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# Converting $n_e$ to $E_0$ by a correlation $E_0 - n_e$ modulated by $n_\mu/n_e$ abundance by using GAMMA facility measurements and CORSIKA simulations

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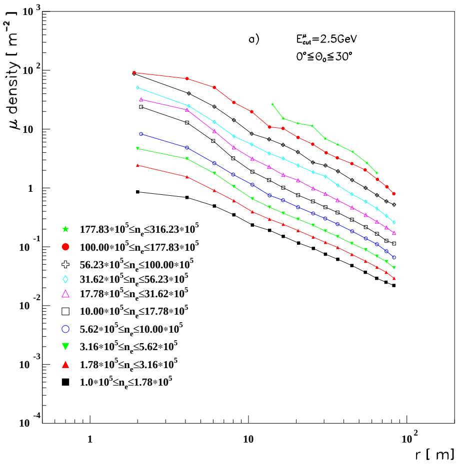

**Abstract.** The comparison of measured (experimental data of GAMMA facility on Mt. Aragads (3200m a.s.l.)) and simulated (CORSIKA 5.62 code) muon LDFs for $2.5GeV$ and $5GeV$ muon cut-off energies in the energy range $1.5 \cdot (10^5 \div 10^7)$GeV is done. The appropriate estimated energies for the experimental shower sizes have been calculated by formula: $E_0 = [a \ln\left(\frac{n_\mu}{n_e}\right) + b]n_e$.

## 1 The Method of the Approach

The theoretical aspects to overcome the "inverse problem" of energy estimation by correlation between $n_e$ and $E_0$ modulated by the relative dependence of different components (for instance muon-electron) have been investigated in particular at the end of 80's and the beginning of 90's by J.-N. Capdevielle et al.. They have proposed (Capdevielle et al. , 1991) a new approach introducing **estimators** of the general form:

$$E_0 = \left\{[a \ln\left(\frac{n_\mu}{n_e}\right) + b]^\alpha + c\right\}n_e \qquad (1)$$

converting the electron size to primary energy by a **cor**relation $E_0 - n_e$ **mod**ulated by muon - electron abundance (so called **Co-Mod** method) (Capdevielle et al. , 1993).
In the first approach we will consider the case when $\alpha = 1$ and $c = 0$ which bring us to the more simple form proposed earlier a first in (Capdevielle and Gabinski , 1990):

$$E_0 = [a \ln\left(\frac{n_\mu}{n_e}\right) + b]n_e. \qquad (2)$$

They have systematically investigated for all the Monte-Carlo samples including showers generated by $\alpha$, $CNO$, $Fe$ primary nuclei for levels of detection around $700g/cm^2$ and zenith angle from $0^o$ to $30^o$ how such relation can work, from a linear square fit between $E_0/n_e$ and $ln(n_\mu/n_e)$, event by event. As a result in particular they present the fitting coefficients adapted to the different varieties of muon electron abundance.

## 2 Experimental Data Presentation

The results of experimental measurements received on the Gamma facility are published in particular in (Eganov et al. , 2000) (the last year's experimental data set) and (Chilingarian et al. , 1999) (the old experimental data set). The present experimental data set is differ profitably from those of earlier analysis by more precise and detailed taking into account of the peculiarities of the Gamma experiment (see present Proceedings) (Ivanov et al. , 2001). These data are collected into two groups with respect to two triggering conditions with $2.5GeV$ and $5GeV$ muon cut-off energies.
The muon lateral distribution functions (LDF) at mountain altitudes normalized on the number of electrons for $2.5GeV$ and $5GeV$ muon cut-off energies for ten intervals of shower

