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Brief Reports

Brief Reports are short papers which report on completed research which, while meeting the usual **Physical Review** *standards of scientific quality, does not warrant a regular article. (Addenda to papers previously published in the* **Physical Review** *by the same authors are included in Brief Reports.) A Brief Report may be no longer than 3½ printed pages and must be accompanied by an abstract. The same publication schedule as for regular articles is followed, and page proofs are sent to authors.*

Delayed cascades

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Emission of electromagnetic cascades due to photons of energies >3 GeV from 300-GeV proton-nucleus collisions has been studied in emulsion. The curious "delayed-cascading" effect is evidently much enhanced at larger emission angles, >25 mrad. Samples of 384 "normal" cascades and 642 "slow" cascades have therefore been extracted from among those cascades of long (> 20 mm) rectilinear path length. The angular distribution shown by the slow cascades is different from that for the normal cascades, lending support to the suggestion that two kinds of photons might convert to primary pairs in the experiment.

Energetic electromagnetic cascades arising both from primary photons and incident electrons have been studied in emulsions.[1,2] Alignment of a cascade on the scattering stage, measurement of primary-track momenta, and precise location of secondary-pair (> 25 MeV) vertices provide information on early ($< 10^{-10}$ sec) cascade development hitherto obtained by no other instrument. The photons produced by 200-GeV pion-nucleus collisions convert to primary pairs, and those primary-member tracks of energies > 3 GeV show initial bremsstrahlung conversion in accord with theoretical expectation.[3] The photons emergent from 300-GeV proton-nucleus collisions, however, materialize as pairs of which the energetic primary members show cascading delay $\sim 10^{-11}$ sec.[3] This striking phenomenon is best observed with an incident proton beam of low intensity, and reasonably free of pion contamination.

Efforts to identify possible errors in this result continue. Systematic beam-following in the proton stacks gives an average (inelastic) nuclear-collision path length which is an indirect check on radiation length as well as a measure of beam contamination. The occurrence of cascade origins with respect to beam travel distance d into the stack has also been checked. Low occurrence near the input edge ($5 < d < 10$ mm) of the proton stacks is found to rise to a plateau at $35 < d < 55$ mm, so that the great majority of primary photons are evidently generated locally.

If further observations confirm delayed cascading for the photons from proton-nucleus collisions, with a reduced effect for the photons from pion-nucleus collisions, it would become reasonable to infer the existence of two kinds of photons. It might be supposed that, while pion-nucleus collisions produce mostly "normal" photons, proton-nucleus collisions produce a mixture of "normal" and "long" photons, of which the latter give rise to "slow" cascades. Slow cascades evidently transform rapidly into normal cascading mode[4] and can only be distinguished in a detector of short-time resolution. We attempt here a simple phenomenological distinction between normal and slow cascades for primary photon energies > 3 GeV.

An alternative experimental approach has been suggested by the prediction of direct photon emission from energetic nuclear collisions.[5,6] Such "prompt" photons are expected to show large transverse momenta, and efforts are being made to distinguish them.[7] We have therefore examined our accumulated cascades from the 300-GeV proton experiment in a preliminary search for an angular effect. There are $N_{>10\,\mathrm{mm}} = 1917$ primary-pair member tracks of visible path $T > 10$ mm and energies >3 GeV from 1195 primary vertices. The $n_{<9\,\mathrm{mm}} = 236$ initial secondary pairs (> 25 MeV) which are found at distances $y < 9$ mm along these 1917 candidate tracks give, after trident correction, parameter

$$f^{\mathrm{corr}}_{<9\,\mathrm{mm}} = n^{\mathrm{corr}}_{<9\,\mathrm{mm}} / N_{>10\,\mathrm{mm}} = 0.106 \pm 0.008 \ ,$$

in agreement with earlier results,[3] and in contrast to theoretical $P_{<9\,\mathrm{mm}} = 0.158$. The quantities y, T, and emission angle θ are explained in Fig. 1. It is noted that θ is determined from its projection θ_p on the emulsion plane combined with dip angle and is measured with uncertainty ~ 2 mrad. There is now sufficient material to allow examination of $f_{<9\,\mathrm{mm}}$ in two intervals of θ, as shown in Table I. The delayed-

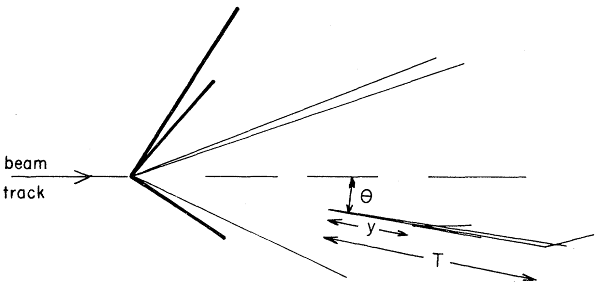

FIG. 1. Explanation of quantities y, θ, and T.

cascading effect is evidently much reduced, relative to the average, at emission angles $\theta < 20$ mrad, and enhanced at larger emission angles. The likelihood that this divergence might have occurred by chance is $< 1.0\%$. The observations of Table I provide further evidence that delayed cascading cannot be ascribed to some radiation-length anomaly in those emulsions in which it is found.

