Additional shielding behind the LHCb muon detector

Internal Note

Issue:	1
Revision:	0
Reference:	LHCb-INT-2012-034
Created:	December 19, 2012
Last modified:	January 10, 2013

Prepared by: Robert Paluch[a], Rolf Oldeman[b c], Burkhard Schmidt[c]

[a]Warsaw University of Technology, Poland

[b]University of Cagliari, Italy

[c]CERN, Switzerland

Abstract

This note presents studies on the effect of backsplash hits in the last station of the LHCb muon detector (M5) and the results of Monte Carlo simulations of various additional shielding behind M5. These particles are delayed in comparision with normal muons coming from the interaction point, so the backsplashes are late by up to $50\,\mathrm{ns}$. During the winter 2011/2012 shutdown, ~ 5 tons of iron were installed to reduce the backsplashes. The iron was placed on the top of the last muon filter (MF4), in front of the concrete beams above the corrector magnet. After Long Shutdown 1 (LS1), the beam energy will be increased to $\sim 6.5\,\mathrm{TeV}$ (now is $4\,\mathrm{TeV}$) and the spacing between bunches decreased to $25\,\mathrm{ns}$ (now is $50\,\mathrm{ns}$). It will cause a big increase of number of backsplash hits (approximately 2.25 times more). This document focuses on possible methods of installing additional shielding behind M5. Various methods were tested using MC simulations. In each kind of simulated shielding, the distribution and the number of hits were analysed. The most effective shielding requires ~ 42 tons of extra iron and reduce backsplashes by more than a factor 3.5 (comparing to estimated number of backsplashes after LS1 in case of no use additional shielding), bringing them after LS1 to a level $\sim 40\%$ less than during the 2012 run.

Document Status Sheet

1. Document Title: Additional shielding behind the LHCb muon detector			
2. Document Reference Number: LHCb-INT-2012-034			
3. Issue	**4. Revision**	**5. Date**	**6. Reason for change**
Draft	1	December 19, 2012	First version.

Contents

List of Tables

1 Introduction

Backsplash hits in the last station of the LHCb muon detector (M5) come from behind MF4 and are the effect of secondary and tertiary interactions. The main sources of these backward particles are a corrector magnet and a quadrupole magnet in the LHC tunnel. Most of the backsplashes affect the outer region (R4), above MF4. Simulations show that the backsplashes can be $\sim 45\%$ of all hits in M5R4 in the case of absence of additional shielding. One can easly distinguish true hits from backsplashes which are much later in time (they come from secondary interactions) so one can observe them between collisions ($\sim 75\%$ backsplashes are in TAE+1, the rest in TAE+2). Unfortunately this distinction will be impossible after LS1 because the spacing between bunches will be a factor two less (25 ns). During the winter technical stop in 2011/2012 additional shielding was installed on top of MF4. This shielding has been built with 336 iron blocks, ~ 15 kg each (10x10x20 cm). The 2012 iron shielding has dimensions 480x70x20 cm, weight ~ 5 tons and is attached to the concrete beam (which is behind MF4). This iron reduces backsplashes by about a factor two (simulations shows $\sim 46\%$ reduction, $\sim 53\%$ in TAE+1 and $\sim 25\%$ in TAE+2, see Table 1). After LS1, the beam energy is going to be increased to ~ 6.5 TeV (instead of 4 TeV), so the effect of backsplashes will be more serious. To avoid this situation, it is necessary to install additional shielding.

	Number of hits in M5R4	
	TAE+1	TAE+2
No iron	1353 ± 37	424 ± 21
2012 iron	638 ± 25	$318 \pm 18\%$

Table 1: Effect of putting the shielding (2012 iron) on top of MF4. The simulations were carried out with the beam energy of 3.5 TeV and include 3000 event each.

2 Simulation of different shieldings

Many MC simulations have been done to test various posibilities of adding new shielding. The software used in simulation was `Gauss v42` [1] (see Table 2). `Panoramix v21` [1] was used to preview modifications in the geometry (see pictures in appendix). To simulate backsplashes, geometry parts `AfterMuon` and `Infrastructure` have to be enabled. This increased the CPU time of the simulation by a factor two. Several inaccuracies in the geometry behind M5 have been corrected [2]. These corrections have been submitted to be included in the next version of the geometry. While these corrections have a big effect on backsplashes, they do not affect regular LHCb simulations where geometry parts `AfterMuon` and `Infrastructure` are disabled.

The parameters of the beam in `Gauss` simulations are defined in a special configuration file (see Table 2). A beam energy has been set at 7 TeV, which is close to the beam energy in 2015 (~ 6.5 TeV) and is ultimate energy of the LHC. The luminosity has been left at default value of $2.47 \cdot 10^{29}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ per colliding bunch which corresponds to total luminosity of about $3.13 \cdot 10^{32}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ with 1262 colliding bunches in IP8 as it was during 2012 LHC proton-proton run. Each of the simulations include 3000 events.

detector description	head-20120413
detector condition	sim-20120420-vc-md100
beam configuration file	Beam3500GeV-md100-MC11-nu2-50ns.py
beam energy	7 TeV
luminosity	$2.47 \cdot 10^{29}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$

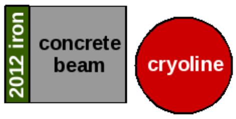
Table 2: Parameters of simulations.

The results of the simulations are presented in the following. In each paragraph there is a simple diagram with a new shielding, dimensions and weights of the elements, the numbers of hits in M5R4 (TAE+1 and TAE+2) and the total mass of the new shielding. The diagrams contain shielding elements in side view, in which the Interaction Point is on the left side. In the diagrams these elements which are enumerated in dashed circles are behind elements enumerated in normal circles.

Histograms with distributions of hits in M5R4 and pictures of the geometry made in `Panoramix` are presented in an appendix.

