Laser alignment system

Status report

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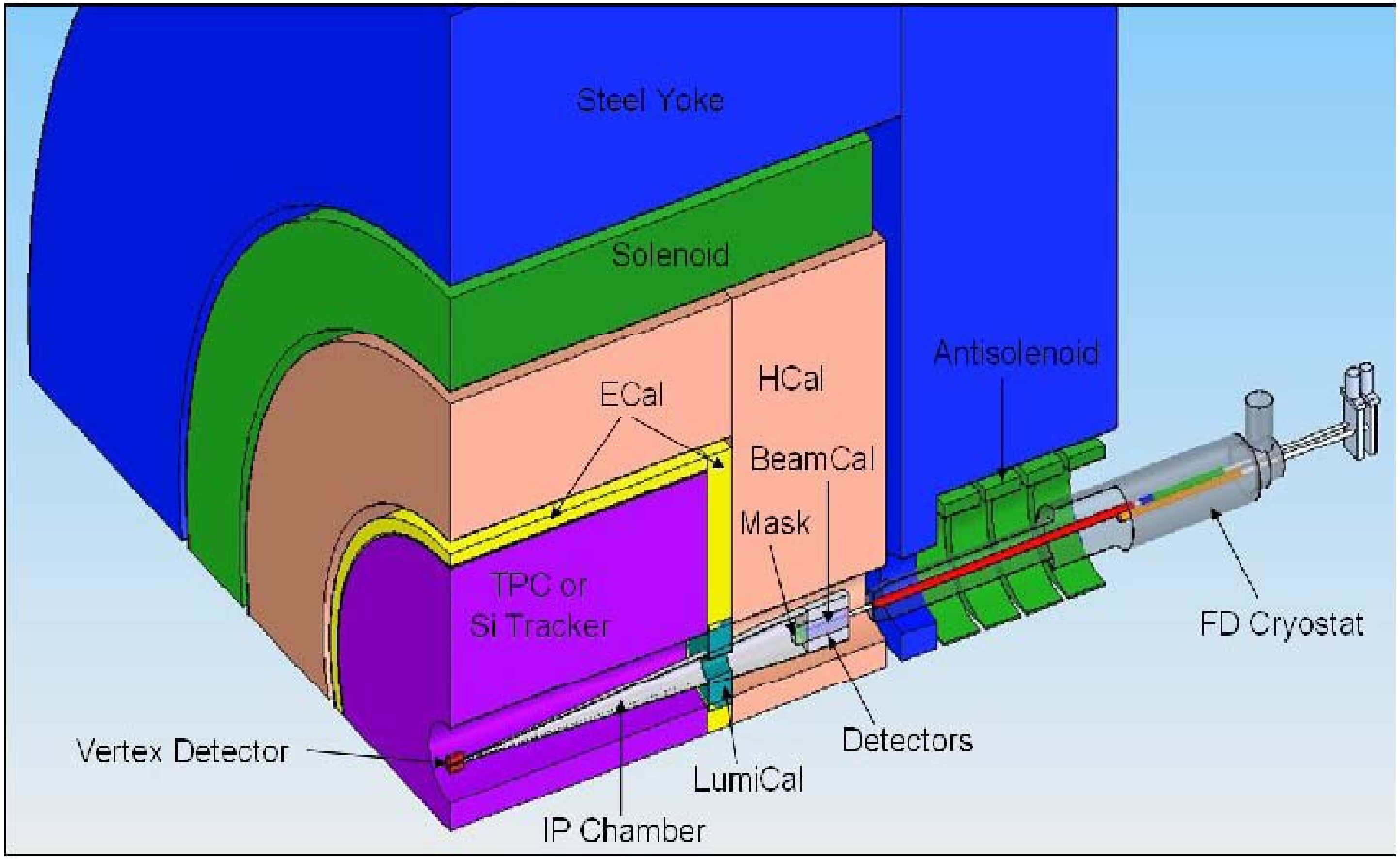
LumiCal - luminosity measurement

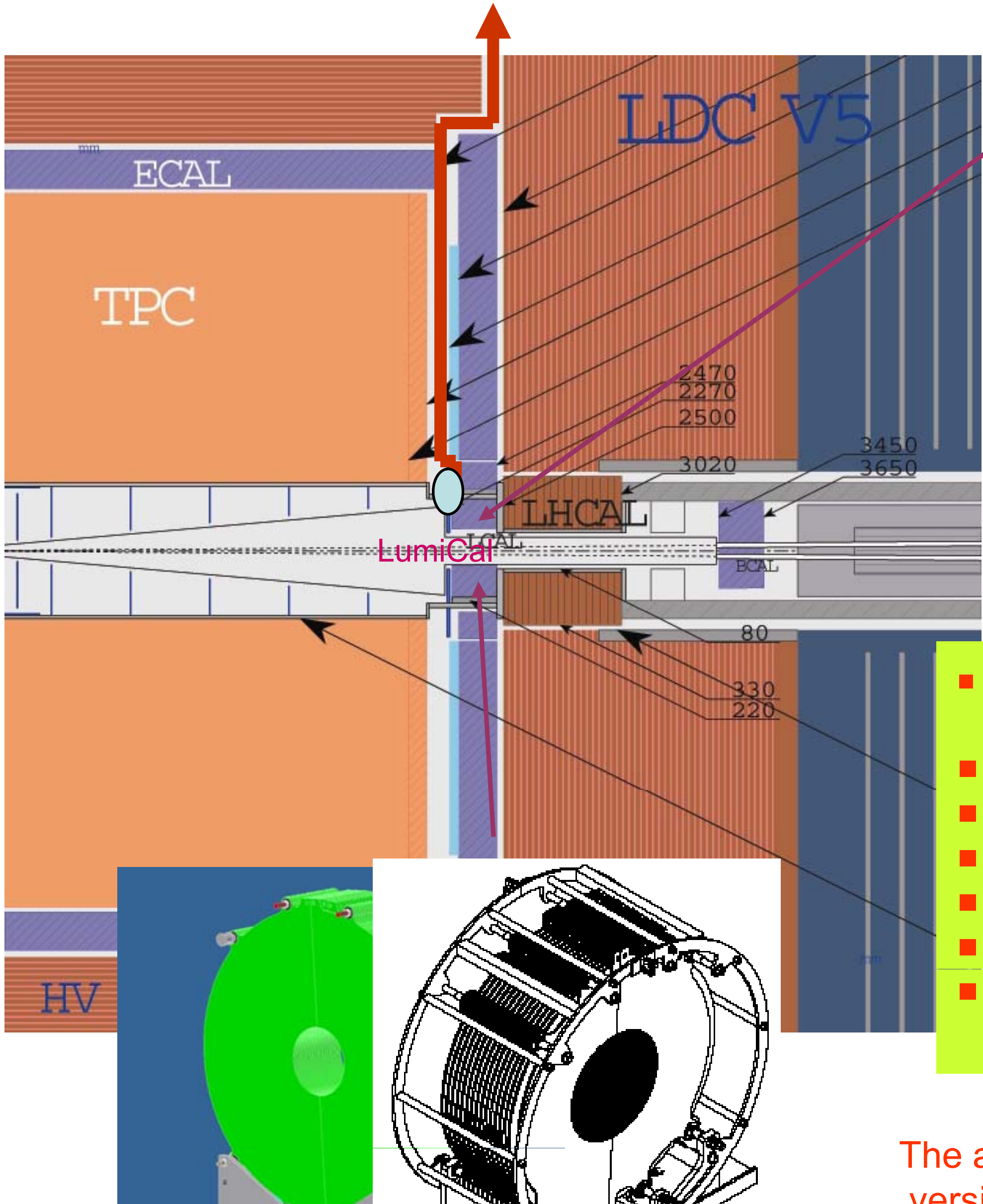
Counting rate **N** of the **Bhabha events : $e^+e^- \rightarrow e^+e^- \gamma$**
in small forward calorimeter LumiCal will be used to measure the integrated luminosity : $L = N / \sigma$ where σ is precisely calculated from theory

ILC physics -
the required precision of integrated luminosity measurement $\Delta L/L \sim \Delta N/N$:
better than $< 10^{-3}$ at $\sqrt{s} = 0.5$ TeV (or $< 10^{-4}$ for Giga Z mode)



LumiCal and LDC geometry

LumiCal : W / Si calorimeter



- LumiCal can be mounted to special support fixed to the 'construction' pipe
- Cables and cooling water pipes can be feed out in the gap between TPC and ECAL endcap.

