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Progress Report

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University of Massachusetts

Principal Investigators:

Stanley S. Hertzbach
Richard R. Kofler

Calendar Year 1993

Synopsis

The High Energy Physics group at the University of Massachusetts has continued its' program of experimental studies of electron-positron interactions at the Stanford Linear Accelerator Center (SLAC). The group activities have included: analysis of data taken between 1982 and 1990 with the TPC detector at the PEP facility, continuing data collection and data analysis using the SLC/SLD facility, planning for the newly approved B-factory at SLAC, and participation in design studies for future high energy linear colliders. This report will briefly summarize these activities.

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PROGRESS REPORT

Group Personnel

Faculty:

Richard R. Kofler. Prof Kofler has been associated with SLAC physics projects since 1979 when he spent a full year sabbatical at LBL working on the TPC project, followed by a 2 year leave of absence from the University in order to help complete the implementation of the TPC at PEP. Prof Kofler continues to work on TPC data analysis, along with a participation in the SLD project and a beginning participation in the B-factory at SLAC. He is co-spokesman of the TPC collaboration, along with Mike Ronan from LBL and he is an elected member of the SLAC Users Organization (SLUO) Executive Committee.

Stanley S. Hertzbach. Prof Hertzbach joined the group in 1986 when he spent a full year sabbatical at SLAC working on SLD design studies. He has played a major role in the design and implementation of SLD beamline elements, including beampipe, masking, and precision wire movers. He is a member of the SLD Advisory Group and he represents UMass on the SLD collaboration Council. His other activities include a participation in design studies for future linear colliders and a participant in the recent B-factory Workshop at SLAC.

Professors Hertzbach and Kofler both spend a full semester and summer at SLAC through an arrangement at UMass which allows a double teaching assignment for one semester of the academic year, with no teaching assignment for the remaining semester. Thus, Prof. Hertzbach spends the summer and fall semester at SLAC, and Prof. Kofler spends the spring semester and summer at SLAC. This full-time faculty presence at SLAC allows a contribution to the SLAC program that is larger than the size of the group might suggest.

Post Doctoral Research Associate:

Michael Strauss. Mike Strauss joined the group in the summer of 1988 and resides in the Stanford Area. He has been and continues to be the primary contributor to all areas of software for the SLD vertex detector as well as one of the more active members of the QCD and B-physics analysis groups.

Graduate Students:

Richard Belcinski. Richard has been with the group and resident at SLAC since 1987. He has participated in both the TPC and SLD projects and is finishing his Ph.D. thesis research topic: an analysis of the photon structure function using a sample of "doubly tagged" 2 photon interaction events from the TPC data set.

Ed Eckel. Ed spent the summer of 1993 at SLAC working on computer simulations of backgrounds in the SLD detector. He has expressed an interest in joining the group in 1994 after he passes his Ph.D. qualifying exams at the University of Massachusetts in Amherst.

TPC PROJECT

When the 1991 TPC data run was cancelled in November of 1990 for lack of adequate resources to run both PEP and the SLC, the collaboration decided not to request further data taking and has concentrated on completing the analysis of the full data sample (a total of 200 pb^{-1} , including 50 pb^{-1} with a "straw chamber" vertex detector). The analysis is centered at LBL (for the annihilation data set) and at SLAC (for the 2 photon interaction data set). The collaboration published the following paper in 1993:

"STUDY OF χ_{C2} PRODUCTION IN PHOTON-PHOTON COLLISIONS." Phys. Lett. B 302:345-350, 1993, and SLAC-PUB-5949, Oct 1992. 19pp. By the TPC/Two-Gamma Collaboration (D. Bauer, et al.)

