The effect of radiation background on the MDT data acquisition

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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 muon counts as available on the atlas website. The calculated rates serve as input to the DAQ simulation program, in which the electronics response, in terms of data volume, is simulated for each trigger. It is possible to adjust parameters in this program, which correspond to properties of the DAQ system.

2 Background rates in the muon detector

As the input rates originate from a logarithmic plot (figure 1), care has to be taken when interpreting the numbers. Their precision does not allow for a very detailed study of the variation of the rate over a chamber. In the barrel chambers, the following rates have been used:

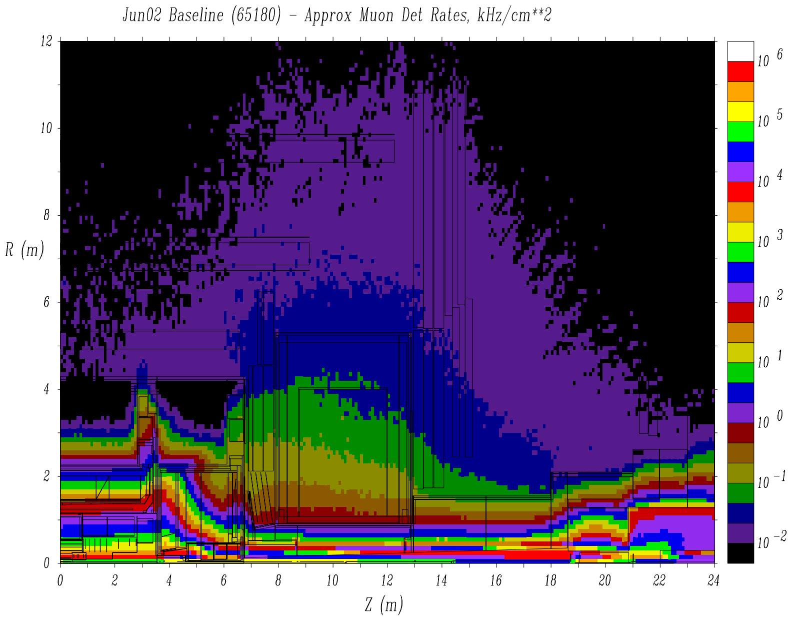

Figure 1: Muon counts as function of position (atlas web site)

Chamber	Rate (Hz/mm^2)
BO?	0.1
BM?	0.2
BI?	0.5

Note that a '?' stands for an arbitrary letter, thus all BO-chambers are simulated to have a background counting rate of 0.1 Hz. For the endcap chambers, things are more complicated. Here the following values are used:

Chamber	Rate (Hz/mm^2)
EIS1	2
EIS2	1
EIL1	2
EIL2	1
EIL3	.8
EIM4	.5
EIL4	.5
EE?	0.5
EM?	1.
E??	0.2

This simplification of reality can be easily improved without affecting the flow of the program. The rate per tube is determined by multiplying the rates in the table with the tube length (which is chamber dependent) and diameter (30 mm). Some chambers in the end-cap consists of tubes of different length. Here, the maximal tube length has been taken for this rate calculation. The result of this calculation is listed in appendix A. The values listed here are used as input for the simulation of the DAQ-response to this background.

3 The muon DAQ system

The muon DAQ system, as simulated, consists of a ROD, 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 TDC-window of 800 ns is simulated. Should there be a hit in the first 100 ns (of any TDC input channel), a TDC-mask word will be set. The hits in the final 700 ns are saved, and 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 transport from CSM to ROD and from ROD 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	700 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 ROD
ROD-ROB	1 bits/ns	data transfer speed between ROD and ROB
TRIGRATE	0.1 MHz	actual triggerrate
TRIGDEAD	100 ns	minimal time between triggers

Next to the TDC, the MROD also adds words to the data. The background rates of the individual tubes can be multiplied with an input parameter, which makes it possible to investigate higher (lower) noise rates.

3.1 The MROD

The MROD is the only piece of electronics which is modeled in more detail. It may have up to 4 MROD-IN boards, and an MROD-OUT buffer. Each MROD-IN is thought to consist of two chunks of ZBT memory (one for each channel), and a SHARC. In both places possible buffering is assumed. When the end-of-event is received in both ROD-IN channels, the event is piped to the SHARC. Whenever all data from all ROD-IN sharcs are complete, the data are moved to the MROD-OUT 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

4 Simulation

4.1 TDC hit simulation

For each TDC-channel, noise hits are simulated according to an $e^{-t \times f}$ distribution, where t is the time between triggers, and f the rate. The total time window in which hits are simulated consists of the sum of the TDC-mask and TDC-window, or 800 ns. Hits which fall in the first 100 ns are only used to set the mask-word, whereas hits which fall in the normal window add normal TDC words to the data. Figure 2 show the time difference between hits for both generated and accepted hits (for side D tower 31). The figure clearly shows the mask window, as well as the tdc-window. Hits are generated according to the specified

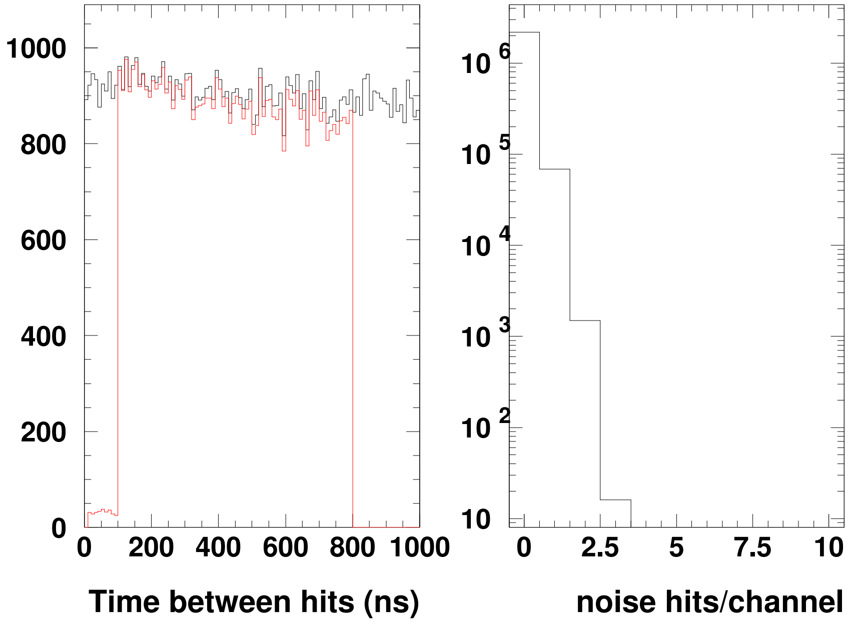

Figure 2: Generated and accepted noise hits (left). Number of noise hits per TDC channel distribution (right)

noise rate in the channel under consideration, as long as the hits are within the trigger window of the corresponding channel. This method is performed for each individual channel. When comparing the accepted to the generated hits, it is clear that no hits are accepted outside of the trigger window (i.e. after 800 ns), and that the efficiency for accepting hits is slowly going down even before. The latter is due to events with multiple noise hits in a single TDC channel. The multiple hits also cause an acceptance for hits that follow a previous hit within 100 ns.

