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STUDY OF HIGH-P_T EVENTS WITH A CALORIMETER HODOSCOPE

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Study of High-p_T Events with a Calorimeter Hodoscope

I. Objectives

The detailed study of hadron-hadron inelastic events of high-p_T, and particularly of correlations among particles in such events, promises to add significantly to our understanding of strong interaction processes at very small distances, and may throw light on the possible presence of point-like components -- partons -- in hadrons.

A major feature to be expected in high-p_T events is the presence of correlated groups or clusters of high-p_T particles -- i.e., of (transverse) jets. An elementary mechanism which will give such jets is the production of high-p_T resonances, which can give multi-particle clusters carrying an internal transverse momentum of a few tenths GeV/c. A more exciting possibility, first suggested by Berman, Bjorken and Kogat (BBK),[1] is that parton collisions may produce jets, and that by studying jets one may be able to study parton-parton collisions. In any event, we proceed from the viewpoint that clustering effects do occur. The resonance mechanism at least must produce jets; and there is already experimental evidence showing an increasing clustering effect with increasing p_T, as seen in the results of the CCR and PSB groups. To gain further insight into the nature and meaning of high-p_T events, and of associated clustering effects, one should measure the momentum of individual particles occurring in proximity to a high p_T particle.

We propose to make a detailed measurement of high-p_T jets, at the ISR. Our principal detector system will be a calorimeter hodoscope, covering somewhat more than 1/2 steradian net (about one steradian gross). This calorimeter will use basically a steel and liquid scintillator sandwich construction, of a design which we have tested and which has good resolution at energies as low as a few GeV. With this calorimeter, and with an auxiliary charged particle detector to show directions of all charged particles over a considerably larger solid angle, we expect to be able to make measurements giving information on the following questions.

1. To what extent do jets occur as groups of high-p_T particles, distinctly separated in momentum space from other particles in a given event? (See Figs. 1 and 2, taken from ref. 5, illustrating jet.)

2. What is the differential cross section for jets, $\frac{d\sigma}{d^3P/E}$, as a function of $P_T)_J$ and θ_J, for $P_{jet})_{visible} \sim 4$ GeV/c to 10 GeV/c, and θ_{jet} from about 45^o to 80^o. (We define a jet as an event with at least one particle of high p_T, and include in the jet 3-momentum all particles lying "unusually" close in angle -- for a jet near 90^o, e.g., this means all particles within an angle of 1/3 to 1/2 radian of the highest p_T particle detected. See below for further details.)

3. How does the jet cross section, $\frac{d\sigma}{d^3P/E}$, compare with the single-particle cross section $\frac{d\sigma}{d^3p/E}$? (A parton-parton mechanism is expected to produce a theoretical intensity ratio, for jets compared to π^o, of the order of 50 or 100 to 1, roughly independent of momentum. Because the low energy members of a parton jet cannot be unambiguously associated with the jet, one expects instead an observed intensity ratio of the order of 10 or 20 to 1.)

4. What is the distribution of longitudinal and transverse momentum among the particles of a jet? And what effective masses (i.e., invariant masses) are present in jets? (For example, we expect

to see ρ's and ω's rather clearly, if they are present in any appreciable fraction of jets.)

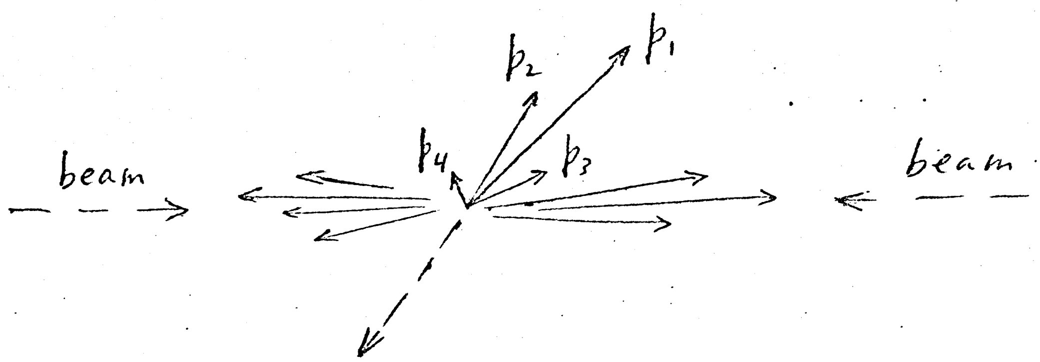
5. What particle ratios are present in jets? We expect to get some information, perhaps rough, on relative numbers of π^o, K^o and neutrons. (See below.)

If this experiment gives sufficiently interesting results, we expect that it would then be very important to continue on to install a second jet detector (calorimeter hodoscope) on the other side of the collision region, to try to measure properties of pairs of jets. Such pairs, if found, could be the first hard evidence of collisions between point-like components in hadrons.

II. Some speculative properties of jets

Bjorken[1,2] and collaborators have suggested the general properties that parton jets might have. In fact, whether or not parton jets exist, "resonance jets" certainly must, and will have the superficially similar property of an internal transverse momentum of a few tenths GeV/c. That low transverse momentum, when present along with high longitudinal momentum of the individual fragments, gives a relatively close angular clustering, and it is this clustering of high p_T particles that characterizes what we call a jet.

Schematically, a jet consists of a cluster of particle vectors in momentum space, as indicated below by vectors $p_{1,2,3,4}$.



Particles at a wide angle from the jet axis cannot be unambiguously associated with the jet, and therefore one will in general have to be satisfied with a measurement of an apparent jet energy, which will be less than the true jet energy. (We will use the terms "jet energy" and "jet momentum" interchangeably, although to be precise they are somewhat different for the "true" jet.) How much energy will be missed, for this reason?

