MONTECARLO RESULTS:

NBLM RESPONSE TO ESS SCENARIOS

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CARTOUCHE D'EVOLUTION - *DOCUMENT REVISION HISTORY*			
Éditions ***Editions***	**Dates** ***Dates***	**§ modifiés** ***Modified part(s)***	**Commentaires –** ***Observations***
1st	19/04/2017		
2nd	12/05/2017	3	Calculate the rates in 14Hz also. Add tables for 1% 1W/m losses

CONTENTS

1. Introduction

In this document the latest results from simulations are shown. This documents intend to complete the PDR1.1 [1] delivered in December 2016 taking into account previous discussions we have had with the ESS and after more scenarios have been simulated. For an introduction to the project we refer to document [1].

In [1] we define the geometry of the prototypes through MonteCarlo simulations using Geant4. The results led to the design of the first prototypes that we will start testing in June 2017. In addition, first results studying the response of the detector to ESS scenarios where also shown. The ESS scenarios are discussed in [2] and where produced by the BI-ESS group. We used the produced particles in different loss cases as the inputs to the nBLM-G4 simulations. In this document, a more complete list of cases were studied for the case of the accidental losses, varying also the position of the detectors. Furthermore, we studied more carefully and after discussions with the ESS, the normal operation and the case of the 1W/m uniform losses. The results are summarized in the following.

2. Accidental losses

2.1. Response of the slow module

The accidental losses scenarios simulated by the BI-ESS and discussed in [2] correspond to 13 different cases listed in Appendix A. They represent localized losses of protons of a given energy. The produced losses are located in the first and last tanks, DTL-1 and DTL-5 (lower and higher proton energy regions respectively) at different locations. As shown in [1] in our nBLM-G4 code the nBLM detectors are placed around the DTL tanks using the same coordinate system as used in the ESS simulations to study their response to the different lost scenarios. Also, as discussed in [1], we have interpreted that the z axis goes from -2639 cm to +1276 cm and *x*, and *y* goes between ±61cm in the ESS simulations. The *z* distance corresponds to the distance where the 5 DTL tanks are installed. In Figure 16 we can see the position of the produced neutrons in an accidental loss scenario when entering the nBLM phantom volumes placed around the DTLs. As it can be seen, there are some peaks corresponding to the space between the DTL's where an nBLM volume was also simulated. The comparison between the coordinates system in the BI-ESS simulation and the distances in the accelerator is done in Appendix B. The particles launched in the nBLM-G4 simulations discussed here have as initial position, momentum and energy the ones from the ESS simulation. The time from the ESS simulation, corresponding to the time since proton lost to neutron creation and detection in the nBLM module, has been added to the nBLM-G4 simulation *GlobalTime*. This later time corresponds to the time since particle creation in the nBLM-G4 simulation to interaction in the gas in the nBLM chamber. Therefore, we are taking into account the total time since lost starts until detection in the nBLM detectors. In [2] it is specified that the lost has been considered instantaneous and therefore, the time of the development of the lost is not included.

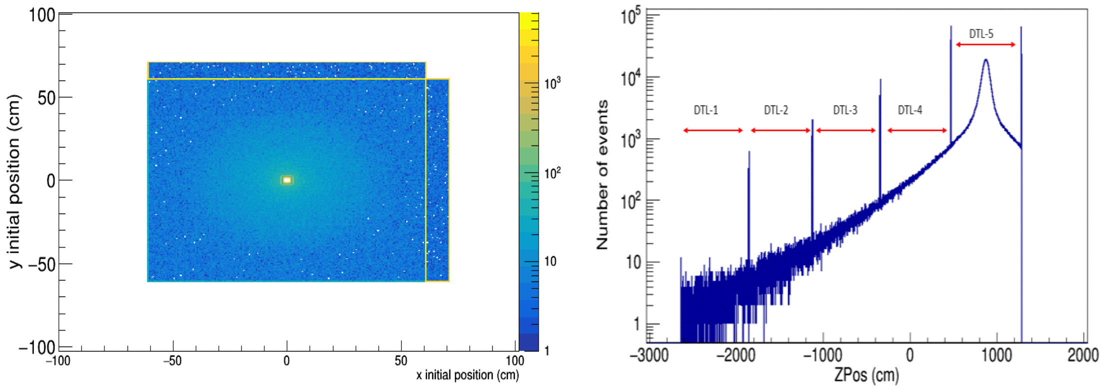


Figure 1 *x vs y (left) and z positions (right) for the particles produced in the ESS file sim0-0 DTL-detectors.mcpl and sim2-13-DTL-detectors.mcpl respectively that corresponds to a uniform lost and a lost produced in the middle of DTL-5. They represent the initial positions of the neutrons we launched in our nBLM-G4 simulations. From the z-plot we can determine which regions corresponds to each DTL (indicated in red). This positions will be used in our code to place the nBLM detectors appropriately around the DTL tanks. In the x-y plot we can see the three phantom nBLM volumes defined in the BI-ESS simulations: one on top, one on the lateral, and one in the middle (region between tanks).*

In [1] the scenarios studied corresponded to a lost in the middle of DTL-1 and in the middle of DTL-5 (sim2-0 and sim2-13 respectively). In this document the results for more scenarios are shown. Following the suggestions from [2] we have simulated 4 possible locations of the nBLM modules along the DTL tanks, at 0, ¼, ½ and ¾ of their length, labelled as det1, det2, det3 and det4 in the rest. They were placed on the top of the accelerator, at a distance of 65 cm from the center and facing with the MMs towards the accelerator. We have also taken into account the length of the detector of ~20cm. The positions are summarized in Table 1, corresponding to detectors placed on top of the accelerator tube. The study is repeated placing the detectors in the lateral for two cases as we will show in next subsection. Also placing them *in-between* modules. As explained in [1] in order to obtain the rate per bunch we can normalize the results because we have the initial number of protons simulated in each scenario to produce the losses. They are summarized in Table 2. The initial number of neutrons simulated in our simulations are listed in Table 3.

	Position (cm)						
DTL-1	x	y	z	DTL-5	x	y	z
det 1	0	65	-2649	det 1	0	65	465
det 2	0	65	-2455	det 2	0	65	665
det 3	0	65	-2261	det 3	0	65	865
det 4	0	65	-2067	det 4	0	65	1065

Table 1 *Position of the nBLM detectors in the G4-nBLM simulations carried out using the ESS data as input. Four detectors have been placed on top of the linac along the z-axis of the DTL-1 and DTL-5 to study their response to the simulated losses scenarios. They have been placed with respect to the input file reference system.*

ESS simulation	Loss location	Protons simulated	Neutrons produced	p/bunch	#of bunches	Neutrons/ bunch
sim2-0	Mid DTL-1	6.00E+08	2.90E+05	1.10E+09	5.45E-01	5.31E+05
sim2-1	¾ DTL-1	1.00E+08	2.33E+05	1.10E+09	9.09E-02	2.56E+06
sim2-2	¼ DTL-1	1.00E+09	6.68E+04	1.10E+09	9.09E-01	7.35E+04
sim2-3	Mid DTL-1	6.00E+08	2.86E+05	1.10E+09	5.45E-01	5.24E+05
sim2-4	*¼ DTL-1*	*7.00E+08*	*3.60E+01*	*1.10E+09*	*6.36E-01*	*5.66E+01*
sim2-5	*¼ DTL-1*	1.30E+09	9.07E+04	1.10E+09	1.18E+00	7.68E+04
sim2-6	*¼ DTL-1*	1.30E+09	1.88E+04	1.10E+09	1.18E+00	1.59E+04
sim2-7	*¼ DTL-1*	1.30E+09	1.33E+04	1.10E+09	1.18E+00	1.12E+04
sim2-8	Start DTL-5	4.00E+07	4.33E+06	1.10E+09	3.64E-02	1.19E+08
sim2-9	Start DTL-5	4.00E+07	4.03E+06	1.10E+09	3.64E-02	1.11E+08
sim2-10	Start DTL-5	4.00E+07	4.06E+06	1.10E+09	3.64E-02	1.12E+08
sim2-11	End DTL-5	4.00E+07	4.38E+06	1.10E+09	3.64E-02	1.20E+08
sim2-12	End DTL-5	4.00E+07	3.94E+06	1.10E+09	3.64E-02	1.08E+08
sim2-13	Mid DTL-5	4.00E+07	3.94E+06	1.10E+09	3.64E-02	1.08E+08

Table 2 *Number of protons simulated in the BI-ESS simulations. Also the table shows the number of neutrons produced in each loss scenario. With this information and assuming we have a 1.1 10^9 protons/bunch, the number of neutrons expected per bunch can be calculated. The scenarios used are highlighted in red. Scenario sim2_4 has very few statistics to be used.*

In addition, the rate can be also calculated, as explained in [1], taking into account that the response of the slow detector is slower than the frequency of the accelerator. Therefore, we will start detecting events from the second bunch before we full detect the events from the first bunch. In order to compute it we select two cases, the number of counts detected in the first µs and in the first 3 µs. Results are summarized in Table 14. The rate after the first µs is also shown in Figure 2 with respect to the position of the nBLM along the beam axis and for the different scenarios. As it can be seen we can also say something about the location of the loss within ± 2m (the distance between detectors). For example, if we observe the scenario with a loss in the middle of DTL-1 (orange curve), the detector placed in the middle of the tank detects more events that the other two placed on its sides and further from the lost.

There are two special cases simulated different than the others. One is sim2-3 that is as sim2-1 but with the lost pointing in the opposite direction (but detected in the opposite direction). They are the orange and purple curves in Figure 2, and as it can be seen there is no difference in the rates in the location of the loss (at the middle of DTL-1) but it changes a factor 2 in the detectors placed before the lost. In addition, scenario sim2-11 and sim2-12 represent losses in the end of DTL-5 with the only difference that one is with the parameter beam sigma xy =0 (pencil beam) instead of 1 (Gaussian beam with $\sigma_x = \sigma_y = 1$mm (the most frequent one if we check the list in the Appendix).

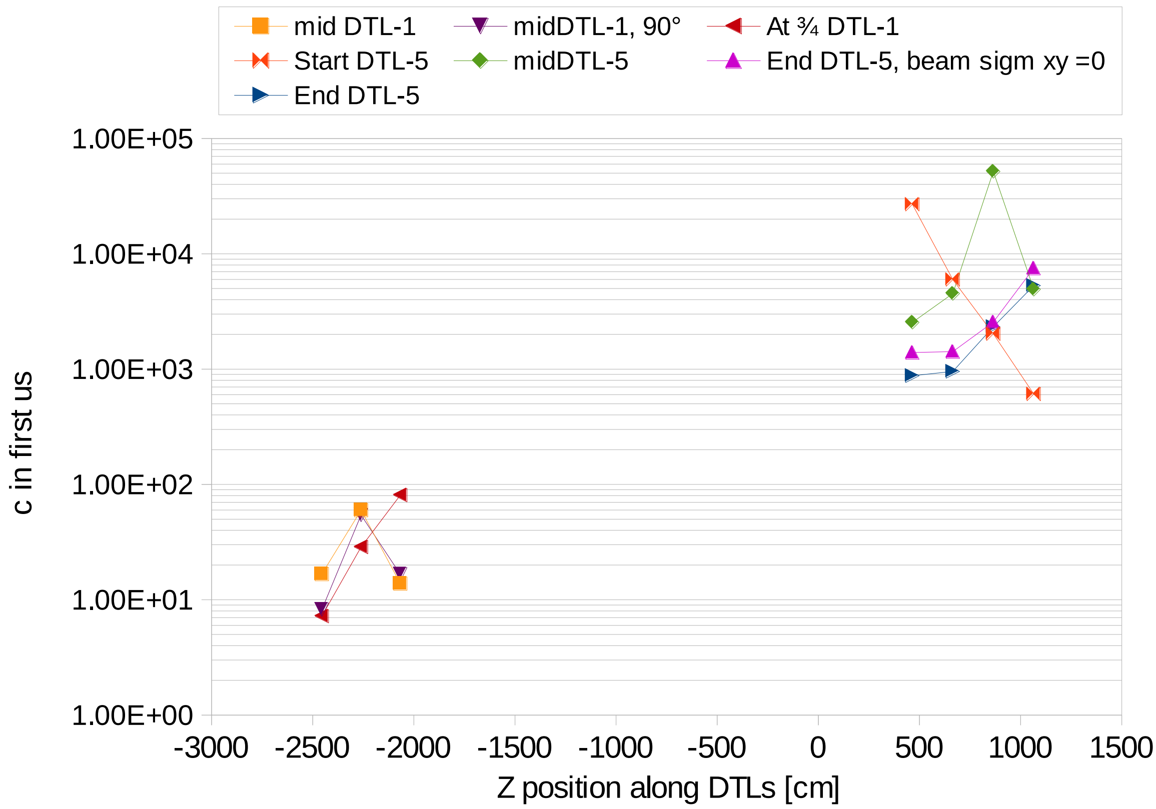


Figure 2 *Rate detected in the nBLM slow detectors placed at different locations along the beam axis and for different lost scenarios provided by the ESS. The detectors are placed more exactly around DTL-1 and DTL-5. The rate has been computed after the first µs after the accident.*

