NAL Proposal No. 395

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CALORIMETER-ARRAY STUDY OF HIGH P_T EVENTS

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SUMMARY

An experiment is proposed to study high p_T events with a calorimeter array of advanced design and of intermediate size relative to E-246. The objectives include detailed study of single- and multiple-particle high-p_T events with an individually segmented detector. Major specific objectives are the measurement of:

(1) frequency of high-p_T groups relative to high-p_T single-particle events

(2) total-p_T dependence for such groups

(3) some angular correlation information in a two-arm system.

(These objectives are discussed in more detail in the E-246 Proposal.) The detector will consist of a hadron calorimeter on one side of the beam--27 elements of 0.06 to 0.1 sr each--, and a "π^o" hodoscope of 20 elements on the other side. Emphasis is placed, in the detector, on obtaining the cleanest possible identification of very rare events, to a level of one event in 10^9 to 10^{10} beam tracks. With a beam of 200 GeV/c p/π, 10^6 per pulse, a substantial number of events can be obtained out to at least 5 GeV/c p_T.

Running time requested is 450 hours total, consisting of 150 hours testing and 300 hours data taking. Data taking is planned as 200 hours at 200 GeV/c and 100 hours at 300 GeV/c.

OUTLINE

1. Introduction
2. Comparison with E-236 and E-260
3. Results of our module tests
4. Detector
5. Running Time and Rates
6. Costs
7. Manpower

I. Introduction

In high p_T hadron physics, several prime questions promise to be answered only by the use of a segmented calorimeter detector. These questions include the following:

(1) What is the frequency of high-p_T groups relative to single-particle high p_T events?

(2) What is the total-p_T spectrum of such groups, if they exist?

(3) What is the angular correlation, in a two-arm system, between high-p_T singles and/or groups on opposite sides of the beam?

These questions are being tackled by E-236 and E-260, and are to be studied in a more comprehensive way in our own experiment E-246.

It appears that E-246 will still be delayed for some time, perhaps 2 years, because of delays in building the beam and the experimental area. We propose here an intermediate experiment, to come before E-246, and to be carried out in the Meson Lab about a year from now. Recent tests of a few modules of our design, in M-2, gave results which on the whole were very successful. We believe our design will give much cleaner information on high-p_T events than E-236 and E-260, and we believe the physics importance of understanding high-p_T processes is so great that their study with a fully segmented calorimeter should be carried out as soon as possible.

2. Comparison with E-236 and E-260

There are two major differences between the calorimeter design of this experiment (and E-246) and the designs of E-236 and E-260.

(1) In our design each segment is small in both lateral dimensions--in E-236 and E-260 the segments are strips, relatively long in one direction.

(2) In our design we can readily obtain much better resolution for the lower particle energies involved in a wide-coverage high-p_T experiment (4 to 20 GeV), than is feasible for the designs of E-236 and E-260.

In addition, our design has other features which are of some advantage--the system is segmented several-fold in depth, and the system is modular, so can be readily augmented or re-arranged.

The above advantages promise to be important in obtaining much cleaner and more extensive information on high-p_T events. These are very rare events (one in 10^6 to one in 10^{10} beam tracks). There will probably be many ways in which spurious effects can simulate and confuse the true high-p_T events, and one can expect that it will be important to have very detailed information on each event, with best possible energy resolution so as to minimize problems in unfolding the true p_T distributions. Brief further

remarks may be in order on the importance of points (1) and (2) above.

On (1), the relative disadvantages of strip segments: With strip segments, the p_T threshold becomes quite smeared, because the actual threshold for a segment must be set in terms of energy deposited, and the p_T value of a given energy depends on angle from the beam. This smearing of the p_T threshold appreciably hampers the determination of the total-p_T dependence of events.

In E-236 crossed sampling strips are used. Although this improves somewhat the information on individual events it still leaves multi-particle events ambiguous. More important, the use of crossed strips worsens the energy resolution for lower particle energies.

