Radiation Test Facilities in the New PS East Hall at CERN

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Abstract

At the CERN Proton Synchrotron (PS), the 24 GeV/c primary beam allows the operation of two new irradiation facilities. One is using directly the primary proton beam and the other one is using secondary particles (mainly ~ 1 MeV neutrons) produced in a cavity after a beam stopper. For both facilities, samples to be irradiated are brought to the irradiation positions by means of automatic shuttles. Designs, Monte Carlo simulations of particle spectra and background are presented as well as the performance achieved.

I. INTRODUCTION

The future Large Hadron Collider (LHC), as well as its associated physics detectors, are being built at the European Organization for Nuclear Research (CERN). Materials and components to be positioned close to the beam pipe or close to the interaction points will be exposed to electromagnetic and hadronic radiation, and radiation damage is to be expected. For safe and reliable operation, the radiation hardness of these components must be tested prior to their selection. In electronics and in optical components, radiation damage depends on the nature and on the energy of the particles. For several years, a mixed gamma-neutron irradiation facility, the PSAIF [1, 2], and a 24 GeV/c PS-T7 proton irradiation facility have been used. Both facilities were closed at the end of 1997.

Taking advantage of the recent beam line reshuffling in the East Hall of the Proton Synchrotron and following the large demand for testing the radiation hardness of components and detectors for the LHC era, two new irradiation facilities [3] were designed: a proton irradiation zone, IRRAD1, and a neutron irradiation zone, IRRAD2. Fig. 1 shows their location in the PS beam lines. Both are equipped with a shuttle in order to move the samples to be irradiated in and out from the counting rooms to the irradiation positions without interruption of the PS beams. The design of the shuttles, moving on rails in stainless steel conduits 12-15 meters long, allows the irradiation of samples with a maximum size of about 10x10x10 cm^3 (maximum weight of the order of 1 kg) and the possibility of biasing them if needed.

II. PROTON IRRADIATION ZONE

The IRRAD1 zone is operational since August 1998 and is using the primary PS-T7 24 GeV/c proton beam with a maximum intensity of 2×10^{11} protons per spill (duration = 400 ms). A secondary emission chamber (SEC) monitors the proton beam intensity. Fig.2 shows the lay-out of the proton irradiation area. A defocusing-scanning system allows to spread the beam. Over a surface of about 2 cm^2, the flux homogeneity is better than ± 10%.The flux is about $2.5 - 7.5 \times 10^9$ cm^{-2} s^{-1}, depending on the beam profile optimisation and on the number of spills (1 to 3) per PS supercycle (14.4 - 19.2 s). The fluence can be measured by activation of aluminium foils. This method, measuring the gamma decay of ^{24}Na produced by the protons in ^{27}Al, permits a fluence measurement accuracy of ± 7 %.

Fig.3 shows the background contamination coming from secondary particles back-scattered from the marble shielding wall 20 cm behind the irradiation point, where the proton beam is stopped. The hadronic background contribution to the proton beam consists of less than 0.05% of neutrons with an energy greater than 200 keV. This is confirmed by activation of aluminium, nickel, gold and indium.

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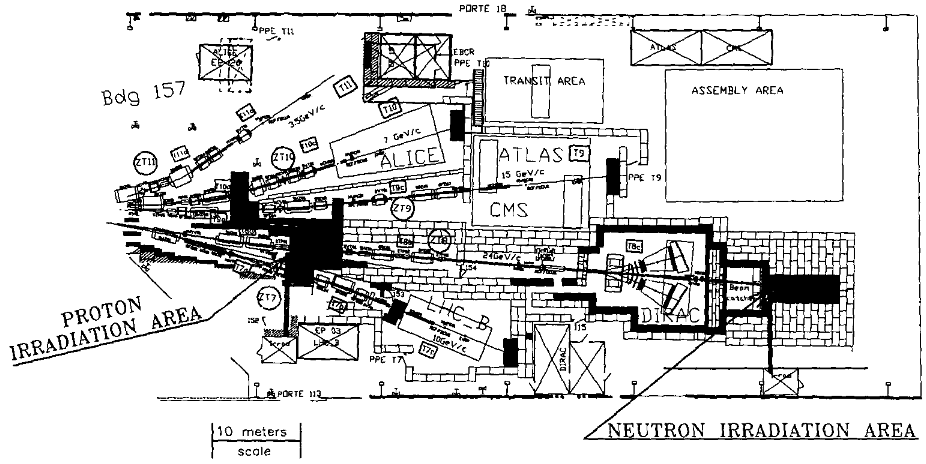

Fig. 1. Lay-out of the CERN-PS beam lines and areas in the East Hall after July 1998, showing the proton and the neutron irradiation areas.

