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S.Berceanu, T.Ponta

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S.Berceanu[1], T.Ponta[2]

ON MULTIPLICITY SYSTEMATICS OF π^0, K^0_s AND Λ PRODUCED IN HIGH ENERGY COLLISIONS

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[1] On leave of absence from the Institute of Atomic Physics, Bucharest.

[2] Institute of Atomic Physics, Bucharest.

Берчану Ш., Понта Т.

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О систематике множественности π°, K°_{s}, Λ, рожденных в столкновениях при высоких энергиях

Показано, что экспериментальные данные по множественности для π°, K°_{s}, Λ в $\pi^{-}p$- и pp-взаимодействиях можно параметризовать единственной функцией в виде, предсказанном KNO о скейлинге по множественности, начиная с более низких энергий, чем считалось раньше. Кроме того, по-видимому, отношения моментов $<n^{q}\,n_{c}><n>^{-q}<n_{c}>^{-1}$ растут с энергией.

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Berceanu S., Ponta T.

E1 - 7901

On Multiplicity Systematics of π°, K°_{s} and Λ Produced in High Energy Collisions

It is shown that the experimental data on π°, K°_{s} and Λ multiplicities in $\pi^{-}p$ and pp collisions can be parametrized by a unique function within the framework of the KNO semi-inclusive scaling prediction on larger energy ranges than those quoted earlier. However, the ratios of moments $<n^{q}n_{c}><n>^{-q}<n_{c}>^{-1}$ seem to increase with energy.

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Multiplicity distributions are relatively easy measurable and new high-energy data are now available. Parallelly, a considerable effort is spent for their theoretical and phenomenological understanding. Some time ago Koba, Nielsen and Olesen [1] (KNO) have derived from the Feynman scaling for n-particle inclusive reactions that the topological cross section σ_n of the semi-inclusive hadronic reaction $a+b\to n$ charged particles normalized to the total inelastic cross section σ_{inel} behaves for $s\to\infty$ like $<n>^{-1}\Psi(n/<n>)$. Here $<n>$ is the mean charged multiplicity and the dependence of the function Ψ on the squared center of mass energy s is an implicit one in $z=n/<n>$. This prediction was tested against new experimental data from Serpukhov and NAL [2-4]. Since the assumptions on which the KNO scaling was deduced are not satisfied in this energy range, the early onset of the KNO limiting prediction is interpreted as an empirical regularity of the data on topological cross sections [3-4].

However, in a complete description of high energy collisions, information on neutral particle production must be included, too. Recently [5], it was pointed out that the arguments of ref. [1] for the production of neutral particle c (particularly π°) in the semi-inclusive reaction

$$a+b\to n \text{ charged particles} + c + \text{other neutrals} \quad (1)$$

imply the following scaling law

$$\lim_{s\to\infty} <n>\sigma^{c}_{n}/<n_{c}>\sigma_{inel} = \Phi(z), \quad (2)$$

where σ_n^c is the cross section for reaction (1), $\langle n_c \rangle$ is the mean multiplicity of neutral particle c, and the function Φ is different from Ψ. Similarly to the equivalence of the KNO scaling with the asymptotic constancy of $C_q = \langle n^q \rangle / \langle n \rangle^q$ $(q = 2, 3 \dots)$ /1/, the scaling law (2) for reaction (1) is equivalent with the asymptotic constancy of the following ratios of moments /5/:

$$C^\circ_q = \langle n^q n_c \rangle \langle n \rangle^{-q} \langle n_c \rangle^{-1}, \quad q = 1, 2, \dots \qquad (3)$$

On the data of π° production in 69, 205 and 303 GeV/c pp collisions and 15 GeV/c $\bar{p}p$ collisions Dao and Whitmore /5/ have presented an evidence for the law (2) $(0 \le z \le 2.9)$, and for the constancy of C°_q $(q = 1, \dots, 4)$. In the same energy range, Cohen /6/ has observed a similar behaviour for the K°_s and Λ particles produced in pp collisions. It was emphasized /1/ that generally, the function Ψ is not a universal one, i.e., it depends on the colliding and produced particles /7-9/.

