Placement strategy and survey in Atlas – C. Lasseur TS-SU-EM

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The survey team is responsible for checking that each of the detector components:

- conforms to the manufacturing dimensional tolerances
- is placed within its approved space envelope
- conforms to its initial alignment relative to the nominal beam line
- position is reproduced after opening and closing

The task of surveying, placement and precise positioning, for the ATLAS experiment has been a big challenge due to the size, nature, complexity and global scale of the work. The survey team has been following the evolution of ATLAS from the fabrication and assembly phases, operating off-site CERN measures in manufacture premises to validate the geometrical quality and surveying all the installation phases at point 1. The survey data will be employed during the operation phases.

Adding to the complexity is the fact that ATLAS is being assembled in a relatively small cavern and thus every centimeter was important. The aim was to optimize any space made available once an installation was complete. Thus as soon as the cavern was delivered by the civil engineers, and before any infrastructure was installed, an exhaustive scanning was carried out in order to check the as-built work [1] and [2].

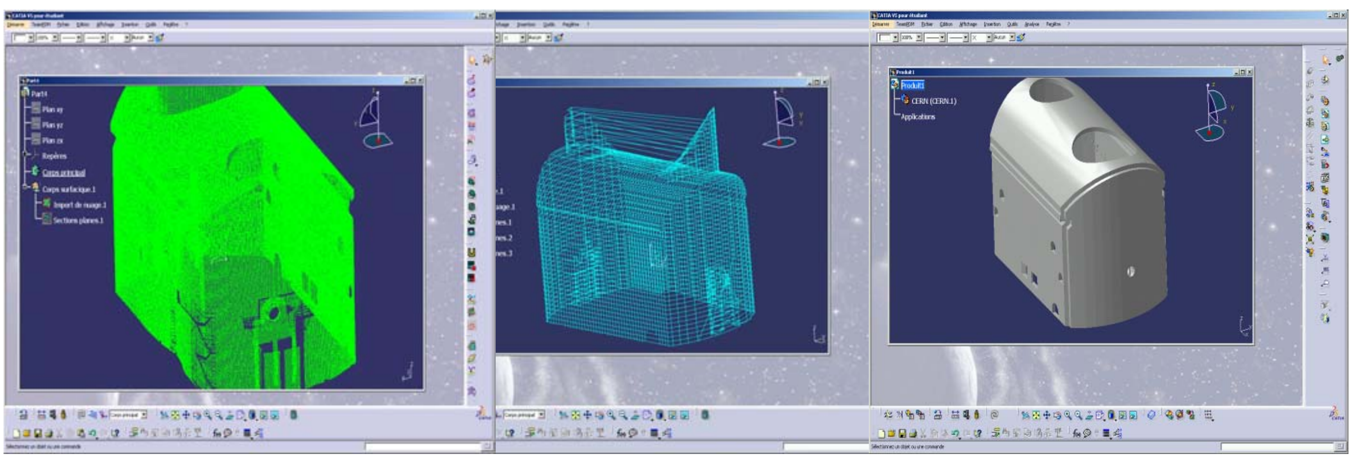


Fig. 1: As-built cavern model - measured points cloud, 30 cm grid and final design

The work of the survey team has been critical to the development, definition and implementation of the regular geometrical controls at all the steps of assembly. They have also been an important partner in determining the placement strategy of the detector components.

Determination of the collision point and the survey reference grid in the cavern

The nominal beam line is defined by the best fit alignment line of the low-beta quadrupole magnets each 60 m distance from either side of the interaction point. This reference line can deviate from the real beam line by as much as 2-3 mm. The primary reference line was defined and used during the

installation and positioning of the detectors in the cavern. This primary one is given by the reference sockets in the tunnel from which the machine elements are installed. The final control is carried out on the elements themselves - inner triplets included - relative to each other [3]. A range of spatial uncertainty within 0.5 mm to 1.2 mm at 1 sigma was estimated for any fiducial mark with respect to the nominal beam line depending of the location of the given target.
The datum (interaction point, radial orientation of the colliding beams and reference plane) is given by the initial geometry in the tunnel and the final positioning of the low-beta quadrupole magnets. The survey grid reference in the cavern, is linked to the machine geometry via standard geometrical measures and permanent monitoring systems, hydrostatic and wire positioning capacitive sensors, implemented in the survey galleries and joining the low-betas Qpoles via the cavern and radial tubes [2] see 'The question of the I.P', [3] and [4].

Fig.2: Survey galleries and scheme of the link towards the machine geometry

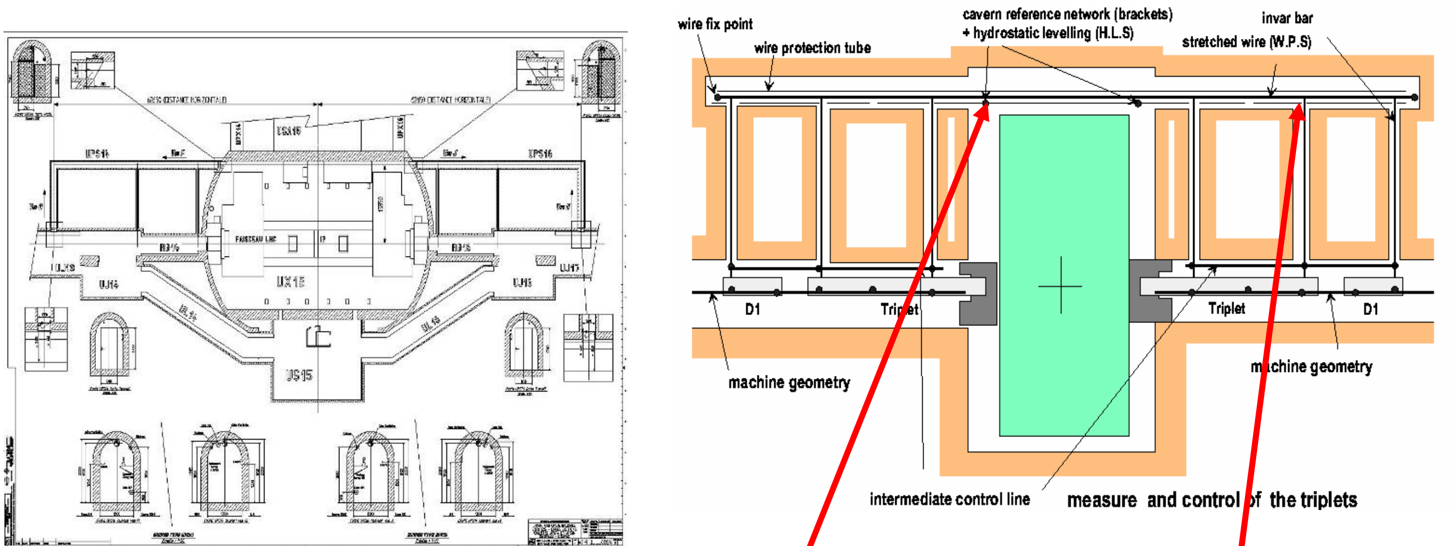
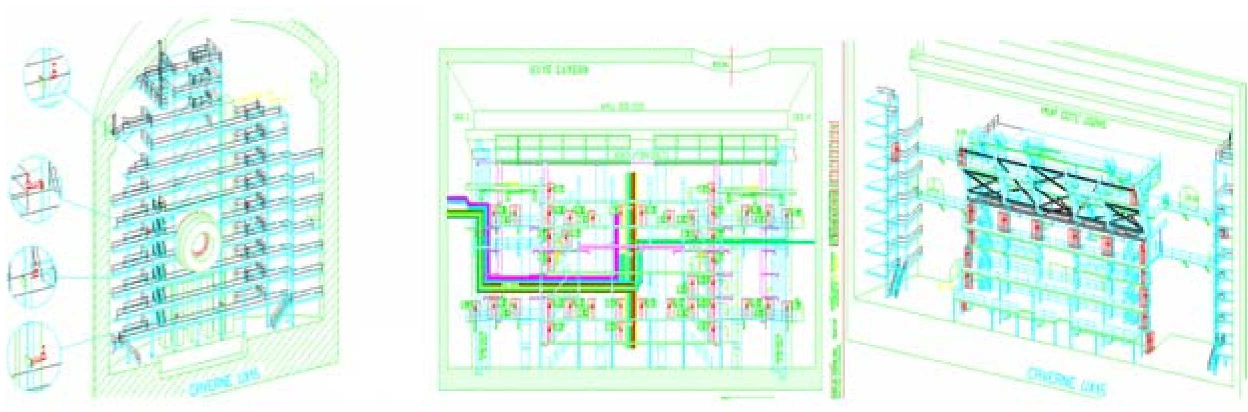


Fig. 3: hydrostatic stations in the cavern and capacitive sensor in the survey gallery

That grid is composed by numerous plug-in brackets surrounding the detector and arranged on concrete walls and metallic structures.

Fig. 4: Locations of reference brackets in the cavern (in red)



