TRIUMF Experiment E614: TWIST

Crosstalk Report

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Introduction

In order to successfully reconstruct particle tracks in the detector, we must minimize false signals caused by electromagnetic coupling between channels in the electronics, cables or chamber wires. To do this, we must first identify these crosstalk hits so we can quantify the effect and minimize it by adjusting high voltages and thresholds in the drift chambers (DCs) and proportional chambers (PCs). The remaining crosstalk can be removed by code during later analysis.

Crosstalk pulse shape

Bench testing of preamp boards indicates how we can identify crosstalk hits by there relation to real signals. The shape of crosstalk signals across channels adjacent to the one pulsed is presented in figure 1[1]. Two types of crosstalk are observed. First, an inverse inductive pulse is present. This pulse is not detected. There is also a positive capacitive pulse generated that is superimposed. This is the big peak visible in the first adjacent channels (42 and 44). We see that further away (channels 46 to 50), this pulse is smaller than the inductive pulse and therefore is not detected either. So apart from the first adjacent channels, when crosstalk is detected, it is the more complicated sum of these pulses and ringing that produce a peak seen clearly in channels 41, 46 and 47. In both cases, the peak is delayed from the original signal. One last thing to notice is that the crosstalk pulses are enhanced in the end channels of a preamp die (41, 46 and 47).

[1] Note that the figure shown here was not done with the final board configuration. Crosstalk has been suppressed further since this test, but characteristics pointed out here still apply.

Algorithm

Finding hits

To identify crosstalk hits, we first find hits that have a TDC width larger than a given cut value (namelist variable). This value should ideally be both above the largest measured crosstalk width and below the smallest width of a hit that can cause detectable crosstalk (the larger the threshold, the larger this value will be). Once such a "wide hit" is found, we look on adjacent cells for "narrow hits" (below the same width value). These hits will be considered crosstalk if they are within a small time interval following the wide hit TDC time. A further restriction is that the width difference must be large enough (also a namelist variable). Since the crosstalk pulse is proportional to the wide pulse, if the latter is close to the cut, we want to avoid identifying a false crosstalk hit that would have a similar width, just below the cut.

Currently, some good PC hits are identified as crosstalk by the code. This happens when the particle goes through the corner of a second cell. The hit is delayed because of drift time and it will be narrow because not much ionization occurs in that cell. A way to recover these hits would be to require a different time interval for crosstalk hits on the first adjacent cell. We have already seen that the delay is shorter on the first adjacent channels in figure 1. More evidence from the data will be shown later. This problem is much less important (if present at all) in DCs because the longer drift time will cause hits in the cell corners to be read long after the crosstalk time interval cuts.

To get correct statistical results, we also need to consider cases where the particle goes through two cells with resulting wide hits close in time[2] as a single wide hit. Otherwise, we would increment wide hit counters twice when they can only cause one crosstalk hit per wire. However that part of the code is not executed by default, when we are not analyzing crosstalk but only looking to identify the hits.

It should be noted that the reverse algorithm was also considered, i.e. finding narrow hits first and looking on adjacent wires for an earlier wide hit. It was rejected because it required more looping, comparisons and/or structures and was therefore less efficient.

Latest developments to optimize the code include using crosstalk hit identification so they are not inserted in time windows instead of removing them from the global hit structures before windowing. (The public logical arrays PC_IsXtalk and DC_IsXtalk, which are indexed on hit number (like the TDC arrays), record which hits were identified as crosstalk.) Also, many

[2] The hits must be detected within (upper limit on crosstalk time difference cut) – (lower limit on crosstalk time difference cut) + (width cut) to be considered a single hit. Within that time, it is possible that the second wide hit would occur in the middle of a crosstalk hit caused by the first wide hit. In that case, it could not cause a second crosstalk hit on that wire. Note that it is also possible within that time for the second wide hit to cause a second crosstalk hit on the same wire if they are narrow enough. This is however less probable and we opted for the conservative solution, with a small bias that will give higher crosstalk statistics rather than a bigger bias towards lower crosstalk.

parts of the code are only used to analyze crosstalk and get statistical results. These are not executed by default, speeding up the code by a factor of 13.

Statistical measurements

Four measurements can be gathered to quantify crosstalk with the current code:

1. The fraction of all recorded hits that are identified as crosstalk.
   This fraction is useful for quantifying crosstalk per plane, but can be misleading per wire since wires away from the beam focus would have relatively few real hits but would still get crosstalk hits, increasing this fraction considerably. This effect would depend on the focus of the beam, the distance from the center of the focus, the type and energy of the particles and the level of crosstalk.

2. The fraction of wide hits that cause one or more crosstalk hit.
   This fraction is also intended for plane statistics (not wire). It can give us an idea of the minimum width for a hit to cause crosstalk by looking at different width intervals. Currently, widths are divided in 7 bins, but more are needed for a good analysis. Also, one may need to modify the width cut as well as set the width difference cut to 0 to avoid biases.

3. Average number of hits caused by a wide hit.
   Again, this can be looked at for different width intervals. As noted in footnote 2, double wide hits close in time can cause a small increase in this number.

4. Likeliness of wires to produce crosstalk.
   This is the best measure for crosstalk per wire. It is the fraction of times a crosstalk hit is found on a wire when a wide hit is adjacent. This fraction is recorded separately by how far the adjacent wide hit was (in number of cells).

The crosstalk code also measures plane and wire multiplicity. Plane multiplicity is usually given as the average number of hit cells in a plane while wire multiplicity is given as the fraction of hit cells that have more than one hit.

Mofia usage

Here are the settings one can modify for crosstalk identification and analysis. Default values are in parenthesis.

XTFindXtalk (T): Find and tag crosstalk hits. When using QOD, if QfillHist is also true, raw crosstalk hits per wire histograms will be filled and analyzed.

XTAnalyze (F): Detailed analysis of crosstalk hits, adjacent groups of hits in a plane, remaining narrow hits after crosstalk removal, etc. with statistical counters and many histograms. The code will be approximately 13 times slower when set to true. When false, a simple and fast version of the same algorithm only identifies crosstalk hits.

XTNotInWindow (T): Once the crosstalk hits are identified, don't insert them in time windows. This is simpler (and faster) than removing hits before the windowing code is called. It could eventually be used to look at crosstalk hits after tracking to find out if some good hits were misidentified.

XTRemoveWhits (F): Remove crosstalk hits from DCWhits and PCWhits structures. This option is only available when XTAnalyze is true. It is not needed by default.

XTUseWindows (F): Look for crosstalk hits in the window specified by XTwindow. In this case, the crosstalk routine is called after the windowing code. This is globally slower, since the windowing code benefits from having fewer hits to sort.
XTWindow (2): Find crosstalk only in this window.

XTPrintMore (F): Print extensive plane and wire crosstalk statistics when using func 11 (if false, prints only basic plane results). XTAnalyze had to be true during analysis.

XTDebug (F): Print hit width, time and other details on screen for debugging. Available when XTAnalyze is true.

XTDCnaway (40), XTPCnaway (32): Number of adjacent wires to check.
XTDCWidthCut (50), XTPCWidthCut (40): Maximum crosstalk hit width (ideally hits of this width don't cause crosstalk).
XTDCWidthDiffCut (60), XTPCWidthDiffCut (60): Minimum width difference between a wide hit and a crosstalk hit.
XTDCTimeDiffCuts (5, 65), XTPCTimeCoincidence (5, 60): Lower and upper time difference limits between good and crosstalk hits.

Results

Crosstalk distribution

The number of crosstalk hits per wire is greater for channels at the ends of preamp dies. This is clearly visible in DCs in figure 2[3]. We also see the same effect for PCs, but it is less apparent because ganged wires and central wires show a greater contrast. Having a higher gain, ganged wires should be set at a higher threshold as to equalize efficiency and crosstalk with central wires.

The effect of varying high voltage and threshold are easily seen when looking at the number of crosstalk hits as a function of distance from the wide hit that caused them (see figure 3 and 4). The higher voltage on PCs causes them to have much more wide spread crosstalk across

[3] Figures 2 to 17 are from run 5542: 29.4 MeV/c muons stopping near the target, 80% helium, 20% CO_2 in the gas degrader, high voltages: DCs 1900 V, upstream and downstream PCs 2050 V, PC 5 2050 V, PC 6 1983 V, PC 7 1918 V, PC 8 2025 V, thresholds: DCs and target PCs –125 mV, outer PCs –175 mV.

the chamber. This effect can however be minimized by adjusting threshold as seen in figure 4.

The fact that there is less crosstalk in the first adjacent cell than the next for DCs is probably due to the fact that the capacitive and inductive crosstalk pulses cancel better at that distance. We have already seen in figure 1 how drastically the shape of crosstalk pulses can vary from the first adjacent channel to the next. In PCs, the effect is hidden by the real pulses that are misidentified on the first adjacent cells. As explained before, the fast drift time in the PCs causes small second hits to fall within the crosstalk time interval. This effect was reduced when we were using argon/isobutane gas in the PCs instead of the faster CF_4/isobutane. Note that the effect is negligible in the much slower DME gas in the DCs.

Therefore, if we believe a good fraction of the crosstalk hits on the first adjacent cell in PCs are in fact good hits, we would find a similar reduced crosstalk as in DCs. However, we also see a reduced crosstalk in the second and third adjacent cells for PCs, but not for DCs. Since PC wires are 2 mm apart while DC wires are 4 mm apart, this could indicate that the effect originates in the chamber wires rather than in the preamp boards, which are the same for PCs and DCs. It could also be in the lamels or other places where the electronics or cables are closer together.

