Laser alignment system

Status report

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FCAL Collaboration
High precision design

EUDET

LumiCal - luminosity measurement

Counting rate N_B of the Bhabha events : $e^+e^- \rightarrow e^+e^- \gamma$

in small forward (Left-Right) LumiCal calorimeter will be used to measure the integrated luminosity : $L = N_B / \sigma_B$ where σ_B is precisely calculated from theory

ILC physics:

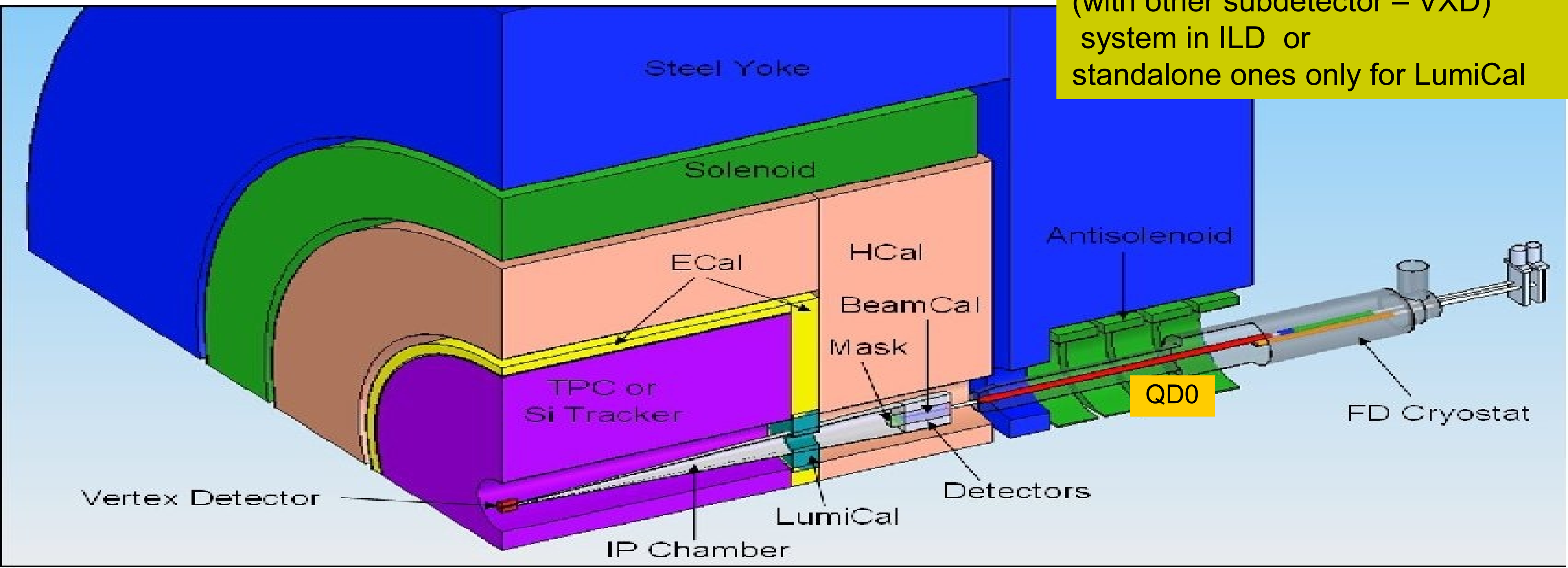
the required precision for $\Delta L/L \sim \Delta N_B / N_B$ should be better than **$< 10^{-3}$**

(at production of 10^6 W^+W^- or q^+q^- / year) or **$\sim 10^{-4}$** (for Giga Z mode – 10^9 / year)

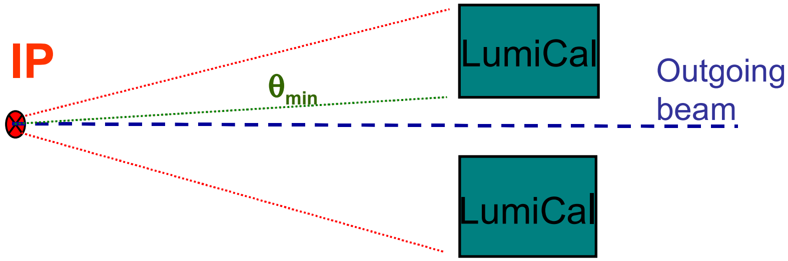
To fulfil this task it is necessary to build:

- luminosity detector with micrometers precision
- on-line running system (**Laser Alignment System, LAS**) for precisely measurements the positions of the LumiCal

Question: can LA be an integrated (with other subdetector – VXD) system in ILD or standalone ones only for LumiCal

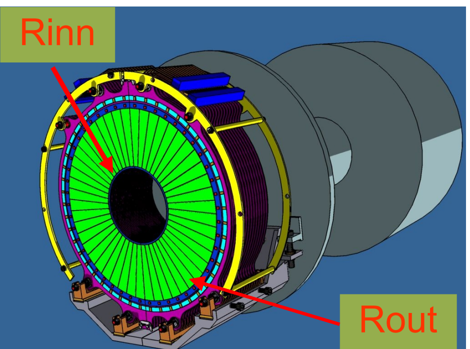


Limit on LumiCal displacement



Single (Left / Right) LumiCal alignment

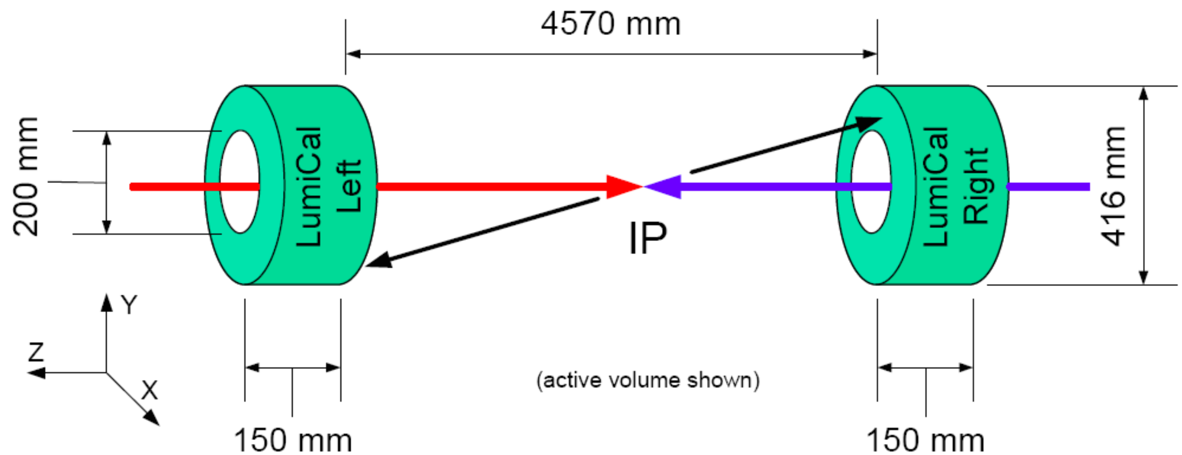
LumiCal X, Y position with respect to the incoming beam (pipe, PBM, QD0) should be known with accuracy better than ~700 μm (optimal ~100 -200 μm)
(LumiCal's will be centered on outgoing beam)



30 X_0 W / Si (sensors) layers
W – 3.5 mm, Si -0.32 mm
Rinn / Rout (Si) 80/180 mm
θ range 35 -84 mrad,
64 divisions
φ (azimuthal) -
48 divisions

