

# DOMs and the DAQ Demystified

## Part I: DOMs

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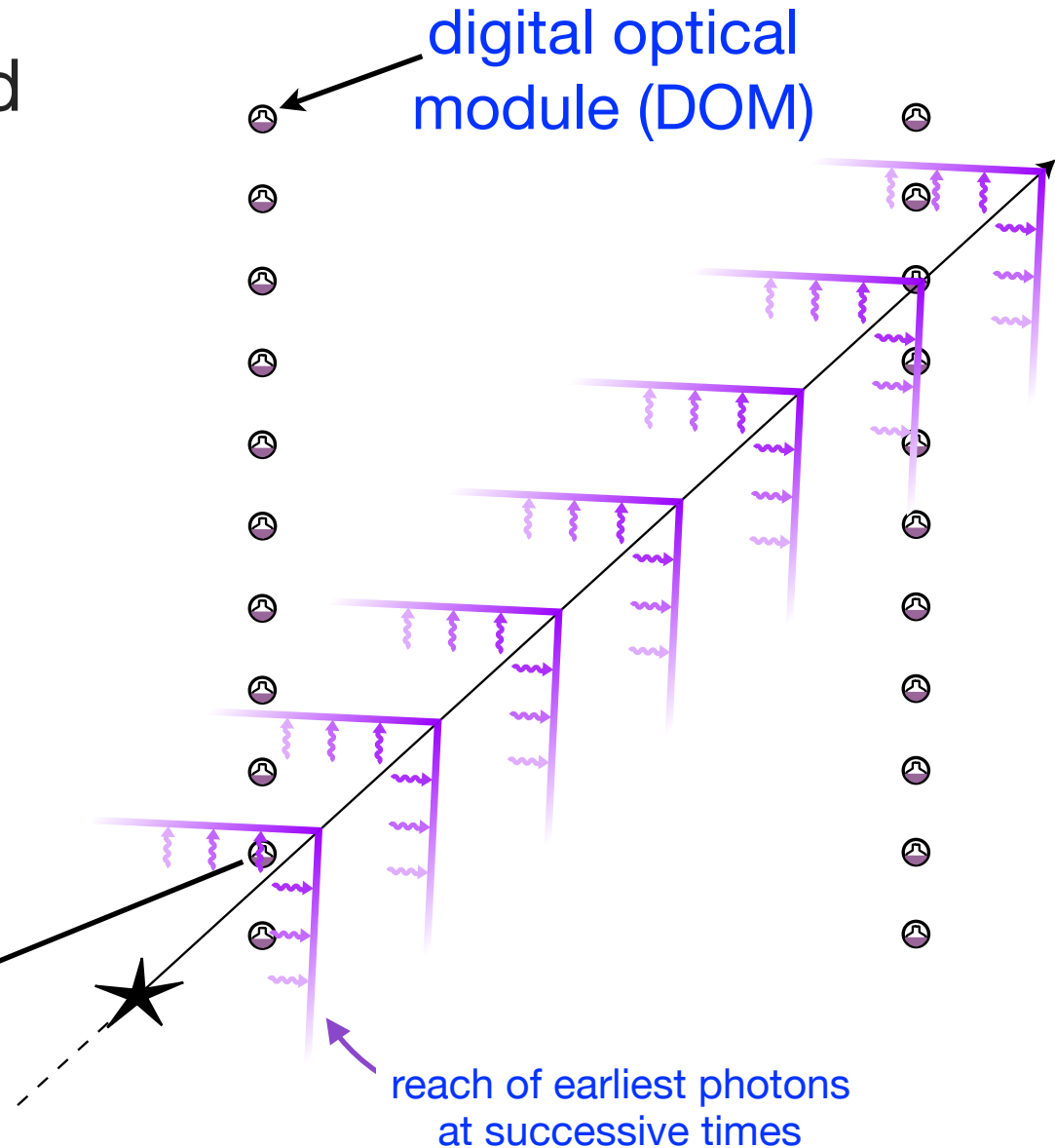
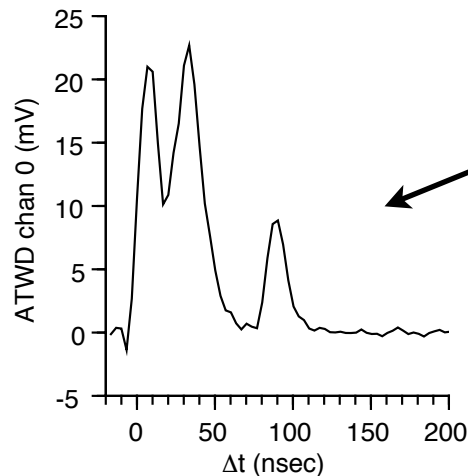
John Kelley  
UW-Madison

