Particle identification in Bigbite Spectrometer

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1 Introduction

In the experiment E05-102 we were measuring double-polarized assymetries in following reactions $^3\vec{H}e(\vec{e},e',d)$, $^3\vec{H}e(\vec{e},e',p)$ and $^3\vec{H}e(\vec{e},e',n)$. For the measurement of the neutron channel (e',n) we were using the neutron detector (HAND) in coincidence with the Right High Resolution Spectrometer (HRS-R). For the (e',p) and (e',d) channels we were using Bigbite Spectrometer in coincidence with the Left High Resolution Spectrometer. My mission was to put together electronics for the coincidence trigger between BigBite and HRS-L. In this report I will briefly describe the trigger construction. Before and during the experiment I made a series of checks made with an oscilloscope and simulated pulses. As a result of those tests I got a lot of scope plots which can be now compared with the trigger schematics in order to see if the triggers work properly. Another set of test was made during the production running using the TDC and scaler data from all the triggers. Using this information we were able to check if the real triggers work the way we tried to design them.

2 BigBite Spectrometer

BigBite spectrometer is a large momentum and angle acceptance spectrometer. It was originally used in NIKHEF and was brought to TJNAF in 2003. It consists of a single normal conducting dipole magnet (please see figure below) and a detector package. Th maximum magnetic field in the spectrometer is 0.92T (at current 510A), which enables the detection of the particles with momentum $< 700MeV/c$. The hadron detector package consists of two Multiwire Drift Chambers and two scintillation planes. Both scintillation planes are made of 24 scintillation paddles each approximately 8cm wide (see figure 1). First dE-scintillation plane is 3mm thick while the second E-plane is made of 3cm thick material. The photons from each paddle are read with two Photonis XP 2262B Photomultipliers attached to each side of the paddle. The basic characteristics of the spectrometer can be found in table 1...

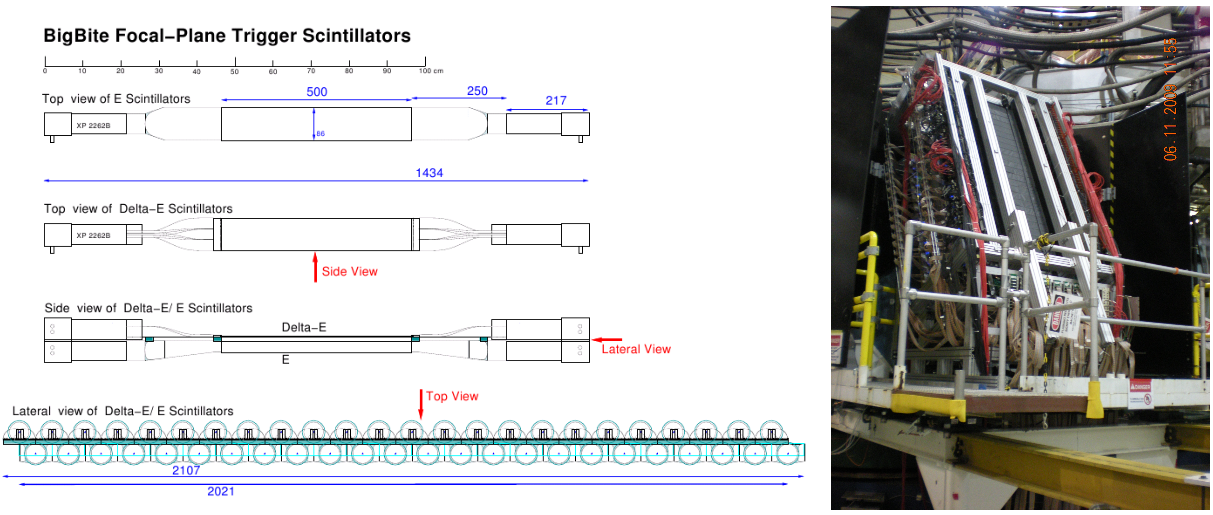


Figure 1: *Left:* Schematics od the Scintillation counters used for the BigBite trigger detector; *Right:* Picture of the BigBite Spectrometer. Scintillation planes are clearly seen on the back of the spectrometer.

BigBite characteristics	
Configuration	Dipole
Momentum range	$200 - 900$ MeV
Momentum acceptance	$-0.6 \leq \frac{\delta p}{p} \leq 0.8$
Momentum resolution	4×10^{-3}
Angular acceptance	≈ 100 msr
Angular resolution	≈ 1 msr

Table 1: Table shows main characheristics of the Big Bite spectrometer. It has a large momentum and angular acceptance which makes it a great probe for the detection of the quasi-elastic hardons [?].

3 HRS-L and Bigbite Triggers

Triggers are electronic pulses that tell us when particle hits detector or detectror package in a spectrometer. From the combination of these signals that we get at given moment we than decide whenever we want to detect given physical proccess or not. This means that only after the trigger is accepted we start downloading data from ADC and TDC modules to the disks. All data that were read (saved) after one trigger are together called event. In our experiment (E05-102) we had seven different triggers for the combination of BigBite and HRS-L spectrometer

3.1 Trigger T1:

Trigger T1 is a BigBite main trigger. It is triggered whenever we get a valid hit in one of the paddles of the E-scintillation plane. Its complete electronics scheme is shown in figure 2. The signals from the PMTs are

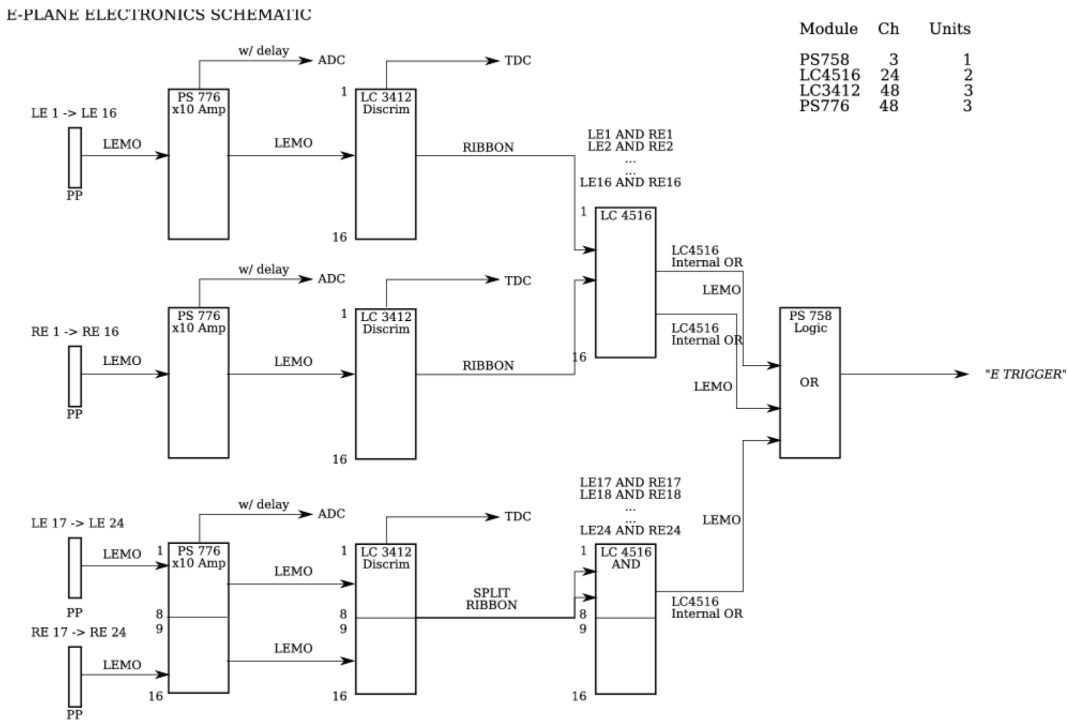


Figure 2: First part of the electronics scheme of the T1 trigger.

led from the detector patch pannel (PP) to the patch pannel in BigBite weldment where all the electronics is situated. For that we used 30 m coaxial cables. Once in weldment we lead all 48 signals to the analog amplifiers where they were multiplied by a factor of 10. For the multiplification we have used Phillips modules PS-776[?]. Then we led amplified signals over 8ns LEMO cables to discriminators. We used LeCroy LC-3412 modules with electronicaly controlled threshold which enabled us to remotely control the threshold during the experiment. We used twisted pair ribbon cables to connect discriminators with the LeCroy logical units LC-4516 where we first made a logical AND[1] between the signals from the left and right PMTs from each scintillation paddle and than

[1] In our experiment we dedided that valid hit in E-plane should have pulses in both left and right PMT.

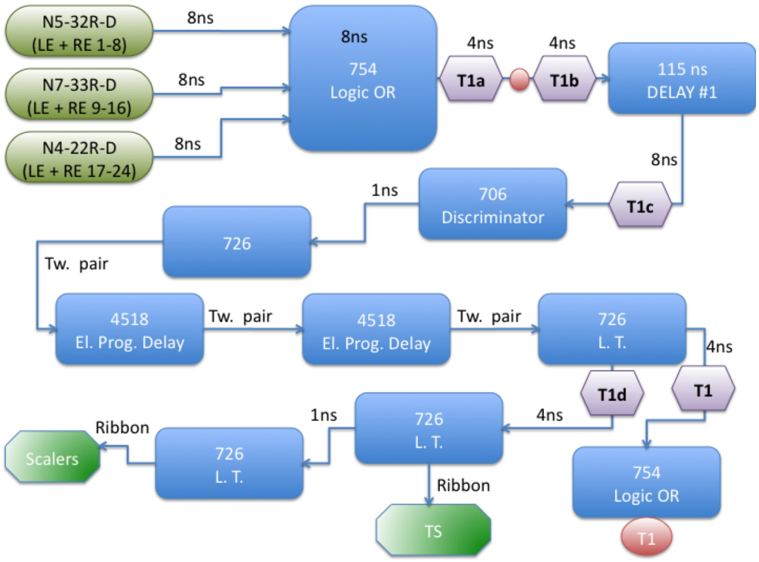


Figure 3: First part of the electronics scheme of the T1 trigger.

a logical OR between all the channels. Since our detector has 24 PMTs/channels we have to use two LC-4516 modules with sixteen channels. On the output of these two modules we got three signals, each representing an or between eight paddles. We than led these three signals over 8ns LEMO cables to the Philips module PS-754 where we made a final logical OR between these signals and in the end got T1-trigger pulse.

