29. RADIATION ENVIRONMENT AND SHIELDING

The radiation environment at the LHC is known to be very hostile for almost all subdetectors envisaged [29-1]. Most of this intense background radiation is due to the beam-beam collision. At the nominal peak luminosity of 10^{34} cm^{-2} s^{-1}, we expect 8 x 10^8 inelastic proton-proton collisions per second. A significantly smaller contribution arises from the expected level of beam losses in the straight section of the LHC ring [29-2]. It must be noted that the maximum luminosity will be reached only at the beginning of a fill. The day-averaged luminosity will depend on the number of fills per day, but is expected to be about half of the peak value. The CMS physics program foresees the accumulation of 5 x 10^5 pb^{-1}. This corresponds to 5 x 10^7 seconds at the peak luminosity. Unless explicitly otherwise stated all radiation level values will be given for the total integrated luminosity of $5x10^5$ pb^{-1}.

The solution, adopted by CMS, to have the whole calorimetry inside of the superconducting coil provides efficient shielding against the intense radiation emerging from the interaction point.

The radiation levels in the experimental hall are dominated by cascade development in the collimator region. This radiation needs to be considered for installation and estimation of maintenance needs of any radiation sensitive equipment in the experimental hall. The coil itself, however, is protected against this background component by the massive flux return yoke.

For the radiation environment simulations primary proton-proton collisions have been generated with the DPMJET-II event generator [29-3], which is optimised for the generation of minimum bias events. About 15 % of the generated events are single diffractive, so that one of the participating protons suffers only a small deflection and does not add to the radiation background in the experimental area. Because DPMJET-II includes heavy flavours only up to charm, events containing b-quarks were obtained separately from PYTHIA and added to the DPMJET-II events. The cross section estimated for b-production was 0.35 mb, to be compared with the 80 mb estimated for the total inelastic cross section. In order to sample enough of the potentially important b-events a weighted sampling scheme was used, favouring the selection of b-events.

The cascades were followed through the CMS geometry with the FLUKA code [29-4]. Neutrons were transported to thermal energies, other hadrons below the interaction threshold were ranged to zero energy. Electromagnetic energy cuts were adjusted according to the region. In the experimental hall they were 100 keV for $e^{\pm}$ and 30 keV for photons. In the coil and its surroundings 300 keV for $e^{\pm}$ and 100 keV for photons. A relatively rough geometry description was used for the CMS detector and the experimental area. In particular no civil engineering installations, except for the dedicated shielding, were taken into account. Cylindrical symmetry was assumed everywhere. The hall was taken to have flat end walls and a half-length of 26 m. The radius of the hall was taken to be 12 m. It has been shown that the radiation field is not significantly changed if a more detailed geometry of the hall is used [29-5].

The iron yoke provides significant shielding, not only to the inner muon stations and the coil, but also to the central parts of the experimental hall. The massive detector sits like a plug in the centre of the hall and results in relatively low radiation levels in the region $|z| < 7$ m.

Figure 29.1 shows the estimated neutron fluence and total radiation dose close to the lateral wall of the CMS experimental hall in the region R = 8 -12 m. Since the main concern lies in radiation hardness of electronics, only neutrons with kinetic energy in excess of the 'silicon damage threshold' of 100 keV have been considered. The neutron fluence shows a weak radial dependence but is typically of the order of 10^{10} cm^{-2} in the centre of the hall and increases to almost 10^{11} cm^{-2} at z = ±20 m. Charged hadrons cause similar displacement damage as energetic neutrons, but their fluence outside of the detector is 1-2 orders of magnitude below the neutron fluence.