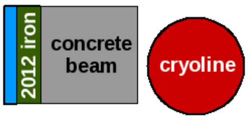
Simulation nr 0 - present shielding

The iron on top of MF4 has dimensions 486x74x20 [cm] and a weight of 5.4 tons. In this simulation no new elements have been added therefore total mass of additional shielding is 0.0 tons. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	No additional shielding	1074 ± 33	471 ± 22	0.0 tons

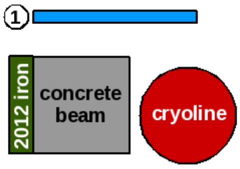
Simulation nr 1

Extra 10 cm of thickness has been added to the current (2012) iron shielding. It is the simplest improvement so it is not very effective. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 486x74x10 [cm] (2.7 tons)	953 ± 31	464 ± 22	2.7 tons

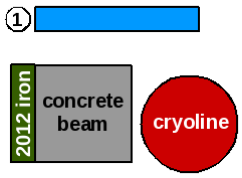
Simulation nr 2

The top iron plate (1) has been placed 30 cm above the concrete beam. This is first approach with the top shielding and it has quite good efficiency. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 640x10x140 [cm] (6.7 tons)	691 ± 26	428 ± 21	6.7 tons

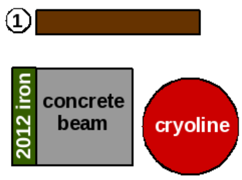
Simulation nr 3

The top iron plate (1) like in the simulation 2, but in thicker (20 cm) version. Large decrease of the number of hits in TAE+2. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 640x20x140 [cm] (13.4 tons)	619 ± 25	340 ± 18	13.4 tons

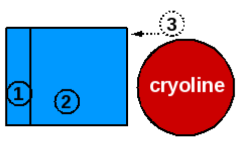
Simulation nr 4

The top plate (1) like in the simulation 3, but in lead version. Lead is much denser than iron but simulation shows is less effective. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 640x20x140 [cm] (20.3 tons)	671 ± 26	376 ± 19	20.3 tons

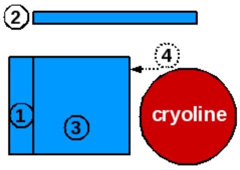
Simulation nr 5

The 2012 iron has been extended (1) to the left and right side of the concrete beam. New elements (2,3) have been added on the sides of the concrete beam. This is very easy improvement which does not need additional support structure. It is quite effective in TAE+1. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x74x20 [cm] (5.4+1.6 tons) 2. 20x81x80 [cm] (1.0 tons) 3. 20x81x80 [cm] (1.0 tons)	841 ± 29	440 ± 21	3.6 tons

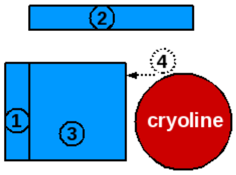
Simulation nr 6

The combination of shielding from the simulations 5 and 2 which are rather independent. Efficiency in TAE+2 is even above expectations. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x74x20 [cm] (5.4+1.6 tons) 2. 640x10x140 [cm] (6.7 tons) 3. 20x81x80 [cm] (1.0 tons) 4. 20x81x80 [cm] (1.0 tons)	499 ± 22	317 ± 18	10.3 tons

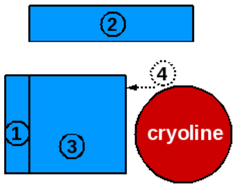
Simulation nr 7

The shielding from the simulation 6 but with thicker (20 cm) top plate. Little increase of efficiency in TAE+1 and TAE+2. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x74x20 [cm] (5.4+1.6 tons) 2. 640x20x140 [cm] (13.4 tons) 3. 20x81x80 [cm] (1.0 tons) 4. 20x81x80 [cm] (1.0 tons)	442 ± 21	289 ± 17	17.0 tons

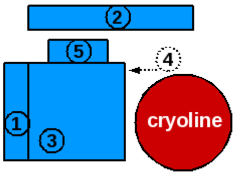
Simulation nr 8

The shielding from the simulation 7 but with thicker (30 cm) top plate. There is very little difference between 20 and 30 cm thickness of the top shielding. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x74x20 [cm] (5.4+1.6 tons) 2. 640x30x140 [cm] (20.1 tons) 3. 20x81x80 [cm] (1.0 tons) 4. 20x81x80 [cm] (1.0 tons)	438 ± 21	286 ± 17	23.7 tons

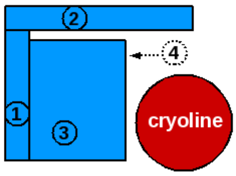
Simulation nr 9

The shielding from the simulation 6 with additional block of iron on top of the concrete beam. The decreases of numbers of hits in TAE+1 and TAE+2 are lower than uncertainties. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x74x20 [cm] (5.4+1.6 tons) 2. 640x20x140 [cm] (13.4 tons) 3. 20x81x80 [cm] (1.0 tons) 4. 20x81x80 [cm] (1.0 tons) 5. 591x20x50 [cm] (4.4 tons)	412 ± 20	270 ± 16	21.4 tons

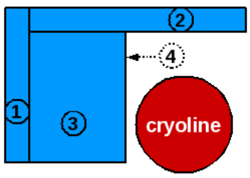
Simulation nr 10

Similar amount of iron like in the simulation 9. Elements 1,3,4 have been increased. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x103x20 [cm] (5.4+4.4 tons) 2. 631x20x160 [cm] (15.1 tons) 3. 20x100x80 [cm] (1.2 tons) 4. 20x100x80 [cm] (1.2 tons)	389 ± 20	247 ± 16	21.9 tons

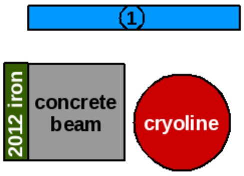
Simulation nr 11

The next step in improving shielding from the simulations 9 and 10. The front (1) and the sides (3,4) are combined with the top (2). The top shielding is overlong to the wall. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x123x20 [cm] (5.4+6.2 tons) 2. 631x20x166 [cm] (15.7 tons) 3. 20x110x80 [cm] (1.3 tons) 4. 20x110x80 [cm] (1.3 tons)	316 ± 18	219 ± 15	24.5 tons

