The inclusive differential cross section of $p\bar{p} \to \Upsilon(1S)$ at $\sqrt{s} = 1.96$ TeV

Freya Blekman for the DØ Collaboration
Presented at the International Europhysics Conference on High Energy Physics,Lisboa, Portugal
Imperial College, UK
(Dated: July 21st - 27th 2005)

We present measurement of the inclusive production cross sections of the $\Upsilon(1S)$ bottomonium state in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV. Using the $\Upsilon(1S) \to \mu^+\mu^-$ decay mode for a data sample of 159 ± 10 pb^{-1} collected by the DØ detector at the Fermilab Tevatron collider, we determine the differential cross section as a function of the $\Upsilon(1S)$ transverse momentum for three ranges of the $\Upsilon(1S)$ rapidity: $0 < |y^\Upsilon| \leq 0.6$, $0.6 < |y^\Upsilon| \leq 1.2$ and $0.6 < |y^\Upsilon| \leq 1.2$.

I. INTRODUCTION

Bottomonium states are produced in abundance at the DØ detector at the Tevatron Collider at Fermilab [1]. We present a measurement of the differential cross section of the $\Upsilon(1S)$ as a function of its transverse momentum (p_T^Υ) and in three ranges of rapidity (y^Υ).

This is the first measurement of this type at the upgraded Tevatron energy of $\sqrt{s} = 1.96$ TeV. The CDF collaboration has performed a similar measurement in Tevatron Run 1 ($\sqrt{s} = 1.8$ TeV), but only for a limited rapidity range: $0 < |y^\Upsilon| \leq 0.4$ [3].

Differential cross section measurements of the Υ are necessary due to the fact that at Tevatron interaction energies, the $b\bar{b}$ bound states only have limited p_T. This means that it is not possible to calculate the distributions by analytical techniques in perturbative QCD (pQCD). The main source of divergences is the handling of initial state gluons, which has led to a plethora of phenomenological non-perturbative models. As these models predict the dependence of the differential cross section as a function of p_T^Υ and y^Υ, Υ production is an ideal testing ground for theories describing heavy quark production mechanisms.

II. EXPERIMENTAL SETUP

The DØ detector is a general-purpose particle physics detector that is situated on the Tevatron $p\bar{p}$ collider, which has an interaction energy of $\sqrt{s} = 1.96$ TeV. In the analysis presented in this paper, we use the muon system up to $|\eta| < 2$, where $\eta = -\ln(\tan[\theta/2])$ and θ is the azimuthal angle. As the presented measurement is limited by systematic uncertainties, we use only a small subset of DØ data, collected in 2002 and 2003. The dataset is equivalent to an integrated luminosity of $\mathcal{L} = 159 \pm 10$ pb^{-1}. The data was collected with di-muon triggers, which were 100% efficient after the standard DØ muon identification cuts.

A. Event selection

Standard DØ muon identification criteria include a match to a matching track in the central tracker, quality cuts and cosmic muon rejection. Additional requirements on the muon isolation are applied, as are cuts on minimum transverse momenta ($p_T^\mu > 3$ GeV/c) and rapidity ($|y^\mu| < 2.2$, where $y = \frac{1}{2}\ln\frac{E+p_z}{E-p_z}$) of the muon candidate. Two opposite sign muons are then used to reconstruct Υ candidates.

III. DETERMINATION OF THE CROSS SECTION

The Υ classified in bins of p_T^Υ and y^Υ. The number of candidates is determined independently in each bin using a fit to the data as described in Section III A

A. Fit procedure

For each bin, the number of $\Upsilon(1S)$ candidates ($N(\Upsilon(1S))$) is determined by fitting three double Gaussian distributions with five free parameters:$N(\Upsilon(1S))$, $N(\Upsilon(2S))/N(\Upsilon(1S))$, $N(\Upsilon(3S))/N(\Upsilon(2S))$, the Υ mass (M_Υ) and the Υ

$\lvert y^{\Upsilon}\rvert$	$d\sigma(\Upsilon(1S)/dy$ [pb]
$0.0-0.6$	732 ± 19(stat) ± 73(syst) ± 48(lum)
$0.0-1.2$	762 ± 20(stat) ± 76(syst) ± 50(lum)
$1.2-1.8$	600 ± 19(stat) ± 56(syst) ± 39(lum)
$0.0-1.8$	695 ± 14(stat) ± 68(syst) ± 45(lum)

TABLE I: a caption

width ($\Lambda(\Upsilon(1S))$). The numbers of $\Upsilon(2S)$ and $\Upsilon(3S)$ candidates is not used for the cross section determination. The mass difference between the different $\Upsilon(NS)$ resonances is fixed to the PDG value [4], while the width of the second and third resonances are fixed to the width of the $\Upsilon(1S)$. The background is fixed with a third order polynomial function.

B. Inclusive Cross Section

The determined numbers of $\Upsilon(1S)$ candidates are then used to calculate the cross section as described in detail in [2]. The resulting cross sections as normalised per unit of rapidity are listed in Table I. The listed statistical uncertainty includes the uncertainty on the number of $\Upsilon(2S)$ candidates, as determined in the fit parameter $N(\Upsilon(1S))/N(\Upsilon(2S))$. The systematic uncertainties are dominated by the fit procedure and the corrections that have to be made for the difference between Monte Carlo simulation and data.

