ICARUS T600 Trigger Study at the Short-Baseline Neutrino Experiment

EP-NU meeting

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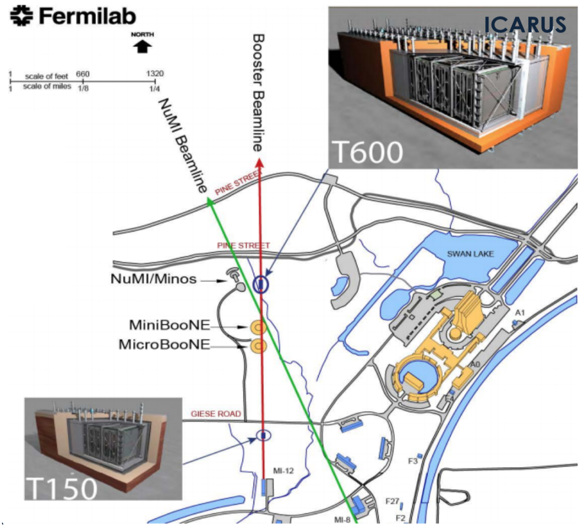
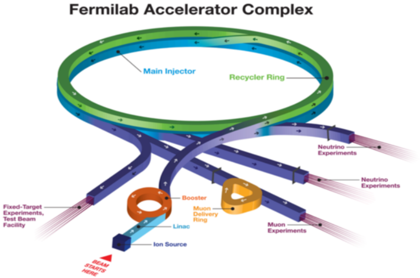
BNB and NuMI beams

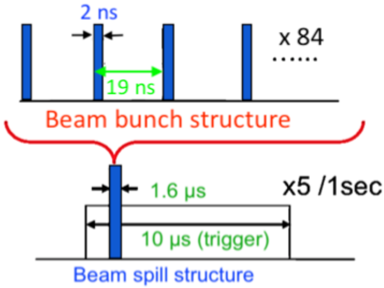
- Short Baseline Neutrino experiment at Fermilab makes use of the well established Fermilab Booster Neutrino Beamline (BNB).
- 8 GeV proton beam, ν flux peaks at 700 MeV.
- ICARUS also sees the NuMI beam (used for NOvA) at $\sim 6°$ off-axis.



Fermilab neutrino beams

- The particles are successively accelerated in the Linac (400 MeV), Booster (8 GeV), and the Main Injector (120 GeV).
- The timing structure of the Booster:

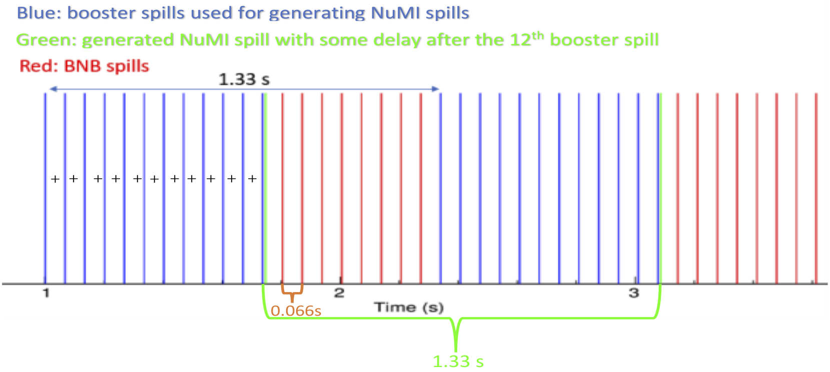




- The 81 **bunches** that comprise one **batch** are 2 ns wide with a 19 ns spacing between each bunch.
- **Spill** refers to the timing structure of the extraction beam, multiple batches can be part of a spill.

BNB and NuMI beams time structures

- The Booster spill duration is 1.6 μs with nominally 5×10^{12} protons per spill.
- The NuMI spill duration is 9.5 μs with nominally 6×10^{13} protons per spill.

