Charmonium production in heavy-ion collisions with CMS

Magdalena Malek (KU)
On behalf of the CMS Collaboration

Quarkonium 2014 @ CERN

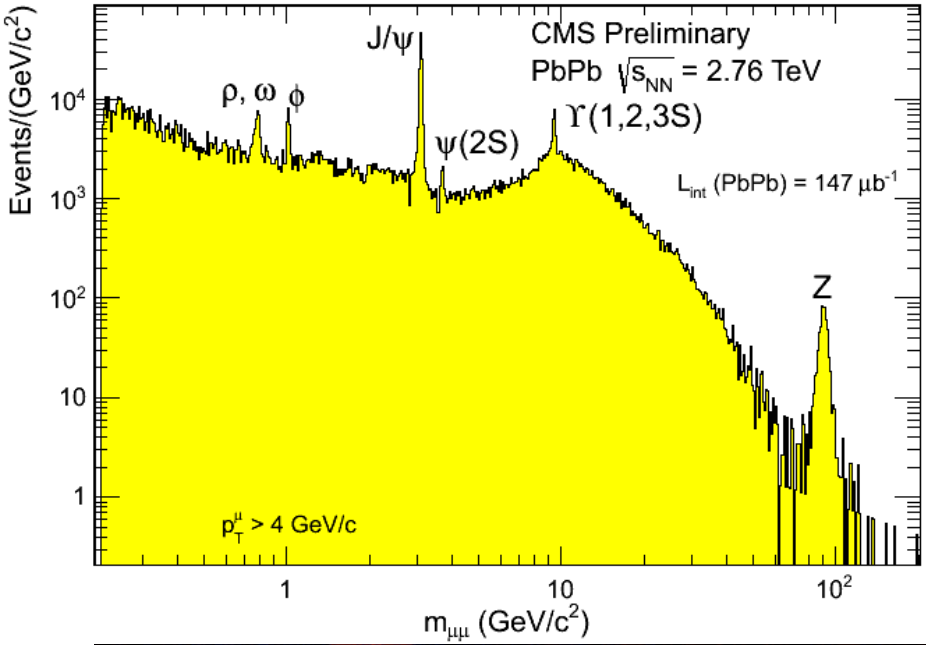
Outline

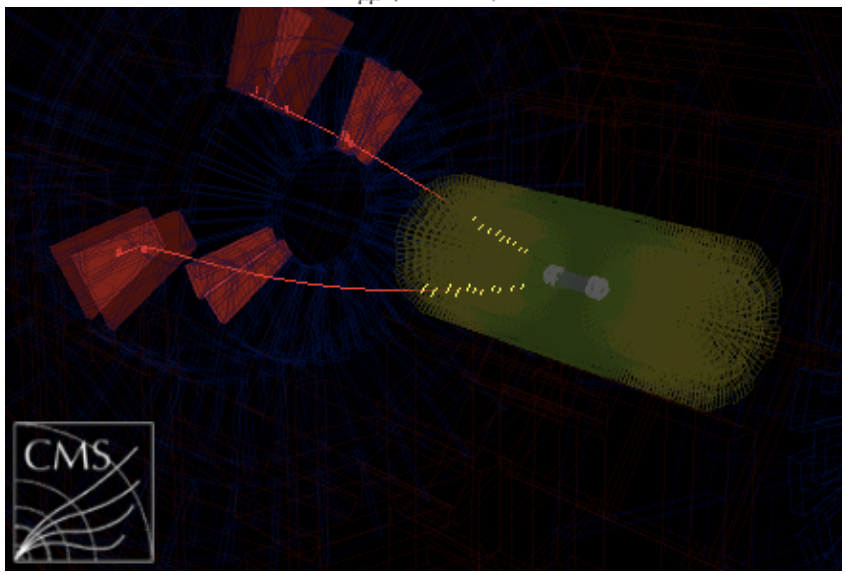
- Charmonium in hadronic collisions: J/ψ, ψ(2s)
- Physics motivation
- R_{AA}, v_2, double ratio

- Charmonium in UPC collisions
- UPC physics
- Coherent J/ψ with nuclear breakup
- Breakup modes

NEW

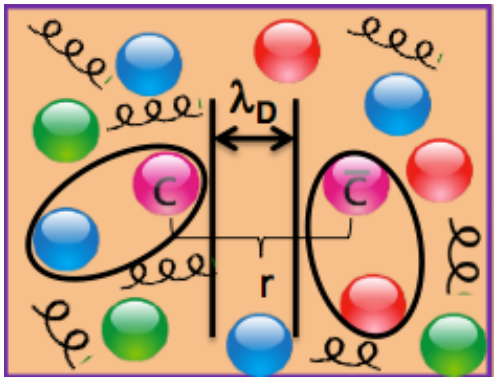
- Conclusions

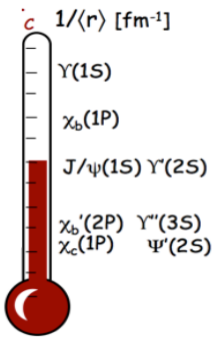




Why charmonium in PbPb collisions

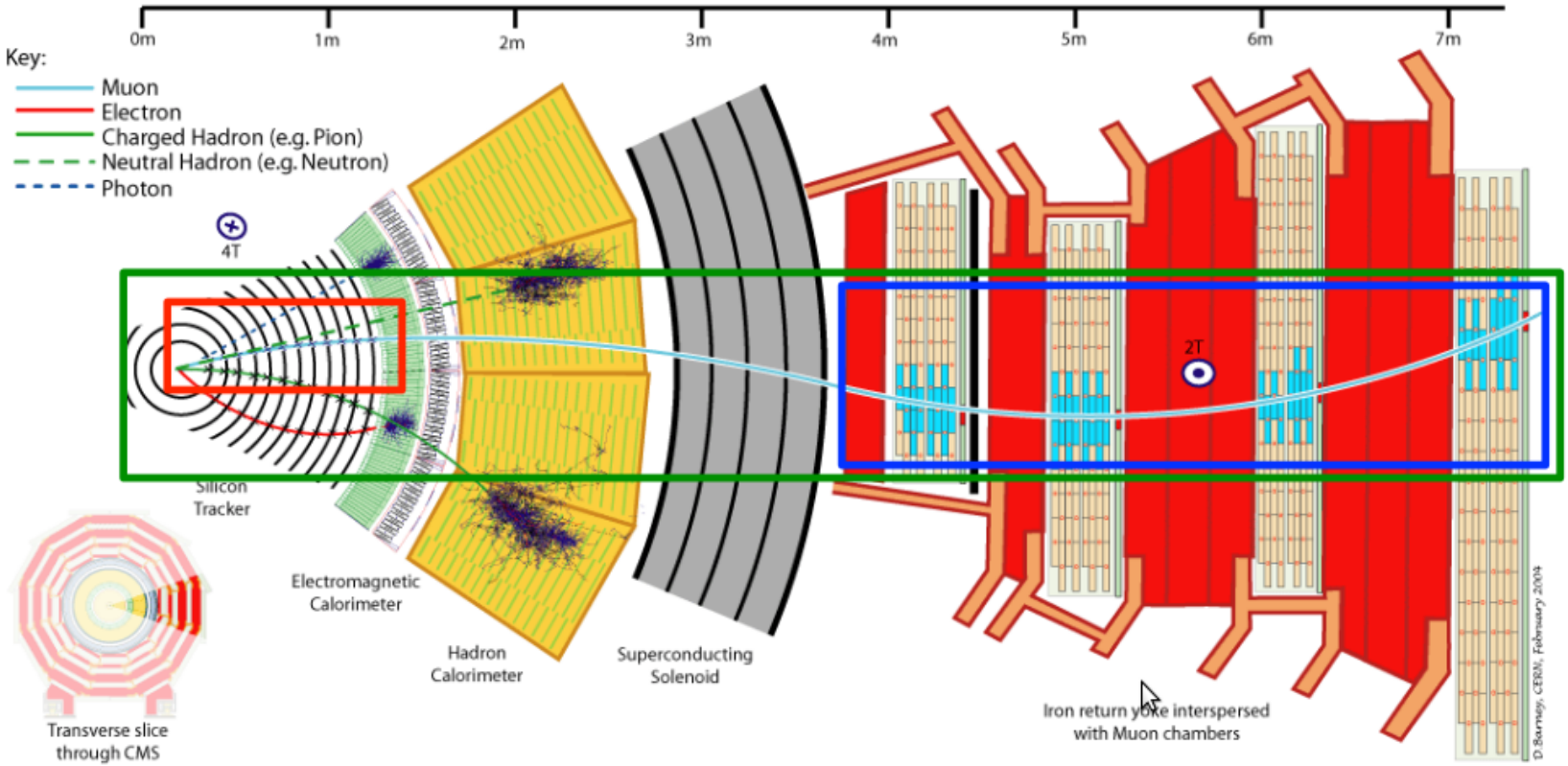
- Study the deconfined state of the matter QGP
- In 1986, J/ψ was proposed as an "unambiguous" signature of QGP
  - produced early in the collision
  - color screening of static potential between heavy quarks
  - quarkonia sequential melting above certain temperature threshold





