Study of Dark Noise Rate in Super-Kamiokande

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1 Introduction

This report examines the dark noise rate in photo-multiplier tubes in the outer detector of Super-Kamiokande. Super-Kamiokando is a large water Cherenkov detector located in Kamioka, Japan. Before an event registers in the detector, the photo-multiplier tubes still claim a certain number of hits. These hits are considered dark noise, since there is no Cherenkov light in the detector from the triggering event. A rate for this dark noise can be determined by calculating the number of hits in a specific time frame. The rate was studied over the full run of the experiment thus far (1999-2009) with a focus on SK4, the current version of the experiment. A more accurate dark noise rate will in turn provide more accurate simulations of neutrino events.

To come up with this dark noise rate, it was necessary to consider hits that are out of time, that is, hits in the detector that register before an event. There is a peak in the distribution immediately following a neutrino event, but the most important hits in this study were counted in the time frame 8000 to 500 nanoseconds before the neutrino event. See Figure 1 for reference.

2 Simulations with OD Hits

Simulations were run with varying levels of dark noise in order to determine how this noise affects quantities used in selecting and reconstructing neutrino events. The levels ran between 4000 and 6000 Hz. In the left image of Figure 2, the distributions of these simulations are displayed for hits registered on the OD of SK. There are 1253 events, each event registering a certain number of hits. The hits seem to peak in similar

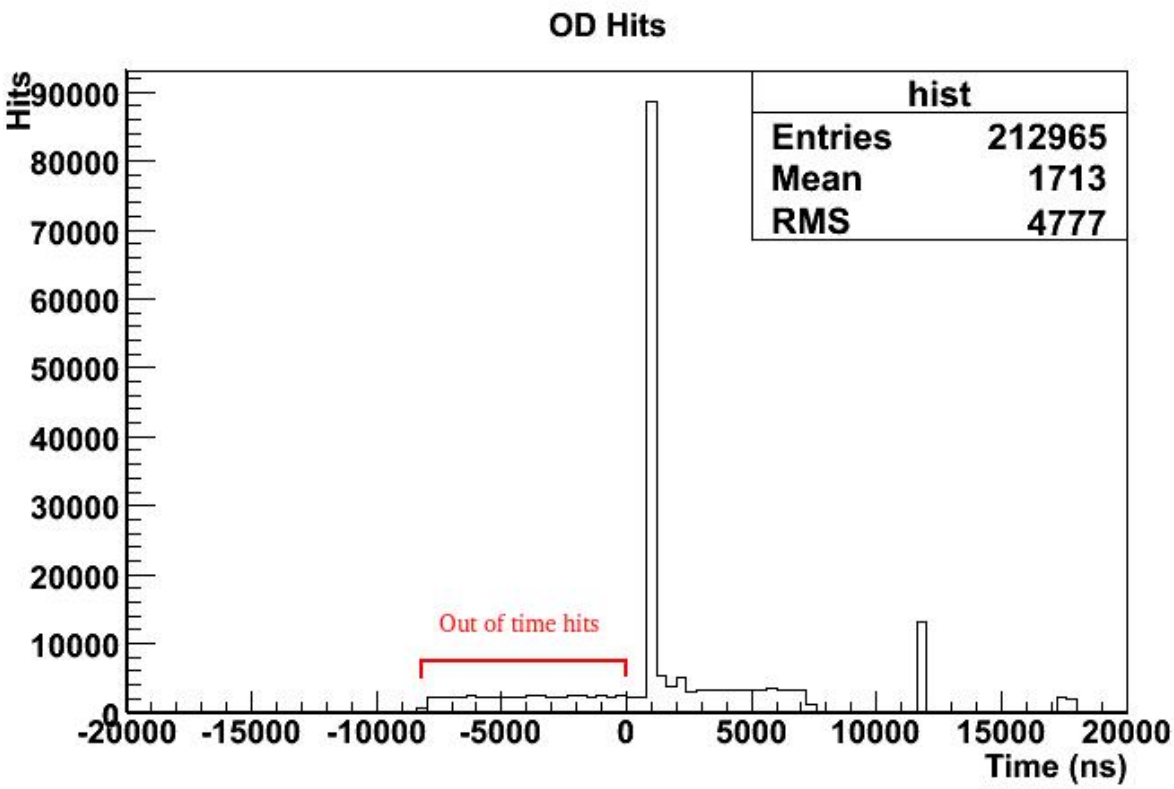

Figure 1: Hits in the outer detector with an emphasis on out of time hits

locations, independent of the inputted dark noise rate. In a time frame (T) of 1000 nanoseconds in the outer detector, which has 1885 photo-multiplier tubes (N), you would expect to get N*R*T extra hits, where R is the dark noise rate from the simulations. So for 4000 Hz, you would expect about 7 extra hits, 5000 Hz correlates with 9 hits, and 6000 Hz theoretically shows 11 extras.

The figure on the right shows a similar simulation, but with a wider range of dark noise rates (from 1000-7000 Hz for every 500 Hz) and plotted as hits vs. dark noise rate. These are the averages of 1253 events. With a dark noise rate ranging between 1000 and 7000 Hertz, the hits in the outer detector only increase by about 8.