To give an answer one must take some model of the jet internal momentum distribution. Feynman,[3] and Bjorken,[4] have suggested that a parton jet, like the jets along the beam direction, may have a "plateau" region of hadrons in the rapidity variable y. On such a model, one finds that the missing energy, the energy contained outside the angle θ, is given by

$$\Delta E\Big]_{\theta}^{90^\circ} \approx \frac{\langle p_T \rangle}{\theta} \frac{dN}{dy} ,$$

where $\frac{dN}{dy}$ is the rapidity density of particles in the plateau region, per event, and $\langle p_T \rangle$ is the average transverse momentum of jet members, with respect to the jet axis. From single-particle inclusive distributions we take the values $\langle p_T \rangle \approx \frac{1}{3}$ GeV/c and $\frac{dN}{dy} \approx 2$. If these apply to parton jets, as would follow from Feynman's suggestion, then we have

$$\Delta E\Big]_{\text{angles} > \theta} \approx \frac{0.67}{\theta} \text{ GeV.}$$

(Bjorken[2] has obtained this result by a related argument. We thank him for introducing this result to us.) Thus if one includes particles up to, but not beyond, one radian from the jet axis, one can expect to lose on the average about 2/3 GeV outside that angle.

But it is difficult to include particles as far away as one radian, in the operational definition of a jet. Such particles will have in general quite low momenta - with $\langle p \rangle$ within 10% or so of $\langle p_T \rangle$ - and thus will not be in any way clearly associated with a jet in any particular direction. Moreover, the average density of particles, $dN/d\Omega$, is large enough that a one-radian half-angle cone ($\Delta\Omega \approx 3$ sr) will on the average include at least one random particle, for a jet at 90^o to the beam, or many more for a jet at 45^o. So we should perhaps plan to use an angle cut of 1/3 to 1/2 radian from a jet axis, in defining particles which belong to a jet. For a cutoff angle of 1/3 radian, appropriate to studying jets at angles as small as 40^o or so, the missing energy may thus be of the order of 2 GeV. (From the above model this missing energy might take the form of three particles, at angles of 0.4, 0.6, and 1.0 radian from the jet axis, and with momenta of 0.9, 0.6, and 0.4 GeV/c respectively.) This missing energy plays an important role in the detectability of jets, in the measurement of the jet energy spectrum, and in the ultimate possibility of determining the energy and momentum-transfer variables in a parton-parton scattering, s' and t'. We discuss these matters further below. Moreover, the apparent multiplicity of a jet, as well as the apparent energy, can be much smaller than the values for the true jet. For example, while a 10 GeV (true) jet might have 6 or 7 particles according to the multiplicity observed for ordinary events at ISR, the slowest 3 or 4 would be lost by a cut at 1/3 radian, leaving about

8 GeV (apparent) in 3 particles. For lower energy jets the effects are much more drastic: a 5 GeV (true) jet, of multiplicity 5 or 6, would appear as a single pair, of total energy 3 GeV.

(For a schematic representation of what a beam jet and a transverse jet look like in momentum vectors, on the model of flat rapidity distribution, see reference 5.)

III. Energy Spectrum of Jets

The energy spectrum of jets can be related to the energy spectrum of their fragments, if one makes some assumption about the "fragmentation function", the g(x) of BBK. (g(x) is the fractional energy distribution $\frac{1}{E_{total}} \frac{dE}{dx}$ in the jet; it is analogous to $\nu W_2(x)$.) The behavior of g(x) near x = 1 is of principal importance for determining the relation between jet spectrum and fragment spectrum.

Bjorken and Kogut[6] have used a correspondence principle argument to obtain the result that g(x) for the π meson behaves like (1-x) at x near 1. Bjorken[2] has shown how if this behavior is characteristic of partons then a p^{-n} jet spectrum gives also a p^{-n} pion spectrum, but weaker by about (3/2)(n-1)(n-2). n is defined here by $\sigma' \equiv \frac{d\sigma}{d^3p/E} \sim \frac{A}{p^n}$ -- i.e., $n = -d \log \sigma'/dp$. From this chain of argument, and with $n \sim 8$, a value appropriate to the ISR 90° π^0 spectrum, 3 to 8 GeV, one may expect jets of a given total energy p_1 to be ~ 50-100 times more numerous than single π^0's of energy p_1. The exponent n as defined above varies slightly with momentum, but is close to 8 over a wide range.

If this series of arguments is correct, then the ratio of jet event rate to single π^0 event rate, at high p_T, will be a quite large number. If such a high ratio were to be observed, it might provide important support for a parton-parton collision model and for partons; at the least such a result would probably be an important aid in distinguishing between different models.

The actual ratio of rates, jet vs. π^o, which one can expect to measure is not as high as the ratio corresponding to the true jet energy spectrum, however. This is because the lower energy members of a jet cannot be unambiguously associated with the jet, as discussed in section II above. As an example, we consider the case that the jet is taken to include only particles within a cone of half angle 1/3 radian (or 2/3 radian). Then the jet signal can be expected to be $\sim$ 2 GeV (or 1 GeV) smaller than the true jet energy. One then obtains, on the model just discussed, expected results as shown in Table I.

From Table I one sees that to test this major point, on the question of the rate of jet events compared to the rate of single π events, one should look for jets of the highest possible energy. For example, if the estimates in Table I are not too far wrong, then measurements of jets of energy as low as 4 GeV will give very little useful information on a parton model -- at 4 GeV the number of jets per GeV may be 5 or even 10 times the number of π^o's per GeV, but in addition to single π^o's one will find single π^+, π^-, $K^\pm$, K^o, and baryons, and therefore the observed rate of "jets" (at this jet energy that means primarily observed multiplicity of only 2 correlated particles) will not be enough larger than single-particle rates to provide by itself useful discrimination between a parton model and other models.

The conclusion that it is of high importance to look for jets of the highest possible energy -- perhaps 8 to 12 GeV -- has implications for the solid angle, luminosity, and background conditions required.

TABLE 1

Expected Jet Energy Spectrum, Near 90° *

$p_{observed}$ (LAB)	$\frac{d\sigma(jet)/dPd\Omega}{d\sigma(\pi^o)/dpd\Omega}$ a) if $\theta \le 1/3$ **	b) if $\theta \le 2/3$ **	Rate of jet signals*** above p_{obs}, in 1/4 sr (lab), at 90°, at $L=2\times10^{30}$: if $\theta \le 1/3$	(rate of single π^o in 1/4 sr)
4 GeV	3½	13	600 evs/hr	160
6	8	21	80	10
8	14	28	8	0.6

* This table is based on the observed CCR data for $\frac{d\sigma(\pi^o)}{dpd\Omega}$, and the model discussed in the text. n is taken as 8.

