Implementation of the trigger system of the ICARUS-T600 detector at Fermilab

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The ICARUS-T600 liquid argon (LAr) time projection chamber (TPC) detector is currently deployed as a far detector of the Short Baseline Neutrino (SBN) program at Fermilab (USA) to search for a possible LSND-like sterile neutrino signal at $\Delta m^2 \sim 1 eV^2$ with the Booster (BNB) and Main Injector (NuMI) Neutrino Beams. A global physical event rate of ~0.6 Hz, including the genuine neutrino interactions in LAr, beam halos and cosmic interactions inside the proton pulse time windows, is expected, roughly corresponding to ~4 PB of data for the total 6.6 10^{20} pot exposure if the full ICARUS-T600 detector is read-out (~200 MB event size). The designed trigger system described here would collect the genuine neutrino interactions with a ~ 95 % expected efficiency.

1 – The ICARUS trigger

The ICARUS-T600 detector, installed at shallow depth under 3 m of concrete overburden, is composed of 2 cryostats containing 2 TPCs each, surrounded by the Cosmic Ray Tagger system (CRT).

The trigger system exploits the coincidence of the BNB and NuMI beam spills, 1.6 and 9.5 µs respectively, with the prompt scintillation light produced by charged particles in liquid argon as detected by the PMT (Photo Multiplier Tube) system installed behind the wire planes of each of the 4 TPCs (90 tubes per TPC).

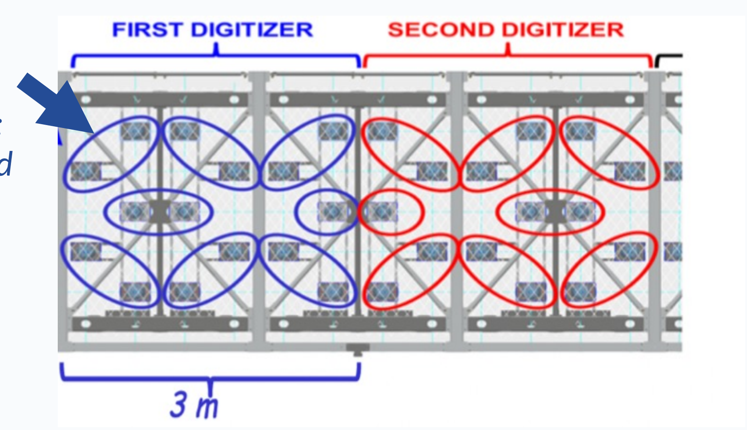
The generation of the beam spill gates to trigger the readout of the detector is based on receiving "Early Warning" (EW) signals for BNB and NuMI beams, 35 and 730 ms in advance of proton on target respectively. Logical signals from the PMT digitizers are processed by programmable FPGA boards to implement a trigger *Majority* logic (a minimum requirement of PMT signals above a threshold) for the activation of the ICARUS detector read-out. Additional trigger signals are generated for calibration purposes in correspondence with a subset of the beam spills without any request on the scintillation light (Min-Bias trigger), and outside of the beam spills to detect cosmic ray interactions (Off-Beam trigger) for background modeling.

To synchronize all detector subsystems readout with the proton beam spill extraction at the level of [a] few nanoseconds accuracy, a White Rabbit Network (WR) has been deployed for distributing the beam extraction signals. An absolute GPS timing in the form of pulse per second (PPS) is used as a reference for generating phase locked digitization clocks (62.5 MHz for the PMT and 10 MHz for the TPC) and for time-stamping the beam gates and trigger signals.

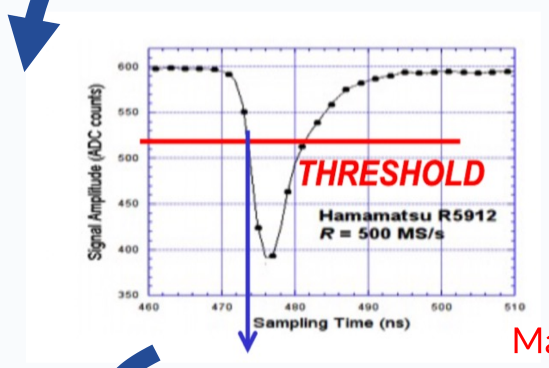
2 – The ICARUS trigger working principle

