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Laser Alignment System for LumiCal
Status report

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Abstract

The silicon-tungsten calorimeter LumiCal, located in a very forward region of the future detector at the International Linear Collider, is proposed for precise luminosity measurement. One of the requirements to fulfil this task is the availability of the information on the actual position of the calorimeter relative to the beam interaction area which should be known with the accuracy of a few micrometers. In this paper the possible solutions for the positioning of the LumiCal detector using laser alignment system (LAS) are discussed. The basic components of this system are laser beams and CCD camera. The results of the several displacement measurements are presented. The measurements achieved the accuracy ± 0.5 μm in X, Y and ± 1.5 μm in Z direction. The further studies on the laser alignment system development are discussed.

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1 Introduction

In the future detector for the International Linear Collider (ILC) with colliding beams of electrons and positrons e^+e^-) [1], the very forward region is a particularly challenging area for instrumentation. The LumiCal detector [2] is expected to give a required precision luminosity measurement and to extend calorimetric coverage of small angles of electron emission from 28 to 90 mrad. The luminosity measurement will be based on the detection of Bhabha event rate and a relative precision of the integrated luminosity of 10^{-4} will be enabled. A precise measurement of the scattering polar angles requires an ultimate precision in detector mechanical construction and metrology. The crucial point is to monitor on-line the detector displacement under operation with respect to the colliding beams.

2 Requirements

The luminosity measurement requires extremely precise alignment of the two LumiCal detectors (Left, Right), each with respect to the other, and a very precise positioning each of them (Up, Down) with respect to the beam line and the interaction point, as illustrated on Fig. 1.

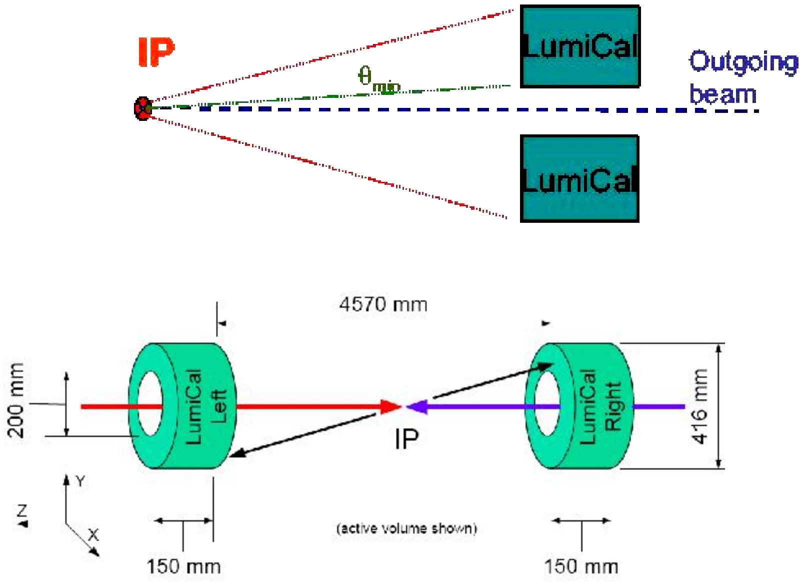

Fig. 1. The schematic view of the single (Up, Down) (top) and whole (Left, Right) (bottom) LumiCal detector.

Monte Carlo simulations have shown [3] that the inner radius of sensors' layers have to be known with the accuracy better than 4 µm, the distance between calorimeters along the beam axis must be known to the accuracy of (60 – 100) µm over the 5 m distance and the transversal displacement (X, Y) with respect to the beam should be known with the accuracy better than 700 µm (with optimal 100 – 200 µm), where LumiCal will be centered on outgoing beam (with the basic parameter of 14 mrad crossing angle for beams for ILC). Initial inner radius of the detector can be measured in the lab using optical methods and precision movable table with the cross check of interferometer. 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 and tension sensors should be installed on the beam pipe to control and correct the mechanical dimensions. The Beam Position Monitors are mounted at a well-known position inside the vacuum pipe, which would allow for determining the actual position of LumiCal with respect to the beam position.

