STATUS REPORT ON THE SURVEY AND ALIGNMENT ACTIVITIES AT CERN

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Abstract

The commissioning of the LHC machine has started in the sectors already cooled, and first beams are foreseen for mid 2008. The two injections lines have been tested with beams, and the installation of the 4 detectors is progressing well. If CERN is today mainly occupied by the LHC, several other projects are nevertheless under way. A new injection linac is under study, and above all CLIC studies are taking more and more importance. After a brief status of the LHC machine, which is already presented in other papers, and the status of the 4 experiments ATLAS, CMS, ALICE and LHC-b, this paper describes the LINAC4 project, and focuses on the CLIC studies which are under way in the Survey group at CERN.

THE LHC AND ITS 4 DETECTORS

LHC

The LHC is now in the final phase of its installation, and is moving into the commissioning phase. All the elements have been installed, aligned, and connected. In February 2007 the first of the eight 3.3km long sectors has been cooled down successfully for the first time to 1.9 K, and the alignment of all the elements in this sector have been controlled when cooled.

Now the sector 4-5 is cooled down, and the cooling of four other sectors is under way. It is planed to have the first beams circulating in the middle of this year.

This work is described in [1], as far as the survey and alignment is concerned, and in parallel, the installation and the construction of the four detectors ATLAS, ALICE, CMS and LHC-b is also in its final phase.

After several years of quality controls in the assembly halls at CERN and at the manufacturer's premises, nearly all of the magnetic and detecting elements have been positioned with respect to the common accelerator/ experiment reference system. In spite of the viewing difficulties, the required accuracy has been ensured - geometrical monitoring of the reference frames and structural deformations of critical detectors having been carried out regularly. See Ref [2] and [3]

ATLAS

One of the most spectacular activities in ATLAS is the positioning of the 6 muon end cap big-wheels of 25 m diameter. Photogrammetry (D2X camera with a combination of 17 mm and 24 mm lenses - short recording distances and high accuracy requirement) measurements processed with Aicon/3DStudio), and supplemented by a few long total station distances for scale, provides an overall object accuracy of around 0.2 mm at 1 sigma.

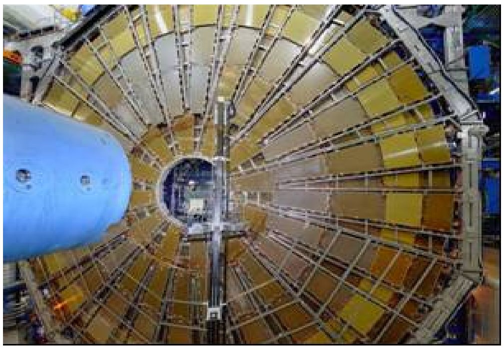

Figure 1: ATLAS muon end-cap wheel

Vertical movements of the central part (8500 T) have been monitored regularly by purely optical direct levelling of the ground and an HLS network located in the experiment support beams bedded in the foundations. This HLS network comprises 8 capacitive sensors that enables both the real-time tracking of any movements during the installation of heavy elements, and the permanent monitoring of the long term stability, with an overall accuracy of around 5 microns all along the nearly 70 m long system surrounding the spectrometer [4]. An heave of up to 1.5 mm due to the hydrostatic pressure was recorded during the first 2 years after the civil engineering completion, a stability within 0.3 mm has been recorded since the assembly of the large pieces.

CMS

The CMS barrel detection systems have been positioned in the cavern. Numerous photogrammetric operations have been completed to provide the spatial coordinates of the barrel muon chambers, the elements of the internal alignment systems, the calorimeters layers and the central tracker which are now in place. A relative accuracy better than 0.2 mm at 1 sigma has been obtained.

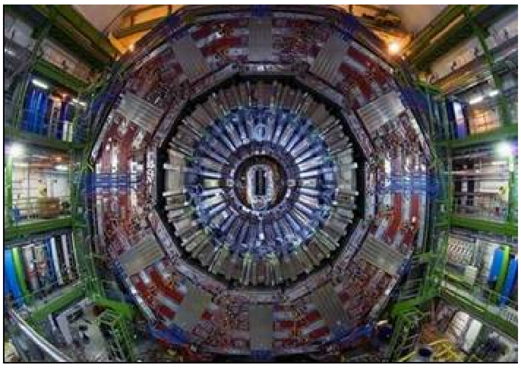

Figure 2: CMS barrel with the central tracker

An HLS network is being installed around the 4 feet of the central wheel of CMS and an HLS sensor is directly connected to the HLS system linking the two separate low-beta triplets in the machine. In this way, any vertical movements of CMS will be recorded with respect to the machine itself. Five deep reference rods have been installed in the cavern floor at different depths in a hole drilled down more than 27 m into the bed-rock. They provide an absolute datum for the future stability measurements of the 14 000 T experiment.

