Test beam 2003
Second short status of data analysis

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Abstract

This document contains an updated[1] analysis of the data collected during the 2003 test beam. All previously found puzzles are solved and therefore close to final results on correlations and efficiencies are given.

1. Previous report is available as http://cms.pd.infn.it/testbeam/TB2003_report1.pdf

1. Introduction

The preliminary analysis of 2003 test beam data showed several points that could not be immediately understood, although some hints on the possible explanations were offered. Further work on the emulator allows now to firmly establish the reasons of the behaviour of the default trigger configuration. As in the previous case a limited amount of data (50000 events per run) was used.

2. Data selection

Data selection was slightly modified to exclude out of time triggers, while keeping an unbiased selection. The BTI device has got a programmable dead time that protects its computations in case of multiple hits on the same cell due to afterpulses, electromagnetic background or multiple beam tracks. The first detected hit on each BTI channel triggers a signal that rejects hits coming after it and falling in a programmable time window (by default set equal to the maximum drift time). Therefore only hits detected in the range $-T_{MAX} \leq t_0 \leq 2T_{MAX}$ can disturb the BTI calculations: hits arriving before will mask the good one modifying the trigger decision, while hits coming afterwards will restart the BTI calculations adding noisy triggers.

The final cuts were set as follows:

a) scintillator trigger with ±2 ns tolerance on average time
b) > 2 cells with recorded hits in the beam region
c) < 3 hits recorded outside the time interval $-400\text{ns} \leq t_0 \leq 800$ ns

On average about 20% of the events were rejected mainly due to the last request. A relevant number of apparently simultaneous double muons was anyway passing these cut. This is evident from Figure 1,where the number of recorded hits in the selection time interval is plotted: the first peak is associated to single beam tracks, while the second one could be interpreted due to double beam muons or to other noisy tracks, rather than to afterpulses. Cutting harder on out of time hits cannot be accepted since the results of the trigger analysis could be biased. Once the multimuon analysis will have progressed we may consider revising this set of cuts or introducing new ones.

3. Efficiency

The bunch crossing efficiency (i.e. we just checked that there was any trigger at the right bx without checking that the right parameters are calculated) is slightly different with respect to the previous report because of the modification of the selection requests. On the other hand some bugs were corrected in the emulator code and therefore we report in Figure 2 the efficiency recomputed on this sample. The overall agreement between hardware results and emulation processing is slightly better. Unfortunately there are still some ununderstood differences. These problems are shown in Figure 3 and Figure 4: there is still a significant number of missing HH triggers compensated by an excess of HL triggers and there is a lower number of second tracks produced from the emulator.

The HH triggers deficit in the emulator results is reduced by about a factor two with respect to previous results after few bugs correction. The remaining deficit is probably due to differences in the actual data processing inside the BTI since we could not find any systematics pointing to particular problems, but rather we identified only cases with drift-times very close to

	-10 degrees		+10 degrees	
Configuration	Default	Modified	Default	Modified
Higher Quality	2.0	2.5	7.8	1.5
Lower Quality	3.8	8.9	4.3	8.6
Total	5.7	11.5	12.3	10.1

Table 1- Emulator percent fraction of higher level and lower quality level triggers compared for two angles of incidence in the default and proposed modified configuration (see text).

the edge of the clock. In this case a marginal variation of the sampling time could modify the result. A careful analysis of data treatment at each step inside the emulator needs to be performed.

The situation with second tracks is instead the opposite with respect to previous results: again a deeper check inside the emulator in needed. A particular attention was taken to the fact that there is a clear asymmetry between positive and negative incident angles. The reason of this difference is a redundancy problem in the BTI default setup that was already found in a previous BTI test[1]. Second tracks are produced in the local trigger system in order to allow identification of dimuons inside a chamber and to recover good tracks that were masked from noise hits in the first track choice procedure. The trade off of the choice to allow multitrack output is the fact that the system detects some false alignments in close BTIs due to internal equation redundancies and possible noise hits. These redundancies are really dangerous as far as they produce higher quality triggers (of types HH, HL, H_o, H_i) that can more likely produce false tracks in the Track Finder. The same paper offered a solution that we could check now making use of the emulator. The proposed solution can reduce the dangerous triggers, but on the other hand will produce a larger amount of lower quality ones (of types LL, L_o, L_i), since it is not anymore possible to require redundant equations suppression. After redefining the default set of equations we found that the fraction of higher quality second tracks was reduced at positive angles and the fraction of lower quality tracks was raised at negative angles. As seen in Table 1 this choice of equations produces more or less symmetric results with respect to track inclination. The excess of lower quality second tracks should not be a problem since the Track Finder has some noise suppression algorithms reducing its impact. At the moment the absolute value cannot be safely stated since we still have the discrepancy between emulator and hardware trigger results of Figure 4, but we believe that this solution is acceptable and must be adopted.

5. Correlations

The output trigger parameters can be cross-checked with the result of track fitting done using the TDC hits. The rough correlations (Figure 5) showed that there are some problems in the Look-Up Tables computation. In fact in the radial angle versus fit position correlation there was a line break in the position corresponding to the border between TRACOs and there was a gap between correlated, inner and outer triggers. The emulator was able to reproduce the gap but showed a continuous line (Figure 6). The gap could be partially understood as a problem in the comparison since the TRACO evaluation is done in different positions, but the extrapolation was still leaving a narrow gap between trigger types.

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1. NIM A 438 (1999) 302-316: check paragraph 7.1.

Both these problems are explained as errors in the TRACO LUTs calculation routine:

i) the drift velocity parameter was not coherent with the corresponding actual BTI settings, causing a progressive error in each location evaluation that was reset at each TRACO, thus explaining the non continuous behavior of the correlation. The effect of repeating the same error in the software emulator is shown in Figure 7. Even if so evident, the systematic difference between the two LUTs is negligible (about 2 mrad) and does not prevent the use of the data.
ii) the origin of the coordinate system was set at the center of the chamber in the TRACO routines and is instead offset by ~29.3 cm in the fit routines. The comparison must account for it.

The comparison is easier if we transform the TRACO radial angle and the position in the same units and reference frame. After applying this transformation there is no difference among the trigger results at any incidence angle and for any trigger type. After transformation the correlation between the radial angle measured from the fit and the radial angle calculated from the trigger algorithms is shown in Figure 8, where data from all the default files (i.e. any tested muon incident angle) are superposed. Apart from the line break when changing TRACO, the correlation is rather impressive.

The presence of a large number of double muon tracks has a non negligible effect on the trigger algorithm. They can be rejected using a cut on the number of hits inside the selection time window. The effect of a cut requesting less than 20 hits in this window is shown in Figure 9,where the incident angle and the radial angle without applying this cut and with its application is showed. The performance of the trigger system on this subsample is significantly improved. As shown in Figure 10, using this cut, there is a significant change in the fraction of Second Tracks. We obviously have to revise the quoted results once the cuts to apply to select the dimuon sample will be properly defined.

6. Resolutions

The determination of the resolution of the trigger parameters is complicated from the quantized nature of the output and from the already pointed out break in the radial angle correlation. The internal calculations done in the BTI and TRACO devices should provide the same resolution on radial angle for all kind of triggers and a rather different one on incident angle for correlated and uncorrelated trigger types.

This is a structural difference that has its origin in the actual device which provides the result. The radial angle least count is ~0.25 mrad and the incident angle least count is instead ~2 mrad. But in the case of a correlated trigger the calculation is done from the TRACO that works at full resolution, while for uncorrelated triggers the calculation is done from the BTI that has a lower resolution. There is also a slight difference between uncorrelated HTRGs and uncorrelated LTRGs, due to the different way used in computing the parameters. As a construction choice, the position resolution is kept constant in the correlator: a resolution on radial angle independent of trigger type is therefore expected. Instead the track k-parameter calculation is improved from the TRACO causing a difference between uncorrelated and correlated triggers. The least count of the k-parameter is not constant in angle, but at normal incidence it corresponds to ~50 mrad for BTI (i.e. for uncorrelated triggers) and ~6 mrad for TRACO (i.e. for correlated triggers).

The fact that we succeeded in reducing hardware and fit data in the same units and reference frame allows direct comparison of the parameters simply checking their difference and thus providing a measurement of the resolutions. The error in the calculation of the LUTs is

Angle(degrees)	-42	-30	-20	-10	0	10	20	30
HH resolution (μrad)	226	281	216	214	191	258	258	257
H_i resolution (μrad)	321	303	256	245	204	274	279	304
L_i resolution (μrad)	507	372	369	314	282	280	376	394

Table 2- Variance of a gaussian fit to the difference in radial angle computed from fit and hardware trigger for various angle and different trigger types.

reflected in the radial angle difference, while it should not give a contribution in the incident angle difference since there is a factor 8 between the two least counts. In fact this error is the reason of double peaks sometimes appearing in Figure 11,where the difference between radial angles computed from the fit and from the trigger system for HH trigger types is plotted. There is still a systematics remaining in the data, since the difference is not centered around zero: this is probably due to uncertainty in the corrections that we had to apply in order to recover from known errors. The remaining systematics is not harmful, being limited to few milliradians.

