Laser Alignment Monitoring System (LAMS) for the RICH

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2nd LHC Detector Alignment Workshop

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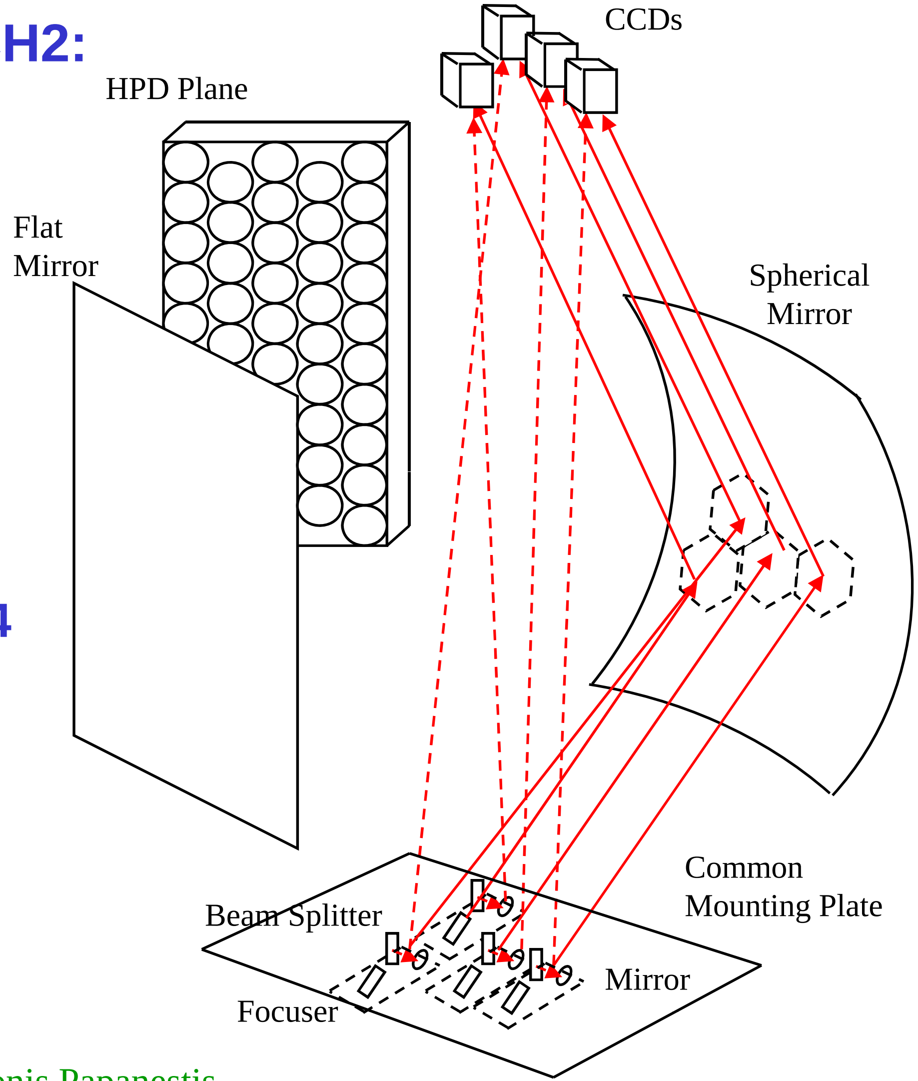
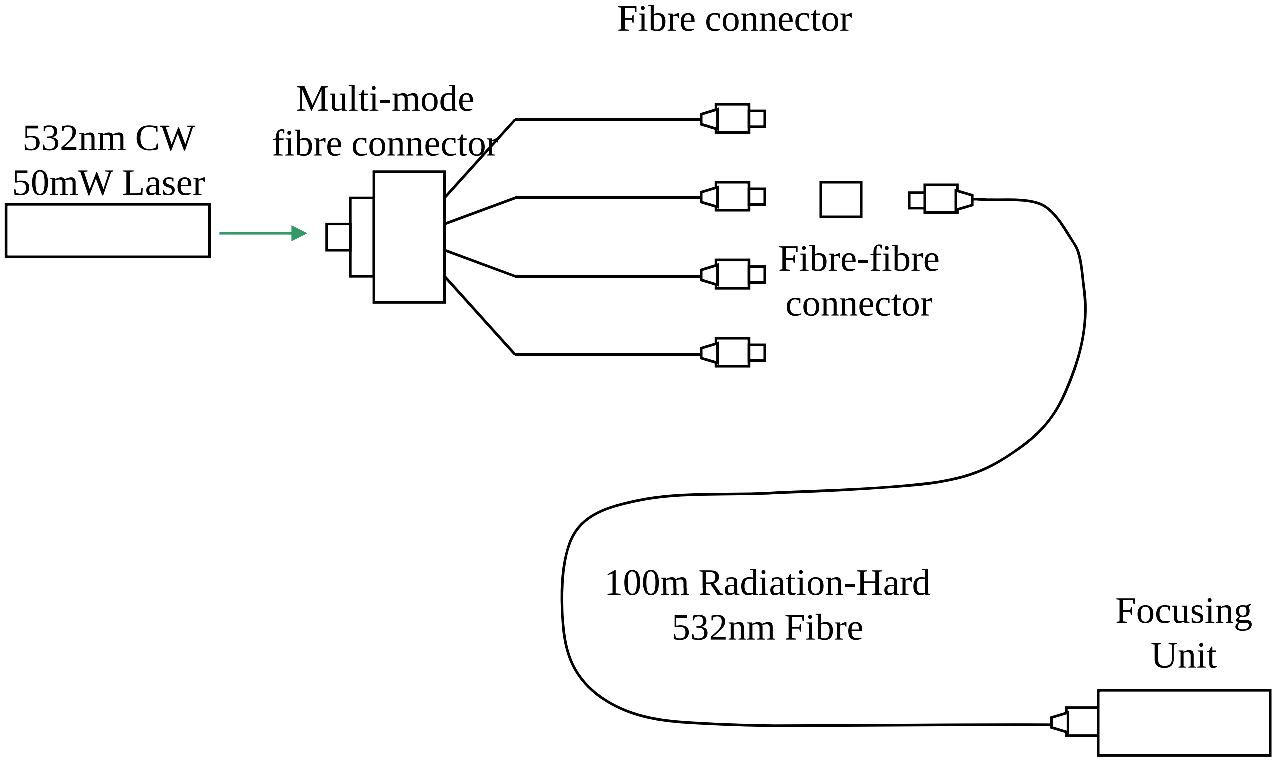
Laser alignment monitoring system

- **Mirror alignment system for RICH2:**
  - **Requires 0.1 mrad resolution as seed for final software alignment**
  - **Monitors changes in selected mirror segments**
  - **Laser with optical fibre coupling system delivers light to 16 fibres.**
  - **Each fibre has a focusing unit at its end and is focused onto a mirror segment (4 spherical and 4 flat per side).**
  - **A beam splitter provides a reference beam for each fibre**
  - **All laser signals monitored by CCDs on roof of RICH2.**



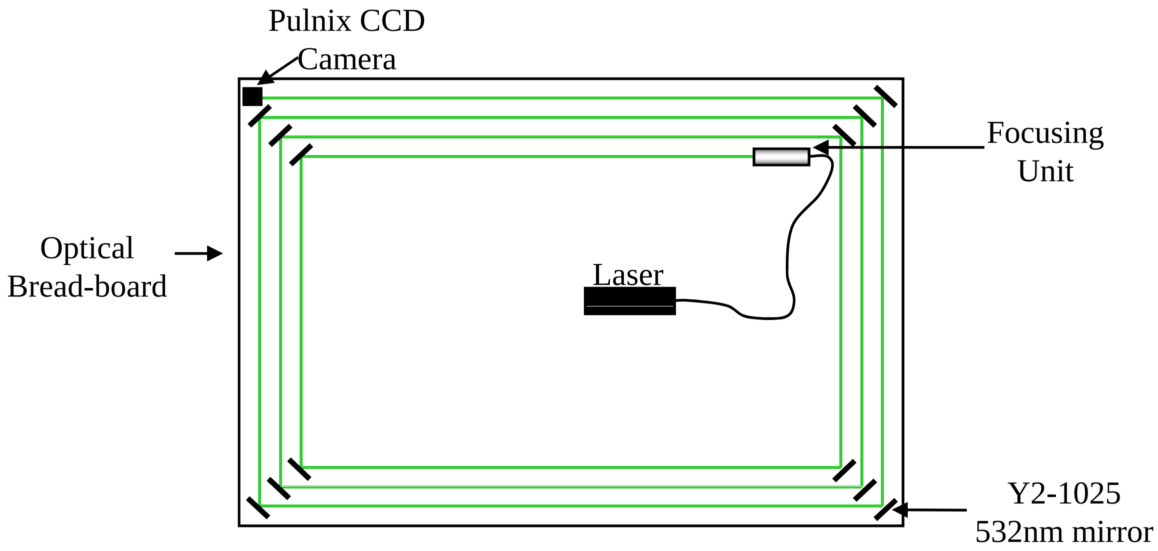
Laser and fibre couplers

- **Laser system:**
  - **Multi-mode connector can connect to 16 fibres**
  - **All components commercially available**



