Laser positioning system for LumiCal

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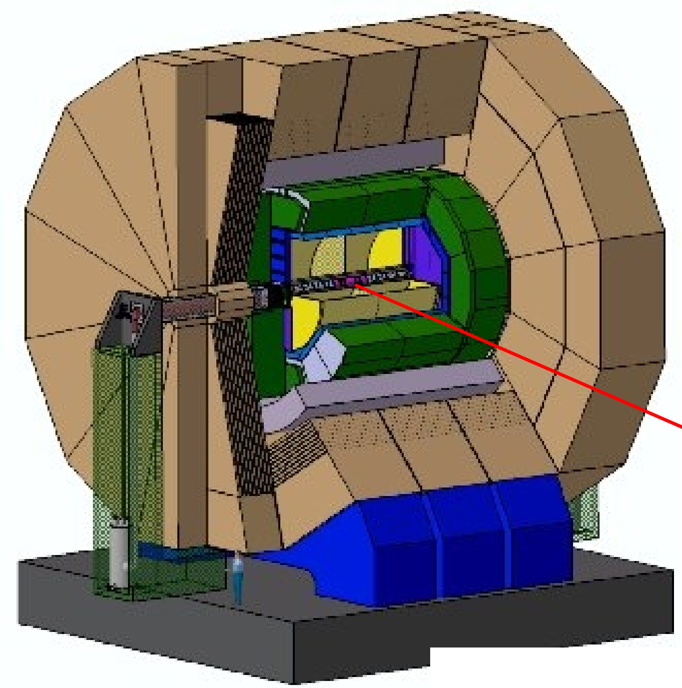
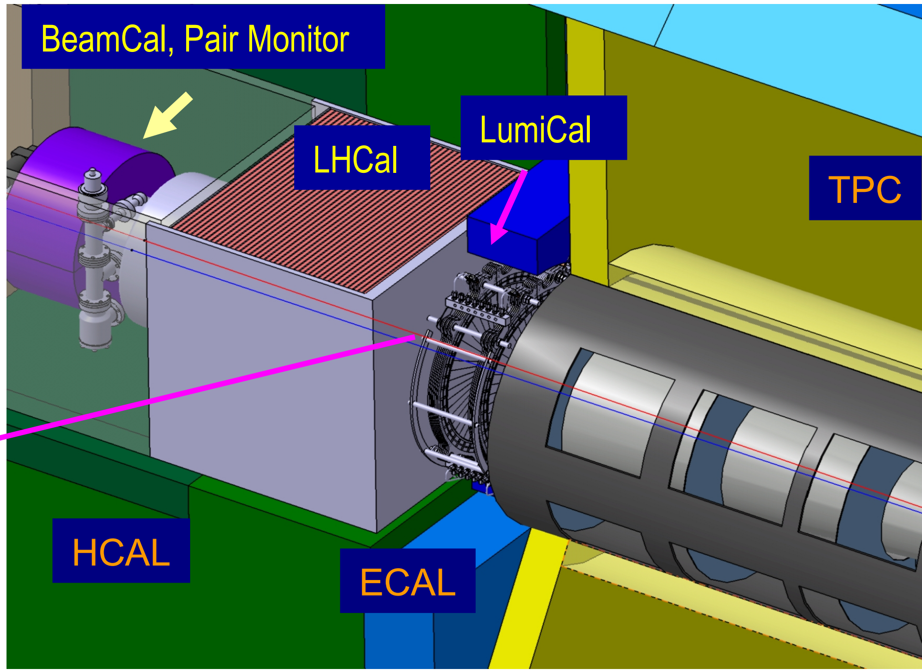
Collaboration
High precision design

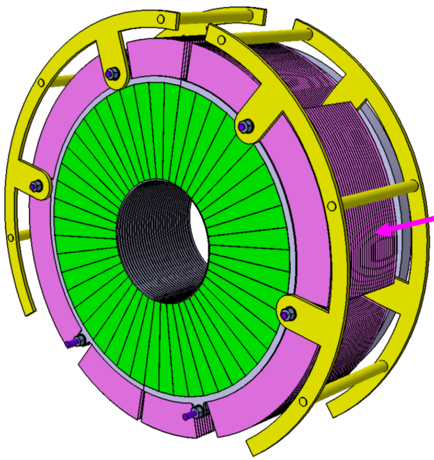
LumiCal and ILD detector



LumiCal - one of the special detectors which are foreseen in very forward region of the future Linear Collider: ILC (CLIC).