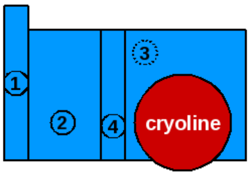
Simulation nr 12

The comparison between two versions of the top shielding. Short version (140 cm) has been tested in the simulation 3. In this simulation the top shielding is overlong to the wall. Closing a gap above the cryoline gave 16% less backsplashes in TAE+1 than a short top plate. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x20x166 [cm] (15.7 tons)	517 ± 23	333 ± 18	15.7 tons

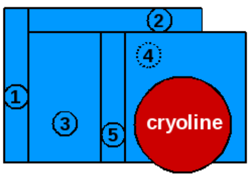
Simulation nr 13

The fully enclosed sides. The best possible results without installing support structure for the top plate is 32% less backsplashes in TAE+1 and 30% less in TAE+2. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x123x20 [cm] (5.4+6.2 tons) 2. 20x110x60 [cm] (1.0 tons) 3. 20x110x166 [cm] (2.7 tons) 4. 76x110x20 [cm] (1.3 tons)	733 ± 27	330 ± 18	11.2 tons

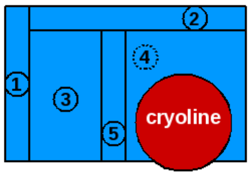
Simulation nr 14

The combination of shielding from the simulations 13 and 3. A gap above the cryoline has been left in case the support structure requirements. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x123x20 [cm] (5.4+6.2 tons) 2. 631x20x140 [cm] (13.3 tons) 3. 20x110x60 [cm] (1.0 tons) 4. 20x110x166 [cm] (2.7 tons) 5. 76x110x20 [cm] (1.3 tons)	333 ± 18	224 ± 15	24.5 tons

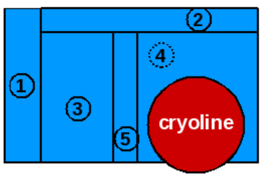
Simulation nr 15

The combination of shielding from the simulations 12 and 13. A gap above the cryoline has been closed and it gave 17% less hits in TAE+1. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x123x20 [cm] (5.4+6.2 tons) 2. 631x20x166 [cm] (15.7 tons) 3. 20x110x60 [cm] (1.0 tons) 4. 20x110x166 [cm] (2.7 tons) 5. 76x110x20 [cm] (1.3 tons)	276 ± 17	225 ± 15	26.9 tons

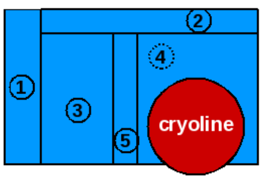
Simulation nr 16

The shielding from the simulation 15 with thicker front shielding (on top of MF4) by 10 cm. This improvement is not very effective but very easy to implement. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x123x30 [cm] (5.4+12.0 tons) 2. 631x20x166 [cm] (15.7 tons) 3. 20x110x60 [cm] (1.0 tons) 4. 20x110x166 [cm] (2.7 tons) 5. 76x110x20 [cm] (1.3 tons)	261 ± 16	197 ± 14	32.7 tons

Simulation nr 17

The next step in improving the shielding from simulations 15 and 16 is adding 10 cm to the thickness of the top plate. To keep in all simulations the same space (30 cm) between top of the concrete beam and the top plate, the hight of the front shielding has been increased by 10 cm. The results of this simulation are the best from all simulations. It is a maximal decrease of the backsplashes which can be achieved using shielding in reasonable way. See the distribution of hits and the image from `Panoramix` in appendix.

Diagram	Dimensions and weights of the elements	TAE+1 hits	TAE+2 hits	Total mass
	1. 631x133x30 [cm] (5.4+13.5 tons) 2. 631x30x166 [cm] (23.6 tons) 3. 20x110x60 [cm] (1.0 tons) 4. 20x110x166 [cm] (2.7 tons) 5. 76x110x20 [cm] (1.3 tons)	238 ± 15	162 ± 13	42.0 tons

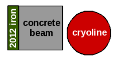
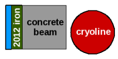
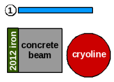
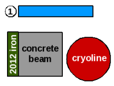
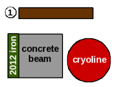
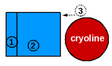
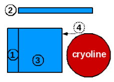
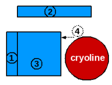
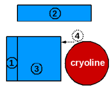
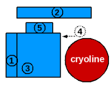
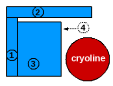
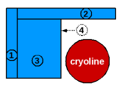
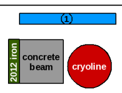
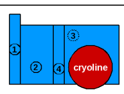
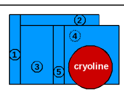
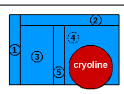
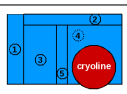
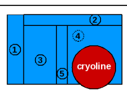
Nr	Diagram	TAE+1 hits	In comparison to present shielding	TAE+2 hits	In comparison to present shielding	Total mass [tons]
0		1074 ± 33	-	471 ± 22	-	0.0
1		953 ± 31	$-11\% \pm 3\%$	464 ± 22	$-1\% \pm 5\%$	2.7
2		691 ± 26	$-36\% \pm 2\%$	428 ± 21	$-9\% \pm 4\%$	6.7
3		619 ± 25	$-42\% \pm 2\%$	340 ± 18	$-28\% \pm 4\%$	13.4
4		671 ± 26	$-38\% \pm 2\%$	376 ± 19	$-20\% \pm 4\%$	20.3
5		841 ± 29	$-22\% \pm 3\%$	440 ± 21	$-7\% \pm 4\%$	3.6
6		499 ± 22	$-54\% \pm 2\%$	317 ± 18	$-33\% \pm 4\%$	10.3
7		442 ± 21	$-59\% \pm 2\%$	289 ± 17	$-39\% \pm 4\%$	17.0
8		438 ± 21	$-59\% \pm 2\%$	286 ± 17	$-39\% \pm 4\%$	23.7
9		412 ± 20	$-62\% \pm 2\%$	270 ± 16	$-43\% \pm 3\%$	21.4
10		389 ± 20	$-64\% \pm 2\%$	247 ± 16	$-48\% \pm 3\%$	21.9
11		316 ± 18	$-71\% \pm 2\%$	219 ± 15	$-54\% \pm 3\%$	24.6
12		517 ± 23	$-52\% \pm 2\%$	333 ± 18	$-29\% \pm 4\%$	15.7
13		733 ± 27	$-32\% \pm 3\%$	330 ± 18	$-30\% \pm 4\%$	11.2
14		333 ± 18	$-69\% \pm 2\%$	224 ± 15	$-52\% \pm 3\%$	24.5
15		276 ± 17	$-74\% \pm 2\%$	225 ± 15	$-52\% \pm 3\%$	26.9
16		261 ± 16	$-76\% \pm 2\%$	197 ± 14	$-58\% \pm 3\%$	32.8
17		238 ± 15	$-78\% \pm 1\%$	162 ± 13	$-66\% \pm 3\%$	42.0

Table 3: Results of the main simulations. The simulations were carried out with the beam energy of 7.0 TeV and include 3000 event each.