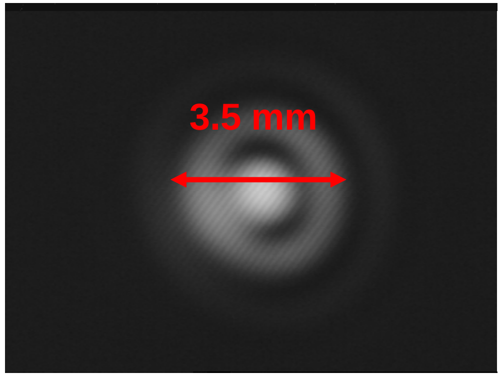
~10 m focal length

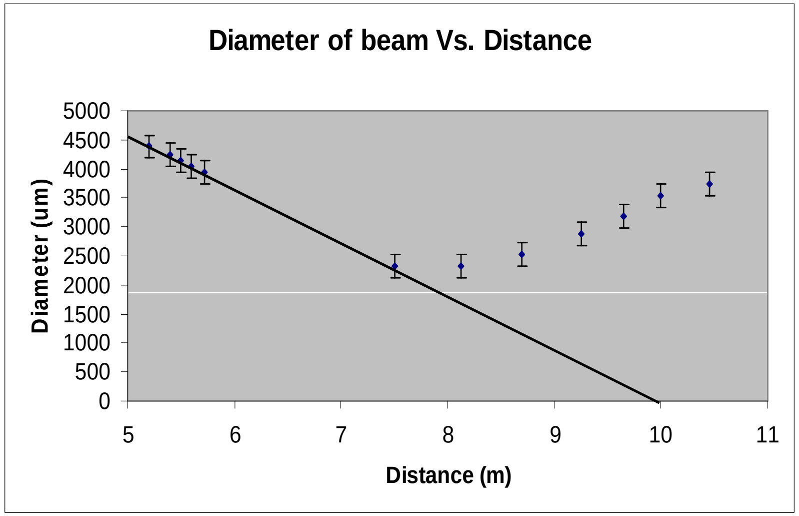
Prototype system



Prototype setup

Beam spot at 10 m

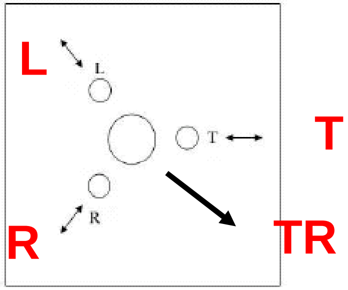




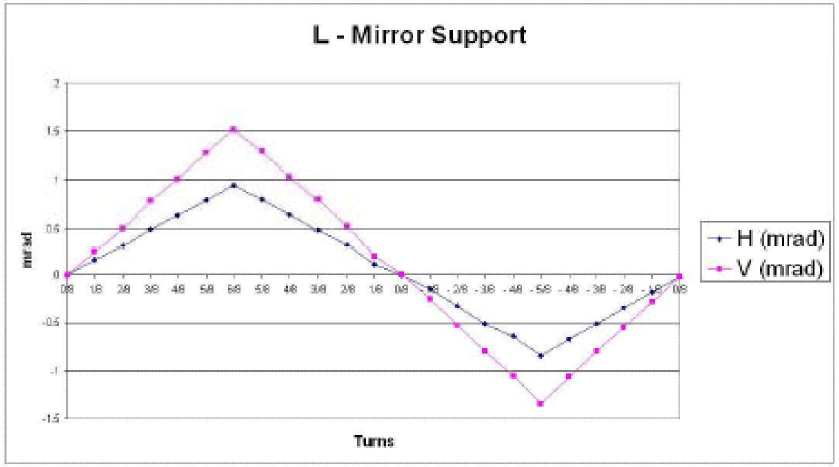
- **Focal length at 10 m gives optimal size at ~8m**
- **CCD: 752(H) x 582(V) pixels with dimensions: 8.6μm(H) x 8.3μm(V)**
- **Used single mode fibre (2 μm core); Multi-mode fibre (200 μm core) also tested.**

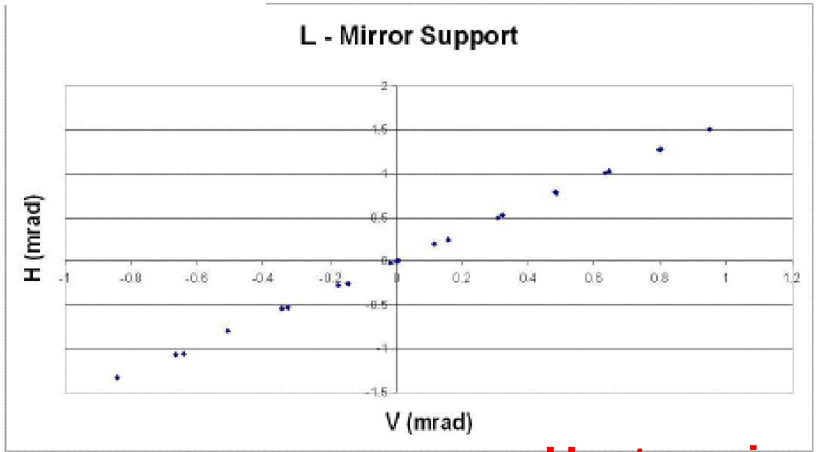
Test of mirror support

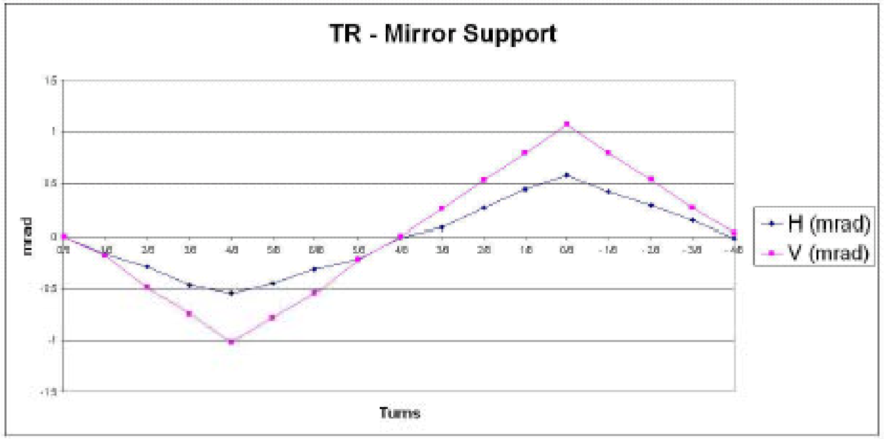
- Adjustment mirror support and measurement mirror movement:



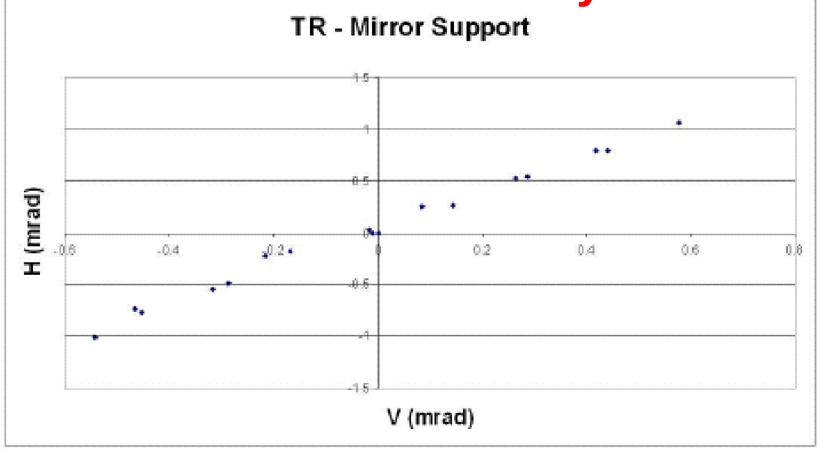
Hysteresis







Hysteresis



Pap

Simulation of laser system

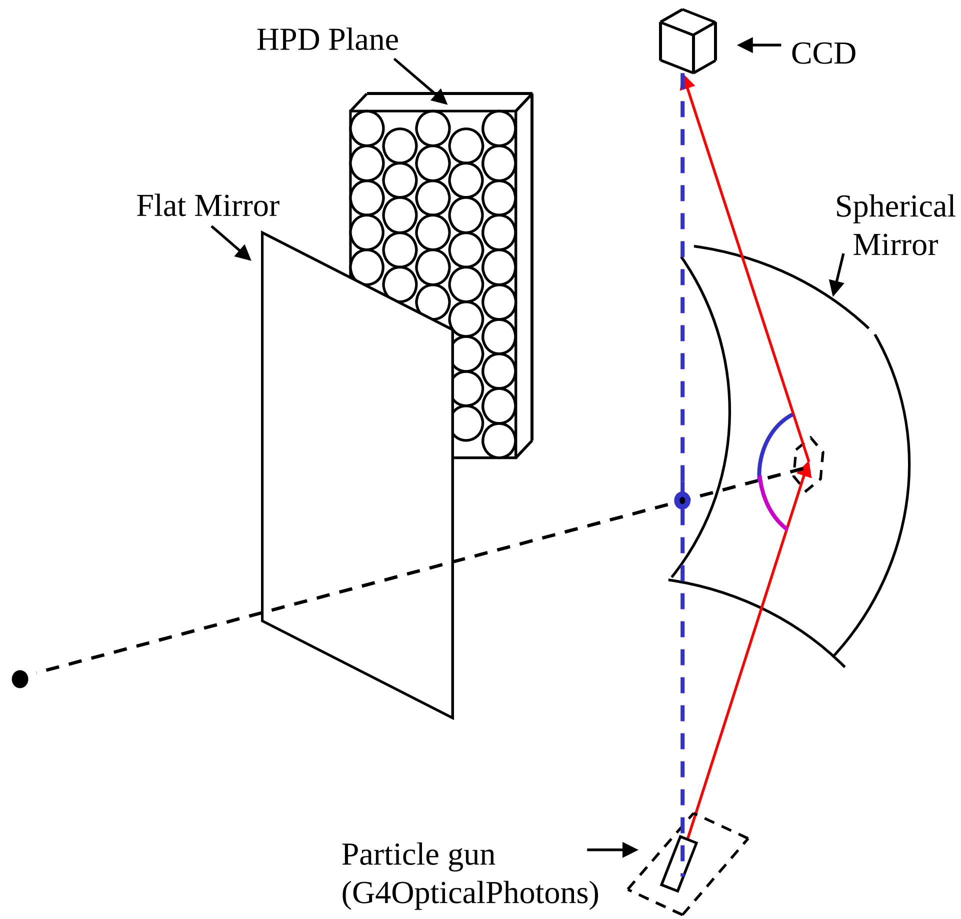
- Implemented within Gauss (GEANT4)
- "Particle gun" to fire visible photons onto mirror segments
- Software implementation done in 2003-04.
- Recording plane (sensitive volume) on top of RICH2 to simulate CCD.
- Observe movement of beam spot onto recording plane
- Linear transformation between tilt ($\Delta\theta_x, \Delta\theta_y$) vs movement of spot on CCD ($\Delta x, \Delta y$) :

$$\Delta\theta_x = A\,\Delta x + B\,\Delta y$$

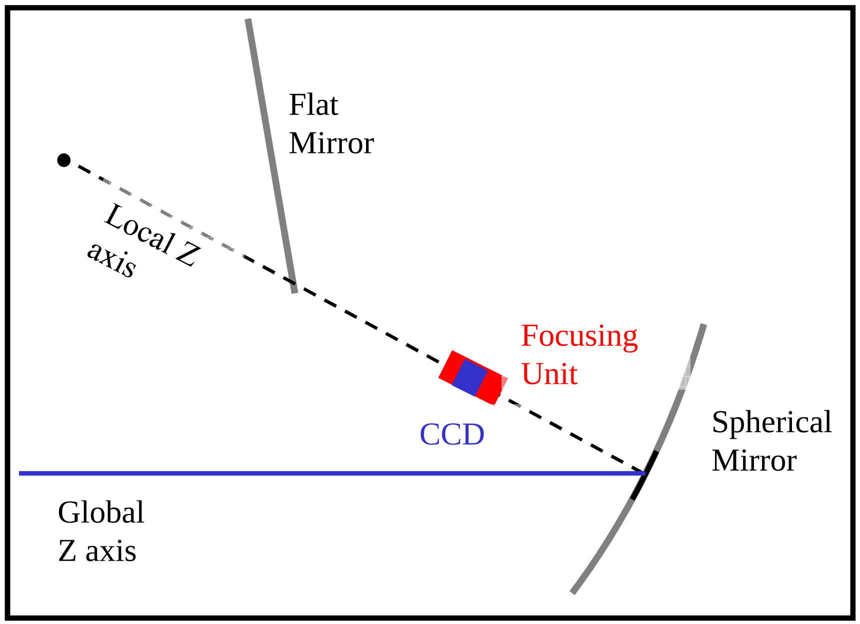
$$\Delta\theta_y = C\,\Delta x + D\,\Delta y$$

Can recover tilts by inverting transformation after observing spot movement.

