Laser Alignment System for LumiCal

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December 16, 2008

Abstract

The main achievements in laser positioning system for LumiCal calorimeters, developed within EUDET project and FCAL Collaboration, are reported. LumiCal will be used to measure precisely the luminosity in experiments at the future ILC. The optical method for the displacement measurements of the LumiCal was tested using laboratory setup with two laser beams and CCD camera as the basic elements. The precision of the displacement measurements is estimated to be 0.5 μm in X and Y direction and 1.5 μm in Z direction The system was sensitive to temperature changes on the level below 1 μm /1^0 C. These results allowed us to design and build the prototype with a dedicated CMOS sensor instead of CCD camera. Such a compact system will be applied for automatic sensor readout and position calculations. Presently, tests of the readout chain and the transfer data to the host PC are ongoing. The integration of the LumiCal within the ILD detector concept leads to some possible solutions for the absolute distance measurements between the Left and Right calorimeters of LumiCal. The other activity concentrates on a method for measurements of the displacement of the individual sensor layers inside LumiCal.

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1 Introduction

In the framework of the International Large Detector (ILD) [1], one of the three detector concepts considered for the International Linear Collider (ILC) [2], the luminosity detector LumiCal will be located in a very forward region, which is a particularly challenging area for instrumentation. The LumiCal detector [3], which contains two silicon-tungsten calorimeters, is expected to give a required precision luminosity measurement and to extend calorimetric coverage mainly for electrons and photons at low polar angles between 30 and 80 mrad. The luminosity measurement will be based on the determination of Bhabha events rate and a relative precision of the integrated luminosity better then of 10^{-3} will be achievable. To fulfill this task it is necessary to build a detector with micrometers precision and to have an online system (laser positioning system) for a displacement monitoring of the LumiCal [4] with an accuracy of a few hundred micrometers and the displacement of its internal layers with an accuracy of a few micrometers. The integration of the LumiCal with ILD raises several questions related to available free space also for elements of such a laser alignment system (LAS) and detector installation procedure. Another problem can stem from requirements to have easy access to subdetectors. Hence, further extensions and modifications of the LAS will be necessary.

2 Requirements

The luminosity measurement requires precise alignment of the two LumiCal calorimeters (Left, Right), each to the other, and very precise positioning of each of them with respect to the beam line and the interaction point, as illustrated in Figure 1.

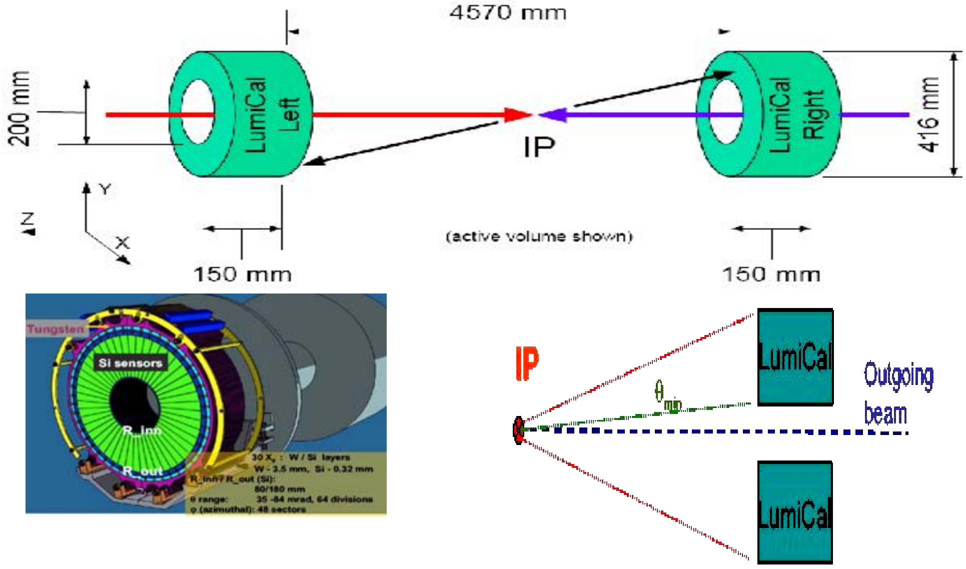

Figure 1. The parts of the LumiCal detector located in respect to Interaction Point (IP). Top: Left and Right calorimeters; Bottom: The structure of the single calorimeter.

