DISTINGUISHING BETWEEN MODELS FOR LARGE TRANSVERSE
MOMENTUM PROCESSES BY A MEASUREMENT OF ' JET-ASSOCIATED BARYON NUMBER*

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#### Abstract

We propose that a measurement of the number of protons and antiprotons in the hemisphere opposite a large transverse momentum proton can distinguish between two important models for large transverse momentum processes. The Parton Jet Model (PJM), where the underlying mechanism is assumed to be quark-quark scattering, is characterized by a surplus of protons over antiprotons in the jet opposite the detected proton, while the Constituent Interchange Model (CIM) predicts that the jet opposite the trigger proton be populated on the average by more antiprotons than protons.


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## I. INTRODUCTION

A number of models have recently been proposed to account for the inclusive production of high transverse momentum particles. ${ }^{1-5}$ The predictions for the shape and energy dependence of the single particle distributions are different in the rival models and this should allow for a fair amount of discrimination between them. For example the Parton Jet Model (PJM) with intermediate vector gluon exchange predicts an asymptotic form ${ }^{1-2}$

$$
\begin{equation*}
E d^{3} \sigma / d^{3} p \sim\left(p_{T}\right)^{-4} F\left(x_{T}=2 p_{T} / \sqrt{s}, \theta\right) \tag{1.1}
\end{equation*}
$$

for the single particle inclusive distribution. The Constituent Interchange Model (CIM) of Blankenbecler, Brodsky and Gunion, ${ }^{3}$ in contrast, disallows any direct quark-quark interaction except that necessary to bind hadrons and predicts that the inclusive distribution should assume an asymptotic form for moderate $\mathrm{x}_{\mathrm{T}}\left(.2 \lesssim \mathrm{x}_{\mathrm{T}} \lesssim .5\right)$ of

$$
\begin{equation*}
\mathrm{Ed}^{3}{ }_{\sigma} / \mathrm{d}^{3} \mathrm{p} \sim\left(\mathrm{p}_{\mathrm{T}}\right)^{-8} \mathrm{~F}^{\prime}\left(\mathrm{x}_{\mathrm{T}}, \theta\right) \tag{1.2}
\end{equation*}
$$

Experimental evidence from NAL and ISR ${ }^{6-7}$ seems to disagree with the PJM result (1.1) while the CIM can achieve a substantial quantitative agreement with data through the addition of some nonleading terms to (1.2).

However, the anticipated discrimination is not clear-cut. Halzen and Luthe ${ }^{8}$ have recently argued that including finite mass effects can make the single particle inclusive data consistent with either (1.1) or (1.2). In addition, it may be possible to modify the fundamental quark-quark interaction in the PJM leaving the rest of the structure of the model intact so that the vector gluon exchange prediction (1.1) is invalidated. For both theoretical and experimental ${ }^{9}$ reasons it is therefore desirable to seek an alternative test to distinguish the models.

It has been suggested that it is fruitful to examine in detail the phase space structuxe in events containing at least one large transverse momentum particle. ${ }^{5}$ Both the models we are considering here are characterized to some extent by jet structure. That is, the particles in a given event are confined in momentum space either to a cigar-shaped low $-\mathrm{p}_{\mathrm{T}}$ region along the beam direction or to one of two approximately coplanar jet regions in opposite hemispheres along the direction of the highest $\mathrm{p}_{\mathrm{T}}$ particle. The hypothesis of jet structure has not been tested conclusively by experiment although there does seem to be some support from data on associated multiplicities. ${ }^{10}$ As pointed out by Bjorken ${ }^{5}$ there is some difference between the kinds of jets found in the PJM and CIM in that one of the jets in the latter most likely contains only a few hadrons. Accurate data on associated multiplicities at very high energies could, in principle, distinguish the two types of jet structure but is unlikely to be decisive until jets of $\mathrm{p}_{\mathrm{T}} \gtrsim 10 \mathrm{GeV} / \mathrm{c}$ are measured.