Inner radius (Rinn) accuracy: a few (~4) μm

Two LumiCal's (L,R) alignment



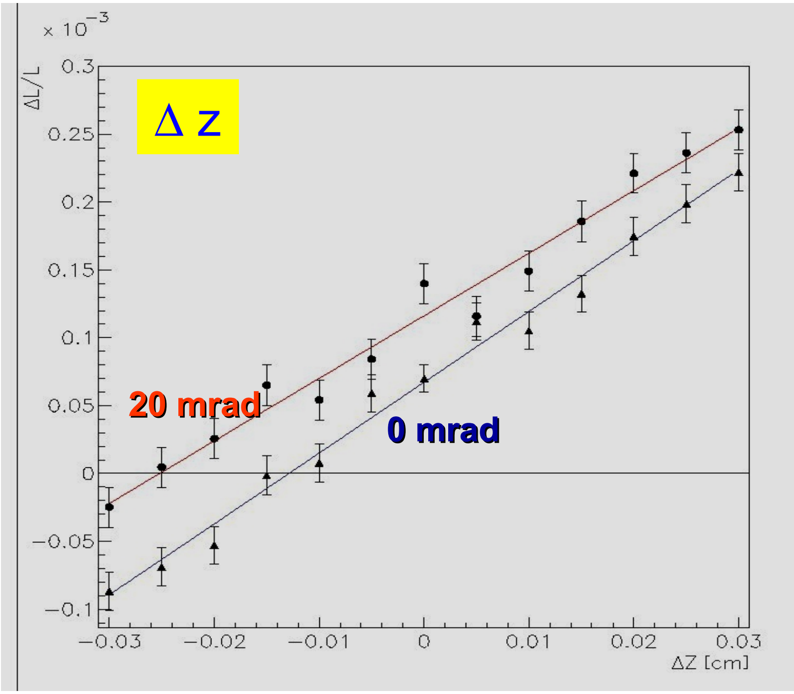
Distance between two LumiCal's should be known with accuracy better than ~60 -100 μm (14 mrad crossing angle)

MC : displacement of the LumiCal

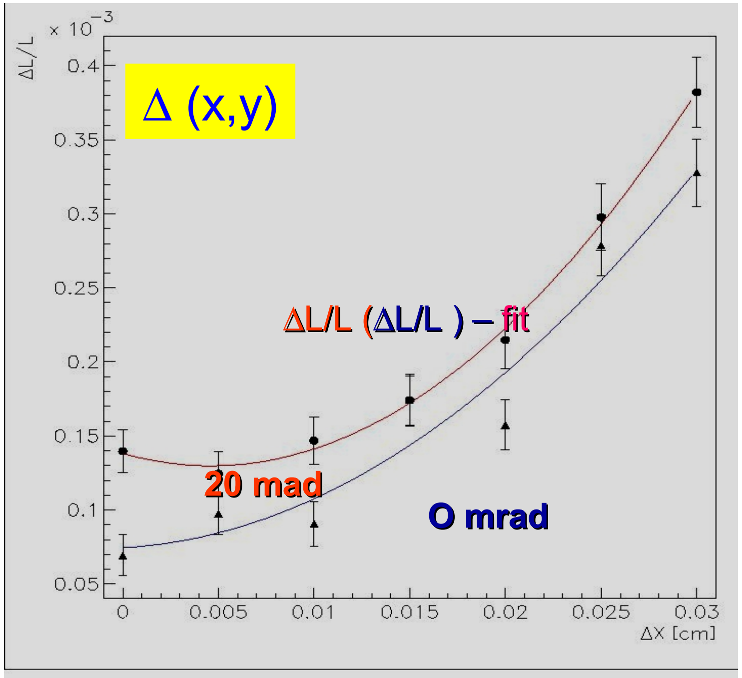
Mont Carlo : BHLUMI $\rightarrow$ Bhabha events $\rightarrow$ Luminosity $\frac{\Delta L}{L} = \frac{\Delta \sigma}{\sigma} \cong 2\frac{\Delta \theta}{\theta_{\min}}$

Two crossing angles for beams : 0 and 20 mrad (RDR – 14 mrad)
LumiCal displacement relative to IP, detector axis or outgoing beam

ΔZ : 50 μm steps for Z in range (-300, 300) μm



ΔX : 50 μm for (X,Y) in range (0., 300) μm



Value ~ 100 μm of the displacement $\rightarrow$ acceptable changes in luminosity measurement

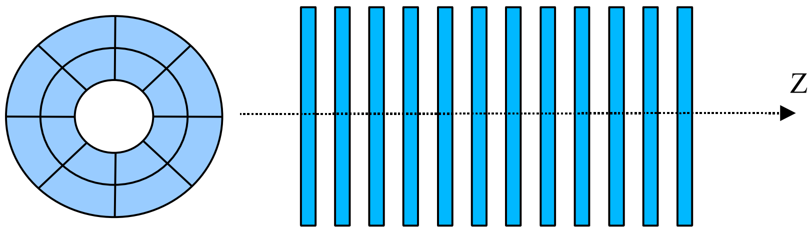
The similar conclusion from other MC studies :

A. Stahl , LC-DET-2005-004,
R. Ingbir or A. Sapronov ,talks given at FCAL meetings

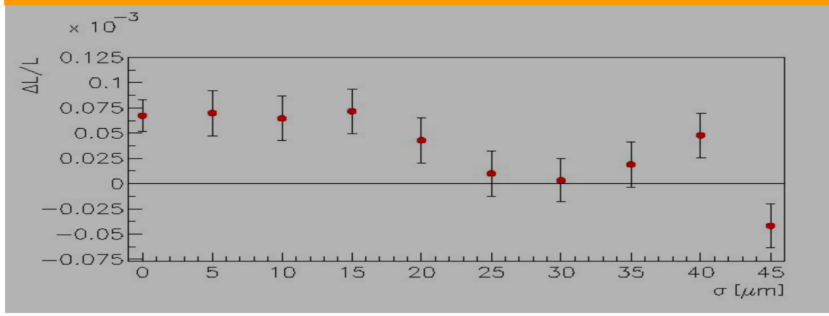
MC : the internal structure deformation

Changes in X,Y and Z positions of the Tungsten and Si sensors layers

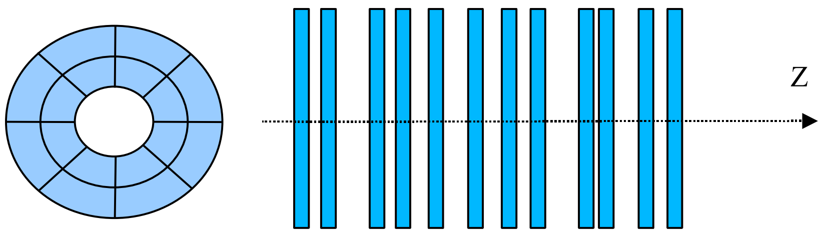
ideal



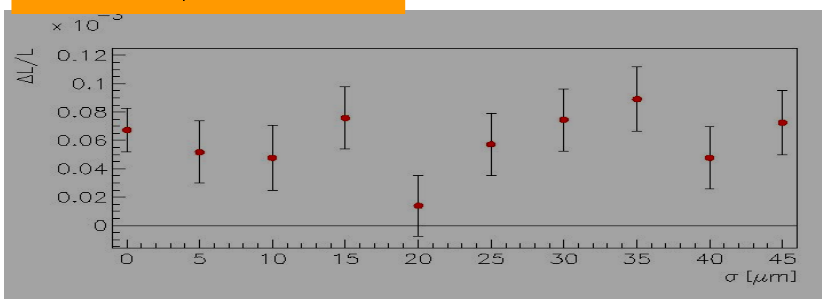
The changes in relative luminosity according to changes in internal structure along Z axis



