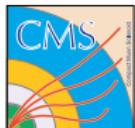


# Quarkonium suppression in PbPb collisions with CMS

Émilien Chapon

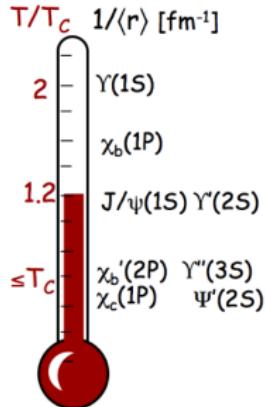
Laboratoire Leprince-Ringuet, École polytechnique, Palaiseau

QCD@LHC, August 22-26<sup>th</sup>, 2016  
ETH Zurich

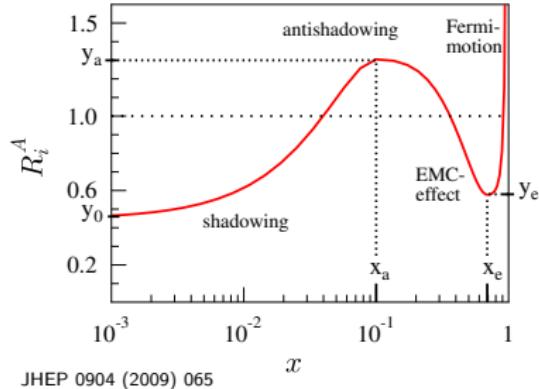


LM

# Quarkonia in heavy ion collisions



EPJC 61 (2009) 705

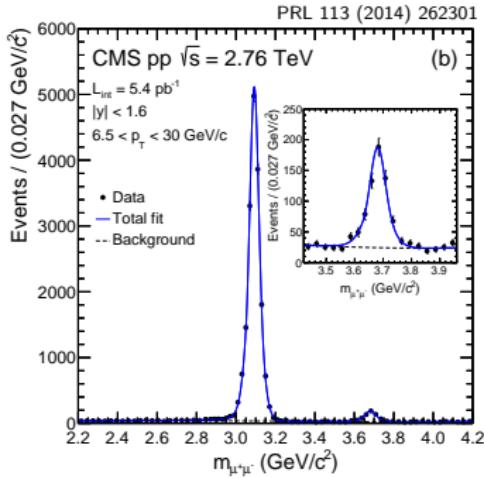


- Quarkonia as good probes of the medium evolution.
- Two families (charmonia, bottomonia), several excited states: importance of quark mass, binding energy and size
- Many ingredients needed, taken from different collision systems:
  - pp collisions: production mechanism “in vacuum”
  - Ultra-peripheral PbPb (and pPb): gluon shadowing
  - Central PbPb: quark gluon plasma



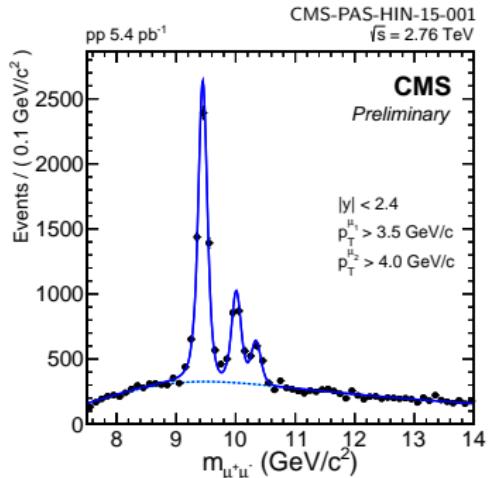
LLR

# Charmonia vs bottomonia



Charmonia ( $c\bar{c}, M \approx 3 \text{ GeV}/c^2$ )

- $p_T > 3 \text{ GeV}/c$  (UPC:  $p_T > 0 \text{ GeV}/c$ )
- Feed-down:  $\chi_c, \psi(2S)$
- Non-prompt from  $B$  decays