One of the distinctive features of these models involves the quantum numbers carried by the hadrons in a high- $\mathrm{p}_{\mathrm{T}}$ jet. This fact reflects the implicit assumption that there is a single "hard" interaction responsible for the large transverse momentum. We would like to discuss in this paper a simple example of the use of this quantum number signature of the two models in order to distinguish cleanly between them.

We propose a measurement which can be made in a double arm spectrometer if it is possible to differentiate protons, mesons and antiprotons. For proton-proton scattering the experiment is depicted schematically in Fig. 1. Two detectors, D1 and D2, are located at $90^{\circ}$ to the beam axis in the C. M. frame. The experiment consists of triggering on a large transverse momentum proton in D1 and counting the number of protons and antiprotons with large
transverse momentum in D 2 . Let $\left\langle\mathrm{p}_{2}\right\rangle_{1}$ be the average number of protons detected in this way and $\left\langle\overline{\mathrm{p}}_{2}\right\rangle_{1}$ the average number of antiprotons. These averages will, in general, depend on the transverse momentum of the trigger particle as well as the kinematic acceptance of D 2 . The ratio

$$
\begin{equation*}
\mathrm{R}\left(\mathrm{p}_{\mathrm{T} 1}, \sqrt{\mathrm{~s}}\right)=\frac{\left\langle\mathrm{p}_{2}\right\rangle_{1}-\left\langle\overline{\mathrm{p}}_{2}\right\rangle_{1}}{\left\langle\mathrm{p}_{2}\right\rangle_{1}+\left\langle\overline{\mathrm{p}}_{2}\right\rangle_{1}} \tag{1.3}
\end{equation*}
$$

provides a sensitive measure of the average baryon number associated with the jet opposite to the large $-\mathrm{p}_{\mathrm{T}}$ proton.

In the PJM of Refs. 1 and 2 as well as all other models allowing a direct quark-quark scattering there is a range of $p_{T}$ for which the ratio (1.3) approaches plus one since the production of antibaryons in the opposite jet is suppressed. In the CIM of Blankenbecler, Brodsky, and Gunion, ${ }^{3}$ as a consequence of the absence of any elastic quark-quark scattering, just the opposite is true: Antibaryons are predicted to be more copious than baryons and the ratio (1.3) should be negative and approach minus one for the same range of kinematic variables. We emphasize that, subject to the existence of some kind of jet-like structure, this test is simple, definite, and can be performed with high statistics.

In the next two sections we shall consider the ratio (1.3) in PJM and CIM respectively. Our treatment is simplified by our placing of detectors at $\pm 90^{\circ}$ in Fig. 1, which insures that the proton-proton C. M. coincides with the C. M. of the constituent-constituent collision within the protons. In addition the empirical fact that at most one baryon or antibaryon tends to be present in a jet above some moderate $\mathrm{X}_{\mathrm{T}}$ makes our explanation easier than it could be otherwise.

## II. THE PARTON JET MODEL

We want now to consider a simple calculation of the jet-associated baryon number in the PJM. When we refer to the PJM we mean any model in which the dominant mechanism.leading to large-transverse-momentum particles is the elastic collision of pointlike constituents of the beam and target. Our results depend strongly on the assignment of quark quantum numbers to the constituents but are, as we shall see below, relatively insensitive to the form of the underlying parton-parton amplitude.

Consider proton-proton scattering in the C. M. frame where there is a single hard collision leading to two jets as shown in Fig. 2. For simplicity in what follows we will neglect the transverse momentum of partons within the proton and the momentum of hadrons transverse to the direction of the jets. The experimental situation is not expected to be so straightforward in that there can be a great deal of smearing in the direction of the hadrons away from clean coplanar jets. This simplifying assumption does not provide a fundamental restriction on our results which are valid as long as there is some sort of underlying jet structure.

