DOE/ER/40291--13

DE92 015616

UNUSUAL INITIAL AND FINAL STATE EFFECTS IN QUANTUM CHROMODYNAMICS

Annual Progress Report
for the period July 15, 1991 - December 20, 1991

Charles A. Nelson

Department of Physics
State University of New York at Binghamton
Binghamton, New York 13902-6000

December 1991

Prepared for

THE U.S. DEPARTMENT OF ENERGY
AGREEMENT NO. DE-FG02-86ER40291

Abstract

We have constructed a number of fundamental tests which can be used to probe discrete symmetries, and their possible violations, in the required "new physics" beyond the standard model. On-going experiments with unpolarized $e^- e^+$ collisions contain many events for the production-decay sequence $e^- e^+ \rightarrow Z^o, \gamma^* \rightarrow \tau^- \tau^+ \rightarrow (A^- X) (B^+ X)$. From the beam referenced spin-correlation function for this sequence, the photon and Z^o boson couplings of the tau lepton can be completely measured. There are four distinct tests for CP/T violation in $Z^o \rightarrow \tau^- \tau^+$, and in $\gamma^* \rightarrow \tau^- \tau^+$. The Lorentz structure of the associated helicity amplitudes is very simple. In other research programs, we are (i) continuing to investigate our proposal that partons be identified with nearly degenerate, coherent quark-gluon "jet" states, and are (ii) investigating the novel consequences of q-analogue quantization of quantum fields, and of a completeness relation for the q-analogue coherent states.

Text

During the past year, most of our research effort has been on constructing symmetry tests from generalized spin correlation functions for the production-decay sequence $e^- e^+ \rightarrow Z^o, \gamma^* \rightarrow \tau^- \tau^+ \rightarrow (A^- X) (B^+ X)$. This concentration has produced the results reported in the publications listed at the end of this "Annual Performance Report." These proposed electroweak tests are particularly relevant to several on-going experiments at the Z^o boson at the CERN $e^- e^+$ collider LEP and to experiments in the 10-GeV region by the ARGUS and CLEO-II collaborations. These tests enable a complete measurement of the photon and Z^o-boson couplings of the tau lepton. Our decision to concentrate much of our past year's effort on this subject, appears to us, to have been sound. Some of our research time has been spent on other topics, particularly on QCD projects and on the physical implications of the q-analogue harmonic oscillator and of an associated completeness relation for the q-analogue of the usual coherent states.

A. CONSTRUCTION OF FUNDAMENTAL DISCRETE SYMMETRY TESTS FOR NEW PHYSICS

The $\phi\phi$ parity test proposed by Chang and myself in 1978, as an analogue of C.N. Yang's parity test, was used by the Mark III group at SLAC-SPEAR to experimentally determine the parity of the η_c (2980) meson [Phys. Rev. Lett. 52, 2126 (1984)] and to show that the $\omega\omega$ mass distribution peak at about 1.8 GeV in $J/\psi \rightarrow \gamma\omega\omega$ is predominantly pseudoscalar [Phys. Rev. Lett. 55, 1723 (1985)]. The technique was generalized by ourselves in 1984 and by other authors as tool in searching for and establishing the CP eigenvalue of a technipion/Higgs via the Z pair or the W pair decay mode (or the $\tau^- \tau^+$ mode) at a large hadron collider such as the SSC. [J. Phys. (France) Colloq. 46, C2 (1985); Phys. Rev. D33, 93 (1986); Nuc. Phys. B320, 61 (1989)].

In 1984 we also showed that the spin-correlation technique can be used to demonstrate and analyze CP violation in $X \rightarrow S_1 S_2$ sequential decays [Phys. Rev. D30, 1937 (1984)]. Recently

several physicists have further developed this technique for the study of the B^o or $\bar{B}^o \rightarrow \psi + K_+^*$ process at a b-factory [See, for example, Dunietz, et.al., Phys. Rev. D43, 2193 (1991)].