- Enhancement of quarkonia: large heavy-quark multiplicity at LHC
- Cold nuclear matter effects

CMS detector



- Muon reconstruction: silicon tracker + muon subdetectors
- Tracker p_T resolution: 1-2% up to p_T ~ 100 GeV/c
- Measurement of J/ψ down to p_T ~ 0 GeV/c in the forward y

J/ψ acceptance

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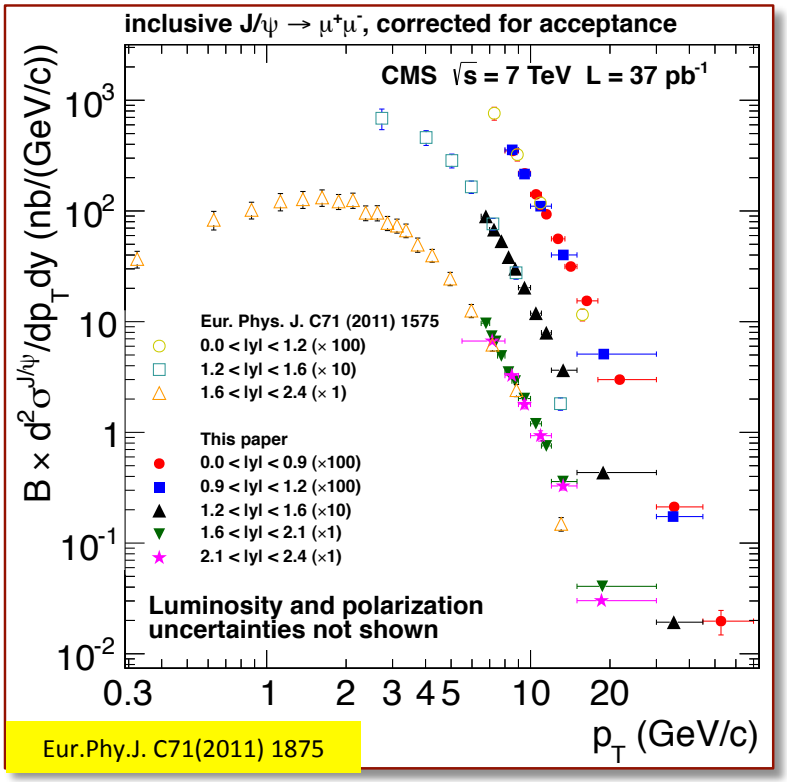
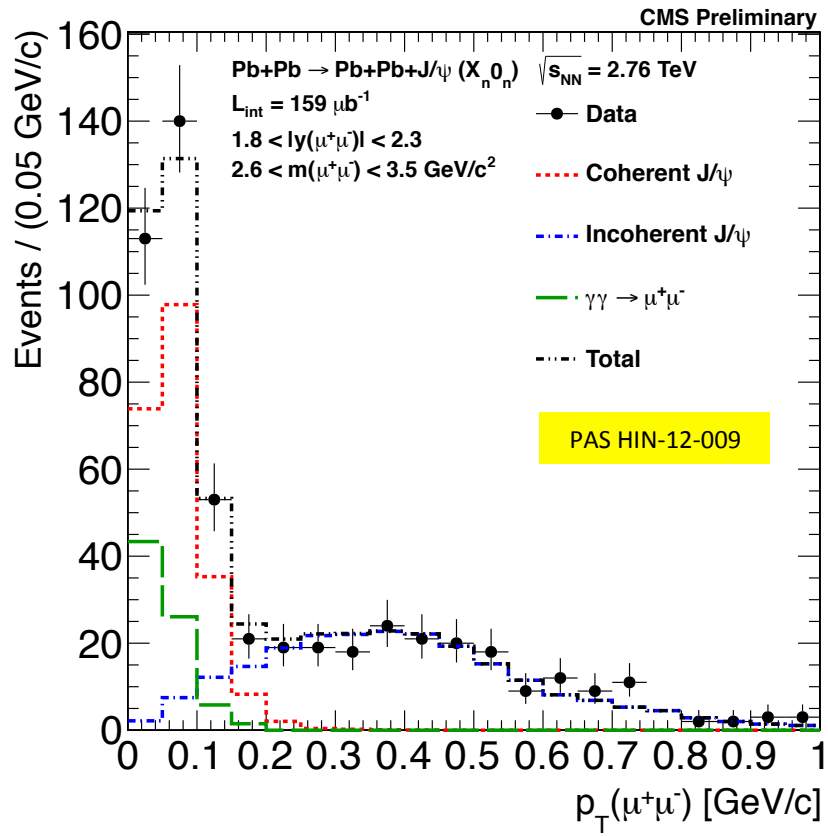
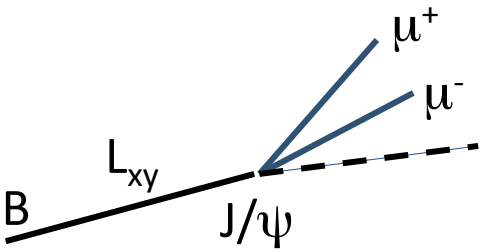




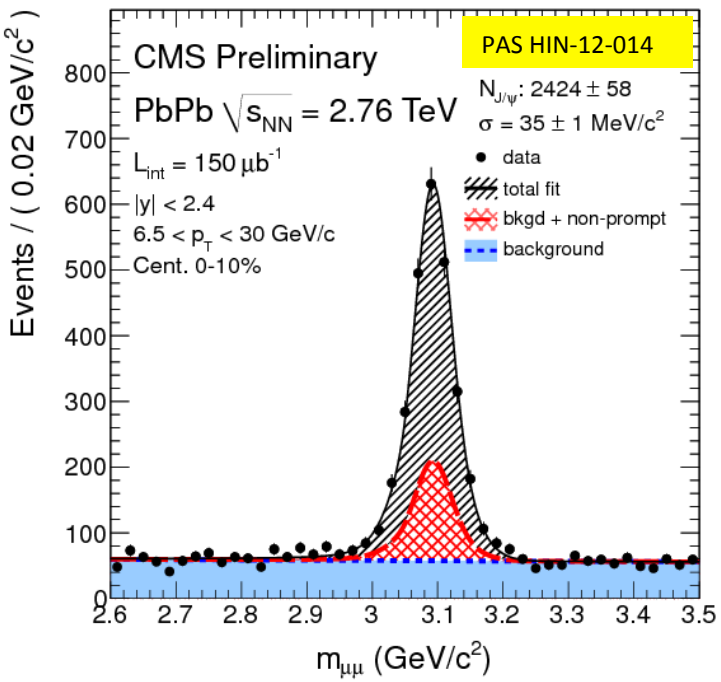
- pp : J/ψ $p_T > 0$ GeV/c for $1.6 < |y| < 2.4$
- PbPb: J/ψ $p_T > 3$ GeV/c for $1.6 < |y| < 2.4$
- UPC PbPb: J/ψ $p_T > 0$ GeV/c for $1.8 < |y| < 2.3$

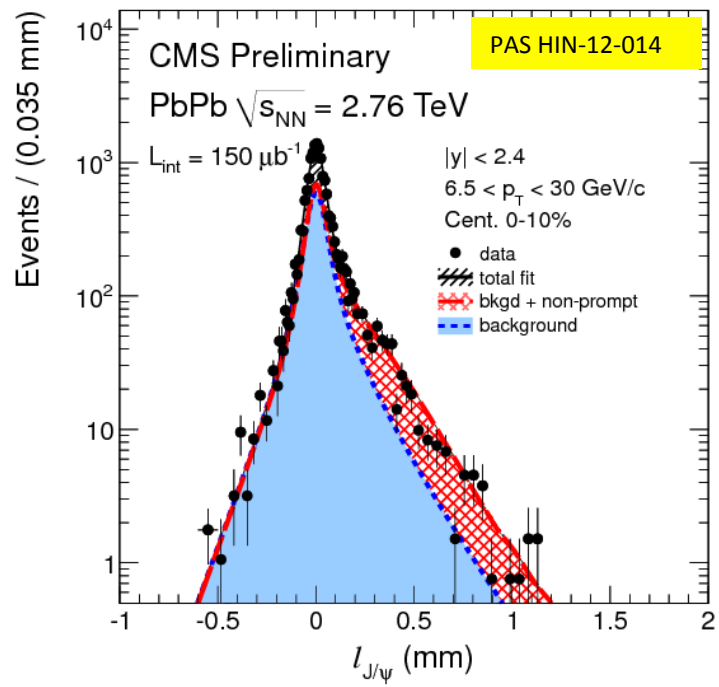
J/ψ separation

- Inclusive J/ψ
  - prompt J/ψ (direct and from ψ(2s) and χ_c decay)
  - non-prompt J/ψ from B decays

