CMS Heavy Ion Results of Quarknoia and Heavy Quarks

Yongsun Kim

on behalf of CMS collaboration

Presented in

SQM, JINR, Dubna

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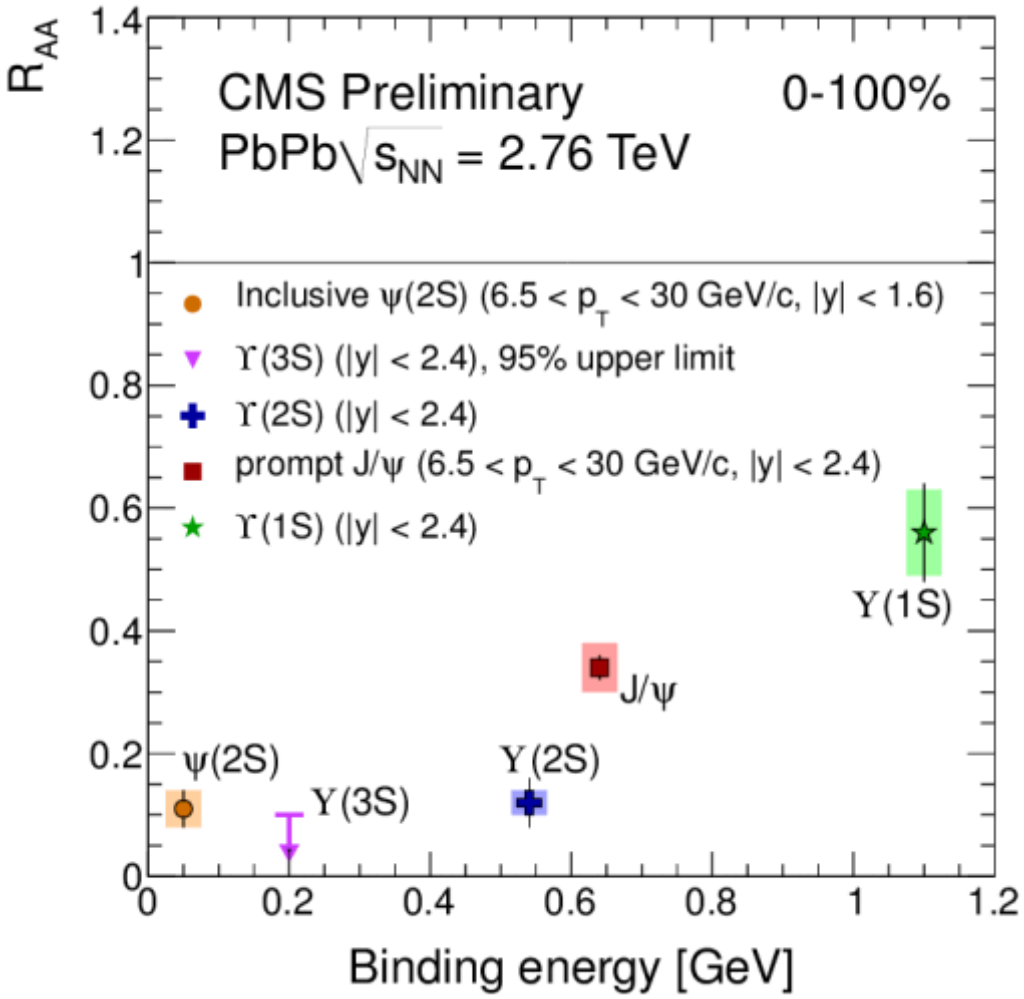
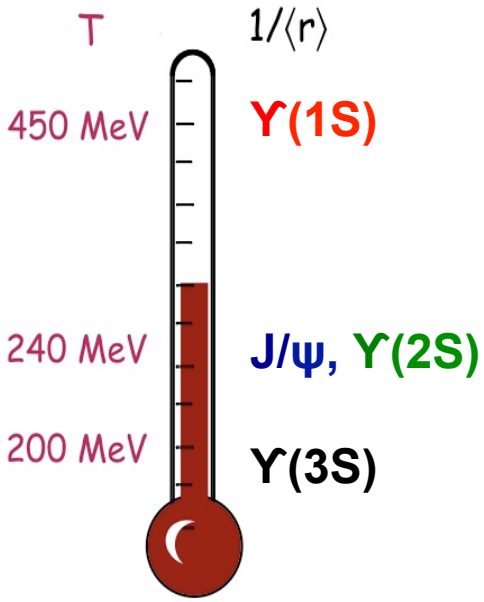
Overview of CMS results in 2013 SQM





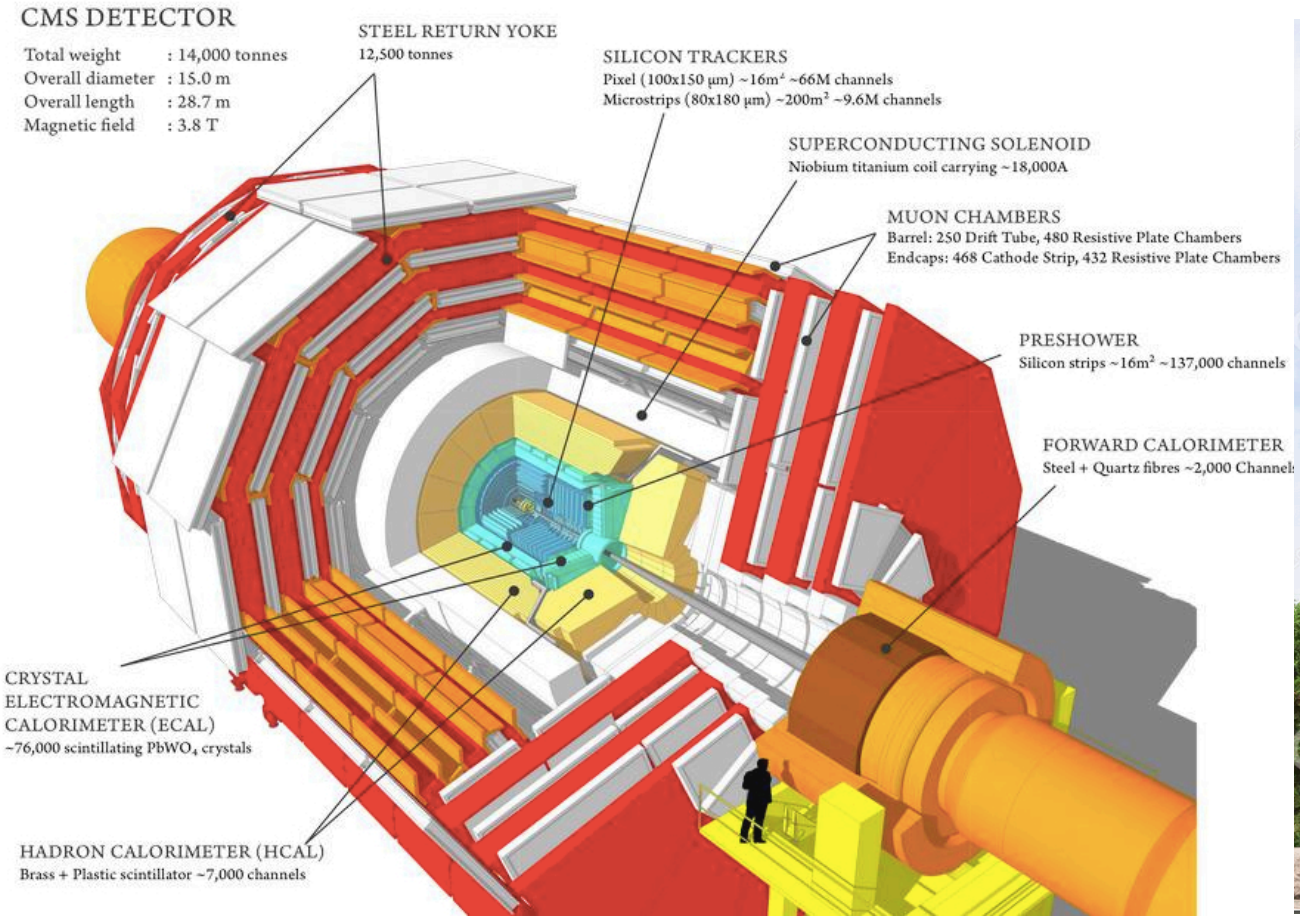
Sequential melting of quarkonium states

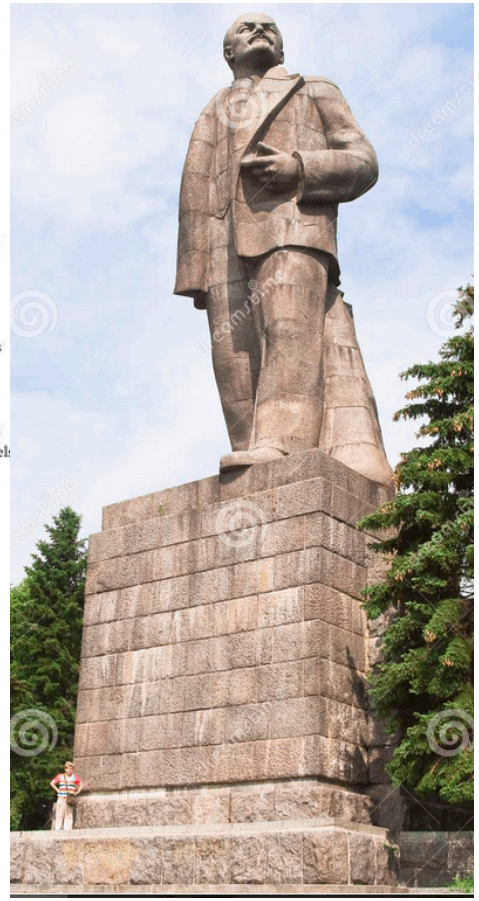
Overview of CMS results in 2015 SQM

	Charmonia	Bottomonia	Open beauty
Pb+Pb 2.76 TeV	J/ψ R_{AA} CMS-HIN-12-014 J/ψ Flow CMS-HIN-12-001 ψ(2S) PRL 113 (2014)262341 J/ψ in UPC CMS-HIN-12-009	ϒ(nS) modification PRL 109(2012) 222301 CMS-HIN-15-001 (update)	B jet R_{AA} PRL 113 (2014) 132301
p+Pb 5.02 TeV p+p 7 TeV Heavy ion relevant analysis	J/ψ cross section CMS-HIN-14-009	ϒ(nS) modification JHEP 04 (2014) 103 Polarization in p+p CMS-HIN-15-003	B jet R_{pA} CMS-HIN-14-007 B meson R_{pA} CMS-HIN-14-004

- New results of p+Pb collision at 5.02TeV
- x20 higher luminosity of p+p collision at 2.76TeV
- Re-analysis of Pb+Pb with improved muon reconstruction (2.76TeV)

CMS detector

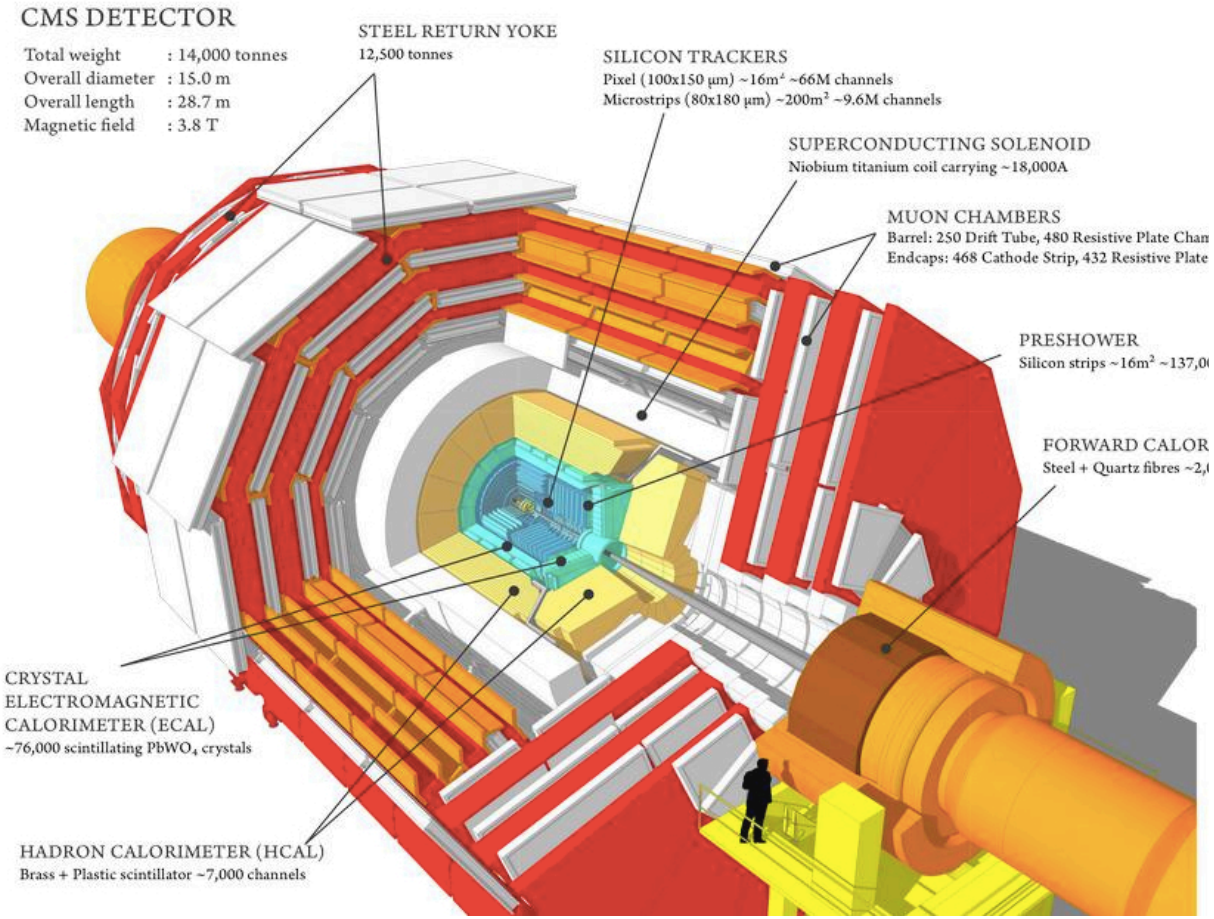


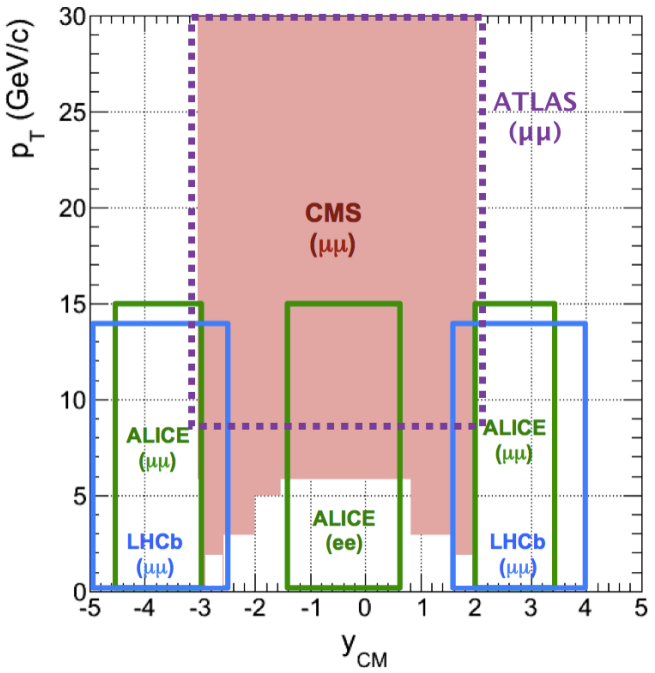


Hermetic coverage for muon and charged hadron

-RPC, CSC, DT for reconstruction of muons

CMS detector



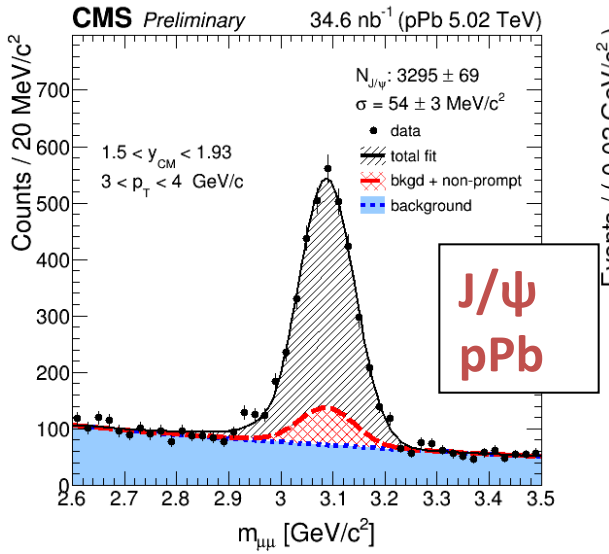


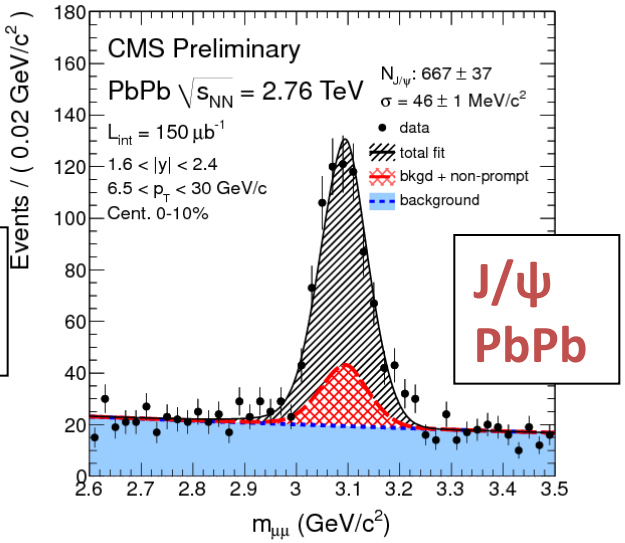
J/psi measured in p+Pb

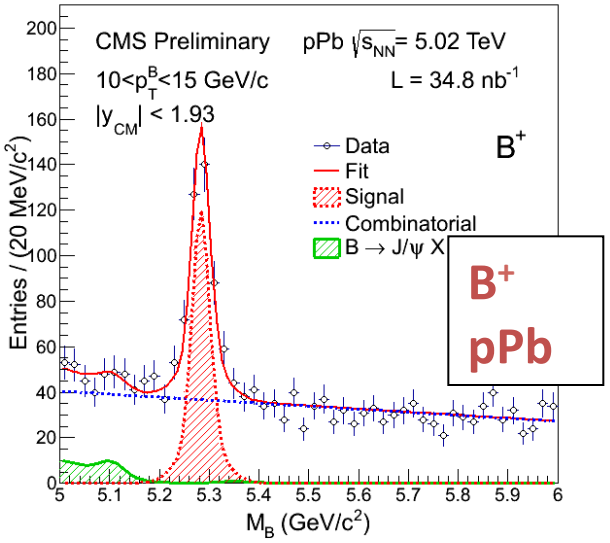
Hermetic coverage for muon and charged hadron

