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SUMMARY

The High Energy Physics group at University of Alabama is a member of the L3 collaboration studying e^+e^- collisions near the Z^0 pole at the LEP accelerator at CERN. About 2 million Z^0 events have been accumulated and the experiment has been prolific in publishing results on the Z resonance parameters, the Z couplings to all leptons and quarks with mass less than half the Z mass, searches for new particles and interactions, and studies of strong interactions and/or weak charged current decays of quarks and leptons abundantly produced in Z decays.

Our group is contributing to data analysis as well as to detector hardware. In particular, we are involved in a major hardware upgrade for the experiment, namely the design, construction and commissioning of a Silicon Microvertex Detector (SMD) which has successfully been installed for operation during the present grant period.

We present here a report on our recent L3 activities and our plans for the next grant period of twelve months (April 1, 1994 - March 31, 1995).. Our main interests in data analysis are in the study of single photon final states and the physics made more accessible by the SMD, such as heavy flavor physics. Our hardware efforts continue to be concentrated on the high precision capacitive and optical alignment monitoring systems for the SMD and also includes gas monitoring for the muon system. We are also planning to participate in the coming upgrade of the L3 detector.

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I. INTRODUCTION

The experimental High Energy Physics group at the University of Alabama is participating in the L3 experiment at CERN studying e^+e^- physics at the highest available center of mass energy. In this experiment members of the Alabama group are working in data analysis and also have taken on major hardware responsibilities for a silicon micro vertex detector. These L3 activities are supported by a grant from the Department of Energy.

The group is also interested in detector development for the next generation of accelerators, LHC and SSC, and has recently joined the Solenoid Detector Collaboration. Present activities concentrate on the muon detector and include designing and building instrumentation to measure wire tension in about 90,000 drift tubes and providing a drift velocity monitor system. There are plans to participate in geometrical alignment and electronics. Three of these projects are directly related to our L3 efforts. Support for this work is currently provided by a grant from the Texas National Research Laboratory Commission.

As important as the SDC program is, for the near future the L3 experiment will continue to be the group's primary research activity.

Faculty, Staff, Students

There are five physicist positions in our group: two faculty (associate professor Dr. Laszlo Baksay, assistant professor Dr. Jerome Busenitz), one research associate (Dr. Johannes Tuchscherer) working on L3 and permanently stationed at CERN, and one research scientist and one research associate working on SDC on campus. Dr. Tuchscherer is a new member of our L3 group so we have attached biographical information on him at the end of this chapter.

A research specialist technician position is held by Mr. Gyula Zilizi. In addition to being an electronics specialist he also provides general technical support. He is also the system manager for the groups computer systems. Mr. Zilizi has a Masters Degree in Physics, Technology and Computer Science, as well as experience with computer systems, electronics design, and accelerator experimentation.

The University continues to provide half-time secretarial support. We have recently hired Mrs. Janet Kirkwood, who has several years of secretarial experience.

Four graduate students have chosen to work with us (Rhett Allain, Brad McClure, Scott Mackall, Brad Brinkley). One undergraduate physics major (George Karatheodoris) has spent the summer as an intern with the group.

Research Facilities

Analysis

Analysis facilities within the high energy physics group include an Apollo DN10000 and two DN3500's, as well as the University IBM 3090 and access to the Alabama CRAY XMP24 supercomputer. The DN10000 serves as the group's principal machine for L3 data analysis and detector simulation.. One Apollo DN3500 is principally used to support the group's electronic circuit simulation and design program, MENTOR GRAPHICS. It has been used in electronics development for L3 and can be also useful in the future for SSC/LHC work. All workstations are Internet hosts.

Measurement

Laboratories and offices of the high energy group have been consolidated in the Physics Building giving us more space and convenient location.

In addition to standard read-out electronics units of NIM, CAMAC, and VME standard, the group's instrumentational support includes a CAD system for 3-dimensional engineering design and a VLSI evaluation system. Each system is driven by its own HP 9000 workstation.. This equipment also includes a 1 GHz digitizing oscilloscope, picoammeters, and a logic state analyzer.

The group also has a unique stand alone high pressure test stand allowing R + D on high pressure gas detectors for High Energy Physics up to 500 atm.

BIOGRAPHICAL INFORMATION

JOHANNES TUCHSCHERER

Dr. Johannes Tuchscherer is presently a Research Associate at the University of Alabama. He studied physics at the Technical University Aachen and received his Ph.D. degree in 1938. Between 1978 and 1982 he was engaged in a spark chamber neutrino scattering experiment at CERN with the Aachen-Padova collaboration. In his analysis he was able to put a stringent limit on neutrino oscillations. From 1983 till 1988 Dr. Tuchscherer was a member of an Aachen-Zeuthen-SIN collaboration working at the Paul Scherrer Institute searching for light Higgs particles such as the axion in a beam-dump experiment. He was involved in the experiment through planning, installation and data taking and led the data evaluation. In 1988 Dr. Tuchscherer joined the UA1 collaboration and has since then been permanently stationed at CERN. He had responsibility for the large area drift chambers built by the Aachen group and in particular had to provide the correct geometry and alignment for the reconstruction software. After the completion of the UA1 experiment Dr. Tuchscherer participated in preparatory work for muon physics at the LHC. As one of the authors of the letter of intent for the RD5 research and development project at CERN he has been working on that experiment since 1991. As the deputy leader of the Aachen group at CERN he was in charge of the muon chambers. He was also involved in writing the muon part of the letter of intent for CMS one of the two detectors for LHC. In addition he worked on the development of the "Wall-Less Drift Chamber", one of the leading concepts for muon detection at the LHC.