Figure 12 shows the radial angle difference for different trigger types. Identifying TRACO 10 from the emulator, only the shaded peak is left.

Table 2 reports the variance of a gaussian fit to a single peak. The radial angle resolution is almost constant for any trigger type (in fact slightly worse for single LTRGs) and compatible with the parameter least count.

The same simple situation does not arise for the incident angle. In this case the expected resolution is rather different for correlated and uncorrelated triggers. The fact is anyway not important, since muon transverse momentum is evaluated from position and bending angle is only used for extrapolation between chambers.

As examples Figure 13 shows the situation at normal incidence and Figure 14 the situation at the largest tested incident angle. The variance of the correlated triggers distribution is around 5 mrad. while the one of uncorrelated triggers is close to 40 mrad. It is worth noting that there is not anyway a dependence on the angle of incidence.

A further step in efficiency calculations can be taken using the fact that we can cut on the difference in radial angle to get the actual efficiency to identify correctly the muon. A correction for the remaining systematics must be applied and a window of ±4 mrad (a smaller window is not applicable due to the error in the LUTs) in the radial angle difference is used. Something we can call muon identification efficiency is reported in Figure 15.

7. Conclusions

Most of the problems found in the first rough analysis round could be understood and solved. In particular efficiencies and correlations understanding is now on the good path. Still some work is needed in order to update the emulator and a particular care must be taken in treating the multimuon environment.

Next step on single muons analysis will be a first round of studies on noise (in time and out of time). A dimuon study is already in progress and will be released as soon as possible.

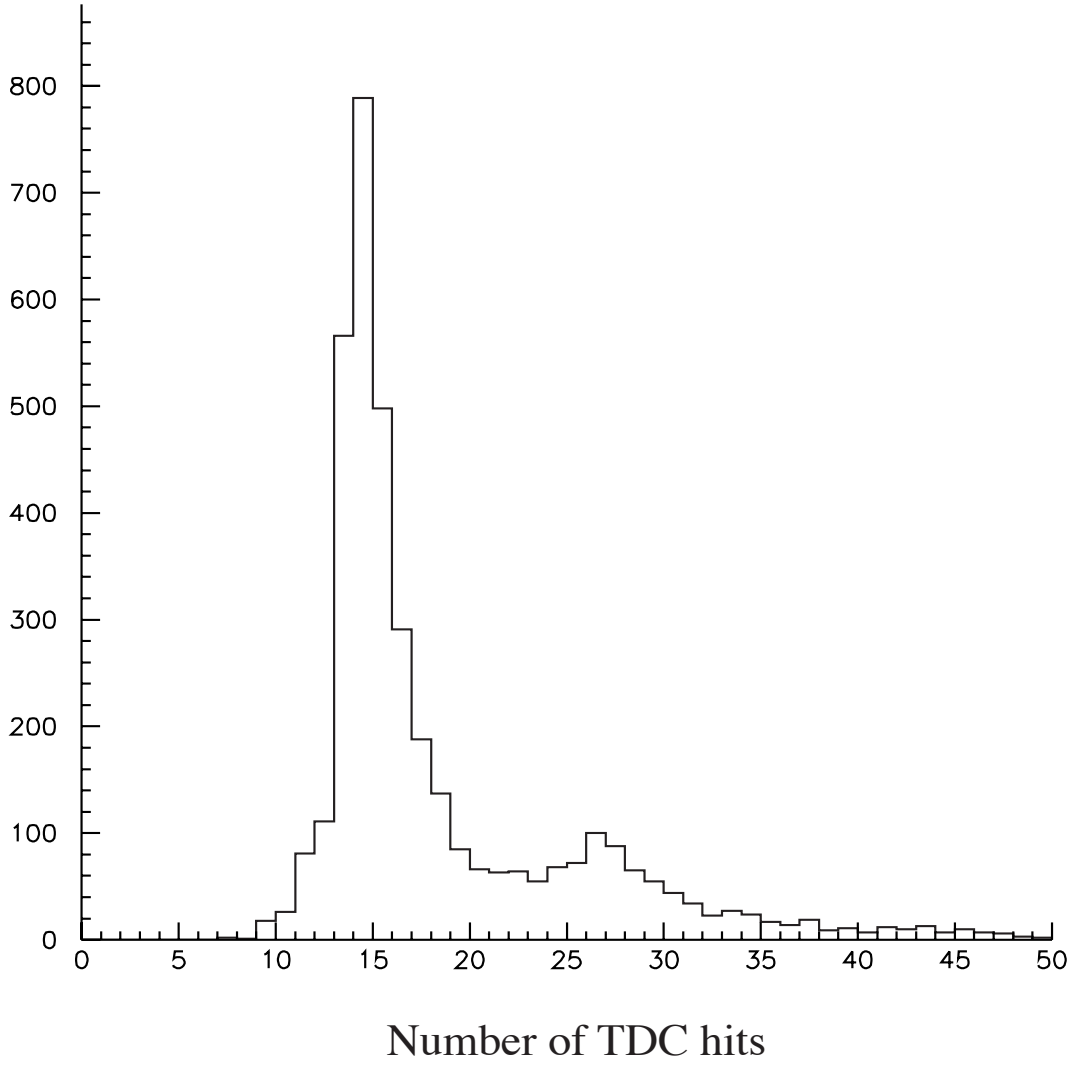

Figure 1- Number of hits recorded from TDC inside the selection window for normal incidence muons ($-400ns \leq t_0 \leq 800ns$). The first peak (fourteen hits) corresponds to fully efficient single muons (twelve layers + two scintillators signals); the second peak (twenty six hits) may correspond to fully efficient double beam tracks. Data at other incident angles show the same behaviour.

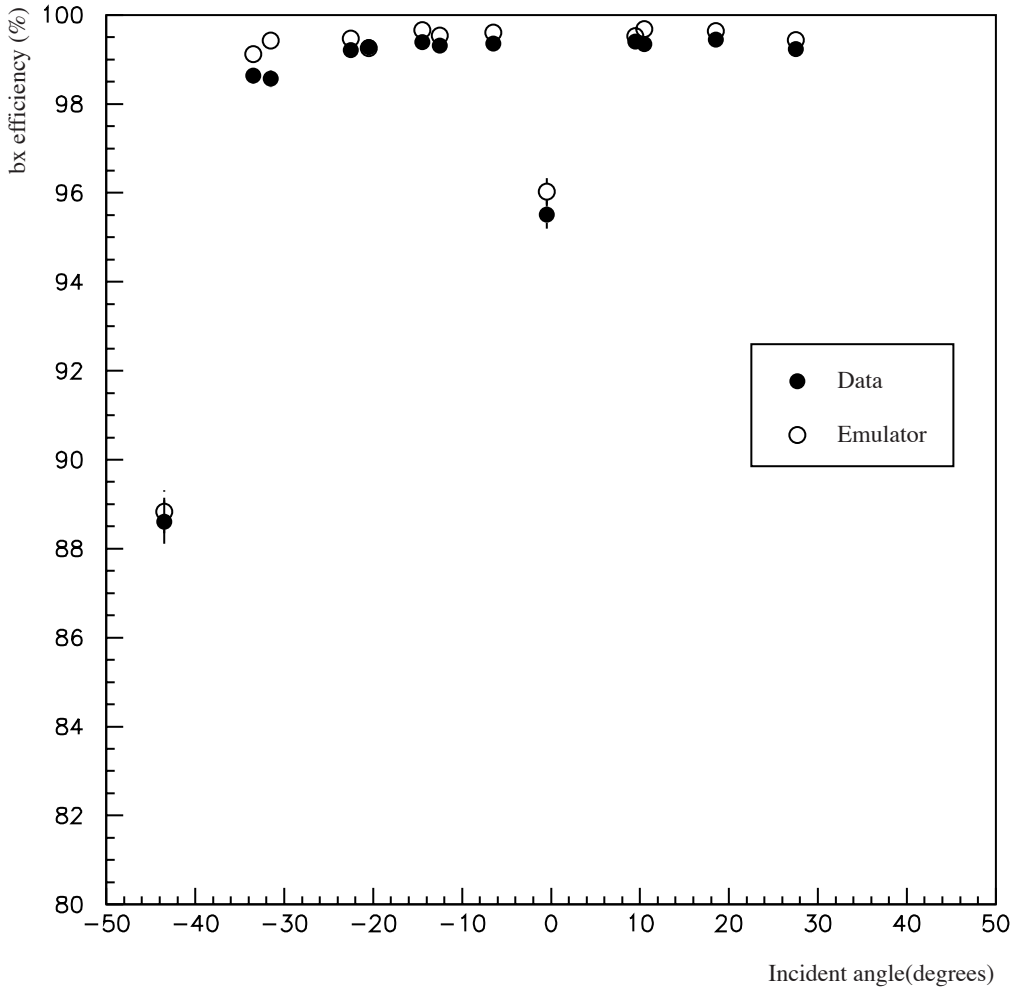

Figure 2- Bunch crossing efficiency as a function of incident angle. Recorded data efficiency is compared to efficiency computed with the software emulator.

