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Meetings and Conferences

SECOND INTERNATIONAL CONFERENCE ON NONLOCAL QUANTUM FIELD THEORY

(Azau, 15–24 March, 1970)

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THE 2nd International Conference on Nonlocal Quantum Field Theory organized by the Joint Institute for Nuclear Research (JINR) was held from March 15th through March 24th in Azau (the Kabardino-Balkarsk A.S.S.R.). About eighty scientists from eleven countries, including eight member countries of the JINR, Italy, France and the Federal Republic of Germany, participated in the conference. Among the scientists who took part in the work of the conference were some of the most prominent scientists of the Soviet Union—from such institutions as FIAN (the P.N. Lebedev Institute of Physics of the U.S.S.R. Academy of Sciences), Moscow; ITÉF (Institute of Theoretical and Experimental Physics), Moscow; IAÉ (Institute of Atomic Energy), Moscow; IFVÉ (Institute of High Energy Physics), Serpukhov; MIAN (the V. A. Steklov Institute of Mathematics of the U.S.S.R. Academy of Sciences), Moscow; MGU (Moscow State University); LGU (Leningrad State University); ITF (Institute of Theoretical Physics), Kiev; the Khar'kov Polytechnical Institute; and some others.

In comparison with the 1st International Conference on Nonlocal Quantum Field Theory (Dubna, July, 1967), the range of problems considered was considerably widened. On the whole, the conference at Azau was devoted to the main problems of quantum field theory; the problems of nonlocal and local quantum theory, essentially nonlinear and nonrenormalizable interactions, the problems of chiral symmetry and the Yang-Mills interaction, the problems of functional methods in field theory, a review of the experimental facts, and a number of other questions concerning the structure of the quantum theory of fields.

About fifty papers, nine of which were devoted to a survey of recent achievements in the various branches of quantum field theory, were presented at the conference.

The second conference on nonlocal quantum field theory was opened by the Chairman of the Organizing Committee of the conference, Professor **D. I. Blokhintsev.** In his opening address, he stressed the importance of the conference for the general progress of theoretical physics and noted the rising interest in the problems before the conference, an evidence of which was the considerable increase in the number of papers to be presented at the conference as compared with the number at the previous one held at Dubna in 1967.

On behalf of the Organizing Committee, D. I. Blokhintsev thanked the representatives of the local authorities of the Kabardino-Balkarsk A.S.S.R. for their hospitality and help in the organization of the conference.

In an introductory report entitled "The Present State of Nonlocal and Nonrenormalizable Field Theory", **D. I. Blokhintsev** (U.S.S.R.) stressed the common tendency of all nonlocal theories to reject in one form or the other, in the region of small dimensions, the law of propagation of "signals" with the velocity of light in free space.

Subsequently, the review was devoted to the main investigations carried out at the Theoretical Physics Laboratory of the Joint Institute for Nuclear Research (TPL JINR).

Special mention was made of the directions connected with the construction of a nonlocal scattering matrix satisfying the conditions of macroscopic causality and unitarity, and field-theory investigations describing essentially nonlinear interactions. The report touched on work done in the TPL, JINR, in which the role of gravitation in the theory of elementary particles, namely, the problem of quantization in curvilinear space and the possible importance of gravitation for the construction of a theory of particles having no divergences.

Investigations into quantization in curvilinear momentum space were also noted in the report.

M. A. Markov (U.S.S.R.) gave a talk on the extended particle model in the general theory of relativity—the so-called "Friedmon." It can be considered as a specific example of a model with a form factor, when, owing to the variation of the metric, a signal propagates with a velocity less than the velocity of light. In a flat space the form factor, as a rule, leads to the appearance of superluminal signals (signals propagating with velocities greater than the velocity of light). M. A. Markov called attention to the fact that unique possibilities for the introduction of particle dimensions arise in the general theory of relativity.

