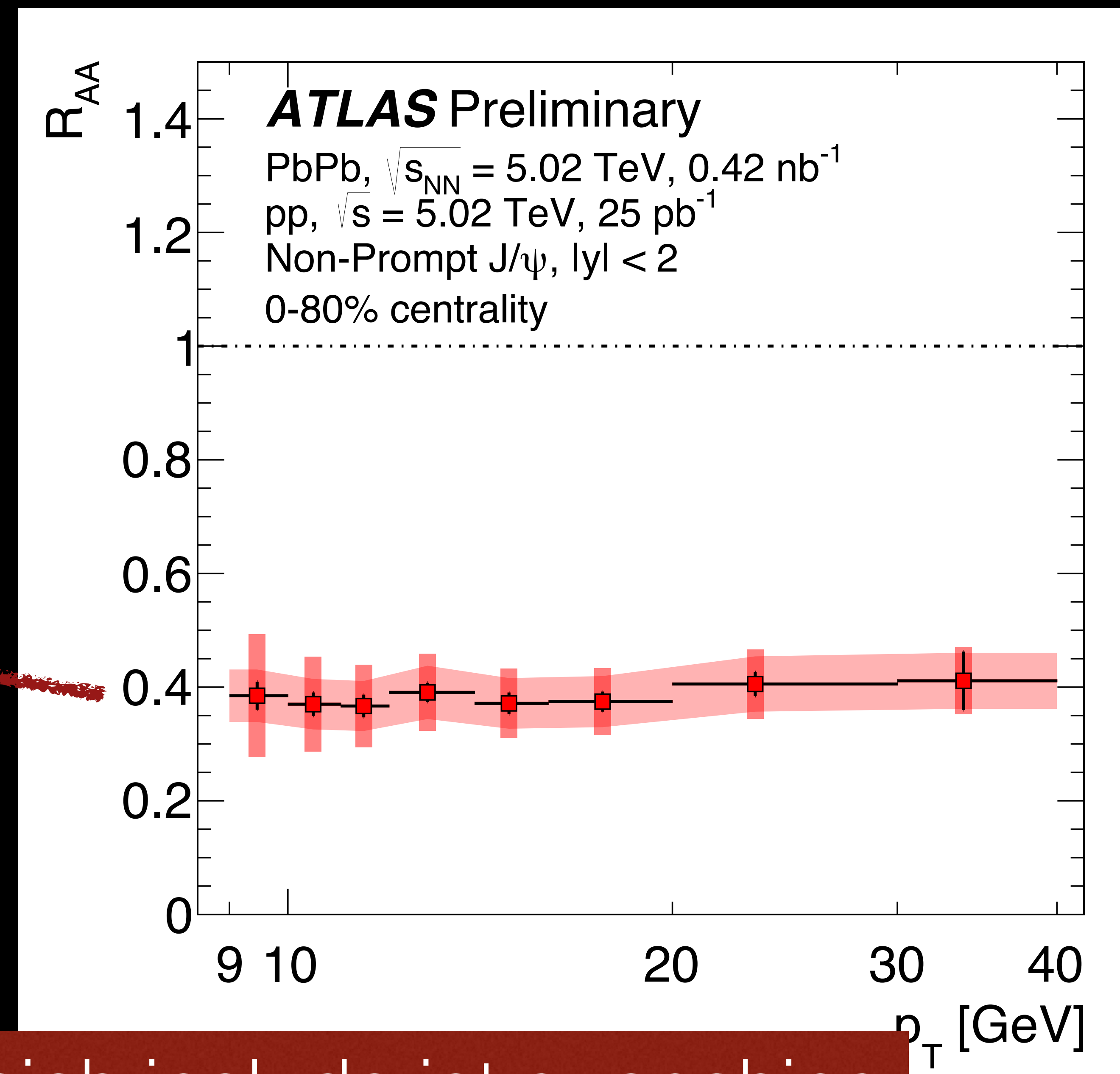
R_{AA} vs. p_T

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

arXiv:1106.3061v2

Non-prompt





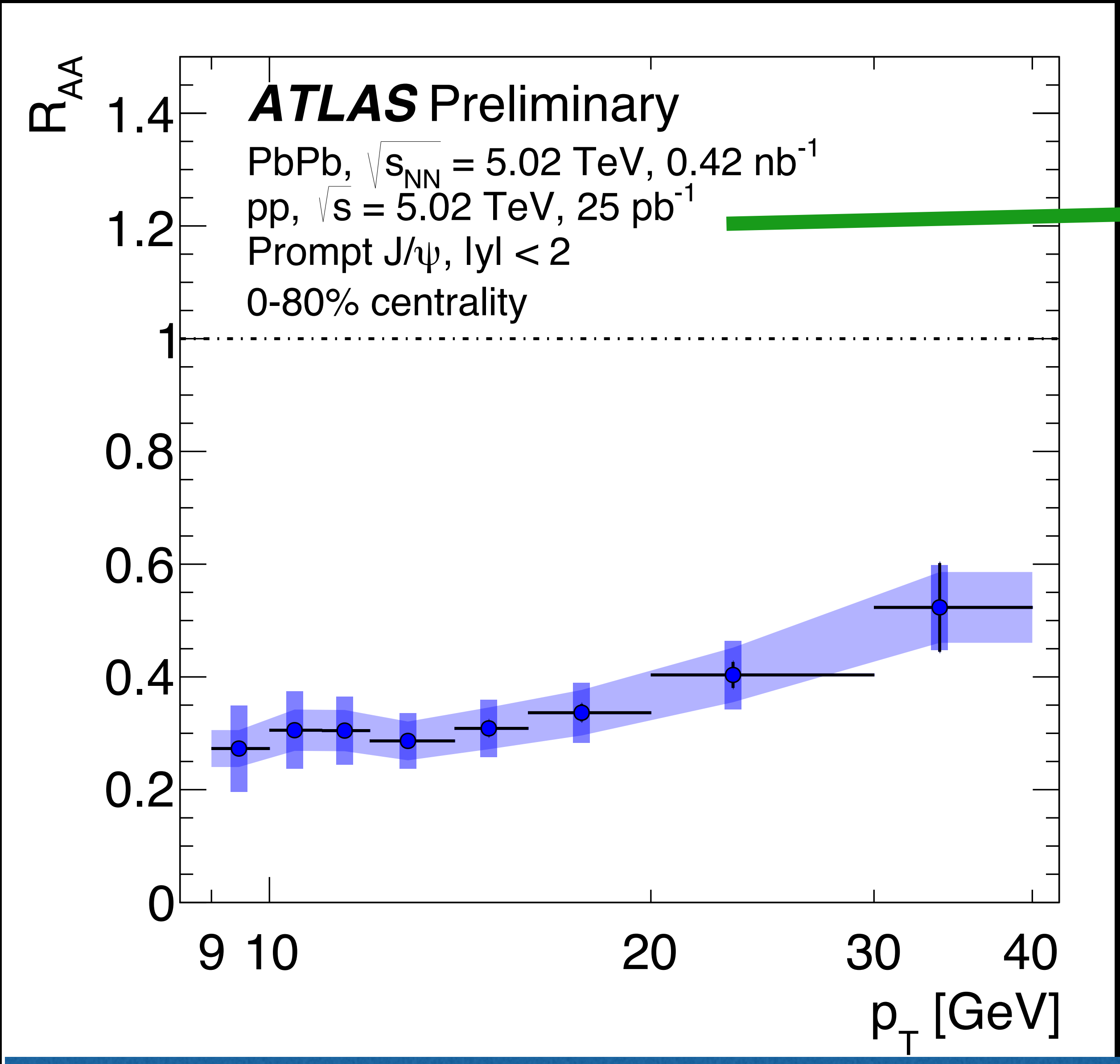
Shape predicted by models which include jet quenching

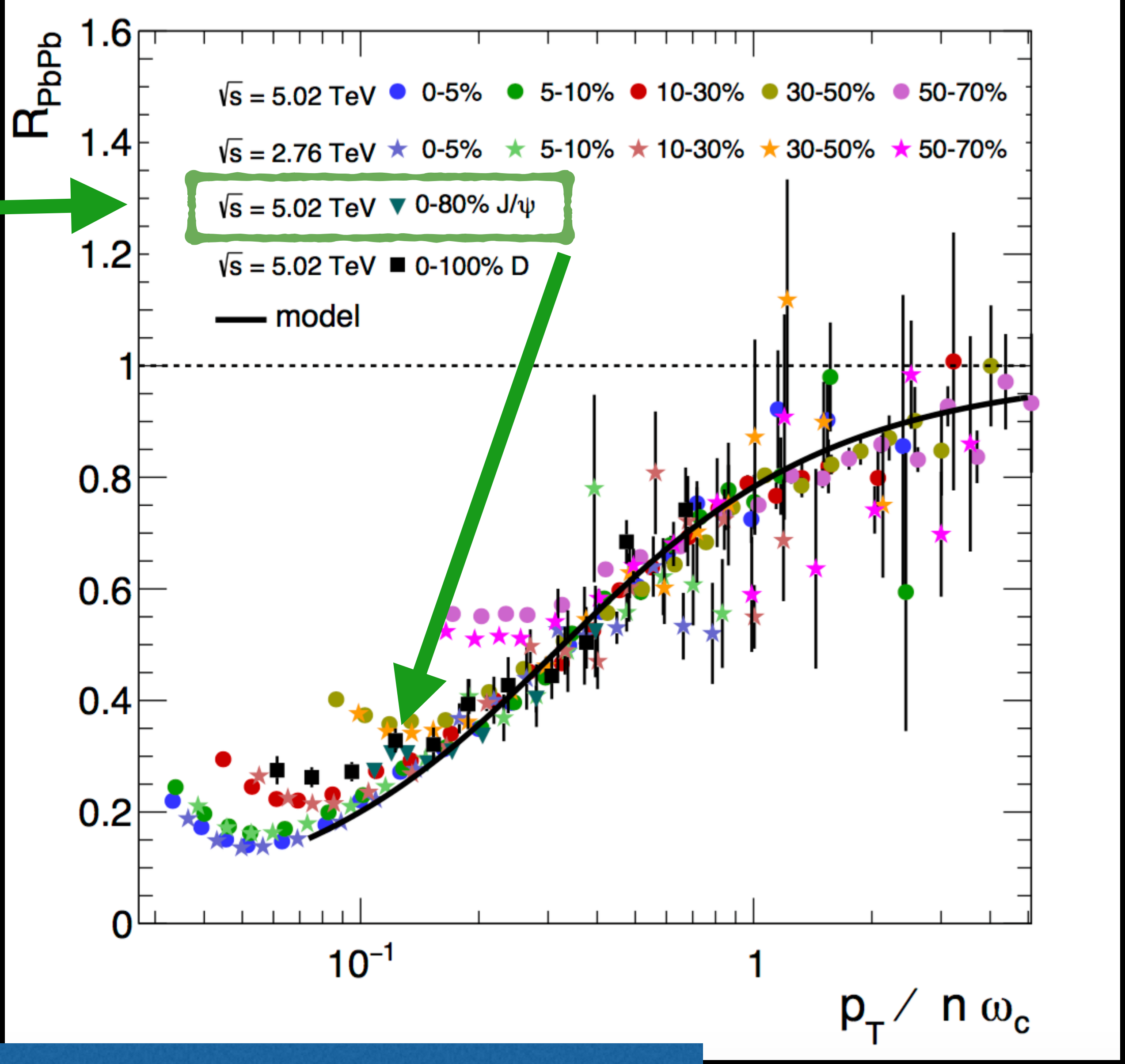
R_{AA} vs. p_T

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

Prompt

arXiv:1703.10852

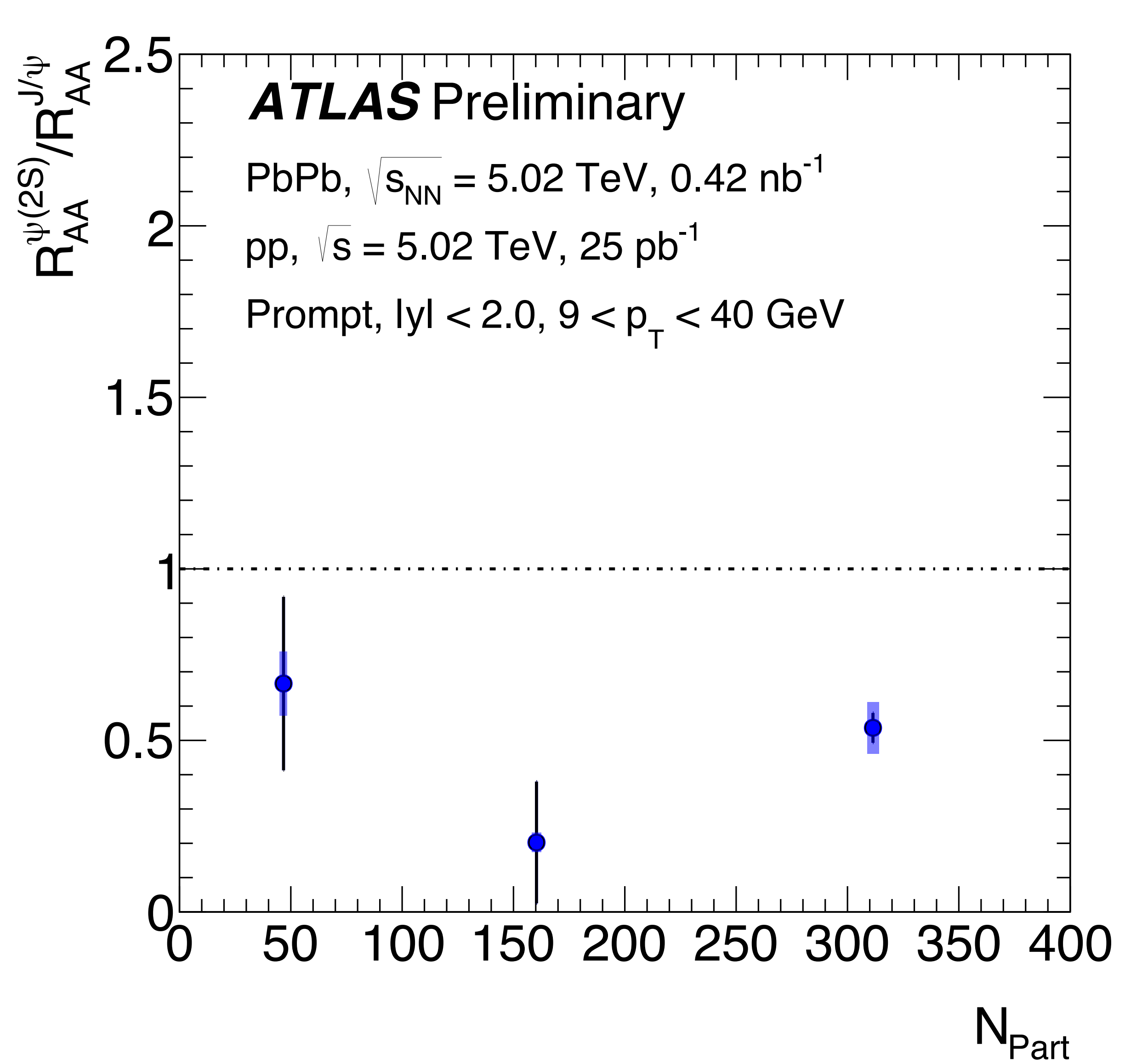




R_{AA} increasing trend is reproduced by energy loss model, but still an open question