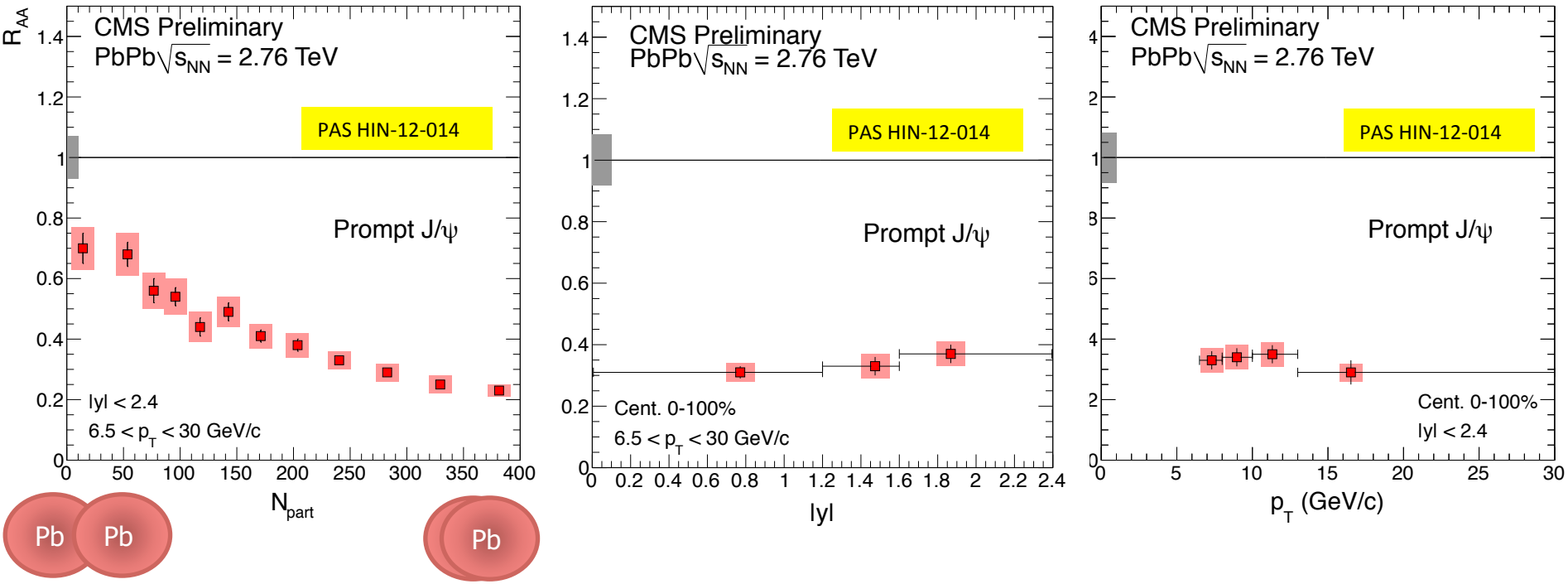


$$\ell_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$$



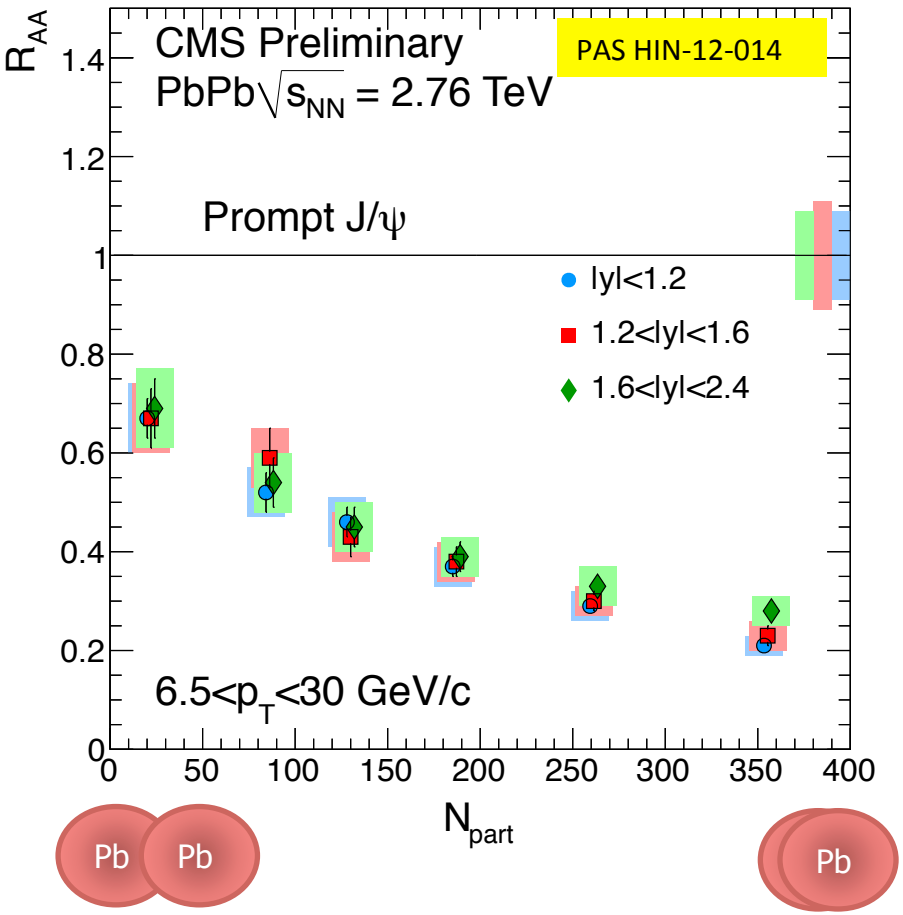


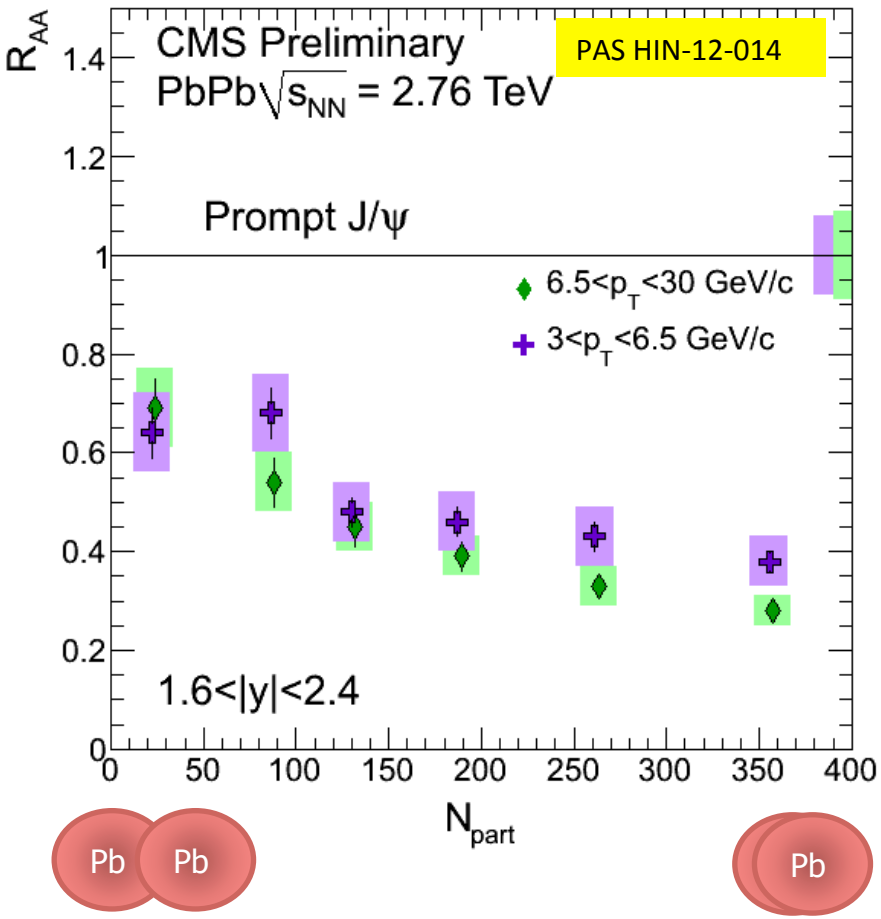
R_{AA} of prompt J/ψ



- R_{AA} vs centrality
  - for 0-5% suppression factor of ~5; R_{AA} = 0.20 ± 0.03 (stat) ± 0.01 (syst)
  - for 60-100% suppression factor of ~1.4
- No significant p_T and rapidity dependence

