Overview of results on heavy flavour and quarkonia from the CMS collaboration

Camelia Mironov

(LLR/Ecole polytechnique)

ERC grant "QuarkGluonPlasmaCMS"

for the CMS Collaboration

Quark Matter conference, Washington DC

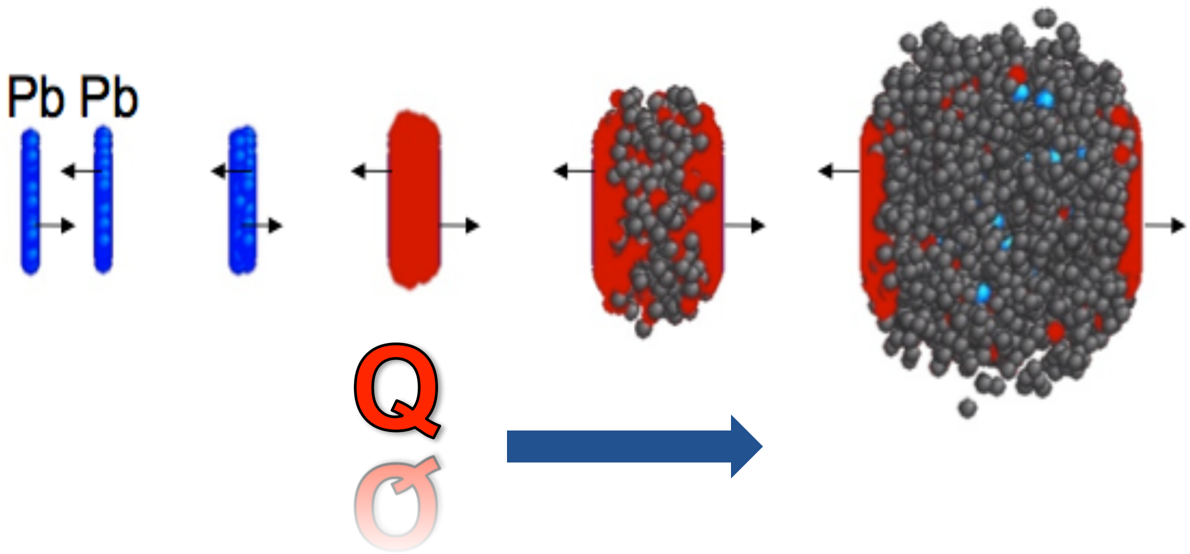
August 16th, 2012

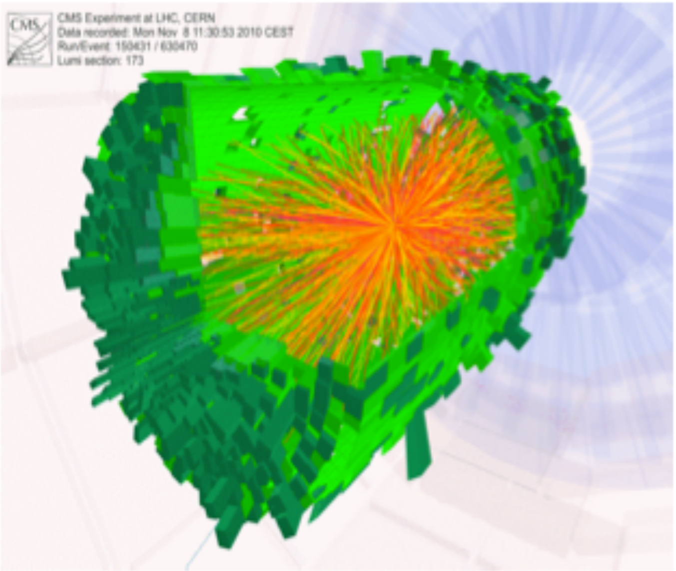
Outline

- Heavy quarks and QGP
- C μ S
- 2nd year of PbPb@LHC
  - J/ψ, ψ(2S), Υ(1S,2S,3S)
  - B→J/ψ
- The big picture

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN

Heavy quarks and QGP

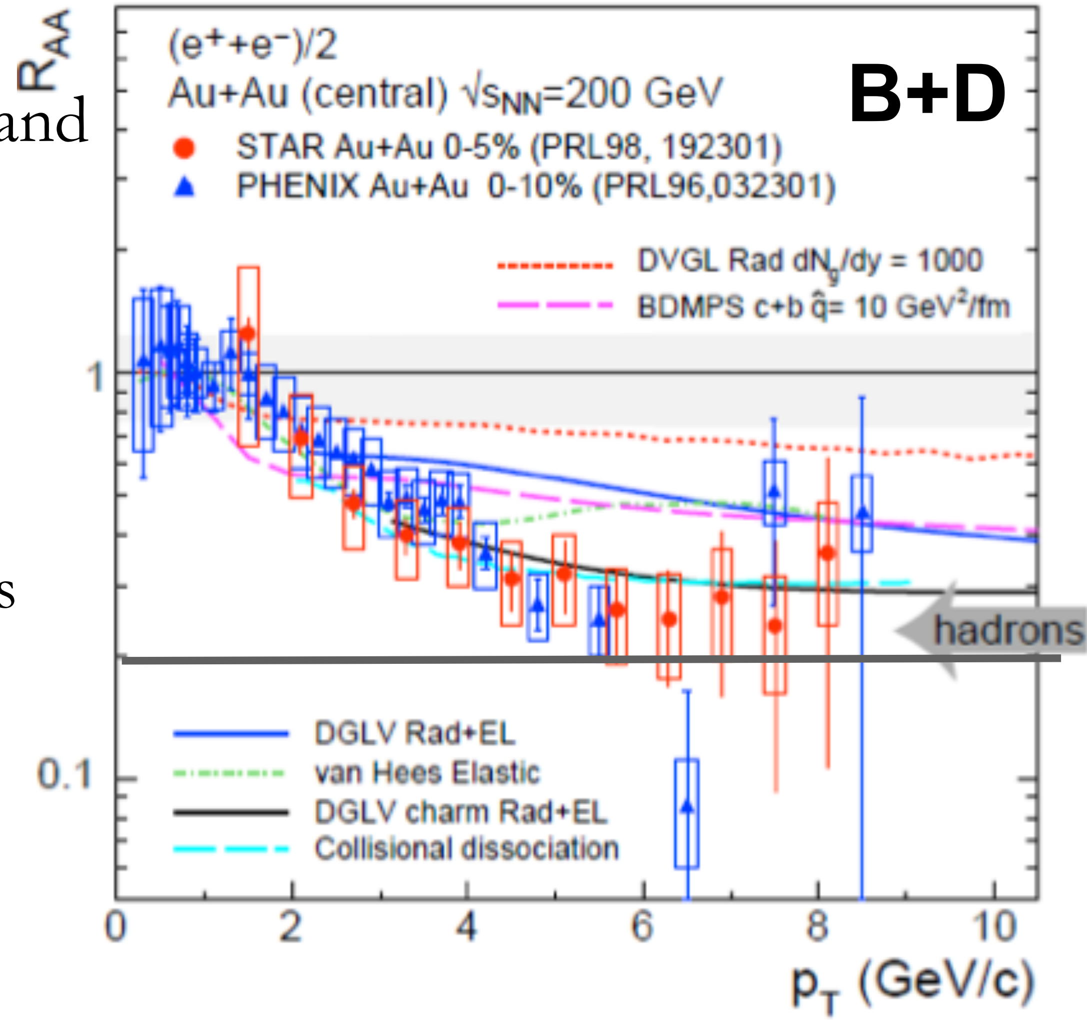




- **Produced early in the collision**
  - They map the evolution of the medium
  - Their measurements reflect the medium characteristics

Open heavy flavour (HF)

- **Theoretically:**
  - $R_{AA}^{light} < R_{AA}^{D} < R_{AA}^{B}$
  - Interplay of collisional and radiative energy loss

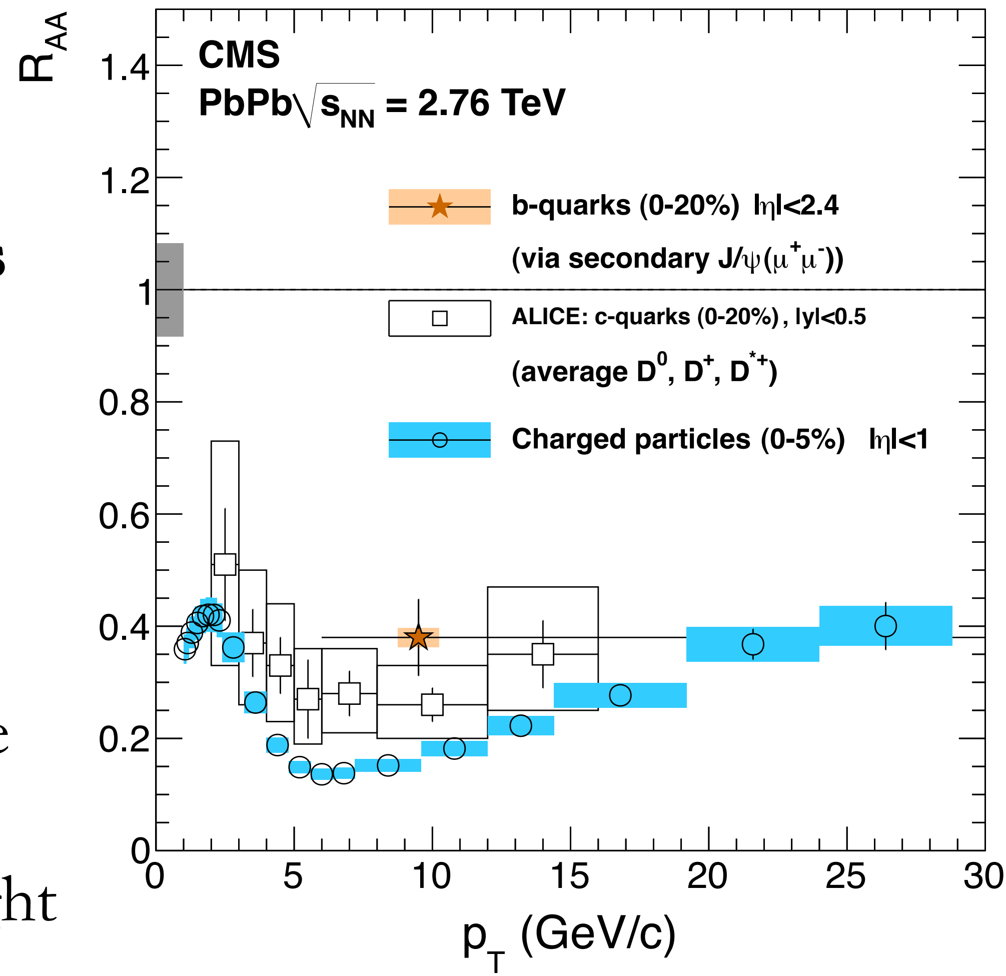


- **Experimentally:**
  - high-p_T non-photonic electrons as suppressed as light hadrons

- **Essential to separate charm from bottom**

Open HF: status before 2nd PbPb@2.7TeV

- **LHC: First unambiguous separation in heavy-ion collisions of charm and bottom**
  - One giant step for HI, one (first) small step for understanding heavy vs light parton energy loss differences

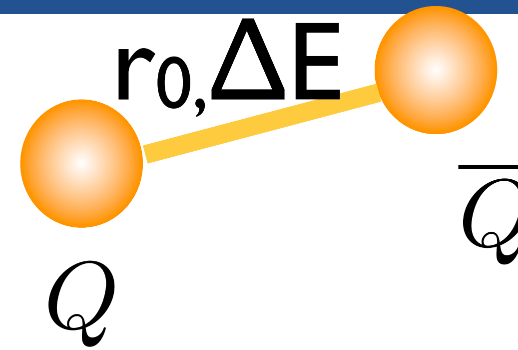


JHEP 1205 (2012) 063
arXiv:1205.6443
EPJC 72 (2012) 1945

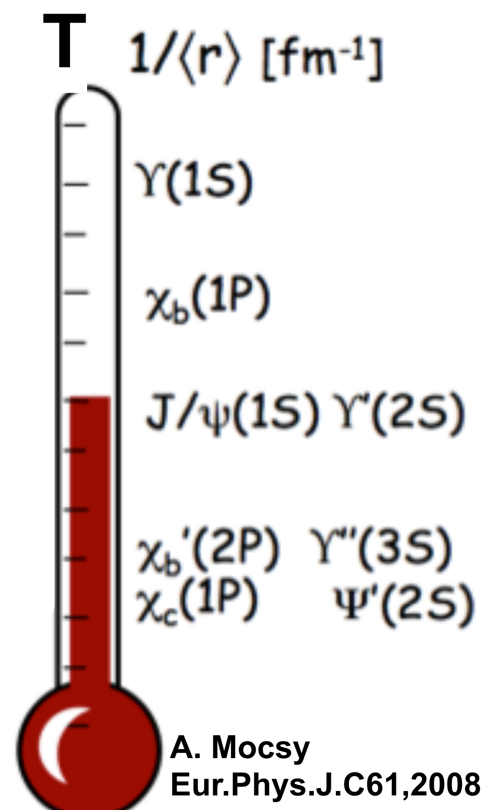
Hidden heavy flavours

arXiv:0901.3831

	Ψ (2S)	ϒ(3S)	ϒ(2S)	J/ψ	ϒ(3S)
Δ E(GeV)	0.05	0.20	0.54	0.64	1.10



- **Onia state in a deconfined, colour charged medium: Debye screening**
  - if $\lambda_D(T) < r_0$ → screening → melting of the bound state → yields suppressed
  - Screening at different T for different states → sequential melting

