LHCb-INT-2014-015
LPHE-2014-002
June 19, 2014

ST performance in 2011 and 2012

F. Dupertuis[1].

[1] *Ecole Polytechnique Féderale de Laussane, Lausanne, Switzerland*

Abstract

Results on the ST hit efficiency, resolution and signal-to-noise ratio measured in 2011 and 2012 are presented.

Contents

1 Introduction

Relevant variables to demonstrate the performance of the IT and TT and their results are presented in this section.

1.1 Hit efficiency

The *hit efficiency* is the probability that a cluster will be reconstructed when a charged particle crosses an active silicon sensor. This efficiency depends on the silicon sensor thickness and the clustering parameters. The sensor should be thick enough to obtain a good signal-to-noise ratio and thin enough to reduce multiple scattering. Once the signal size is large enough, the clustering algorithms and parameters need to be set to get a signal hit efficiency larger than 99% and a noise cluster rate of about 10^{-5} required for efficient tracking. Since the hit efficiency directly impacts the reconstruction efficiency of a track, it needs to be monitored. Two hit efficiencies will be measured, the average hit efficiency of the reconstructed tracks and the *sector hit efficiency* which is the average hit efficiency of each sector.

The hit efficiency is measured in the following way: from a sample of tracks, a search window is opened for each IT and TT module where a hit is expected, *i.e.* the track crosses geometrically the active region of the module using the knowledge of the positions and geometrical description of the modules. If a hit is found within the search window then the found hits counter, i.e. the numerator of the efficiency, is incremented. The number of expected hits is the denominator of the efficiency.

Measuring hit efficiency comes with several caveats that need to be considered. The first one is that experimentally it is difficult to disentangle hit and tracking efficiencies. In order to construct a long track, some sub-detectors are used for which hit efficiency wants to measured. This is the case for the IT but not for the TT for which hits are added to the track to improve the long track resolution if hits are found within reasonable search window. Ideally, the tracking algorithm would be launched excluding one by one each module to measure its hit efficiency. This procedure is extremely computationally intensive, therefore not attempted. What makes the measurement still feasible and unbiased is that the number of hits required in the tracking is significantly lower than the number of tracking layers and that the hit efficiency is greater than 99%. The tracking actually requires nine hits in the T-stations whereas twelve layers are actually available.

A second point is the presence of *ghost tracks* in the tracks sample. Ghost tracks are the result of a wrong combination of hits. Their direct effect is to artificially lower the measured hit efficiency. To address this point, in the upcoming results, as for the alignment, daughter tracks from clean samples of $J/\psi \to \mu^+\mu^-$ mesons are used which contain low numbers of ghost tracks.

A third point is the presence of real and close-by tracks that can enhance the measured hit efficiency, ie extra hits can leak in the search window. A track isolation requirement is added to the code that measures the hit efficiency by asking no more than one found hit per sector.

A fourth point is the knowledge of the modules positions, *i.e.* the alignment, and the finite precision on the prediction of the hit position, *i.e.* the track resolution. These two elements drive the size of the search window. They also affect the hit efficiency measurement for tracks close from sensor edges. In addition, the edges of the sensors are inefficient due to guard rings. These effects are suppressed by removing expected hits from the computation for tracks crossing the module within an edge tolerance.

A fifth point is the effect of multiple scattering. The search window should be larger than the one expected from pure hit resolution and misalignments, in order to account for small variation of the track direction due to multiple scattering after each material crossing. The effect of the multiple scattering decreases with increasing momentum, therefore a cut on the track momentum is applied.

And the last point is the effect of the decay and absorption of charged particles. A long track can be reconstructed without the third T-station if nine hits are found in the two first stations although the track decayed just before the third T-station or stopped in the previous station. This effect is suppressed by the use of muons from J/ψ decays where segments are found in the muons stations, *i.e.* tracks that traverse the whole tracker.

1.2 Hit resolution

The *hit resolution* is the spread of the *unbiased hit residuals* distribution. The hit residual is the cluster central position with respect to the position where the extrapolated particle crossed the silicon sensor. The unbiased hit residual is the case where the hits found in the module are excluded from the track fit. The resolution mainly depends on the micro-strip pitch, ie the inter-strip distance, and the amount of charge sharing which depends on the amount of energy deposited by the particle. The expected hit resolution for the IT and TT is between 50 and 60 μm.

The sub-detector hit resolution is taken as the sum of the unbiased hit residuals of the modules, which means that remaining misalignments are included in the hit resolution. The spread of all the module mean unbiased residuals is called the *sector biased resolution*. The sector biased resolution is driven by remaining misalignments and statistical fluctuations.

1.3 Signal-to-noise ratio

The *signal-to-noise ratio* is the cluster charge divided by the noise of the cluster's central strip. During the R&D and testing periods with particle beams, it was found that a signal-to-noise ratio better than 10 is required to keep a hit efficiency over 99%.

2 Track selection

The J/ψ candidates are taken from the inclusive detached J/ψ stripping line from Stripping20. The muons of these selected J/ψ decays are refitted and extra track quality and momentum cuts are applied. The final selections are summarised in Table 1. A momentum

Table 1: Selections for hit resolution, signal-to-noise ratio and efficiency measurements.

Decay mode	Cut	Hit resolution, S/N	Hit efficiency
$\mu^{\pm}$	$p_T(\mu^{\pm})$	> 0.55 GeV/c	> 0.55 GeV/c
	$p(\mu^{\pm})$	> 10 GeV/c	> 10 GeV/c
	$\chi^2_{\text{track}}/\text{nDoF}(\mu^{\pm})$	< 3	< 2
	$\chi^2_{\text{Velo segment}}/\text{nDoF}(\mu^{\pm})$	–	< 2
	$\chi^2_{\text{T track}}/\text{nDoF}(\mu^{\pm})$	–	< 2
	$\chi^2_{\text{Match}}/\text{nDoF}(\mu^{\pm})$	–	< 2
	clone distance $(\mu^{\pm})$	> 5000	> 5000
$J/\psi \to \mu^+\mu^-$	$\Delta\ln\mathcal{L}_{\mu\pi}(\mu^{\pm})$	> 0	> 0
	$\chi^2_{\text{vtx}}/\text{nDoF}(J/\psi)$	< 16	< 16
	Decay Length Sig. (J/ψ)	> 3	> 3
	$M(\mu^+\mu^-)$	$\in [3060, 3140]$ MeV/c^2	$\in [3060, 3140]$ MeV/c^2

Table 2: Specific requirements used for hit efficiency measurements for IT and TT separately.

Requirement	IT	TT
Search window	0.4 mm	0.4 mm
Min expected sectors	6	2
Min stations passed	3	1
Sensor edges tolerance in X	2 mm	2 mm
Sensor edges tolerance in Y	2 mm	2 mm
Single hit per sector	Yes	Yes

cut is applied to reduce multiple scattering and absorption effects. Tighter and extra track χ^2 cuts are used for hit efficiency measurements to further reduce the number of ghost tracks. The list of the cuts and requirements used for hit efficiency measurements are summarised in Table 2.