Width and time difference cuts

Optimizing the values of width and time difference cuts to find the most crosstalk hits while not misidentifying good hits can be difficult. To see how changing these values affect the result, we look at different histograms of TDC width and time.

To get an idea of the amount of crosstalk hits and their TDC width, we compare the width spectra for three cases. In figure 5, the first plot is for cases where there is only one hit in a plane. In such cases, there is no crosstalk or ringing detected. The second plot is for one wire hit in a plane, but that wire can have more than one hit. The peak that appears on the left is due to ringing in wires after a hit. DCs show a considerable amount of ringing, but it is negligible in PCs. The last plot is for all hits so it includes crosstalk as well as ringing. Comparing the height of the small width peak with the previous plot, we know that crosstalk is important in both DCs and PCs, but that there width is small and has a fairly restricted range. By looking at that same plot after crosstalk removal, we find out how effectively the code identifies the hits (see figure 6).

The next cuts are on the time difference between a wide hit and the crosstalk hits that it causes. Two nicely defined peaks are visible on this time difference spectrum (figures 7 and 8). They are separated in DCs but overlap in PCs. Figure 8 is limited to crosstalk hits on the first adjacent cell only, and we see that these are the hits that form the first peak. As we had seen in figure 1, hits on the first adjacent cells are due to a large capacitive pulse and occur earlier than other crosstalk hits. This important fact will be very helpful in helping us recovering misidentified hits in PCs if we decide we need to do so. Finally, looking at this spectrum per plane in figure 9, we notice that there are important variations in PCs. It is intriguing that the first peak (for first adjacent hits) is not seen in PC 5. In the other target

PCs, the peak is replaced by a more or less continuous spread up to 0. This is not yet understood.

In figures 10 and 12, we see a new detail about the crosstalk hit width. It seems there are two distinct peaks in crosstalk width but they are not related to the two peaks in time difference. The smaller width crosstalk only appears for later crosstalk (hits that are not on the first adjacent wire) as visible on figure 10. This could be an indication of crosstalk across planes, but it is not clear why we would detect so many of these hits in DCs with the current code, since they have to be coincident with a wide hit in the same plane to be identified.

By looking at the width difference (between the wide hit and crosstalk hit) distribution in figure 11, we find that our cut is well below the bulk of identified hits, but in PCs, there is a spread that goes down in width difference and time difference past our cut. We believe these are cases where the particle went through two cells and we are associating crosstalk hits caused by the first (and widest) of these two hits with the second (smaller). This is consistent with the fact that both the width difference and time difference would be smaller than usually. This would also not be observed in DCs because the longer drift time would cause the second wide hits to occur after the crosstalk hit caused by the first wide hit.

Multiplicity

The number of hits per plane (figure 13) is similar in PCs and DCs and the distribution is as expected. As noted before, the number of hits per wire (figure 14) is much larger in DCs than PCs, where it is almost always 1. These hits are currently not identified in code as they don’t affect tracking, but we must remember that hits on a wire are sorted in reverse time order, so the first hit in time (the hit we’re interested in in most cases) will be the last one in the wire hit structure (...hits(dc_whits(iplane,iphit)%nhits) should be used, not ...hits(1)).

Remaining narrow hits after crosstalk removal

Plots of TDC width vs. time for all PC hits are shown in figure 15 before and after crosstalk hits are removed. Let’s first identify each region in this plot looking at figure 16. The left plot shows the early and wide muon hits that cross a cell near the wire. The second plot shows hits on the first adjacent wires. Real hits start at the main muon region and they go down in width and occur later in time as the particle crosses the cell closer to the edge, leaving less ionization in the cell. The spot below this spread consists of prompt crosstalk hits on the first adjacent wire. Finally, the right plot shows other hits, mostly crosstalk, and we see that this region falls right at the end of the second real hit region. Going back to figure 15, the only region not identified (below the main muon region) consists of beam and decay positrons.

Comparing the two plots of figure 15, we find that most of the crosstalk hits are removed, but some narrow hits with the typical crosstalk width remain. We also see that the tail of the second real hits region was removed. As noted earlier, we could probably recover these by modifying the time difference cuts for the first adjacent cells.

To find out if remaining narrow hits after crosstalk removal were due to cuts that were too strict, we looked at each of them and classified them according to their relation to other hits in the plane. The results are in figure 17. For DCs, most fall in case 3: there was a wide hit around, but it was much too early (over twice the cut) or after the narrow hit and could not have caused it. These hits could be another evidence of crosstalk across planes. The second most important case for DCs is case –1: there was a wide hit on this wire before the narrow one. These hits are clearly ringing, and we did see in figure 5 that there was a considerable amount of it in DCs.

The picture is quite different for PCs. Most narrow hits fit case 2: they were rejected by cuts but not by much. Further analysis shows that the responsible cut is width difference most of the time. While discussing figure 11 we suggested that most of these were associated with the wrong wide hit, but if that were the case, they would be removed when the correct wide hit was investigated. Since they were not, we might need to adjust the width or width difference cuts, but we should first understand what these hits are. The second case in importance for PCs is case 1: the hit was crosstalk, it fits all the cuts, but it was further away from the wide hit than we were looking. In this case, we were looking half a plane away (32 cells), we should increase this to the whole plane if we want to remove these hits.

At this point, we should stress that removing crosstalk effectively in PCs is not a priority. PCs are used for timing, not for tracking. Even if we remove a few real hits or leave some narrow hits, no timing information is lost since there will always be some wide hits remaining. Also, the ADCs for the target PCs show very little crosstalk, so they do not depend on TDCs to find out which hit to consider for energy loss analysis.

The last case (0) is when there are no wide hits in the plane. This is yet another candidate for crosstalk across planes, but there is another possibility here. It has been observed that in some events one or more planes have one or more small hits recorded on every cell. In many cases, no wide hit was found that could explain this as crosstalk. The classification would identify these narrow hits as case 0.

So for DCs, it seems the code works well (the cuts are well adjusted) and not many hits are missed although most narrow hits remaining are unexplained. In PCs, we know some crosstalk hits far from the wide hit that caused them are not identified with the current cuts. There are also a number of hits that could be crosstalk but that were rejected because of the width difference cut. This cut should probably be modified once these hits and the spread in figure 11 is better understood.

Crosstalk vs. threshold

The variation of crosstalk with threshold was analyzed with runs 5614-5629. Only the threshold on the outer PCs was modified. Note that these runs were muons stopping near the target, so downstream crosstalk numbers are for decay or beam positrons. All PC high voltages are 2050 V.

While it has been noted that efficiency does not drop too fast for most PCs when raising the threshold from –175 to –400 mV, in this same region, crosstalk seems to increase exponentially (see figures 19 and 20). In each plot the two crosstalk curves (solid, white) go with the axis on the left. They represent the fraction of all recorded hits that are identified as crosstalk and the fraction of wide hits that generated crosstalk. The two multiplicity curves (dashed, green) go with the axis on the right. They represent plane and wire multiplicity (as described under statistical measurements). Note that plane multiplicity does not vary much: a change from 5% to 40% crosstalk would theoretically only increase plane multiplicity from an average of 1.053 hits to 1.67 hits. This is comparable to what is obtained, the higher value being accounted for by other real hits.

Crosstalk is also noticeably higher in the first PC of each group (1, 5 and 9). This is highlighted in figure 18, which shows crosstalk for PC 1 and 2, ganged wires and central wires separately. The higher crosstalk in ganged wires is expected since pulses from four wires are added. This can be corrected for by having a higher threshold on these wires.

Conclusion

We now have the tools necessary to identify crosstalk hits in both DCs and PCs. The amount of remaining narrow hits after crosstalk removal and their classification show that the code works well for DCs and is adequate for our use of the PCs, although there remains a few unanswered questions such as the amount (if any) of crosstalk between planes and how many real PC hits are removed by the code. This last question will soon be answered by analyzing Monte Carlo data with the crosstalk code. We expect the amount of misidentified hits in DCs will be negligible, and small in PCs where the effect doesn't affect our results anyway.

Comparison of crosstalk and efficiency at different high voltage and threshold settings will continue, but we already have found a good operating point that maintains efficiency above 99.9% while minimizing crosstalk. Current recommendations are conservative and lean towards higher efficiency and crosstalk since the latter can be removed by code. They are listed in table 1 below.

	High Voltage (V)	Threshold (mV)
DCs	1900	-125
Target PCs[4]	2000	-150
Outer PC central wires	2050	-250
Outer PC ganged wires	2050	-300

Table 1: Current operating high voltage and threshold recommendations.

[4] At the time this report was written, crosstalk and efficiency as a function of threshold data was not taken for target PCs, so the threshold recommendation here is very conservative (low). After study, it will probably be the same as other non-ganged wires.

