The effect of radiation background on the MDT data acquisition

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September 1, 2003

Abstract

The effect of the background radiation on the throughput requirements of the MDT DAQ system was evaluated, taking the overall system architecture into account.

1 Description of the method used

The effect of the background muon count on the MDT data acquisition is estimated as follows. First, the background rate of each muon tube is estimated using the simulated photon counts as available on the atlas website. The calculated rates serve as input to the DAQ simulation program, in which the electronics response is simulated as far as the data volume is concerned. Furthermore, using a simulated trigger behavior, the throughput and buffering requirements are evaluated. It is possible to adjust several parameters in this program, which correspond to properties of the DAQ system.

2 Background rates in the muon detector

The muon background rates have been derived from the calculated photon flux, which can be found on the web[1]. For each chamber, the average photon flux is determined. The dimensions and location of the detector are obtained from the parameter book[2]. The muon count rate is taken to be 1 % of the average photon

[1] http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/RADIATION/Radiation_Levels.html
[2] http://atlas.web.cern.ch/Atlas/GROUPS/MUON/layout/MDT-parameter-book.html

flux[3]. The DAQ simulation has been set-up to simulate each TDC-channel (or MDT-tube) individually. The background rates for all tubes in a chamber are calculated from the average muon rate in a chamber (thus they are the same). The tube-area is determined as the diameter times the length of the tube. The results of the rate calculation are listed in appendix A for the 48 barrel and 48 end-cap towers. Note that the background rates of the individual tubes can be multiplied with an input parameter (safety factor), which makes it possible to investigate higher, or lower, noise rates.

3 The muon DAQ system

The muon DAQ system[4], as simulated, consists of a MROD, which sends data to a single ROB and receives data from up to 6 CSMs. Each CSM receives data from up to 18 TDCs, and each TDC contains maximally 24 input channels.

For each trigger, a total time-window of 850 ns is simulated. This window is divided into two parts. The first 100 ns precedes the trigger. If there is a hit in this period, a bit in the TDC-mask word is set. If any bit in the TDC-mask word is set, the word is saved, and will be sent to the next level of electronics, otherwise this word is omitted. Any hits during the drift-time of at most 750 ns directly following the trigger are digitized. The data are sent, together with a header, trailer and potentially a mask word, to the next level of electronics (the CSM) at a rate of 0.040 bits/ns. The throughput limits from CSM to MROD and from MROD to ROB are taken to be 1 bit/ns. Some of the more important parameters used in the simulation are listed in the table below.

Parameter	value	description
TDC Mask	100 ns	time window in which the mask-word is set
TDC Window	750 ns	time window to accept hits
TDC Distance	10 ns	minimal time between hits
TDC-CSM	0.04 bits/ns	data transfer speed between TDC and CSM
CSM-ROD	1 bits/ns	data transfer speed between CSM and MROD
ROD-ROB	1 bits/ns	data transfer speed between MROD and ROB
TRIGRATE	0.1 MHz	actual trigger-rate
TRIGDEAD	100 ns	minimal time between triggers

Table 1: Parameters used in the simulation of the DAQ.

[3] suggested by S. Falciano.

[4] e.g. http://www.hef.kun.nl/atlas/Pub/lecc2002-prest-mrod.pdf

Next to the TDC, the MROD also adds words to the data[5]. A brief description of the effect the MROD has on the throughput is given in the next section.

3.1 The MROD

The MROD is modeled in somewhat more detail. It may contain up to 4 MRODin boards, and an MRODout buffer. Each MRODin consists of two chunks of ZBT memory (one for each channel), and a SHARC. It is assumed in this simulation that in both places buffering is possible. When the end-of-event is received in both MRODin channels, the event is piped to the SHARC. Whenever all data from all MRODin SHARCs are complete, the data are moved to the MRODout buffer. The parameters used in this simulation are as follows:

Parameter	value	description
ROD-ZBT-SRC	0.64 bits/ns	80 MB/s from ZBT to SHARC
ROD-SRC-ROL	0.32 bits/ns	40 MB/s from SHARC to ROL

Table 2: Parameters used in the simulation of the MROD.

4 Simulation

4.1 TDC hit simulation

For each TDC-channel, hits are simulated according to an $e^{-t \times f}$ distribution, where t is the time between triggers, and f the background rate. The total time window in which hits are simulated consists of the sum of the TDC-mask and TDC-window, or 850 ns. Hits which fall in the first 100 ns are only used to set the mask-word, whereas hits which fall in the regular drift window add normal TDC words to the data. Figure 1 show the time difference between hits for both generated and accepted hits (for end-cap tower 31). The figure clearly shows the mask window, as well as the tdc-window. Hits are generated according to the specified noise rate in the channel under consideration, as long as the hit-time is within the trigger window of the corresponding channel. This method is performed for each individual channel. When comparing the accepted to the generated hits (in figure 1), it is clear that no hits are accepted outside of the trigger window (i.e. after 850 ns), and that the efficiency for accepting hits is slowly going down even before. The latter is due to events with multiple noise

[5]The data format is described in http://www.hef.kun.nl/atlas/Pub/mrodfmt100.pdf

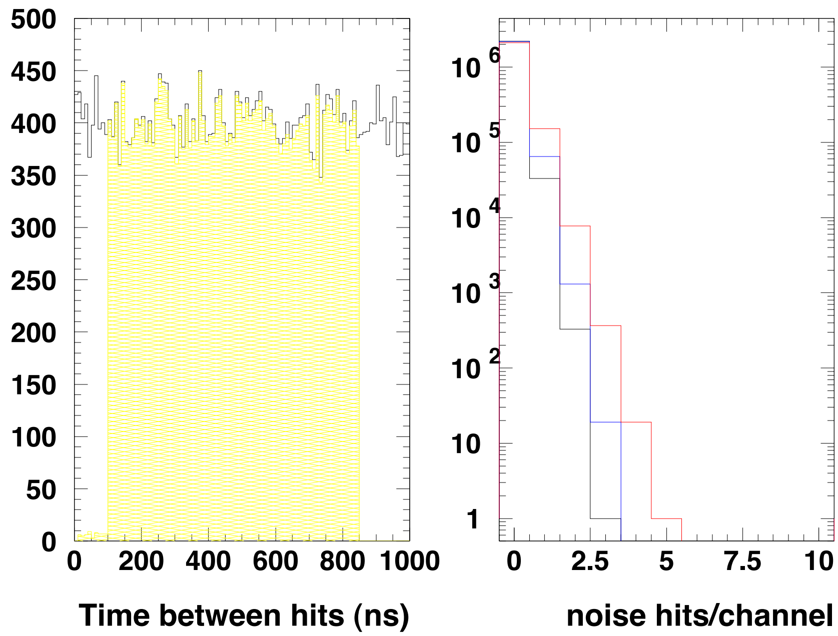

Figure 1: Generated and accepted noise hits (left). Number of noise hits per TDC channel distribution (right)

hits in a single TDC channel. The multiple hits also cause an acceptance for hits that follow a previous hit within 100 ns.
Throughout this document the simulation has been performed for:

- the default background rate, or a safety factor of 1 (in the plots shown in black).
- 2 times the background rate, or a safety factor of 2 (in the plots shown in blue).
- 5 times the background rate, or a safety factor of 5 (in the plots shown in red).

Furthermore, the behavior of end-cap towers 31 and 32 are usually shown. These towers are illustrative as examples of towers that require a large throughput. The results of all other towers have been analyzed as well. The results are summarized in the conclusion.

4.2 Making a complete event

First, the hits of the individual TDC channels are added together. A TDC header and trailer word are added, which make up the complete data-volume for a single TDC. Next the data volume for a complete CSM is calculated by adding the data from the input TDC's. Afterward, the data is sent to the MRODin ZBT while adding 4 words for each connected front-end link. The data from two input channels are combined into the SHARC. The data from up to 4 MRODins are combined into the MRODout buffer. In this buffer another 13 header and trailer words are added to the event. All of this makes the data for a complete event for a single tower, as shown in figure 2. The average number of words per event for each tower is listed in the tables below.

tower	BG words	BG×2 words	BG×5 words	tower	BG words	BG×2 words	BG×5 words
0	213.2	233.3	293.5	24	216.1	235.8	294.0
1	213.2	233.3	293.5	25	216.1	235.8	294.0
2	213.2	233.3	293.5	26	216.1	235.8	294.0
3	213.2	233.3	293.5	27	216.1	235.8	294.0
4	213.2	233.3	293.5	28	216.1	235.8	294.0
5	237.5	257.8	319.0	29	202.8	220.5	274.0
6	213.2	233.3	293.5	30	202.8	220.5	274.0
7	237.5	257.8	319.0	31	216.1	235.8	294.0
8	221.6	238.1	287.4	32	221.5	250.4	336.0
9	221.6	238.1	287.4	33	221.5	250.4	336.0
10	221.6	238.1	287.4	34	221.5	250.4	336.0
11	221.6	238.1	287.4	35	221.5	250.4	336.0
12	221.6	238.1	287.4	36	221.5	250.4	336.0
13	182.0	194.8	233.5	37	269.9	298.7	385.4
14	182.0	194.8	233.5	38	221.5	250.4	336.0
15	221.6	238.1	287.4	39	269.9	298.7	385.4
16	222.1	246.6	320.4	40	204.9	224.6	284.0
17	222.1	246.6	320.4	41	204.9	224.6	284.0
18	222.1	246.6	320.4	42	204.9	224.6	284.0
19	222.1	246.6	320.4	43	204.9	224.6	284.0
20	222.1	246.6	320.4	44	204.9	224.6	284.0
21	273.9	298.6	372.0	45	177.1	193.0	240.9
22	194.6	216.1	281.1	46	177.1	193.0	240.9
23	273.9	298.6	372.0	47	204.9	224.6	284.0

Table 3: Total number of words for a barrel-tower for a single event.

