Atlas barrel spectrometer alignment: hardware elements and calibration

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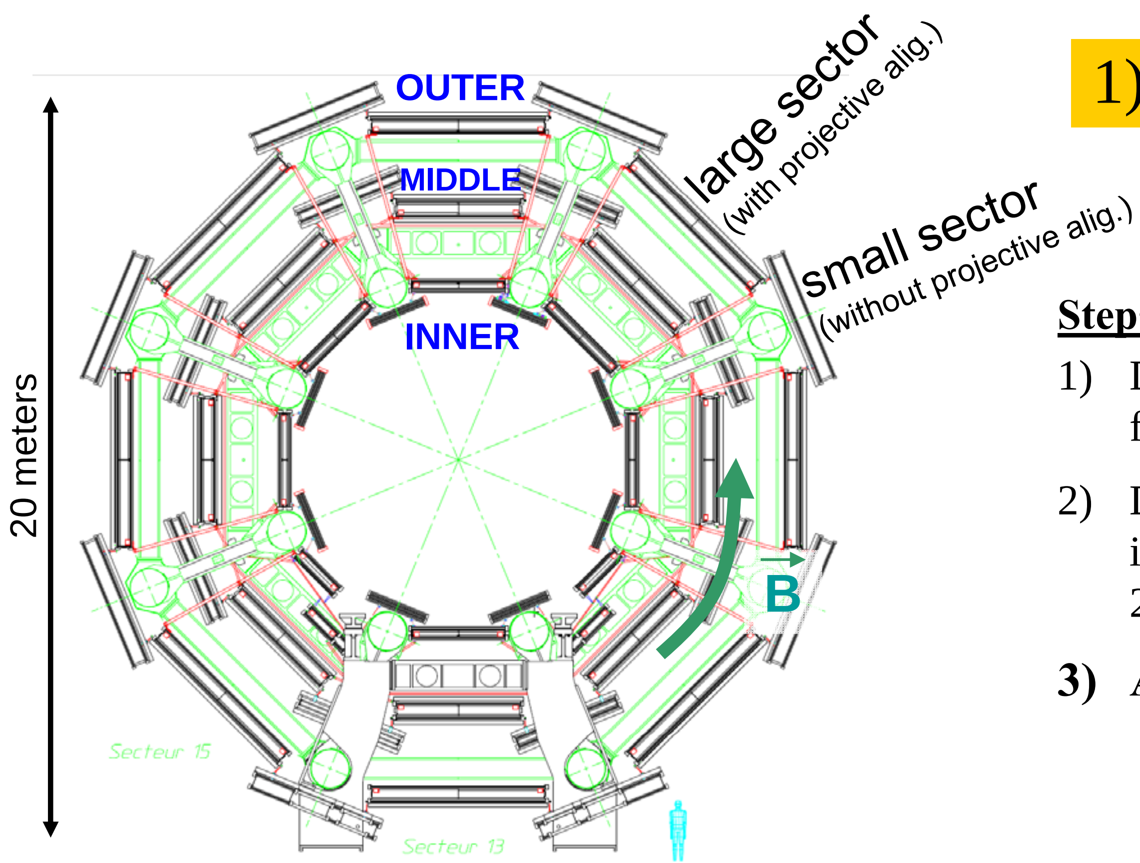
On behalf of the Barrel Alignment teams: DAPNIA + NIKHEF

1. Atlas muon spectrometer principle
2. Description of the alignment system
3. Individual optical alignment components
4. Calibration of alignment sensors: Projective and Praxial
5. Current calibration status
6. Conclusion and Remarks…

1) Atlas muon spectrometer principle

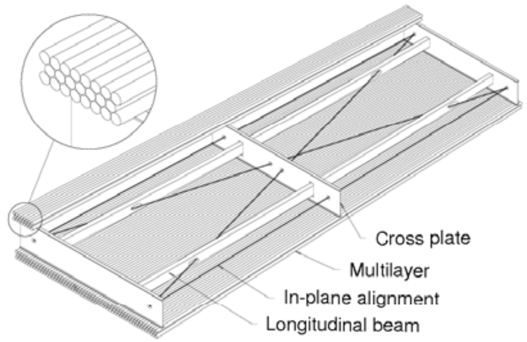


Steps to reconstruct and measure a muon track:

1) Deflection of the muon inside the toroidal magnetic field

2) Detection of the muon with a triplet of drift chambers: inner, middle and outer (+ trigger chambers, also for 2nd coordinate meas.)

3) **Alignment corrections** (each ~20')

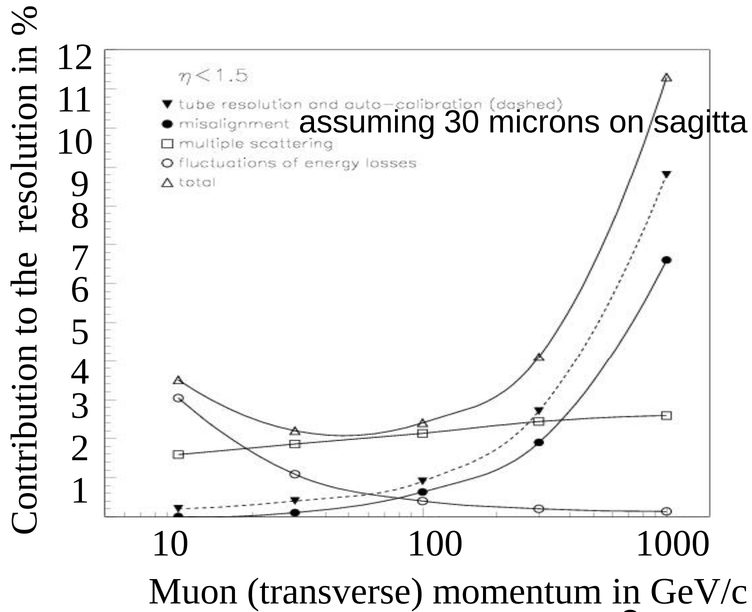


Drift chamber: σ ~ 80 μm / drift tube, combining 6 (or 8 tubes) gives σ ~ 60 μm

Muon reconstruction constraint:

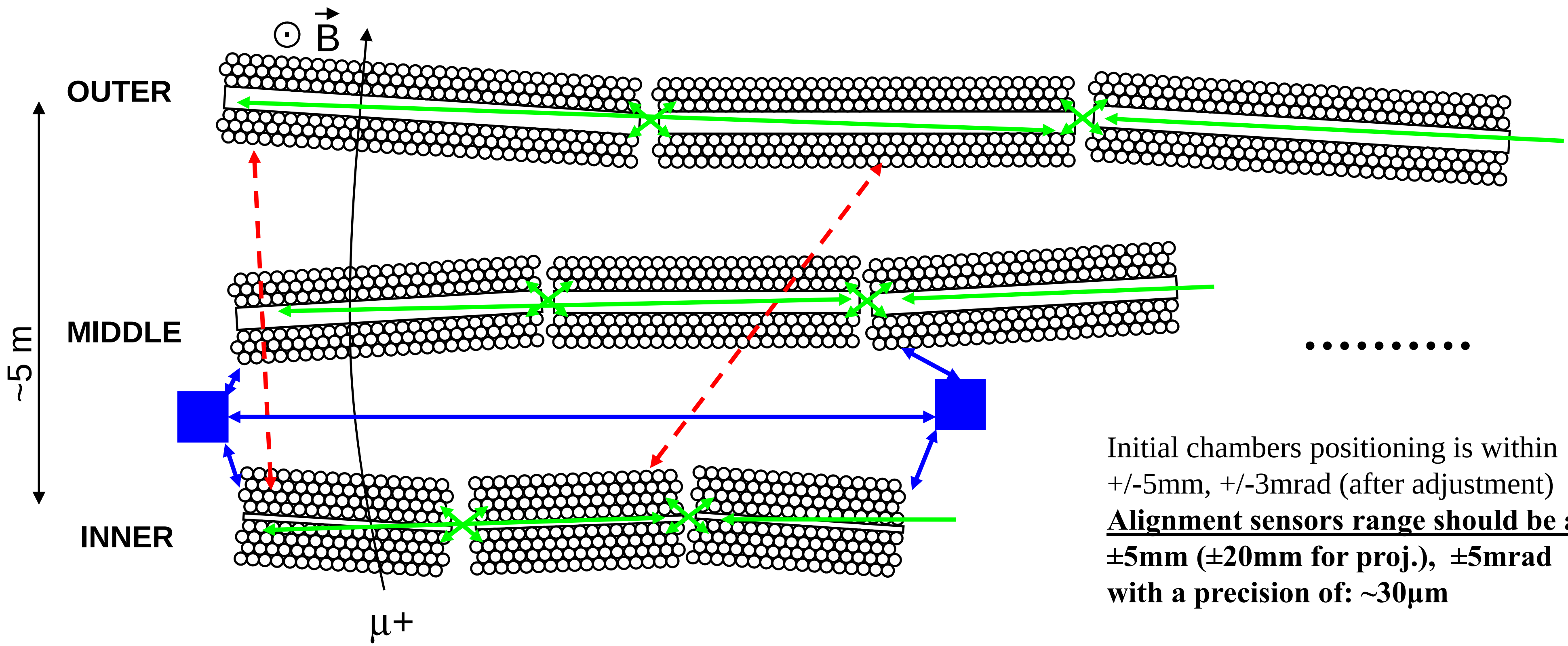
At 1 TeV the sagitta is as small as ~600 μm. So a 10% resolution requires a 60 μm precision for the drift chambers measurement.

Thus the alignment contribution should be negligible and should be ~30 microns on sagitta.



2) How many alignment systems?

Projective and internal ch. alignment are mandatory!



Initial chambers positioning is within +/-5mm, +/-3mrad (after adjustment)

Alignment sensors range should be about:
±5mm (±20mm for proj.), ±5mrad
with a precision of: ~30μm

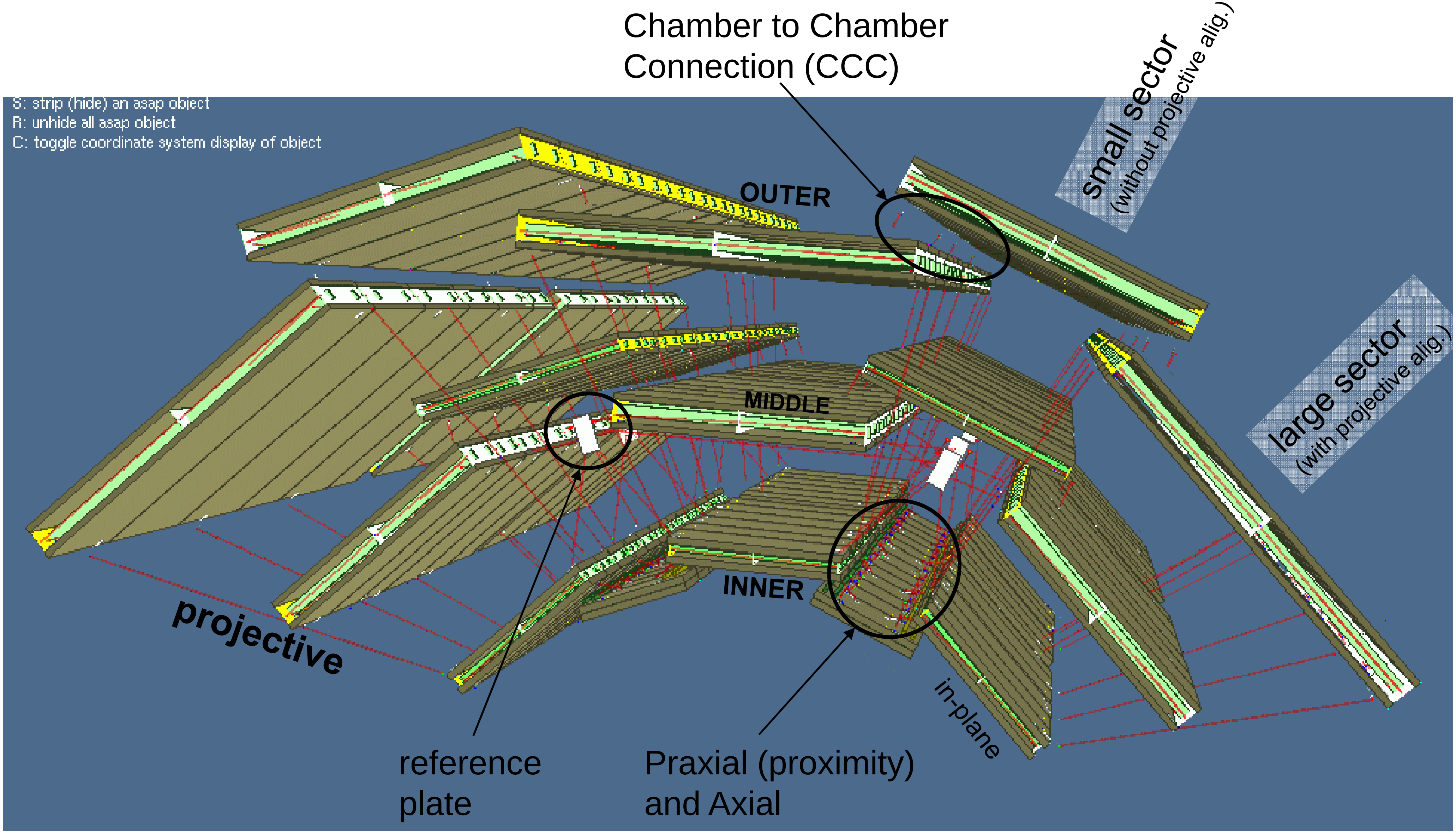
We reduce the number of projective lines in order to minimize cut-outs on (small) chambers and on voussoirs and struts of the toroid

Alignment systems:

- Projective
- **Proximity** (called Praxial) + **Axial** (neighboring chambers)
- Internal (chamber deformation)
- Reference (because of ambiguities of proj.)
- CCC (connect Large and Small chambers)

+ special zones (feet regions): BBC, etc…

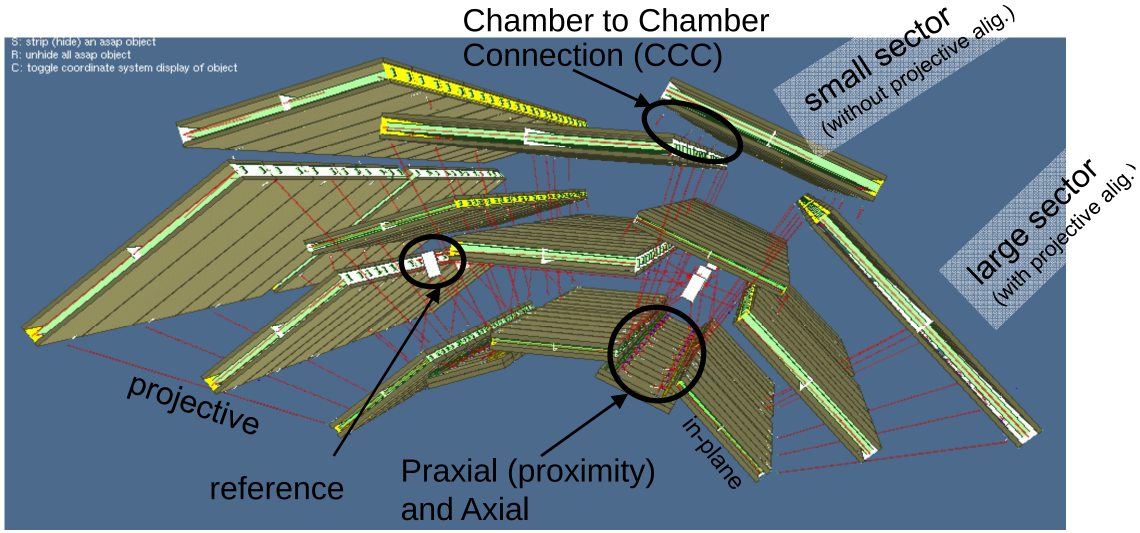
2) How many alignment systems?