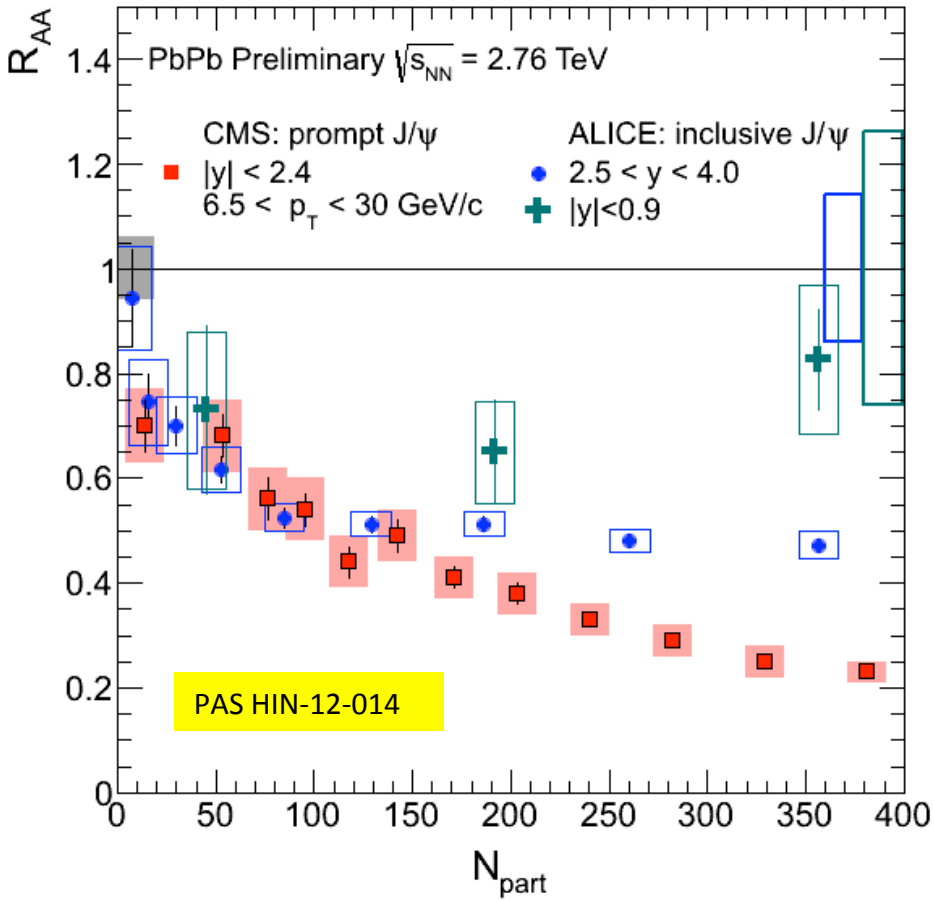
R_{AA} of prompt J/ψ





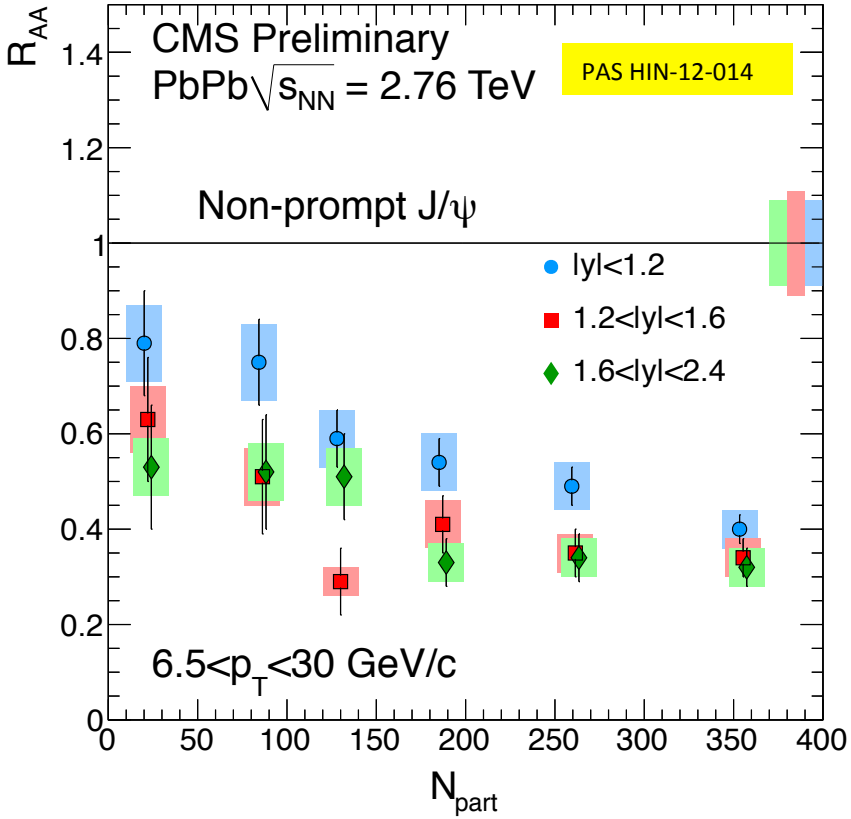
- No rapidity dependence for J/ψ with $6.5 < p_T < 30$ GeV/c
- J/ψ with $3 < p_T < 6.5$ GeV/c slightly less suppressed than J/ψ with $6.5 < p_T < 30$ GeV/c

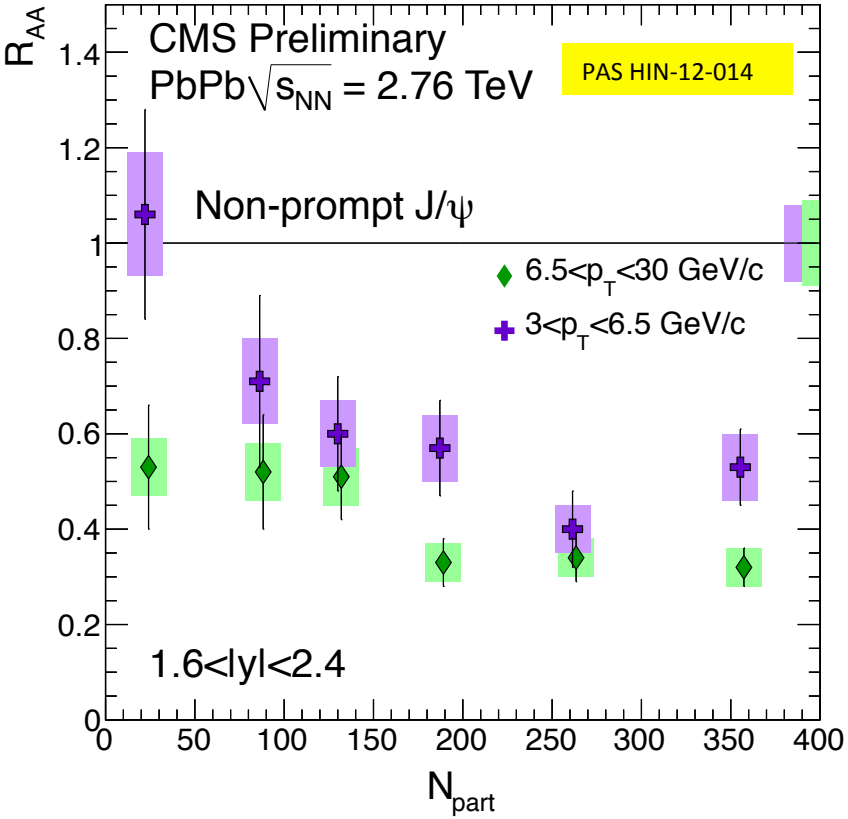
R_{AA} of prompt J/ψ: CMS vs. ALICE



- More suppression seen for high p_T J/ψ (CMS) compared to low p_T J/ψ (ALICE)
- Sign of (re)generation for low p_T J/ψ?

