Measurement of the inclusive J/ψ production cross sections in $\bar{p}p$ and pp collisions at $\sqrt{s} = 24.3$ GeV

Presented for the UA6 collaboration [1] by

J. P. Perroud

Institut de Physique Nucléaire, University of Lausanne

CH-1015 Lausanne, Switzerland

Abstract

The inclusive cross section times branching ratio for $J/\psi \to e^+e^-$ has been measured in the forward region in the UA6 experiment for both $\bar{p}p$ and pp collisions at $\sqrt{s} = 24.3$ GeV. The ratio of the pp to $\bar{p}p$ cross sections is found to be $0.76 \pm 0.14 \pm 0.06$. This demonstrates that gluon-gluon fusion dominates over quark-antiquark annihilation in the formation of the $c\bar{c}$ state.

Apparatus

The experiment [Fig. 1] is located in a straight section of the CERN SPS tunnel. A hydrogen jet target provides a collimated stream of clusters of hydrogen molecules with a density of 4×10^{14} protons/cm^3. The width of the jet at the beam position is 4 mm and its length is 8 mm.The luminosity is monitored with four silicon detectors [2] by counting protons recoiling near 90° in the laboratory frame from elastic scattering.

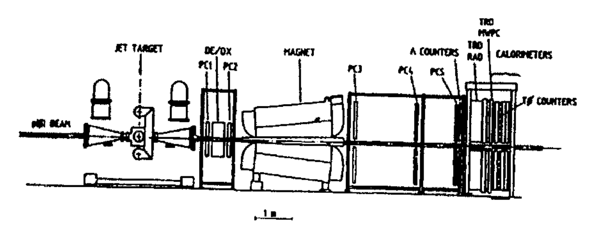

Fig. 1 Layout of the UA6 experiment.

The apparatus consists of a double-arm magnetic spectrometer: Each arm includes five multiwire proportional chamber, two in front of the magnet and three behind, a transition radiation detector (TRD) and an electromagnetic calorimeter. The calorimeter is of the gaz-proportional tube sampling type [3]. It consists of thirty lead plates 4 mm thick, interleaved with alternating layers of vertical and horizontal proportional tubes. The calorimeter is divided into three identical modules (A, B and C) each 8 radiation lengths or 0.25 nuclear interaction length thick. Test beam results with electrons show linear energy response from 10 to 100 GeV, an energy resolution of $\sigma_E = 0.33\ [\mathrm{GeV}]^{1/2} \sqrt{E}$ and a spatial resolution (rms) which improves from 4.8 mm at 3 GeV to 1.7 mm at 70 GeV. The absolute energy scale of the calorimeter is established by adjusting the reconstructed π^0 and η masses. Each arm covers opening angles from 20 to 100 mrad in the laboratory frame and about 70° in azimuth for a total acceptance of 1.8 sr per arm.

A hodoscope of seven horizontal scintillation counters is located between the first and second modules of the calorimeter. The two electrons from J/ψ decay are found predominantly one in each arm. The trigger therefore consisted of any coincidence between a counter in the top arm with a counter in the bottom arm.

Data analysis

Charged particle track reconstruction is performed using the information given by the three MWPC's behind the magnet. Assuming that the center of the jet is the vertex of the J/ψ decay, the resolution on the invariant mass of the electron pair is 140 MeV/c^2.

J/ψ candidates are those pairs of tracks, one in each arm with momenta $10 < p < 100$ GeV/c, which are associated with energy clusters in at least the first two modules of the calorimeter (AB and ABC cluster types). Besides cuts set at 2 standard deviations for the geometrical matching between the track and the associated cluster position in module A (4.5 mm and 3.5 mm in vertical and horizontal directions), resulting in an efficiency of 90 % per electron, the spectrometer and calorimeter informations are used to get a normal energy match distribution (ESD). The parameter ESD is the difference between the track momentum and the associated calorimeter energy divided by the estimated resolution on the difference :

$$ESD = \frac{p_{spectrometer} - E_{calorimeter}}{\sqrt{\sigma_p{}^2 + \sigma_E{}^2}}$$

$\sigma_p = 1.44 \times 10^3\ [GeV/c]^{-1}\ p^2$, the spectrometer resolution worsened, due to the high multiplicity of hit wires, to $\sigma_p = 2.10 \times 10^{-3}\ [GeV/c]^{-1}\ p^2$ per electron. A cut on ESD set at 2 standard deviations leads to an efficiency of 95 % per electron and provides a good electron-hadron discrimination, as well as a rejection of the background of charged particles which do not come from the jet. Further hadron rejection is obtained by cutting on the ratio of the energy deposited in module A to the total energy of the cluster in the calorimeter, E_A/E_{tot}. An efficiency of 95 % per electron is obtained with the cut $E_A/E_{tot} > 0.35$.