Also it is interesting to notice that in the detector placed at ¼ of DTL-1 length we never detect anything. The same occurs with the fast module as we will see later. This indicates that in this region the sensitivity is very low and we will probably not consider to place a detector there. *Or is it just a simulation artefact as we don't have contribution from previous section?*

Input	DTL	Simulated number of neutrons (x10^8)			
		det0	det1	det2	det3
sim2-0-DTL	1	5.5	5.5	21.5	21.5
sim2-1-DTL	1	11	11	11	11
sim2-3-DTL	1	11	11	11	11
sim2-8-DTL	5	11	11	11	11
sim2-11-DTL	5	11	11	11	11
sim2-12-DTL	5	11	11	11	11
sim2-13-DTL	5	11.0	1.72	2.2	2.75

Table 3 *Number of simulated neutrons for each of the nBLM "first module" detectors placed as indicated in Table 1 around the DTL-1 and DTL-5 for the different input files used from ESS.*

ESS input	nBLM	Bunches simulated	Counts detected	c /bunch	c in the first µs (MHz)	c in the first 3µs
sim2-0 *midDTL-1*	det1	1035.78	0	---	---	---
	det2	1035.78	1765 ± 42	1.70 ± 0.04	16.70 ± 4.09	117.24 ± 10.83
	det3	4048.96	33163 ± 1734	7.45 ± 0.04	59.81 ± 7.73	433.50 ± 20.82
	det4	4048.96	12985 ± 114	3.21 ± 0.03	13.82 ± 3.72	118.65 ± 10.89
sim2-1 *¾ DTL-1*	det1	429.69	0	---	---	---
	det2	429.69	532 ± 23	1.24 ± 0.05	7.20 ± 2.68	57.26 ± 7.57
	det3	429.69	1780 ± 42	4.14 ± 0.10	28.60 ± 5.35	218.81 ± 14.79
	det4	429.69	4970 ± 50	11.57 ± 0.16	80.76 ± 8.99	665.61 ± 25.80
sim2-3 *midDTL-1*	det1	2099.24	0	---	---	---
	det2	2099.24	3310 ± 58	1.58 ± 0.03	8.21 ± 2.87	
	det3	2099.24	12646 ± 112	6.02 ± 0.05	54.28 ± 7.37	
	det4	2099.24	6192 ± 79	2.95 ± 0.04	16.64 ± 4.08	
sim2-8 *startDTL-5*	det1	9.24	25824 ± 161	2793.69 ± 17.38	26830.00 ± 163.80	175838.00 ± 419.33
	det2	9.24	7542 ± 87	815.91 ± 9.40	5974.00 ± 77.29	41318 ± 203.27
	det3	9.24	3784 ± 82	409.36 ± 6.65	2021.00 ± 44.96	16479.00 ± 128.37
	det4	9.24	2388 ± 49	258.34 ± 5.29	608.20 ± 24.66	8458.90 ± 91.97
sim2-11 *endDTL-5*	det1	9.17	2880 ± 54	314.18 ± 5.85	1392.00 ± 37.31	12928.90 ± 113.71
	det2	9.17	3080 ± 56	336.00± 6.05	1418.00 ± 37.66	12111.80 ± 110.05
	det3	9.17	5494 ± 74	599.35 ± 8.09	2557.00 ± 50.57	23912.40 ± 154.64
	det4	9.17	10768 ± 104	1174.69 ± 11.32	7504 ± 86.63	58655.90 ± 242.19
sim2-12 *endDTL-5*	det1	10.19	2612 ± 51	256.45 ± 5.02	875.50 ± 29.61	7709.00 ± 87.80
	det2	10.19	3440 ± 59	337.75 ± 5.76	954.50 ± 30.89	9395.00 ± 96.93
	det3	10.19	5158 ± 72	506.42 ± 7.05	2328.00 ± 48.25	19971.10 ± 141.32
	det4	10.19	11334 ± 106	1112.79 ± 10.45	5300.00 ± 72.80	47375.00 ± 217.66

sim2-13 *midDTL-5*	det1	10.19	5403 ± 74	530.48 ± 7.22	2545.03 ± 50.45	20073.70 ± 141.68
	det2	1.07	889 ± 30	827.69 ± 27.76	4518.26 ± 67.22	36455.10 ± 190.93
	det3	2.04	7656 ± 87	3758.40 ± 42.95	51790.90 ± 227.58	302911.00 ± 550.37
	det4	2.04	1568 ± 40	769.65 ± 19.44	4914.98 ± 70.11	37477.80 ± 193.59

Table 4: *Number of counts detected in each nBLM slow module in each scenario and counts per bunch and number of counts after the first 1 µs and 3 µs after the accident happens. Errors are only statistical errors.*

2.2. Response of the fast detector

Same studies have been carried out with the geometry of the fast detector. Their results are shown along this section. Two scenarios were studied in [1], sim2-0 and sim2-13, here results of other cases are also evaluated. The number of initial neutrons simulated is summarized in Table 5 for each of the nBLM fast modules simulated in each scenario. Unfortunately in this case the statistics are lower due to the lower efficiency of the detector and in some cases implies a huge statistical error in the number of detected events. Therefore, we only compute the rates where we have at least few tens of events. As in previous section we can calculate the expected number of events per bunch. The fast module has a response of few ns, therefore we will detect all the events of a bunch before the next arrives, so we can easily calculate the rate expected per µs. Both rates are summarized in Table 6 for the different scenarios but showing only the detectors with more statistics. They are shown with respect the position of the nBLM along the beam axis in Figure 3.

	DTL	Simulated number of neutrons (x10^8)			
Input		det0	det1	det2	det3
sim2-0-DTL	1	4.4	4.4	6.5	4.4
sim2-1-DTL	1	22	22	22	22
sim2-8-DTL	5	22	22	22	22
sim2-11-DTL	5	22	22	44	44
sim2-12-DTL	5	22	22	22	22
sim2-13-DTL	5	4.4	4.4	22	22.9

Table 5 *Number of simulated neutrons for each of the nBLM "second module" detectors placed as indicated in Table 1 around the DTL-1 and DTL-5 for the different input files used from ESS.*

ESS input	nBLM detector	Bunches simulated	Counts detected	c/bunch	c/µs (MHz)
sim2-0-DTL	det3	1224.11	78 ± 9	0.060 ± 0.007	22.44 ± 2.54
sim2-1-DTL	det3	859.38	26 ± 5	0.030 ± 0.005	10.65 ± 2.09
sim2-8-DTL	det1	18.49	975 ± 31	52.70 ± 1.69	18569.94 ± 594.71
	det2	18.49	26 ± 5	1.41 ± 0.28	495.20 ± 97.12
sim2-11-DTL	det3	36.67	34 ± 6	0.93 ± 0.16	326.50 ± 56.00
	det4	36.67	202 ± 14	5.51 ± 0.39	1939.82 ± 136.49
sim2-12-DTL	det3	20.37	18 ± 4	0.88 ± 0.21	311.14 ± 73.34
	det4	20.37	78 ± 9	3.83 ± 4.34	1348.27 ± 152.66
sim2-13-DTL	det3	20.37	1676 ± 41	82.28 ± 2.01	285970.55 ± 707.65
	det4	21.20	8 ± 3	0.38 ± 0.13	132.85 ± 46.97

Table 6 *Number of counts detected, c/bunch and c/µs for the fast nBLM modules for which we have the higher statistics in each scenario. The error are statistical error in the simulated number of events. No statistical error from the bunch production have been included.*

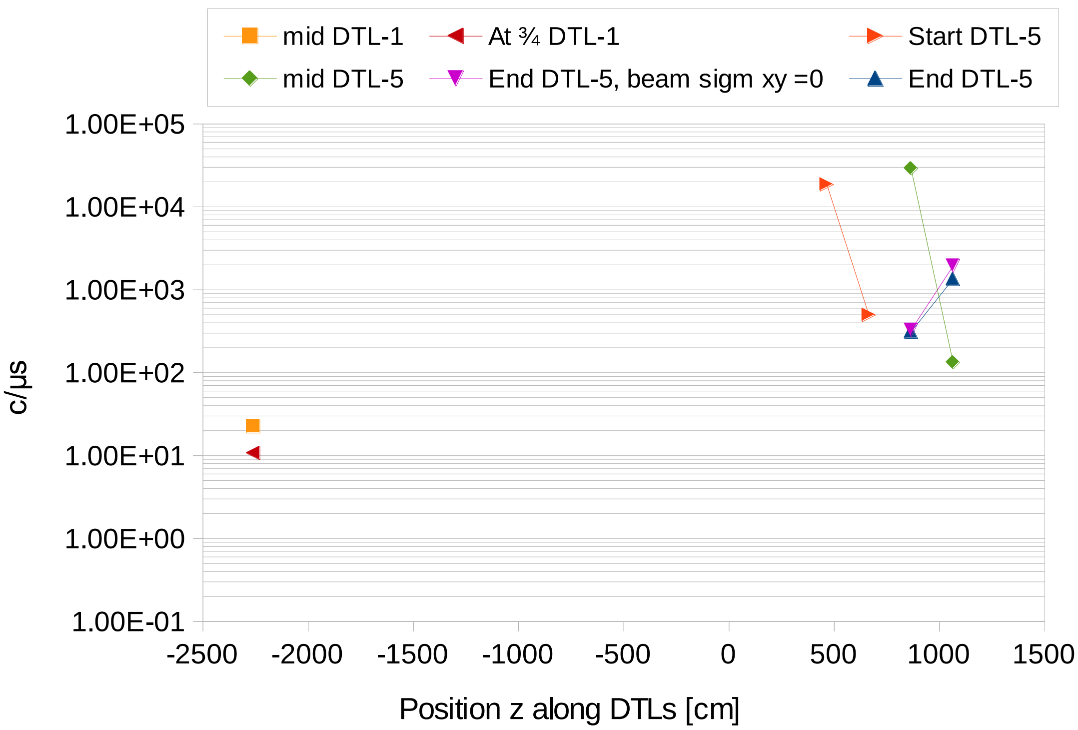


Figure 3 *Rate detected in the nBLM fast modules placed at different locations along the beam axis and for different lost scenarios provided by the ESS. The detectors are placed around DTL-1 and DTL-5.*

2.3. Response if the detectors are placed on the lateral

Two of the previous scenarios, input files sim2_0 and sim2_13, have been studied placing the nBLM slow and fast modules in the lateral side of the accelerator instead of on top. The positions are summarized in Table 7. The simulated number of neutrons in all cases is $1.1x10^9$. The analysis is the same as in previous sections, so we summarize the expected rates in Table 8 and in Table 9 for the slow and fast module respectively. We can compare their response with the one obtained with the modules placed on top (Figure 4). If we compare the slow detectors, the rate is slightly higher if they are located on the top, of about a factor 2 in the position of the lost for DTL-1 but pretty much the same in all locations for DTL-5 (just a factor of 1.3 maximum). While for the fast modules it is also slightly higher for the top detectors, of about a factor 2-5 in the position of the lost and just a difference of 0.5 away from the lost location.