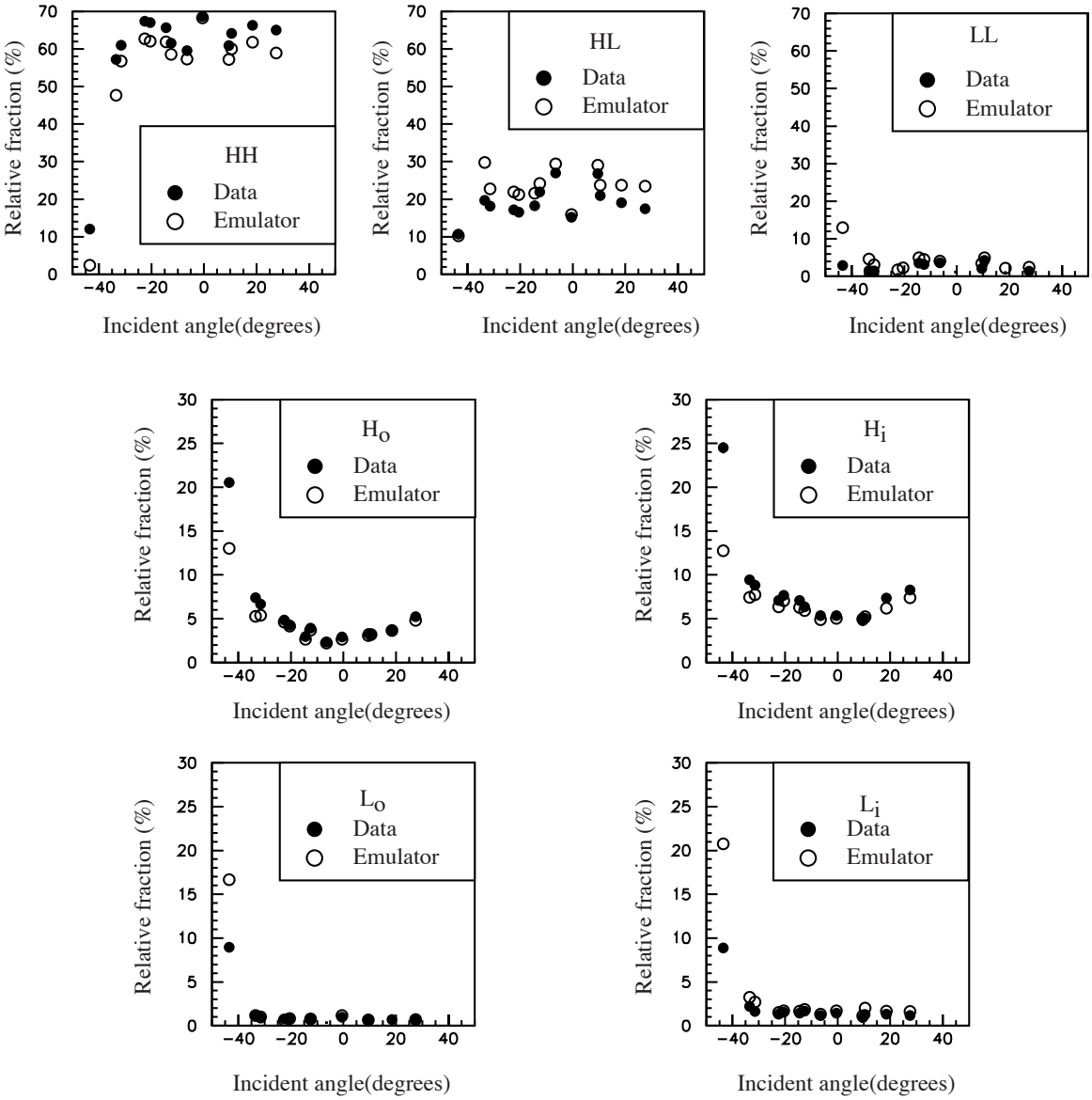

Figure 3- Relative contribution to bunch crossing efficiency of any trigger type. Data are compared to emulator results

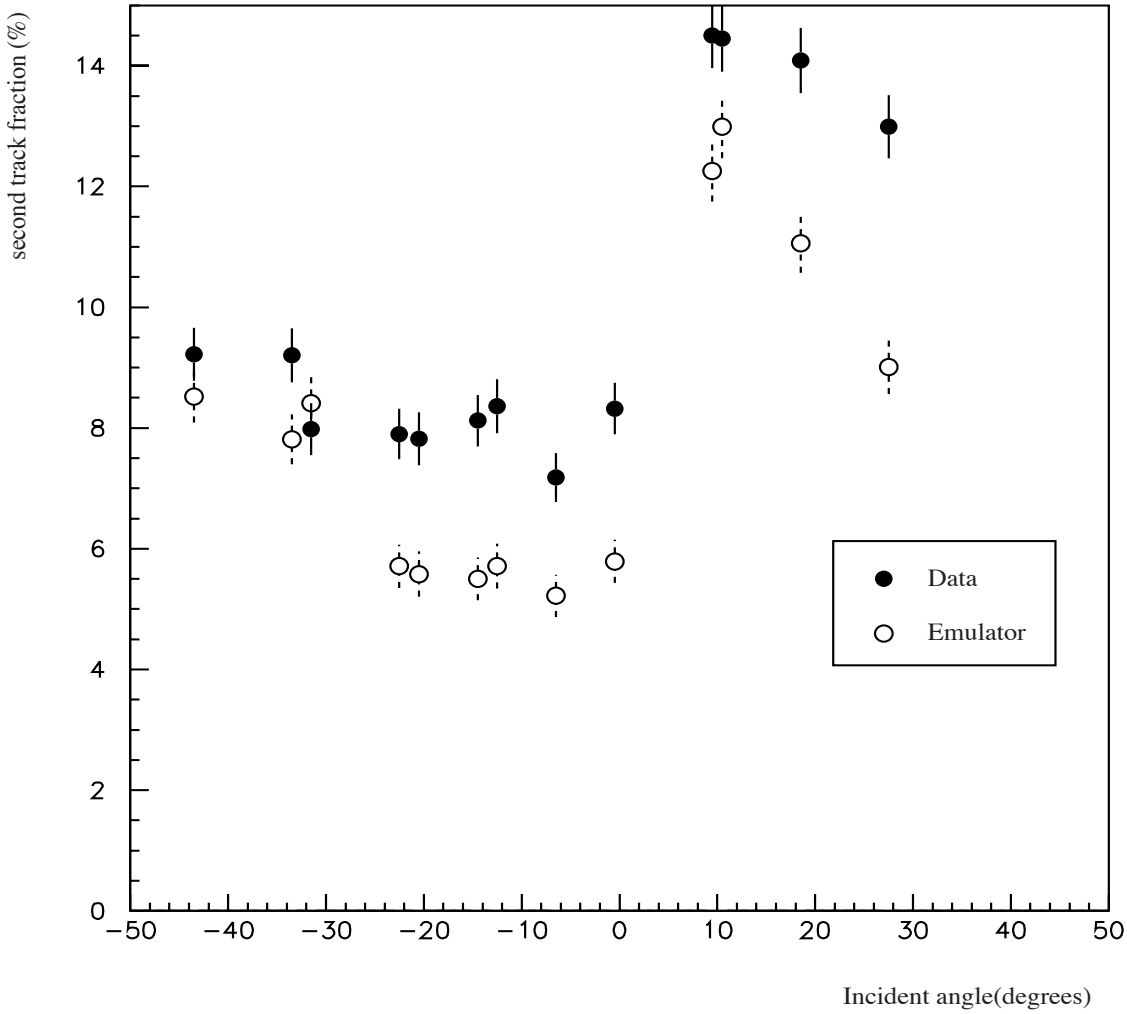

Figure 4- Fraction of events with a second track at the correct bunch crossing as a function of incident angle. Data are compared to emulator results.