Monte Carlo simulations have shown [4,5] that the inner radius of sensors layers has to be known with the accuracy better than 4 µm, the distance between calorimeters along the beam axis must be known to an accuracy of 100 µm over the 4.5 m distance, and the transversal displacement (X, Y) with respect to the beam must be known with an uncertainty better than 700 μm. According to [2], the crossing angle for electron and positron beams at ILC will be 14 mrad and LumiCal will be centered on outgoing beam. What is particularly important for measuring precisely the luminosity is the knowledge of the inner acceptance radius of LumiCAl which defines the minimum polar angle angle θ_{min} (Fig. 1). Practically, the radial position of the sensors has to be measured with an uncertainty of 4 μm. The initial value for this radius can be measured in the lab using optical methods and precision movable table. The beam pipe is proposed as a suitable reference for the distance along the beam and transversal displacement and can be precisely surveyed before installing under different conditions (i.e. temperature). The temperature sensors should be installed on the beam pipe to control and correct the mechanical dimensions. Additionally, the Beam Position Monitors are mounted at a well known position inside the vacuum pipe, which allows for determining the actual position of LumiCal with respect to the beam position. A similar method can be used by choosing well known positions of QD0 magnets as reference frame. The online monitoring of the detector position should not interfere with the beam pipe, hence a non contact system is preferred. For this purpose an optical laser system with a CCD matrix sensor to measure the transversal (X, Y) and longitudinal (Z) displacement of the LumiCal with respect to the beam pipe flange has been chosen. The position sensors will be placed between the rear side of the detector and beam pipe flange. To minimize the influence of radiation in that area, the radiation hard CMOS matrix sensors can be used instead. The use of a few position sensors per calorimeter would give the possibility of measuring also the angle between detector axis and beam direction. For absolute measurements of the distance between two calorimeters it will be necessary to implement the frequency scanned interferometry (FSI) system.

3 The laser positioning system

For the LumiCal position measurements and monitoring, the laser positioning system was proposed by INPPAS Cracow and then built and tested in laboratory environment [4]. Figure 2 shows the laboratory setup which was used to test the principle and determine the accuracy of the position measurement. The base elements were CCD camera, laser beams, mirrors and filters. The camera was placed on the XYZ travel translation stage with 10 micrometers steps and the corresponding lasers were mounted in a special

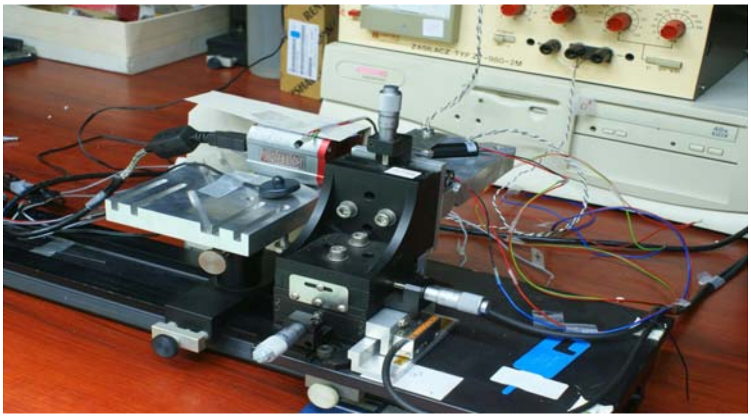

Figure 2. The laboratory setup used in tests of the laser positioning system.

holder in front of the camera. The camera displacement has been controlled independently by using optical linear encoder with resolution of 0.1 μm. The reduction of the laser light intensity needed to avoid saturation in the pixel sensor was done with colour-neutral filters.