Continuing with cascades in the 300-GeV proton experiment, we now examine those 1026 primary-pair members of energies > 3 GeV (over the first 10 mm) which may be followed over visibly rectilinear paths for distances $T > 20$ mm. These tracks emerge from 687 primary vertices. It is realized that subjective factors arise in identifying such cascades. These include rejection of some tracks on account of visible deflection or degradation, $10 < T < 20$ mm, and increased chances that secondary pairs might escape detection. We seek an arbitrary criterion by which slow cascades might be distinguished from normal cascades, and choose $y < 20$ mm to designate 384 normal primary members. It is noted that, for a few-GeV electron, there is a $(57 \pm 3)\%$ probability of initial secondary-pair conversion, $y < 20$ mm and energy > 25 MeV.

TABLE I. Comparison of delayed-cascading effect at small and large emission angles. $N_{>10\,\mathrm{mm}}$ is the number of candidate tracks with energies > 3 GeV, while $n_{<9\,\mathrm{mm}}$ is the number of initial secondary pairs (> 25 MeV) formed along those tracks. The correction is for direct secondary-pair production.

	Small angles 0–20 mrad	Large angles 25–110 mrad
$N_{>10\,\mathrm{mm}}$	891	639
$n_{<9\,\mathrm{mm}}$	129	61
$n^{\mathrm{corr}}_{<9\,\mathrm{mm}}$	113	49
$f^{\mathrm{corr}}_{<9\,\mathrm{mm}}$	0.127 ± 0.013	0.077 ± 0.011

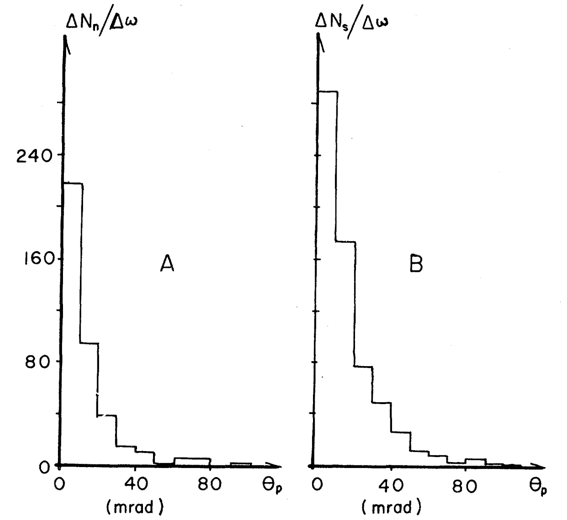

FIG. 2. Angular distributions (A) for 384 normal cascades and (B) for 642 slow cascades. Normal cascades show initial secondary pair at distances $y < 20$ mm, while "slow" means $y > 20$ mm. These cascades are formed by primary-pair members of energies > 3 GeV and rectilinear path length > 20 mm.

The angular distributions for (A) 384 normal cascades and (B) 642 slow cascades ($y > 20$ mm) are compared in Fig. 2, where 10-mrad intervals of θ_p represent uniform elements of solid angle, $\Delta\omega = 3 \times 10^{-4}$ sr, because of the interval of dip angle defined by the path-length requirement, $T > 20$ mm. The enhancement of delayed cascading at larger

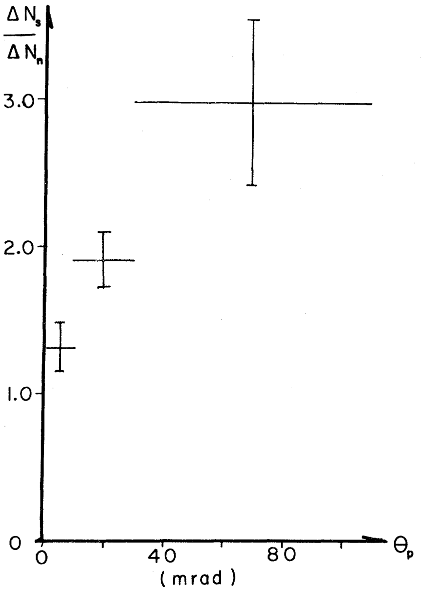

FIG. 3. Comparison of slow to normal cascade occurrence with respect to projected emission angle. Slow cascades evidently emerge with greater probability at larger angles.

emission angles again becomes evident, with effective expression through the ratio $\Delta N_s/\Delta N_n$ vs θ_p shown in Fig. 3. Again we note that the above-mentioned error sources, which affect the "normal" or "slow" designation of a cascade, are unlikely to be angle dependent. It is appropriate to remark here that, ideally, the criterion of "normality" or "slowness" should be applied to both members from a primary vertex, but such a procedure greatly restricts the available data.

The evident divergence in angular distribution between these crudely identified normal and slow cascade samples argues both a distinction in the properties of the respective primary photons and differences in production mechanisms. Under the assumption that both normal and long photons convert to primary lepton pairs, it is possible to estimate the long-to-normal ratio in the photon flux. We attribute all 384 normal ($y < 20$ mm) cascades to normal photons so that there are then 384/0.57 or 673 normal cascades among our sample of 1026 primary members. This gives a long/normal ratio,

$$\gamma_l/\gamma_n = 0.53 \pm 0.12 \ ,$$

when account is taken of uncertainties in the premises. The notion of long-photon conversion to oppositely charged light-particle products must, however, be considered with no assumption of mass symmetry between those products. If only one of those products might be of electronic mass, the above γ_l/γ_n result would be erroneous.

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