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The FLASH Thin Target Experiment: Total and Spectrally Resolved Air Fluorescence Yield Measurement using 28.5 GeV electrons

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To reduce the systematic uncertainty of experiments using the air fluorescence technique we have measured the fluorescence yield (photons/meter/charged particle) of 28.5 GeV electrons in air and nitrogen. The FLuorescence in Air from SHowers (FLASH) experiment was performed in the final focus test beam (FFTB) facility at SLAC. Narrow band, wide band and spectrograph measurements are used to provide a spectrally resolved yield measurement. The effects of shower development, humidity, pressure, and varying oxygen content on the yield have also been studied. Electron shower measurements are presented separately.

1. Introduction

Fluorescence technique cosmic ray experiments use telescopes to measure the number of ultraviolet photons arriving from distant air showers. The energy assigned to the cosmic ray is directly related to the number of photons produced per unit length per shower particle. This number is known as the fluorescence yield,

$$Y(\lambda) = \frac{N_\gamma(\lambda)}{N_{shower}\, m}. \tag{1}$$

The objective of the <u>FL</u>uorescence in <u>A</u>ir from <u>SH</u>owers (FLASH) experiment is to provide a precise measure of the total and spectral yield of ultraviolet fluorescence photons in electromagnetic showers in air.

There are several previous efforts, including our own, to measure the fluorescence yield [1][2][3][4][5]. We wish to add a detailed and precise measurement of the total and spectral yields at the level of 10% absolute uncertainty. The FLASH experiment was carried out in the final focus test beam (FFTB) facility. In order to achieve our desired level of precision, exhaustive efforts have been made in calibrating both our optical system and our particle counting toroid [6].

As newer fluorescence telescopes are now able to observe showers at distances beyond 30 km, the spectral distribution of light has become increasingly important. This increasing observation distance has increased effect of Rayleigh scattering($1/\lambda^4$). For example, at emission $\sim 30\%$ of the fluorescence light is in the wavelength range of $370-400$ nm. After 30 km of scattering this wavelength range contributes $\sim 50\%$ of the observed signal.

2. Experimental Setup and Program

The FLASH thin target setup, shown in Figure 1, was installed in a short gap in the FFTB beam line. The chamber, a 15.2 cm long by 10.2 cm diameter cylindrical volume was sealed on both ends using 25 μm aluminum beam windows. Similar beam windows sealed the beam pipe terminations.

The fluorescence chamber was installed concentric with the electron beam. A 1 cm gap, between two interior 16 mm radius aluminum tubes, defined the observed length of the beam. The light emitted then traveled down baffled optical arms, reflected 90° from a 38 mm aperture elliptical UV enhanced aluminum coated mirror and passed through an optical filter before it entered a Photonis XP 3062 (HiRes) PMT. The PMTs were read out using a LeCroy 2249W ADC. The ADC pedestal values were tracked with prescaled out of time triggers. The optical filter was remotely changeable using an optical filter wheel. The vertical symmetry of the system provided two simultaneous measurements. The two sides are labelled north and south according to the installed orientation in the (east-west) FFTB beam line.

A set of twelve, 1 $in.$ diameter, optical filters provided for measurements from 296 to 425 nm. The filters have nominal FWHM of $\sim$ 10 nm except for the 425 nm filter with 20 nm FWHM. A "HiRes" band pass filter ($300-400\ nm$) and no (open) filter setting measured the total yield and a black (solid metal) filter was used for background measurements. The transmission curves of the filters were measured using a spectrophotometer. They are shown in Figure 2 along with a generic quantum efficiency curve for a HiRes PMT. The actual calibration of the complete mirror-filter-PMT assembly is being worked on. A toroid system was specially developed and calibrated to measure the beam charge at the percent level. Both calibration efforts are described in [6].

A gas system, controlled outside the FFTB, allowed for a variety of pressure measurements to be made ranging from atmospheric down to $< 10\ torr$. The system consisted of multiple gas inlets, a vacuum reservoir and vacuum pump. Pure nitrogen, dry air and filtered humid atmospheric air ($\sim 1\%\ H_2O$) were used to fill the fluorescence chamber.

Finally, in order to track background radiation levels, two additional HiRes PMTs were installed in the same orientation and immediately beside the signal PMTs. In addition to these "blind" tubes a scintillator/PMT combination provided a third background counter. The optical arms and PMTs were surrounded by lead bricks in order to minimize background levels. Beam spot and position monitoring were also employed to provide real time feedback allowing these parameters to be tuned to minimize noise.

In September 2003, data were collected with pressure ranging from 5 to 750 $torr$. At each pressure all 15 filter settings were used and 5-10,000 beam pulses collected at 10 Hz. The data presented here are all at atmospheric pressure. A second data run occurred in July of 2004 at which time we were able to remeasure the yield in humid air to within a few percent of the first run showing the stability of our system over a long time period.

