DATA ANALYSIS FOR A LASER BASED DISPLACEMENT MONITORING SYSTEM OF A SILICON STRIP DETECTOR AT CERN

Gyöngyi L. Marian*
Kossuth Lajos University, Institute of Experimental Physics
Debrecen 4001, POB: 105, Hungary
and Institute for Nuclear Research of the Hungarian Academy of Sciences, Debrecen

Mark Behrens †
Department of Physics and Astronomy
University of Alabama
Tuscaloosa, AL 35487 USA

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ABSTRACT

The Silicon Microvertex Detector (SMD) is a subdetector of the L3 experiment at CERN. We determined the global and local displacements of the SMD sensors by analyzing data from the Laser Displacement Monitoring System.

INTRODUCTION

CERN, the European Center for Particle Physics, is located near Geneva, Switzerland. It is the largest particle physics research center in the world. In the Large Electron-Positron Collider (LEP), laboratory conditions very similar to the first few hundred billionths of a second of the beginning of the universe can be recreated. In the LEP, beams of electrons and positrons orbit in opposite directions in a 27 km circumference vacuum pipe buried in a tunnel 70 m under the surface. The beams, traveling near the speed of light, are guided by magnets to four collision points, where the L3, ALEPH, DELPHI and OPAL experiments are placed. Figure 1 shows L3, the largest detector. It has several subdetectors arranged in a layered structure: Silicon Microvertex Detector (SMD) [1]; Electromagnetic Shower Counter (BGO); Hadron Calorimeter and Muon Drift Chamber. The SMD subdetector is

Gyöngyi L. Marian graduated from the Kossuth University in Hungary. She is now a graduate student in the high energy physics group there and is a technical consultant for the Florida Institute of Technology.

Mark Behrens graduated from The University of Alabama. He is now a graduate student in mathematics at the University of Chicago.

Together, the performed the research described here at CERN (Switzerland), Kossuth University (Hungary) and the University of Alabama (USA).

Figure 1
The L3 detector consists of 5 subdetectors: Silicon Microvertex Detector (SMD), Time Expansion Chamber (TEC), Electromagnetic Shower Counter (BGO), Hadron Calorimeter and the Muon Drift Chamber. The SMD is the closest to the beam pipe. It is capable of detecting short-lived particles such as the τ *lepton .*

Figure 2
The geometry of the outer layer of the SMD. There are 12 double-sided silicon ladders (each of which has two separate half-ladders) mounted on the outer and on the inner wall of the SMD. The laser data analysis is performed taking in consideration only the data from the outer sensors of the SMD, since the laser spots illuminate only the outer half-ladders of this detector.

situated nearest to the beam pipe. It is designed to provide high precision position measurements near the interaction point. The measurements allow for reconstruction of the tracks to determine the decay point (the vertex) of short lived particles such as the τ lepton. The position of the SMD (as a rigid body) and its individual parts (sensors) might change due to thermal or other effects. Since the displacements can exceed the tracking precision, they must be monitored. The optical alignment monitoring system [2] (LDMS) identifies the location of the individual silicon sensors of the SMD with respect to the TEC to a precision on the order of 10 μm. The LDMS provides a continuous position measurement, tracking changes in the SMD geometry throughout the operational life of the detector. The LDMS was developed as a collaboration between the University of Alabama (USA) and the Kossuth Lajos University (Hungary) with contributions from the Central Research Institute for Particle Physics of the Hungarian Academy of Sciences (Hungary, the Technical University of Budapest (Hungary) and the Swiss Federal Institute of Technology (Switzerland). The present responsibility for the LDMS lies with the Florida Institute of Technology (USA) and Kossuth Lajos University (Hungary).