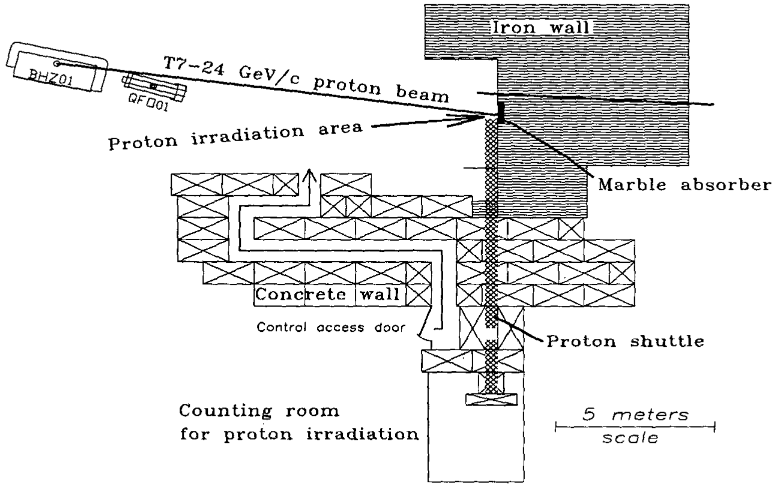

Fig. 2. Lay-out of the proton irradiation zone (IRRAD-1)

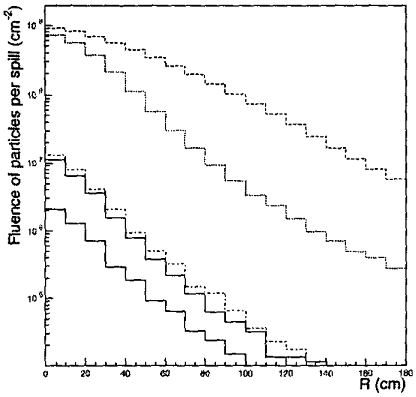

Fig. 3 : IRRAD1; Radial distribution of backscattered particles at a distance of 20 cm from the shielding wall

(from top to bottom: neutrons, gammas, positive pions, negative pions, and protons).

The primary beam intensity is 4 10^{11} protons.

In addition to this irradiation facility using the shuttle, the 24 GeV/c proton beam can also be used to perform cold irradiation (at about $-10^{\circ}C$) without using the shuttle. A cooled container is placed about one meter in front of the irradiation shuttle and is used to irradiate large (~ 6x6 cm^2) segmented silicon detectors for the LHC experiments. The irradiation uniformity is achieved by a step-by-step remote controlled displacement of the samples in front of the beam. The use of this facility requires access to the primary zone of the T7 beam, requiring the interruption of all the beams to the PS East Hall.

III. NEUTRON IRRADIATION ZONE

The IRRAD2 zone was installed in June 1999 and is being commissioned since then. Fig. 4 shows its lay-out. The irradiation is performed in a pit of cross-section 40x40 cm^2 with the secondary particles produced by the primary PS-T8 24 GeV/c beam after crossing 50 cm of graphite, 23 cm of iron and 10 cm of lead. The cavity is embedded in a iron-concrete shielding where the beam is stopped.

Fig. 5 shows the Monte Carlo simulation [4] of the radial fluence distributions expected for direct and back-scattered hadrons in the cavity and in the shuttle access channel, this fluence is normalised to one incident proton. In the centre of the cavity, in the beam axis, and for an average beam intensity of 2×10^{11} protons per spill every super-cycle (14.4 s), a hadron flux of the order of 10^9 cm^{-2} s^{-1} is expected among which 92% are neutrons, 4% are pions and 4% are protons.

