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The FLASH Thin Target Experiment: A Precision Optical Calibration of the FLASH Thin Target Experiment

P. Hüntemeyer for the FLASH collaboration

University of Utah, Department of Physics and High Energy Astrophysics Institute, Salt Lake City, UT 84112, USA

Presenter: P. Hüntemeyer (petra@cosmic.utah.edu), usa-huentemeyer-P-abs1-he15-poster

The thin target mode of the FLASH (Fluorescence in Air from Showers) experiment was conducted over the past two years 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 445 nm. The calibration of the thin target setup is crucial in minimizing the systematic uncertainty of the measurement. We will describe how the physics of Rayleigh scattering is used to derive an absolute end-to-end calibration of the thin target experiment from first principles. In addition, a method for a relative calibration will be presented using a setup with a mercury lamp, a monochromator and a NIST calibrated photo diode in a light sealed black box. The combination of both calibration methods will provide an absolute calibration of the thin target experiment.

1. Introduction

The FLASH experiment [1] was conducted in the Final Focus Test Beam (FFTB) of the Stanford Linear Accelerator Center (SLAC) during three run periods over the past two years. It consisted of a thin and a thick target run which are described elsewhere in these proceedings [2]. The objective of the FLASH experiment is a precise measurement of the fluorescence yield between 300 and 400 nm integrally and spectrally resolved. The yield is commonly expressed in units of number of photons N_γ per number of electrons N_e per distance d traveled by the electron:

$$Y = \frac{N_\gamma}{N_e \cdot d}. \tag{1}$$

The number of electrons per beam was measured with a toroid installed upstream of the thin and thick target. The toroid device is calibrated at SLAC after data taking with a precision charge coupled to the toroid and by charge injection at the front end amplifier input. In order to translate the measured fluorescence signal in units of ADC counts into units of photons per unit length the experimental setup of the thin target is calibrated at the University of Utah after data taking. In comparison with previous fluorescence yield measurements [4, 5, 6], which corrected their data based on piece-by-piece calibrations, for FLASH a new method of an end-to-end calibration of the entire setup is applied making use of Rayleigh scattering of a nitrogen laser beam injected in the thin target through the beam ports. The aim of such an end-to-end calibration is to improve the accuracy of the present yield measurement by decreasing the detector calibration error, which usually represents the largest contribution to the overall uncertainty. The uncertainties of previous yield measurements [4, 5, 6, 3] were larger than 10%. The FLASH experiment aims to reduce the uncertainty to below 10%. Since a nitrogen laser is used, the end-to-end calibration only measures the number of photons per unit length at a wavelength 337 nm. To extend the calibration to the entire wavelength range between 300 and 400 nm, in a second step the detector assembly is calibrated against a silicon photo diode using a high pressure mercury arc lamp – monochromator combination as light source. Both setups for the thin target chamber calibration and in particular the method of the end-to-end calibration step will be described in more detail in the following sections.

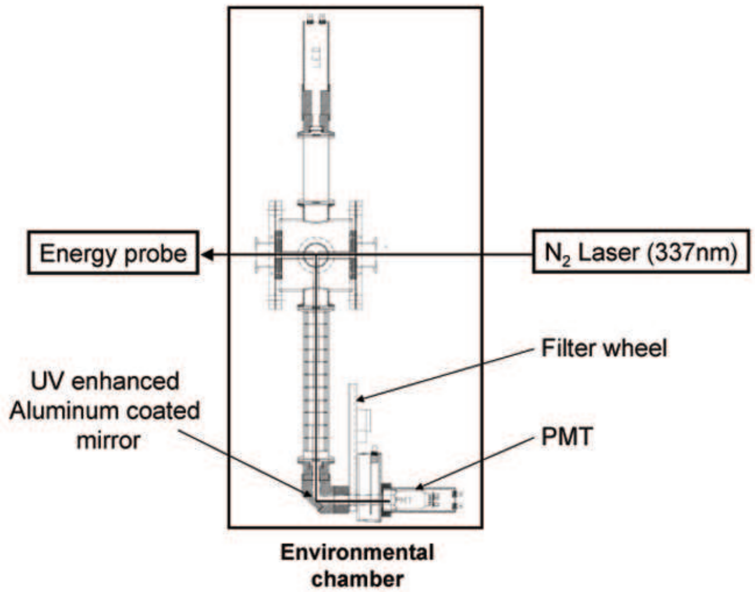

Figure 1. The calibration setup showing the thin target chamber with one of two orthogonal optical pathways through baffled channels, and a 45 degree reflection to a photomultiplier tube (PMT), the laser, the laser beam, and the energy probe.

2. Experimental Setup of the End-to-End Calibration

A schematic of the experimental set-up of the end-to-end calibration is shown Figure 1. As can be seen the thin target chamber (fully assembled) is installed in an environmental chamber. Using a temperature controller the temperature in the environmental chamber is kept at 29°C, which was the average temperature measured in the FFTB tunnel at SLAC. A nitrogen laser is mounted at a distance of approximately 2 m from the chamber. It injects a beam of 337 nm photons into the chamber along the electron beam axis. The light beam intensity is decreased by an aperture which is mounted on the beam port facing the laser. Thus the laser beam is confined to the center of the chamber. The laser beam as well as the path of the light scattered off the air molecules at 90 degrees is indicated by solid lines in Figure 1. The scattered light passes through the baffled detector arms, is reflected by the UV enhanced aluminum coated mirror, passes through a filter in the filter wheel, and finally reaches the PMT. The signal of the photo multiplier tubes is recorded with a LeCroy ADC and read out by a computer. Simultaneously with the PMT signal, the energy (and thus the number of photons) of the outgoing laser beam is measured by a pyroelectric energy probe installed on the opposite side of the chamber. The pressure inside the chamber is recorded as well. Based on Rayleigh scattering calculations as discussed in [7] and taking into account that fluorescence light is emitted isotropically, it then is possible to calculate the number ADC counts per emitted 337 nm fluorescence photon per meter, G. In order to be able to take measurements at different pressures inside the chamber coated glass windows with close to 100% transmission efficiency in the UV range are attached to both beam ports. The thin target chamber is connected to a vacuum pump and a pressure gauge. Data are taken at several different pressures between vacuum and atmospheric

