Brief Reports

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Charge distributions of hadrons associated with hadronic J/ψ production

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In π^-Be interactions at 225 GeV/c, we have compared the average charge of forward-going hadrons in events with and without J/ψ particles. We have studied the forward charge as a function of the Feynman x of the J/ψ and compared the results with various models.

The mechanism by which J/ψ mesons are produced in hadronic interactions is a subject of current interest. Much attention has been focused on the production cross section and Feynman x (x_F) distribution of the observed J/ψ, but relatively little work has been done on the properties of hadrons associated with J/ψ production. One such property is the charge of the forward-going hadronic system [i.e., of those hadrons with positive center-of-mass (c.m.) rapidity]. We report here on a measurement of this forward charge in π^-Be interactions at 225 GeV/c.

In the hadronic production of a J/ψ, two (or more) of the available partons from the beam or target hadrons are annihilated, leaving the rest to fragment into other hadrons. The noninteracting partons from the beam should mostly determine the characteristics of produced hadrons in the forward region. Two specific mechanisms have been proposed to explain J/ψ production in π^--nucleon interactions. In light-quark fusion [Fig. 1(a)], the valence antiquark $\bar{u}$ from the beam π^- combines with the valence quark u from the nucleon to produce the J/ψ. This leaves the d quark from the π^- to carry forward a charge of $-\frac{1}{3}$ (Feynman-Field fragmentation[1] modifies this to -0.4). In gluon fusion [Fig. 1(b)], the quarks are all spectators to the gluon in-

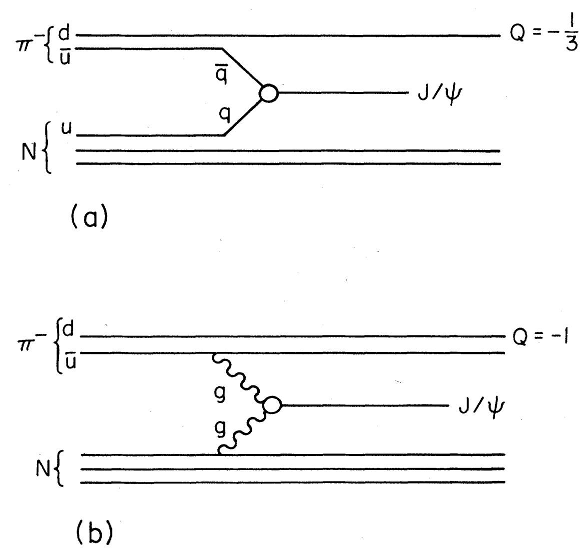

FIG. 1. Simple models for J/ψ production in π^-N interactions. (a) Quark fusion leaving net forward charge of $-\frac{1}{3}$. (b) Gluon fusion leaving a net forward charge of -1.

teraction; thus, the full negative charge -1 of the π^- is projected forward. Quark and gluon fusion both seem to contribute to J/ψ production in $\pi^- N$ interactions at our energy.[2] The average forward charge is likely to be some intermediate negative value which is difficult to predict; however, one may be able to separate quark- and gluon-fusion contributions by studying the forward charge as a function of the x_F of the J/ψ. Processes involving gluons tend to occur at smaller x_F than those involving valence quarks. Specficially, we would expect the forward hadronic charge to become less negative as the x_F of the J/ψ increases.

This experiment (E610) was performed at Fermilab using the Chicago Cyclotron Particle Spectrometer facility (CYCLOPS) shown in Fig. 2. Most of the data were obtained using a trigger biased so as to prefer high-mass dimuons that penetrate the iron wall,[3] although some minimum-bias hadron-interaction data were also recorded. The apparatus was specifically designed to allow measurement of particles accompanying the muons from J/ψ decay. There was a 25-plane proportional chamber system partially imbedded within the 1.4-T, cylindrically symmetric field of the analyzing magnet. The chambers were carefully aligned and operated without beam deadeners so as to preserve charge-symmetric detection. As a rule, at least 70% of the planes through which the particle should have passed were required to have a hit along the path.[4] After traversing the field region, the higher-momentum particles encountered three large drift-chamber planes and a scintillation-counter hodoscope. Although these planes were not required in the pattern-recognition algorithm, they did provide additional confirming hits and improved momentum resolution.

Hadron acceptance was computed by a Monte Carlo program which took into account the geometry of the apparatus, the measured detector efficiencies, and all track-finding criteria.[4] The acceptance is between 90% and 100% over almost the entire forward region. Furthermore, the effect of acceptance corrections on forward-charge averages has been found to be negligible compared with statistical errors. However, a detailed study of possible residual charge biases which were not modeled by the Monte Carlo program requires the assignment of a systematic error of ± 0.05 to all forward-charge measurements.

