Charmonia in pp and PbPb with CMS
(Prompt J/ψ's azimuthal anisotropy and updated ψ(2S) measurement)

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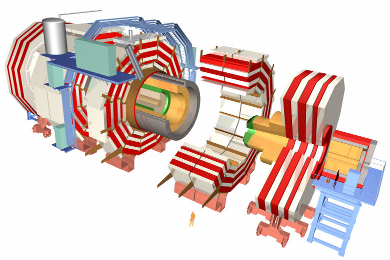
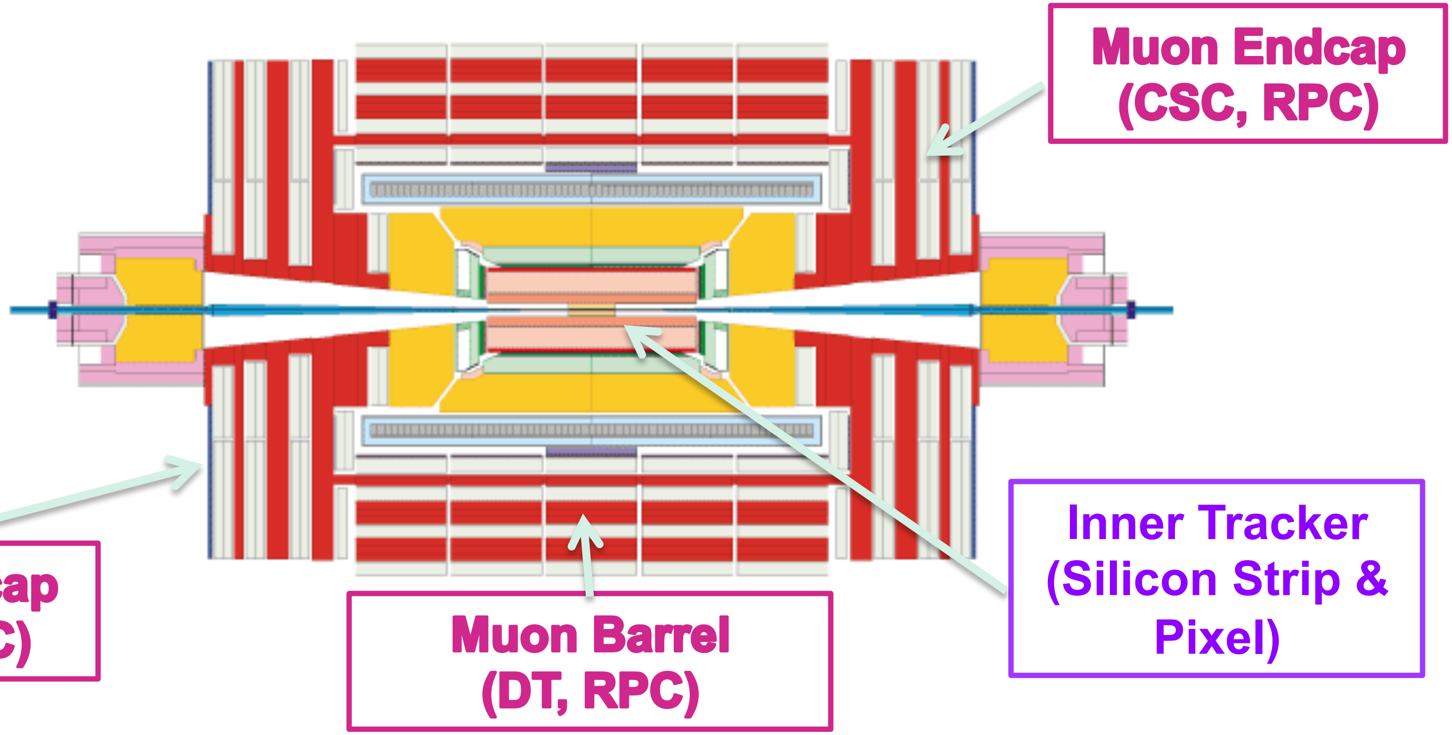
(University of Illinois at Chicago)
for the CMS Collaboration

Quark Matter conference, Darmstadt
20th May, 2014

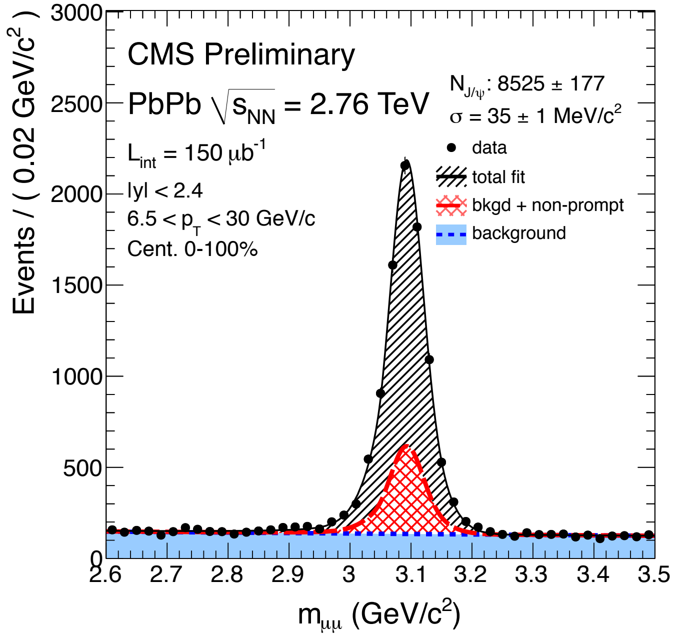
Muons in CMS

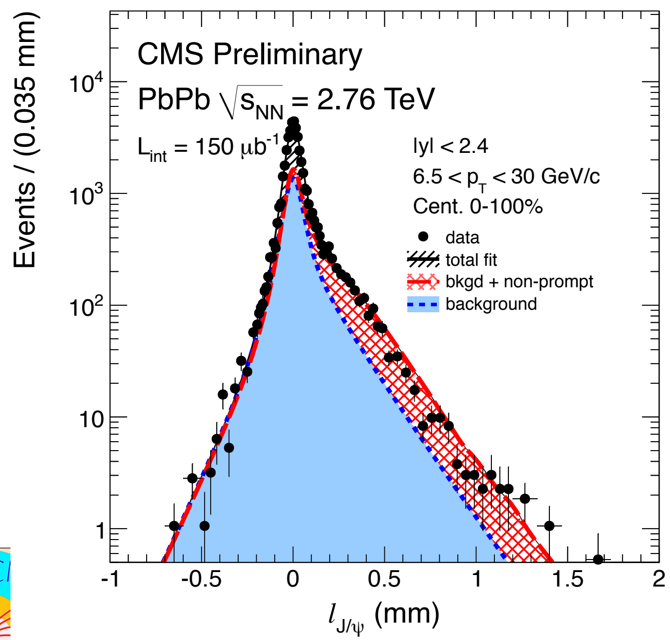




- Excellent Muon momentum resolution
  - Combination of muon detectors and inner silicon tracking (overall resolution up to p_T 100 GeV/c): 1-2%
- J/ψ acceptance
  - In PbPb: mid-y(p_T > 6.5 GeV/c) and forward y(p_T > 3 GeV/c)
  - In pp and pPb: goes down to 0 GeV/c of p_T in forward rapidity with softer muon ID cut

Prompt and non-prompt J/ψ separation





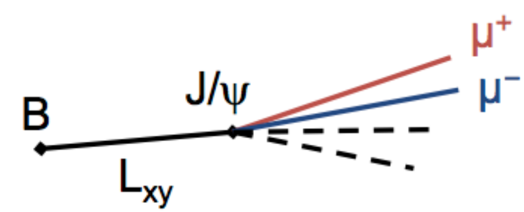
Inclusive J/ψ

Prompt J/ψ
- **Direct J/ψ**
- **Feed down from ψ(2S) and χ_c**

Non-Prompt J/ψ
- **Decayed from B**

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

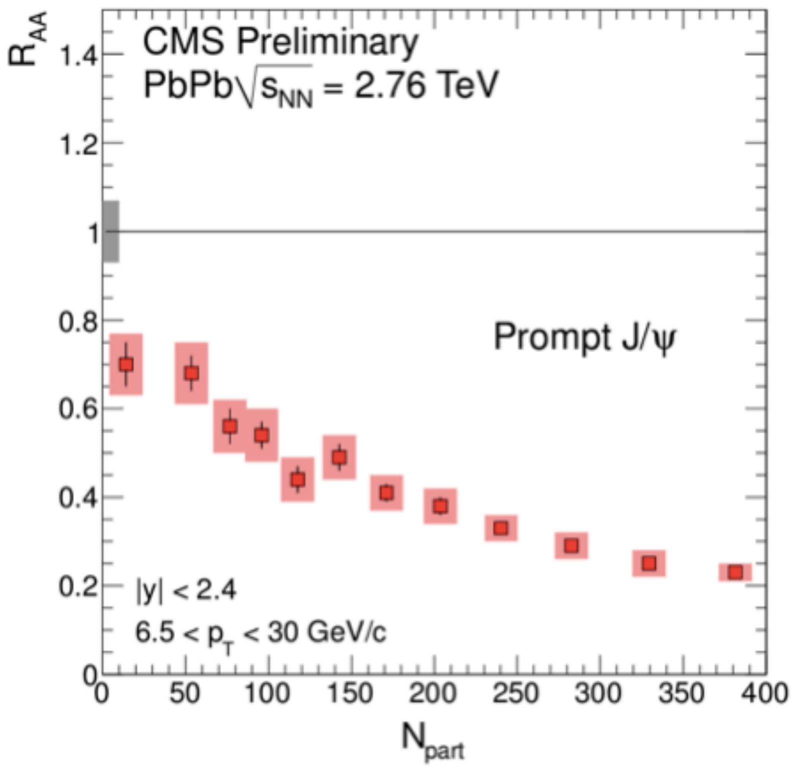
$$\ell_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$$