Additional analysis projects, brought to completion in 1993, have been submitted for publication:

"EVIDENCE FOR SPIN ONE RESONANCE PRODUCTION IN THE REACTION $\gamma \gamma^* \rightarrow \pi^+ \pi^- \pi^0 \pi^0$." *Accepted* for publication in Phys. Rev D

"MEASUREMENT OF THE KAON CONTENT OF THREE PRONG TAU DECAYS." *Submitted* for Publication in Phys. Rev. Letters

There are a number of analysis projects which received attention this year at both locations and which are expected to lead to publication in the near future. These include:

"A STUDY OF TWO-PHOTON PRODUCTION OF RHO-OMEGA IN E^+E^- INTERACTIONS", being prepared for publication in Physical Review Letters.

"JET PRODUCTION IN PHOTON-PHOTON INTERACTIONS AT PEP", being prepared for publication in Physical Review D

"A MEASUREMENT OF THE PHOTON STRUCTURE FUNCTION IN DOUBLE TAGGED $\gamma \gamma$ INTERACTIONS" being prepared for publication in Physical Review Letters.

The last 2 of these analysis projects are solely UMass projects. The Jet Production analysis has been described in a previous progress report; the analysis is being updated with comparison of the data to a recent model of Drees and Godbole in which they calculate QCD predictions for jet production in photon-photon collisions. The photon structure function measurement, Belcinski's Ph.D. project, has proceeded rapidly and preliminary results are now mature enough so that he has successfully passed his oral thesis defense. He is putting the final touches on the written thesis and will prepare the results for publication early in 1994. His measurement of the structure function uses the "doubly tagged" 2 photon data sample and is made in two separate kinematic regions. The first result has only one other result reported in the literature, a measurement by the Pluto collaboration at PETRA. Our measurement uses a data sample that is more than twice the size of the PLUTO analysis and has a Q^2 measurement accuracy that is far superior, due to the NaI tagging calorimeter in the TPC detector. Our PRELIMINARY RESULTS are shown in Figures 1 and 2 below.

Figure 1

Photon Structure Function, F/α , in the kinematic range defined by the variables:

$$0.04 < P^2 < 1.40$$

$$1.50 < Q^2 < 5.50$$

where: P = the 4-momentum of the "target photon" in GeV^2 ;

and Q = the 4-momentum of the "probing photon" in GeV^2 ;

The data are shown with error bars. The curves are model calculations with massless quarks (solid and dotted lines) and massive quarks (dashed line). The model calculations assume a parameterized Vector Dominance (VDM) contribution along with a Quark Parton (QPM) contribution. This measurement is consistent with the PLUTO measurement, but with the increased precision alluded to above. The second measurement uses a data sample with a "probing photon" of higher Q^2 (larger angle) and is a first measurement in this kinematic region. The result is shown in Figure 2 below:

Figure 2

Photon Structure Function, F/α , in the kinematic range defined by the variables:

$$0.04 < P^2 < 1.40$$

$$10.0 < Q^2 < 50.0$$

This second result, although the statistics are limited, is most intriguing, since the measurement gives values for the structure function which are substantially larger than predicted by the models. We have looked hard for sources of error and/or backgrounds, but have, so far, found neither. The agreement of our lower Q^2 result with the PLUTO measurement as well as the theoretical models also gives added credence to our analysis techniques. We are continuing to pursue our re-examination of this result and hope to finish early in 1994 with publication to follow shortly after that. The TPC project is expected to be completed by the end of 1994.

SLD PROJECT

Following a successful data run in 1992, the SLD collaboration has published its first analysis result during 1993, based on the data sample which contained 10,000 events with the electron polarization $\sim 20\%$:

"FIRST MEASUREMENT OF THE LEFT-RIGHT CROSS SECTION ASYMMETRY IN Z BOSON PRODUCTION BY E^+E^- COLLISIONS." Phys. Rev. Lett. 70 (1993), 2515-2520

"FIRST MEASUREMENT OF THE LEFT-RIGHT ASYMMETRY IN Z BOSON PRODUCTION." Mod. Phys. Lett. A8 (1993), 2237-2248.

