TRIGGER RATES OF DESY BEAM TELESCOPE

Muhammad Afif Izzatullah – DESY ATLAS Group
Electrical Engineering, Institut Teknologi Bandung, Indonesia

Summer student program 2015

Supervisor: Jan Dreyling-Eschweiler

Abstract

The EUDET/AIDA beam Telescope which is used in DESY occasionally has a function to test and determine the properties of Device Under Tests (DUTs). The EUDET TLU is used as the trigger logic unit to generate a trigger signal to the DUT in order to read-out the data from the sensor. This project focuses in the study of trigger rates of the DESY beam telescope. There are three kind of measurements, first is using internal trigger, the second one is by using the external trigger from the pulse generator, which both of these tests will be done in the Electronic Lab DESY. The third test will be in the testbeam area. It will use the DESY Testbeam 21 with the 4 PMTs (Photon Multipliers) as the input of the TLU.

Table of Contents

I. Introduction

1.1 Particle Physics Introduction

"Particle physics is the study of the basic elements of matter and the forces acting among them. It aims to determine the fundamental laws that control the make-up of matter and the physical universe. RAL is one of the leading laboratories investigating this. Experiments at particle accelerators, such as LEP, where sub-atomic particles collide at very high energies, reveal details of particles and conditions that prevailed just after the Big Bang over 15 billion years ago. Most experiments involve large international collaborations and are performed at overseas laboratories such as CERN in Geneva and DESY in Hamburg. These collaborations typically involve more than 300 people and the work at CERN is supported by 19 European countries."[1]

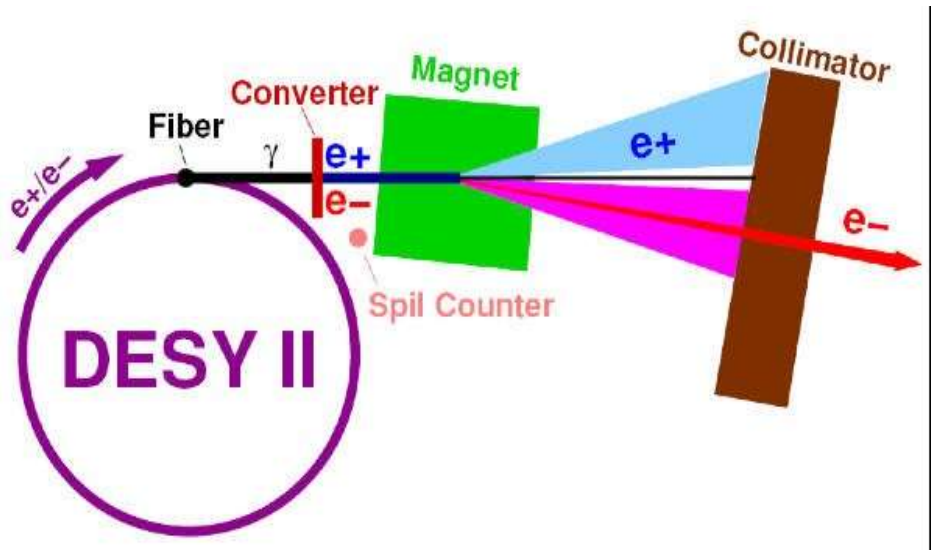

Figure 1. DESY II Accelerator

"One of the part of the particle physics is the detector. Detectors are used to examine tracks made by the new particles that are produced when accelerated particles collide. In the early day's photographic film, spark chambers and bubble chambers were used. Since the late 1960s electronic detectors have taken over. There are two basic kinds - tracking detectors which reveal the trajectories of individual charged particles, and calorimeters which measure energies. A modern electronic detector is built like an onion, with layers of trackers and calorimeters to give as much information as possible about the particles produced in each collision."[2]

1.2 DESY Testbeam Introduction

"Mimosa telescopes originated from a EUDET project before 2010. The first telescope was established to enhance the available test-beam infrastructure, which is necessary for detectors research and development in particle physics. Originally, it

[1] http://hepwww.rl.ac.uk/public/Phil/ppintro/ppintro.html
[2] http://hepwww.rl.ac.uk/public/Phil/ppintro/ppintro.html

was intended to provide a high-resolution pixel telescope which can be even operated in magnetic fields > 1 T."[3]

The EUDET/AIDA beam Telescope which is used in DESY occasionally has a function to test and determine the properties of Device Under Tests (DUTs) which also has high resolution (σ < 2 μm). The beam telescope consists of six sensor planes which are mounted on a Hardware Telescope frame. The whole frame is placed on a Hardware Moveable (green) support. Therefore, the frame can be aligned, so that the direction of the test beam is perpendicular to all sensor planes. Using Hardware #PI-stages for moving DUTs, a DUT can be moved accurately and remotely.

Figure 2. Beam Telescope

You can see from figure 2, the telescope consists of six sensor planes as the reference while doing the precision of tracking configuration which has a pixel pitch 18.4 um. In the front and the behind of the 6 planes, the scintillators are placed that can be read out using the photomultiplier tubes (PMTs). The overall diagram of the system you can see in figure 3.

