Fermi National Accelerator Laboratory

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DØ

Measurement of the Υ Cross Section at DØ Using Dimuons

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MEASUREMENT OF THE Υ CROSS SECTION AT DØ USING DIMUONS

The DØ Collaboration[1]

(July 1995)

The DØ experiment has measured the Υ differential cross section in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV for $|y^{\Upsilon}| < 0.7$. We find the measured cross section to be a factor of five larger than the $\mathcal{O}(\alpha_s^3)$ QCD prediction for $p_T^{\Upsilon} > 5$ GeV/c.

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INTRODUCTION

Recent measurements of the charmonium production cross sections have shown there to be significant contributions in addition to the expected b-quark fragmentation and direct channels (1), (2). It is reasonable to investigate bottomonium production as well; to date no measurements at $\sqrt{s} = 1.8$ TeV have been published. Measurements at $\sqrt{s} = 630$ GeV are approximately a factor of 2 above the $\mathcal{O}(\alpha_s^3)$ QCD prediction for $p_T^{\Upsilon} > 5$ GeV/c (3).

In $p\bar{p}$ collisions, Υ's are understood to be produced via gluon-gluon fusion into χ_b states ($\mathcal{O}(\alpha_s^2)$) which radiatively decay into Υ or through parton-parton scattering into Υ or χ_b states ($\mathcal{O}(\alpha_s^3)$). QCD predictions for Υ production from the above processes are given by an event generator written by Mangano (4) which gives similar results to calculations by Baier and Rückl (5).

DATA SELECTION CUTS AND EFFICIENCIES

The data were collected with the DØ detector (6) from $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV during the 1992-1993 Fermilab Tevatron run. A hardware (Level 1) and software (Level 2) dimuon trigger selected events with two muons having $p_T^{\mu} > 3$ GeV/c and $|\eta^{\mu}| < 1.7$. The trigger efficiency (including muon chamber efficiencies) was determined by complete Monte Carlo simulation of the detector and trigger. Efficiency uncertainties were taken as the difference between Monte Carlo efficiencies and those found using data collected with a single muon plus jet(s) trigger. The combined Level 1 and Level 2 trigger efficiency ranges between 7 and 13% for $|y^{\Upsilon}| < 0.7$. Note that all results presented in this paper are preliminary.

Subprocess	Number of events $6 < M_{\mu\mu} < 35$ GeV/c^2
Υ	90 ± 11
Cosmic Rays	8^{+6}_{-5}
QCD	120^{+13}_{-14}
Drell-Yan	31^{+11}_{-10}

TABLE 1. Results of the simulataneous maximum likelihood fit.

Offline cuts were applied to select two high quality muons. Each muon was required to have a good track fit and impact parameter in the bend and non-bend views. Additionally each track needed to have a good match to a track in the central tracking chamber and reconstructed vertex. At least 1 GeV of energy in the hit calorimeter cells plus their first nearest neighbors was required for each muon as well. Kinematic cuts of $|\eta^\mu| < 0.8$ and $p_T^\mu > 3.25$ GeV/c were also applied. A fiducial cut removing muons in the region $80^\circ < \phi_\mu < 110^\circ$ was employed since the chamber efficiencies in that region were very low due to radiation damage effects from the main ring accelerator.

Υ candidates were then selected by further cuts. The invariant mass of the dimuon pair had to be greater than 6 GeV/c^2 and less than 35 GeV/c^2 and the muon pair was required to be of opposite sign. In order to remove additional cosmic ray background, an opening angle cut between the two muons of less than 165° was imposed. Finally both muons were required to be isolated since it is expected that the muons from Υ decays will be isolated compared with semileptonic heavy quark decays. Here we define isolation as $E^{2NN}_{\rm pred} - E^{2NN}_{\rm obs} \leq 3\sigma$ where E^{2NN} refers to the energy in calorimeter cells hit by the track plus two nearest neighbors, and σ is the uncertainty of the expected energy.

The efficiency of the muon quality and Υ selection cuts were determined primarily by using appropriate data samples and Monte Carlo events respectively. The total efficiency (including geometric and trigger efficiency) after all cuts ranges between 1.1% and 2.3% $|y^\Upsilon| < 0.7$. A total of 249 events remain after all cuts and the total data sample corresponds to an integrated luminosity of $\int \mathcal{L}dt = 6.6 \pm 0.4$ pb^{-1}.

