



Fluorescence Yield Results of FLASH (SLAC-E165)

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Abstract: The thin target mode of the FLASH (Fluorescence in Air from Showers) experiment was conducted at SLAC. The aim was to measure the total and spectrally resolved fluorescence yield of charged particles traveling through air to better than 10%. The setup consisted of a 15.24 cm thick gas volume which was viewed by two PMT detectors each equipped with 15 remotely interchangeable narrow band filters to measure the fluorescence spectrum between 300 and 430 nm. Measurements are reported of the yield and spectrum of fluorescence, excited by a 28.5 GeV electron beam, in air at a range of pressures of interest to ultra-high energy cosmic ray detectors. System calibration has been performed using Rayleigh scattering of a nitrogen laser beam and will be reported on separately at this conference.

Introduction

We report on a measurement of the fluorescent yield of air at wavelengths and pressures of interest to large area cosmic ray shower detectors. Telescope arrays imaging fluorescence in large volumes of the atmosphere continue to probe the spectrum of ultra-high energy cosmic rays (UHECR). The present work is a step in establishing the foundation for the energy scale calibration of UHECR observations.

UHECR atmospheric fluorescence detectors observe air showers in an ultraviolet window with low sky light background between 300 and 400 nm. The fluorescence light in this wavelength range is dominated by nitrogen emission lines, with major bands near 315, 337, 355, 380 and 391 nm, (95% of the light) and a few others of lesser intensity [1, 2].

In order to match the advancing capabilities of the UHECR detectors, the fluorescence yield is being studied experimentally by several groups using different techniques [3, 4, 5, 6, 7, 8, 9]. The yield and spectrum, as a function of atmospheric pressure, has been reported at several, often quite low, electron energies. A study of the light yield as a function of depth in electromagnetic showers, and the sensitivity of the spectrum to depth, has been reported [10]. The present paper con-

tributes light yield measurements over the range of pressures important for UHECR showers, and broken down into the relevant spectral bands. It makes use of a detector calibration technique systematically different from other approaches. The goal was to reduce systematic uncertainties in the fluorescence yield and spectrum below 10%, commensurate with other UHECR experimental uncertainties. Additionally, work towards the theoretical modeling and calculation of the fluorescent light yield is also progressing [1, 11, 12, 13].

Experimental method

Much of the work reported so far has used radioactive sources to excite the air in a test cell. This corresponds to the low end of the dominant part of the shower's electron spectrum. The use of pulsed high energy electrons entails a different set of systematic issues, and has some advantages. For example, the monochromatic electron trajectories are easy to model, together with the fiducial length for light emission from the test gas. With a pulsed beam, the light signals can be strong, statistics may be collected relatively quickly, and photomultiplier tube random dark noise does not contribute a background. On the other hand, heavy shielding is necessary from stray radiation, and backgrounds must be studied.

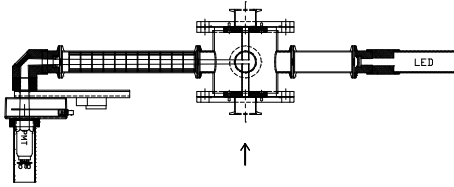


Figure 1: The FLASH thin target setup.

The beam available for this study was in the Final Focus Test Beam (FFTB) facility at the Stanford Linear Accelerator Center. Electrons at 28.5 GeV were delivered at 10 Hz in pulses 3 ps long. The apparatus was installed in an air gap in the beam vacuum line, with 50 micron thick stainless steel vacuum windows upstream and downstream. The beam particle trajectories were effectively parallel, and their transverse distribution was measured nearby using transition radiation in visible wavelengths emitted by a titanium foil in the beam. This light was imaged by a CCD camera and image capture system. Beam spot widths were typically ~ 1 mm.

The value deduced for the fluorescence efficiency depends directly on the measurement of the beam intensity. A toroid was mounted in the beam line for this purpose [14]. The toroid winding was coupled to front-end electronics, close to the beam line, which amplified the current impulse and used a bandpass filter to improve noise rejection. This signal was sent to the remote data collection system where it was digitized on every beam pulse. The calibration factor has been established with an overall uncertainty of better than 3%.

The apparatus in which the fluorescence occurred, and was measured, is illustrated in Fig. 1. It consisted of a 15 cm long, 10 cm diameter stainless steel cylinder, mounted coaxially with the electron beam. A pair of thin aluminum cylinders were placed coaxially with the beam, with the observation length defined by the gap between them.

Light from the gap could pass down two light channels which extended out radially through the cylinder walls. The channels were at right angles to each other, and were designated North and South. The light underwent a right angle reflection at a UV enhanced aluminum coated mirror. This turn

allowed lead shielding to be placed between the photon detector and the beam line to remove the direct path for background radiation.

