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Study with special TOF paddle

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Abstract

This short report looks at the performance of a special Time-Of-Flight (TOF) paddle that was installed on the upstream end of the TOF detector to test the operation of a PMT with internal amplifier on the base.

1 Motivation

At high detector rates above 1 MHz the current in the PMT generated by the signals becomes too large. In order to reduce this current one possibility is to reduce the signal amplitude thereby reducing the current and then increase the signal amplitude after the last dynode with a built in amplifier to reach signal heights that can be processed by the following discriminator and ADC electronics.

To test the performance of such a TOF paddle in terms of timing resolution a narrow 3 cm wide and 252 cm long TOF paddle was equipped with a PMT with a regular base on one end and a PMT with a modified base on the other. As depicted in figure 1 the test paddle is located in front of paddle 21 of the horizontal plane and paddle 14 of the vertical plane is used to look for coincidence events. The width of the test paddle and paddle 21 is the same namely 3 cm while the width of paddle 14 is 6 cm. They are all one inch thick and have the same length.

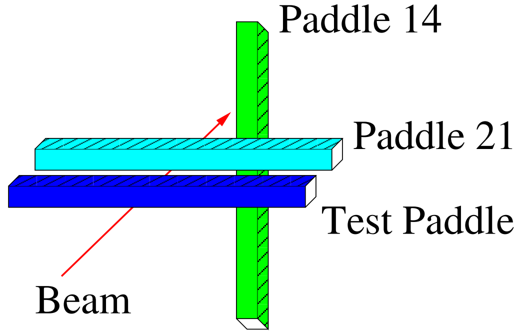

Figure 1: Schematic setup of the test paddle with respect to the horizontal and vertical TOF planes.

2 Data Analysis

The raw data were selected for the test paddle and paddle 21 and treated the same way by determining the proper walk correction and applying it to correct the TDC times. This automatically implies that coincidences between ADC and TDC hits are done. The resulting hits are then sorted for left and right PMTs and coincidences between left and right hits of a given paddle are formed. From these coincidences time differences (DT) and mean times (MT) can be formed.

$$DT = \frac{1}{2} \cdot (T_{right} - T_{left}) \quad (1)$$

$$MT = \frac{1}{2} \cdot (T_{right} + T_{left}) \quad (2)$$

The paddle hits with timing for the vertical paddle 14 are selected from TOF hit paddle factory and events are selected that have hits in both the paddle 14 and either the test paddle or paddle 21 of the horizontal plane. For these events the time difference DT is then plot for the test paddle versus paddle 14 or paddle 21 versus paddle 14.

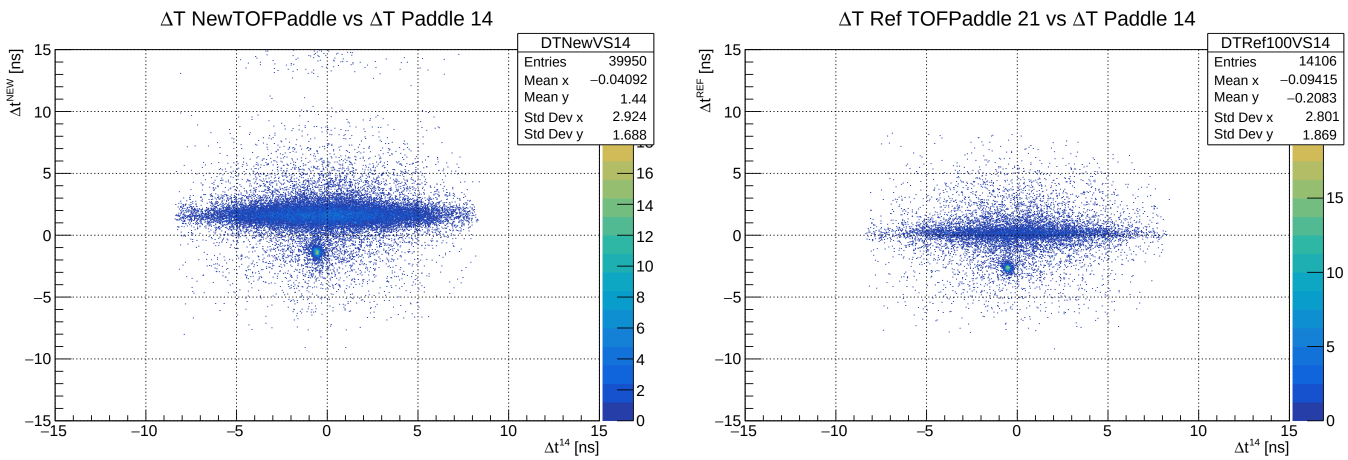

Figure 2: DT of the test paddle versus DT of paddle 14 and the same for paddle 21. The sharp blob below zero represents tracks that pass through both the horizontal and vertical paddle. Note that there are significantly more random coincidences between the test paddle and paddle 14 than with paddle 21 and paddle 14.