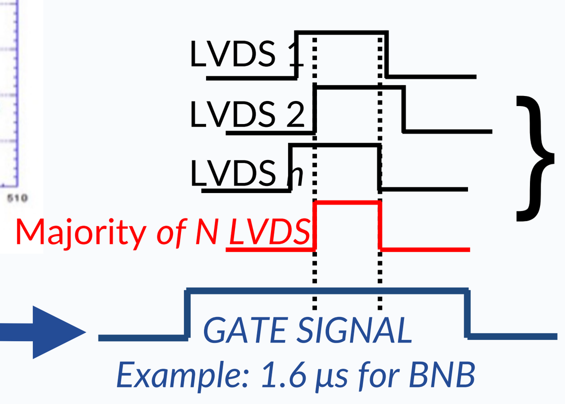
PMT signals are digitized by CAEN V1730B boards. These CAEN modules produce also LVDS logical outputs, in terms of OR signal of adjacent PMTs (180 PMTs per cryostat), above a threshold which are processed by an FPGA according to a *Majority* logic to produce a Global Trigger (GT) when it occurs during a beam gate. This GT activates the acquisition of TPC wires and PMTs. Recorded data are sent to the DAQ together with the information that characterizes the trigger event (such as Time stamps, the beam type, and more). The CRT data recorded separately is later used in the event reconstruction to reject the cosmic background.

PMT PAIRS: both OR and AND logics are possible



The 18 m long TPC wall containing 90 PMTs each, has been divided in three consecutive slices of 6 m each (30 PMTs). At least 5 LVDS signals in each opposite facing slices is required to produce a PMT trigger primitives signal (*Majority* Trigger).





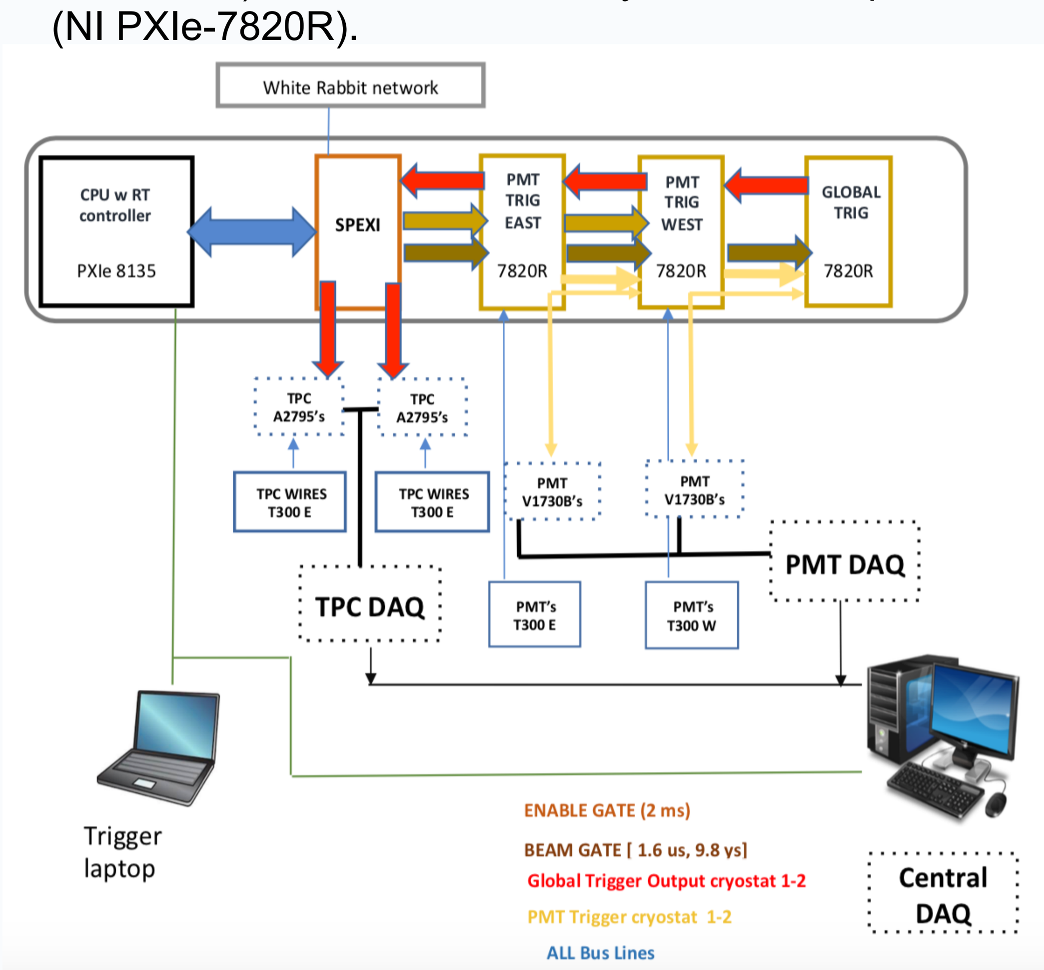
TRIGGER PRIMITIVE: Majority of N LVDS formed by PMT pairs over a given threshold

IT'S A GLOBAL TRIGGER! When a trigger primitive is found in coincidence with the beam gate!