tower	BG words	BG×2 words	BG×5 words	tower	BG words	BG×2 words	BG×5 words
0	188.8	216.8	301.9	24	266.9	300.6	401.8
1	175.8	202.8	283.9	25	266.9	300.6	401.8
2	175.8	202.8	283.9	26	266.9	300.6	401.8
3	175.8	202.8	283.9	27	266.9	300.6	401.8
4	188.8	216.8	301.9	28	266.9	300.6	401.8
5	147.4	169.7	237.4	29	266.9	300.6	401.8
6	175.8	202.7	283.9	30	266.9	300.6	401.8
7	175.8	202.7	283.9	31	266.9	300.6	401.8
8	186.7	204.3	257.3	32	254.0	306.1	463.7
9	186.7	204.3	257.3	33	254.0	306.1	463.7
10	186.7	204.3	257.3	34	254.0	306.1	463.7
11	186.7	204.3	257.3	35	254.0	306.1	463.7
12	186.7	204.3	257.3	36	254.0	306.1	463.7
13	186.7	204.3	257.3	37	254.0	306.1	463.7
14	186.7	204.3	257.3	38	254.0	306.1	463.7
15	186.7	204.3	257.3	39	254.0	306.1	463.7
16	203.4	233.9	325.6	40	205.4	229.9	303.4
17	203.4	233.9	325.6	41	205.4	229.9	303.4
18	203.4	233.9	325.6	42	205.4	229.9	303.4
19	203.4	233.9	325.6	43	205.4	229.9	303.4
20	203.4	233.9	325.6	44	205.4	229.9	303.4
21	203.4	233.9	325.6	45	205.4	229.9	303.4
22	203.4	233.9	325.6	46	205.4	229.9	303.4
23	203.4	233.9	325.6	47	205.4	229.9	303.4

Table 4: Total number of words for an end-cap tower for a single event.

When using an average trigger rate of 100 kHz, there is a linear dependence between the number of words and the required throughput for each link. This required throughput is given in figure 3. One should note that the average throughput required between MROD and ROB is, in the example used, very close to (or above) 1 Gb/s, which implies that additional work needs to be done to ensure adequate throughput.

4.3 Event throughput

Next to the event size, the event flow through the whole system is simulated, using the delays as specified above. An example of such an event flow through the simulated DAQ is given below:

TDC	CSM	ZBT	SHARC	MRODOUT
2 words 1750 ns				
3 words 2625 ns				
3 words 2625 ns				
4 words 3500 ns				
4 words 3500 ns				
2 words 1750 ns				
2 words 1750 ns				
3 words 2625 ns				
2 words 1750 ns				
2 words 1750 ns				
	27 words 3500 ns	31 words 5050 ns		
....				
	28 words 2625 ns	32 words 4225 ns		
			63 words 11350 ns	
....				
	24 words 3500 ns	28 words 4900 ns		
....				
	33 words 3500 ns	37 words 5350 ns		
			65 words 11850 ns	
....				
	33 words 2625 ns	37 words 4475 ns		
....				
	41 words 2625 ns	45 words 4875 ns		
			82 words 13075 ns	
				223 words 20211 ns

Table 5: Example throughput of a single event.

In the table, the number of words generated by (or flowing through) an electronics module is listed, as well as the time when the words are out of the module, relative to the trigger time. This specific (typical) event takes 20 microseconds to get through the DAQ chain into the ROB, when using only the simulated delays as indicated before. Note that for this event previous events did not cause any

additional delay. However, these effects are taken into account in the simulation.

4.4 Trigger simulation

In the trigger simulation, an average trigger rate of 100 kHz is assumed. As the minimal time between triggers is 100 ns, the simulated trigger rate in the remaining time is 101 kHz, which nicely averages out to 100 kHz overall. The time between triggers is simulated according to

$$\mathrm{e}^{-t \times f}$$

where t is the time between triggers, and f the rate. The result is shown in figure 4. When combining the trigger simulation with the event simulation, the buffering requirements of each module, as well as potential bottlenecks in the system, can be evaluated.

4.5 Required buffering

Using the simulated trigger times as shown in figure 4, it is possible to analyze the number of events that have to be buffered in the front-end modules. This requires knowledge of the throughput of the different types of links, which is the only delay simulated. Note that there will not be any significant buffering in the CSM. Thus the only buffering is in the TDCs and in the MROD. Figure 5 shows the amount of buffering required for the tower containing the busiest TDCs. Note that this simulation shows that a buffering of 16 events in the TDC is required to be able to deal with background rates that are a factor of 5 higher than expected.

The MROD-buffering is performed in three steps. At the MRODin, buffering in the ZBT and in the SHARC is simulated. Furthermore, there is buffering in the MRODout. The buffering in the MRODin is shown in figure 6. This figure shows the number of events buffered in the SHARC, as well as the corresponding ZBTs. It is clear that the 40 MB/s link from the SHARC to the MRODout forms a huge bottleneck, as two of the SHARCs simply fills up. Note that the number of channels as well as the background rate plays a role. Even when no hits are registered in a TDC it contributes to the data volume. Next to the number of events, one can look at the number of words to be stored in the MRODin. This is shown in figure 7 (for end-cap tower 32), and shows a similar behavior as the number of events to be stored. The required buffering capacity in the SHARC is nicely shown to be multiples of single events.

The MRODout buffering needs for this specific tower are negligible, as the MRODins cannot push the event through fast enough, whereas the MROD-ROB

link is a lot faster. A nice example to look at is tower 32 in the end-cap. For this specific tower the required MROD-ROB throughput is very close to (or even above) 1 bit/ns, thus the buffering requirement should be high, however the throughput to the MRODout is the limiting factor so that there is very little need for buffering in the MRODout.

4.6 Zero suppression

In order to overcome the problem of contributions from TDCs which do not contain any hits, a simple lossless zero suppression algorithm could be used. This algorithm would simply be to have the MROD remove the TDC header and trailer if and only if there is no timing information recorded by the TDC. As a good fraction of the TDCs contain no recorded hits (at the default background rates), this is a significant data reduction. The resulting data volume is shown in the tables below.

tower	BG words	BG×2 words	BG×5 words	tower	BG words	BG×2 words	BG×5 words
0	92.4	139.3	247.8	24	89.7	136.1	242.9
1	92.4	139.3	247.8	25	89.7	136.1	242.9
2	92.4	139.3	247.8	26	89.7	136.1	242.9
3	92.4	139.3	247.8	27	89.7	136.1	242.9
4	92.4	139.3	247.8	28	89.7	136.1	242.9
5	97.4	145.2	258.0	29	86.2	127.9	226.0
6	92.4	139.3	247.8	30	86.2	127.9	226.0
7	97.4	145.2	258.0	31	89.7	136.1	242.9
8	83.3	124.0	221.3	32	112.7	174.0	307.5
9	83.3	124.0	221.3	33	112.7	174.0	307.5
10	83.3	124.0	221.3	34	112.7	174.0	307.5
11	83.3	124.0	221.3	35	112.7	174.0	307.5
12	83.3	124.0	221.3	36	112.7	174.0	307.5
13	69.4	100.9	177.9	37	122.0	184.5	326.5
14	69.4	100.9	177.9	38	112.7	174.0	307.5
15	83.3	124.0	221.3	39	122.0	184.5	326.5
16	104.7	159.0	282.7	40	91.2	136.6	240.8
17	104.7	159.0	282.7	41	91.2	136.6	240.8
18	104.7	159.0	282.7	42	91.2	136.6	240.8
19	104.7	159.0	282.7	43	91.2	136.6	240.8
20	104.7	159.0	282.7	44	91.2	136.6	240.8
21	112.4	168.6	297.3	45	81.0	117.8	202.4
22	91.4	139.1	247.6	46	81.0	117.8	202.4
23	112.4	168.6	297.3	47	91.2	136.6	240.8

Table 6: Total number of words for a barrel-tower for a single event after zero suppression.

tower	BG words	BG×2 words	BG×5 words	tower	BG words	BG×2 words	BG×5 words
0	105.8	163.2	286.7	24	132.4	200.3	355.0
1	99.1	153.8	271.5	25	132.4	200.3	355.0
2	99.1	153.8	271.5	26	132.4	200.3	355.0
3	99.1	153.8	271.5	27	132.4	200.3	355.0
4	105.8	163.2	286.7	28	132.4	200.3	355.0
5	83.5	129.0	227.0	29	132.4	200.3	355.0
6	99.1	153.8	271.5	30	132.4	200.3	355.0
7	99.1	153.8	271.5	31	132.4	200.3	355.0
8	85.6	126.7	221.7	32	159.3	243.6	441.0
9	85.6	126.7	221.7	33	159.3	243.6	441.0
10	85.6	126.7	221.7	34	159.3	243.6	441.0
11	85.6	126.7	221.7	35	159.3	243.6	441.0
12	85.6	126.7	221.7	36	159.3	243.6	441.0
13	85.6	126.7	221.7	37	159.3	243.6	441.0
14	85.6	126.7	221.7	38	159.3	243.6	441.0
15	85.6	126.7	221.7	39	159.3	243.6	441.0
16	114.3	173.1	304.0	40	96.2	146.0	259.6
17	114.3	173.1	304.0	41	96.2	146.0	259.6
18	114.3	173.1	304.0	42	96.2	146.0	259.6
19	114.3	173.1	304.0	43	96.2	146.0	259.6
20	114.3	173.1	304.0	44	96.2	146.0	259.6
21	114.3	173.1	304.0	45	96.2	146.0	259.6
22	114.3	173.1	304.0	46	96.2	146.0	259.6
23	114.3	173.1	304.0	47	96.2	146.0	259.6

Table 7: Total number of words for an end-cap tower for a single event after zero suppression.