Fig.6 shows the radial distribution of absorbed dose measured by means of an alanine-based dosimetric cable [5]. This shows that the total dose in plastics is 10 times higher than the dose resulting from the neutron flux. In silicon, the neutron dose is less than 1% of the total dose.

Figures 5 and 6 show that at a distance of 50 cm from the centre of the cavity (beam axis), the neutron flux decreases by a factor of 2 while the pion and proton components disappear (decrease by a factor of 100), and the gamma flux decreases by a factor of 8. It is to be noted that the simulations in the beam axis underestimate (by a factor of about 3) the total fluxes because the integrated area is (10x20) cm^2. The dose measurements (made every 3 cm) confirm that at the same distance of 50 cm, the absorbed dose has decreased by almost a factor of 40. This strong decrease comes from the decrease of the fluxes and by the fact that the particles' energies are higher on the beam axis than further away. The shuttle movement allows users to select the irradiation position, hence adjusting the relative contribution of neutrons, other hadrons and absorbed dose.

Fig. 7 shows the simulated energy spectra [4] for the hadrons in the beam axis and at a distance of 50 cm. The broad energy spectra are centred on 0.5 MeV, 800 MeV and 500 MeV for neutrons, pions and protons, respectively. The neutron-flux was measured by means of activation foils and of PIN silicon diodes. These diodes, of the type DN 156 from Harshaw, give a response *corresponding to 1 MeV equivalent neutrons* [2, 6]. They confirm that the average value of the spectrum is lower at 50 cm than in the beam axis : the measured values are 7.6×10^{-2} cm^2 and 2.1×10^{-2} $n.cm^{-2}$ per incident proton respectively in the beam axis and at 50 cm. The activations of aluminium and nickel also confirm the shape of the spectrum; the table below gives the measured neutron fluence (in the beam axis, per incident proton) above several thresholds.

Reaction	Threshold	Fluence
Co58 in Ni	2 MeV	2×10^{-2} n cm^{-2} p^{-1}
Na24 in Al	6 MeV	6×10^{-3} n cm^{-2} p^{-1}
Na22 in Al	30 MeV	3×10^{-3} n cm^{-2} p^{-1}

The next table confirms that at 50 cm from the beam axis, the neutron fluence measured by the nickel is reduced by about a factor of 10 (the activity in Al was too low to be measured.)

Reaction	Threshold	Fluence
Co58 in Ni	2 MeV	1.6×10^{-3} n cm^{-2} p^{-1}

Activations of gold and indium tend to show a higher low-energy neutron contribution than simulated. These measurements will have to be redone.

IV. RADIATION SAFETY

Hadron irradiation induces activation of material. It is the case for the samples to be irradiated as well as the moving part of the shuttle support. It has been measured that the activity induced by 10^{14} n cm^{-2} in one week-end induced an equivalent dose rate of the order of 1 mSv/h at the distance where the operator has to work. Hence the operation of these multipurpose irradiation facilities needs to be well controlled and must follow the CERN radiation safety rules as summarised in [7]. After a long irradiation, samples have to stay in a storage position before being manipulated. Samples belonging to outside institutes cannot leave CERN without formal approval by the radiation-protection group of the safety commission.