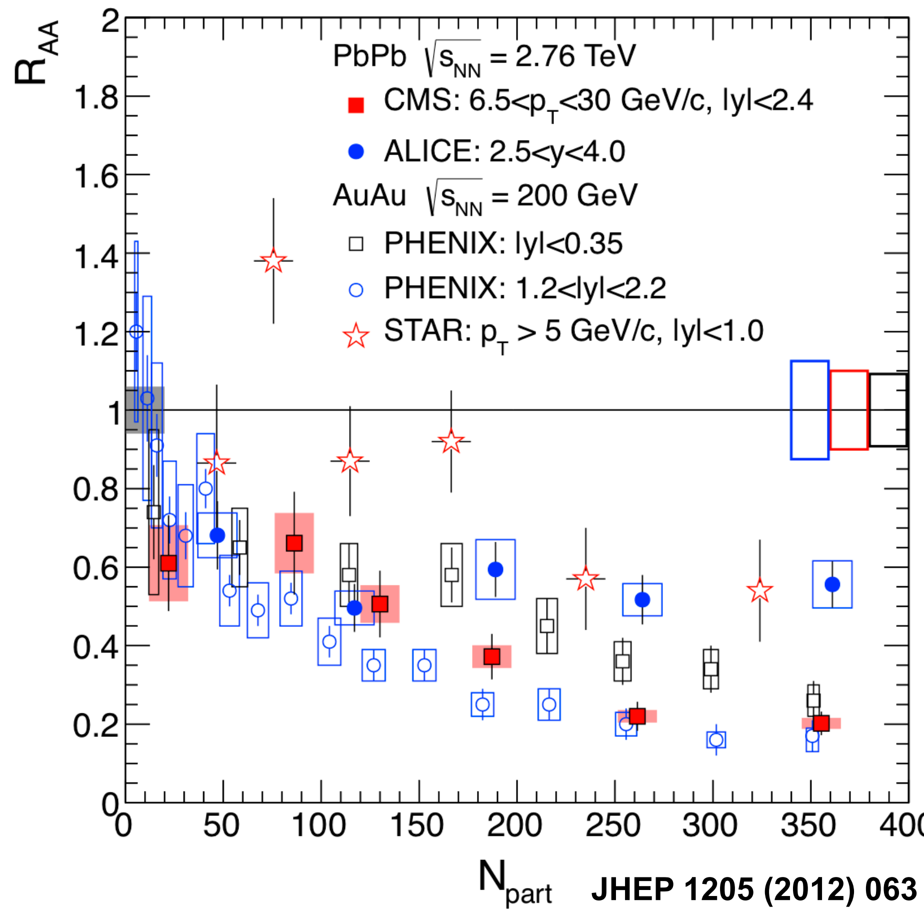


A. Mocsy
Eur.Phys.J.C61,2008

- **Onia: thermometer for the QGP**

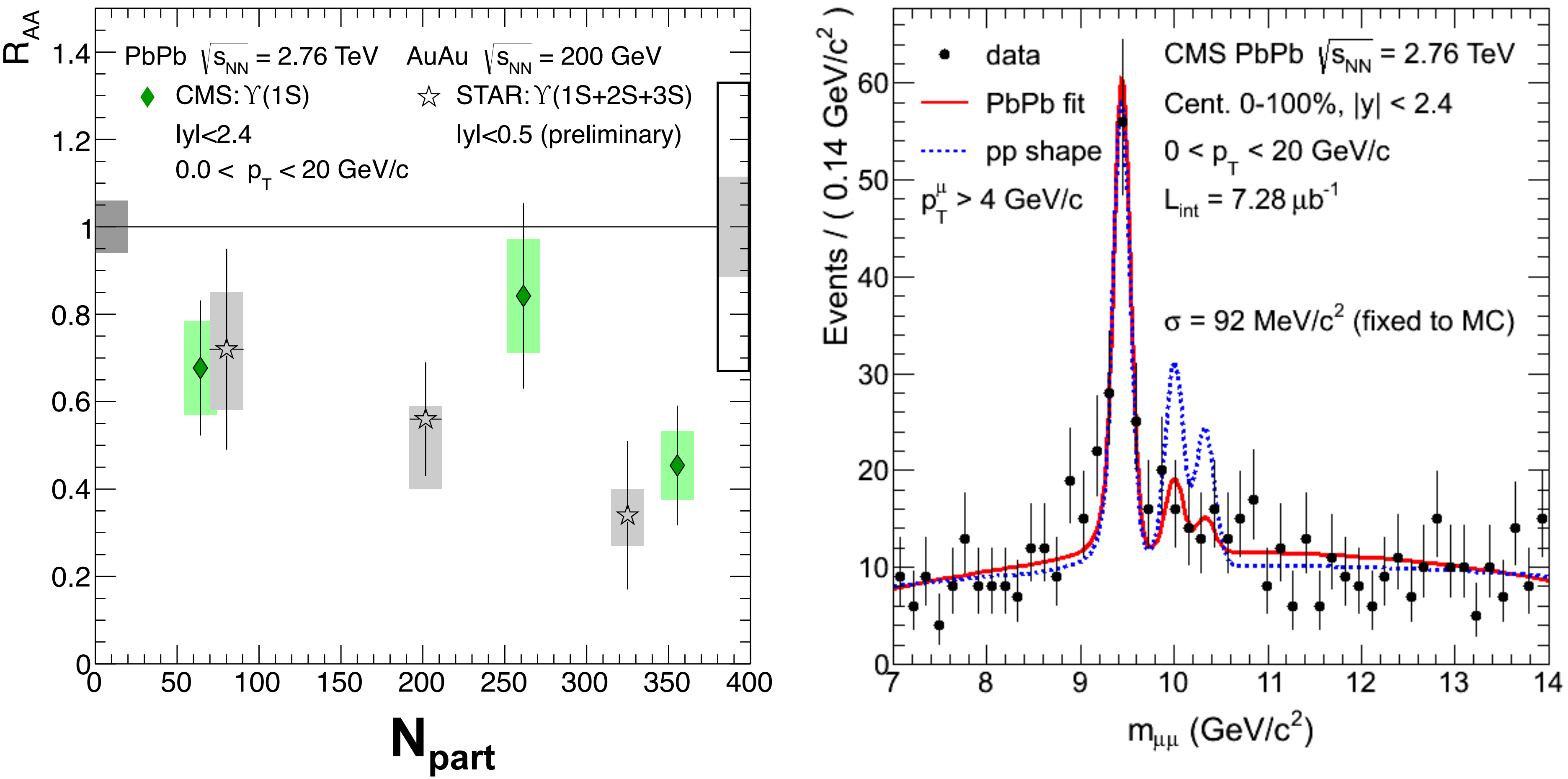
Charmonia: status before 2nd PbPb@2.7TeV

- **All suppressed, but no clear pattern/picture**
- **Interplay of hot and cold medium effects**
  - Shadowing, nuclear absorption
  - Regeneration, colour screening
  - feed-down (p_T-dependent)
- **Quarkonium production in pp is not fully understood theoretically**



JHEP 1205 (2012) 063
JHEP 1205 (2012) 063
PRL 98 (2007) 232301
PRC 84 (2011) 054912

Bottomonia: status before 2nd PbPb@2.7TeV

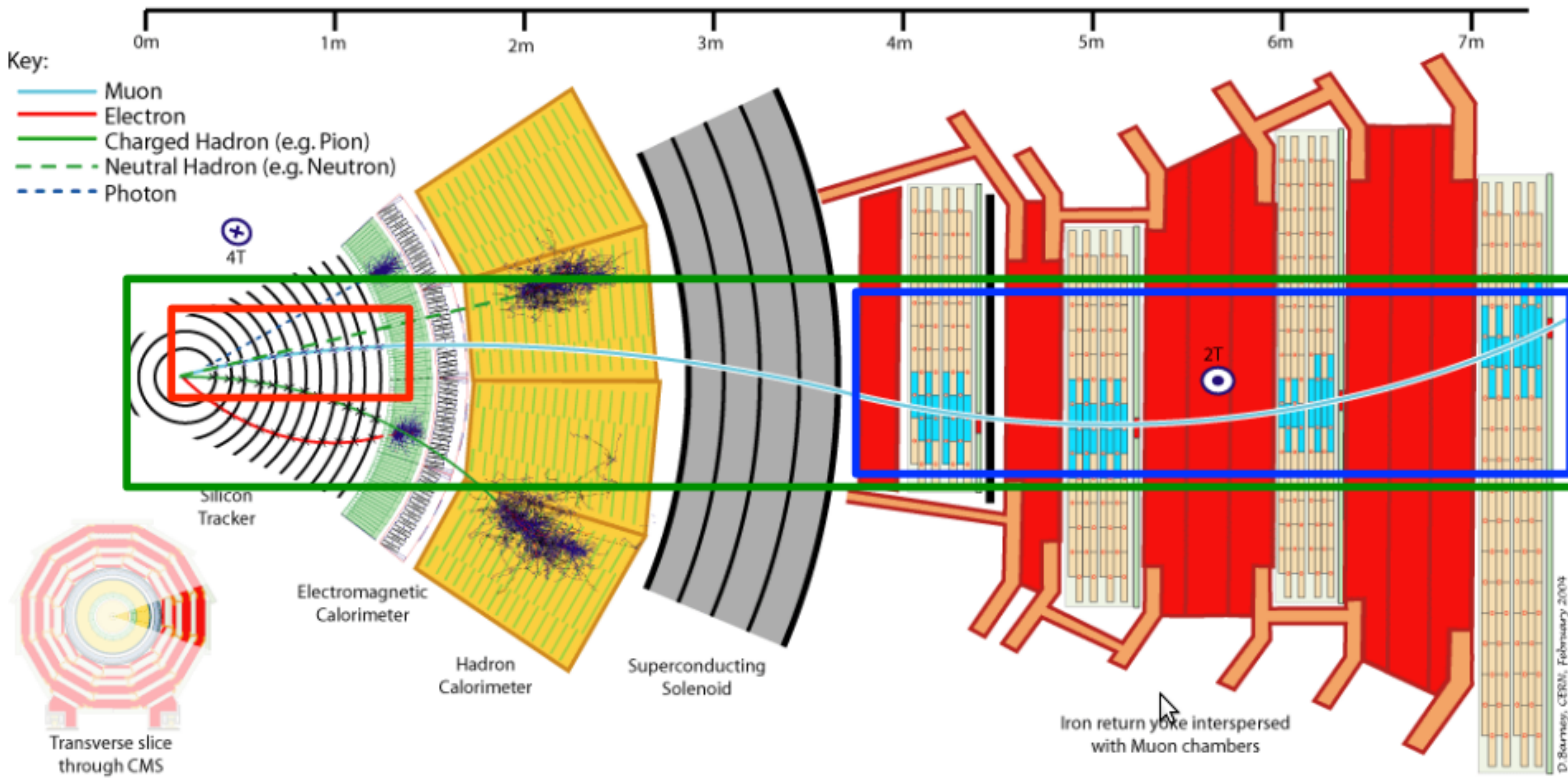


- **Ground state** suppressed
  - ~50% feed-down contribution above p_T>8GeV/c
- **Excited states** more suppressed than ground state

PRL 107 (2011) 052302
JHEP 1205 (2012) 063

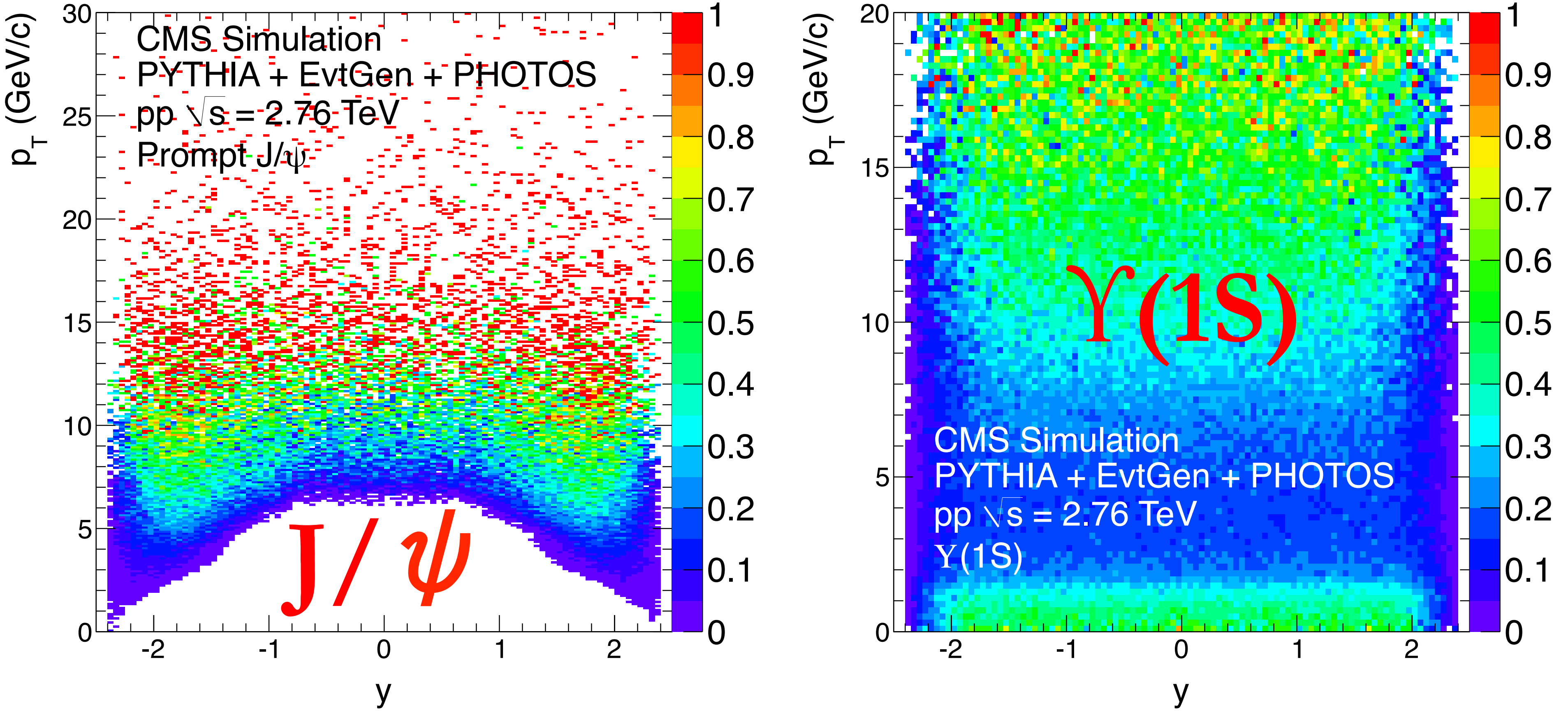
C μ S

Muon reconstruction



- **Muons: silicon tracker + muon subdetectors**
  – Tracker p_T resolution: 1-2% up to $p_T \sim 100$ GeV/c
    - Separation of quarkonium states
    - Displaced tracks for heavy-flavour measurements

