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THE SEPARATIONS BETWEEN HADRONS AND ELECTROMAGNETIC PARTICLES USING AN IONIZATION CALORIMETER

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The separation of hadrons from photons or electrons using an ionization spectrometer or calorimeter is studied. The separate recording of ionization and Cherenkov signals from the same sampling layer is suggested as a means of achieving a separation down to 0.1%.

There are many circumstances where an ionization calorimeter is used to determine the energy of high-energy particles and where it is not possible to otherwise identify the nature of the particle. This is particularly true with neutral beams where photons, neutrons, and kaons may all be present and leave a similar signal in a calorimeter[1]). Even with charged particles, space, technology, and monetary restrictions may limit auxiliary devices such as Cherenkov counters and transition radiation detectors. In such cases electrons and positrons will not be separated from pions, kaons, and charged nucleons.

An old proposal has been to employ a detector which contains about three radiation lengths of electromagnetic shower detector ahead of a calorimeter of lower-Z material such as iron. If the shower detector contains three radiation lengths (1.4 cm) of lead plates interspersed with ionization detectors, the probability of a photon converting in the shower detector is about 90%, while the probability of a neutron converting is only 8.7%. In the case of charged particles the separation is less clean as the bremsstrahlung of an electron is much less evident than the pair production by a photon. In five radiation lengths 85–90% of all electrons would be accompanied by at least one pair and 14% of incident protons would have experienced a nuclear interaction.

In many instances this degree of separation is not adequate, and it is to these cases that the present suggestion is directed.

It has been established by calculation and by measurement that over 30% of the energy loss in a high energy hadron-initiated cascade is taken up in nuclear dissociation and nuclear fragments (protons, neutrons, alphas, and beta and gamma decays)[2]). On the other hand, the probability for a nuclear interaction of an electron or photon is very small. Separation of the two types of cascades should therefore be possible if it can be ascertained whether or not nuclear fragments are present. It should be recalled that in a given sampling detector immersed in an absorber the ionization detected is on the average proportional to the partition of energy among the various components in the cascade at that depth (nuclear fragments, electromagnetic showers, produced mesons). However, the nuclear fragments (e.g. protons) have higher ionization and shorter range in general so that the statistical fluctuations in these components may be greater than in the others. And yet Willis has determined that a calorimeter made of uranium plates gives rise to a 30% greater pulse height for hadrons than one with iron plates, and thus with significantly better energy resolution[3]). This he ascribes to the detection of fission fragments from the uranium; surely shorter-range particles than protons.

The method proposed here for separately identifying hadrons and electromagnetic particles involves including in some of the sampling spaces between converter plates two different detectors: one sensitive to ionization and the other to Cherenkov radiation. The latter could be water or a non-scintillating plastic with wavelength-shifter added. The two detectors would give the same response (relative to a calibration level derived from penetrating muons, for example) for cascades initiated by photons or electrons. On the other hand, hadron-initiated cascades would be expected to produce signals at least 10% greater in the ionization detector than in the Cherenkov detector, again relative to a calibration signal. At high energy the statistics of each signal should be very good (the peak ionization in a hadron-initiated cascade is roughly equal to the incident hadron energy in GeV times the ionization of a single relativistic particle) so that the required discrimination at the 10% level should present no problem. It should be noted that this resolution may be much better than the energy resolution of the detector; the energy resolution is dominated by the statistics of the cascade process, not by the precision of determination of ionization or pulse height at a particular depth.

A specific calorimeter design might utilize plates of iron 3–4 cm thick with argon (gas or liquid) ionization detectors between plates. Plastic scintillator is less satisfactory in this case as its response falls for highly ionizing particles. Then every 5–6 plates (about each nuclear interaction mean free path) a sheet of plastic with wavelength shifter added (such as Pilot 425) could be inserted in addition to the proportional counter or ionization chamber. The energy would be determined in the normal way; the particle type would be determined by digitizing the ratio between the signals in the ionization detectors and the adjacent Cherenkov detectors. For this purpose, all detectors of the respective pairs could be summed and only one ratio determined.

For completeness, it should be recalled that the characteristic profile of the cascade as a function of depth in the detector also provides a handle for separating the two particle types. Thus an electromagnetic cascade develops and decays more rapidly in general than a hadronic cascade. This separation may be limited by the statistical fluctuations from event to event, particularly in the case of hadronic cascades. However, when the instrumentation provides for digitization of each calorimeter layer, this method provides an independent measure of particle type. The separation in this case should be improved if the entire calorimeter were made of converter of a heavy element (W, Pb, or U) to accentuate the difference between radiation and interaction lengths.

There is a small residual ambiguity in particle separation which is unavoidable. High-energy photons have a cross section for hadronic interaction with nuclei of about 100 μb per nucleon (e.g. $\sigma \cong 0.1A$ mb), so that the probability of a photon initiating a hadronic cascade in lead is 0.05% and in iron is 0.1%. On the other hand, a very energetic hadron has a very small probability of producing charged hadrons nearly at rest in the laboratory and leaving almost all of its energy in neutral pions, which subsequently decay to gamma rays and initiate electromagnetic cascades. No explicit estimate of this process is made here as it depends on the cutoff momentum of the charged fragments, however from bubble chamber data above 100 GeV it seems unlikely that such processes exceed 10^{-3} probability.

In conclusion, it appears reasonable to separate photons and electrons from hadrons using only an ionization calorimeter by comparing the signals from an ionization detector with those from a Cherenkov detector in addition to observing the depth of the first interaction and the longitudinal profile of the energy deposition. This separation should be good to at least the 0.1% level beyond which essential ambiguities arise.

References

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