IceCube Bootcamp, 2018-06-19

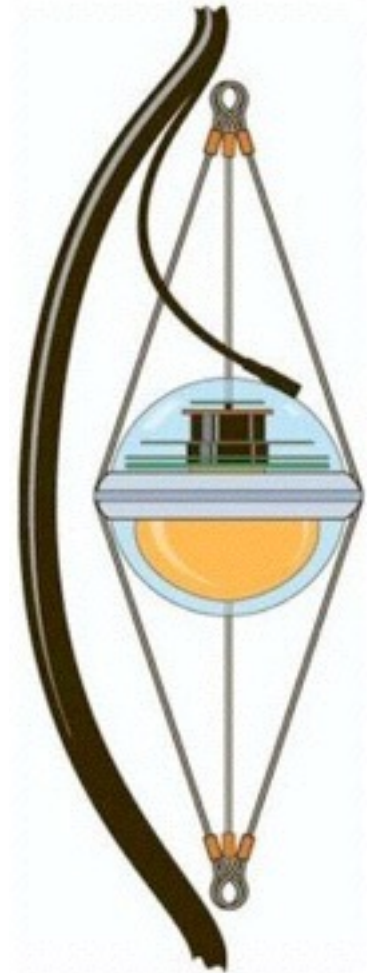
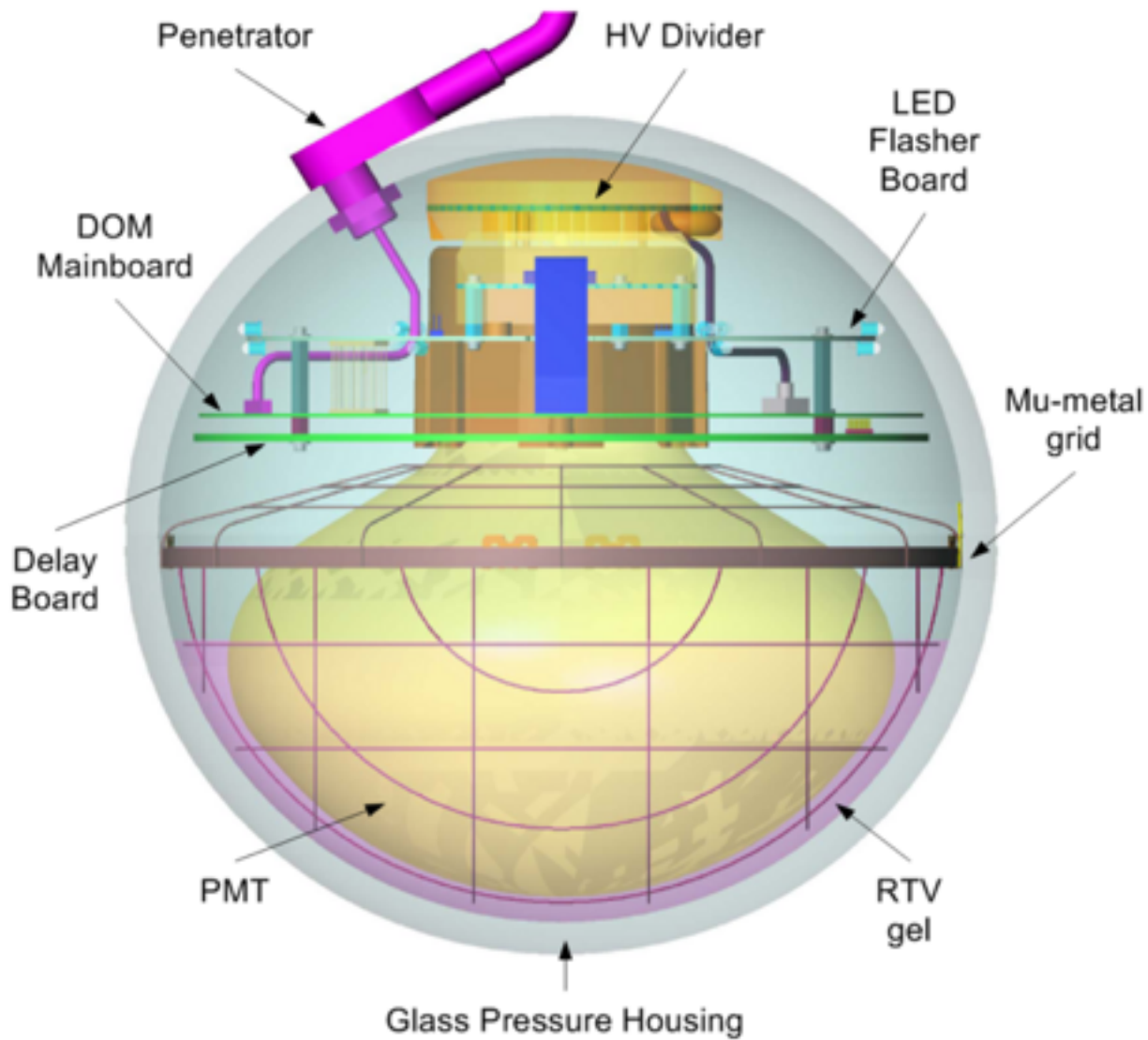
with thanks to Chris Wendt

# $\nu_\mu \rightarrow \mu$ Detection

- Light is mostly emitted in small bursts along muon track
- Photon arrival times, and how many there are, tell us the direction and the energy of the muon



