Triggerless Detection of Dark Matter Candidates with DarkSide-20k

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On behalf of the Darkside-20k Collaboration

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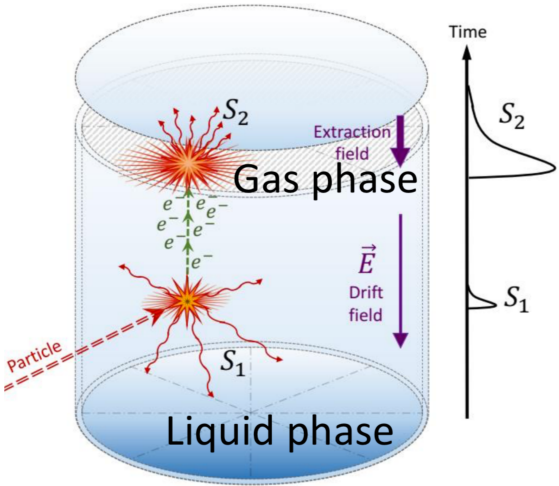
Darkside-20k

Credit: NASA, ESA, D. Coe *et al.*

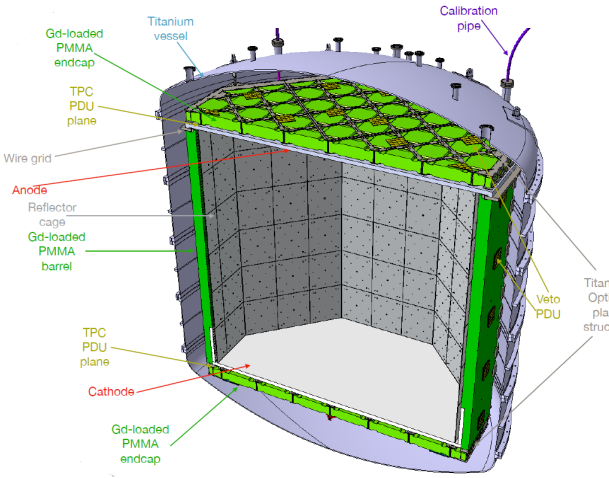
- Darkside-20k is a planned experiment at the Gran Sasso National Laboratory (Italy)
- Direct search of *Weakly Interacting Massive Particles*, a hypothetical particle that constitutes the Dark Matter content of the Universe

Darkside-20k - Technology



- Target: Dual-phase liquid Argon Time Projection Chamber
- Readout: Two planes (top and bottom) of arrays of cryogenic solid state photosensors (SiPM)
- Incoming particle produces a flash of VUV light, called S1
- Additional created electrons drift to the anode plane, passing from the liquid to the gas phase
- Drift in the gas phase produces (large) flash of VUV light, called S2

Darkside-20k - Technology cont'd



- TPC active volume is 50 t of underground (low radioactivity) Argon
- TPC is surrounded by the neutron veto
- Veto is used to tag neutrons ("dangerous" background to WIMP search)
- Outer veto to reject cosmogenic signals

DAQ Relevant Parameters

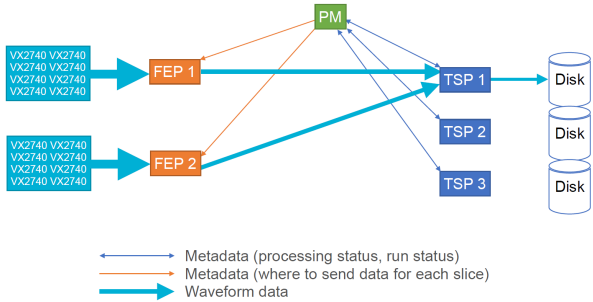
- Typical S1 duration $\sim 5\mu$s
- Typical S2 duration $\sim 20\mu$s
- Maximum time difference between S1 and S2 $\sim$4 ms

