First Measurement of Υ production in PbPb and pp collisions at the LHC

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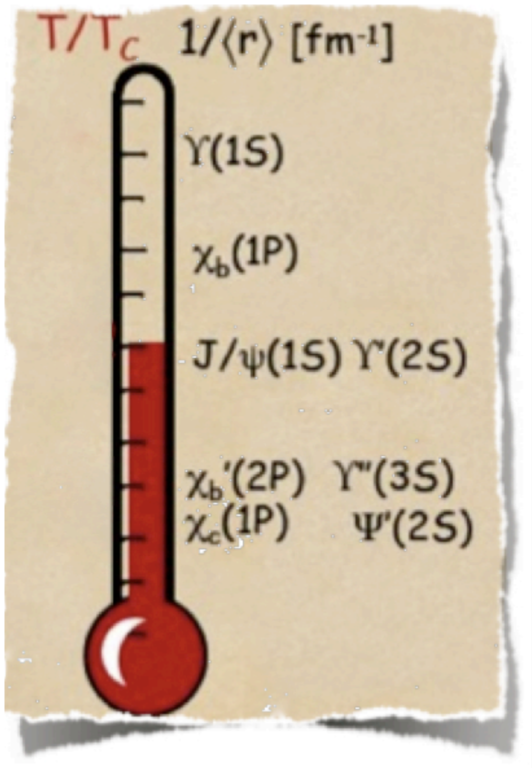
for the CMS Collaboration

Motivation

- Υ in pp (Accepted by PRD, arXiv:1012.5545)
  - The hadroproduction of quarkonia is not well understood. None of the existing theories successfully reproduce both the differential cross section and the polarization measurements
  - The LHC produces high p_T Υ at a large rate and has the potential to discriminate between the emerging new models

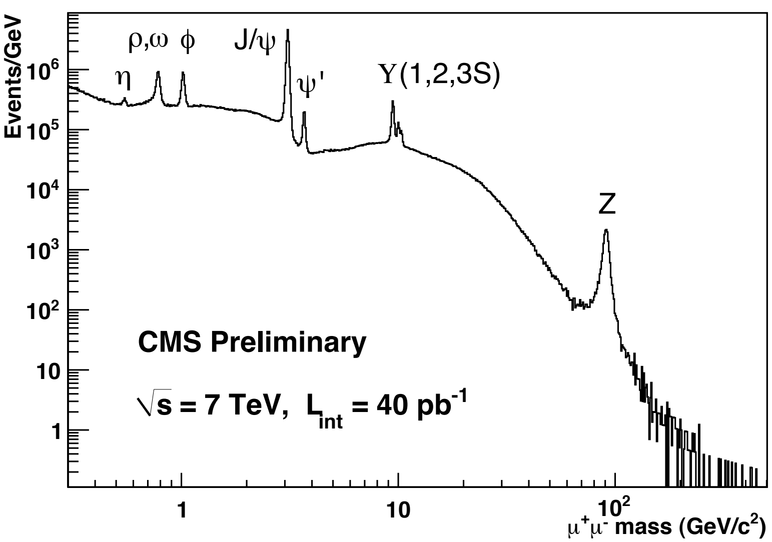
- Υ in PbPb (CMS-HIN-10-006)
  - Bottomonium measurement helps characterize the dense matter produced in heavy-ion collisions beyond the SPS and RHIC charmonium results
  - The full spectroscopy of quarkonium states has been suggested as a possible thermometer for the QGP
  - Suppression of quarkonia is a longstanding classical prediction as QGP signature
  - Suppression is also produced by nuclear absorption?

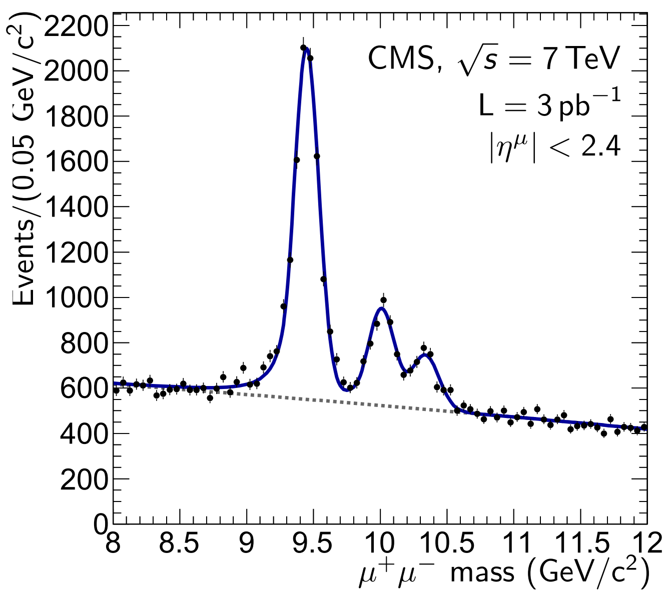


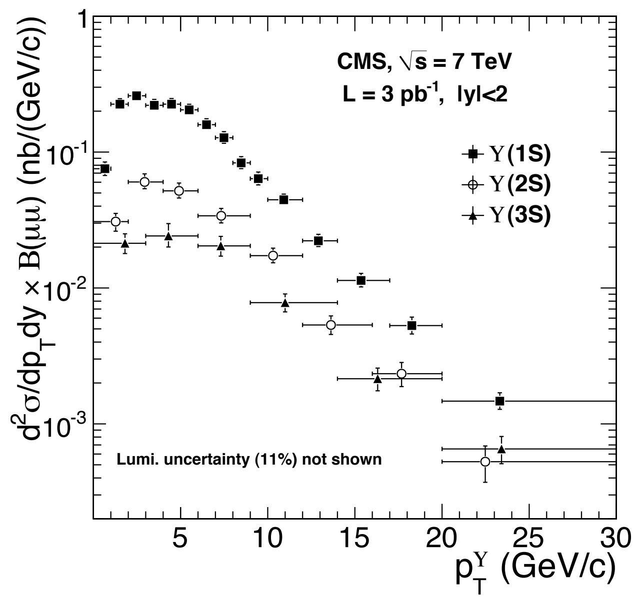
Υ Cross Section for pp @ 7 TeV

- pp run 2010 @ 7 TeV (L_{int} = 3.1 pb^{-1})
- Cross section
- Result (The Υ(nS) cross section at 7 TeV integrated over the rapidity range |*y*|<2)

$$\sigma(pp \to \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \to \mu^+\mu^-) = 7.37 \pm 0.13(\text{stat.})^{+0.61}_{-0.42}(\text{syst.}) \pm 0.81(\text{lumi.})\,\text{nb}\,,$$
$$\sigma(pp \to \Upsilon(2S)X) \cdot \mathcal{B}(\Upsilon(2S) \to \mu^+\mu^-) = 1.90 \pm 0.09(\text{stat.})^{+0.20}_{-0.14}(\text{syst.}) \pm 0.24(\text{lumi.})\,\text{nb}\,,$$
$$\sigma(pp \to \Upsilon(3S)X) \cdot \mathcal{B}(\Upsilon(3S) \to \mu^+\mu^-) = 1.02 \pm 0.07(\text{stat.})^{+0.11}_{-0.08}(\text{syst.}) \pm 0.11(\text{lumi.})\,\text{nb}\,.$$







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Data Sample and Event Selection

