A NOTE ON TOTAL ABSORPTION DETECTORS IN THE 100-GeV ENERGY RANGE

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ABSTRACT

A brief review is given of the basic features of total energy detection for hadronic and electromagnetic cascades. It appears that statistical fluctuations, which limit the resolution of many cascade detectors at low energies, will allow simple discretely sampling detection devices to be quite competitive at NAL energies. In particular, counters sensitive mainly to the electron-positron component (i.e., to the highest velocity particles) will benefit from the fraction of the total cascade energy contained in the electromagnetic part, which increases with energy. Simple and inexpensive sandwich counters may well be very appropriate detectors for many applications. We urge early tests of these phenomena.

1. INTRODUCTION

Of the vast zoology of particles known to be produced in nucleon-nucleon collisions at the 200-400 GeV accelerators, all but neutrinos and muons can conveniently be detected in total energy absorption devices. Such detectors can be made to yield localization information, but for charged incoming particles, it will mostly be more convenient to use spectrometers plus trajectory-defining devices for full kinematical information.

Neutral particles, however, are harder to track down. Therefore, the fact that all hadrons induce nuclear cascades has been utilized by cosmic-ray and particle physicists for a long time. The basic detection process is simple: a cascade develops, many particles in the cascade have electric charges, and these charges are detectable by known processes (scintillation, Cerenkov radiation, ...). The detector integrates in some fashion over the track length of the charged particles and thereby gives a measure of the total energy deposited. The pitfalls met by such detection devices are mostly statistical in nature--their seriousness therefore decreases with increasing energy. This note is written in order to stress the basic simplicity of the method and its usefulness for building relatively low-cost detectors adequate for most applications, and their vastly improved performance at higher energies, and to urge the availability of a low-intensity test beam for performance studies of such devices on a parasitical basis.

II. CHARACTERISTICS OF ELECTROMAGNETIC AND NUCLEAR CASCADES

Electromagnetic cascades have been well studied theoretically and experimentally. We know that the charged constituents are almost exclusively electrons with β values appropriate for Cerenkov detection. We know that the main source of cascade leakage from a given finite volume is due to photons around the critical energy and does not seriously affect the resolution if properly taken into account.

Hadronic cascades are more poorly explored. We do not know what the constituent charged particles at any given cascade depth are. There are many different basic processes happening in the cascade which make for large statistical fluctuations in the 5-20 GeV range. Secondaries may be heavy particles with low β values unsuitable not only for Cerenkov detection but even for scintillation detection because of the non-linear response of organic scintillators to low-velocity particles. Many secondaries are emitted at large angles (whereas the electromagnetic cascade develops mostly forward), and lateral leakage of cascade constituents may be serious. Typically, a 300-GeV cascade is expected to lose roughly 1/3 of its energy in nuclear disintegrations, 1/3 in ionization loss of charged products, and 1/3 to electromagnetic secondaries. We will come back to this last point. Fluctuations are due mainly to the first item.

When it comes to practical applications of cascade detection, the basic methods are very similar for both hadron-induced and electron-photon-induced cascades. The difference lies in the β value of secondaries and in the energy range at which statistical fluctuations become less important (or negligible). Since we have plenty of experience on this latter point with e-γ cascades, some feeling may be developed for the hadronic case.

III. PERFORMANCE OF ELECTROMAGNETIC CASCADE DETECTORS

There is a great deal of experience with e-γ shower counters.[2,3] Choosing materials of appropriately small radiation length, containment of the shower is no great problem. The types in use are: 1) continuously sampling (homogeneous) counters, either scintillating crystals or heavy Cerenkov radiators (lead, glass, or crystals), 2) discretely sampling counters (sandwich counters using heavy plates for shower development, interspersed with scintillator or lucite Cerenkov radiators for sampling).

The fluctuations of low-energy showers make the continuous sampling method preferable for good energy resolution below a few GeV, although the cost is considerably higher. Sandwich-type counters have essentially equal resolution with type (1) at energies above 5-10 GeV. (At the lower energies, poor photon statistics in the transparent fluor indicate the use of scintillator; in the multi-GeV region, lucite will produce enough Cerenkov radiation to obviate this preference.) Energy resolution improves as $E^{-1/2}$ down to the level where the strong interactions become important (~ 1%).

For resolution of particle energies doped NaI crystals are in a class by themselves. Their properties are described by Hofstadter.[4] Their disadvantage lies in the fact that their pulse decay time is extremely slow (~250 nsec) and their cost (for the large sizes needed) is inordinately high. Their possible application will therefore be severely limited.

IV. PERFORMANCE OF HADRONIC CASCADE COUNTERS

The total energy contained in hadronic cascades has often been measured with ionization calorimeters by cosmic-ray physicists. L. Jones describes the present state of this art.[5] A typical energy resolution value for such devices used around accelerators is ~40-50% FWHM at 15-20 GeV incident particle energy decreasing quite slowly with increasing energy. Such calorimeters contain sequences of heavy absorbers and ionization detectors with geometrical parameters that do not appear to be carefully optimized.

Hofstadter and collaborators[6] have proposed to use NaI or other heavy crystals for hadron detection as well as for e-γ showers. It appears that quite aside from the extremely high cost (M $0.25-0.5 for a 200-GeV detector) and the known timing disadvantages of such a crystal, there is a strong possibility that the errors inherent in the cascade process prevent one from using the luminosity of the NaI crystal to best advantage.

