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Comparison of High p_T Events Produced by Pions and Protons

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ABSTRACT: We have measured high p_T π^0's and jets with a two arm calorimeter detector. Pions produce large x_T jets more readily than protons. We report the first direct measurement of two arm jets. We find that the jet pairs have roughly balanced p_T and that pions produce jet pairs at more forward angles than do protons. These results give evidence for a constituent scattering model, with constituents of higher average momentum in the pion.

We present results from an experiment performed at Fermilab comparing the production of high p_T π^0's and jets by pion and proton beams. In a quark scattering model one would expect more abundant production of particles of high x (both $x_T = 2p_T/\sqrt{s}$ and $x_L = 2p_{||}/\sqrt{s}$) from pions than from protons[1]. Naively, this expectation is simply a reflection of the fact that pions have fewer constituents (only two valence quarks) than do protons (three valence quarks); and therefore on the average the constituents of the pion carry a larger fraction, x, of the incident momentum than do those of the proton.

In terms of constituent models for hadrons, the momentum distributions of the constituents are described by structure functions $G(x)^{(2)}$. If the constituents of the pion have larger high x components than do those of the proton, then $G_p(x)/G_\pi(x)$ will decrease at high x, and effects of two types can be expected: (1) The ratio of proton produced events to pion produced events will decrease as x_T increases. (2) If the pion's initial constituents tend to carry more momenta than the proton's, then the high x_T products of the interaction will tend to go more "forward" for pion produced events than for proton produced events.

Strong effects of both types have been reported in a measurement of inclusive high p_T π^0's (3,4). The present experiment used a two arm hadron calorimeter, each arm of substantial solid angle. Consequently, not only π^0's but jets as well were detected. This two arm capability provided significant new results in the study of p/π production cross-sections for high p_T events.

The experiment was performed in the M-2 beam line at Fermilab. This present analysis considers data taken at +130 and +200 GeV/c. The apparatus, shown in Fig. 1, consisted of a two arm segmented calorimeter array and six planes of drift chambers. Each calorimeter arm covered a solid angle of about 1.5 sr. A massive iron and concrete shield effectively eliminated beam halo particles and other upstream sources of background. Not shown in the figure are two independent differential Cerenkov counters used to identify pion and proton beam particles. The calorimeter was of modular construction, segmented (with independent readout) in area and depth. The left arm covered about 1.5 sr CM for π^0's and about 1.0 sr for other hadrons; the right arm covered about 1.5 sr for both. All modules were calibrated and balanced with beam particles to give uniform response to a few percent over the entire array.

Data were taken simultaneously with a number of triggers, each of which required the sum of the pulse heights in a particular group of modules, weighted by the sines of their angles in the lab ($p_T = p \sin \theta_L$), to be greater than some adjustable threshold. Signals were arranged to provide four trigger types: A right arm trigger (R), a left arm trigger (L), a summed trigger (L + R), and triggers from smaller groups of the modules forming single particle triggers (SP) from both L and R sides. π^+ and p induced events were recorded simultaneously, thus reducing the possibility of systematic errors in comparing their cross-sections.

Before proceeding to a discussion of the results, we remark briefly on the general character of the events (more details are presented elsewhere(5,6,7)). (1) We find jet events similar to those reported by Bromberg et al.(8), and with a similar cross-section ratio of jets to single π^0's, typically a few hundred to one. (2) Background contributions were studied in some detail. We found it possible to eliminate them readily for jet p_T values up to about 5 GeV/c. (3) We find for both the one arm jets and for the two arm jets that pion induced and proton induced jets of the same p_T are similar enough in size to produce no appreciable effect, in this experiment, on the p/π cross-section ratio(9).

As reported below, we observe strong differences in pion and proton initiated high p_T jet events. From point (3) above, we conclude that these differences are to be associated with differences in the pion and proton structure functions, and not with differences in the fragmentation functions of the high p_T groups, nor with the particular size of our detector.

We first show results for a sample of π^0-like events. These events were obtained by using the SP(R) trigger, and then selecting events whose energy deposition pattern in area and in depth is characteristic of inclusive single

π^0's. The results for the p/π production cross section ratio,

$$R_{\pi^0} \equiv \sigma(pp \to \pi^0 + X) / \sigma(\pi^+ p \to \pi^0 + X),$$

are shown in Fig. 2 for events taken in the 75° to 90° CM region at +130 and +200 GeV/c. The results agree with the 90° results of Donaldson et al.[3,4] to within the systematic error in our x_T scale due to energy calibration uncertainties, a maximum of 10% for individual modules.

