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CSC Trigger Primitive Rates in ORCA

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Abstract

Recent work in ORCA has prompted us to make a new estimate of the background rates in the Level-1 CSC Trigger Primitives. We report our findings for SimHit, digi, and LCT rates, as well as the input LCT rates in the Muon Port Cards. We compare our estimates with two earlier results (Level-1 Trigger TDR, and "Background LCT Rates by CSC Type Using the Forward Muon Trigger Simulation in CMS100" by Breedon, Fisyak, Ko and Rowe), and observe some differences attributed to geometry changes, improved shielding, and improved CSC and Level-1 Trigger simulation.

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1 Introduction

An important concern for the Cathode Strip Chambers (CSCs), because of their forward location, is the high level of backgrounds expected from low-momentum primary and secondary muons, punchthrough hadrons, and neutron capture followed by gamma conversion or Compton-scattering. The rates of these backgrounds have previously been estimated in 1996 by Breedon, Fisyak, Ko and Rowe (BFKR) [1], and in 2000 by Wrochna [2]. The hit rates discussed in the Level-1 Trigger TDR (L1 TDR) were obtained assuming that every charged particle crossing the CSC produced exactly one hit per layer, and did not use the detailed simulation of the chambers and of their trigger electronics. Therefore, the work of BFKR remains the only currently available estimate of the rate of track segments found by the anode and cathode electronics of the CSC Level-1 Trigger. (These segments are also often referred to as Local Charged Tracks, LCTs.)

Since the time of BFKR there have been many modifications (e.g., in shielding, CSC geometry and trigger electronics, Monte Carlo event generators, etc.) which could result in substantial variations of LCT rates. In particular, we have recently upgraded the CSC Level-1 Trigger simulation software in ORCA [3]. In this note we present updated rate estimates for hits and LCTs, and compare our results with rates given in the L1 TDR and BFKR.

The rates presented below were obtained using two data sets generated at the University of Florida [4]: 1) a data set of 99,566 minimum bias pp interactions with kinetic energy (KE) and time-of-flight (TOF) cutoffs such that long-TOF low-energy neutron background is not included, and 2) a data set of 103,800 such minimum bias pp interactions superimposed with a simulation of the low-energy neutron background.

The first data set (to which we refer below as to “cutoff minimum bias” events) was produced as follows: First, the generation of “unweighted” minimum bias pp events using PYTHIA version 6.1 was performed. The detector response to these events was then simulated with CMSIM version 121; the KE cutoffs for particle transport were: 10 keV for $e^{\pm}$ and γ, 1 MeV for neutrons and 100 keV for other hadrons. Lastly, the digitization (simulation of the electronic response) and the generation of CSC Trigger Primitives (LCTs) were performed with ORCA version 5.2.0. At the digitization step there was a pile-up of an average of 17.3 minimum bias events per bunch crossing (bx), which corresponds to a total inelastic cross-section of 55.2 mb at a design luminosity of 10^{34} cm^{-2}s^{-1} (if one assumes that 20% of the beam crossings have no collisions because of gaps). All rates in this note are instantaneous rates between beam gaps; rates averaged over time intervals including beam gaps will be correspondingly lower.

This data set, however, did not include the CSC hits arising from thermal neutrons. Since these hits can occur as long as a tenth of a second after the pp interaction that originally produced a neutron, they were generated in a dedicated CMSIM run [5], in which the KE cutoff for neutrons was lowered down to 10^{-4} eV and the neutrons were followed for very long times. The CSC hits at times longer than 250 ns (10 bx) from the primary collision were parameterized in a so-called mc_junk parameterization of a long-TOF low-energy neutron background [5, 6]. This parameterization was used to generate our second data set, of “complete minimum bias” events, in which the neutron background hits given by the mc_junk supplemented “prompt” hits from cutoff minimum bias events. The low-energy neutron background was created using DTUJET93 for an event generator and the Muon TDR version of the CMS detector geometry (as was implemented in CMSIM version 100) because a parameterization based on PYTHIA and the latest detector geometry was unavailable; however, it contains correlations among neutron-induced hits which are not yet otherwise available. (A comparison of the neutron-background hit rates given by the mc_junk with those generated with PYTHIA 6 and accordingly the latest geometry and shielding (CMSIM version 121) showed an agreement at the 20-50% level [7].) There are slight mismatches in the two data sets which we believe are small compared to the intrinsic uncertainty in the low-energy neutron data set.

Some technical details regarding the extraction of rates from these data sets are in the Appendix.

2 Number of Hits and Digis per Bunch Crossing

The CSCs contain anode wires and cathode strips. In this Section we present rates for SimHits, Wire digis and the hardware-processed Strip digis, which we call Half-strip digis since they give half-strip position resolution. SimHits are the output of the CMSIM (GEANT3-based) simulation of the Cathode Strip Chambers; they contain an entry point, exit point, and energy deposition of a particle as it passes through a CSC gas layer. Therefore the rate of SimHits can be interpreted as the rate of charged particles traversing the CSC system.

Wire digis and Strip digis are the electronic signals caused by SimHits in the CSC anode wires and cathode strips, respectively. Their simulation [8] is performed in ORCA and includes modelling of the ionization losses in thin gas layers, description of the charge collection on the wires and strips, and simulation of the front-end CSC electronics. Wire digis, which correspond to groups of anode wires ganged together, are used without further processing. On the other hand, there are several Strip digis per particle, since the induced charge is spread over several strips in the chamber. Comparators in the front-end electronics compare signals on adjacent strips and determine a peak position with a half-strip precision. Such half-strip locations are stored in a subset of Strip digis, namely those whose signal is over the comparator threshold (eight times the RMS pedestal noise), and whose signal remains larger than both of its neighbors for 50 ns after it went over threshold. We call these digis "Half-strip digis". In this memo we present rates for Half-strip digis, which correspond closely to particle fluxes, rather than those for all Strip digis.

Figure 1 shows the distribution of the number of SimHits produced in cutoff minimum bias pp events in one bunch crossing in each CSC station. As expected, the highest rate, an average of 7.3 hits per bx, is in ME1; it drops by a factor of four in ME2, and by a factor of eight in ME3 and ME4. A peak centered at six in each of the graphs corresponds to non-showering particles traversing all 6 layers of a chamber. Some events have large numbers of SimHits confined to one station; we have hand-scanned a few of these events and found them to contain extensive electromagnetic showers. The distributions of the number of Wire digis and Half-strip digis caused by cutoff minimum bias events in one bunch crossing (Figs. 2 and 3) are similar to those of SimHits.

Table 1 gives a summary of the average numbers of SimHits, Wire digis, and Half-strip digis per bunch crossing in each of the four stations. In the last column we show the average numbers of Half-strip digis from the BFKR memo [1)]. In the first three stations the differences between the numbers obtained by BFKR and ours are no greater than 50%; the BFKR rate in ME4, however, is more than an order of magnitude higher than ours. This higher rate is due to backsplash from the outside of the CMS detector, which has since been reduced because of updates in shielding and geometry of CMS subdetectors.

	SimHits	Wire digis	Half-strip digis	BFKR (∼Half-strip digis)
ME1	7.3	5.6	5.3	5.1
ME2	1.7	1.6	1.3	1.2
ME3	0.9	0.9	0.7	1.1
ME4	0.8	0.9	0.6	8.5

Table 1: Average number of SimHits, Wire digis, and Half-strip digis produced in cutoff minimum bias pp interactions in one bunch crossing in the four CSC stations (sum of the two endcaps). The last column shows the average numbers obtained by BFKR [1], which correspond to Half-strip digis.

Figures 4 and 5 show the number of Wire digis and Half-strip digis per bunch crossing with a background that includes low-energy neutrons. There is a much larger number of both Half-strip and Wire digis in all stations, especially in ME1 and ME4. The average number of Wire digis in ME1 increases from 5.6 (no neutrons) to 25.9 (with neutrons); there is a similar shift in ME4 (0.9 to 20.0), while the shifts in ME2 and ME3 are much smaller (1.6 to 4.8 in ME2). Also of interest is that the number of bunch crossings devoid of digis is close to zero for ME1 and ME4.

