The 5th International Workshop on Charm Physics (Charm 2012)
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LHC Results on Charmonium in Heavy Ions

Byungsik Hong
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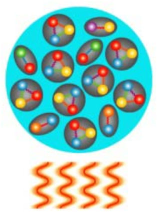
On behalf of ALICE, ATLAS and CMS

Outline

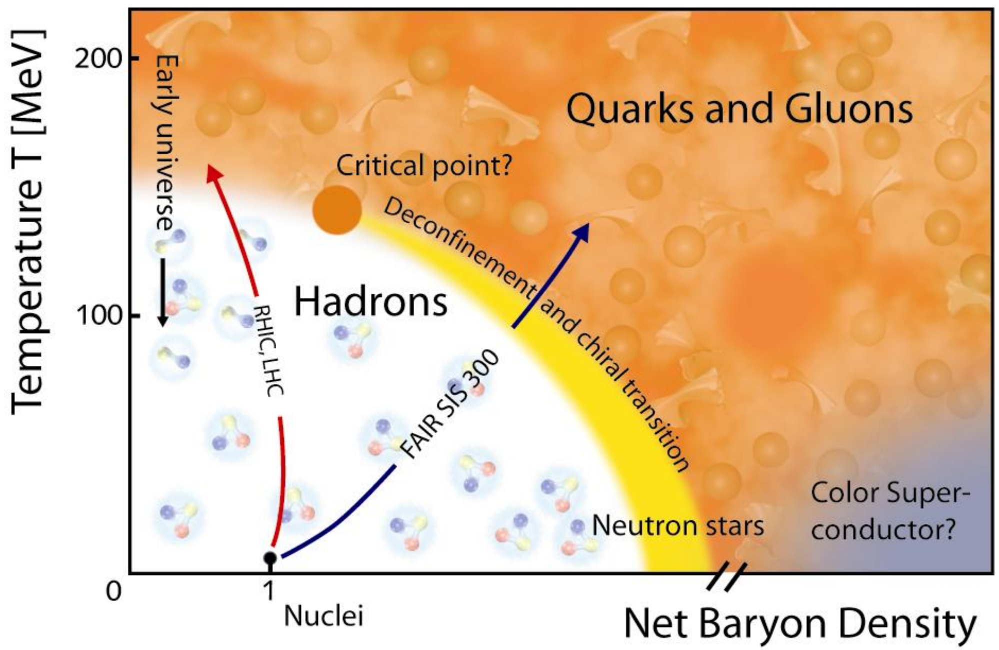
1. Introduction
   – Heavy-ion collision and quark-gluon plasma (QGP)
   – Charmonium in heavy-ion collisions
2. Experimental data
   – Early inclusive high-p_T results from ATLAS
   – Later detailed high-p_T results from CMS
     • Separation of prompt and non-prompt J/ψs
     • p_T, y and centrality dependences
   – Low-p_T results from ALICE
3. Summary

Introduction

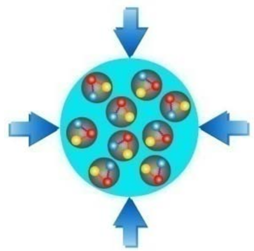
- Quark-gluon plasma (QGP)
  - Primordial matter existed a few μs after the Big Bang
  - $T \geq 170$ MeV, $\varepsilon_0 \geq 1$ GeV/fm^3
  - Critical to understand QCD at extreme conditions



Colliders LHC/RHIC



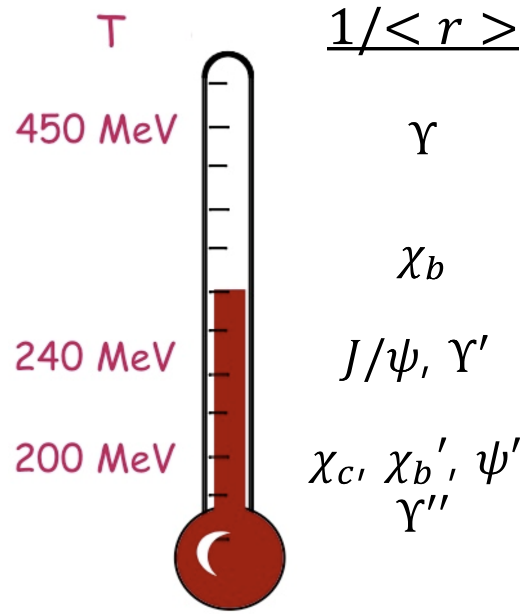
Fixed Target SIS300 (2018～)



Quarkonium in Heavy Ions

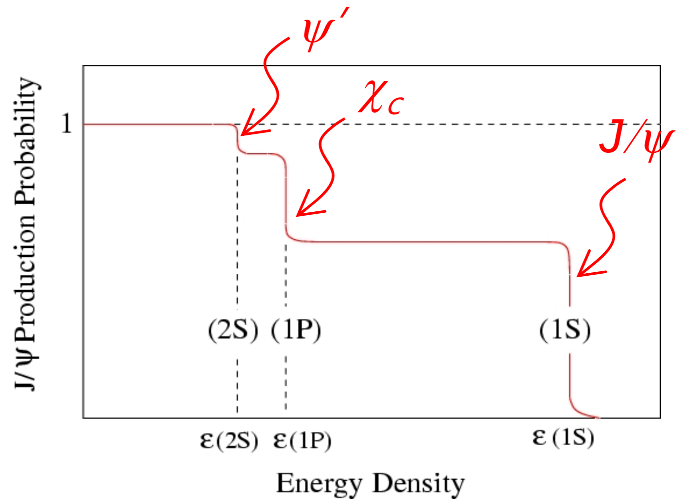
- Powerful tool to probe QGP
  - Large mass: a large momentum transfer needed in hard gg scattering at early stage
  - Color screening: various quarkonium states melt at different temperatures
  - Important signature of the QGP formation

  [Matsui & Satz, PLB178, 416 (1986)]



State	J/ψ (1S)	χ_c (1P)	ψ' (2S)
m (GeV/c^2)	3.10	3.53	3.68
r_0 (fm)	0.50	0.72	0.90

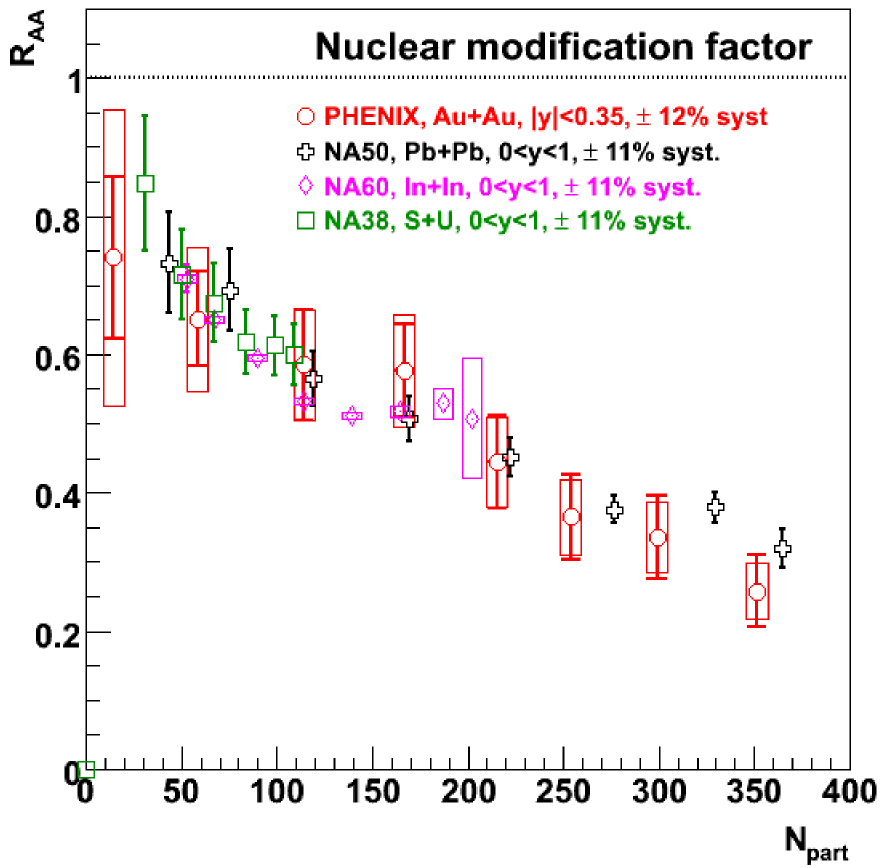
Υ (1S)	χ_b (1P)	Υ' (2S)	χ_b' (2P)	Υ'' (3S)
9.46	9.99	10.02	10.26	10.36
0.28	0.44	0.56	0.68	0.78



J/ψ at Lower Energies

- Two puzzles
  1) At midrapidity, similar suppression at RHIC & SPS, while density must be higher at RHIC

$$R_{AA}(p_T) = \frac{d^2N_{AA}/dp_T d\eta}{< T_{AA} > d^2\sigma_{NN}/dp_T d\eta}$$