A wheel of optical filters was installed immediately after the right angle reflection. Various narrow band filters were available, detailed below, as was a sample of the 300 - 400 nm filter used for the HiRes telescope, a clear aperture, and a blank position to study “dark” backgrounds. The rotation of the filter wheels was controlled remotely.

Diametrically opposite each of the light channels was a shorter cylinder in which was mounted an ultraviolet LED that was flashed between beam pulses to monitor PMT gain stability. Beside each of these PMTs was placed a similar tube with a hood over its photocathode, intended to monitor noise not associated with fluorescent light, particularly the effects of penetrating radiation. Although the apparatus, and in particular the PMT section, was encased to the extent possible in lead shielding, some radiation could penetrate and excite the PMTs, depending on beam conditions.

A gas system, with its controls outside the beam radiation enclosure, allowed the fluorescence cylinder to be filled with dry air, nitrogen, or, for systematic studies, with ethylene which fluoresces only very weakly in the relevant wavelength range. For some measurements, ambient moist air was used to investigate the effect of water vapor. The system pressure was varied in steps covering the range from 10 Torr to 750 Torr.

The optical calibration and systematic uncertainties of the FLASH experiment are reported on separately at this conference [15].

Data analysis

Data processing and background subtraction

The data were accumulated in runs of several thousand beam pulses, and the gas pressure or optical filter were changed between runs. The data was corrected for zero-beam ADC pedestals, and the measured PMT pulse charges fit against the beam intensity signal from the toroid. The slope of this fit is proportional to the fluorescent excita-

tion caused by the electron beam, together with a beam-related background.

The latter backgrounds were not negligible, especially during the measurement of narrow spectral ranges with weak emission. Direct measurement of the backgrounds was achieved by rotating the filter wheel to the opaque position. Runs in this condition were interspersed among the others. The source of the backgrounds was expected to vary, however, so the signals recorded for the three permanently hooded “background” PMTs were used to monitor these variations. In the case of the runs taken with the filter used in the HiRes cosmic ray facility (HiRes filter), the measured background averaged about 7.5% of the observed signal. After subtraction, the remaining signal was 480 ± 8 ADC counts per 10^9 beam electrons.

The systematic uncertainties are largely from the Rayleigh scattering calibrations. Uncertainties are discussed elsewhere in this conference[15].

Spectral bands selected by optical filters

The fluorescent yield has also been sampled in narrow bands within, and close to, the HiRes pass-band of 300 to 400 nm. The measurement was performed as described above, but these more tightly filtered signals were weaker, and in some cases not much above the radiation-induced background. On the other hand, both PMTs and their electronics were always working within their linear range. As may be seen from Fig. 2, there was considerable overlap between the transmission curves of some of the filters, and also several emission lines contributed, with different transmission coefficients, for each filter.

Using the measured yields for all the narrow band filters as a target, a search was made to find a consistent set of initial emission line strengths that would lead to the observed values. A hypothesized initial spectrum was folded with the optical transmission and PMT quantum efficiency envelopes. This was done repeatedly, changing the input spectrum in a random search, until the test input pattern yielded the observed pattern within 0.1% at each filter setting. Lines lying too close to each other to be estimated separately will be reported in groups. To improve the performance of the procedure, constraints from higher resolution obser-

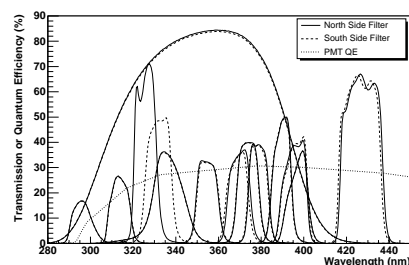


Figure 2: Optical filters used in the FLASH experiments.

vations, described next, were applied to constrain lines, known to be weak, in the neighborhood of strong ones.

Spectrographic observations

During part of the data taking an opportunity arose to use an independent arrangement in the beam line to record emission spectra with relatively high resolution. Fluorescence light was observed perpendicularly to the beam through a 120 mm focal length spectrograph [16] in a heavily shielded enclosure. Signals were measured pulse by pulse by using a multi-anode photomultiplier tube with a linear array of 32 pixels spaced at 1 mm [17]. Observations covered ~ 300 -415nm.

Between runs the light path was deflected from the spectrograph slit, and this gave a background measurement for off-line subtraction. The background, including the ADC pedestal, was subtracted. Figure 3 shows a sample of the spectra recorded.

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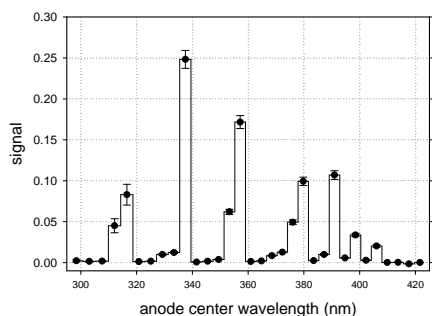


Figure 3: Sample of the FLASH spectrograph data.

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