For completeness we show in Figure 6 the distribution of the energy deposition in the SimHits originating from the low-energy neutron background.

3 Radial Dependence of SimHit Rates

Figure 7 shows the rates of SimHits as a function of the radial distance R from the beam line[2)]. Each plot includes two distributions: the solid histogram represents the cumulative rate of hits from minimum bias pp interactions with low-energy neutrons, whereas points with error bars show the rate of hits from minimum bias pp interactions without the low-energy neutrons. The rates in each of the stations were averaged over two endcaps and six gas layers; they can be compared to Figure 8.14 of L1 TDR, giving the rate of charged particles passing through the CSCs and the rate of hits due to thermal neutrons.

The highest rate of SimHits from pp collisions without low-energy neutrons, about 350 Hz/cm^2, is in the small R (large η) region of ME1. In all four stations, the pp hit rate rapidly decreases with R and is as low as 0.1 Hz/cm^2

[1)] These numbers were obtained from the total numbers of hits in 2,000 minimum bias events given in Table 1 of Ref. [1], assuming that 17.3 events are piled-up in every bunch crossing; they correspond to Half-strip digis in our nomenclature.

[2)] We do not discuss the R-dependence of the rates of Wire and Half-strip digis since it is similar to that of SimHits.

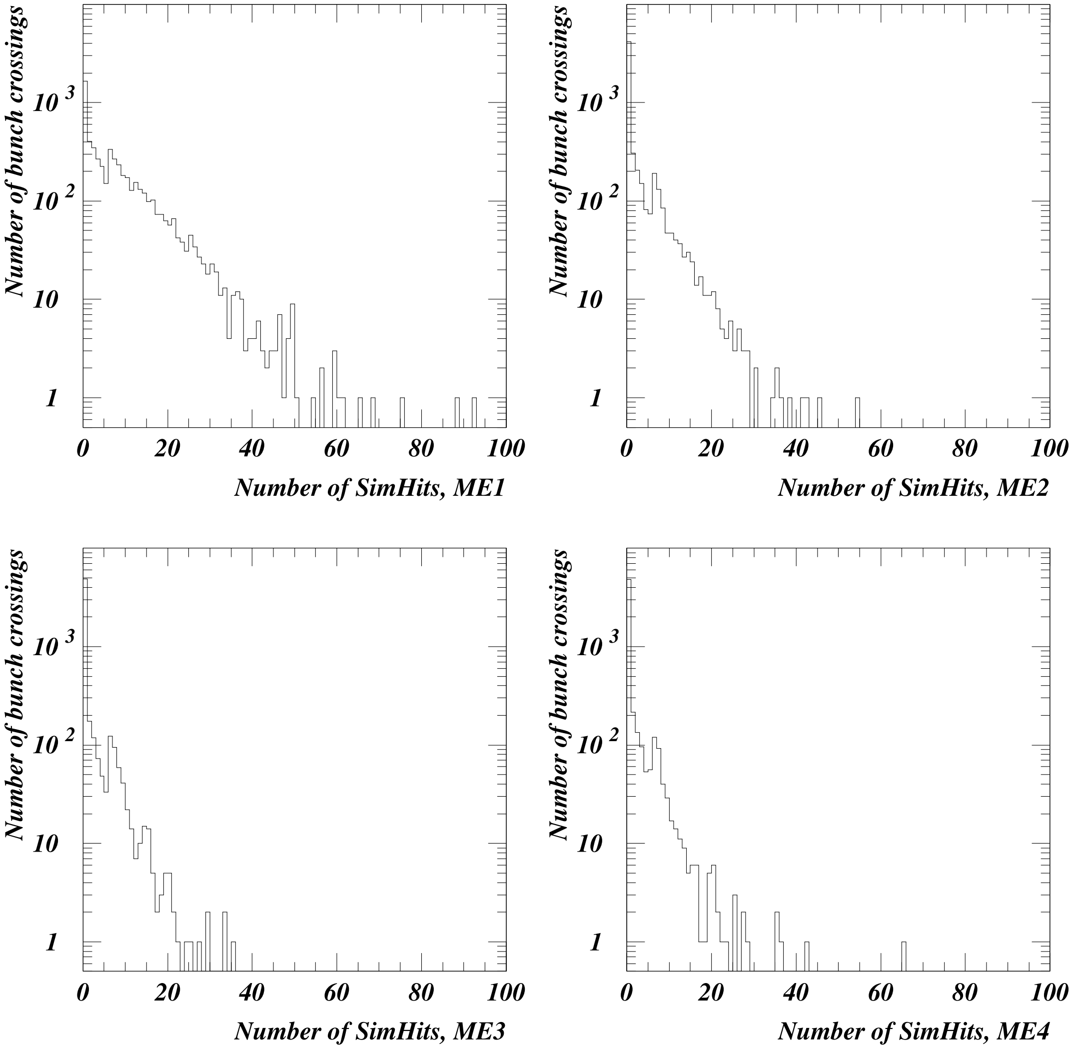

Figure 1: Number of SimHits per bunch crossing in each CSC station (sum of the two endcaps). Background induced by low-energy neutrons is not included. The peak at six hits (one per plane) is apparent.

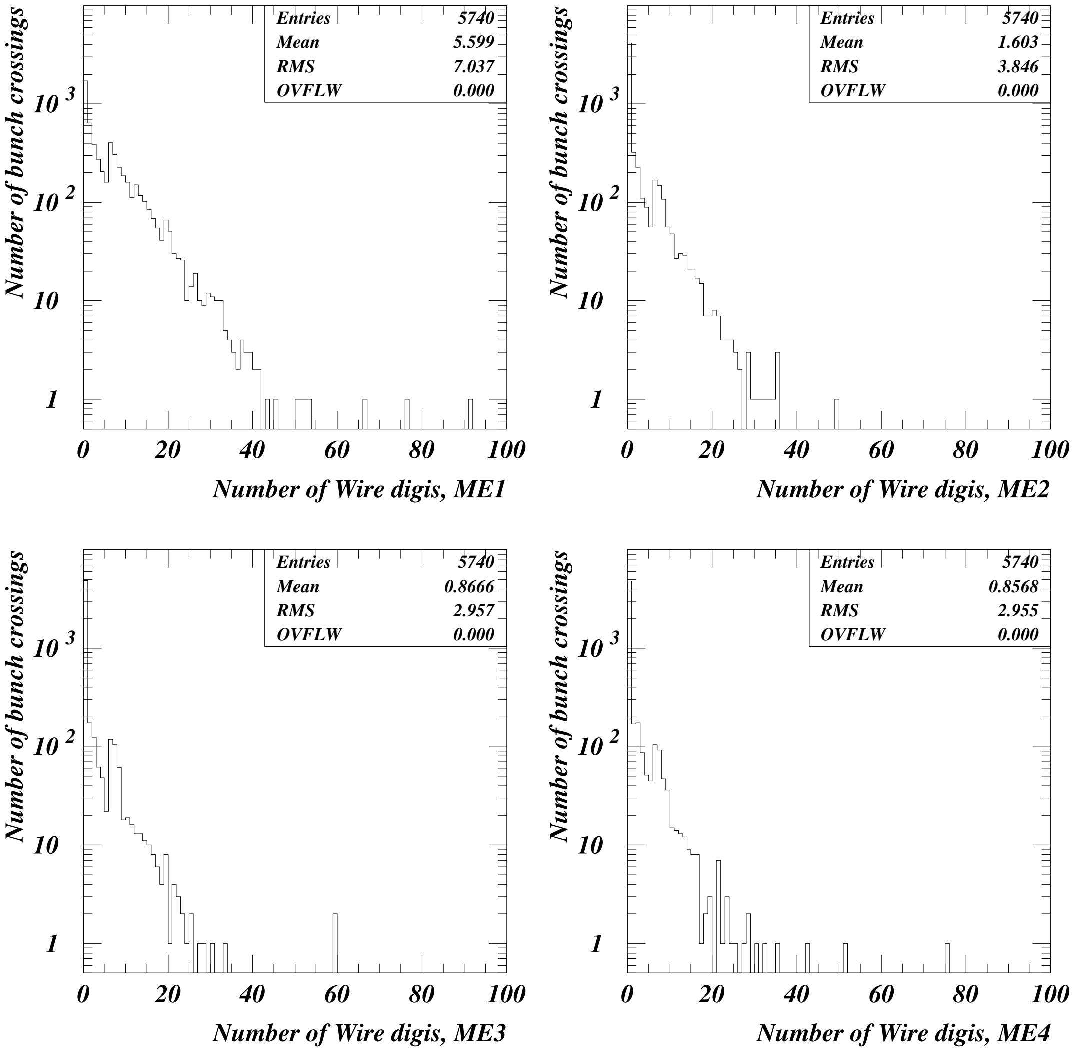

Figure 2: Number of Wire digis per bunch crossing in each CSC station (sum of the two endcaps). Background induced by low-energy neutrons is not included; Fig. 4 includes these neutrons.