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. Afterward, the data is sent to the ROD-IN ZBT, in here 4 words are added for each connected front-end link. The data from two input channels are added together into the

SHARC. The data from up to 4 ROD-INs are combined into the ROD-OUT 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 3. This exercise has been performed for 48 barrel and 48 endcap towers. The average number of words per event for each rod is listed in the table below.

barrel				endcap			
tower	words	tower	words	tower	words	tower	words
0	228.6	24	222.8	0	285.8	24	304.2
1	228.6	25	222.8	1	272.1	25	304.2
2	228.6	26	222.8	2	272.1	26	304.2
3	228.6	27	222.8	3	272.1	27	304.2
4	228.6	28	222.8	4	285.8	28	304.2
5	253.0	29	208.3	5	237.2	29	304.2
6	228.6	30	208.3	6	272.1	30	304.2
7	253.0	31	222.8	7	272.1	31	304.2
8	232.4	32	229.2	8	251.0	32	281.2
9	232.4	33	229.2	9	251.0	33	281.2
10	232.4	34	229.2	10	251.0	34	281.2
11	232.4	35	229.2	11	251.0	35	281.2
12	232.4	36	229.2	12	251.0	36	281.2
13	191.8	37	276.7	13	251.0	37	281.2
14	191.8	38	229.2	14	251.0	38	281.2
15	232.4	39	276.7	15	251.0	39	281.2
16	234.3	40	208.8	16	251.0	40	220.7
17	234.3	41	208.8	17	251.0	41	220.7
18	234.3	42	208.8	18	251.0	42	220.7
19	234.3	43	208.8	19	251.0	43	220.7
20	234.3	44	208.8	20	251.0	44	220.7
21	286.3	45	181.2	21	251.0	45	220.7
22	222.8	46	181.2	22	251.0	46	220.7
23	222.8	47	208.8	23	251.0	47	220.7

It is clear that the endcap is noisier, thus contains more data than the barrel.

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 4. One should note that the average throughput required between ROD and ROB is very close to 1 Gb/s, which implies that (assuming the background rates are correct) 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	RODOUT
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

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.

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 5. When combining the trigger simulation with the event simulation, the buffering requirements of each module can be evaluated.

4.5 Required buffering

Using the simulated trigger times as shown in figure 5, it is possible to analyze the number of events required 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 ROD. Figure 6 shows the amount of buffering required for the tower containing the busiest TDCs. Even for this tower we have not seen a single occurrence beyond 8 triggers stored (in 1000 simulated events).

The ROD-buffering is performed in three steps. At the ROD-IN, buffering in the ZBT and in the SHARC is simulated. Furthermore, there is buffering in the ROD-OUT. The buffering in the ROD-IN is shown in figure 7. 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 ROD-OUT forms a huge bottleneck, as one of the sharcs simply fills up. Note that this is due to the number of channels this specific ROD-IN has to handle, the background rate in these channels is only a small addition to the datavolume. Next to the number of events, one can look at the number of words to be stored in the ROD-IN. This is shown in figure 8 (for endcap tower 0), and shows a similar behaviour 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 ROD-OUT buffering needs for this specific tower are negligible, as one of the ROD-INs cannot push the event through fast enough, whereas the ROD-ROB link is fast enough. A nicer example to look at is tower 31 in the endcap. For this specific tower the required ROD-ROB throughput is very close to 1 bit/ns, thus the buffering requirement is high.

4.6 Zero suppression

In order to overcome the problem shown above, a simple lossless zero suppression algorithm could be used. This algorithm would simply be to have the ROD 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, this is a significant data reduction. The resulting data volume is shown in the table below.

barrel				endcap			
tower	words	tower	words	tower	words	tower	words
0	128.1	24	106.4	0	255.7	24	207.0
1	128.1	25	106.4	1	247.3	25	207.0
2	128.1	26	106.4	2	247.3	26	207.0
3	128.1	27	106.4	3	247.3	27	207.0
4	128.1	28	106.4	4	255.7	28	207.0
5	135.1	29	99.7	5	219.2	29	207.0
6	128.1	30	99.7	6	247.3	30	207.0
7	135.1	31	106.4	7	247.3	31	207.0
8	110.5	32	129.2	8	204.2	32	207.0
9	110.5	33	129.2	9	204.2	33	207.0
10	110.5	34	129.2	10	204.2	34	207.0
11	110.5	35	129.2	11	204.2	35	207.0
12	110.5	36	129.2	12	204.2	36	207.0
13	94.0	37	140.2	13	204.2	37	207.0
14	94.0	38	129.2	14	204.2	38	207.0
15	110.5	39	140.2	15	204.2	39	207.0
16	132.0	40	100.9	16	198.7	40	129.2
17	132.0	41	100.9	17	198.7	41	129.2
18	132.0	42	100.9	18	198.7	42	129.2
19	132.0	43	100.9	19	198.7	43	129.2
20	132.0	44	100.9	20	198.7	44	129.2
21	144.4	45	91.2	21	198.7	45	129.2
22	116.5	46	91.2	22	198.7	46	129.2
23	144.4	47	100.9	23	198.7	47	129.2

The reduction in the endcap is slightly less than in the barrel. This is due to the fact that in the endcap more channels contribute hits to the data volume. A comparison between figures 10 and 9 clearly shows the effect of this zerosuppression. It reduces the number of words/event, thus the amount of buffering needed per event. But it also increases the flow of the event through the DAQ, thus reducing the number of events to be stored. However, this level of zero-suppression is not enough to enable the throughput of endcap tower 0. This is caused by the very high background rates of 172 kHz per channel in CSM 4 (as can be seen in appendix A).

4.7 Additional lossles data reduction

In addition to the zero suppression, it is possible to remove the TDC trailer words to further reduce the amount of data, while only removing redundant information. The net result in terms of datavolume can be seen below.

barrel				endcap			
tower	words	tower	words	tower	words	tower	words
0	100.3	24	84.6	0	206.9	24	161.4
1	100.3	25	84.6	1	199.7	25	161.4
2	100.3	26	84.6	2	199.7	26	161.4
3	100.3	27	84.6	3	199.7	27	161.4
4	100.3	28	84.6	4	206.9	28	161.4
5	106.1	29	80.1	5	178.2	29	161.4
6	100.3	30	80.1	6	199.7	30	161.4
7	106.1	31	84.6	7	199.7	31	161.4
8	87.5	32	101.2	8	161.6	32	162.1
9	87.5	33	101.2	9	161.6	33	162.1
10	87.5	34	101.2	10	161.6	34	162.1
11	87.5	35	101.2	11	161.6	35	162.1
12	87.5	36	101.2	12	161.6	36	162.1
13	74.9	37	110.5	13	161.6	37	162.1
14	74.9	38	101.2	14	161.6	38	162.1
15	87.5	39	110.5	15	161.6	39	162.1
16	103.1	40	80.9	16	156.4	40	101.0
17	103.1	41	80.9	17	156.4	41	101.0
18	103.1	42	80.9	18	156.4	42	101.0
19	103.1	43	80.9	19	156.4	43	101.0
20	103.1	44	80.9	20	156.4	44	101.0
21	113.4	45	74.2	21	156.4	45	101.0
22	91.2	46	74.2	22	156.4	46	101.0
23	113.4	47	80.9	23	156.4	47	101.0

The effect of this second data reduction step is such that the dataflow for endcap tower 0 is on the edge, as can be seen from figure 11. The figure shows that the complete DAQ chain up to the ROB can now barely keep up with data production, whereas it could not without the data reduction step.

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 zerosuppression and datareduction. Figures 12 and 13 show this throughput time distribution for endcap towers 31 and 0 respectively. The figures clearly show the effect of the data reduction; and also that for tower 0 both effects are needed to be able to keep up with the data production.

4.9 Decrease of SHARC readout time

It is possible to double the readout of the ROD-IN boards, and thus remove the bottleneck for endcap tower 0. This is done by adding a SHARC, and thus effectively doubling the bandwidth. The effect is clearly visible in figure 14. In this figure, no zerosuppression is assumed and already the flow out of the ROD-IN into the ROD-OUT is comfortable. The throughput of the events through the whole DAQ chain is visible in figure 15. Again, even without zerosuppression the DAQ is able to handle the data when the SHARC readout is doubled. However, zerosuppression would be welcome to reduce the total readout time of the events.

5 Conclusion

The throughput requirements on the MDT-DAQ system have been evaluated using a simplified model of both the background rates and the electronics. The procedure used allows for a modification of both the DAQ throughput and background rates. The results obtained show that the current version of the DAQ system is matched to the requirements, provided some data reduction algorithms will be adopted. A doubling of the readout speed of the ROD-IN SHARC would be very welcome for some towers.

