III-7. High Energy Theory

Chairman: G. B. ZHDANOV
Secretary: M. NAMIKI

Date	Time	Paper Numbers
Sept. 13	15 : 30 – 17 : 30	from III-7-1 to III-7-6
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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-7-1. On a Non-Local Theory of High Energy Interactions

G. WATAGHIN

Istituto di Fisica dell' Universita di Torino, Italy

The following report concerns the interpretation of some available experimental data on high energy collisions on the basis of a non-local theory formulated in previous notes[1),2)].

Observation of high energy jets shows that:

1) the average transverse momentum of particles produced in collision is limited by the relation:

$$\langle p_{\perp}\rangle_{CM} \leq \frac{1}{2}M\,, \qquad (1)$$

where M is the proton mass and CM indicates the center of momentum frame of the incident particles.

2) the average longitudinal momentum of created particles is also limited by a similar relation

$$\langle p_{/\!/}\rangle_{CM} \leq M\,. \qquad (2)$$

If the jet is isotropic or nearly isotropic in the CM-system of incident particles, then the relation (2) is obvious. If one considers a two center model and a strongly anisotropic case, then the outgoing particles are created in a delayed secondary process of the decay of the two fire balls. The CM-frame is in this case the rest-frame of the fire-ball. With reference to this frame the shower particles are emitted isotropically and with momenta $|\boldsymbol{p}|\leq M$. The emission of these fire-balls (two or more) is also subject to a cut-off in a non-local theory. The observations have revealed so far moderate values of the velocities of the two centers ($\bar{\gamma}\leq 5$) and thus also in the primitive CM-system the $\langle p_{/\!/}\rangle_{CM}\leq NM$ where $N\leq 3$. We ignore the properties of CM-fire-balls of very high energy.

3) The dominant feature of many high energy collisions is the low value of the momentum transfer (cases of "peripheral collisions"[5)]): (for the definition of Δ compare e.g. reference[2)]). These three groups of experimental data seem to indicate that in the production processes the probability of

obtaining particles, created with CM-momentum and CM-energy higher than M, is small, and the probability of large momentum transfers is also reduced. In other words a cut-off factor G depending on $|p|_{CM}$ and $|p_0|_{CM}$ can represent the reduced statistical weight in the creation processes, and thus, also in the absorption processes. That assumption constitutes the basic assumption of a non local theory. It can be shown that in a non-local relativistic theory the propagation of particles or fields must be treated separately from the calculations concerning the interactions in which particles are absorbed and created. The last problem can be solved either by means of a Schroedinger stationary equation in momentum variables and in the CM-reference frame of particles, or approximately using an S-matrix in momentum variables. Considering the case of n_i incident particles and n_f outgoing physical particles one can write the following well known expression for the cross section σ (in the case of $n_i=2$):

$$\sigma=(2\pi)^2\frac{1}{I}\mathrm{S}_f\mathrm{S}_i\delta^4(P_f-P_i)|\langle f|M|i\rangle|^2$$

where P_i and P_f are the total initial and final energy-momentum 4-vectors.

If one starts with writing σ in a local theory then the modifications required by a non-local theory can be introduced only in the elements $\langle f|M|i\rangle$ of the interaction. In order to preserve the covariance, the invariant cut-off factors can and must be introduced every time a creation or an absorption operator (a_k^* or a_k) appear in $\langle f|M|i\rangle$ and thus also in the perturbation calculations such a factor appears twice in any "internal line" of a diagram.

In the recent formulation of our theory, we distinguish two different types of second quantization: in one case the created particle is a stable physical particle (final states) and in another the created state is a virtual state out of the "energy shell" and represents an unstable particle. Usually the element $\langle f|M|i\rangle$ can be represented by means of $(3n-10)$ relativistic invariants, where $n=(n_i+n_f)$ and $n>4$, formed with the 4-momenta of the n_i incident and n_f outgoing particles.

Out of these invariants we chose two invariants for each state, which we call $I_t(k)$ and $I_s(k)$ formed as follows: let $u_\mu=1/m\cdot P_\mu$ indicate a unit 4-vector, where P_μ is the total momentum of incident particles, and $m^2=P_\mu P^\mu>0$. Then if $l=1/M$ is a universal length, we write:

$$I_t(k)=lk_\mu u^\mu\,,$$
$$I_s(k)=l(I_t^2-k_\mu k^\mu)^{1/2}\,.$$

Obviously, in the CM-system:

$$I_t=l(k_0)_{CM}\,,$$
$$I_s=l|\boldsymbol{k}|_{CM}\,.$$

Then cut-off factors which we introduce in $\langle f|M|i\rangle$ associated with each creation operator a_k^* are:

$$G^+(k)=G_s(I_s)G_t^+(I_t)$$
$$=(1+I_s^2)^{-3/2}(1+iI_t)^{-1}$$

and associated with an absorption operator a_k:

$$G^-(k)=G_s(I_s)G_t^-(I_t)$$
$$=(1+I_s^2)^{-3/2}(1-iI_t)^{-1}$$

This choice is suggested by the mathematical simplicity, by the causality requirement and by some experiments.