C. Differential Inclusive Cross Section

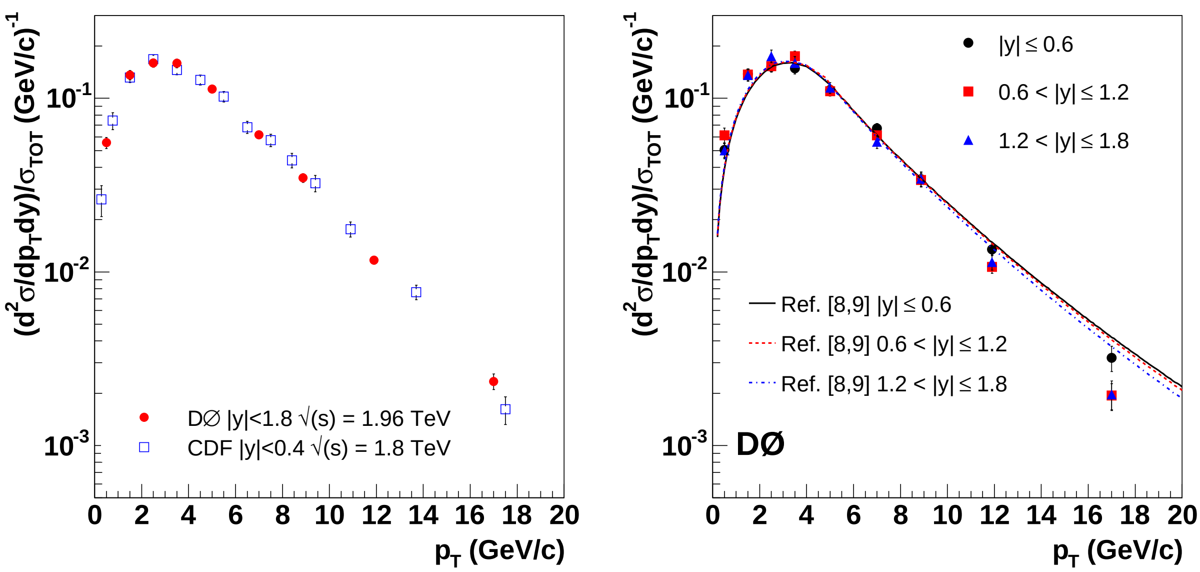

FIG. 1: The differential $\Upsilon(1S)$ cross section.

Instead of integrating over all p_T^{Υ} bins, it is also possible to look at σ^{Υ} as a function of transverse momentum. Figure 1 shows the new DØ data (integrated over $0 < y^{\Upsilon} < 1.8$), compared to the previously measured cross section by CDF ($y^{\Upsilon} < 0.4$). The CDF contribution is corrected for the increase in Tevatron collision energy and includes only the statistical uncertainty. The two results are consistent.

The cross section for three different rapidity ranges is shown in Figure 2. In this figure we also show the differential cross section as predicted by theory, in this case by one of the leading Colour Octet models [5].

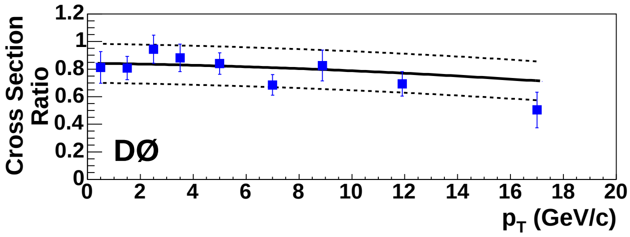

FIG. 2: The differential cross section compared to theory.

No significant change in the shape of the cross section as a function of p_T^Υ was observed for the different y^Υ bins. Figure 1 shows that the dependence of the ratio $\sigma(y^\Upsilon < 0.6)/\sigma(1.2 < y^\Upsilon < 1.8)$ is independent of p_T^Υ in DØ data (points). This agrees with predictions from Colour Singlet models as for instance used in the PYTHIA event generator [6] (line).

D. Polarisation of Υ

The CDF collaboration has measured the polarisation of $\Upsilon(1S)$ to be consistent with zero: $\alpha = -0.12 \pm 0.22$ [3]. To study the effect of a possible small polarisation term, the cross section measurement was repeated with variations of α of ± 0.15 and ± 0.30. The resulting cross sections were changed by 4% and 15%, respectively. No change in the dependence of p_T^Υ was observed.

IV. CONCLUSION

The DØ collaboration has measured the differential cross section of $\Upsilon(1S)$ bottomonium at $\sqrt{S} = 1.96$ TeV in three rapidity bins. The rapidity range is greatly increased with respect to previous measurements presented by the CDF collaboration for Tevatron Run 1 [3]. After correction for the increase in beam energy, the two measurements agree within reasonable limits. The observed dependence of the cross section as a function of the rapidity and transverse momentum of the $\Upsilon(1S)$ candidates agrees with current theoretical models [5, 6]. For future measurements the DØ collaboration is preparing a study of the $\Upsilon(1S)$ polarisation, as much larger datasets are available at the Tevatron.

[1] V.M. Abazov *et al.,* DØ Collaboration, Submitted to Nucl. Instr. and Methods, hep-physics/0507191
[2] V.M. Abazov *et al.,* DØ Collaboration, Phys.Rev.Lett. 94 (2005) 232001, hep-ex/0502030
[3] D. Acosta *et al.,* CDF Collaboration, Phys.Rev.Lett. 88 (2002) 2094
[4] Particle Data Group, S. Eidelman *et al.,* Phys.Lett.B 592, 1 (2004)
[5] E.L. Berger, J. Qui, and Y. Wang, hep-ph/0411026
[6] The PYTHIA event generator, T. Sjöstrand, L. Lönnblad, and S. Mrenna, hep-ph/0108264