

Measurement of $\Upsilon(nS)$ production at 7 TeV at the CMS experiment

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Abstract. The $\Upsilon(nS)$ production cross section in proton-proton collisions at $\sqrt{s} = 7$ TeV is measured using the CMS detector at the LHC from data corresponding to $(3.1 \pm 0.3) \text{ pb}^{-1}$ of integrated luminosity. In the rapidity range $|y| < 2$, we find that $\sigma(\text{pp} \rightarrow \Upsilon(1S)X) \cdot \mathcal{B}(\Upsilon(1S) \rightarrow \mu^+\mu^-) = (7.37 \pm 0.13^{+0.61}_{-0.42} \pm 0.81) \text{ nb}$, where the uncertainties are statistical, systematic and luminosity, respectively. We also report differential cross sections for the three lowest Υ states as a function of transverse momentum and rapidity and compare them with other experiments and model predictions.

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The hadroproduction of $\Upsilon(nS)$ and other quarkonia states is not completely understood. None of the current models can successfully reproduce both the differential cross section and the polarization observed for the J/ψ or Υ states [1]. The measurement of production of the Υ resonances at the Large Hadron Collider (LHC) provides an important test of alternative theoretical approaches [2, 3] and can be compared with measurements done at the Tevatron [4, 5].

In this proceeding, we summarize the measurement of the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ production cross sections using the CMS detector at the LHC including the differential cross sections as a function of transverse momentum (p_T) and rapidity (y). The full details of this measurement are contained in Ref. [6]. Reference [7] contains a description of the CMS detector operating at the CERN LHC. The results documented in this proceeding make use of simulations that rely on software packages including PYTHIA [8], EvtGen [9], PHOTOS [10, 11] and GEANT4 [12]. The data used in these measurements were collected during 2010 and corresponds to an integrated luminosity of $(3.1 \pm 0.3) \text{ pb}^{-1}$.

SELECTION

We reconstruct Υ candidates in their decays to two muons. Events are initially selected for having fired a basic dimuon trigger. This trigger requires the presence of two muons at the level of the hardware trigger and makes no additional selection in subsequent trigger layers. We require that muon candidates have at least 12 hits in the silicon tracking detector, at least one of which must be in the pixel detector, and that the track χ^2 per number of degrees of freedom be less than five. In addition the tracks are required to be consistent with originating from a cylinder of 2 mm radius and 50 cm

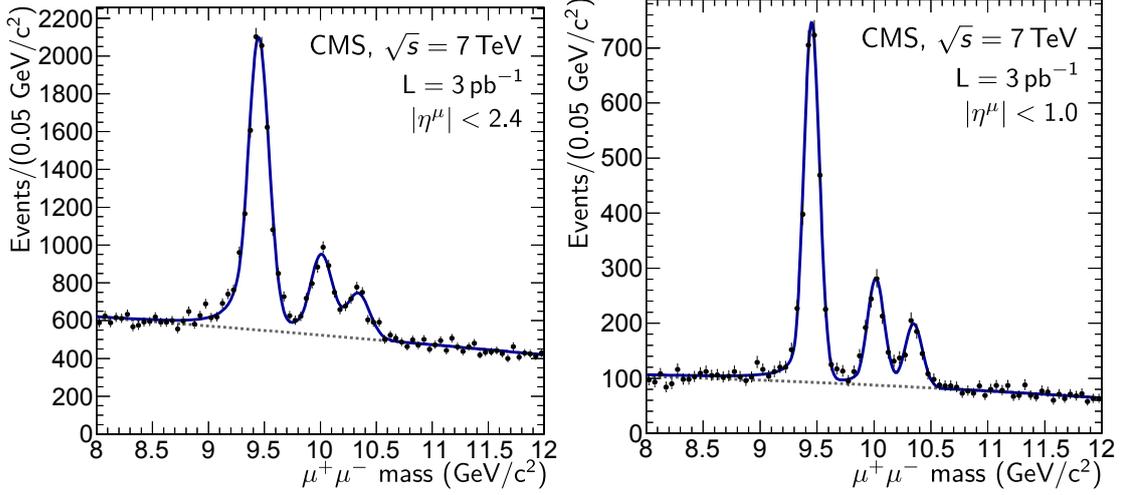


FIGURE 1. The invariant mass spectrum of selected $\Upsilon(nS)$ candidates. The solid line is a projection of the fit onto the spectrum, and the dashed line is the background contribution. The right figure shows the entire pseudo-rapidity coverage, and the left is for central muons where $|\eta^\mu| < 1$.