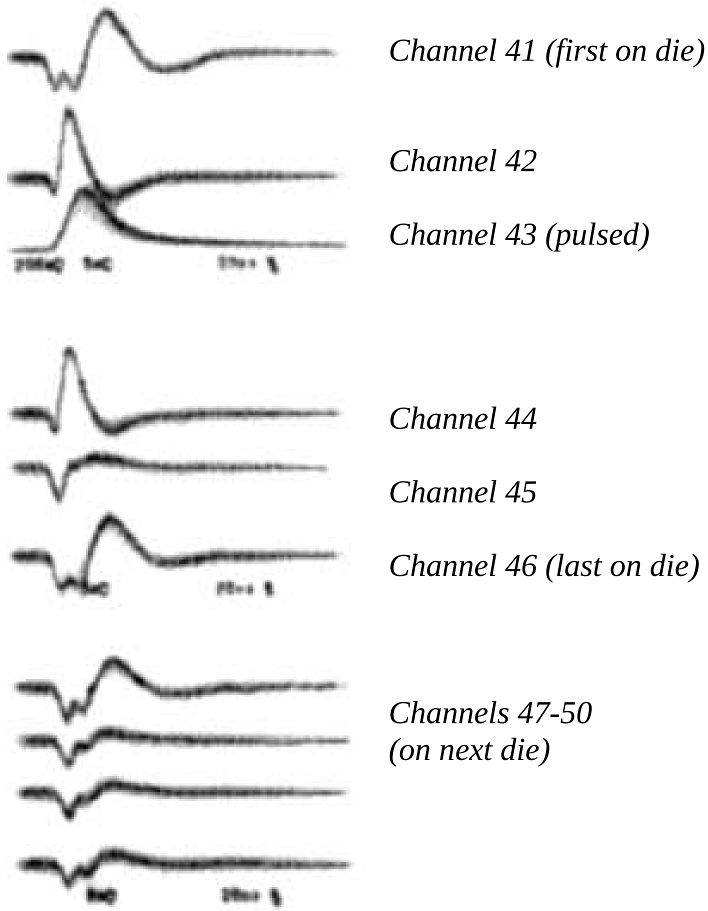

Figure 1: Pulse shape of crosstalk signals across preamp channels (different scale for pulsed channel 43).

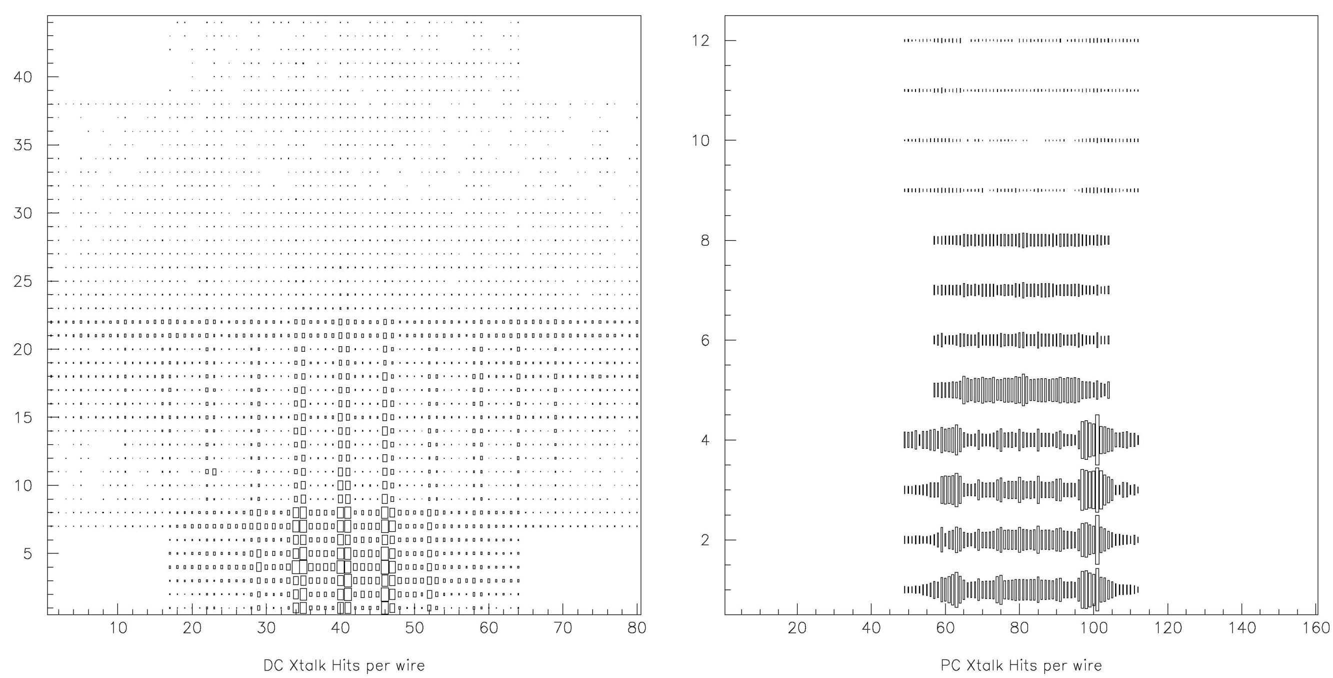

Figure 2: Crosstalk hits per plane (left: DCs, right: PCs).

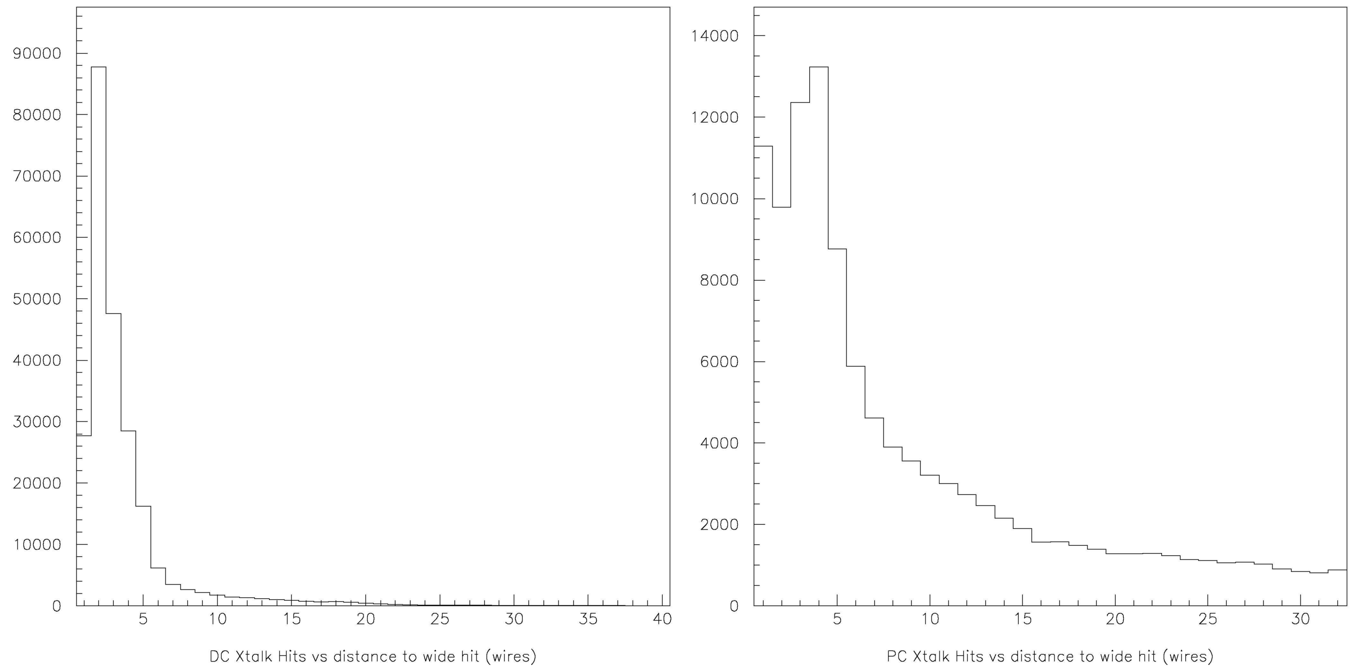

Figure 3: Crosstalk hits vs. distance from wide hit (in wires) (left: DCs, right: PCs).

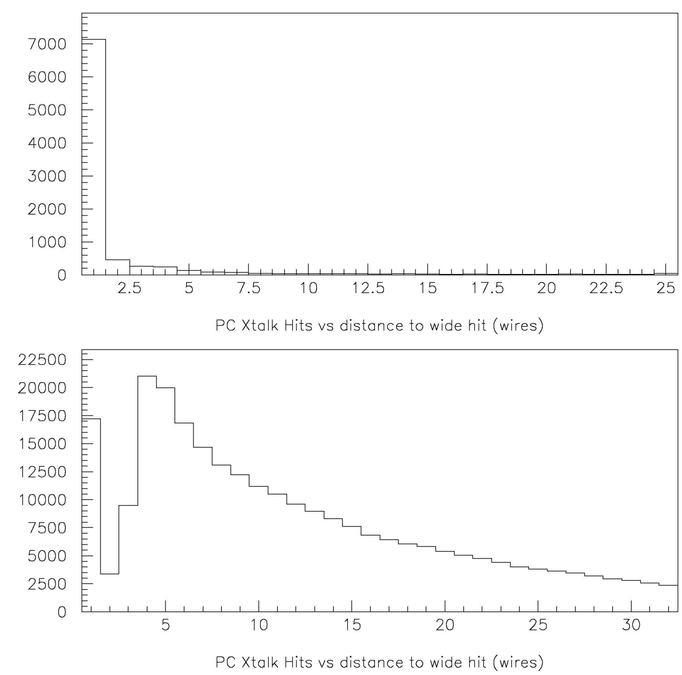

Figure 4: Crosstalk hits vs. distance from wide hit (in wires) for PCs for high threshold (top) and low threshold (bottom).