6 Appendix A

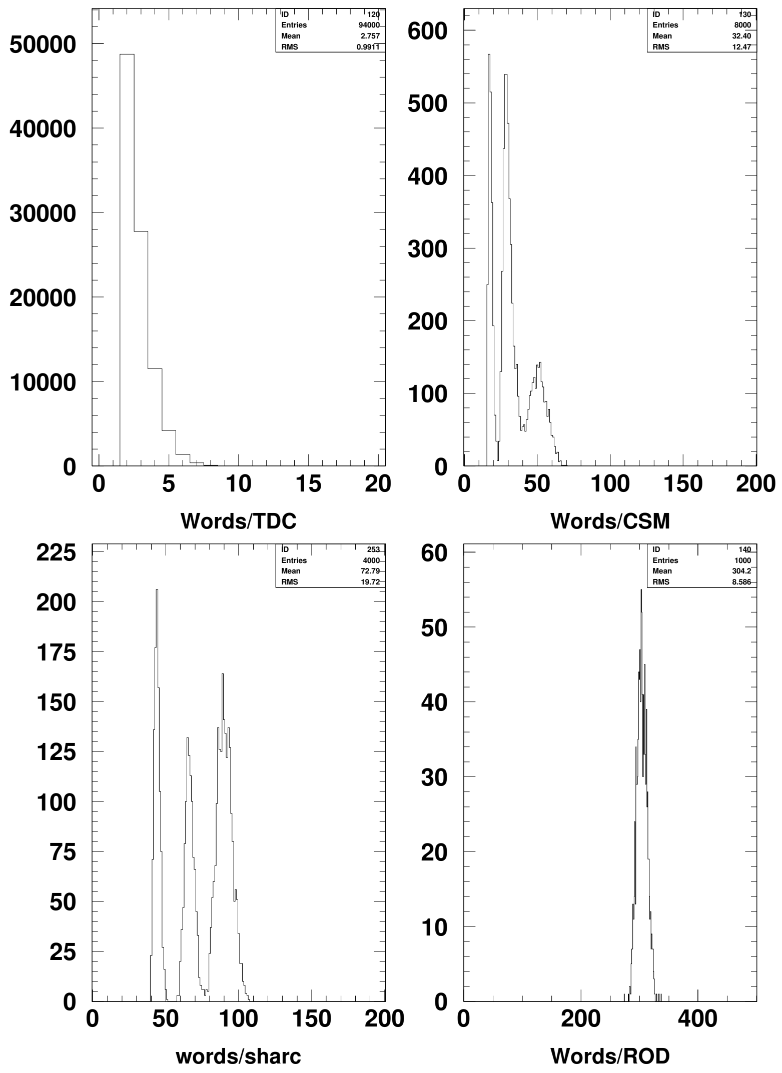

Figure 3: The total number of words in a tower (endcap tower 31) for an event.

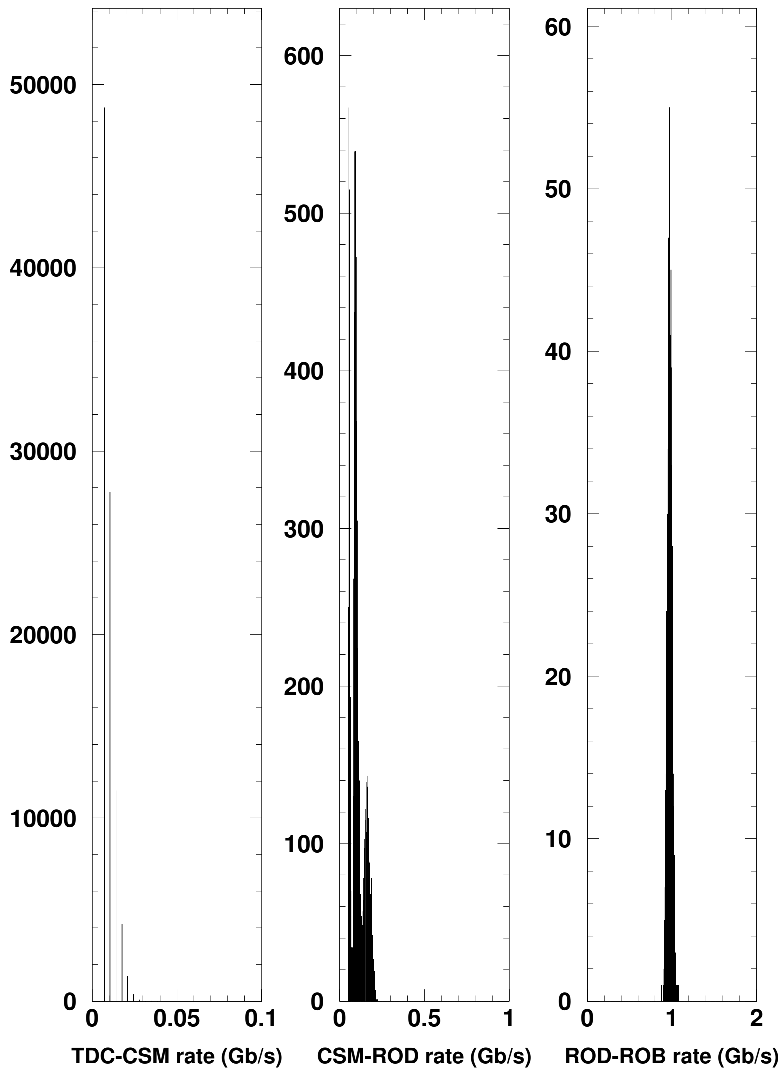

Figure 4: The throughput required for each link in a tower (endcap tower 31).

