Measurement of Charmonium Production in PbPb Collisions at 2.76 TeV with CMS

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Korea Univ.
On behalf of CMS

Outline

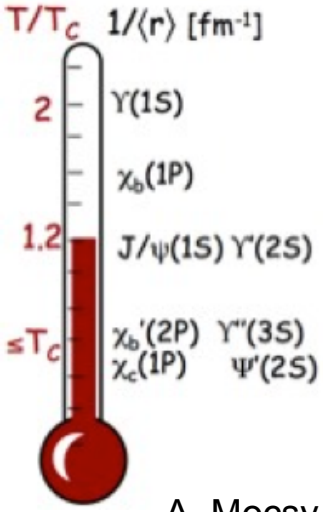
- Introduction
- 2010 PbPb Run (JHEP 1205 (2012) 063)
- 2011 PbPb Run
- Summary

Quarkonia in heavy-ion collisions

- One of most powerful tools to understand the QGP
  - Heavy quarks created at the early stage and with a large momentum transfer in gluon-gluon fusion.
  - Sequential melting
    - By Debye screening.
    - Play a role to quantify medium properties (as thermometer).

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

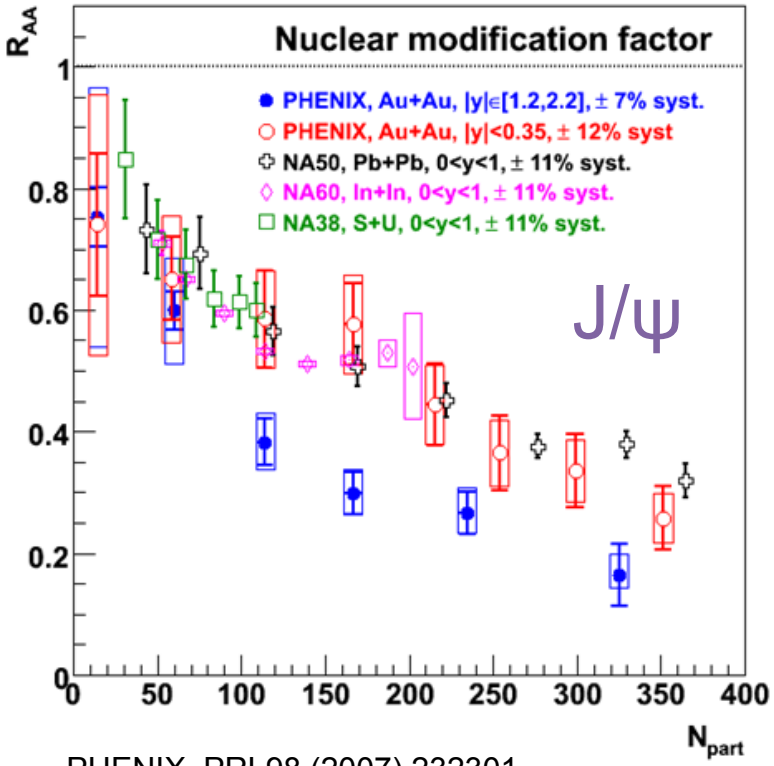
Υ (1S)	χ_b (1P)	Υ' (2S)	χ_b' (2P)	Υ'' (3S)
9.46	9.99	10.02	10.26	10.36
0.28	0.44	0.56	0.68	0.78



A. Mocsy
Eur.Phys.J.C61,2009

Puzzles at previous experiments

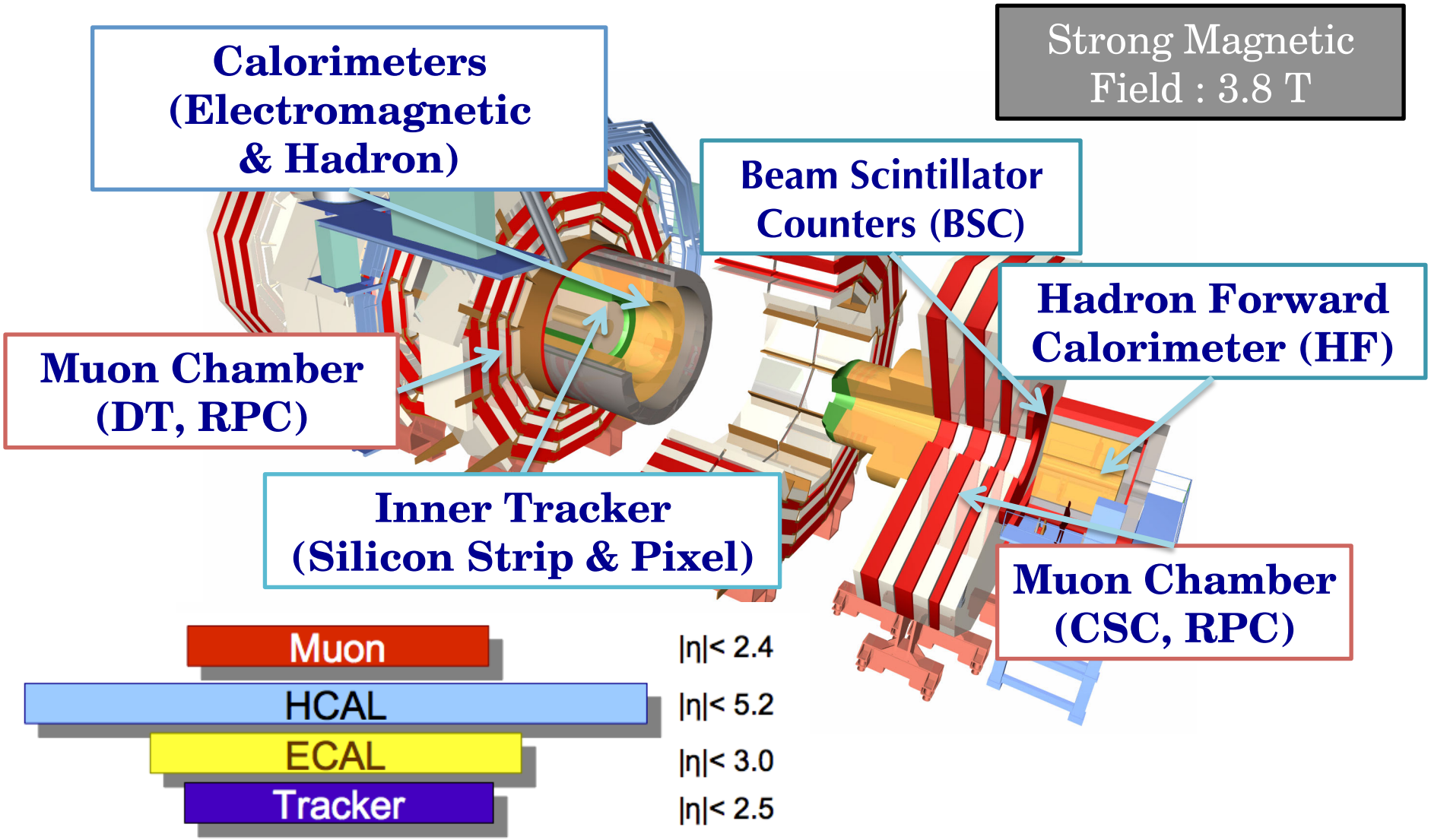
- At RHIC & SPS



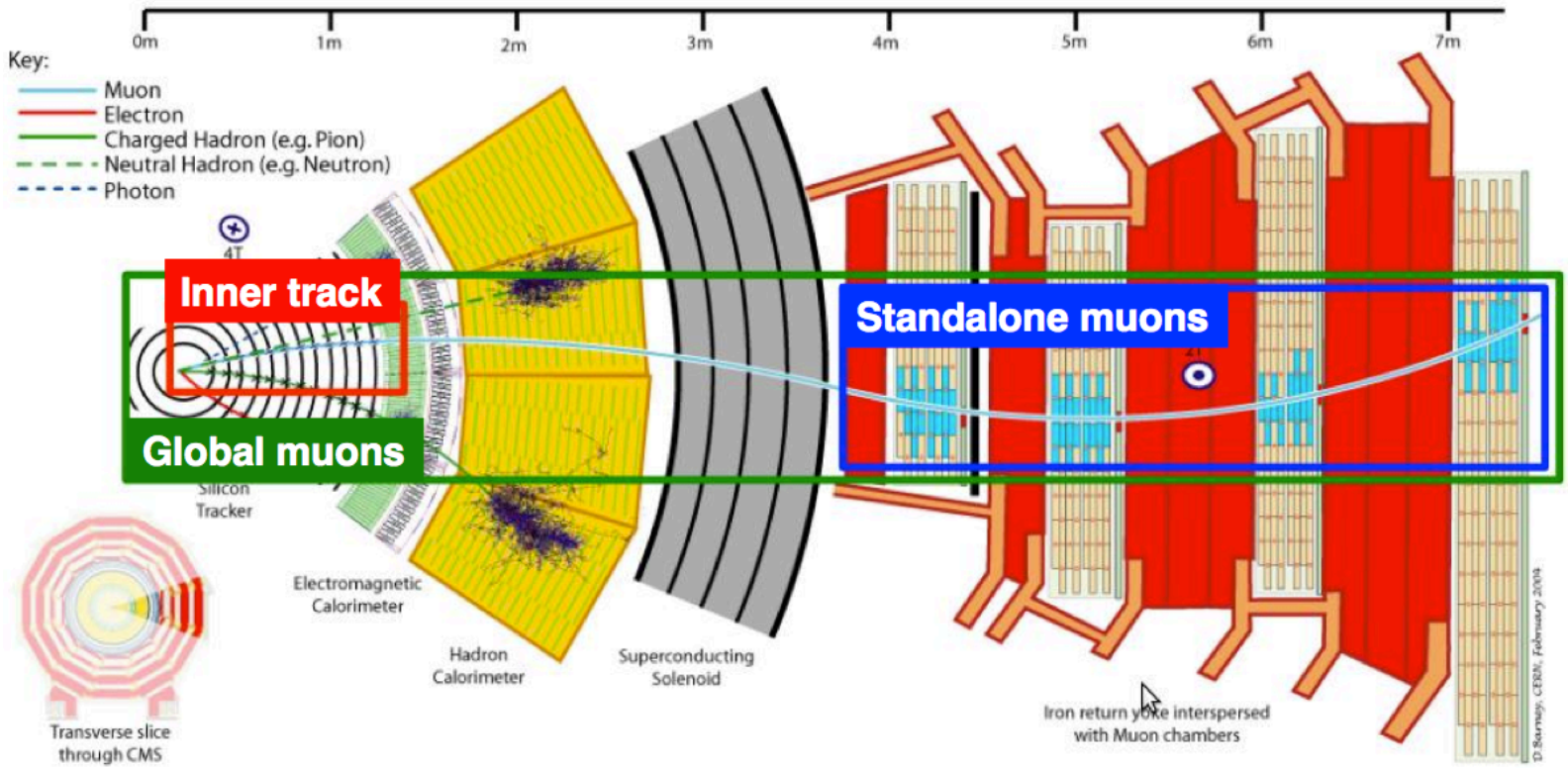
PHENIX, PRL98 (2007) 232301,
Phys.Rev. C84 (2011) 054912,
SPS from Scomparin @ QM06

- Similar suppression trends observed
  - Effect of recombination ?
- More suppression at forward rapidity
  - Effect of recombination ?
  - Gluon saturation ?
  - Shadowing ?
- So, how about the LHC ?
  - Enhancement by a recombination.
  - Further suppression by a increased temperature.