	Position (cm)						
DTL-1	x	y	z	DTL-5	x	y	z
det 1	65	0	-2649	det 1	65	0	465
det 2	65	0	-2455	det 2	65	0	665
det 3	65	0	-2261	det 3	65	0	865
det 4	65	0	-2067	det 4	65	0	1065

Table 7: *Position of the nBLM detectors in the G4-nBLM simulations carried out using the ESS data as input. They have been placed with respect to their reference system. 4 detectors have been placed on the lateral of the linac along the z-axis of the DTL-1 and DTL-5 to study their response to the simulated losses scenarios.*

ESS input	nBLM detector	Bunch simulated	Counts detected	c/bunch	c in the first μs (MHz)
sim2-0	det1	2062.15	0	---	---
	det2	2062.15	2690 ± 52	1.30 ± 0.03	6.56 ± 2.56
	det3	2062.15	16232 ± 127	7.87 ± 0.06	69.73 ± 8.35
	det4	2062.15	6800 ± 82	3.30 ± 0.04	18.72 ± 4.33
sim2-13	det1	10.14	5808 ± 76	572.84 ± 7.52	2322.79 ± 48.20
	det2	10.14	8204 ± 91	809.16 ± 8.93	3473.09 ± 58.93
	det3	10.14	35800 ± 189	3530.96 ± 18.66	41326.30 ± 203.29
	det4	10.14	8436 ± 92	832.04 ± 9.06	4639.46 ± 68.11

Table 8: *Number of counts detected, c/bunch and c in the first μs after the accident, in the slow modules placed on the lateral of the accelerator for two different loss accidental scenarios.*

ESS input	nBLM detector	Bunches simulated	Counts detected	c/bunch	c/µs (MHz)
sim2-0	det3	2071.6	60 ± 8	0.029 ± 0.001	10.20 ± 1.32
	det4	2071.6	14 ± 4	0.007 ± 0.002	2.38 ± 0.64
sim2-13	det1	10.2	11 ± 3	1.08 ± 0.33	380.28 ± 114.66
	det2	10.2	11 ± 3	1.08 ± 0.33	380.28 ± 114.66
	det3	10.2	153 ± 12	15.02 ± 1.21	5289.37 ± 427.62

Table 9 *Number of counts detected, c/bunch and c/µs for the fast nBLM simulated detectors for which we have the higher statistics when placed on the lateral of the accelerator and studying two different loss accidental scenarios.*

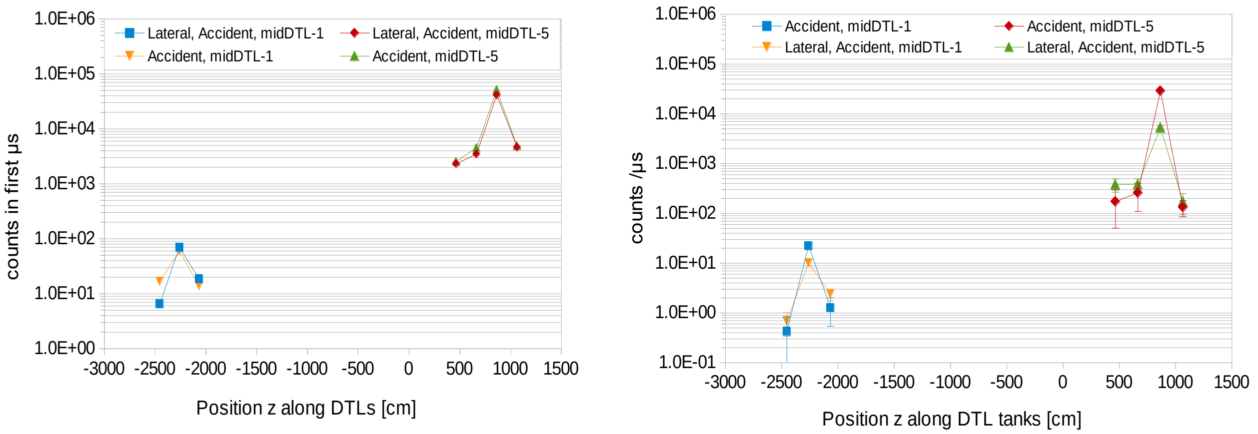


Figure 4 *Rate detected in the nBLM slow detectors (left) and fast (right) placed at different locations in the lateral of the accelerator, for two different lost scenarios provided by the ESS. These rates are compared with the rates if the detectors were located on the top of the accelerator.*

2.3.1. Different energy threshold

Up to now, all the analysis were carried out assuming a threshold of 10 keV on the deposited energy. In this section, the results for the lateral placed slow detectors shown in previous section have been obtained again with different thresholds (10, 50 and 500 keV). In Figure 5 the rate (in c/µs) is shown for two scenarios (loss in middle of DTL-1 and in the middle of DTL-5) for the 4 detectors and with the three deposited energy thresholds. The rates are decreased almost nothing when using a threshold of 50 keV compared with using 10 keV. On the other hand, they are decreased a factor 3-4 in the case of 500 keV threshold. This result give us another way to be more flexible when tuning the detectors to cope with high energy regions fluxes. The study was also performed with the fast module and again, the rate is almost the same in the case of using 10 or 50 keV threshold and above 500 keV there is almost no events detected so it was not obtained.

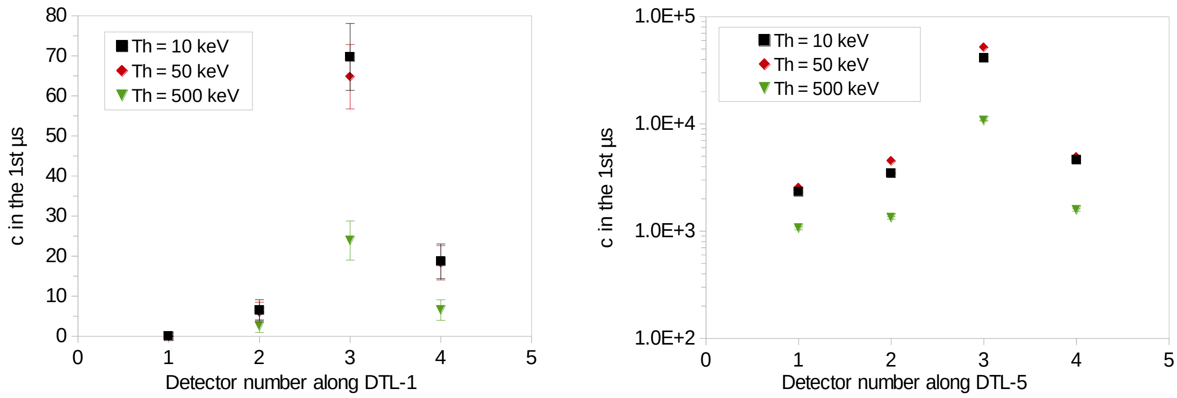


Figure 5 *Detected neutrons in the 1st µs in each slow module detector placed along the DTL-1 (left plot) and DTL-5 (right plot). The rate is shown for three different detected energy thresholds of 10 keV, 50 or 500 keV.*

2.4. Response of the in-between detectors

For the control of accidental losses we aim to install the nBLM modules also in the regions between the tanks. In this case we will install only the fast module as we are especially interested in the alarm functionality of the system at these locations. Four lost scenarios have been used as input: an accident in the middle of DTL-1 (sim2_0), and accident at ¾ of DTL-1 (sim2-1), and an accident at the end of DTL-5 (sim2-11 and sim2-12). The exact positions of the modules are listed in Table 10 and the number of the initial simulated neutrons is 1.1×10^9 in all cases except sim2-0 with 2.2×10^9 and sim2-12 detector at the end of DTL-5 with 2.75×10^9 simulated neutrons. The analysis is carried out in the same way as before and the results are summarized in Table 11. We show also the cases we detect at least 1 event, although the rates are not obtained in these cases as they don't make too much sense, just to show which detectors have some sensitivity. It can be seen that for a lost in the middle of DTL-1 the detector placed between DTL-1 and DTL-2 already detect few events/µs, being its detection increased by a factor 90 when the lost happen at 2m from the end of DTL-1. Similarly, when the lost occurred at the end of DTL-5 the detector placed at the end of it detects a rate of about 5GHz, while the one placed between tanks 4 and 5 has a very low statistics. Therefore in general we can say that the detectors placed in-between the tanks where the lost happen and in between the next ones will be the ones being able to detect the lost and the sensitivity will be different depending where along the tank the lost has happened. So this could also help to delimit the location of the lost.

	Position (cm)		
Between DTL tanks	x	y	z
1-2	0	0	-1858
2-3	0	0	-1128
3-4	0	0	-344
4-5	0	0	+470
End of 5	0	0	+1281

Table 10 *Positions for the case of the fast module placed between the tanks.*

ESS input	nBLM detector between	Bunches simulated	Counts detected	c/bunch	c/µs (MHz)
sim2-0-DTL *(mid DTL-1)*	DTLs 1-2	4315.59	16 ± 4	0.004 ± 0.001	1.36 ± 0.34
	DTLs 2-3	4315.59	2 ± 1	Low stats	Low stats
sim2-1-DTL *(¾ DTL-1)*	DTLs 1-2	429.69	119 ± 11	0.28 ± 0.03	97.52 ± 8.94
	DTLs 2-3	429.69	2 ± 1	Low stats	Low stats
sim2-11-DTL *(end DTL-5)*	End of 5	9.17	22 ± 5	2.40 ± 0.51	845.07 ± 180.17
sim2-12-DTL *(end DTL-5)*	DTLs 4-5	10.19	2 ± 1	Low stats	Low stats
	End of 5	25.46	381 ± 20	14.96 ± 0.77	5268.63 ± 269.92

Table 11 *Number of neutron detected, neutron/bunch and per µs for the fast nBLM simulated detectors for which we have the higher statistics when placing them between the DTL-s under different loss scenarios.*

2.5. Conclusions

In conclusion, for the accidental losses, taking into account the scenarios simulated by the BI-ESS, the nBLMs will detect very high rates with the standard geometry. More specifically, the slow modules will have rates between 10 MHz and 50 GHz in one µs, at low energy and high energy regions respectively. The detected events of the fast module will be lower due to its lower efficiency, but as the time response is faster the rates are comparable or even larger than in the slow module, between 10 and 200 GHz depending on the initial energy of the protons (i.e. on the location). In case these rates are too high for the electronics, we can decrease the efficiency of the modules changing some parameters as for example their voltage gain or, physically, the boron layer or polyethylene thickness. In addition, is more than probably that the operation configuration and maybe also the geometry will be different at the low and high energy region in order to accommodate to the different rates in each region.

These rates are more or less the same if we place the detectors on the lateral of the accelerators instead than on top, for both the fast and slow modules. In addition, the response of the fast modules has been also addressed if placed in-between the DTLs. In this case the expected rate is between 1-90MHz to 5GHz at the high energy region of the accelerator.

Furthermore, we have seen that we can also identify the location of the lost with an accuracy depending on the distance between our detectors (in these studies, within ±2m) comparing the rates in the surrounding detectors. As suggested in [2] the case of a lost happening with an angle -90° compared to 0° has been also done with the slow modules (sim2-3 compared to sim2-0), observing almost no difference. In addition, also the case where the variable labelled as *beam sigm xy* is different has been addressed (sim2-11, pencil beam, compared to sim2-12 Gaussian beam with $\sigma_x = \sigma_y = 1$mm), with an small difference of about 1.5 except in the detector on top of the lost for which this difference is almost nothing (factor 1.09).

The next question is to compare these rates with the case of normal operation to see if we will be able to detect the accidental lost. Also to see to which level we are able to start detecting losses of few % of 1W/m. These questions are addressed in next sections.

3. Response under accelerator normal operation

After studying the cases of accidental losses we need to answer to the questions if we are going to be able to see an accident above the "noise" produced by the normal operation and to what level we are sensitive to monitor the normal operation of the accelerator. Two of the scenarios provided by the ESS corresponds to normal operation and uniform loss of 1W/m. They are the ones labelled *sim1-0-DTL-detectors.mcpl* and *sim0-0-DTL-detectors.mcpl* respectively and are explained in more detail in document [2]. The files are read and used as in the case of the accidental losses. However, we have had some problems in order to normalize our results to these cases as we don't know if they correspond to losses per second, per bunch, per pulse… Therefore, in the following we explained the strategies used in order to address the response of the nBLM system under these conditions.

3.1. Using the accidental case to study the 1W/m case

The first case, after discussions with Tom Shea, we decided to use the accidental cases to determine the case of a uniform loss of 1W/m. In addition, to the most realistic case of a loss of 1% of 1W/m. The advantage of using the accidental scenarios is that we have a lost occurring in a clear location with a known number of protons with a fixed energy. Therefore, we can calculate the produced power (listed in Table 12 for each scenario), and used it to normalize the counts detected in the nBLM to the 1W/m case. We assume it is lost in 1 meter. After that, we will normalize for the considered active time. For example, we can assume if the lost is loss along one pule (2.86 ms duration) or along the duty cycle (14*2.86ms). Concretely, the normalization is:

$$c_{det} \cdot \frac{N_N}{N_N^{Simu}} \cdot \frac{1W/m}{x\,W/m} \cdot \frac{1}{\text{Active Time}} \qquad \text{Eq. 1}$$

where c_{det} is the events detected in the nBLM, N_N is the number of neutrons produced in the corresponding BI-ESS scenario, N_N^{simu} is the number of simulated neutrons by us and x is the calculated power emitted in these scenario (listed in Table 12). In Table 13 we show the counts after normalization and the rate produced in just one pulse, i.e. dividing by 2.86ms, and converted per µs (to compare with accidents) for each of the simulated scenarios. In this second version of the document, we have attached in a table also what is expected emitted uniformly (in 14 Hz) and taking into account the 1% of 1W/m and not 1W/m. This is summarized in Table 14. We compare this values with the accidental rates in Figure 6. The rates obtained in this way (normalizing the accidental scenarios to 1% 1W/m) and the case of an accident obtained in previous sections are compared. A factor between 3.49 x 10^4 and 7.65 x 10^5 of difference is expected in the rates, assuming all the lost occurs uniformly. That means, losses of 0.1 kHz to 68 kHz (100c/s to 68000c/s, in the low and high energy region respectively).

