Study of the Fluorescence Yield for Electrons Between 0.5 - 2.2 MeV

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Abstract

The fluorescence yield in air is an important parameter for the reconstruction of air showers events. The new generation of air fluorescence experiments demands for a better precision of the fluorescence yield, and several efforts are being done to get it. We present some preliminary results of measurements performed at University of Campinas. Using ^{90}Sr as source of electrons and a prototype chamber we obtained firsts measurements of the fluorescence light produced in nitrogen and in dry air. The analysis is aided by a detailed Monte Carlo simulation

1. Introduction

The cosmic ray experiments based on the fluorescence technique (AUGER [1], HiRes [2], OWL [3], EUSO[4]) are (or will be) running with more ambitious goals as regards the control of systematic uncertainties, a main source of which is precisely the yield of fluorescence light. Assuming that the instrumentation issues can be kept under control, and the atmosphere can be characterized during data taking (e.g. by LIDAR or other techniques), the physics of fluorescence produced by shower particles plays a fundamental role in the shower reconstruction chain. The previous works concerning the FY [5, 6] have left some important open questions like absolute yields in each emission line and the correlation of the FY with the Bethe-Bloch curve. This scenario has led to many efforts to accurately measure the FY under different physical conditions [7]. The Campinas group of the Auger collaboration started a set of measurements of FY using a ^{90}Sr source and a prototype chamber. We report the following results: i) the relative fluorescence efficiency (η) of nitrogen and dry air and ii) the fluorescence time constant in nitrogen (τ_N), both integrated over all wavelengths and under atmospheric pressure.

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2. The Experimental Setup

Our detection system is composed by a fluorescence chamber in which the gas volume is viewed by PMTs, with a plastic scintillator detector for electron beam monitoring and trigger purposes. The aspects related to chamber geometry and particle-matter interactions were studied using a simulation code [8] based on the GEANT4 package routines. The code provides tracking of photons, estimates of signal contamination by secondary particles and numerical evaluation of the acceptance. The chamber is built using a stainless steel cylindrical tube with length $l = 0.25\ m$ and diameter $\phi = 0.18\ m$, being completely sealed against pressure or light leakage and having black inner surfaces. Two PMTs Hamamatsu R1398 are housed in transverse capsules placed at the cylinder half-length and perpendicular to chamber axis. The PMTs radial distance can be changed, providing control over the solid angle between the photocathode and the particle beam. The photocathodes are totally exposed inside the chamber, no windows or spectral filters are being used. The photo-counting ability of the system was checked measuring the single photo-electron spectrum of the PMTs which has also been used to estimate the gain. The cylinder caps have fast connection valves for the gas flux system. The radioactive source holder and the particle monitor are internally fixed to the caps and aligned with the chamber axis, opposed from each other. The source is covered by a 6 mm aluminum layer and has a 1 mm diameter central hole, acting as a beam collimator. The β-decays ^{90}Sr→^{90}Y→^{90}Zr supply the electrons in the 0.5÷2.2 MeV range. The particle monitor is composed by a plastic scintillator slab, thick enough to stop the particles from the radioactive source, facing the photocathode of a third Hamamatsu R1398 PMT. The main goal of this prototype chamber is to observe the integral fluorescence light emission inside the PMTs spectral range under atmospheric pressure. Figure 1 shows a schematic view of the chamber cross section.

3. Fluorescence Measurements and Results

We used NIM-CAMAC standard modules controlled by a GPIB interface to measure counting rate, charge and relative time of the three PMTs. The trigger was formed by coincidences between signals from the particle monitor and any one of the photon detectors within a time window of 150 ns. We define $Y = N_{exc}/N_{e^-}$ where N_{exc} is the counting excess (trigger rate after subtraction of random coincidences) and N_{e^-} the electron counting rate. We started the measurements filling the chamber with dry air (20% O_2 + 80% N_2) untill measure a stable Y value (Y_{air}). When nitrogen was flown inside the chamber, we observed a clear increasing in Y up to reach a maximum (Y_N), indicating the saturation of nitrogen inside the chamber (see Figure 2). We notice that the observed excesses in air or nitrogen were $\sim 3\sigma$ above the background. The relative fluorescence

