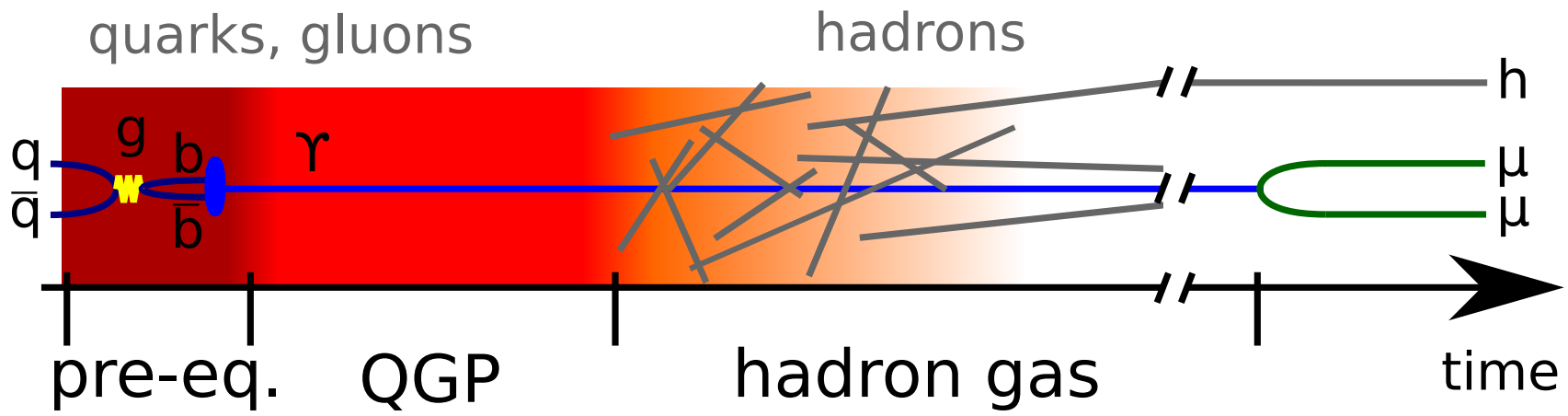
Recent charmonium and bottomonium results from CMS in heavy ion collisions

Émilien Chapon
on behalf of the CMS experiment

CERN

QWG 2017
12th International Workshop on Heavy Quarkonium

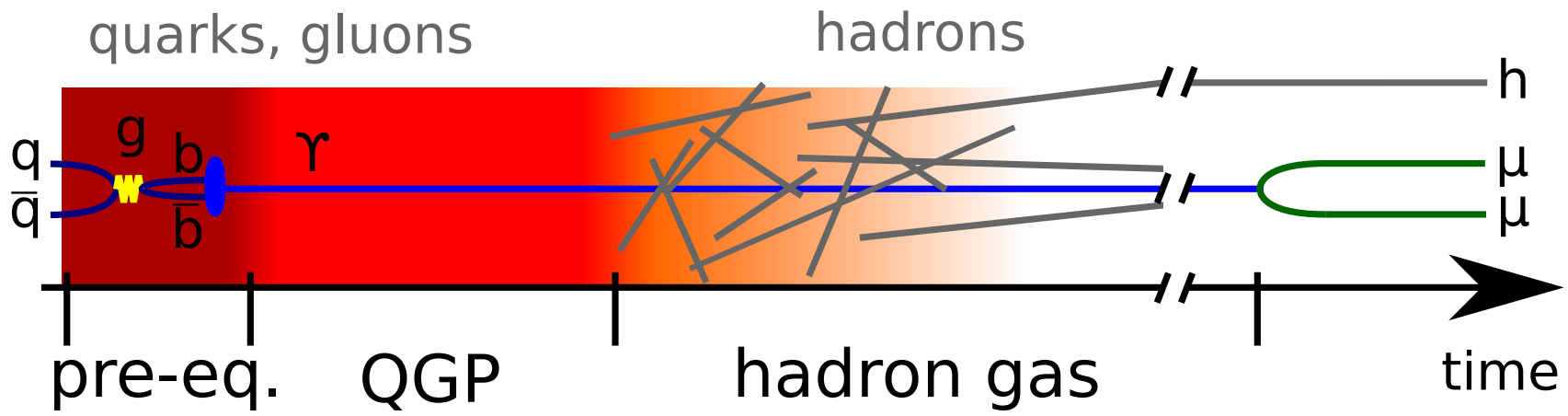
Quarkonia in heavy ion collisions



Quarkonia are **good probes of the medium evolution**

- Excellent probes for the **Quark Gluon Plasma**
  - **Color screening**: melting depending on temperature and binding energy
  - **Regeneration** (mostly for charmonia)
  - **Energy loss** at high p_T

Quarkonia in heavy ion collisions



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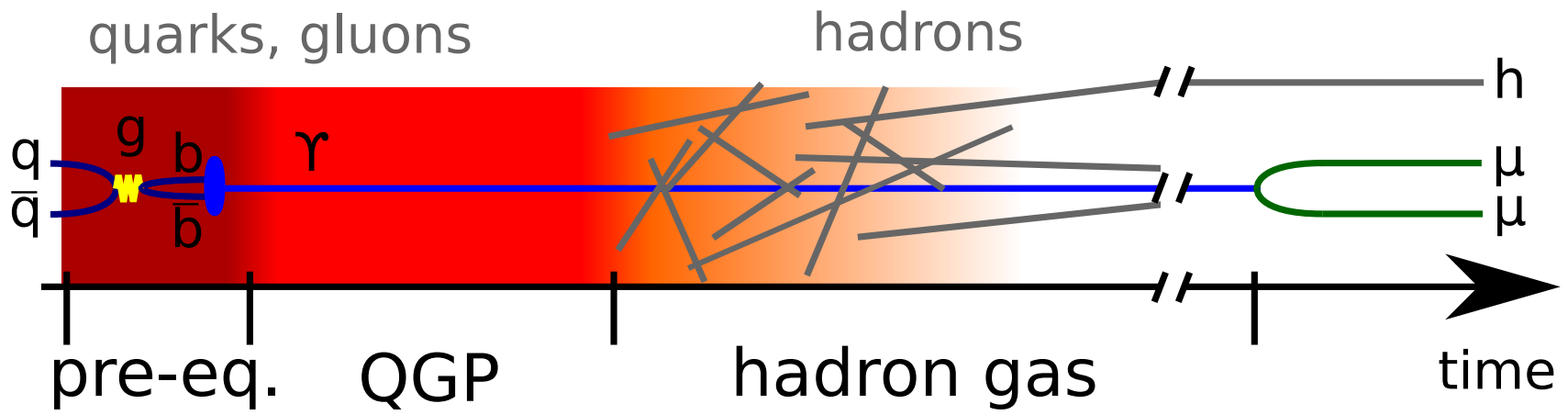
- Also sensitive to **cold nuclear matter effects**
  - Nuclear PDFs, coherent energy loss, interaction with comovers?

Quarkonia in heavy ion collisions



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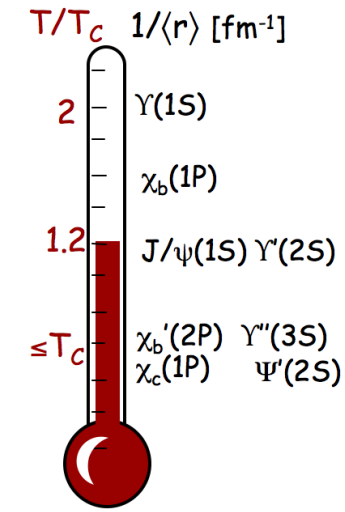
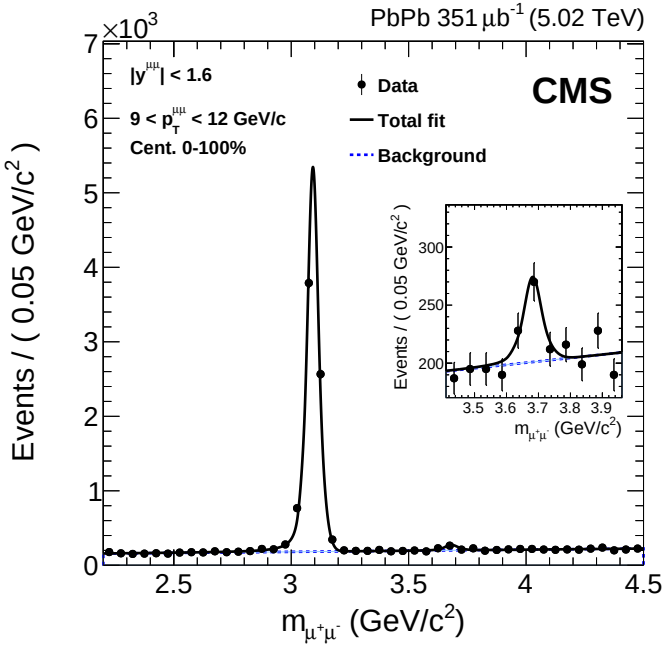
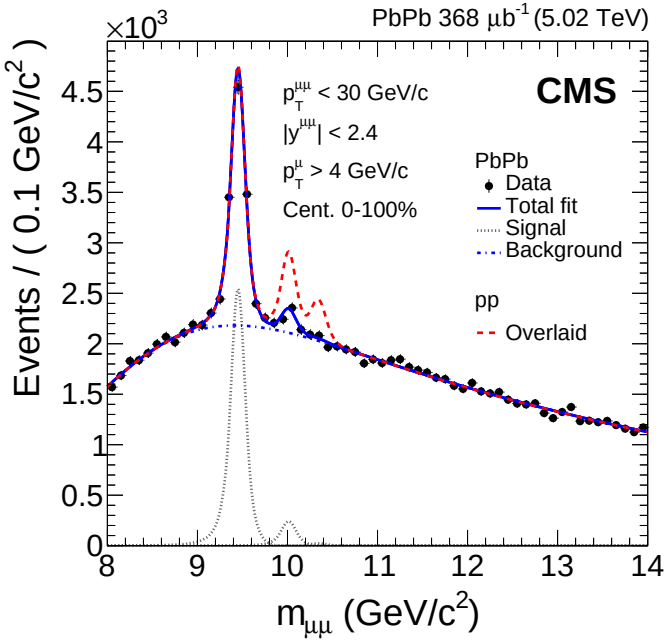
  - **Energy loss** at high p_T
- Also sensitive to **cold nuclear matter effects**
  - Nuclear PDFs, coherent energy loss, interaction with comovers?
- **A family of states** (J/ψ, ψ(2S), Υ(1S,2S,3S)) to explore the importance of quark flavour, mass, binding energy



Signal extraction

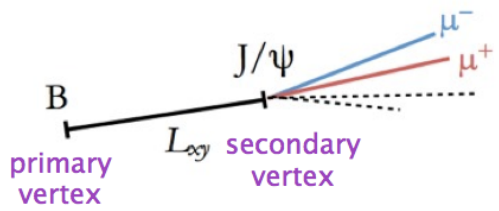




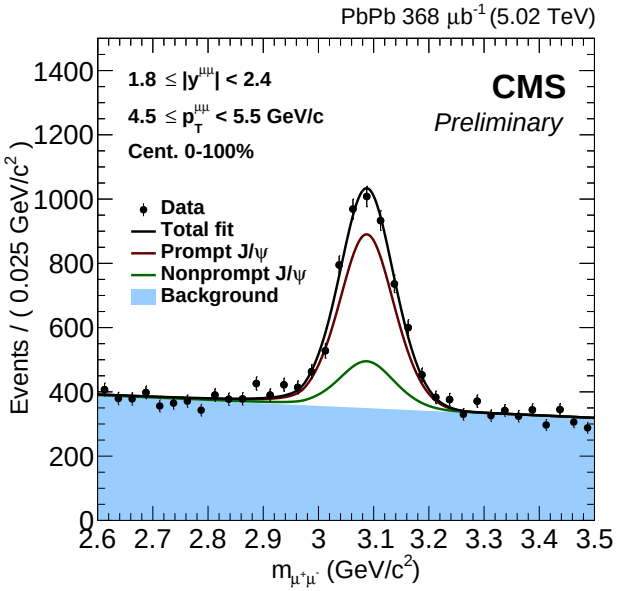
- Extract the different resonances (J/ψ, ψ(2S), Υ(nS)) from a fit to $M_{\mu^+\mu^-}$
- In the case of charmonia: need to reject B meson feed-down