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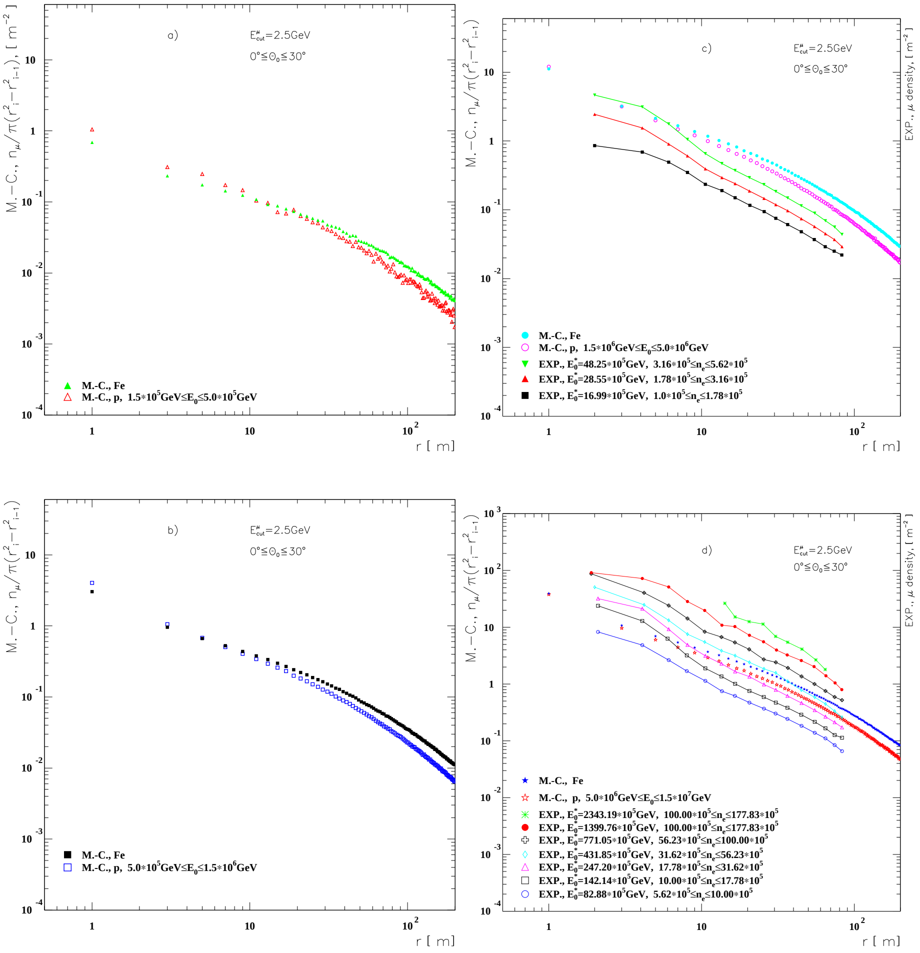

**Fig. 2.** Comparison of CORSIKA simulated and Gamma measured muon lateral distribution functions for 2.5GeV muon cut-off energies.

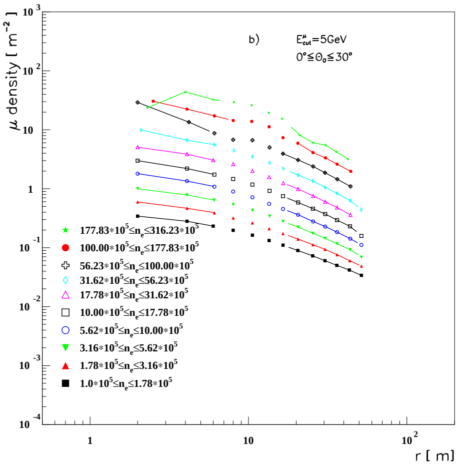

**Fig. 1.** Experimentally measured muon lateral densities for tunnel - a), and hall -b) experimental data sets for ten intervales of shower sizes respectively.

sizes are given in Figure 1. a) and b) respectively. During the understanding and analyzing of these experimental data one have to take into account that a mis-classification of the muons with 2.5 and $5GeV$ thresholds is possible for both sets of experimental curves up to the distances 8 -15 meters from shower axis, because when the shower core is close to the boundary of the hall and tunnel of Gamma facility the muons with large angle of generation at the end of absorber can pass from tunnel ($E^{\mu}_{cut-off} = 2.5GeV$) into hall ($E^{\mu}_{cut-off} = 5GeV$) and vice-versa.