CMS detector

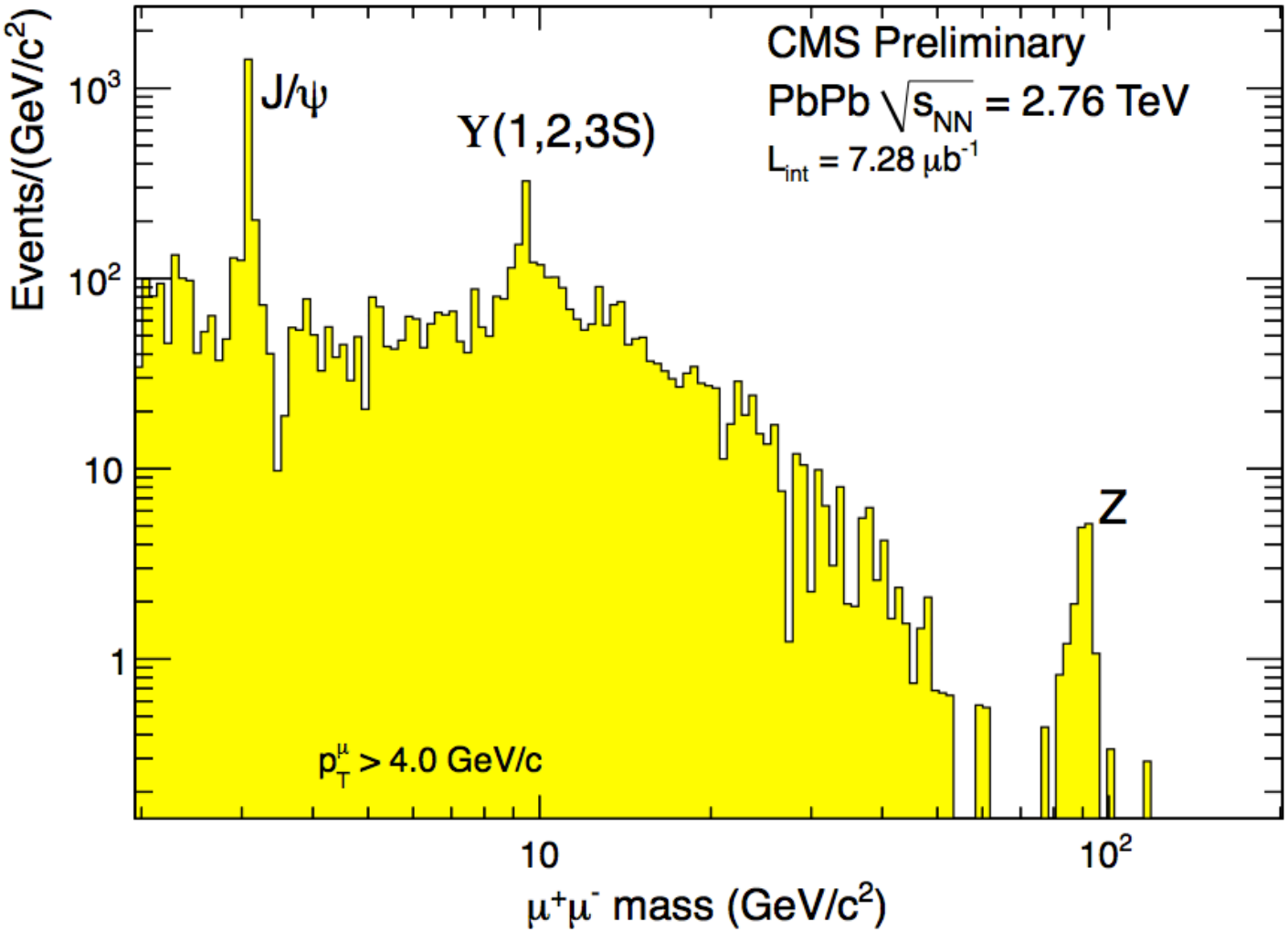


Muon reconstruction

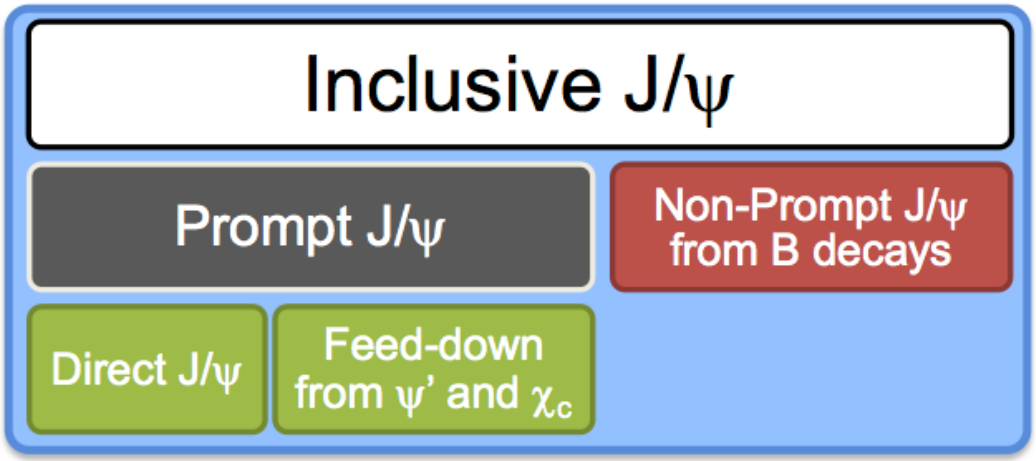


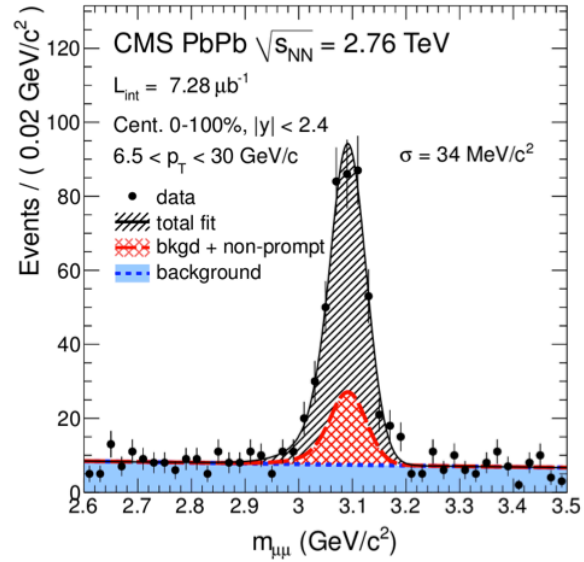
- Excellent muon identification & triggering in muon system.
- Excellent momentum resolution of tracking system.
  - Overall resolution: 1~2 %

Dimuon spectrum in 2010 PbPb



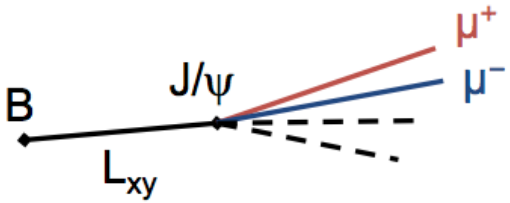
Prompt/non-prompt J/ψ

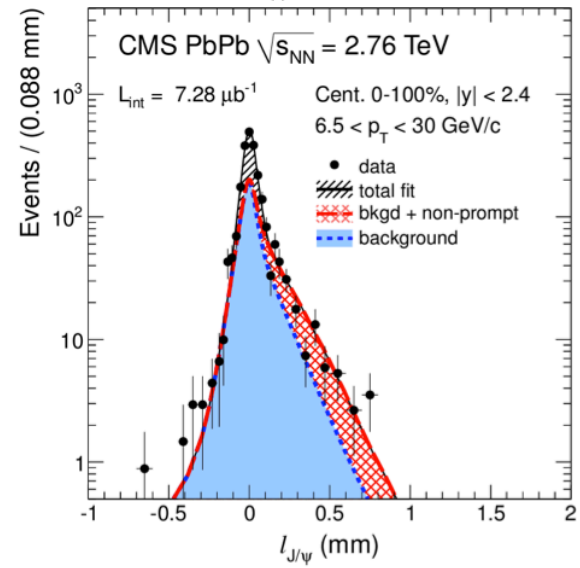




- Reconstruct opposite sign muon vertex
- 2-D unbinned maximum likelihood fit of dimuon mass and pseudo-proper decay length ($l_{J/\psi}$)

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





So far, the only time that prompt and non-prompt J/ψ are separated in heavy-ion collisions

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R_{AA} of prompt J/ψ vs N_{part}

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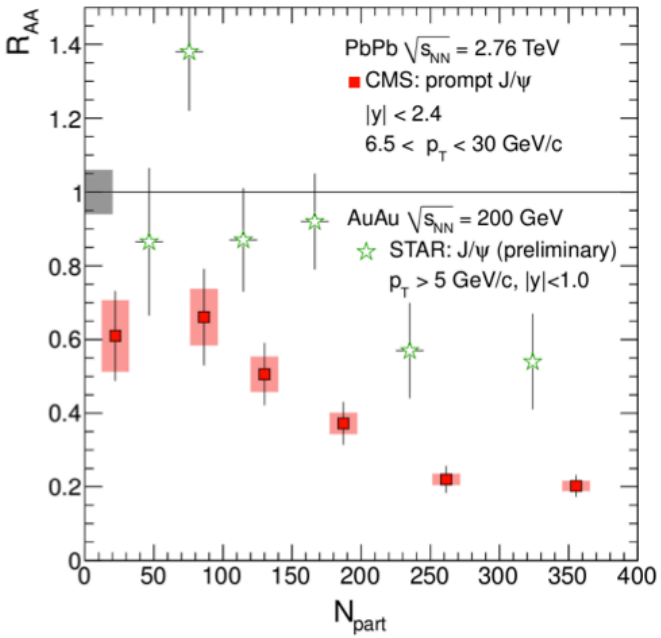
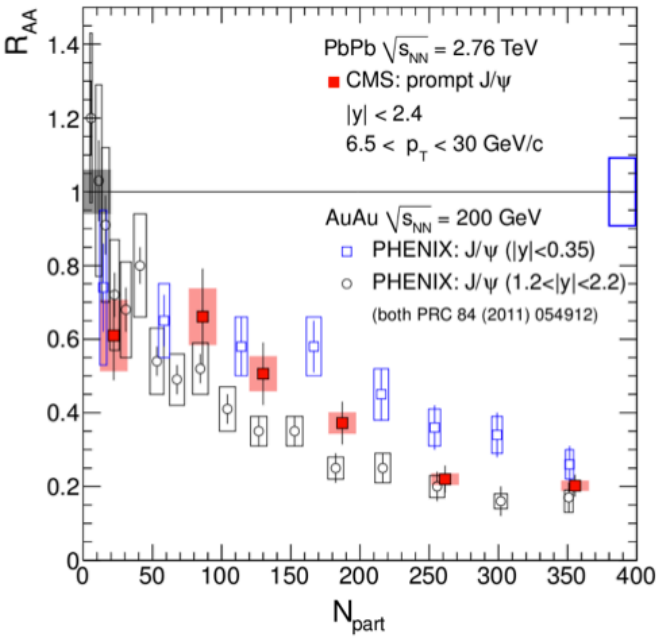


