Inner Tracker Survey Strategy

Note

Issue:	1
Revision:	0
Reference:	LHCb-2008-068
Created:	December 17, 2008
Last modified:	December 17, 2008

Prepared by: Géraldine Conti [a], Sandra Berni [b], Marc-Olivier Bettler[a], Frédéric Blanc[a], Jean-Christophe Gayde[b], Christian Lasseur[b], Mihn Tam Tran[a]

[a]EPFL, Switzerland

[b]BE/ABP group, CERN

LHCb-2008-068
17/12/2008

Abstract

In the present note, the survey strategy and methods applied to the Inner Tracker sub-detector are described.

Contents

Acknowledgment

We would like to thank Rodolfo Gonzalez[a] for his work in the LHCb cavern regarding the preparation of the IT stations for the survey measurements (installation of the survey targets), as well as his help for the alignment of the stations once surveyed. We also thank André Froton[b] and Jean-Noel Joux[b] for their contributions to the Silicon-sensor survey measurements.

1 The Inner Tracker Survey Strategy

1.1 The IT sub-detector

The tracking sub-system of the LHCb experiment used to reconstruct the trajectories of charged particles and measure their momenta is composed of four planar tracking stations (TT, T1-T3) (Fig.1). The T1-T3 tracking stations located just behind the magnet employ two detector technologies : the *O*uter *T*racker (OT), using straw-tube drift chambers, covers the regions away from the beam pipe, whereas the region around the beam-pipe with the highest particle density is covered by the *I*nner *T*racker (IT) containing silicon microstrip detectors [1]. About 20% of all charged particles produced close to the interaction point, and which pass through the tracking station, will pass through the IT area.

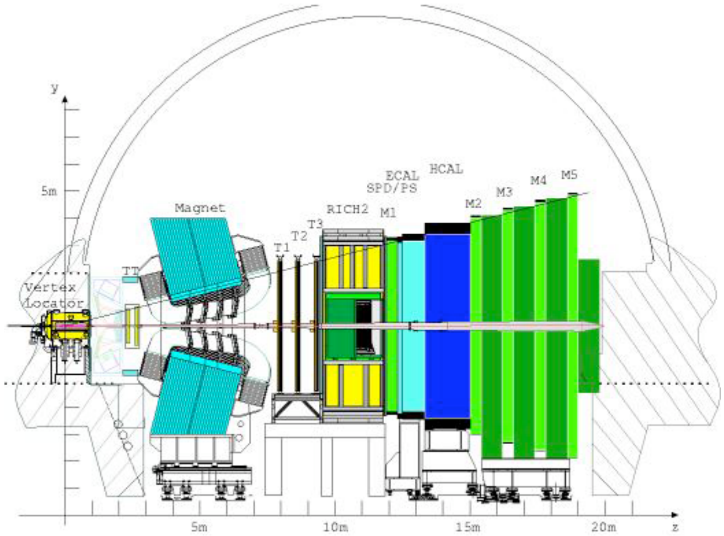


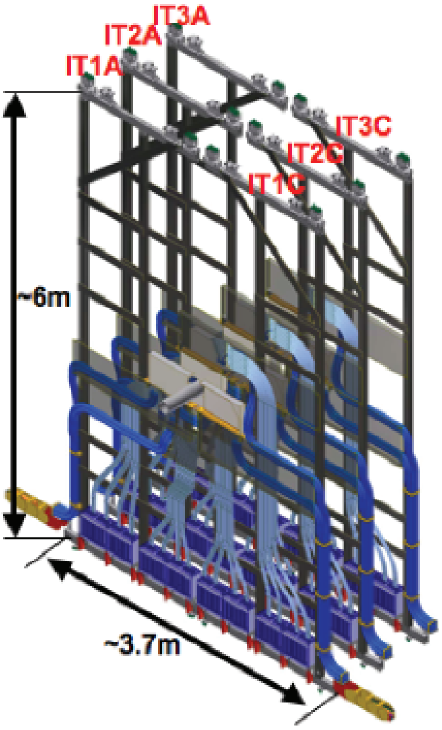
Figure 1 Sideview of the LHCb spectrometer. The tracking sub-system is composed of the *T*rigger *T*racker station (TT) and the T1-T3 stations where the OT and IT sub-detectors are located [1].

The IT sub-subdetector is part of the T1, T2 and T3 tracking stations. These station are placed at equidistant positions along the beam line inbetween the downstream area of the magnet and the entrance window of the RICH2 (Fig.2) .

The half-frames on the *C*ryogenic side are called IT1C, IT2C and IT3C, whereas the half-frames on the *A*ccess side are called IT1A, IT2A and IT3A. They are made of Glass-Carbon fibre pillars (section 76 x 76 mm^2, thickness 3.2 mm) and very light Aramid honeycomb plates (thickness 8mm) covered by 0.5 mm Carbon fibre skins.

The half-frames are hung on the “Inner Tracker rails” of the so-called *Amstel Bridge* and guided on rails on the bottom. As the length of the rails does not allow to have a good guiding of the frames, four precise guiding rails (with machining precision: μm) have been added on each rail near the end position of the half-frames. When approaching their end positions, the left and right top trolleys of each half-frames get engaged on these precision rails and the precision of the location is then better than 200 μm in the z direction.

In each tracking station, four detector boxes are hung on the Carbon fibre - Aramic honeycomb plates and cover a cross-shaped area of 1.3% around the beam pipe of about 120cm wide and 40cm high (Fig.3). The boxes are called ”Top Box”, ”Bottom Box”, ”A Side Box” or ”C Side Box”, depending on their position with respect to the beam pipe. Top Boxes are mounted on the frames upside down compared to the other IT detector boxes, such that readout hybrids, cooling plate and box mechanics face away from the beam pipe (Fig.3). The Carbon fibre - Aramic honeycomb plate of the C-side half-plane is connected to the pillars of A-side and the two lower plates are also connected.



	Zmin (cm)	Zmax (cm)
IT1	767.3	782.8
IT2	836.0	851.5
IT3	905.0	920.5

Figure 2 View of the IT1A, IT2A, IT3A and IT1C, IT2C, IT3C half-frames and z positions of the frames.

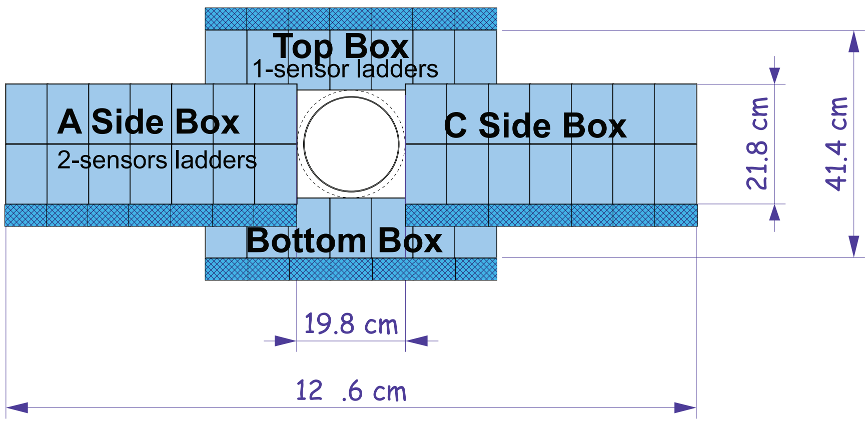


Figure 3 Cross-shaped area around the beam pipe covered by the IT detector boxes.

