QUALIFICATION OF ELECTRONIC COMPONENTS AND SYSTEMS IN A LHC TUNNEL RADIATION ENVIRONMENT

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Abstract

Around 10.200 electronic crates will be installed in the LHC underground areas of which some 4.200 will be connected to the machine control network. Some of the electronic equipment will be housed under the cryostats of the main dipoles inside the tunnel. Other equipment will be placed alongside the tunnel, in the alcoves or in galleries parallel to the machine.

In the regular arcs and in the dispersion suppressers areas the expected annual dose is low, i.e. only a few Gy/y. However, preliminary radiation tests showed that electronic equipment fails even at such low dose rates. Since radiation qualification of all tunnel electronics is essential in order to guaranty its reliable operation over the lifetime of the machine, a LHC radiation test facility was commissioned in the North Experimental Area of the SPS accelerator.

This paper presents the simulation study concerning the radiation environment of the LHC Radiation Test Facility and gives an overview of the various underground electronic systems as they are planned today. Preliminary conclusions about the qualification of electronic components and systems to be installed in the LHC tunnel will be given.

1 RADIATION TESTING OF MACHINE COMPONENTS AND SYSTEMS

1.1 Radiation Environment in the Accelerator Tunnel

Machine components in the vicinity of the two counter rotating proton beams will experience damage from prompt radiation when there are circulating beams (i.e. collision of protons with residual gas molecules) and from induced radioactivity (in water, air, ...) when there is no beam. In order to quantify the effects of radiation on the tunnel electronics, knowledge of the dose rate and the particle spectra of this mixed radiation field is required. However, simulation of the LHC radiation field is a complicated task since the received dose depends on the position (longitudinal and transverse) with respect to the beams. In addition, the particle spectra outside the shielding depend on the type and thickness of the shielding material, both of which vary along the 27 km long ring (figure 1). The annual dose levels have been computed with a Monte Carlo simulation code FLUKA [1], which takes into account the exact accelerator geometry. The results show that annual doses on the cryostat surface or on the tunnel wall vary between 0.8 Gy and 30 Gy per year. There are also a few exceptional “hot spot” positions that may receive more than 1000 Gy per year.

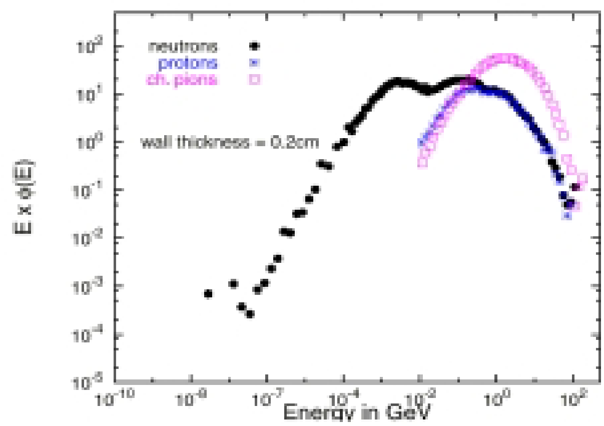

Figure 1: Example of computed particle spectra found in the LHC tunnel in the case of thin shielding material (spectrum normalized to 100 keV neutrons).

Better knowledge of the radiation dose pattern inside the LHC accelerator tunnel had important consequences. First, wherever possible, machine components were migrated to “colder” areas situated mostly inside the “alcoves” perpendicular to the main accelerator tunnel. Second, the LHC Radiation Test Facility was commissioned to allow accelerated testing of all electronic components that have to be placed inside the LHC underground areas.

1.2 On-Line Radiation Test Facility

The test zone is driven by a 400 GeV proton beam that has an intensity of 1.2×10^{13} protons. The primary beam hits the primary target (figure 2) and this creates a hadron shower. The protons that do not interact in the primary target (about 5×10^{12}) are bent by the quadrupole and dipole magnets and are collimated by the TAX (Target Attenuator EXperiment) where they initiate a second hadron shower. The latter eventually causes the irradiation of the test zone.

