Laser measurement of the LumiCal detector displacement[1]

J. Błocki, W. Daniluk, M. Gil, A. Moszczyński, K. Oliwa, B. Pawlik,
W. Wierba, L. Zawiejski[2], M. Karbowiak,[3] W. Słomiński,[4] L. Suszycki[5]

on behalf of the FCAL collaboration[6]

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Abstract

The silicon-tungsten calorimeter LumiCal, located in very forward region of the future detector at the International Linear Collider, is proposed for precisely luminosity measurement. One of the requirements to fulfil this task is available information on the actual position of the calorimeter relative to the beam interaction area which should be known with accuracy of a few micrometers. In this paper we discuss the possible solutions for the positioning of the LumiCal electron detector by optical method. The results of the displacement measurement using a laser beam and a CCD camera are described. The measurements were performed on a proof-of-principle basis and achieved the accuracy of about ± 1 μm in x, y and ± 3 μm in z direction.

[1] Report No. 1985/PH, 2006, IFJ PAN, Cracow, Poland
[2] Institute of Nuclear Physics PAN, Cracow, Poland
[3] diploma student
[4] Jagiellonian University, Cracow, Poland
[5] AGH, University of Science and Technology, Cracow, Poland
[6] list of authors can be found: http://www-zeuthen.desy.de/ILC/fcal/

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 27.5 to 83.1 mrad. The luminosity measurement will be based on detection of Bhabha event rate and a relative precision of the integrated luminosity of 10^{-4} will be enable. 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 each to other and very precise positioning with respect to the beam line and the interaction point. 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 a accuracy of 60 µm over the 6 m distance and the transversal displacement (x, y) with respect to the beam is required to be known to 100 µm accuracy. 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 well known position inside the vacuum pipe also and that would allow determining the actual position of LumiCal with respect to the beam position.

The position monitoring of the detector should not interfere with the beam pipe, hence a non contact system is preferred. We have chosen 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. The position sensors will be placed between the rear side of the detector and 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 case the radiation dose is not acceptable, we can use radiation hard CMOS matrix sensors. The use of a few position sensors per calorimeter would allow to determine also the angle between detector axis and beam direction and assures better reliability in case of position sensor failure.

3 Measurement setup

We have set up an experiment using 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 laser is mounted in a special precision alignment holder on the optical bank. The camera is placed on the XYZ ThorLabs ½” travel translation stage MT3 with micrometers (smallest div. 10 µm). To control independently the camera displacement, we are using the Renishaw optical head linear encoder RG24 with resolution of 0.1 µm. We have to reduce the amount of laser light using 3 neutral density filers with the attenuation factor of 2 each because the sensor saturates. The simplified diagram of the setup is presented in Fig. 1.

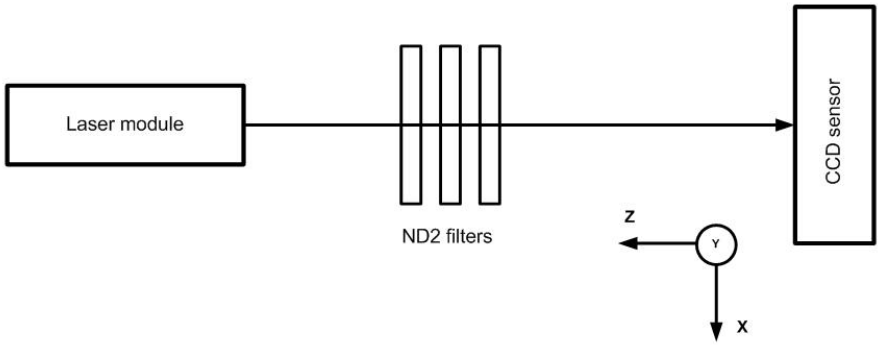

Fig.1. The setup for the transversal (x, y) displacement measurement with single laser beam.

The camera was translated in one direction in 50 µm steps and picture was taken.
To measure the longitudinal (z) displacement we use a second laser beam lighting the sensor with the angle of 45 degrees (Fig. 2).