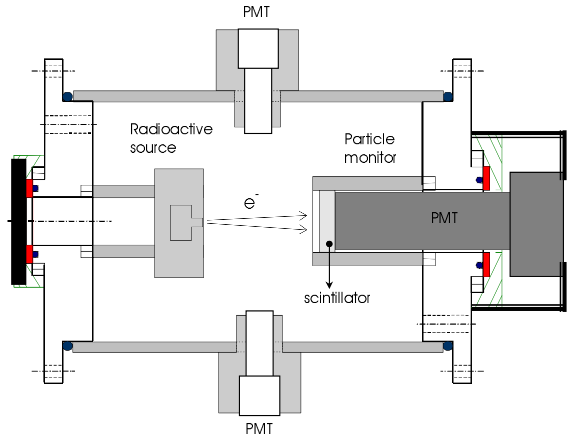

Fig. 1. Schematic view of the fluorescence chamber

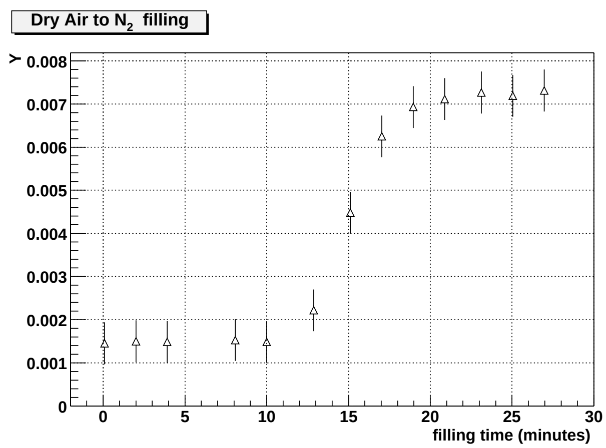

Fig. 2. Y vs. time during nitrogen filling. For t=0 the chamber was filled with dry air. At t=10 min nitrogen was injected in the chamber. The lower *plateau* corresponds to Y_{air} and the upper one to Y_N.

efficiency between nitrogen and dry air can be taken as $\eta = Y_N/Y_{air} = 5.1 \pm 0.3$, very close to the value $\eta = 5.6$ previously reported in reference [6]. When $Y = Y_N$ we recorded charge (ADC) and time (TDC) of the three PMTs pulses. Only the TDC results are relevant for this discussion. Figure 3 shows a typical distribution of the relative times between photon and electron detections (Δt). The exponential behavior is clear and fitting the Δt distribution we obtained the fluorescence decay time constant $\tau_N = 3.52 \pm 0.04$ ns (the reciprocal value of the slope, see figure box), again in good agreement with other measurements [9].

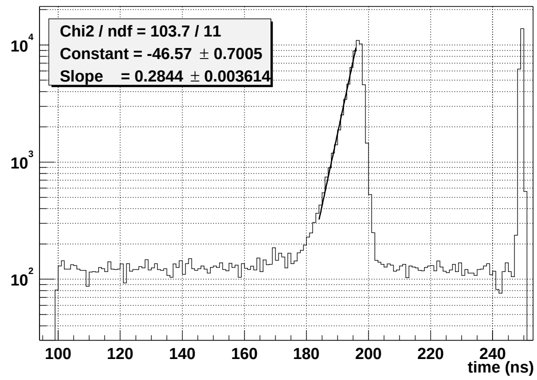

Fig. 3. Δt distribution. The line is the exponential fit.

4. Conclusions

We built a prototype chamber * to measure the fluorescence yield produced by charged particles in atmospheric gases. We observed $\sim 3\sigma$ excesses above the expected level of random triggers. Furthermore, the values obtained for the relative fluorescence efficience η and the fluorescence decay time constant τ_N are in very good agreement with the current literature (see text), pointing that we are unquestionably performing detection of fluorescence photons with our prototype. For next steps, we intend to built a more sophisticated system, with full control over the gas characteristics (pressure and temperature) and improvements on the light detection system (fine acceptance control and wavelength selection), to have a wide range of atmospheric and optical variables which are relevant to the fluorescence phenomenum. In addition, different gas mixtures will be measured, allowing a more detailed study of the quenching effect.

5. References

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