The forward-charge sum is formed by algebraically adding the charges of all hadrons with positive c.m. rapidity. To check that our hadron-finding algorithm is charge-symmetric, we have examined the average forward-charge sum for hadrons from the minimum-bias hadron-interaction data. Our value (-0.62 ± 0.02) corresponds reasonably well with that derived from the world data of $\pi^- p$ bubble-chamber experiments (-0.70 ± 0.02) (Ref. 5), given that our nuclear target probably dilutes the forward charge slightly due to secondary interactions.[6] At our energy, the forward charge is also modified from the beam charge (-1) by leakage of slow, predominantly positive hadrons from the target fragmentation. Thus, we can make no claim to be actually measuring quark charges but only the differences in charge caused by different production mechanisms.

Maxwell and Teper[7] have proposed a "charge measure" intended to be less sensitive to such contamination. In their method, one orders the N observed hadrons by c.m. rapidity (from large positive to zero) and computes the sum

$$Q_m = [Nq_1 + (N-1)q_2 + \cdots + q_N]/N \ .$$

The leading hadron is most heavily weighted in this charge measure. The average value obtained in this manner is -0.46 ± 0.01. This method was designed to measure the charge of a single fast quark and may not apply to processes involving diquark fragmentation.

From the dimuon-trigger data, we obtain the $\mu^+\mu^-$ invariant-mass distribution shown in Fig. 3. The peak region from 3.02 to 3.18 GeV/c^2 contains 1340 events, of which 86% are J/ψ and 14% are background, mainly hadron decay. The J/ψ events have a very different average forward charge from unbiased interactions. After correction for the average forward charge of the 14% background, which was taken to be that of the hadron interactions, we obtain a value of -0.38 ± 0.05 for J/ψ events. A previous measurement[8] of this quantity for J/ψ appears to be somewhat more negative (-0.60 ± 0.08) than our value, but their value for interactions (-0.76 ± 0.10) is also more negative than ours. The differences between the forward charges for interaction data and for J/ψ data are the same within errors for the two experiments. Table I summarizes these average forward charges.

In an attempt to compare our data directly with parton-fusion-model predictions, the J/ψ events were than separated into x_F bins (of the J/ψ). The average forward-charge

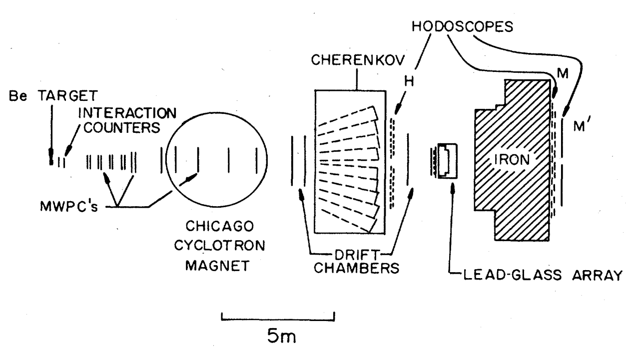

FIG. 2. The CYCLOPS facility for E610. The last five multiwire proportional chambers are triple planes. The M hodoscope provided the high-mass dimuon trigger. Hadron interactions were indicated by large signals from two scintillation counters just downstream of the target.

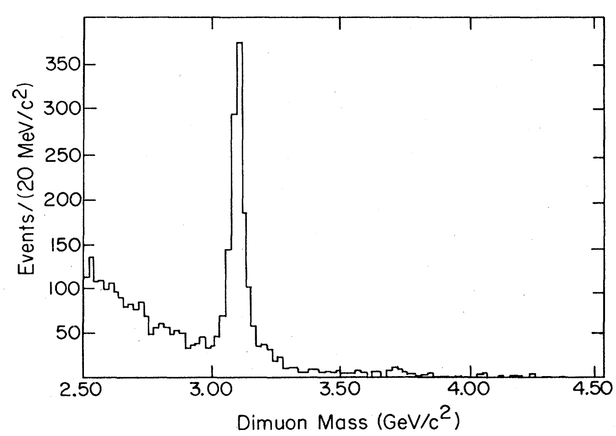

FIG. 3. The high-mass part of the dimuon spectrum. The J/ψ region includes masses from 3.02 to 3.18 GeV/c^2.

TABLE I. Average forward hadronic charges.