[3] https://telescopes.desy.de/Main_Page

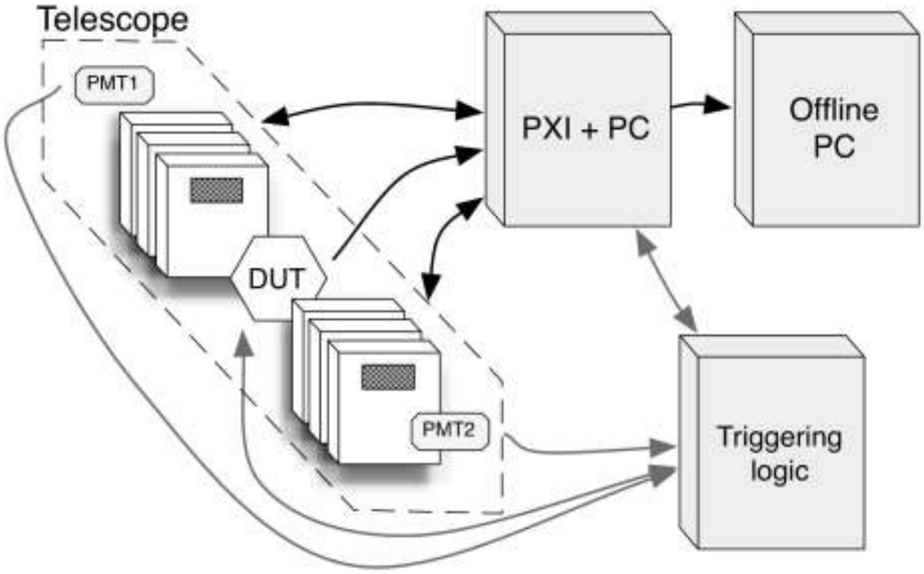

Figure 3. Beam Telescope System

The PMTs will be placed before the first plane and after the last plane of the beam telescope. In between the first three and the second three of planes is place for DUT or Device Under Test, in order to do some testing of the material. The DUT will be read-out by the Mimosa sensors. But before taking the data, the Mimosa sensors need such a signal as the trigger. Therefore, there has to be a triggering logic device to produce a signal that initiates sensors and the DUT can be read out.

At the DESY beam telescope, the hardware for producing the trigger signal is the so-called Trigger Logic Unit (TLU). The TLU will receive inputs from the PMT and scintillators and then process it in order to generate a trigger signal. The trigger signal will be sent be back to the DUT so that the PC can readout the data from the sensors.

1.3 Trigger Logic Unit (TLU)

"The TLU has LVDS and/or TTL interfaces to the beam-telescope readout and any devices under test, PMT signal and/or NIM level signal interfaces to the beam-trigger and a USB interface to the DAQ. It uses an FPGA housed on an "off-the-shelf" FPGA board[4]. The TLU v0.2c is a development of TLU v0.1. Firmware and software written for TLU v0.1 can be used with the TLU v0.2 without damage. However with v0.1 firmware the Busy input multiplexing on a TLU v0.2 cannot be controlled (it defaults to the RJ45 inputs) and the LEDs cannot be controlled. Circuit schematics for the mother-board, clock-board and LEMO-IO daughter-board are available online."[5]

[4] University of Bristol, UK
[5] http://www.eudet.org/e26/e28/e42441/e57298/EUDET-MEMO-2009-04.pdf

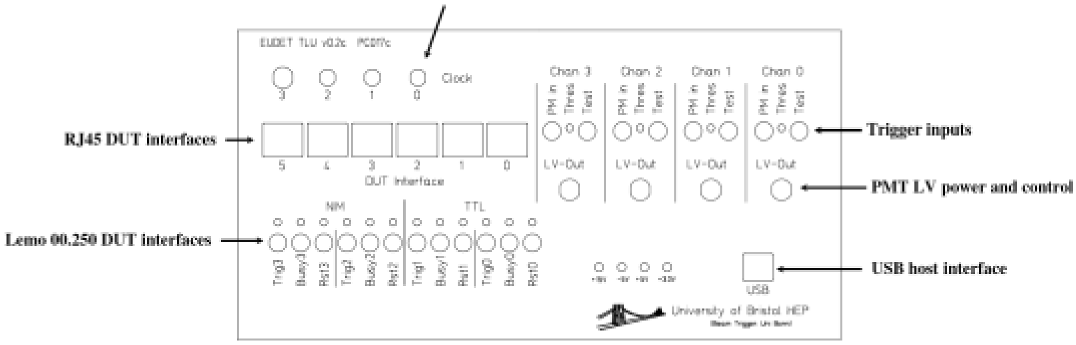

Figure 4. Front panel of the TLU

II. Configuration and Method of the Measurement

The goal of this project is a study of the TLU rates on Beam Telescope using the TLU in the laboratory and in the Testbeam 21 area of DESY. There are 3 steps of the procedure to do this kind of measurement:

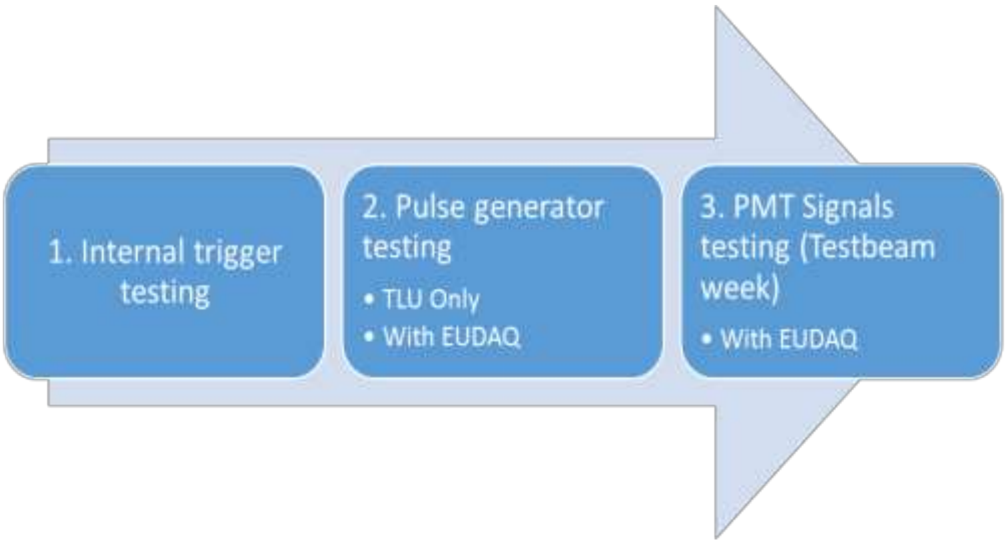

Figure 5. Steps of measurement

The first one is using the internal trigger inside the TLU. This step has purpose to test the functionality of the TLU. We can set up the internal frequency, choose the LEMO or RJ45 cable, and test the output of DUT, the busy signal and also the respond signal using the oscilloscope. In this step we also are able to test the handshake mode of the TLU in order to use for further test if we use the pulse generator in the second step and the testbeam in the last test.