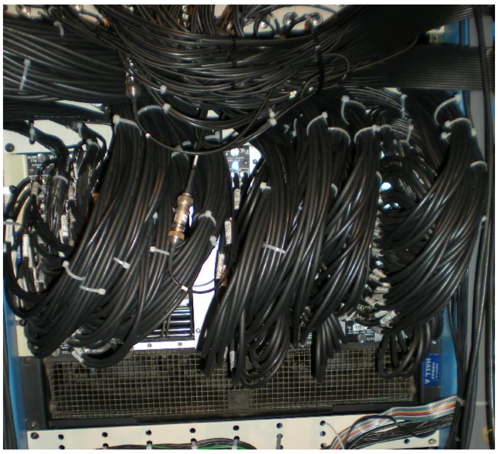
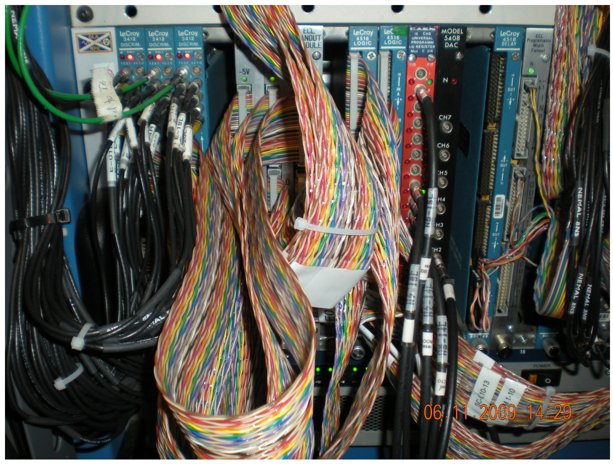
a.)  b.) 

Figure 4: Trigger T1 electronics. *a.)* Analog anplifiers, where signals from PMTs are amplified by factor 10. *b.)* Three discrimination modules LC-3412

We also had to consider, that Trigger pulses from al detectors do not come at the same time. It turned out that in order to be able to form a coincidence triggers with the left arm, we had to apply some additional delay to trigger T1. For that we used two electronically progmamable delay modules, each being able to delay signal for 32 ns. This has given us ability to control and adjust delay remotely during the experiment. In figure 3 you can see that we have put two level translation modules PS-726 before and after programmable delay modules. We needed these to modules because we had to translate signals from LEMO cables to twisted-pair wires in order to be able to connect to these two modules. For the rest of the needed delay we used ordinary 115ns cable delay. To refresh the signal, after it comes out of the long cable we used a discriminator PS-706.

3.2 Trigger T2:

Trigger T2 is a secondary BigBite trigger and is triggered when we have a valid hit in a dE-scintillation plane. When looking at the T2 electronics scheme in figure 5, we can notice that it is constructed a bit different than trigger T1. After the amplification we do not discriminate the signals and than make logical operations with

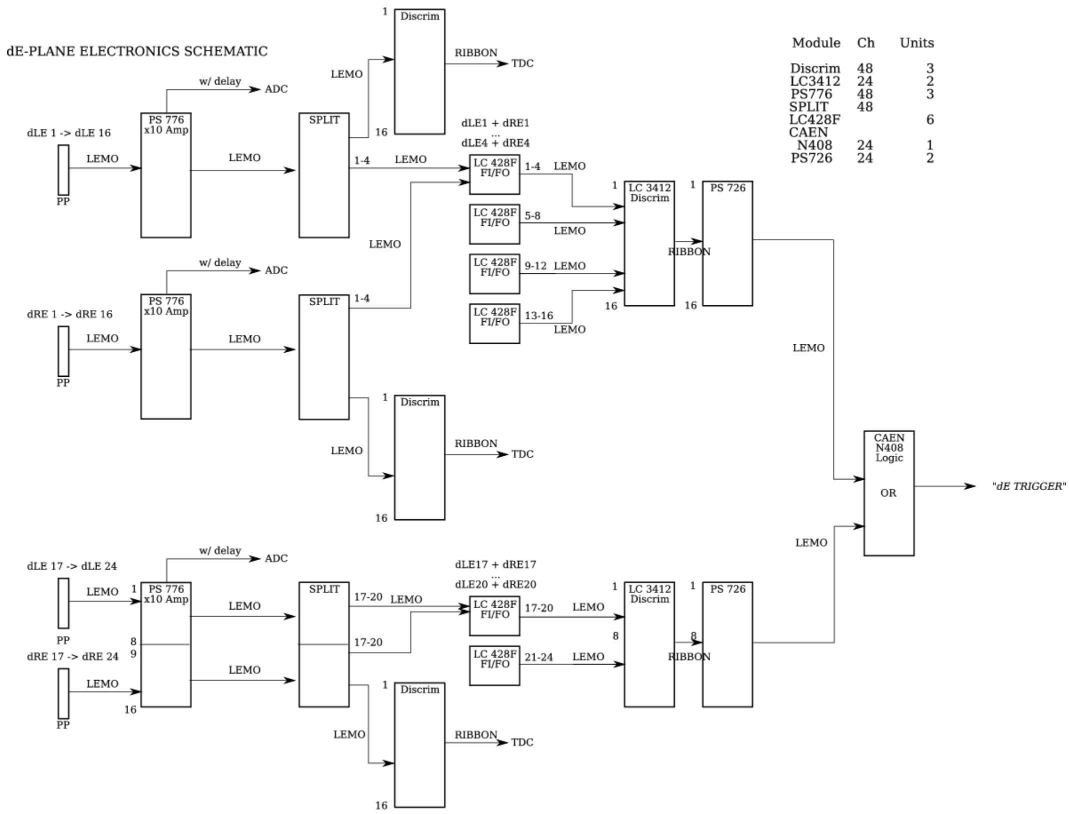


Figure 5: First part of the electronics scheme of the T2 trigger.

into digital pulses, as we did for the T1-trigger. Instead, we first do the analog sum of the signals from the left and right PMT and than discriminate the sums. This way we also accept signals from detector where only one PMT fer paddle was hit, as long the detected signal was big enough to come through the discriminator.The main reason for such construction was to detect particles with very small momenta. To do the sum we used LeCroy LC-428F modules. These modules have two outpus - a capatited and non-capacited. During the debugging process of our electronics we realized that we should use only capacited outputs, otherwise we got 60Hz noise in our signals, caused by the power supply cables.From the output of the discriminators we led the signals to the PS-726 modules, in order to translate signals from Ribbon to LEMO cables. We then took these wires and attach them to CEAN module N408 to make a logical OR between them in order to get our T2 trigger.

Once we had T2 trigger we also had to apply some additional delay to it. From figure 6 we can see that basically we did the same thing as we did for the T1, but with a bit shorter cable delay, because trigger T2 comes few ns later than T1. This time difference is caused by additional electronics and cables that we used for the construction of this trigger.

3.3 Triggers T3, T4, T5 and T6:

Triggers T3 and T4 are HRS-L triggers. I will not discuss their construction in detail here. It is enough to know, that trigger T3 is a main trigger and is triggered every time when there are valid signals in both S1- and S2- scintillation planes. Valid signal means that in hit scintillation paddle both left and right PMTs saw light. Trigger T4 is a supplementary HRS-L trigger and is triggered when ony S1-plane and Cerenkov detector, which is positioned in between the two planes, have valid pulses. From here we can see, that we can not have both

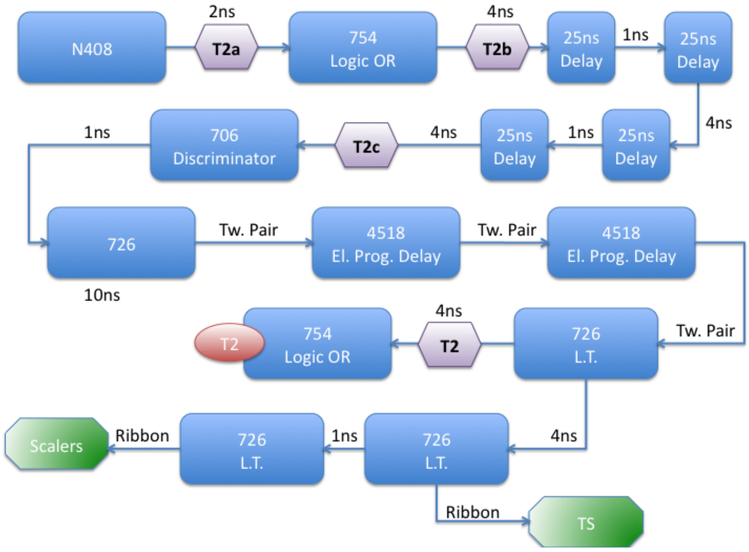
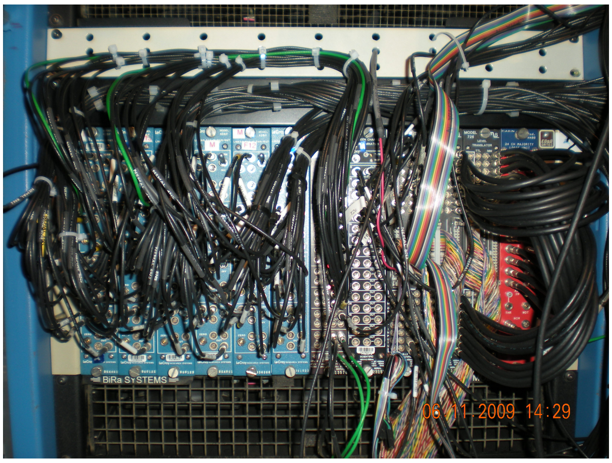


Figure 6: Second part of the electronics scheme of the T2 trigger.

a.) 

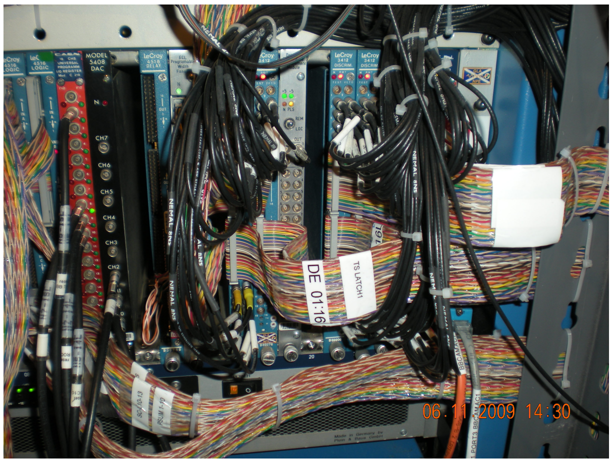
b.) 