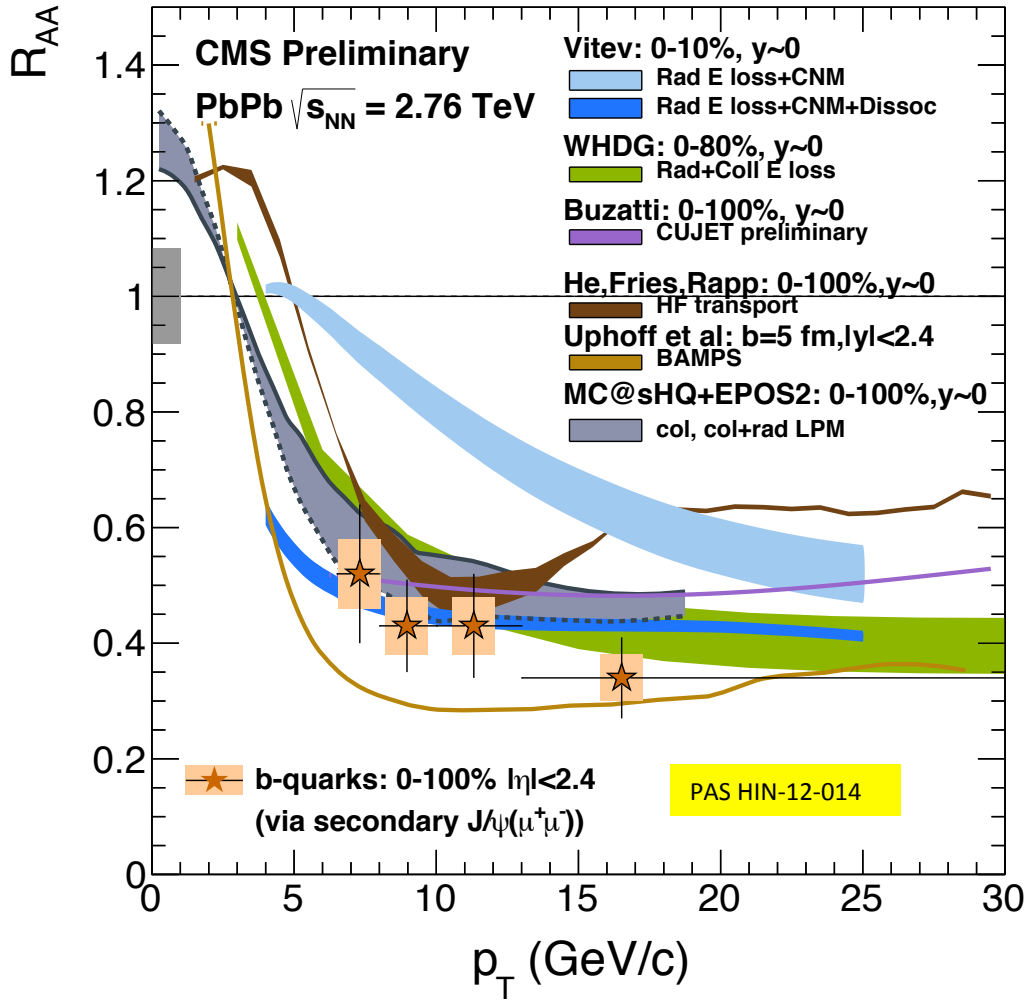
R_{AA} of non-prompt J/ψ



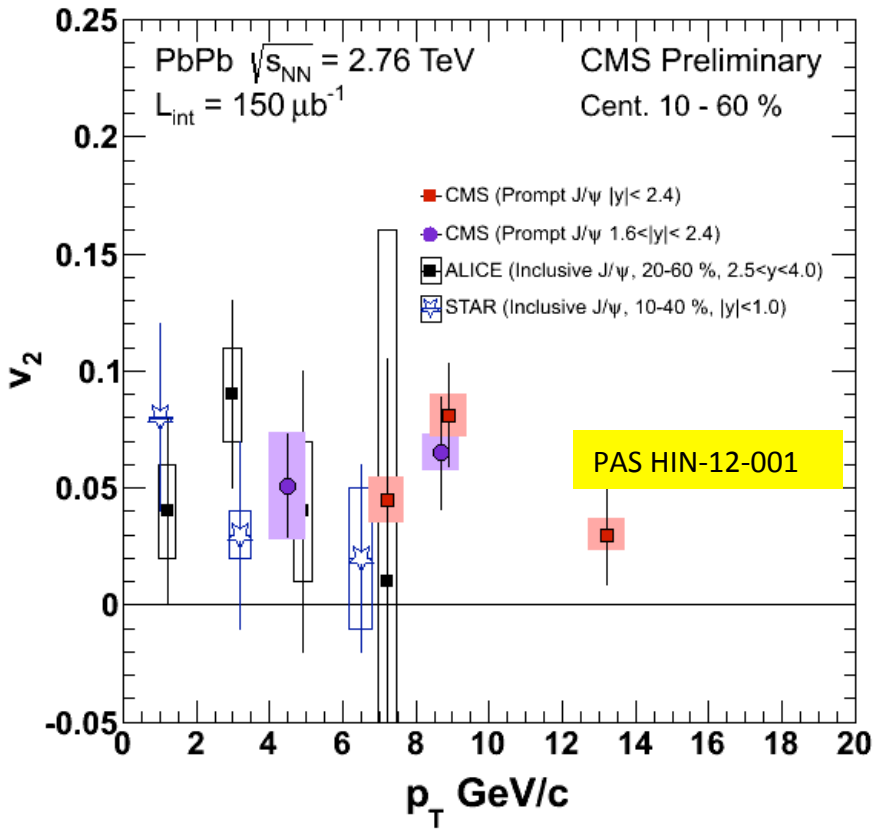


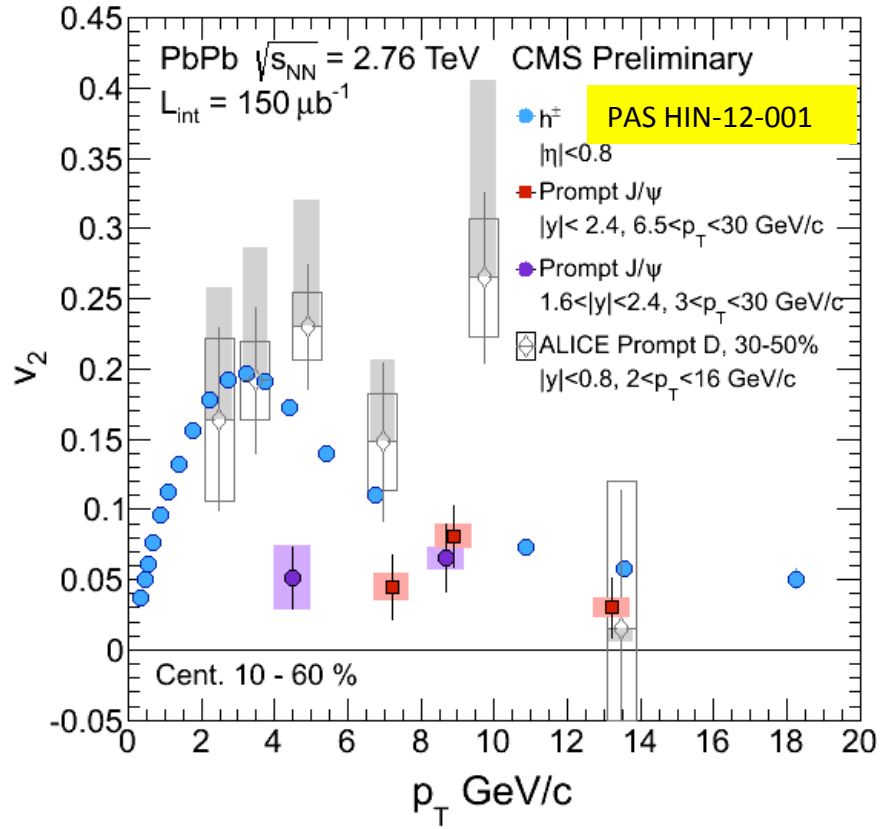
- Centrality dependent suppression for all rapidity bins
- At and forward rapidity, low p_T non-prompt J/ψ has stronger centrality dependence and is less suppressed than high p_T J/ψ