We define the probability for finding a quark-parton of type $j$ in a proton with a fraction x of the proton's momentum to be

$$
\begin{equation*}
P_{j}^{p}(x) d x=\frac{F_{j}^{p}(x)}{x} d x \tag{2.1}
\end{equation*}
$$

In addition we can define the probability that a parton j emits a hadron h with a fraction $y$ of the parton momentum as

$$
\begin{equation*}
P_{h}^{j}(y) d y=\frac{G_{h}^{j}(y)}{y} d y \tag{2.2}
\end{equation*}
$$

With these definitions we can find the invariant single particle cross section for producing hadron a with large transverse momentum $\mathrm{p}_{\mathrm{Ta}}$ at a right angle to the pp collision axis (regardless of the orientation of the other jet): ${ }^{2}$

$$
\begin{align*}
&\left.E_{a} \frac{d^{3} \sigma_{a}}{d^{3} p_{a}}\right|_{\theta \cong 90^{\circ}}= \frac{4}{\pi x_{T a}^{2}} \sum_{\left\{j_{i}\right\}} \int d x_{1} d x_{2} F_{j_{1}}^{p}\left(x_{1}\right) F_{j_{2}}^{p}\left(x_{2}\right) \\
& {\left[\frac{d \sigma}{d t} j_{1} j_{2} \rightarrow j_{3} j_{4}\right.}  \tag{2.3}\\
&(\hat{s}, \hat{t})] \frac{x_{1} x_{2}}{\left(x_{1}+x_{2}\right)^{2}} G_{a}^{j_{3}}\left(x_{T a} / x_{1}\right)
\end{align*}
$$

Here, $x_{1}$ and $x_{2}$ are the fractions of the proton momenta carried respectively by partons $j_{1}$ and $j_{2}, x_{T a}=2 p_{T a} s^{-1 / 2}$ and $\frac{d \sigma}{d t}{ }^{j_{1} j_{2} \rightarrow j_{3} j_{4}} \hat{(\hat{s}, \hat{t})}$ is the partonparton cross section evaluated at $\hat{s}=x_{1} x_{2} s$ and $\hat{t}=\frac{x_{1} s}{\left[1 / x_{1}+1 / x_{2}\right]}$. For the PJM we only consider elastic scattering so that $\mathrm{j}_{1} \mathrm{j}_{2}=\mathrm{j}_{3} \mathrm{j}_{4}$ but Eq. (2.5) is written so that simple comparison with the CIM can be made later. With the same approximations the two particle inclusive cross section for detecting hadron a and hadron b both at $90^{\circ}$ in opposite hemispheres is found to be ${ }^{11}$

$$
\begin{align*}
& \left.E_{a} E_{b} \frac{d^{6} \sigma}{d^{3} p_{a} d^{3} p_{b}}\right|_{\substack{\theta_{a} \cong 90^{\circ} \\
\theta_{b} \cong 90^{\circ}}}=\frac{4 .}{\pi s x_{T a}^{2} x_{T b}^{2}} \sum_{\left\{j_{i}\right\}} \int d x_{1} x_{1} F_{j_{1}}^{p}\left(x_{1}\right) F_{j_{2}}^{p}\left(x_{1}\right) \\
& {\left[\frac{d \sigma}{d t}{ }^{j_{1} j_{2} \rightarrow j_{3} j_{4}}(\hat{s}, \hat{t})\right] \quad G_{a}^{j_{3}}\left(x_{T a} / x_{1}\right) G_{b}^{j_{4}}\left(x_{T b} / x_{1}\right) \delta\left(\phi_{a}-\phi_{b}+\pi\right) .} \tag{2.4}
\end{align*}
$$

The limit of integration in (2.4) is $\left[\mathrm{x}_{\mathrm{Ta}}, \mathrm{x}_{\mathrm{Tb}}\right]_{\max } \leq \mathrm{x}_{1} \leq 1$ where $\mathrm{x}_{\mathrm{Ta}}=2 \mathrm{p}_{\mathrm{Ta}} \mathrm{s}^{-1 / 2}$, $x_{\mathrm{Tb}}=2 \mathrm{p}_{\mathrm{Tb}} \mathrm{s}^{-1 / 2}$ and $\hat{\mathrm{s}}=\mathrm{x}_{1}^{2} \mathrm{~s}, \hat{\mathrm{t}}=\mathrm{x}_{1}^{2} \mathrm{~s} / 2$. (This limit is insured automatically since $G(y)=0$ for $y>1$, and $F(x)=0$ for $x>1$.) The $\delta$-function in azimuthal angle reflects the coplanarity of the hadrons due to the extreme assumption of
the neglect of all transverse momenta associated with the F's and G's. A more realistic expression would allow a spread in azimuthal angle associated with some "smearing" of direction.