D. Yu. Bardin, S. M. Bilen'kiĭ and B. M. Pontecorvo (U.S.S.R.) demonstrated in their paper that the totality of the existing experimental investigations in the area of neutrino physics is not inconsistent with the hypothesis about the existence of a strong neutrino-neutrino interaction.

L. D. Solov'ev (U.S.S.R.) presented a review of high-energy experimental data obtained with the Serpukhov accelerator. At present, these experiments cannot be used to verify any definite theory: they are used to verify the most general theoretical principles and very special models. The following problems were touched upon in the report: the verification of dispersion relations, the constancy of the differences between cross-sections for mesons and antimesons, the possible increase of cross sections, total cross sections and complex angular momenta, radiative corrections to total cross sections, the contraction of the diffraction cone in proton-proton scattering, the differential cross sections and polarization characteristics of elastic meson-nucleon processes, new particles, CPT, and experiments with neutrinos and muons.

V. A. Petrun'kin and S. A. Startsev (U.S.S.R.) considered the possibility of verifying quantum electrodynamics by means of colliding beams. Theoretical difficulties arise when strong interactions are taken into account. It was demonstrated that if the accuracy of experimental measurements of cross sections is taken to be 10% and deviations from theory not less than 20% are considered as reliable, then the measurement of the cross sections of the processes $e^- + e^+ \to e^- + e^+$ and $e^- + e^+ \to \mu^- + \mu^+$ involving c.m.s. energies of 7–10 GeV, corresponds to the verification of quantum electrodynamics up to distances of 10^{-15}–6×10^{-16} cm.

V. A. Petrun'kin also presented a review of experimental data on the verification of the applicability of local quantum electrodynamics. The totality of the experimental data is in agreement with the deductions of the local theory.

A paper presented by **G. V. Efimov** (U.S.S.R.) opened an important topic of the conference—"Nonlocal Field Theory." In the paper, a review was made of the present state of nonlocal quantum field theory. Definite progress has lately been made in nonlocal theory and has placed it on a level of rigor obtaining in the local theory. In the framework of the construction of the perturbation-theory series for a nonlocal interaction Lagrangian, the connection between the requirements of unitarity and causality of the S-matrix and the admissible class of form factors was exhibited. It turned out that there exists a fairly wide class of form factors with the aid of which we may construct a finite S-matrix which is unitary and satisfies the requirements of macroscopic causality in each order of perturbation theory.

In the framework of the axiomatic approach, it proved possible not only to formulate the axioms of nonlocal theory, based on the expansion of the space of admissible generalized functions, but also to obtain all the important results of axiomatics: CPT-invariance, the connection of spin with statistics, and the existence of asymptotic relations.

M. Z. Iofa and V. Ya. Faĭnberg (U.S.S.R.) reported on the axiomatic approach to nonlocal quantum field theory. Their approach is based on the enlargement of the space of admissible generalized functions. The space of the principal functions then contains only analytic functions. It turns out that the Wightman functions in the nonlocal theory also have some region of holomorphy which contains Jost's points. This makes it possible to prove the theorems about CPT-invariance, the connection between spin and statistics, and the existence of asymptotic states and, consequently, of the S-matrix.

In a paper by **D. I. Blokhintsev and G. I. Kolerov** (U.S.S.R.), "Perturbation Theory with a Cut-off," an algorithm was described which allows the construction of successive approximations in the interaction constant. The basis of the algorithm is the introduction of a form factor depending on the total momentum of each unconnected Feynman diagram. The method ensures the satisfaction of the conditions of macroscopic causality and unitarity of the scattering matrix.

N. N. Meĭman (U.S.S.R.) showed that if the amplitude T(s) in the nonlocal theory increases in the complex s plane not more rapidly than an exponential of the first order of increase, and increases in the physical region more slowly than any linear exponential, then this amplitude is $T(s) = \exp(-i l^2 s) T_1(s)$, where the function $T_1(s)$ increases more slowly than any linear exponential in the upper half-plane.