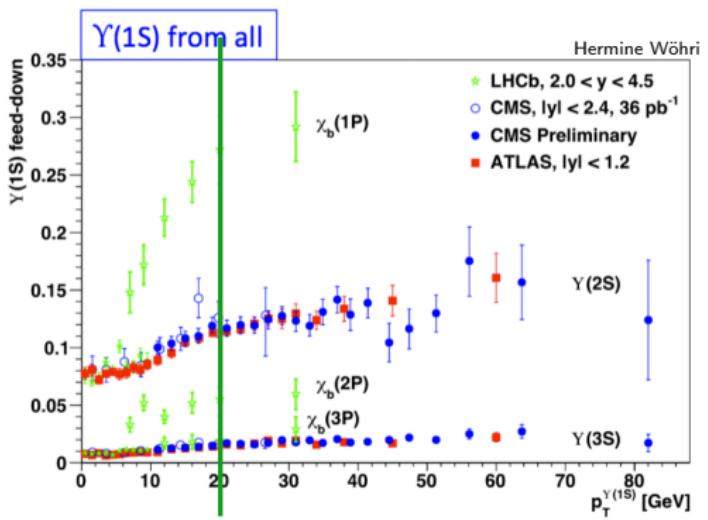
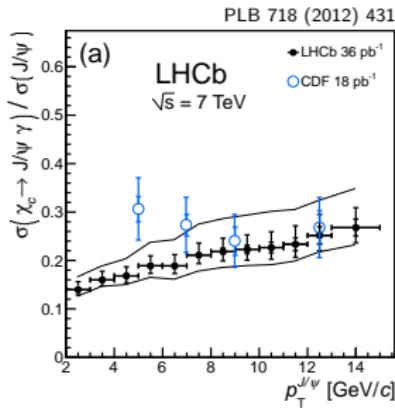
Bottomonia ( $b\bar{b}, M \approx 10 \text{ GeV}/c^2$ )

- $p_T > 0 \text{ GeV}/c$
- Feed-down:  $\chi_b, \Upsilon(nS)$
- No non-prompt



LLR

# Feed-down contribution

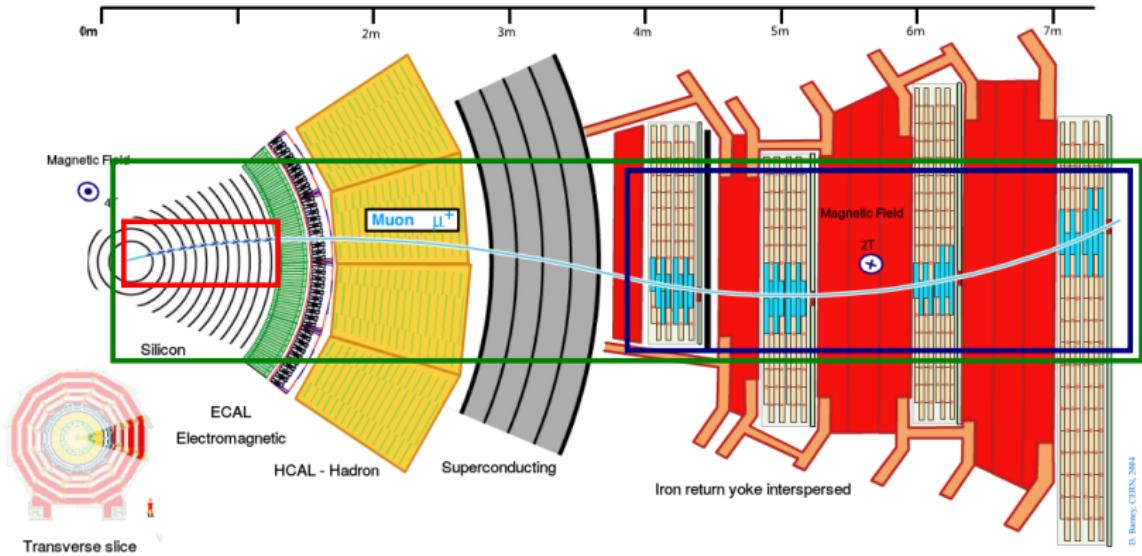


Significant fraction of  $J/\psi$  and  $\Upsilon$  coming from feed-down contributions



LLR

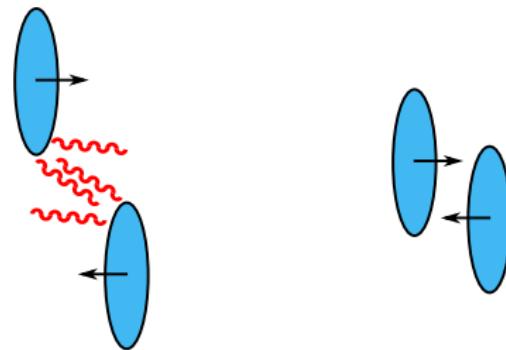
## Muons in the CMS experiment



- Muon reconstruction: silicon tracker + muon sub-detectors
    - Tracker  $p_T$  resolution: 1-2% up to  $p_T \sim 100 \text{ GeV}/c$ .
    - Excellent  $p_T$  resolution.
      - separation of quarkonium states
      - displaced tracks for heavy-flavour measurements

# Outline

- ①  $\Upsilon(nS)$  suppression in PbPb
- ②  $J/\psi$  in ultra-peripheral PbPb
- ③  $J/\psi$  suppression in PbPb