3 Results

Table 3 summarises all the results of hit efficiency, sector hit efficiency, hit resolution, sector biased resolution and signal-to-noise ratio obtained from data and MC for both IT and TT. All the distributions from which these results were extracted can be found in Sect. 4.

The first result is that the measured hit efficiency in MC is not 100% for both IT and TT. For the IT, it is partially due to sectors presenting high common mode noise levels for which a lower hit efficiency is set at the digitalisation step, based on results obtained in 2010 [1]. However, it was found that the hit inefficiency is not applied to the correct read-out sectors as illustrated in Fig. 2. This will be fixed for the next simulation

Table 3: Hit efficiency, sector hit efficiency, hit resolution, sector biased resolution and signal-to-noise ratio measurements for IT and TT from data and MC.

	Measurement	2011 Data	2012 Data	MC2011	MC2012
IT	Hit efficiency	99.82%	99.88%	99.92%	99.92%
	Sector hit efficiency	99.82%	99.86%	99.91%	99.90%
	Hit resolution	50.3 μm	54.9 μm	53.8 μm	53.9 μm
	Sector biased resolution	9.6 μm	10.7 μm	1.2 μm	1.6 μm
	Signal-to-Noise ratio	17.3	17.4	17.6	17.6
TT	Hit efficiency	99.73%	99.76%	99.90%	99.89%
	Sector hit efficiency	99.77%	99.79%	99.89%	99.89%
	Hit resolution	52.6 μm	53.4 μm	47.8 μm	48.0 μm
	Sector biased resolution	30.0 μm	28.4 μm	1.8 μm	1.7 μm
	Signal-to-Noise ratio	14.1	14.1	14.2	14.3

round. However, for the TT, all the read-out sectors are set to be 100% efficient. A deeper investigation shows some evidence that the sectors with a large number of masked strips are less efficient by a factor of up to one per mille. This can be easily understood from the clustering algorithms. The last part of the hit inefficiency possibly come from some remaining ghost tracks and badly reconstructed tracks. In data, the hit efficiency is worse by 1-2 per mille. This is due to the significantly worse purity of the J/ψ samples in data compared to MC. The hit efficiency for 2012 is a bit better than 2011, possibly due to improvements made in the calibration before the 2012 data taking.

Hit resolutions measured in data are worse than MC, because of the additional remaining misalignments that are present in data. However, the measured hit resolution in 2011 for IT is significantly smaller than in 2012 data and the MC. This is not understood and requires further investigation. Sector biased resolutions are measured to be below 2 μm in MC where there is no misalignment and therefore are due to statistical fluctuations. In data, the number of reconstructed J/ψ events is two up to three times larger than MC, and so the statistical fluctuations are expected to be smaller than MC. Thus, the measured sector bias resolutions in data are dominated by misalignment effects. Whereas the misalignments for IT are within an acceptable range, they are unexpectedly large for TT and require further investigation by alignment experts.

Signal-to-noise ratio measurements are in relatively good agreement with MC and are above the limit of 10. Below this value, the hit efficiency will decrease. Looking at Fig 10, it can be noticed that twelve sectors of the top and bottom boxes have significantly larger signal-to-noise ratios compared to the other modules. This is known to come from the thicker sensors installed in these boxes. However, the signal-to-noise ratio obtained in MC for the four sectors in the IT2 Bottom box is significantly different to the data results. This can be due to a poor charge calibration of these sectors.

4 Additional plots

References

[1] J. Luisier and M. Needham, *Measurement of the Inner Tracker Efficiency*, LHCb-INT-2010-031.

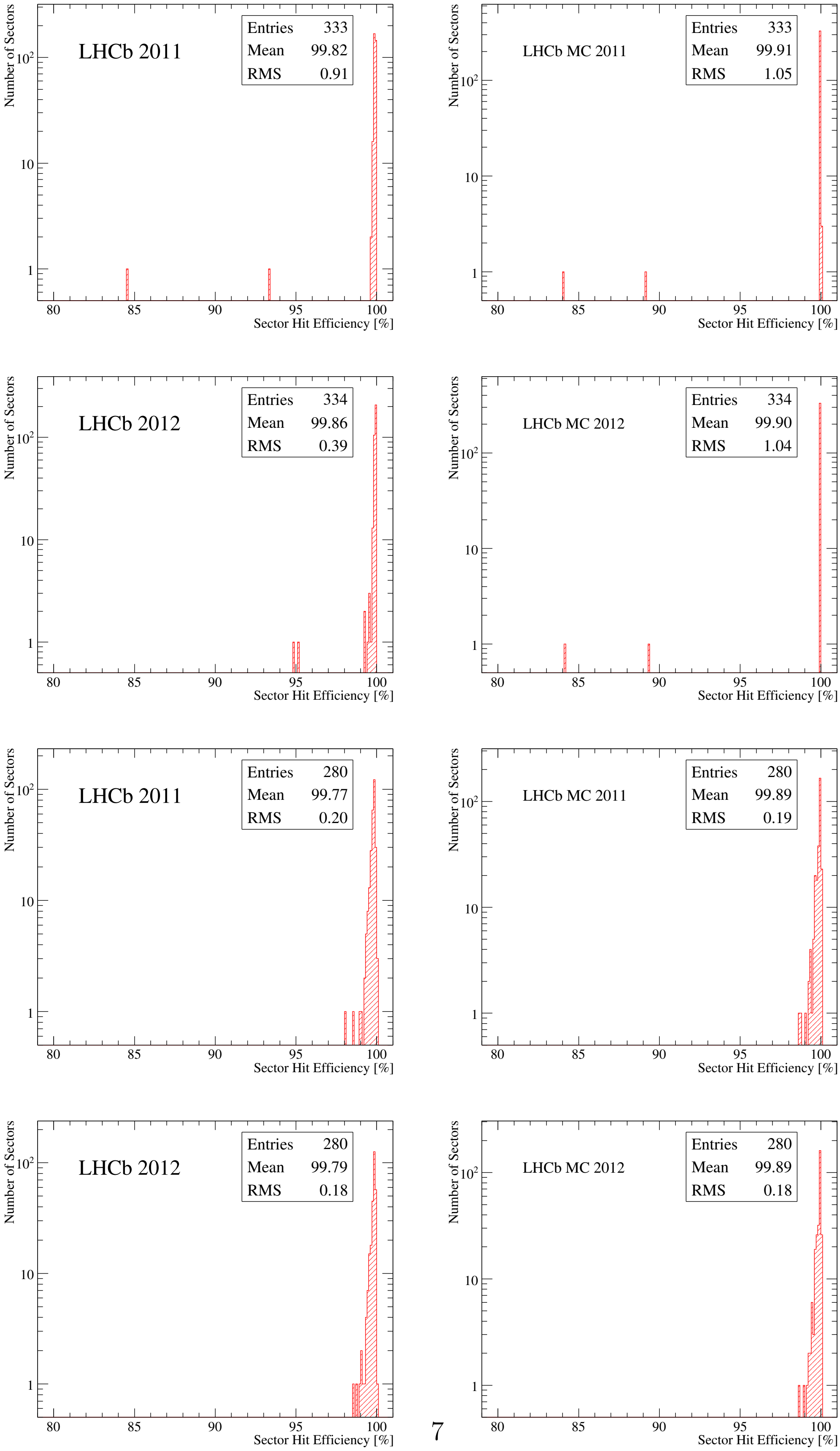


Figure 1: Sectors hit efficiency measured using 2011 and 2012 real data and MC samples for IT (*four top plots*) and TT (*four bottom plots*).