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II. OVERVIEW OF L3 AND UA PARTICIPATION

L 3

The L3 detector [1] is a high precision spectrometer for electrons, photons, and muons designed to study e^+e^- collisions at center of mass energies from the Z pole to above WW threshold (Fig. II.1). It covers 99% of 4π and consists of a central tracking chamber (TEC), a forward-backward tracking chamber, a high resolution electromagnetic calorimeter composed of bismuth germanium oxide (BGO) crystals, a ring of scintillation counters, a uranium and brass hadron calorimeter with proportional wire chamber read-out, and a high precision muon spectrometer. In 1993 a Silicon Microvertex Detector (SMD) has been installed. These detectors are located in a 12 m diameter magnet which provides a uniform field of 0.5 T along the beam direction.

The principal physics program in this experiment includes high precision tests of the Standard Model, searches for new physics within (Higgs) and outside (super-symmetry and other new particles) the Standard Model.

At the Z^0 mass, the spectrometer's mass resolution, $\Delta M/M$, is approximately 1% for di-electron and di-muon final states, and roughly 10% for hadronic final states. Precision on the knowledge of the beam energy has improved to a point where uncertainty in Z mass from uncertainty in beam energy is now 5 MeV. High precision reconstruction of leptonically decaying Z^0 's is also crucial in missing mass searches for new particles far off the Z^0 pole.

Cross section measurements are normalized using luminosity measurements of small angle (typically 30 to 65 mrad) Bhabha scattering events by forward BGO arrays on either side of the detector. The total systematic error on this luminosity measurement is about 0.5%.

During the last twelve months L3 has produced over 20 papers reporting measurements of quantities such as the parameters of the Z resonance, the average b-hadron lifetime, tau polarization, as well as setting limits on phenomena such as lepton flavor violation, the Standard Model Higgs boson, neutral heavy lepton, etc.. Chapter VI. on single photon physics describes

analysis work of particular interest to us. A list of published L3 papers is given in Table II.1 .

The participation of the Alabama group in L3 consists of both, contributions to detector hardware as well as data analysis. Particular hardware interests are in the muon spectrometer and the Silicon Microvertex detector. Therefore, we give below a very brief overview of these two subsystems. Detailed information can be obtained from the references given

In analysis we have so far concentrated on single photon final states. With the advent of the SMD we intend to also branch out into physics , such as heavy flavour, emphasizing SMD capabilities , and are also interested in new initiatives.

We anticipate a long-term involvement with the SMD. We began this by first planning the alignment systems, then went through construction, commissioning, on-line software and we are now continuing through off-line and eventually physics analysis.

We expect our present hardware systems to soon reach a stage when mainly routine maintenance will be required. Therefore, we are determined to participate in upgrades planned for L3, such as the forward/backward muon chambers, the very exciting prospect of a silicon forward tracking system., or other options.

The Muon spectrometer

The muon detector system has been designed to measure high energy muons to an accuracy of $\Delta p/p = 2\%$ at 50 GeV, providing a 1.4% dimuon mass resolution at 100 GeV [2]. This is achieved using a configuration of three layers of wire drift chambers which very precisely measure the curvature of the muon trajectory. In the magnetic field a 50 GeV muon track deviates from a straight line by a sagitta of about 4 mm. To obtain the above mass resolution Δs must be measured to 70 μm . Since several wires (16 resp. 24) are used to obtain final tracking accuracy, this translates into an intrinsic position measurement accuracy of about 200 μm per wire over a drift distance of about 5 cm. This has been achieved [3]. However, high precision monitoring of geometrical and chamber operating parameters is necessary.

We have provided a device to monitor the stability of drift velocity in the muon chambers as described in chapter V. The details of the muon detector are described in ref. 1.

The Silicon Microvertex Detector (SMD)

During the past LEP winter shutdown, L3 inserted a silicon microvertex detector into the space between the beam pipe and the inner wall of the central tracker (TEC).

The SMD consists of two concentric layers of double-sided silicon detectors covering the polar angle between 22 and 158 degrees. With double-sided detectors one has the capability to measure both the $r\phi$ and z coordinates of the track at each layer. The single-layer resolution for a high-momentum track at 90 degrees (normal incidence) is about 7 microns in $r\phi$ and 14 microns in z . Used in conjunction with the TEC, the SMD improves charge determination of tracks, tagging of heavy quark jets, and the measurement of the z -coordinate of tracks. At LEP1 this improved capability directly benefits the study of b physics and τ polarization while at LEP2 it increases L3's capability to precisely measure ZWW and γ WW couplings and to reduce the background to Higgs searches.

