THE MULTIPLICITY AND THE SPECTRA OF SECONDARIES CORRELATED WITH THE LEADING PARTICLE ENERGY

N.A.Kruglov, A.S.Proskuryakov, L.I.Sarycheva and L.N.Smirnova

Institute of Nuclear Physics, Moscow State University, Moscow II9899, USSR

Abstract. The spectra of leading particles of different nature in pp-collisions at $E_0 = 33$ GeV are obtained. The multiplicities and the spectra of secondaries π^+, π^-, $K^\pm$ -mesons, γ-quanta, Λ and $\bar{\Lambda}$ -hyperons and protons for different leading particle energy ranges are determined.

The interactions in which the leading particle conserves a great fraction of the initial energy are essential for the development of nuclear cascades in the atmosphere. The leading particles form a deeply propagating part of the cosmic rays. The accompaniment of these particles is determined by the peculiarities of the low-inelasticity interactions. Besides, the events with a leading particle are reliably identified in the cosmic-ray detectors.

The main information on the multiple production of particles obtained from accelerators, is averaged over all types of events. This paper reports the multiplicities of π^+, π^-, γ, $K^\pm$, Λ and $\bar{\Lambda}$ -particles, the partial coefficients of inelasticity and the spectra of particles in $p\bar{p}$-interactions at $E_0 = 33$ GeV in the lab.system that are correlated with the origin and energy of the leading particle.

The experimental conditions

The experimental material consists of 200 thousands of inelastic interactions of antiprotons with the momentum 32 GeV/c observed in the liquid hydrogen Mirabelle bubble chamber. The large dimensions of the chamber provided high detection efficiency of photons, K_s^0-mesons and $\Lambda/\bar{\Lambda}$ -hyperons. We use the events where all charged tracks are measured.

For the particles with the momentum $p_{lab} < 1.2$ GeV/c the protons were discriminated from the π^+-mesons by comparing track ionization. Neutrons and antineutrons are the only unobservable species in the chamber. Their mean characteristics are restored proceeding from the condition of energy balance /I/. In the present paper all inelastic interactions are analyzed in the system of an incident antiproton which will be mark in following as lab-system. This choice of system enabled us to establish the nature of a leading particle with the fraction of initial energy $\varkappa_{lead} = E/E_0 \geqslant 0.4$.

Classification of events

The particle carrying away the maximum, as compared with other particles, fraction of energy in the lab.system in an event is assumed to be the leading particle. When the total energy of unobservable neutral particles exceeds the energy of the leading particle, a neutral system X^0 is regarded to be the leader. Table I presents the cross sections of the events with the leading particle of different nature in different ranges of u_{lead}.

Table I

The cross sections of the picked out classes of interactions σ, mb

leader	leading energy ranges		u lead
	0.4 - 0.6	0.6 - 0.8	0.8 - I.0
p π^+ π^- X^0	2.83 ± 0.03 I.23 ± 0.02 0.59 ± 0.0I 7.46 ± 0.04	3.43 ± 0.03 0.23 ± 0.0I 0.084 ± 0.005 6.78 ± 0.03	3.55 ± 0.I5 0.0I5 ± 0.002 0.007 ± 0.002 4.49 ± 0.03
Λ γ K^0_s	0.35 ± 0.04 0.I5 ± 0.09 0.09 ± 0.02	0.24 ± 0.03 0.0I7 ± 0.0I5 0.007 ± 0.005	0.07 ± 0.02 0.004 ± 0.004 -

$\sigma^{p\bar{p}}_{tot}(32^{GeV/c}) = 45.6 \pm 0.3$ mb, $\sigma^{p\bar{p}}_{in} = 37.2 \pm 0.5$ mb, $\sigma^{p\bar{p}}_{nonann} = 30.7 \pm 0.5$ mb /2/.

The events with the leader p, π^+, π^- and $u_{lead} \geq 0.4$ make up I2 mb, i.e. (32 ± 0.4)% of the inelastic $p\bar{p}$-cross section. The events with the leaders Λ, γ, K^n (= $K^0 + \bar{K}^0$) at $u_{lead} \geq 0.4$ with the cross section I.04 ± 0.II mb are observed.

