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CHARGE RATIO OF COSMIC PIONS IN THE ATMOSPHERE

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Abstract: It is found that the CERN Intersecting Storage Ring data on $pp \to \pi^{\pm} + X$ inclusive reactions can be represented by a single scaling variable $\eta = 2p_T^2 x/(c \ln(s/s_0))$ for $0.075 \leq x \leq 0.3$ and $0.2 \leq p_T \leq 1.5$ GeV/c. The charge ratio of cosmic pion spectrum at the top of the atmosphere has been estimated using this new type of scaling variable and the primary nucleon spectrum of Grigorov et al. has been used as a hadron source at the top of the atmosphere.

1. Introduction

The charge ratio in the pion spectrum at the top of the atmosphere is of phenomenological importance in the cosmic ray physics.

Earlier Frazer et al.[1], Yekutieli[2], Morrison and Elbert[3], Adair et al[4], Yen[5], Hume et al.[6], Erlykin et al.[7] have calculated the charge ratio of pions originated from pp interactions used different models.

In the present work we have fitted the Intersecting Storage Ring reaction data of Capiluppi et al.[8] for $pp \to \pi^{\pm} + X$ reactions by our proposed new scaling variable[9]. Using the primary cosmic ray spectrum of Grigorov et al.[10] the pion charge ratio has been estimated. The present result has been compared with the values presented by different authors[1-7].

2. New scaling variable and pion charge ratio

The CERN Intersecting Storage Ring data on inclusive reactions $pp \to \pi^+ + X$ and $pp \to \pi^- + X$, respectively have been represented in Figs. 1 and 2 as functions of new scaling variable

$$\eta = \frac{2 p_T^2 x}{\bar{c} \ln (s/s_0)},$$

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where $x = 2p_L/\sqrt{s}$, p_L is the center of mass longitudinal momentum of the detected particle and $\sqrt{s}$ is the total c. m. energy; p_T is the center of mass transverse momentum. The new scaling variable is taken to be dimensionless by taking $c' \approx 1$ $(\mathrm{GeV/c})^2$ and s_0 to be 1 GeV, for $0.075 \leq x \leq 0.3$ and $0.2 \leq p_T \leq 1.5$ GeV/c. The parametrization of the invariant cross section used in the present work is of the following

$$\left(E\frac{d^3\sigma}{d^3p}\right)\ln(s/s_0) = A\exp(-a\eta + b\eta^2). \tag{1}$$

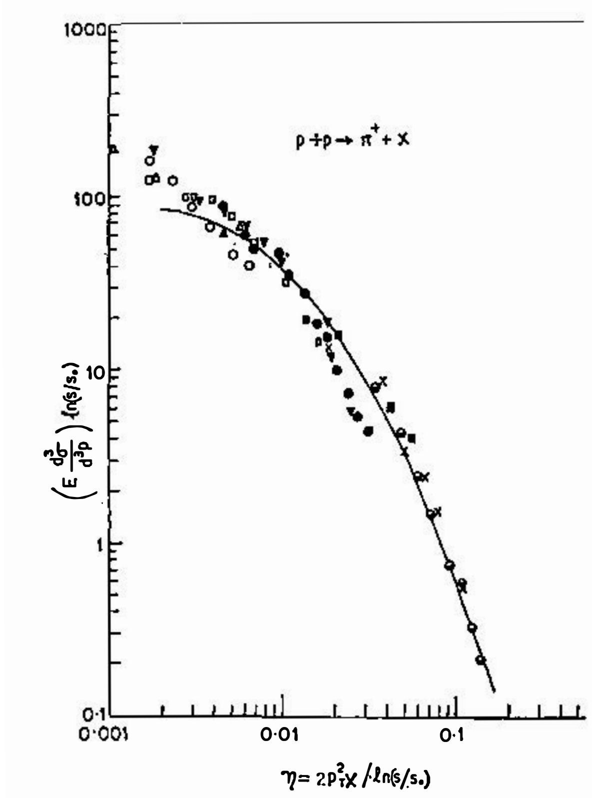

Fig. 1. The cross section data for $p + p \to \pi^+ + X$ reactions, $E(d^3\sigma/d^3p)\ln(s/s_0)$ vs $\eta = 2p_T^2x/\ln(s/s_0)$ have been plotted from the work of Capiluppi et al.[8]. Solid curve shows the fit from Equ. (1).

Experimental data:

$\sqrt{s} = 23{,}3$ Gev,	△	for $x = 0.15$,	▲	for $x = 0.3$;		
$\sqrt{s} = 30.6$ GeV,	□	for $x = 0.15$,	■	for $x = 0.3$;		
$\sqrt{s} = 44.6$ GeV,	▽	for $x = 0.075$,	▼	for $x = 0.15$,	×	for $x = 0.3$;
$\sqrt{s} = 53.0$ GeV,	○	for $x = 0.075$,	●	for $x = 0.15$,	◒	for $x = 0.3$.

The fit in Fig. 1 for positive pions corresponds to $A = 168.7$, $a = 113.9$, $b = 683.4$ and the fit to Fig. 2 corresponds to $A = 46.06$, $a = 85$, $b = 510$ for negative pions (Roy Choudhury and Bhattacharyya[9]).

