JOINT INSTITUTE FOR NUCLEAR RESEARCH

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V.S. Barashenkov

THE MULTIPLE PRODUCTION OF STRANGE PARTICLES

(Report on the International Conference in Padova-Venezia;
22-28 September 1957)

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1957.

I am going to make a short report about theoretical works conducted at the Joint Institute for Nuclear Research in studying multiple production of strange particles in collision of elementary particles with the high energy BeV range and about some results obtained.

Nowadays the statistical theory of multiple production affords quantative results which are in full accordance with experiments in the region of this high energy BeV range.

The predictions of this theory help to choose necessary method of the experiment at the big accelerators like ours, at Dubna.

We think, that statistical theory of multiple production will be of great importance in future, even if field theory of particle interaction at high energes will be created, like the importance of gas statistical theory thoughwe know exactly now the law of gas particles interaction.

Since the first works of Fermi this theory was considerably improved in the direction of effective calculation of statistical weights as well as in physical content of model. As it has been shown in professor's Belenky and his co-workers articles |1| |2| taking into account resonance nucleon interaction with pions in the state of ρ; T = 3/2, the relative multiple of different number of pions and nucleons predicted by statistical theory and their impulse and charge distribution in (NN) - and (π N) - collisions are in agreement with the experiment. Separate anomalouses in angel distribution of produced particles in particular narrow meson shower, observed in many experements |3|, can be explained by peripheral collisions |4|. But it is quite different position for strange particles produced in these collisions. The theory predicts that the magnitude ratio of probable production of strange particles to the probable production of pion and nucleon σ_{st}/σ_{o} considerably greater than experimental dates obtained by American physicists.

Table I gives theoretical and experimental nambers of this ratio for (ΠP) - collisions, Table II - for (NN) - collisions.

Table I

E BeV	Theory	Experiment
0,95	25%	~ 4%
1,3	19%	
5	134%	
7	201%	

Table II

E BeV	Theory (pp)	Theory (pn)	Experiment	
3	16%	20%	~ 3%	x/
5	34%	38%	2-"	xx/

The conservation of strangeness and baryon number if taken into account in these calculations. Recently professor Blokhintsev showed, that in the region of high energies colliding particle forms first of all one "compound-particle", where all the energy is concentrated in the interaction energy but not in the proper energy of the particles[8]. The demensions of the regions of energy localization is specific for every concrete type of interaction.

So the term "particle" looses its physical content.

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x/ (pp) - collision (-6)

xx/ Calculated for one nucleon from experiments[7] with heavy nucleons.

With space expansion "compound-particle" decays in elementary particle of their usual meaning. When radious of the regions of interaction energy localization equals Compton wavelength of nucleon, it is necessary to expect "crystallizing" and separation of free nucleons. But we have no such thing, Because of strong interaction with pion field: pour production and different exchange effects.

"Crystallizing" of free nucleons begins at the same time with pions from the volume with radious equal to Compton wavelegth of pion. This fact explains, why statistical theory of Fermi has only one parameter - volume of "crystallizing" field. This fact finds its reflection in anomalous dimensions of core. But it is quite another position for strange particles. We should think that pion interaction with K-meson is weaker than with nucleons (or ratio σ_{st}/σ_0 will be larger experimental data, as it was shown above). Consequently, the separation of free K-meson begins earlier from the region equal to Compton wavelength of K-meson. It this case in formula for statistical weight space factor Fermi,

$$V_1 = \left(\frac{\hbar}{m_\pi c}\right)^3 \frac{1}{G}\, \Omega(E)$$

must be substituted by

$$V_2 = \frac{(k+\ell\xi)\,\xi^{k-1}}{nG}\, \Omega(E)$$

if Λ^-; Σ^-; Ξ -particle is produced in the same volume as K-particle.

Here K is a number of strange particles: $\ell = n-k$ - number of conventional particle.

$$\xi = (m_\pi / \pi_K)^3 = 0{,}02320$$

This case would take place if pion interaction with Λ-

Σ^-; Ξ -particle comparatively weakly than with nucleonics [9], [10], or V_1 substituted by

$$V_3 = \frac{(\gamma - \ell\xi)\xi^{j-1}}{nG}\,\Omega(E)$$

if Λ-; Σ; Ξ-particle is produced in the same volume with ordinary particles. Here j-number of K-meson; j = n - j. This case corresponds to Gell-Mann's and Schwinger's hypothesis about "global interaction" pions with baryons.

Near threshold of strange particle production, when with production of K-particles conservation of energy and strangenessis connected production of Λ - or Σ - particle but this particle should be produced in the same volume as K-particle, independently of interaction pions and nucleons. Calculation with weight factor $V_3(\pi^- p)$ -collisions are closer to the experiment:

Table III.

E BeV	σ_{st}/σ_{in}	
	V_2	V_3
0,95	0,6%	13%
1,3	0,4%	9%

~~Table~~

Results of the same calculation for (NN) - collisions are given in Table IV:

Table IV.

E BeV	σ_{st}/σ_{in}			
	(pp)		(pn)	
	V_2	V_3	V_2	V_3
3	0,27%	5,7%	0,32%	6,7%

And in this case calculation with factor V_3 in nearer to the experiment. A small number of strange particle are produced near threshold and we shouldn't expect full agreement with statistical theory and experiment.

However, minimum ratio σ_{st}/σ_{in} in the region ~ 1 BeV which has only statistical character, is proved by experiment We should expect better agreement with experiment in the region of higher energies.

Table V gives ratios of the average number of produced in (π N) - collisions of strange particles S% antinucleons $\tilde{N}$% and antihyperons $\tilde{V}$% to the average number of produced pions and nucleons.

Table VI gives the same results for (NN) - collisions.