To find the average number of hadrons of type b in some range $\Delta \theta$ around $90^{\circ}$ and with some minimum fraction $\mathrm{x}_{\mathrm{T} 0}$ of the protons' momenta in the hemisphere opposite the trigger particle a observed at $\mathrm{x}_{\mathrm{Ta}}$, we write

$$
\begin{equation*}
\left\langle n_{b}\left(a, x_{T a}\right)\right\rangle \cong \frac{\Delta \theta_{b} \int d \phi_{b} \int_{x_{T 0}}^{1} x_{T b} d_{T b}\left[E_{a} E_{b} d_{\sigma / d^{6}}^{3} p_{a} d^{3} p_{b}\left(x_{T a}, x_{T b}\right)\right]}{\left[E_{a} d^{3} / d^{3} p_{a}\left(x_{T a}\right)\right]} \tag{2.5}
\end{equation*}
$$

Using (2.5) with (2.4) it is clear that by making $\mathrm{x}_{\mathrm{Ta}}$ large enough (so that we sample only the valence region in (2.1-2)) we can guarantee that throughout the range of integration the contribution from quark-quark scattering can be made to dominate all other terms. After making this restriction we can choose $\mathrm{x}_{\mathrm{T} 0}$ large enough so that emission of any antiprotons above $\mathrm{x}_{\mathrm{T} 0}$ by the scattered quark is extremely disfavored. These two conditions suffice to give

$$
\begin{equation*}
\left.\left\langle\mathrm{n}_{\overline{\mathrm{p}}}\left(\mathrm{x}_{\mathrm{Ta}}, \mathrm{a}\right)\right\rangle \lll \mathrm{n}_{\mathrm{p}}\left(\mathrm{x}_{\mathrm{Ta}}, \mathrm{a}\right)\right\rangle \tag{2.6}
\end{equation*}
$$

so that the ratio ( 1,3 ) is close to plus one. This fact does not depend sensitively on the exact mechanism for the parton-parton scattering as can be discerned from (2.3)-(2.5).

In order to get a quantitative estimate of the dependence of $<\mathrm{n}_{p}\left(\mathrm{x}_{\mathrm{Ta}}, \mathrm{a}\right)>$ and $\left\langle\mathrm{n}_{\overline{\mathrm{p}}}\left(\mathrm{x}_{\mathrm{Ta}}, \mathrm{a}\right)>\right.$ on the cutoff $\mathrm{x}_{\mathrm{T} 0}$ and on the kinematic variables of the trigger particle we need expressions for the $F_{j}^{p}(x)$ and the $G_{a}^{j}(x)$. If we assume standard quark model assignments for the quantum numbers of the partons we can determine the forms of $\mathrm{F}_{\mathrm{j}}^{\mathrm{p}}(\mathrm{x})$ from data on deep inelastic electroproduction, neutrino
scattering, etc. For convenience we can use the empirical description of these distributions proposed by McElhaney and Tuan, ${ }^{12}$

$$
\begin{gather*}
\mathrm{F}_{\mathrm{u}}^{\mathrm{p}}(\mathrm{x})=\mathrm{u}_{\mathrm{v}}(\mathrm{x})+\mathrm{c}(\mathrm{x}) \\
\mathrm{F}_{\mathrm{d}}^{\mathrm{p}}(\mathrm{x})=\mathrm{d}_{\mathrm{v}}(\mathrm{x})+\mathrm{c}(\mathrm{x}) \\
\mathrm{F}_{\mathrm{s}}^{\mathrm{p}}(\mathrm{x})=\mathrm{F}_{\mathrm{s}}^{\mathrm{p}}(\mathrm{x})=\mathrm{F}_{\mathrm{u}}^{\mathrm{p}}(\mathrm{x})=\mathrm{F}_{\mathrm{d}}^{\mathrm{p}}(\mathrm{x})=\mathrm{c}(\mathrm{x}) \tag{2.7}
\end{gather*}
$$

where, for $0 \leq x \leq 1$,

$$
\begin{align*}
& u_{v}(x) \cong 1.74 x^{1 / 2}(1-x)^{3}(1+2.3 x) \\
& d_{v}(x) \cong 1.11 x^{1 / 2}(1-x)^{3.1} \\
& c(x) \cong 0.10(1-x)^{7 / 2} \tag{2.8}
\end{align*}
$$