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, designed 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 the beam pipe flange. The radiation dose in that area seems to be small because of shielding, but the radiation hardness of the sensor has to be studied. In the event that the radiation dose is not acceptable, one can use radiation hard CMOS matrix sensors. The use of a few position sensors per calorimeter would allow us to determine also the angle between detector axis and beam direction and would assure better reliability in case of position sensor failure.

3 Measurement setup

The laboratory setup includes the semiconductor laser module LDM635/1LT from Roithner Lasertechnik with the wavelength of 660 nm and BW camera DX1-1394a from Kappa company 640 x 480 with Sony ICX424AL sensor 7.4 µm x 7.4 µm unit cell size.

The corresponding lasers are mounted in a special precision alignment holder on the optical bank. The CCD camera is placed on the XYZ ThorLabs ½” travel translation stage MT3 with micrometers (smallest div. 10 µm). To control independently the camera displacement the Renishaw optical head linear encoder RG24 with resolution of 0.1 µm was used. In case of the sensor saturation, the reduction of the amount of laser light was done using 3 neutral density filters with the attenuation factor of 2 each. The principle of the method for the LumiCal displacement measurements with LAS is presented in Fig. 2. The camera was translated in one (X,Y) direction in 50 µm steps and the picture was taken. To measure the longitudinal (Z) displacement the second laser beam lighting the sensor with the angle of 45 degrees was used.

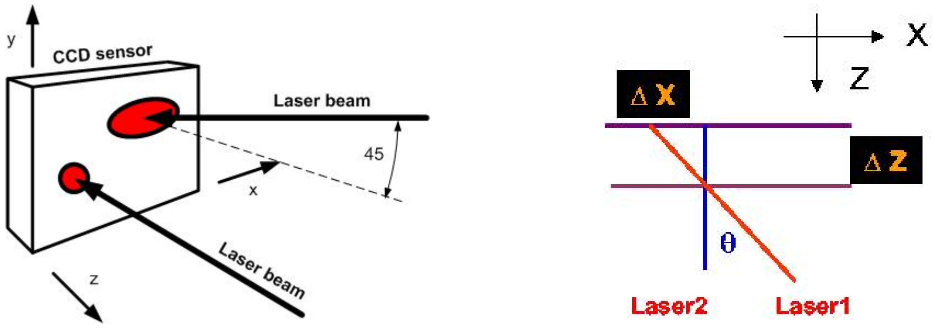

Fig.2. Simplified diagram of two laser beams setup used in the LAS method.

In the first measurements with only one laser we used a half transparent mirror to split the laser beam and another mirror to direct it to the sensor with the proper angle. The picture of the laboratory setup is shown in Fig. 3.

Fig. 3. Picture of the laboratory setup with split laser beam (left) and two laser beams (right).

The shape of laser beam spots on the face of CCD camera are shown in Fig. 4.

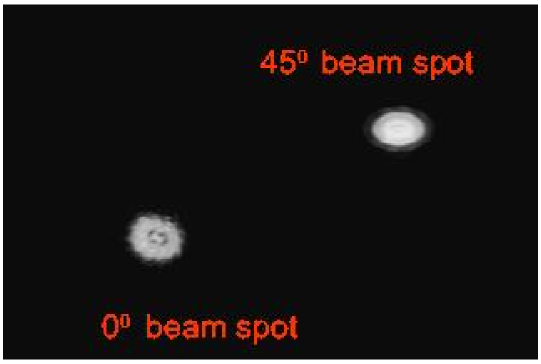

Fig. 4. The shape of two laser spots on the face of CCD camera.