The total energy of the particles attending the charged and neutral leader is presented in units of $u = \Sigma E_i/E_0$ in fig.I. It is seen that the taking account of $\langle u_{lead} \rangle$ in the events with the charged leader permitted the complete recovery of the interaction energy. The measured fraction of energy of the attending particles in the events with the leader X^0 is higher as compared with the events with the p and $\pi^{\pm}$-leader. In this case according to the selection criteria a fraction of energy of the neutral leader X^0 is carried by photons and the mean value of this energy is measured in the chamber for each group of events. The unobservable energy is carried away by an outgoing neutron. The mean fraction of this energy is indicated in fig.I. Consequently, the class of events with the leader X^0 contains mainly the events with a leading neutron. The groups with u_{lead} (X^0) ≥ 0.6 correspond to the events with $u_{lead}(n) \geq 0.4$, since the mean value of α_γ in these events is ≤ 0.2. The events with the leader X^0 and $u_{lead} \geq 0.6$ are considered in what follows as two groups of events with a leading neutron: $\langle u_{lead} \rangle = 0.78 \pm 0.01$ and 0.50 ± 0.01. The cross sections of the events with a leading proton and neutron with $u_{lead} \geq 0.4$ are actually the same. This means that the leader in (68.8 ± 0.5)% of the nonannihilation $p\bar{p}$-interactions is a nucleon with $u_{lead} \geq 0.4$.

In fig.I there is no evidence for a fast neutron in the events with the $\pi^{\pm}$-leader and we therefore conclude that these events are mainly due to the $p\bar{p}$-annihilation. The cross sections of the events are in accord with this conclusion.

Experimental Results

The spectrum of leading protons is uniform within $u_{lead} = 0.5 \div 0.9$ /2/. The spectra of leading $\pi^{\pm}$ and K^{n}-mesons with $u_{lead} \geq 0.5$ decrease with increasing u_{lead} and are described by the function $A_{exp}(-B u^2_{lead})$ with the parameters $B_{\pi^+} = 12.4 \pm 0.9$ and $B_{\pi^-} = 12.6 \pm 0.4$. To the spectrum of leading Λ with $u_{lead} \geq 0.5$ there corresponds the parameter $B_{\Lambda} = 8.1 \pm 0.3$.

The total multiplicity of the particles attending the leading p, n, π^+, π^-, Λ is shown in fig.2a. The right scale shows the ratio of the observed multiplicity to the estimated total multiplicity $\langle n_{tot} - 1 \rangle$ for pp-interactions at 32 GeV/c /3/. It is seen that at u_{lead} close to 0.5 the multiplicity reaches the mean value.

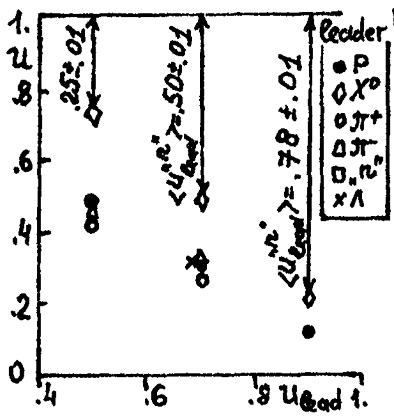

Fig.I. A fraction of the measured energy in the events with different leaders

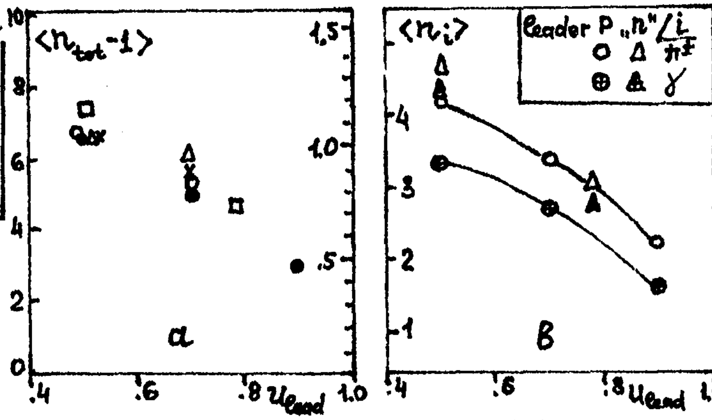

Fig.2. Total multiplicity (a) and multiplicity of the attending particles of species i (b) for different leaders

The multiplicity of $\pi^{\pm}$ and K^{n}-mesons and photons attending the leading nucleon is shown in fig.2b. The total multiplicity of $\pi^{\pm}$-mesons is similar in the events with a leading proton and "neutron". The value of $\langle n_{\gamma} \rangle$ proves to be higher for a leading "neutron" which can be connected with the identification procedure used.

The mean fraction of energy carried away by the attending π^+, π^-, K^{n}, γ is shown in fig.3. The mean fraction of energy per π^+ and γ is the same whether the leader is a proton or a "neutron". The total fraction of energy carried away by these particles is plotted in fig.4 versus u_{lead} of a proton and "neutron".

The spectra of the attending particles are rather complex and concentrated in the region of low u for high u_{lead}. The parameters of the function describing these spectra are listed in table 2.

In the events with a leading proton a great fraction of the "invisible" energy carried away by the photons. In this case $\Sigma E_{\gamma} \approx E_0 - \Sigma E_{\pm} - \Sigma E_{K\xi, \Lambda/\pi}$ and the spectrum of photons can be obtained from the variable $u_{\gamma} = E_{\gamma}/\Sigma E_{\gamma}$ used in the cosmic rays. The spectra $d\sigma/du_{\gamma}$ are presented in fig. 5

for the events with a leading proton at $u_{lead} > 0.8$ and $u_{lead} = 0.4 \div 0.8$.