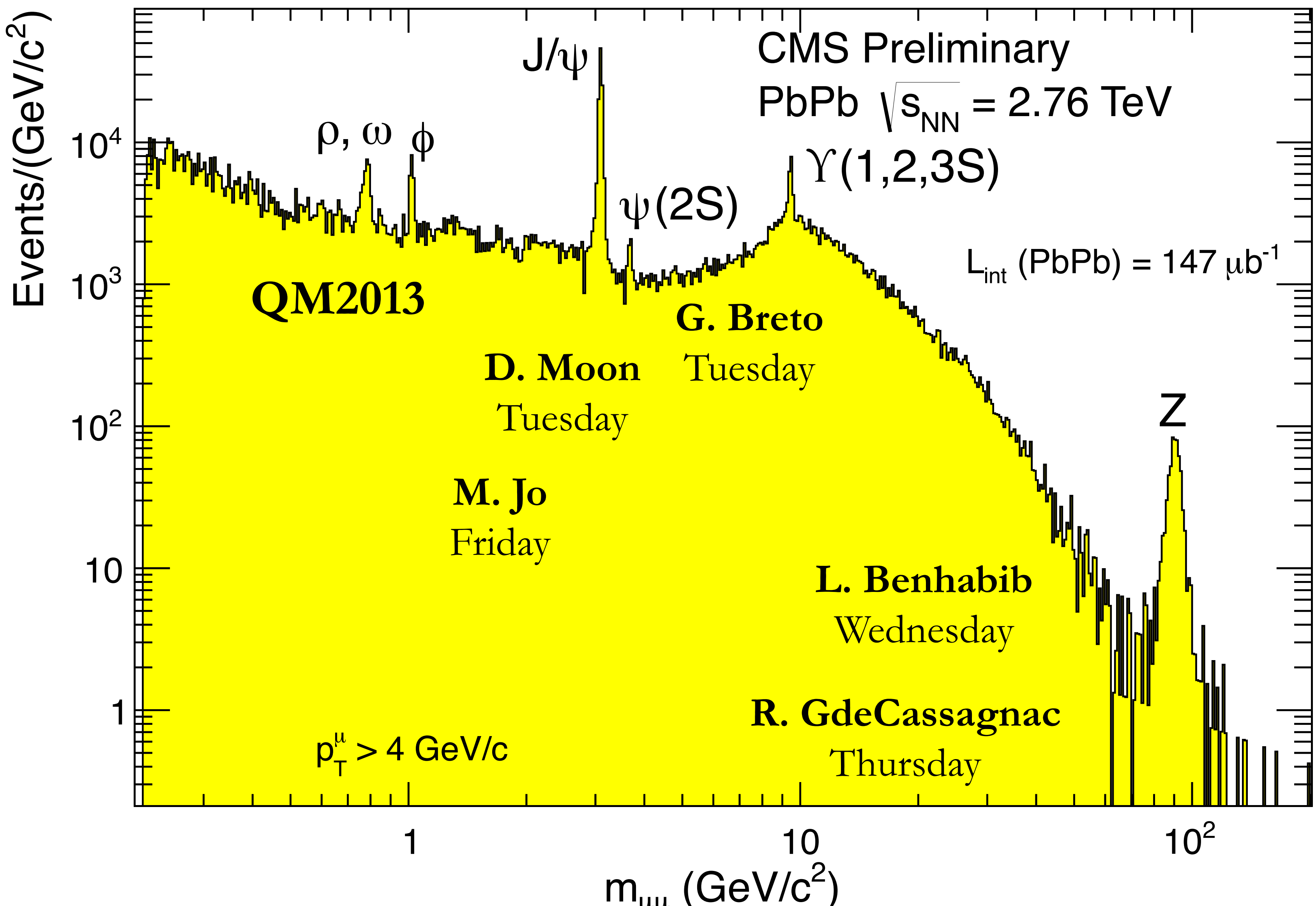
(di)Muon acceptance



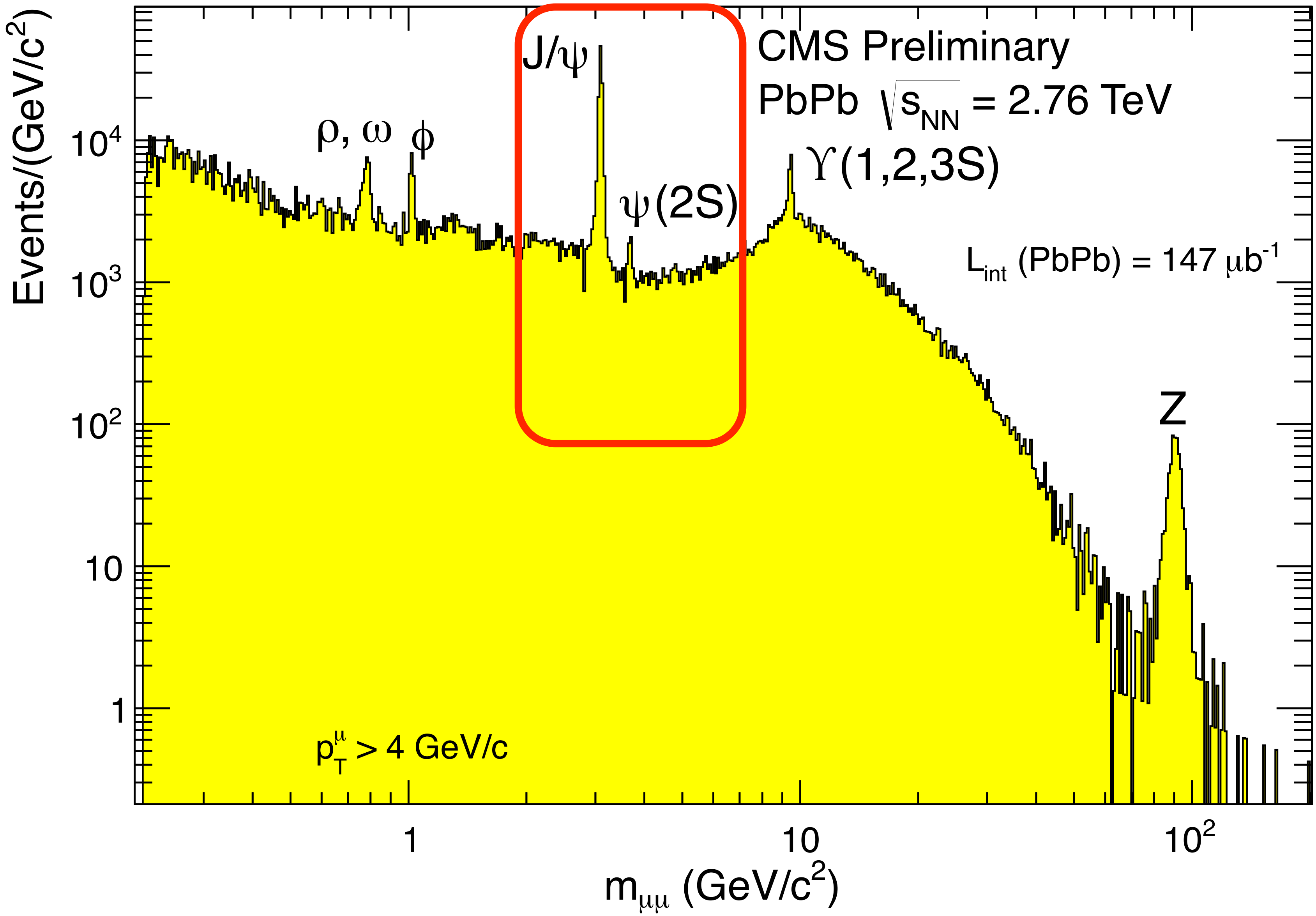
- **Single muons: p_{min} ~ 3-5 GeV/c for muon stations**
  - J/ ψ : p_{Tmin} ~ 3 GeV/c for |y| > 1.6
  - Υ: p_{Tmin} = 0 GeV/c for |y| < 2.4