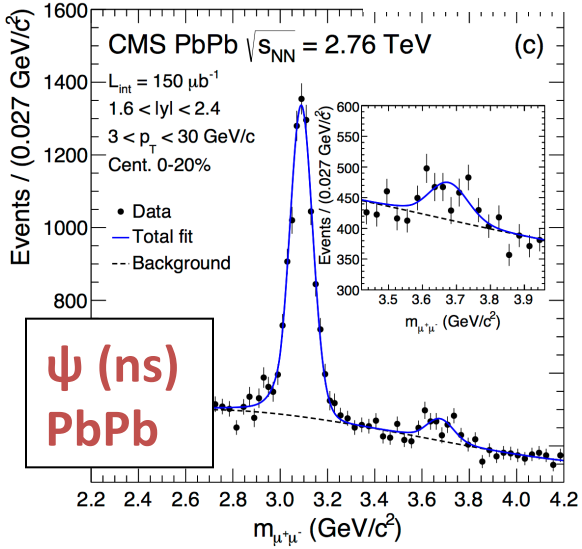
-RPC, CSC, DT for reconstruction of muons

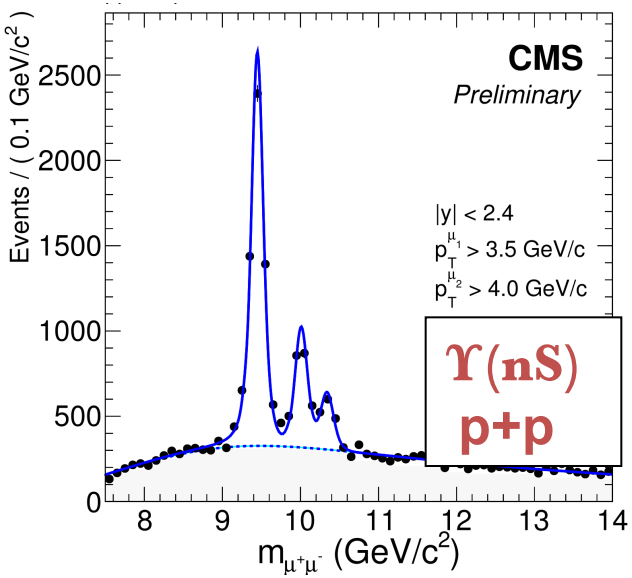
Various signal peaks of muon pairs in CMS

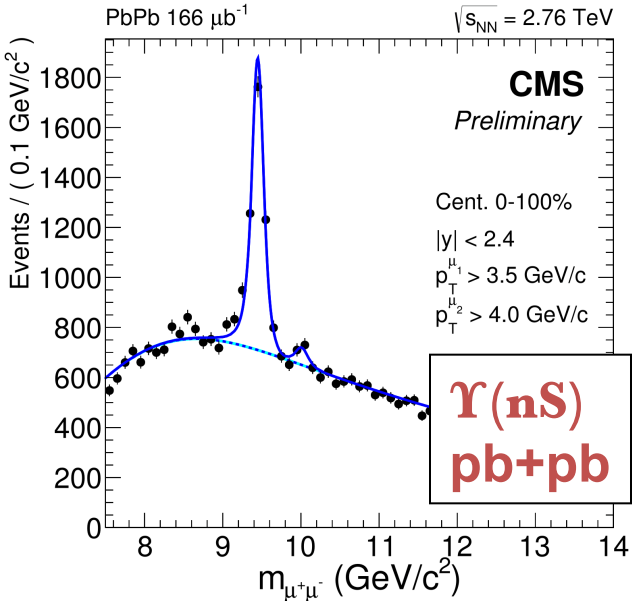










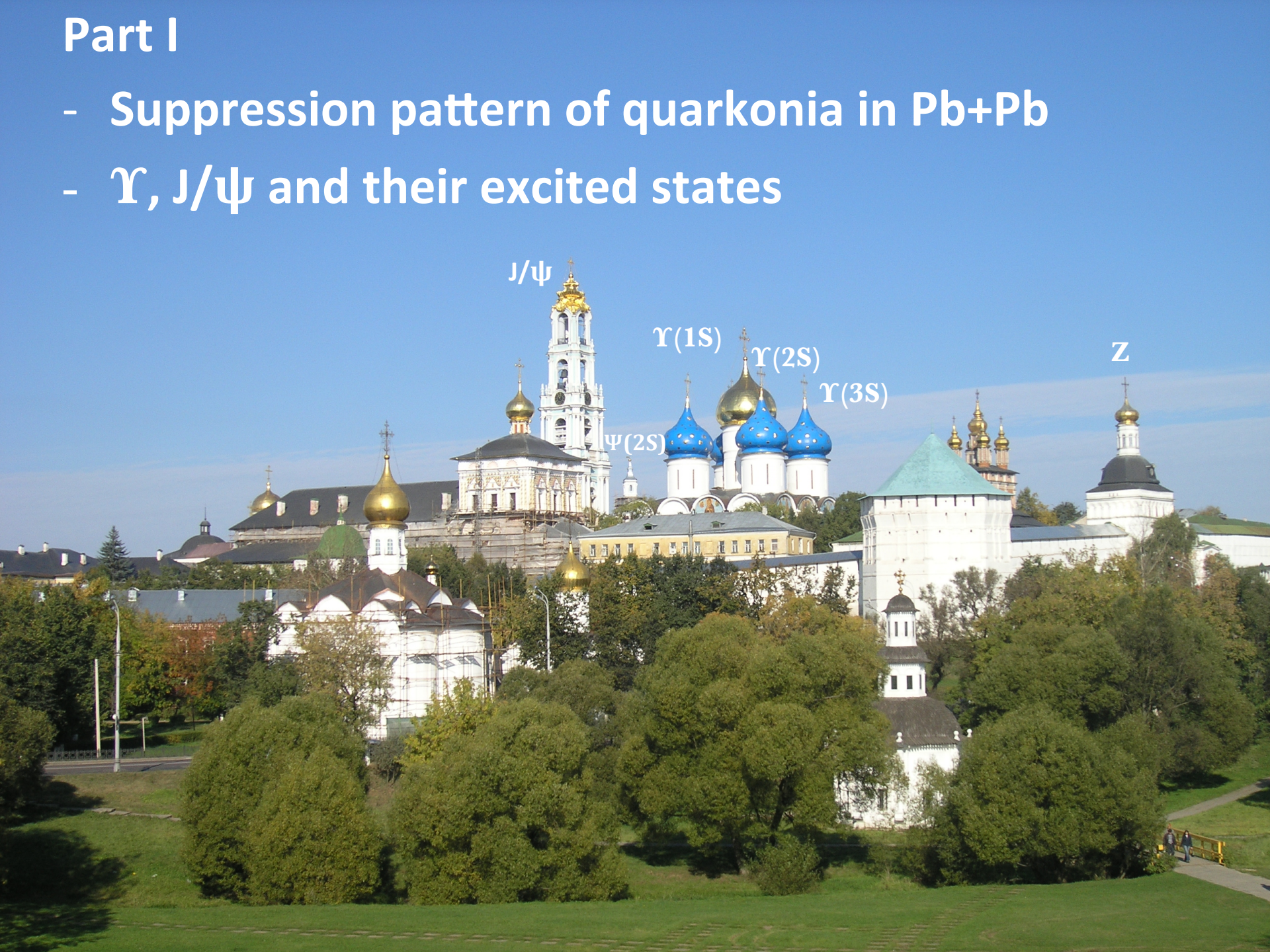


Outline of today's story

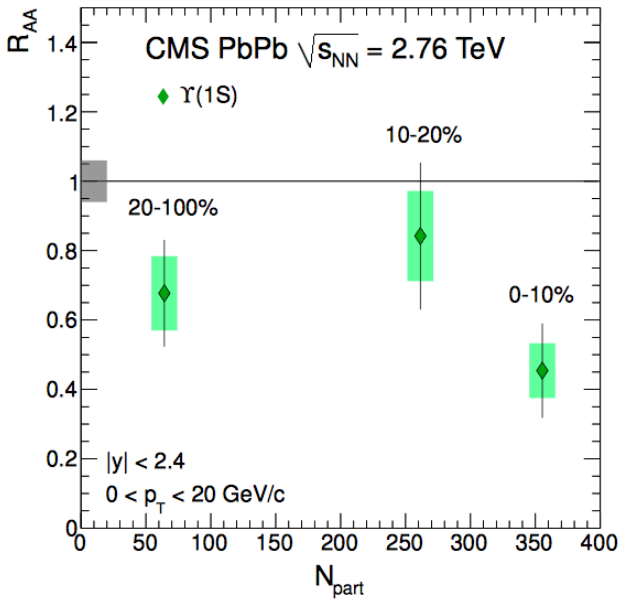
- Lessons from Υ(nS) suppression and its dependence on kinematics in in Pb+Pb collision
- Comparison of Υ(nS) vs. J/ψ in Pb+Pb
- Comparison of p+Pb vs. Pb+Pb system in terms of Υ(nS)
- Investigation of cold nuclear matter effect in p+Pb using Υ, J/ψ, B meson and B jet

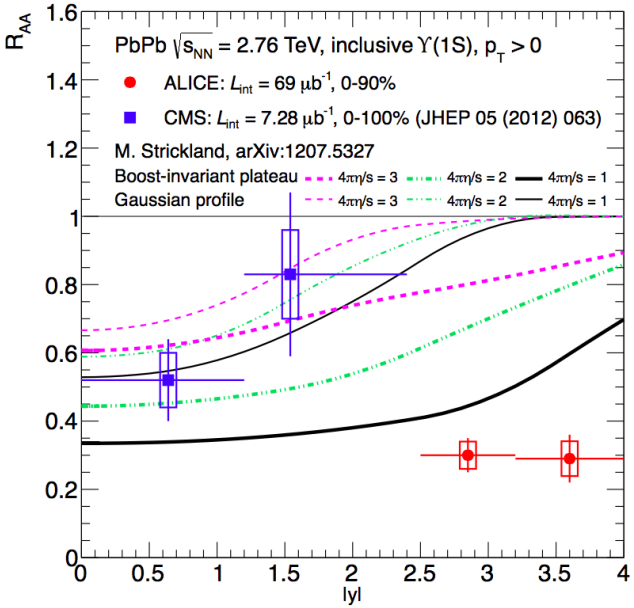
Part I

- Suppression pattern of quarkonia in Pb+Pb
- Υ, J/ψ and their excited states

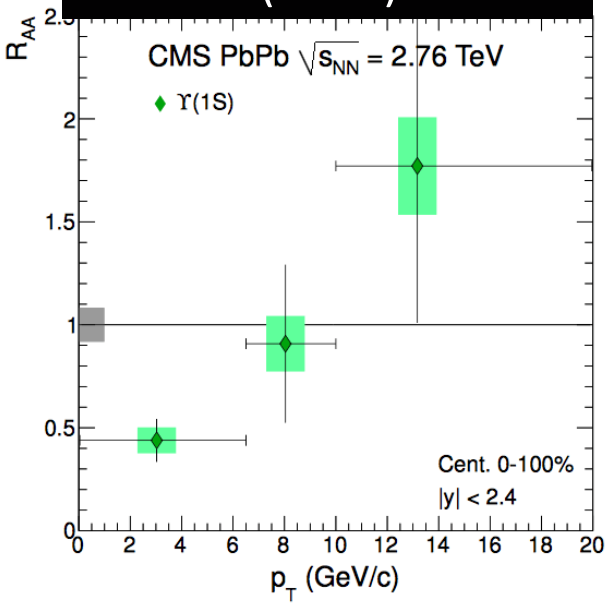


Υ results in 2013



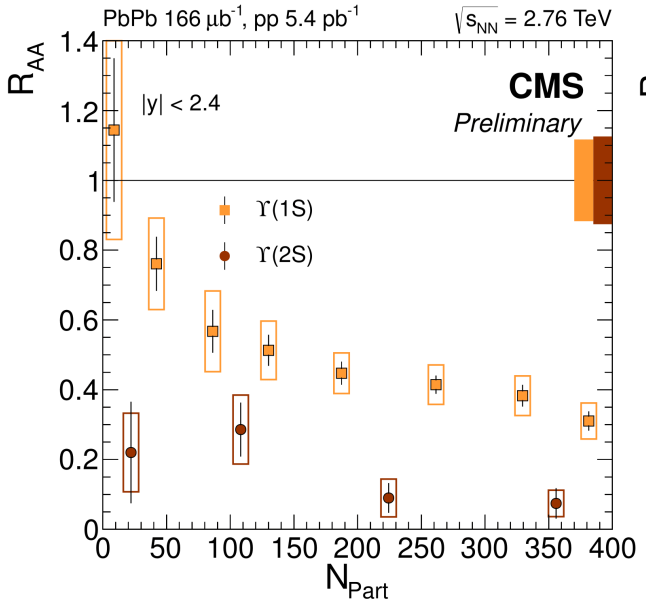


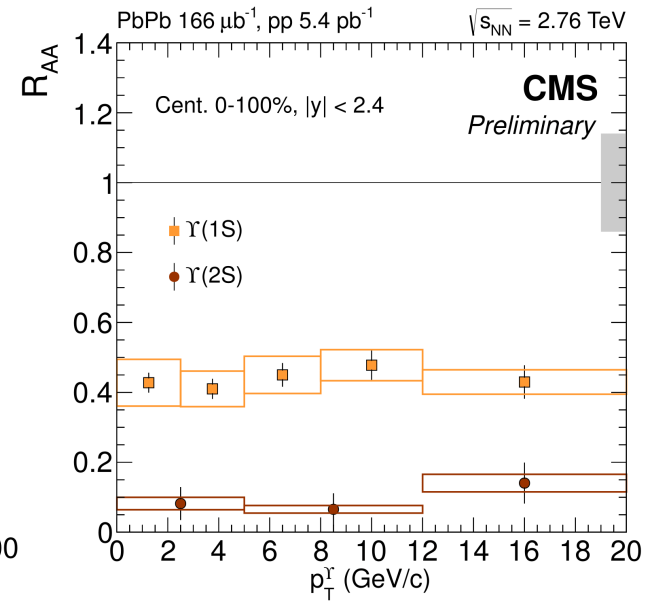
PRL 109(2012) 222301



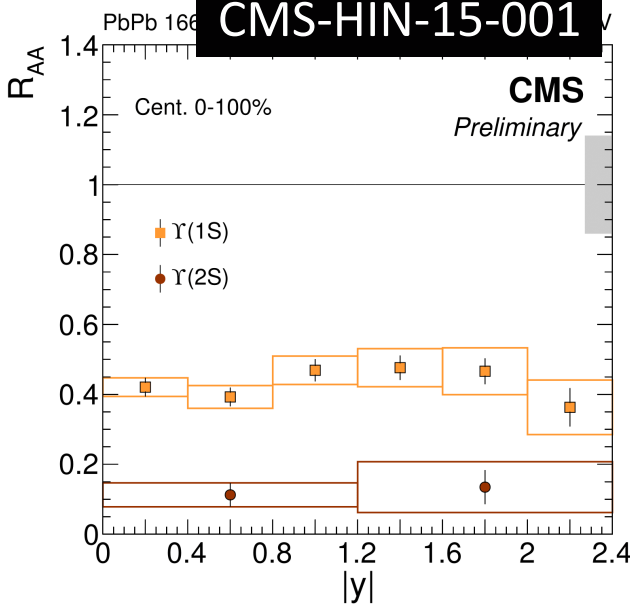
- Suppression of Υ in Pb+Pb collision was clear, but statistical uncertainty was too large for differential cross-section