In Fig. 3a we plot our results for the ratio

$$R_{jet} \equiv \sigma(pp \to jet + X) / \sigma(\pi p \to jet + X)$$

as a function of x_T, again near 90° CM. The ratio R_{jet} has basically the same shape as R_{π^0} but the curve is shifted to higher x_T. In Fig. 3a we show again the solid curve[10] of Fig. 2, along with a dashed curve which is the solid curve shifted to the right by a factor of 1.4 in x_T. The fact that the two distributions R_{π^0} and R_{jet} have approximately the same shape may indicate that the high p_T single π^0's originate from jets in which a roughly constant percentage of the jet p_T has been given to the single π^0. We note however that some of the additional p_T observed for jet events compared to π^0 events for a given value of R may arise from particles associated with beam and target jet fragments. Our analysis is not sufficiently refined to estimate the magnitude of this beam jet contribution, nor its variation with x_T.

For comparison we have plotted the results for R_{jet} of Bromberg et al.[6] in Fig. 3b. Their results are not in close quantitative agreement with our data, although they do show the same general trend with increasing x_T.

Finally we discuss some two arm correlation data taken with the (L + R) trigger at +130 GeV/c with the total p_T (sum of the p_T magnitudes in the two arms) selected to be in the interval $\approx$ 5.0 to 5.5 GeV/c. For such a selection we find that the momenta in the two arms balance, with each arm having an average p_T of 2.6 GeV/c, and a FWHM of 1.2 GeV/c[5]. It is important to note that this equality of the p_T in each arm is not forced by any aspect of the detector, trigger, or analysis. It thus constitutes evidence of correlated two-jet structure, such as would be expected in constituent scattering models.

We first bin the events according to the observed directions of the jet vector polar angles in the overall CM system on the left (θ_L^*) and right (θ_R^*). (These angles are calculated neglecting rest mass effects for individual particles.) The p/π ratio R_{jet} (θ_L^*, θ_R^*) is plotted in Fig. 4 as a function of θ_R^* for bins of constant θ_L^*. These angular correlation data show, for a given jet direction on the left, whether the opposite side jet emerges preferentially at different angles for incident protons than for incident pions. It is seen that at small θ_L^* and θ_R^* there is a larger cross-section for pion induced events ($R_{jet} < 1$), and that at larger θ_L^* and θ_R^* there is instead a larger cross-section for proton induced events ($R_{jet} > 1$). That is, in these two arm events at this x_T pions produce high p_T events at more forward angles than do protons.

In summary: (1) We have measured the ratio R_{π^0} for pion and proton induced events and found it to be consistent with a previous experiment[3]. (2) We have also measured R_{jet} and found that it has a form similar to that of R_{π^0} but at perhaps 40% higher p_T. The value of R at high x_T indicates that pions produce high p_T jet events much more readily than protons. (3) From our measurement of $R_{jet}(\theta_L^*, \theta_R^*)$ we observe that pions produce correlated two arm high p_T events at more forward angles than do protons. These results taken together indicate that the high p_T events we are observing have characteristics in agreement with constituent scattering models, and that the constituents of the pion which produce these events have on the average a significantly higher fractional momentum x than those of the proton.

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FOOTNOTES AND REFERENCES

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1. See for example, S. M. Berman, J. D. Bjorken and J. B. Kogut, Phys. Rev. D4, 3388 (1971); R. Blackenbecler, S. J. Brodsky, and J. F. Gunion, Phys. Letters 42B, 461 (1972).

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9. As one example of such evidence, we have found that the form of R_{jet} in Fig. 3 is very similar for jets triggering the L arm ($\Delta\Omega \approx 1$ sr for hadrons) and for jets triggering the R arm ($\Delta\Omega \approx 1.5$ sr for hadrons).

10. R. Field and R. Feynman, Phys. Review D15, 2590 (1977).

FIGURE CAPTIONS

Fig. 1. Plan view of the apparatus. The anti-counters vetoed charged particles emerging from the shield. The target was 45 cm of LH_2. Four of the six drift chamber planes provided "x" information only; the other two planes provided coordinated "x-y" information from a delay line readout. The right arm of the calorimeter consisted of 105 modules stacked in essentially a 5 x 5 array, 4 layers deep. The front layer consisted of Pb-scintillator modules; the remaining layers were Fe modules. The left arm consisted of 24 Pb modules (π^0 detector) followed over a large portion of its area by Fe modules.