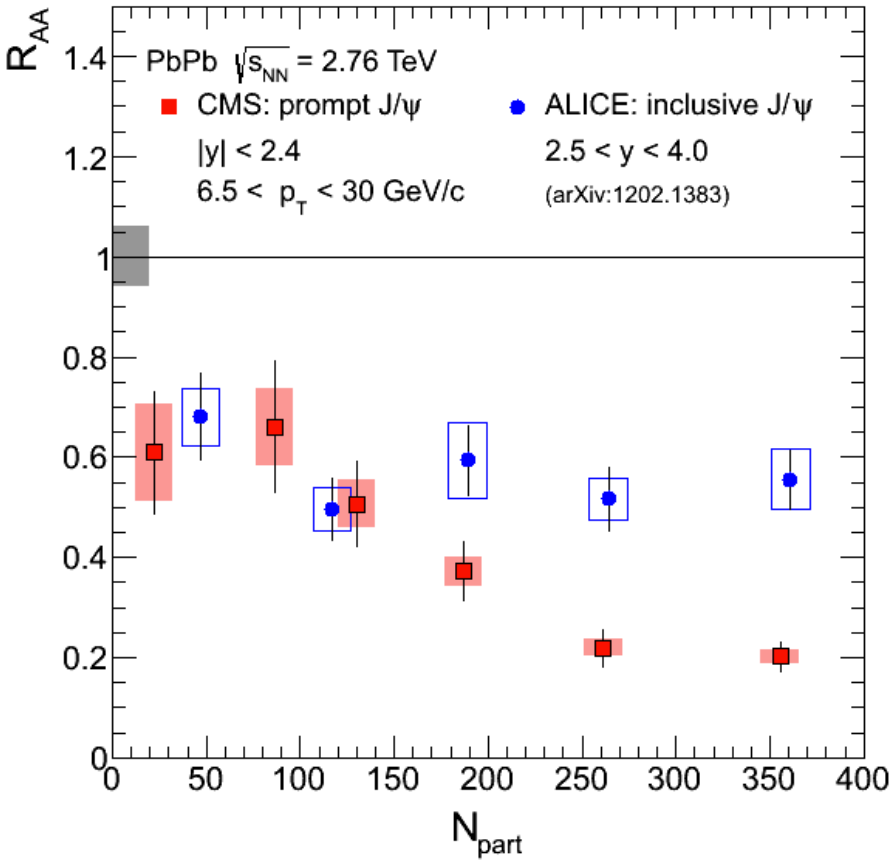


$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{\mathrm{MB}}} \frac{N_{\mathrm{PbPb}}(J/\psi)}{N_{pp}(J/\psi)} \frac{\varepsilon_{pp}}{\varepsilon_{\mathrm{PbPb}}(\mathrm{cent})}$$

- At most central (0 – 10 %) suppressed by factor 5 with respect to pp.
- At peripheral (50 – 100 %) suppressed by factor 1.6 with respect to pp.
- STAR measures less suppression at high p_T (> 5 GeV/c) and mid-rapidity.
- CMS and PHENIX observe similar magnitude, though different p_T.

R_{AA} of prompt J/ψ vs N_{part}

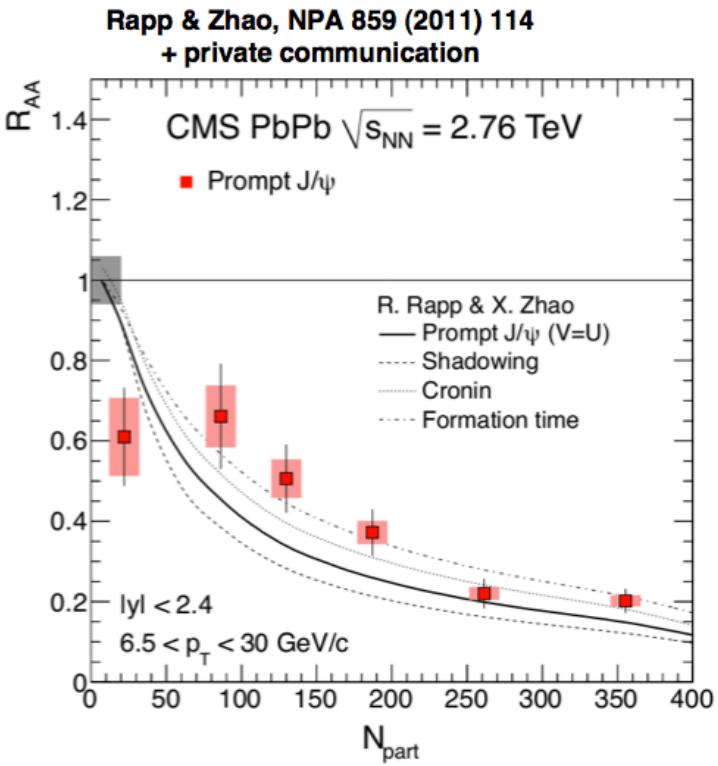
JHEP 1205 (2012) 063

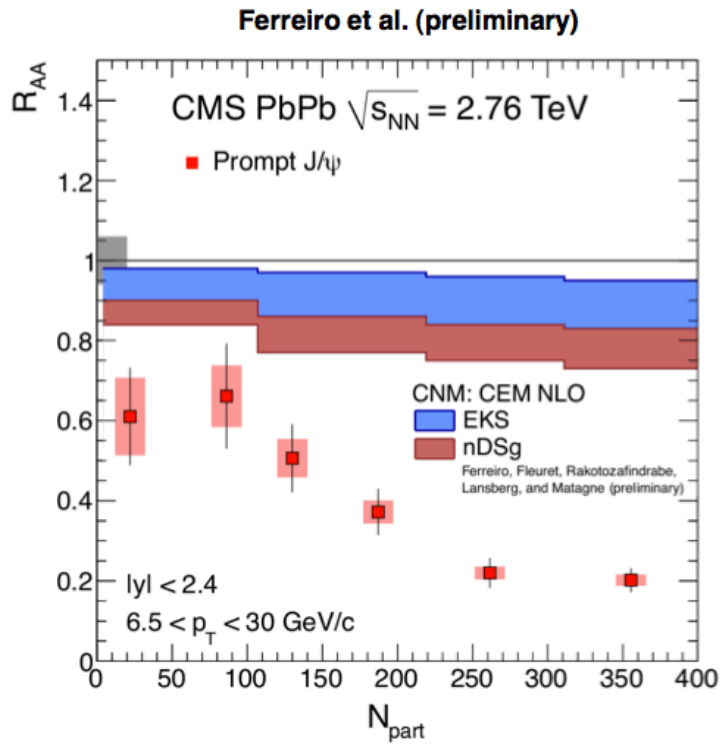


- ALICE (inclusive J/ψ) measured less suppression and centrality dependence than CMS at forward rapidity (2.5 < y < 4.0) and low p_T down to 0.
- If regeneration, expected at low p_T, thus more in ALICE than in CMS.
- Note: R_{AA} of prompt J/ψ could shift down by ~11 % due to ~10 % b-fraction at low p_T in pp at ALICE.

R_{AA} of prompt J/ψ vs N_{part}

- Theory comparison

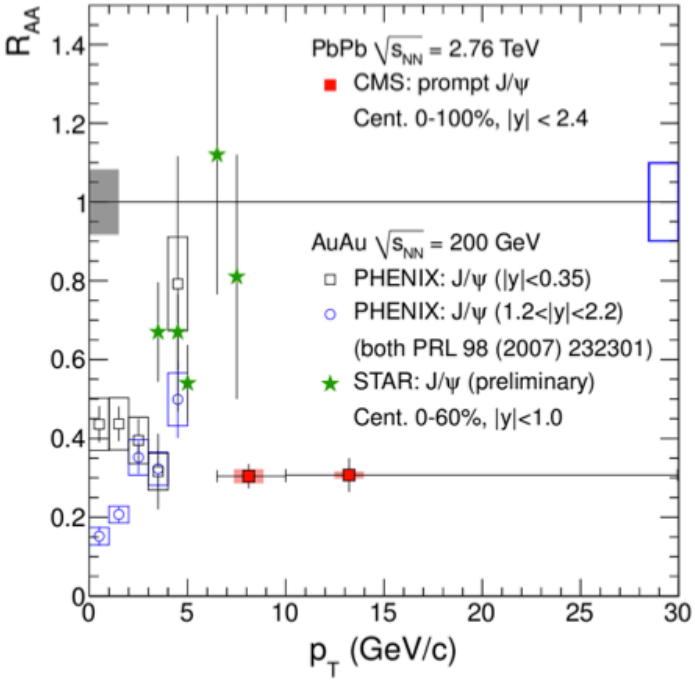




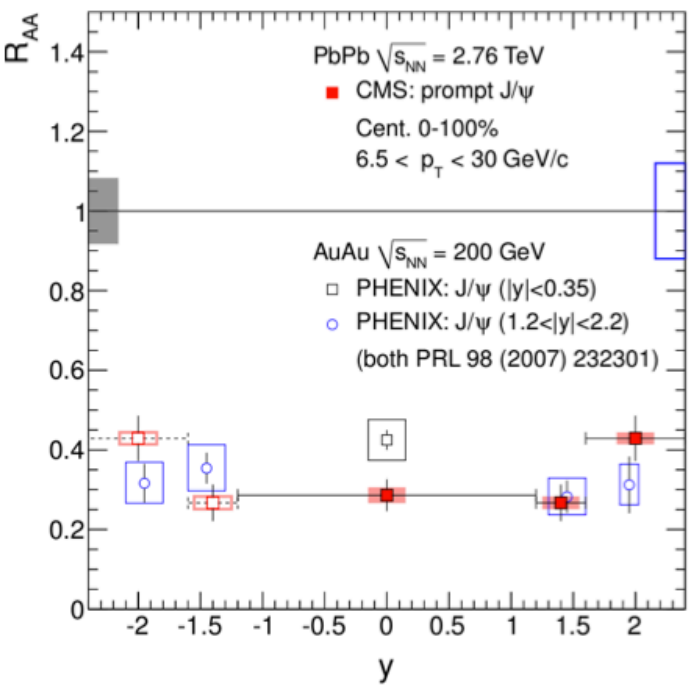
In this calculation, recombination not significant for p_T > 6.5 GeV/c

CNM effects are too small to account for the full suppression

R_{AA} of prompt J/ψ vs p_T & y



- p_T dependence
  - CMS (p_T > 6.5 GeV/c)
    - Suppressed by a factor 3.
  - STAR (5 < p_T < 8 GeV/c)
    - No significant suppression at high p_T.



- y dependence
  - CMS (p_T > 6.5 GeV/c)
    - Slightly less suppression at forward rapidity.
  - PHENIX: lower p_T
    - Opposite trend of rapidity dependence.