An IT detector box contains four detection layers of Silicon in the orientation 0°, 5°, -5°, 0°, called respectively X1, U, V and X2. Each layer contains seven Silicon-sensor modules, which are fixed on one of the two cooling rods (Fig.4). Two types of modules are used : One-sensor ladders (11cm long) for the Top/Bottom boxes and two-sensor ladders (22cm long) for the A/C Side boxes (Fig.3).

To ensure full acceptance coverage, adjacent ladders overlap by a few mm, resulting in an alternation of modules placed in a "forward" (completely visible) or "backward" (partially hidden by the "forward" modules) position inside the layers (Fig.5). X1 and V layers have "forward" modules at their two extremities, four in total over seven modules. X2 and U layers have "backward" modules at their two extremities.

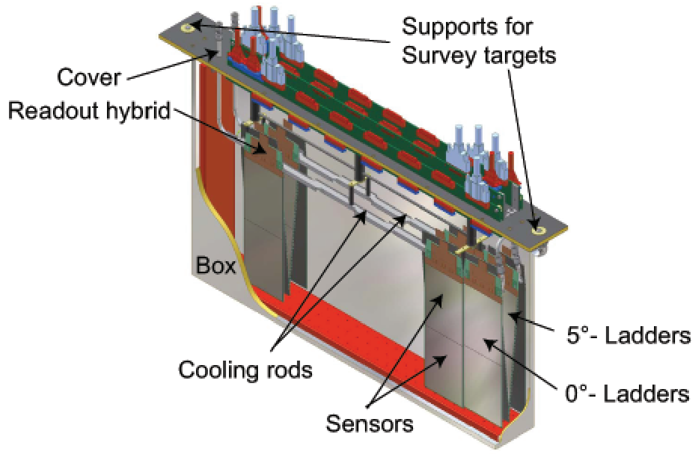


Figure 4 [1] IT detector box containing four detection layers of seven ladders. The two external layers have vertical detection cells and the two internal ones have detection cells rotated by an angle of 5°.

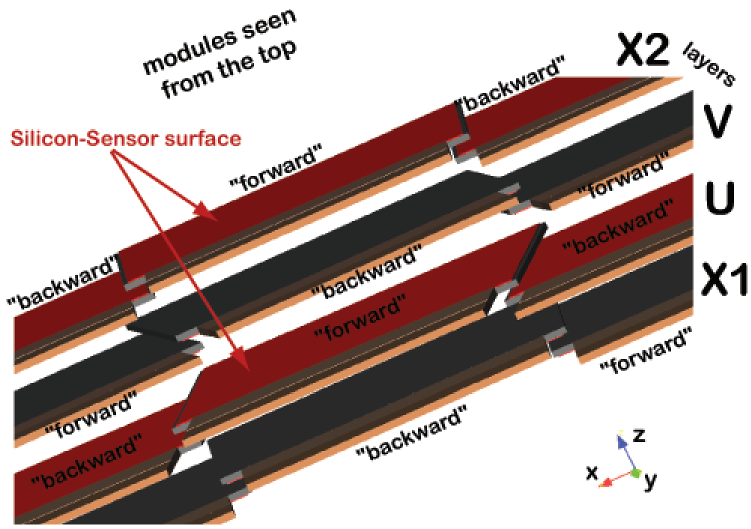


Figure 5 Forward and Backward positions of the modules inside the layers.

1.2 The Survey Measurement Strategy

The goal of the IT sub-detector survey is to align the silicon microstrip sensors of the ladders as close to their nominal values as possible. Measurements at different levels were performed :

1. The IT Silicon-sensors Survey measurements (Section 2) give the positions of targets printed on the sensors with respect to a target located on the detector box cover.
2. The same target has also been visualised during the IT Frame and Detector Box Survey in the UX-85 cavern (Section 3), when the positions of the IT detector boxes on each frame were measured and compared to their nominal values.

From the survey measurements, a first corrected description of the IT sub-detector geometry can be provided for the LHCb software [2].

1.3 Survey Measurement Methods

1.3.1 Theodolite Measurements

A theodolite (Fig.6, left) measures horizontal and vertical angles from the station where it is placed (Fig.7) to the observed target (Fig.6, right). In addition, some theodolites - called total stations - equipped with a distancemeter are also able to measure distances between the station and the target. Note that, due to the fact that the measurement is made point by point and takes time, the theodolite station and the surveyed object must be stable.

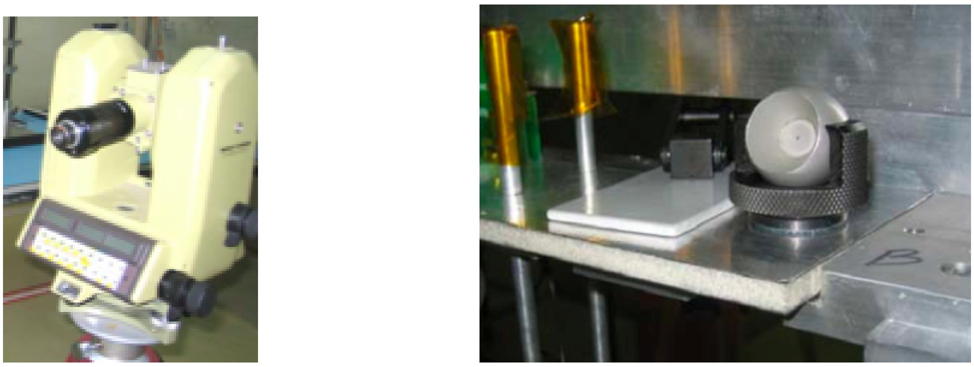


Figure 6 Leica T3000 Theodolite and standard CERN survey target.

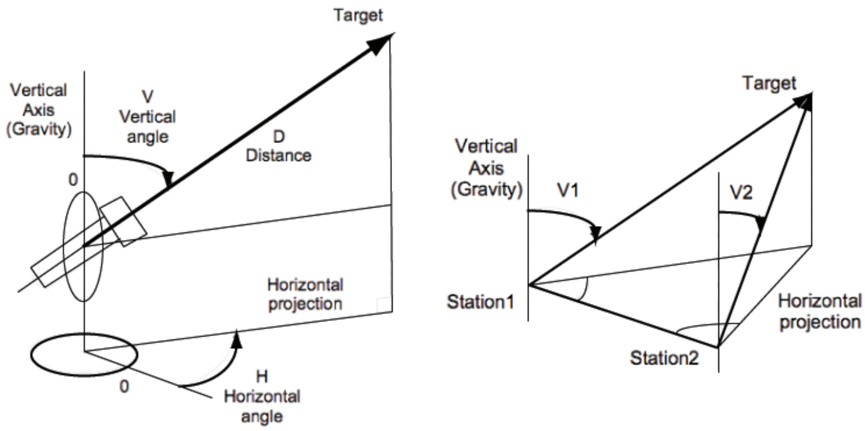


Figure 7 Theodolite measurement basics.