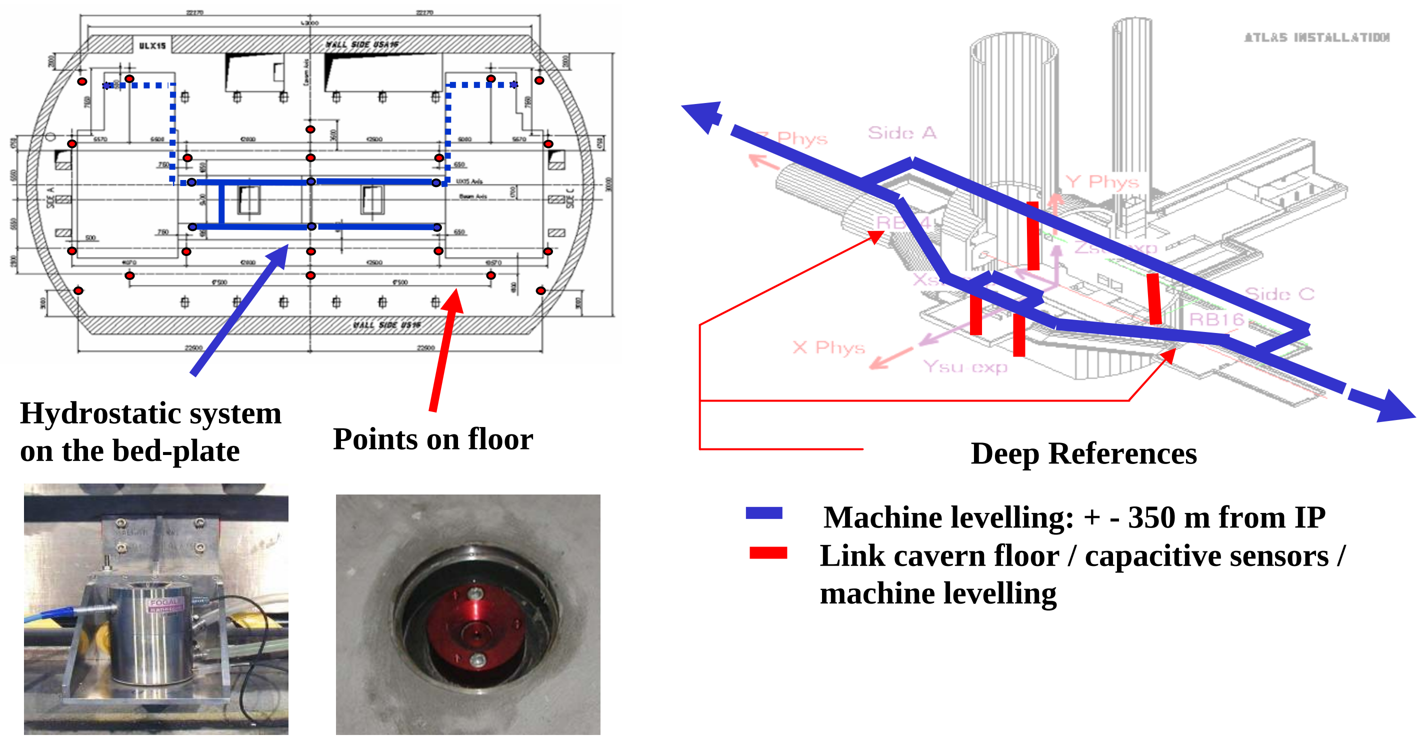
Each bracket, foldable on wall, repeatable on metallic structure, is equipped with a precise mechanical centering device permitting the using of various types of survey instrumentation within accuracy of repeatability and reproducibility better than 50 microns. The isostatic plug-in system enables the repeatability of a given bracket within better than 50 microns as well. The grid has been regularly monitored during the installation and refreshed co-ordinates are addressed.

Fig. 5: CERN plug-in reference brackets on wall and on metallic structure with centering socket

Stability measurements of the floor and of the bed-plate

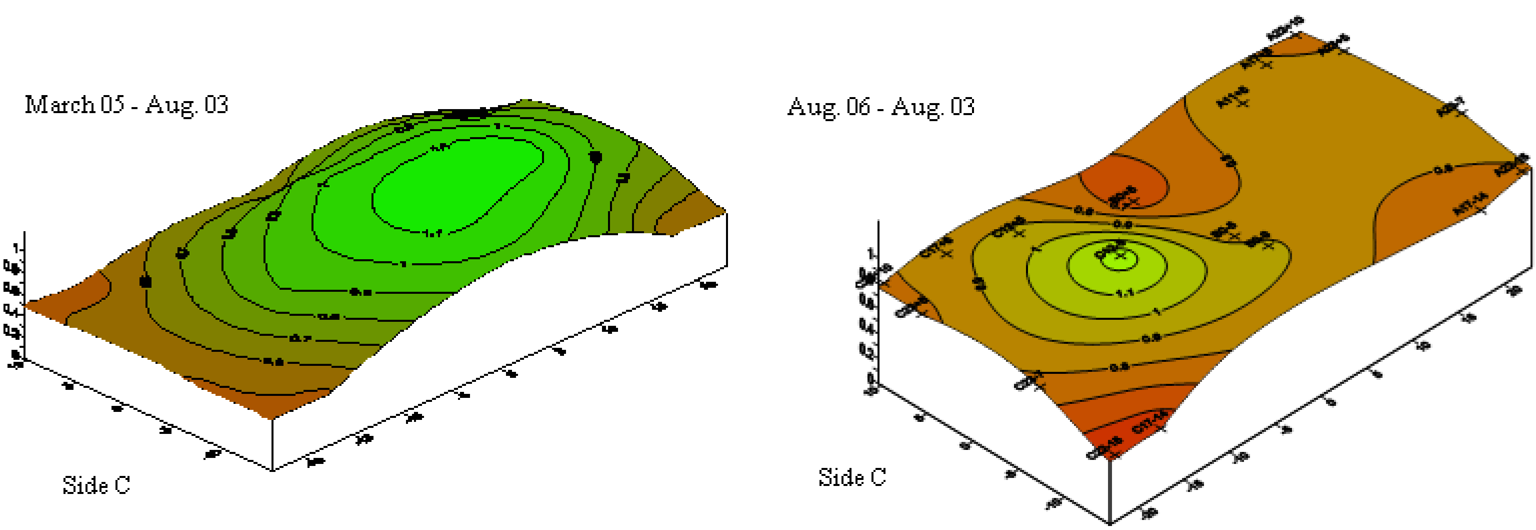
Civil Engineering calculations indicated possible vertical floor movements of up to 6 mm settlement due to the loading of the experiment and a 1 mm per year lift due to hydrostatic pressure. ATLAS has a very limited adjustment capability once the detector elements have been placed in-situ and a placement strategy was developed to place all elements within their tolerance, relative to the interaction point and the nominal beam line as described above [5].
To monitor these predicted movements, regular and periodical measures, referred to the machine leveling and deep references in the tunnel, have been carried out on about 20 reference marks embedded in the cavern floor and full reports have been given since the first measurements in August 2003 [6].
In addition to these measures, a permanent hydrostatic system has been implemented in the bed.-plate: it consists in 6 capacitive sensing stations monitoring water plane in two 25 m long tubes - 55 mm in diameter - parallel to the beam and linked by a transversal tube [7]. Two additional stations have been installed in the extreme trenches, recognized as stable zones, and linked to the bed-plate system. Altogether that is as if a reference water plane of 75 m long were inspected by 8 sensors attached to the structure (bed-plate and stable floor) within an accuracy of better than 20 microns.

Fig. 6: Scheme of the monitoring system in the cavern and link to the machine



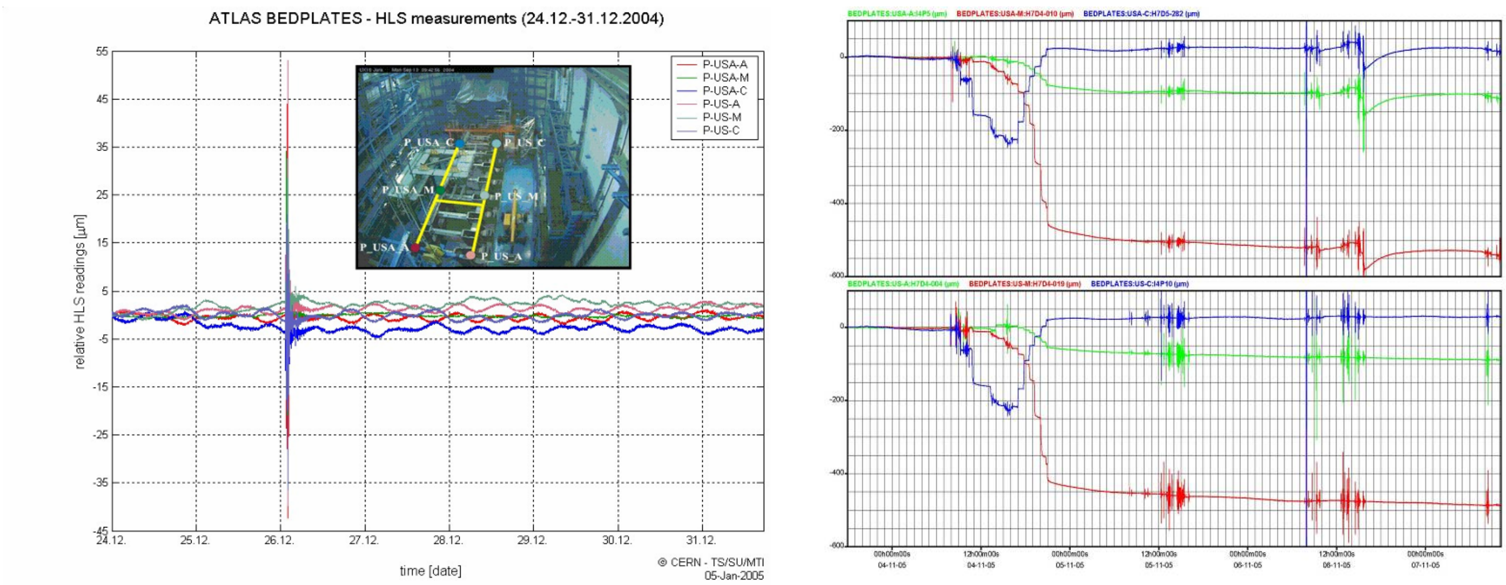
The results from the measures on the floor show that an heave of the floor up to 1.2 mm happened in the central part of the cavern during the first 20 months since after the completion of the civil engineering (March 05/August 03) and a global stability of the cavern is recorded after loading of about 85 % of the total charge between March 05, August 06 and February 07. The absolute accuracy between two epochs with respect to the deep references in the tunnel is estimated to 0.3 mm 1 sigma.

Fig. 7: Vertical movements of the cavern floor since August 03



The hydrostatic system (HLS) in the bed-plate gives immediate movements of the supporting structure within of a few microns and was used to monitor local movements when inserting the tile barrels [8].

Fig. 8: Bed-plate HLS system - recording of the tsunami (December 04) and the tile barrel insertion



It has been agreed with the responsible persons for the beam steering and the closed-orbit [9] that the machine apart the low-beta quadrupoles plus a bit farther to ensure the correct smoothing of the magnetic elements will be realigned once the beam deviates significantly from its nominal position with respect to the Atlas reference frame.

Survey and measure of as built parameters of some critical elements

Dimensional and geometrical validation measures, either by standard survey or digital photogrammetry, on critical items had been achieved off-site CERN before their delivery. All of them were done at the request of the project responsible persons, as examples the muon alignment test Datcha in Saclay, the ECA and ECC cryostats in Italy, the first two barrel toroïd feet in Russia.