4 Results

Two algorithms to calculate the center of each beam spot were developed and both are in agreement. The development of algorithms to determine the center of beam spots is still in progress because there is an area to achieve better accuracy. The results with the use of the last developed algorithm shown in Fig. 5 for measurement in X direction are very promising. The difference between real (as obtained with Renishow optical head linear encoder) and calculated (using algorithm) position was ± 0.5 µm.

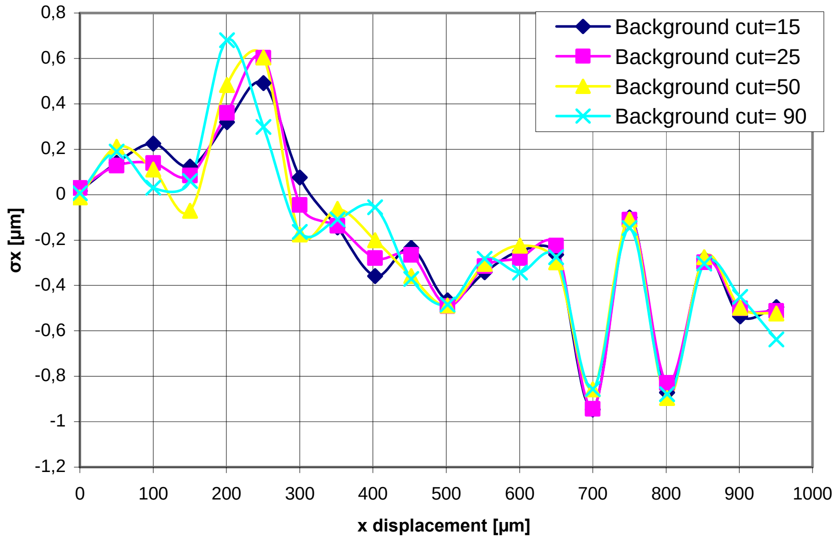

Fig. 5. The difference between calculated and real position in X direction.

Such a value comes from a lot of series of measurements and the results vary little.
The previous results of displacement measurements in transversal direction using a low cost web camera can be found in [4]. The progress of the measurement method development was presented during a few workshops [5].
The results of displacement measurement in Z direction are shown in Fig. 6.

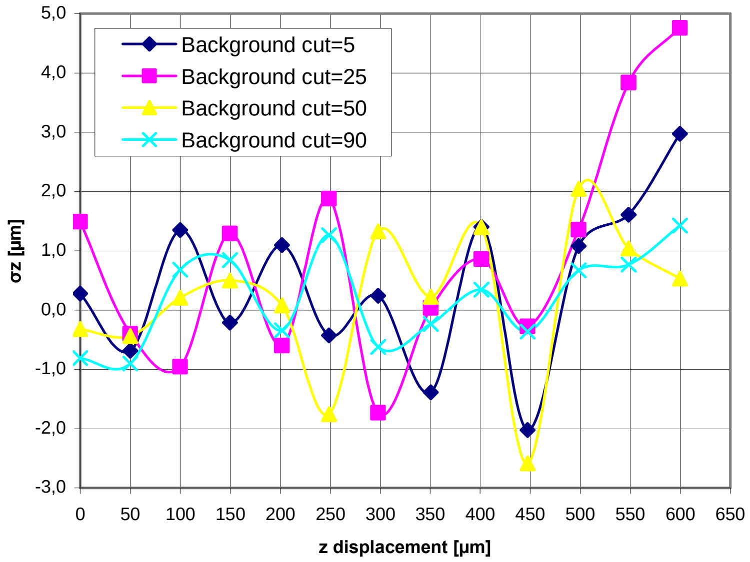

Fig. 6. The difference between calculated and real position in Z direction.

The accuracy obtained in Z direction measurements was ± 1.5 μm. For both kinds of measurements the results are presented with different background cuts on the light intensity (range 0-255). One can notice that for X (Y) displacement measurement such a background cut changes the results slightly, but in Z direction the changes are higher, probably due to the beam spot shape. This effect should be investigated further.