In the second step of this project, we will use the function generator or pulse generator providing a signal which has the same criteria as the PMT signal as the input of the TLU. And for the last test we will use the DESY Testbeam 21 during the beam week for DESY summer student.

Figure 6. Electronic Laboratory (left) and Testbeam 21 DESY area (right)

So overall of the project we will use two kind of place for the testing. For the internal and external trigger test, we use the electronic Laboratory in DESY building 1. For the second test during the testbeam week we will use the Test beam area, which is the place that has been set up the Beam telescope with the TLU, and six Mimosa sensor planes.

III. Trigger Rates of DESY Beam Telescope

3.1 Internal Trigger Test

Trigger is produced internally and is set to 1 kHz (option –t 1).

3.1.1 Internal Trigger Test with LEMO

The result from the test using the LEMO output (channel 3), we can see from the three pictures the trigger has been successfully produced with the handshake mode and without the handshake mode. The system which is not using the handshake mode will produce the double trigger. This is actually one of the errors of the TLU itself. Another result test, if we use the handshake mode, the graph shows that the trigger produce as the single trigger, which is the good one.

```
./TLUControl.exe -t 1 -d 8 -hm 0

Particles (input): 60963
Triggers (output):  60287
Entries:   1103
TS errors: 0, 0 (redundancy, re-read)
Timestamp: 0x56c670e48 (23293529672) = 60.659
Time: 60.765 s, Freq: 992.489 Hz, Average: 992.134 Hz
```

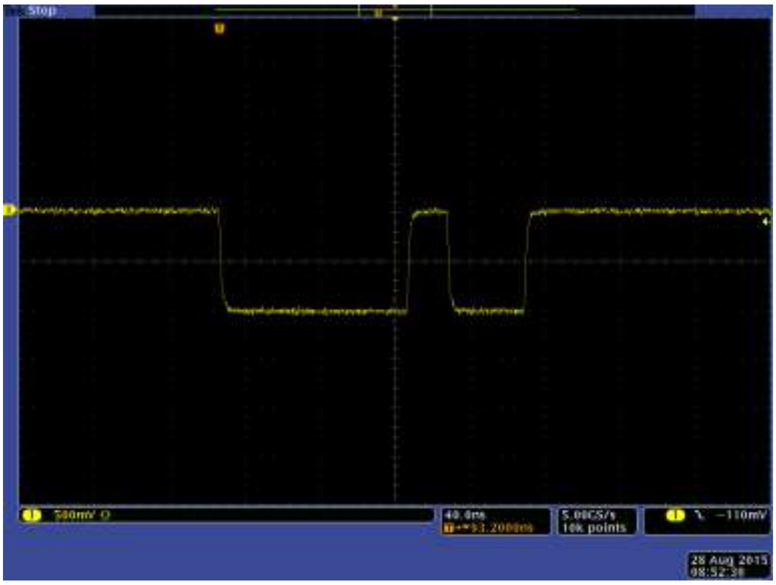

Figure 7. Trigger output without handshake mode

```
./TLUControl.exe -t 1 -i LEMO -d 8 -hm 8

Particles: 61146
Triggers:  60333
Entries:   1116
TS errors: 0, 0 (redundancy, re-read)
Timestamp: 0x56d3f0488 (23307682952) = 60.6958
Time: 60.809 s, Freq: 997.847 Hz, Average: 992.168 Hz
```

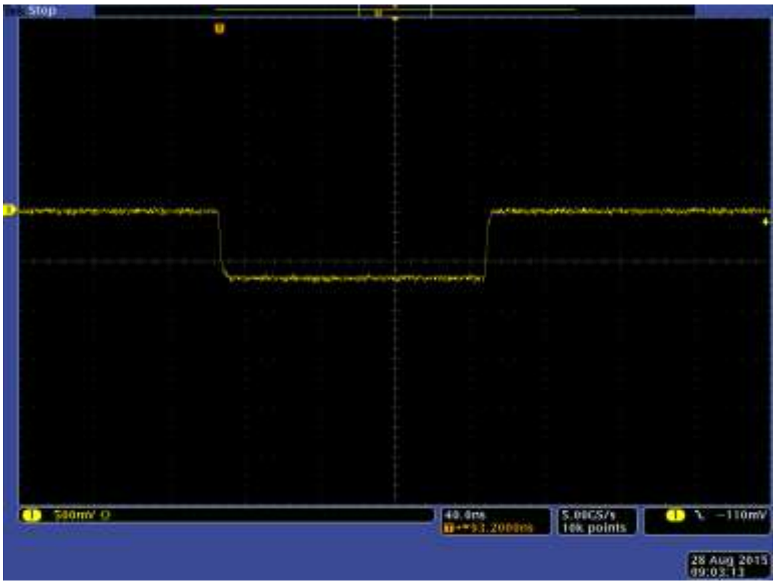

Figure 8. Trigger ouput –hm 8

```
./TLUControl.exe -t 1 -i LEMO -d 8 -hm 63
```

```
Particles: 62253
Triggers:  61415
Entries:   1110
TS errors: 0, 0 (redundancy, re-read)
Timestamp: 0x586601f08 (23729282824) = 61.7937
Time: 61.907 s, Freq: 992.129 Hz, Average: 992.048 Hz
```