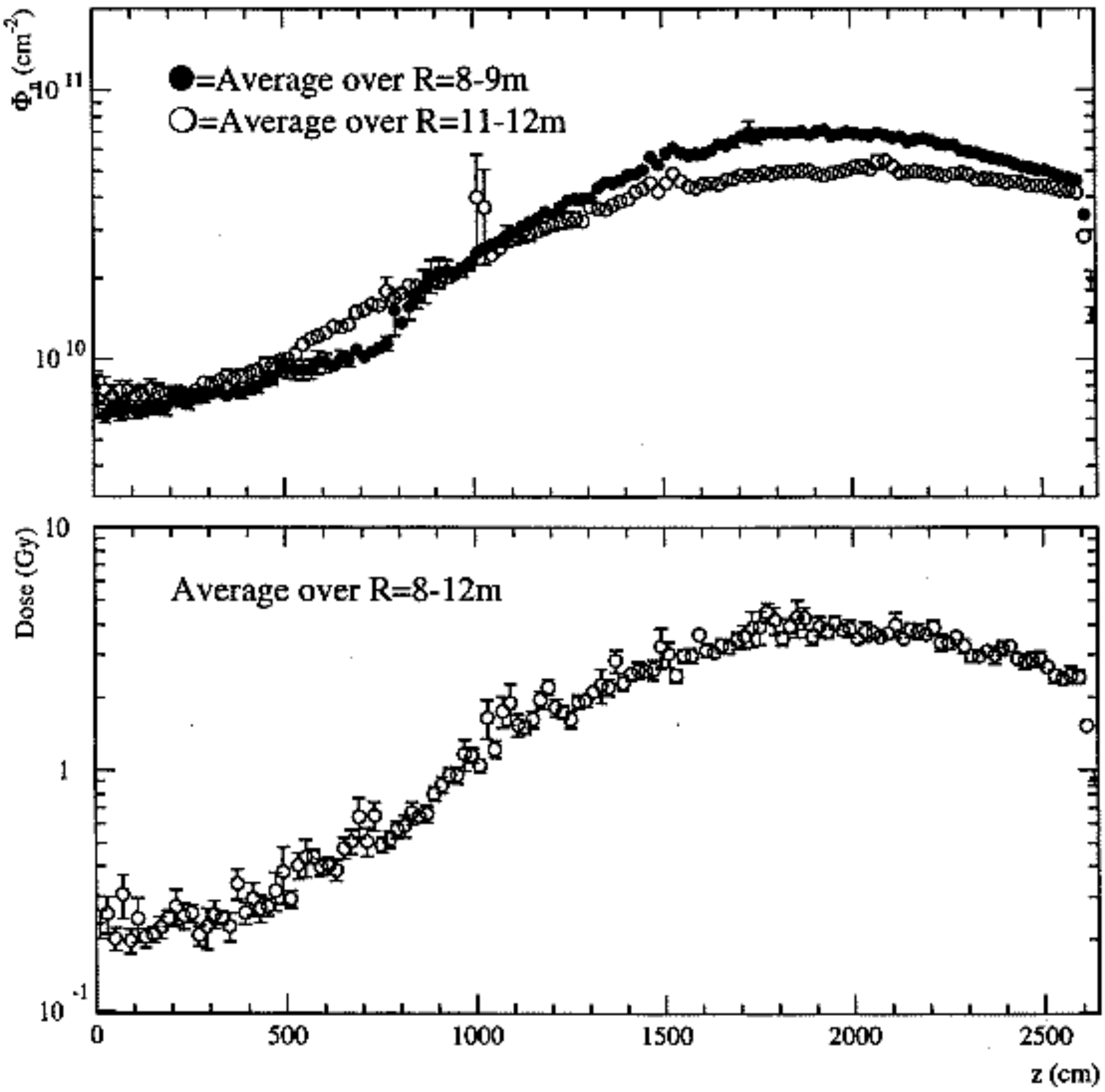

Fig. 29.1: Neutron fluence and radiation dose close to the lateral wall of the CMS experimental hall. Values are for 5 x 10^5 pb^{-1}. The error bars indicate only the statistics of the simulations.

The radial dependence of the dose is negligible in the region R = 8 - 12 m, and only the average is shown. Also the dose varies by roughly one order of magnitude as a function of the z-co-ordinate. The values range from the minimum of 0.3 Gy to about 4 Gy. Two-dimensional maps of the neutron (>100 keV) fluence and the radiation dose in the experimental area are shown in Fig. 29-3, p. C-69, and Fig. 29.4, p. C-70.