On (2), the importance of good energy resolution for lower particle energies: These lower energies, 4 to 20 GeV, are of dominating importance for the backward CM hemisphere (lab angles of 0.1 to 0.3 radians). In this energy range calorimeters of the design of E-236 and E-260 have regularly given longish tails on the pulse height spectrum, and these can make it nearly impossible to obtain clean information on the p_T spectrum. In our own design, we use a much larger "sampling fraction", made economically practical by the use of liquid scintillators. We have shown that this gives considerably improved resolution. In addition, our modular construction also permits us to try using uranium plates

for the lower energies (i.e., larger angles), following the dramatic improvement in resolution shown by Willis with this change.

It would be inappropriate to spell out these points in more detail here. We would be glad, however, to supply further details if the PAC wishes them.

3. Results of our module tests

A. Shower size and energy resolution.

We tested a set of 4 modules, one behind the other, at energies of 20 to 200 GeV. The geometry is shown in Fig. 1. The modules are 2 ft. x 2 ft. in area; each module contains 4 optically divided segments each 1 foot square. More details and a description of early results are given in a report to the Calorimeter Workshop (Fermilab, May 9-10).

With this system, reading out 16 PM's, we measured many details of shower size and obtained considerable information on the factors affecting energy resolution. Preliminary results include the following:

(1) With the PM gains balanced only in a preliminary way, we obtain about 30% FWHM ($\sigma \approx 13\%$) for 100 GeV/c π^-, with no significant high energy tail to the extent of 1 count in 10,000.

(2) We see correlations in pulse height and in energy deposition pattern (in depth, in length of shower, and in transverse character of shower). Our own preliminary studies,

and those of other workers, indicate that resolution can be improved by using information on the detailed energy deposition pattern, particulary longitudinal.

(3) Shower size, edge effects, and uniformity of response, are indicated in Fig. 2 for two examples. Edge effects are appreciable in this array. Detailed consideration indicates that better energy resolution would be obtained in a larger array.

(4) At 40 GeV the resolution is about 37% FWHM. Preliminary study indicates that this is broadened by escape from the sides. A crude empirical correction for the amount of energy sent sideways (heavier weighting of outer segments) lowers the FWHM to 30%, but is not a usable procedure for multi-particle events. However, we expect that a larger array, with better side-containment, would give substantially better energy resolution.

B. <u>High p_T trigger-background test.</u>

We operated for about 10 hours with the array of Fig. 1 located off the beam line, aiming at a 1-inch thick Be target. We also had a single module on the other side of the beam, with Pb plates (∿18 r.l.), equipped as a π^0 trigger. The purpose of this run was to see if we could operate a calorimeter in a high-p_T trigger mode quite close to the beam, without serious background problems.

We used calorimeter distances as close as 6 inches from the beam line for the nearest point of the calorimeter; the array was approximately 15 feet downstream from the target. Target-IN/target-OUT measurements, for all calorimeter distances used, showed clean signals coming from the target, up to a p_T value where the counting rate disappeared. Target-OUT rates were consistantly about 45% of the target-IN rates at each p_T, and were consistent with the rate expected from several scintillation counters just ahead of the Be target.

We used fiducial scintillators to define entrance apertures so as to measure cross sections both for charged particles (array of Fig. 1) and for π^o's (separate π^o module on the other side). Only a preliminary analysis has been made so far, but it indicates that clean high-p_T triggering can be obtained, in the geometry used, at least for π^o's as close as 8 inches to the beam and charged particles as close as 18 inches to the beam. (Charged particle measurements for closer distances were complicated by a PM problem we encountered, described below.) Representative results are shown in Fig. 3, for a fiducial region of $\sim$ 0.07 sr CM centered near a lab angle of 0.11 radian. The beam was 100 GeV/c, approximately half protons, half π^+. Beam flux was about 10^6 per burst, the last data point (at p_T = 2.5 GeV/c) corresponds to 0.5 counts/10^6 beam, and represents about 20 minutes of running.

It can be seen that the calorimeter trigger, at least for this run, in the vicinity of 90° CM, is quite clean,

reproduces the measurements of Cronin et al. reasonably closely[beam momentum and composition are somewhat different], permits triggering to a level below 1 in 10^7 beam tracks without difficulty, and with $\Delta\Omega$ of 0.07 sr CM gives reasonable statistics out to 2 or 2 1/2 GeV p_T in a fraction of an hour at a beam flux of 10^6.