View of higher sectors drift chamber

Visualization from Atos (adapted from Ch.Amelung software)

2) Number of elements per alignment system



624 muon drift chambers (barrel)
Layout = layout "Q" (starting from A!)

Optical sensors:

Projective:	**117** cameras, **117** lenses (11 focal length), **117** targets
CCC (small ch. to large ch.):	224 cameras and 224 targets (each of 8 types)
Reference (on toroid ribs):	256 cameras and 128+128 targets (11 types)
Axial (neighboring ch.):	2432 elements of 12 types (1036 lenses, 44 focal length)
Praxial (neighboring ch.):	2010 elements of 7 types
In-plane (within ch.):	2166 optical lines
Bir-Bim connection (feet):	2x32 optical lines

on same support (Axial, Praxial)

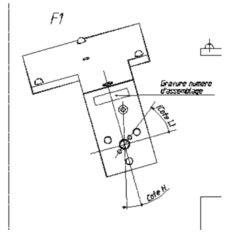
5873 optical lines (117 proj.)

Mechanical supports:

Projective:	351 platforms and 351 extension plates
CCC:	448 platforms and 448 extension plates
Reference:	32 plates on ribs and 128 platforms on chambers
Praxial/Axial:	2432 platforms
Bir-Bim connection:	128 platforms

measured on CMM

(and ~800 platforms for magnetic field probes)



+ thousands of drawings…

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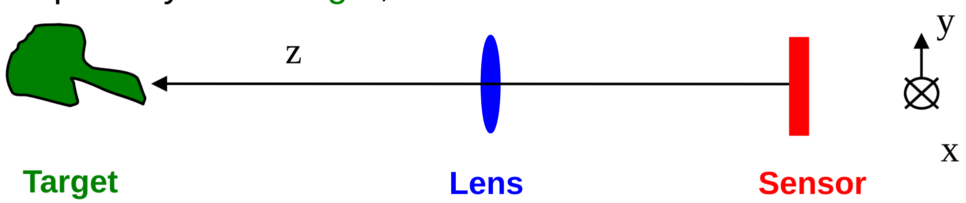
3) Individual optical alignment components

3 point system: target, lens and a CCD



Rasnik precision:

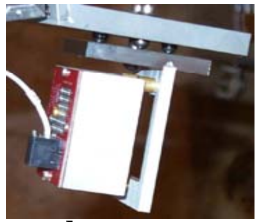
Transverse measurement (x/y axis): ~1µm

Rotation along optical axis: ~150 µrad

Magnification (d1/d2): 10^{-5} to 10^{-4}

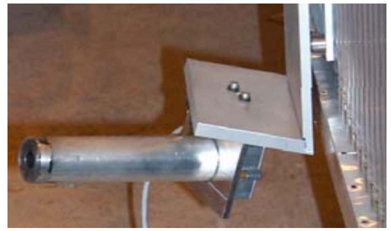
(used in **Projective**, Axial, **Praxial**, In-plane, BBC)

Rasnik



Chess pattern

lens

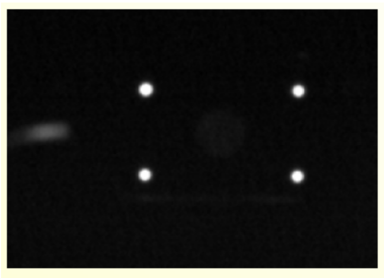


camera

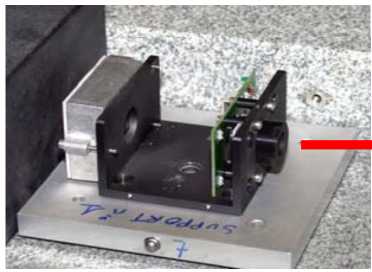
Two target types in Atlas:

a) Chess pattern (Rasnik)

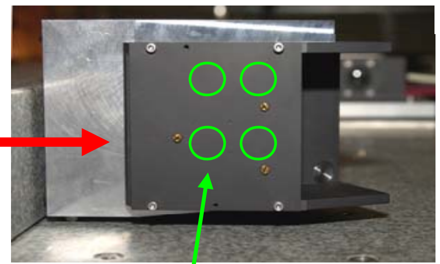
b) four Led targets (SacLed)



SacCam



SacLed



A camera looks toward 4 small light spots

SacCam precision (at 5m):

Transverse measurement (x/y axis): ~20µm

Rotation along optical axis: >200 µrad

Distance along z axis: ~2mm

System used in: Reference and CCC
(new image analysis program on Nov. 2006)

3) Projective alignment components

Camera with its IR filter
(117 elements)

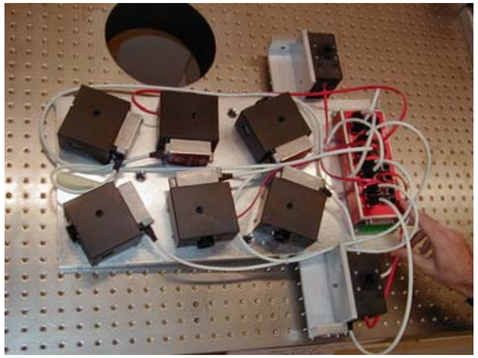
Extension plates with:
4 positioning spheres + pos. pin (sensor side)
3 positioning spheres (chamber side)
(measured on CMM)

Lenses with/without a diaphragm

45 by 45 mm^2 masks

3) Praxial / Axial and Reference alignment components

Praxial / Axial elements (2432 boxes)



Reference plate (measured on CMM) positioned
on toroid rib (32 plates), here with its camera (SacCam)

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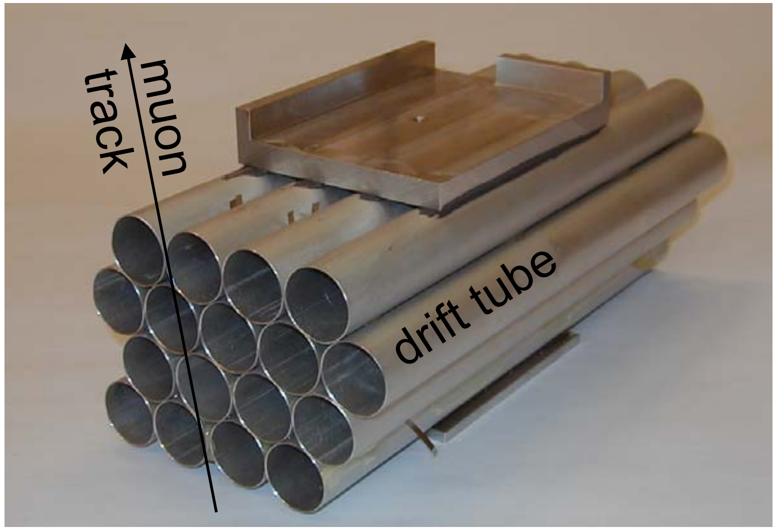
4) Calibration of alignment sensors