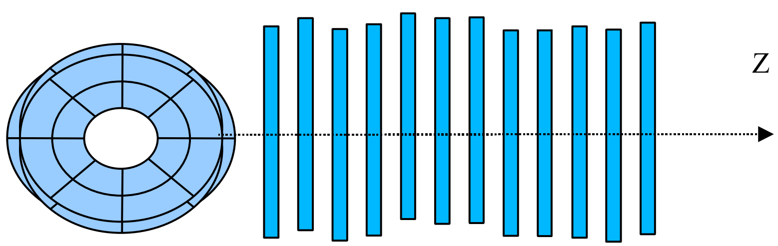
deformation in Z



and in X,Y directions

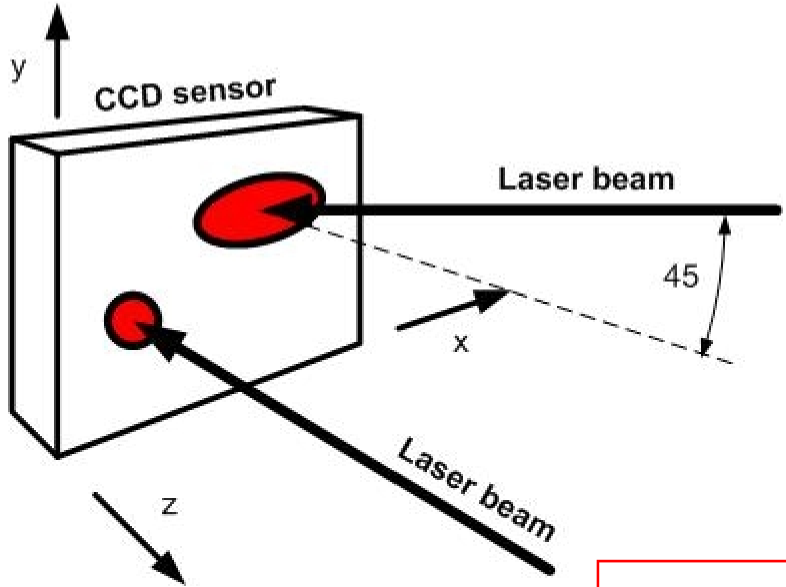


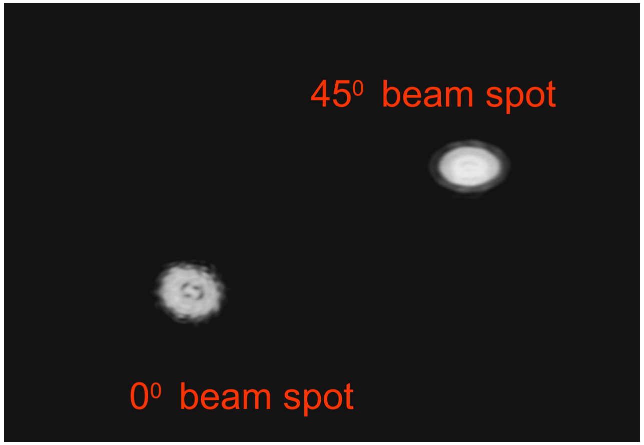
deformation in X and Y



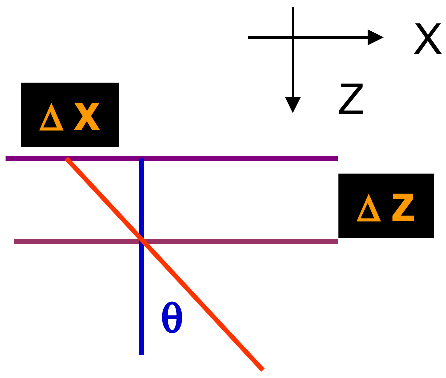
Possible systematic effect: one order smaller in comparison to possible displacement the Lumical detector as whole but still should be treated carefully as possible significant contribution to total error in luminosity calculation

LAS - method





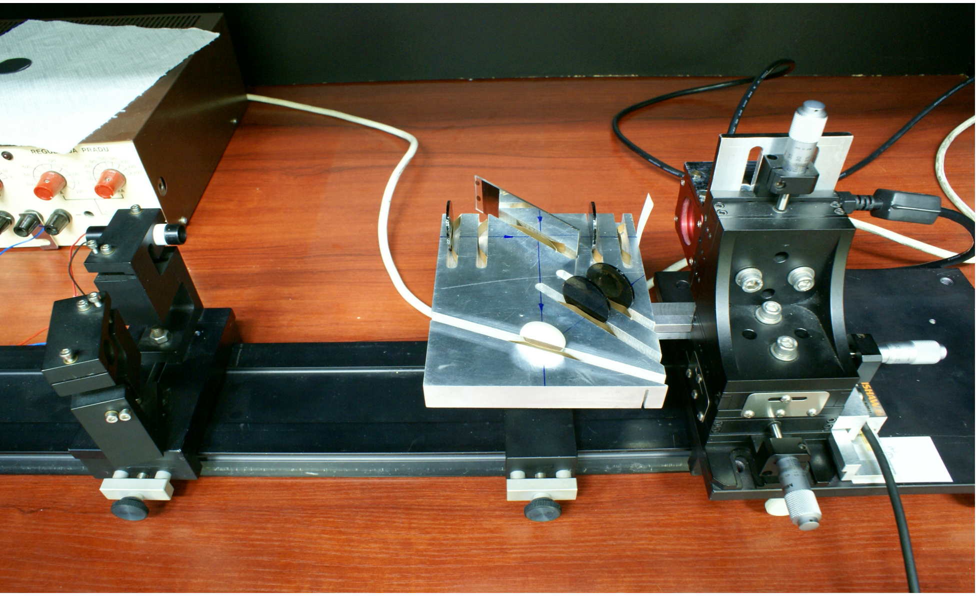
Laser beam spots on the surface of CCD camera (640 x 480 pixels)



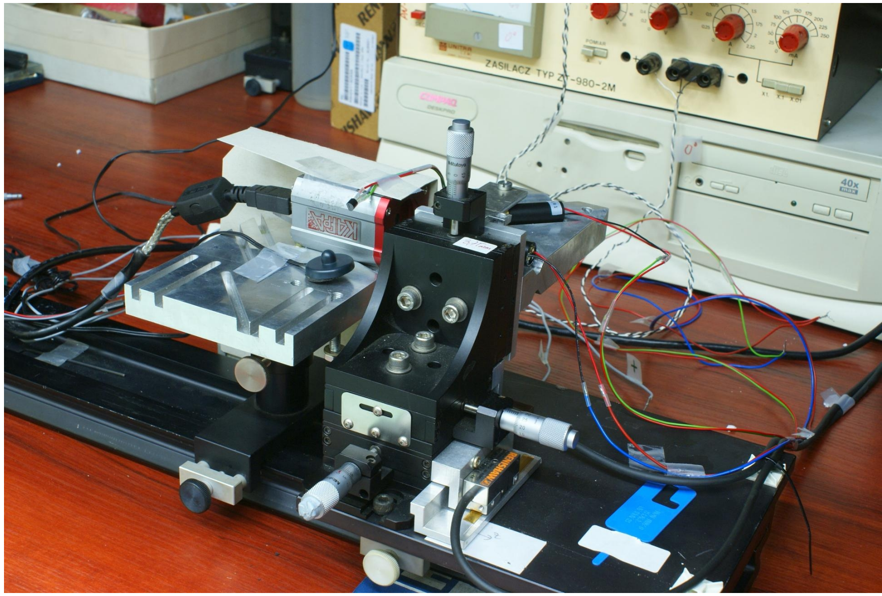
- Two laser beams, one perpendicular, second with the angle of 45˚ to the CCD/CMOS sensor surface, are used to calculate the position shift
- The CCD camera and lasers can be fixed to the LumiCal and beam pipe
- Three (more) sensors can be used to measure tilt of each LumiCal (L/ R)
- Six (more) laser beams from one to another LumiCal passing inside the 'carbon support' tube can be used :
  - to measure the relative position shift (the method described above)
  - the distance between two LumiCal's