C. Spurious PM signal.

We discovered one substantial problem, in our test. The photomultipliers are contained inside the modules. It is, therefore, easily possible for the core of a shower to pass through the PM. We found that the shower core, for a 50-100 GeV entering particle, is extremely tight, and typically carries of the order of 50 particles, and 1/3 to 1/2 the total energy, in a region less than 1 inch in diameter (see Fig. 2). When this concentrated core passes through the glass face-plate or side wall of a PM, very large spurious signals can result, as large as 1000 to 2000 photo-electrons for a 50 GeV particle.

We carried out detailed studies of this PM effect, using a small (1/4" square) and almost pure μ beam. We studied several different types of photomultipliers, in many different orientations. In the most unfavorable direction, with a particle passing edge-wise through the end window, a single μ gives about 200 photo-electrons for a 2" tube. In our modules we had mounted the tubes facing upward, so shower particles could in fact traverse the tube in this most unfavorable direction.

We have determined that this large spurious signal is due to Cerenkov light in the glass of the PM. For example, a muon traversing the end-window of a 4517 perpendicularly, from inside the tube to outside, gives about 10 photo-electrons; but when the end window is sprayed with black paint the signal drops to less than 1 photo-electron average.

There are several ways of overcoming this spurious signal. The most promising is to build a new phototube, with a very thin cathode-bearing transparent layer mounted just inside the end window. Running the tube "tail-on" to the showers, no Cerenkov light from the end window will then give a spurious signal, and yet light from an external source can still enter the tube normally. Two samples of such a tube, using otherwise normal 6342A/V1 components, are being built for us, and are scheduled to be delievered in July for testing. We expect this design to remove the PM problem. A production price of $175 has been quoted to us for lots of 100.

Because of the very concentrated shower cores which occure, any unusually sensitive "hot spot" in the calorimeter can give falsely high p_T signals. Part of our present light pipe arrangement, namely light pipes bringing signals from scintillator layers downstream of the PM, gives a satisfactorily small signal in this respect, but part, light pipes sampling scintillator layers upstream of the PM, gives too big a signal, which will not average out. We will re-arrange the

PM locations in our modules, and may have to sample with 6 PM's over the full depth of the calorimeter instead of the present 4, for each "segment". This is slightly more expensive, but has incidental advantages in providing cleaner information and better energy resolution.

4. Detector

Figure 4 shows the detector layout. The detector consists of a 27-segment hadron calorimeter, covering about 1 1/2 sr in the CM (or more if the target is moved closer to the calorimeter), and a 20-segment π^0 calorimeter on the other side. This array will make possible the detailed study of items (1) and (2) in Section 1 above, and will give some information on item 3.

We will investigate the use of uranium in the outer segments for possible major improvement in energy resolution for lower energy particles.

5. Running Time and Rates

We request 450 hours of running time, in M2 or M1. Calorimeter modules and tracking hodoscopes will be fully tested in M5 prior to installation in M2 or M1. We estimate that 150 hours will be used to check out the fully assembled system, and 300 hours for data taking. Tentatively, 200 hours will be used for 200 GeV running, p and π^+ both present in the beam, and tagged, and 100 hours for 300 GeV running.

Rates can be estimated directly from our measured rates in the test, quoted in Section 3. We would use a 30 cm hydrogen target (see explanation in E-246 proposal), and the trigger rate

per beam particle and per unit $\Delta\Omega$, for a given p_T, would thus be about the same as measured above--slightly more, because we would use a higher beam energy.

To what p_T could we then go? In the test, for $\Delta\Omega^* = 0.07$ sr, we measured about 100 events per hour above $p_T = 2.5$ GeV/c. Here we propose to run 200 hrs., and with about 20 times the solid angle. We thus would have 4000 times the sensitivity of a one-hour run in the test, assuming a beam flux of $\sim 10^6$, and could thus get $\sim$ 100 single-particle high-p_T events above $p_T \gtrsim 5$ GeV/c. The number of multiple-particle events at that p_T we do not know--but it would be of the greatest interest to find out.

