# PROPOSAL

## An Experimental Test of the Landau-Pomeranchuk-Migdal Effect

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## ABSTRACT

We propose to make a quantitative measurement of the Landau-Pomeranchuk-Migdal effect using the wide-band photon beam facility at the Tevatron during the next fixed-target running period. This effect, a modification of the Bremsstrahlung spectrum at low gamma energies from dense, high-Z radiators, has never been quantitatively measured, although there have been some qualitative verifications. It is of not only theoretical interest, as a departure from standard Q.E.D. Bethe-Heitler theory, but it is of practical interest as a phenomenon which becomes more relevant at SSC energies and in ultra-high energy cosmic ray experiments. Following set-up and debugging of the apparatus, only one or two weeks of data collection should be required to obtain Bremsstrahlung spectra from a variety of radiators with excellent statistics. The wide-band beam as presently set up appears ideally suited for this measurement; all that is required is a detector of photons of 100 MeV-300 GeV and appropriate pulse-height analyzers.

## I. INTRODUCTION

The Landau-Pomeranchuk-Migdal (LPM) effect was predicted and quantitatively calculated by these Russian authors in the 1950's[1]. Qualitatively, it argues that an electron which radiates a photon at high energy experiences a longitudinal momentum transfer, $q$ which is very small, corresponding to a longitudinal distance, $z$ (from the Uncertainly Principle) which may be macroscopic; e.g. microns. If the electron is disturbed, e.g. scattered, within this distance, the radiation is suppressed. In naive language, the uncertainty principle says that the electron "doesn't know it has radiated" over this distance. Quantitatively,

$$q = p_e - p'_e - k = \sqrt{E_e^2 - m^2} - \sqrt{E_e'^2 - m^2} - k$$

where $p_e, p'_e$, and $E_e$, $E'_e$ are the electron momentum and energy before and after the interaction respectively, and $k$ is the photon energy. For high energy electrons, this simplifies to

$$q \simeq k/2\gamma^2,$$

where $\gamma$ is $E_e/m$, and this holds for $k \ll E_e$. The corresponding distance, which may be called the "formation zone", is

$$z = \hbar c \gamma^2 / k.$$

If, over this distance, the electron experiences multiple Coulomb scattering by an angle larger than the angle of Bremsstrahlung radiation, the radiation is suppressed. Qualitatively, a useful parameter is an energy E(LPM), where E(LPM) $= m^4 X_o / c\hbar E_s^2$ or E(LPM) (TeV) = 7.6$X_o$ (cm); $E_s$ is 21 MeV. The photon spectrum is suppressed relative to the classical Bethe-Heitler spectrum for photon energies less than

$$k < E_e^2/\mathrm{E(LPM)}.$$

Detailed quantitative calculations have been made by Stanev and by Maciaszczyk, et al.[2]; some useful graphs are appended hereto for reference (Fig. 1). It is seen that the LPM effect causes a suppression of Bremsstrahlung spectrum for 300-400 GeV electrons on tungsten below about 30 GeV, with a suppression of a factor of (about) 4 at one GeV. The corresponding suppression in carbon is only apparent below about one GeV.

Beyond the theoretical interest (see Bell, ref. 3, for example), the LPM effect is of very practical interest in the design of detectors for energies above a TeV at the SSC. It is also very relevant in cosmic ray physics, leading to an elongation of the electromagnetic cascades from primary gammas or electrons of energies above hundreds of TeV. It should be noted that there is a corresponding LPM effect in the pair-production process, however its onset is at a higher energy.

This experiment was first suggested in a Letter of Intent from L.W. Jones to John Peoples March 2, 1990, and subsequently discussed with Taiji Yamanouchi in the spring of 1991, with a follow up letter May 14, 1991.

## II. EXPERIMENT

The proposed experiment consists simply of careful, high-statistics measurements of the Bremsstrahlung spectra from a variety of radiators in the wide-band photon lab, using a 350 GeV electron beam, together with appropriate background checks, etc.

A. Beam. The required beam is the 350 GeV electron (or positron) beam as it exists entering the wide-band photon laboratory. The entire experimental setup would be upstream of the photon experiments set up in that lab. One desirable (but not absolutely necessary) modification would be to increase the length and thus reduce the field strength of the first bending magnets beyond the Bremsstrahlung radiator, in order to reduce the synchrotron radiation background. This possibility will be explored.