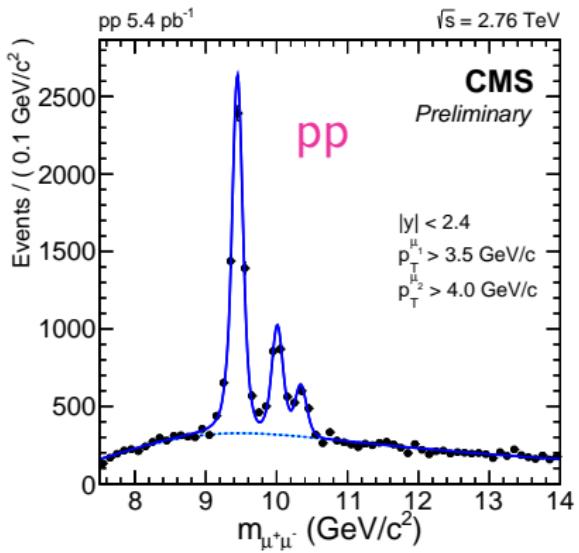


# $\Upsilon(nS)$ in pp and PbPb at $\sqrt{s_{NN}} = 2.76$ TeV: signal extraction

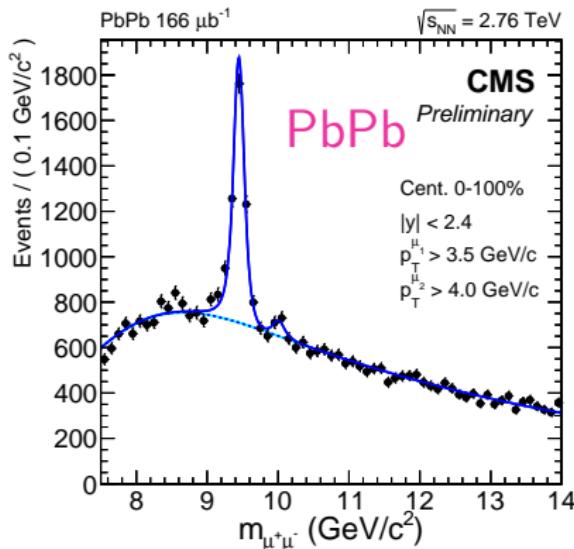
CMS-PAS-HIN-15-001

Different single muon cuts for different states:

- $\Upsilon(1S)$ :  $p_T^{\mu_1} > 3.5$  GeV,  $p_T^{\mu_2} > 4$  GeV
- $\Upsilon(2S, 3S)$ :  $p_T^{\mu_{1,2}} > 4$  GeV



$\sim 5000 \Upsilon(1S)$  in pp



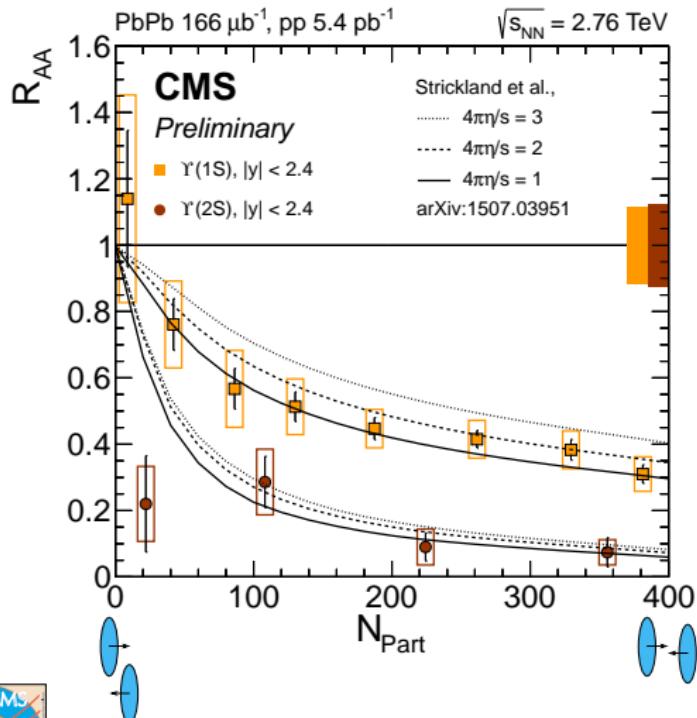
$\sim 2500 \Upsilon(1S)$  in PbPb

LLR



# $R_{AA}(\Upsilon(nS))$ : centrality dependence

CMS-PAS-HIN-15-001



$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA}N_{MB}} \frac{N_{AA}}{N_{pp}} \frac{\epsilon_{pp}}{\epsilon_{AA}}$$

$\Upsilon$  production is suppressed in PbPb,  
with **binding energy ordering**.  
Integrated results (Min. bias):