In this note we discuss the range of validity of the scaling law (2) for π°, K°_s and Λ production in $\pi^- p$ and pp collisions, the possibility of existence of a unique function Φ for these particles, and the constancy of C°_q with respect to s. We emphasize that the data /10/ indicate both the validity of eq. (2) for energies l o w e r than those quoted earlier for π° /5/, K°_s and Λ /6/ produced in $\pi^- p$ collisions, and the c o m p a t i b i l i t y with a u n i q u e function Φ for π°, K°_s and Λ production in $\pi^- p$ and pp collisions. However, the ratios of moments C°_q for π° seem to increase with s.

In order to test the scaling law (2), the function Φ was chosen as the exponential of a polynomial /4-7/:

$$\Phi(z) = A \exp\left(\sum_{i=1}^{4} B_i z^i \right) \qquad (4)$$

with alternating signs for the coefficients B_i and $B_4 < 0$. An acceptable fit can be performed with an odd number of parameters B_i, but we prefer a decreasing Φ for large z /1/. For systematization, the contribution of each experiment to χ^2 * is listed in Table 1. The results of the fit for π° (see Table 1, line e) suggest the validity of the scaling law (2) for π° produced in $\pi^- p$ and pp interactions in the range 25-205 GeV/c ** and 69-303 GeV/c respectively $(0 \le z \le 3.3)$. An acceptable fit is obtained for K°_s production in 40 GeV/c $\pi^- p$ and 69-303 GeV/c pp collisions (see Table 1, line f), and for Λ production in 18.5 GeV/c $\pi^\pm p$, 20-40 GeV/c $\pi^- p$ and 69-205 GeV/c pp collisions (see Table 1, line g). The experimental data /10/ indicate that the behaviour of K°_s / π° production cross section ratios seem to be independent of the associated multiplicity. Indeed, we got an acceptable common fit for π° in 25-205 GeV/c $\pi^- p$ and 69-303 GeV/c pp collisions and for K°_s in 69-303 GeV/c pp collisions (Table 1, line h). However, the Λ contribution is relatively large in the common fit $\pi^\circ - \Lambda$ (Table 1, line i).

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* Compiling the data, the policy has been adopted to use internally consistent data, e.g., if there are some differences between the quoted values of $\langle n \rangle$, $\langle n_c \rangle$ or σ_{inel} and the corresponding values derived by us from the values of σ_n and σ_n^c, we used the last ones. In estimating the errors of the function Φ and C°_q needed for the fit /11/ the errors of σ_n and σ_n^c have been taken into account. For comparison, our procedure of errors estimation gives quite the same errors for $\Psi(z)$ and C_q quoted by Slattery /4/ from Monte-Carlo generation, smaller errors for C°_q comparatively with /12/ and slightly smaller errors for $\Phi(z)$, than the errors read from the plots of ref. /5,6/.

** The contributions to χ^2 of the experiments at 25 and 40 GeV/c $\pi^- p$ interactions are relatively large, but we include them in the accepted fits because they give a large contribution to χ^2 in only 2 points: $n = 14$, respectively $n = 2$. The other high multiplicities at 25 GeV/c give acceptable χ^2; at 40 GeV/c there are not taken into account the systematical errors in separating the elastic 2-prongs from the inelastic ones. It is interesting that the charged multiplicity distribution from 25/7/ and even 50/8/ GeV/c $\pi^- p$ interaction do not verify the KNO scaling.

Table 1

Summary of the contributions of each experiment to the $\chi^2 = \Sigma(\Phi_{exp} - \Phi_{th})^2/\sigma^2_{\Phi_{exp}}$, where Φ_{exp} and Φ_{th} are given by eq. (2), respectively (4). $\sigma\Phi_{exp}$ is the error on Φ_{exp}, calculated from the errors of the experimental data /10/.* a), b), c) and d) represent the neutral produced particle in the collision beam -proton, the beam, the momentum of the beam in the lab.system (GeV/c), and the number of data points in each experiment, respectively. There are presented the only accepted ** fits from all attempted combinations. For values of the parameters A, B_i, i = 1,... 4, see the text.