The electron beam intensity is about $10^8$ per spill (20 seconds), which is more than enough; if anything, we would perhaps reduce this by about an order or magnitude.

B. Radiator. A wheel containing a variety of radiators will be used so that radiators may be changed easily. Radiators of about 2%-5% of a radiation length will be used. Obvious radiators of interest are dense, high-Z metals such as W, Au, Bi, U, Pb, and Ta. Contrasting low density, low-Z targets are C, Li, and Be. One or two intermediate targets such as Al, Cu, and Ag would be interesting as well. And of course one position should be empty for measurement of background; this will include synchrotron radiation plus Bremsstrahlung from windows and other residual materials in the electron beam.

By limiting the radiator to about 5%, there will be on the average only one photon radiated above 10 MeV for every 2 electrons, so that photon pileup should not be a problem.

C. Detector. The gamma detector is not yet determined, although any of a large number of existing detectors may be used; lead glass, BGO crystals, NaI, CsI, a Pb or W-scintillator calorimeter, etc. We would hope to have a detector composed of a matrix of crystals, or in any event with position resolution of the gamma conversion point, in order to identify the profile of the gamma flux.

The detector(s) output would be fed to a pulse height analyzer. The desired energies are primarily from 100 MeV to about 10 GeV, although it would be appropriate to cover up to the full energy of the electron beam (about 400 GeV). It may be sensible to use two PHA's with overlapping ranges, one connected to the anode of the PMT and the other to a dynode with a gain 20-50 times less in order to span a dynamic range of over $3 \times 10^4$.

D. Rates. With a beam of $2 \times 10^7$ electrons per 20 second spill, there would be about $10^6$ photons recorded per spill, or a rate of only 50 kHz. And yet a Bremsstrahlung spectrum containing $10^8$ photons could be collected in 100 beam pulses; more than adequate statistics if spread into 100 channels, even with the statistics of background subtraction.

E. Background. The largest background of concern is synchrotron radiation of the electrons in the sweeping magnets beyond the radiator (necessary to separate the electron beam from the gammas). The "critical energy" for 350 GeV electrons is 82 B(MeV), where B is the magnetic field strength in Teslas[4]. This puts an effective lower limit to the Bremsstrahlung energies which may be studied. Szadkowski and Maciaszczyk have plotted the synchrotron radiation spectrum together with the Bremsstrahlung for our situation [5]; (Fig. 2). Quantitatively, the synchrotron radiated gamma energy from 350 GeV electrons is 178 B MeV per milliradian of bend (B in Teslas). For our configuration, about 2 mr are necessary to clear the photon beam, and the total bend for the full energy electrons is 5 mr. Thus the synchrotron background to be subtracted from the Bremsstrahlung will be about 200-500 MeV per electron.

Other background effects, e.g. transition radiation, are important only at energies below several MeV, and are not important for our range of parameters.

*F.* Required Running Time. As noted above, a high-statistics Bremsstrahlung spectrum should require only about an hour of beam time. A reasonable target data sample is a set of spectra from 3 radiator thicknesses of a high-Z target (e.g. tungsten) and 3 radiator thicknesses of a low-Z radiator (e.g. carbon), plus single spectra from at least 2 other high-Z and 2 other low-Z radiators as well as 3 intermediate-Z targets. Interspersed among these runs should be at least 3 background (no radiator) runs and at least 3 repeat runs of two "reference" radiators. Thus we should plan on a data set of about 25 complete Bremsstrahlung spectra. At 100% efficiency, this should require less than 2 full days of running.

Realistically, we should plan on 2 weeks, preferably one week followed by a break of a week or more (to understand and correct any problems) and then a second week of serious data collection.

It seems, from a visual inspection of the wide-band lab last June, that our detector could be placed upstream of the existing experiments in the wide-band hall, and could be easily installed or removed as running time allocations required. Hence this experiment qualifies as nearly parasitic, or (in the grand Wilsonian tradition) as a "Nook and Cranny" experiment. It is assumed that, in the time before the next fixed-target running period, we would assemble and bench-test a detector together with the required electronics.