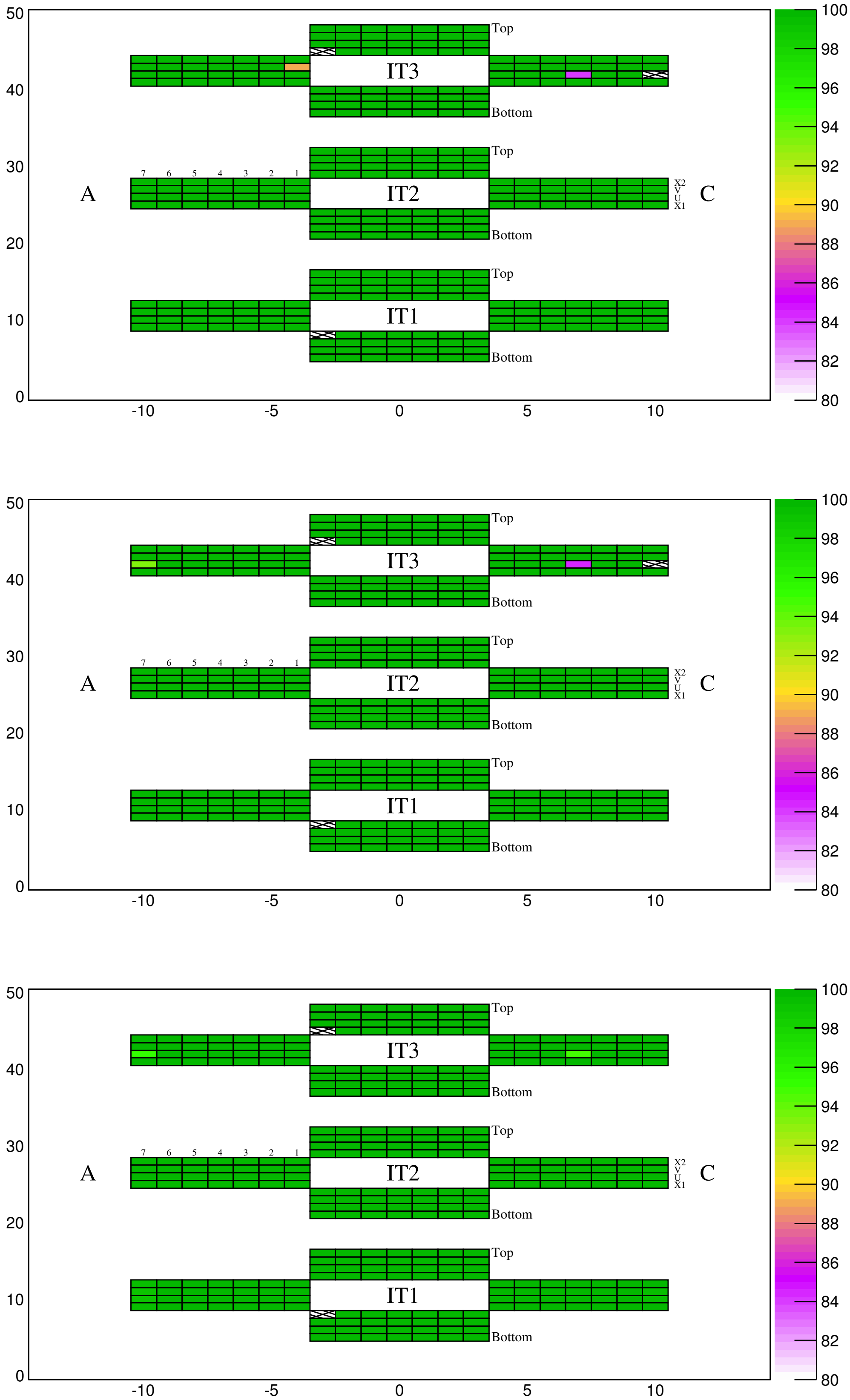


Figure 2: 2D map of sectors hit efficiencies measured using 2011 MC (*top*), 2011 (*middle*) and 2012 (*bottom*) real data samples for IT.

