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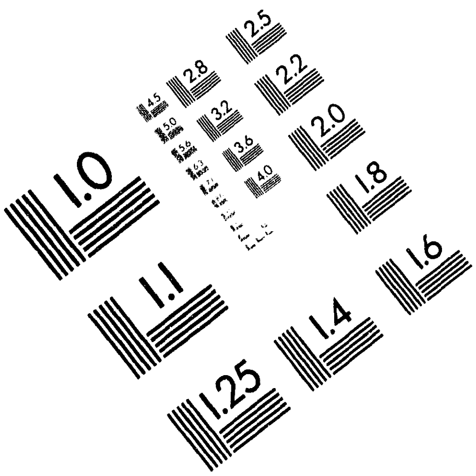

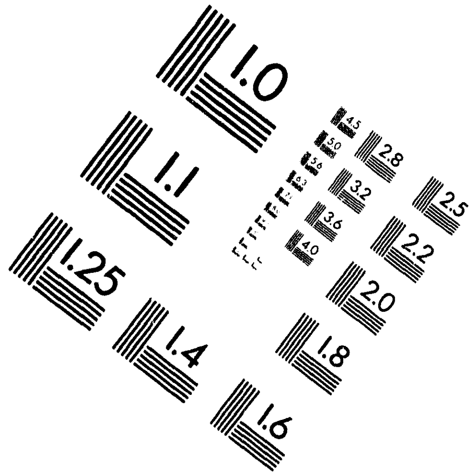

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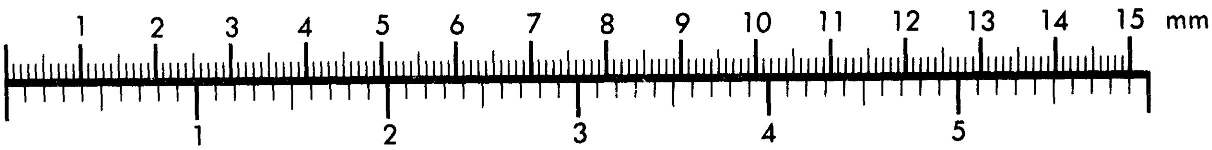

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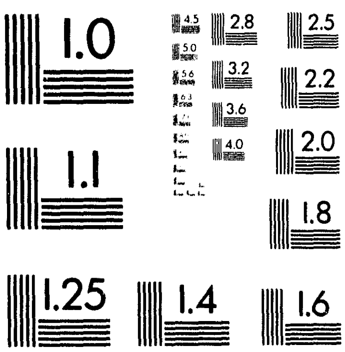