3 Simulation of different beam parameters

Apart from simulations presented in previous paragraph, one more important simulation has been done. This simulation was performed without any additional shielding (even 2012 iron), with a beam energy of 7 TeV and with 50 ns bunch spacing. The results of this simulation are following: 2069 hits in TAE+1 and 683 hits in TAE+2. Table 4 contains the summary of all simulations and the estimated numbers of backsplashes for different configurations of beam energy, bunch spacing, luminosity and shielding.

The top number in each cell is the number of backsplash hits. The bottom number is the number of backsplash hits divided by the current number of backsplash hits (beam parameters and geometry in 2012). For 50 ns bunch spacing, the number of backsplashes is the number of hits in TAE+2 because the detector doesn't count hits in TAE+1. For 25 ns bunch spacing, the number of backsplashes is the sum of the number of hits in TAE+2 and TAE+1. However, for a given luminosity the pile-up in 25 ns bunch spacing is a factor two less than in 50 ns, therefore the sum of hits in TAE+2 and TAE+1 has to be divided by two.

The numbers of backsplashes for a beam energy of 3.5 TeV and 7 TeV (50 ns) have been used to find linear interpolation in log-log scale and estimate the number of backsplash hits for a beam energy of 4 TeV.

The luminosity in simulations for a beam energy of 3.5 TeV and 7 TeV (50 ns) was slightly lower than it is written in table (see paragraph Simulations), but the number of backsplash hits increases linearly with the luminosity, so it does not matter for the conclusions. The backsplashes after LS2 with the upgraded detector and the luminosity of $1.0 \cdot 10^{33}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ were calculated by multiplying by a factor 2.5 the number of backsplash hits for the beam energy of 7 TeV, the bunch spacing of 25 ns and the luminosity of $4.0 \cdot 10^{32}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$.

BEAM	GEOMETRY		
	2011	2012	2015
3.5 TeV, 50 ns, [TAE2] $3.5 \cdot 10^{32}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ (2011)	424 1.24	318 0.93	
4.0 TeV, 50 ns, [TAE2] $4.0 \cdot 10^{32}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$ (2012)	465 1.36	343 1.00	
7.0 TeV, 50 ns, [TAE2] $4.0 \cdot 10^{32}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$	683 1.99	471 1.37	162 0.47
7.0 TeV, 25 ns, [TAE1+TAE2] $4.0 \cdot 10^{32}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$	1376 4.01	772 2.25	200 0.58
7.0 TeV, 25 ns, [TAE1+TAE2] $1.0 \cdot 10^{33}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$	3440 10.03	1930 5.63	500 1.46
7.0 TeV, 25 ns, [TAE1+TAE2] $2.0 \cdot 10^{33}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$	6880 20.06	3860 11.25	1000 2.92

Table 4: Effects of extra shielding. The top number in each cell is the number of backsplash hits. The bottom number is the number of backsplash hits divided by the number of backsplash hits in 2012. Geometry in 2015 is the most effective from possibilities presented in previous paragraph (Simulation nr 17, see Table 3).

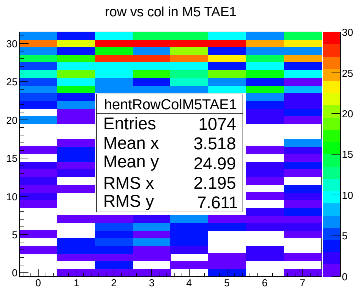
4 Conclusion

After installing extra iron in winter 2011/2012 the number of backsplashes is $\sim 19\%$ less in 2012 than in 2011. After LS1 (in 2015) with shielding improvements (requiring 42 tons of iron) backsplashes can by reduced by $\sim 53\%$ (50ns bunch spacing) and $\sim 42\%$ (25 ns bunch spacing) in comparison to 2012. The estimated level of backsplashes after the upgrade with a luminosity $1.0 \cdot 10^{33}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$, 25 ns bunch spacing and a beam energy of 7TeV is $\sim 46\%$ higher than present (in 2012) and is still acceptable. When luminosity will increase up to $2.0 \cdot 10^{33}\,\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1}$, the number of backsplash hits will be a factor three bigger than present which means that further improvements will be needed.

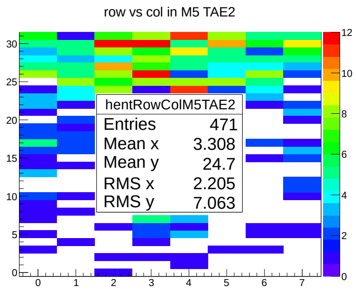
5 Appendix

Below are presented histograms with distributions of hits in M5R4 from simulations. Each paragraph contains plots from TAE+1 and TAE+2. Screenshots from `Panoramix` showing geometries of simulations are attached also.