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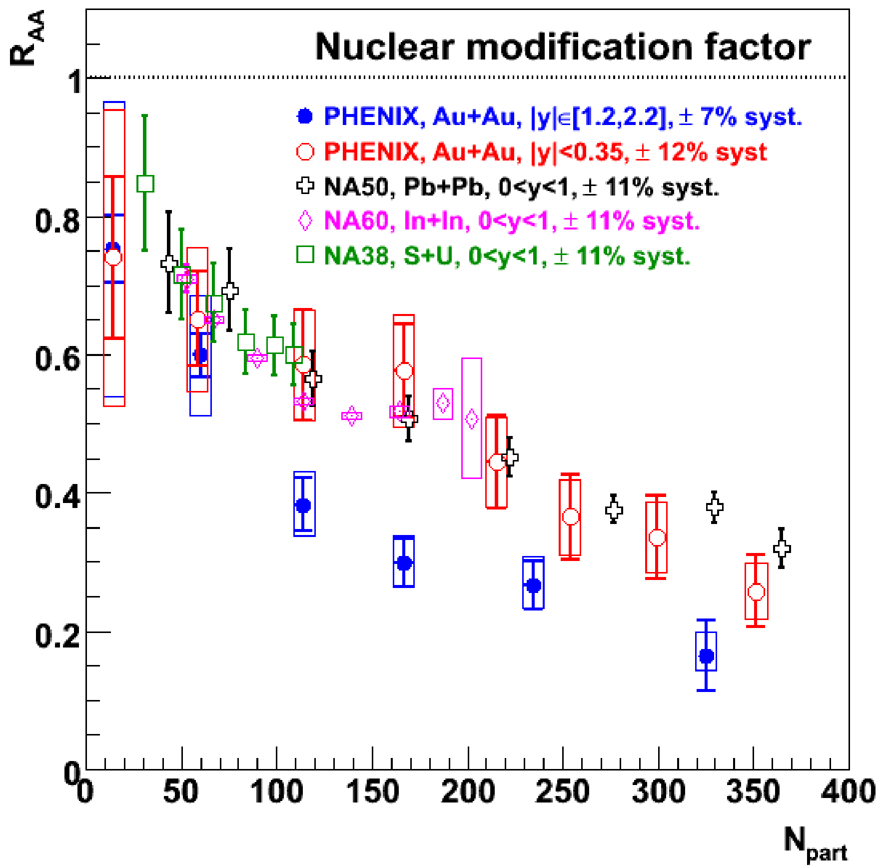
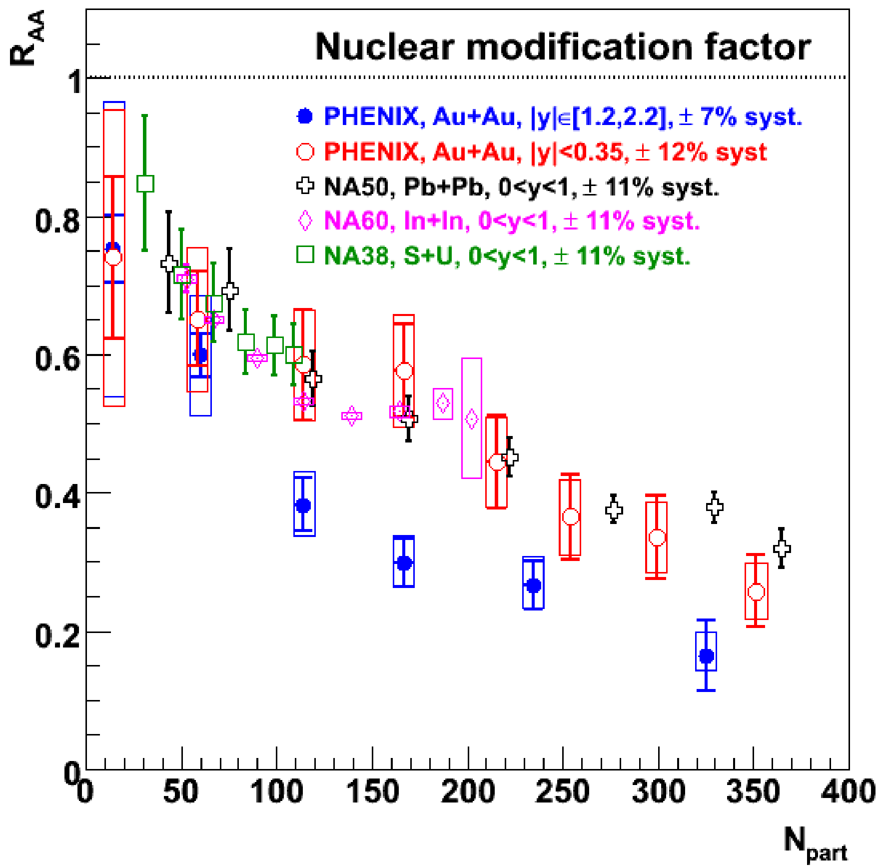


J/ψ at Lower Energies

- Two puzzles
  1) At midrapidity, similar suppression at RHIC & SPS, while density must be higher at RHIC
  2) More suppression at forward rapidity, while density must be lower
- Two possibilities
  1) Cold: shadowing, saturation brings the forward yield down
  2) Hot: recombination of uncorrelated $c\bar{c}$ brings the midrapidity yield up

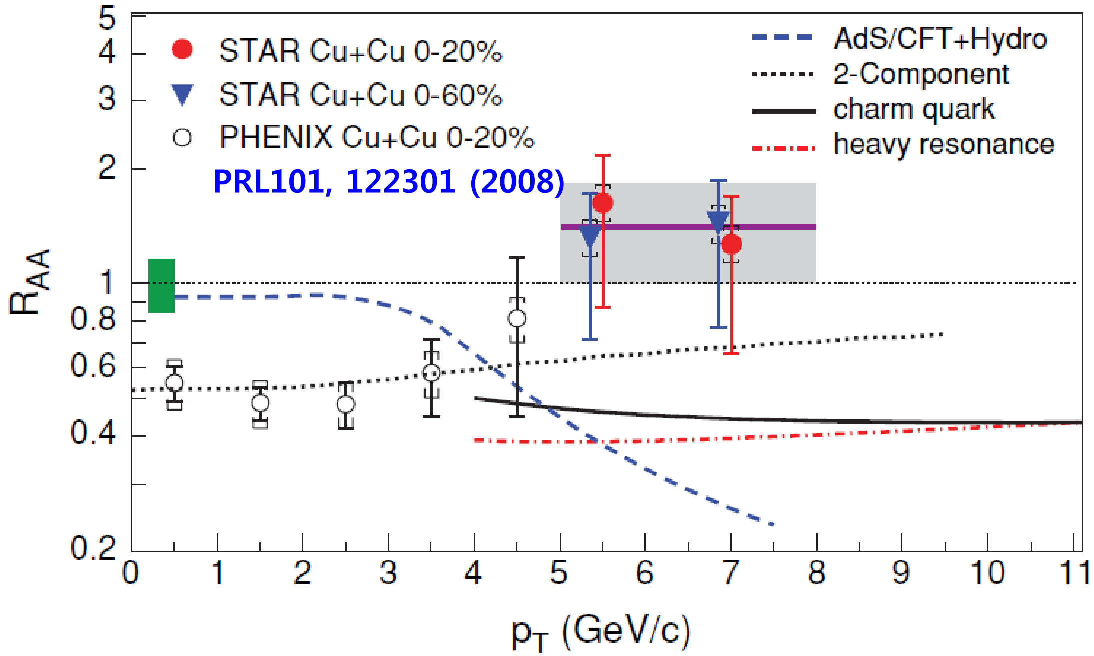
$$R_{AA}(p_T) = \frac{d^2N_{AA}/dp_T d\eta}{< T_{AA} > d^2\sigma_{NN}/dp_T d\eta}$$



J/ψ at Lower Energies

J/ψ suppression can not be satisfactorily explained by models.

STAR, PRC80, 041902 (2009)



Diverse theoretical results

QGP+recombination+…

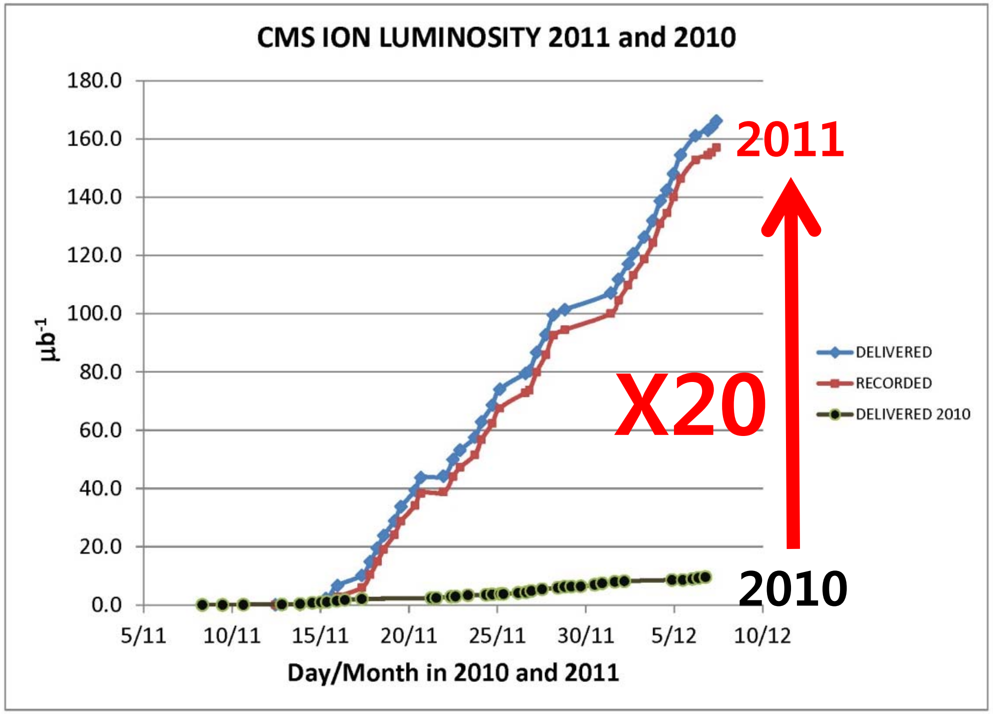
Calculations for open charm

AdS/CFT

- LHC data with higher temperature and density will help to resolve the J/ψ puzzles.

Heavy-Ion Runs at LHC

- **First heavy-ion run**
  - Nov. - Dec. 2010
  - PbPb @ $\sqrt{s_{NN}}$ = 2.76 TeV
  - Rec. luminosity: 7.28 μb^{-1}
- **Reference pp run**
  - March 2011
  - pp @ $\sqrt{s_{NN}}$ = 2.76 TeV
  - Rec. luminosity: 225 nb^{-1}
  - Equivalent statistics for hard probes like quarkonia
- **Second heavy-ion run**
  - November 2011
  - PbPb @ $\sqrt{s_{NN}}$ = 2.76 TeV
  - Rec. luminosity: 150 μb^{-1}
  - About 20 times of 2010 statistics