In the final test measurements two laser beams were used. One was perpendicular to the face of a CCD camera while the other forms 45 degrees angle with the face. Reading out the CCD camera one can find two laser spots of different shape as shown in Figure 3. The spot position of the perpendicular laser beam gives displacement in (X-Y) plane whereas the distance measurement between two spots

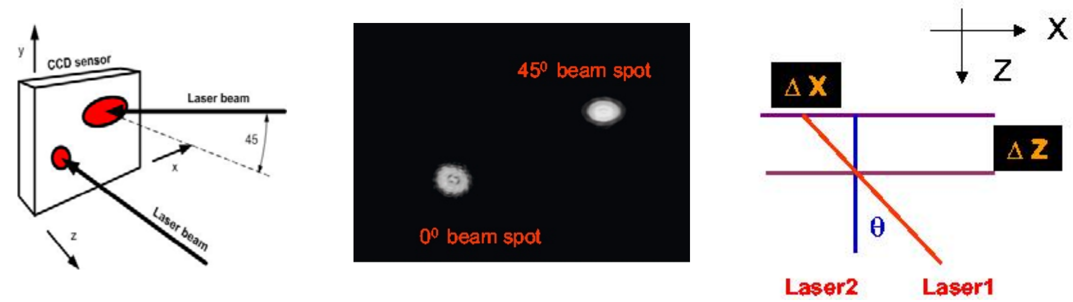

Figure 3. Simplified scheme of the method of X,Y and Z displacement measurements with two laser beams created the beam spots observed on the face of CCD camera.

allow for the displacement calculation in Z direction. The centre of the spots were calculated using an algorithm to calculate an average of the pixel coordinates within the spot weighted by the light intensity. A threshold on the ixel signal is applied to remove electronics noise. The obtained accuracy in X and Y position measurements was 0.5 µm and in Z direction 1.5 µm [4]. The sensitivity of the system to the temperature changes was found to be below 1 µm/1^{0}C in the long term measurements. Figure 4 (left) shows as an example changes in the values of both laser beam spots centres as calculated in relation to reference values when temperature changes were 5 degrees while the Figure 4 (right) shows the changes in the relative distance between two spots when

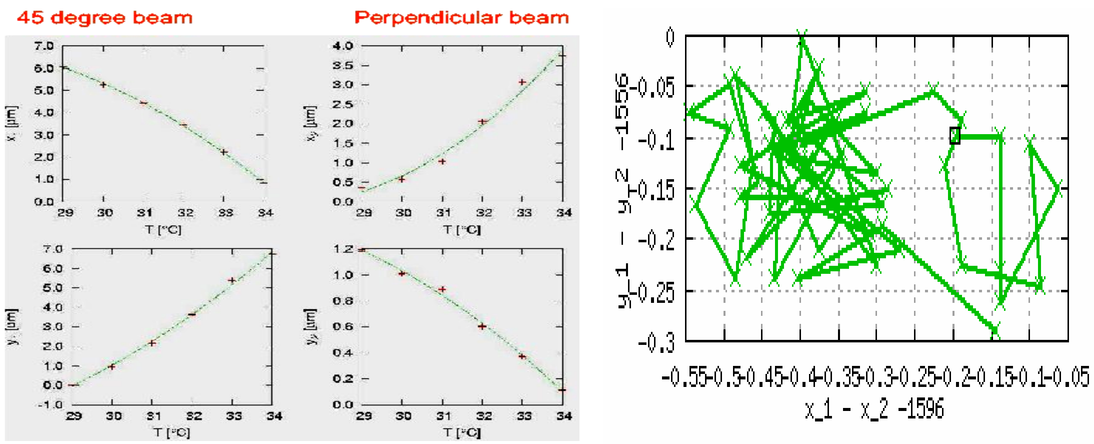

Figure 4. Left: The shift of the laser beam spot positions according to temperature rise in thermally insulated chamber; Right: The relative distance in the long term measurements with a fixed value of the temperature.

the temperature was stabilized at level 0.1 degree. These results satisfy completely the necessary precision required for LumiCal position monitoring.
Therefore in the next step of laser positioning system development this laboratory system was replaced by a prototype with a dedicated CMOS sensor instead of CCD camera [6].