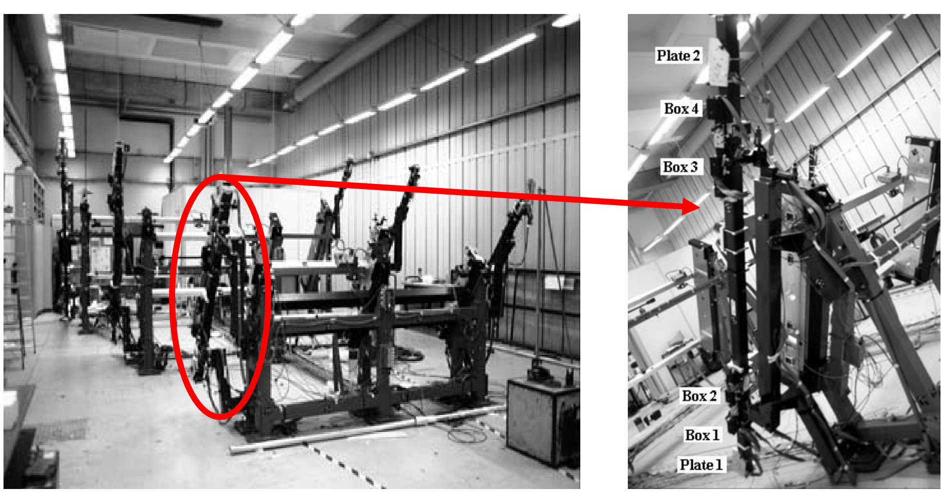
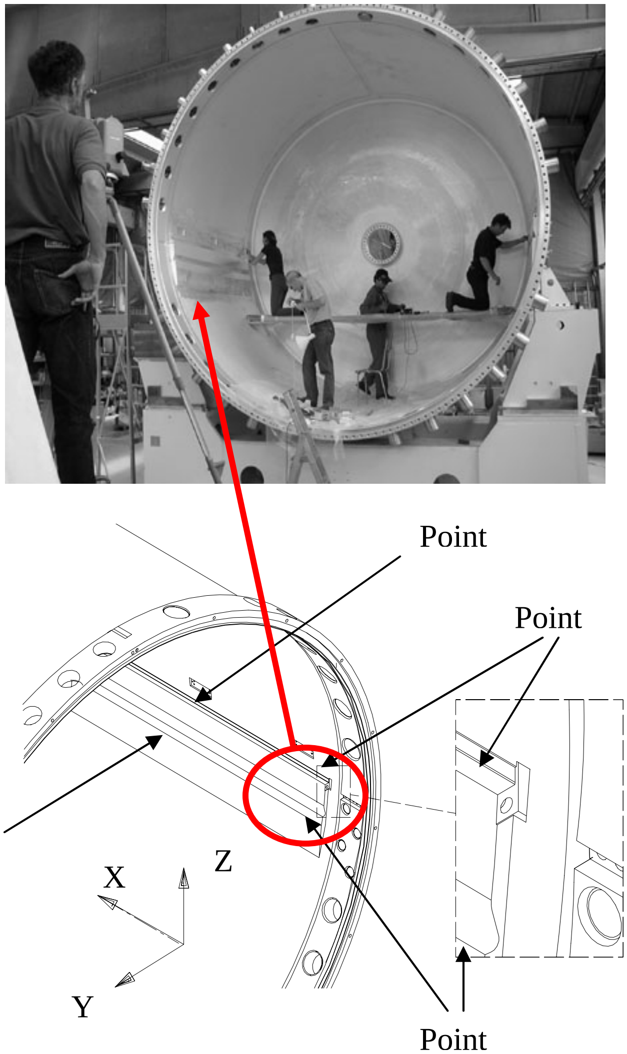


Fig. 9: Saclay - Datcha - validation of the muon alignment test.



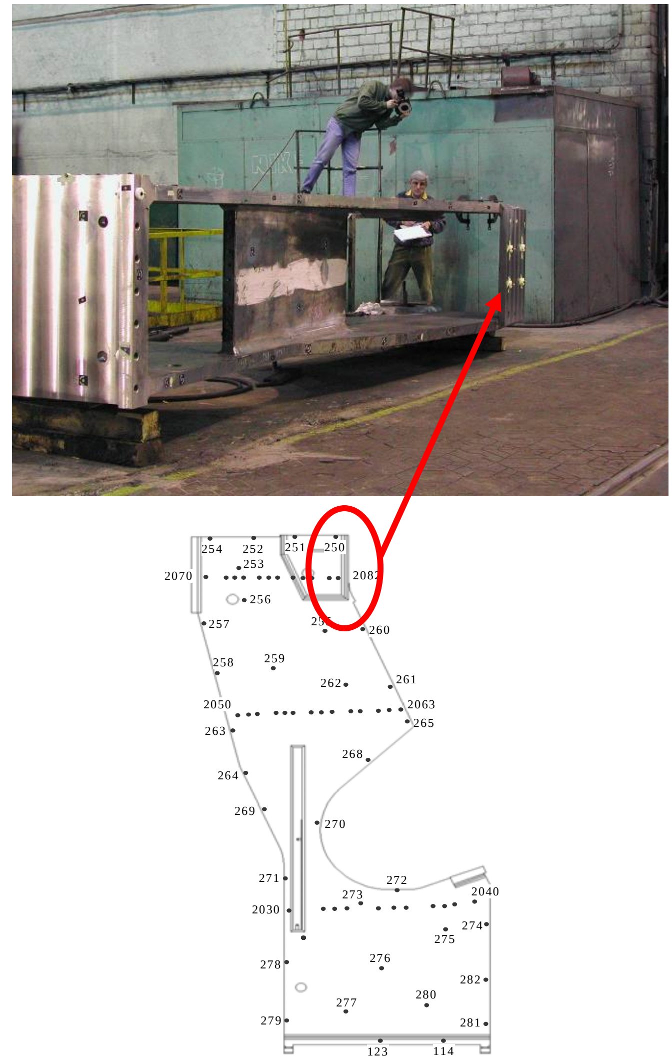


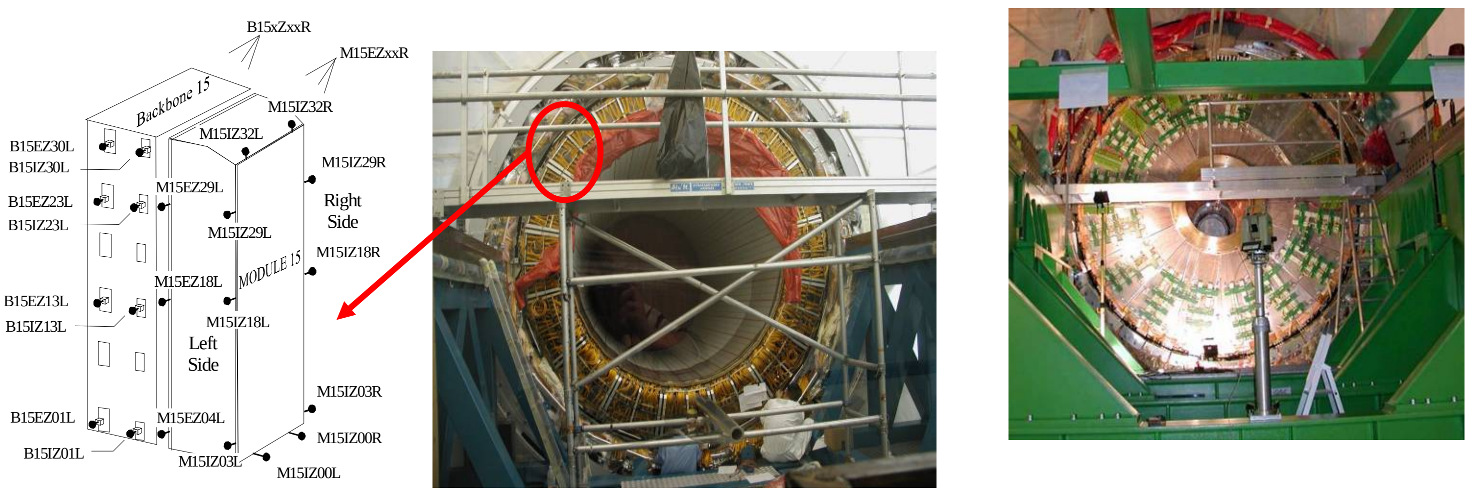
Fig. 10: Italy - Simic - EC cryostats

Fig. 11: Russia - Izhorskiye Zavody – barrel foot

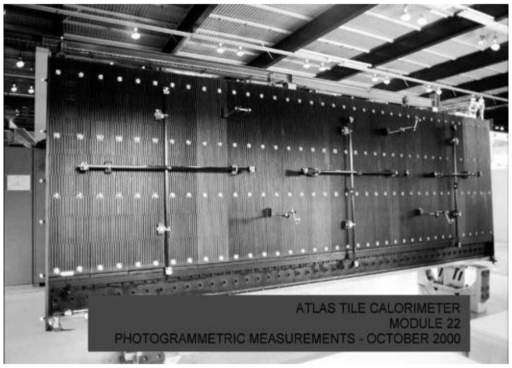
Survey assemblies as they are done on the surface at CERN

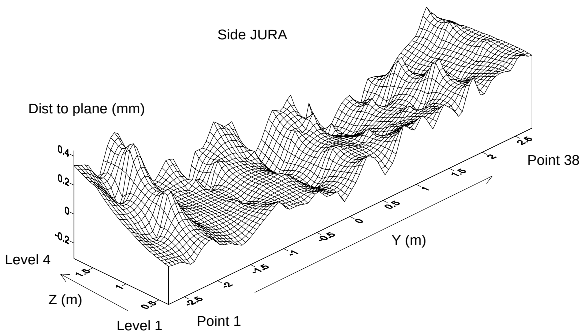
Nearly all the detectors and their constituents assembled on surface were surveyed at a given step of their mounting. First were the EM modules and wheels plus the EMEC and HEC wheels metrology and their insertion into their respective LArg vessels.

Fig. 12: EM module metrology, EM wheel in the barrel LArg, EMEC wheel in the LArg EC



Dimensional and envelope controls of the Tile barrel and extended modules were carried out once delivered at CERN. The barrel and the two end-caps pre-assemblies were surveyed. Most of the operations were performed with photogrammetry.