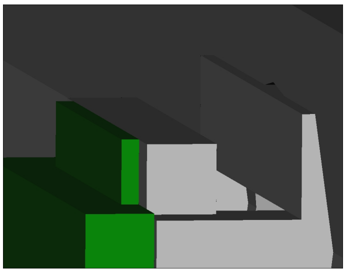
Simulation nr 0



(a) TAE+1 hits



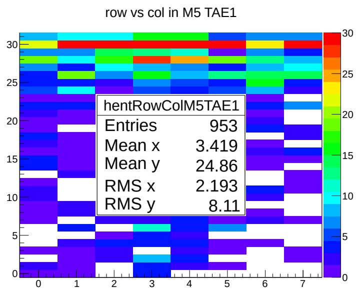
(b) TAE+2 hits



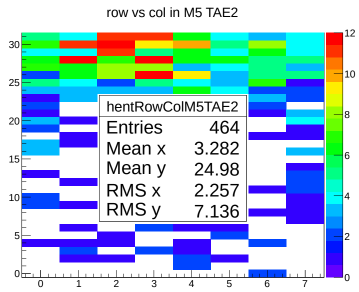
(c) Picture from `Panoramix`

Figure 1: Histograms with hits and `Panoramix` screenshot from simulation nr 0.

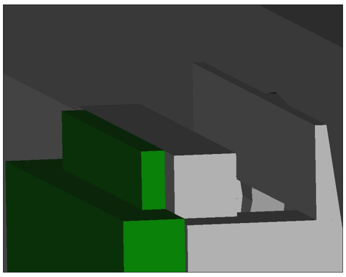
Simulation nr 1



(a) TAE+1 hits



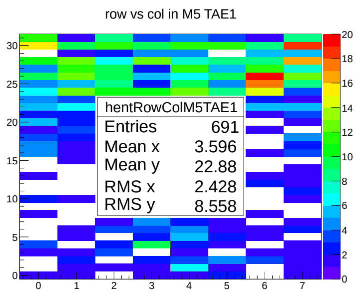
(b) TAE+2 hits



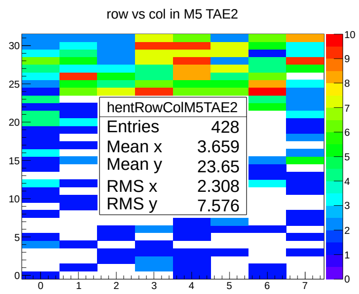
(c) Picture from `Panoramix`

Figure 2: Histograms with hits and `Panoramix` screenshot from simulation nr 1.

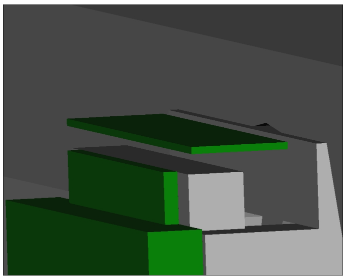
Simulation nr 2



(a) TAE+1 hits



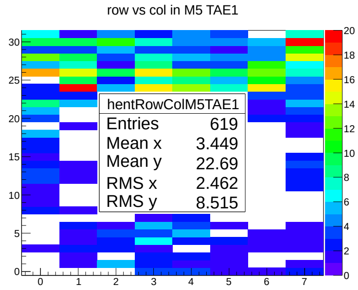
(b) TAE+2 hits



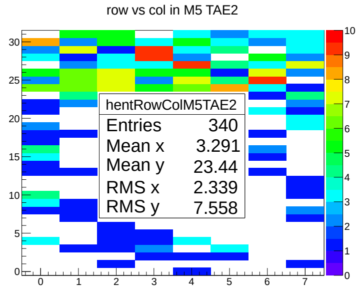
(c) Picture from `Panoramix`

Figure 3: Histograms with hits and `Panoramix` screenshot from simulation nr 2.

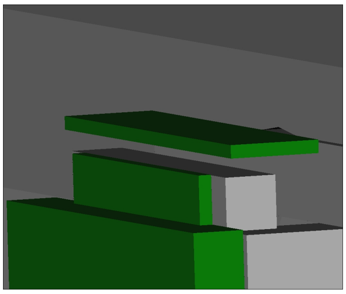
Simulation nr 3



(a) TAE+1 hits



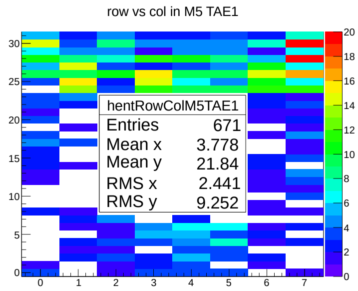
(b) TAE+2 hits



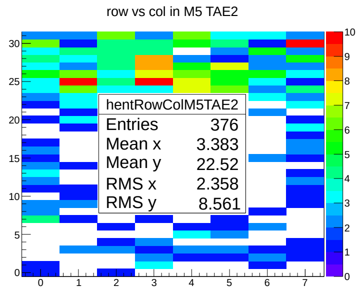
(c) Picture from `Panoramix`

Figure 4: Histograms with hits and `Panoramix` screenshot from simulation nr 3.

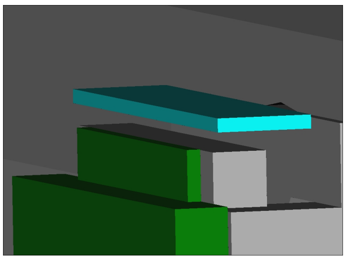
Simulation nr 4



(a) TAE+1 hits



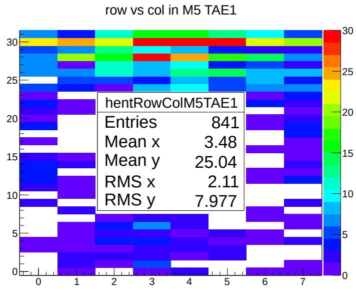
(b) TAE+2 hits



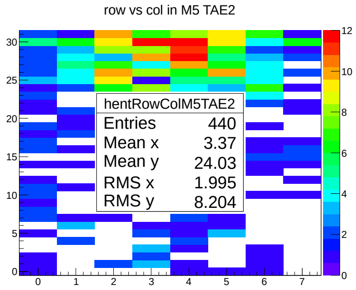
(c) Picture from `Panoramix`

Figure 5: Histograms with hits and `Panoramix` screenshot from simulation nr 4.