Υ suppression in Pb+Pb updated



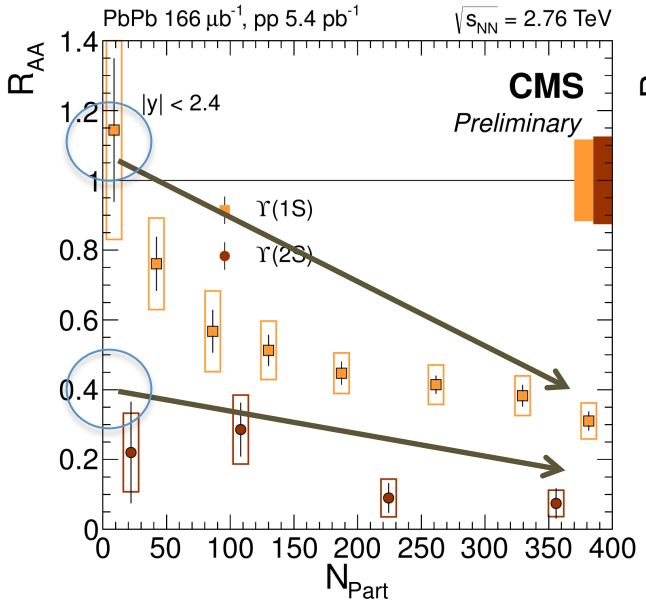


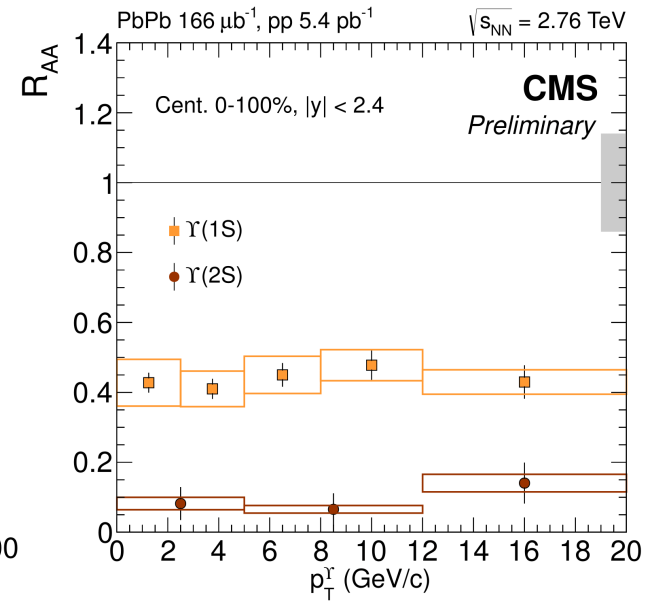
CMS-HIN-15-001



- Confirmation of centrality dependence of Υ suppression
- Almost flat R_{AA} for 1S and 2S states in $|y|<2.4$, $p_T < 20$GeV/c.
- Expect to constrain theoretical models
- 3S states not observed. Suppressed by more than 7 at 95% confidence level

Υ suppression in Pb+Pb updated





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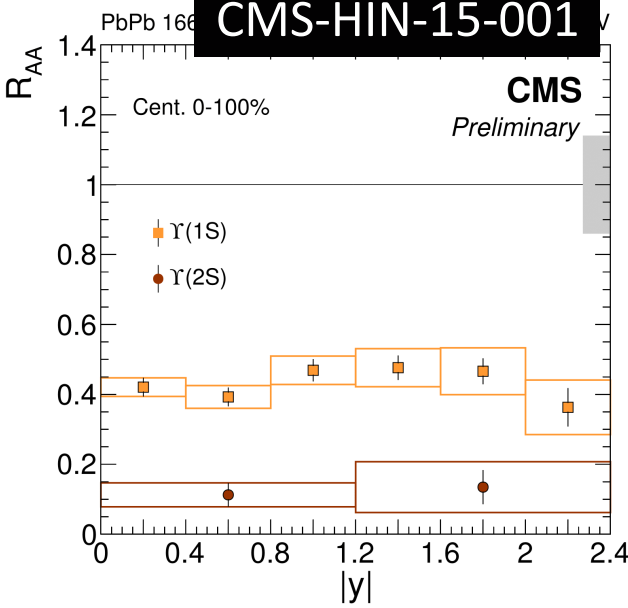

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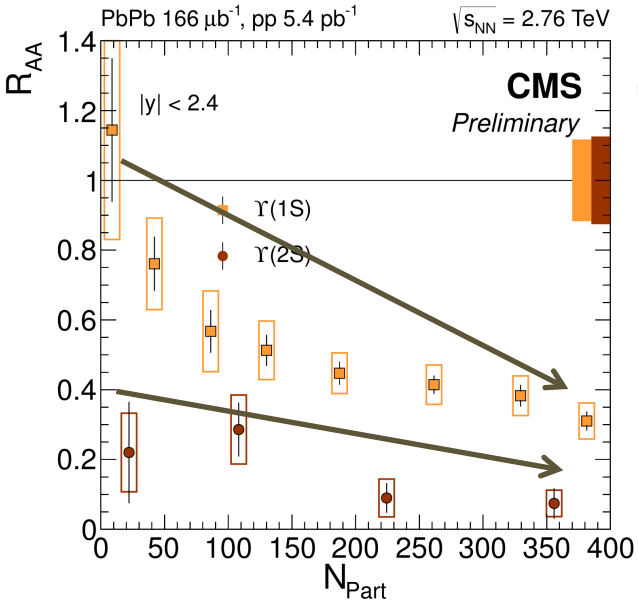

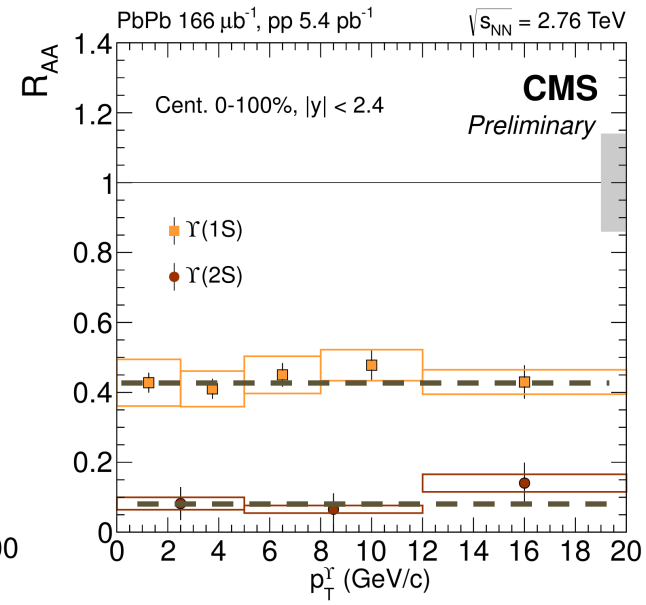

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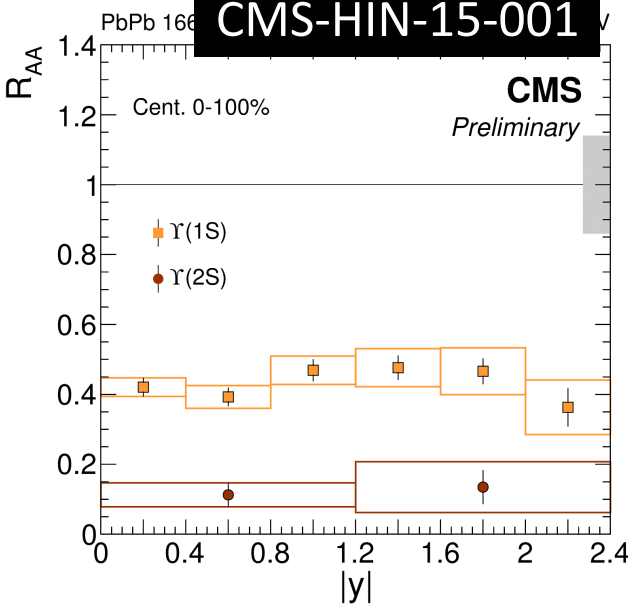

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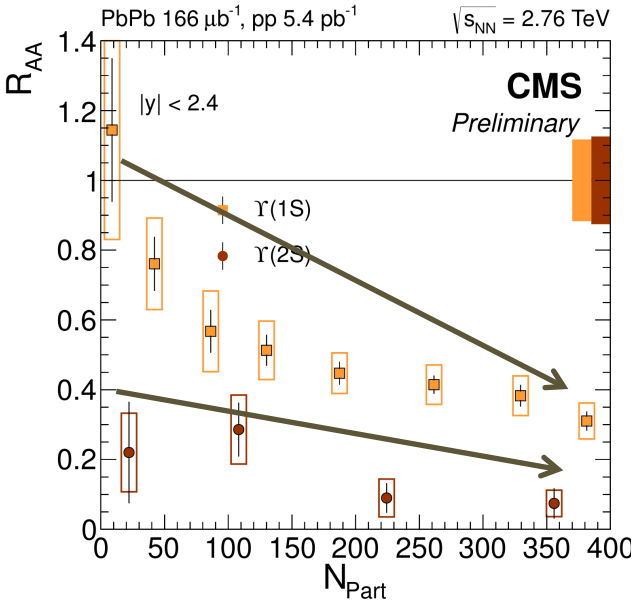
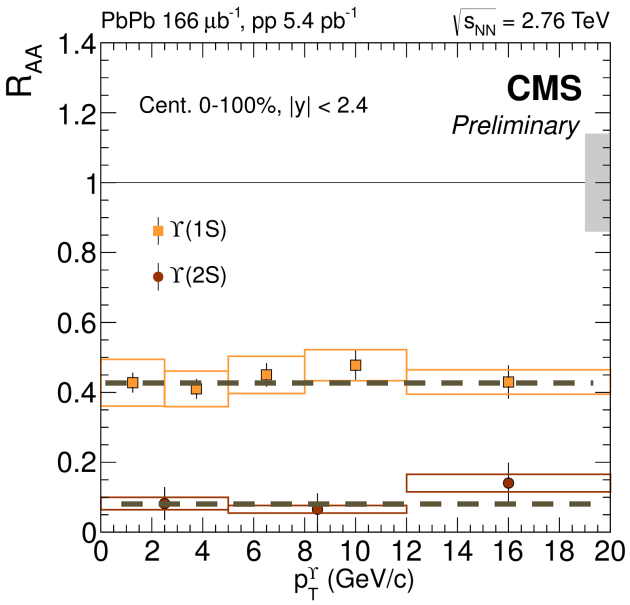
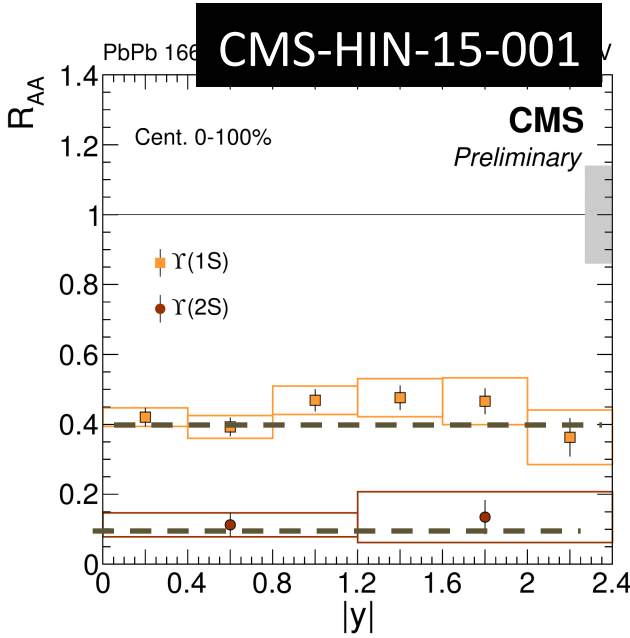
Υ suppression in Pb+Pb updated







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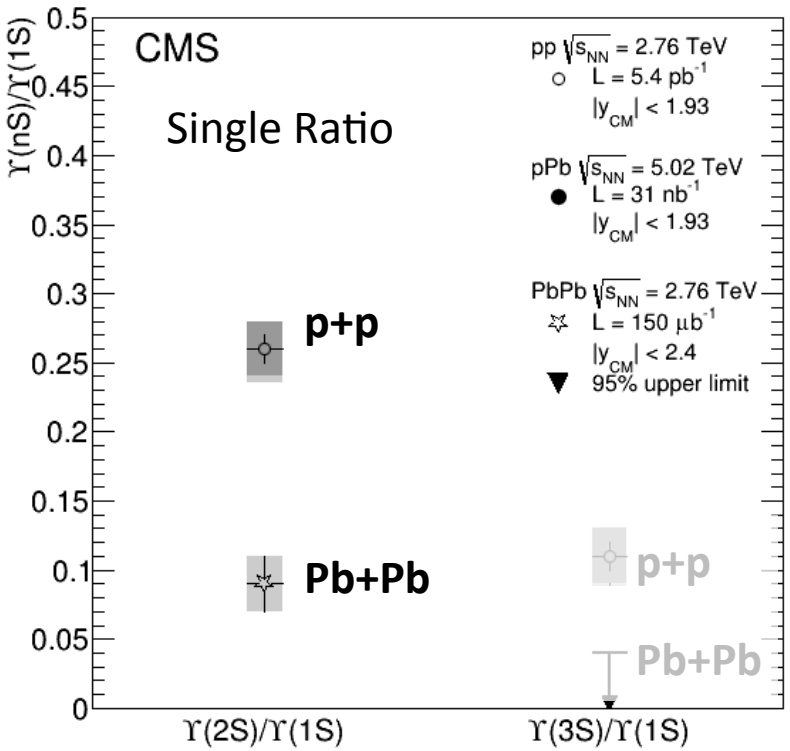
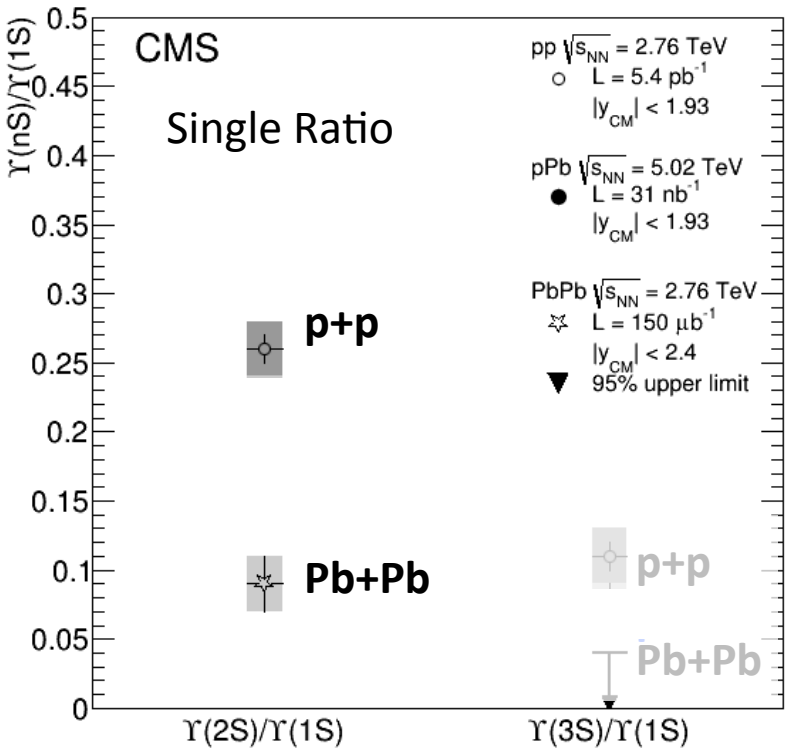
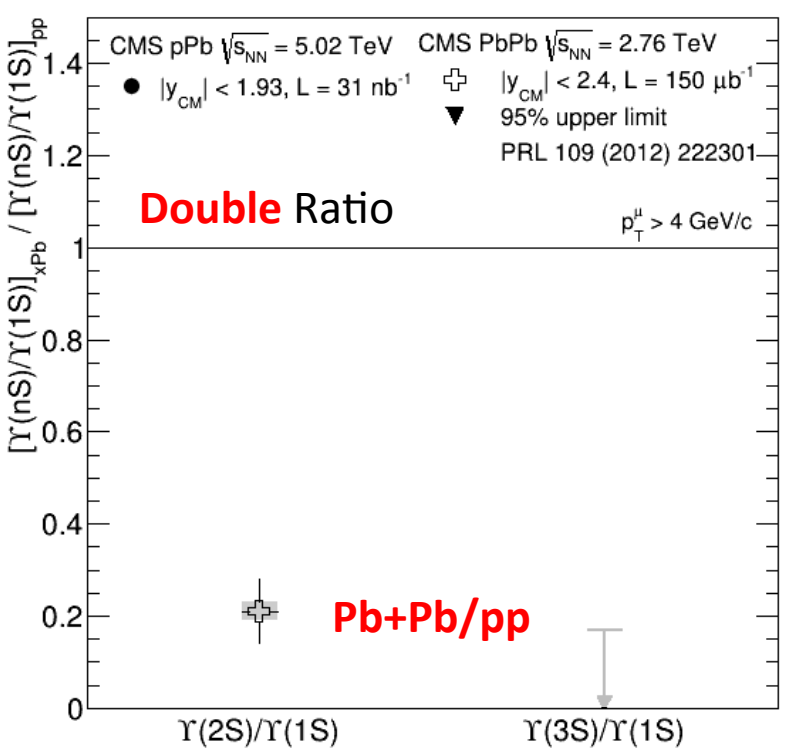
ϒ(2S) suppression in Pb+Pb



- The distinctive suppression patterns of ϒ(nS) is quantified as ϒ(nS)/ϒ(1S) ratios for p+p and Pb+Pb respectively

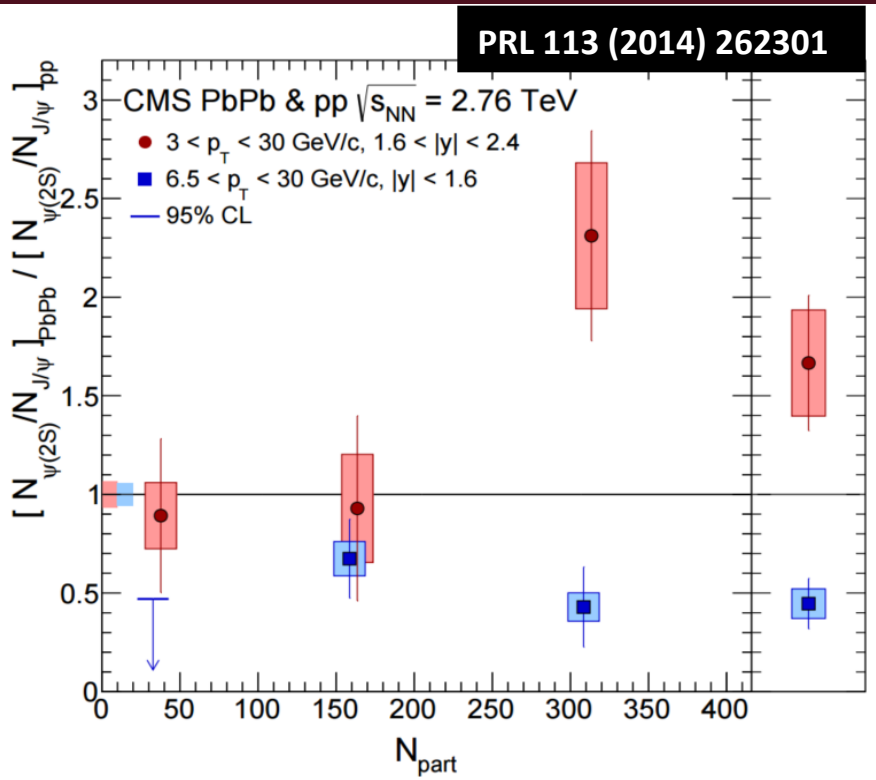
Yield modification of Υ(2S) in p+Pb





- Double ratio (Pb+Pb)/(p+p) means how much the suppression patterns in Υ(nS) are different from Υ(1S)
  - 1 : Υ(2S) equally suppressed as Υ(1S)
  - <1 : Υ(2S) more suppressed than Υ(1S) ← PbPb result
  - >1 : Υ(2S) less suppressed than Υ(1S)

$\psi(2S)/\psi(1S) \approx \Upsilon(2S)/\Upsilon(1S)$?