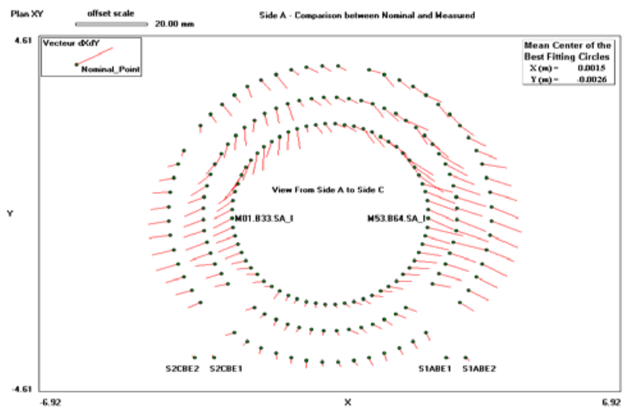


Fig. 13: Tile module envelope, full Tile 64 modules, forms and dimensions.

Envelope and critical regions of every constituent of the 8 coils of the barrel toroïd system – about 400 points per coil - and the 18 bottom feet in upright position were fully measured.

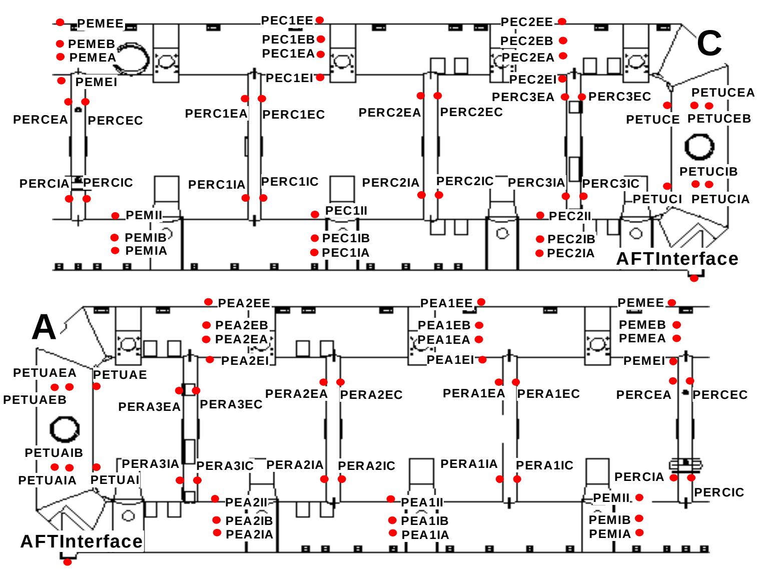


Fig. 14: Envelope points for each barrel toroïd coil and geometrical control of a foot in upright position

High precision metrology measures have been carried out on every assembly step of the various parts of inner detectors, barrel and end-caps, in the SR1 hall. An accuracy within better than 100 microns for the mechanical linking rails in between these parts has been requested and an accuracy within better than 50 microns for the precise knowledge of the detectors after their insertion has been achieved. These operations have been performed with photogrammetry mostly.

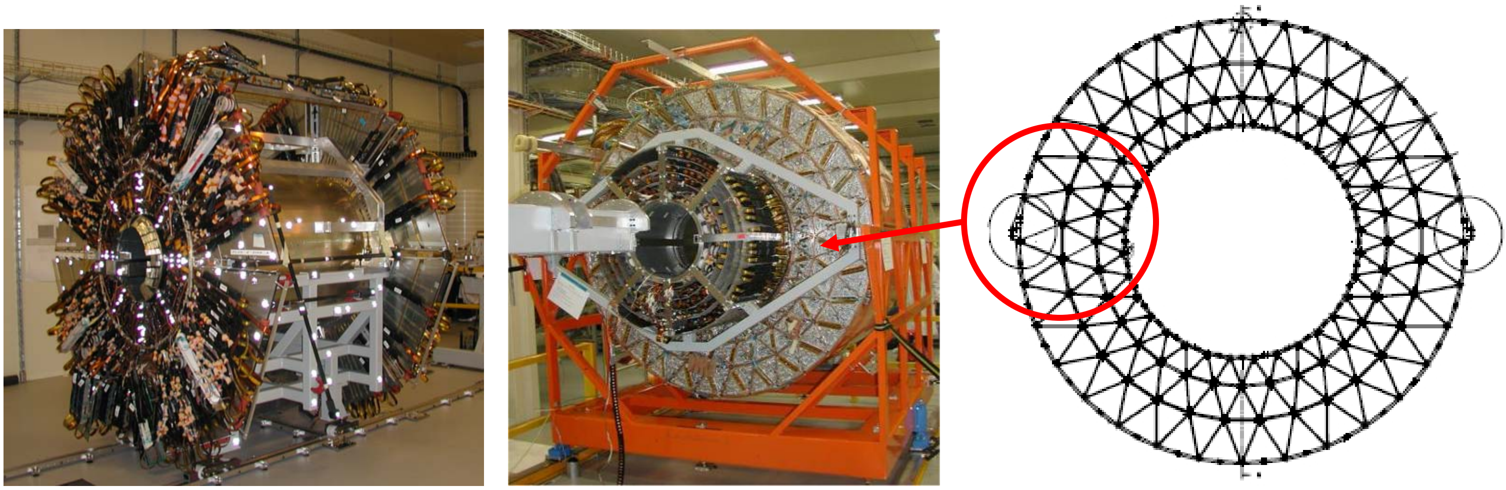


Fig. 15: SCT barrel with FSI and pixel JIG, TRT and SCT barrel together, SCT reference points

Once the TGC chambers have been adjusted on the corresponding assembly table forming a sector, each of the 72 ones has been measured and fiducialised by photogrammetry - about 12000 digital photos altogether - before their lowering and assembling to form the big-wheels down in the cavern.

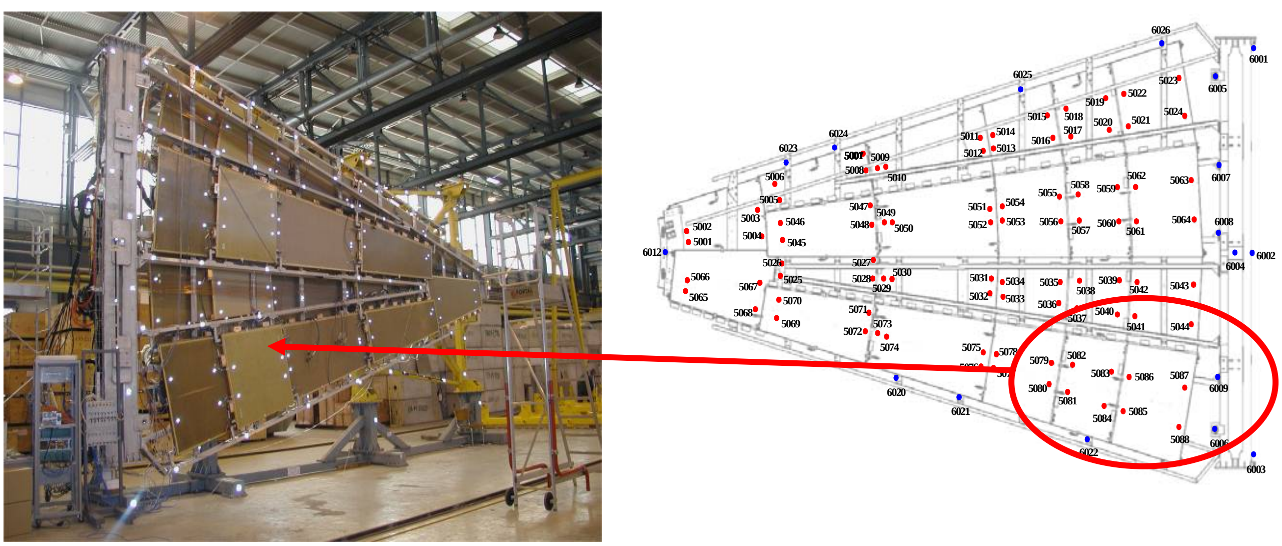
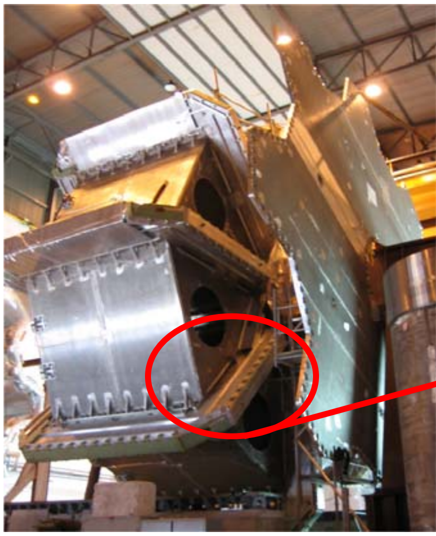


Fig. 16: TGC sector – chamber and reference points, naming and lay-out

Complete elements of the forward magnetic, shielding and muon regions have been also measured after their assemblies like the coils of the End-cap toroïds, the JD disks with the TGC chambers fixations specifically and the small wheels with the CSC chambers fixations.



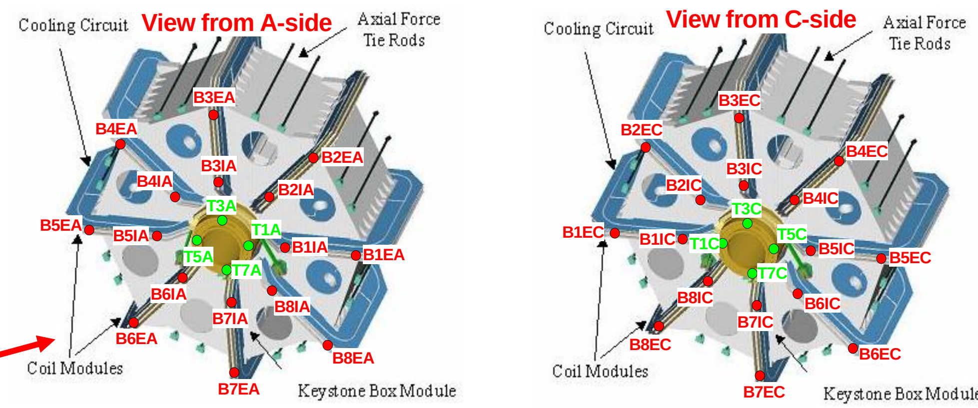
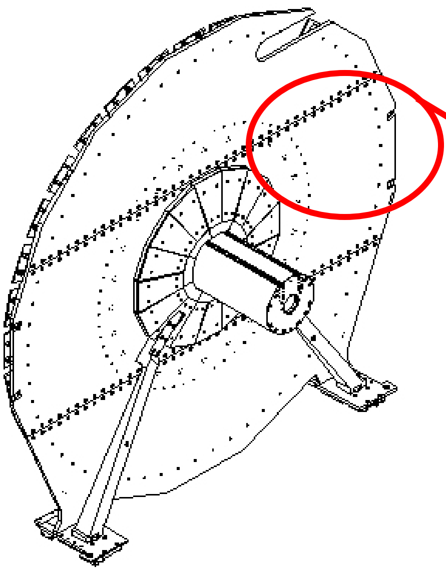


