NAL PROPOSAL No. 200

Scientific Spokesman:

C. Rubbia
Department of Physics
Harvard University
Cambridge, Massachusetts 02138

FTS/Off-Net: 617 223-2100
495-1000

Search for High Transverse Momentum Jets with a Magnetic Spectrometer

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D. Cheng, C. Rubbia, L. Sulak and R. Piccioni
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*C. Rubbia is the Scientific Spokesman.

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Introduction and Motivation.

The Bjorken[1] scaling behavior as interpreted by Feynman[2] and Bjorken-Paschos[3] is compatible with the existence of constituent pointlike scattering when leptons collide with hadrons. In pure hadron collisions the possible existence of pointlike or parton scattering behavior was suggested by Berman, Bjorken and Kogut.[4] Recent experiments at the CERN ISR measuring hadron collisions at high transverse momentum show clear deviations from the sharp exponential cut-off observed at small $P_\perp$ and associated with "surface" scattering of hadrons.[5,9] The characteristics of this data that suggest pointlike scattering are[5,6]

1. Power law fall off in $P_\perp$ as $1/P_\perp^8$[6]
2. Approximate scaling behavior in the variable[6,7] $x' = \sqrt{s}/P_\perp$ (i.e. $\frac{Ed^3\sigma}{dp^3} \sim \frac{1}{s^2}(\sqrt{s}/P_\perp)^8$)

These and other data suggest that the partons scatter via vector gluon exchange in a manner similar to the scattering of electrons via photon exchange.[4]

In this model the primary parton scattering behavior follows a $1/P_\perp^4$ law, and the hadron form factors introduce an additional $1/P_\perp^4$ behavior. If the individual partons could be detected in the scattering process the $P_\perp$ dependence could be $\sim 1/P_\perp^4$, therefore, in strong analogy to Coulomb scattering ($\sim 1/Q^4$).

As pointed out by Bjorken and Feynman many times, an unadvoidable consequence of the parton model is the existence of hadron jets associated with the parton momentum vector after the scattering process. The jet defines the angle and momentum of the parton. Unfortunately, in pure hadron collisions it was not possible to reliably directly estimate the cross section for such jets and even now the multiplicity and angular spread can only be guessed. However, with the advent of recent ISR measurements and the resulting phenomenological analyses, it is possible to crudely estimate the cross section for such jet production to the point of planning an experiment to detect them and measure their properties.

The observation and study of such jets coupled with a test of the scaling law (assuming that $1/P^4_{\perp JET}$ holds for the jet production)[11]

$$\frac{Ed\sigma}{d^3 P_{JET}} \sim \frac{1}{s^2}\left(\frac{\sqrt{s}}{P_{\perp JET}}\right)^4 \propto (\text{const})\left(\frac{1}{P^4_{\perp JET}}\right)$$

could provide dramatic evidence for the pointlike constituent of hadrons.

In the simple parton-parton scattering picture with gluon exchange it would be expected that jets occur on both sides of the incident beam direction in a coplanar configuration and collinear in the center of mass of the collision. The observation of such "correlated" jets would add further evidence for the constituent scattering picture.

Lacking a reliable estimate of the expected properties of jets, an experimental detector must be sufficiently broad to be insensitive to these properties. In addition, the jet would be "detected" by the observation of a large localized energy flow from the collision with a very small cross section. Clearly, this requires that the total energy must be approximately measured on-line. We have considered two techniques to "trigger" on a large directional energy release (1) by hadron calorimeters and (2) a combination proportional chamber - magnetic spectrometer-lead glass counter arrangement. Our experience with E120 suggests that operating an appropriate large solid angle hadron calorimeter at C_0 would be marginal because of the large accidental rates.[8,10] Option 2 is much preferable as explained below, but requires technical developments on the forefront of particle physics technology. However, we believe that a preliminary version of option 2 can be carried out by a simple modification of the spectrometer being used for E184. A nice fallout from the use of the magnetic spectrometer is the possibility of measuring the mean charge carried by the jet.