Our argument runs as follows: The inherent errors of a reasonable-sized hadron cascade detector are expected to be on the few percent level at ~100 GeV and above. Thus, unlike the e-γ case, it is impossible to reach the level where the superior resolution of expensive giant crystal detectors is felt. Rather, we expect that just as the sampling shower detectors' resolution catches up with continuously sampling lead glass or PbF_2 counters in the region > 10 GeV, thoroughly thought-out sandwich detectors may well catch up with the energy resolution of heavy crystals for hadron detection in the energy region above, say, 100 GeV. This statement ought to be tested experimentally at the earliest possible date (see below), but indications at present accelerators point in this direction: the author and C. Prescott[7] exposed sandwich counters of the lead-scintillator and lead-lucite variety to e and π beams at SLAC at energies up to 15 GeV. The results strongly resemble those of Hofstadter et al.,[8] taken in the identical beam, with a large PbF_2 crystal.

V. DETAILS ABOUT THE RESOLUTION OF HADRON CASCADE COUNTERS

We can substantiate this contention somewhat further. Other known sources of inefficiencies in hadron total-absorption counters are:

1. Lateral escape of neutrons of energies $\gtrsim$ 20-50 MeV. This is probably the largest error for most existing counters; to a large extent, an increase in lateral dimensions can reduce this error.

2. Escape of high-energy muons (from e.g., pair production) due to their large range. This effect is probably very small.

3. Loss of binding energy of nucleons kicked out of nuclei. This energy can usually not be recovered for the radiator output. It is probably on the level of $\lesssim 1\%$.

4. π^+ and K^+ may stop and decay in the detector. The long lifetime of the decay μ leads to an energy loss depending on the fraction of slow K^+, π^+ in the cascade, error probably on the $\gtrsim 1\%$ level.

All this is very loose; we do not have the data to be more precise. Still, it indicates that there may well be inherent errors for all hadron total energy detectors on the few percent level so that a sampling device may well be all it takes for optimum performance (at a cost of maybe 2-10% of giant crystal counters).

A particular feature that will be helpful is the fact that with increasing total energy of a nuclear cascade, the fraction contained in the electromagnetic component (mostly due to π^o decay) becomes more important (~20% in the energy region of interest here, ~85% at 1000 GeV).[1] Should the error in this fraction become small, the excellent detection efficiency for e-γ cascades will help towards better overall resolution if we weight the electron component properly in the detection process.

This can be done by taking a sandwich counting device where the radiator is a Cerenkov radiator (lucite), detecting mostly particles of very high velocity and thus favoring the electrons. Jones[5] points out that a large part of the error in ionization calorimeters may be due to the non-linearity of scintillator response to slow secondaries of nuclear stars. This source of error does not exist in the suggested device consisting of slabs of absorber (e.g., steel) and lucite.

VI. NECESSITY OF APPROPRIATE TESTS

Since much of this discussion is deplorably qualitative, due to our ignorance of the details of the development of hadronic (nuclear) cascades, let us do something about this soon.

We would urge the inclusion, in the first-generation design of experimental areas, of a readily accessible test area for detection devices with various particles of the full energy range up to 200 GeV. This area should, if possible, be run parasitically, and the intensity of the beams can be very low (10^3-10^5/pulse). Ready accessibility would be the main criterion. This may turn out to be within the scope of the diffracted proton beam,[9] or it may be a tiny pinhole beam downstream from a 0° beam plug.

This area should serve, for testing purposes, all types of equipment including the counters described here. Also, a proper set of simple experiments could be run to study in detail the development of cascades of energy up to final machine energy initiated by all available particles.

VII. ASPECTS NOT STUDIED HERE

We left out the study of rather important parameters of total absorption devices, notably their time resolution and their spatial information as well as problems of uniformity of response.

1. Time resolution: in plastic scintillators and Cerenkov counters, it is determined by the risetime of the phototubes and by the time jitter induced by the size of the radiator inside which the light bounces around. Beware of gigantic sizes! Timing problems in conjunction with scintillating crystals are discussed in Ref. 4. They are obviously hard to overcome.

2. Spatial definition: various hodoscopes can be employed in conjunction with total absorbing counters strategically inserted at given depths of the cascade development (thick-plate spark chambers, wire chambers, scintillator hodoscopes, Charpak chambers, . . .). Low efficiency is often unavoidable, and a fully satisfactory method has not yet been found.

3. Uniformity: this problem is well-known and studied. It is of primary importance that the phototubes be strategically located, that the radiator be uniform and as transparent as possible (making lucite particularly attractive), and that light collection be optimized (militating against, e.g., liquid scintillator with absorber slabs inserted, since we would then give up the important agent of total internal reflection of light).

All of these problems are not unique, and we will not treat them any further here.

VIII. CONCLUSIONS

The simplicity and ready availability of total absorption detectors for hadron and electron-photon detection is stressed. We strongly suggest that simple, cheap, and fairly predictable devices using the discrete sampling technique may well be fully satisfactory for many applications in the energy region above 100 GeV. Finally, we urge the ready availability of an accessible low-intensity parasitic beam for studies of the unknown parameters.

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