Fig. 17: Measure of the ECT coil mass before the closing



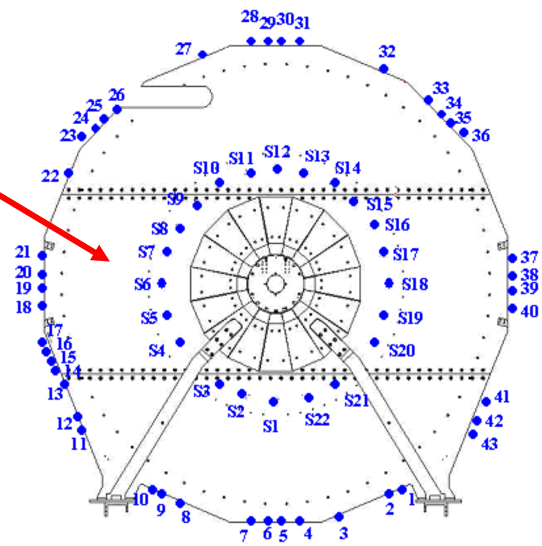


Fig. 18: Measure of the JD disk and the TGC chambers fixations

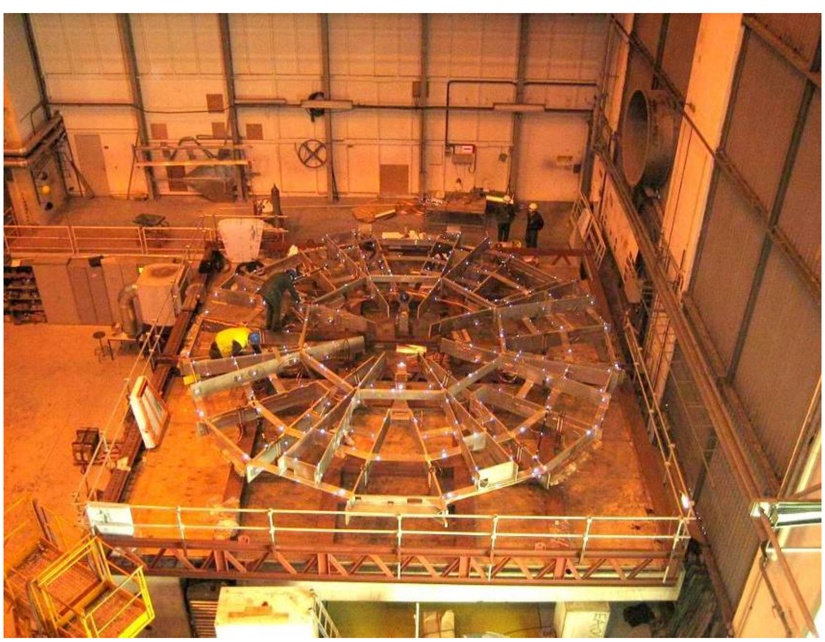
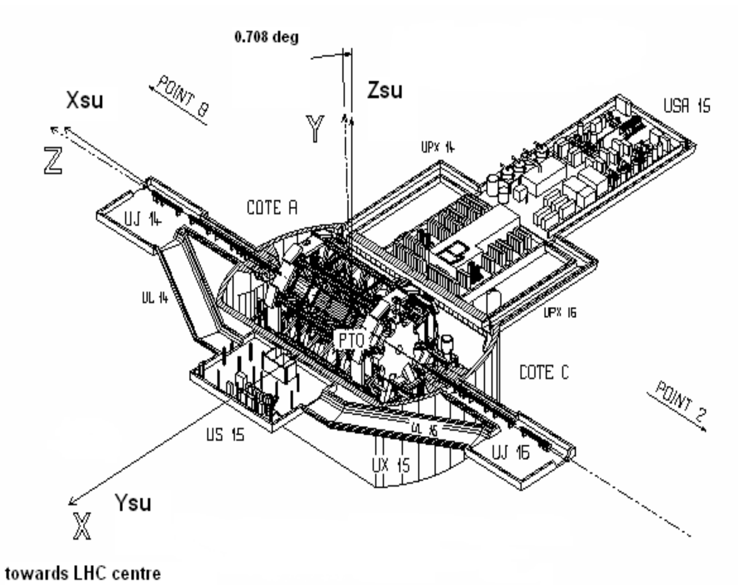


Fig. 19: Photogrammetry of the small wheel and the CSC chambers fixations

Survey assemblies as they are placed in situ in the cavern

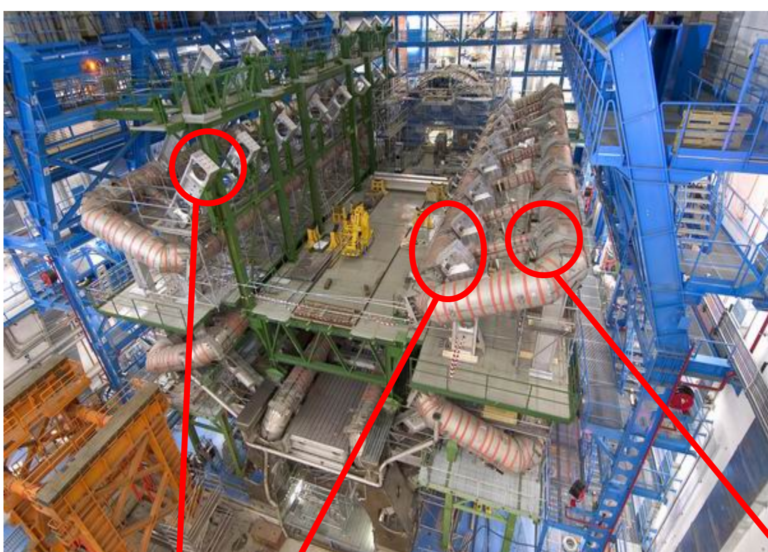


The geometrical measures are done in the survey cartesian system Xsu,Ysu,Zsu, linked to the gravity. All the results are edited in the Atlas cartesian detector coordinate system X, Y, Z, where X is horizontal, perpendicular to the plan YZ, Y is perpendicular to the beam line and in the vertical plane containing the beam line and Z follows the beam line.

Fig. 20: Survey and Atlas detector systems

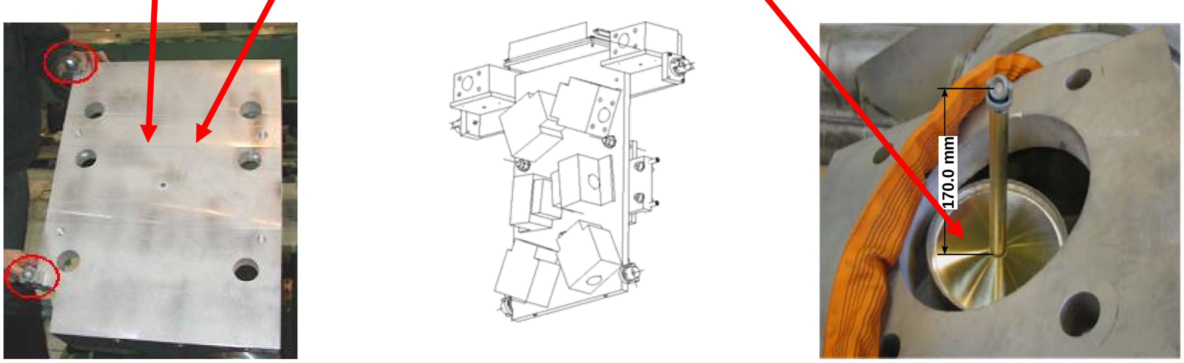
The bed-plates and the 18 barrel toroïd feet were the first elements to be placed in the cavern. Several iterations were needed and important services, like the holes for the internal alignment lines, had to be known within a good precision.

Fig. 21: Adjustment of barrel toroïd feet after the precise adjustment of the bed-plate



Several elements - cryostops, points on struts and voussoirs, alignment camera plates, transport stops, tie rod heads etc constituting the barrel toroïd - were measured. The complete geometry of the BT was given after the release from the jacks so that the conductors can be located and the pre-adjustments of the muon rail brackets plus the alignment systems could be prepared [10]. The barrel toroïd rails were also controlled and adjusted.

Fig. 22: Control of the BT – Struts, voussoirs, camera plates, cryostops, BT rails



Regular deformation measures at both ends of each coil on the transport stops have been done since October 2005. Vectors up to 7 mm have been recorded, well accordance with expected values.

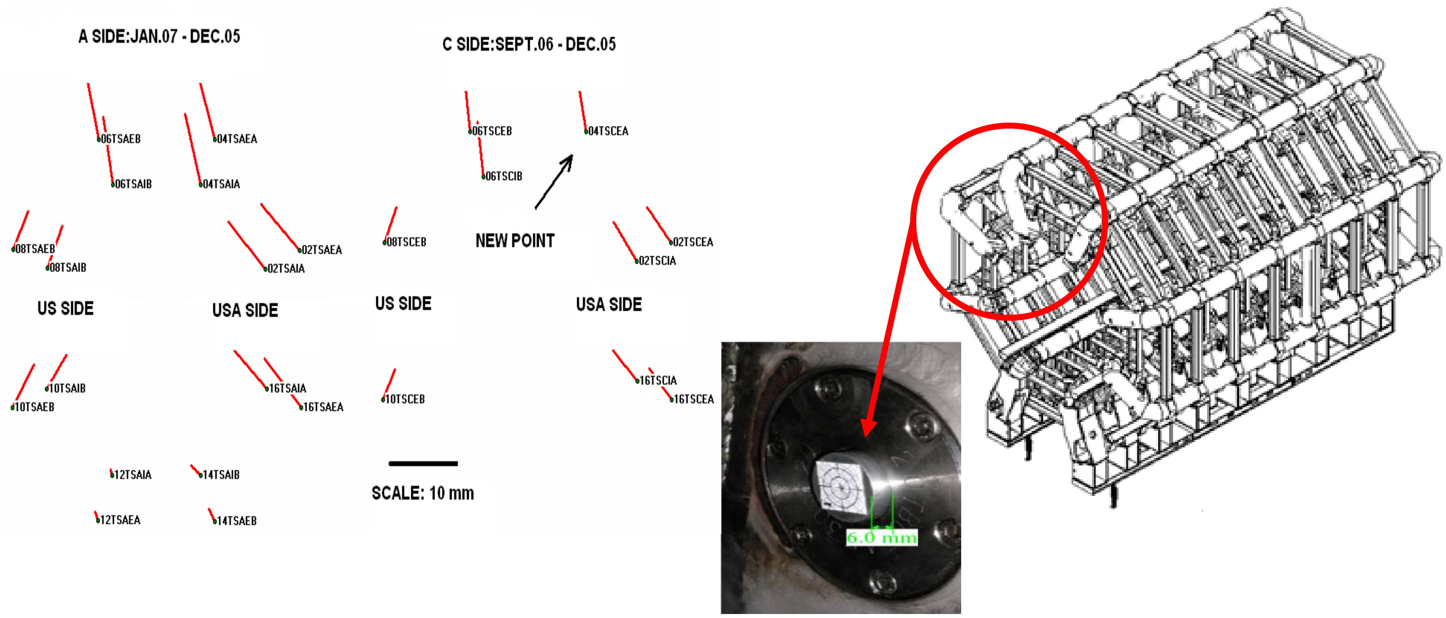


Fig. 23: Deformations of the BT coil extremities (transport stops)

The assemblies of the tile and the extended barrels, the inner envelope specifically, plus the insertions of the LArg barrel and end-caps were controlled and the final validations were done by photogrammetry.