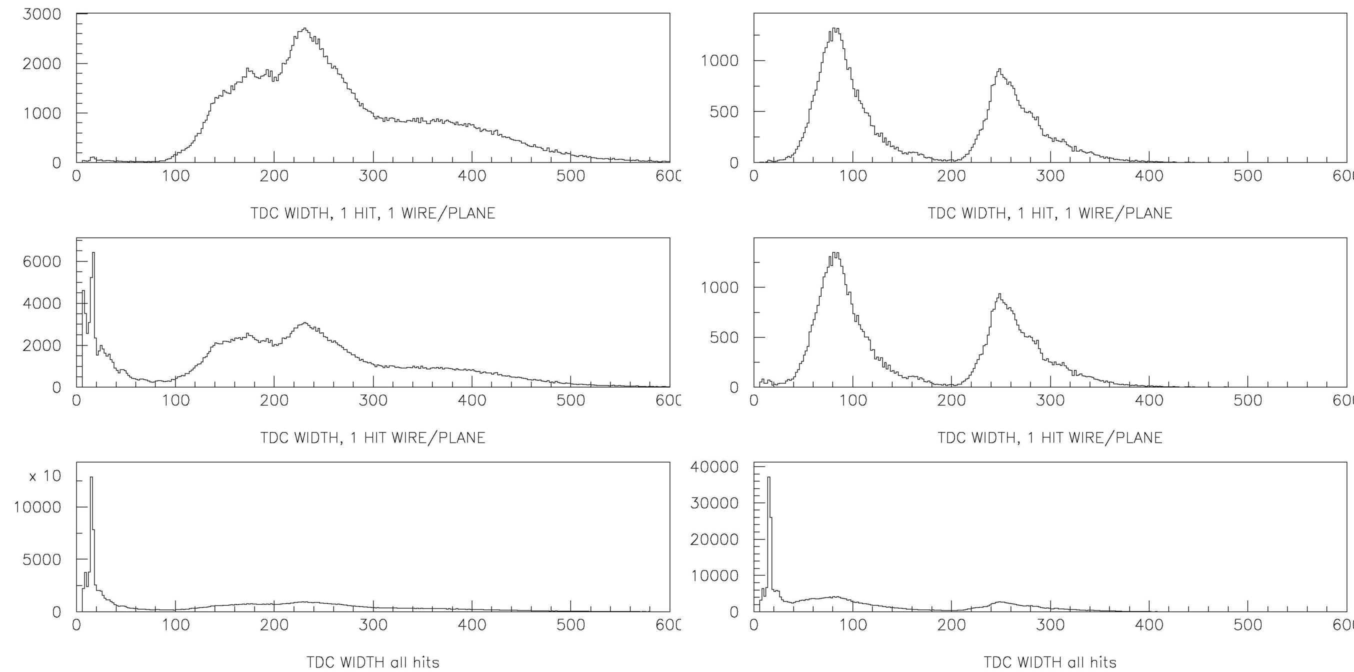

Figure 5: TDC width spectrum with various restrictions (ns) (left: DCs, right: PCs). Top to bottom: only one hit per plane, only one wire hit per plane, all hits.

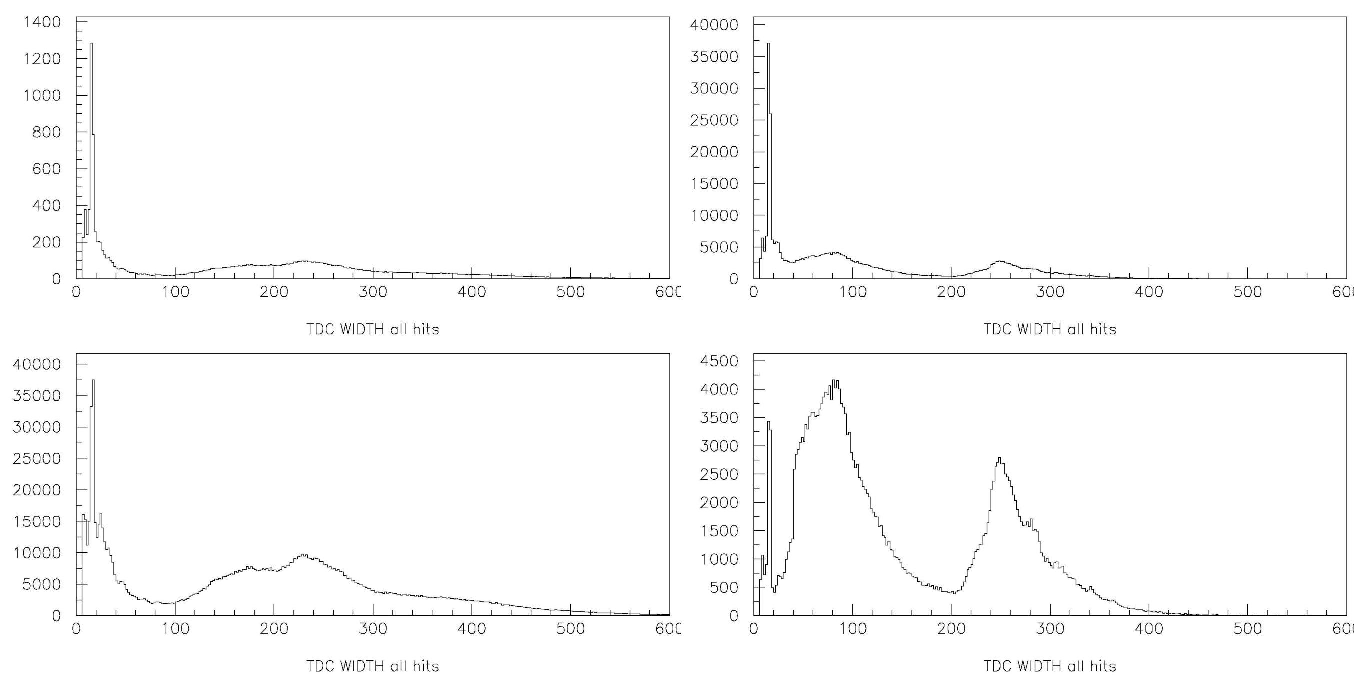

Figure 6: TDC width spectrum for all hits before (top) and after (bottom) crosstalk removal (ns) (left: DCs, right: PCs).

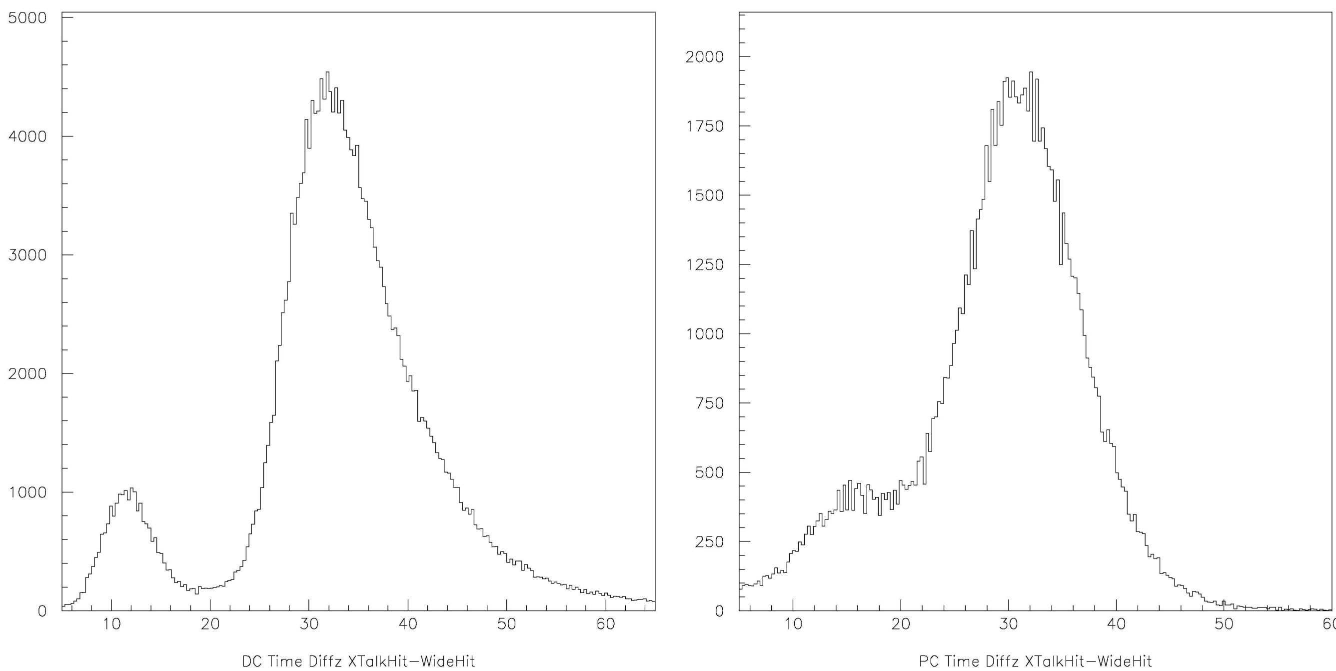

Figure 7: TDC time spectrum of crosstalk hits (ns) (left: DCs, right: PCs).

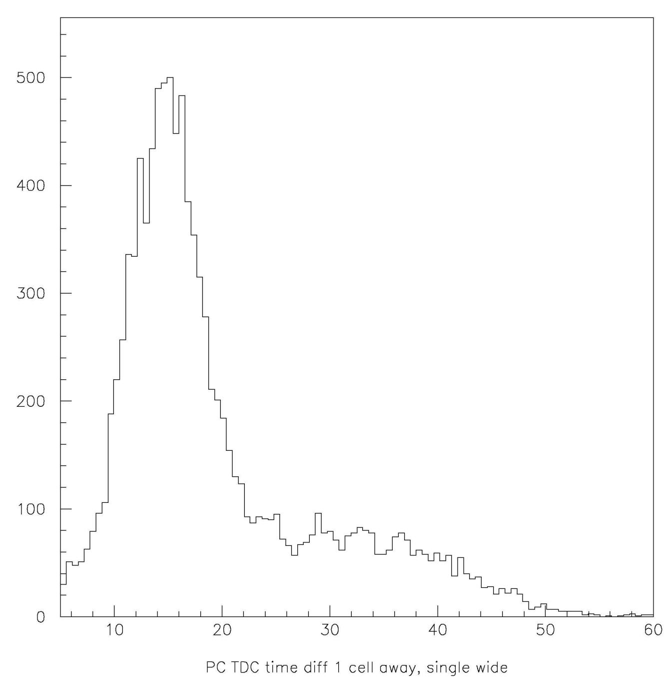

Figure 8: TDC time spectrum (ns) of crosstalk hits on first adjacent cell for PCs, when the wide hit is a single hit (there is no coincident wide hit on first adjacent cells).