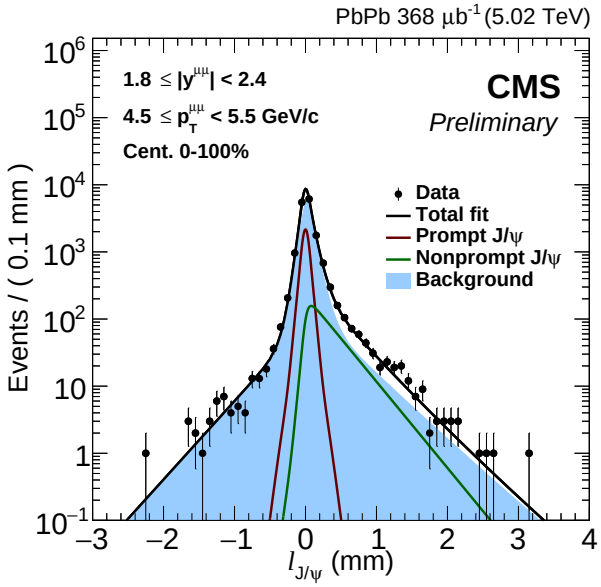
Prompt and nonprompt J/ψ

- Prompt J/ψ
  - Direct J/ψ
  - Feed-down from ψ(2S) and χ_c
- Nonprompt J/ψ, from B decays



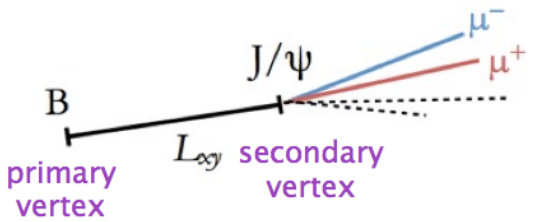
Prompt vs nonprompt charmonia



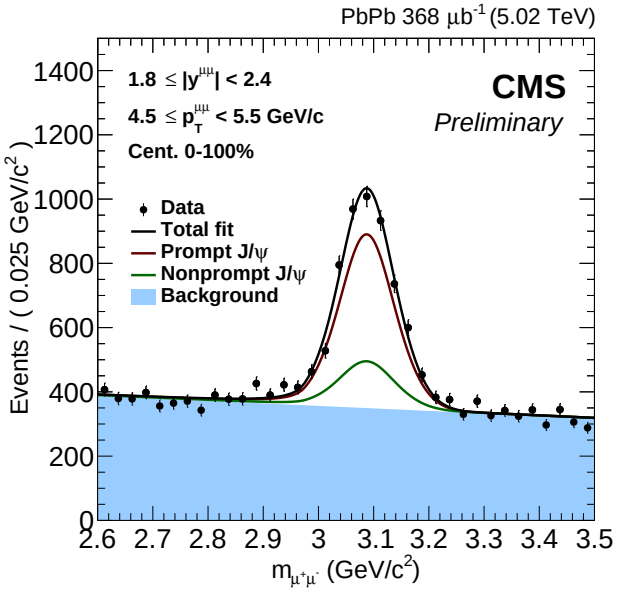


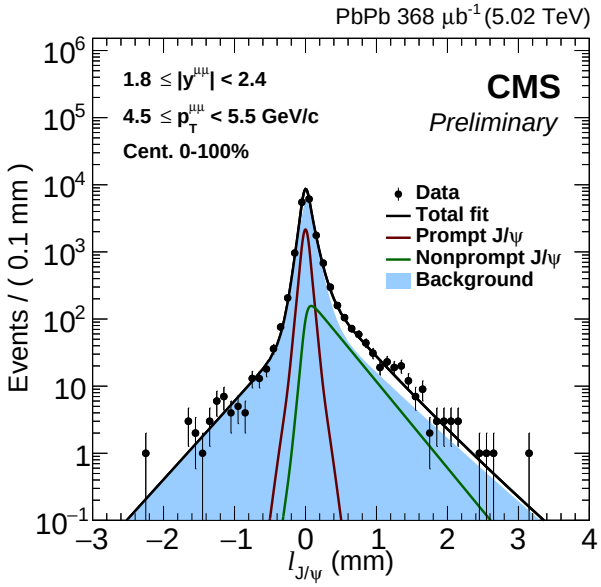
Two methods:

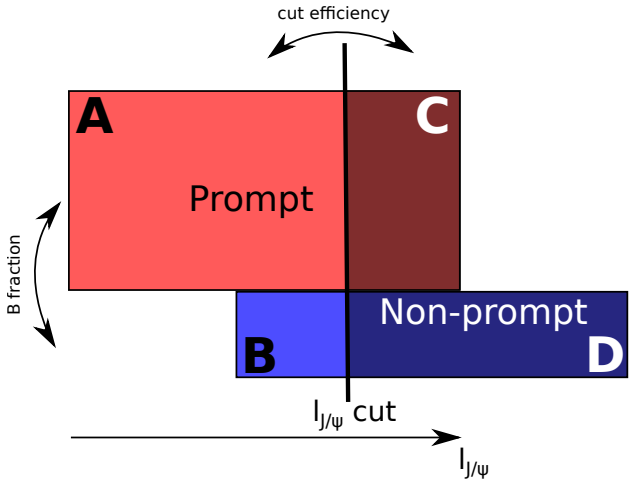
- **2D fits** of dimuon mass and pseudo-proper decay length $\ell_{J/\psi} = L \cdot \frac{m_{J/\psi}}{p_{\mu\mu}}$



Prompt vs nonprompt charmonia

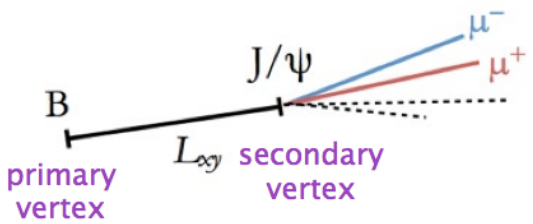






Two methods:

- **2D fits** of dimuon mass and pseudo-proper decay length $\ell_{J/\psi} = L \cdot \frac{m_{J/\psi}}{p_{\mu\mu}}$
- Rejecting nonprompt **using a cut** on $\ell_{J/\psi}$
  - Used for the $\psi(2S)$ because of the smaller S/B
  - Data-driven correction for the nonprompt contamination in the low $\ell_{J/\psi}$ region



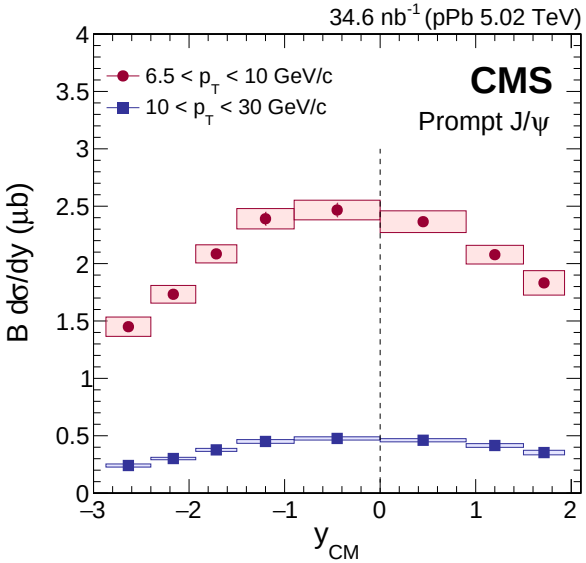
Outline

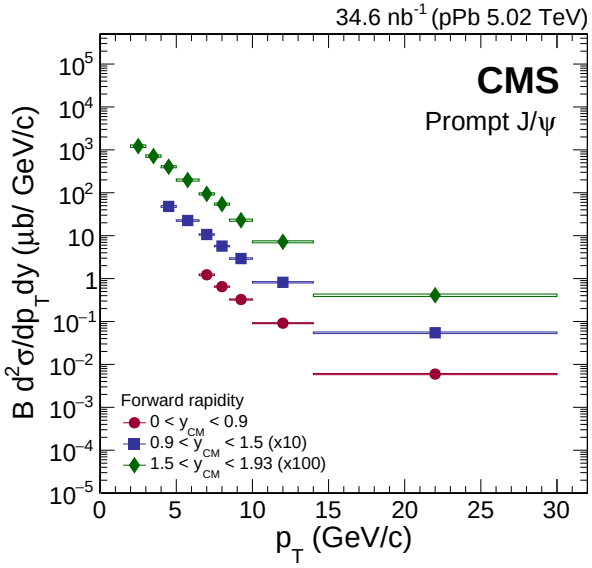
1. pPb collisions
   - Prompt J/ψ
   - Prompt ψ(2S)
2. PbPb collisions
   - Prompt J/ψ
   - Prompt ψ(2S)
   - Υ(nS)

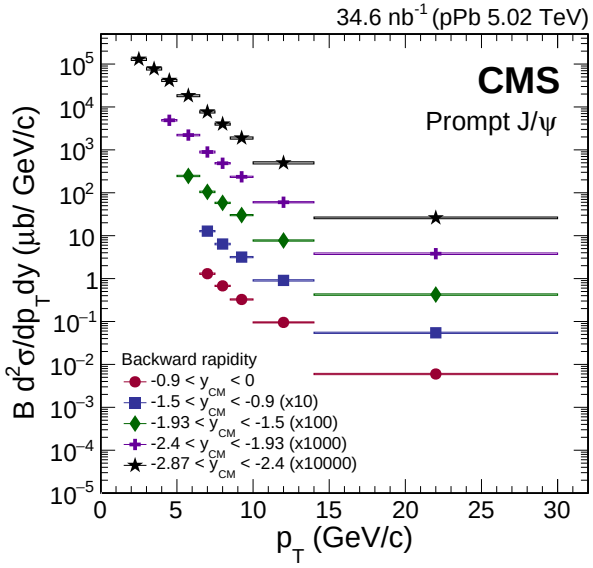
Outline

Cross sections: prompt J/ψ in pPb (and pp) (5.02 TeV)

EPJC 77 (2017) 269

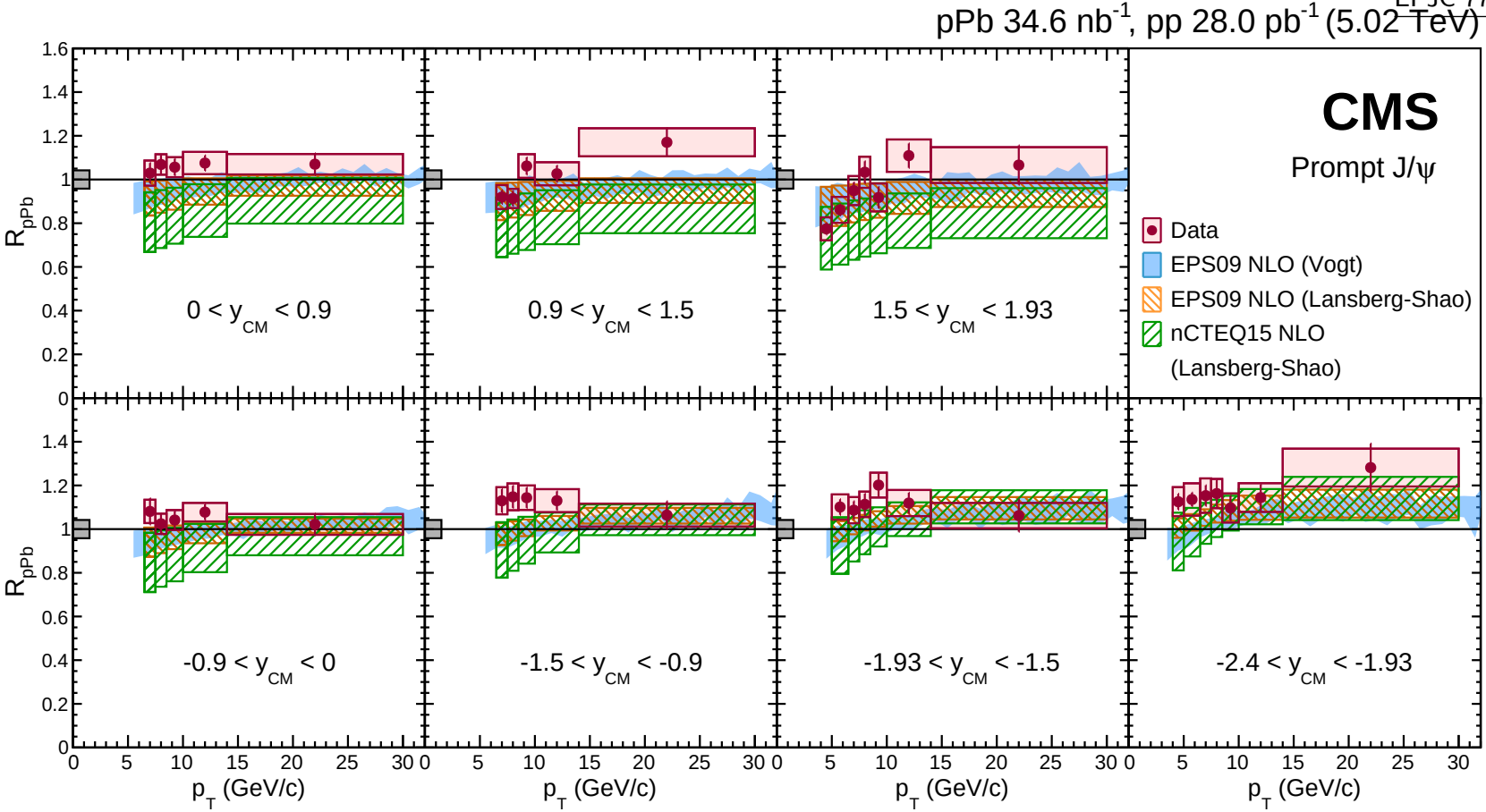






- Available in pp and pPb at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$
- Measured over a wide kinematic range ($2 < p_\text{T} < 30\,\text{GeV}/c$, $-2.87 < |y_{CM}| < 1.93$)
- Direct input to production models