It will be used for the precise measurement of the luminosity. Inside ILD detector structure (ILC), LumiCal consists two EM calorimeters located on both sides of the interaction point (IP), 2.5 m from it.





A prototype of the silicon-tungsten sandwich LumiCal calorimeter.

LumiCal: physics requirements relative to luminosity measurement

Counting rate N of the Bhabha scattering events, $e^+e^- \to e^+e^- \gamma$ in LumiCal calorimeters allows for measurement of the luminosity: $L = N/\sigma_B$ where cross section, σ_B, is calculated from theory. For small angles : $d\sigma_B \sim 1/(s\theta^3)$ where θ - is polar angle of the scattered lepton to the beam and s –center-of mass energy squared

ILC physics: the required precision of integrated luminosity measurement $\Delta L/L \sim \Delta N/N$ should be better than 10^{-3} at $\sqrt{s} = 0.5$ TeV (or $< 10^{-4}$ for Giga Z). For CLIC (3 TeV), upper limit for $\Delta L/L$ will be $\sim 10^{-2}$.

To achieve such precision in luminosity measurement by the LumiCal detector the following conditions must be met:

- The mechanical frame and internal structure of the LumiCal must be built with micrometer precision

- The position of each LumiCal calorimeters with respect to a reference frame - QD0 magnet (beam pipe) must be controlled with accuracy ~ 100 μm. A similar limit is expected for the distance between both calorimeters. It can be performed by an optical system FSI (frequency scanned interferometry) and system of position sensors (transparent, CCD)

- Any displacement of the internal layers (silicon sensors) must be known with accuracy of a few micrometers – realization needs probably other positioning system

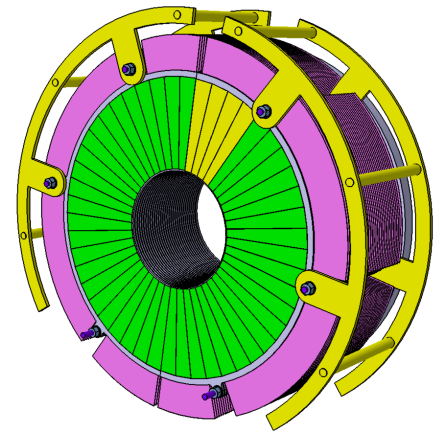
LumiCal - mechanics

Single sampling calorimeter : 30 X_0 Si / W
thickness tungsten plane: 3.5 mm (~ 1 X_0), calorimeter will be split into half cylinders (left and right) and will be clamped around the beam pipe. Odd/even planes rotated by 7.5 degree

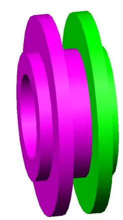
Opening/closing with accuracy better than ~4 μm.
To each tungsten plate, on one side, silicon detectors will be glued.
X/Y/Z position: 15.9/0/±2500 mm with respect to the outgoing beam
The outer radius of the calorimeter: 280 mm to cover the space for FE electronics, readout cables, cooling system and precision positioning sensors (alignment).
The mechanical inner radius: 76 mm
the outer radius of tungsten plates: 200 mm
The final shape of tungsten planes – 3 (2) „ears"
Water cooling system is required to reduce heat of ~ 30 W created by FE electronics .

The calorimeter weight leads to a vertical displacement ~ 20 μm,
at temperature changed within of 1 Kevin –deformation of the shape in tungsten plane was ~ 25 μm.

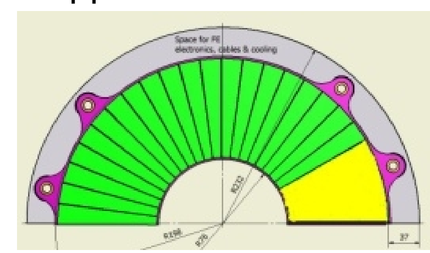
Sensor thickness: 320 μm (Hamamatsu)
The sensitie region: (80 – 195.2) mm in radius
64 rings which cover θ range: 35.3 – 83.9 mrad
48 azimuthal divisions;
~ 90 k readout channels



Towards the final structure

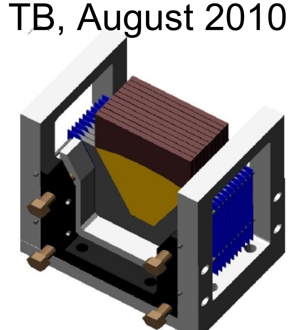


In mechanical construction two types of rings are required, With the special bolts, calorimeter can be asembled and placed on the support.