Now from the above assumptions we can deduce the experimental facts 1, 2 and 3 quoted at the beginning. The limitations concerning $\langle p_\perp\rangle_{CM}$ and $\langle p_{/\!/}\rangle_{CM}$ follow from the limitation of $|\boldsymbol{p}|_{CM}=l^{-1}I_s(p)$ for each created particle in the final state due to the cut-off factor $G^+(p)$. The limitation of the momentum transfer Δ, corresponding to an internal line comes from the factor $G^+(\Delta)G^-(\Delta)$. Some anisotropic angular distributions in the CM-system can be described by means of invariants introduced elsewhere[3]. These invariants belong to the group of $(3n-10)$ invariants mentioned above. But there are cases (e.g. the two center model), in which the total process is split in two or more steps; *e.g.*, first two fire balls created, then they disintegrate into final shower particle. Obviously in the description, we will need new parameters to describe the intermediate states and the new types of interactions, and therefore the $(3n-10)$ invariants will not be sufficient for that purpose.

One way to derive theoretically a two center model[4] could be developed on the following lines: we introduce the attractive forces between pions and between K-mesons. It is known that two, three and four pion states and also K$-\pi$ states exist. One can make the assumption that also higher order types of groups of bosons could be formed. Then at the moment of a high energy collission an amount $(\Delta E)_{CM} \gg M$ of energy is released in the form of these new unstable particles. It can give rise to several channels, the competition between different channels being of essentially statistical nature (acausal). If one takes into account the cut-off factors, and the masses of resonant states, one finds that a two-step process (or a n-step process) considered in the two-center model has a greater probability than the direct multiple production. This seems to be the origin of the two-center model or of the model with many centers. The life-time of the groups of bose-particles is known if the resonant state is known (it can be $\sim 10^{-24}$ sec.). The two centers are moving approximately in the direction of the incident particles because also Δ and $\boldsymbol{p}^{(f)}$ of the outgoing nucleons have nearly the same direction.

Let us consider the S-matrix in a local perturbation theory approach and let X_μ ($\mu=0,1,2,3$) indicate a vertex point of a diagram. In a non-local theory one introduces for each line starting or ending in this vertex (for each particle created or absorbed) a new internal parameter η_μ, adding to the phase factor $\exp(ik_\mu x_\mu)$ the factor $\exp(ik_\mu x_\mu) f(\eta_\mu)$ where $f(\eta_\mu)$ defines a 4-dimensional domain D_l of the size $\sim l^4$ in which the interaction is not vanishing, $f(\eta_\mu)$ is the Fourier transform of the cut-off factor $G(k)$ and in the CM-system

$$|f(\eta)|^2 \sim \exp(-|\eta|/l)\exp(-\eta_0/l).$$

By transforming the S-matrix to the momentum space (as is necessary) the elimination of η_μ by integration:

$$\int \exp(ik_\mu \eta_\mu) f(\eta_\mu) d^4\eta_\mu = G(k),$$

gives rise to the appearance of a cut-off factor in each creation or absorption process.

These 4-dimensional domains D_l appear in the non-local theory instead of the interaction volumes introduced by Fermi in his statistical and thermodynamical theory of multiple production and give rise to a kind of cell-structure of the space-time. Their volumes are invariant and constant. The resulting cut-off factors are mass-dependent. One interesting case of the application of the above considerations is encountered in the statistial calculation of the ratio n_{K^+}/n_{π^+} in the production of K-and π-mesons at 25 GeV laboratory energy. This calculation induced Hagedorn and Cerulus[6] to choose the ratio of the Fermi-interaction volumes $\Omega_K/\Omega_\pi \sim 0.5$. In our calculations, the cut-off factors give rise to a ratio $|G_K|^2 : |G_\pi|^2 \sim 0.5$, in accord with the experimental results.

References

1) G. Wataghin: Nuovo Cimento **5** (1957) 689; Nuovo Cimento **14** (1959) 1157 and Reports to the Kiev and Moscow Conf., (1959).
2) D. Ito, A. Zimerman, S. Raguza and T. Miyazima: Nuovo Cimento **20** (1961) 876.
3) G. Wataghin: Nuovo Cimento **14** (1959) 1157.
4) P. Ciok, T. Coghen, J. Gierula, R. Holynski, A. Jurak, M. Miesowicz, J. Saniewska and O. Stanisz: Nuovo Cimento **8** (1958) 166. P. Ciok, T. Coghen, J. Gierula, R. Holynski, A. Jurak, M. Miesowicz and T. Saniewska: Nuovo Cimento **10** (1958) 741.
5) G. T. Zatsepin: (1950). See Izvestia, Jan. (1955).
6) Private communication.