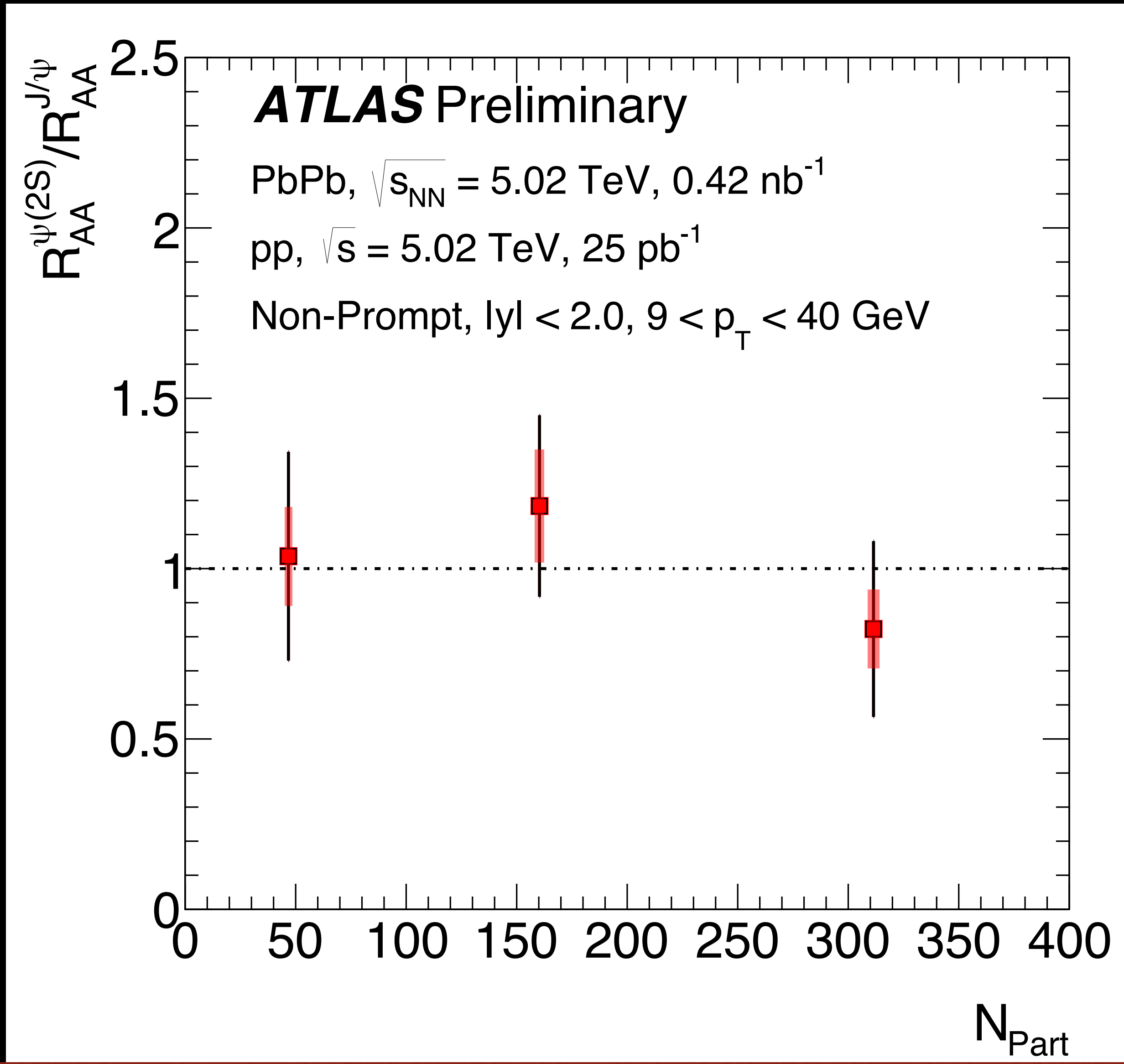
ψ(2S) to J/ψ ratio vs N_{part}

Prompt



- Stronger suppression of ψ(2S) with respect to the J/ψ
- Consistent with ψ(2S) having a weaker binding than J/ψ

Non-prompt

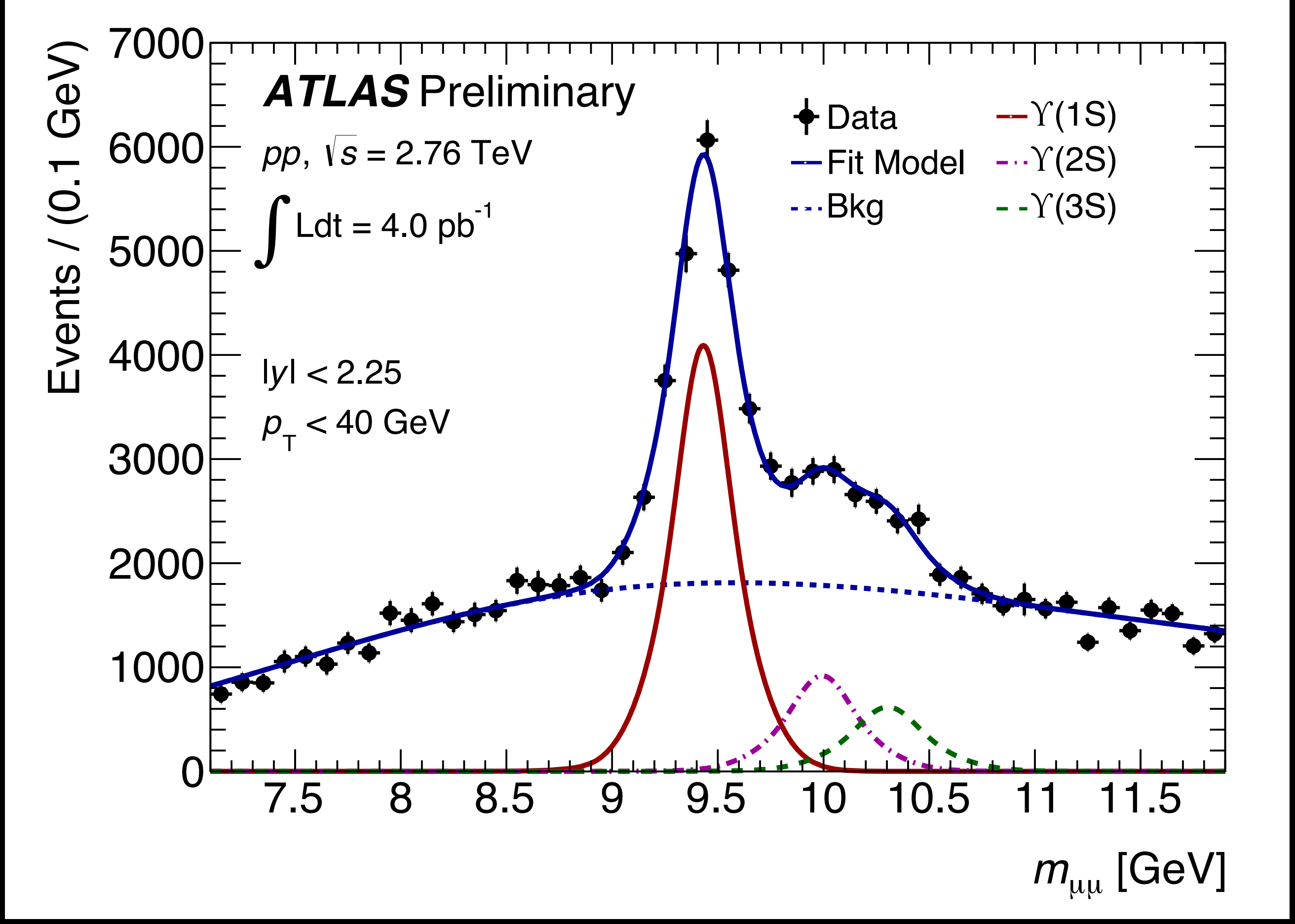


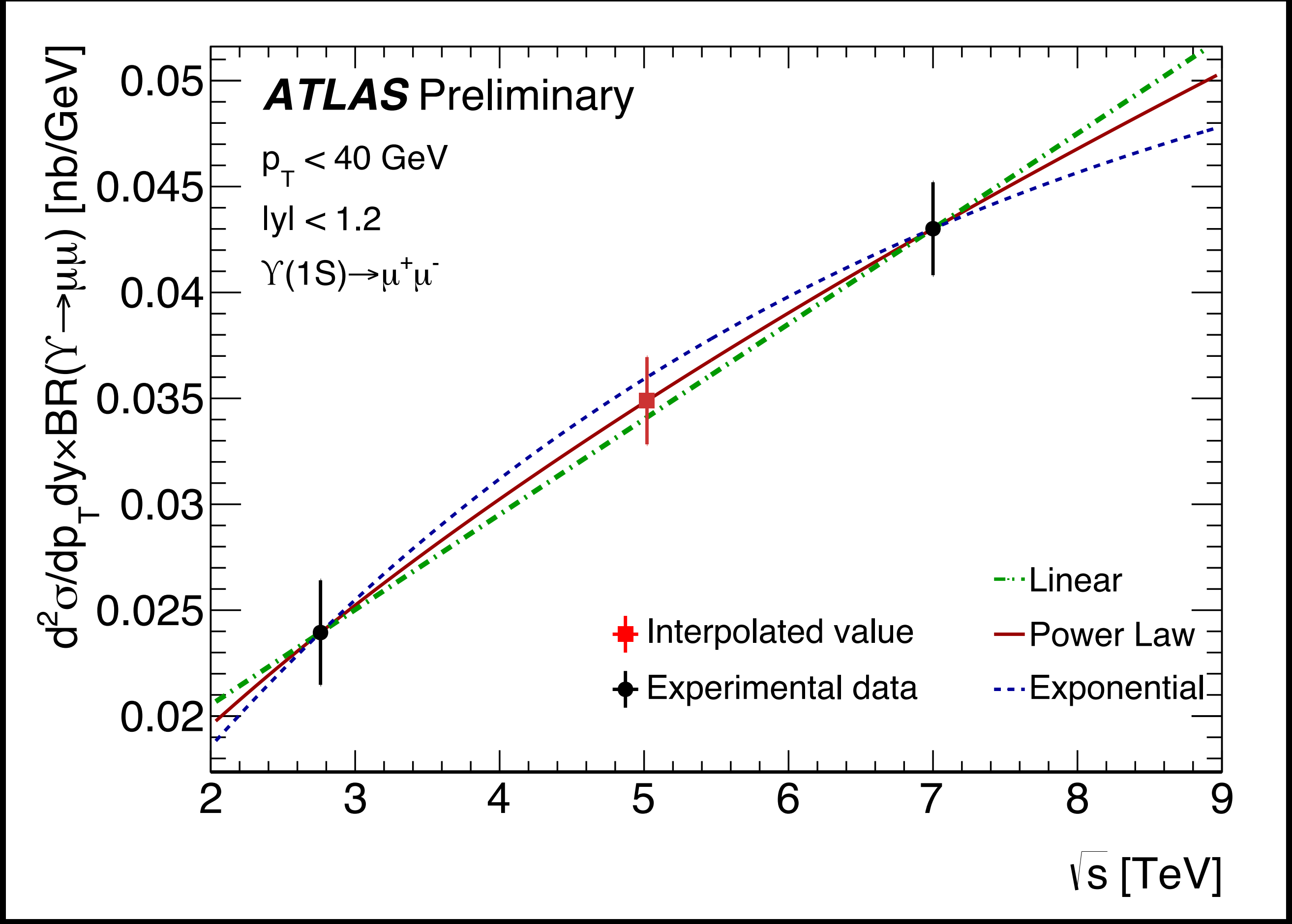
- Consistent with unity and with the picture of the B-hadron decaying outside the hot medium

ATLAS-CONF-2016-109

Upsilon measurement

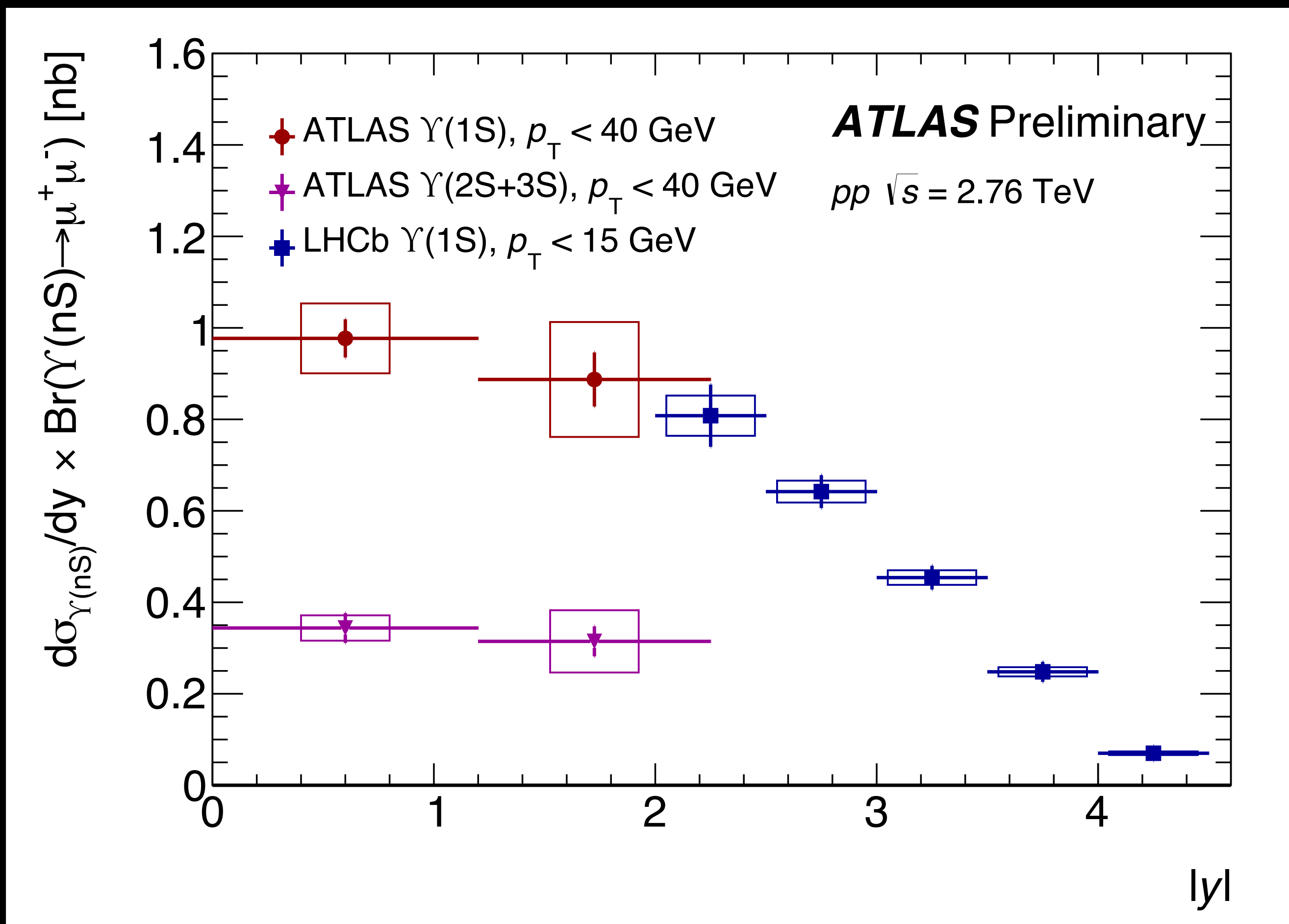
- Di-muon channel, 7.6 < $m_{\mu\mu}$ < 12. GeV
- Di-muon Trigger
- Kinematic Range: p_T < 40 GeV and -2.25 < y* < 1.2
- Yield extracted with a binned least squared fit.