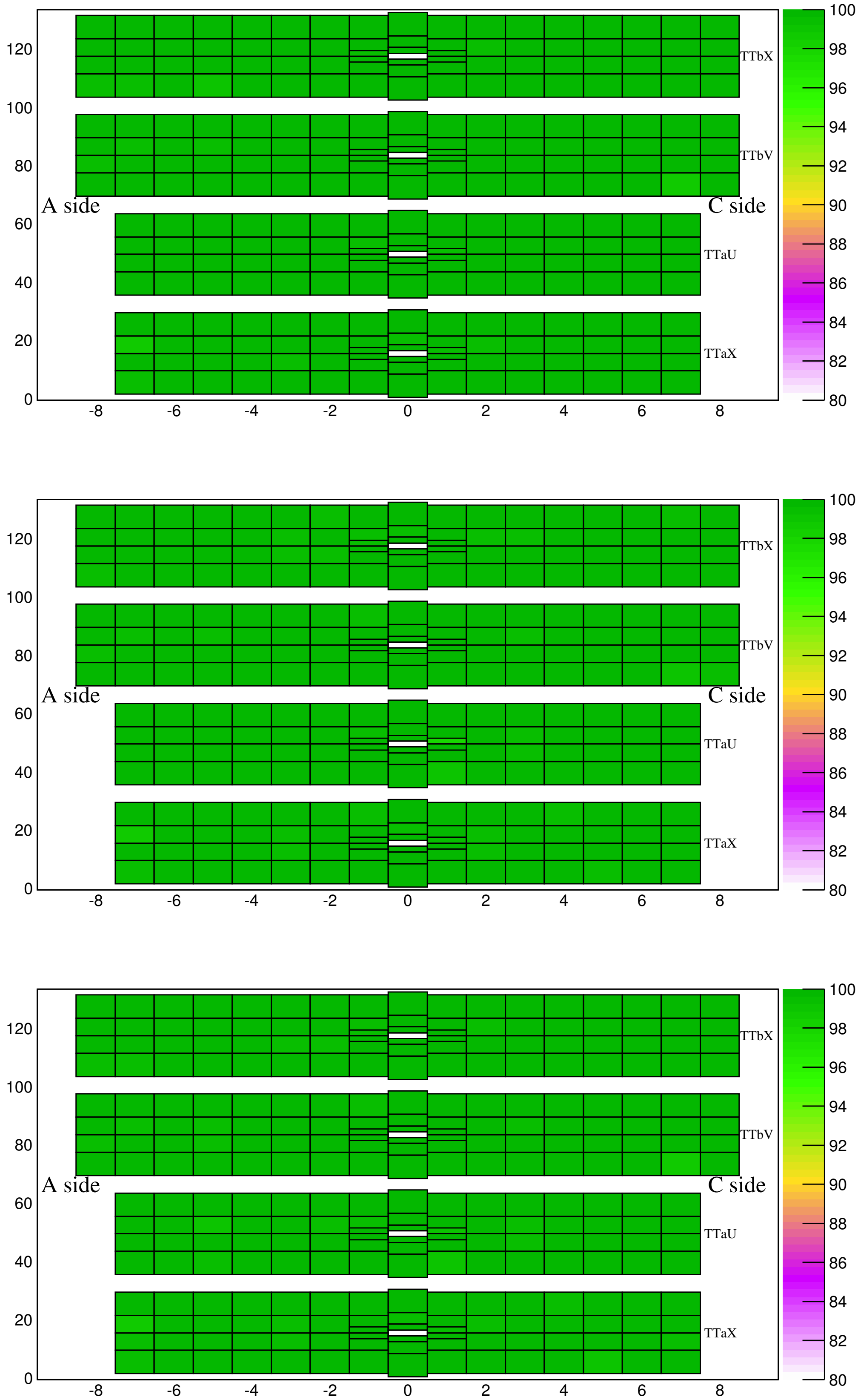


Figure 3: 2D map of sectors hit efficiencies measured using 2011 MC (*top*), 2011 (*middle*) and 2012 (*bottom*) real data samples for TT.

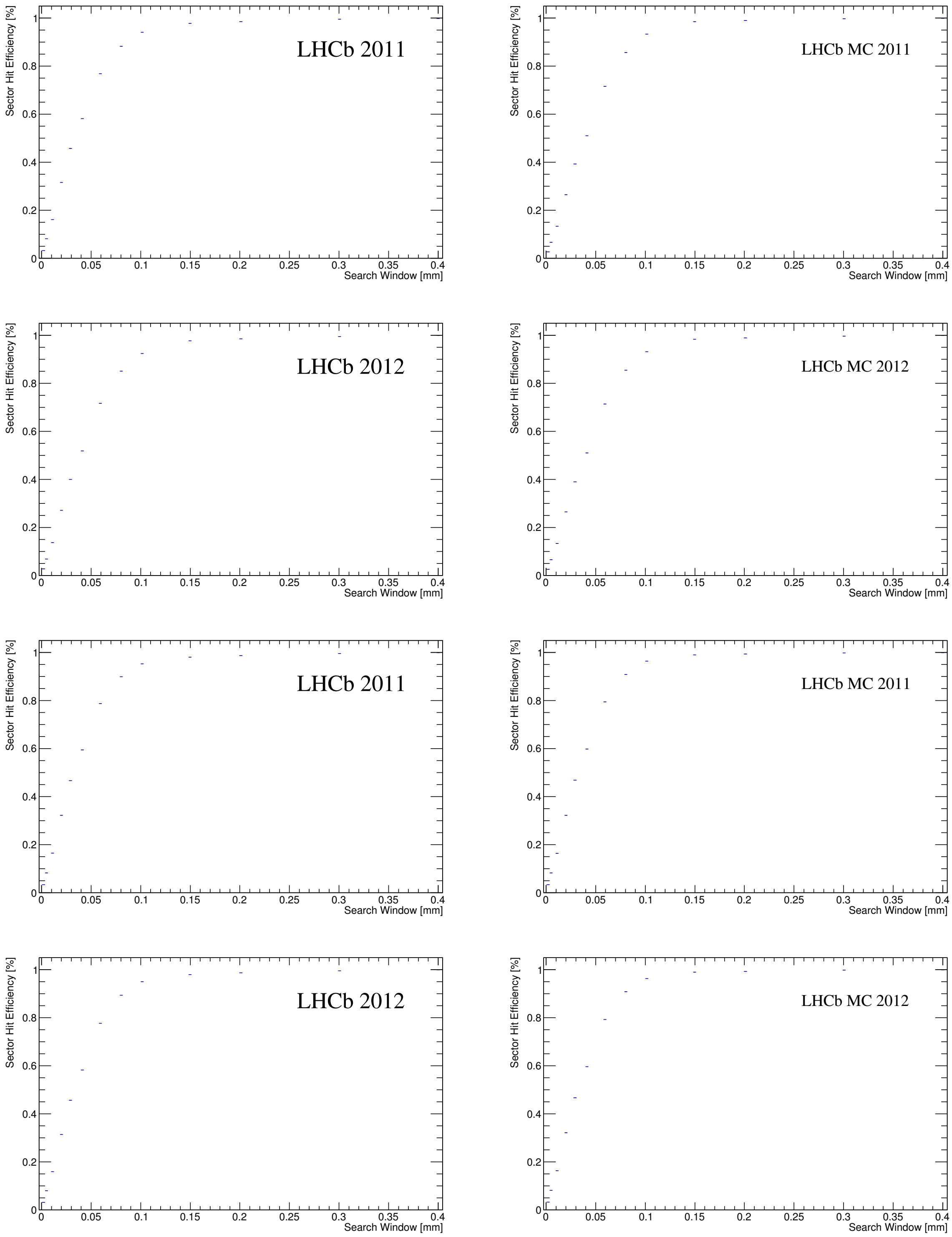


Figure 4: Hit efficiency as a function of the search window for a random sector measured using 2011 and 2012 real data and MC samples for IT (*four top plots*) and TT (*four bottom plots*).