2nd PbPb run at the LHC

Dimuons with muon $p_T > 4$ GeV/c

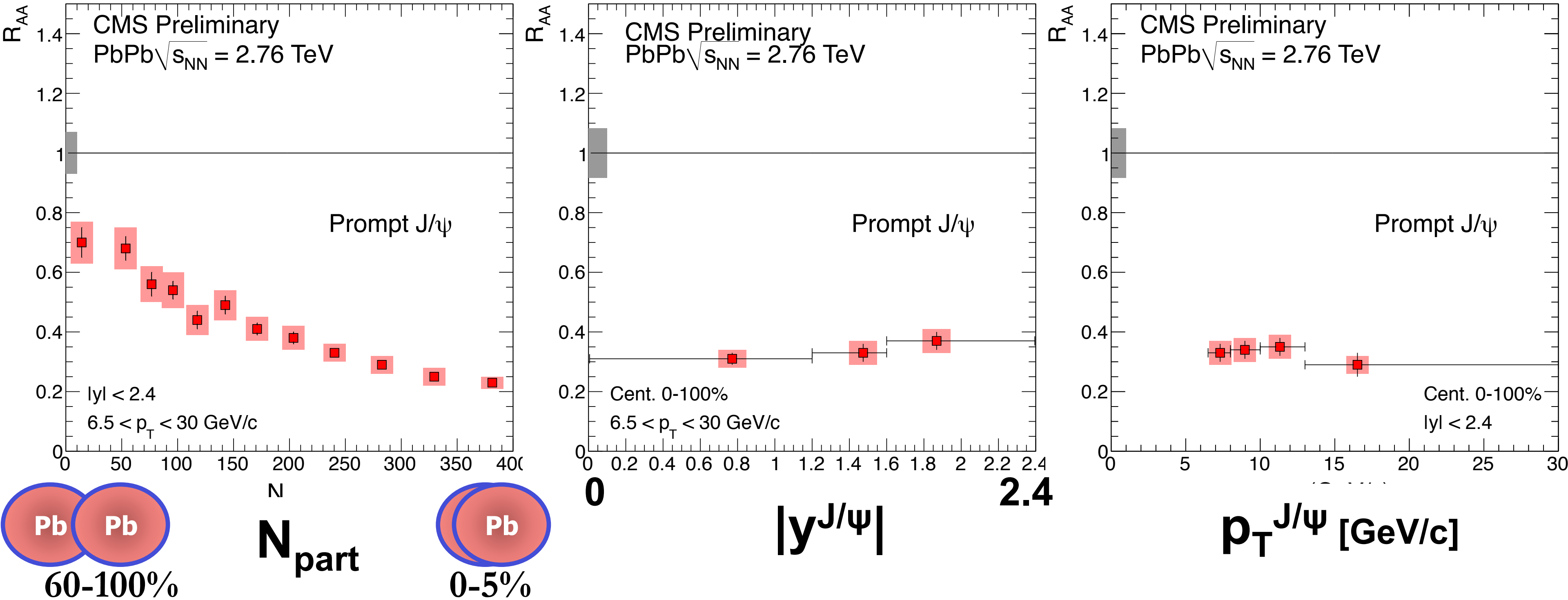


Charmonia



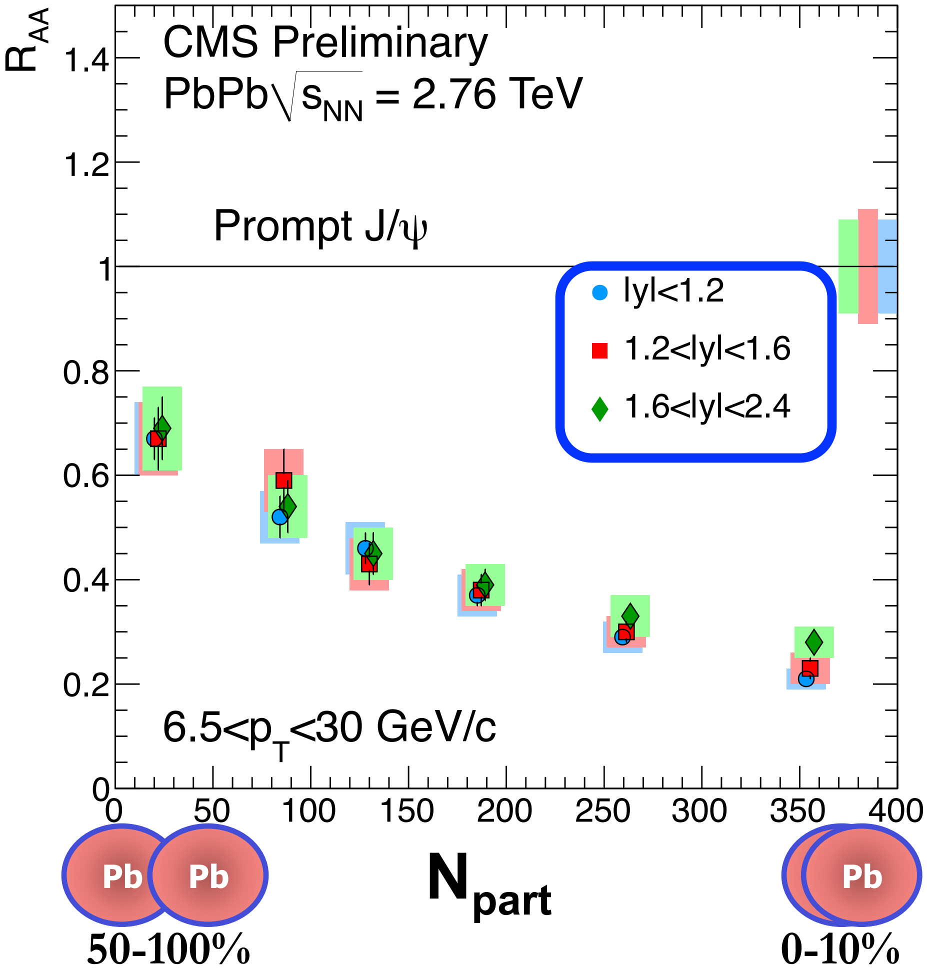
CMS Preliminary
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
L_{int} (PbPb) = 147 μb^{-1}
J/ψ
ψ(2S)
ρ, ω
φ
ϒ(1,2,3S)
Z
p_T^{μ} > 4 GeV/c
Events/(GeV/c^2)
$m_{\mu\mu}$ (GeV/c^2)
10^4
10^3
10^2
10
1
1
10
10^2

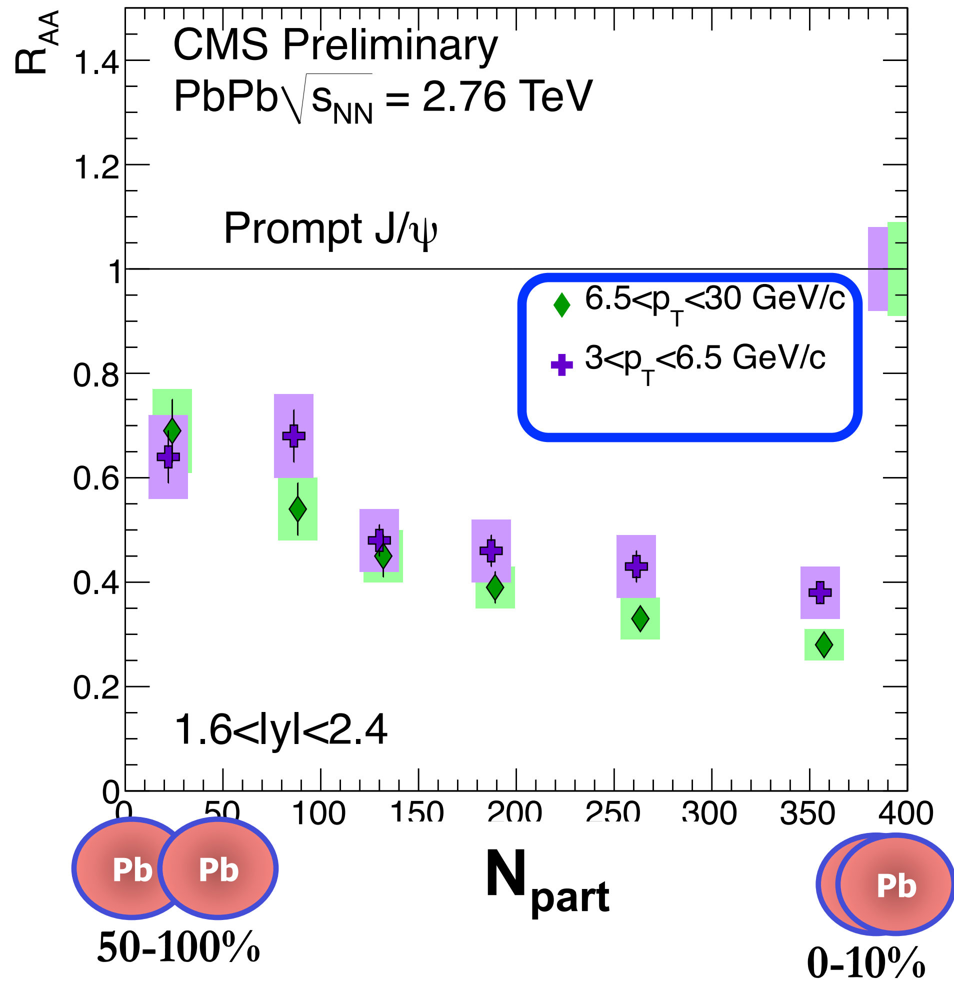
R_{AA} prompt J/ψ



- **Centrality (p_T, y integrated)**: smooth increase of R_{AA}
  - 0-5% factor ~5 suppression
  - 60-100% factor ~1.4 suppression
- **y and p_T (centrality integrated):** no significant dependence

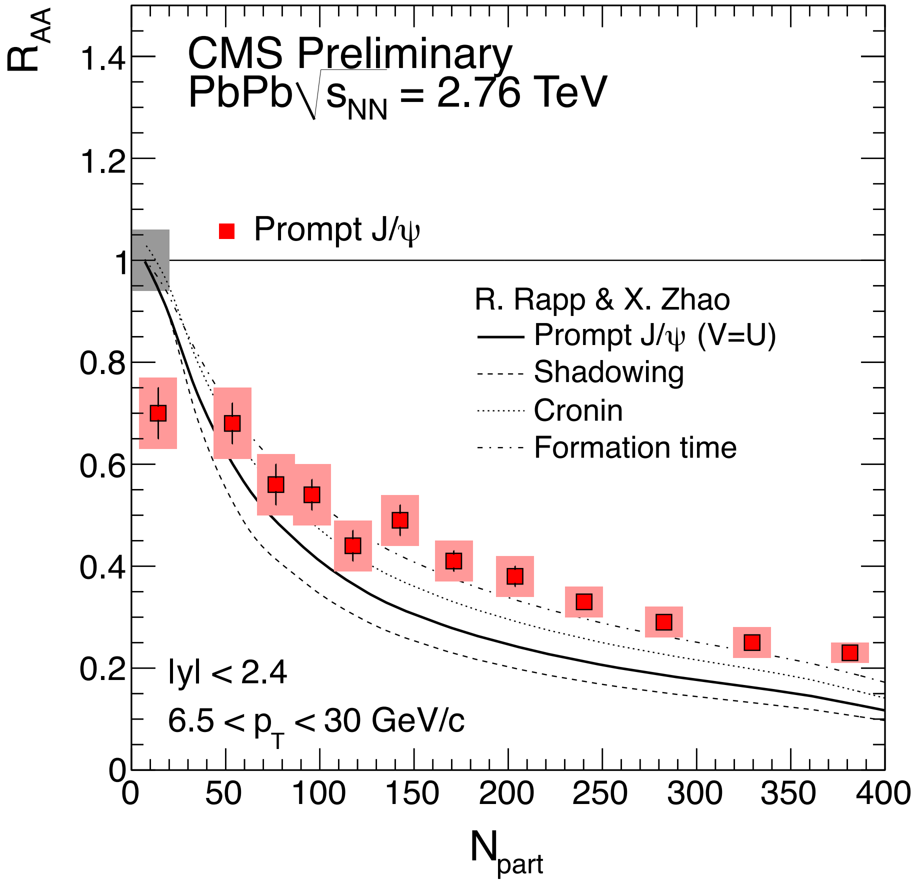
R_{AA} prompt J/ψ: double-differential



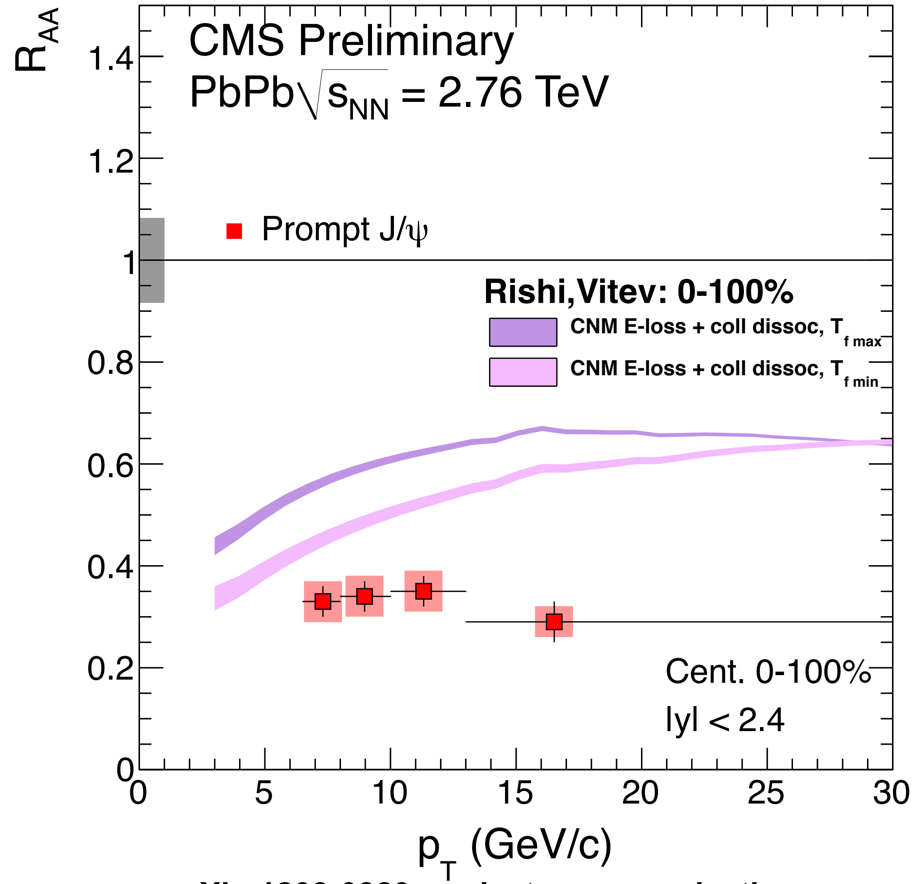


- **6.5 < p_T < 30 GeV/c:** no rapidity dependence
- **1.6<|y|<2.4:** low-p_T little less suppressed than high-p_T

R_{AA} prompt J/ψ: theory



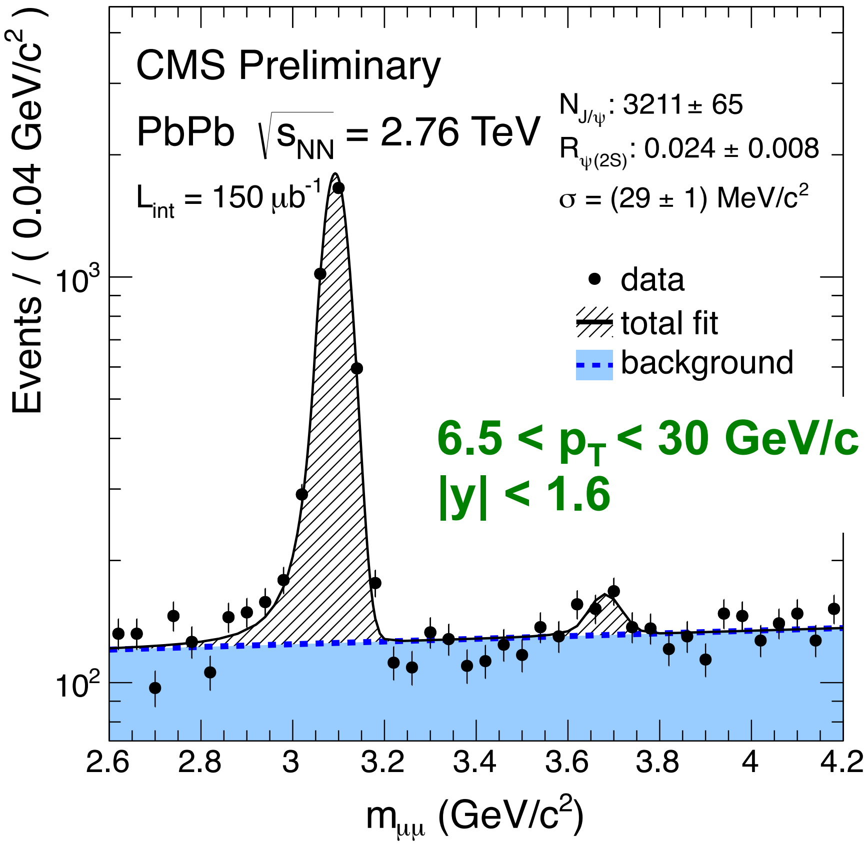
NPA 859 (2011) 114 + private communication

