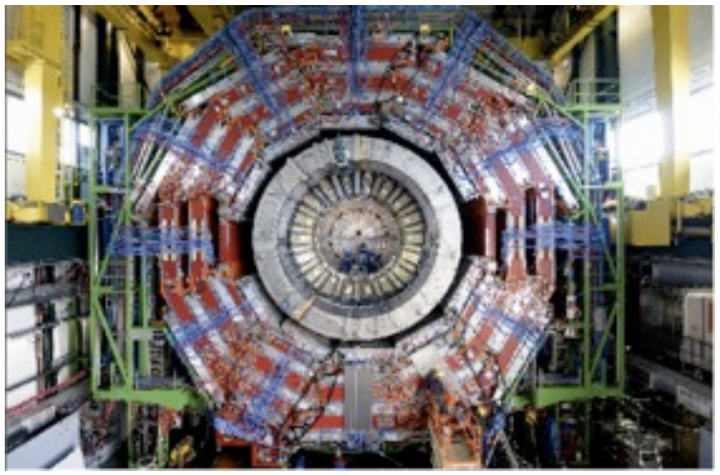
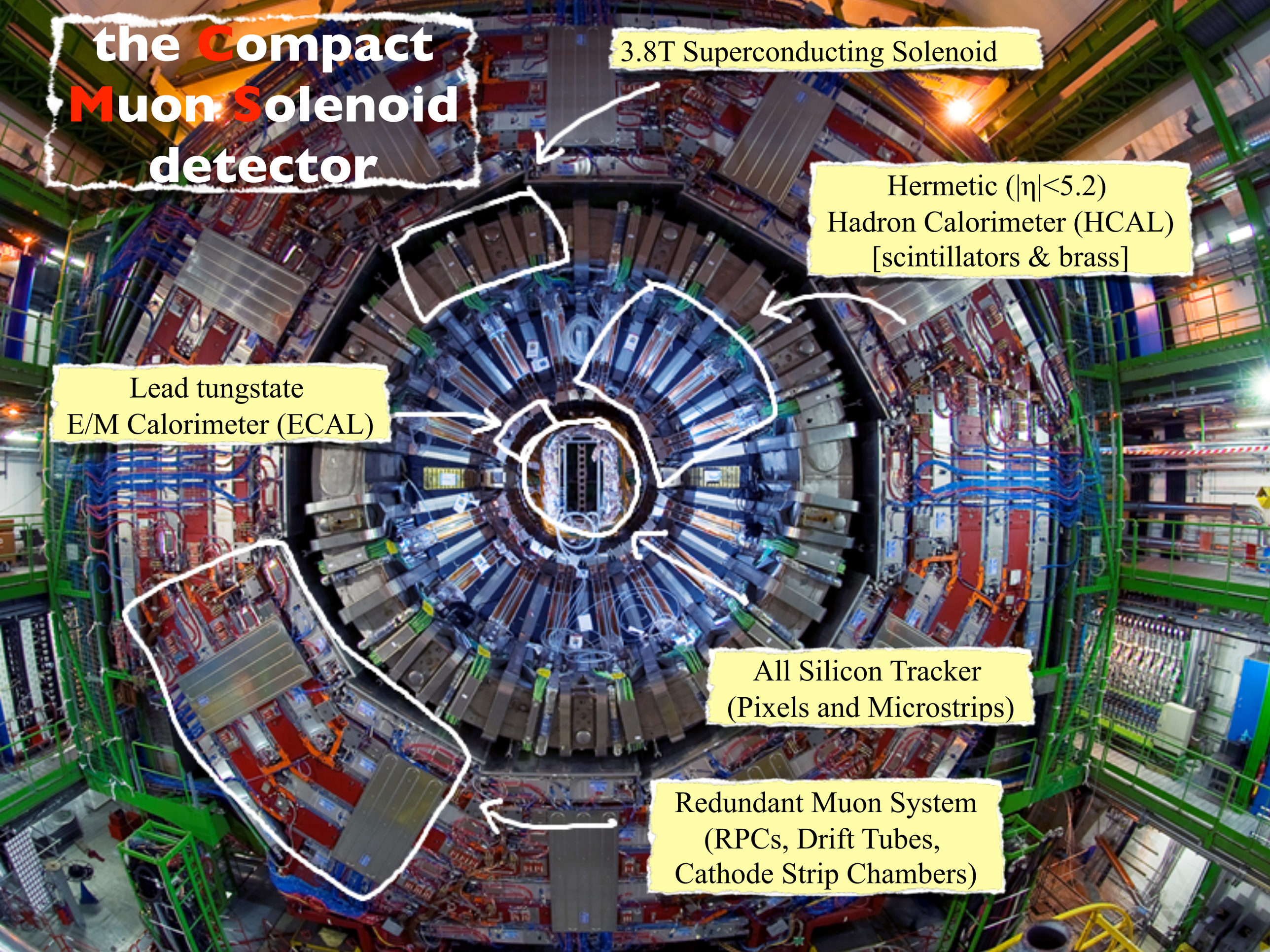
# Quarkonium suppression in PbPb collisions @ CMS



Nuno Leonardo
(Purdue University)
On behalf of the CMS Collaboration

ICHEP 2012, July 6

ICHEP2012
Melbourne


the Compact Muon Solenoid detector
3.8T Superconducting Solenoid
Hermetic (|η|<5.2) Hadron Calorimeter (HCAL) [scintillators & brass]
Lead tungstate E/M Calorimeter (ECAL)
All Silicon Tracker (Pixels and Microstrips)
Redundant Muon System (RPCs, Drift Tubes, Cathode Strip Chambers)

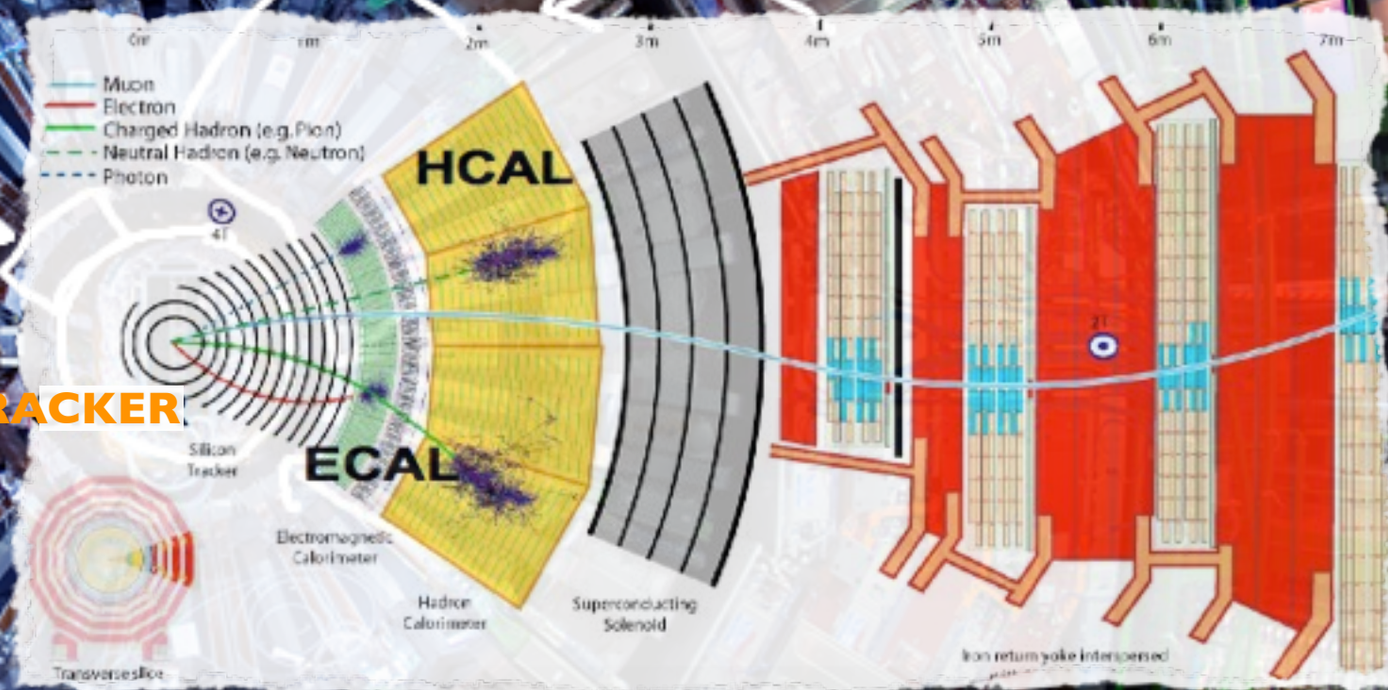
# the Compact Muon Solenoid detector

Text

3.8T Superconducting Solenoid

Hermetic (|η|<5.2)
Hadron Calorimeter (HCAL)
[scintillators & brass]

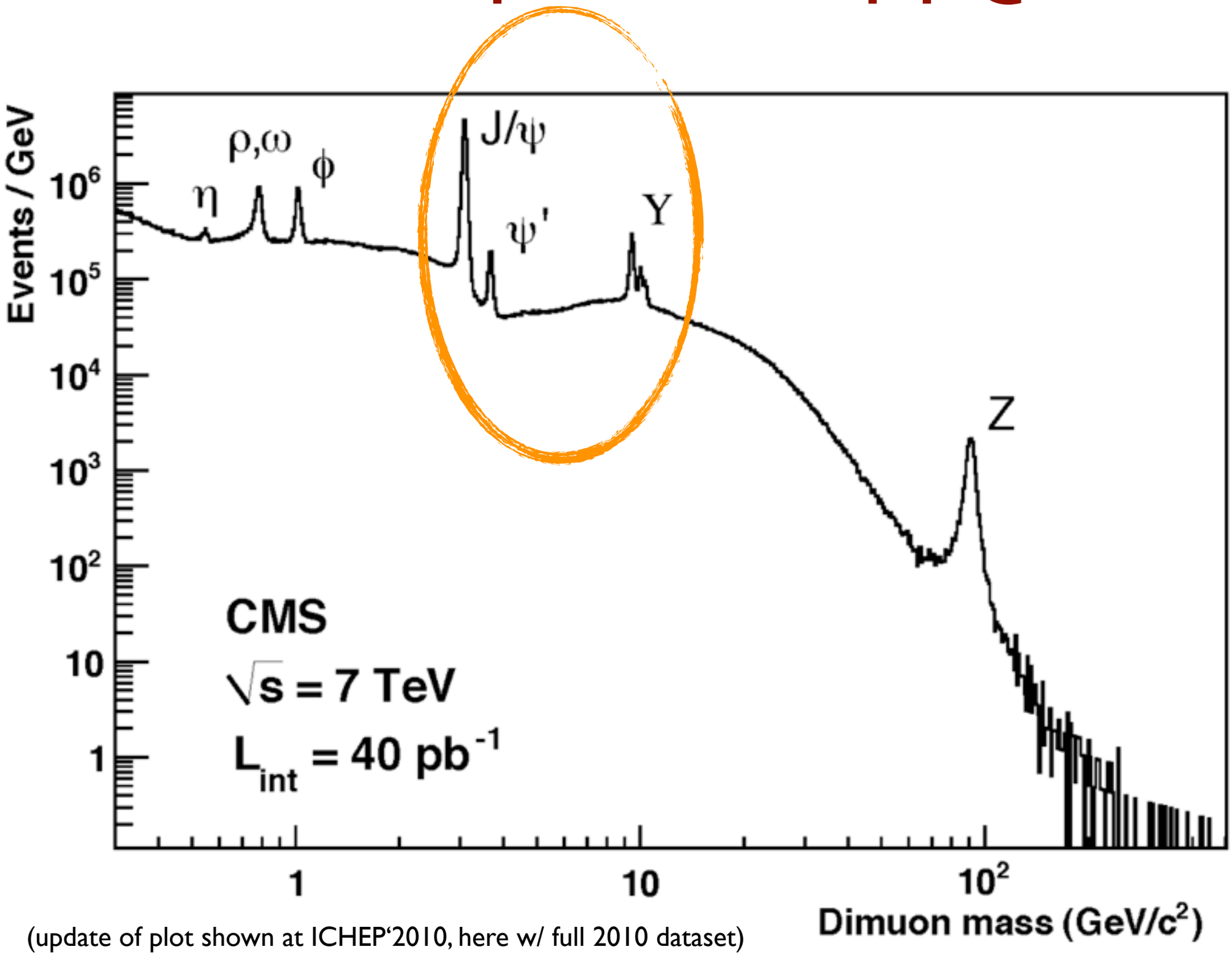
Lead tungstate
E/M Calorimeter (ECAL)




All Silicon Tracker
(Pixels and Microstrips)

Redundant Muon System
(RPCs, Drift Tubes,
Cathode Strip Chambers)