R_{AA} of non-prompt J/ψ vs theory



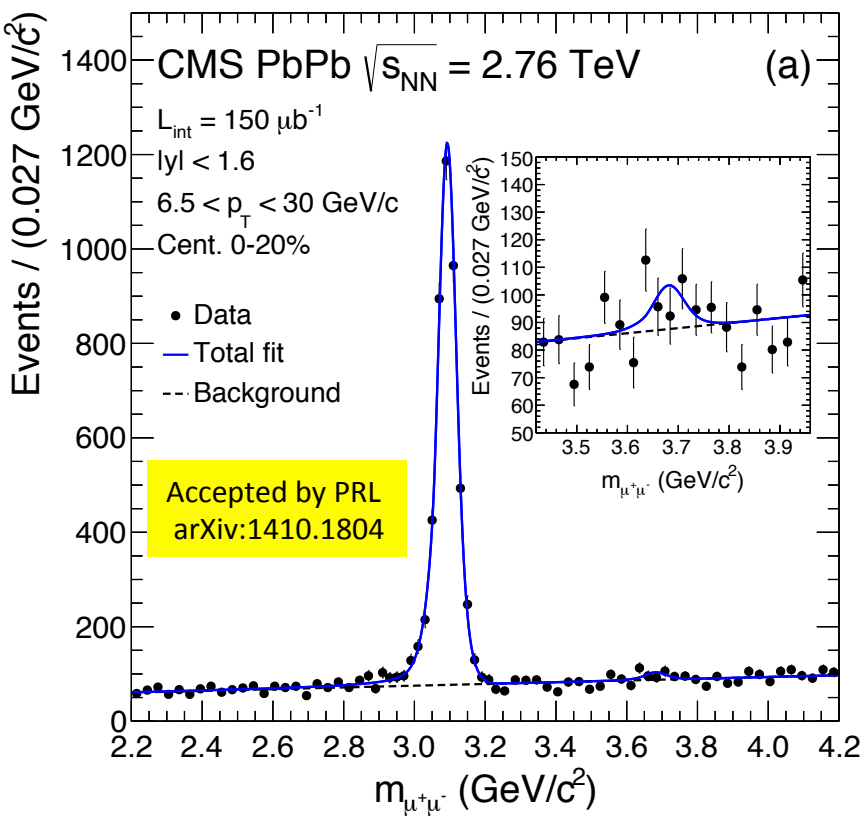
v_2 of prompt J/ψ

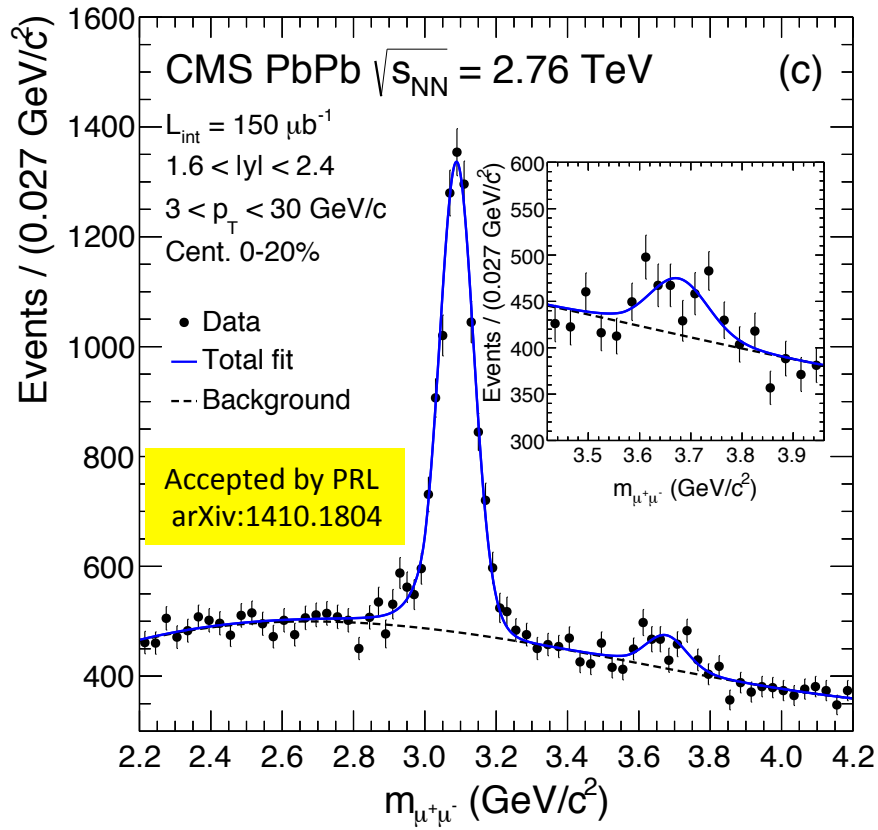




- Measurement extended up to high p_T; observed non-zero v_2
- STAR results are consistent with zero in $2 < p_T < 10$ GeV/c
- Low p_T: v_2 of J/ψ < v_2 charged hadrons and v_2 D mesons (ALICE)
- High p_T: $8 < p_T < 10$ GeV/c: similar v_2 for J/ψ and $h^{\pm}$

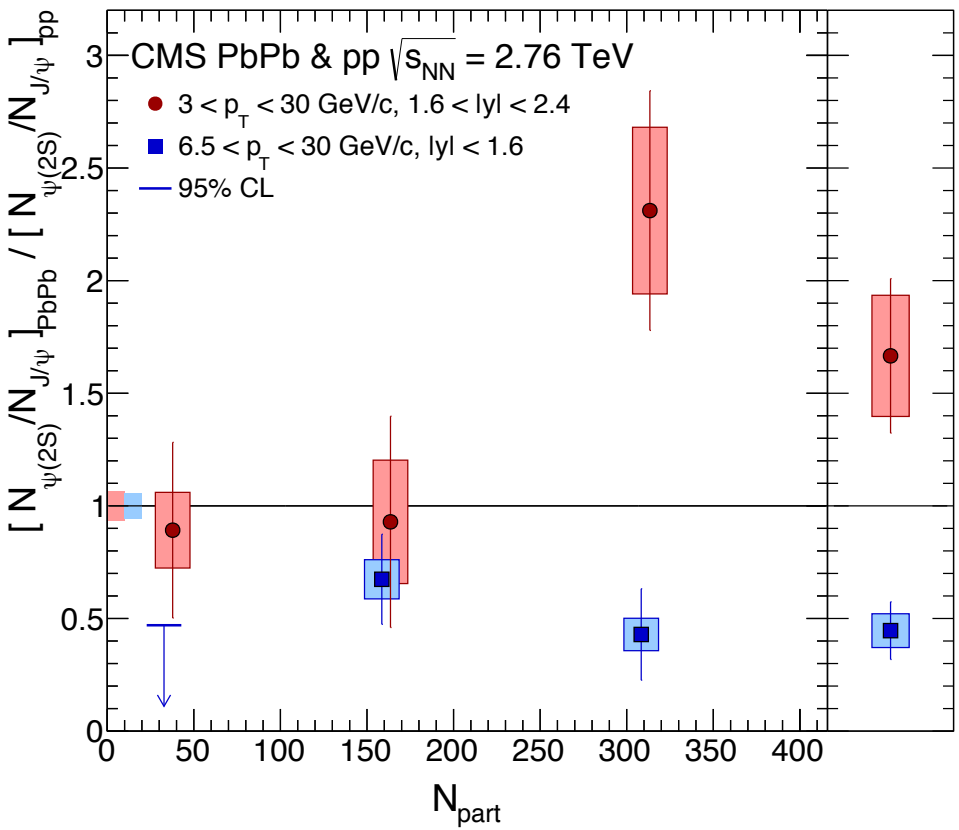
J/ψ and ψ(2s)





- In [0-20%] most central events, ψ(2S) is clearly visible in high-p_T (6.5 < p_T < 30 GeV/c) and in low-p_T (3 < p_T < 30 GeV/c)

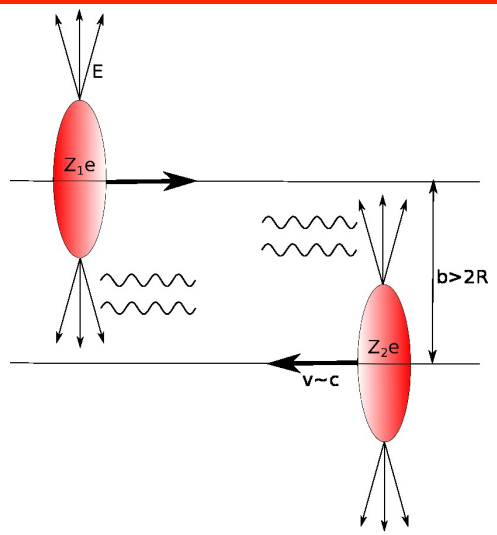
$[\psi(2S)/J/\psi]_{PbPb}$ / $[\psi(2S)/J/\psi]_{pp}$

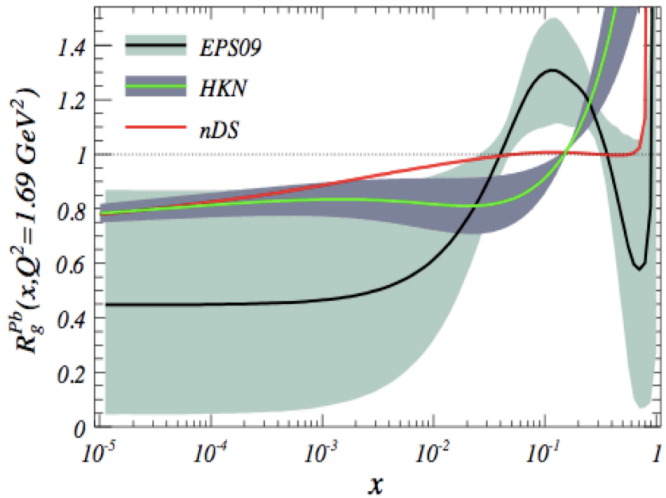


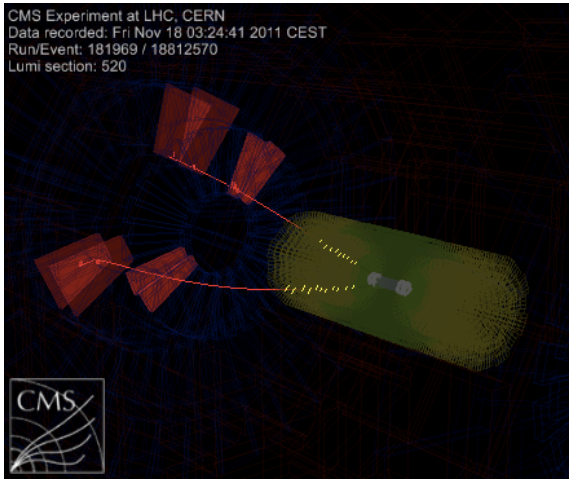
Accepted by PRL
arXiv:1410.1804

- ψ(2S) suppressed in PbPb collisions wrt to pp
- For p_T > 6.5 GeV/c, |y| < 1.6: ψ(2S) are more suppressed than J/ψ
- For p_T > 3 GeV/c, 1.6 < |y| < 2.4: indication of ψ(2S) being less suppressed than J/ψ but large uncertainties on pp