** True jet energy = $\begin{cases} \text{observed energy + 2 GeV for } \theta = 1/3 \text{ radian.} \\ \text{observed energy + 1 GeV for } \theta = 2/3 \text{ radian.} \end{cases}$

*** Obtained from CCR results for π^o's, multiplied by the ratios in the previous columns. We assume an "outside" detector.

IV. Calorimeter Hodoscope

1. Introduction

We wish to detect jets of total energy about 3 to 12 Gev and beyond, with individual particle energies as low as about 1 Gev. On the model discussed above, the true jet energy spectrum, in $\mathbb{P}_T$, may be roughly similar to the π^0 energy spectrum; in fact, because of the problem of the missing low energy members of the jet, the observed jet energy spectrum will appear flatter with energy than the true spectrum.

We can therefore expect to have reasonable energy resolution on jets if we have reasonable resolution in the presence of the π^0 energy spectrum. The required energy resolution for that purpose is discussed in reference 5. As discussed there, it is important, in measuring a steeply falling spectrum, to have the high energy tail of the resolution curve not extend too far. One important measure of this tail is the distance from the peak to the last 1% to 5% of the area. In reference 5 it is shown by an example that the necessary energy resolution to the 1% level is roughly $\left(\frac{\Delta E]\text{ apparent, to 1\% level}}{E_{peak}}\right)$ $\leq$ 30 to 40%, for E = 3 to 5 Gev. A more careful calculation, based on the CCR data, shows that for energies from about 2 Gev to 10 Gev one can in fact tolerate a spread $\left(\frac{\Delta E]\text{ apparent, to 1\% area}}{E_{peak}}\right)$ of 40 to 50%. For any reasonably well-behaved resolution shape, the FWHM will be roughly the same as the value of $\Delta E)_{\text{to 1\% level}}$.

The BNL-Penn-Wisconsin collaboration, of Turkot, Selove, Erwin et. al. have built a test calorimeter which in brief preliminary measurements has given resolution of approximately this quality. We also have evidence that this resolution can be appreciably improved by minor refinements. The test calorimeter, and some of the results, are described below.

2. Test calorimeter and results.

A test calorimeter of 10 ton design has been built, and preliminary test results have been obtained at the AGS in 2 days of running at the end of May. The resolution obtained was about 50% FWHM from about 3 to 10 Gev, for π's and protons; there is no very long tail. These preliminary measurements were made with an incomplete and crudely adjusted system, and we have evidence that the resolution can be readily improved to a value of about 40% at 5 Gev. (It appears that other design refinements could improve this figure appreciably, to perhaps 25% FWHM at 5 Gev, though perhaps at substantially higher cost.)

The calorimeter is 1.2 m square. It has a series of modules, with layers of steel and liquid scintillator. The runs in May were made with layers of approximately 12 mm steel and 38 mm scintillator, with a total thickness of about 1.8 m. (But in May the first 30 cm of the calorimeter had only one steel layer out of 3, in place.) Each 45 cm of depth is viewed by two 5-inch phototubes, one on each side, through 27 light pipes on each side. There were thus 8 phototubes total, in our tests. For the loaded system, each 45 cm is about one collision length.

In the May runs we adjusted the relative PM gains using mesons, and had time only to make the gains roughly equal -- perhaps to $\pm$ 10%. Most of the data was taken with only the summed signal recorded, on a PHA. We also took a small amount of data, with 7 Gev/c protons, with individual ADC's reading out the 8 tubes, on each event. These latter data are valuable in showing several features. (1) The length of the cascade is typically about two collision lengths. (2) There is a contribution to the low energy tail coming from leakage out the back. (These runs were made with a total of about 4 collision lengths; the test calorimeter is designed to have up to 50% more length, and in later runs we will use 5.5 collision lengths or more.) (3) The absence of steel in the first part of the calorimeter, particularly with our particular arrangement of phototubes, gives an appreciable broadening of the resolution. If we correct (by cuts) for all of these effects, and correct also for the differing gains in the different PM-ADC channels, then the FWHM drops from about 50% to about 30% -- but with very poor statistics. We believe that in practice it would be easy to obtain 40% resolution.

A few representative pulse height distributions, from PHA and from summed video, are shown in Figures 3 and 4. These illustrate in brief the following features we found from the test run:

(1) The response is quite linear from 3 to 7 Gev.

(2) Pions give about 65% the pulse height of electrons. Protons give about as much pulse height per Gev

of kinetic energy as pions give per Gev of total energy.

(3) For pions and protons from about 3 to 10 Gev the pulse height spectrum (uncorrected sum) has about 50% FWHM.

(4) For electrons the width (uncorrected sum) is about 20% FWHM.

We also made some measurements of edge effects, and found they were small, less than 5 or 10%, for particles entering farther than 30 cm from an edge.

3. Calorimeter hodoscope - general design features.

We wish to cover about one steradian gross, which corresponds to somewhat over half a steradian net after allowing for edge effects. We will cover this with a matrix roughly 4 x 4 units of area, each about 1/4 radian by 1/4 radian. The array will be located asymmetrically so as to cover a range of angles going from (gross angles) near 90% to angles much closer to the beam -- 35 or so. This asymmetrical arrangement is to enable us to study high p_T events with a considerable range of sin θ_J, where θ_J is the angle between jet and beam.

The hodoscope elements will be approximately 2 m in depth. Exact thickness will be chosen after further tests with our test calorimeter, using different layer thicknesses. Light will be collected by mounting small phototubes right at each module. (We have calculated the light collection uniformity, for a design we are currently building in a test version, and find that non-uniformity should contribute a standard deviation less than 5% for 3 Gev showers.) Total mass of the array will be about 50 tons.

The front section of the array will have Pb plates instead of steel, for a total thickness (Pb plus scintillator) of about 30 cm. This is necessary so that π^o energies can be properly identified. (Otherwise, a signal of a given size might correspond to a $\pi^{\pm}$ of 6 Gev, or a π^o of less than 4 Gev. That same signal size, it should be noted, might also correspond to a proton with a momentum of 7 Gev/c.)

Sketches of the proposed layout, assuming operation with a streamer chamber, are shown in Figures 5 and 6 .