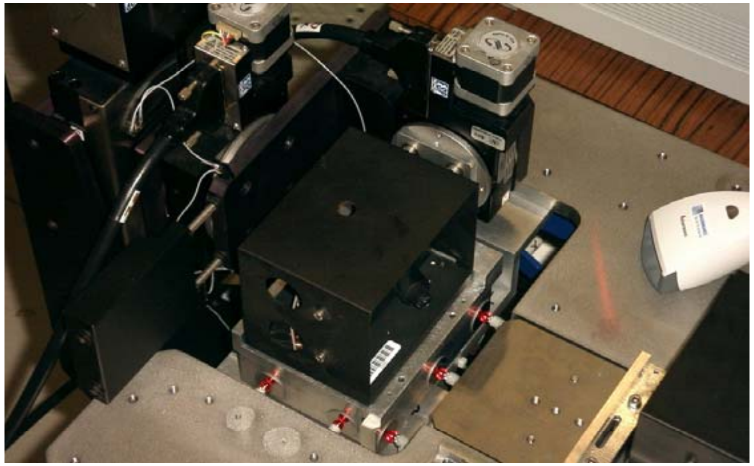
Calibration means to know: x, y, z, θx, θy, θz of all elements (w.r.t. drift tube wires): platforms, extension plates, cameras, leds, targets, plates on rib, etc…



All muon chamber drift tubes are made with a anode wire centered with a ~10µm precision

Positioning tools for platform gluing (BML chamber)

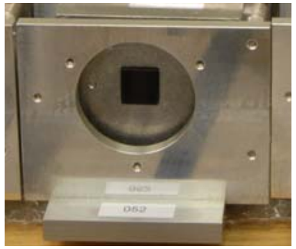
Praxial calibration (Saclay)

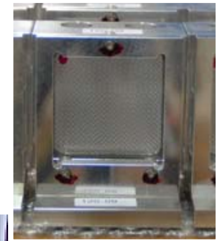


Projective calibration (Nikhef)

4) Projective sensors and calibration

(same procedure for the Axial system)





Meas. on CMM

The Projective system is based on Rasnik elements: camera-lens-mask

The calibration is performed in three steps:

(i) built special BLOCKs (<5μm precision) equipped with an active element (camera, mask, lens) and calibrate each BLOCK by rotating it on a stable square ruler (8m long)

(ii) each Projective element to be calibrated (3x117) is adjusted on its support in order to be centered on the positioning sphere (~40μm precision => induce syst. error <1μm!)

(iii) each Projective element is then positioned on the ruler replacing the corresponding BLOCK. By comparing the measurement with the BLOCK and with the element => calibration with a 5 μm precision

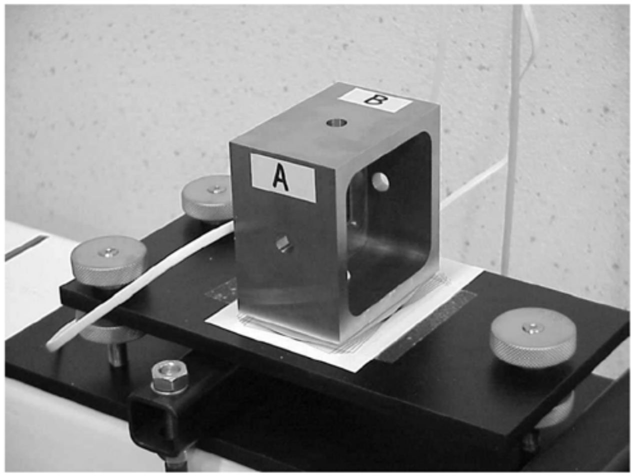


Fig 9a. A quad calibration block in its 'A' position (when seen from the side!). Note the rotX line diagram below the quad block.

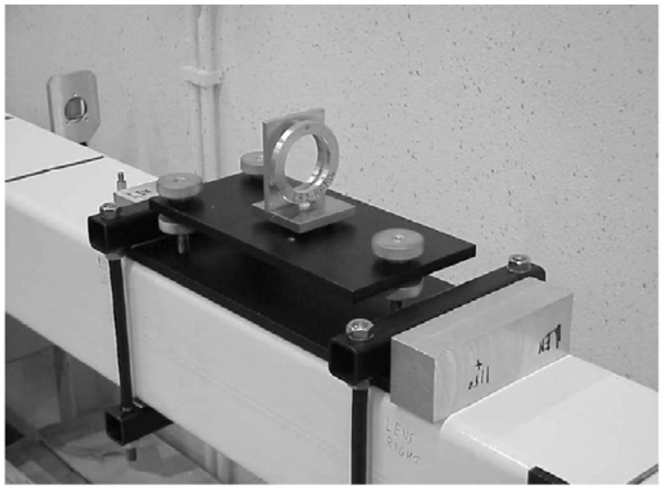


Fig 4. The block support. Angles rotY and rotZ can be adjusted by means of the three brass clamping wheels.

