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DE89 010067

Annual Report

DE-FG06-85ER40224

part I

Task A

DISCLAIMER

N.G. Deshpande

Research was carried out in several areas of phenomenology with relevance to present and future accelerators. I gave a invited talk on the Gauge Sector at the Conference on "Beyond the Standard Model" at Ames, Iowa in November 1988. Research was also presented at the Conference on Rare Decays in TRIUMF, Canada in December 1988. Summary of the publications and reports completed in the last year are given below. Many have been done in collaboration with Dr. Josip Trampetic, who is a post doctoral research associate here.

1. Decays of Z' from superstrings into W's and higgs'.

The heterotic string gives rise to effective E_6 grandunified group with fermions and Higgs in the 27 representation. The low energy group could under certain conditions have an extra U(1) factor giving an extra gauge boson Z'. the fermionic decay modes of Z' have been discussed previously by us. A new and promising mode is $Z' \rightarrow W^+W^-$. This mode is surprisingly large, even though it goes through Z-Z' mixing which is quite small. We give the reason for this curious phenomena by pointing out that W's in the decay are predominantly longitudinal. This suggests that the mode really arises through $Z' \rightarrow H_u^+H_u^-$ where H_u are the unphysical Higgs, that would have been the Goldstone modes. The rate for this mode is then the measure of the U(a) quantum numbers of Higgs bosons. As such, the measurement of this mode is a test of the whole idea of spontaneous breakdown of symmetry. We have analyzed this and other modes of decay in detail for arbitrary Z' from superstring theory [OITS 383] The sum of decays in W;s and Higgs are found to be independent of vacuum expectation values and range from 10 to 20% of the total rate. In a separate report we have shown that this mode can be detected at the proposed supercollider if the mass of Z' is less than 1.5 TeV.

2. Signature of Right-Handed Gauge Bosons through their decays into W's and Z's.

We investigated Left-Right symmetry model to see if W_R and Z' in this theory could be detected in the Z Higgs, and W^+W^- mode. To good accuracy we found that $Z' \rightarrow e^+e^-$ was the same as $Z' \rightarrow W^+W^-$. The range of detectability is about the same as the previous case. [OITS 382]

3. B decays into Charmless baryons.

Intriguing hints of possible observation of charmless baryonic modes of B decays by ARGUS collaboration prompted us to make theoretical estimates of two and three body decay modes. The importance of these observations arises form the fact that this would be the first unambiguous proof of finiteness of V_{ub}. Our estimates suggest that, if the experimental data holds up, V_{ub} is surprisingly large [OITS 370]

4. Rare B decays.

We have been involved in a systematic investigation of B decays through the electromagnetic penguin diagram. At the quark level this leads to the transition $b \rightarrow s\gamma$. We have used a constituent quark model to estimate $B \rightarrow K^*\gamma$. There are other ways of getting the same contribution. For example through $B \rightarrow K^*\psi$ and ψ converting to a photon. We call these the long distance contributions and we have estimated these [OITS 392]. Another process that also depends on electroweak theory at one loop is $b \rightarrow s\, e^+e^-$. This leads to decays like $B \rightarrow Ke^+e^-$ and $B \rightarrow K^*e^+e^-$. These rates were estimated [OITS 379]. there can be long distance contributions to those process coming from charmonium production and subsequent decay to e^+e^-. These were investigated and it was shown that these could be reduced by suitable cuts [OITS 394]

Publications in the Past Year

OITS 379: Improved Estimates for Processes $b \rightarrow s\, e^+e^-$, $B \rightarrow Ke^+e^-$ and $B \rightarrow K^*e^+e^-$, N.G. Deshpande and J. Trampetic. Phys.Rev. Lett.60,2583(1988).

OITS 382: Signatures of Right-Handed Gauge Bosons Through Their Decays into W and Z Bosons in High-Energy pp Collisions, N.G. Deshpande, J.Grifols and A. Mendez. Phys. Lett.208,141(1988).