Space and access to connectors

LumiCal has to be centered on the outgoing beam

- Two half barrels to clamp LumiCal on the beam pipe
- 30 tungsten/silicon detector layers
- Odd/even planes rotated by 7.5 degree
- Total weight of ~250 kg (one LumiCal)
- Self supporting design of the tungsten structure
- „C" frames for supporting cables,cooling, alignment
- Movable support to open LumiCal – temporary support necessary

Accuracy in Si sensors placement should be in order of a few micrometers

The angular aceptance (active part -sensors) for this version of Lumical structure : **$51 < \theta < 98$ mrad**

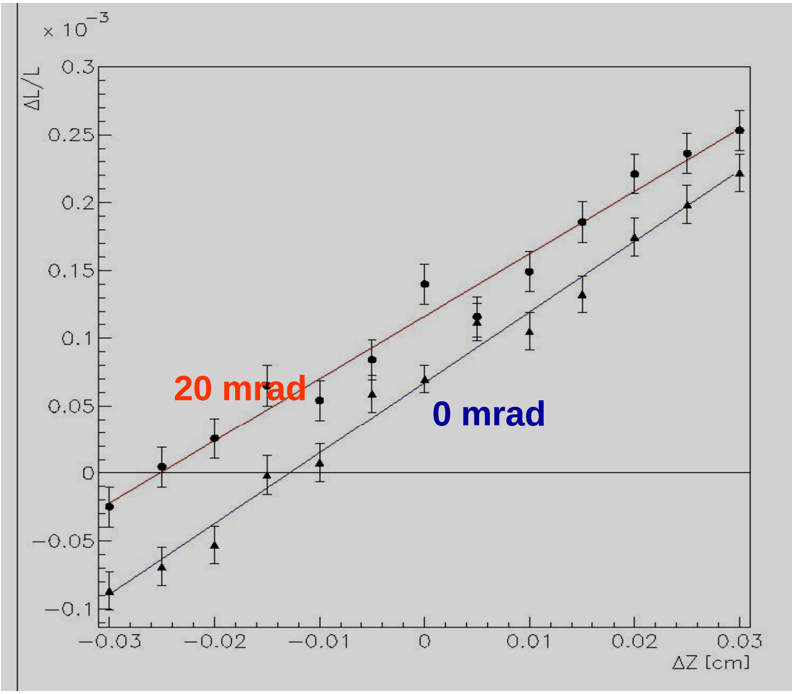
Example from MC studies : displacement of the LumiCal

Mont Carlo : BHLUMI -> Bhabha events

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

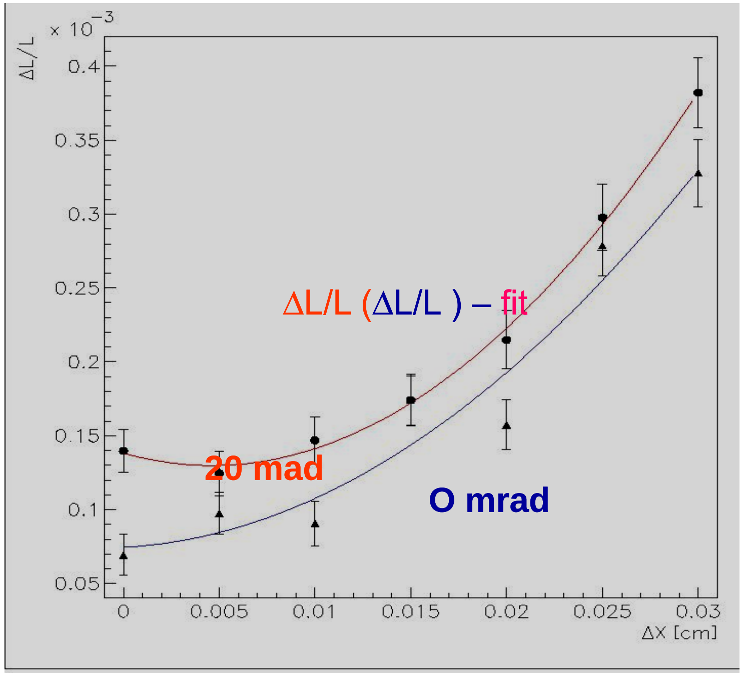
Δ z

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



Δ (x,y)

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

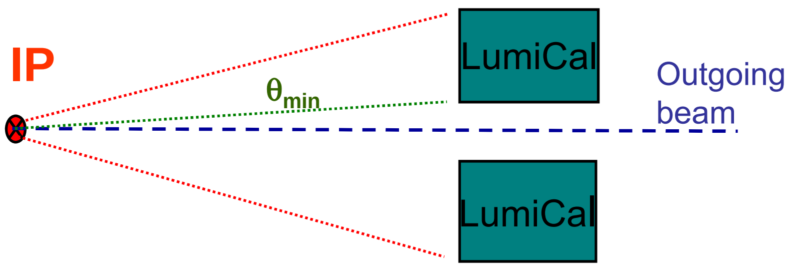


Value ~ 100 μm of the displacement $\rightarrow$ acceptable changes in luminosity measurement

The similar conclusion from other MC studies :

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

High precision in luminosity measurement and high accuracy in determination of LumiCal position

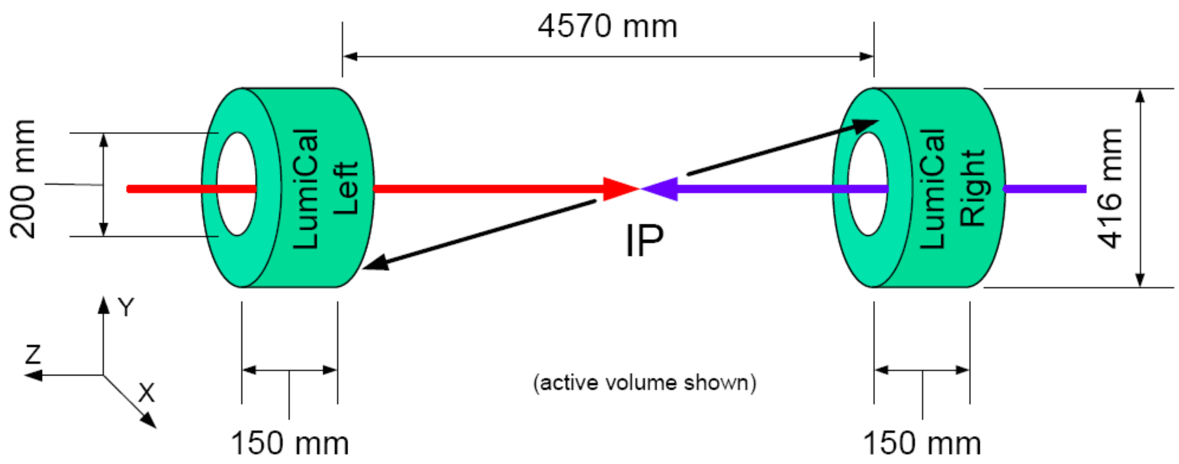


$$\frac{\Delta L}{L} = \frac{\Delta \sigma}{\sigma} \cong 2\frac{\Delta \theta}{\theta_{\min}}$$