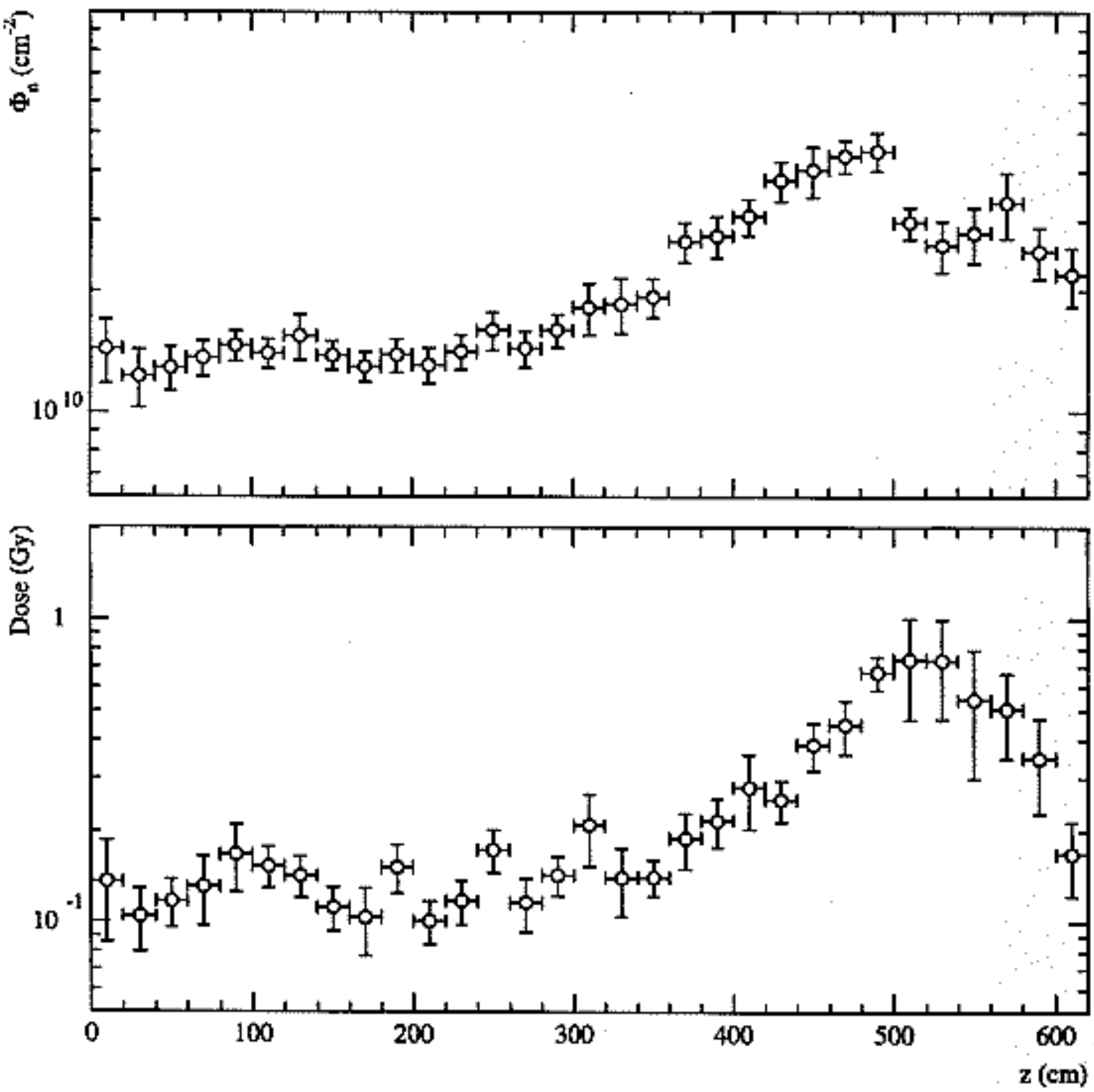

Fig. 29.2: Neutron fluence and radiation dose in the superconducting coil. Values are for 5 x 10^5 pb^{-1}. The error bars indicate only the statistics of the simulations.

The coil is exposed to neutrons leaking out of the hadron calorimeter. It can be seen from Fig. 29.2, that the neutron fluence is of the order of 10^{10} cm^{-2} in the central parts of the coil. At the ends of the coil we observe a notable increase of the neutron fluence. A pronounced peak comes from the crack between the HB and the HE and reaches a maximum of about 5x10^{10} cm^{-2}. A smaller peak appears due to the channel provided by the slot for the muon chamber ME1.

The radiation dose at the coil remains at very moderate values, not exceeding 1 Gy even in the region of the HB/HE crack.

Especially concerning the neutron fluence in the coil, it should be taken into account that final service and cable layout might affect the neutrons. The simulation set-up has been constructed to be pessimistic by underestimating the amount of material in the cracks. So the values shown should represent upper estimates.