## III. COLLABORATION

The spokesman for this experiment is Lawrence W. Jones from the University of Michigan. Other collaborating Michigan physicists will be Professor Byron P. Roe, Dr. Robert C. Ball, and Dr. H. Richard Gustafson. Dr. Gustafson is resident at Fermilab about half time, and can serve as liasson to the group during the preparation of the experiment.

A major collaborating group is from the University of Lódź in Poland. There has been ongoing discussion with Professor Tomaszewski and members of his group over the past two years, and they are eager to contribute and participate. They have considerable familiarity with the LPM effect from their cosmic ray work, and have both theoretical and experimental expertise to contribute. We are applying to the NSF Office of International Programs for financial assistance to facilitate their participation. This is obviously a chicken-and-egg situation, in that the approval of this grant will be greatly enhanced by approval of the experiment, and experimental approval will be enhanced by their guaranteed participation.

Other collaborators will be Dr. Mary Anne Cummings of the University of Hawaii group, currently working on D0, and a recent Michigan Ph.D. Also Professor Jeffrey Wilkes, Professor Jere Lord, and Dr. Steven Strausz of the University of Washington (Seattle). Dr. Wilkes and his group have also been active cosmic ray experimentalists and have been sensitive to the impact of the LPM effect on high-energy cosmic ray observations. Professor Wilkes is a former colleague of L.W. Jones in the Echo Lake cosmic ray experiments some years ago.

It is expected that graduate students from at least Michigan and perhaps Washington will join this experiment; it is an ideal thesis-sized project.

## IV. OTHER EXPERIMENTS

There have been modest attempts to study the LPM effect. Of particular note is an experiment in a 40 GeV beam at Serpukhov in the 1970's[6]. From the study of the development of electromagnetic cascades in cosmic ray emulsion chambers, a qualitative verification of the effect was also obtained[7]. Recently we have seen a proposal for a SLAC experiment to study the LPM effect in a 25 GeV electron beam (SLAC-Proposal-146)[8]. As the gamma energy at which the LPM effect becomes important is proportional to the primary electron energy squared, they will be constrained to look at much lower energies than in our case. Their advantage is that the synchrotron radiation is also much less for these low electron energies. Although their experiment will probably run earlier than ours, we believe that ours should be more definitive. We will in any event communicate with them and learn from their experience.

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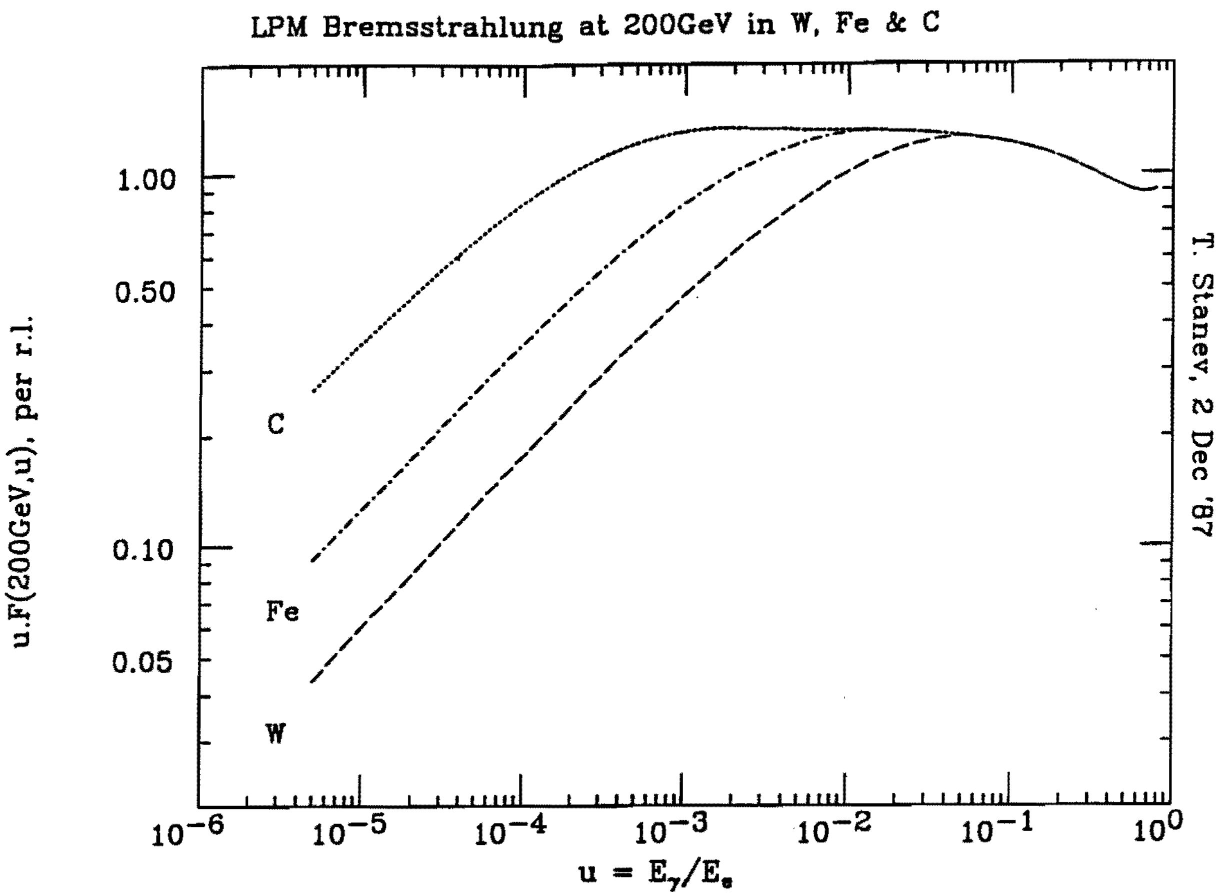