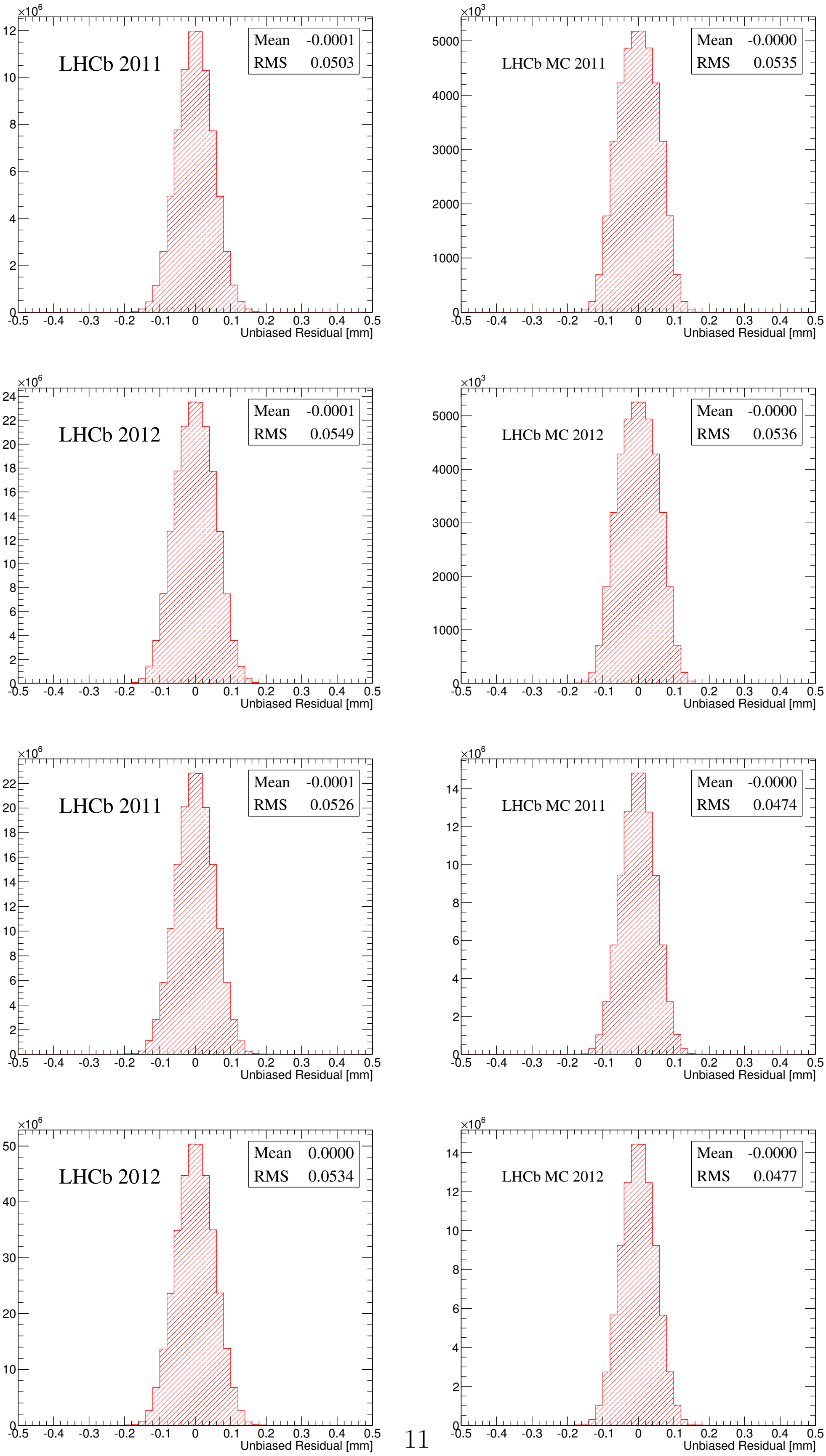


Figure 5: Hit resolution measured using 2011 and 2012 real data and MC samples for IT (*four top plots*) and TT (*four bottom plots*).

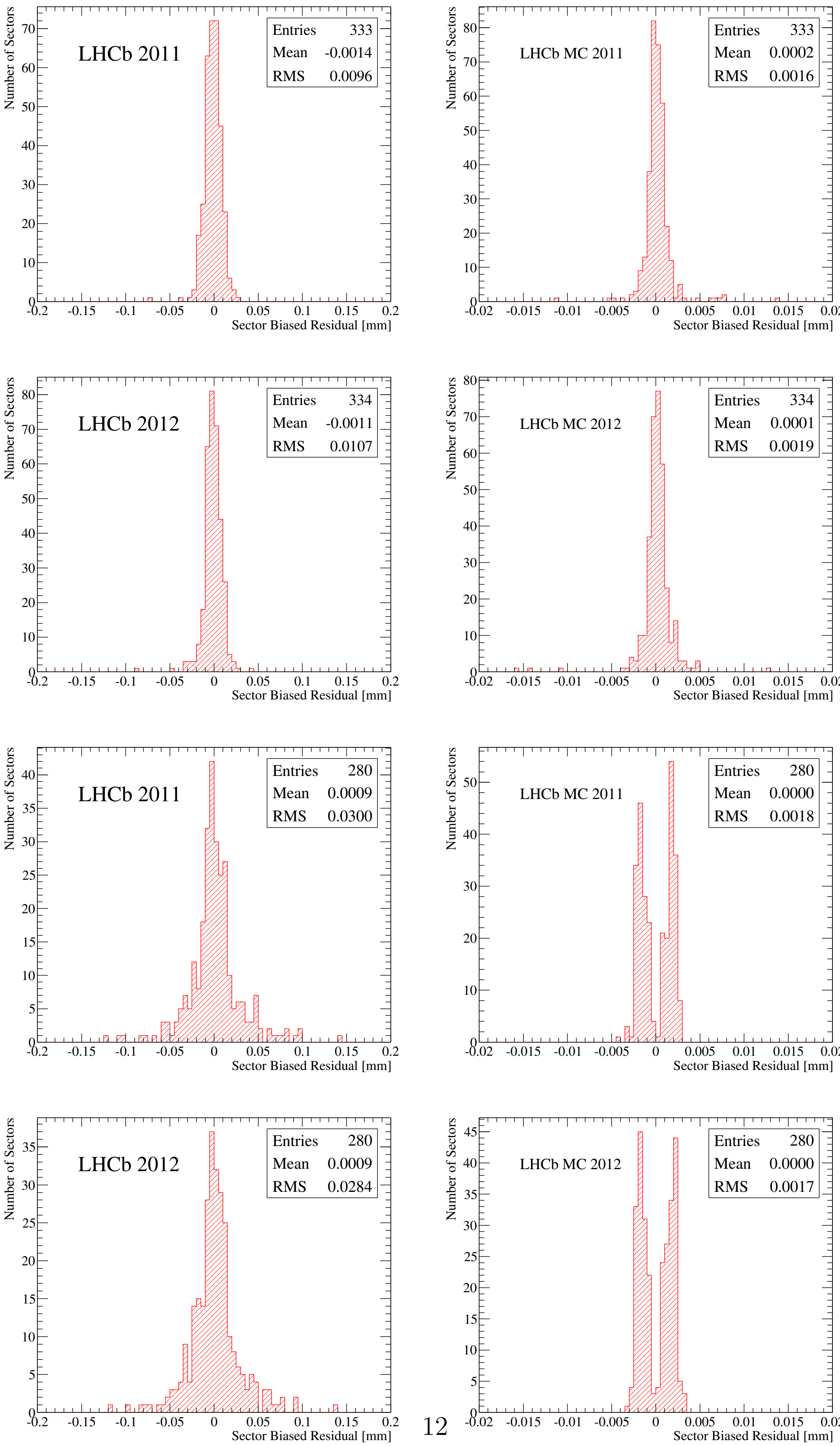
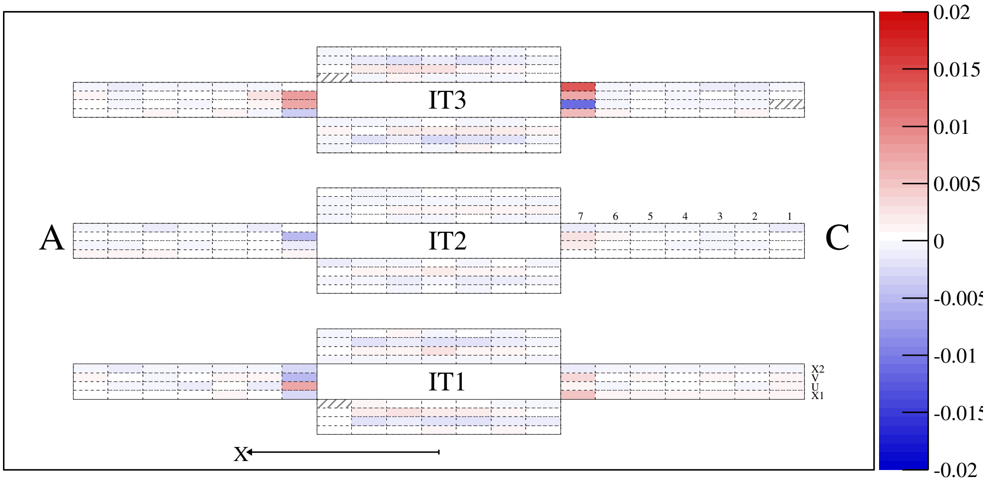
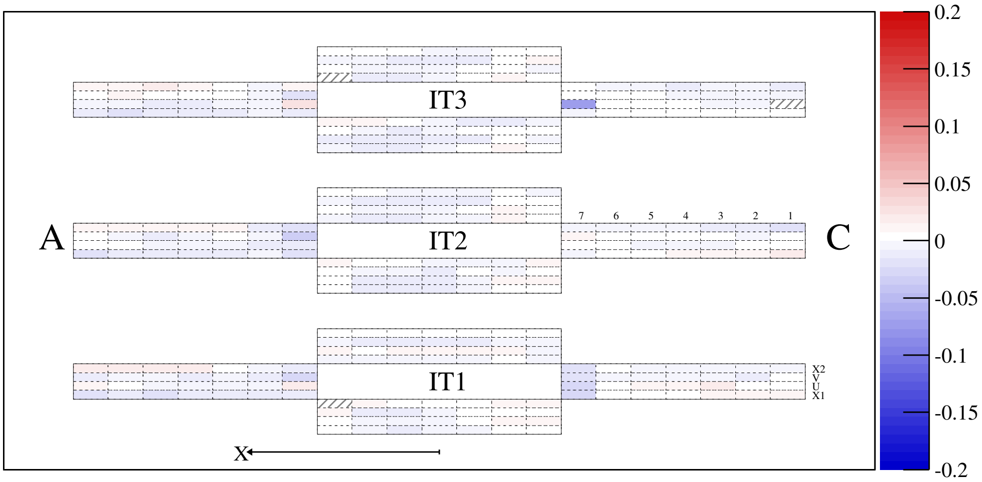