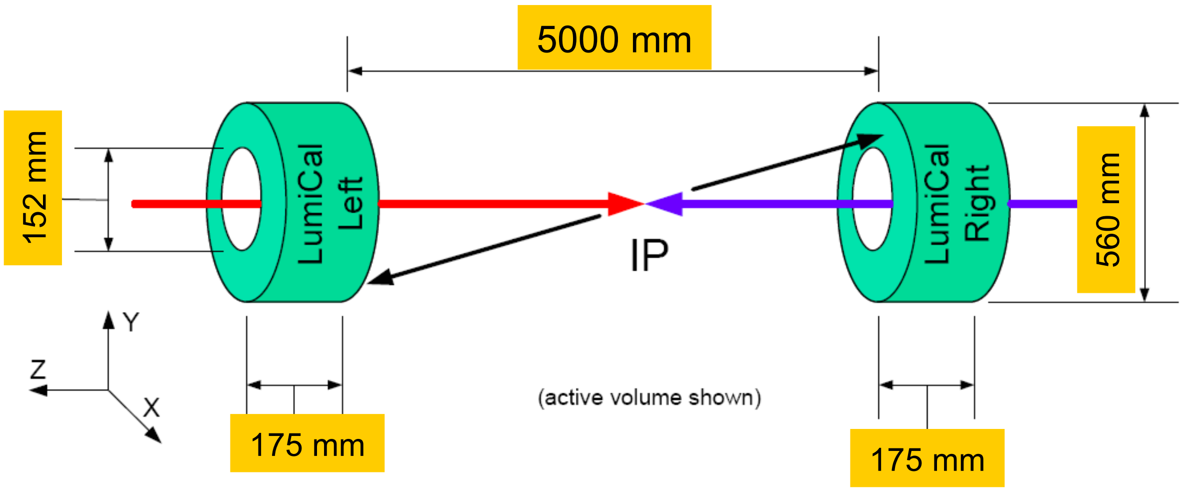
Yellow sector was tested at DESY electron TB, August 2010

Proposed structure for the next testbeam measurements with prototype of laser alignmet system

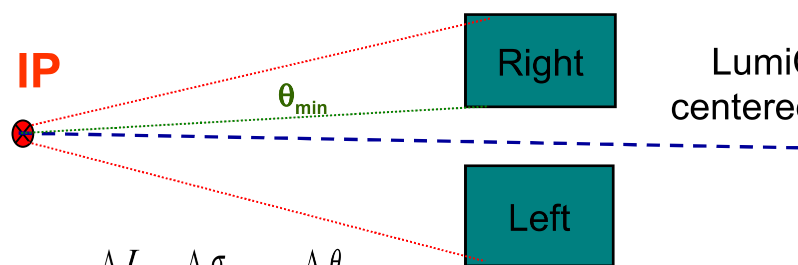


LumiCal – limits for position measurements

Monte Carlo studies: influence of LumiCal displacements on ΔL/L accuracy



Distance between two LumiCal's should be known with accuracy less than 100 μm.



LumiCal calorimeters - centered on outgoing beam

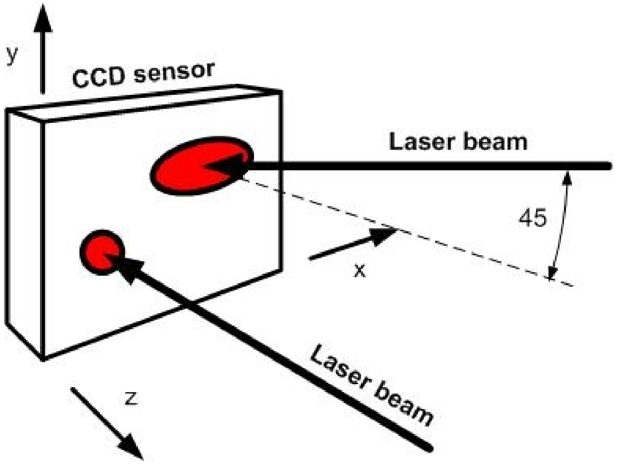
LumiCal X, Y position with respect to the reference frame – QD0 magnet, beam pipe, should be known with accuracy better than ~100 μm)

