An Experiment to Measure the Air Fluorescence Yield in Electromagnetic Showers

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Abstract

FLuorescence in Air from SHowers (FLASH) or E-165 is an experiment to be carried out at the Stanford Linear Accelerator Center (SLAC). It aims to measure the total and the spectrally resolved air fluorescence yield of electromagnetic showers with an accuracy of better than 10%. The experiment explores the energy dependence of the yield down to the lowest energies effective in air showers, ~ 100 keV. For this experiment, the SLAC linac will deliver a 28.5 GeV electron beam at intensities of 10^7 to 10^9 particles per pulse. A thin target run will allow us to measure the fluorescence yield per beam track depending on pressure and atmospheric impurities. Later, the interaction of the beam in a thick target will mimic the distribution of electron energies found deep in cosmic ray induced air showers. In June 2002, a test experiment at SLAC measuring the total fluorescence of air and nitrogen between 300 and 400 nm in a thin target mode has proven the feasibility of such an experiment. Results of this test run will be presented.

1. Introduction

To measure the energy spectrum of ultra high energy cosmic rays (UHECR) is the goal of several past, present, and future experiments using the air fluorescence technique. Perhaps the most interesting question in this regard today is if there is a GZK cut-off[1,2] as predicted by well-established physical laws or if there is no end point and if the spectrum extends beyond 10^{20} eV. The High Resolution Fly's Eye (HiRes) detector utilizes air fluorescence to detect cosmic rays and to measure their energy. HiRes began operation in 1997 and has since then observed one event above 10^{20} eV[3]. AGASA, the world largest ground array located in Japan, utilizes the particle sampling technique. AGASA has accumulated data for a decade and has found seven super-GZK events with an aperture similar to that of HiRes[4]. The HiRes flux measurement is systematically lower than that of AGASA[5]. The importance of the physics involved, the disagreement between HiRes and AGASA, and the expectation that other systematic uncertainties in existing and proposed future fluorescence-based cosmic ray experiments will be

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reduced significantly makes careful studies of the fluorescence yield necessary.

2. An Experiment to Measure the Air Fluorescence Yield

In his thesis from 1967 Bunner[6] summarized all existing data and quoted errors of around 30% on the listed fluorescence efficiencies. In a more recent experiment Kakimoto *et al.*[7] measured the total fluorescence yield between 300 and 400 nm with an uncertainty of >10%. The newest measurement using a ^{90}Sr β source by Nagano *et al.*[8], determined the total fluorescence yield between 300 nm and 406 nm with a systematic uncertainty of 13.2%. Both experiments also measured a number of individual spectral lines. The proposed FLASH experiment using the final focus test beam at SLAC aims for a systematic uncertainty of less than 10% in the net fluorescence yield and also in the yield of the individual spectral lines. SLAC is an ideal site for this study because the SLAC beams interacting in a thick target produce secondary electron energy distributions similar to those generated in extensive air showers (EAS). In addition, all the relevant N_2 fluorescence transitions are only accessible by electron excitation. Finally, the final focus test beam (FFTB) pulse has an energy equivalent to that of an EAS in the range of 10^{15} to 10^{20} eV.

The experimental program of FLASH is designed in view of the basic fluorescence issues:

- The gas composition will be varied, starting with a measurement of the yield in dry air. Then the yield in pure nitrogen and in a range of intermediate N_2/O_2 concentrations will be measured. In addition it is planned to introduce small quantities of argon, water vapor and possibly carbon dioxide to check for possible enhanced de-excitation effects from trace contaminants that are known to be present in the atmosphere.

- The pressure dependence of the yield will be studied with great precision in pressure sweeps between 10 Torr and 760 Torr.

- The fluorescence yield Y is expected to vary linearly with the energy deposited in the gas by the passing electrons. This will be studied by showering a beam in blocks of material of different thicknesses, and measuring the air fluorescence produced by the emerging particles.