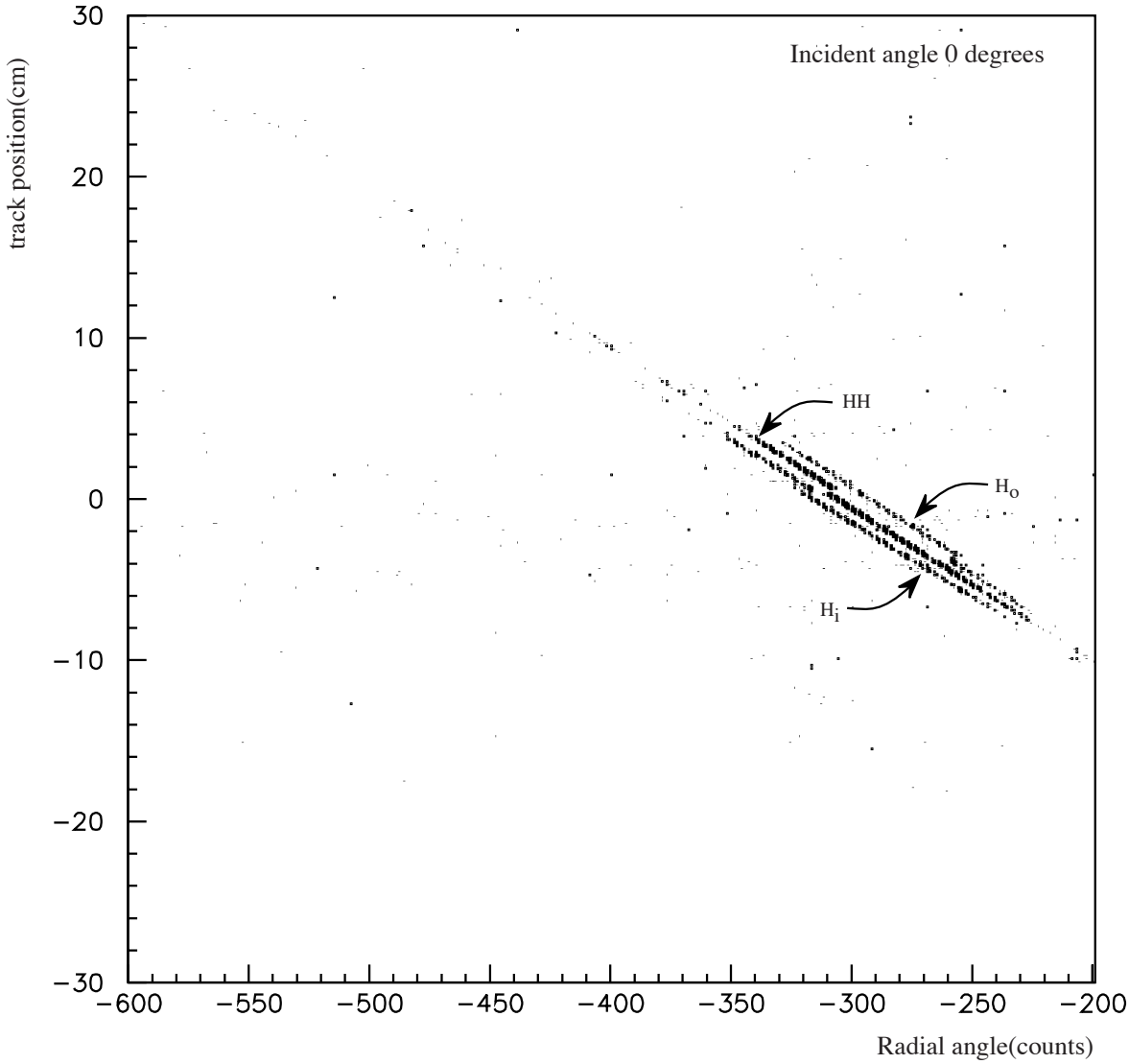

Figure 5- Rough correlation between hardware TRACO radial angle output parameter and fitted track position at 0° incident angle.

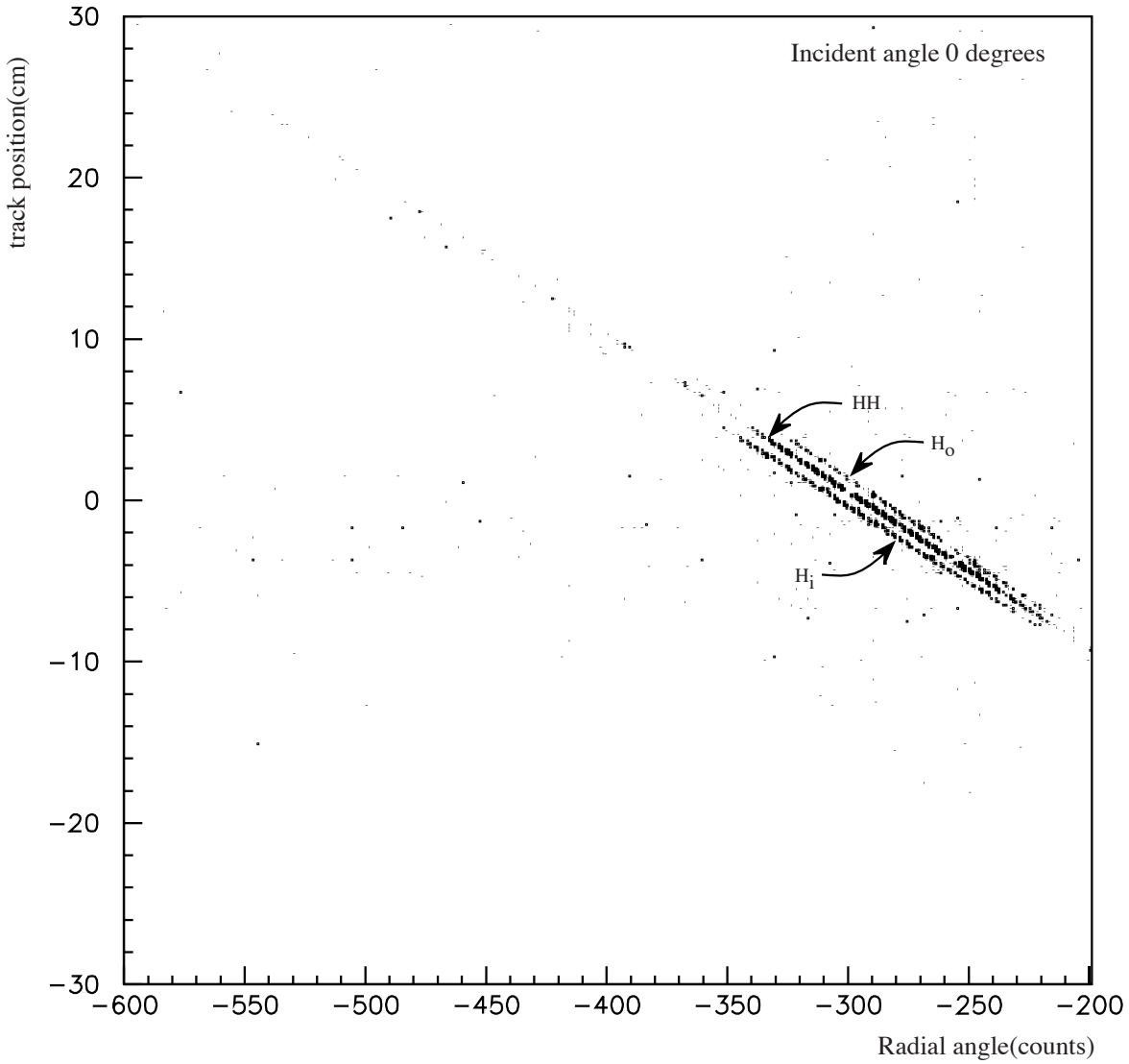

Figure 6- Rough correlation between TRACO radial angle output parameter and fitted track position as obtained from software emulator at 0° incident angle.