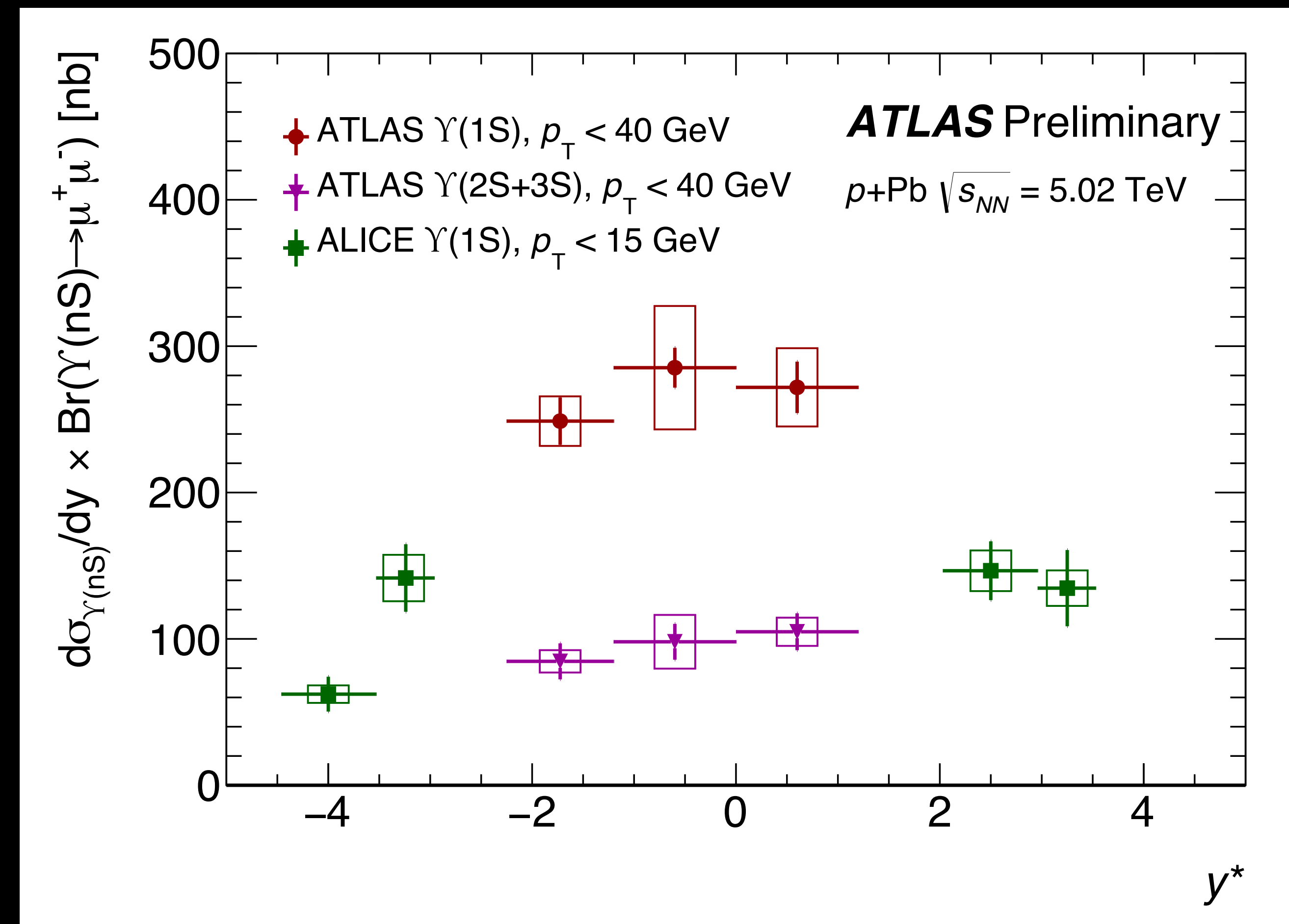




- ATLAS-CONF-2015-050, 2013 p+Pb @ 5.02 TeV and p+p @ 2.76 TeV

Cross section in p+Pb data



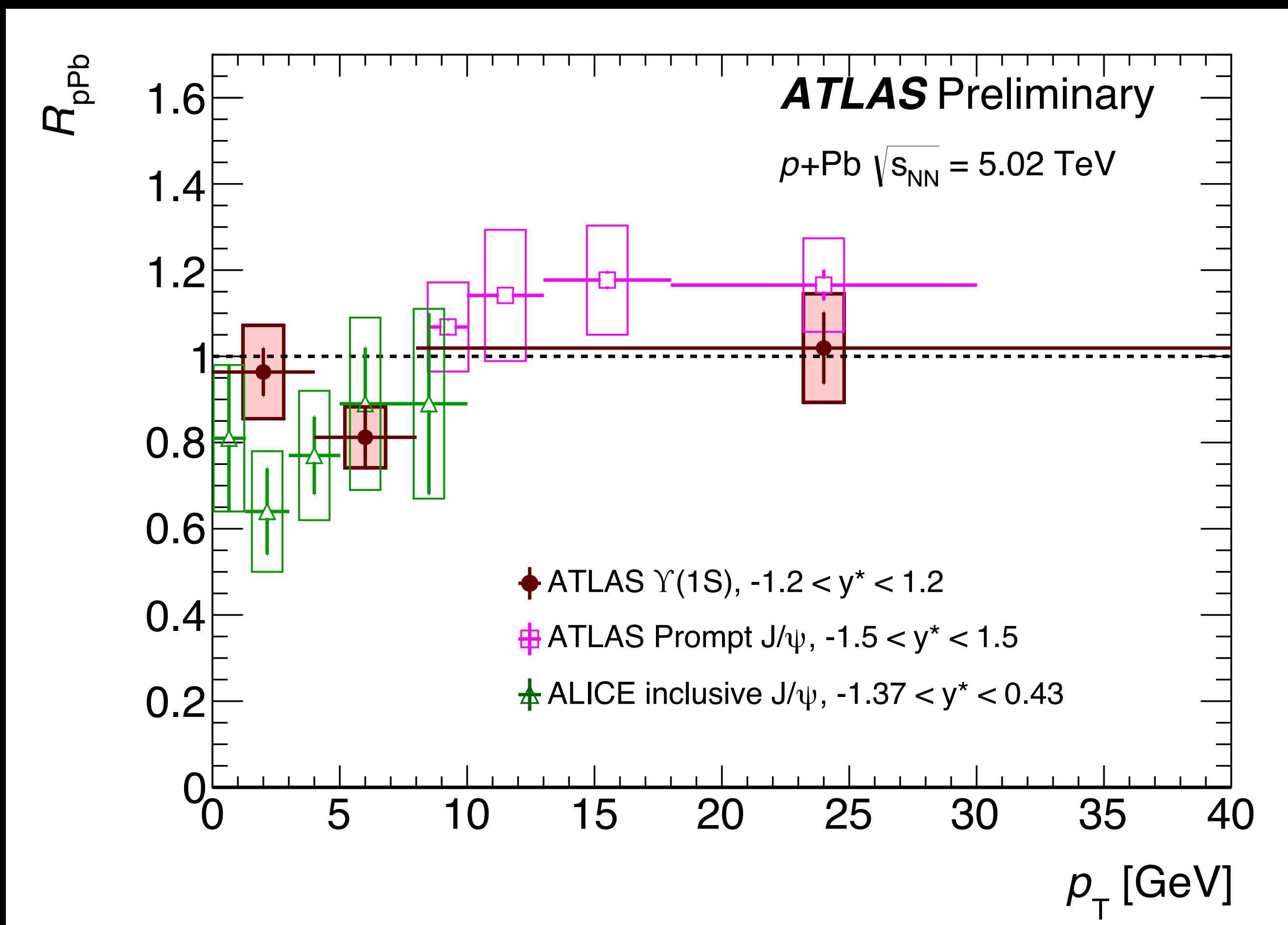


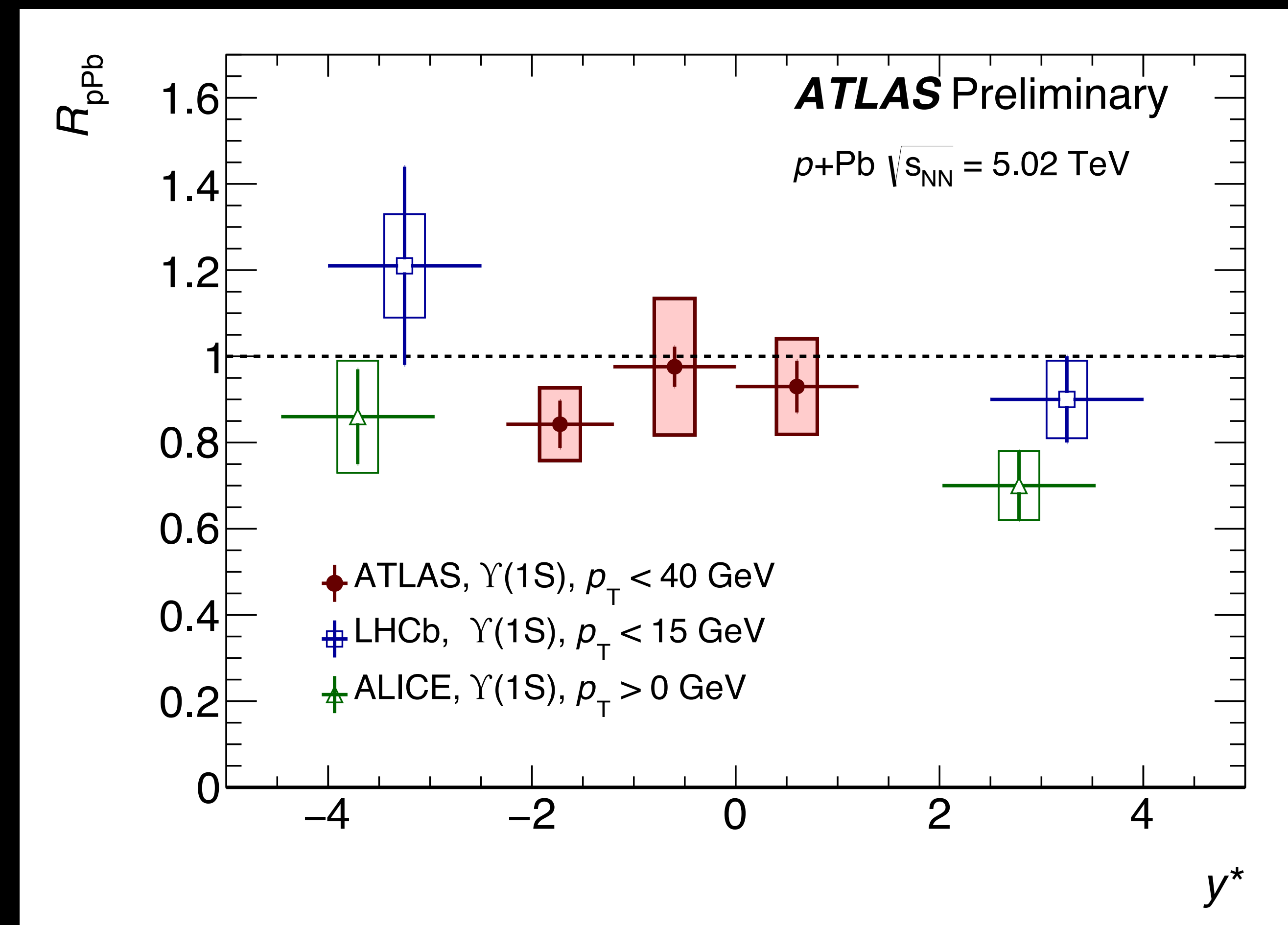
Cross section in good agreement with LHCb and ALICE experiments

ATLAS-CONF-2015-050

R_{pPb} vs. p_T and y*

$$R_{\mathrm{pPb}} = \frac{N_{\mathrm{pPb}}}{A * \sigma_{pp}}$$





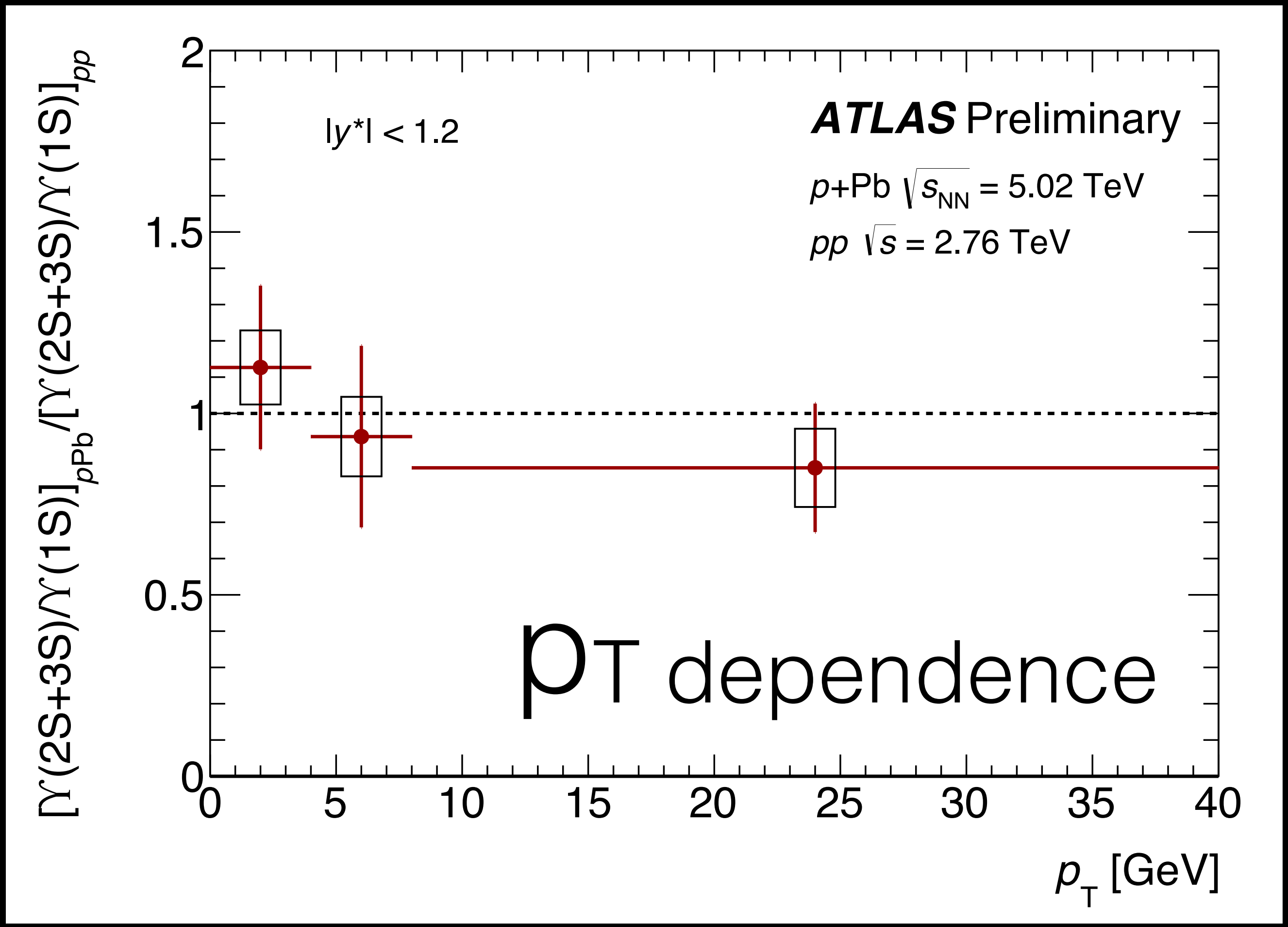
Compatible with results of J/ψ R_{pPb} from ALICE and ATLAS

