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Measurement of J/ψ, ψ' and Υ total Cross Sections in 800 GeV/c p-Si interactions

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Abstract

We report on the analysis of Charmonium and Bottomium states produced in p-Si interactions at $\sqrt{s} = 38.7\ GeV$. These data have been collected with an open geometry fixed target spectrometer at the FNAL Experiment E771. J/ψ, ψ' and Υ total cross sections have been measured and compared with extrapolations from data at lower energies.

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The hadronic production of the J/ψ, ψ' and Υ states has been, and still is, an important test of QCD. Given the energy scale of this process and the relatively small coupling constant, perturbative QCD is expected to produce a reliable description of the production. The expected leading production processes at the Fermilab Tevatron fixed target energies are gluon-gluon (at low x_F) and quark-antiquark fusion (at high x_F).

In this paper we present the analysis of heavy quark resonance production in p-Si interactions at 800 GeV/c. The data were taken by Experiment E771 at the High Intensity Laboratory of Fermilab, where the hidden charm and beauty mesons were detected via their decay into a dimuon final state.

The E771 open geometry, large acceptance spectrometer [1], [2] consisted of 22 planes of multiwire proportional chambers and 9 planes of drift chambers (DC) positioned upstream of the analysis magnet, and of a set of 12 DC planes and 6 drift/pad chambers (2 wire planes, 1 strip plane and 1 pad plane per chamber) located downstream of the magnet. The chambers were deadened in a region around the beam axis, resulting in a minimum acceptance angle of about 25 mrad. The spectrometer included a 12 plane silicon microstrip vertex detector and an electromagnetic calorimeter, neither of which were used in the following analysis. A $185 \times 95\ cm^2$ aperture dipole analysis magnet provided, in the horizontal plane, a p_T kick of about 0.821 GeV/c. In order to identify and distinguish muons from charged hadrons, a muon detector was located downstream of the tracking chambers. The muon detector consisted of three planes of scintillator and three planes of Resistive Plate Counters [3] (RPCs) interspersed among the steel and concrete shielding walls. The walls imposed a lower bound of approximately 6 GeV/c (10 GeV/c in the central region) on the muon momentum.

The average beam intensity during the E771 data run was approximately 4×10^7 protons/s in a 22 second spill every 56 seconds, resulting in an integrated number of live protons on target of 1.313×10^{13}. The target consisted of 12 silicon foils (each foil 2 mm thick) spaced 4 mm apart, representing a total of 5.2 % of an interaction length. Using the muon detector, selective single and dimuon triggers were implemented, with a muon defined by the triple coincidence of signals in an approximately projective set of pads of the three RPC planes [4]. A sample of 1.27×10^8 events was stored on tape using the dimuon trigger. The events were reconstructed using all tracking elements of the E771 spectrometer except the silicon detector and the calorimeter.

Muons candidates were firstly identified in the muon detector and their trajectories were reconstructed by using the RPC pads and the scintillators. Track segments downstream of the analysis magnet were then reconstructed using the downstream chambers hits within a search window defined by the RPC muon tracks. Subsequently, track segments upstream of the analysis magnet were reconstructed and matched to downstream muon segments to form momentum-assigned muon tracks. Opposite sign dimuon pairs were required to originate from a common vertex. In a given event, only the dimuon pair forming the best common vertex was selected for the resonance studies.

The dimuon mass spectrum of these best pairs is shown in Fig. 1. Clear J/ψ and ψ' peaks can been seen in the invariant mass spectrum, as well as a Υ signal (with a negligible background). Superimposed on the dimuon mass spectrum in Fig. 1 is a fit to the data obtained with the sum of two gaussians for the J/ψ peak, a single gaussian for the ψ' peak and the form:

$$\frac{a}{m_{\mu\mu}^3} exp(-bm_{\mu\mu}) \qquad (1)$$

for the continuum background. The use of two gaussians is suggested by the Monte Carlo analysis of our resolution functions. By fixing the widths of the gaussians and their ratio, according to the MC studies, one gets from a fit to Fig. 1, $N_{J/\psi} = 11660 \pm 139$ and $N_{\psi'}$=218±24 for the background subtracted number of events in the J/ψ and ψ' peaks, respectively.