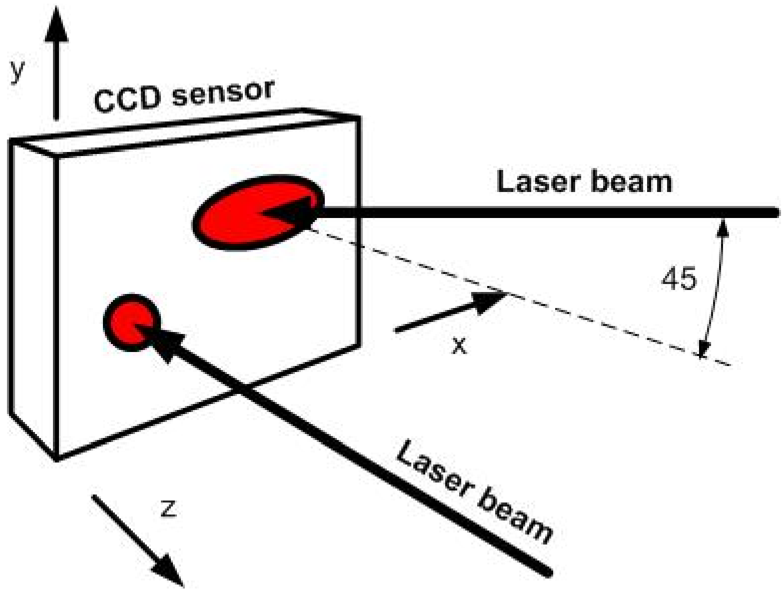

Fig.2. Simplified diagram of two laser beams setup.

For the present setup we have 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 present setup is shown in Fig. 3.

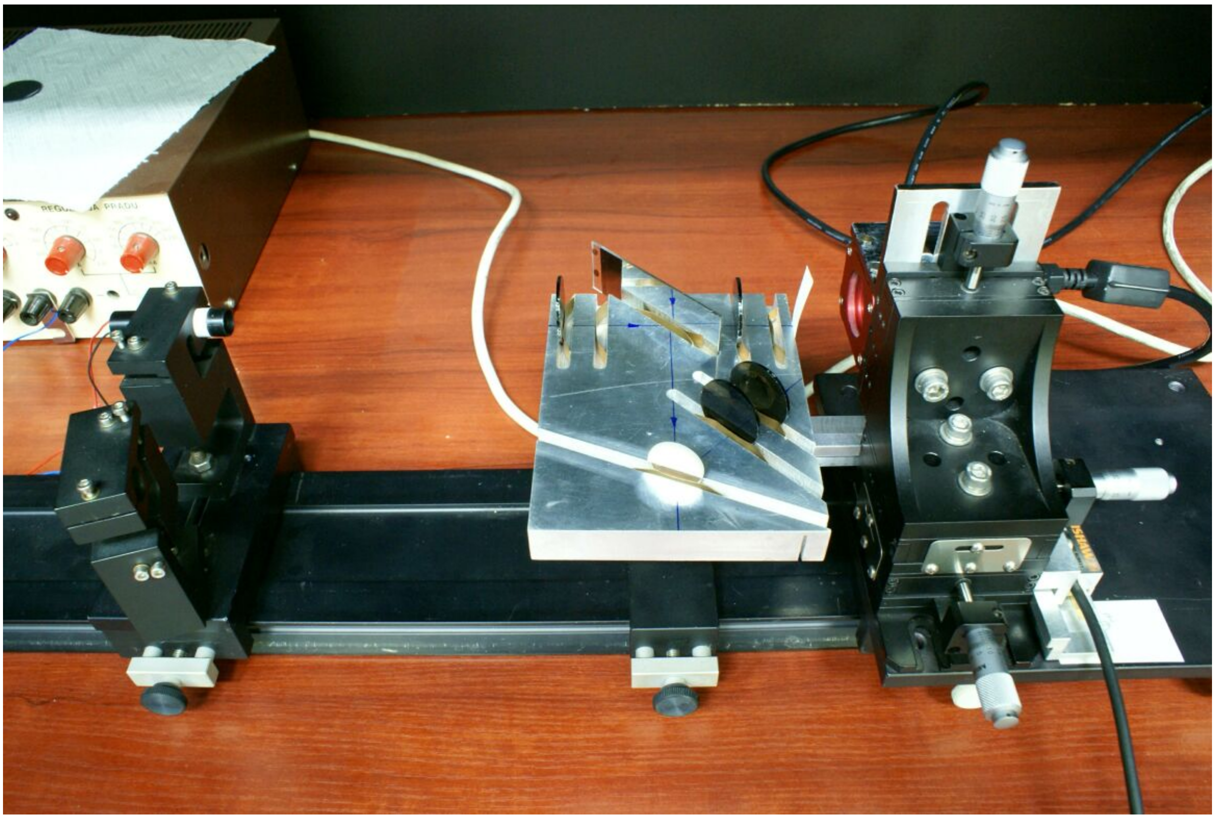

Fig. 3. Picture of the setup with splited laser beam

First measurements of z displacement shows, that calibration of the mirror angle is crucial for the final accuracy.

4 Results

The CCD camera was moved across the laser beam in 50 μm steps and the pictures were taken at every step. The beam spot shape is shown in Fig. 4.