3 Rate Compared to Tube Location

It seemed plausible that the dark noise rate in the outer detector is not homogeneous across tubes, and therefore it was important to discern if the rate varies according to location of each tube. Figure 3 shows

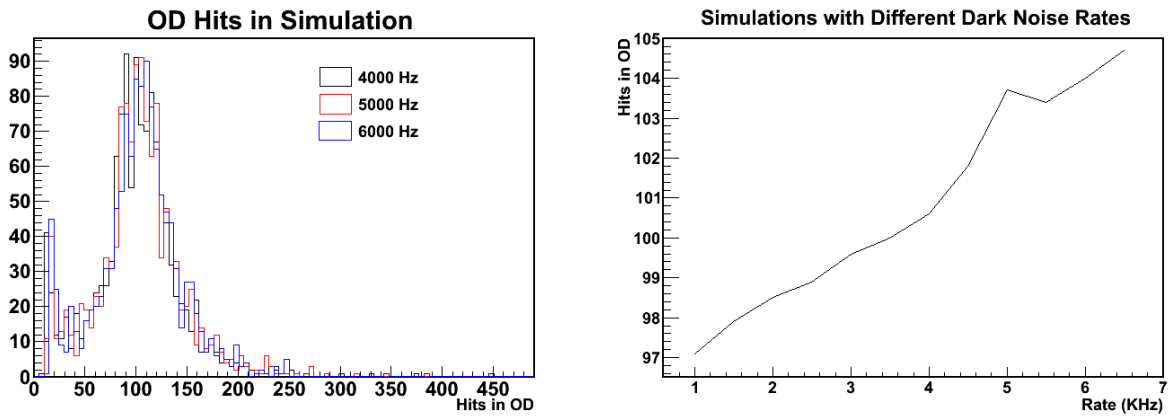

Figure 2: Simulations to determine background noise dependence

flat rollouts of the outer detector with the average dark noise rate for SK1, SK2, SK3, and SK4 . SK1 has a max value of 9,000 Hertz, while the rest have a maximum value of 10,000 so that a pattern can be seen. There does appear to be a pattern of dark noise, but it is not immediately apparent what this correlation is. The rate could be dependent on height, huts, or some other unknown factor. The next sections cover several of these possibilities. The graphs showing SK3 and SK4 show an increased rate in one particular spot at the top of the detector, around tubes 340, 339, 357, and 356. The hot spot persists in every run sampled throughout this time period. This could possibly be contributed to a light leak in the tank.

Figure 4 is another rollout of the outer detector, divided into huts to see if this compares to the striations in the rollout of the dark noise rates. There are four huts in the outer detector, and each photo-multiplier tube goes through a hut. However, they are divided into four large chunks by location, and it appears the huts are not the cause for dark noise differences.

The next possibility to consider is the tube location. The set of graphs for Figure 5 show that the dark noise rate is indeed influenced by position in the outer detector (wall, top, and bottom). The rate is decidedly lower in the top of the tank, and slightly lower on the bottom. Also, the average rates in the old tubes seem lower than the rates in the new tubes.

More specifically, it is interesting to observe the differences based on position on the detector wall, from the base of the detector to the top. From Figure 6, dark noise rate can be seen to be decreasing as height increases, in a linear fashion. There is also an unaccounted for excess in the middle of the detector.

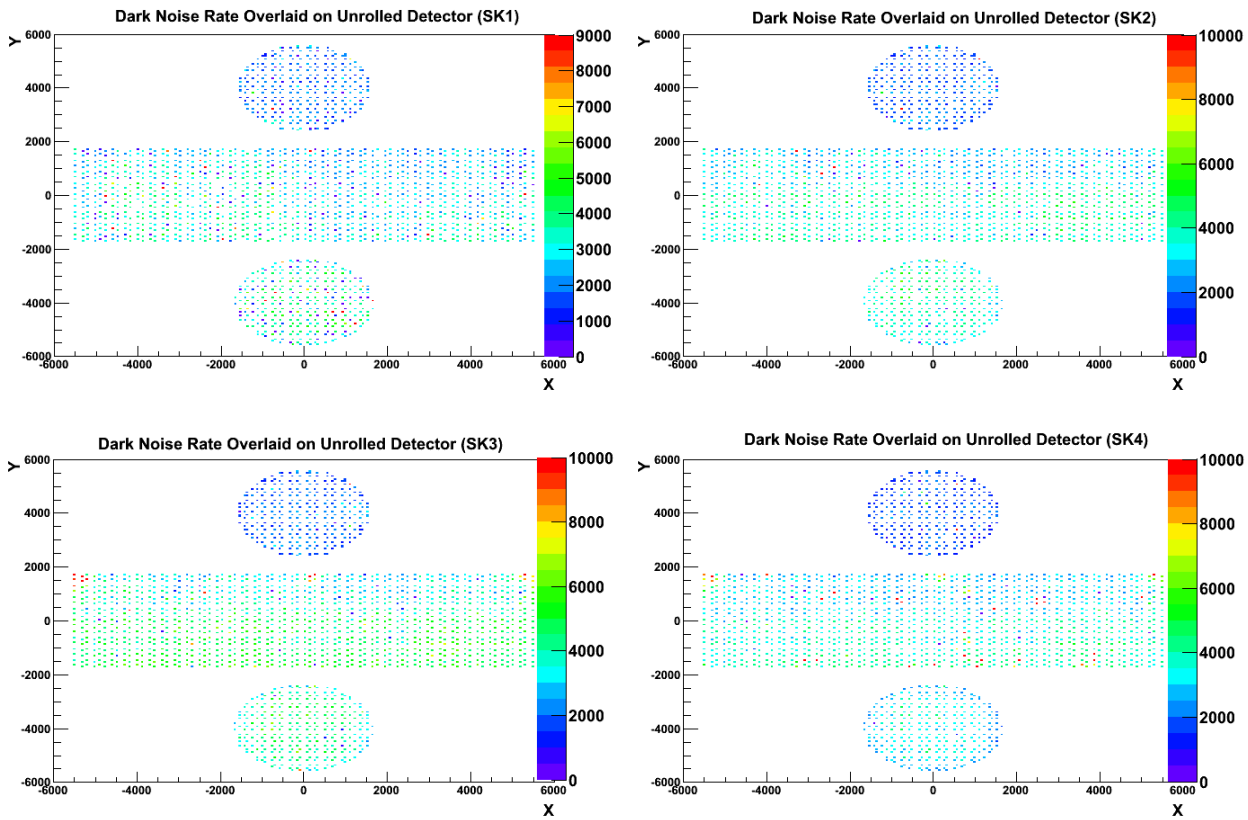

Figure 3: Dark noise visualization for runs in SK4

4 Rate Compared to Time

Next, dark noise rates were considered over a period of time to see if there was large fluctuation, or if the rate seemed to settle over time (which does appear to be the case.) In SK1, SK2, and SK3, a run was analyzed once every month, but in SK4 a run was taken into account every week, considering the short amount of time SK4 has been active.