ESS Input	Position of the loss	Ep (MeV)	Ep (J)	N_P	N_N	W/m/s
sim2-0-DTL	Mid DTL-1	11.5	1.84×10^{-12}	6.00×10^{8}	2.90×10^{5}	1.10×10^{-3}
sim2-1-DTL	¾ DTL-1	17.9	2.86×10^{-12}	1.00×10^{8}	6.68×10^{4}	2.86×10^{-4}
sim2-3-DTL	Mid DTL-1	11.5	1.84×10^{-12}	6.00×10^{8}	2.86×10^{5}	1.10×10^{3}
sim2-8-DTL	Start DTL-5	71.8	1.15×10^{-11}	4.00×10^{7}	4.33×10^{6}	4.60×10^{4}
sim2-11-DTL	End DTL-5	86.5	1.38×10^{-11}	4.00×10^{7}	4.38×10^{6}	5.54×10^{4}
sim2-12-DTL	End DTL-5	86.5	1.38×10^{-11}	4.00×10^{7}	3.94×10^{6}	5.54×10^{4}
sim2-13-DTL	Mid DTL-1	79.0	1.26×10^{-11}	4.00×10^{7}	3.94×10^{6}	5.06×10^{4}

Table 12 *Lost produced in W/m/s in each of the accidental losses scenarios simulated*

1W/m in 2.86 ms				
ESS input	nBLM	c after normalization	c/2.86ms	c/µs (MHz)
sim2-0 *(mid DTL-1)*	det1	---	---	---
	det2	842 ± 20	294.74 ± 7.02	0.29 ± 0.01
	det3	3685 ± 21	1288.54 ± 7.42	1.29 ± 0.01
	det4	1586 ± 13	554.71 ±4.86	0.55 ± 0.01
sim2-1 *(3/4 DTL1)*	det1	---	---	---
	det2	393 ± 17	137.68 ± 5.97	0.14 ± 0.01
	det3	1317 ± 31	460.65 ± 10.92	0.46 ± 0.01
	det4	3678 ± 52	1286.19 ± 18.24	1.29 ± 0.02
sim2-3 *(mid DTL-1)*	det1	---	---	---
	det2	779 ± 14	272.56 ± 4.73	0.27 ± 0.01
	det3	2978 ± 26	1041.34 ± 9.26	1.04 ± 0.01
	det4	1458 ± 19	509.88 ± 6.48	0.51 ± 0.01
sim2-8 *(start DTL-5)*	det1	$(22.12 \pm 0.14)10^{4}$	$(7.73 \pm 0.04)10^{4}$	77.35 ± 0.48
	det2	$(6.46 \pm 0.07)10^{4}$	$(2.26 \pm 0.03)10^{4}$	22.59 ± 0.26
	det3	$(3.24 \pm 0.05)10^{4}$	$(1.13 \pm 0.02)10^{4}$	11.33 ± 0.18
	det4	$(2.05 \pm 0.04)10^{4}$	$(0.72 \pm 0.01)10^{4}$	7.15 ± 0.15

sim2-11 *(end DTL-5)*	det1	$(2.07 \pm 0.04)10^4$	$(0.72 \pm 0.01)10^4$	7.24 ± 0.02
	det2	$(2.22 \pm 0.04)10^4$	$(0.77 \pm 0.01)10^4$	7.75 ± 0.02
	det3	$(3.95 \pm 0.05)10^4$	$(1.38\pm 0.02)10^4$	13.82 ± 0.02
	det4	$(7.74 \pm 0.07)10^4$	$(2.71 \pm 0.03)10^4$	27.08 ± 0.03
sim2-12 *(end DTL-5)*	det1	$(1.69 \pm 0.03)10^4$	$(0.59 \pm 0.001)10^4$	5.90 ± 0.12
	det2	$(2.23 \pm 0.04)10^4$	$(0.78 \pm 0.001)10^4$	7.78 ± 0.13
	det3	$(3.34 \pm 0.05)10^4$	$(1.67 \pm 0.001)10^4$	11.67 ± 0.16
	det4	$(7.33 \pm 0.07)10^4$	$(2.56 \pm 0.001)10^4$	25.64 ± 0.24
sim2-13 *(mid DTL-5)*	det1	$(3.83 \pm 0.05)10^4$	$(1.34 \pm 0.02)10^4$	13.38 ± 0.18
	det2	$(5.98 \pm 0.20)10^4$	$(2.09 \pm 0.07)10^4$	20.88 ± 0.70
	det3	$(27.12 \pm 0.31)10^4$	$(9.48 \pm 0.11)10^4$	94.82 ± 1.08
	det4	$(5.56 \pm 0.14)10^4$	$(1.94 \pm 0.04)10^4$	19.42 ± 0.49

Table 13 *Rates obtained for the nBLM slow modules simulated in each accidental scenario but normalizing to the case of 1W/m, and distributed in one pulse, as explained in the text.*

1% 1W/m uniformly in 14 Hz					
ESS input	nBLM	c/ms (kHz)	ESS input	nBLM	c/ms (kHz)
sim2-0 (*mid DTL-1)*	det1	---	sim2-11 *(end DTL-5)*	det1	5.17 ± 0.10
	det2	0.21 ± 0.01		det2	5.53 ± 0.10
	det3	0.92 ± 0.01		det3	9.87 ± 0.13
	det4	0.396 ± 0.003		det4	19.34 ± 0.19
sim2-1 *(¾ DTL1)*	det1	---	sim2-12 *(end DTL-5)*	det1	4.22 ± 0.08
	det2	0.098 ± 0.004		det2	5.56 ± 0.10
	det3	0.33 ± 0.01		det3	8.34 ± 0.12
	det4	0.92 ± 0.01		det4	18.31 ± 0.17
sim2-3 *(mid DTL1)*	det1	---	sim2-13 *(mid DTL-5)*	det1	9.56 ± 0.13
	det2	0.195 ± 0.003		det2	14.92 ± 0.50
	det3	0.74 ± 0.01		det3	67.73 ± 0.78
	det4	0.364 ± 0.005		det4	13.87 ± 0.35
sim2-8 *(start DTL-5)*	det1	55.25 ± 0.35			
	det2	16.14 ± 0.19			
	det3	8.09 ± 0.13			
	det4	5.10 ± 0.11			

Table 14 *Rates obtained for the nBLM slow modules in each accidental scenario but normalizing to the case of 1% 1W/m, and distributed uniformly in 14Hz, as explained in the text.*

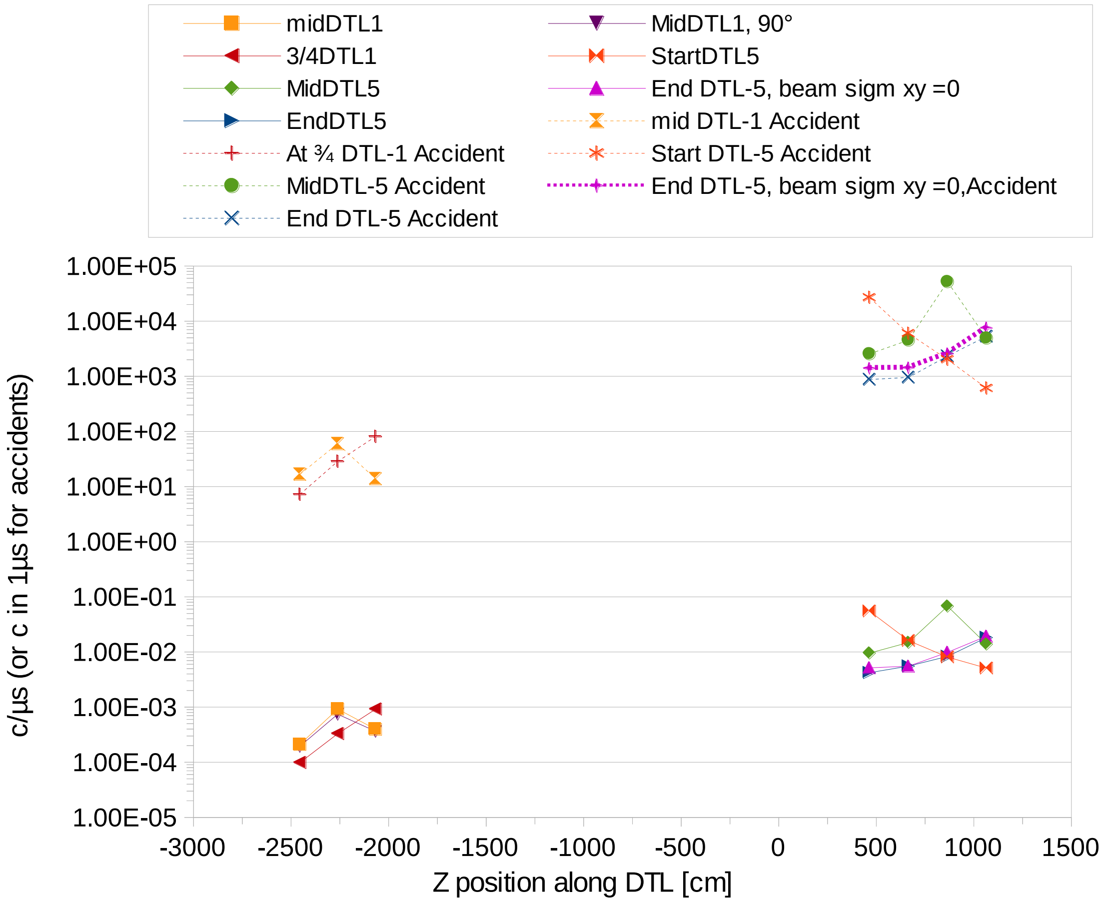


Figure 6 : *Comparison between the rates obtained in case of accidents (dashed lines) with respect normalizing it to 1W/m loss (solid lines). They have been computed for different loss scenarios in which the nBLM slow detectors have been placed at different location around DTL-1 and DTL-5 (x-axis).*

3.1.1. Fast module

The same study has been done with the fast module. Results are summarized in Table 15 for 1W/m in one pulse and in Table 16 for 1% 1W/m uniformly distributed in 14 Hz. They are compared with the accidental rates in Figure 7. Only the detectors with enough statistics have been used for the calculations. The rate ranges between 2.5 Hz to 1.5 kHz, at the low and high energy regions respectively. As in the case of the slow modules there is a clear difference between rates at normal operation and in cases of accidents. In this case it is a factor about $3x10^5$ and $3x10^8$. In this case we will be talking of rates between 2c/s and ~1500c/s at low and high energy regions in the case of 1% 1W/m uniform losses.

1W/m in 2.86 ms				
ESS input	nBLM	c after normalization	c/2.86ms	c/µs (MHz)
sim2-0	det3	32 ± 4	11.02 ± 1.25	0.011 ± 0.001
sim2-1	det3	10 ± 2	3.36 ± 0.66	0.003 ± 0.001
sim2-8	det1	4180 ± 134	$(1.46 \pm 0.05)10^3$	1.46 ± 0.05
	det2	111 ± 22	39.94 ± 7.63	0.04 ± 0.01
sim2-11	det3	61 ± 11	21.38 ± 3.66	0.021 ± 0.0036
	det4	363 ± 26	127.00 ± 8.94	0.127 ± 0.009
sim2-12	det3	58 ± 14	20.36 ± 4.79	0.020 ± 0.005
	det4	252 ± 29	88.22 ± 9.99	0.09 ± 0.01
sim2-13	det3	5940 ± 145	$(2.08 \pm 0.05)10^3$	2.08 ± 0.05
	det4	27 ± 10	9.52 ± 3.36	0.009 ± 0.003

Table 15 *Rate obtained for the nBLM fast modules simulated in each accidental scenario but normalizing to the case of 1W/m, as explained along the text.*

1% 1W/m in 14 Hz		
ESS input	nBLM	c/ms (kHz)
sim2-0	det3	0.008 ± 0.001
sim2-1	det3	0.0024 ± 0.0005
sim2-8	det1	1.04 ± 0.03
	det2	0.028 ± 0.006
sim2-11	det3	0.015 ± 0.003
	det4	0.091 ± 0.006
sim2-12	det3	0.015 ± 0.003
	det4	0.063 ± 0.007
sim2-13	det3	1.48 ± 0.04
	det4	0.007 ± 0.002

***Table 16** Rates obtained for the nBLM fast modules simulated in each accidental scenario but normalizing to the case of 1% 1W/m, and distributed uniformly in 14Hz, as explained in the text.*