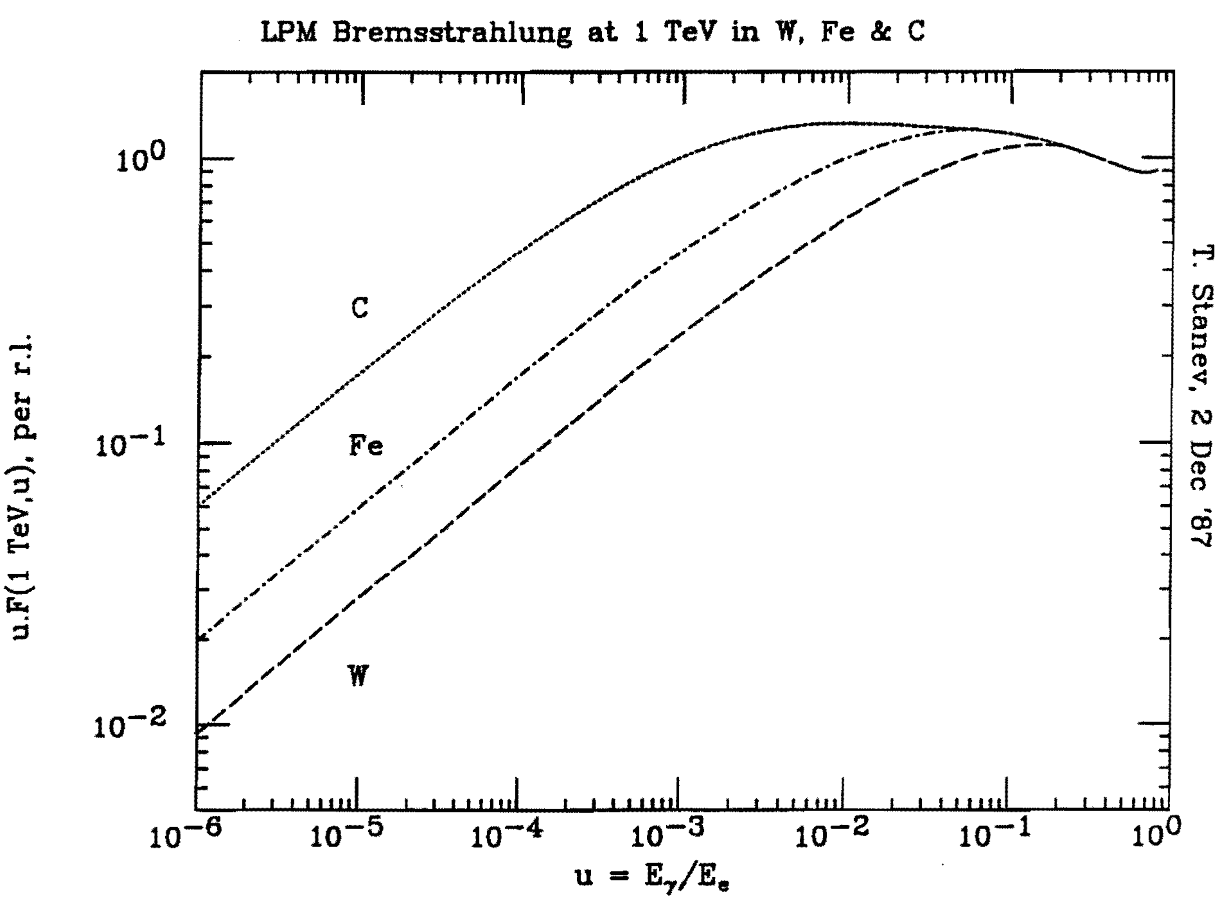


Figure 1a. LPM Effect in C, Fe, and W for 200 GeV and 1 TeV electrons (from Stanev).