Figures 7 and 8 are scans of dark noise rate over time for a few select tubes over SK3 and SK4, and also SK1-SK4. New and old tubes by location are placed side by side for comparison. The error bars in both sets of figures are statistical. Figure 9 superimposes the last five sets of graphs to emphasize the differences in rate by location of the tubes.

Ultimately, it appears that the dark noise rate in the outer detector has settled over time, although it is hard to tell with SK4 having run a much shorter time span than the other versions of the experiment. It seems as though a dark noise rate for the OD would need to incorporate a location dependent model.

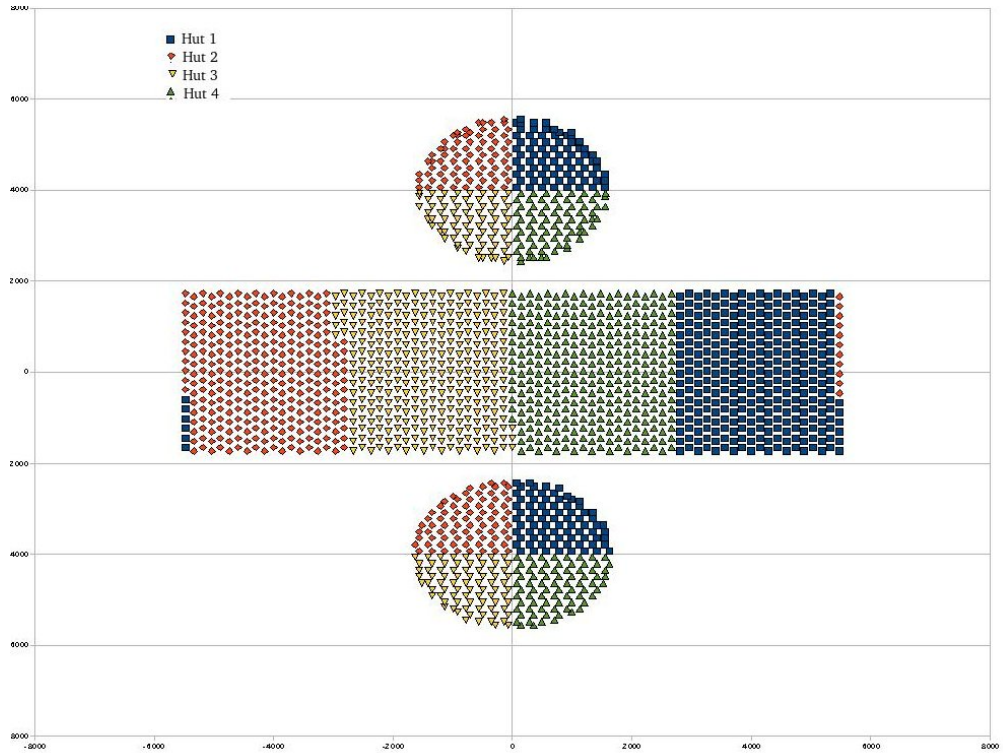

Figure 4: SK detector divided into huts

5 Tube to Tube Comparison

Figures 10 and 11 show direct comparisons between different SK versions for every tube. So for every tube there is a point comparing SK1, SK2, or SK3 to SK4. A direct x=y correlation would mean that the rates were exactly the same in every tube for different runs. This function is overlaid on several of the graphs to make the comparison more obvious. Colors show dependence on location or type of tube in order to accentuate dependence on the values.

There is a fair amount of correlation between SK1 and SK4. the rates seem even more consistent between SK2 and SK4, having an almost 1:1 ratio over all the tubes. In the graph comparing SK3 and SK4, there appears to be a correlation between the two, but the rates in SK3 are higher than in SK4. Also in the SK3 to SK4 comparison, the dark noise rate in the bottom of the detector is higher in SK3.

6 Distribution of Rates in SK3 and SK4

As can be seen in Figure 12, the distribution of dark noise rates in SK3 is wider than in SK4. Each entry in the histogram represents the dark noise rate for one run in SK3 and SK4. SK3 has 26 represented runs in total, while SK4 only has 18. It is expected that SK3 would have a higher peak (having more hits for certain rates due to the number of runs), but not necessarily more spread out, as appears to be the case. It is possible there is more variation within SK3 because its data was taken over a longer period of time. The trends of dark noise rate over time were not taken into account in this study.

7 Conclusion

A decrease in dark noise rate compared to time can be contribute to a settling of the photo-multiplier tubes after the detector is closed and light is no longer allowed inside, and possibly because of a decrease in radioactive backgrounds. Also, the rate may be higher on the bottom of SK due to better water quality on the bottom. The most interesting trend is the decrease in rate from bottom to top, with an excess in the middle of the detector. Less likely possibilities include a light leak or temperature differences. a light leak would have a higher rate near the top, and the detector would have a lower temperature near the bottom, which should correlate with a lower rate. The radon in the water could possibly contribute to a higher rate at the bottom, but again, the most likely cause of the difference in rate is due to the water quality. The water has a better quality at the bottom, which is generally associated with a higher dark noise rate.