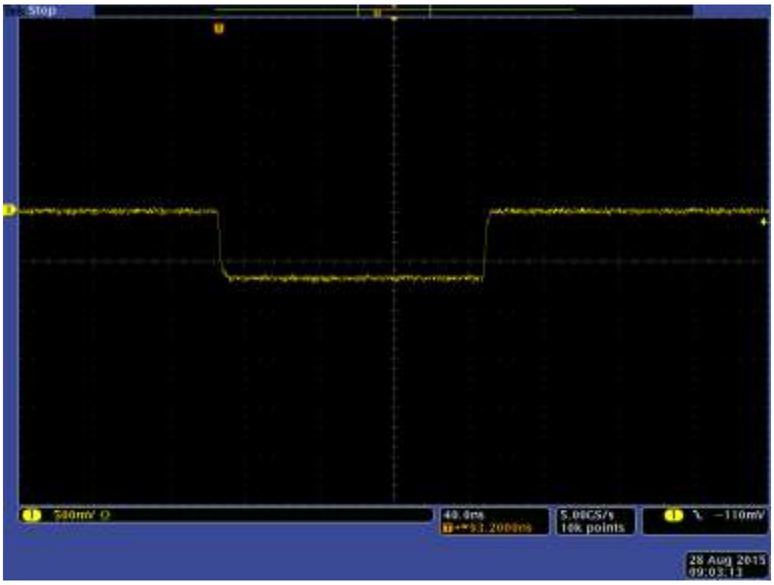

Figure 9. Trigger output –hm 63

The second result by this testing is we can also look at the number that can be used to activate the handshake mode. There are 2 kind of range of the number to use to activate the handshake mode, those are the range 0 – 7 which will make the system operating without the handshake mode and the second range is 8 – 63 which will make the system activating the handshake mode which will produce the single trigger and is waiting to receive the busy signal. Busy signal are provided by feeding back the trigger signal. This number when we test is looping, if we use 64 – 71 it will turn off the handshake mode and over the 72 as well it will activate the handshake mode on.

3.1.2 Internal Trigger Test with RJ45

From this test, we will use the different output which is the RJ45. The result is totally the same with the LEMO output. It will produce the double trigger as well by using no handshake mode and will produce a good single trigger by using the handshake mode. Therefore for the rest of the test, we will use the RJ45. It will be also useful with RJ45, because for the next generation of TLU named AIDA Mini TLU, the main connector type is using the RJ45 and HDMI.

```
./TLUControl.exe -t 1 -d 8 -hm 0

Particles: 60886
```

```
Triggers:  60220
Entries:   1086
TS errors: 0, 0 (redundancy, re-read)
Timestamp: 0x56a9e7848 (23263606856) = 60.581
Time: 60.668 s, Freq: 993.483 Hz, Average: 992.602 Hz
```

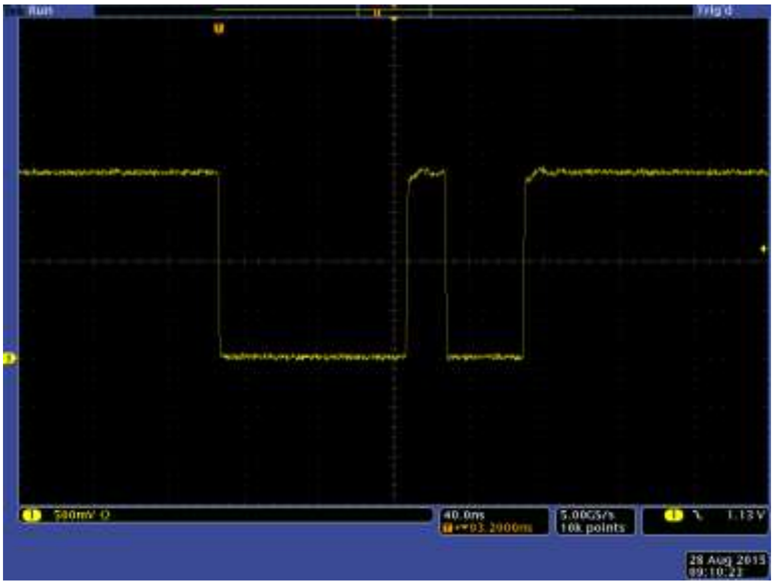

Figure 10. Trigger output RJ45 without –hm 0

```
./TLUControl.exe -t 1 -i RJ45 -d 8 -hm 63

Particles: 60901
Triggers:  60073
Entries:   1089
TS errors: 0, 0 (redundancy, re-read)
Timestamp: 0x5676b8868 (23209937000) = 60.4413
Time: 60.552 s, Freq: 975.074 Hz, Average: 992.076 Hz
```

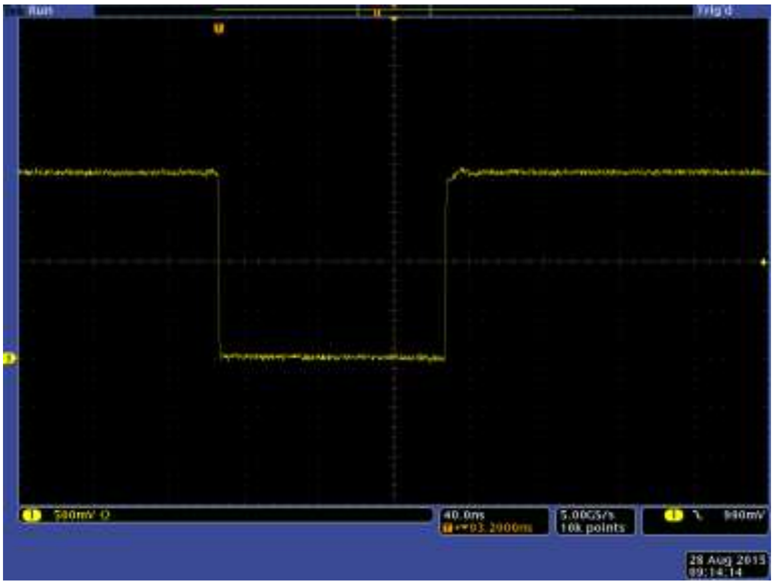

Figure 11. Trigger output RJ45 –hm 63

The second result we can also see the number of trigger rates produces if we use the internall trigger 1 kHz.