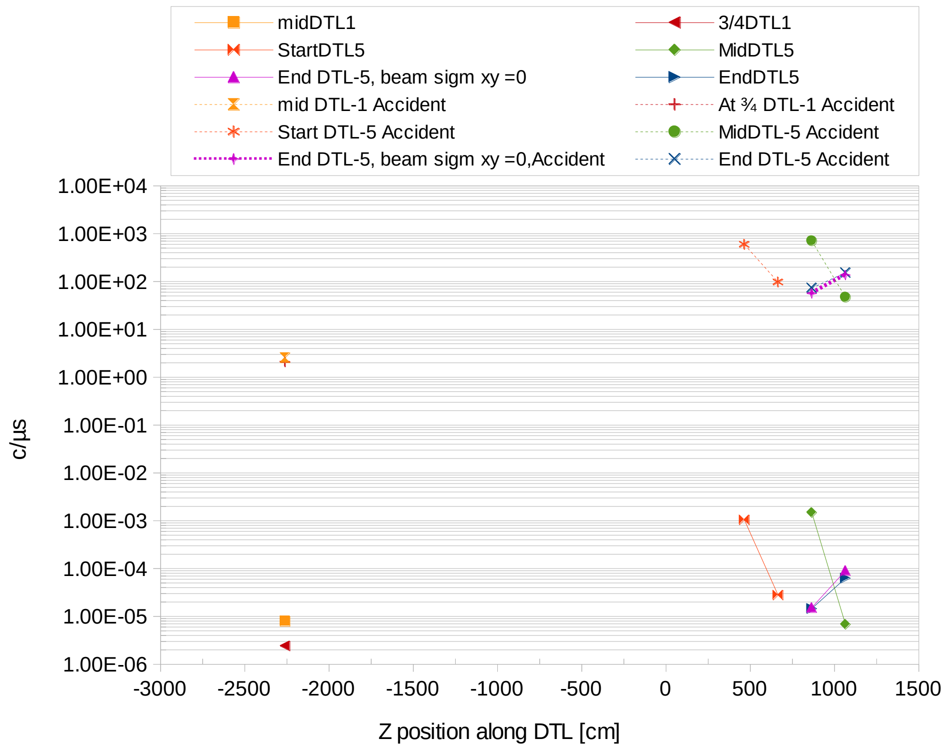


***Figure 7:** Comparison between the rates obtained in case of accidents (dashed lines) with respect normalizing it to 1W/m loss (solid lines), for the fast modules. They have been computed for different loss scenarios in which the nBLM fast detectors have been placed at different location around DTL-1 and DTL-5 (x-axis).*

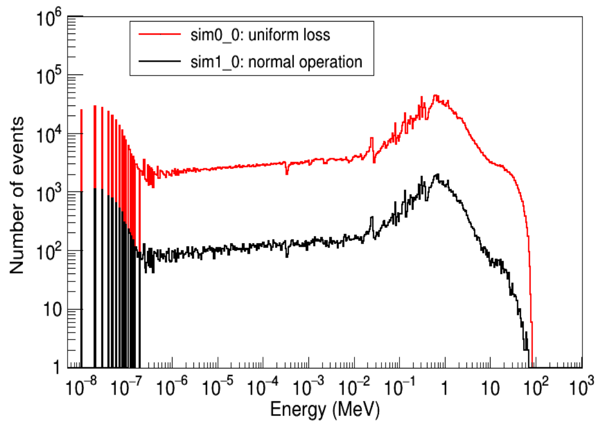
3.2. Normal scenario

One scenario simulated by the BI-ESS took into account the beam dynamics, in which the lost protons were sampled from the lost particle distribution (page 48 in [2]). It is labelled as normal scenario case and corresponds to file *sim1_0-DTL-detectors.mcpl*. However, we don't know how many protons of each energy has been contributed to the different regions. Therefore, it is difficult to interpret the results in the nBLM-G4 simulation when we have used this file as the input. So, we have followed two strategies with few assumptions. Something similar occurs with the scenario corresponding to a uniform loss of 1W/m (*sim0_0-DTL-detectors.mcpl).* In Table 17 we show the initial number of protons launched by the ESS and how many neutrons were produced in both cases. In this section, however, we will focus first in the normal scenario case.

In order to understand better the scenarios, in Figure 8 we can see the distribution of the produced neutrons along the beam axis in the normal and uniform loss scenarios (right) and their energy distribution (left). In addition, a plot showing the energy versus the z-position of the neutrons is shown in Figure 9 for the normal operation (right) and the uniform loss scenarios (left).

		Protons simulated	Neutrons produced	p/Bunch	#of bunches	Neutrons/bunch
Uniform loss	Sim0-0	1.00×10^{8}	3.14×10^{6}	1.1×10^{9}	9.09×10^{-2}	3.45×10^{7}
Normal operation	Sim1-0	8.00×10^{8}	1.27×10^{5}	1.1×10^{9}	7.27×10^{-1}	1.75×10^{5}

Table 17 *Number of protons simulated in two different scenarios by the BI ESS group and the produced number of neutrons/bunch.*



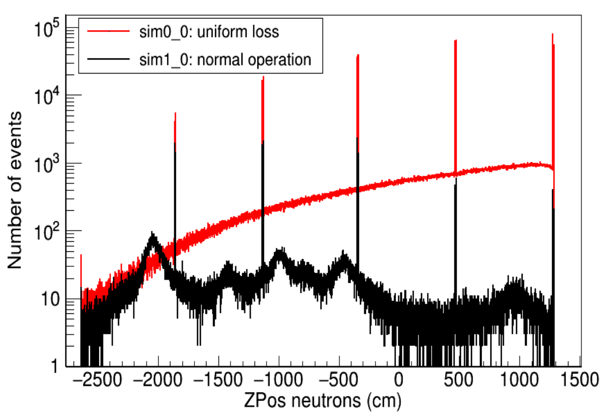


Figure 8 *Energy distribution (left) and position along the DTLs (right) for the ESS simulated scenarios corresponding to normal operation (black) and uniform loss (red). Note that they have a different number of initial protons (100 M in the uniform loss scenario and 800M in the normal operation one) and they are not normalized.*

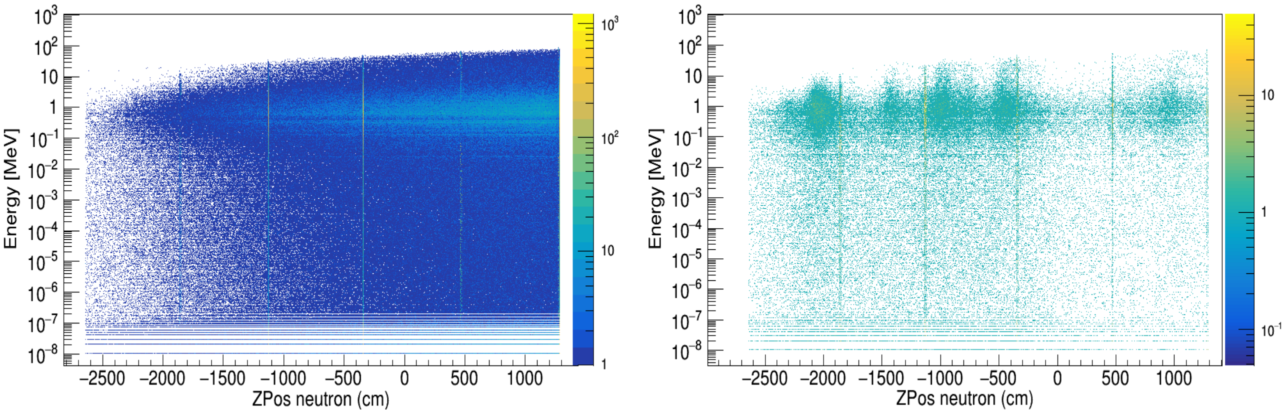


***Figure 9** Energy vs z-position for the neutrons produced in the losses in the uniform loss scenario simulated from ESS (sim0_0) at the left and for the normal operation scenario (sim1_0) at the right.*

	Simulated number of neutrons (x10^9) at different z positions								
Input / Z position (cm)	-2649	-2455	-2261	-2047	-681	280	665	865	1065
Sim0-0-DTL	0.40	0.80	2.20	2.20	2.00	3.30	1.65	2.20	0.10
Sim1-0-DTL	1.26	3.30	2.20	2.20	0.60	3.30	2.20	2.20	0.75

***Table 18** Number of neutrons simulated in the nBLM simulation for the uniform (sim0_0) and normal (sim1_0) scenarios. The slow module was placed at different locations along z also indicated in the table.*

Different runs have been simulated using the normal scenario as input where the nBLM have been placed at different locations along z. They are listed in Table 18 together with the number of launched neutrons sampled from the distribution in the file. We use two approaches to normalize the number of detected events, c_{det}, in the nBLM modules. The question is that we don't know how many protons of each energy have been produced (as we knew in the case of the accidents) and what they represent. Therefore, in order to calculate them we have made several assumptions.

First of all, in both cases, we have assumed that the initial number of protons simulated by the BI-ESS, N_P^{simu}, have been produced evenly along the Linac. So, dividing the protons simulated by the total DTLs distance, 40m, we obtain how many protons have been launched per meter. Specifically, 8x10^8 protons were simulated, so we assume N_P^{simu} = 2x10^7protons/m. To know the initial energy of the protons we can refer to document [3] where the relationship between the proton energy and the distance along the accelerator is shown. We can see that in the DTL region this is almost linear. Therefore, the energy of the protons per meter can be obtained (shown in Table 19). In the first approach, we calculate how many protons, N_p, are needed to produce 1W and assume we lost it per meter and per second. Then we can normalize the counts detected in the nBLM taking into account the number of protons simulated in the scenario, N_P^{simu}. Note that we are assuming that the protons contributing to a lost in a given region are mainly the protons of this region. This is a big assumption, needed if we want to, at least, approximate some rates for this scenario as we don't have the initial number of protons per meter.

In addition, we need to normalize also taking into account the number of neutrons that are produced in the scenario per meter, N_N^{simu}/m, by the number of neutrons we simulated following the scenario sample, N_N. In order to obtain N_N^{simu}/m, the graph in Figure 8 has been re-binned to 1m binning. The values are shown in Table 19.

In the second approach, instead of assuming a loss of 1W/m we have used document [4], where a summary of the error study performed on the baseline beam physics lattice of ESS linac is shown. In particular, in the figure 6 of the report we can see the expected powerloss per element (in W) as a function of the beam axis. Therefore, we can obtain the expected loss/m in this region (shown in Table 19). In fact, this figure corresponds to a worst scenario as the dynamic RF tolerances have been increased by a factor 3, however, if compared with figure 5 in the document there are not big differences in the region of the DTLs. We can use this W/m to obtain N_P.

In both cases what we do is:

$$c_{det} \cdot \frac{N_p}{N_p^{Simu}} \cdot \frac{N_N}{N_N^{simu}/m} \cdot \frac{1}{ActiveTime} \quad \textit{Eq. 2}$$

Only N_P changes, depending if we assume a loss of 1W/m or if we use the values from [4]. As before, we then normalize by the active time, in this case, as before, we normalize per pulse, to obtain the rate per µs. Results obtained for both cases are summarized in Table 20 and shown in Figure 10 together with the accidental case. In next section, the same it is computed for 14Hz, 1% 1W/m.

Z position (cm)	E_P (MeV)	N_N^{simu}/m	Powerloss (W/m) (from [4])
-2649	10.10	618	0.30
-2455	10.10	998	0.30
-2261	10.10	2510	0.30
-681.5	43.00	2510	0.80
280	64.20	639	0.70
665	71.00	873	0.70
865	78.00	1178	0.10
1065	80.00	1627	0.10

Table 19 *Position where we have placed the nBLM detectors when using as input the normal scenario. Also the proton energy expected in this region is shown, based on the graph from document* **[3]**. *We also listed the number of produced neutrons in the lost in each region obtained from file sim1_0 when rebinning Figure 8 in 1m binning. In the last column the expected loss per meter is shown based on the study in* **[4]**.

In Figure 10, the c/µs obtained in both cases are shown, together with accidental rates expected after the first µs of the accident happening. In this case, the expected rate ranges between 0.1kHz to 1MHz if we use the expected losses from **[4]** (black line). During normal operation there are hot spots regarding the loss locations, so to compare with the accidents, we compare at same location, implying very different differences from a factor 30 to 10^8. In the case of normalizing to a 1W/m loss, the rates change a factor between 2 to 10. Still very distinguishable from the accidental cases.