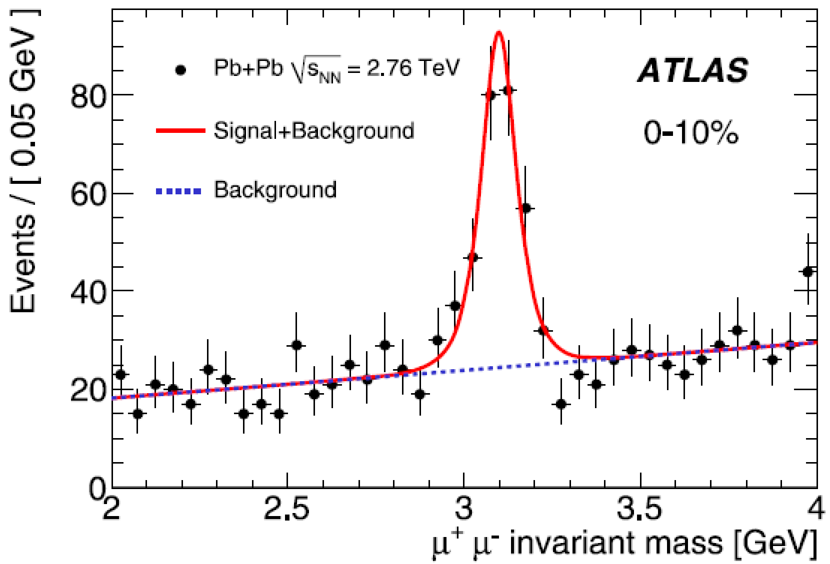
*Luminosity quotes from CMS

All results presented in this talk are from 2010 run data

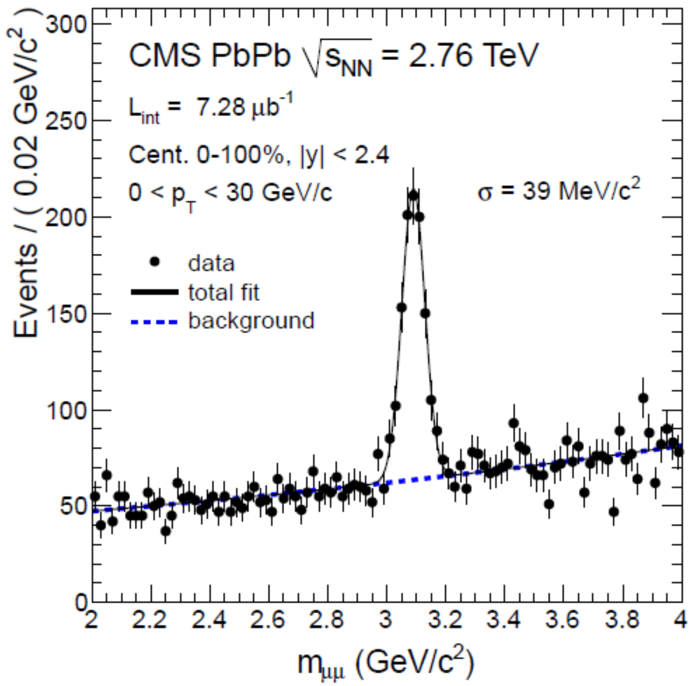
High-p_T J/ψ

- ATLAS & CMS territory
  - Large acceptance and high bandwidth
  - Material and relatively high B-field prevent detecting low-p_T muons (thus low-p_T J/ψ)

ATLAS, PLB697, 294 (2011)



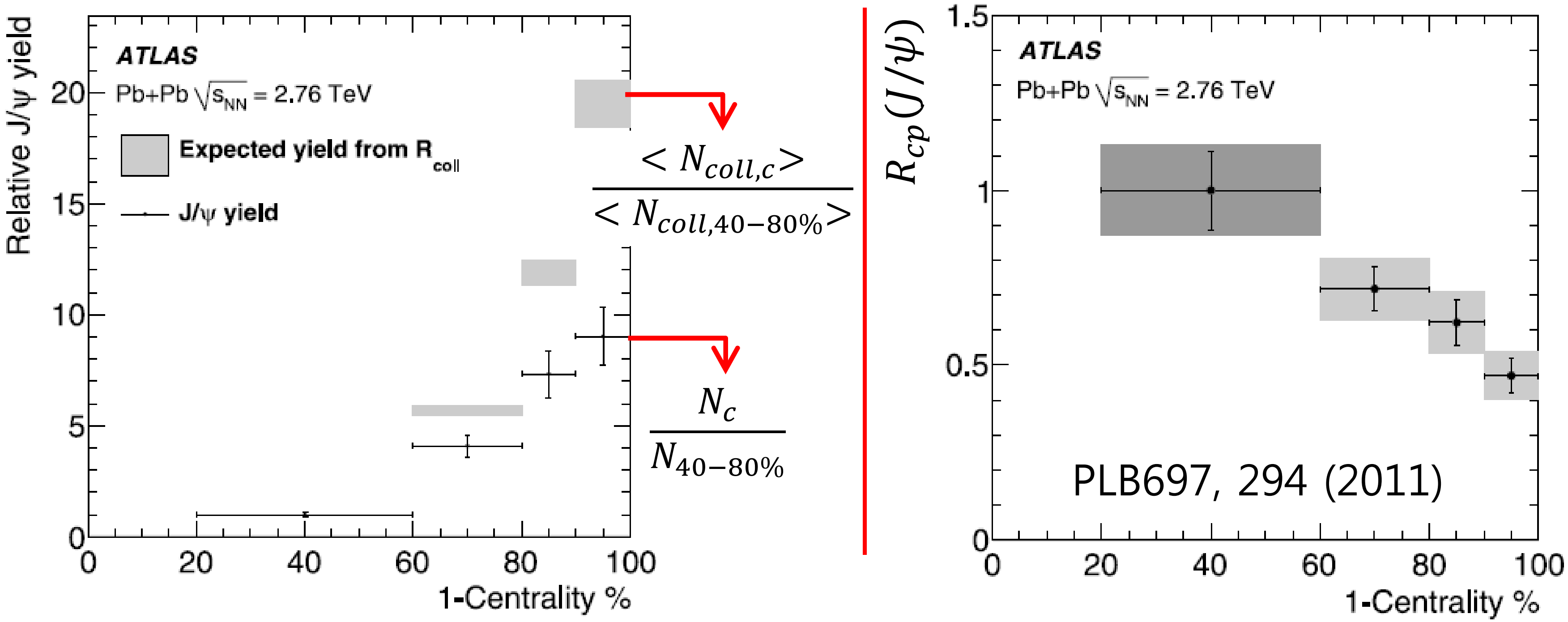
CMS, arXiv:1201.5069
(accepted by JHEP)



Early Results from ATLAS

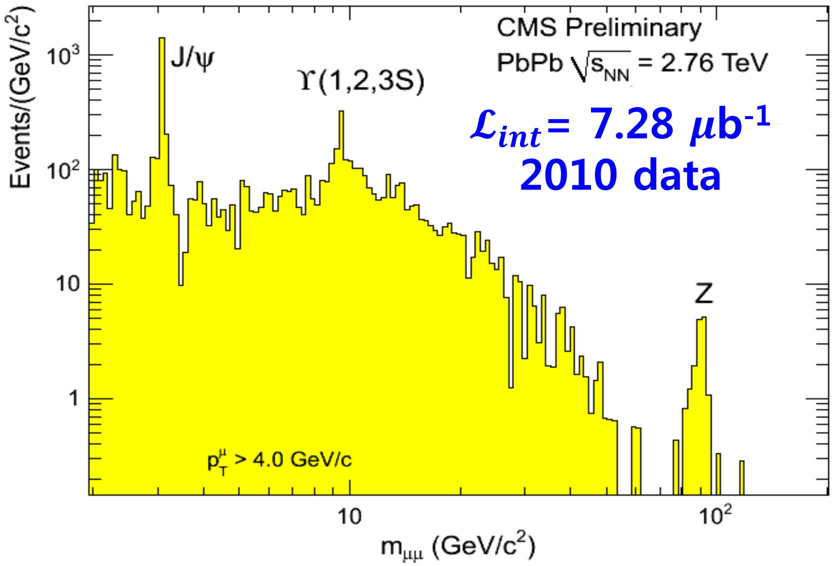
No pp reference, instead central-to-peripheral ratio

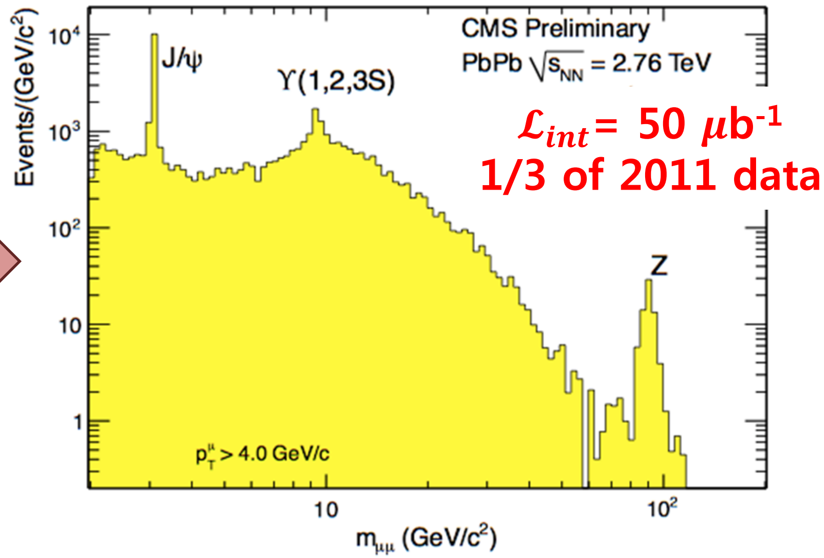
$$R_{cp} = \frac{N_c / < N_{coll,c} >}{N_{40-80\%} / < N_{coll,40-80\%} >}$$



- Muon p_T cut: 80% of the reconstructed J/ψ in p_T>6.5 GeV/c
- Definitely suppressed: larger effect for more central collisions

Later Results from CMS





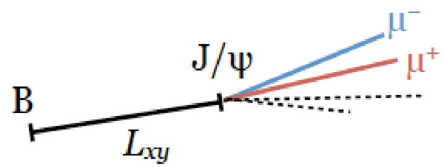
- Similar constraints on the muon pairs
  - p_T > 6.5 GeV for $|y|$ < 1.2
  - Down to p_T = 3 GeV for the most forward bin, 1.6<$|y|$<2.4
- Analyzed R_{AA} (not R_{cp}) using pp reference
- More centrality bins
- Subtraction of $B \rightarrow J/\psi$ component
  - 20-30% at this p_T range (see later slides)

