

PRODUCTION OF Υ BY 194 GeV/c NEGATIVE PIONS ON TUNGSTEN

NA 10 Collaboration

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On the basis of 2000 Υ , Υ' and Υ'' events obtained in π^- -W interactions at 194 GeV/c we extract a value for the cross section times the branching ratio of $B_{\mu\mu}\sigma = (0.96 \pm 0.04 \pm 0.17)$ pb nucleon⁻¹. The $(\Upsilon' + \Upsilon'')/\Upsilon$ ratio is found to be 0.53 ± 0.19 . The observed differential x_F and P_T distributions are compared with those of the Drell-Yan continuum, and the cross section and the x_F distribution are compared with theoretical predictions.

Hadronic production of Υ resonances has been extensively studied via QCD [1-6]. The calculations, which are based on the gluon-gluon (gg), quark-gluon (qg, $\bar{q}g$), and quark-antiquark ($q\bar{q}$) fusion processes, suffer from uncertainties in the structure functions to be used, the primordial transverse momentum distributions, the quarkonium wave function, and the value of the scale-violation parameter Λ . Theoretical

predictions can be tested only with a limited experimental data set. The p-W reactions at Fermilab gave the most precise cross section measurement for the hadronic Υ production [7]. At higher $\sqrt{s}$ values ISR results for pp interactions are available [8]. The NA 3 Collaboration at CERN observed Υ production by $\pi^\pm$, p, and K beams on a platinum target [9].

While at presently available energies the Υ production by protons is largely dominated by the gg fusion process, the pion-induced reactions are dominated by the valence $q\bar{q}$ annihilation. Valence-quark distributions of nucleons and pions are better known than the gluon distributions. Measurements of pion-induced Υ production are therefore better suited for comparisons

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between experiment and theory than nucleon-induced reactions.

In this letter we present π^- -W data at 194 GeV/c beam momentum. An accurate Υ cross section, the production ratio $(\Upsilon' + \Upsilon'')/\Upsilon$, differential x_F and P_T cross sections, measured for the first time in π -induced reactions, are given. The total cross section and the x_F distribution are compared with theoretical predictions.

The measurements were performed with the dimuon spectrometer of the NA 10 Collaboration [10] at the CERN SPS. Up to 2×10^9 π^- per burst hit a tungsten target of either 12 cm or 5.6 cm length. A 4.8 m long absorber protects the spectrometer from the intense hadronic and electromagnetic showers in order that only the Drell-Yan continuum or the decay muons from (mainly) J/ψ and Υ resonances are analysed with the set-up. The opening angles and the momenta of the muon pairs are measured with two sets of twelve proportional chambers installed upstream and downstream of a toroidal magnet. Two trigger

hodoscopes are placed within the first set of chambers, a third one in the second set, and a fourth behind an iron wall (μ filter) at the far end of the apparatus. Special care was given to the measurement of the pion intensity ($\pm 4\%$) and to the overall event detection efficiency. The beam spot (5 mm FWHM) at the target (18 mm diameter) was continuously monitored assuring a 100% targeting efficiency.

Fig. 1a is a plot of the invariant mass of the dimuons and contains some 160 000 events above 4.0 GeV/c². The integrated luminosity amounts to $(1.58 \pm 0.14) \times 10^{40}$ cm⁻² nucleon. Whereas a good fit of the Drell-Yan continuum was obtained in our structure function analysis [11], we have for reasons of convenience preferred here a phenomenological ansatz suggested by Kinoshita [12]. The Υ region, defined as the interval from 8.4 to 11.0 GeV/c², has been excluded in the fit. In fig. 1a the continuum is indicated with a full line. Subtracting this contribution from the data, one obtains the Υ peak shown in fig. 1b, which