Fig. 2. Results of this experiment for $R(\pi^0)$ as defined in the text, near 90° CM. The curve is a calculation of Field and Feynman (Ref. 10), which agrees closely also with data of Donaldson et al. (ref. 3).

Fig. 3. Results of (a) this experiment, (b) Bromberg et. al. (200 GeV; see Ref. 6), for $R_{jet}(x_T)$. The solid curve is the calculation of Field and Feynman and the dashed curve is this same calculation shifted to the right by a factor of 1.4 in x_T.

Fig. 4. Angular correlation results of this experiment for two arm jets, at 130 GeV. The variables are defined in the text.

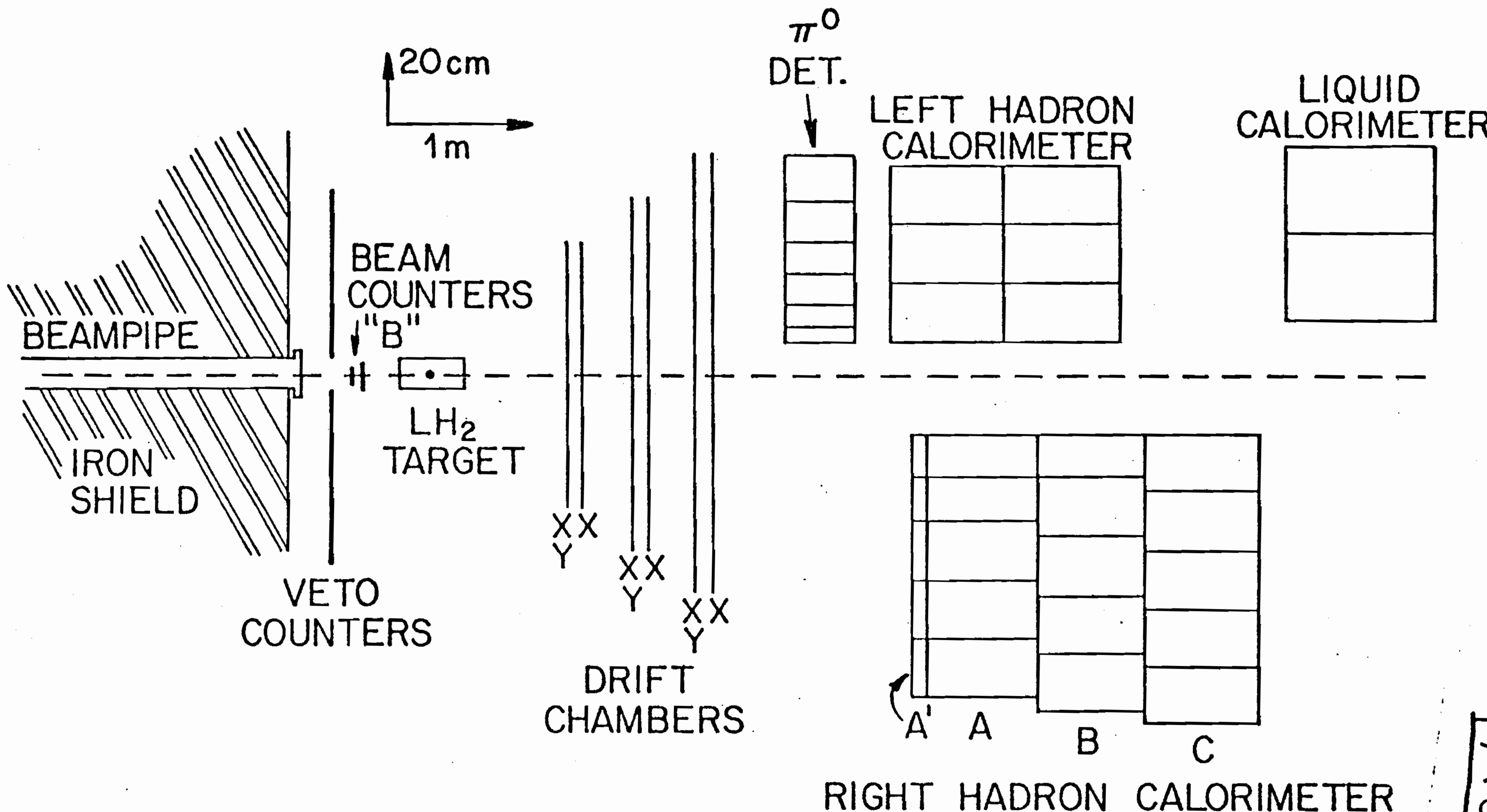

20cm
1m
π^0 DET.
LEFT HADRON CALORIMETER
LIQUID CALORIMETER
BEAM COUNTERS
"B"
BEAMPIPE
IRON SHIELD
LH_2 TARGET
XX Y
XX Y
XX Y
VETO COUNTERS
DRIFT CHAMBERS
A'
A
B
C
RIGHT HADRON CALORIMETER

