Developments of the supernovae trigger in DUNE

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Introduction

Thesis on the development of the DAQ system for the detection of Supernova neutrinos in the DUNE experiment (Deep Underground Neutrino Experiment). Thesis at the border between detector developments and physics.

Outline

- DUNE Physics
- Detector
- Compression/Decompression
- Trigger primitives finding

The Primary DUNE Scientific Goals



 \rightarrow Need sophisticated massive detectors O(10 kton) in order to study tiny effects :

- Accurate identification of neutrino flavors via final state lepton (muon, electron, tau)
- Precise measurement of neutrino energy

Supernova neutrinos

- 99% of energy released in a core-collapse supernova is carried away by neutrinos (cf.: 0.01% carried away by light)
- Rich information embedded in neutrino signal:
 - **Supernova physics:** core-collapse mechanism, black hole formation, shock stall/revival, nucleosynthesis, cooling, ...
 - **Particle physics:** flavor transformations in core, collective effects, mass ordering, nuclear equation of state, exotica



S. Woosley and T. Janka Nature Physics 1, 147 (2005)



Detector

- Argon liquid tank 12x12x60 m³
- Tracks created by charged particles appearing during interactions of neutrinos with liquid argon
- Acquisition of ionization by CRPs (Charge Readout Planes 3x3 m2):
 - ▶ 80 CRP above the detector



10 kton dual-phase design based on protoDUNE dual-phase, full scale demonstrator at CERN: 6x6x6 active volume \rightarrow 1/20 of 10 kton readout system



Supernova Neutrino Bursts

- Vast information from flavor-energy-time profile of events
- Unique sensitivity to v_e 's:
 - Elastic scattering: $v_x + e^- \rightarrow v_x + e^-$ (x = e, μ , τ)
 - Absorption: $v_e + {}^{40}\text{Ar} \rightarrow e^- + {}^{40}\text{K}^*$ (E>1.5 MeV), $\overline{v_e} + {}^{40}\text{Ar} \rightarrow e^+ + {}^{40}\text{Cl}^*$ (E>7.5 MeV)
 - $\circ \quad \textbf{NC}: \boldsymbol{\nu_x} + {}^{40}\textbf{Ar} \twoheadrightarrow \boldsymbol{\nu_x} + {}^{40}\textbf{Ar}^{\boldsymbol{*}} \text{ (x = e, } \boldsymbol{\mu}, \boldsymbol{\tau})$





Need sensitive detector and have the data on a 10 second time window

NC rate ~ absorption rate

10 kpc 40 kton

Challenges of the trigger system

- 154 000 channels continously sampled at 2.5MHz on 12 bits -> 4,6 Tb/s of data
- Supernova trigger needs to look at 10 second time window -> 46 Tb in computer's memory
- Looking for hits of Supernova neutrino interactions in the DAQ Back-End by using trigger primitives -> this is the most challenging task
- Beam triggers and cosmic triggers can also be retrieved from the 10 second window -> selection of 8 ms drift window by using beam timing or energy deposition algorithm
- Handling this large data flow implies dealing with compression/decompression of data and trigger primitive (isolated energy deposition on each channel) search in real time
- Many units working in parallel following the scheme at the right



DUNE dual-phase DAQ/network infrastructure



Constraints on the acquisition and objectives

- Very large volume of data generated by the detector : ~4,6 Tb/s
- Impossibility of permanently storing all this data, especially as the majority of the data contains noise
- Need to sort data to be able to store only interesting physics events
- However, very difficult to achieve because it requires very large memory and computing power with conventional processor-type architectures
- Evaluation of solutions to analyze the data flow in real time on FPGA boards
 - Compression/Decompression
 - Trigger primitives finding



Arria FPGA Board reading up to 12 crates (640 channels each)

Evaluation of treatments on DAQ Units -Lossless Compression / Decompression

- To limit the dataflow, the data are compressed
- Custom lossless Huffman compression
- Encoding the ADC difference between
 2 consecutive samples if it is < 4
- If the differences are outside this table, the actual ADC value is written entirely with a flag

ADC difference	Code
0	01
-1	001
+1	0001
-2	00001
+2	000001
-3	0000001
+3	0000001
Repeated 4 times	1

11

- In DUNE Baseline, data are compressed on the 64 ADC Readout boards
- Need to decompress the data before doing online analysis like trigger primitives finding

Huffman decompression implementation on an Arria 10 FPGA Board



Full crate decompression implementation on Arria 10 FPGA





13

The firmware in ARIA 10 includes:

- 160 decompressor Units
- Automatically configure and control the AMC boards
- Decompressed samples are not stored
- Compute pedestals on decompressed samples
- The number of decompressed sample is displayed (should be 10000)

Some Huffman decompression results

Compression ratio and Decompression Duration 576 channels (9 boards pedestals only)



- Resources taken:
 - Logic utilization (in ALMs): 27%
 - Total block memory bits: 54%



• Functional verification by comparing pedestals after decompression with a direct measurement.

Evaluation of treatments on DAQ Units -Trigger primitives finding

- Simple algorithm analyzing the data stream in real time:
 - Pedestal finding by computing an estimated median on consecutive input samples
 - Fixed threshold relative to the median to detect a hit
- Retrieving information on the primitive like when the charge deposition starts, when it ends and the charge integral within this time window (proportional to the energy deposit)



15

Trigger primitives finding implementation on an Arria 10 FPGA Board

- Architecture optimized for one crate:
 - Reusing the same module to redirects the packets as in the decompression firmware
 - Need a memory to save information on channels and retrieve them before treating a data packet
- Context memory State of the channel to retrieve:
 - Estimated median
 - Primitive start time
 - Current sum value



Trigger primitives finding results - Test on a single crate

- Real time primitive finding checked with offline analysis of the same data
- 100% reproducibility
- Very little FPGA resources used for this implementation
 - Logic utilization (in ALMs): 1%
 - Total block memory bits: 14%
- This allows using this backend Arria 10 card for multiple crates

Prim Counter = 3 Primitive = 03000e4c0002005f Board = 03 Channel = 00 Start nb = 0e4c / 3660 Samples OT = 0002 Sum = 005f / 95

Prim Counter = 2 Primitive = 03000e4f0008017d Board = 03 Channel = 00 Start nb = 0e4f / 3663 Samples OT = 0008 Sum = 017d / 381

Prim Counter = 1 Primitive = 03000e5900020060 Board = 03 Channel = 00 Start nb = 0e59 / 3673 Samples OT = 0002 Sum = 0060 / 96

Prim Counter = 0 Primitive = 03000e660002005e Board = 03 Channel = 00 Start nb = 0e66 / 3686 Samples OT = 0002 Sum = 005e / 94

Conclusions

- The DUNE DAQ/Trigger system is very challenging given the task to define triggers for supernova neutrino bursts
- In Lyon, we have been studying possible solutions for the basic back-end elements capable of treating the front-end dataflow in real time for data decompression and trigger primitives search
- The basic front-end units are uTCA crates digitizing 640 channels. The ultimate goal is concentrate treatments of several crates on one FPGA board:
 - The decompression turns out to be resource consuming on FPGA cards interfacing the backend, even optimized we could only concentrate maybe 2 crates in one FPGA card
 - The primitive search standalone can be implemented with current FPGA cards resources and should be able to concentrate several crates in one FPGA card
- Further work:
 - Trigger primitive architecture tested so far for 2 crates on the same FPGA card, plan to extend up to 12 crates