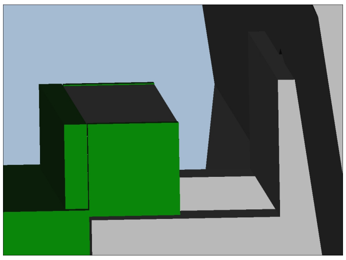
Simulation nr 5



(a) TAE+1 hits



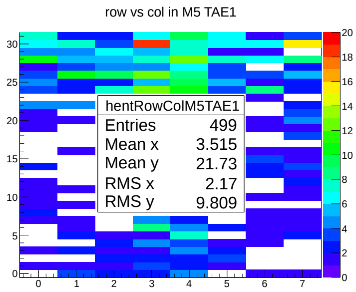
(b) TAE+2 hits



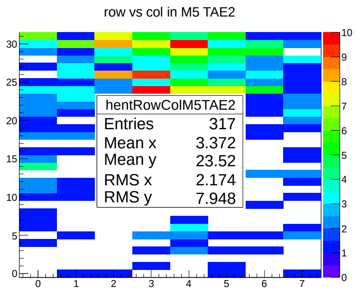
(c) Picture from `Panoramix`

Figure 6: Histograms with hits and `Panoramix` screenshot from simulation nr 5.

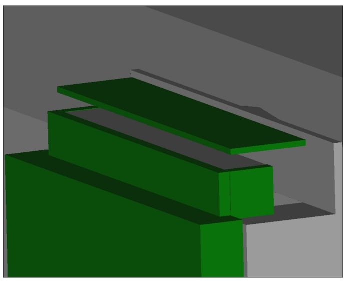
Simulation nr 6



(a) TAE+1 hits



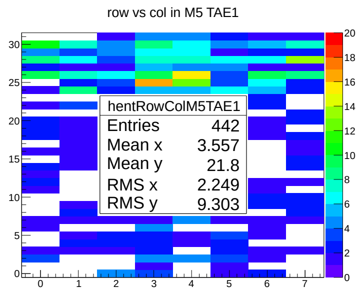
(b) TAE+2 hits



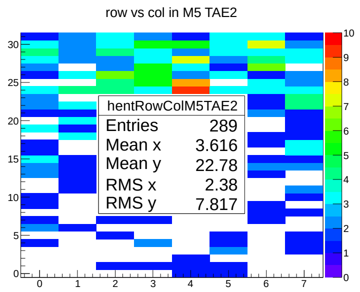
(c) Picture from `Panoramix`

Figure 7: Histograms with hits and `Panoramix` screenshot from simulation nr 6.

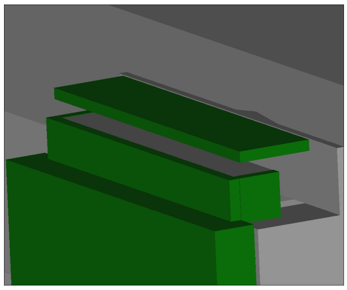
Simulation nr 7



(a) TAE+1 hits



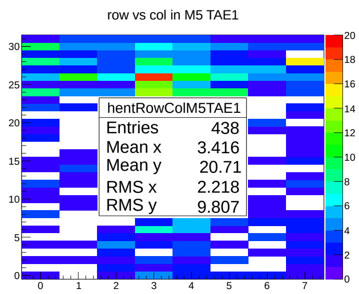
(b) TAE+2 hits



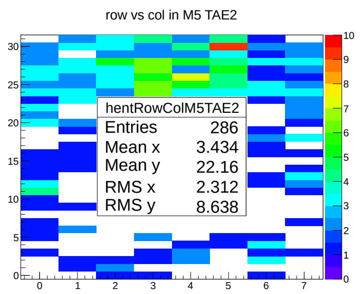
(c) Picture from `Panoramix`

Figure 8: Histograms with hits and `Panoramix` screenshot from simulation nr 7.

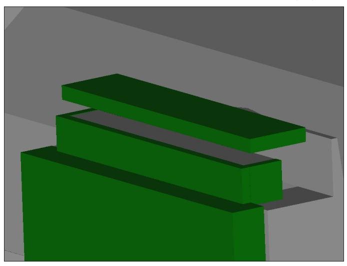
Simulation nr 8



(a) TAE+1 hits



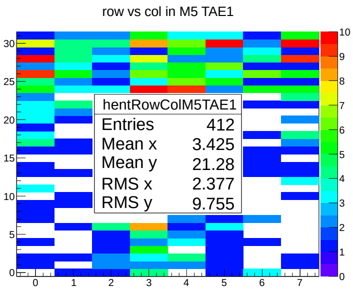
(b) TAE+2 hits



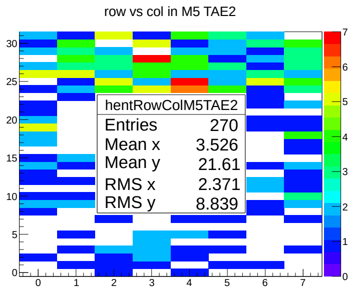
(c) Picture from `Panoramix`

Figure 9: Histograms with hits and `Panoramix` screenshot from simulation nr 8.

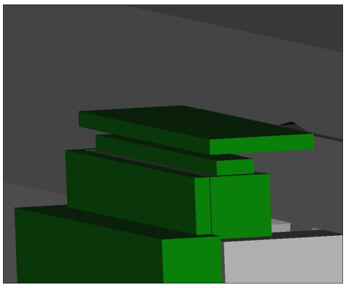
Simulation nr 9



(a) TAE+1 hits



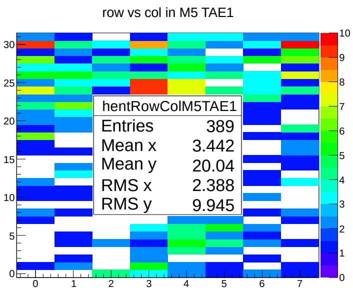
(b) TAE+2 hits



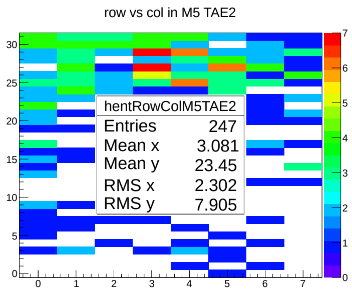
(c) Picture from `Panoramix`

Figure 10: Histograms with hits and `Panoramix` screenshot from simulation nr 9.