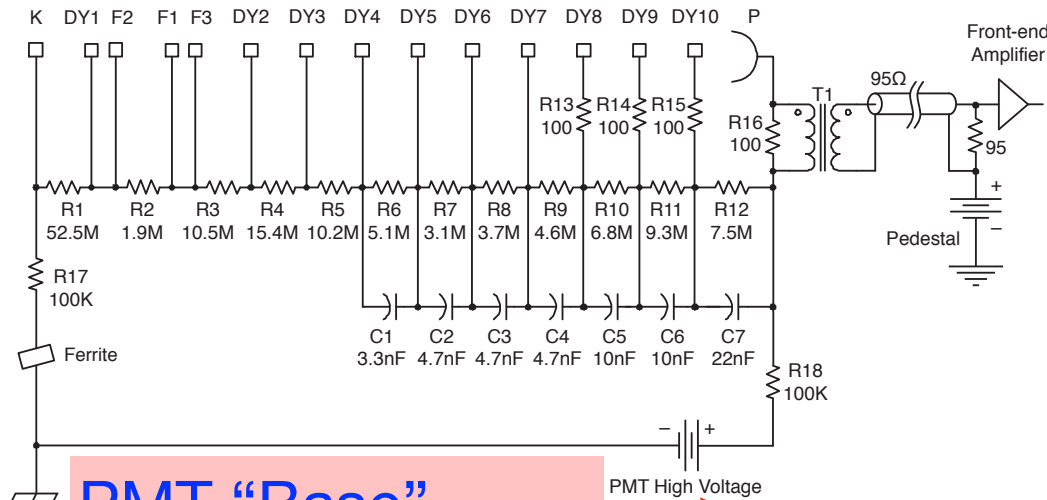
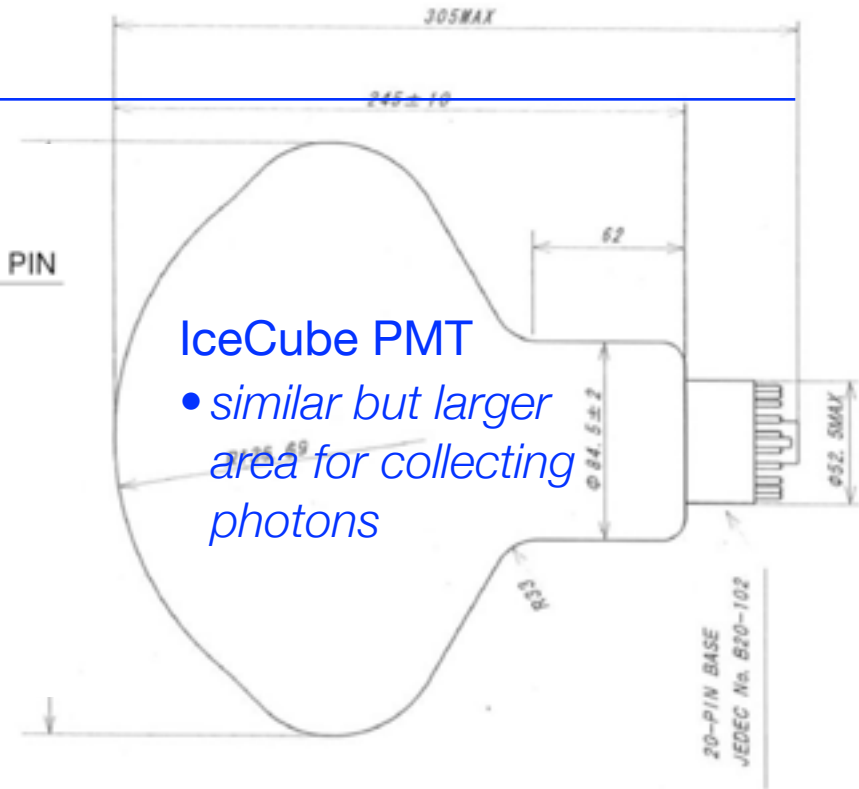
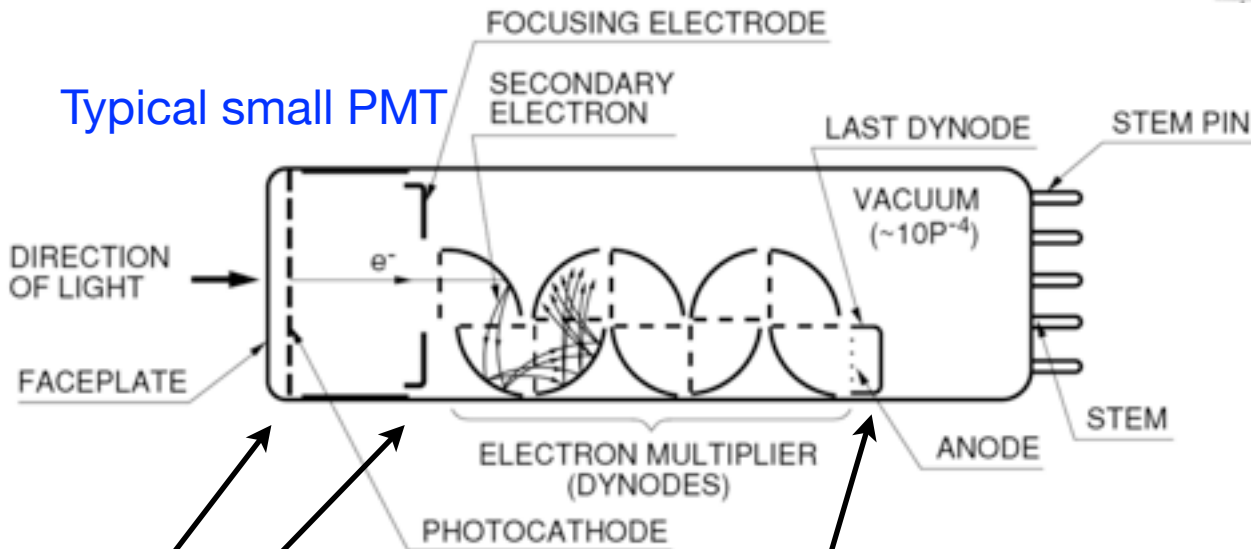
# What's in a DOM?