Forward $\psi(2S)$

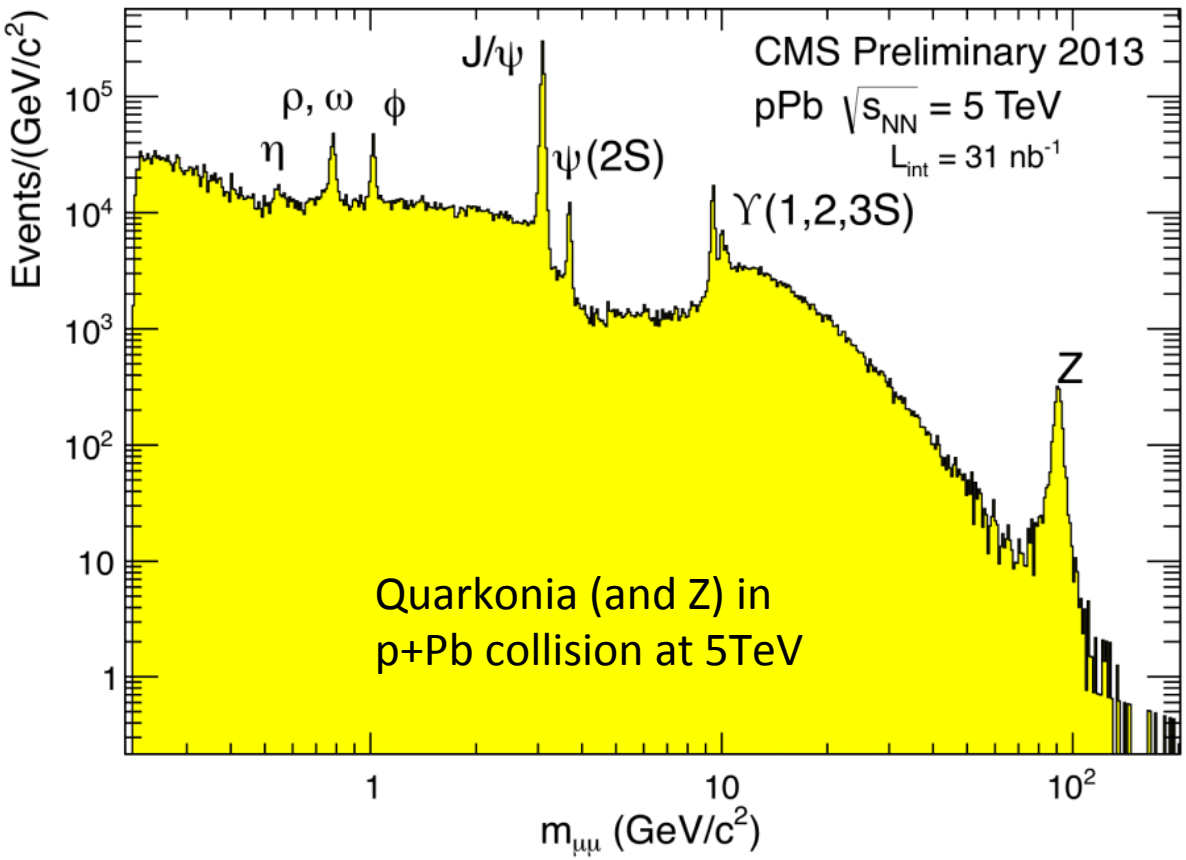
Mid-rapidity $\psi(2S)$

- No. The double ratio significantly depends on rapidity range
- In 1.6 < |y| < 2.4, $\psi(2S)$ was less suppressed than $\psi(1S)$, which was not observed for $\Upsilon(nS)$
- Not explained by only naïve thermal suppression of quarkonia states

Part II

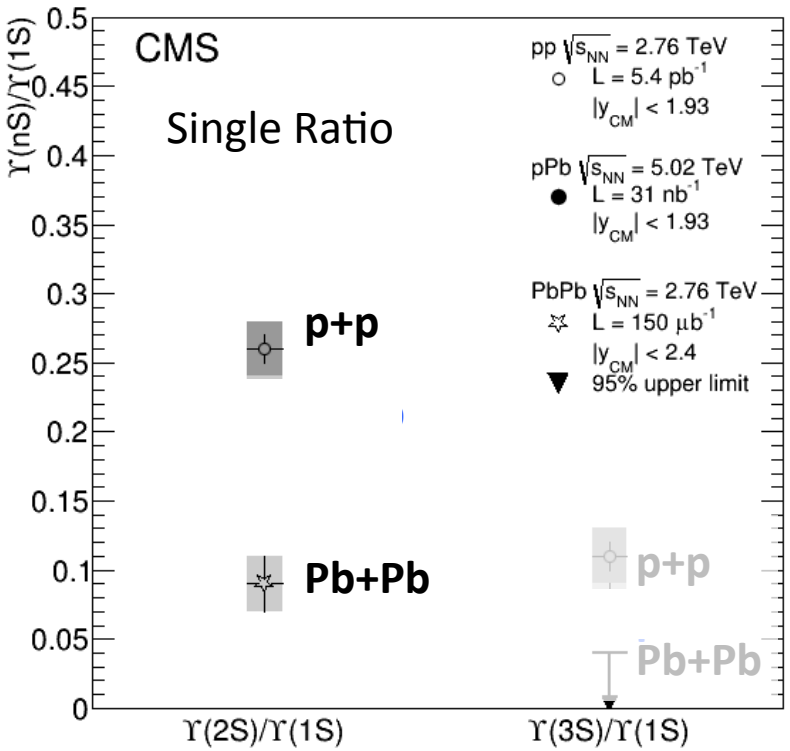
- Modification of quarkonia in p+Pb collision

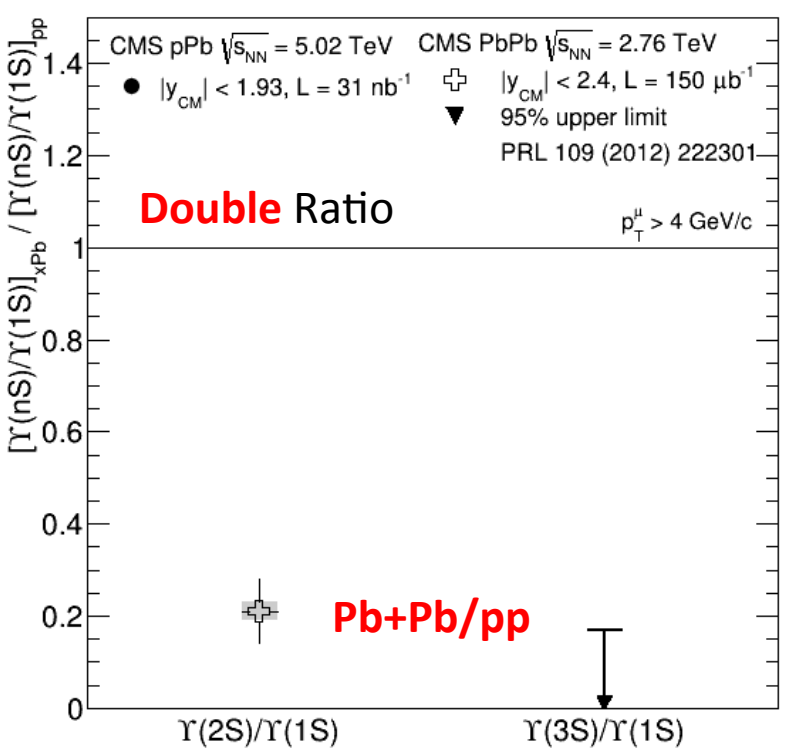
Efforts to understand cold medium



- Beyond suppression by hot medium, quarkonia production is subject to several cold nuclear matter effects
  - Before Quarkonia production : nPDF modification, Cronin effect, energy loss
  - After Quarkonia production : absorption, co-moving hadron collision

ϒ(2S) suppression in Pp+Pb





- Double ratio (Pb+Pb)/(p+p) means how much the suppression patterns in ϒ(nS) are different from ϒ(1S)
  - 1 if ϒ(nS) is suppressed by same factors of ϒ(1S)
  - <1 if ϒ(nS) is more suppressed than ϒ(1S) ← PbPb result
  - >1 if ϒ(nS) is less suppressed than ϒ(1S)

Yield modification of Υ(nS) in p+Pb

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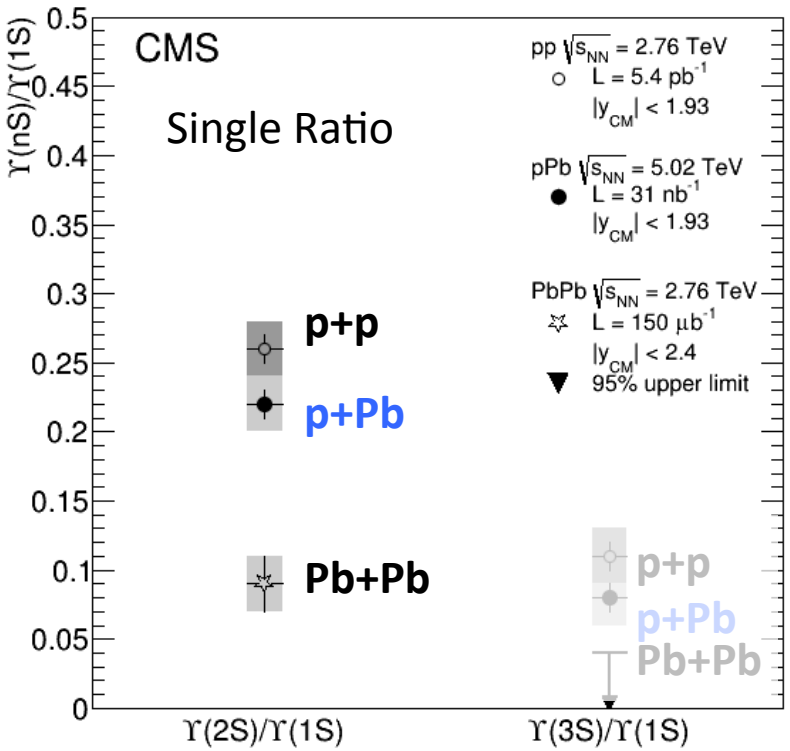

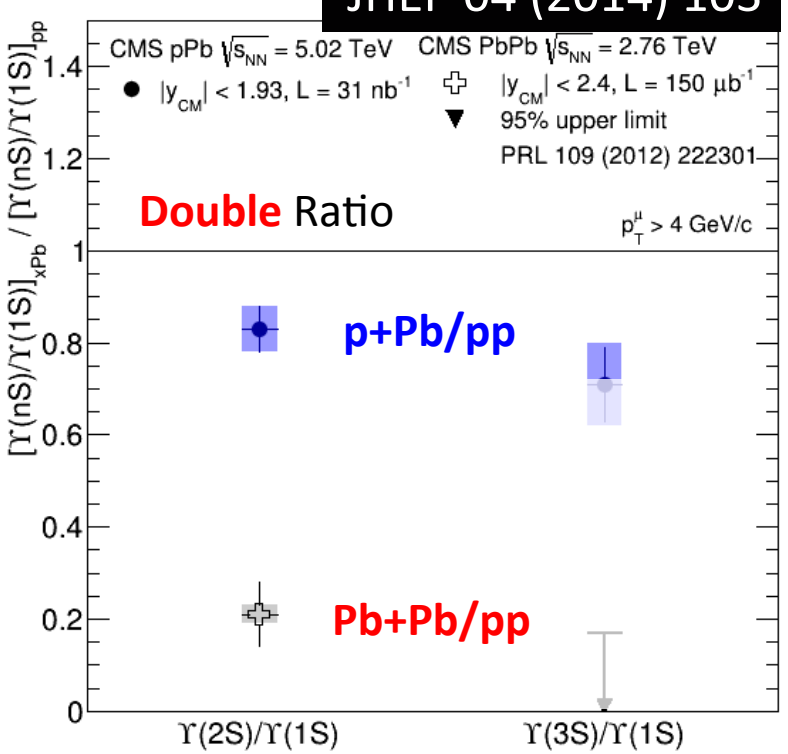

- Confirms that the large suppression of Υ(nS) in Pb+Pb is the final state effect
- Yet, we see a considerable modification of yield in p+Pb . How is this phenomenon compared to those in PbPb and pp?

Multiplicity dependence of ϒ yield

- ϒ(2S)/ϒ(1S) ratio monotonically drops as a function of multiplicity in p+p, p+Pb and Pb+Pb system
- Follow-up questions
  - When is modification happening? Before or after formation of $Q\bar{Q}$ bound state?
  - Are p+p and p+Pb comparable for same multiplicity events?
- The polarization information can help to understand the quantum properties of the pre-resonant state
- Let's stop by our **NEW** polarization result of Υ in p+p for the next 2 slides and come back to heavy ion physics

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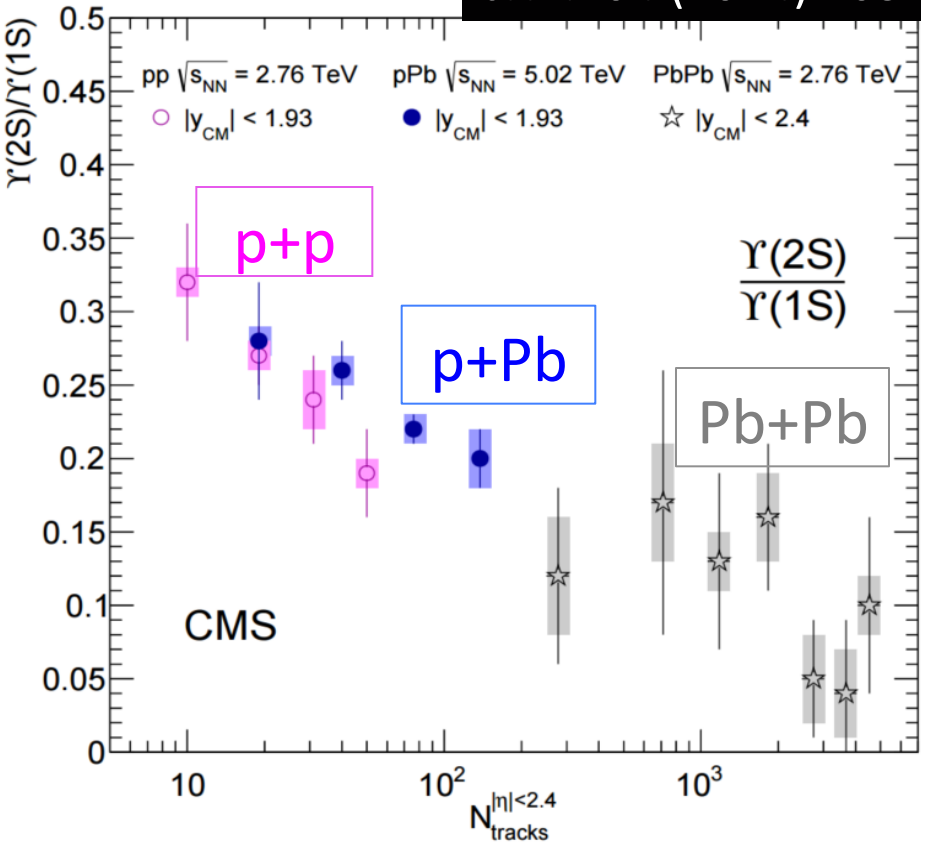
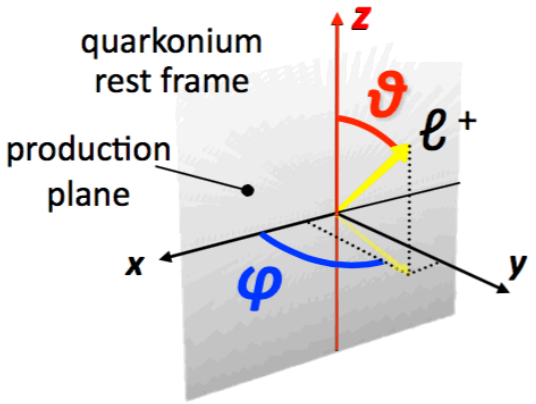


Same phenomenology in p+p, p+Pb and pb+Pb? Or too hasty conclusion?