Construction of Electroweak Symmetry Tests for $e^- e^+$ Collisions:

We are currently further developing several techniques for measuring electroweak coupling parameters from beam-referenced τ spin correlation functions in $e^- e^+$ collisions. Previously we showed [Phys. Rev. Lett. 62, 1347 (1989); Phys. Rev. D40, 123 (1989); D41, 2327(E)] that measurement of the energy correlation function $I(E_A, E_B)$ for $Z^o \rightarrow \tau_1^- \tau_2^+ \rightarrow A^- B^+ X$ determines independently the fundamental parameters $\sin^2\theta_W$, the tau Michel parameters, and for hadronic tau decays the analogous "chirality parameter" ξ_A which tests for right-handed currents. Similar tests follow for a center of mass energy, e.g. 10 or 4 GeV, where an off-shell photon dominates.

The publications listed below report on the new tests and the new information about tau couplings which can be obtained by including the direction of the e^- beam relative to the final A^- and B^+ momentum directions in the Z^o (or γ^*) rest frame. In principal, from the resulting "beam-referenced spin-correlation function" (BRSC) the photon and Z^o boson couplings of the tau lepton can be completely measured: A major result is four distinct tests for CP/T violation at the Z^o or γ^* vertex, depending on the value of $E_{cm} = \sqrt{s}$. Nine measurable (slashed/primed) vertex intensity parameters are useful signatures for CP/T violation respectively. Should such signature(s) be discovered, vertex intensity relations can be used as a check and to characterize the effect in terms of the polar parametrization of the $Z^o \rightarrow \tau^- \tau^+$ or $\gamma^* \rightarrow \tau^- \tau^+$ helicity amplitudes. The Lorentz structure of these helicity amplitudes is very simple and is given in the Vancouver paper.

The standard model contributions simulating T violation from the interference of the Z^o and γ^* amplitudes are found to be small. Interference of the γ^* and indirect quarkonium amplitudes does not simulate T violation. At the Z^o, the T violation-like contribution from the 1-loop electroweak (τ - Z^o - τ) vertex correction is also found to be small. If $\kappa' \neq 0$ is found at LEP, it would signal new

physics; $\kappa' = 2\,\mathrm{Im}\,[T(+\,-)\,T(-\,+)]/\mathcal{N}$ where $\mathcal{N} = \Sigma|T|^2$.

From statistical error analysis for A and B = π, ρ, one concludes that in practice from 10^7 Z^o events the moduli of the $Z^o \rightarrow \tau^- \tau^+$ helicity-conserving neutral-current amplitudes $|T(-\,+)|$ and $|T(+\,-)|$ can be measured to the 1% level (ideal statistical error), and their relative phase β_{+-} to the 3° level. Unless experimental surprises occur, the helicity-changing neutral-current amplitudes T(++) and T(- -) will not be measured by this technique ($\Delta|T(-\,-)|/T(-\,-)| = 6$). From 10^7 $\tau^- \tau^+$ events at $\sqrt{s}$ = 10 GeV, the modulus $|t(-\,+)| = |t(+\,-)|$ for $\gamma^* \rightarrow \tau^- \tau^+$ can be measured to the 0.5% level and their relative phase B_{+-} to 0.5°; the modulus $|t(++)| = |t(-\,-)|$ to 1% and their relative phase B_{++} to 4°; and the remaining relative phase β_o to 1°. Similar $\gamma^* \rightarrow \tau^- \tau^+$ ideal statistical error levels are found for a τ/charm factory ($s \sim 4^\circ$ GeV).

Most of the Z^o, and γ^*, decay intensity parameters can be well measured from fewer-variable angular distributions such as in the use of the azimuthal correlation function $I(\phi_e, \phi)$ to measure the phase difference β_{+-} (i.e. κ') of the helicity-conserving amplitudes. The analytic distributions for $I(\phi_e, \phi)$ in the standard model limit have been compared by us with those generated by the tau pair Monte Carlo simulation KORALB. The results agree, which provides a nontrivial check of both methods.

A masters student, Stephen Goozovat, contributed significantly in various phases of this project over the last two years. Five undergraduate students participated in the research during the spring term and summer of 1991. Their participation was particularly helpful in getting the Monte Carlo simulation KORALB operational and in using it to check our analytic results in the standard model limit. Both for the research accomplished and for the educational experience of the undergraduates, I would like to be able to continue such undergraduate research participation in future summers.

B. q-ANALOGUE SYMMETRY STRUCTURES

Partially as an outgrowth of our work on the usage of coherent quark-gluon "jet" states in QCD, we have investigated some properties of the q-analogue of the usual coherent states. These states can be constructed using the q-oscillator realization of quantum groups. In 1990 with a masters student, Robert Gray, we used q-integration to prove a completeness relation for these states. [Lett. to Editor, J. Phys. A: 22, L945 (1990)].