3. Data Analysis

The yields are calculated from measured PMT ADC counts (N_{signal}) by

$$Y(\lambda) = \frac{N_{\text{ADC signal}} - N_{\text{pedestal}} - N_{\text{BG}}}{N_{e^-}} \times C_{\gamma/m/N_{\text{PMT,ADC}}} \times \frac{QE(\lambda)}{QE(337\,nm)} \times \frac{1}{T(\lambda)} \tag{2}$$

where $N_{pedestal}$ and N_{BG} are the number of pedestal and background counts respectively. C_γ is a measured optical calibration factor and QE and T are the wavelength dependent quantum efficiency and filter transmission.

The background term (N_{BG}) is calculated for each of the three counters by

$$N_{\text{BG}} = \frac{N_{\text{signal PMT black filter}}}{N_{\text{BG counter black filter}}} \times N_{\text{BG counter}} = N_{\text{signal PMT black filter}} \times \frac{N_{\text{BG counter}}}{N_{\text{BG counter black filter}}}. \tag{3}$$

In practice, a more robust method using a Monte Carlo simulation to include spectral shape, relative quantum efficiency and filter transmission curves replaces terms 3 and 4 in Equation 2. However, this equation provides the quick look at the spectral measurements as shown in Figures 3, 4 and 5. These figures are overlayed with the Bunner spectral shape (solid line) for reference and the line measurements from Nagano (open triangles) [4], each set to an arbitrary scale. The different scales of the Nagano, Bunner, and FLASH results can be explained by the different electron energies in each case. The vertical error bars include only statistical and background subtraction errors. The horizontal error bars represent the nominal FWHM of the filter transmissions. Finally, the data marker is located at the maximum of the product of filter transmission and Bunner spectral shape.

The expected decrease in the fluorescence yield in the presence of water vapor is observed in Figure 4. Also note that the south side PMT was run at a much higher gain. This PMT saturated on open and HiRes filter settings in air and on the bright lines in nitrogen as seen in Figure 5.

At the time of writing final calibration efforts are in progress and the results presented in this paper are still preliminary. We expect to publish results shortly with a total uncertainty at the 10% level.

4. Conclusions

The thin target run of the FLASH experiment has measured the pressure dependent total and spectral fluorescence yield of $28.5\ GeV$ electrons. No large discrepancies from other recent works are immediately evident but detailed analysis will follow.

5. Acknowledgments

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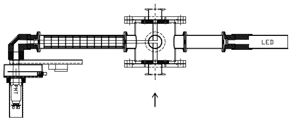

Figure 1. The FLASH thin target setup. Electrons travel through the chamber center, as indicated by the arrow, and fluorescence light is observed through optical filters.

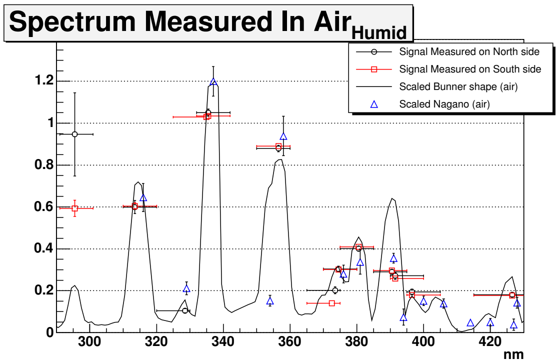

Figure 4. Simple spectrum measured in humid air.

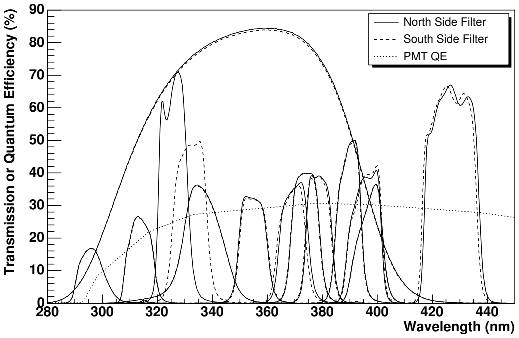

Figure 2. Measured filter transmission curves

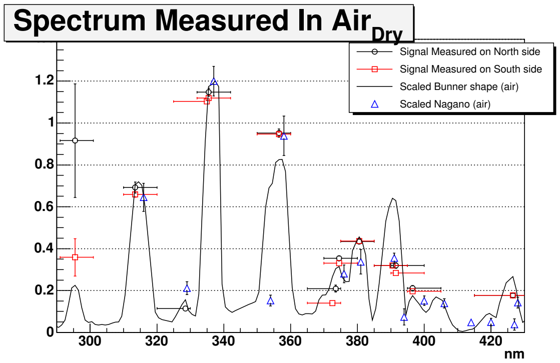

Figure 3. Simple spectrum measured in dry air.

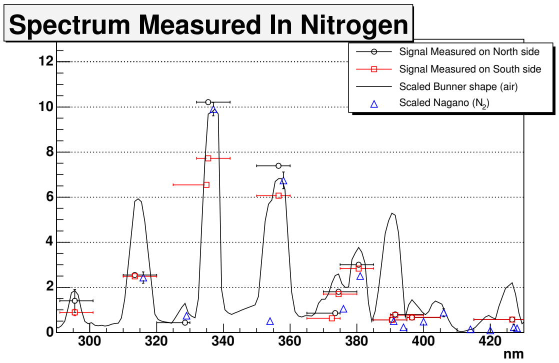

Figure 5. Simple spectrum measured in nitrogen.