The 3D coordinates of the observed target are determined :

1. By triangulation (Fig.7, right) using only the horizontal and vertical angles observed from different stations, a condition being that at minimum one distance between two points is known in the model to fix the scale. This measurement is slightly redundant as four angles (two horizontal & two vertical angles) are observed for three unknown variables (x, y and z).
2. By polar coordinates (Fig.7, left) from the station using horizontal angle, vertical angle and distance observations. In this case, there is no redundancy.
3. When possible, 1. and 2. are combined from several different stations to get good redundancy.

For the IT survey, types 1. and 2. of 3D coordinate determination methods are used. The first one is used in the case of the IT Silicon-Sensors Survey in a clean room (section 2), the second one for the positioning of the IT detector boxes in the cavern (section 3).

Generally, accuracy in the range 0.2 to 0.5mm at 1σ level can be obtained for the measured point coordinates. It strongly depends on the way the theodolite is used to minimize the instrumental errors, the quality of the targeting, the configuration and the environmental conditions. In some cases, the accuracy can be improved. In the IT Silicon-Sensor case, as the survey was performed in excellent conditions (clean room, stable temperature, good lightning) using a method which minimize mechanical and instrumental errors, the accuracy was improved up to 0.05mm (section 2).

1.3.2 Photogrammetry Measurements

Close-range photogrammetry relies on the reconstruction of an object (in IT survey : a target) simultaneously from at least several images (Fig.8). Different and best possible perspectives ensure a suitable geometry of intersecting rays. The photogrammetric network is reconstructed from the bundle of ray. The internal parameters of the camera and the object coordinates and the orientation parameters of the network are estimated simultaneously in a common process called bundle adjustment [3].

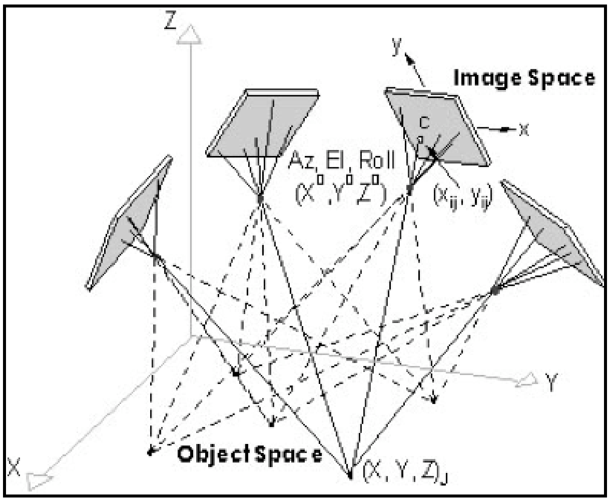


Figure 8 Photogrammetry measurement basics.

In the IT half-frame case, the 3D coordinates of the photogrammetric targets are determined from a hundred of pictures taken from different points of view by a Nikon D2X digital camera (Fig.9) connected via WiFi to a portable PC. The AICON 3D-Studio software package is used for data taking, image processing and bundle adjustment. Accuracy in a range 0.03mm to 0.5mm can be expected depending on the object size (from some decimeters up to more than 20m) and working conditions. For the IT frame measured in opened position, an accuracy of 0.1mm at 1σ level was obtained for the point coordinates in the object space.

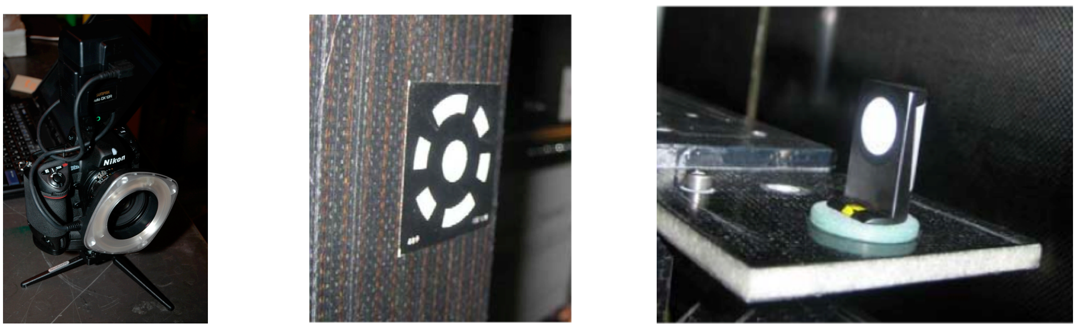


Figure 9 Camera, coded and non coded targets used for the photogrammetry measurements.

This method is applied in the LHCb cavern to determine the relationship between the frame fiducial marks and the IT detector boxes positions (subsection 3.4).

2 IT Silicon-sensors Survey in a clean environment

Eight fiducial marks - crosses with 0.2mm long branches - are etched on each Silicon-sensor (Fig.10, red squares). To ensure a full area of detection, the modules overlap by a few mm inside a layer. On the Silicon-sensors placed in a forward position, the four targets at the corners of the Silicon-sensor have been surveyed, although all of them were visible, but this has been decided sufficient to obtain the information about the position of the Silicon-sensor with a very good accuracy. On the Silicon-sensors placed backwards, the two visible targets placed in the middle of the Silicon-sensor were surveyed, except for the ladders placed at the extremities of the X2 layer where four targets were visible. No measurements could be performed on the U and V internal layers, hidden by the external X1 and X2 layers. An accuracy better than 0.1mm was required for the two coordinates in the Silicon Sensor plane, this accuracy requirement being relaxed in the direction perpendicular to the sensor (corresponding approximately to the LHCb z coordinate in the experiment).

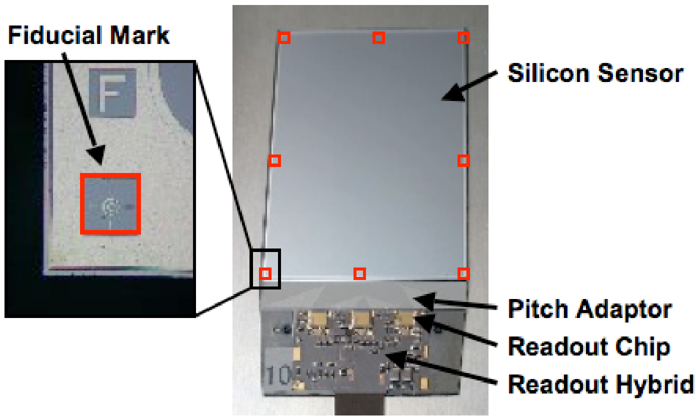


Figure 10 Cross-shaped fiducial marks locations (red squares) on the sensors.

The IT Silicon-sensor survey is performed in a clean environment by two electronic theodolites of high precision LEICA T3000 equipped of a panfocal telescope. The instruments are installed on tripods fixed to the floor and are working simultaneously (Fig.11). Neon lights are used to ease the detection of the fiducial marks without heating locally the room air to avoid pointing errors due to air turbulences. Before surveying, the horizontality of the cover is checked with a bubble level (precision of 0.3mm/m) (Fig.12).

To get the reference direction, the theodolites point to each other using a special process in order to align their optical axis. Each fiducial mark is then observed from both theodolites and then coordinates are calculated using triangulation. As triangulation consists in angle measurements only, at leas one distance has to be added in the process to fix the scale (subsection 1.3.1). In IT Silicon-Sensors survey case, in order to avoid any theodolite centering error, these distances are not observed between the two tripods before installation of the instruments but they are given by the measurement of targets installed on four invar or carbon fibre scales bars (Fig.12) observed simultaneously with the IT Sensors . The distance between the scale bar targets was calibrated on a CMM machine in the CERN Metrology Lab with an accuracy better than 20μm.

