PROCEEDINGS OF SCIENCE

The Fluorescence Radiation Yield Induced in Atmosphere by Ultra-High Energy Cosmic Rays

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In the Extensive Air Shower (EAS) the particles deposit part or all their energy by ionization of air molecules and produce fluorescence radiation leaving a track of fluorescent light as the shower develops. A detailed study on the energy deposit of electromagnetic particles in several atmospheric layers is addressed. We take into account parameterizations for density and temperature of each layer and test two different formulations for the energy deposit in different measurements for fluorescence yield.

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1. Introduction

This work presents an analysis on the dependence of some calculations of the fluorescence yield (FlY) for two forms of energy deposit dE/dx. This is callculated using Bethe-Bloch formula [1, 2] with corrections due to the polarization effects of the medium density (parameter δ) by Leo [3], and corrections of Sternheimer *et al.* for NIST (National Institute of Standards and Technology) [4].

In the ionization, the energy loss per unit path is described, in general, by the Bethe-Bloch formula [1, 2]. In 1994, W.R.Leo [3], discribed it:

$$-\frac{dE}{dx} = \frac{B\rho Z}{\beta^2 A}\left[\ln\frac{\tau^2(\tau+2)}{2(\frac{I}{m_e c^2})^2} + F(\tau) - \delta - \frac{2C}{Z}\right] \tag{1.1}$$

where $B = 0.1535\,MeV/(g/cm^2)$, ρ is the density, Z the atomic number, A the number of mass of the absorber medium, τ the kinetic energy of incident particle in units of $m_e c^2$ ($F(\tau)$ is a function whose form depends whether particle is a electron or positron), $\beta = v/c$ of incident particle, I is the mean excitation potential, δ is the density correction (This is derived from the fact that the electric field of the particles tend to polarize the atoms on his way. Because of this polarization, electrons away from the path of the particle will be shielded and contribute less to the energy loss, and its contribution will be deducted) and C/Z is a fixed for high speeds.

To compare the values of the equation 4 we used the program ESTAR [5] from NIST (National Intitute of Standards and Technology) [4]. It uses the theory of Bethe, with a density-effect correction evaluated according to Sternheimer (1952, 1982) [6]. The data to construct the curve, showed in the figure 1, was obtained by output of this program with interval of energies between 0.001 – 10000 MeV.

On figure 1 there is a comparation of the dE/dx from Leo and NIST. The results was calculated to dry air, at sea level (760 mmHg), 288^o Kelvin and $\rho = 1,2Kg/m^3$. The diference between the minimun[1] of both curves (about 1 MeV) is approximately 10%.

2. The Method

The showers were simulated with the CORSIKA[7] program version 6617 using the hadronic model Sibyll 2.1 [8]. The chemical composition of the primaries were chosen to be proton and the energies fixed in 10^{17}, $10^{17.5}$, 10^{18}, $10^{18.5}$, 10^{19}, $10^{19.5}$, 10^{20} and $10^{20.5}$ eV, where 1000 events were simulated for each energy. The thinning factor used was of 10^{-5} and the zenith angles were sorted between 0^o and 60^o.

Kakimoto *et al.* does a parameterization of the fluorescence emission in function of the energy and altitude to the total emission of photons in the range of 300 nm and 430 nm. Nagano *et al.* use the equation of Kakimoto *et al.* but with other energy normalization, where the first term is the main emission peak and the second term are the other emissions. Thus the equation for the total emission of fluorescence is given by:

$$FlY = \frac{\left(\frac{dE}{dx}\right)}{\left(\frac{dE}{dx}\right)_{E_o}}\rho\left\{\frac{A_1}{1+\rho B_1\sqrt{T}} + \frac{A_2}{1+\rho B_2\sqrt{T}}\right\} \tag{2.1}$$

[1] This value is the dE/dx of reference $(dE/dx)_{E_o}$.