4.1 The temperature effect on the displacement measurements

The sensitivity of the position measurements using LAS to temperature was studied in several measurements, where temperature changes were ± 5 degrees (by heating or cooling down the LAS environment). For each temperature point, the average position of the spot centers from multiple measurements was calculated using the improved algorithm. As an example, Fig. 7 shows changes in the positions of the centres of both laser spots as calculated in relation to reference values.

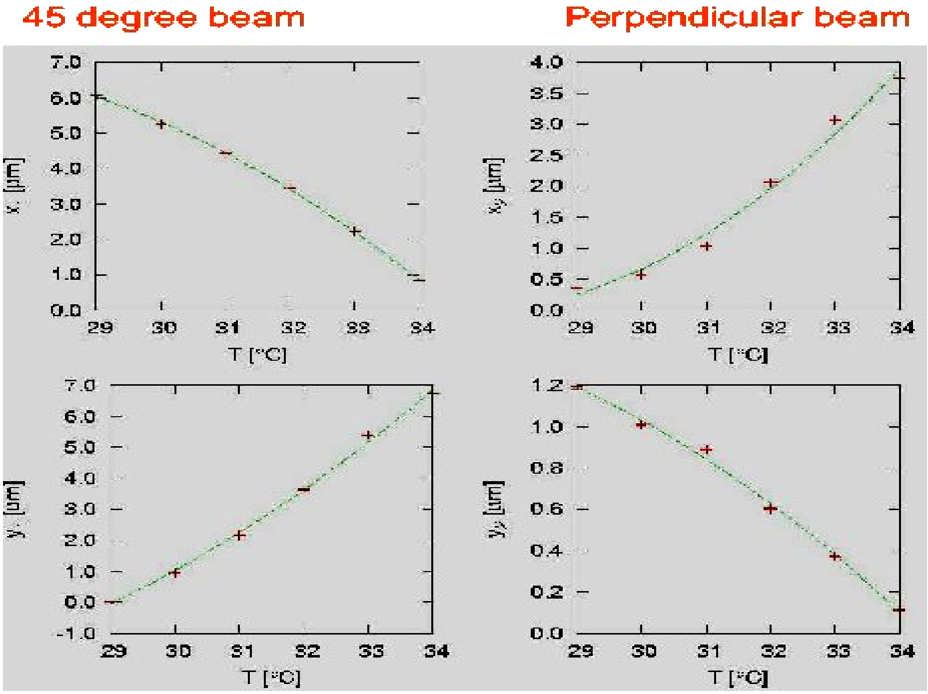

Fig. 7. The shift of the laser beam spot positions according to a temperature rise in a thermally insulated chamber.

The observed changes in spots positions did not exceed 1 µm on 1^0 C.

4.2 Measurements with temperature stabilization

In other long term (> 8 hours) measurements, where the temperature was stabilized (the changes not larger then $\pm 0.1^0$ C were accepted), we checked the possibility of appearance of the effects coming from the nature of the laser spot itself, together with systematic uncertainties in the used algorithm. Figure 8 shows the observed fluctuations in the positions of both laser spots. Those positions were calculated on the basis of the algorithm and compared with the true positions.