a). Produced particle	Λ							K^0_s					π^0							Kinds of particles from each fit	Total χ^2 / NDF	Labels for fits.
b). Beam	π^-	π^+	π^-	π^-	p	p	p	π^-	p	p	p	p	π^-	π^-	p	p	π^-	p	p			
c). Momentum	18.5	18.5	20	40	69	102	205	40	69	102	205	303	25	40	69	102	205	205	303			
d). No. of data	6	5	6	6	6	6	9	9	6	9	7	9	9	8	8	9	10	8	11			
Partial χ^2 for various fits													15	21	9	5	7	6	11	π^0	74/57	e
								12	1	8	8	9								K^0_s	40/34	f
	9	8	5	9	2	8	8													Λ	49/38	g
									11	5	7	12	14	17	4	5	7	5	9	π^0-K^0_s	99/88	h
				4	15	17	4						15	18	11	5	7	7	12	π^0-Λ	120/84	i
				4	14	15	4	20	3	6	6	9	16	18	12	5	7	8	13	π^0-K^0_s-Λ	162/124	j
				3	7	9	4	10	1	10	10	9								K^0_s-Λ	65/61	k

Finally, an acceptable common fit is possible for π^0, K^0_s and Λ produced in the range 25-303, 40-303, 40-205 GeV/c, respectively (see Table 1, line j and Fig. 1). The parameters of this fit

$$A = .054 \pm .005,\quad B_1 = 10.07 \pm .20,\quad B_2 = -10.41 \pm {}^{.78}_{.51},$$

$$B_3 = 4.54 \pm .57,\quad B_4 = -.82 \pm .02$$

are different from those of the K^0_s-Λ fit (Table 1, line K):

$$A = .109 \pm .019,\quad B_1 = 7.30 \pm {}^{.51}_{.54},\quad B_2 = -6.09 \pm {}^{.80}_{.90},$$

$$B_3 = 1.67 \pm {}^{.48}_{.58},\quad B_4 = -.19 \pm {}^{.07}_{.12},$$

and quite similar with those for the π^0 fit alone:

$$A = .050 \pm .005,\quad B_1 = 10.19 \pm {}^{.26}_{.25},\quad B_2 = -10.55 \pm {}^{.30}_{-1.07},$$

$$B_3 = 4.75 \pm {}^{.64}_{.59},\quad B_4 = -.88 \pm {}^{.04}_{.10}.$$

The values of the parameters of K^0_s-Λ fit are similar to the values of the parameters quoted in ref. /5/ for the π^0 fit and compatible, in errors, with those quoted in ref. /6/ for the K^0_s fit. However, the differences between the above parameters give appreciable differences between the shapes of the corresponding curves $\Phi(z)$, especially for large z ($z > 2.5$, see Fig. 1). As the $\pi^0 - K^0_s - \Lambda$ fit is not the best one for each individual particle, the present data suggest only an approximate unique function Φ. More accurate data are needed for a definite conclusion.

The dependence of C^0_q (q=1,2,3) on <n> was also investigated (see Fig. 2). For π^0, a linear increase of C^0_1,