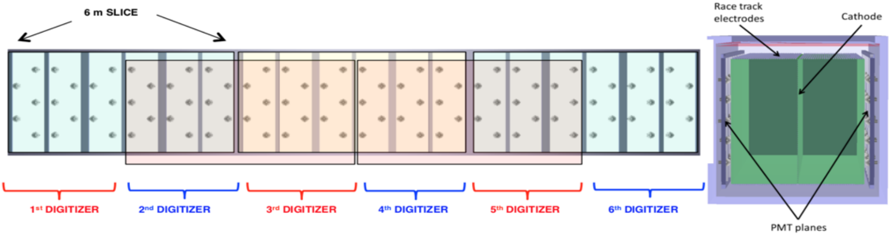


Event rates

1. **BNB: $5{\times}10^{12}$ POT/spill in 1.6 μs spill window at 5 Hz repetition rate**
   - $\sim$ 1 ν interaction every 180 spills.
   - A similar rate is expected from beam-associated events: mainly interactions of muons from beam halo and some neutrinos interacting in the material surrounding the T600 detector.
   - The dominant event rate, 1 over 55 spills, is due to cosmic rays inside the beam spill time window.
   - In summary, $\sim$1 event over 35 spills, i.e. $\sim$1 event every $\sim$7 s, is expected in T600 due to above three sources.
2. **NuMI: $6{\times}10^{13}$ POT/spill in 9.5 μs at 0.75 Hz repetition rate**
   - $\sim$1 ν interaction every 53 spills.
   - 1 background event, mainly due to cosmic rays, is expected every 7 spills.
   - In summary, $\sim$1 event over $\sim$6 spills, i.e $\sim$ 1 event every $\sim$9 s is expected in the T600.
3. **Background due to Ar^{39} decays and due to random noise**
   - $\sim$ 1.2 decay in the BNB beam window, and 7 decays in NuMI beam window.

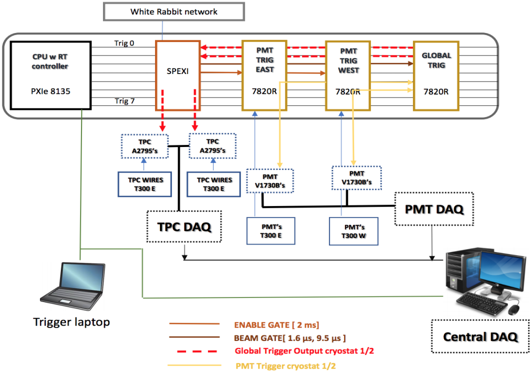
Trigger system for ICARUS

The trigger system is based on the detection of the fast signals from the LAr scinitillation light, detected by the PMT system, in coincidence with the extraction of the neutrino beam.



Trigger architecture

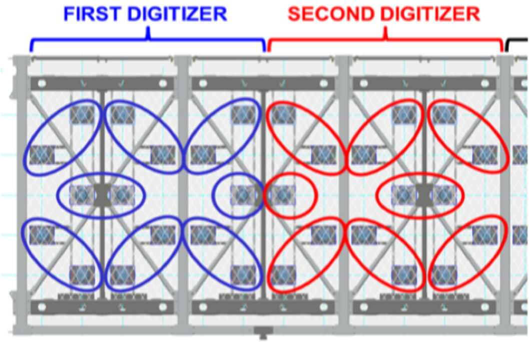
- **RT Controller** implements all the features that imply communication with the DAQ.
- **SPEXI** synchronizes timing of the whole detector and handles beam extraction messages.



- **2 PMT Trigger 7820 boards** generate the PMT trigger and the start of the PMT digitizers.
- **General Trigger 7820 board** combines PMT Trigger with SPEXI signal to generate a *Global Trigger* in coincidence with beam extraction.

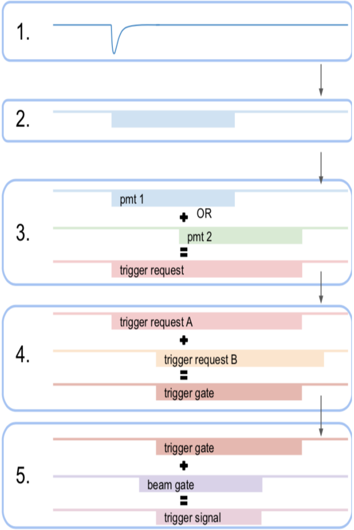
Trigger system of the ICARUS T600 detector

- The trigger hardware takes the combined discriminated signals of paired PMTs.
- The combination is done using either AND or OR logic.
  - AND - both PMTs have signals above threshold at overlapping times.
  - OR - at least one PMT has signal above threshold.



Trigger implementation in the simulation

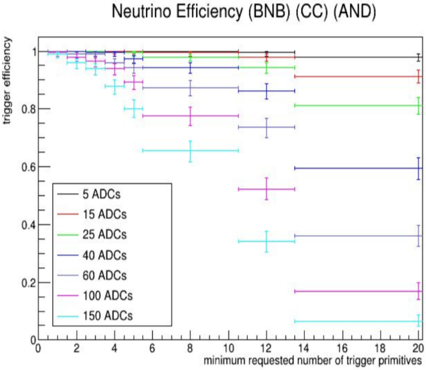
1. Implementation of the PMT digitised signals (waveforms).
2. The waveforms are converted into discriminated waveforms with a length defined by a PMT gate.
3. Discriminated waveforms from paired PMTs are combined with either AND or OR logic to form a single trigger request.
4. Trigger requests are then combined with all other requests to form a combined trigger gate.
5. The combined trigger gate that occurs in coincidence with the neutrino beam gate is labeled as taken.