LAS : laboratory setup

Previous – one laser beam with mirror



Present – two laser beams

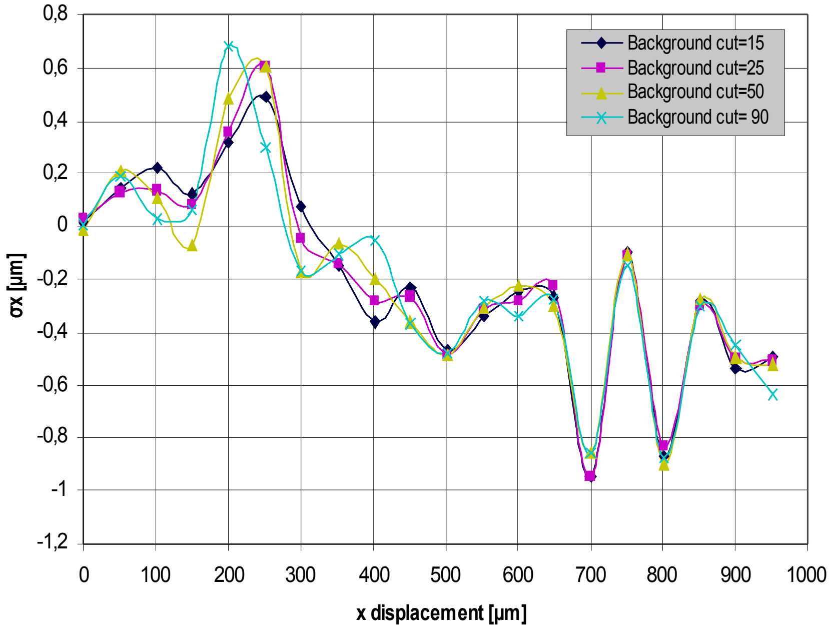


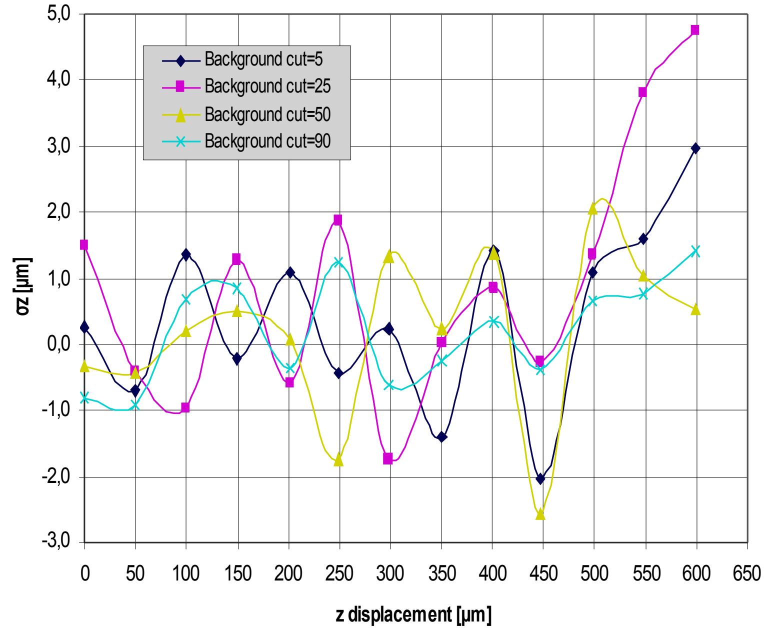
- BW camera DX1-1394a from Kappa company 640 x 480 with Sony ICX424AL sensor 7.4 μm x 7.4 μm unit cell size
- Laser modules LDM635/1LT from Roithner Lasertechnik
- ThorLabs ½” travel translation stage MT3 with micrometers (smallest div. 10 μm)
- Neutral density filters ND2
- Renishaw RG24 optical heads (0,1 μm resolution) to control movement of the camera
- Half transparent mirror
- New support for mirrors and filters

Results of X & Z position measurements

X, Z displacement measurement relative to reference system

X_{cal} and Z_{cal} positions – from improved algorithm for centre beam spot determination.





σx = Xcal - Xtrue
displacement (µm) : ± 0.5 µm

σz = Zcal - Ztrue
displacement (µm) : ± 1.5 µm

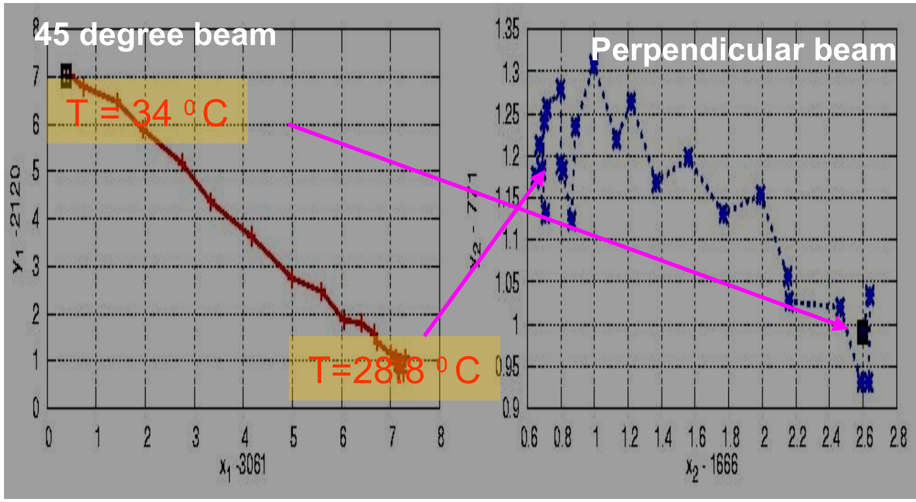
- Camera was translated in steps of 50 µm.
- The distances Xtrue and Ztrue was measured with Renishaw RG-24 optical head with the resolution of ±0.1 µm

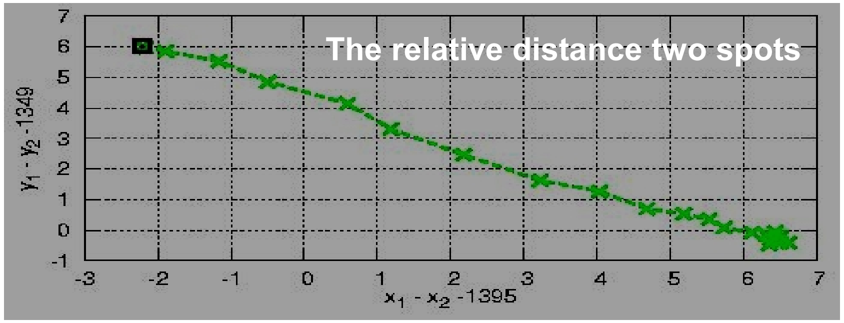
Stability - temperature dependence

The temperature dependence of the beam spots position in CCD camera: heating or cooling down environment of the laser system.