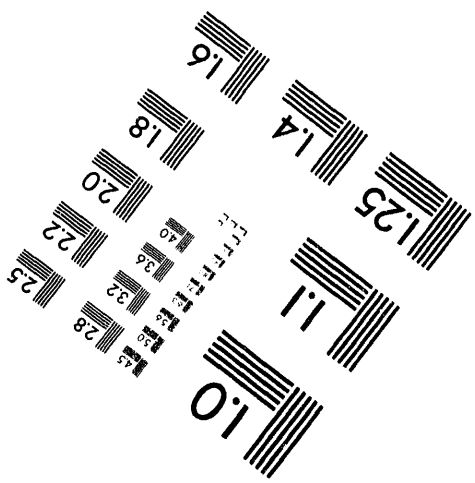

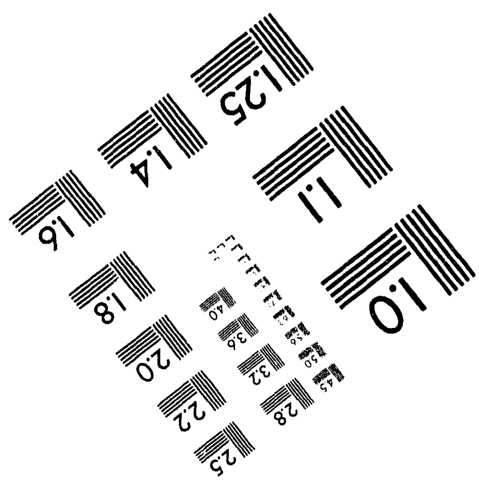

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UNUSUAL INITIAL AND FINAL STATE EFFECTS IN QUANTUM CHROMODYNAMICS

Annual Progress Report
for the period December 18, 1992 - December 20, 1993

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DISCLAIMER

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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 $e^- e^+ \rightarrow Z^o, \gamma^* \rightarrow \tau^- \tau^+ \rightarrow (A^- X) (B^+ X)$. By inclusion of ρ polarimetry observables such experiments enable two distinct tests for leptonic CP violation in $\tau \rightarrow \rho \nu$ decay (similarly in $\tau \rightarrow a_1 \nu$ decay) by generalization of the energy correlation function for Z^o, or $\gamma^* \rightarrow \tau^- \tau^+ \rightarrow (\rho^- \nu) (\rho^+ \overline{\nu})$. 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 the possible existence of q-bosons and of a related completeness relation for the q-analogue coherent states. This year we have also written papers on the zeros of the q-analogue exponential function, and on the number and phase uncertainties of the q-analogue quantized field.

Since December of 1992, we have written 3 long papers, 1 short paper, and 1 medium-length conference review paper. The latter, which will appear in a proceedings, discusses our research on the coherent state approach to QCD and on our other research on the physical properties of the q-boson quantum field. All the papers are being submitted for publication (see list at the end of this report).

During the past year, a major part of our research effort has been on constructing symmetry tests from generalized spin correlation functions for the production-decay sequence $e^- e^+ \rightarrow Z^o, \gamma^* \rightarrow \tau^- \tau^+ \rightarrow (A^- X) (B^+ X)$. 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. There are two tests for non-CKM-type leptonic CP violation in $\tau \rightarrow \rho\nu$ decay by inclusion of ρ polarimetry observables in the energy correlation function for Z^o, or $\gamma^* \rightarrow \tau^-\tau^+ \rightarrow (\rho^- \nu) (\rho^+ \bar{\nu})$. Some of our research time has been spent on other topics, particularly on QCD projects and on the physical implications of the possible existence of q-bosons 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

We are currently further developing several techniques for measuring electroweak coupling parameters from 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.

In October of 1993, the ALEPH collaboration at LEP [CERN-PPE/93-181] reported a measurement of ξ_π and ξ_ρ by the above energy correlation function $I(E_A, E_B)$. The measured values, $\xi_\pi = -0.95 \pm 0.11 \pm 0.05$ and $\xi_\rho = -1.03 \pm 0.11 \pm 0.05$, agree with the $\xi = -1$ prediction for the Standard Model. This method has also been applied to measure ξ_π from CLEO-II data by Jun Masui who is a graduate student working under R. Galik [A.P.S. Meeting, Washington D.C., April 1993].

In May of 1993, we were contacted via e-mail by Z. Waz at CERN concerning an error in the KORALB Monte Carlo program which had been found by Holger Thurn of the ARGUS collaboration at DESY. We accordingly re-investigated our reported test of KORALB [see Phys. Rev. D44, 2818 (1991)] and found that our earlier check of KORALB was not sensitive to this error. This fact was included by S. Jadach and Z. Waz in their "Update on KORALB" from CERN in June 1993. In it they explain the error and how to correct KORALB.

In 1984 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 Tevatron or LHC. [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)].

In 1989, we extended some of this work to top quark physics. W polarimetry information from $W \rightarrow \bar{\ell} \nu$ can be used to test for possible CP violation in top quark decay $t \rightarrow W\, b$ arising from a $t\bar{t}$ production process. Examples of useful analogies between τ polarimetry and t polarimetry tests are in C.A. Nelson, Phys. Rev. D41, 2805 (1990).

In 1990-1993 we investigated what new information about tau couplings 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. [Phys. Rev. D43, 1469 (1991); D44, 2818 (1991); Phys. Letts. B267, 128 (1991)]. In principle, 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.