These papers report a determination of the Left-Right asymmetry in Z^0 decays:

$$A_{LR} = 0.10 \pm 0.044 \pm 0.004$$

With reasonable assumptions, this result determines a value for the weak mixing angle:

$$\sin^2\theta_w = 0.237 \pm 0.006 \pm 0.004$$

Another data analysis result, a determination of the QCD parameter, α_s , has been submitted for publication:

"A MEASUREMENT OF ALPHA-S FROM JET RATES AT THE Z^0 RESONANCE.",
Submitted to Physical Review Letters, (SLAC-PUB-6133, Jul 1993, 18pp.)

Additional analysis results from the 1992 data sample have been reported at conferences and recorded in the SLAC PUB notes:

"STUDIES OF QCD B PHYSICS AND JET HANDEDNESS AT SLD.", Presented at Rencontre de Moriond, QCD and High-Energy Hadronic Interactions, Les Arcs, France, Mar 20-27, 1993., (SLAC-PUB-6225, Jun 1993, 12pp.)

"SLD RESULTS FROM THE STUDY OF POLARIZED Z^0 PRODUCED AT THE SLC.", Presented at Rencontres de la Valle d'Aoste, La Thuile, Italy, Mar 7-10, 1993., (SLAC-PUB-6285, Jul 1993, 18pp.)

"A STUDY OF JET HANDEDNESS AT THE Z^0 RESONANCE.", Submitted to Int. Europhysics Conf. on High Energy Physics, Marseille, France, Jul 22-28, 1993., (SLAC-PUB-6362, Oct 1993, 3pp.)

"A MEASUREMENT OF $R(B) = \text{GAMMA}(Z^0 \rightarrow B \text{ ANTI-B}) / \text{GAMMA}(Z^0 \rightarrow \text{HADRONS})$ AT SLD.", Submitted to Int. Symp. on Lepton - Photon Interactions, Ithaca, NY, Aug 10-15, 1993., (SLAC-PUB-6292, Sep 1993, 10pp.)

The goals for the 1993 SLC/SLD data run were the accumulation of a data sample in excess of 50,000 events at the Z^0 peak, and electron beam polarization reliably in excess of 40 %. The luminosity goal was easily reached, and the beam polarization was maintained at levels in excess of 60% throughout the run. These performances, shown graphically in Figures 3 and 4, represent a major accomplishment for the SLC physics and operations staff. Since asymmetry measurements have a statistical significance proportional to polarization squared, the polarization goal was, in effect, exceeded by a factor of 2.

Figure 3
SLC Luminosity and Integrated Luminosity for the 1991, 1992, and 1993 Data Runs

Figure 4
Electron Beam Polarization History for the 1992 and 1993 Data Runs

The UMass group participated in the 1993 SLC/SLD physics run, which began in March and continued until the end of August, again taking a significant share of all shifts, more per physicist than most University collaborators. The ability to do this is but one of the benefits of the flexible teaching arrangement for the faculty. Hertzbach, Kofler, and Strauss all took "liaison" or "expert" shifts, and we served several weeks as the SLD Run Coordinator.

The major SLC luminosity improvement over 1992 was the implementation of "flat" beams, a mode of running which had been tested at the end of the 1992 run. The damping rings are operated such that the vertical and horizontal emittances are decoupled, resulting in a slightly increased horizontal spot size at the IP, a significantly reduced vertical size, typically smaller than 1 micron, and a smaller beam area at the IP than the initial SLC design goal. The peak luminosity approached 50 Z per hour, and SLD recorded on tape as many as 4400 Zs per week. Both the SLC and all systems of the SLD functioned reliably during the run. The smaller vertical beam size also resulted in a significant reduction in detector backgrounds relative to 1992, and backgrounds were rarely a problem.

The average electron polarization at the interaction point (IP), measured by the precision Compton scattering polarimeter (62%), was achieved by replacing the bulk GaAs photocathode with a strained lattice photocathode, and upgrading the source laser system.