Cable: many twisted pairs, each pair carries power & communications for 2 DOMs

# Photomultiplier Tube (PMT)

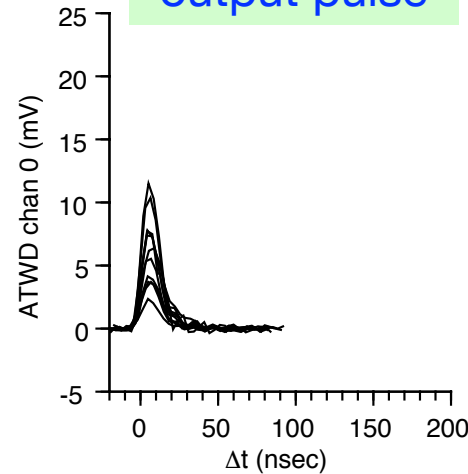
Typical small PMT



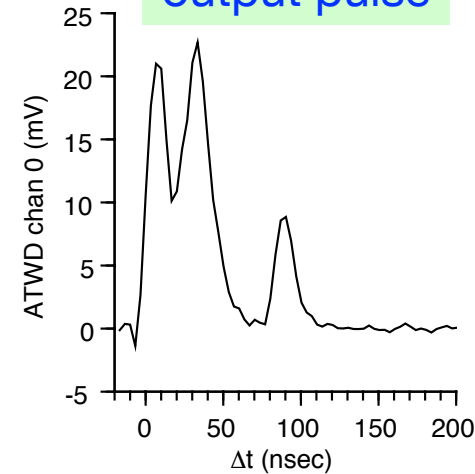
PMT "Base"  
= Voltage Divider

~1500 volts

Single photon output pulse

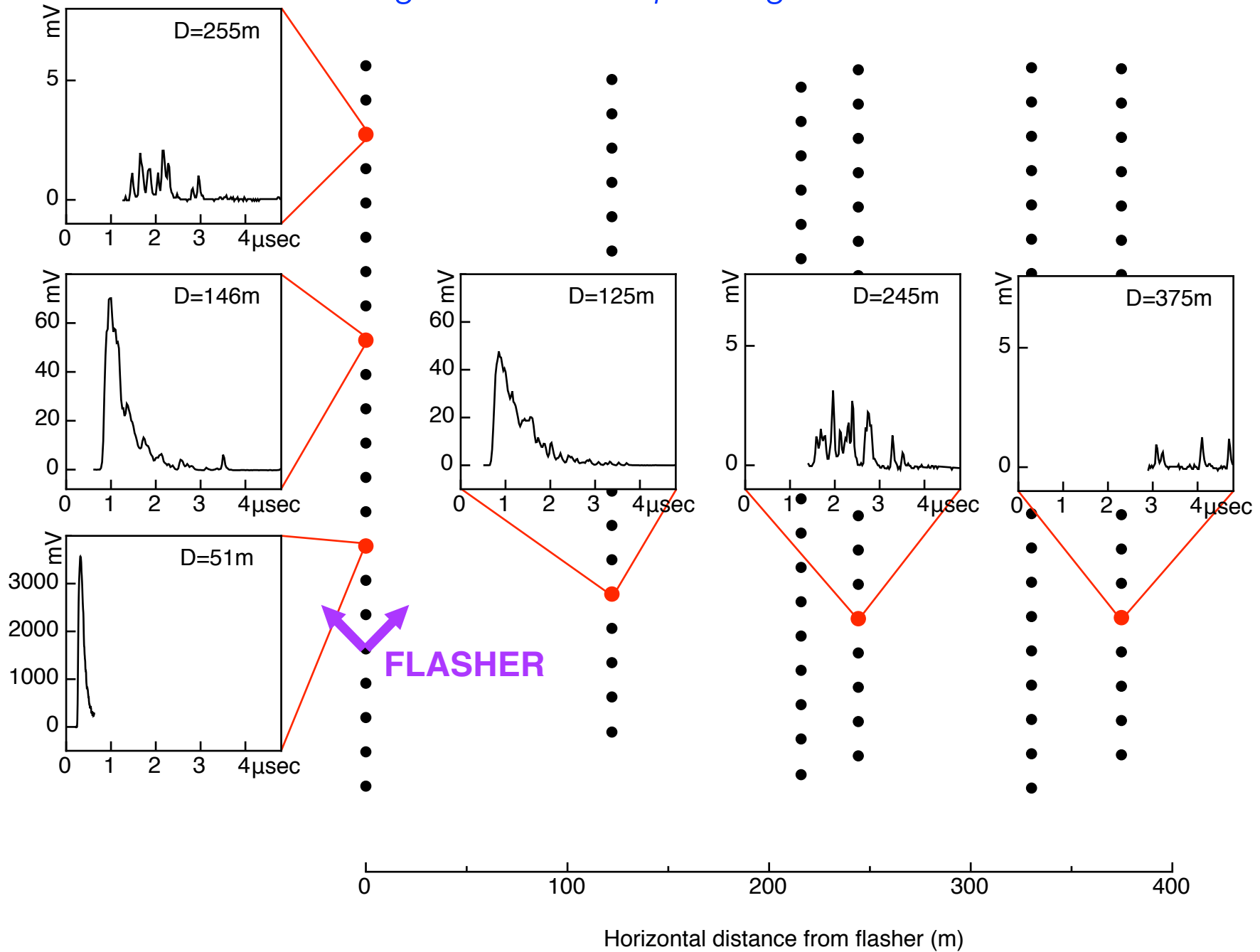


Multi-photon output pulse



# DOM signals resulting from localized light flash

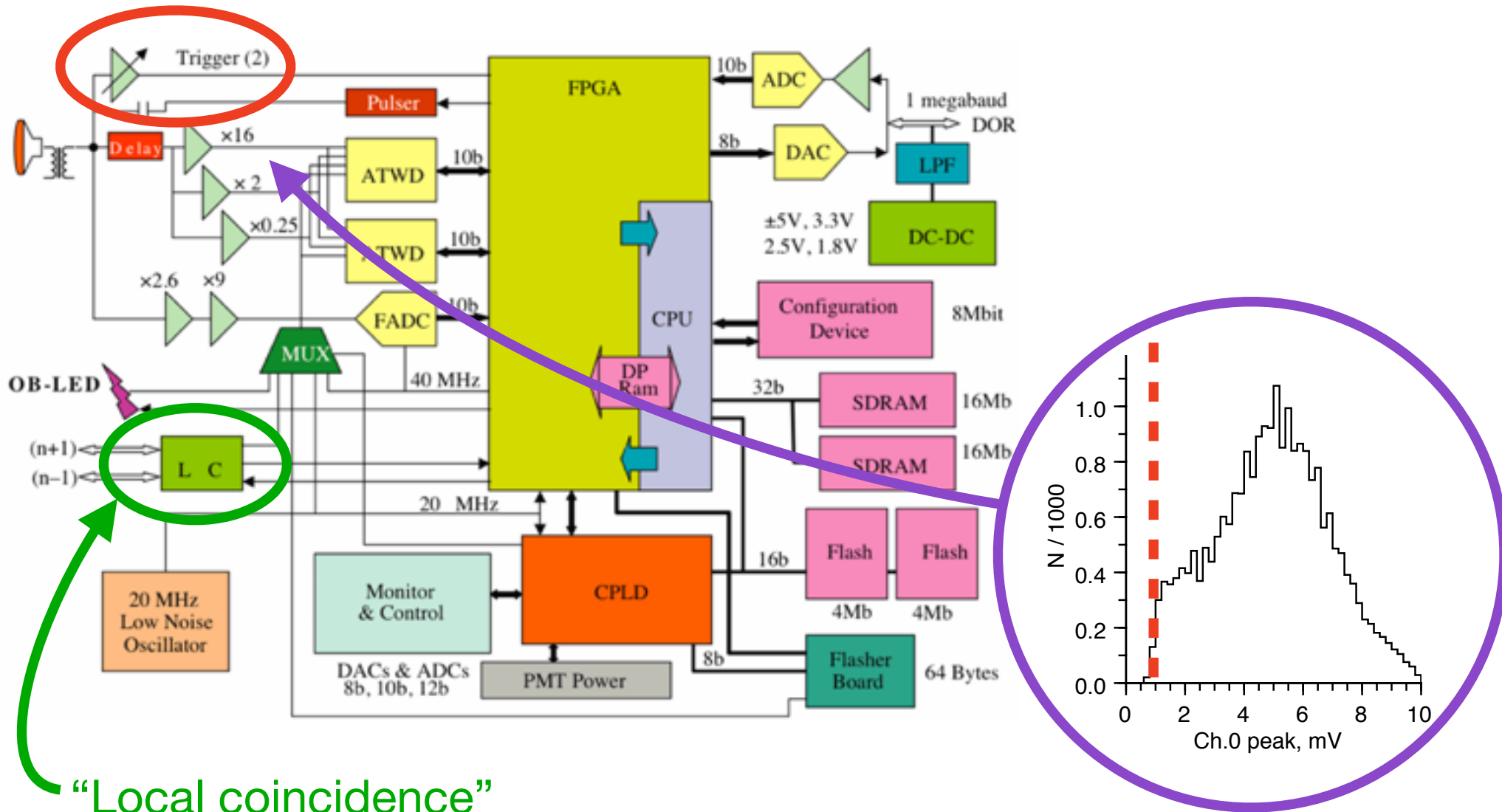
- *Big differences depending on distance from source*