Figure 7: Trigger T2 electronics. *a.)* FI/FO modules LC-428F where we do the sum of the analog signals from left and right PMTs. *b.)* Discriminaton modules. three modules are used for the discrimination of the TDC signals and two for the discrimination of the summed signals.

triggers at the same time - when there is T3 there is no T4. Because we believed that majority of our scattered electrons comes through both scintillation planes we did not pay much attention to T4, but only dealth with T3.

Triggers T5 and T6 were our coincidence triggers. We started the construction of these two triggers ambitiously. We considered programmable coincidence window width as well as position of the window relative to T1 or T2. However when we did our first simulated tests of the experimentr. We realized that because of the long cables T3 comes very late from HRS-L which would consequently cause ADC-gate to come to late to read the pulses from the BigBite. Because of that we have to make much simpler version of coinciidence trigger with out any extra features.

Figure 8 show the scheme of our final coincidence trigger. Coincidence trigger between T1 and T3 was T5 while coincidence trigger between T2 and T3 was T6 Trigger T3 from the HRS-L goes firts into the discriminator in order to refresh the pulses. The output signal is then lead to the PS-755 module where we make a coincidence window out of it. We have set coincidence window to be approximately 80ns wide. Once we had coincidence

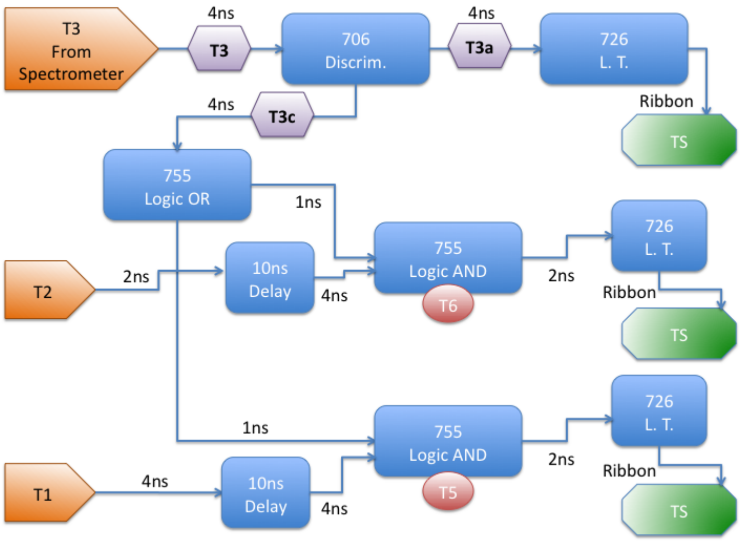


Figure 8: Trigger T5 and T6 schemes.

window we were able to form coinidence triggers. We simpli took two PS-755 modules and make an AND between coincidence window and properly delayed T1 and T2 signals. The outputs from these two moduls represent coincidence triggers.

3.4 Trigger T7:

During the set-up period, when there was no electron beam available, we were using cosmics to test if the BigBites detectors (especially MWDC) work properly. For that purpose we designed special cosmics trigger, that we named T7. We put an additional 2m long scintillation bar (HAPPEX paddle) in the middle in between the two wire chambers. This bar was long enough to vertically cover MWDC and Scintillation planes. We used this paddle to check if the particle that hit dE- and E-planes also managed to come though the MWDC. The signals from the left and right PMT on this paddle were led the same way as all other signals to the BigBite weldment. There we firt amplified them and than make a logical OR between them. In the end we formed an AND between this signal and T1 to get coincidence comsics trigger T7. When the real experiment started the this additional (HAPPEX) paddle was removed. Therefore there should not be any T7 event in the production data.

3.5 Trigger supervisor and Level One Accept pulse:

Once we have all the triggers we need to send them to the Trigger Supervisor (see figure **??**). The delays of triggers T1,T2 and T3 are set in a way that they come into the TS at approximately the same time. Triggers T5 and T6 come approximately 30ns later. When signals come to Trigger supevisor, it decides whenever to accept or decline the given trigger. If it accepts the trigger it returns a Level one accept (L1A) pulse which we than use to start the TDC and ADC read-out.

During real experiment rates of all the trigger are not the same due to various reasons: spectrometers have different accespances, and since we are interested mostly in coincidence event we do not want to much single arm events. Therefore we can specify the rates with which we want to accept each trigger, by setting proper prescales. This also enables us to correctly set the total rate of information that we can store so that we do not have to large dead time. At the moment we are limited to 2.5k events per second or approximately 5.5MB per second. If trigger

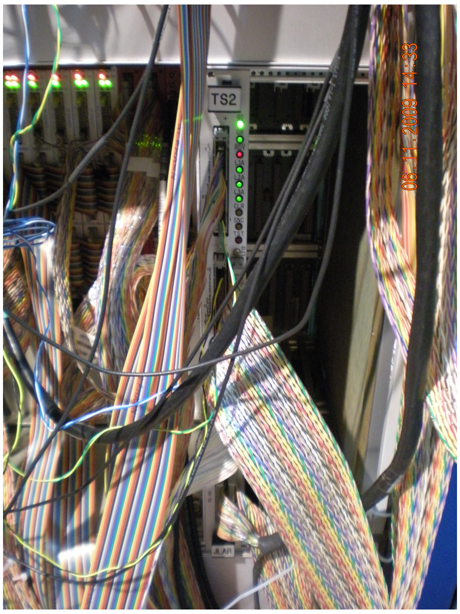


Figure 9: BigBite and HRS-L Trigger supervisor (TS2) with all corresponding cables.

3.6 BigBite Re-Timing

We could use L1A signal directly to start read-out of the ADCs and TDCs. However, in our experiment we wanted these signals always to be relative to T1 or T2 if they exist. For that we used additional electronics that is shown in figure 10. We named this part BigBite Re-timing. First we use a PS-755 module to form a logic

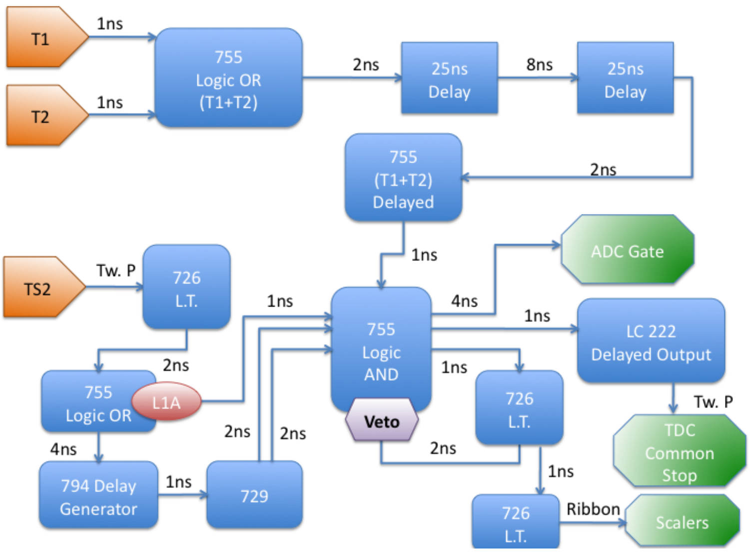


Figure 10: BB-retiming scheme

OR between T1 and T2. Delays of these two triggers are set in a way that T1 comes approximately 2ns before T2. This way TDC signals will always be timed off T1, if T1 exists. If there is no T1 then they will be timed off T2. After made (T1 or T2) we take this signal through some additional delay. We need this delay because TS2 needs some time to think and decide before sending the L1A signal. The delay is set in so that L1A alwas comes before (T1 or T2). This is the idea of this circuit. Then we take both signals and put them into another PS-755 modeule where we make an AND between them to get our final output signal, with which we start the read-out of the ADCs and TDCs.

However, it can also happen that in given event there is no T1 nor T2 but only T3. Since we would also like to take those events but only then when there is really no T1 or T2 we added modules PS-794 and PS-729 which delay L1A signal for approximately 90ns. If there is really no T1 or T2 then circuit decides to take un-timed, delayed L1A. Module PS-755 wich makes a final AND is set to setting 2, which means that it makes an AND between any two sinput signals. In the case of proper events these two singal are L1A and (T1 or T2). When there is no T1 or T2, then these two signals are two delayed copies of the L1A. However, we need to be caeful here. In a case of any proper event we also get delayed L1A signal thant always comes 90ns after the non-delayed one. This would mean that we need to stop reading the input until this signal has ended. Therefore we make a loop and lead a delayed output signal back into the module as a VETO, which prevents delayed L1A signal to form a bogus event.

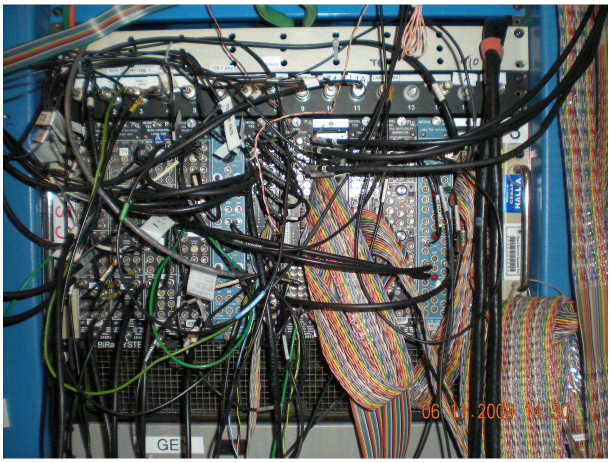


Figure 11: BigBite re-timing electronics.