Professor Hertzbach designed several experimental background studies, and dedicated shifts were obtained at the end of the run to carry out a subset. The data obtained were analyzed by experts from each subsystem involved, and we collated and interpreted the results in view of our background models. A summary of some of this work appears in the Backgrounds section of the Proposal to Upgrade the SLD Vertex Detector. These background studies are important, not only for the proposed upgrade, but also in preparation for the 1994 SLC/SLD run, because improvements in the SLC Final Focus optics will inevitably result in increased backgrounds and we will have to pay close attention to prevent this from becoming a significant problem. Now that SLC is using "flat" beams, we are studying the collimation system to determine if changes can be made to further reduce backgrounds, and perhaps even allow a smaller beam pipe for the upgrade. A proposal is being prepared for additional background studies early in the 1994 SLC/SLD run.

Hertzbach and Strauss participated in the design of the proposed SLD vertex detector upgrade, and helped prepare both this and the proposal to extend the SLD run to obtain one million Z events. Both proposals recently received a positive review by the SLAC Experimental Program Advisory Committee. One of the most significant parameters of an upgraded vertex detector is the radius of the innermost layer, and we evaluated the potential impact of several beampipe and masking options on detector backgrounds. Unfortunately for this aspect of the experiment, upgrades of the SLC optics will result in larger beam sizes throughout most of the final focus, and thus will most likely also result in increased backgrounds. The conclusion was that the upgrade cannot utilize a smaller beam pipe without increased backgrounds or radical changes in SLD masking, and the conservative decision was not to change masking or beam pipe significantly. We are continuing with detailed studies of the modifications to the beam pipe and masking geometry required for the upgrade. As indicated above, we also continue to monitor backgrounds and related machine parameters, with the hope of finding a conservative approach to reducing the beam pipe radius.

When there appeared to be an anomaly in the polarization measurements, Professor Hertzbach was one of a small team asked to review the measurements made with the Moller polarimeter at the end of the Linac. He also participated in taking data with the new Extraction Line Moller Polarimeter (see below). A decision has not yet been made, but if it is decided to run the Extraction Line Moller in 1994, improvements will be needed prior to the start of the run, and Professor Hertzbach will oversee that work. Some aspects of this work are being started in order to be ready at the start of the 1994 run.

Note: The Moller polarimeter at the end of the Linac yielded a significantly higher polarization than was being measured by the Compton polarimeter just beyond the IP. Initially it had been assumed that the difference was due to depolarizing effects as the electrons traversed the SLC north arc, but measurement of

the energy dependence of the polarization at the Compton polarimeter ruled out such large depolarizing effects. In August another Moller polarimeter was hastily assembled in the extraction line to the electron dump. The analysis of the data from this detector has yielded ambiguous results and pointed out alignment errors which will have to be corrected if it is to be successfully used in 1994.

The increased luminosity and polarization of the 1993 data run represent an increase in the statistical significance of the Left-Right asymmetry measurement by a factor of ~ 50 over the 1992 result and the resulting error on the A_{LR} and $\sin^2\theta_W$ measurement will be smaller by a factor of ~ 7 . That analysis has yielded a very significant result that is being held private pending resolution of the discrepancy between the Compton and Moeller beam polarization measurements. A theoretical paper by a Russian theorist has been uncovered which indicates that the Moeller polarization measurement is biased at extreme relativistic electron energies, and we are becoming increasingly confident in the Compton measurement. It is sufficient to state here the statistical and systematic errors on the asymmetry and mixing angle measurements:

$$\delta A_{LR} = 0.007 \text{ (stat)} \pm 0.003 \text{ (syst)}$$

$$\delta \sin^2\theta_W = 0.007 \text{ (stat)} \pm 0.003 \text{ (syst)}$$

These measurements, made possible by the electron beam polarization, are competitive with similar measurements at LEP, in spite of the much larger data sample of the combined LEP experiments, as shown in Figure 5.