Due to the small size of the cleanroom, the two external layers of the IT box (layers X1 & X2) are measured independently. A rotating frame to be placed on a support table stabilized with diagonal bars was designed in order to improve the accuracy of the relationship between the two sets of measurements. This relationship is obtained after a 3D best fit transformation using six common targets visible in the two positions of the rotating frame and placed on the sides of the rotating frame (Fig.12). The final coordinates are calculated in a local IT-Silicon-Sensor coordinate system linked to the object.

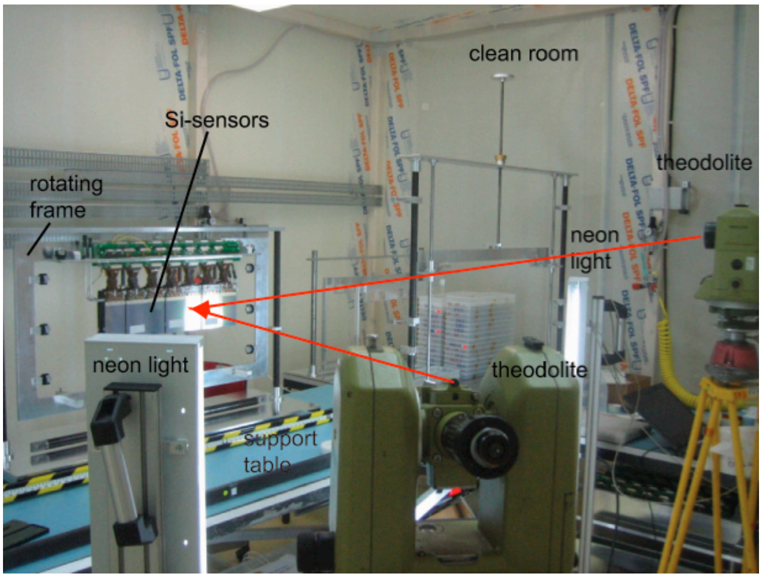


Figure 11 Survey measurements with two theodolites in a cleaned environment. Neon lights are used to ease the detection of the fiducial marks on the sensors.

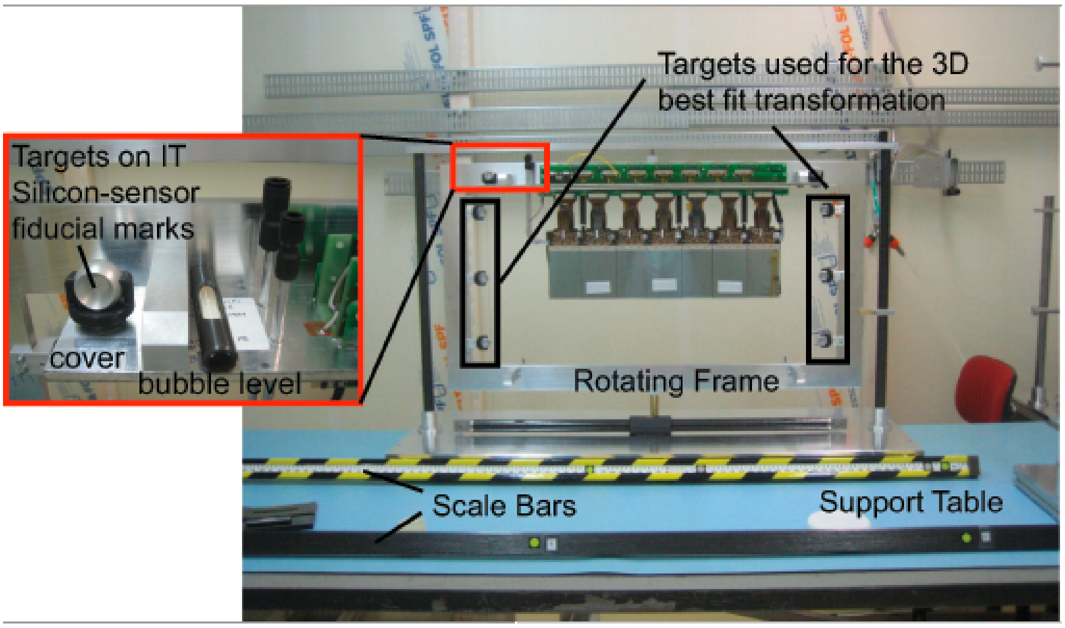


Figure 12 Six common targets are placed on the rotating frame to get a redundant relationship between the measurements of the layers X1 & X2. Special scale bars are used to provide the global scale of the system. Before the survey measurements, the cover is checked to be horizontal with a bubble level.

A first test of the IT survey procedure was performed on October 2006, which gave an accuracy of 0.05mm for the coordinates of the detector crosses in the sensor plane [4]. For the final IT-sensors survey measurements, the typical accuracy obtained is :

- 0.05mm for the coordinates on detector crosses
- 0.10mm for the SU targets
- 0.20mm for the geometrical link between the two sides

The survey reports for all the IT detector boxes can be found in the EDMS documents [5] or in the Annexe of [2].

3 IT Frame and Detector Box Survey in the LHCb cavern

The measurements have proceeded according to the following steps :

1. Geometrical validation of the IT E half-frames structures and relationship between the IT E half frame fiducial marks (Subsection 3.2).
2. Check of the verticality and vertical position of the IT E frames structures (Subsection 3.3.)
3. Determination of the relationship between the frame fiducial marks and boxes position (Subsection 3.4).
4. Final determination of the position of the IT detector boxes (Subsection 3.5).

3.1 LHCb Survey and Physicist Coordinate Systems

The LHCb Survey Coordinate System and the LHCb Physicist Coordinate System have the same origin, at the interaction point (IP). They also have colinear horizontal components, respectively called Y SU and X PHYS. The Survey Coordinate system is characterized by its Z SU vertical axis, while the Physicist system has its Z PHYS component along the nominal beam line (Fig.13).

LHCb Survey Coordinate System :

- Origin : Interaction Point (IP)
- X SU axis : beam projection in the horizontal plane, positive from the cavern to the IP (from RB86 to RB84)
- Y SU axis : horizontal, perpendicular to the X SU Z SU plane, positive to the LHC centre (from A side to C side)
- Z SU axis : vertical, positive to the top

LHCb Physicist Coordinate System :

- Origin : Interaction Point (IP)
- X PHYS axis : perpendicular to the nominal beam line, horizontal, positive from the C side to the PZ side (from C side to A side)
- Z PHYS axis : along the nominal beam line, positive from the IP to the cavern (from RB84 to RB86)
- Y PHYS axis : perpendicular to the X PHYS - Z PHYS plane, positive to the top

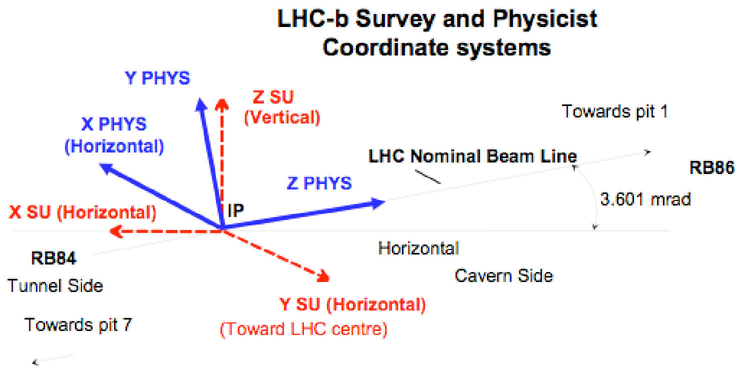


Figure 13 LHCb Survey (red) and Physicist (blue) Coordinate Systems.

