Fermi National
Accelerator Laboratory

Summer internship

Final report

Commissioning of the trigger system for the ICARUS T600 LAr-TPC detector in SBN Program

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Intern:
Maria De Luca

Supervisor:
Angela Fava

Contents

Abstract

The ICARUS experiment at Fermilab is the far detector of the *Short Baseline Neutrino Program* (SBN), aimed at studing the neutrino oscillation to find a fourth type of neutrino, called sterile neutrino.
A key component for this detector is the trigger system, which aims to identify and isolate the physical interactions from the background events.
In this framework my internship program was dedicated to the development of trigger logic and trigger inhibit mechanism in order to select the genuine neutrino interaction and to guarantee a correct functioning of the readout system. These two steps, that represent a part of the commissioning of the trigger system, were implemented with LabVIEW Software.
The obtained results are a fundamental step towards a succesful activation of the detector in the next few months.

Chapter 1

Introduction to the ICARUS T600 Experiment

The ICARUS T600 detector is a Liquid Argon Time Projection Chamber (LAr-TPC) installed at Fermilab as far detector of the Short-Baseline Neutrino program (SBN).
It will perform studies on sterile neutrino oscillation in order to resolve some anomalies found in previous experiments on short baseline neutrino oscillations.
This chapter presents the SBN phyisics program and a brief description of the ICARUS T600 detector.

1.1 The Short Baseline Neutrino Program at FermiLAB

The Short-Baseline Neutrino program consists of three LAr-TPC's located on-axis on the the Booster Neutrino Beam at the Fermi National Accelerator Laboratory.
The detectors - *SBND*, *MicroBooNE* and *ICARUS*- are exposed to the ν_μ (or $\bar{\nu}_\mu$) beam, with average energy about 0.8 GeV at different distance from the target $110m$, $470m$ and $600m$ respectively (Fig. 1.1).
The main goal of this program will be the search of a possible 4^{th} type of neutrino, called *sterile* (in the $1\,\mathrm{eV}^2$ mass range) through the measure of neutrino oscillation, over short baseline. The peculiarity of this program is its capability to study both the possible appearance of electron neutrinos associated with the $\nu_\mu \to \nu_e$ oscillation and the possible concurrent signal in disappearance of muonic neutrinos, incontrovertible evidence of the existence of the sterile neutrinos.

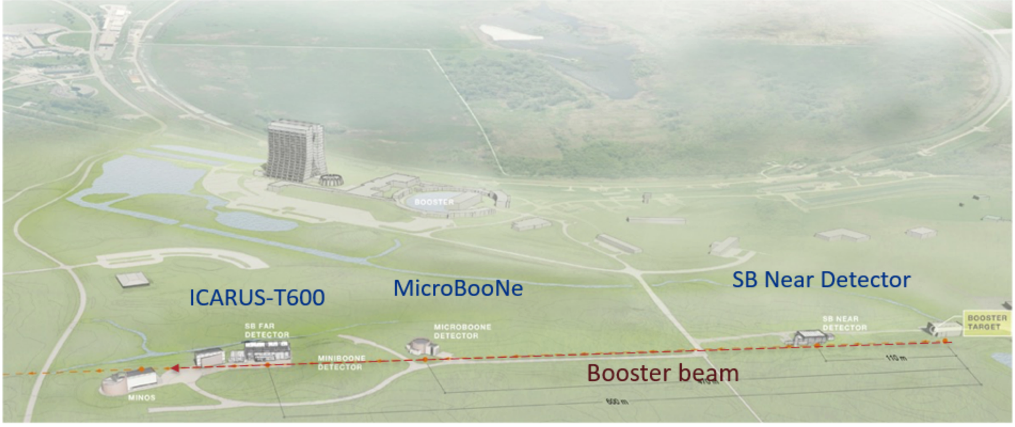


Figure 1.1: Sheme of the three detectors in SBN Program. The first detector, near the Booster target is SBND, the far detector is ICARUS T600 and in the middle there is MicrooBooNE.

Additional physics search of the SBN Program includes the study of neutrino-argon cross sections with millions of interactions using the well characterized neutrino fluxes of the BNB. The SBN detectors will also record events from the off-axis flux of the NuMI neutrino beam, with its higher electron neutrino content and different energy spectrum.
Finally, the SBN Program plays an important role for study and developement of liquid argon TPC detectors technology for the future long-baseline *DUNE* neutrino program [1].

1.1.1 The search of Sterile Neutrino in the SBN Program

In the Standard Model (SM) of particle physics neutrinos exist in three flavours (ν_e, ν_μ, ν_τ) as neutral, left-handed and massless leptons. The feature of neutrinos to have zero mass has turned to be antithetical to observations of neutrino oscillation, a phenomena where the flavour of a neutrino changes as it moves through space and matter. The rate at which the flavour changes can be measured directly counting the number of neutrinos of a given flavour at point A and the same at another point B. Because the probability oscillation between two neutrinos states

$$P_{\nu_\alpha \to \nu_\beta} = sin^2(2\theta) sin^2 \left(1.267 \frac{\Delta m^2 L}{E_\nu} \frac{GeV}{eV^2 km} \right) \tag{1.1}$$

depends only on:

- $\Delta m^2 = m_2^2 - m_1^2$, i.e. the mass square difference in eV^{-2};
- θ, i.e. the mixing angle states 1 and 2;
- L, i.e. the distance traveled by neutrinos;
- E, i.e. the neutrino's energy

by measuring neutrino oscillation important informations on fundamental ν properties such as Δm^2 and θ can be extracted. A multitude of neutrino oscillation experiments so far allowed to identify two clearly separate oscillation regimes, the so called "atmospheric" $\Delta m_{31}^2 = 2.5 \cdot 10^{-3}$ and "solar" $\Delta m_{21}^2 = 7.54 \cdot 10^{-5}$, and to measure with high precision a set of oscillation parameters compatible with the 3-flavour paradigm.

However, in recent years, several experimental "anomalies" have been reported of short baseline, which, if experimentally confirmed, could be hinting at the presence of additional neutrino states with larger mass-squared differences participating in the mixing.
Two such classes of anomalies pointing at additional physics beyond the Standard Model in the neutrino sector, can be distinguished (Table 1.1).

- The "reactor anomaly" refers to the deficit of electron anti-neutrinos observed in numerous detectors a few meters away from nuclear reactor sources compared to the predicted rates [2]. A similar indication for electron neutrino disappearance has been recorded by the SAGE and GALLEX solar neutrino experiments when measuring the calibration signal produced by intense k-capture sources of ^{51}Cr and ^{37}Ar at very short distances("Gallium anomaly") [4] [3].
- The "LSND anomaly", involves results from the LSND and MiniBooNE short-baseline $\nu_e/\bar{\nu}_e$ appearance experiments [5] [6].