CMS-PAS-HIN-12-014

Prompt J/ψ in PbPb Collisions

Prior observation of significant suppression of prompt J/ψ



- Interest in improving our understanding
  - ➟ Sequential melting phenomena
  - ➟ Regeneration of thermalized c quarks
  - ➟ Path-length differential suppression

- Two measurements of prompt charmonia to help shed light
  - (1) Azimuthal anisotropy (elliptic flow) of J/ψ in PbPb
  - (2) New results of ψ(2S) in pp and PbPb

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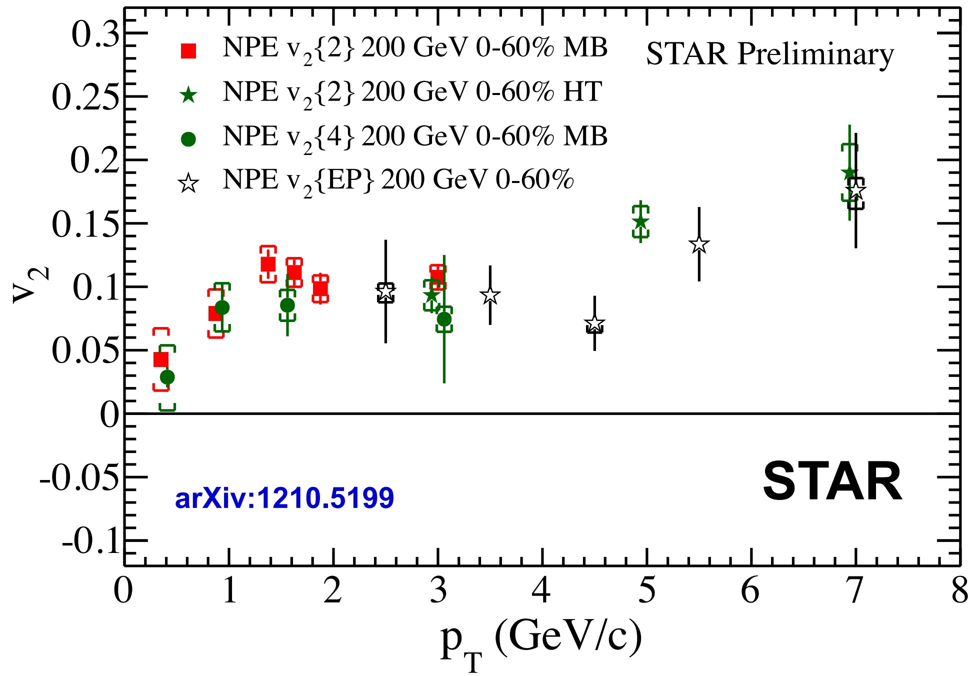
DARMSTADT 2014

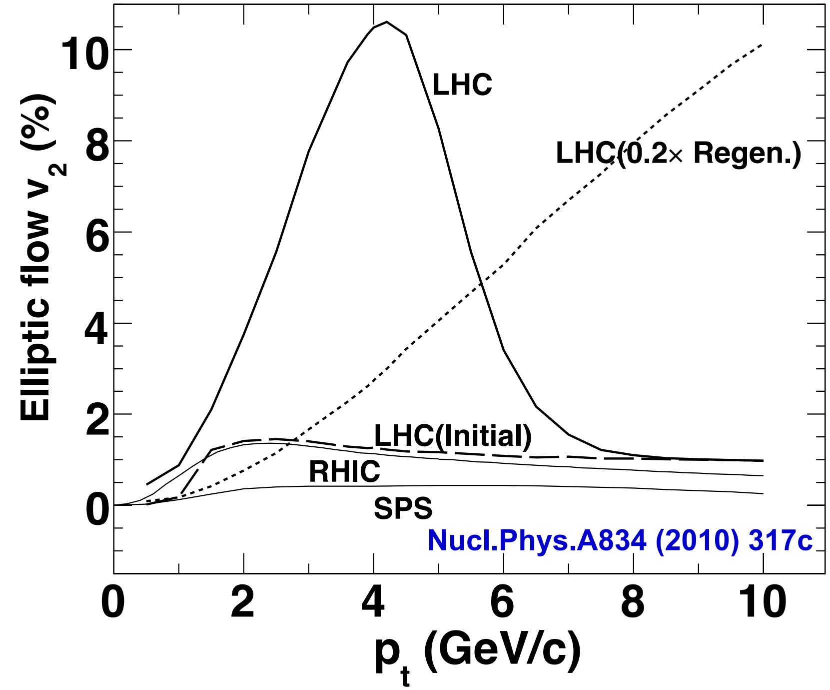
Azimuthal anisotropy of prompt J/ψ in PbPb collisions

NPE v_2 at RHIC and prediction of J/ψ v_2 at LHC

NPE (Non Photonic Electron) v_2

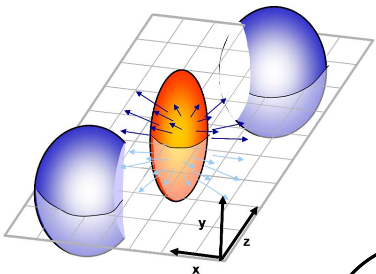


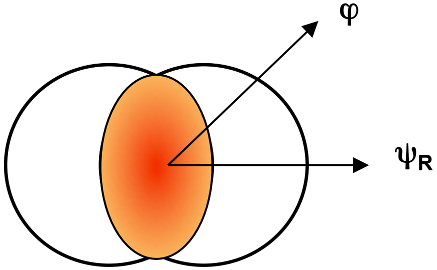
Prediction of elliptic flow of J/ψ



- Charm quarks flow as can be seen from the v_2. Strong indication of some form of thermalized charm
  - ➡ If there is (re)generation of J/ψ they should inherit this flow as well
  - ➡ In contrast to primordial J/ψ that survived the QGP phase, J/ψ v_2 should discriminate between (re)generated J/ψ and primordial J/ψ

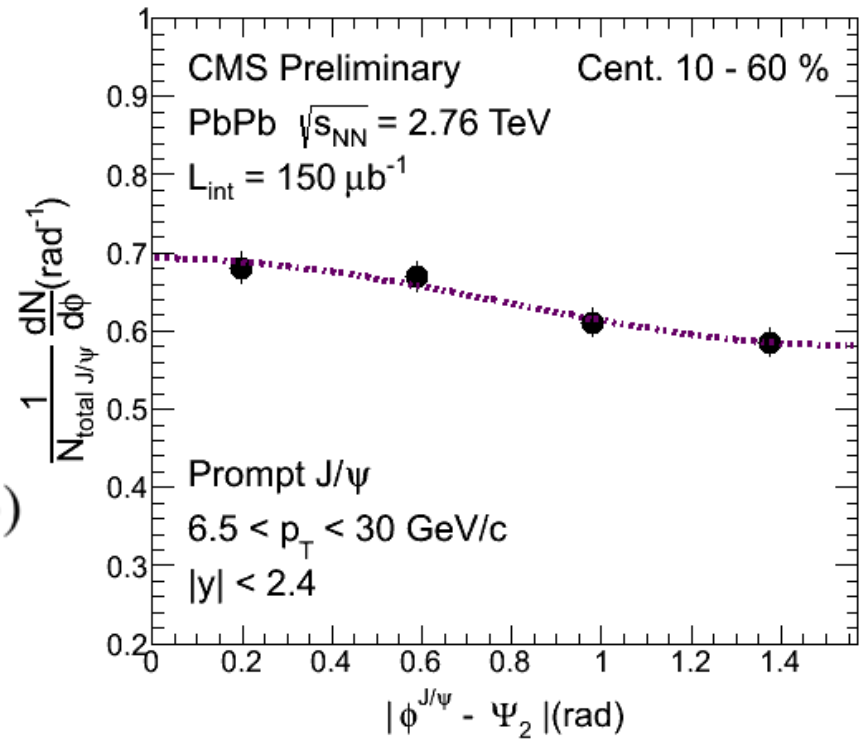
Prompt J/ψ Azimuthal Anisotropy in CMS





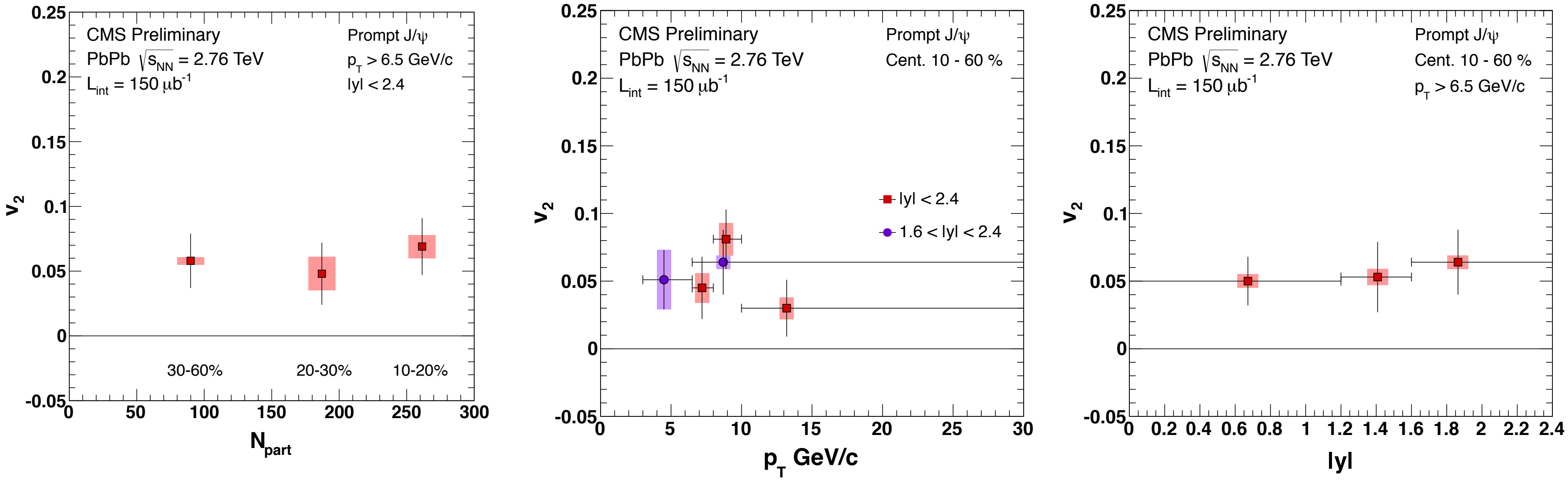
$$\frac{dN}{N_{total\ J/\psi}\, d\Delta\phi} = \frac{2}{\pi}\left(1 + 2v_2\cos(2\Delta\phi)\right)$$