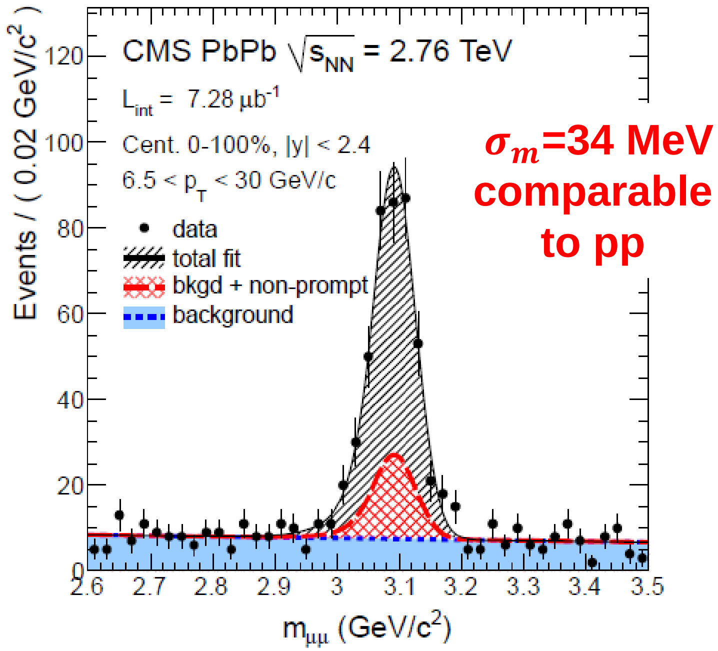
J/ψ Analysis in CMS

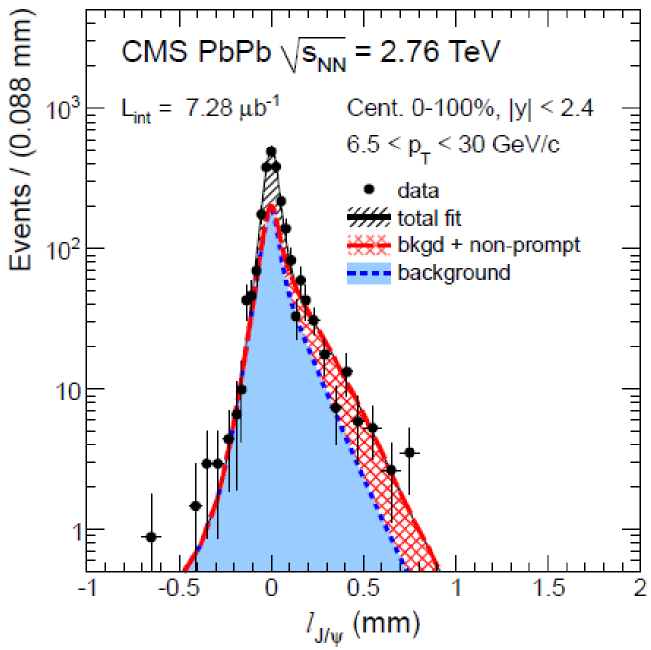
- **Inclusive J/ψ**
  - **Prompt J/ψ**
    - **Direct J/ψ**
    - **Feed-down from ψ' and χ_c**
  - **Non-prompt J/ψ from B decays**

- Simultaneous fit
  - $\mu^+\mu^-$ invariant mass
  - Pseudo-proper decay length

$$l_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$$





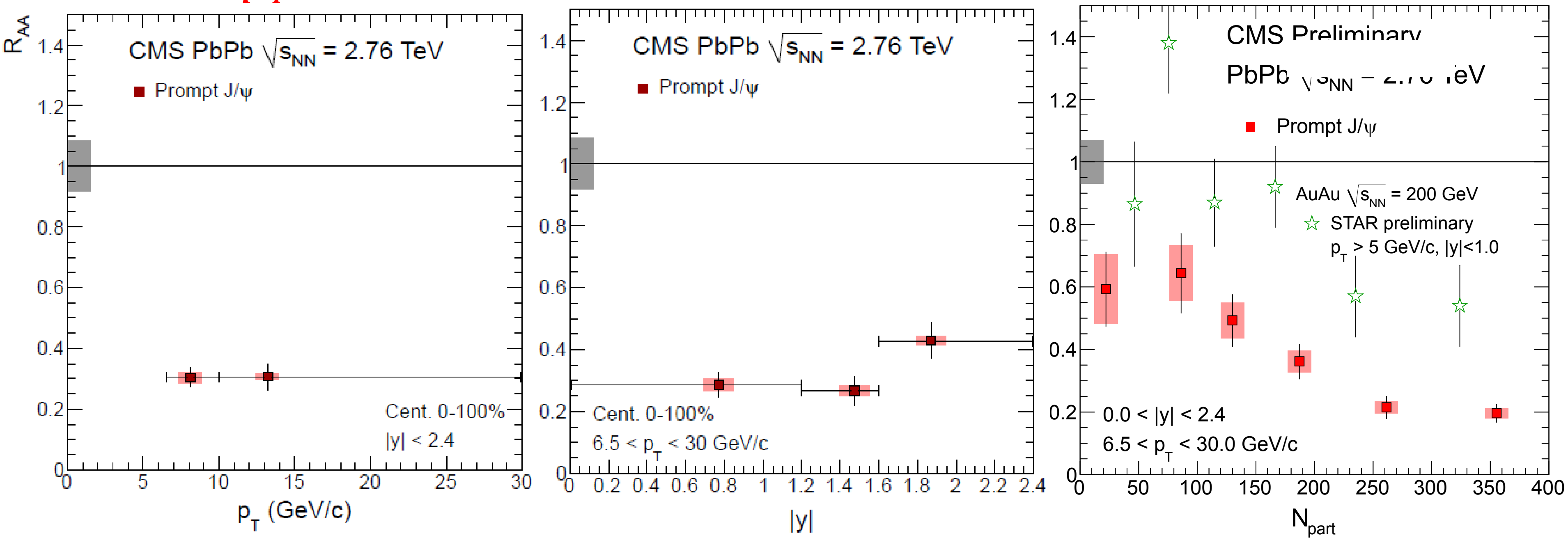


CMS, arXiv:1201.5069 (accepted by JHEP)

Prompt J/ψ

CMS, arXiv:1201.5069 (accepted by JHEP)

2 p_T bins 3 y bins 6 centrality bins



- $R_{AA} = 0.20 \pm 0.03(stat) \pm 0.01(sys) \pm 0.01(global)$ for 0-10%
  - Factor 5 suppression
  - More suppression than at RHIC at high p_T

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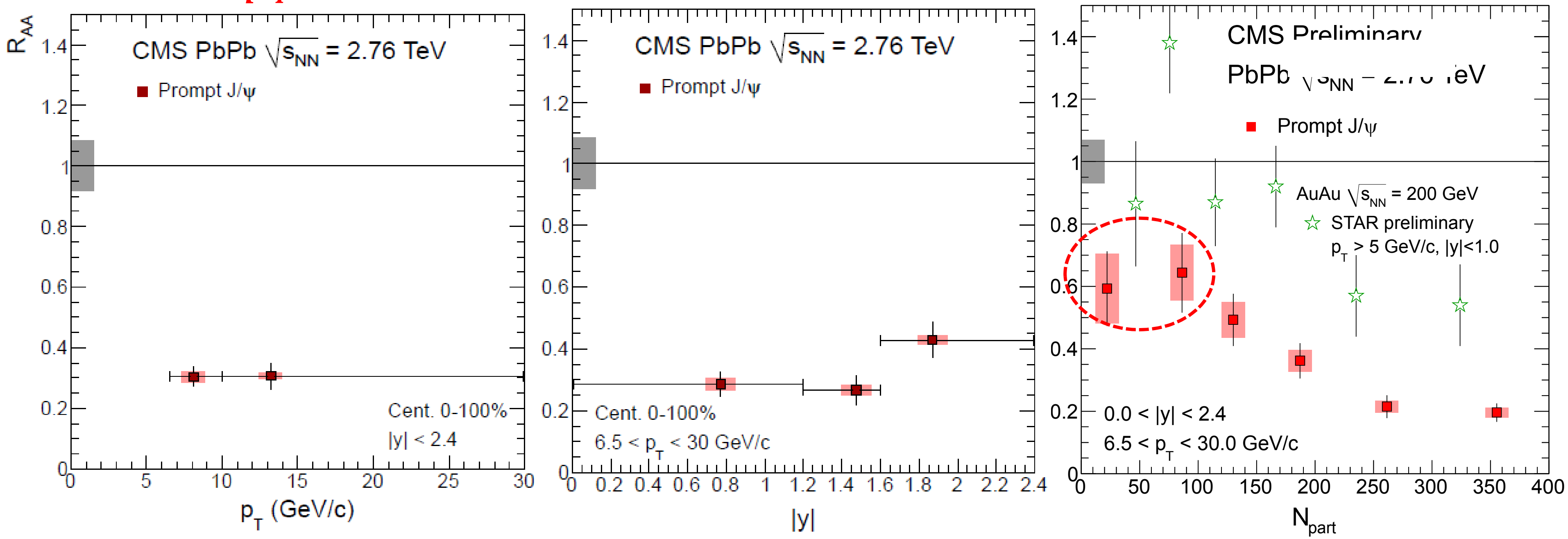

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- Suppression also in peripheral events (cf. ATLAS R_{cp} for 40~80%)

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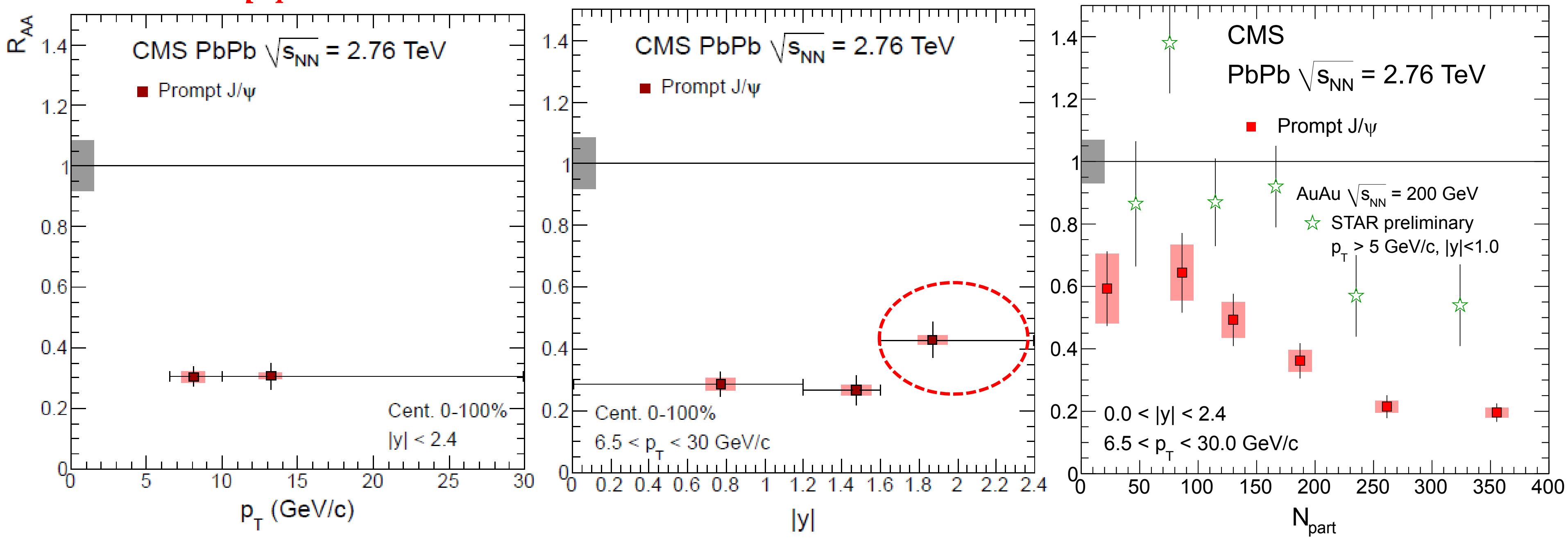