- Insulated heating box .
- For each temperature point, the mean position of the spot centers from multiple measurements were calculated using improved algorithm

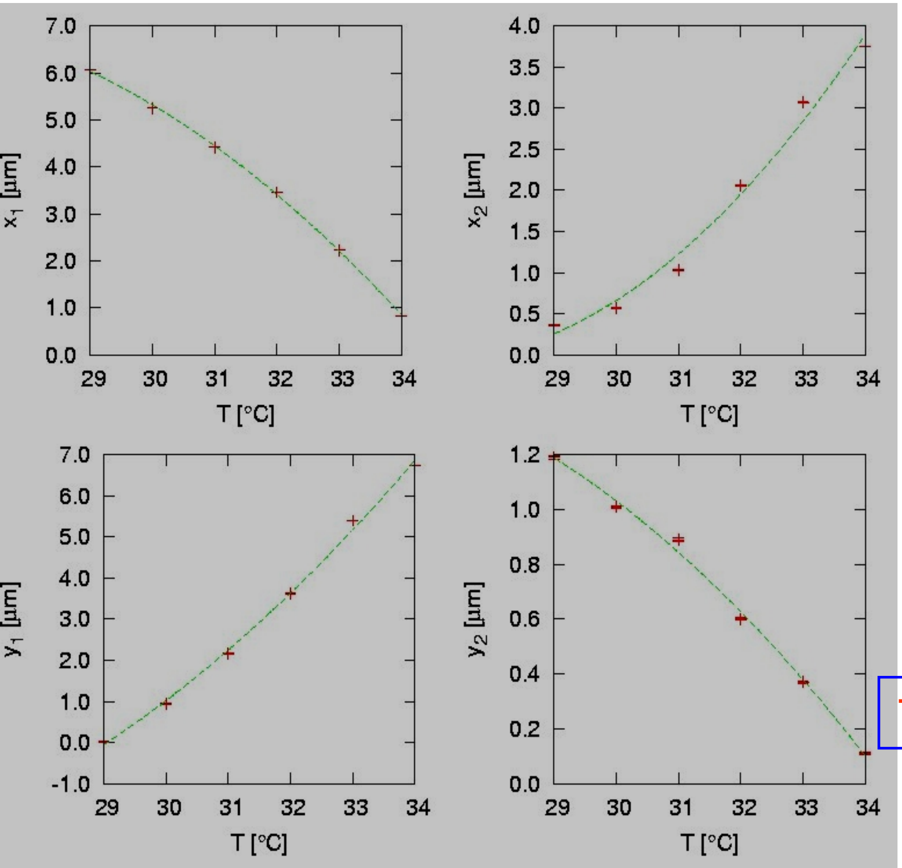
Cooling down – measurement for each 5 minutes
Over the $\Delta T = 5.2\ ^0$ C. Position calculated from algorithm





45 degree beam

Perpendicular beam

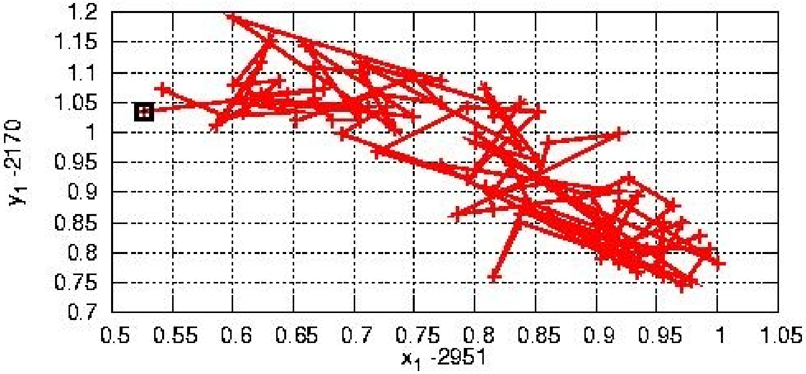


The observed changes are on the level ~ 1 μm/1 ^{0}C

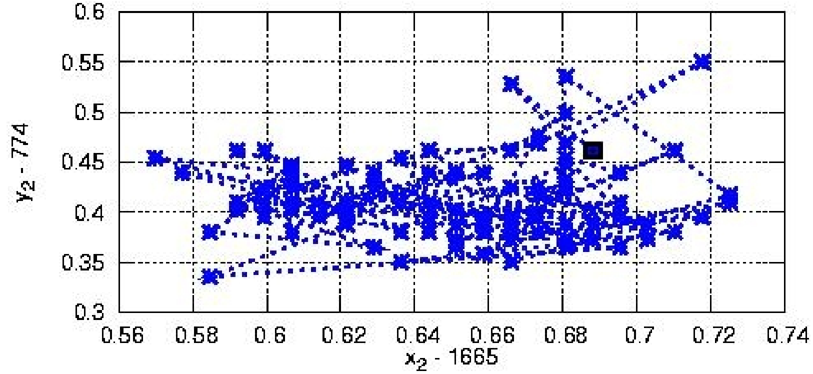
Temperature stabilization

> 8 hours measurements : temperature changes within $\Delta T \sim 0.1$ degree

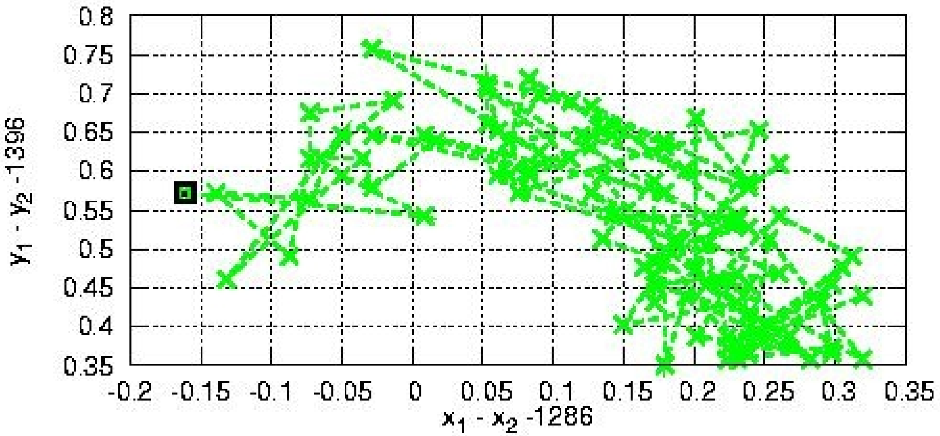
45 degree beam



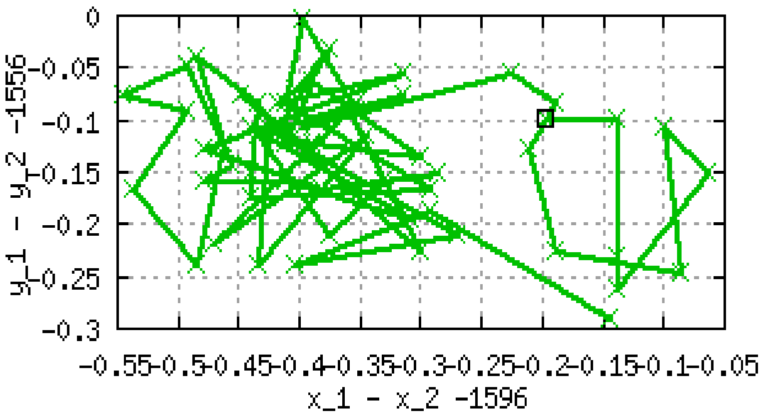
0 degree beam



The relative distance between laser beams



> **24 hours : $\Delta T \sim 0.2$ degree**

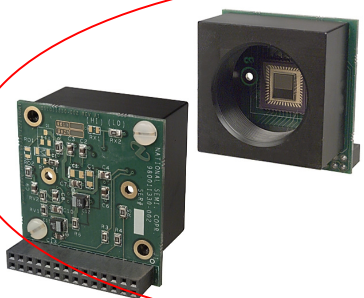


The observed changes in calculated X,Y spots positions are on the level 0.5 μm.

