AIT/WATCHMAN Data Acquisition (DAQ) Hardware Working Group

Working Group Leads:

Lee Thompson (Sheffield)

Doug Cowen (Penn State)

DAQ Hardware Working Group

Charge to *ad-hoc* Working Group:

- Discuss possible designs
- Assemble requirements
- Take measure of each design against requirements
- Recommend design to Collaboration

Charge to Working Group

- Design, test, procure, install, commission and maintain DAQ electronics

---

Working Group Info.:

- Conference calls: Ramping up to every other Monday, noon PST
- Wiki: https://ntpc.ucllnl.org/rrm/index.php/DAQ_Electronics
- Listserv: watchman_daq@llnl.gov

Composition of Working Group

Institution	Personnel
Iowa State	Jonathan Eisch, Matt Wetstein
LLNL	Adam Bernstein
Penn State	Doug Cowen, Tyler Anderson
UC Davis	Bob Svoboda
U. Hawaii	John Learned, Kurtis Nishimura, Gary Varner, 4 students
UC Irvine	Mark Vagins
U. Penn	Christopher Mauger
U. Sheffield	Lee Thompson

System Designs Under Consideration

- Custom design with TARGETX ASIC
  - Advanced switched capacitor array (SCA) developed at U. Hawaii (TeV Array Readout Gsa/s Electronics w/Trigger)

New!

- ANNIE-based design with commercial 500 MSPS ADC
  - Leverage existing design for ANNIE but with higher channel density
- Custom design with commercial 250 MSPS ADC
  - Off-the-shelf ADC, in system developed at Penn State and UW-Madison (*on back burner for now*)
- CAEN 250 or 500 MSPS
  - ~Turn-key system

These are all triggerless, zero-deadtime, full-waveform-digitization designs.

Down-select process is starting. Will complete once have requirements established and eval boards tested.

Key DAQ Hardware Physics Design Goals

- Timing and charge resolutions good enough to be dominated by other detector elements (viz., PMTs)
- Noise-tolerant
  - Underground noise environment is not yet known
    - Realtime firmware DSP algorithms can reject spurious pulses
    - SNO DAQ HW expert (R. Van Berg): noise issues were manageable
- "Triggerless" DAQ for lowest possible threshold
  - Could accept events with as few as ~4 PMTs hit in ~30 ns
  - Zero deadtime with ~continuous digitization
  - Reconstruction online and offline to remove junk

Semi-Quantitative Comparisons

Salient Differences

	TARGETX (SCA) U. Hawaii	ANNIE (ADC) Iowa State	IceCube-ish (ADC) Penn State	CAEN (1725 [1730])
Timing resolution	< 0.2 ns	< 2 ns(?)	< 2 ns (250 MSPS)	< 2 ns (250 [500] MSPS)
Noise tolerance	Pre-waveform recording: analog discriminator. Post recording: firmware-based DSP algorithms	Continuous waveform digitization: very flexible, firmware-based DSP algorithms	Continuous waveform digitization: very flexible, firmware-based DSP algorithms	Continuous waveform digitization: limited flexibility for DSP algorithms
Trigger threshold	Formed in firmware: 4 channels in 100ns window (7kHz PMT dark rate; 2MHz trigger rate)	Could be formed in firmware: 4 channels in 100ns window (7kHz PMT dark rate; 2MHz trigger rate)	Formed in firmware: 4 channels in 100ns window (7kHz PMT dark rate; 2MHz trigger rate)	Formed offline in PC: ~4 channels in 100ns window (7kHz PMT dark rate; 2MHz trigger rate)
Dead time	~0 for up to 100 kHz aggregate into each TARGETX	~0 since continuous digitization means no bottlenecks.	~0 since continuous digitization means no bottlenecks.	~0 since continuous digitization means no bottlenecks.
Cost/channel* (Labor)	~$100 (~3 FTE-yrs)	~$1000 (~2 FTE-yrs)	~$225 (3 FTE-yrs)	~$500? [~$800?] (1 FTE-yr)
Current design status	multichannel production versions exist (CTA: 2048 chans./camera; Belle: 20,000 chans)	4-channel boards in use; 16-channel prototyped; firmware available; integrated with ToolDAQ	single channel prototype exists; performance verified w/R7081	available ~now; we assemble; custom firmware possible; bench testing now
Footprint @3200 PMTs	~5 racks	~5 racks	~5 racks	~5 racks