4. Identification of neutral species.

Single particle inclusive measurements show that with increasing p_T the ratio of non-pions to pions grows. It would be of much interest to have information on particle ratios present in jets. For neutral members of jets we expect to obtain some information on this question, though perhaps only rough information. First of all, π^o's will be identified separately, as discussed above. We then wish to sort the remaining neutrals into K_L^o and neutrons. We hope to do this to some extent, on a statistical basis (not event by event), by obtaining some information on K_L^o by seeing the rate of K_S^o. The rate of K_S^o we hope to determine, roughly, by observation of actual V's from $K_S^o \to \pi^+\pi^-$ in an auxiliary charged-particle detector, and by effective-mass determination of events with two π^o's.

5. Comparision of scintillator calorimeter with Willis calorimeter, and further remarks on energy resolution.

W. Willis has developed a very interesting calorimeter design, using liquid argon (LA) in a pulse-ion-chamber mode. That design has many attractive features, including the feasibility of using a more nearly homogeneous mixture of steel (say) and LA, with consequent improved energy resolution. (In reference 5, W. Selove has discussed the importance of having a short collision length and a short radiation length; this consideration indicates that one would probably not want to use pure LA in a calorimeter array at ISR.)

The iron plus liquid scintillator (Fe plus LS) design we propose to build can not readily be built with very fine layers of Fe and LS. The LS system does however have an advantage in time resolution over the LA system, by a factor which is not precisely determined but which is probably of the order of 5 or 10. This better time resolution may be of considerable importance, particularly if one wishes to work at the highest possible luminosity, so as to study jets of the highest possible p_T .

As for the energy resolution, we make the following remarks.

1) The ultimately usable energy resolution for the study of jets is limited by two factors presently beyond our control:

(a) A proton of momentum $p \gg M_{proton}$, gives a calorimeter signal approximately 1 Gev smaller than a pion of the same momentum. For 5 Gev jets, say, this is in some sense equivalent to a 20% FWHM contribution if protons are present of the order of half the time in such jets.

(b) The low energy members of a jet can not even in principle be associated unambiguously with the jet. This effect, discussed above, represents an uncertainty of 1 to 2 Gev -- so an equivalent FWHM contribution of 20% to 40% at 5 Gev, or 12% to 25% at 8 Gev.

2) A major contribution to the width of the resolution curve comes from the variation, from event to event, of the percentage of the incident energy which goes into π^0's in the course of the total absorption cascade. (See reference 5 for a discussion of this effect particularly in its extreme form, the "full-energy-blip".) That part of the cascade energy which is electromagnetic delivers a larger signal, because no energy is lost in binding energy, neutrinos, and other similar effects. These considerations have led H. Brody [7] to suggest that one might profit from having a simultaneous measurement of a Cerenkov-radiation-produced signal, in a cascade. Our test calorimeter provides physically for a sampling Cerenkov signal of this kind. Calculations made by T. Gabriel and R. G. Alsmiller [8] on LS and Cerenkov signals for a geometrical arrangement very close to that of our test calorimeter have given preliminary results (a) showing reasonable agreement with our measured energy resolution, and (b) indicating a high correlation between LS and Cerenkov signals. By using this

correlation it appears that the resolution of our calorimeter could be improved to perhaps 25% FWHM at 5 Gev.

V. Auxiliary Charged Particle Detector

In addition to the calorimeter hodoscope, a large-solid-angle charged particle detector is essential for this experiment. Its principal purposes are (1) to show all tracks within about 1 radian or more around the calorimeter solid angle, to permit seeing whether an observed jet stands alone, (2) to give more accurate information on charged particle directions, for tracks giving signals in the calorimeter, and (3) to assist in discriminating against background, by showing whether calorimeter-associated tracks come from the intersection region. Detection --i.e., conversion--of π^0's is also desirable, in a radiator of 1 or 2 radiation lengths, for the same reasons.

Our detector of choice for this purpose is a streamer chamber. The streamer chamber of the Aachen-CERN-Munich collaboration would be excellent for this purpose, and we hope we can make some arrangement to work with that chamber, preferably in collaboration with the Aachen-CERN-Munich group. If that should prove not possible, an alternative charged particle detector could be a set of cylindrical chambers, like those the BNL-VPI-Penn-Purdue-Wisconsin collaboration has used in the Argo spectrometer system at BNL. This is a working set of 6 cylindrical magnetostrictive chambers, 75 cm long, and with radii from 15 cm to 47 cm.

We make some remarks here on the comparison of magnetic and non-magnetic charged particle detectors for this experiment. To be specific, we compare the SFM and the streamer chamber.

First we note that if one wants to study jets, and wants to measure the energy spectrum of jets, then even with a magnet one also needs a calorimeter. A magnet system like the SFM has some serious disadvantages relative to a non-magnetic system, in this case:

(1) The angular aperture through which the neutral members of a jet can reach the calorimeter is quite limited, by the pole tips and coils.

(2) The calorimeter system cannot be brought close to the intersect, with the SFM, because the magnet and its chambers extend quite far to the side. Hence the calorimeter expense would be considerably greater with the SFM, for a given solid angle coverage, than with a non-magnetic detector.

(3) Most important, triggering on jets is very difficult with a magnetic system like the SFM, because the magnet disperses the charged tracks. This makes it very difficult to select out the 100-1000 events per hour desired from the 10^8 or so occurring per hour.

We further note that the better energy resolution on charged tracks, with a magnet, is of limited value in determining jet energy. This is true because one still has the calorimeter resolution width on neutral particles--and the still broader resolution effect on jet energy from the missing members of a jet.

VI. Triggering; background

The fundamental trigger mechanism we would use would be total energy deposition in the calorimeter, with some adjustable threshold required. This trigger is designed to study the jet energy distribution, and to obtain a sample of jets in various energy bands, for study of the internal momentum distribution in jets, and for obtaining some information on particle ratios in jets.

Additional trigger modes of interest would be (a) π^0 energy, in the calorimeter, and (b) total jet transverse momentum, from the calorimeter energy contributions weighted by sin θ.