This is the result from the LEMO output

```
Time: 60.809 s, Freq: 997.847 Hz, Average: 992.168 Hz
```

This is the result from the RJ45 output

```
Time: 60.552 s, Freq: 975.074 Hz, Average: 992.076 Hz
```

We can see from the measurement around 60 seconds for 1 kHz internal trigger, we got the number around 992 kHz which is 99.2 % efficiency of the trigger rate generated internally.

3.2 External Trigger Test

In order to imitate the signal of the PMT we will use the following configurations (figure 12). Firstly we use a squared pulse signal. The height of the signal is set to -80mV because the threshold voltage is compared to the TLU is -40mV. Then the third one, we will use the width signal 10ns which almost the same with the width of the PMT signal (10-20ns). Finally we can select the frequency of the signal.

Figure 12. Pulse Generator configuration

For the first test we use a high input signal of 1MHz. Thus, the trigger signal can be visualized using an oscilloscope and the trigger rate produced by the TLU can be read-out by TLU control software.

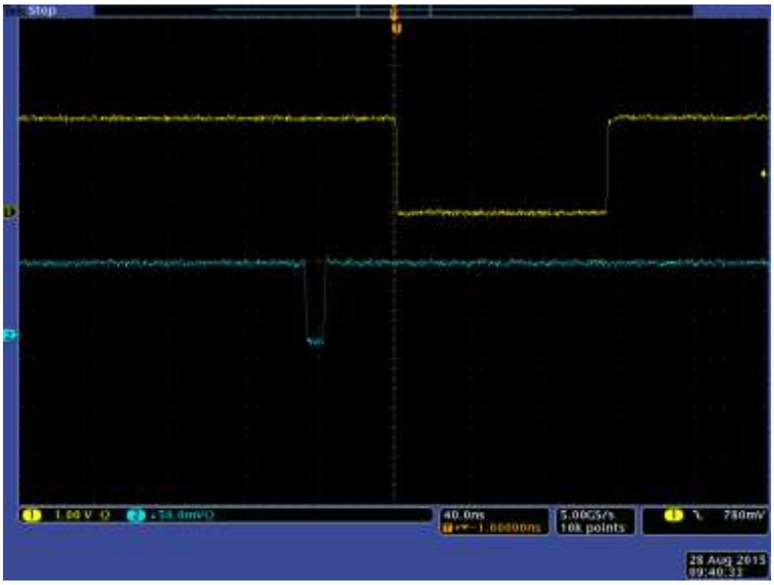

Figure 13. Pulse generator input (green) and Trigger output (yellow)

We can see in the graph the trigger signal (yellow) is after the input signal (blue). The result here, if we use only the TLU with TLU control software we get a limit of the trigger rate of 2.8 kHz.

3.2.1 EUDAQ Pre-Test Configuration

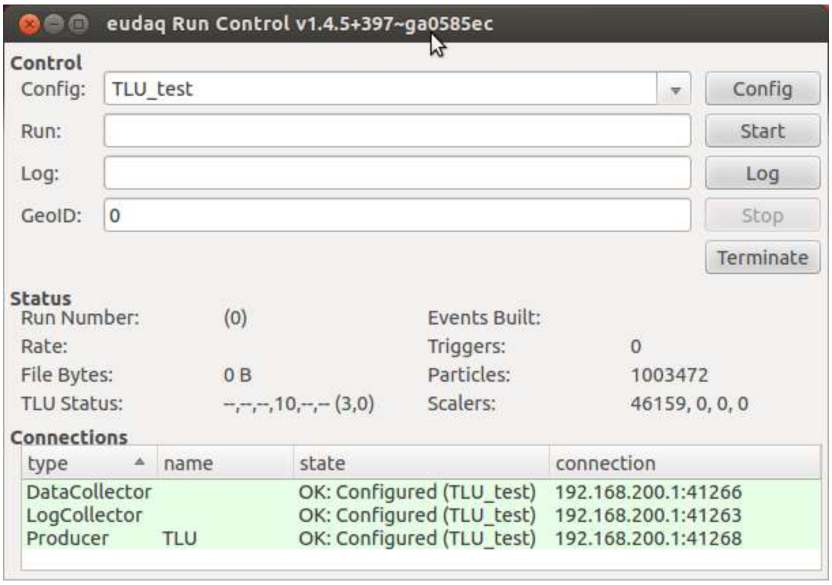

Figure 14. EUDAQ Pre-configuration: TLU_test.conf

For the rest of the test, we will use EUDAQ software that has been installed in the computer lab. In this test, because we want to measure and test the TLU only, the configuration that we use the TLU only which activates the TLU processing the input from the pulse generator. We can see from figure 14 that, the status bar in the below of the table, it successfully configures the data collector, log collector and the TLU producer itself.

3.2.2 Input rate 1MHz with EUDAQ

For the first test, we will use a very high frequency for the single TLU input that we can set by the pulse generator. The purpose of this test is to see the limit of the trigger rate produced if the input has high frequency. From figure 15 we can see after the EUDAQ is started, the TLU producer will run and in this measurement we will use an acquisition time of ~60 seconds.