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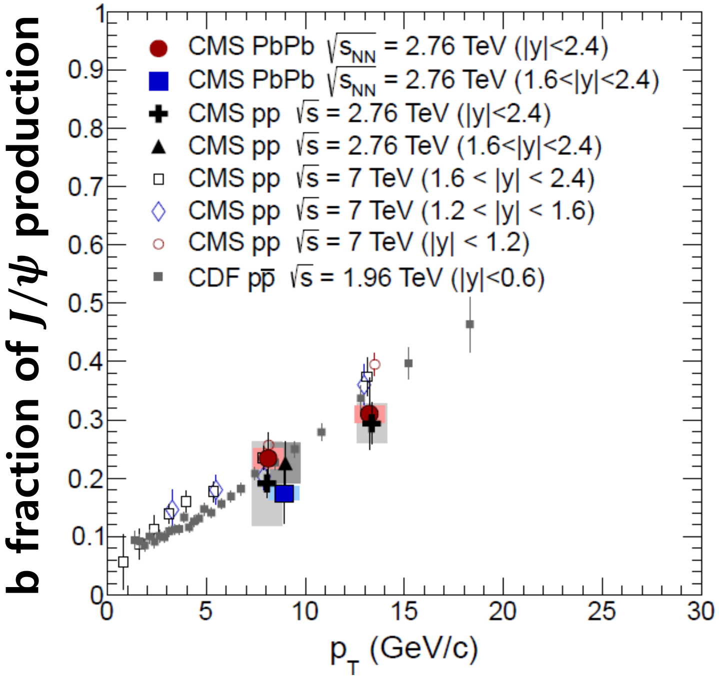
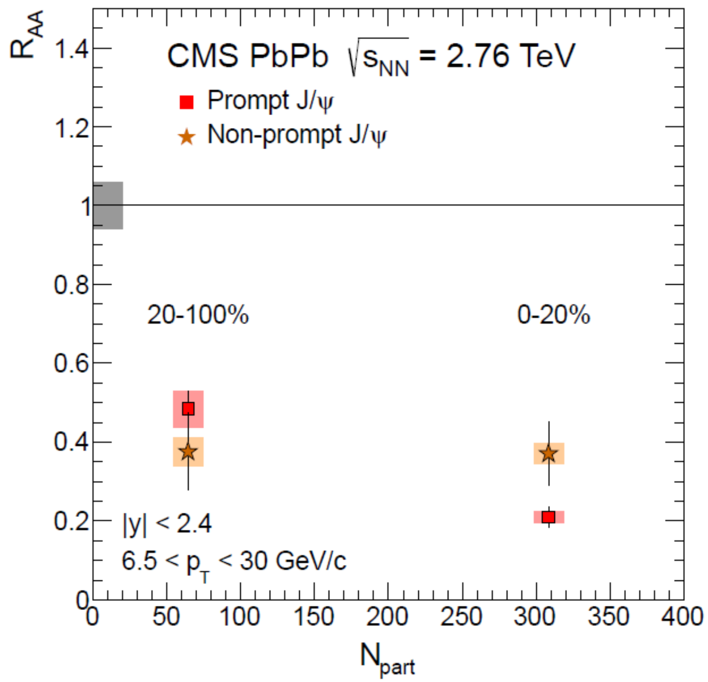
  - Factor 5 suppression
  - More suppression than at RHIC at high p_T
- Suppression also in peripheral events (cf. ATLAS R_{cp} for 40~80%)
- Less suppression at forward rapidity (anti-shadowing effect?)

Non-Prompt J/ψ



20-30% in CMS p_T range
(10-12% overall $< p_T > \cong 2.5$ GeV)

arXiv:1201.5069 (accepted by JHEP)

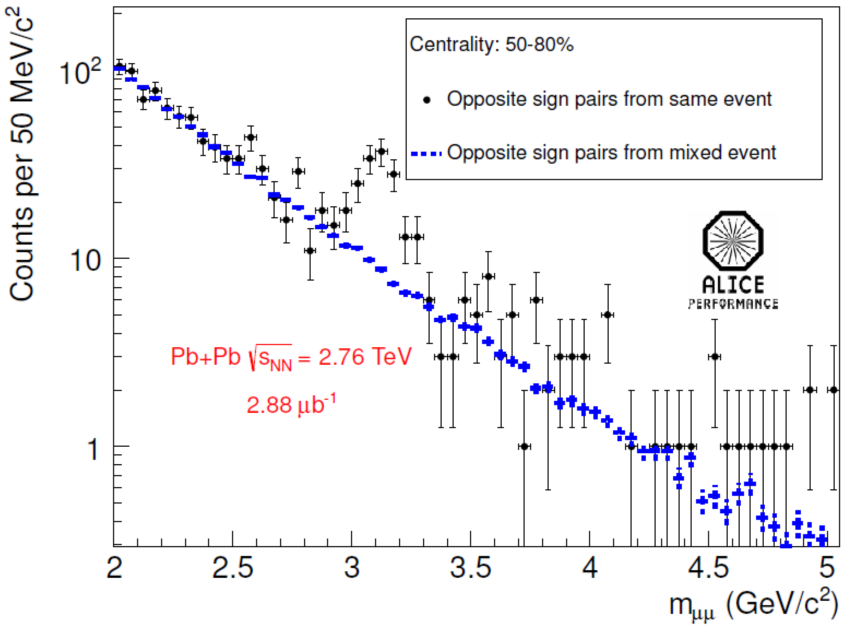


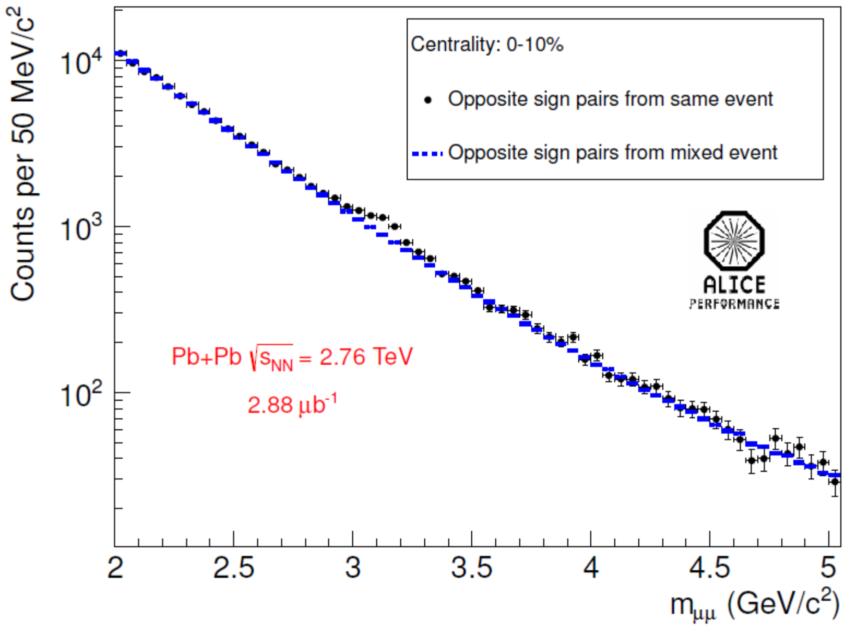
- Secondary J/ψ from B decay also suppressed strongly
  - $R_{AA} = 0.37 \pm 0.08(stat) \pm 0.02(sys) \pm 0.02(global\ scale)$
  - Factor ~3 suppression for the most central 20%
- First hint of b-quark energy loss in the medium

Low-p_T J/ψ

- ALICE territory
  - Measuring low-p_T muons down to p_T=0.5 GeV/c
    (J/ψ down to p_T =0)
  - More backgrounds at low p_T

Mid-central (50-80%) → Central (0-10%)

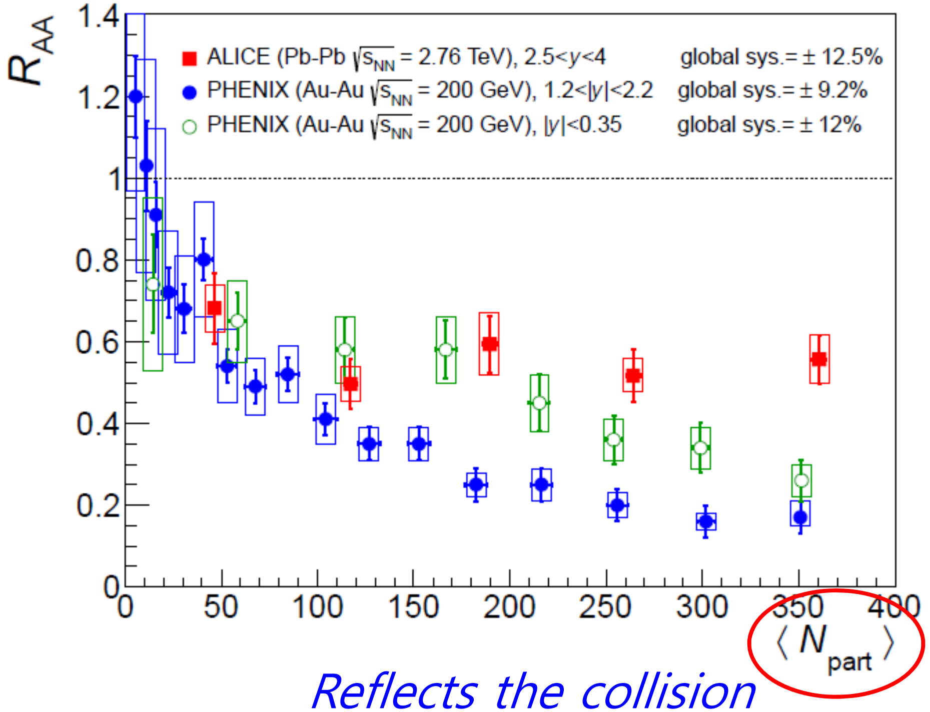




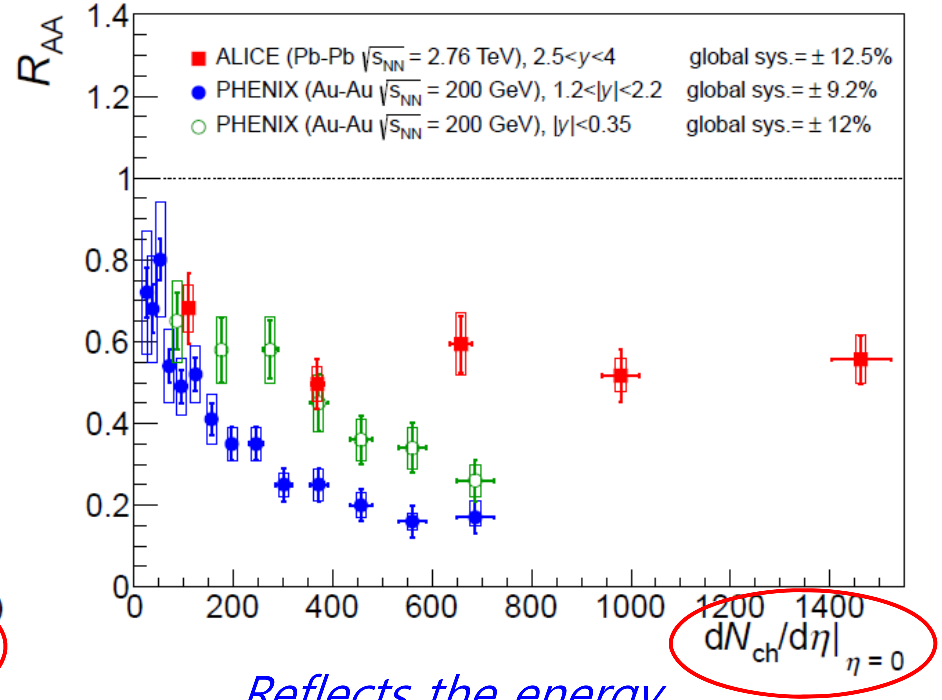
ALICE performance plots from A. Andronic