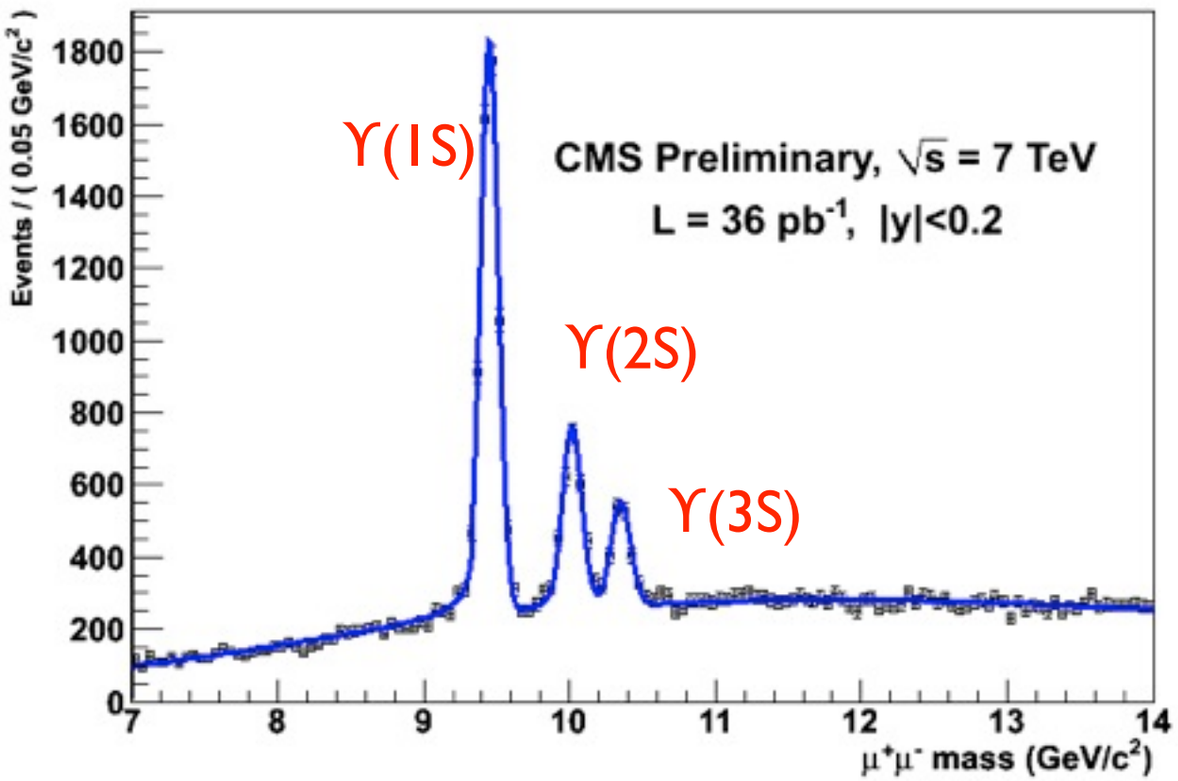
# dimuon spectrum pp@7TeV

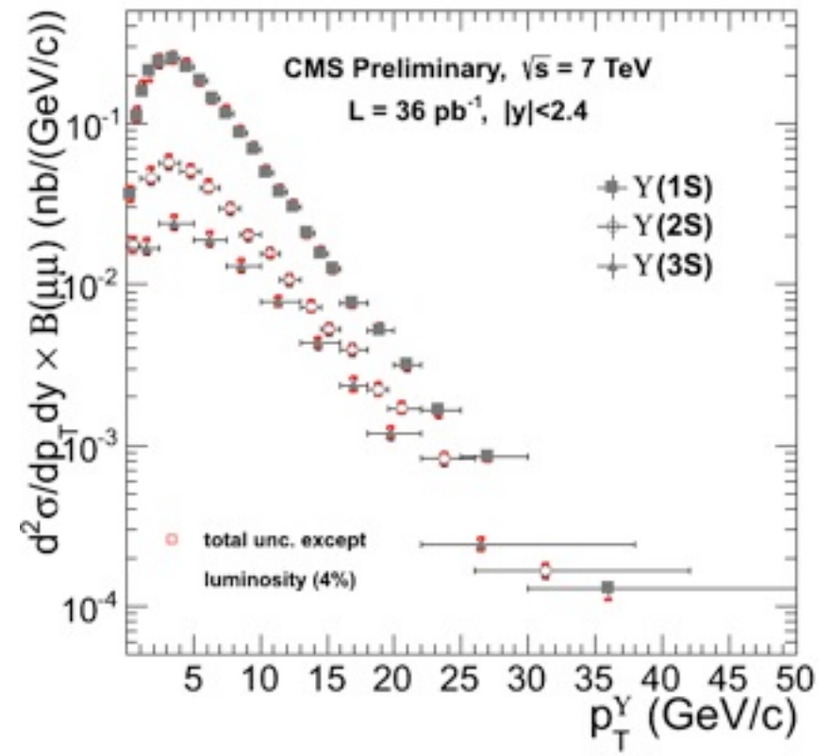



(update of plot shown at ICHEP'2010, here w/ full 2010 dataset)

