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SPHEROCITY AND THRUST DISTRIBUTIONS IN HIGH ENERGY NEUTRINO INTERACTIONS

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ABSTRACT

A study of the hadronic system of charged current neutrino interactions in terms of the variables Spherocity (S) and Thrust (T) is presented. It is found that $\langle S \rangle$ and $\langle 1-T \rangle$ for fixed hadronic energy are similar for neutrino interactions, e^+e^- annihilations and π^-Ne interactions.

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The purpose of this letter is to present experimental results related to the jet structure of secondary hadrons produced in neutrino-nucleon collisions. Our data are compared with results from the process $e^+e^- \rightarrow$ hadrons, as well as from hadron induced interactions at similar values of W, the invariant mass of the hadronic system. The comparison of the neutrino data with the prediction of Quantum Chromo Dynamics (QCD) is also made.

The experimental data consist of approximately 1200 charged current neutrino events obtained in BEBC filled with 74 mol per cent Ne/H_2 mixture, exposed to the CERN SPS narrow band neutrino beam. The momentum of the parent particles was 200 GeV/c, giving a neutrino spectrum covering a range of hadronic invariant mass W up to 20 GeV. In this letter we also present results on samples of a few hundred π-Ne interactions in BEBC at 70 GeV/c and 110 GeV/c which had been measured, for calibration purposes, by our Collaboration. Details of the experimental method of analysis of the neutrino events have been reported previously [1,2].

One of the most interesting results of our previous analysis of the hadron secondaries [3] was the dependence of the mean transverse momentum squared $\langle P_\perp^2 \rangle$ of the individual hadrons, relative to the total visible hadronic momentum vector, on both Q^2 (the 4-momentum transfer squared) and on W^2. Those results could not be interpreted in terms of hadronic jets with limited $p_\perp$ observed in <u>low energy</u> hadron interactions. Qualitatively, the increase of $\langle p_\perp^2 \rangle$ with Q^2 at high energy is consistent with the estimates based on first order QCD predictions [4], where the process of hard gluon bremsstrahlung by the struck quark is expected to contribute a term of the form $\langle \Delta p_\perp^2 \rangle \sim Q^2/(\ell n\, Q^2/\Lambda^2)$, with Λ being a scale constant.

In the context of QCD, several variables have been proposed which describe the shape of the hadrons in momentum space; here we discuss Thrust (T) and Spherocity (S). Theoretically, these variables were first proposed for the case of e^+e^- annihilation to hadrons. Corresponding calculations for neutrino-hadron scattering have recently become available [5].

The variables S and T are defined as follows:

$$S = \min \left(\frac{4}{\pi} \frac{\Sigma |p_\perp|}{\Sigma |p|} \right)^2$$

$$T = \max \frac{2\tilde{\Sigma} p_L}{\Sigma |p|}$$

where p_L and p_T are the longitudinal and transverse momenta respectively of the hadrons, $\Sigma|p|$ is the sum of the moduli of all hadron momenta in the c.m.s. and $\tilde{\Sigma}$ indicates summation over only the forward hemisphere. In order to be able to compare these neutrino data with published results from $e^+e^- \rightarrow$ hadrons as well as with our π^-Ne data in what follows the quantities S and T are plotted as functions of W after corrections for hadronic energy losses as explained in ref. [2].

Though the above definitions imply that a maximization is required to find the thrust axis, in this analysis we use the fact that in a scattering experiment a natural axis already exists. The final axis is chosen by: (a) estimating the c.m.s. of the hadrons using the resultant 4-momentum vector of all measured hadrons and (b) taking those hadrons that travel forward in this c.m.s. The direction of the resultant momentum of these forward hadrons defines the thrust axis. In the case of the π^-Ne data the thrust axis is chosen in exactly the same way as in the neutrino interactions. We have checked that if the incident π^- direction is instead used as the thrust axis, no essential difference is observed in the S and T distributions.