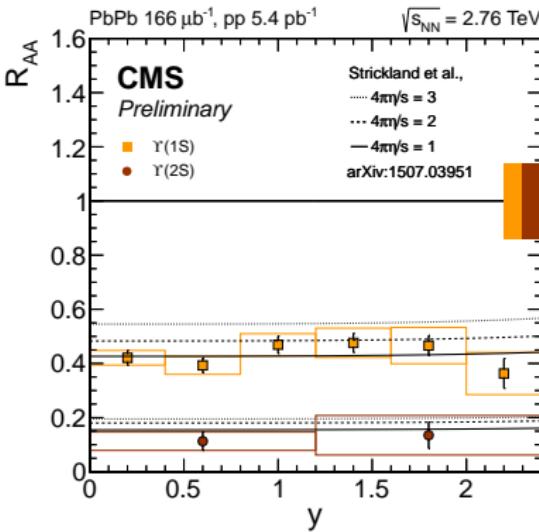
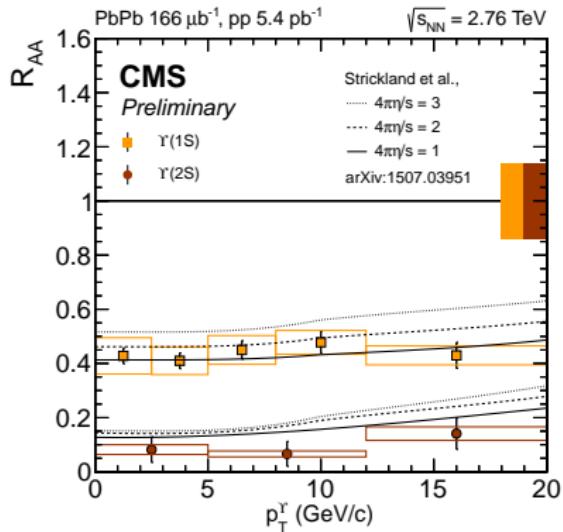
- $R_{AA}(\Upsilon(1S)) = 0.43 \pm 0.03 \pm 0.07$
- $R_{AA}(\Upsilon(2S)) = 0.12 \pm 0.03 \pm 0.02$
- $R_{AA}(\Upsilon(3S)) < 0.14$  at 95% C.L.

- Stronger suppression in central events
- Significant  $\Upsilon(2S)$  suppression in peripheral events

# $R_{AA}(\Upsilon(nS))$ : $p_T$ and rapidity dependence



CMS-PAS-HIN-15-001



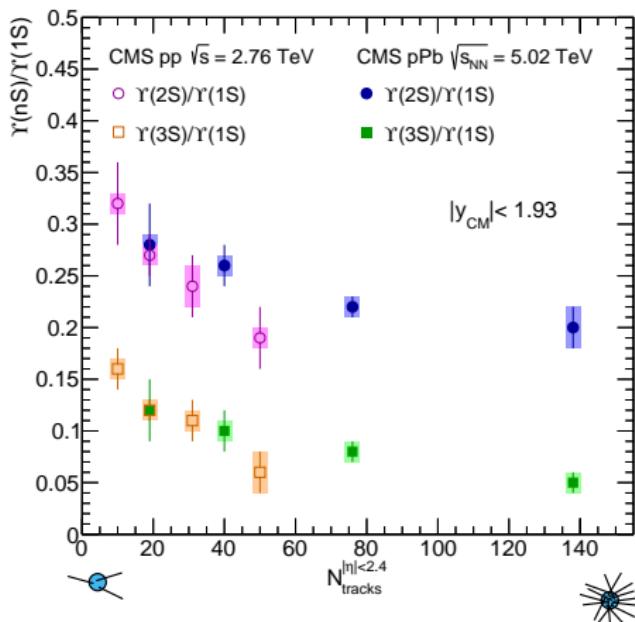
- No significant  $p_T$  dependence over the measured range.
- $\Upsilon(1S)$  well described, some tension for  $\Upsilon(2S)$  and at forward rapidity
- No significant  $y$  dependence over the measured range



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$\Upsilon(nS)/\Upsilon(1S)$  in pp and pPb

JHEP 1404 (2014) 103



Excited state “sequential suppression” also seen in high multiplicity pp and pPb: effect of event activity on  $\Upsilon(nS)$  production?