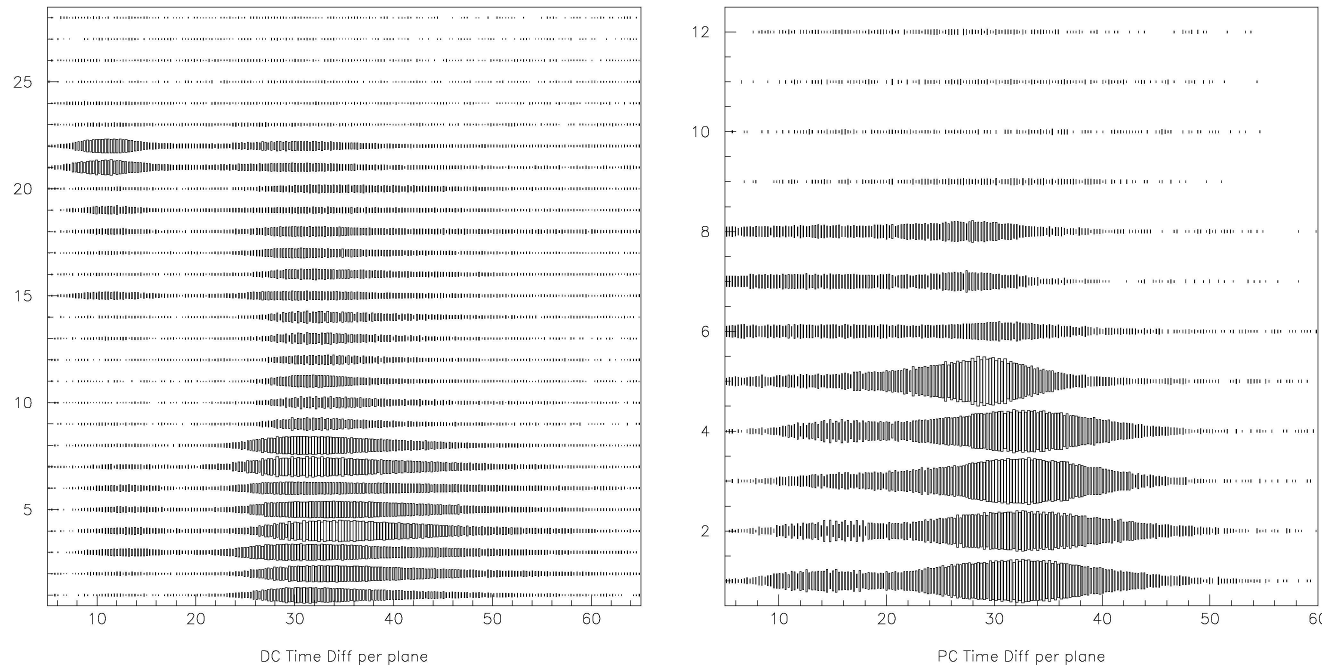

Figure 9: TDC time spectrum of crosstalk hits per plane (ns) (left: DCs, right: PCs).

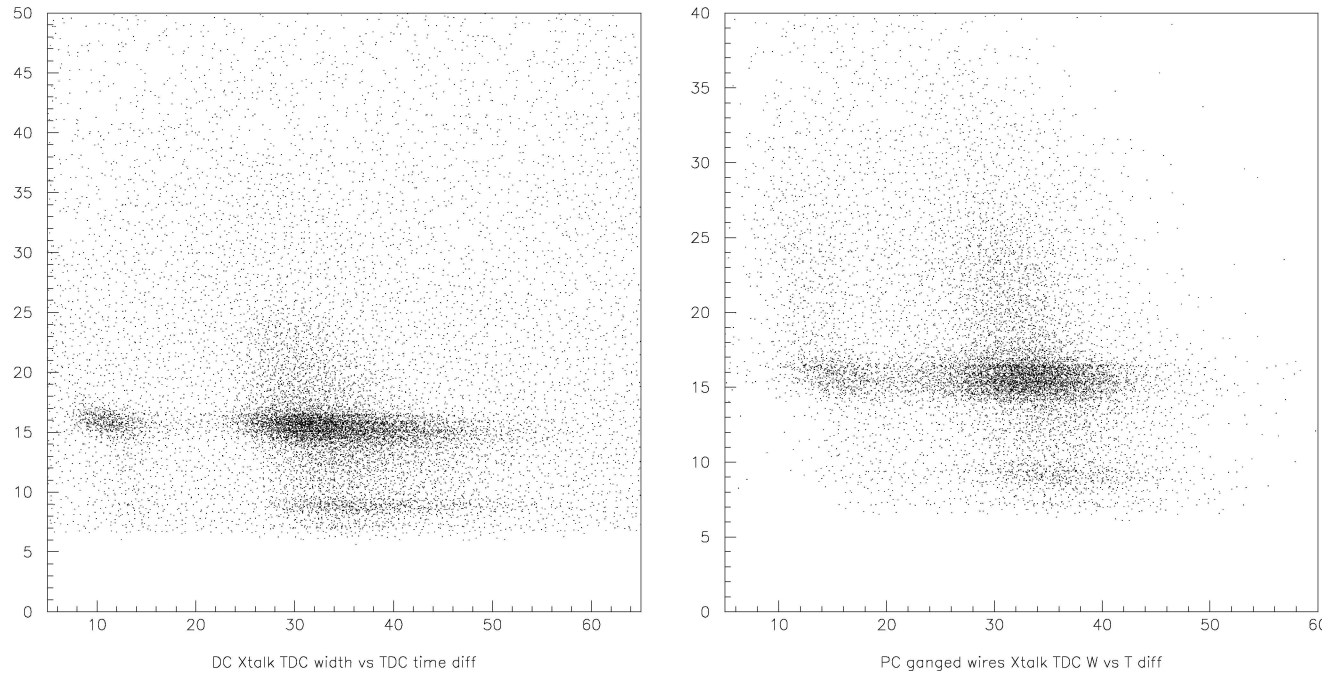

Figure 10: Width of crosstalk hit vs. time difference between wide hit and crosstalk hit (ns) (left: DCs, right: PCs).

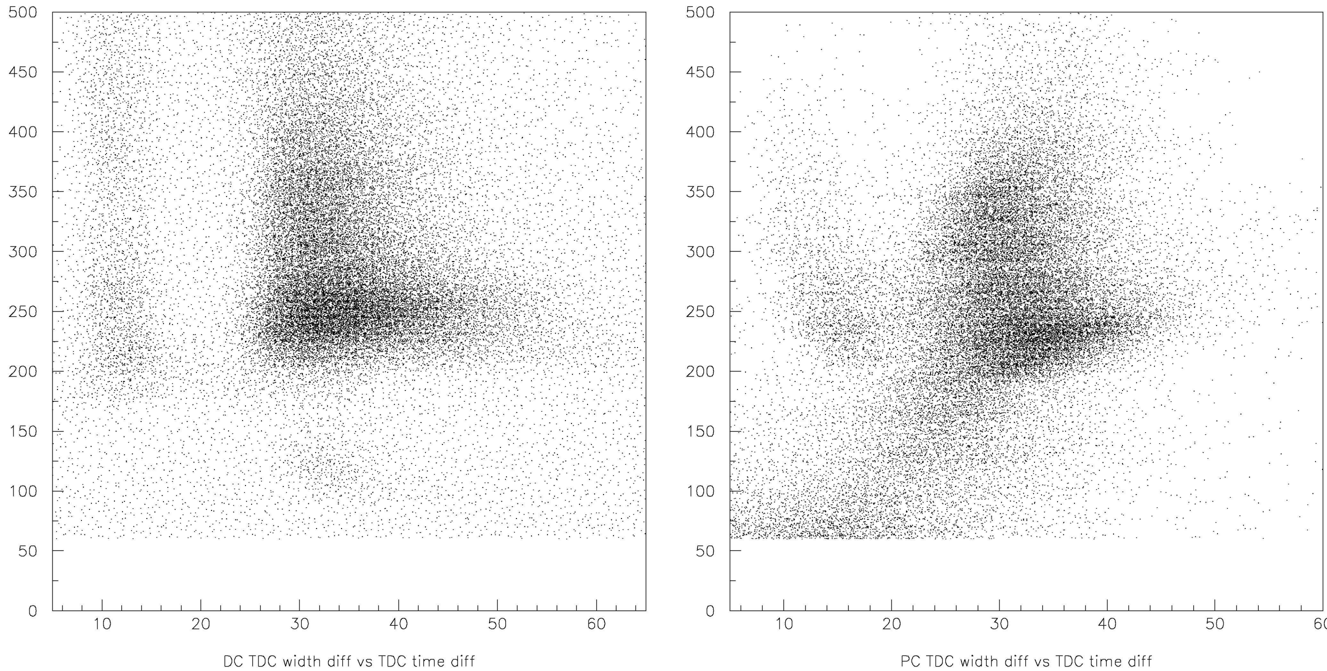

Figure 11: TDC width difference vs. time difference between wide hit and crosstalk hit (ns) (left: DCs, right: PCs).