G. V. Efimov and Sh. Z. Sel'tser (U.S.S.R.) introduced into the theory of electromagnetic and weak interactions the hypothesis that the neutrino is the "carrier" of "nonlocality," which, in perturbation theory, effectively leads to a change in the free neutrino propagator. The resulting theory turns out to be renormalizable and gauge-invariant.

E. Kapuscik (Poland) tried to employ A. Jaffe's methods, developed in the Hilbert space of states, to prove the existence of a nontrivial $\lambda\varphi^2$-theory in nonrenormalizable spinor theories.

K. L. Nagy (Hungary) considered with the aid of simple solvable models of field theory the problem of unitarity in connection with the suggestion made by Lee and Wick that an indefinite metric might be used to construct a theory of electrodynamics free of ultraviolet divergences.

V. G. Kadyshevskiĭ (U.S.S.R.) reported on attempts to construct a quantum field theory on the basis of a geometrical modification of the concept of relative momentum. The author proceeds from the hypothesis that relative 4-momenta in quantum field theory belong to a space of constant curvature, which is realized on the 5-dimensional hyperboloid:

$$p_0^2 - p_1^2 - p_2^2 - p_3^2 - p_4^2 = -\frac{\hbar^2}{l^2}.$$

The parameter l plays the role of fundamental length. By letting it tend to zero, we return to the conventional theory. The author shows with the Wightman functions as an example that the formulation of field theory in terms of non-Euclidean relative momenta does not lead to a modification of the concept of a combined 4-momentum and does not invalidate the law of conservation of this quantity.

In his paper, **H. P. Dürr** (West Germany) discussed the problem of unitarity and macroscopic causality in quantum field theory with an indefinite metric. It is shown that the introduction of "ghost states" with a complex mass and definite computation rules preserves unitarity and macroscopic causality of the theory.

In a paper by **B. V. Medvedev, V. P. Pavlov, and A. D. Sukhanov** (U.S.S.R.) it is demonstrated that, in contrast to the traditional view, there is no direct correlation between the properties of hermiticity and locality of the interaction Lagrangian, on one hand, and the properties of unitarity and causality of the scattering matrix, on the other. They demonstrate with the aid of concrete models of field theory that a nonlocal or a non-hermitian Lagrangian provides a correct scattering matrix. Such anomalies exist also in the renormalizable theories owing to the counter terms with derivatives or derivatives in the bare Lagrangian.

The next big topic of the conference, "essentially nonlinear and nonrenormalizable interactions," was opened with a survey report by **M. K. Volkov** (U.S.S.R.).

A review was made of the methods employed in quantum field theory with rapidly increasing spectral functions. To such type of theory describing nonrenormalizable interactions of elementary particles correspond, for example, the neutral pseudoscalar theory with a pseudovector coupling of the scalar and the spinor fields, the parity non-conserving weak interaction of the neutral vector meson with a spinor field, the weak four-fermion interaction, the theories with Lagrangians possessing chiral symmetry, and others. In constructing the particle scattering-matrix elements in such theories, one uses in place of the conventional propagator some generalized two-point Green's function, which takes into account the possibility of creation of any number of particles at each vertex. It may be called a superpropagator.

Two difficulties are encountered in investigations of this super-propagator. The first is connected with the appearance of ultraviolet divergences on going over into momentum space, since this function contains poles of any order at the zero of the interval, while in localized interactions there is even an essential singular point.

The other difficulty is a characteristic feature of nonlocalizable interactions and lies in the fact that the infinite series in powers of the free particle propagators, in terms of which the superpropagator is expressed in X-space, does not converge and is an asymptotic series.

The main requirements that must be satisfied in solving these problems are that the S-matrix of the final theory be finite and unitary. The conditions of microscopic causality must be fulfilled in theories with localizable interactions, and the conditions of macroscopic causality in theories with nonlocalizable interactions.