	Distributed in one pulse			
	c after normalization		10^{-3} c/µs (1 kHz)	
Z position (cm)	1W/m	Using values From [4]	1W/m	Using values from [4]
-2649	0	0	----	----
-2455	3.44 ± 0.10	11.45 ± 0.33	4.74 ± 0.38	1.42 ± 0.01
-2261	26.09 ± 0.53	86.98 ± 1.75	32.13 ± 1.85	9.64 ± 0.01
-2047	1277.57 ± 11.25	1277.57 ± 11.25	446.70 ± 11.25	446.70 ± 1.38
-681.5	61.29 ± 1.22	76.61 ± 1.53	32.22 ± 1.85	25.78 ± 0.18
280	1.27 ± 0.03	1.82 ± 0.04	0.79 ± 0.05	0.553 ± 0.004
665	2.68 ± 0.06	3.84 ± 0.08	1.68 ± 0.10	1.174 ± 0.008
865	2.02 ± 0.06	2.89 ±0.08	1.29 ± 0.10	0.129 ± 0.001
1065	0.88 ± 0.03	8.76 ± 0.27	3.13 ± 0.28	0.313 ± 0.003

Table 20: *Expected rate at different locations along the beam axis for the normal scenario assuming two power loss cases as explained in the text.*

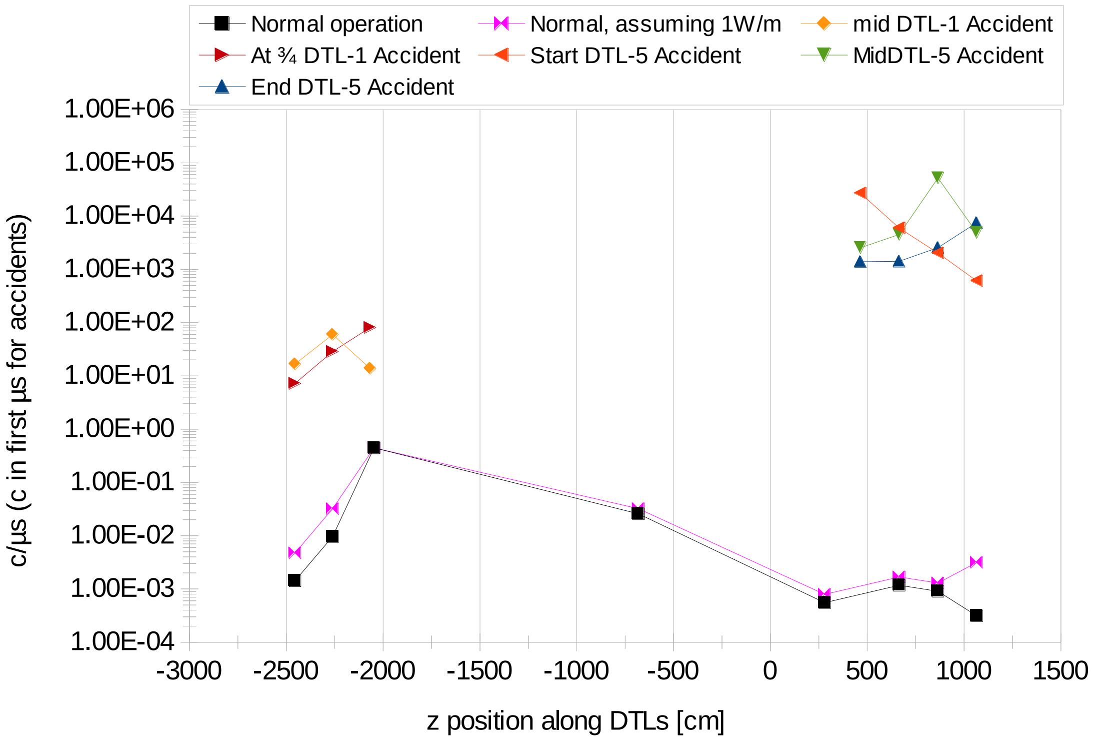


Figure 10: *Normal operation rates detected at the slow nBLM module placed at different locations along the LINACs assuming a power-loss of 1W/m (magenta line) or the losses described in* **[4]** *(black line). They are plotted together with the rates obtained in the case the accidents after the first µs, as obtained in section 2.1.*

3.2.1. 1% 1 W/m case in 14 Hz

As in the case of scaling the accidents down to the case of 1W/m the most relevant value is to obtain the expected rate for the 1% of 1W/m and distributed in 14 Hz. This is summarized for the two mention cases for the normal scenarios in Table 21 for the 1% of 1W/m and for the 1% of the values listed in [4]. In this case we are talking about rates between 0.5-320 Hz (0.5-320 c/s). A very big difference between normal operation and localized accidents (factor 10^4-10^{10}). Results are also plotted together with the case of accidents in *Figure 11*.

Furthermore, in [2], it is suggested to obtain the rate in the place with the smallest expected lost during normal operation, i.e., looking at Figure 8 will be around 280cm. In this case we expect a rate of about 0.5 Hz. In order to obtain the lowest limit it is suggested to calculate the 1 and 10% of it. Therefore we are talking about $5x10^{-2}$ - $5x10^{-3}$ c/s. **So, the lowest limit with the standard geometry of the slow detector will be of less than a c/s detected during normal operation.**

	1% of the power loss distributed in 14 Hz	
	c/s (1 Hz)	
Z position (cm)	1% 1W/m	1% of values from [4]
-2649	----	----
-2455	3.39 ± 0.10	1.02 ± 0.03
-2261	22.95 ± 0.46	6.89 ± 0.14
-2047	319.07 ± 2.80	319.07 ± 2.80
-681.5	23.01 ± 0.46	18.41 ± 0.37
280	0.56 ± 0.01	0.40 ± 0.01
665	1.20 ± 0.03	0.84 ± 0.02
865	0.92 ± 0.02	0.65 ± 0.02
1065	2.24 ± 0.06	0.22 ± 0.01

***Table 21**: Expected rate at different locations along the beam axis for the normal scenario assuming two power loss cases as explained in the text and scaling them down to 1% of the power loss and distributed in 14 Hz.*

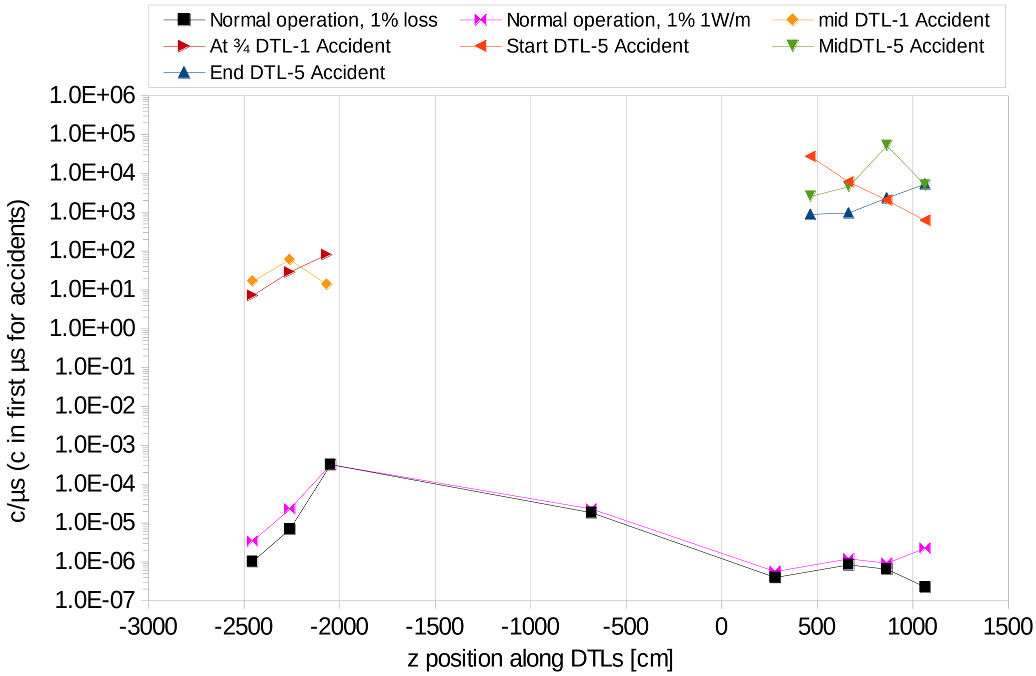


***Figure 11:** Normal operation rates detected at the slow nBLM module placed at different locations along the LINACs assuming a power-loss of 1% 1W/m (magenta line) or 1% of the losses described in **[4]** (black line). They have been calculated assuming a distribution along the operation duty cycle.. They are plotted together with the rates obtained in the case the accidents after the first µs, as obtained in section 2.1.*

3.2.2. Uniform loss scenario

Another simulation performed by the BI-ESS corresponds to a uniform loss. The produced particles in these scenario are in file *sim0_0-DTL-detectors.mcpl* shown also in the Appendix A. In principle it corresponds to the 1W/m scenario. Same locations as for the normal scenario have been simulated where we use this file as the input for the nBLM.

Similarly to the normal case, we have to know the normalization factor to normalize the counts detected in the nBLM modules to the scenario. As before, we start calculating how many protons, N_P, are needed to produce a loss of 1W/m taking into account the energy of the proton at each position. In the simulation, 10^8 protons were simulated. We assume again that they have been distributed uniformly along the DTLs so we can calculate N_P^{simu} as before, $N_P^{simu} = 10^8/40$. From Figure 8 we can obtain the number of neutrons produced per meter at this scenario, N_N^{simu}. Then we normalize by the number of neutrons we simulated, N_N. Finally, we apply both factors as in Eq.2. Also in this case we are assuming that the only protons that contribute to the lost produced in a given region are the ones in this region.

Once we normalize the number of counts detected we can calculate the rate assuming, for example, the lost is produced per pulse (dividing by 2.86ms) or in a second (14x2.86ms). In Table 22 the results assuming it is lost per pulse are shown. We plot it together with the rates obtained for the accidental cases in Figure 12. Again we observe a large difference between the uniform losses of 1W/m with respect the accidental scenarios. In this case the rates are between 5kHz and 10 MHz at low and high energy regions respectively. Comparing with the normal scenario we are talking about differences of a factor as high as from ~$5x10^2$ to ~$5x10^3$ in the high and low energy region respectively. Assuming 1% of this lost implies rates between 50c/s in the low energy region to $1x10^6$c/s in the high energy region.

Z position (cm)	c after normalization	c/µs (MHz)
-2649	0	----
-2455	15.56 ± 3.18	0.005 ± 0.001
-2261	68.61 ± 5.57	0.022 ± 0.002
-2047	74.55 ± 5.62	0.0261 ± 0.002
-681.5	7994.84 ± 379.42	2.63 ± 0.12
280	21204.17 ± 178.38	6.63 ± 0.06
665	26857.75 ± 294.73	8.90 ± 0.10
865	28202.56 ± 263.73	9.38 ± 0.09
1065	35213.40 ± 1422.26	11.42 ± 0.46

Table 22: *Expected rate at different locations along the beam axis for the uniform scenario assuming 1W/m loss.*

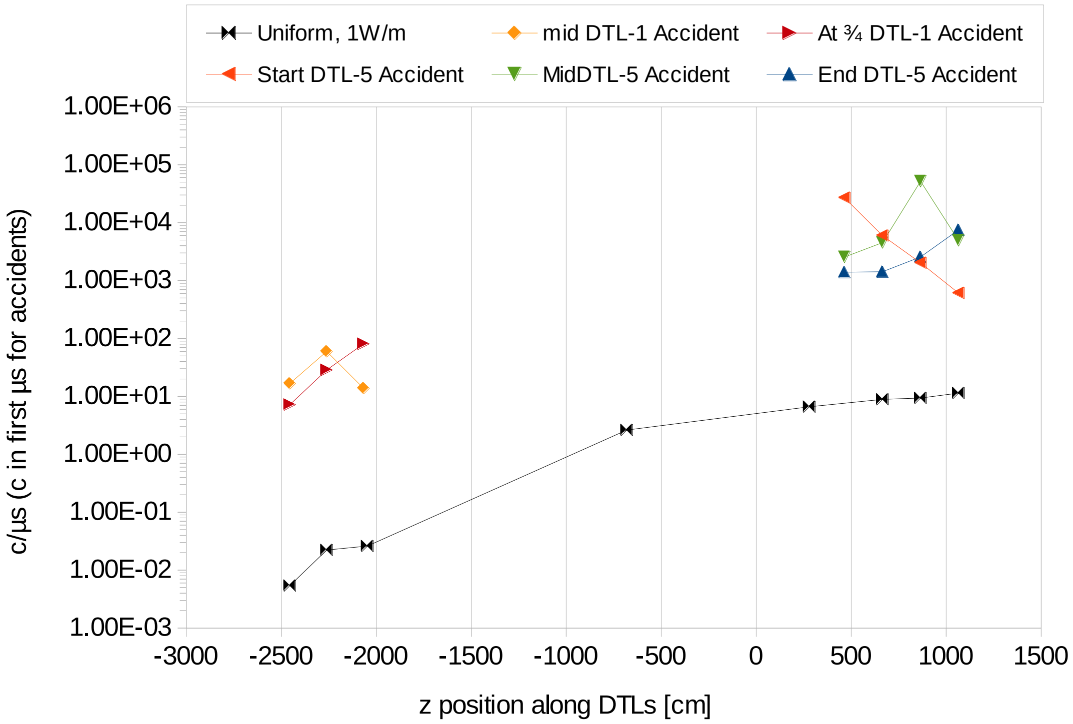


Figure 12: *Uniform operation rates detected at the slow nBLM module placed at different locations along the LINACs assuming a power-loss of 1W/m (black line). They are plotted together with the rates obtained in the case the accidents after the first µs, as obtained in section 2.1.*

3.2.3. 1% 1 W/m case in 14 Hz

As in the previous subsection, it is more interesting to quote the expected rates assuming a loss of 1% 1W/m and distributed uniformly in 14Hz. The results are summarized in Table 23 and plotted together with the cases of the accidents in Figure 13. In this case we are talking about rates between 4 Hz and 8 kHz (4 c/s - 8000 c/s). A difference between 6x10^5 and 8x10 for normal operation with respect to localized accidents is found.