To use the SMD to fullest advantage, its alignment with respect to the TEC must be known precisely. Using a sample of di-muons from Z decay, an achievable goal on the precision of the TEC-SMD alignment is 10 microns. In order to determine the global alignment to this accuracy, one requirement is that the determination of the alignment must be carried out over an interval in which the global alignment is stable to within 10 microns. Denoting such an interval as a "period of stability", the alignment between TEC and SMD must be monitored with sufficient resolution so that the periods of stability throughout the LEP run can be reliably identified. In the case that the period of stability does not span an entire run, an alignment monitoring system which can resolve changes in SMD-TEC alignment which are small compared to 10 microns is also able to provide useful information on interpolating the global alignment between neighboring periods of stability.

The UA group was responsible for the design and construction of two alignment monitoring systems and is now in charge of their operation and analyzing the

data to determine the periods of stability during the LEP run. One system exploits the principle that capacitance depends on geometry and the other uses a method in which the SMD is illuminated with light pulses originating from sources fixed on the TEC.

The two systems are complementary in the degrees of freedom to which they are most sensitive yet have been designed to be redundant in each by itself meeting the minimum requirements on alignment monitoring. A detailed description of the system designs and results from prototype studies may be found in Reference 1.

The data taken with each of these systems during the 1993 run to date are now being analyzed. In chapters III and IV, we give a brief description of each system and present first results from the data analysis.

Analysis

The UA group has been involved in single photon analysis on L3 since 1990. Chapter VI of this report describes past activities and present plans.

In addition to the single photon analysis we are also exploring other possible new initiatives, in as much as our other commitments allow. For example, the theory group at Alabama did calculations and suggested a possible explanation for the difference between the measurements of $a_3(M_Z)$ from the hadronic branching ratio of the Z^0 and the world average of other measurements. This leads to consequences for supersymmetry breaking models. According to their prediction effects might be observable in the L3 data. There are other topics along the same line where we might be able to use the advantage of direct local communication.

The University of Alabama is one of the remote sites at which Monte Carlo detector simulation for L3 is being carried on. Files of generated events are transferred via Internet from CERN to Alabama. These events are then passed through the L3 detector simulation program SIGEL3 running on the Alabama Apollo DN10000 workstation. The simulated events are copied to Exabyte tapes, which are periodically sent to CERN for event reconstruction and analysis.

Some On-campus activities

One graduate student is involved in the Monte Carlo simulations on the Apollo DN10000 mentioned above.

In the hardware area, the shop work for the capacitive displacement monitoring system, such as building voltage references, power supplies, probe holders, and ground targets, has been done in the Physics Department's electronics and machine shops.

This year we expect to begin doing some of the optics work in a laboratory we newly occupied.

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Figure II.1. Schematic View of the L3 Spectrometer

III. CAPACITIVE DISPLACEMENT MONITORING SYSTEM (CDMS)

One unit of CDMS consists of a sensor mounted on the SMD support structure facing a grounded conducting surface (ground target) mounted on the inner wall (beryllium tube) of the TEC. The sensor is instrumented by electronics which (a) excites the sensor with an AC current of fixed frequency (≈ 15 kHz) and constant magnitude and (b) amplifies, rectifies, and filters the potential difference between the sensor and ground target to produce an essentially DC output voltage which varies inversely with the capacitance between sensor and ground. As capacitance is geometry-dependent, the variations of the output voltage can therefore be converted, using calibration data, into information on relative displacements between the sensor and ground target.

For use in L3, the sensors are grouped in sets of three (hereafter referred to as triplets) and each triplet faces a ground target contoured for measuring displacements in two dimensions. Figure III.1 shows a projection view, based on looking radially outward from the beamline, of the two types of configurations. For Type I, the ground target is contoured so that the middle sensor is sensitive to radial displacements Δr only while the end sensors are sensitive to both Δr and $r\Delta\phi$. With respect to Type II, again the middle sensor is sensitive to Δr only while the outputs of the end sensors vary with Δr and Δz . While two-dimensional displacements can be measured using only two sensors, the redundancy obtained with three sensors may be used to reduce the effects of noise and correlated displacement-independent drift, which were expected from prototype studies and have since been observed in actual operation.

Six triplets are mounted on the SMD support, 3 (2 Type I + 1 Type II) on either side of the interaction point. In z , the triplets are located about 5 cm further away from the interaction point than the end of the active area of the detector. The locations in ϕ and sensor sensitivities are given in Table 1. (The notation used is RBxx-yyy (ab) where xx = 24 (26) indicates the +z (-z) side, yyy is the nominal ϕ coordinate in degrees, and a and b are the dimensions to which the triplet is sensitive. ∂x refers to either $r\partial\phi$ or ∂z .) The sensor output voltages as a function of the position of the ground target relative to the triplet were measured in detail prior to installation, and it is this data from which the sensitivities have

Cross-hatched regions of ground target
are 2 mm further away from sensor face
than open region.

Figure III.1. Triplet-ground target configurations

been inferred. The fractional uncertainties in the radial sensitivities are 5-10% while those in the transverse uncertainties are 15-20%.