# quarkonium production pp@7TeV

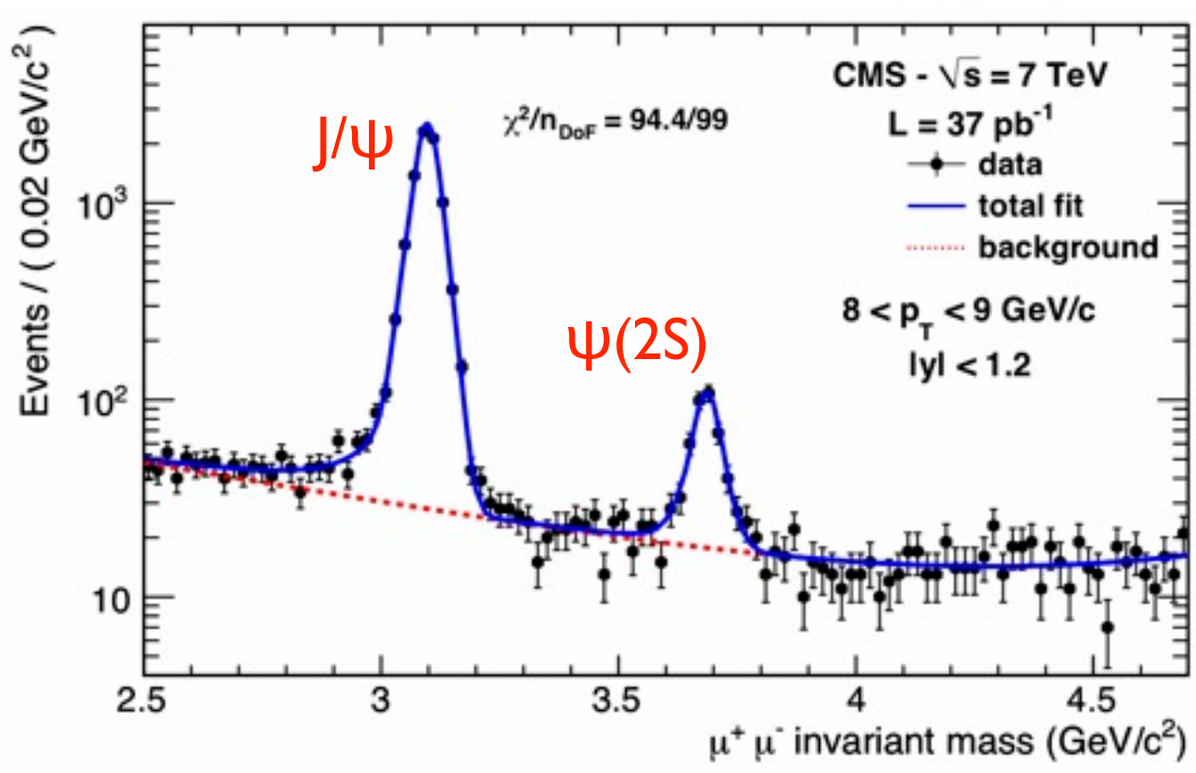
bottomonia

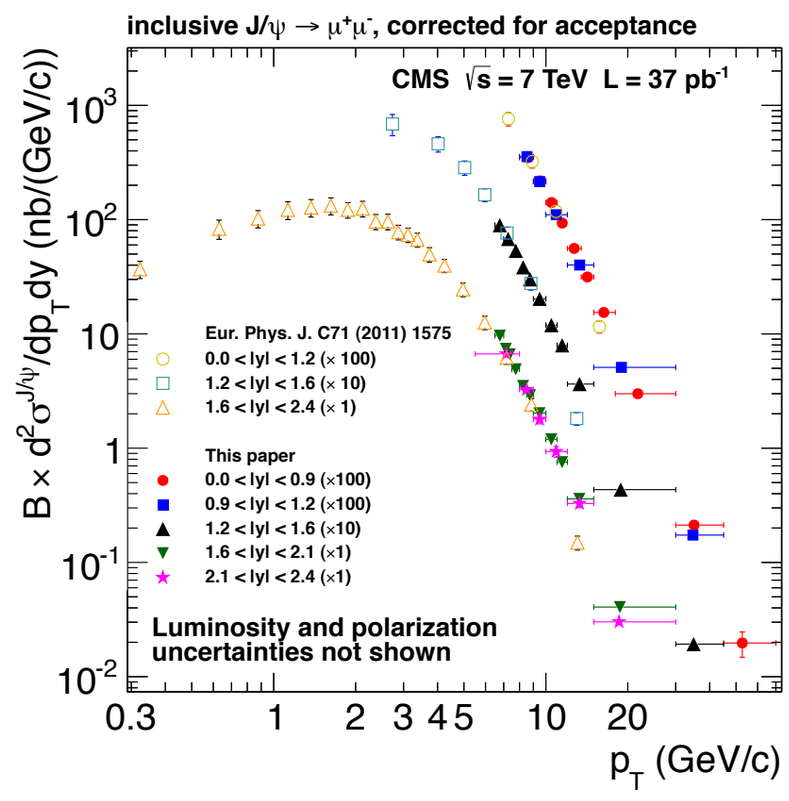



CMS-BPH-11-001

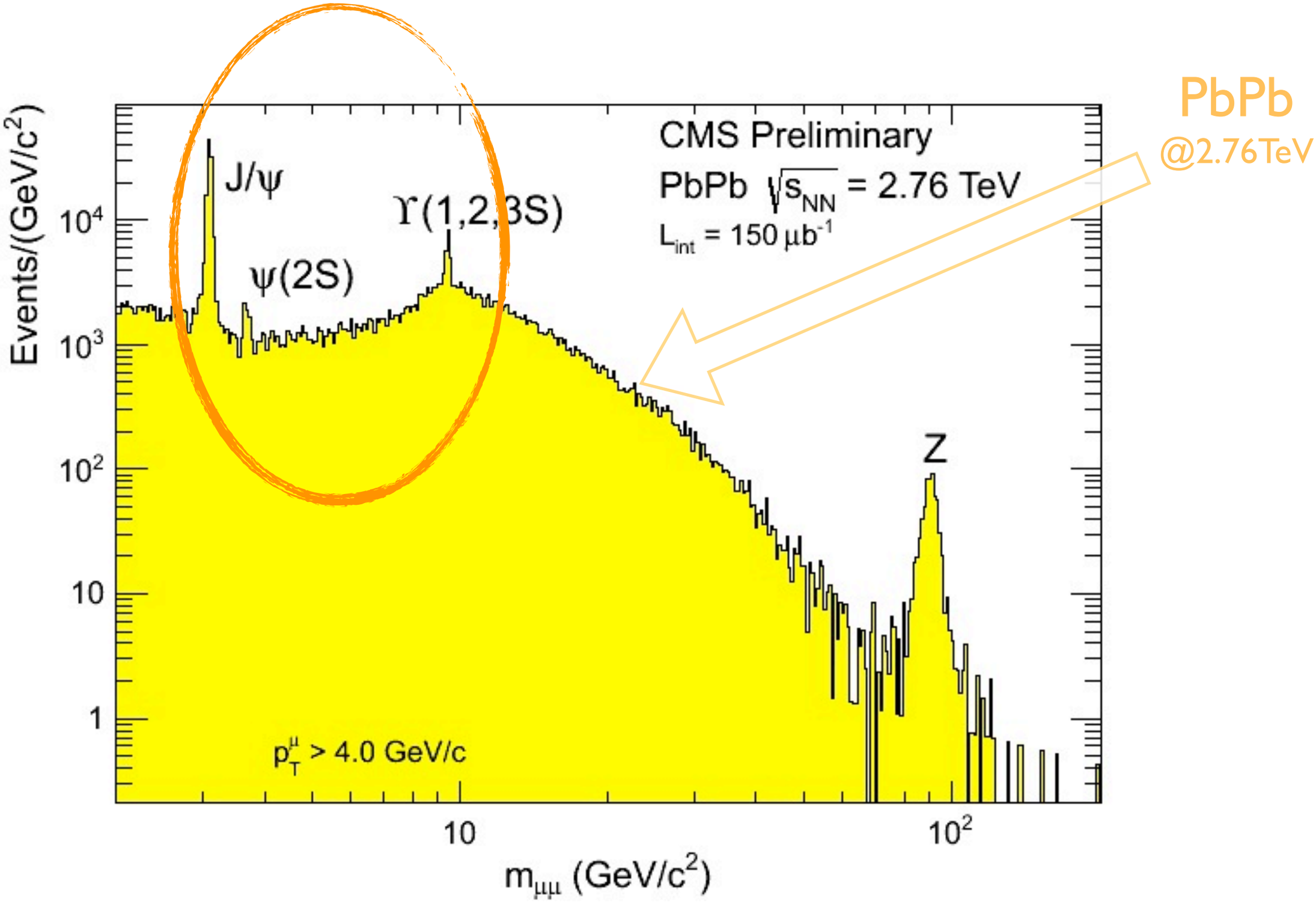
charmonia



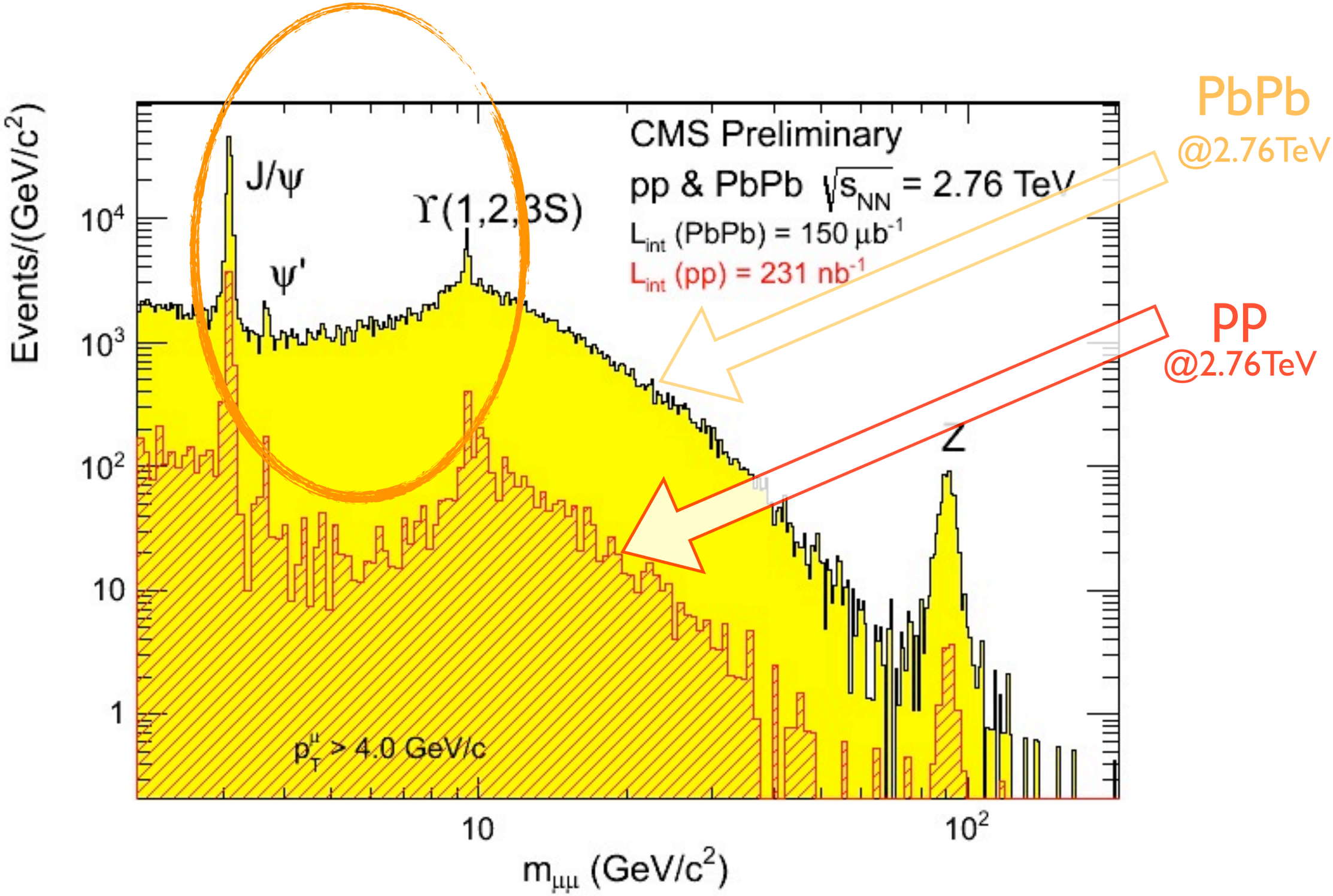




JHEP 02 (2012) 011

# dimuon spectrum @2.76TeV

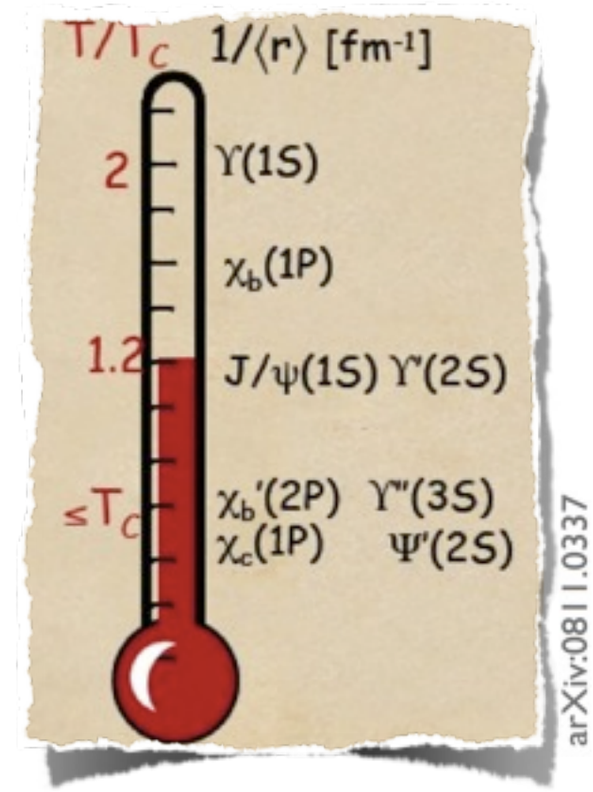


# dimuon spectrum @2.76TeV



# quarkonia as probe for QGP

- one of the most striking expected characteristics of QGP formation is the suppression of quarkonium states
  - Debye color-screening of the $Q$-$\overline{Q}$ binding potential
  - suppression pattern ⇒ indication of medium temperature

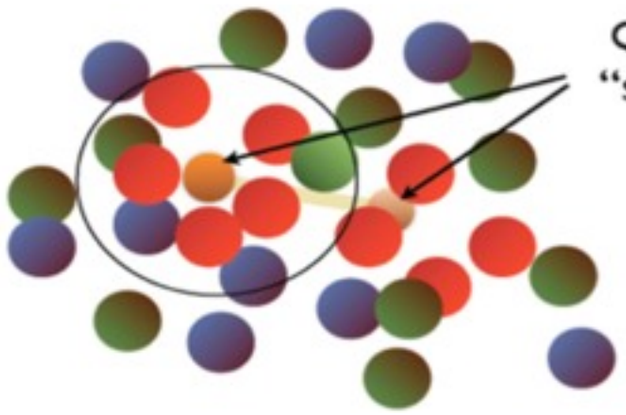



expect sequential melting

## Matsui-Satz: screening the potential

PLB178, 416 (1986)

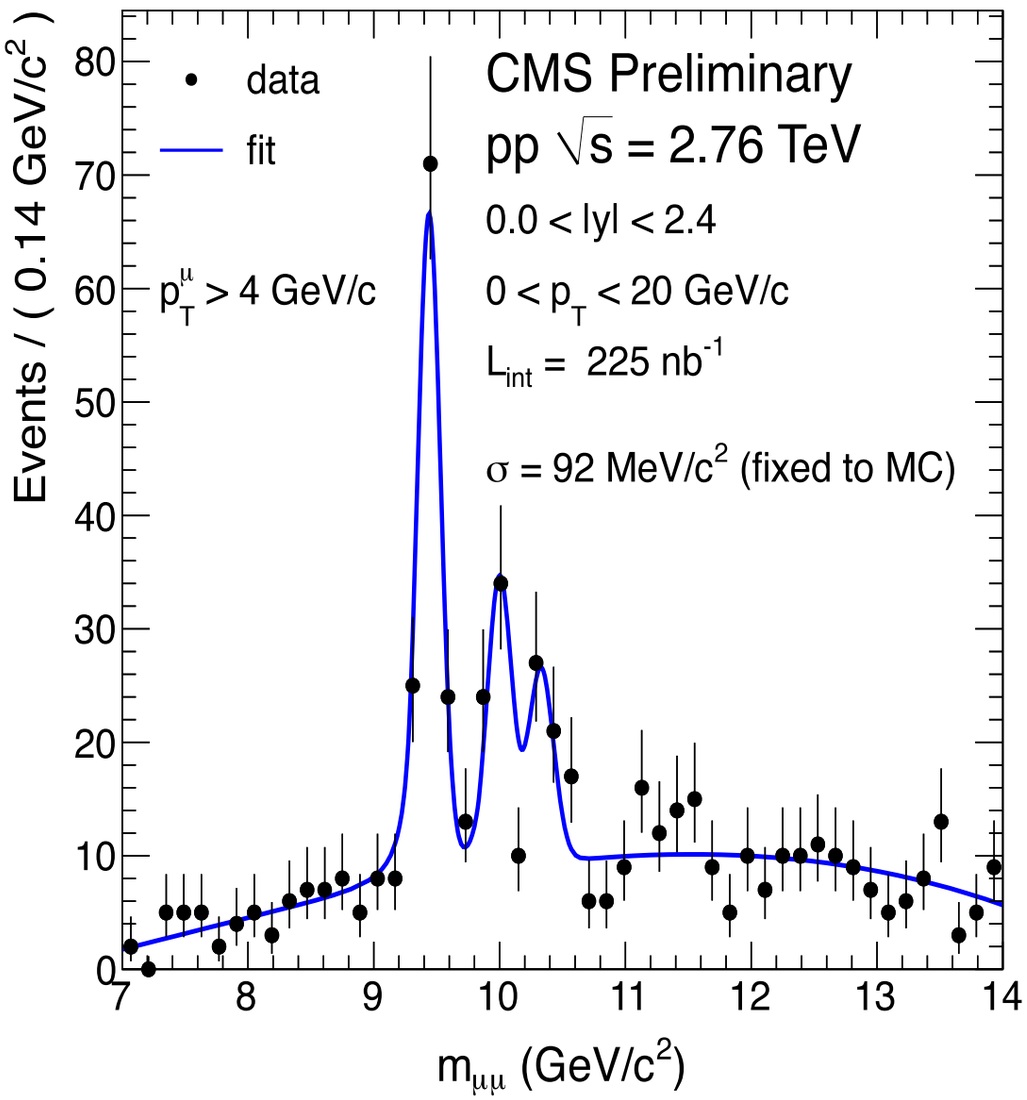
Screening in a deconfined medium: effective charge of $Q$ and $\bar{Q}$ reduced



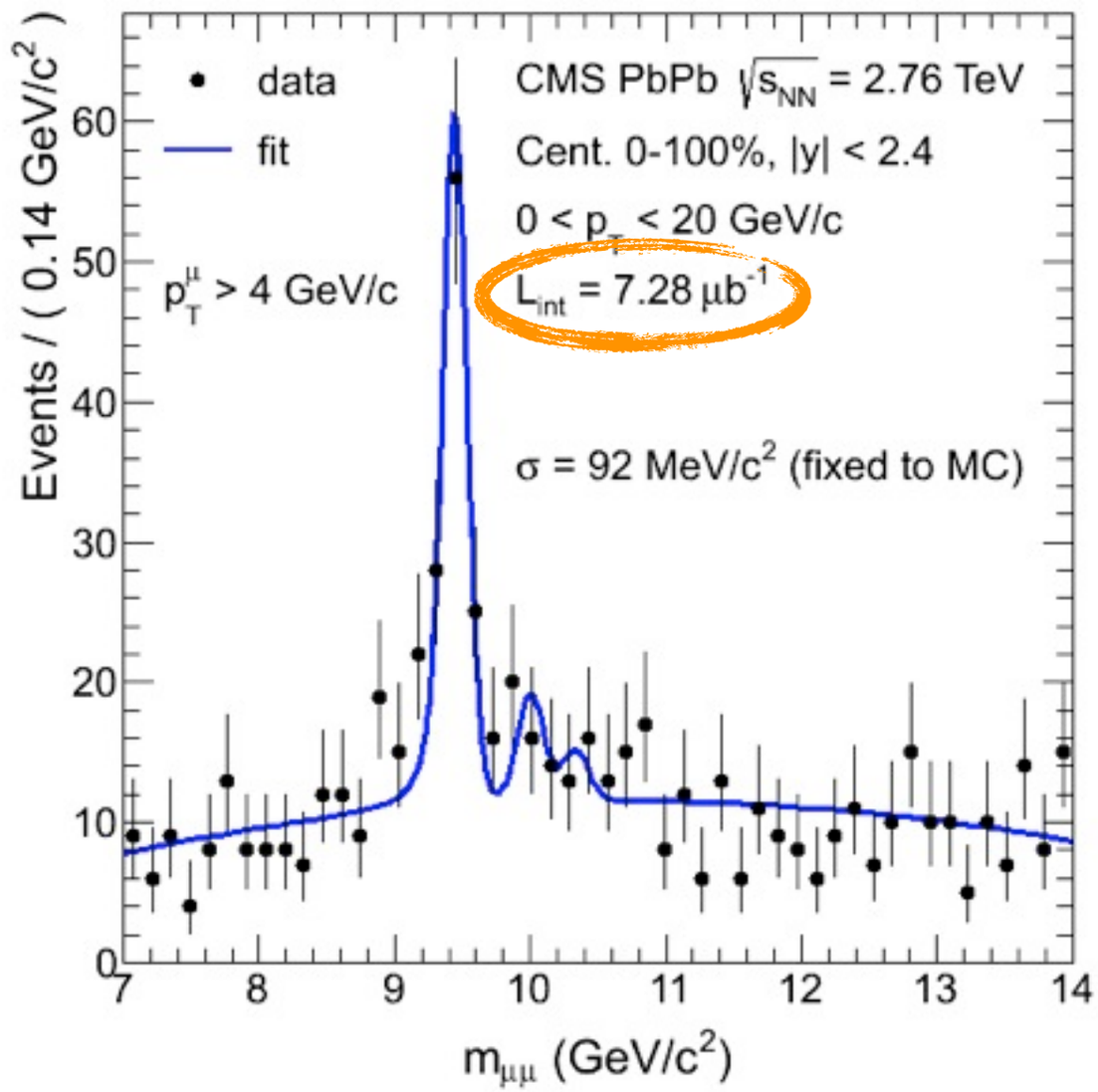
$Q$ and $\bar{Q}$ cannot "see" each other
$r_D < r_{Q\bar{Q}}$

| | charmonia | | | bottomonia | | | | |
|---|---|---|---|---|---|---|---|---|
| State | $J/\psi$ (1S) | $\chi_c$ (1P) | $\psi'$ (2S) | $\Upsilon$ (1S) | $\chi_b$ (1P) | $\Upsilon'$ (2S) | $\chi_b'$ (2P) | $\Upsilon''$ (3S) |
| m (GeV/c$^2$) | 3.10 | 3.53 | 3.68 | 9.46 | 9.99 | 10.02 | 10.26 | 10.36 |
| $r_0$ (fm) | 0.50 | 0.72 | 0.90 | 0.28 | 0.44 | 0.56 | 0.68 | 0.78 |