3.7 BigBite ADCs, TDSs and Scalers

Figure 12: Left figure shows BigBites high resolution TDC modules. Right figure shows CEAN ADC modules

In order to get a deposited energy information from the BigBite PMTs we take a second copy of the amplified signals in modules PS-776 and lead them to the ADC modules where we transform analog signals to the digital form. For the transport of the ADC signals we first used ordinary twisted-pair ribbon cables. However, during the tests we realized that this is not a good choice. The signals in a given wire were strong enough to induce bogus signals in neighbouring wires. Since this woud cause a lot of problems we changed these bales with the ribbon cables made of small coaxial cables. With those cables induced noise dissapeared. We also used hi-pass filters on the inputs to the ADC modules to get read of the low frequency (i.e. 60Hz) noise. Looking at figures 2 and 5 we can see that aADC signals before going into the ribbon cables go through some delay. It is very important to delay these signals enough, so that they do not come to the ADC modules before ADC-window is opened by BigBite re-timing pulse. Total amount of delay from the output of the amplifier to the input of the ADC module is approximately 500ns. In this experiment we have used CEAN V792 ADC modules shown in figure 12.

Figure 13 shows the scope plots of the ADC window and analog pulses from dE- and E-plane right before going

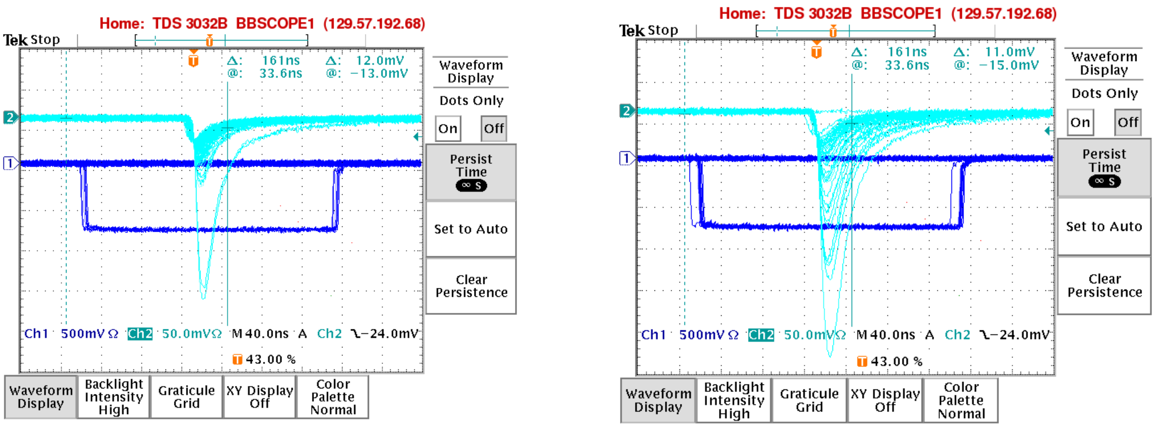


Figure 13: *Left:* Position of the analog signal from the dE-1L PMT relative to the ADC gate. *Right:* Position of the analog signal from the E-1L PMT relative to the ADC gate.

into the ADC modules. The ADC gate is approximately 250ns wide. For the ADC gate we simply used the BigBite re-timing pulse from the output of the PS-755 module (see figure 10), where we increased the lenght of the pulse on that module to the correct value.

We are also interested in time information i.e. when some particles hit a detector relative to the other. For that we have used F1-TDC modules with resolution of 60ps shown that are shown in figure 12. We were running these modules in the common stop mode. These modules have an acceptance window, through which data are constantly flowing. When the common stop signals appeares module reads the data, that are currently withing its window and stores them. For the common stop pulse we again used the BigBite re-timing pulse, which was properly delayed using the LC-222 module.

In the case of the E-plane we take signals for the TDCs from the discriminator modules LC 3412 and with ribbon cables transport them to the F1-TDC modules. With dE-plane signals are connected to TDCs somehow different. First we use splitters made of resistors to divide analog signal that is comming from the amplifiers into to copies. First copy goes to the FI/FO mudules as already mentioned. The second copy goes directly to discriminators and then thorugh the ribbon cables to the TDC modules. Because of the resistor-splitters the signals going to the TDCs have half of the initial amplitude. It is very important to consider this when setting the thresholds for discriminators. They should be set to the approximately half of the value used for the E-plane discriminators.

Besides the signals from all the PMT we also decided to connect all triggers to the TDC. This turned out to be very useful. We were able to monitor triggers during the experiment to check if they work properly. On the other hand, assuming that triggers work properly, we were dircetly able to see coincidence peaks and with limited resolution seperate deuterons from protons. In this case we used FastBus TDCs with resolution 500ps. In order to monitor rates at different stages of electronics we attached the relevant signals to the scaler modules. We led to scalers copies of all 96 TDC signals and copies of all 48 signals that we get after we do AND between left and right PMT. We have used these scalers to monitor the operation of all the chanells in the scintillation planes. If rates in one of the channels would be dramaticaly different than in others, than that would suggest that something is wrong with that channel.

The most important signals led to scalers are on the other hand copies of the triggers. Monitoring the trigger rates enables us to correctly set the prescale factors so that dead time in our data aquisition system is not to big. Through these scalers we can also see if something wrong happened with our expoeriment i.e. target

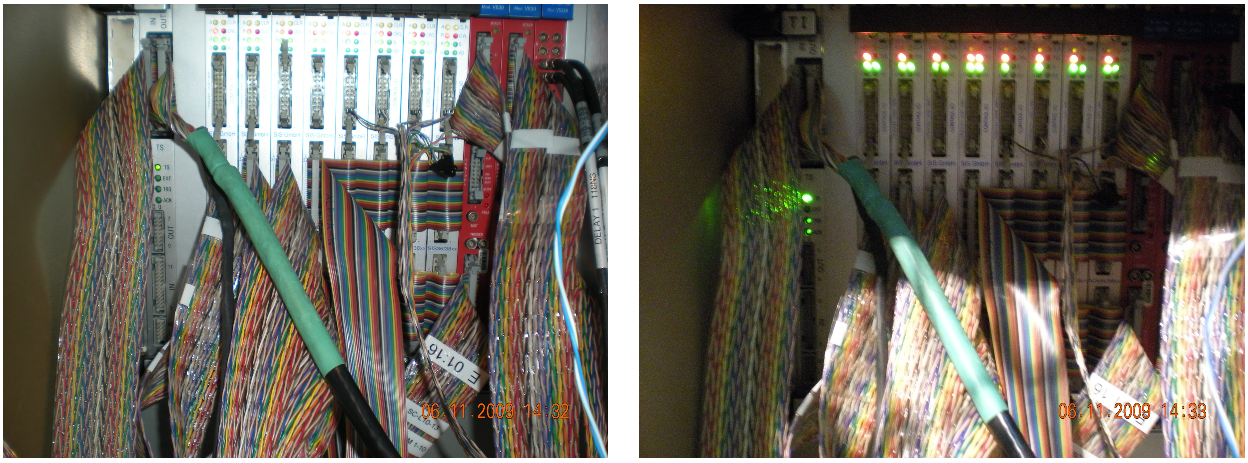


Figure 14: Scaler modules

cell exploded or sometring happened with the beam. In our experiment we were using polarized beam as well as polarized target. Therefore we used four scaler modules to monitor trigger rates, each for one beam-target setting: $[Beam\ Target] = [++], [-+], [+-], [--]$. Using this teqhnique we were able to estimate raw assymetries of our experiment on-line directly from the scalers, without detailed analysis of our data.

4 EDTM tests

In order to test the electronics that we build and to correctly set the delays for each trigger we used artificial signals that simulated real physical processes. For that purpose we used two EDTM modules (Event Dead Time Monitor), one configured as master in the HRS-L and the other in the BigBite weldment as a slave. The master EDTM sends out simulated pulses to the HRS-L electronics and one pulse the the slave-EDTM. The slave module is programmed in a way that sends the simulated signals to the bigbite electronics with the delay which correspodns to the real physical delay. For that we had to consider the difference in flight paths and flight times of the proton and electron and the length of the cables going from HRS-L to BigBite weldment.

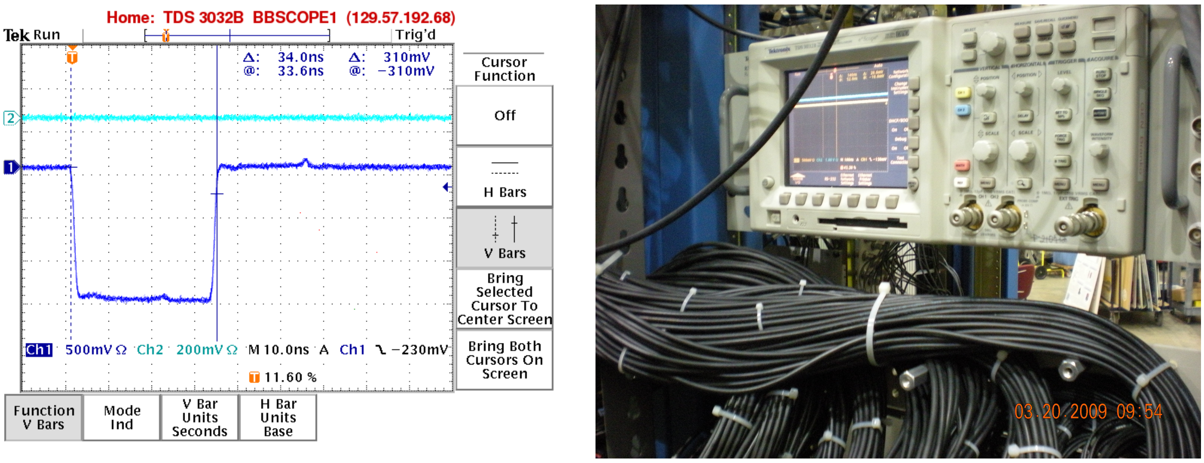


Figure 15: *Left:* The width of the EDTM pulse, going into the dictriminators and FI/FO modules. *Right:* Textronix oscilloscope TDS2012B.

For the E-plane we connected the EDTM signals to the test inputs of the LC-3412 discriminators. In the case of the dE-plane we fausted the EDTM signal as an extra input to the FI/FO modules LC-428F. We set the EDTM modules to send out signals with frequency approximately 20 Hz. Once we had simulation running we were able to check our electronics. For that we used two channel Tektronix Oscilloscope TDS2012B shown in figure 15, which supprots Ethernet connection. Therefore we were able store the scope screen shots over the interenet and later comapre them with the electronics shematics described in this paper. Figures 16 to 40 show various scope plots that we made during our tests and short descriptions of how well they agree with the shematics.