By choosing $\mathrm{x}_{\mathrm{Ta}} \gtrsim 0.3$ we see using (2.7) and (2.8) that the ratio

$$
\begin{equation*}
\frac{\mathrm{F}_{\mathrm{u}}^{\mathrm{p}}(\mathrm{x})+\mathrm{F}_{\mathrm{d}}^{\mathrm{p}}(\mathrm{x})+\mathrm{F}_{\mathrm{s}}^{\mathrm{p}}(\mathrm{x})}{\mathrm{F}_{\overline{\mathrm{u}}}^{\mathrm{p}}(\mathrm{x})+\mathrm{F} \frac{\mathrm{p}}{\mathrm{~d}}(\mathrm{x})+\mathrm{F}_{\frac{\mathrm{s}}{}(x)}^{\mathrm{p}}} \geq 10 \tag{2.9}
\end{equation*}
$$

This means that quark-quark scattering dominates quark-antiquark scattering by at least this amount over the region of integration.

The $G_{a}^{j}(x)$ are not so well known although there are theoretical arguments leading to correspondence laws which relate $G_{a}^{d}(x)$ and $F_{j}^{a}(x)$ as $x \rightarrow 1$. We will use the estimates

$$
\begin{align*}
& G_{p}^{q}(x)=G_{\bar{p}}^{\bar{q}}(x) \propto x^{1 / 2}(1-x)^{3}  \tag{2.10}\\
& G_{p}^{\bar{q}}(x)=G_{\bar{p}}^{q}(x) \propto x^{1 / 2}(1-x)^{7} \tag{2.11}
\end{align*}
$$

(An empirical form for these fragmentation functions is lacking. If the theoretical notion of reciprocity were reliable throughout $0<x<1$ they could be written in terms of (2.7-8). The particular parameterization used here is motivated by CIM arguments - which unfortunately also would suggest a slightly different behavior for $\mathrm{c}(\mathrm{x})$ in (2.8) - but is not dependent on that model's validity. A parameterization based on reciprocity with (2.7-8) leads to the same general results that we find with this one.)

With these parameterizations the value of the ratio (1.3) for various values of $\mathrm{x}_{\mathrm{Ta}}$ and $\mathrm{x}_{\mathrm{T} 0}$ is indicated in Fig. 3. As can be seen from the discussion above the value of the ratio does not depend critically on the exact mechanism $\frac{d \sigma}{d t}(\hat{\mathrm{~s}}, \hat{\mathrm{t}})$ for parton-parton scattering. The specific form (2.4-5) indicates that the composition of particles in $\mathrm{j}_{2}$ does not depend on the trigger particle a but should approximately reflect the ratio of particles found in single particle distributions. This idea of "independent jets" is certainly an important feature of the PJM and should be checked experimentally. If we examine this assumption in detail it becomes hard to understand why quark quantum numbers are not observed. Indeed, Feynman has conjectured that, on the average, quark quantum numbers are deposited with the hadrons in the fragmentation region of the quark. This would imply, for example, that a net average baryon number

$$
\begin{equation*}
\left\langle\mathrm{n}_{\mathrm{B}}\left(\mathrm{x}_{\mathrm{Ta}}, \mathrm{a}\right)\right\rangle-\left\langle\mathrm{n}_{\overline{\mathrm{B}}}\left(\mathrm{x}_{\mathrm{Ta}}, \mathrm{a}\right)\right\rangle \sim \frac{1}{3} \tag{2.11}
\end{equation*}
$$

should be deposited in each jet in a quark-quark collision. There are model counterexamples ${ }^{13}$ where Feynman's conjecture does not work but the possibility that it is valid experimentally remains open. To test this hypothesis in large transverse momentum collision requires the ability to detect neutral baryons a prospect which does not seem bright in the near future.