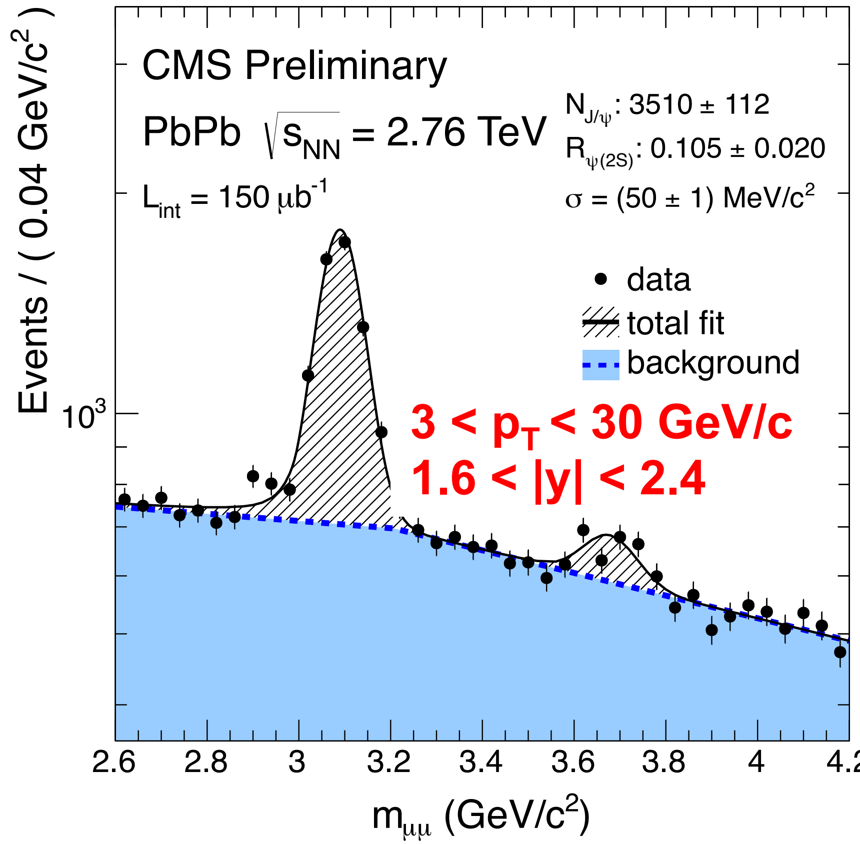


arXiv:1203:0329 + private communication

- High-p_T: no need for regeneration to describe data
- Treatment of onia energy loss similarly as open heavy flavour energy loss, without colour-octet included, is not supported by data

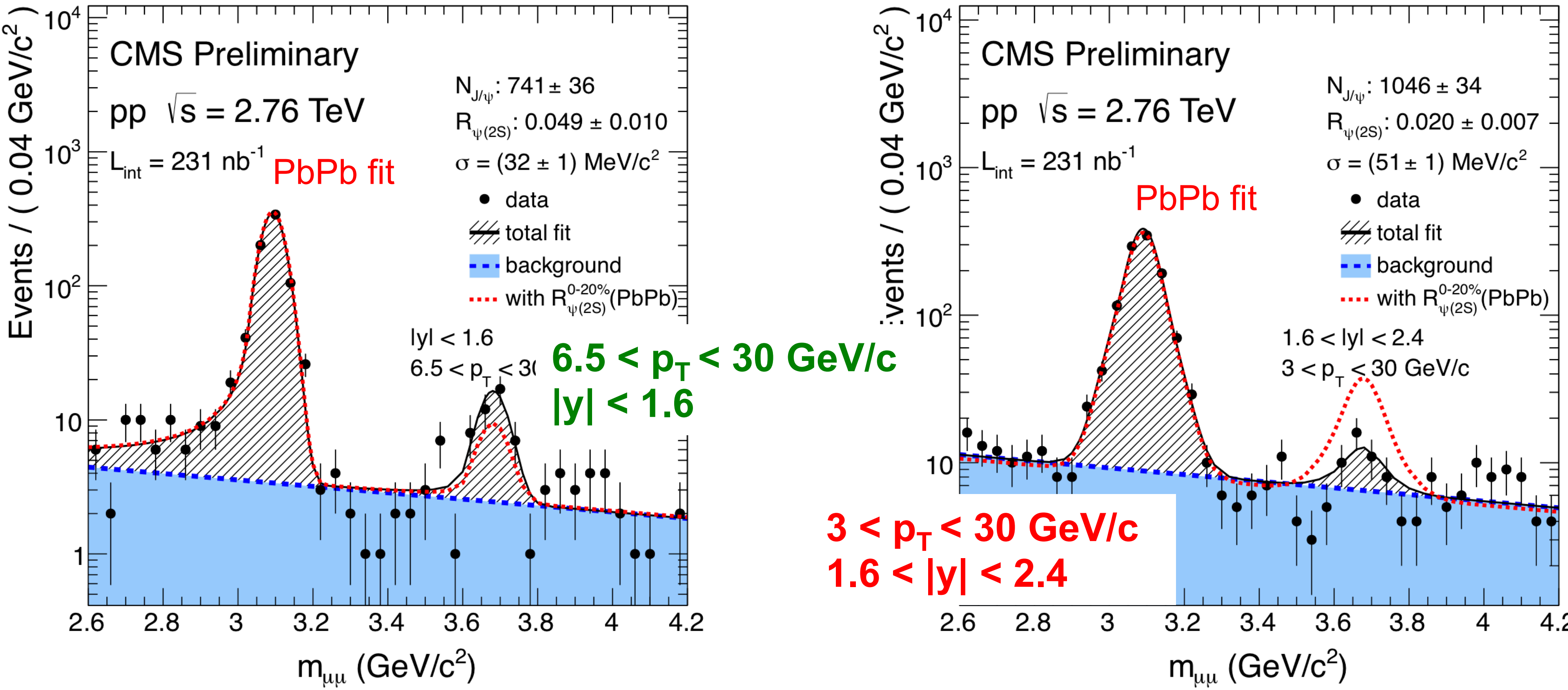
ψ(2S) vs J/ψ: PbPb 0-20 %





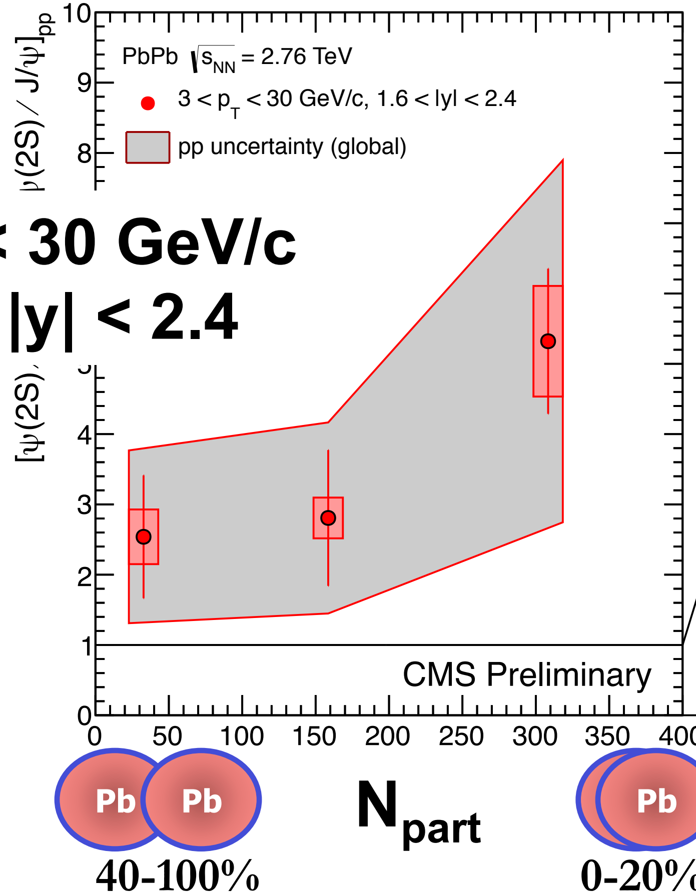
- **We do see ψ(2S) at high-p_T and low-p_T in PbPb**

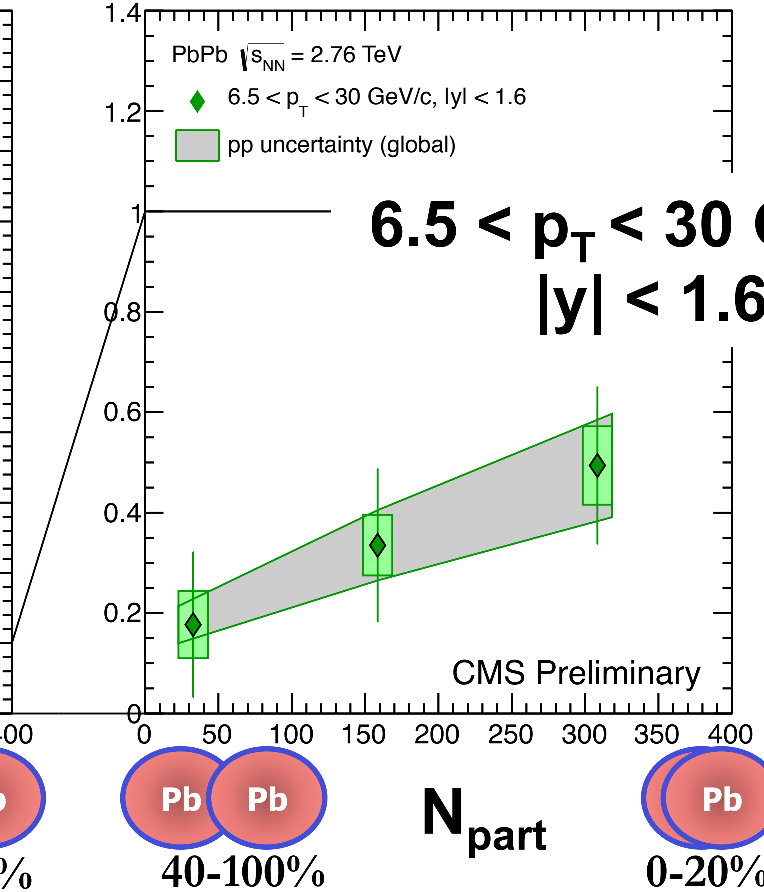
ψ(2S) vs J/ψ: pp vs PbPb (0-20%)



- **Raw ratios:** $R_{\psi(2S)} = N_{\psi(2S)} / N_{J/\psi}$
  - High-p_T: $R_{\psi(2S)}^{PbPb} \sim 0.5 \times R_{\psi(2S)}^{pp}$
  - Low-p_T: $R_{\psi(2S)}^{PbPb} \sim 5 \times R_{\psi(2S)}^{pp}$ (low significance)

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

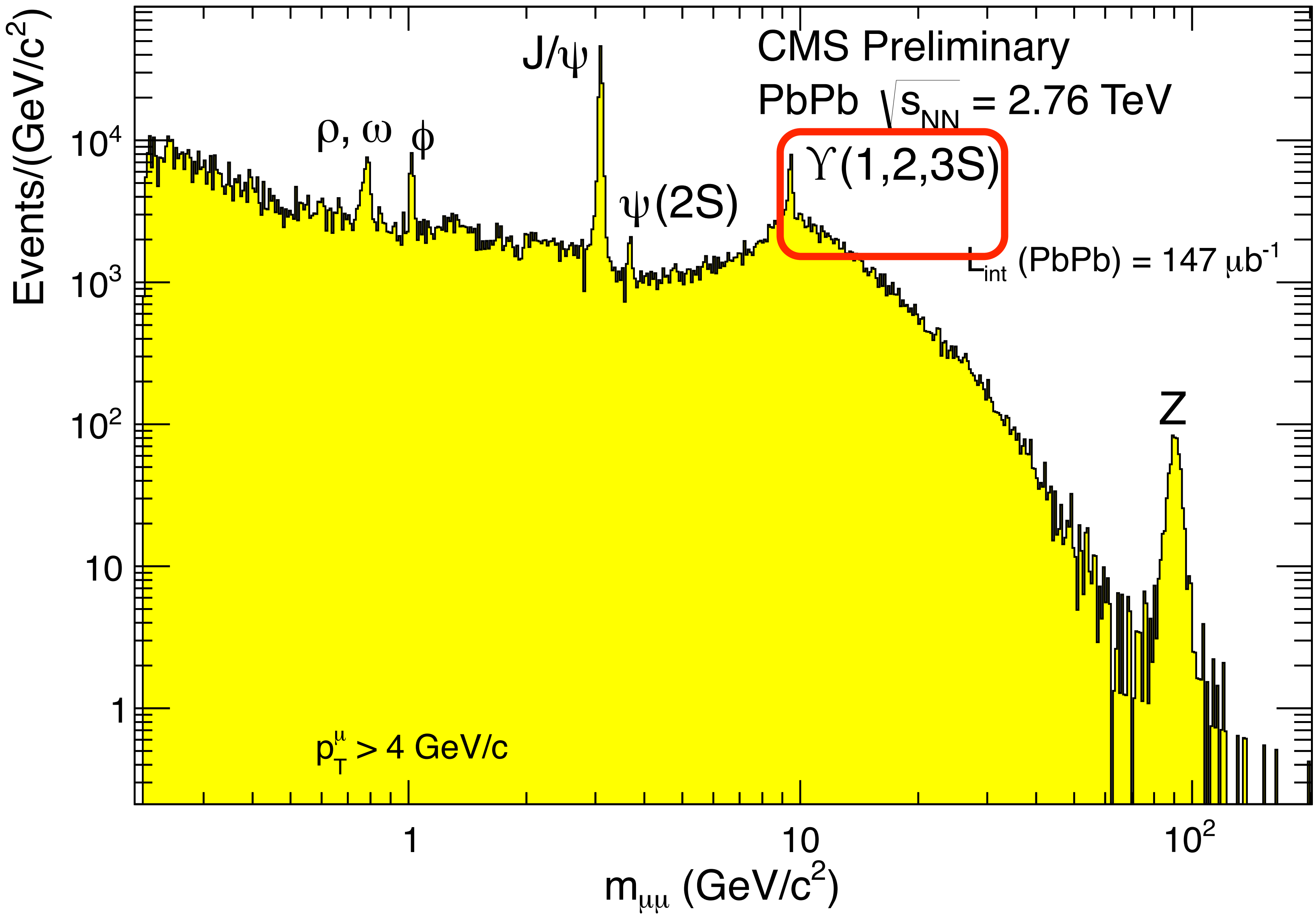




$$\frac{N_{\psi(2S)}/N_{J/\psi}|_{PbPb}}{N_{\psi(2S)}/N_{J/\psi}|_{pp}} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}$$