Why charmonium in UPC PbPb collisions



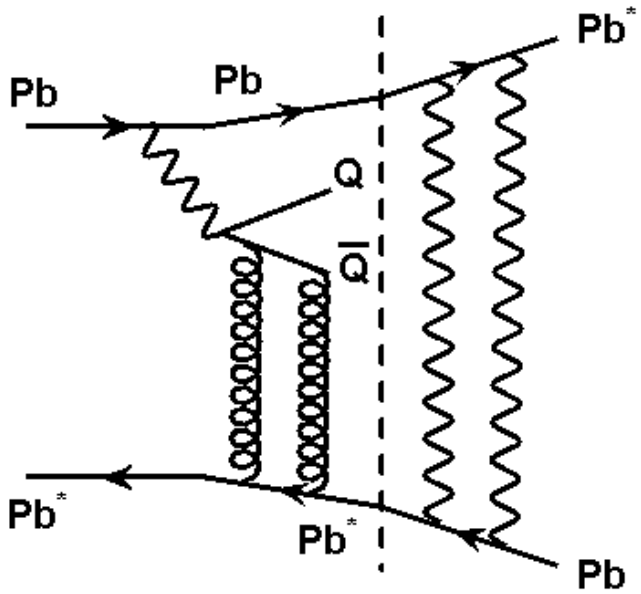


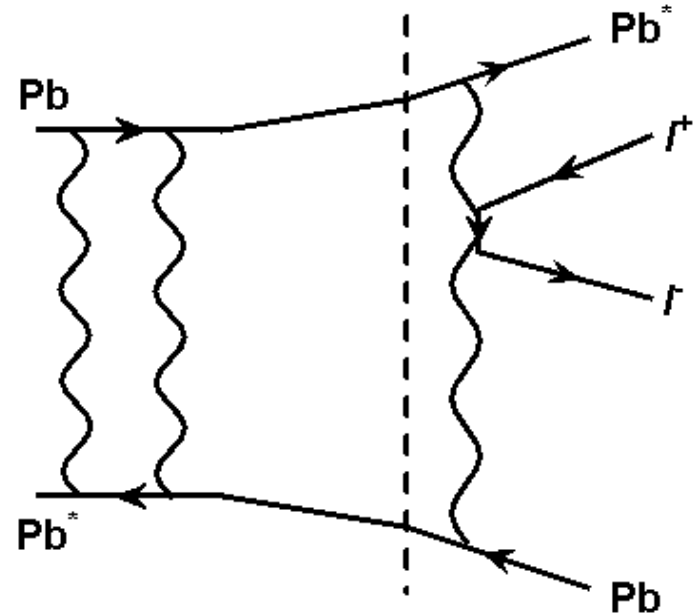


- Impact parameter b > 2R (radius of nuclei) γ-induced reactions
- Electromagnetic field (coherent action of 82 proton charges): generated equivalent flux of γ proportional to Z^2
- Production of vector mesons is sensitive to the square of the gluon density in the nucleus
- x ~ 10^{-2} – 10^{-4}

$$\frac{d\sigma_{\gamma p,A\to V_{p,A}}}{dt} = \frac{\alpha_s^2\Gamma_{ee}}{3\alpha M_V^5}16\pi^3[xG(x,M_V^2/4)]^2$$

γ+A ad γ+γ interactions



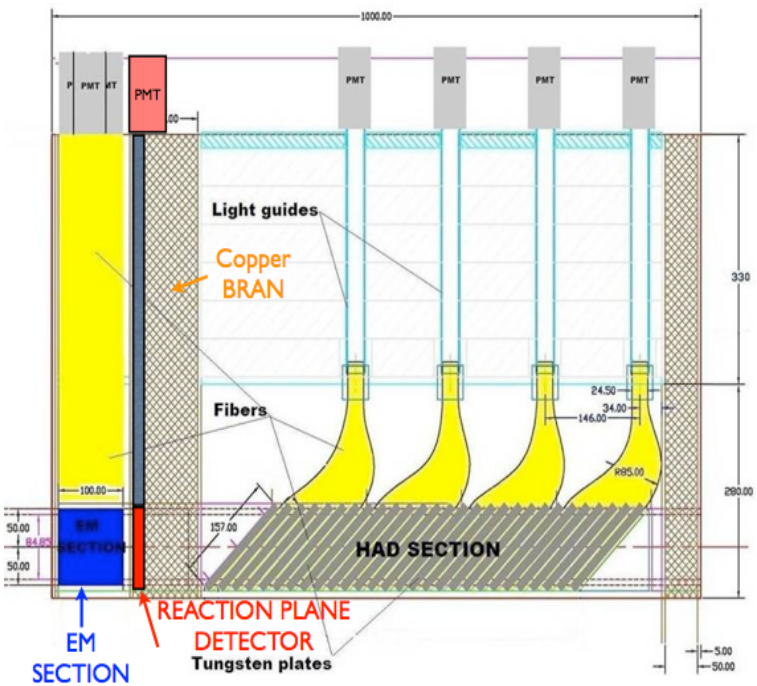


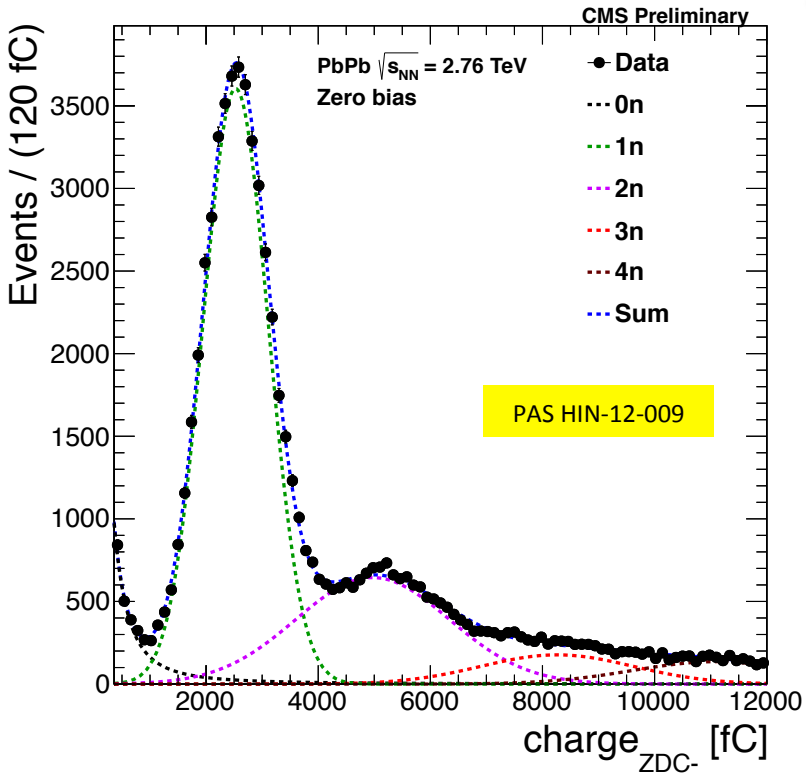
- γ+Pb (photonuclear) collisions
  - coherent interaction: γ interacts with the entire nucleus coherently
  - incoherent interaction: high p_T γ interacts with nucleon
- γ+γ: two photons collide to produce dimuon
- ~ 50 % of interactions is accompanied by the Coulomb excitation of one or both nucleus: breakup with neutron emission at forward rapidities
- **In this study we look for events having J/ψ and at least one neutron in either ZDC (X_n0_n breakup mode)**

Neutron tagging

- γ hits nucleus: nucleus often emit neutron(s): detection with ZDC
- ZDC covers |η|>8.3: 5 EM and 4 HAD channels
  - presence of neutron: signal in ZDC is greater than a certain threshold
  - signal in each ZDC built from weighted sum of signal in

