PROGRESS REPORT FOR A RESEARCH PROGRAM
IN THEORETICAL HIGH-ENERGY PHYSICS

David Feldman
Professor of Physics
Principal Investigator

Department of Physics
Brown University
Providence, Rhode Island

E(11-1)-3130 (Task A-Theoretical)

1 June 1975

NOTES
This report was prepared as an outcome of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

Last year's research program dealt with a variety of topics including eikonal/multiplicity studies (elastic and inelastic distributions by a semi-classical method, Gribov calculus); analytic parametrization (total cross sections, real to imaginary ratios of forward amplitudes, charge-exchange processes); multiperipheral cluster models (pion-pole dominance); narrow-width particles (conventional hadronic model for $\psi(3.1)$ and $\psi(3.7)$, baryon-antibaryon resonances, decays of long-lived hadrons); neutrino-nucleon collisions (charmed particles, neutral-current processes); models for permanently bound quarks (scalar quarks in one dimension, meson decays, spin- $\frac{1}{2}$ colored quarks); spontaneous symmetry breaking (excitation of composite fields, non-abelian gauge theories); properties of model field theories (Nambu model, Luttinger model); functional techniques for many-body systems (multiparticle production, phase transitions); topics in general relativity; as well as other studies involving the strong, electromagnetic, and weak interactions of elementary particles.

Progress Report for a Research Program
in Theoretical High-Energy Physics

The Department of Physics of Brown University, with the support of the U. S. Energy Research and Development Administration under Contract E(11-1)-3130, has been carrying out a research program in Experimental and Theoretical High-Energy Physics since 1958. The Theoretical Program has been under the direction of David Feldman, Professor of Physics. This report serves to summarize the progress which has been made during the present contract year (1 September 1974 - 31 August 1975) by the Theoretical Group (Task A).

The report is divided into three sections:

- I. Present Status of the Theoretical Group;
- II. Theoretical Papers Published During the Preceding Year and Papers in Press;
- III. Scientific Personnel Associated with the Theoretical Program.

I. Present Status of the Theoretical Group.

During the past year, the overall scope of the theoretical program remained essentially unchanged from that of previous years. Thus, the major effort continued to be devoted to theoretical studies in the physics of high-energy phenomena, the properties and interactions of elementary particles, and quantum field theory. Other problems of current interest such as applications of field-theoretic methods to the general theory of relativity were also considered.

During the past year, the continuing eikonal/multiplicity studies of Professor Fried, in collaboration with Dr. H. Moreno, have led to the application of a semi-classical method within a new context, viz., certain elastic and inelastic distribution functions may be estimated by replacing sums over large numbers of pions by the production of equivalent classical pions, particles which satisfy a self-consistent, non-linear differential equation. This approach has been shown to yield a phenomenology corresponding

to the simplest possible unitary model (Ref. 320)¹; furthermore, partial solutions of the non-linear equation have been obtained. Together with Professor R. Blankenbecler, Professor Fried has also initiated a program to reproduce solutions of the Gribov calculus by an eikonal method; estimates of total cross sections increasing with energy as $(\ln E)^p$ have been obtained, but a satisfactory application of unitarity - which should limit the value of the parameter p - has not yet been carried through. Finally, a formulation by Professor Fried of statistical problems in the language of functional methods is currently in progress; it is expected that these methods will provide a certain insight into high-energy multiplicity distributions, while clarifying some aspects of the general subject of phase transitions.

Professor Guralnik's investigation, with Professors C. M. Bender and J. E. Mandula, of scalar quarks bound by ϕ^4 potential models has been described in two publications (Refs. 314, 315). The first paper contains a detailed examination of quarks in one spatial dimension with the imposed requirement that the matrix element $\langle q | \phi^2 | q' \rangle$ is singular in a specified manner, where $|q'\rangle$ is a single quark state of momentum q' and the singularity assures that multiple quark systems are always bound. It turns out that in this case the problem of the particle spectrum is mathematically equivalent to finding the modes of a vibrating elliptical drum, and that, at least to lowest order, the approximation techniques employed are entirely consistent with the field-theoretic structure of the model. In the second paper, a perturbation technique was developed to calculate higher-order corrections to the theory and this technique was applied to the calculation of meson decays. Professor Guralnik and his collaborators have also been considering the generalization of the scalar theory to realistic models involving spin-one-half colored quarks. Professor Guralnik and Mr. Kasdan have been examining a new kind of spontaneous symmetry-breaking solution for interactions of the form $\lambda \left(\sum_{a=1}^n \phi_a^2 \right)^2$ where all fields have the same bare mass; they have found that it is possible to have a Goldstone boson excited by composite fields with the form $\phi_a(x)\phi_b(x)$ if at least two of the renormalized single field