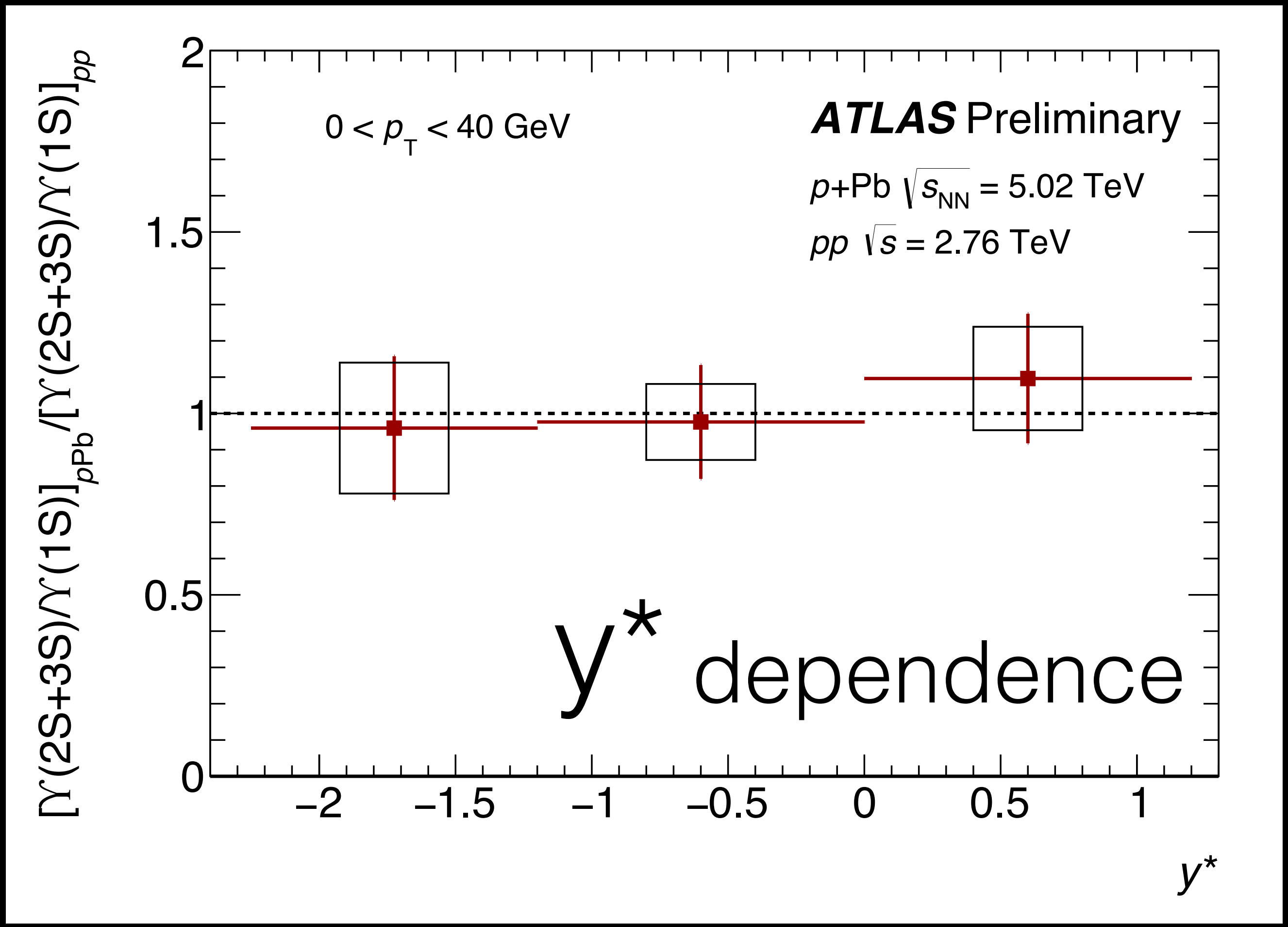
Comparison with Υ(1S) results of ALICE and LHCb

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

ATLAS-CONF-2015-023

Υ(2S+3S) to Υ(1S) ratio vs p_T and y*





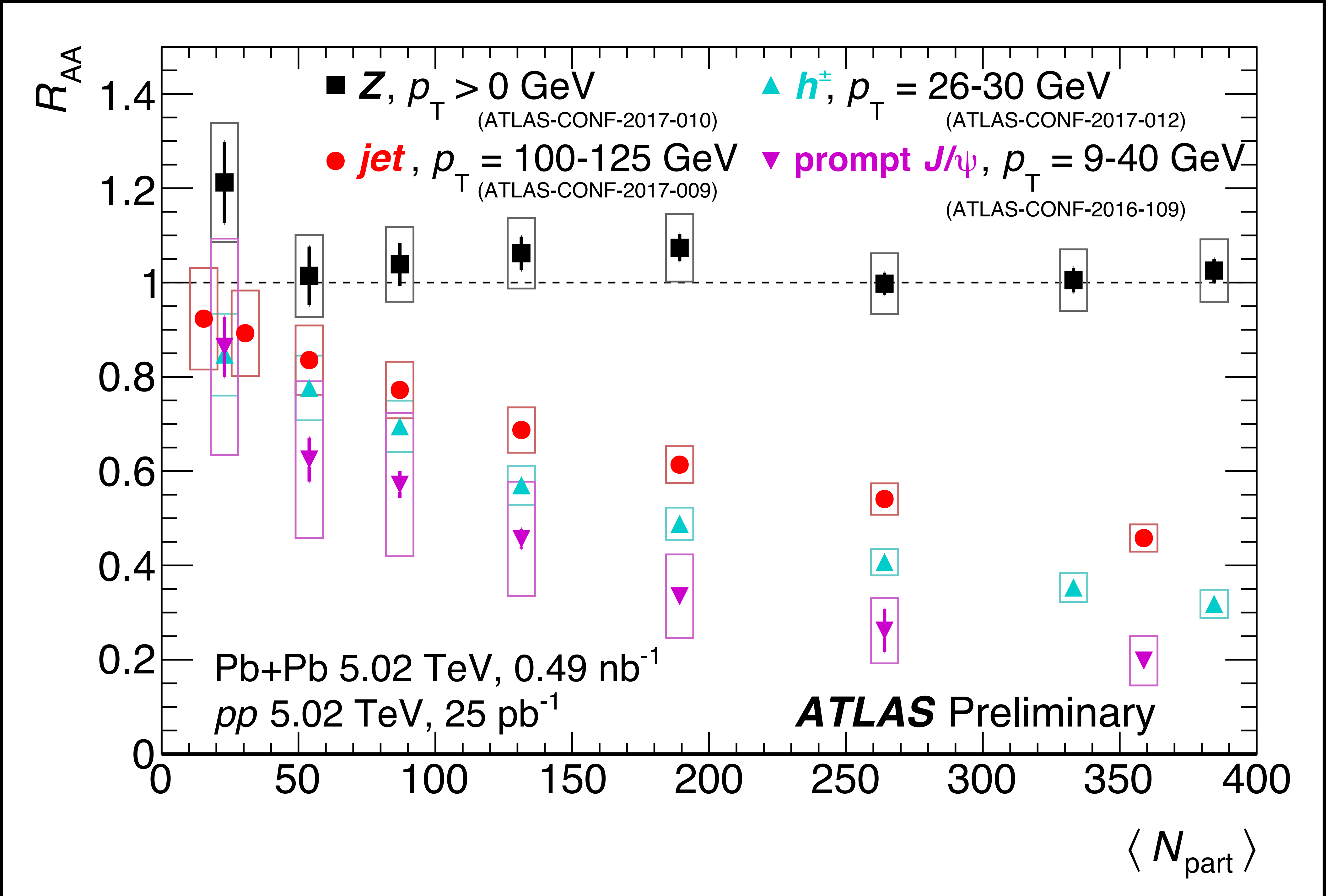
$$\frac{[\Upsilon(2S+3S)/\Upsilon(1S)]_{\mathrm{PbPb}}}{[\Upsilon(2S+3S)/\Upsilon(1S)]_{\mathrm{pp}}}$$

No significant difference in production, no suppression in higher states

pp @ 2.76 TeV

ATLAS-CONF-2015-023

R_{AA} of different probes



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

Conclusions

- Quarkonia production in pPb and PbPb collision have been presented.
- p-Pb:
  - Charmonium R_{pPb} show no obvious p_T or rapidity dependence.
  - Υ(1S) R_{pPb} compatible with prompt J/ψ
  - No clear evidence of CNM effects
- Pb-Pb:
  - A strong suppression for J/ψ and ψ(2S) is observed.
  - R_{AA} as a function of p_T shows a different trend for prompt and non-prompt components.

Additional Slides

Definition of y*

$$y^* = y_{lab} - 0.465$$

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

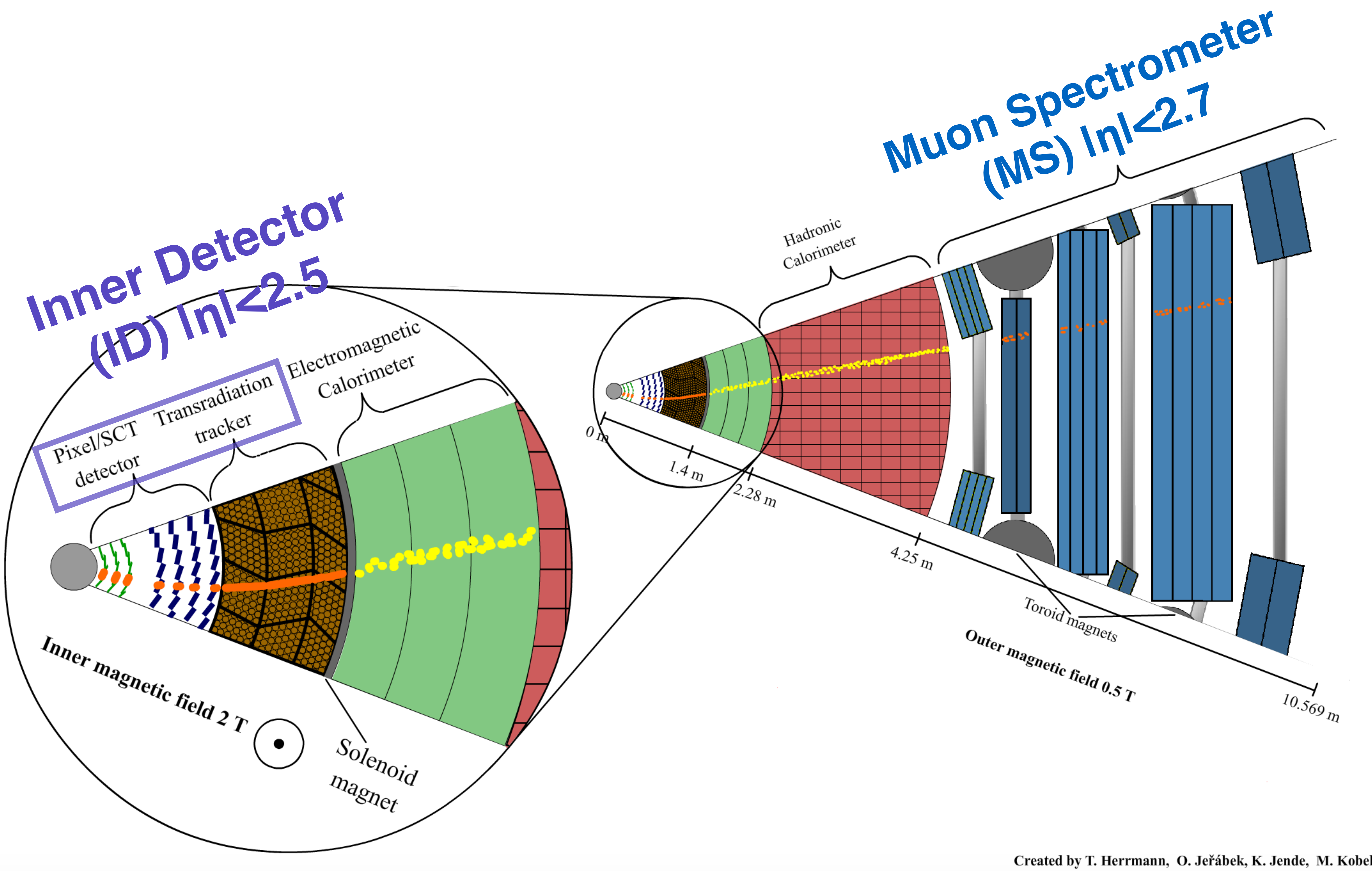
due to shift in the center mass

y* is defined positive in the proton beam direction

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

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

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


Inner Detector
(ID) |η|<2.5
Muon Spectrometer
(MS) |η|<2.7
Pixel/SCT
detector
Transradiation
tracker
Electromagnetic
Calorimeter
Hadronic
Calorimeter
Inner magnetic field 2 T
Solenoid
magnet
0 m
1.4 m
2.28 m
4.25 m
Toroid magnets
Outer magnetic field 0.5 T
10.569 m
Created by T. Herrmann, O. Jeřábek, K. Jende, M. Kobel

Centrality

Glauber model

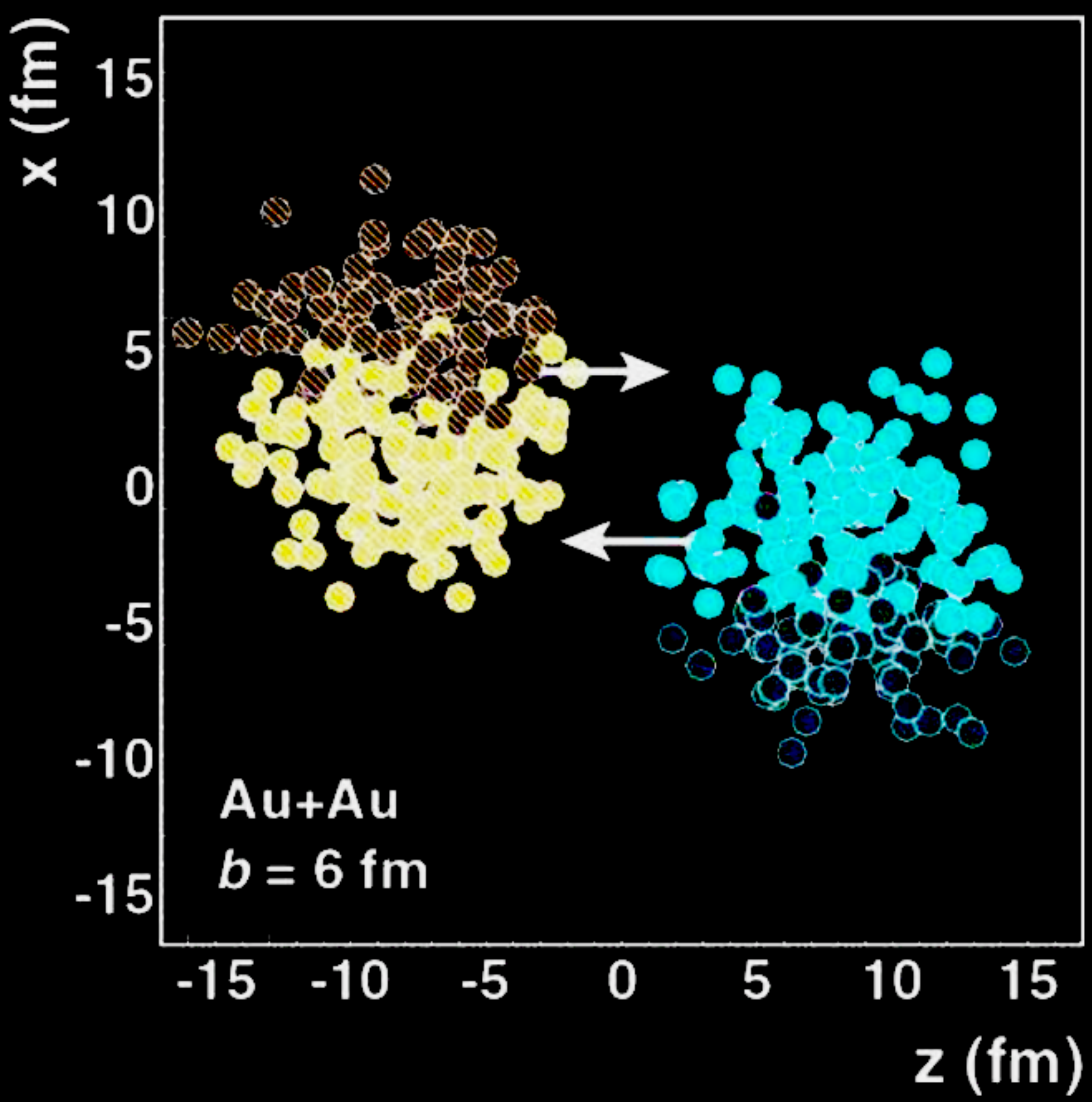
1) Generate two colliding nuclei with 3D nucleon positions chosen from measured density distributions (e^- scattering)