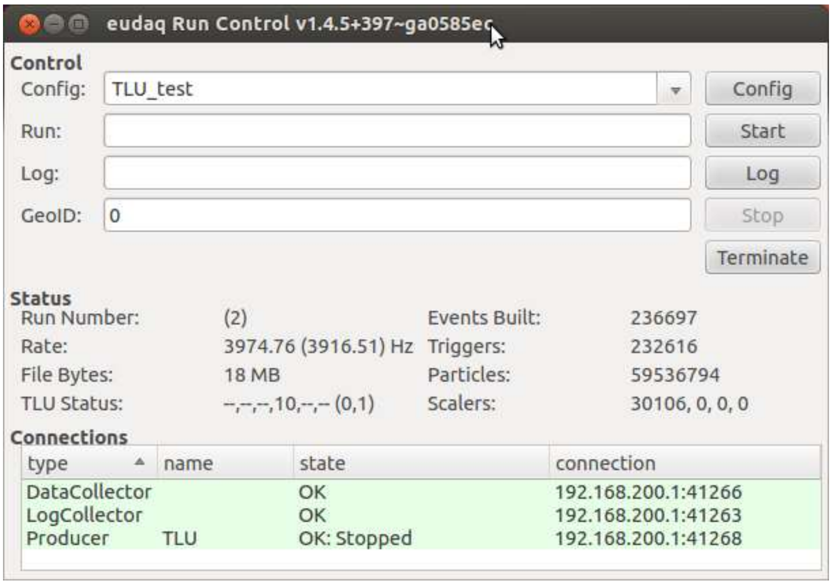

Figure 15. EUDAQ result with 1 MHz input

```
[Producer.TLU]
AndMask = 1
DutMask = 8
(handshake mode, default -63)

Measurement time: ~59.5 sec,
Trigger rate (output): 3974.8 Hz
```

From the result, it shows that with the measurement time around one minute, the particles produced almost 6 MHz which is correctly like it is supposed to be. But the number of the trigger produced is far lower than the particles, or from the EUDAQ interface that the average trigger rate generated is 3974.8 Hz or around 3.9 kHz. So the conclusion of this test is the limitation of the trigger rate is 3.9 kHz.

3.2.3 Input rate 10 kHz with EUDAQ

The next test will use the frequency 10 kHz which appropriately matches the Testbeam rate in DESY testbeam area. The procedure is analogue to the previous test, but here the pulse generator is set to generate a 10 kHz signals.

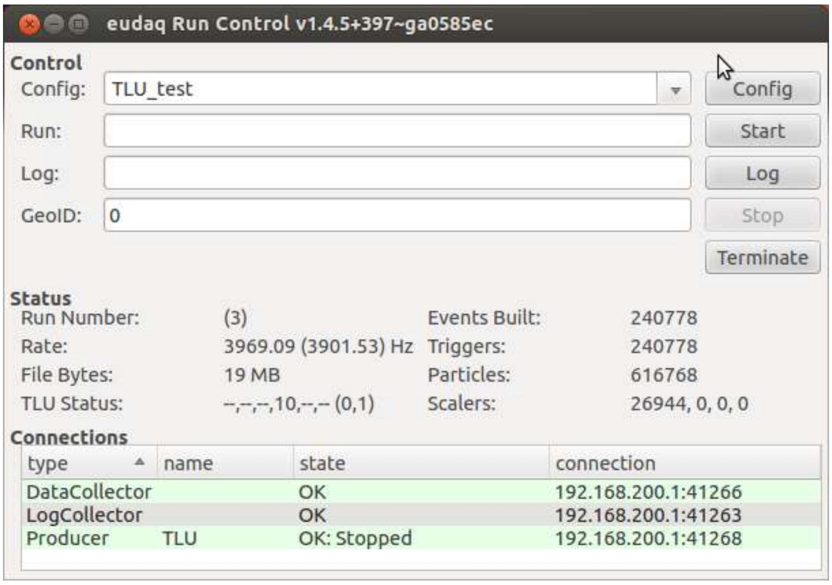

Figure 16. EUDAQ result with 10 kHz input

```
[Producer.TLU]
AndMask = 1
DutMask = 8
(handshake mode, default -63)

Measurement time: ~61.6 sec
Trigger rate (output): 3969.1 Hz
```

With the measurement time of 61.6 seconds the particles produced are still stable 616,768. But the trigger rate is lower than the particles. From EUDAQ the average of trigger rate produced is 3901.53 Hz or around 3.9 kHz same like before. The conclusion after this test is the limit value of the trigger rate is still 3.9 kHz using 10 kHz input.

3.2.4 Coincidence of 10 kHz 4 inputs for the TLU with EUDAQ

For the next test, it will be used the 4 signals input to the TLU as the coincidence. The purpose of this test is to measure the trigger rate limit, if it is used the 4 signals as the input which is the same like the situation in the Testbeam area that uses the coincidence of the 4 PMTs as the input.

The source that is used in this measurement is the same, the pulse generator at 10 kHz. The configuration of the hardware can be seen in the figure 17. We use the 4 branches of a LEMO cable, from one source of signals. Therefore we need to increase the pulse height to -160 mV in order to produce a -80mV output signal of each of the LEMO cable.