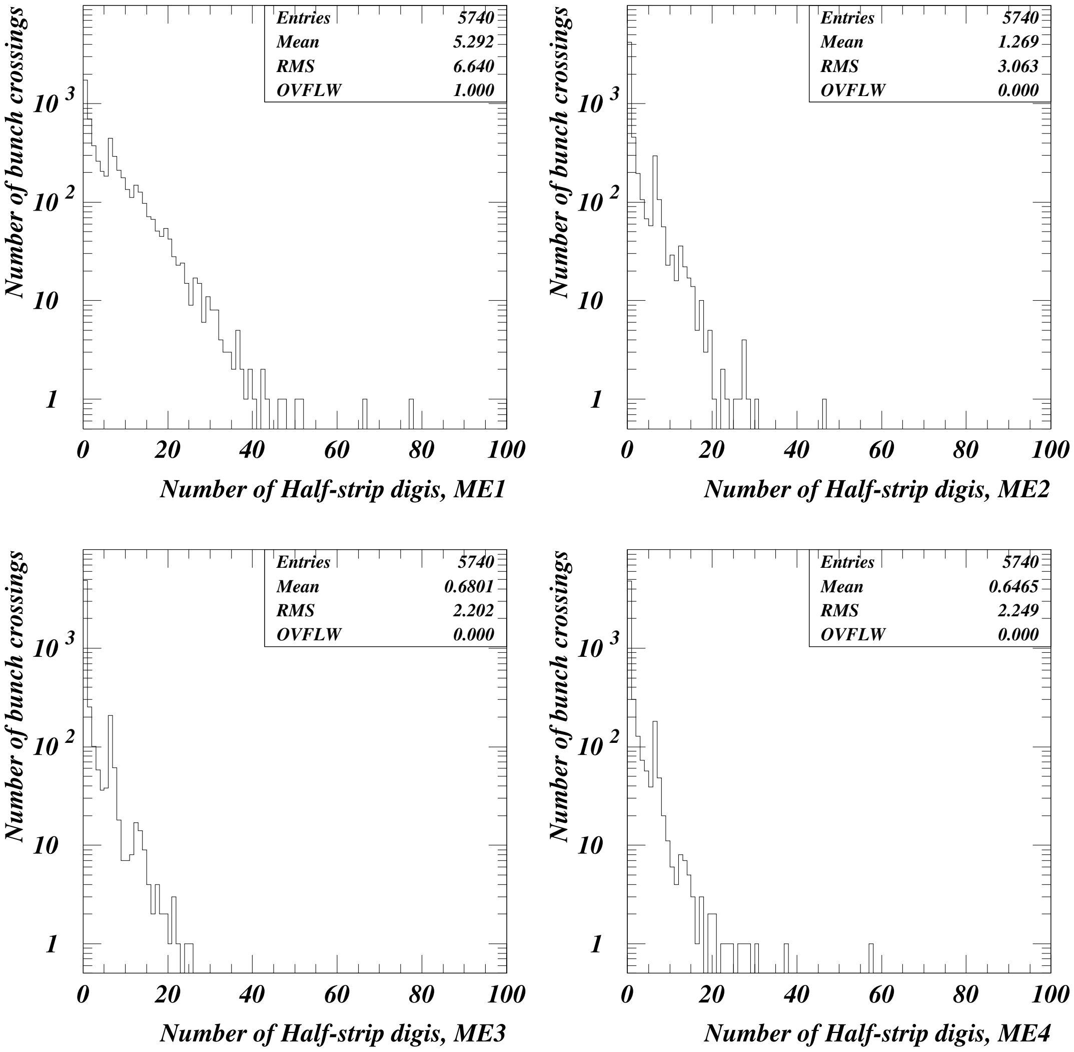

Figure 3: Number of Half-strip digis per bunch crossing in each CSC station (sum of the two endcaps). Background induced by low-energy neutrons is not included; Fig. 5 includes these neutrons.

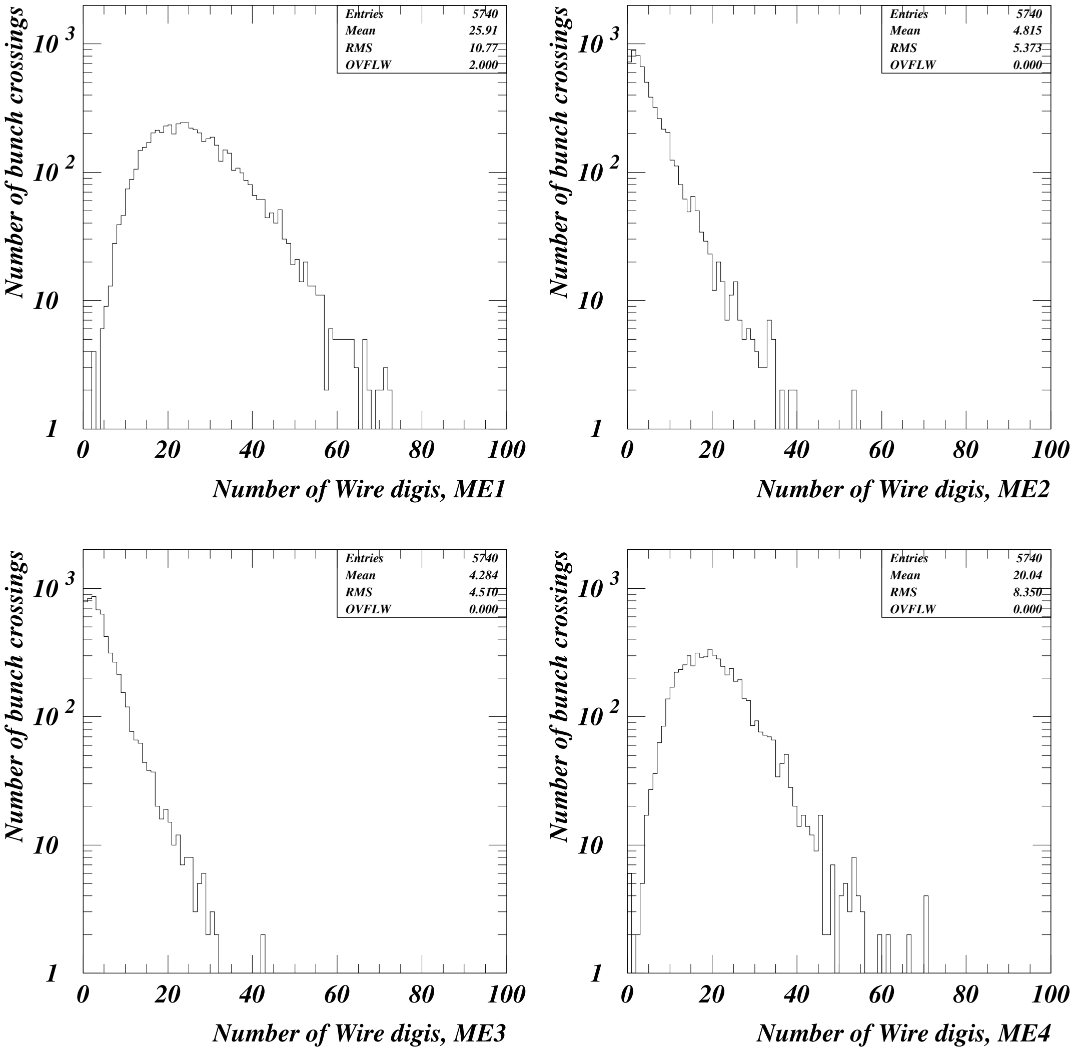

Figure 4: Number of Wire digis per bunch crossing in each CSC station (sum of the two endcaps). Both cutoff minimum bias events and the low-energy neutron background are included.