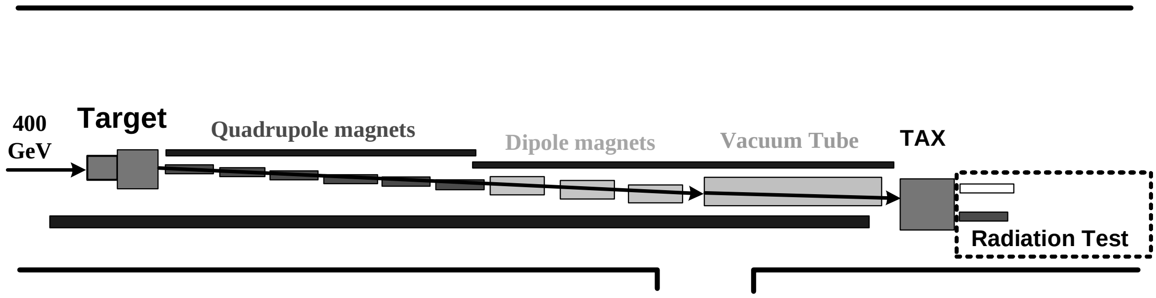

Figure 2: Top view of the 60 meter long beam-line driving the LHC Radiation Test Facility. A proton beam at 400 GeV/c^2 hits the primary target and produces kaons and charged pions. The Target Attenuator EXperiment (TAX) absorbs off-momentum particles and produces a secondary hadron shower in the Radiation Test zone.

The particle spectrum in the test zone behind the TAX is similar to that found in the LHC tunnel [2]. The part of the spectrum concerning high-energy hadrons is nearly identical to that found in the LHC. However, there is a higher contribution to the dose from low energy neutrons above 100 keV. The differences in the radiation environments originate from the partial compensation of the particle fluence and the dose per proton.

The test area is monitored by active and passive dosimetry measurements. The active dosimetry measurements consist of 8 gas ionization chambers that are read out on line with an integration time of 1 hour. The passive dosimeters (PAD, RPL and PIN diodes) are taken out and processed every week. The accumulative doses in the 2001 radiation campaign are shown in figure 3. The accumulated dose depends on the positioning of the equipment inside the zone.

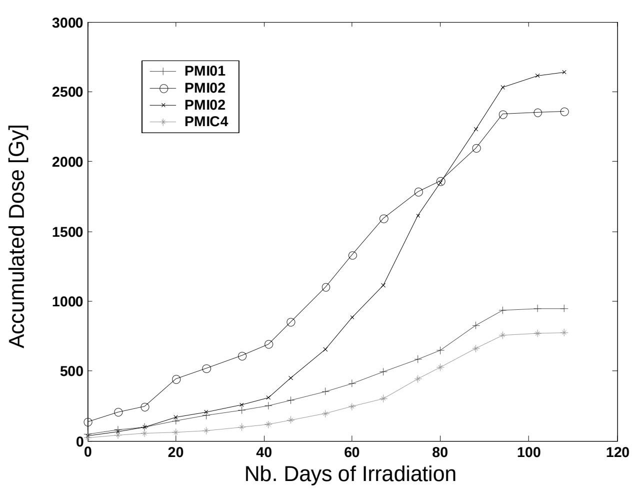

Figure 3: Accumulated dose in Gray at different positions inside the Test Zone area for the 2001 irradiation campaign.

1.3 Radiation Hardness Testing

At the start of the yearly radiation campaign, the test zone is filled with electrical and mechanical components or even complete systems. The position of the equipment inside the zone is deduced from the simulated radiation at the future position inside the LHC accelerator tunnel and the computed radiation map inside the test zone. The duration of the irradiation is derived from the total accumulative dose measurements using the passive dosimeters. In many cases, the duration should correspond to 25-year operation, which is the expected lifetime of the LHC accelerator. The active dosimeters are used to monitor the test area during operation. This allows observing, for example, changes of proton intensity behind the primary target.

Throughout the run, the experimenters monitor on-line most of their equipment using the control room at the surface and/or from their offices. During the 2001 campaign, some 20 experiments have been conducted in the zone with varying success. Some experiments use only standard COTS (Components Of The Shelf) products. In some cases, it was sufficient to test all commercially available products to make a proper selection. In other cases, none of the standard components are sufficiently radiation hard. Minor modifications are made during short shutdowns once a week before testing is restarted. In addition, equipment that will be positioned very close (10-20 cm) to the LHC beam is normally entirely custom built using radiation hard components. It remains the responsibility of every experimenter to ensure the radiation hardness of his/her equipment before installation in the accelerator tunnel.