$$\rho(r) = \frac{\rho_0}{1 + exp([r - R]/a)}$$

2) Nucleons interact when transverse distance satisfies

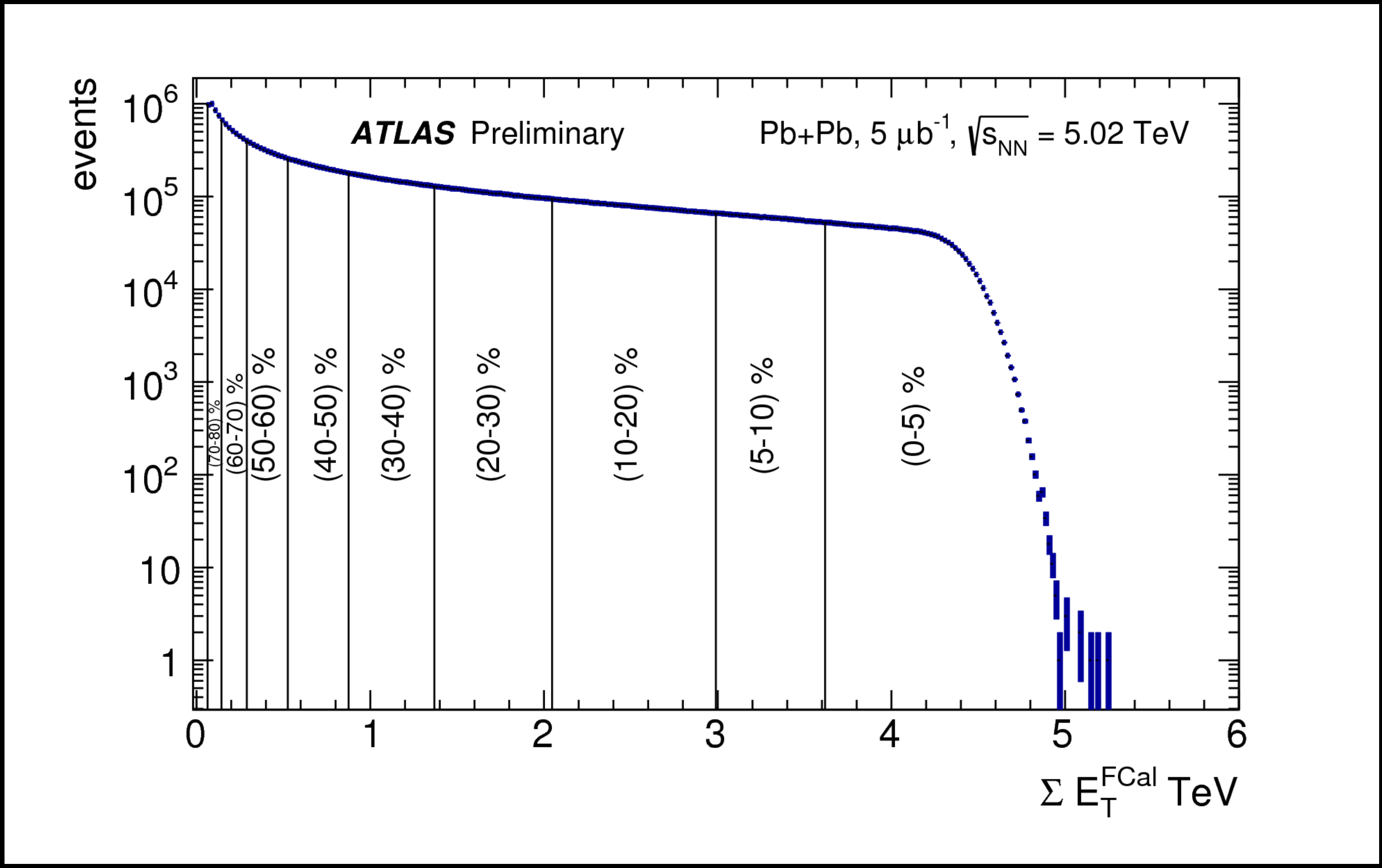
$$d < \sqrt{\sigma_{NN}/\pi}$$

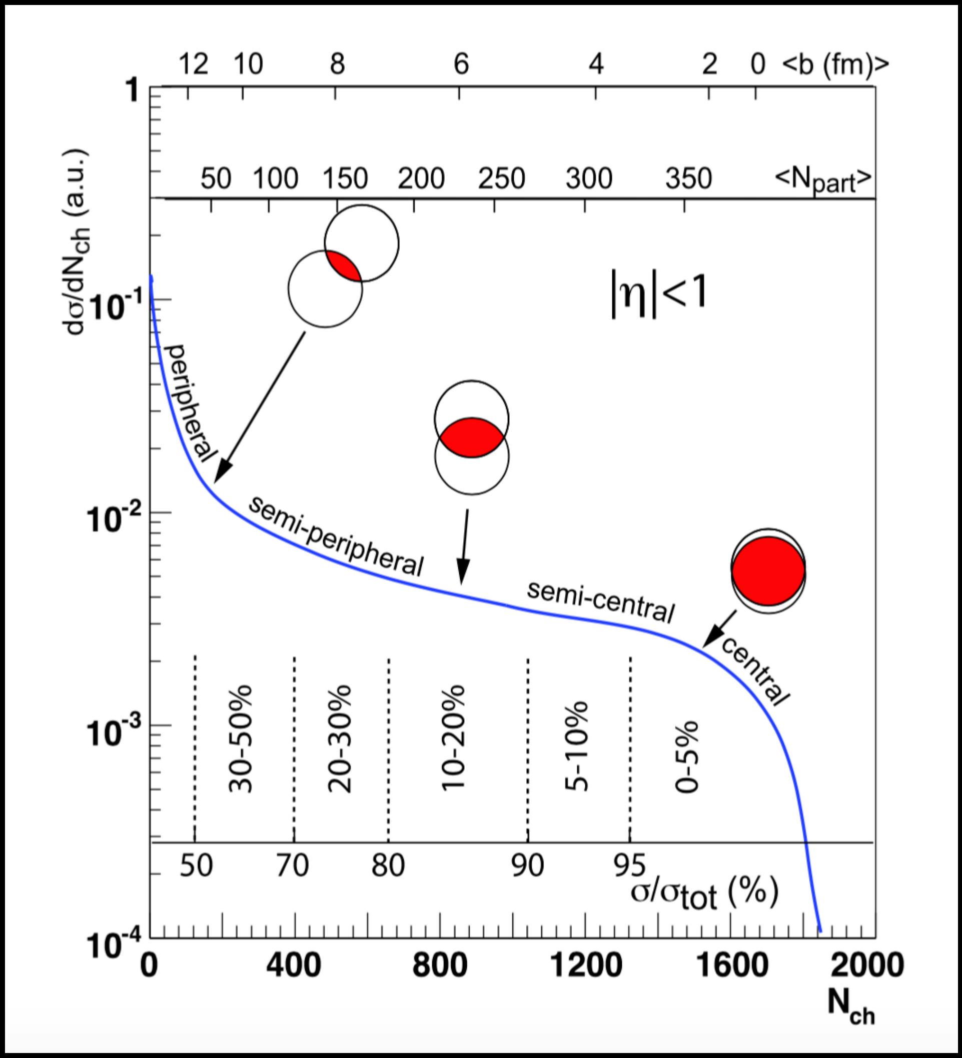
typically using the inelastic pp cross section for NN



Centrality

Energy deposited in the forward calorimeters





$\sum E_T^{FCal}$ = Sum of energy deposited in the forward calorimeters

Data is then divided into percentile bins: Models allow extraction of <N_{part}>, <N_{coll}> and <T_{AA}>.

Method

J/ψ and ψ(2S) reconstructed in the di-muon channel, $2.6 < m_{\mu\mu} < 4.2$ GeV

Pb-Pb Trigger

- L1 Trigger: 1 muon, $p_T > 4$ GeV
- High Level Trigger: 2 muons, $p_T > 4$ GeV

pp Trigger

- L1 Trigger: 2 muons, $p_T > 4$ GeV
- High Level Trigger: 2 muons, $p_T > 4$ GeV

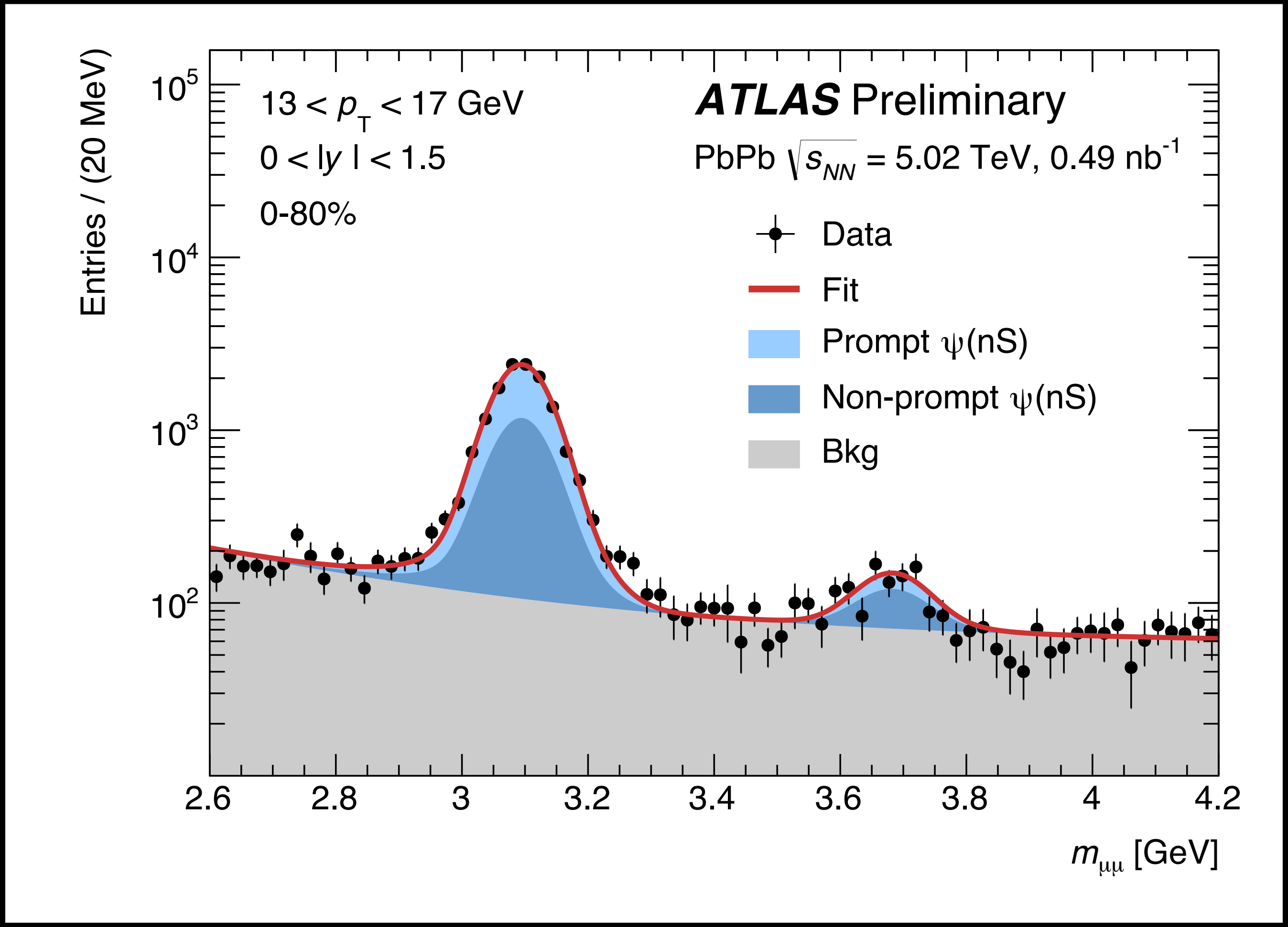
Kinematic Range: $9 < p_T < 40$ GeV and $|y| < 2$, centrality 0-80%

Perform weighted 2D unbinned maximum likelihood fit

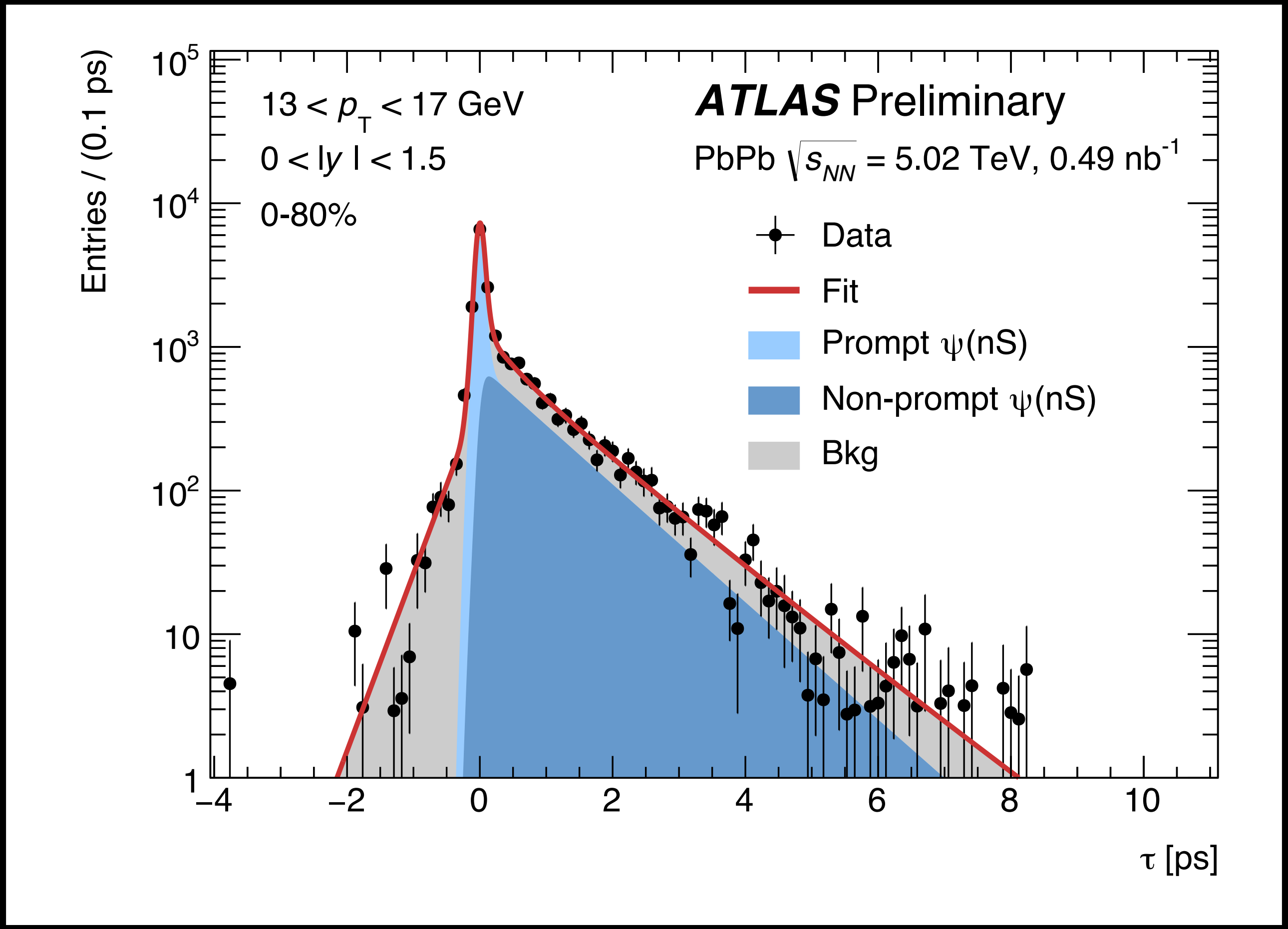
- Di-muon Invariant mass and lifetime
- Extract fraction of prompt and non-prompt J/ψ and ψ(2S)
- Per-dimuon weight: trigger, reconstruction and acceptance