3.2 Geometrical validation of the IT E half-frames structures and relationship between the IT E half frame fiducial marks

The aim of this survey is the geometrical control of the IT E half frames with respect to their design. This measurements include the fiducial marks on each IT half-frame : seven (F1-F7) on the half frame beams, one on each the *T*op (CT) and *B*ottom (CB) *C*arbon Plates (Fig.14, red circles), as well as characteristic half frame points on the IT detector box support brackets (Bi) and close to the rollers.

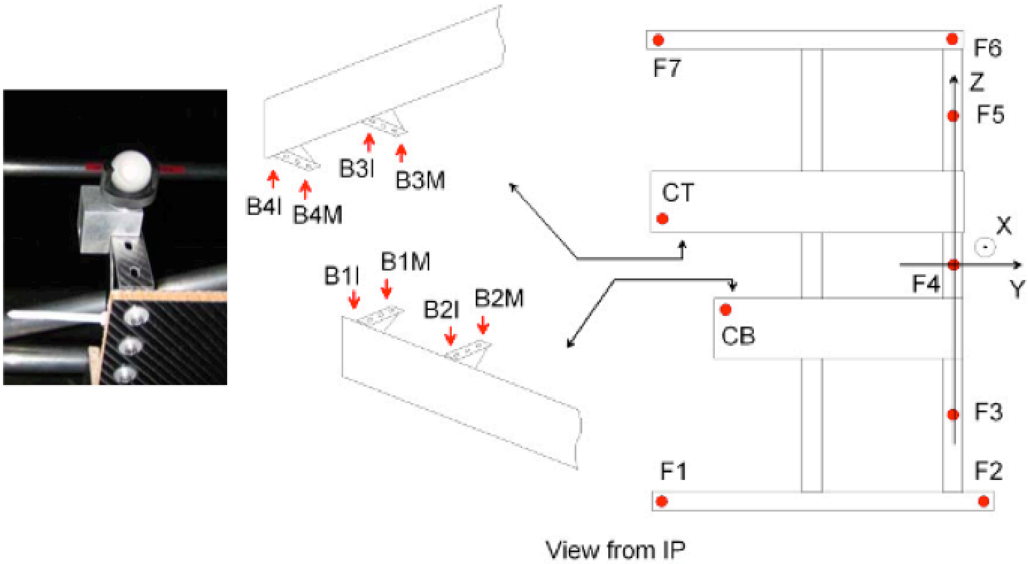


Figure 14 IT half-frame with fiducial marks (red circles) and IT detector box support brackets.

Theodolite measurements are performed on special targets (Subsection 1.3.1) placed on purpose in the fiducial marks. The coordinates are given in a local SU system linked to each IT E half-frame (Fig.13).

3.3 Check of verticality and ZSU position of the IT E frames structures

Once the real shape of the IT E half frame is known, it must be rolled in the precision rails and adjusted for their position along the ZSU axis and their orientation in the XSU-ZSU plane. Before February 2007, these operations were started for IT3 half frames [6] using theodolites placed inside the magnet while the beam pipe and its protection box were not in place. The measurements were done on the half frame fiducial marks and for the first time on dummy IT Silicon-Sensor box covers installed [a] .

These measurements led to the discovery of a mis-mounting of the rolling carts which has, as a consequence, an inclination of the frame plane with respect to the vertical plane. Once fixed, the measurements also allowed to adjust the position along the ZSU axis of the frames by tuning the attachment of the frame onto the upper rolling carts.

3.4 Determination of the relationship between the frame fiducial marks and boxes position

Once the beam pipe and its first version of protection were in place, the theodolite measurement of the IT E half frames equipped with dummy sensor cover was stopped because it was unsafe to set the theodolite in the magnet and a part of the reference points became invisible or not accessible.

At this time, it was decided to split this adjustment in two steps :

[a] As the IT detector boxes were not finished at the time when the first frame measurements had been performed, those were substituted by dummy boxes (IT box covers) to measure the coordinates of the targets located on them.

1. A photogrammetric measurement of all the reference points was done on the completely opened IT half frames to get the mapping of the E frame structure including the IT dummy covers of the detectors (Fig.15). As there were no stable positions to install theodolite stations at different levels in front of the opened half frame, the photogrammetric method was chosen.

2. Then a theodolite measurement of the visible targets were performed when the IT half frame was almost in closed position, the rolling carts being engaged on the precision rails.

To get the complete mapping of the E frame in closed position, a best fit 3D transformation was calculated using the full set of point coordinates measured in open position. The transformation parameters were calculated using two best fits of the common points measured in both open and closed positions by photogrammetry and by theodolite.

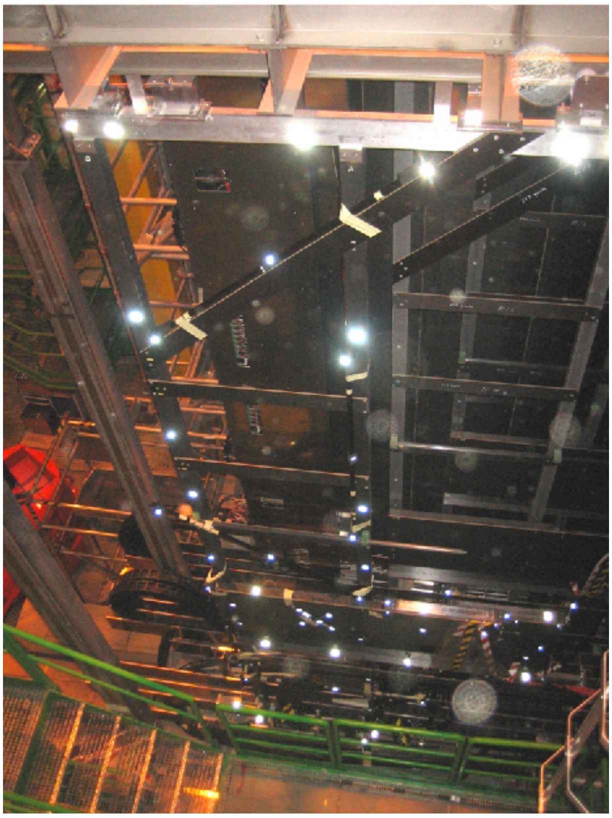


Figure 15 Photogrammetry measurements of the reflecting photogrammetric coded and not coded targets on the IT1A half-frame [7].

The photogrammetric measurements started in February 2007, but were not conducted to their completion due to several factors :

- The positioning of the half frames was not accurately reproducible [8] because of a weak positionning element of the frame, which was later replaced with a stronger one (Fig.16).
- The working conditions to make photogrammetric measurements became not optimal due to co-activities and work on other sub-detectors in the LHCb cavern close to the IT frames.

The decision to work directly on the position of the boxes while accepting the defaults of the frames has led us to the final determination of the position of the IT detector boxes.