CP Violation in Tau Decay Amplitudes:

From (1991 - to present) we have investigated possible tests for CP violation in $\tau \rightarrow \rho \nu$ and in $\tau \rightarrow a_1 \nu$ decay. Since the ρ mode has the largest branching ratio, $B(\tau \rightarrow \rho\, \nu) \approx 25\%$, on-going experiments with unpolarized $e^-\, e^+$ collisions contain many events for the production-decay sequence.

$$e^-\, e^+ \rightarrow Z^o,\ \gamma^* \rightarrow (\rho^-\, \nu_\tau)\, (B^+\, X)$$

where $B = \rho,\ \pi,\ \mu,$ e and $X = \bar{\nu}_\tau$ or $\bar{\nu}_\tau\, \nu_\ell$, and for the CP-conjugate sequence. In August we wrote a long paper reporting our results [SUNY BING 8/16/93].

There are two tests for leptonic CP violation in $\tau \rightarrow \rho\nu$ decay by inclusion of ρ polarimetry observables in the energy correlation function for Z^o or $\gamma^* \rightarrow \tau^-\tau^+ \rightarrow (\rho^- \nu)(\rho^+ \bar{\nu})$. By CP invariance the moduli ratio of, and phase difference between, the two helicity amplitudes for $\tau^- \rightarrow \rho^- \nu_\tau$ decay should equal those for $\tau^+ \rightarrow \rho^+ \bar{\nu}_\tau$ decay. The full angular distribution for the above process, including the $\pi^{\mp}$ momentum direction versus that of the $\rho^{\mp}$ momentum, can be used to test for such a non-CKM-type leptonic CP violation in $\tau \rightarrow \rho\nu$ decay. Since this adds on spin-correlation information from the next stage of decays in the decay sequence, we call such an energy-angular distribution a "Stage 2 Spin-Correlation" function (S2SC). Ideal statistical errors for $\tau \rightarrow \rho\nu$ decay are calculated for possible application at the Z^o, at a B factory, or at the τ-charm threshold. S2SC's should be useful for testing for possible non-CKM-type CP violation in top quark and in W boson decay processes.

A recent masters student Hui-Chun Yang has extended part of the above calculation to the $\tau \rightarrow a_1\nu$ decay mode.

A masters student, Stephen Goozovat, contributed significantly in various phases of the $\tau \rightarrow \rho\nu$ project. 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. [Three are now in graduate programs in physics (at the University of Pennsylvania, Cornell and City College]. 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. PHYSICAL IMPLICATIONS OF QUANTUM GROUP SYMMETRIES

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)]. Joined by another masters student, Alan Chiu, we began investigating the "classical limit" of the q-analogue quantized radiation field. [Phys. Lett. A164, 237 (1992)] The usual quasi-classical coherent states characterize cooperative behavior in the q=1 case so it is reasonable to use the $|z\rangle_q$ coherent states to investigate the consequences of the possible existence of q-bosons in nature.

In 1993 we have written two long papers in this area. In December we completed a paper on the "Number and Phase Uncertainties of the q-Analogue Quantized Field." It is with M. Fields, a former student who is now doing graduate work in physics at Yale. We use the q-analogue coherent states $|z\rangle_q$, to identify some of the canonical physical properties of the single-mode q-analogue quantized radiation field in the $|z\rangle_q$ "classical limit" where $|z|$ is large. In this quantum-optics-like limit, the fractional uncertainties of most physical quantities (momentum, position, amplitude, phase) which characterize the quantum field are shown to be O(1), and only vanish as O(1/|z|) when $q = 1$. In contrast to this more-quantum-like behavior for $q \neq 1$, the fractional uncertainties do still approach zero for the usual number operator, N, and the N-Hamiltonian $H_N \equiv \hbar\omega\,(N + 1/2)$ which describes a free q-boson gas. An empirical signature for q-boson counting statistics is that $(\Delta N)^2/\langle N\rangle \rightarrow 0$ as $|z| \rightarrow \infty$. Properties of the q-analogue generalizations of the approximate phase operators of Susskind-Glogower and of the approximate phase operator $\hat{\phi}_q$ of Pegg-Barnett are investigated. In contrast to the SG operators for moderate $|z|^2$, the "Hermitian" phase operator $\hat{\phi}_q$ still exhibits normal classical behavior in the $|z\rangle_q$ basis. In particular, the conventional (approximate) number-phase uncertainty-relation, $\Delta N \Delta\hat{\phi}_q \geq 1/2$, and approximate commutation relation of Dirac, $[N, \hat{\phi}_q] = i$, are found to