Experiment	Channel
Reactors	ν_e disappearance
GALLEX/SAGE	ν_e disappearance
LSND	$\bar{\nu_\mu} \rightarrow \bar{\nu_e}$
MiniBooNE	$\nu_\mu \rightarrow \nu_e$
MiniBooNE	$\bar{\nu_\mu} \rightarrow \bar{\nu_e}$

Table 1.1: Summary of the experimental anomalies found in shprt-baseline oscillation experiments.

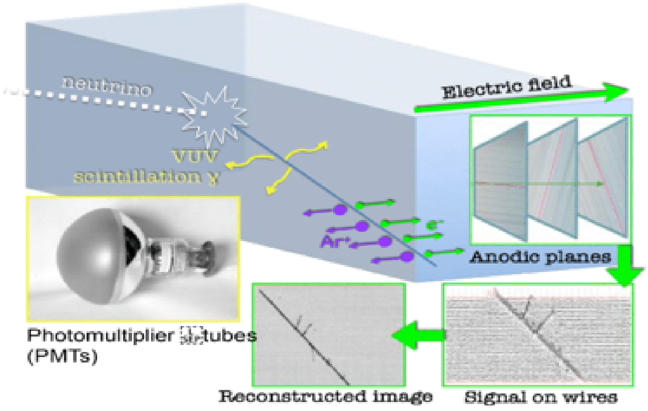


Figure 1.2: Scheme of detection of neutrino interaction in LAr-TPC detector. The scintillation light, produced by excitation of Argon atom, is recorded by PMTs while the eletrons, produced by the ionization, drift towards the anode and produce a signal on TPC wires.

One possible explanation of these results, suggesting important new physics, is the existence of at least one fourth non-standard neutrino state, driving neutrino oscillations at a small distance, with typically $\Delta m^2_{new} > 0.1eV^2$. Sterile neutrino states, if they exist, are not directly observable since they do not interact with ordinary matter through the weak interaction, but active-sterile mixing could generate new oscillations among the standard neutrino flavors [7].

SBN is designed to address the possible existence of 1 eV mass-scale sterile neutrinos using multiple, functionally identical detectors (LAr-TPC), sitting along the same neutrino beam, which is the key to the experiment's world-leading sensitivity [1].

1.1.2 LAr-TPC detection technology

Liquid-Argon Time Projection Chamber, or LAr-TPC, is one of the most promising detection technique for the study of rare events such as neutrino interactions.

The working principle of the device is illustrated in Fig. 1.2. When a neutrino undergoes an interaction with an argon nucleus, resulting charged particles ionize and excite argon atoms as they propagate in the liquid. When excited argon atom de-excites, it produces scintillation light that can be recorded

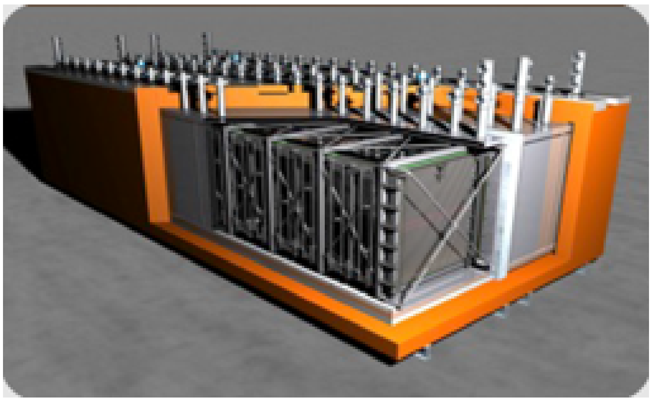


Figure 1.3: ICARUS T600 detector.

by light detection systems such as $PMTs$ (photomultiplier tubes). The ionization produces pairs of ions (Ar^+) and electrons (e^-). These electrons are transported by a uniform electric field to sets of wire planes with different orientations placed at the end of the drift path, where they induce signals and permit the simultaneous measurement of the same event in different projections.

The LAr-TPC is a continuously-sensitive and self-triggering detector, characterized by high granularity and spatial resolution, providing 3D imaging of any ionizing event. Moreover, this detector is an excellent homogeneous calorimeter that provides efficient particle identification based on the density of the energy deposition [1].

1.1.3 ICARUS T600 LAr-TPC detector

The ICARUS T600 detector (Fig. 1.3) with a total active mass of 476 $tons$ on the whole filled with 760 $tons$ of liquid argon kept at a temperature of $89K$, consists of two identical and adjacent T300 modules [8]. Each one houses an inner detector composed of two time projection chambers, with a common cathode. Each TPC is equipped with an anode, a field-shaping system, monitors, probes and liquid argon scintillation light detection system. The $1.5m$ distance between the cathode and the wires corresponds to a maximum drift time of $1ms$ at the nominal $500V/cm$.

The TPC anode is composed by three parallel planes of wires, the first composed of horizontal wires, the other two at ± 60° compared to the horizontal.

The total number of wires and electronic channels in T600 is ≈ 54.000. The information is read both by electric charge induction on the first two readout planes and by electric charge collection on the last readout plane. The signals from the three wire planes, together with measurement of the drift time, provide a full 3-D image reconstruction of the event.

The scintillation light detection system of ICARUS T600 is composed by 360 $Hamamatsu\ R5912 - mod\ PMTs$ and all detector is surrounded by a CRT that is a Cosmic Ray Tagger, composed of plastic scintillations labs read out by SiPMs in order to mitigate cosmic generated backgrounds.

Chapter 2

The trigger system for the ICARUS T600 detector

The goal of the trigger system for the ICARUS T600 detector is prompty identifying all physical interactions that occur in LAr-TPC while minimizing the occurence of background events. The expected rate of physical interactions that is about $0.2Hz$, includes neutrino interactions from Booster Neutrino and NuMI beams, the muon beam halo and cosmic rays.
For the BNB, at the nominal intensity of 5 $10^{12}pot/spill$ extracted in $\approx 1.6\mu s$ time window with a standard $5Hz$ repetition rate, almost 1 neutrino interaction every 180 spills is expected to occur in the T600 detector. A similar event rate, almost 1 over 210 spills comes from the muon beam halo and the interaction in the material surronding the T600. The dominant event rate is due to the cosmic ray inside the spill, 1 over 55 spills. In overall, 1 event over $8.8s$ is expected from BNB source.
For NuMI, 1 neutrino event is expected every $150s$, and the most dominant component is again due to cosmic rays.
In the framework of development, optimization and commissioning of such a trigger system, my internship focused on two major topics.

- Accounting for the fact that the general trigger architecture is based on same PMT signal inside a beam gate (sect 2.1), an initial logic scheme was developed for processing the PMT primitives, based on majorities (sect 2.2) and was implemented and tested using LabVIEW (sect. 2.3).
- To guarantee a correct functioning of the readout system, for example in the cases in which all the buffer of the TPC read-out are full and a trigger distribuited in that moment would crash the system, a trigger inhibition mechanism was developed (sect. 2.4) and tested through the exchange of UDP packets using LabVIEW again.