Low-p_T Results from ALICE

ALICE, arXiv:1202.1383



Reflects the collision geometry



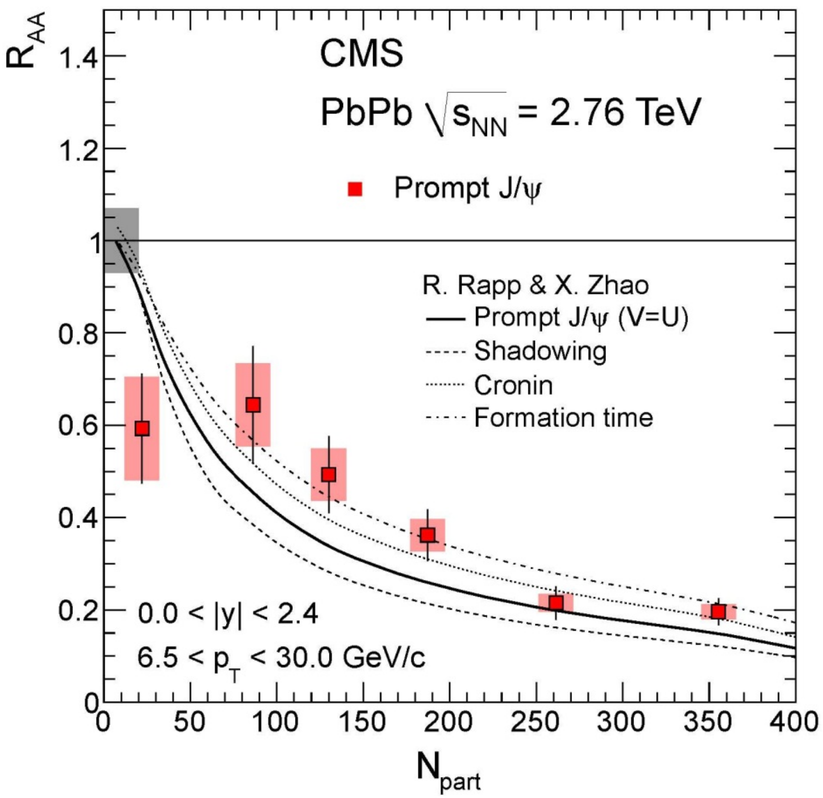
Reflects the energy density of the medium

- Less suppression than at RHIC at low p_T
  - $R_{AA}(2.5<y<4)$ from ALICE > $R_{AA}(1.2<|y|<2.2)$ from PHENIX
  - Opposite to the high- p_T behavior

A Possible Explanation

CMS: p_T > 6.5 GeV, $|y|$ < 2.4

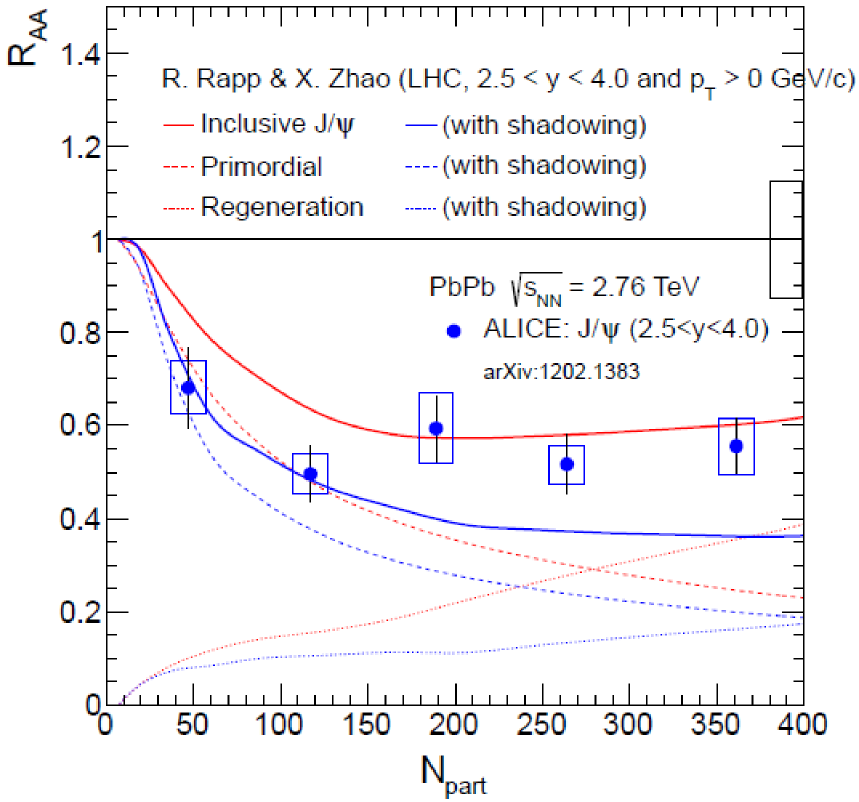
arXiv:1201.5069 (accepted by JHEP)