The pion nucleon flux ratio can be derived for p-p collisions in the following way

$$P(E_\pi, E_p)\,\mathrm{d}E_\pi = \frac{\pi}{\sigma_{in}} \int_{p_T} \mathrm{f}(x, p_T)\,\frac{\mathrm{d}x}{x}\,\mathrm{d}p_T^2, \tag{2}$$

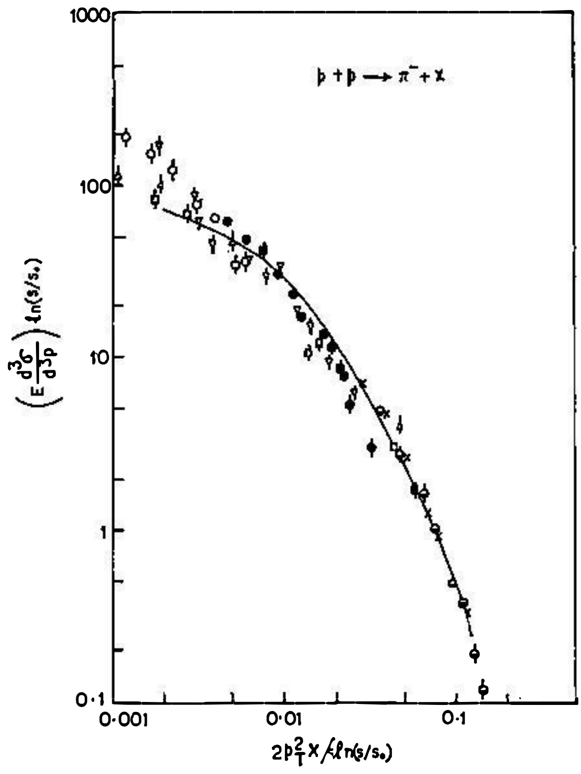

Fig. 2. The cross section data for p + p → π^- + X reactions, $E(\mathrm{d}^3\sigma/\mathrm{d}^3p)\ \ln(s/s_0)$ vs $\eta = 2p_T^2x/\ln(s/s_0)$ have been plotted from the work of Capiluppi et al.[8]. Solid curve shows the fit from Equ. (1).

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$\sqrt{s} = 44.6$ GeV,	▽ for $x = 0.075$,	▼ for $x = 0.15$,	× for $x = 0.3$;	
$\sqrt{s} = 53.0$ GeV,	○ for $x = 0.075$,	● for $x = 0.15$,	⊖ for $x = 0.3$.	

where E_p is the primary nucleon energy and E_π is the secondary pion energy in the laboratory system. For large E_p and not too small value of x close to zero, x is given by

$$x \approx E_\pi / E_p. \tag{3}$$

From (2) and (3) we find

$$P(E_\pi, E_p)\, \mathrm{d}E_\pi = \frac{\pi A}{2\,\sigma_{in}} \frac{\mathrm{d}x}{x^2} I(\beta), \tag{4}$$

$$\text{where } I(\beta) = \int_0^\beta \exp(-a^2/4b) \exp\{\eta - a/2b)^2\}\, \mathrm{d}\eta. \tag{5}$$

The integral over η is cut off at some suitable value (actually $\beta = 0.1$ is sufficient for the data analysed here) $I(\beta)$ can also be expressed in the following form

$$I(\beta) = \frac{\exp(-a^2/4\,b)}{\sqrt{b}} \left[\exp(a^2/4\,b)\, D(a/2\sqrt{b}) + \exp\{b(\beta - a/2b)^2\, D\{\sqrt{b}(\beta + a/2b)\}\right], \tag{6}$$

where $D(x)$ is the Dawson integral (Abramowitz and Stegun[11]),

$$D(x) = \exp(-x^2) \int_0^x \exp(t^2)\, \mathrm{d}t. \tag{7}$$

Taking the hadron source spectrum of Grigorov et al.[10], their result follows the power law of the following form

$$N(E_p)\, \mathrm{d}E_p = N_0\, E_p^{-\gamma}\, \mathrm{d}E_p, \tag{8}$$

where $N_0 = 2.54$ and $\gamma = 2.6$, E_p is expressed in GeV and the differential nucleon intensity $N(E_p)\, \mathrm{d}E_p$ is expressed in units per (cm^{2}s sr GeV). We get the pion nucleon flux r ratio in the top of the atmosphere by the following relation

$$\pi(E_\pi)\, \mathrm{d}E_\pi = \int P(E_\pi, E_p\, (N(E_p)\, \mathrm{d}E_p\, \mathrm{d}E_\pi = \frac{\pi\, A\, I(\beta)}{2\sigma_{in}} N_0\, E_\pi^{-\gamma} \int_0^1 x^{\gamma-3}\, \mathrm{d}x\, \mathrm{d}E =$$

$$= \frac{\pi\, A\, I(\beta)}{2(\gamma - 2)\,\sigma_{in}} N(E_\pi)\, \mathrm{d}E_\pi. \tag{9}$$

3. *Results and discussion*

It is evident from relation (9) that the pion nucleon flux ratio decreases with increase of σ_{in} with energy. Taking σ_{in} = 35 mb from the Intersecting Storage Ring data of Capilupi et al.[8] at center of mass energy $\sqrt{s}$ — 52.8 GeV we get the flux ratio of chargend pion-nucleon, at the top of the atmosphere, which is presented in the Table 1.

Table 1

Charged pion nucleon flux ratio estimated from the relation (9)

Flux	Ratio value
π^+/N	0.1037
π^-/N	0.069

The calculated charge ratio of the pion spectrum (π^+/π^-) in the atmosphere has been presented in the Table 2 along with the results of different authors[1-7].

Table 2

π^+/π^- ratio determined by different authors

Authors	Exponent of the integral spectrum	Charge ratio π^+/π^-
Frazer et al.[1]	1.70	2.02
Yekutieli[2]	1.70	2.06
Morrison and Elbert[3]	1.70	1.46
Adair et al.[4]	1.70	1.83
Yen[5]	1.70	1.70
Hume et al.[6]	1.60	1.72
Erlykin et al.[7]	1.62	1.54
Present Work	1.60	—

Our calculated charge ratio of cosmic pions in the top of the atmosphere agrees with the results of Yen[5] and Hume et al.[6].

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