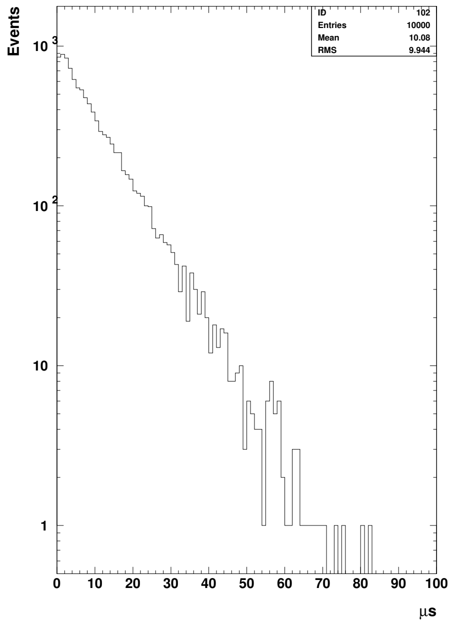

Figure 5: Simulated time between consecutive triggers

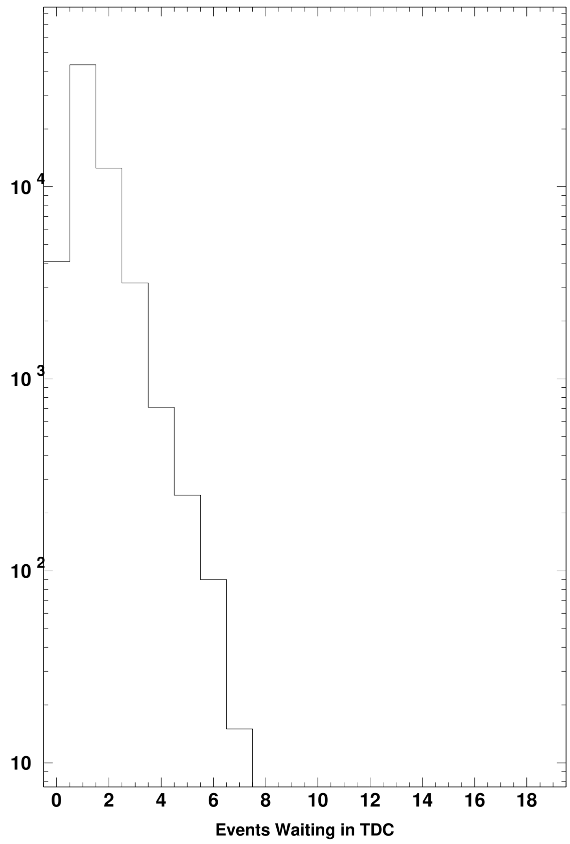

Figure 6: Buffering required in TDC for endcap tower 0

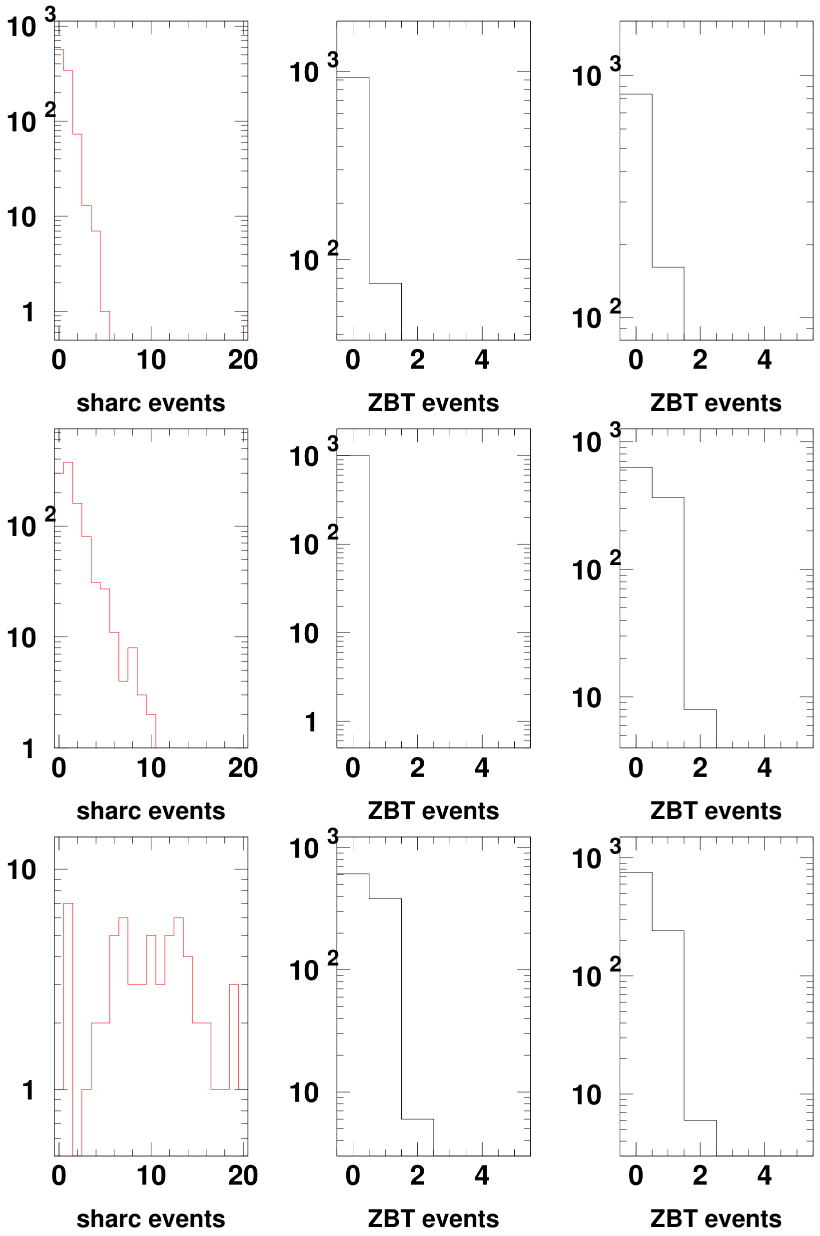

Figure 7: Buffering (events) required in the ROB-IN endcap tower 0

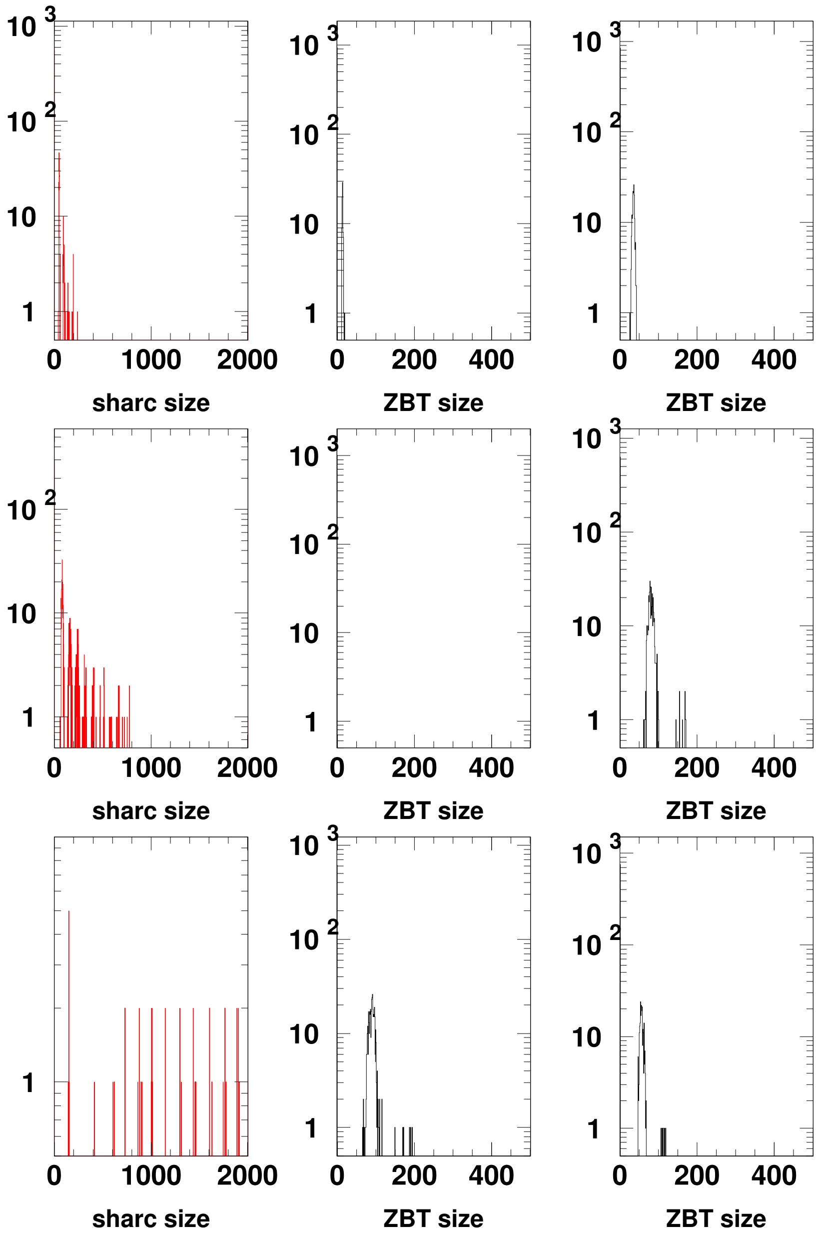

Figure 8: Buffering (in words) required in the ROB-IN endcap tower 0

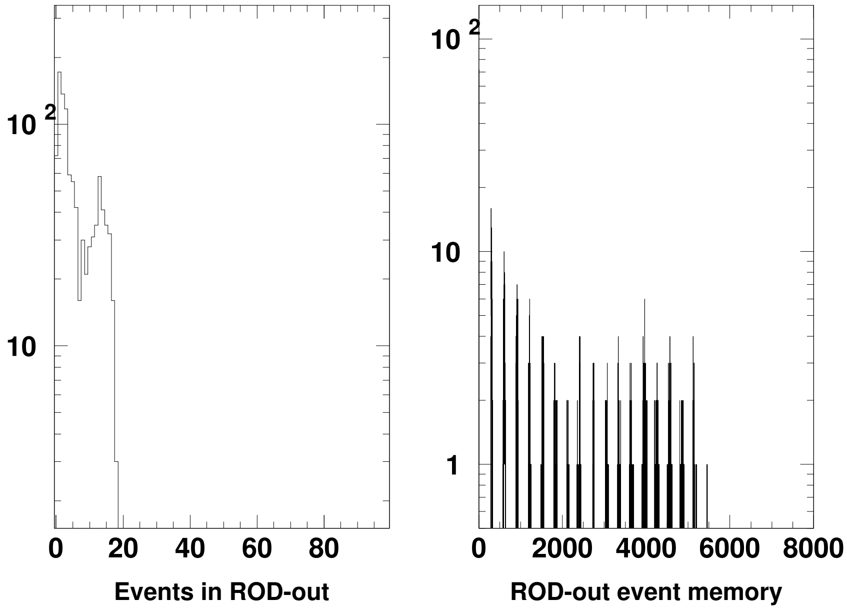

Figure 9: Buffering (right: number of events, left: words) required in the ROD-OUT endcap tower 331

