ANOMALIES IN COSMIC RAYS: NEW PARTICLES vs CHARM?

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For a long time two anomalies are observed in cosmic rays at energies $E \sim 100$ TeV: 1) the generation of "long-flying" cascades in the hadron calorimeter (the so-called Tien-Shan effect) /1/; 2) the enhancement of direct muon yield as compared with the accelerator energy region /2/. The aim of this paper is to discuss the possibility that both anomalies have common origin arising from production and decays of the same particles. The main conclusions are the following: 1) direct muons cannot be generated by any new particles with mass exceeding $10 \div 20$ GeV; 2) if both effects are originated from the charmed hadrons, then the needed charm hadroproduction cross section is unexpectedly large as compared with the quark-gluon model predictions.

When energy grows from $E \sim 10$ TeV to $E \sim 100$ TeV, an increase of the hadron cascade mean penetration length is observed. This phenomenon is interpreted by the authors of Tien-Shan experiment /1/ as production (in the cosmic shower interactions with the calorimeter nuclei) of unstable particles which carry a substantial part ($\langle x \rangle \gtrsim 0.25$) of the incident energy and simultaneously have small inelasticity (or small cross section of the interactions with the calorimeter substance). When the incident energy becomes ~ 100 TeV, the mean decay path of these particles $\ell \sim \langle x \rangle E c \tau / m$ reaches the scale of the calorimeter vertical size ($\ell \sim 1$ m) so that the resulting hadron cascade is observed as "long-flying". The mass range of these particles is estimated /1/ as $2\ \text{GeV} \lesssim m \lesssim 450$ GeV, their lifetime being respectively in the interval $10^{-12}\,\text{sec} \lesssim \tau \lesssim 10^{-10}$ sec. The hadroproduction cross section of "long-flying" particles is $\sigma \sim 3 \div 5$ mb/nucleon at $E \sim 100$ TeV.

The direct muons produced in the primary pN-collisions with definite energy E_μ are characterized by the ratio of their yield to the number of pions produced with the same energy. We have obtained for this ratio R integrated over the primary spectrum with power $\gamma + 1 = 2.65$ the following estimate

$$R(E_\mu) \simeq 11.5 < n_\mu (E_\mu / <x_\mu>) > \int_0^1 \frac{dN}{dx_\mu} x_\mu^\gamma \, dx_\mu \qquad (1)$$

Here the familiar parametrization of pion inclusive cross section from /3/ was used and scaling for direct muons was assumed ($<n_\mu> = \sigma(\mu^+\mu^-)/\sigma_{tot}$ is the direct muon mean multiplicity, dN/dx_μ is the normalized spectrum over $x_\mu = E_\mu/E$; $<x_\mu>$ is the value at which the integrand in eq.(1) reaches its maximum). Due to the x_μ^γ factor the ratio R becomes a good analyzer of muons carrying a large part of the incident energy. Data from a few experiments /2/, although with large uncertainties, indicate that in the region E_μ = 1÷100 TeV R may reach an order of 10^{-3} value.

Suppose that starting from 10÷100 TeV some new X-particles (of hadronic origin) are produced, which simultaneously are "long-flying" and have muonic decays. It turns out that already available SPS collider ($\sqrt{S}$ = 540 GeV, i.e. E ~ 150 TeV) data sample allows us to reject too heavy X-particles generating large $p_\perp$ muons. To demonstrate this, we have calculated the ratio

$$\Delta(M_x) = \frac{\int\limits_{P_{\perp\mu} > 5\,\mathrm{GeV}} dp_{\perp\mu}^2 \int\limits_{|x_\mu| < 0{,}3} dx_\mu \frac{d\sigma}{dx_\mu \, dp_{\perp\mu}^2} (p\bar{p} \to \underset{\hookrightarrow \mu}{X} + \ldots)}{\sigma(p\bar{p} \to \underset{\hookrightarrow \mu}{X} + \cdots)} \qquad (2)$$