CMS-PAS-HIN-12-001



- Integrated v_2 in p_T > 6.5 GeV/c
  - ➠ 0.054 ± 0.013 (stat.) ± 0.006 (syst.) in |y| < 2.4, 10-60 %
  - ➠ significant (3.8σ) v_2 at high-p_T prompt J/ψ

Prompt J/ψ Azimuthal Anisotropy in CMS

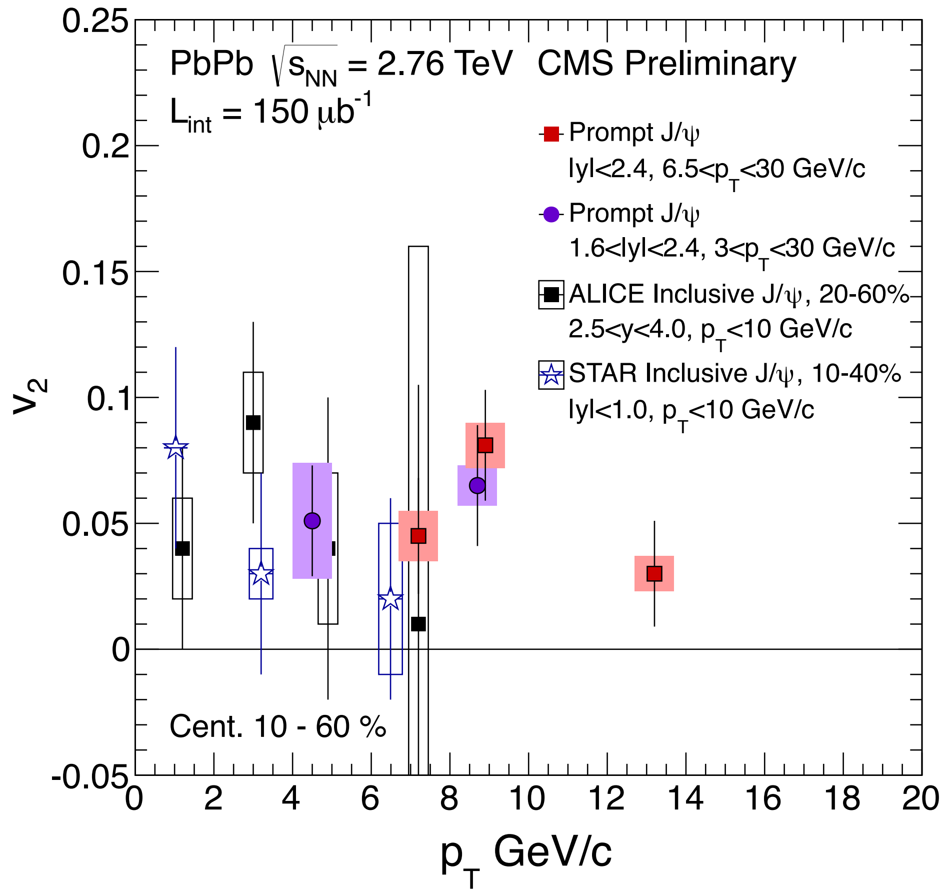


CMS-PAS-HIN-12-001

- Low p_T (3-6.5 GeV/c) measured in forward (1.6<|y|<2.4)
- No strong dependences on centrality, p_T, rapidity

Comparison to STAR/ALICE

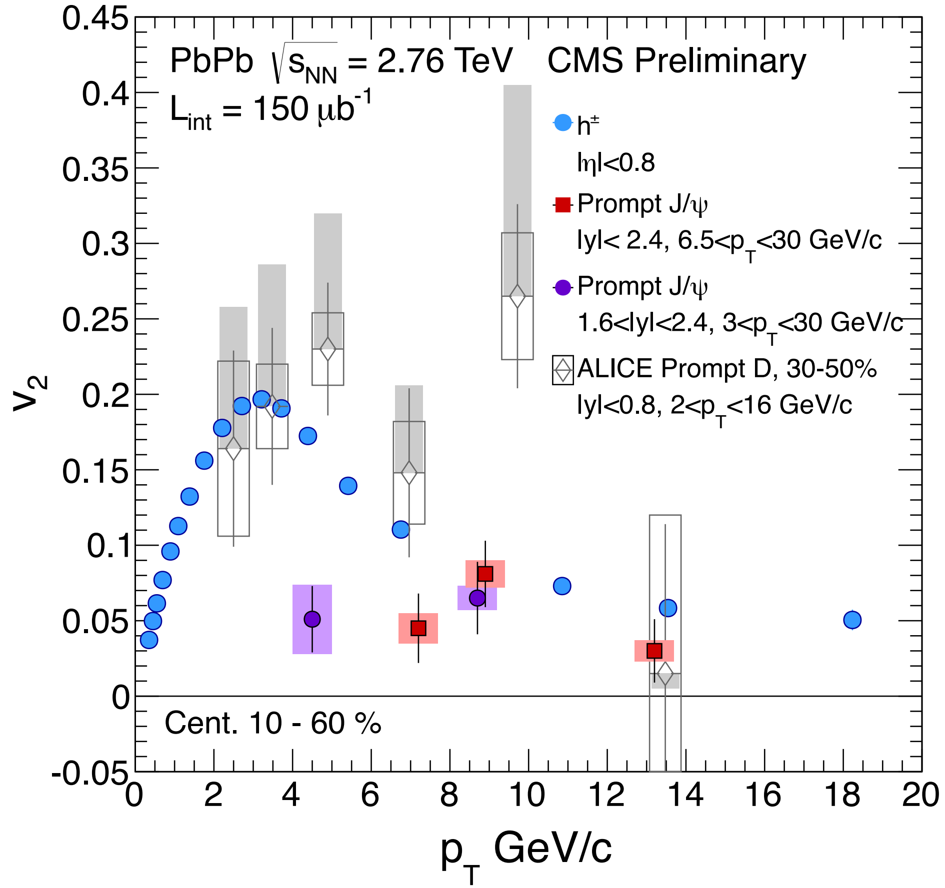
CMS-PAS-HIN-12-001, Phys. Rev. Lett. 111, 052301 (2013), Phys. Rev. Lett. 111, 162301 (2013)



Extended available measurement up to high p_T region(6.5 – 30 GeV/c) and observed non-zero v_2

Comparison to Charged Hadrons & D mesons

CMS-PAS-HIN-12-001, Rev. Lett. 109 (2012) 022301, Phys. Rev. Lett. 111 102301 (2013)



1) low p_T

v_2(light quark) ≈ v_2(open c) > v_2(closed c)

2) high p_T

v_2(light quark) ≈ v_2(open c) ≈ v_2(closed c) : pure path-length dependence ?

Updated ψ(2S) in pp & PbPb collisions

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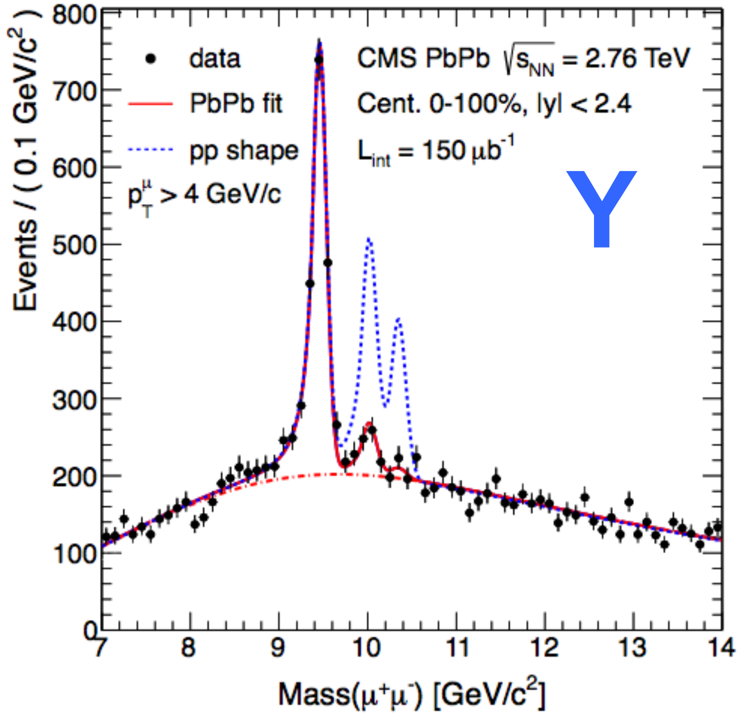
Excited Quarkonia States in PbPb

Observed stronger suppression of excited states than ground state in bottomnia measurement. What about charmonia ?

