EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE

CERN - TS Department

EDMS Nr: 473718 TS-Note-2004-007
Group reference: TS-LEA 4 May 2004

INTEGRATION OF FORWARD PHYSICS DETECTORS INTO THE LSS OF THE LHC

D. Macina

Abstract

Experimental detectors will be installed in the Long Straight Sections (LSS) of the LHC. The reasons why the experiments need to locate detectors in the machine tunnel will be explained. A detailed description of the TOTEM Roman Pot in the LSS5 and the ALICE Zero Degree Calorimeter (ZDC) in the LSS2 will be given. A few new proposals in the LSS1 and the LSS8 will also be mentioned. Integration issues will be discussed in detail including the foreseen radiation levels. Roman Pots need to be integrated in the primary vacuum of the machine while the ALICE ZDCs have to be integrated into the combined experimental and injection insertion at IR2. The AB/BDI group project that foresees the installation of luminosity monitors in the LSS will be mentioned in relation to the integration of the experimental detectors.

Presented at the TS Workshop
Archamps, France, May 4 – May 6, 2004

1 INTRODUCTION

Both ATLAS and CMS are building a multipurpose detector to search for a new set of particles like Higgs bosons, super-symmetric (SUSY) particles, quark compositeness etc. The experimental observation of these rare events is characterized by the detection of particles or jets produced at large angle from the beam axis and at high transverse momentum (p_T). Hence the geometrical acceptance of the ATLAS and CMS detectors has been optimized to cover a pseudo-rapidity range up to $|\eta| = 5$ [1]. However, with such an acceptance most of the energy, which leaves the interaction region via particles typically emitted under small angles, remains undetected. A full event spans in general up to $|\eta| \sim 10$. These large pseudorapidity regions are usually called “forward regions” and have been so far rather poorly studied at hadron colliders. The understanding of the forward particle production is a “first class challenge” to theory since the Quantum Chromo-Dynamics (QCD), which is the current theory for strong interactions, is not able to make reliable predictions. In fact this forward region could well contain new and unexpected physics. In addition the knowledge of the energy distribution of particles emitted in the very forward region is absolutely necessary for the understanding of the cosmic ray phenomena whose data continue to suggest new physics. Finally, it should be remembered that the detection of very forward events, like proton (p) elastic scattering, is very important for the study of the total pp cross section (σ_{TOT}) since the two are intimately related through the optical theorem. The high energy behavior of the σ_{TOT} is still a matter of debate and the most recent σ_{TOT} measurements at Tevatron, if correct, may give an indication of a new and interesting contribution at high energy which could be confirmed at the LHC.

The measurement of elastically scattered protons can also be used for a precise determination of the absolute luminosity which is in general a difficult task at the hadron colliders. This is obtained measuring the σ_{TOT} with the “luminosity independent method” [2] which requires simultaneous measurement of the elastic scattering at low momentum transfer (very forward region) and of the total inelastic rate. The absolute luminosity can then be inferred via the usual relation: $R = \sigma L$ where R is the total event rate and L is the absolute luminosity. In addition, one of the methods to monitor the luminosity during collisions is the detection of the high fluxes of neutral particles which are produced at and close to zero degrees with respect to the beam axis and which are proportional to the number of collisions and hence to the luminosity. This technique will be used by the AB/BDI group to monitor the LHC luminosity at the four interaction points.

When the LHC operates as a heavy ion collider, the event by event determination of the centrality of the collision plays a basic role: it is used at the trigger level to enhance the sample of central collisions, and, more generally, to estimate the energy density reached in the interaction. The energy carried away by the non-interacting nucleons (spectators) emitted in the very forward region is the measurable quantity most directly related with the centrality of the collision. In addition the measurement of the rate of the forward neutrons produced at and close to zero degrees through the Mutual Coulomb dissociation is a very clean way to monitor the luminosity and to measure it with high precision.

2 DETECTOR INTEGRATION IN THE LHC EXPERIMENTAL INSERTIONS

The reasons listed in the previous section explain why the experiments have decided to install very forward detectors in the LHC. Their optimal location depends on the physics to be studied, on the technology used and on the geometry of the LHC vacuum chamber. As it will be explained later, it turns out that all very forward detectors have to be integrated in the Long Straight Sections (LSS) of the experimental insertions.

---

[1] The pseudorapidity is defined as $\eta = -\ln \tan(\theta/2)$ where θ is the angle from the beam direction. Hence $|\eta|=5$ corresponds to an angle $|\theta|=0.77°$

[2] The “luminosity independent method “ requires the measurement of the rate of the inelastic interactions and of the rate of the elastic scattering which is related to the pp total cross section via the optical theorem. No information on the absolute luminosity is needed.