6. Costs

To build the system shown in Fig. 4 will require about $115K for construction, with the following breakdown:

photomultipliers (200)	$ 35K
uranium development (12 segments)	25
other calorimeter construction	40
electronics	15
	$ 115K

Equipment required from PREP will amount to approximately $130K. (Approximately $70K was used in our recent test; the increase is principally in ADC's, TDC's, and other CAMAC units.) We have our own PDP-11 system except for a disc and a CRT system, which we will require from FNAL.

7. Manpower

Present manpower consists of: A. Erwin,(1) E. Harvey,(1)

A. Kanofsky,[2] W. Kononenko,[3] G. Lazo,[2] R. Loveless,[1] W. Selove,[3] F. Turkot,[4] B. Yost,[3] and D. Winn.[1]

((1): University of Wisconsin; (2): Lehigh University; (3): University of Pennsylvania; (4): FNAL.) We expect to have 2 to 3 additional Ph.D's working full time on this experiment.

FIGURES

Fig. 1 4-box test array.

Fig. 2 Uniformity and shower size results.

(a) 20 GeV/c π^-;

(b) and (c): 200 GeV/c π^-.

Fig. 3 Measured p_T distribution.

Fig. 4 Experimental layout.

(a) top view; (b) front view.

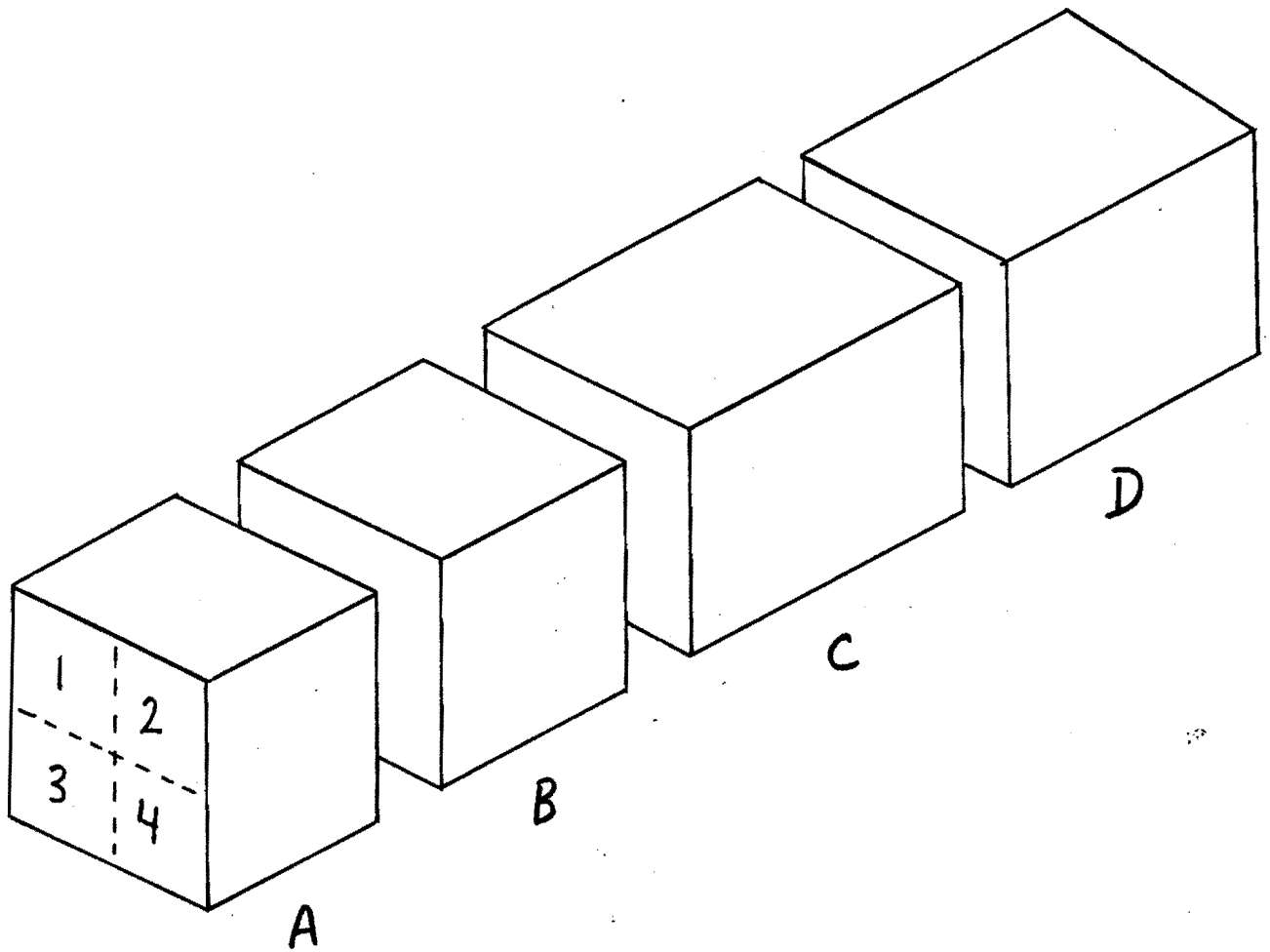

FIG. 1

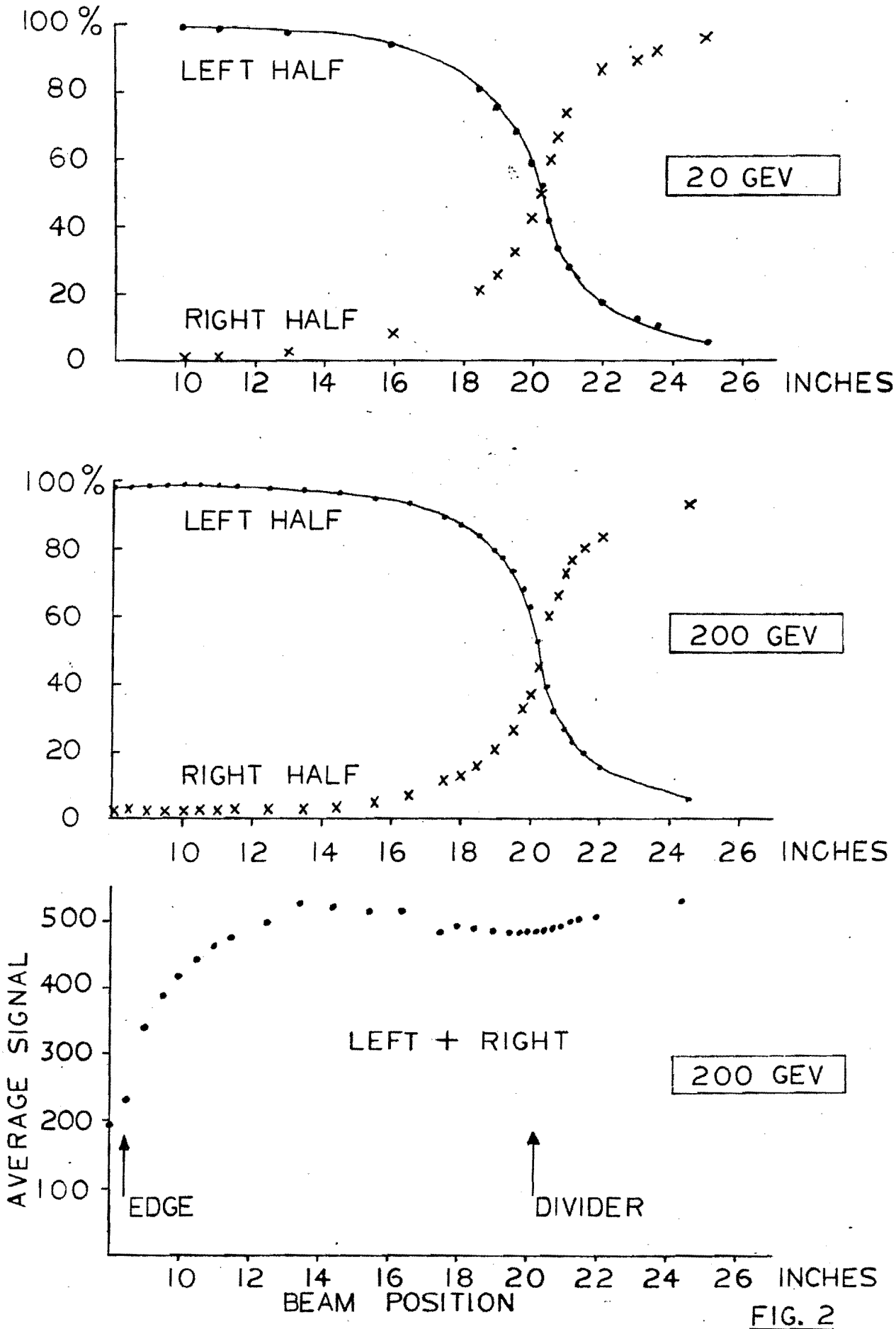
100 %
80
60
40
20
0
LEFT HALF
RIGHT HALF
20 GEV
10 12 14 16 18 20 22 24 26 INCHES
100 %
80
60
40
20
0
LEFT HALF
RIGHT HALF
200 GEV
10 12 14 16 18 20 22 24 26 INCHES
500
400
300
200
100
AVERAGE SIGNAL
LEFT + RIGHT
200 GEV
EDGE
DIVIDER
10 12 14 16 18 20 22 24 26 INCHES
BEAM POSITION

