Leading nucleon and the hadronic flux in the atmosphere

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Abstract

Using an Iterative Leading Particle Model to describing nucleon-air collisions, we determine the hadronic flux in the atmosphere and compare with cosmic ray experimental data.

We present in this paper a calculation of the hadronic flux in the atmosphere. Analytical solutions for the nucleonic diffusion equation in the atmosphere having as boundary condition the primary spectrum and calculated with the leading particle model, shows a strong correlation between the inelastic proton-air cross section and the momentum of the leading particle distribution, because the nucleonic shower penetration in the atmosphere depends on the primary spectrum. In order to analyse experimental data on the hadronic flux we correlate the moment of the leading particle distribution in nucleon-air collisions with the respective one in proton-nucleus coliisions using the Glauber model (Glauber 1959; Glauber et al. 1970).

For proton-nucleus scattering, at low energy, several models for describing the leading particle spectrum have been proposed (Iteracting Gluon model and Regge-Mueller formalism) (Yama et al. 1997; Durães et al. 1993; Batista et al. 1998) Here, we shall work in the Iterative Leading Particle Model (Hwa 1984; Hufner & Klar 1984) and use the notation of Frichter, Gaisser and Stanev (Fritcher et al. 1997). In this model the leading particle spectrum in $p + A \rightarrow$ *N(nucleon)*$+ X$ collisions is built from sucessive interacions with ν interacting proton of the nucleus A and the behaviour is controlled by a straightforward convolution equation. It should be mentioned that, strictly speaking, the convolution should be 3-dimensional. Here we only considered the 1-dimension approximation.

It is straightforward to show that in this model the $\gamma - th$ moment of the nucleon-air leading particle distribution, $< x^{\gamma} >_{N-air}$, is correlated wiht the respective nucleon-proton moment, $< x^{\gamma} >_{N-p}$, by means of the following relation

$$\sigma_{in}^{N-ar}(1- < x^{\gamma} >_{N-air}) = \int d^2b[1 - [\eta(\gamma)\exp[-(1 - K(\gamma)\sigma_{tot}^{pp}T(b)] + (1 - \eta(\gamma)\exp[-\sigma_{tot}^{pp}T(b)]]] \tag{1}$$

where $T(b)$ is the nuclear thickness and given by means of the Woods-Saxon model (Woods & Saxon 1954; Barrett & Jackson 1977)

$$\eta(\gamma) = \frac{< x^{\gamma} >_1^N}{K(\gamma)} \tag{2}$$

$$K_{\nu-1}(\gamma) = \beta_{\nu-1}\int_o^1 dyy^{\gamma}S_{\nu}^{+}(y) + (1 - \beta_{\nu-1})\int_o^1 dyy^{\gamma}S_{\nu}^{-}(y) \tag{3}$$

The differential nucleonic flux in the atmosphere at some depth t ,is given by

$$F_N(E,t) = N_o E^{-(\gamma+1)}\exp[-\frac{t}{\Lambda(E)}] \tag{4}$$

where $N_o E^{-(\gamma+1)}$ is the primary spectrum at $t = 0$ and $\Lambda(E)$ is the nucleonic attenuation length wich is given by

$$\frac{1}{\Lambda(E)} = \frac{\sigma_{in}^{N-ar}(1- < x^{\gamma} >_{N-air})}{24100}(g/cm^2)^{-1} \tag{5}$$

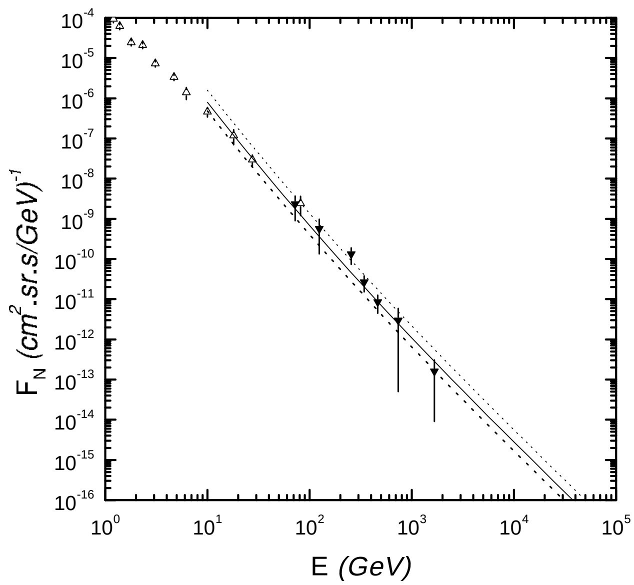

Figure 1: Nucl onic flux at sea level. Experimental data from (Brook et al. 1964; Ashton et al. 1968; Ashton et al. 1970). Cont inuous line, result of fit. Dash lines, maximal and minimal values of the calculated nucleonic flux.