Source of data	Method of counting charge	Hadron interactions	J/ψ Events (corrected for 14% background)
This experiment (π^-Be at 225 GeV/c)	Charge sum	-0.62 ± 0.02[a]	-0.34 ± 0.05[a]
Same as above	Charge measure	-0.46 ± 0.01[a]	-0.27 ± 0.04[a]
Reference 5 (π^-p at 10–360 GeV/c)	Charge sum	-0.70 ± 0.02[b]	· · ·
Reference 8 (π^-Be at 190 GeV/c)	Charge sum	-0.76 ± 0.10	-0.60 ± 0.08
Model calculation as described in text	Charge sum	· · ·	-0.50 ± 0.07

[a]A systematic error of ± 0.05 applies.
[b]This result comes from a fit to the π^-p data shown in Fig. 4 of Ref. 5.

sum of the hadrons in each bin was plotted at the average x_F of the bin as shown in Fig. 4 (again with correction for the 14% interaction background). The trend of the J/ψ forward charges does not match our naive expectation that the forward charge should become less negative with increasing x_F.

To investigate this effect further, we have generated forward-charge distributions using two recent parametrizations of J/ψ production.[9,10] Four separate contributions were considered in decreasing order of importance: gluon fusion, valence quark $\bar{u}u$ fusion, the fusion of the valence d quark from the pion with a nucleon sea $\bar{d}$, and pion sea quark plus nucleon valence quark fusion. These models

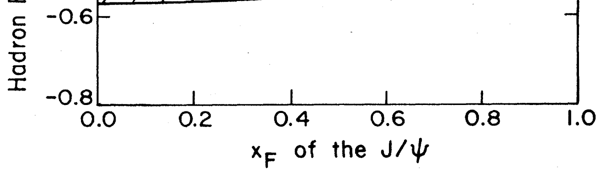

FIG. 4. Hadronic charge sum vs x_F of the J/ψ, with the average shown by the dotted line. These charge sums have been corrected for the average charge of the 14% background. Horizontal bars show x_F bin boundaries. Vertical errors are only statistical, although a systematic error of ± 0.05 applies. The solid curve in the middle of the shaded band results from model (a) in the text. The upper and lower boundaries result from models (b) and (c), respectively.

supply the relative amounts of the subprocesses as a function of x_F. We must assign average forward charges for each, taking into account the problem of charge leakage from the target to the region of positive rapidity, in order to compare with our data. We have measured the average forward charge for π^-Be interactions, which would naively be -1, to be -0.62 (Table I). We therefore assume the same dilution of forward charge for the gluon-fusion and sea-quark-fusion processes, which also naively would be -1. We have no direct measurement from which we could infer the forward charges for the pion-valence-quark-fusion mechanisms. Thus, we consider three possible models.

(a) The first model assumes that the actual forward charges are modified from the naive predictions (-0.4 from $\bar{u}u$ fusion and -0.6 for $d\bar{d}$ fusion) by the same multiplicative factor as in hadron interactions (0.62) giving forward charges of -0.25 for $\bar{u}u$ and -0.37 for $d\bar{d}$.

(b) The second assumes that the forward charges may be altered in an additive way by the same amount ($+0.38$) as in hadron interactions which would lead to values of -0.02 for $\bar{u}u$ and -0.22 for $d\bar{d}$.

(c) The third assumes that the forward charges are those of the naive predictions.

The results of these model calculations are shown as the shaded bands on Fig. 4. The average forward charge from the first model calculation is -0.50 ± 0.07.

There are several possibilities which might affect the relation between theory and experiment. First and foremost, the leakage of charge to positive rapidity from the target fragmentation region is a poorly measured phenomenon which may depend on the production process, or on the available energy for hadrons. Such effects would alter the relative normalization of the data and model calculations and perhaps even introduce an x_F dependence.

Secondly, as has been noted in the literature,[11] models such as the ones we consider must break down when the fusion of partons within the incident hadron becomes the dominant process. At our c.m. energy, however, this affects only the region $x_F > 0.5$.

Finally, we have determined within the same experiment that approximately $\frac{1}{2}$ of all J/ψ are indirectly produced via decays from χ and ψ' states.[12] Interpreting these as directly produced would cause us to make the forward-charge plots at the wrong x_f values. Monte Carlo estimates of this effect indicate that the correct x_F value is larger by 0.0 to 0.1 with an average of 0.05. Such an effect would not improve our agreement with the theory. The emission of soft gluons, if the charmonium state is produced as a color octet, may cause a similar smearing in x_F values.

We have chosen to study a property, the forward charge of hadrons accompanying J/ψ, which is both experimentally accessible and potentially predictable from QCD-based models. The data seem to prefer somewhat less negative forward charges than the theory would predict at low x_F. Higher statistics and an improved understanding of hadron fragmentation are needed to make quantitative conclusions about parton-fusion models.

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