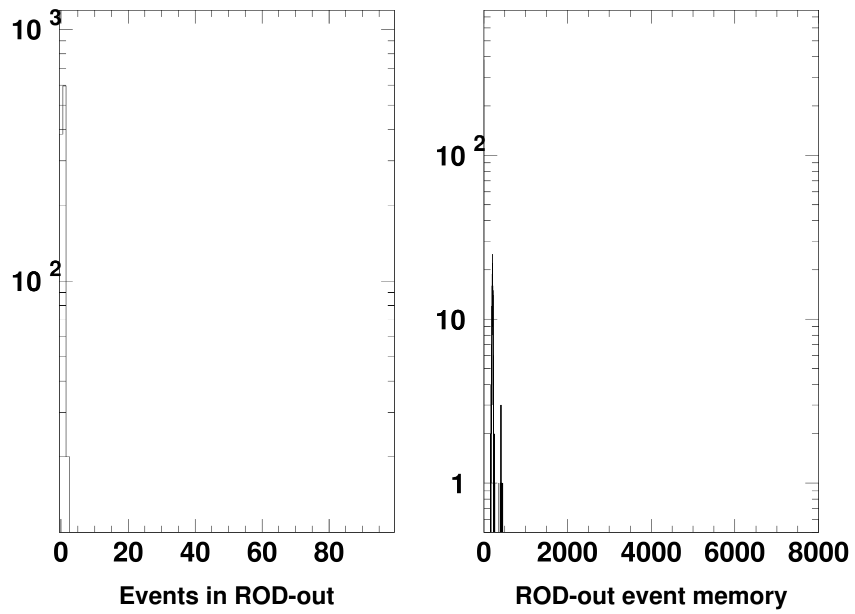

Figure 10: Buffering (right: number of events, left: words) required in the ROD-OUT endcap tower 331, after zerosuppression

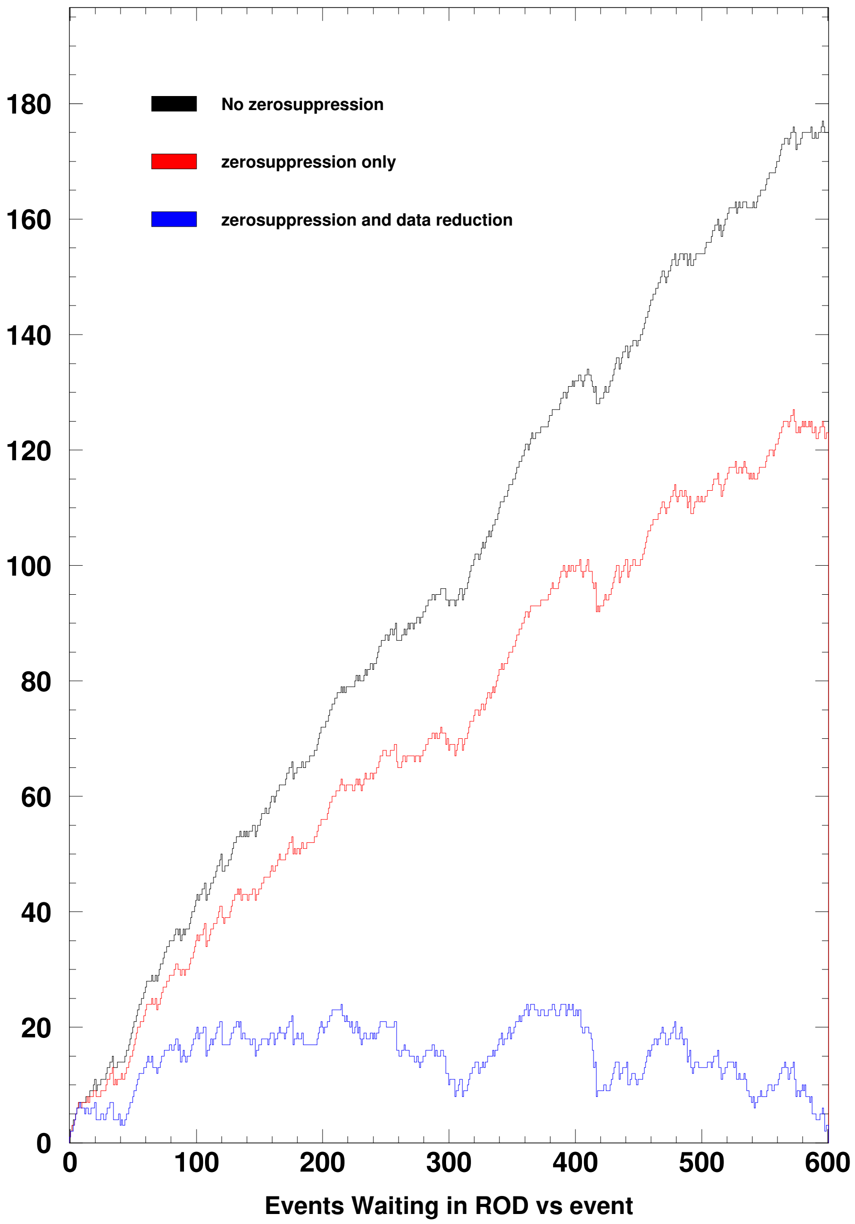

Figure 11: Events in the DAQ chain

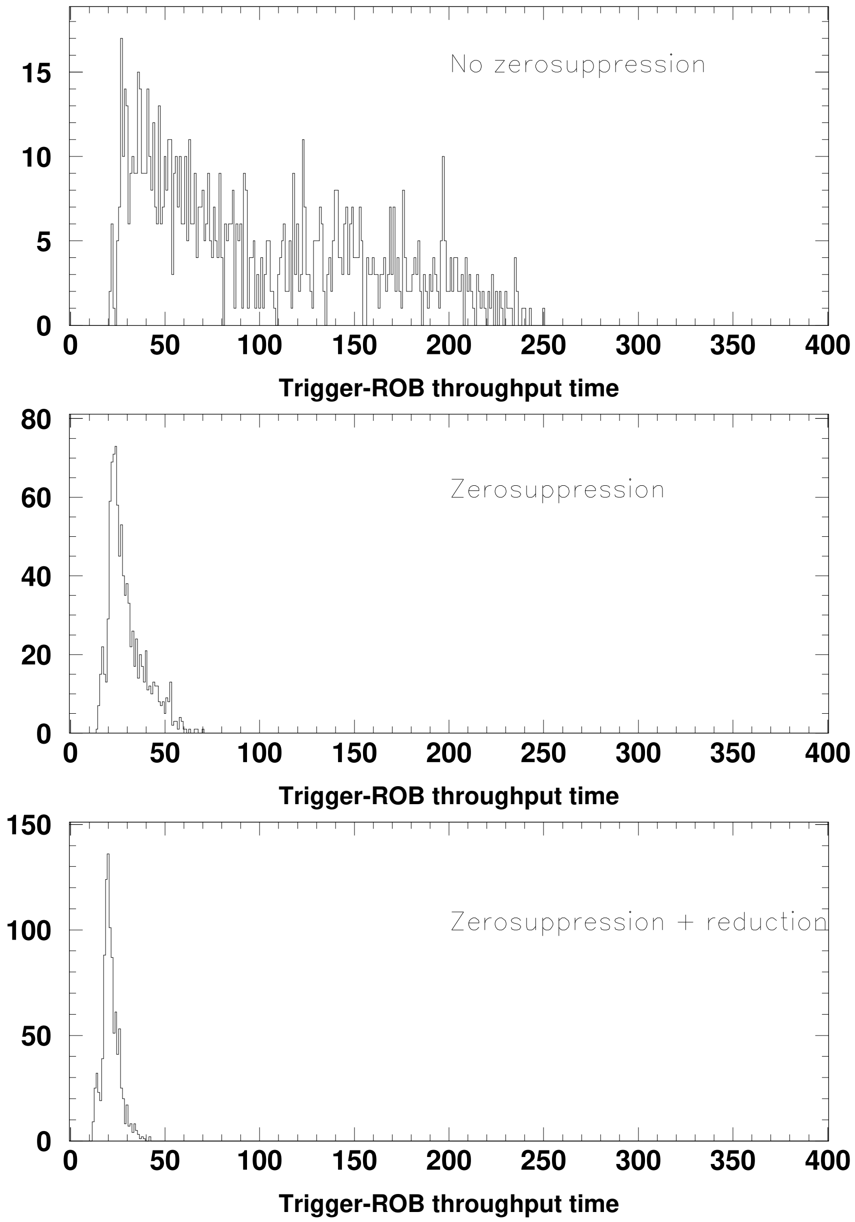

Figure 12: Duration of the event-flow through the DAQ (in μs) for endcap tower 31