These uncertainties are due mainly to the uncertainty in the position of the ground target relative to the triplet after installation.

Table 1
Triplet Sensitivities (mV/micron)

	Sensor 1		Sensor 2		Sensor 3	
Triplet	$\partial V/\partial r$	$\partial V/\partial x$	$\partial V/\partial r$	$\partial V/\partial x$	$\partial V/\partial r$	$\partial V/\partial x$
RB24-322 (rz)	2.45	0.55	2.79		1.54	-0.51
RB24-202 (r ϕ)	1.85	0.53	2.42		1.46	-0.52
RB24-22 (r ϕ)	1.42	0.52	2.43		1.80	-0.53
RB26-202 (rz)	2.86	-0.72	2.13		1.96	-0.51
RB24-322 (r ϕ)	2.46	-1.00	3.06		2.15	0.94
RB26-142 (r ϕ)			2.42		2.06	0.58

A schematic of the overall CDMS system is shown in Figure III.2 The main electronics is housed in two crates in the L3 support tube, one on each side about 8 meters from the interaction point. In addition to the 9 channels on each side sensitive to SMD-TEC relative displacements, there is one reference channel (located near the crate) for which the sensor-ground target geometry is fixed. As with the inherent redundancy in the triplets, the information from this sensor is used to correct for electronics drift. Silicon oil having an input temperature of $18 \pm 0.1^\circ\text{C}$ is circulated through screens mounted in close proximity to the electronics in order to stabilize the temperature, and in addition, the temperature at four points inside and near the electronics is monitored as it is known, again from prototype studies, that a significant source of drift is temperature variations in the electronics.

The 28 output voltages from the capacitive and temperature sensors are multiplexed to a 16-bit ADC. The stability of the multiplexers and ADC are

Figure III.2 Schematic of CDMS system

monitored applying reference voltages of 5V and 10V to two inputs of each multiplexer. The voltages are digitized and read out via CAMAC once per minute. The readings are averaged over sequential 15-minute intervals and the resulting information (averages and standard deviations) are transferred to the SMD database, the TEC/SMD on-line monitoring program, and an additional file being used as a backup to the database.

The CDMS has been recording data since May 1993. Four of the six triplets (two on each side) and the associated electronics have operated well through the time of this writing. Of the two remaining triplets, one (RB26-142) has a sensor which has been inoperational from the beginning due to a broken cable between the sensor and electronics. (The other two sensors being operational, displacements in the two dimensions can still be measured; only the local redundancy has been lost.) The other triplet (RB24--202) exhibited large monotonic voltage drifts in the latter part of May--we suspect that either the sensor holder or ground target came unglued--and it has since been disregarded in the CDMS data analysis. (Both these problems will be repaired during the LEP winter shutdown while the SMD is removed.) Under normal data-taking conditions, the electronics temperature has been stable to ± 0.1 °C in the presence of ambient temperature swings of ± 1 °C. This has allowed us to ignore temperature variations at the electronics in correcting the CDMS sensor data for drift. The gain of the ADC/MUX system has proved to be stable to 1 part in 10^4 , as expected.

With respect to the performance of the main part of the CDMS system, the variation of CDMS sensor voltages has an important component which is inconsistent with relative SMD-TEC displacements. Simple approaches to remove this component using the reference sensor information and the triplet redundancy have had considerable success, and more recent work to refine these approaches with care taken to analyze only data taken under normal SMD operating conditions has obtained results indicating that the goal of a long-term resolution of 10 microns or better for each triplet can probably be reached. As one example, we show the raw data and derived displacements for the two working triplets on the RB24 side for a 6.5 day period in August. Figure III.3 shows the raw voltage variations for the two triplets and the

reference sensor. One can see that the voltage variations for the two triplets are largely correlated with variations in the reference sensor.

Correcting the triplet outputs using this correlation and then averaging the two independent determinations of Δr and Δz ($r\Delta\phi$) for RB24-322 (RB24-22) yields the distributions shown in Figure III.4. The degree to which residual electronics instability and other displacement-independent effects are responsible for the width of the distributions has not yet been estimated, but assuming that width is due entirely to displacements, one concludes that the SMD-TEC alignment at the location of these triplets was stable to better than 10 microns over this period.

At this writing, we are working to finish the development of a line of analysis which can be used on all the CDMS data taken under normal SMD conditions and then to apply that analysis to identify periods of stability for SMD-TEC alignment. The project of aligning the SMD and TEC for the 1993 run is expected to start by the end of the year.

Figure III.3 Sensor output voltages as a function of time

Figure III.4. Derived SMD-TEC displacements

IV. OPTICAL ALIGNMENT MONITORING SYSTEM

INTRODUCTION

The goal for the optical alignment monitoring system is to give a spatial reference to identify the location of the silicon sensors to a precision on the order of a few μm . It will also provide a stable position measurement tracking changes in the SMD geometry throughout the operational lifetime of the detector. The laser alignment system is designed to measure changes in sensor location spanning the entire length of the SMD. To complement the Capacitive Displacement Monitor System (CDMS), which is sensitive to local radial and longitudinal displacements, the optical alignment system will provide additional global information on angular displacements of the SMD with respect to the Time expansion chamber (TEC).