To determine the overall reconstruction efficiencies and acceptance, we generated $\approx 8\times10^5$ Monte Carlo J/ψ decays into dimuons and $\approx 1\times10^5$ ψ'. In the simulation of J/ψ and ψ' production we used the x_F and p_T distributions, parametrized as $(1-x_F)^n$ and $p_T exp(-bp_T)$ with the starting values for n and b taken from published data on J/ψ production at lower energies [5]. The dimuons were propagated through a GEANT simulation of the E771 detector, which incorporated measured detector and trigger efficiencies, multiple scattering, and other effects that degraded the track quality. The hits information from this simulation was superimposed onto real dimuon events in order to provide a realistic estimate of the background from noise and other tracks associated with the events. The overlaid MC events were then processed with the same tracking programs as those used on the data. New x_F and p_T distributions, corrected by the resulting acceptance and efficencies, were then inserted into the Monte Carlo for further iterations until we reached convergence. The global acceptance of the apparatus, including the RPCs efficiencies and the trigger efficiency, is 5.81% for the J/ψ and 6.63% for the ψ' decays into muon pairs. The total efficiency after we apply our tracking program, with some cuts to reduce background, is 1.53% for the J/ψ and 1.73% for the ψ'. The estimated overall systematic error is $\approx 5\%$. The error on the acceptance is dominated by the uncertainty in the RPCs efficiencies and in the trigger efficiency.

The total inclusive cross section per nucleon has been evaluated assuming an atomic weight dependence of A^α with $\alpha = 0.920 \pm 0.008$ [6]. The inclusive J/ψ production cross section (for all x_F) is:

$$B(J/\psi \to \mu\mu)\sigma(J/\psi) = 21.8 \pm 0.26 \pm 1.4 \; nb/nucleon$$

where the first error is statistical and the second is systematic.

Applying a similar technique to the ψ' we determined the inclusive ψ' production cross section to be:

$$B(\psi' \to \mu\mu)\sigma(\psi') = 0.36 \pm 0.04 \pm 0.024 \; nb/nucleon$$

The systematic error is dominated by the uncertainty in the total efficiency ($\approx 5\%$) and luminosity ($\approx 5\%$).

We have compared our J/ψ $B\sigma$ result to that of previous experiments (correcting them for the latest branching ratio measurement and atomic dependence) as a function of $\sqrt{s}$. The data in Fig. 2 have been fit [8] to a threshold production parametrization

$$B(J/\psi \to \mu\mu)\sigma(J/\psi) = \sigma_0(1 - M_{J/\psi}/\sqrt{s})^\beta, \qquad (2)$$

with $\sigma_0 = (59 \pm 6)$ nb/nucleon and $\beta = 11.7 \pm 0.5$.

From our measured total inclusive cross sections we also obtain a ratio

$$\frac{B(\psi' \to \mu\mu)\sigma(\psi')}{B(J/\psi \to \mu\mu)\sigma(J/\psi)} = (1.65 \pm 0.20)\%$$

that we compared in Fig. 3 with the values obtained from other experiments as a function of $\sqrt{s}$. From theoretical predictions [10] one can extract the direct J/ψ cross section assuming a contribution from χ_1, χ_2 and ψ' decays of about 50% at the E771 energy. The ratio

$$\frac{\sigma(\psi')}{\sigma_{dir}(J/\psi)} = 0.257 \pm 0.064$$

obtained is comparable with the predicted value [11] of 0.24 ± 0.03, with the values of branching ratios taken from [7].

The inset in Fig. 1 shows a $\Upsilon(1S) + \Upsilon(2S)$ signal in the dimuon mass plot. A fit to these data with a gaussian for the peak gives 10 ± 4 events. To determine the bottomium production cross section, we used the previously described Monte Carlo program to generate both $\Upsilon(1S)$ and $\Upsilon(2S)$ using the p_T and x_F distributions measured in [9]. Since our resolution at these masses does not allow the separation of the two states, we used the relative production ratio measured in [9] to determine cross-section for both resonances. The result is:

$$B\sigma(\Upsilon(1S)) = 6.1 \pm 1.99 \; pb/nucleon$$

for the $\Upsilon(1S)$ and

$$B\sigma(\Upsilon(2S)) = 1.89 \pm 0.63 \; pb/nucleon$$

for the $\Upsilon(2S)$.