Simultaneous Fit Method

PbPb projections



Invariant dimuon mass and lifetime



Weights: Acceptance, trigger and reconstruction efficiency

Simultaneous Fit Method

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

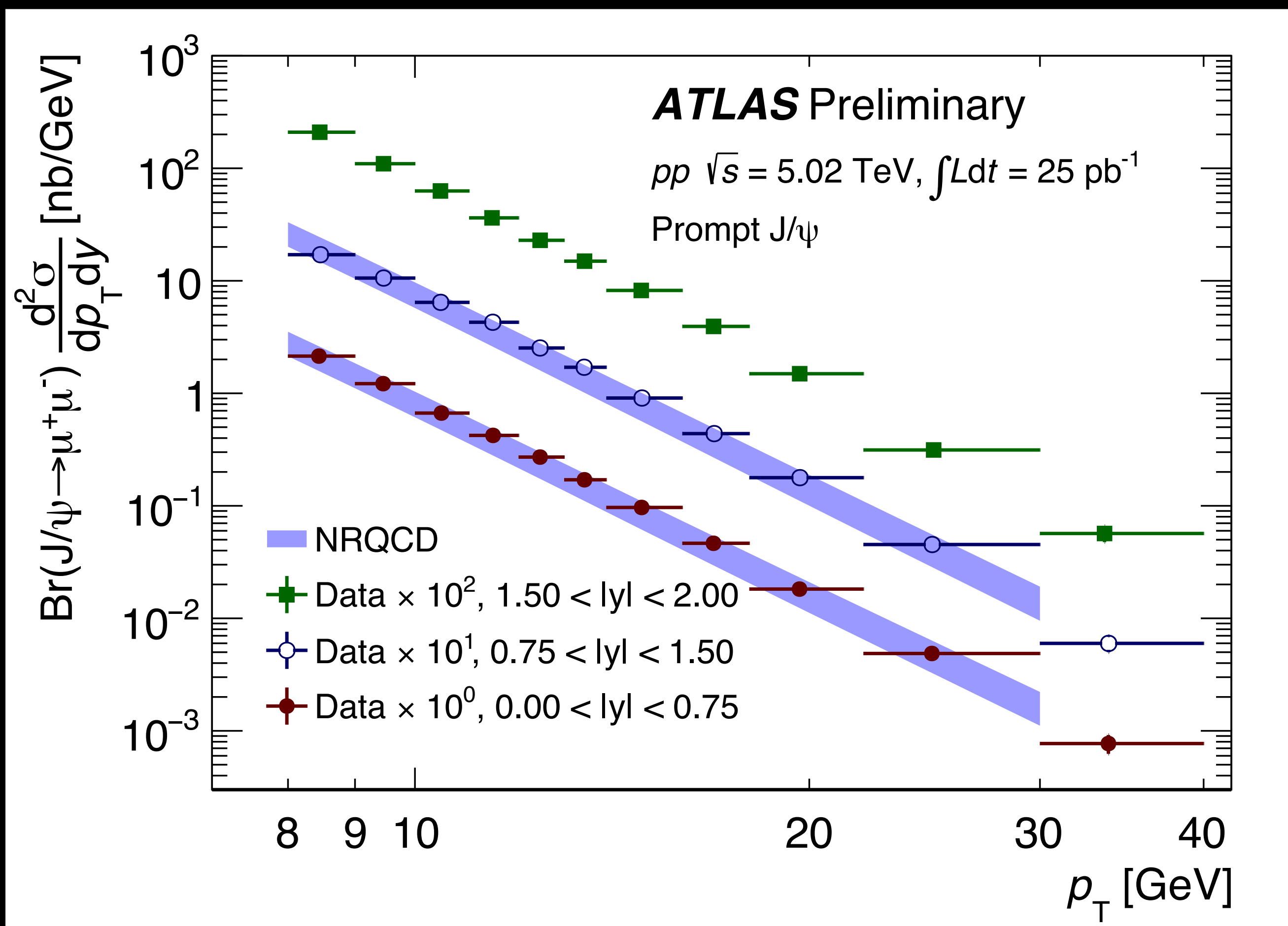
i	Type	Source	$f_i(m)$	$h_i(\tau)$
1	J/ψ S	P	$\omega_i \mathrm{CB}_1(m) + (1-\omega_i)\mathrm{G}_1(m)$	$\delta(\tau)$
2	J/ψ S	NP	$\omega_i \mathrm{CB}_1(m) + (1-\omega_i)\mathrm{G}_1(m)$	$\mathrm{E}_1(\tau)$
3	$\psi(2S)$ S	P	$\omega_i \mathrm{CB}_2(m) + (1-\omega_i)\mathrm{G}_2(m)$	$\delta(\tau)$
4	$\psi(2S)$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

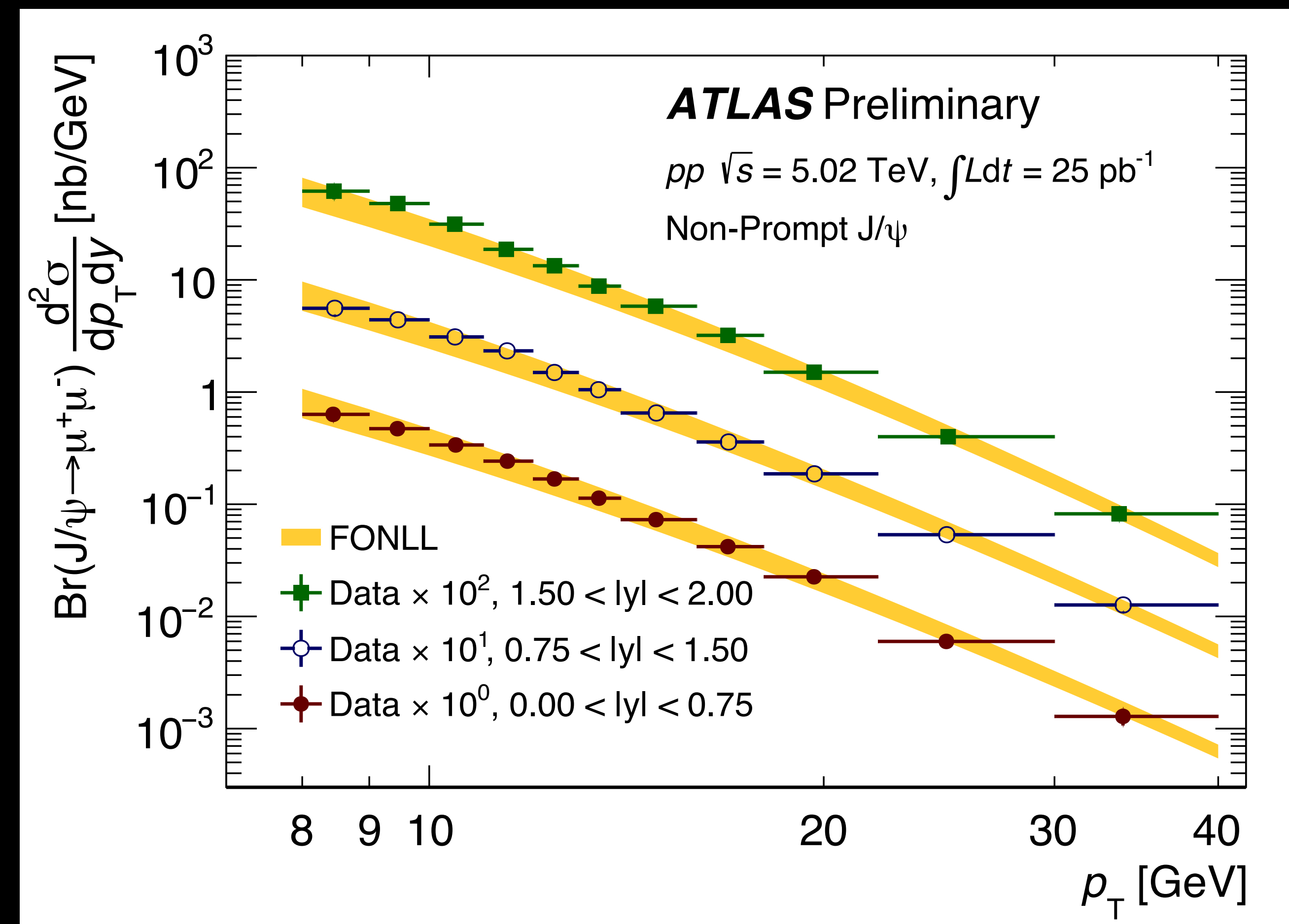
The composite PDF terms are defined as follows:

- CB - Crystal Ball;
- G - Gaussian;
- E - Exponential;
- Resolution function $g(\tau)$ is a double Gaussian function;
- δ - delta function.

Differential Cross Section

Prompt and Non-prompt J/ψ production



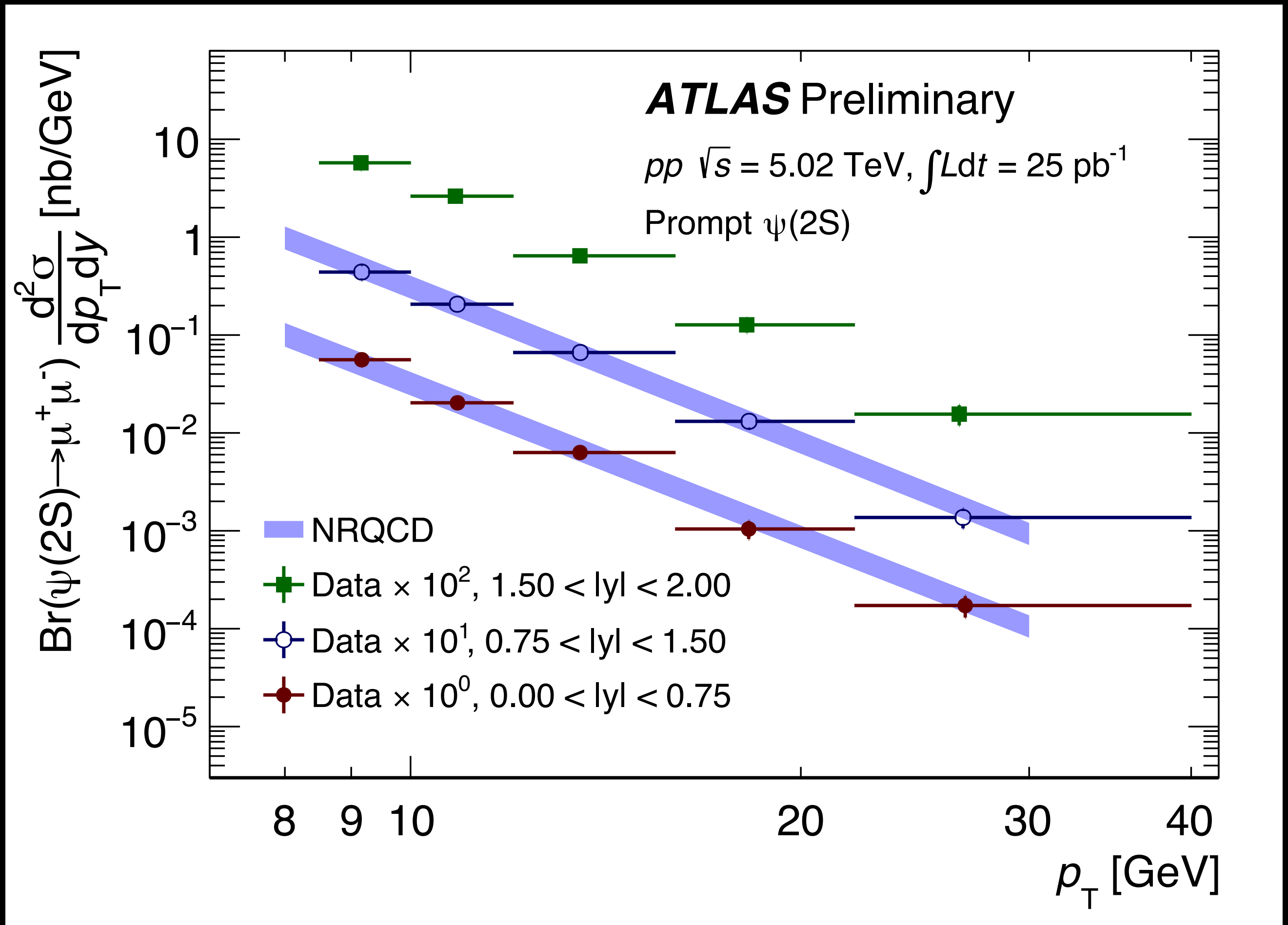


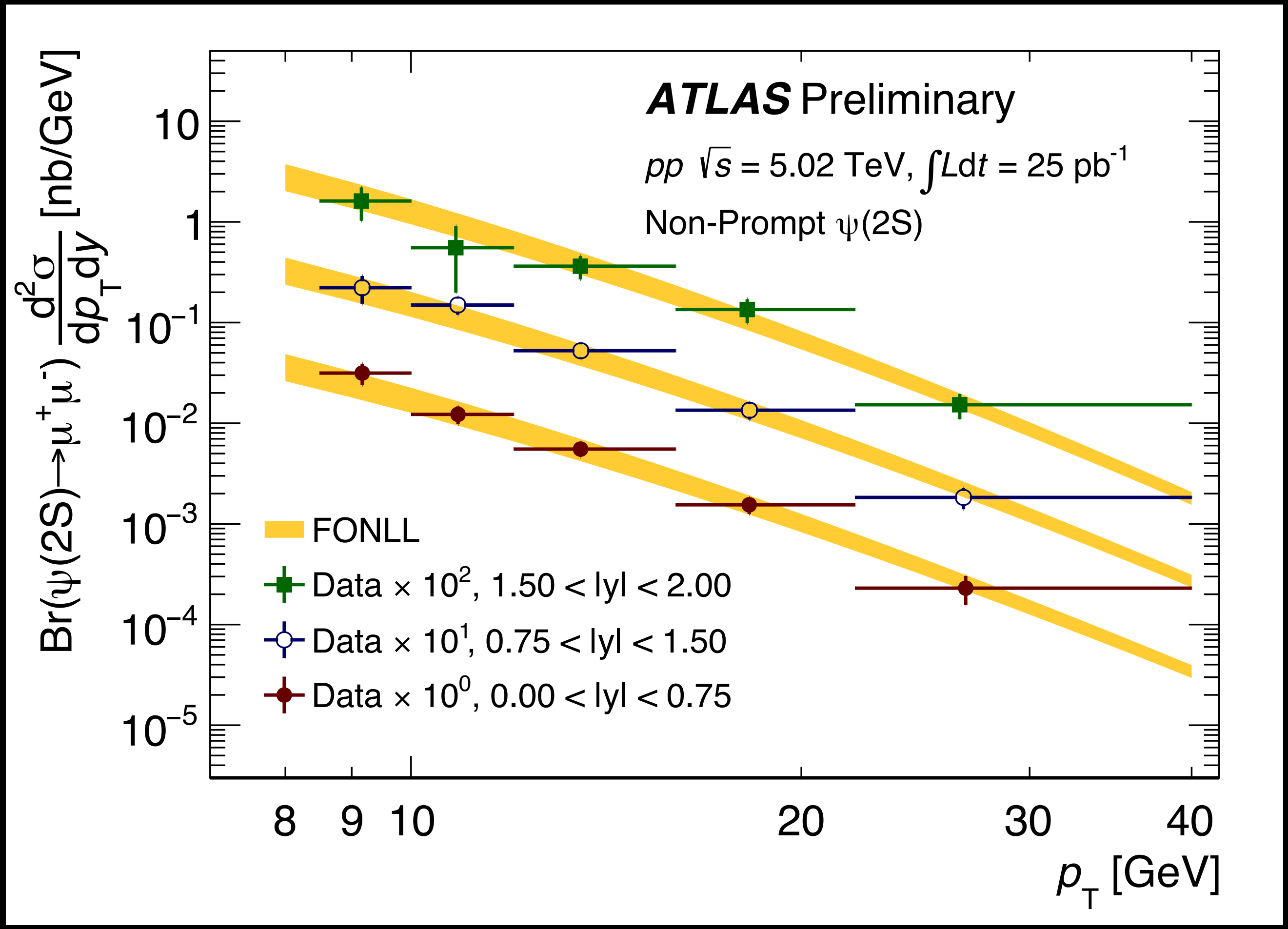
NRQCD and FONLL model the data very well, the comparison is limited by the uncertainties on the theory, not on the experiment.

