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ESTIMATION AND ANALYSIS OF THE MACHINE-INDUCED BACKGROUND AT THE TOTEM ROMAN POT DETECTORS IN THE IR5 OF THE LHC

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Abstract

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Abstract

The problem of background generation in the experimental insertion IR5 of the LHC during machine operation in the dedicated TOTEM mode with low intensity beams and the specially designed $\beta^* = 1540$ m optics is discussed. The sources of the machine-induced background in the IR5 forward physics areas are identified and their relative importance is evaluated. The results of the background simulation in the IR5 are presented, based on the most recent estimates of the residual gas density for TOTEM beam conditions. The methods for background analysis and rejection are explained.

SIMULATION APPROACH

The physics programme of the TOTEM experiment at LHC requires the measurement of elastic *p*-*p* scattering down to a four-momentum transfer of $-t \sim 10^{-3}$ GeV^2 [1]. A set of Roman Pot detectors will be located in the insertion region IR5 along the beam inside the LHC tunnel symmetrically on both sides of the interaction point IP5. Each side of IP5 is featured by strong fields in the inner triplet, heavy shielding and the TAS absorber with a small mechanical aperture [2]. For the background in the detectors on Beam 1 only those interactions of beam particles with the residual gas that occur on the machine sector between upstream TAS and the Roman Pot station need be taken into account. Simulation of beam-gas collisions and subsequent secondary cascades was performed using the methodical approach developed for the solution of the radiation problems in the LHC [3]. Technical details of simulations for Roman Pot detectors can be found in [4].

ROMAN POT DETECTORS IN IR5

The mechanical layout of the right part of IR5 long straight section whose model was used in simulations is shown in Figure 1. Three locations marked as XRP1–3 are foreseen for Roman Pot stations with their positions determined in an interplay with the development of the high-β^* optics and by the requirements of integration with other LHC components. The estimations of machine induced background are presented for a plane at 220 m from the IP5, in the region of the Roman Pot station XRP3.

Each Roman Pot station is composed of two units, separated by a distance of 4 m, with each unit consisting of

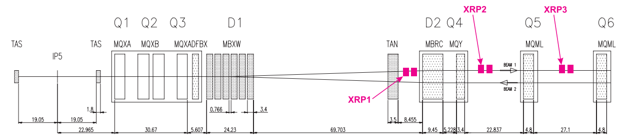

Figure 1: Mechanical layout of IR5 right straight section part with the locations of Roman Pot stations XRP1-3.

two pots that move vertically and one that moves horizontally. The model of a Roman Pot detector insertion and a sketch of the detector positions in one unit are given in Figure 2 where $\pm\, 10\sigma$+0.5cm indicates the nominal distance between the Roman Pot detectors and the beam.

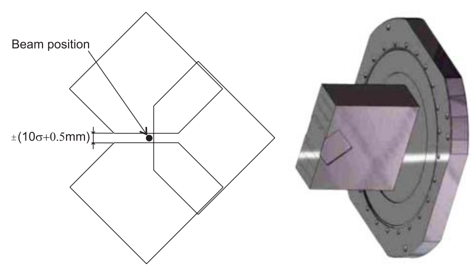

Figure 2: 3D model of Roman Pot (right) and a sketch (left) showing the overlap of two vertical and one horizontal pot.

MACHINE CONDITIONS AT TOTEM OPERATION

One of the requirements for the study of elastic and diffractive proton scattering at the LHC is the possibility to measure scattering angles down to a few μrads. For this purpose a specific option of parallel-to-point optics was designed for the TOTEM operation in IR5 of the LHC [1]. Optics functions for this solution are given in Figure 3 compared to the nominal optics of IR5. This optics provides the phase advance of $\pi/2$ at the location of the detectors, allowing the position of the scattered proton in the detector to be obtained independently of its transverse position at the interaction point. The required phase advance is achieved at a distance of 220 m from the IP5 in both planes.

The minimal detectable angle is proportional to $\sqrt{\varepsilon/\beta^*}$ so for a nominal emittance a value of β^* greater than 1000 m is required. With the increase of the upstream Q6 quadrupole gradient to 3.4 % above the nominal setting a value of $\beta^* = 1540$ m can be obtained. This optics option was introduced in the model of simulations. Since this high-β^* optics differs significantly from the nominal

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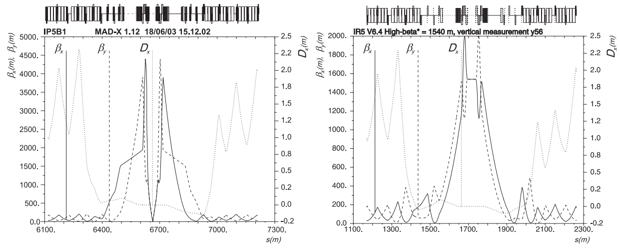

Figure 3: Functions for IR5 nominal optics ($\beta^* = 0.55$ m) (left) and special high-β^* optics (right) of LHC beam 1.

optics for high luminosity insertions, the formation of the machine induced background in the IR5 during TOTEM operation is different from the nominal machine running scenario.