1. References cited are listed in Section II of this report.

masses are different and $\langle 0 | \phi_a | 0 \rangle = 0$ for all a . Because of the terms involving four non-abelian gauge fields in Yang-Mills-type theories, this form of spontaneous symmetry breaking should prove especially interesting in determining how non-abelian gauge theories can generate their own masses without the introduction of scalar fields into the Lagrangian; Professor Guralnik, in collaboration with Professor T. W. B. Kibble and Mr. Snyderman, has tentatively confirmed the feasibility of this approach. Together with Mr. Snyderman, Professor Guralnik has also been examining the structure of the Nambu model, with particular emphasis on its renormalizability and interactions with electromagnetic fields. Finally, Professor Guralnik and Mr. Tamvakis have begun a study of the relation of the Luttinger model to the Thirring model with a spatially non-local potential, and the relation, in turn, of these models to the sine-Gordon equation.

The research activities of Professor Kang during the past year were directly concerned with interpretations of new experimental results. First, with Dr. B. Nicolescu, he carried out an analysis of the Fermilab data for the π^+p , K^+p , pp , and $\bar{p}p$ total cross sections (Ref. 310). The rising nature of these cross sections (except for the last) as well as the characteristic curvature of the difference between the particle and antiparticle cross sections indicate that simple-minded Regge models are no longer operative. Professor Kang and Dr. Nicolescu have suggested certain analytic parametrizations for high-energy scattering as solutions of the "quasi-local" relations which are based on analyticity, crossing symmetry, and the rigorous constraints of unitarity. Upon consideration of all available data for $p_L \geq 10$ GeV/c, they were led to conclude that the crossing-odd part of the elastic amplitude cannot be negligible at high energies. Furthermore, the Serpukhov πp data are statistically incompatible with other lower as well as higher energy data; indeed, the revised Serpukhov data (which became available after this work had been completed) for the ratio of the real to the imaginary parts of the forward π^+p amplitude agree with the theoretical predictions of Professor Kang and Dr. Nicolescu, thus supporting their suspicion of the earlier Serpukhov data. Since the completion of the work described in Ref. 310, new data on the pion charge-exchange reaction for $p_L = 20-100$ GeV/c have been reported. These results, when compared with the Fermilab

$\sigma_{\pi^-p} = \sigma_{\pi^+p}$ data, have led some Regge phenomenologists to suggest that charge symmetry is violated at high energies. However, with the help of the non-negligible odd-signature amplitude, Professor Kang, together with Dr. G. Bialkowski and Dr. B. Nicolescu, was able to use the parametrization of Ref. 310 to explain both sets of data simultaneously (Ref. 313). Professor Kang and Mr. Rizvi have investigated the exact consequences of the SU(4) quark-parton model as applied to the deep-inelastic neutrino (antineutrino)-nucleon process. In Ref. 311, they propose a test for the presence of the charmed quark in the nucleon target via two local relations of the charged-current leptonproduction structure functions below and above the charm threshold; the test can be generalized for any nuclear target. In Ref. 312, Professor Kang and Mr. Rizvi studied the effect of the charmed quark in the neutral-current process by parametrizing and analyzing the available experimental data. Finally, we note that this material has served as the basis for Mr. Rizvi's doctoral thesis, entitled "Charm in High Energy Neutrino-Nucleon Collisions."

It has been well established² that multiparticle production in high-energy hadron collisions takes place predominantly via a multiperipheral or short-range-correlation mechanism. However, a realistic multiperipheral model which exhibits all the characteristics of high-energy hadron collisions still does not exist. One unusual phenomenon discovered in recent correlation data at NAL and ISR energies is the presence of strong correlations in the longitudinal rapidity; this can be understood in terms of the independent cluster or multiperipheral cluster pictures. Recently, Professors Tan and Tow have examined the consequences of pion-pole dominance in models which incorporate this mechanism of particle production (Ref. 317). They showed that the observed size of total hadronic cross sections and the observed average multiplicities were incompatible with the premise that the dominant high-energy production was due to a repeated pion exchange in a multiperipheral cluster chain. They then discussed the implications of their findings and commented on various alternatives in the search for a realistic multiperipheral cluster model.

2. W. R. Frazer, R. D. Peccei, S. S. Pinsky, and C.-I Tan, Phys. Rev. D 7, 2647 (1973) (Report No. COO-3130TA-269).

The announcements of the discovery and the subsequent confirmation of the existence of the new narrow-width particles at 3.1 and 3.7 GeV led to an intensive collaborative effort on the part of Professors Tow, Tan, Kang, and Fried. To account for the masses, widths, and branching ratios of the new particles, these authors proposed that $\psi(3.1)$ and $\psi(3.7)$ are a bound state and a resonance, respectively, of the $\Omega\bar{\Omega}$ system where $\psi(3.1)$ decays predominantly into three $\lambda\bar{\lambda}$ mesons (Ref. 318). They argued further that the small width of $\psi(3.1)$ is due to its bound-state nature and the small Q values for its decays which can be explained in terms of conventional hadronic couplings. Also, the branching ratios of $\psi(3.1)$ and $\psi(3.7)$ were calculated; in particular, it is expected that the $\Omega\bar{\Omega}$ decay mode of $\psi(3.7)$ will enhance the world's supply of Ω events. Subsequently, Professor Tow proposed an alternative argument to account for the small ψ widths (Ref. 319). The argument is based on the assumption that non-strange quarks are more easily created or emitted than strange quarks; the implications for ψ' and other baryon-antibaryon systems were discussed. Professor Tow has also presented a review and critique of various specific $\Omega\bar{\Omega}$ models for the new particles (Ref. 321).