Background is a non-trivial problem, not in terms of very large numbers of triggers per second, but rather because upstream single-beam interactions can give appreciable numbers of triggers (hundreds per hour) with large energy deposition in the smaller-angle hodoscope elements. For example, to reach a calorimeter element at about 40° from the median beam direction (i.e., 33° from one beam), beam-beam events must produce a particle at 40°, with p_t^* about equal to 0.6 p_{lab}. But to reach that calorimeter element from say 2 meters upstream, with the calorimeter layout shown above in section IV, a beam-gas or beam-wall event must produce a particle with a p_t^* of only about 0.3 p_{lab}. For p_{lab} about 6 GeV, for example, the event rate for events of the latter type to reach the small-angle part of the calorimeter will be of the order of 100 times the rate for beam-beam events to do so, based on typical single-beam vs. beam-beam event rates. A major part of this potential background effect can be removed by shielding--an attenuation factor of over 100 would be provided by one meter of iron. Final discrimination against background events, however, is likely to require a charged particle detector with good track-direction determination.

VII. Time Scale

The calorimeter system can be ready for testing in place in 6-8 months after approval. The time interval would be on the shorter side of this range if European collaborators contribute a part of the work on the calorimeter construction. We strongly desire European collaborators.

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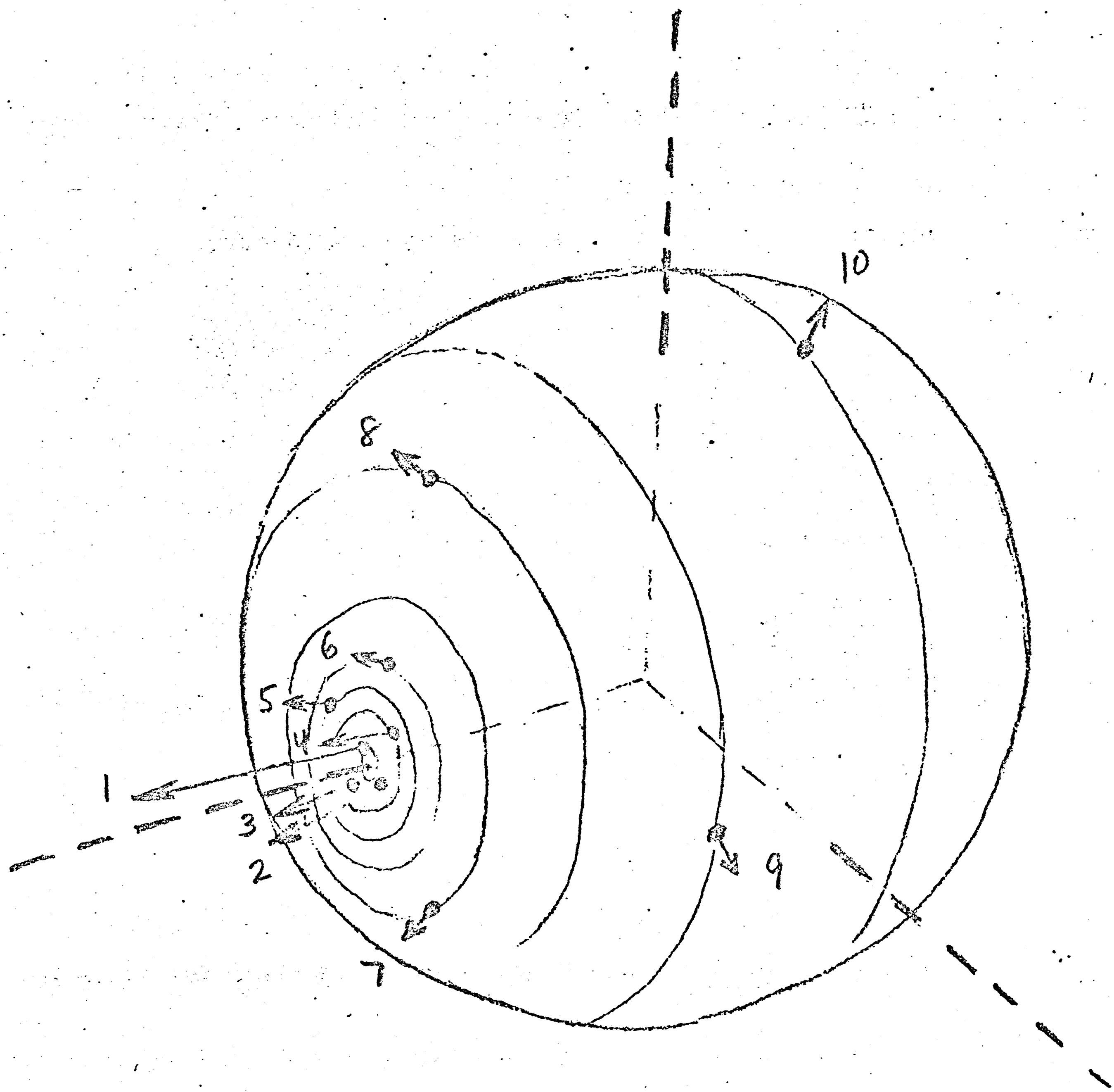
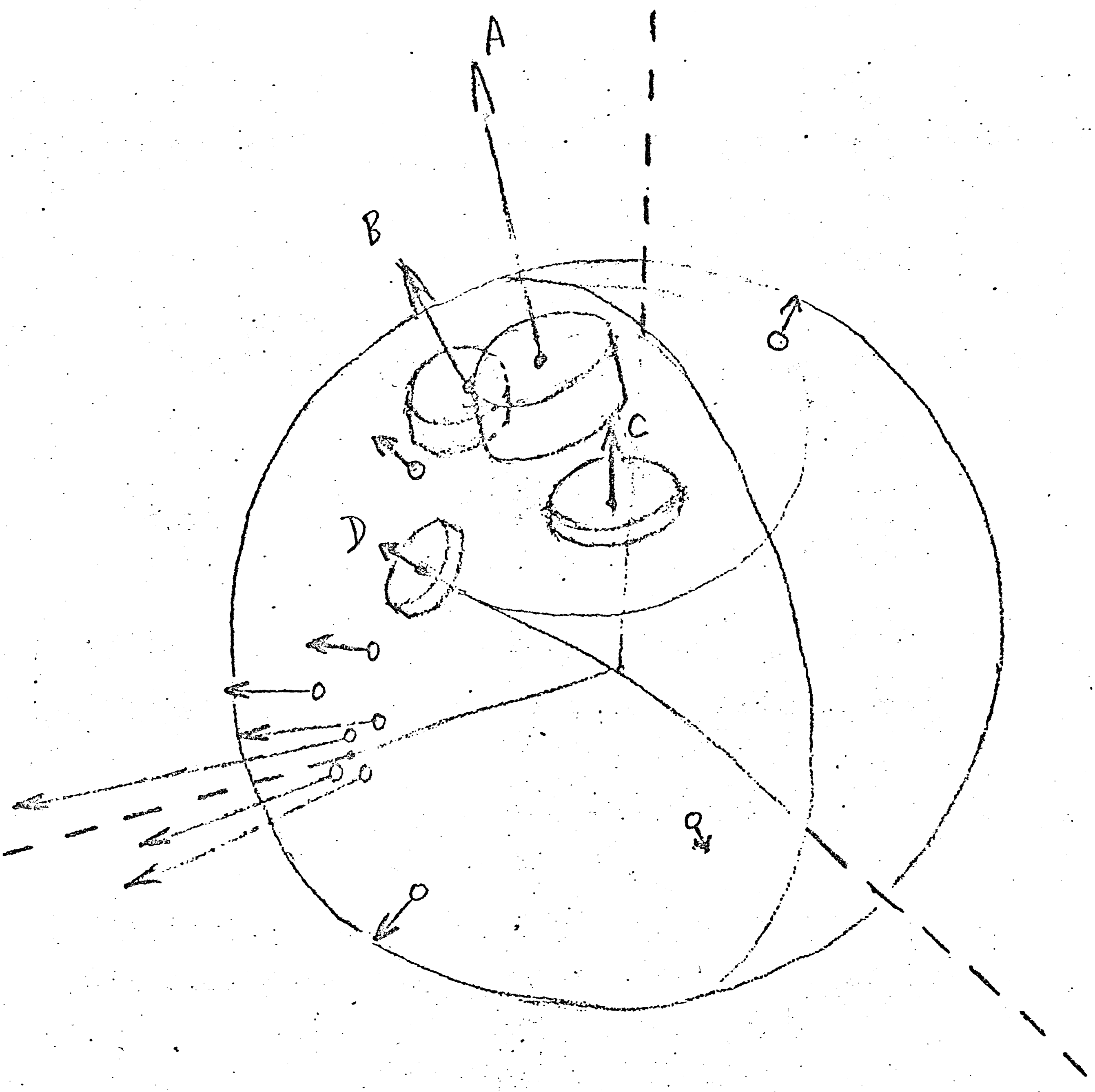
FIG 1