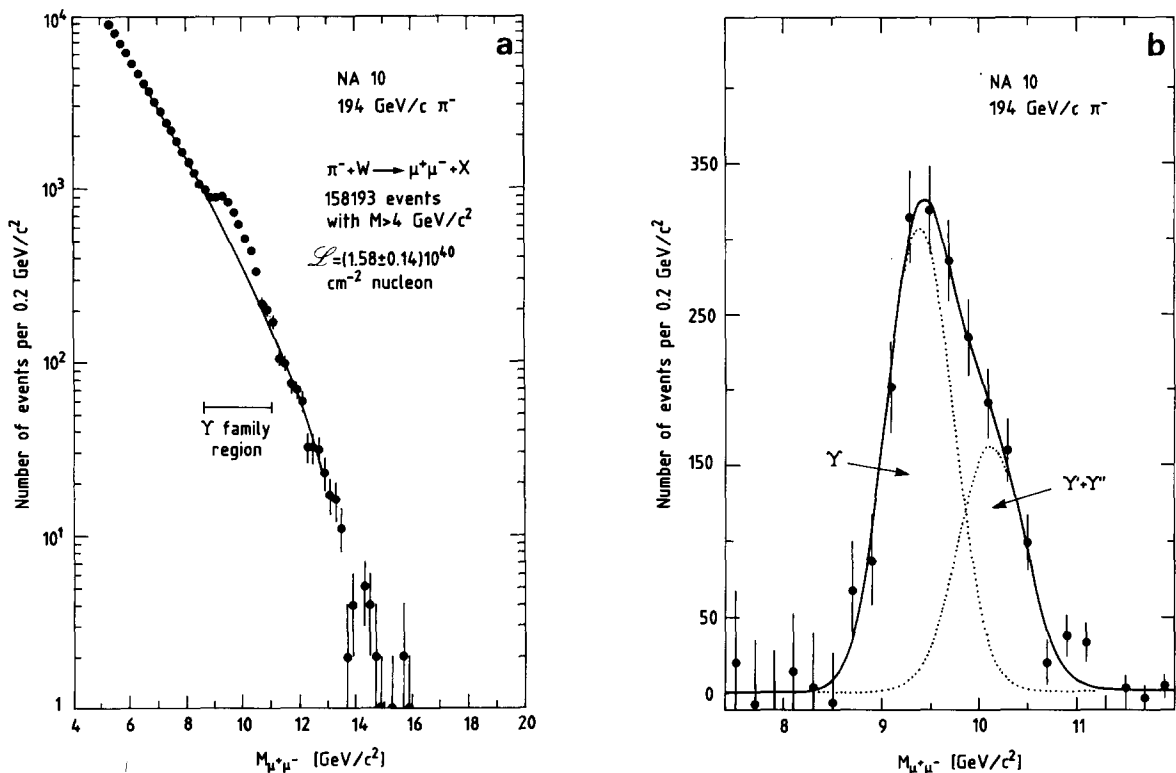


Fig. 1. (a) Mass distribution. The full line is the fit to the Drell-Yan continuum described in the text. (b) Υ family mass spectrum.

contains 2000 events. Assuming the same acceptance for the Υ , the Υ' , and the Υ'' (it is indeed constant within $\pm 2\%$), the data were fitted to a sum of three gaussians. Keeping all parameters free (masses, widths, and normalizations) gave results in good agreement with a fit where the masses were fixed at their known values and a single width was assumed. This latter fit ($\chi^2/\text{NDF} = 12.9/8$) gave $(\Upsilon' + \Upsilon'')/\Upsilon = 0.53 \pm 0.19$; the width of $(0.33 \pm 0.05) \text{ GeV}/c^2$ is in agreement with a Monte Carlo estimation [10].