The work of Professor Westervelt on the transfer of gravitational energy and momentum in the induction field generated between two laser beams of finite length is nearing completion. Professor Westervelt has also started an analysis of the coupling of gravitational waves to specific models of mechanical oscillators. The first model studied consisted of a parallel-plate capacitor the charged plates of which are separated by a one-dimensional photon gas; preliminary results³ indicate that there is no coupling for this case. An attempt is being made to generalize these results so that they will be model independent. Finally, we note that Professor Westervelt has presented a paper on the gravitational radiation by ultrarelativistic bodies at the International Conference on Gravitation and Relativity held in Tel-Aviv, Israel during the period 24-28 June 1974.

Professor Feldman has begun an investigation of some aspects of quantum field-theoretic models in the presence of a curved space-time metric. Particular emphasis is being placed on the question of the finiteness of renormalization constants and the properties of gauge fields.

3. P. J. Westervelt, J. Acoust. Soc. Am. 57 (Suppl. No. 1), S30 (1975).

II. Theoretical Papers Published During the Preceding Year and Papers in Press.

- TA-310 K. Kang and B. Nicolescu, "Models for Hadron-Hadron Scattering at High Energies and Rising Total Cross Sections," Phys. Rev. D (in press).
- TA-311 K. Kang and S. M. A. H. Rizvi, "A Test of Charm through Lepto-Production," Phys. Letters (submitted).
- TA-312 K. Kang and S. M. A. H. Rizvi, "Weinberg Angle in Quark-Parton Model with Charm for High Energy Neutrino-Nucleon Collisions," Phys. Rev. D (in press).
- TA-313 G. Bialkowski, K. Kang, and B. Nicolescu, "High Energy Data and the Structure of the Odd Signature Amplitude of Pion-Nucleon Scattering," Nuovo Cimento Letters (submitted).
- TA-314 C. M. Bender, J. E. Mandula, and G. S. Guralnik, "Self-Consistent Binding Force Between Quarks in One Dimension," Phys. Rev. D 11, 429 (1975).
- TA-315 C. M. Bender, G. S. Guralnik, and J. E. Mandula, "Meson Decay in a Theory of Bound Quarks," Phys. Rev. D 11, 438 (1975).
- TA-316 M. Rosenberg and N. Snyderman, "A Quantum Electrodynamics Approach to Non-Linear Plasma Processes," Internal Report (1974).
- TA-317 C.-I Tan and D. M. Tow, "Can Pions be the Dominant Linkage in Multi-peripheral Cluster Models?" Phys. Letters 53B, 452 (1975).
- TA-318 D. M. Tow, C.-I Tan, K. Kang, and H. M. Fried, "Conventional Hadronic Model of the New Particles at 3.1 and 3.7 GeV," Phys. Rev. Letters 34, 499 (1975).
- TA-319 D. M. Tow, "New Argument for the Small Widths of ψ 's in the $\Omega\bar{\Omega}$ Model," Phys. Rev. Letters (submitted).
- TA-320 H. Moreno and H. M. Fried, "Inelastic Eikonal Phenomenology in a Stationary Phase Approximation," Phys. Rev. D (submitted).
- TA-321 D. M. Tow, "Comments and Critique of the $\Omega\bar{\Omega}$ Model for the New Resonances," *Proceedings of the IVth International Symposium on Nucleon-Antinucleon Interactions, Syracuse, New York, 2-4 May 1975*, in press.

III. Scientific Personnel Associated with the Theoretical Program.

1 September 1974 - 31 August 1975

D. Feldman - Professor
H. M. Fried - Professor
G. S. Guralnik - Professor
K. Kang - Professor
P. J. Westervelt - Professor
C.-I Tan - Assistant Professor
D. M. Tow - Assistant Professor (Research)
S. C. Choi - Graduate Research Assistant
D. A. Fitzpatrick¹ - Graduate Research Assistant
S. Kasdan - Graduate Research Assistant
S. M. A. H. Rizvi - Graduate Research Assistant
N. J. Snyderman - Graduate Research Assistant
K. K. Tamvakis - Graduate Research Assistant

1. From 1 June 1975.