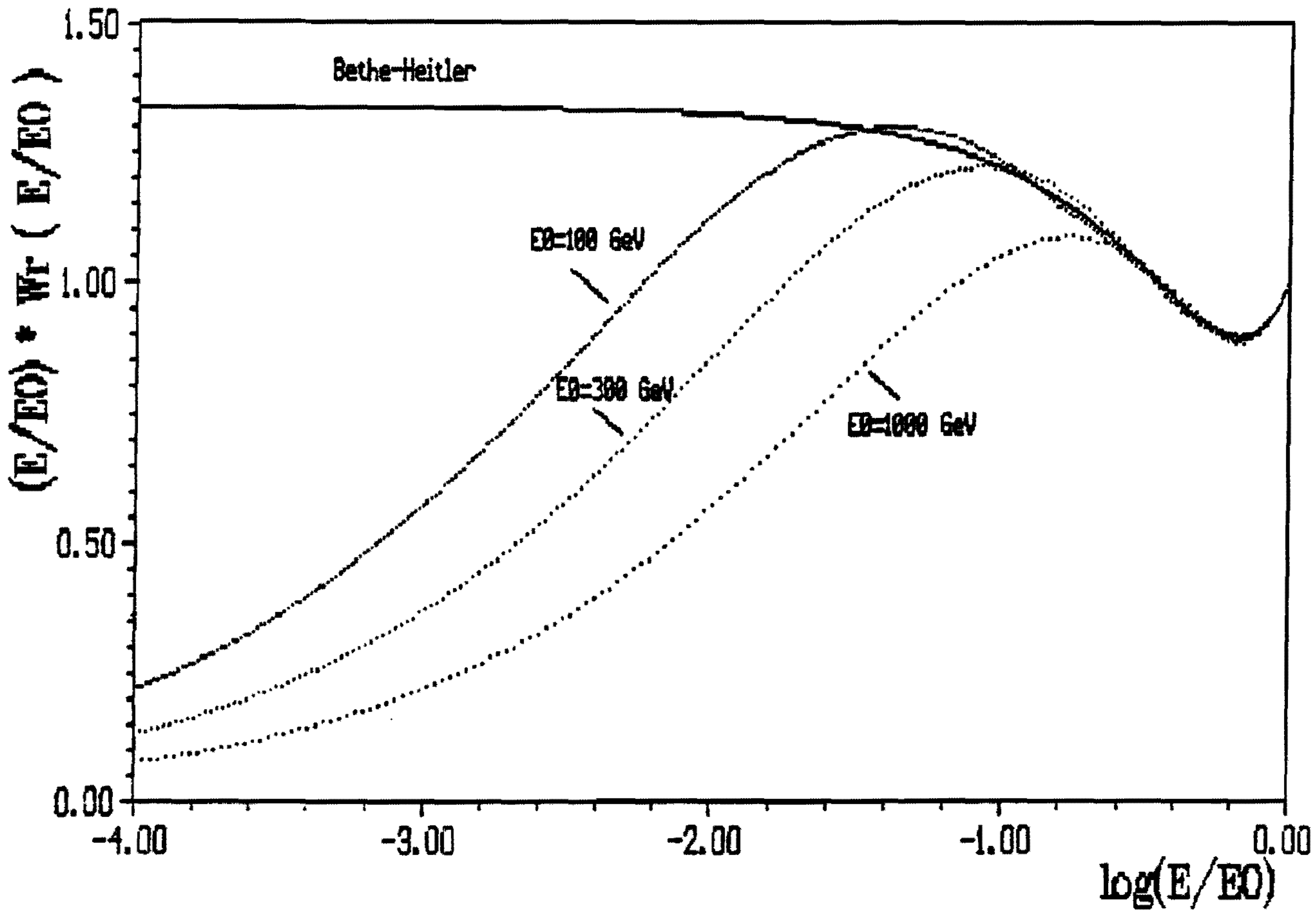


Figure 1b. Energy distribution from Bremsstrahlung photons for 100, 300 and 1000 GeV electrons in Pb. The full curve is for BH cross section (very large energy limit) (from Masiaszczyk, et al.).