This prototype, compact in shape, will be applied for an automatic readout and position calculation. Presently, the work is concentrated on the test readout of this prototype. Figure 5 shows the system undergoing the laboratory tests.

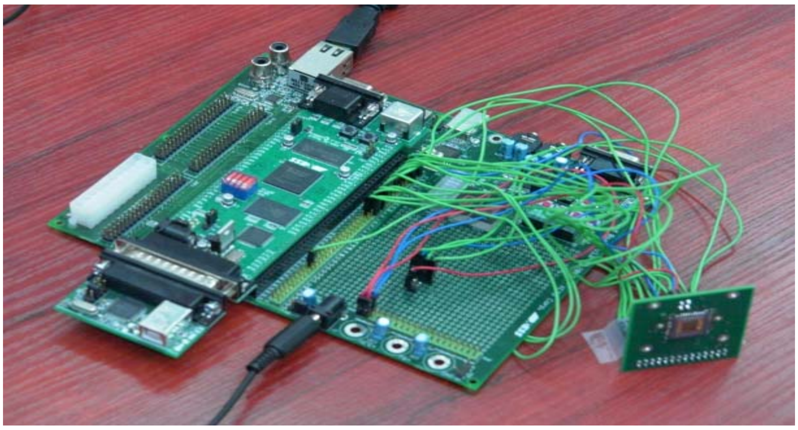

Figure 5. The prototype of the system which will be used readout of the dedicated CMOS and data transfer for automatic position calculations.

The block diagram of the whole chain including the readout system of the dedicated CMOS sensor and data transfer to host PC where the position calculation will be done, can be seen in Figure 6.

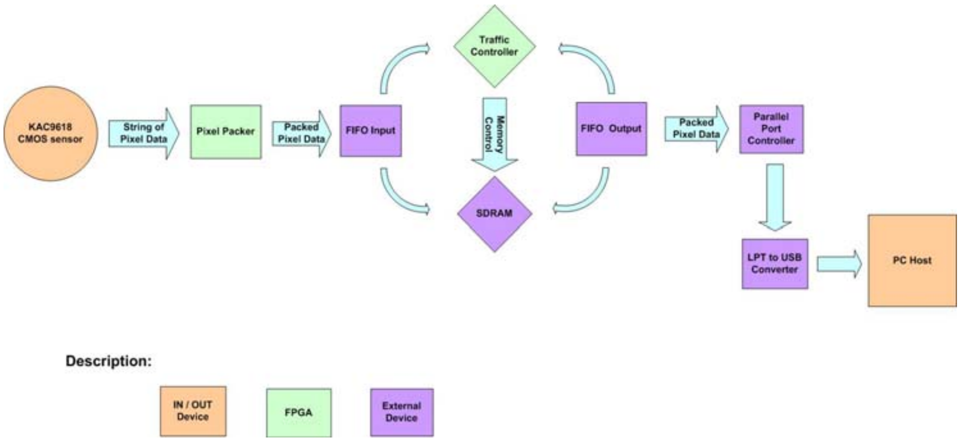

Figure 6. Block diagram of the readout system with dedicated CMOS optical sensor and data transfer to a host PC.

The data collected by CMOS sensor will be readout on-line and transformed to the output format acceptable for a host PC computer, where all displacement calculations will be performed. The test of readout system of the prototype is ongoing [7].

Futher development of laser positioning system for LumiCal concentrates presently also on an aspect of integration of LumiCal into the ILD detector and the design of the system which will allow for the displacement meaurement of the individual sensor layers inside LumiCal.

4 Integration with ILD

LumiCal will be placed inside the ILD detector as shown in Figure 7. An extension of the LAS should allow the displacement measurement of the calorimeters with respect to QD0 magnet or the beam position monitors. This requires additional infrastructure around the beam pipe. In an simplified approach e.g. six laser beams of the laser positioning system described above will be installed inside the carbon support for the beam pipe.