length centered on the luminous region and parallel to the beam line. To ensure high trigger and reconstruction efficiencies, we further impose kinematic requirements that the muon p_T and pseudo-rapidity ($\eta = -\ln[\tan(\theta/2)]$) satisfy

$$p_T^\mu > 3.5 \text{ GeV}/c \text{ if } |\eta^\mu| < 1.6, \text{ or } p_T^\mu > 2.5 \text{ GeV}/c \text{ if } 1.6 < |\eta^\mu| < 2.4.$$

An Υ candidate is formed using oppositely charged muon candidates. These muons must have a longitudinal separation at their points of closest approach to the beam line less than 2 cm. The two muon helices are fit with a common vertex constraint, and the resulting χ^2 probability is required to be greater than 0.1%. The dimuon candidate is confirmed to have passed the dimuon trigger requirements. If multiple Υ candidates are selected in the same event, the candidate with the best vertex quality is retained; a procedure shown to reject only 0.2% of simulated signal events. Finally, Υ candidates with rapidity, defined $y = \frac{1}{2} \ln\left(\frac{E+p_\parallel}{E-p_\parallel}\right)$, less than two, transverse momentum less than $30 \text{ GeV}/c$, and invariant mass between $8 \text{ GeV}/c^2$ and $14 \text{ GeV}/c^2$ are kept for further analysis. The invariant mass spectrum of the candidates from $8 \text{ GeV}/c^2$ to $12 \text{ GeV}/c^2$ is shown in Fig. 1

RESULTS

We determine the corrected yield of each Υ resonance via an unbinned maximum likelihood fit to the the invariant mass spectrum in the bin of interest. To correct for acceptance and efficiency, each event is weighted according to the kinematic properties of the candidate and its muon daughters. The acceptance of each candidate is determined from studies of simulated Υ decays, and the efficiency of each candidate is extracted largely from collision data. Details on the determination of the acceptance, efficiency,

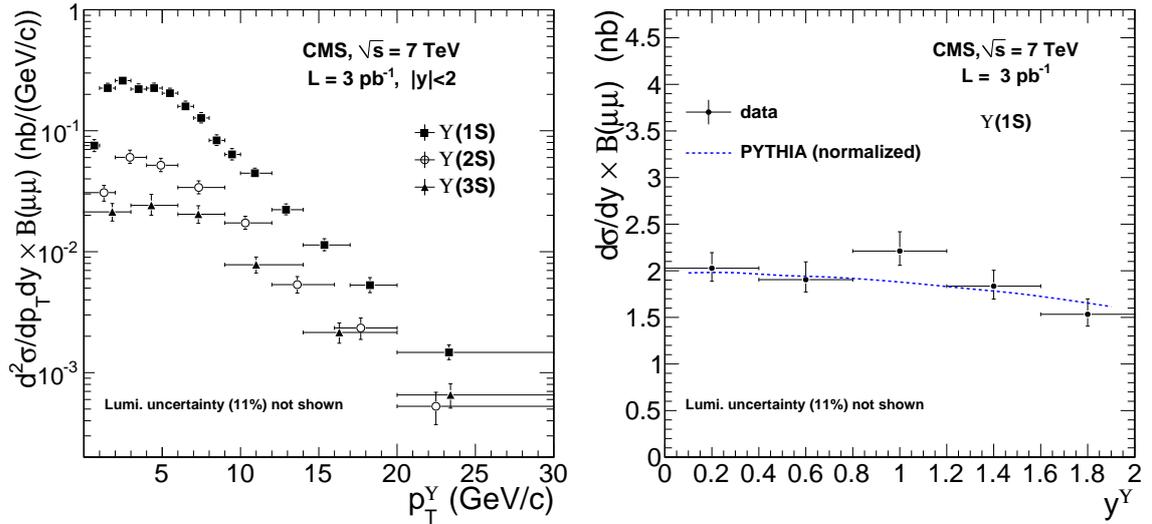


FIGURE 2. The differential production cross section of the $\Upsilon(nS)$ resonances. The right figure is the differential cross section as a function of p_T for all three Υ states. The left figure is the differential cross section as a function of rapidity for the $\Upsilon(1S)$ and includes the shape predicted by PYTHIA and normalized to our result.