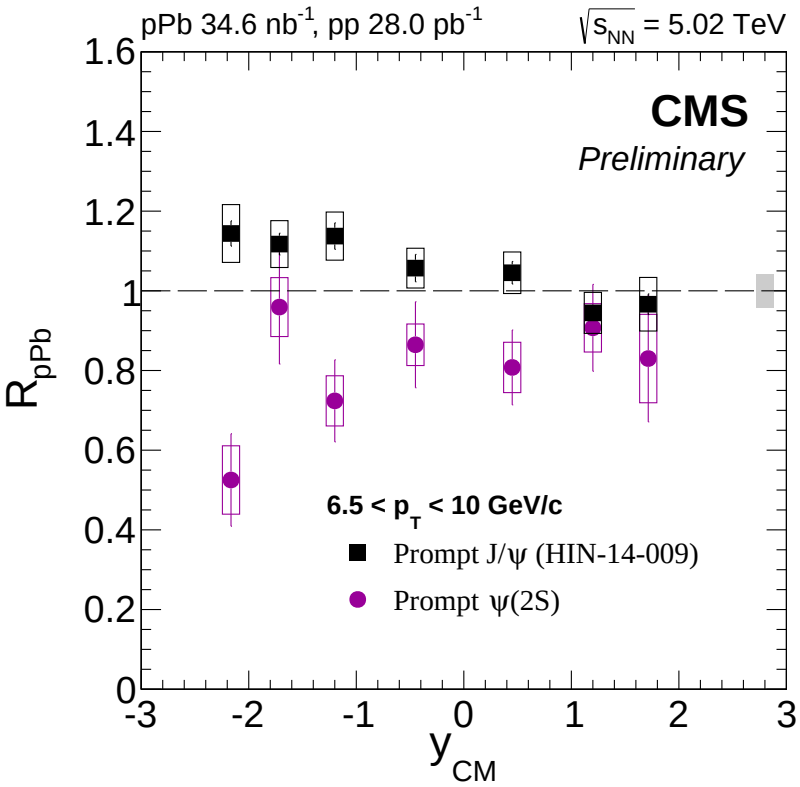
Nuclear modification factors: prompt J/ψ (5.02 TeV)

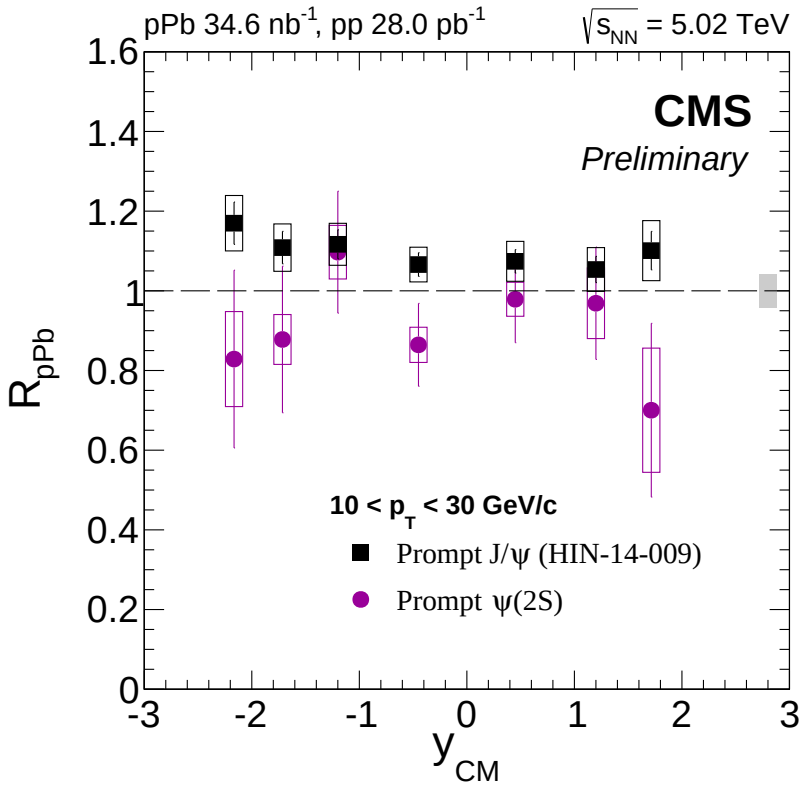


- Prompt J/ψ R_{pA} above unity in most bins
- Suppression only in the most forward bin ($1.5 < y_{CM} < 1.93$) for $p_{\mathrm{T}} < 7.5\,\mathrm{GeV}/c$
- nPDF calculations slightly lower than data

Excited vs. ground state: prompt $\psi(2S)$ vs prompt J/ψ (5.02 TeV)

CMS-PAS-HIN-16-015



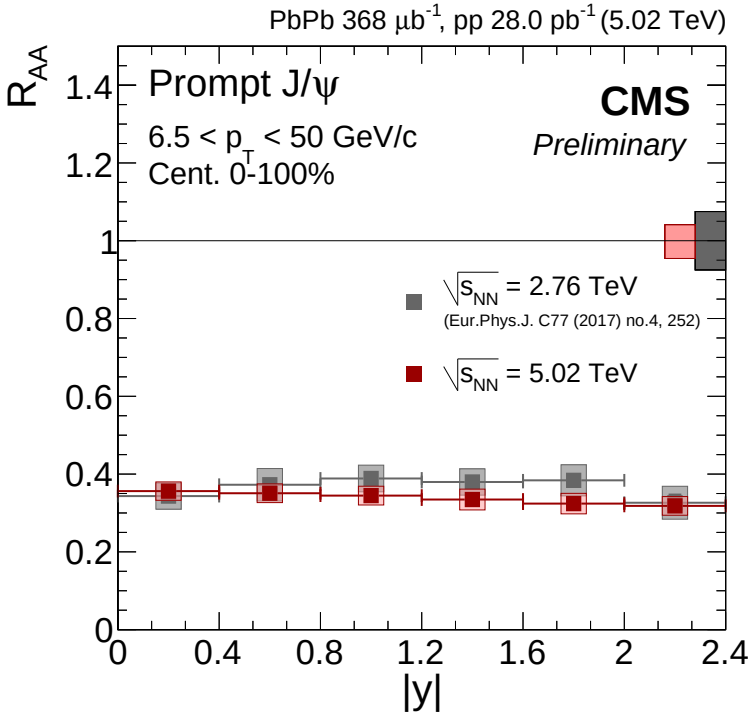


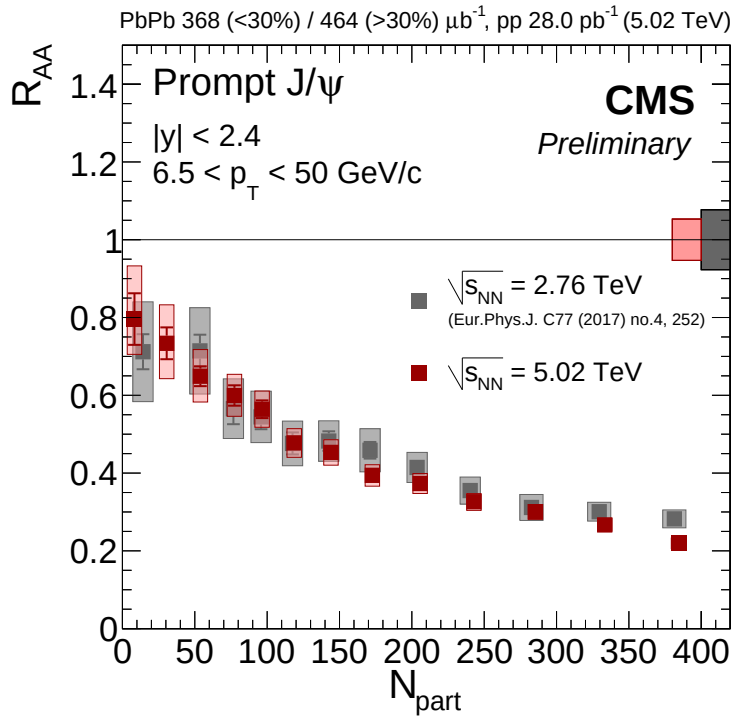
- Expecting similar effects from nPDF for J/ψ and $\psi(2S)$
- Hint for a different modification in the data (in the Pb-going direction)
- Is the more "fragile" $\psi(2S)$ affected by final state effects?

Outline

Nuclear modification factors: prompt J/ψ (2.76 TeV, 5.02 TeV)

CMS-PAS-HIN-16-025

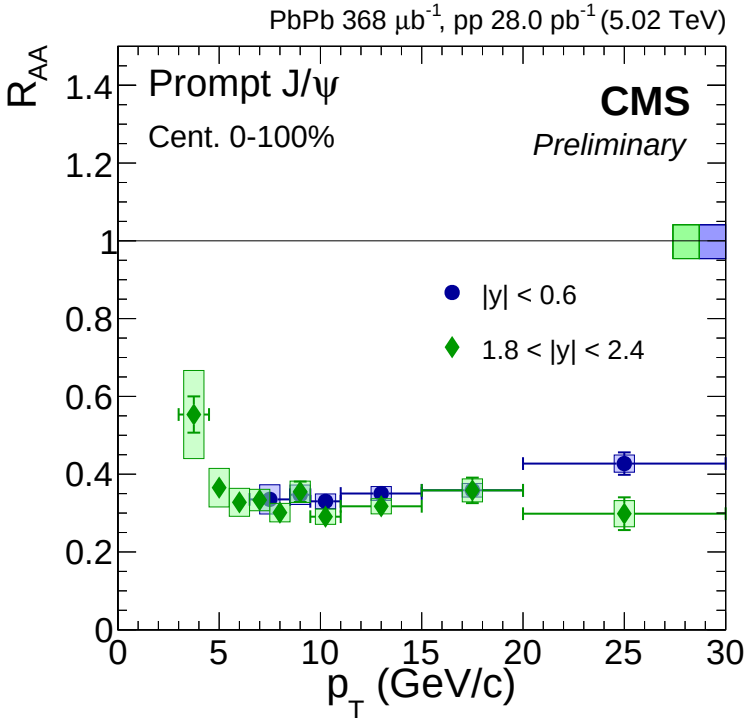


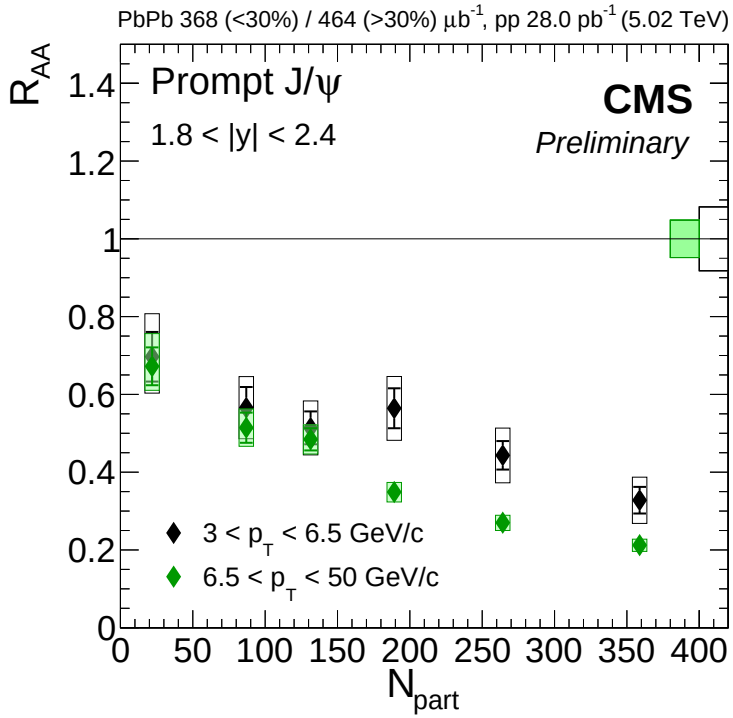


- Similar suppresion at 5.02 TeV and 2.76 TeV
- No strong rapidity dependence
- Suppression increases towards central events:
  $R_{AA}(0-5\%) = 0.219 \pm 0.005(\text{stat}) \pm 0.013(\text{syst})$