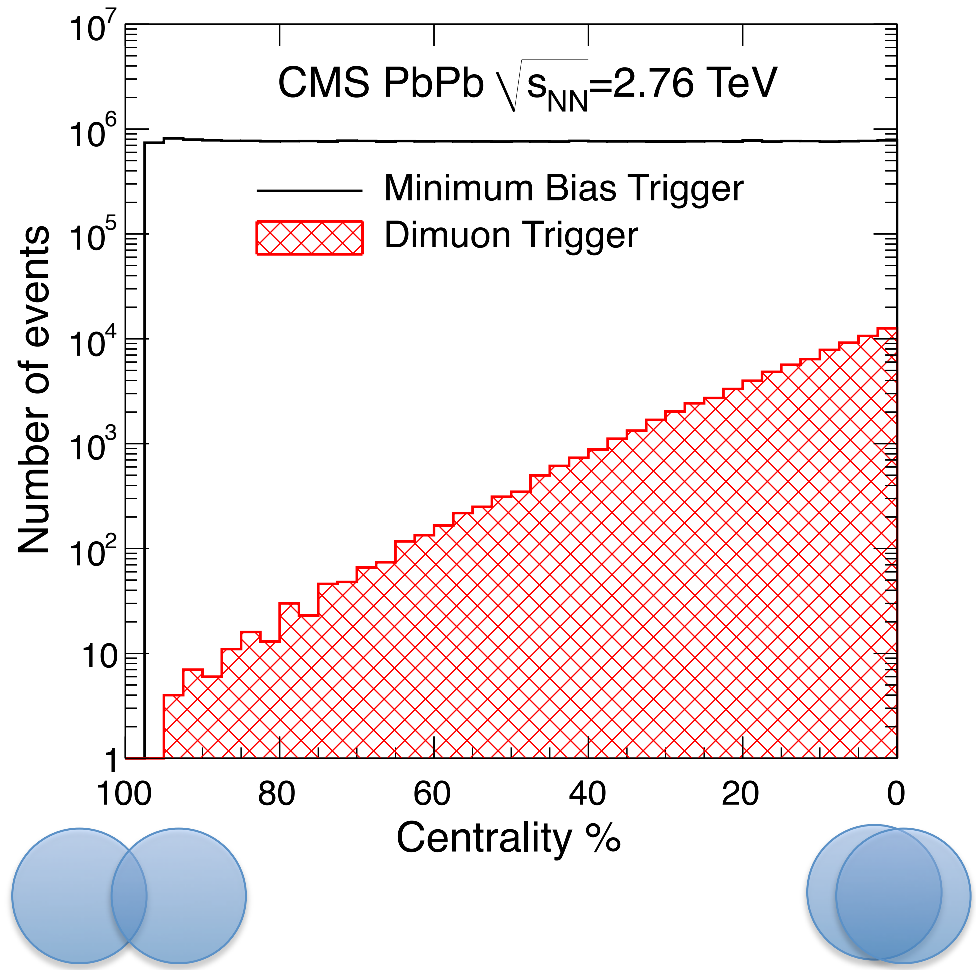
- PbPb run 2010 @ $\sqrt{s_{NN}}$ = 2.76 TeV (L_{int} = 7.28 μb^{-1})
  pp run 2011@$\sqrt{s}$ = 2.76 TeV (L_{int} = 225 nb^{-1})

– Online Dimuon trigger

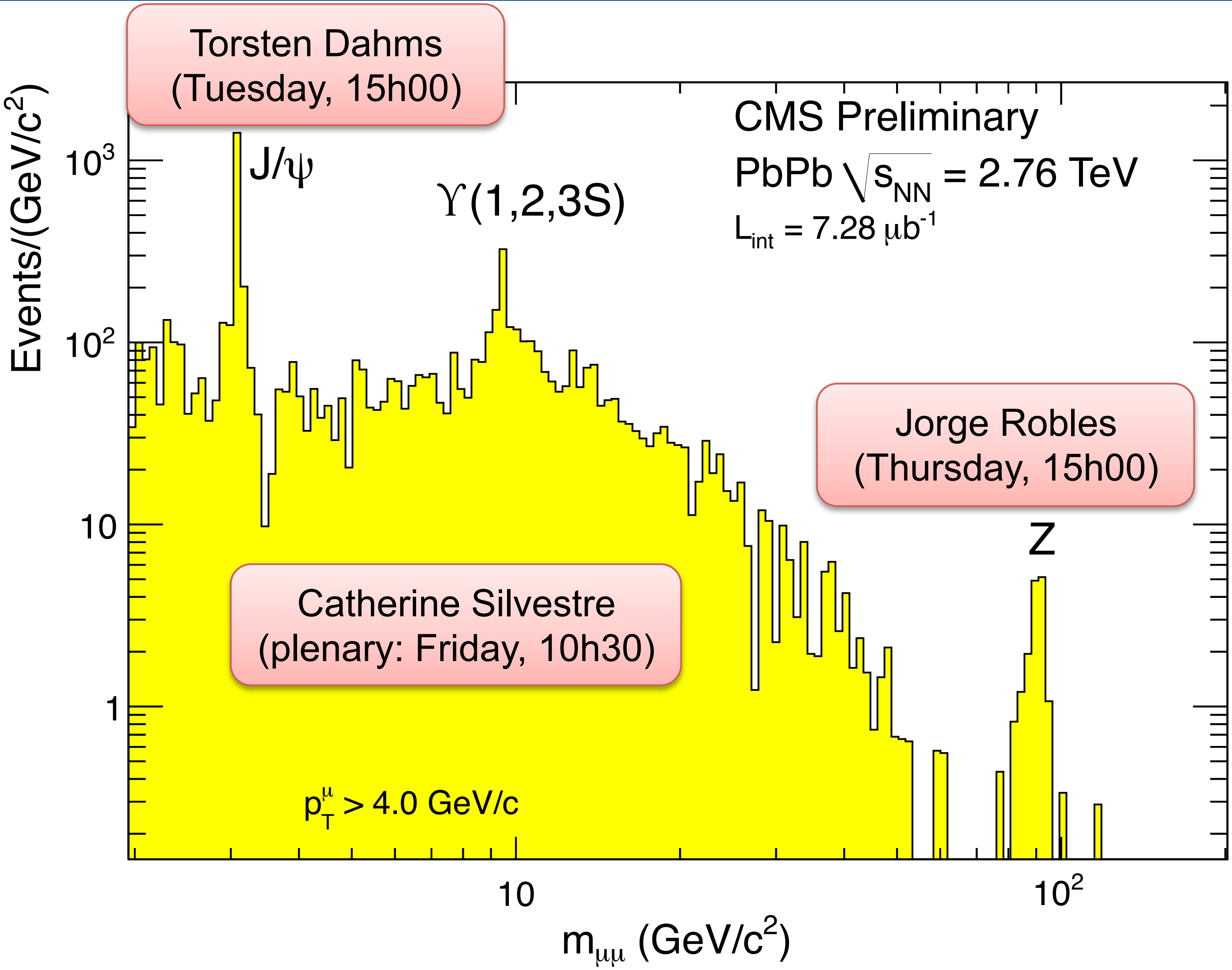
– Heavy ion offline selection for the PbPb data

– Similar offline selection for the pp data

– Both datasets reconstructed with same heavy ion tracking algorithm



Muon Pairs in PbPb



- Muon quality cuts studied with Pythia-generated signal embedded in HYDJET (heavy-ion generator) and background from data
- Further kinematic cuts applied to reduce background level
  - Single muon: $p_T^{\mu} > 4$ GeV/c, $|\eta^{\mu}| < 2.4$

What do we want to measure?