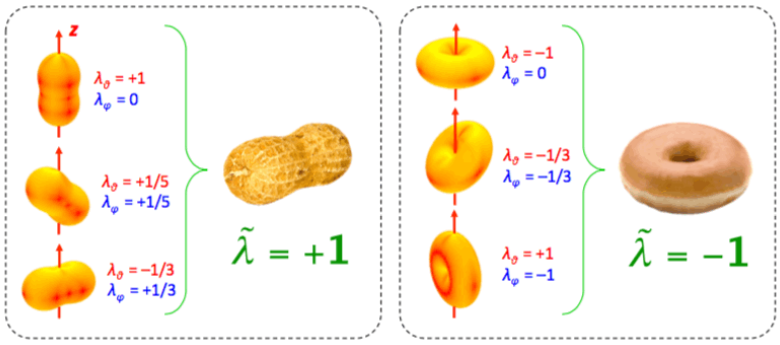
Polarization of Υ in p+p at 7TeV

- Modification of polarization can be thought of as the signal of interaction exerted during the formation of $Q\bar{Q}$ bound state ➔ final state effect
- Polarization of Υ states propagates to the anisotropic angular distribution of the decayed muons
- $\tilde{\lambda}$, frame independent variable, was used to quantify the distribution shape
- Dependence on particle multiplicity in p+p collisions was investigated to find the correlation with surrounding hadrons



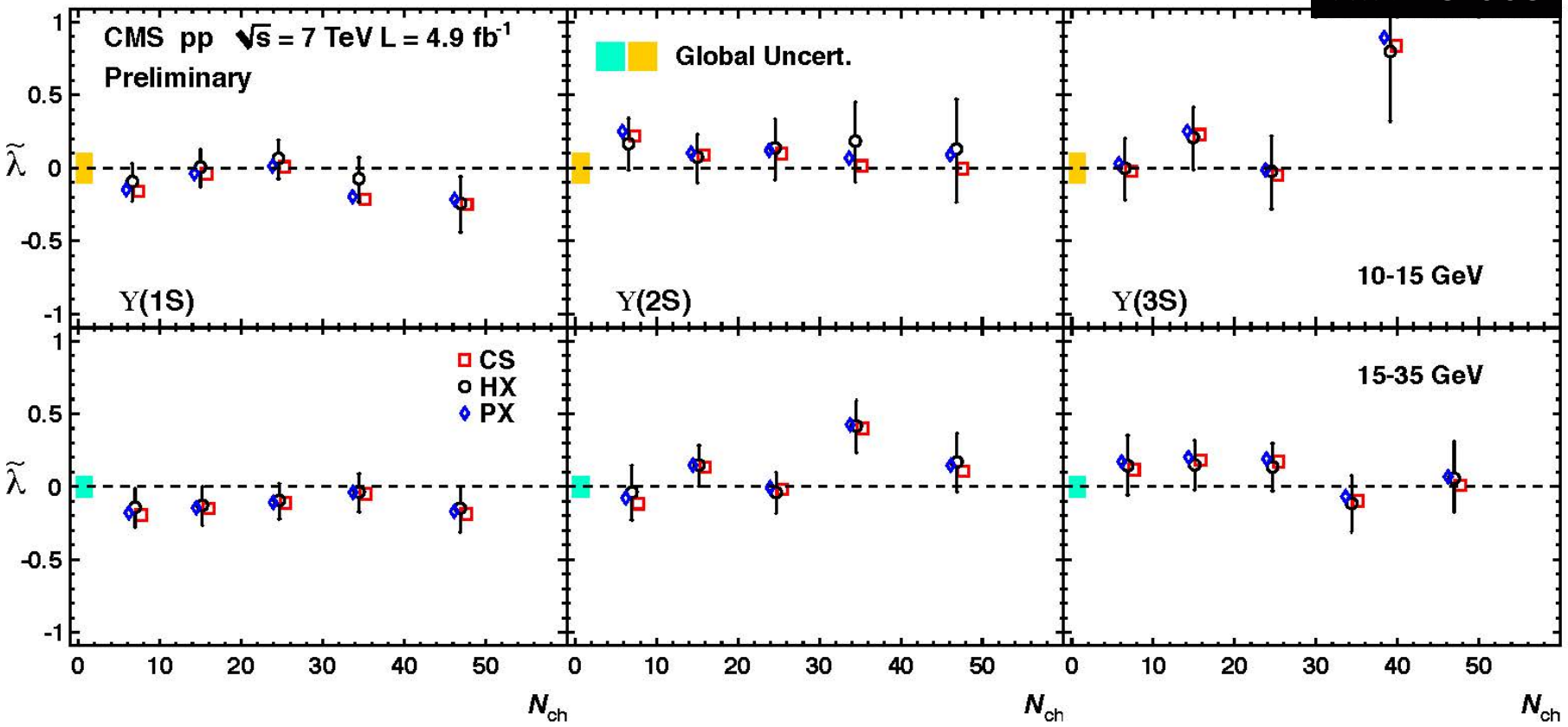
$$W(\cos\vartheta, \varphi|\vec{\lambda}) = 1 + \lambda_\theta \cos^2\vartheta + \lambda_\varphi \sin\vartheta\cos 2\varphi + \lambda_{\vartheta\varphi} \sin 2\vartheta \cos\varphi$$

$$\tilde{\lambda} = \frac{\lambda_\vartheta + 3\lambda_\varphi}{1 - \lambda_\varphi}$$



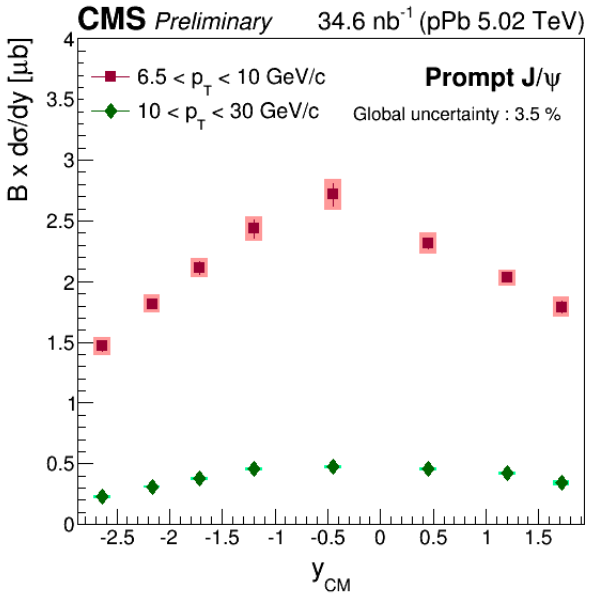
Polarization of Υ in p+p at 7TeV

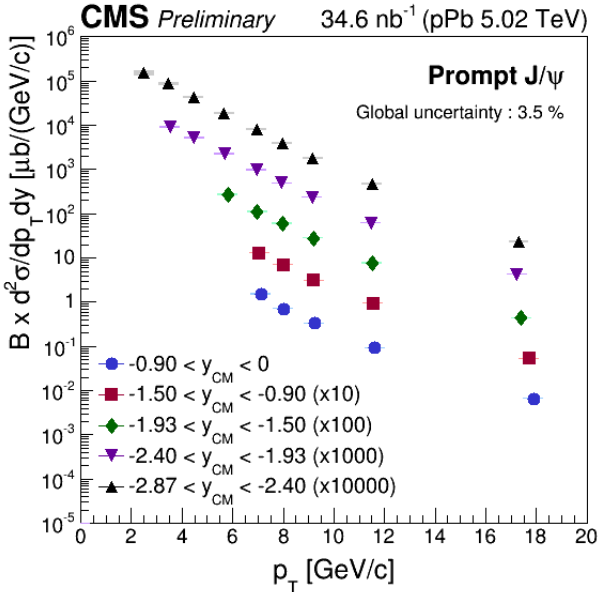
HIN-15-003

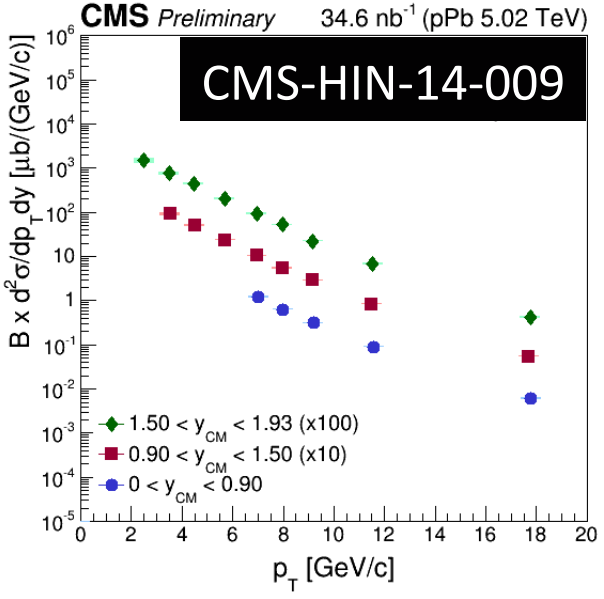


- Y polarizations were shown to remain near the unpolarized limit, with no significant dependence on particle multiplicity
- The result excludes the case of intense modification of quarkonium production processes by underlying events

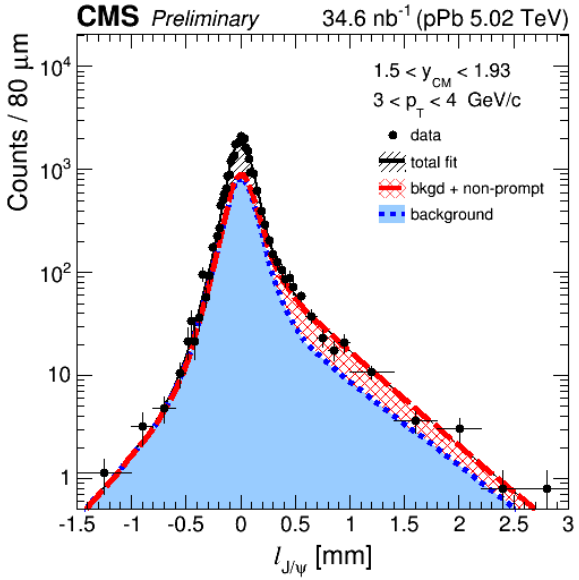
J/ψ in p+Pb

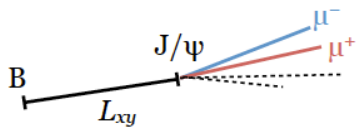




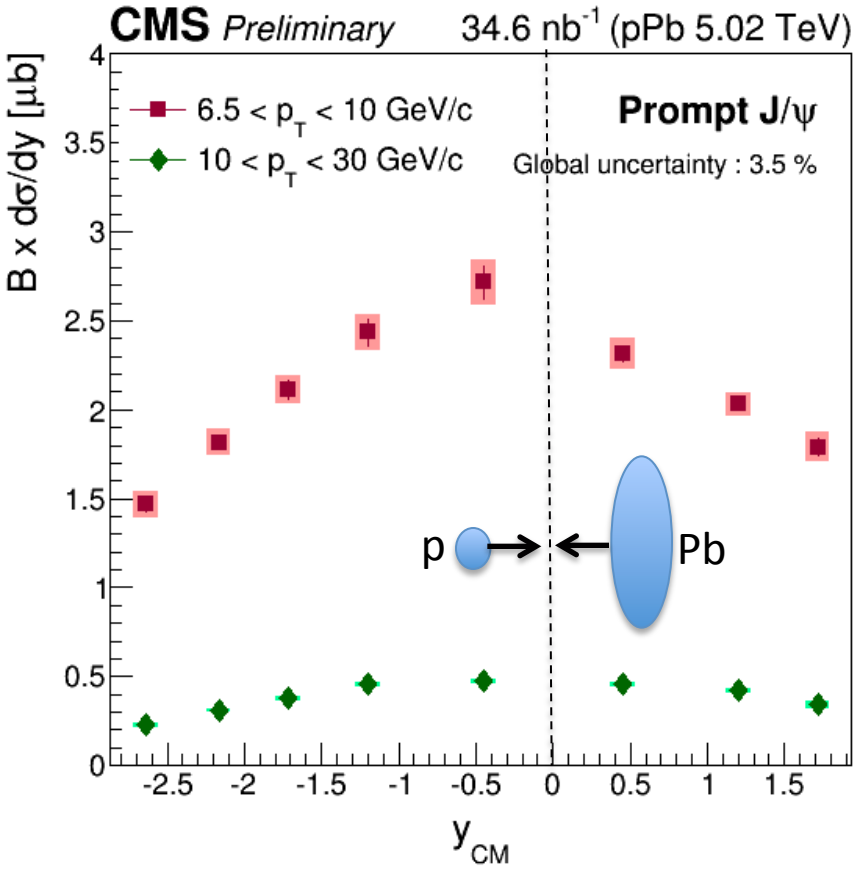


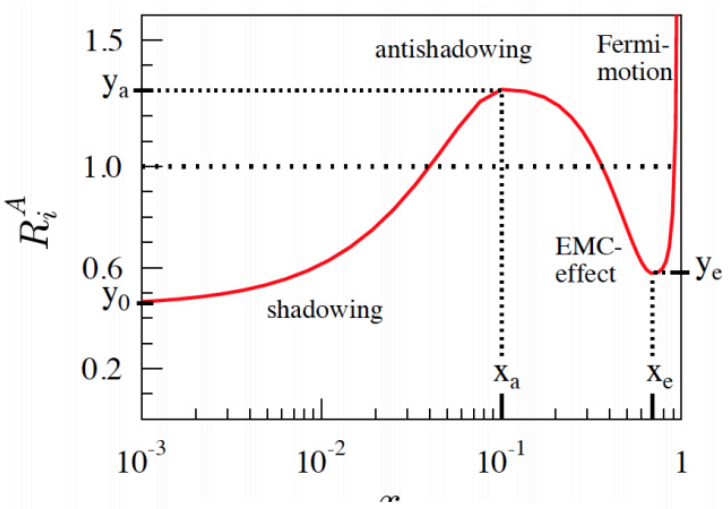
- CMS measured the double differential cross-section of J/ψ
- Non-prompt J/ψ (from B meson) are separated using decay length recognition





Lessons from J/ψ cross-section in p+Pb



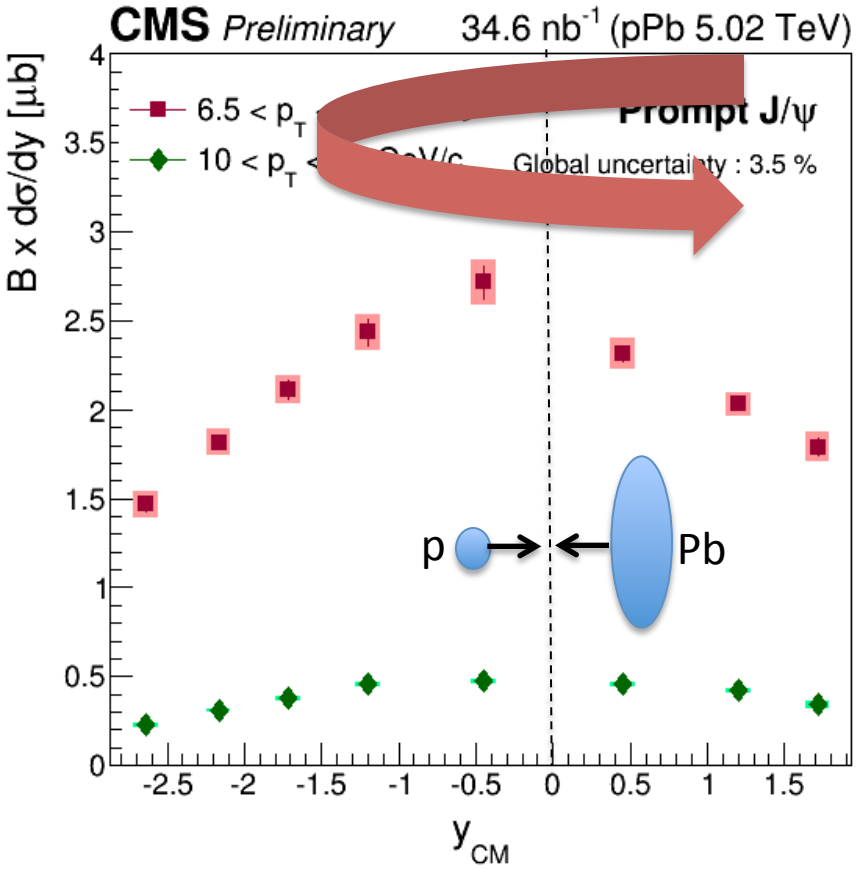


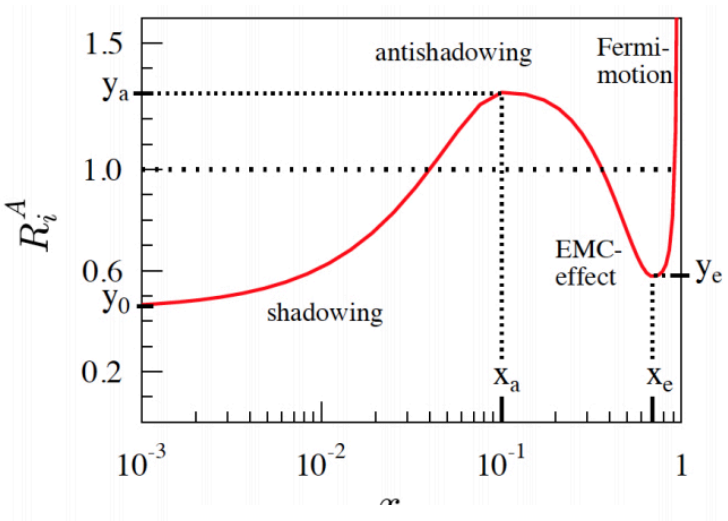
$$x_{1,2} = \frac{\sqrt{m^2_{J/\psi} + p^2_{T\,J/\psi}}}{\sqrt{s}} \cdot e^{\pm y}$$