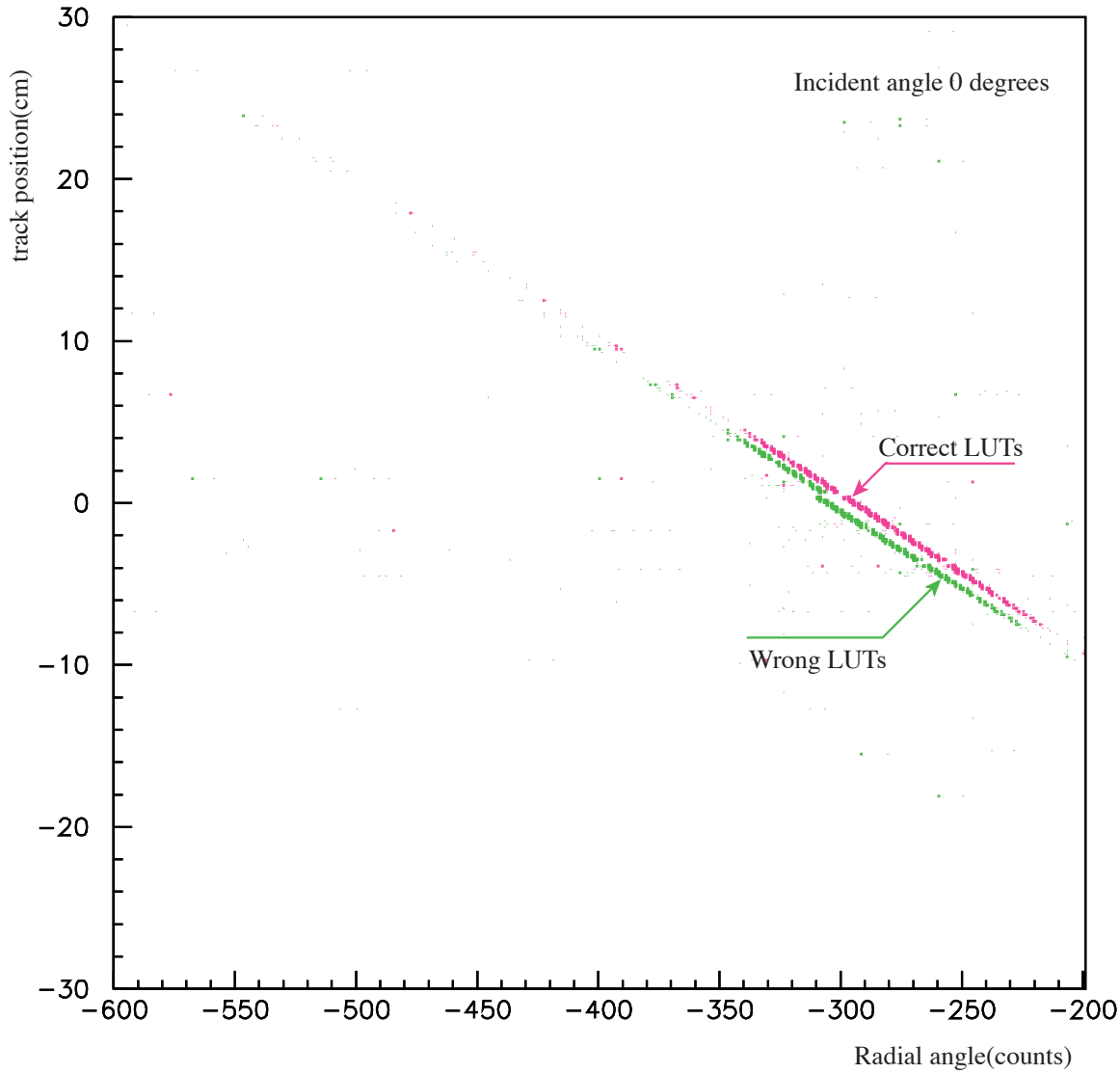

Figure 7- Comparison of emulator results for HH triggers using LUTs loaded in the test beam and using the correct LUTs.

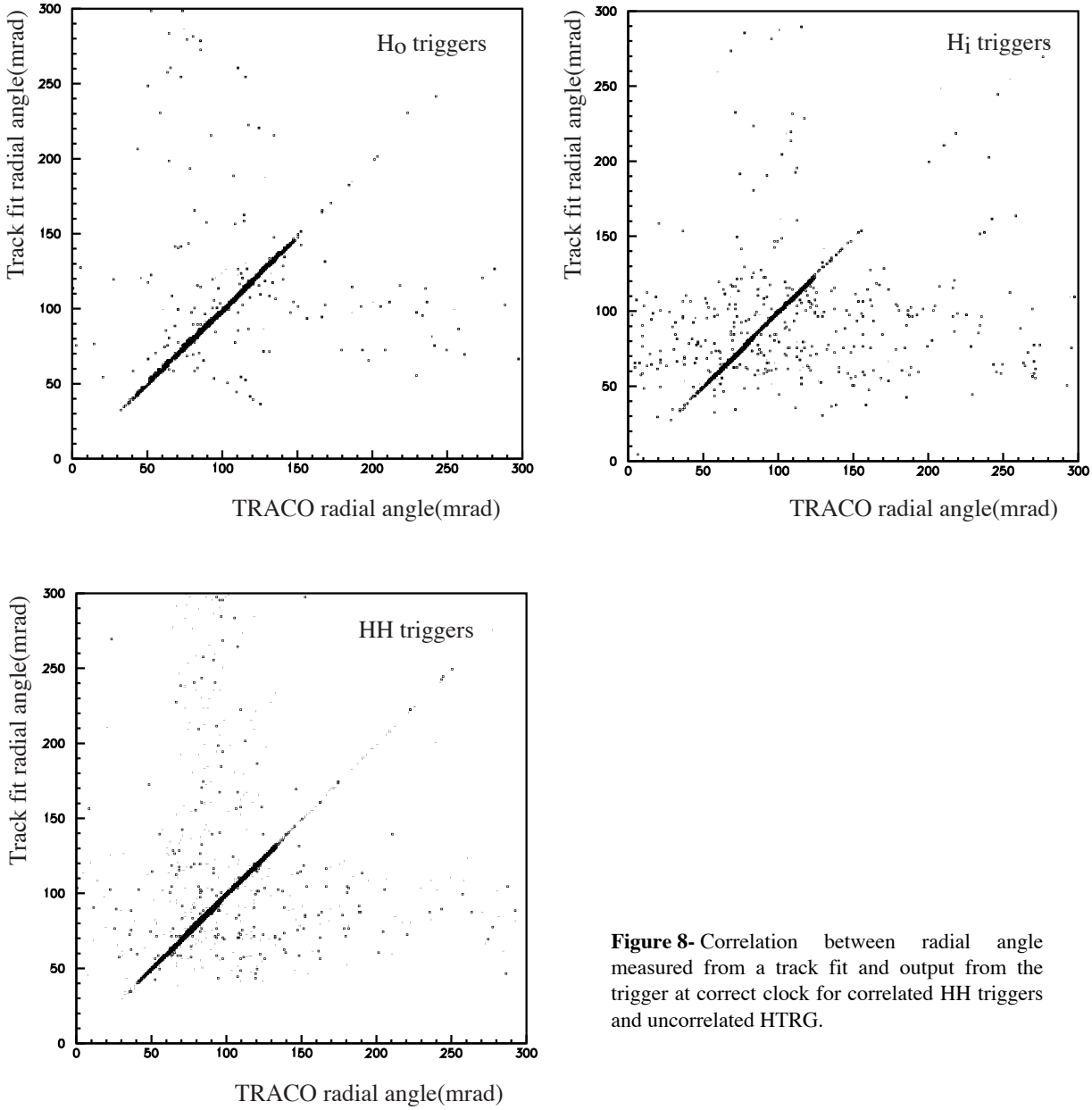

Figure 8- Correlation between radial angle measured from a track fit and output from the trigger at correct clock for correlated HH triggers and uncorrelated HTRG.