- Yields of Υ(1S) as function of p_T, rapidity, and centrality of the collision

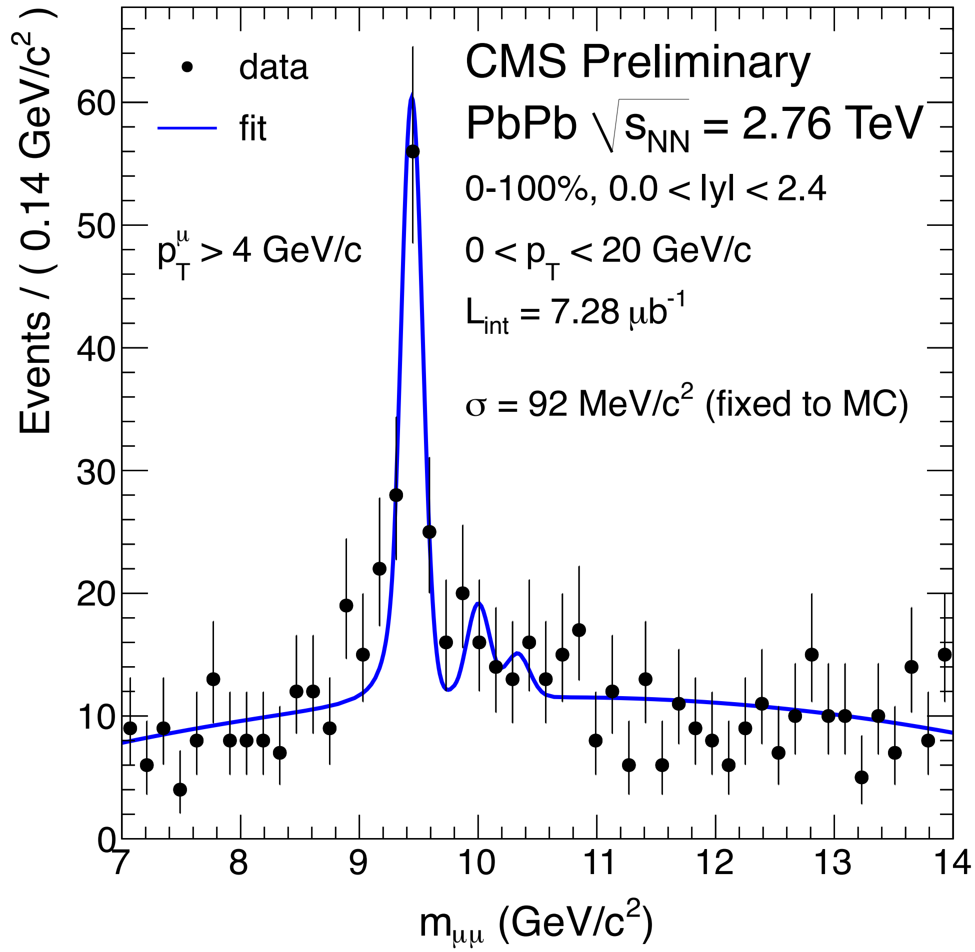
$$\frac{1}{T_{AA}} \cdot \frac{d^2N}{dp_T dy} = \frac{1}{T_{AA}} \cdot \frac{1}{\Delta y\, \Delta p_T} \cdot \frac{N_{Q\overline{Q}}}{\alpha\, \varepsilon\, N_{\mathrm{MB}}}$$

  - N_{QQ} : 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})

- Centrality bins: 0 - 10% , 10 - 20% , 20 - 100%
- p_T bins (GeV/c): 0 - 6.5 , 6.5 - 10 , 10 - 20
- Rapidity bins: $0 < |y| < 1.2$, $1.2 < |y| < 2.4$

Υ(nS) Signal Extraction

- Extended unbinned maximum likelihood fit
  - Signal
    - Core Gaussian with power law tail of EM final state radiation
    - Resolution fixed from MC simulation
    - Peak separation fixed to PDG
  - Background
    - Second order polynomial
- Signal + background template was used successfully in 7 TeV pp analysis [3/pb data]