DAQ

3 – The ICARUS Trigger hardware setup

The Trigger system layout is based on NI (National Instruments) PXIe instrumentation fully contained in a single PXIe crate (NI-1082) and consists of: a Real Time (RT) controller (NI PXIe-8840), one SPEXI board by INCAA Computers, and three FPGA programmable boards (NI PXIe-7820R).



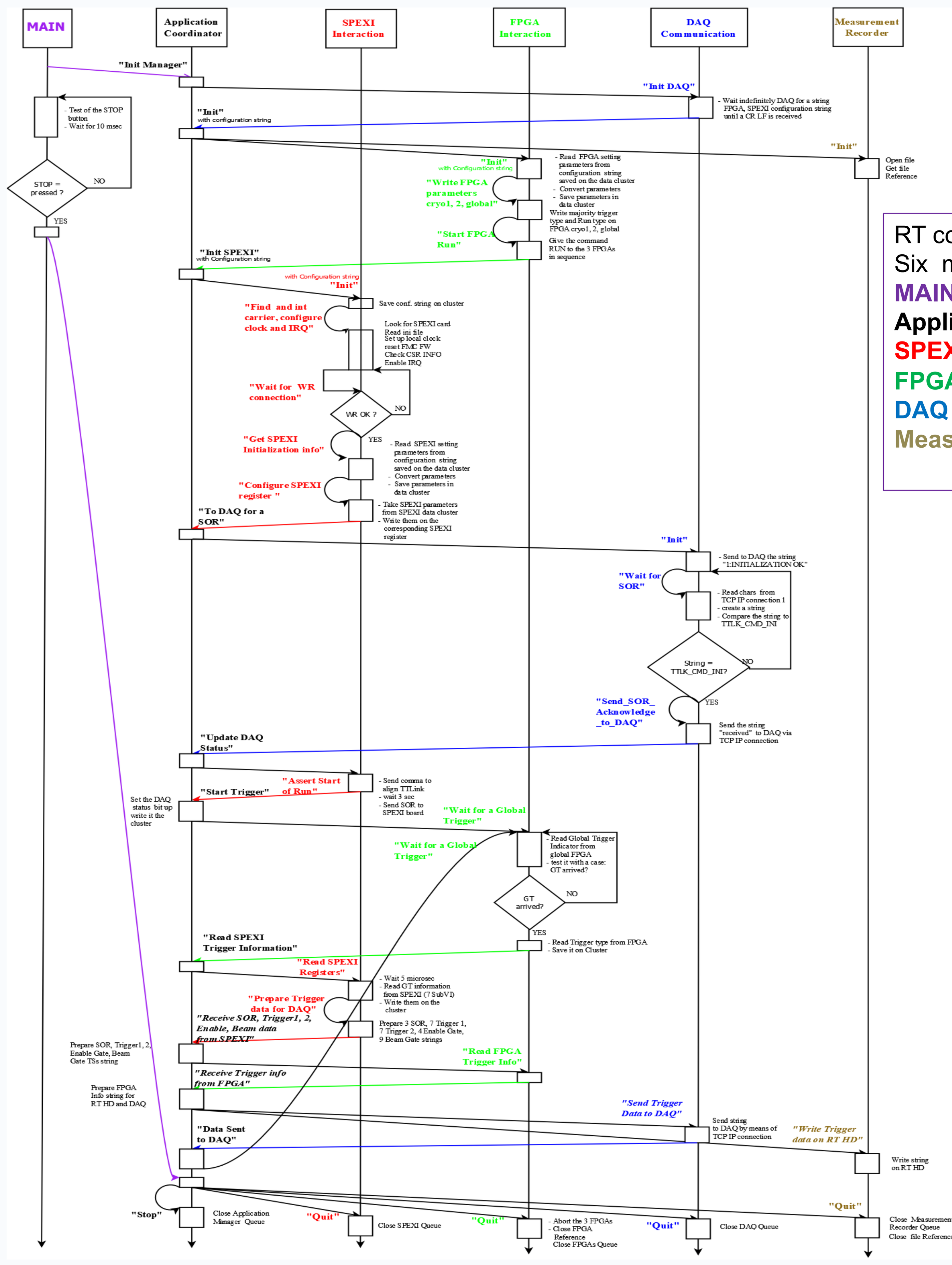
Trigger system installation

The SPEXI board receives the information of the beam from the WR network and produces a pulse on one PXIe bus line with width equals to the duration of the beam spill. Two of the three FPGAs (one per cryostat) evaluate the presence of a certain number of PMTs over a threshold (Majority level). If this happens in coincidence with the beam gate, a Global Trigger is asserted to activate the data acquisition of the whole detector (TPCs, PMTs and CRT) by the DAQ.