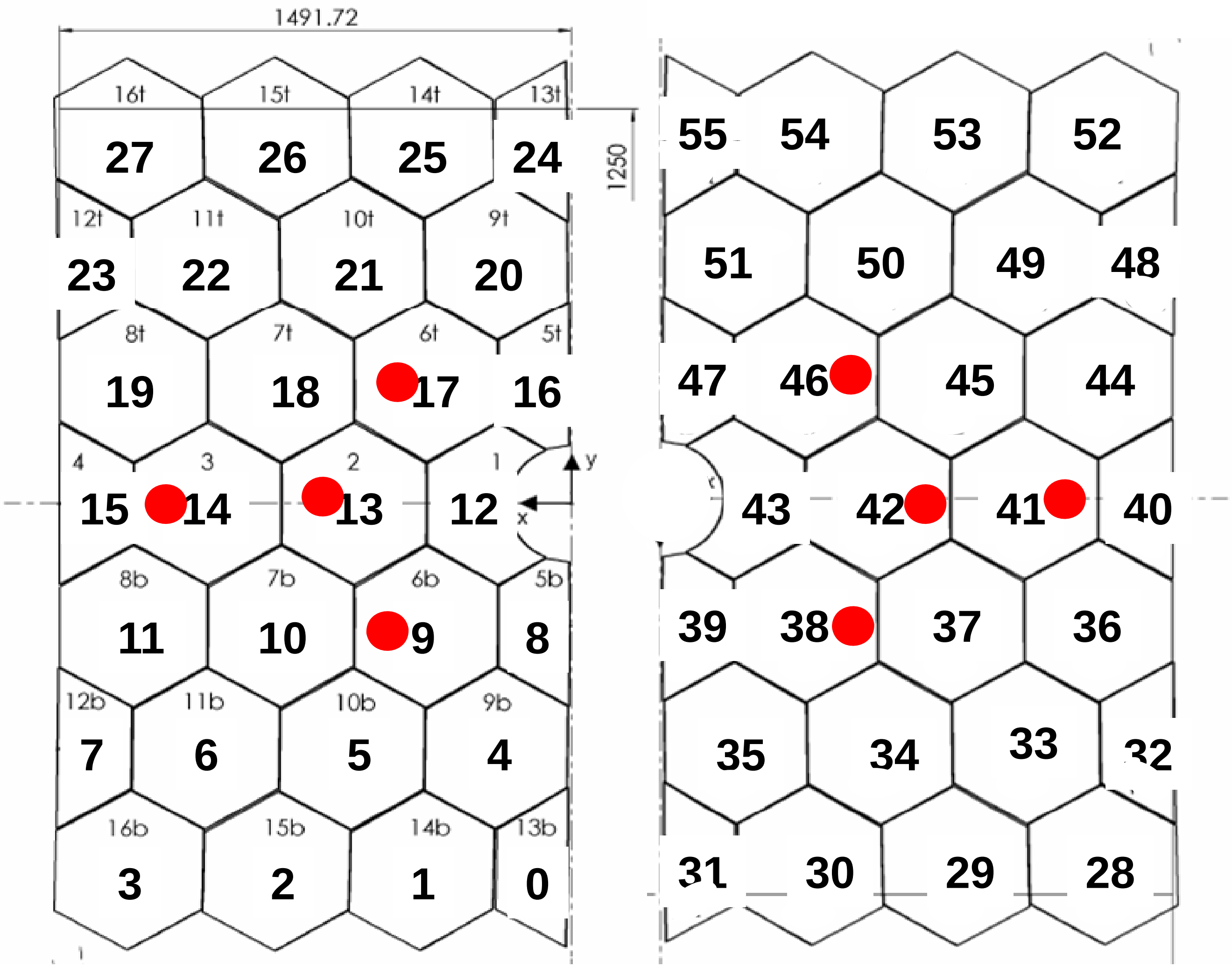
Component location process



Focusing unit and CCD are placed along the Local Z axis of the mirror segment (perpendicular to the centre of the segment).



Mirrors monitored in RICH2

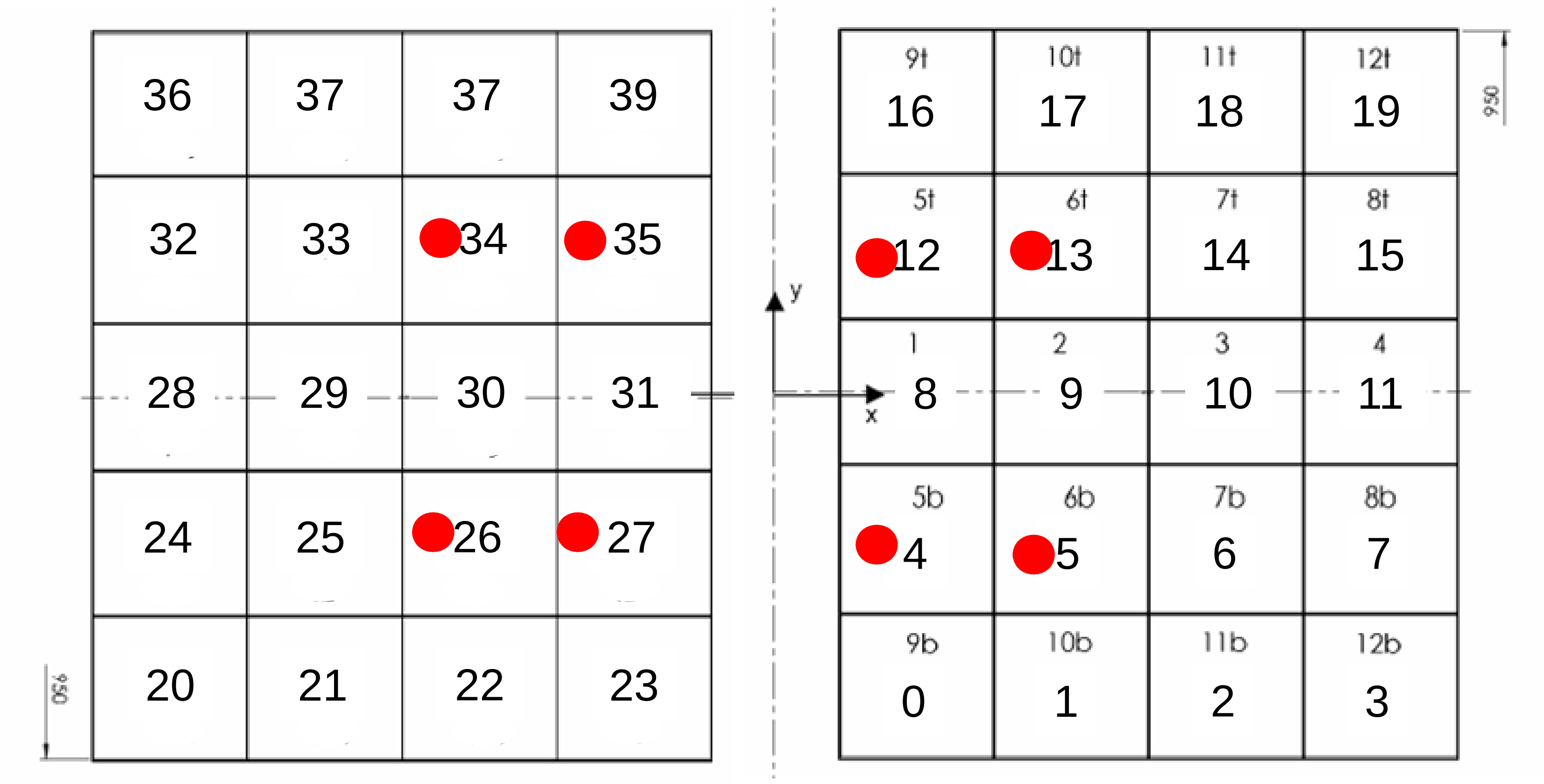


Positive x

Negative x

Antonis Papanestis

Flat mirrors monitored in RICH2



Looking towards the interaction point

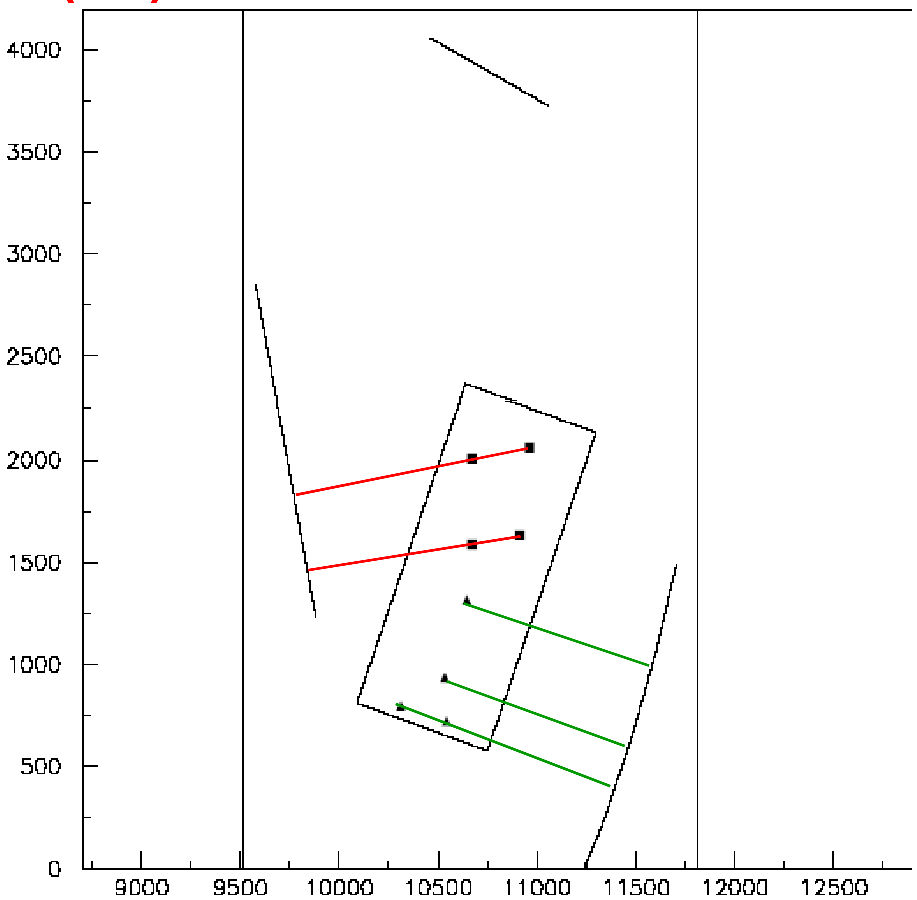
Negative x

Positive x

Positions of optical elements

CCDs (top)