The S and T distributions for the neutrino events are shown in figs 1(a) and (b), respectively, for a W range of 8-12 GeV. A comparison with the predictions from first order perturbative QCD calculations, [5] not including hadronization effects, shows that the predictions do not reproduce the data.

Figs 2(a) and (b) show(*) the average values of $\langle S \rangle$ and $\langle 1-T \rangle$ as functions of W. For comparison the results of $e^+e^- \rightarrow$ hadrons are shown, from the experiments at DORIS and PETRA by the PLUTO and the TASSO Collaborations [6,7,8] covering a similar W range and excluding the ψ, ψ' and Υ resonance regions. Also shown are the points obtained from π^-Ne interactions, measured and analysed in exactly the same way as the neutrino events. There is a striking agreement among these three different processes in the overlapping ranges of W(**).

The disagreement of the data with first order perturbative QCD calculations is again evident. There is also good agreement between the neutrino data and the π^-Ne data which - presumably - are dominated by non perturbative processes.

Figs 3(a) and (b) show the $\langle S \rangle$ and $\langle 1-T \rangle$ plotted against W for two different values of the Bjorken scaling variable x_B. For the range of W explored in this experiment there is no strong evidence for any dependence on x_B at fixed W. These plots illustrate that it is W (rather than x_B or Q^2) which determines these properties of the hadronic final states.

To summarize:

(1) We observe, that for W less than 15 GeV neutrino nucleon interactions $e^+e^- \rightarrow$ hadrons and π^-Ne interactions have the same variation of $\langle S \rangle$ and $\langle 1-T \rangle$ versus W.

(2) Moreover, the observed $\langle S \rangle$ and $\langle 1-T \rangle$ distributions do not agree with existing predictions from first order QCD.

(*) Note that the W variable used here is the W corrected for energy loss in a statistical way; this introduces a systematic shift of the order of 1 - 2 GeV towards high W when compared to the W values obtained using only the momentum vector of the observed hadrons.

(**) If we apply to the neutrino data the same multiplicity cut (i.e. exclude events with less than 4 charged hadrons) as has been done in the e^+e^- data, [6,7] in the relevant region of W > 5 GeV the $\langle 1-T \rangle$ values increase by $\lesssim$ 10%, but the agreement is unchanged.

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FIGURE CAPTION

Fig. 1 (a) Spherocity and (b) Thrust distributions for W between 8 and 12 GeV. The solid line is the first order QCD calculation from ref. 5 .

Fig. 2 (a) Mean Spherocity and (b) mean 1 - Thrust plotted versus W. The solid lines are the predictions from first order QCD calculation ref. [5]. The dotted line is the corresponding QCD calculation for e^+e^- interactions from ref. [9]. The crosses and the open squares show the e^+e^- data points from the PLUTO [6,7] and the TASSO [8] experiments respectively. The triangles are from the π^-Ne interactions at 70 and 110 GeV/c measured and analysed in this experiment in the same way as the neutrinos.

Fig. 3 (a) Mean Spherocity and (b) mean 1- Thrust plotted versus W for different x_B regions.

