AIRFLY: Air Fluorescence Induced by Electrons in a Wide Energy Range

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Abstract

The goal of the AIRFLY (AIR FLuorescence Yield) experiment is to measure the fluorescence yield in atmospheric gases with better than 10% precision. AIRFLY takes data in 2003 at the Beam Test Facility of the INFN Laboratori Nazionali di Frascati, which will allow a measurement of the fluorescence yield induced by electrons in a wide range around their critical energy. Details of the experimental apparatus and first tests performed on the beam line are reported.

1. Introduction

Fluorescence detection of ultra high energy cosmic rays is a well established technique. It is based on atmospheric nitrogen excitation by the charged particles of the air shower, mainly electrons and positrons, followed by emission of photons mostly in the 300-400 nm range. One electron produces about 4 photons per m of air. A precise measurement of the fluorescence yield is essential for the absolute calibration of ultra high energy ($> 10^{18}$ eV) cosmic ray detectors based on the fluorescence technique. In fact, new generation experiments, like Hires [1] and Auger [2], have sensibly reduced the systematic uncertainties related to the measurement technique, and the knowledge of the fluorescence emission efficiency is currently one of the most relevant contribution to the absolute energy calibration.

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A specific aspect of the AIRFLY experimental programme is the measurement of the fluorescence yield as a function of particle energy, in a wide energy interval from 50 to 800 MeV. The AIRFLY experiment has been approved at the Beam Test Facility (BTF) [3] of the Laboratori Nazionali di Frascati. Electron and positron beams are available at the BTF, with intensities from single particle up to 10^{10} particles per bunch. The measurement at the BTF represents the first measurement of the fluorescence yield in the range of the electron critical energy in air. A low energy measurement at few MeV with radioactive β sources is also foreseen, which will allow direct comparison with recent precise measurements of the fluorescence yield [4]. A detailed measurement of the fluorescence emission spectrum, with a spectrophotometer, is part of the AIRFLY programme. as well as its dependence on pressure, temperature and gas composition, corresponding to atmospheric conditions at altitudes relevant for fluorescence telescopes based on earth as well as in space.

2. The AIRFLY chamber and first test beam results

A dedicated beam period for AIRFLY took place at the BTF in March 2003. The main objectives of this first test were the characterization of the beam and related background and the operation of the AIRFLY chamber, in preparation for more extensive measurements. The experimental apparatus consisted of a 6-way cross aluminum chamber, with 400 mm length along the beam. The beam entrance and exit aluminum flanges had a 1 mm thickness to minimize beam interactions. Three fused silica viewports are placed orthogonally to the beam direction, equipped with 2 inch diameter Photonis XP2262 photomultipliers, selected for low noise. A filter wheel was associated to each PMT. The filter wheels hosted interference filters of central wavelength corresponding to the main emission lines (315, 337, 360, 381, 391, and 401 nm), a M-UG6 band pass filter (300 to 400 nm) and a shutter used for background measurements. The filters, with effective aperture of 22 mm diameter, were placed at 175 mm distance from the beam. The beam fluorescence region viewed by the PMTs was limited to 100 mm by cylinders attached to the entrance and exit flanges. All aluminum parts of the chamber were black anodized to minimize light reflections. The light from a xenon flash lamp complemented with a M-UG6 filter was brought into the chamber by a UV transmitting optical fiber for PMT monitoring during the measurements. In order to minimize the background, the PMTs are surrounded by a lead shield. A vacuum pump and a set of remotely controlled electromagnetic vacuum valves were used to allow the gas into the chamber at the desired pressure, from few mb to atmospheric pressure. The system could be operated in a static gas configuration, as well as in a gas flow condition. Measurements with dry air and pure nitrogen gas were performed. The AIRFLY chamber installed in the BTF beam line is shown in Fig. 1.a. The data acquisition system, based on the VME