2.1 TOTEM Roman Pots integration at IR5

TOTEM is an experiment dedicated to the measurement of total cross section, elastic scattering and diffractive processes at the LHC [[1]]. The measurement of the elastic scattering and diffractive processes [3] requires the detection of protons produced at very small angles (at the LHC typical angles are of the order of µrad). In practice this is achieved by placing the detectors into special units mounted on the vacuum chamber of the accelerator, which have become known as "Roman Pots" and were first used at the CERN ISR. In its retracted position the Roman Pot leaves the full aperture of the vacuum chamber free for the beam, as required at the injection stage when the beam is wide. Once the final energy is reached and the circulating beams are stable, the Roman Pot is moved toward the machine axis by compressing the bellow, until the inner edge of the detector is at a distance of few millimeters from the beam. The TOTEM experimental apparatus consists of forward inelastic detectors placed in the CMS experimental cavern and integrated into the CMS detector, and of three sets of Roman Pots Stations, placed symmetrically on both sides of the IP5 far downstream in the machine tunnel at ~ 200 m from the interaction point. The exact position of the Roman Pots Stations is defined by the special optics used by TOTEM and by the space available between the LHC magnets. Each station is composed of two units, separated by a distance of 4 m, with each unit consisting of two pots that move vertically and one that moves horizontally. Their design is driven by the constraints imposed by the performance and safe operation of the LHC as well as by the TOTEM physics requirements. The radiation level at the Roman Pot location has been simulated in detail and doses of ~ 10^3 Gy/yr are expected at a distance of ~ 10 cm from the beam pipe during normal operation [[2]]. In addition the LHC tunnel will be a restricted access area and it will not be accessible during beam operation. This implies that all components of the Roman Pots and their services have to be highly radiation hard and highly reliable.

The first Roman pot prototype has been designed and built within the TOTEM group in collaboration with the TS department [[3]] and is being prepared for test on the SPS beam in autumn 2004. Detailed drawings can be found on the CERN CDD [[4]].The main issues concerning the Roman Pot design and its integration in the LHC tunnel are listed below:

- At the Roman Pot locations, the two beams are physically separated in two independent vacuum chambers horizontally spaced by 194 mm. The tight space between the two beam pipes requires a design with a mechanics asymmetrically placed on the side of the vacuum chamber.
- The pots movement is guided by stepping motors which are remotely controlled. High precision screws provide the link between the pots and the stepping motors and allow the pots to be moved precisely along these screws without any backlash. These screws offer, together with the stepping motors, a positioning resolution of a few microns. The stepping motors commercially available are in general sufficiently radiation hard to withstand the radiation levels present in the tunnel. This is not the case for the control electronics which therefore has to be placed far away.
- Due to the primary vacuum of the machine, the pots are pulled into the main vacuum chamber with a force of ~ 1000 newtons. A compensation system which neutralises this force is provided by two bellows connected to a secondary vacuum pump.
- The Roman Pot has been designed to minimise the impact on the machine impedance budget and RF contact fingers have been foreseen when the pot is in its retracted position.
- The Roman Pot is fixed to the ground of the tunnel by means of a stable pedestal on which an adjustable table supports the Roman Pot. The pedestal defines the position of the Roman Pot along the beam axis while the table defines the vertical position and the horizontal reference plane.
- All components placed into the machine primary vacuum have to be compatible with the Ultra High Vacuum (UHV) requirements of the LHC. Hence, since the TOTEM detectors and electronics do not fulfill such requirements, they must be physically separated from the primary

[3] One characteristic property of the final state of most diffractive processes is the appearance of leading protons, i.e. protons with a momentum close to the beam momentum.

vacuum of the machine to prevent an unacceptable outgassing. The detectors and electronics are then placed inside a pot that will also provide the required shielding from the electromagnetic pick up from the circulating bunches. The pot design has been optimized to minimize the amount of material in front of the detectors and the dead space between the beam and the detectors themselves. This is achieved via a 0.2 mm thick window which is positioned at the bottom of pot. During normal operation, a secondary vacuum in the pot minimizes the deformation of the window towards the beam. During the detector maintenance, or in the unlikely event of a secondary vacuum leak, the window is subject to a differential load due to the atmospheric pressure on the detector side and the primary vacuum of the LHC on the other side. This represents a severe constraint on the strength of the window and requires careful choice of the UHV compatible material and of the technology used to join the thin window to the thicker wall of the pot. Inconel 718 with its high strength and stiffness presents the best characteristics for the thin window of the Roman Pot. The thin window is brazed directly on the thicker part of the pot which is machined from Inconel 600.