2.1 Coincidence of DT with vertical paddle 14

Projections can now be established to the horizontal and vertical axis to determine the width of this blob to give the resolution of DT for either paddle. The same distribution can also be generated for paddle 21 with respect to paddle 14. And then compare the vertical projection of paddle 21 to the test paddle. In this way we have a one to one comparison of the test paddle with paddle 21 and minimizing any bias.

Assuming that the resolution of the PMTs of paddle 21 and the regular PMT of the test paddle are the same one can use the two resolution measurements for DT of paddle 21 and the test paddle to determine the resolution of the modified PMT. The 157 ps resolution in DT for paddle 21 leads to an individual PMT resolution of 222 ps. Note that DT is the time difference between right and left PMT divided by 2. Using this number will lead to a resolution of the modified PMT of 504 ps.

2.2 Explore overlap of the test paddle with paddle 21

An alternative approach to estimate the resolution of the PMT with the amplifier is to look at coincident events between the test paddle and paddle 21. Tracks passing through both paddles hit the paddle at similar locations. So one can look at the time differences between the two left PMTs and the two right PMTs using the left PMT time difference to estimate the resolution of the un-modified PMTs and assuming that they are all the same. These time differences (not divided by 2) are shown in figure 4 where the left time difference has a sigma of 243 ps resulting in a single PMT timing resolution of 172 ps. Using this number in the calculation of the right PMT time difference results in a resolution for the PMT with a pre-amplifier of 293 ps.

Note that in this approach the time difference is not divided by a factor of 2 and the assumption is still the same as above that the left PMT of paddle 21 has the same resolution as the PMTs on both sides of paddle 21. This assumption may not be correct as the following section may suggest.

2.3 Single PMT from paddle 14 as reference.

Here a single PMT from paddle 14 is used as reference time and build time differences between the PMTs on both ends of the test paddle with this reference PMT. This can be done with either PMT on either side of paddle 14

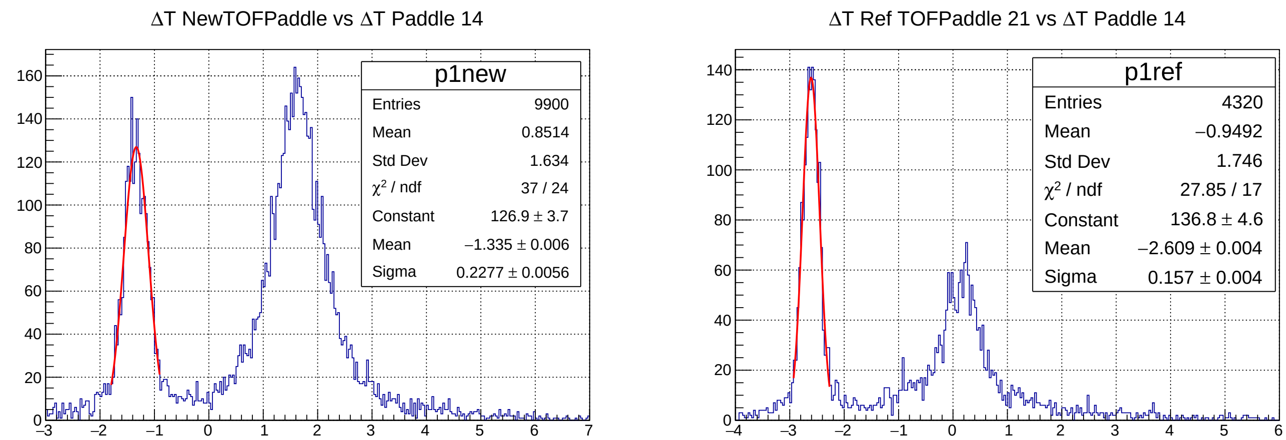

Figure 3: DT timing resolution for both the test paddle and paddle 21.