The measured chamber efficiency is 97 % per plane. Overall reconstruction efficiency is determined by a hybrid Monte-Carlo method, injecting generated $J/\psi \rightarrow e^+e^-$ into real data and analyzing them in the same way as the normal data. About 6 % of the electrons are lost due to the requirement of having AB and ABC types of clusters, and less than 1 % of the surviving electrons are lost because of the track momentum restriction to $10 < p < 100$ GeV/c. The measured overall reconstruction efficiency amounts to 55 % per J/ψ.

The geometrical acceptance is estimated as a function of center-of-mass rapidity and p_T with J/ψ's generated by Monte-Carlo. The accepted rapidity region is $-0.5 < y < 1.2$. Triggering conditions were monitored on a run-by-run basis,the average efficiency of the trigger was around 55 %.

A J/ψ is defined as an e^+e^- pair having an invariant mass between 2.8 and 3.3 GeV/c^2. This restriction causes a loss of 10 % of real detected J/ψ, as shown by the hybrid Monte-Carlo simulation in which bremsstrahlung has been included. The hybrid Monte-Carlo simulation also shows that the combinatoric background of the unlike-sign mass spectrum is well reproduced by the like-sign mass spectrum. The number of J/ψ candidates is therefore obtained by subtracting the like-sign from the unlike-sign invariant mass spectra [Fig. 2]. Within the rapidity window $0 < y < 1$, where the acceptance is significant, (87 ± 10) J/ψ candidates are extracted from an integrated luminosity of 540.7 nb^{-1} in $\bar{p}p$ run, and (146 ± 14) J/ψ candidates are extracted from an integrated luminosity of 1496.9 nb^{-1} in the pp run.

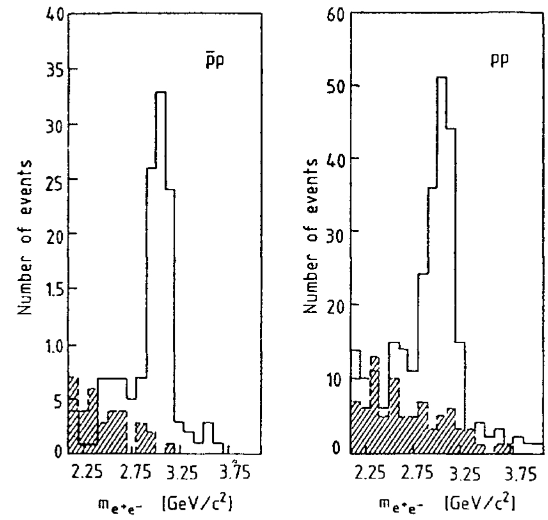

Fig. 2 Invariant mass distributions for unlike sign pairs (solid line) and like sign pairs (hatched area)

Each J/ψ candidate is corrected by its geometric acceptance and trigger efficiency according to its measured rapidity and p_T. The average geometrical acceptance over the (y,p_T) region covered by the experiment is about 15 % .

Agreement between the data and hybrid Monte-Carlo is found for the shape of the J/ψ mass spectrum, for the distribution of the rear chamber wire multiplicity for J/ψ events and for the distribution of the Gottfried-Jackson angle for accepted e^+e^- pairs decaying isotropically from a J/ψ. In all cases, an acceptable agreement was found for both pp and $\bar{p}p$ data.
The total systematic uncertainty on $\sigma \cdot B(J/\psi \rightarrow e^+e^-)$ is 7%. It includes : 4% error on the luminosity monitoring, 2% error on the Monte-Carlo evaluation of the geometric acceptance and the trigger efficiency, 4% error in the track reconstruction efficiency, 3% error introduced by the cuts selecting electrons.

Results and conclusion

The product of the cross section for inclusive J/ψ production integrated over rapidity from 0 to 1 and the branching ratio into e^+e^- is $(5.1 \pm 0.7 \pm 0.4)$ nb for $\bar{p}p$ and is $(3.9 \pm 0.5 \pm 0.3)$ nb for pp. The average p_T is (0.9 ± 0.2) GeV/c in $\bar{p}p$ interactions and (1.1 ± 0.2) GeV/c in pp collisions. Using the Bourquin-Gaillard parametrization [4], the data have been extrapolated to the full forward hemisphere. The results are $(5.9 \pm 0.8 \pm 0.4)$ nb for $\bar{p}p$ collisions and $(4.5 \pm 0.5 \pm 0.3)$ nb for pp interactions. Our $\sigma \cdot B(J/\psi \rightarrow e^+e^-)$ values in the forward hemisphere are in good agreement [6] with other experiments [7-17].