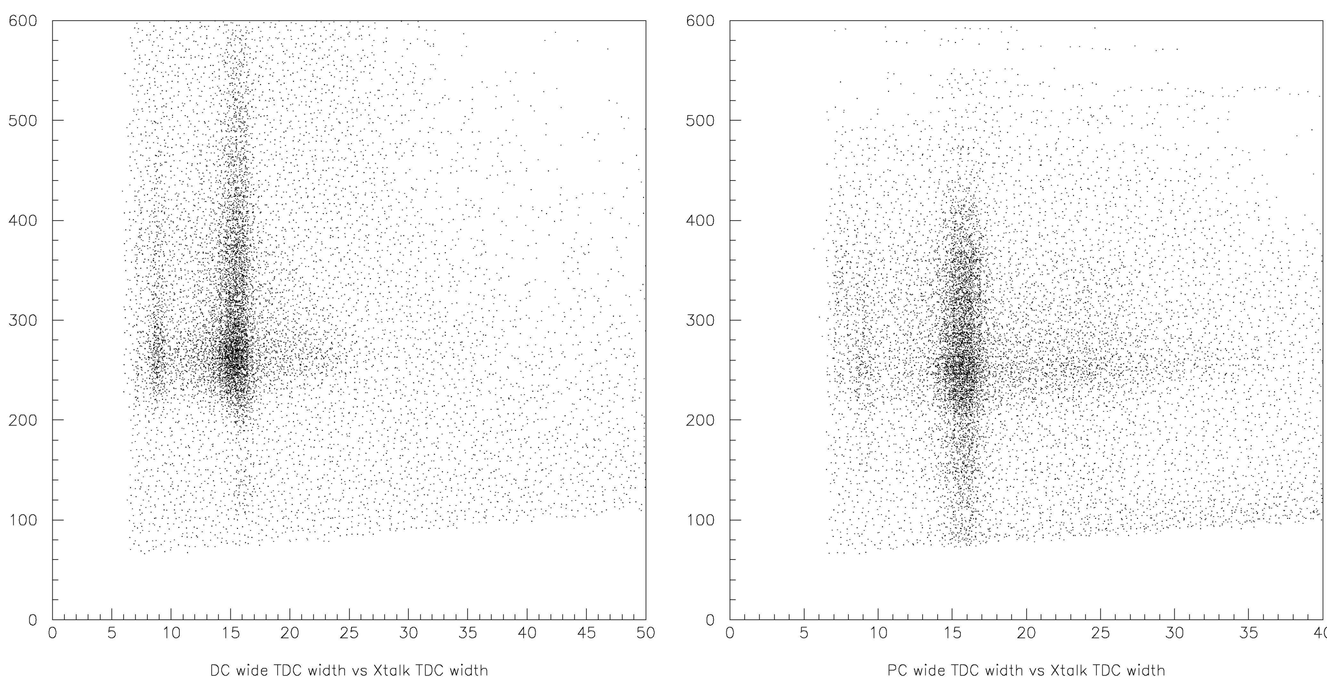

Figure 12: TDC width of wide hit vs. crosstalk hit (ns) (left: DCs, right: PCs).

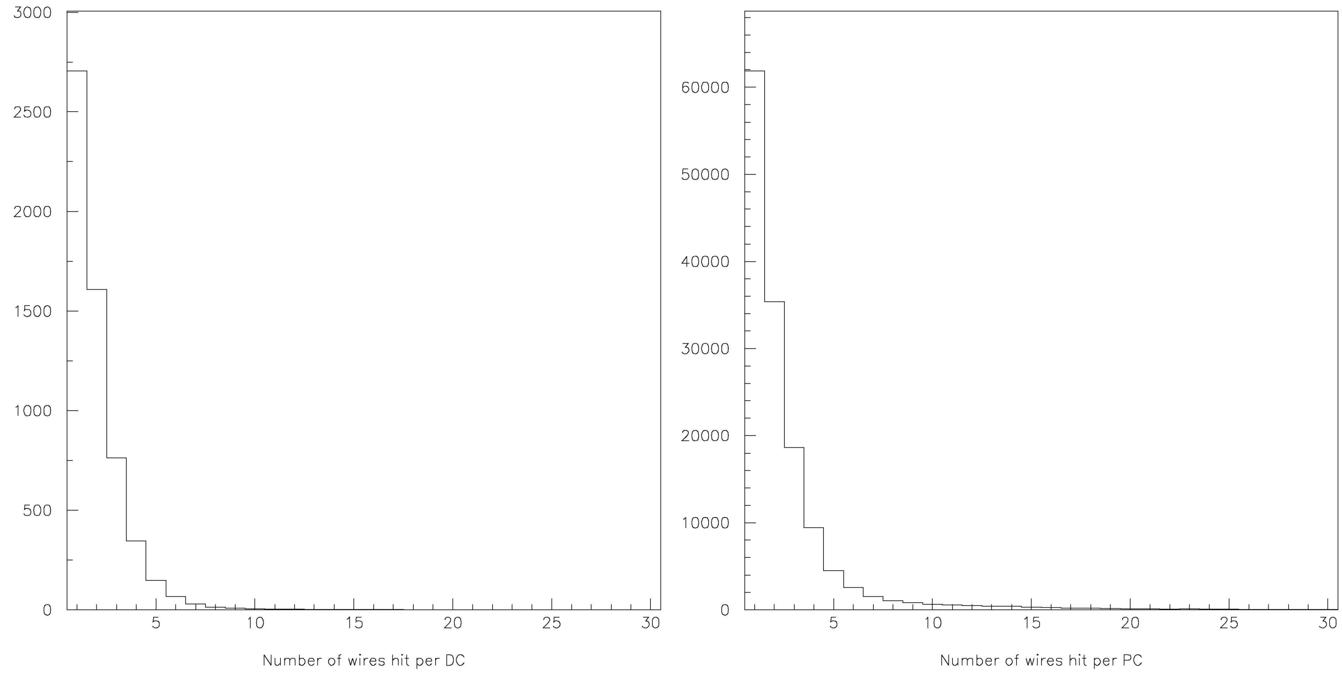

Figure 13: Plane multiplicity: number of wires hit per plane (left: DCs, right: PCs).

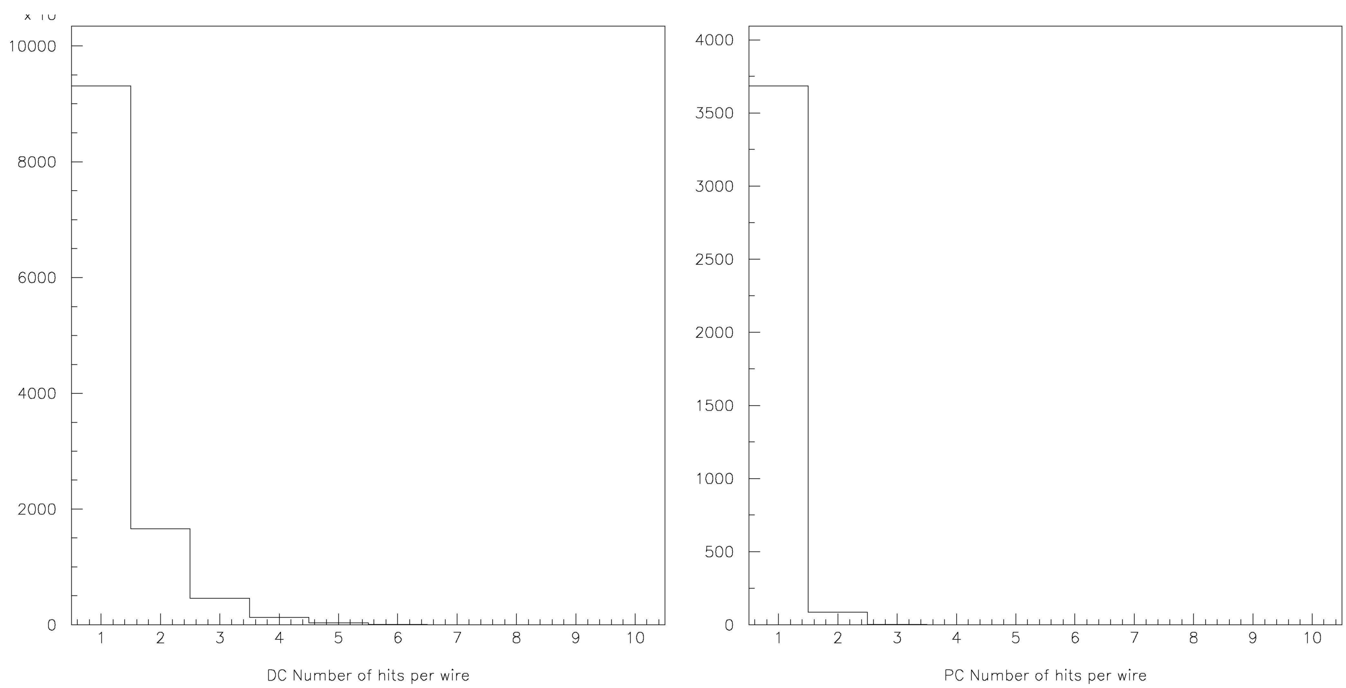

Figure 14: Wire multiplicity: number of hit per wire (left: DCs, right: PCs).