CMS covers : $10^{-4} < x_2 < 10^{-2}$
In case of 2 -> 1 process

- Gluon distribution directly reflects to (p_T, y) distribution of prompt J/ψ
- Modification of PDF can be probed by asymmetry of J/ψ yield between p-going direction and pb-going direction

Lessons from J/ψ cross-section in p+Pb



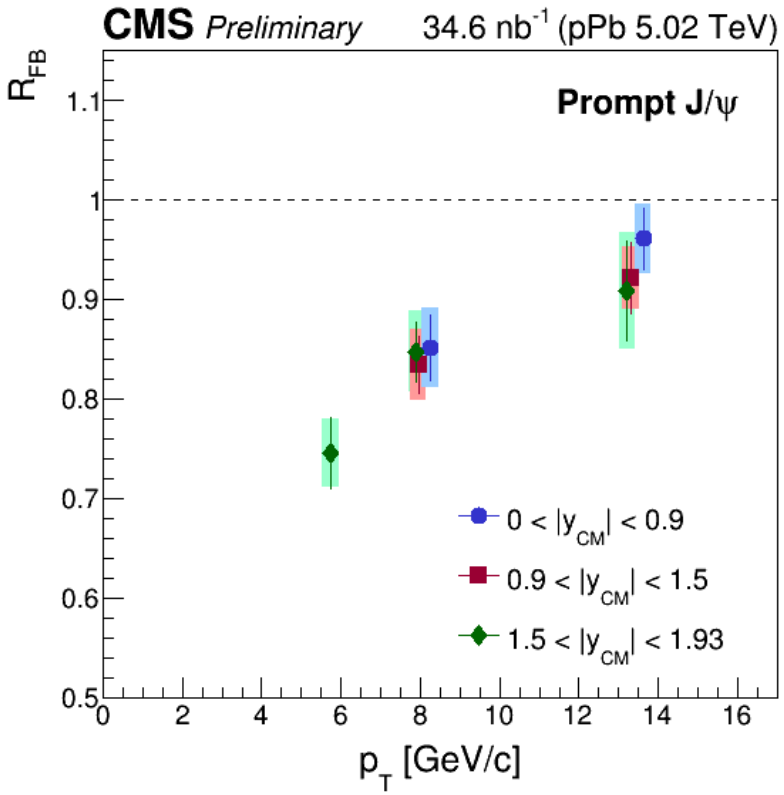


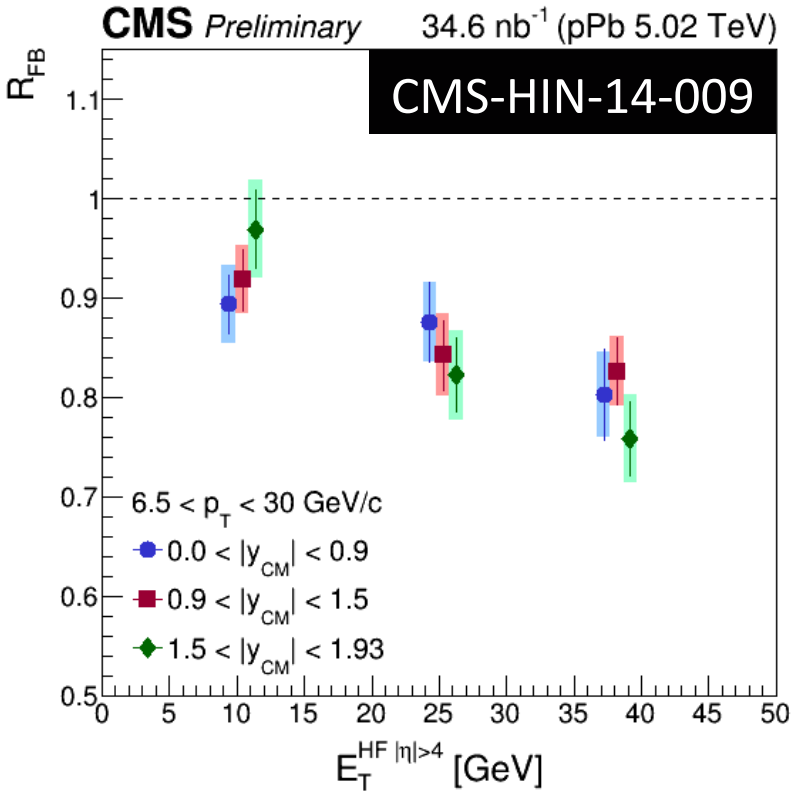
$$x_{1,2} = \frac{\sqrt{m_{J/\psi}^2 + p_{T\,J/\psi}^2}}{\sqrt{s}} \cdot e^{\pm y}$$

CMS covers : $10^{-4} < x_2 < 10^{-2}$
In case of 2 -> 1 process

- Gluon distribution directly reflects to (p_T, y) distribution of prompt J/ψ
- Modification of PDF can be probed by asymmetry of J/ψ yield between p-going direction and pb-going direction
- Let's fold plot around y_{CM}=0 to compare Forward/Backgrward yields, **R_{FB}**

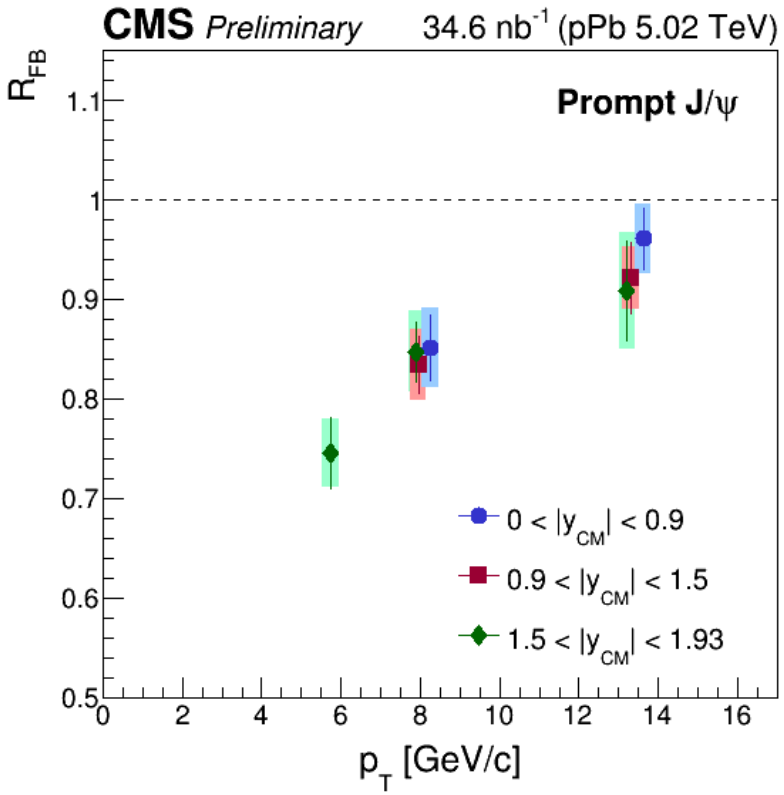
Lessons from J/ψ cross-section in p+Pb

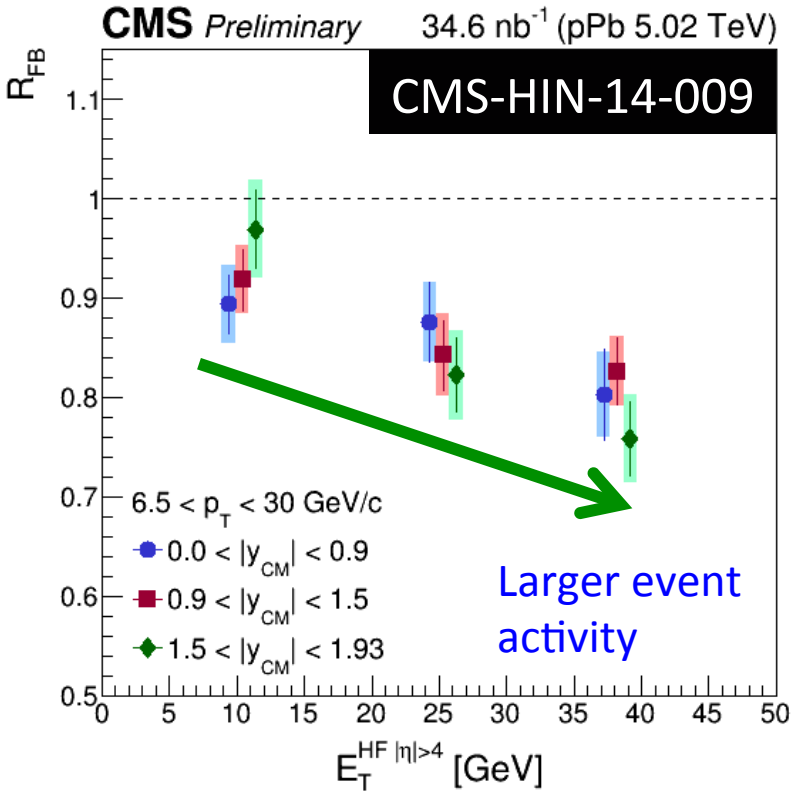




- (Left) The R_{FB} monotonically decreases for low p_T confirming significant modification of PDF.

Lessons from J/ψ cross-section in p+Pb

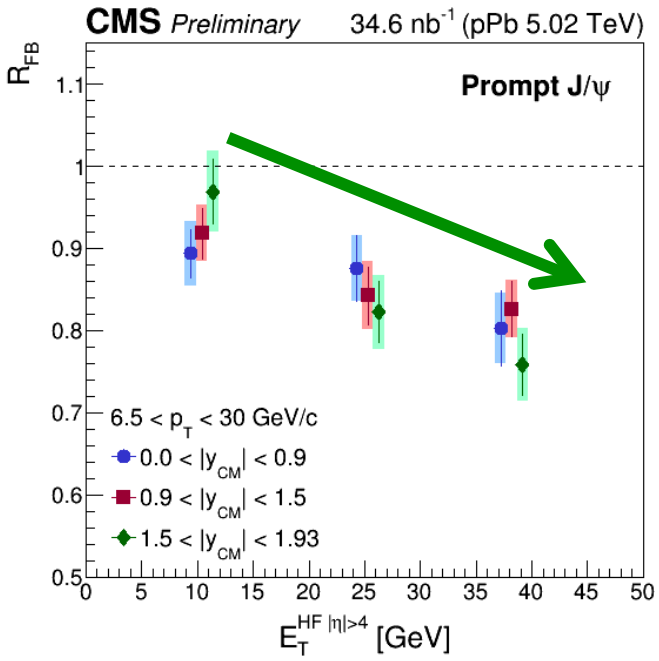




- (Left) The R_{FB} monotonically decreases for low p_T confirming significant modification of PDF.
- (Right) Measured R_{FB} as a function of event activity* to investigate centrality dependence. Asymmetry is enhanced for higher event activity bins

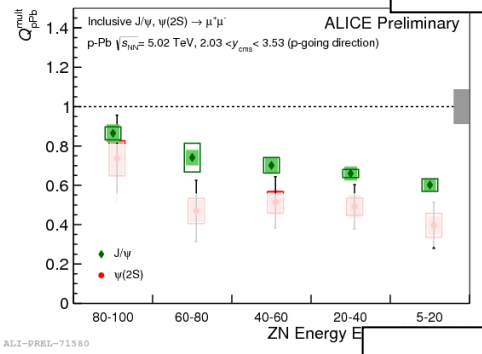
*Event activity = transverse energy deposited in forward calorimeter 4<|η|<5.2

Lessons from J/ψ cross-section in p+Pb

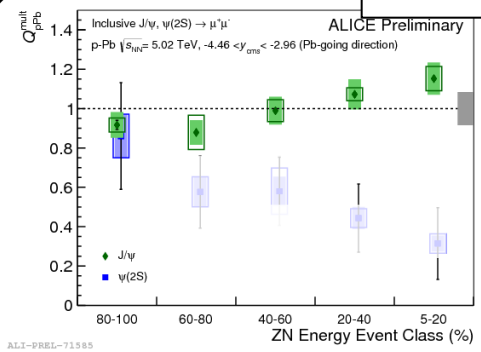


Consistent with ALICE J/ψ result ➔

ALICE forward



ALICE backward



- (Left) The R_{FB} monotonically decreases for low p_T confirming significant modification of PDF.
- (Right) Measured R_{FB} as a function of event activity* to investigate centrality dependence. Asymmetry is enhanced for higher event activity bins