Zhao & Rapp, NPA859, 114 (2011)
+private communication

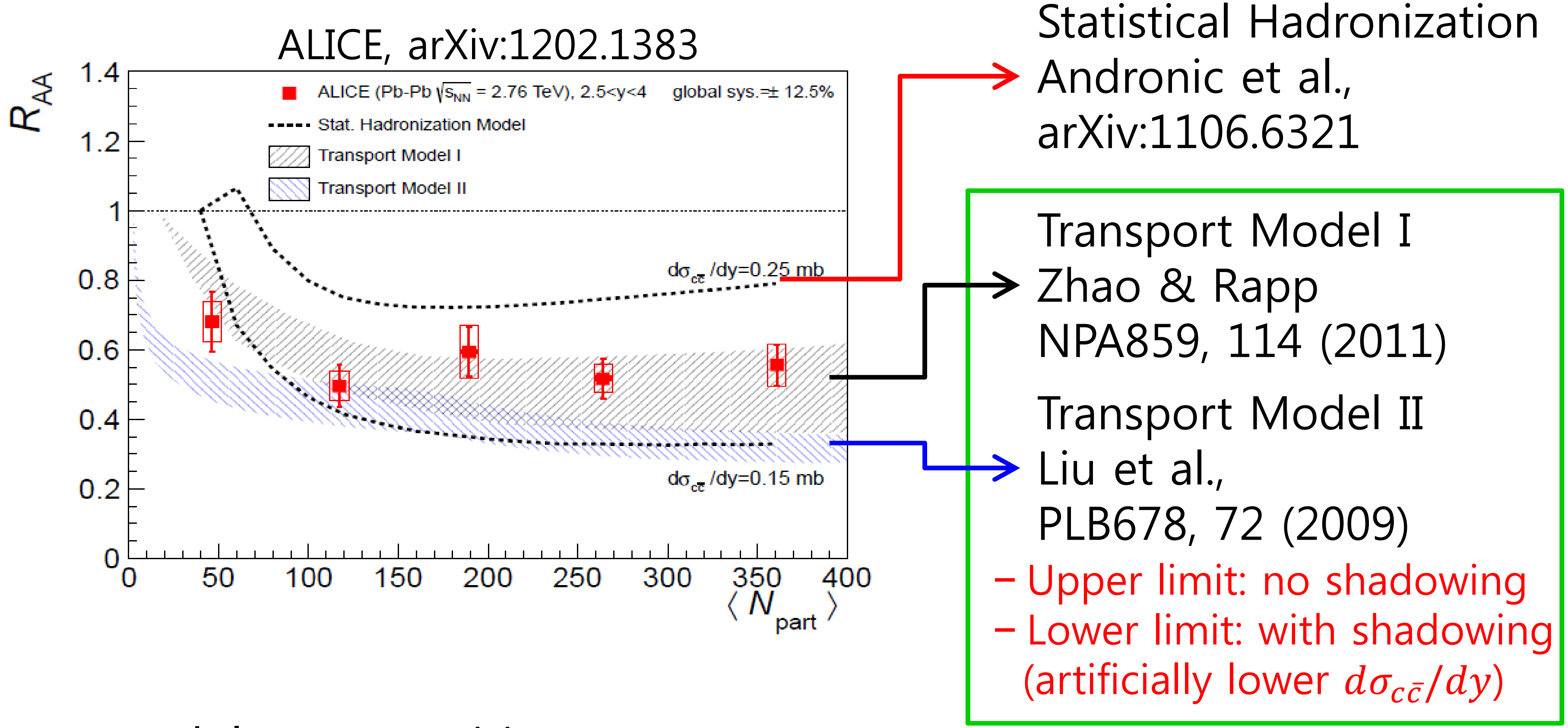
ALICE: p_T > 0 GeV, 2.5 < y < 4

ALICE, arXiv:1202.1383



- Recombination should be important at low p_T

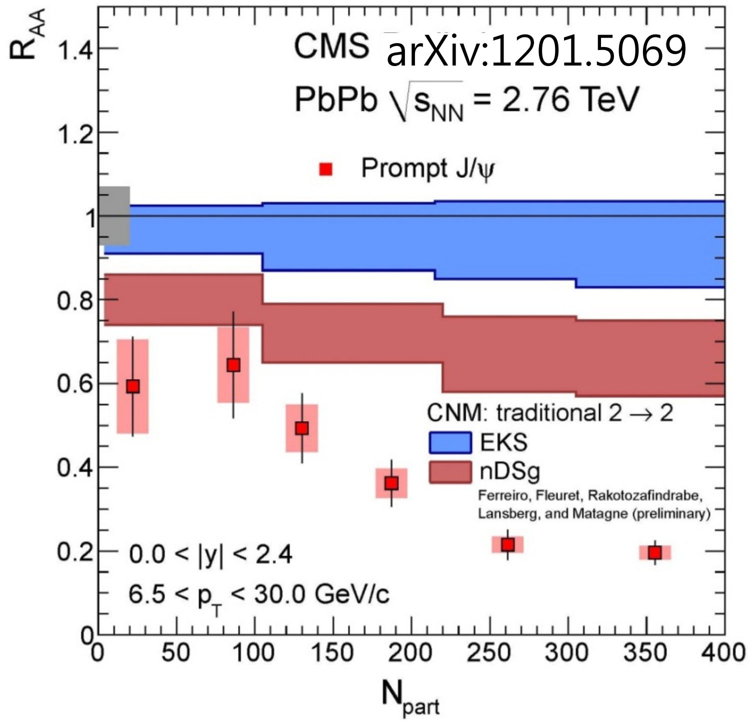
More on Recombination

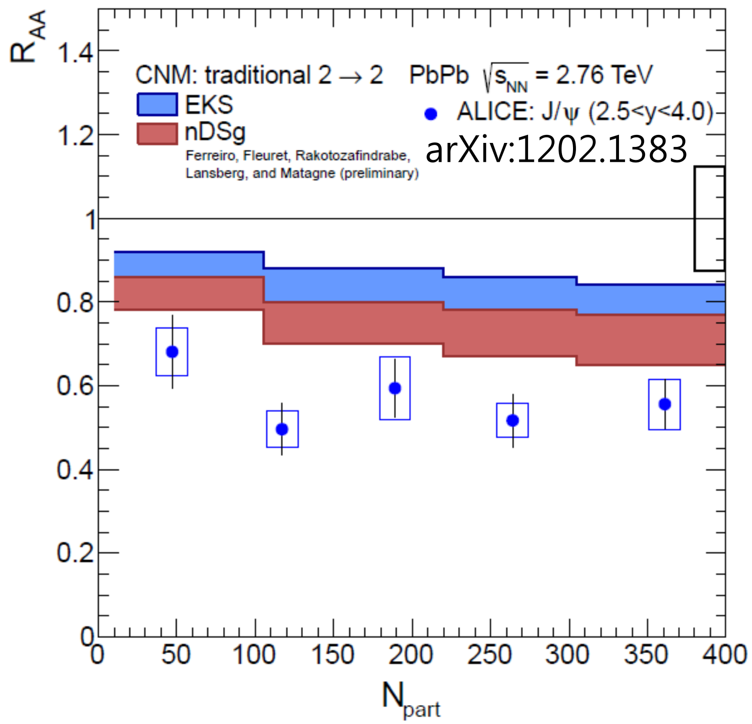


- Models are sensitive to $d\sigma_{c\bar{c}}/dy$
- The transport models are sensitive to the rate equation controlling the J/ψ dissociation and regeneration
  - For the most central collisions, recombination component is ~50%

Cold Nuclear Matter Effects

Preliminary theoretical calculations:
Ferreiro et al., BNL and EMMI Workshops in 2011





- CNM for traditional 2 → 2 $(gg \rightarrow J/\psi + g)$
  – Different parametrizations of nPDF (EKS and nDSg)

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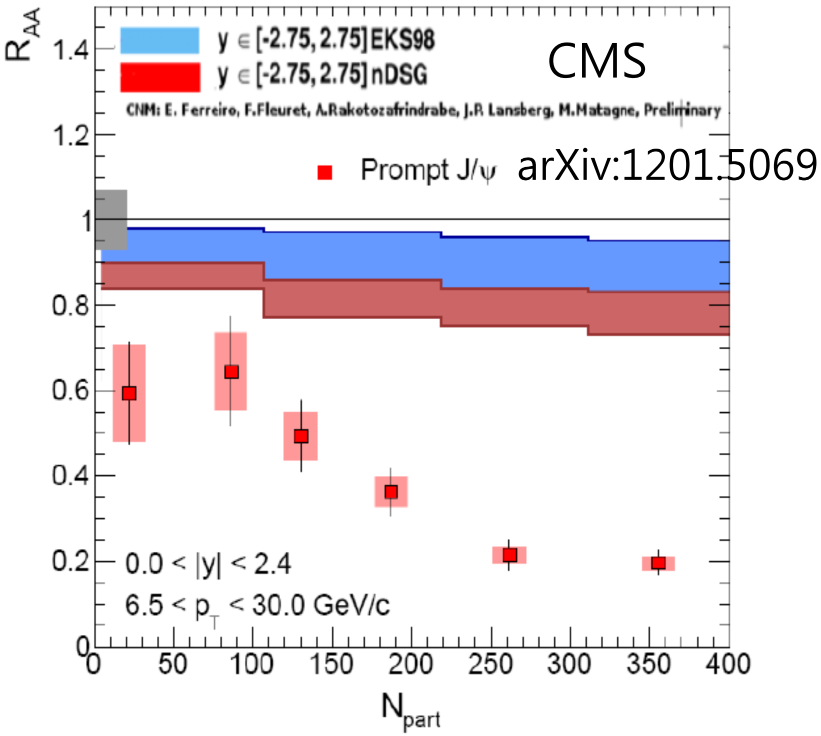
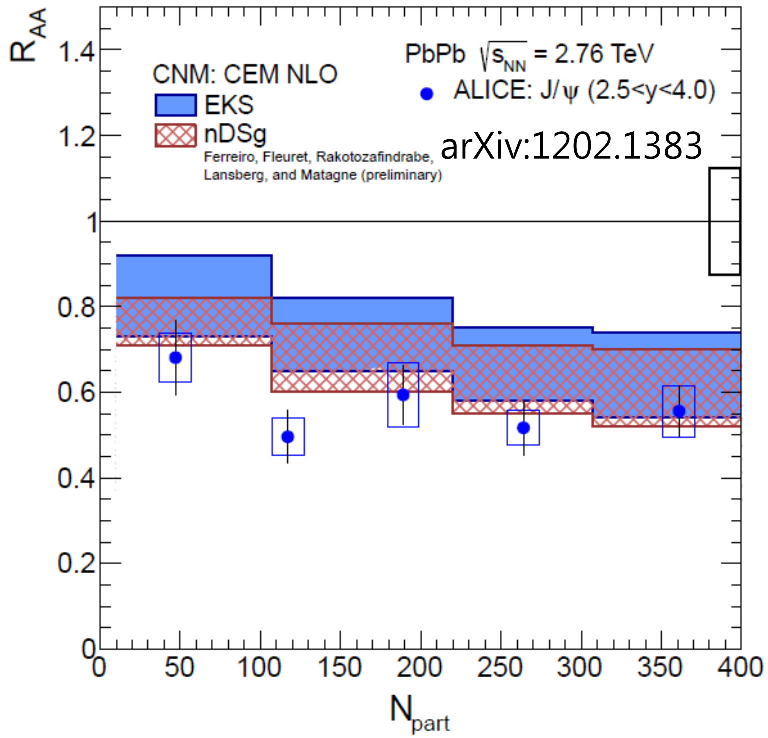


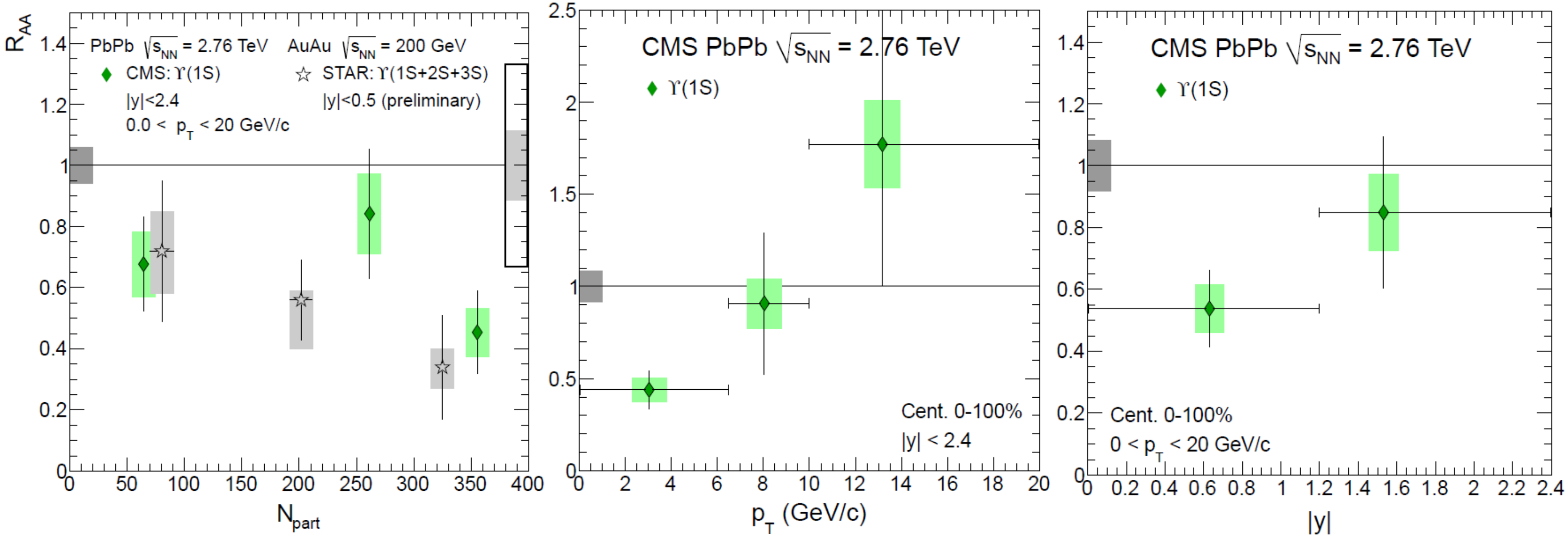


- CNM effect from CEM NLO before k_T smearing
  - Different parametrizations of nPDF (nDSg and EKS)
- pPb run this year will help a lot for the CNM effect

Υ(1S)

Not a subject for this Workshop
But quite relevant to the J/ψ production in heavy ions