The reduction of the data volume changes dramatically when increasing the background rates. This is normal as when the background increases, more channels contribute to the data volume, thus the data reduction scheme is less effective. Similar as before, the distribution of the data volume throughout the electronics chain is shown in figure 9. Note that the difference between figures 9 and 2 is only in the MROD, thus only the bottom plots are affected by this algorithm, as was expected. Unfortunately, the main bottleneck remains the throughput between SHARC and MRODout. As shown in figure 10 it is still not possible to manage the data volume of the SHARCS, when the background rates are multiplied by a factor of only 2.

4.7 Additional (lossless) data reduction

In addition to the zero suppression, it is possible to remove the TDC trailer words (even when there are hits in the TDC) to further reduce the amount of data, while only removing redundant information. The net result in terms of data volume can be seen below.

tower	BG words	BG×2 words	BG×5 words	tower	BG words	BG×2 words	BG×5 words
0	74.8	108.3	192.7	24	72.9	106.0	188.4
1	74.8	108.3	192.7	25	72.9	106.0	188.4
2	74.8	108.3	192.7	26	72.9	106.0	188.4
3	74.8	108.3	192.7	27	72.9	106.0	188.4
4	74.8	108.3	192.7	28	72.9	106.0	188.4
5	79.5	113.5	200.5	29	70.5	100.2	176.0
6	74.8	108.3	192.7	30	70.5	100.2	176.0
7	79.5	113.5	200.5	31	72.9	106.0	188.4
8	68.5	97.0	170.4	32	89.1	134.2	243.7
9	68.5	97.0	170.4	33	89.1	134.2	243.7
10	68.5	97.0	170.4	34	89.1	134.2	243.7
11	68.5	97.0	170.4	35	89.1	134.2	243.7
12	68.5	97.0	170.4	36	89.1	134.2	243.7
13	57.7	79.9	137.7	37	97.9	143.6	188.4
14	57.7	79.9	137.7	38	89.1	134.2	243.7
15	68.5	97.0	170.4	39	97.9	143.6	257.7
16	83.4	122.8	221.6	40	74.0	106.6	188.4
17	83.4	122.8	221.6	41	74.0	106.6	188.4
18	83.4	122.8	221.6	42	74.0	106.6	188.4
19	83.4	122.8	221.6	43	74.0	106.6	188.4
20	83.4	122.8	221.6	44	74.0	106.6	188.4
21	91.1	131.6	232.8	45	67.0	93.4	159.6
22	73.0	107.6	194.3	46	67.0	93.4	159.6
23	91.1	131.6	232.8	47	74.0	106.6	188.4

Table 8: Total number of words for a barrel-tower for a single event after additional data reduction.

tower	BG words	BG×2 words	BG×5 words	tower	BG words	BG×2 words	BG×5 words
0	83.3	126.0	230.0	24	105.6	156.4	284.2
1	77.4	118.2	217.8	25	105.6	156.4	284.2
2	77.4	118.2	217.8	26	105.6	156.4	284.2
3	77.4	118.2	217.8	27	105.6	156.4	284.2
4	83.3	126.0	230.0	28	105.6	156.4	284.2
5	65.4	99.3	182.2	29	105.6	156.4	284.2
6	77.4	118.2	217.8	30	105.6	156.4	284.2
7	77.4	118.2	217.8	31	105.6	156.4	284.2
8	70.2	99.5	173.5	32	124.6	192.9	369.7
9	70.2	99.5	173.5	33	124.6	192.9	369.7
10	70.2	99.5	173.5	34	124.6	192.9	369.7
11	70.2	99.5	173.5	35	124.6	192.9	369.7
12	70.2	99.5	173.5	36	124.6	192.9	369.7
13	70.2	99.5	173.5	37	124.6	192.9	369.7
14	70.2	99.5	173.5	38	124.6	192.9	369.7
15	70.2	99.5	173.5	39	124.6	192.9	369.7
16	90.8	135.5	246.8	40	76.8	114.0	207.1
17	90.8	135.5	246.8	41	76.8	114.0	207.1
18	90.8	135.5	246.8	42	76.8	114.0	207.1
19	90.8	135.5	246.8	43	76.8	114.0	207.1
20	90.8	135.5	246.8	44	76.8	114.0	207.1
21	90.8	135.5	246.8	45	76.8	114.0	207.1
22	90.8	135.5	246.8	46	76.8	114.0	207.1
23	90.8	135.5	246.8	47	76.8	114.0	207.1

Table 9: Total number of words for an end-cap tower for a single event after additional data reduction.

When comparing tables 8 and 9 to 6 and 7, it is clear that the additional data reduction removes about 50 words (or 20 %) from the data volume. This corresponds to the number of TDCs having at least one hit in one channel. From figure 11 it is clear that the bottleneck remains for only one of the SHARCS. When looking at appendix A it is clear that some re-cabling may solve the problem as the two busiest CSM's are connected to the same SHARC, thus resulting in a bottleneck in the readout.

The simulation also shows the total number of events that are buffered in the DAQ-chain simulated. Figure 12 clearly shows that for this tower, as already shown before, there is a bottleneck, thus the total number of events in the chain

is increasing with event number.

4.8 Throughput time

The simulation contains the information of how long it takes between the trigger and the arrival of the complete event in the ROB. This naturally depends on zero suppression and data reduction. Figures 13 and 14 show this throughput time distribution for end-cap tower 32 and barrel tower 30 respectively. The figures clearly show the effect of the data reduction; and also that both effects are needed to be able to keep the readout time below 100 μs, even in a quiet tower in the barrel. Furthermore, as noted before, in some instances the data volume cannot be handled due to the speed of the SHARC readout.

4.9 Decrease of SHARC readout time

It is possible to double the readout of the MRODin boards, and thus remove the bottleneck for end-cap tower 32. This is done by adding a SHARC, and thus effectively doubling the bandwidth. The effect is clearly visible in figure 15. In this figure, both zero-suppression and data reduction are assumed, and even now the MRODin throughput is just not enough to deal with a background rate of five times more than expected. The throughput of the events through the whole DAQ chain is visible in figure 16. The figure clearly shows that the situation has improved with respect to figure 12, but handling a factor of five more background than expected in the current configuration is not easy.

5 Conclusion

In the previous sections an emphasis was put on the throughput requirements set by one of the busiest towers. The analysis has been performed for 48 barrel and 48 end-cap towers, and the results can be summarized as follows:

- Without zero-suppression all towers can handle the data rate caused by background, though sometimes a large buffer is needed in the MRODin
- Without zero-suppression only few towers can handle the data rate when applying a safety factor of two
- With zero-suppression all towers in the barrel can handle a safety factor of two
- with zero-suppression all but towers 32-39 in the end-cap can handle a safety factor of two

- With zero-suppression only a fraction of the towers can handle a safety factor of five
- With zero-suppression and data reduction all barrel towers, except 16-23 and 32-39 can handle a safety factor of five
- With zero-suppression and data reduction about half the end-cap towers can handle a safety factor of five.
- With zero-suppression and data reduction end-cap towers 32-39 cannot handle a safety factor of two

In all cases the bottleneck is in the SHARC readout speed. A doubling of this speed would be helpful, and in most cases enough. A re-cabling of the MROD, thus spreading the load over the input SHARCs would be an easy option which would reduce the effect of this bottleneck considerably.

6 Appendix A

	CSM Barrel A and C-sides							
Tower	0	1	2	3	4	5	6	7
0	8084.68	8496.91	11150.6	11767.4	16019.1	16905.4	-1	-1
1	8084.68	8496.91	11150.6	11767.4	16019.1	16905.4	-1	-1
2	8084.68	8496.91	11150.6	11767.4	16019.1	16905.4	-1	-1
3	8084.68	8496.91	11150.6	11767.4	16019.1	16905.4	-1	-1
4	8084.68	8496.91	11150.6	11767.4	16019.1	16905.4	-1	-1
5	4820.05	8559.47	11150.6	11767.4	16019.1	16905.4	5247.66	-1
6	8084.68	8496.91	11150.6	11767.4	16019.1	16905.4	-1	-1
7	4820.05	8559.47	11150.6	11767.4	16019.1	16905.4	5247.66	-1
8	4870.55	5176.09	9886.19	10249.4	12046.7	12528	-1	-1
9	4870.55	5176.09	9886.19	10249.4	12046.7	12528	-1	-1
10	4870.55	5176.09	9886.19	10249.4	12046.7	12528	-1	-1
11	4870.55	5176.09	9886.19	10249.4	12046.7	12528	-1	-1
12	4870.55	5176.09	9886.19	10249.4	12046.7	12528	-1	-1
13	4870.55	5176.09	10036.9	12066	-1	12595	-1	-1
14	4870.55	5176.09	10036.9	12066	-1	12595	-1	-1
15	4870.55	5176.09	9886.19	10249.4	12046.7	12528	-1	-1
16	9873.59	9515.6	12973.3	15138.8	18920.2	21298	-1	-1
17	9873.59	9515.6	12973.3	15138.8	18920.2	21298	-1	-1
18	9873.59	9515.6	12973.3	15138.8	18920.2	21298	-1	-1
19	9873.59	9515.6	12973.3	15138.8	18920.2	21298	-1	-1
20	9873.59	9515.6	12973.3	15138.8	18920.2	21298	-1	-1
21	5337.29	5527.22	12973.3	15138.8	18920.2	21298	3943.66	5697.46
22	9873.59	9515.6	12973.3	-1	18920.2	21298	-1	-1
23	5337.29	5527.22	12973.3	15138.8	18920.2	21298	3943.66	5697.46