ALICE

The ALICE TPC detector has been positioned inside the large magnet to within 0.5 mm with respect to the main ALICE reference network. Surrounding calorimeter detectors are still being installed in the space frame structure. The stability of the latter under loading tests was regularly monitored via a permanent polygonal-shaped BCAM network (Brandeis Camera Angle Monitor) and cross-checked by theodolites measurements once installed in the magnet so that pre-adjustments of detectors could be taken into account.

Figure 3: TPC and space-frame in the magnet

LHCb

Even if the main configuration of the LHC-B looks like a linear arrangement, the intricacy of the detectors has led to their measurements using conventional and standard three-dimensional techniques, in the very cramped conditions.

Figure 4: Trackers supporting structures

The main reference network has to be adapted continuously so that additional and ad-hoc setting stations have to be created to meet the specific positioning operations. LHC-b is the smallest among the 4 LHC experiments but it contains the more concealed difficulties.

A NEW INJECTOR FOR LHC

With the construction of the LHC collider in its final phase at CERN, a new programme was approved by the CERN Council, in the summer of 2007, with an eye towards the renewal of the injector chain [5].

The approved programme includes the construction of a new 160 MeV H- linac (Linac4), approximately 90 m in length, to replace the present 50 MeV proton linac (Linac2). The TDR [6] for this machine was published at the end of 2006. Design studies will also be made for two further accelerators with a ~4 GeV superconducting proton linac (SPL), and a ~50 GeV synchrotron (PS2), to replace the PS Booster and PS rings respectively. These would in turn provide beam to an upgraded SPS accelerator.

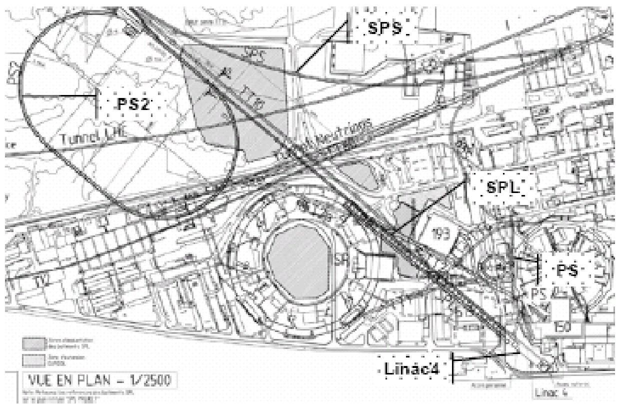

Fig. 5: Provisional layout of the injector complex

Construction of Linac4 and the transfer line to the PS Booster is approved as a high priority project starting in January 2008 and lasting 5 years (2008-12). The requirement of the management is to start the PSB with the beam from the new Linac4 in 2013. To meet this goal, construction is planned to start in the second half of 2008. The location of the Linac (Figure 5) has been chosen to be compatible with both its use as an injector into the PS Booster, and its future use as an injector into the SPL / PS2 accelerators. The new facility includes the tunnel for the Linac itself, together with a surface building to house the klystrons and other infrastructure, and an additional tunnel for the transfer line to connect up to the existing line to the PS Booster.

Having already been involved with the TDR, as well as the new facility and implantation studies, the Survey Group's work for the Linac4 project continues in 2008 with the integration of the survey alignment system into the 3D models of the accelerator and tunnel, the initial metrology work on the first prototype drift tubes, and the provision of coordinates, in the CERN Coordinate System, of points to control the civil engineering works. Construction of the new facility is expected to finish in 2010, and the installation of the machine will be in the second half of 2011 / start of 2012.

Following the great success of the as-built measurements in the LHC, using a laser scanner, it is anticipated to carry out similar surveys of the tunnel, surface building and the associated infrastructure for the Linac4 Project.

THE STATUS OF CLIC ALIGNMENT STUDIES

Organisation of the CLIC alignment studies

Between the 16th and 18th of October 2007, CERN held the first CLIC workshop, with 200 participants registered from 49 institutes of 19 countries, which shows the interest in this project CLIC'07 provided a forum to review all aspects related to the accelerator, detector and particle physics of a Multi TeV collider based on the CLIC technology. [7]

The CLIC study is a site independent feasibility study aiming at the development of a realistic technology at an affordable cost for an electron-positron linear collider in the post-LHC era for physics to the multi-TeV center of mass colliding beam energy range (nominal 3 TeV). The present goal is to demonstrate the feasibility of the CLIC technology, to estimate its cost, to study the CLIC physics and the associated detectors, and to prepare a Conceptual Design Report to be published in 2010.