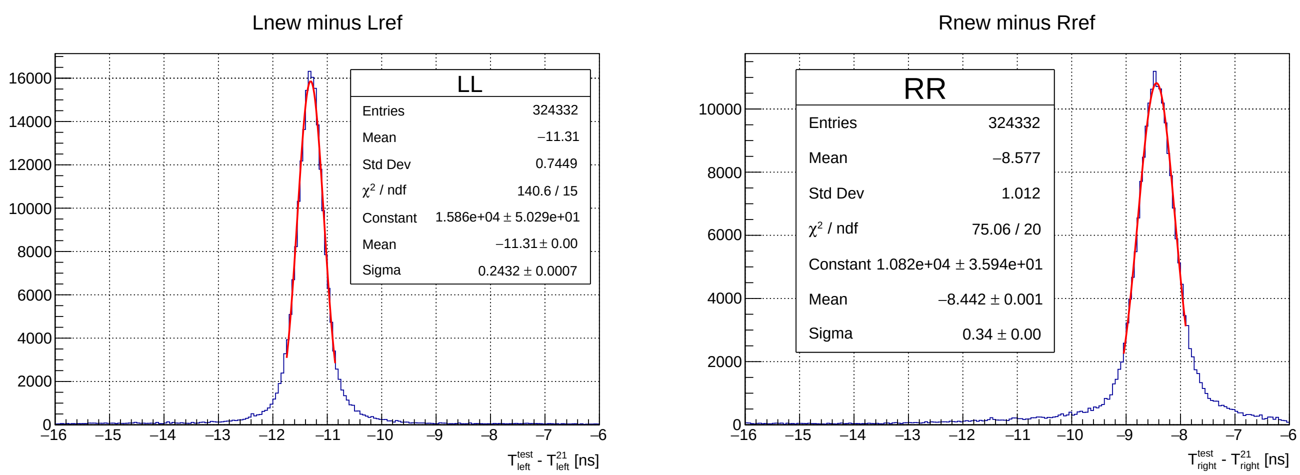

Figure 4: Time differences of the two left PMTs and the two right PMTs, respectively.

separately and if the resolutions of these two PMTs are the same or similar then the resulting distributions should have similar width too for the same PMT on the test paddle. Using the left PMT of paddle 14 we find 381 ps and 362 ps for the left and right PMT time differences, respectively. This is shown in figure 5.

The time resolution of the reference PMT of paddle 14 can be determined from DT of paddle 14 obtained from either distributions of figure 2. While from the distribution with the test paddle a σ of 119 ps is obtained from the distribution of the reference paddle 21 a σ of 102 ps is obtained. Since the test paddle is further away from paddle 14 than the reference paddle 21 this may have cause an increased variation on the possible overlap of the two paddles and increase time smearing. The 102 ps timing resolution of DT for paddle 14 will result in a single PMT time resolution of about 144 ps.

From these numbers we find a timing resolution for the left PMT of the test paddle of about 353 ps and for the right PMT a value of about 332 ps. This result clearly suggests that the above assumption of the left PMT of the test paddle having the same or a similar resolution as the PMTs of the reference paddle 21 or paddle 14 is not correct.

Using the right PMT of paddle 14 as reference time we find resolutions of 374 ps and 383 ps respectively for the time differences with the left and right PMT of the test paddle. These values are very similar to the previously obtained values shown in figure 5.

As a final test the same procedure is applied to the reference paddle 21 in order to estimate potential bias

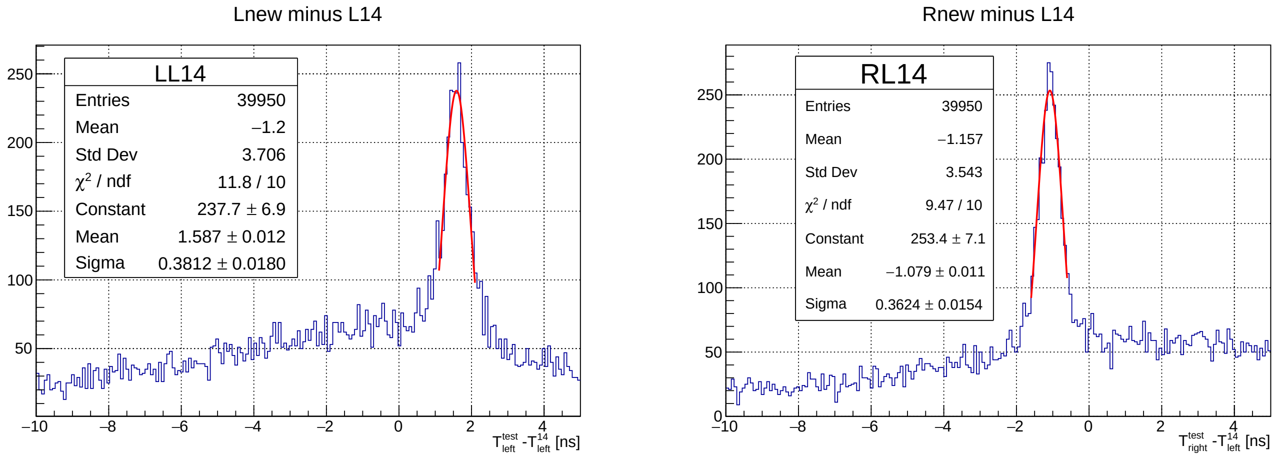

Figure 5: Time differences of the left and right PMT of the test paddle with respect to the left PMT of paddle 14.

