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LPM Effect in the SSC Detectors

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1. Introduction

The LPM effect (Landau and Pomeranchuk, 1953; Migdal, 1956) decreases the bremsstrahlung and pair-production cross-section in dense materials at high energy and modifies the secondary production spectra. As a results the development of electromagnetic cascades is slowed down and the cascades penetrate deeper. Although it has been estimated that the effect affects cascade development significantly only at energies $> 61.5 L_{cm}$ TeV (where L_{cm} is the value of the radiation length of the material in cm) (Stanev et al., 1982) the need to use heavy materials in the SSC calorimeters calls for a new and more detailed estimate. Another manifestation of the LPM effect is that with the decreased bremsstrahlung cross-section the electron energy loss becomes so small that at TeV energies some electrons might be misidentified as muons.

The LPM effect is due to the interference between multiple scattering and radiation when the distance between neighbouring nuclei is comparable to the radiated photon wavelength. When the two electron momenta (initial and final electron momenta for radiation processes or e^+, e^- momenta for pair production) become ultrarelativistic, the mass of the system at the vertex is negligible, so that the longitudinal momentum transfer$q_{||}$ can be very small. Conversely the distance l along which the radiation occurs becomes very long.

$$l \sim \frac{\hbar}{q_{||}} \sim \frac{2E(E-ck)}{(mc^2)^2}\frac{\hbar}{k} \tag{1}$$

where E is the initial electron energy, k is the photon momentum, and m is the electron mass. In media with sufficient density more that one atom is encountered on the distance l. These additional atoms cause multiple

Coulomb scattering of the two electron waves introducing decoherence between the two states which reduces the result of the integration to obtain the transition matrix element.

The suppression of the radiation matrix element becomes important when when the rms multiple-Coulomb-scattering angle $\langle\theta_s^2\rangle^{1/2}$ becomes larger than the scattering angle θ_r due to the radiation process. A parameter s is defined as

$$s[\xi(s)]^{1/2} \equiv \theta_r/2\langle\theta_s^2\rangle^{1/2} \sim \frac{u}{1-u} \tag{2}$$

for the case of bremsstrahlung, where $\xi(s)$ is a logarithmic factor $O(1)$ and u is the fractional energy of the radiated photon. The effect must be considered for $s \leq 1$. For pair production $s \sim 1/(v-v^2)$, where v is the fractional energy of the electron in the created pair, and since $1/(v-v^2) \geq 4$ (while $u/(1-u)$ can be arbitrarily small) , the LPM effect in pair production becomes important at energies approximately two order magnitudes higher then for radiation.

Experimentally the LPM effect has been studied in cosmic rays, where it has been only qualitatively confirmed. A quantitative result comes from a comparison of the intensity ratios of 20 to 80 MeV photons from Pb relative to Al targets and from W relative to C in experiments with a 40 GeV electron beam in Serpukhov (Varfolomeev et al., 1976).

Since the LPM effect is much stronger for electrons and in heavy materials we have calculated the bremsstrahlung cross-section and the electron energy loss in uranium. These results give an upper limit of the influence of the LPM effect in the SSC energy range.

2. Bremsstrahlung cross-section and energy loss in uranium

Fig. 1 shows the photon production spectrum in uranium as a function of the fractional photon energy. The full line represents the Bethe-Heitler spectrum, while the dash, dash-dot and dot lines show the decrease of the probability for radiation of low energy photons with the energy. At fractional photon energies of 10^{-8} the suppression is significant ($\sim$ factor of 100) even at electron energies of 1 GeV. For 10 TeV electrons the suppression is up to four orders of magnitude.

This graph is, however, somewhat misleading, since from experimental point of view the interesting parameter is the probability for radiation of photons above certain energy threshold. Such a result is shown on Fig. 2,