Tests for the possibility of unusual statistics in fundamental physics has remained somewhat poorly developed. [See, e.g., Sec. VI-5, in Particle Data Group Review, Phys. Lett. B239, 1(1990)]. In part for this reason in the past year we decided to study the consequences of a q-oscillator structure for the quantized radiation field in the "classical limit." The usage of the usual quasi-classical coherent states in the physical description of quantum optics phenomena, and other bosonic cooperative phenomena, is generally accepted by the scientific community. But, surprising to us, this has not been a subject studied by physicists interested in better understanding unusual statistics in fundamental physics.

Joined by another masters student, Alan Chiu, we are investigating the "classical limit" of the q-analogue quantized radiation field. We have shown that results for the number-phase uncertainty relations can be q-independent in the number basis. The variance of the generic electric field is found to be $\geq \lambda \dfrac{\hbar\omega}{2\varepsilon_0 V}$, where $\lambda > 1$ if $q \neq 1$. At large amplitudes, the amplitude itself would be quantized if the available resolution of unity for the q-analogue coherent states is accepted in the formulation. The properties of the q-analogue coherent states, and of the associated q-analogue quantized field, is definitely novel.

While this remains, to us, an exploratory investigation, some further work is warranted because of the mathematical definiteness of the fundamental ideas, because of the tractability of the necessary analysis, and because of the novel features of the testable physical consequences.

Remarks:

(i) Importance of travel support:

During the past year, the travel budget has been very useful to our research for it has enabled us to consult with other physicists and visitors at Cornell University, and in August at Argonne and at the DPF Meeting at Vancouver. Associated discussions and electronic-mail exchanges with CLEO-II experimentalists and with LEP experimentalists have been particularly valuable to our work on tests for tau lepton couplings.

(ii) Upgrading of office computer system:

With funds from the current budget, I have purchased a 486/33C Gateway 2000 and it is now operating in my office. The Mathematica software package MS-DOS 386/7 version has been installed. Yet to arrive are the Hewlett-Packard Desk Jet 500 printer, and the Intel FAX/modem board. This upgrading is very important for our future research programs.

Time Committed to Project:

The principal investigator committed 100% of his time to the project from July 15, 1991 through August 26, 1991. From August 26, 1991 until May 22, 1992, he will commit about 40% of his time. He expects to contribute 100% of his time from May 22 through July 14, 1992.

Seminars Presented:

I presented a talk entitled "Tests of Tau Couplings" at the Division of Particles and Fields Meeting of 1991 which was held at Vancouver, Canada in August. A written version will appear in the proceedings.

In October, I presented a high energy seminar at Cornell on some of the new tests for tau couplings which we have developed. The emphasis was on the more recent tests (the publications listed below, and work-in-progress).

Publications to Date: (3 reprints of each submitted previously to DOE)

1. Test for "Maximal P, Maximal C" violation in $e^- e^+$ Collisions from Beam-Referenced Spin-Correlation functions, Phys. Rev. D43, 1465 (1991).
2. Four Distinct Tests for CP/T Violation in $e^- e^+ \rightarrow \tau^- \tau^+$, with S. Goozovat, Phys. Lett. B267, 128 (1991).
3. Tests to Completely Measure the Photon and Z^o-Boson Couplings of the τ Lepton, with S. Goozovat, Phys. Rev. D44, 2818 (1991).
4. Tests of Tau Couplings, with S. Goozovat, Proceedings of Division of Particles and Fields Meeting of 1991, Vancouver, Canada (to appear).

Preprints to Date: (1 copy submitted previously to DOE)

1. The q-Analogue Quantized Radiation field and Its Uncertainty Relations, with S.-H. Chiu and R.W. Gray, SUNY BING 7/29/91.

Masters Theses:

1. Stephen Goozovat, "The Forward-Backward Asymmetry of $e^+ e^- \rightarrow \tau^- \tau^+$ at the Z^o, "Masters Thesis, January 1991.
2. Shao-Hsuan Chiu, "Uncertainty Relations for the q-Analogue Quantized Field," Masters Thesis (May 1992, expected).
3. Joseph Willie, "Tests of Top Quark couplings," Masters Thesis (January 1993, expected).

END

DATE FILMED

8/11/92