	CSM Barrel A and C-sides							
Tower	0	1	2	3	4	5	6	7
24	6082.84	6264.26	11088.9	12534.6	14257.2	15913.4	-1	-1
25	6082.84	6264.26	11088.9	12534.6	14257.2	15913.4	-1	-1
26	6082.84	6264.26	11088.9	12534.6	14257.2	15913.4	-1	-1
27	6082.84	6264.26	11088.9	12534.6	14257.2	15913.4	-1	-1
28	6082.84	6264.26	11088.9	12534.6	14257.2	15913.4	-1	-1
29	6082.84	6264.26	11598.7	13852.5	16025.2	15259.5	-1	-1
30	6082.84	6264.26	11598.7	13852.5	16025.2	15259.5	-1	-1
31	6082.84	6264.26	11088.9	12534.6	14257.2	15913.4	-1	-1
32	9800.09	12098.1	17506.6	18892.6	22911.7	23442.3	-1	-1
33	9800.09	12098.1	17506.6	18892.6	22911.7	23442.3	-1	-1
34	9800.09	12098.1	17506.6	18892.6	22911.7	23442.3	-1	-1
35	9800.09	12098.1	17506.6	18892.6	22911.7	23442.3	-1	-1
36	9800.09	12098.1	17506.6	18892.6	22911.7	23442.3	-1	-1
37	5712.42	6970.14	17506.6	18892.6	22911.7	23442.3	6641.58	5908.33
38	9800.09	12098.1	17506.6	18892.6	22911.7	23442.3	-1	-1
39	5712.42	6970.14	17506.6	18892.6	22911.7	23442.3	6641.58	5908.33
40	5665.19	6139.27	13890.4	14658.6	16604.5	16846.5	-1	-1
41	5665.19	6139.27	13890.4	14658.6	16604.5	16846.5	-1	-1
42	5665.19	6139.27	13890.4	14658.6	16604.5	16846.5	-1	-1
43	5665.19	6139.27	13890.4	14658.6	16604.5	16846.5	-1	-1
44	5665.19	6139.27	13890.4	14658.6	16604.5	16846.5	-1	-1
45	5665.19	6139.27	14244.1	16727.2	16493.5	16707.4	-1	-1
46	5665.19	6139.27	14244.1	16727.2	16493.5	16707.4	-1	-1
47	5665.19	6139.27	13890.4	14658.6	16604.5	16846.5	-1	-1

	CSM EndCap A and C-sides							
Tower	0	1	2	3	4	5	6	7
0	13406.9	22173.2	1677.73	22011.8	22614.2	21453.9	-1	-1
1	21453.9	22173.2	1677.73	22011.8	22614.2	-1	-1	-1
2	21453.9	22173.2	1677.73	22011.8	22614.2	-1	-1	-1
3	21453.9	22173.2	1677.73	22011.8	22614.2	-1	-1	-1
4	13406.9	22173.2	1677.73	22011.8	22614.2	21453.9	-1	-1
5	21453.9	22173.2	1677.73	22011.8	22614.2	-1	-1	-1
6	21453.9	22173.2	1677.73	22011.8	22614.2	-1	-1	-1
7	21453.9	22173.2	1677.73	22011.8	22614.2	-1	-1	-1
8	8243.3	7724.1	14808.9	14029	13874.3	14489	-1	-1
9	8243.3	7724.1	14808.9	14029	13874.3	14489	-1	-1
10	8243.3	7724.1	14808.9	14029	13874.3	14489	-1	-1
11	8243.3	7724.1	14808.9	14029	13874.3	14489	-1	-1
12	8243.3	7724.1	14808.9	14029	13874.3	14489	-1	-1
13	8243.3	7724.1	14808.9	14029	13874.3	14489	-1	-1
14	8243.3	7724.1	14808.9	14029	13874.3	14489	-1	-1
15	8243.3	7724.1	14808.9	14029	13874.3	14489	-1	-1
16	46008.9	22775	22587	12914.6	13780.6	14704.7	-1	-1
17	46008.9	22775	22587	12914.6	13780.6	14704.7	-1	-1
18	46008.9	22775	22587	12914.6	13780.6	14704.7	-1	-1
19	46008.9	22775	22587	12914.6	13780.6	14704.7	-1	-1
20	46008.9	22775	22587	12914.6	13780.6	14704.7	-1	-1
21	46008.9	22775	22587	12914.6	13780.6	14704.7	-1	-1
22	46008.9	22775	22587	12914.6	13780.6	14704.7	-1	-1
23	46008.9	22775	22587	12914.6	13780.6	14704.7	-1	-1

	CSM EndCap A and C-sides							
Tower	0	1	2	3	4	5	6	7
24	43132.2	24962.2	13479.7	13922.6	14156.7	8103.59	8605.21	9172.58
25	43132.2	24962.2	13479.7	13922.6	14156.7	8103.59	8605.21	9172.58
26	43132.2	24962.2	13479.7	13922.6	14156.7	8103.59	8605.21	9172.58
27	43132.2	24962.2	13479.7	13922.6	14156.7	8103.59	8605.21	9172.58
28	43132.2	24962.2	13479.7	13922.6	14156.7	8103.59	8605.21	9172.58
29	43132.2	24962.2	13479.7	13922.6	14156.7	8103.59	8605.21	9172.58
30	43132.2	24962.2	13479.7	13922.6	14156.7	8103.59	8605.21	9172.58
31	43132.2	24962.2	13479.7	13922.6	14156.7	8103.59	8605.21	9172.58
32	72203.4	54081.6	30136.6	11388.6	12282.7	12743.6	-1	-1
33	72203.4	54081.6	30136.6	11388.6	12282.7	12743.6	-1	-1
34	72203.4	54081.6	30136.6	11388.6	12282.7	12743.6	-1	-1
35	72203.4	54081.6	30136.6	11388.6	12282.7	12743.6	-1	-1
36	72203.4	54081.6	30136.6	11388.6	12282.7	12743.6	-1	-1
37	72203.4	54081.6	30136.6	11388.6	12282.7	12743.6	-1	-1
38	72203.4	54081.6	30136.6	11388.6	12282.7	12743.6	-1	-1
39	72203.4	54081.6	30136.6	11388.6	12282.7	12743.6	-1	-1
40	37216.2	18189.5	7538.9	7446.84	7835.17	-1	-1	-1
41	37216.2	18189.5	7538.9	7446.84	7835.17	-1	-1	-1
42	37216.2	18189.5	7538.9	7446.84	7835.17	-1	-1	-1
43	37216.2	18189.5	7538.9	7446.84	7835.17	-1	-1	-1
44	37216.2	18189.5	7538.9	7446.84	7835.17	-1	-1	-1
45	37216.2	18189.5	7538.9	7446.84	7835.17	-1	-1	-1
46	37216.2	18189.5	7538.9	7446.84	7835.17	-1	-1	-1
47	37216.2	18189.5	7538.9	7446.84	7835.17	-1	-1	-1

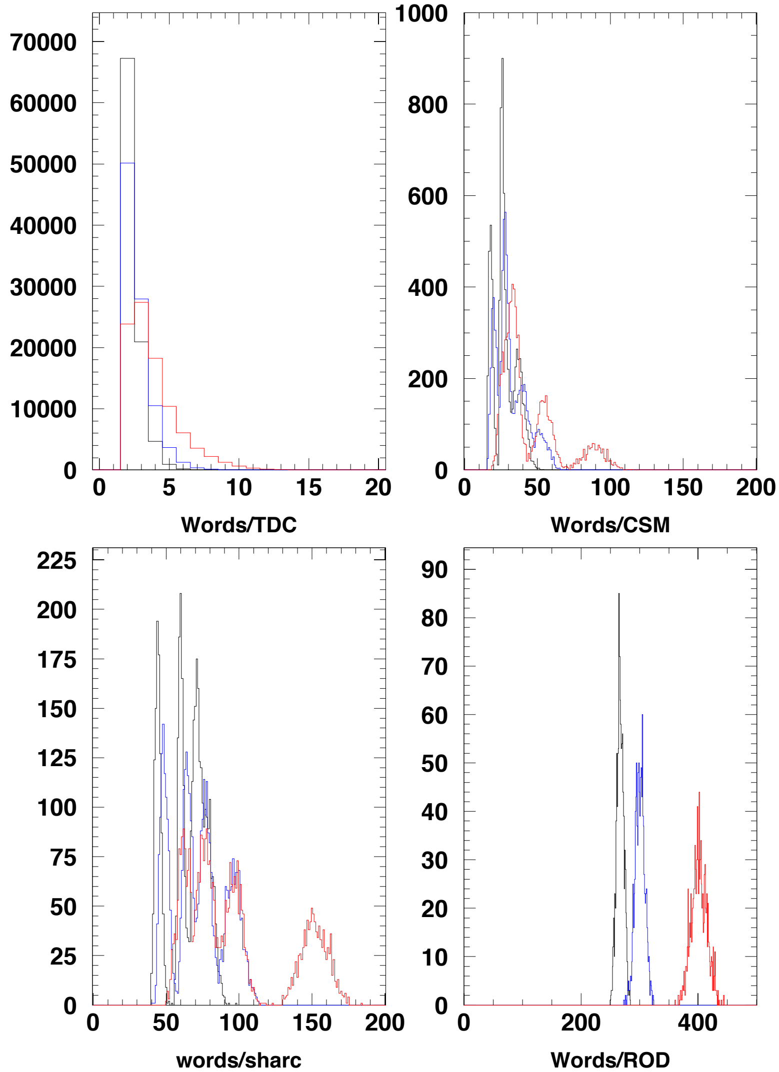

Figure 2: The total number of words in a tower (end-cap tower 31) for an event.