Single (Left / Right) LumiCal alignment

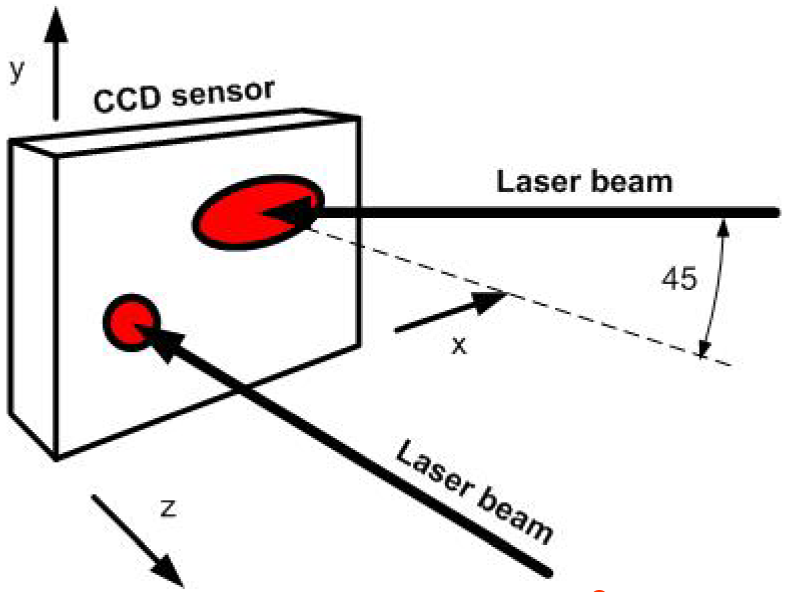
LumiCal X, Y position with respect to the incoming beam should be known with accuracy better than ~700 μm (optimal ~100 -200 μm)
(LumiCal's will be centered on outgoing beam)

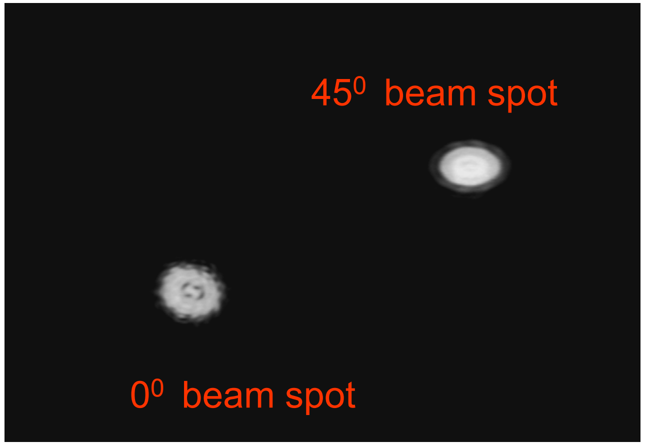
Two LumiCal's (L,R) alignment



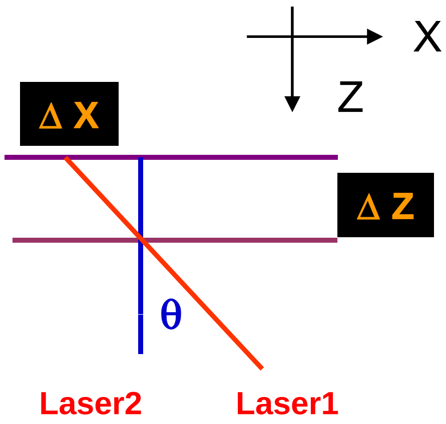
Distance between two LumiCal's should be known with accuracy better than ~60 -100 μm (14 mrad crossing angle)

Laser alignment system (LAS)





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

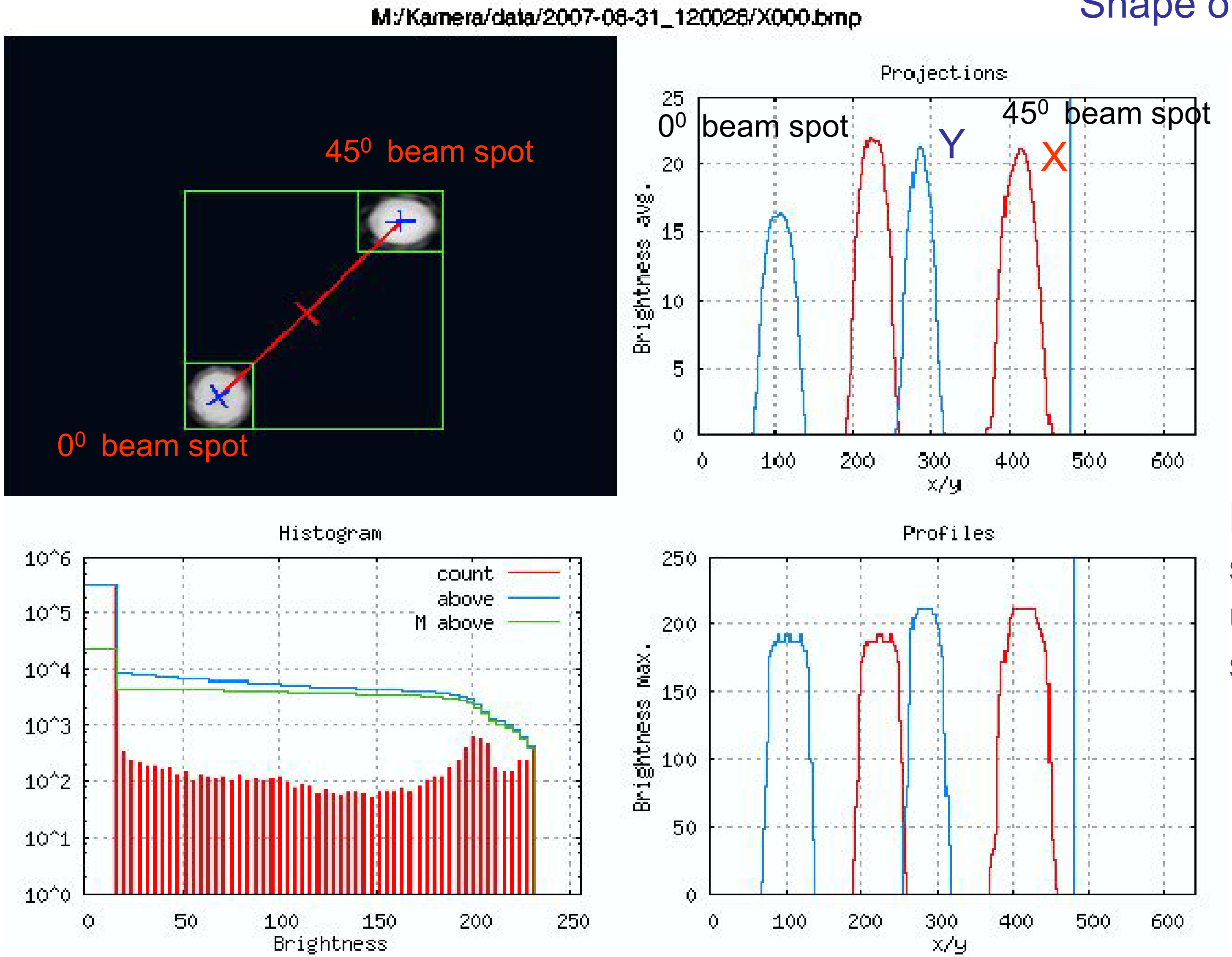


- Two laser beams, one perpendicular, second with the angle of 45° to the CCD/CMOS sensor surface, are used to calculate the position shift
- The CCD camera and lasers can be fixed to the LumiCal and beam pipe
- Three or more sensors can be used to measure tilt of each LumiCal
- Six (?) laser beams from one to another LumiCal passing inside the 'carbon support' pipe can be used :
  - to measure the relative position shift (the method described above)
  - the distance between two LumiCal's (very challenging, not solved yet)