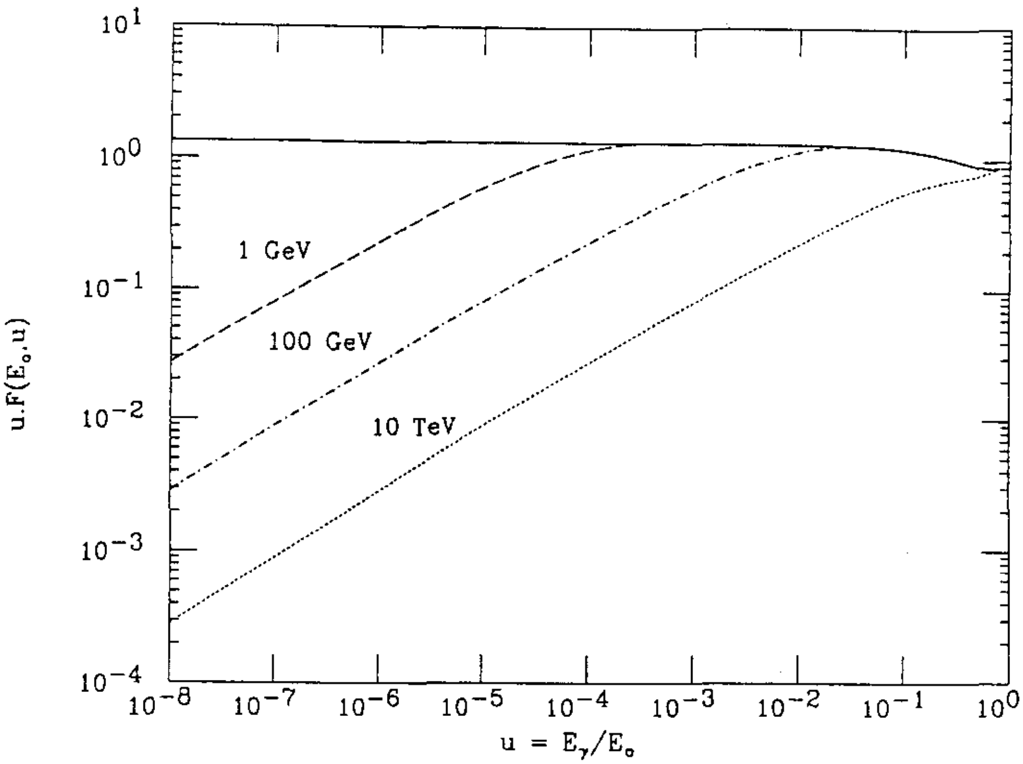

Fig.1. Differential bremsstrahlung intensities per radiation length in uranium. The solid line is for the limiting Bethe-Heitler cross-section. The energy of the incomming electron is indicated by each curve.

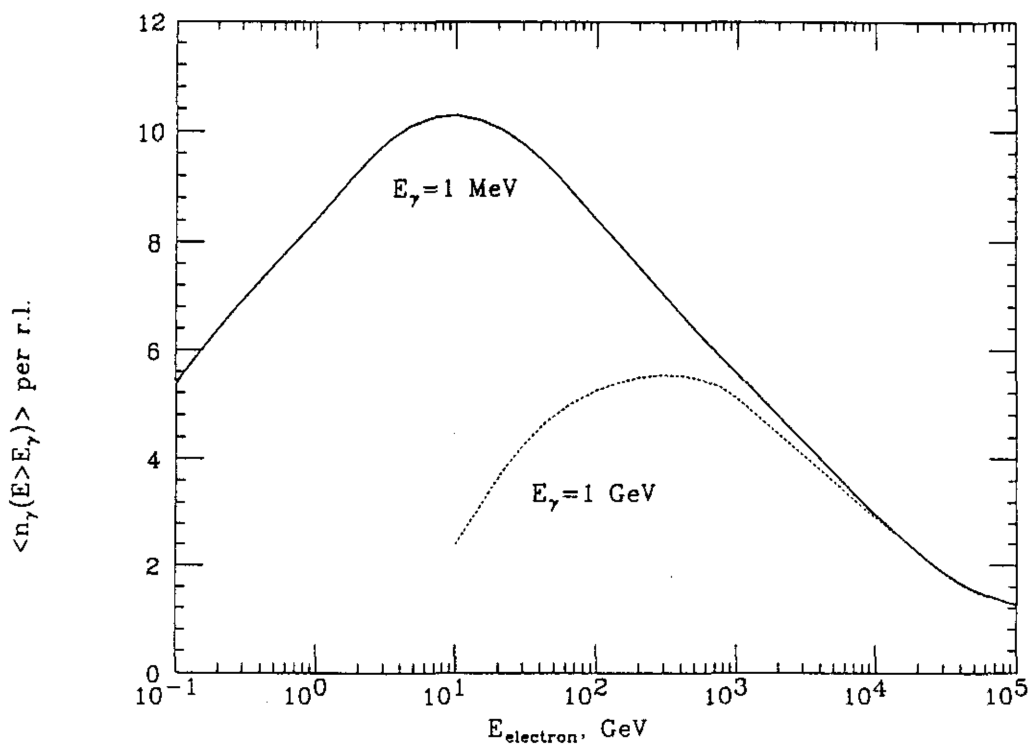

Fig.2. Average number of photons with energy > 1 MeV and > 1 GeV (dotted line) radiated on one radiation length of uranium as a function of the electron energy.

where the average number of photons radiated with energy above 1 MeV and 1 GeV is plotted versus the electron energy. Without the account for the LPM effect $\langle n_\gamma(E > E_\gamma)\rangle$ would continue to grow logarithmicaly with the electron energy. Because of the LPM effect the production of > 1 MeV photons reaches a maximum at ~ 10 GeV and significantly declines in the TeV region. At 10 TeV the production of > 1 MeV photons is lower than the Bethe-Heitler spectrum by a factor of 7.