FIG. 2

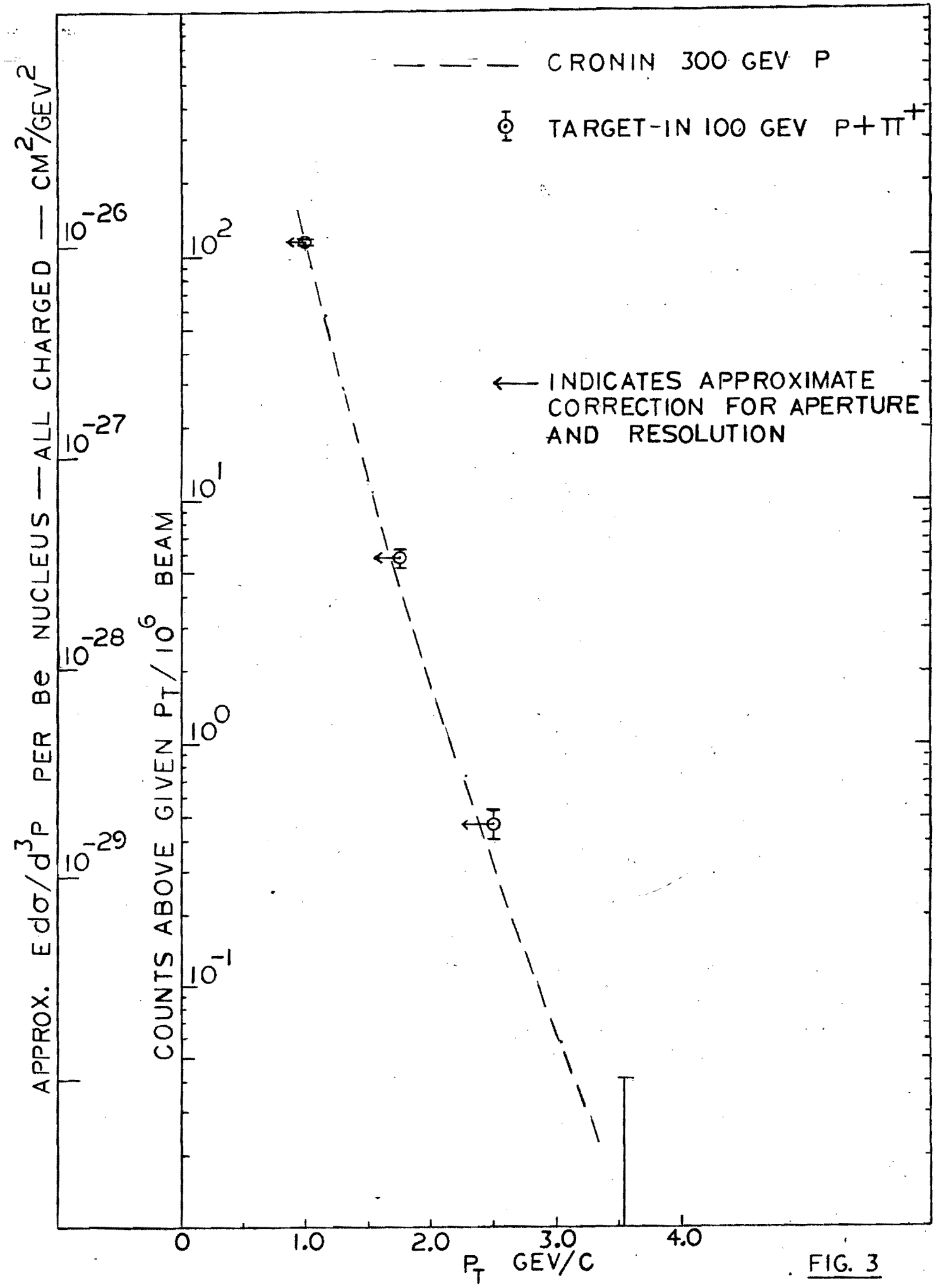
CRONIN 300 GEV P
TARGET-IN 100 GEV P+π+
INDICATES APPROXIMATE CORRECTION FOR APERTURE AND RESOLUTION
APPROX. E dσ/d³P PER Be NUCLEUS — ALL CHARGED — CM²/GEV²
COUNTS ABOVE GIVEN PT/10⁶ BEAM
10⁻²⁶
10⁻²⁷
10⁻²⁸
10⁻²⁹
10²
10¹
10⁰
10⁻¹
0
1.0
2.0
3.0
4.0
PT GEV/C