Figure 5

Precision of the present SLD measurement $\sin^2\theta_W$ compared with the various measurements of the LEP experiments. Note: for comparison purposes, only the SLD error is shown; it is arbitrarily centered on the "World" value

It is clear that the precision of the SLD measurement exceeds any category of LEP measurement. The success of the 1993 run has given the SLD collaboration, as well as the SLAC management and the high energy physics community, confidence that an extended experimental run can yield the definitive measurement of this important parameter of the Standard Model. The goal of the extended run is the accumulation of a data sample approaching 1 million Z^0 events with electron polarization in excess of 70%. The statistical significance of a $\sin^2\theta_W$ determination from a data sample that large is shown in Figure 6.

Statistical Error on $\sin^2\theta_W^{\text{eff}}$

Figure 6
Statistical Error on a determination of $\sin^2\theta_W$ by means of the Left-Right Asymmetry in Z^0 decay. The curve assumes an electron beam polarization of 65%. Shown on the curve are the 1992 and 1993 measurement errors and the theoretical limit, which is approached with a sample of 106 Z^0 events.

In addition to the definitive measurement of the weak mixing angle, a data sample of 1 million Z^0 events enables a number of other unique measurements. Most intriguing are the unique studies of heavy flavor mesons made possible by the small and stable beam spots, the beam polarization and the superior vertex detector and particle identification capabilities of the SLC/SLD collider/detector. Among other very interesting studies, we expect to be able to observe CP eigenstate oscillations in the B_s system.

As has already been pointed out, the UMass group has played a very active role in the planning of detector improvements for the extended run. Mike Strauss has been the main contributor to the cluster finding, track reconstruction, and Monte Carlo simulation software for the present vertex detector. When the question of detector enhancements arose, he was quick to respond with a simulation package for future vertex detector design studies; he provided the tracking and Monte Carlo software packages (more than 70 routines) from which the optimum design for a next generation vertex detector has arisen.

The members of the UMass group have also played an active role in the various physics analysis groups. Prof Hertzbach is actively engaged in the Electroweak study group and, as has been pointed out earlier, he has played an important role in the resolution of beam polarization issues. Prof Kofler and Mike Strauss are both involved in the QCD and B-Physics study groups. Mike Strauss reported on his search for 4-quark states at the Collaboration Meeting in spring of 1993. He is also actively engaged in measurement of the forward-backward asymmetry, A_{FB} , and the strong coupling constant, α_s , in b-quark events.

Given the heavy involvement of our group in a wide spectrum of areas of the SLC/SLD project, it has been most satisfying to have had such a successful and productive year.

B Factory and NLC

Consistent with our interest in the physics potential of future e^+e^- colliders, we have followed closely, and contributed to, the SLAC efforts toward both a B-factory and the design studies for the next generation of linear colliders. Our participation in the design studies was sought because of our experience in backgrounds and final focus beamline issues in the SLC/SLD. Prof Hertzbach has provided some simulations of the synchrotron backgrounds to be generated by some of the designs under consideration. Our interest in the B factory is natural for several reasons. First and foremost, it is a natural extension of our interest in pursuing the study of heavy quark states at e^+e^- colliders. Secondly its timing and location is ideal; it makes it possible to pursue an ongoing, data producing experiment (SLD), while helping to design and build the next generation experiment at the same site. The SLD data taking will reach completion at about the same time that the B factory nears readiness for its first beams. We all attended the B factory detector workshop at SLAC during the first week of December, 1993. Although we have not identified the area of our participation at this time, we are interested in the areas of vertex detector design, software design, and physics simulation. A newly hired faculty member at UMass, Juan Jose Gomez, will arrive at UMass in the Fall of 1994; although he has other commitments at this time, he is very interested, and has expertise, in silicon vertex detectors. We expect to formulate the nature of our participation in the B factory early in the Spring, since both Prof Kofler and Hertzbach (on sabbatical) will be at SLAC for the spring and summer of 1994.

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