Rate Estimates for Single Jet Production

We assume that the high $P_{\perp}$ events observed at the ISR in the process[5]

$$p + p \rightarrow \pi^{o} + (\text{all}) \qquad (1)$$

are examples of jets with the jet decaying into one particle. Another experiment at the ISR observes that charged particles are more copiously produced suggesting that[9]

$$\frac{\text{Branching Ratio of Jet} \rightarrow \pi^{o}}{\text{Branching Ratio of Jet} \rightarrow (\text{protons} + \text{kaons})} \lesssim \frac{1}{4}$$

Furthermore, for high energy jets we may guess that a much larger multiplicity than 1 would be the average case, hence we conservatively guess

$$\frac{\text{Branching Ratio of Jet} \rightarrow \text{single particle}}{\text{Branching Ratio of Jet} \rightarrow \text{multiparticles}} < \frac{1}{3}$$

for $P_{JET} \sim 70$ GeV produced at 100 mr in the lab. Note that the average hadron multiplicity of a diffracted proton jet in pp collisions with 70 GeV of energy is in the range of 3-6. Combining these factors results in a net suppression of the π^{o} decay of the jet of ~ 12. Assuming a solid angle of $\sim 10^{-4}$ and taking the cross section for process 1 measured at the ISR at $P_{\perp} \sim 7$ GeV/c[5] and for 10^{9} interactions/sec with the rotating fiber internal target, the rate of jet production is ~ 100 jets/hour.

Assuming a detection efficiency of 50% gives 50 jets/hour with $P_{\perp JET} > 7$ GeV/c. This is at best only an order of magnitude guess but indicates that it should be possible to observe such phenomena at the internal target laboratory and to measure the $\sqrt{s}$ dependence of the production cross section with a modest number of running hours.

In this estimate we have assumed that the magnetic spectrometer for E184 is opened up to an acceptance of 10 cm x 10 cm at 5 meters from the target and that the Fe magnets are removed. The angular acceptance of the spectrometer is ± 10 mr. Figure 1 shows a schematic layout of this spectrometer as it is used for E184. Our experience with E120 suggests that such a spectrometer will only be useful if four conditions are satisfied:

1. The timing resolution of the spectrometer must be good enough to separate individual machine bunches (one every 20 ns).
2. The direction resolution must be adequate to accept only events "pointing back" to the target.
3. An on-line computation of the particle momentum must be accomplished to allow rejection of the enormous number of low energy particles present. Multiparticle events must be selected on-line.
4. An association of individual tracks in multiparticle processes where the particles are clustered over a small area and all having approximately the same angles from the target, must be made.

The magnetic spectrometer for E184 has these properties and utilizes the first three for E184. The good time and space resolution for this spectrometer is accomplished by using proportional chambers with 1 mm wire spacing and 10 μ wires. The fast decision making is accomplished by using a PDP 1147 computer.

Technical Innovations Required to Detect Two Jets and to Study Angular Correlations at C_0

In summary, it is seen that the detection of jets likely requires extremely good time and spacial direction resolution as well as a relatively large solid angle spectrometer that is capable of measuring the total energy carried by charged particles. The energy carried by photons and a fraction of the energy carried by neutrons can be detected by placing the Pb glass spectrometer for E120 directly behind the E184 spectrometer. In order to detect an accompanying jet the uncertainty in the expected direction of the jet in the laboratory system provides stiff requirements on the kind of spectrometer that can be used. A subgroup of this group (the Harvard group) has developed a drift chamber system that provides extremely good resolution (70 μ) for a relatively coarse wire spacing. The time resolution is also extremely good. We believe that this principle can be used with a radial wire arrangement to provide the type of second arm spectrometer required to observe a second "correlated" jet. We are also considering the application of a modest, available magnet with an appropriately shielded tube for the machine vacuum pipe in conjunction with this spectrometer. We expect that within one month a decision on the "correct" approach can be made and an addendum to this proposal will be submitted.

Summary and Specific Proposal

The detection of a single high transverse momentum jet at the C_0 target appears to be feasible from the standpoint of rate. A high resolution magnetic spectrometer with good time resolution will likely be needed. The E184 spectrometer with some minor changes (eg. opening the magnet from 1" to 4") can be used. It is probably crucial that high $P_\perp$ multiparticle events be selected on line in order to reduce the background and computer dead time. We request that a short period of time be allotted after the end of the E184 experiment for this jet search. The addition of a second arm to the present equipment is being studied and likely requires technical advances due to the large solid angle it would subtend and the enormous instantaneous rates near the internal target.