As seen in the section comparing dark noise rates over time, there does seem to be a steady enough rate in each photo-multiplier tube to discern the average dark noise. The dark noise rate will be incorporated into skdetsim for better simulations.

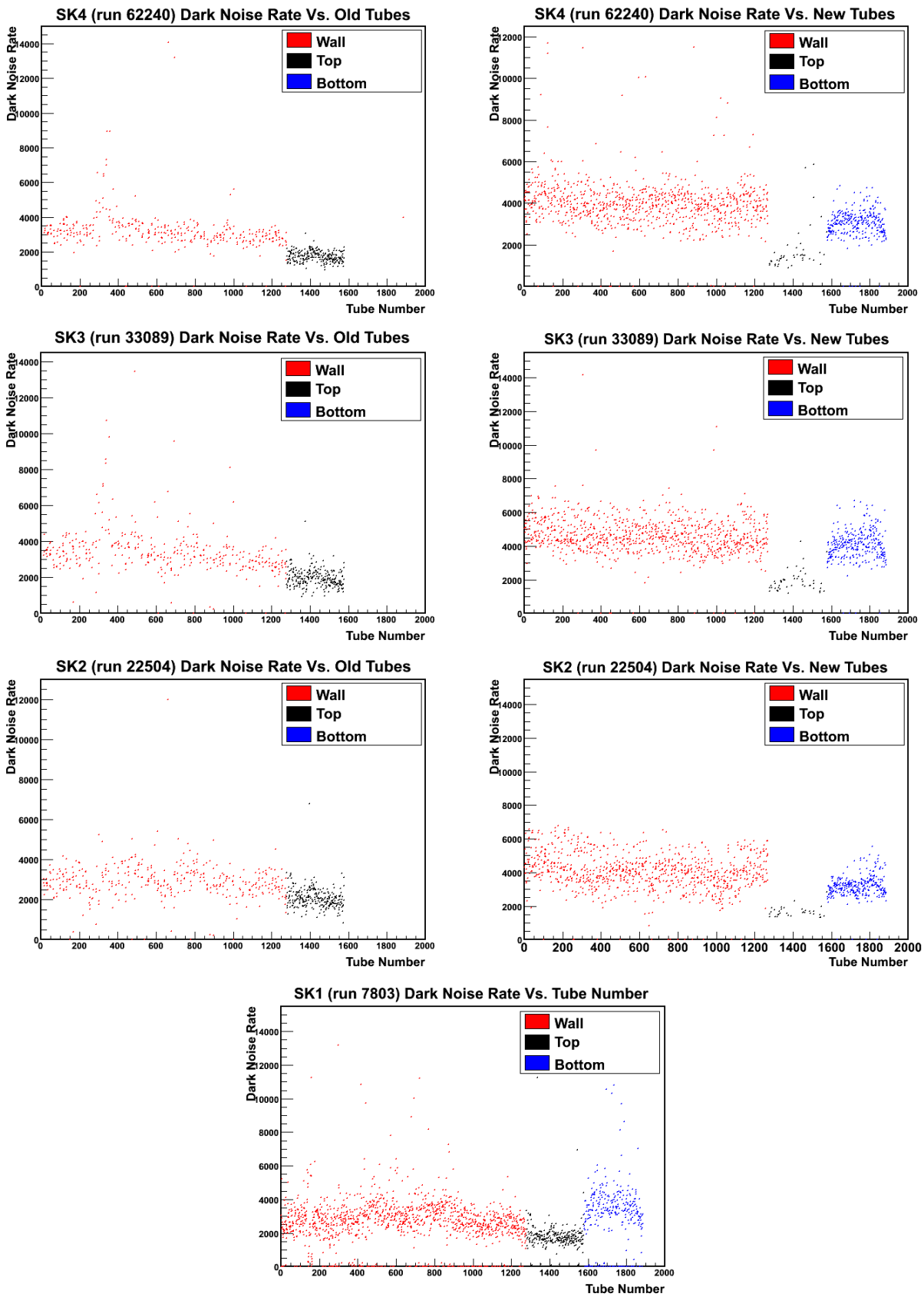

Figure 5: Set of graphs for dark noise rate by location

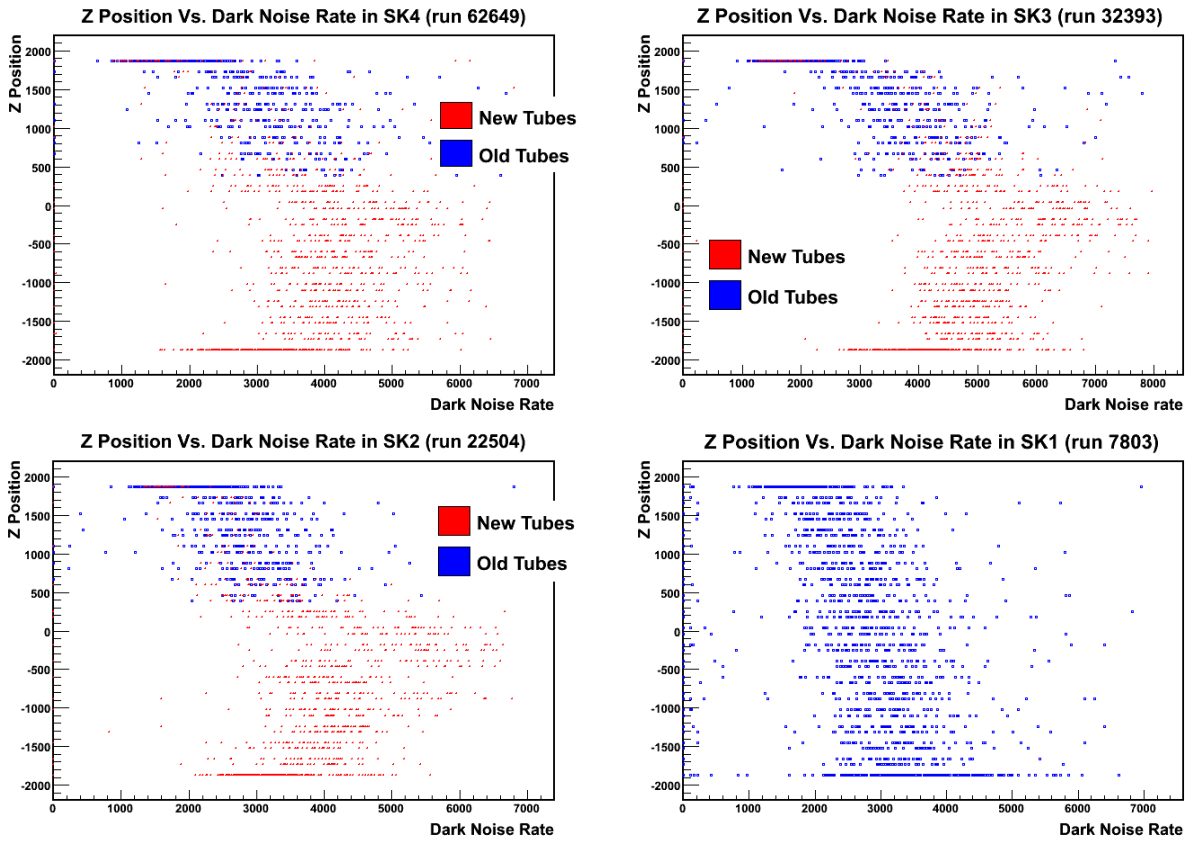

Figure 6: Dark noise by height in SK detector