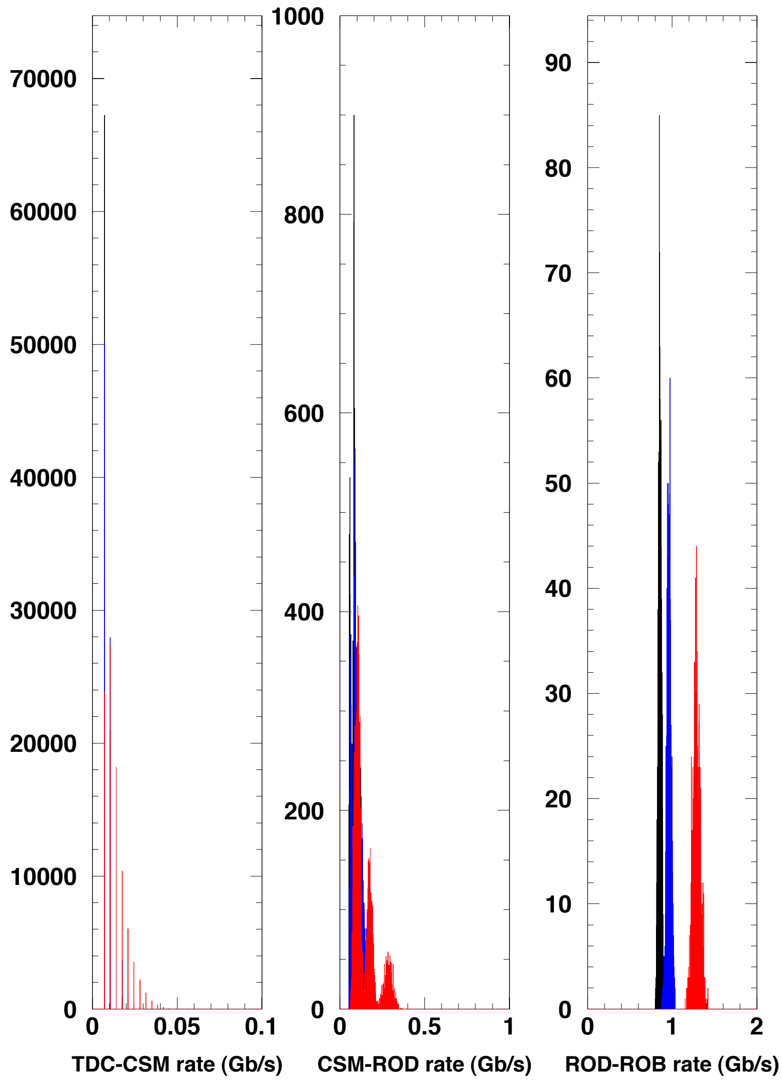

Figure 3: The throughput required for each link in a tower (end-cap tower 31).