ATLAS-CONF-2016-109

Differential Cross Section

Prompt and Non-prompt ψ(2S) production

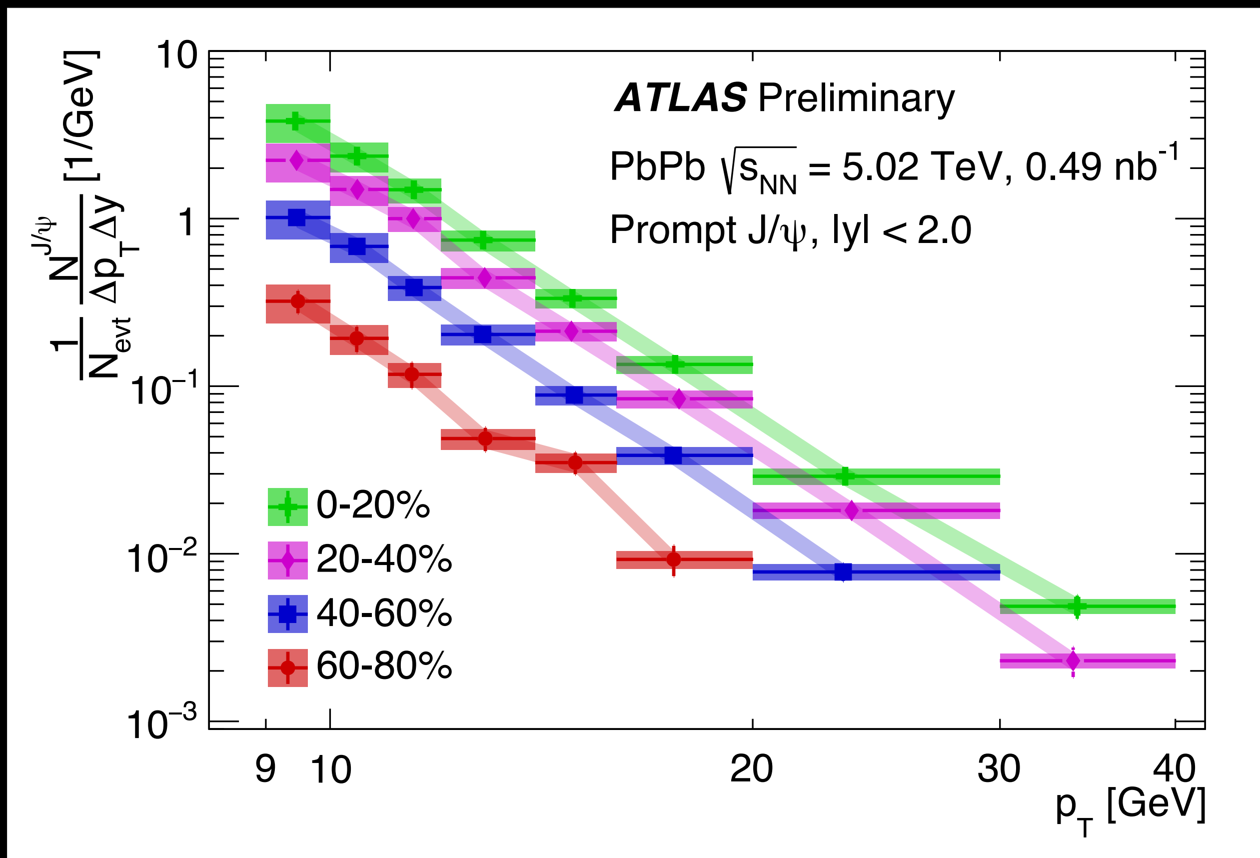


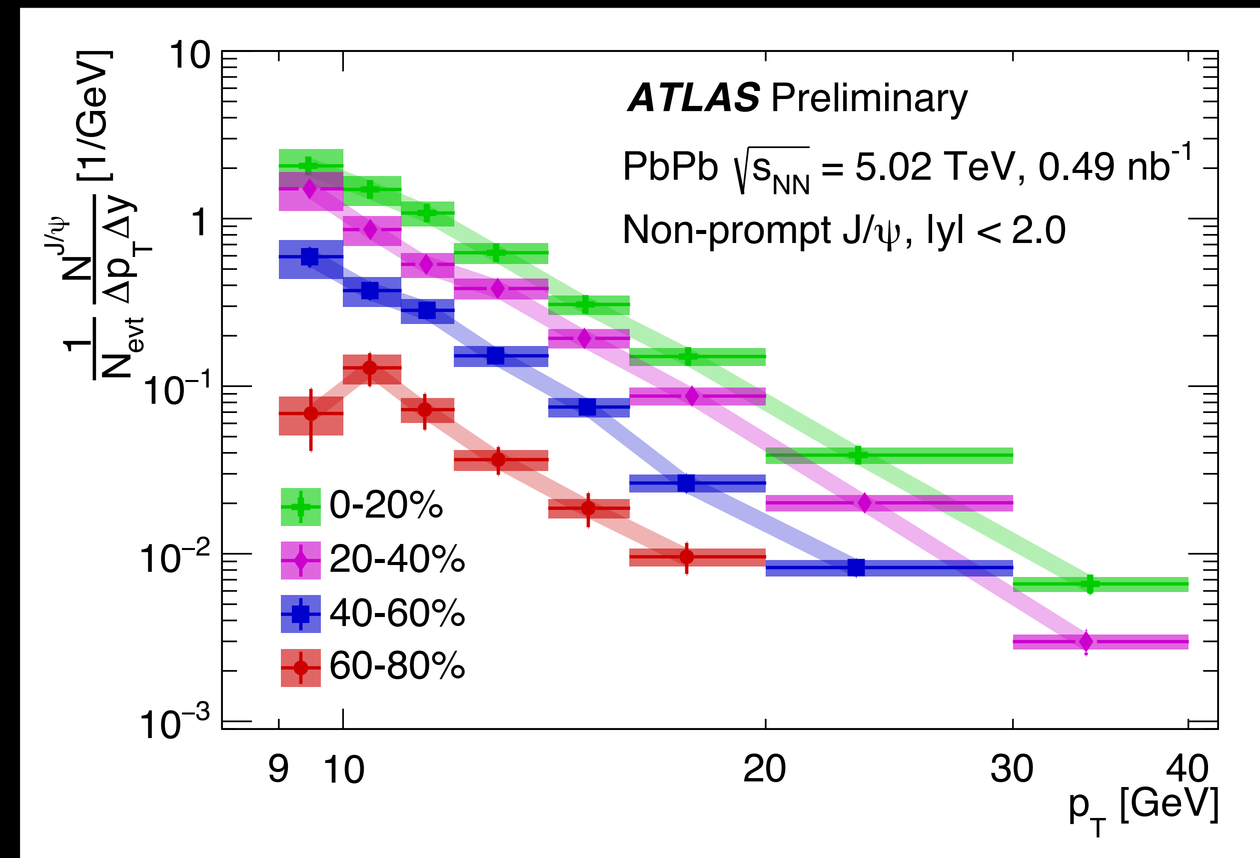


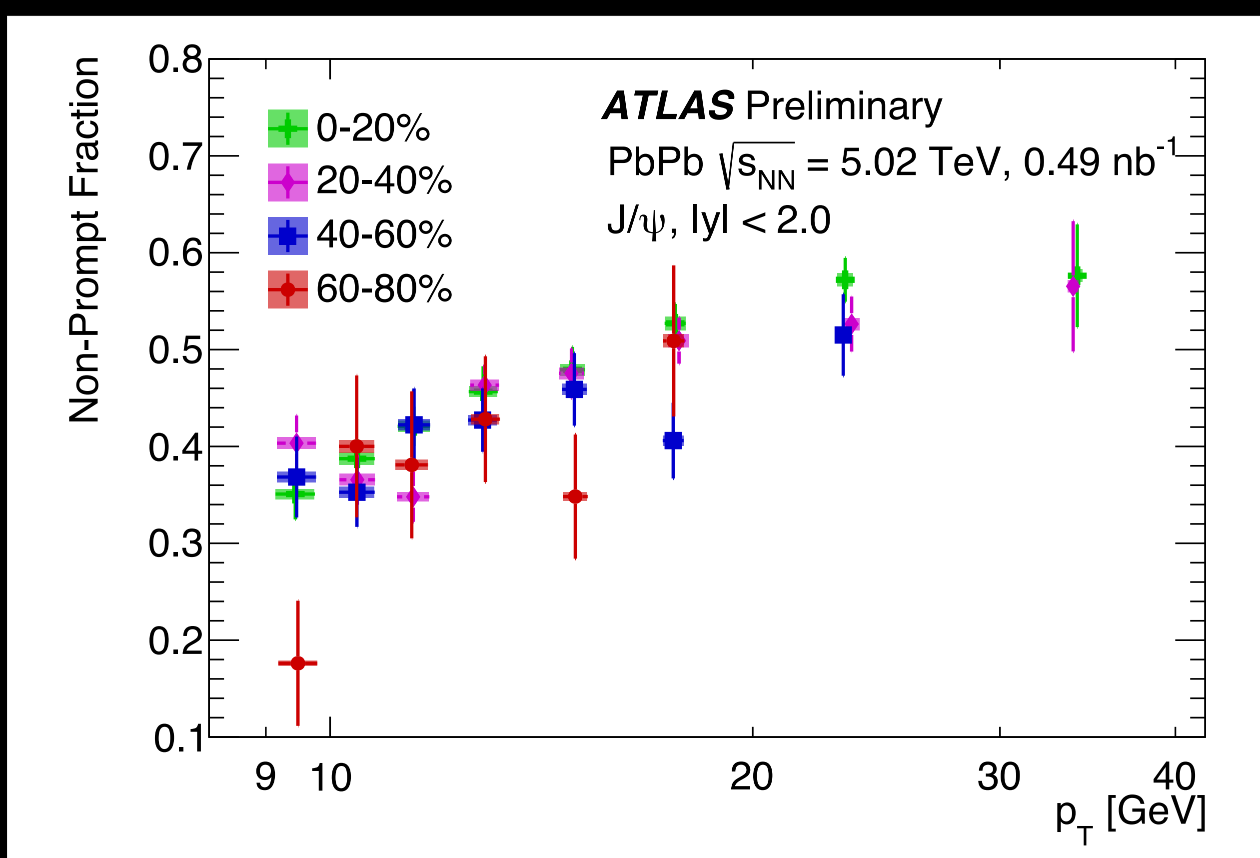
The data are in very good agreement with the theoretical prediction within the uncertainties.

ATLAS-CONF-2016-109

Per-event-yields prompt and non-prompt J/ψ

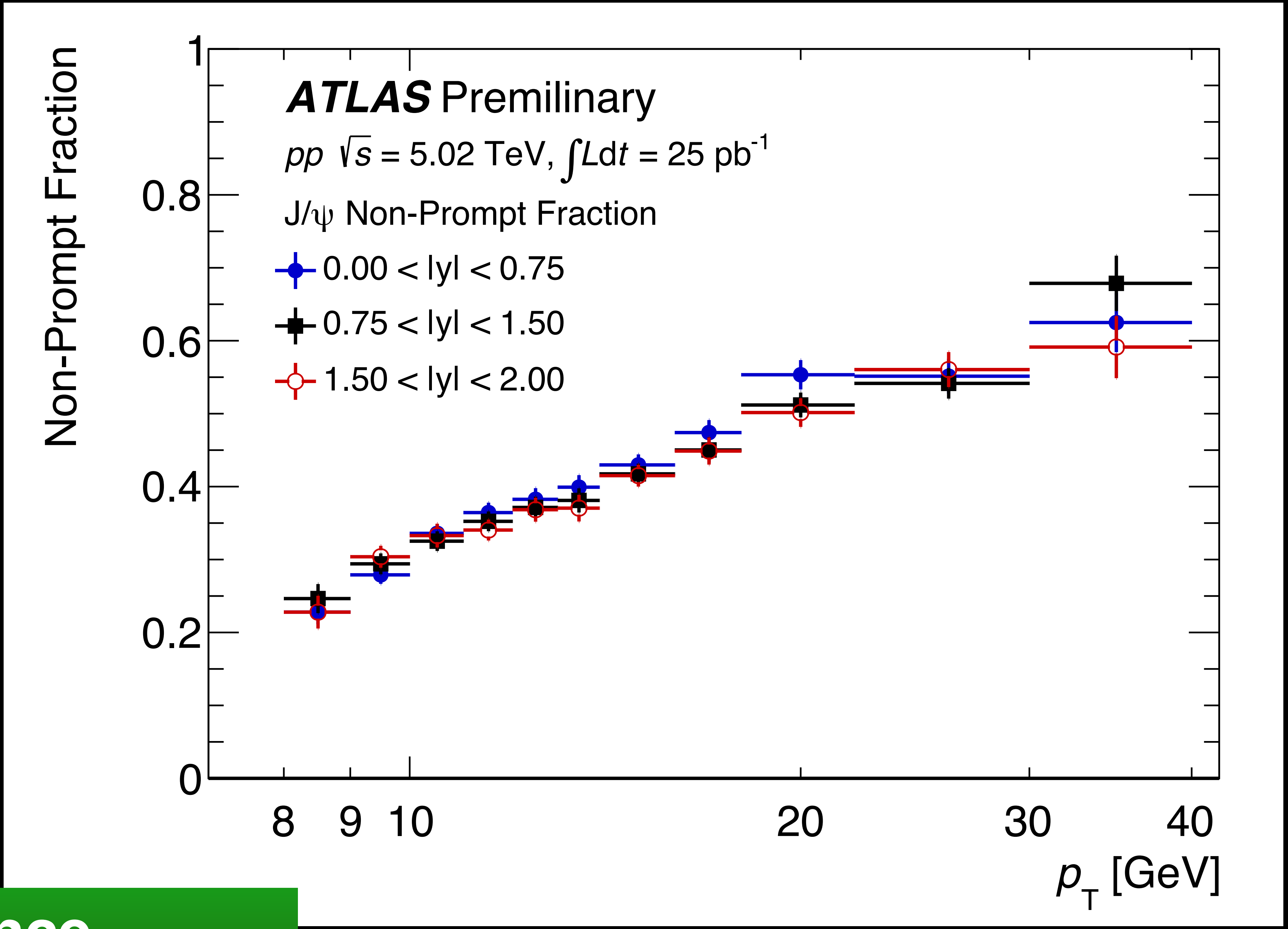






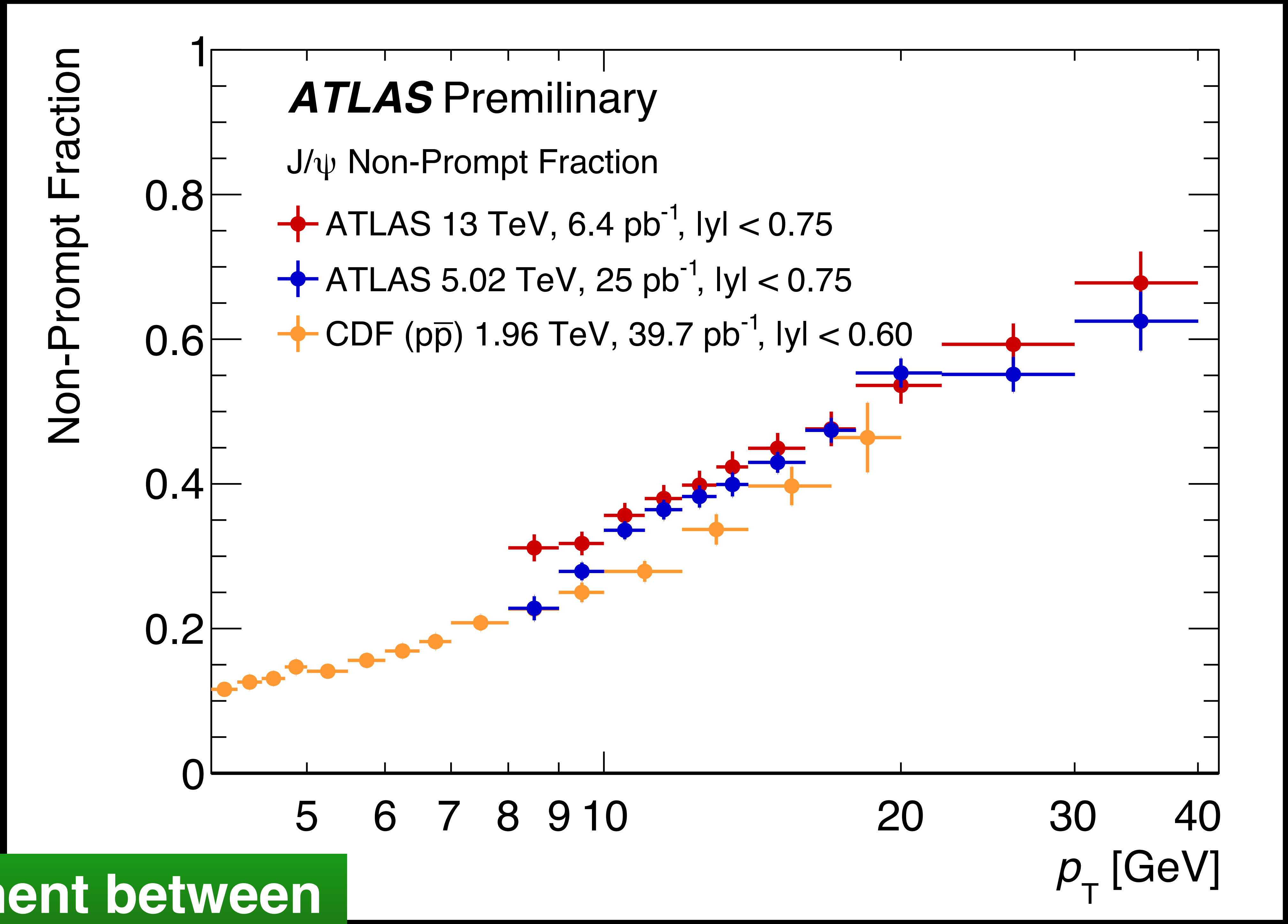
Non-prompt fraction of J/ψ in pp 5.02 TeV vs. pT for |y| slices

$$f_{\mathrm{NP}}^{\psi(nS)} = \frac{N_{\mathrm{NP}}^{\psi(nS)}}{N_{\mathrm{NP}}^{\psi(nS)} + N_{\mathrm{P}}^{\psi(nS)}}$$