DATA ANALYSIS

The signal and background contributions were resolved using a maximum likelihood fit to the data. A simultaneous fit was made to the dimuon invariant mass, energy in a halo about each muon ($E_{\rm cal}^{\Delta R=0.6} - E_{\rm cal}^{\Delta R=0.2}$), and reconstructed time offset from beam crossing (called floating t_0) distributions. The t_0 distribution is calculated using chamber drift time information. The contributing processes to the data distributions in addition to the Υ signal were backgrounds of QCD ($b\bar{b}$, $c\bar{c}$, and π/K) production, Drell-Yan production, and cosmic rays. The mass distributions for signal and background processes were taken from Monte Carlo. All Monte Carlo events were processed through full detector and trigger simulations and then reconstructed and analyzed identically to the data. The energy halo distributions were taken from appropriate data samples as were the chamber t_0 distributions. The results of the fit are shown in Fig. 1 and listed in Table 1.

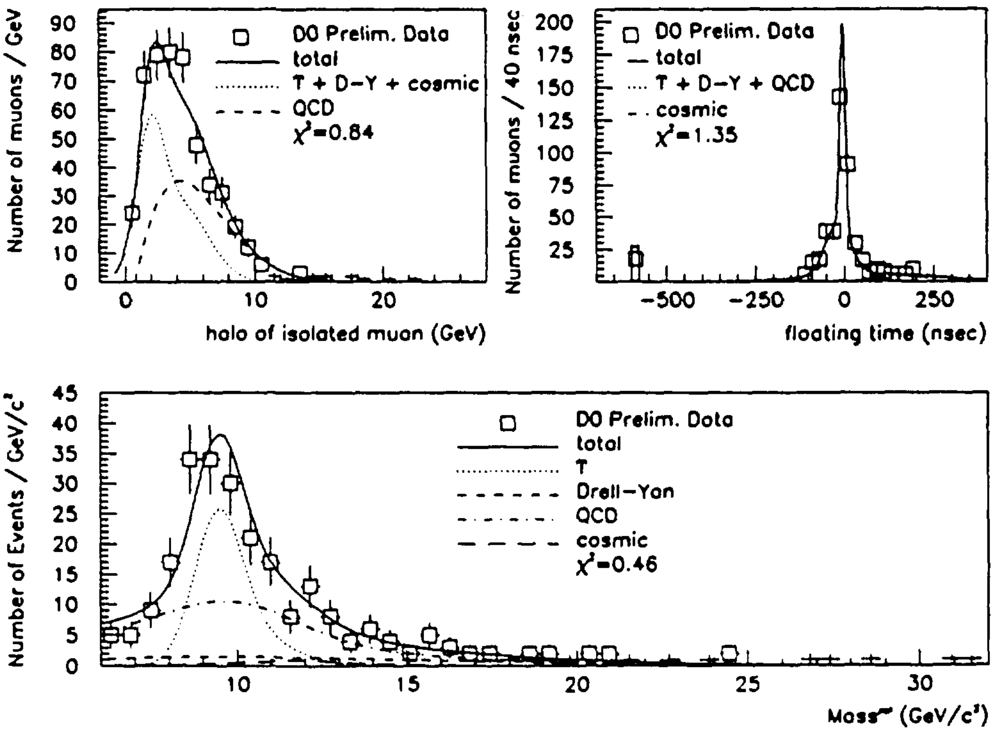

FIG. 1. Results of the simultaneous fit.

p_T bin [GeV]	$BR \cdot d\sigma/dp_T$ [pb $\cdot$ GeV^{-1}] with statistical and systematic errors
0 – 3	$96.6 \pm 19.8 \pm 24.4$
3 – 5	$167.1 \pm 29.3 \pm 39.4$
5 – 8	$115.9 \pm 26.5 \pm 31.3$
8 – 12	$19.6 \pm 6.1 \pm 6.1$
12 – 25	$1.88 \pm 0.99 \pm 0.92$

TABLE 2. $BR \cdot d\sigma/dp_T$ for $|y^\Upsilon| < 0.7$. There is an additional 14%(upper)15%(lower) systematic error for p_T independent sources which is not included in the table.