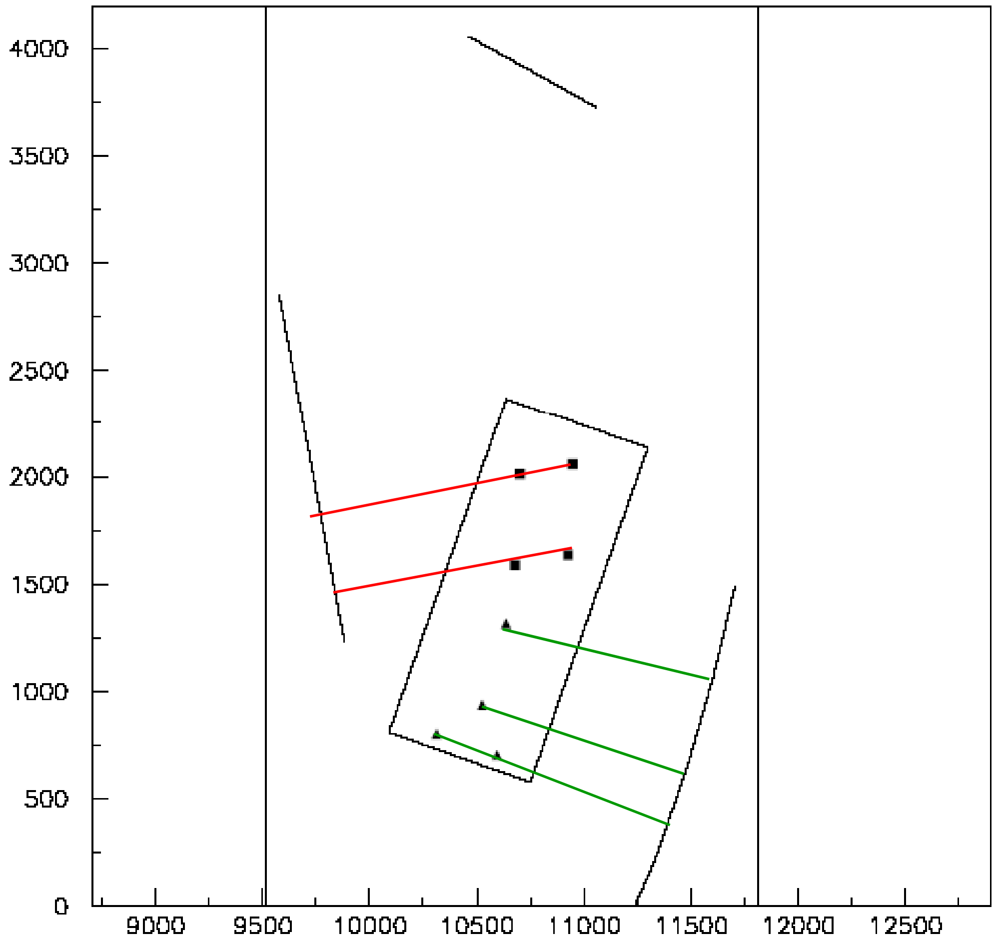
x (mm)



z (mm)

Focusing units (bottom)

x (mm)

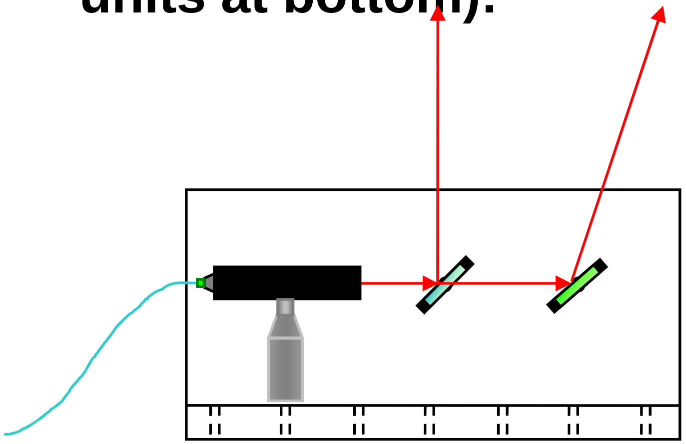


z (mm)

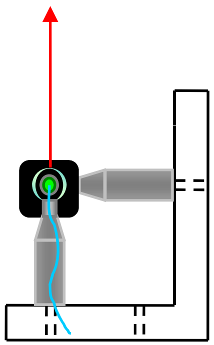
Plates installed February
CCDs 11-14 July

Mount holders

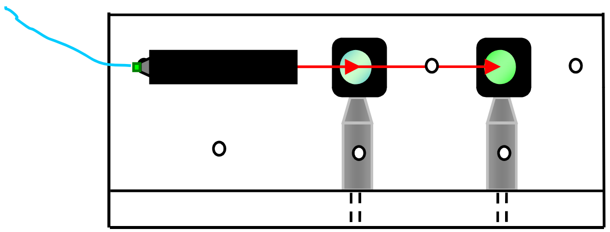
- Mount holders (focusing units at bottom):



Side view

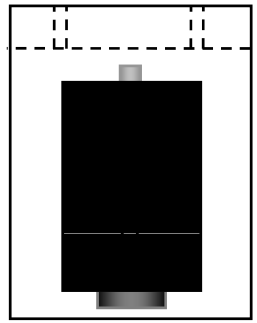


Front view

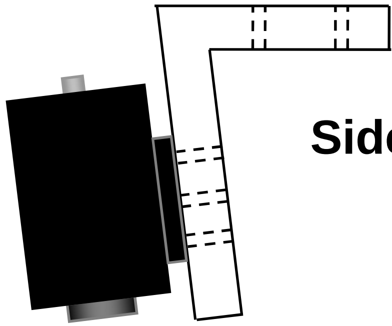


Top view

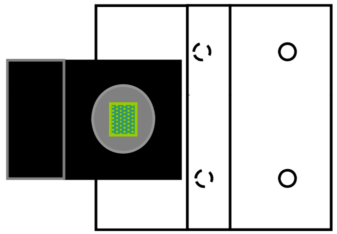
- Mount holders (CCD at top):



Front view



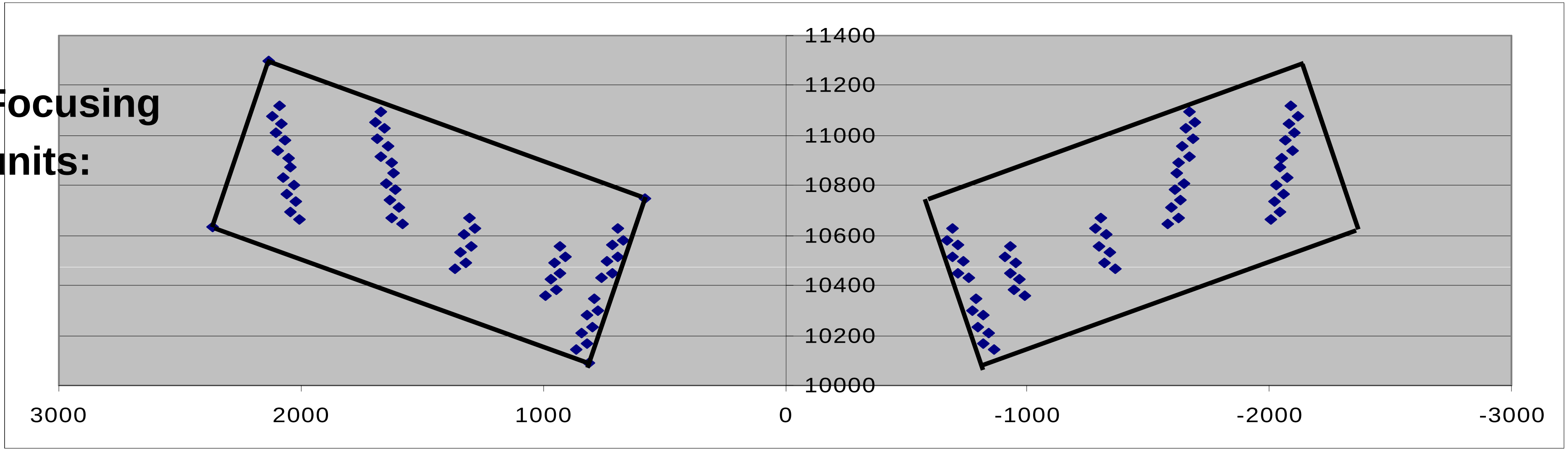
Side view



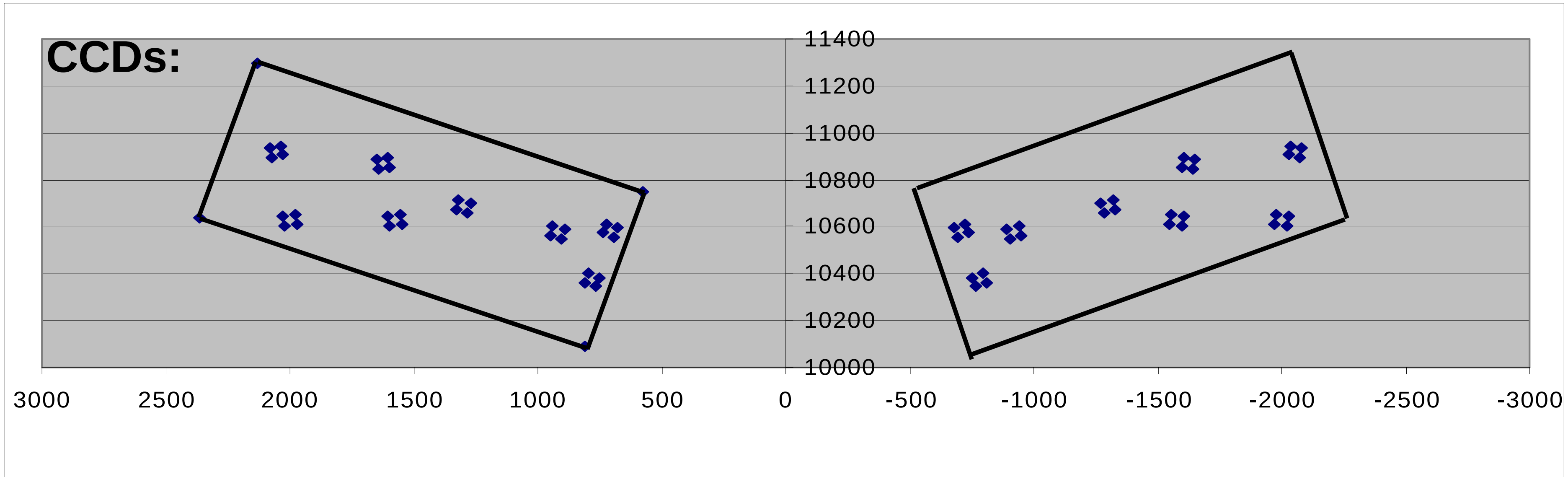
Top view

Position optical elements

Focusing units:

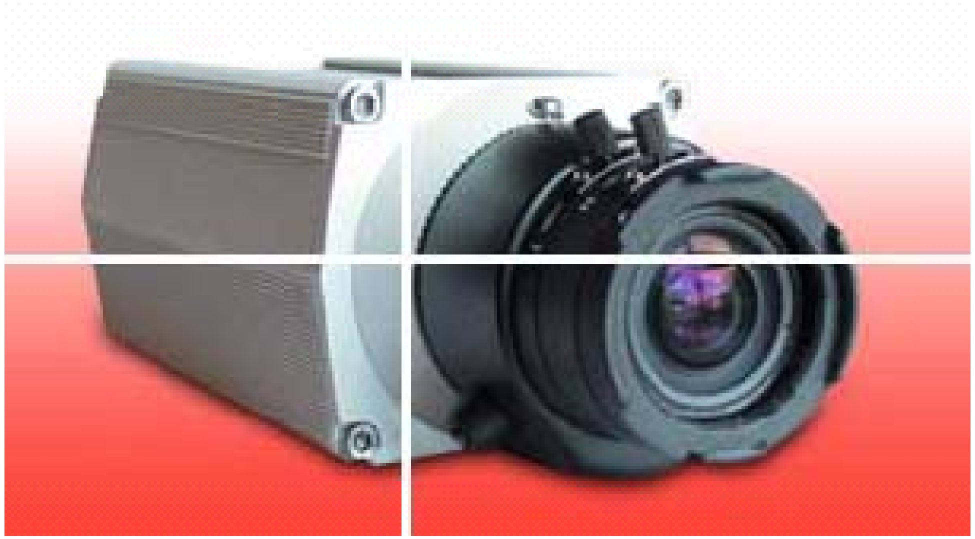


CCDs:



Sensors

- **Lumenera (Ontario, Canada) Le175M monochrome camera:**
  - **1280x1024 CMOS sensor (1/2”, 7.7mm x 6.1mm)**
  - **1.3 M pixels, 6 μm square pixels at 25 frames/s**
  - **Ethernet connection**
  - **Power: 9-24 V (< 4W)**
  - **300 g**

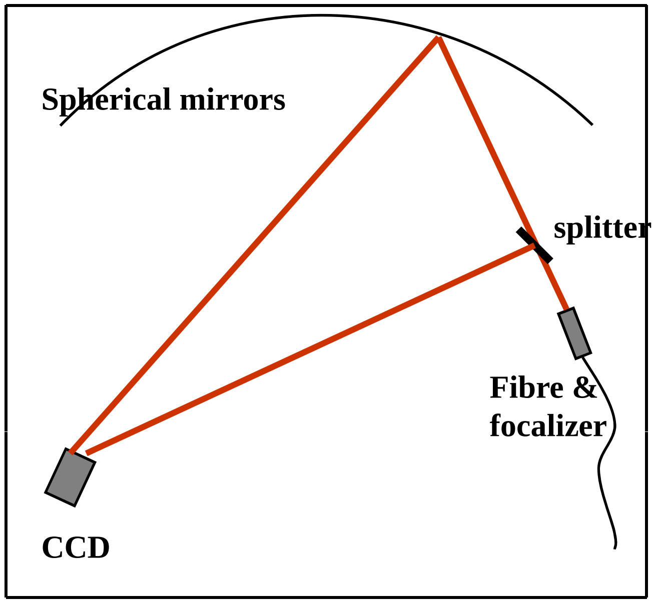


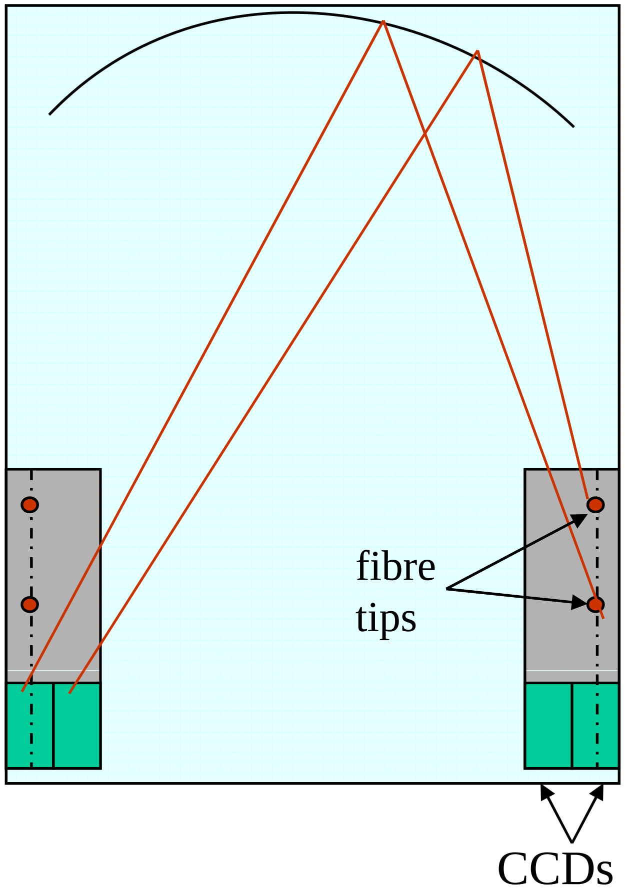
- **Dose at y= +- 3000 m:**
  < 6x10^{-14} Gy/collision
  x1.6x10^{14} collisions/yr =
  10 Gy/yr = 1 kRad/yr
  (http://lhcb-elec.web.cern.ch/lhcb-elec/html/radiation_hardness.htm)
  Standard CMOS should be able to withstand this radiation.

LAMS for RICH1

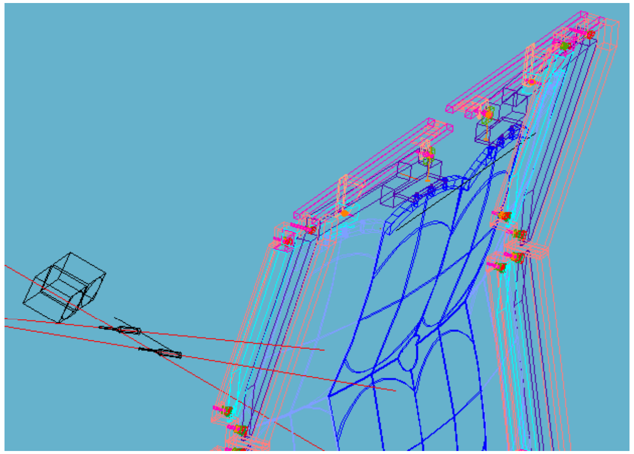
- System for RICH1 should be similar to RICH2, except in **horizontal plane** rather than vertical plane
- Required accuracy 0.3 mrad
- Monitor 4 spherical mirrors (R=2700mm):