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R_{AA} of B → J/ψ

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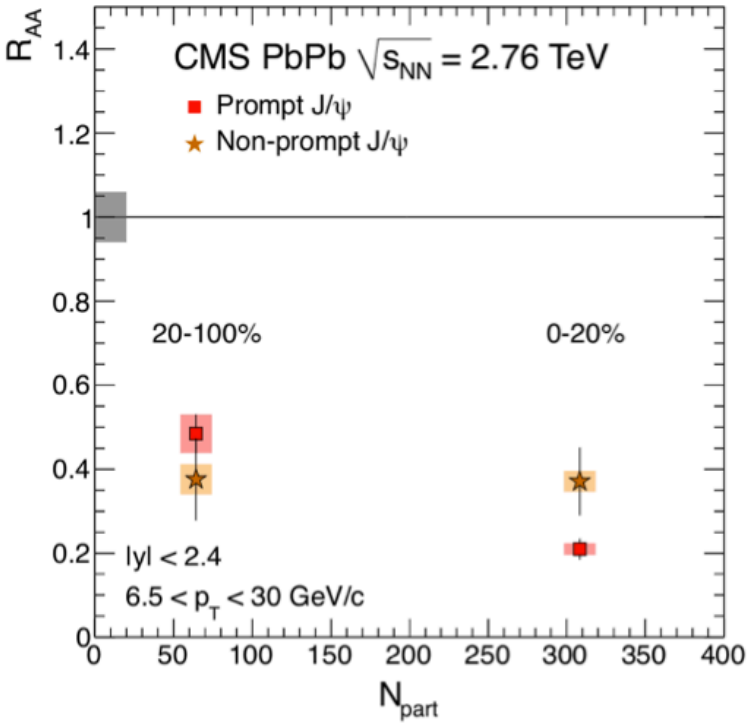
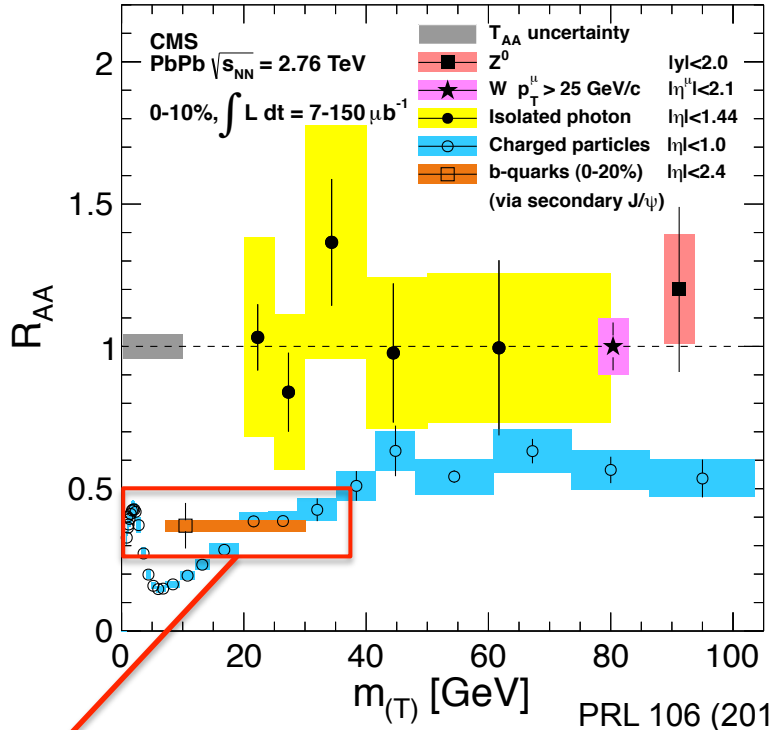


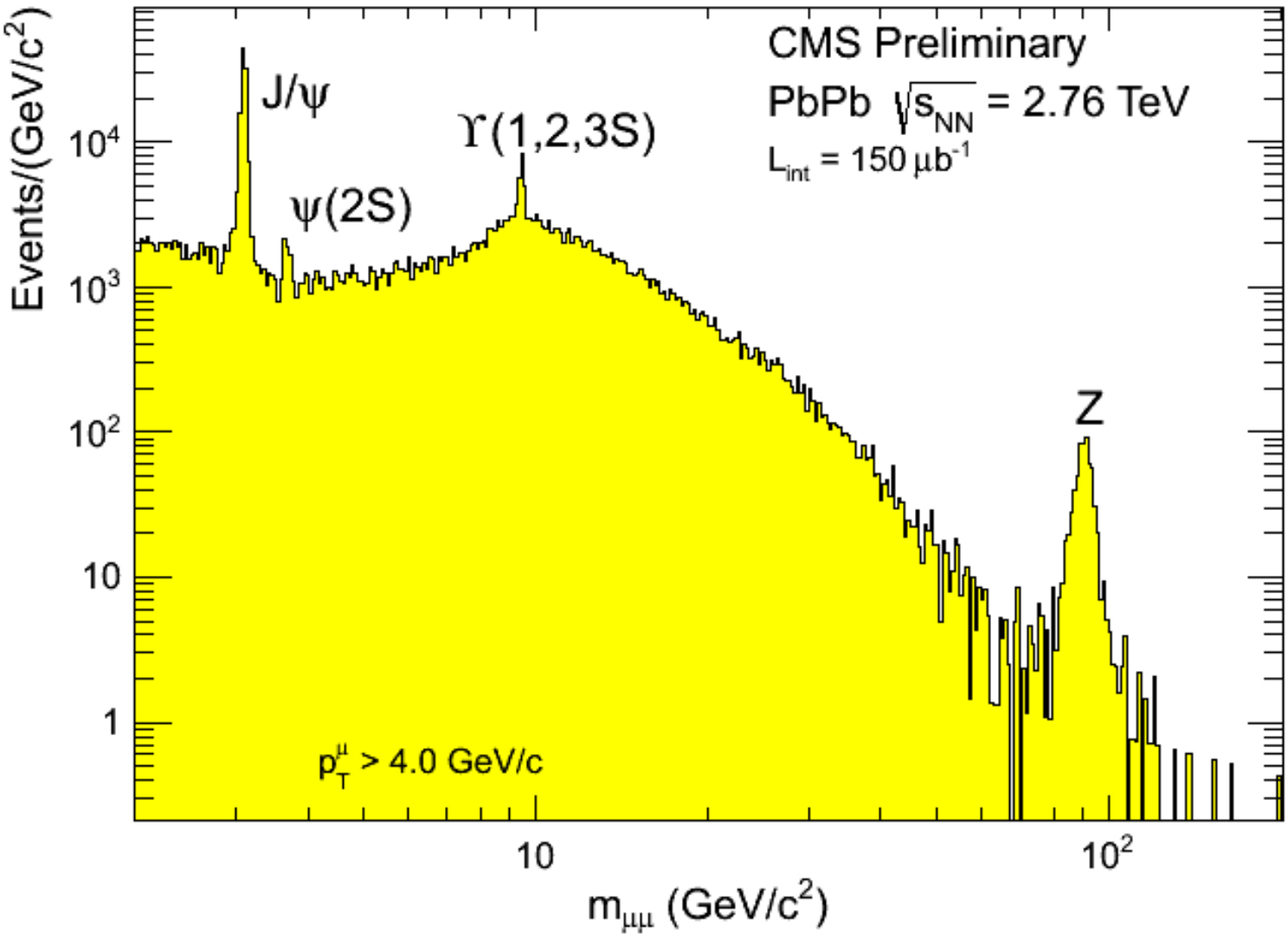


PRL 106 (2011) 212301
CMS-HIN-11-008
PLB 710 (2012) 256
EPJ C 72 (2012) 1945
JHEP 1205 (2012) 063

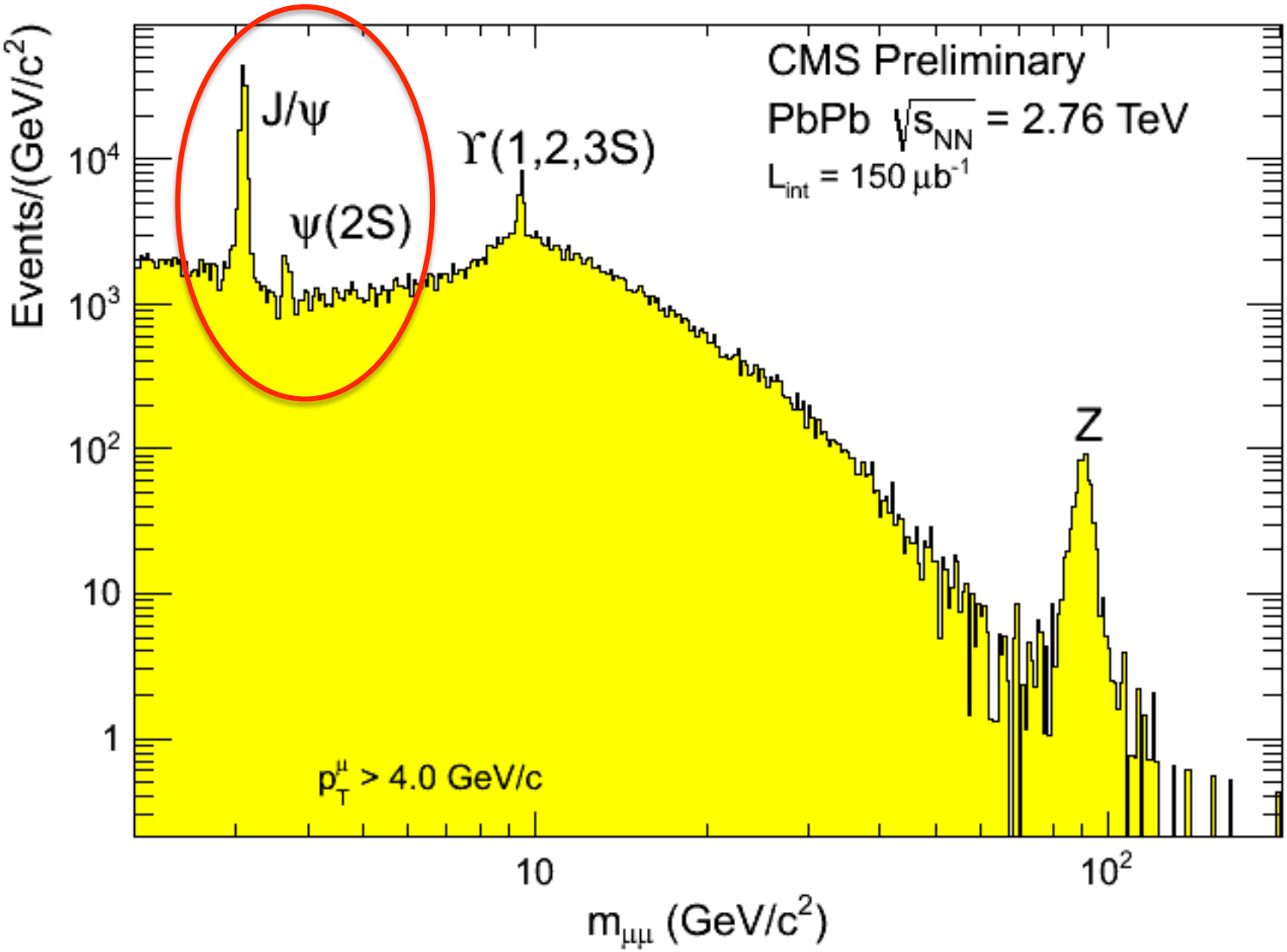
- Suppression of non-prompt J/ψ observed in min. bias and central PbPb collisions.
- No strong dependence of centrality.

  - First indications of b-quark quenching !