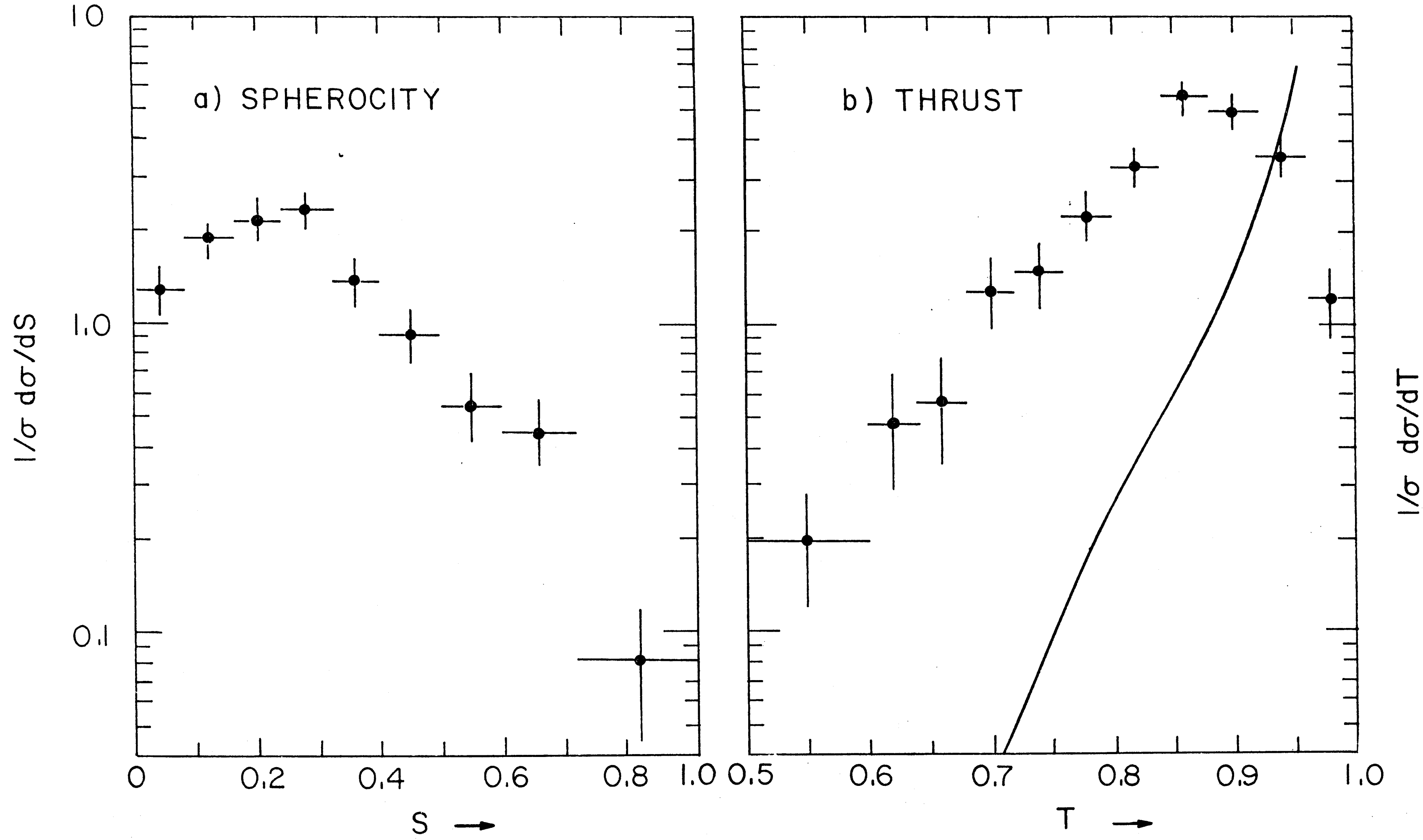