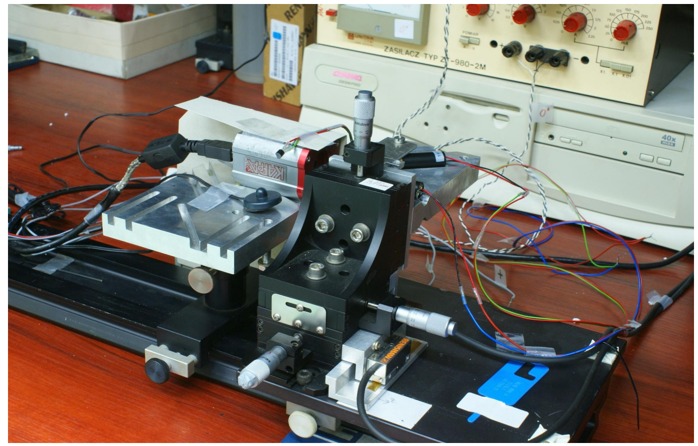
$$\frac{\Delta L}{L} = \frac{\Delta \sigma}{\sigma} \cong 2 \frac{\Delta \theta}{\theta_{min}}$$

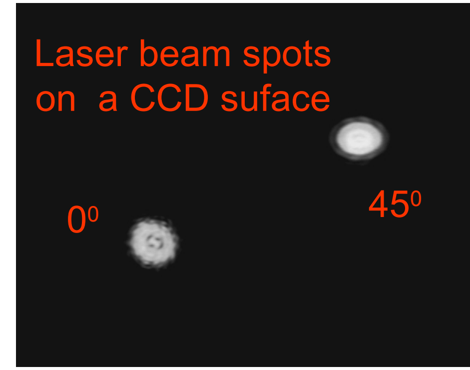
Un uncertainty in position measurements of inner radius of LumiCal calorimeters should be less 4 μ m (40 μm) for Giga Z (ILC 500 GeV)

A. Stahl , LC-DET-2005-004,
B.Pawlik, Geant 3 and Geant 4,
R. Ingbir, A. Sapronov , Geant 4
talks at FCAL meetings and PRC Reports

Laser alignment system (LAS) – prototype

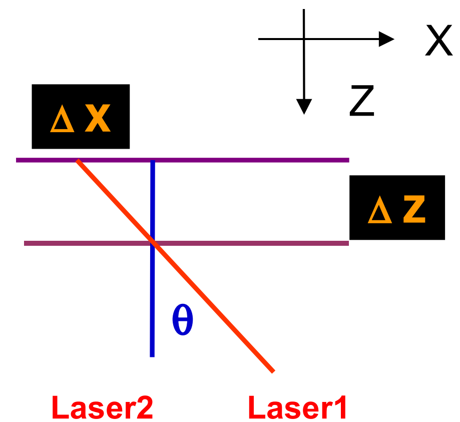






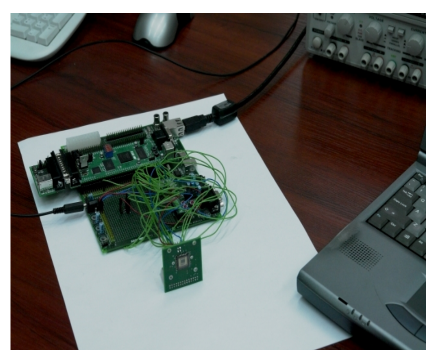
- Two laser beams at 0° and 45° angles to the CCD sensor surface respectively (beam spots) are used to calculate the position shift
- The CCD camera and lasers can be fixed to the LumiCal and beam pipe

EUDET-Report-2008-05
W.Daniluk et al.,
Laser Alignment System for LumiCal
EUDET-Report-2009-08,VFCAL task status report, S.Schuwalow for FCAL Collaboration;
PRC Report , DESY, 2009, FCAL Collaboration