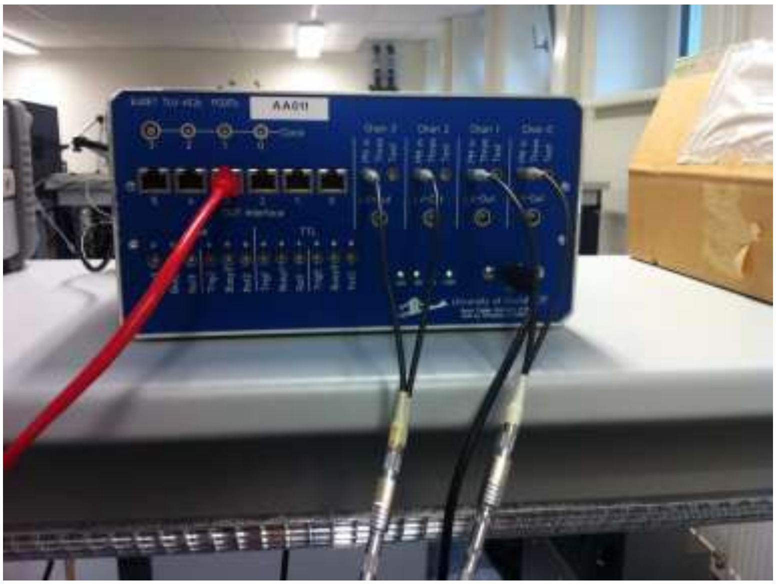

Figure 17. TLU configuration with 4 input

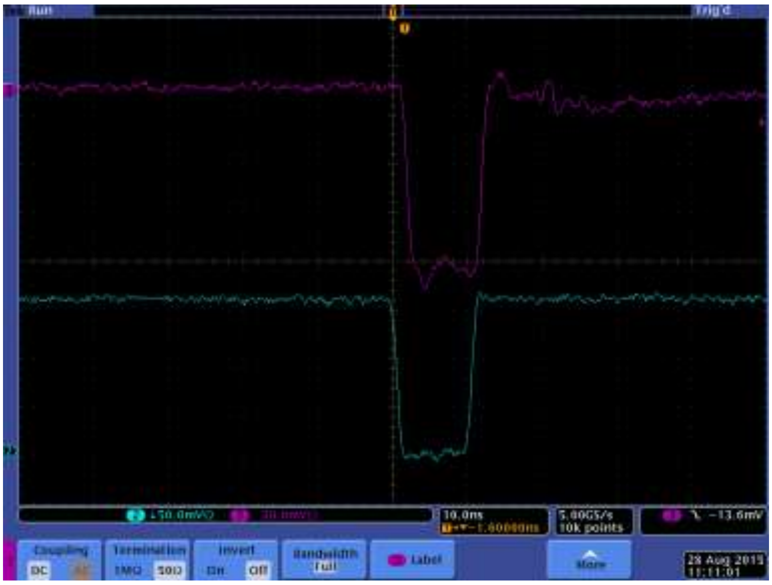

Figure 18. Four divisions signal (purple) and original signal

Dividing the signal into 4 signals can be seen in figure 18. The signal has a bit reflection (purple) if it is compared to the normal pulse signal (green).

After using the 4 signals into the TLU, the EUDAQ produces the result in the figure 19.

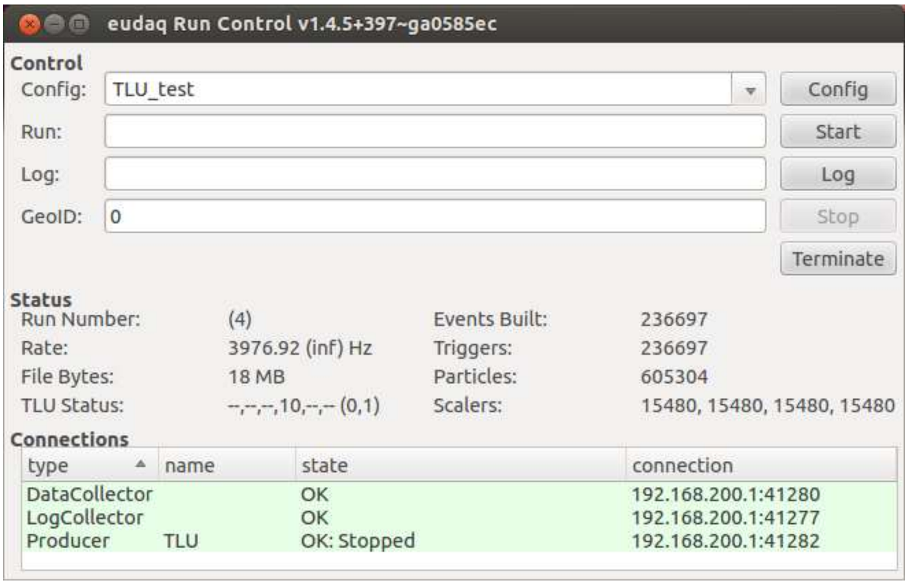

Figure 19. EUDAQ result with coincidence four 10 kHz inputs

```
[Producer.TLU]
AndMask = 15
DutMask = 8
(handshake mode, default -63)

Measurement time: ~60.5 sec
Trigger rate (output): 3976.9 Hz
```

It can be seen the particles produces are still stable like in the previous measurement. The same value of average trigger is produced which is around 3.9 kHz. Therefore the final conclusion from the lab test that the limit of trigger rate is 3.9 kHz of the TLU.

3.3 DESY Testbeam 21 Test

The final measurement is using the Testbeam 21 in DESY testbeam area. In here we will use the coincidence of the four PMTs as the input to the TLU.

3.3.1 The result with TLU-only reading

By using the EUDAQ software in the testbeam area, we got the rates of the particles of the beam is 10.5 kHz in maximum. But in here the result of average trigger rate generated is only 3.6 kHz. It is lower than the rate that we got from the lab test. But after looking at the signal of the beam, it has an instability in the frequency. There are two kind of areas which we can see in figure 20. There are high frequency and low frequency beam with constant time that the effective input rate is maybe much lower. The conclusion is the number of the trigger rates is lower than the lab test probably because of the instability of the beam.