PRL 109 222301 (2012)



R_{AA} of Υ(1S)>Υ(2S)>Υ(3S)

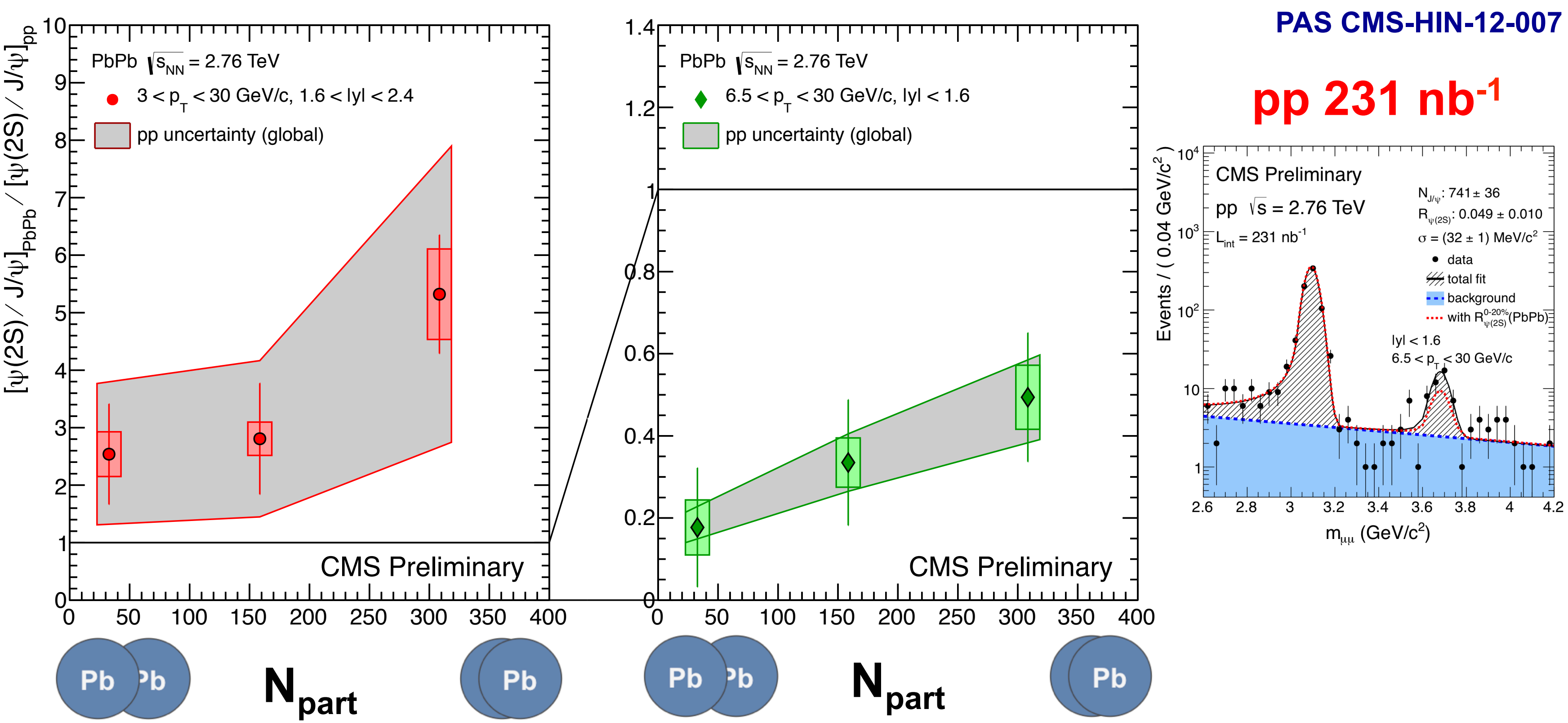
Charmonia ?

Expectations:

- CNM: R_{AA} of (J/ψ)>ψ(2S)
- Sequential melting: R_{AA} of (J/ψ)>ψ(2S)
- (Re)generation: R_{AA} of (J/ψ)>ψ(2S)

Bottomonia: Wed 09:40
Abdulla A. V. Kizhakkepura

Previous results of ψ(2S) Measurements



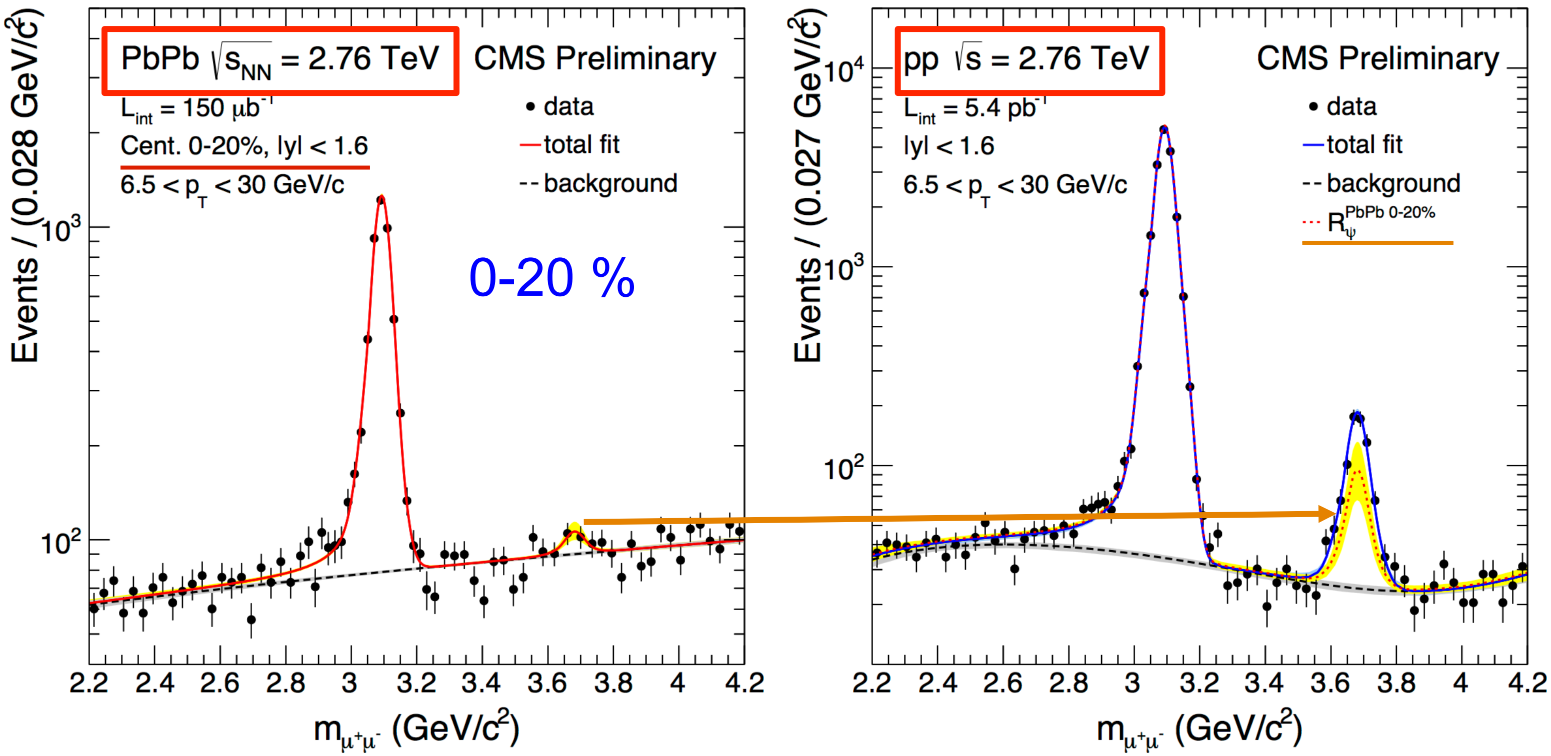
- Double ratio of inclusive ψ(2S) to J/ψ
- Stronger suppression of ψ(2S) than J/ψ in mid-rapidity and high p_T (as predicted from sequential melting)
- Hint of ψ(2S) enhancement relative to J/ψ in central PbPb at low p_T and forward rapidity, however, severely limited by large pp uncertainty

New ψ(2S) measurement in PbPb

- Thanks to pp run in 2013: ~ 20 times larger data sample
- Reject non-prompt contribution by cut on pseudo-proper decay length
- Keep 90% of prompt charmonia: cancels in double ratio
- Non-prompt contamination ~5%: included in systematic uncertainties

Prompt ψ(2S) in mid-rapidity (high p_T)