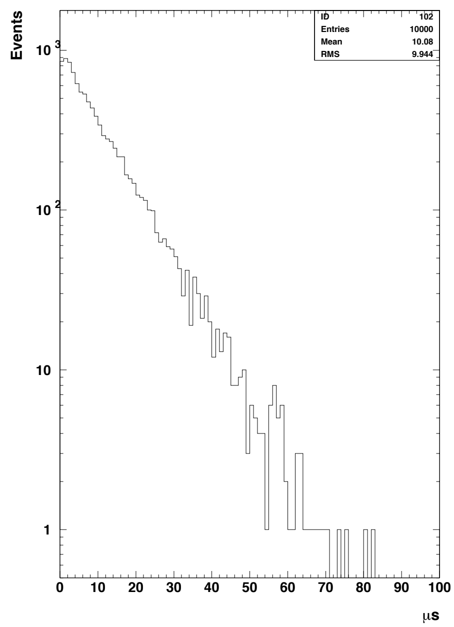

Figure 4: Simulated time between consecutive triggers

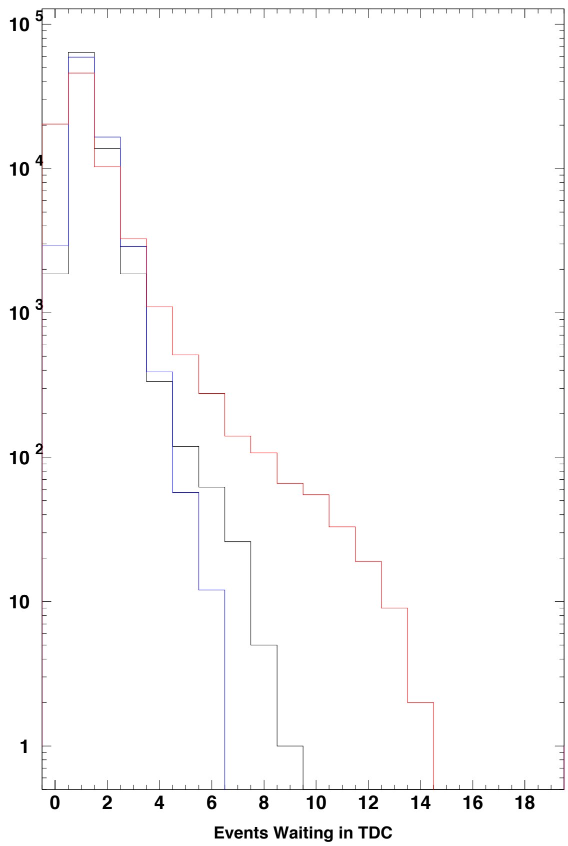

Figure 5: Buffering required in TDC for end-cap tower 32

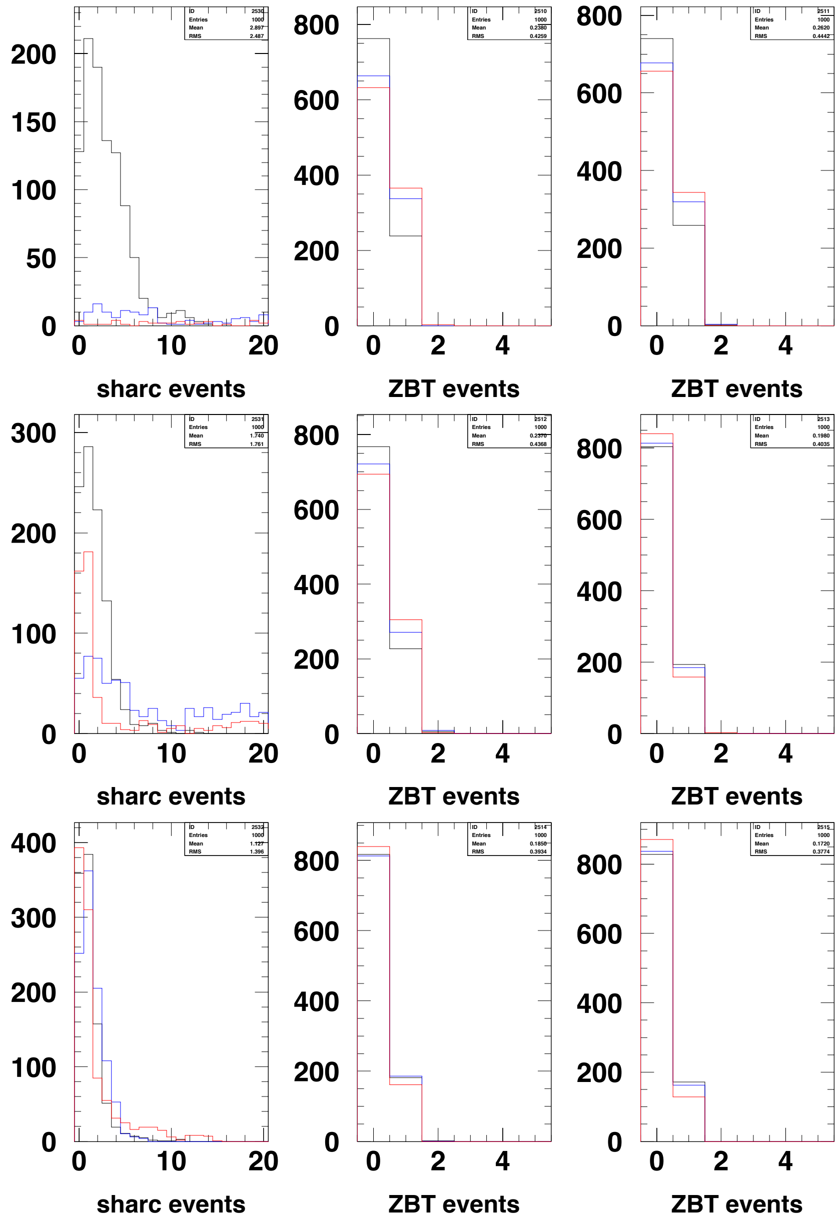

Figure 6: Buffering (events) required in the MRODin end-cap tower 32

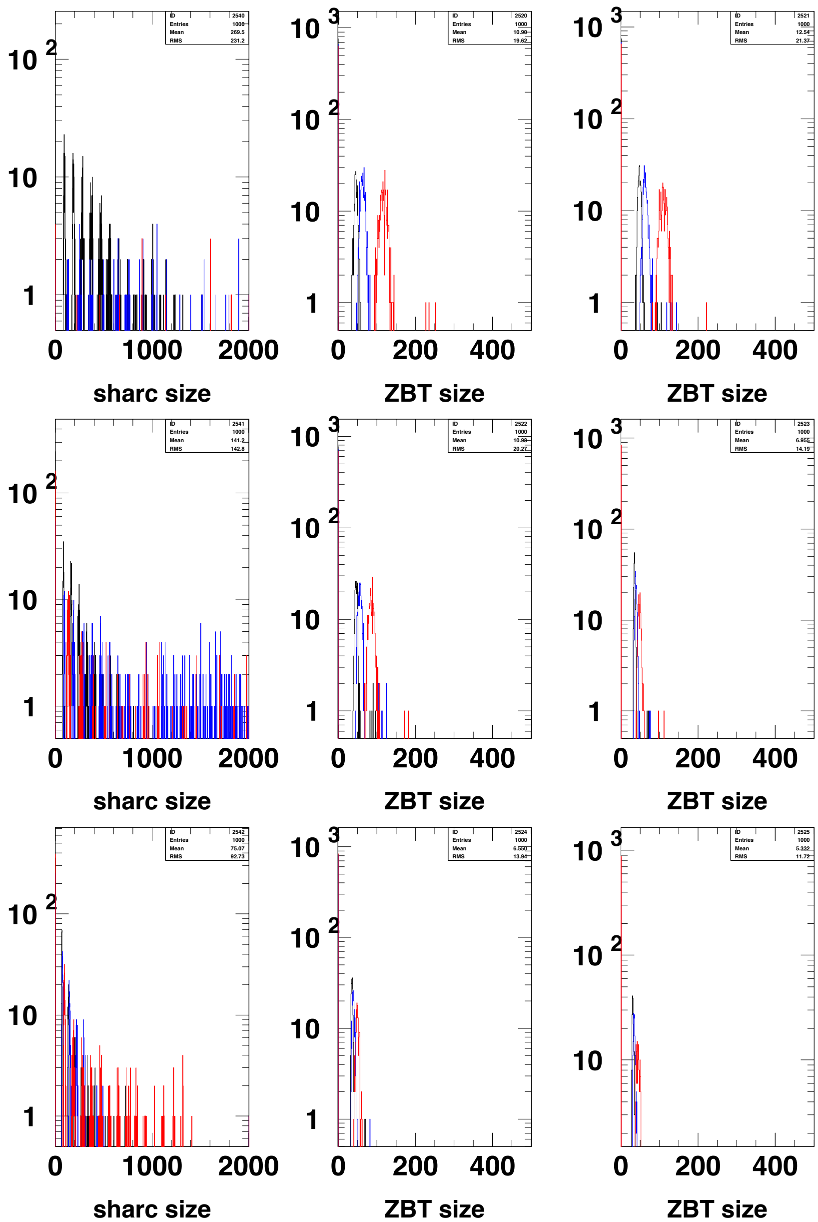

Figure 7: Buffering (in words) required in the MRODin end-cap tower 32

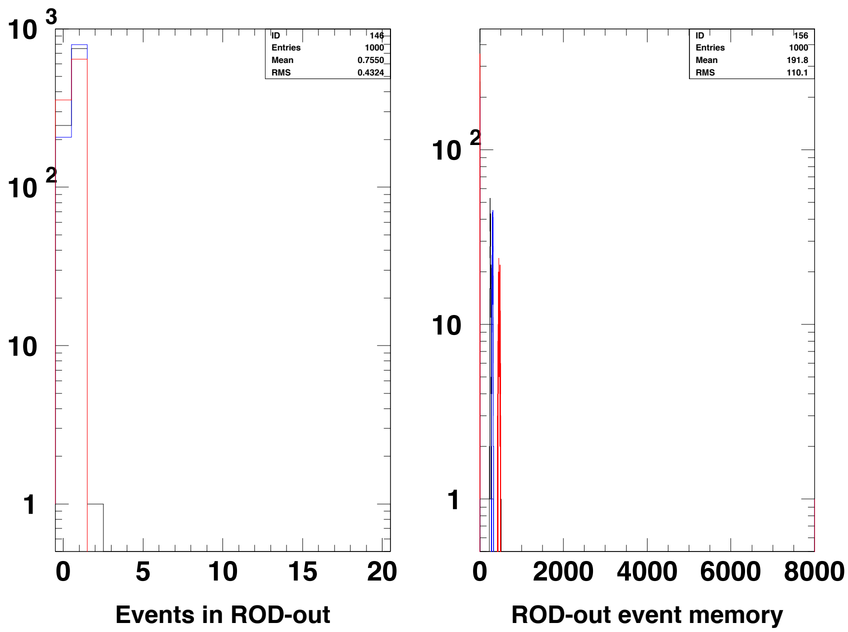

Figure 8: Buffering (left: number of events, right: words) required in the MRODout end-cap tower 32

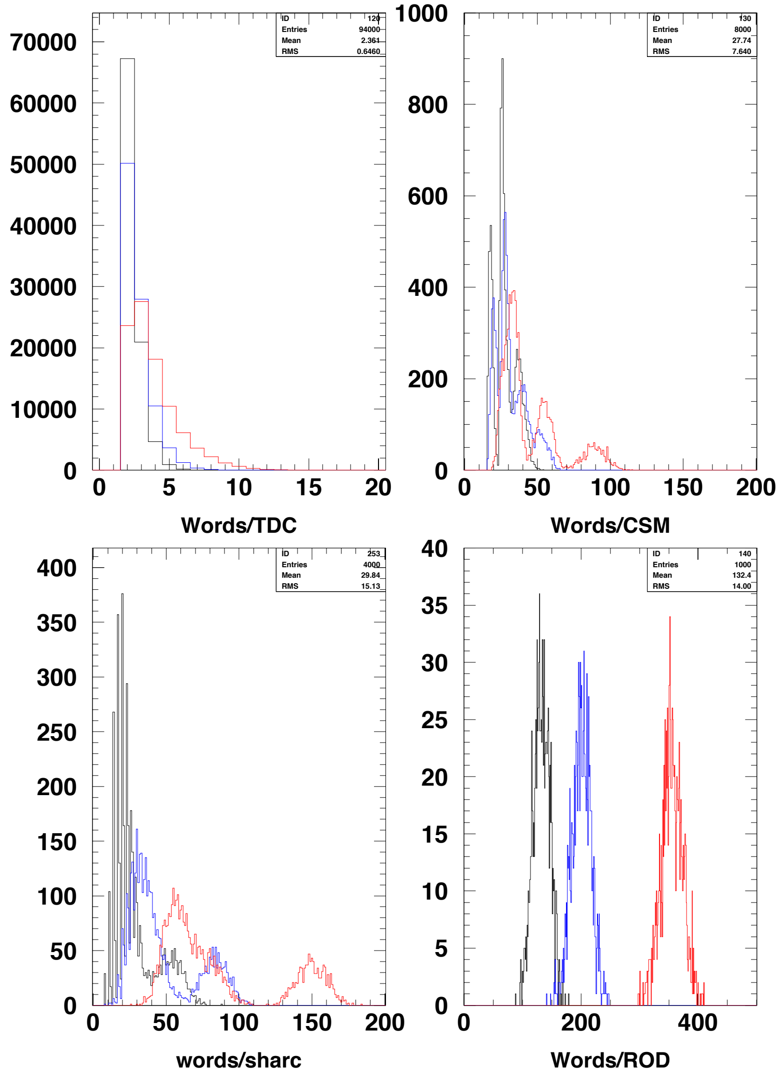

Figure 9: The total number of words in a tower (end-cap tower 31) for an event, after zero suppression.

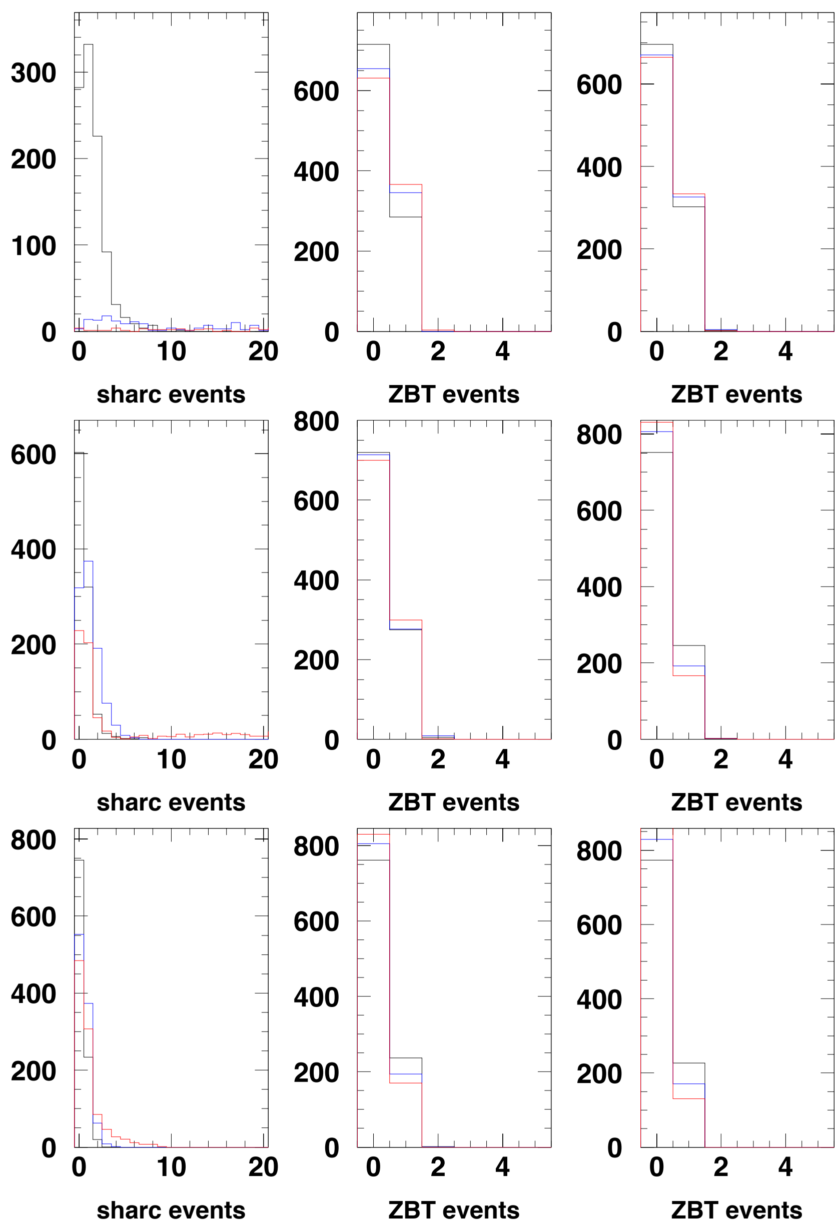

Figure 10: Buffering (in words) required in the MRODin end-cap tower 32 after zero suppression