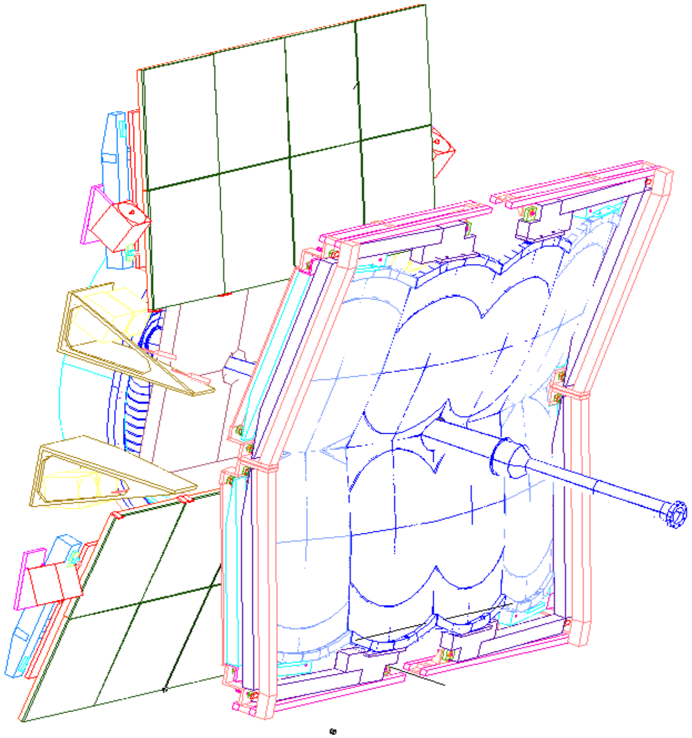
4 fibres + 4 CCDs, same laser as RICH2

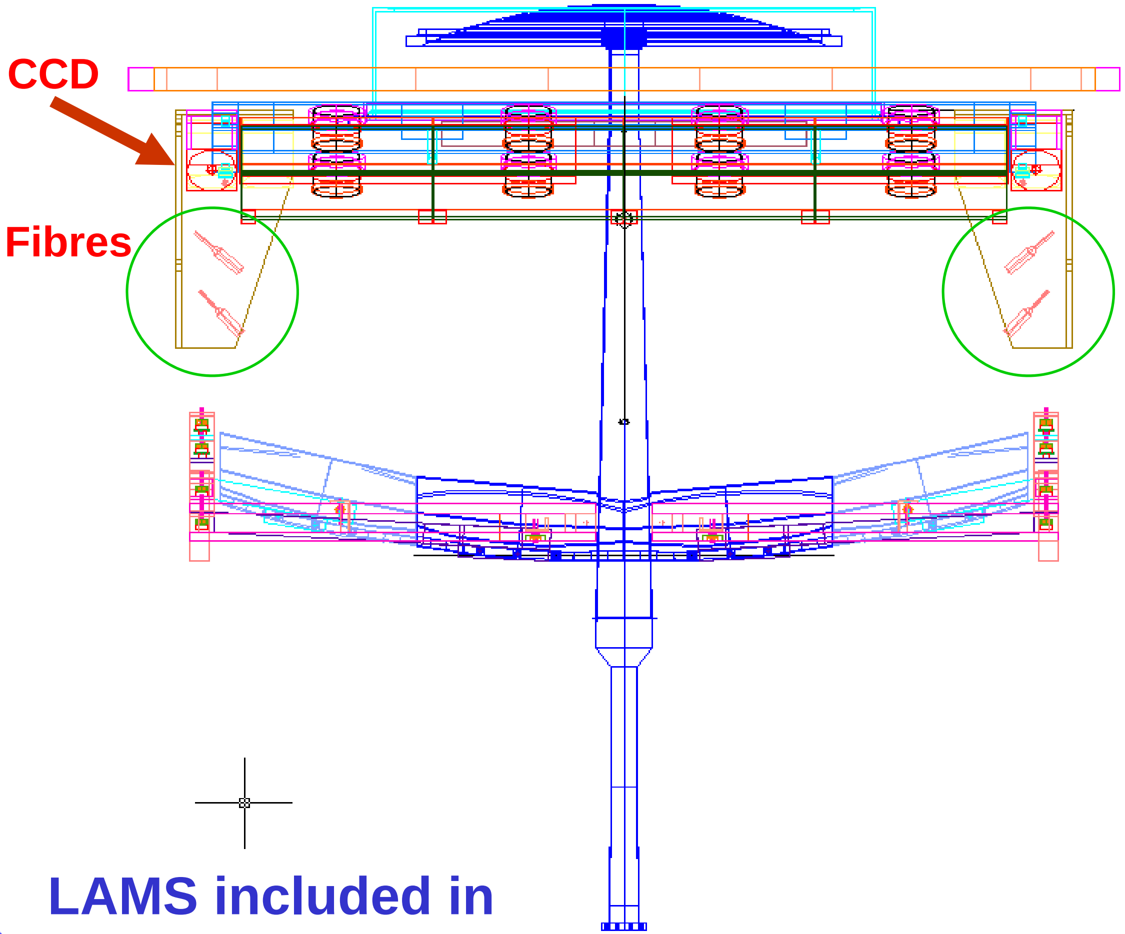




LAMS for RICH1







LAMS included in mechanical designs

LAMS for RICH1

- **Issue: radiation dose for CCD sensors in RICH1**

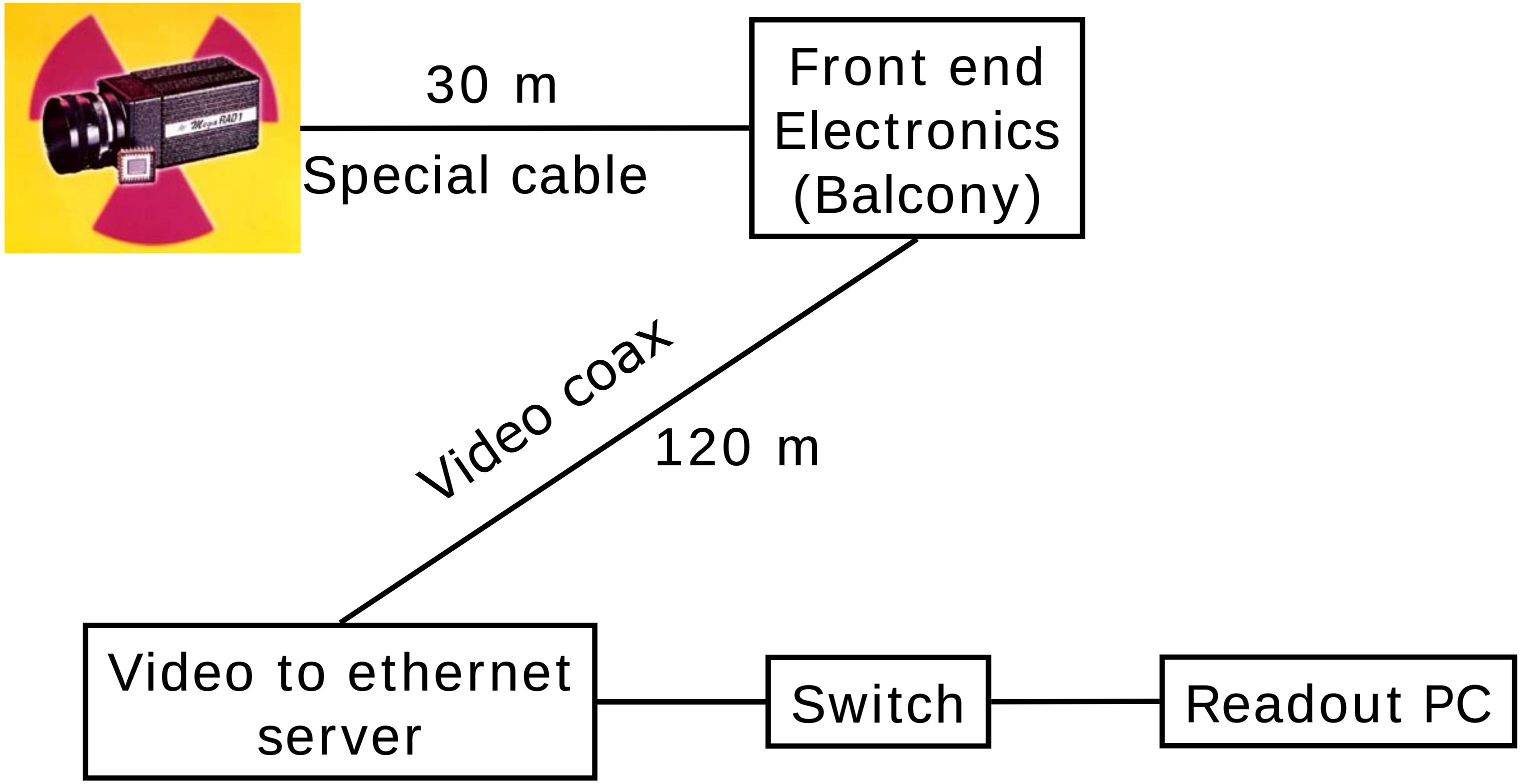
  x=700-800mm, y=+-275mm

  Dose: 10^{-12} Gy/collision x 1.6×10^{14} collisons/yr = 160 Gy/yr=

  16 kRad/yr!!

  (http://lhcb-elec.web.cern.ch/lhcb-elec/html/radiation_hardness.htm)
- **Off-the-shelf CMOS sensors rated to 1-2 kRad, so Lumenera sensors not suitable.**
- **Thermo Sceintific CID8712D1M Radiation Hard Solid State Camera.**
  - **Dose up to 1 MegaRad.**
  - **Separate sensor and readout electronics.**

RICH1 LAMS schematic diagram

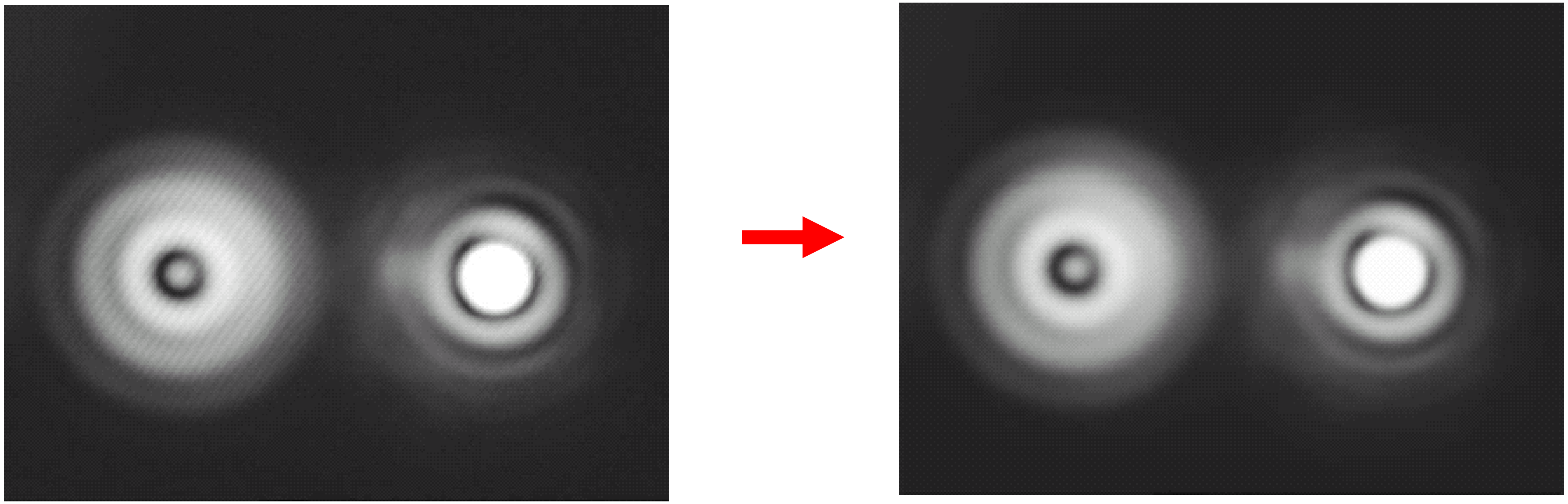


Analysis software

- Analysis software needs to recover centre position of reference and reflected beam with optimum accuracy and robustness.
- Beam not a perfect Gaussian so fitting method is not appropriate for a variety of differently shaped beams
- Adopt a different approach using techniques borrowed from image processing.
- Have a multi stage approach:
  1. Smoothing filter
  2. Edge enhancement
  3. Sobel mask edge detection
  4. Hough transform accumulator to determine centre of beam
  5. Anomaly cut for spurious centre elimination
  6. Centre spot location mask
  7. Weighted average for centre determination.

Analysis software

1. Smoothing filter



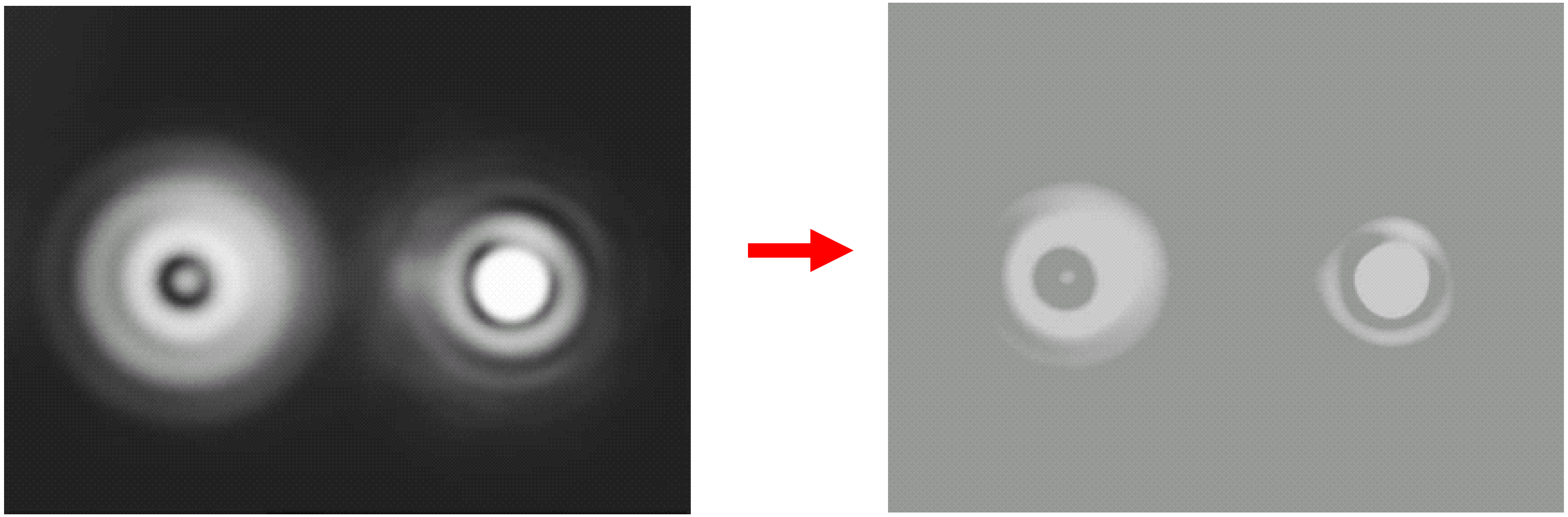
Removes striations in image (dark and light diagonal bands) probably due to CCD aliasing effects.