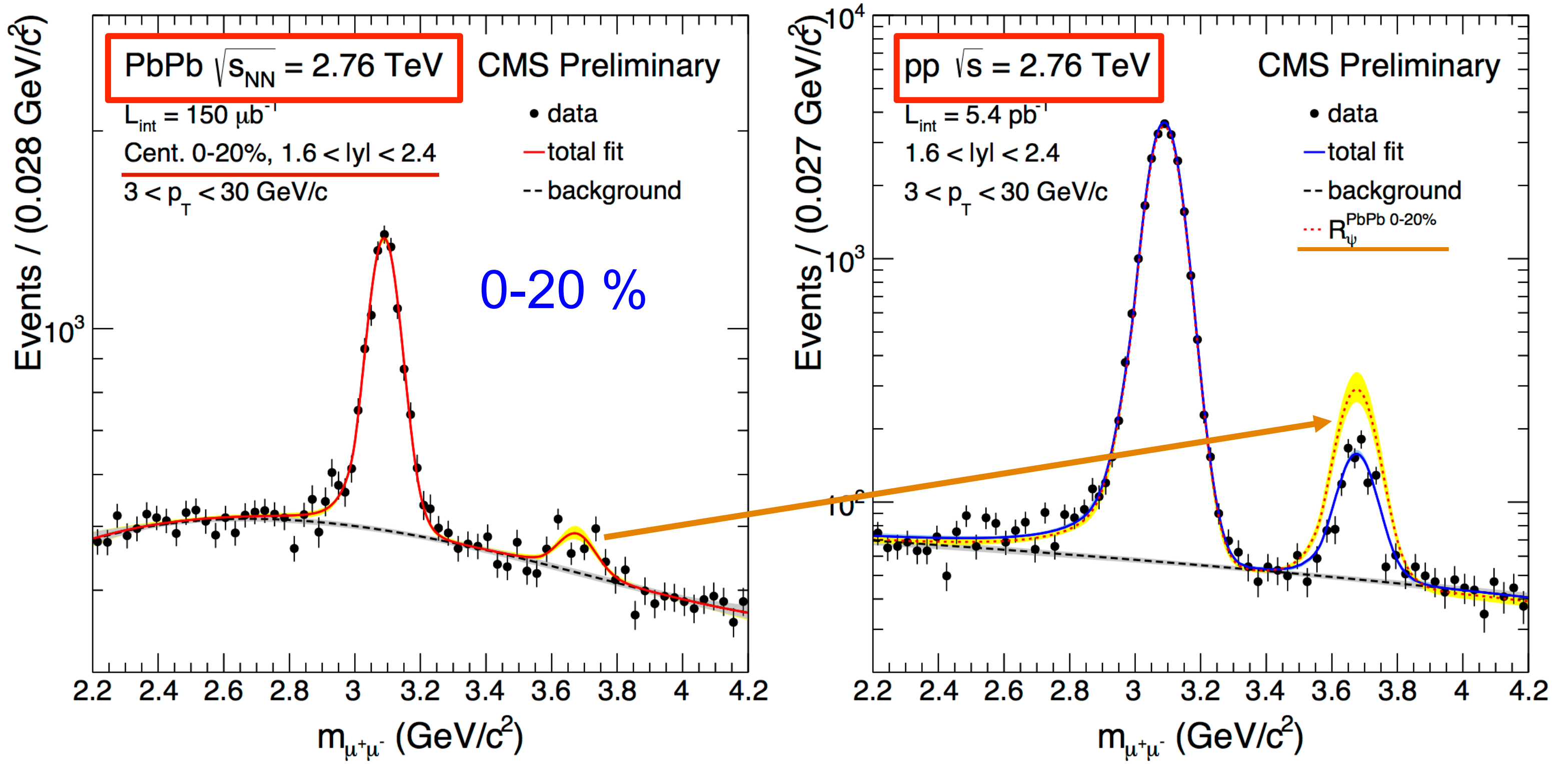
PAS CMS-HIN-12-007



- Thanks to pp run in 2013: ~ 20 times larger data sample
- Reject non-prompt contribution by cut on pseudo-proper decay length
- Keep 90% of prompt charmonia: cancels in double ratio
- Non-prompt contamination ~5%: included in systematic uncertainties
- In high p_T (mid-rapidity): ψ(2S) in PbPb is smaller than in pp with respect to the J/ψ as seen with 2010 pp data.

Prompt ψ(2S) in forward rapidity (low p_T)

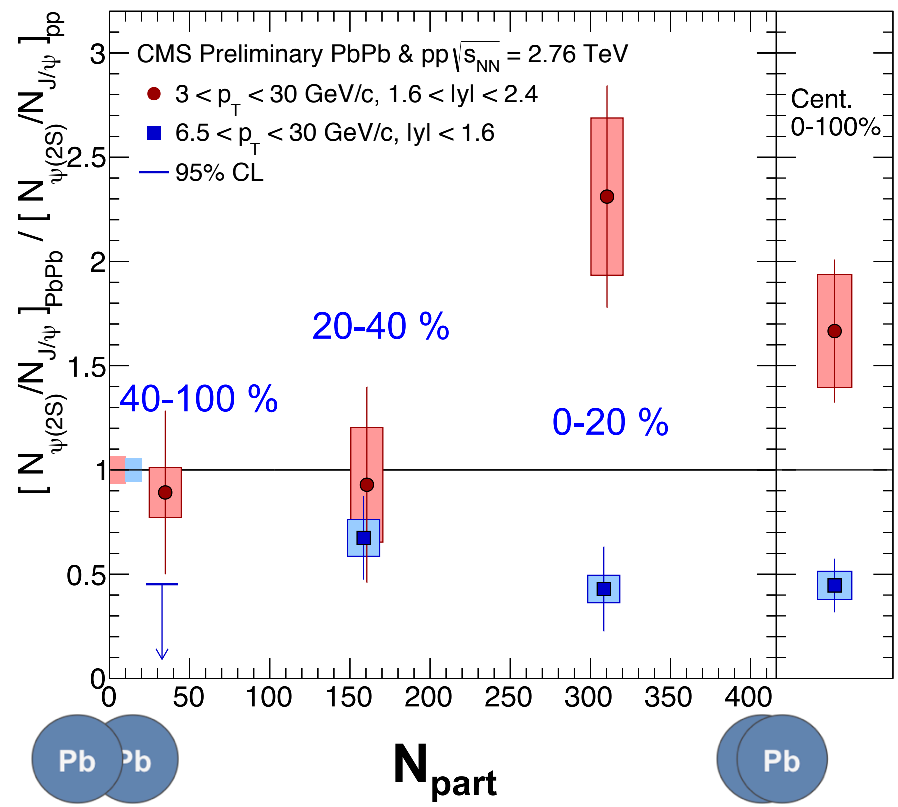
PAS CMS-HIN-12-007



- Thanks to pp run in 2013: ~ 20 times larger data sample
- Reject non-prompt contribution by cut on pseudo-proper decay length
- Keep 90% of prompt charmonia: cancels in double ratio
- Non-prompt contamination ~5%: included in systematic uncertainties
- In low p_T (forward-rapidity): ψ(2S) in PbPb is higher than in pp with respect to J/ψ as seen with 2010 pp data.

Double Ratio of Prompt ψ(2S)

PAS CMS-HIN-12-007



Double Ratio = Ratio of R_{AA}

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

- Observe a difference in ψ(2S) production for both central and minbias PbPb at high p_T (mid-rapidity) vs low p_T (forward-rapidity)
  - ➡ At high p_T and mid-rapidity ψ(2S) is more suppressed than J/ψ in PbPb collisions (as expected from sequential melting)
  - ➡ At low p_T and forward rapidity ψ(2S) is less suppressed than J/ψ at mid-rapidity and high p_T (contrary to expectations from sequential melting and/or regeneration)