Nuclear modification factors: prompt J/ψ, low p_T (5.02 TeV)

CMS-PAS-HIN-16-025

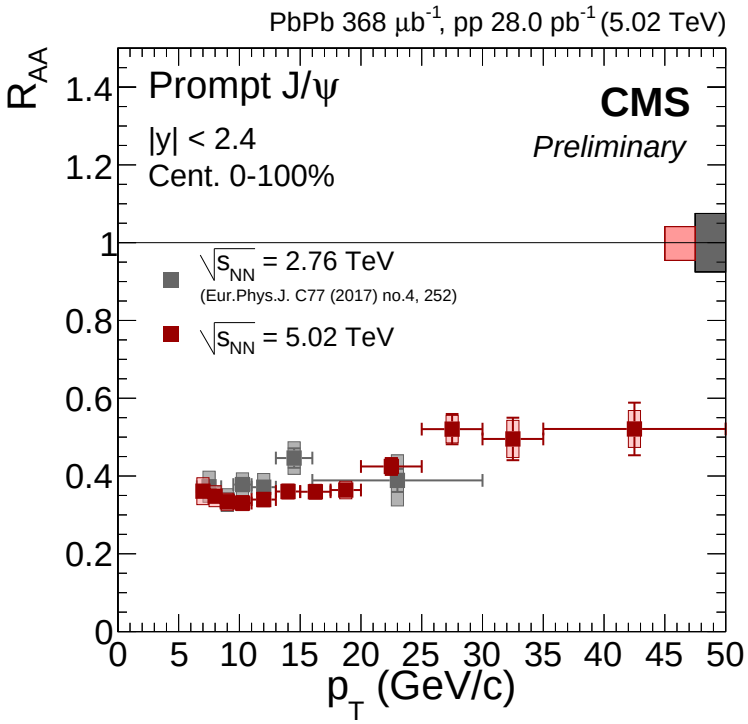


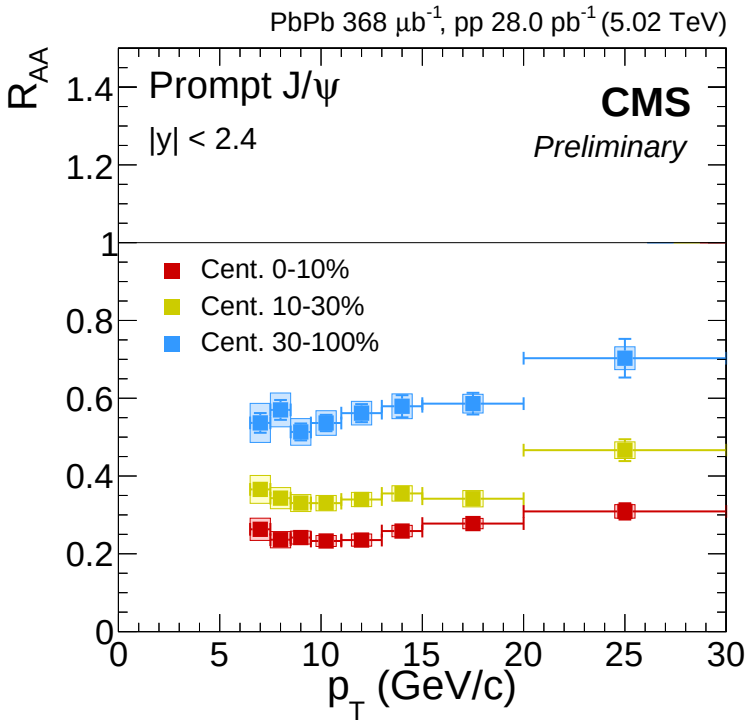


- Similar p_T trend for different rapidities
- Less suppression at lowest p_T
- Less suppression at lowest p_T for most central events ($> 30\%$): **hint of regeneration**?

Nuclear modification factors: prompt J/ψ, high p_T (2.76 TeV, 5.02 TeV)

CMS-PAS-HIN-16-025

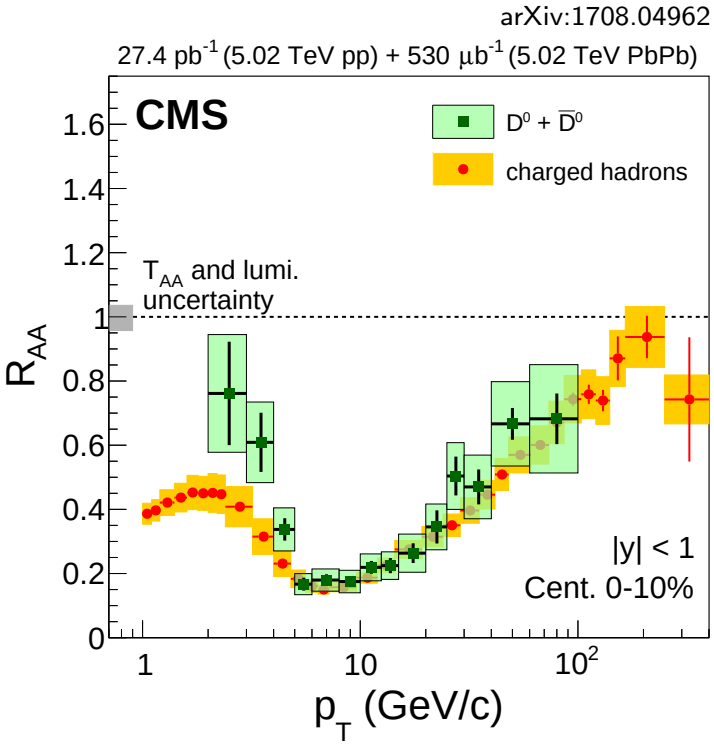


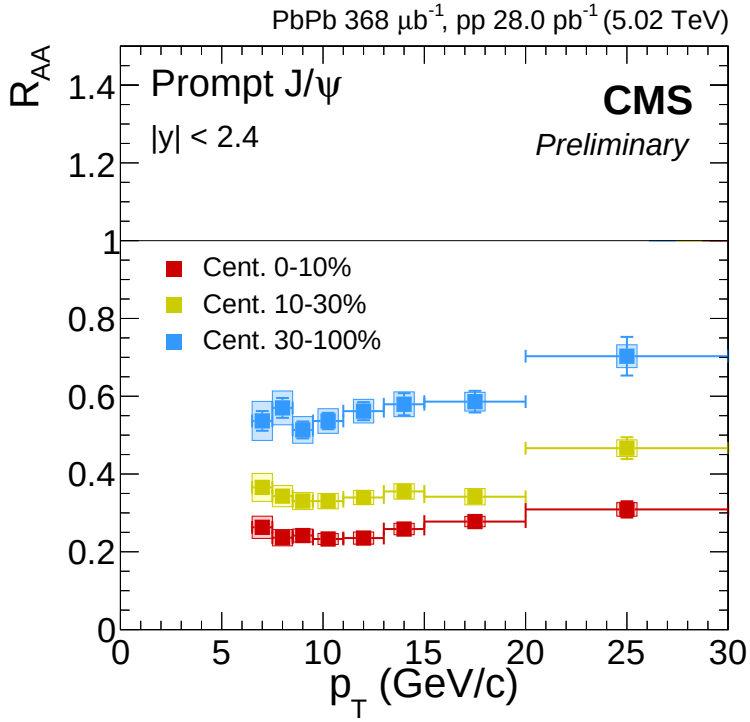


- Less suppression at high p_T: **contribution of energy loss**?
- Similar p_T trend vs centrality, with similar increase at high p_T

Nuclear modification factors: prompt J/ψ, high p_T (2.76 TeV, 5.02 TeV)

CMS-PAS-HIN-16-025





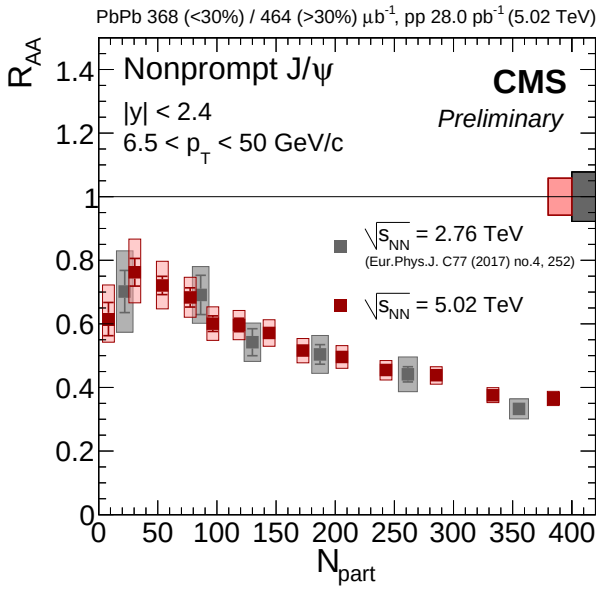
- Less suppression at high p_T: **contribution of energy loss**?
  - same as D mesons and charged hadrons?
- Similar p_T trend vs centrality, with similar increase at high p_T

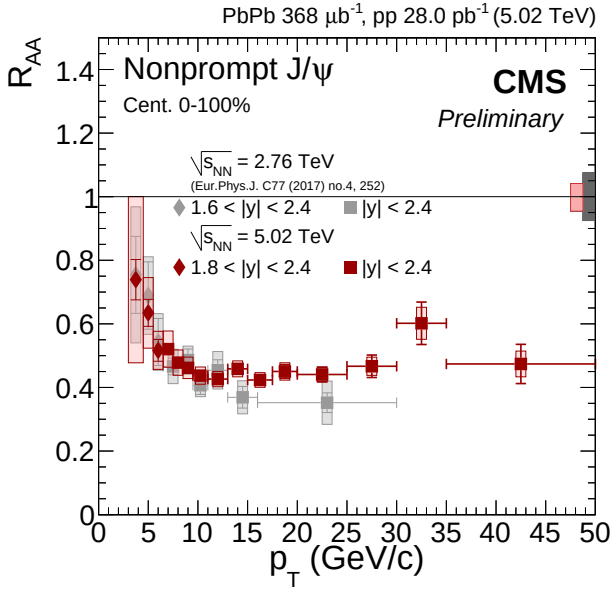
Nonprompt J/ψ (open beauty) (2.76 TeV, 5.02 TeV)

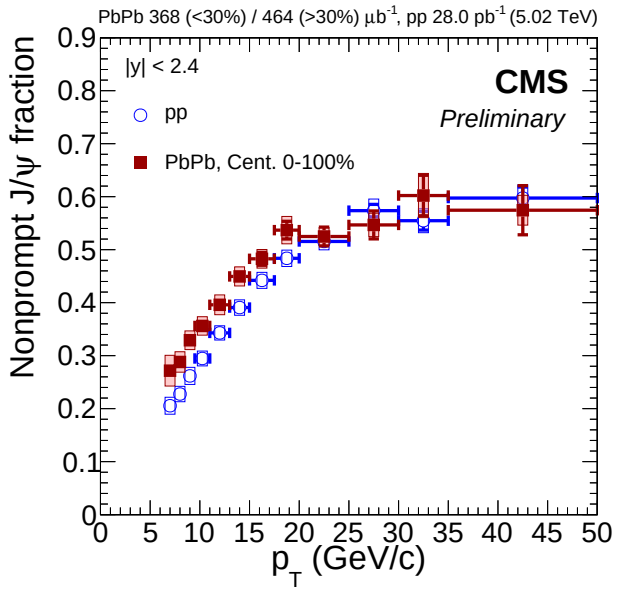
CMS-PAS-HIN-16-025

Also available: nonprompt J/ψ results (including B fractions)