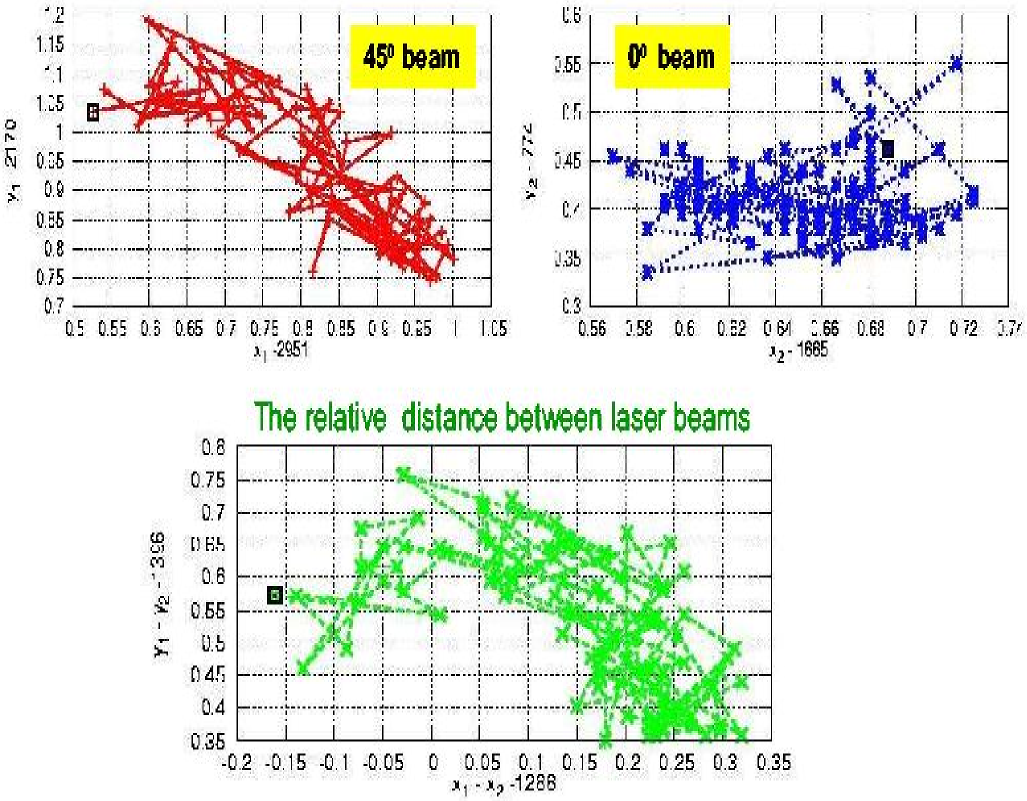

Fig. 8. The individual laser spots positions and their relative distance in the long term measurements with a fixed value of the temperature.

The observed changes in calculated X (Y) spots positions were on the level 0.5 µm. Such measurements indicate that even with temperature stabilization the other effects partially related to the nature of the laser spot and uncertainties in used algorithm can contribute to measurement results on the level below 1 µm. In further studies also the collimator for the laser beam spot and laser optics will be improved.

5 The development of LAS

Several activities on the LAS development are being conducted:

1. The readout electronics for dedicated silicon sensor CMOS with automatic calculation of the detector displacement and compact shape of the system
2. Integration of the LumiCal and LAS in the framework of the main ILC detector LDC (ILD)
3. The method which allows us to measure the displacement of the individual sensor layers inside the LumiCal.

5.1 CMOS sensor and readout electronics

Figure 9 shows the schematic view of the dedicated CMOS sensor and the elements of the readout electronics. The information collected by CMOS sensor will be readout on-line and transformed to the output format acceptable for host PC computer, where all displacement calculations will be performed [6].