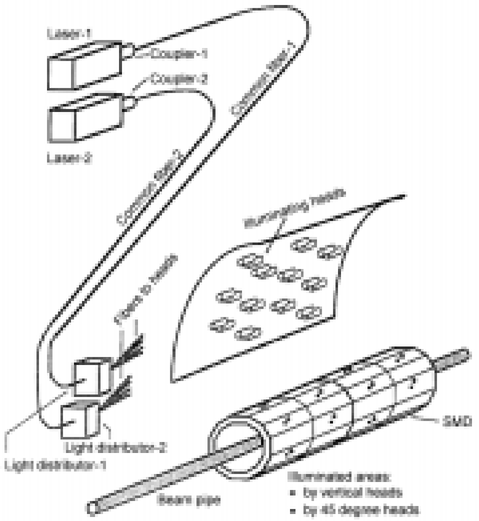

Figure 3
Schematic view of the optical laser displacement monitoring system (LDMS). Illuminating laser heads are mounted on the inner wall of the TEC (Time Expansion Chamber) which reflect the light on the surface of the SMD.

EXPERIMENTAL SETUP

The SMD is a microstrip semiconductor detector. It consists of two cylindrical layers of double sided silicon strip detectors. Each layer contains 12 silicon ladders, each of which consists of two separate half-ladders as shown in Figure 2. The latter are two electrically and mechanically joined double sided silicon sensors (wafers).

To describe the position of the pieces, a cylindrical coordinate system (r,ϕ,z) with the z axis pointing along the beam lines was chosen. On the outer side (the ϕ side) of the silicon wafer, there are strips (formed by doping the silicon and by lithographing aluminum contacts over the doped regions) that run parallel to the beam pipe intended to measure the (r- ϕ) coordinates. On the inner side (z side), the strips are perpendicular to the beam pipe and the outer strips. These strips are used when measuring the z coordinate. The readout pitch (the distance between one edge of one silicon strip to the same edge on the next silicon strip) of the SMD is 50 μm on the ϕ side and 200 μm on the z side (several strips are ganged on the z side).

The optical system of the LDMS (see Figure 3) has two IR (905 nm) laser diodes that are triggered every 10 seconds to produce 50 ns pulses. The light transmission system has two optical fibers of core diameter 400 μm transmitting the laser light to twenty four 50 μm core diameter fibers. These smaller diameter fibers transmit the light to optical heads, glued rigidly to the inner wall of the TEC. Each

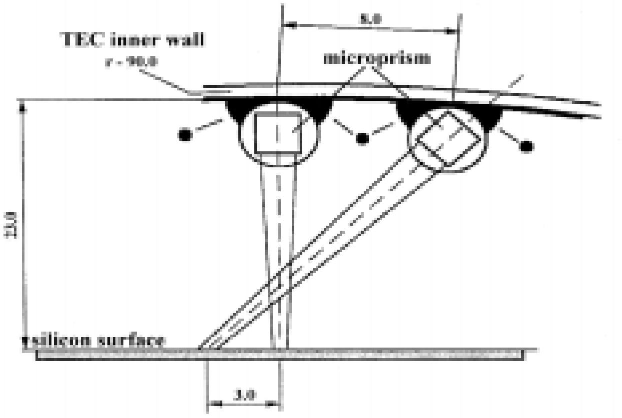

Figure 4
The optical laser heads reflect the light at 45˚ and 90˚ *angles, allowing 3 measurements in r, r-ϕ , and z directions (the r is equivalent to the distance between the 45˚ and 90˚ laser spot positions)*

head has a focusing lens and a prism that reflects the light at 45˚ and 90˚ onto the surface of the SMD as shown in Figure 4. There are 22 laser heads mounted one to a half-ladder, so there are a total 44 laser spots on the outer sensor layer. Each laser spot illuminates several neighboring readout strips. The laser light creates electron-hole pairs inside the semiconductor. Due to the electrical field applied between the two sides of this silicon sensor (junction - ϕ side and ohmic - z side), the charge carriers begin to drift and they are collected on the electrodes (strips). The electrical charge is collected from these by capacitors. At the end of each ladder, a complex read-out electronics converts the analog signals to digital format. The digitized signals are then sent to an optical receiver at the DAQ (data acquisition) “front-end” electronics. This optical receiver contains a receiver chip that converts the light signals back to electrical ones before passing them to the remainder of the DAQ.