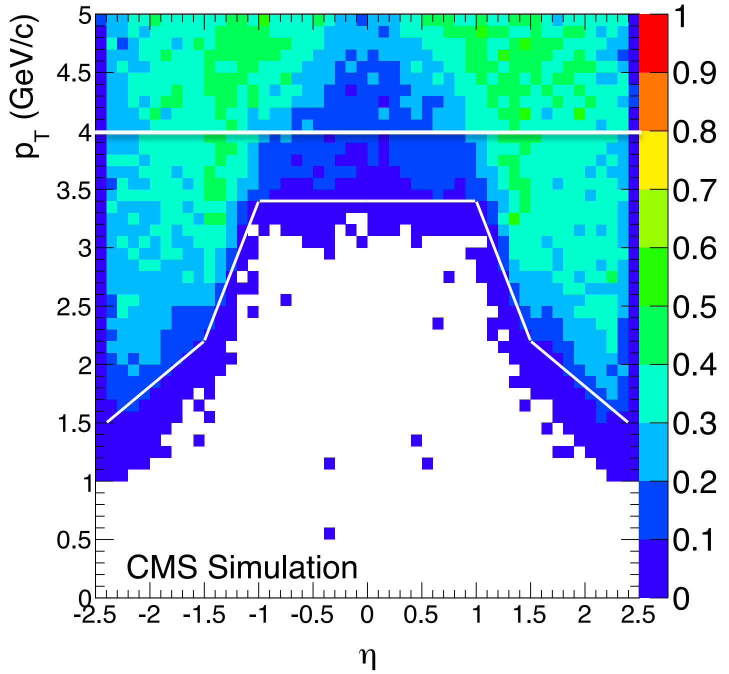


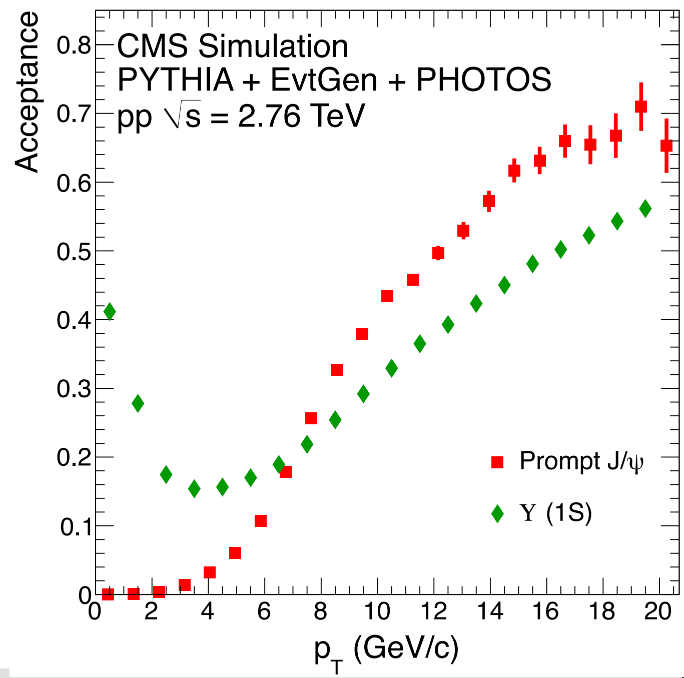
Υ(1S) raw yields: 86 ±12

Acceptance

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

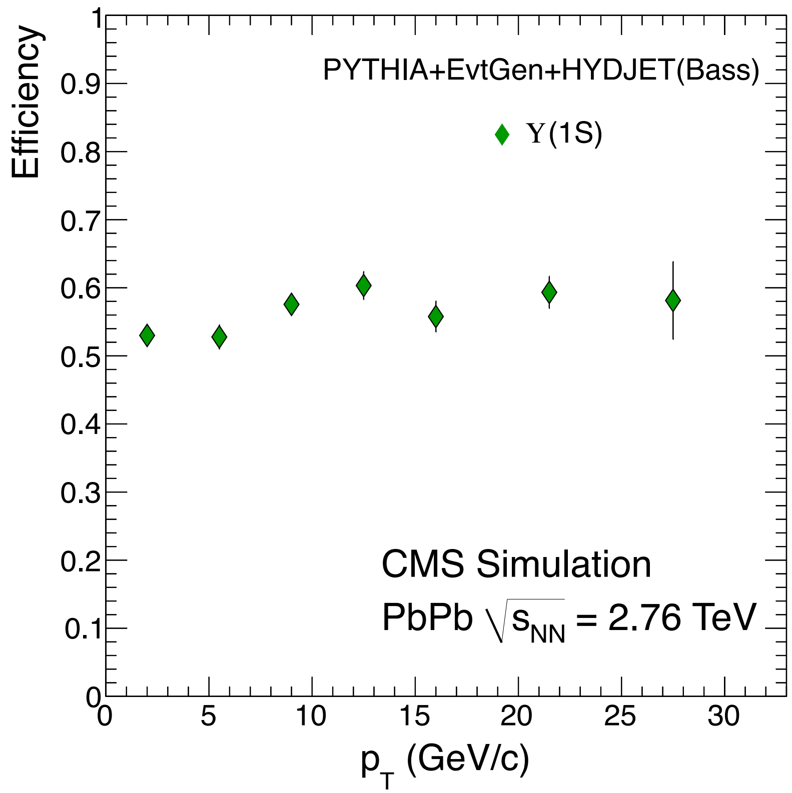
- $N^{dimuon}_{reconstructible,M}$: the number of generated events in the MC simulation, declared detectable in a given acceptance cuts, within a mass interval for Upsilon
- $N^{dimuon}_{|y^{dimuon}|<2.4}$: the number of all dimuons generated within the muon stations coverage of the CMS detector ($|\eta| < 2.4$)
- Υ(1S) acceptance: 21.6%
- The systematic uncertainty: 2.8%

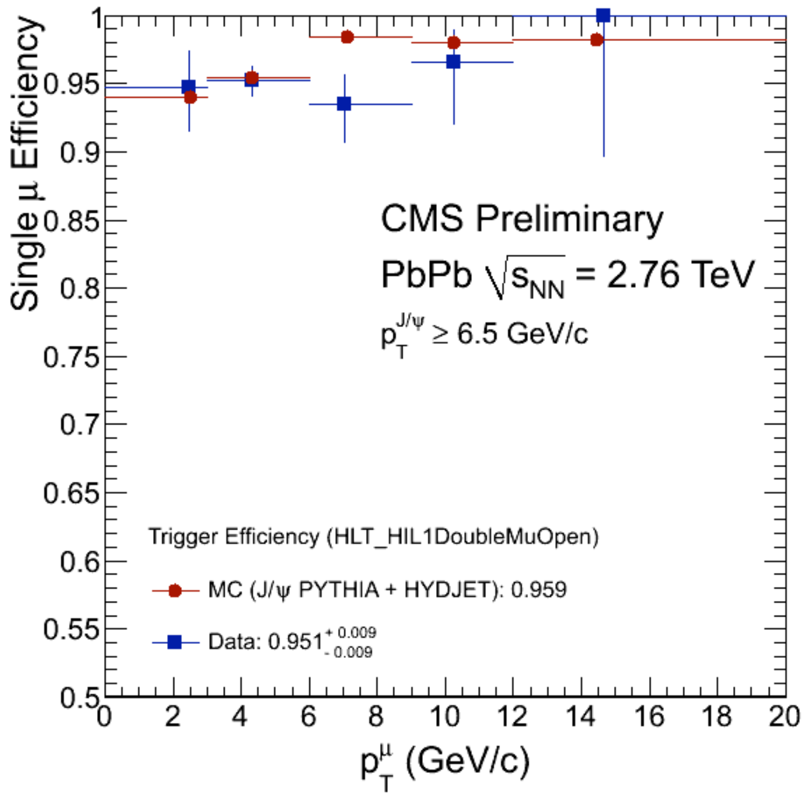




Efficiency

- Trigger efficiency, reconstruction efficiency estimated using MC
- Efficiency definition:
  - [reconstructed signal passing all the analysis selections] / [the generated signal]
  - Only muons in the acceptance kinematic region are considered
- $\Upsilon(1S)$ efficiency: 54.5%.
- The MC efficiency cross checked with $J/\psi \to \mu^+\mu^-$ in data using real data
  The statistical uncertainty from data is taken into account in systematic

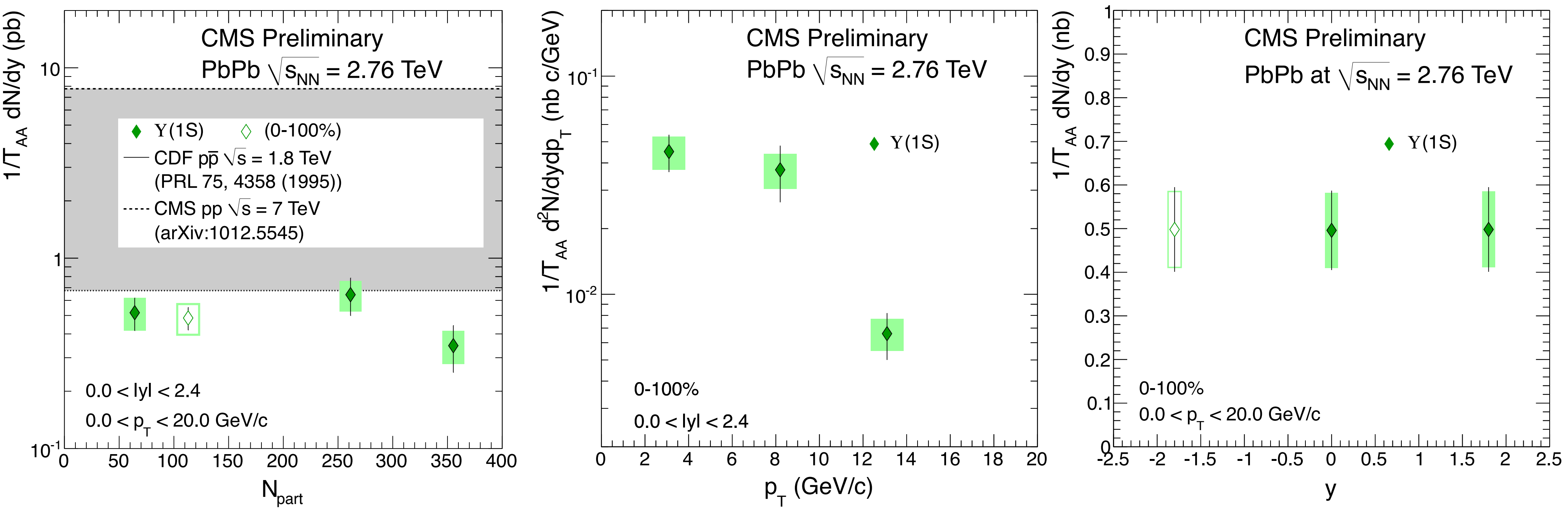




Υ(1S) Invariant Yields in PbPb

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

- No obvious rapidity dependence
- No clear centrality dependence (but 20–100% is not very peripheral)



- Systematic uncertainties:
  - Yield extraction: 8–14%. Acceptance: 1–5%. Efficiency: 14%. T_{AA}: 4.3–15%
- Statistical uncertainties: 5–20%