event weights, fitting models and procedures are contained in Ref. [6]. The projection of the fit onto the integrated data sample is shown in Fig. 1. We find the unpolarized production cross section times branching fraction in nb for $p_T < 30 \text{ GeV}/c$ and $|y| < 2$ to be

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

Apart from the luminosity uncertainty which is listed separately, the dominant systematic uncertainty arises from the determination of the efficiency used in weighting the events. The results of the differential cross-section are shown in Fig. 2. Please refer to Ref. [6] for the numerical values and more details on the systematic uncertainties.

Our measurements can be compared with other experiments and with phenomenological models. Figure 3 shows our results overlaid with results from the experiments at the Tevatron normalized by the total cross-section of each experiment [4, 5]. Figure 4 shows how our results compare in shape to those predicted by PYTHIA (the normalization being taken from our measurement). In all of these examples, the agreement is quite good.

SUMMARY

The CMS collaboration has measured the differential cross section of the $\Upsilon(nS)$ states in the kinematic region $|y| < 2$ and $p_T < 30 \text{ GeV}/c$. These measurements agree well

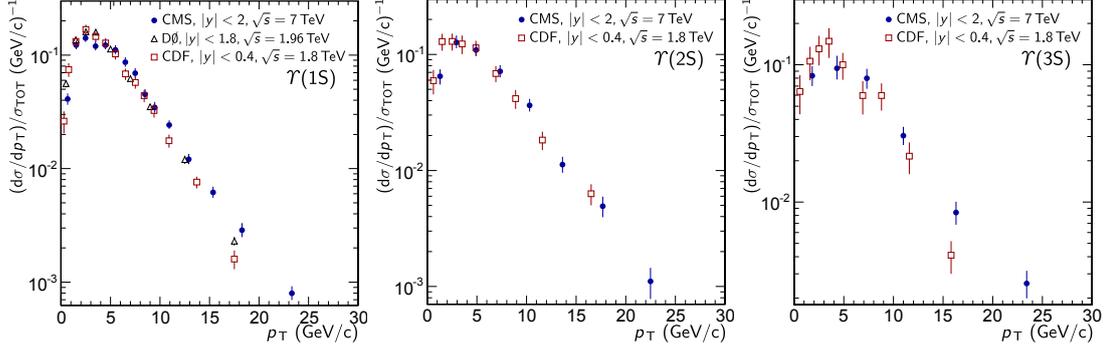


FIGURE 3. Differential cross section measurements normalized by total cross section of each $\Upsilon(nS)$ resonance from CMS overlaid with those from CDF and D0.

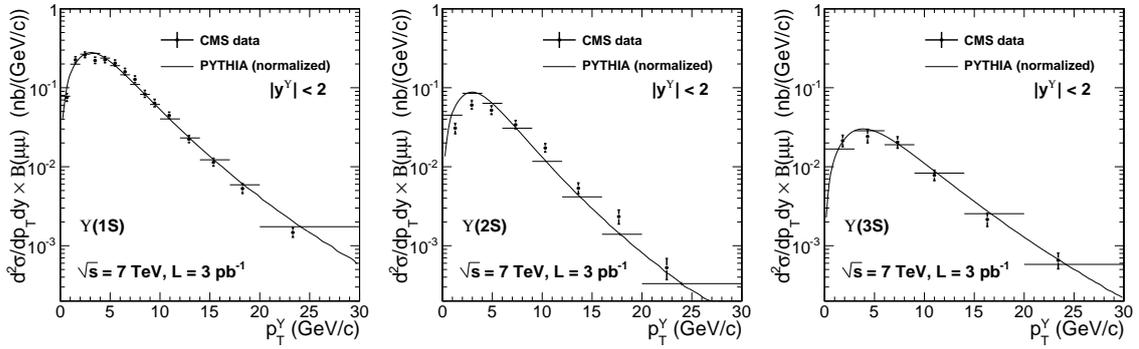


FIGURE 4. Differential cross section for each $\Upsilon(nS)$ resonances overlaid with the PYTHIA shape normalized to the measured total cross section.

with those from the Tevatron and should provide an additional constraint for models predicting quarkonia hadroproduction.

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