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RESULTS FROM HIGH P_T STUDIES WITH A TWO-ARM CALORIMETER SYSTEM

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ABSTRACT: We have measured jets and single particles with a two arm calorimeter array and a liquid hydrogen target. We give results on

(1) jet ("core") structure

(2) apparent jet cross sections vs. p_T at 130, 200, 400 GeV, with beams of π^+-and-protons at 130 and 200, and protons at 400

(3) p_T and angle correlations for both single arm and double arm triggers

(4) the $\sigma_{pp}/\sigma_{\pi p}$ production ratio for high p_T events, single arm and double arm

(5) an approximate structure function for partons in the pion

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1. Introduction.

This paper is an update and a supplement to several reports on results from experiment E-395 carried out at Fermilab[1-4]. Those reports are included herewith and should be read in conjunction with the present report.

In this report, we give some further results, and also note briefly some of the most important results described in references 1 through 4.

2. Jet structure.

By a jet in hadron-hadron collisions we shall mean a multi-particle group with a high value of $\Delta p_T/\Delta\Omega$[1,5]. Ideally, a jet would include several particles, each of unusually high p_T, clustered sufficiently closely in angle to be (1) very clearly distinct from any other high p_T particles or groups and (2) distinctly non-random in angular concentration. In reference (1), and also in an earlier calorimeter triggered experiment by Bromberg et al[6], clusters are reported with up to 40% to 50% of $\sqrt{s}/2$ carried into 1 steradian or so by a multi-particle group. Not only does such a concentration show the large $\Delta p_T/\Delta\Omega$ expected from jet models; with such a large fraction of $\sqrt{s}/2$ concentrated in 1 sr there clearly can not be many other multi-particle concentrations with such high $\Delta p_T/\Delta\Omega$ present in that event. These concentrations thus have characteristics corresponding to those which have been predicted for jets. Moreover, a considerable amount of information on two-particle correlations and multi-particle correlations and multi-particle correlations has been reported from previous experiments[7,8,9]. We report here some further information on the concentrated character of high p_T clusters observed with a calorimeter trigger.

In Figure 1 we show a front view of the "right" arm of our 2-arm calorimeter array. (For a more detailed description of the apparatus, see

reference (1).) This arm consists of a 5 x 5 array of calorimeter segments. A typical trigger, a "right arm" trigger, selects events for recording when the sum of the p_T magnitudes in each segment exceeds an adjustable threshold.

This right arm was operated typically at such a distance from the target as to cover approximately 2 steradians, to the calorimeter edges. We now study the character of events selected in software as having deposited large p_T in the central 3 x 3 segments of this array -- that is, in a central "inner" region of 0.83 sr, surrounded by an "outer" region of 1.3 steradian. Note that in making this selection we impose no conditions on the p_T present in the outer 1.3 sr.

The results are shown in Figure 2, for the selection PT(inner) = 3.8 to 4.3 GeV/c. We see that for this case the average value of PT(inner) is 4.0 GeV/c in 0.83 sr, and the average value of PT(outer) is 0.8 GeV/c in 1.3 sr. Thus in effect when we "trigger" on 4 GeV/c events with a 0.8 sr detector we find that the events consist of quite concentrated clusters, with only an additional 0.8 GeV/c in the outer region, a region with $1\frac{1}{2}$ times as much solid angle as the inner region. In fact, of the 0.8 GeV/c average registered in the outer segments, we estimate that about half is "spillover" from the more concentrated $\Delta p_T/\Delta\Omega$ in the inner region. Thus we estimate the net value of $\Delta p_T/\Delta\Omega$ in the outer segments to be about 15 times smaller than in the inner group.

A further important feature of these events is the multiplicity of particles carrying the inner and outer p_T. Independent study shows that the 4 GeV/c inner p_T is carried by about $2\frac{1}{2}$ particles, while in the outer region the 0.8 GeV/c (estimated 0.4 GeV/c net) is carried on the average by .7 particles; 50 % of the time there are no particles in the outer region. (See Figure 2.)

While at first sight it may seem surprising that when one selects the inner region, 0.8 sr, as the effective trigger region one finds rather little p_T outside of that region, this effect can in fact be predicted[4], on the basis of a rapidity plateau type of jet model[3,10], combined with the steep p_T spectrum observed for jets. Using such a model, one predicts[11]

that for a detector solid angle of the order of 1 steradian or more, the dominant contribution to jets of a given measured p_T comes from those jets, of only slightly higher average p_T, which happen to fragment very "compactly", with no wide angle fragments.