OITS 383: Decay of Z′ in W^+W^- and Higgs Modes, N.G. Deshpande and J. Trampetic. Phys. Lett.206,665 (1988).

OITS 392: Decay Modes $B \rightarrow K\psi$, $K^*\psi$ and Long Distance Contribution to $B \rightarrow K^*\psi$ from $\psi - \gamma$ Transition, N.G. Deshpande, Josip Trampetic, and Kuriakose Panose. To be published in Phys. Lett.

OITS 394: Resonance Background to the Decays $b \rightarrow s\, e^+e^-$, $B \rightarrow K^*\, e^+e^-$, $B \rightarrow K\, e^+e^-$, N.G. Deshpande, Josip Trampetic, and K. Panose.

R. C. Hwa

Extensive progress has been made this year in carrying out the research program started last year in both areas of investigation: (A) multiparticle production in hadronic processes, and (B) relativistic heavy ion collisions.

A. Multiparticle Production

1. A review article was written on branching models. Starting from stochastic methods, it covers perturbative and non-perturbative multiparticle production processes that can be described by branching equations. The article was published in the review volume "Hadronic Multiparticle Production", edited by P. Carruthers. (374)
2. The survey talk that was given at the Shandong Workshop was written up during this contract year. It reviews the various models that are currently being developed to describe the low-p_T processes. Comparisons were made; differences and commonalities were pointed out. (378)
3. A review of the valon model, recombination model, production in the central and fragmentation regions, and application to nuclear collision processes was written. (384)
4. The geometrical branching model with jets has been reviewed at two conferences.
   a. Second International Conference on Elastic and Diffractive Scattering held at Rockefeller University. (380)
   b. Shandong Workshop on Multiparticle Production, Jinan (398)
5. It has been suggested by Van Hove several years ago that a rise-plateau-rise pattern (ledge effect) in the multiplicity dependence of average transverse momentum would indicate a phase transition. Last year my student, X. Wang, and I have shown in a concrete hydrodynamical calculation that transverse collective flow cannot yield a second rise. During this past year we considered minijet production in the framework of the geometrical branching model and found the ledge effect for $p\bar{p}$ collisions at high energy. This is confirmed by the data of CO collaboration at the Tevatron, though the error bars at high n are large. Although there is no guarantee that the same effect can be seen in

nucleus-nucleus collisions, it strongly suggests that the ledge effect is an unreliable indicator of whether there is a phase transition. (387, 397)

6. Chen, Wang and I have found a universal property among hadron-hadron and hadron-nucleus collisions, resulting in a parameter-free description of the impact-parameter dependence of the particle-productivity function. (386, 390)

7. The hadron-nucleus collision problem has been formulated in the framework of the geometrical branching model. It differs from all previous approaches in that it allows the incident hadron to be broken up after the first collision, and that it then treats the propagation of the broken hadron through the target nucleus in a detail way using the geometrical branching model. A general formula for the average multiplicity is obtained. The multiplicity distribution is also derived. Without any free parameters we have obtained results that are in excellent agreement with the data. The work is described in two massive papers: I. Formalism and II. Phenomenology. (388, 389)

B. Relativistic Heavy-Ion Collisions

1. A hydrodynamical calculation of the collective transverse flow in a relativistic heavy-ion collision was carried out for the two cases of with and without phase transition. By considering a constraint between the impact-parameter and the initial temperature, it is shown that there is no second rise in $\langle p_T \rangle$ vs dN/dy, for dN/dy up to 50. (399)

2. The study of multiplicity fluctuation as a possible signature for collective effects has continued to be a topic of investigation during the past year. The suggestion made at the Quark Matter '87 Meeting has spurred some interest in the experimental community with the result that the data on multiplicity fluctuations have been analyzed by various groups, yielding the slope parameter sought for. The separation into geometrical and dynamical sources of the fluctuation was considered. From the data so far obtained, one can conclude that dynamical correlation due to collective effects is insignificant, if any. (385, 393)