Filter works by averaging blocks of 5x5 pixels scanned over whole CCD:

a1	a2	a3	a4	a5
a6	a7	a8	a9	a10
a11	a12	a13	a14	a15
a16	a17	a18	a19	a20
a21	a22	a23	a24	a25

Analysis software

2. **Edge enhancement: cuts at > 60% and <80% of maximum**



3. **Sobel mask edge detection:**

- **2D spatial gradient method using two spatial masks**
- **Finds magnitude: $G=\mathrm{sqrt}(Gx^2+Gy^2)$ and angle: $\theta=\arctan(Gy/Gx)$**

G_x

-1	0	+1
-2	0	+2
-1	0	+1

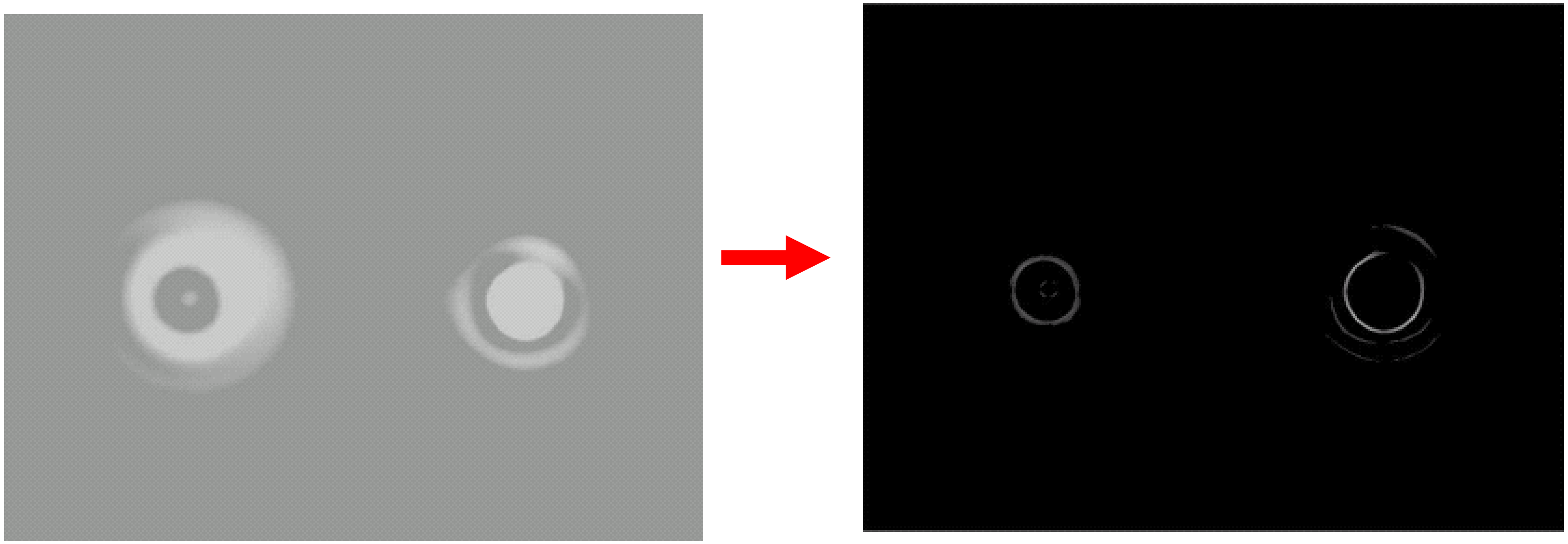
G_y

+1	+2	+1
0	0	0
-1	-2	-1

Analysis software

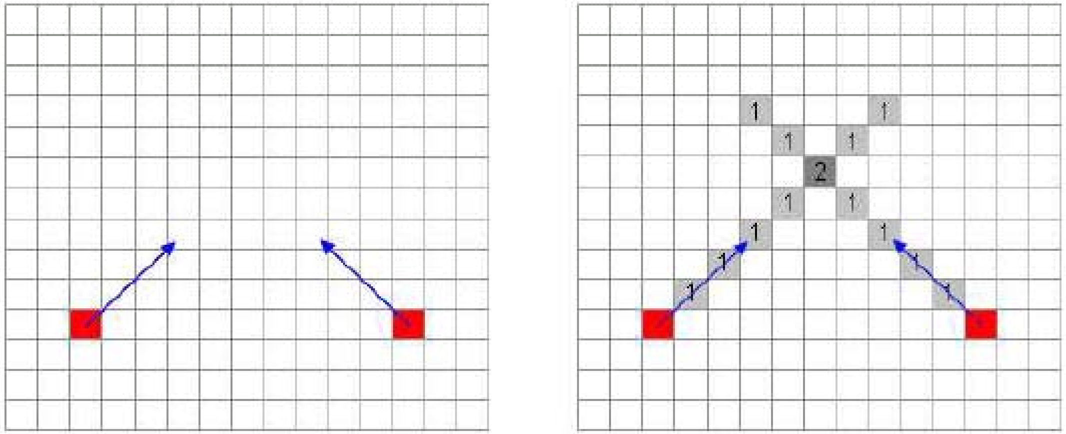
3. Sobel mask edge detection (cont.)

Gradient: |G|



4. Hough transform accumulator

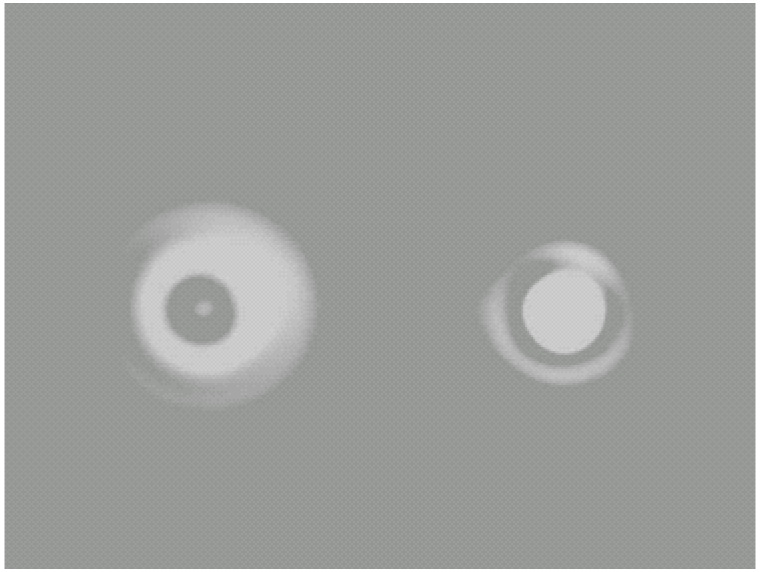
- From Sobel edge, sum of image values along Sobel gradient angle.
- Central accumulator gives maximum at centre image

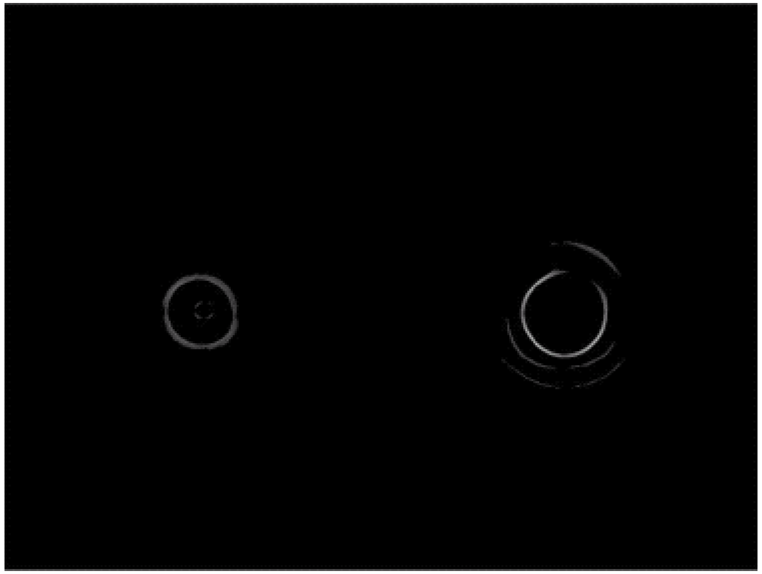


Analysis software

3. Sobel mask edge detection (cont.)

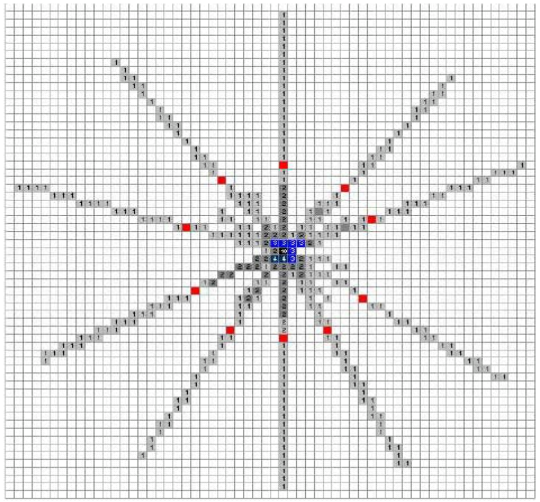
Gradient: |G|





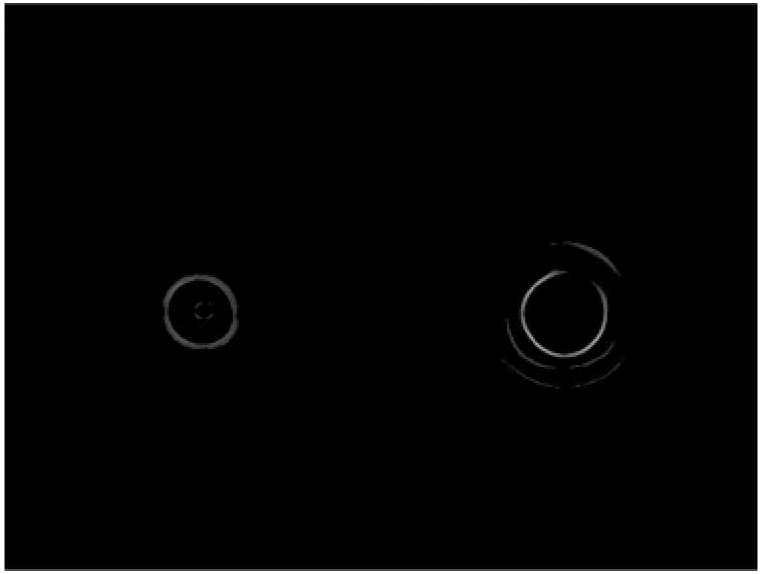
4. Hough transform accumulator

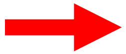
- **From Sobel edge, sum of image values along Sobel gradient angle.**
- **Central accumulator gives maximum at centre image**

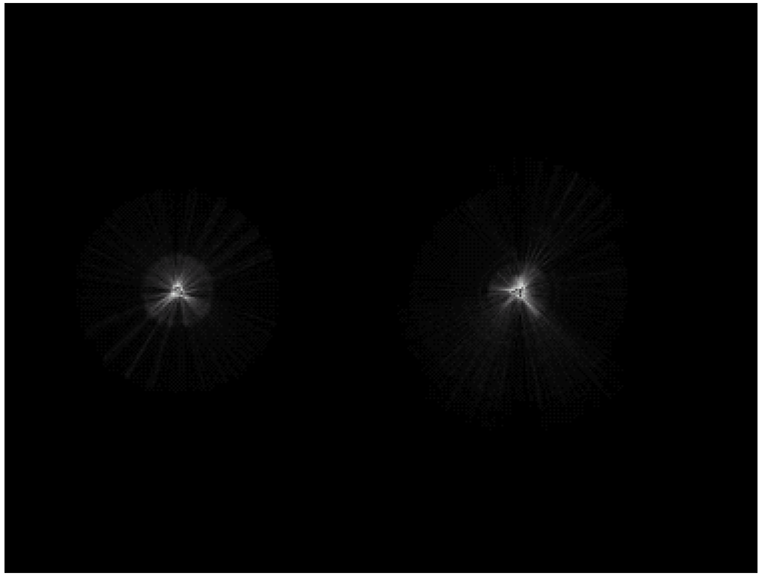


Analysis software

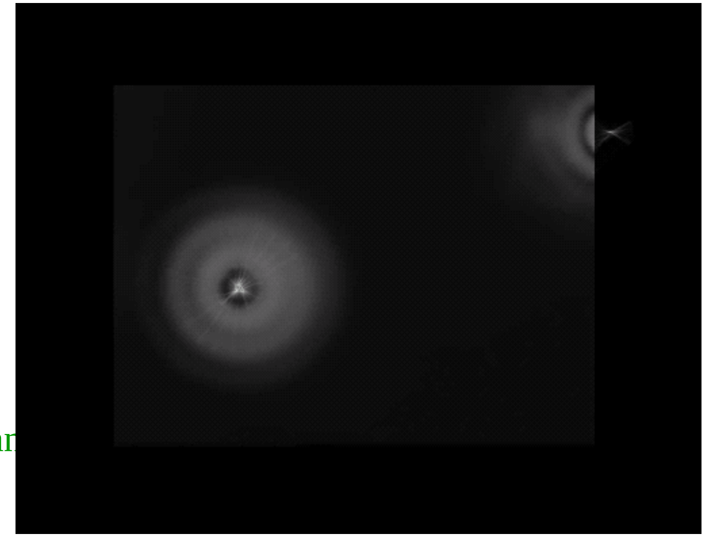
4. Hough transform accumulator (cont.)