3.5 Final determination of the position of the IT detector boxes

The weak positioning element has been changed to a stiffer one (Fig.16). In the mean time, a new beam pipe protection with new supports and sliding protection covers was designed. This was a common effort from IT/OT/Survey/Design office to allow the work on completely closed IT or OT frames. The design was optimised to allow IT survey from the wall in RICH1 region, in order to minimise the access inside the magnet.

Figure 16 Weak positioning element (left) and the stiffer one that has replaced it(right).

The final step is to measure by theodolite the IT detector boxes once the frame is completed. This is achieved from both sides of the RICH1 region, with the RICH1 being completely opened or closed during the measurements. Multipoint target bars have been designed because of lack of visibility in the LHCb cavern and in order to obtain information about the rotation around the YSU axis, information that is indeed missing if we take into account only two points on the covers.

- The multipoint target bars used are equipped with retroreflective stickers, even though the precision of distance measurement is worsened from 0.2mm for a standard glass reflector to 0.5mm. This was accepted mainly for safety reasons. In fact, the use of standard glass reflectors means an access is needed to put and remove the target for each individual point measurement. This is not allowed because the frames are closed around the unprotected region of the beam pipe. In addition, due to the IT survey configuration, this change in precision influences mostly the coordinate in the beam direction, for which the demanded accuracy is relaxed. The retro-reflective target choice makes also the multipoint bar design easier and cheaper.
- Three types of multipoint bars, upon which the target stickers are glued, were produced : 150mm-bars with three target stickers at 30,100 and 140mm (Fig.17); 500mm-bars with four target stickers at 30, 270, 400 and 490mm (Fig.18); 600mm-bars with three target stickers at 510, 560 and 590mm (Fig.19). The target centres are aligned on the supports. The distances between the targets are known with an accuracy better than 0.1mm. More than the two needed targets (three or four) are used to get some redundancy.

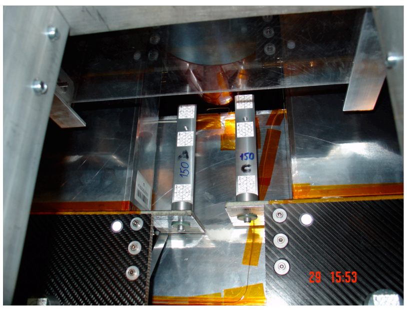


Figure 17 150mm-bars with three target stickers at 30,100 and 140mm.

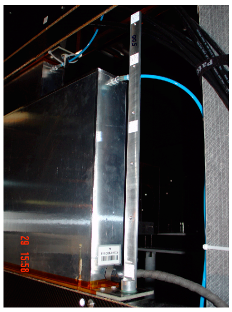


Figure 18 500mm-bars with four target stickers at 30,270,400 and 490mm.

The whole station is surveyed a first time in the final closed position (Fig.20). From the method of calculation of Euler angles in the 321 representation and offsets developped for the analysis of the survey measurements, which is presented in [2], corrections to be applied at the level of the brackets supporting the boxes are calculated. The final survey measurement of the station is then performed and the results are presented in the EDMS documents [9] and in the Annexe of [2] . The accuracy of the target survey measurements in the LHCb cavern is ±0.5mm for the YSU and ZSU coordinates, and ±1mm for the XSU component. No reproducibility tests have been performed due to a lack of time with respect to the LHCb schedule of June 2008.

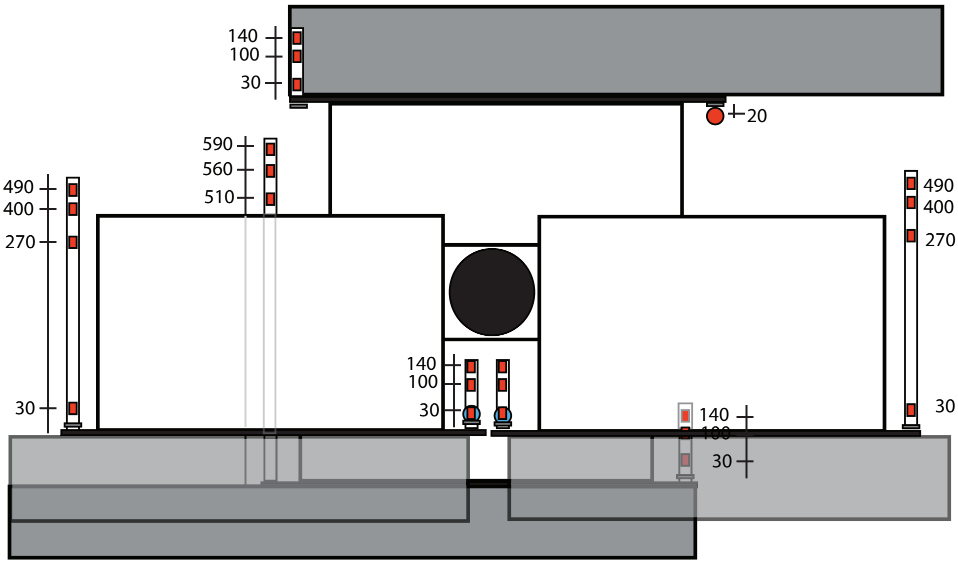


Figure 19 Targets positions used for the survey measurement of the detector boxes in the LHCb cavern.

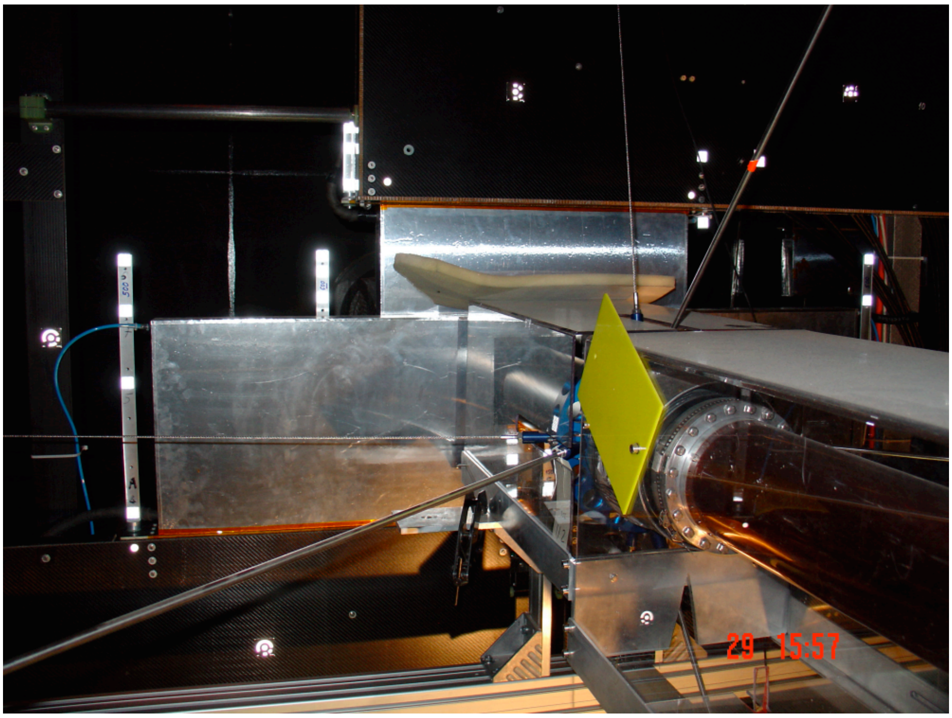


Figure 20 Survey of a whole station in the final closed position from the RICH 1 region.