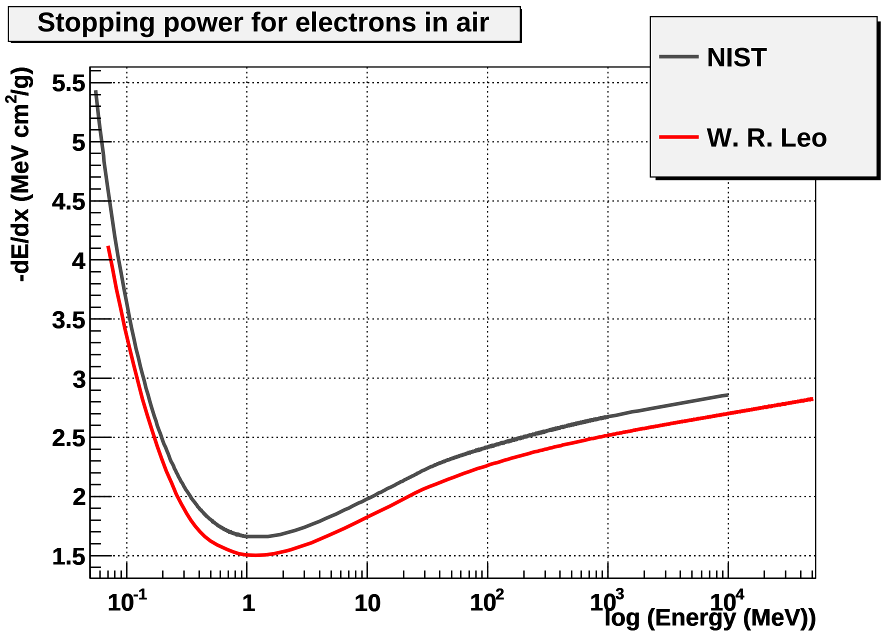

Figure 1: dE/dx for Leo and NIST.

where $(dE/dx)_{E_o}$ is the energy loss normalized to E_o (the ref. [9] take it 1.4 MeV and the ref. [10] use 0.85 MeV), ρ is the medium density in kg/m^3, T is the medium temperature in Kelvin and the constants A_1 and A_2 in $[m^2kg^{-1}]$, and B_1 and B_2 in $[m^3kg^{-1}K^{1/2}]$ are derived from the experiments. See the values in table 1.

	A_1	A_2
`ref. [9]`	89.0 ± 1.7	55.0 ± 2.2
`ref. [10]`	147.4 ± 4.3	69.8 ± 12.2
	B_1	B_2
`ref. [9]`	1.85 ± 0.04	6.50 ± 0.33
`ref. [10]`	2.40 ± 0.18	20.10 ± 6.90

Table 1: Constants used in equation (2.1).

To compare these two models with other possibility we have used the program offline. This has several models of FlY already implemented and we can be set up these different models to be used in the same data set. So, we configured this for the models from Kakimoto, Nagano, Keilhauer and Airfly. Since results are dependent of the wave-length, λ we add all the values of FlY for each λ in the each depth.

To make the graphics FlY with dE/dx we use showers simulated by CORSIKA, whose output data provides the number of electrons and positrons in atmospheric depth. Are 208 levels between $0 - 1040 g/cm^2$, so divided in intervals of $5 g/cm^2$. Using the formula of Kakimoto and Nagano for dE/dx we can calculate the energy deposited for each one these levels. In the case of data table of FlY from the outputs of Offine we can not calculate the exact amount for each level, so we made a linear interpolation to approximate values of FlY of each level corresponding to the levels of the outputs of CORSIKA.

The version of the Offline used was v2r5p7-Godot compiled with script ape0.98.

3. Results - Fluorescence Yield

The influence of these corrections in FlY was higher than expected, as we can see in Fig. 2, 3, 4 and 5. The results are discrepant around 30% near the altitude of 12 km between the curves Leo-Kakimoto (Offline) and NIST-Nagano (Offline).

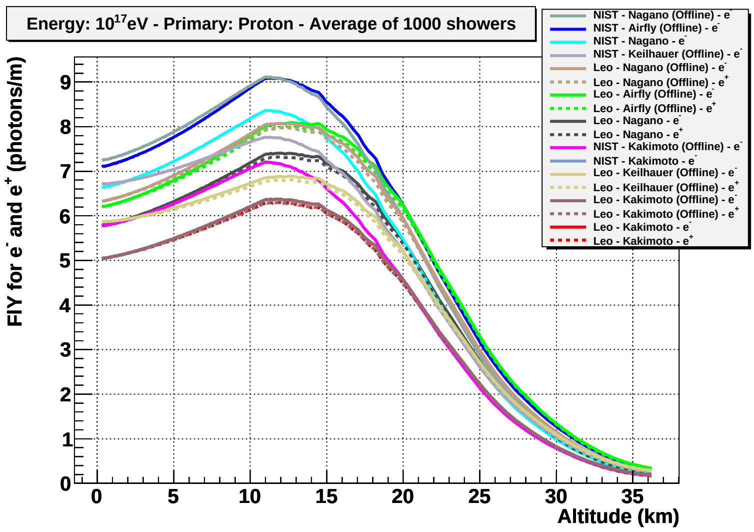

Figure 2: FlY for average of 1000 showers of **proton** with 10^{17} eV.

