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HIDDEN AND OPEN BEAUTY PRODUCTION IN 920 GEV PROTON-NUCLEUS INTERACTIONS

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The $b\bar{b}$ and Υ production cross sections have been measured by the HERA-B experiment in proton-nucleus collisions at a center of mass energy of $\sqrt{s} \approx 41.6$ GeV. Preliminary results are presented.

1 Introduction

Despite the good theoretical description of open charm and charmonium production in various environments, the beauty production description is still not very satisfactory, at least for higher center of mass energies. While the behaviour of differential cross sections as a function of kinematical variables is usually reproduced rather well, the absolute values are still in some disagreement with experimental results [1]. Even though lately the discrepancy was reduced, the theoretical predictions contain still large uncertainties, and anyhow the measured cross sections and QCD NLO expectations are not yet in good agreement [2].

In particular the $b\bar{b}$ production cross section in the kinematical region of $\sqrt{s} \approx 40$ GeV is poorly known. Besides a recent HERA-B result based on very limited statistics [3], only two measurements exist, from E789 [4] and E771 [5]. Their results are affected by large uncertainties and show poor compatibility. Also for Υ production the experimental situation is controversial in the same energy regime. New accurate measurements are highly desirable as an important input to perturbative QCD calculations.

The HERA-B experiment at DESY [6] can provide important information in these fields. It uses target wires of different materials which are positioned in the halo of the HERA 920 GeV proton beam. Interactions are produced at a center of mass energy of $\sqrt{s} \approx 41.6$ GeV. A sophisticated dilepton trigger selects rare events containing a quarkonium state $(J/\psi, \Upsilon)$, which decays into $\ell^+\ell^-$. In the analysis presented here, these decays are used to measure the production cross section for open $(b\bar{b})$ and hidden (Υ) beauty. Preliminary results obtained from part of the full statistics collected by HERA-B during its last data-taking are presented.

2 The HERA-B experiment and data samples

HERA-B is a fixed target experiment at the HERA storage ring at DESY: it was designed to handle high multiplicity events (up to 40 MHz interaction rates) and to offer very large acceptance (from 15 to 220 mrad in the bending plane, from 15 to 160 in the vertical one). The HERA-B forward spectrometer features high resolution tracking and vertex reconstruction, good particle identification over a large momentum range, and a multilevel dilepton trigger [6].

The target consists of two stations separated by 4 cm along the beam direction. Each houses 4 wires which can be moved independently into the proton beam halo. The use of various materials (C, Al, Ti, W) allows to study the dependence of proton-nucleus interaction properties as a function of atomic number.

The Vertex Detector System (VDS), located after the target, consists of high precision silicon microstrip detectors and provides high resolution reconstruction of primary and secondary vertices. A resolution of about 500 μm on decay vertices along the direction of flight, allows the identification of relatively long lived particles such as the B mesons, which fly on average about 7 mm in the HERA-B environment.

The main tracking system is located behind a 2.2 Tm bending magnet and uses different technologies depending on the distance to the beam center (MSGCs equipped with GEM foils closer to the beam, and honeycomb drift chambers in the outer region). Particle identification is performed by a Ring Imaging CHerenkov detector (RICH), an Electromagnetic CALorimeter (ECAL) and a muon system.

The dilepton trigger is initiated by pretrigger signals from either the muon system or ECAL. These create a sequence of regions of interest to search for tracks in the main tracking system. If successful, a second level trigger performs the extrapolation of found tracks through the magnet and follows them in the VDS, and finally applies a mild vertex constraint.

During the data-taking period between October 2002 and March 2003, 150 million dilepton triggered events were recorded by HERA-B. Reaching a rate of up to 1400 J/ψ/hour, a total sample of about 300,000 J/ψ's was collected (approximately half in the muon and half in the electron channel). Preliminary results presented here refer to a fraction of the complete data sample.

3 Open beauty production

The $b\bar{b}$ production cross section $\sigma^A_{b\bar{b}}$ on a nucleus of atomic number A is obtained from the inclusive reaction $pA \to b\bar{b}X$ with $b\bar{b} \to J/\psi X' \to (e^+e^-/\mu^+\mu^-)X'$. b-hadron decays into a J/ψ are distinguished from the large prompt J/ψ background taking advantage of the relative long b lifetime with a dedicated detached vertex analysis. The availability of both $\mu^+\mu^-$ and e^+e^- decay channels of the J/ψ helps increasing the statistics and allows consistency checks on the results.