Nuclear Modification Factor: R_{AA}

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

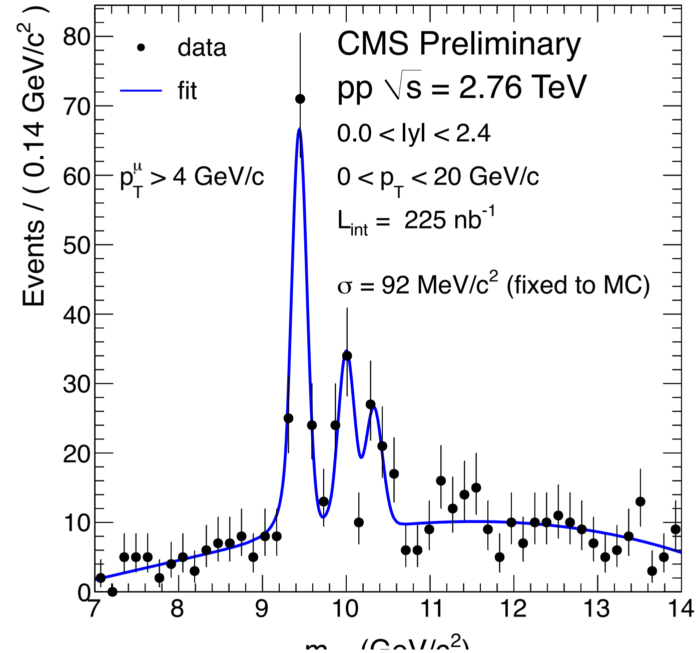
$$R_{AA} = \frac{\mathcal{L}_{\text{int}}^{pp}}{T_{AA} N_{\text{MB}}} \frac{N_{Q\overline{Q}}^{\text{PbPb}}}{N_{Q\overline{Q}}^{pp}} \cdot \frac{\varepsilon_{pp}}{\varepsilon_{\text{PbPb}}(\text{cent})}$$

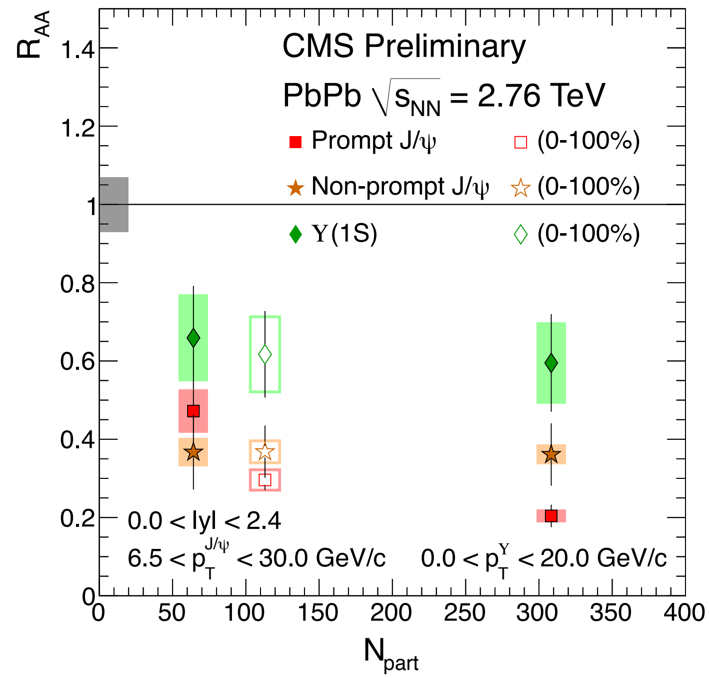
- N_{PbPb} = 86 ± 12[stat] ± 3[syst]
- N_{pp} = 101 ± 12[stat] ± 3[syst]
- T_{AA} = 5.66 mb^{-1}
- N_{MB} = 55.7M MB PbPb collisions
- L_{pp} = 225 nb^{-1}

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

Υ(1S) R_{AA} in the most central 20%

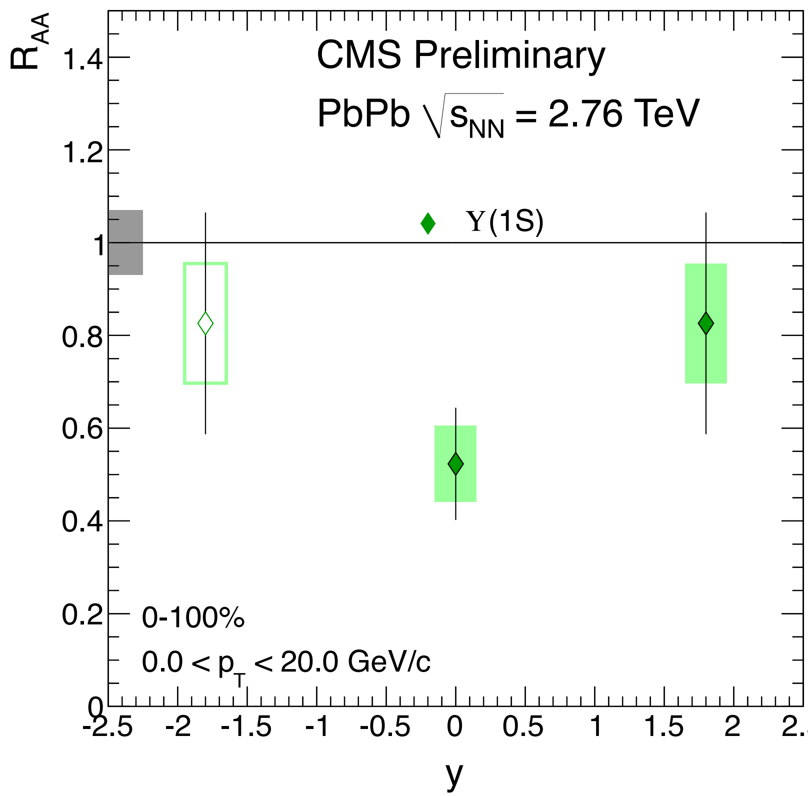
- **0.60 ± 0.12(stat.) ± 0.10(syst.)**
- consistent with the suppression of excited states (50% feed-down contribution measured by CDF)