# suppression of excited Υ(nS) states




2010 PbPb data

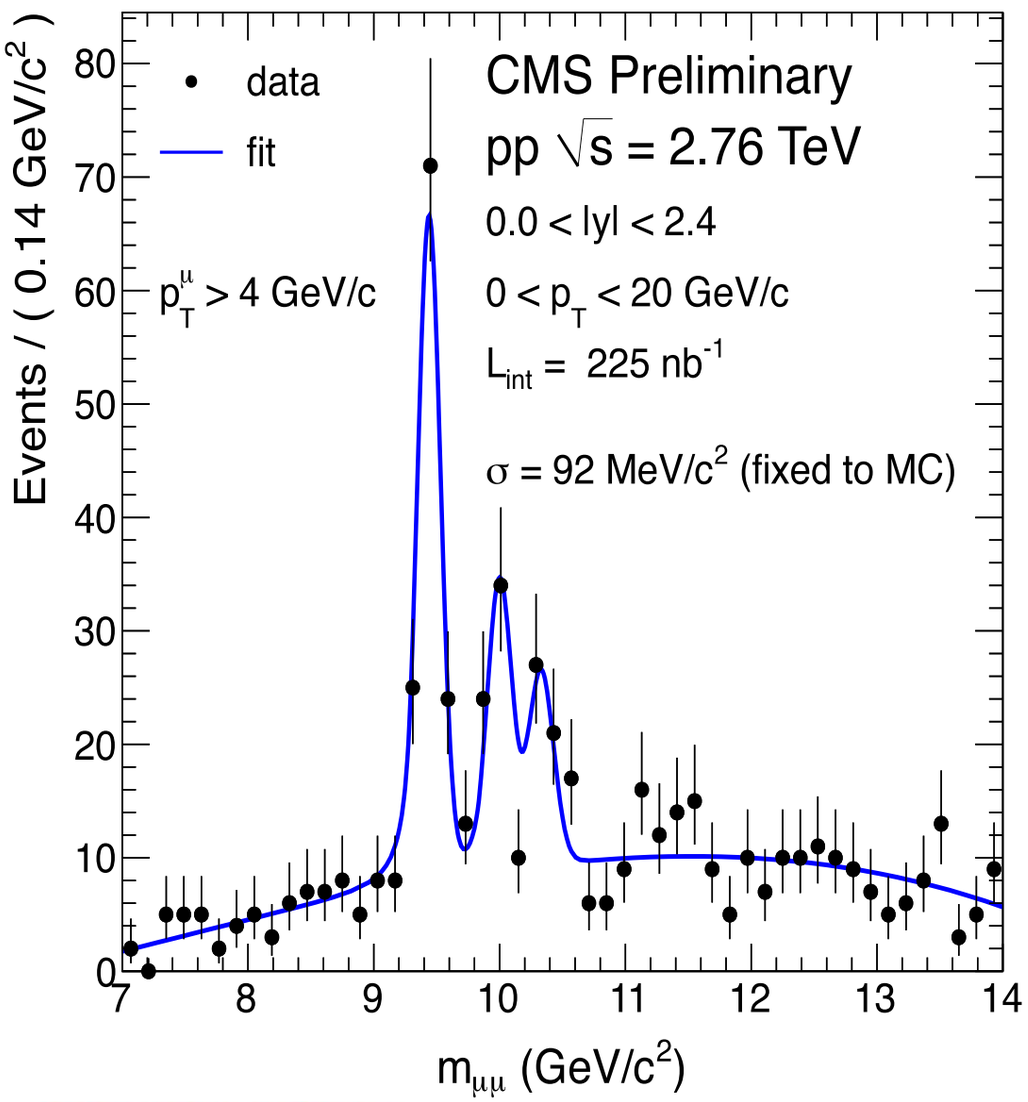



$$\frac{N_{\Upsilon(2S+3S)}/N_{\Upsilon(1S)}|_{\mathrm{PbPb}}}{N_{\Upsilon(2S+3S)}/N_{\Upsilon(1S)}|_{\mathrm{pp}}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$

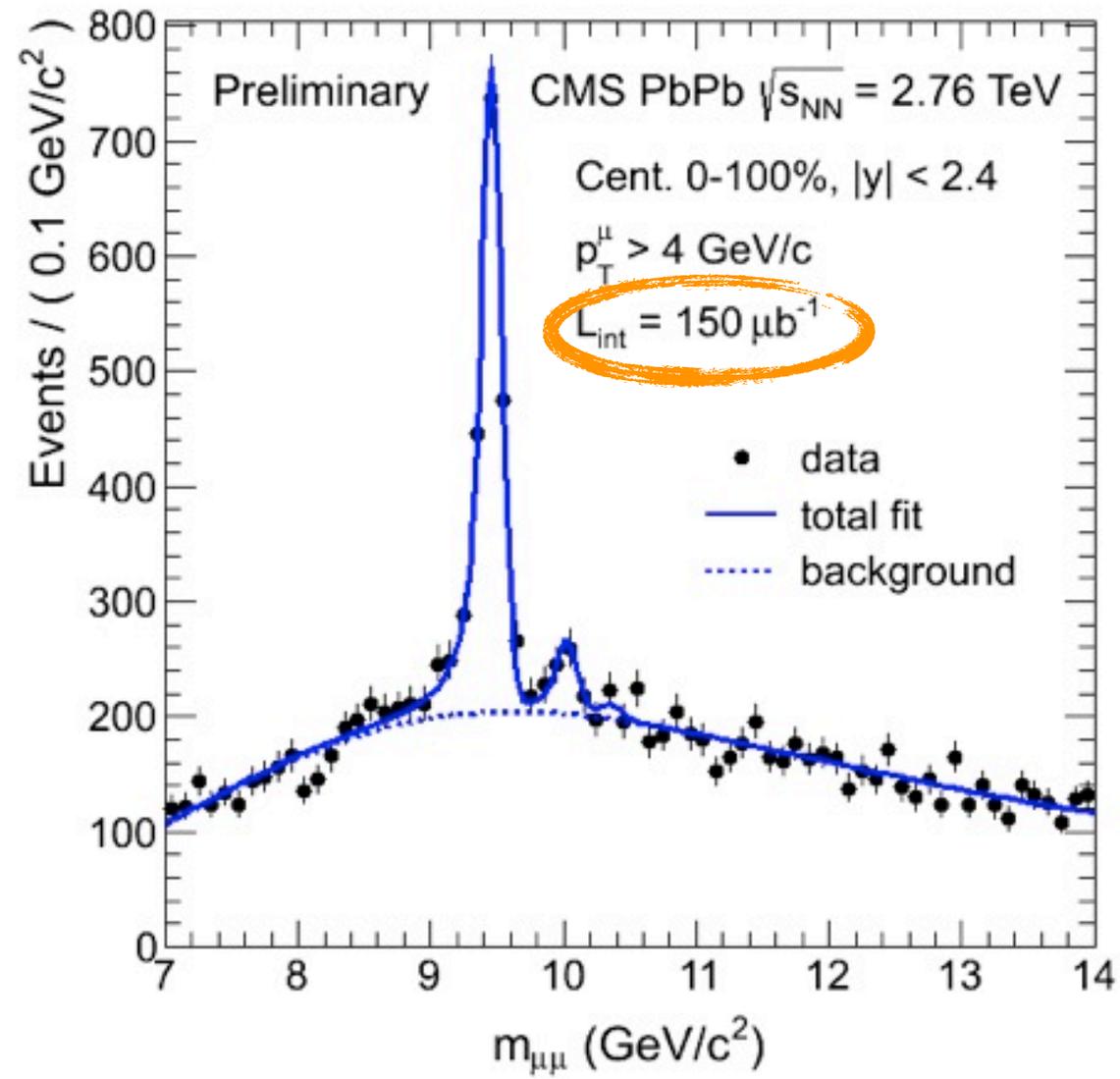
indication of 2S+3S relative suppression
(significance: 2.4σ, p-value 0.9%)

**PRL 107 (2011) 052302**

# suppression of excited Υ(nS) states




**2011 PbPb data**




$$\frac{\Upsilon(2S)/\Upsilon(1S)|_{PbPb}}{\Upsilon(2S)/\Upsilon(1S)|_{pp}} = 0.21 \pm 0.07 \pm 0.02$$

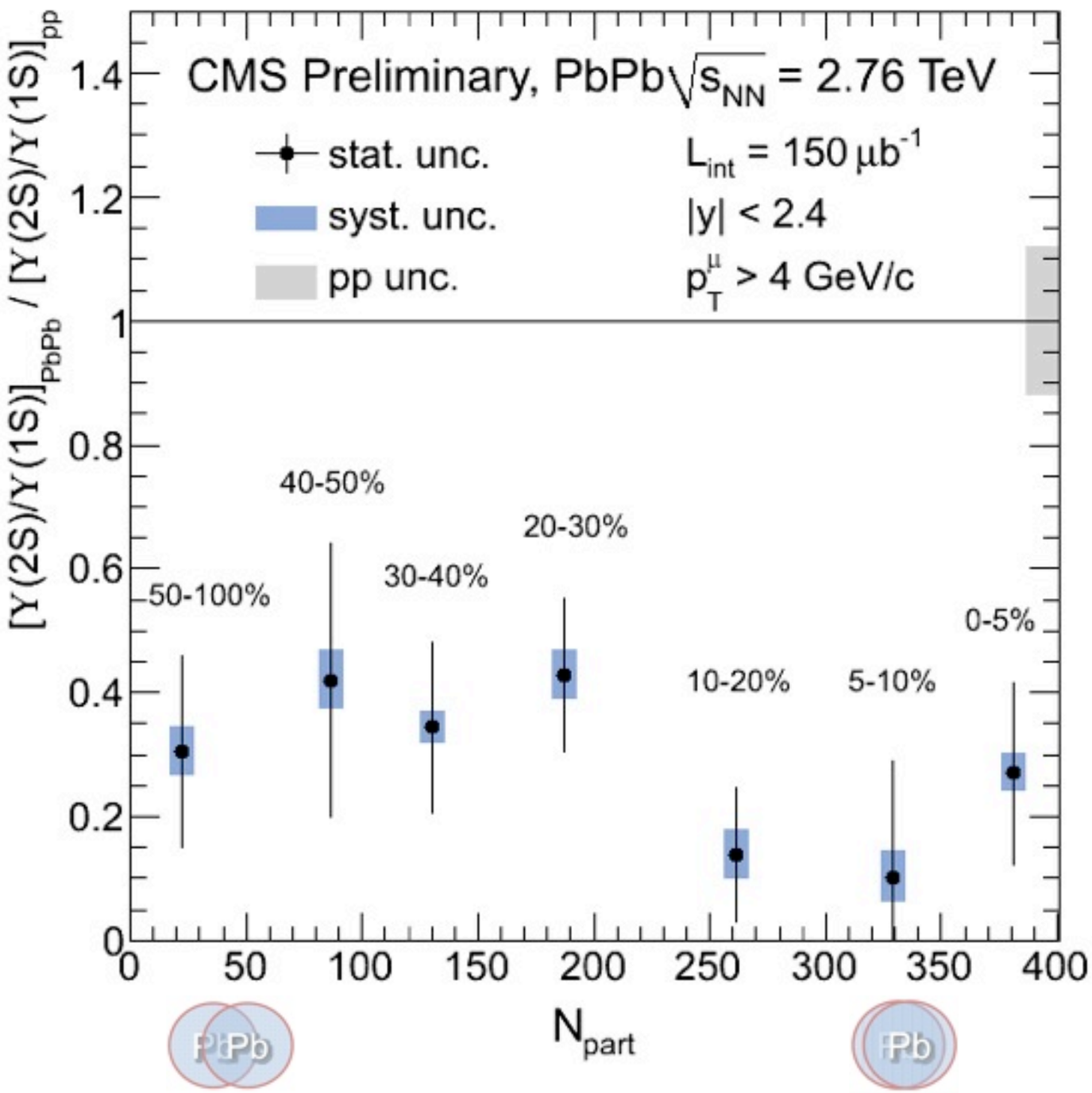
$$\frac{\Upsilon(3S)/\Upsilon(1S)|_{PbPb}}{\Upsilon(3S)/\Upsilon(1S)|_{pp}} < 0.17 \quad (95\%\ \text{C.L.})$$

observation of relative suppression (significance larger than 5σ)

**HIN-11-011**

# Υ(nS)/Υ(1S) double ratio

HIN-11-011




- double ratio: experimentally (acceptance and efficiencies cancel out) and theoretically robust observable
- all 3 states separated
- suppression of Υ(2S) relative to Υ(1S) does not vary strongly with PbPb collision centrality

# Absolute Υ(nS) suppression

- nuclear modification factor ($R_{AA}$)

$$R_{AA} = \frac{\sigma(\mathrm{PbPb})}{\sigma(\mathrm{pp}) \times N_{coll}}$$

- **>1** enhancement
- **=1** no medium effect
- **<1** **suppression**

$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{\mathrm{MB}}} \frac{N_{\mathrm{PbPb}}(\Upsilon(\mathrm{nS}))}{N_{pp}(\Upsilon(\mathrm{nS}))} \frac{\varepsilon_{pp}}{\varepsilon_{\mathrm{PbPb}}}$$