- Probing **open beauty** (energy loss of b quarks, etc.) rather than **hidden charm**
- Similar suppression at 2.76 TeV and 5.02 TeV
- Hint for less suppression at low p_T



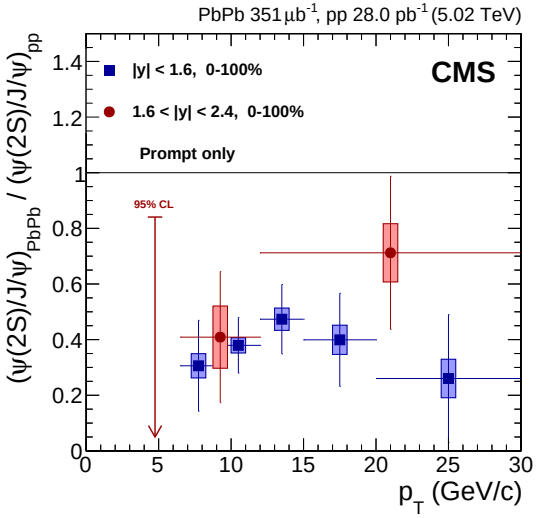


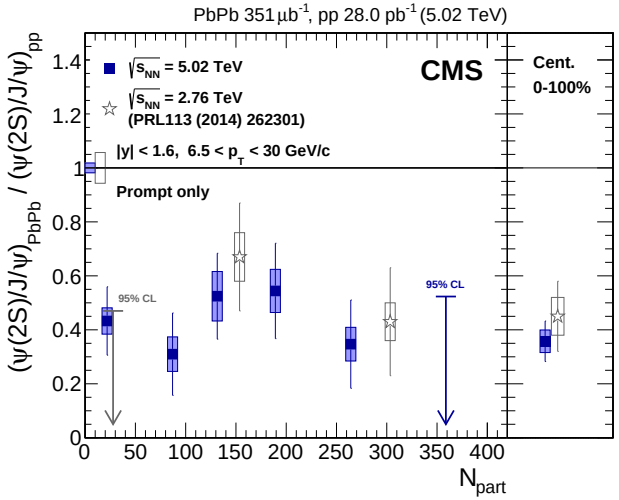


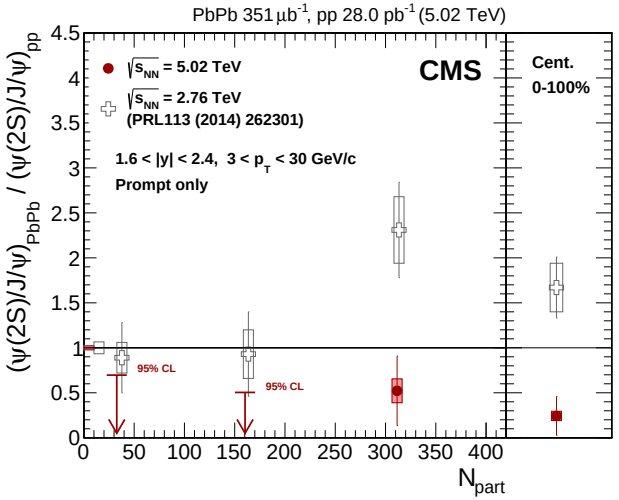
Prompt J/ψ, prompt $\psi(2S)$: excited vs ground state (2.76 TeV, 5.02 TeV)

PRL 118 (2017) no.16, 162301

$$\frac{[\psi(2S)/J/\psi]_{PbPb}}{[\psi(2S)/J/\psi]_{pp}} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}$$





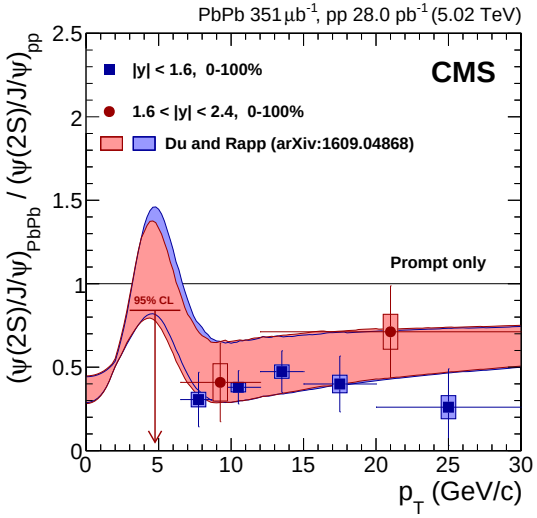


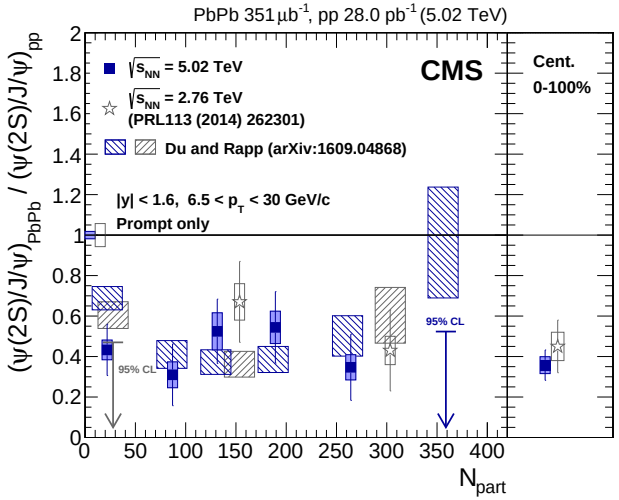
- Larger $\psi(2S)$ suppression: sequential ordering?
- No clear p_T dependence
- Hint for a different behaviour with energy

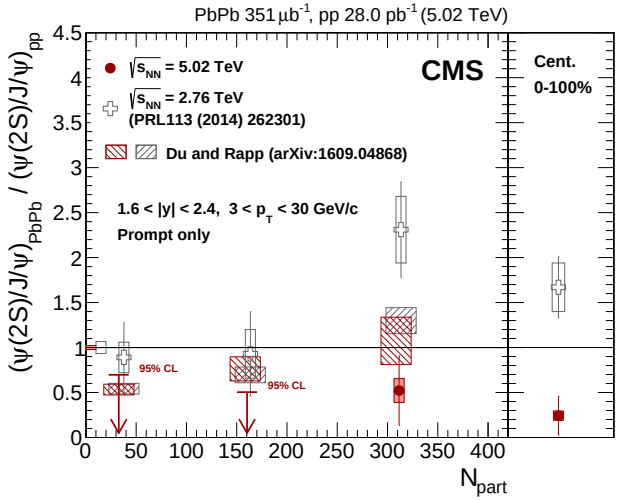
Prompt J/ψ, prompt $\psi(2S)$: excited vs ground state (2.76 TeV, 5.02 TeV)

PRL 118 (2017) no.16, 162301

$$\frac{[\psi(2S)/J/\psi]_{PbPb}}{[\psi(2S)/J/\psi]_{pp}} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}$$

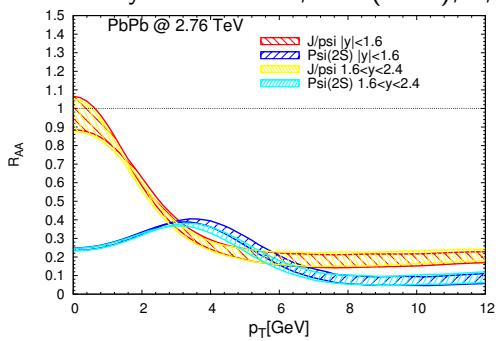






- X. Du and R. Rapp: $\psi(2S)$ regenerated later than J/ψ in the fireball evolution

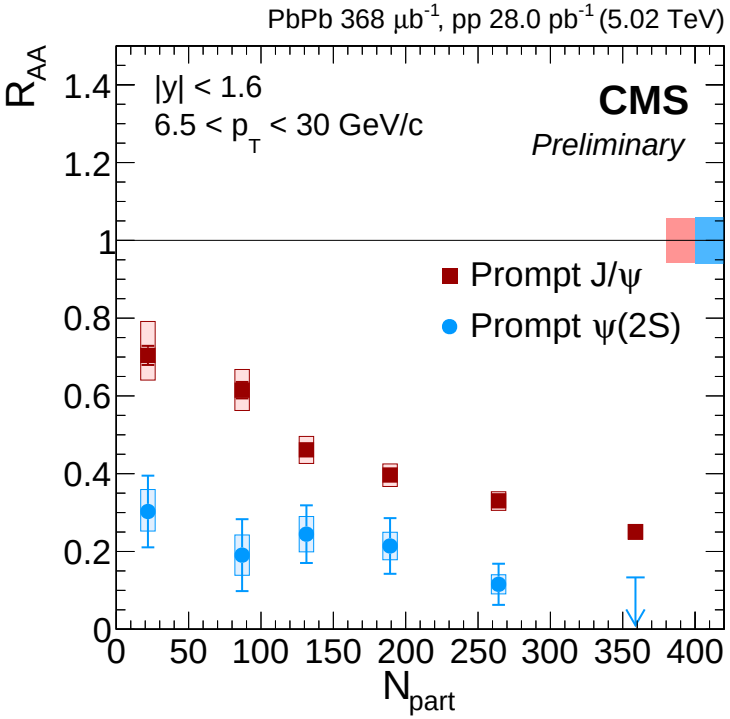
J. of Phys. Conf. Ser., 779 (2017), 1, 012042

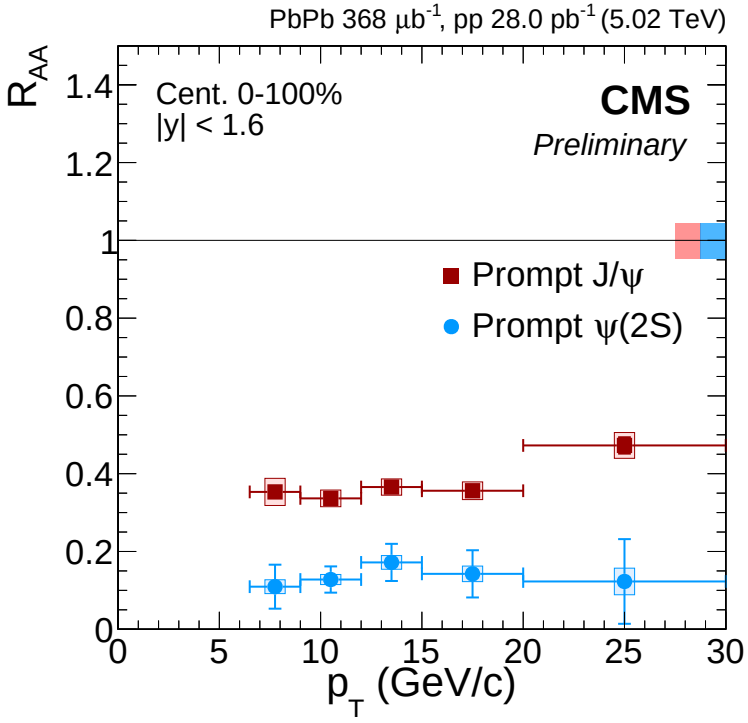


Prompt $\psi(2S)$ R_{AA} (5.02 TeV)

CMS-PAS-HIN-16-025

- $\psi(2S)$ more suppressed in central events?