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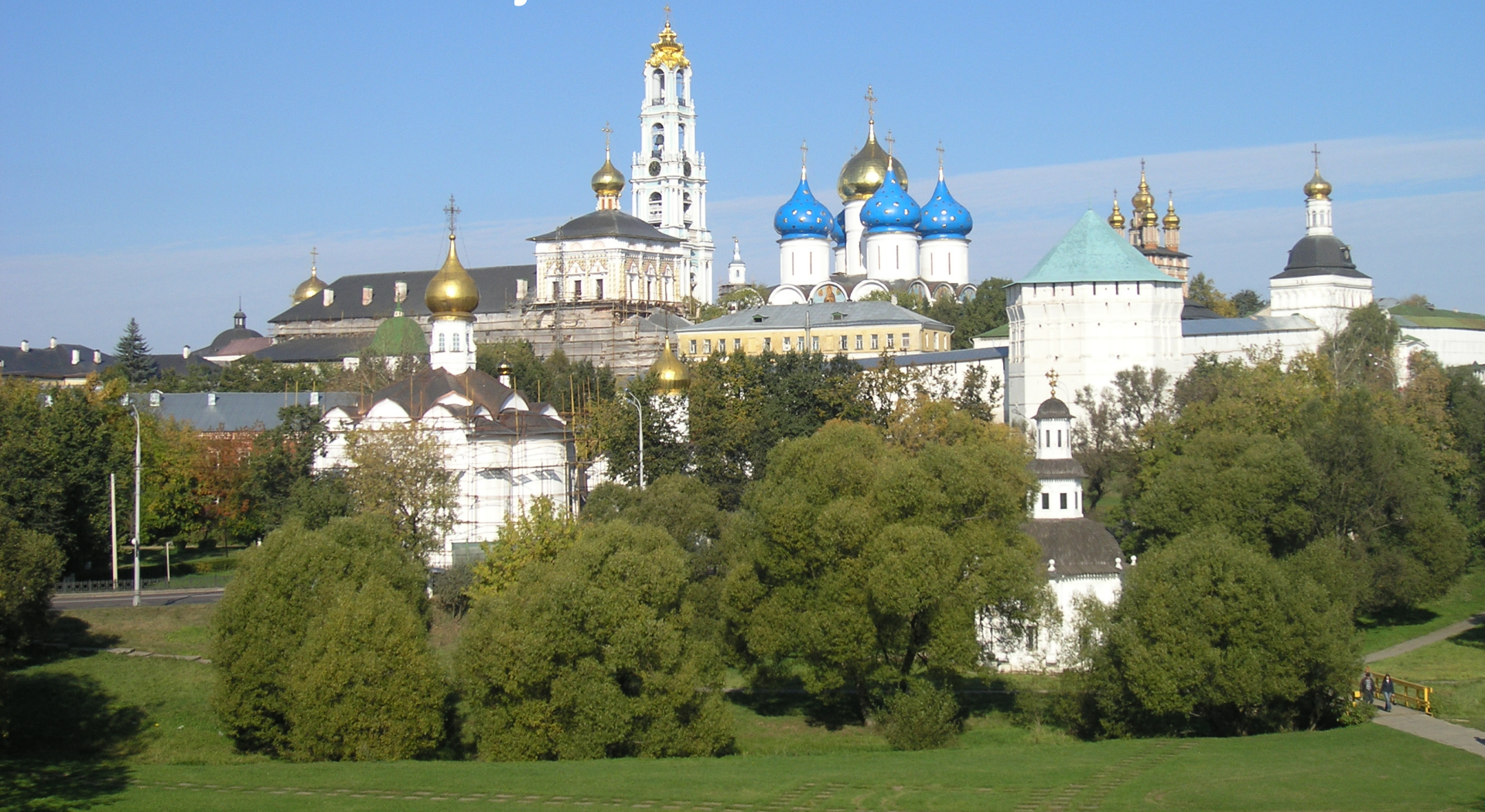
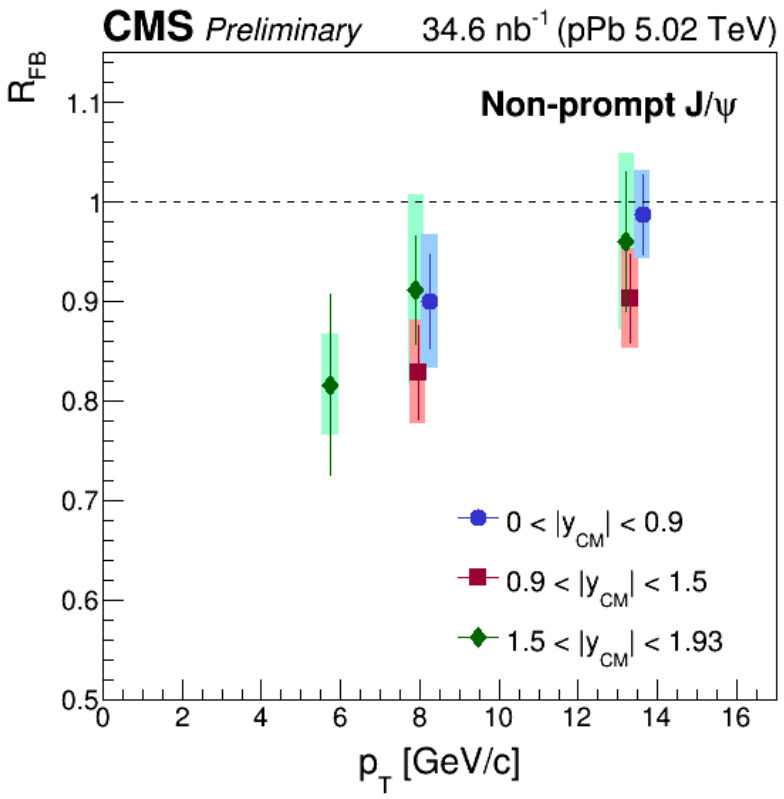
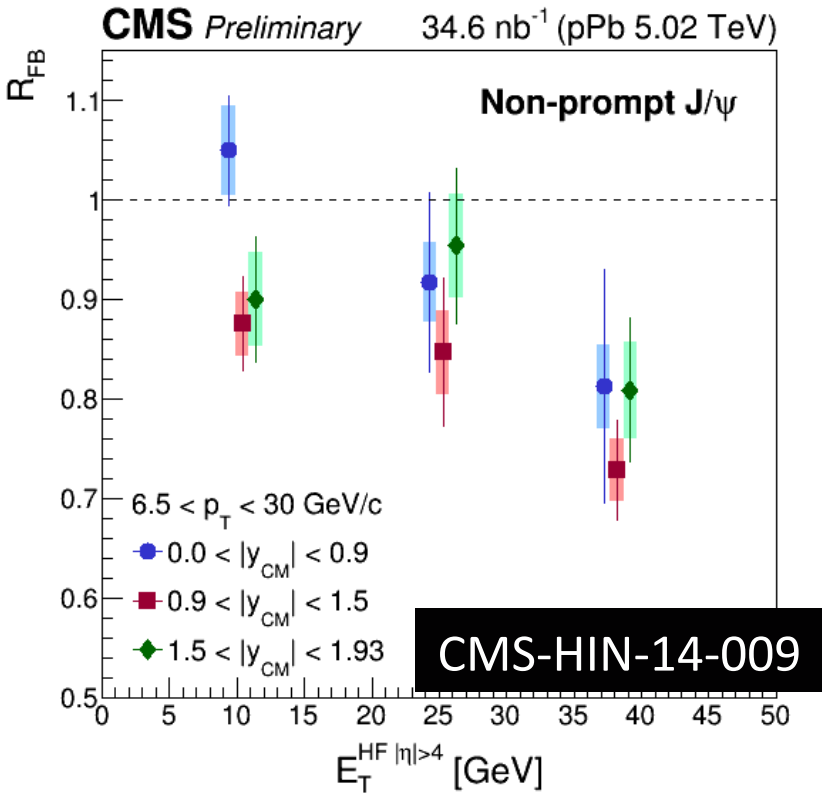
Part III

- Modification of heavy quarks in p+Pb collision
- B meson and B jet



Result of non-prompt J/ψ (feed from B meson)



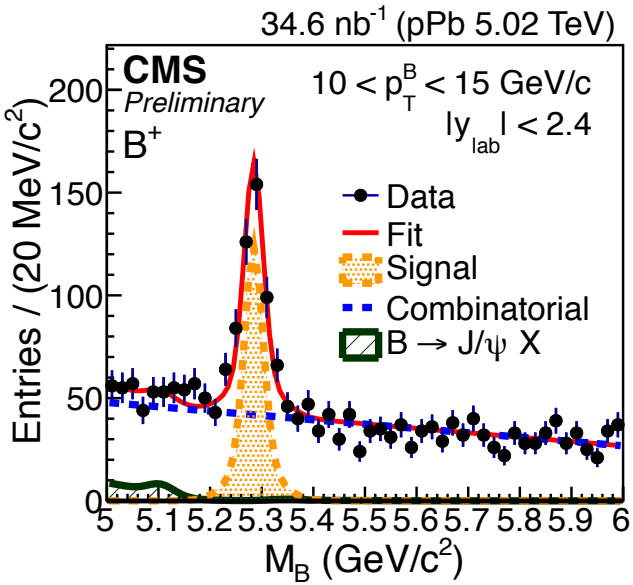


- Non-prompt J/ψ results show same trend with prompt J/ψ, but the effect is less significant by larger uncertainty

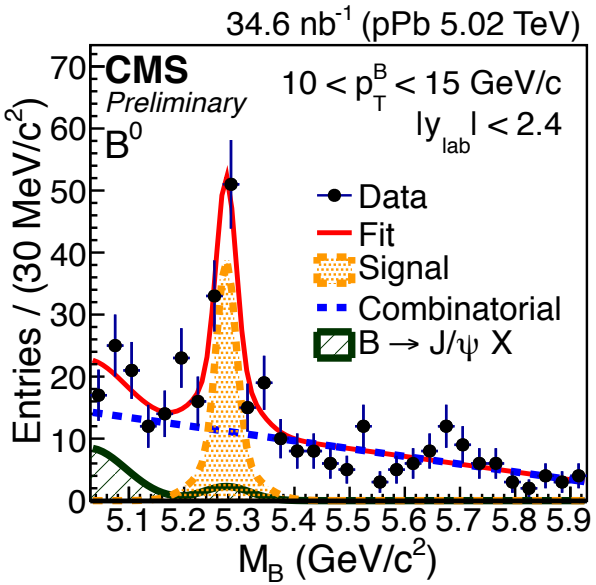
Fully reconstructed B-meson

Non-prompt J/ψ combined with…

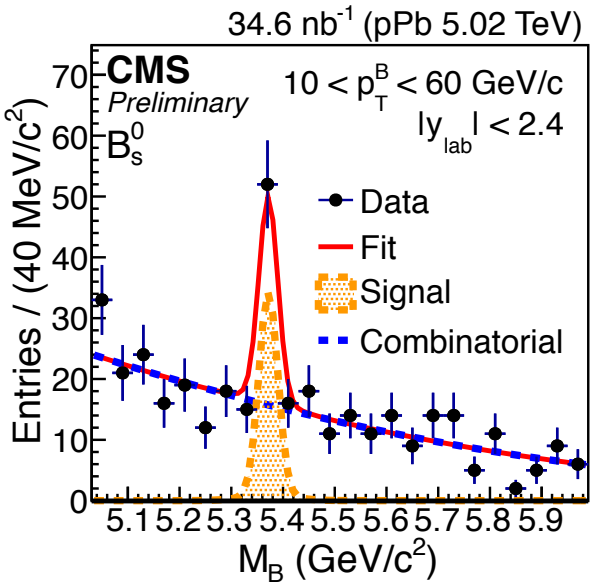
…K^+



…K^*_0 ($K^+ + \pi^-$)



…Φ ($K^+ + K^-$)

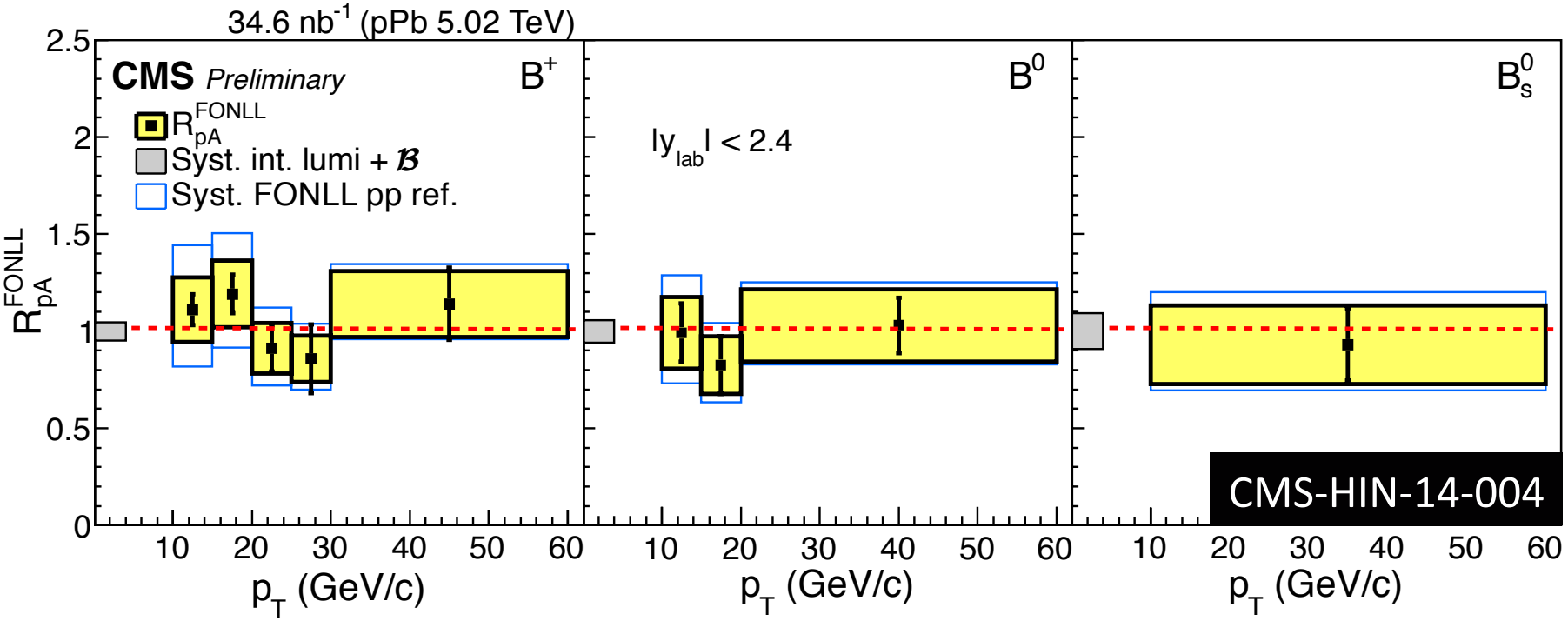


CMS-HIN-14-004

- Two kinds of background rejected to extract signal
  - (1) Combinatorial backgrounds
  - (2) Peaking structure by mis-identification of decay-channel

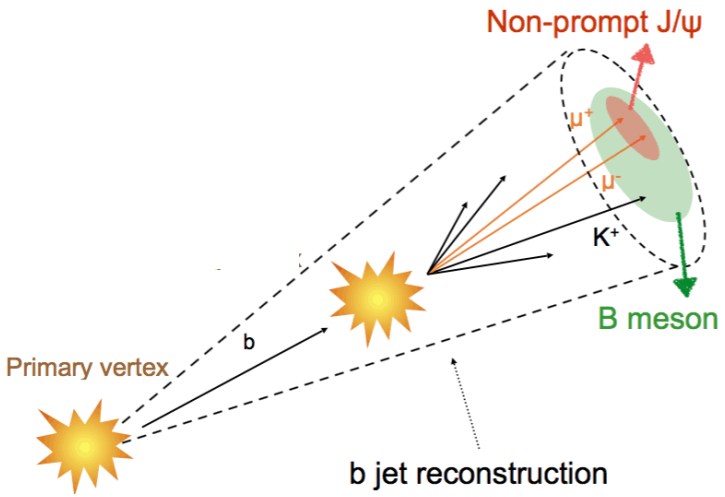
Fully reconstructed B-meson

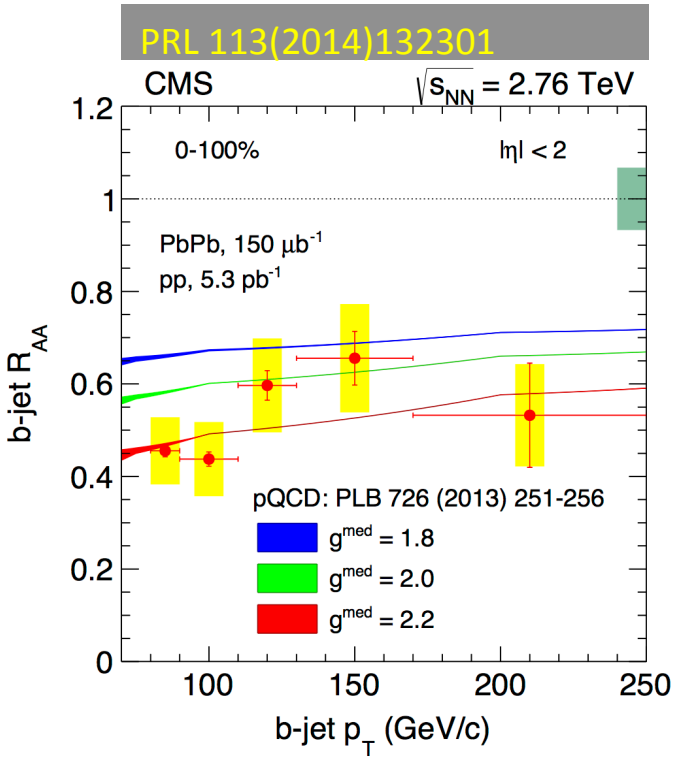
Non-prompt J/ψ combined with…



- Largest uncertainty source is the p+p reference from FONLL calculation
- R_{pPb} is consistent with unity within uncertainty
- No significant suppression of B quark observed in p+Pb

Different b-quark reconstruction

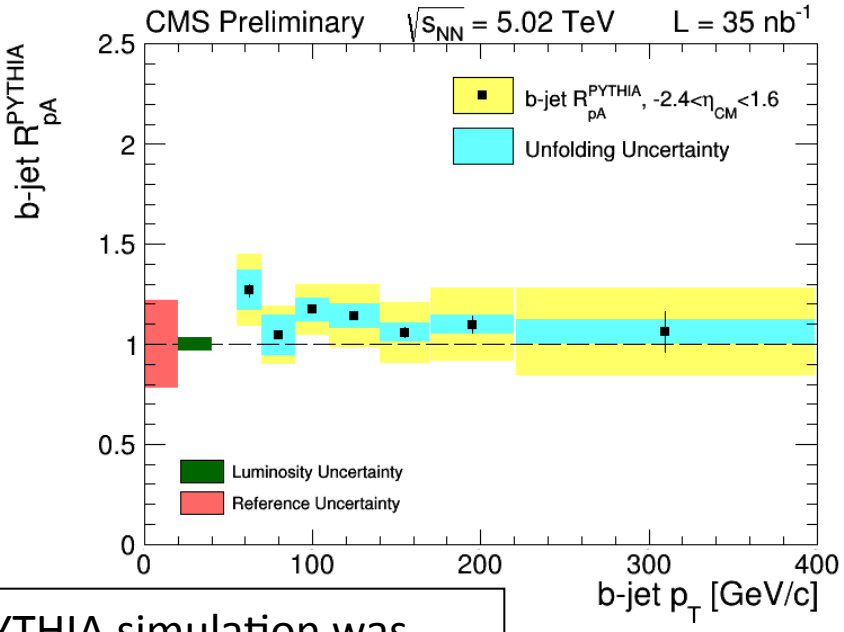


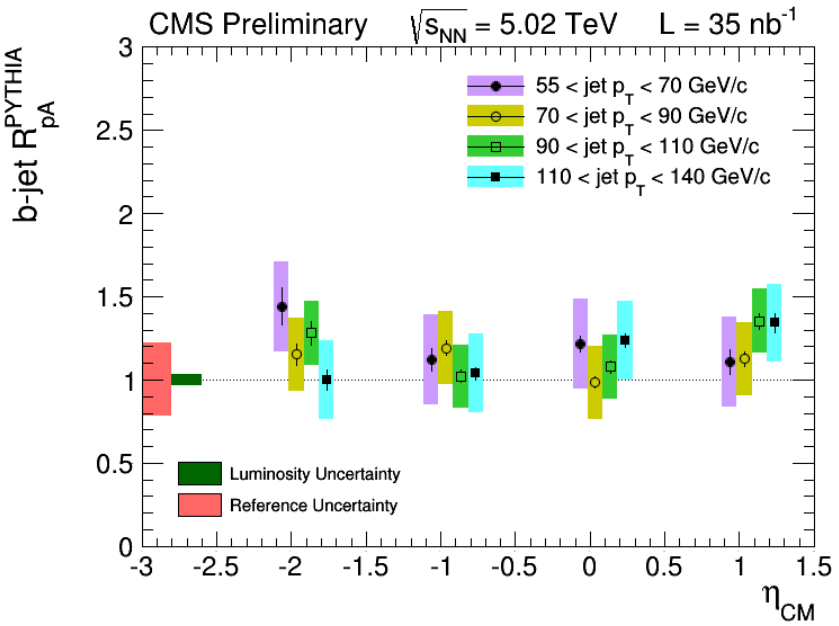


- B Jet can be reconstructed using secondary vertex of charged particles in jet cone
- Big advantage of high statistics by Branching Ratio factors
  - BR(B->J/ψ +X) x BR(J/ψ -> μμ) ~ O(1000)
- We already reported preliminary b-jet results of PbPb in SQM2013