The strategy to address the key issues is the following: the key issues common to all linear colliders are studied in close collaboration with the International Linear Collider (ILC) at an Accelerator Test Facility (ATF1 and ATF2 at KEK), or with European Laboratories in the frame work of CARE (Coordinated Accelerator Research in Europe) and EUROTEV (design study funded by EU Framework programs). The key issues specific to CLIC technology are covered by the CLIC study and addressed in the CLIC Test Facility CTF3.

Already 24 institutes involving 16 funding agencies from 13 countries participate in the R&D on the feasibility of CLIC, in the frame work of a CLIC/CTF3 collaboration. The objective is to build a small scale version of the CLIC RF power source, in order to demonstrate the full beam-loading accelerator operation, the electron beam pulse compression and the frequency multiplication using RF deflectors. The facility will provide also the RF power to test the CLIC accelerating structures and components.

The CLIC Test Facility CTF3 has been under construction in different phases for a number of years, and the "initial phase" started with the installation of the CTF3 Linac in 2004. In 2006 the Delay Loop and the transfer line (TL2) to the Combiner Ring were installed, aligned and commissioned, and last year (2007) the elements of the Combiner Ring were installed and the accelerator was also successfully commissioned with beam. 2007 also saw the completion of the new CLEX building and the start of installation of the infrastructure and the accelerators.

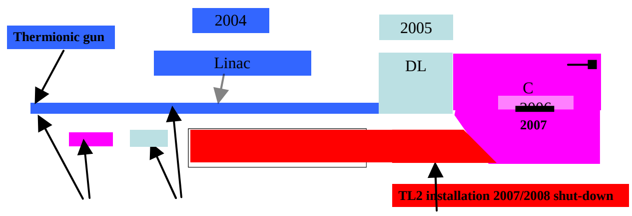

Fig. 6: The CTF3 facility

During the Winter shutdown 2007-08, the transfer (TL2) line to the CLEX will be installed and aligned, together with the first phase of the beamlines in the CLEX facility. With a small line of the CTF3 Linac, it has been possible to test different power extraction structures. With the commissioning of the TL2 and CLEX beam lines, the efficient extraction of energy from a drive beam and the use of a drive beam to accelerate a second "probe beam" will be tested.

The challenge of the CLIC alignment

The CLIC accelerator is based on a technology known as the "two beam acceleration" concept. The beam is accelerated using high frequency structures (12 GHz) subjected to a strong accelerating field (100 MV/m). RF power required by these structures comes from other structures, the Power ExTraction Structures (PETS), located along a high current electron beam (drive beam) running parallel to the main beam. In the case of the 3 TeV configuration, the CLIC accelerator complex would have a length of less than 50 km.

One disadvantage of this technology is that the higher CLIC RF frequency makes the scheme more sensitive to alignment errors and ground stability. As a matter of fact, the tolerance necessary for the alignment of the components of this collider is ± 10 microns (3 σ) on a 200 m long sliding window along the 20 km of each linac, in order that the pilot beam can be detected by the Beam Position Monitors (BPM). This implies an active pre-alignment, e.g. according to the readings of sub-micrometric alignment sensors, the components are continuously readjusted thanks to stepping motors before the injection of the first beam. Another point that is very challenging is the requirement on the stabilization. The 4000 main beam quadrupoles have to be stabilized to within 1 nm in vertical (above 4 Hz) along the linacs, and 0.1 nm in the final focus.

The R&D studies

Because of such a challenge, the CLIC alignment R&D studies started in 1989, providing a global proposal concerning the active pre-alignment described in [8]. The very precise alignment of the components along a 20 km straight line between the first and last reference points of the linacs is carried out using overlapping references of at least 200 m. In order to simplify the problem and taking into account the size of the components, the components will be pre-aligned on girders, which leads to aligning the girders, and not every component, with respect to the propagation network. Two possibilities for the propagation network are under study:

- A stretched wire, for which the remaining problems are the determination of the geoid within a few microns, the knowledge of the gravity effects on this reference, and the development of low cost sensors allowing sub-micrometric absolute measurements ("absolute" meaning that the zero of the sensor is determined with respect to the object to align).
- A laser beam under vacuum studied, in a collaboration frame with NIKHEF [9], with the following problems: it is only a 3 point alignment system, and the improvement towards an n-point system is not straight forward. It implies the need to insert, and withdraw, targets under vacuum with a repeatability of a micron.

The feasibility of the CLIC active pre-alignment must be shown before 2011: an R&D program has been proposed with 4 objectives:

- The mechanical alignment of the elements on the supporting girder with a precision of a few microns, in a way that allows for an industrial production.
- A method of fiducialization of a few microns
- A method of pre-alignment of 10 microns (3σ) over at least 200m
- An optimization of cost

The studies are underway [10]. They concern the alignment techniques, the effects of the gravity on the measurements, and the mechanical and motorization aspects. Several facilities in various locations: long and stable tunnels, or mock-ups located in an accelerator environment will allow the validation of the proposed solution.

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