The $b\bar{b}$ cross section is measured relative to the known prompt J/ψ cross section $\sigma^A_{J/\psi}$. This method allows to minimize systematic effects and remove the dependence on the absolute luminosity determination. Within the HERA-B acceptance (-0.35< x_F <0.15), the cross section can be written as:

$$\Delta\sigma_{b\bar{b}} = \Delta\sigma_r \cdot \frac{n_B}{n_P} \cdot \frac{1}{\epsilon_r \cdot \epsilon_B^{\Delta z} \cdot BR(b\bar{b} \to J/\psi X)} \qquad (1)$$

where n_B and n_P are the observed detached and prompt J/ψ events and $BR(b\bar{b} \to J/\psi X) = 0.0232 \pm 0.002$ is the branching ratio measured at LEP [7]. ϵ_R is the efficiency ratio of b to prompt J/ψ in the prompt signal selection (including therefore trigger, reconstruction and prompt cuts) and $\epsilon_B^{\Delta z}$ is the detachment cuts efficiency. These efficiencies are determined with a dedicated MC simulation, which uses a combination of the PYTHIA 5.7 [8] and FRITIOF 7.02 [9] event generators to simulate heavy quark production in proton-nucleus interactions.

$\Delta\sigma_r$ is the reference prompt J/ψ cross section reweighted to the HERA-B acceptance (which covers f_P=77% of the produced J/ψ). Results from two fixed target experiments (E789 [10] and E771 [11]) are used. After correcting for the most recent measurement of the nuclear dependence A^α with $\alpha = 0.955 \pm 0.005$ (E866 [12]) and scaling to HERA-B energies, a reference cross section of $\sigma(pN \to J/\psi) = (357 \pm 2 \pm 26)$ nb/nucleon is obtained. The term in formula (1) writes: $\Delta\sigma_r = f_P \cdot \sigma(pN \to J/\psi) \cdot A^\alpha$.

$\Delta\sigma_{b\bar{b}}$ is the measured cross section in the HERA-B acceptance (f_B=90.6%). Since no nuclear suppression has been observed in D meson production [13] and a similar behaviour is expected in the b channel, a nuclear dependence of α=1.0 is assumed for the $b\bar{b}$ production cross section in this analysis, and therefore $\sigma_{b\bar{b}}^A = \sigma(pN \to b\bar{b}) \cdot A$.

Results presented here are obtained with only 35% of the 2002/3 dilepton triggered sample, taken with C and W target wires. The prompt J/ψ signal is selected with simple requirements on the dilepton vertex quality and some lepton identification (the likelihood from the muon system and the cluster energy over track momentum ratio for muons and electrons respectively). We select about 40 (36) thousand prompt J/ψ candidates in the muon (electron) channel, as shown in Fig. 1.

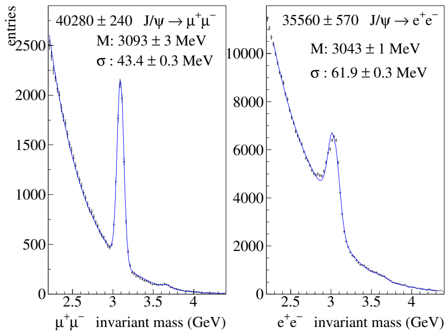

Figure 1. The $\mu^+\mu^-$ (left) and e^+e^- (right) invariant mass spectra selected for the $b\bar{b}$ production cross section preliminary measurement.

Dilepton vertices are then associated to a target wire and a specific primary vertex on the base of geometrical considerations. The detached vertex analysis aims at selecting only J/ψ clearly produced in a secondary decay vertex (of a b hadron) well separated from the primary interaction on the target wire. The detachment cuts are determined using a blind analysis technique: optimal cuts are obtained by an automatic procedure which maximizes the significance of the B MC signal in presence of background contributions described by MC (prompt J/ψ, open $c\bar{c}$ and open $b\bar{b}$) and data (same sign dilepton pairs or upstream events).

Cuts on the separation between the dilepton vertex from the wire, on the lepton impact parameters to the wire and on the lepton closest distance of approach to the associated primary vertex are applied. With an efficiency of approximately 30-45%, the mass spectra shown in Fig. 2 (left and central plots) were obtained. The two samples are well compatible with each other and provide a combined cross section preliminary measurement of $\sigma(b\bar{b}) = 12.3^{+3.5}_{-3.2}{}_{stat}$ nb/nucleon. The systematic error is currently estimated to be around 25%. With the inclusion of the full 2002/3 sample, this contribution will be reduced to about 15-18%.