4) Projective sensors and calibration

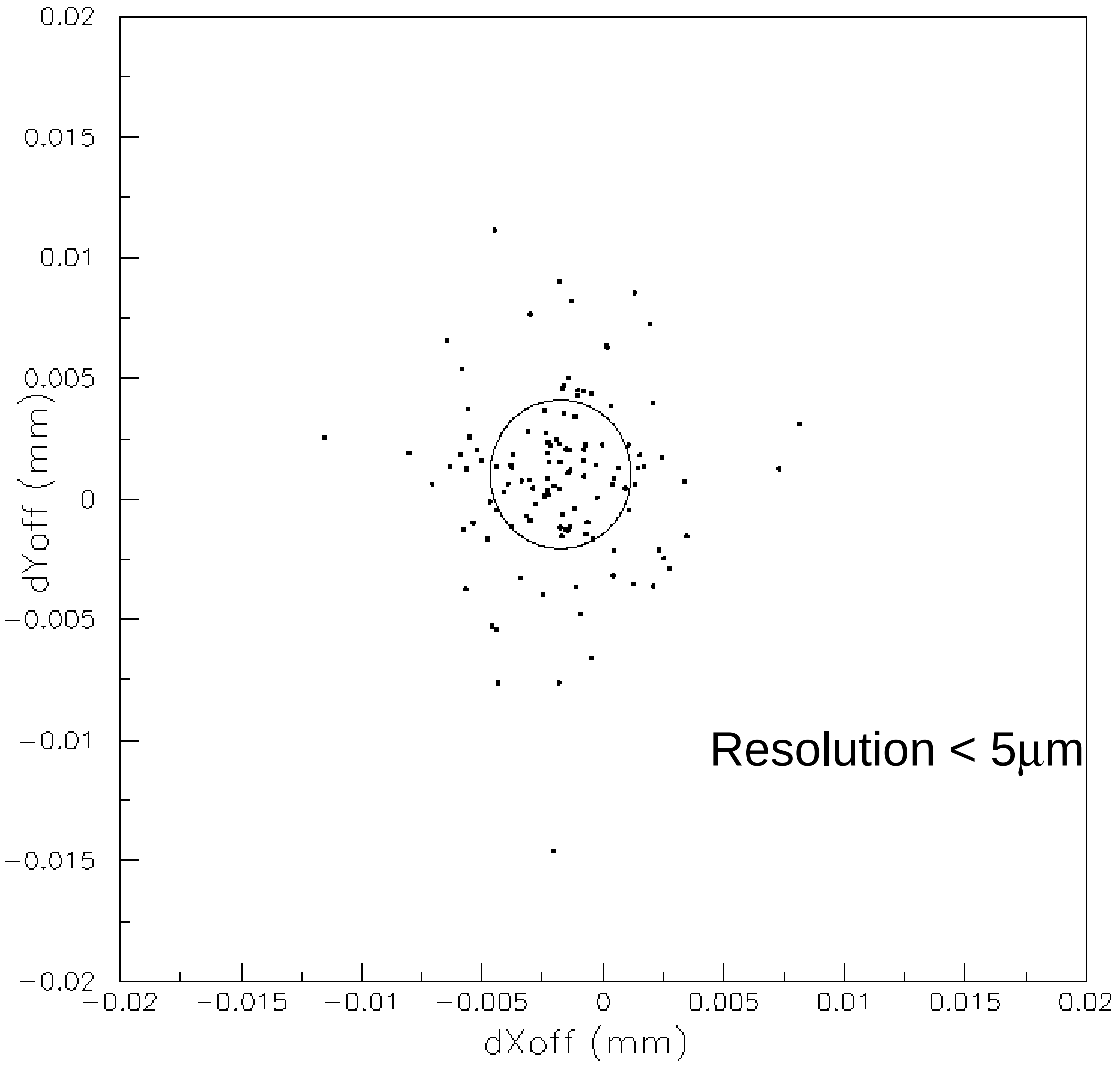
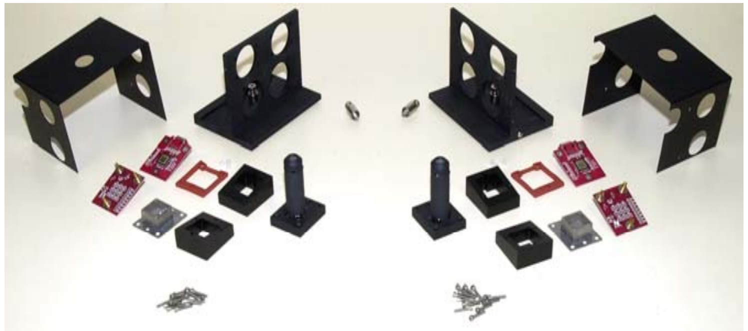


Fig. 3. 2D plot of the differences dXoff and dYoff of two calibrations of the MSK blocks. The contour indicates the σ-boundary. Fit parameters (mm): X_c = -2µm, Y_c = 1 µm, σ_x = 3 µm, σ_y = 3 µm.

Mechanical support measured on a CMM: resolution <10µm

(flexion?, screwing?)

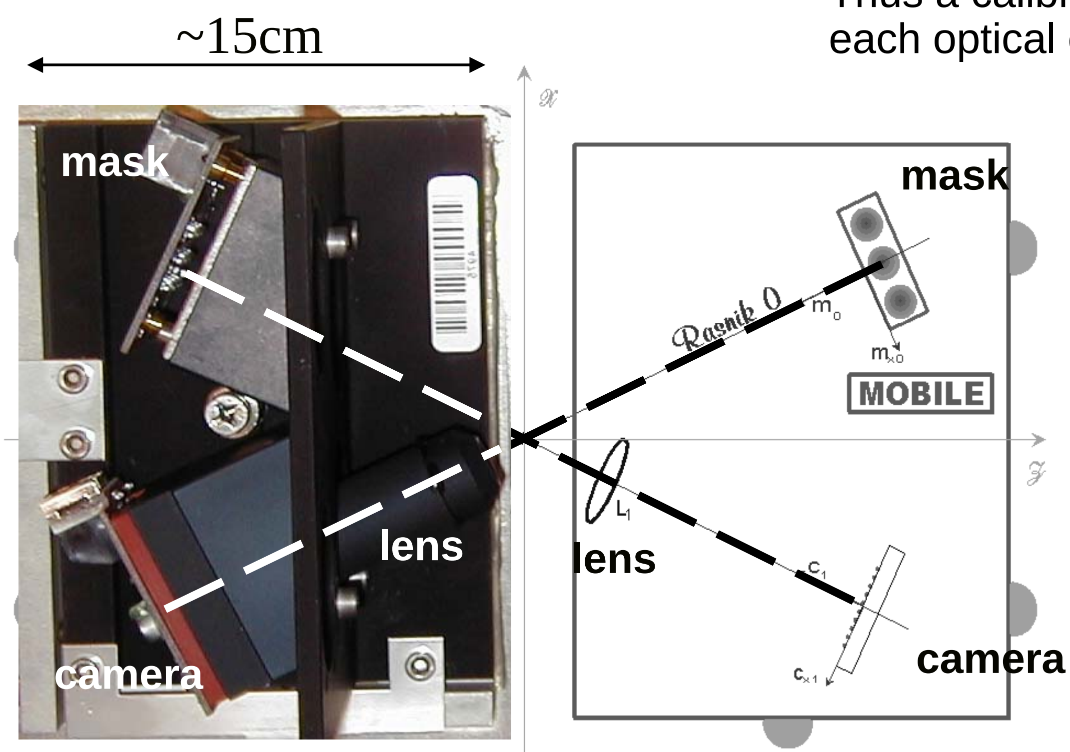
4) Praxial sensors and calibration



Praxial sensors are made with 2 crossed Rasnik => 2×4 measurements: ok for measuring position of two neighbouring chambers.

There is 2010 (=2x1005) Praxial sensors of 7 types! The positioning of each optical elements could not be better than ~1mm (mechanical precision of the screwing, gluing, etc…).

Thus a calibration bench is needed in order to determine each optical element position w.r.t. the positioning spheres

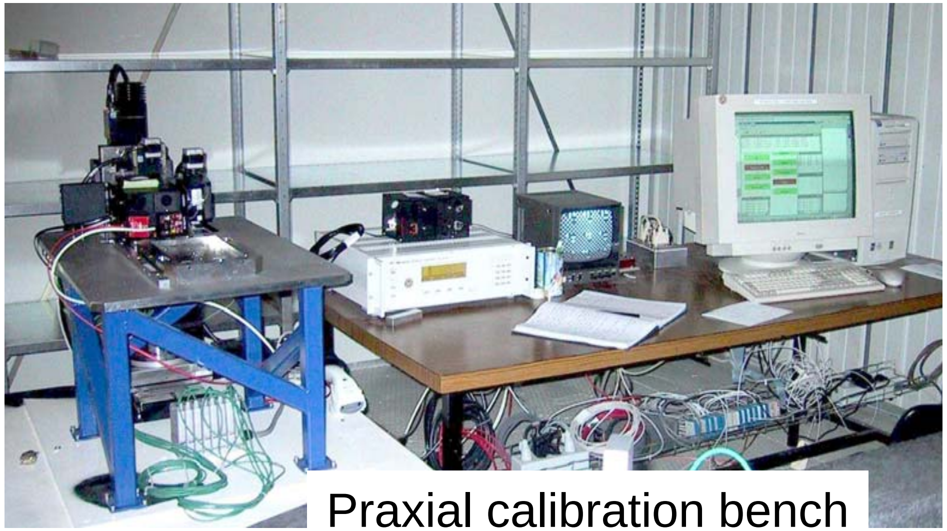


Top view of Praxial sensors

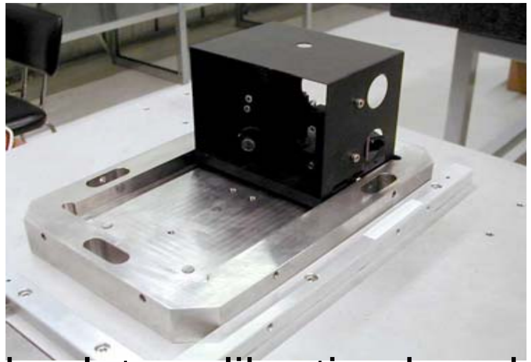
Resolution requirements: ~20µm and ~200µrad.