NEW





Signal extraction

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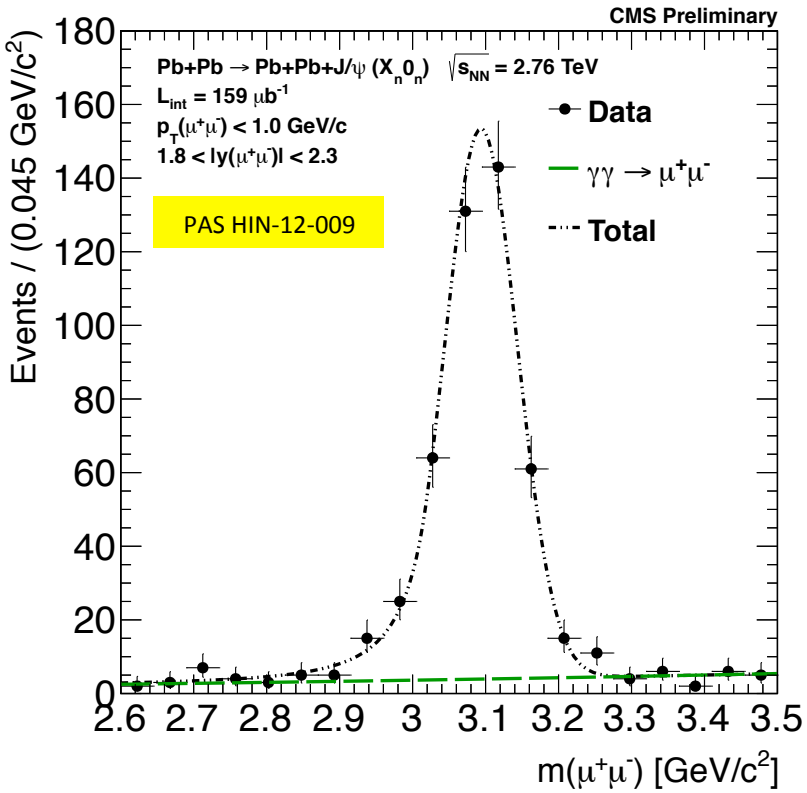
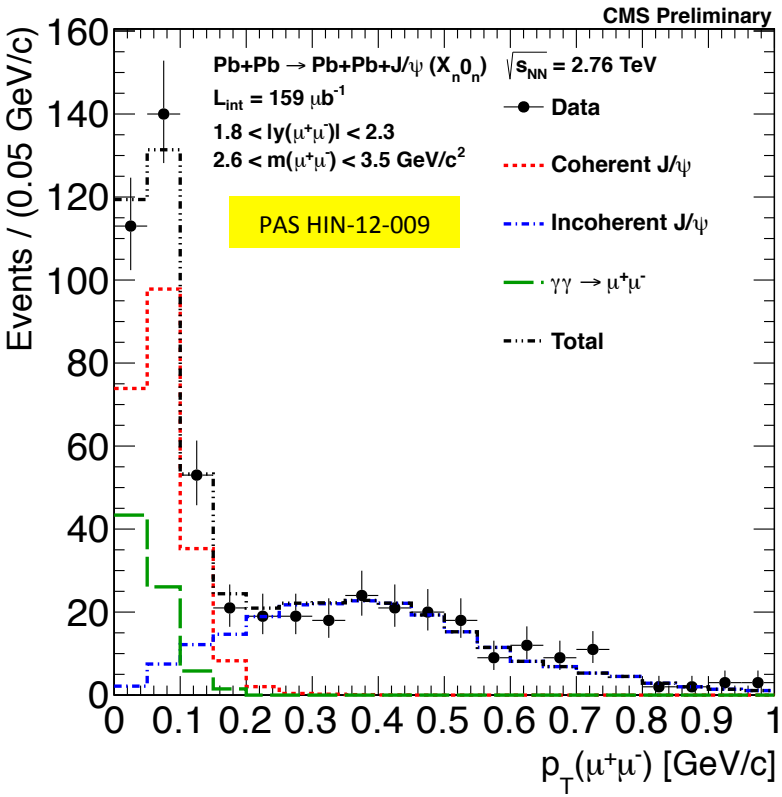
- Invariant mass and p_T simultaneously fit to the sum of γ+γ, coherent J/ψ and incoherent J/ψ components
- Yield of γ+γ, coherent J/ψ and incoherent J/ψ are free parameters



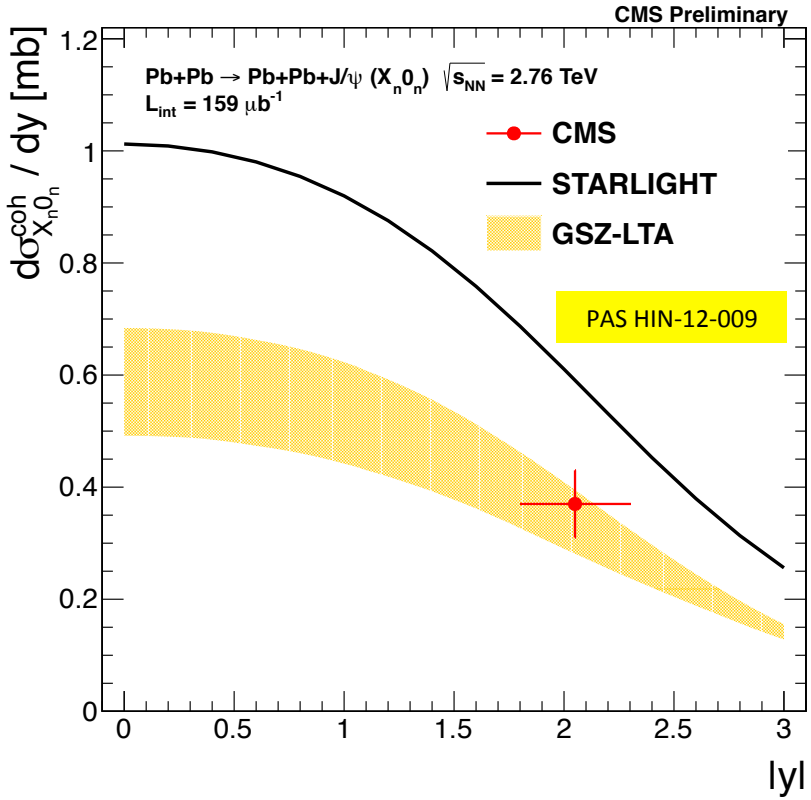


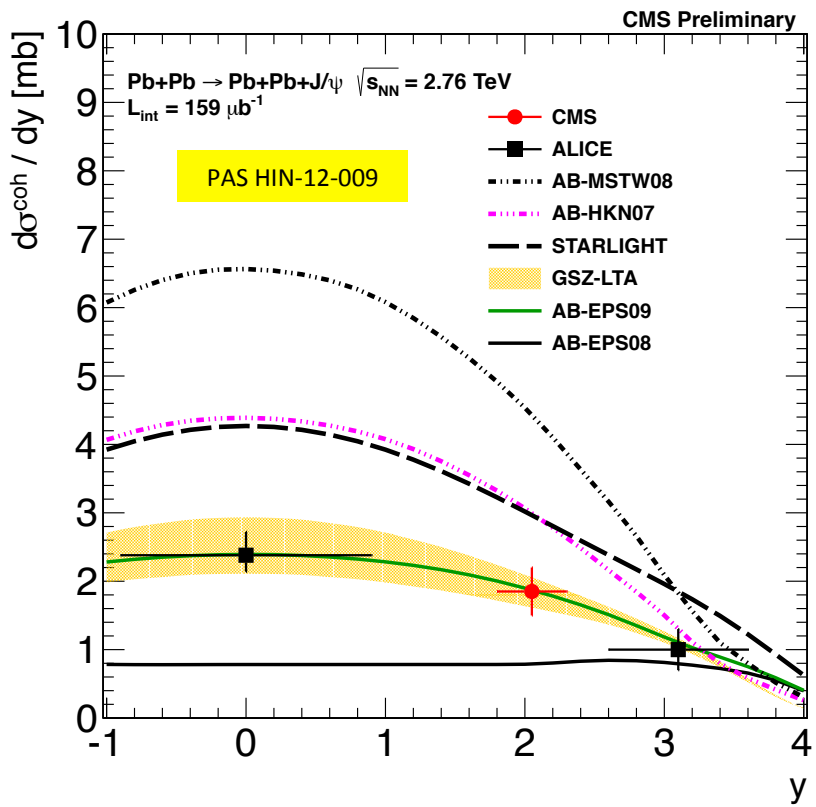
- For $p_T < 0.15$ GeV and $1.8 < |y| < 2.3$: $N_{coh}^{J/\psi} = 207 \pm 18$ (stat)

Cross section

NEW

- For $1.8 < |y| < 2.3$: $N_{coh}^{J/\psi} = 207 \pm 18$ (stat)
- Coherent cross section in X_n0_n
- Coherent cross section





- Coherent J/ψ cross section in X_n0_n = 0.4 ± 0.04 (stat) ± 0.04 (syst) mb
- Data favor the calculations including gluon shadowing

Breakup modes

- Measured neutron configurations
  - X_n0_n: one of the ZDCs has at least one neutron, the other ZDC have signal consistent with noise (dominant)
  - X_nX_n: both ZDCs have at least one neutron
  - 1_n0_n: one ZDC have one neutron, the other ZDC have signal consistent with noise
  - 1_n1_n: both ZDCs have exactly one neutron

NEW

	XnXn/Xn0n	1n0n/Xn0n	1n1n/Xn0n
data	0.36 ± 0.04 (stat)	0.26 ± 0.03 (stat)	0.03 ± 0.01 (stat)
STARLIGHT	0.37	N/A	0.02
GSZ	0.32	0.30	0.02

- STARLIGHT and GSZ describe data reasonably

Summary/Conclusions

- **Hadronic charmonium**
  - prompt, non-prompt J/ψ and ψ(2s) measurement
  - suppression of yield seen in R_{AA}
  - high p_T v_2 J/ψ has non-zero flow close to one of charged hadrons
  - ψ(2s) are more suppressed than J/ψ
  - sequential suppression in order of binding energies
- **UPC charmonium**
  - measurement of cross section for coherent J/ψ production associated with nuclear breakup X_n0_n at given rapidity
  - compared to ALICE and theory
  - measurements favor calculations with the nuclear gluon shadowing
  - various breakup modes measured
- **With more data in Run 2**
  - PbPb: more precise studies of existing measurements
  - UPC PbPb: correlation between J/ψ and neutron rapidity direction (Eur. Phys. J C (2014) 74:2942)