- As for the other machine components in the warm sections of the LHC, the pot and the vacuum chamber will have to be baked out in situ at 250°C to reach the low pressure required for the LHC operation. Mechanical calculations show a very high stress level on the brazing between the thin window and the pot. Thermal tests have to be performed to address this problem and also to characterize the strength of the brazing after the bake-out.
- In case of beam accident, the pot may have to stand the impact of a full LHC bunch. Even though rough calculations show that the pot should survive such an accident, a detailed simulation still needs to be performed. Fast beam loss monitors are foreseen at the location of the Roman Pot to detect particle losses due to beam accidents and to trigger a beam dump if necessary.
- The silicon detectors and the front-end electronics housed inside the pot require cooling and temperature stability. The potential parasitic use of part of the LHC cryogenics in the tunnel (QRL) or of the CMS cryogenic infrastructure has been considered by the AT/ACR and AT/ECR groups. The result of this study indicates several incompatibilities and excessive cost of the necessary modifications. So a dedicated cooling system has been designed by the AT/ECR group [5]. In view of the large distances between the Roman Pot stations in the tunnel no cryogenic link is considered between them. Instead each station will be independently equipped with a dedicated modular cryogenic system of the same design. The external cryogenic system consists mainly of a common refrigerator, a cryostat and six (one per pot) heat pipes connected to the internal part of the Roman Pots. The cryo-cooler is of the pulse tube type and relies only on a simple helium compressor. All supervision and control will be done remotely and hence no personnel access is required during normal operation. The system operating temperature may range from 130 K to 250K.
- Additional services, like cabling, are not very demanding. Cables need to be pulled from each Roman Pot station to the CMS services cavern. The total cross section required for one Roman Pot station on a cable tray in the tunnel has been estimated to ~ 10 x 10 cm^2. A particular effort is put on the integration of the trigger cables since the distance between the Roman Pot stations and the CMS services cavern is at the limit of the trigger capability.
- As for all elements moving inside the LHC beam pipe, a risk analysis has to be performed to address possible failure scenarios which could lead to important machine downtime.

2.2 ALICE Zero Degrees Calorimeters integration at IR2

As already mentioned, the measurement of the centrality of the heavy ion collisions is done by measuring the energy carried by the non-interacting nucleons (produced at the IP) flying at zero degree with respect to the beam direction, by means of Zero Degree Calorimeters. One set of two calorimeters will be installed in the LSS2 on both sides of IP2 at 116 m from the interaction point where the common beam pipe coming from the experimental cavern is separated into two vacuum chambers (recombination chamber) before entering the D2 dipole magnet. The spectator protons and neutrons will be separated from the ion beams via the separator magnet D1. Since the D1 magnet will also deflect the spectator protons, separating them from the spectator neutrons (which will fly at zero degrees), a set of two calorimeters is needed: the ZN, positioned between the two beam pipes, to intercept the spectator neutrons, and the ZP, external to the outgoing beam, to collect the spectator protons. Both calorimeters make use of highly radiation hard quartz fibres as active material embedded in a tantalum matrix in the case of the ZN and in a brass matrix in the case of the ZP. The Cherenkov light produced by the passing particles in the quartz fibres is optically guided by the same fibres to photomultipliers (PMTs). In addition both calorimeters are placed on a movable support table which will be lowered during injection to minimise the absorbed dose and to protect the calorimeters from possible beam losses at injection. The total volume requested to accommodate the ZDCs, the readout electronics (fibres and PMTs) and the movable support has been defined in detail in an ECR [6] which is at the moment under approval. The main issues for the ZDC integration in the tunnel are listed below:

- The vacuum layout and the devices located between the D1 dipole and the ZP should be designed to leave enough aperture for the spectator protons (>75% acceptance in the ZP). This is not an easy task given the number of protection devices which are foreseen and proposed for operation both at injection and collision. About 14% of the spectator protons are lost before the end of the D1 cryostat. A modification of the D1 cold mass is at this stage of the LHC project not feasible. However, the design of the cold-warm transition at the end of the D1 cryostat can still be optimized and it is at the moment under ALICE evaluation. The beam position monitor BPMSX, which is foreseen at ~ 4 m from D1, is a serious aperture restriction. An ECR will be submitted soon to displace it as close as possible to D1 and to enlarge its inner diameter (ID) from 74 mm to 80 mm. The design of the various protection devices is checked by the ALICE Collaboration as soon as they become available. No major problems are foreseen at the moment. A ~ 23 m long enlarged vacuum tank (ID = 797 mm) is foreseen after the last protection device to ensure a good acceptance for the spectator protons.
- The amount of material in front of the ZDCs should be minimized. This affects the design of both the last part of the enlarged vacuum tank and of the recombination chamber. The present design foresees the same recombination chamber as for IR8 with the exception of the flanges which have been suppressed to minimize the material budget. In fact, in this case the two beam pipes are directly welded to the recombination chamber. This design looks compatible with the ZN requirements. The possible integration of a thin window at the exit of the big vacuum tank to further minimize the material in front of the ZP is under evaluation. The vacuum supports design should also be optimized for the same reason.
- The space between the two beam pipes after the recombination chamber should be enough to fit in the ZN, to allow the beam pipe bake-out and to allow a safe movement of the ZN. The actual beam pipe design, as shown in [6], fulfills the above requirements.
- The support table will be designed by the AB/ATB group for the ALICE collaboration. Since the support table will have to be remotely controlled, radiation issues and reliability will have to be taken into account.
- The ZDCs services are rather simple. Cables have to be installed along the LHC tunnel all the way to the UX25. The total cross section required for each set of ZDCs on the cable tray in the tunnel is 20x10 cm^2.
- The proposed AB/BDI luminosity monitor heavily interferes with the ALICE ZN. An ad hoc meeting was called to look into the possible problems and solutions [7]. The result of the meeting was positive and a proposal which accommodates both the luminosity monitor and the ZDC has been agreed. Furthermore, the possibility of installing a miniTAN was discussed if simulations show that an absorber is needed in front of the D2 dipole to avoid quenches during heavy ion operation. Given the lack of space between the recombination chamber and D2, the possibility of installing the miniTAN on top of the ZN has been addressed. According to this proposal the miniTAN will protect D2 in case the ZN, for any reason, is not in the data taking position. At first sight, the proposal seems reasonable.