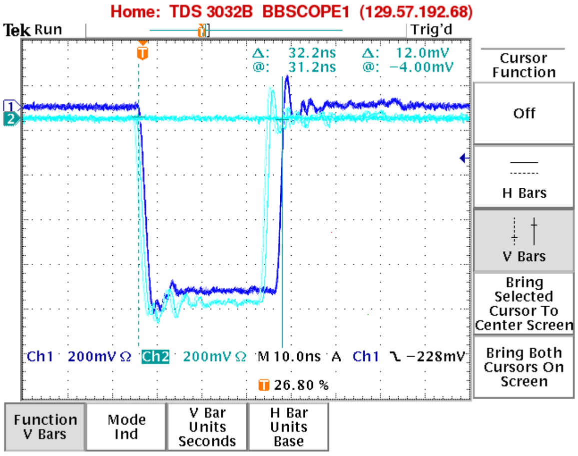


Figure 16: Plot shows the time difference between T1s(cyan) and T3s(blue) on the input to the scalers. We can see, that both triggers come to the scalers at approximately the same time (difference is smaller than 1ns)

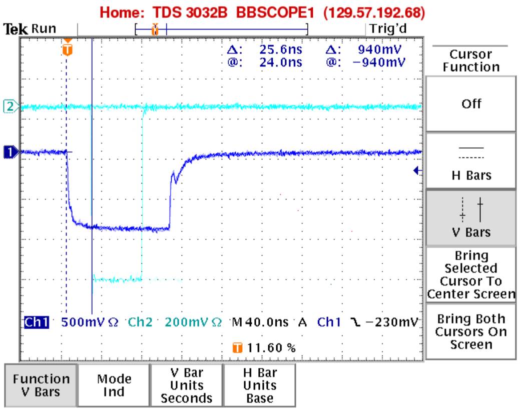


Figure 17: This plot shows time difference between trigger T1(cyan) on the output from module PS-755 and trigger T3(blue) on the end of the cable from HRS-L. Time difference between the two is 26ns. Looking at figures 3 and 8 we see that T3-to scalers comes $4+10+4+5 = 23ns$ after T3 and that T1-to scalers comes $5-3ns$ before T1. That means that according to schematics T1 also comes $23+3 = 26ns$ after T3.

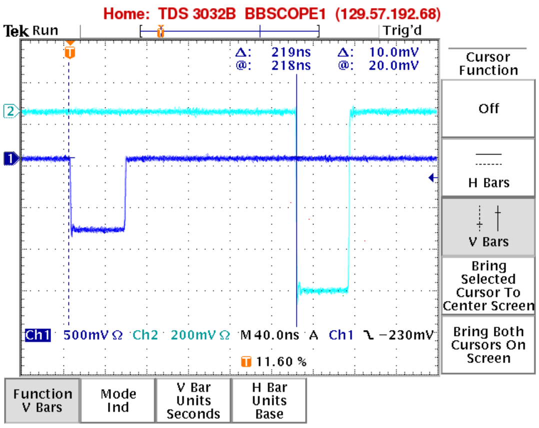


Figure 18: Plot shows the time difference between the output from the PS-754 module (figure 3) where we make an OR between the signals from the LC-4516 module and trigger T1 output. Time differece was set to be 219 ns

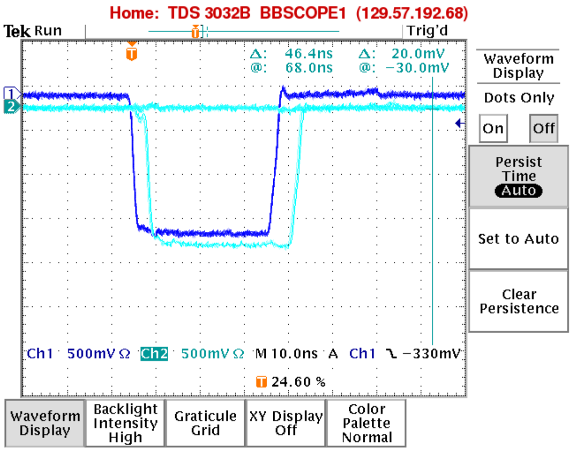


Figure 19: Plot shows the time difference between trigger T3 (blue) and T2(cyan) at the input to the scalers. The time difference between them is 4ns. That also means that time difference between the T1 and T2 on the input to the scalers is also approximately 4ns.

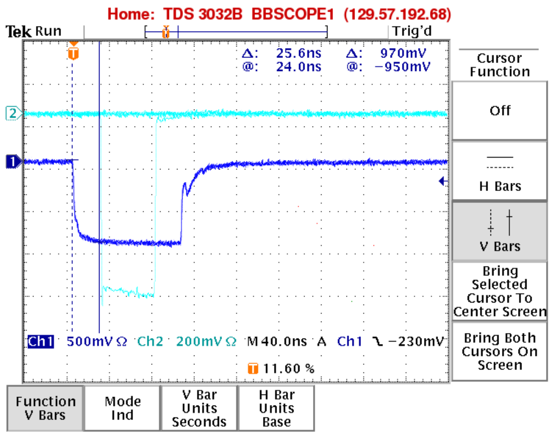


Figure 20: Plot shows time difference between final trigger T2(cyan) on the output from module PS-755 and trigger T3(blue) on the end of the cable from the HRS-L. Time difference between the two is 28ns. We already know that according to figure 8 T3-to scalers comes 23ns after T3 and that T3-to scalers comes 4ns before T2-to-scalers. By looking at figure 6 we also realize that T2-to scalers comes 3ns before T2. In the end this gives us $23 + 3 + 4 = 30ns$ difference according to schematics.

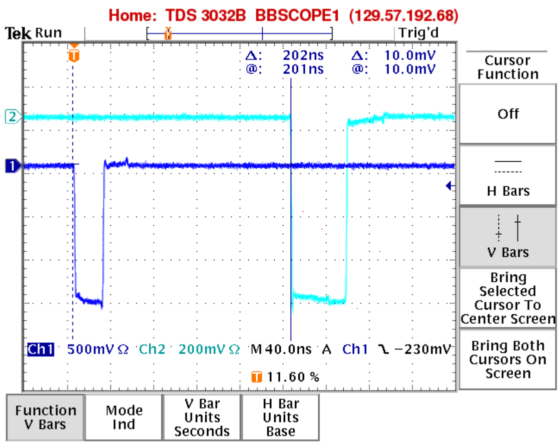


Figure 21: Plot shows the time requred for the signal to come from the output of the module PS-754 module (figure 6) right after it comes from the module N408, to the trigger T2 output. Time differece was set to be 202 ns

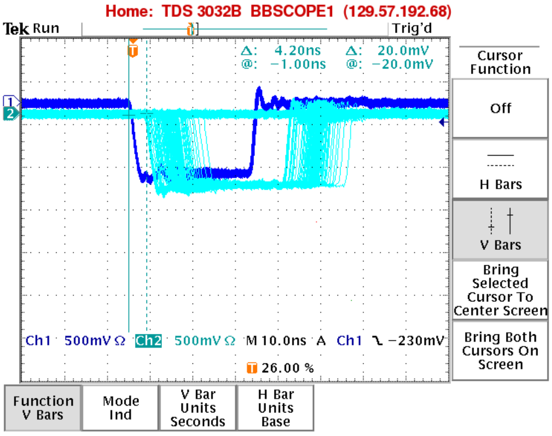


Figure 22: Minimal difference between the trigger T1(blue) and T2(cyan) on the input to the scalers is 4.2ns. The maximal difference between the two is 18ns, but this happens rearly.

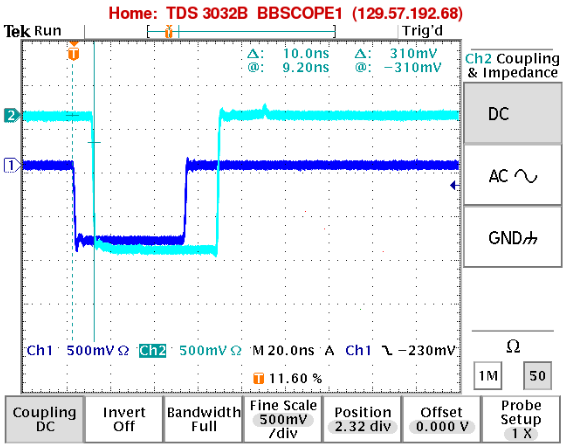


Figure 23: Time difference between signal (T1 or T2) on the output from module PS-755 and trigger T1 is approximately 10ns. According to figure 8 this time difference should be $8 + 1 = 9$ ns.

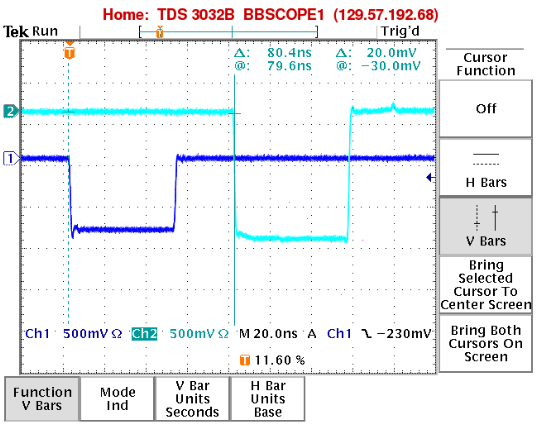


Figure 24: Plot shows the time difference between the T1(blue) on the output of the module PS-754 and $(T1orT2)_{D}elayed$ pulse on the output of the module PS-755 after the cable delay. The time difference is 80.4ns. According to figure 8 this time difference should be: $1 + 8 + 2 + 25 + 8 + 25 + 2 + 8 = 79ns$. This agrees quite well.

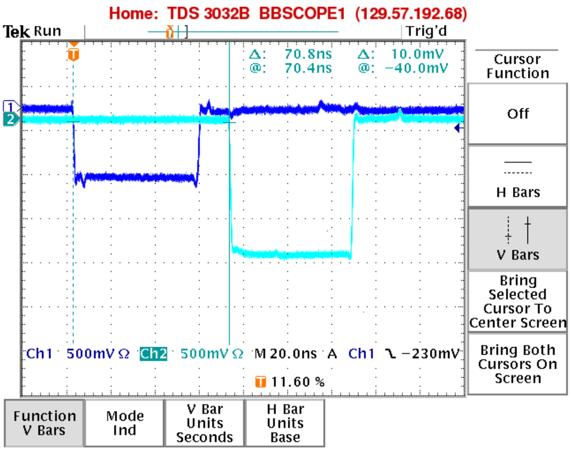


Figure 25: Plot shows the time difference between the (T1 or T2)(blue) on the output from the module PS-755 and $(T1orT2)_Delayed$(cyan) pulse on the output of the module PS-755 after the cable delay. The time difference is 70.8ns. According to diagram 8 this time difference should be: $2 + 25 + 8 + 25 + 2 + 8 = 70ns$. This agrees quite well.