3. A review of the expectations and realities in relativistic heavy-ion collisions was given at a plenary session in an International Conference on Medium- and High-Energy Nuclear Physics held in Taipei. The topics covered were (a) multiplicity

dependence of average transverse momentum, (b) J/psi suppression, and (c) multiplicity fluctuation. (391)

C. Other Activities

1. Perugia Workshop. I helped organized the sequel to the highly successful Shandong Workshop on Multiparticle Production, this time held in Perugia, Italy during June 21-28, 1988, with the help of local organizers G. Pancheri and Y. Srivastava. There were about 40 participants, small enough to generate an intimate atmosphere in which extended exchange of ideas was possible. Proceedings for the Workshop will be published by World Scientific.
2. Review Volume on Quark-Gluon Plasma. Editorial work on assembling review articles on Quark-Gluon Plasma is proceeding smoothly as the number of contributors has risen to fourteen. It will appear as volume 6 of the Advanced Series on "Directions in High Energy Physics" of World Scientific. The volume will contain a good collection of timely review of all important topics in the subject written by highly qualified authors. Only three of the fourteen authors are from the U.S., which is a sad statement about the U.S. effort in this subject.
3. CCAST Symposium on Relativistic Heavy Ion Collisions. I am organizing the 1989 Symposium on relativistic heavy-ion collisions to be held at the Chinese Center of Advanced Science and Technology in Beijing. T.D. Lee is the director of that Center. He has asked me to coordinate the program of the two-week long Symposium. There will be eight lecturers, five from CERN, one from BNL, one from LBL, and one from Oregon. The distribution is another indication of the European dominance of the field, a fact which I hope the research administrators in the U.S. should emphasize during the deliberations on the construction of RHIC.

Papers Written During the Past Contract Year

1. OITS-374: "Branching processes in multiparticle production," in Hadronic Multiparticle Production, Advanced Series on Directions in High Energy Physics, Vol. 2, edited by P. Carruthers (World Scientific, Singapore, 1988).
2. OITS-378: "A Comparative survey of theoretical approaches in multiparticle production", in Multiparticle Production, Proceedings of the Shandong Workshop, Jinan, edited by R. C. Hwa and Xie Qubing (World Scientific, Singapore, 1988).
3. OITS-380: "Geometrical Scaling, Furry branching, and minijets," in Elastic and Diffractive Scattering (second "Blois Workshop"), edited by K. Goulianos (Editions Frontieres, France, 1988).
4. OITS-384: "From Geometrical branching to nuclear collisions," in Multiparticle Production, loc. cit.
5. OITS-385: "Multiplicity fluctuation as a possible signature for collective effects," in Proceedings of the International Conference on Physics and Astrophysics of Quark-Gluon Plasma, Bombay, edited by B. Sinha (World Scientific, Singapore, 1988).
6. OITS-386: "A parameter-free description of particle productivity" (with W.R. Chen).
7. OITS-387: "The effect of jet production on the multiplicity dependence of average transverse momentum" (with X.N. Wang), Phys. Rev. D 39, #1, (1989).
8. OITS-388: "Multiplicity distributions of high-energy hadron-nucleus collisions: I. formalism (with X.N. Wang), Phy. Rev. D (submitted).
9. OITS-389: "Multiplicity distributions of high-energy hadron-nucleus collisions: II. Phenomenology (with X.N. Wang), Phys. Rev. D (submitted).
10. OITS-390: "Particle productivity in pp and pA collisions" (with W.R. Chen and X.N. Wang), an expanded version fo OITS-386, Phys. Rev. D 38, #11 (1988).
11. OITS-391: "Expectations and realities in relativistic heavy-ion collisions" in the Proceedings of the Int'l Conference on Medium- and High-Energy Nuclear Physics (World Scientific, Singapore, 1988).
12. OITS-393: "Geometrical and dynamical multiplicity fluctuations in high-energy nuclear collisions" Int. J. Mod. Phys. A3, #12 (1988).
13. OITS-398: "Cross sections and multiplicity distributions with minijets" (with W.R. Chen) in Multiparticle Production, loc. cit.
14. OITS-399: "Transverse momentum in high energy A-A collisions" with X.N Wang) in Multiparticle Production, loc. cit.