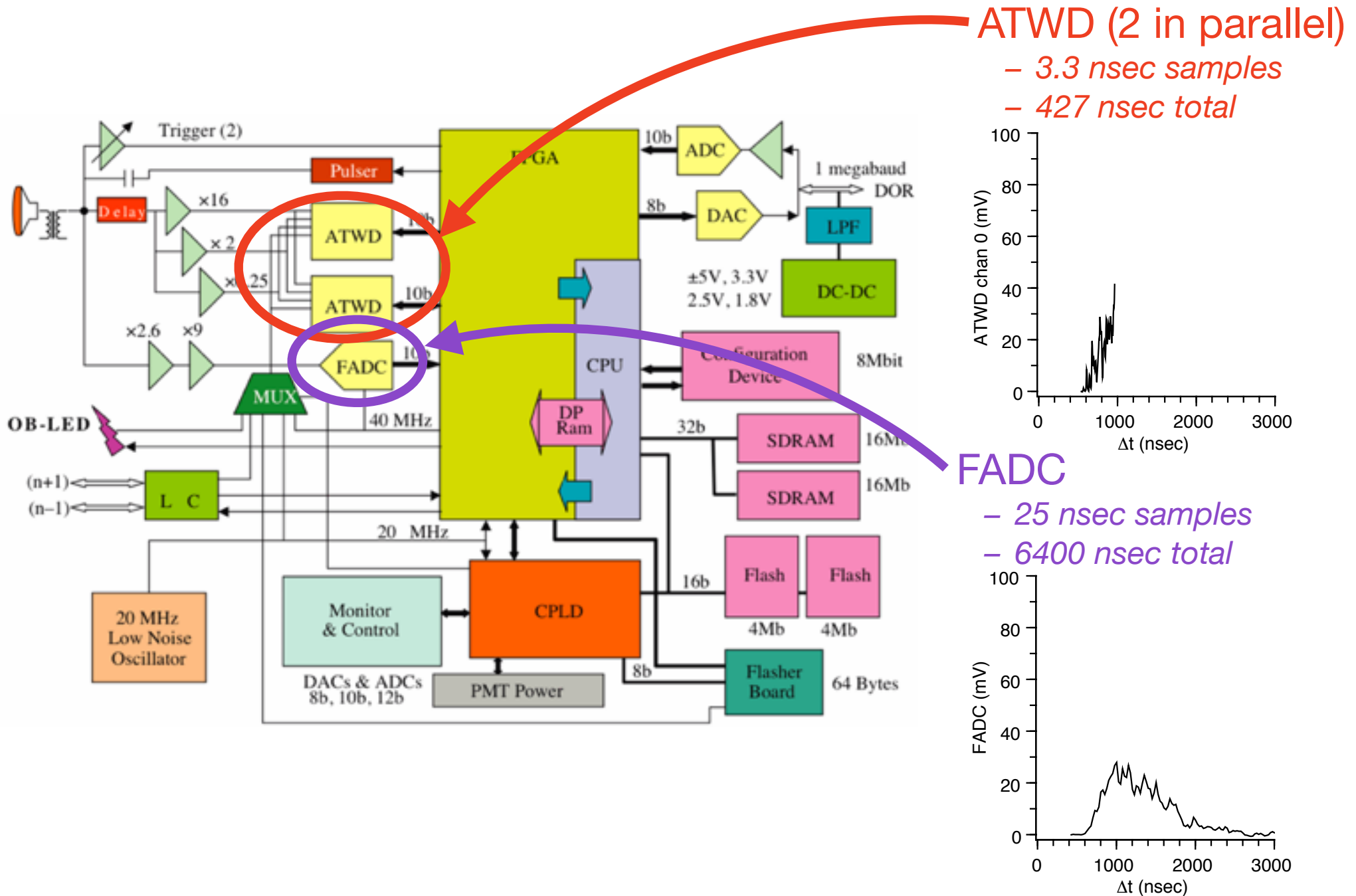


# Triggering on single photons

Actually single photoelectrons, "SPEs"