2.1 Trigger Architecture

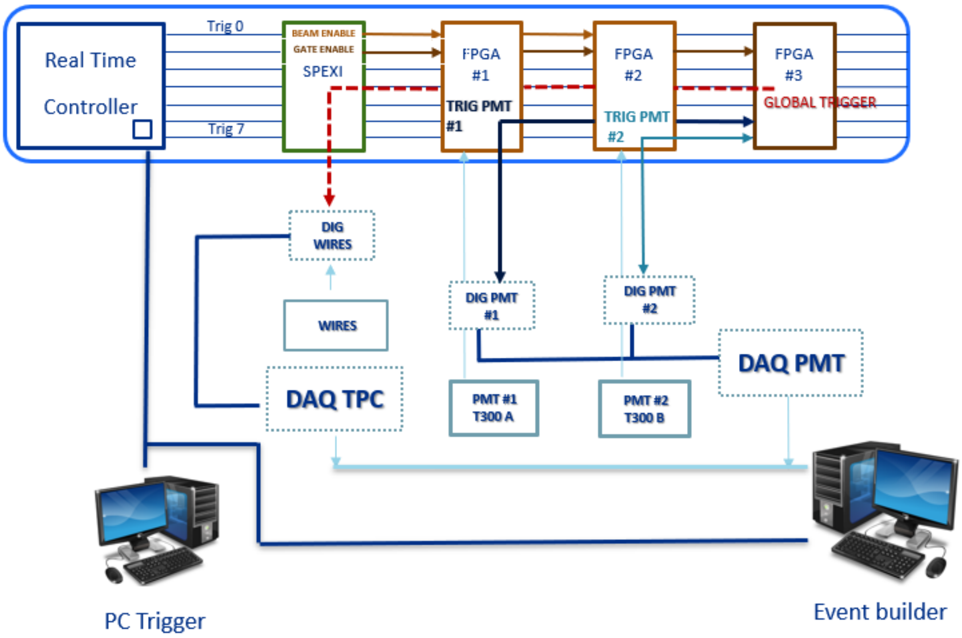


Figure 2.1: Representation of the trigger layout. Even if, here, it is shown one digitizer for PMT 1, one for PMT 2 and one for the wires of the TPC, the real structure is more branched, because there are 360 $PMTs$ and 54.000 $wires$.

To identify the genuine neutrino interactions from the backgrounds due, above all, to the PMT dark noise and the natural radiactivity of the Ar^{39}, the trigger system is based on the detection of the scinitillation light by the PMT (faster than the ionization signal collected by the TPC wires), in coincidence with the extraction of the neutrinos beam. This is carried out by means of NI-PXIe instrumentation (Fig. 2.1): a National Instrument crate contains Real Time Controller (PXIe 8135), one SPEXI board by Incaa Computer and three NI FPGA boards (PXIe-7820R).

The RT Controller is a CPU that communicates with the boards through the bus lines on the backplane of the crate, and with the outer DAQ central system through a PC Trigger.

The SPEXI board receives the information that the neutrino beam is going to be exctracted from BNB and consequently generats:

- a $50MHz$ clock for the PMT digitizers;
- a TT-Link signal carrying trigger and clock information for the TPC digitizers;
- a $2ms$ wide beam enable signal for activating the PMT read-out (*beam enable*);
- a $10\mu s$ wide beam gate signal (*gate enable*), in which to look for a PMT-Trigger signals in order to generate a Global Trigger for the wires read-out.

In the three FPGA boards, a "Trigger Logic" is implemented in order to generate the General trigger.

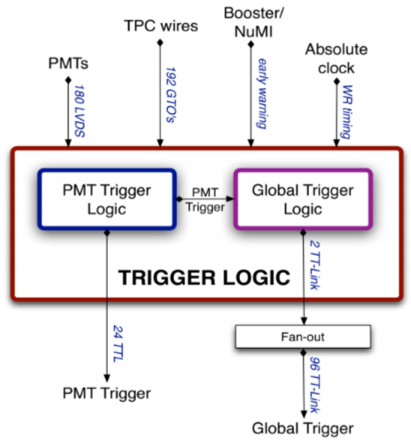


Figure 2.2: Representation of the trigger logic layout.

The purpose of the "Trigger Logic" is to create an opportune logical scheme able to distinguish and isolate a neutrino interactions, that is a rare event, from the other interactions which occur in LAr-TPC detector.
This is achieved in two steps:

- *Local Trigger* implemented in the first two FPGA boards. It is a *PMT* Trigger signal, one for each T300 module, generated on the basis of the PMT signal majorities and AND/OR patterns in association with a beam enable signal generated by SPEXI.

- *Global Trigger* implemented in the third board. It combines the imputs from the PMT Trigger signals together with the *gate enable* signal generated by SPEXI and other inhibit information coming from the DAQ.

2.2 The PMTs system of ICARUS T600 detector

The first step to create the ICARUS trigger is to generate a Local Trigger based on the scintillation light recorded by the PMT system.

The ICARUS T600 light collection system is composed by 360 photomultipliers $Hamamatsu\ R5912-MOD$ with $8''$ diameter. They are positionated in the 30 cm space behind the wire planes, 90 per each TPC chamber. The adopted layout maximizes the photo coverage (5% of the wire plane area) while getting a uniform response signal to particles interacting in the detector. The layout of PMT system is shown in Fig. 2.3.

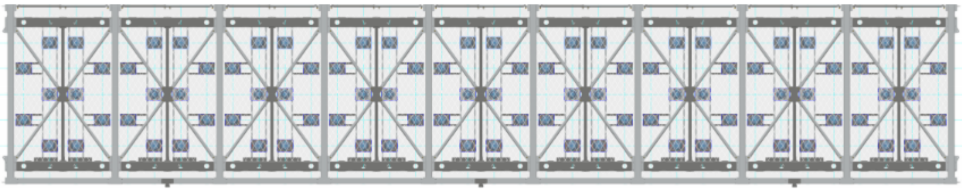


Figure 2.3: Layout of the ICARUS T600 PMT System for one TPC.

The 90 $PMTs$ for each T600 chamber are read out by 6 $CAEN\ V1730B$ digitizers with 16 channels each.

Each digitizer allows a waveform recording of each individual channel. It also provides a discriminated digital output, i.e. the OR/AND logic of two adjacent signals from PMTs over a defined threshold (Fig. 2.4). The threshold is configurable and will be set to guarantee the full detection efficiency of neutrino interactions and cosmic events while rejecting the low energy background, i.e. typically in the order of few photoelectrons (phe). These digital output, available for the trigger purposes, are $LVDS$ (Low Voltage Differential Signal) standard.