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CMS-PAS-HIN-16-025

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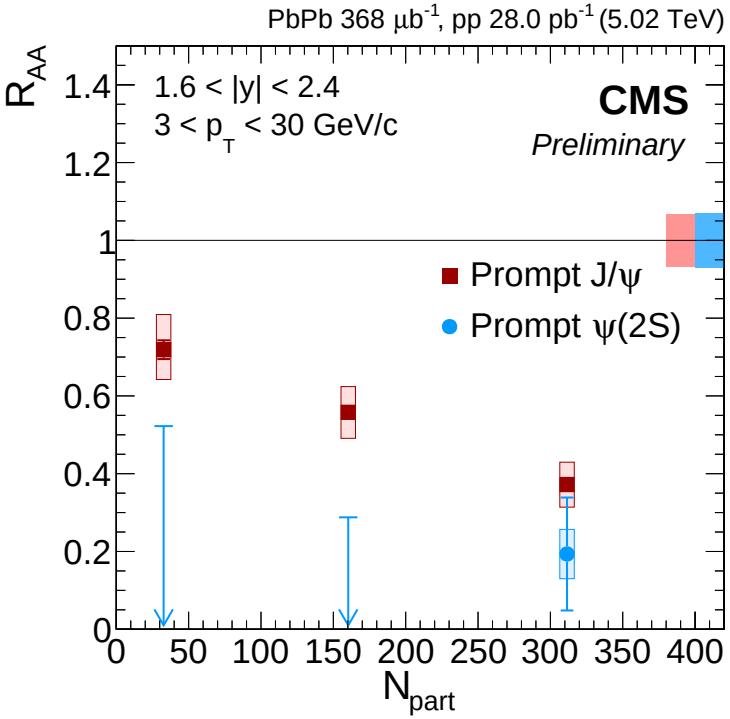
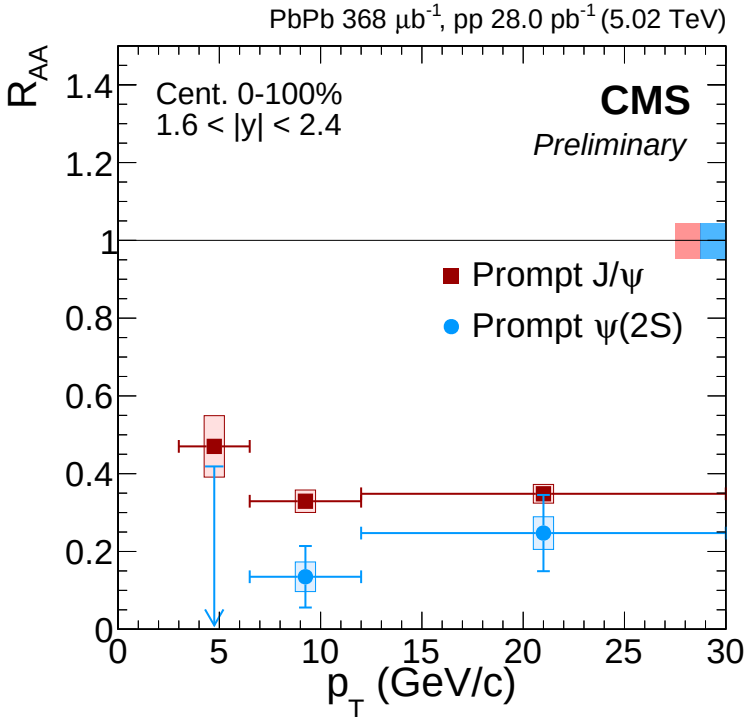
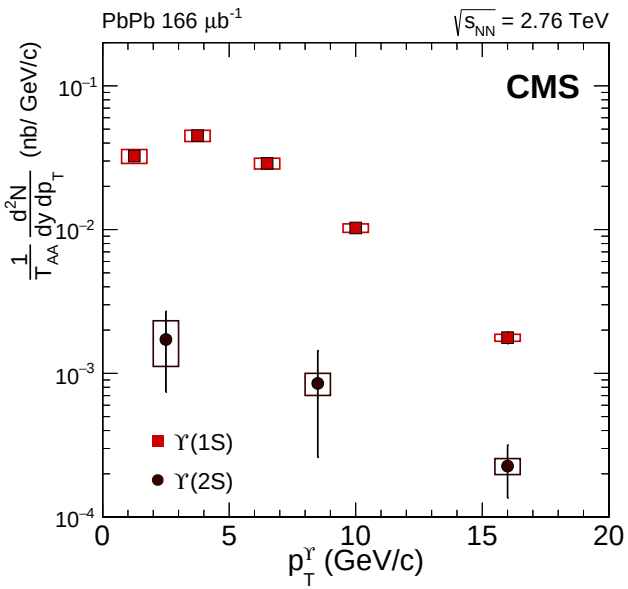


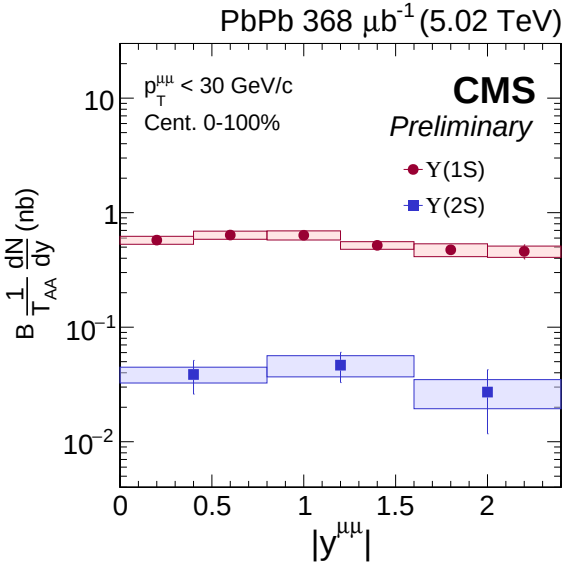


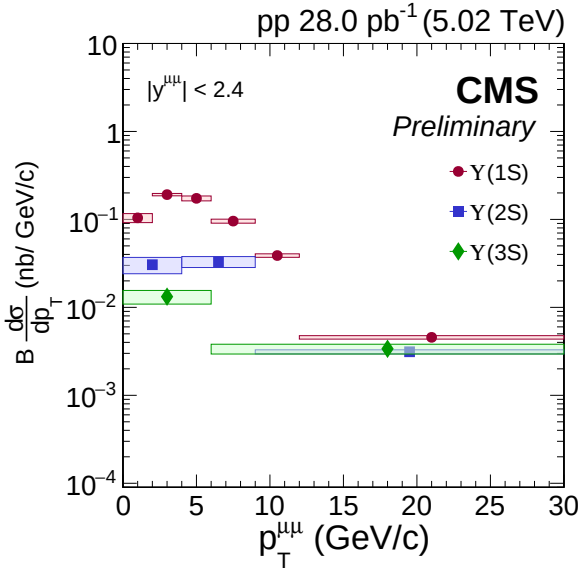
ϒ(nS): cross sections in PbPb (and pp) (2.76 TeV, 5.02 TeV)

PLB 770 (2017) 357, CMS-PAS-HIN-16-023

Bottomonia in pp and PbPb





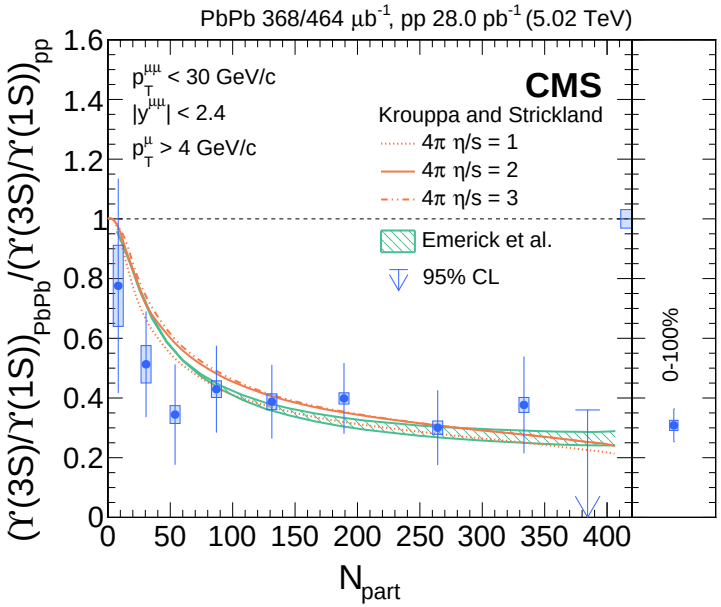


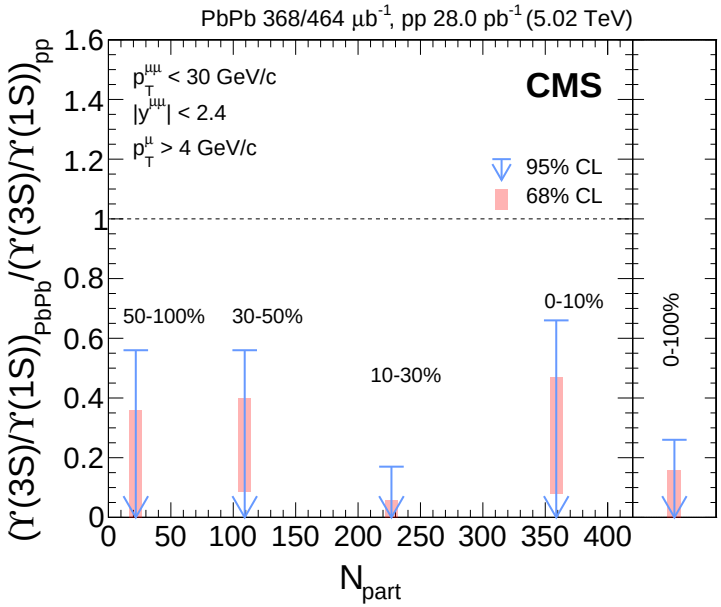
- Differential cross sections, at 2.76 TeV and 5.02 TeV, in pp and PbPb

ϒ(nS) double ratios (5.02 TeV)

arXiv:1706.05984

$$\frac{[\Upsilon(nS)/\Upsilon(1S)]_{PbPb}}{[\Upsilon(nS)/\Upsilon(1S)]_{pp}} = \frac{R_{AA}(\Upsilon(nS))}{R_{AA}(\Upsilon(1S))}$$

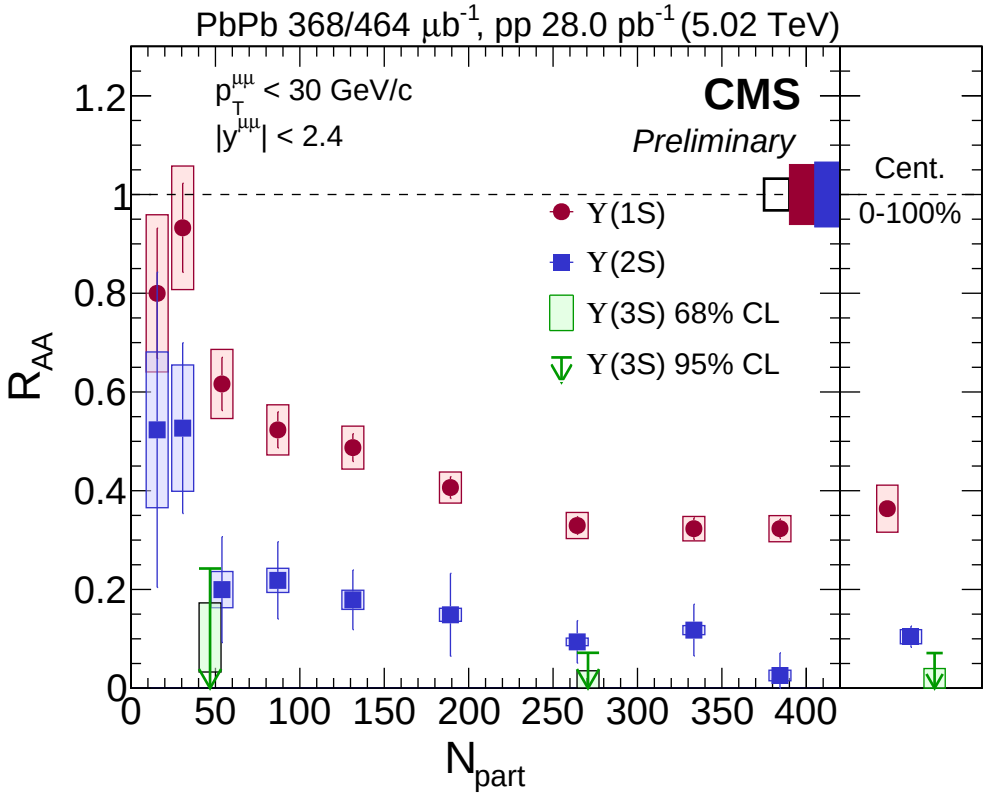




- Increasing suppression of the ϒ(2S) compared to the ϒ(1S) with centrality
  - 95% CL upper limit in the most central 0-5% bin
- Strong suppression of the ϒ(3S) relative to the ϒ(1S) in all studied centralities

Nuclear modification factors: Υ(nS) (5.02 TeV)