# Waveform recorders (digitizers)



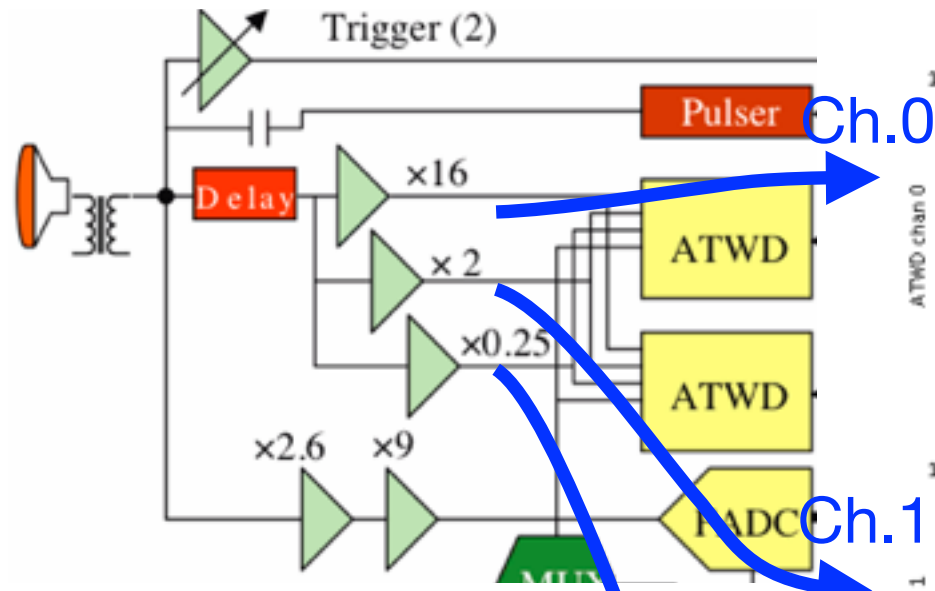


# Waveform digitizers “ATWD” Channel 0,1,2

Different gains for small, big pulses

RAW COUNTS  
0-1023

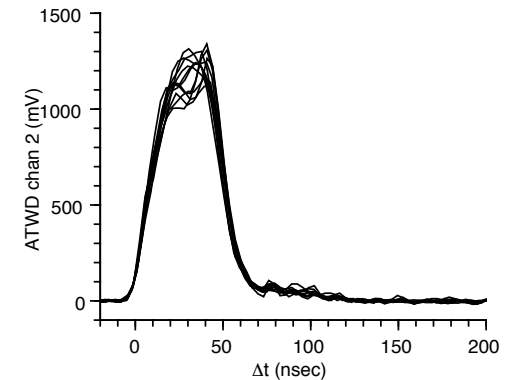
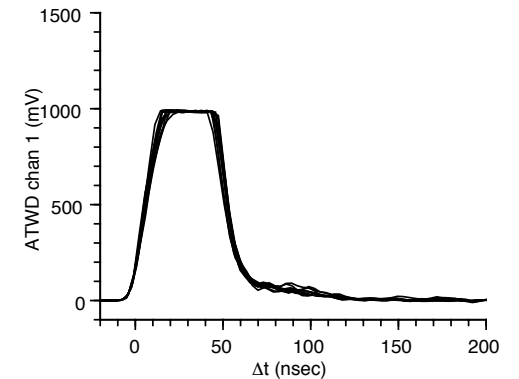
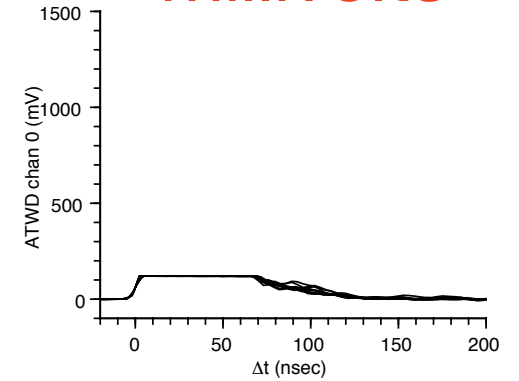
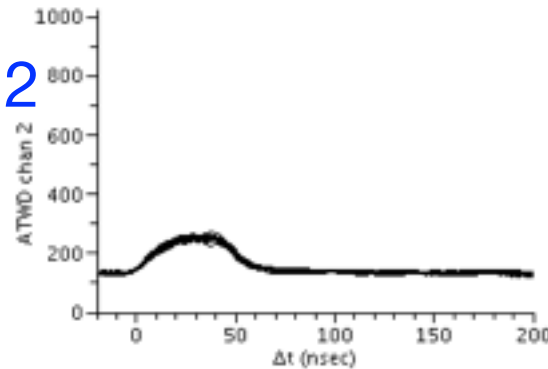
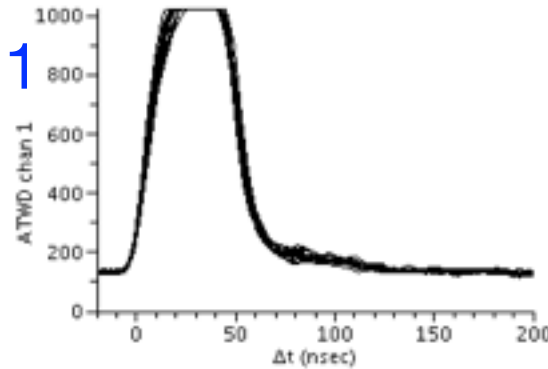
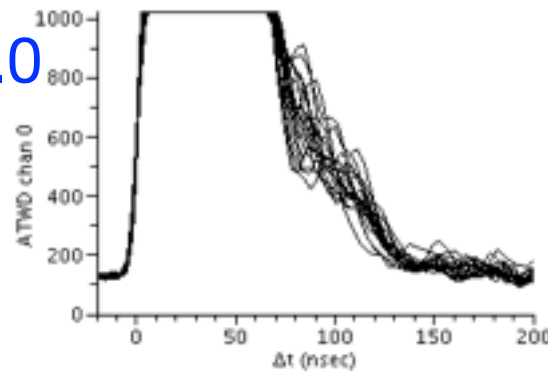
Scaled to  
millivolts