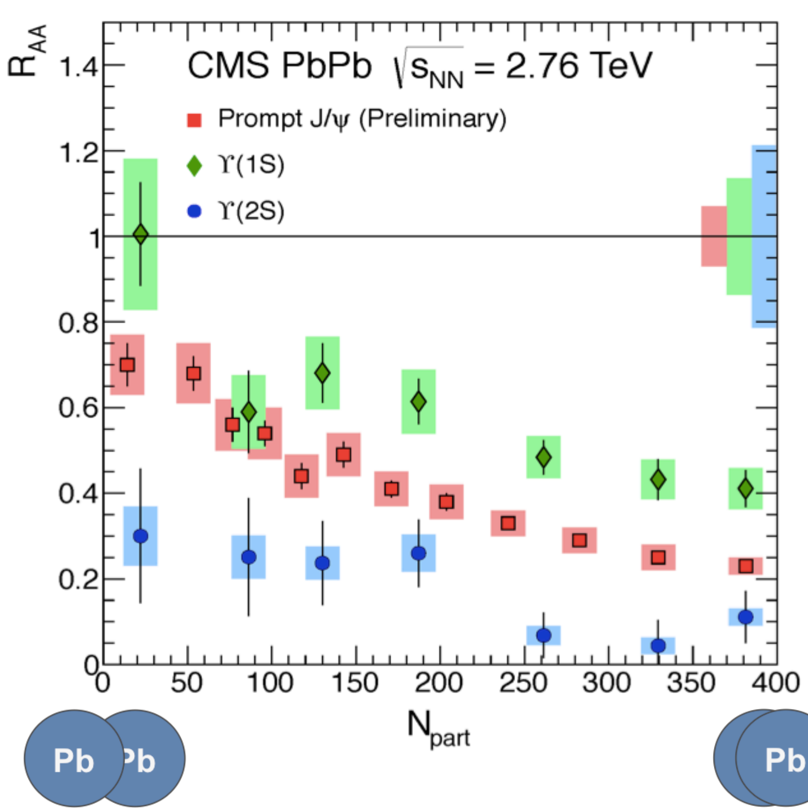
Summary

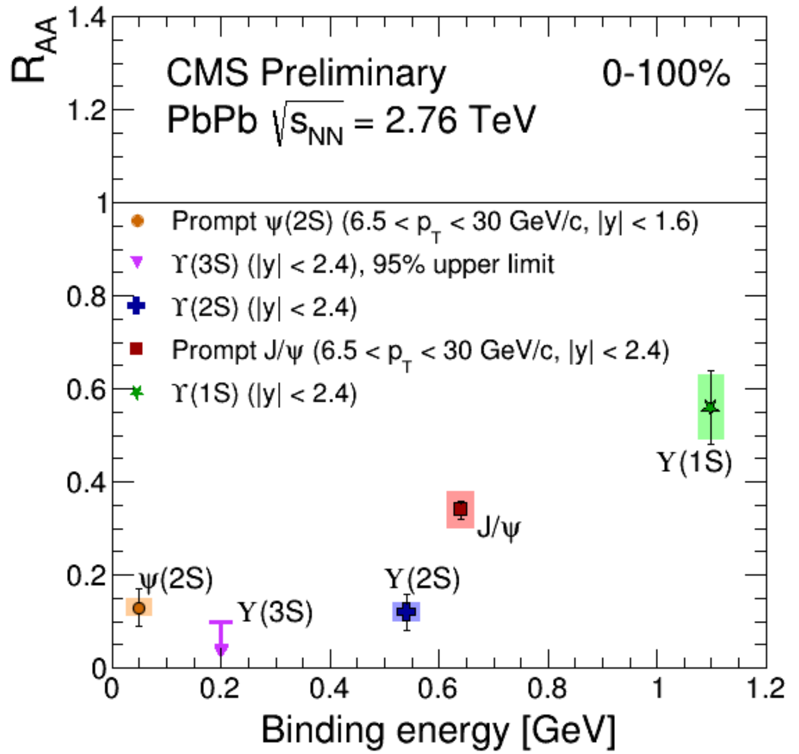
- Prompt J/ψ v_2 in PbPb
  - Integrated v_2 (10-60%, $|y| < 2.4$ and $6.5 < p_T < 30$ GeV/c)
    - 0.054 ± 0.013 (stat.) ± 0.006 (syst.) (3.8σ)
- Double ratio of ψ(2S)
  - Clear difference mid-rapidity (high p_T) and forward rapidity (low p_T)
    - Mid-rapidity (high p_T) : suppressed as predicted from sequential melting
    - Forward rapidity (low p_T) : opposite trend to the mid-rapidity (high p_T) results and also opposite to expectation from sequential melting or regeneration

Charmonia Poster: Tue 16:30
Songkyo Lee

Back up slide

Quarkonia Suppression in Hot Medium





CMS-PAS-HIN-12-014
PRL 109 (2012) 222301

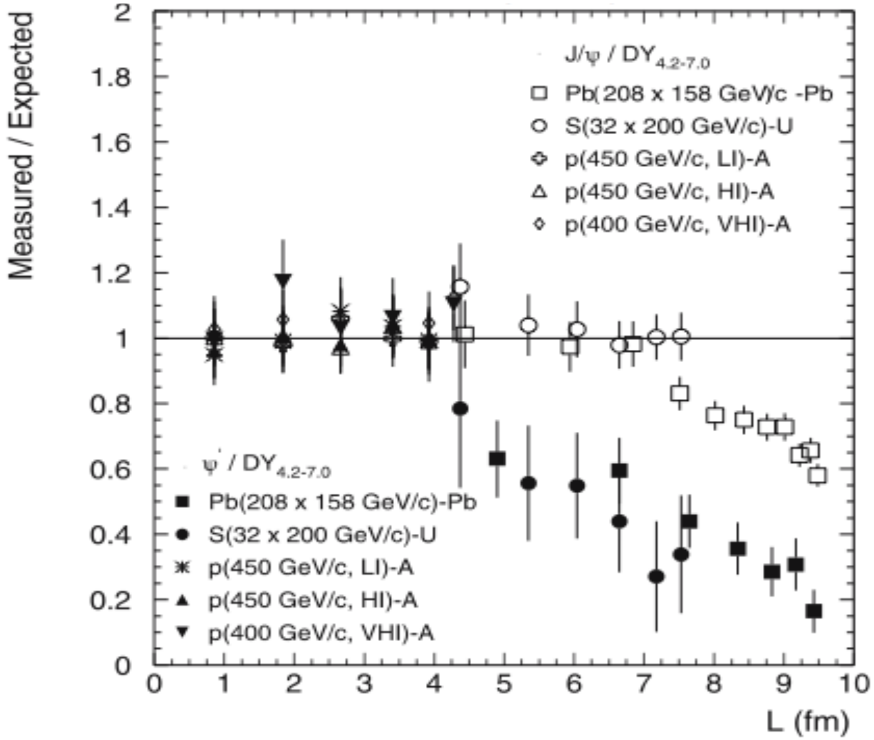
$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}}{N_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

Observed

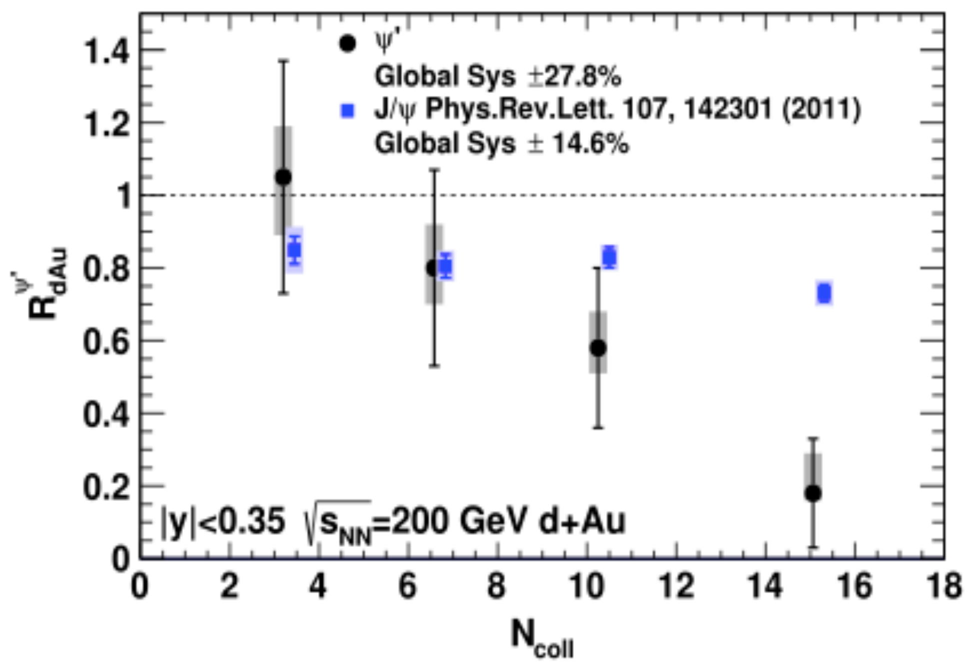
- **Significant suppression of J/ψ and ϒ (1S, 2S, 3S) at PbPb collisions**
- **Expected hierarchy in the suppression of the states with different binding energy**