SAMPLE EVENT, $n = 18$

PARTICLE NO.	1	2	3	4	5	6	7	8	9
ANGLE	2°	3.5°	6°	9°	13°	20°	30°	50°	70°
P	9	6	4	2.7	1.8	1.2	.8	.5	.35

FIG 2



A JET ACCORDING TO PARTON MODEL.

A	5 GEV
B	2,5
C	1,25
D	0.6

SPACE RESOLUTION 0,28 RADIAN DIA AT 70°
0.16 AT 30°

FIG 3

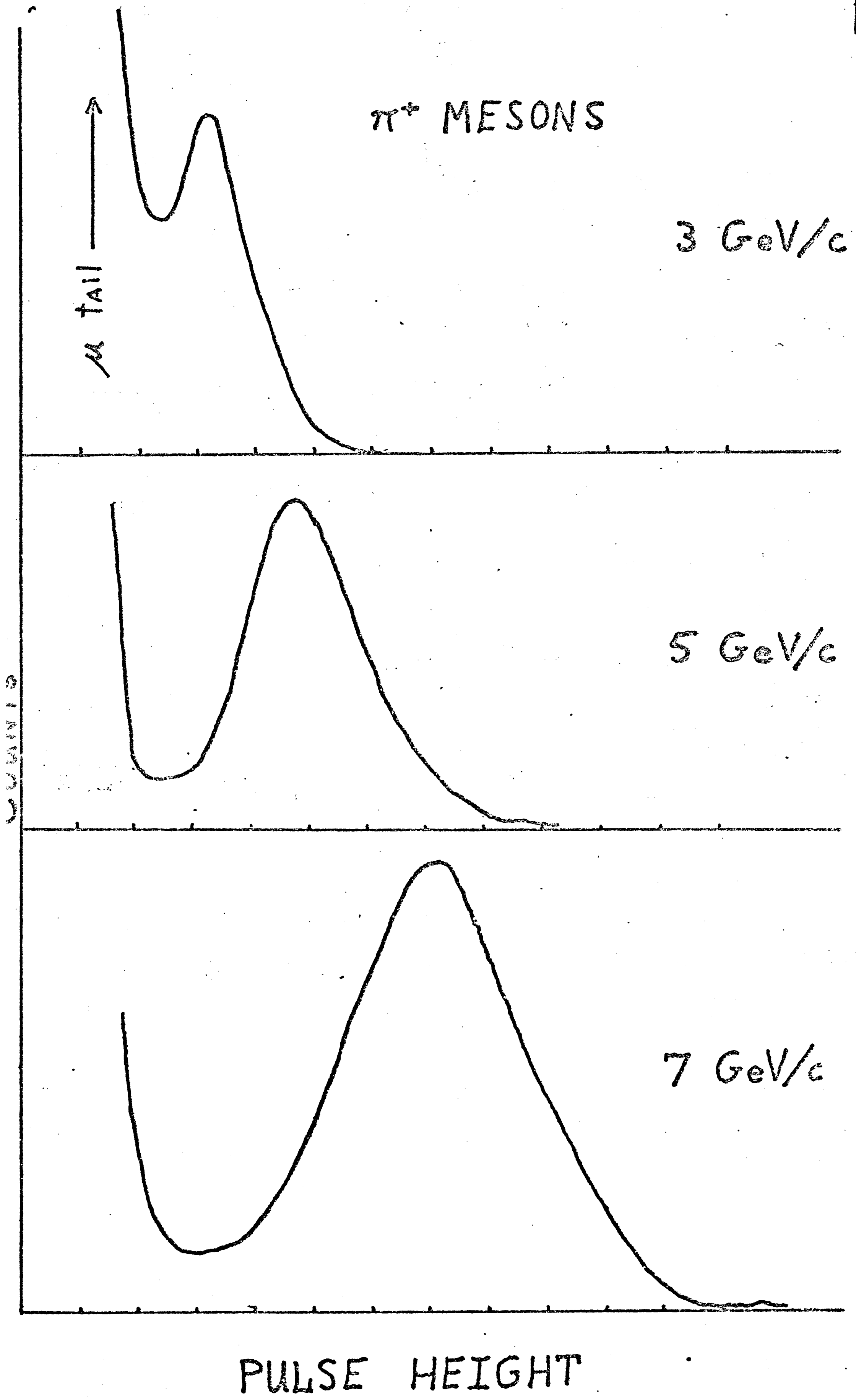
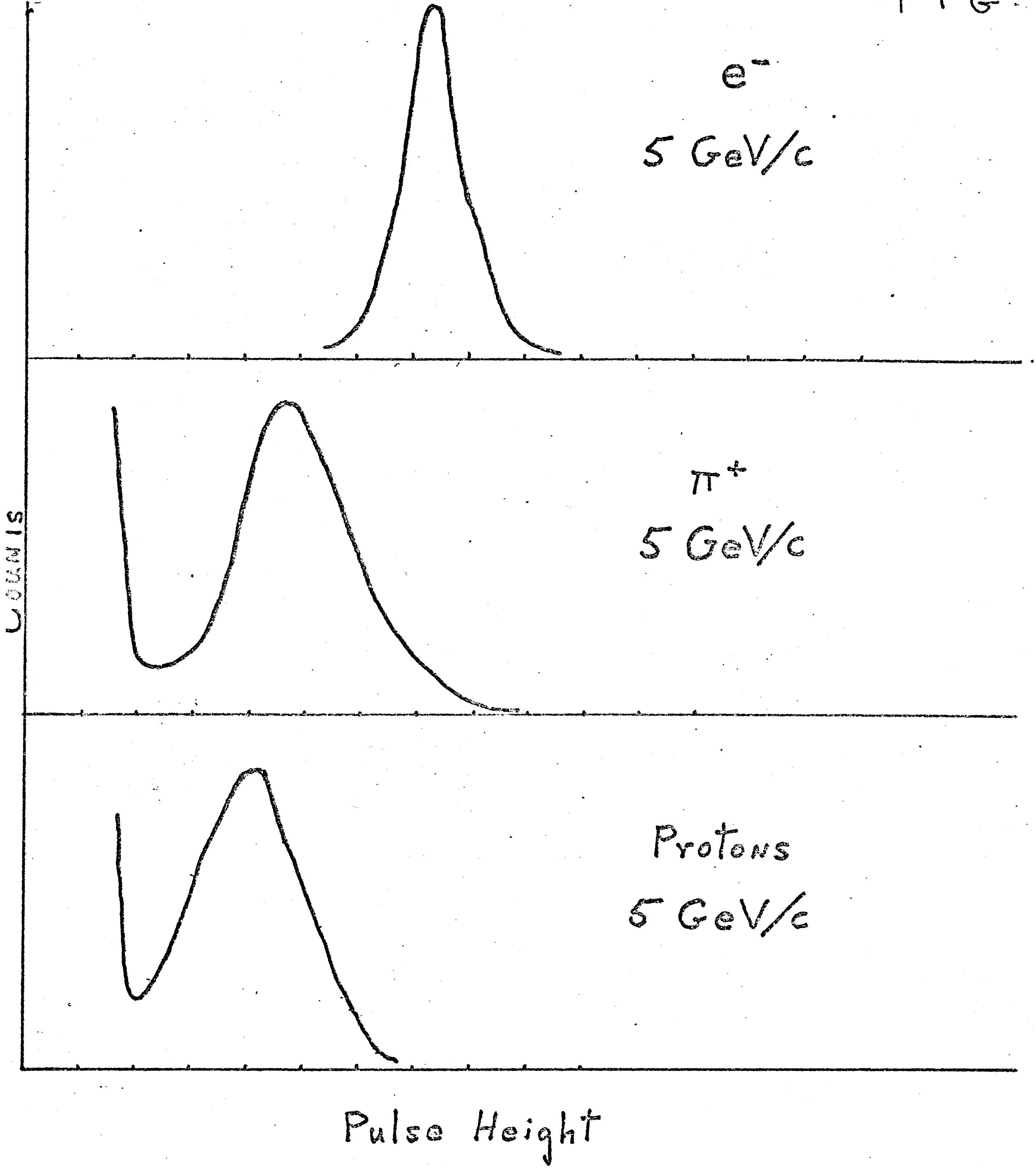


FIG. 4



CALORIMETER HODOSCOPE (PLAN VIEW)