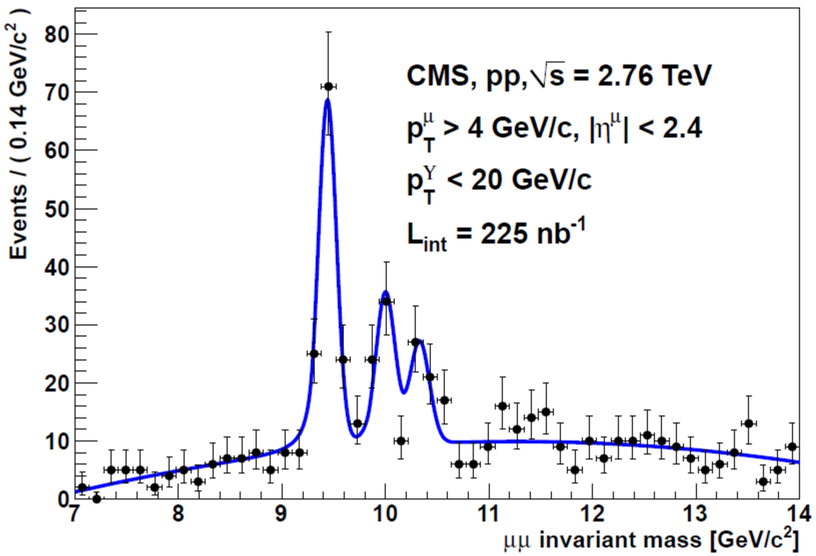
CMS, arXiv:1201.5069 (accepted by JHEP)

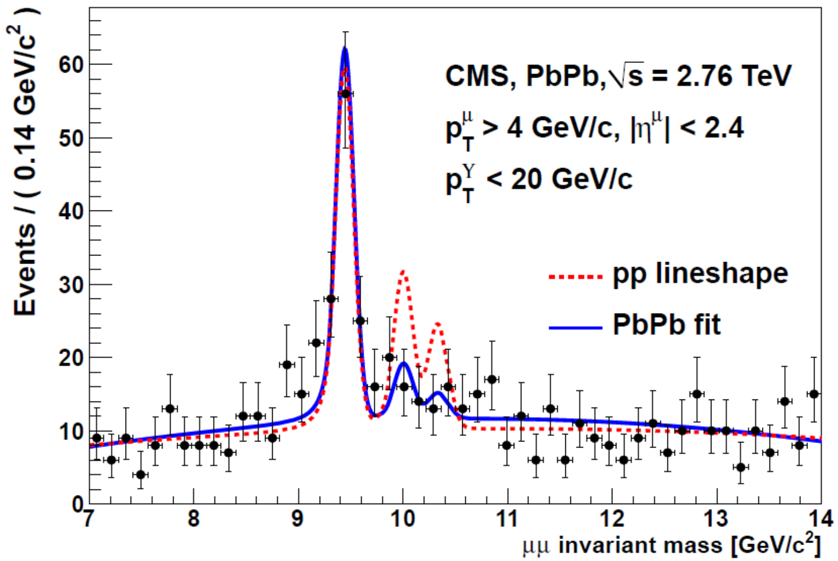


- Υ(1S) suppression at low p_T
  - $R_{AA} = 0.44 \pm 0.10(stat) \pm 0.06(sys) \pm 0.04(global\ scale)$ for 0 < p_T < 6.5 GeV/c in minimum bias
- Υ(1S) suppression for central events
  - $R_{AA} = 0.45 \pm 0.14(stat) \pm 0.08(sys) \pm 0.03(global\ scale)$ for 0 < p_T < 20 GeV/c in the most central 10%

Υ(2S+3S)

CMS, PRL107, 052302 (2011), PbPb MinBias





$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$

- Probability to obtain the measured value, or lower, from the background fluctuation is 0.9% (2.4σ effect)

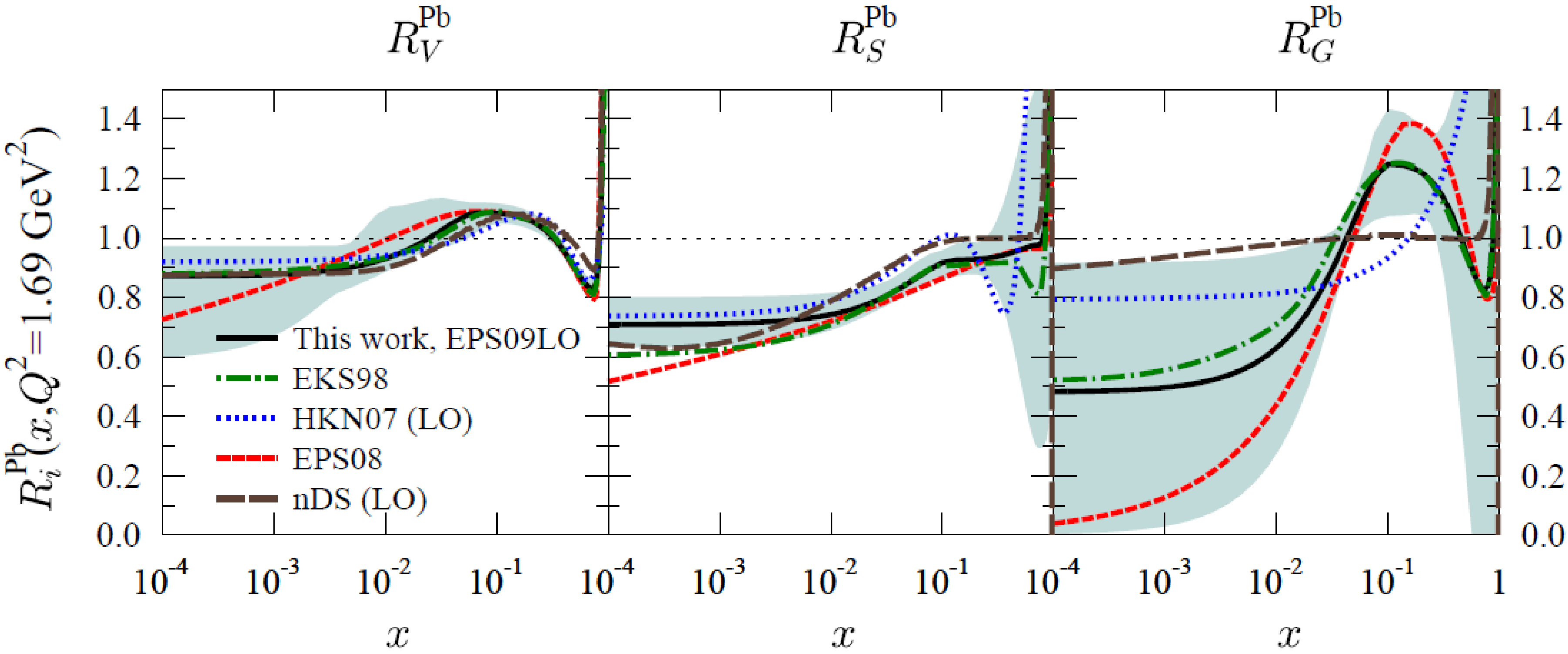
Summary

1. Suppression of J/ψ in PbPb
   - More suppression at high p_T than at low p_T (note: different y)
   - More suppression at LHC than at RHIC at high p_T for $|y|$ < 2.4
   - Less suppression at LHC than at RHIC at low p_T for 2.5 < y < 4
2. Current understanding
   - Recombination is important at low p_T
   - Initial state effect is important
     - pPb run this year will help to understand the initial state effect
3. On the b sector
   - Non-prompt J/ψ is suppressed
     - First hint of b-quark energy loss in medium
   - $\Upsilon(1S)$ is suppressed
   - $\Upsilon(2S+3S)$ is suppressed with respect to $\Upsilon(1S)$

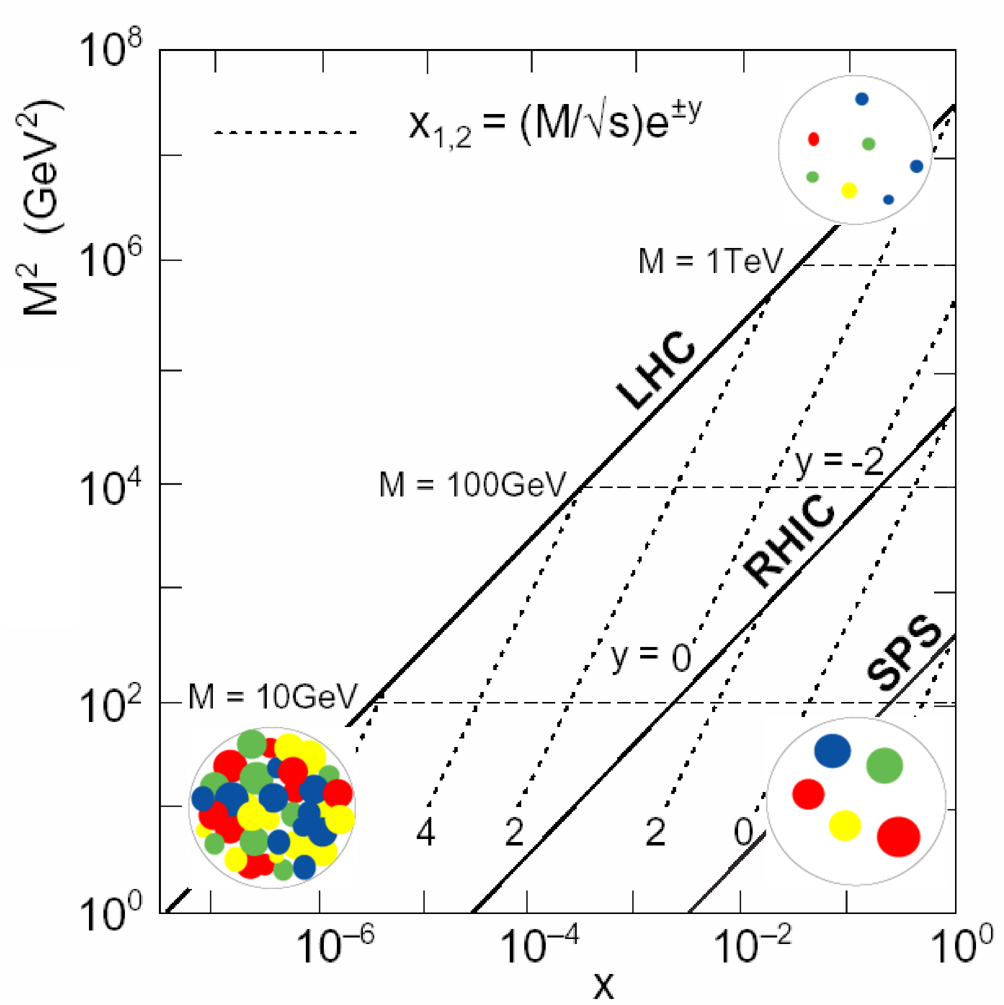
Backup

nPDF

Eskola et al., hep-ph/0902.4154v1



Kinematic Coverage



ALICE $m_{\mu^+\mu^-}$ Plot with Fit