A change in the measured centroid of the laser spots indicates relative rotational and/or translational motion between the SMD silicon sensors and the TEC. Translational movement parallel to the beam pipe is monitored on the z side; the rotation about the beam pipe is monitored on the outer ϕ side and the radial displacement from the interaction point is determined by observing the distance between the 45˚ and 90˚ spots.

ANALYSIS METHOD

The L3 event reconstruction program (REL3) is thousands of lines of FORTRAN code. It is a program that stages and reads data from tapes/disks and incorporates into its interpretation of the data important information about calibration, geometry of the detector and anything else necessary to prepare data for analysis. REL3 reads events one by one from the data storage and calls the Reconstruction User Analysis (RUANAL) subroutine. The user introduces analysis code in this subroutine.

The SMD events are retrieved from the L3 raw data stores.

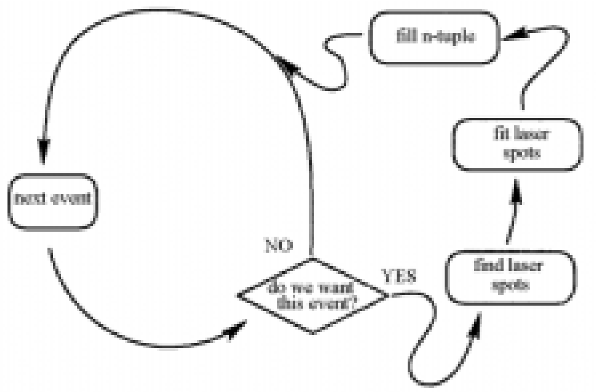

Figure 5
The event loop. The laser events are read out one by one and processed through an event loop.

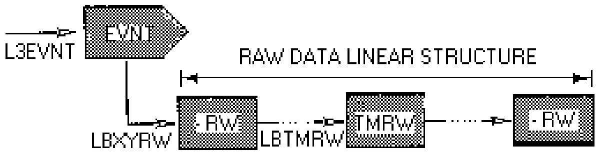

Figure 6
ZEBRA event structure. Beam Gate/laser events can be retrieved from zebra data banks using event pointers (LBEVNT, LBXYRW, LBTMRW etc.). The BG/laser bit, run number, date and time of event are in the EVNT event bank. The raw laser data can be retrieved from the TMRW data bank by following the raw linear structure the raw data banks.

The bulk of the analysis is performed at this stage. The laser spots are found and the shapes are fitted with Gaussian functions. The mean of the fitted signals, the centroid of the spot, is taken to be the positions of the laser spots. Time averages of individual positions are calculated. The reconstruction program produces an ‘hbook’ [4] file which contains ‘n-tuples’, documenting the laser spot positions with respect to time. These ‘n-tuples’ are like data tables, where the variables are the columns and each event is a row, that document the strip by strip ADC values (amplitude proportional to charge/strip) with respect to time. A set of histograms displaying the laser line shapes in the laser event is generated.

Getting an event

Inside hbook, the various data elements are stored as a ZEBRA data structure, one for each ‘identifier’.[6] In fact, all identifiers (histogram or n-tuple numbers) are stored in an ordered array in a ZEBRA bank. Access to the information associated with the hbook data is via the reference link at the same offset as the identifier in the data part of the bank. Laser events (beam gate events) can be retrieved from ZEBRA data banks with calls to subroutines in the ZEBRA data manager package (ZEBRA MZ) . From the EVNT bank, we can retrieve the run number, date and time of the event. (see Figure 6). We also are able to look at the trigger word, in which we mainly are concerned with bit 13, the Beam Gate/laser trigger. We then follow the structural link to the XXRW->YYRW linear structure, in which all of the raw data may be found. In this linear structure, the TMRW bank in which the raw LDMS data are stored, is picked out.

Finding the spots

We developed a simple clustering algorithm to pick out the laser signal. The aim was to be quick, yet versatile enough to compensate for the lack of uniformity in the laser signals. Windows were defined on the appropriate half-ladders in which the laser signals were expected to appear from the design geometry. The ADC counts read in the strips within these windows were then scanned by a cluster finding algorithm to determine the existence and approximate location of the laser signal.