There is little doubt that the observation of parton initiated jets would be of considerable importance to the future of our understanding of hadrons and for this reason we feel that such an experiment should be carried out at the earliest possible time at NAL.

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4. S. M. Berman, J. D. Bjorken and J. B. Kogut, Phys. Rev. D4, 3388 (1971).

5. CERN - Colubmia - Rockefeller Collaboration contribution to the NAL Chicago Conference (Sept. 1972).

6. D. Cline, F. Halzen and M. Waldrop, "Hadron Collisions at High Transverse Momentum", submitted to Nuclear Physics (1972).

7. S. Brodsky, private communication.

8. The Harvard-Wisconsin photon survey experiment. In this experiment the instantaneous rate in a well shielded Pb glass counter situated approximately 60 feet from the target at 15 mr with respect to the beam direction when charged particles are incident was found to be on the order of megacycles. In a background study for E184 carried out at 40 feet from the target and 50 mr with respect to the beam direction higher rates were observed in a 2 cm x 2 cm area scintillation counter telescope. Scaling these rates up to 30 cm x 30 cm area calorimeter situated at 5-10 meters from the target indicates that possibly unacceptably large accidental rates would be observed. Such a calorimeter would only have a sensitive surface area of only ∿ 10 cm x 10 cm, with one collision length around the edge being necessary for good energy resolution in the calorimeter.

9. Banner et al., presented at the NAL Conference.

10. A rudimentary background study for the observation of low multiplicity jets is being carried out in conjunction with #120 using the lead

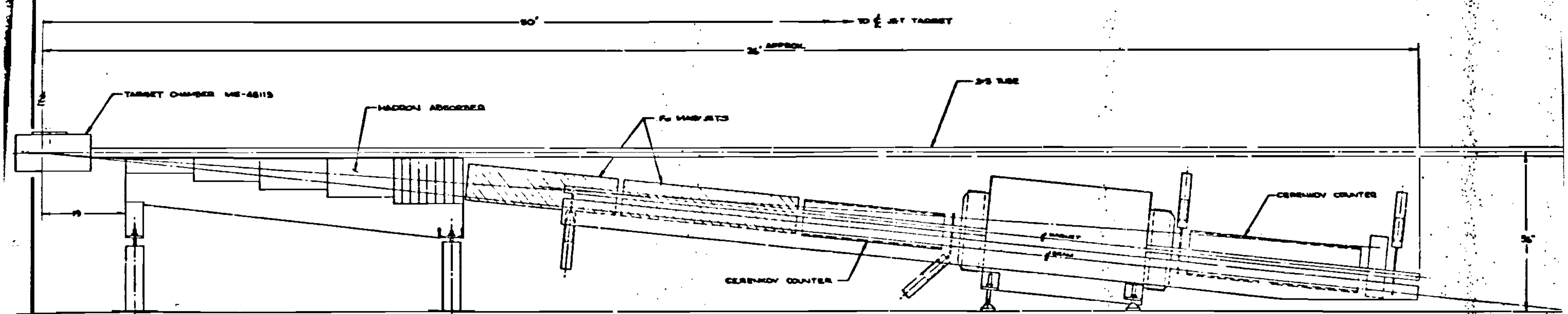
glass counter (two collision lengths long) as a mini-calorimeter. This measurement falls out of the photon background study. However, the angular acceptance of the system is only ± 1 mr and is likely inadequate for the observation of parton jets. In this study the accidental rate in the lead glass counter is observed to be $\geq$ 20%.

11. A more realistic estimate of the $P_{\perp JET}$ distribution would likely result in a $1/P^n_{\perp JET}$ fall off where $8 > n \gtrsim 4$.

FIGURE CAPTIONS

Fig. 1 Schematic of E184 spectrometer. In order to search for jets the solid iron magnets would be removed and the hadron absorber would be opened fully. The gas cherenkov counter would be kept in place and a Pb glass detector would be placed directly behind the last scintillation counter.

FIG 1



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