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AN EXPERIMENTAL TEST OF THE LPM EFFECT: BREMSSTRAHLUNG SUPPRESSION AT HIGH ENERGIES*

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ABSTRACT

We are preparing an experiment at SLAC to test the LPM (Landau-Pomeranchuk-Migdal) effect. In bremsstrahlung from high energy electrons, the longitudinal momentum transferred from the nucleus is very small. Then, by the uncertainty principle, the interaction must occur over a distance much larger than the atomic scale. In the LPM effect, multiple scattering changes the electron trajectory within the interaction distance, and so suppresses the bremsstrahlung. This effect, predicted in the 1950's, has never been quantitatively studied. For dense, high Z, targets in a 25 GeV electron beam, suppression is significant for photons below a few hundred MeV. By comparing bremsstrahlung from targets of different (Pb, U, W and C), it is possible to measure the suppression accurately. We will also study the longitudinal density effect, where very low energy photon emission is suppressed due to the dielectric effect of the medium.

1. The LPM Effect

In the early 1950s, it was realized that, in contrast to the classical picture, bremsstrahlung is not a point interaction[1] When a high energy electron exchanges a virtual photon with a nucleus and emits a photon via bremsstrahlung, the longitudinal momentum transfer between the electron and the nucleus is very small[2]

$$q_{\|} \sim \frac{m^2 E_\gamma}{2E_e(E_e - E_\gamma)} \sim \frac{E_\gamma}{2\gamma^2}$$

where γ is E_e/m, and the latter relationship only holds for $E_\gamma \ll E_e$. Because $q_{\|}$ is small, by the uncertainty principle, the exchange must take place over a finite distance, $\hbar/q_{\|}$. For example, a 25 GeV electron emits a 100 MeV photon over a 2μ long formation length. If something happens while the electron travels this distance, the emission is suppressed.

A number of things can perturb the electron and so suppress the bremsstrahlung. In the LPM effect, when the electron multiple scatters by an angle larger than the photon emission angle $1/\gamma$, then the emission is suppressed.

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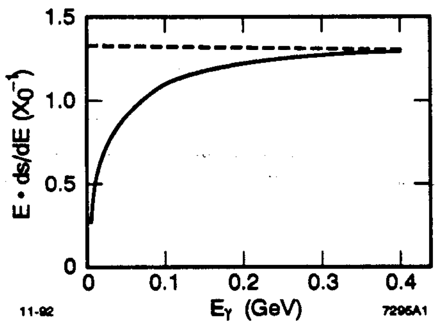

Fig. 1. Comparison of the LPM (solid line) and Bethe-Heitler (dashed line) bremsstrahlung cross sections for 25 GeV electrons in uranium.

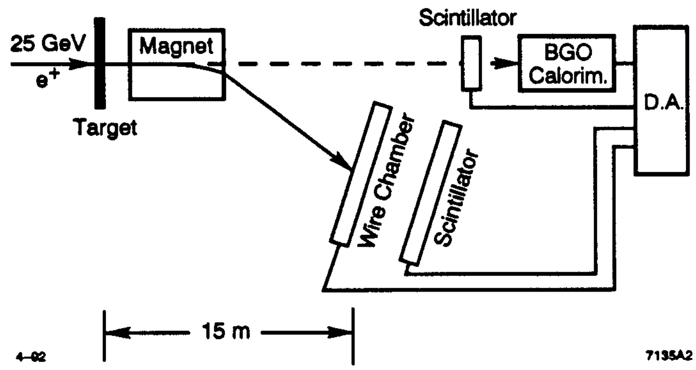

Fig. 2. Layout of the proposed experiment. The scintillators are used for triggering and to veto charged particles hitting the calorimeter.

This happens when the photon energy is less than E_e^2/E_{LPM}, where E_{LPM} is a material-dependent constant, 2.6 TeV in uranium and 4.2 TeV in lead. For example, for a 25 GeV electron in uranium, the suppression is significant for photon energies below 250 MeV.

Figure 1 compares the results of a detailed calculation[3] with the traditional Bethe-Heitler calculation. A similar effect occurs for pair creation by high energy photons. Because the LPM effect depends on the electron energy, the effect influences photon conversions only at higher energies. At high enough energies, the LPM effect increases the effective radiation length, lengthening electromagnetic showers.

For low-energy radiated photons, another phenomenon, the longitudinal density effect, becomes important.[4] In it, the dielectric constant of the medium gives the photon a phase shift over the length of the formation zone. Then, contributions to the photon amplitude from different portions of the formation zone stop adding coherently, reducing the photon amplitude. This occurs when $\exp(i(k \cdot x - \omega t))$ changes significantly over the formation zone, which happens when $k \cdot x - \omega t \approx 1$ for $x = l = ct$. Here $k = \sqrt{\epsilon}\omega/c = \omega/c\sqrt{1-\omega^2/\omega_p^2}$ where ω_p is the plasma frequency (60-80 eV in dense media). Some algebra shows that this effect is significant for photon energies below $\gamma\omega_p$, which occurs for $E_\gamma/E_e < \omega_p/m_e$, which is 10^{-4} in lead.

A number of previous experiments have studied the LPM effect qualitatively; several with cosmic rays. In 1977, a group at Serpukhov studied the LPM effect using 40 GeV electrons. They saw a somewhat larger effect than predicted by theory, but with large systematic uncertainties.[5]

2. The Experiment

The experimental apparatus is shown in Figure 2. A low-intensity (single e^-) beam hits a thin target, emitting a photon. The photon travels downstream into BGO calorimeter. The electrons are bent by a magnet into a wire chamber.

The wire chamber provides a rough measurement of the electron momentum, allowing us to completely reconstruct the event.

The experiment is assembled almost entirely from existing equipment. The calorimeter is a 45 crystal BGO array, with an energy resolution of 8% FWHM at 40 MeV. The calorimeter is 50 meters downstream, giving an angular resolution of 0.1 mrad, allowing us to study the angular dependence of the LPM effect.

We plan to take data with four target materials: carbon, lead, uranium and tungsten, at two thicknesses, 0.05 and 0.10 X_0. These thicknesses are a tradeoff between a high rate and pileup from a single electron interacting twice in the target. The remaining double photon pileup is corrected for by Monte Carlo simulation.

Other backgrounds include synchrotron radiation from the bending magnets, transition radiation from the target, and non-bremsstrahlung interactions.

3. A Parasitic Test Beam

This experiment requires a low-intensity beam. We believe that we have developed a design to produce such a beam parasitically during SLC operations. The beam originates in the Sector 29 collimators, which typically scrape off about 10% of the SLC beam. Since the collimators are relatively thin (2.2 X_0), some high energy photons escape from the collimators and continue downstream into the beam switchyard. There, they hit an existing 0.6 X_0 valve, and are converted into e^+e^- pairs. The electrons are captured and transported to the end station. Simulations indicate that the parasitic beam should have a flux larger than 1 e^-/pulse at 25 GeV, increasing at lower energies, subject to a few assumptions about the beam. Therefore, we are preparing for a January 1993 test to measure the beam flux. If the test is successful, we plan to take data in the spring of 1993.

4. Acknowledgements.

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5. References

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