Annual Report

Michael J. Moravcsik

The past twelve monthswere both a very exciting and at the same time a frustrating period. The research into the polarization structure of reactions continued to produce spectacular results.

In particular, further progress has been made on the investigation of the planar transverse amplitude phase pattern, firming up its phenomenological basis, and exploring some possibilities of its interpretation. More about this below.

The effort, however, has been seriously hampered by the DOE's refusal to furnish funds for a normal-sized manpower unit to proceed with this novel and potentially far-reaching investigation. My own summer salary has been cut in half, and neither student nor postdoctoral assistance is available for this research. Indeed, the research would have been made even more difficult if Firooz Arash had not been able to support himself through temporary non-research type resources. I want to make a strong appeal for the reinstitution of a modest but non-zero effort, consisting of two summer months for me and a research assistant or half-time research associate.

Now let me turn to the particulars.In what follows the [..] numbers refer to the list of publications appended to this annual report.

1) The planar transverse amplitude phase pattern.

As reported in the last few annual reports, our analysis of strong interaction reactions in terms of optimal amplitudes of the planar transverse type has uncovered a pattern in which the relative phases of the complex reaction amplitudes in this system tend strongly to be 0, 90, 180, or 360 degrees.

Originally this pattern was found in elastic proton-proton scattering at 6 GeV/c, but by now the pattern has been pinpointed in all reactions we have analyzed. The number of reactions and the kinematic ranges in which such an analysis can be carried out is somewhat limited by the availability of a sufficiently detailed set of polarization experiments so as to enable the determination of the amplitudes.

Nevertheless, so far the existence of this pattern does not appear to be limited by the type of reactions or the kinematic domains [60, 61]. After a number of elastic scattering reactions, we turned to inelastic reactions [65] to see the pattern there also. As to energy range, the pattern is also seen [58] at as high energies as 45 GeV/c, while it is also in evidence at 1-200 MeV [59].

To be sure, the pattern is more prominent in some situations than in others, and one may discern from the data that the pattern is more dominant at higher energies and at larger angles than at lower energies and smaller angles. If so, this would suggest that the pattern reflects the nature of the shorter range strong interaction.

Very preliminary results also suggest that the phase angle

between given amplitudes remains the same over the whole kinematic range of a given reaction, but the exploration of this is one of the many aspects of this problem area that in this past grant period we had to forego in detail because of the lack of research resources. Other aspects of this problem to be addressed will be listed under the proposed work for the next grant instalment period.

2) The determination of electromagnetic form factors.

Since a number of electron accelerator centers, among them CEBAF, DESY, and BATES, are intrerested in the determination of electromagnetic form factors through polarization measurements in electron elastic scattering, we have undertaken a general study of how this can be attained. Using our previously evolved optimal formalism for the description of the spin structure of reactions, we described such structure in the presence of electromagnetic interactions.

The results thus obtained give a general prescription for the determination of the form factors in elastic electron scattering on a target of arbitrary spin [63].

A byproduct of this work is a theorem [62] according to which one can completely determine all of the elastic form factors in such a situation without having access to polarized electrons either in the initial or in the final state. This result is a specific consequence of the electromagnetic interaction since in general in a reaction one would not obtain a complete determination of the reaction amplitudes when the polarization of one of the participating particle remains unmeasured.

In practice one may or may not avail oneself with this theorem, since measuring electron polarization may help avoiding some complicated measurement of the target polarization. How such a trade-off works will be studied in the next grant period.