LLR

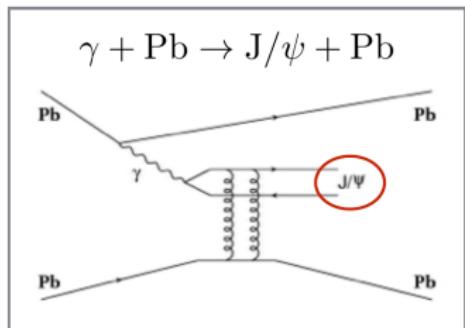


# UPC $J/\psi$ : motivation, event selection

arXiv:1605:06966

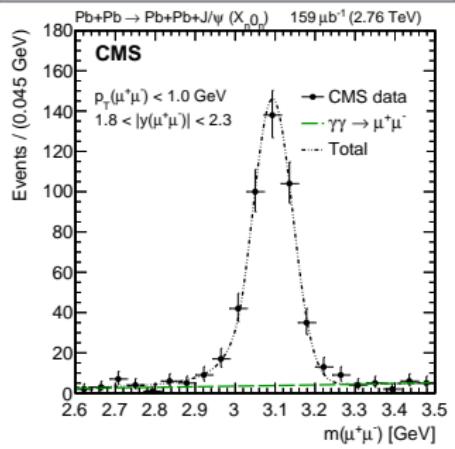
## Ultra-Peripheral Collisions (UPC)

- Impact parameter  $> 2R$
- Cross section  $\propto (\text{gluon density})^2$  and  $Z^2$
- Probing gluon PDFs at low  $x$  ( $10^{-5} - 10^{-2}$ ) and low  $Q^2$  (few GeV $^2$ ) (shadowing)



## Events selection

- $X_n 0_n$  break-up mode
  - selected thanks to Zero Degree Calorimeters
  - $> 1$  neutron on one side,  $= 0$  on the other
- Two muons and nothing else
  - very low signal in the Hadronic Forward calorimeters

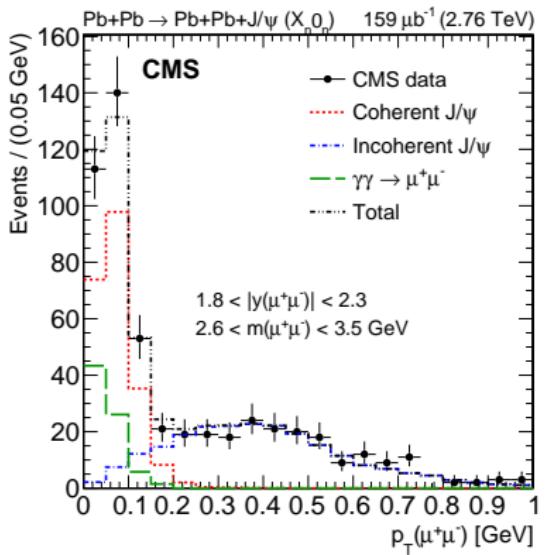


UPC  $J/\psi$ : different processes

arXiv:1605:06966

Three processes (modelled using STARLIGHT MC):

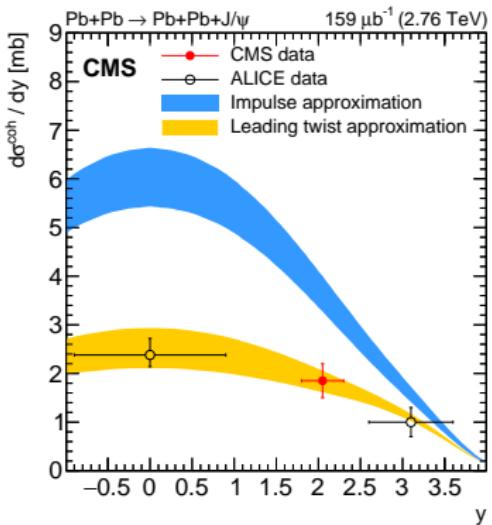
- **Coherent**: interaction with the whole nucleus
- **Incoherent**: interaction with a single nucleon
- $\gamma\gamma$ : non-resonant  $\gamma\gamma \rightarrow \mu^+\mu^-$



LLR

UPC  $J/\psi$ : coherent  $J/\psi$  cross section

arXiv:1605:06966



$$\frac{d\sigma^{coh}}{dy}(J/\psi) = 1.82 \pm 0.22 \text{ (stat.)} \pm 0.20 \text{ (syst.)} \pm 0.19 \text{ (theo.) mb}$$

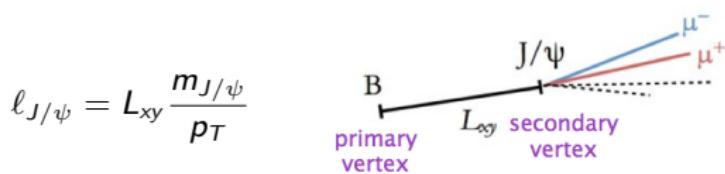
- Favouring the leading-twist approximation (including effective gluon shadowing) over the impulse approximation (no nuclear effects)
- Rapidity range complementary to ALICE