The density of gas components defines the rate of interactions between beam protons and the nuclei of residual gas. Gas density distributions in LHC experimental insertions for the latest design of the LHC vacuum chambers and pumping system, different machine filling schemes and periods of operation are given in [5]. The estimations of gas densities for the machine start-up period were used in the simulations, with 156 bunches and 1.15×10^{11} protons/bunch which gives the value of 35 mA for the current.

Corresponding profiles of gas density are given in Figure 4. The vacuum chamber inside the cold mass of the magnets will be cooled down to 1.9 or 4.5 K while in the interconnections the cold bore will operate at 10 K. There a high pressure of hydrogen is predicted, represented by the spikes of the H_2 curve in Figure 4, since this gas component will not be pumped onto the surface of the cold bore in these regions. The relatively high density of other gas components there is determined by higher desorption

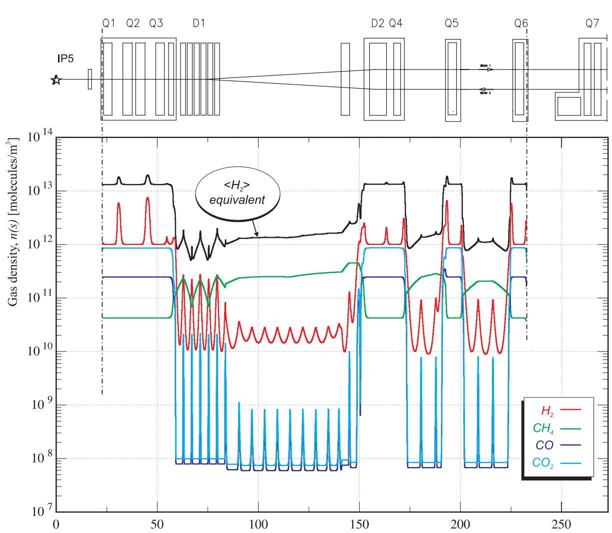

Figure 4: Profile of residual gas density components in IR5 for the period of machine start-up with nominal bunch intensity and 156 bunches [5].

yields from the unbaked surfaces. The methane is the dominant component in the room temperature regions since NEG coating there does not pump CH_4. Other peaks show the locations of uncoated and unbaked elements of vacuum chamber like stainless steel bellows and pumping ports.

PARTICLE FLUXES AND SPECTRA

The results of the simulations were particle distributions recorded at the scoring plane at 220 m with a 100 keV threshold on kinetic energy, including only those produced in the interactions with the residual gas or in the subsequent cascades. Concerning the proton flux, this excludes the unperturbed primary beam particles. Figure 5 gives particle flux maps on the cross-section of the Q5–Q6 warm vacuum chamber. Charged hadrons are clearly focused and defocused by quadrupoles of the insertion in vertical and horizontal planes, while neutrons are centered around the beam position.

Radial distributions of hadron fluxes and spectra for all particle types considered in these simulations are given in Figure 6. The peak flux density at the center of the beam is a few kHz/cm^2 for all components while pions start to dominate in the background flux at high radii. At a distance of 3–4 cm from the beam the density of $\pi^\pm$ flux exceeds the flux density of protons and neutrons by about an order of magnitude. The energy distribution of protons is featured by the diffractive peak at an energy close to 7 TeV. The pion spectra are clearly dominated by the first generation particles which are produced directly in the primary proton interaction on gas nuclei and have a resulting energy of ~ 1 TeV. Since $\pi^\pm$ also dominate in the radial distribution of particle flux, this high energy component is the most important part of the machine induced hadron background at the location of the Roman Pot station at 220 m.

BACKGROUND REJECTION

To evaluate the contamination of the Roman Pot triggers with the background, several rejection criteria were applied on the particle distributions, shown on the Figures 5 and 6:

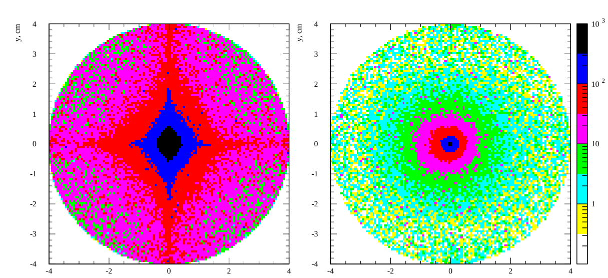

Figure 5: Particle flux density [particles/cm^2/s] for charged hadrons (left) and neutrons (right) inside the warm vacuum chamber at the location of the Roman Pot station at 220 m.