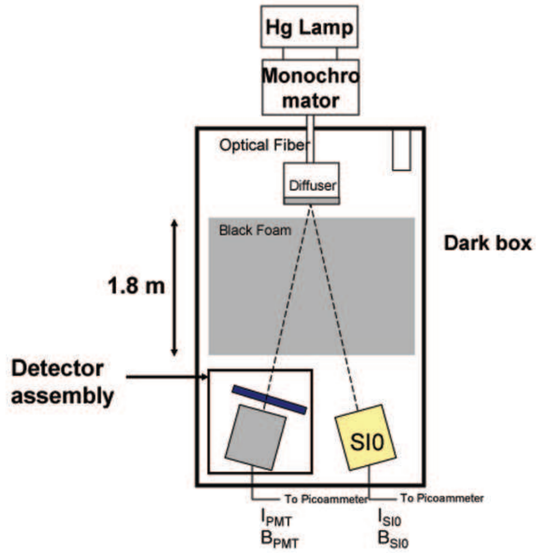

Figure 2. The mercury lamp – monochromator calibration setup.

pressure, and a linear fit,

$$\frac{N_{ADC} - N_{ped}}{E} = G \cdot F \cdot \frac{S \cdot P}{T} + k_0 \tag{2}$$

is performed to the data. Here, N_{ADC} is the signal counts recorded for each PMT, N_{ped} is the number of pedestal counts measured in the respective signal channel, F is the transmission efficiency of the selected filter, P, and T are the pressure and temperature measured in the chamber, and k_0 accounts for the light background from scattering of the laser beam with the chamber material. The proportionality constant S was calculated based on [7] assuming air and 337 nm light, and takes into account the difference in angular distribution between Rayleigh and isotropic scattering. Thus,

$$\frac{S \cdot P \cdot E}{T} \tag{3}$$

is equivalent to the total number of photons per meter from isotropic emission. The fit parameters G and k_0 are varied and, after χ^2minimization, G represents the calibrated number of ADC counts per emitted photon per meter.

3. Experimental Setup of the Detector Assembly Calibration

The second step of the detector assembly calibration is illustrated in Figure 1. As can be seen in Figure 1, the detector assembly consists of a PMT, a filter wheel, and a aluminum coated mirror. The complete unit is calibrated in a standard HiRes calibration setup at the University of Utah. A schematic of the calibration setup is shown in Figure 2. It consists of a 100 W high-pressure mercury arc lamp, a monochromator, a light guide and a diffuser as the light source, a 1.8 m light path in a baffled foam tube, and a stand with a NIST calibrated silicon photo diode installed next to the detector assembly. The diffuser, the baffled light path, the Si photo diode and the detector assembly are enclosed completely in a dark box. The detector assembly and the silicon photo diode are aligned so that they are directly facing the diffuser. During calibration the monochromator scans the wavelength region between 260 nm and 420 nm in 1 nm steps. After several monochromator scans are recorded, the PMT and photo diode are swapped. In this manner light emitted by the mercury lamp is collected by the PMT assembly and the diode. The current output of each detector is measured by a pico ampere meter. From the calibration curve of the wavelength dependent responsivity of the silicon photo diode in units of A/(W/cm^2), and the measured size of the entrance pupil of the detector assembly, its wavelength dependent responsibility can be calculated in units of A/(W/cm^2).

4. Summary

After the completion of data taking of the FLASH experiment various calibration efforts have been worked on at SLAC and at the University of Utah. A high precision calibration of the beam charge measuring toroid has been performed at SLAC. At the University of Utah, an end-to-end calibration of the thin target chamber has been worked on and a relative calibration of the detector assembly using a high pressure mercury arc lamp in combination with a monochromator is being finalized. Preliminary results of all three calibrations will be presented in a poster.

5. Acknowledgments

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References

[1] J. Belz *et. al.*, “Fluorescence in Air from Showers (FLASH)”, E-165 Proposal (2002), [http://www.slac.stanford.edu/grp/rd/epac/Proposal/index.html].

[2] K. Reil, P. Hüntemeyer for the FLASH collaboration, “The FLASH Thin Target Experiment: Total and Spectrally Resolved Air Fluorescence Yield Measurement using 28.5 GeV electrons”, these proceedings; J. Belz, for the FLASH collaboration, “The FLASH Thin Target Experiment: Direct Measurement of Air Fluorescence Yield in Electromagnetic Showers”, these proceedings.

[3] A. N. Bunner, Ph. D. thesis (Cornell University) (1967).

[4] F. Kakimoto, E. C. Loh, M. Nagano, H. Okuno, M. Teshima, S. Ueno, Nucl. Instrum. Meth. **A 372** (1996) 527.

[5] M. Nagano, K. Kobayakawa, N. Sakaki, and K. Ando, Astropart. Phys. **20** (2003) 293.

[6] M. Nagano, K. Kobayakawa, N. Sakaki, and K. Ando, Astropart. Phys. **22** (2004) 235.

[7] A. Bucholtz, Appl. Opt., **34** (1995), 2765;
B. Bodhaine, N.B. Wood, E.G. Dutton, J.R. Slusser, J. Atmos. Oceanic Technol., **16** (1999) 1854.