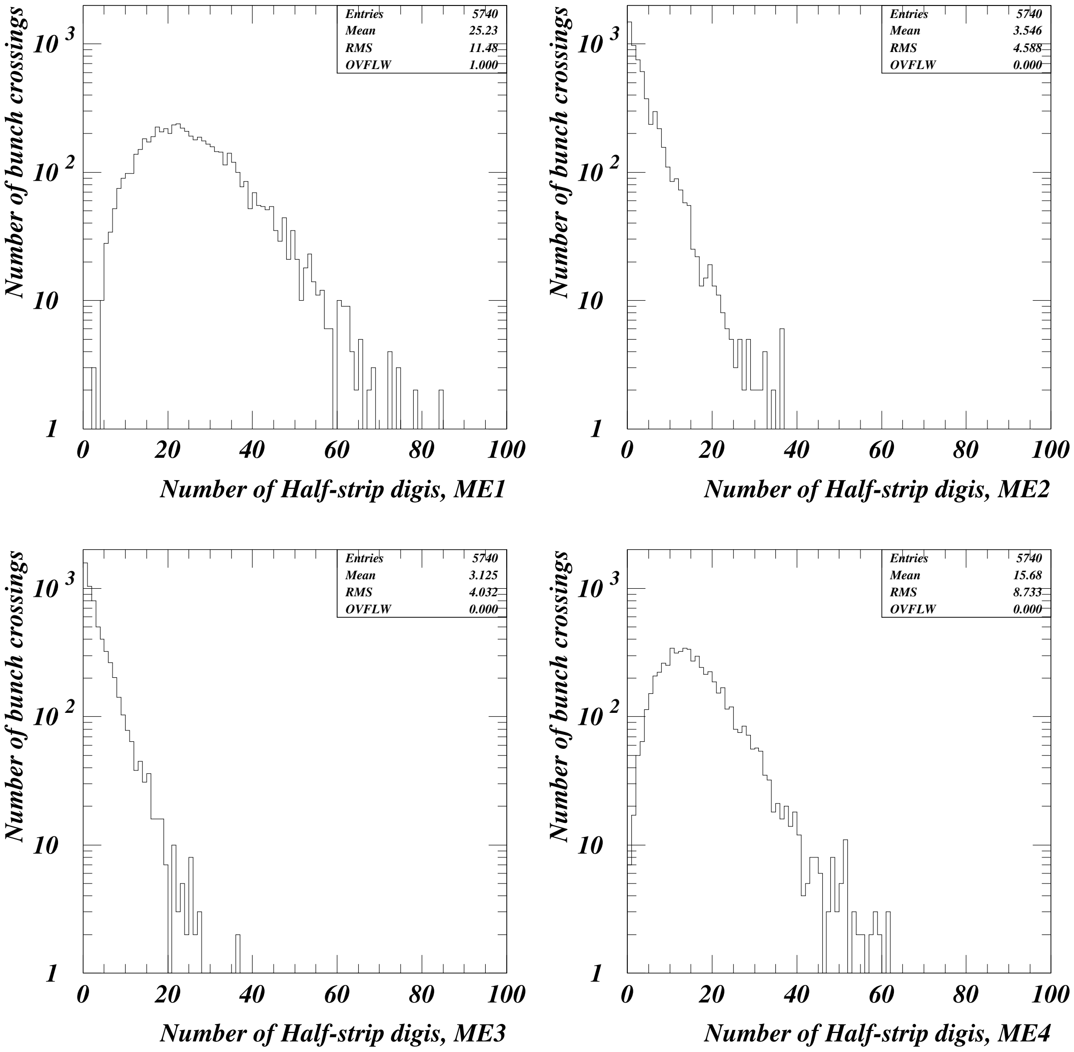

Figure 5: Number of Half-strip digis per bunch crossing in each CSC station (sum of the two endcaps). Both cutoff minimum bias events and the low-energy neutron background are included.

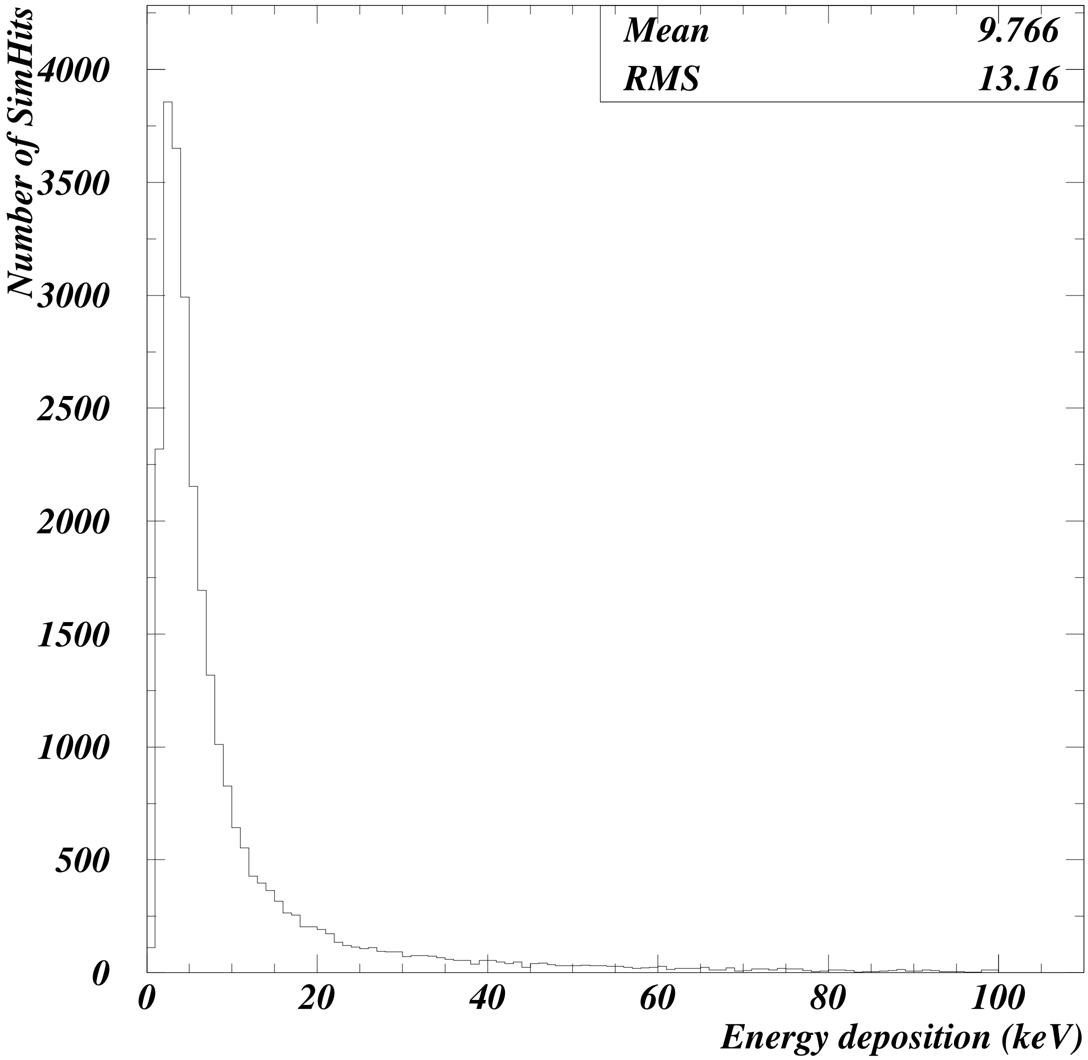

Figure 6: Energy deposition in the SimHits produced by the low-energy neutron background [9]. (The mean energy loss of a 100 GeV muon traversing 1 cm gas gap of the CSC is 3.4 keV [8].)