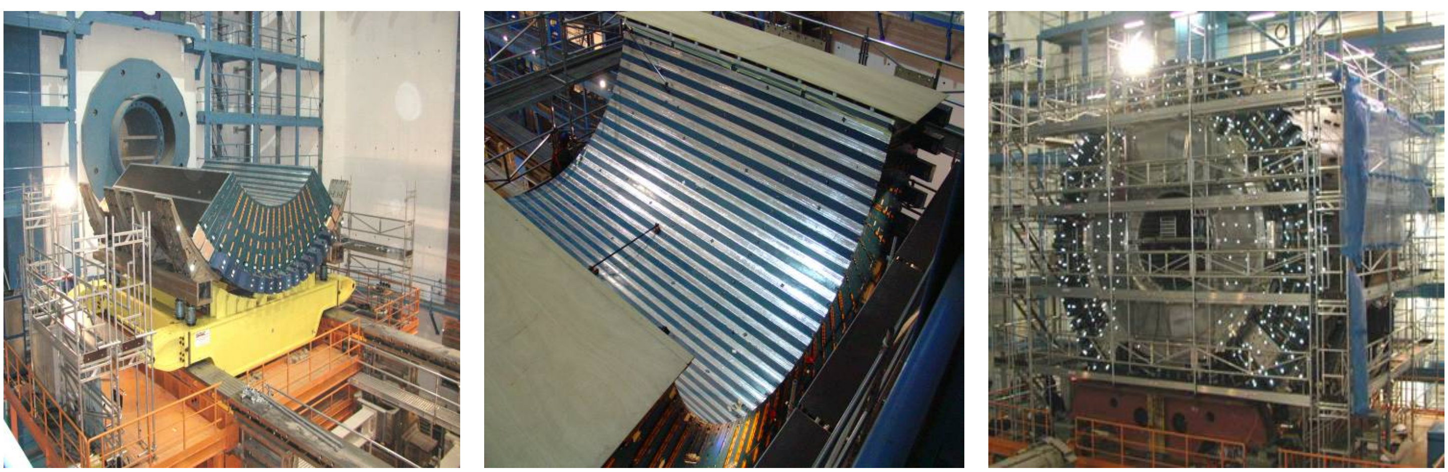


Fig. 24: Tile barrel - Control of 18 and 30 modules and photogrammetry of all the 64 modules.

Their positioning with respect to the beam line was monitored by survey and the deformations of the BT rails when moving were inspected by the bed-plate HLS system [8] and [11]. In addition to survey, the radial positioning of the extended barrels with respect to the tile barrel was monitored by using the BCAM system (Brandeis camera angle monitor).

The axes with respect to the nominal beam line of the barrel inner warm vessel and solenoid plus the positions of the extended barrels in closed positions were given.

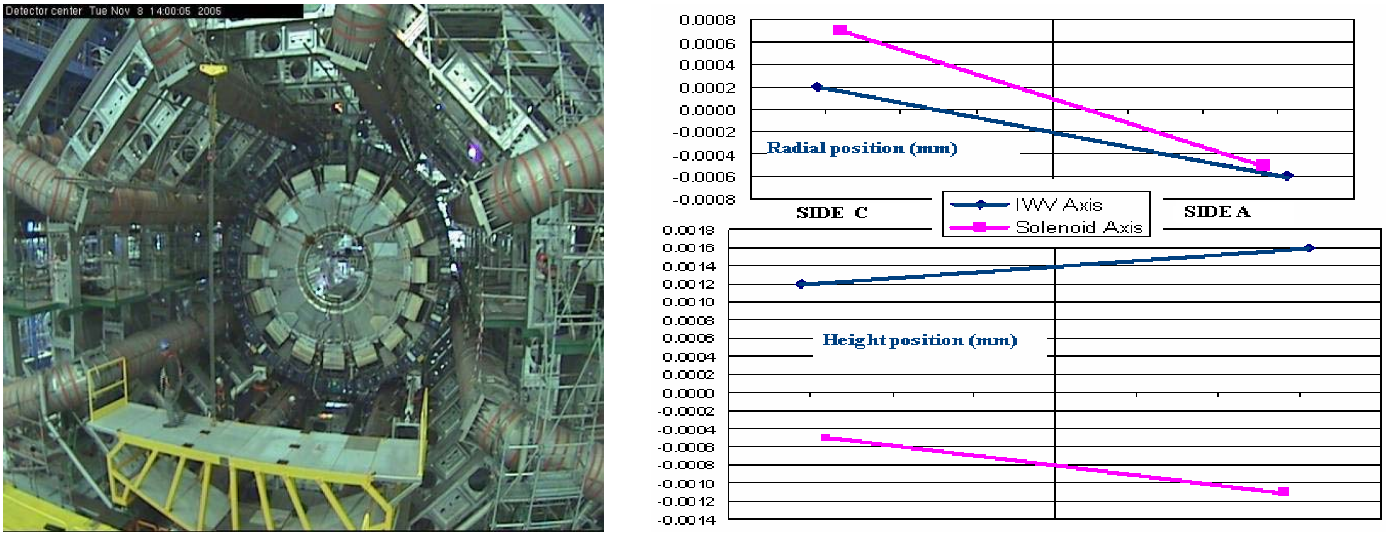


Fig. 25: Tile barrel at the nominal beam position and relative axes of the inner warm vessel and solenoid

All the brackets and muon barrel rails plus each type of chambers at specific extremity and intermediate locations were controlled. Several iterations were needed because the required positions depended of the expected deformations of the barrel toroïd at the given place and the definitive installation could not be achieved in a continuous process. All the BIR chambers were verified several times particularly and a large part of the other types of chambers also.

Fig. 26: Brackets, control of BOL rails, BIS reference mark and BIR chamber

After several measures and adjustments of the inner detector rails in the barrel inner warm vessel under conditions vacuum, the ensemble TRT/SCT barrel was inserted and measured.

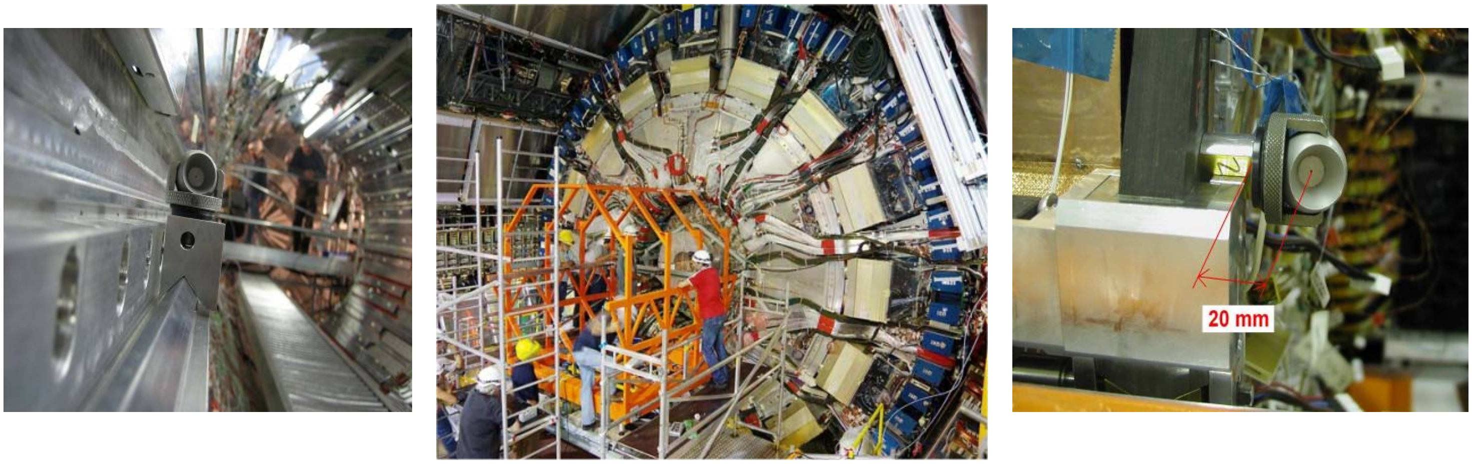


Fig. 27: Inner detector guiding rail, the TRT/SCT during the insertion and survey mark

Once the precise adjustments under survey of the inner and outer rims plus the pins on the spokes supporting and linking the TGC sectors were achieved, the corresponding big wheel was put in place and measured by photogrammetry, including the individual sectors marks and permanent survey points on the chambers and the structure.