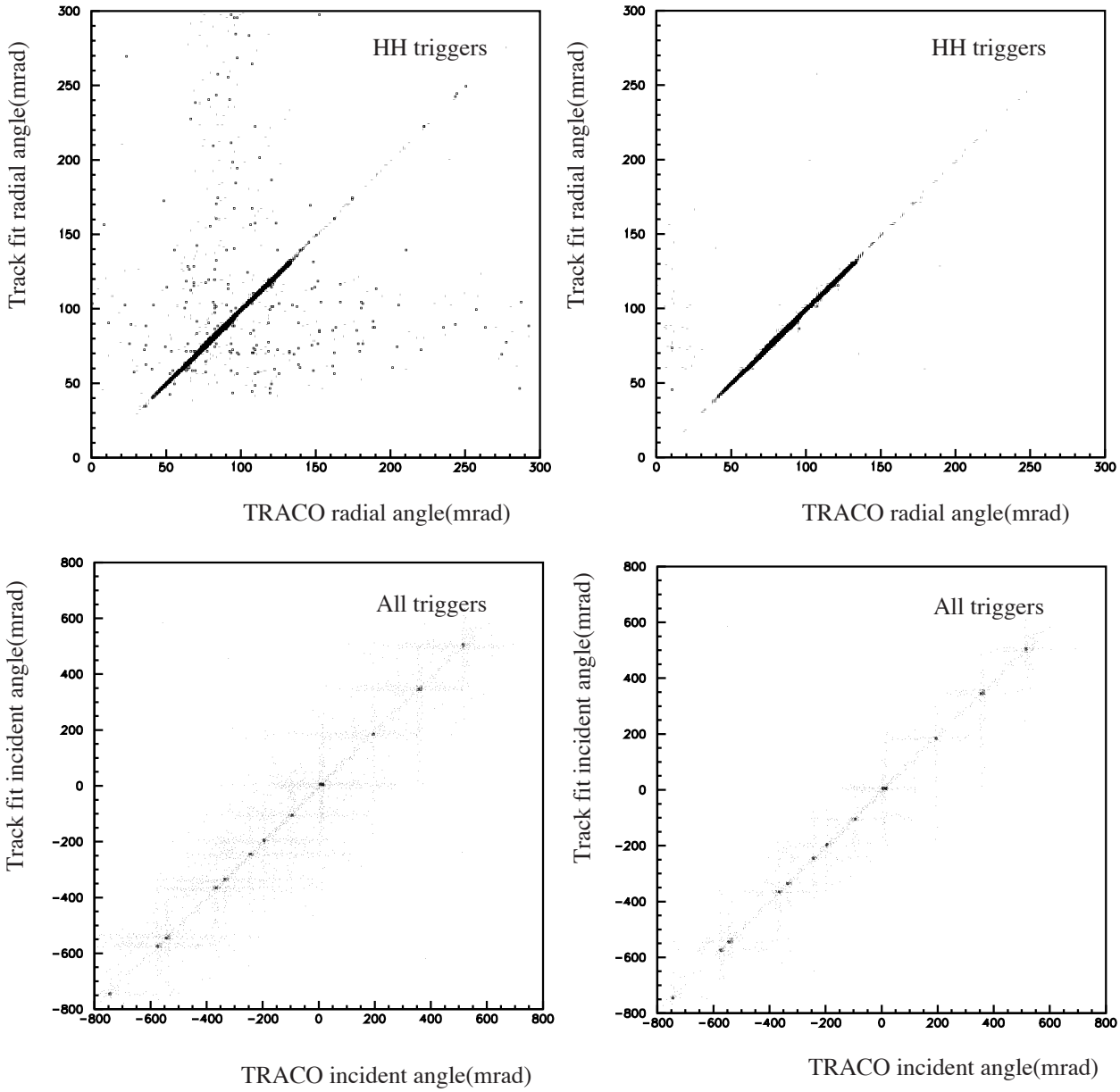

Figure 9- Correlation between hardware output parameters and track fit parameters without double muon tracks rejection (left) and with double muon tracks rejection (right)

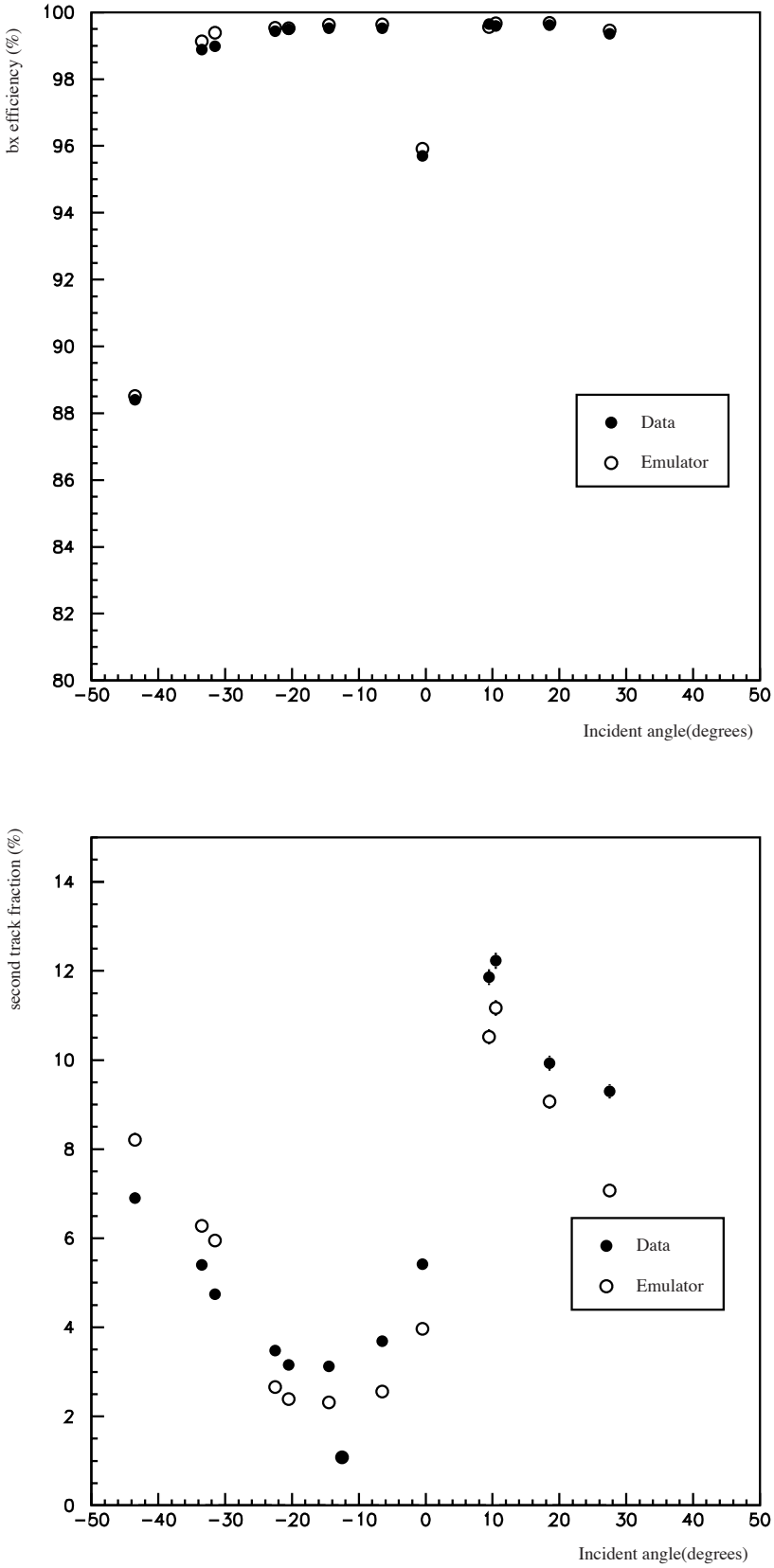

Figure 10- Bunch crossing efficiency and second track fraction applying a cut on the total number of hits recorded from the TDC inside the selection window.