The acceptance of our spectrometer at the Υ mass was obtained with a simulation program. In a first step the x_F and P_T distributions were taken from experimental data on the J/ψ production [13], and an isotropic angular distribution of the muons in the di-muon center-of-mass was assumed. The resulting Υ acceptance was then used to determine new x_F and P_T distributions, which were then inserted into the Monte Carlo program. By iteration we finally got a global acceptance for the Υ family of $(13.2 \pm 0.1 \pm 0.5)\%$ (statistical and systematical errors, respectively). Assuming a linear A -dependence, we find for the cross section σ times the branching ratio $B_{\mu\mu}$ a value

of $(0.96 \pm 0.04 \pm 0.17) \text{ pb nucleon}^{-1}$. Non-isotropic decays of the Υ , leading to a $1 + \lambda \cos^2\theta$ distribution, would result in an increase of the quoted cross section by a factor of $1 + 0.35\lambda$. According to refs. [9,14], and also to theoretical expectations, σ varies rapidly as a function of $\sqrt{s}$ in the range of this experiment. Since the center-of-mass energy s is smeared by the beam momentum bite and the Fermi motion, we allowed for the $\sqrt{s}$ dependence of σ in our analysis.

The differential cross sections (figs. 2a and 2b) were obtained analogously to the procedure described above, by parametrizing the continuum distributions above and below the Υ region in each of several bins in x_F or P_T , respectively, and thereafter subtracting these contributions from the corresponding event distribution in the Υ region. Nine bins in x_F and 14 in P_T were used. The data so obtained were corrected for acceptance and divided by the luminosity. The dotted lines in fig. 2 represent the corresponding Drell–Yan distributions normalized to the same area. No significant differences in shape are observed. In particular, the average transverse momentum $\langle P_T \rangle_{\Upsilon} = (1.08 \pm 0.07) \text{ GeV}/c$ is practically identical with that of the Drell–Yan events.

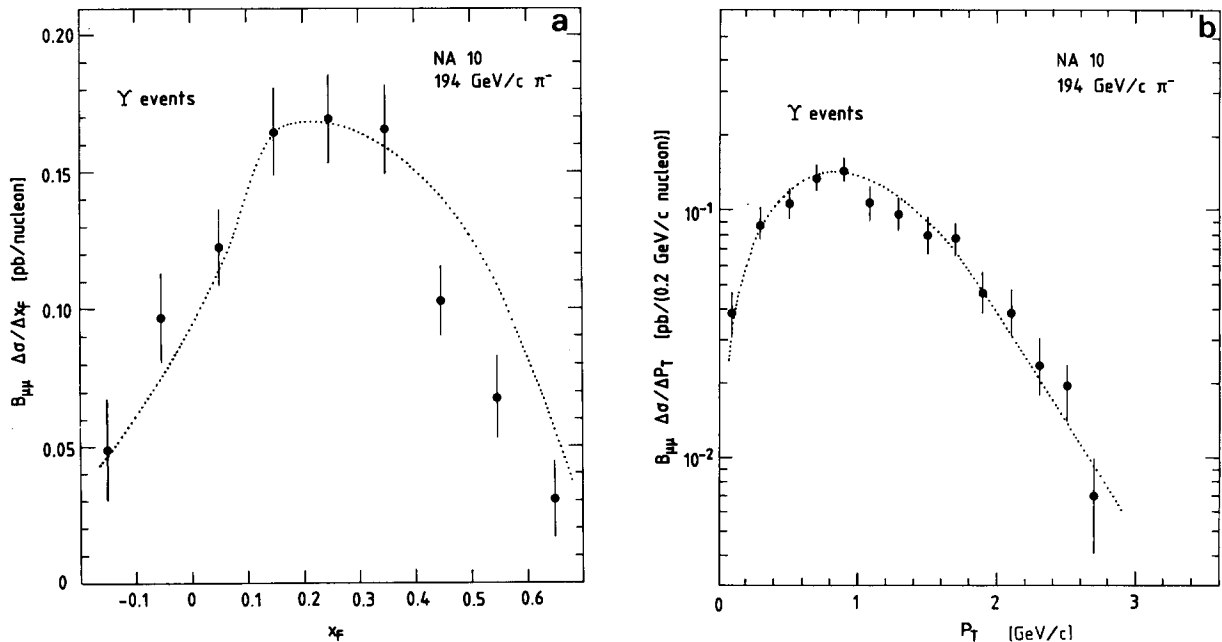


Fig. 2. (a) Differential cross section $\Delta\sigma/\Delta x_F$ for the Υ family. (b) Differential cross section $\Delta\sigma/\Delta P_T$ for the Υ family. The dotted lines correspond to the Drell–Yan events in the mass region of the Υ , normalized to the total Υ cross section. The errors are statistical only.