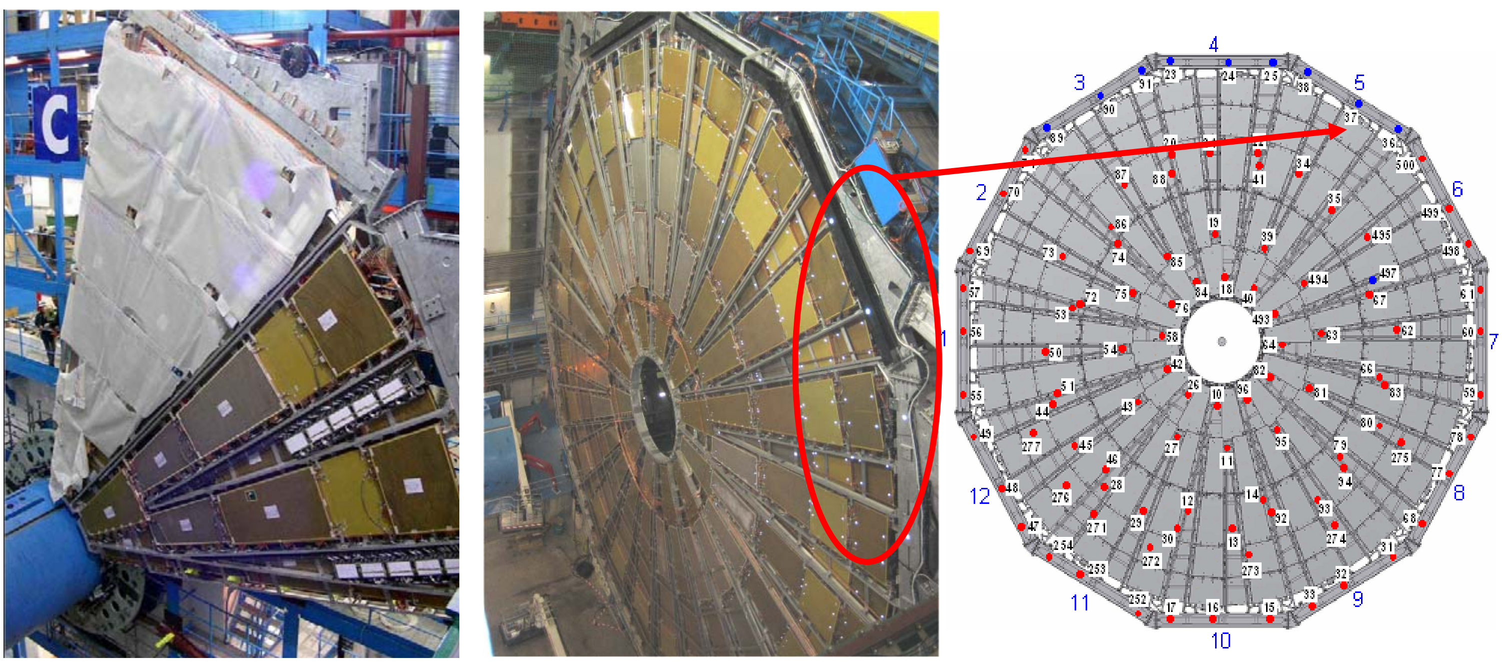
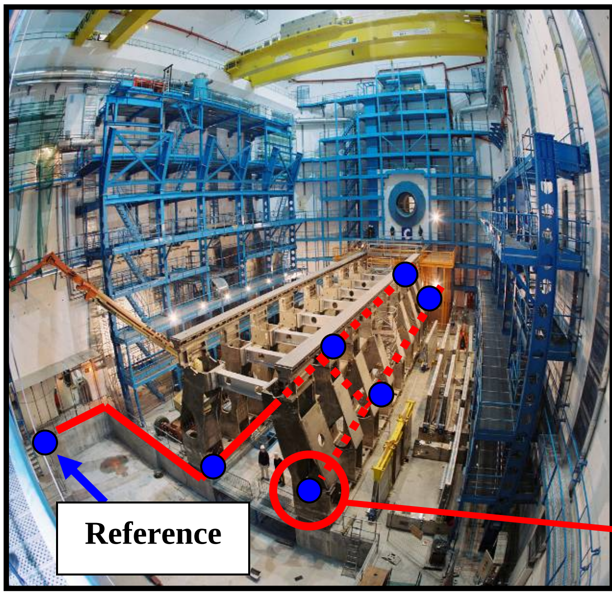


Fig. 28: Assembly of TGC sectors, photogrammetry of the TGC1 in place and permanent survey points.

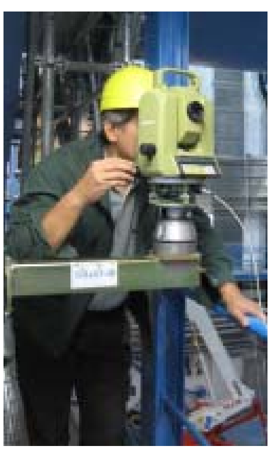
Monitor the movement of the assemblies – extensions of BCAM lines

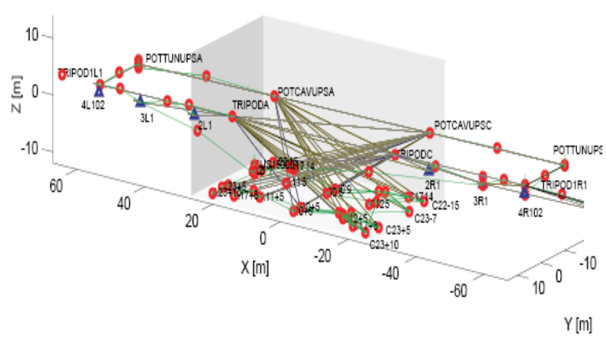


The bed-plate hydrostatic system, sensitive to relative vertical movements at some microns level, monitor permanently longitudinal and transverse inclinations plus changes in vertical positions of the whole barrel toroïd with respect to the gravity and the water plane. Two sensors installed in proved stable areas are the datum references. An expert and client mode for visualization of the HLS results is being prepared and will be logged in a data base. The system is combined with the standard leveling of the floor and linked to the low-betas Qpoles [12].

Fig. 29: Layout of the bed-plate HLS and sensor

The regular measures from the cavern reference network on the elements monitor their radial movements. The space limitations, the confined working conditions, the installation of detectors and services masking views plus the deformation of cavern structures, make that the initial network degrades and is measured more and more under rather incomplete and quite poor configurations. An adaptive Kalman filter approach is used to analyze the networks as a kinematics system in such a way that the primary high network reliability is maintained and the point deformations is included in the model [13].





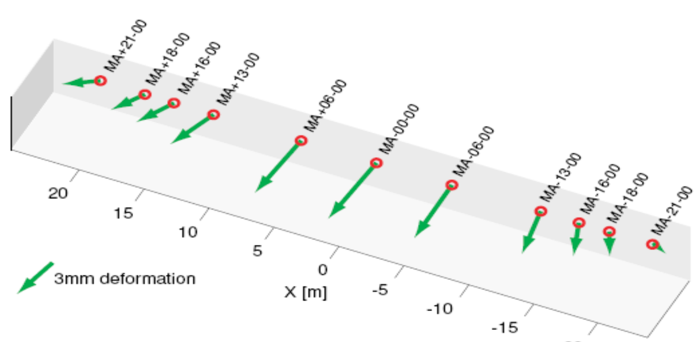
$$x(t_i) = x(t_{i-1}) + \Delta t_i \cdot \dot{x}(t_{i-1}) + \frac{1}{2}\Delta t_i^2 \cdot \ddot{x}(t_{i-1}) + w(t_{i-1})$$

$x(t_i)$ ... position at time t_i

$\Delta t_i = t_i - t_{i-1}$

$w(t_{i-1})$ ... random noise

Fig. 30: Station and part of the reference network, Kalman filter basis, USA wall deformation over 3 years.



The Kalman filter approach permits to deal with incomplete network measurements and to give a correct identification and prediction of point's movements.

A project of extending and adapting the BCAM lines that were used for the positioning of the EBA/ECA and EBC/ECC with respect to the tile barrel [14] is being studied. The BCAM itself is calibrated with respect to its proper reference plate that can be surveyed with respect to the geometry of the element to which it is attached and to the Atlas reference system. BCAM and plate are mounted to an adjustable support. Therefore relative positions of elements plus their locations in the experiment system could be monitored and recorded as on-line position data. The project aims to include the EBA/ECA, EBB/ECB, EBC/ECC, the JDs and the SWs and would consist in three main lines at about 90 degrees, plus several dual BCAMs and retro corner prisms possibly.

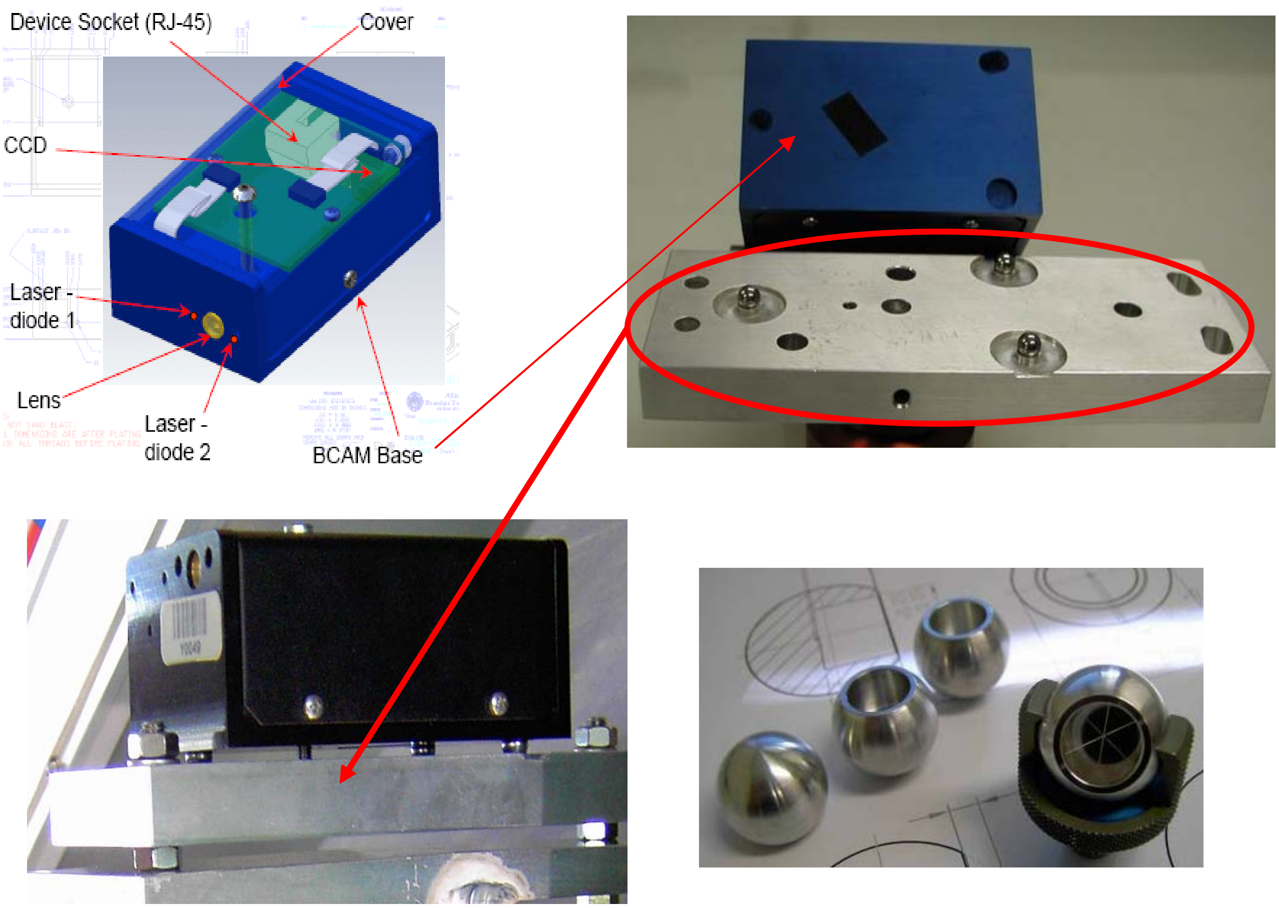


Fig. 31: BCAM system, reference plate, support and corner prism.