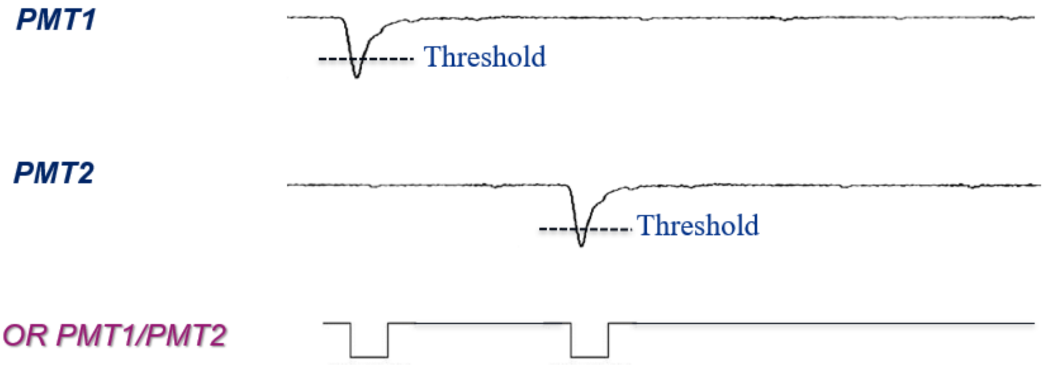


Figure 2.4: Schematic representation of the LVDS outputs of the CAEN V1730B digitizer. The first two are the waveform of the signals recordered by PMT1 and PMT2; the third shows the digital output, i.e. the OR logic of two adjacent PMTs over threshold.

The digitizers continually process the signals coming from the PMTs system, but the waveform is recorded by the DAQ system only in presence of a local trigger instance.

2.2.1 Majority Logic

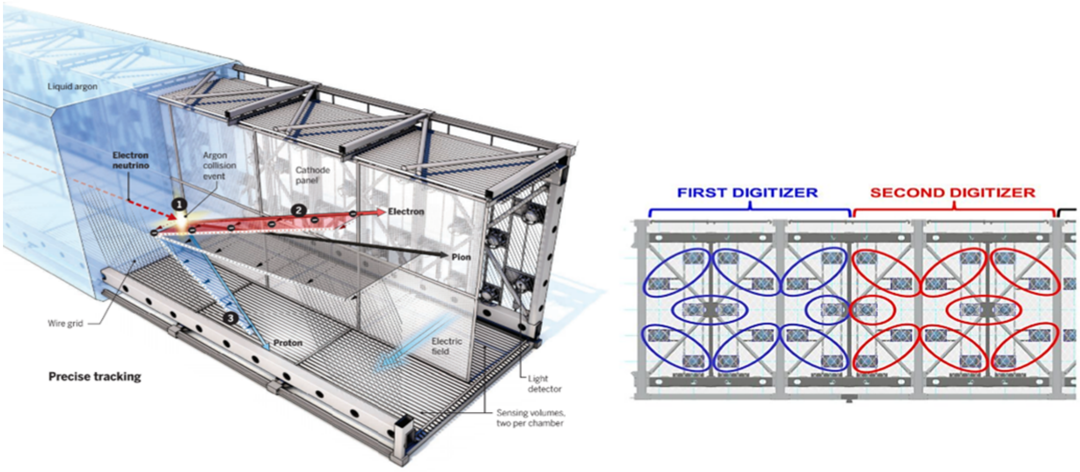


Figure 2.5: Left: schematic representation of a neutrino interaction in LAr-TPC, in case of a ν_e CC event. Right: each CAEN V1730B digitizer processes the signals from 15 PMTs, i.e. $\sim 3m \cdot 3m$.

A majority logic has been chosen as the reference starting point for the generation of the local trigger.
It consists of a logic signal that is true when the number of logical inputs true at the same time exceeds a M_j parameter set.
When implementing this logic in the trigger system, additional features have been added to monitor the rates for each channel (*"Counts Channel"*) and the rates for all possible majority levels from 1 to 8 (*"Counts Multiplicity"*).
The modularity chosen as a starting point is 15 $PMTs$, accounting for the fact that neutrino interactions in the ICARUS detector are expected to be spatially confined in a small section $\sim 3m$ long which exactly corrisponds to $\sim$ 15 PMTs, i.e. one digitizer (Fig. 2.5).
The majority logical scheme is represented in the block diagram in the Fig. 2.6. In input at the *PMT Logic* there are the 8 LVDS from the digitizer and the ”*Insert*” ”*Majority*” (M_j). The outputs are "Count Channels" from 0 to 7; "Digital Majority", i.e. the logical output true when the number of inputs simultaneous at high level is bigger than M_j; "Counts Multiplicity" from 1 to 8.

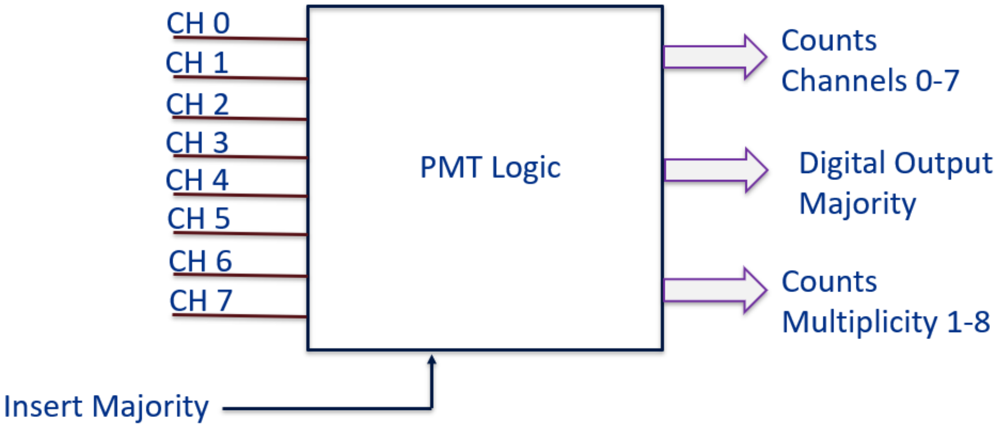


Figure 2.6: The 8 LVDS, obtained as OR between the signals from two adjacent PMTs, are sent in inputs of a PMT *Logic* box with a "Insert Majority" parameter. The outputs are "Counts Channels", "Digital Output Majority" and "Counts Multiplicity".

2.2.2 *Local* and *Global* triggers

Local Trigger
A *Local Trigger* logic has been initially realized for a system of three digitizers, for a total of 24 *Chs* or 45 PMT from a single TPC chamber (Fig. 2.6). The "Insert Majority" parameter is the same for all PMT Logic box. A *PMT Trigger* signal is defined by the OR between the Digital Output Majority of the three PMT Logic boxes.
In this way, even if just one of the three Digital output is at high level, for example the first is 1 and the other two are 0, the output is at high level. The scheme will have to be extended to include all 180 PMTs ($T300A$) to be processed by the same FPGA board, corrisponding to 6 digitizers. The same thing will be done for the second module $T300B$, processed by the second FPGA.