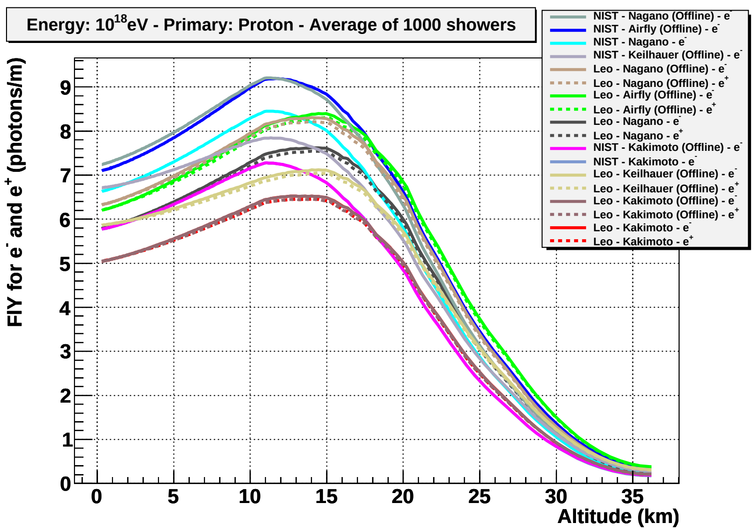

Figure 3: FlY for average of 1000 showers of **proton** with 10^{18} eV.

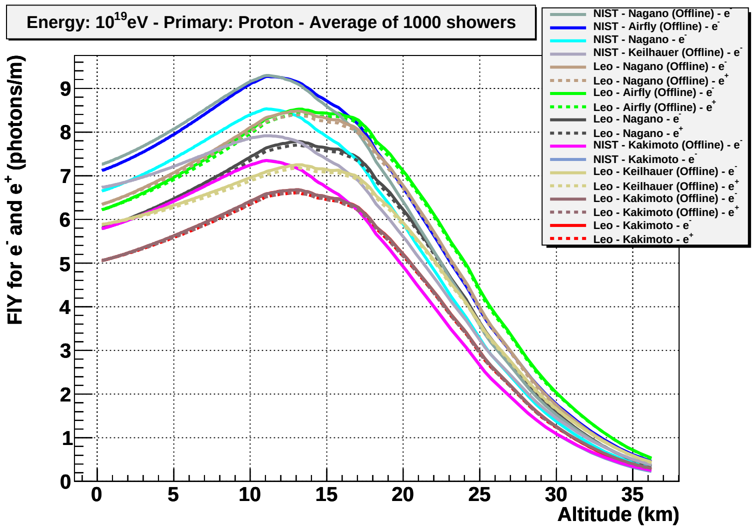

Figure 4: FlY for average of 1000 showers of **proton** with 10^{19} eV.

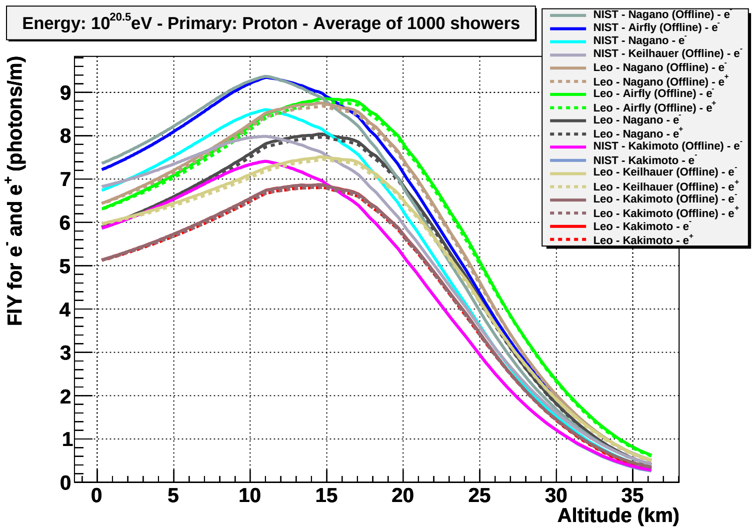

Figure 5: FlY for average of 1000 showers of **proton** with $10^{20,5}$ eV.

4. Conclusions

i) The combination given by equation with parameterization by Kakimoto *et al.* [9] is the closest to the expected results in the literature [11]; and we use this to evaluate the reliability of our results.

ii) The influence of the dE/dx term in the *FlY* was much larger than expected reaching 30% between the curves Leo Kakimoto (Offline) and NIST-Nagano (Offline).

iii) The next step is to simulate showers with different chemical compositions and calculate the number of photons in the shower axis in order to check the propagation of this effect in the calculation.

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