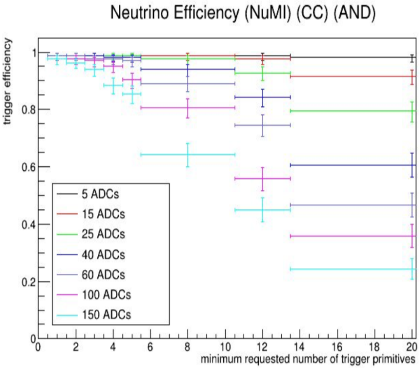


Trigger Monte Carlo Study

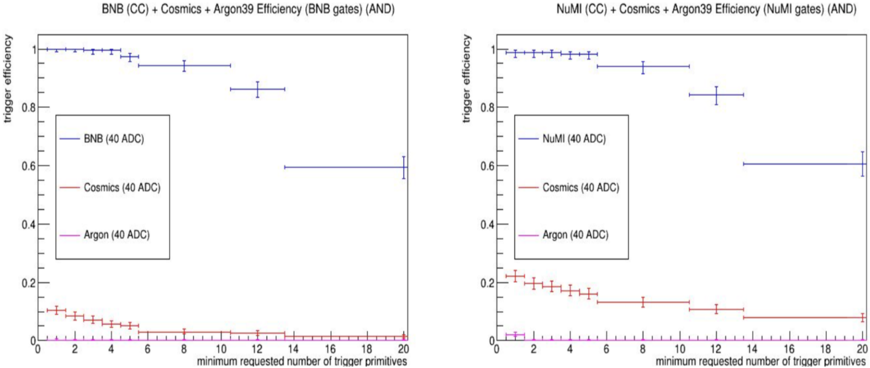
- The evaluation of the trigger system in terms of the efficiency of detecting neutrino interactions.
- The following trigger parameters are used to evaluate the signal and background trigger rates:
  - AND/OR logic,
  - trigger gate length,
  - PMT multiplicity requirement,
  - waveform discrimination threshold.
- The study has been performed in parralel for the two beams due to different physical features and beam gate windows of the NuMI and BNB beams.
- The study has been focused on the charged current (CC) interactions, because they result in at least one charged particle (charged lepton) in the final states and measureable amount of scintillation light is provided for the trigger evaluation.

Trigger Efficiencies in a function of the waveform discrimination threshold





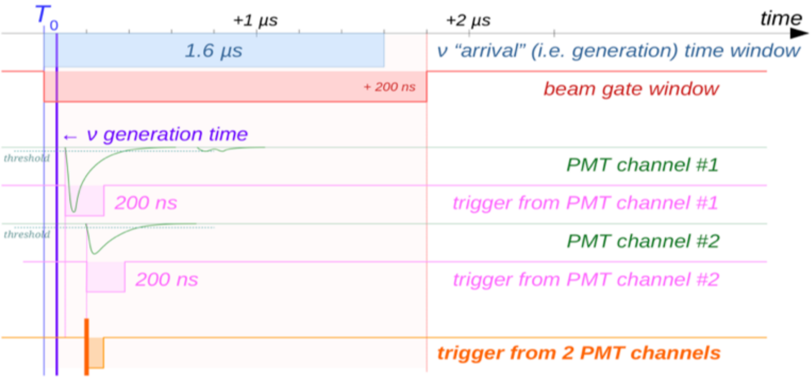
Trigger Efficiencies vs. background



Initial results of the trigger simulations for ICARUS T600

- Monte Carlo simulation has delivered the following initial values of the trigger parameters:
  - trigger gate length: 200 ns - reduces trigger rates due to long lasting cosmic background;
  - ADC threshold: 40 ADC - reduces trigger rates of cosmic rays, Argon-39 decays, and random noise;
  - PMT multiplicity requirement: 2 (BNB) or 3 (NuMI) - reduces trigger rates of Argon-39 decays and random noise;
  - trigger logic: AND - reduces trigger rates of Argon-39 decays and random noise;
- The optimization of above parameters serves for minimizing the background trigger rates and maximizing the trigger efficiency of neutrino interactions.
- Charged current neutrino interactions from the BNB beam will be triggered more efficiently than those from NuMI.

Trigger timing



- The number of the PMT pairs whose trigger gates overlap with the beam gate are called *LVDS on*.
- If the channels trigger gate overlaps with the beam gate, the channel contributes to the trigger.