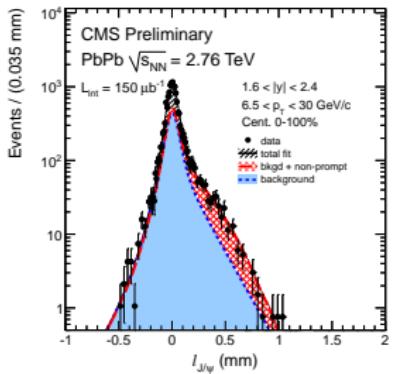
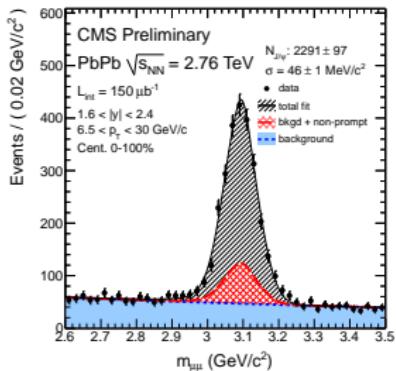
LLR

$J/\psi$  in pp and PbPb at  $\sqrt{s_{NN}} = 2.76$  TeV

CMS-PAS-HIN-12-014



- 2D fit: dimuon mass, pseudo-proper decay length
- Excellent IP resolution of CMS ( $\sim 25 - 90 \mu\text{m}$ )
- Separation of prompt and non-prompt  $J/\psi$

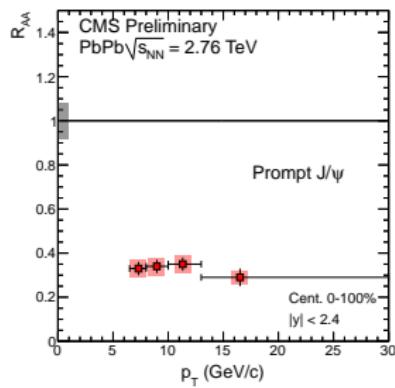
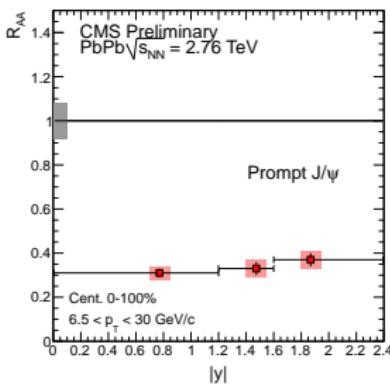
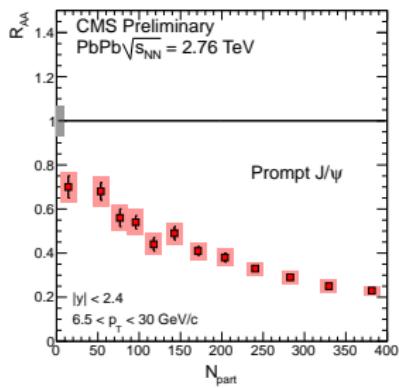


LHC



$J/\psi$  in pp and PbPb at  $\sqrt{s_{NN}} = 2.76$  TeV

CMS-PAS-HIN-12-014



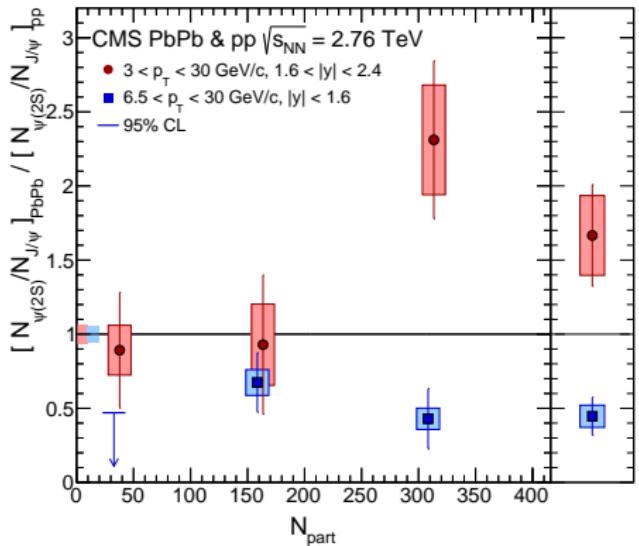
- Strong centrality dependence (stronger suppression in central events)
- No significant rapidity or  $p_T$  dependence