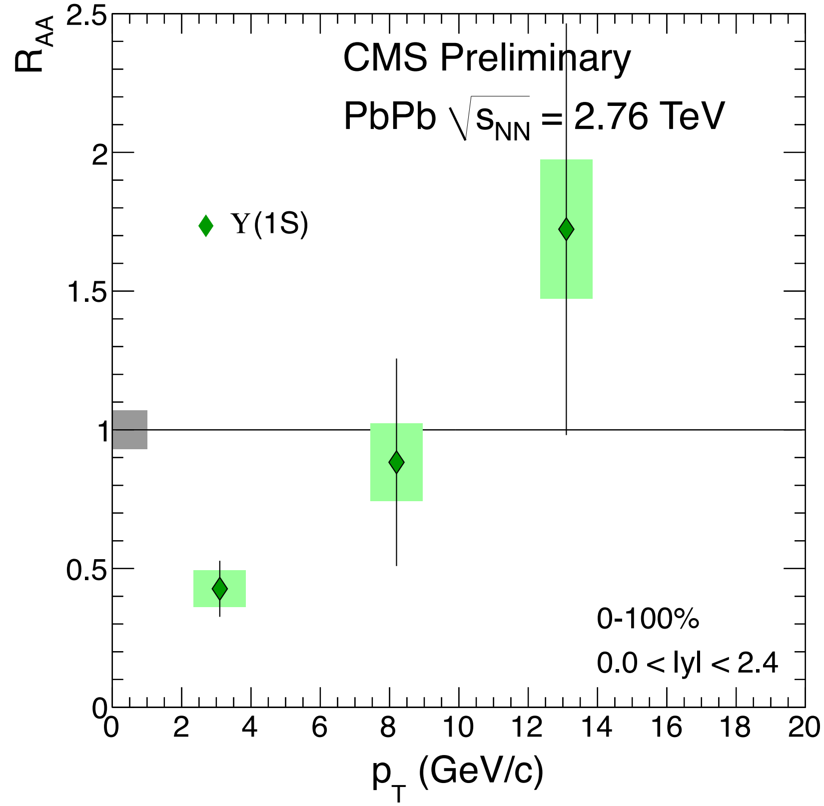




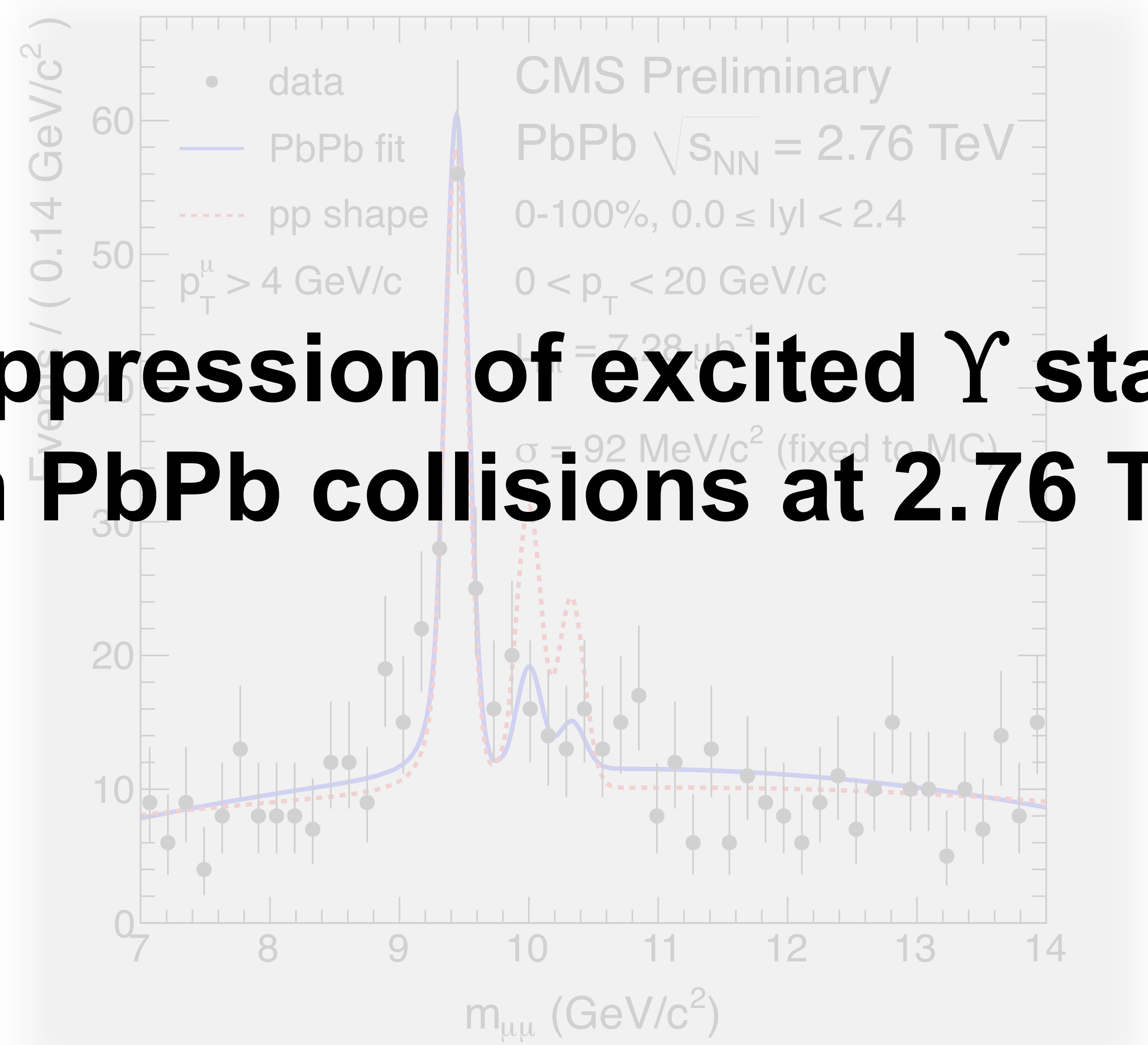
$\Upsilon(1S)$ R_{AA}

- 0-100% $R_{AA} = 0.62 \pm 0.11 \pm 0.10$
- No obvious rapidity dependence
- High p_T not as suppressed ?
- Waiting for more data next year





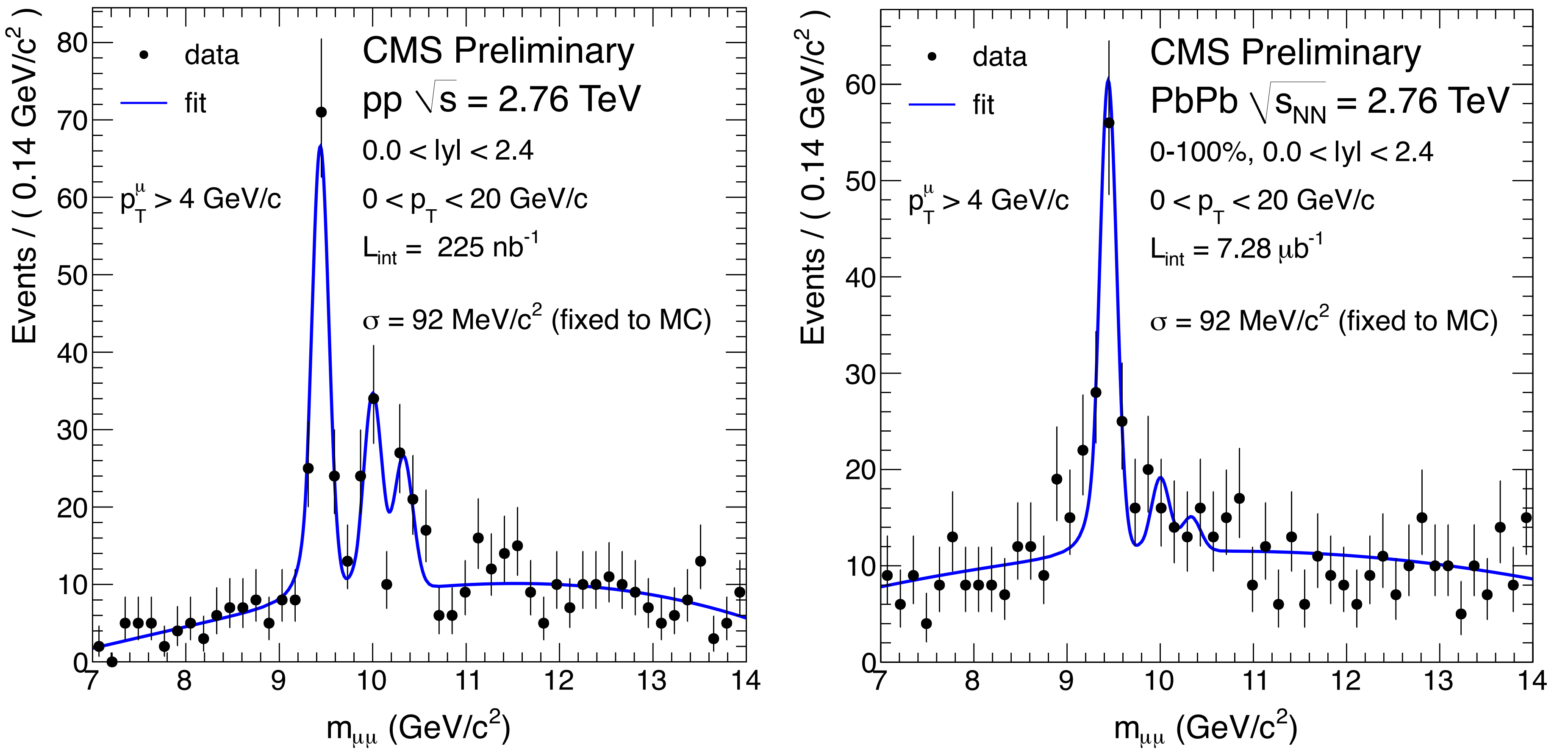
Suppression of excited Υ states in PbPb collisions at 2.76 TeV