2 UNDERGROUND INSTALLATION OF ELECTRONIC EQUIPMENT

The underground electronic systems planned to control the LHC machine are currently being discussed, developed and some prototypes are already being tested; only a few final decisions have been taken at this stage [4]. The results of the radiation tests are important factors that influence the final decisions concerning the type of electronic, its position either in the tunnel or in a protected area and the number of cables required.

Electronic equipment will be housed under the cryostats, along the tunnel, in alcoves, in enlargements of the tunnel, in the galleries parallel to the machine tunnel and in dedicated areas located at the bottom of the pits.

Taking into account the necessary room for accessing the cryostats interconnections and their support jacks up to 13 Standard Euro-Crates may be placed under each dipole (14,56 m long). In order to simplify their installation four or five electronic crates may be regrouped into a single box. The cooling air is aspired from the rear side, flows through the electronic crate and is blown out at its bottom level towards the transport area of the tunnel.

Four cable trays are foreseen along the LHC tunnel: three of them are fixed on the wall and one is located on the top of the QRL (Cryogenic Refrigeration Line) for local interconnections.

In order to commission each QRL as soon as it is installed it will be necessary to gradually control and monitor its vacuum. All control cables will be laid in the lowest cable tray and electronic boxes, such as repeaters, will be fixed under it.

A standard cabling methodology for fieldbuses (Profibus and WorldFIP) has been adopted, cables and recommended fieldbus components have been selected.

The electrical distribution is housed in 16 alcoves around the LHC tunnel as well as a 120 kVA non-interruptible and redundant power supply, the cooling and the ventilation systems. The front-end equipment for the various electronic systems will be mounted in racks. As far the radiation level and equipment hardness permit, electronic crates will preferably be installed in the tunnel under the cryostats. Radiation sensitive systems will be housed in the alcoves where the radiation level is low.

In the long straight sections of the tunnel the radiation level precludes installation of electronics; thus electronics will be located into galleries parallel to machine tunnel and in dedicated areas on the bottom of the pits.

3 PRELIMINARY TEST RESULTS

From results obtained in the previous years we already know that intelligent sensors and actuators are radiation sensitive elements [5]. Industrial PLCs and I/O modules with a microprocessor and memory as well as NMOS switching power supplies do not work reliably.

On the positive side, we have found passive and active components working well above the LHC tunnel radiation level. This is the case for optical fibres, resistors, capacitors, signal conditioners, operational amplifiers, ADCs, DACs, FPGAs, EPROMs, sensors, actuators, gauges, positioners, valves, flowmeters, etc… We have found commercial of the shelf modular power supplies with serial regulation, bipolar transistors and transformer coupling feedback which work perfectly up to 400 Grays.

Radiation tolerant systems may be designed with conventional components using adequate hardware or software techniques and methodologies. Typical examples are the development of the quench heater power supplies for the protection of the cryostats by selecting carefully passive and active components and of special power supply controllers using two redundant processors sharing a memory with EDAC (Error Detection And Correction). Another example is the use of radiation qualified fieldbus interfaces (WorldFIP or Profibus) to control and to monitor cryogenic instrumentation in simple Command/Response mode.

4 CONCLUSION

The definition of the major electronic systems for underground installation, in the tunnel, alcoves, galleries and at bottom of the pits is well advanced. Some systems have to be finalised and decisions will depend on the radiation hardness of their components.

The On-Line Radiation Test Facility is now qualified and further experiments on electronic components and systems will proceed with confidence and with the insurance that the results obtained are valid.

5 ACKNOWLEGMENTS

The authors would like to thank the many colleagues, from both the Tunnel Electronics and Radiation Working Groups (TEWG and RADWG), who have provided the information and the material for this article and for having communicated their results.

Special thanks to Claire Fynbo and Graham Stevenson who have done the radiation simulation and environment comparison of the Radiation Test Facility to the LHC tunnel.

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