3. The polarization structure of photoproduction processes

Our polarization studies have continued to benefit from an association with various particle physics laboratories. Among them are TRIUMF, the University of Bonn, SIN, CEBAF, and Saclay. In this context the analysis of pion photoproduction in terms of the various polarization measurements arose in an interaction with Bonn.

We exhibited the polarization structure of this reaction in several convenient optimal frames, and defined the experimental programs which are needed for the determination of the reaction amplitudes, as well as the measurements needed to test various dynamical mechanisms for this reaction [64].

4. Symmetries and polarization

Three papers written during the past year pertain to this heading. Two of them [66, 67] explored the constraints of parity conservation and time reversal invariance, respectively, on a four-particle reaction with arbitrary spins. This is helpful in the discussion of specific reactions, since previously one needed

to write out first the polarization structure for the general case of Lorentz invariance only, and then impose the parity constraints for each situation separately.

This work will help in the construction of a computer program to wriute out the polarization structure of an arbitrary reaction, planned for the upcoming grant period.

The third paper pertaining to symmetries [68] is a fruit of collaboration with TRIUMF, and specifically arose from my annual visit (of 10-12 days) to that laboratory. It gives a complete description of all experiments available in neutron-proton scattering in which the validity of charge symmetry can be tested. The optimal formalism permits this to be carried out simply and transparently.

Interaction with other research centers.

As mentioned before, we have continued the interact strongly with other research centers interested in polarization physics. Our results were presented at the Trieste Adriatico conference in January 1988 and at the Minneapolis international spin conference in September 1988, where I was also the rapporteur for one of the sessions. In addition, I visited TRIUMF, CEBAF, as well as a number of research groups in Europe, including the University of Geneve, Milano, Padua, Graz, Julich, and Hannover. At these places I gave lectures and exchanged views with the local researchers.

Much of the work contained in this report continues to be performed with Gary Goldstein at Tufts, and three of them have coauthors from Graz [63], Karlsruhe [59], and Queen Mary College,London [65]. The results of our research continue to be published in numerous papers in the top journals, including letter journals. As mentioned at the outset, the work appears to produce novel enough results and a large enough output to deserve a much better treatment than it has received from DOE in the last 2-3 years.

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(With G.R.Goldstein)
(submitted for publication) (1988)

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(With G.R.Goldstein, L. Mathelitsch, and K. Schwarz)
(1988)

& 64. "Exploring Photoproduction Dynamics Through Polarization Experiments"
(With G.R.Goldstein and F. Arash)
(1988)

& 65. "The Planar-Transverse Amplitude Phase Pattern in Non-Elastic Reactions"
(With G.R.Goldstein, F.Arash, and B.V.Bugg)
(1988)

& 66. "Parity Constraints on the Polarization Structure of Reactions"
(submitted for publication) (1988)

& 67. "Constraints of Time Reversal Invariance in the Polarization Structure of Reactions"
(submitted for publication) (1988)

& 68. "A Complete Formalism for Charge Symmetry Tests in n-p Elastic Scattering"
(With F. Arash) (submitted for publication) (1988)

* Mentioned in last year's annual report and accepted for publication since then

** Mentioned in last year's report and appeared in print since then

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& Written since last year's report and submitted for publication

&& Written since last year's report and appeared in print

D.E. Soper

I had the opportunity this year to spend six months working in the program on QCD and its Applications that took place from January through June at the Institute of Theoretical Physics at Santa Barbara. My research at Santa Barbara and at Oregon concerned QCD and its use in looking for deviations from the standard model in high energy interactions.

1. Treatment of heavy particles as constituents of hadrons

"Ultra-Heavy Particle Production from Heavy Partons at Hadron Colliders," Nucl. Phys. **B306** (1988) 697 ,with R.M. Barnett and H.E. Haber.