$\Upsilon(2S+3S)$ vs $\Upsilon(1S)$

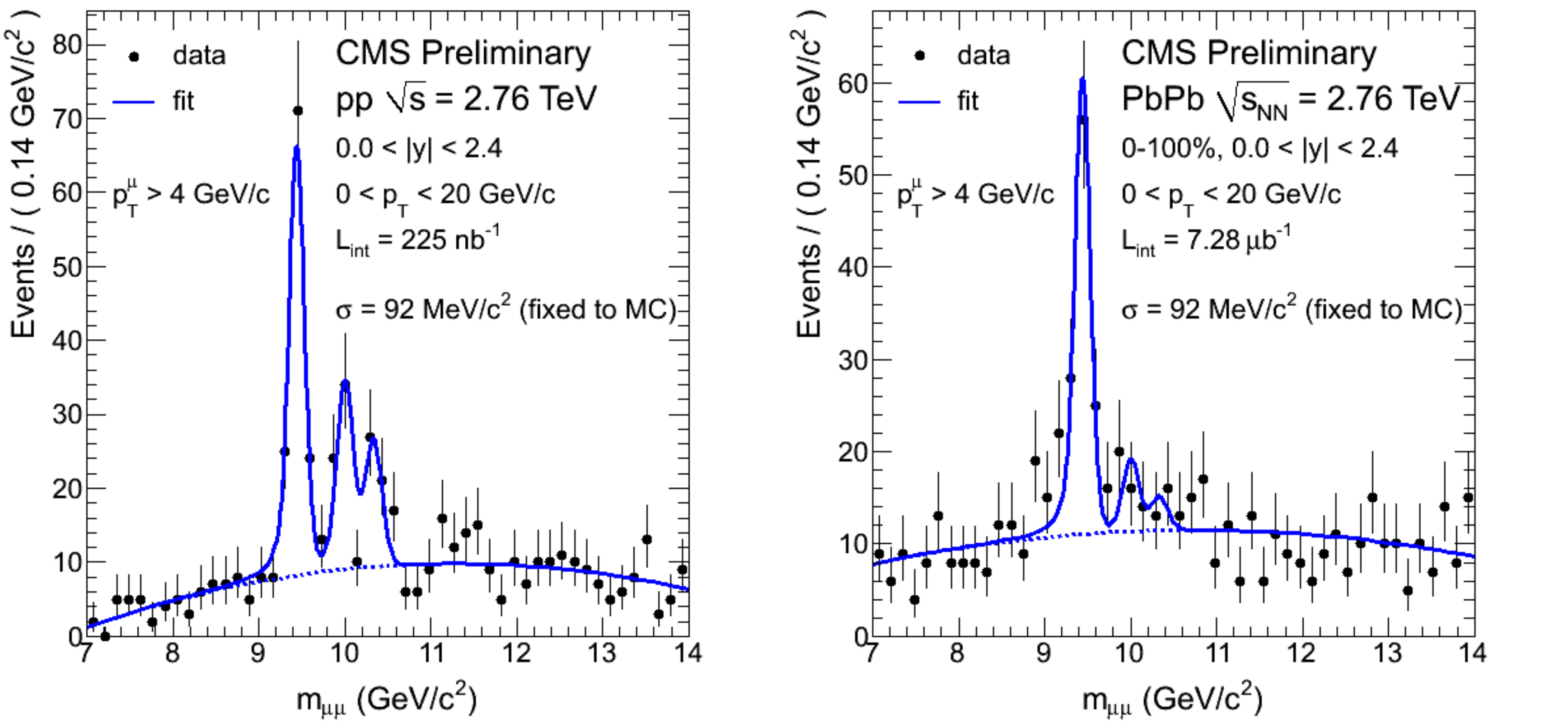
- Measure the fraction of excited states $\Upsilon(2S+3S)$ relative to $\Upsilon(1S)$
- Fraction extracted directly from the fit to the PbPb and pp data sample (both at 2.76 TeV)

$$\Upsilon(2S+3S)/\Upsilon(1S)\Big|_{pp} = 0.78^{+0.16}_{-0.14} \pm 0.02 \qquad \Upsilon(2S+3S)/\Upsilon(1S)\Big|_{PbPb} = 0.24^{+0.13}_{-0.12} \pm 0.02$$



Double Ratio

- Compare ratios of Υ(2S+3S) relative to Υ(1S) in PbPb & pp
  - Extract double ratio directly from simultaneous fit to both samples
  - Also divide results from fits to each sample as cross check
  - Simultaneous fit results $\dfrac{\Upsilon(2S+3S)/\Upsilon(1S)|_{PbPb}}{\Upsilon(2S+3S)/\Upsilon(1S)|_{pp}} = 0.31^{+0.19}_{-0.15}(\text{stat.})$



Systematics for Double Ratio

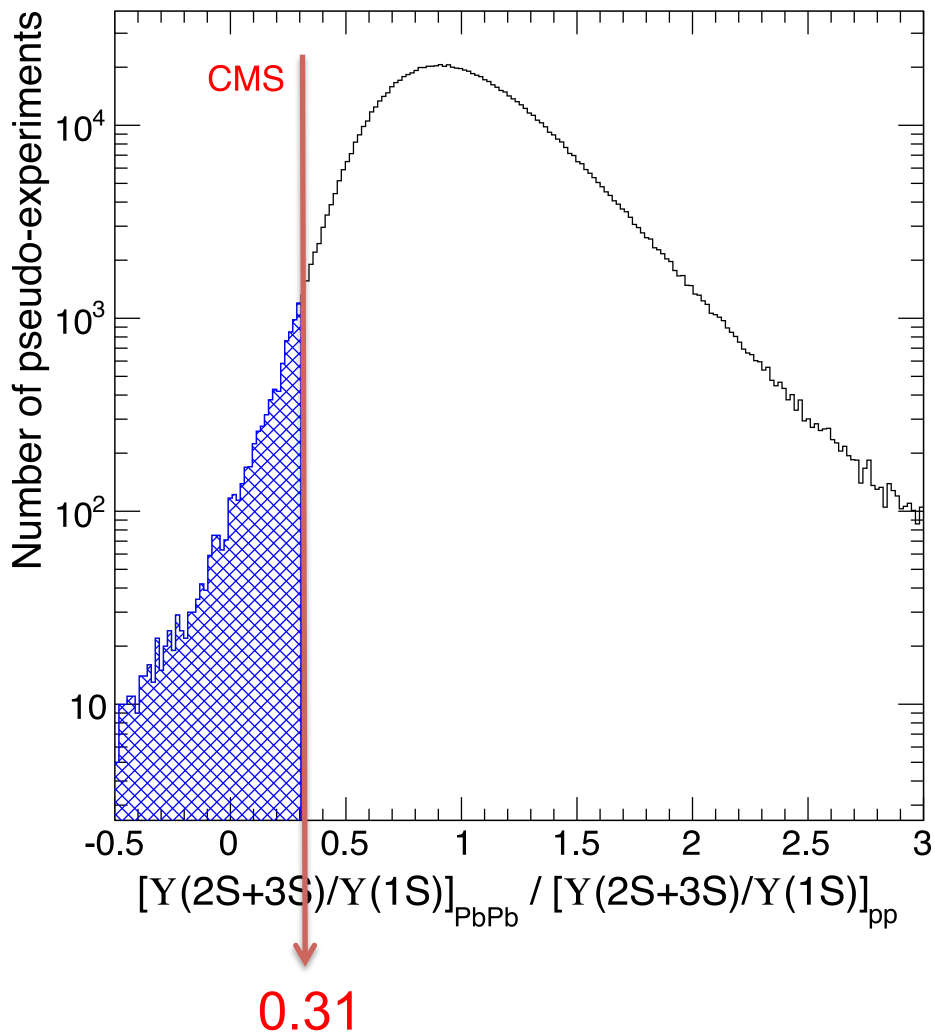
- Υ(2S+3S)/Υ(1S) ratio in pp and PbPb benefits from cancellation of possible acceptance and efficiency differences
  - Reconstruction and selection efficiencies: 0.5%
  - Trigger efficiencies: negligible effect
- Systematic uncertainty from the fitting model
  - Signal shape: 0.9%
  - Mass resolution: 3.7%
  - Background PDF and fit range: 8.2%
  - Sum: 9.1%
- Statistical uncertainty (dominant): 55%

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

p-value

Could background fluctuation produce a result as extreme as observed in data?