follow for the single-mode q-analogue quantized field. So, N and $\hat{\phi}_q$ are almost canonically conjugate operators in the $|z>_q$ classical limit. The $|z>_q$ CS's minimize this uncertainty relation for moderate $|z|^2$.

In June we wrote a mathematical-physics paper on the zeros of the q-analogue exponential function. It is with M.G. Gartley, who is a junior in physics. Some arguments in an earlier version of the preprint have been improved (and will appear in the published version) because of discussions with Cosmas Zachos (during our visit to Argonne) and with Robert F. Riley in the Mathematics Department here at SUNY Binghamton. We obtain asymptotic formulas for the zeros, z_n, of the entire function $e_q(x)$ for $q << 1$ and for those of its derivatives and indefinite integrals. As q increases above the first collision point at $q_1^* \approx 0.14$, these zeros of $e_q(x)$ collide in pairs and then move off into the complex z plane. They move off as (and remain) a complex conjugate pair. The zeros of the ordinary higher derivatives and of the ordinary indefinite integrals of $e_q(x)$ vary with q in a similar manner. Properties of $e_q(z)$ for z complex and for arbitrary q are deduced. For $0 \leq q < 1$, $e_q(z)$ is shown to be an entire function of order 0. By the Hadamard-Weiserstrass factorization theorem, infinite product representations are obtained for $e_q(z)$ and for the inverse function $e_q^{-1}(z)$. If $q \neq 1$, the zeros satisfy the sum rule $\sum_{n=1}^{\infty} (1/z_n) = -1$. The $e_q(z)$ function frequently appears in the current literature on quantum algebras. Knowledge of the simple properties of e_q, and of the inverse function $e_q^{-1}(z)$, for z complex and for arbitrary q should be useful to formal investigations, to applications of q-symmetries, and to other applications of the $e_q(z)$ function in physics.

C. VISIT OF PROFESSOR ZURONG YU

Because of my on-going research on the physical implications of quantum group symmetries, Professor Zurong Yu visited SUNY Binghamton for about 8 months

(mid-April to early October, 1993). He is in the Department of Physics, Tongji University, Shanghai, China. He has a number of publications in nuclear physics, and on irreducible representations and Clebsch-Gordon coefficients for quantum groups.

While here, he completed 3 papers which have been submitted for publication. We collaborated on one of the papers:

(*i*) q-Deformation of the Pairing Model in a Single j Shell, submitted to Physics Letters B (1993).

(*ii*) Tensor-like Operator and Their Applications to the $su_q(2/1)$ Algebra, submitted to J. of Physics A (1993).

(*iii*) On the Coherent States and the Squeezed States, with C.A. Nelson, submitted as a Letter to Editor, J. Phys. A. [SUNY BING 6/1/93].

In our collaborative paper we report on a new "projector" definition of the usual coherent states and of the squeezed states. For instance, the CS's can be defined using a "projector" operator

$$P = \sum_n \frac{(-1)^n b^{\dagger n} b^n}{n!}$$

to transform the old vacuum state $|0\rangle = |0\rangle_a$ into a new vacuum state $|0\rangle_b$, where $b|0\rangle_b = 0$ with $b = a - z$. Explicitly, $P|0\rangle_a = |0\rangle_b = e^{-|z|^2} e^{za^\dagger} |0\rangle$. Similarly the usual "squeezed vacuum state" $S(\alpha)|0\rangle$, and the usual "coherent squeezed state" $|z, \alpha\rangle \equiv D(z) S(\alpha)|0\rangle$ can be defined using projectors. This procedure may be useful in future applications of CS's to physical phenomena.