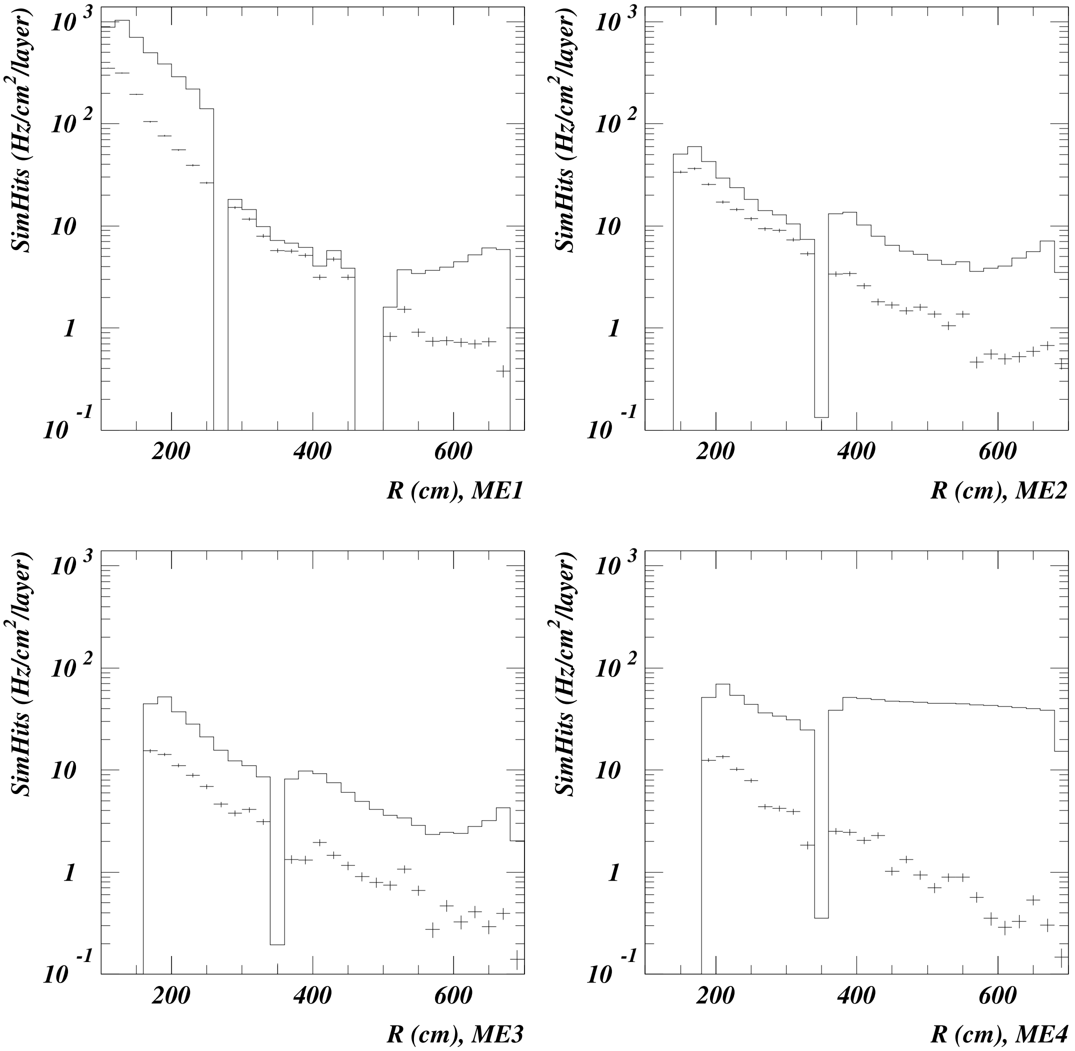

Figure 7: The simulated rates of SimHits (given in Hz/cm^2/layer) in each CSC station, as a function of the radial distance from the beam line. The solid histogram represents the cumulative rate of hits from cutoff pp interactions and low-energy neutrons; points with error bars show the rate of hits from minimum bias pp collisions without the low-energy neutrons (the errors are statistical).

near the outer edges of ME3 and ME4. Punchthrough and backsplash hadrons account for about 17% of the total number of "prompt" SimHits; the mean momentum of these hadrons in the CSCs (averaged over all four stations) is only ~ 500 MeV. The remaining 83% of "prompt" pp hits are produced by low momentum muons ($\langle p_\mu^{\rm CSC} \rangle \sim 2$ GeV) and electromagnetic showers.

The presence of the low-energy neutron background significantly increases the hit rate. This increase is the largest, more than an order of magnitude, in ME4/2. The highest total rate of SimHits, about 1000 Hz/cm^2, is again in the small R region of ME1/A.

In addition to minimum bias pp collisions, there are two other potential sources of background hits in the CSC chambers: cosmic rays and particles produced in the interactions of the primary protons with the beam elements (often referred to as beam halo muons). These two sources are not currently included in our study. The contribution of cosmic rays is expected to be $\sim 2 \times 10^{-4}$ Hz/cm^2 [2], a negligible amount. The estimated rate of beam halo muons varies from 10^{-2} Hz/cm^2 to 1 Hz/cm^2 depending on the radial distance from the beam; it is expected to reach its maximum value near the beam line and decrease with R [10]. Comparing the R-dependence of the beam halo muons with the cutoff pp rates shown in Figure 7, we can conclude that the relative contribution of beam halo muons can reach at most 10% of the pp background rate; this relative contribution is expected to be the largest in those regions of R where the pp hit rate is the lowest.

Table 2 compares the rates in the L1 TDR with those of the present study. In ME1, the L1 TDR pp rates are almost a factor of two lower than ours near the beam line and remain lower until the outer edge of the chambers. L1 TDR pp rates in ME2 and ME3 are similar to ours near the beam line, but are about two times less than ours at larger R values. The largest discrepancy is in ME4 where the L1 TDR predicts three times our pp rate at small R, and about five times ours near the CSC outer edge. Higher rates in the first three stations found in the present study are probably due to electromagnetic showers and secondary interactions which were not taken into account in the L1 TDR estimates [11]. The lower rate in ME4 is likely due to improved shielding from backsplash hadrons.

A look at the inclusion of low-energy neutrons shows that ME1/1 and ME4/2 are the only two regions in the CSC system where the L1 TDR rates are significantly different from ours. The L1 TDR rates are about a factor of three lower than ours in ME1/1 and about a factor of four lower in the inner part of ME4/2. These differences are most likely due to intrinsic differences in the models used to simulate the neutron background in our study and in the L1 TDR [12].

		200 cm		300 cm		400 cm		500 cm		600 cm		700 cm	
		pp	pp+n	pp	pp+n	pp	pp+n	pp	pp+n	pp	pp+n	pp	pp+n
ME1	TDR	34	91	8.2	12	4.0	7.2	0.3	1.2	0.1	3.1	–	–
	This work	66	340	13	16	4.2	5.2	0.8	1.6	0.7	4.2	–	–
ME2	TDR	24	61	3.7	25	1.3	6.0	0.4	4.8	0.2	3.7	0.2	3.0
	This work	21	36	8.2	12	3.0	12	1.5	5.0	0.5	4.0	0.4	3.5
ME3	TDR	18	44	3.0	36	1.1	8.7	0.6	4.1	0.6	3.8	0.3	5.0
	This work	13	45	3.9	12	1.7	9.6	0.8	3.9	0.4	2.4	0.1	2.0
ME4	TDR	35	85	5.8	24	1.7	12	1.7	11	1.2	14	1.4	13
	This work	13	60	4.0	32	2.3	51	0.8	46	0.3	42	0.1	15

Table 2: Hit rates (in Hz/cm^2/layer) for several R values in each CSC station, obtained in the Level-1 Trigger TDR (Figure 8.14 of Ref. [2]) and in this study. For each R, the first column (labelled pp) shows the rate for cutoff minimum bias events only, the second column (labelled pp+n) shows the sum of rates for cutoff minimum bias events and low-energy neutrons.