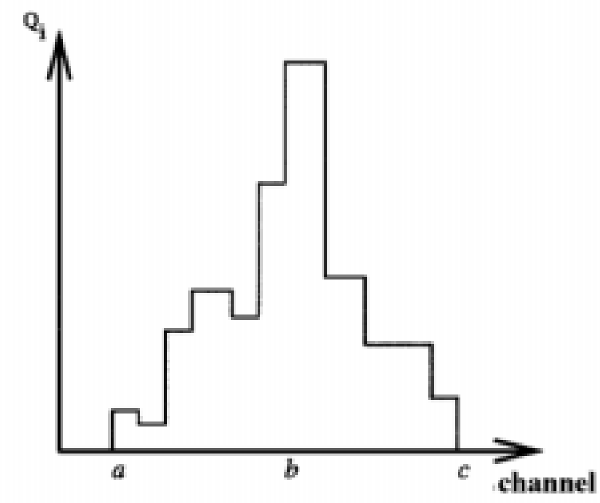

Figure 7
An example of the distribution of the charge produced by the laser light in the silicon sensor. a, b and c correspond to the first, last and maximum channel of the 'cluster'.

Cluster fitting
In LDMS data analysis, 'cluster' (see Figure 7) means groups of ADC signals. Having determined the existence of a cluster, the next step is to measure its position. We assume that:

° The charge Q_i read in the i^{th} channel of the cluster follows a normal distribution:

$$P(Q_i)dQ = \frac{1}{k\sqrt{2\pi < Q_i >}} \exp\left[-\frac{\left(Q - <Q_i>\right)^2}{2k^2 <Q_i>}\right] dQ, \tag{1}$$

where k is a constant of proportionality with dimensions of the square root of charge and δQ_i proportional to the square root of the expectation value $<Q_i>$:

$$\delta Q_i = k\sqrt{<Q_i>}\ . \tag{2}$$

° The charge distribution produced in the silicon by the laser itself follows a normal distribution.

Hence, we may fit the charge distribution with a Gaussian by minimizing:

$$\gamma^2(N, <x>, \sigma) = \sum_i^{\infty} \frac{\left[Q_i - N \exp \frac{\left(x_i - <x>\right)^2}{2\,\sigma_2^2}\right]^2}{k^2 Q_i}, \tag{3}$$

where x_i is the spatial position of the i^{th} strip in the cluster, N, $<x>$ and σ are the normalization, mean and width of the fitted Gaussian and $<x>$ is the position of the laser spot. The associated error of $<x>$, $\delta<x>$, is obtained numerically from the principal radius of curvature of γ^2 (Equation 3) about its minimum in the <x> direction.

Time Averaging
The time average position is determined for each spot on an event by event basis. The laser spot position can be determined to a resolution of about 10 µm using Equation 3. The time average interval was chosen to be approximately 15 minutes, as movement due to temperature changes occurs over longer times. The time average, $<X>$ is found using a least squares method:

$$< X > = \frac{\sum_i \frac{< x_i >}{\left(\delta < x_i >\right)^2}}{\sum_i \frac{1}{\left(\delta < x_i >\right)^2}}, \tag{4}$$

where the position values $<x_i>$ are weighted by the inverse square of their errors $\delta<x_i>$. The associated error $\delta<X>$ is given by:

$$\delta < X > = \frac{1}{\sqrt{\sum_i \frac{1}{\left(\delta < x_i >\right)^2}}}. \tag{5}$$

RESULTS

The laser signal produced by one laser head at five different times of the year is presented in Figure 8. In Figure 9, the displacements are plotted versus time. The error bars represent statistical errors. The resolution of the z displacements is not as good as that of either the radial or tangential position due the readout pitch of the SMD is 150-200 µm on the z side as compared to 50 µm on the ϕ side. One can see the breaks in the data separating three L3 data taking periods. The gap around day 250 was caused by a crate power failure.