- **High-p_T:** $R_{AA}^{0-100\%}(\psi(2S)) = 0.11 \pm 0.03(\mathrm{stat}) \pm 0.02(\mathrm{syst}) \pm 0.02(\mathrm{pp})$
- **Low-p_T (<2σ):** $R_{AA}^{0-100\%}(\psi(2S)) = 1.54 \pm 0.32(\mathrm{stat}) \pm 0.22(\mathrm{syst}) \pm 0.76(\mathrm{pp})$

Bottomonia



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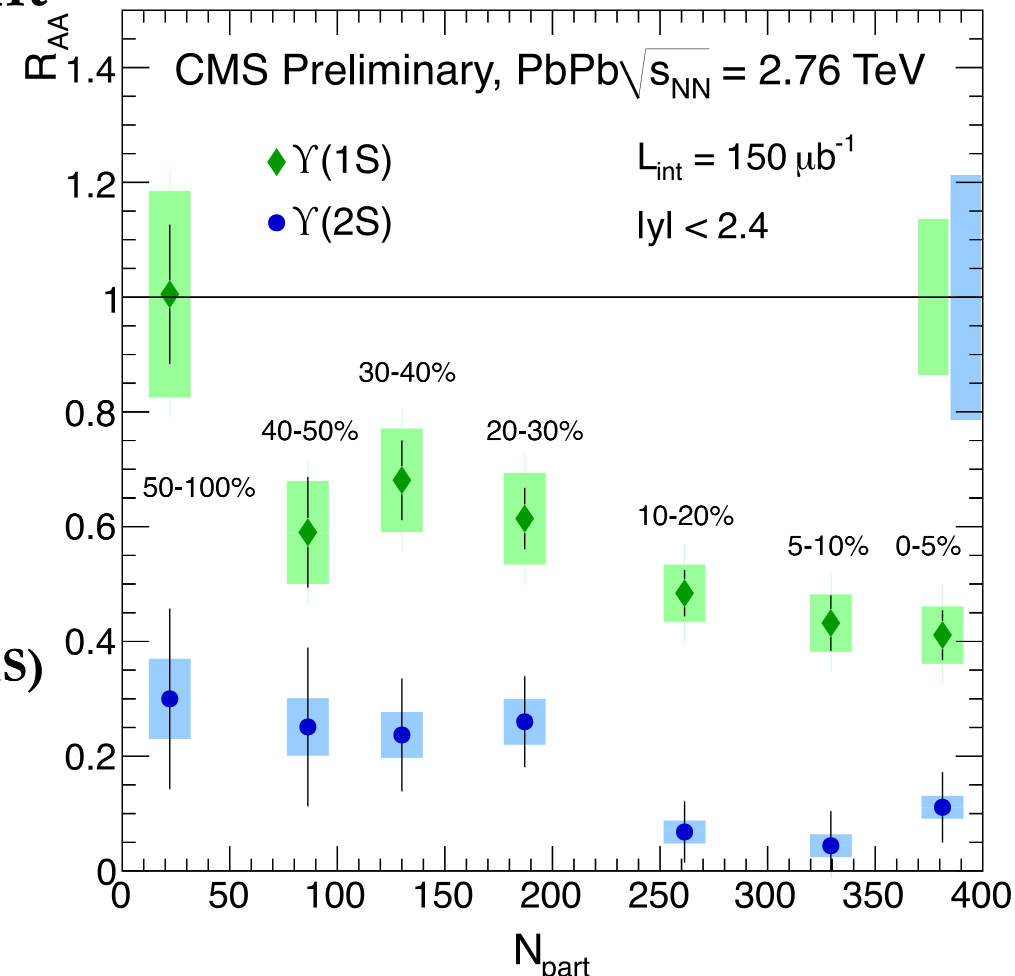
p_T^{μ} > 4 GeV/c
Events/(GeV/c^2)
$m_{\mu\mu}$ (GeV/c^2)

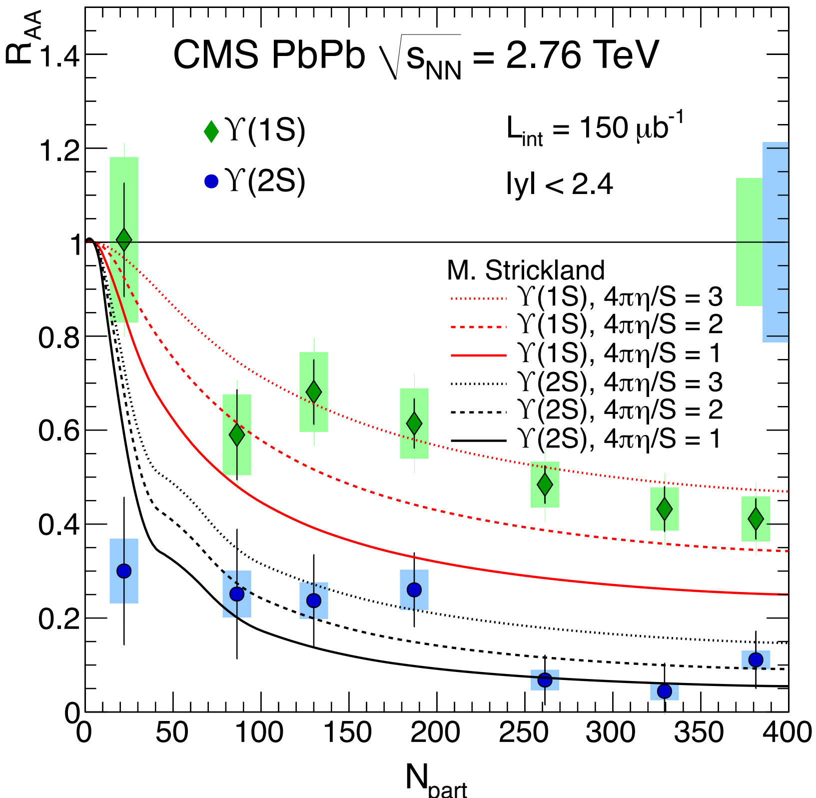
R_{AA}: Υ(1S), Υ(2S), Υ(3S)

- **First $R_{AA}^{\Upsilon(2S)}$ measurement**
- **Centrality integrated:**
  - Υ(1S): 0.56±0.08±0.07
  - Υ(2S): 0.12±0.04±0.02
  - Υ(3S): <0.10 at 95% CL
- **$R_{AA}^{\Upsilon(3S)} < R_{AA}^{\Upsilon(2S)} < R_{AA}^{\Upsilon(1S)}$**

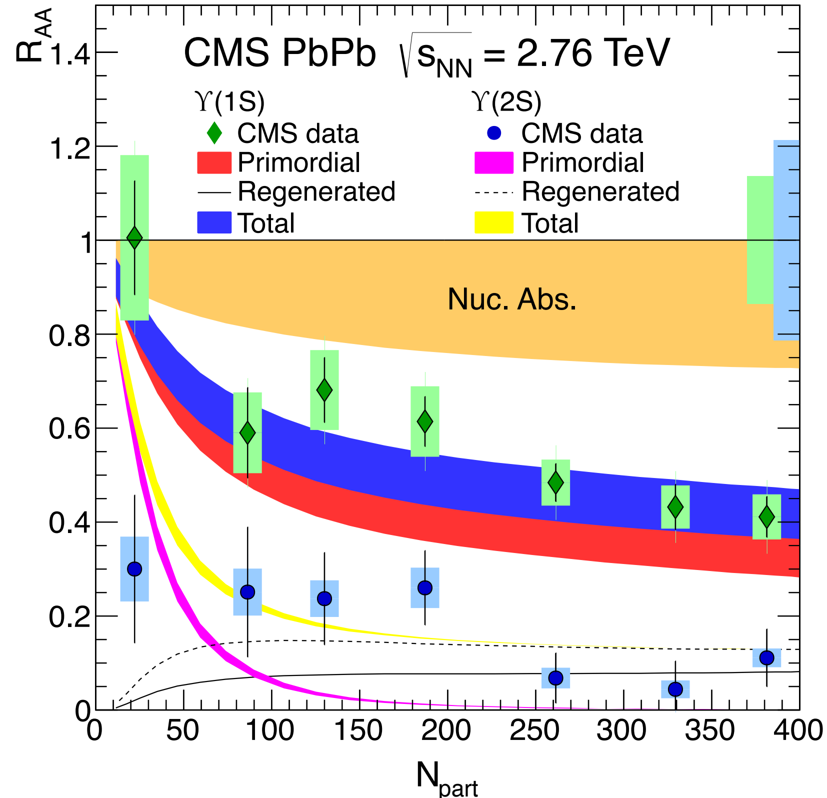


- **Ordered suppression → sequential melting**

Bottomonia: theory



arXiv:1207.5327v2



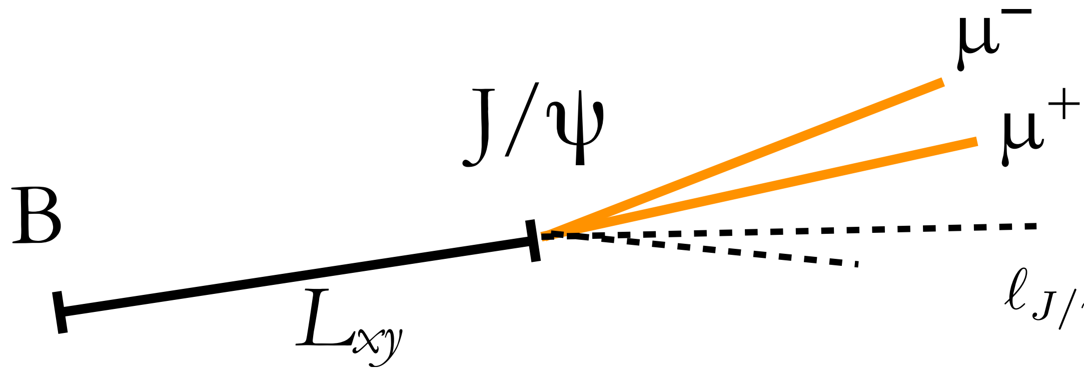
Eur.Phys. J. A48 (2012) 72

- **Against religion**: regeneration for the excited state, absorption/ shadowing to be considered