Table V.

E BeV	(π^+P)						(π^-P)					
	S%		$\tilde{N}$%		$\tilde{V}$%		S%		$\tilde{N}$%		$\tilde{V}$%	
	V_2	V_3	V_2	V_3	V_2	V_3	V_2	V_3	V_2	V_3	V_2	V_3
5	0,62	5,5	0	0	0,72	0,69	0,72	6,5	0,029	0,017	1,0	0,97
7	0,83	8,6	0,023	1,5	5,5	5,1	0,92	10	0,031	2,0	5,9	5,5

Table VI.

E BeV	(PP)						(Pn)					
	S%		$\tilde{N}$%		$\tilde{V}$%		S%		$\tilde{N}$%		$\tilde{V}$%	
	V_2	V_3	V_2	V_3	V_2	V_3	V_2	V_3	V_2	V_3	V_2	V_3
3	0,13	2,0	-	-	-	-	0,16	3,4	-	-	-	-
5	0,29	6,0	-	-	-	-	0,32	6,4	-	-	-	-
7	0,34	5,9	0,017	0,016	-	-	0,36	6,3	0,022	0,020	-	-
10	0,32	5,1	0,59	0,56	0,0221	0,017	0,34	5,4	0,62	0,58	0,0224	0,

These calculations were made taking into account the conservation of energy, isotopic spin, strangeness, baryon number. Particle spin was calculated by multiplier $\prod_i (2S_i + 1)$. Energy weights in in (NN)-collisions for 3 and 5 BeV is calculated by Maksimenko's and Rosental's formulas; in the rest cases we used improved method, worked out in our laboratory. The case of two and three particles in all cases was calculated by precise Block's formulas.

In all cases we took into account resonance interaction pions with nucleons.

To our sorrow, at present in the field of energies more than 3 BEV we possess only experiments on the heavy nucleons, what makes difficult to compare it with theory.

Now we can say, that results of these experiments to 7 BeV do not contradict both variants of the theory, but variant V_3 is probably closer to the experiment.

This problem is being studied closely. An interesting consequence of the assumption, that strange particles are produced in smaller volume than pion and nucleon is maximum in the ratio the number of produced in (NN)-collisions strange particles in reppect to the number of pions and nucleons with $E \sim 7$ BeV. The reason is that probability of the reaction $(NN) \longrightarrow (N \Lambda K \cdot n\pi)$ and $(NN) \longrightarrow (N \Sigma K \cdot n\pi)$ with trensition from $E \approx 5 - 7$ BeV to $E = 10$ BeV decreases and the probability of the reaction with greater number of K-meson for instance $(NN) \rightarrow (NN k\bar{k} \; n\pi)$; $(2\Lambda \cdot 2K \cdot n\pi)$ etc., though it increases with energy, however, cannot considerably change the summary probability, because K-mesons are produced in the smaller volume and the probability of their production is strongly suppressed in comparison with pions and nucleons.

From the statistical point of view the ground of decrease of comparative number of strange particles with $E \sim 7$ BeV the same

~~with~~ as minimum in ($\pi^- P$)-collisions with $E \sim 1$ BeV.

In variant of calculation with V_3 at higher energies reaction with baryons may be of great importance, like $(NN) \rightarrow (NN\ \Lambda\Lambda\ n\pi)$, etc. and we should expect, that the share of strange particle will increase. On the contrary in variant with factor V_2 the share of strange particles will be decreasing further with increasing energy, and would be in contradiction with the cosmic ray experiments.

The number of produced antinucleons is slightly dependent on the choise of variant of volumes pace and in (NN) collisions equal approximately one antinucleon per 2-3 thousent pions for the energy of 7 BeV and one antinucleon per 1-2 hundred pions at the energy 10 BeV. This result can be put into agreement with experimental data (one antinucleon for $6\cdot10^4 - 5\cdot10^5$ of the negative pions, obtained when bombarding copper target by the protons with energy about 6 BeV by the magnitude, if we take into account small antinucleon range in nuclear matter in respect to the annihilation:

$$\ell_{an} = 1/\sigma_{an} n \sim \hbar/m_{\pi} c$$

Due to this fact antinucleons, produced on one of the nucleons in the nucleus of Cu practically annihilates on the following nucleon and from the nucleus Cu only antinucleons, produced on the nucleons surface, may energe.

Taking into account that the incident nucleon interact in the nucleons Cu with the "tube" containing on the everage 3 - 4 nucleons and that $\sigma_{el}/\sigma_{in} \sim 0.25$ obtain the probability for the incedent nucleon of reaching the last nucleon in the tube with small energy loss

$$W \sim 5\cdot10^{-2}.$$

It is these nucleons that give the basic contribution to the production of antinucleons on the nucleus of Cu because the cross-section of the antinucleon production quckly decreases with the energy decreases. (See Table VI). The given consideration decreases the ratio of the number of the produced antinucleons to the number of pions up to the magnitudes experimentally observed[x/].

An anologous phenomenon is well-known in the atomic reactor theory. It is called "block-effect".

In our case the nuclei of Cu play the roll of "block".

We have made analysis of the cha~~y~~rge of strange particles.

In all cases the ratio of average number of produced $K^{\pm}$ and K^{-} particles is in agreement with experiment:

$K^{+}/K \sim 150$ for (NN) -collisions

$K^{+}/K \sim 1-2$ for (πN) -collisions

At present more exact comparison with experiment is being conducted.

[x/] We should take into account, that nucleon in the nucleus of Cu possesses Fermi energy equal $E \simeq 25$ MeV; due to this the colliding nucleon in the experiments possessed the same energy in the center of mass system as in free nucleon collision with the Energy $E =$ 7 BeV.

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