Obtained accuracy : 0.5 μm in X,Y direction
1.5 μm in Z direction

Sensitive to temperature changes: ~ 0.5 μm/1 C°

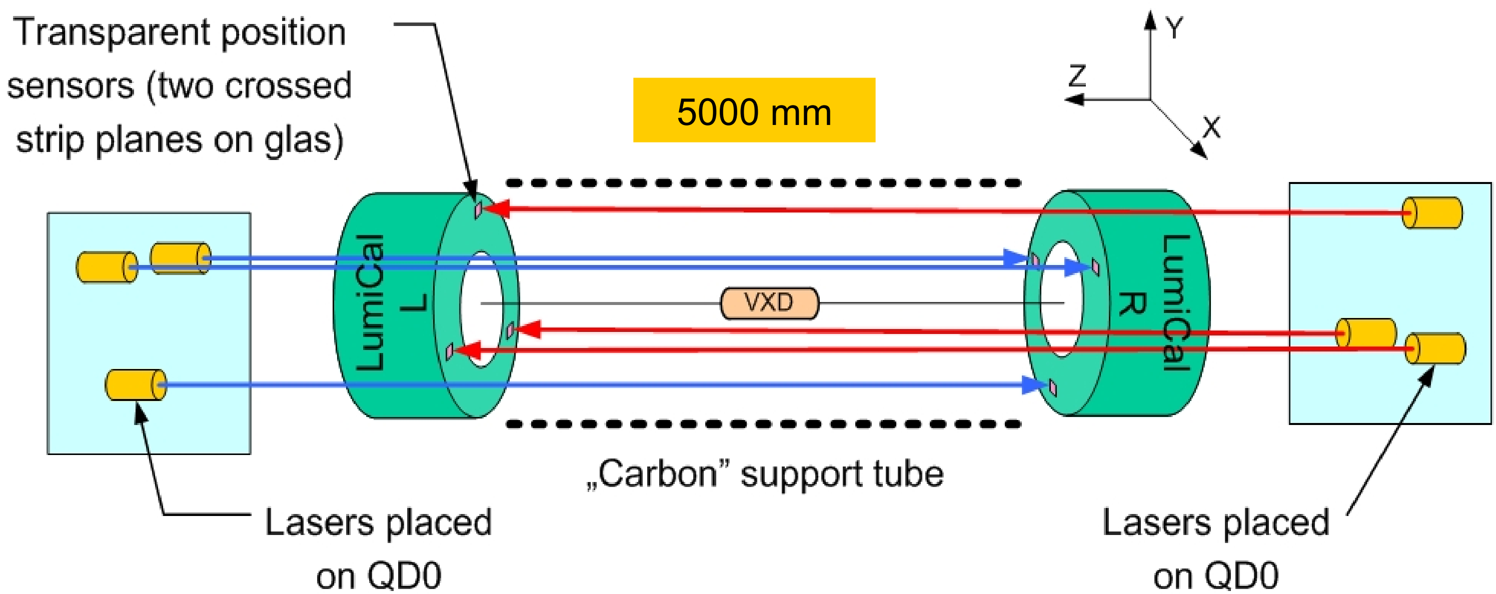


A protype of data transfer system using data from CMOS sensor to PC host was built and partially successfuly tested.
As the other type of sensors are considered in LAS prototype, this system was no longer developed.

LumiCal LAS – further steps

Possible displacement measurements between two (L-R) calormeters:

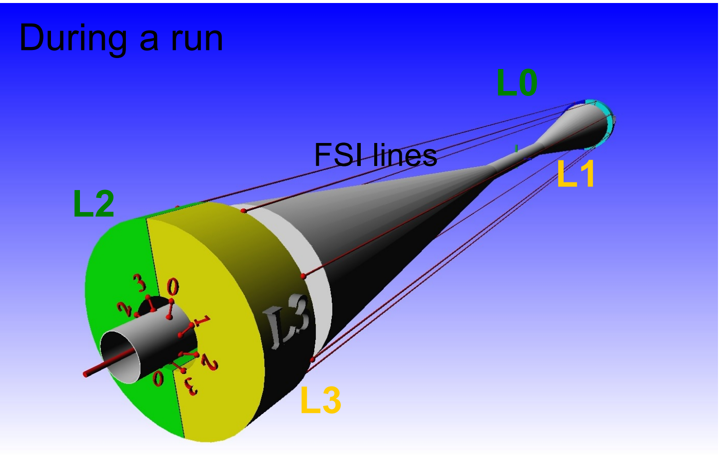
- Laser beams and sensors - at least 6 for space orientation both calorimeters - inside 'carbon' support tube – need additional vacuum pipes ?
- System with interferometer, FSI (frequency scanned interferometry)