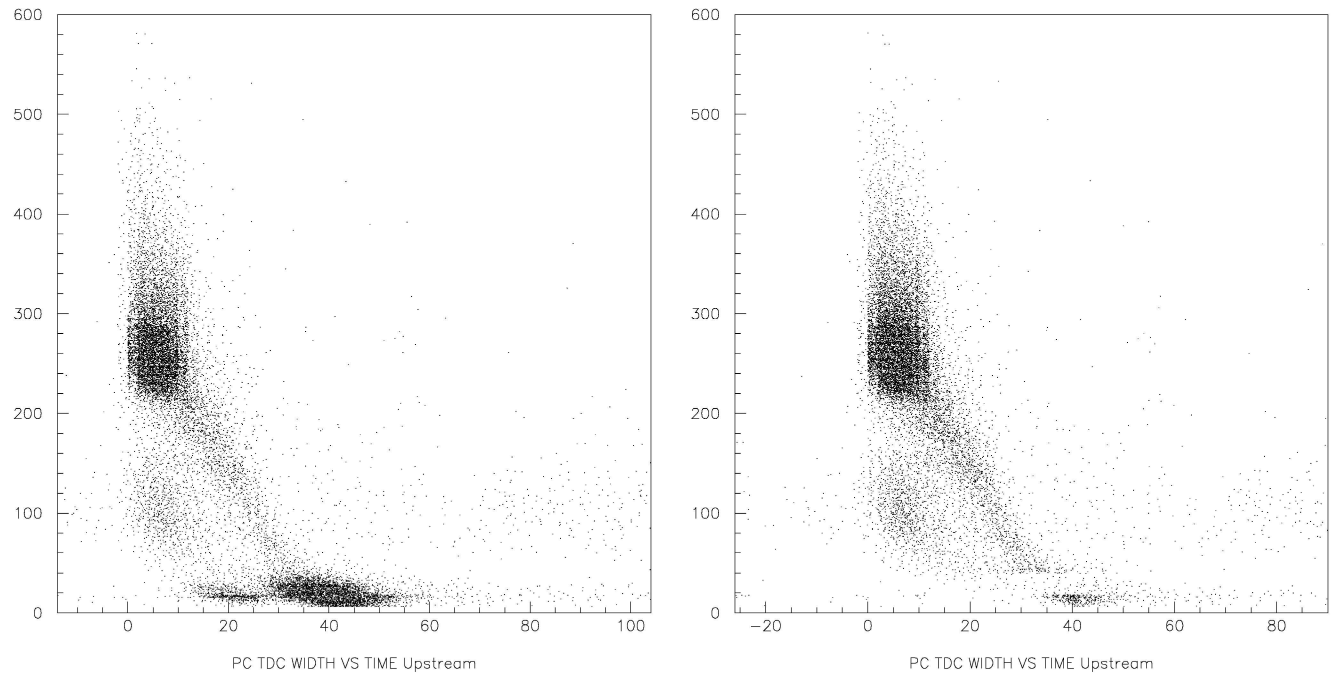

Figure 15: TDC width vs. time for all PC hits (ns)
(left: before, right: after crosstalk removal).

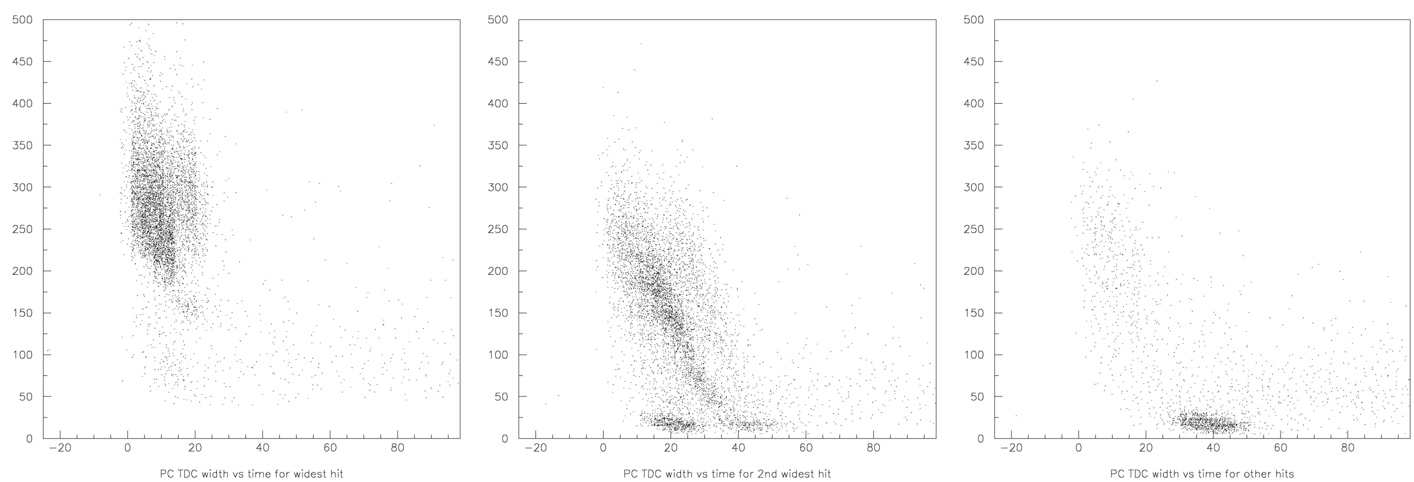

Figure 16: TDC width vs. time (ns). From left to right: widest hit, first adjacent hits to widest, other adjacent hits.

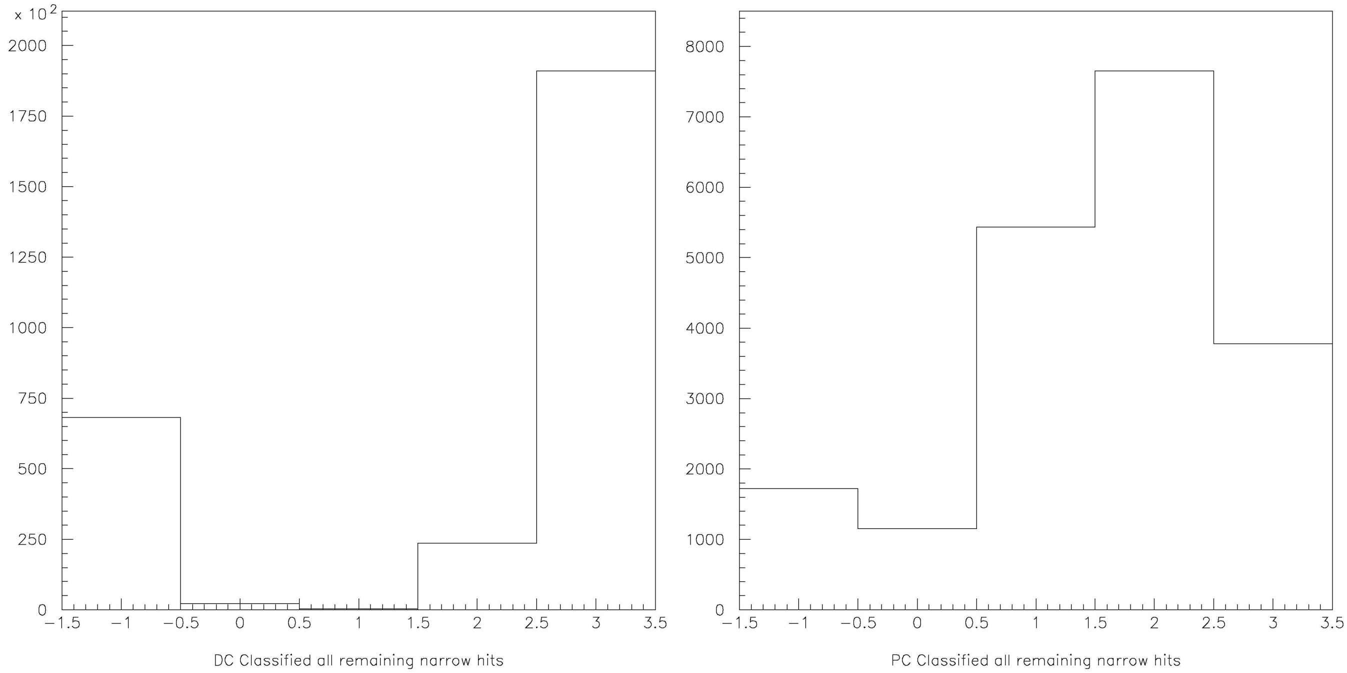

Figure 17: Classification of narrow hits after crosstalk removal (left: DCs, right: PCs). -1: Could be ringing, 0: Unknown, no wide hits in plane, 1: Fits all cuts, but too far from wide hit, 2: Was outside some cuts, but not by a lot, 3: Unknown, was well outside all cuts.