Global Trigger
The *Global Trigger* realized in $FPGA3$, is obtained as an AND between three logical inputs (Fig. 2.8). The first is the OR output, that is the *Local Trigger* developed before. The second is the $Veto\ On/Veto\ Off$ information, sent by the DAQ cental system to inhibit (in case of $Veto\ On$) or allow ($Veto\ Off$) the distribution of the trigger when the buffers of the TPC read-out are full or available. The last is the *Beam enable* information,

generated

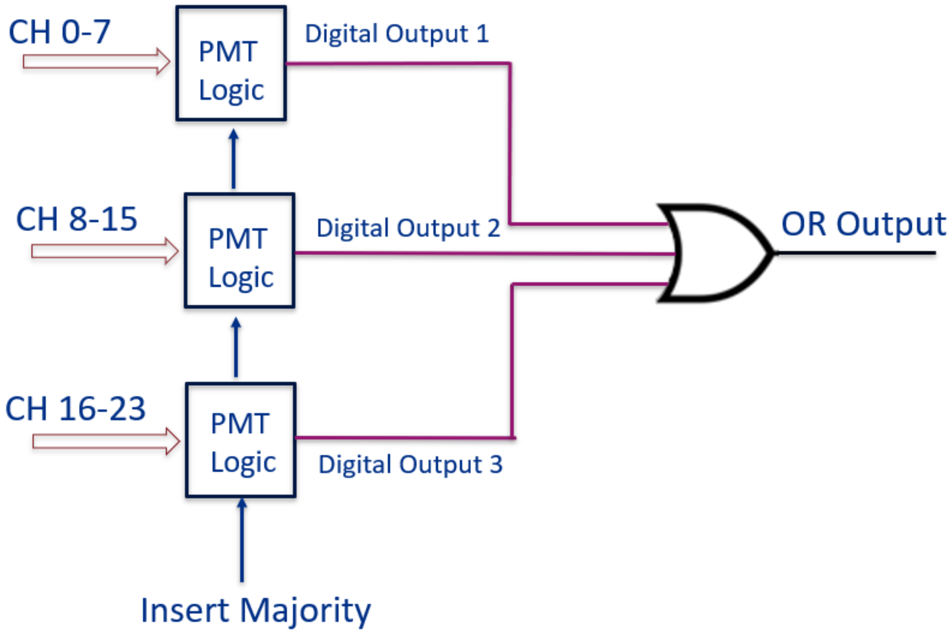


Figure 2.7: The *Local Trigger* logic has been developed for a system of three digitizers, for a total of 24 *Chs*. The "Insert Majority" parameter is the same for all "PMT Logic" boxes. The PMT Trigger is obtained as an OR between the three digital majority outputs.

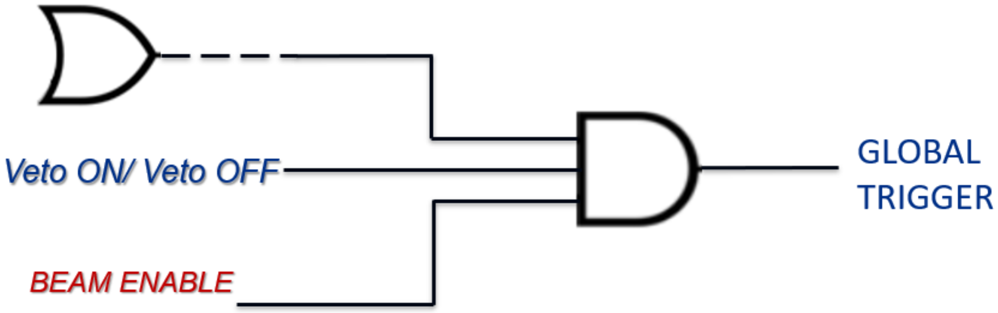


Figure 2.8: The *Global Trigger* logic is obtained as an AND among the PMT-Trigger signal, the *Veto On* or *Veto Off* and the Beam enable information.

by SPEXI board when neutrinos from BNB or a NuMI are expected to arrive in the detector. Because the beams were not in operation during the intership, this last logical input was implemented as always true.

2.3 LabVIEW software

All the logical scheme previously descrived have been implemented through LabVIEW Software.
LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a development environment for applications oriented to data acquisition, signal analysis and instrumentation management. The environment is user friendly as it provides a graphic programming called "G language", which allows programming through block diagrams. It is very similar to traditional programming environments, because it presents all types of data, allows generating new data and controlling its execution by using data flow control structures, through cycles and structures, for selective execution of the code.
A program created with LabVIEW takes the name of Virtual Instrument VI, where the term "Instrument" means that the program presents to the user during the execution an interface similar to that of a measuring instrument, while the term "Virtual" refers to the fact that the interaction takes place through a running program and not with a dedicated measuring instrument.
The source code is very similar to a flow chart formed by nodes, each performing a specific functions, connected to each other via wires that determine the order of data flow execution.
Each VI consists of three basic parts:

- Front Panel, i.e. the interface between the program and the user;
- Block diagram, that contains the code through the block diagram representation;
- Icon/Connector, i.e. a graphic symbol that allows to transform the program into a software Object.

In the following, details of the realization of the logics escribed in sect. 2.2.1 and 2.2.2 are presented.

Measurement of rates

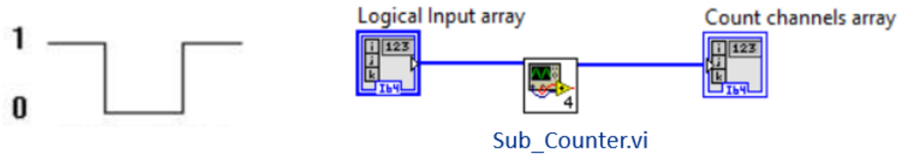


Figure 2.9: Left: example of a transition from 0 to 1, where every change of state is a count. Right: block diagram of the *CountsChannels.vi*. In input there is an array of 8 logical signals, in output an array of 8 counts channel. The icon is the *sub.vi* that contains the Counter function.

The rate of the occurrence of a given signal (ex "counts channel" in Fig. 2.6) is measured by counting the transitions of an input line form level 0 to level 1. The 8 channels are processed at the same time using arrays both for the input and output lines (Fig. 2.9). The Icon is the *sub.vi* called *Sub-Counter.vi*, and cointans all the instructions that the *vi program* follows to carry out the Counter function.

Digital Output Majority

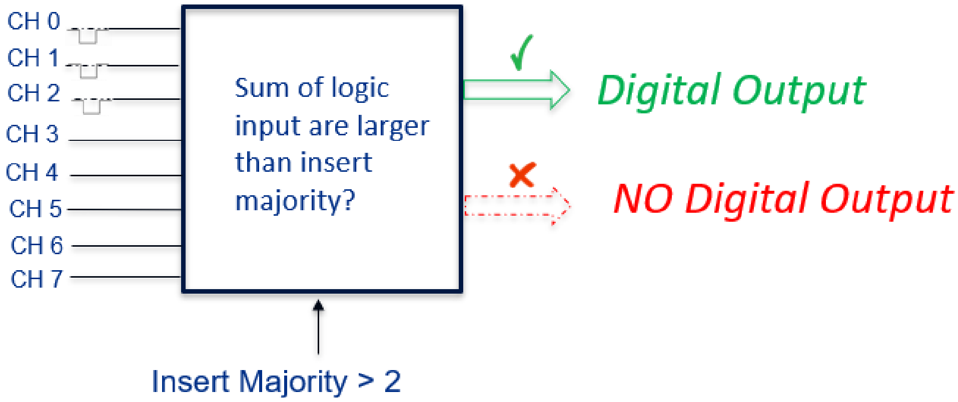


Figure 2.10: Logic scheme of the realization of the majority logic in LabVIEW. Considering the signals in corrispondence of the $CH0$, $CH1$, $CH2$, if the sum of these three logical input is larger than the parameter M_j (2 in this example), then in output there is a Digital signal.