Remarks

(*i*) ***Importance of travel support:***

During the past year, the travel budget has been very useful to our research. We attended and consulted with other physicists at the "International Conference on Coherent

States" (Oak Ridge, TN) and at the "16th International Symposium on Lepton and Photon Interactions" (Cornell U.). In addition, besides our regular visits for theory and experimental seminars at Cornell, we visited the Theory Group of the High Energy Physics Division at Argonne for four weeks in July - August. While at Argonne, we attended some of the sessions of two separate workshops on "QCD, Nuclear Physics & High Energy Physics" which were held at Fermilab and at Argonne (in the Nuclear Physics Division). Discussions and electronic-mail exchanges with CLEO-II and ARGUS experimentalists, and with LEP theorists and experimentalists have been particularly useful to our work on tests for tau lepton couplings.

In February, I will attend the IFT Workshop on "Yukawa Couplings and the Origins of Mass" (University of Florida, Gainesville). In March, I will present a talk on "q-analogues of harmonic oscillators and possible applications in quantum optics, field theory and high energy physics" at the Harmonic Oscillators II Meeting (Cocoyoc, Mexico). In March, I will attend the La Thuile meeting on "Results and Perspectives in Particle Physics." I have submitted a request to the organizers to present a talk on my work on spin-correlation tests for tau lepton couplings.

(*ii*) ***Upgrading of computer system:***

With funds from the current budget, I have purchased a Texas Instruments laptop computer with modem board, and an IBM portable printer. On it are installed a Mathematica software package, the latest MS-DOS upgrade, and the upgraded Scientific-WORD software. The laptop system was used last summer while I was at Argonne. I expect to use this system while away during future summers and while on sabbatical leave (Sept. '94 to May '95).

For our office computer system, this Spring we plan to purchase a laser printer with "postscript" driver so as to more simply and reliably print preprint figures from electronic

bulletin boards. This computer upgrading and development of bulletin-board usage software will continue to take some of our time, but it is important for our future research programs.

Time Committed to Project:

The principal investigator committed 100% of his time to the project from July 15, 1993 through August 16, 1993. From August 28, 1993 until May 17, 1993, he will commit about 40% of his time. He expects to contribute 100% of his time from May 16, through July 14, 1993.

Publication and Invited Talk: (3 copies previously submitted to DOE)

"Asymptotic Coherence of Gluons and of q-Bosons," International Conference on Coherent States, June 1993 [to appear in the proceedings, and SUNY BING 7/15/93].

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

1. Stage 2 Spin-Correlation Functions: Tests for Non-CKM Type Leptonic CP Violation in $\tau \rightarrow \rho\nu$ Decay, with H.S. Friedman, S. Goozovat, J.A. Klein, L.R. Kneller, W.J. Perry, and S.A. Ustin, submitted to Phys. Rev. D. [SUNY BING 8/16/93].
2. On the Coherent States and the Squeezed States, with Zurong Yu, submitted as a Letter to Editor, J. Phys. A. [SUNY BING 6/16/93].
3. On the Zeros of the q-Analogue Exponential Function, with M. Gartley, submitted to J. Phys. A [SUNY BING 6/16/93].

December 1993 Preprint: (Being typed; 1 copy to be submitted to DOE in January 1994)

Number and Phase Uncertainties of the q-Analogue Quantized Field, with M.H. Fields,

submitted to Phys. Rev. A [SUNY BING 12/15/93].

Masters Theses:

1. Ming-Hsun Yang, "Density Matrices for Top Quark Processes," Masters Thesis (May 1993).
2. Hui-Chun Yang, "Spin Correlation Test for Tau Lepton Decay," Masters Thesis (May 1993).
3. Minseob Kim, "Simple Empirical Tests for CP Violation in $\tau \rightarrow \rho\nu$ and $\tau \rightarrow a_1\nu$ Decay," Masters Thesis (May 1995, expected).

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