LAS : system with CCD camera

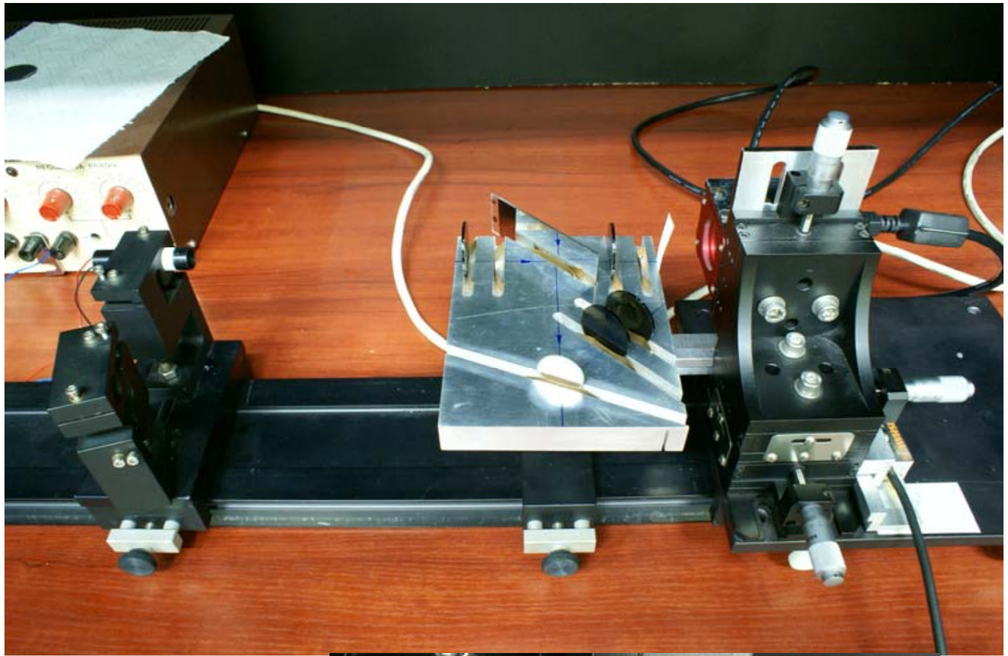
The picture on the face of pixel CCD silicon camera

Shape of the spots



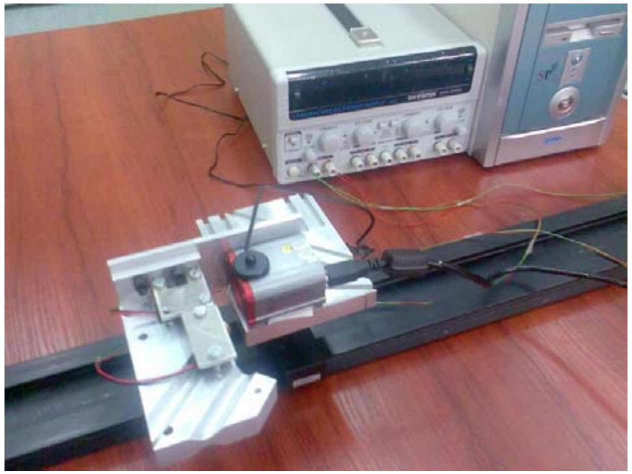
Pixels saturation - use some filters

LAS : laboratory setup



Present setup – dual laser beam

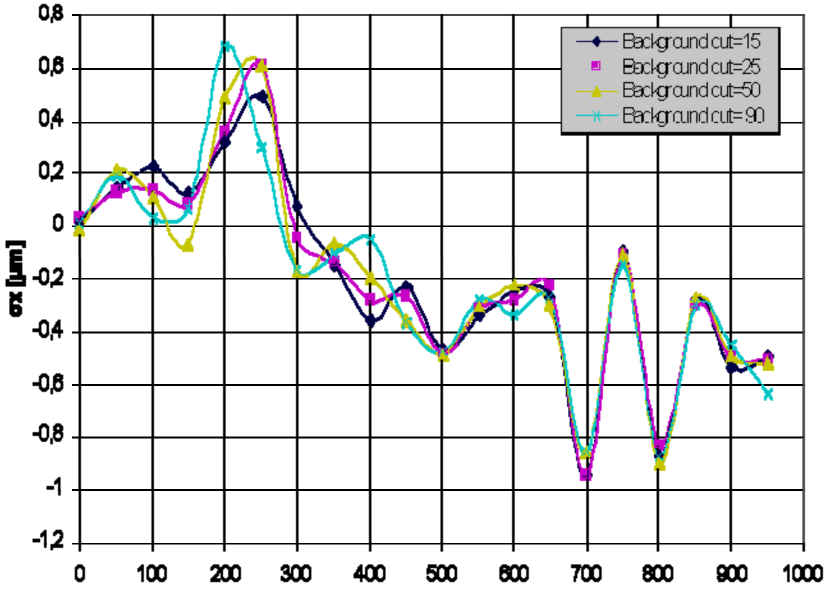
- BW camera DX1-1394a from Kappa company 640 x 480 with Sony ICX424AL sensor 7.4 μm x 7.4 μm unit cell size
- Laser module LDM635/1LT from Roithner Lasertechnik
- ThorLabs ½” travel translation stage MT3 with micrometers (smallest div. 10 μm)
- Neutral density filters ND2
- Renishaw RG24 optical head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