Table 2

Parametrization of the spectra of the particles attending the leading protons and "Neutrons" by the function $f = u^N \exp(-B1 u - B2 u^2)$

leader	u_{lead}	type of a secondary particles	N	BI	B2
p	0.4-0.6	π^+	-I.00±0.0I	-5.5 ±0.3	22.6±0.6
		π^-	-I.6I±0.0I	-7.5I±0.07	24.6±0.3
		γ	0.027±0.0I4	34.3 ±2.6	-9.0±I3.6
	0.6-0.8	π^+	-I.3I±0.06	-II.0±I.3	4I ± 2
		π^-	-I.85±0.0I	-7.9I±0.08	32.5±0.4
		γ	0.027±0.0I4	44.I ±2.3	-28 ±I0
	0.8-I.0	π^+	-0.2I±0.0I	3I.0 ±0.9	-I5.6±5.4
		π^-	-2.62±0.0I	I0.8 ±0.2	-6.7±I.4
		γ	-I.I5±0.05	32.5 ±I.8	58.3±6.3
X^0 ("n")	0.6-0.8	π^+	-I.25±0.02	-I4.9±0.4	54.8±0.7
	$\langle u_{"n"} \rangle$=0.50	π^-	-I.20±0.05	-2.3 ±I.I	39.8±2.3
	±0.01	γ	-2.4I±0.02	-20.2±I.3	83.4±8.4
	0.8-I.0	π^+	-2.66±0.0I	64.0±0.I	287.4±0.9
	$\langle u_{"n"} \rangle$=0.78	π^-	-I.98±0.0I	-20.I±I.0	I79 ±7.8
	±0.01	γ	-2.3 ±0.I	-I7.2±4.3	83.4±8.4

References:

I. Vinitskii A.A. et al., Sov.Journ.Nucl.Phys., I984, 40,474.
2. Hanumejah B. et al. Nuovo Cim., I982, 68A, I6I; I7 ICR, I98I, HE I-7, v.5, p.22.
3. Nikitaev D.N., Smirnova L.N. Sov.Journ.Nucl.Phys.,I985, 4I, No.3.

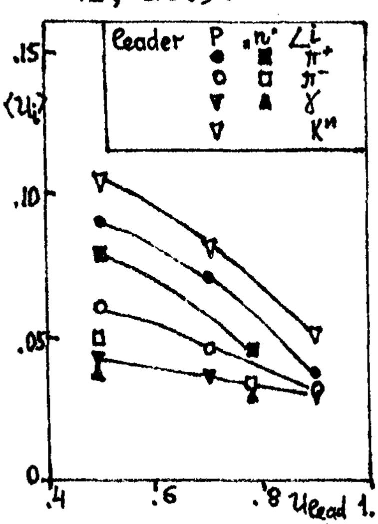

Fig.3.Mean fraction of energy per particle of species i for different leaders

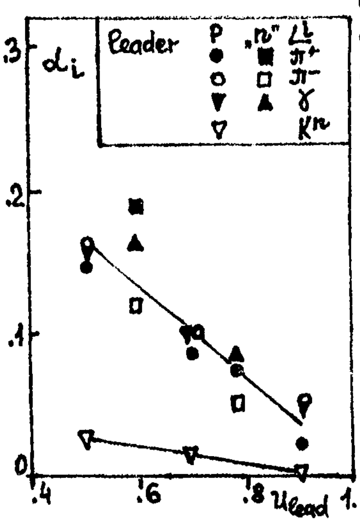

Fig.4.Partial coefficients of inelasticity of particles α_i for different leaders: $\alpha_i = \langle u_i \rangle \langle n_i \rangle$

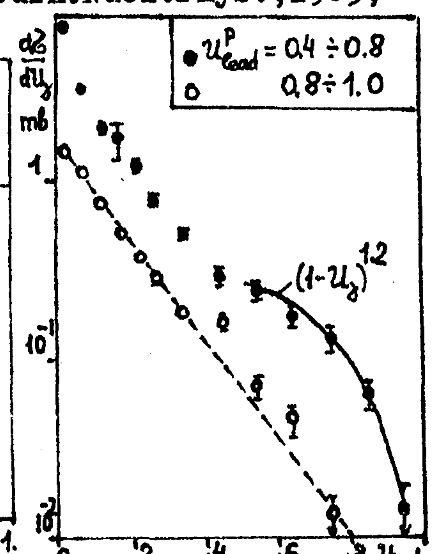

Fig.5.Spectra of γ in $u_\gamma = E_\gamma / \Sigma E_\gamma$ for the events with a leading proton