which determines that part of direct muons from X-particles to which the collider detectors are sensitive. In fact, $\Delta(M_X) > 10\%$ at $M_X > 10$ GeV (20 GeV), if the muon creates in $X \to \mu^\pm \nu$, $\mu^+\mu^-$ $(X \to \mu^\pm \nu + H, \mu^+\mu^- + H)$ decays, where M_H may be $\leq \frac{1}{2} M_X$. The X-particle mean $P_\perp$ was chosen ~ 1 GeV/c (i.e. too low for real heavy particles) to decrease artificially the share of large $p_\perp$ muons. Nevertheless due to the large X-mass the substantial part of muons are produced with $P_{\perp\mu} \geqslant 5$ GeV. At the same time, the value of Δ shows practically no change when the longitudinal X-spectrum is varied in wide limits (from $d\sigma/dx \sim (1-x)^5/x$ to $d\sigma/dx \sim x(1-x)$). From the UA1-data sample on the $W \to \mu\nu$ search /4/ we conclude that $\sigma(p\bar{p} \to \mu(P_{\perp\mu} > 5\,\mathrm{GeV}) + \cdots) \sim 0.2\,\mu b$ at E $\sim$ 150 TeV. By means of coefficient (2) we immediately obtain the upper limit for the cross section of hypothetical X-particles:

$$\sigma(pN \to X + \cdots)\, B(X \to \mu) \leq 2\,\mu b \tag{3}$$

which holds for all variants of X-production and decays mentioned above (we suppose that $\sigma(pN \to X + \cdots) \simeq \sigma(p\bar{p} \to X + \cdots)$ which is justified at such energies). It is easy to verify that the upper bound given by eq.(3) allows too few direct muons from X-particles ($R \ll 10^{-4}$). In addition, we think that: 1) more detailed scenarios of X-decays (involving a second muon and/or neutrino) will decrease the upper limit of the allowed X-masses up to the b-flavored hadrons; 2) the analogous consideration of jets from pure hadronic X-decays will allow also to reject too heavy X as "long-flying" cascade source. At the same time it is evident that the collider data obtained in the large $p_\perp$ region are not too sensitive to the muons from charm decays produced predominantly with $p_{\perp\mu} \lesssim$ 1 GeV.

As it was noted earlier /1,5,6/, the charmed hadrons (Λ_c and $\mathcal{D}$) are really good candidates for "long-flying" particles. Particularly important is that their expected inelasticity is small as comaper with light hadrons due to the specific effect of c-quark leading inside Λ_c or $\mathcal{D}$ /6/. It is known also that the mean part of incident energy $\langle x \rangle$ carried by charmed hadrons may be really large. In particular, Λ_c -baryons were detected at ISR (E $\sim$ 2 TeV) /7/ with spectrum

$$d\sigma/dx \simeq 3/2\, \sigma \sqrt{1-x} \tag{4}$$

where $\sigma \leq 0.3$ mb, $\langle x \rangle \sim 0.4$. The whole effect of "long-flying" cascades may be understood in terms of charm if achieves $\sim$ 3 mb at E $\sim$ 100 TeV. Therefore, it is necessary to postulate a rapid growth of charm yield in the <u>fragmantation region</u> ($X > 0.1$). We have chosen it as follows:

$$\sigma \simeq 0{,}3\,\mathrm{mb}\left(1+\ln\left(\frac{\sqrt{S}\ (\mathrm{GeV})}{60}\right)\right)^2 \qquad (5)$$

The muon spectrum from semileptonic decays of charm ($B(c\to\mu)$ = 10%) produced according to eqs.(4),(5) was calculated. This spectrum behaves like $(1-x_\mu)^6/x_\mu$ at $X_\mu > 0.05$ and gives $R \sim 1.3\cdot10^{-3}$ at $E_\mu \sim 10$ TeV.

Therefore, both effects: the "long-flying" cascades and direct muons are simultaneously explained if we suppose abundant charm production in the fragmentation region. Note that this phenomenon is rather unexpected in quark-gluon models of charm hadroproduction. Although the whole picture of heavy quark hadroproduction is yet far from understanding, it is clear that in the fragmentation region some nonperturbative mechanisms are essential. The models describing this region predict /8-10/ too slow rise ($\sim \ln E$) of the cross section fragmentation part so that at $E \sim 100$ TeV in eq.(4) $\sigma \lesssim 0.5 \div 0.8$ mb.

We conclude that more detailed information about inclusive cross section of charmed hadroproduction at energies ~ 100 TeV would be of great interest from the viewpoint of the quark-gluon physics. New data on the cosmic ray anomalies at superhigh energies are therefore needed. Note that the proposed ANI installation /11/ will have a unique possibility to detect both "long-flying" cascades and direct muons.

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