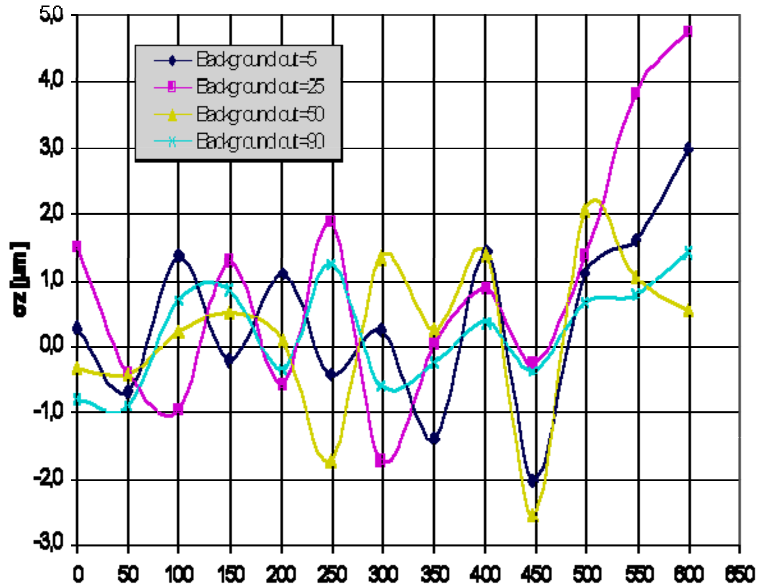


Results of X & Z position measurements

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

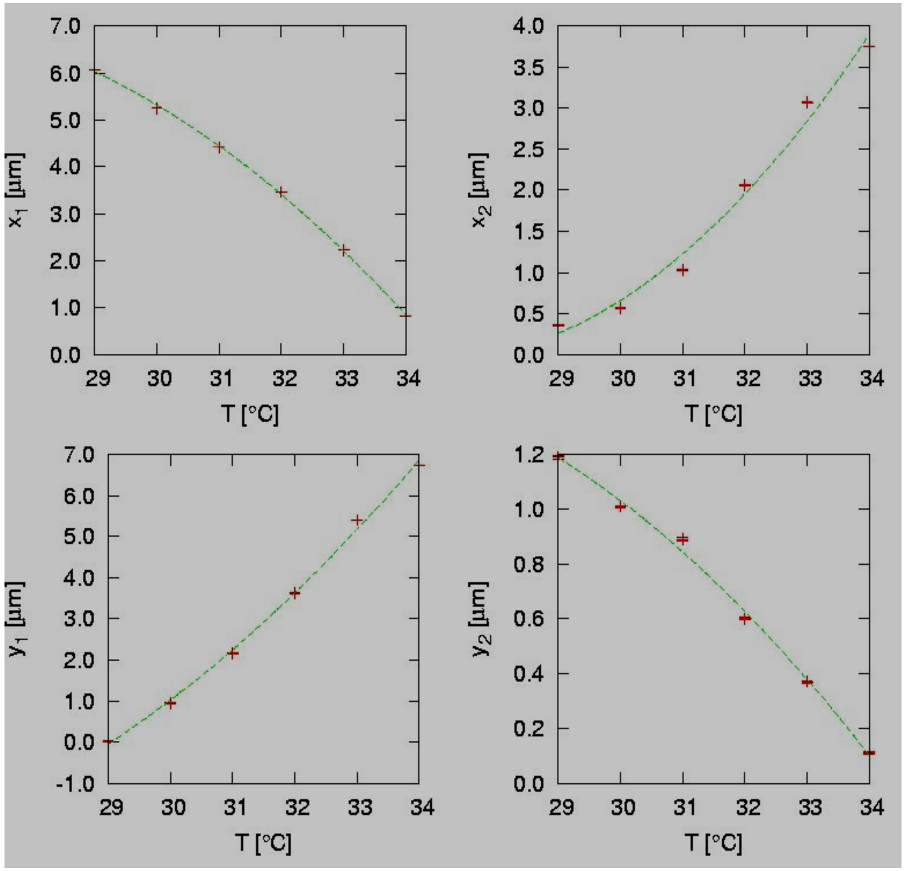
- Camera was translated in steps of 50 µm.
- The distances Xtrue and Ztrue was measured with Renishaw RG-24 optical head with the resolution of ±0.1 µm

Stability - temperature dependence

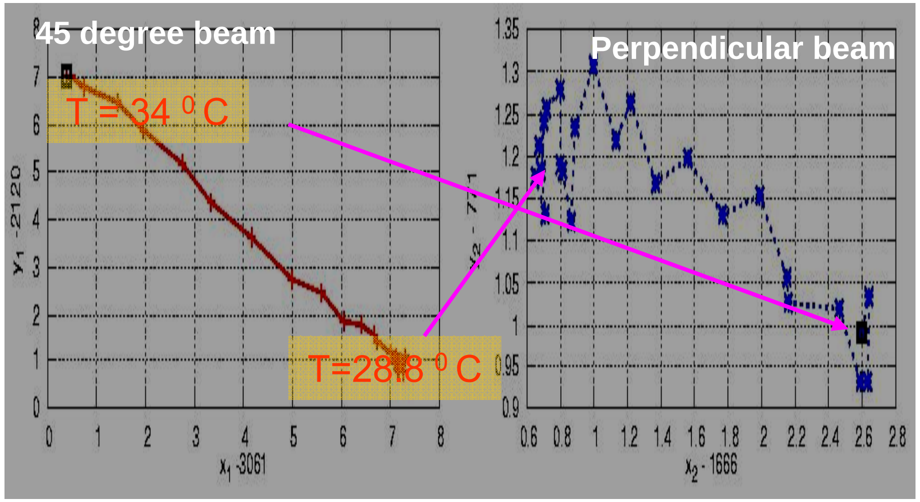
The temperature dependence of the beam spots position in CCD camera: heating or cooling down environment of the laser system.

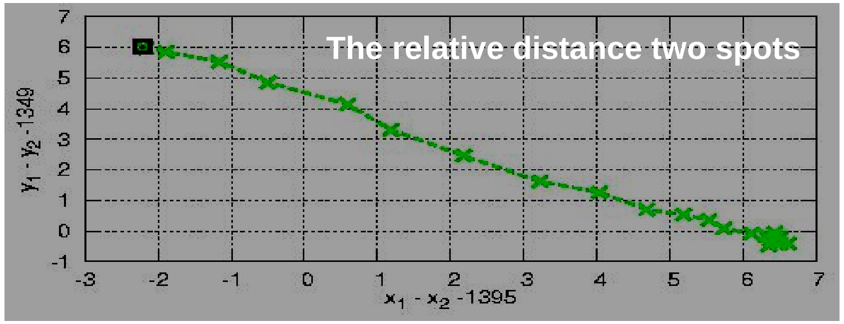
- Insulated heating box .
- For each temperature point, the mean position of the spot centers from multiple measurements were calculated using improved algorithm

45 degree beam   Perpendicular beam



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



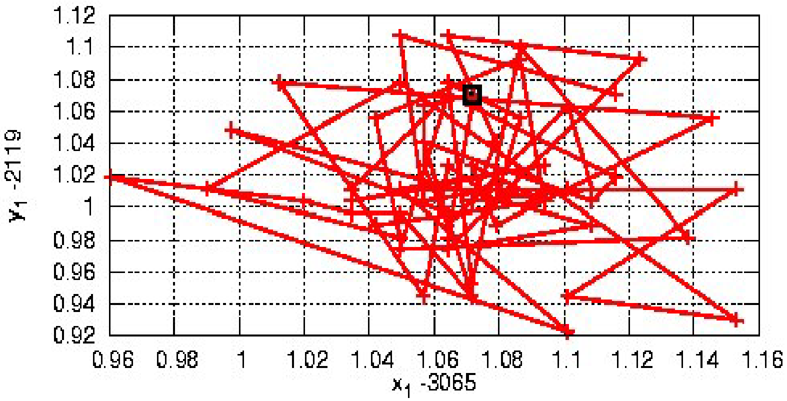


The observed changes on the level ~ 1 μm/1 ^{0}C

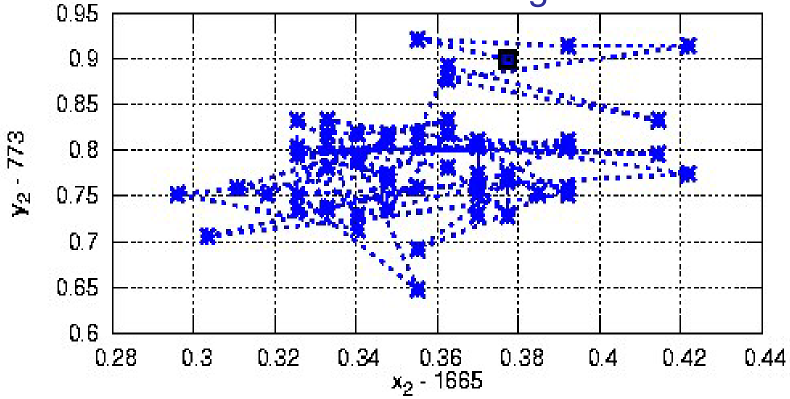
Temperature stabilization – the small temperature changes ($\Delta T \sim 0.1^0$ C)

5 minutes measurements:

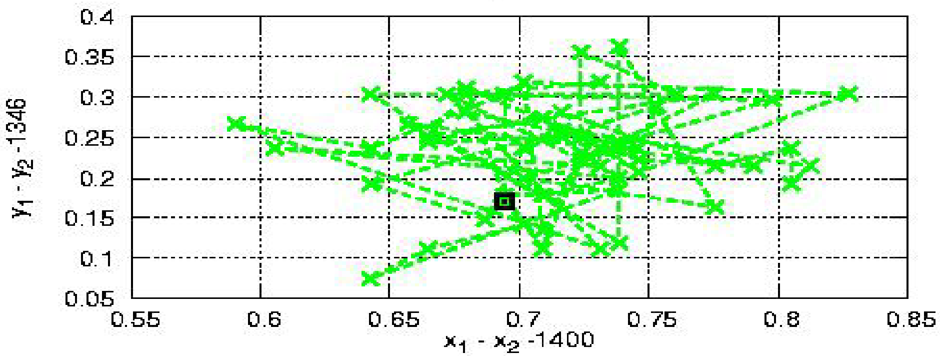
beam– 45 degree



beam – 0 degree



The calculated X,Y positions of both beams - the relative changes are on the level $\pm$ 0.3 μm