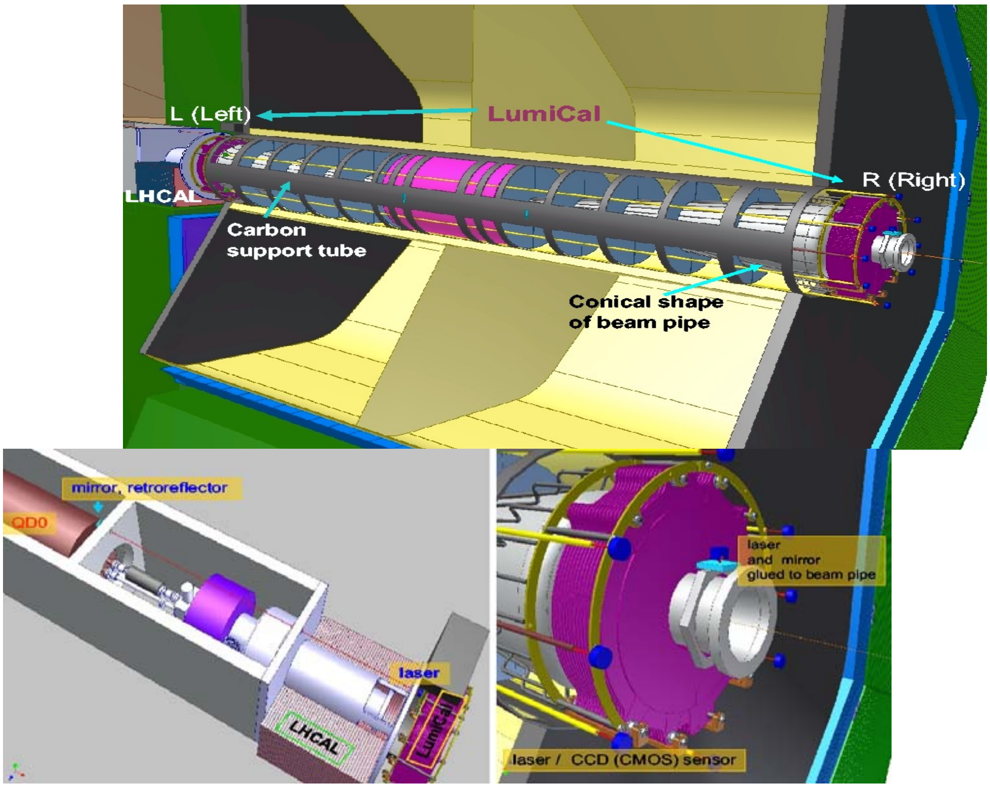

Figure 7. Top: The LumiCal calorimeters inside ILD detector geometry with laser beam lines which can be used in the distance measurement between calorimeters; Bottom: possibility of use the positions information of QD0 magnet and beam pipe for LAS of LumiCal detector.

For the monitoring of the distance between the two calorimeters a more sophisticated system based on frequency scanned interferometry (FSI) should be used [8]. Such a system may be designed together with a more general alignment system of the detector and was not the subject of this project.

5 Conclusions

A method was proved to monitor displacements of the LumiCal detector using two laser beams with 0 and 45 degrees angles and a CMOS pixel sensor. The accuracy reached 0.5 μm for shifts in the plane perpendicular to one of the laser beams and 1.5 μm in the direction along this laser beam is better than required from physics.
The integration of the system into a detector concept like ILD will require additional modifications. Due to the limited space around the beam pipe the system may be used for position monitoring with respect to reference points not too far from the LumiCal.
To control displacements over large distances, e.g. the distance between the two calorimeters, the systems based on other principles must be developed.

Acknowledgements

This work is partly supported by:
Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area", contract number RII3-026126
and
The Polish Ministry of Science and Higher Education
under Agreement No. 141/6.PR UE/2007/7.

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