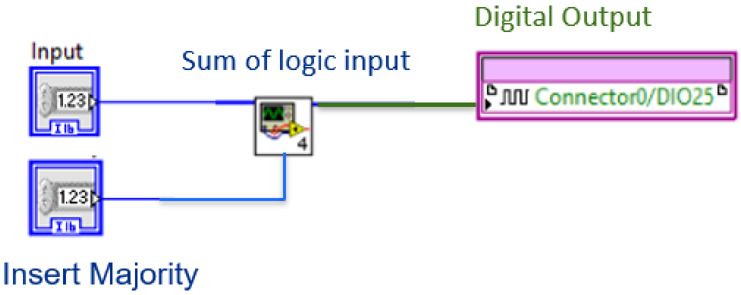


Figure 2.11: Block diagram realized with LabVIEW to implement the Digital Output Majority.

The majority logic is realized summing all the logical inputs and checking if the sum level is larger than the M_j parameter (Fig. 2.10). The figure 2.11 is the block diagram realized with LabVIEW Software. In input there are an array of 8 channels, named "Input", and the "Insert Majority" parameter; the output is the "Digital Output" conneted with the "Connector0/DIO25" of the $FPGA$.

2.3.1 Test Trigger Logic

A test was setup in order to verify the proper functionality of the developed programmes.

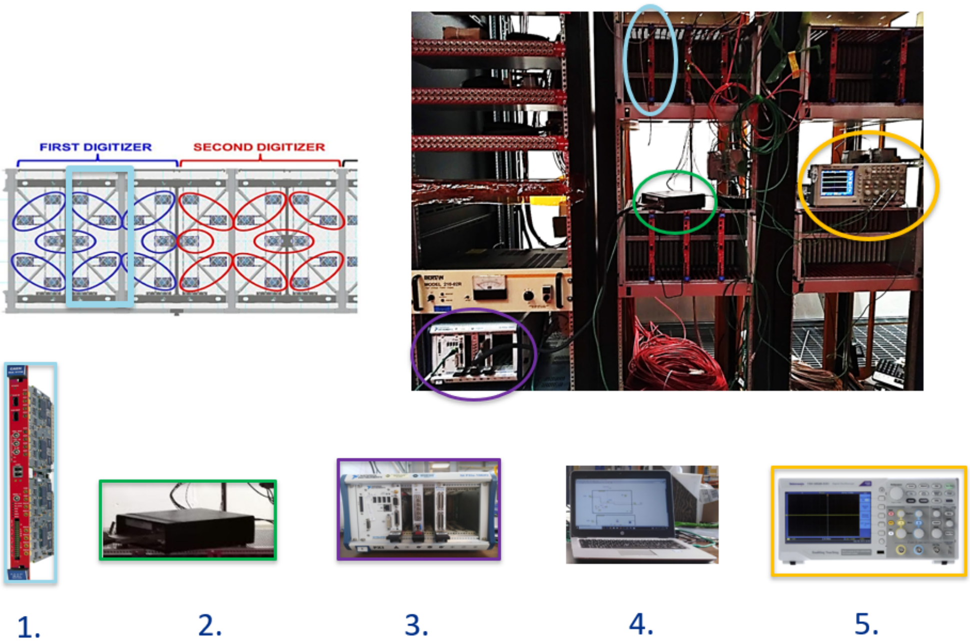


Figure 2.12: Left: the set of PMTs used is highlighted in the light blue box. Right and bottom photos of the experimental setup. 1. CAEN V1730B digitizer, 2. level shifter, 3. National Instrument crate, 4. PC Trigger with LabVIEW Software and 5. oscilloscope.

The test was carried out for a set of 5 PMTs in the East-most TPC of the ICARUS T600 detector. The PMT signals were connected to 5 non adjacent inputs of one digitizer, therefore producing 5 LVDS outputs.

These $LVDS$ signals are sent to a $Level\ Shifter$ to be converted to TTL, and then input in a FPGA board in the NI crate (Fig.2.12).

The RT Controller is managed by $PC\ Trigger$ to which it is connected with a LAN. The $PC\ Trigger$ contains all the VIs of the "Trigger Logic" developed before.

The complete sheme of the "Trigger Logic" used for this test, is shown in the Fig. 2.13. Even if there are three "PMT Logic" boxes, one for each digitizer,

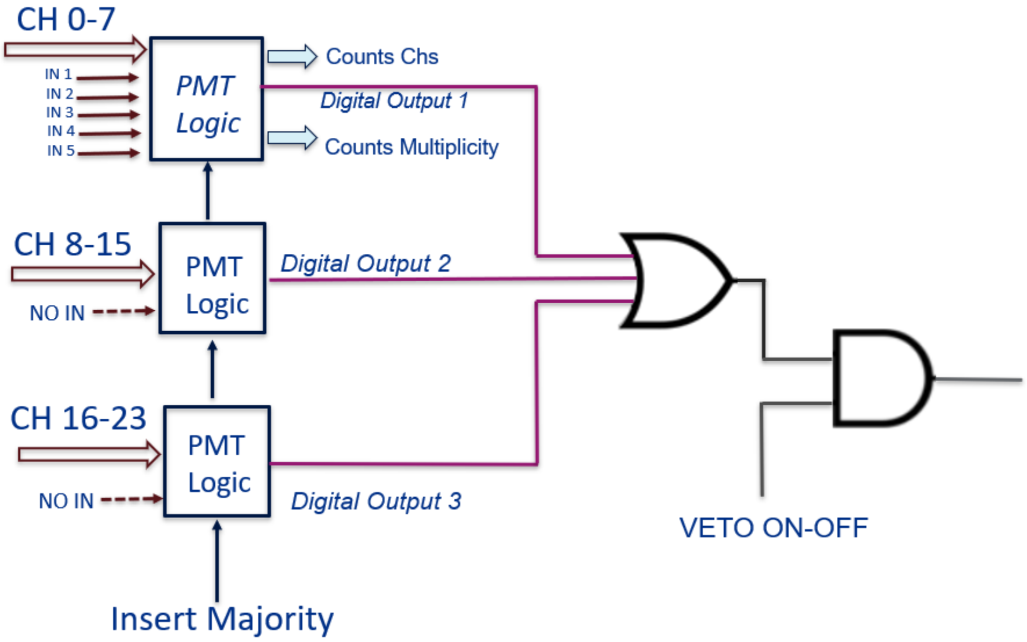


Figure 2.13: The complete scheme of the "Trigger Logic". The Local Trigger is OR output, it is at high level even if only the first input is 1 while the other are 0 (because there are no inputs in the last two PMT Logic boxes). The Global trigger is the AND of this Local Trigger with the Veto On-Off, that was always true in this test.