In many instances, a heavy particle of mass $m_h \gg 1$ GeV plays a role in a process with a momentum scale Q that is large compared to m_h. An important class of such processes is the production, mediated by the h-particle, of an ultraheavy particle U with a mass $M_U \gg m_h$. (One example from beyond-the-Standard-Model physics is $t\bar{b} \to H^+$ with h = t and U = H^+. Another is $\tilde{g}q \to \tilde{q}$ with h = $\tilde{g}$ and U = $\tilde{q}$.) In such cases, the heavy particle h can be formed inside one of the incoming hadrons on a time scale that is long compared to the time scale $1/M_U$ of the hard interaction. One should thus treat the h particle as a possible constituent of the hadron. However, it is necessary to calculate the distribution function for finding h-particles in the hadron and to calculate the overall process in a consistent fashion so that the same physical process is not counted twice. Work on this project was completed in winter 1987-8 and the paper has now been published.

2. Factorization in the Drell-Yan process

"Soft Gluons and Factorization," Nucl. Phys. **B308**, 833 (1988), with J.C. Collins and G. Sterman.

J. Collins, G. Sterman and I completed a paper in spring 1988 that fills in some gaps in the reasoning used in our paper arguing that factorization works for the Drell-Yan process at all orders in QCD perturbation theory. The problems we confront have to do with the role of soft gluons in this process (and, by extension, other hard processes in hadron collisions.) We returned to this problem because we feel that is important to be sure that the results of standard QCD calculations for hadron collisions are reliable consequences of the basic theory.

3. Jet cross section

"Jet Theory at Santa Barbara," to be published in Proc. XIX International Symposium on Multiparticle Dynamics, Arles, June, 1988.

"The One Jet Inclusive Cross Section at Order α_s^3: Gluons Only," to be published in Proc. XXIV International Conference on High Energy Physics, Munich, August, 1988, with S.D. Ellis and Z. Kunszt.

"The One Jet Inclusive Cross Section at Order α_s^3: Gluons Only," preprint OITS 396, with S.D. Ellis and Z. Kunszt.

Three years ago, R.K. Ellis and Sexton calculated the order α_s corrections to the squared matrix elements for parton + parton $\rightarrow$ parton + parton and the Born level squared matrix elements for parton + parton $\rightarrow$ parton + parton + parton, with divergences controlled by dimensional regularization. This is the basic calculation necessary to compute the order α_s corrections to jet cross sections. It is highly desirable to have these corrections. With them, the experimental measurement of the jet cross section can be a good test of QCD, perhaps enabling us to see a breakdown of the theory at the highest values of the jet transverse momentum. In addition, at lower values of the jet transverse momentum the measurement can provide perhaps the best determination of the distribution of gluons in the proton. Unfortunately, no one has made use of the matrix element calculation to produce a jet cross section. S. Ellis, Z. Kunszt and I are doing so. As part of this project, we provide a definition, adapted for the purpose of using jet physics to test QCD, of what one should mean by a jet as measured in a calorimeter. Another group, Aversa, Chiappetta, Greco, and Guillet, have calculated single particle production using the Ellis et al matrix element and are also applying their calculation to jet production. However, their jet cross section is only valid in the limit of a small jet cone size, while the use of low order perturbation theory for the calculation is only valid for a jet cone size of order 1.

Our work until now has been confined to a simplified problem in which we use QCD with gluons only, without quarks. This problem has all of the essential physics, but is not as complicated from the point of view of organization. We have now completed this phase of the project. The preprint OITS 396 gives results of the calculation. A much longer preprint that we are still working on will explain the method.

4. The pedestal effect

I worked at Santa Barbara with S. Ellis and F. Paige on the so-called pedestal effect, that is, the increased soft hadronic activity associated with hard interaction events. I believe that we, along with Webber and Marchesini, who also worked on the problem, made quite a lot of progress in understanding this issue. I have reported some of this understanding at the Arles multiparticle conference.