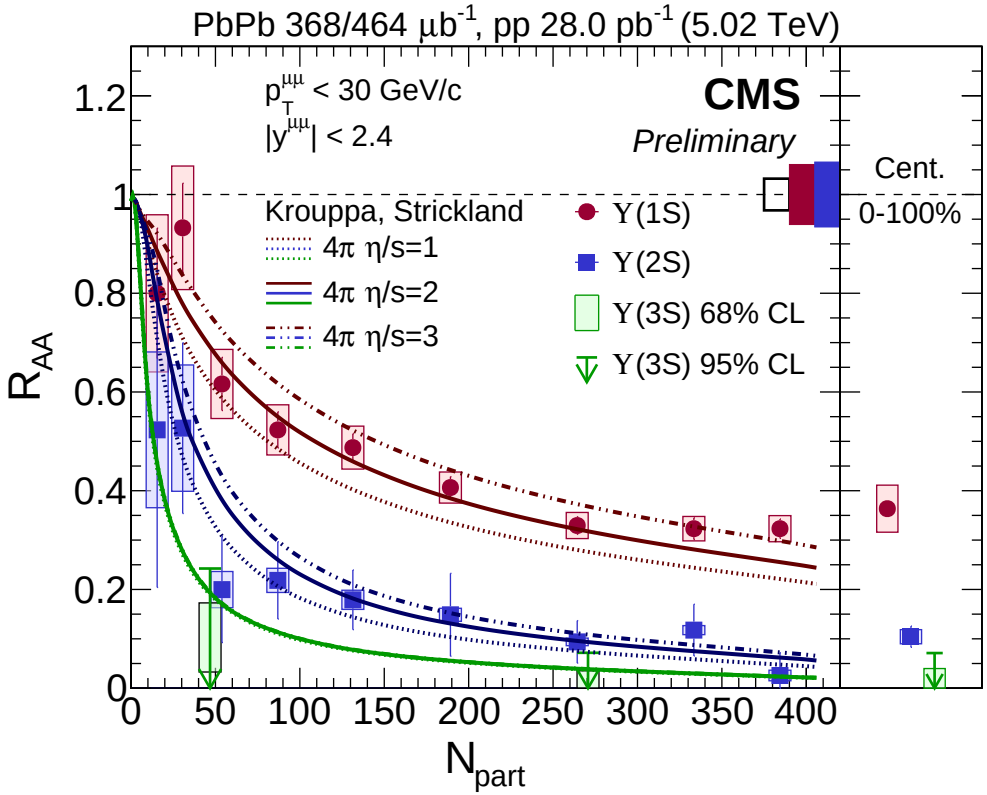
CMS-PAS-HIN-16-023



- Clear ordering : $R_{AA}(\Upsilon(3S)) < R_{AA}(\Upsilon(2S)) < R_{AA}(\Upsilon(1S))$
- Increasing suppression with centrality
- More weakly bound states melt more easily
- Υ(3S) still unobserved in PbPb collisions

Nuclear modification factors: Υ(nS) (5.02 TeV)

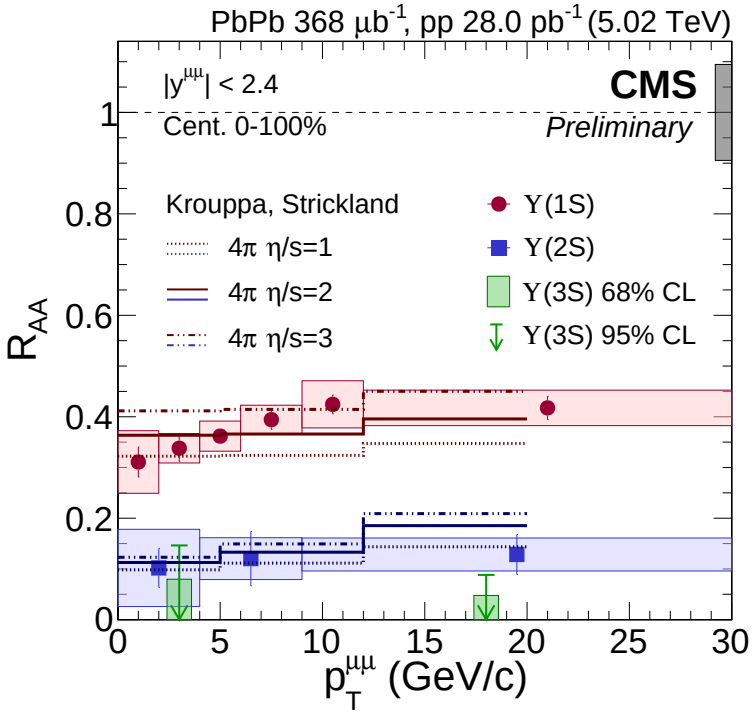
CMS-PAS-HIN-16-023

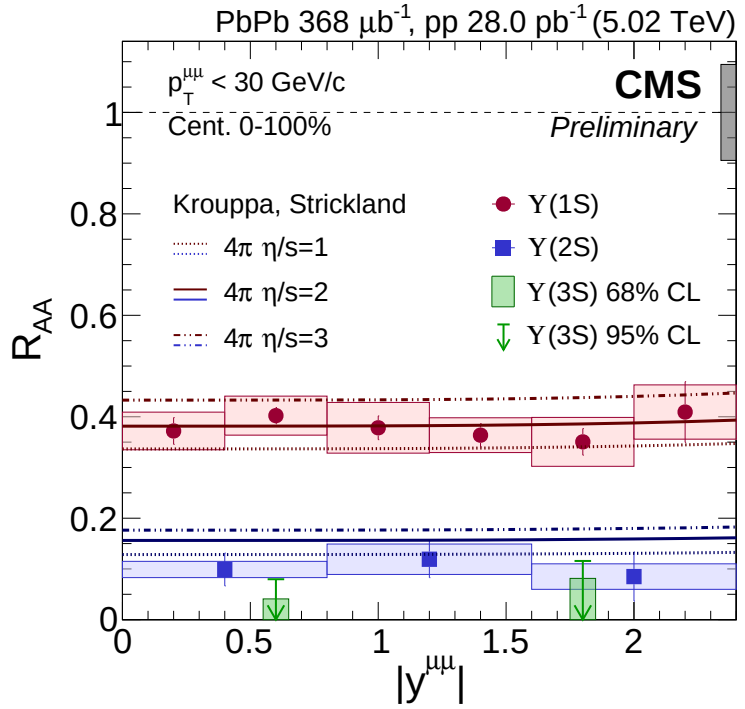


- Clear ordering : $R_{AA}(\Upsilon(3S)) < R_{AA}(\Upsilon(2S)) < R_{AA}(\Upsilon(1S))$
- Increasing suppression with centrality
- More weakly bound states melt more easily
- Υ(3S) still unobserved in PbPb collisions
- Comparison with an hydrodynamic model (Krouppa et al.)

Nuclear modification factors: ϒ(nS) (5.02 TeV)

CMS-PAS-HIN-16-023

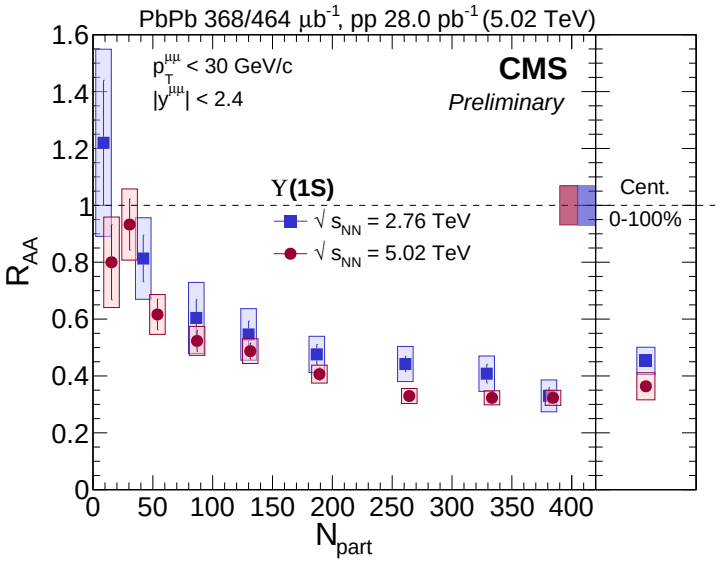


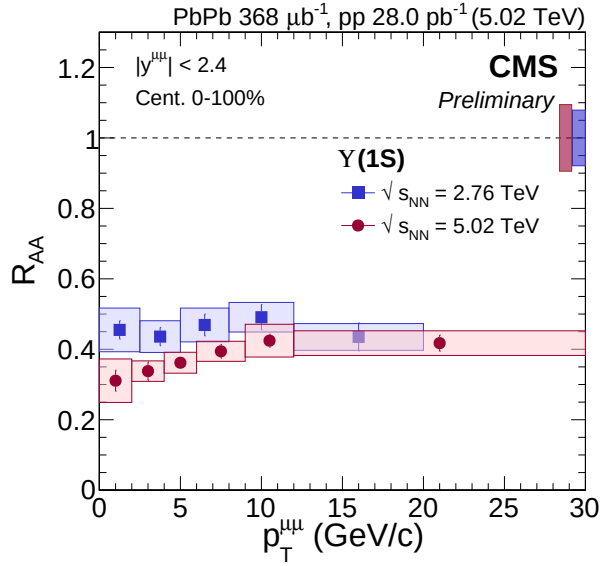


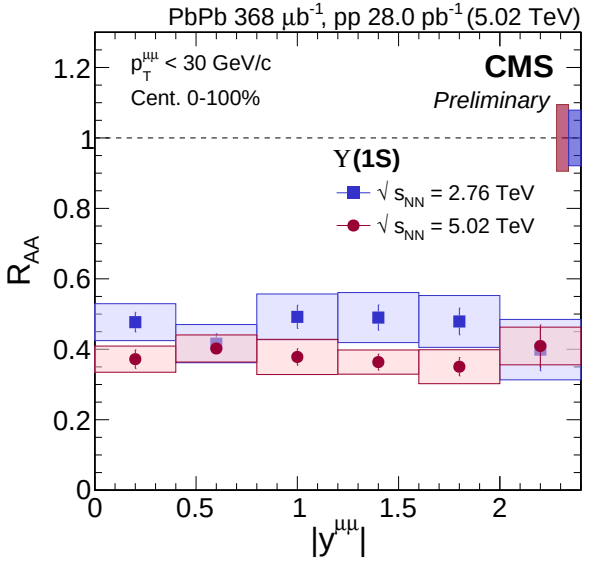
- Hint for an increasing ϒ(1S) R_{AA}?
- No significant y dependence

Collision energy dependence: Υ(1S) (2.76 TeV, 5.02 TeV)

CMS-PAS-HIN-16-023

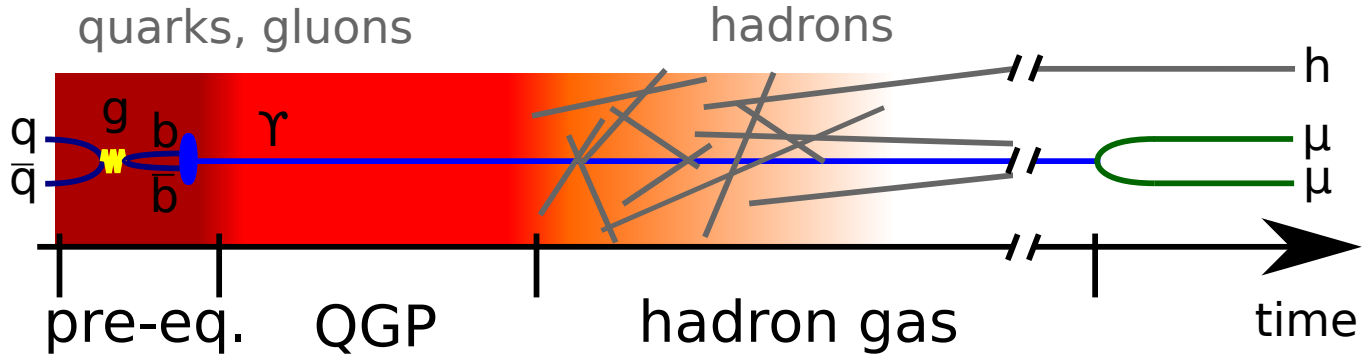






- Higher p_T reach at 5.02 TeV
- Consistently lower R_{AA} at 5.02 TeV: indication of a collision energy dependence?

Summary



Quarkonia in heavy ion collisions: a large toolbox for studying nuclear effects

- Measuring cross sections and ratios: production mechanism
- pPb collisions: is there more than nPDFs? (cf $\psi(2S)$)
- PbPb collisions: sequential melting? Hints of regeneration at low p_T, energy loss at high p_T?