systematic uncertainty in this procedure. Figure 6 shows the distribution of the time difference between the PMTs of the reference paddle 21 with the right PMT of paddle 14. The resolution of the two peaking distributions are found to be 278 ps and 248 ps,for the left and right PMTs, respectively. These values are clearly much smaller than for the test paddle and indicate that the resolution of the PMTs on the reference paddle are much better than on the test paddle. However the resulting timing resolutions of these PMTs are around 200 ps and as such larger than paddle 14.

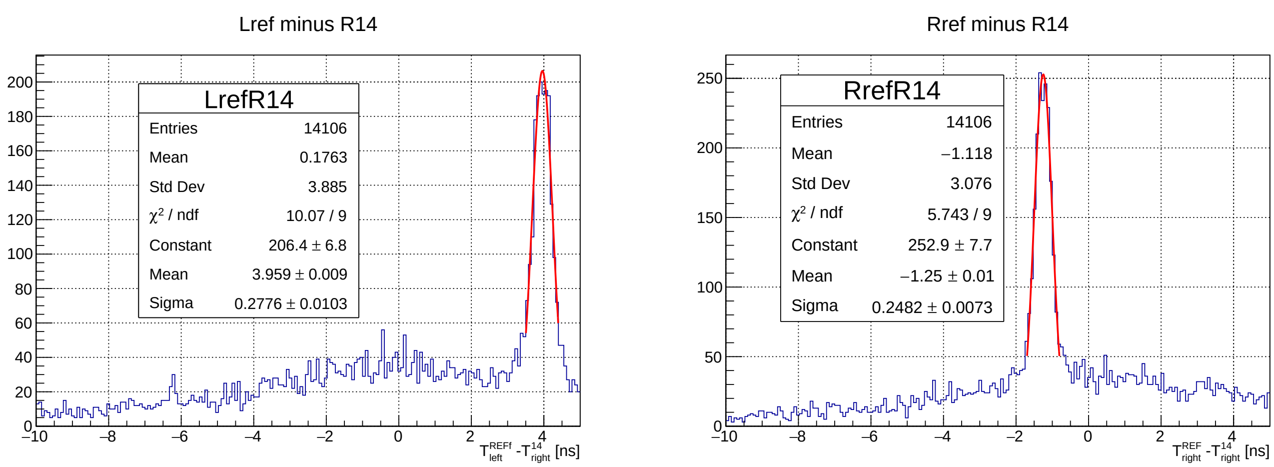

Figure 6: Time differences of the left and right PMT of the reference paddle 21 with respect to the right PMT of paddle 14.

Similarly we can also determine the same quantities using vertical paddle 31 which is located symmetrically on the other side of the photon beam line. The results are tabulated in the following tables 1 and 2.

3 Conclusion

The above analysis of the test paddle data clearly shows that the test paddle did not perform as expected and the time resolution of the paddle as a whole is inferior to the TOF paddles in operation. It does not appear that the PMT with a pre-amplifier has a worse timing resolution than the PMT with a regular base. The data indicate that

Ref.Time	σ_{left}^{test}	σ_{right}^{test}
PMT_{left}^{14}	381 ps	362 ps
$\mathrm{PMT}_{right}^{14}$	374 ps	383 ps
PMT_{left}^{31}	395 ps	704 ps
$\mathrm{PMT}_{right}^{31}$	395 ps	676 ps

Table 1: Time difference of test paddle PMTs with respect to left and right PMT from paddle 14 and paddle 31 respectively.

Ref.Time	σ_{left}^{21}	σ_{right}^{21}
PMT_{left}^{14}	314 ps	252 ps
$\mathrm{PMT}_{right}^{14}$	278 ps	248 ps
PMT_{left}^{31}	366 ps	321 ps
$\mathrm{PMT}_{right}^{31}$	303 ps	371 ps

Table 2: Time difference of reference paddle 21 PMTs with respect to left and right PMT from paddle 14 and paddle 31 respectively.

the whole paddle did not peform well. The most likely cause of this degraded performance are high voltage settings that were too high. Below for reference the resulting resolutions of the test paddle and the reference paddle 21 with respect to paddle 14 are explicitly shown in table 1 and 2.