## III. THE CONSTITUENT INTERCHANGE MODEL (CIM)

The fundamental assumption of Blankenbecler, Brodsky and Gunion ${ }^{3}$ in the formulation of the CIM is that the direct elastic quark-quark scattering which is the basic mechanism for producing high- $\mathrm{p}_{\mathrm{T}}$ secondarics in the PJM is suppressed or absent. There is no underlying theoretical groundwork for this assumption but it remains an interesting possibility which deserves consideration. There has recently been some interesting speculation that color symmetry involved in the binding mechanism of the quarks might enforce this kind of selection rule but these arguments are far from precise。 ${ }^{14}$ By far the best justification of the CIM has been its phenomenological success. By leaving out any $\mathrm{qq} \rightarrow \mathrm{qq}$ scattering, the CIM does not predict a scale-invariant $\left(\mathrm{p}_{\mathrm{T}}\right)^{-4}$ behavior for the single particle inclusive cross section, (1.1). In fact there are several terms in the expression for the invariant cross section which may be important at NAL and ISR energies. The weakest fall off in transverse momentum is of the form (1.2) and the CIM is therefore currently in better agreement with the data on single particle inclusives.

Let us now look at the jet-associated baryon number in this model. In the absence of any $q q \rightarrow q q$ interaction the expressions (2.3) and (2.4) for the single particle and two particle inclusive distributions can be used directly as long as particles $\mathrm{j}_{1-4}$ participating in the "irreducible" cross section $\left[\frac{\mathrm{d} \sigma}{\mathrm{dt}} \mathrm{j}_{1} \mathrm{j}_{2} \rightarrow \mathrm{j}_{3} \mathrm{j}_{4}\right]$ are specified. For the process $\mathrm{pp} \rightarrow \mathrm{pX}$ the participants in the irreducible process can be, for example $\mathrm{Bq} \rightarrow \mathrm{Bq}, \mathrm{B}(\mathrm{qq}) \rightarrow \mathrm{B}(\mathrm{qq}), \mathrm{qq} \rightarrow \mathrm{Bq}, \mathrm{q}(\mathrm{qq}) \rightarrow \mathrm{BM}$, $\mathrm{qM} \rightarrow \mathrm{qM}$, etc., where q is a quark, ( qq ) a diquark "core", B a baryon, and M a meson. The sum over $\left\{\mathrm{j}_{\mathrm{i}}\right\}$ in (2.3) and (2.4) which in the PJM extended only over the possible types of quarks which were contained in the proton is, in the CIM, understood to extend over all the possible irreducible mechanisms.

We need also, therefore, extend our definitions of $F_{j}^{p}(x)$ and $G_{a}^{j}(x)$ to cover the more general definition of a "constituent $j$ " applicable in the CIM. This model compensates, to some extent, for having a great many more densities which can be important by presenting a definite prescription for them. According to the rules ${ }^{3,15}$

$$
\begin{gather*}
F_{j}^{p}(x) \cong G_{p}^{j}(x)  \tag{3.1}\\
G_{a}^{j}(x)=f(x) x^{1-\alpha_{a}(0)}(1-x)^{2 n(j / a)-1} \tag{3.2}
\end{gather*}
$$

where $n(j / a)$ is the minimum number of quarks which can be produced in the process $\mathrm{j} \overline{\mathrm{a}} \rightarrow$ quarks, $\alpha_{\mathrm{a}}$ is the leading regge trajectory in the $\mathrm{a} \overline{\mathrm{a}} \rightarrow \mathrm{j} \bar{j}$ channel and $f(x)$ is some smooth function of $x$ often taken to be a constant. To supplement (3.1) and (3.2) we must now also consider the probability that hadron a "emits" itself in (2.3) and (2.4)

$$
\begin{equation*}
\mathrm{G}_{\mathrm{a}}^{\mathrm{a}}(\mathrm{x}) \cong \mathrm{c} \delta(1-\mathrm{x}) \tag{3,3}
\end{equation*}
$$