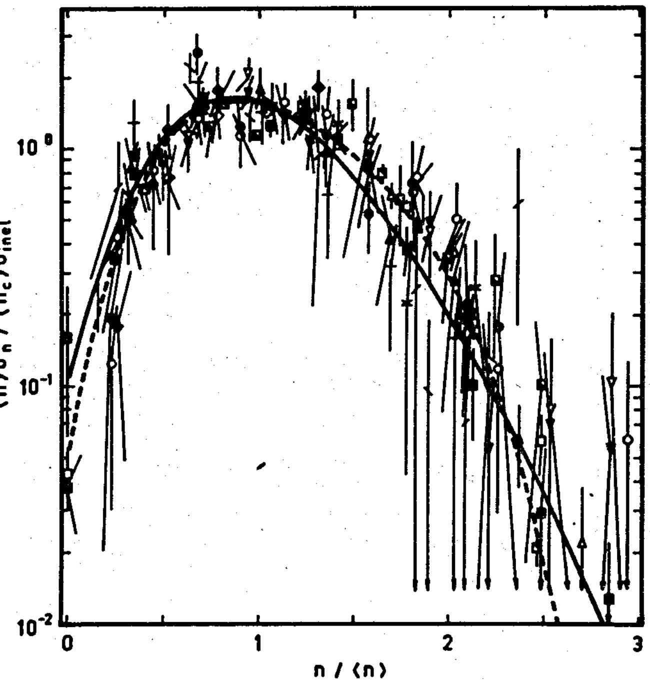

Fig. 1. $\Phi(z)$ versus z for π°, K_s° and Λ produced in the semi-inclusive reaction (1): ◪ $\pi^- p = \pi^\circ$ – 25 GeV/c, □ $\pi^- p = \pi^\circ$ – 40 GeV/c, Δ pp = π° – 69 GeV/c, ∇ pp = π° – – 102 GeV/c, ◩ $\pi^- p = \pi^\circ$ – 205 GeV/c, ◊ pp = π°–205 GeV/c, o pp = π° – 303 GeV/c, ■ $\pi^- p = K_s^\circ$–40 GeV/c, ▲ pp = K_s° – – 69 GeV/c, ▼ pp = K_s° – 102 GeV/c, ◆ pp = K_s° –205 GeV/c, ● pp = K_s° – 303 GeV/c, x $\pi^- p = \Lambda$ – 40 GeV/c, + pp = Λ–69GeV/c, ∖ pp = Λ – 102 GeV/c, ⁄ pp = Λ – 205 GeV/c. Data from literature /10/. The dashed line is the best fit /11/ to all the data included in the plot and the full line is the best fit to K_s° and Λ data with $\Phi(z)$ given by eq. (4). For the values of the parameters, see the text; for the contribution of each experiment to the χ^2, see Table 1.

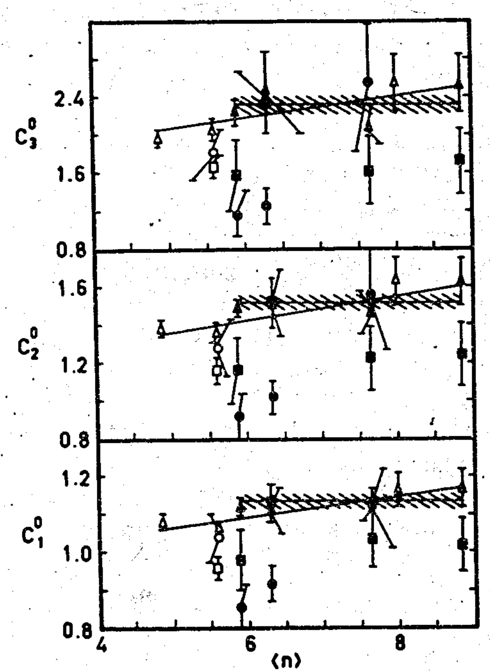

Fig. 2. C_1°, C_2°, C_3° versus <n>, o $\pi^- p = \Lambda$, ● pp = Λ, □ $\pi^- p = K_s^\circ$, ■ pp = K_s°, Δ $\pi^- p = \pi^\circ$, ▲ pp = π°. Data from literature /10/. The constant lines and the error corridors represent the fit to a constant for π° production in the range 69-303 GeV/c lab. momentum. The oblique lines represent the fit to the linear increase of C°–s with <n> for π° produced in $\pi^- p$ 25-205 GeV/c and pp 69-303 GeV/c collisions. See the text.

C_2° , C_3° on the whole interval seems to be preferable to a constant value (confidence levels: 19%, 61%, 67% for linear dependence comparative with 2%, 11%, 15% for constant value respectively). However, for the range 69-303 GeV/c, the fit can not discriminate between linear increase of C_1° , C_2° (C.L.: 81%, 64%) and constant value (C.L.: 64%, 56% respectively), the coefficient of $\langle n \rangle$ in the linear dependence being practically consistent with zero, in one standard error (.017 ± .015 respectively .042 ± .039). Also C_q° (q=1,2,3) for K_s° and Λ seem to increase with energy. It is observed that the values of C_q° (q=1,2,3) for K_s° are lower than the corresponding ones for π°. The increase of $C_q - s$ was recently recognized too (see, for example, ref. /13/).