*does not include HV cost

Qualitative Comparisons

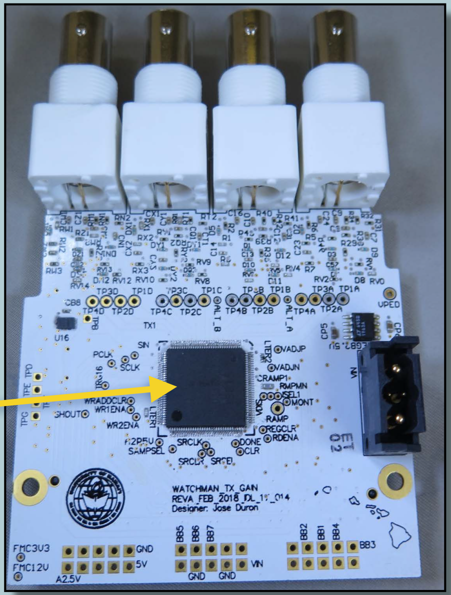
	TARGETX (SCA) U. Hawaii	ANNIE (ADC) Iowa State	IceCube-ish (ADC) Penn State	CAEN (1725 [1730])
Timing resolution	Most "future-proof" for R&D	Reasonably "future-proof" for R&D	Hard to go above ~300 MSPS	@500 MSPS, okay for R&D, but unclear how handle complex waveforms
Noise tolerance	Fairly flexible and likely to be sufficiently noise tolerant.	Fairly flexible and likely to be sufficiently noise tolerant.	Most flexible and likely to be most noise-tolerant.	Somewhat flexible system with possible user programmability.
Trigger threshold	Likely to satisfy even most aggressive trigger setting	Likely to satisfy even most aggressive trigger setting	Likely to satisfy even most aggressive trigger setting	Should be able to satisfy most aggressive trigger setting
Dead time	~0	~0	~0	~0
Cost/channel* (Labor)	~$100 (~3 FTE-yrs)	~$1000 (~2 FTE-yrs)	~$225 (3 FTE-yrs)	~$500? [~$800?] (1 FTE-yr)
Current design status	Solid prior experience; Eval board being made	Solid prior experience; Rely on UChicago to build	Simplest architecture but least developed system	Available now (and 3 years from now)
Footprint @3200 PMTs	~5 racks	~5 racks	~5 racks	~5 racks