ψ(2S) Measurements in PbPb

EPJ C 49 (2007) 559



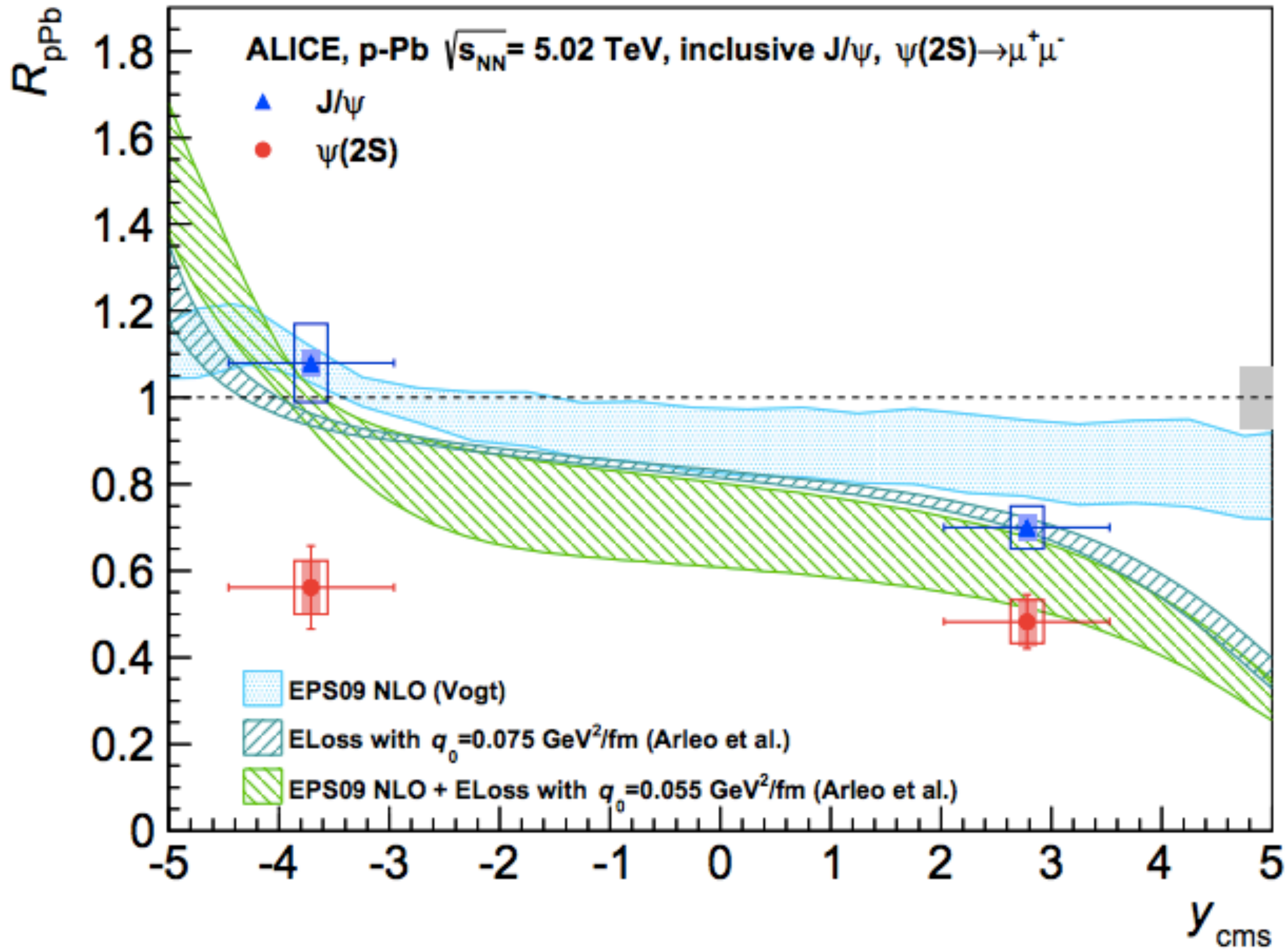
PRL 111 (2013) 202301



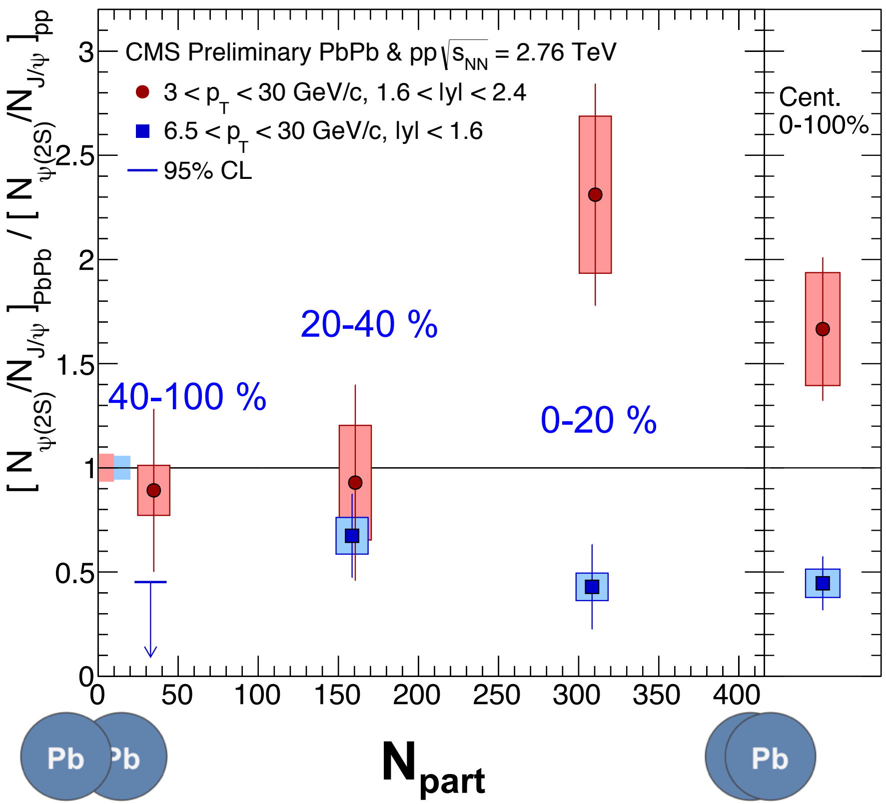
- NA50 (PbPb) : stronger suppression of ψ(2S) than J/ψ in central collisions
- Cold nuclear matter effect (dAu) : stronger suppression of ψ(2S) than J/ψ in central collisions
- (Re)generation : less generation of ψ(2S) than J/ψ (*X. Zhao and R. Rapp, Nucl. Phys.* ***A 859****(2011) 114*)

J/ψ and ψ(2S) in pPb at ALICE

arXiv:1405.3796



Double Ratio of Prompt ψ(2S)



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

PAS CMS-HIN-12-007

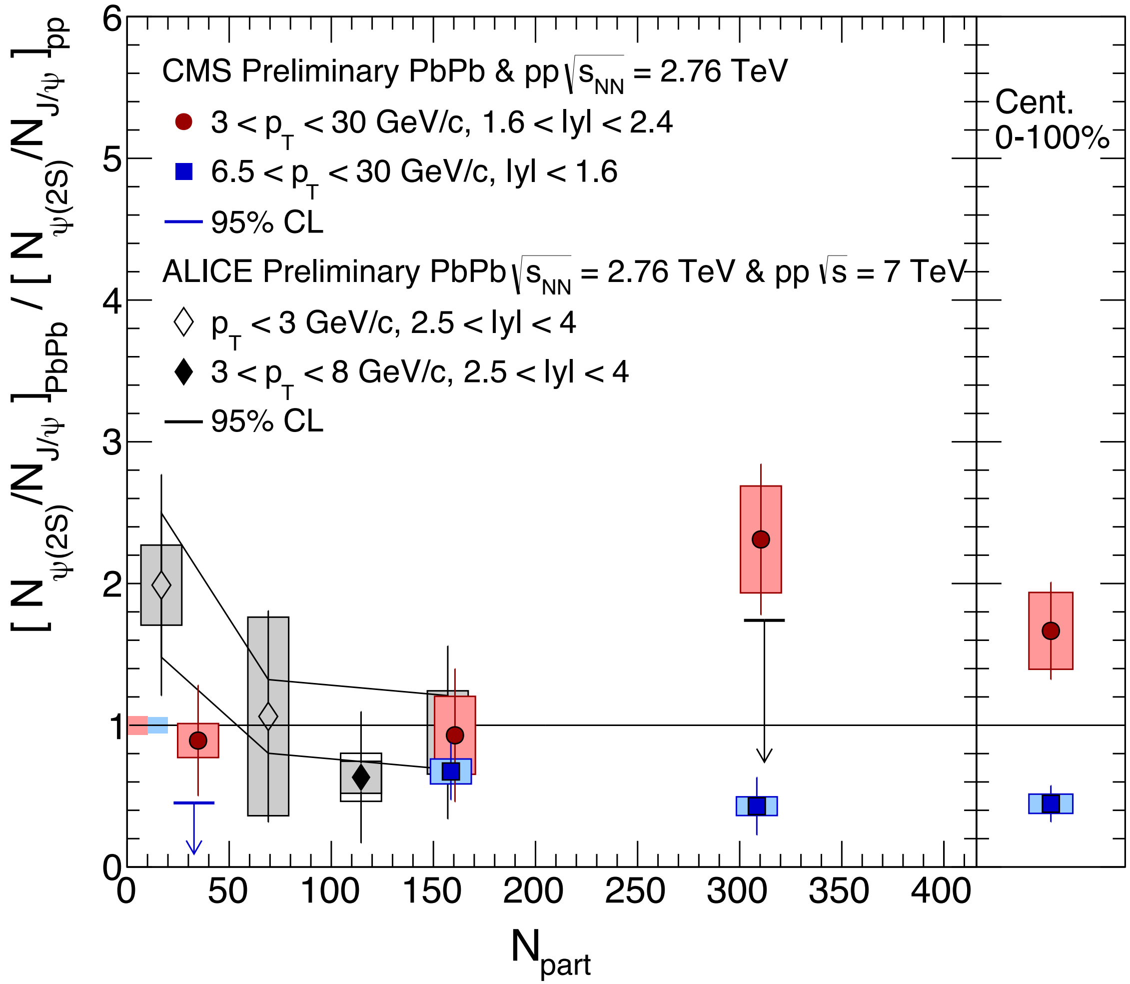
R_{AA} (mid-rapidity & high p_T):

- J/ψ 0.29 ± 0.03(stat.) ± 0.02(syst.) ± 0.02(pp) >
ψ(2S) 0.13 ± 0.04(stat.) ± 0.02(syst.) ± 0.01(pp)

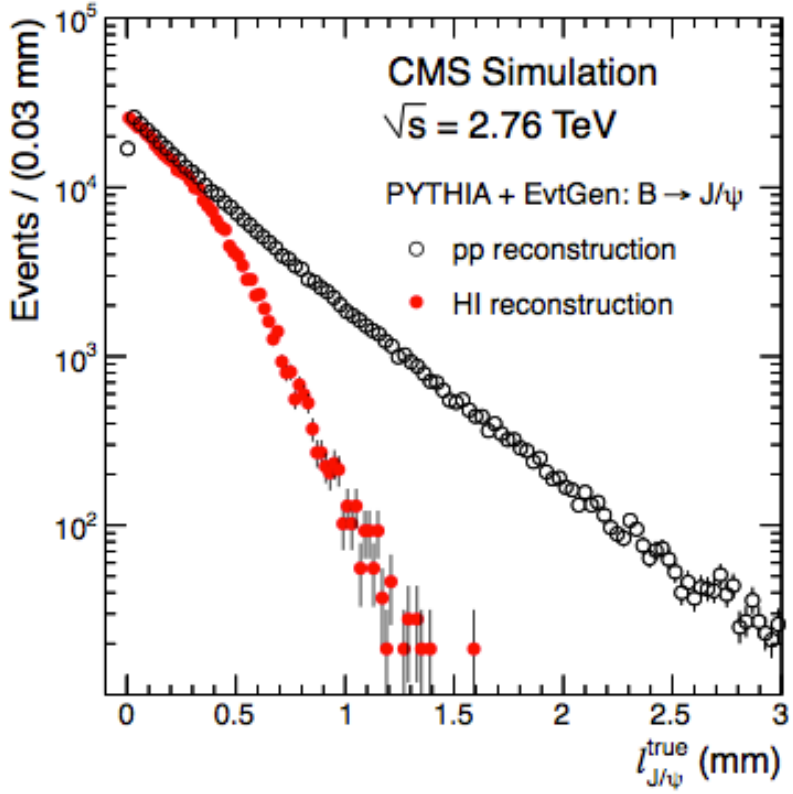
R_{AA} (forward rapidity & low p_T):