- 2112 readout channels TPC
- 480 readout channels Veto (inner)
- Expected event rate: 88 interactions/s in the TPC active volume

DAQ design principle for DarkSide-20k

- **Single photon detection**
- Detectors are readout without global (hardware) trigger
- Digitized waveform are processed in real time
- Flexible selection of events from full state of the detectors (software)
- On-the-fly *data reduction* before writing to disk

DAQ Overview



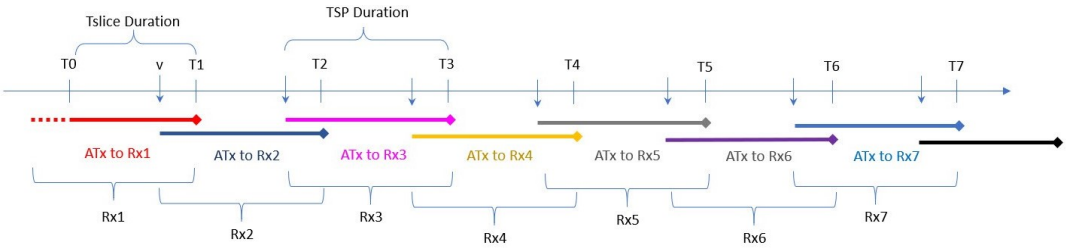
1st stage SiPM signal digitization with CAEN VX2740

2nd stage Front-End Processors collects waveforms from digitizers

3rd stage Time-Slice Processor acquires data from all FEPs

Pool Manager coordinates data transfer from FEP to TSP

Time Slice Concept



- Digitized waveforms are time-stamped with a global time source: the *Time Slice Marker*.
- The detector event analysis is performed on fully assembled data collected over a fixed time period.

- The analysis task is assigned to a given computer node: TSP.
- A TSP receives all the waveforms (fragments) prior to starting the analysis.

DAQ Challenges

- Input to WaveForm Digitizers (WFD) 64 channels @ 125MS/s
- 64 ch. x 2 B/Sample x 125MS/s $\sim$ 16GB/s
- WFD max throughput: 125 MB/s (1Gbps)

- Necessary reduction factor to match WFD bandwidth:120

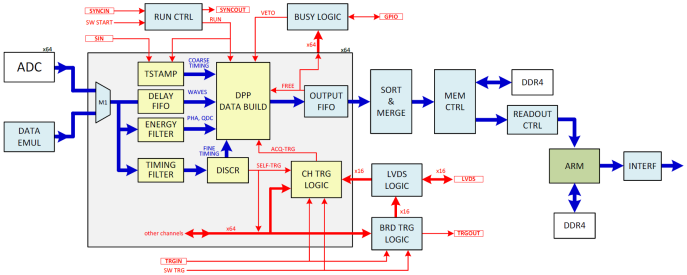
- Number of digitizer boards for TPC readout: 36
- Number of digitizer boards for inner and outer Veto readout: 12

- Assuming 2 WFD per FEP
- 24 FEP are required
- FEP input $\sim$250MB/s

DAQ Challenges

- Data rate into TSP: 1.25 GB/s (10Gbps)
- Necessary reduction factor to match TSP bandwidth: 5
- Expected maximum data logging rate: 65 MB/s = 2 PB/y
- Required reduction factor to match logging rate: 19