The previous measurement obtained by HERA-B with the limited statistics collected in 2000 [3] and the current preliminary result are shown in Fig. 2 on the right, and compared to theoretical predictions [14]. The new result is 1.5 σ lower than the previous one, but still compatible within the large errors due to the very limited statistics available after the year 2000 data-taking.

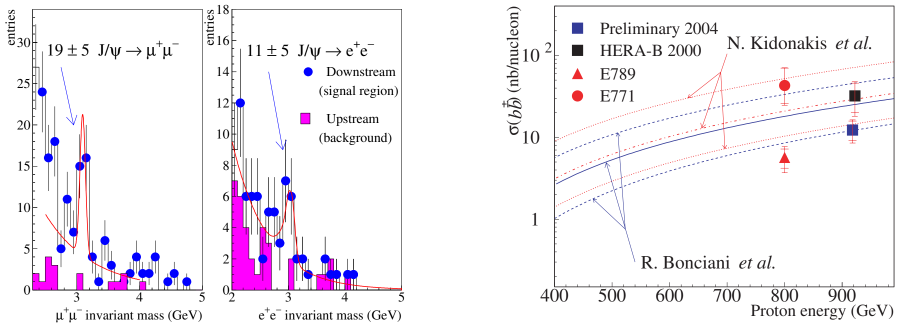

Figure 2. The $\mu^+\mu^-$ (left) and e^+e^- (center) invariant mass spectra after the detached vertex analysis. Comparison of the HERA-B $\sigma_{b\bar{b}}$ measurements with theoretical predictions (right).

4 Hidden beauty production

The HERA-B dilepton trigger is also selecting $\ell^+\ell^-$ decays of the Υ mesons produced in the reaction $pN \to \Upsilon X$. Using the full 2002/3 statistics, signals are seen in both muon and electron samples, as shown in Fig. 3 (left and central plots). The signal shape is derived from the MC simulation, and the relative production rates of the three Υ states is fixed on E605 data [15]. The background is described by a term for combinatorial background and a Drell-Yan term, dominating at high invariant masses.

Also in this case, the production cross section is determined relative to the prompt J/ψ cross section. The results of both subsamples are in good agreement. We obtain a combined production cross section times branching ratio at mid-rapidity of $BR(\Upsilon \to \ell^+\ell^-) \times \left.\frac{d\sigma_\Upsilon}{dy}\right|_{y=0} = (3.4 \pm 0.8)$ pb/nucleon. The found Drell-Yan yield is well compatible with recent measurements.

The HERA-B result is compared to previous measurements in Fig. 3 on the right: it can be seen how the new result can help to clarify the controversial situation around $\sqrt{s} \approx 40$ GeV. The experimental points are fitted with the Craigie parametrization $BR \times \left.\frac{d\sigma_\Upsilon}{dy}\right|_{y=0} = \sigma_0 \cdot exp(-\frac{m_0}{\sqrt{s}})$ [16].

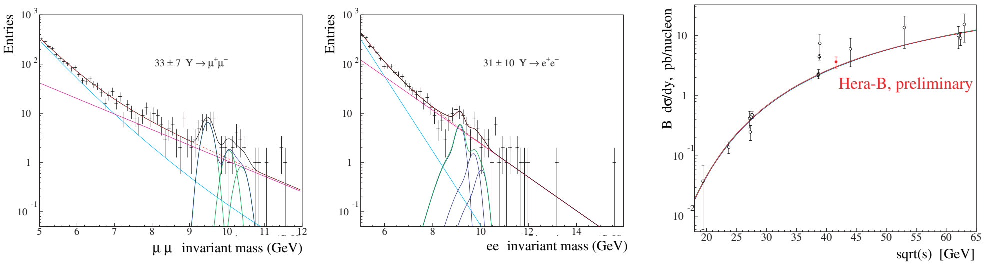

Figure 3. The $\mu^+\mu^-$ (left) and e^+e^- (center) invariant mass spectra for the Υ search. The HERA-B Υ production cross section compared to other experimental results (right).

5 Conclusions

The final data-taking of the HERA-B experiment provided a sample of 150 million dilepton triggered events produced mostly in pC and pW interactions at a center of mass energy of about $\sqrt{s} \approx 41.6$ GeV. A new measurement of the Υ production cross section was presented. A preliminary result on the $b\bar{b}$ production cross section is available: this measurement will be improved by the inclusion of the whole data sample and will provide a new experimental point from a beauty sample of unprecedented statistics from a fixed target experiment.

Searches for exclusive b decays and for double semileptonic decays are in progress. They can potentially provide alternative $\sigma_{b\bar{b}}$ measurements and a cross check for the inclusive measurement discussed here.

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