4) Praxial sensor calibration principle and results

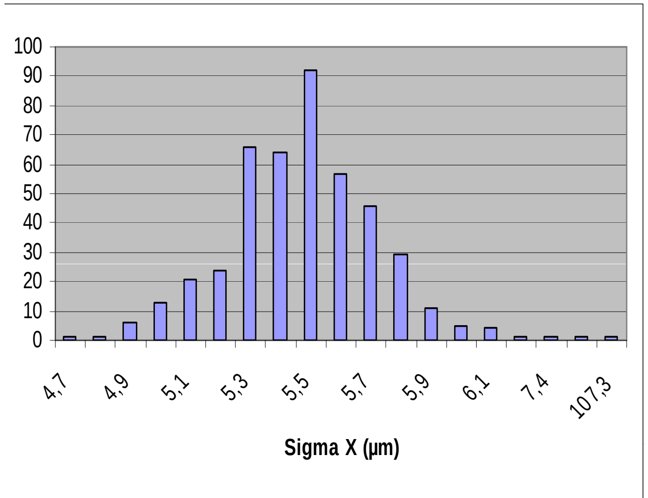
6D stages of the bench



Praxial calibration bench



Absolute calibration bench

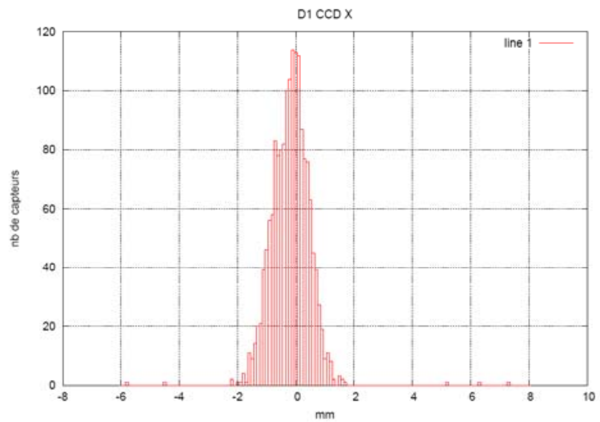


Example of final resolution <10µm (range: 5mm, 5mrad)

<u>Calibration procedure (2 Praxial boxes together):</u>

1) Perform 66 accurately known (2µm) movements
2) Record each time both Rasniks
3) With information from (1) and (2) calculate a transfer matrix giving the Praxial relative position any Rasnik outputs

4) The absolute positioning is obtain using a perfect mechanical frame (5µm precision)
5) Test the transfer matrix on a new set of know movements



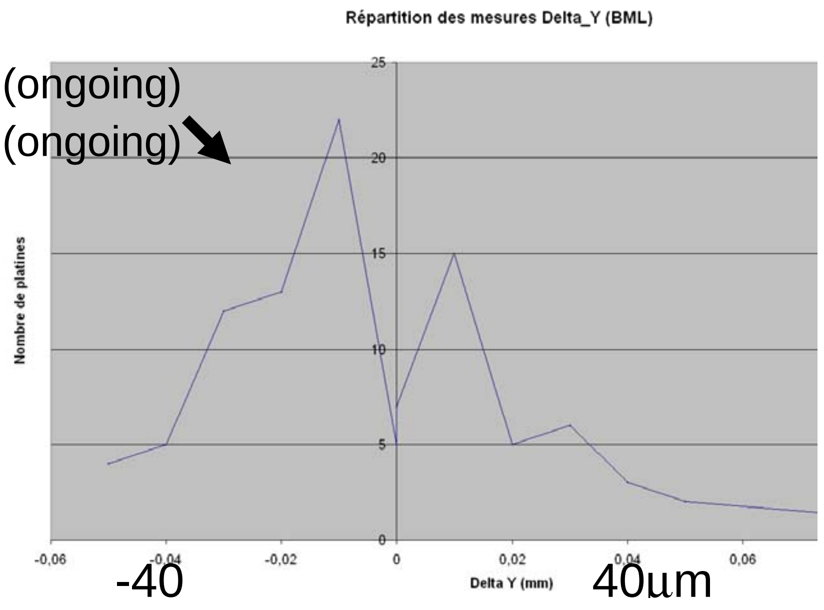
Positioning precision of the optical elements is ~1mm (as expected)

5) Current calibration status

(hardware calibration is now done)

Calibration status for the following elements for the following alignment system (i.e. calibration integrated in the official alignment software -ASAP-):

	sensors	ext. plates	platforms
Projective	yes	yes	no
Reference	no	yes	--
CCC	no	yes (+plates on ribs)	--
Praxial	yes	--	no (ongoing)
Axial	to be debugged	--	no (ongoing)
Feet Chambers Connection	no tested in Atlas configuration yet…		



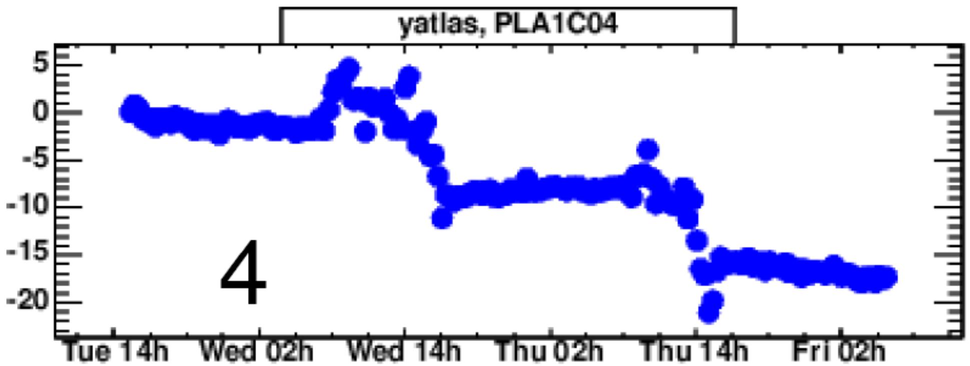
6) Conclusion

The calibration procedure (30µm level for some of them) is now finished both in Saclay and Nikhef for a total of:

5817 optical elements (5 bench)
831 mechanical elements (on CMM)
(+2166 optical lines glued on drift chambers by 8 institutes)

Some systems are well understood -Projective, Praxial- (platform still to be analyzed) but the calibration constants are not completely understand for others. Still lot of work and debugging here…

In **relative mode**, test beam performed in 2004 and 2005 have shown that the barrel alignment system works with a 20µm resolution.
On one of the Atlas sectors, the **absolute mode** have been partially tested with a (present) resolution of ~500µm (06/2007).