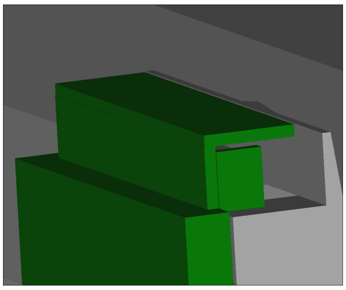
Simulation nr 10



(a) TAE+1 hits



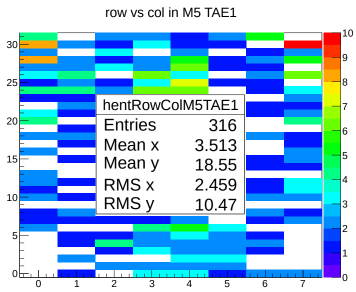
(b) TAE+2 hits



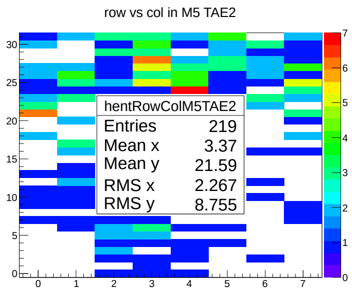
(c) Picture from `Panoramix`

Figure 11: Histograms with hits and `Panoramix` screenshot from simulation nr 10.

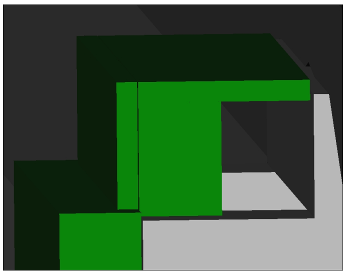
Simulation nr 11



(a) TAE+1 hits



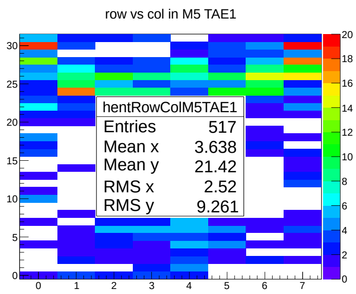
(b) TAE+2 hits



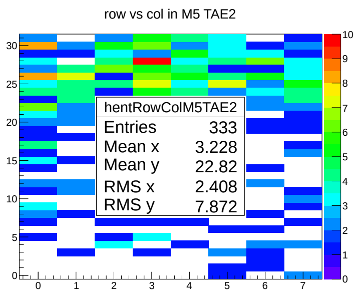
(c) Picture from `Panoramix`

Figure 12: Histograms with hits and `Panoramix` screenshot from simulation nr 11.

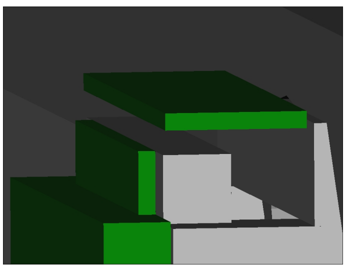
Simulation nr 12



(a) TAE+1 hits



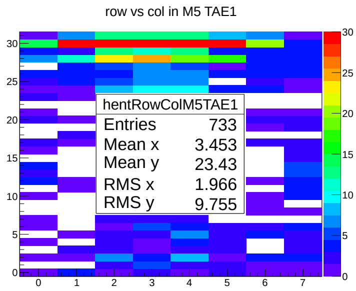
(b) TAE+2 hits



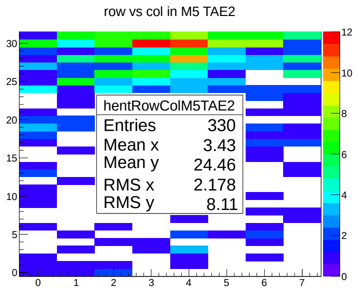
(c) Picture from `Panoramix`

Figure 13: Histograms with hits and `Panoramix` screenshot from simulation nr 12.

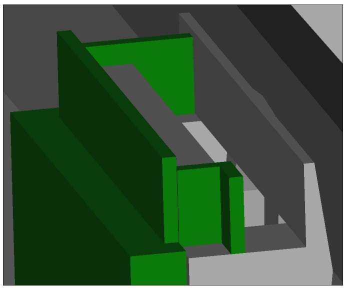
Simulation nr 13



(a) TAE+1 hits



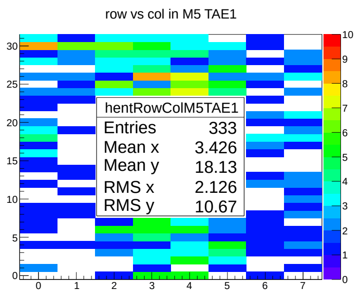
(b) TAE+2 hits



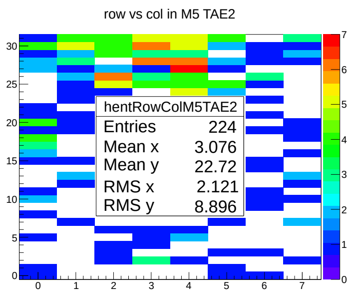
(c) Picture from `Panoramix`

Figure 14: Histograms with hits and `Panoramix` screenshot from simulation nr 13.

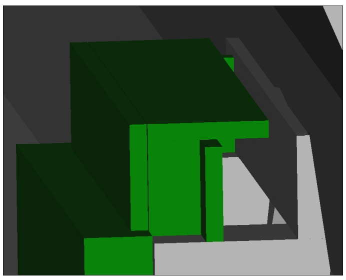
Simulation nr 14



(a) TAE+1 hits



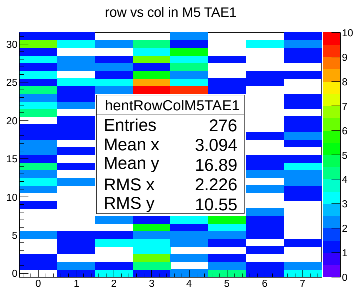
(b) TAE+2 hits



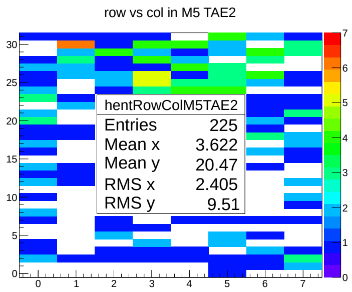
(c) Picture from `Panoramix`

Figure 15: Histograms with hits and `Panoramix` screenshot from simulation nr 14.