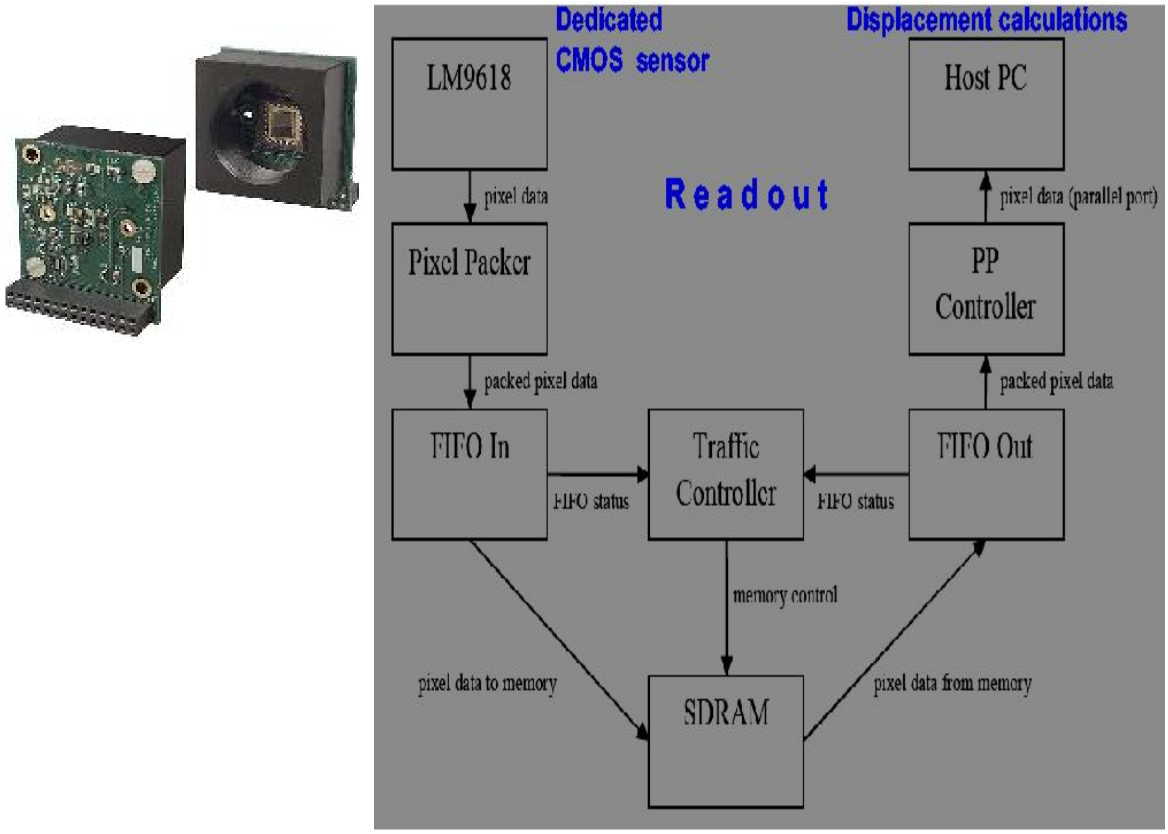

Fig. 9. Schematic diagram of the readout electronics for dedicated CMOS sensor.

5.2 Integration with the main detector LDC (ILD)

The LumiCal, being one of the detectors working in very forward region, will be placed inside the main ILC detector, LDC (ILD), in way as illustrated in Fig. 10. The complete phase of integration will give rise to many problems related to available free space and to the mechanical LumiCal installation together with the whole readout electronics and cooling system. Another problem can result from providing the access to the detector. Also the LAS will require several modifications. There are concepts which involve the use of another optical alignment system like RASNIK [7] or the method based on interferometers and frequency scanned interferometry (FSI) system.