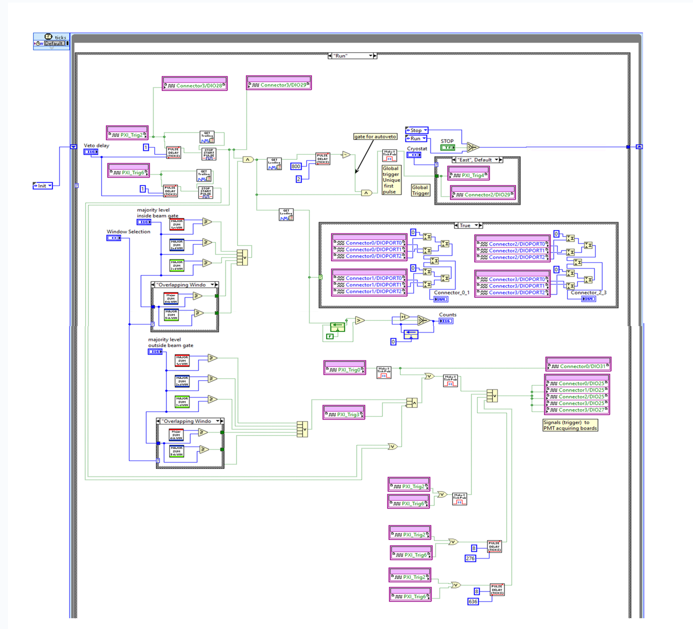
At the same time, the PXIe RT controller reads the time stamp of the beam gate from the SPEXI and the timestamp of GT trigger and transfers those data to DAQ by mean of a TCP/IP data transfer protocol.

4 – LabVIEW code

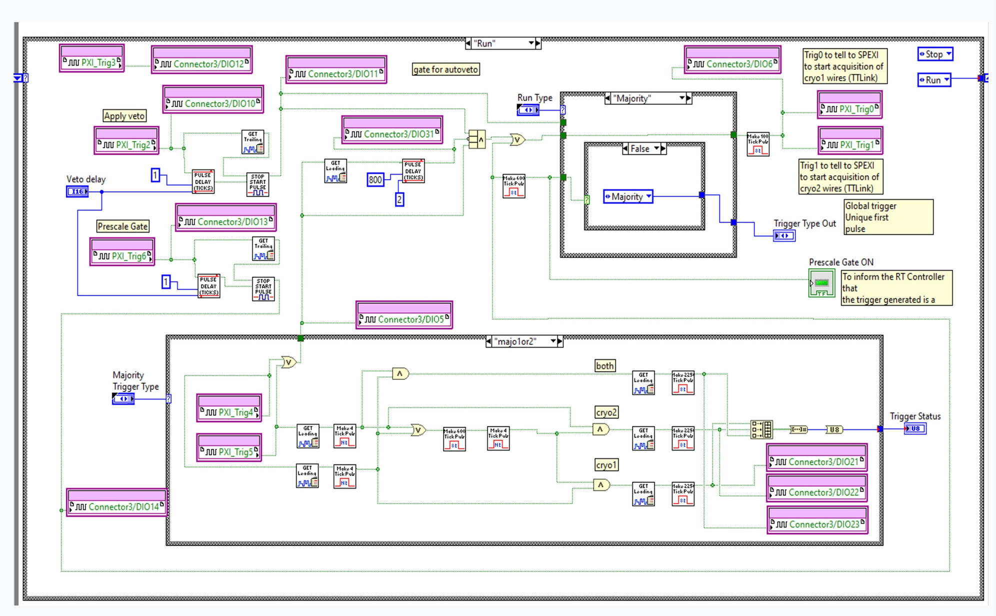
The code that handles these operations is written in NI-LabView 2020 with Real Time and FPGA modules . The RT controller .vi, based on the LabVIEW Queue Message Handler (QMH), supervises all boards interactions, including the initialization of SPEXI and FPGAs, the communication with the DAQ . In the presence of a GT, sends the trigger information to the DAQ. The RT controller block diagram is shown here. The PMTs and Global FPGA .vi below.