We will not go into a justification of the forms (3.1)-(3.3) here; an introduction to the subject can be found in the review of Blankenbecler. ${ }^{3}$

In order to specify the CIM for a particular process we must know which "irreducible" subprocesses are important. In the CIM the answer is again given by quark counting according to the rules proposed by Brodsky and Farrar : 3,15

$$
\begin{equation*}
\left.\frac{\mathrm{d} \sigma}{\mathrm{dt}} \mathrm{j}_{1}^{\mathrm{j}_{2} \rightarrow \mathrm{j}_{3} \mathrm{j}_{4}} \underset{(\mathrm{~s}, \mathrm{t})}{ }\right|_{\mathrm{t} / \mathrm{s} \text { fixed }} \sim s^{-\left(\mathrm{n}_{1}+\mathrm{n}_{2}+\mathrm{n}_{3}+\mathrm{n}_{4}\right)+2} \mathrm{f}(\mathrm{t} / \mathrm{s})^{\left(\bmod \log ^{n} \mathrm{~s}\right)} \tag{3.4}
\end{equation*}
$$

where $n_{i}$ is the number of elementary fields ( $e_{0} g_{0}$, quarks) in $j_{i^{\circ}}$ Using (3.1)(3.4) and (2.4) we see that the two most important contributions to the process $p p \rightarrow p X$ near $\theta_{a, b}= \pm 90^{\circ}$ for non-wee $x_{T}$ 's arise from $j_{1} j_{2} \rightarrow j_{3} j_{4} \equiv B q \rightarrow B q$
and $q q \rightarrow B \bar{q} \cdot$ Given these rules the contributions of these two subprocesses to the single particle distribution in $\mathrm{pp} \rightarrow \mathrm{pX}$ are

$$
\begin{gather*}
\frac{\mathrm{j}_{1} \mathrm{j}_{2} \rightarrow \mathrm{j}_{3} \mathrm{j}_{4} \text { in }(2.4)}{\mathrm{Bq} \rightarrow \mathrm{~Bq}} \\
\mathrm{qq} \rightarrow \mathrm{~Bq} \tag{3.5}
\end{gather*}
$$

$\underline{E d^{3} \sigma / d^{3} p[p p \rightarrow p x], x_{T} \rightarrow 1}$
$\left(p_{T}\right)^{-12}\left(1-x_{T}\right)^{3}$
$\left(\mathrm{p}_{\mathrm{T}}\right)^{-8}\left(1-\mathrm{x}_{\mathrm{T}}\right)^{7}$
The relative weights of these two contributions are, in general, arbitrary. The faster falloff in $p_{T}$ of the subprocess $B q \rightarrow B q$ can, at moderate energies, be compensated by its slower $\mathrm{x}_{\mathrm{T}}$ falloff as $\mathrm{x}_{\mathrm{T}} \rightarrow 1$. At fixed $\mathrm{x}_{\mathrm{T}}$, however, as we increase the incident energy this subprocess is going to die away compared to $q q \rightarrow \overline{\mathrm{~Bq}}$ as $1 / \mathrm{s}^{2}$ so that the latter process will eventually dominate. When this happens the CIM predicts that the jet opposite the detected proton will carry the quantum numbers of an antiquark! Using (2.3), (2.4), (2.9) and (2.10) we see that we should then find a surplus of antiprotons over protons in the opposite jet.

The relative sizes of the two terms can be determined by looking at the energy dependence of the single particle ratios $(p p \rightarrow p) /(p p \rightarrow \pi)$. The indication is that $q q \rightarrow B \bar{q}$ should be the dominant contribution to (2.4) at ISR energies over a wide range of moderate $\mathrm{x}_{\mathrm{Ta}} \cdot{ }^{10}$ A calculation of the behavior of the ratio (1.3) as a function of energy in the CIM is shown in Fig。3, where it can be compared to the corresponding PJM predictions.