The comparative contemplation of the corresponding plots of Figure 1 ( a) with b) ) allows one to observe that the muon density curves for the $2.5GeV$ thresholds (the tunnel data) are systematically higher than those for $5GeV$ thresholds (the hall data) for the same shower size intervals.
The registration level of Gamma facility is 3200m (a.s.l.) which amounts approximately $700g/cm^2$. The zenith angles of selected showers' cores varies in $[0^o, 30^o]$ interval. For such a sample of experimental data the above mentioned phenomenological approach of the $n_e \rightarrow E_0$ conversion is acceptable. We have done this conversion using formula (2), and the appropriate values of fitting coefficients have chosen from the reference (Capdevielle et al. , 1990) as follows:
for all experimental data set $a = 1.88$ and $b = 11.35$, because $k \equiv (n_\mu/n_e) \cdot 100\% \geq 0.666$ and $n_e \geq 25800$; (see (Capdevielle et al. , 1990)).

**Table 1.** Estimated energy values with correspondence of $n_\mu/n_e$ modulation.

| $n_e$ $interval \cdot 10^5$ | $\langle n_\mu \rangle \cdot 10^3$ | $n_\mu/n_e$,% | $E_0^* \cdot 10^5$, GeV |
|---|---|---|---|
| $1.00 \div 1.78$ | 2.61 | 1.93 | 16.99 |
| $1.78 \div 3.16$ | 3.59 | 1.53 | 28.55 |
| $3.16 \div 5.62$ | 5.04 | 1.23 | 48.25 |
| $5.62 \div 10.00$ | 7.37 | 1.01 | 82.88 |
| $10.00 \div 17.78$ | 11.01 | 0.85 | 142.14 |
| $17.78 \div 31.62$ | 17.22 | 0.75 | 247.20 |
| $31.62 \div 56.23$ | 28.07 | 0.69 | 431.85 |
| $56.23 \div 100.00$ | 49.70 | 0.68 | 771.05 |
| $100.00 \div 177.83$ | 98.35 | 0.76 | 1399.76 |
| $177.83 \div 316.23$ | 163.94 | 0.76 | 2343.19 |

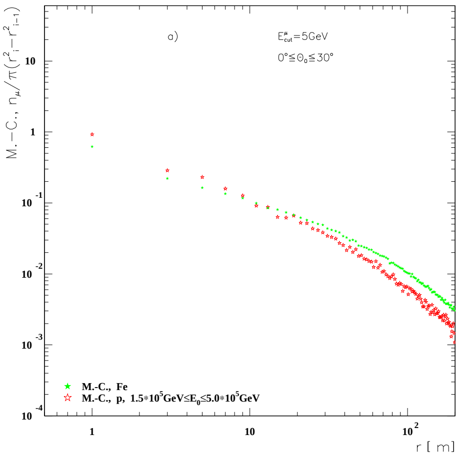

**Fig. 3.** Comparison of CORSIKA simulated and Gamma measured muon lateral distribution functions for 5GeV muon cut-off energies.

## 3 Results of Estimation and Comparison

The values of the estimated energies $(E_0^*)$ for ten intervales of the shower sizes as well as the mean values of the measured numbers of muons and the $k$ are presented in the Table 1. From the Table 1 one can see that for last two shower size intervals the dicrease of the $n_\mu/n_e$ ratio ceases near the crucial value $k = 0.666$ less of which the coefficients $a$ and $b$ are chenged (see (Capdevielle et al. , 1990)), and even this ratio increases which causes in its turn to the heighten estimated values of the energies. This circumstance can be explained by the obvious alteration of the behaviour of the probability density function of muons presented in this Proceedings by Ivanov et al. (Ivanov et al. , 2001) and perhaps also by the small experimental statistics in the last three shower size intervals.