1% 1W/m in 14 Hz	
Z position (cm)	c/ms (kHz)
-2649	----
-2455	0.004 ± 0.001
-2261	0.016 ± 0.001
-2047	0.019 ± 0.001
-681.5	1.88 ± 0.09
280	4.74 ± 0.04
665	6.36 ± 0.07
865	6.70 ± 0.06
1065	8.16 ± 0.33

Table 23*: Expected rate at different locations along the beam axis for the uniform scenario assuming 1% 1W/m loss and distributed in 14 Hz.*

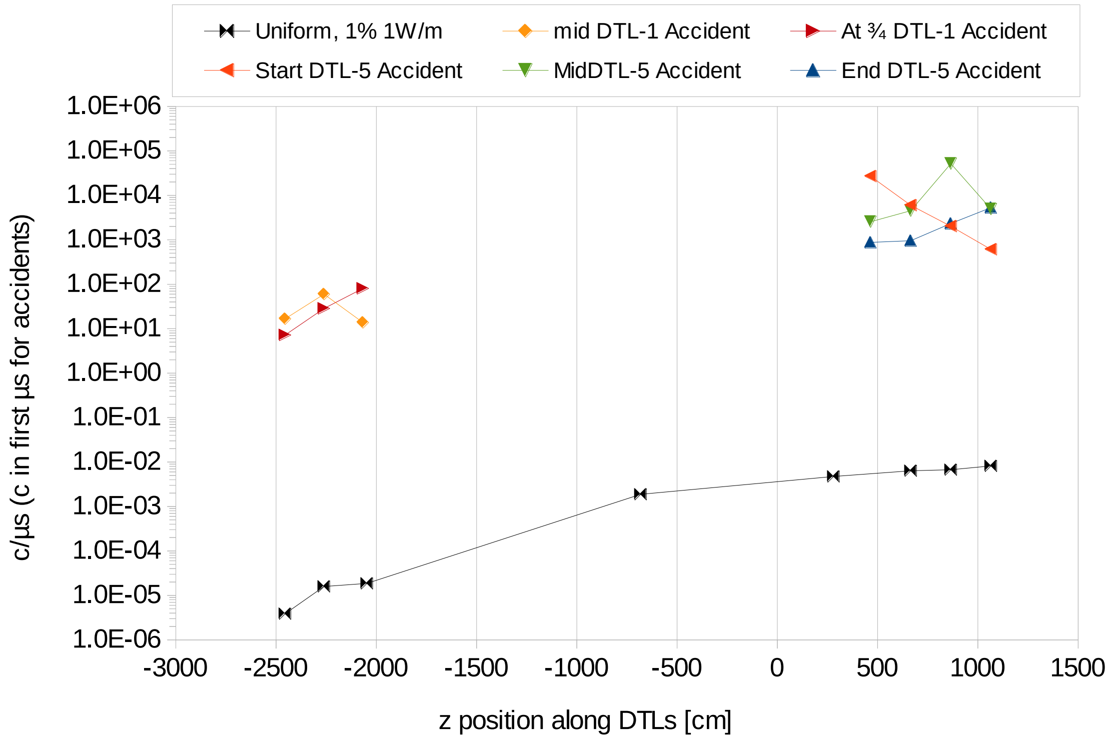


Figure 13***:*** *Uniform operation rates detected at the slow nBLM module placed at different locations along the LINACs assuming a power-loss of 1W/m (black line). They are plotted together with the rates obtained in the case the accidents after the first μs, as obtained in section 2.1.*

3.2.4. Comparing the different "normal" scenarios

We can compare the three scenarios we have considered as "normal" operation between them in Figure 14 and Table 24. We have listed the rates detected in the different cases assuming a loss of 1% 1W/m in 14Hz.

Using the accident cases to scale down to 1 W/m seems the best assumption of all, as we know the number of protons producing the lost. In the other two cases we are assuming the only protons contributing to the loss are the ones in the region where the detector is. In that sense, in the normal and uniform case we are underestimating the expected rates.

	"Normal" operation, 1% of the power loss in 14 Hz				
	Normal scenario, Sim1_0		Uniform,1W/m Sim0_0	Accidents scale to 1% 1W/m	Accidents
Z position (cm)	Assuming 1W/m *c/s (1Hz)*	Using values from [4] *c/s (1Hz)*	*c/ms (1kHz)*	*c/ms (1kHz)*	*c in 1st μs (1MHz)*
-2649	----	----	----	---	---
-2455	3.39 ± 0.10	1.02 ± 0.03	0.004 ± 0.001	0.21 ± 0.01	16.70 ± 4.09
-2261	22.95 ± 0.46	6.89 ± 0.14	0.016 ± 0.001	0.92 ± 0.01	59.81 ± 7.73
-2067				0.396 ± 0.003	13.82 ± 3.72
-2047	319.07 ± 2.80	319.07 ± 2.80	0.019 ± 0.001		
-681.5	23.01 ± 0.46	18.41 ± 0.37	1.88 ± 0.09		
280	0.56 ± 0.01	0.40 ± 0.01	4.74 ± 0.04		
665	1.20 ± 0.03	0.84 ± 0.02	6.36 ± 0.07	14.92 ± 0.50	4518.26 ± 67.22
865	0.92 ± 0.02	0.65 ± 0.02	6.70 ± 0.06	67.73 ± 0.78	51790.90 ± 227.58
1065	2.24 ± 0.06	0.22 ± 0.01	8.16 ± 0.33	13.87 ± 0.35	4914.98 ± 70.11

Table 24 *Comparing the scenarios we have for normal operation in the three first columns. Normal scenario: taking into account the beam dynamics (sim1_0), uniform scenario: assuming a uniform loss of 1W/m (sim0_0), using the accidentals to normalize to 1W/m (sim2_x). They are compared with the accidental losses listed in the last column.*

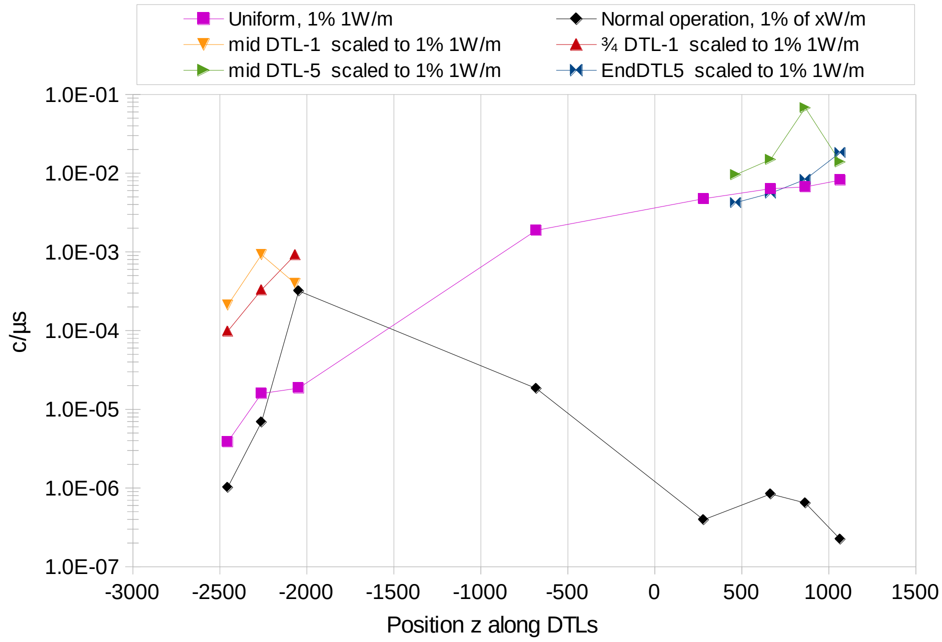


Figure 14 *Comparing the scenarios we have for "normal" operation in the three cases. Normal scenario taking into account the beam dynamics (sim1_0 in black) and scaling to 1% of the expected loss in* **[4]**, *uniform scenario: assuming a uniform loss of 1% 1W/m (sim0_0 in magenta), using the accidentals to scale to 1% 1W/m (sim2_x, orange, green, red and blue).*

3.3. Conclusions

In this section the response of the nBLM detectors to normal accelerator conditions have been addressed. Three cases have been studied: scaling the accidental cases to 1W/m loss; using the so called normal operation scenario (sim1_0) normalized to 1W/m and to the values found in [4] and using the uniform loss scenario (sim0_0), assuming a loss of 1W/m. In the three cases we have also shown the rates expected in the case of 1% of the loss distributed along the duty cycle of the accelerator.

The detected number of counts in each simulated scenario has been normalized to each scenario. Then, we can calculate a rate assuming they are loss in, for example, one pulse. In all cases, the obtained rates are at least one order of magnitude different than the rates in the case of an accident. This factor is even much larger (10^{10}) depending on the scenario used and on the energy region the detector is placed.

As mentioned in previous section, using the accident cases to scale down to 1 W/m seems the best assumption of all, as we know the number of protons producing the lost. In the other two cases we are assuming the only protons contributing to the loss are the ones in the region where the detector is. In that sense, in the normal and uniform case we are underestimating the expected rates.

These results imply the detectors need to be in general sensitive to a very big dynamic range of rates, what is not always possible from the point of view of the gain or electronics. Therefore, we may need to define some detectors for monitoring purposes and others for safety, with different gains. In addition, the geometry may also need to be different at different locations along the linac. Moreover, if we confirm very high rates we may need to consider working on current mode instead of counting mode. Unfortunately, there are some assumptions along the normalization process of these calculations that may vary the results and, therefore, limit right now the possibility of a decision regarding the design (both mechanically and of the electronics) until we take experimental data to confirm it or until we obtain more information from the ESS on the normalization factors.

The lowest expected rates in normal operations are of few c/s, rate that in principle we are able to detect if the environmental background is small.

4. Replacing Cd by mirrobor in the slow detector

In the PDR1.1 we discuss about the use of Cd at ESS that is not allowed, so we found a possible replacement, a borated rubber. Here are the results using this material instead of Cd in the simulations.

We bought this material, called MirroBor, from MirroTron LTD [5] and I introduce its composition in the nBLM Geant4 code. It consists of 80% B_4C + 20%glue. The B_4C is made by natural boron with 20% ^{10}B and 80% ^{11}B. The glues is made by C (70%), O (25%) and H (5%). Its thickeness is 5mm.

First of all we have checked its effect on the response of the detector to different initial neutron energies. As in the first part of PDR1.1 we checked for a large dynamic range between 0.1 eV to 100 MeV. Results are compared with those from Cd in Figure 15 left for different thickness of Mirrobor. As expected, from the different crossection between Cd and B-10 and 11, the mirrobor has higher absorption for lower neutron energies that will reduce the thermal neutron background. In fact, using one or another thickness will reduce up to different energies. In Figure 15 right we compared the time response of the detector and there is no change.

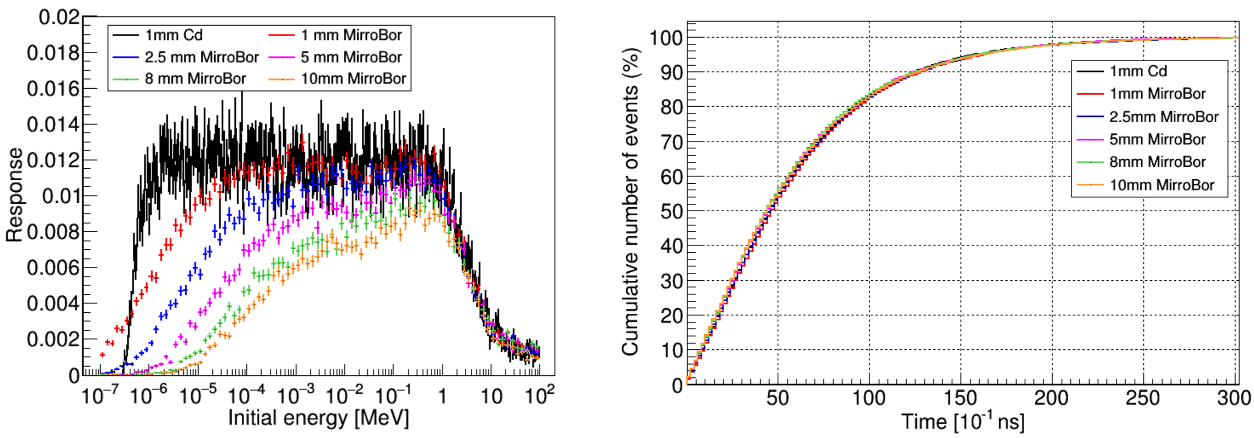


Figure 15: (left) *Response to an initial flux of neutrons isolethargic distributed between 0.1eV to 100 MeV. The response is shown for different thicknesses of mirrobor (1mm in red, 2.25 mm in blue, 5mm in magenta, 8 mm in green and 10 mm in orange) compared with the case of 1 mm Cadmium (black).* ***(Right)*** *Comparison of the time response between the same cases.*

The geometry of the slow module using MirroBor instead of Cadmium is implemented in an ESS scenario to see its effect to the response under this conditions. The case of an accidental loss at the middle of DTL-5 (file sim2_13) has been chosen to compare with previous results using Cd. Instead of 1mm Cd, 2mm of mirrobor has been defined. In this case 2.2×10^{8} neutrons have been launched following the distribution from the BI-ESS file sim2_13 and placing the detectors at the same 4 different positions on top of DTL-5 as before. The response of each detector is shown in Figure 17. Results are also shown for the efficiency and temporal response comparing with the 1mm Cd for different mirrobor thicknesses in Figure 17. Results are also listed in Table 25. In this case the nBLM module was placed just on top of the lost, as the one we call det3. As we can see the c/bunch are identical in all cases and the rate is slightly smaller when using Mirrobor (of maximum a factor 1.3 different).