Besides the quantum numbers of the jets, a distinction can be made between the PJM and the CLM in that, in the latter, the detected baryon should not be associated with a large number of extra particles in its jet. This could in principle be recognized by studies on associated multiplicities. However, since the $B$ in (3.5) and (3.6) can be an excited baryon which decays to a proton plus
mesons it is hard to quantify what this distinction might mean at a given energy: it is also difficult to say how fundamental this prediction is in the model, though without it much potential specificity of CIM is lost. ${ }^{16}$ In the PJM at fixed $\mathrm{x}_{\mathrm{T}}$ the associated multiplicities on the same side should eventually grow as $\ln \left(\mathrm{p}_{\mathrm{T}}^{2}\right)$ just as the associated multiplicity in the opposite jet but at energies accessible in the near future this prediction may be impossible to verify because of important phase space effects.

## IV. CONCLUSION AND SUMMARY

The distinction between models for producing large transverse momentum particles has thus far been primarily based on their predictions for single particle distributions. It is important that these distinctions be supplemented by the investigation of other tests of the models. In this paper we describe a rather striking difference in the prediction for the jet-associated baryon number in the two most popular models, the Parton Jet Model (PJM) and the Constituent Interchange Model (CIM). In the PJM the jet opposite a detected particle should always have, on the average, more protons than antiprotons. In the CIM, when the trigger particle is a proton the opposite jet should contain more antiprotons than protons. Our restriction $\theta_{a, b}= \pm 90^{\circ}$ was for convenience and explicitness; the same results as we have found here should be found in other more general configurations. An experiment which could count the number of protons and antiprotons recoiling against a large transverse momentum proton should provide a clean and straightforward way of testing whether the quantum number signature of high transverse momentum production processes is more indicative of the PJM or the CIM.

Other tests of the two models which are important but not so clearcut as that of jet-associated baryon number can also be enumerated. If the PJM is
essentially valid, the composition of a single jet should reflect the ratios of particle production in general and not correlate significantly with the particles in the other jet. In the CIM this is not the case as there are mechanisms which lead to correlations between the quantum numbers of the two jets. The associated multiplicity and phase space occupation are also different in the two models. In the CIM the multiplicity of the jet on the same side of a large transverse momentum particle at fixed $x_{T}$ should be limited, not grow as $\ln \left(p_{T}^{2}\right)$ as it does in the PJM.

We emphasize that it is important to examine the structure in phase space of all the particles in an event which contains a large transverse momentum particle in order to understand something of the underlying mechanism.

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17. Schematic representation of the proposed set-up. Detectors D1 and D2, each of which performs single particle inclusive measurements and is capable of differentiating protons, antiprotons, and mesons, are placed at $90^{\circ}$ to the beam axis in C.M. A proton is detected in D1, and the average number of protons and antiprotons in D2 are counted.
18. Scattering diagram showing the assumed single hard collision of $j_{1}$ and $j_{2}$ within the protons, leading to final state $j_{3}$ and $j_{4}$. In $\operatorname{PJM} j_{1}$ and $j_{2}$ are quarks, and $j_{1} j_{2}=j_{3} j_{4}$; in CIM we have more general combinations possible as discussed in the text.
19. The ratio $R \equiv\left[\frac{\left\langle\mathrm{p}_{2}\right\rangle_{1}-\left\langle\overline{\mathrm{p}}_{2}\right\rangle_{1}}{\left\langle\mathrm{p}_{2}\right\rangle_{1}+\left\langle\overline{\mathrm{p}}_{2}\right\rangle_{1}}\right]$ when $\mathrm{x}_{\mathrm{T} 0} \gtrsim 1 / 2 \mathrm{x}_{\mathrm{Ta}}$ as a function of $\mathrm{x}_{\mathrm{Ta}}$ in the PJM (solid line) and the CIM (dashed line). The PJM calculation assumed gluon exchange and the CIM calculation assumed $q q \rightarrow B \bar{q}$ dominates below $\mathrm{x}_{\mathrm{Ta}} \cong 0.5$.

## $\square$



Fig. 1


Fig. 2


Fig. 3


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