We tested Eq. (1) in comparison with cosmic ray data on nucleonic flux (Brook et al. 1964; Ashton et al. 19 68; Ashton et al. 1970) and hadronic flux in the atmosphere (Mielke et al. 1993; Mielke et al. 1994; Aglietta e t al. 1997). Forσ_{tot}^{pp} we used the UA4/2 Collaboration parametrization (Burnett et al. 1992) and estimated σ_{in}^{N-air} by means of the Glauber model (Glauber 1959; Glauber et al. 1970) and for the $T(b)$ nuclear thickness we used the Woods-Saxon model (Woods & Saxon 1954; Barrett & Jackson 1977). The parameters η and K were left free. The best fit ($\aleph^2/d.o.f. = 2.61$) corresponds to $\eta = 1$ and $K = 0.34$ and is shown in Fig. 1 (nucleonic flux at sea level) (Brook et al. 1964; Ashton et al. 1968; Ashton et al. 1970) in Fig. 2 (hadronic flux at sea level) (Mielke et al. 1993; Mielke et al. 1994) and in Fig. 3 (hadronic flux at $t = 840 g/cm^2$) (Aglietta et al. 1997). The hadronic flux was obtained multiplying the nucleonic flux in Eq. (6) by the Kascade factor (Mielke et al. 1993; Mielke et al. 1994)

$$R = \frac{\pi^+ + \pi^-}{p+n} = 0.04 + 0.27 \ln(E/GeV) \qquad (6)$$

in order to count the number of pions in the hadronic flux. We have used the same primary spectrum as in (Bellandi et al. 1998). We also show in these figures the maximal and minimal values for the flux considering the experimental errors in the primary spectrum.

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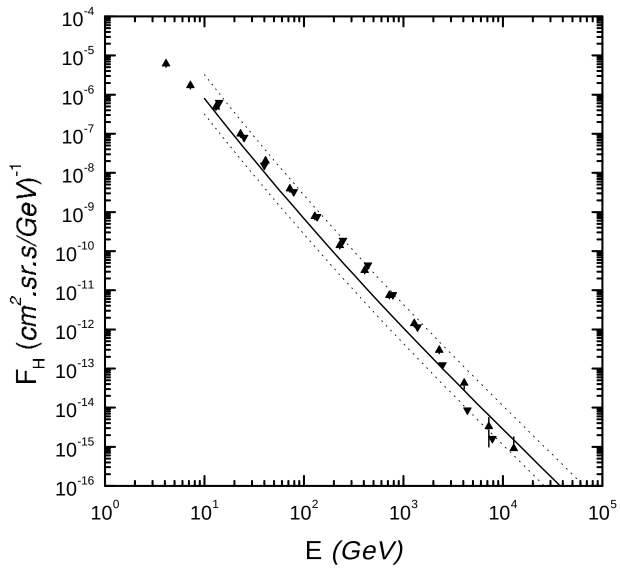

Figure 2: Hadronic flux at sea level. Experimental data from (Mielke et al. 1993; Mielke et al. 1994). Continuous line, result of fit. Dash lines, maximal and minimal values of the calculated hadronic flux.

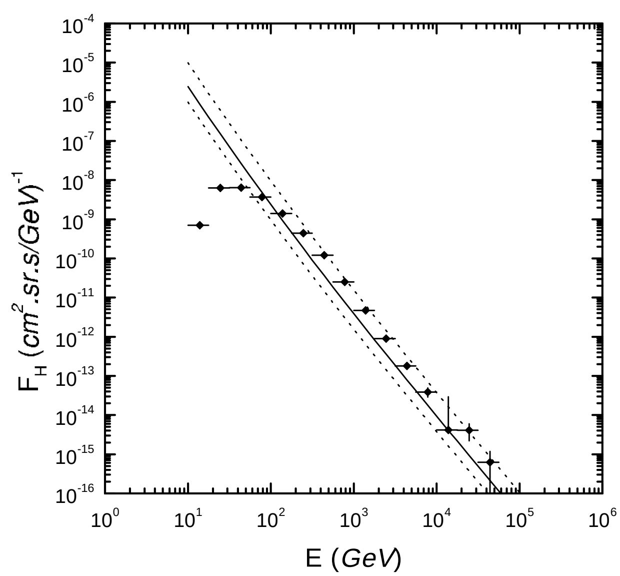

Figure 3: Hadronic flux at $t = 830\ g/cm^2$. Experimental data from (Aglietta et al. 1997). Continuous line, result of fit. Dash lines, maximal and minimal values of the calculated hadronic flux.

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