FIG. 1

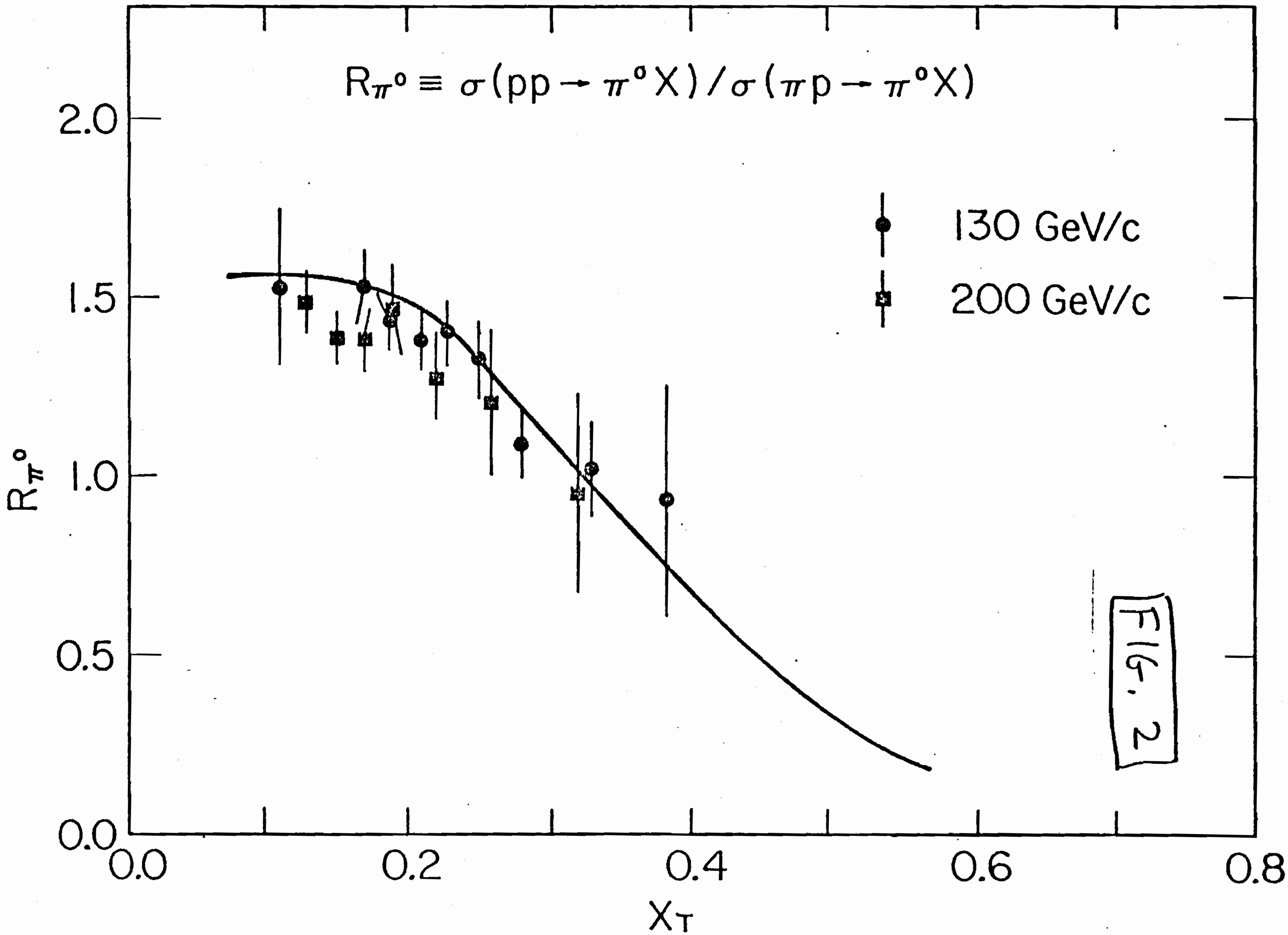
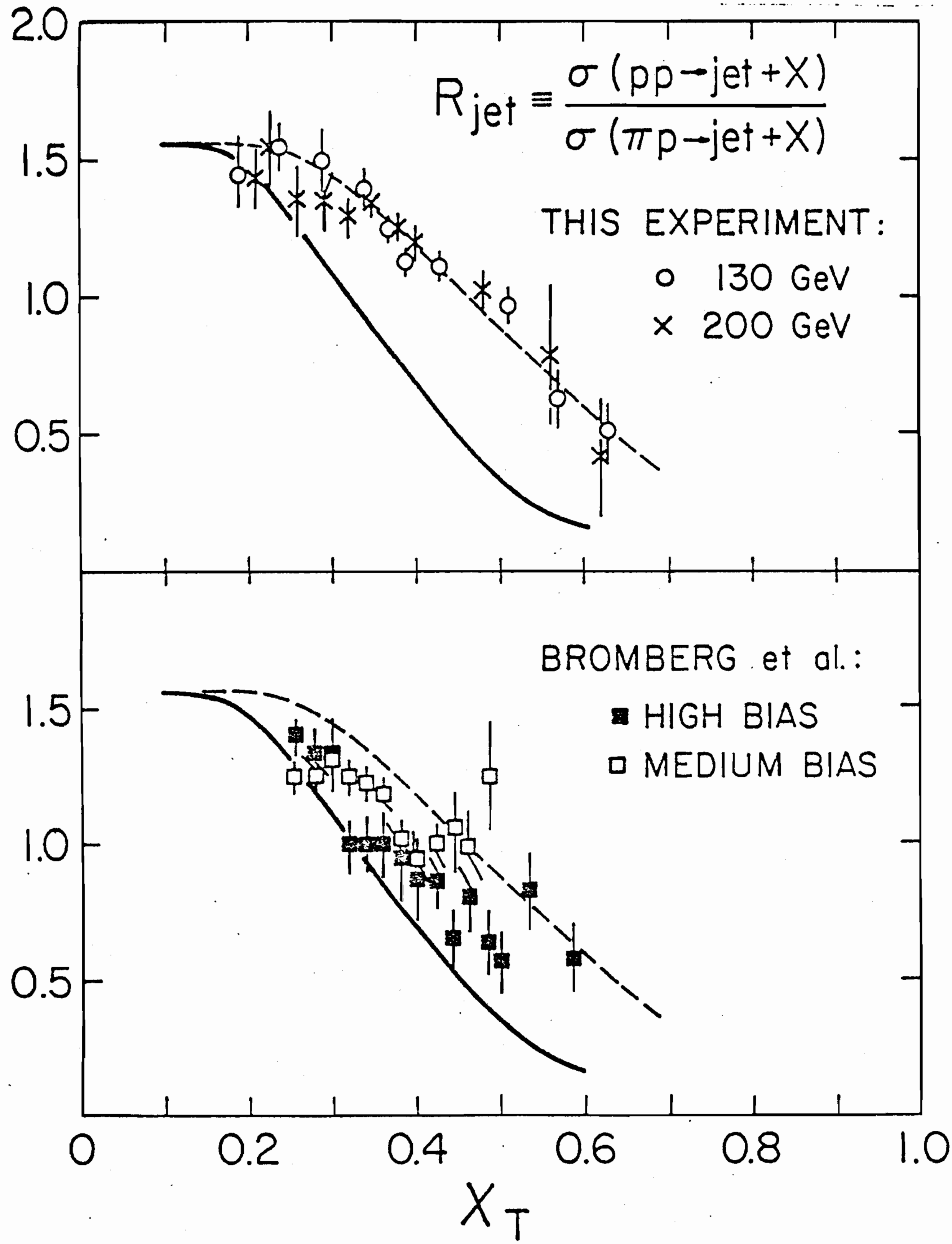
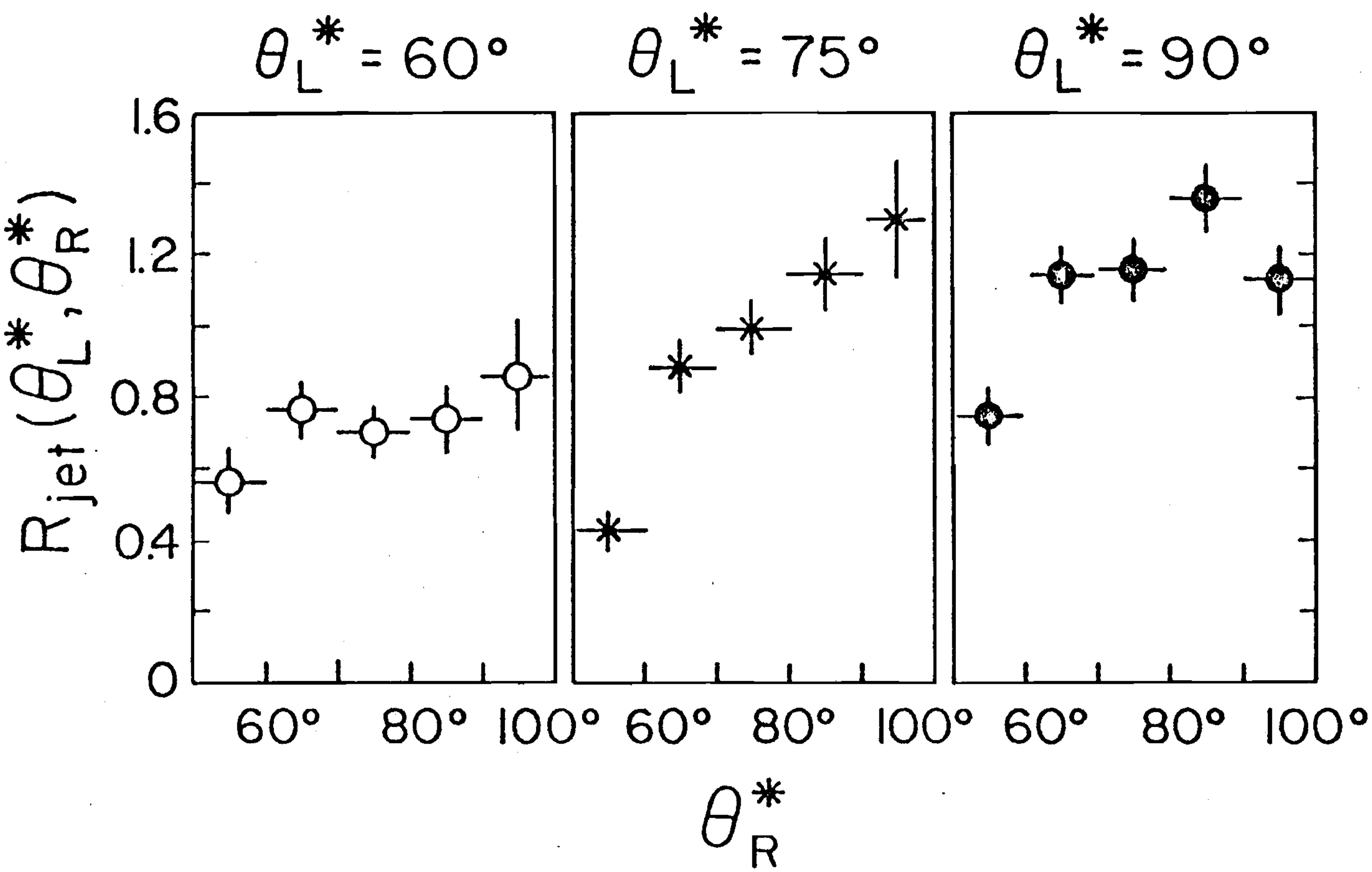

$R_{\pi^0} \equiv \sigma(pp \to \pi^0 X)/\sigma(\pi p \to \pi^0 X)$
130 GeV/c
200 GeV/c
2.0
1.5
1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
R_{π^0}
X_T

FIG. 2

FIG. 3



2.0
1.5
1.0
0.5
$R_{jet} \equiv \frac{\sigma(pp \to jet + X)}{\sigma(\pi p \to jet + X)}$
THIS EXPERIMENT:
○ 130 GeV
× 200 GeV
BROMBERG et al.:
■ HIGH BIAS
□ MEDIUM BIAS
0
0.2
0.4
0.6
0.8
1.0
X_T



$\theta_L^* = 60°$
$\theta_L^* = 75°$
$\theta_L^* = 90°$
1.6
1.2
0.8
0.4
0
$R_{jet}(\theta_L^*, \theta_R^*)$
60° 80° 100°
60° 80° 100°
60° 80° 100°
θ_R^*

FIG. 4