- Generate pseudo-experiments following the *null-hypothesis* (i.e. no suppression)
- Fit pseudo-data samples with nominal fit
- Count fraction of occurrences for which the ratio (taken as test statistic) is same or lower than observed:
  - p-value: 0.9%
  - 2.4σ (1-sided Gaussian test)



Conclusion 1

First observation of suppression of excited Υ states

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

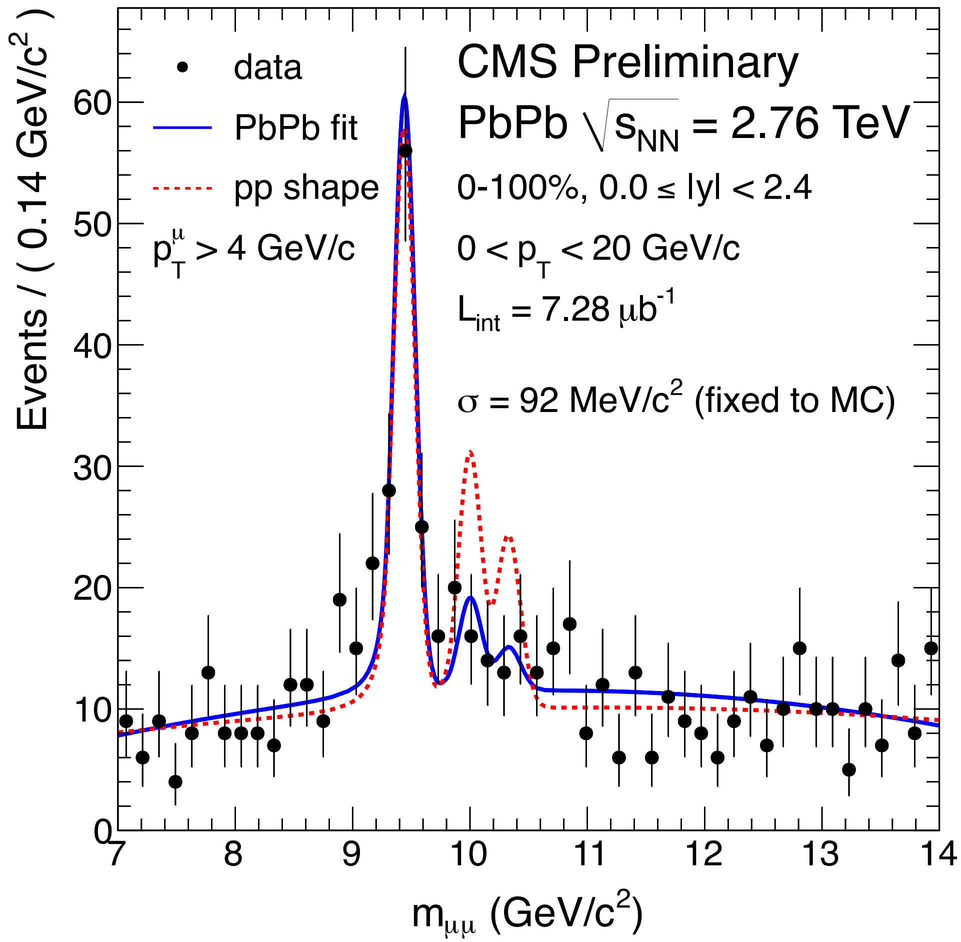
$$\Upsilon(2S+3S)/\Upsilon(1S)\big|_{PbPb} = 0.24^{+0.13}_{-0.12} \pm 0.02$$

Double ratio:

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

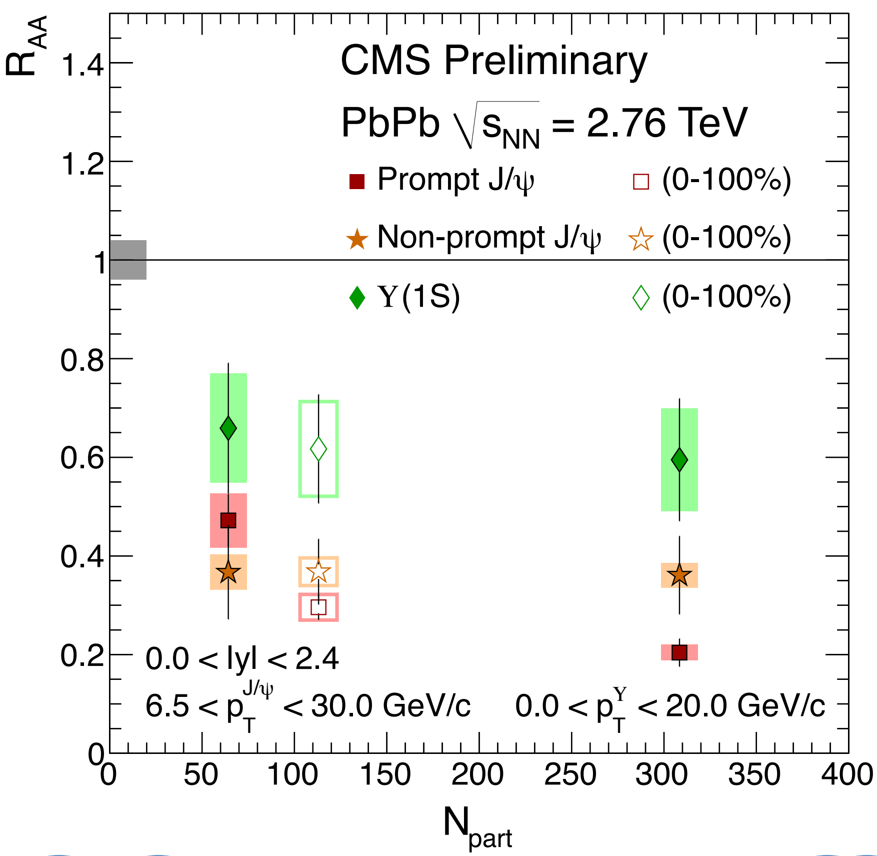
The suppression is checked with pseudo-experiments

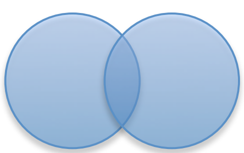
- The probability to obtain the measured value or lower, if the real double ratio is unity, has been calculated to be less than 1%

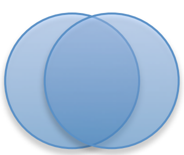


Conclusion 2

- Measured Υ(1S) invariant yields as a function of centrality, p_T, and y
- Υ(1S) is suppressed (In the most central 20%, R_{AA} = 0.60 ± 0.12 ± 0.10)







- Taken together these two conclusions are consistent
  - the suppression of the Υ(1S) is the result of the excited Υ states suppression
- Comparing with prompt and non-prompt J/ψ
  - Prompt J/ψ suppressed the most, Υ(1S) the least (in 0-20%)
  - More details in J/ψ talk and quarkonia overview talk

Torsten Dahms (Tuesday, 15h00)

Catherine Silvestre (plenary: Friday, 10h30)

Thanks !