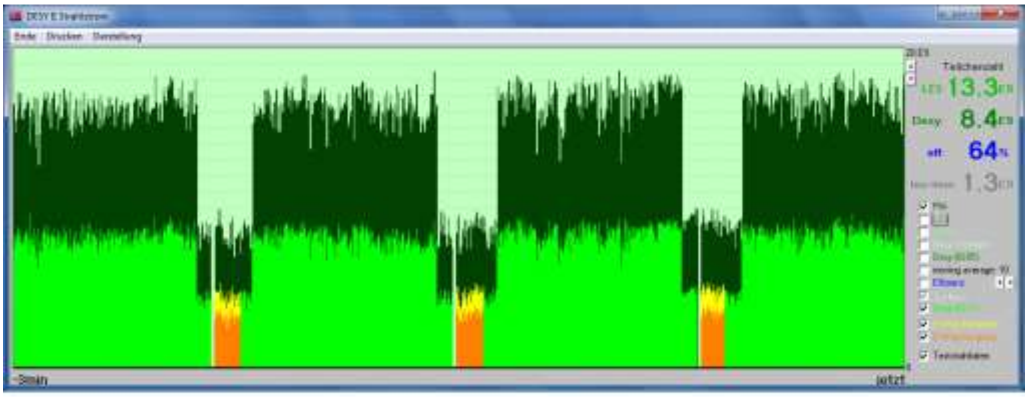

Figure 20. Beam output TB 21 DESY

3.3.2 The Result with the Mimosa Sensor Read-out

The final test of this project is using the TLU with the Mimosa Sensor Read out at the beam Telescope. We can see in figure 21, the 6 planes of which have each a Mimosa sensor which are on one line with the beam (indicated in red).

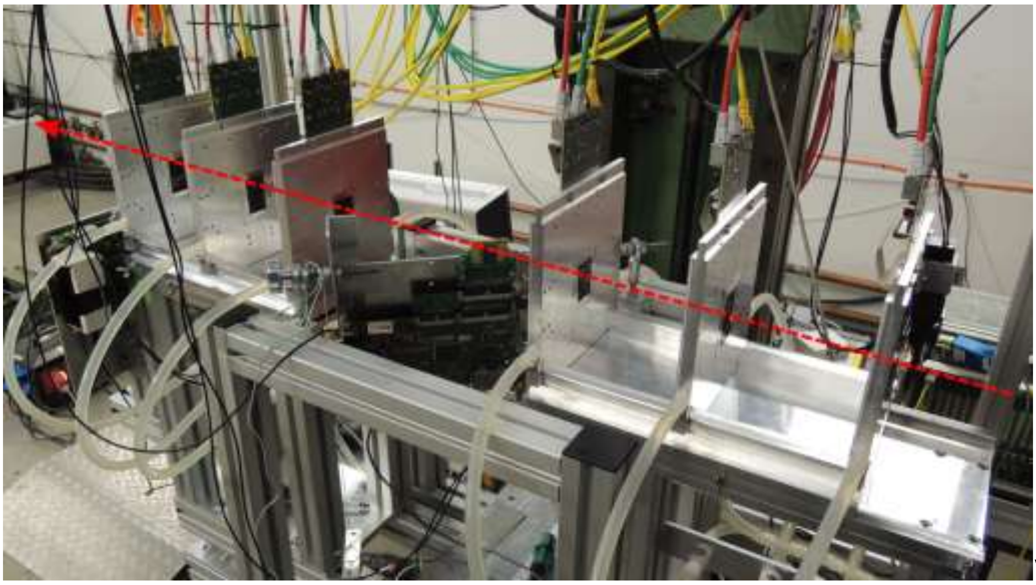
\

Figure 21. Beam Telescope with Mimosa Reading-out

Then after the measurement, the trigger rates of the TLU generated with the Mimosa sensor reading out, is around double lower than the rates of the TLU only. The average number of the trigger rate produced is only 2.0 kHz. Therefore the final conclusion of this measurement that the limit of the trigger rate that can be generated from the TLU while the Mimosa sensor reading-out is 2.0 kHz

IV. Summary and Outlook

The EUDET TLU has two kind mode which are handshake mode and normal mode. The handshake mode is by using the busy signal from the DUT while reading out the data. It can be activated by fill up the code with the number –hm 8 to 63. Furthermore the EUDET TLU has also a limit of the trigger rates generated. If it is the TLU only, the limit of the trigger rates is 3.9 kHz. If it is used with the Mimosa sensor reading out in the telescope beam, the limit of the trigger rates is 2.0 kHz. There will be a next generation of TLU that will be used at the DESY beam telescope which is named AIDA Mini TLU. It has more efficiency trigger rates and also use the new interaction cable with RJ45 and HDMI. The progress now is still in an installing step which is successfully installed the firmware of the AIDA Mini TLU. The outlook project will be more focus on installing and testing this kind of TLU in the testbeam area.

References

[1] Igor Rubinsky, An EUDET/AIDA pixel beam telescope for detector development

[2] D. Cussans, Description of the JRA1 Trigger Logic Unit (TLU), v0.2c. EUDET-Memo-2009-4. [3] David Cussans, AIDA Common DAQ Timing/Triggering/Control Hardware Interface Version: 0.1

[3] P. Rolo_, "The EUDET high resolution pixel telescope", Nucl. Instrum. Meth., A604, (2009)

[4] Daniele Areoluci, "AIDA & EUDET TLU characterization tests", DESY Summer student program 2014

[5] https://telescopes.desy.de/Main_Page

[6] http://hepwww.rl.ac.uk/public/Phil/ppintro/ppintro.html