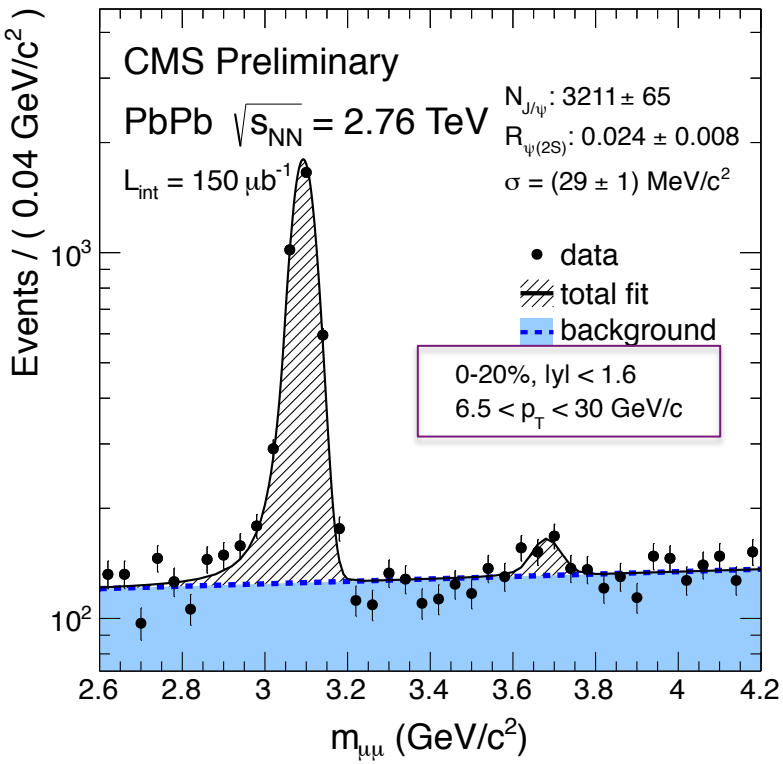
Dimuon spectrum in 2011 PbPb

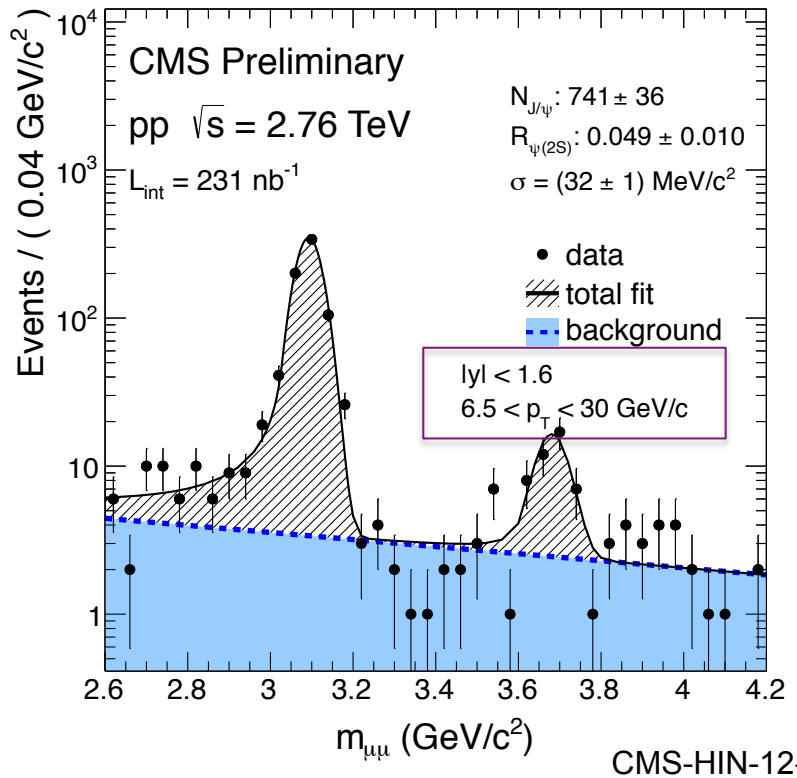


Dimuon spectrum in 2011 PbPb



ψ(2s) in PbPb & pp @$\sqrt{s_{NN}}$ = 2.76 TeV

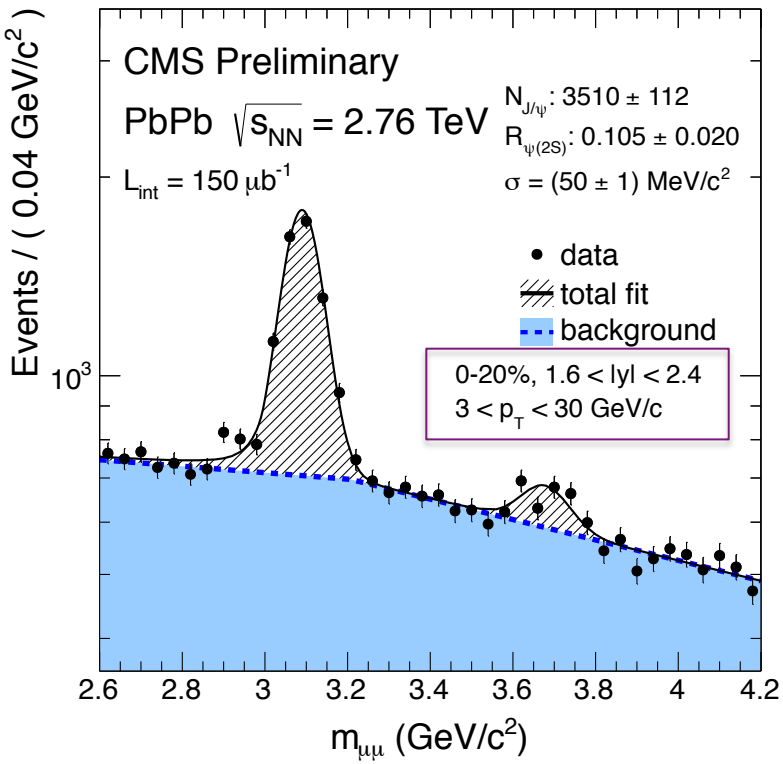


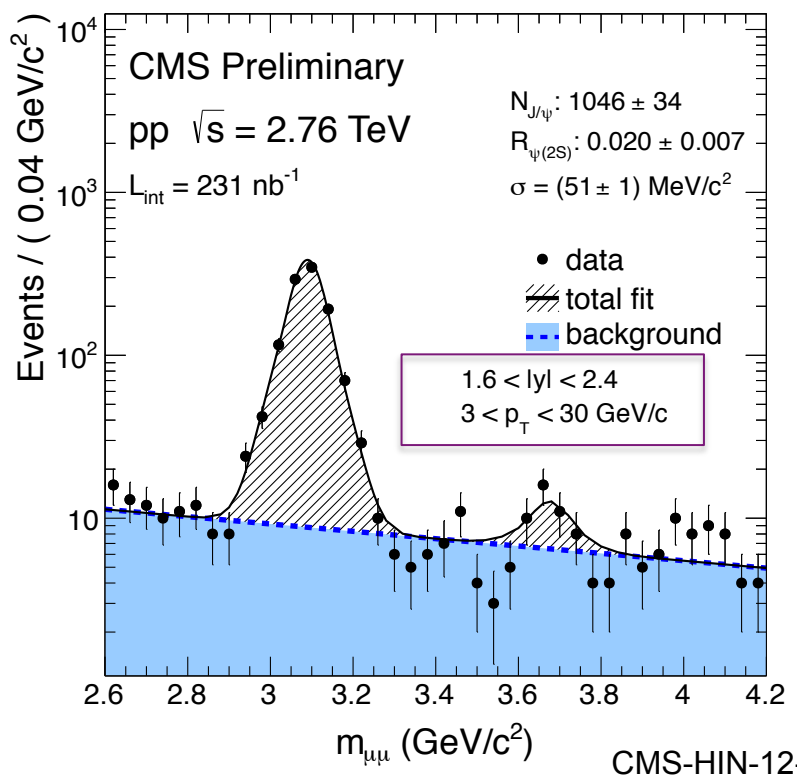


CMS-HIN-12-007

- $R_{\psi(2S)}$ (Raw ratio of ψ(2S) / J/ψ) in |y| < 1.6 and 6.5 < p_T < 30 GeV/c.
  - PbPb, 0-20 %: 0.024 ± 0.008 (stat.)
  - pp: 0.049 ± 0.010 (stat.)
  - $R_{\psi(2S)}$ in PbPb is ~2 times smaller than pp.

ψ(2s) in PbPb & pp @$\sqrt{s_{NN}}$ = 2.76 TeV





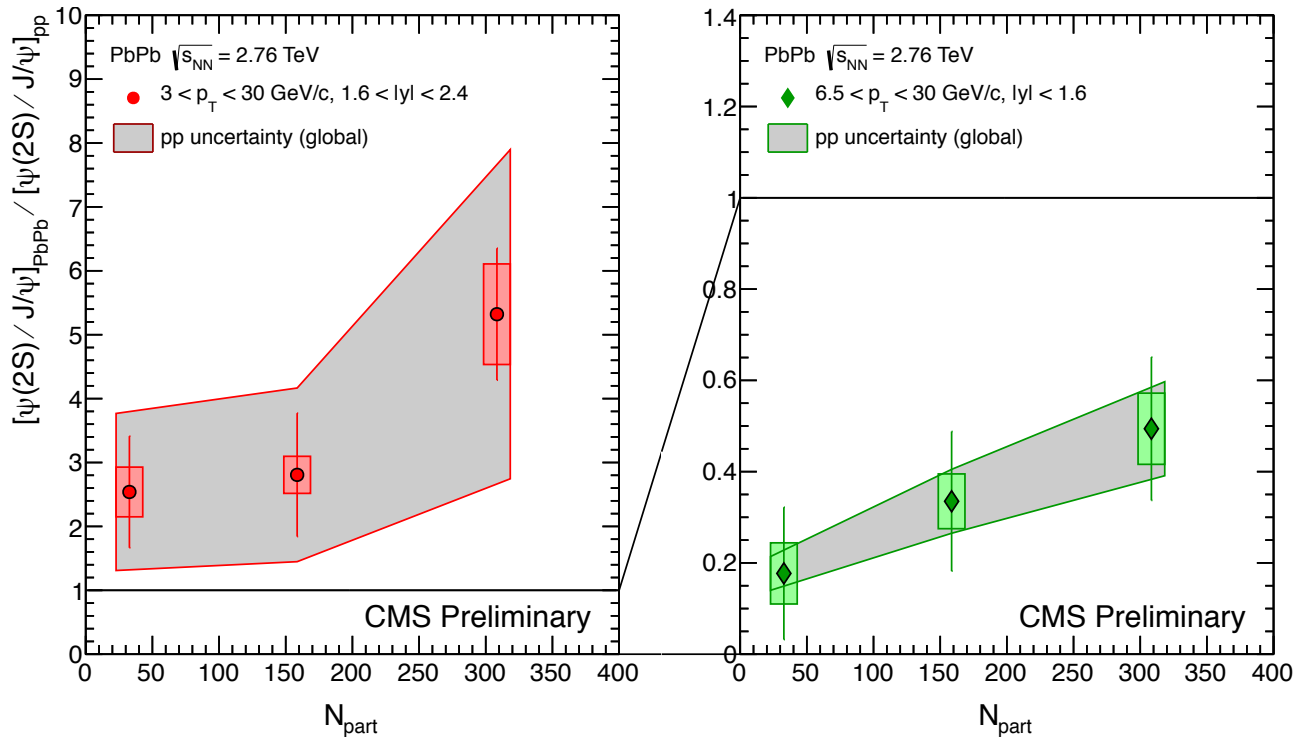
CMS-HIN-12-007

- $R_{\psi(2S)}$ (Raw ratio of ψ(2S) / J/ψ) in 1.6 < |y| < 2.4 and 3 < p_T < 30 GeV/c.
  - PbPb, 0-20 %: 0.105 ± 0.020 (stat.)
  - pp: 0.020 ± 0.007 (stat.)
  - $R_{\psi(2S)}$ in PbPb is ~5 times larger than pp.

Double ratio of ψ(2s) & J/ψ

$$\frac{R^{\mathrm{PbPb}}_{\psi(2S)}}{R^{\mathrm{pp}}_{\psi(2S)}} = \left[\frac{N_{\psi(2S)}}{N_{J/\psi}}\right]_{\mathrm{PbPb}} \Bigg/ \left[\frac{N_{\psi(2S)}}{N_{J/\psi}}\right]_{\mathrm{pp}}$$

CMS-HIN-12-007



In 3.0 < p_T and 1.6 < |y| < 2.4, ψ(2S) are less suppressed than J/ψ (uncertainties (especially from pp) are large).