4 Rates of Anode and Cathode Local Charged Tracks

Within a six-layer station, a coincidence of Wire digis on at least four CSC layers within one of several pre-defined six-layer templates defines an Anode Local Charged Track (Anode LCT, or ALCT). Similarly, a coincidence of Half-strip digis on at least four layers defines a Cathode LCT, or CLCT. (The templates for CLCTs allow for bending as well.)

In order to estimate the rate of ALCTs or CLCTs, we analyzed the sample of cutoff minimum bias events in two different ways: 1) one collision at a time, multiplying the resulting rate by 17.3 (thus making an assumption that

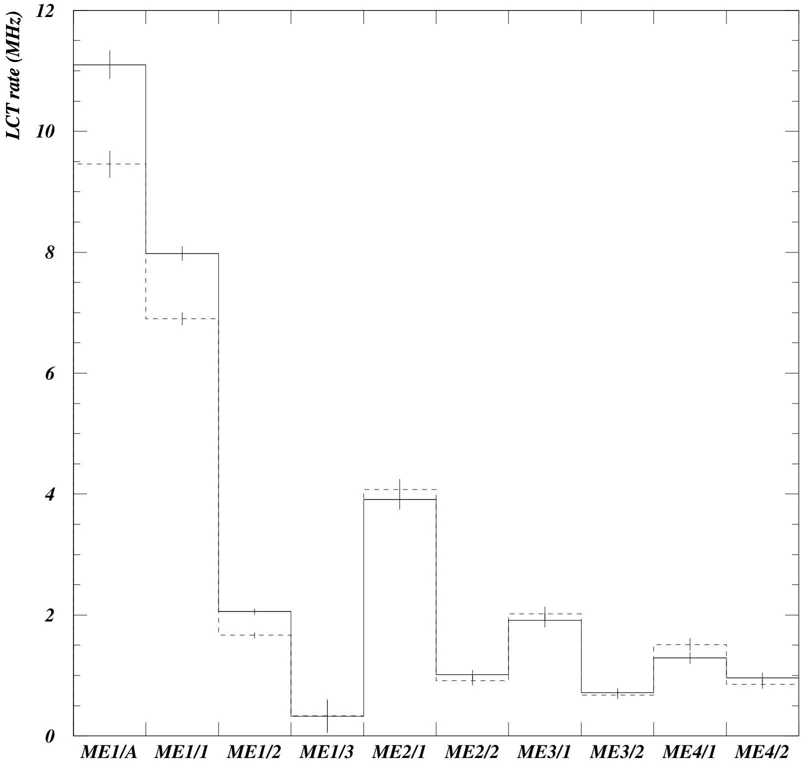

Figure 8: The measured simulated rate of ALCTs (solid line) and CLCTs (dashed line) from cutoff minimum bias pp interactions without the low-energy neutron background, in all types of CSC chambers (sum of the two endcaps). The errors are statistical.

the rate scales linearly with the pile-up), and 2) superimposing SimHits from n events, where n is sampled from a Poisson distribution with a mean of 17.3. The rates obtained with the two methods were similar: if the events are piled-up (method 2), the overall rate of both CLCTs and ALCTs increases by only about 7% compared to the linear pile-up assumption. In the rest of this Section we discuss the results obtained with method 2.

The rates of ALCTs and CLCTs originating from cutoff minimum bias pp interactions are shown by chamber type in Figure 8. The highest rate is in ME1/A: about 11 MHz for ALCTs and 9.4 MHz for CLCTs. The lowest rate, about 0.3 MHz, is in ME1/3 which covers the smallest η region among all rings of CSC chambers. Also, the rates in ME4/2 are $\sim$ 30% higher than in ME3/2; this could be due to a combination of a more forward location of ME4/2 and a larger backsplash.

A separate comparison of ALCTs and CLCTs reveals that in ME1 there are 17% fewer CLCTs than ALCTs. We believe this is due to a currently defined set of CLCT patterns: these patterns are narrow enough to exclude the large bending of very low p_T tracks. All other stations have nearly equal CLCT and ALCT rates.

The rates of ALCTs and CLCTs in minimum bias pp interactions superimposed with the low-energy neutron background are shown by chamber type in Figure 9. For comparison we also show the rates in minimum bias events without low-energy neutrons. An inclusion of the neutron background results in a moderate rate increase of 30% or less in the first three stations, but leads to a rate three times higher in ME4 (more than 5 times the cutoff minimum bias rate in ME4/2 alone). ME4/2 has the highest rate due to neutrons, 5.1 MHz and 4.0 MHz for ALCTs and CLCTs, respectively. The highest total rates are again in ME1/A: 12.9 MHz ($\sim$ 180 kHz/chamber) for ALCTs and 10.4 MHz ($\sim$ 140 kHz/chamber) for CLCTs.

A comparison to the ALCT and CLCT rates of BFKR [1] shows that our rates in the absence of low-energy neutrons are somewhat higher in all the stations except for ME4/2. Again, the rate in ME4/2 is different because there was no YE4 shielding wall and the forward beam line shielding was not yet optimized in the 1996 design. A

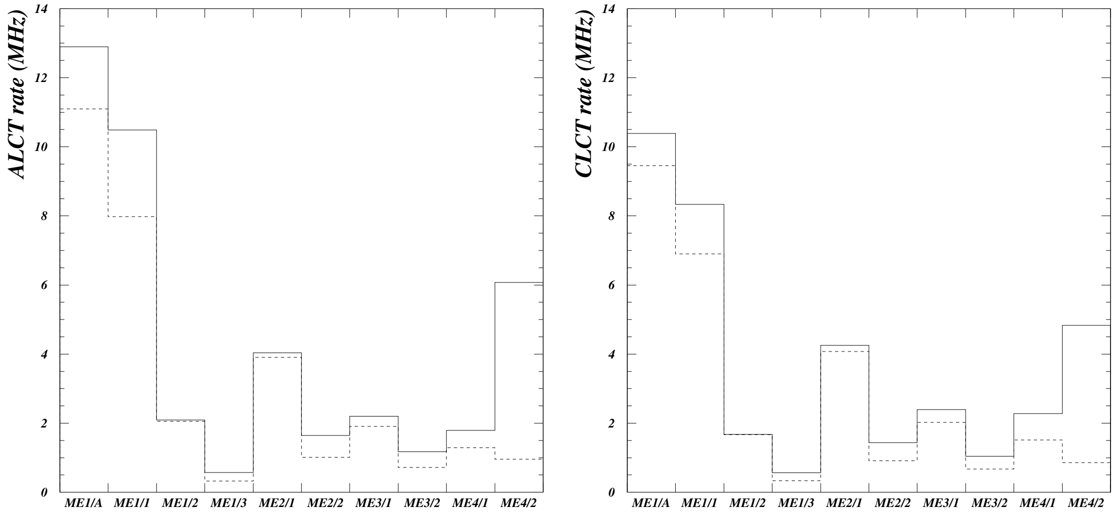

Figure 9: The measured simulated rate of ALCTs (left) and CLCTs (right) from cutoff minimum bias pp interactions without the low-energy neutron background (dashed line) and with the low-energy neutron background (solid line), in all types of CSC chambers (sum of the two endcaps).

more detailed comparison is made difficult by very low statistics of the Monte Carlo sample used for the BFKR study (their estimates of the rates in the first three stations are based on 16 CLCTs and 10 ALCTs) [13].

5 Number of Input LCTs to the Muon Port Cards

The next step in the Level-1 Trigger Primitive process is the attempt to match ALCTs with CLCTs, performed by the Trigger Motherboards. The results of the attempted matches are known simply as LCTs. If either an ALCT or a CLCT is absent in the matching, we call the LCT an "uncorrelated LCT". Likewise, if both are present, we call the LCT a "correlated LCT". Both correlated and uncorrelated LCTs are transmitted to the Muon Port Cards (MPCs); hardware bits are used to identify each kind. Since the Port Cards must reduce the rate by selecting only a few of the best LCTs, measurement of the number of LCTs going from the Trigger Motherboards into the MPCs is crucial for questions concerning data acquisition and physics searches.