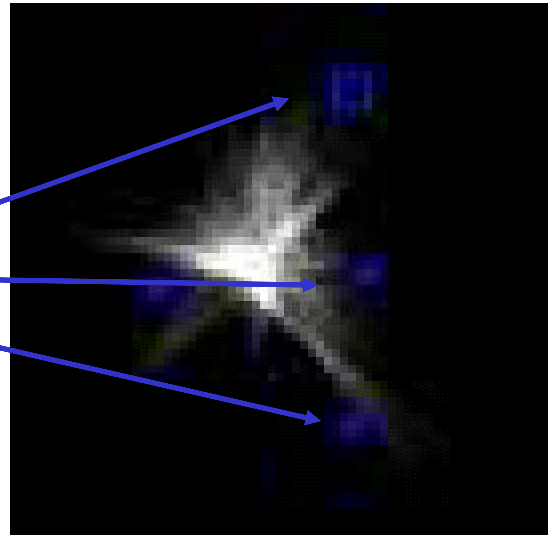


Can find centre outside detector:



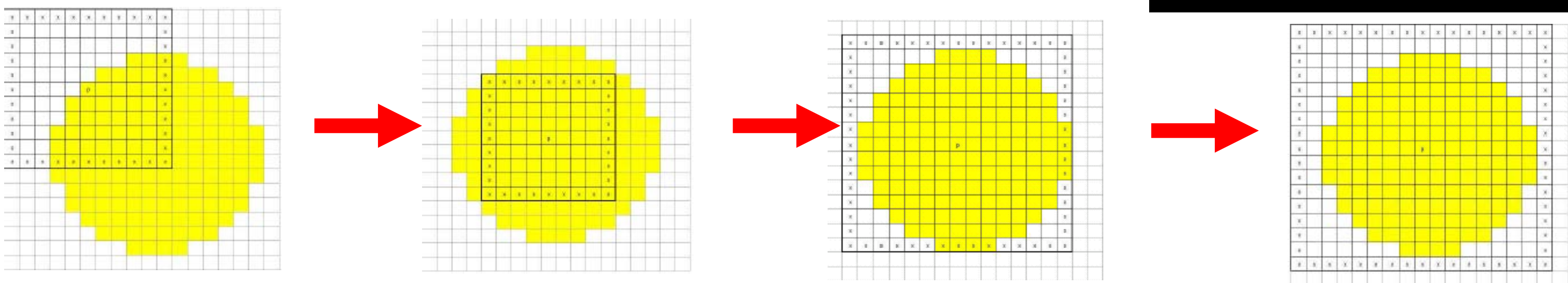
Analysis software

5. **Anomaly cut for spurious centre elimination:**
   - **Apply 70% cut on Hough accumulator**
   - **Spurious maxima removal by selecting masks of increasing size (regions of interest)**



6. **Centre spot location mask:**

Finds region of interest around centre:



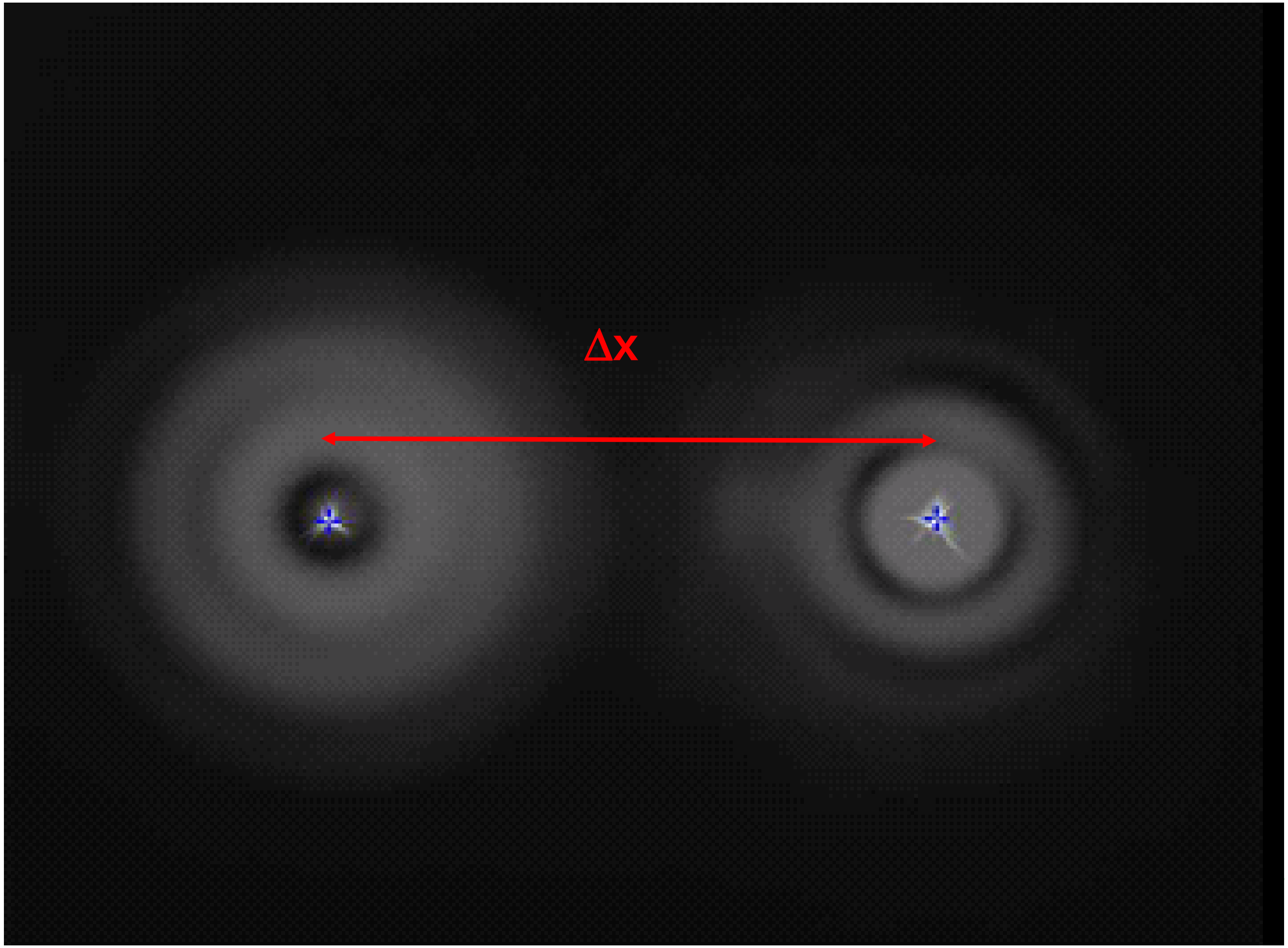
7. **Weighted average for centroid determination.**

$$WeightedX = \frac{\Sigma(x_1 \times R_1 + x_2 \times R_2 + \ldots x_n \times R_n)}{N}$$

$$WeightedY = \frac{\Sigma(y_1 \times C_1 + y_2 \times C_2 + \ldots y_n \times C_n)}{N}$$

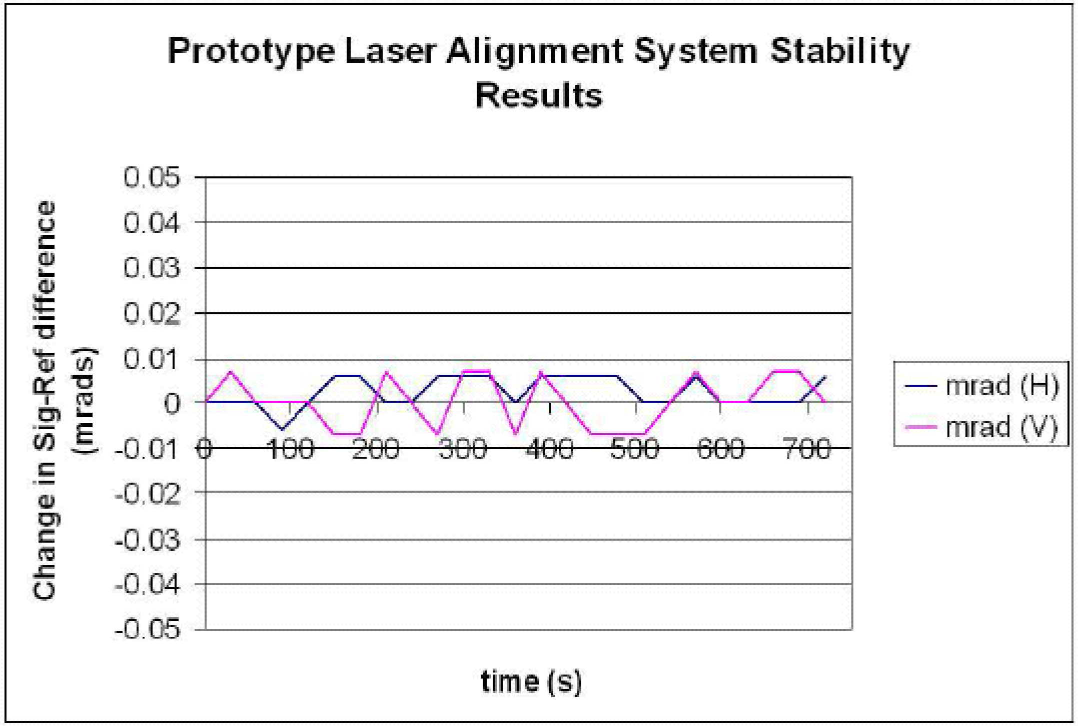
Analysis software

Final centroid finding result: robust algorithm that does not depend on shape of beam



Analysis software

Can track difference between two beam spots, even if spots move: Accuracy of monitoring less than 0.01 mrads.



Conclusions

- **Main design:**
  - **Basic idea of laser alignment monitoring system well developed**
  - **System consists of 532 nm laser coupled to 16 optic fibres attached to focusing units on bottom of RICH2. Readout to be carried out with CCDs on top of RICH2**
  - **GEANT4 simulations have shown optimal positions for focusing units and CCDs 16 mirror segments in RICH2**
  - **For RICH1, concept is the same except that CCD and focusing units on horizontal plane on either side of RICH1. Mechanical design includes shelves for LAMS.**
- **Sensors:**
  - **Lumenera Le175 CMOS sensor 1280x1024 with ethernet readout for Rich2**
  - **CID8712D1M Radiation Hard Solid State Camera for Rich1.**
- **Multi stage image analysis software.**