LLR

$\psi(2S)$  in pp and PbPb at  $\sqrt{s_{NN}} = 2.76$  TeV

PRL 113 (2014) 262301



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

$$\left[ \frac{\psi(2S)}{J/\psi(1S)} \right]_{pp}$$

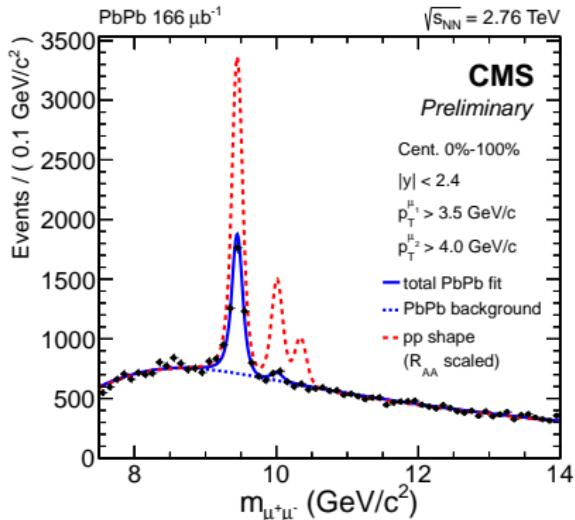
In central events, different behaviour vs rapidity /  $p_T$ :

- Enhancement of  $\psi(2S)$  w.r.t.  $J/\psi$  at medium  $p_T$
- Suppression of  $\psi(2S)$  w.r.t.  $J/\psi$  at high  $p_T$

What about  $\sqrt{s_{NN}} = 5.02$  TeV? Coming soon!



## Summary and outlook



Charmonia and bottomonia in Run 1  $\text{PbPb}$ :

- Stronger suppression in central events
- Stronger suppression of excited states
  - unobserved  $\Upsilon(3S)$  in  $\text{PbPb}$
  - what about medium  $p_T \psi(2S)$ ?
- Evidence for nuclear effects in UPC

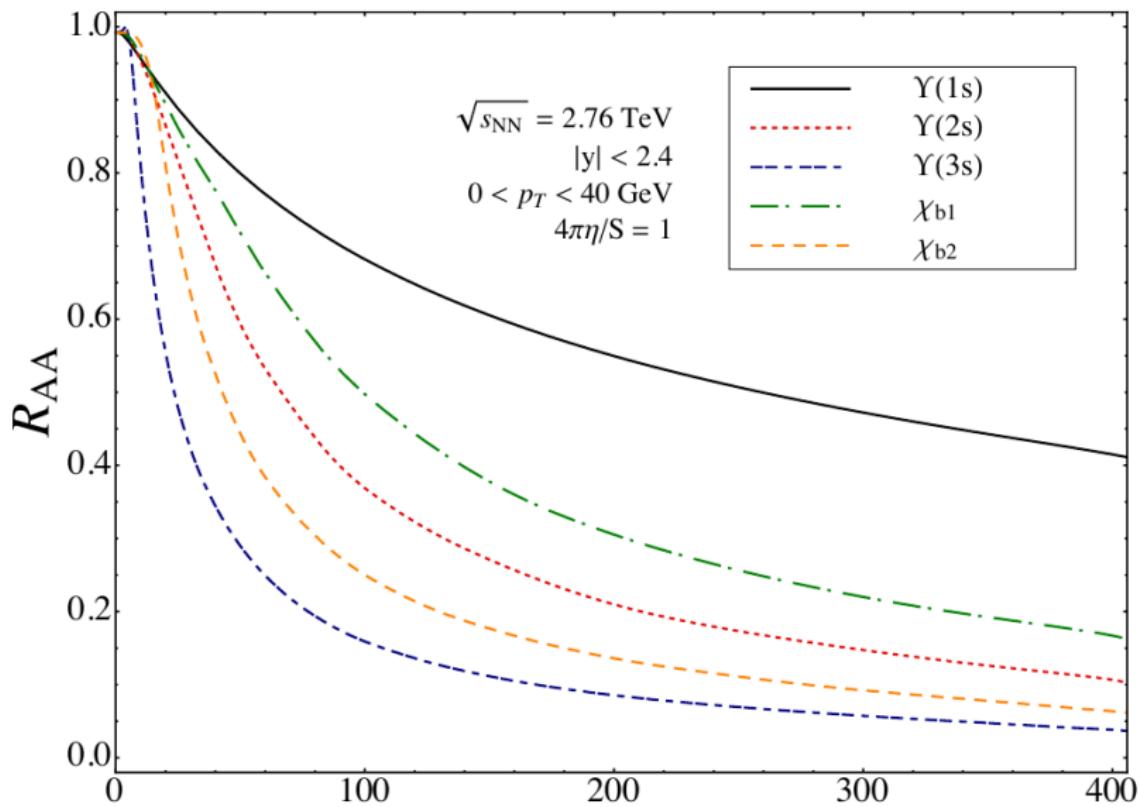
2015  $\text{PbPb}$  data ( $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ )

- What is happening to the  $\psi(2S)$ ?
- How suppressed really are  $\Upsilon(3S)$ ?