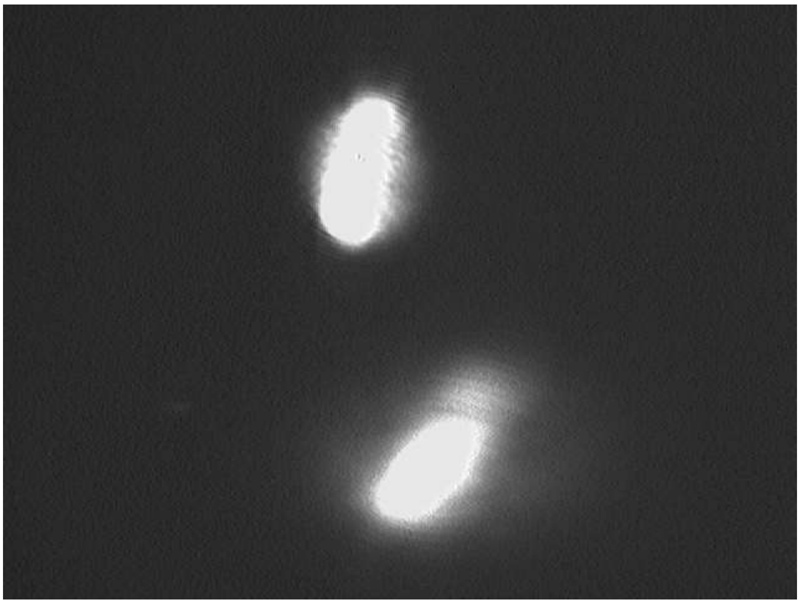

Fig. 4. The shape of two laser spots, the lower one is the 45 degree beam.

Two algorithms to calculate the centre of the beam spot was 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 using the last developed algorithm shown in Fig. 5 are very promising, the difference between real and calculated position is less than ± 1 μm.

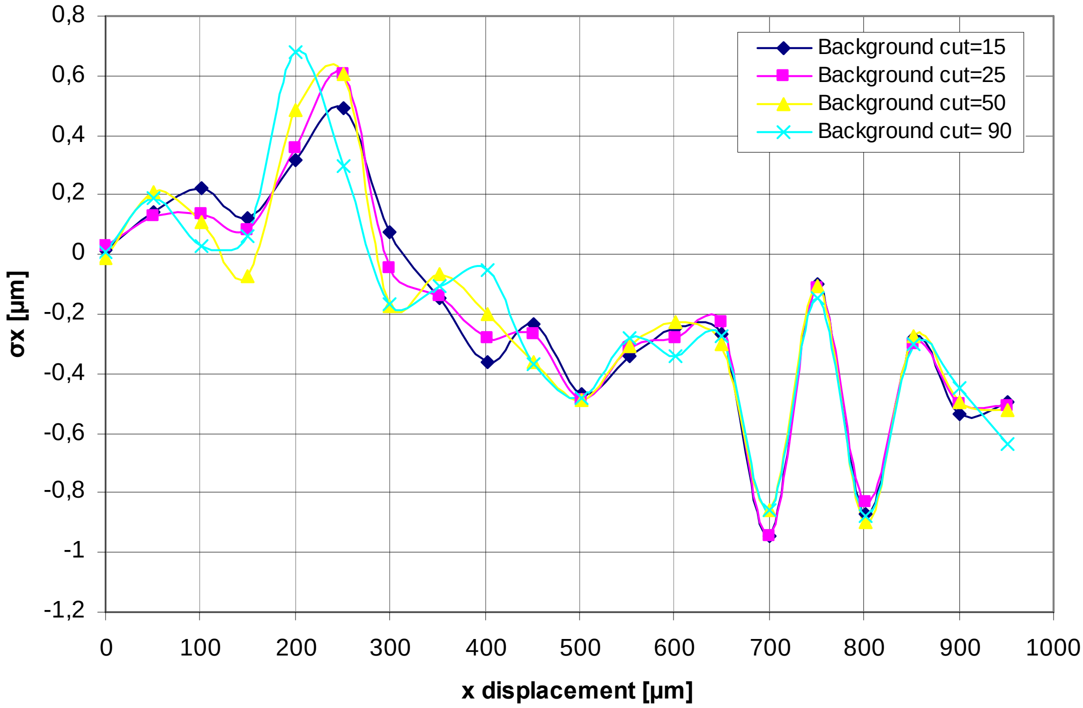

Fig. 5. Difference between calculated and real position in x direction

We have made a few series of measurements and the results vary a little.
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 on a few workshops i.e. [5].
The results of displacement measurement in z direction are shown in Fig. 6.