3.6 External constraints on the IT sub-system

3.6.1 Measurements of the Magnetic Forces applied on the Bridge

During the LHC runs, the LHCb magnet will not be kept always at full field, but the field will be reduced to some intermediate values after each fill of the accelerator with protons and then ramp up to full field. As the LHCb magnet is brought up to full field, it is not excluded that sub-detectors close to the magnet will slightly shift [10].

The Amstel bridge (Fig.21), on which the IT stations are hanged, is 20m long and 10m high and is made of stainless steel, as well as are the pillars supporting it. The aluminium platform, on which the pillars are standing, is called table and contains three sets of three rails, where the first one is always used for the support structure of the Inner Tracker. It is not excluded that some of the joints of the bridge could have been magnetised during the assembly procedure. Moreover, in order to give to the bridge more rigidity along the beam direction, it had been fixed to the magnet by means of two stiffening bars. The attachement point was selected as a point where the magnet structure was measured not to move more by more than 1mm, but this had to be checked again.

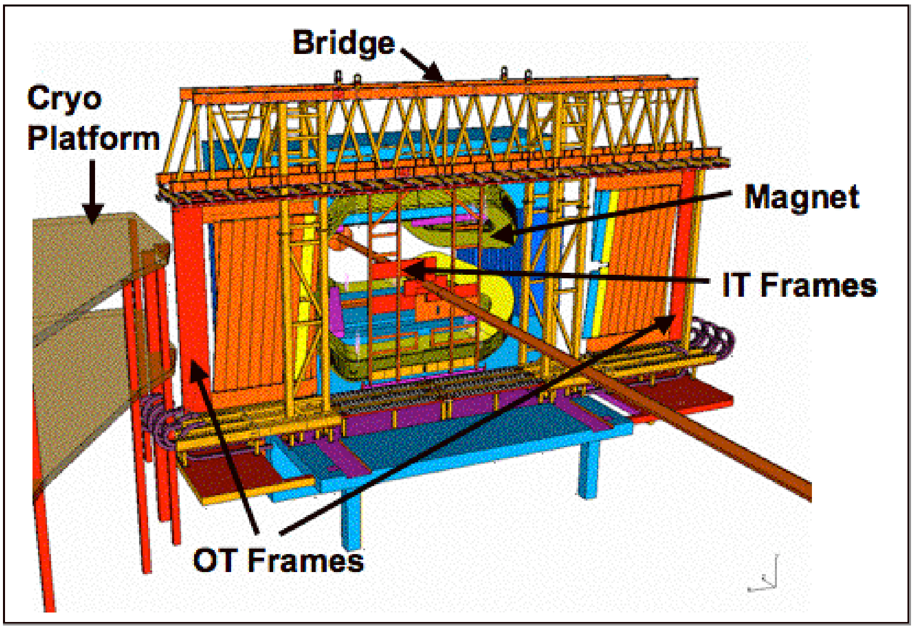


Figure 21 Scheme of the bridge holding the IT and OT frames.

Results [11] show that the maximum absolute value of the movement in the XSU direction is 0.6mm and the one in the ZSU direction is 0.8mm (Fig.22). The accuracy for these measurements is quoted by the surveyors to be of order 1mm because of the measurement conditions (lack of light and large distance between the theodolite and the target). Therefore, it is concluded that the bridge does not move more than 1mm due to magnetic forces applied on it. The surveyors have also observed that the yoke of the magnet does not move when the magnet is on.

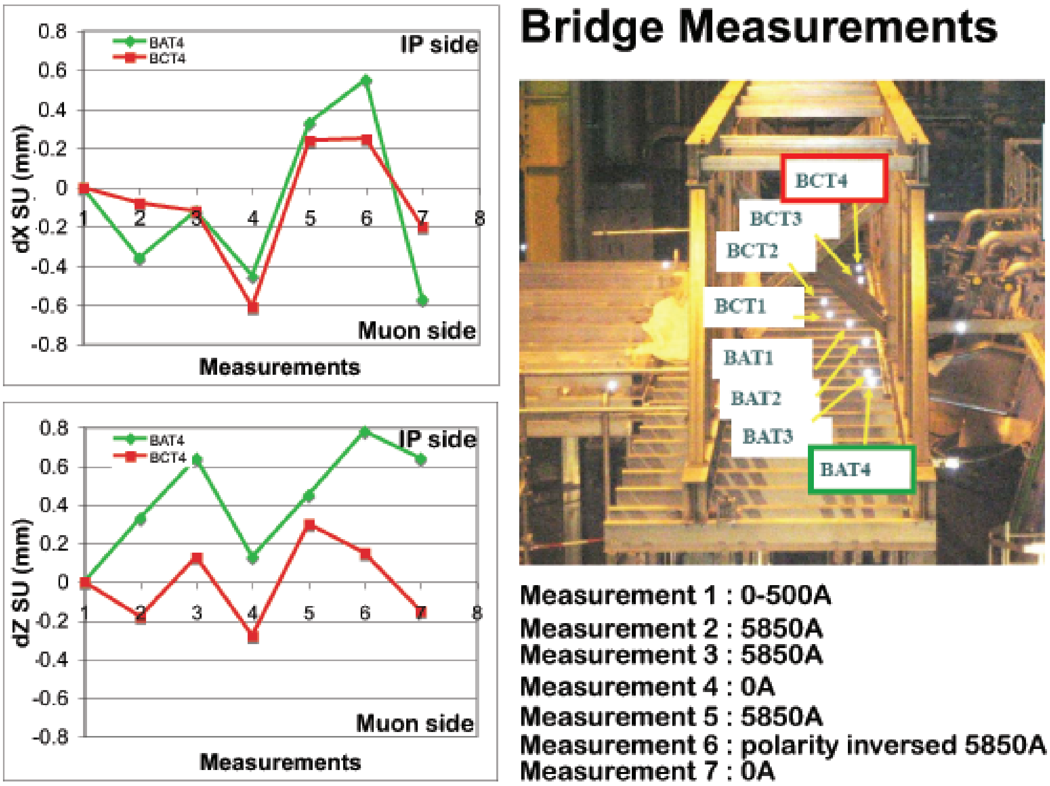


Figure 22 Mouvements in z and y directions of the Amstel Bridge during the magnetic field test [11].

3.6.2 Forces applied on the Bridge by the Outer Tracker sub-detector

During the final measurements of the position of the IT detector boxes, the stations of the Outer Tracker (OT) were in the open position. To estimate the influence on the IT stations of the OT being in its final closed position, a measurement has been performed on the IT1 station. It has been found that the IT1 station went down by 0.4-0.5mm.

The IT3 station is observed to be about 1mm lower than after survey and adjustment. This is probably due to the weight of the OT sub-detector.

4 Positioning process upgrade

In the future, the Inner Tracker (and other LHCb detectors like Outer Tracker) will be opened and closed several times during the shutdown periods. The implementation of electro-optical instrumentation such as BCAM (Brandeis CCD angle monitoring) [12] or 3D precise scanning could be studied to speed up the detector adjustment process and give an eventual possibility of position monitoring.