only the first one is used. The "Global Trigger" is the output of the AND between the Local Trigger output and the $Veto\ On\text{-}Off$ information. For the purpose of this test, the veto is off, corrisponding to logic level "1".
The counts of single PMTs and the number of majorities for the 5 PMTs for different settings of the threshold, were saved in files. To set the threshold, initially the CAEN digitizer baselines are all set to the same value, after which the differences between the two channels are measured. The noise is around 3 ADC counts corresponding to 0,366mV $(1,2207mV/ADC)$.
The threshould is set starting from -4 ADC counts $(-0.488mV)$ and proceeding in steps of 4 until -80 ADC $(-9,7656mV)$. Fig. 2.12 shows the rate (Hz) of the PMT dark current in function of the various values of the threshold in ADC counts (in absolute value)for each of the five channels.

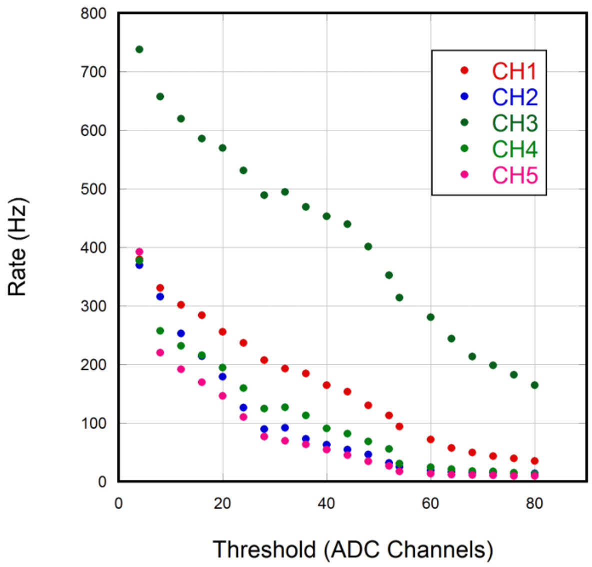
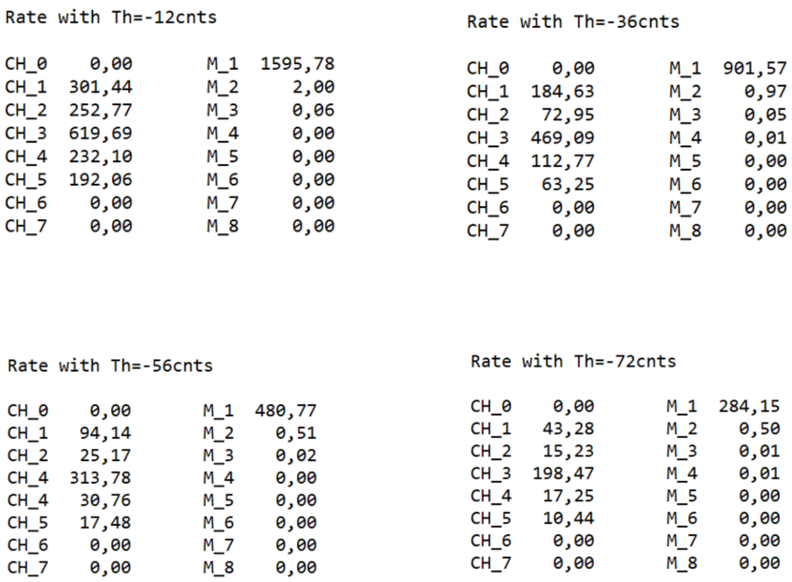


Figure 2.14: Rate(Hz) in function of the absolute value of the Threshold (ADC Channels). As expected the rate decreases as the threshold increases.



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Rate with Th=-12cnts

CH_0    0,00        M_1  1595,78
CH_1  301,44        M_2     2,00
CH_2  252,77        M_3     0,06
CH_3  619,69        M_4     0,00
CH_4  232,10        M_5     0,00
CH_5  192,06        M_6     0,00
CH_6    0,00        M_7     0,00
CH_7    0,00        M_8     0,00
```

```
Rate with Th=-36cnts

CH_0    0,00        M_1  901,57
CH_1  184,63        M_2    0,97
CH_2   72,95        M_3    0,05
CH_3  469,09        M_4    0,01
CH_4  112,77        M_5    0,00
CH_5   63,25        M_6    0,00
CH_6    0,00        M_7    0,00
CH_7    0,00        M_8    0,00
```

```
Rate with Th=-56cnts

CH_0    0,00        M_1  480,77
CH_1   94,14        M_2    0,51
CH_2   25,17        M_3    0,02
CH_4  313,78        M_4    0,00
CH_4   30,76        M_5    0,00
CH_5   17,48        M_6    0,00
CH_6    0,00        M_7    0,00
CH_7    0,00        M_8    0,00
```