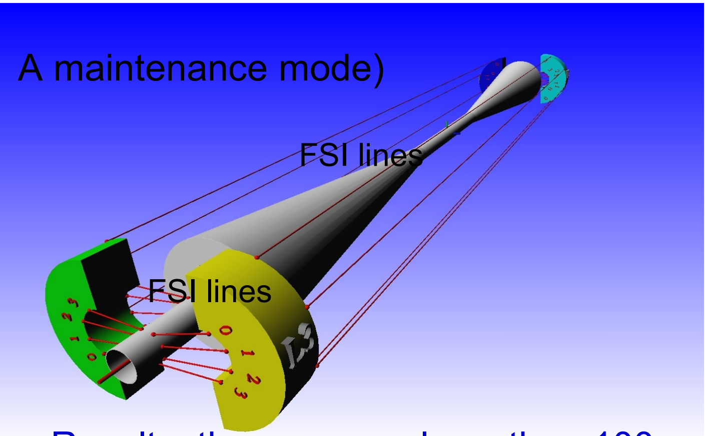


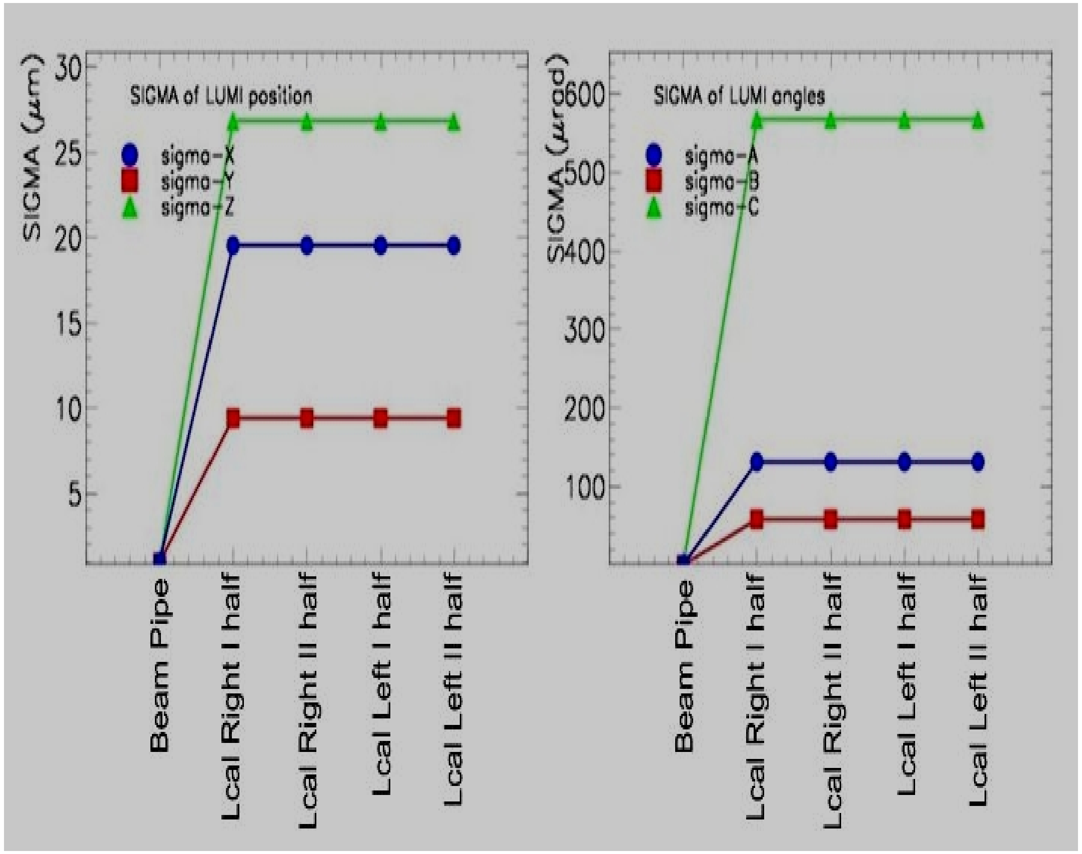
LumiCal's silicon sensors planes x, y position measurement versus well positioned QD0

LumiCal - Monte Carlo simulation of LAS system

SIMULGEO program: calculations of the distances for Lumical modules choosing beam pipe as reference. For FSI laser beams, an accuracy 1 µm was used