All the methods of construction of superpropagators may be divided into four groups:

1. Determination of the superpropagators in X-space (G. V. Efimov, E. S. Fradkin, B. W. Lee and B. Zumino).
2. Determination of the superpropagators in p-space (M. K. Volkov and W. Guttinger).
3. Determination of the superpropagators with the aid of the solution to the corresponding equations (G. Feinberg and A. Pais, B. A. Arbuzov and A. T. Filippov).
4. Determination of the superpropagators by means of the introduction of nonlocal form factors (G. V. Efimov).

In his paper "Higher Order Approximations in Renormalizable Field Theories," **A. T. Filippov** (U.S.S.R.) briefly reviewed the methods of summation of the Feynman diagrams which are used for the computation of higher order approximations in nonrenormalizable field theories. As a model, he considered the theory of renormalization for scattering by a singular potential. The results of this investigation are carried over into field theory in the framework of two methods: 1) Summation of "ladder" diagrams; 2) a method based on the use of partial symmetries of the gauge type and equivalence theorems. In both cases it is possible to obtain linear integral equations for Green's functions, which in Euclidean momentum space lead to linear differential equations with definite boundary conditions. The solutions of these equations have, in the nonrenormalizable theories, a branch point with respect to the coupling constant g at $g = 0$ and an essential singularity at infinity with respect to momentum, which explains the utter inconsistency of the conventional perturbation theory in this case.

Let us note that the methods based on the use of partial symmetries lead to the same results as the methods of Okubo, Efimov, Fradkin and Volkov. In particular, the definitions of superpropagators (i.e., expressions of the form $\exp(\lambda \Delta_F(x)$, etc.) coincide.

In their paper, **H. Lehmann** and **K. Pohlmeyer** (West Germany) discussed the propagator in field-theoretic models with exponential coupling (the so-called superpropagator). They adduced some physical arguments to support the choice of the superpropagator in the form as made by M. K. Volkov and others. They required right from the beginning maximum regularity from the superpropagator and proved that the dynamics of the model has the simplest possible structure for that particular choice of the superpropagator.

In a paper "On the Quantization of an Extremely Nonlinear Field" by **D. I. Blokhintsev**, the problem of quantization of a field described by an equation whose characteristics depend on the field itself and its derivatives is considered. This is first illustrated with the quantization of a similar system with one degree of freedom. Then a method for the quantization of an extremely nonlinear field of the Born-Infeld type is described. The method is based on the introduction of the concept of an "effective Planck's constant."

In his paper, **A. V. Efremov** (U.S.S.R.) considered the model of interaction of the π-meson field with a δ-type potential. This model is an example of a nonrenormalizable theory which can be solved exactly. It illustrates one of the peculiar features of nonrenormalizable theory—the progressive increase of the scattering amplitude with increasing order of the perturbation theory and a decrease of the exact value of the amplitude.

E. Rajski (Poland) discussed effects of nonlocality type arising as a result of the introduction into the theory of nonlinear Lagrangians of the form $L' = \tan^{-1} L$, where L is the ordinary total Lagrangian of the fields under consideration.

In a paper by **F. Kaschlun** and **E. Wieczorek** (East Germany), the singularities of the Wightman functions for various asymptotic behaviors of the spectral functions were considered. In the case of increase of a spectral function of the type $\sigma(q^2) = \exp(\alpha q^2)$, Borel's summation methods were used.

M. A. Braun (U.S.S.R.) noted a number of difficulties encountered in nonpolynomial quantum field theory, but, unfortunately, he did not indicate any positive program for surmounting them.