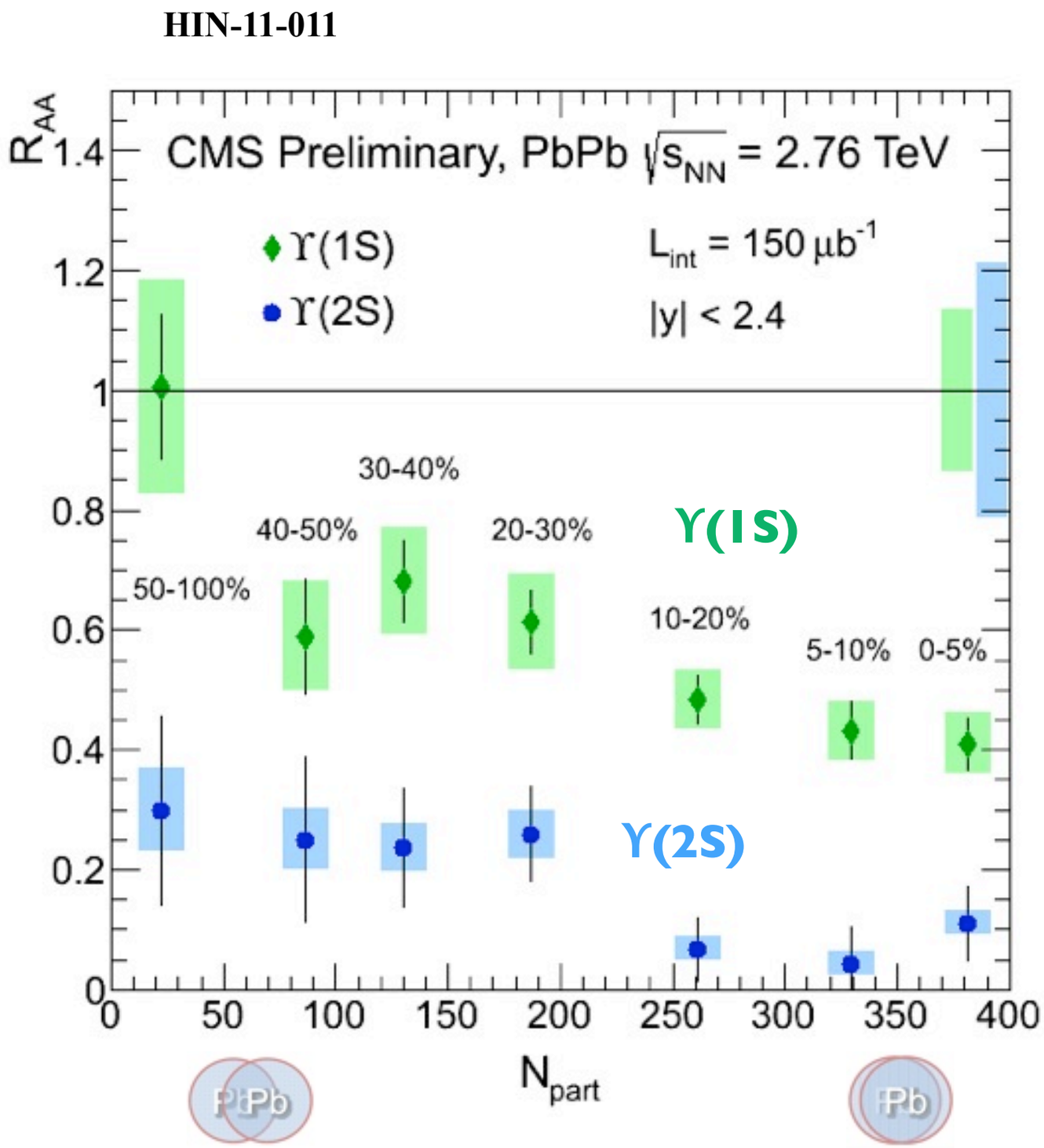
- measured for the first time for the individual Υ states

$$\begin{aligned} R_{AA}(\Upsilon(1S)) &= 0.56 \pm 0.08\,(\mathrm{stat.}) \pm 0.07\,(\mathrm{syst.}) \\ R_{AA}(\Upsilon(2S)) &= 0.12 \pm 0.04\,(\mathrm{stat.}) \pm 0.02\,(\mathrm{syst.}) \\ R_{AA}(\Upsilon(3S)) &= 0.03 \pm 0.04\,(\mathrm{stat.}) \pm 0.01\,(\mathrm{syst.}) \\ &< 0.10 \quad (95\%\ \mathrm{C.L.})\,. \end{aligned}$$

(centrality integrated, 0-100%)

- Υ states are suppressed sequentially: Υ(3S) → Υ(2S) → Υ(1S)
- Υ(1S) not incompatible with excited state suppression only
  - considering ~50% excited to ground state feed-down

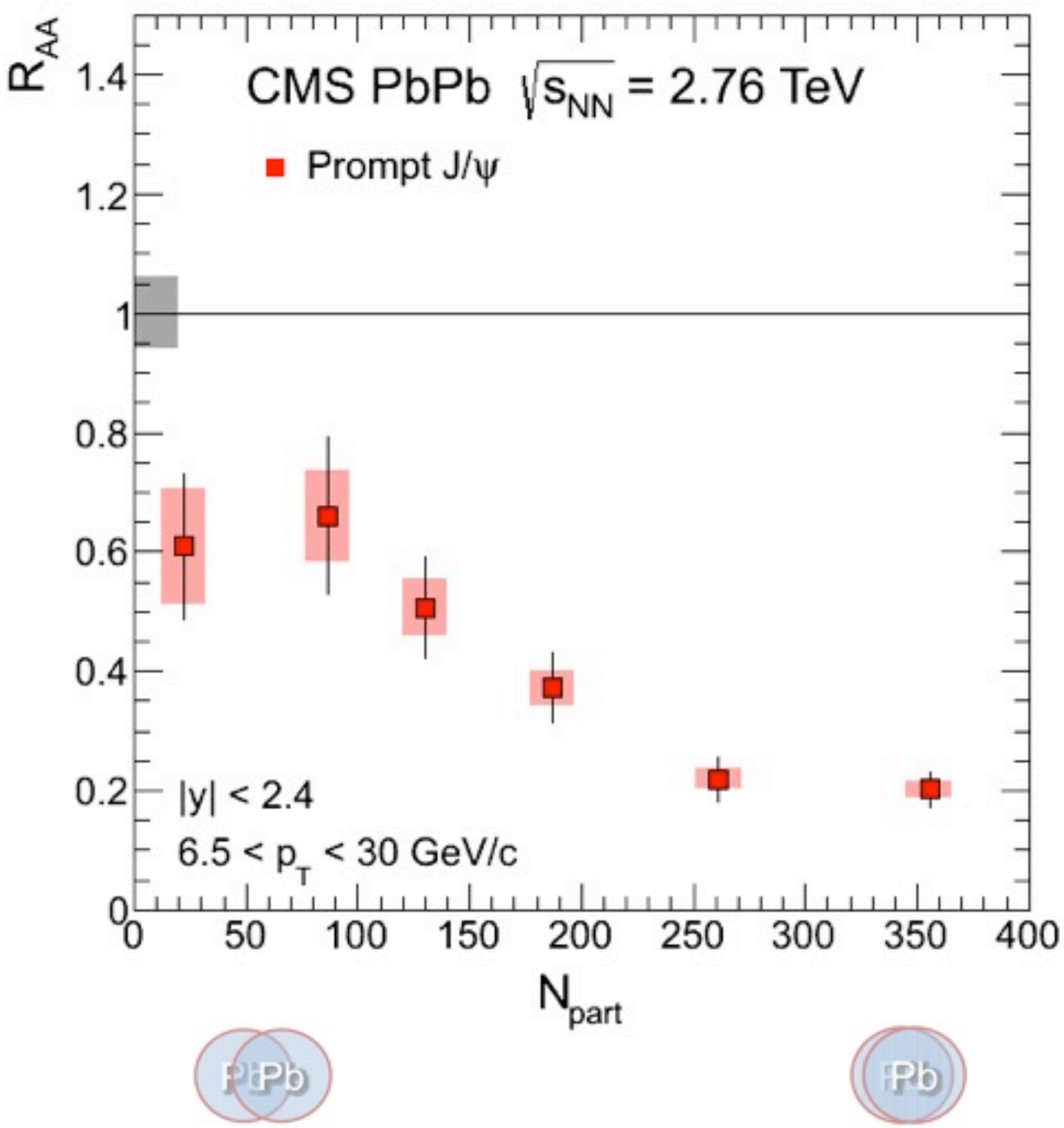
# $R_{AA}$ vs centrality




- suppression observed to increase with the centrality of the collisions
- $\Upsilon$(2S)
  - always more suppressed than ground state
  - still suppressed in 50-100% centrality bin (which is broad)
- consistent with rapid onset of excited states suppression
  - detailed studies of onset will require very high statistics

# J/ψ suppression

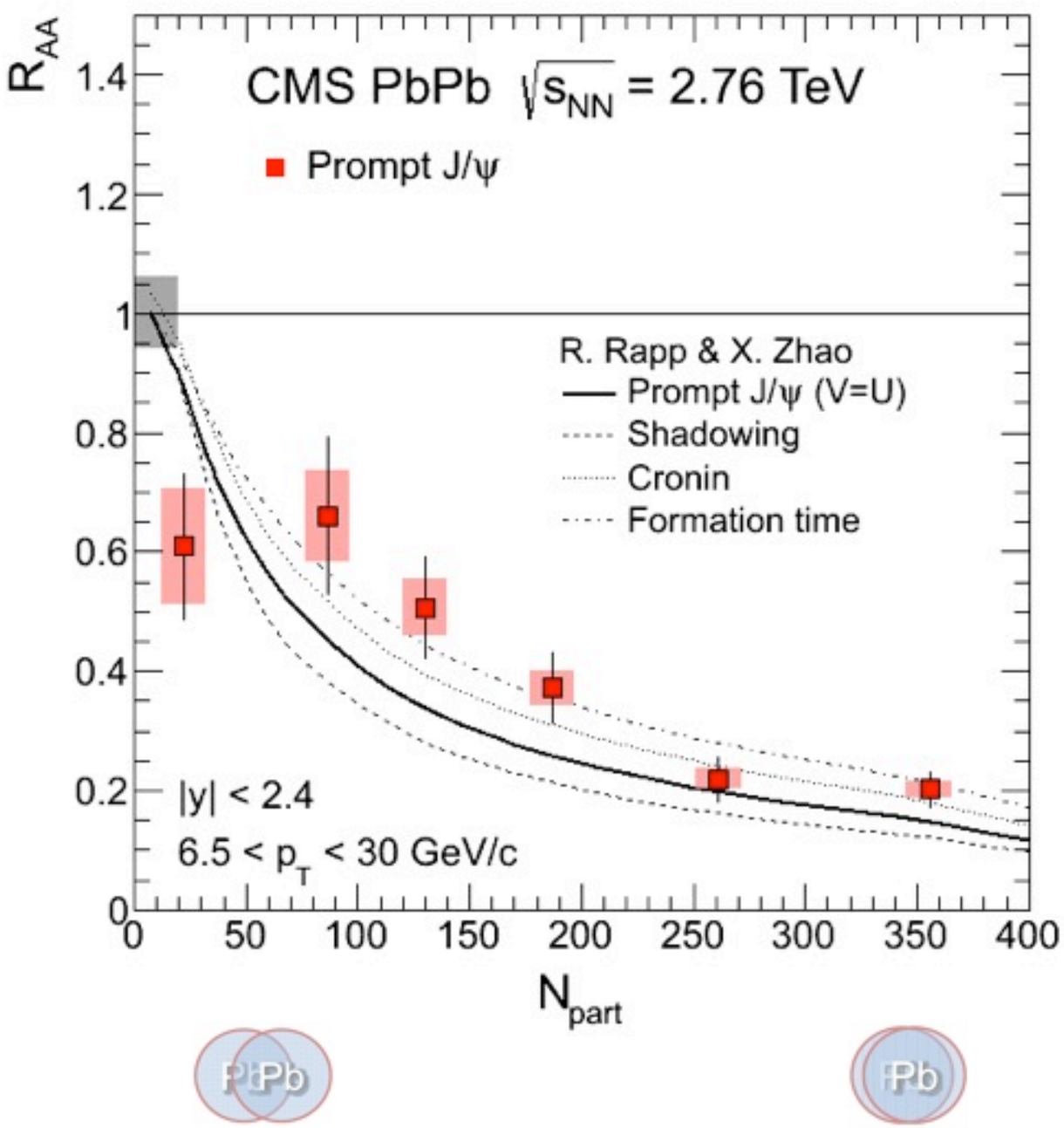
JHEP 1205 (2012) 063




- prompt J/ψ: clear suppression, with strong centrality dependence
  - suppression by factor 5 in 0-10%

# J/ψ suppression

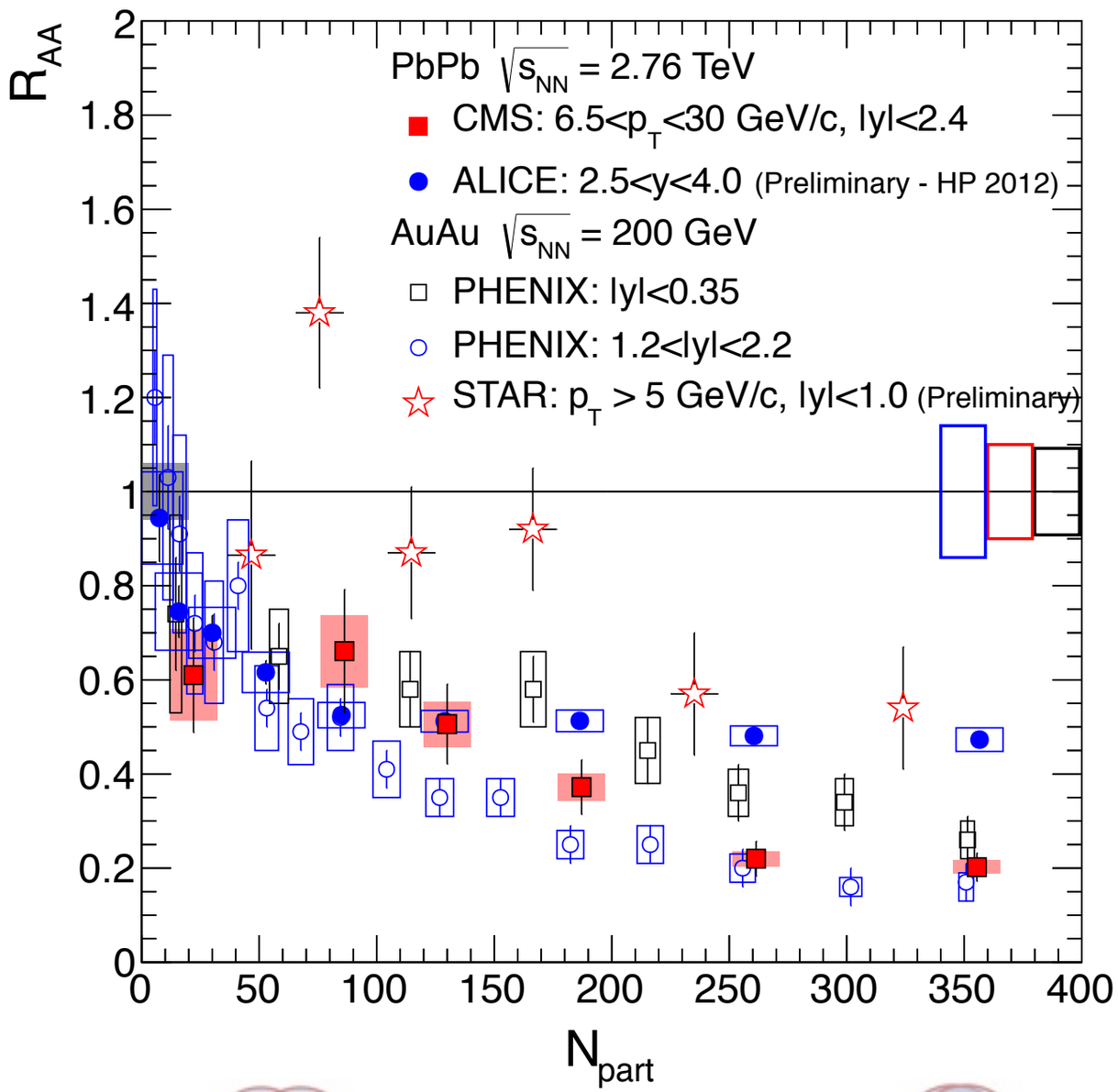
JHEP 1205 (2012) 063




- prompt J/ψ: clear suppression, with strong centrality dependence
  - suppression by factor 5 in 0-10%
- comparison w/ theory
  - recombination effects expected to be small at high $p_T$