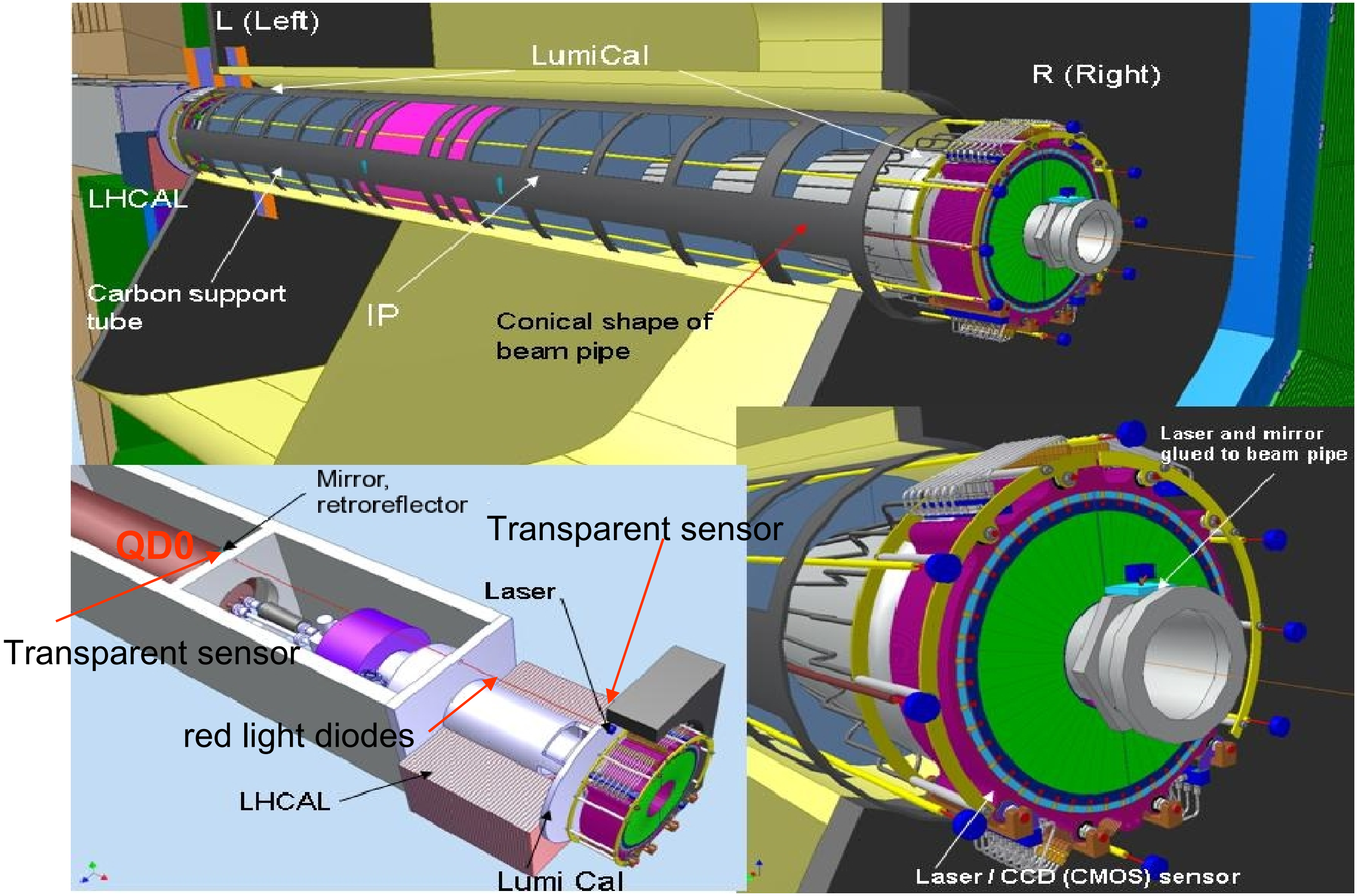


Results: the accuracy less than 100 µm was obtained for module (L0,L1,L2,L3) distances, as measured relative to beam pipe.

The worse accuracy, up to 600 µm was obtained in calculations, selecting one modul as a refernce frame

LumiCal LAS and ILD

In stand-alone approach, the laser beam lines (FSI) can be used for the displacement measurement both (L,R) calorimeters relative to QD0 (beam pipe) and a distance between them