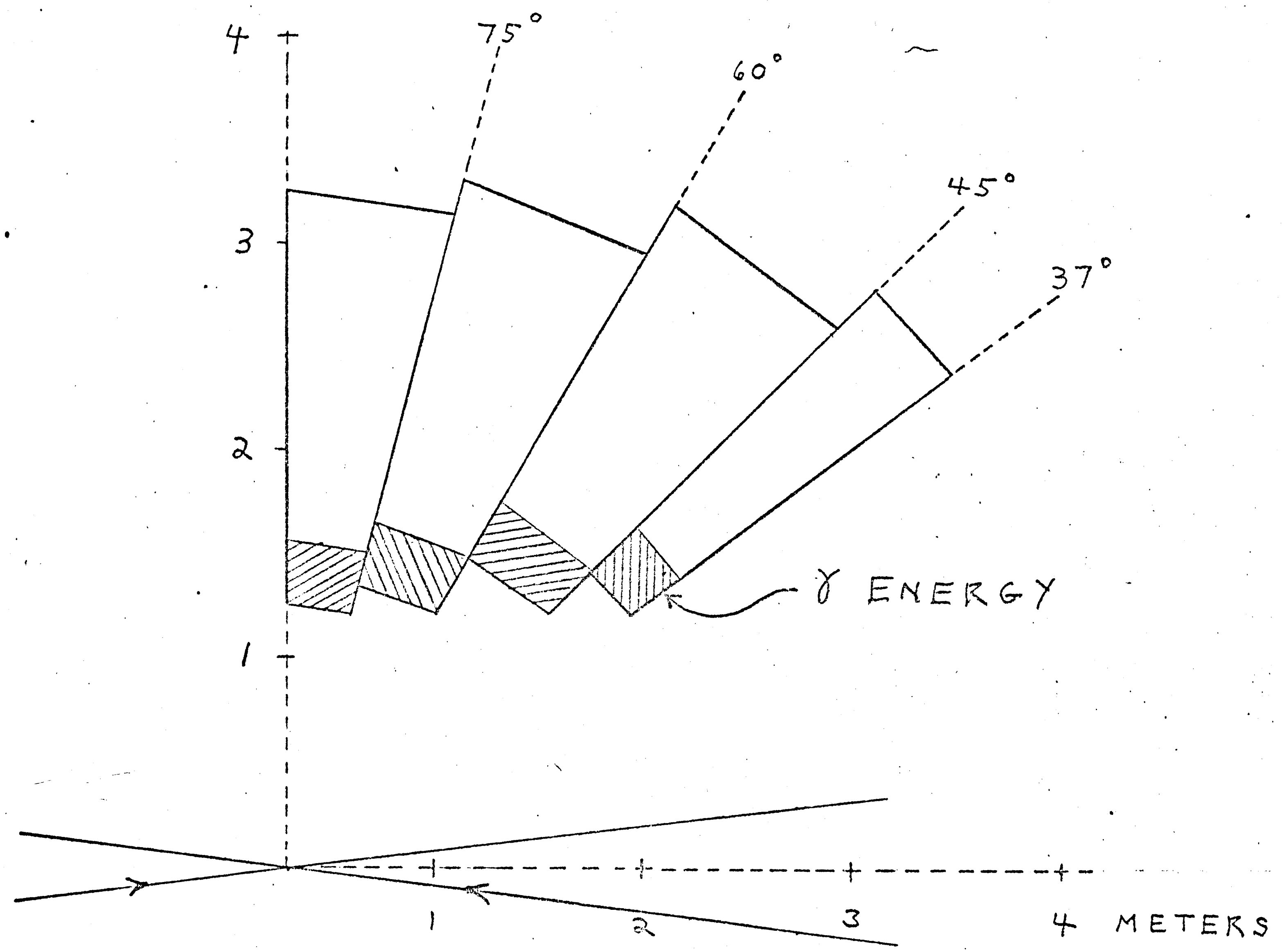
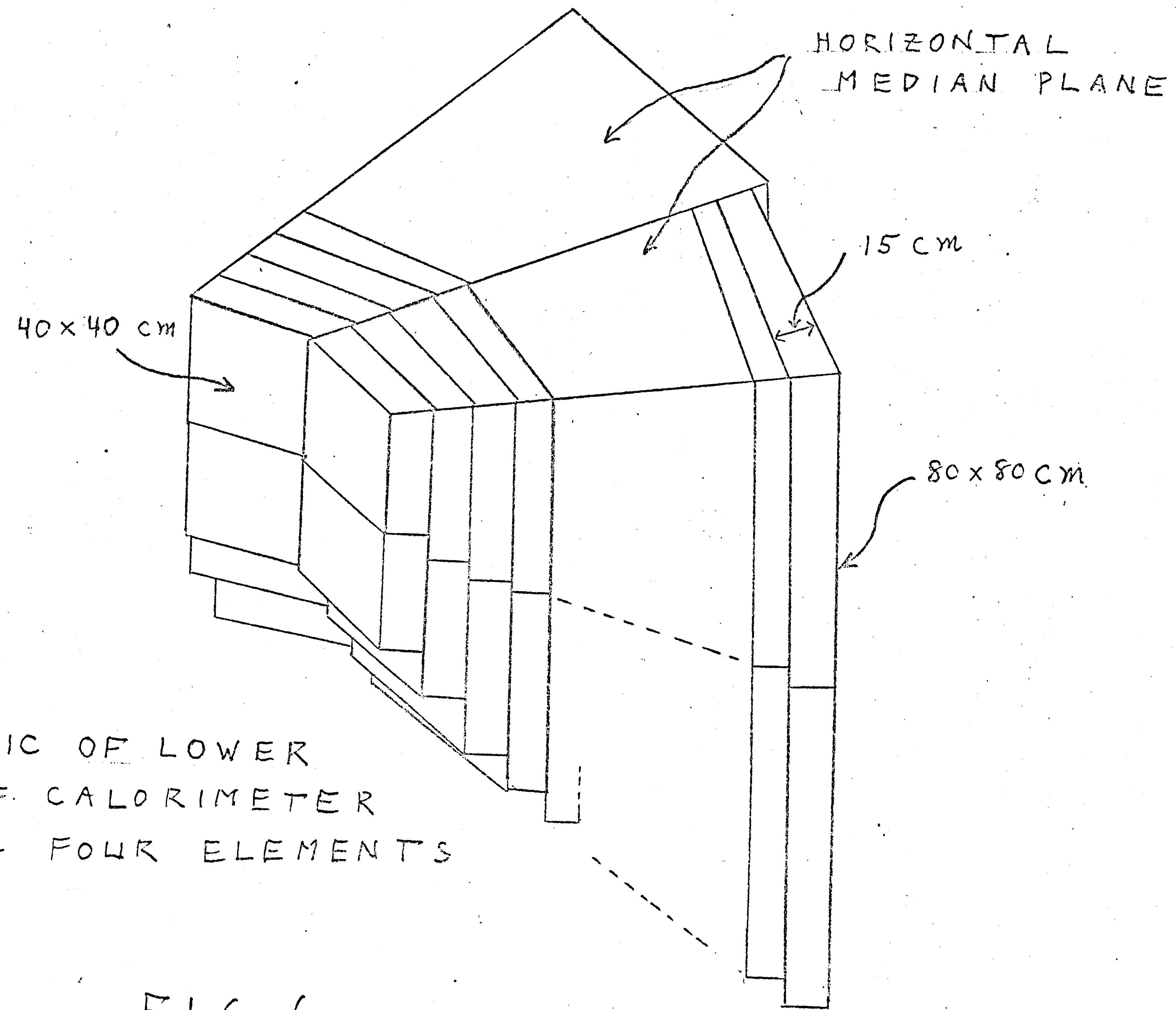


FIG 5



SCHEMATIC OF LOWER
HALF OF CALORIMETER
SHOWING FOUR ELEMENTS

FIG 6