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Author(s): Thomas A. Coan, P-25
W. Wayne Kinnison, P-25
Jon Kapustinsky, P-25
Jayant Shukla, P-25

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L3 Physics at the Z Resonance and a Search for the Higgs Particle

Thomas A. Coan, W. Wayne Kinnison* Jon Kapustinsky, and Jayant Shukla
Physics Division, Los Alamos National Laboratory

Abstract

This is the final report of a three-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory. Electroweak interactions were studied using the L3 Detector on the Large Electron-Positron Collider (LEP) at the European Center for Nuclear Study (CERN). The specific physics studied utilized the Silicon Microvertex Detector (SMD) of L3, which Los Alamos had previously played a major role in proposing, designing, constructing, and commissioning. This dector enabled L3 to investigate short-lived mesons containing b-quarks.

1. Background and Research Objectives

One of the most successful theories of modern physics is the Standard Model of Electroweak Interactions. That theory, which explains the unification of electromagnetic and weak interactions, has been experimentally investigated for almost twenty years. During that time many experiments have been conducted to test the model with ever increasing levels of precision in an attempt to uncover possible short comings. The model has never failed to explain the data. Nevertheless, there are two short comings of the model. One is that the model contains a large number of "free" parameters. The other is that one of the basic underpinnings of the model is that one or more Higgs particles should exist and such particles have never been observed.

The purpose of this project was to use the L3 Detector on the Large Electron-Positron Collider (LEP) at the European Center for Nuclear Study (CERN) to study electroweak interactions. That work was carried out while the LEP operated on the Z^0 resonance and when it first increased its center-of-mass energy to 140 GeV. The specific studies that the

*Principal Investigator, e-mail: wwk@lanl.gov

Los Alamos group concentrated on was the physics of short-lived vector mesons with an emphasis on the τ lepton and mesons containing the b quark. Such studies would naturally lead to the detailed search for the Higgs meson as LEP continued to increase its operating center-of-mass energy towards its maximum of approximately 200 GeV. This group also participated in the early stages of that research.

In order to meet the above stated physics goals, the Los Alamos collaborators on L3 developed new vertex-finding algorithms that are applicable to all colliding-beam, high-energy physics experiments. The intent of that activity was also to make overall improvements in L3's capabilities to find possible extensions to the Standard Model.

2. Importance to LANL's Science and Technology Base and National R&D Needs

This project is part of Los Alamos' core competency in Complex Experimentation and Measurement with a secondary competency in Theory, Modeling, and High-Performance Computing. In this case, these are related to both the Laboratory and DOE missions of conducting and supporting forefront basic research.

The project has drawn upon Los Alamos' scientific and technological base in high-energy physics research and advanced detector development. As shown below, the specific research carried out in this project depends heavily upon the L3 Silicon Microvertex Detector (SMD) for which Los Alamos played a major role in proposing, designing, constructing and commissioning. The technology that was employed in the development of the SMD is now being applied to Los Alamos' efforts on the PHENIX Experiment, which is being built at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory and which is the highest priority nuclear physics construction project of DOE.

3. Scientific Approach and Accomplishments

In order to study short-lived mesons and τ decays in a colliding-beam, high-energy physics experiment, it is important to be able to detect secondary vertices that are as close as a few hundred micros of the primary vertex. In 1992, physicists at Los Alamos in collaboration with other members of the L3 Experiment proposed the SMD to provide the needed secondary vertex capability for the experiment. By 1994, when this LDRD project began the SMD. The SMD was installed into L3 and ready for commissioning. Jayant Shukla, a Los Alamos post-doctoral student stationed at CERN, began to take a lead role in that commissioning at the beginning of this project.

In order to begin using the SMD for physics studies, much of the existing analysis software and calibration constants for L3 had to be improved. That in turn required that numerous improvements be made in the Monte Carlo codes used by the experiment. These improvements were required to fully realize the 100 μm secondary vertex finding capability of the SMD. Part of the improvements in the analysis and calibration constants that Shukla incorporated into the complete analysis codes of L3 included development of code and calibrations for the "z" chambers, which allow a determination of the z-positions of tracks in the detector and which no one else had been able to satisfactorily include in previous analysis efforts. Until the work by Shukla, all analysis of L3 data had used ϕ projections only. By allowing full three-dimensional reconstructions, many other analysis projects by the L3 Experiment benefited in addition to those involving the Los Alamos team.

After the "z" chambers of L3 were fully brought on line for analysis, an independent source of z-positions was available and could be used to calibrate the z-positions of the SMD to the required position for use in a full three-dimensional analysis. After that calibration had been completed, Shukla with assistance from Wayne Kinnison, began to work on developing a new methodology for reconstructing secondary vertices in the L3 Experiment. The new method that was developed used the full power of three-dimensional tracking. In the end, a closed form method of secondary vertex finding and fitting was developed that was far superior to any algorithms that have used by colliding beam experiments in the past. The method, which is described in detail in a paper recently submitted for publication (Publication 14), has been applied to other colliding beam experiments. It has the advantage of not only finding the secondary vertices, but also generating the full covariance matrix of the tracks that are associated with the vertex. That in turn results in improved and better defined errors being associated with the physics analysis results.

After the above tools had been developed, the capabilities of the L3 Experiment had been extended sufficiently that a completely new physics experiment could be carried out utilizing the new capabilities of the detector. The methods were first applied in the measurement of b-quark branching ratios (see Publication 11). Most recently, the L3 Experiment has applied the new methods and all of the work carried out during the lifetime of this project to place limits on the Higgs boson at LEP (see Publication 13).

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