The fluences and radiation doses for the coil and the experimental hall set bounds for the radiation to be expected in the cryogenics and service line which is located between the barrel wheels YB0 and YB1. The similarity of the values in the hall and at the coil indicate a maximum neutron fluence of 3 x 10^{10} cm^{-2} and a radiation dose of no more than 0.5 Gy for this region.

Error estimates, except those from the run statistics which are indicated in the figures, are difficult to obtain by any direct and well defined method. The neutron fluence and radiation dose are affected by uncertainties in the physics models, in the cross section data used by the simulation code and by the approximation done when describing the geometry of CMS for the simulation code. Based on published benchmarks of the FLUKA code [29-6] and on intercomparison of results with different independent geometries, simulation codes (MARS95 and GCALOR) and cross section data sets, the overall error for the neutron fluences and doses presented here can be estimated to be about a factor of three.

The high hadron fluences at LHC imply severe activation of several subdetectors. Again the magnet coil itself is so well protected that its activation is negligible. On average 1.4 high energy hadronic interactions, 'stars', are produced in the coil per cubic centimetre per second at LHC peak luminosity. This star production rate is slightly higher close to the HB/HE crack, reaching up to 5 per second per cubic centimetre. Even if we use a very pessimistic value of 10^{-8} (Sv/h) / (star/cm^3/s) for the w-factor [29-7], the dose rate in contact with the coil is only about 10 nSv/h. For access to the coil, the activation of the endcap calorimeters might be more significant than the activation of the coil itself. Their proper shielding will be discussed in the relevant Technical Design Reports.

29.1 SHIELDING AND RADIATION PROTECTION IN THE UNDERGROUND AREA

The radiological danger to humans is usually expressed as dose equivalent and measured in Sievert (Sv). It is related to the dose (measured in Gy) by a quality factor, which depends on the radiation type but is always greater than unity. The dose equivalent rate in the CMS area during machine operation is shown in Fig. 29.5, p. C-71, it reaches an average of about 1 mSv/h when the LHC operates at its peak luminosity. The design limit for occupied areas is 10 μSv/h [29-8]. Therefore the whole experimental cavern will be a radiation exclusion area and no access to it will be permitted during LHC operation.

The counting room area (Fig. 26.7, p. C-57) is separated from the experimental hall by a 7 m thick concrete wall, which provides by far sufficient protection and access will be normally granted to the experimental teams, while the LHC and the magnet are on, under the restrictions applicable to controlled radiation areas.

The cavern itself will be shielded at the bottom of Personnel shaft PM 54 by a moveable 300-tonne concrete door which will slide aside using air pads suspension. The by-pass for personnel access to the cavern from the bottom of the Personnel shaft and from the technical gallery will be permanently under control from the MCR using the LHC key-access system.

There will be several small penetrations and bypasses leading from the experiment to the counting room. The radiological impact of all these has been discussed in [29-9], and they have been shown to provide sufficient safety margin. The two 1-meter diameter ducts provided for the cryogenic and the pumping lines, and for the electrical busbars from the technical gallery to the magnet through the shielding wall, will not necessitate any special shielding but only a safe fence prohibiting any human passage.

The attenuation of dose equivalent in the large cable ducts which have been designed as long labyrinths starting below the CMS endcap is shown in Fig. 29.6, p. C-72. It can be seen, that the 10 μSv/h limit allows access to part of the cable duct even when the machine operates at peak luminosity.

29.2 THE MAIN SHIELDING PLUG ON TOP OF PX 56

To shield the outside world, the top of the experiment shaft PX 56 is closed by a 2000-tonne reinforced concrete plug which will slide onto rollers in the surface assembly hall.

As this reinforced concrete plug will serve as a static transit member during the operation of lowering down all of the constitutive magnet and detector elements (see Chapt. 26 and Fig. 26.15, p. C-65), it will be tested under 110% overload calculated on the heaviest element which is the central ring with coil and vacuum tank, i.e. about 1900 tonnes. Thus the overload of 2100 tonnes will be provided by some 1000 tonnes of iron blocks already available for the test of the air pads system and platform (see Chapt. 10), plus some 1100 tonnes of steel coming from the decommissioning of the Omega magnet. In addition to this test, the 2000 tonne overload mentioned above plus the 2000 tonne weight of the plug itself will be used as dead-weight to test the rented 4000-tonne gantry (see Chapt. 26) as well as the foundations it requires on both sides of the access shaft and very close to it by anchoring the lifting cables through the plug.