Discussion

Yamaguchi, Y.: How do you obtain the value $\langle p_{/\!/}\rangle_{CM}$? It seems to me too small.

Wataghin, G.: The values quoted do refer to the CM-system of the two centers and they are small. If in the CM-system of incident particles isotropic distribution is observed, then $\langle p_{/\!/}\rangle_{CM} \sim \langle p_\perp\rangle_{CM} \sim M$, whereas in the two center cases, (where e.g. strong anisotropy can occur) one must consider the creation processes of final shower particles as a delayed secondary processes and one must refer them to the CM-system of each fire ball (in which they are created). Then since in each center the distribution is nearly isotropic, one obtains also in these cases $\langle p_{/\!/}\rangle_{\text{CM of the center}} \sim M$.

Okubo, S.: How can the unitarity condition be satisfied in your theory? I ask you, since you introduce cut-off factors.

Wataghin: It is satisfied if the local S-matrix obtainable by putting all the cut-off factors=1, is unitary. Indeed, let us consider in a local theory the reaction matrix K related to S by

$$S=\left(1-\frac{1}{2}iK\right)\Big/\left(1+\frac{1}{2}iK\right).$$

If one introduces in K the cut-off factor G, then, since $|G|^2=G^+G^-$ is real and G^+ and G^- are hermitian conjugate, the non-local K remains hermitian and thus the non-local S is unitary.

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III-7-2. High Energy Interactions on the 'Molecular Model' of the Elementary Particles

Seitaro NAKAMURA
Department of Physics, University of Tokyo and Nihon University, Tokyo, Japan

In this talk I intend to give a brief remark of my speculation on the structure of the elementary particles. I am going to show you that the high energy interactions of several to several thousands Gev would reveal the typical effects which can directly be related to the structure of particles. A basic premise of the present model is a variant scheme of the internal degrees of freedom for baryons in which strangeness and hyper charge are not used. In order to classify baryons we introduce three kinds of 'charge spins', τ, ζ, and κ, and assume that the third components of these 'spins' are simultaneously quantized.

Here electric charge, $Q_e=\tau_3+\zeta_3$, can independently be defined from κ-charge, $Q_\kappa=\kappa_3+1/2$, which is a substitute for hypercharge in our scheme. You may here recall the even-odd rule instead of strangeness rule because we classify nucleon and the Ξ-particles in one group with $\kappa_3=1/2$ while the Σ-and Λ-particles in the other group with $\kappa_3=-1/2$. Instead of the ordinary isotopic spin, we consider the four-dimensional one that is composed of τ and ζ. In this scheme we can define the new isotopic spin $\mathbf{J}=\boldsymbol{\tau}+\boldsymbol{\zeta}$ independently from the κ-spin. We have, however, to make sure that we can give a reasonable explanation of

Table I. Quantum numbers of baryons.

Baryons	τ_3	ζ_3	κ_3
p	$\frac{1}{2}$		
n	$-\frac{1}{2}$	$\frac{1}{2}$	
Ξ^0	$\frac{1}{2}$		$\frac{1}{2}$
Ξ^-	$-\frac{1}{2}$	$-\frac{1}{2}$	
Σ^+	$\frac{1}{2}$		
Y^0	$-\frac{1}{2}$	$\frac{1}{2}$	
Z^0	$\frac{1}{2}$	$-\frac{1}{2}$	$-\frac{1}{2}$
Σ^-	$-\frac{1}{2}$		
$Y^0=\frac{1}{2}(\Lambda-\Sigma^0)$			
$Z^0=\frac{1}{2}(\Lambda+\Sigma^0)$			

Table II. The list of mesons and their quantum numbers.

Mesons	τ_3	τ	ζ_3	ζ	κ_3	κ
π^+	1		0		0	
π^0	0	1	0	0	0	0
π^-	−1		0		0	
$\pi^{0\prime}$	0	0	0	0	0	
K^+	0	0	1			
τ^0	0	0	0	1	1	1
L^-	0	0	−1			
θ^0	0	0	0	0		
D^+	0	0	1			
D^0	0	0	0	1	0	1
D^-	0	0	−1			
$D^{0\prime}$	0	0	0	1		
L^+	0	0	1			
$\tilde{\tau}^0$	0	0	0	1	−1	1
K^-	0	0	−1			
$\tilde{\theta}^0$	0	0	0	0		