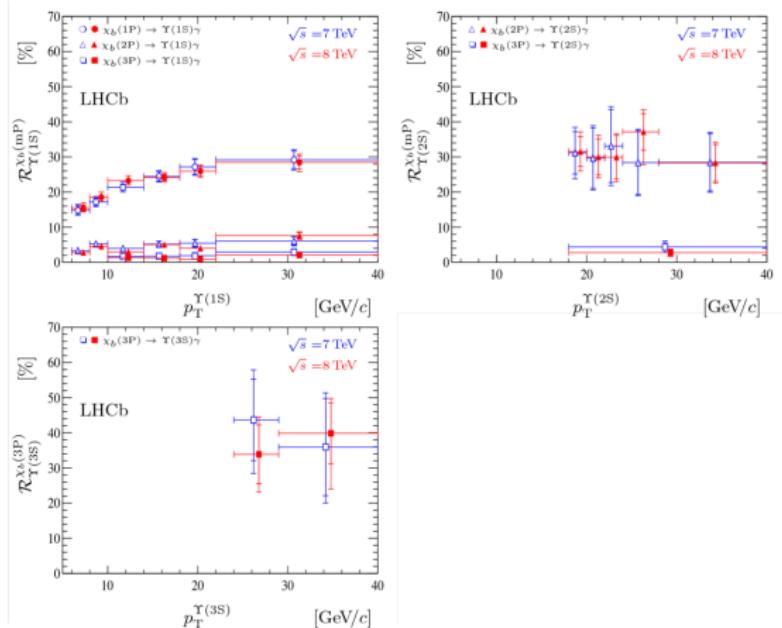
Stay tuned for 5.02 TeV results!

## Additional material

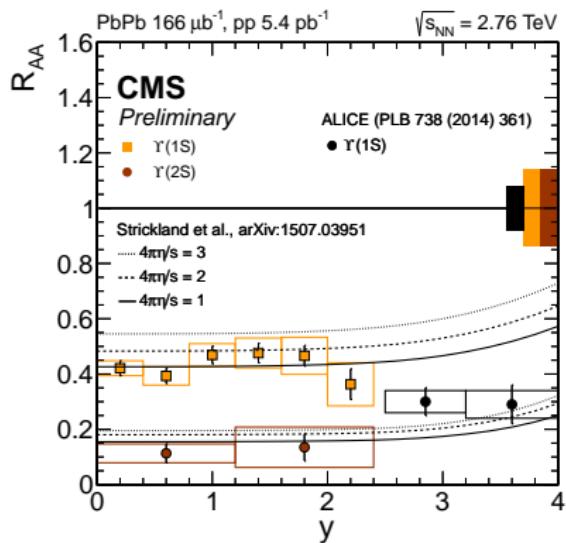
# Raw $R_{AA}$ (Strickland, 1507.03951)



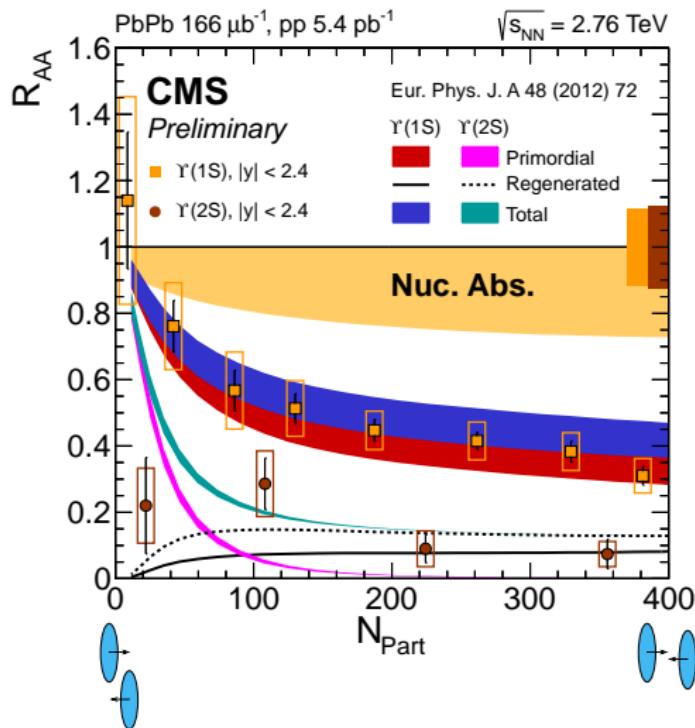
# Feed down contributions (LHCb, EPJC 74 (2014) 3092



# $R_{AA}(\Upsilon(nS))$ : rapidity dependence, comparison with ALICE



# $R_{AA}(\Upsilon(nS))$ : centrality dependence



- Stronger suppression in central events
- Significant  $\Upsilon(2S)$  suppression in peripheral events
- TAMU: also includes CNM and regeneration effects
  - Regeneration dominates for  $\Upsilon(2S)$  in central events