*does not include HV cost

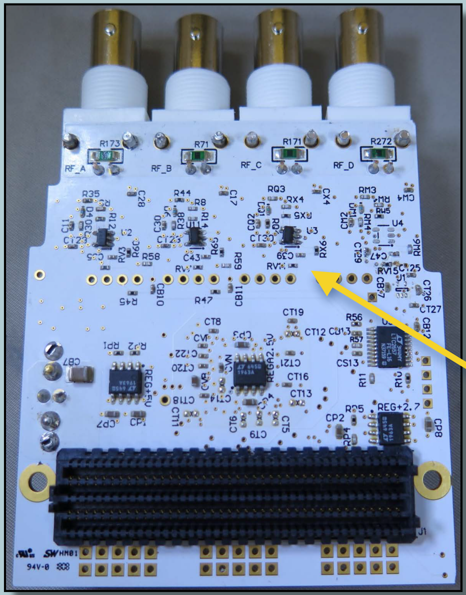
Status Summary: TARGETX

Prototype card with 4 inputs @ 4 gains

TARGET ASIC

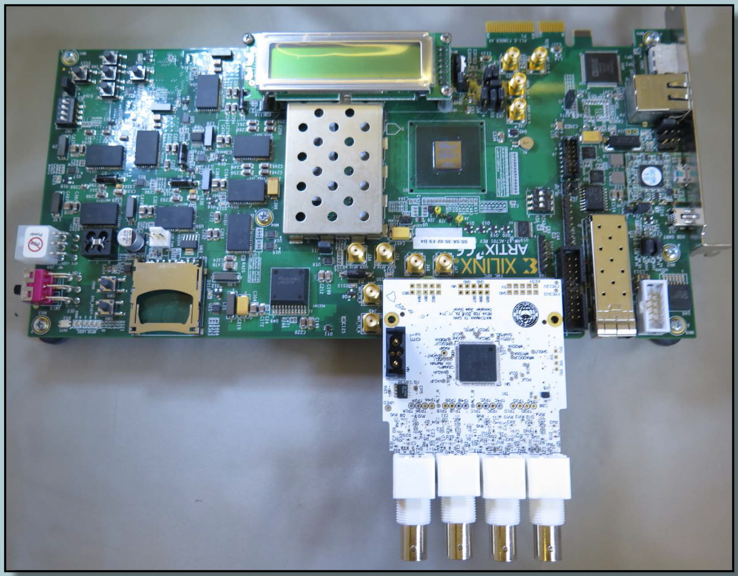


TARGET side



x10 amps

Backside



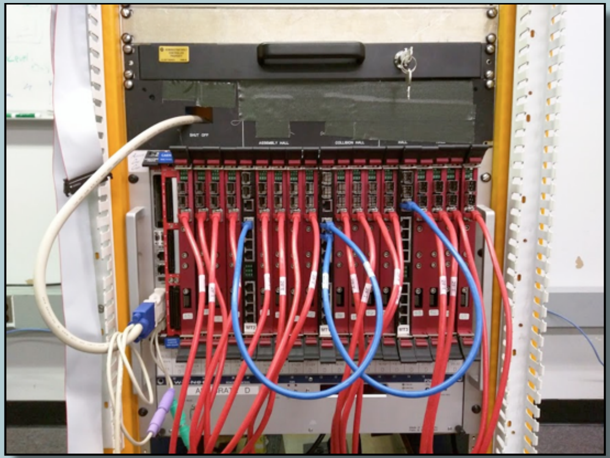
Evaluation board with Xilinx FPGA and working firmware; being debugged.
Adapting firmware for triggerless operation.

Team:
Varner, Nishimura;
Master's students Duron, Schluchin, Hendricks;
Grad. student Keefe

Status Summary: ANNIE DAQ for WATCHMAN

VME crate with KOTO (4-ch) boards.

See http://edg.uchicago.edu/~bogdan/ for more info



Slot 1: GE VME-7807RC CPU
Slot 2: CAEN V1495 Trigger Card
Slots 7,12, 17: “MT Cards”
Other 16: 500 MHz ADC Cards

16-channel 500MHz boards have been designed and prototyped. Would need minor tweaks before production run.

Would require fiber readout for higher data rates.

Continuous digitization should be possible with minor mods to existing firmware.

Team:
Wetstein;
Postdoc Eisch

Status Summary: CAEN

Tyler and I had day-long meeting with CAEN reps. at Penn State.
CAEN option seems feasible.
Got loaner 8-ch desktop version of digitizer.
Running tests on it now.