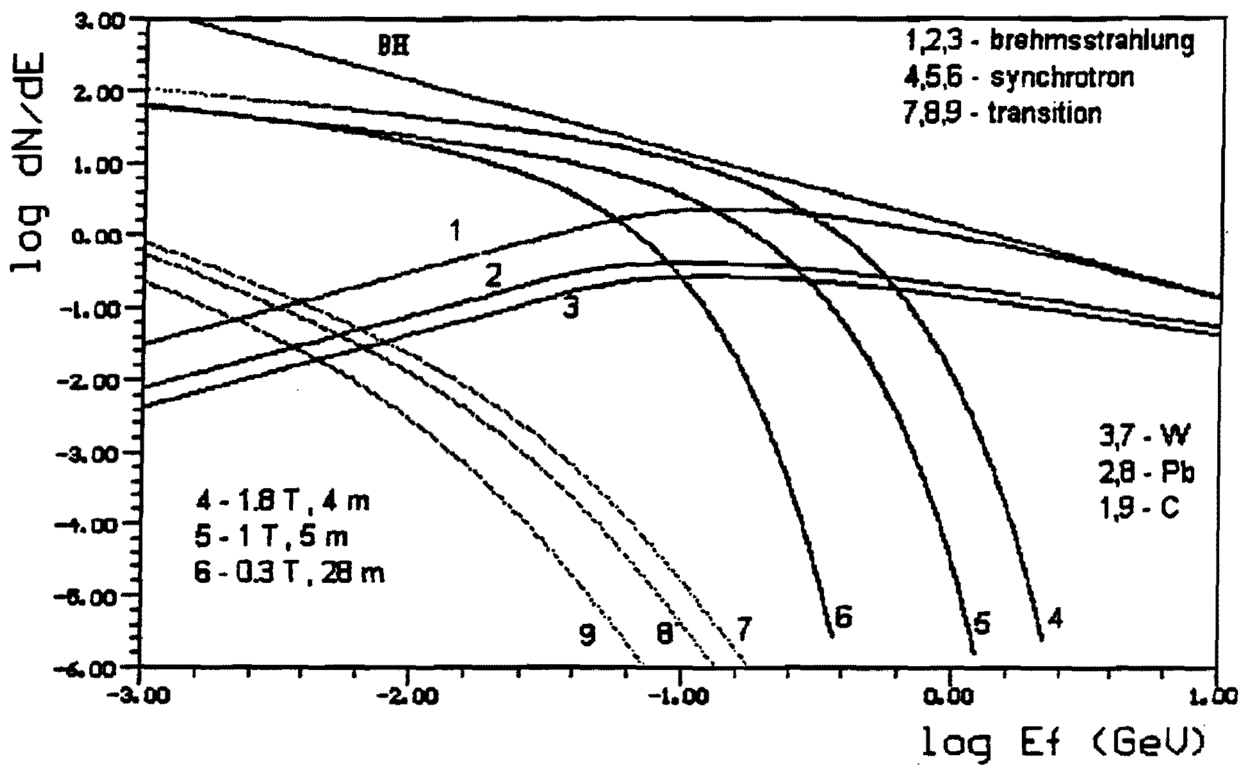


Figure 2. Comparison of the contributions of Bremsstrahlung, transition radiation, and synchrotron radiation to the gamma flux for 350 GeV electrons (from Szadkowski, et al.).