- A detailed measurement of the fluorescence spectrum resolved to 10 nm is important in limiting the systematic uncertainty of fluorescence-based cosmic ray experiments, since the λ^{-4} dependence of Rayleigh scattering in the atmosphere leads to a significant distortion in the differential spectrum of light arriving at a detector from that emitted at the air shower.

- The decay time of fluorescence is a function of the transition involved and of the gas pressure. A measurement of the pressure dependence of the decay time for each spectral line is an important cross-check confirming that indeed air or N_2 fluorescence is measured and that possible backgrounds are understood.

The implementation of FLASH will be done in two stages. The first stage of the experiment will be run in a thin target mode. The electron beam will pass largely undisturbed through a small volume of gas at a rate of 10-30 Hz. In a test run in June 2002 (T-461), two PMTs located at 40 cm from the beam and viewing a 1 cm length of the beam line measured the fluorescence light directly produced by the beam electrons. T-461 has shown that Y is linear with respect to beam intensity below $\sim 10^9$ e^- / pulse. Like in T-461, HiRes wide-band filters will be used for FLASH to measure the total fluorescence yield between 300 nm and 400 nm. The PMT response stability will be monitored with UV LEDs fired between beam pulses and the background will be measured by filling the system with a non-fluorescing gas and by a installing a shutter in front of the detectors. Narrow band filters will be used to measure emission spectrum between 300 nm and 450 nm.

In the second stage of the implementation, the experiment will be run in a thick target mode to study the relation of Y to dE/dx. An electromagnetic shower is generated by the introduction of varying thicknesses of radiator into the beam. Al_2O_3 is the preferred material and will be assembled in remotely removable layers of square cross section, approximately 2 to 4 radiation length thick. A fluorescence chamber will be installed behind the shower material, with a thickness of only 4 cm along the beam to reduce the effect of the fast lateral spread of the showers in air.

3. Results of the Test Run

In figure 1. the photon yields versus electron energy as measured by Kakimoto and Nagano *et al.* are plotted together with the preliminary result of T-461 at atmospheric pressure. The dE/dx curve is normalized to the Kakimoto measurement at an electron energy of 1.4 MeV. Assuming that Y scales as dE/dx a good agreement of the preliminary result of T-461 with the preceding measurements by Kakimoto *et al.* and Nagano *et al.* is observed. The assigned systematic uncertainties of T-461 of around 10% are preliminary and subject to ongoing studies. A refinement of the analysis is in progress.

4. Conclusions

In November 2002 the experiment FLASH or E-165 was approved by the Experimental Program Advisory Committee (EPAC) at SLAC. Since then the

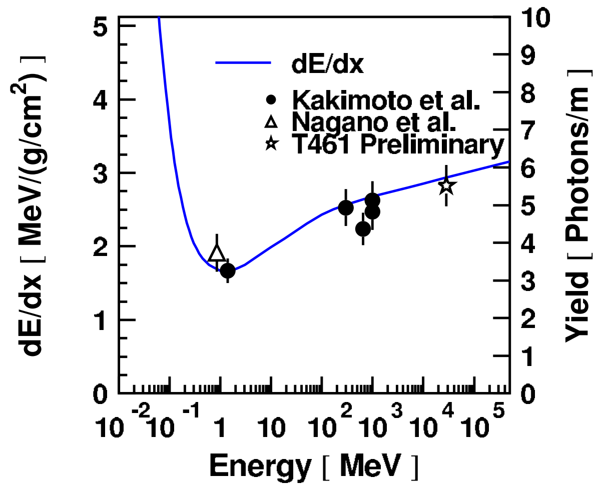

Fig. 1. Energy dependence of N_2 fluorescence in dry air at atmospheric pressure

FLASH collaboration has been preparing the implementation of both the thin and thick target modes of the experiment in the test beam area of SLAC where we will measure the total and spectrally resolved fluorescence yield in air. The preliminary results of a test run at SLAC in June 2002 are consistent with measurements of the total fluorescence yield by earlier experiments and serve as a valuable input to the experimental design and program of FLASH.

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