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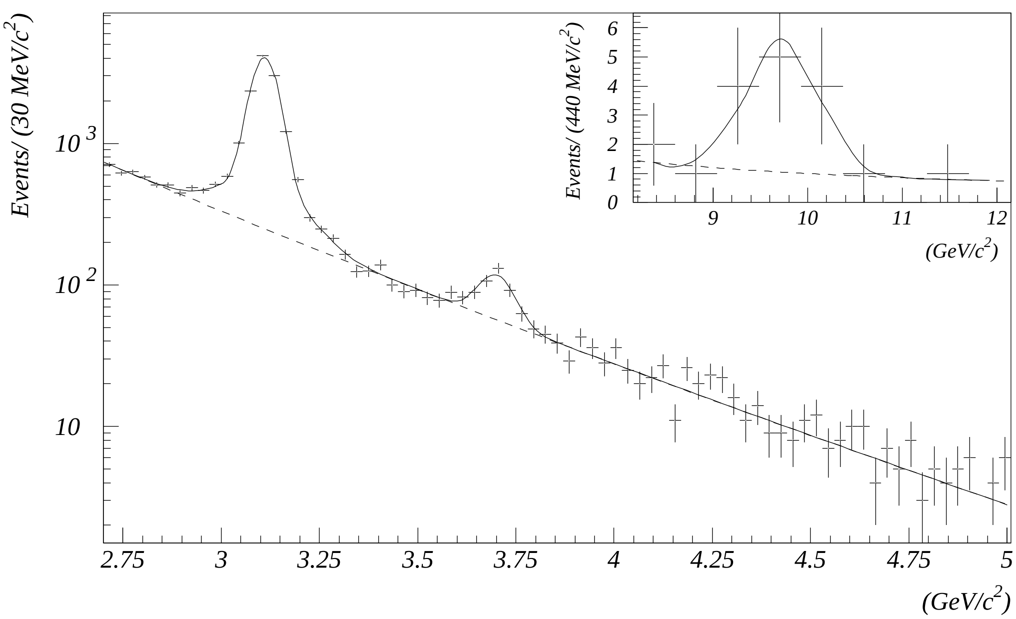

Figure 1: Opposite-sign muon pair mass spectra in the J/ψ and ψ' region. The solid line is the fit described in the text and the dashed line is the background. The inset shows the Υ signal.

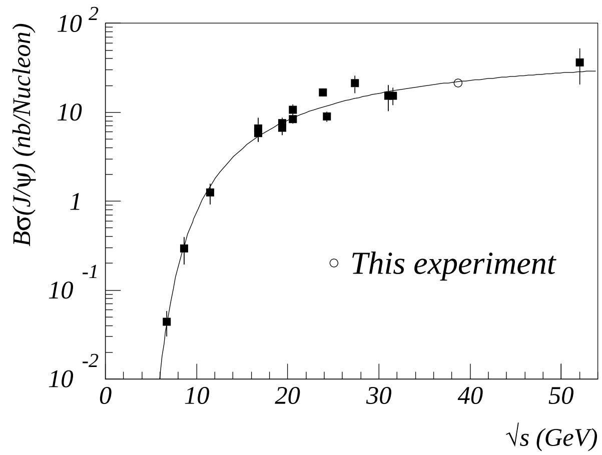

Figure 2: J/ψ cross section as a function of the center of mass energy measured from different experiments. Superimposed to the data is the fit described in the text

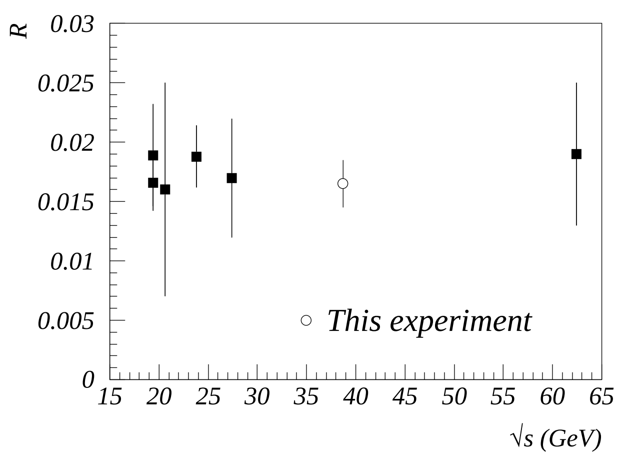

Figure 3: The $B\sigma(\psi')/B\sigma(J/\psi)$ ratio versus the center of mass energy