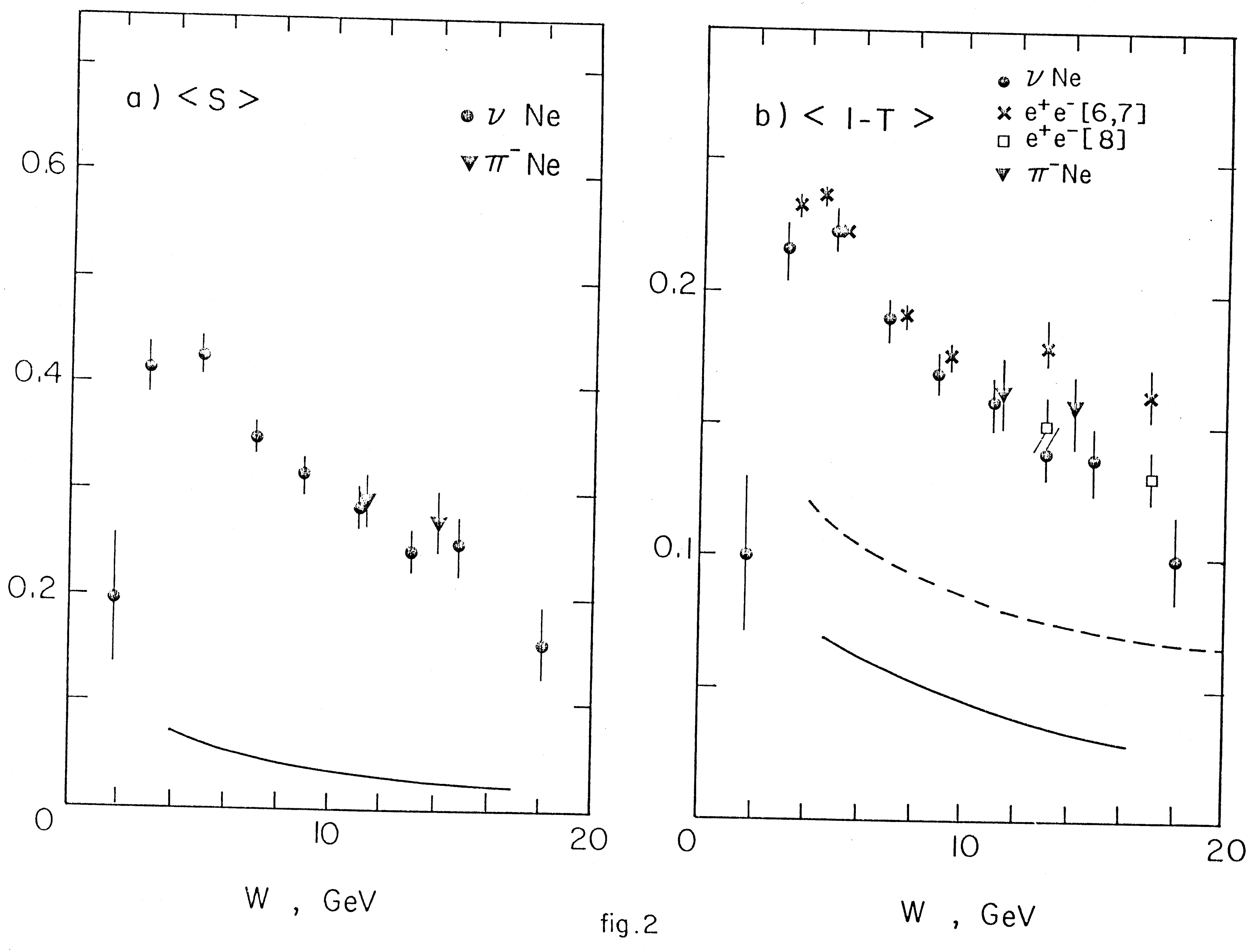