THE PRINCIPLE

The optical position monitor system measures the displacements of the SMD with respect to the TEC. Light pulses provided by laser diodes are coupled into optical fibers. The other end of a fiber is connected to a light distributor transferring the light to a bundle of illumination fibers and a photodetector for monitoring. The illumination fibers are attached to the inner wall of the TEC and terminate in specially designed optical heads, creating a light spot impinging on the silicon strips (Fig. IV.1) at various locations across the SMD (Fig. IV.2). The charge generated in the sensors by the light pulse is read out by the regular SMD electronics. The diameter of each light spot is large enough so that it produces signals on several neighbouring strips. This gives the possibility to reconstruct the light beam centroids with the required accuracy of a few μm . Since the heads are fixed to the TEC inner wall reference surface, any change of the centroid position can only originate from the displacement of the SMD with respect to the TEC. There are two independent systems, including two lasers, using two different illumination directions (vertical and 45 degree). This allows to measure the tangential as well as the radial displacements. Each half-ladder is illuminated by both types of heads giving information about all the separate silicon detectors and providing the possibility of testing the detectors as well as the read-out system with a light source.

TECHNICAL DESCRIPTION

The system[1][2] can be divided into three parts: electronics, optics, and mechanics.

Electronics

The electronics system is shown schematically in Fig. IV.3. The trigger signal coming from a LEP bunch crossing clock with 44 kHz repetition rate is used for synchronisation of the system to LEP. This signal is prescaled by a variable divider into a trigger with the order of 100 Hz repetition rate. Two lasers and their electronics are housed in one NIM module.

Optics

The optical part of the system is shown schematically in Fig. IV.2. Two synchronously triggered independent semiconductor lasers are used, one for vertical and one for 45 degree illuminating heads. The roughly 50 nsec long laser pulses emitted at 905 nm wavelength are taken to optical distributors located near the SMD by 400 μm core diameter optical fibers. The incoming light is distributed into 50 μm fibers. The thin fibers end in illuminating heads containing a microlens-micropism optical element projecting the image of the fiber core end in the form of 60-100 μm lightspots(Fig.IV.1). to the surface of the silicon detector through 10 mm diameter holes cut in the thermal/electrical noise shield of the SMD. The total number of the thin fibers and the heads is 48.

Mechanics

To maintain micron level precision, the illuminating heads were tested for stability in the expected range for humidity, and temperature. Their shape change was found to be under one micron in that range.

The assembly involves inserting and glueing the micro-optics into the illumination heads, threading and glueing the thin fibers into their holders, adjusting and fixing the holders in the heads, glueing the heads onto the wall of the TEC, and assembly of the optical distributor.

Accurate mechanical installation into the SMD is very difficult mainly because of inaccessibility and very tight tolerances. For instance, the clearance between the illumination heads and the Matay-noiseshield is only about two mm.

Bench tests

A system was put together to test characteristics of the components. Data acquisition was set up, software was written, the complete system could be tested, and some questions regarding optical behavior were investigated. We used a CCD camera with 20 μm pixel size. Since multimode optical fiber is used the output of the fibers shows a speckle pattern. With the 200 μm fiber the speckle size of the pattern at the fan-out input was comparable to the size of the thin fiber. This could potentially give rise to problems, since some of the fibers at the output might not receive much light. The speckle size, however, should decrease with an increase in the size of the input fiber. We have assembled two complete chains from laser to lens and made measurements of light intensity and its distribution. The optical distributor was investigated for choosing the best solution giving maximal homogeneity of energy in each thin fiber at tolerable energy losses.

After concluding the bench tests with satisfactory results, a simplified system consisting of a laser, fibers, and two illuminating heads (one for each direction) was put together on the request of the SMD sensor test group and has been delivered for read-out tests of the SMD sensors at CERN. This new application will also help us test our system more extensively and represents an unexpected success of our approach.

Testbeam run

During a beam test at CERN for various components of the SMD we inserted one chain of the optical alignment monitoring system and checked the performance of all components as well as the integration into the SMD system. For mechanical installation a mock up of the TEC was used. Based on this experience and the needs of some collaborators it was decided to mount the optical heads directly onto the TEC inner wall instead of using the kapton sheet scheme.

It was during the test beam run that for the first the laser actually illuminated an SMD sensor. The monitor was fully integrated into and controlled by the data acquisition, to the same extent as it will be in the SMD. As Fig. IV.4 shows, a spatial resolution in the few micron range can be expected.

Before Installation

Following the bench tests and the testbeam run remaining questions were answered and solutions were found to potential problems, along the lines outlined in last year's proposal:

The speckle problem was further studied, in particular its dependence on the thickness of the long fiber. Eventually, we found a better solution by using a "twin" laser diode, which has two independent internal sections thus avoiding the coherence based interference effect.