Survey documentation and reports of measurements, project AtlasSurvey3D

All the communications (TMB, ad-hoc meetings, [15]) on survey in Atlas can be found in the EDMS TS-SU Large Scale Metrology Web Navigator under Id: CERN-0000003473. The documents of survey measurements are created via this navigator and edited in the main EDMS Atlas Web Editor under Id: ATL-0000007362. The description detector by detector, the structure and the procedure of approbation have been established by the Atlas Technical Coordination and can evolve at request [16].

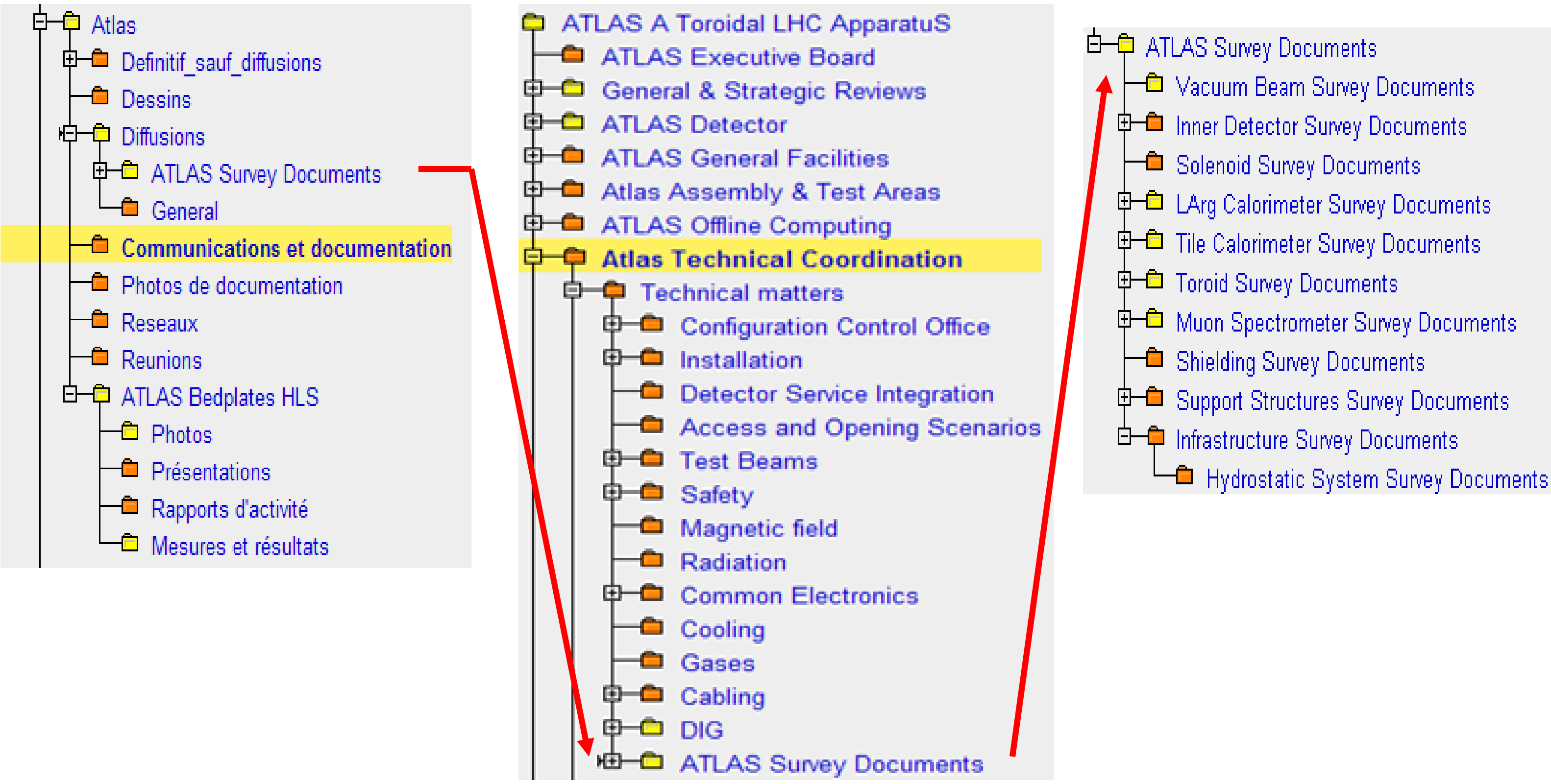


Fig. 32: Atlas Survey Documents - TS-SU and ATLAS EDMS structures

The project AtlasSurvey3D is a survey database for the experiment. The survey data information is stored inside the Technical Coordination 3D detector description Oracle tables. An interface using AtlasEditor3D for histograms representation and data extraction is available and used to monitor displacements of the sub-detectors from their nominal position in the ATLAS reference system. The first application was done for the tile barrel modules and will continue for the end caps and the LArg vessels [17] and [18].

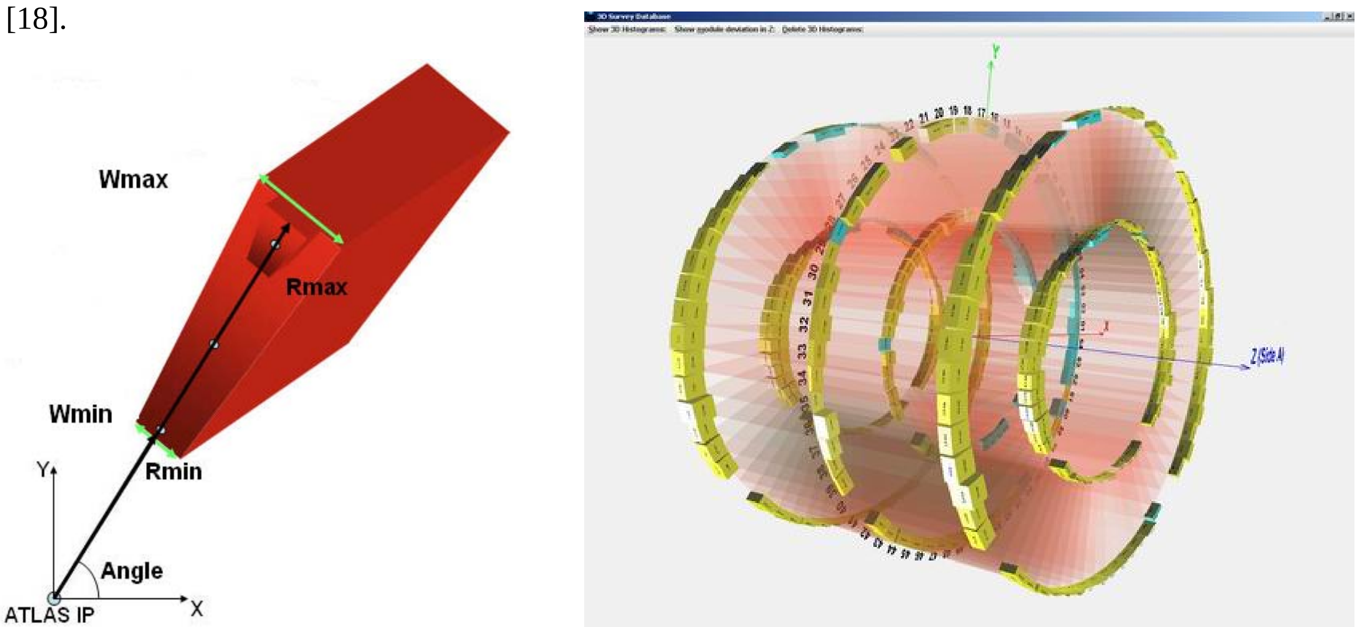


Fig. 33: Parameters description and 3D Tile barrel modules survey database

References:

[1] C.Lasseur: https://edms.cern.ch/file/394608/1/TMBCL0603.pdf
[2] C.Lasseur: https://edms.cern.ch/document/811822/1/TAB3
[3] C.Lasseur: https://edms.cern.ch/document/330354/1
[4] D.Lissauer: https://edms.cern.ch/file/394608/1/PLACEMENTDL0702.pdf
[5] G.Bachy and all: https://edms.cern.ch/document/314946/1
[6] J.C.Gayde: https://edms.cern.ch/document/780077/1
[7] C.Lasseur and all: https://edms.cern.ch/document/381590/3
[8] A.Herty: https://edms.cern.ch/document/682138/2
[9] M.Hatch and all: https://edms.cern.ch/document/320043/1
[10] D.Mergelkuhl: https://edms.cern.ch/document/674092
[11] A.Herty: https://edms.cern.ch/document/724599/1
[12] J.C.Gayde and all: https://edms.cern.ch/document/742398/1
[13] A.Lippisch: https://edms.cern.ch/document/830744/1
[14] J.C.Gayde: https://edms.cern.ch/document/752854/1 and https://edms.cern.ch/document/753329/1
[15] D.Lissauer: https://edms.cern.ch/document/579625/1
[16] C.Lasseur and all: https://edms.cern.ch/document/769369/6
[17] K.Pommes and all: https://edms.cern.ch/document/804033/1
[18] J.Molina-Perez: http://atlassurvey3d.web.cern.ch/AtlasSurvey3D/