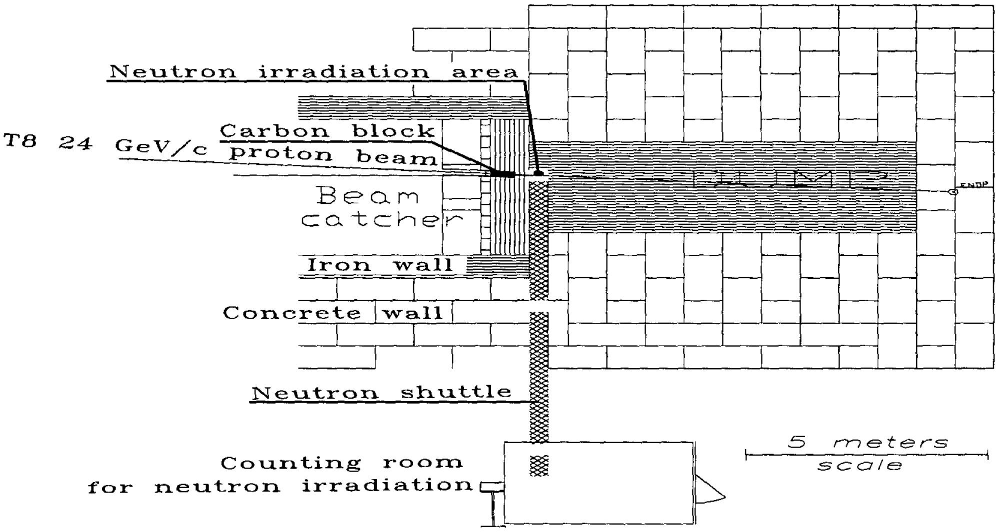

Fig. 4. Lay-out of the neutron irradiation zone (IRRAD-2)

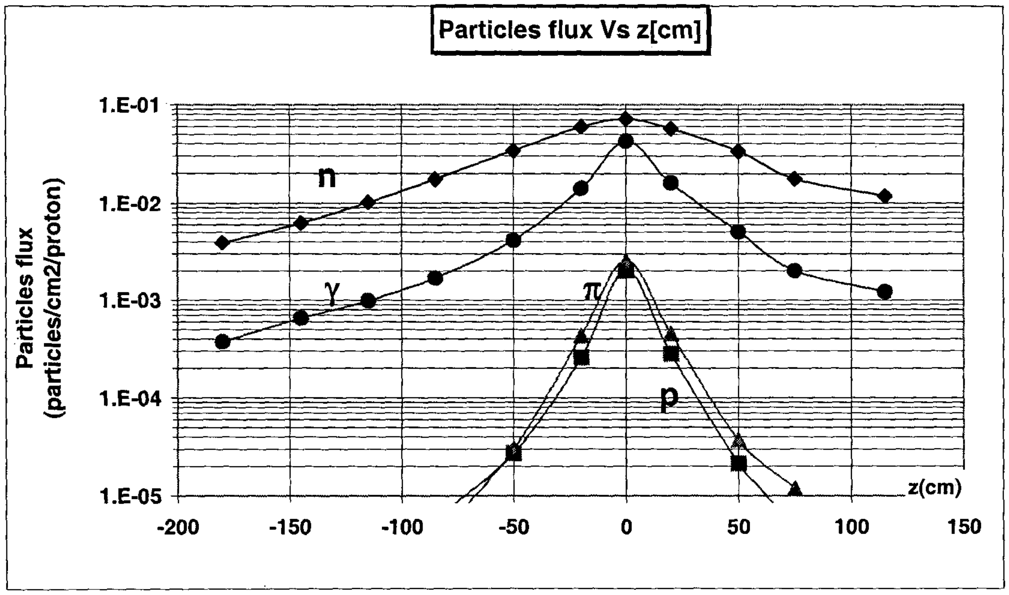

Fig. 5: Radial distribution of secondary particles in the cavity of the IRRAD2 facility, produced by 1 incident 24 GeV/c proton after crossing 50 cm of graphite, 23 cm of iron and 10 cm of lead.