We have studied in detail the characteristics of the lasers used. During the test beam the average charge of the strip clusters due to laser firing was much more than that due to m.i.p. It was concluded that it might be advantageous or even necessary to be able to change the laser intensity to adjust to the SMD setting. Optical attenuation was one suggestion. We decided to investigate if it was possible to adjust intensity by changing the laser supply voltage from the specified 15V. It was also an open question if stable laser operation could be achieved. As Fig. IV.6 shows it is possible to operate with an increase of about a factor of 2 and a decrease of about a factor of five using the supply voltage range between 11 V and 20 V.

Fig. IV.5 shows the block diagram for the stability measurements of laser pulse amplitude. At the nominal operating voltage of 15 V the width was about 5%. Fig. IV.7 shows the block diagram for the timing measurements. The jitter between laser trigger and output pulse was negligible compared to the length of the beam gate for the SMD.

SMD installation

The complete laser system was ready for installation into the SMD according to schedule. We inserted it during the shutdown at the beginning '93. During and after installation we did all checks that were possible, such as continuity of light path at all reachable points, performance of the control electronics, and the homemade laser driver.

Since the laser alignment system is using the actual SMD, the read out for the laser system is the SMD readout. Therefore a complete check of the laser system requires proper functioning and understanding of the SMD readout hardware and software. In fact, the two systems are tied into each other. The laser system

was used in a very early stage for an SMD check: a laser signal was found on one of the ladders which proved the functioning of the detector at least in some part. Fig. IV.8 shows an early laser event. The bottom plot shows an area of the SMD without the beam gate. the top plot shows an event with beam gate and the 'laser bit' on, identifying a laser event. The laser signal is clearly visible. The appearance of a big "horn" centered around channel 270 is not related to the laser system. It is an effect in the SMD which is understood. Fig. IV.9 shows the superposition of 100 laser events after common noise subtraction on a particular ladder (rfi side) far from any "horn" region.

STATUS AND PLANS

So far progress on the laser alignment system has been according to schedule. The installation into the SMD has been carried out successfully. Using the SMD readout clear laser signals are seen on-line and off-line.

Work still needs to be done. We do not see laser signals on all ladders. We know that some of this is due to SMD problems which are being solved or are at least understood. We must do a systematic study of all rfi and z ladders. There is also a question about a possible influence by the geometry of the noise shield. The SMD software is also still under development. We must better understand common noise, pedestal, horn subtraction to establish signal shape. We have to analyse more data to quantitatively assess the system performance and spatial resolution.

During the coming period, we plan to run-in and maintain the optical alignment system. We are getting more involved with the SMD off-line software, especially through our research associate at CERN, who will play a substantial role in this.

In our last proposal we had mentioned the idea of aligning the inner layer of the SMD by some optical system capable of penetrating the outer layer. The coordinator of the SMD project has in the meantime expressed intense interest in this possibility. In cooperation with colleagues at the Kossuth University in Hungary, we have briefly looked at the problem. Fig. IV.10 shows the results of transmission measurements of a silicon wafer similar to the SMD, and a piece of SMD z-fanout Kapton. The result is encouraging. Around 1.1 micron absorption in the wafer seems small enough to at least warrant further

investigation. Based on this, we would like to perform a systematic study of this problem. This work is also useful in connection with one of the suggested upgrades for L3, a forward silicon tracker.

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- [2] L.Baksay, J. Busenitz, "Renewal proposal for the High Energy Physics program at the University of Alabama", Task B, submitted to the DOE, November 1992

FIGURE CAPTIONS

Figure IV. 1	Principle
Figure IV. 2	Schematic of optics
Figure IV. 3	Schematic of electronics
Figure IV. 4	Laser pulse center of gravity
Figure IV. 5	Block diagram: pulse height measurements
Figure IV. 6	Laser output power versus driver voltage
Figure IV. 7	Block diagram: timing measurements
Figure IV. 8	Laser event in SMD
Figure IV. 9	Superposition of 100 laser events
Figure IV.10	Transmission in silicon wafer and kapton

Figure IV.1 Principle

Figure IV.2 Schematic of optics

Figure IV.3 Schematic of electronics

BinSize= 0.001 Number of Bins: 100 RunTime= 948 sec
 Lo/Up= 54/ 82 Sum= 858 Mean/Stg= -3.6777/ 0.0035