There is one MPC for every 20 degree subsector in ME1. These Port Cards select only 2 out of a possible 16 LCTs/bx (16 since each subsector contains 8 chambers, and each chamber can process 2 LCTs/bx). The MPCs in the other stations are slightly different; with a coverage of 9 chambers over 60 degrees, they select 3 out of 18 possible LCTs. Physics searches can be affected by these restrictions. For example, if both muons from a $J/\psi \rightarrow 2\mu$ decay cause LCTs confined to a single subsector in ME1, an additional LCT from in-time minimum bias events might be selected instead and might result in a loss of a desired trigger.

Figure 10 shows the number of LCTs entering the Port Card, for minimum bias events without low-energy neutrons. In 5740 bx's, only 13 MPCs out of 206,640 (36 MPCs $\times$ 5740 bx's) in ME1 have more than 2 LCTs; the fraction of MPCs in ME1 with more than 1 LCT is 0.1%. The highest number of LCTs is 5; it occurs only twice, and is still less than one third of the highest possible number (16) of input LCTs. The other stations have only one occurrence with an input number greater than 2. The mean input LCT number for ME1 is 0.016, that of the other stations is 0.008; clearly most MPCs are completely empty. When including the low-energy neutron background (Figure 11), this number is not much bigger: 0.019 (ME1) and 0.012 (everywhere else); this is not surprising since neutrons contribute to only an $\sim$ 30% higher LCT rate in all stations except ME4.

6 Rates of LCTs

In this Section we discuss the rates of LCTs selected by the Muon Port Cards. As noted above, the term "LCT" is used to designate either a "correlated" or "uncorrelated" LCT. For this reason, the total LCT rate (correlated plus uncorrelated) should be higher than either the ALCT or CLCT rates. A comparison between Figure 12 and

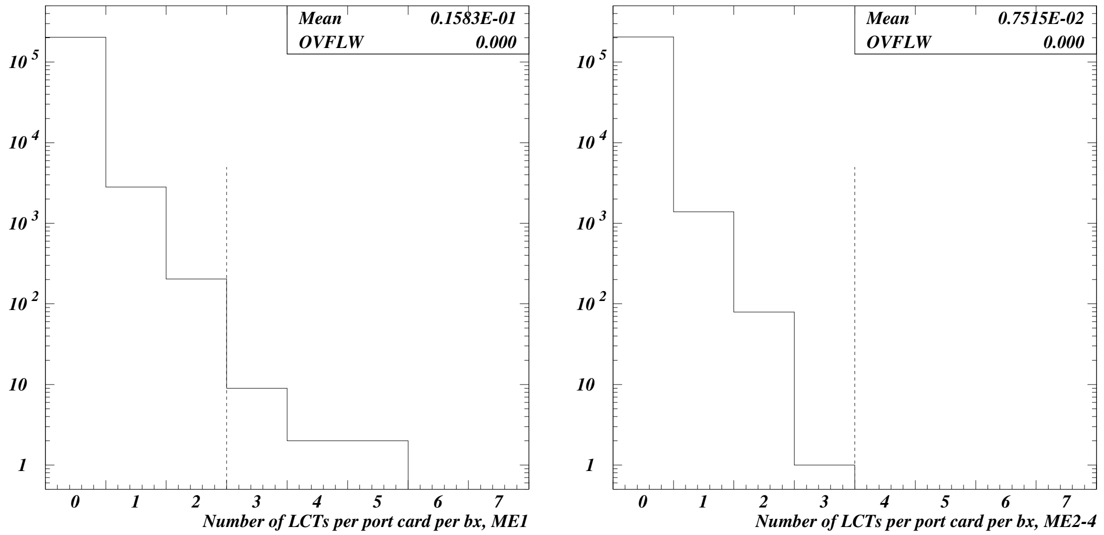

Figure 10: Number of input LCTs (correlated and uncorrelated) per Port Card and per bunch crossing in minimum bias pp interactions without low-energy neutrons, in ME1 (left) and in ME2, ME3 and ME4 (right). The maximum allowed number of output LCTs per MPC (2 in ME1 and 3 in all other stations) is shown in vertical dashed lines.

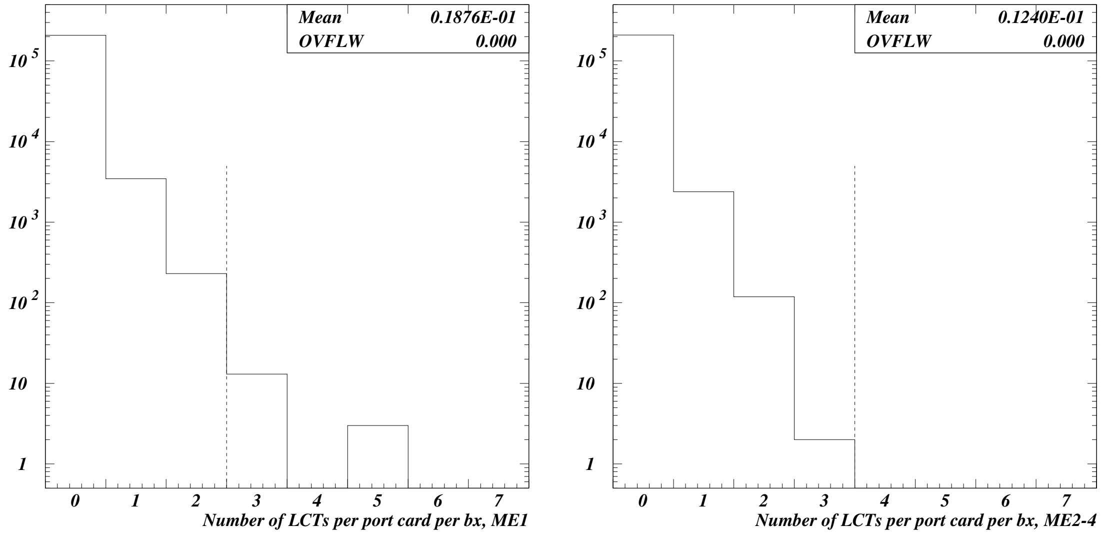

Figure 11: Number of input LCTs (correlated and uncorrelated) per Port Card and per bunch crossing in minimum bias pp interactions including the low-energy neutron background, in ME1 (left) and in ME2, ME3 and ME4 (right). The maximum allowed number of output LCTs per MPC (2 in ME1 and 3 in all other stations) is shown in vertical dashed lines.

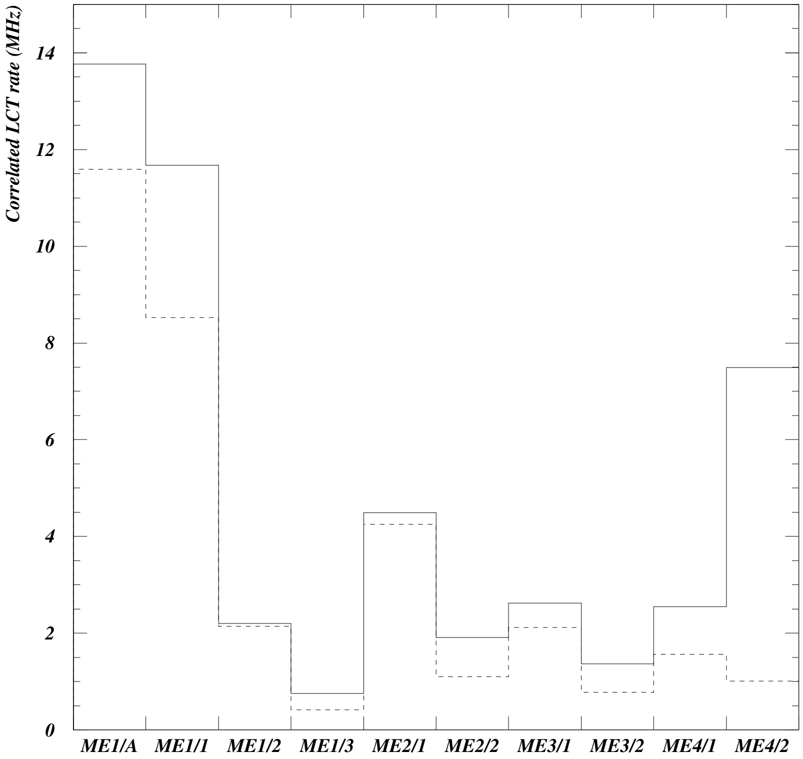

Figure 12: The rate of LCTs (correlated plus uncorrelated) selected by the Muon Port Cards in minimum bias pp interactions without the low-energy neutron background (dashed line) and with the neutron background (solid line), in all types of CSC chambers (sum of the two endcaps).