In 6.5 < p_T and |y| < 1.6, ψ(2S) are more suppressed than J/ψ.

Summary

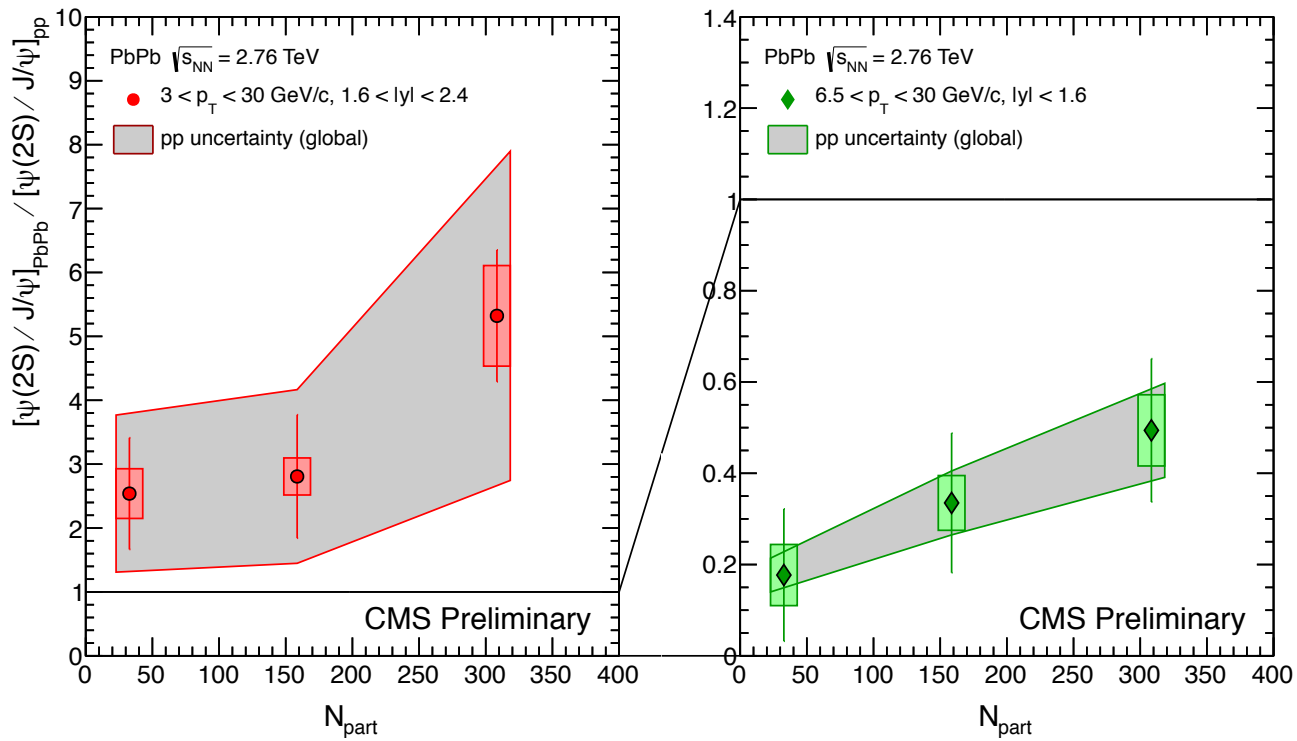
- CMS measured R_{AA} of prompt and non-prompt J/ψ separately in heavy-ion collisions.
  - Prompt J/ψ suppressed significantly at high p_T.
  - Non-prompt J/ψ suppressed (indicating b-quark quenching).

- Double ratio of charmonium (ψ(2S) and J/ψ) measurement is performed, using 150 μb^{-1} taken in 2011.
- Different features of ψ(2S) are observed at lower p_T (forward rapidity) and high p_T (mid-rapidity) regions.
  - stronger suppression than J/ψ at high p_T and mid-rapidity.
  - less suppressed than J/ψ at lower p_T and forward rapidity, but uncertainties are large (need more pp).

Back Up

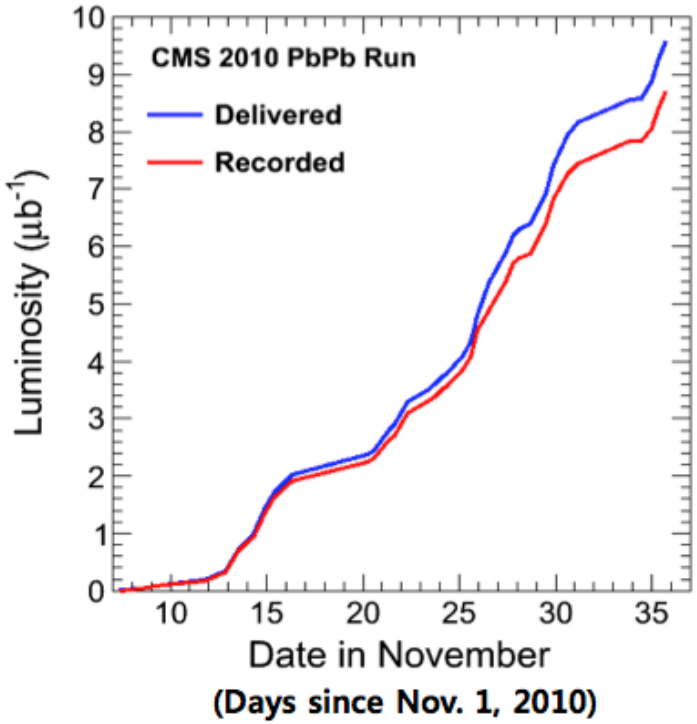
Double ratio of ψ(2s) & J/ψ

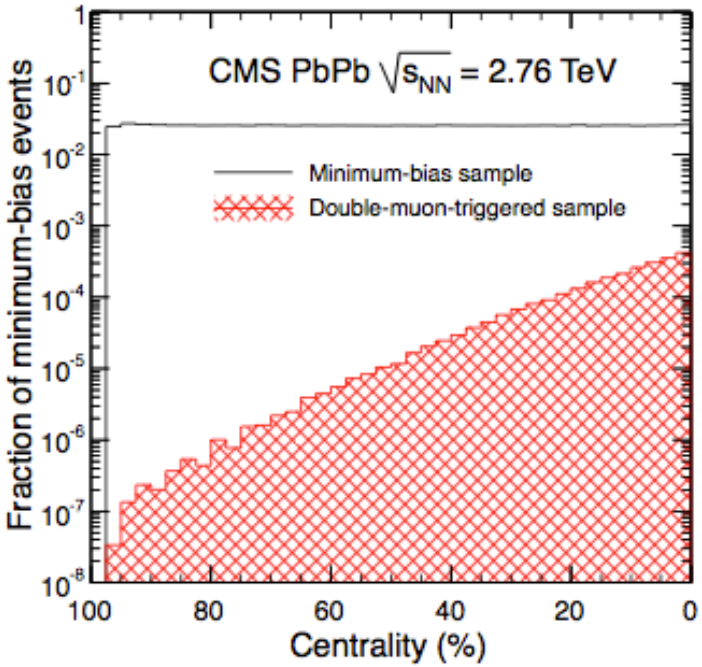
CMS-HIN-12-007



- For p_T>3 GeV/c and 1.6<|y|<2.4: large uncertainties on pp
  Indication of ψ(2S) being less suppressed than J/ψ
  - Significance: not more than 2σ, work is ongoing, but we need more pp!
- For p_T>6.5 GeV/c and |y|<1.6:
  ψ(2S) are more suppressed than J/ψ

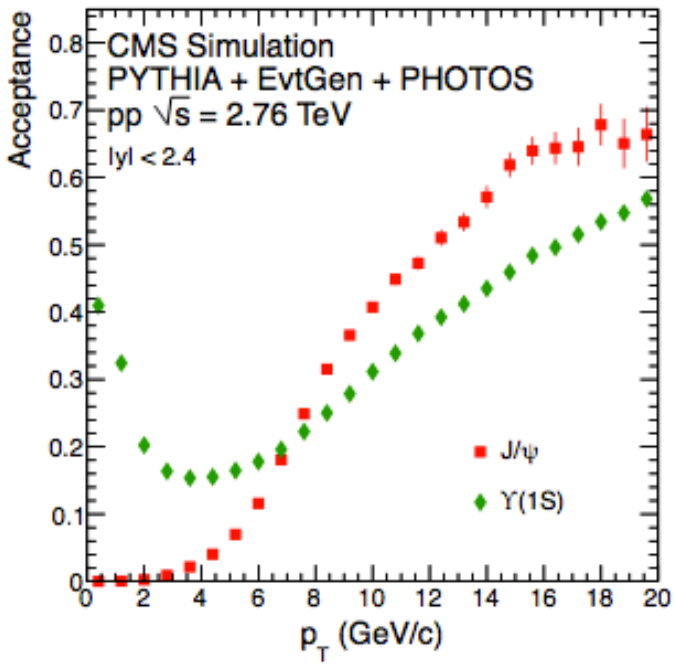
Data taking in 2010 PbPb (pp) run

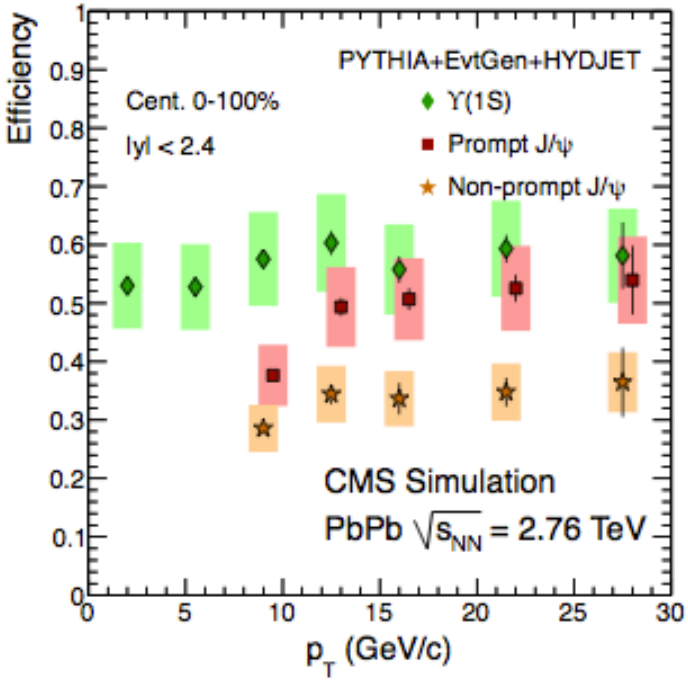




- Recorded luminosity PbPb: 7.28 μb^{-1} ($\sqrt{s_{NN}}$ = 2.76 TeV).
- Reference pp data: 231 nb^{-1} ($\sqrt{s_{NN}}$ = 2.76 TeV).