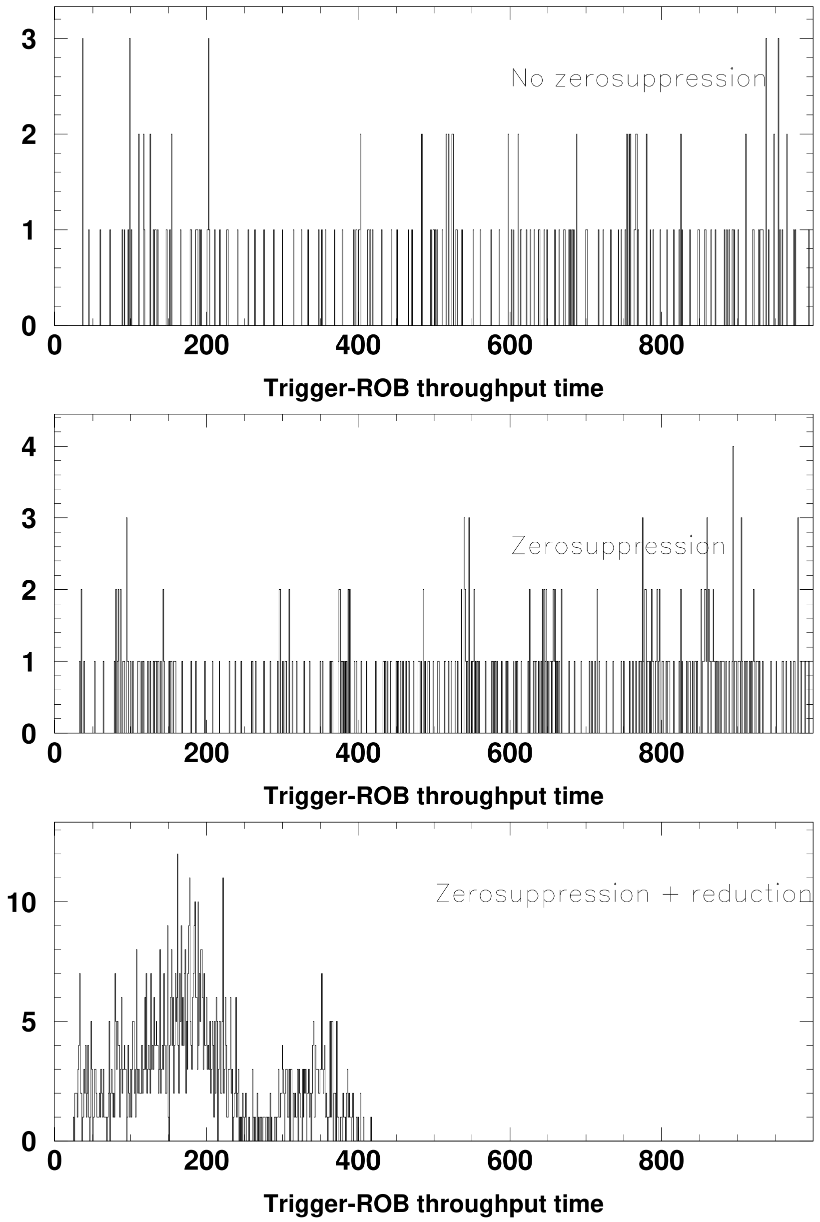

Figure 13: Duration of the event-flow through the DAQ (in μs) for endcap tower 0

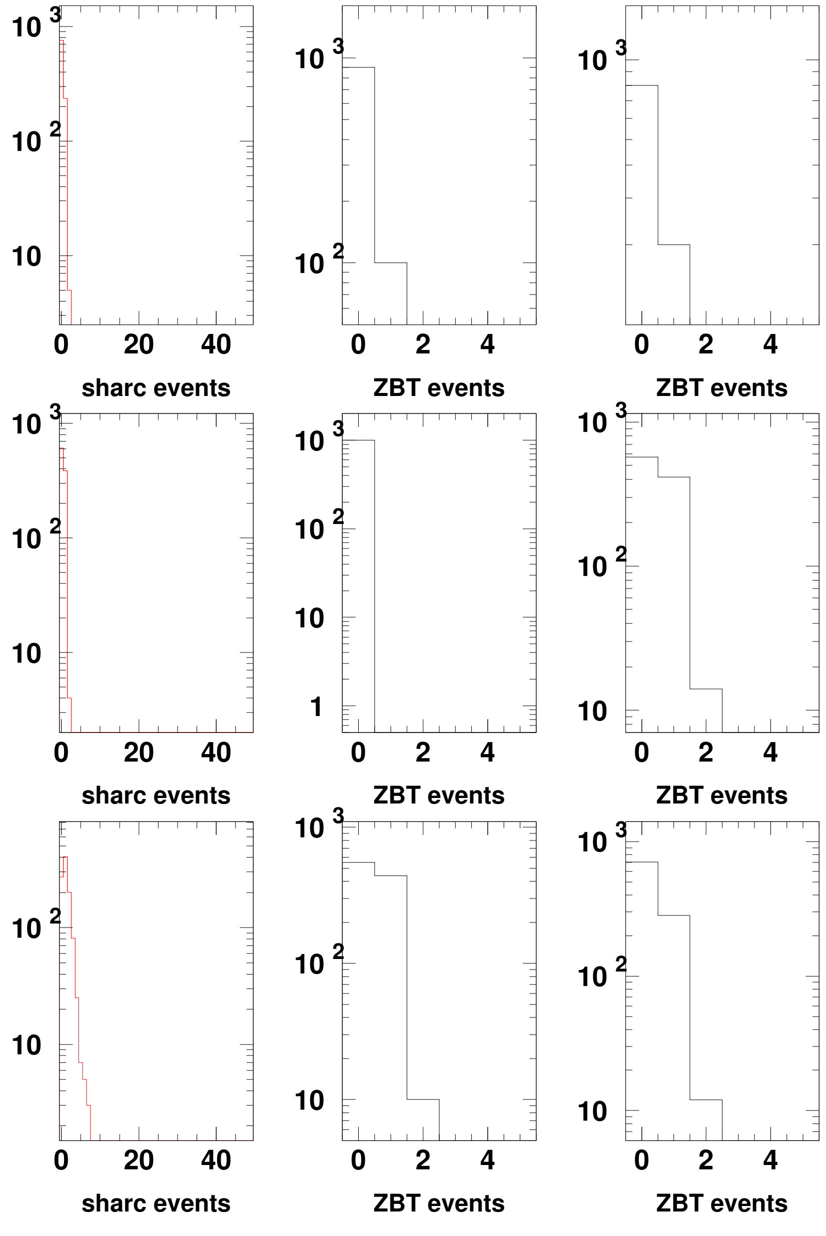

Figure 14: Buffering (events) required in the ROB-IN endcap tower 0, assuming a double SHARC readout