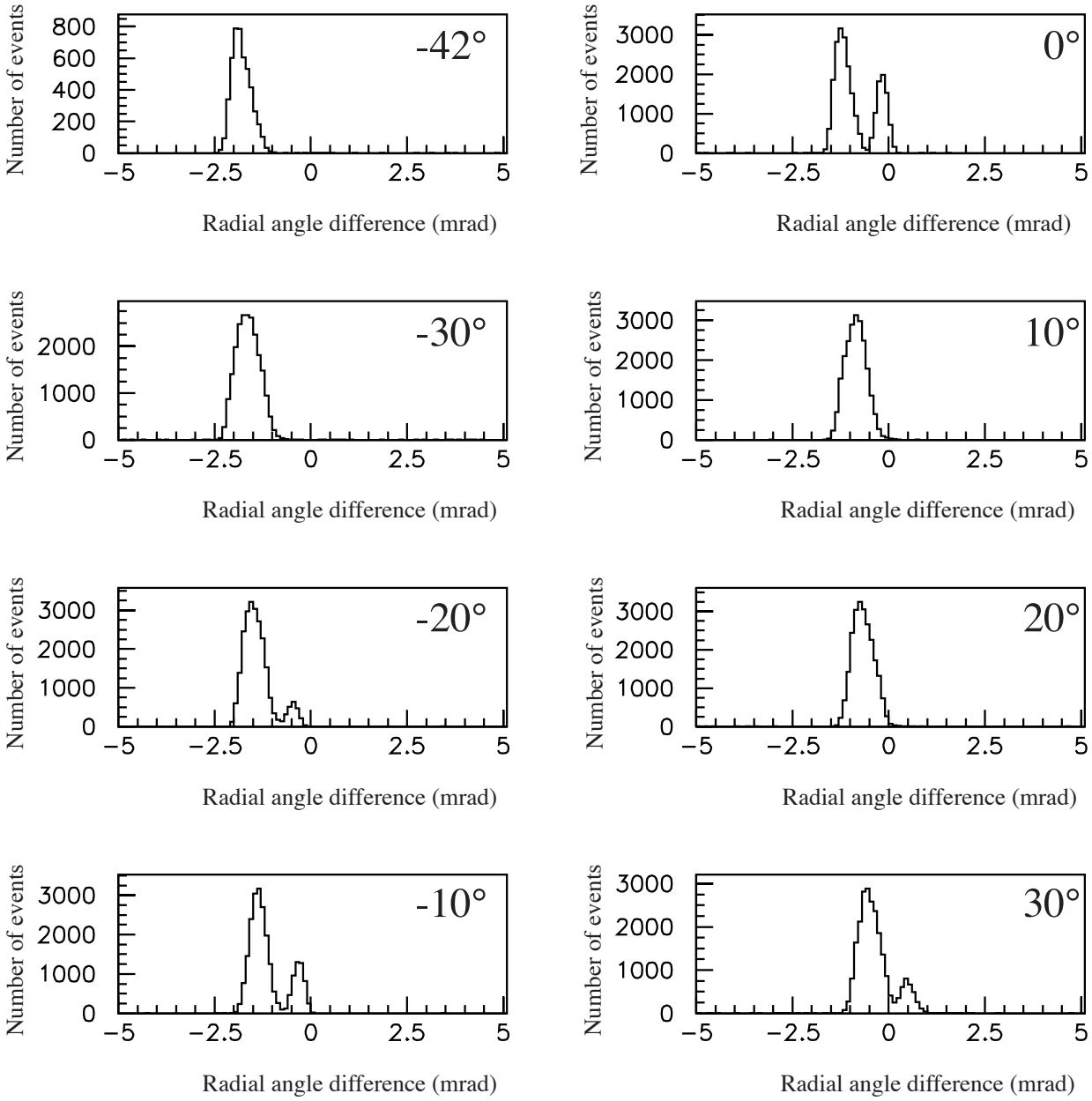

Figure 11- Difference between the radial angle output from trigger system and the one computed from a track fit for HH triggers at different incidence beam inclinations.

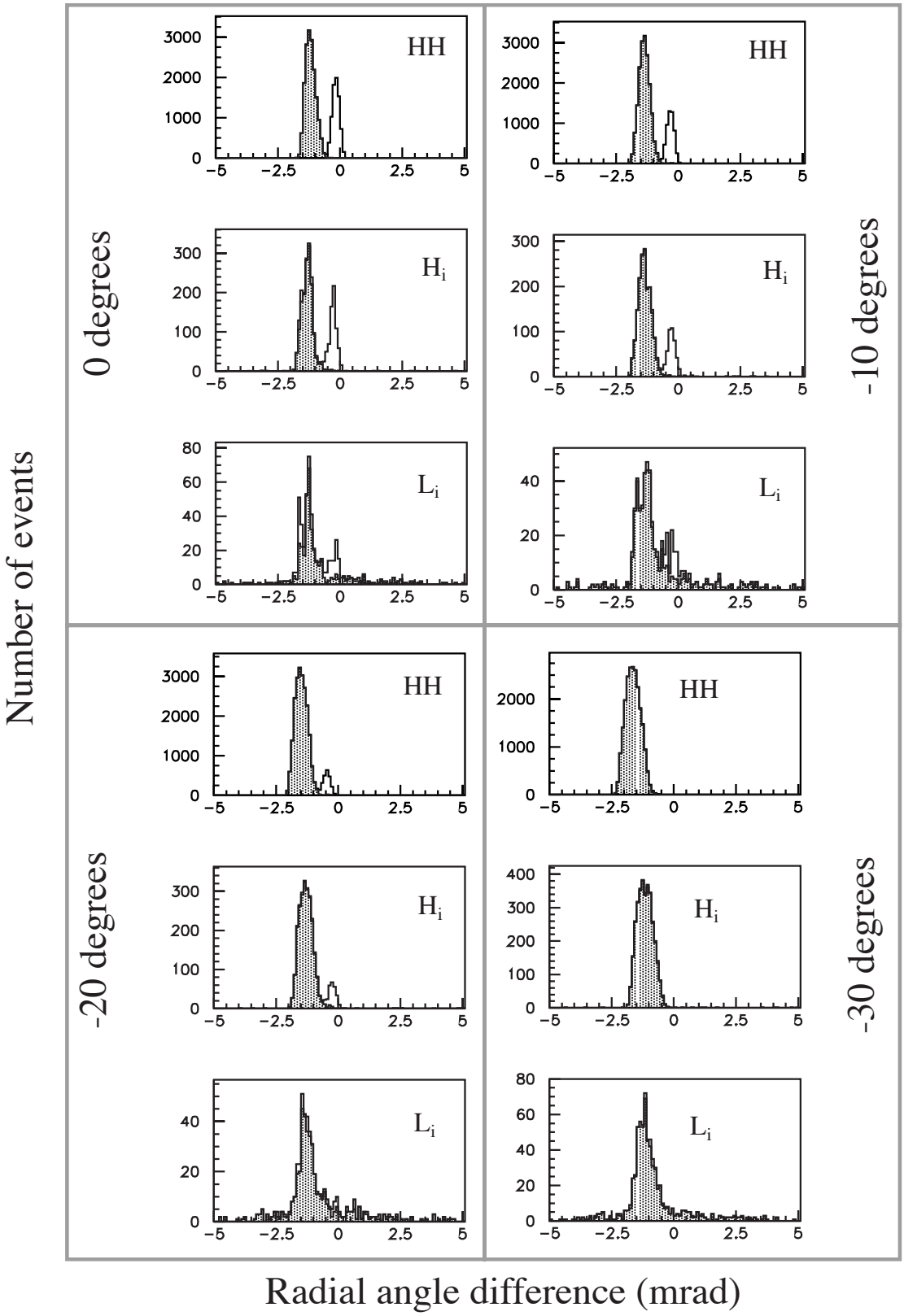

Figure 12- Difference between radial angle measured from a track fit and output from the trigger at correct clock for different angles of incidence and trigger types. Shaded area is the contribution of TRACO 10 alone.

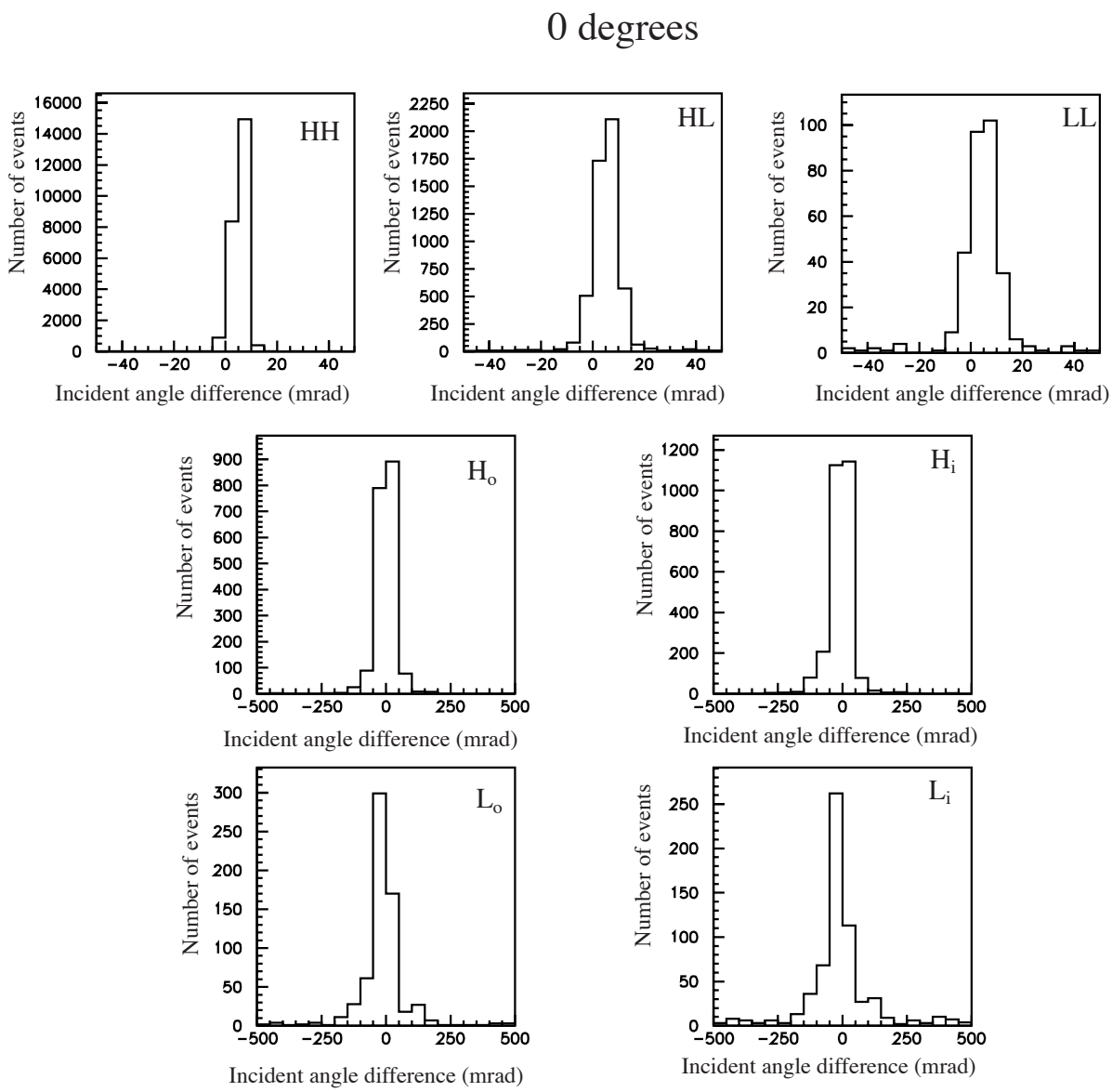

Figure 13- Difference for data at normal incidence between incident angle as computed from the track fit and incident angle as computed from bending angle output from trigger.