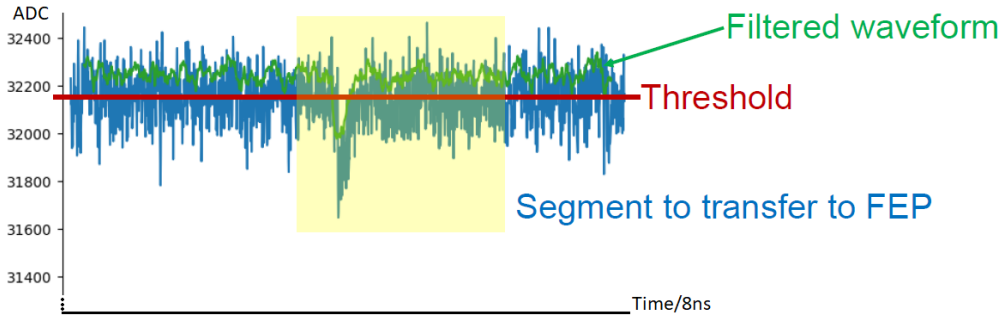
Waveform Digitizer



Credit: CAEN

- VX2740 provides a service OpenFPGA for integration of user firmware code.
- Configuration and data acquisition occurs through a dedicated Ethernet connection.

Waveform Digitizer

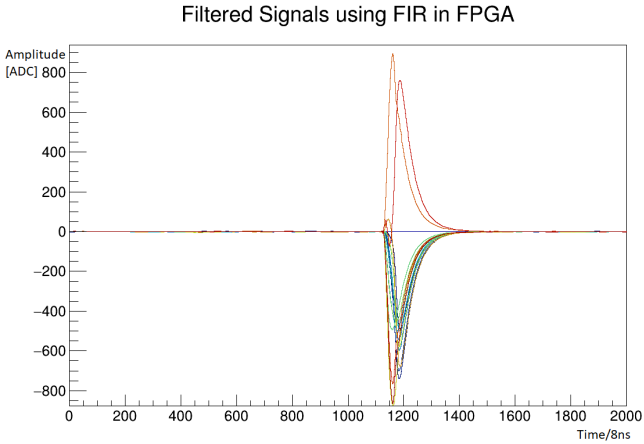


Digitized waveform (blue) with example of FPGA processing

- Finite Impulse Response (FIR) filter waveform
- Identification of signal above threshold
- Transfer segment $\geq 5\mu$s

- FPGA filtering successfully tested with hardware last June
- Development of firmware and simulation is ongoing

Waveform Digitizer



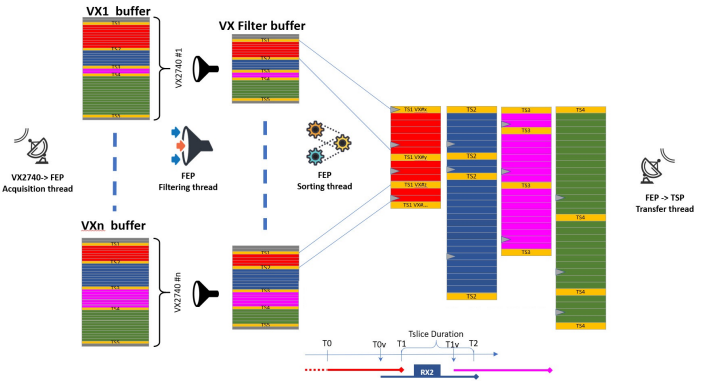
Initial test with custom firmware:

- FIR filter with 48 coefficients a_i

$$y_n = \sum_{i=0}^{47} a_i x_{n-i},$$

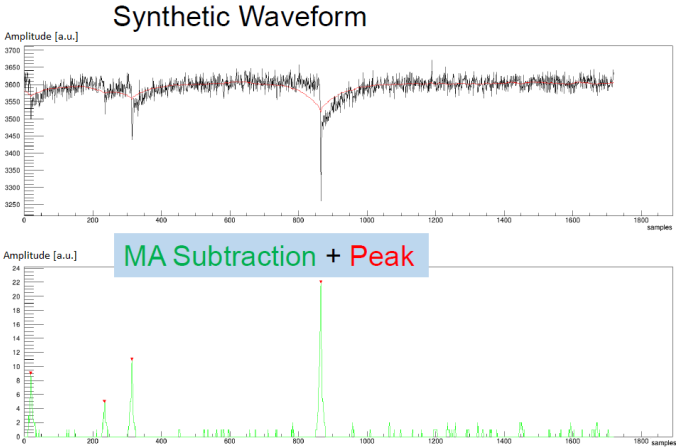
where x is the raw waveform and y the filtered one.