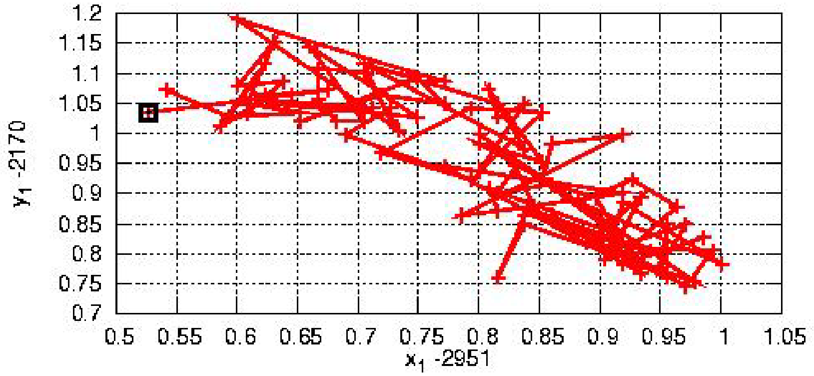
The changes in distance betwen spots: on the level $\pm$ 0.4 μm

Even without temperature influence some effect coming from nature of laser spot and systematic uncertainties in used algorithm can be important

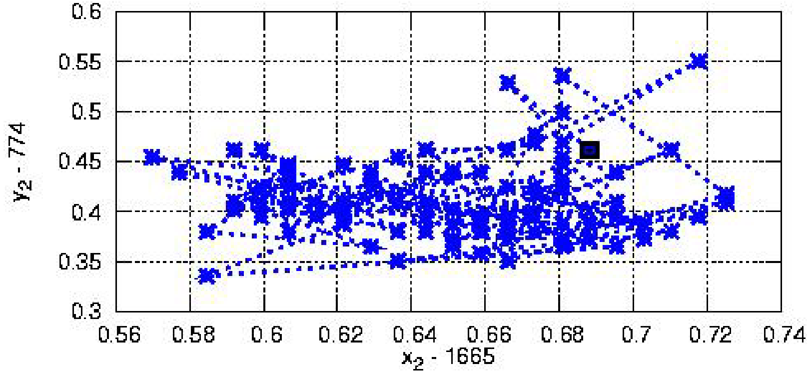
Temperature stability

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

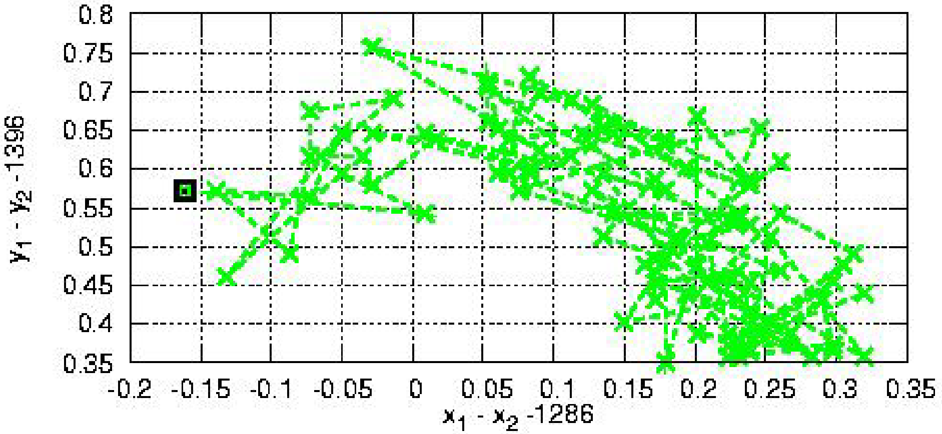
45 degree beam



0 degree beam



The relative distance between laser beams

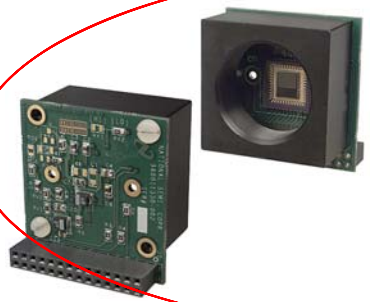


The observed changes in calculated X,Y spots positions are on the level 0.5 μm.
Contribution from other effects ?

- It is necessary to stabilize the temperature of camera (stabilized chamber is under design)
- Collimator and laser optics should be improved

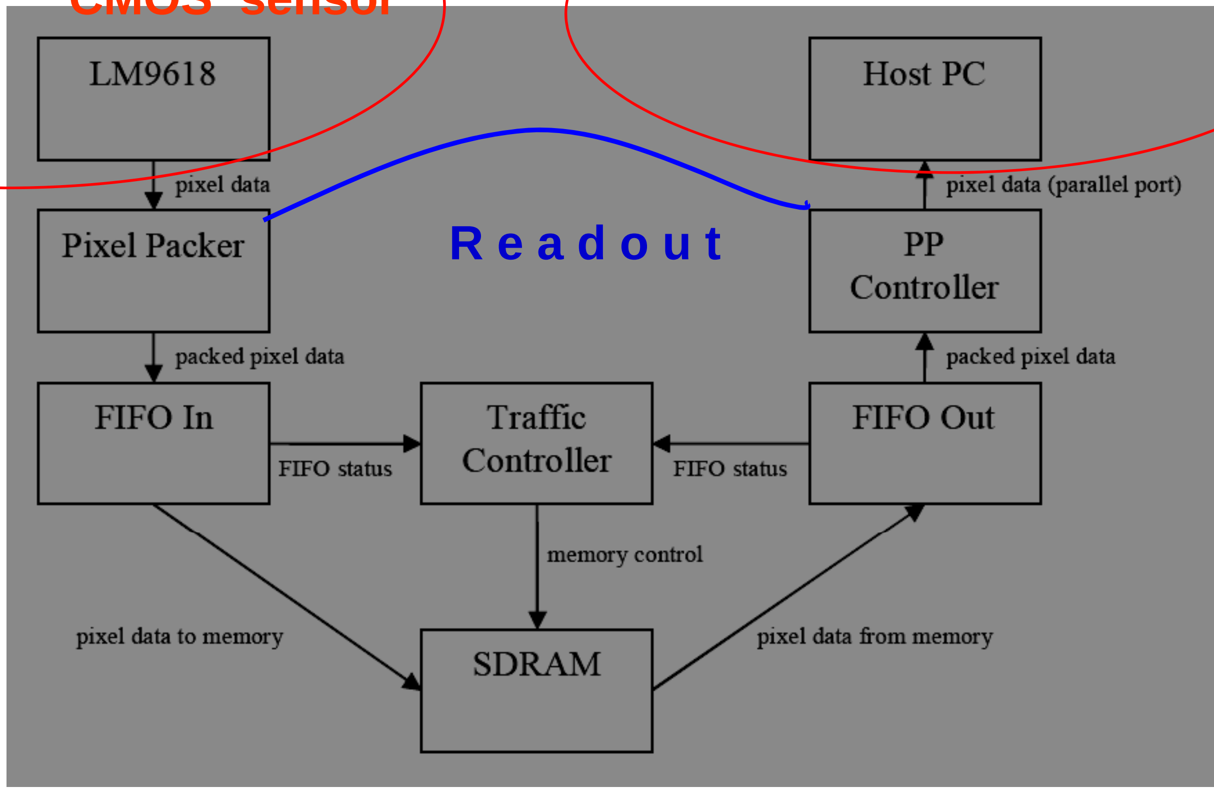
LAS : the development steps

Work on : design of the readout electronics for dedicated silicon sensor,
automatic (online) displacement calculation,
a compact shape of the system