For the ratio $\sigma(pp \rightarrow J/\psi + X)/\sigma(\bar{p}p \rightarrow J/\psi + X)$ in the forward hemisphere at $\sqrt{s} = 24.3$ GeV, the UA6 measurement gives $0.76 \pm 0.14 \pm 0.06$.

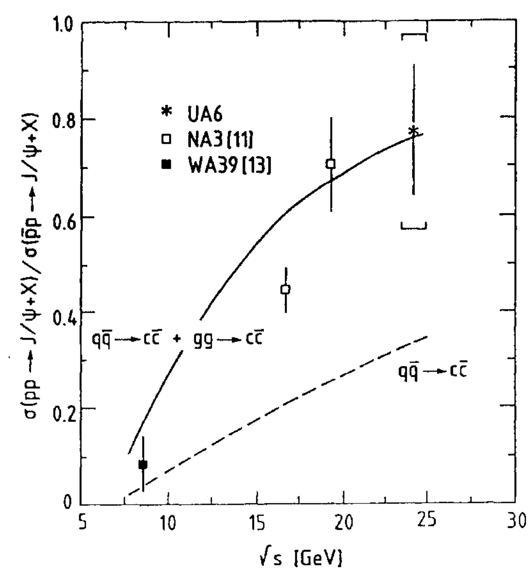

Fig. 3 Ratio $\sigma(pp)/\sigma(\bar{p}p)$. The solid line shows the result of a simple open charm model [18] with both the gluon-gluon and the quark-antiquark fusion contributions. The dashed line represent the quark-antiquark contribution alone.

Our result is compared [Fig. 3] with other available experimental data [11,13] and with the predictions of a simple QCD model of open charm production [18] which mixes quark-antiquark annihilation and gluon-gluon fusion mechanisms and uses the parametrization of Duke-Owens set 1 of the structure functions [19]. At our energy the prediction for this ratio is 0.75, in agreement with our measurement : $\sigma(q\bar{q})/\sigma(gg)$ is about 0.19 for pp collisions and about 0.58 for $\bar{p}p$ interactions. As shown in figure 3, the gluon contribution is essential : the near equality of the J/ψ cross sections in $\bar{p}p$ and pp interactions demonstrates that $q\bar{q}$ annihilation is not a dominant mechanism in J/ψ production.

References

[1] The UA6 collaboration

1) CERN, CH-1211 Genève 23, Switzerland
L. Camilleri, L. Dick, J.B. Jeanneret and W. Kubischta

2) Lausanne, IPN, Université de Lausanne, CH-1015 Lausanne, Switzerland
C. Morel, A. Bernasconi, B. Gabioud, F. Gaille, C. Joseph, F. Loude, E. Malamud, J.L. Pagès, J.P. Perroud, D. Rüegger, G. Sozzi and M.T. Trân

3) Physics Department, University of Michigan, Ann Arbor, MI 48109, USA
E.C. Dukes, O.E. Overseth, G.R. Snow and G. Valenti

4) The Rockefeller University, New York, NY 10021, USA
R.E. Breedon, R.L. Cool†, P. Cushman, P. Giacomelli, P.T. Cox, R.W. Rusack, and A. Vacchi

[2]R.E.Breedon et al,Phys.Lett.**216B** (1989) 459

[3]L.Camilleri et al, NIM. **A286** (1990) 49

[4]M.Bourquin et al, Nucl. Phys.**B114**(1976)334

[5]B.C.Brown et al, Phys.Rev.**D23** (1981) 604

[6]C.Morel et al, CERN-PPE/90-127, submitted. to Phys.Lett. B

[7]H.D.Snyder et al,Phys.Rev.Lett.**36**(1976) 1415

[8]C.Kourkoumelis et al. Phys.Lett.**91B** (1980)481

[9]A.G.Clark et al,Nucl.Phys.**B142** (1978) 29

[10]E.Nagy et al,Phys.Lett.**60B**(1975)96

[11]J.Badier et al,Z.Phys.**C20**(1983)101

[12]Y.M.Antipov et al,Phys.Lett.**60B**(1976)309

[13]M.J.Corden et al,Phys.Lett.**98B**(1981)220

[14]E.Amaldi et al, Nuov.Cim.Lett.**19**(1977)152

[15]A.Bamberger et al,Nucl.Phys.**B134**(1978)1

[16]K.J.Anderson et al,Phys.Rev.Lett.**37**(1976) 799

[17]S.Katsanevas et al,Phys.Rev.Lett.**60**(1988)2121

[18]M.Glück et al.,Phys.Rev.**D17**(1978)2324

[19]D.W.Duke et al.,Phys.Rev.**D30**(1984) 49

DISCUSSION

Q. **M. Jacob** *(CERN)*: Your annihilation model seems to violate colour conservation.

A. **J.P. Perroud**: Yes, but it is not mine.