Contribution from other effects: nature of laser spot and systematic uncertainties in used algorithm

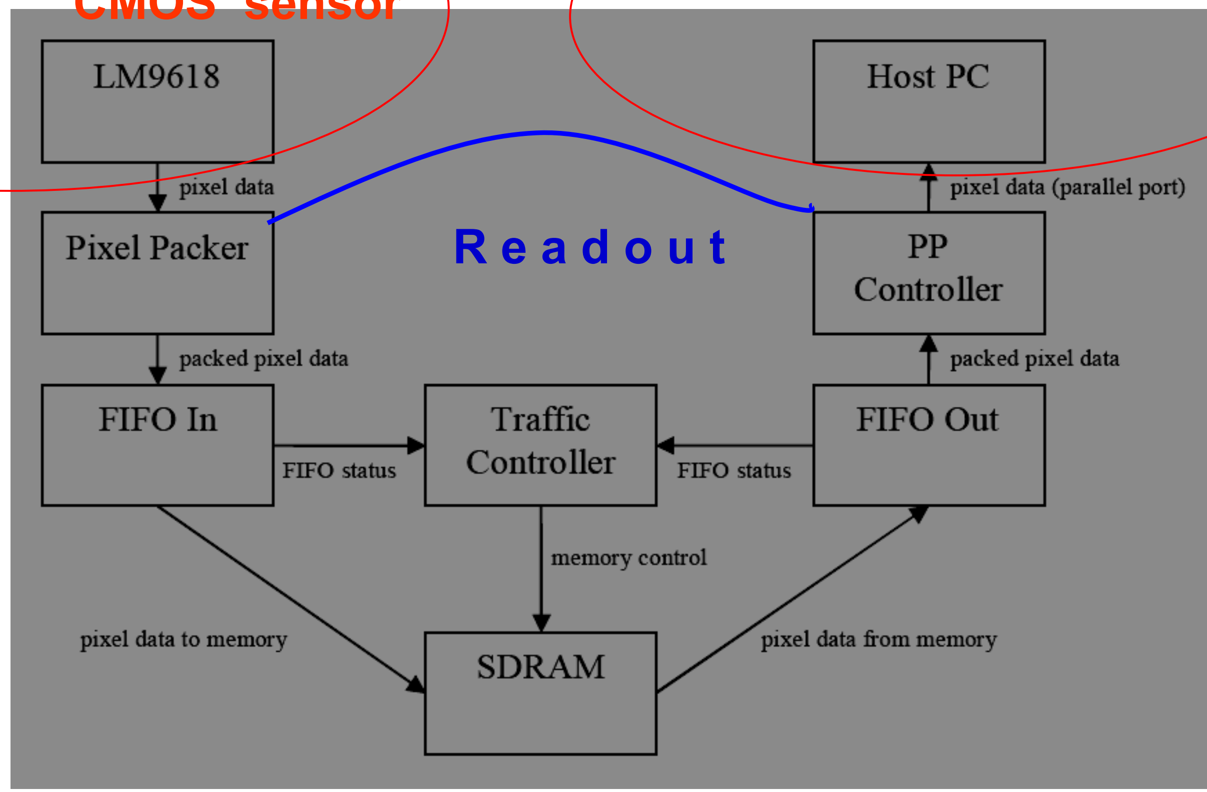
It is necessary to stabilize the temperature of camera

Readout electronics for dedicated silicon sensor, automatic (online) position calculations, a compact shape of the system



Dedicated CMOS sensor

Displacement calculations

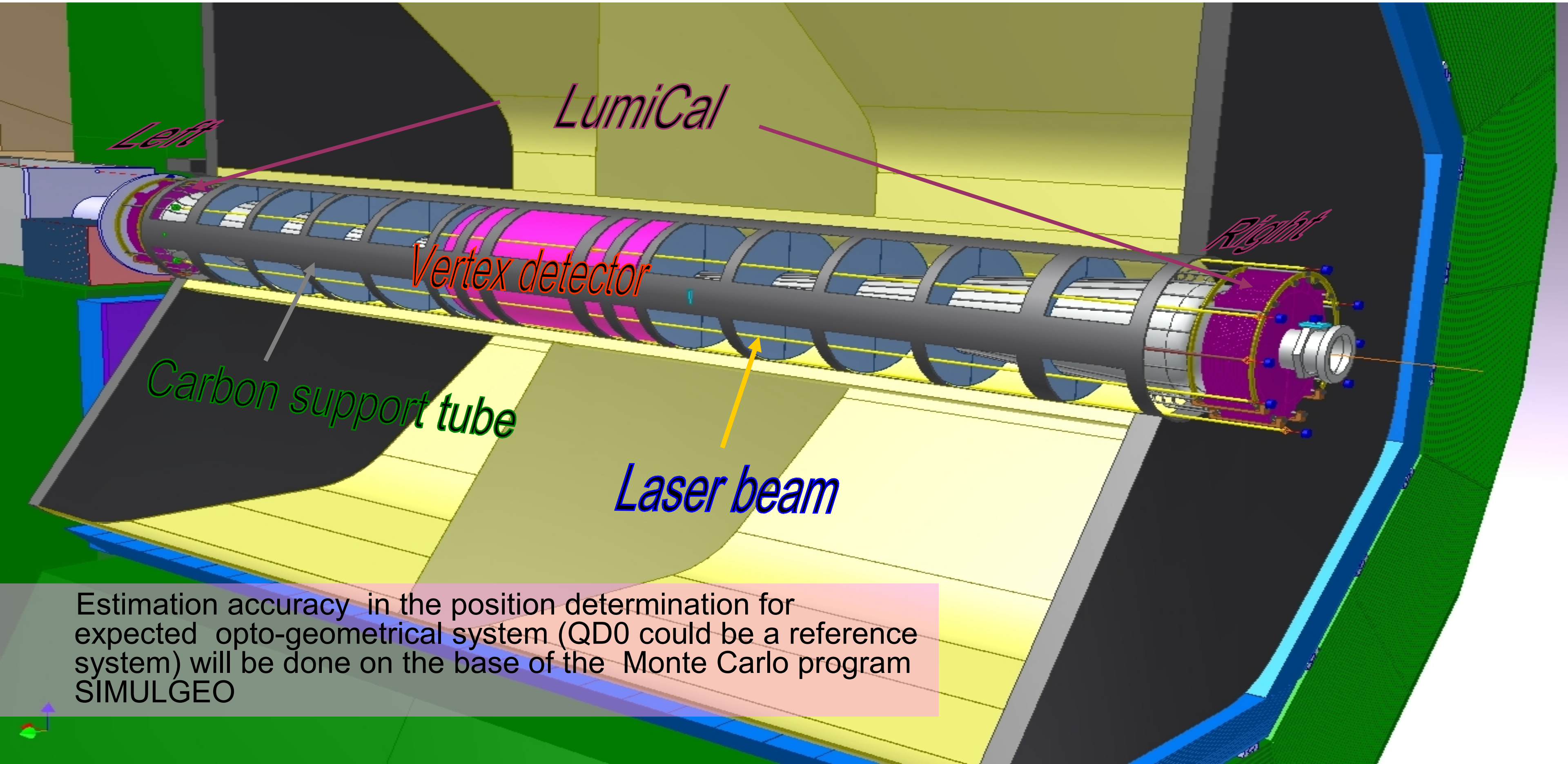


Printed circuit board (PCB) is ready.