The next topic of the conference, "Physical Symmetries in Quantum Field Theory," was opened with a survey report by **D. V. Volkov** (U.S.S.R.), "The Geometrical Approach to the Method of Phenomenological Lagrangians." The method of phenomenological Lagrangians is connected with the concept of dynamical symmetry in systems with Goldstone particles. The presence in any system of Goldstone particles is customarily qualitatively interpreted as a reaction of the system against the re-established symmetries which get broken as a result of the degeneracy of vacuum. The Goldstone particles re-establish the symmetry of the system; the transformation properties are then determined by means of nonlinear transformations—which corresponds to a transition to symmetry of the dynamical type.

In the phenomenological-Lagrangian method the fields of the Goldstone particles are associated with the coordinates of some space which is homogeneous with respect to a transformation of the group G. Then, certain relations are established which are sufficient for the determination of the invariants of the group G, and the construction on the basis of them of the simplest matrix elements.

L. D. Faddeev (U.S.S.R.) in his paper "The Geometrical Meaning of Nonlinear Symmetry" gave an interpretation of nonlinear fields of the Weinberg or Sugawara type as functions which assume their values in a nonlinear intrinsic (say, isotopic) space. The simplest example of such a space is given by the orthogonal group O_3. The transformations of left and right shifts generate the corresponding currents and, thus, realize a natural representation of the chiral group. It was especially emphasized that it is convenient to use in all computations manifestly covariant coordinate-independent methods, since all the physical quantities do not depend on the parametrization of the intrinsic space.

A. A. Slavnov and **L. D. Faddeev** (U.S.S.R.) proposed an invariant method for quantizing the Sugawara model. They have obtained for the S-matrix an expression that does not depend explicitly on the parametrization. In contrast to the usual scheme, the resulting Feynman rules contain only a finite number of vertices.

In another paper, "The Yang-Mills Field," **A. A. Slavnov** (U.S.S.R.) considers gauge fields with arbitrary masses. A general expression in the form of a Feynman integral is obtained for the S-matrix of the gauge field. For zero mass this expression coincides with the result obtained by Faddeev and Popov. The case of non-zero mass is treated in detail. It is shown that the S-matrix of the massive theory does not go over in the limit of zero mass into the S-matrix of the massless theory. To obtain the correct limiting value it is necessary, in addition, to subtract the contribution of scalar particles of zero mass corresponding to longitudinally polarized quanta. The question of renormalizability of the theory is discussed.

A paper by **A. M. Vaĭnshteĭn** and **I. B. Khriplovich** (U.S.S.R.) "On the Question of Passage to the Limit of Zero Mass and Renormalizability in the Theory of the Massive Yang-Mills Field" was devoted to the treatment of the theory of the massive Yang-Mills field. It is shown that passage to the limit of zero mass in perturbation theory is impossible, which is in agreement with results obtained by Slavnov and Faddeev, and Bul'var. Explicit computation of higher-order diagrams reveals the presence of singularities with respect to mass. The question of renormalizability of the theory and the possibility of passage to the limit with respect to mass outside the framework of perturbation theory are discussed.

É. A. Tagirov (U.S.S.R.) read a paper on "Conformally Covariant Interactions." A condition for approximately conformally covariant equations of motion is formulated and discussed in the framework of the general theory of relativity. It is established that conformally covariant interactions of fields with spin 0, $\frac{1}{2}$, and 1 become identical on going over into a flat space with minimal interactions. (Thus, it turns out that the requirement of gauge invariance and the requirement that the coupling constant be dimensionless, which have served as the starting point in the construction of the modern theory of elementary particle symmetry, themselves follow from a unified geometrical principle that is closely related to the general theory of relativity.)

The physical symmetries of a system of n real scalar fields were discussed in the paper "Some Remarks on Physical Symmetries" by J. T. Lopuszanski (Poland). Several generalizations of the formalism connected with the relaxation of certain generally accepted axioms were found.

H. P. Dürr (West Germany) read a paper on "Local Symmetry in Spinor Theories." The author tried to prove the existence of formulations of spinor theories with four-fermion interactions which are invariant with respect to local symmetry groups without the introduction of additional fields.