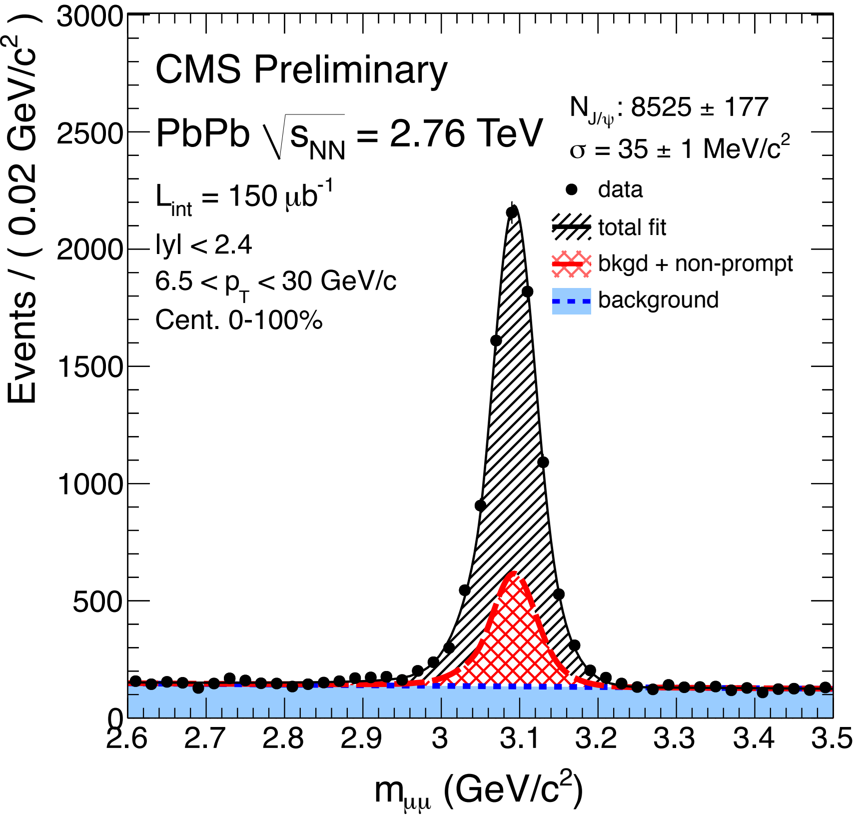
Transition slide …

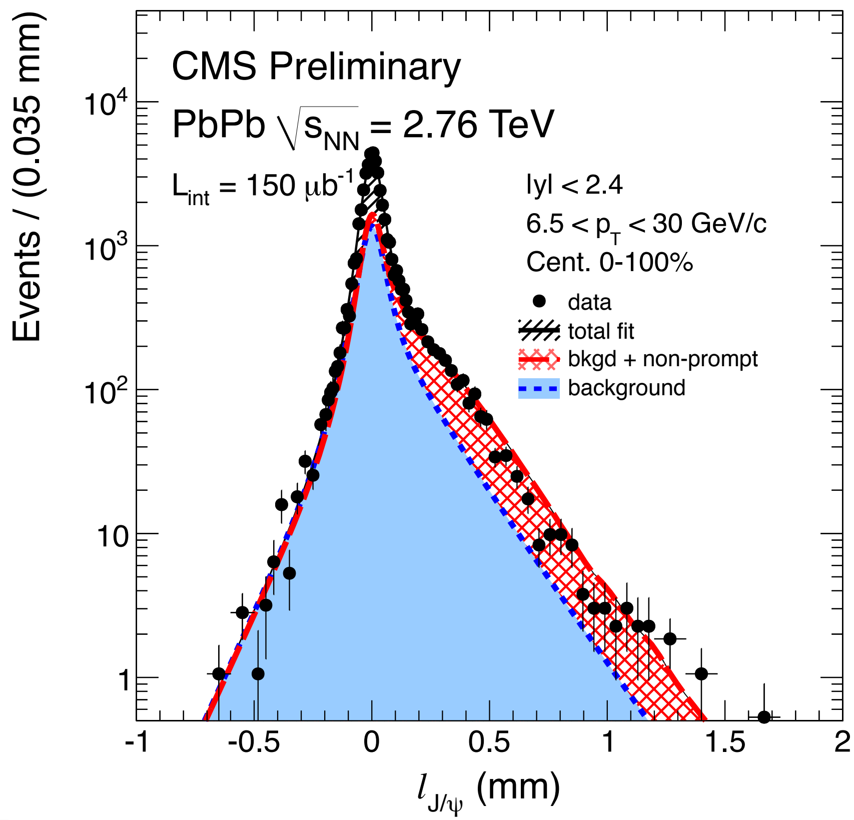
b-quark energy loss: non-prompt J/ψ

Mihee Jo, Friday Parallel 6A



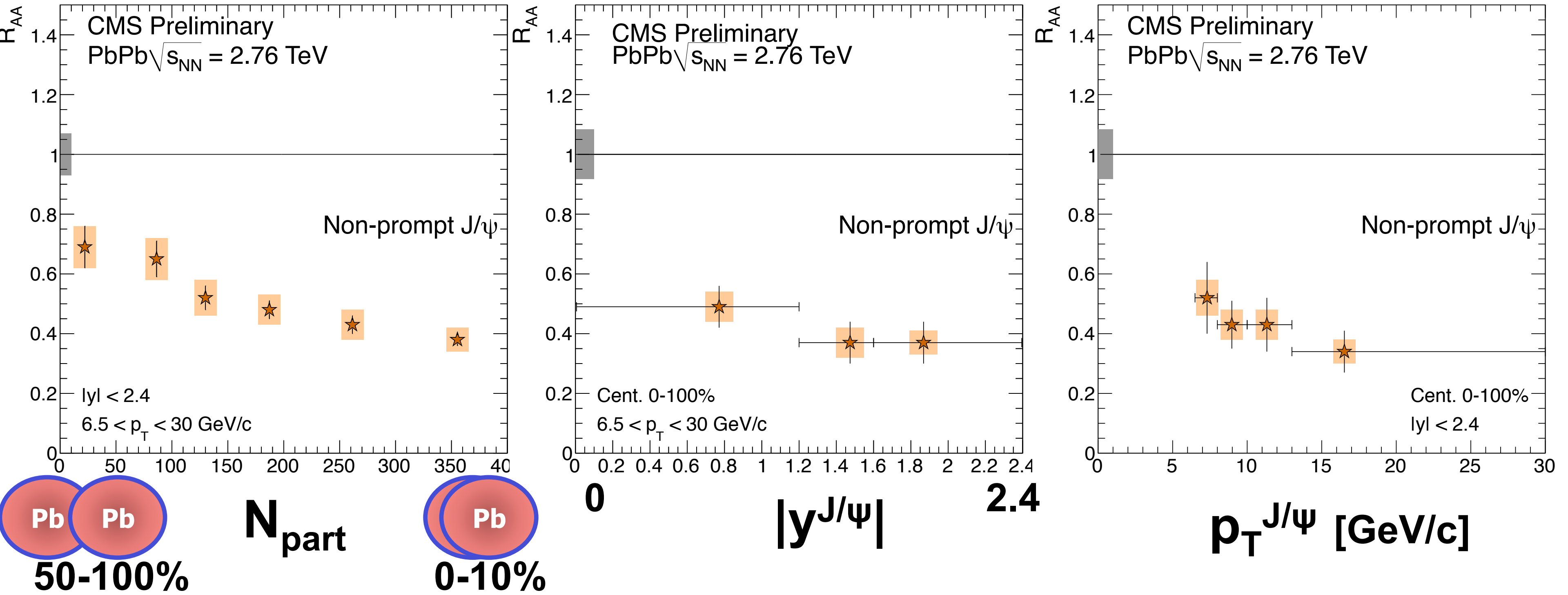
$$\ell_{J/\psi} = L_{xy}\frac{m_{J/\psi}}{p_T}$$





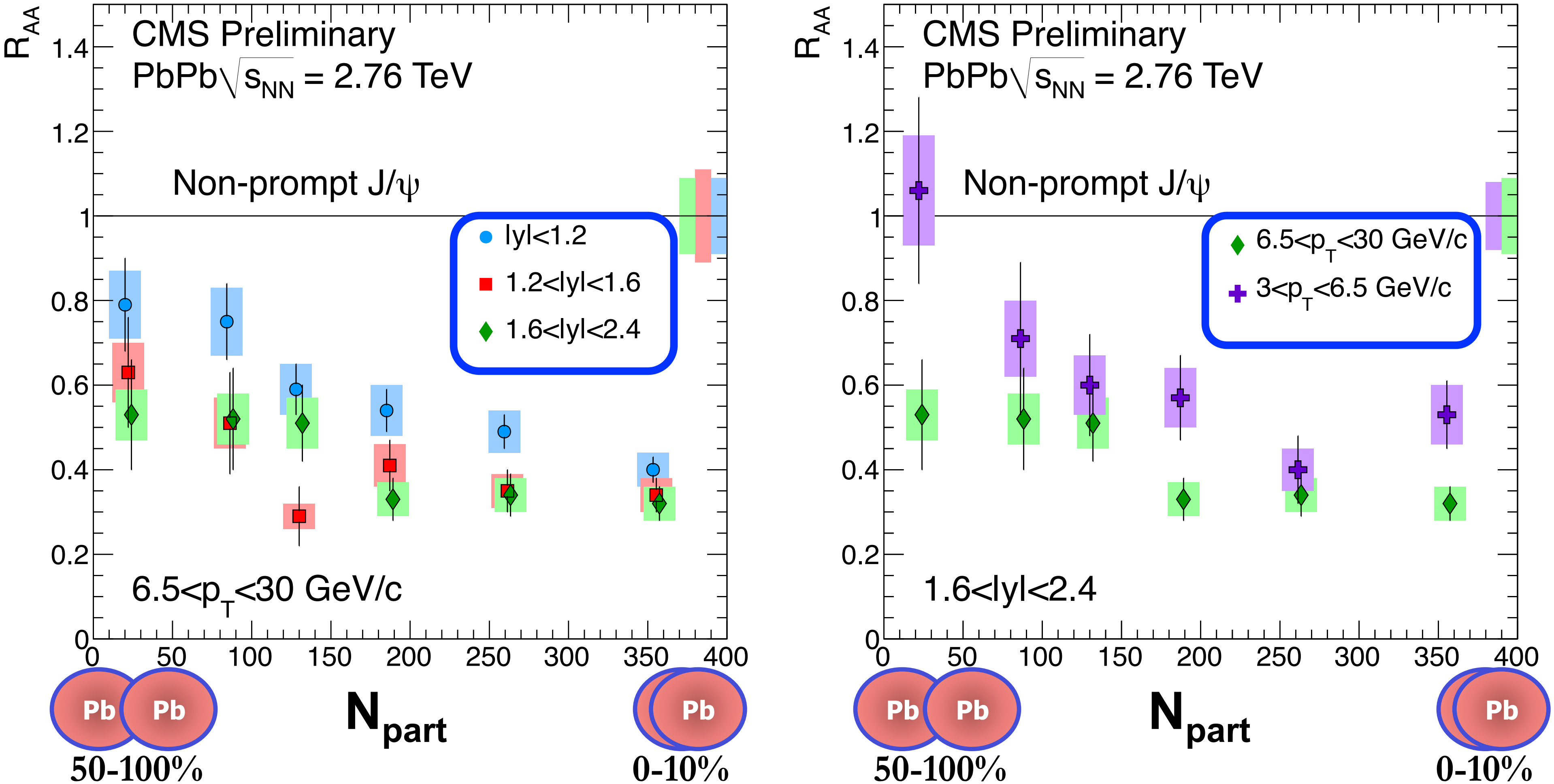
CMS-PAS HIN-12-014

R_{AA}: Non-prompt J/ψ ($B \rightarrow J/\psi$)



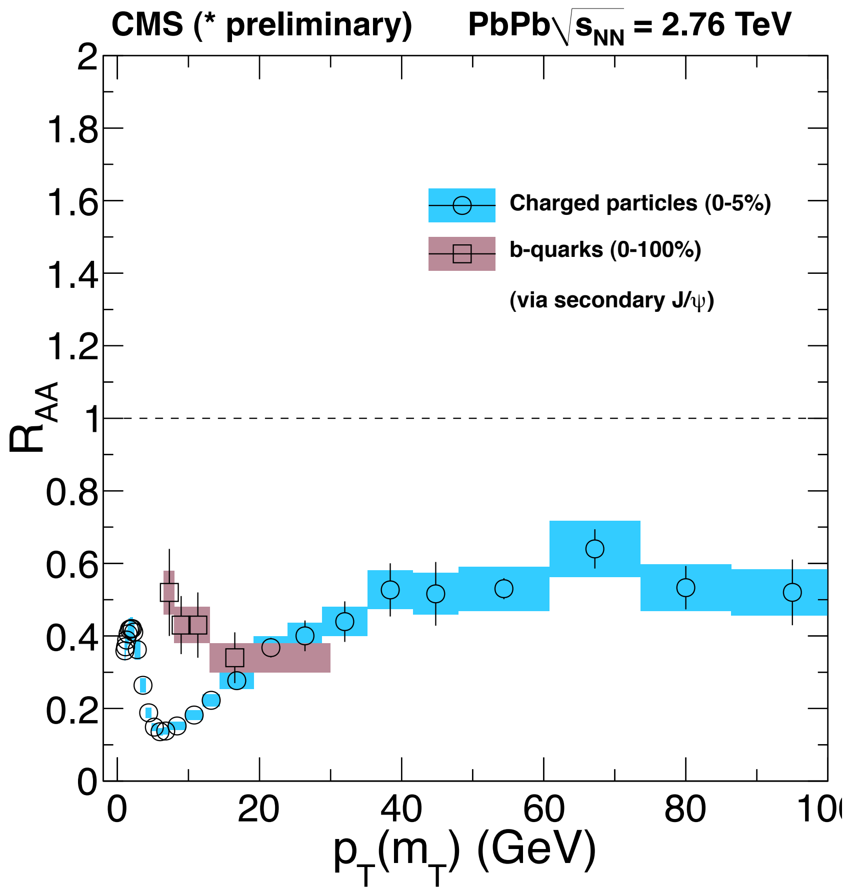
- **Centrality (p_T, y integrated)**: slow decrease of R_{AA}
  - 50-100%: factor ~1.4
  - 0-5%: factor ~2.5
- **y (p_T, centrality integrated)**: hints of less suppression at mid-rapidity
- **p_T(y, centrality integrated)**: hints of increasing suppression at high-p_T