Start/Act. 14. 8.1992 at 13:48/14. 8.1992 at 14: 6 11=

Figure IV.4 Laser pulse center of gravity

Figure IV.5 Block diagram: pulse height measurements

Figure IV.6 Laser output power versus driver voltage

Figure IV.7 Block diagram: timing measurements

laser

lev=1, side=1 layer=4, ldr #11

ADC
COUNTS

row data-rfi

row data-rfi

Figure IV.8 Laser event in SMD

Laser signal from the tilted beam on the outer ladder 9 of side RB26

Figure IV.9 Superposition of 100 laser events

Figure IV.10 Transmission in silicon wafer and kapton

V. DRIFT VELOCITY MONITORING SYSTEM

The drift velocity monitor system is described in detail in ref. 1. We have used electrons liberated from the metallic surface of a cathode of a small drift chamber by means of a laser pulse. This method gives a well localized electron source along the drift direction. The arrangement is shown schematically (not to scale) in Figure V.1. The structure is basically the same as that of the p-chambers in the L3 muon detector, except that the cathode is a gold coated copper surface instead of wires. Light from a pulsed nitrogen laser illuminates the cathode plate through a UV-transparent quartz window. Part of the light is reflected from a beam-splitter into an ultrafast UV sensitive photodetector. This signal serves as a start signal for the drift time measurement. It is connected (after about 900 nsec cable delay) to a LeCroy 2228A 50 ps/channel TDC while the signals coming from the wires are amplified and formed and serve as stop signals for the TDC. Wires with different temperature/resistance coefficients measure the gas temperature in the chamber. The pressure is measured by a semiconductor absolute pressure transducer. The whole device is controlled and the measured data are collected and processed by a VME processor. In addition to the measurement of the drift time, it is also possible to generate test start and stop signals, thereby testing and calibrating the complete electronics. Figure V.2 shows the block diagram of the electronics.

As is typical for nitrogen lasers, the spatial energy distribution of the beam varies from shot to shot. Under such conditions both, the convergent and divergent illuminations have certain advantages and disadvantages. In the case of convergent illumination, we have a well localized source which is independent from the spatial energy distribution. In the case of divergent illumination, however, we can have better statistics because the drift process can be examined in parallel on several wires at the same time. In tests we have also used convergent illumination (about 0.1 mm spot size at the cathode surface) but the chamber installed at L3 uses divergent illumination. The 3 mm x 8 mm laser beam is enlarged to a 15 x 40 mm spot at the cathode surface that enables us to obtain output signals from four different wires.

The electric field in the chamber and the expected drift times under various conditions were calculated using the GARFIELD programme. The calculated drift times and the distribution of the electric field were in good

agreement with observed measurements. To study the properties of the device, a variety of bench tests, such as precise stability measurements, were carried out (see ref. 2)

After the bench tests the device was installed for a test run at CERN. It was found that the equipment worked with the same accuracy as in the bench tests, that is, stability within a few nanoseconds for single shots, and better than ± 1 nsec for averages.

As the bench tests and the test run have shown that the drift velocity monitor we designed and built is able to measure drift time/velocity changes with the required accuracy of better than 0.5%, we installed the system into the experiment. It is connected to the L3 p-muon chamber gas system between the supply and return manifold as a 17th octant from the point of view of gas supply. It turned out that the environment was electrically noisy and some of the signal levels were marginal. For instance, one intermittent problem could eventually be traced back to the TDC start signal coming from the light detector, which after propagating through a long cable was just at threshold. Such problems were solved by rethinking and upgrading some of the electronics. Improvements were also made on the software. F.i., the mode of the data transfer between the VME and the L3 VAX was modified. Work in this area is still on-going to make the processing of the accumulated data more efficient. Our research associate stationed at CERN has taken over the upkeep and maintenance of this system.

REFERENCES

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UV sensitive photo detector

Quartz window

Quartz splitter

Quartz lens

LASER BEAM

3 ns/120 microJoule
UV laser pulse
Wave length 337 nm

Symmetry wire plane

DRIFT CHAMBER

Field wire

Sense wire

Gold plated copper surface

The electrons excited by the laser pulse drift from the gold surface to the sense wires

Beam spot

8 mm

50 mm

0 kV

-1.9 kV

-6.0 kV

5 mm

5 mm

-1.9 kV

Figure V.1 Arrangement of drift velocity monitor

VI. Study of Single-Photon Final States

The UA group continues to actively participate in studying e^+e^- annihilation events at LEP1 ($s^{1/2} \approx m_Z$) in which the only final-state particle detected is a photon. The motivation for studying this class of events is twofold. First, single-photon events can be used to measure the invisible width Γ_{inv} of the Z. Clearly Γ_{inv} depends on all couplings of the Z to stable, weakly interacting final states and thus it is an important quantity to measure in a "global" search for evidence of New Physics. Measuring Γ_{inv} by single-photon counting complements well the measurement based on analysis of the Z line shape and visible decays because it is (a) direct, (b) based on a rather different type of event as far as detection is concerned, and (c) given adequate statistics, comparable in precision. Second, there are a number of New Physics models, e.g. those based on supersymmetry or compositeness ideas, which have as one signature single-photon states in which the photon is energetic. (By "energetic" we mean energies comparable to or greater than $0.2E_{\text{beam}}$.) The advantage of searching for such a signature is that the Standard Model background is small in this region, being due to the fact that in the Standard Model the photons come primarily from initial state radiation (bremsstrahlung) and the energy spectrum is thus peaked toward low energies. A more detailed description of the physics motivation for studying single-photon final states, as well as the technical aspects of such a study, may be found in Reference 1.