The high value of $\Delta p_T/\Delta\Omega$ in the inner region together with the 15 times smaller value in the surrounding region is thus a feature in agreement with predictions of the jet models of references 3, 5, and 10.

A further important feature of the data is the multiplicity found for the high p_T "core", namely not one particle, and not a multiplicity at all approaching that expected for a spray of "soft" particles, of say $\sim \frac{1}{3}$ GeV/c p_T each, but instead about $2\frac{1}{2}$ particles. Thus the core consists of a few particles, with the average p_T per particle being unusually high compared to the average p_T per particle in low-p_T events.

This multiplicity, of $\sim 2\frac{1}{2}$ particles carrying 4 GeV/c into a $\Delta\Omega$ of $\sim$0.8 steradian, also gives a rough estimate of the internal transverse momentum of individual members of the cluster with respect to the "jet" axis. With each of the $2\frac{1}{2}$ particles carrying an average p_T of ~ 1.6 GeV/c, and with all $2\frac{1}{2}$ confined within an angular region of $\sim 25°$ radius, the internal transverse momentum with respect to the axis evidently has an average value per particle less than $\sim \frac{3}{4}$ GeV/c. More detailed studies of a small sample of events show that in the typical case the individual transverse momentum from the jet axis averages about 0.3 to 0.4 GeV/c (reference 1, section 6).

In summary, we have observed that the typical high-p_T event delivering ~ 4 GeV/c into a $\Delta\Omega$ of ~ 0.8 steradian has a "core"-like structure, with a cluster of several particles, each of unusually high p_T (on the average), in relatively close angular proximity, and with that core surrounded by a region of much lower p_T per steradian. Finally, we note that if we use a detector of <u>larger</u> $\Delta\Omega$, we find evidence of a central region with roughly constant $d\sigma/d\Omega$; for $\Delta\Omega$ less than about one steradian no such central plateau region is evident. (See reference 1, Figure 9, in this connection.)

3. Jet containment.

In the jet models of references 3, 5 and 10, one must expect that the low-p_T fragments of a jet could never be unambiguously associated with the jet. Moreover, with a detector of finite solid angle, one must expect that in general some fragments will miss the detector. The early estimates of the magnitude of these effects indicated that for jets of p_T less than perhaps 4 or 5 GeV/c, the missing fragments might seriously affect our knowledge of the direction and magnitude of the jet momentum[3], and might therefore seriously hamper our ability to use the observed jets to study parton-parton scattering[12].

As described in section 2, however, we find that for a detector $\Delta\Omega$ of about 1 steradian or more, the dominant contribution to jets of a given apparent p_T comes in fact from jets with quite little missing momentum. Quantitative estimates[11] indicate that for a large percentage of the jets we detect in this experiment, 50% or more, the missing fragments carry a total of less than 0.2 or 0.3 GeV/c. A jet of apparent p_T 3 GeV/c, for example, with only 0.3 GeV/c missing, has an angle within about 0.1 radian of the angle of the true jet, and has a total measured jet momentum and energy within 0.3 GeV of the values for the "true" jet. These figures for the differences between measured and "true" jet vectors are comparable to those introduced by the angle and energy resolution of the apparatus, and indicate that we can expect to study jet-jet momentum and angle correlations with reasonably good resolution even for jet momenta as low as 3 GeV/c or so. We note however that the magnitude of the jet cross section, as measured using a relatively small central fiducial region in a detector of total solid angle about 1½ sr (roughly like our right calorimeter arm), must be expected to be several times smaller than the "true" cross section.

4. Two-arm jets, momentum and angular correlations, and evidence for parton-parton scattering.

We have studied the momentum and angular correlations of two-jet events, both with one-arm triggers and with a two-arm trigger[1,2]. We find the

following major results.

(1) The p_T magnitudes in the two arms show a spontaneous tendency to roughly balance. This behavior is particularly clear with a two-arm trigger[1,2,3].

(2) The events taken with a two-arm trigger show evidence of coplanarity[13].

(3) Incident pions produce correlated two-arm high-p_T events at more forward angles than do protons[2].

From these results we conclude that the two-arm jet data give strong evidence for hard scattering of hadron constituents, rather than simply for a phase-space type of momentum conservation effect for example. Result 3, together with the other results, indicates that the constituents of the pion have higher average momentum than those of the proton, as is to be expected if scatterings of valence quarks contribute in a major way to the events observed.