Front-End Processor



- Heavily multi-thread
  - Acquisition
  - Processing
  - Transfer
- Data reduction is achieved by identifying *hits*

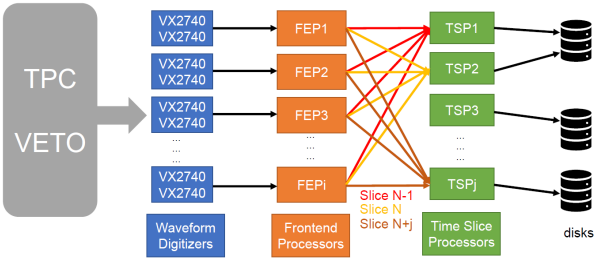
Front-End Processor



Currently under development:

- Signal processing in FEP, example:
  - Match filter of the waveform
  - Subtraction of the moving average of the filtered waveform
  - Time-over-threshold of the result
- Hit definition/size, example:
  - Signal amplitude $\rightarrow$ 2 Bytes
  - Peak time $\rightarrow$ 4 Bytes
  - Channel ID and Timestamp $\rightarrow$ 2 + 4 Bytes

Time Slice Processor

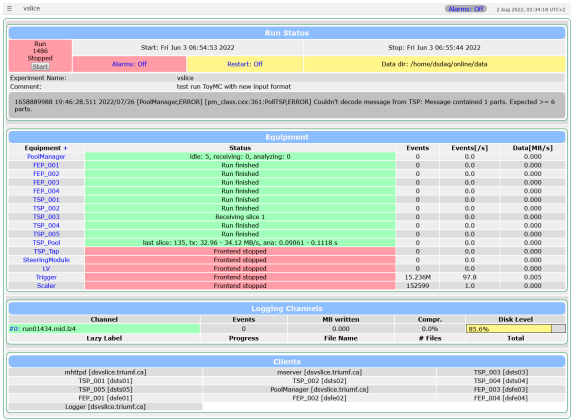


- TSP receives a Time Slice with data from the whole detector
- TSP performs classification of hits based on pulse shape and geometrical clusterization
- TSP assembles an “event” to write to disk

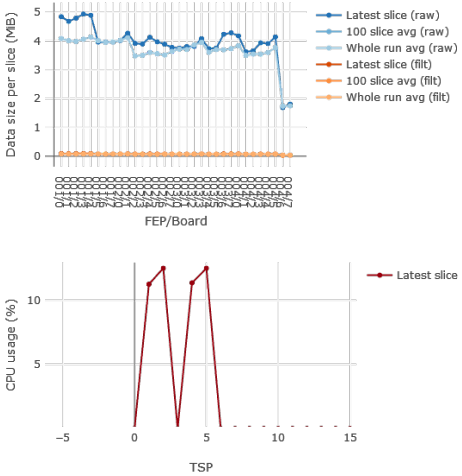
Vertical Slice @ TRIUMF

- 4 FEPs, 5 TSPs, 1 manager
  total 10 nodes
- Simulated data: S1 and S2, Background generation, e.g., radioactive ^{39}Ar
- Testing of FEP processing in progress

Vertical Slice @ TRIUMF



MIDAS status page



Vertical Slice diagnostics

Summary

- The DAQ architecture of the DarkSide 20k experiment is based on the triggerless detection of Dark Matter candidates
- This architecture requires a dedicated computing farm for online processing of the photodetectors waveforms
- Data reduction occurs between the three stages of the processing
- The DAQ design implements the Time Slice model, where one node analyses a fixed length of time from the whole detector
- A vertical slice of the DarkSide-20k DAQ is currently in operation at TRIUMF and provides an essential development platform for this project.