a) SPHEROCITY
b) THRUST
1/σ dσ/dS
1/σ dσ/dT
10
1.0
0.1
0
0.2
0.4
0.6
0.8
1.0
0.5
0.6
0.7
0.8
0.9
1.0
S →
T →

fig. 1



a) < S >
ν Ne
π⁻ Ne
0.6
0.4
0.2
0
10
20
W , GeV
b) < 1-T >
ν Ne
e⁺e⁻ [6,7]
e⁺e⁻ [8]
π⁻ Ne
0.2
0.1
0
10
20
W , GeV

fig.2

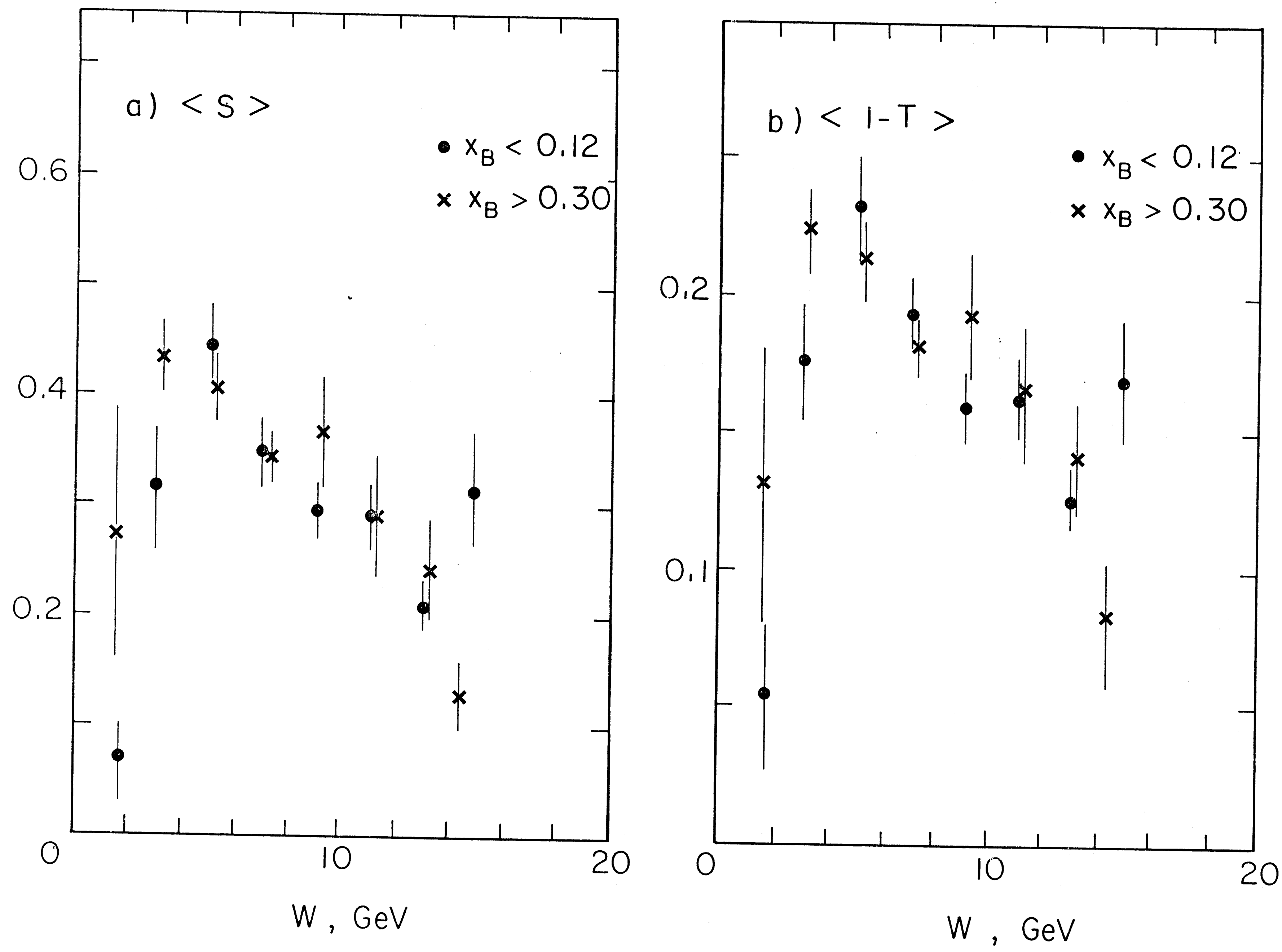

a) < S >
• x_B < 0.12
× x_B > 0.30
0.6
0.4
0.2
0
10
20
W , GeV
b) < i-T >
• x_B < 0.12
× x_B > 0.30
0.2
0.1
0
10
20
W , GeV

fig. 3