Figure 9 shows exactly that: the LCT rates are $5 - 15\%$ higher than the ALCT rates if the low-energy neutron background is not included, and $10 - 30\%$ higher than the ALCT rates when the low-energy neutron background is included.

It is currently foreseen that the uncorrelated LCTs will be used mainly for testing, calibration and efficiency studies, whereas the presence of a correlated LCT will be required to initiate a muon trigger. In Figure 13 and in Table 3 we show the rates of only the correlated LCTs. The highest rate is 9.5 MHz (in ME1/A); the lowest rate is 0.4 MHz (in ME1/3). The highest rate of correlated LCTs due to low-energy neutrons, 2.6 MHz, is again in ME4/2. A comparison between Figure 13 and Figure 9 shows that the rates of correlated LCTs in minimum bias events including the low-energy neutron background are about 30% lower than the ALCT rates in ME1 and in the outer rings of ME2 and ME3, about 10% lower than the ALCT rates in the inner rings of ME2, ME3 and ME4, and almost two times lower than the rate of ALCTs in ME4/2.

	ME1				ME2		ME3		ME4	
	ME1/A	ME1/1	ME1/2	ME1/3	ME2/1	ME2/2	ME3/1	ME3/2	ME4/1	ME4/2
pp	9.0	6.4	1.6	0.3	3.7	0.8	1.8	0.6	1.2	0.8
pp + n	9.5	7.2	1.6	0.4	3.8	1.2	2.0	0.9	1.5	3.4

Table 3: The rate of correlated LCTs (in MHz) selected by the Muon Port Cards in minimum bias pp interactions without the low-energy neutron background (labelled pp) and with the low-energy neutron background (labelled pp+n), in all types of CSC chambers (sum of the two endcaps).

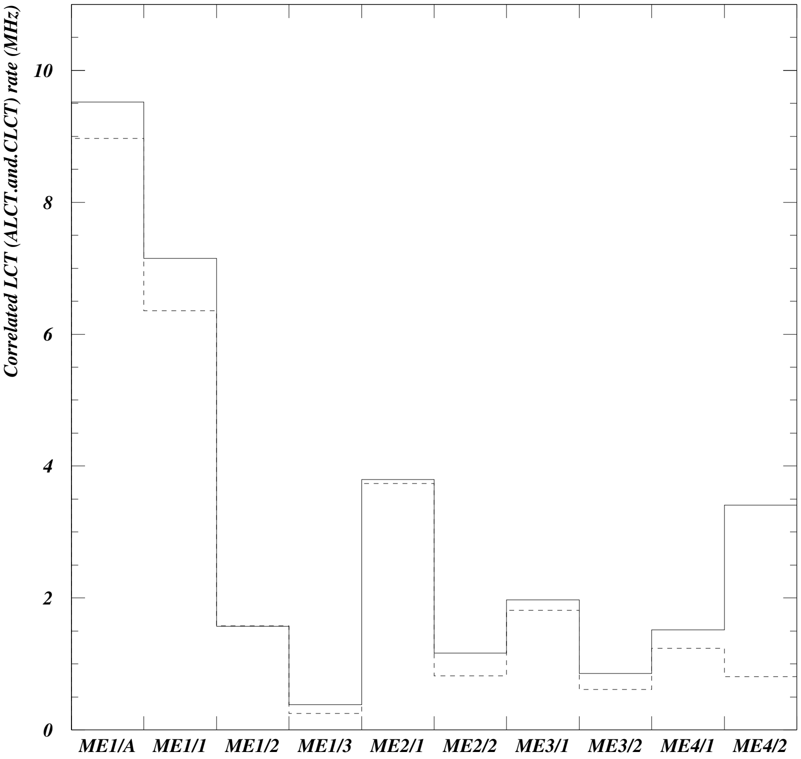

Figure 13: The rate of correlated LCTs selected by the Muon Port Cards in minimum bias pp interactions without the low-energy neutron background (dashed line) and with the neutron background (solid line), in all types of CSC chambers (sum of the two endcaps).

7 Conclusion

The above plots and tables are our first estimates of SimHit, digi, and LCT rates in the CSCs for minimum bias events using recent versions of ORCA and CMSIM. We obtained these estimates both with and without the background arising from thermal neutrons, and compared them with the earlier results. The differences observed are not surprising, given the tools available at the time of previous calculations and the extensive updates in detector geometry, shielding, and software since then.

We include the low-energy neutron background within the framework of the only currently available model which connects neutron flux calculations to the CSC hit rates [5, 6], including correlations of hits from multiple Compton-scatters. The resulting hit rates agree reasonably (within a factor of four or so) with the CSC neutron fluxes predicted by a completely different and well-advanced simulation of the neutron background [12], which has not yet been interfaced to the CSC simulation. Although the presence of the neutron background significantly increases the hit and digi rate in many CSCs, it typically leads only to a moderate increase (of 30% or less) in the rate of LCTs. Overall, the resulting trigger rates, the highest of which is about 13 MHz in ME1/A, seem bearable.

Finally, we show estimates of the numbers of LCTs going from the Trigger Motherboards into the Muon Port Cards. The average numbers of input LCTs seem to be well below the MPC restrictions even in the presence of the neutron background. More studies with the now-available tools are needed to quantitatively estimate the impact of the MPC restrictions on various physics analyses.

Appendix: Technical Notes

Here we briefly mention a few technical details about how our plots and numbers were obtained. The main goal of the procedure outlined below was to circumvent a deficiency in the way the MPC simulation currently handles the out of time LCTs.

Each event in the cutoff minimum bias data set was simulated at the bunch crossing time of zero; neither earlier nor later bx's were included. The SimHit, digi and LCT contributions from earlier and later bx times to the "current" bx were approximated by including into our plots *all* the hits, digis and LCTs produced in the "current" bx at zero, regardless of the "reconstructed" bx time assigned by the digitization (for digis) or by the generation of the Trigger Primitives (for LCTs).

Each event in the complete minimum bias data set contained two sources of SimHits: 1) at zero bx time, from the piled-up cutoff minimum bias pp interactions; 2) in the time interval between -10 and $+10$ bx's, from the low-energy neutron background. In order to obtain the distributions of the number of digis per bx in the presence of the neutron background (such as the ones shown in Figs. 4 and 5), we first histogrammed the number of digis per bx arising exclusively from neutrons. This was done by counting digis at one arbitrary bx time far from zero, where the contribution from the minimum bias events at zero is negligible. At the next step we generated two random numbers, one distributed according to the number of digis in the cutoff minimum bias data set, and one – according to the number of digis exclusively from neutrons, and histogrammed the sum of these two numbers; this step was repeated a sufficient number of times. A similar procedure was also used to obtain the distributions of the number of input LCTs per MPC and per bunch crossing in the presence of the neutron background shown in Figure 11. Finally, the LCT rates including the neutron background (shown in Figs. 9, 12 and 13) were calculated by subtracting the LCT rate in cutoff minimum bias events from the total rate of LCTs in complete minimum bias events, dividing the resulting rate (due to low-energy neutrons, integrated over 20 bx's) by 20, and adding again the LCT rate in cutoff minimum bias events. The same procedure was used to obtain the cumulative rates of SimHits as a function of the radial distance from the beam line (Figure 7).

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