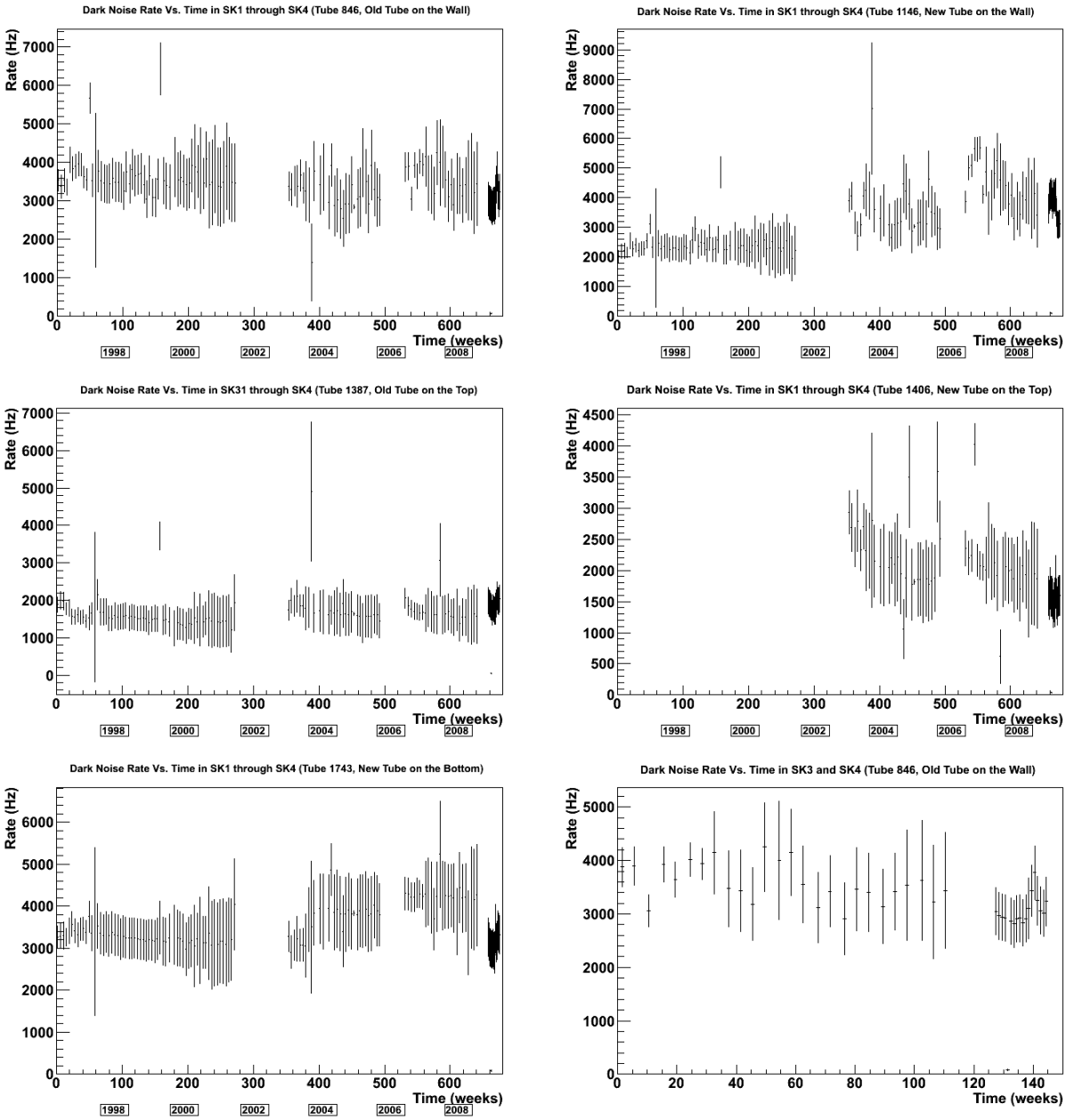

Figure 7: Dark noise as a function of time

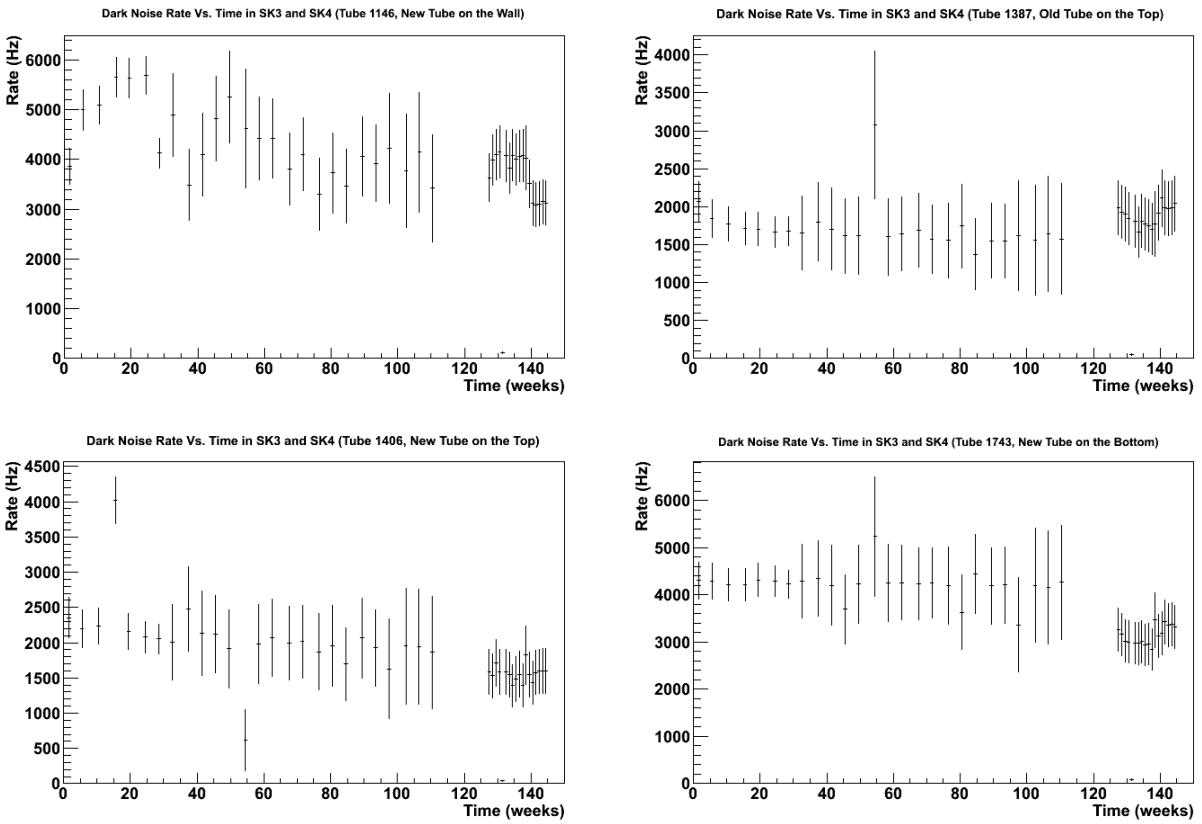

Figure 8: More graphs demonstrating rate vs. time correlation