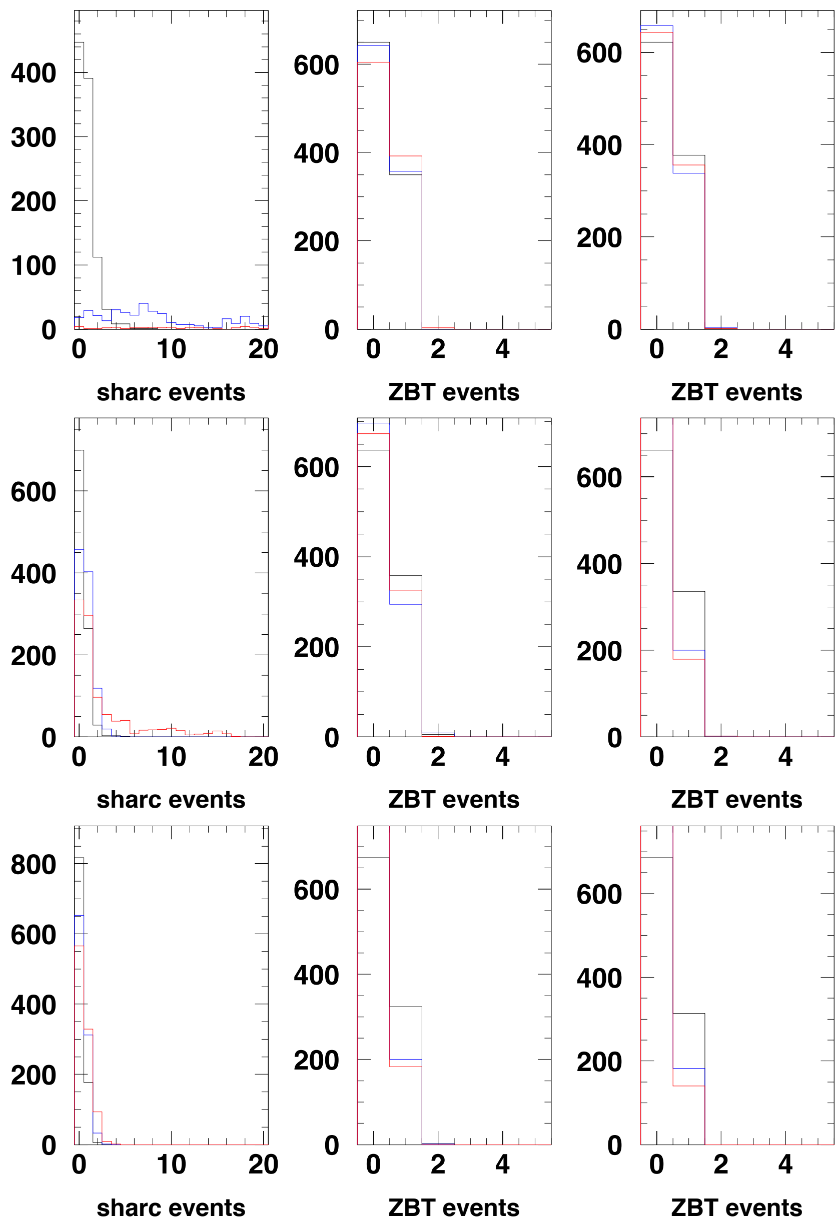

Figure 11: Buffering (in words) required in the MRODin end-cap tower 32 after additional data reduction

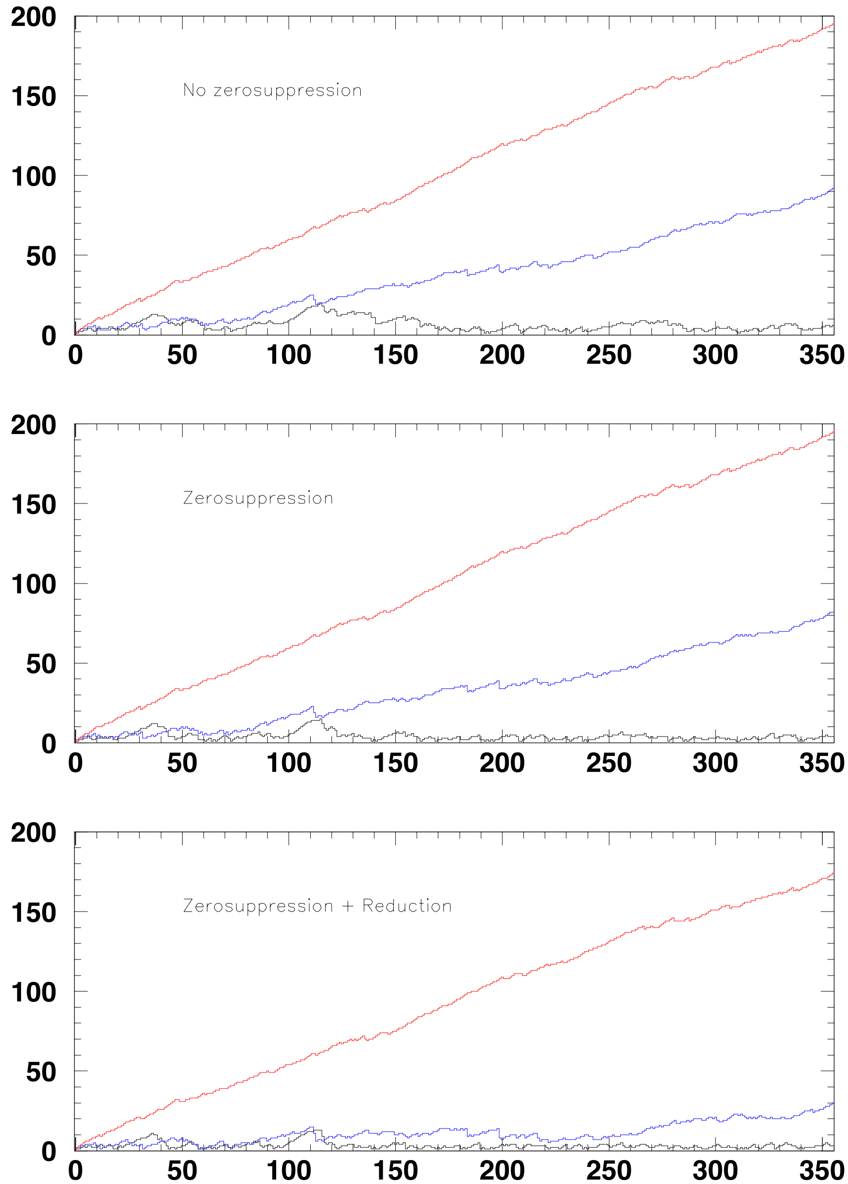

Figure 12: Number of events in the DAQ-chain versus event number (end-cap tower 32)

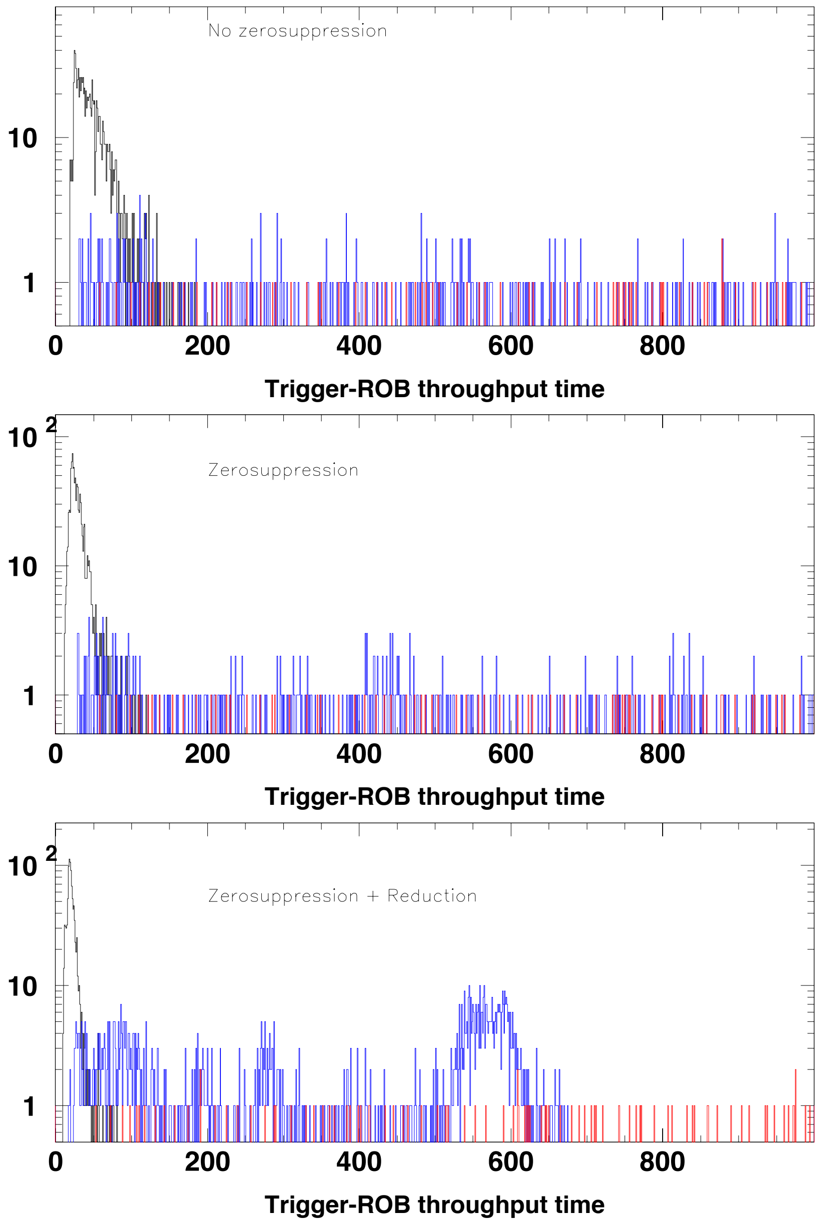

Figure 13: Duration of the event-flow through the DAQ (in μs) for end-cap tower 32