An update of the direct measurement of the invisible width of the Z, using single-photon events collected during the the 1992 LEP run, is nearly finalized. Requiring $E_\gamma > 1 \text{ GeV}$ and $45^\circ < \theta_\gamma < 135^\circ$, Figure 1 shows the energy spectrum of the observed events for 1992, corresponding to an integrated luminosity of 20.8 pb^{-1} at $s^{1/2} = 91.3 \text{ GeV}$. Also shown as shaded histograms are the expected contributions from $\nu\bar{\nu}\gamma$ final states for 3 generations and background processes in which all final-state particles but a photon escape undetected down the beampipe or into a crack in the detector. (Radiative Bhabha events constitute most of the background but $e^+e^- \rightarrow \gamma\gamma\gamma$ and two-photon processes also contribute.) The expectations, coming entirely from the Standard Model, appear to agree well with the data. Quantitatively, by fitting Γ_{inv} to the 1992 L3 single-photon data and taking into account sources of systematic error, we obtain the preliminary result

$$\Gamma_{\text{inv}} = 471 \pm 25 \text{ (stat)} \pm 13 \text{ (syst.) MeV}$$

which is to be compared with the Standard Model prediction of 498 MeV.

In parallel with the measurement of Γ_{inv} , which depends on the observation of low-energy photons as shown in Figure 1, we are carrying out a direct search for energetic single-photon events. Figure 2 shows a L3 scan-program view of a single-photon event found in the 1992 data where the energy of the photon is 30.4 GeV. Such events are rare in the context of the Standard Model--about 0.5 events are expected in 1992 requiring $E_\gamma > 1/2 E_{\text{beam}}$ and $20 < \theta_\gamma < 160$ degrees--so observation of only a handful of energetic single-photon events, say 6 events, would comprise a strong indication of physics beyond the Standard Model. To date no significant excess of such events has been observed and we are using this result to set limits on a variety of New Physics processes. In particular, the UA group is updating and extending an analysis to obtain limits on anomalous $ZZ\gamma$ couplings [2,3] and on a class of supersymmetric models [4] in which the gravitino is assumed to be the lightest supersymmetric particle. This analysis was initiated by the UA group over a year ago, and results based on the 1991 data have already been published [5]. Our plan is to include the results from the present analysis in a L3 paper to be submitted for publication around the end of the year.

Regarding the future, we make four points. The intention of the L3 single-photon analysis group is to continue and further refine the analysis of single-photon events toward making a measurement of Γ_{inv} based on the data collected at LEP1. Realistically, one expects that LEP will continue to operate mainly around the Z pole through at least the end of 1994 with the transition to LEP2 ($s^{1/2} \approx 180$ GeV) commencing in earnest sometime in 1995, so the data used in the measurement will come mainly from 1990-4. LEP's track record through the present writing indicates that the total useful integrated luminosity for single-photon counting will be about 100 pb^{-1} for this period. In that case, the statistical uncertainty will be in the range of 2--3%. Now, given the excellent agreement to date between LEP data and the Standard Model, one would prefer to reach a precision better than 2-3% as deviations, if any, from the Standard Model

are small. Since likely LEP performance precludes achieving smaller statistical uncertainties, however, the best we can do is to reduce systematic errors to the level where the overall error will be dominated by the statistical error. This means reducing the present systematic error by at least a factor of two, which in turn means substantial effort to further improve our understanding of the single-photon trigger efficiency, the electromagnetic energy scale, cosmic contamination, electromagnetic backgrounds, and selection cut efficiency. Continuing along present lines, the UA group will focus on helping understand the electromagnetic backgrounds and selection cut efficiency, especially as it is affected by detector noise levels.

The second point has to do with searching for New Physics via the study of energetic single-photon events at LEP1. As is natural at LEP1, one focuses on processes involving Z-exchange, e.g. $Z \rightarrow Z^* \gamma$, $Z^* \rightarrow \nu\bar{\nu}$ as expected from some compositeness models (Z^* here refers to the daughter Z), and thus the sensitivity is limited by the number of Z's that are produced. For the current run through the end of LEP1, we expect a severalfold increase in Z statistics. A major thrust of the UA group effort in the single-photon analysis will be toward assessing the implications of the increased statistics for New Physics processes having energetic single-photon event signatures.

The third point we make concerning the future of single-photon physics pertains to LEP2. As the energy is increased from LEP1 to LEP2, if the threshold for production of a pair of stable, weakly interacting particles is crossed, the only way the threshold can be detected, if at all, is by observing an increase in the single-photon counting rate. The measurement of $ZZ\gamma$ and $Z\gamma\gamma$ couplings at LEP2 energies using the single-photon channel may also be of interest. The single-photon analysis group is now undertaking studies, using the experience of the single-photon analysis at LEP1 and Monte Carlo simulations of physics at LEP2 energies, to carefully evaluate the potential of single-photon analyses at LEP2 energies.

Finally, we would mention that, beginning with latter part of the 1993 run, the UA group has undertaken responsibility for monitoring the quality of single-photon data from trigger level through the off-line reconstruction and first round of event selection. This is a well-defined task, involving the running of a series of

programs and then checking several output variables and distributions, and can be carried out remotely using Internet. This work will ultimately be taken over by the students within the group who are still in Alabama taking courses and it will not only enable them to provide a valuable service to the single-photon physics effort but also will serve to introduce them to important features of the L3 data acquisition system and offline data processing.

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L3

Figure VI.1. Single-photon energy spectrum

Figure VI.2. Scan-program view of energetic single-photon event

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