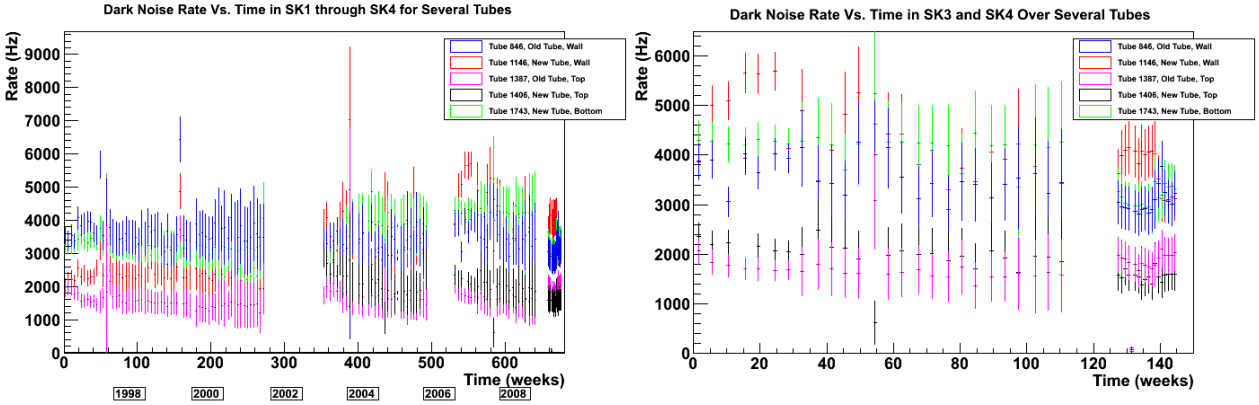

Figure 9: Superposition of rate vs. time graphs of individual tubes

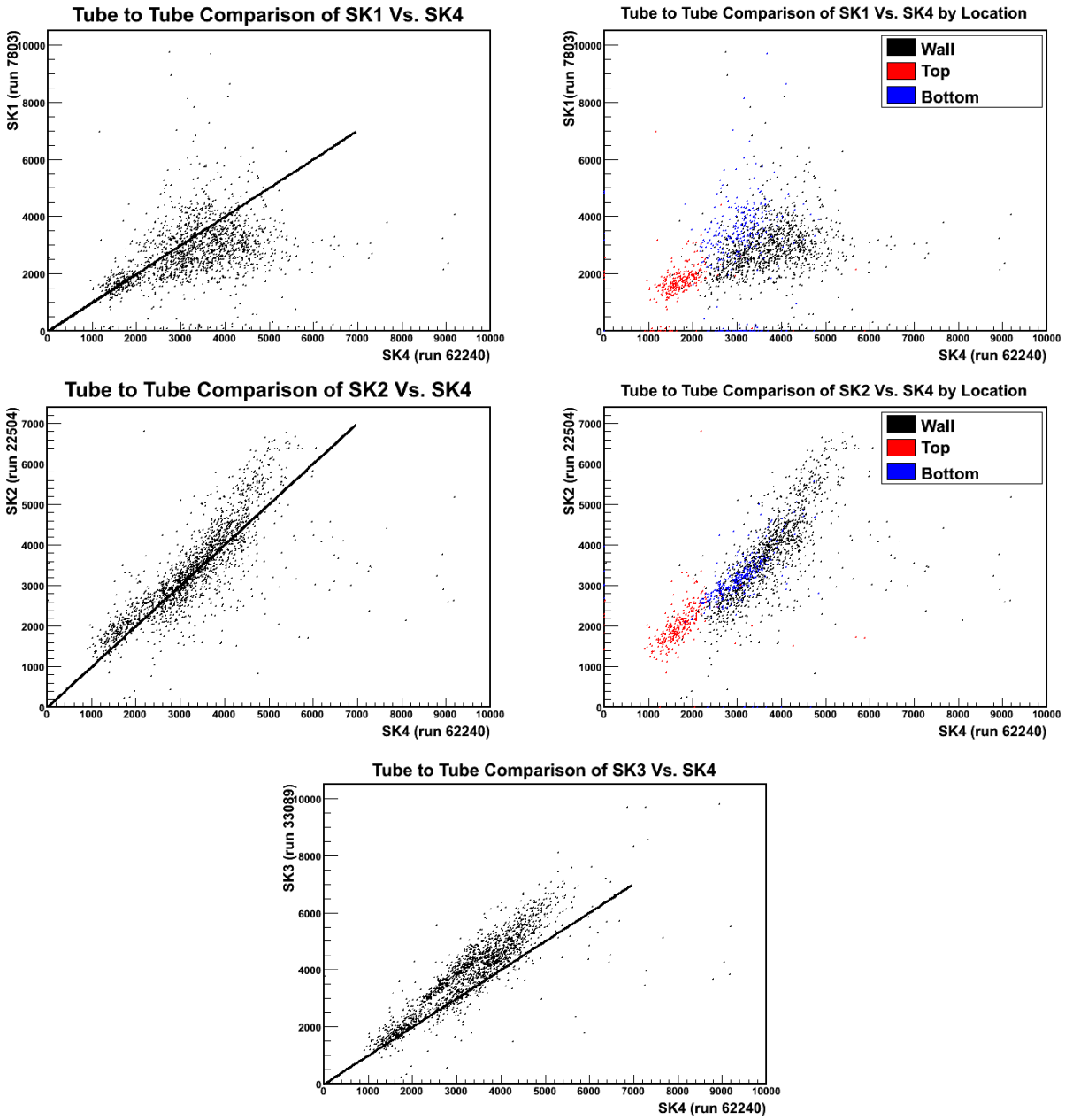

Figure 10: Graphs comparing different versions of SK by tube