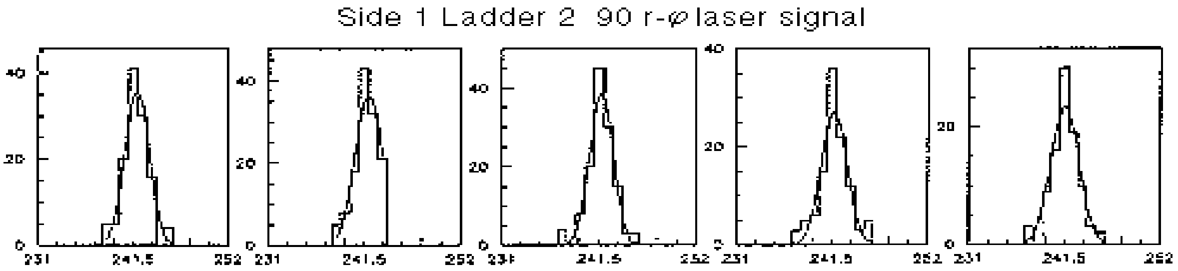

Figure 8
A fitted SMD signal from the same laser head over time.

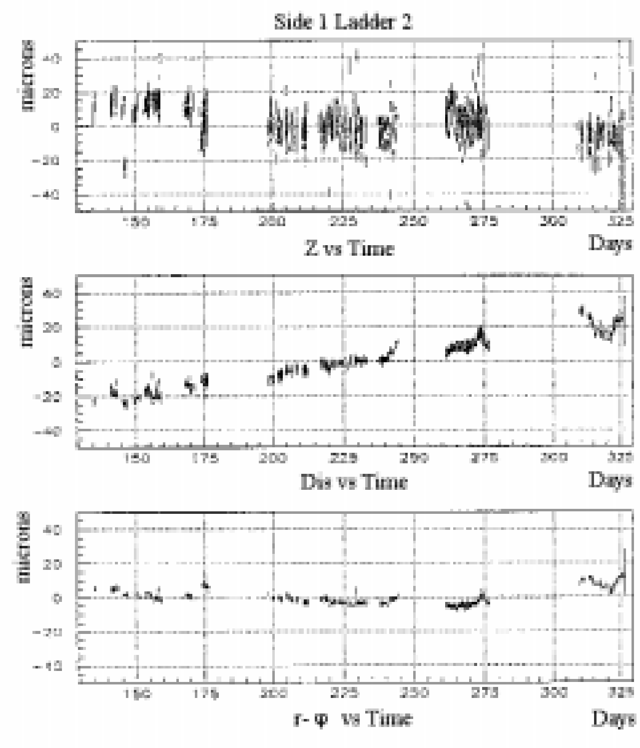

Figure 9
SMD movement parallel to the beam (z vs time); rotationally about the beam ($r-\phi$ vs time); and radially from the interaction point (Dis ≈ R vs time).

The time averaged plots are used to determine the movements of the half-ladders. In Figure 9, notice that the distance between the 90˚ and 45˚ spots is increasing. This indicates that one half-ladder has a steady radial movement of ≈ 40 μm towards the interaction point. In the r-ϕ direction, the rotational movement is ≈10 μm.

The displacements of all of the SMD half-ladders were compared. In the radial directions, a semi-local behavior isolated to a few half-ladders was observed. A small (≈10 μm) global displacement of the half-ladders was also observed.

LDMS is a sensitive and powerful monitor of the SMD displacement. It is sensitive to displacements on the order of a few microns. It is ultimately limited by the SMD's strip pitch, which is an order of magnitude greater. LDMS is able to resolve local as well as global SMD displacement trends. It has fulfilled, and in many respects exceeded, its design parameters.

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* Current address of author: Department of Physics and Space Sciences, Florida Institute of Technology, 150 W. University Blvd., Melbourne, FL 32901. Magyongyi@aol.com

† Current address of author: Department of Mathematics, The University of Chicago, 5734S. University Avenue, Chicago, IL 60637.

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Professor Laszló Baksay, Head
Department of Physics and Space Sciences
Florida Institute of Technology
150 West University Boulevard
Melbourne, FL 32901
baksay@pss.fit.edu