Ch.0

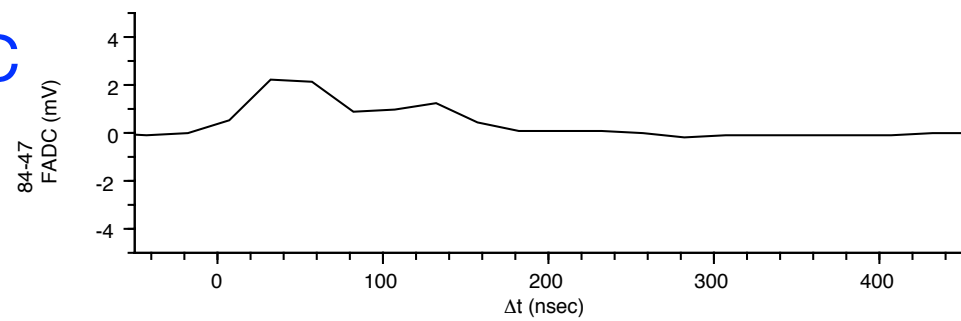
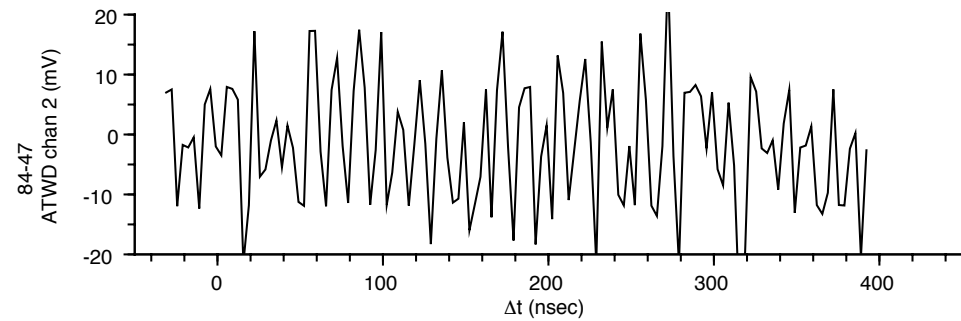
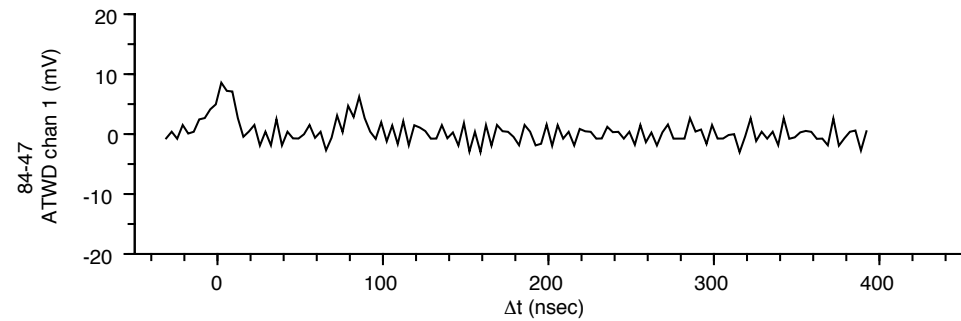
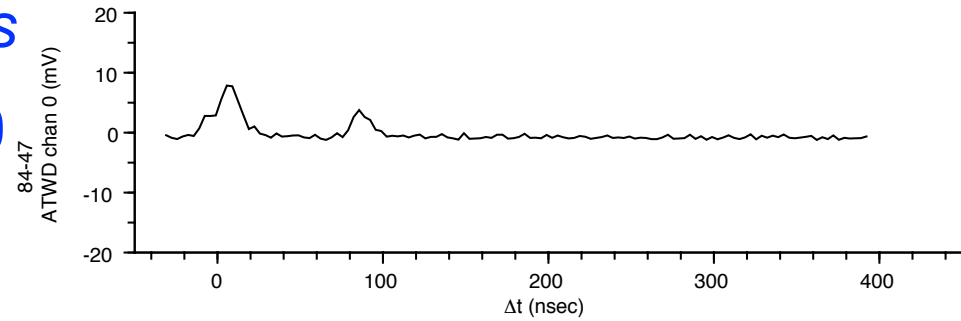
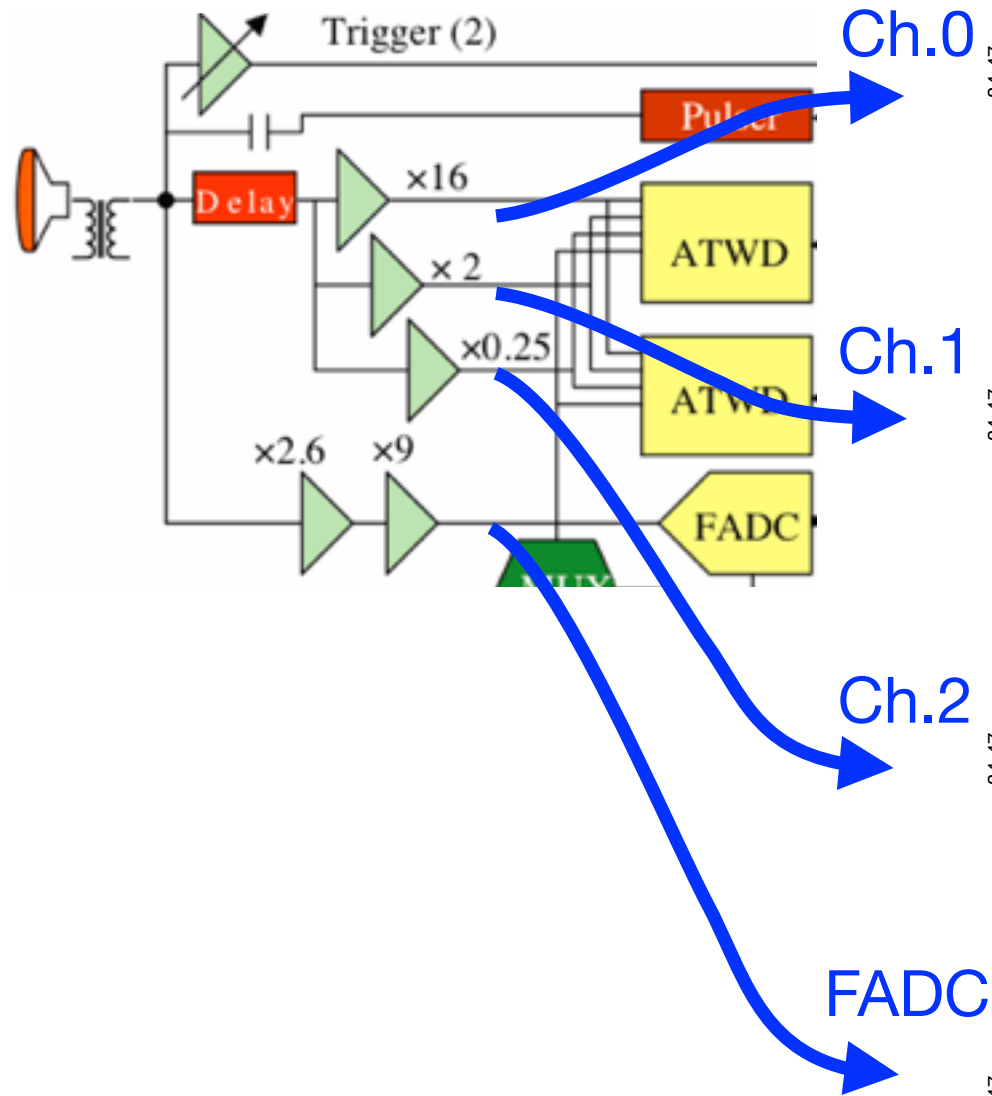
Ch.1