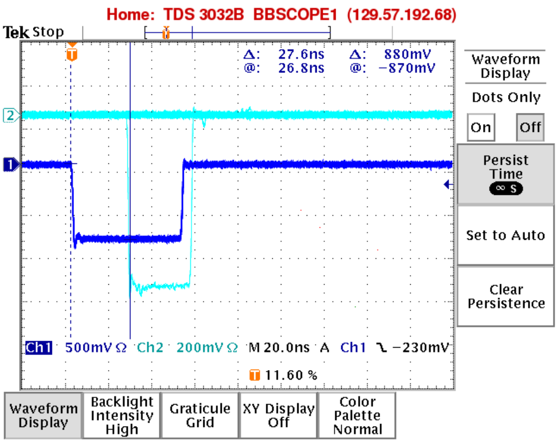


Figure 26: This scope plot shows time difference between trigger T1(blue) and coincidence trigger T5(cyan) which is approximately 27.6ns. Looking at diagram 8 we realize that this difference should be: $4ns + 10ns + 4ns + 8ns = 26ns$. This is good enough.

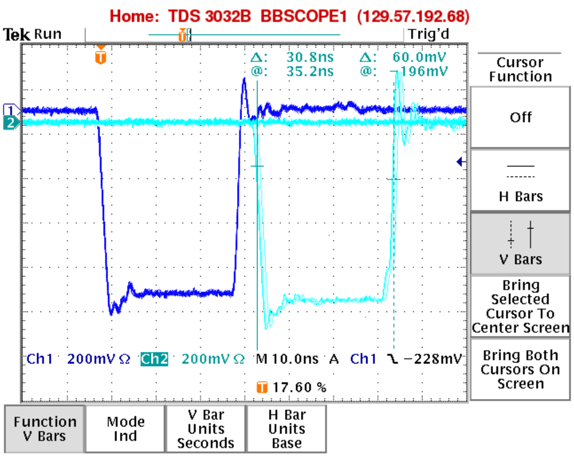


Figure 27: Plot shows time difference between trigger T3(blue) and T5(cyan) on the input to the scalers. Difference between the two is approximately 34ns. From the diagram 8 we know that trigger T3-to-scalers comes 23ns before T3, that T3 comes 26ns before T1, that T5 comes 26ns after T1 and that T5-to-scalers comes 7ns after T5. Putting all these findings together we get $26ns+26ns+7ns-23ns = 36ns$ delay according to out diagrams.

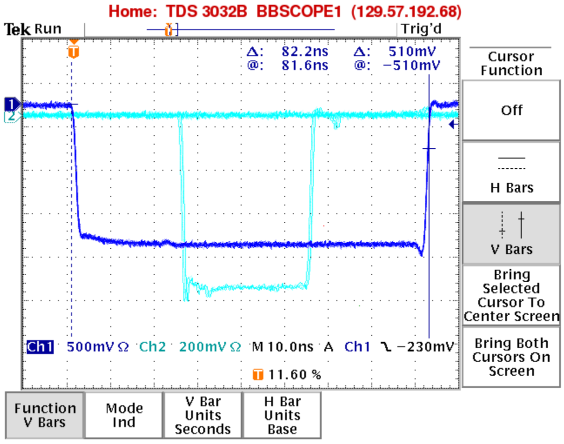


Figure 28: Plot shows coincidence trigger T5(cyan) relative to coincidence window (blue) made of T3. Coincidence window is 82ns wide and comes approximately 25ns before coincidence trigger happens. According to diagram 8 coincidence window should open $4+10+1+8 = 26ns$ after T3. We also know that T5 comes 28ns after T1 and that T1 comes 26ns after T3. This means that by looking at the diagrams the time difference between T3 and T5 should be 28ns.

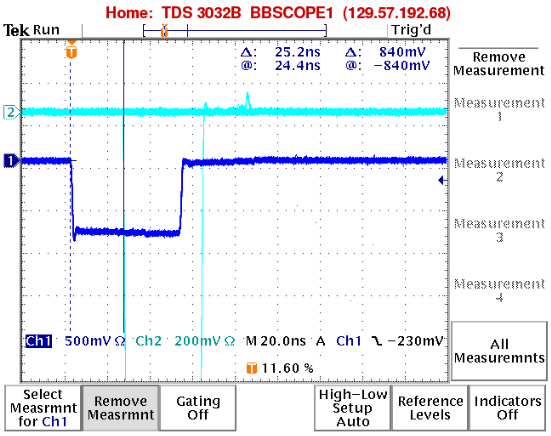


Figure 29: Plot shows time difference between trigger T2(blue) and coincidence trigger T6(cyan) which is approximately 25ns. According to diagram 8 this difference should be: $2ns + 10ns + 4ns + 8ns = 24ns$.

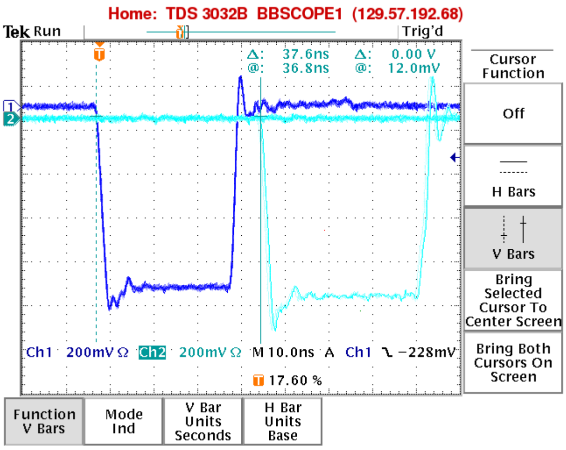


Figure 30: Time difference between trigger T3(blue) and coincidence trigger T6(cyan) on the input to the triggers is according to scope measurement 37.6ns. From the previous discussion we know that T3-to-scalers comes 23ns after T3, that T6 comes 25ns after T2, that T3 comes 28ns before T2 and that T6-to-scalers comes 7ns after T6. This means that time difference should be: $7ns - 23ns + 25ns + 28ns = 37ns$. This is very good.

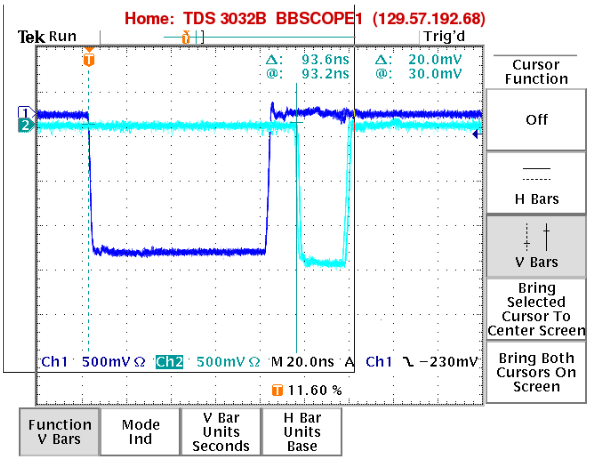


Figure 31: This scope plot shows the time difference between L1A and delayed L1A pulse which is used as suplementary BigBite re-timing pulse when there is no T1 or T2. The time difference is set to be 94ns.

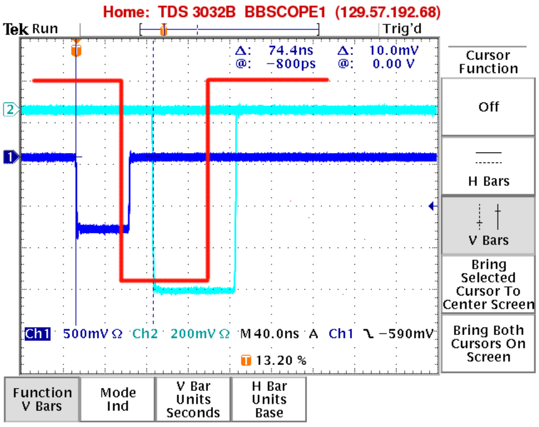


Figure 32: This plot shows the time difference between the trigger T1 (blue) and L1A pulse (cyan) for the case, when Trigger Supervisor accepts coincidence trigger T5. The time difference between the two is approximately 74ns. If the situation, where trigger supervisor would accept T1 or T3 (they come at the same time to the TS) as a valid pulse, than this time difference would be smaller. From the previous discussion we know that T1 comes approximatey 38ns before T5. Consequently this means that L1A would also come 36ns earlier which than gives us: $74 - 36 = 38ns$. The L1A pulse for that situation is drawn on plot with red line.

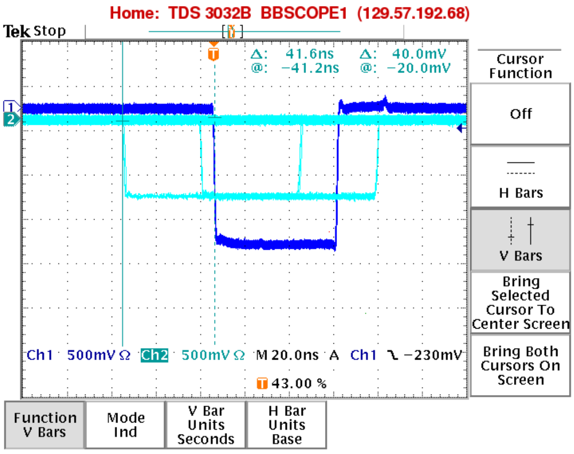


Figure 33: This scope plot shows the time difference between the L1A pulse(cyan) and $(T1orT2)_{Delayed}$ pulse (blue). We can see that we have to cases. In the case when TS accepts trigger T1 or T3, the time time difference is 42ns. In the case when TS accepts coincidence trigger is this difference 6ns. The difference between these two cases is exactly 36ns, which agrees with the time difference between T1 and T5 at the input to the scalers. This agrees with previous plots 24 and 32. The time difference between T1 and $(T1orT2)_{Delayed} = 80ns$, while the time difference between T1 and L1A is 74ns for the coincidence case. Subtracting these two numbers we get exactly $80ns - 74ns = 6ns$.