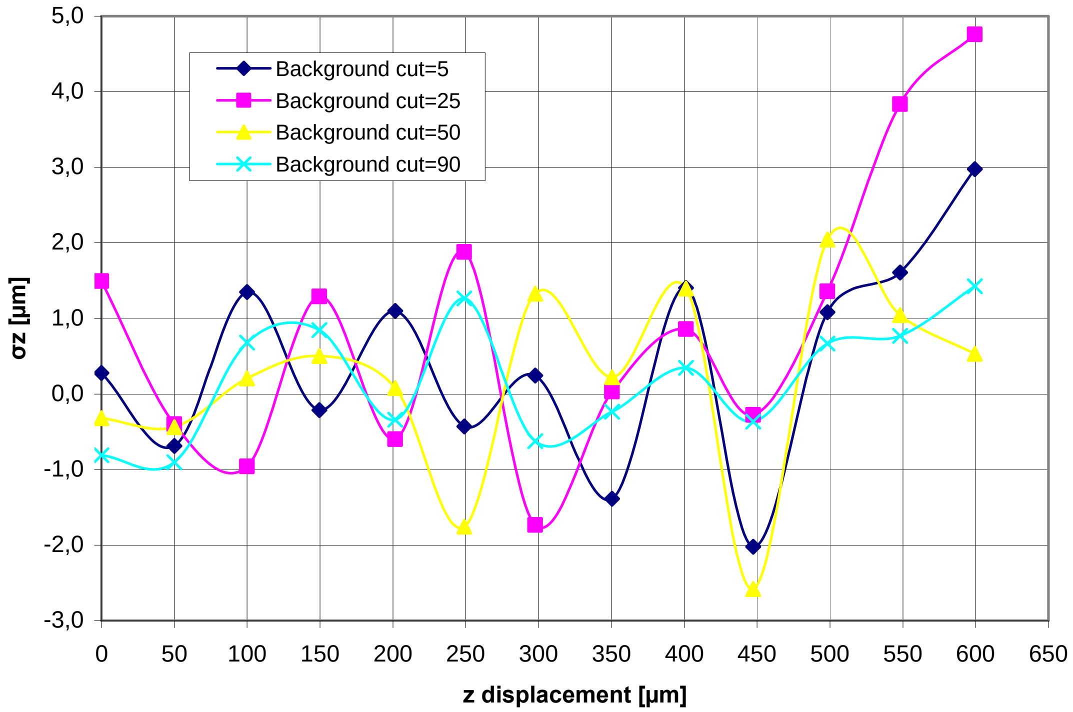

Fig. 6. Difference between calculated and real position in z direction

For both measurements we have presented results with different background cuts on the light intensity (range 0-255). It is clearly seen, that for x displacement measurement cut value changes the results slightly but in z direction the changes are higher because, probably, of the beam spot shape. This effect should be investigated.

5 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 set-up the better picture analysis algorithm can be developed. Two laser system will give us higher reliability and a better beam spot shape. The calibration procedure has to be developed to calibrate the angle between beams to 45 degrees. This calibration is essential to achieve better accuracy in the longitudinal (z) displacement measurement.

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References

1. International Linear Collider: http://wwwlinearcollider.org/cms
2. TESLA Technical Design Report, DESY 2001-011, ECFA 2001-209, March 2001; H. Abramowicz et al., IEEE Transactions of Nuclear Science, 51 (2004) 2983; R&D for ILC – Detector, Instrumentation of the Very Forward Region, The Forward Calorimetry (FCAL) Group, DESY PRC R&D Report 02/01, April, 2006; Large Detector Concept, LDC outline document: http://www.ilcldc.org/documents .
3. A.Stahl, *Luminosity Measurement via Bhabha Scattering: Precision Requirements for the Luminosity Calorimeter.,LC-DET-2005-004, Apr 2005.*
4. W. Wierba, J. Zachorowski, K. Oliwa, *Laser measurement of the LAT detector displacement,* Report No. 1391/PH, IFJ PAN Cracow 2003.
5. W.Wierba, J.Zachorowski, *LAT detector alignment* - talk given at the Collaboration Meeting "R&D for the TESLA-Detector: Instrumentation of the Very Forward Region", ECFA/DESY workshop, Amsterdam, 1. -4. April 2003; W.Wierba, W. Słomiński, J. Zachorowski, *Laser measurement of the LAT detector displacement,* FCAL Workshop, Prague, Czech, April 2004; W.Wierba, K. Oliwa, W. Słomiński, J. Zachorowski, L. Zawiejski, *LumiCal displcement measurement – present status,* FCAL Workshop, Tel-Aviv, Israel, 18.-19. September 2005; W.Wierba, M. Karbowiak, K. Oliwa, W. Słomiński, J. Zachorowski, L. Zawiejski, *LumiCal displacement measurement – present status,* FCAL Collaboration meeting, IFJ PAN Cracow, Poland, 12.-13. Februar 2006.