In a paper **C. George** and **E. Mihul** (Rumania) discussed "Causal Enlargement of the Poincare Group," the possibility of mixing between the orthochronous Poincare group and the internal symmetry groups, which is implicit in the causal enlargement of the space-time group (causality is here understood in the Zeeman sense). A theorem about their structure is proved and some current algebras are obtained.

A number of papers were devoted to functional methods. In a paper by **B. M. Barbashov**, the application of functional methods to the study of infrared and high-energy asymptotes in quantum field theory was considered. The author developed, in the framework of functional integration, a method for approximating the integrals. This made it possible, in particular, to obtain an eikonal representation of the scattering amplitude for high-energy particles, and, also, to take into account the effect of radiative corrections on the nature of scattering. A review of recent achievements in the area of the method of functional integration was also given in the paper.

O. I. Zav'yalov (U.S.S.R.) investigated the problem of justification of the standard Feynman quantization scheme in the framework of a continuous integral in the relativistic case of an infinite number of degrees of freedom.

In a paper by **J. Zuwusski** (Poland) the Hilbert space of entire functionals, which are often used in quantum field theory and in quantum mechanics, was studied. Mathematical estimates of the region of analyticity and of the asymptotic behavior of formal power series of generalized functions and their functional derivatives are given in the paper. Some applications of these estimates to the operators in quantum field theory are considered.

A paper by **G. I. Fomin** (U.S.S.R.) "On the Nature of Divergences in Quantum Electrodynamics Outside Perturbation Theory" was heard with interest. In the communication he drew attention to the fact that even when we partially go outside the framework of perturbation theory, we find that the situation with divergences changes considerably in comparison with the analogous situation in the usual perturbation theory in electrodynamics, which, as is well known, leads to three logarithmically diverging quantities: δm, Z_3 and $Z_2 = Z_1$. If, on the other hand, outside the framework of ordinary perturbation theory we restrict ourselves, by way of an illustration, to the "three-gamma" or "five-gamma" approximation, then the electron self-energy diverges linearly while Z_2 and Z_3 become finite. In the event of fulfillment of certain conditions these deductions remain valid when higher order approximations are taken into account. This method does not lead to the "vanishing" of the renormalized charge, nor does it lead to the nonphysical pole of the photon Green's function.

M. K. Polivanov, B. V. Medvedev and **A. D. Sukhanov** (U.S.S.R.) discussed the connection between the various formulations of the causality condition. A "current" enlargement of the S-matrix off the energy surface is constructed in the framework of the dispersion approach. A correspondence between the Bogolyubov and the Lehmann-Symanzik-Zimmermann causality conditions is established.

A. Visconti (France) talked about the work going on at the National Center for Scientific Research in Marseilles on the use of computers in the calculation of radiative corrections in scalar theories and quantum electrodynamics and for solving nonlinear integral equations.

In a paper by **L. V. Prokhorov** (U.S.S.R.) "Unitarity and the Interaction of Massless Particles," the conditions imposed by the unitarity relation on the form of the interaction of particles of zero mass were investigated, and an attempt was made to classify the various theories from the point of view of the fulfillment of the unitarity conditions.

A. Ullman (West Germany) talked about some interesting properties of the representation of C*-algebra—a new mathematical device which is widely used now in Physics for the description of systems with infinitely many degrees of freedom.

Yu. M. Lomsadze and **E. P. Sabad** (U.S.S.R.) devoted their paper to the study of the limitations on amplitude arising from the principle of microcausality, and to the proof of the asymptotic relations of the type of the Pomeranchuk theorem.

The publishing division of the Joint Institute for Nuclear Research published the collection "The Transactions of the Second International Conference on Nonlocal Quantum Field Theory" in 1971. Because of the large volume of material presented at the conference, only review reports encompassing a wide range of problems could be included in the collection.

Translated by A. K. Agyei