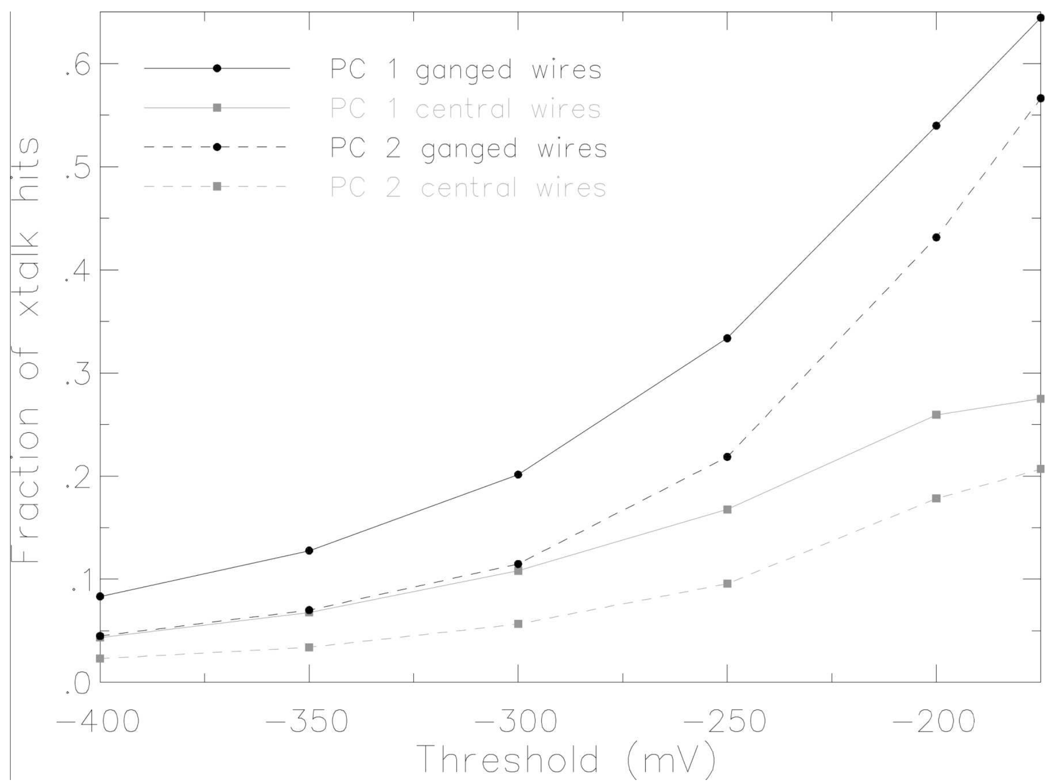

Figure 18: PC 1 and 2 fraction of all recorded hits that are crosstalk vs. threshold, for ganged and central wires.

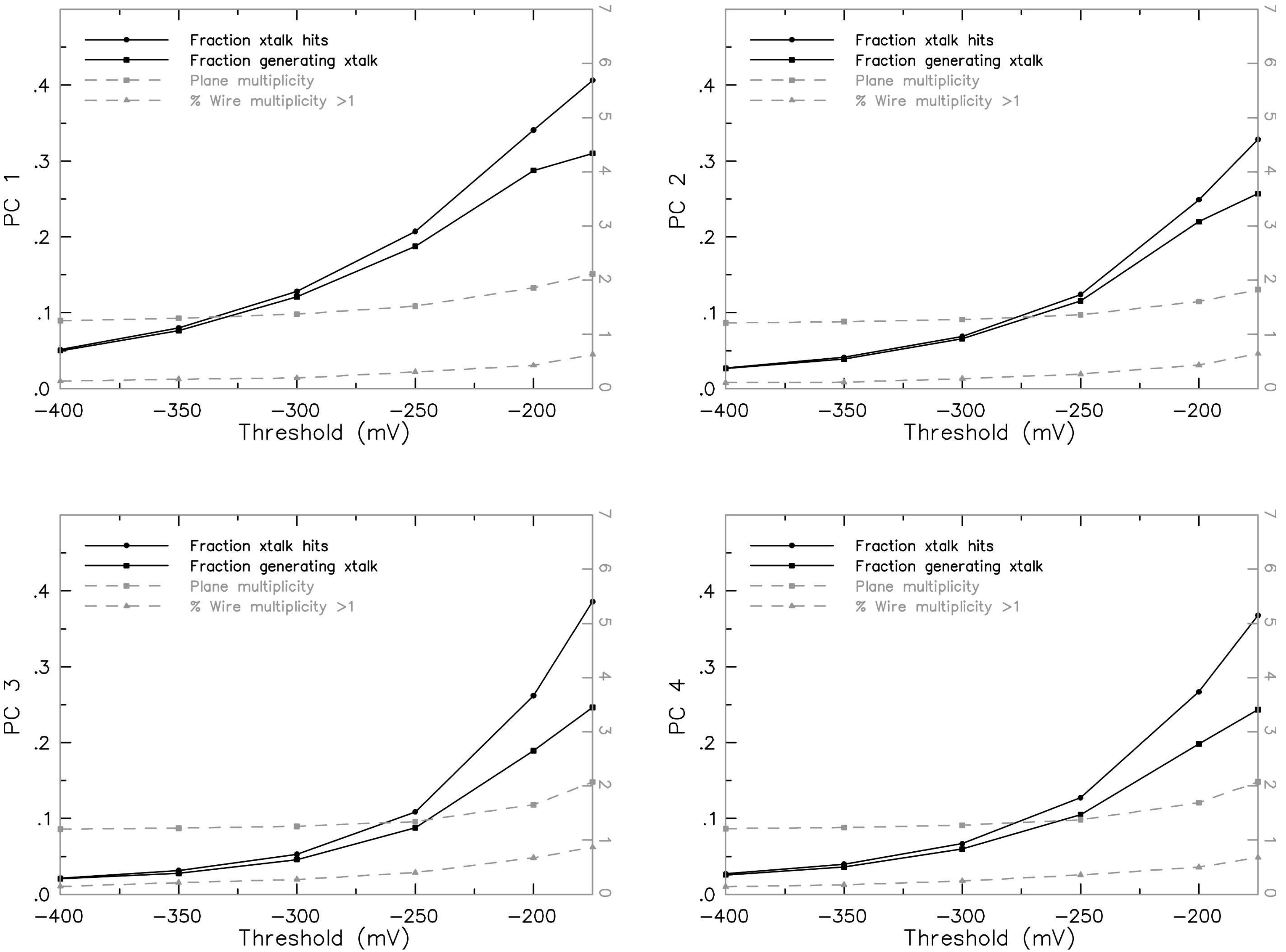

Figure 19: Upstream PC crosstalk and multiplicity as a function of threshold.

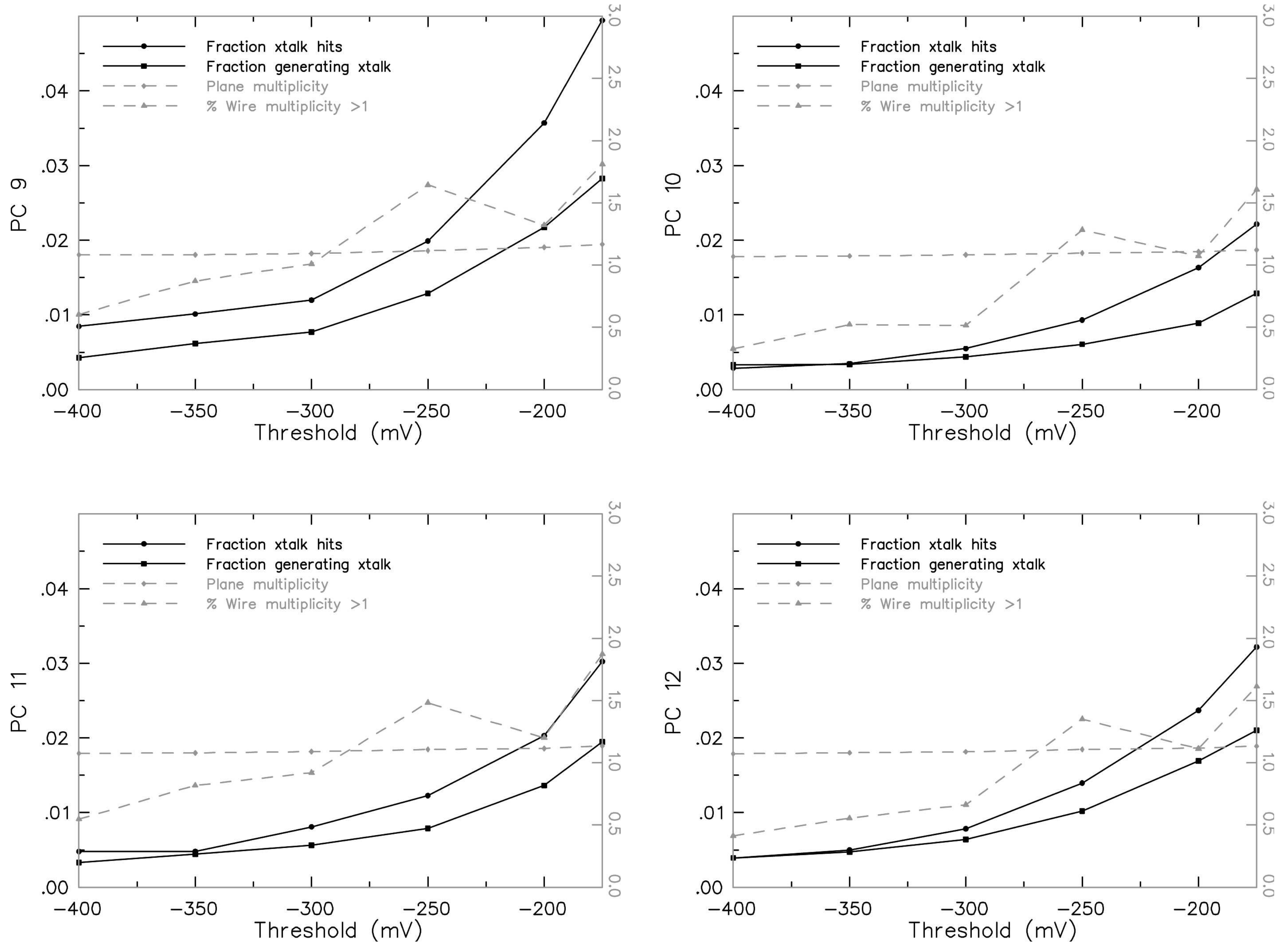

Figure 20: Downstream PC crosstalk and multiplicity as a function of threshold.