B jets in p+Pb

CMS-HIN-14-007





PYTHIA simulation was used for p+p reference

- R_{pPb} is consistent with unity within uncertainty
- Consistent with exclusive B meson measurement
- Suppression observed in Pb+Pb is not coming from cold/initial nuclear effect

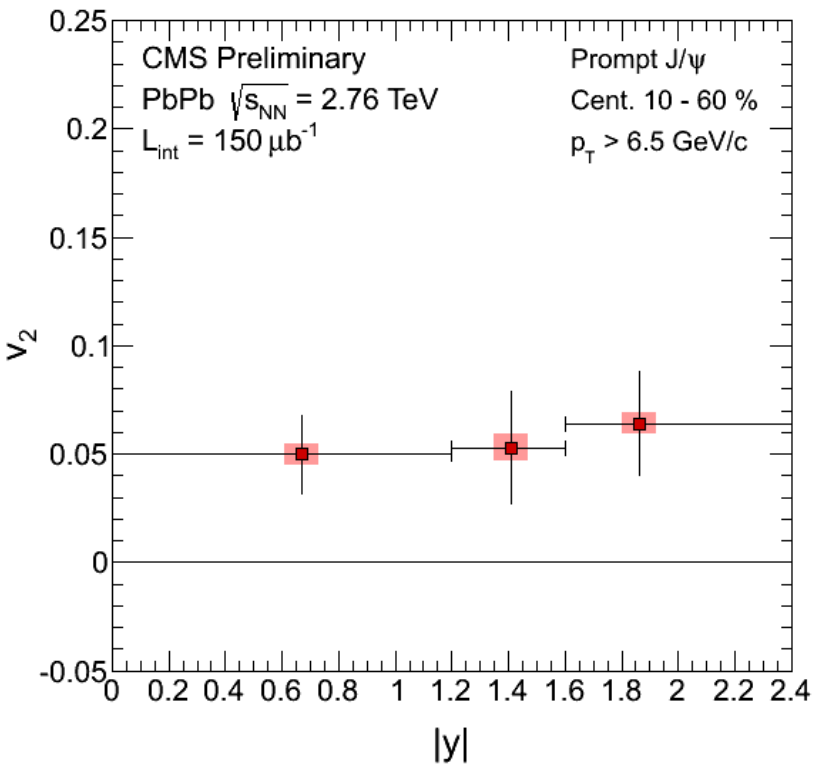
Summary

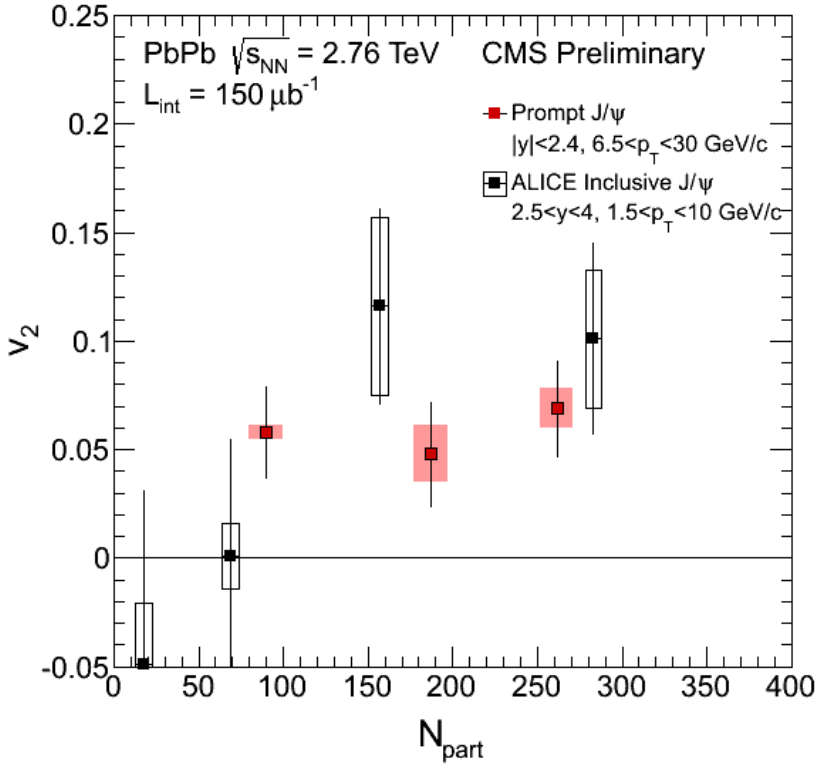
- CMS collaboration extensively measured J/ψ, ψ(2S), ϒ(nS), b meson and b jet in Pb+Pb and p+Pb
- The suppression pattern of excited states of charmonia and bottomonia observed in Pb+Pb can constrain theoretical models of quarkonia's interaction with medium
- R_{pA} results of B meson and b-jet confirms that the strong suppression in PbPb is final state effect
- R_{pA} of ϒ and R_{FB} of J/ψ show a clear signals of cold nuclear matter effect which is moderate than modification in Pb+Pb
- The cold nulcear matter effect of both bottomonia and charmonia has strong correlation with the event activity, indicating the collisional centrality dependence
- Thanks for your attention

BACK UP

Flow of prompt J/ψ

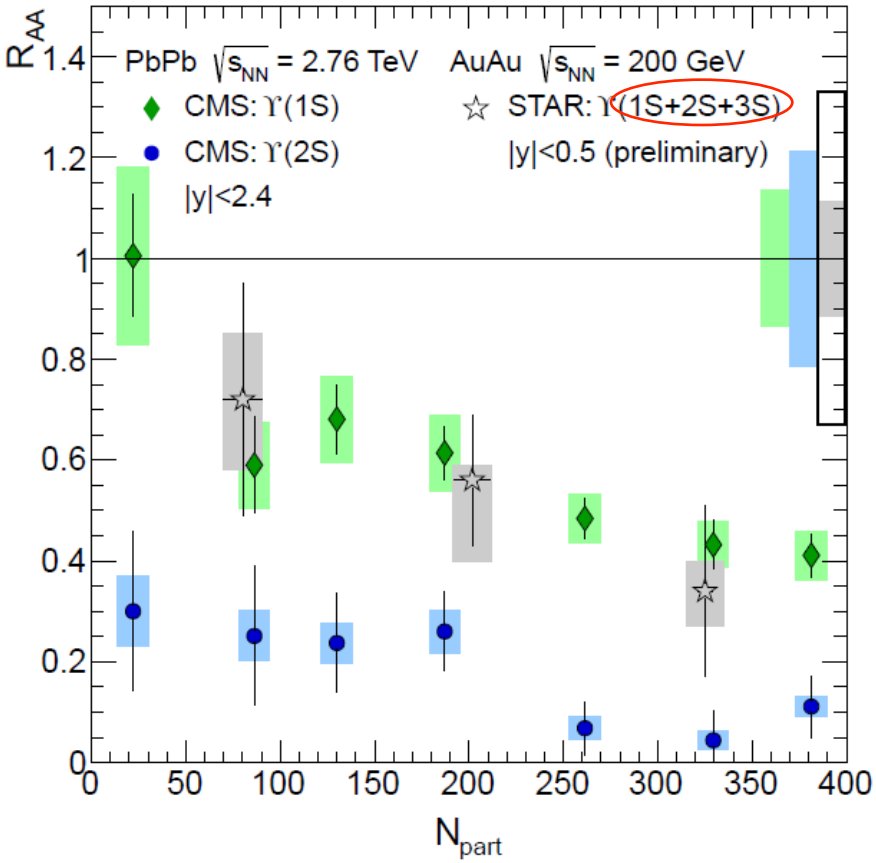
CMS PAS HIN-12-001 Released on Nov. 2013





- Observation of non-zero J/ψ v_2 (or azimuthal asymmetry) supports the medium induced suppression as well as path length dependence

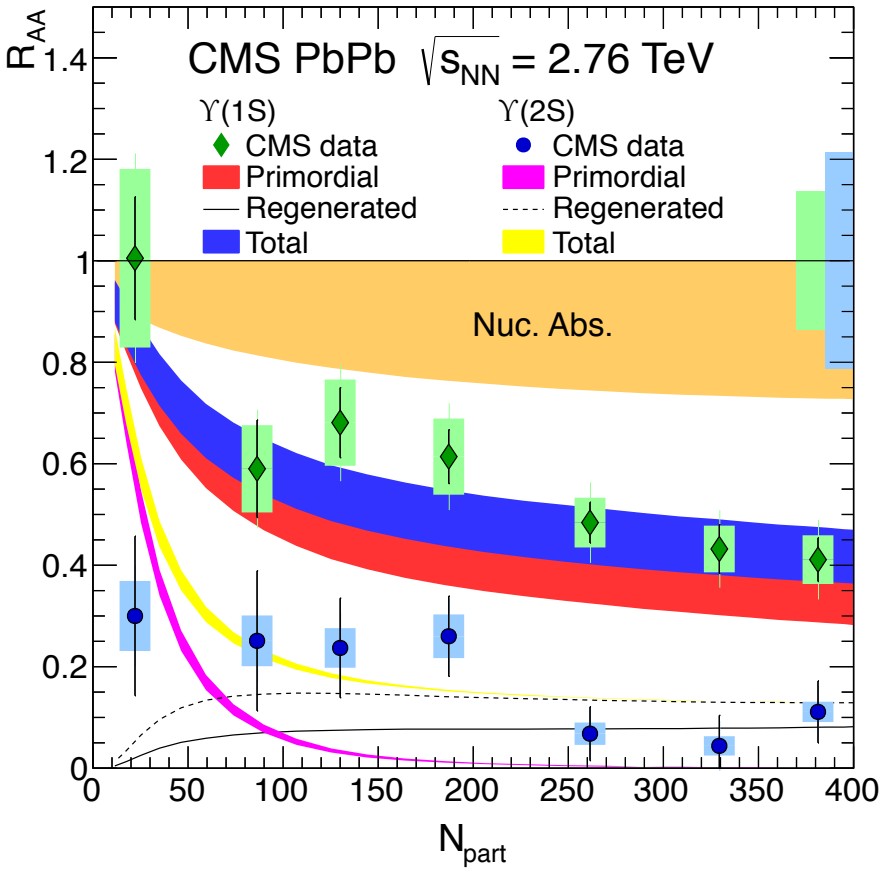
RAA Comparison with RHIC



For Au+Au collisions at 200GeV :

R_{AA} [ϒ(1S+2S+3S)] = $0.56_{\pm 0.21 \pm 0.16 \pm 0.08}$
(STAR arXiv:1109.3891)

RAA Comparison with theory



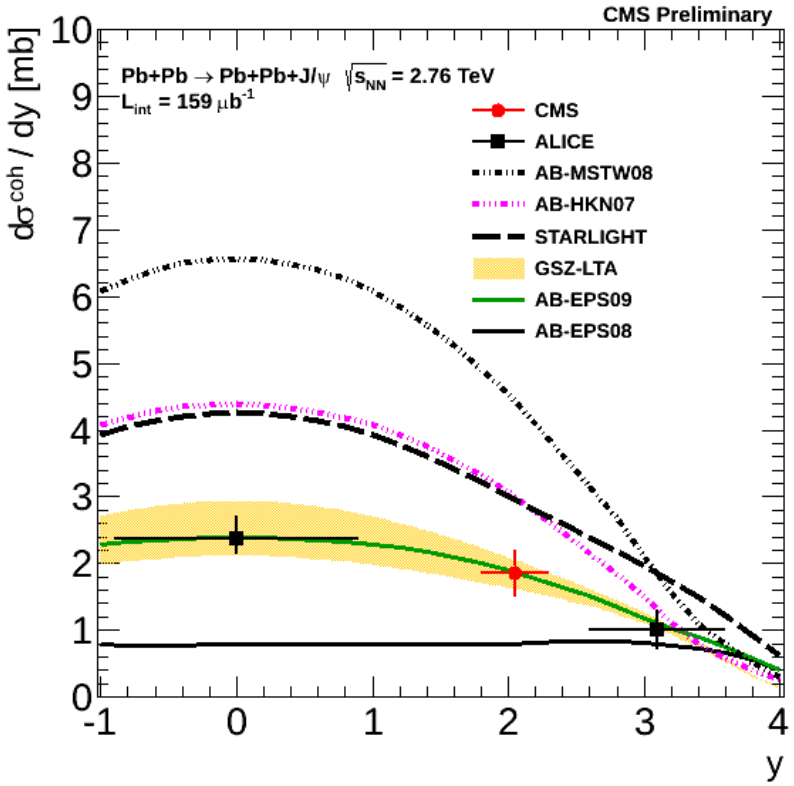
Model calculations:
A. Emerick, X. Zhao & R. Rapp, EPJA 48, 72 (2012)

The data is consistent with the strong Υ binding scenario assuming
- Small regeneration for Υ(1S).
Suppression is mostly primordial
Mostly consistent with data
- Regeneration is dominant in central collisions for Υ(2S)

- Large uncertainty in nuclear absorption! ← can be constrained by pPb data

- Note that T = 610MeV is tuned in this model

nPDF probed via PbPb



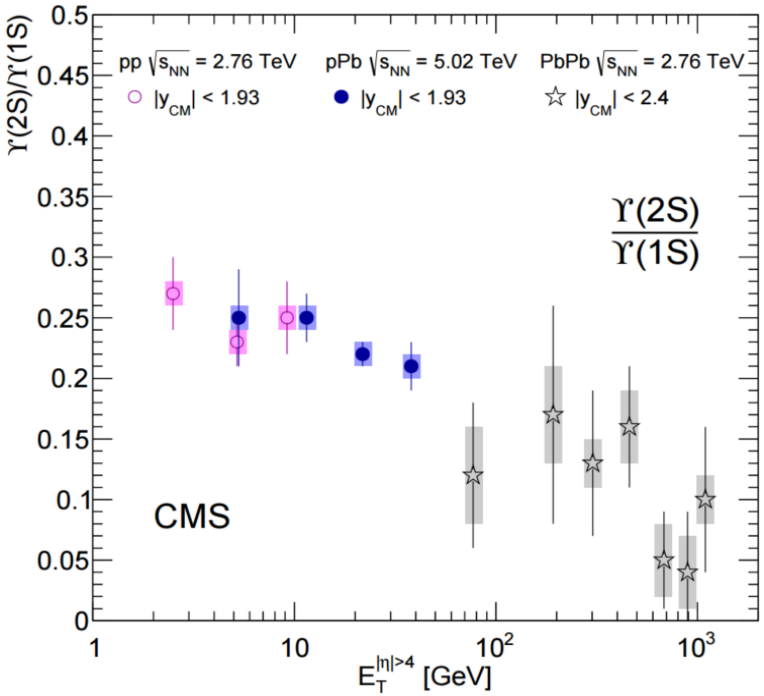
The result, accompanied with ALICE data, favors the models containing moderate gluon shadowing.

➔ Powerful constraint initial state modification models covering wide rapidity range

ALICE result in EPJC 73 (2013) 2617

Event activity dependence of ϒ yield

Vs. forward calorimeter transverse energy

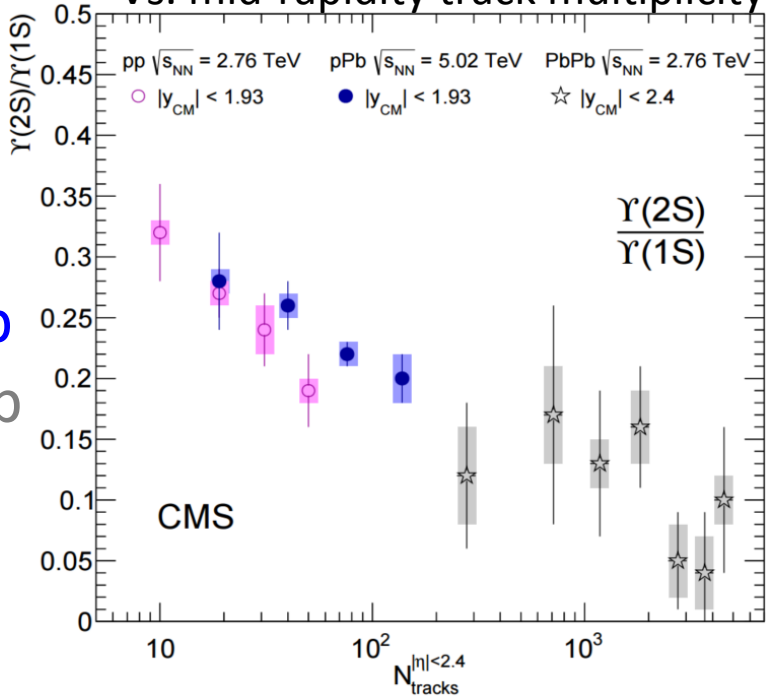


p+p

p+Pb

Pb+Pb

Vs. mid-rapidity track multiplicity



CNM effect observed in 1991