RESULTS

The differential cross section $BR \cdot d\sigma/dp_T$ is extracted using the results of the fit. The dimuon p_T distribution for all events is summed with each event weighted by the probability that it is an Υ. This distribution is then unfolded to account for the p_T resolution of the detector ($\delta(1/p)/(1/p) = [(\frac{0.18(p-2)}{p})^2 + (0.008p)^2]^{1/2}$), ($p$ in GeV/c). This is carried out using a method based on Bayes' Theorem (7). The differential cross section $BR \cdot d\sigma/dp_T$ is then obtained by dividing the number of Υ in each p_T bin by the efficiencies, integrated luminosity, and bin width. The results are shown in Fig. 2 and listed in Table 2. Note the cross section is a sum over all Υ S-states since the DØ detector cannot resolve the different states. The statistical errors come from the maximum likelihood fit. Systematic errors arise from uncertainties in the trigger efficiency, some offline cuts such as the dimuon opening angle cut, and in the unfolding of the p_T spectrum. These range from 23 to 49% and are listed in Table 2. There are also p_T independent sources of systematic error which include uncertainties in the fit input distributions (12%), p_T independent efficiencies (+5%−8%), and luminosity (5%). These uncertainties are taken as an overall normalization uncertainty of approximately 15% are not included in Fig. 2. Integrating the differential cross section and dividing by the rapidity bin width gives a total cross section $BR \cdot d\sigma/dy|_{y=0}$ = 768 ± 81 (stat) ± 142 (sys) pb.

The theoretical curves shown in Fig. 2 are calculated using the Mangano Monte Carlo program mentioned above. The $\mathcal{O}(\alpha_s^3)$ predictions are roughly a factor of 5 lower than the data for $p_T^\Upsilon > 5$ GeV/c and diverge as $p_T^\Upsilon \rightarrow 0$. Good agreement between data and theory can be achieved by assuming an average initial state parton k_T of 3 GeV/c and a K factor of 2.6.

CONCLUSIONS

We have made a preliminary measurement of the differential Υ cross section times branching ratio for $|y^\Upsilon| < 0.7$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. For $p_T^\Upsilon > 5$ GeV/c, the measured cross section is approximately a factor of five above the $\mathcal{O}(\alpha_s^3)$ QCD prediction. Good agreement between data and theory can be achieved by assuming an average initial state parton k_T of 3 GeV/c and a K factor of 2.6.

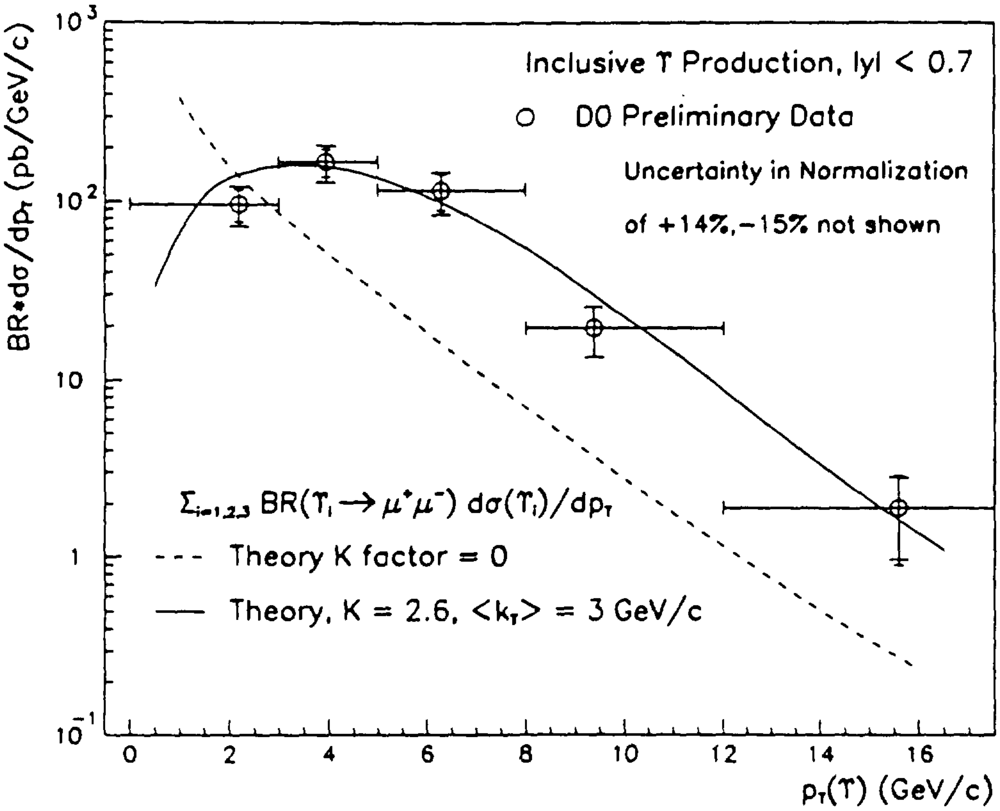

FIG. 2. $BR \cdot d\sigma/dp_T$ for $|y^\Upsilon| < 0.7$. There is an additional 14%(upper)15%(lower) systematic error for p_T independent sources which is not included in the figure.

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