```
Rate with Th=-72cnts

CH_0    0,00        M_1  284,15
CH_1   43,28        M_2    0,50
CH_2   15,23        M_3    0,01
CH_3  198,47        M_4    0,01
CH_4   17,25        M_5    0,00
CH_5   10,44        M_6    0,00
CH_6    0,00        M_7    0,00
CH_7    0,00        M_8    0,00
```

Figure 2.15: The screenshot of counts channel and multiplicity in $100s$ and for different values of the threshold, where $-12\text{cnts} = -1,46484\text{mV}$, $-36\text{cnts} = -4,39453\text{mV}$, $-56\text{cnts} = -6,83592\text{mV}$ and $-72\text{cnts} = -9,7656\text{mV}$.

Fig. 2.15 shows the counts for a few values of threshold, for example for that at -12cnts, -36cnts -56cnts, -72cnts. As expected, the number of counts decreases as the threshold increases. As regards the counts of multiplicity, there is non null probability of a mutiplicity bigger than 1, suggesting the existence of a weak scintillation inside with a production of correlated photons.

2.4 Trigger Inhibit

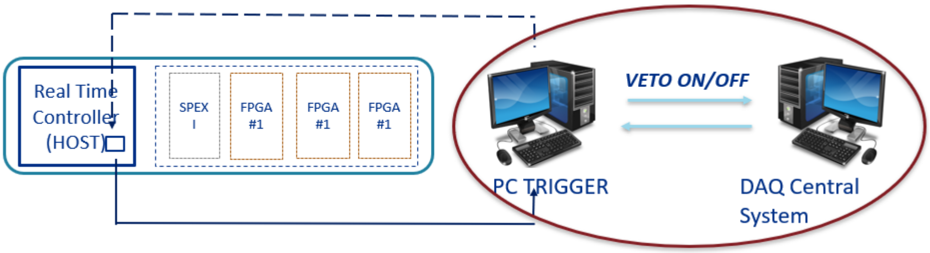


Figure 2.16: Scheme of trigger inhibit. The inhibit information is the *Veto ON* that the DAQ central system exchanges with the PC Trigger, that communicates with the whole trigger system.

The first role of the trigger inhibition system is to guarantee a correct functioning of the readout system even in the rare cases in which all buffers of the TPC readout are full. If a trigger was distributed in this circumstance, the acquisition would crash.
In addition this system is also useful for the prioritization of the possible trigger sources for ICARUS:

- *Booster Neutrino Beam* for the study of sterile neutrinos;
- *NuMI* for the cross section measurement;
- *Cosmic Rays* to calibrate the detector's response.

Because the goal of the SBN far detector will be the search of a sterile neutrinos, the *BNB* beam must have the priority over the other two trigger sources. The prioritization can be done as an example by inhibiting the trigger distribution of the *NuMI* and *Cosmic Rays* beams when only one partition of the buffers of the TPC read-out boards is available.

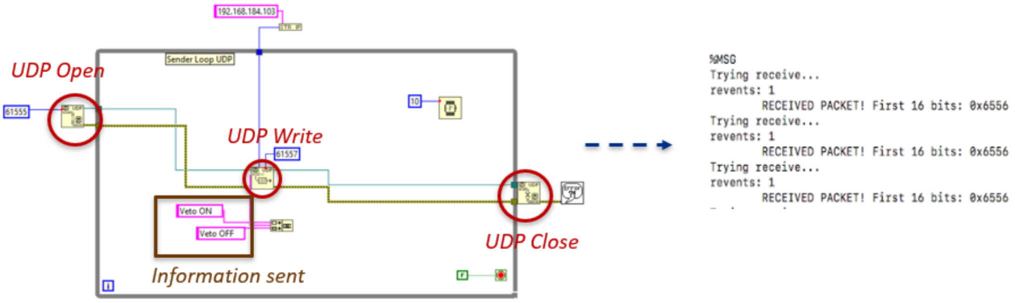
This inhibit is codified as information, for example a *Veto ON*, that the DAQ central system exchanges with the Real Time controller.
Because the RT controller is managed by the PC Trigger, the communication actually takes place between the DAQ central system and the PC Trigger.

2.4.1 UDP protocols in LabVIEW Software

The exchange of the *Veto ON/OFF* information is made through *UDP* (User Data Protocols) packets. With UDP, computer applications can send messages, in this case referred to as datagrams, to other hosts on an Internet Protocol (IP) network. It is a connectionless protocol (distinguished by the fact that the exchange of packet data between sender and recipient (or recipients) does not require a physical or virtual infrastructures for routing the data flow and does not handle packet reordering or retransmission of lost packets. On the other hand it is very fast (there is no latency for reordering and retransmission) and efficient for "light" or time-sensitive applications.
The exchange of UDP packets has been implemented with LabVIEW Software building *Sender.vi* and *Receiver.vi*. The first contains a *UDP write* function and is able to transmit the information to another PC; the second is able to receive information coming from another PC using *UDP read*.

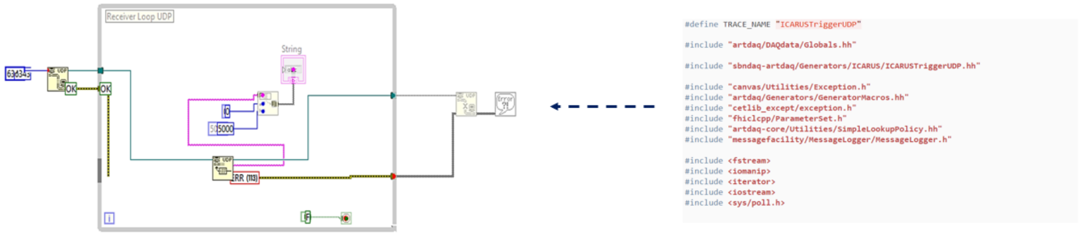
2.4.2 Test of the exchange of UDP packets between PC Trigger and DAQ System

The test of the exchange of UDP packets with the *Veto ON* information was made between DAQ central system and PC Trigger. At first, sending information from PC Trigger to DAQ system, was tested. The *Sender.vi* was used on PC Trigger. On the DAQ an artDaq software was implemented with a program called ICARUSTriggerUDP in *C*. Fig. 2.17 shows that the DAQ receives the information sent by PC Trigger.
The second thing to verify is if the PC Trigger is able to receive the packets that the artDaq software sends to it. The *Receiver.vi* shows an 113 error at the time of decoding with *UDP read*, see the Fig.2.18, possibly caused by the data being read into a buffer that is too small to hold the full size of received packets.
This issue will be further investigated and debugged by ICARUS collaborators.



```
%MSG
Trying receive...
revents: 1
        RECEIVED PACKET! First 16 bits: 0x6556
Trying receive...
revents: 1
        RECEIVED PACKET! First 16 bits: 0x6556
Trying receive...
revents: 1
        RECEIVED PACKET! First 16 bits: 0x6556
```

Figure 2.17: Left: *Sender.vi* sends *Veto ON/OFF* to the DAQ. Right: the DAQ software receives the packets.



```
#define TRACE_NAME "ICARUSTriggerUDP"

#include "artdaq/DAQdata/Globals.hh"

#include "sbndaq-artdaq/Generators/ICARUS/ICARUSTriggerUDP.hh"

#include "canvas/Utilities/Exception.h"
#include "artdaq/Generators/GeneratorMacros.hh"
#include "cetlib_except/exception.h"
#include "fhiclcpp/ParameterSet.h"
#include "artdaq-core/Utilities/SimpleLookupPolicy.hh"
#include "messagefacility/MessageLogger/MessageLogger.h"

#include <fstream>
#include <iomanip>
#include <iterator>
#include <iostream>
#include <sys/poll.h>
```

Figure 2.18: Left: a screenshot of the *Receiver.vi* made on the PC Trigger. It should receive information from the artDaq program. The error 113 shows that the *Veto ON* information arrives but the data is read into a buffer that is too small to hold the full size of received packets.

Conclusions

The main goal in the ICARUS T600 experiment is the search for sterile neutrino at a mass scale where current and previous experiments have found some anomalies as compared to the 3ν flavor paradigm.
One of the most important step to achieve this purpose is the realization of a trigger system, capable of reducing the rate of fake events preserving full efficiency in the identification of neutrino interaction.
During my internship program I contributed the development and commissioning of such a system mainly in 2 areas.
A "Trigger Logic" was developed and implemented with LabVIEW software for generating a Local Trigger primitive in case of production of scintillator light in the liquid argon by neutrino interactions.
A "Trigger Inhibit" was also developed and realized in LabVIEW, with the ultimate goal of selecting a BNB as highest priority trigger source and inhibiting the distribution of the trigger for the other sources when all buffer of the TPC read-out are full.
Initial stress tests of the developed programmes were encouraging and allowed to identify a minor issue in reception of the Inhibit Information, which will be further investigated in the continuation of the commissioning of this system.

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