(Peeking under the hood/bonnet)

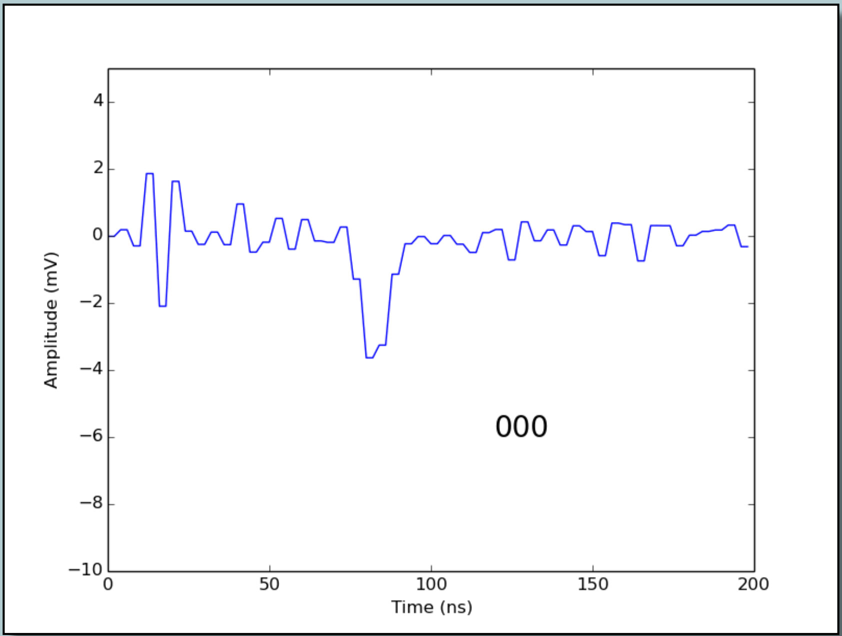
Multiple firmware options, including "Open FPGA" option:

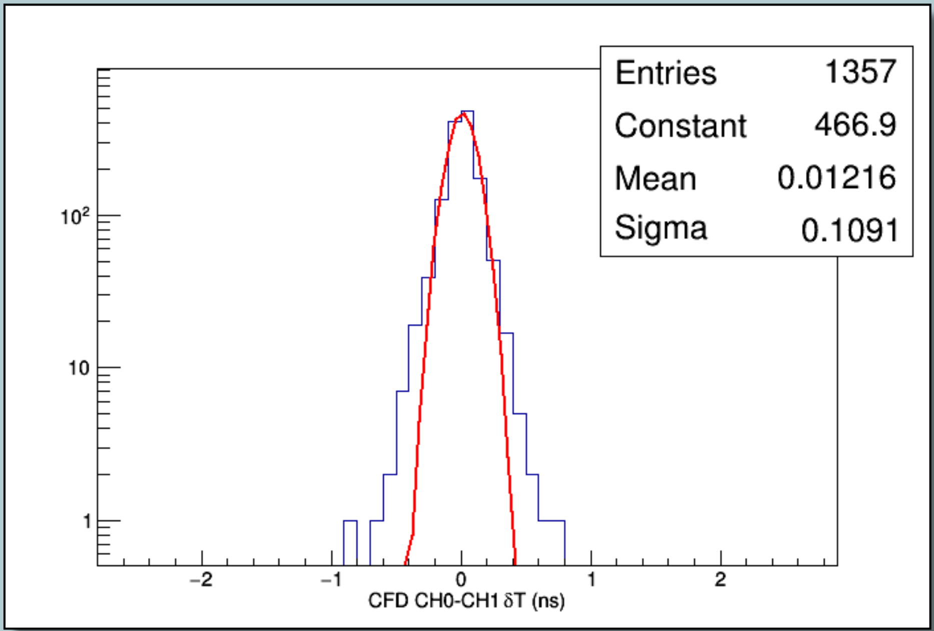
- CAEN provides standard firmware source code as a starting point
- We write our own trigger and (Q,T) extraction code, tailored to our needs
- Minimize dead-time impacts per our requirements

Team:
Anderson,
Thompson,
Cowen

Status Summary: CAEN

Tyler made some measurements with the loaner desktop digitizer:





Quick look at SPEs for IceCube PMT (R7081-02, Gain ~ 1E7)

- **Had some trouble with environmental noise (PMT picks up 90.7FM transmitting at the student union across the street!)**
- **Lots of noise-triggers when triggering on PMT discriminator, so instead, trigger on LED pulse generator (tuned for ~10% occupancy)**
- **Some noise coupling from pulser…jitter due to unresolved issues with digitizer settings (probably user error!)**
- **Still needs some work, but it does provide a feel for what SPEs look like…**