Figure 6: Sectors biased resolution measured using 2011 and 2012 real data and MC samples for IT (*four top plots*) and TT (*four bottom plots*).





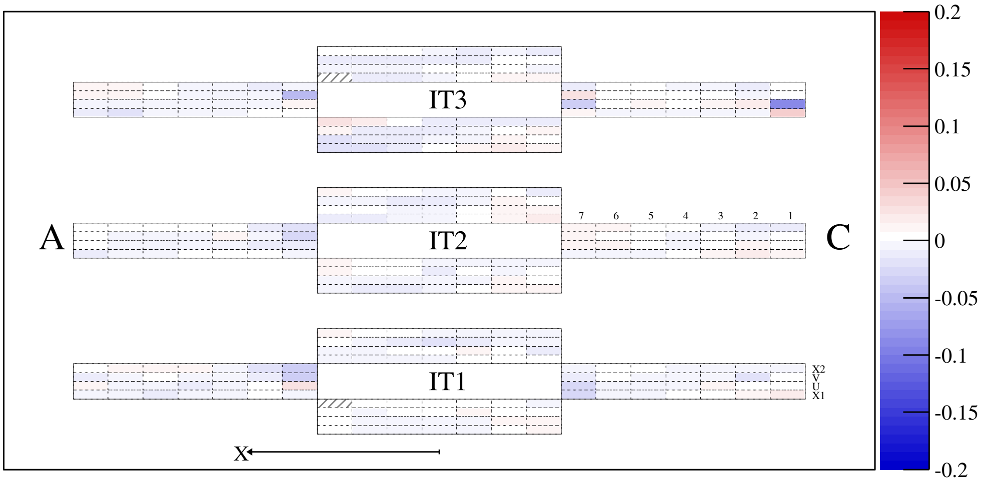


Figure 7: 2D map of sectors biased resolutions measured using 2011 MC (*top*), 2011 (*middle*) and 2012 (*bottom*) real data samples for IT.