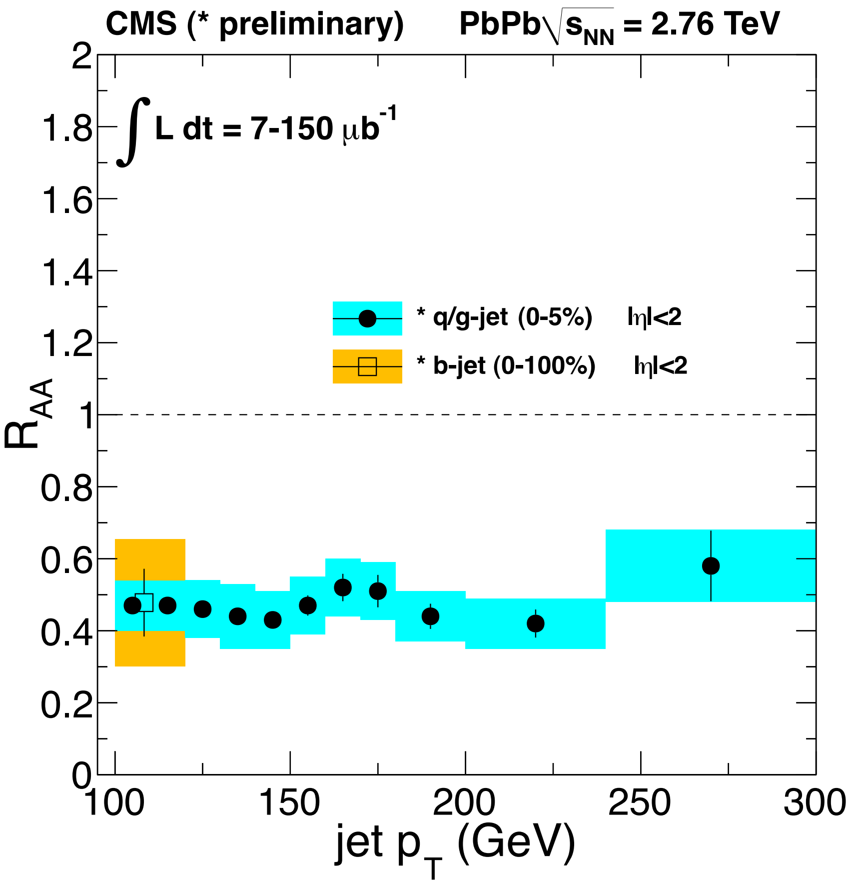
Non-prompt J/ψ: double-differential



- **6.5 < p_T < 30 GeV/c:** hint of more suppression at forward y
- **1.6 < |y| < 2.4:** hint of less suppression for lower p_T

Light vs Heavy partons energy loss



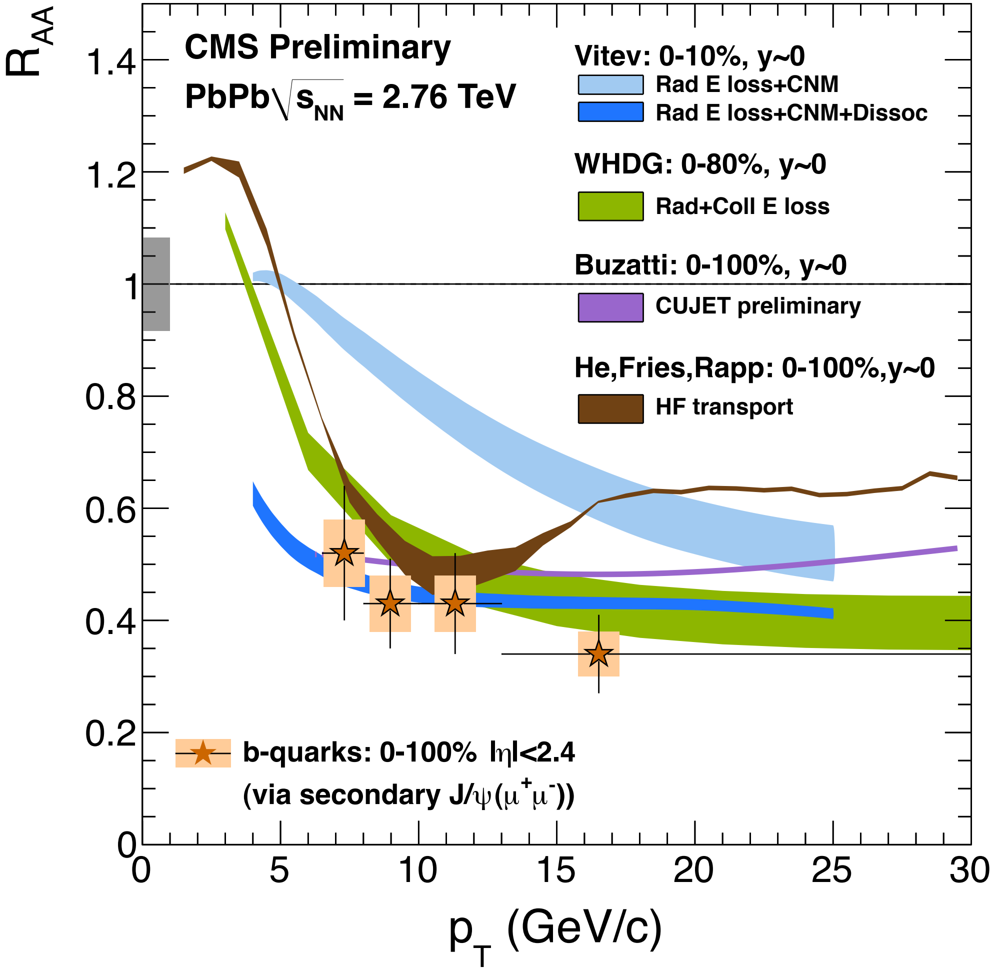


- At low-p_T: different suppression pattern than light
- At high-p_T: b and light similar suppression

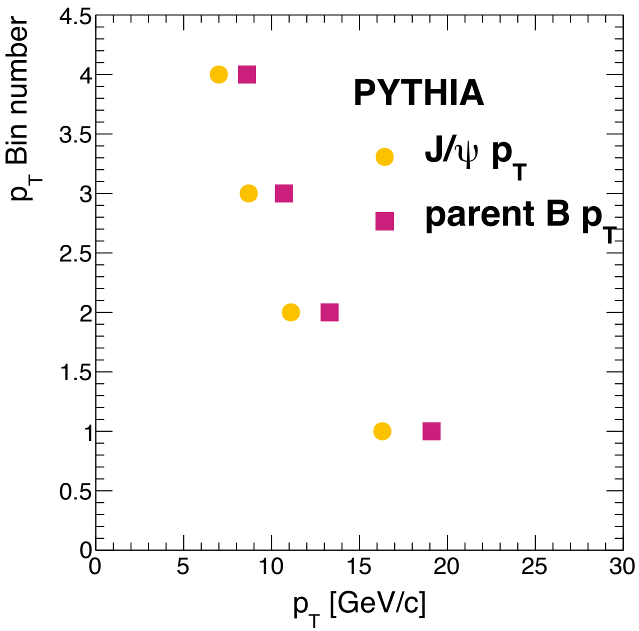
EPJC 72 (2012) 1945

CMS-PAS HIN-12-003
CMS-PAS HIN-12-004
CMS-PAS HIN-12-014

B→J/ψ: theory



- Data points: p_T of J/ψ
- Theory: p_T of B



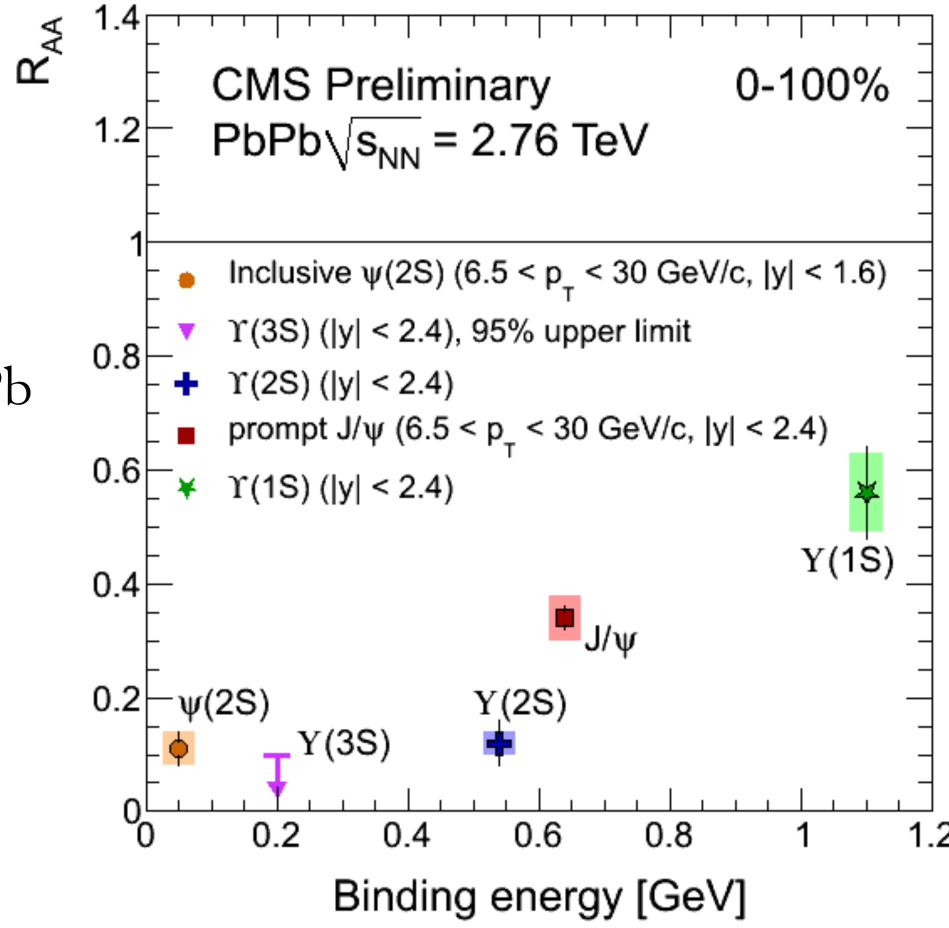
Vitev: J. Phys.G35 (2008) 104011 + private communications
Horowitz: arXiv:1108.5876 + private communications
Buzzatti, Gyulassy: arXiv: 1207.6020+ private communications
He, Fries, Rapp: PRC86(2012)014903+ private communications

- **Radiative energy loss not enough to describe data**

Summary: there is order ...

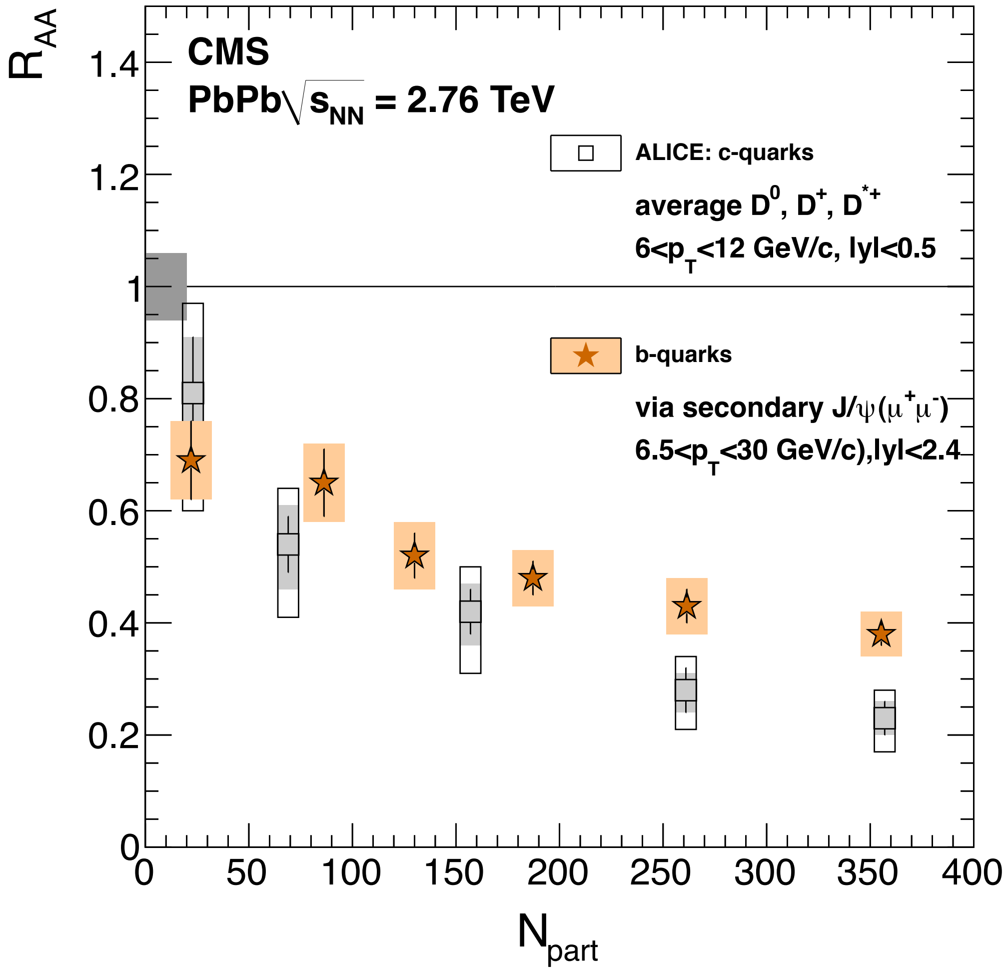
1) Closed charm and beauty: Yes, we can!

- **The sequential melting map is experimentally drawn**
  - Map includes: hot and cold effects (feed-down, nuclear absorption (pPb run), etc)
  - Looser bound states are more suppressed than the tighter bound states



arXiv: 1208.2826
CMS-PAS HIN-12-007
CMS-PAS HIN-12-014

2) Open charm and beauty: Yes, it does!



- In central collisions, R_{AA} hierarchy

$$R_{AA}^{charm} < R_{AA}^{bottom}$$

arXiv:1205.6443

CMS-PAS HIN-12-014