All CMS results in
`https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN`

Additional material

Event activity dependence of Υ(nS) production: self-normalised ratios

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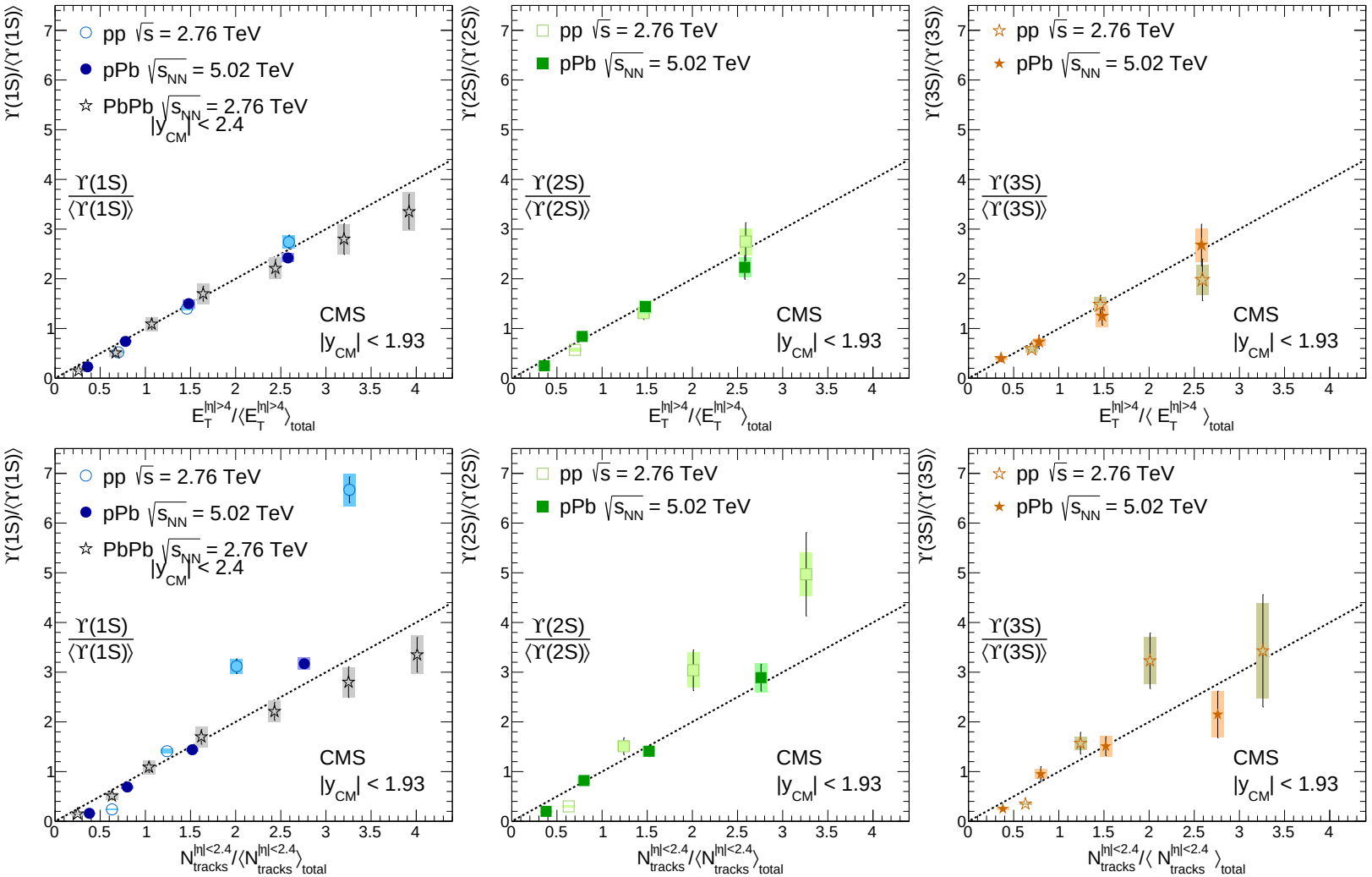
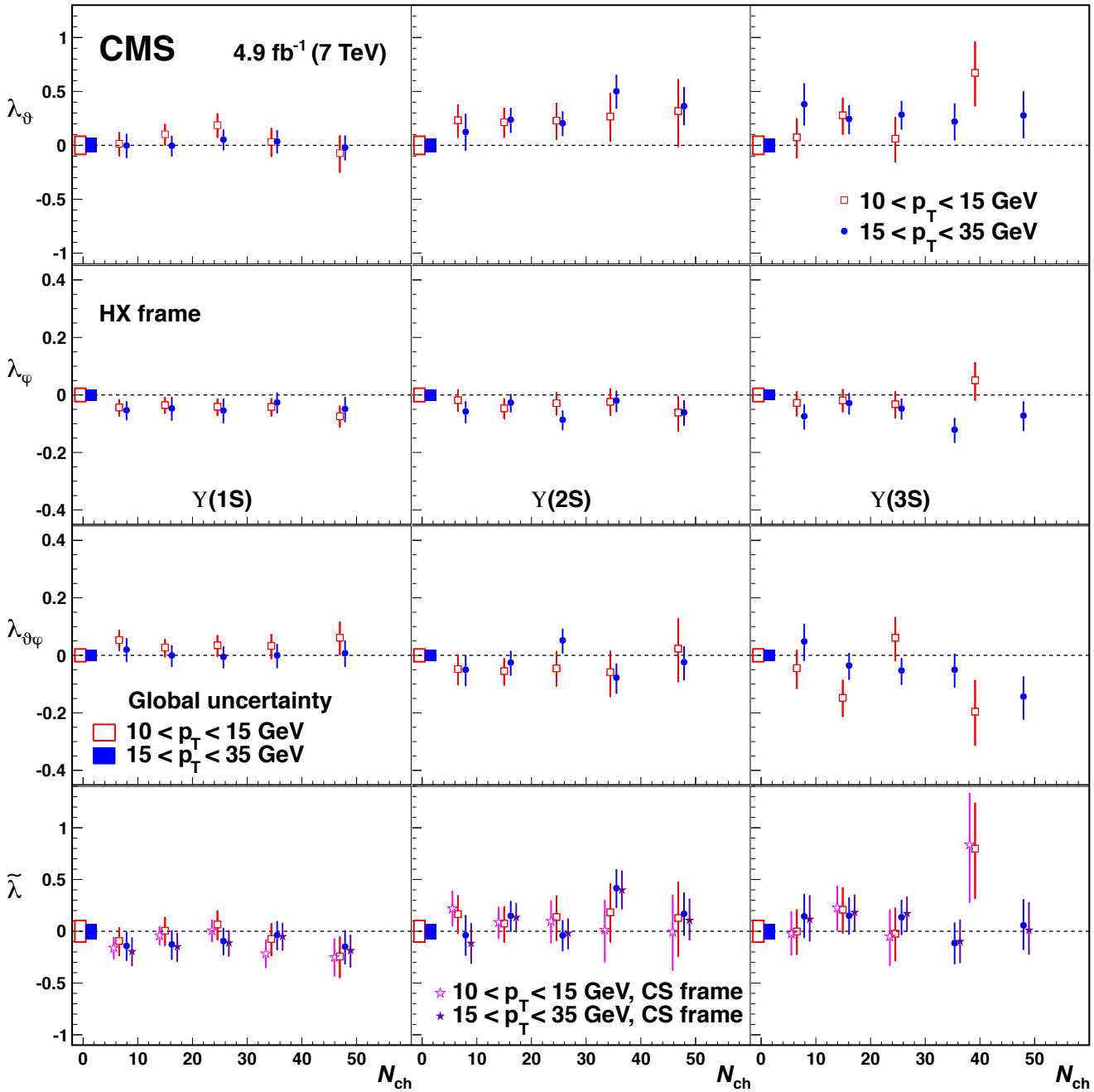


Event activity dependence of Υ(nS) polarisation in pp

7 TeV

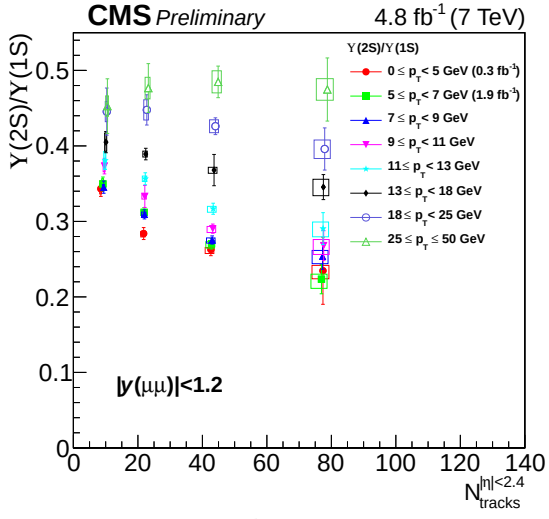
PLB 761 (2016) 31

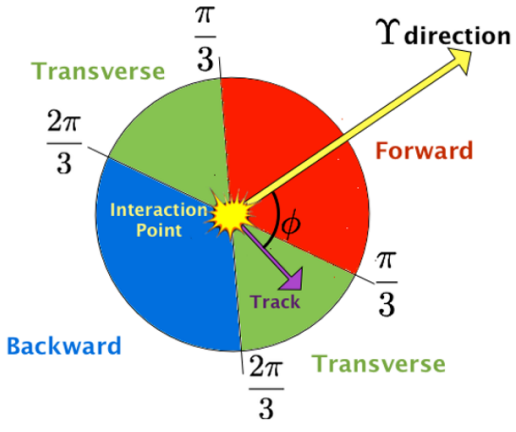


Event activity dependence of Υ(nS) production in pp

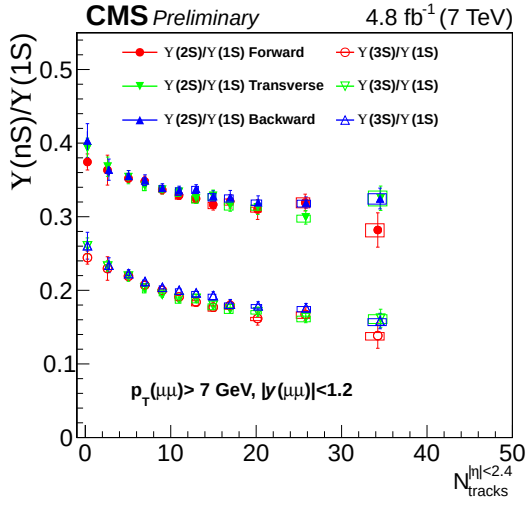
7 TeV

CMS-PAS-BPH-14-009





(a)



(b)

J/ψ flow

(2.76 TeV)

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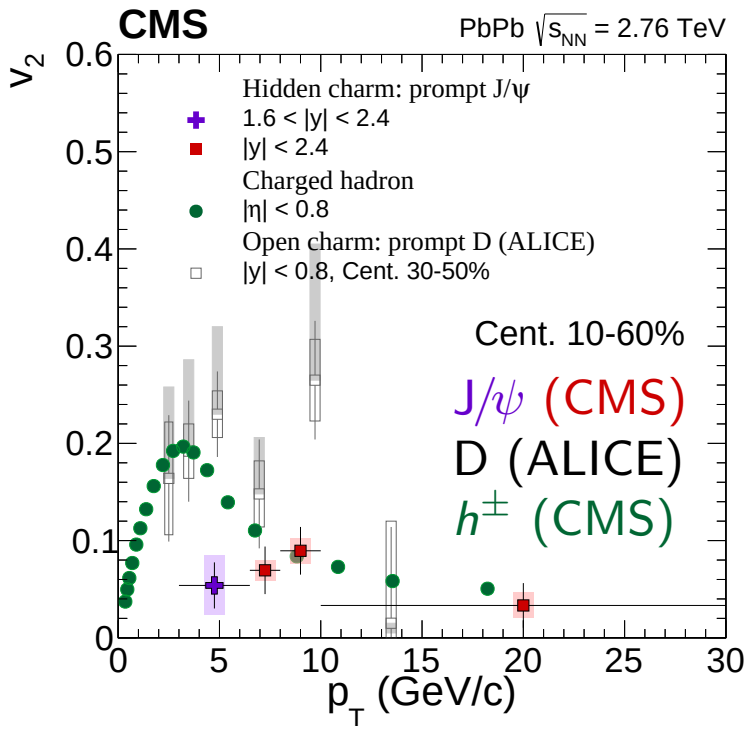

Comparing hidden charm (prompt J/ψ, CMS) to open charm (D, ALICE):

- Smaller v_2 at low p_T, similar at high p_T?
- Flavour independence of energy-loss path-length dependence?