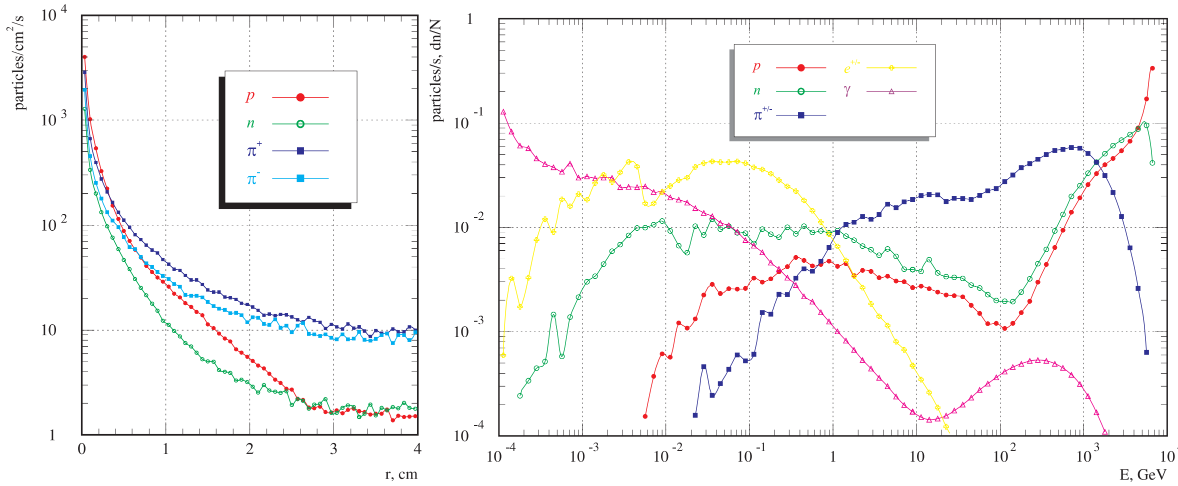

Figure 6: Particle flux density (left) and particle spectra (right) calculated for the region of the Roman Pot station at 220 m.

(1) Simple pot cut Particle must be seen in the sensitive areas of the Roman Pot — this means application of the "three pots" mask from Figure 2 to the flux maps.

(2) Simple coincidence 216×220 m Tracks of the particles are extrapolated from 220 m to 216 m — particles seen in the pot of one unit of the station must be seen also in the same pot of the other unit.

(3) Coincidence with roads Each detector is divided into 16 groups of 32 strips of 66 μm width — particle seen in a ~2 mm wide group in one pot must also be seen in the other unit within a road consisting of the same group and the 2 neighboring groups (this road width is determined by the angular spread of the elastic/diffractive signal).

Background trigger rates for different types of particles obtained by this rejection procedure are given in Table 1. The observed trigger rate from γ is further reduced by the probability of γ to interact in the Roman Pot material. From the spectrum on Figure 6 this "efficiency" correction brings the of γ triggers down to 235 Hz. Similar reasoning reduces the expected neutron trigger rate to 0.5 Hz.

Beam-gas background levels from Table 1 can be compared with the estimates of the background from the *p-p* interactions in the IP, given in [6] for the nominal optics with $\beta^* = 0.55$ m in IP5 and $L = 10^{33}$ cm^{-2}/s. Although as seen

Table 1: Particle rate integrated over the detector area of the Roman Pot station at 220 m with background rejection criteria 1–3 applied sequentially. Units are Hz, except for γ where flux is given in kHz.

	p	n	π^+	π^-	e^+	e^-	γ
1	344	174	616	406	4630	3361	94.72
2	307	131	479	289	75	122	10.17
3	303	129	385	220	21	14	3.9

from Figure 3, nominal optics of IR5 differs dramatically from the optics considered for TOTEM operation, scaling these estimates to the IP5 luminosity of 2.4×10^{29} cm^{-2}/s during TOTEM runs can be used as a first approximation. This gives a total rate of 1.62 kHz integrated over the total detector area, for charged hadron background at 220 m from *p-p* interactions in IP5. The corresponding numbers from Table 1 give a rate of 1.37 kHz for charged hadrons, indicating that at $L = 2.4 \times 10^{29}$ cm^{-2}/s secondary charged hadrons from the beam-gas losses and from the *p-p* interactions will be at the same level. The last holds for the other particle types as well.

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