RT controller flow chart
Six modules:
MAIN
Application Coordinator
SPEXI Interaction
FPGA Interaction
DAQ Communication
Measurement Recorder



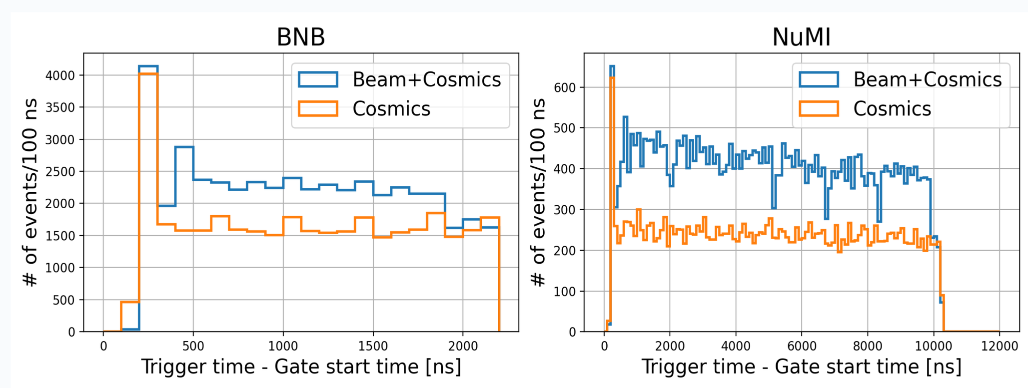
PMT FPGA .vi : evaluates PMT signals above threshold and a majority condition, to generate trigger signals (primitives).



Global FPGA .vi : evaluates coincidence of PMT trigger primitives with beam gate to generate Global Trigger to start the full detector readout.

5 – Commisioning of the ICARUS trigger system

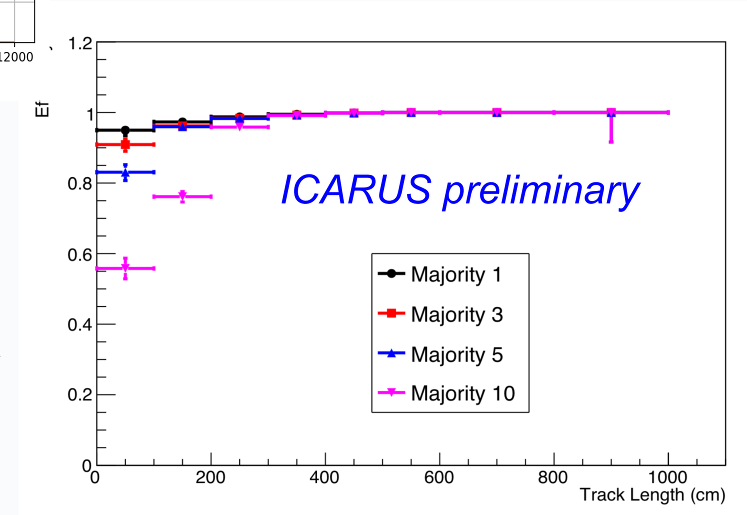
The trigger system is fully operational. The timing of the beam spills has been initially determined by the difference between the EW signals arrival time and the actual proton extraction signal by RWM counters at target. Then neutrino interactions and accompanying muons of the beam spill in excess to cosmic rays have been clearly identified by requiring at least 5 fired PMT pairs in the left and right TPC.



Neutrino interactions excess over the cosmic rays in spill as detected for the BNB (left) and NuMI (right) beams.

The trigger efficiency has been initially studied considering the number of fired PMT pairs associated to cosmic muons crossing ICARUS.

The plot shows the fraction of events which generate a trigger as a function of track length of cathode crossing tracks for required Majority Mj = 1, 3, 5 and 10 PMT pairs: > 95 % efficiency has been set for Mj = 5 and > 1 m track length.



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