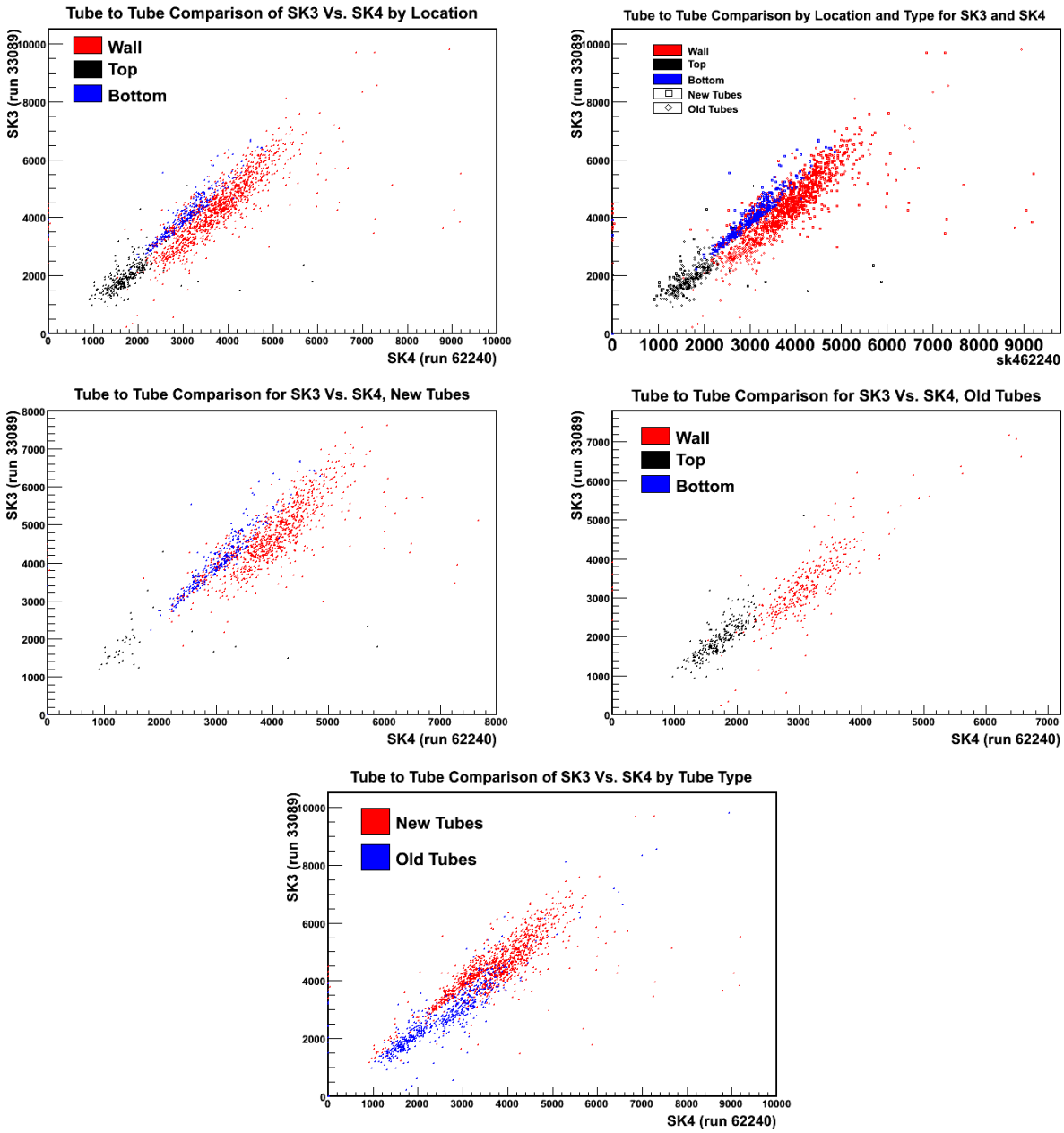

Figure 11: More sets of graphs directly comparing dark noise in tubes for different versions of SK

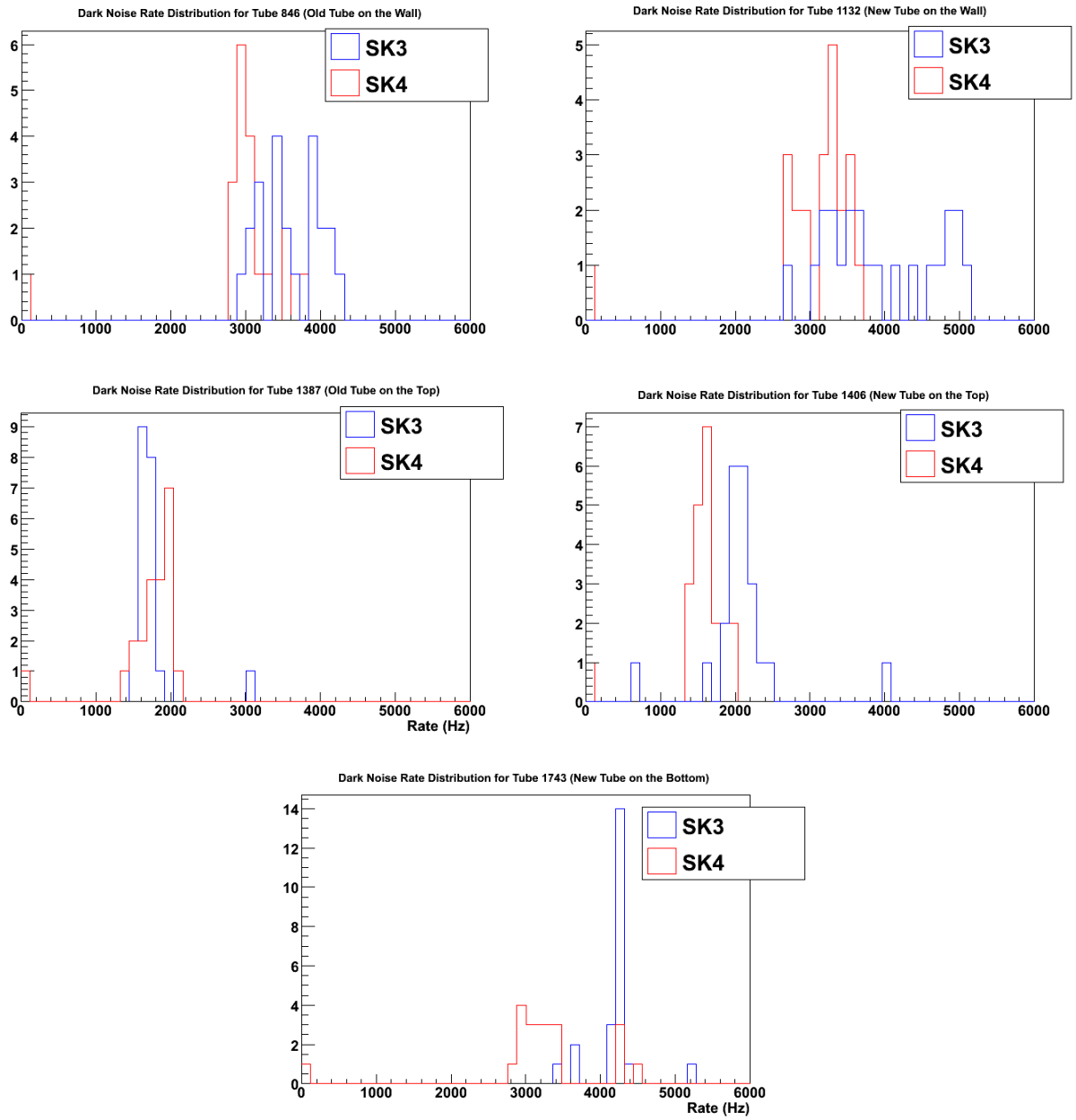

Figure 12: Distributions of rates in SK3 and SK4