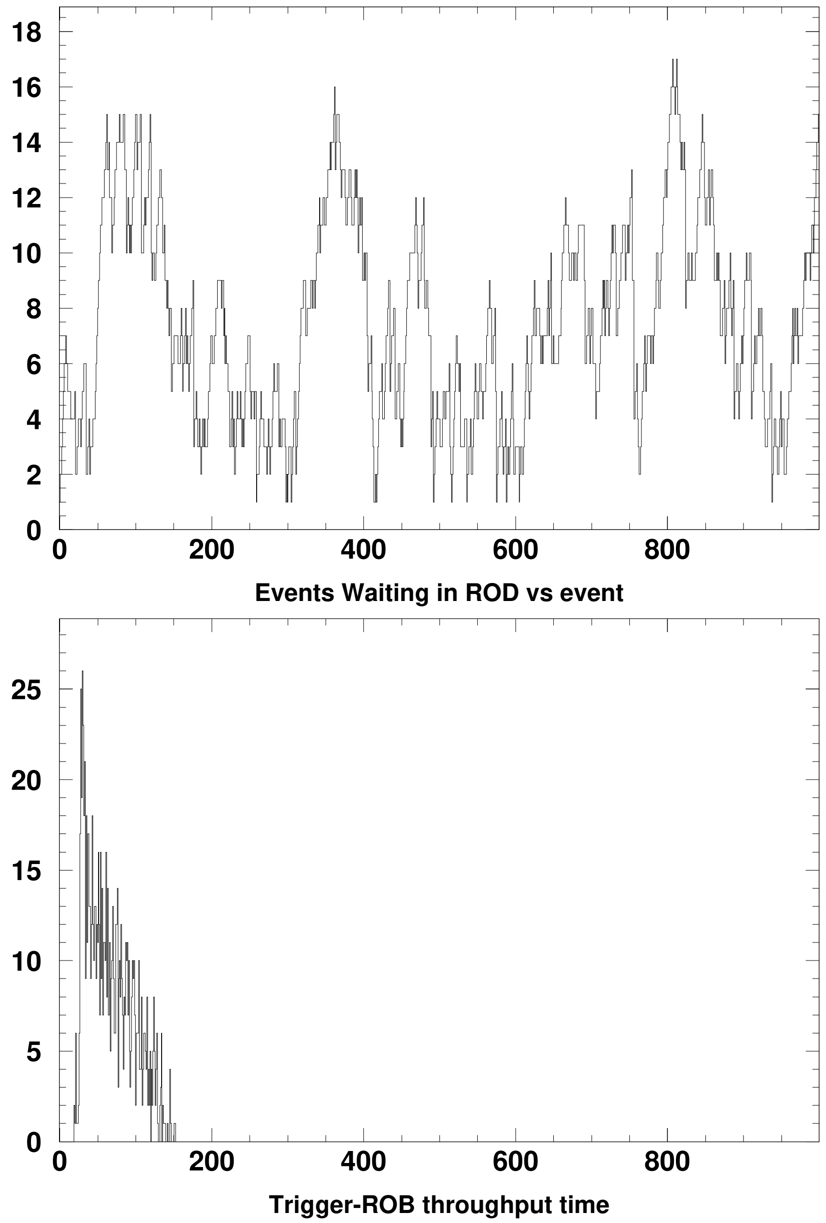

Figure 15: Total number of events in the DAQ-chain (top) and event readout time distribution in μs (bottom) for endcap tower 0, assuming a double SHARC readout

	CSM Barrel A-side							
Tower	0	1	2	3	4	5	6	7
0	39720	39720	21168	21168	14814	14814	-1	-1
1	39720	39720	21168	21168	14814	14814	-1	-1
2	39720	39720	21168	21168	14814	14814	-1	-1
3	39720	39720	21168	21168	14814	14814	-1	-1
4	39720	39720	21168	21168	14814	14814	-1	-1
5	22695	39720	21168	21168	14814	14814	22695	-1
6	39720	39720	21168	21168	14814	14814	-1	-1
7	22695	39720	21168	21168	14814	14814	22695	-1
8	24720	24720	18288	18288	11244	11244	-1	-1
9	24720	24720	18288	18288	11244	11244	-1	-1
10	24720	24720	18288	18288	11244	11244	-1	-1
11	24720	24720	18288	18288	11244	11244	-1	-1
12	24720	24720	18288	18288	11244	11244	-1	-1
13	24720	24720	18288	11244	-1	11244	-1	-1
14	24720	24720	18288	11244	-1	11244	-1	-1
15	24720	24720	18288	18288	11244	11244	-1	-1
16	39720	39720	21168	21168	14814	14814	-1	-1
17	39720	39720	21168	21168	14814	14814	-1	-1
18	39720	39720	21168	21168	14814	14814	-1	-1
19	39720	39720	21168	21168	14814	14814	-1	-1
20	39720	39720	21168	21168	14814	14814	-1	-1
21	22695	22695	21168	21168	14814	14814	16230	22695
22	39720	39720	21168	-1	14814	14814	-1	-1
23	22695	22695	21168	21168	14814	14814	16230	22695

	CSM Barrel A-side							
Tower	0	1	2	3	4	5	6	7
24	24720	24720	18288	18288	11244	11244	-1	-1
25	24720	24720	18288	18288	11244	11244	-1	-1
26	24720	24720	18288	18288	11244	11244	-1	-1
27	24720	24720	18288	18288	11244	11244	-1	-1
28	24720	24720	18288	18288	11244	11244	-1	-1
29	24720	24720	18288	11244	11244	11244	-1	-1
30	24720	24720	18288	11244	11244	11244	-1	-1
31	24720	24720	18288	18288	11244	11244	-1	-1
32	39720	39720	21168	21168	14814	14814	-1	-1
33	39720	39720	21168	21168	14814	14814	-1	-1
34	39720	39720	21168	21168	14814	14814	-1	-1
35	39720	39720	21168	21168	14814	14814	-1	-1
36	39720	39720	21168	21168	14814	14814	-1	-1
37	22695	22695	21168	21168	14814	14814	22695	16230
38	39720	39720	21168	21168	14814	14814	-1	-1
39	22695	22695	21168	21168	14814	14814	22695	16230
40	24720	24720	18288	18288	11244	11244	-1	-1
41	24720	24720	18288	18288	11244	11244	-1	-1
42	24720	24720	18288	18288	11244	11244	-1	-1
43	24720	24720	18288	18288	11244	11244	-1	-1
44	24720	24720	18288	18288	11244	11244	-1	-1
45	24720	24720	18288	11244	11244	11244	-1	-1
46	24720	24720	18288	11244	11244	11244	-1	-1
47	24720	24720	18288	18288	11244	11244	-1	-1

	CSM Barrel C-side							
Tower	0	1	2	3	4	5	6	7
0	39720	39720	21168	21168	14814	14814	-1	-1
1	39720	39720	21168	21168	14814	14814	-1	-1
2	39720	39720	21168	21168	14814	14814	-1	-1
3	39720	39720	21168	21168	14814	14814	-1	-1
4	39720	39720	21168	21168	14814	14814	-1	-1
5	22695	39720	21168	21168	14814	14814	22695	-1
6	39720	39720	21168	21168	14814	14814	-1	-1
7	22695	39720	21168	21168	14814	14814	22695	-1
8	24720	24720	18288	18288	11244	11244	-1	-1
9	24720	24720	18288	18288	11244	11244	-1	-1
10	24720	24720	18288	18288	11244	11244	-1	-1
11	24720	24720	18288	18288	11244	11244	-1	-1
12	24720	24720	18288	18288	11244	11244	-1	-1
13	24720	24720	18288	11244	11244	11244	-1	-1
14	24720	24720	18288	11244	11244	11244	-1	-1
15	24720	24720	18288	18288	11244	11244	-1	-1
16	39720	39720	21168	21168	14814	14814	-1	-1
17	39720	39720	21168	21168	14814	14814	-1	-1
18	39720	39720	21168	21168	14814	14814	-1	-1
19	39720	39720	21168	21168	14814	14814	-1	-1
20	39720	39720	21168	21168	14814	14814	-1	-1
21	22695	22695	21168	21168	14814	14814	16230	22695
22	39720	39720	21168	-1	14814	14814	-1	-1
23	22695	22695	21168	21168	14814	14814	16230	22695