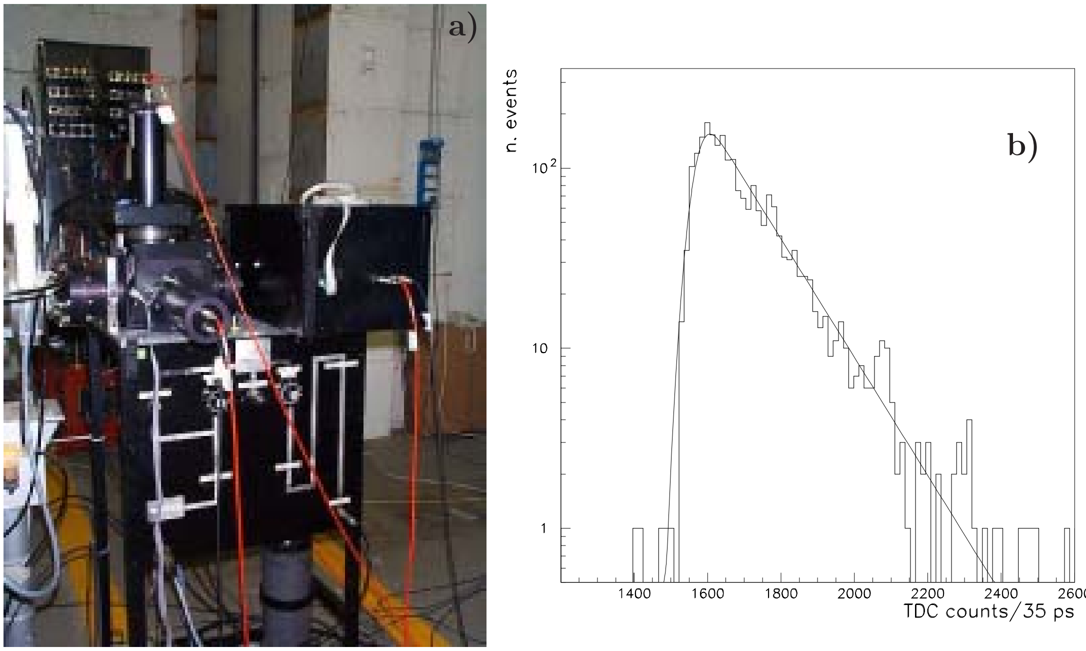

Fig. 1. a) The AIRFLY chamber at the BTF beam line; b) TDC counts distribution, showing evidence for the fluorescence lifetime.

standard, included scalers for single photon counting, charge integrating ADCs and TDCs used for the measurement of the fluorescence lifetime. The trigger was provided by the accelerator timing signal. The beam intensity used in this first test was relatively low, ranging from a few to several hundreds of electrons per bunch at 24 Hz. It was monitored by a lead-scintillating fibers calorimeter placed at the end of the BTF line [5], having single electron resolution. A second beam monitor [5], based on Cerenkov light production by beam particles in plexiglass, was also used, in particular for the highest intensities where the calorimeter saturated. AIRFLY has demanding requirements on the background level, due to the low efficiency of the fluorescence process. Dedicated measurements were performed in order to understand the background. It was found that most of the background was associated to the beam interaction in the upstream target. An improved shielding along the beam line increased significantly the signal to background ratio. The background rate was monitored during the data taking by closing the shutter in front of the PMTs. A short bunch width of ≈ 1 ns was commissioned for the AIRFLY run, allowing the direct measurement of the fluorescence lifetime. As an example, the TDC counts distribution for nitrogen gas at 340 mb with the M-UG6 filter is shown in Fig. 1.b, with a lifetime estimated to be around 5 ns. Several checks of chamber operation were performed, including measurements with the filters and at different pressures. The ratio between fluorescence in nitrogen and air was measured at different beam energies in the range 300 to 500 MeV with the wide band M-UG6 filter, and was found to be around 5.7. A first energy scan was also performed in the range 50 to 500 MeV, with the main objective of understanding the characteristics of the beam at different energies. It was found that at low energy some tuning of the beam optics is needed, which will be implemented in the next test beam run. Another setup was also tested, aiming to maximize the collection of fluorescence photons. An elliptical mirror, with major semi-axis of 80 mm, minor semi-axis of 60 mm and 250 mm length, was placed with the beam running along one focus of the mirror. Fluorescence photons emitted from the beam were collected by optical fibers positioned in the other focus along the mirror length. The optical fibers were joined together in a bundle and brought to a photomultiplier. A significant increase in the light collection was observed (a factor ≈ 10 with respect to the chamber), consistent with a Monte Carlo simulation which takes into account the solid angle coverage and the fibers transmission, which was low close to 300 nm. The sensitivity of the light collection to the beam alignment and profile was also studied.

3. Outlook

The preliminary measurements performed on the Beam Test Facility of the INFN Laboratori Nazionali di Frascati have shown the feasibility of a measurement of the fluorescence induced by electrons in air in a wide energy range around the critical energy of electrons in air. A second AIRFLY test beam, which will focus on measurements with higher beam intensity and on an energy scan over a wide range, will take place in 2003. The AIRFLY experimental programme will continue in 2004, with the goal of an absolute measurement of the fluorescence yield and a detailed measurement of the fluorescence spectrum.

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