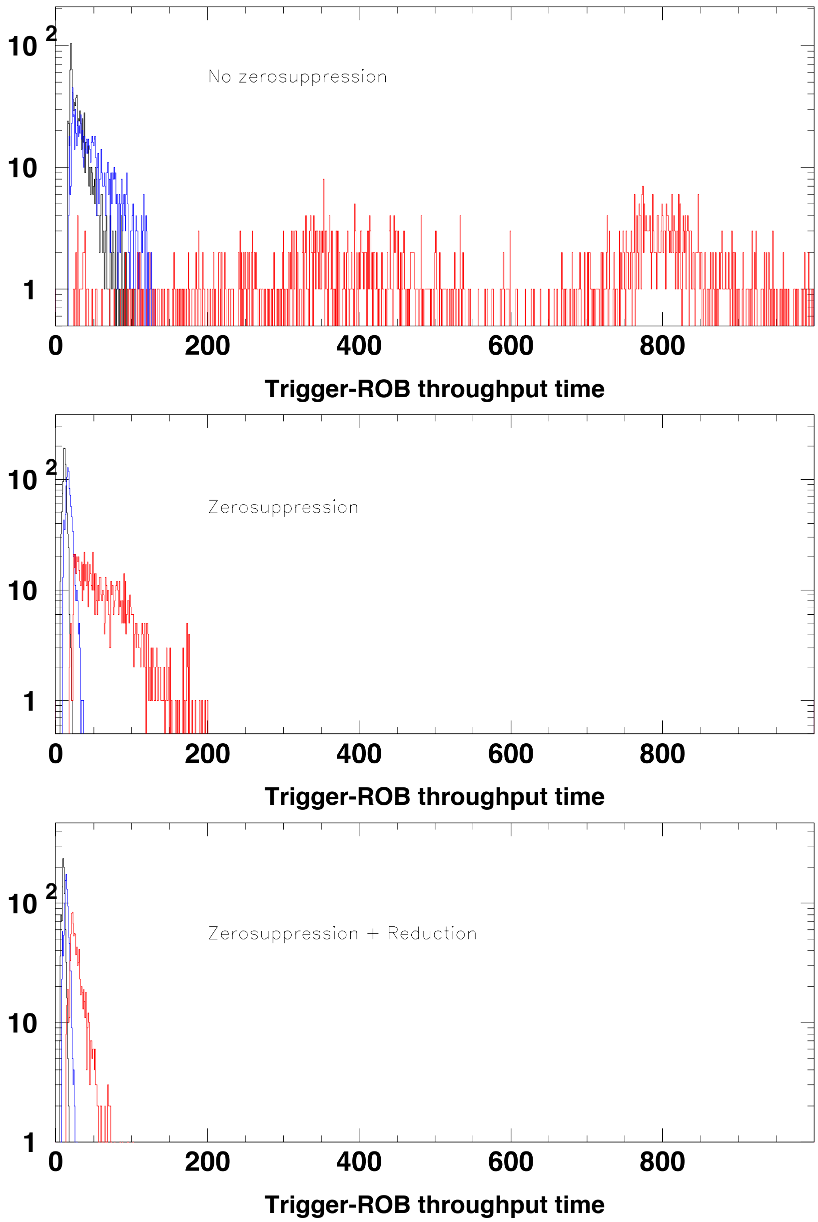

Figure 14: Duration of the event-flow through the DAQ (in μs) for barrel tower 30

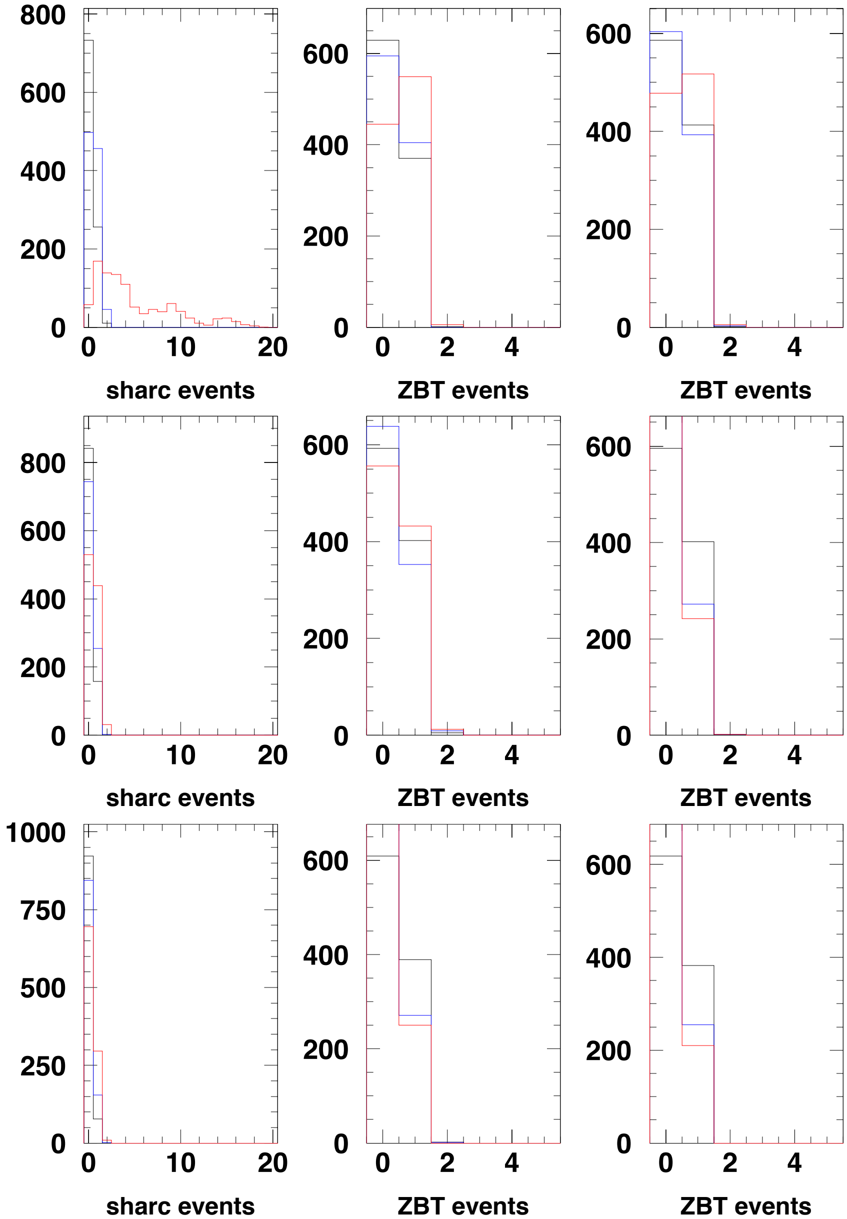

Figure 15: Buffering (events) required in the MRODin end-cap tower 32, assuming a double SHARC readout

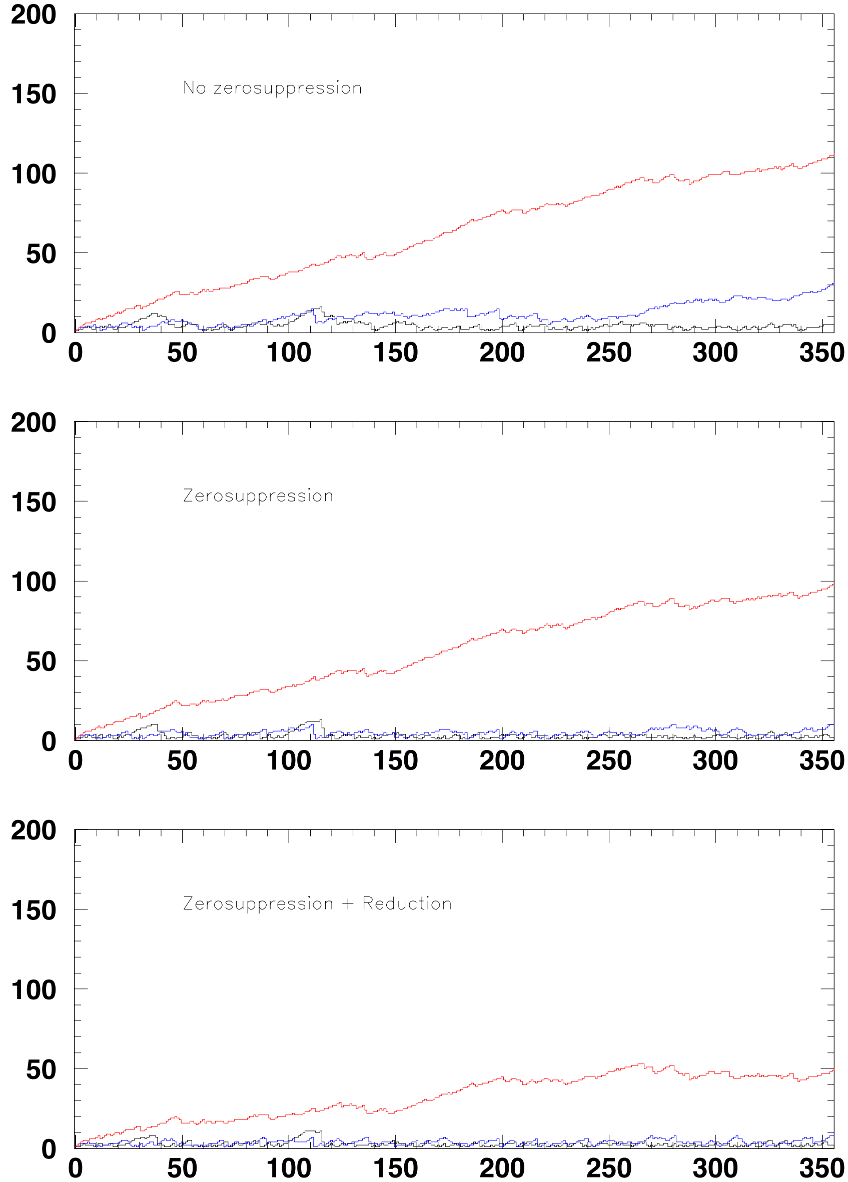

Figure 16: Total number of events in the DAQ-chain versus event number