2.3 Proposal for ATLAS Roman Pots integration at IR1

The ATLAS Collaboration has recently submitted to the LHCC a Letter of Intent (LoI) [8] to propose forward detectors to monitor and measure the luminosity at IP1. In particular, Roman Pot units are envisaged at ~ 240 m from the interaction point between the quadrupole Q6 and Q7 on either side of IP1 to measure elastically scattered protons to determine the absolute luminosity at IP1. ATLAS plans to use a similar Roman Pot design to that developed for the TOTEM experiment. Nevertheless, given the different location in the tunnel and the different technology chosen as baseline for the particle detectors, different integration issues will have to be addressed in comparison with the TOTEM case. In particular the interference between the three dump resistor boxes (DQRs) and the Roman Pot units has to be careful studied even though the result of a first tentative integration looks promising.

Furthermore the ATLAS Collaboration has submitted to the LHCC an additional LoI [9] to describe for the first time the expected potential of ATLAS for the study of heavy-ion collisions. The addition of a ZDC is justified by the same physics arguments as for the ALICE ZDC. The ATLAS ZDC can be incorporated into the TAN neutral absorber which houses the recombination chamber. It can be positioned between the two beam pipes in the slots which have been foreseen for instrumentation. The interference with the AB/BDI luminosity monitor which is also located into the TAN absorber has to be studied in detail.

2.4 Proposal for the installation of a calorimeter in the very forward region of the LHC

A new LHCf Collaboration has submitted to the LHCC a LoI [10] to measure the energy distribution of neutral particles (photons and neutral pions) in the very forward region of the LHC. This measurement is very important for the understanding of cosmic ray phenomena and it is proposed to achieve it by placing a calorimeter in the experimental LSS between the two beam pipes of the recombination chambers (similar location as the ALICE ZDC and the proposed ATLAS ZDC). According to the LoI the calorimeter can be placed in the TAN absorber located either at IR1 or IR5. The interference with the AB/BDI luminosity monitor and the proposed ZDC at IR1 has to be evaluated. Another possible location could be at the recombination chamber at IR8 where only the interference with the AB/BDI luminosity monitor has to be addressed. A similar location at IR2 looks quite improbable due to the clash with both the ALICE ZDC and the AB/BDI luminosity monitor.

3 OUTLOOK

The physics motivation and the main integration issues for the TOTEM Roman Pots located at LSS5 and the ALICE ZDC located at LSS2 have been explained. The most demanding task for the Roman Pots is their integration into the LHC primary vacuum while for the ALICE ZDCs it is their integration in a combined experimental and injection insertion. The new proposals recently submitted to the LHCC will require, if approved, a similar effort in the other experimental insertions.

References

[1] TOTEM Coll., Technical Proposal,CERN/LHCC 99-7, Technical Design Report CERN/LHCC-2004-002

[2] N. Mokhov at al, LHC Project Report 633

[3] M. Oriunno, talk given at Xth Blois Workshop on Elastic and Diffractive Scattering, Helsinki, 2003

[4] TOTEM Roman Pot CDD drawings: LHCXRP__0001-LHCXRP__0076

[5] F. Haug, “Studies on cooling of the TOTEM particle detector at the LHC”, to be submitted at ICEC 20

[6] EDMS Document Id: 459357

[7] WEB page: http://macina.home.cern.ch/macina/ZDC-Lumi/

[8] ATLAS Coll., Letter of Intent, CERN/LHCC/2004-010

[9] ATLAS Coll., Letter of Intent, CERN/LHCC/2004-009

[10] LHCf Coll., Letter of Intent, CERN/LHCC/2003-057