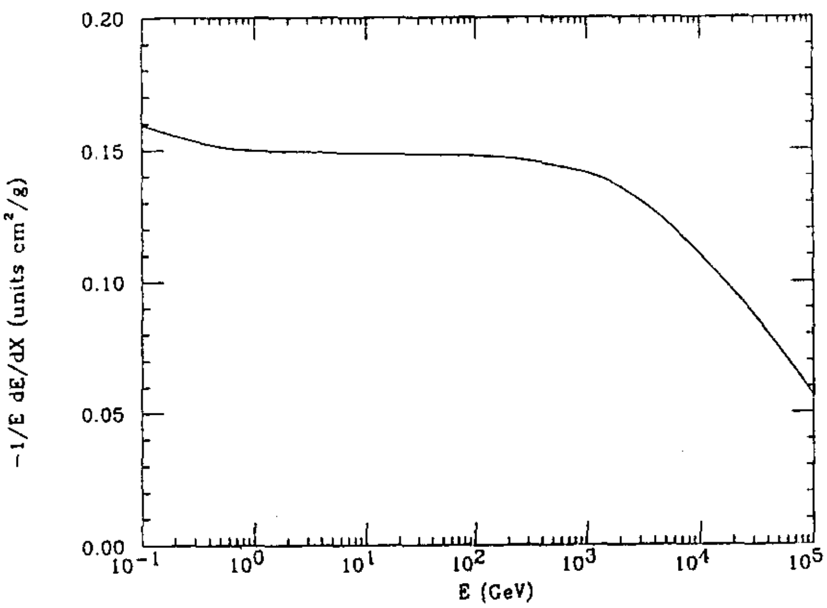

Fig.3. Fractional electron energy loss in uranium.

The decrease of the bremsstrahlung cross-section leads, of course, to a corresponding decrease of the electron energy loss. The energy loss is not affected as strongly as the cross-section because the suppression is stronger at low photon energies (note the $u/(1-u)$ factor in Eq. 2). The fractional electron energy loss per $g.cm^{-2}$ is shown on Fig. 3. The decline in the MeV region is due to the decreasing contribution of the ionization loss to the fractional energy loss. The influence of LPM effect can be detected at ~ 100 GeV but it only makes a difference of less than 30% even at 10 TeV.

3. Conclusions

The LPM effect will be present at the SSC energies, but it can hardly change the present estimates of the energy flow in the planned detectors.

Past calculations of the development of electromagnetic showers with account of the LPM effect (see Stanev et al., 1982 for other references) show that the cascade development is noticeably affected only when the cross-section for $u \sim 1/2$ is decreased, i.e. at 20 TeV in uranium. Some more subtle manifestations of the effect are possible. The angular and lateral distributions of the cascade particles in LPM cascades become narrower. The combination of the narrow angular spread and the larger depth of the first interaction will decrease the electromagnetic albedo from the detectors. Even this effect is not likely to be large, though, because the interaction products are dominated by photons, not electrons.

The decrease of the electron energy loss is not significant enough to cause misidentification of electrons as muons, unless the ratio of electrons to muons is of the order of 10^4. If a muon signal, however, has an electronic background of this order of magnitude, the LPM decrease of the electron energy loss must be accounted for in calculating the expected noise.

Acknowledgments

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References

L. Landau and I. Pomeranchuk, Dok. Akad. Nauk SSSR *92*, 535 (1953); *92*, 735 (1953).

A.B. Migdal, Phys. Rev. *103*, 1811 (1956); Sov. Phys.-JETP *5*, 527 (1957).

T. Stanev, C. Vankov, R.E. Streitmatter, R.W. Ellsworth, and T. Bowen, Phys. Rev. *D25*, 1291 (1982). See also T. Bowen, R.W. Ellsworth, T. Stanev, R.E. Streitmatter, and C. Vankov, At. Data Nucl. Data Tables *24*, 495 (1979).

A.A. Varfolomeev, V.I. Glebov, E.I. Denisov, A.M. Frolov, and A.S. Khlebnikov, Sov. Phys.-JETP *42*, 218 (1976).