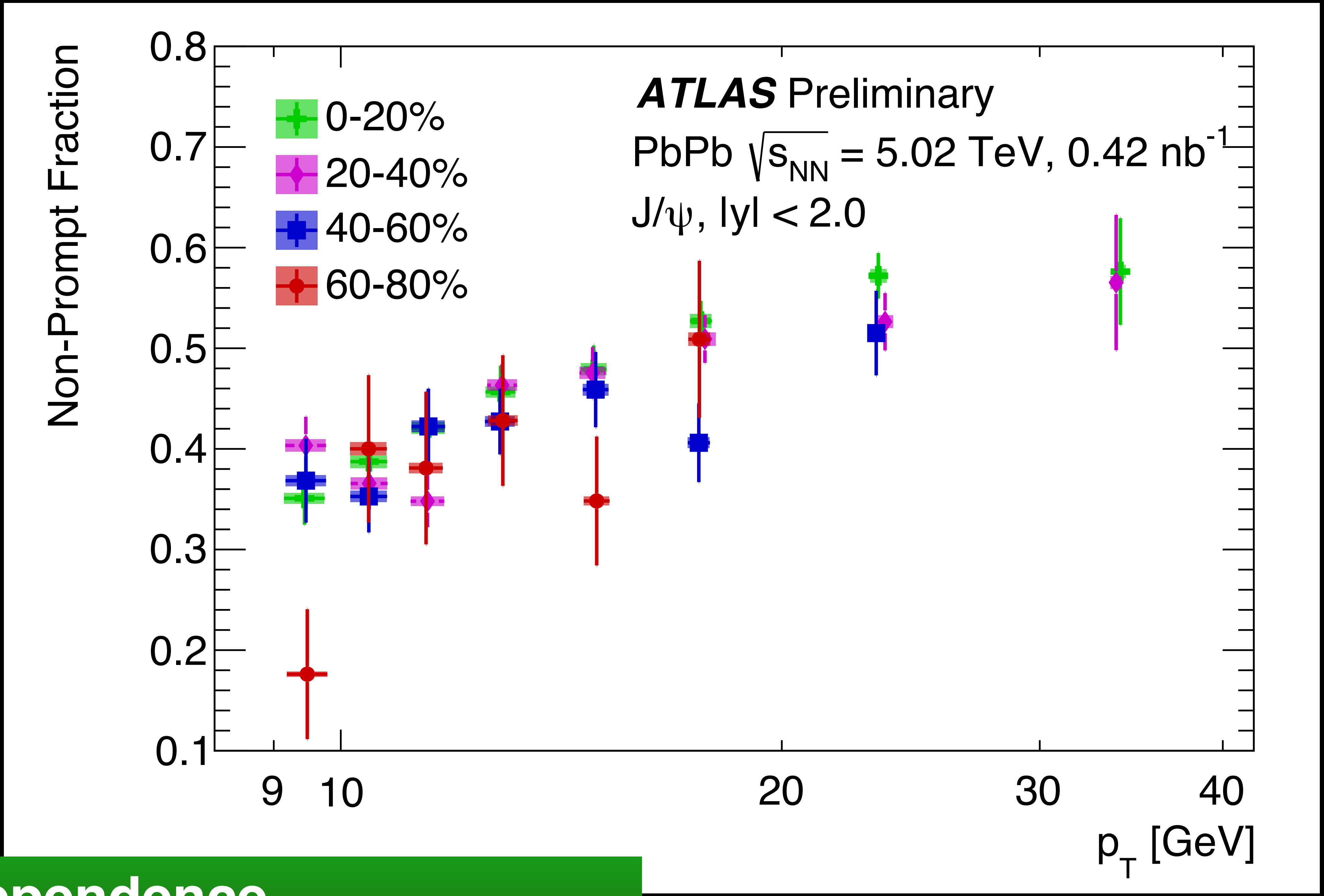
Strong pT dependence
No significant lyl dependence

Non-prompt fraction of J/ψ in pp 5.02 TeV, 13 TeV and 1.96 TeV



fairly agreement between the different energies

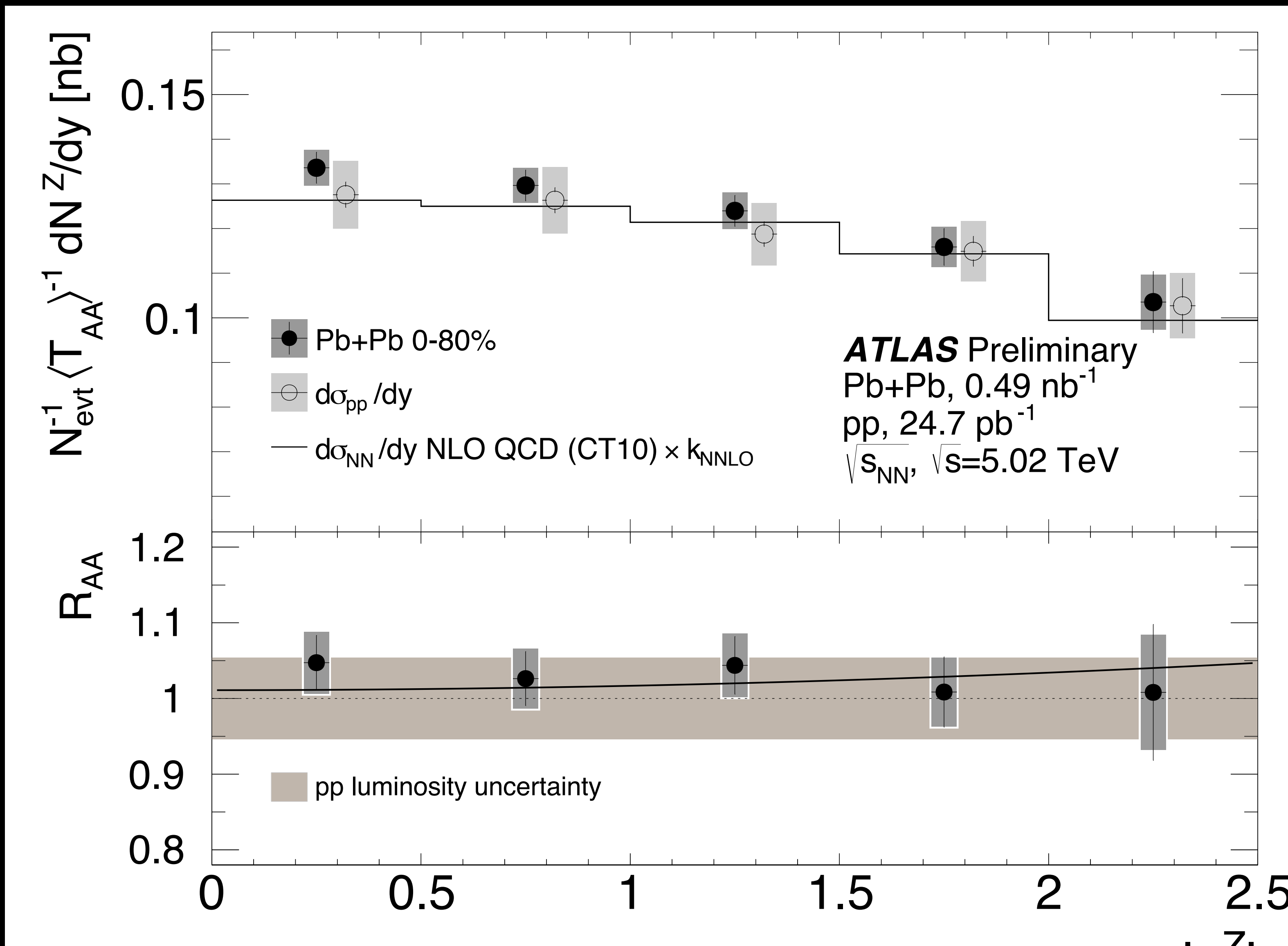
Non-prompt fraction of J/ψ in Pb+Pb 5.02 TeV



Strong pT dependence

No significant centrality dependence

PbPb Nuclear modification factor



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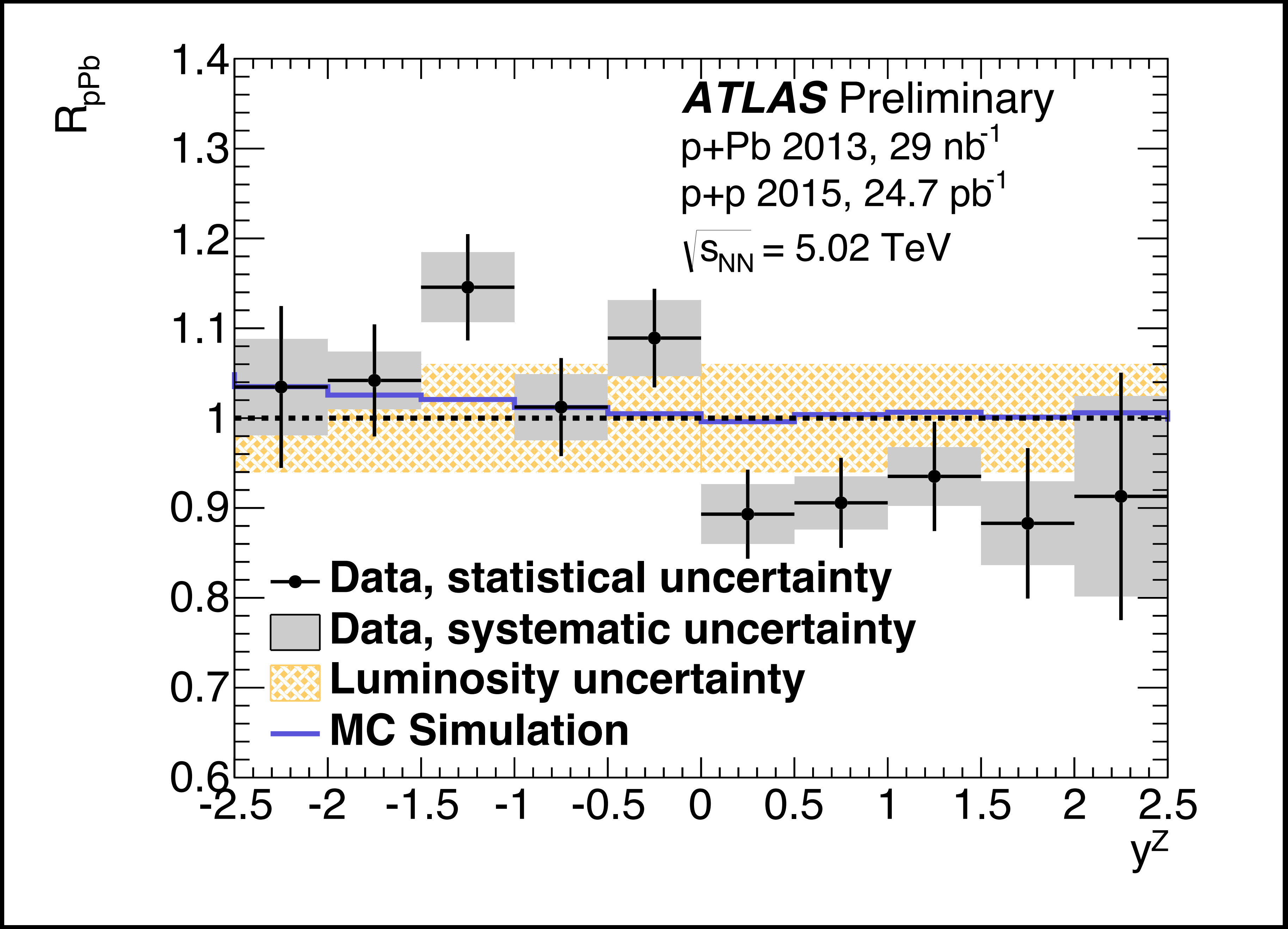
$$R_{AA} = \frac{N_{AA}}{\langle T_{AA}\rangle \sigma^{pp}}$$

pp data agree with pQCD calculations

Good agreement between pp and PbPb after scaling

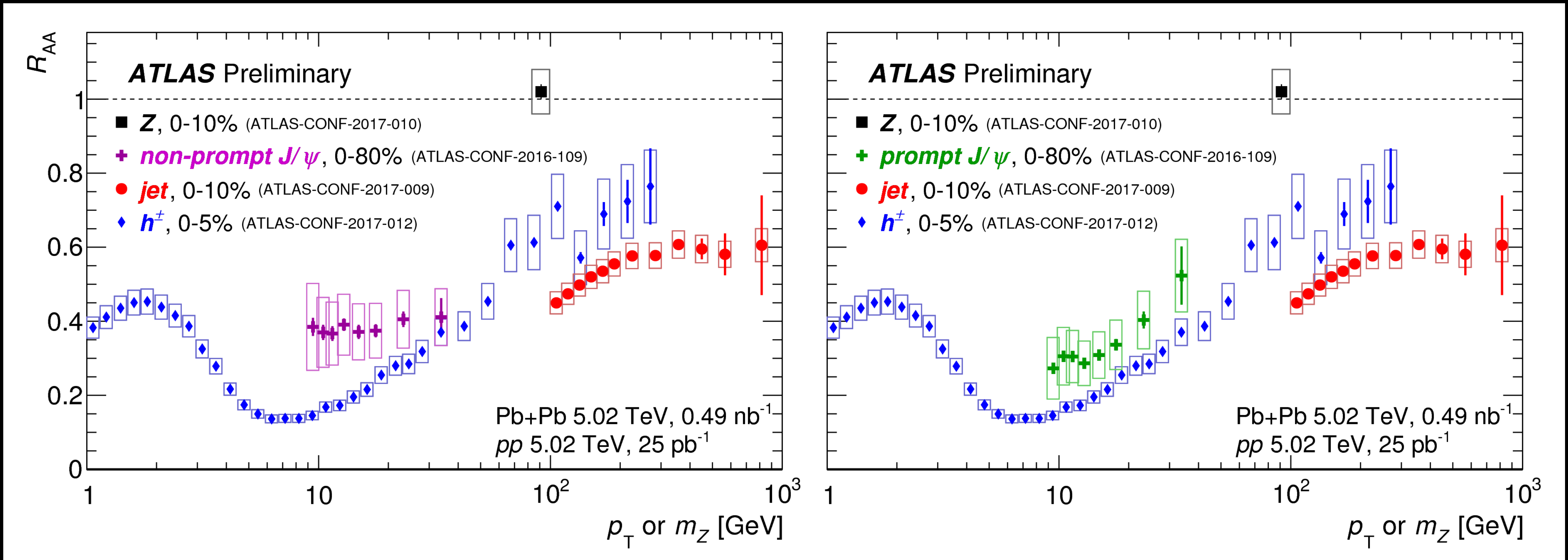
A hint of nPDF effects but not clear with the current resolution

pPb Nuclear modification factor



Suppression is observed at forward rapidity consistent with nuclear shadowing.

R_{AA} of different probes



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults