Studies of Υ states in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV at LHC

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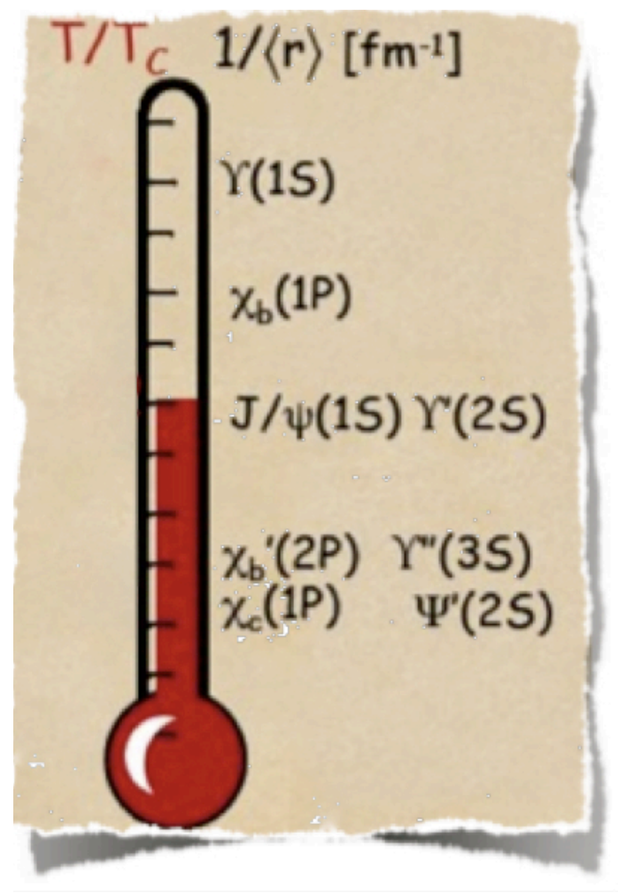
Introduction

- In our universe today, quarks are always bound together by gluons to form "composite" particles. The Quark-Gluon Plasma (QGP) is a hot, dense state in which these quarks and gluons exist freely, unbound. This is thought to be the situation a few millionths of a second after the Big Bang.
- One of the predicted characteristics of the QGP is that its high temperature causes the "melting" of quarkonia. This melting manifests itself as the suppression of quarkonium production in heavy-ion collisions, compared to the number of quarkonia produced in collisions between protons.
- Detailed measurements of bottomonium production will help characterize the dense matter produced in heavy-ion collisions.



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

→ decreasing binding energy

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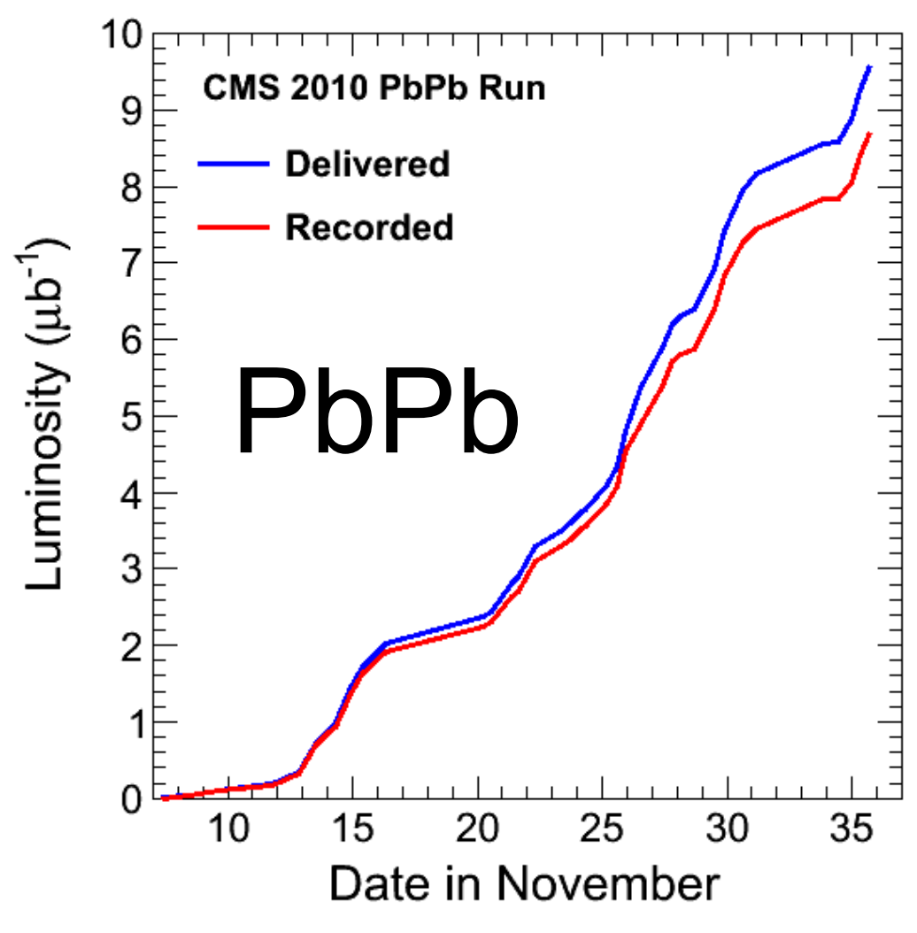
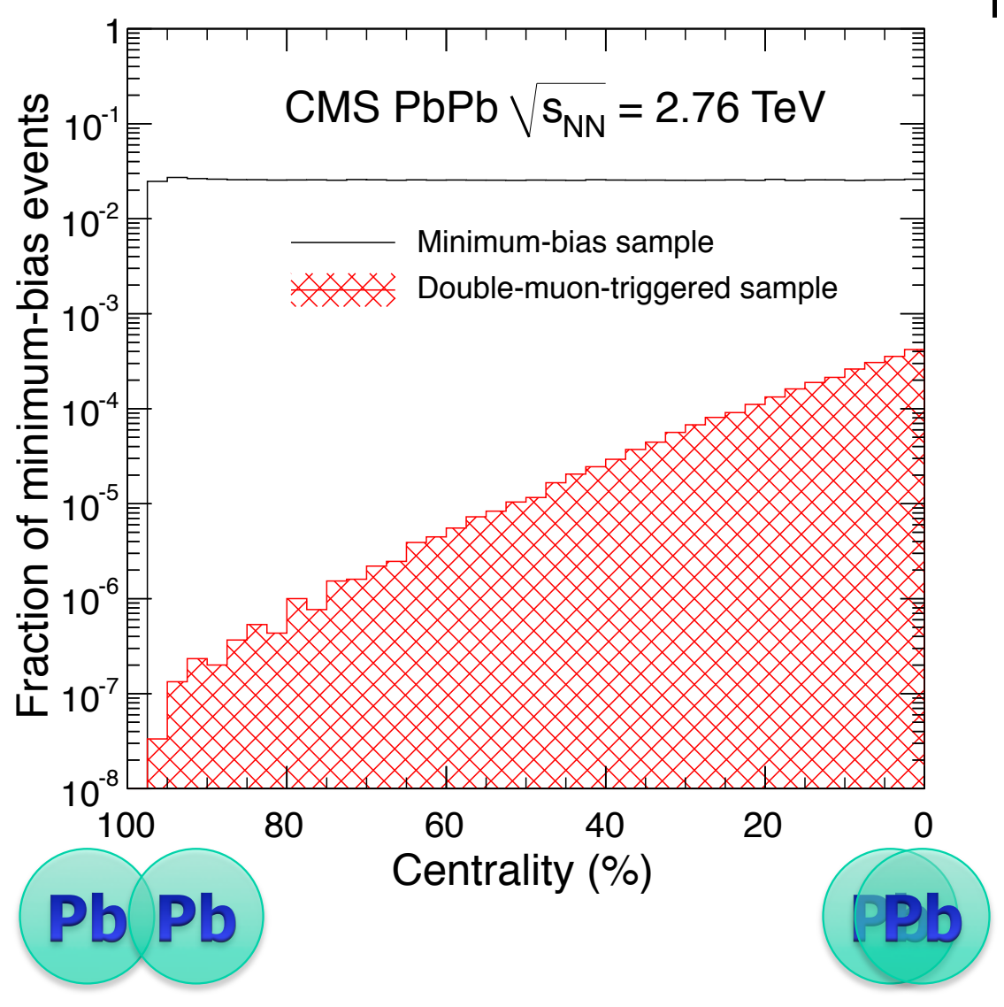
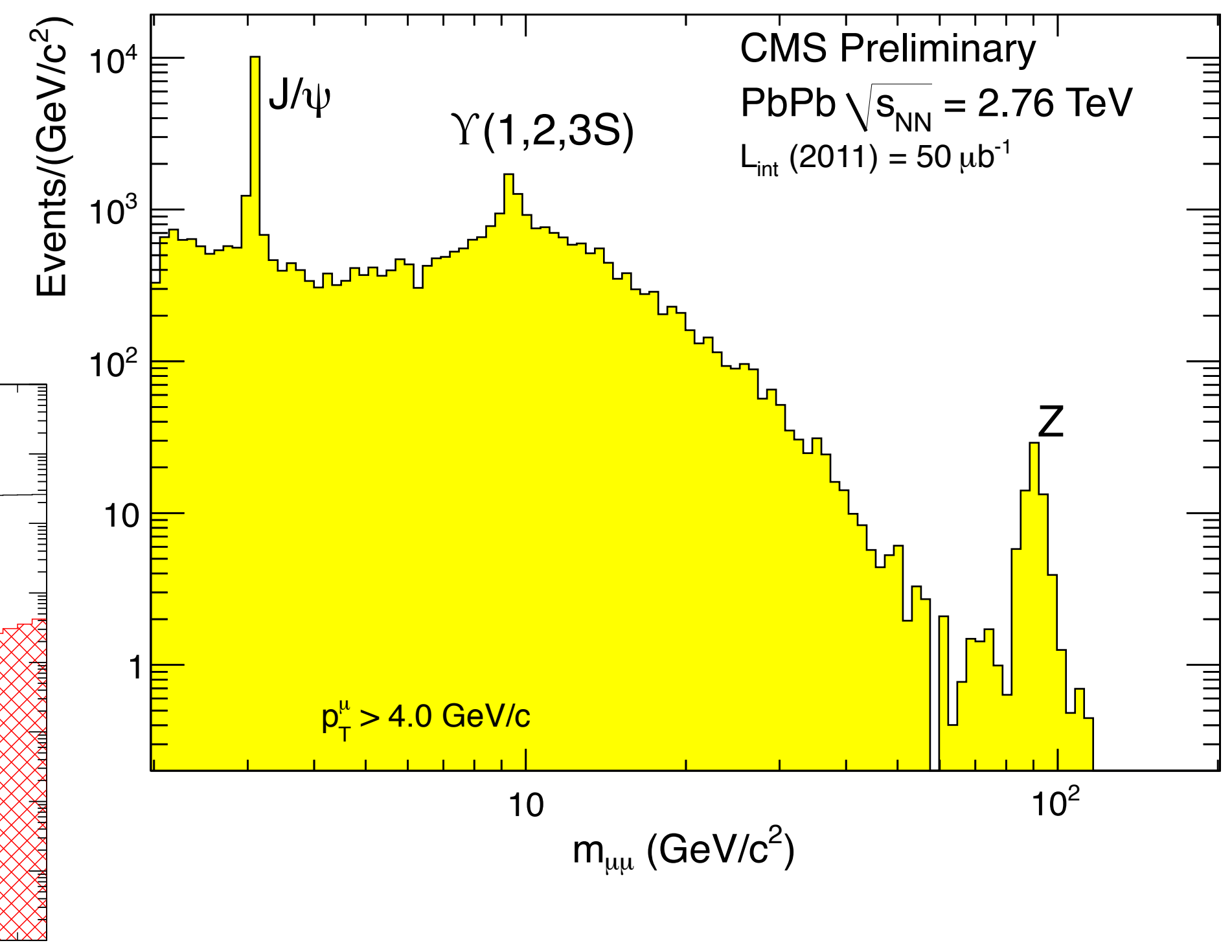
Quarkonia in PbPb Collisions in CMS

- PbPb data sample: PbPb run 2010 @ $\sqrt{s_{NN}}$ = 2.76 TeV (L_{int} = 7.28 μb^{-1})
- pp reference sample: pp run 2011 @ $\sqrt{s}$ = 2.76 TeV (L_{int} = 231 nb^{-1})
- Event selection:
  - ➢ Online dimuon trigger
  - ➢ Offline minBias selection
- Muon selection:
  - ➢ Muon quality cuts
  - ➢ Kinematic cut: $p_T^{\mu} > 4$ GeV/c





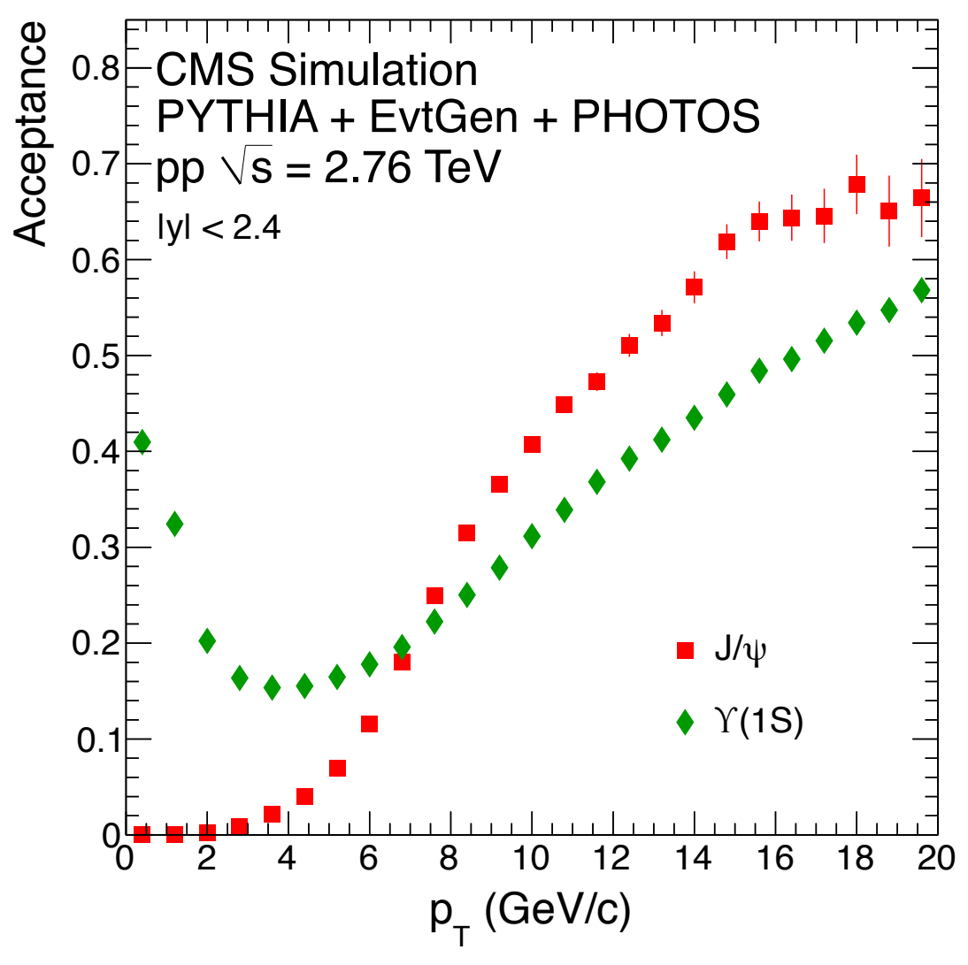


CMS has excellent mass resolution

Nuclear Modification Factor R_{AA} (arXiv:1201.5069)

Acceptance

$$\alpha(p_T, y; \lambda_\theta) = \frac{N^{dimuon}_{reconstructible,M}(p_T, y; \lambda_\theta)}{N^{dimuon}_{|y^{dimuon}|<2.4}(p_T, y; \lambda_\theta)}$$

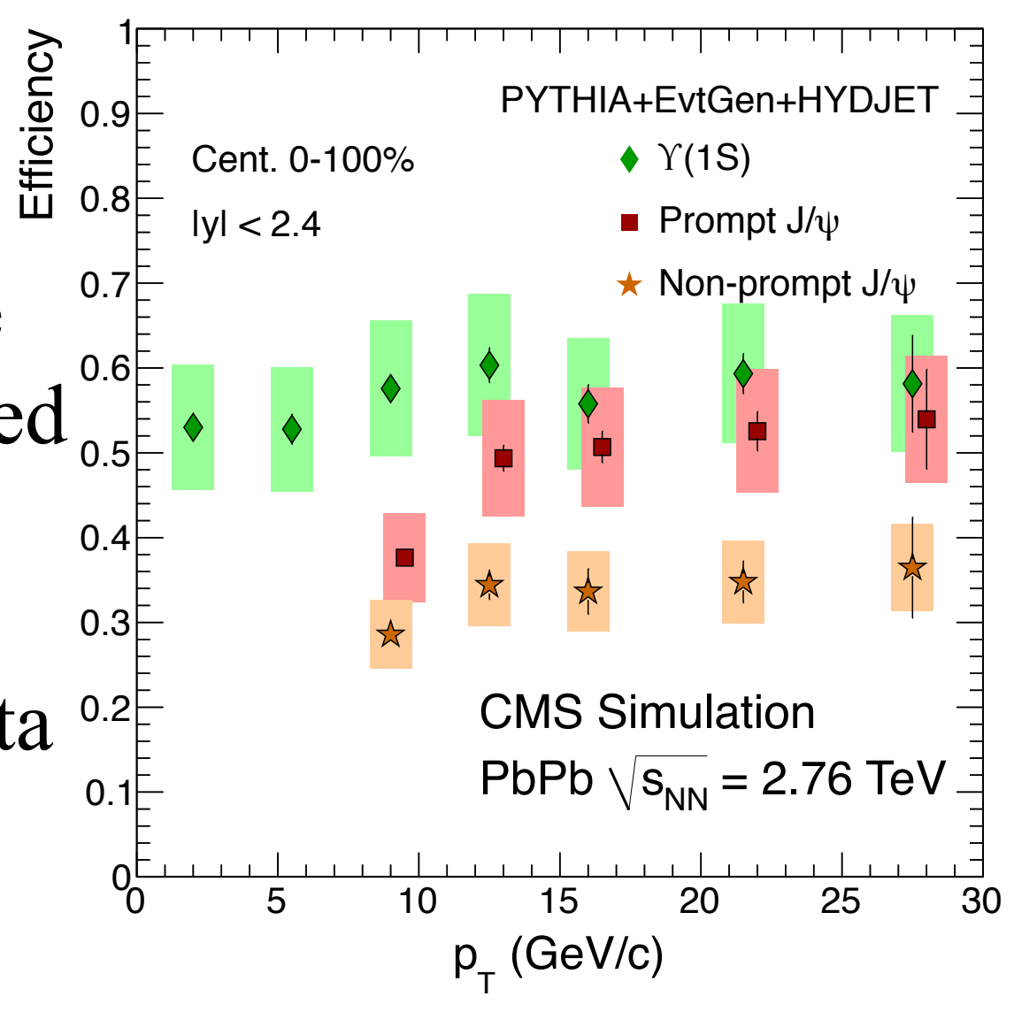


Numerator: the number of generated events in the MC simulation, declared detectable for given acceptance cuts

Denominator: the number of dimuons generated within the muon stations coverage of the CMS detector (|η| < 2.4)

Efficiency

- Trigger efficiency, reconstruction efficiency estimated using MC
- Only muons in the acceptance kinematic region are considered
- MC efficiency cross checked with $J/\psi \rightarrow \mu^+\mu^-$ in data. The statistical uncertainty from data is a source of systematic uncertainty



Signal Extraction

Extended unbinned maximum likelihood fit

Signal

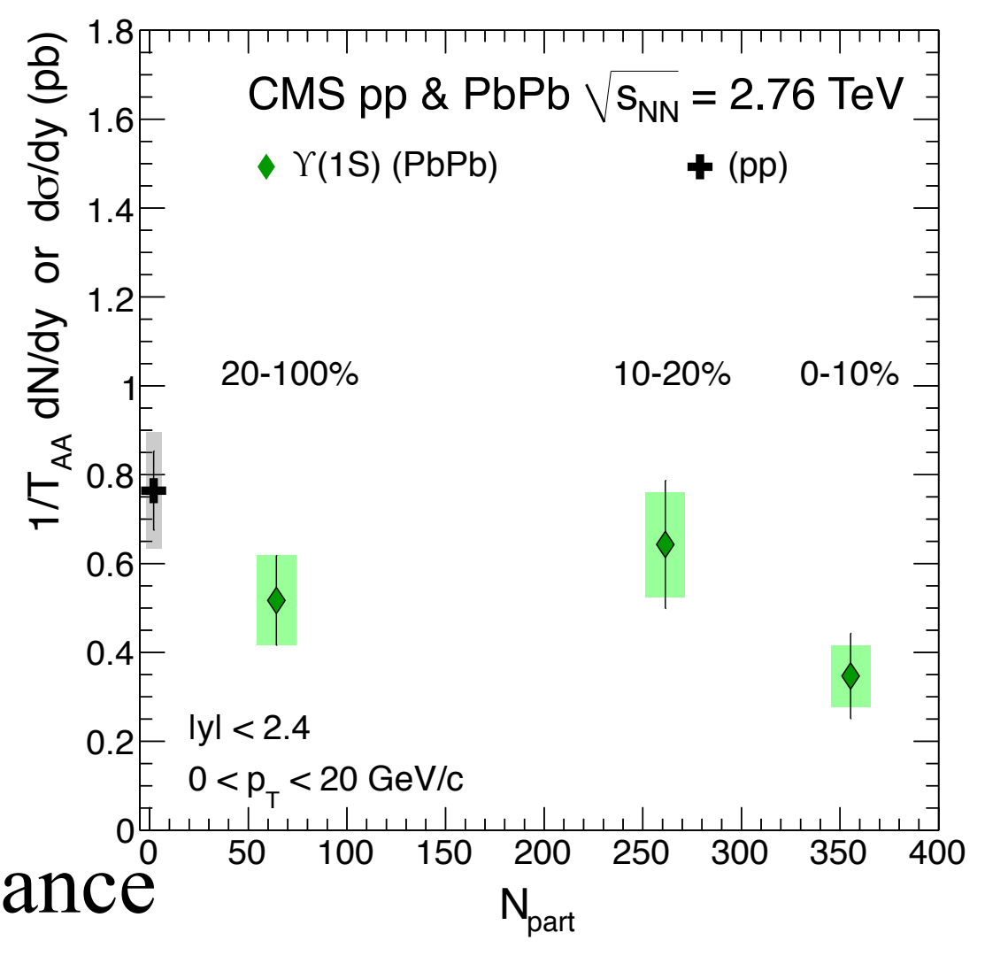
- Core Gaussian with power law tail for final state radiation
- Resolution fixed from MC simulation
- Peak separation fixed to PDG

Background

- Second order polynomial

Υ(1S) invariant Yields in PbPb

$$\frac{1}{T_{AA}} \cdot \frac{d^2N}{dp_T dy} = \frac{1}{T_{AA}} \cdot \frac{1}{\Delta y \, \Delta p_T} \cdot \frac{N_{Q\overline{Q}}}{\alpha \, \varepsilon \, N_{\mathrm{MB}}}$$



- $N_{Q\overline{Q}}$: the number of measured Υ in the $\mu^+\mu^-$ decay channel
- N_{MB} : the number of minimum bias events sampled by the event selection
- α : the geometric acceptance
- ε : the combined trigger and reconstruction efficiency
- Δy and Δp_T : the bin width in rapidity and p_T
- T_{AA} : the nuclear overlap function (varies with the centrality of the collision and has units of mb^{-1})

Υ(1S) R_{AA}

Comparing with the pp @ 2.76 TeV data, we can measure R_{AA}

$$R_{AA} = \frac{\mathcal{L}^{pp}_{\mathrm{int}}}{T_{AA} N_{\mathrm{MB}}} \frac{N^{\mathrm{PbPb}}_{Q\overline{Q}}}{N^{pp}_{Q\overline{Q}}} \cdot \frac{\varepsilon_{pp}}{\varepsilon_{\mathrm{PbPb}}(\mathrm{cent})}$$

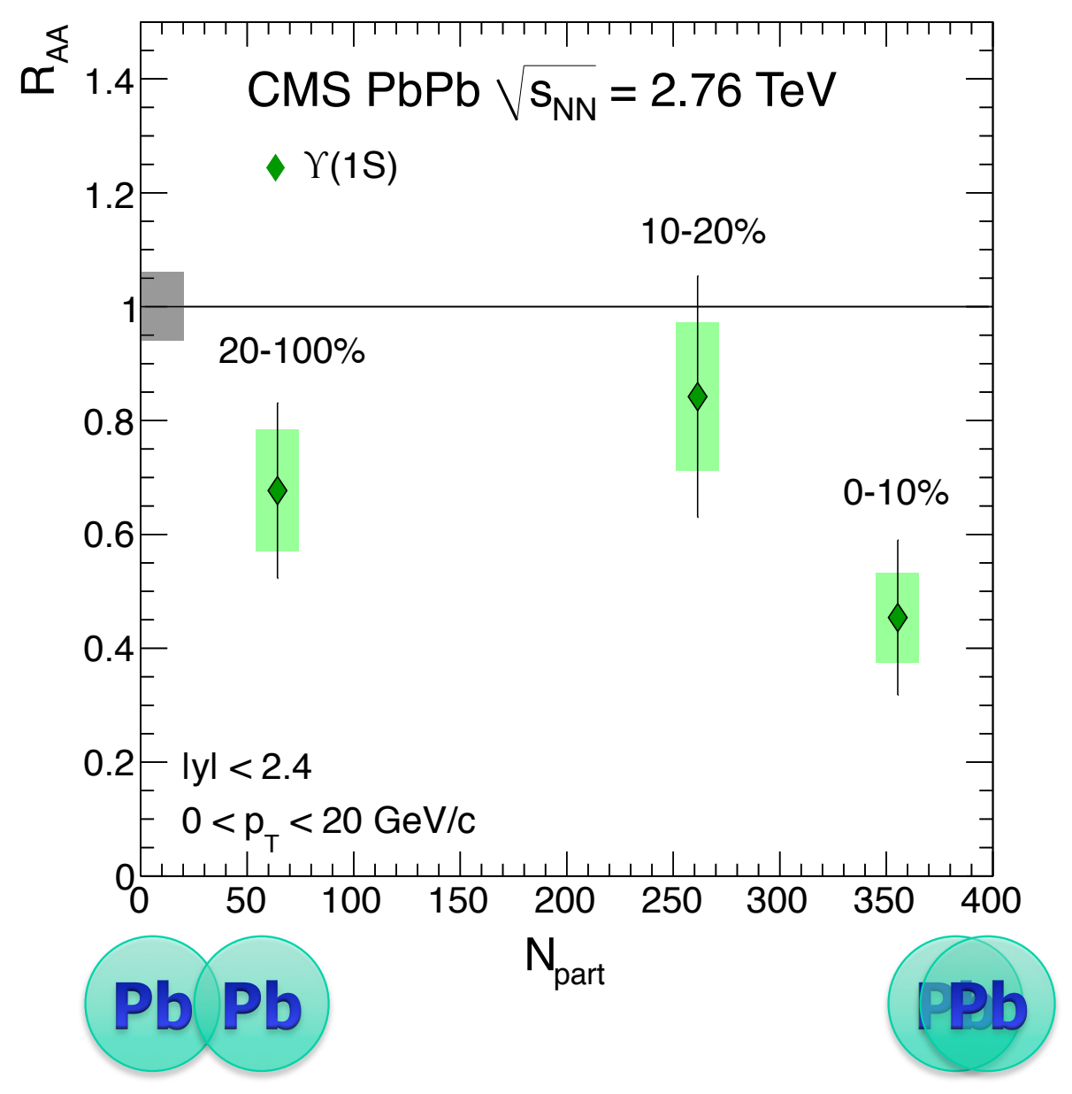
- N_{PbPb} = 86 ± 12[stat] ± 3[syst]
- N_{pp} = 101 ± 12[stat] ± 3[syst]
- T_{AA} = 5.66 mb^{-1}
- N_{MB} = 55.7M MB PbPb collisions
- L_{pp} = 231 nb^{-1}

$$R_{AA} = \frac{1}{T_{AA}} \frac{dN_{AA}}{d\sigma_{pp}} \begin{cases} >1\text{: enhancement} \\ =1\text{: no medium effect} \\ \mathbf{<1: suppression} \end{cases}$$

Υ(1S) R_{AA} in the most central bin (0-20%): 0.60 ± 0.12(stat.) ± 0.10(syst.)

***R_{AA}*<1: suppression**

Consistent with the suppression of excited states (50% feed-down contribution measured by CDF)



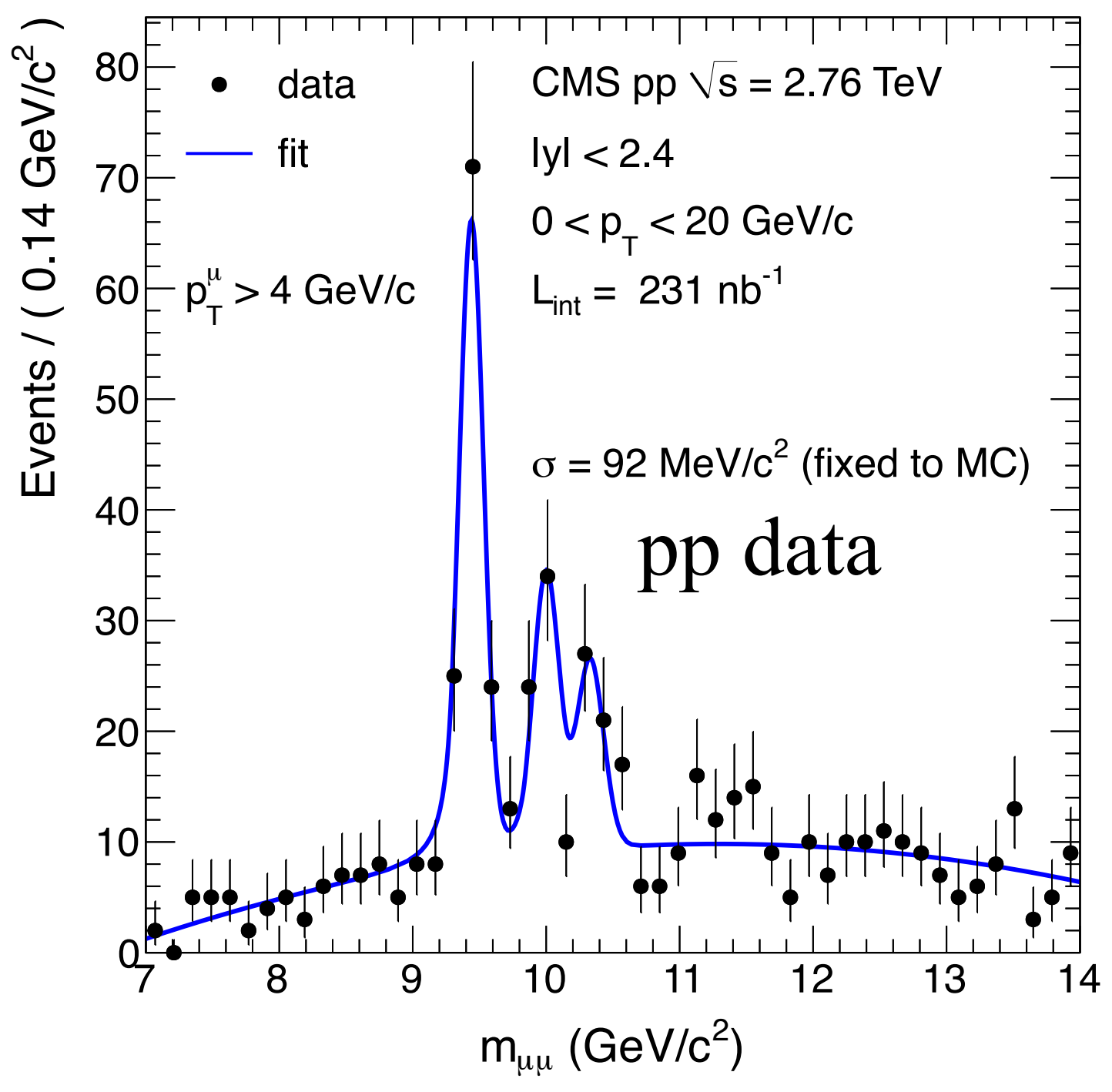
Suppression of Excited Υ States in PbPb Collisions (Phys. Rev. Lett. **107**, 052302 (2011))

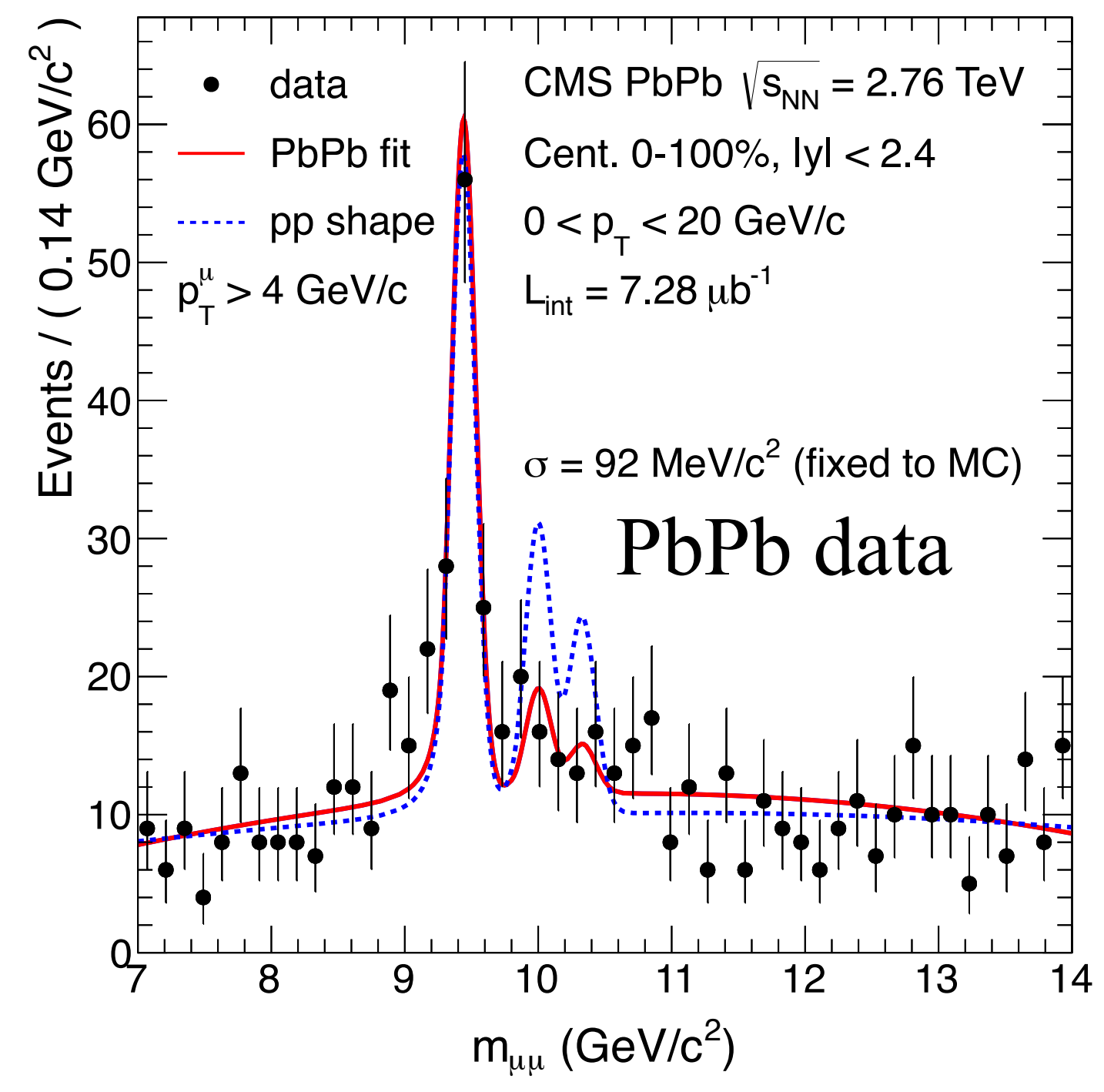
Υ(2S+3S) vs Υ(1S)

- Measure the fraction of excited states Υ(2S+3S) relative to Υ(1S)
- Fraction extracted directly from the fit to the PbPb and pp data sample (both at 2.76 TeV)

$$\Upsilon(2S+3S)/\Upsilon(1S)\big|_{pp} = 0.78^{+0.16}_{-0.14} \pm 0.02$$

$$\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb} = 0.24^{+0.13}_{-0.12} \pm 0.02$$





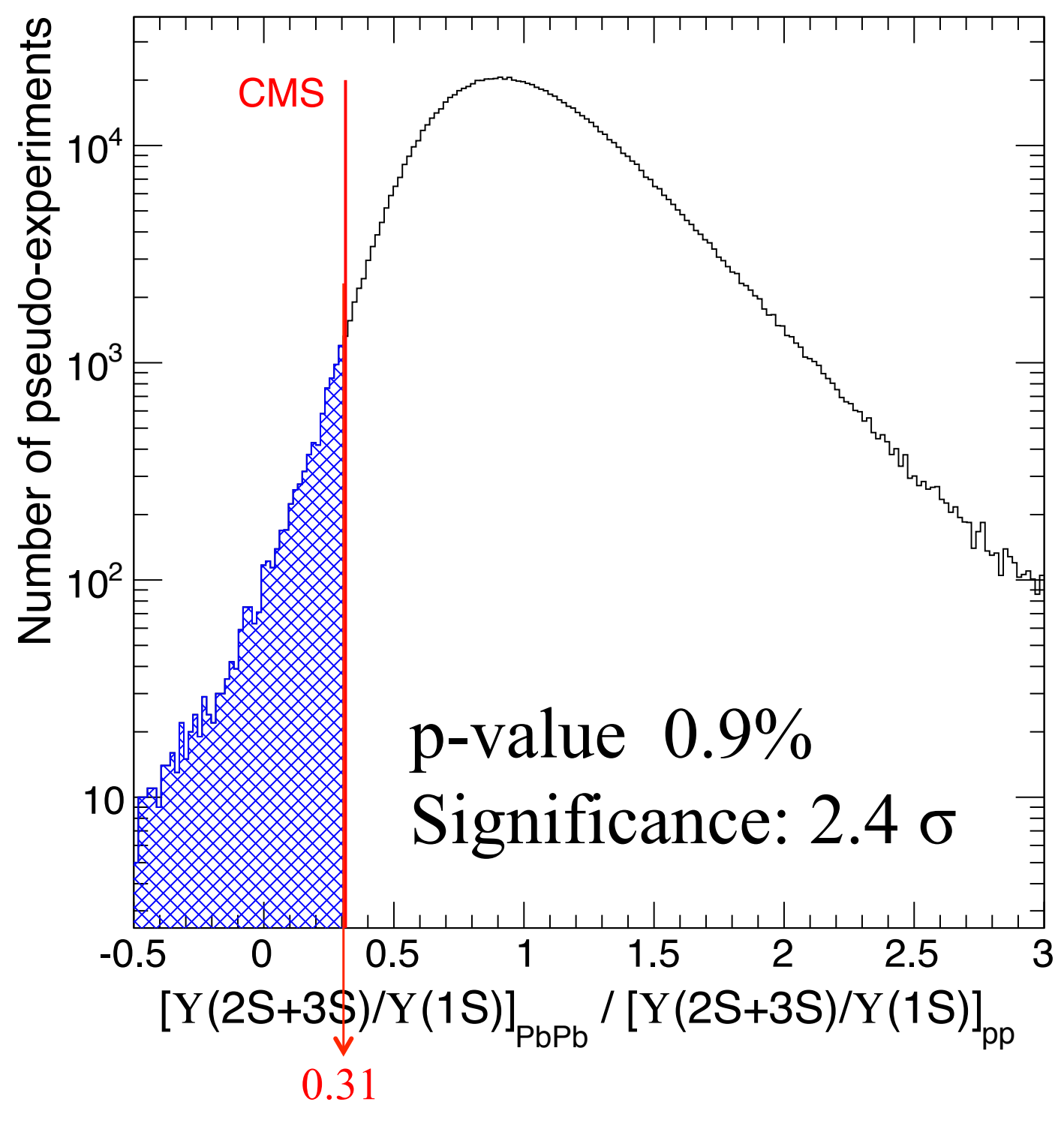
Double Ratio

Compare ratios of Υ(2S+3S) relative to Υ(1S) (ground state) in PbPb & pp:

- Extract double ratio directly from simultaneous fit to both samples

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

- Generate pseudo-experiments following the *null-hypothesis* (i.e. no suppression) to get **p-value**



Systematic for Double Ratio

Pros of a double ratio:

- Acceptance cancels
- Efficiency cancels

Possible differences dominated by systematic uncertainty from the fit model:

- Signal shape
- Mass resolution
- Background PDF and fit range

Total systematic uncertainty: 9.1%

Cold Nuclear Effect

Cold nuclear matter may affect Υ suppression:

- Smaller nuclear absorption cross section than at lower energy and for J/ψ (smaller size)
- Shadowing cancels in the Y(2S+3S)/Y(1S) ratio at least to the first order

References

[1] "Suppression of non-prompt J/psi, prompt J/psi, and Y(1S) in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV", arXiv:1201.5069

[2] "Indications of Suppression of Excited Υ States in Pb-Pb Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV", PRL **107**, 052302(2011)