Start of the readout test of the chain

Left - Right LumiCal alignment inside ILD

- Laser beams (at leat 6 for space orientation) inside 'carbon' support tube – pipes with small diameter ~ a few (10 -15) mm
- System with interferometers

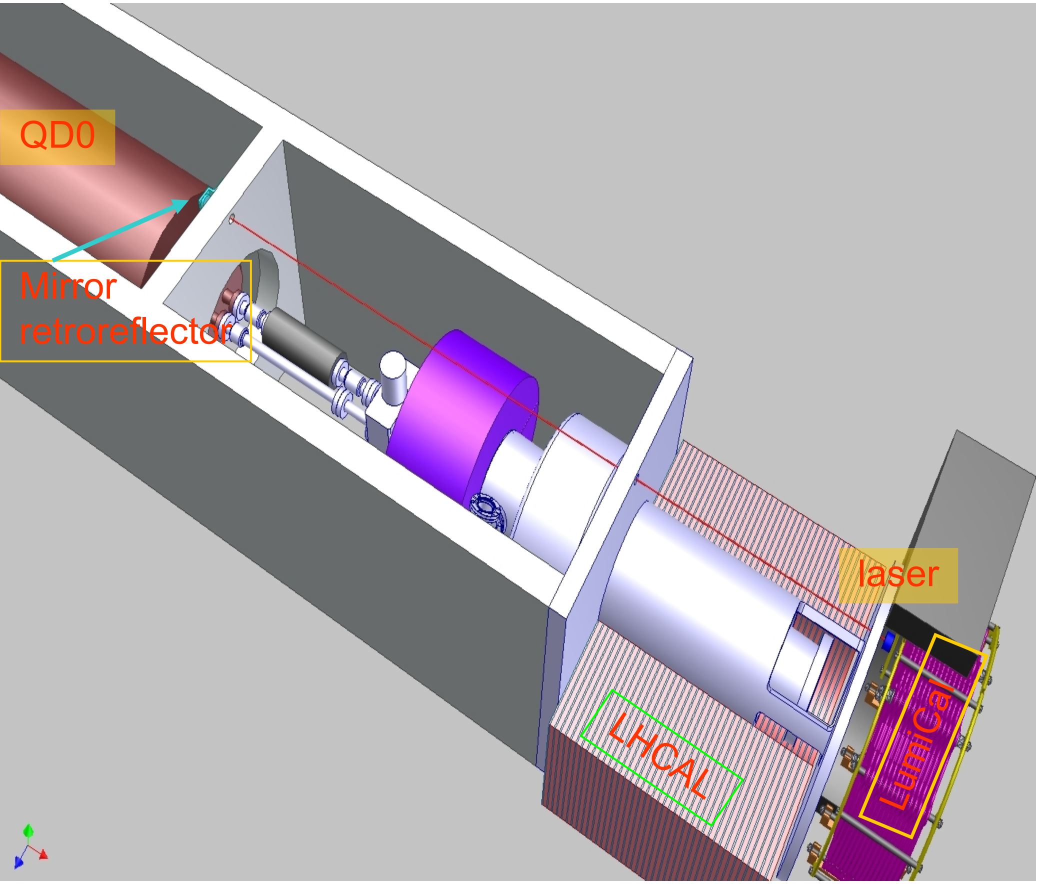


Estimation accuracy in the position determination for expected opto-geometrical system (QD0 could be a reference system) will be done on the base of the Monte Carlo program SIMULGEO

Possible measurements using QD0, beam pipe

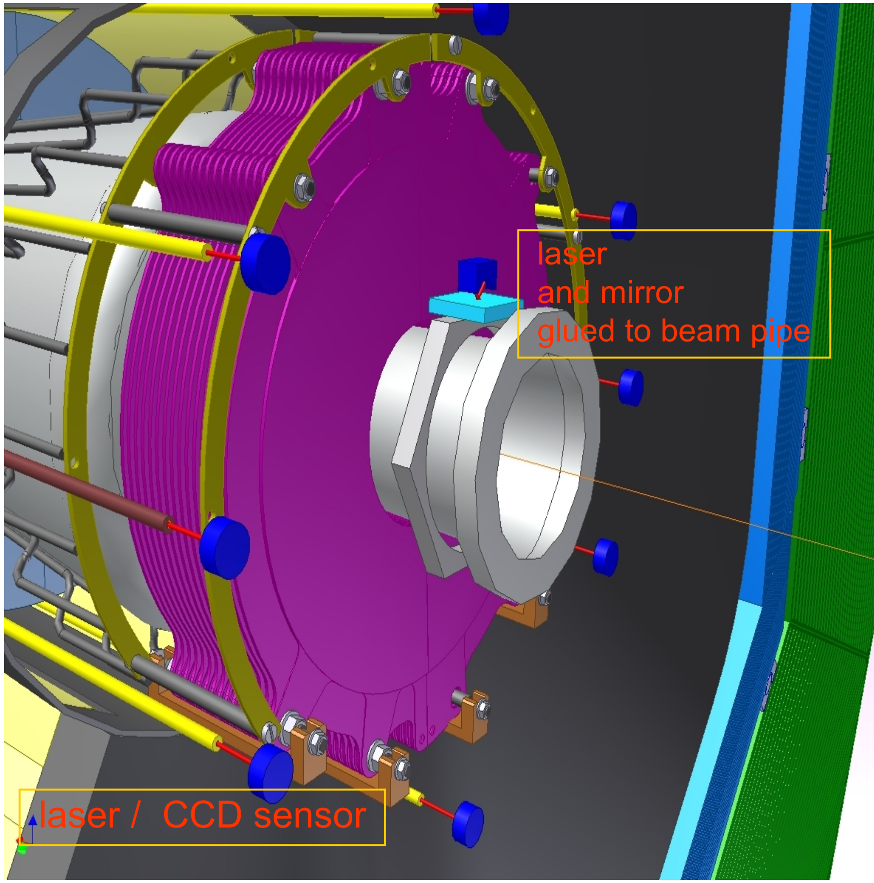
In the framework of ILD detector, LAS can base on measured distances to:

QD0



Accuracy in reflective laser distance measurement ~ 1.0 µm

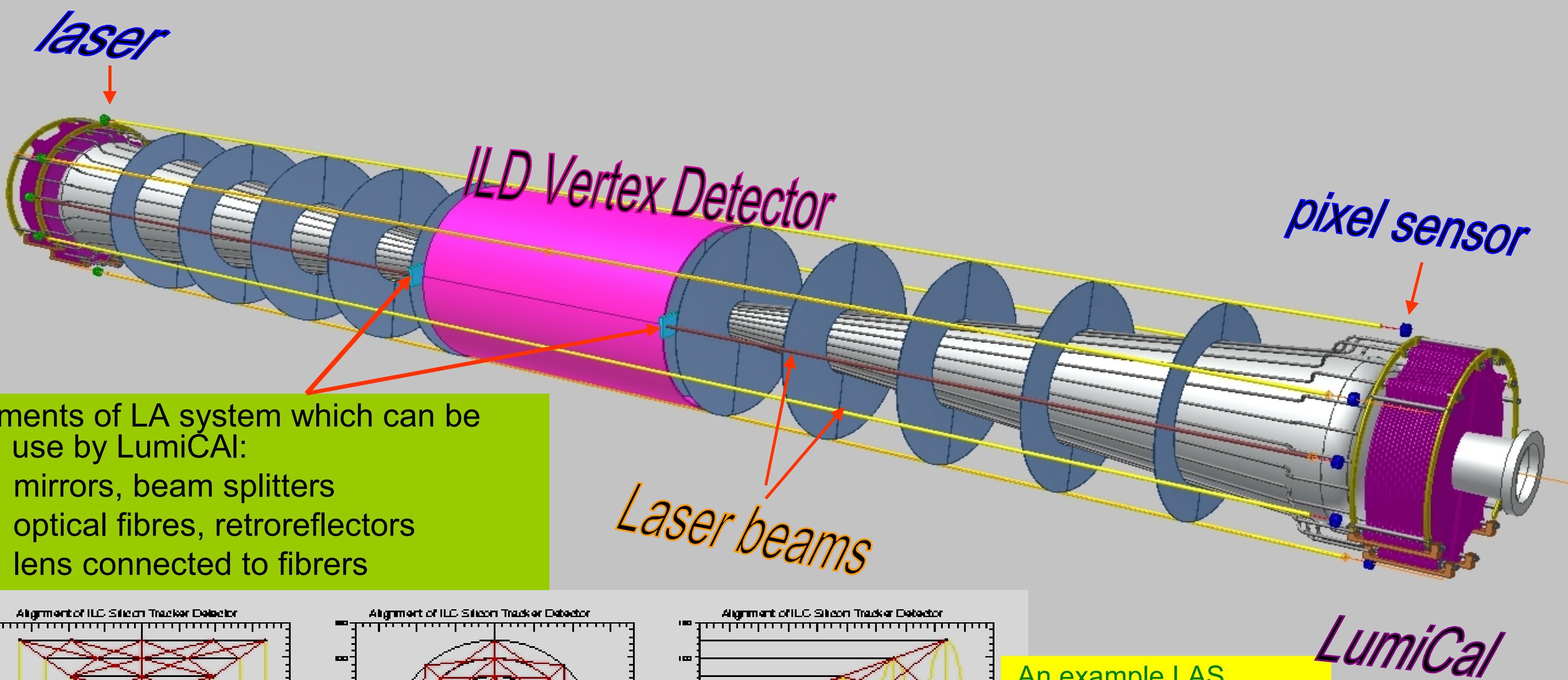
Beam pipe



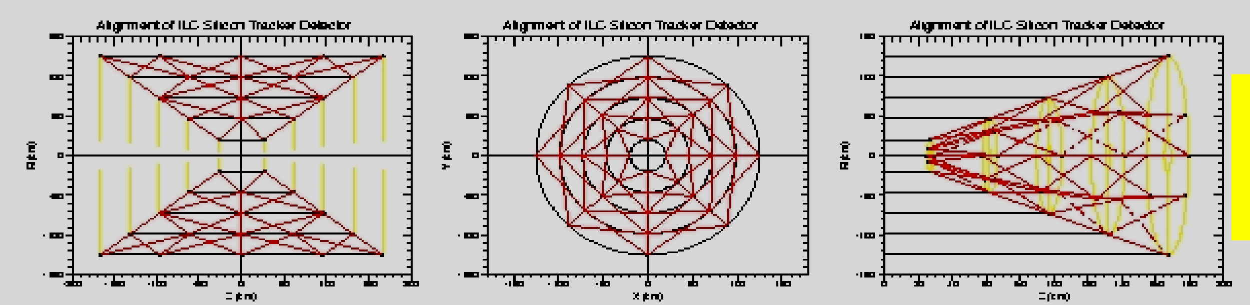
Beam pipe (measured in lab before installing, temperature and tension sensors for corrections) with installed BPM

LAS - toward an integrated system

A possible solution: LAS for Si detector (VXD) and LumiCal - using Frequency Scanned Interferometers (FSI) and optical fibres



Elements of LA system which can be use by LumiCAl:
- mirrors, beam splitters
- optical fibres, retroreflectors
- lens connected to fibrers



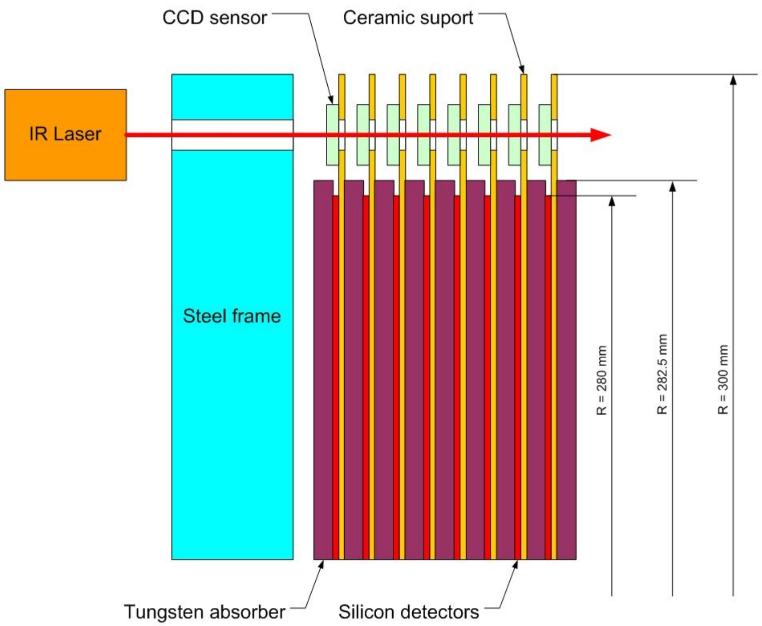
An example LAS for SI tracker: Hai-Jun Yang et al. physics/0506197 (2005)

Laser beams grid with several hundred point-to-point distances which should be measure

Displacement measurement of individual sensor layers

Transparent position sensors :

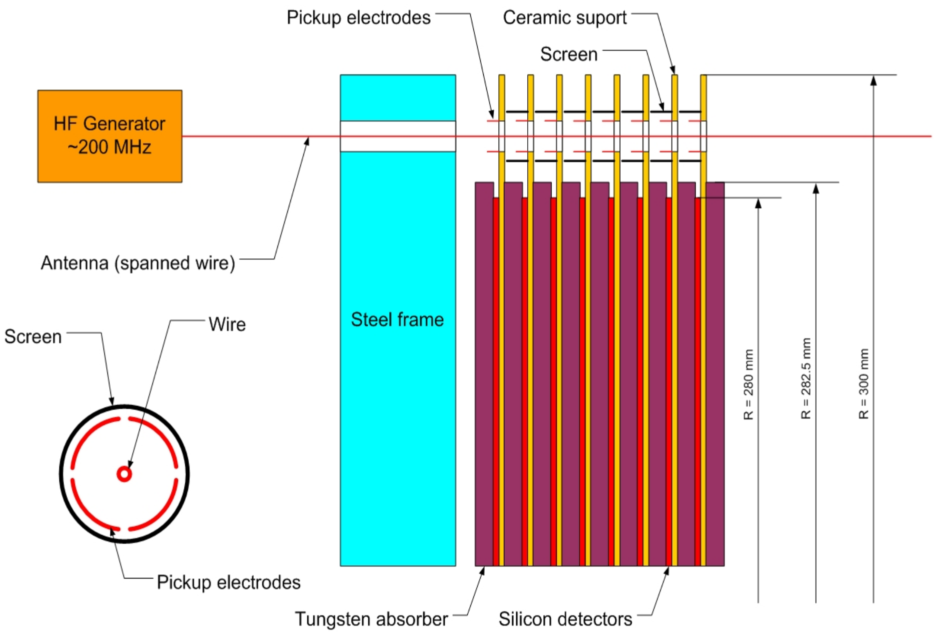
One laser beam lighting or
individual system for each sensor plane



- Special transparent sensors (CMOS, CCD) placed on each sensors plane
- Problems with reflections
- Degradation of the beam shape for deeper planes
- Similar lectronics as in pos. system for calorimeter

Spanned wire method

Spanned wire going through the holes in sensor planes
working as antena and pickup electrodes
to measure the position



- Active during time slots between trains
- Possible interferences
- Accuracy up to ~0,5 μm
- Quite simple electronics
- Need 4 coax cables for each plane

Summary

- LAS is very challenging project in respect to the requirements:
  precisely positioned Si sensors (inner radius accuracy < ~4 μm),
  X & Y alignment with respect to the beam < ~700 μm,
  distance between Calorimeters < ~100 μm, tilts < ~10 mrad

- The current laboratory prototype :
  - the accuracy in position measurements are
    on the level ± 0.5 μm in X,Y and ± 1 μm in Z direction
  - thermal stability of the prototype is ~0.5 μm/ºC

- The technical design required knowledge on final ILD geometry

- More work is ongoing on the system development :
  - alignment of both parts of LumiCal, studies on integrated LAS inside ILD
  - positions of the internal sensor layers,
  - the more compact prototype,
  - readout electronics for dedicated sensors
    and automatic position calculations
- Monte Carlo base estimation the uncertainties of the considered
  opto-geometrical LA system

EUDET Report in preparation