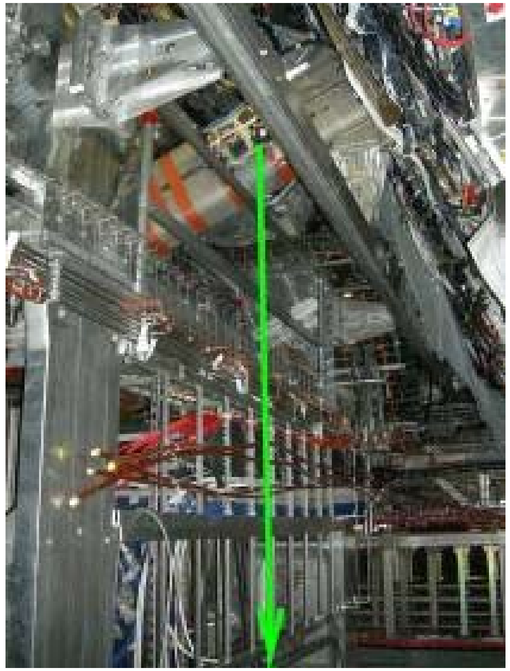


Mechanical release of toroid (11/2005)

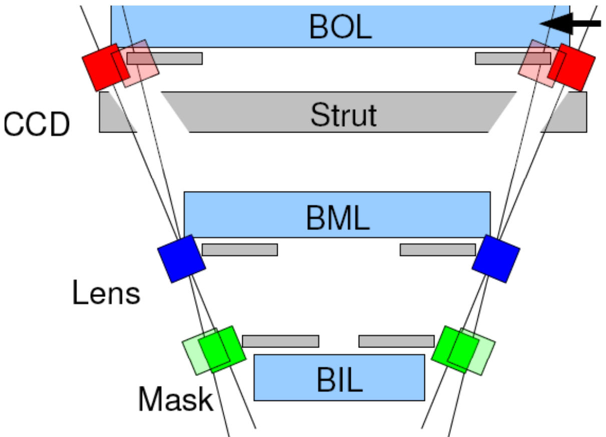
The installation and test in the cavern started ~27 months ago and the system have proved to be (very) useful for chambers positioning and during toroid tests: mech. release 11/2005 and magnetic tests, 11/2006.

6) Remarks

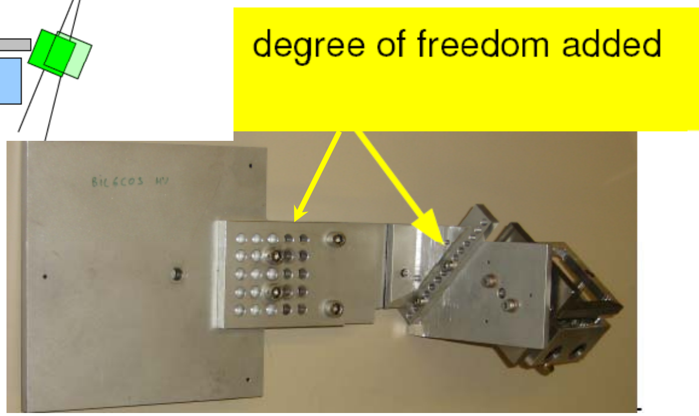
Installation in Atlas cavern is difficult and problematic due to cables, tubes, services, mechanical mistakes…



In particular, today, ~20% of Projective optical lines are blocked by toroid struts (holes wrongly manufactured). Solve this problem will induce a huge effort…



We also discovered (and solved!)
many mechanical
he absolute calibration was



spare

The difficulties arise from the fact that we have to do:

(i) metrological calibration: at the few 10th of microns or below…

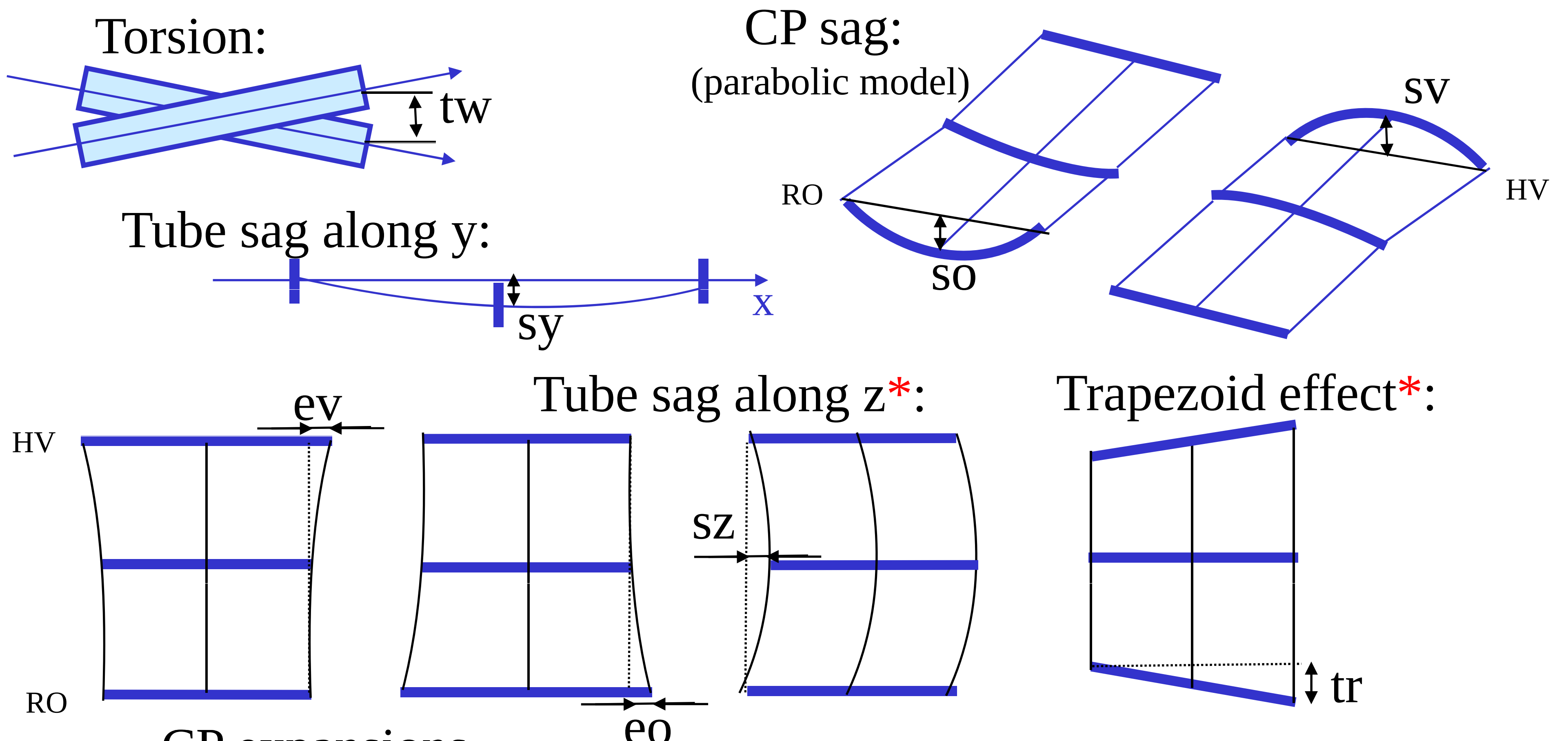
(ii) serie of measurements: several hundred of elements to be calibrated for each type!