Dedicated CMOS sensor

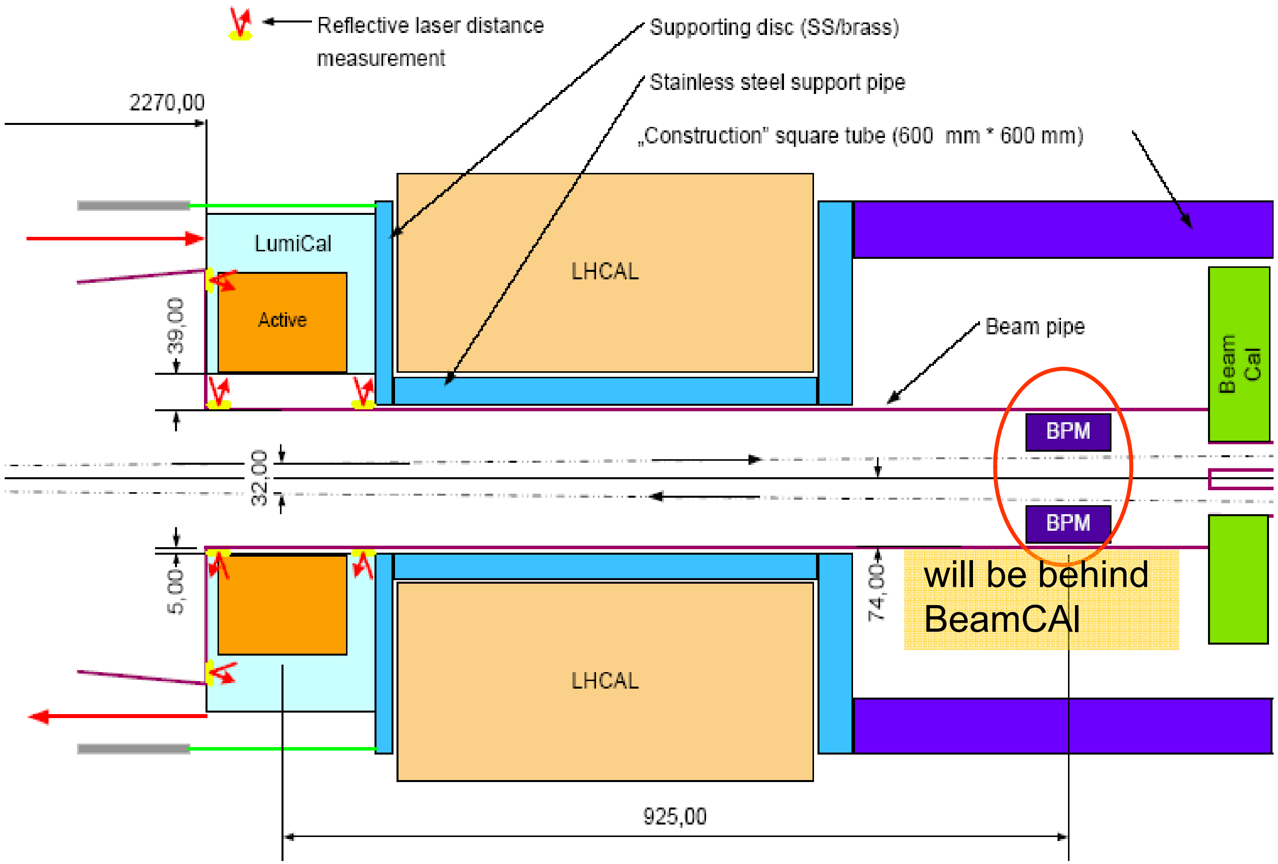
Displacement calculations



LAS development – integration with LDC

Alignment (L/R) measurement based on beam pipe and BPM.s.
Alignment two parts (L+R) of LumiCAl

Beam pipe can be centered on detector axis or on outgoing beam: a different free space for LumiCal



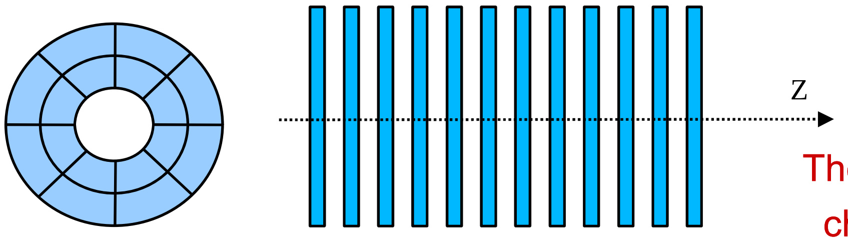
- Reflective laser distance measurement – accuracy ~1-5 μm, resolution ~0.1-0.5 μm
- Mirrors glued to beam pipe
- Calibration of sensors procedure – detector push-pull solution (?)
- Calibration of sensors procedure after power fault (?)

- Beam pipe (well measured in lab before installing, temperature and tension sensors for corrections) with installed BPM
- Laser beams inside 'carbon' pipe (need holes, but possible) – interferometric measurement

Example from MC studies on the internal structure deformation

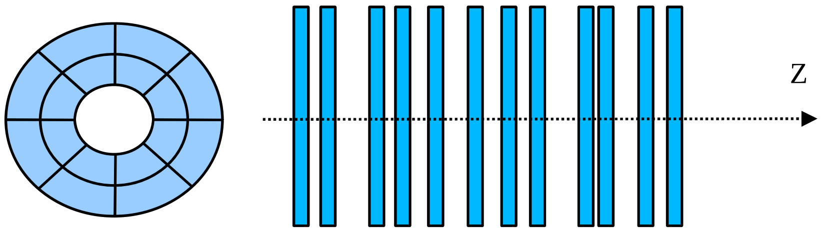
Changes in X,Y and Z positions of the Tungsten and Si sensors layers