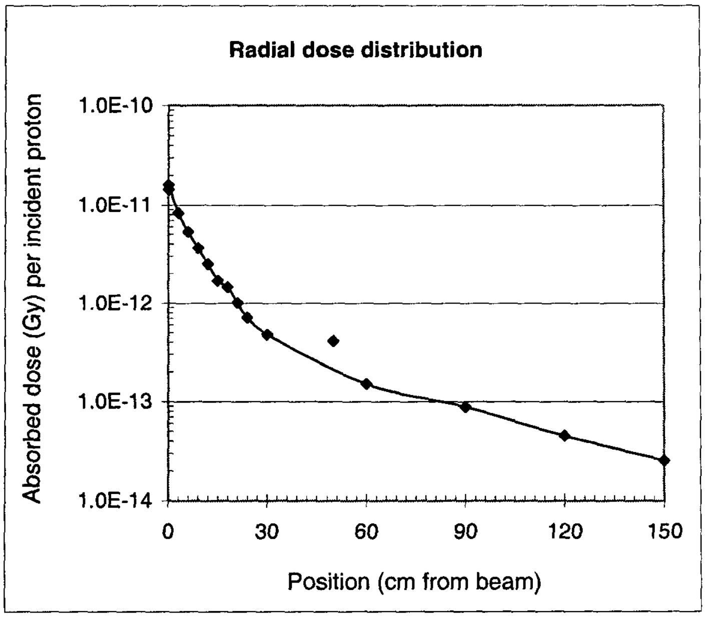

Fig. 6: Absorbed dose distribution (verticaly, from the beam axis) measurements in IRRAD2 cavity (normalized to 1 incident proton).

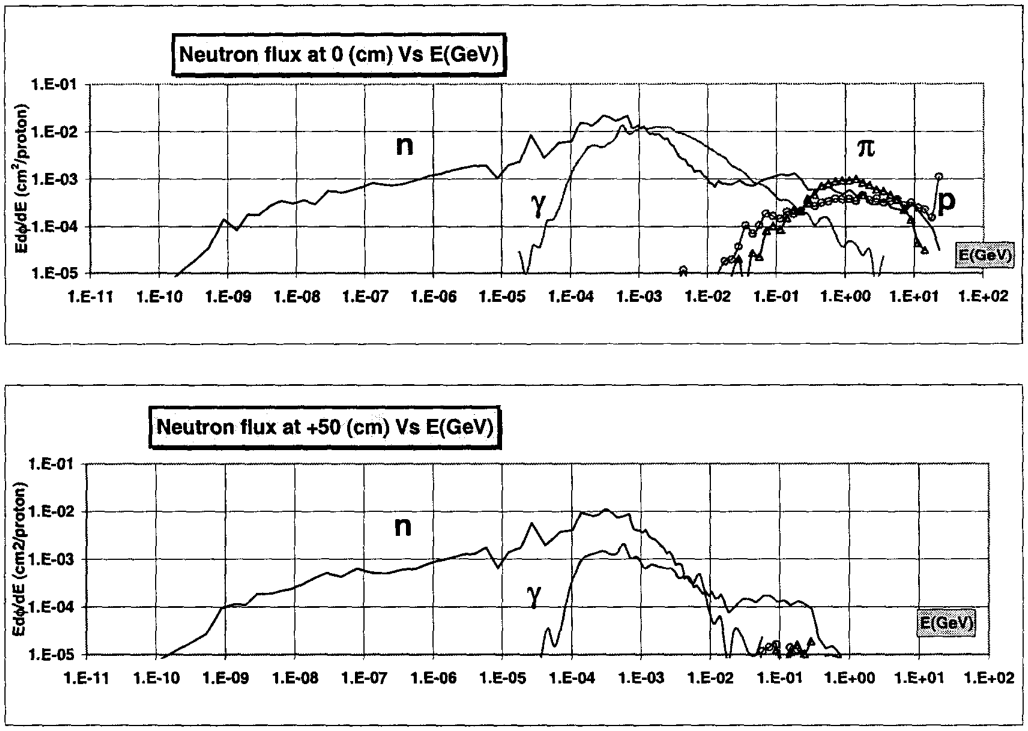

Fig. 7: Energy spectra of neutrons, gammas, protons, and pions, in the beam axis and at 50 cm from the IRRAD2 cavity centre.

V. CONCLUSION

The IRRAD1 zone is convenient for proton irradiation in order to study the typical behaviour of electronic components and semiconductor detectors either at room temperature or at − 10 °C.

In the IRRAD2 zone, the mixed particle and energy radiation field is rather similar to the radiation environment of the LHC trackers (inner parts of the detectors); it includes mainly neutrons and gammas, plus some high-energy particles. The gamma spectrum extends from 100 keV to several hundred MeV, but is mainly between 300 keV and 10 MeV. The neutron spectrum is wider, and extends to much lower energy. Except for the study of single event effects due to very high- energy hadrons, this irradiation facility could be extensively used for the testing of the LHC-experiment components. It is not representative of the radiation field in the LHC tunnel where many neutrons will be thermalised by the concrete walls.

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