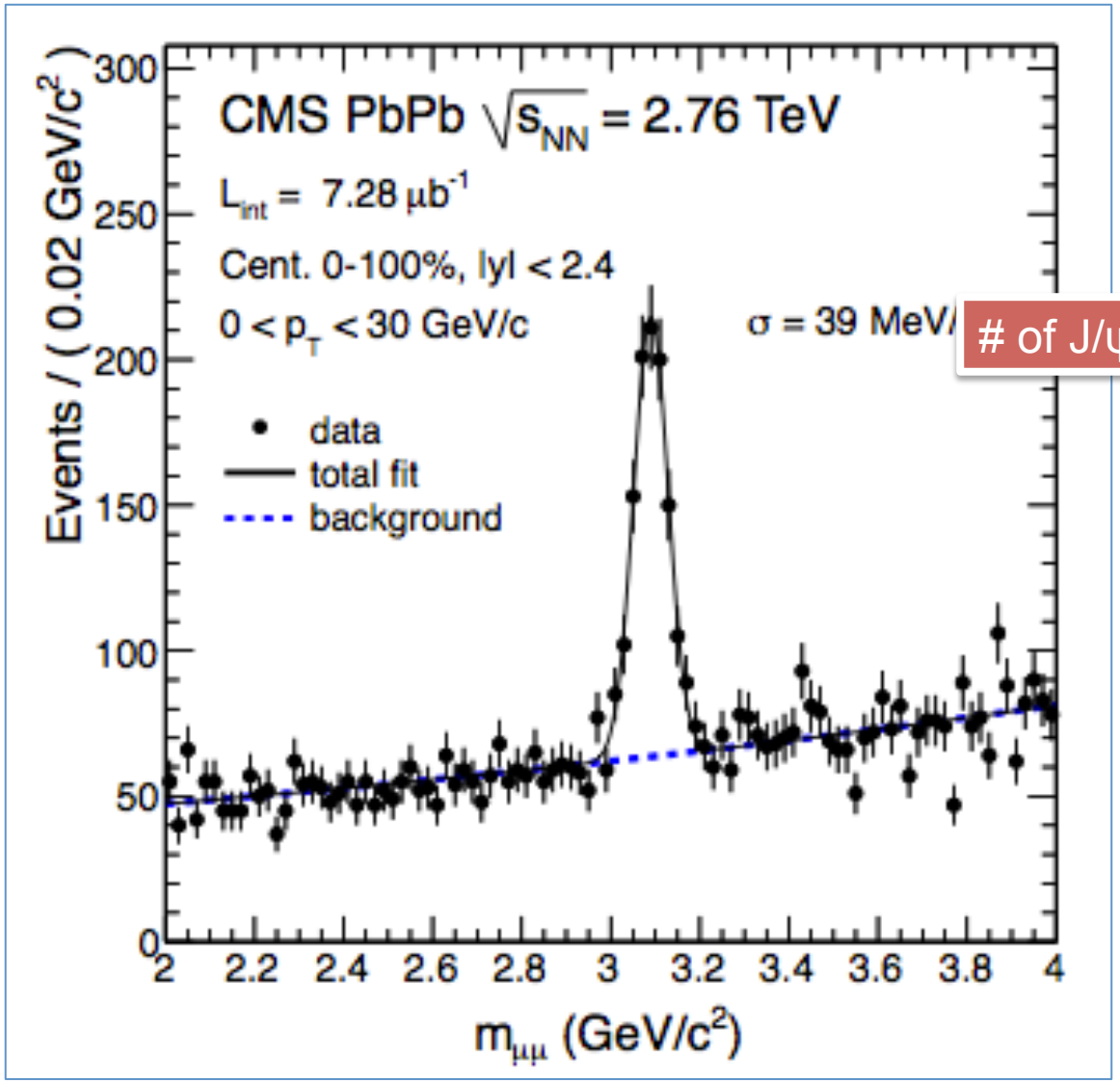
Acceptance and efficiency





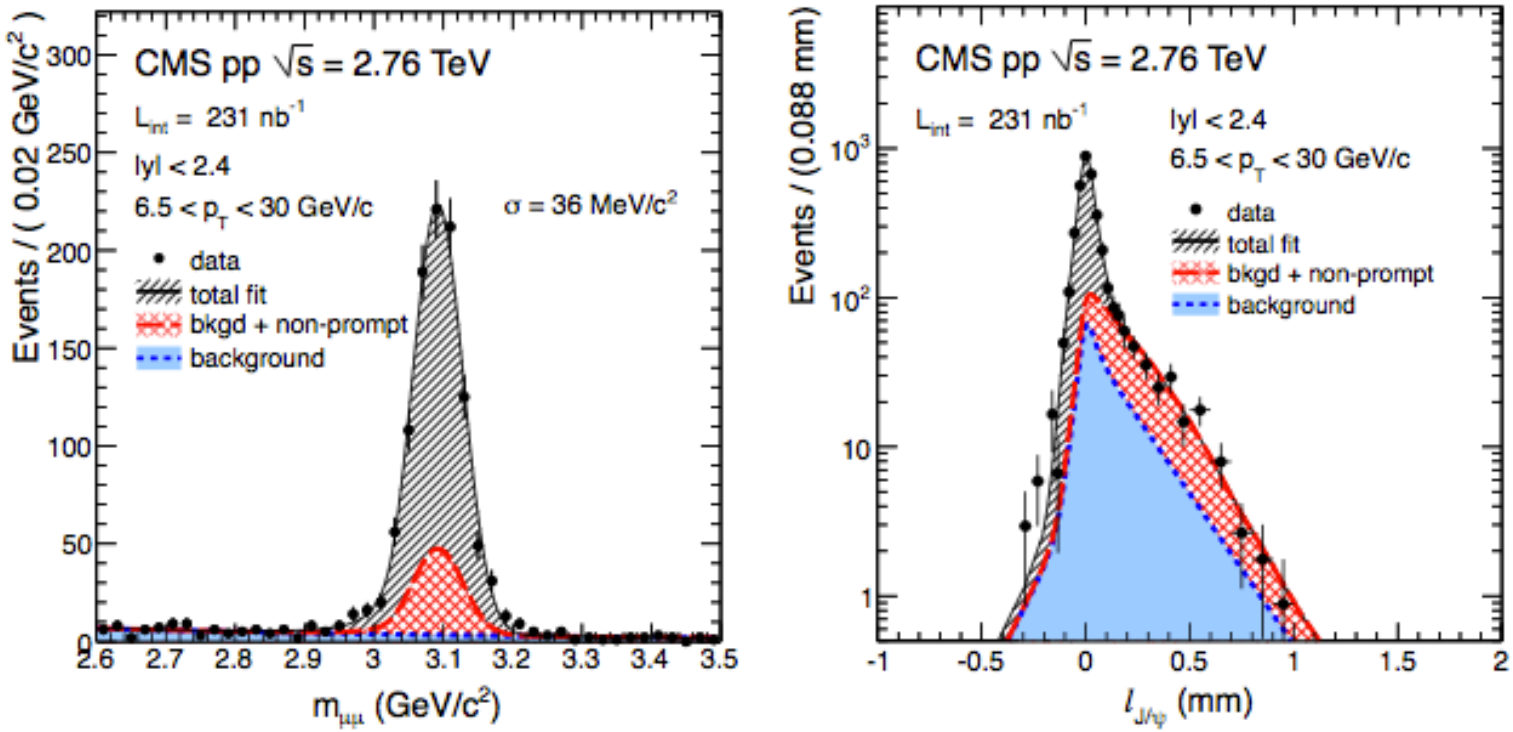
- MC simulation with PYTHIA + HYDJET.
- No acceptance in mid-rapidity for J/ψ with p_T < 6.5 GeV/c but in the forward region 3GeV/c is reached
- Validated by data driven method(Tag and Probe technique) between MC and data

Dimuon spectrum in 2010 PbPb



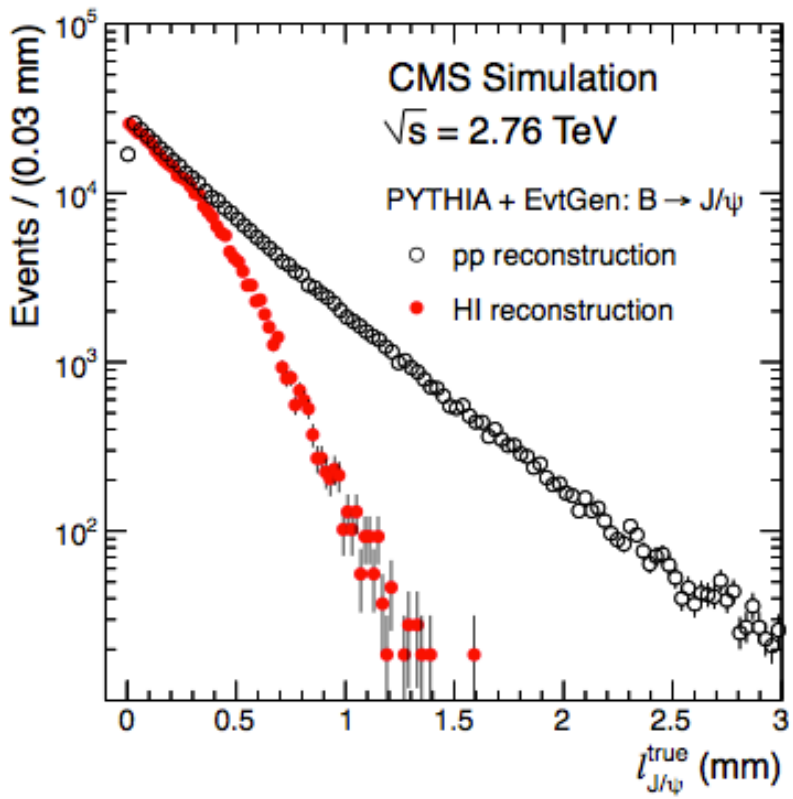
# of J/ψ: 734 ± 54

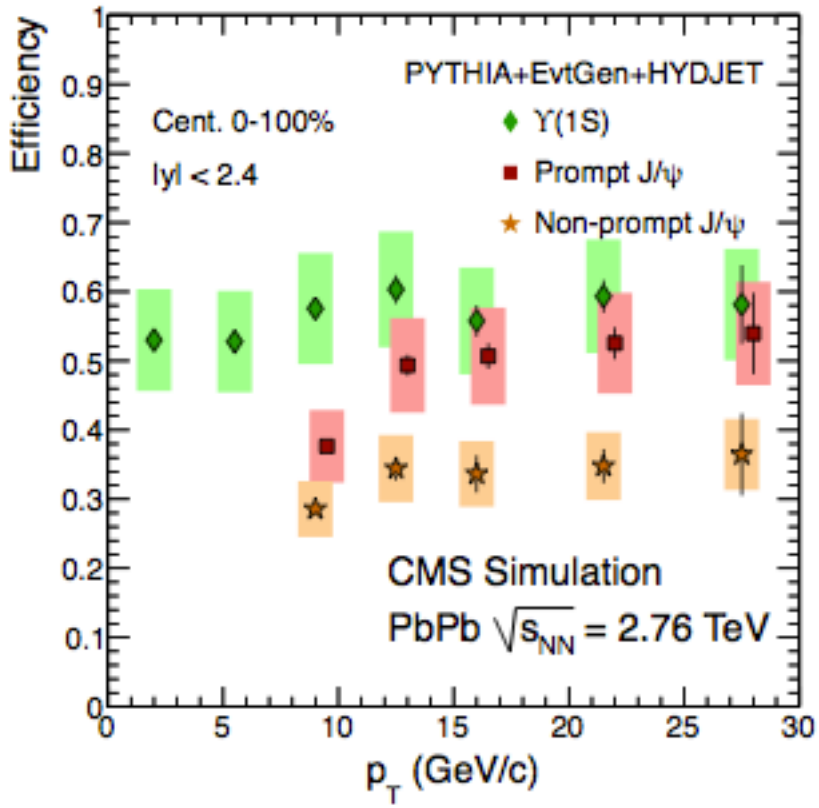
pp reference for R_{AA}



- 231 nb^{-1} data reconstructed by heavy-ion algorithm
- Different trigger condition (HLT_L1DoubleMu0 – slightly higher quality)
- Same acceptance and efficiency condition as heavy-ion analysis