5. Structure function of the pion.

With the evidence reported above indicating that jet-pair events correspond to parton-parton scattering, we have analyzed data taken with incident π^+ and proton beams, using a parton scattering model, and have obtained an effective structure function for the pion in the x range from 0.25 to 0.55[4]. The analysis gives an approximate structure function for quarks plus anti-quarks. The results are in quite close agreement with the values given by previous theoretical models of Farrar[14] and of Field and Feynman[10].

Figure Captions

Figure 1. Front view of the right arm of the calorimeter, as operated 8 meters from the target at 400 GeV. CM angular coverage is shown.

Figure 2. P_T(inner) and P_T(outer), for events selected to give 3.8 to 4.3 GeV/c "P_T(inner)" in the central 9 segments, in 400 GeV pp collisions. P_T(outer) is the P_T found in the outer 16 segments when this cut is made on P_T(inner). Also shown are the "multiplicities", N_{SEG}, the number of segments registering 0.3 GeV/c or more.

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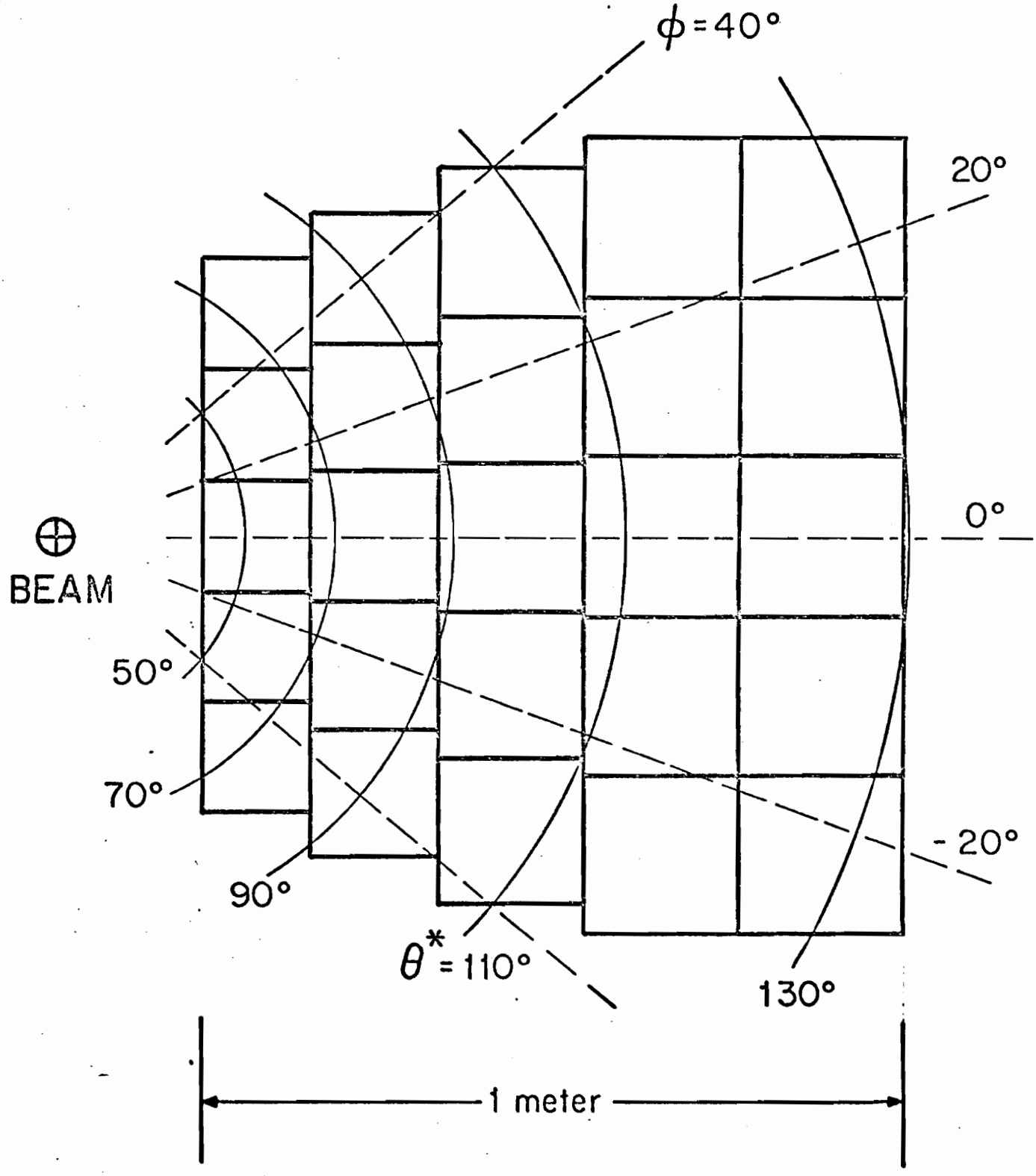
FIG. 1