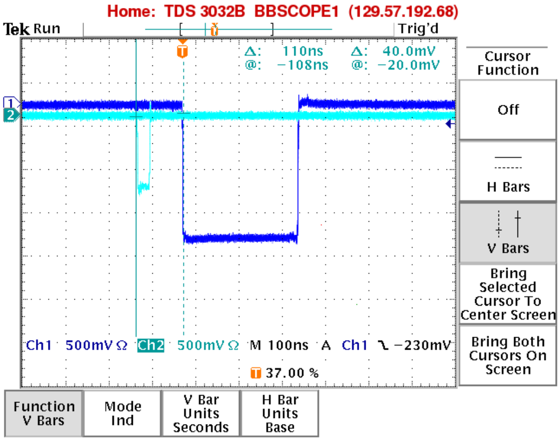


Figure 34: Plot shows the time difference between T1 and BigBite re-timing on the input to the scalers. The time difference is approximately 110ns. According to the electric scheme ?? the time difference should be: $1 + 8 + +25 + 8 + 25 + 2 + 8 + 1 + 8 + 1 + 5 + 1 + 3 = 103ns$. Since the error of our readout from the scope plot is at least 5ns this is a good match. From the plot we can also see, that position of the BigBite re-timing signal is not moving relative to the T1. This is the way that should be, since we designed our circuit so that BigBite re-timing pulse is always timed of T1.

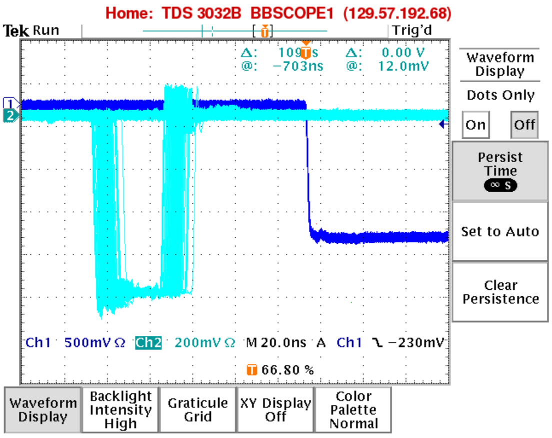


Figure 35: This scope plot shows the time difference between T2 and BigBite re-timing on the input to the scalers. The maximum time difference is approximately 100ns. Minimal time difference is 86ns. From previous plots we know that time difference between T1 and BigBite re-timing is 103ns. If we consider that according to plot 22 T2 comes between 4ns and 18ns after T1 we get almost identical numbers: $103 - 4ns = 99ns$ and $103 - 18ns = 85ns$.

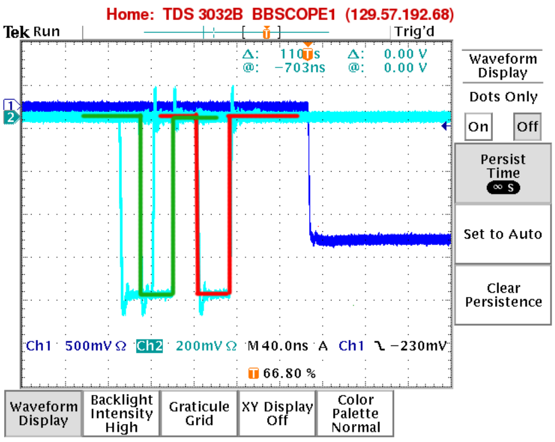


Figure 36: Plot shows the time difference between BigBite re-timing (blue) and trigger T3(cyan) on the input to the scalers. Since we do the re-timing always relative to T1, the time difference between T3 and BigBite re-timing is not constant, but is changing. We get three different peaks with time differences: 104ns, 156ns and 172ns. The first peak (red) corresponds to the situation, where we have both T1 and T3 triggers. Since we know, that they come to the scalers at the same time, the time difference between the T3-to-scalers and BigBite re-timing should be the same as the time difference between T1-to-scalers and BigBite re-timing, which is according to figure 34 103ns. The green peak on the other hand corresponds to the situation, where there is only T3. In this case we know, that L1A comes 37.4ns after T3. From schematics ?? we can conclude that BigBite re-timing comes $94+2+8+1+5+1+5 = 116ns$ after L1A. Together this gives us: $116 + 37 = 153ns$, which agrees with the plot.

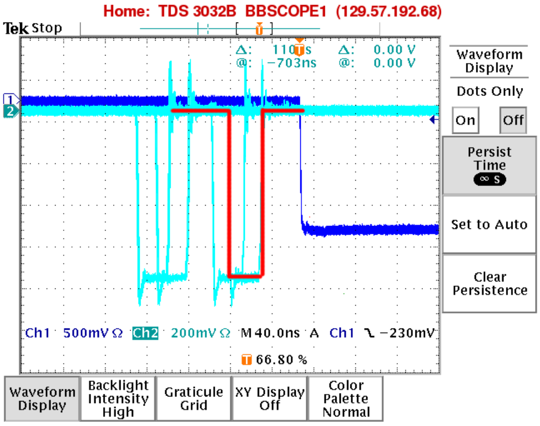


Figure 37: Plot shows the time difference between BigBite re-timing pulse(blue) and trigger T5(cyan) on the input to the scalers. we get multiple peaks which are result of multiple peaks in T3 (see figure 36). The valid peak is marked with red color and comes approximately 68ns before BigBite re-timing. This agrees with our previous findings. We know that time difference between T3-to-scalers and T5-to-scalers is 34ns and that time difference between T3-to-scalers and BigBite re-timing (for the coincidence case) is 104ns. This consequently gives us: $104ns - 34ns = 70ns$.

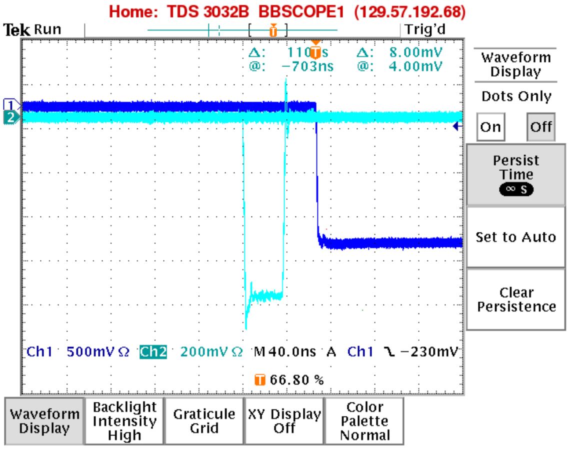


Figure 38: Plot shows the time difference between BigBite re-timing pulse(blue) and trigger T6(cyan) on the input to the scalers and measures approximately 68ns. We know from previous plots that T3-to-scalers comes 37ns before T6-to-scalers and that time difference between T3-to-scalers and BigBite re-timing (for the coincidence case) is 104ns. This consequently gives us: $104ns - 34ns = 70ns$ which agrees with this scope plot.

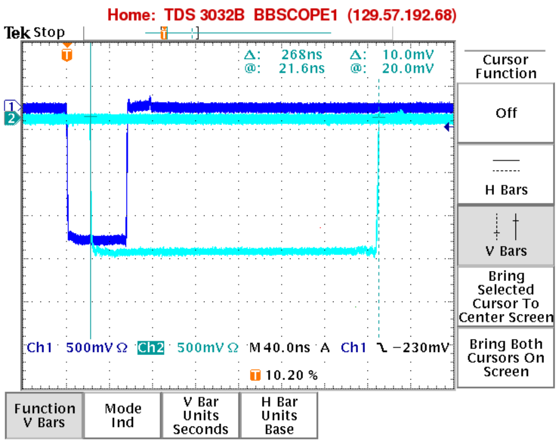


Figure 39: Time difference between BigBite re-timing pulse (cyan) and $(T1orT2)_{Delayed}$ (blue) is approximately 22ns.This agrees well with the scheme **??**, according to which this difference should be: $1 + 8 + 1 + 5 + 1 + 5 = 21ns$.

5 Trigger TDC plots

Beside tests that we made with the scope and simulated pulses we were also able to (as mentioned before) monitor triggers through TDC spectra. Plot 41 shows the TDC spectra of triggers T1, T3 and T5 relative to tbe BigBite re-timing pulse for the deuteron run #2164. Looking at the plot we quickly realie, that it is it is far mor complicated than we have enticipated. Let's try to explain where different peaks come from. Peak

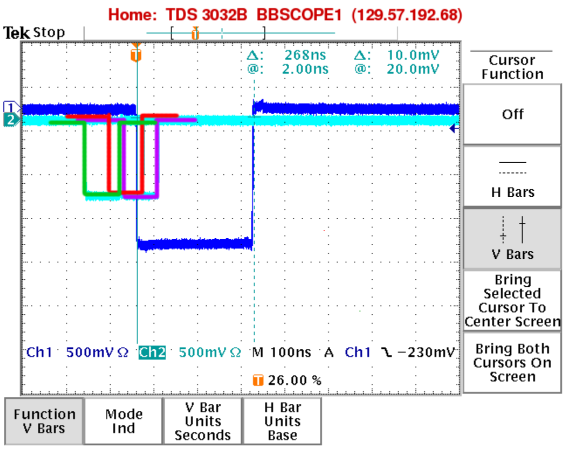


Figure 40: The width of the BigBite re-timing window(blue) i.e. width of the ADC-gate is 268ns. Plot also shows the time differece between BigBite re-timing pulse and L1A (cyan). As a result of different triggers and different situations we get three peaks with differences approximately 30ns (violet), 60ns (red) and 120ns (green). This can also be explained with help previous analysis. From plots 33 and 39 we know that L1A comes 6ns or 42 ns before $(T1orT2)_{Delayed}$ and that $(T1orT2)_{Delayed}$ comes 22ns before BigBite re-timing pulse. Summing these two numbers we get exactly what we need: $6 + 22 = 28ns$ and $42 + 22 = 64ns$. In the case when there is only T3 trigger, delayed L1A pulse opens the BigBite gate. Looking at the scheme **??** we get: $94 + 2 + 8 + 1 + 5 + 1 + 5 = 116ns$ which agrees well with the green line on scope plot.