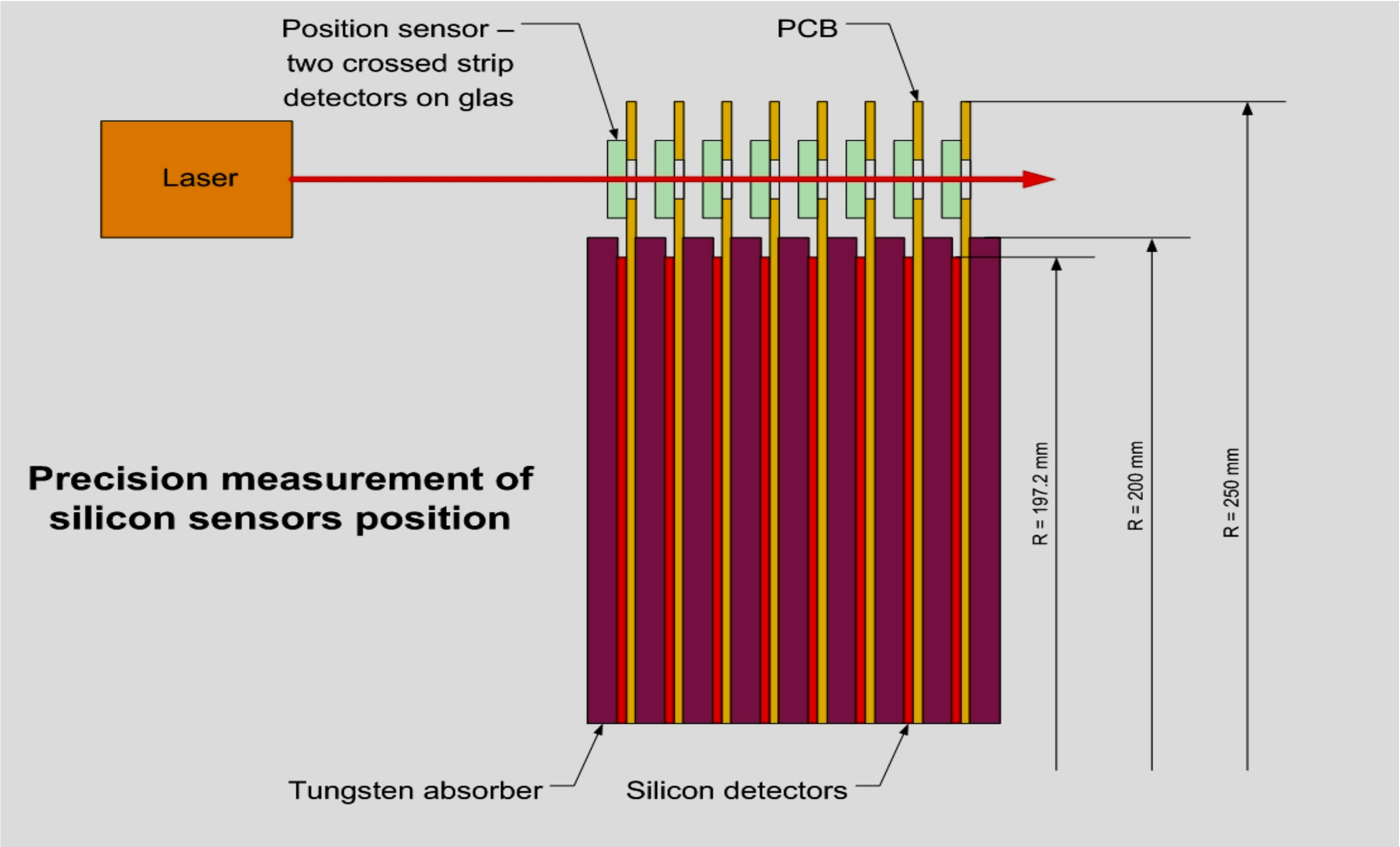


In a modification of the system also transparent position sensors with red light diodes (or infra-red laser beam) is considered.

LumiCal : displacement of the internal silicon layers

Because required accuracy for inner radius of the sensor layers is on a level ~ 4 μm , it is important to build system for measurements of the displacement of LumiCal internal sensor layers

One possibility is to used transparent micro-strip sensors like those used for silicon tracking alignmemt in ILD detector.



Conclusions

- The precisely measurement of the displacements of LumiCal calorimeters as well as their internal layers are necessary to achieve the required accuracy in luminosity measurements.

- Laboratory prototype of simple positioning system with laser beams and CCD sensor (camera) gives high precision in the displacements measurement: ~0.5 μm in (X,Y) and 1 μm Z direction.

- In the next step more advanced alignment system including FSI and transparent micro-strip sensors will be used.
  The measurements will use QD0 magnet or beam pipe as reference frames because their positions will be known with very high precision.

- For displacement measurements of the internal silicon layers, the system of transparent sensors is considered.