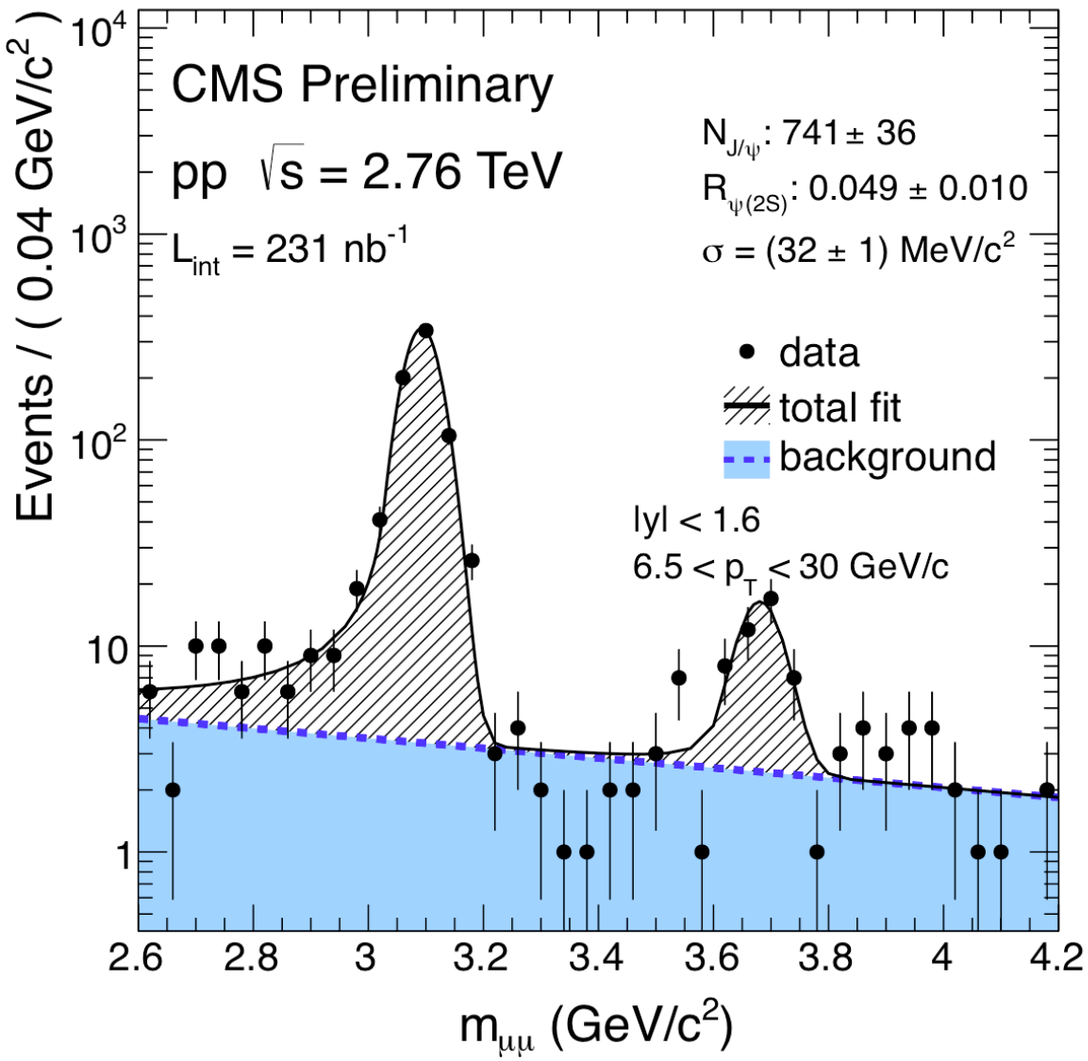
# J/ψ suppression

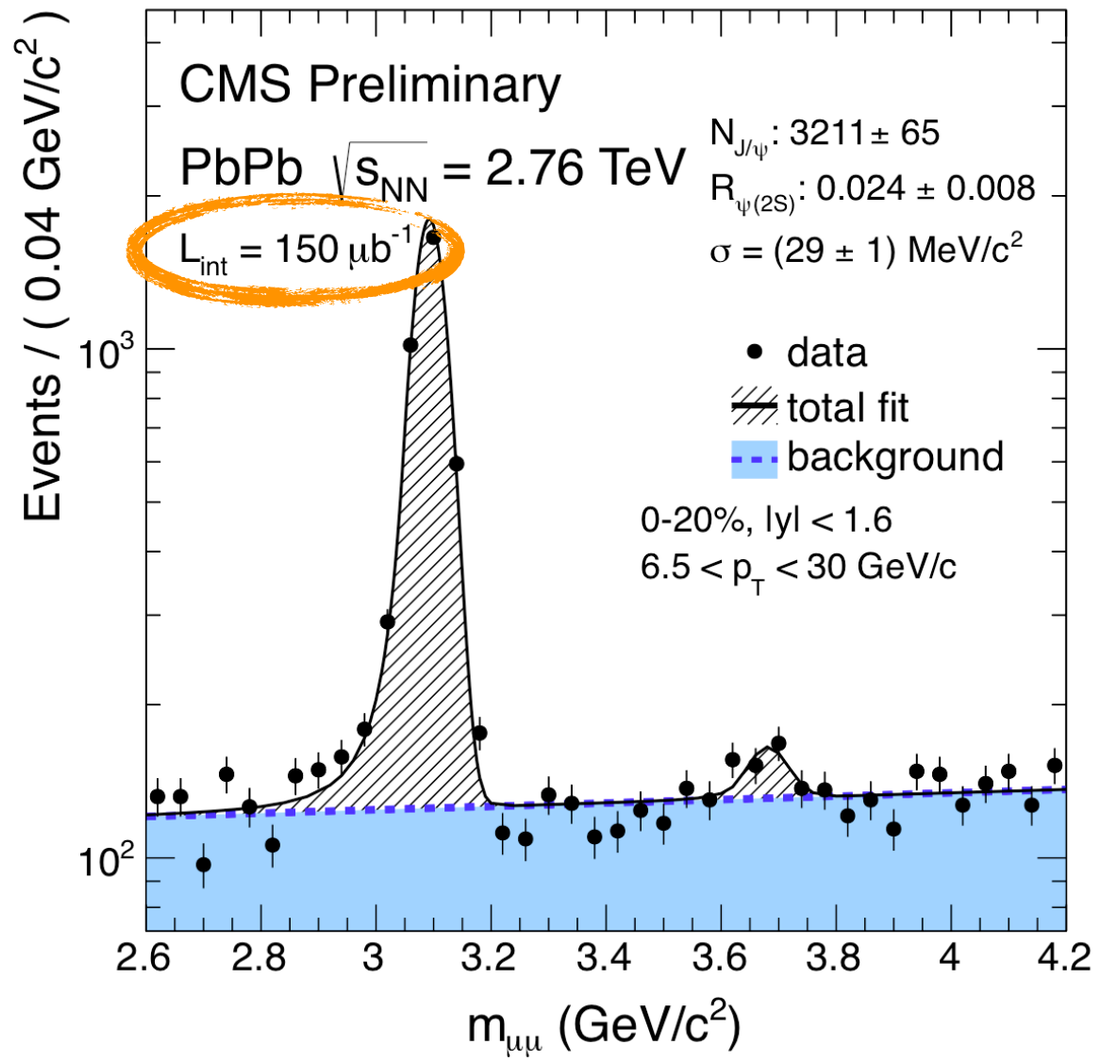
JHEP 1205 (2012) 063




- prompt J/ψ: clear suppression, with strong centrality dependence
  - suppression by factor 5 in 0-10%
- comparison w/ theory
  - recombination effects expected to be small at high pt
- comparison w/ other experiments
- ALICE
  - less suppression at forward rapidity, low pt (includes b-hadron feeddown)
- RHIC
  - similar (PHENIX) and less (STAR) suppression observed than at LHC

# excited charmonia

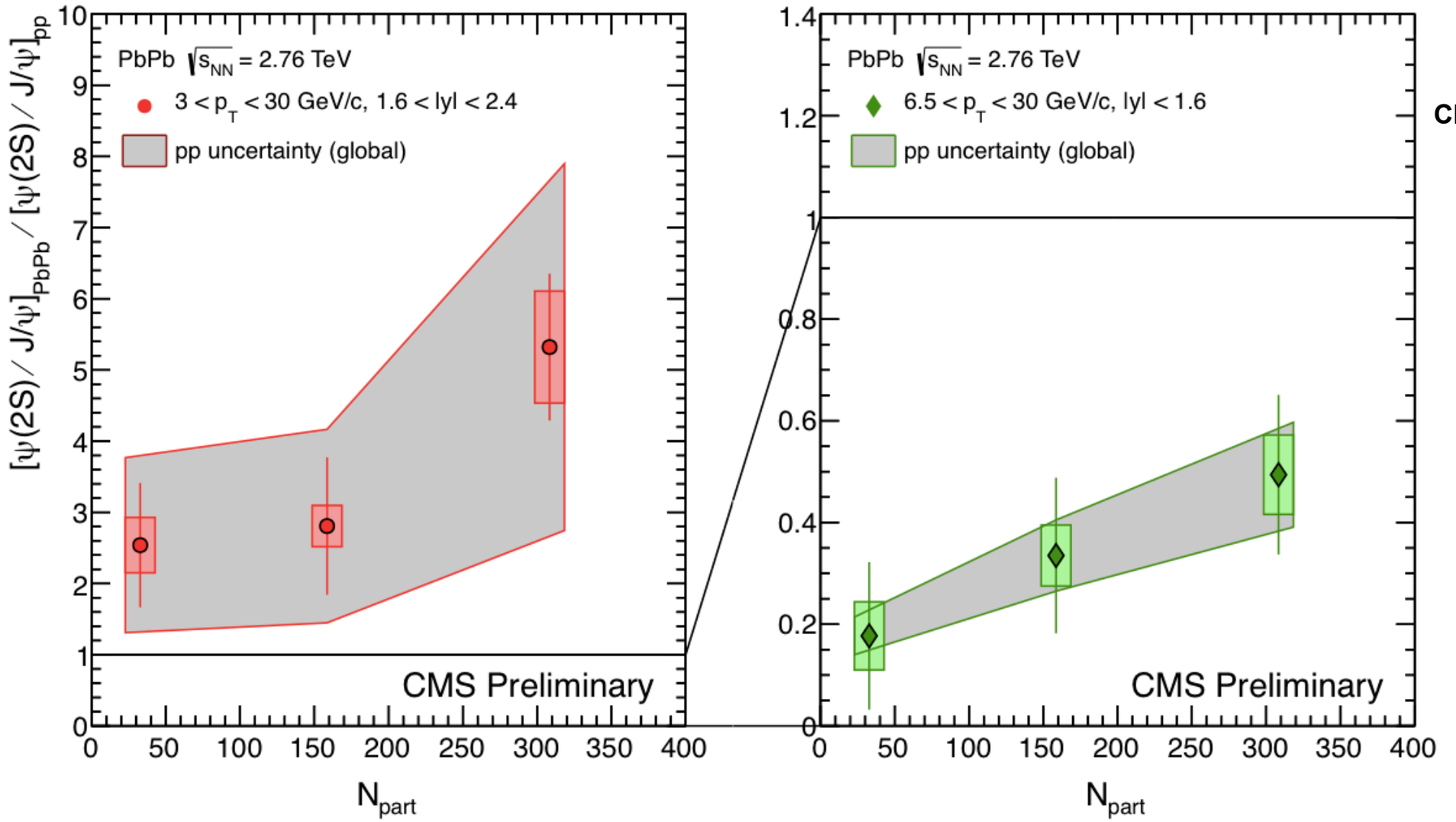



- carry out the measurement of the excited-to-ground state relative suppression in the charmonia as done for the bottomonia case

# ψ(2S) vs J/ψ suppression

double ratio




CMS-HIN-12-007

For $p_T$>3 GeV/c and 1.6<|y|<2.4:
Indication of ψ(2S) being less suppressed than J/ψ, but more pp data is needed.