	CSM Barrel C-side							
Tower	0	1	2	3	4	5	6	7
24	24720	24720	18288	18288	11244	11244	-1	-1
25	24720	24720	18288	18288	11244	11244	-1	-1
26	24720	24720	18288	18288	11244	11244	-1	-1
27	24720	24720	18288	18288	11244	11244	-1	-1
28	24720	24720	18288	18288	11244	11244	-1	-1
29	24720	24720	18288	11244	11244	11244	-1	-1
30	24720	24720	18288	11244	11244	11244	-1	-1
31	24720	24720	18288	18288	11244	11244	-1	-1
32	39720	39720	21168	21168	14814	14814	-1	-1
33	39720	39720	21168	21168	14814	14814	-1	-1
34	39720	39720	21168	21168	14814	14814	-1	-1
35	39720	39720	21168	21168	14814	14814	-1	-1
36	39720	39720	21168	21168	14814	14814	-1	-1
37	22695	22695	21168	21168	14814	14814	22695	16230
38	39720	39720	21168	21168	14814	14814	-1	-1
39	22695	22695	21168	21168	14814	14814	22695	16230
40	24720	24720	18288	18288	11244	11244	-1	-1
41	24720	24720	18288	18288	11244	11244	-1	-1
42	24720	24720	18288	18288	11244	11244	-1	-1
43	24720	24720	18288	18288	11244	11244	-1	-1
44	24720	24720	18288	18288	11244	11244	-1	-1
45	24720	24720	18288	11244	11244	11244	-1	-1
46	24720	24720	18288	11244	11244	11244	-1	-1
47	24720	24720	18288	18288	11244	11244	-1	-1

	CSM EndCap A-side							
Tower	0	1	2	3	4	5	6	7
0	22695	57270	3600	142890	171690	45720	-1	-1
1	45720	57270	3600	142890	171690	-1	-1	-1
2	45720	57270	3600	142890	171690	-1	-1	-1
3	45720	57270	3600	142890	171690	-1	-1	-1
4	22695	57270	3600	142890	171690	45720	-1	-1
5	45720	57270	3600	142890	171690	-1	-1	-1
6	45720	57270	3600	142890	171690	-1	-1	-1
7	45720	57270	3600	142890	171690	-1	-1	-1
8	24720	12420	35265	40665	91320	108600	-1	-1
9	24720	12420	35265	40665	91320	108600	-1	-1
10	24720	12420	35265	40665	91320	108600	-1	-1
11	24720	12420	35265	40665	91320	108600	-1	-1
12	24720	12420	35265	40665	91320	108600	-1	-1
13	24720	12420	35265	40665	91320	108600	-1	-1
14	24720	12420	35265	40665	91320	108600	-1	-1
15	24720	12420	35265	40665	91320	108600	-1	-1
16	68640	49152	114090	28668	32988	37308	-1	-1
17	68640	49152	114090	28668	32988	37308	-1	-1
18	68640	49152	114090	28668	32988	37308	-1	-1
19	68640	49152	114090	28668	32988	37308	-1	-1
20	68640	49152	114090	28668	32988	37308	-1	-1
21	68640	49152	114090	28668	32988	37308	-1	-1
22	68640	49152	114090	28668	32988	37308	-1	-1
23	68640	49152	114090	28668	32988	37308	-1	-1

	CSM EndCap A-side							
Tower	0	1	2	3	4	5	6	7
24	71940	45690	13320	13320	74040	18588	21180	23772
25	71940	45690	13320	13320	74040	18588	21180	23772
26	71940	45690	13320	13320	74040	18588	21180	23772
27	71940	45690	13320	13320	74040	18588	21180	23772
28	71940	45690	13320	13320	74040	18588	21180	23772
29	71940	45690	13320	13320	74040	18588	21180	23772
30	71940	45690	13320	13320	74040	18588	21180	23772
31	71940	45690	13320	13320	74040	18588	21180	23772
32	104880	56490	85290	14268	20028	24348	-1	-1
33	104880	56490	85290	14268	20028	24348	-1	-1
34	104880	56490	85290	14268	20028	24348	-1	-1
35	104880	56490	85290	14268	20028	24348	-1	-1
36	104880	56490	85290	14268	20028	24348	-1	-1
37	104880	56490	85290	14268	20028	24348	-1	-1
38	104880	56490	85290	14268	20028	24348	-1	-1
39	104880	56490	85290	14268	20028	24348	-1	-1
40	39480	56760	9948	12972	15996	-1	-1	-1
41	39480	56760	9948	12972	15996	-1	-1	-1
42	39480	56760	9948	12972	15996	-1	-1	-1
43	39480	56760	9948	12972	15996	-1	-1	-1
44	39480	56760	9948	12972	15996	-1	-1	-1
45	39480	56760	9948	12972	15996	-1	-1	-1
46	39480	56760	9948	12972	15996	-1	-1	-1
47	39480	56760	9948	12972	15996	-1	-1	-1

	CSM EndCap C-side							
Tower	0	1	2	3	4	5	6	7
0	22695	57270	3600	142890	171690	45720	-1	-1
1	45720	57270	3600	142890	171690	-1	-1	-1
2	45720	57270	3600	142890	171690	-1	-1	-1
3	45720	57270	3600	142890	171690	-1	-1	-1
4	22695	57270	3600	142890	171690	45720	-1	-1
5	45720	3600	3600	142890	171690	-1	-1	-1
6	45720	57270	3600	142890	171690	-1	-1	-1
7	45720	57270	3600	142890	171690	-1	-1	-1
8	24720	12420	35265	40665	91320	108600	-1	-1
9	24720	12420	35265	40665	91320	108600	-1	-1
10	24720	12420	35265	40665	91320	108600	-1	-1
11	24720	12420	35265	40665	91320	108600	-1	-1
12	24720	12420	35265	40665	91320	108600	-1	-1
13	24720	12420	35265	40665	91320	108600	-1	-1
14	24720	12420	35265	40665	91320	108600	-1	-1
15	24720	12420	35265	40665	91320	108600	-1	-1
16	68640	49152	114090	28668	32988	37308	-1	-1
17	68640	49152	114090	28668	32988	37308	-1	-1
18	68640	49152	114090	28668	32988	37308	-1	-1
19	68640	49152	114090	28668	32988	37308	-1	-1
20	68640	49152	114090	28668	32988	37308	-1	-1
21	68640	49152	114090	28668	32988	37308	-1	-1
22	68640	49152	114090	28668	32988	37308	-1	-1
23	68640	49152	114090	28668	32988	37308	-1	-1

	CSM EndCap C-side							
Tower	0	1	2	3	4	5	6	7
24	71940	45690	13320	13320	74040	18588	21180	23772
25	71940	45690	13320	13320	74040	18588	21180	23772
26	71940	45690	13320	13320	74040	18588	21180	23772
27	71940	45690	13320	13320	74040	18588	21180	23772
28	71940	45690	13320	13320	74040	18588	21180	23772
29	71940	45690	13320	13320	74040	18588	21180	23772
30	71940	45690	13320	13320	74040	18588	21180	23772
31	71940	45690	13320	13320	74040	18588	21180	23772
32	104880	56490	85290	14268	20028	24348	-1	-1
33	104880	56490	85290	14268	20028	24348	-1	-1
34	104880	56490	85290	14268	20028	24348	-1	-1
35	104880	56490	85290	14268	20028	24348	-1	-1
36	104880	56490	85290	14268	20028	24348	-1	-1
37	104880	56490	85290	14268	20028	24348	-1	-1
38	104880	56490	85290	14268	20028	24348	-1	-1
39	104880	56490	85290	14268	20028	24348	-1	-1
40	39480	56760	9948	12972	15996	-1	-1	-1
41	39480	56760	9948	12972	15996	-1	-1	-1
42	39480	56760	9948	12972	15996	-1	-1	-1
43	39480	56760	9948	12972	15996	-1	-1	-1
44	39480	56760	9948	12972	15996	-1	-1	-1
45	39480	56760	9948	12972	15996	-1	-1	-1
46	39480	56760	9948	12972	15996	-1	-1	-1
47	39480	56760	9948	12972	15996	-1	-1	-1