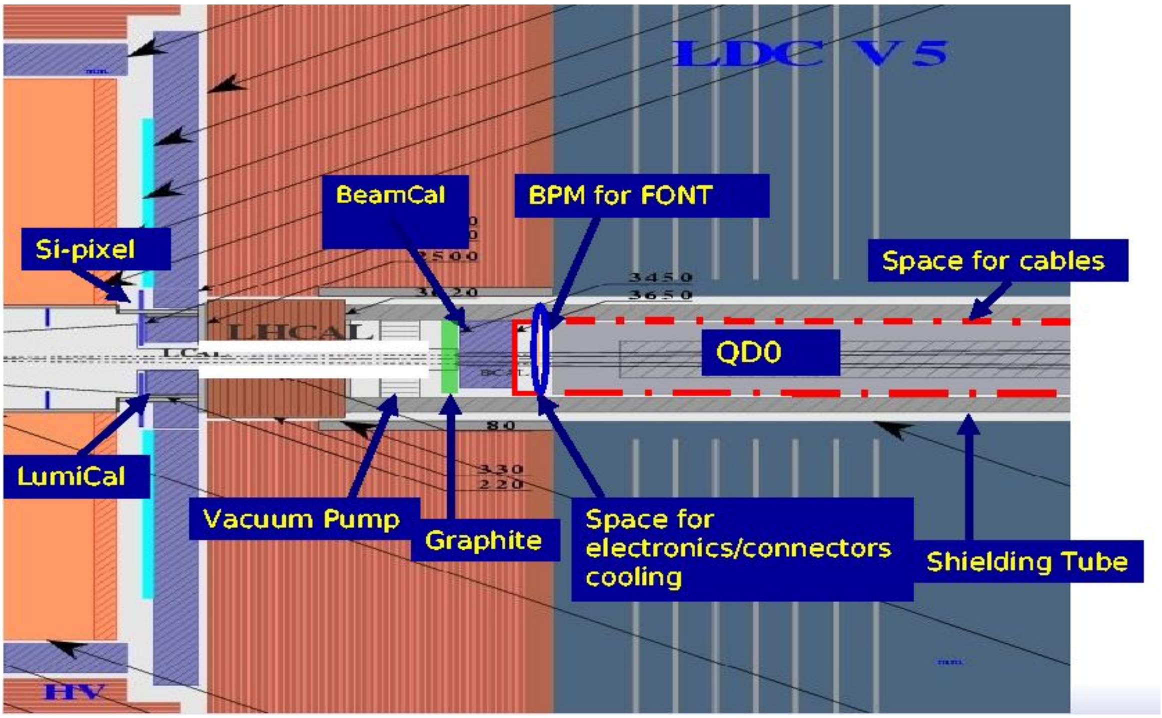

Fig. 10. Location of the LumiCal inside one of the recent versions of LDC detector geometry.

Figure 11 shows the possible extension of LAS which will allow for displacement measurement for single and double LumiCal inside LDC (ILD). It will require at least six laser beams operating inside special carbon support tube (in Fig. 10 only a part of such a pipe in front of the LumiCal is visible). In future this concept can include also a system of interferometers.

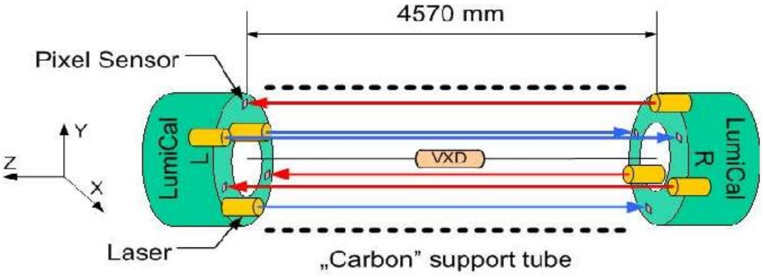

Fig. 11. Proposal of the system with six laser beams for displacement measurement of LumiCal.

5.3 Measurement of the individual sensor layers

Figure 12 shows one of the possibilities for on-line measurements of the individual sensor layers. This method requires a transparent position sensor (CCD, CMOS) placed on each detector sensor layer. One can use one laser beam line or an individual laser system for each sensor plane.