One can select the energy interval of the Monte-Carlo simulated showers by CORSIKA code for comparison of simulated (Capdevielle and Sanosyan , 1999) and experimental ((Ivanov et al. , 2001)) lateral distribution functions by the help of Table 1. The estimated values of energies presented in Table 1 could be evidently assembled with the simulated primary energy intervals as follows:
$16.99,\ 28.55,\ and\ 48.25 \cdot 10^5 GeV$ with $(1.5 \div 5) \cdot 10^6 GeV$; and
$82.88,\ and\ 142.14, \cdot 10^5 GeV$ with $(5 \cdot 10^6 \div 1.5 \cdot 10^7) GeV$.
The remained five estimated energies:
$247.20,\ 431.85,\ 771.05,\ 1399.76,\ and\ 2343.19 \cdot 10^5 GeV$
that exceed the Monte-Carlo simulated primary energy intervals, again we have groupped with $(5 \cdot 10^6 \div 1.5 \cdot 10^7) GeV$.
The comparisons according to the sketched above selections are presented in Figures 2 and 3 for tunnel and hall data respectively. Both these figures show the experimental curves in proportion to the simulated curves for four primary energy intervales of simulated showers. The appropriate estimated energies for the experimental curves have been calculated by formula (2) as above was mentioned and chosen in such a manner that they fall into corresponding intervales of simulated primary energies. The different groups of showers can be identified easily by the help of notations on the figures.
The inspection of these plots shows that the experimental data have no overlaping ranges with those of simulated data for correspondig first two energy intervals of simulated data (see Figures 2. a), b) and 3. a), b)).
For the third simulated energy interval (Figures 2.c) and 3.c)) we have get three experimentally measured muon density functions. In all cases the measured density functios lie down under the simulated LDF curves.
For the fourth simulated energy intervals (Figures 2.d) and 3.d)) we have get as a result of our estimation only two experimentally measured muon density functions. In this energy

interval also the measured density functions lie down under the simulated LDF curves.
From beginning $15m$ of shower axis the slop of experimental curves is almost the same as for proton induced simulated showers.
For the estimated energy value $E_0^* = 431.85 \cdot 10^5 GeV$ the experimental curve takes up a meddle position between the proton and iron induced muon LDF curves. But this coincidence indicates only the fact that the mean values of muons presented in Table 1 are systematically heighten in comparison with earlier experimental data analysis (Eganov et al. , 2000). This circumstance has brought to the heighten values of estimated energies.

Our **conclusion** is the following:
1. If the QGSJET model (Kalmykov et al. , 1997) or the NEXUS model (Drescher et al. , 1999) is the best model for cosmic ray data, we can have quite better results for $a, b, c$, and $\alpha$ parameters in formula (1) by plotting and fitting $E_0/N_e$ versus $ln(N_\mu/N_e)$ shower per shower for a fixed zenith angle by currying realistic Monte-Carlo calculations with CORSIKA 6.xx (Heck and Knapp , 2001; Capdevielle et al. , 1992; Heck et al. , 1998) for the case of the Gamma facility observation level (3200m a.s.l., latitude: $N40.47^o$ longitude: $E44.18^o$).
2. To receive the response of the Gamma facility we have to pass each event thrugh the detectors of the setup having as an input of GEANT (CERNLIB , W5013) or ARES (Haungs et al. , 1999) code the output of the CORSIKA simulation at observation level and by taking into account all peculiarities of the experimental data analysis.
3. To make convertion from shower size to primary energies we have to repeat the aformentioned procedure by using newly calculated $a, b, c$, and $\alpha$ parameters and the reconstructed muon distribution functions.

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