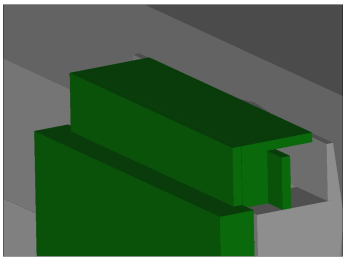
Simulation nr 15



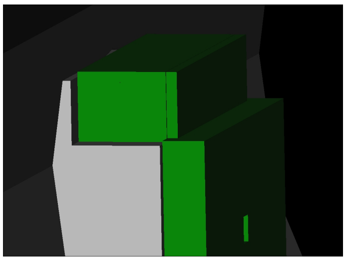
(a) TAE+1 hits



(b) TAE+2 hits



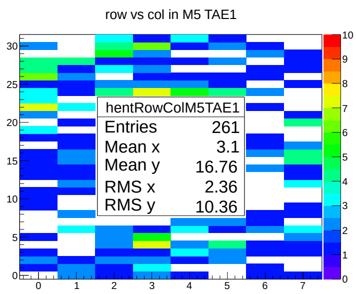
(c) Picture from `Panoramix`



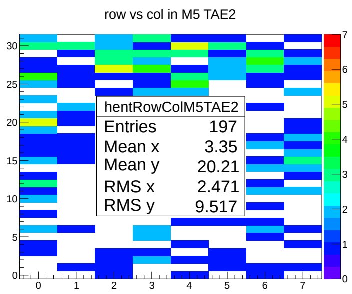
(d) Picture from `Panoramix`

Figure 16: Histograms with hits and `Panoramix` screenshots from simulation nr 15.

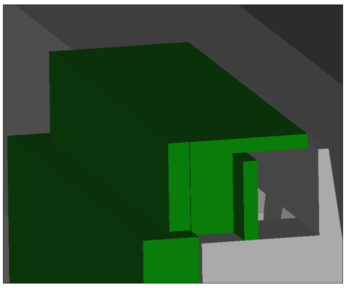
Simulation nr 16



(a) TAE+1 hits



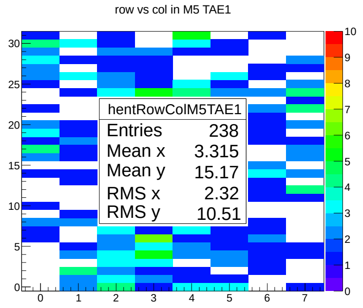
(b) TAE+2 hits



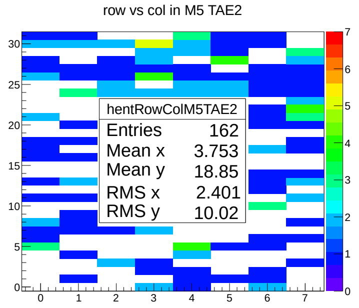
(c) Picture from `Panoramix`

Figure 17: Histograms with hits and `Panoramix` screenshot from simulation nr 16.

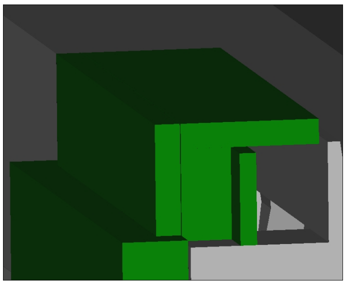
Simulation nr 17



(a) TAE+1 hits



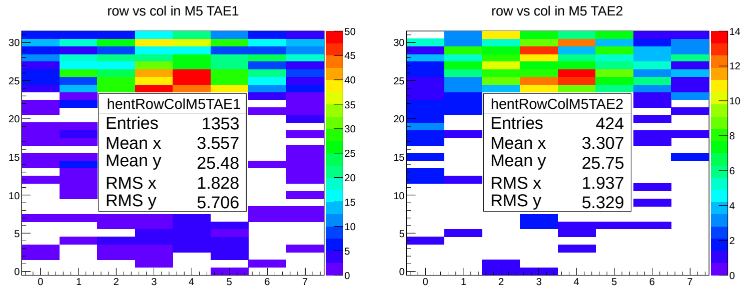
(b) TAE+2 hits



(c) Picture from `Panoramix`

Figure 18: Histograms with hits and `Panoramix` screenshot from simulation nr 17.

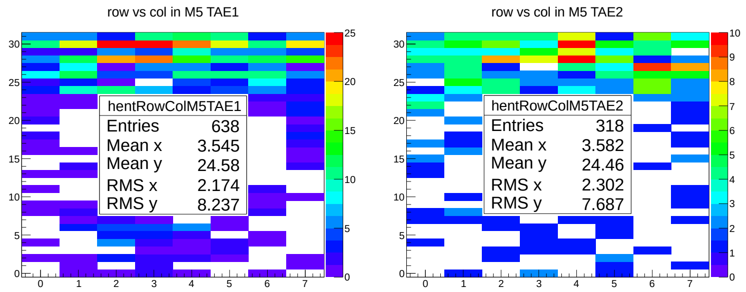
Simulation with the beam energy of 3.5 TeV and with no additional shielding (2011 geometry)



(a) TAE+1 hits (b) TAE+2 hits

Figure 19: Histograms with hits from simulation without any iron shielding.

Simulation with the beam energy of 3.5 TeV and with present shielding (2012 geometry)



(a) TAE+1 hits (b) TAE+2 hits

Figure 20: Histograms with hits from simulation with the 2012 iron and the beam energy of 3.5 TeV.

6 References

[1] *Simulation Advanced Tutorial: how to simulate detectors.*
`https://indico.cern.ch/conferenceDisplay.py?confId=175918`, 2012

[2] Robert Paluch, *Simulation of Muon Filter 4 and area behind it.*
`https://indico.cern.ch/conferenceDisplay.py?confId=208316`, 2012