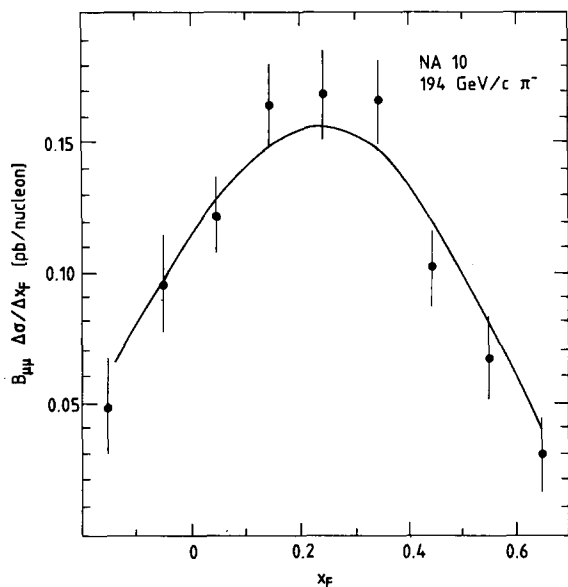


Fig. 3. The x_F distribution, compared to the duality-model (normalized to the data). The quark and gluon distributions used here are taken from refs. [14–16].

The so-called semi-local duality hypothesis is used by Owens and Reya [4] to calculate hadronic quarkonium production. The cross section is obtained here by a convolution of the fundamental cross sections, yielding a free $b\bar{b}$ quark pair with the quark and gluon distributions of the particles involved, and by integrating over Q^2 from the threshold for $b\bar{b}$ production to that of $B\bar{B}$ ($B = b\bar{q}$) meson production. After this, one sums over the flavours of the light quarks and multiplies with an empirical factor F which, in this model, represents the probability of a specific bound state in the mass interval $2m_b - 2m_B$ being formed. The duality model predictions are confirmed by a more elaborate dynamical QCD calculation [1], which furthermore is able to predict the absolute magnitude of the cross sections.

In fig. 3 we compare our x_F distribution with the duality model prediction. The quark and gluon distributions of the nucleon were taken from refs. [11,15], those of the pion quarks from ref. [11] and the pion–gluon distribution from ref. [16]; we note that $q\bar{q}$ annihilation contributes 80% of the cross section. The theoretical curve has been normalized to the data. Quite good agreement is observed. The shape of the

theoretical curve does not change significantly when one adopts different structure functions [4,17–21] for the nucleon and for the pion: the largest effect amounts to a $\pm 7\%$ change in the cross section at $x_F = -0.1$.

The total cross section calculated with the same parton distributions [11,15,16] yields, by comparison with our measured cross section, $F \simeq 1/14$, with a 60% error. This error is contributed by uncertainties in the structure functions, the value of Λ (150 MeV to 250 MeV), the branching ratio $B_{\mu\mu}$, and finally by the error in our experimental cross section.

Conversely, the duality model should enable one to predict the Υ production cross section in pion–nucleon collisions at 194 GeV/c from the corresponding proton–nucleon cross section, normalized $^{+1}$ to the precise experimental result [7] at 400 GeV/c and $x_F = 0$. The value of (0.45 ± 0.15) pb nucleon $^{-1}$ so predicted disagrees with our result of $(0.96 \pm 0.04 \pm 0.17)$ pb nucleon $^{-1}$.

We have measured the Υ production cross section in π^-W interactions at 194 GeV/c. It is larger than the value predicted by duality model calculations. The observed ratio $(\Upsilon' + \Upsilon'')/\Upsilon$ is comparable to that obtained in proton interactions [7]. The x_F and P_T distributions do not greatly differ from those of the Drell–Yan continuum; the x_F distribution is in qualitative agreement with theory.

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$^{+1}$ $F \simeq 1/31$ if the nucleon structure functions of refs. [14–16] are used.

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