Split PMT anode into 2 channels, look at difference in interpolated zero crossing time:

- **Sigma ~ 100ps**

Crudely speaking, this approximates the "digitizer only" contribution to timing resolution

Outstanding Issues & Next Steps

- Quantify requirements
  - Need further interaction with various WGs (see next slides)
- Perform tests of TARGETX chip with R7081 at Penn State
  - Use TARGETX developer's kit (PCB provided by UH)
- Identify group(s) who will write DAQ software (e.g., event builder, system monitoring, calibration control, slow control…)
  - N.B.: ANNIE system already meshes with "ToolDAQ"
    - Presumably our other proposed systems could be made to do so as well
  - ToolDAQ author now at QMUL, might be interested in WATCHMAN…
- With Project Management oversight, by the end of the year recommend to collaboration a system with
  - Projected performance
  - Suggested partitioning of tasks
  - Rough timeline and milestones

Requirements

- Full draft DAQ hardware requirements document available on this meeting's Indico site and on WATCHMAN DAQ wiki here
  - This document needs to be fleshed out with numbers in numerous places
  - The following slide summarizes the information we need from various other WGs to start this process

WG	Requirement
PMT	Provide pulse height spectrum
SAS	Quantify degradation to reco due to time resolution.
PMT	Provide TTS
SAS	Provide impact of loss of linearity on reco quality.
PMT	Provide impact of space charge on linearity.
SAS, Calibration	Provide maximum event rate.
SAS	Provide longest event duration.
SAS	Provide required absolute timing stability for reactor, SN, SNEWS.
SAS	Provide required double pulse resolution for reconstruction.
SAS	Provide required inter-channel timing precision for reconstruction?
SAS	Provide PMT charge distribution. How large are largest hits?
SITE	Provide operating temperature of 0-40C for electronics.
Logistics, Procurement	Provide transportation of electronics minimizing mechanical shock and extreme temps.
SITE	Provide 40-60% humidity level for electronics.
SAS	Confirm that noise at 50% of SPE threshold will not impact reconstruction.
SITE	Provide mains power conditioning as specified by DAQ WG.
PMT	Provide HV rampdown time to minimize possible damage to PMTs
SITE	Provide this level of sustained power.

WG	Requirement
SITE	Provide this peak power level.
SITE	Provide GPS timestamp.
SITE, SAS	Once SAS specifies trigger threshold, data bandwidth to surface can be estimated.
DAQ S/W, SAS	The in-situ storage for built events must be sufficiently large to store one week's data. Storage required depends on SAS-specified trigger threshold.
SITE	Provide space for up to 10 racks of electronics in the mine.
SITE, SAFETY	Provide mechanical and electrical connections of racks to floor/ground.
CAL	Information: External calibration triggers will be supported by DAQ.
Logistics	Provide a unique identifier system for various units in the DAQ system, like PCB cards, crates, racks, etc.
SITE, CLEANLINESS	Comment on use of cadmium, zinc, tin in electronics.
Procurement	Provide commercial parts that will not operate in excess of 80% of manufacturer's spec.
Procurement	Provide high-reliability parts.
Procurement	Do not select parts with overlong procurement lead times.
Procurement	Do not exceed per-channel cost of a fully commercial DAQ solution (e.g., from CAEN)
Procurement	Provide parts from suppliers meeting high standards.
Procurement	Provide sufficient spares to enable construction of double the number of channels predicted to fail.
DAQ S/W, SAS	The in-situ storage for built events must be sufficiently large to store one week's data. Storage required depends on SAS-specified trigger threshold.
SITE	Provide space for up to 10 racks of electronics in the mine.
SITE	Provide underground storage for hot spares.
SITE	Provide an electronics repair facility on the surface.

Requirements Discussion