5 Conclusion

The survey strategy and methods applied to the IT sub-detector have been presented and detailed for the survey measurements of the Silicon-Sensors under clean environment, as well as for the IT frames and the detector boxes in the LHCb cavern. The accuracy of the survey measurements of the Silicon-Sensors within their boxes is ±0.05mm. The accuracy of the measurements in the cavern is of ±0.5mm for the YSU and ZSU coordinates and ±1mm for the XSU coordinate. It has been observed that the magnetic forces on the Bridge do not affect significantly the IT stations position, but the closing of the Outer Tracker sub-system can modify the position of the stations by as much as 1mm. As a consequence of these effects and other mechanical uncertainties, we estimate the alignment determined from the survey measurements in the LHCb cavern to be known within 1-2mm.

In the case of the Inner Tracker, the survey is not only used to position correctly the sub-detector in the LHCb cavern, but the survey values are also used as initial values in the alignment procedure using tracks. The method of implementing them in the LHCb software (321 Euler angle and offset calculations) is described in [2].

6 References

[1] LHCb Collaboration, LHCb Inner Tracker Technical Design Report TDR 008, November 8^{th} 2002

[2] Conti G., Blanc F., IT Survey Measurements Analysis and Implementation in the LHCb Software, LHCb note 2008-069.

[3] Gayde J.C., Humbertclaude C., Lasseur C., Prospects of Close Range Digital Photogrametry in large physics installations August 13^{th} 2001, https://edms.cern.ch/document/321221.

[4] Berni S., Gayde J.C., LHC-b-UX85 Position of Inner Tracker Detector Fiducial Marks, Test on ITD1 Detector, October 26^{th} 2006, https://edms.cern.ch/document/790654.

[5] Berni S., Gayde J.C., Position of Fiducial Marks, Measurement in Clean Room,
LHCb - IT CENTRAL BOX 1 BOTTOM Detector, Box name CB1B - Cover 4TILAUCS00001 May 22^{th} 2007, Version 2, Jan 14^{th} 2008, https://edms.cern.ch/document/848511.

LHCb - IT CENTRAL BOX 2 TOP Detector, Box name CB2T - Cover ITLAUCS000002, Version 3, Jan 14^{th} 2008, https://edms.cern.ch/document/865559.

LHCb - IT CENTRAL BOX 3 Detector, Box name CB3B - Cover 4ITLAUCS000003, Version 2, Jan 23^{rd} 2008, https://edms.cern.ch/document/885230

LHCb - IT CENTRAL BOX 4 TOP Detector, Box name CBT4 - Cover 4ITLAUCS000004, Version 2, Jan ^{14} 2008, https://edms.cern.ch/document/886551

LHCb - IT CENTRAL BOX 5 BOTTOM Detector, Box name CB5B - Cover 4ITLAUCS000005, Feb 15^{th} 2008, https://edms.cern.ch/document/893699

LHCb - IT CENTRAL BOX 6 TOP Detector, Box name CBT6, Mar 6^{th} 2008, https://edms.cern.ch/document/901271

LHCb - IT SIDE BOX A1 Detector, Box name SBA1 - Cover ITLAUCL000001, Version 2, Jan 23^{rd} 2008, https://edms.cern.ch/document/855221.

LHCb - IT SIDE BOX A2 Detector, Box name SBA2 - Cover 4ITLAUCL000002, Version 2, Jan 22^{th} 2008, https://edms.cern.ch/document/892075

LHCb - IT SIDE BOX A3 Detector, Box name SBA3 - Cover 4ITLAUCL000004, Jan 11^{th}

2008, https://edms.cern.ch/document/887469

LHCb - IT SIDE BOX C1 Detector, Box name SBC1 - Cover 4ITLAUCL000007, Mar 28th 2008, https://edms.cern.ch/document/905517

LHCb - IT SIDE BOX C2, Box name SBC2 - Cover 4ITLAUCL000006, Jan 25th 2008, https://edms.cern.ch/document/889841

LHCb - IT SIDE BOX C3 Detector, Box name SBC3 - Cover 4ITLAUCL000003, Version 2, Jan 23rd 2008, https://edms.cern.ch/document/882113

[6] Berni S., Froton A., Gayde J.C., LHC-b-UX85, Inner Tracker, Geometrical control of the IT1C "E" structure, IP side / Cryo side October 18th, 2006, https://edms.cern.ch/document/790118

Berni S., Froton A., Gayde J.C., LHC-b-UX85, Inner Tracker, Geometrical control of the IT2C "E" structure, IP side / Cryo side November 9th 2006, https://edms.cern.ch/document/794872

Berni S., Froton A., Gayde J.C., LHC-b-UX85, Inner Tracker, Position of the IT3A and IT3C "E" structures before adjustment, January 26th 2007, https://edms.cern.ch/document/816280

Berni S., Froton A., Gayde J.C., LHC-b-UX85, Inner Tracker, Position of the IT3A "E" structure, After 1st adjustment, February 1st 2007, https://edms.cern.ch/document/817512

Berni S., Gayde J.C., LHC-b-UX85, Inner Tracker, Geometrical control of the IT3C "E" structure, IP side / Cryo side December 5th 2006, https://edms.cern.ch/document/806184

Berni S., Gayde J.C., LHC-b-UX85, Inner Tracker, Position of the IT3C "E" structure, Before adjustment, February 2nd 2007, https://edms.cern.ch/document/818463

[7] Berni S., Gayde J.C., LHC-b-UX85, Inner Tracker, Photogrammetric measurements of the IT1A "E" structure, March 30th 2007, https://edms.cern.ch/document/834051.

Berni S., Gayde J.C., LHC-b-UX85, Inner Tracker, Photogrammetric measurements of the IT2A "E" structure, April 19th 2007, https://edms.cern.ch/document/839426.

Berni S., Gayde J.C., LHC-b-UX85, Inner Tracker, Photogrammetric measurements of the IT3A "E" structure, May 24th 2007, https://edms.cern.ch/document/847824.

[8] LHCb - UX85 - Inner Tracker, Position of IT1 in closed position, adjustment and open close tests, July 17th-19th 2007, https://edms.cern.ch/document/858931

[9] Berni S., Gayde J.C., LHC-b - UX85 - Inner Tracker IT1 with boxes in closed position after adjustment May 29th 2008, https://edms.cern.ch/document/926156

LHC-b - UX85 - Inner Tracker IT2 with boxes in closed position after adjustment June 3rd 2008, https://edms.cern.ch/document/926742

LHC-b - UX85 - Inner Tracker IT3 with boxes in closed position after adjustment June 4th 2008, https://edms.cern.ch/document/926753

[10] Blusk S., LHCb Alignment Strategy, LHCb-2006-035.

[11] Berni S., Gayde J.C. LHCb- GEOMETRICAL CONTROL, DURING THE MAGNETIC FIELD TEST, October 2007, https://edms.cern.ch/document/874763

[12] James Bensinger, Kevan Hashemi (Brandeis U.), Christoph Amelung, Adriano Garonna, Raphael Goudard, Friedrich Lackner, Christian Lasseur (CERN),
High Precision Optical Instrumentation for Large Structures Position Monitoring : The BCAM System Applied to the CMS Magnet,
9th International Workshop on Accelerator Alignment, IWAA-2006-TH009, September2006