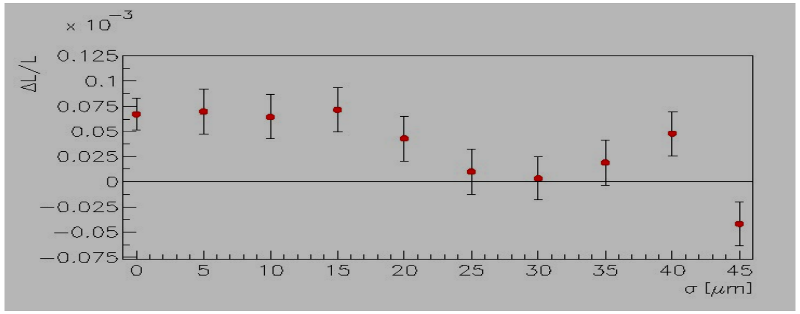
ideal



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

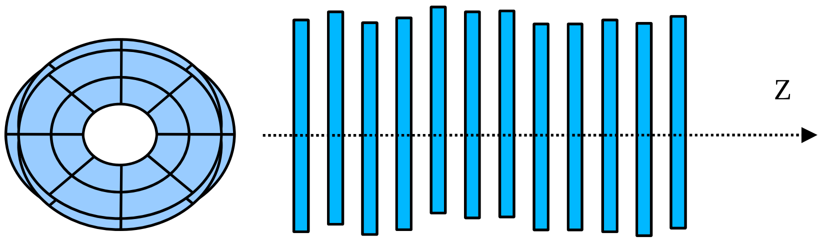
dedormation in Z

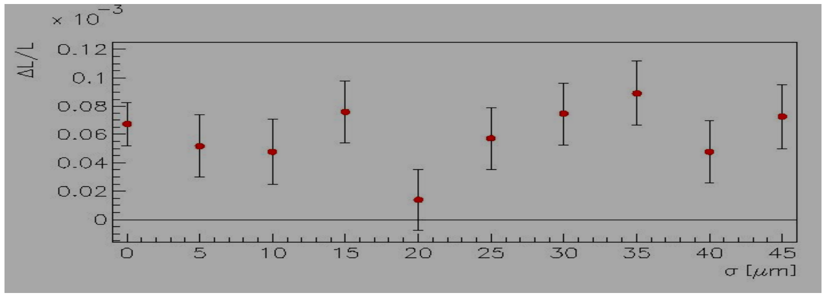




An in X,Y directions

deformation in X and Y





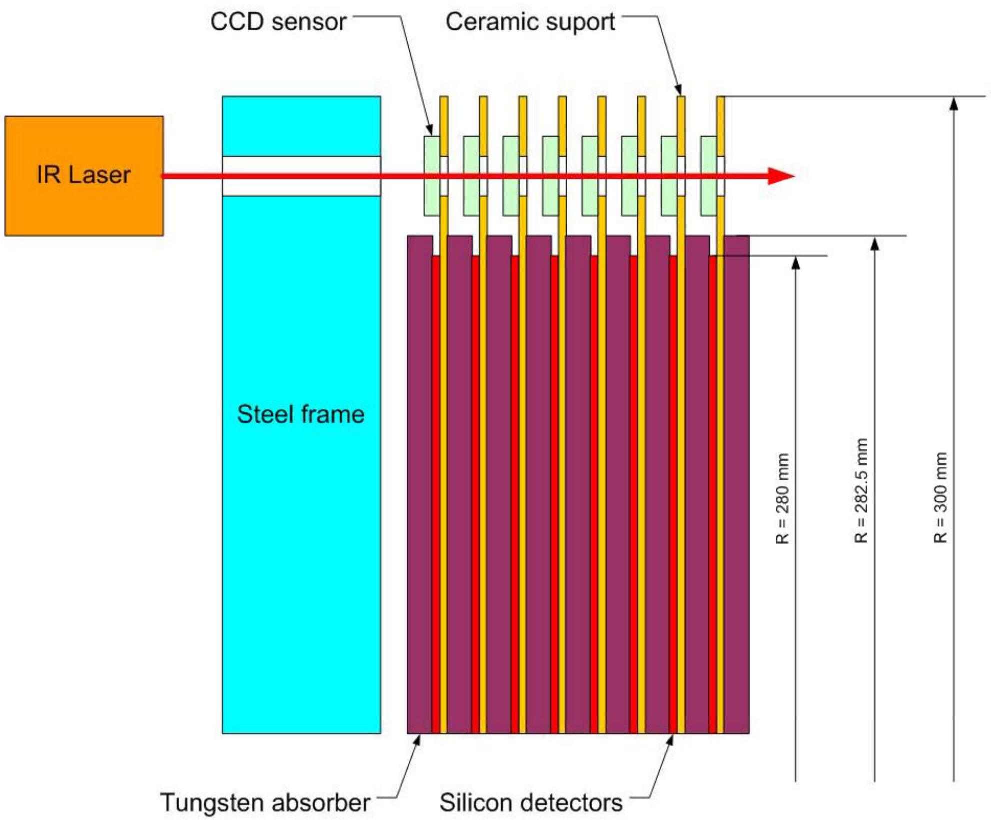
Possible systematic effect on luminosity measurements is expected to be about one order smaller in comparison to possible displacement the Lumical detector as whole but still should be treated carefully as possible significant contribution to total error in luminosity calculation

LAS development – measurement of individual sensor layers

Proposed solutions for the online measurement of the LumiCal sensor planes :

Transparent position sensors :

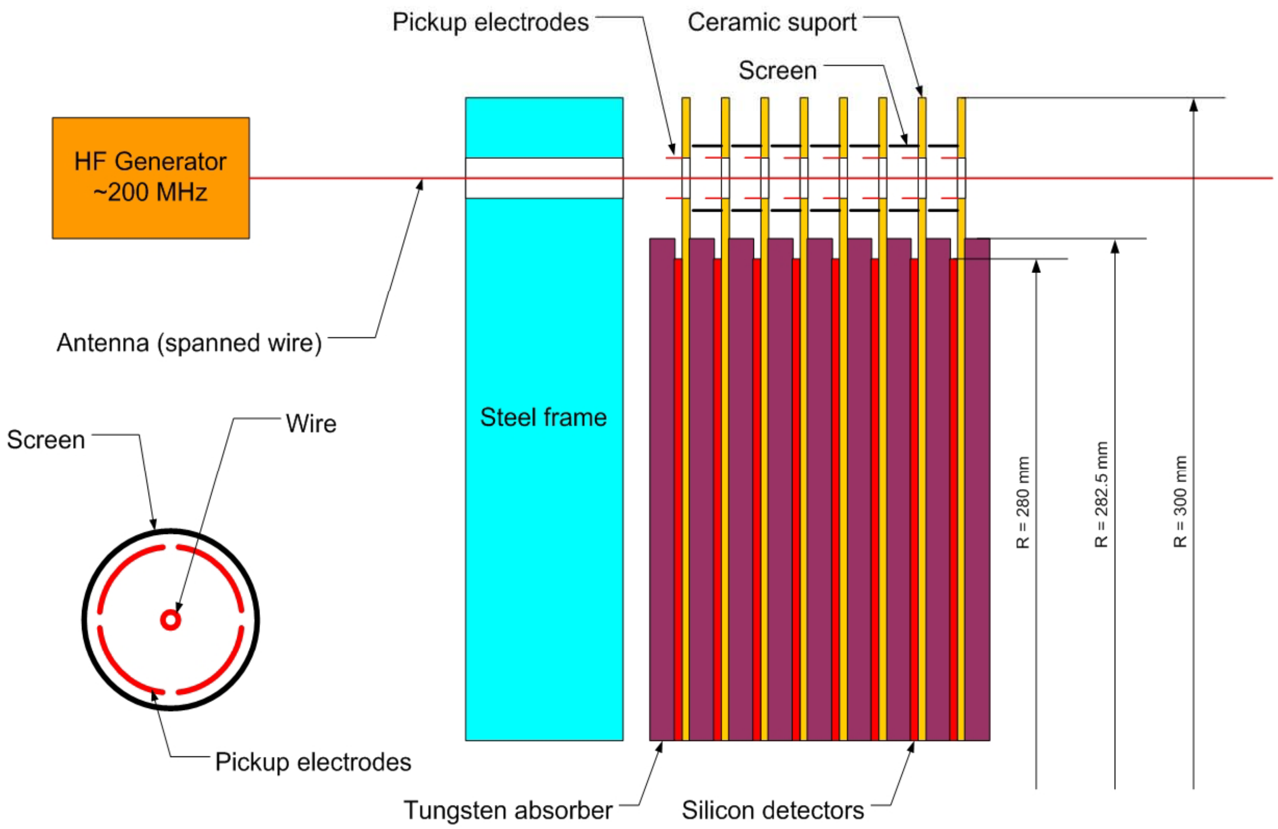
One laser beam lighting or
individual system for each sensor plane



- Special transparent sensors placed on each sensors plane
- Problems with reflections
- Degradation of the beam shape for deeper planes
  - CMOS or CCD sensors
  - Similar electronics as in position system for calorimeter
  - More reliable
  - More lasers
  - More space necessary

or spanned wire alignment :

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 final LAS design will take into account LDC geometry

- More work is ongoing on the system development :
  - alignment of both parts of LumiCal,
  - positions of the internal sensor layers,
  - the more compact prototype,
  - readout electronics for dedicated sensors
    and automatic position calculations