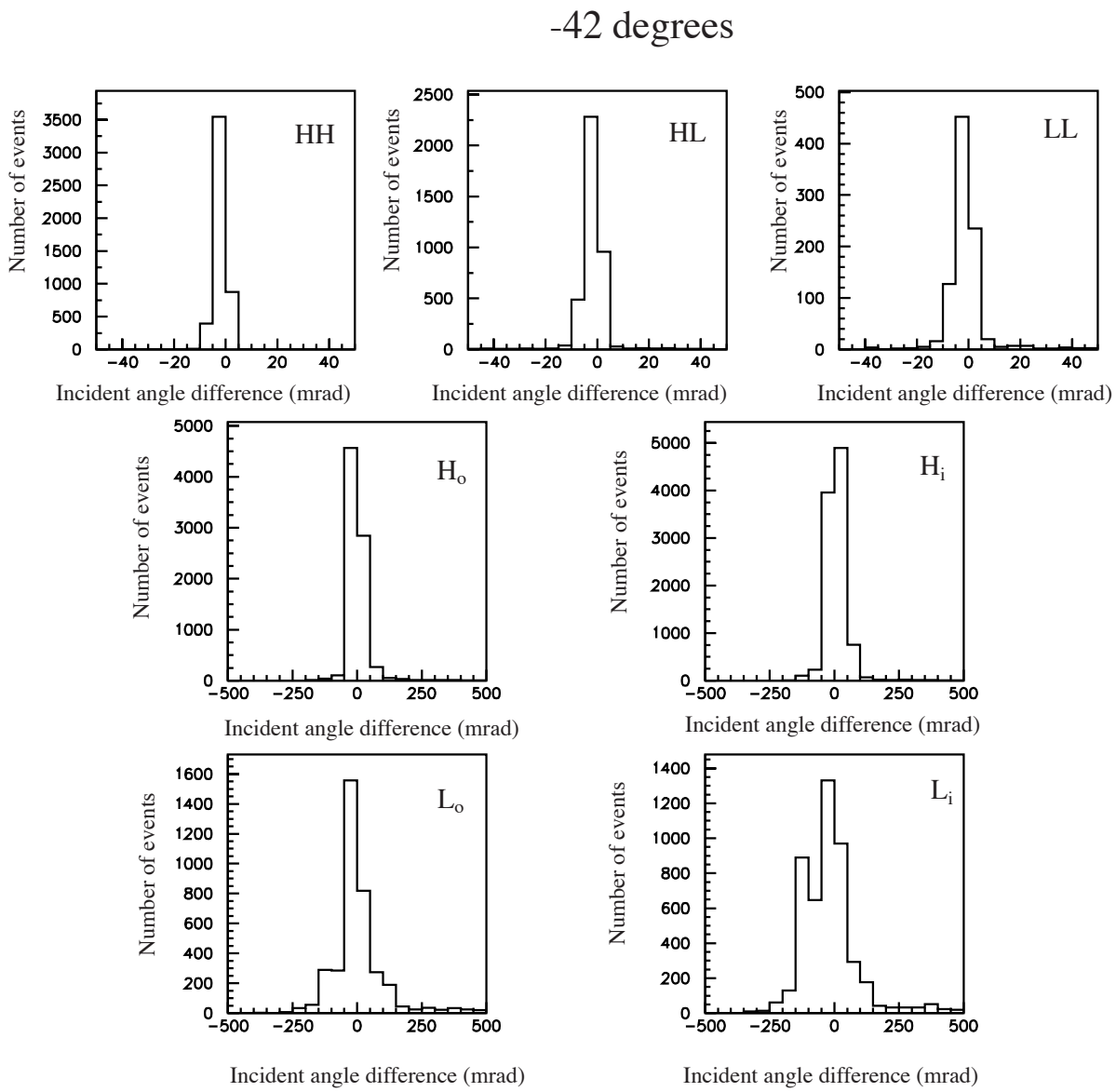

Figure 14- Difference for data at maximum tested incidence between incident angle as computed from the track fit and incident angle as computed from bending angle output from trigger.

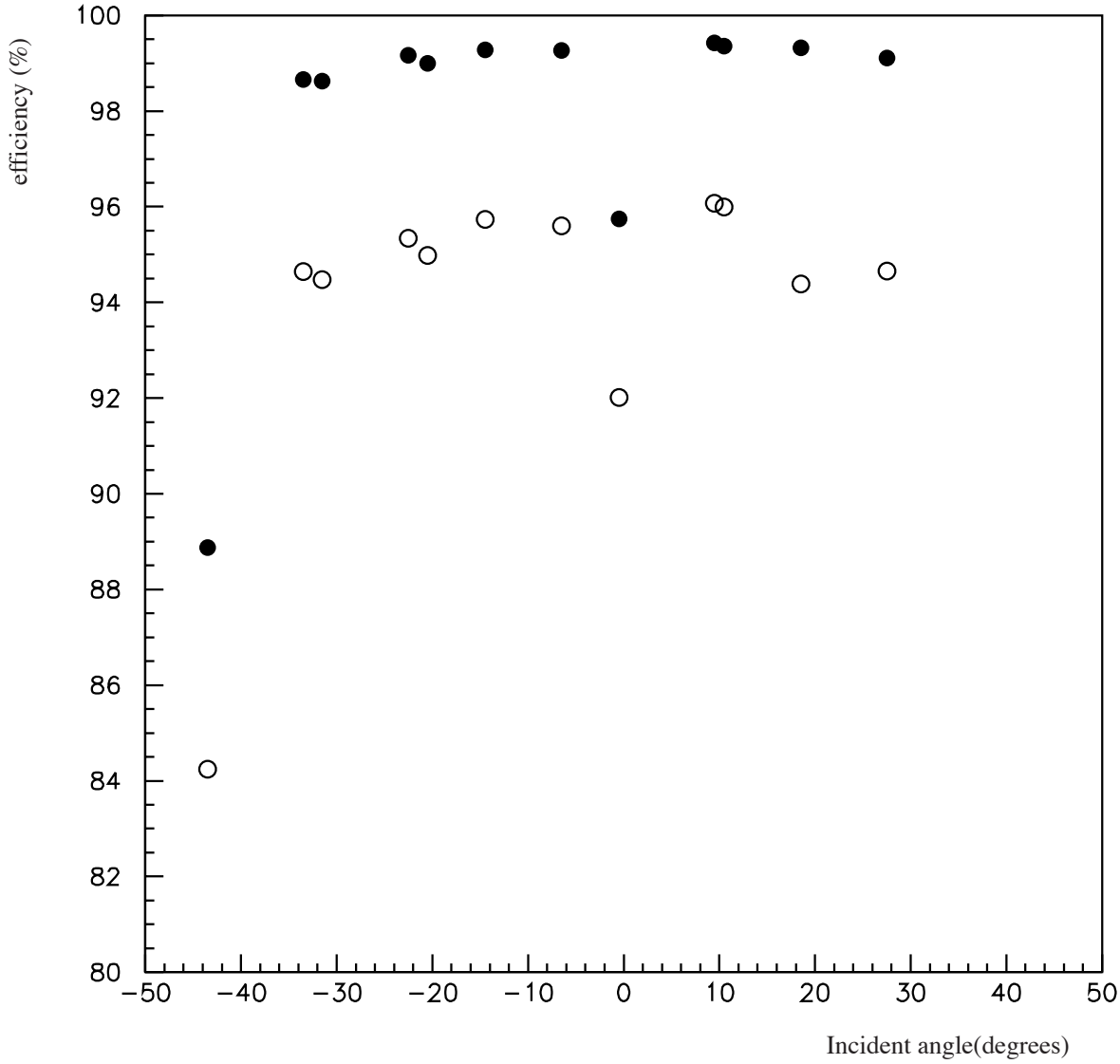

Figure 15- An indication of the quality of the radial angle output from the trigger. Open dots show the fraction of events having the output radial angle being the same as the one measured from a track fit in a ±4 mrad window. Black dots are the corresponding bx efficiency. The systematics on this plot is uncertain and due to events rejected since no track was reconstructed (~1.5%) and to an unknown fraction of events where the trigger was right and the fit was wrong.