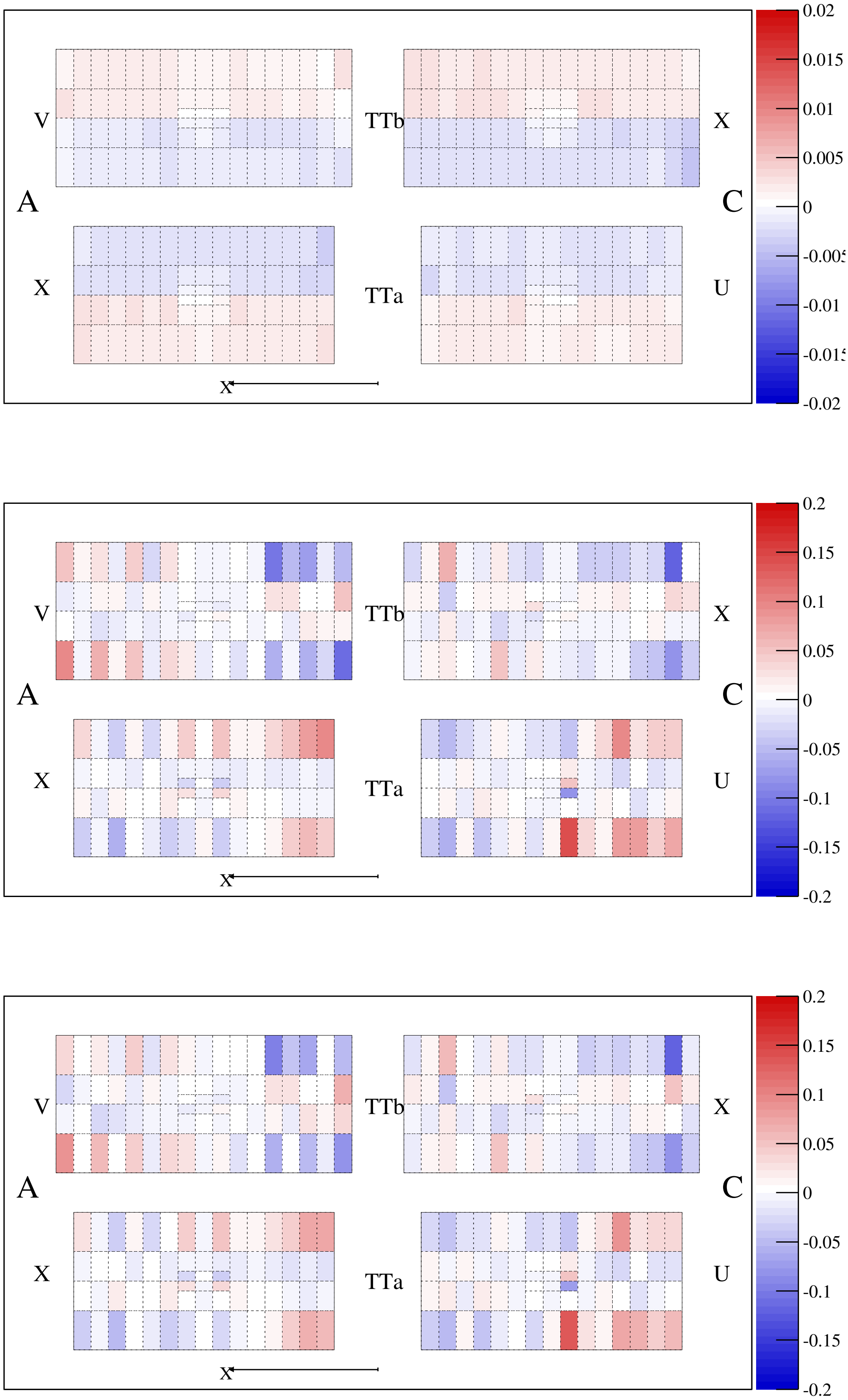


Figure 8: 2D map of sectors biased resolutions measured using 2011 MC (*top*), 2011 (*middle*) and 2012 (*bottom*) real data samples for TT.

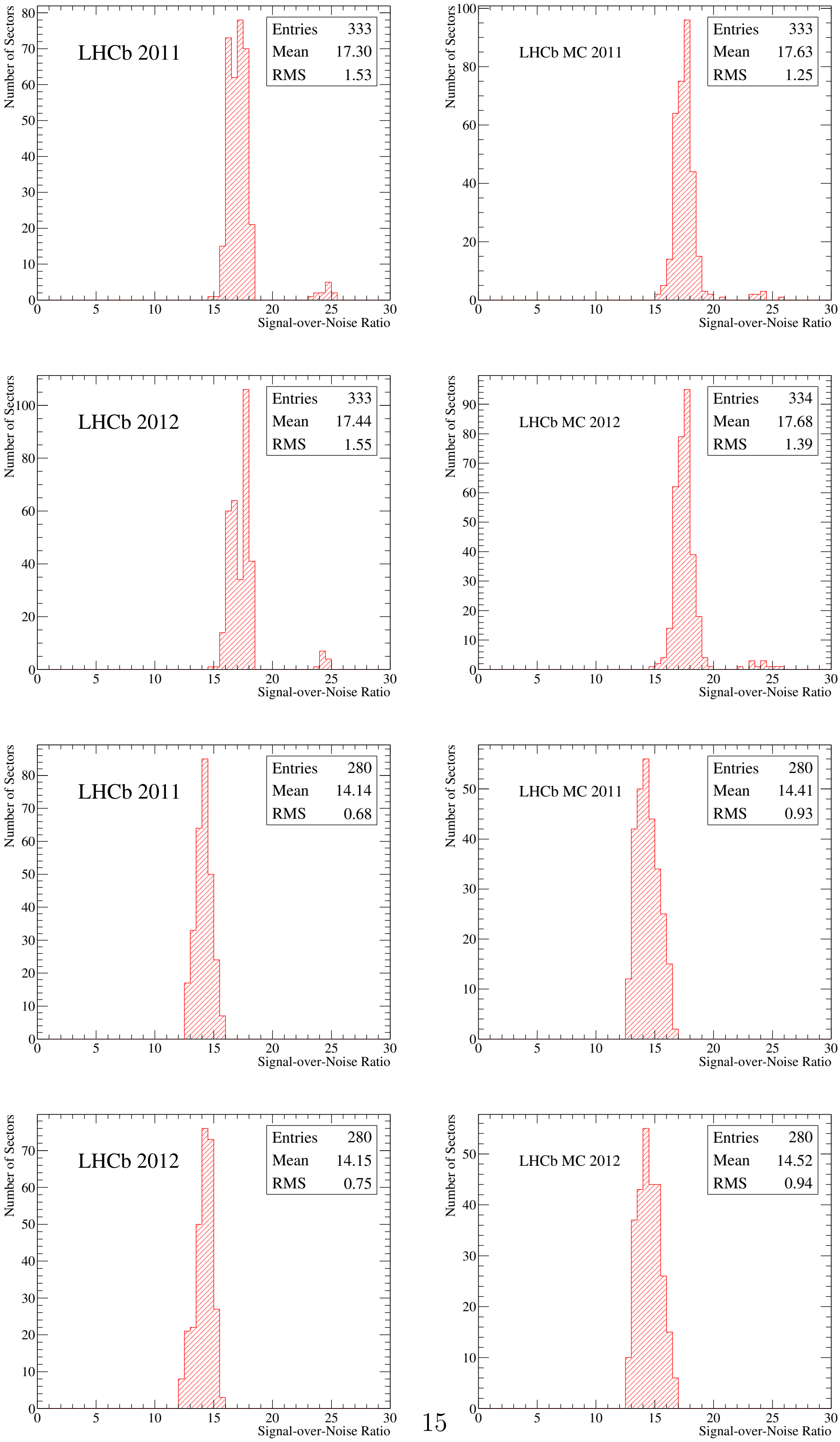
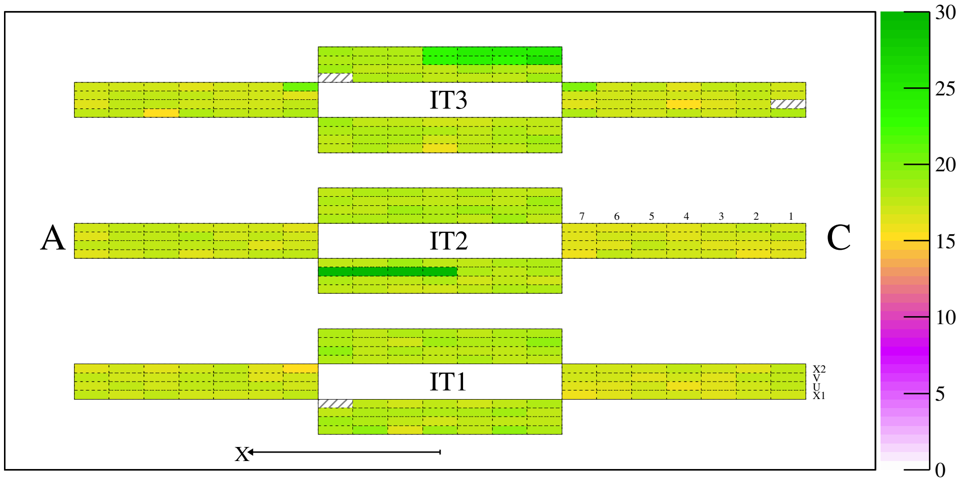
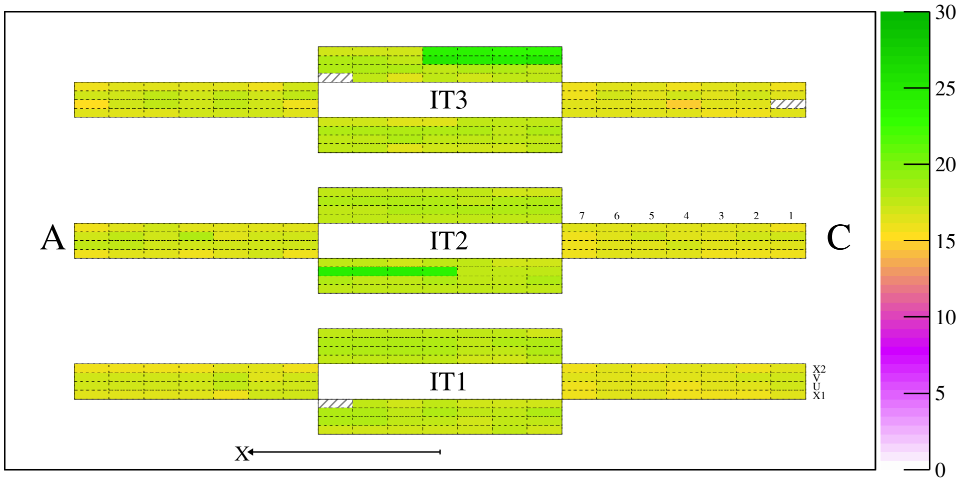