⇓

$$R_{AA}^{0-100\%}(\psi(2S)) = 1.54 \pm 0.32\,(\text{stat}) \pm 0.22\,(\text{syst}) \pm 0.76\,(\text{pp})$$

$R_{AA}$ (J/ψ) = 0.41 ± 0.06

For $p_T$ >6.5 GeV/c and |y|<1.6:
ψ(2S) are more suppressed than J/ψ

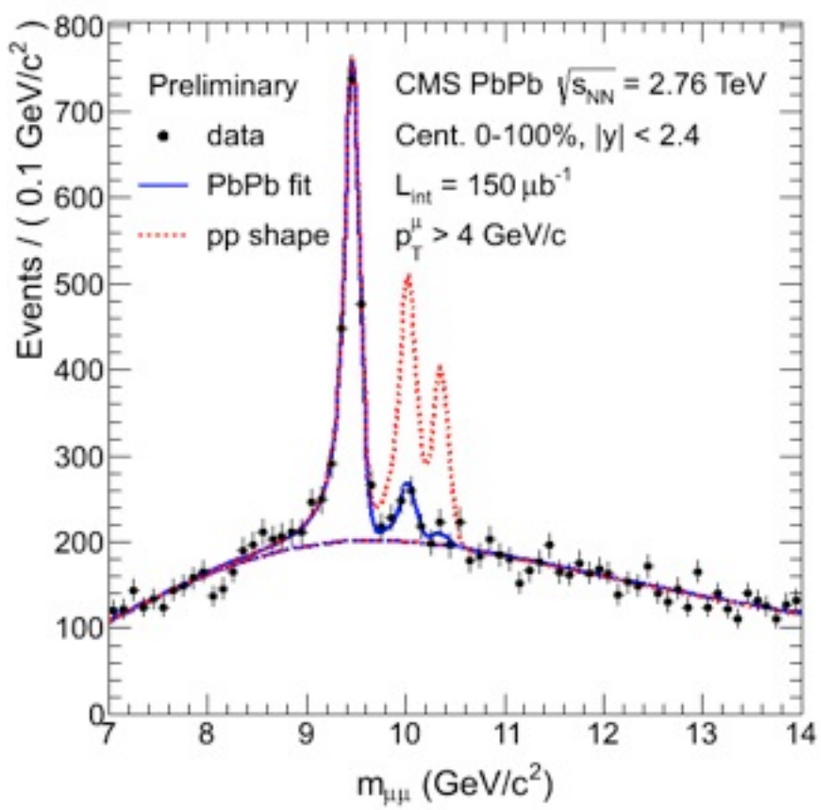
⇓

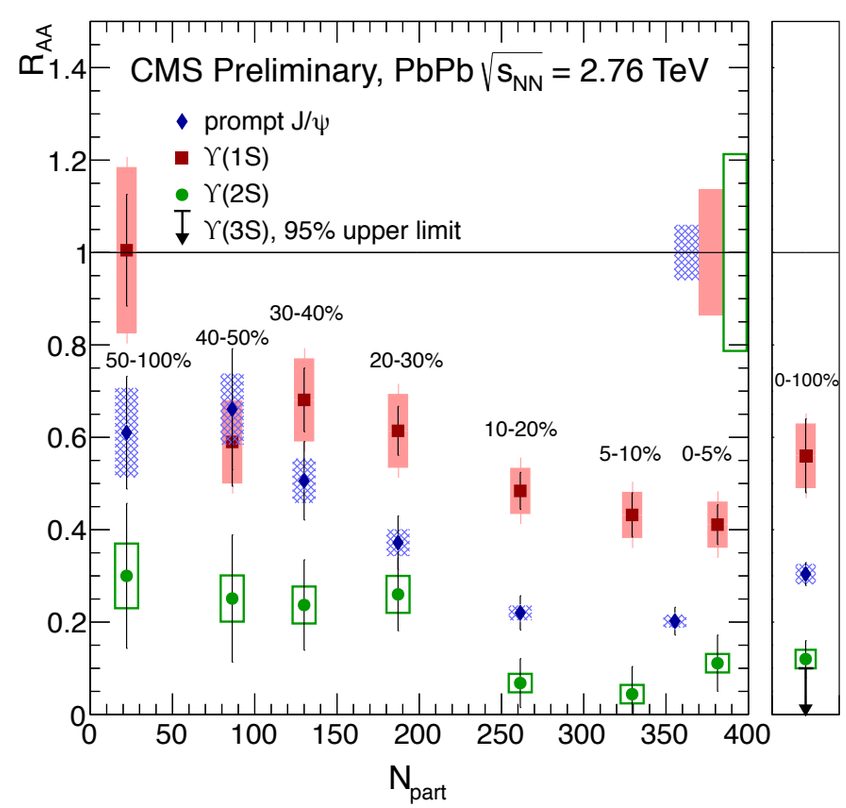
$$R_{AA}^{0-100\%}(\psi(2S)) = 0.11 \pm 0.03\,(\text{stat}) \pm 0.02\,(\text{syst}) \pm 0.02\,(\text{pp})$$

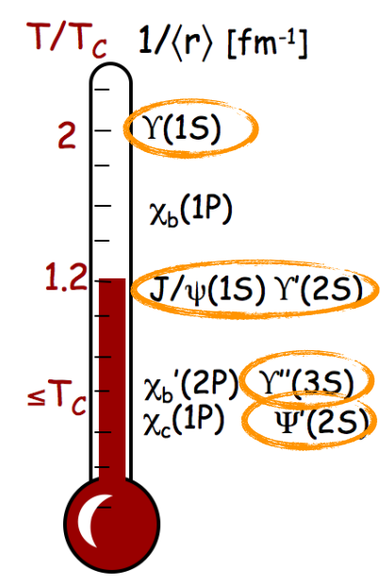
$R_{AA}$ (J/ψ) = 0.29 ± 0.05

# summary

- first measurements of the individual ϒ states in the heavy-ion environment
- established the relative excited-to-ground state suppression (>5σ)
- measured the quarkonium sequential melting:
  - **ϒ(3S) > ϒ(2S),ψ(2S)* > J/ψ* > ϒ(1S)** (* for high-pT charmonia)
- more data (pp, pPb, PbPb) will allow further studies of bottomonia & charmonia
- characterizing the medium properties, one peak at a time.



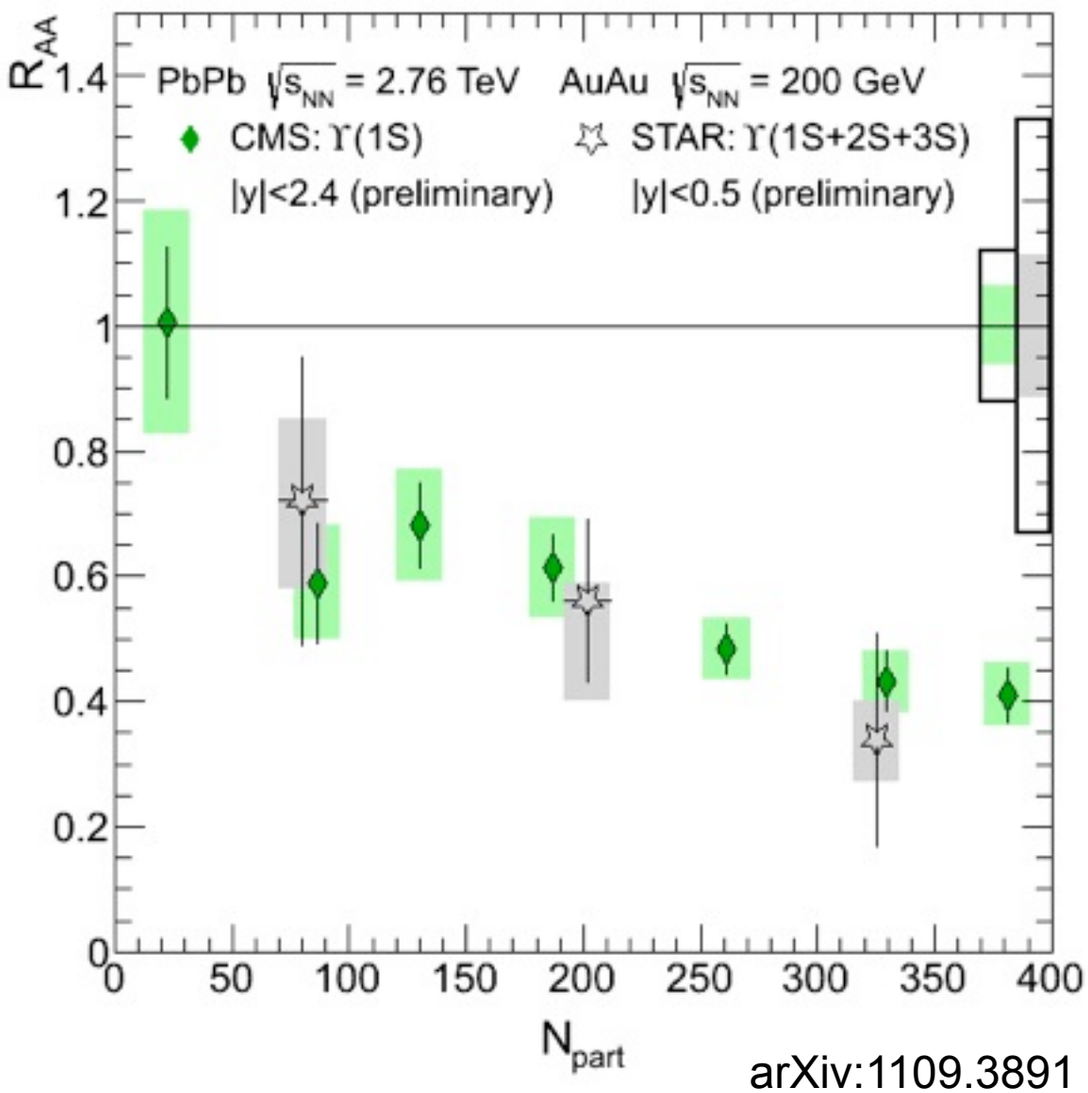
*thanks!*

# overview recap

- CMS & Dimuon spectra
- Quarkonium production in pp
  - baseline reference
  - see also talks in Υ(nS), χc cross sections&ratios (K.Ulmer, Tk5&7, 5/7), Υ(nS) polarizations (V.Knunz, Tr6, 7/7)
- Quarkonium suppression in PbPb
  - Charmonia
  - Bottomonia
- Summary

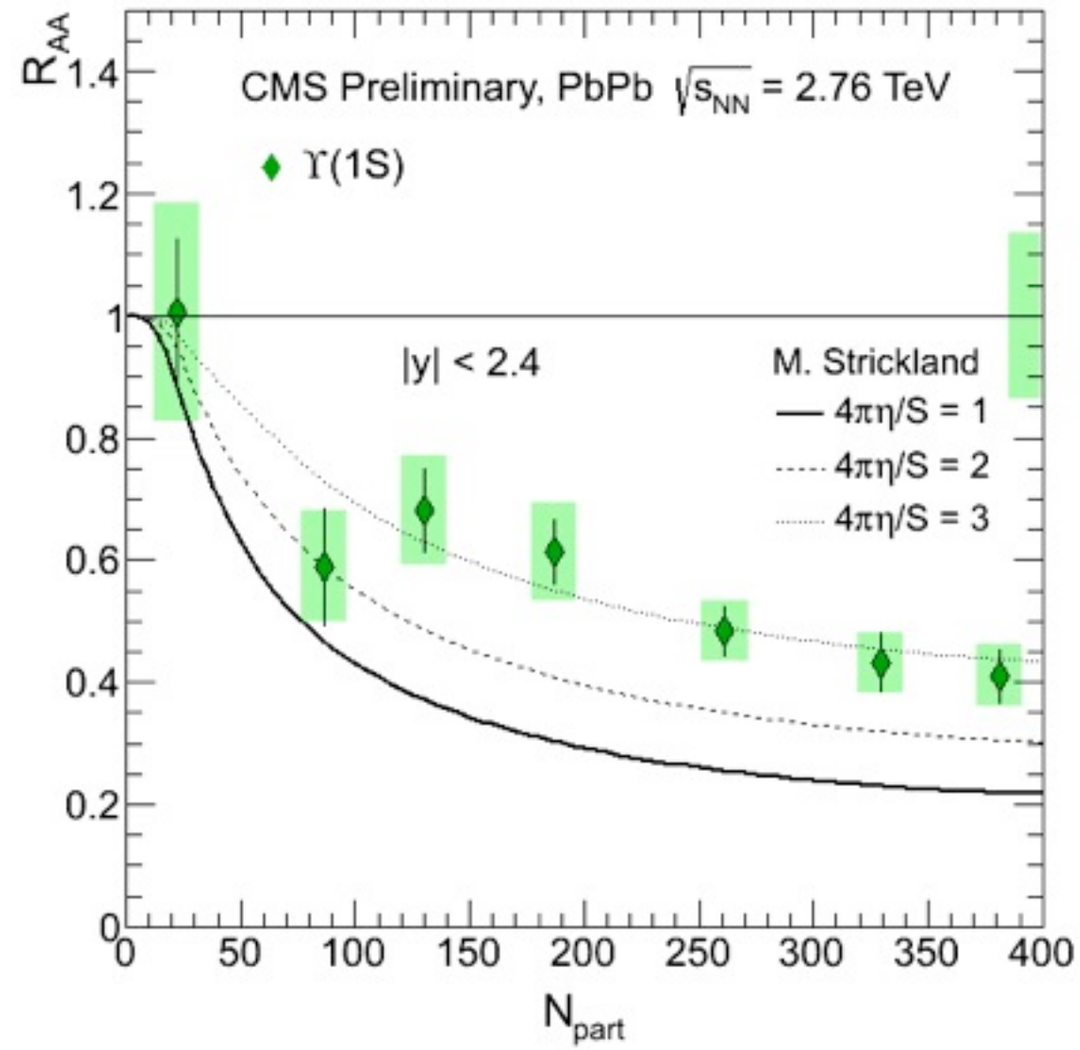
# botomonia comparisons

with RHIC




arXiv:1109.3891

with models (an example)




STAR measured Υ(1S+2S+3S) combined

$$R_{AA}(\Upsilon(1S+2S+3S)) = 0.56 \pm 0.21^{+0.08}_{-0.16}$$

compatible with CMS (≈0.32)