(iii) “optimize” the cost of the system

(iv) simplify as much as possible the installation of the sensors

In-plane alignment for internal chamber deformation measurement

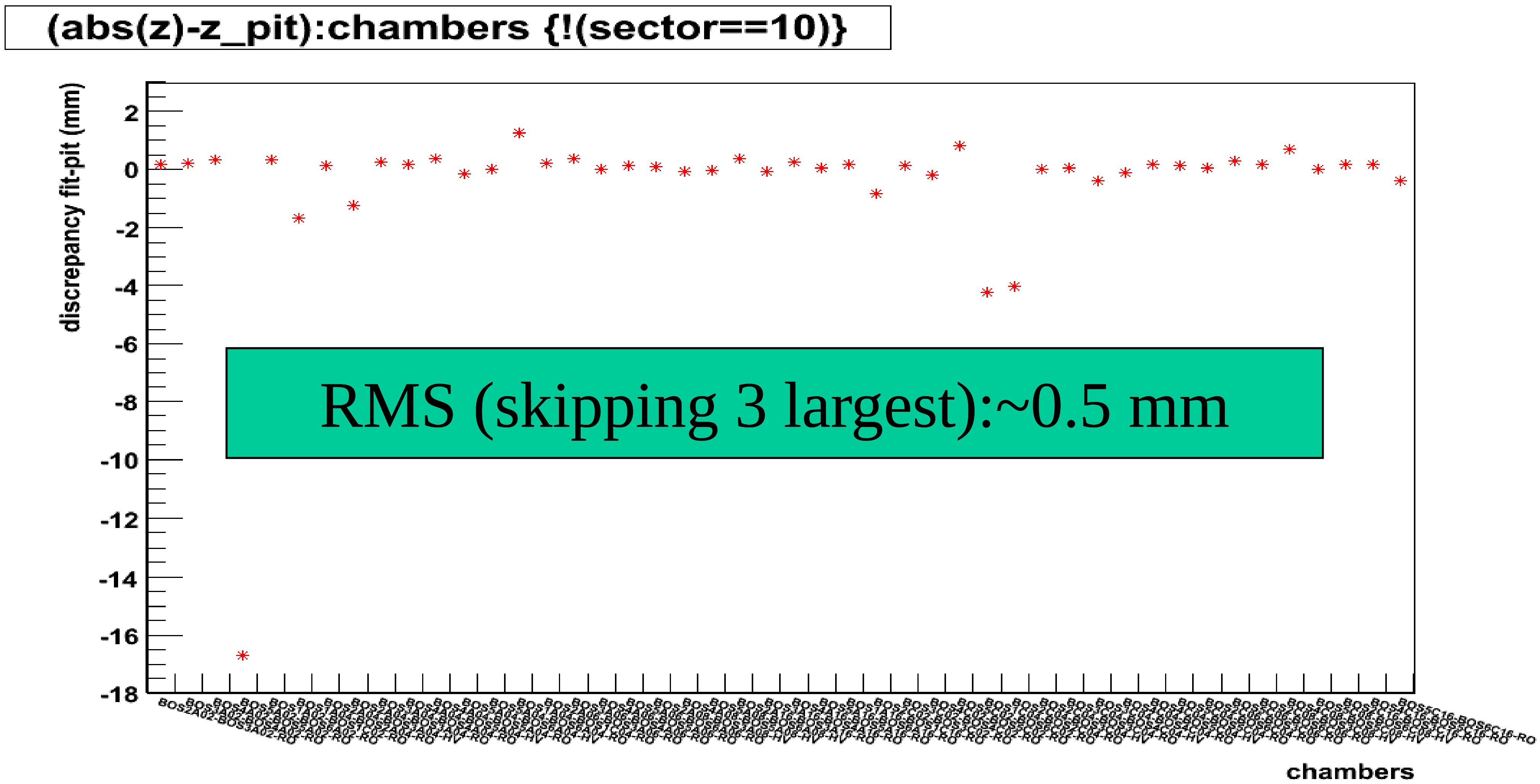
8 deformation parameters (in addition to global T expansion):



CP expansions

* :Not relevant for track reconstruction

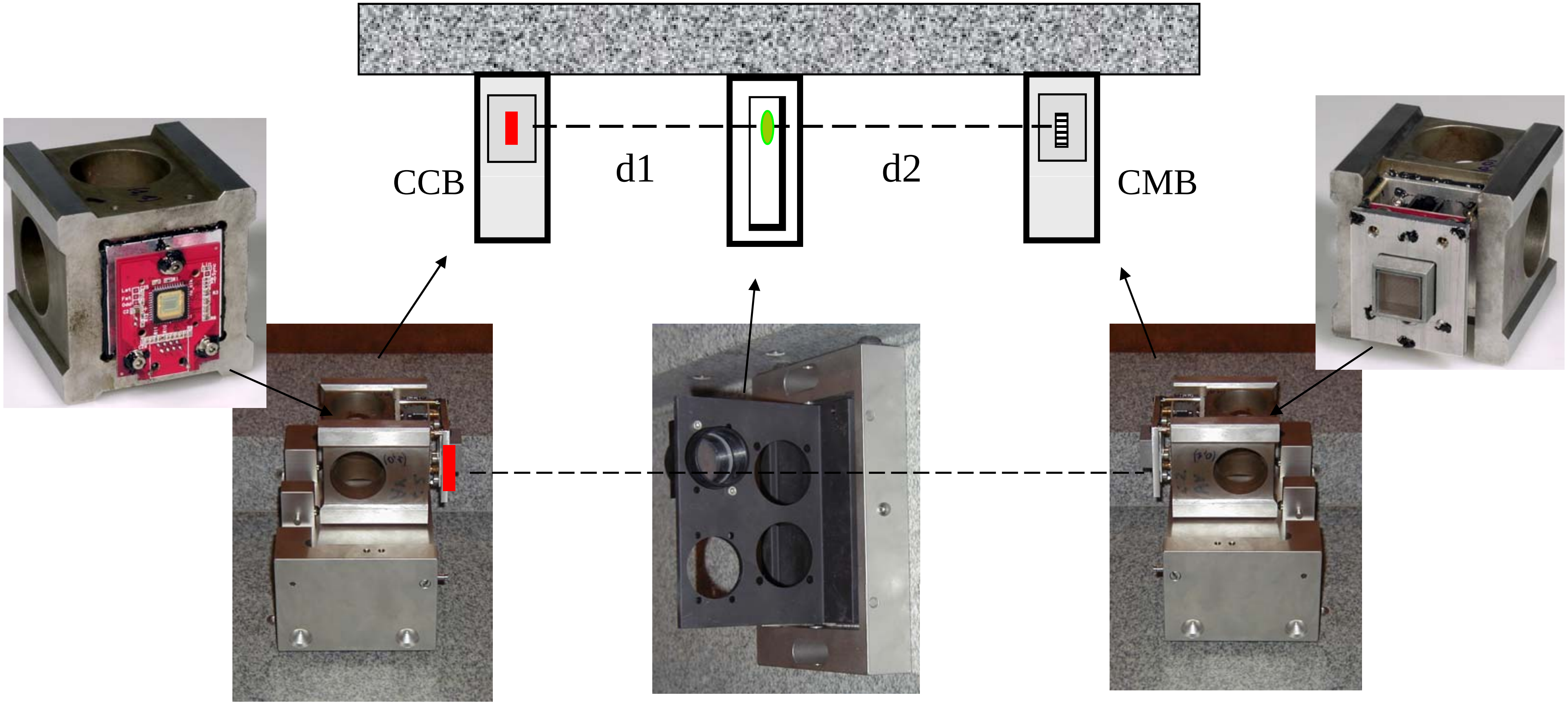
The distance between tubes on adjacent BOS MDT's have been measured (precision ~0.1-0.2mm) by Sonja (MPI) where accessible. The predictions of the fit agree only to the level of ~0.5 mm



Axial calibration bench Saclay

$1/f = 1/d1 + 1/d2$
with f ~ 1 meter

granite ruler on the granite table (top view)



CCB: calibrated camera block

axial lens to be calibrated (x,y)

CMB: calibrated mask block