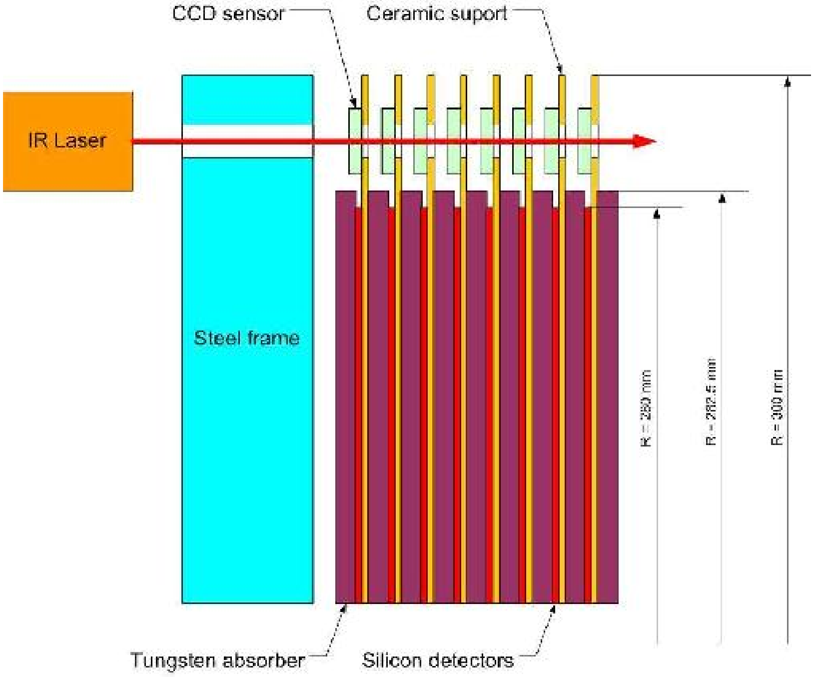

Fig. 12. The method of the displacement measurement for individual sensor layer in LumiCal with the use of a transparent sensor.

In a different method the spanned wire going through the holes in sensor planes works as antenna and picks up electrodes to measure the position. This system will be active during time slots among the bunches in a train. The expected accuracy will be in the order of 0.5 µm. Fig. 13 illustrates this concept.

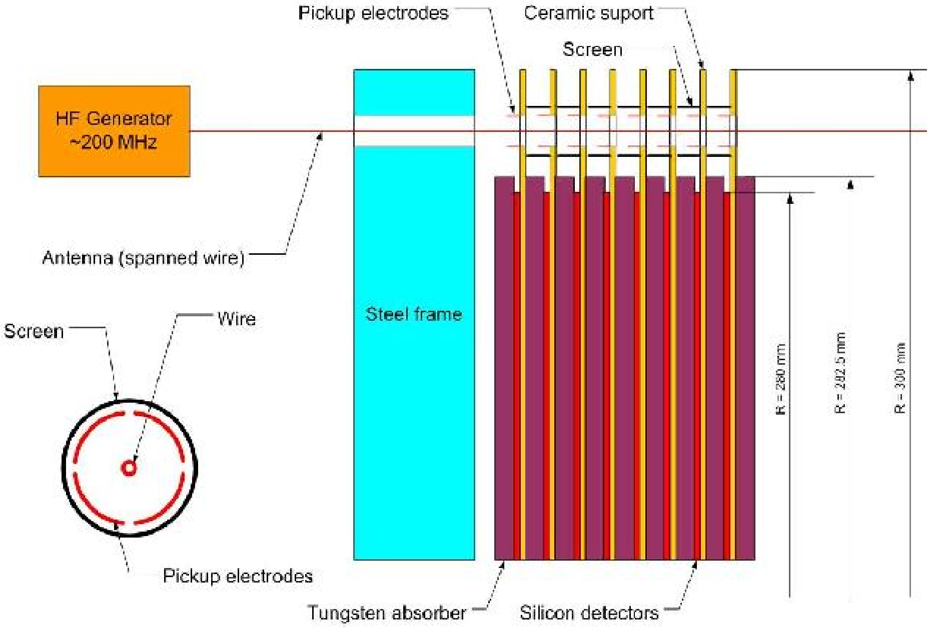

Fig. 13. The scheme of the method involving the spanned wire.

6 Conclusion

We have proved that using the above described method for measuring the detector displacement we can achieve the accuracy better than the required one. With the outlined refinements to the laser alignment system a better analysis algorithm can be developed. Two laser systems will give us higher reliability and a better beam spot shape. The studies of the further LAS development are currently being carried out.

Acknowledgements

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