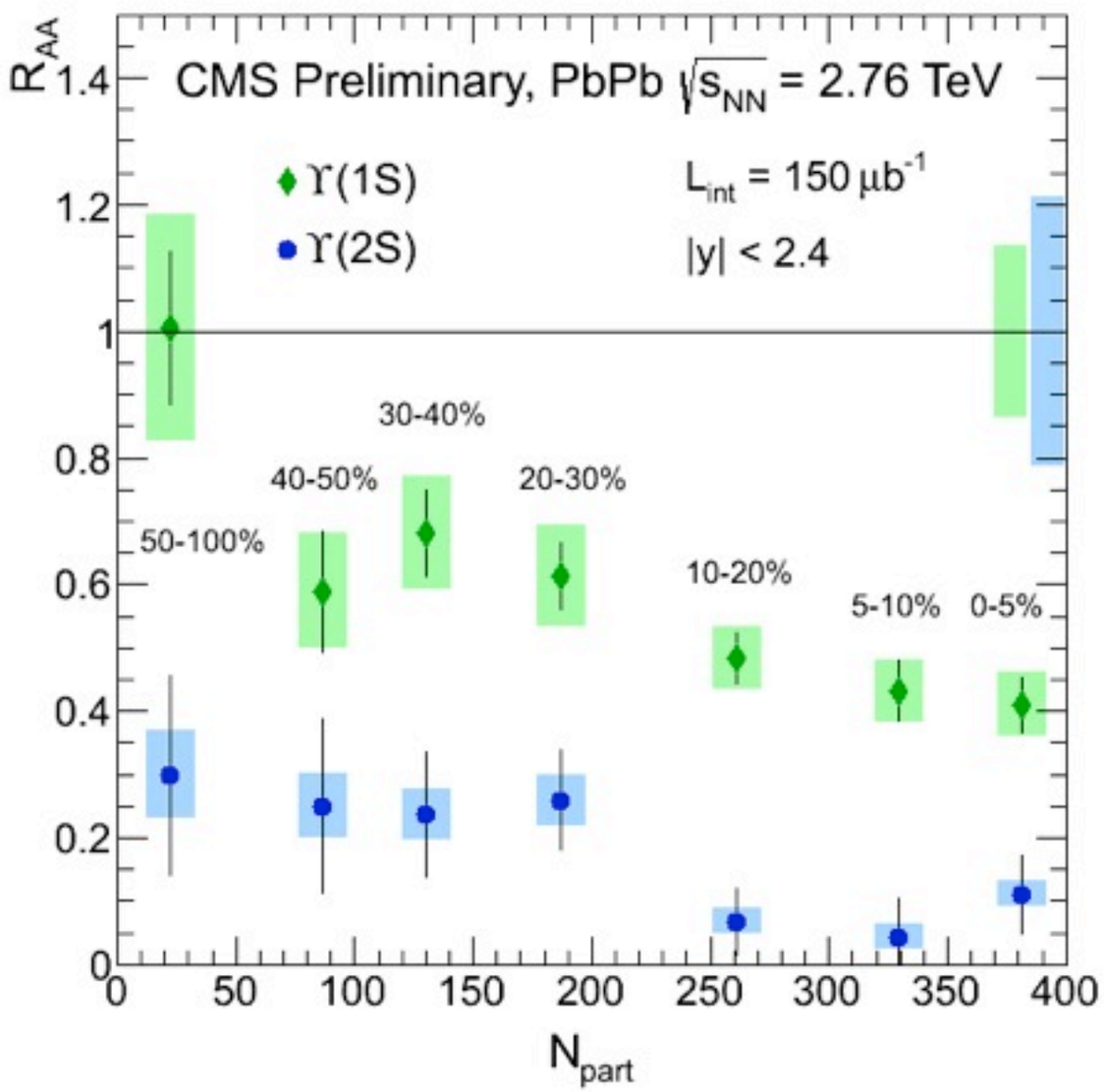
comparison to: M. Strickland, PRL 107, 132301 (2011)

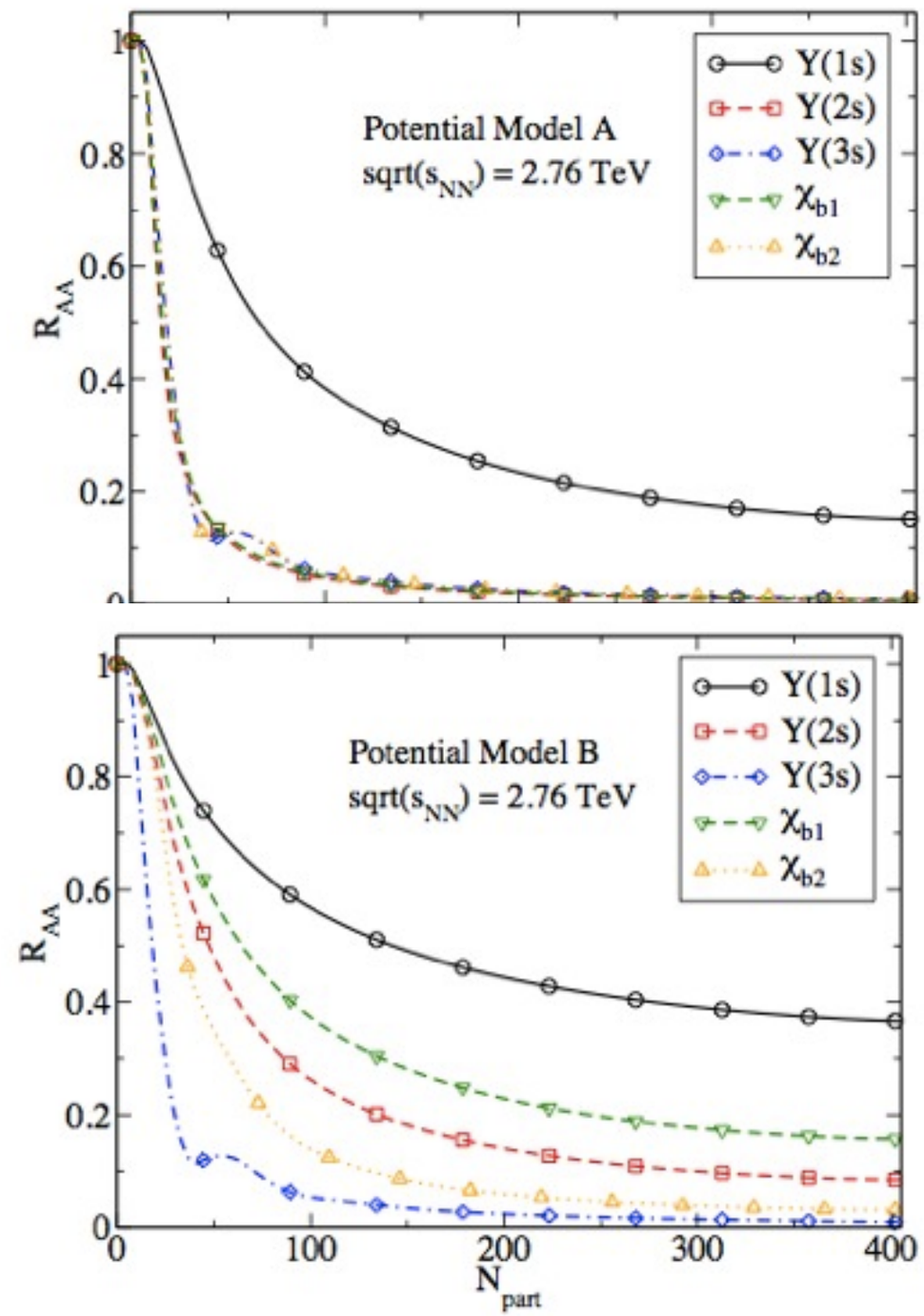
Data indicate:
$552 < T_0 < 580$ MeV, for $3 > 4\pi\eta/S > 1$

# bottomonia suppression vs $N_{part}$

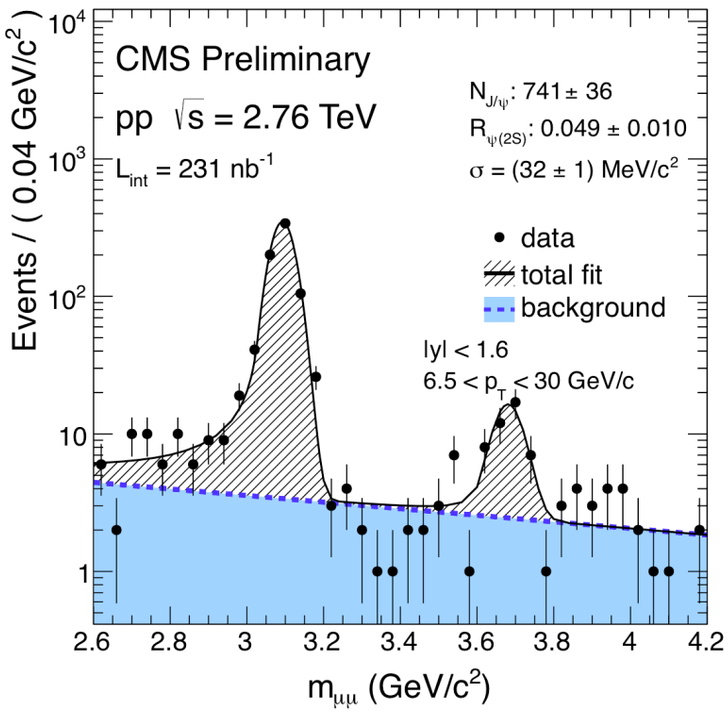
arXiv:1112.2761v4

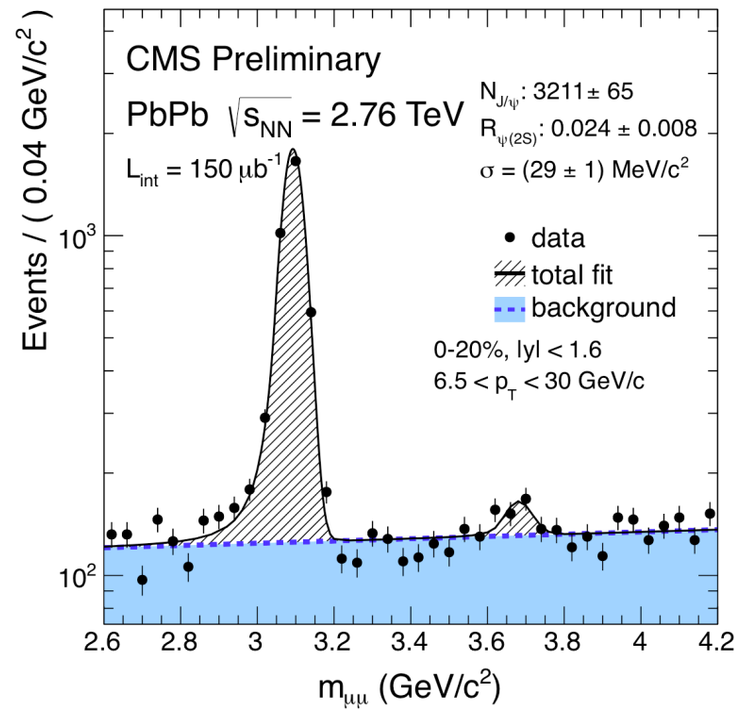
**HIN-11-011**



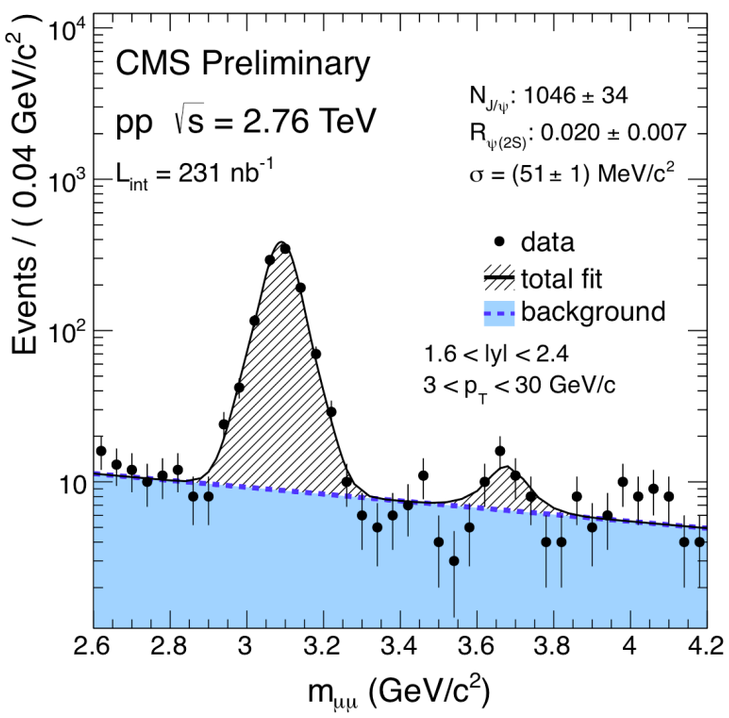



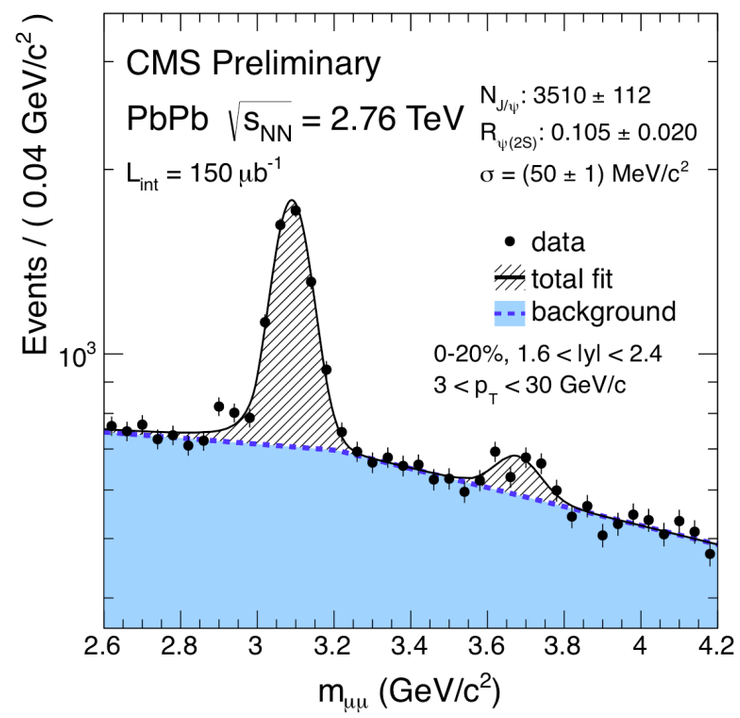
# charmonia




- raw yield ratio of ψ(2S) / J/ψ
- $p_T$>6.5 GeV, |y|<1.6
- in 0-20% PbPb ~ 2x smaller than in pp




- $p_T$>3 GeV, 1.6<|y| <2.4
- in 0-20% PbPb ~5x larger than in pp