Figure 9: Signal-over-noise ratio measured using 2011 and 2012 real data and MC samples for IT (*four top plots*) and TT (*four bottom plots*).





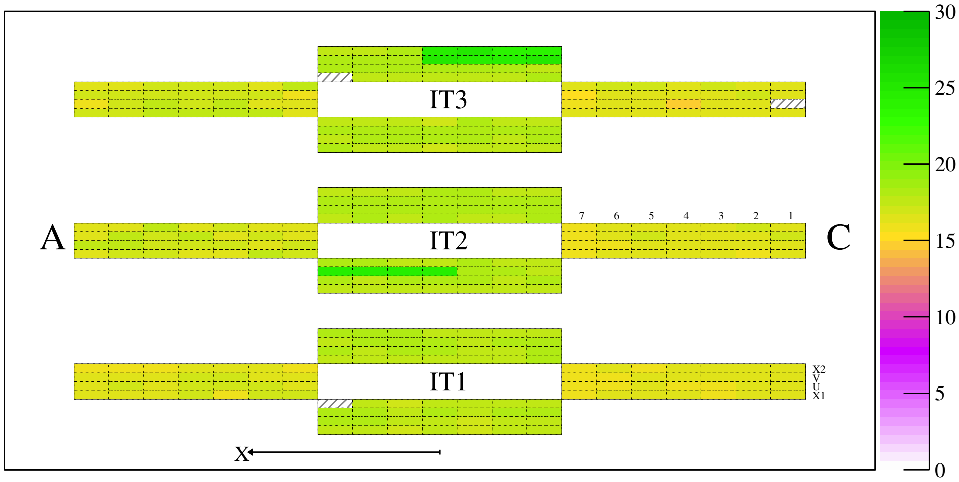


Figure 10: 2D map of signal-to-noise ratios measured using 2011 MC (*top*), 2011 (*middle*) and 2012 (*bottom*) real data samples for IT.

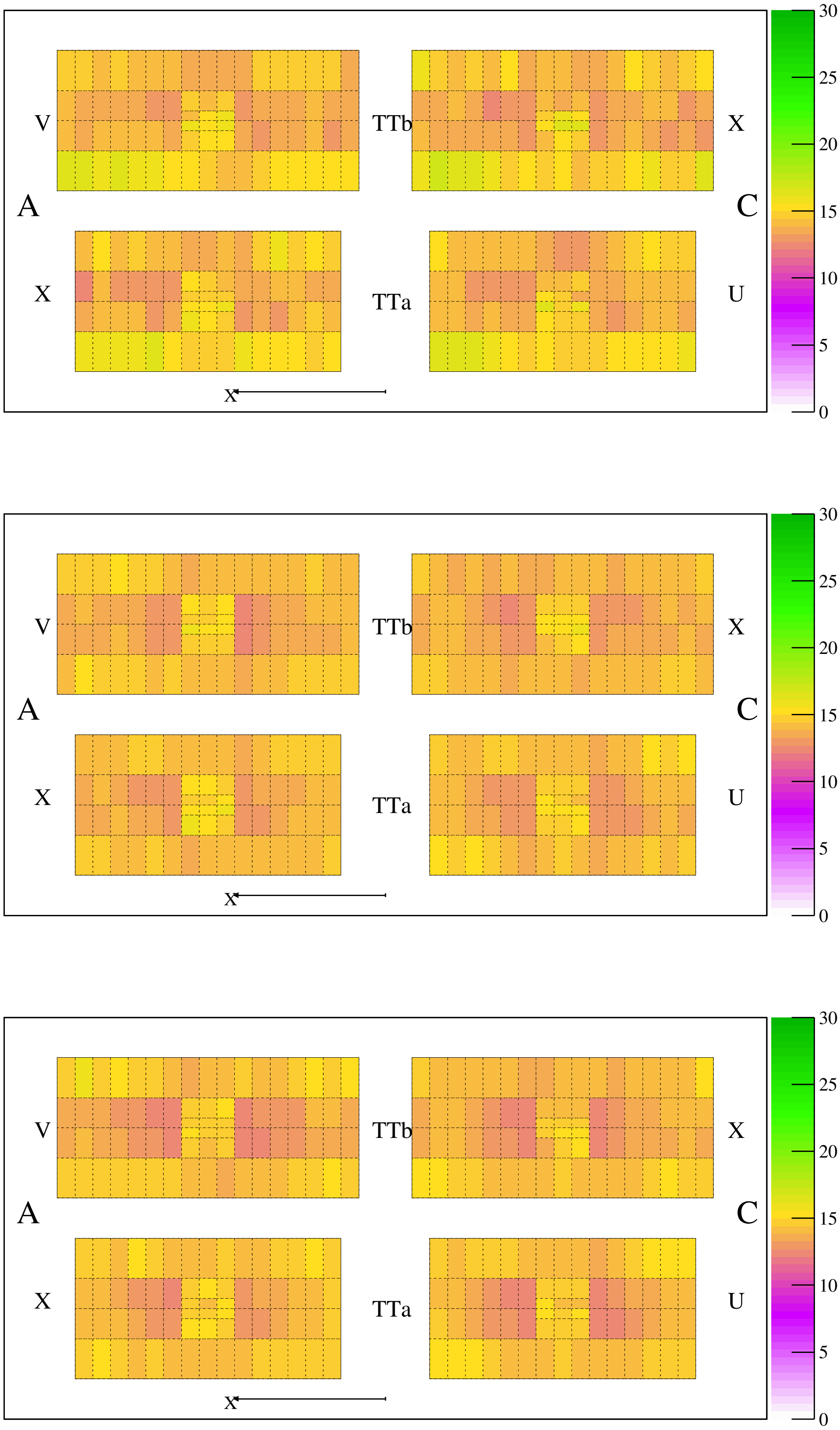


Figure 11: 2D map of signal-to-noise ratios measured using 2011 MC (*top*), 2011 (*middle*) and 2012 (*bottom*) real data samples for TT.