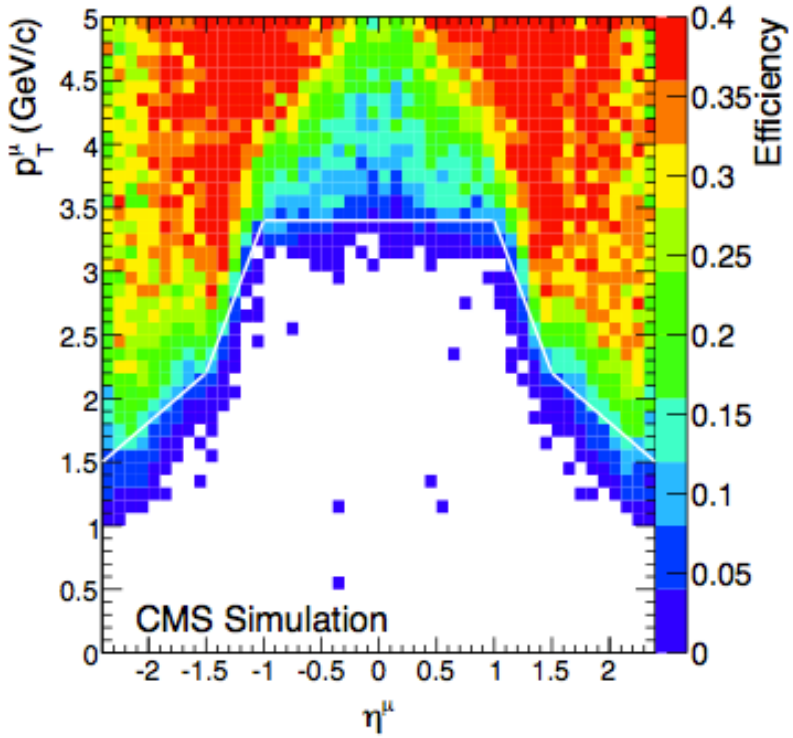
Comparison reco algo





- HI tracking algorithm uses vertex constraint
  - Smaller efficiency for non-prompt than for prompt
  - Effect increases with p_T

Single muon acceptance



$$p_T^\mu > 3.4\,\mathrm{GeV}/c \qquad \text{for } |\eta^\mu| < 1.0,$$
$$p_T^\mu > (5.8 - 2.4 \times |\eta^\mu|)\,\mathrm{GeV}/c \qquad \text{for } 1.0 < |\eta^\mu| < 1.5,$$
$$p_T^\mu > (3.4 - 0.78 \times |\eta^\mu|)\,\mathrm{GeV}/c \qquad \text{for } 1.5 < |\eta^\mu| < 2.4.$$

Systematic uncertainties

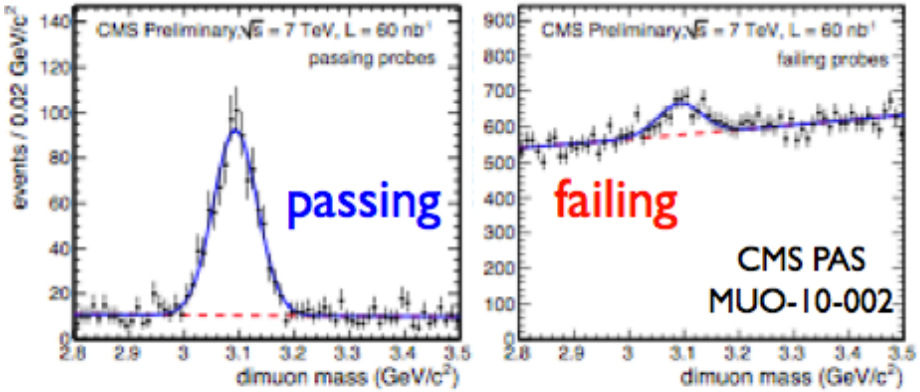
Table 2: Point-to-point systematic uncertainties on the prompt J/ψ, non-prompt J/ψ, and Υ(1S) yields measured in PbPb collisions.

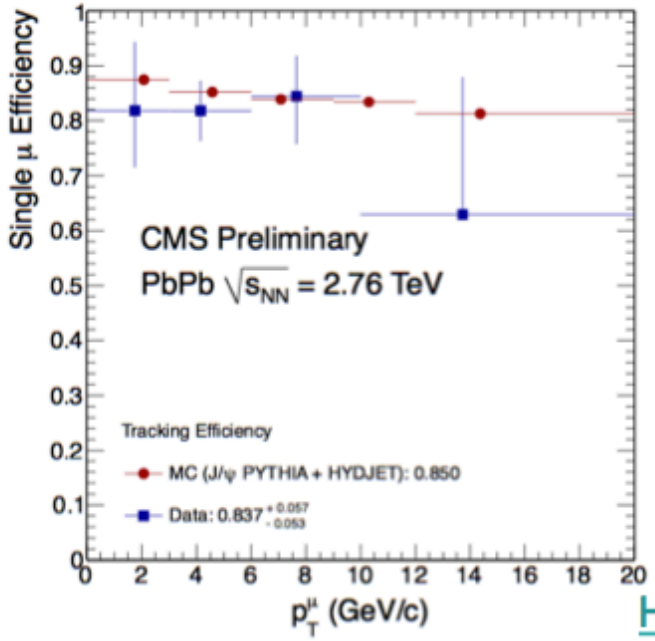
	prompt J/ψ (%)	non-prompt J/ψ (%)	Υ(1S) (%)
Yield extraction	0.5–5.7	1.5–14.0	8.7–13.4
Efficiency	1.8–3.4	2.2–4.2	1.4–2.7
Acceptance	0.9–4.2	2.0–3.2	1.5–2.8
MC Validation	13.7	13.7	13.7
Stand-alone μ reco.	1.0	1.0	1.0
T_{AA}	4.3–15.0	4.6–8.6	4.3–8.6
Total	15–21	15–21	18–20

Table 3: Point-to-point systematic uncertainties on the prompt J/ψ, non-prompt J/ψ, and Υ(1S) yields measured in pp collisions.

	prompt J/ψ (%)	non-prompt J/ψ (%)	Υ(1S) (%)
Yield extraction	0.8–5.3	5.3–16.8	10.0
Efficiency	1.6–3.0	1.4–2.0	0.4–0.9
Acceptance	0.9–4.2	2.0–3.2	1.5–2.8
MC Validation	13.7	13.7	13.7
Stand-alone μ reco.	1.0	1.0	1.0
Total	14–16	15–22	17–18

Tag and probe

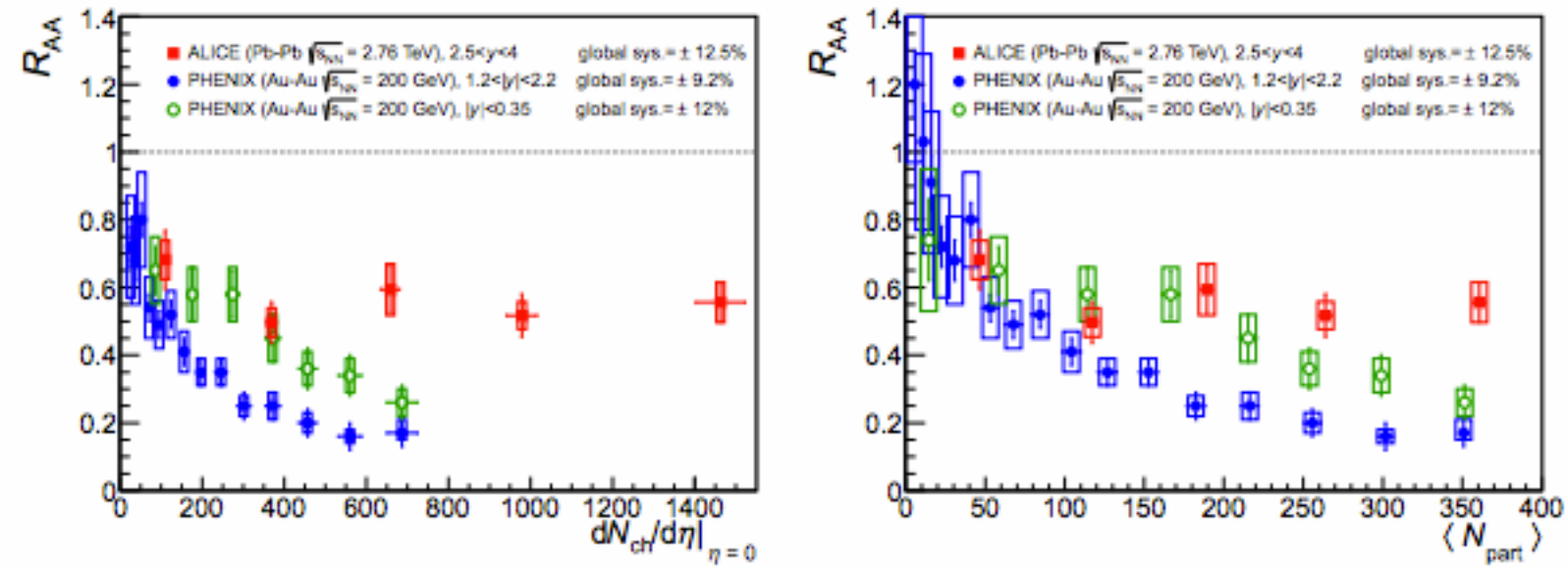


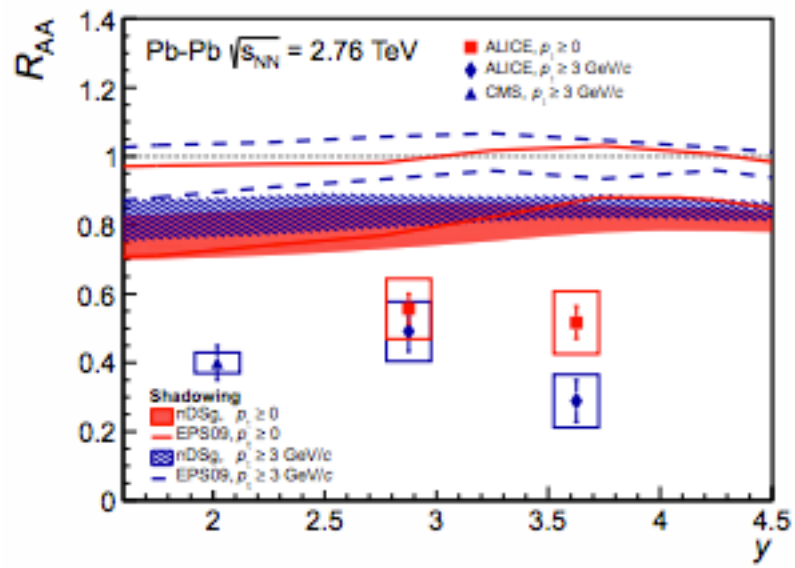


CMS PAS HIN-10-006

- Tracking efficiency:
- Tag: high quality muon
- Probe: track in the muon station
- Passing Probe:
  - Probe that is also reconstructed as global muon (i.e. with a track in the Si-tracker)
- Reconstruct J/ψ peak in passing probe-tag pairs and in failing probe-tag pairs
- Simultaneous fit to passing and failing probes allows us to measure the efficiency of the inner track reconstruction
- Agreement within stat. uncertainty of data → 14% systematic uncertainty on data/MC agreement
  - dominant systematic uncertainties on cross section results in PbPb

ALICE results





arXiv.1202.1383