FIG. 3

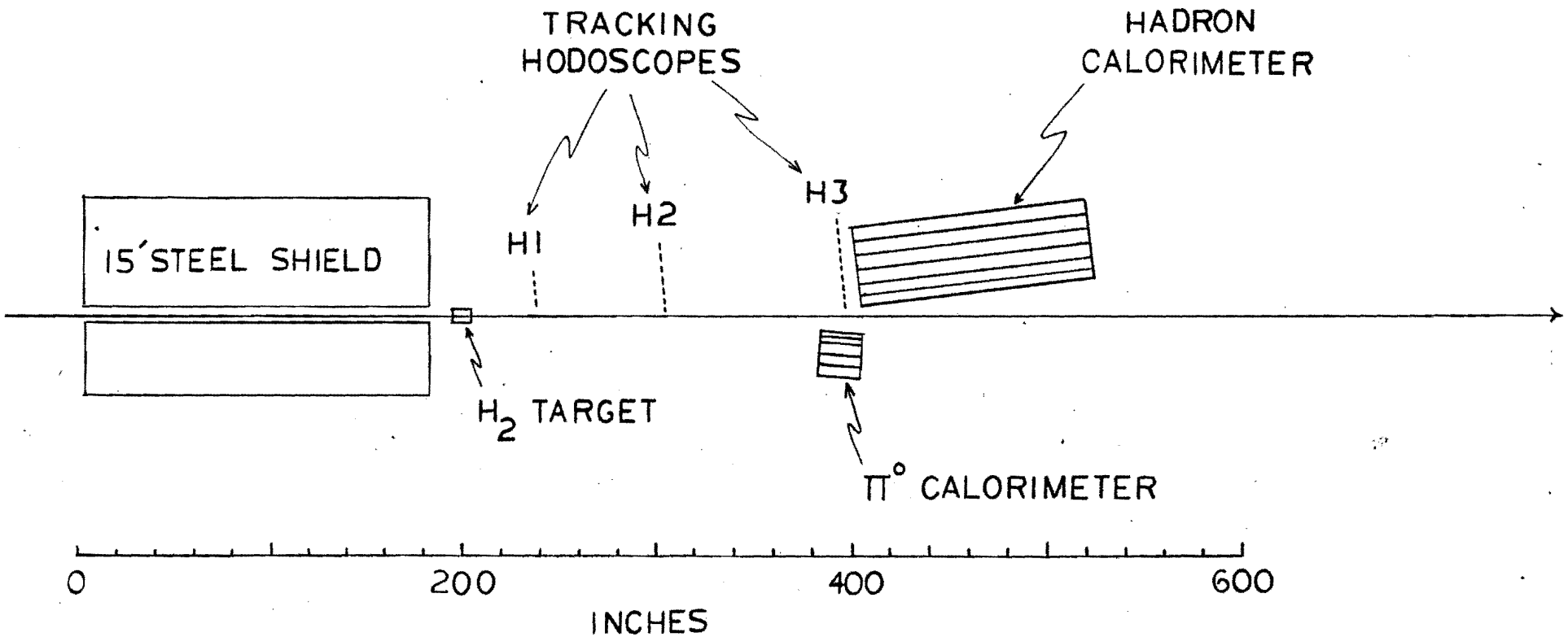
TRACKING
HODOSCOPES
HADRON
CALORIMETER
15′STEEL SHIELD
H1
H2
H3
H_2 TARGET
π^0 CALORIMETER
0
200
400
600
INCHES