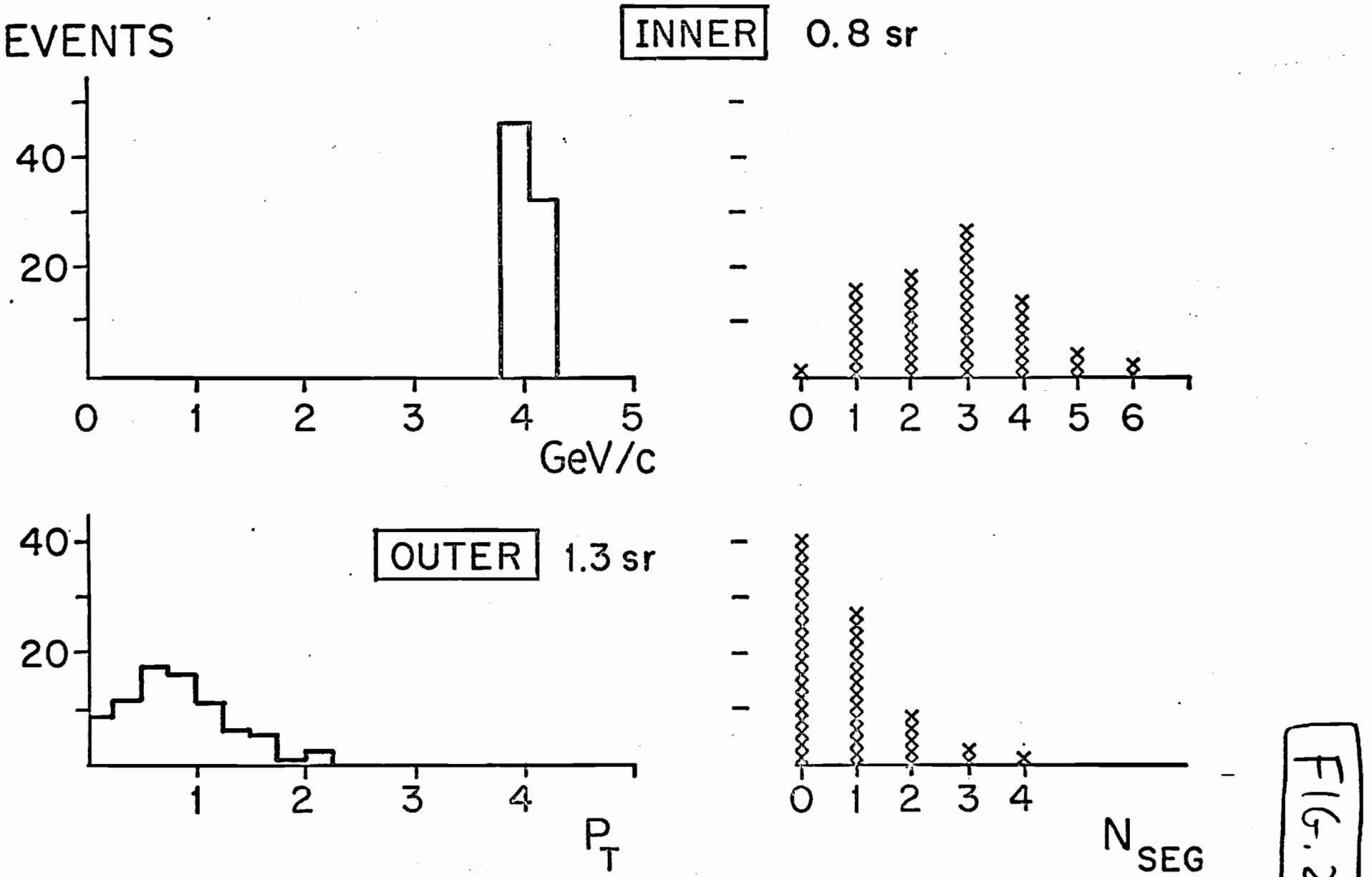

EVENTS
INNER
0.8 sr
40
20
0
1
2
3
4
5
GeV/c
0
1
2
3
4
5
6
OUTER
1.3 sr
40
20
1
2
3
4
P_T
0
1
2
3
4
N_{SEG}

FIG. 2