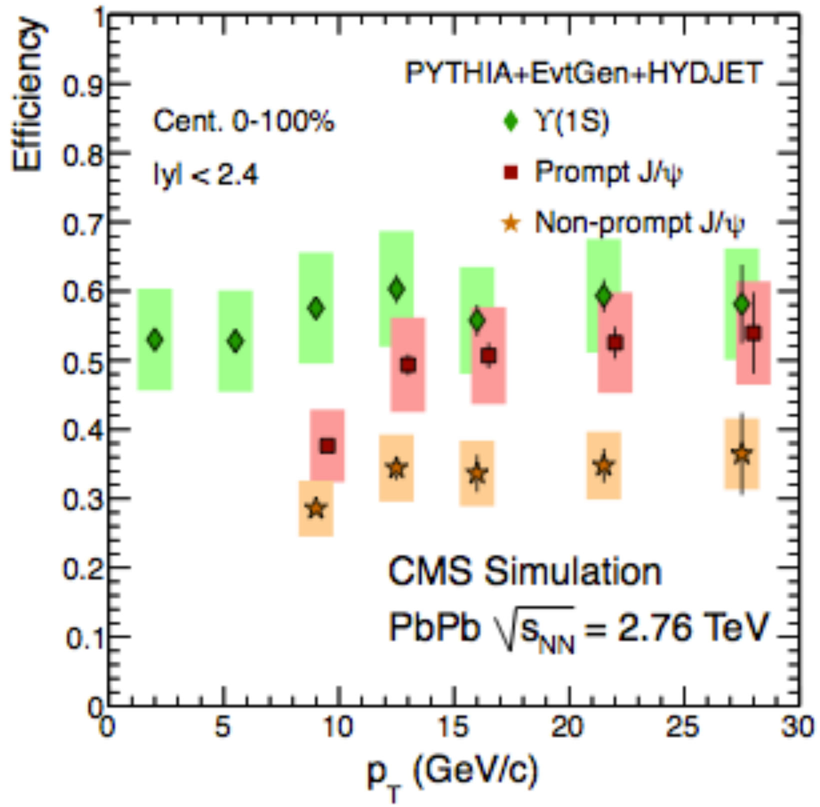
- J/ψ 0.40 ± 0.05(stat.) ± 0.02(syst.) ± 0.03(pp) <
ψ(2S) 0.67 ± 0.16(stat.) ± 0.11(syst.) ± 0.07(pp)

Double Ratio of Prompt ψ(2S) Comarison to ALICE

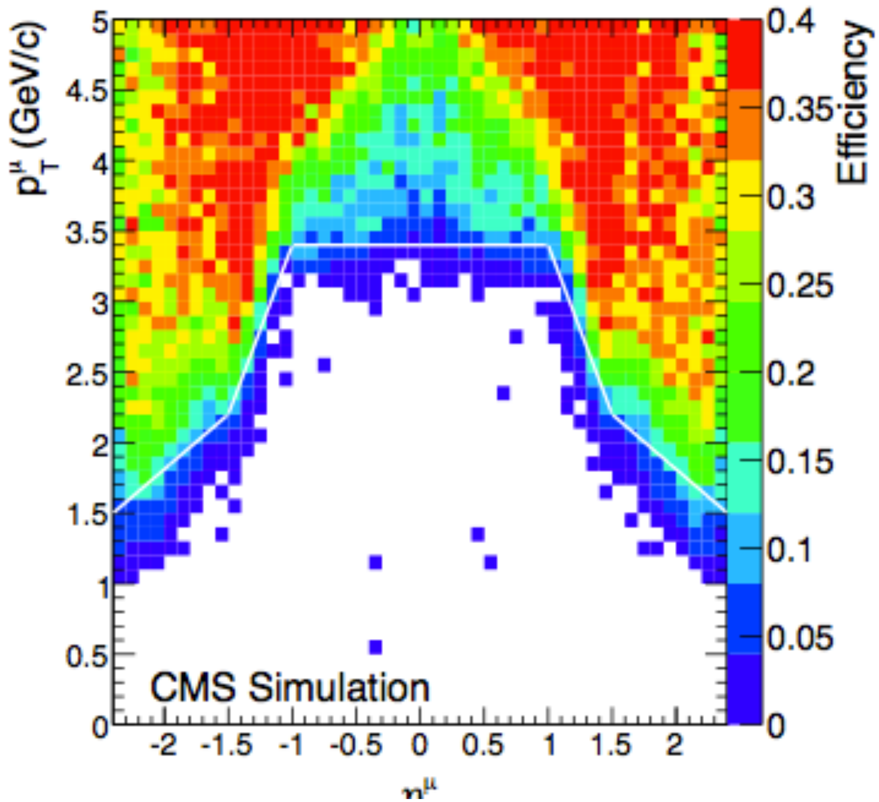


Reconstruction Efficiency



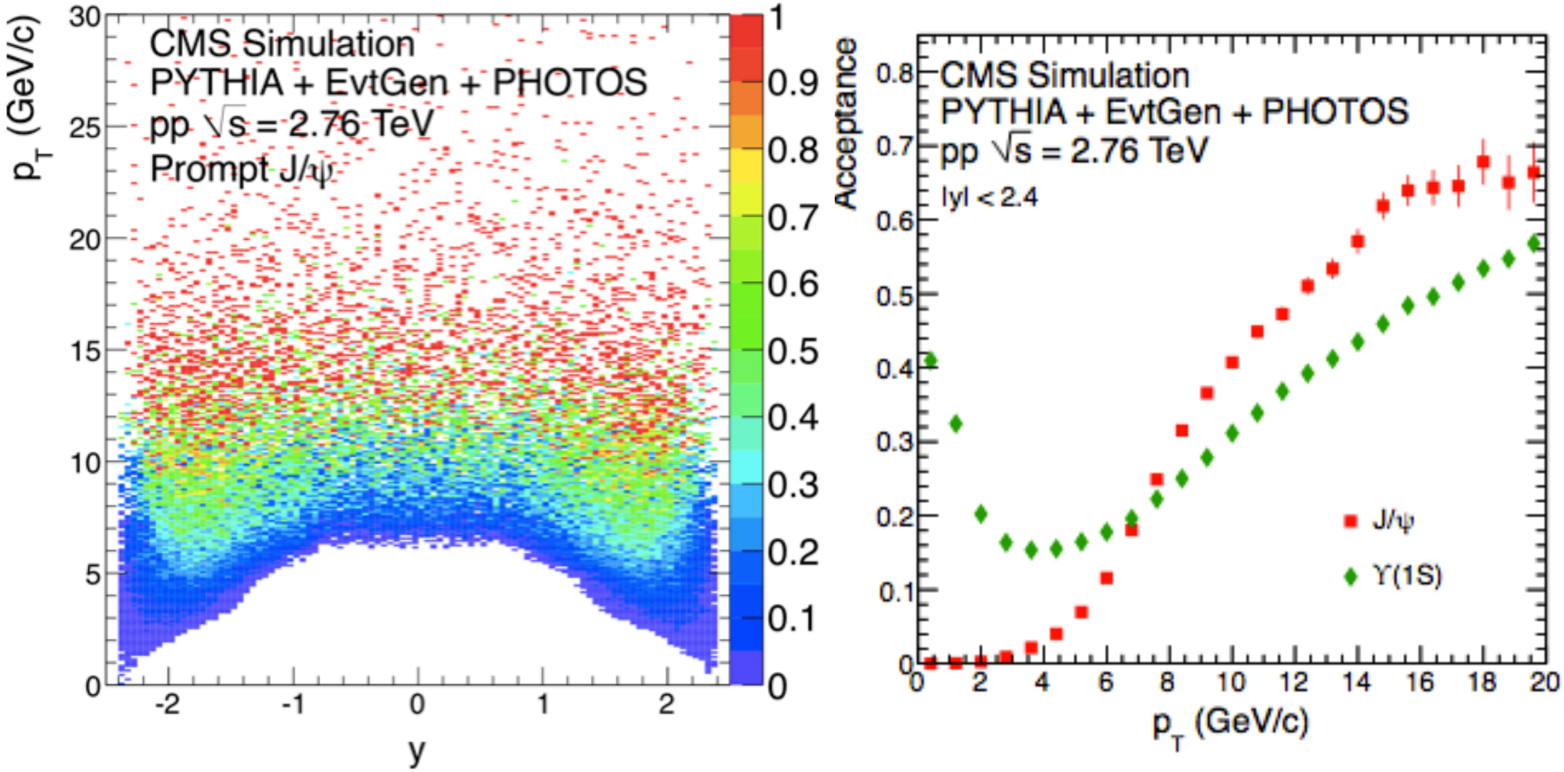


Single muon acceptance



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

Dimuon acceptance



psi(2S) Systematic Study

$\|y\|$	p_T [GeV/c]	Type	0–100%	0–20%	20–40%	40–100%
0–1.6	6.5–30	Fit	11%	12%	8%	92%
		Efficiency	1%	1%	1%	1%
		b contamination	10%	10%	10%	10%
		Systematic	15%	15%	13%	92%
		Statistical	28%	47%	30%	200%
1.6–2.4	3–30	Fit	13%	14%	28%	10%
		Efficiency	5%	5%	5%	5%
		b contamination	8%	8%	8%	8%
		Systematic	16%	16%	30%	14%
		Statistical	20%	23%	50%	44%

J/ψ v_2 Systematic Study

	Relative systematic uncertainties variations (%)
Yield extraction	1 – 20
Efficiency corrections	0 – 42
Event plane	3.5
Total	12 – 46