FIG. 4A

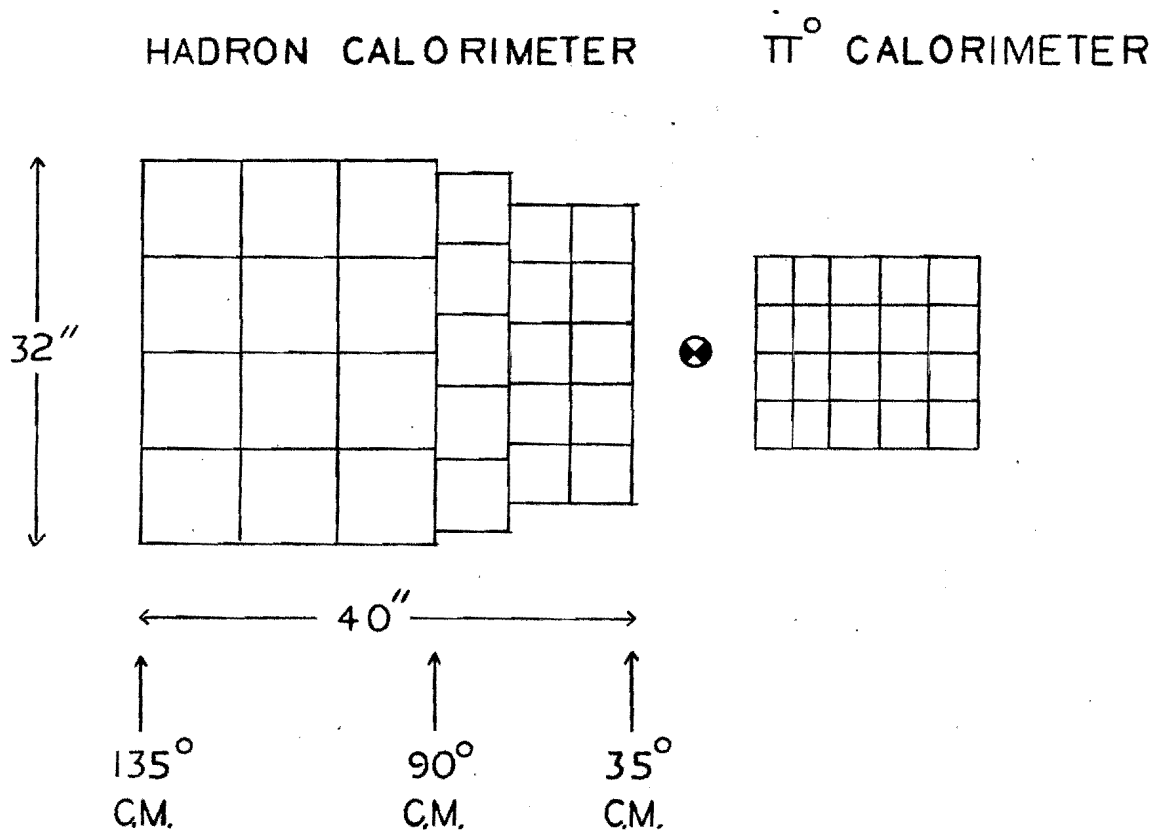

FIG. 4B