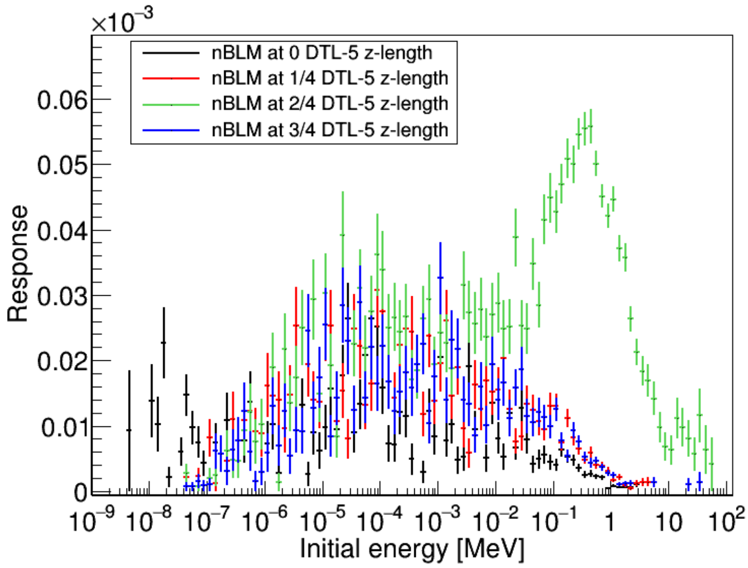
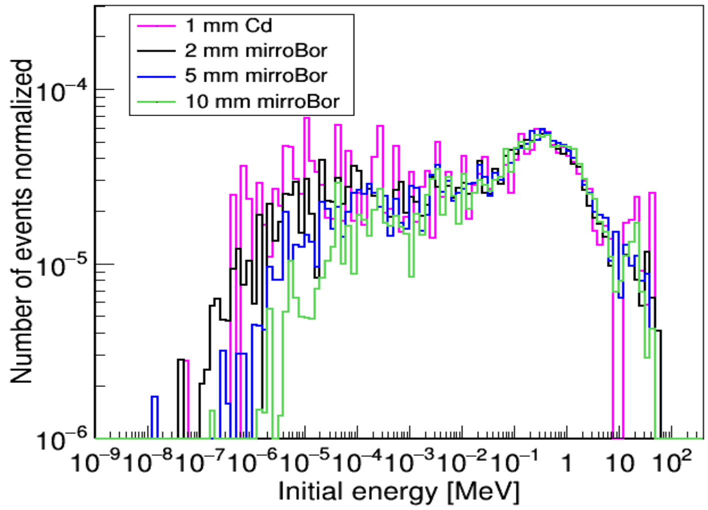
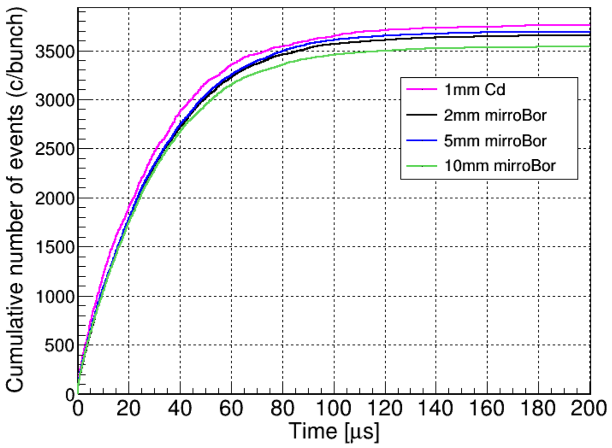


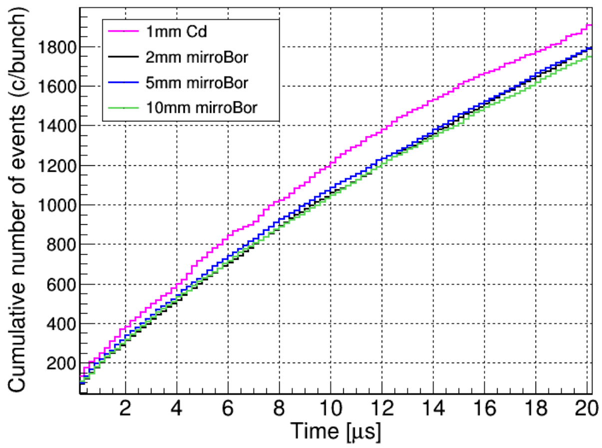
Figure 16: *Response for the nBLM located at different positions along DTL-5 in the scenario where an accident happen in the middle of DTL-5. The green curve corresponds to the detector placed just on top of the lost. In these cases the detectors have a layer of MirroBor as thermalize instead of Cd as in [1].*



(a)



(b)



(c)

Figure 17 *The response of the slow module placed on top of the lost (middle of DTL-5) is shown for different mirrobor thicknesses (top figure). On the bottom, for the same cases the time response is shown.*

	c/bunch	c in 1st µs
Cd-1mm	3758.40 ± 42.95	(5.18 ± 0.23) 10^4
Mirrobor (mm)		
2	3655.80 ± 42.36	(3.83 ± 0.20) 10^4
5	3690.65 ± 42.56	(4.06 ± 0.20) 10^4
10	3540.93 ± 41.69	(3.92 ± 0.20) 10^4

Table 25: *c/bunch and c detected in the first µs when using Cd as absorber or different thicknesses of Mirrobor.*

5. Threshold between "thermal" and fast neutrons

In [2] it is suggested two possible thresholds to separate between "thermal" and fast neutrons. They corresponds to 0.5 MeV or 50 keV.

This is naturally obtained in the fast detector as we can see in Figure (from [1]). As we can see we are only sensitive to initial neutrons energies of ~ 0.2 MeV. In the case of the slow we have some merging playing with the Mirrobor thickness, however, the limits suggested in [2] seems quiet unrealistic as will imply a high efficiency loss.

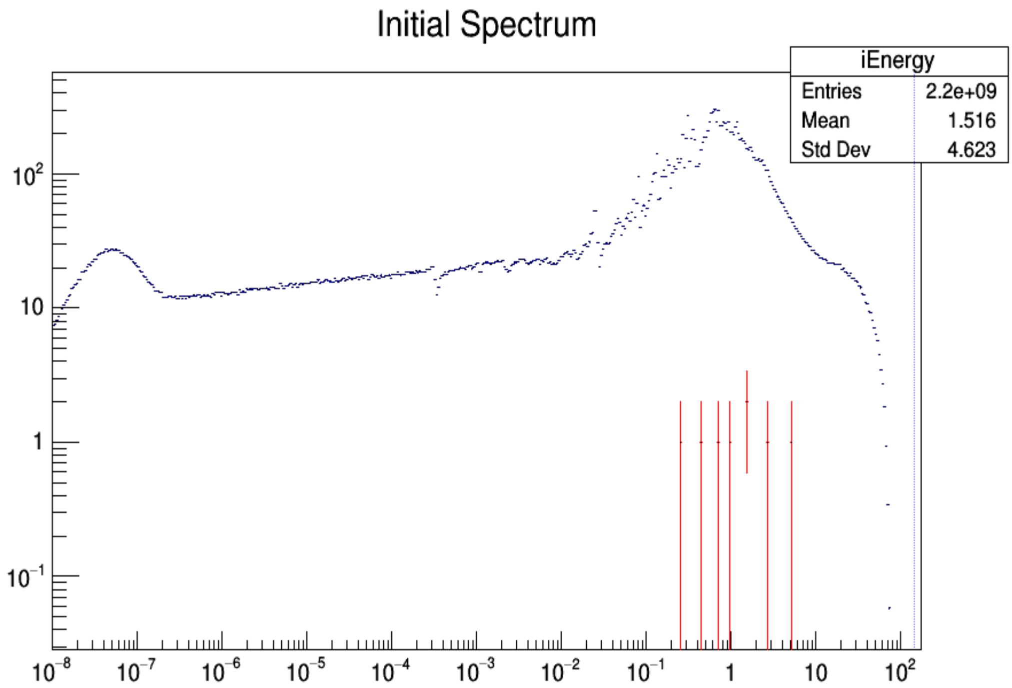


Figure 18: *Initial spectrum (in blue) compared with the neutrons that deposited energy in the nBLM fast detector (red). The detector was placed on top of the DTL-5 when using the scenario sim2_13 corresponding to a lost in the middle of DTL-5. The x-axis represents the initial neutron energy in MeV. As we can see we are only sensitive to initial neutrons energies of ~ 0.2 MeV.*

6. APPENDIX A

List of simulations from the BI group used as input in our studies.

		uniform loss		normal operation		localized loss										
										gun hit						
sim Name	#primaries	beam theta [mrad]	tunnel in	tunnel in	MEBT loss included	gun theta [mrad]	Beam sigmXY [mm]	gun phi [deg]	gun energy [MeV]	geo element	el. Fraction	comment	mesh files	production cuts	edep refined	comment
sim0-0	100 M +1	1	yes										11	e,gamma: 10um p: 0	no (default)	
sim0-1	100 M +1	1	no										11	e,gamma: 10um p: 0	no (default)	
sim1-0	800 M +1			yes	yes								11	e,gamma: 10um p: 0	no (default)	
sim1-1	800 M +1			yes	no								11	e,gamma: 10um p: 0	no (default)	
sim1-2	800 M +1			no	no									e,gamma: 10um p: 0	no (default)	
sim2-0	600 M + 1					50 (max in DTL1)	1	0	11.5	106	0.5	mid DTL1	0	e,gamma: 10um p: 0	yes	
sim2-1	100 M +1					50	1	0	17.9	140	0.5	at 3/4 DTL1	0	e,gamma: 10um p: 0	yes	
sim2-2	1000 M +1					50	1	0	7.6	78	0.5	at 1/4 DTL1	0	e,gamma: 10um p: 0	yes	
sim2-3	600 M + 1					50	1	-90	11.5	106	0.5	mid DTL1	0	e,gamma: 10um p: 0	yes	
sim2-4	700 M + 1					2	1	0	7.6	78	0.5	at 1/4 DTL1	0	e,gamma: 10um p: 0	yes	too little hits
sim2-5	1300 M + 1					50	0	0	7.6	78	0.5	at 1/4 DTL1	3	e,gamma: 10um p: 0	yes	
sim2-6	1300 M + 1					10	0	0	5.8	78	0.5	at 1/4 DTL1	2	e,gamma: 10um p: 0	yes	
sim2-7	1300 M + 1					10	1	0	5.8	78	0.5	at 1/4 DTL1	2	e,gamma: 10um p: 0	yes	
sim2-8	40M +1					10 (max in DTL5)	0	0	71.8	342	0.5	start of DTL5	2	e,gamma: 10um p: 0	yes	
sim2-9	40M +1					10	1	0	71.8	342	0.5	start of DTL5	2	e,gamma: 10um p: 0	yes	
sim2-10	40M +1					5	0	0	69.8	342	0.5	start of DTL5	2	e,gamma: 10um p: 0	yes	
sim2-11	40M +1					10	0	0	86.5	384	0.5	end of DTL5	2	e,gamma: 10um p: 0	yes	
sim2-12	40M +1					10	1	0	86.5	384	0.5	end of DTL5	2	e,gamma: 10um p: 0	yes	
sim2-13	40M +1					10	0	0	79.3	364	0.5	mid DTL5	2	e,gamma: 10um p: 0	yes	

7. APPENDIX B

Positions z along the beam axis used to place our detectors in the system of reference of the BI-ESS simulations compared with the system of reference of the accelerator (distance to the RFQ exit).

Position z (cm) Reference system BI-ESS simulations	Distance from RFQ exit (m)
-2639	3.90
-2649	5.64
-2455	7.58
-2261	9.52
-2067	9.72
-2047	23.38
280	32.99
465	34.84
665	36.84
865	38.84
1065	40.84

8. REFERENCES

[1] L. Segui, “nBLM PDR1.1,” CHESS, ESS-0087794, CEA-ESS-DIA-RP-0013, 2016.

[2] I. Dolenc Kittelman, “Report regarding the MC simulation for BLM-focus on the nBLM,” CHESS, ESS-0066428, 2016.

[3] Y. I. Levinsen, “https://indico.esss.lu.se/event/745/contribution/14/material/slides/1.pdf”.

[4] Y. I. Levinsen, “ESS 2015 Baseline Latitice Error Study,” CHESS ref. ESS-0049433, 2016.

[5] “MiroTron,” [Online]. Available: http://www.mirrotron.kfkipark.hu/shield.html.