$T3 - 1$ corresponds to the electron single events, where there was no detected proton/deuteron in BigBite. In this case, L1A pulse was timed of T3 and therefore is this peak sharp. Peaks $T3 - 1$ and $T3 - 1a$ correspond to coincidence peaks. We believe that T3-1 peak represent coincidence protons, while smaller peak T3-1a on its right side represent elastic deuterons. We can see that time difference the peak T3-1 and T3-3 is approximately 53ns which corresponds to the time This difference agrees with the results from the scope test. If we subtract the Time difference between T1 and BigBite re-timing pulse shown on plot 3 from the time difference between T3 and BigBite re-timing pulse for the T3 only case, we get exactly $156 - 103 = 53ns$. Peak T3-3, which is situated approximately 170ns before BigBite re-timing corresponds to the last peak on plot 41. We actually do not know where does this peak come from, but we can see that these events happen very rare an therefore can be neglected.

Besides these three peaks in T3 spectra we can also observe two sharp peaks T3-4 and T3-5 on the left side of the coincidence peaks. These two peaks akso cause two additional peaks in the coincidence trigger T5 spectrum. Because peaks are sharp, we can assume that in these two cases BigBite re-timing pulse was timed of T3 instead of T1. When me make cuts around these two plots to see, we get results shown in figure 42. From these plots we can see, that these two peak cause a plato that we can observe on the right side of the T1 peak in graph 41. Since the distributions of the T1 are flat in these two cases, that means that these are random events and contain no important physical content. From the detail analysis of the scope plots we can realize that beacause of the different lengths of the pulses and delays it can in some random cases happen, that is BigBite re-timing pulse timed of T3 although there was a T1 present. For example: There is a single T3 event. While we are waiting fo the delayed L1A pulse to form the BigBite re-timing pulse, random T1 comes and it has right enough time to form the coincidence and come into the TDC, where it is read.

Since events in these peaks T3-4 and T3-5 are not important, we can make a cut on the trigger T3 and get rid of this back ground. Plot 43 shows all the triggers with T3 cut: $T3 > 760$.

6 Conclusion

In this report I have described all the triggers, that were used during experiment E05-102 for the combination of BigBite and HRS-L spectrometers. I have shown the electronics shematics for the all the triggers and BigBite re-timing and compared them with the scope plots and TDC histrograms and they seem to agree to the extend that we were able to check so far. Especialy from the TDC plots we can see, that in real spectra we get some additional peaks they we did not expect. However, we have found out the origin of these peaks and proven that they are no relevant for our experiment. Therefore we can conclude that BigBite trigger worked properly.

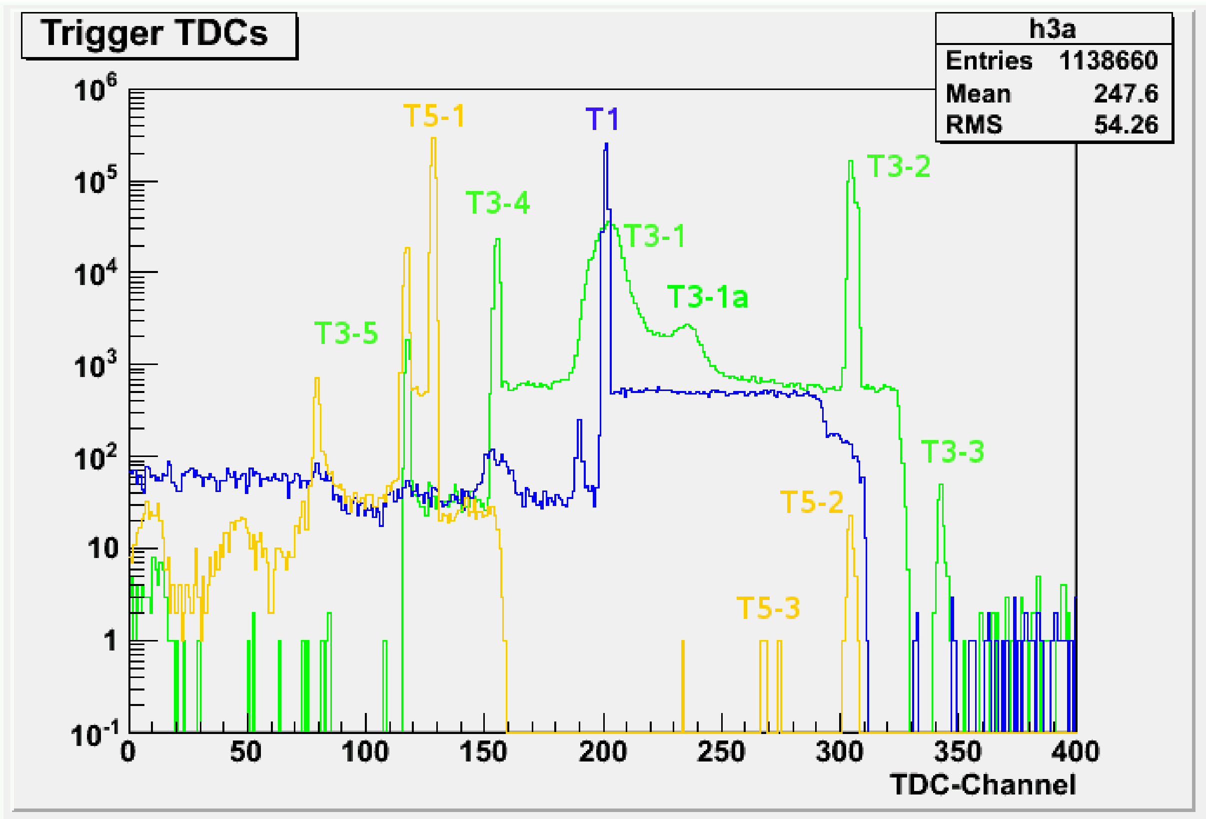


Figure 41: Plot shows the TDC spectra of raw triggers T1, T3 and T5 relative to the BigBite re-timing pulse.

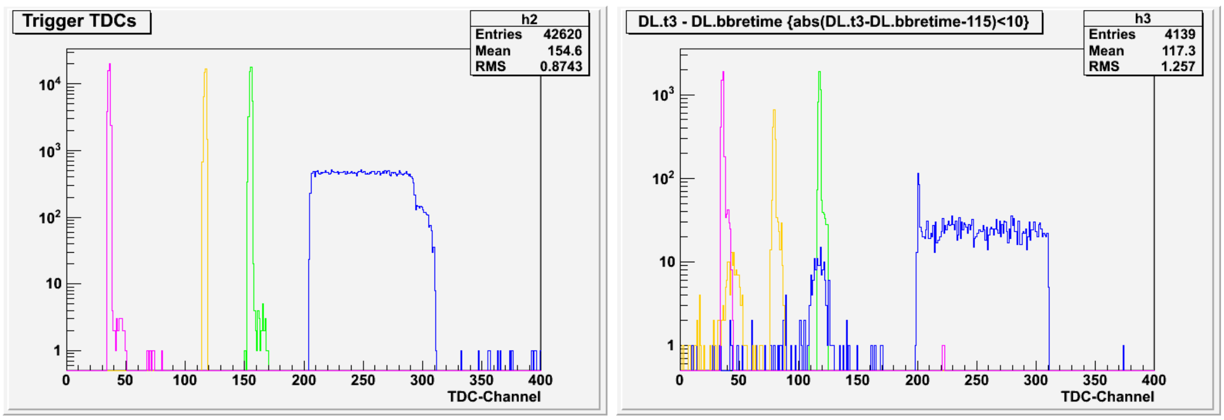


Figure 42: Left plot shows the T1, T3 and T5 triggers with cut $|DL.t3 - 760| < 10 \&\& DL.t1 > 805$. Right plot shows same triggers with cut $|DL.t3 - DL.bbretime - 115| < 10$. From the plots we can see, that in both cases is trigger T1 constant function. This means that physical events in these peaks but just rangom noise.

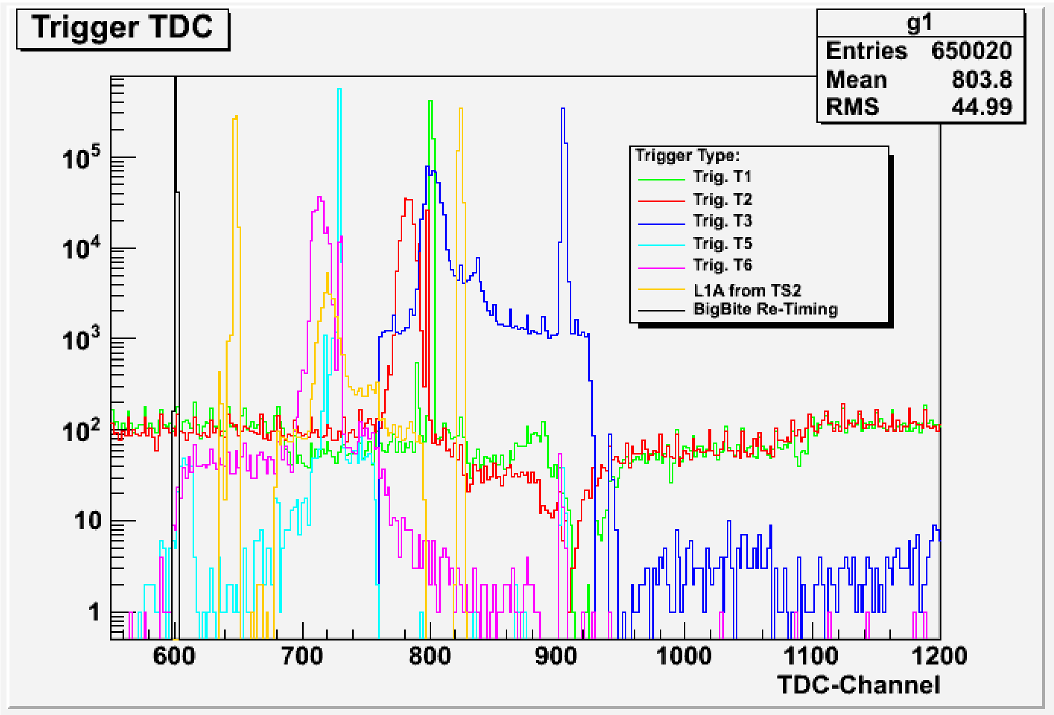


Figure 43: Plot shows the TDC spectra of raw triggers T1, T3, T5 and T6 and signals L1A and BigBite re-timing.