In conclusion, we emphasize that the data for π° , K_s° and Λ production in the above energy intervals indicate an approximate early onset of scaling, but simultaneously suggest an increase of $C_q^\circ - s$ with energy. It must be noted that the validity of eq. (2) and the constancy of (3) are only asymptotically equivalent /1/, but it is possible that the non-scaling contributions to Φ and C_q° have a different behaviour at finite s .

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References

1. Z.Koba, H.B.Nielsen, P.Olesen. Nucl.Phys., B40, 317 (1972).
2. P.Olesen. Phys.Lett., 41B, 602 (1972).

3. P.Slattery. Phys.Rev.Lett., 29, 1624 (1972).
4. P.Slattery. Phys.Rev., D7, 2073 (1973).
5. F.T.Dao, J.Whitmore. Phys.Lett., 46B, 252 (1973).
6. D.Cohen. Phys.Lett., 47B, 457 (1973).
7. F.T.Dao, J.Lach, J.Whitmore. Phys.Lett., 45B, 513 (1973).
8. France-Soviet Union and CERN-Soviet Union Collaboration, Contribution to the 2nd International Conference on Elementary Particles, Aix-en-Provence (1973); G.A.Akopdjanov et al., CERN /D.Ph. II/ PHYS 74-4, CERN preprint (1974), Submitted to Nucl. Phys.B.
9. R.Möller. NBI-HE-74-3, Copenhagen preprint (1974).
10. Experimental data.
    $\pi^\pm p = K_s^\circ, \Lambda$ – 18.5 GeV/c. P.H.Stuntebeck et al. Notre-Dame preprint (1973) - to be published in Phys. Rev. D; J.T.Powers et al. Phys.Rev., D8, 1947 (1973).
    $\pi^- p = K_s^\circ, \Lambda$ – 20 GeV/c. E.Balea et al. Rev. Roum. Phys., 14, 693 (1969); Rev. Roum. Phys., 15, 587 (1970).
    $\pi^- p = \pi^\circ$ – 25 GeV/c. J.W.Elbert et al. Nucl. Phys., B52, 414 (1973).
    $\pi^- p = \pi^\circ, K_s^\circ, \Lambda$ – 40 GeV/c. O.Balea et al. Nucl. Phys., B52 (1973). A.U.Abdurakhimov et al. Dubna Preprint P1-7267 (1973).
    $pp = \pi^\circ, K_s^\circ, \Lambda$ – 69 GeV/c. V.V.Ammosov et al. Phys. Lett., 42B, 519 (1972); H.Blumenfeld et al. Phys. Lett., 45B, 525 (1973); Phys. Lett., 45B, 528 (1973).
    $pp = \pi^\circ, K_s^\circ, \Lambda$ – 102 GeV/c. J.W.Chapman et al. Phys. Lett., 47B, 465 (1973); G.Bromberg et al. Phys. Rev. Lett., 31, 1563 (1973).
    $pp = \pi^\circ, K_s^\circ, \Lambda$ – 205 GeV/c. G.Charlton et al. Phys. Rev. Lett., 29, 515 (1972); Phys. Rev.Lett., 29, 1759 (1972); Phys.Rev.Lett., 30, 574 (1973).
    $\pi^- p = \pi^\circ$ – 205 GeV/c. D.Bogert et al. Phys. Rev. Lett., 31, 1271 (1973); Contribution to the Berkeley Meeting of the American Physical Society, August 13-17 (1973).
    $pp = \pi^\circ, K_s^\circ$ – 303 GeV/c. F.T.Dao et al. Phys. Rev. Lett., 30, 1151 (1973).
11. F.James, M.Roos. MINUITL, CERN Program (1972).
12. A.Krzywicki. Ref. TH-1633-CERN preprint (1973).
13. T.Ferbel. COO-3065-61, Rochester preprint (1973).

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