Ch.2



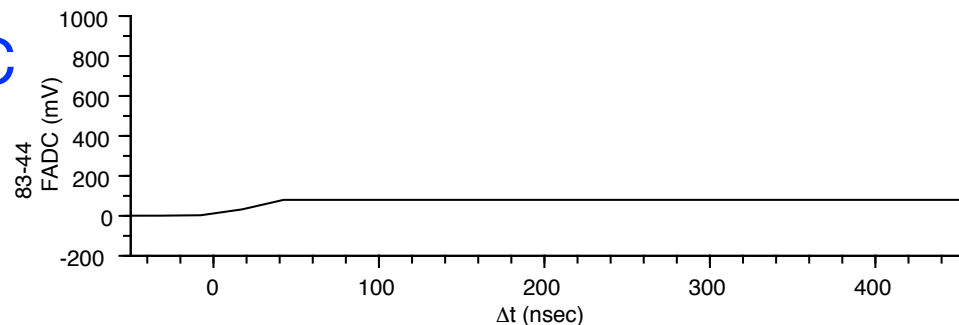
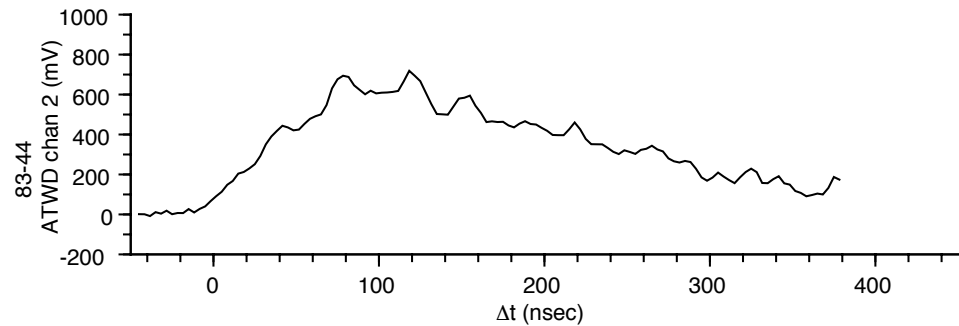
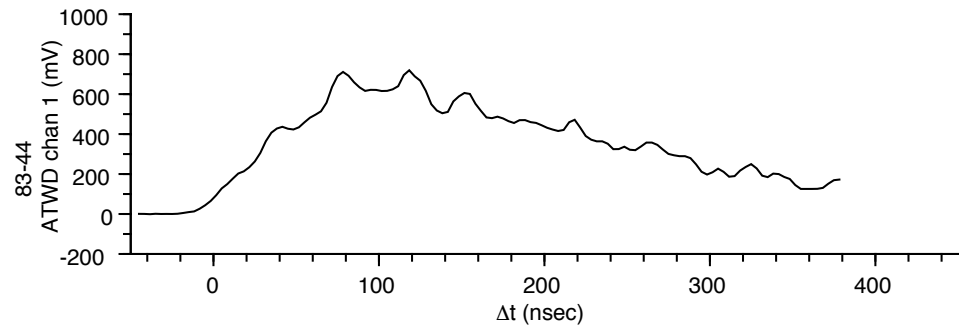
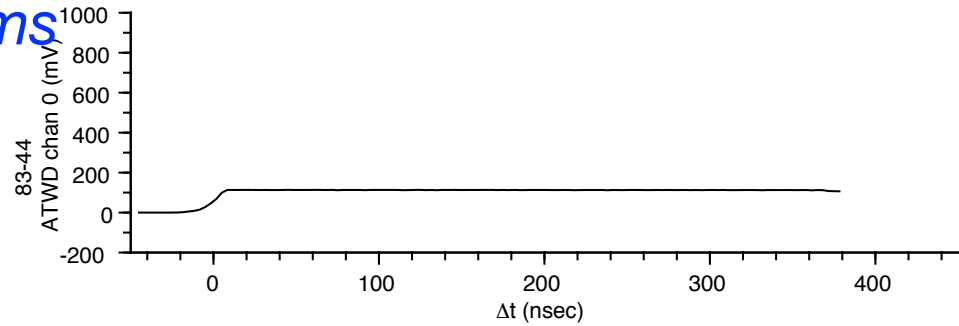
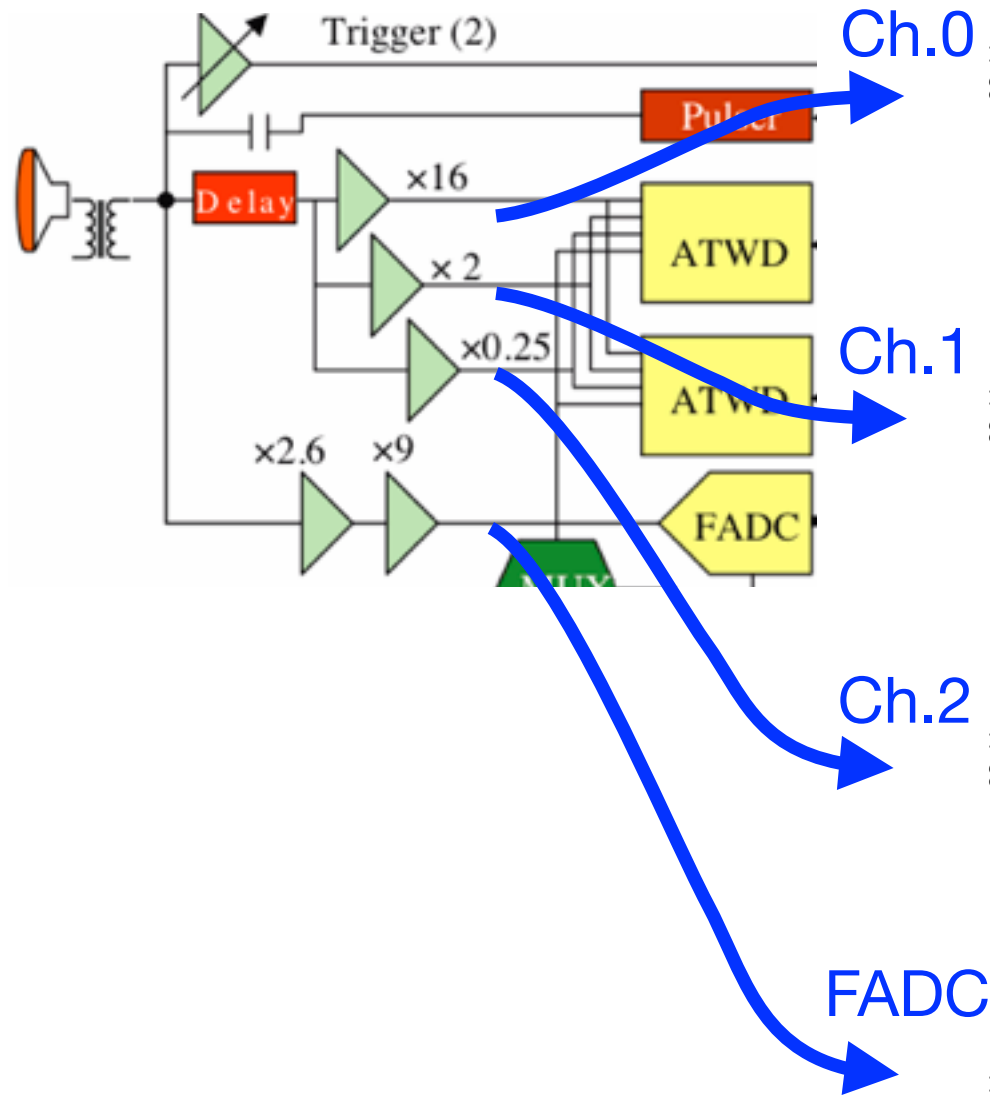
# Waveform digitizers “ATWD” Ch. 0,1,2 and “FADC”

*Ch.0 good for small waveforms*



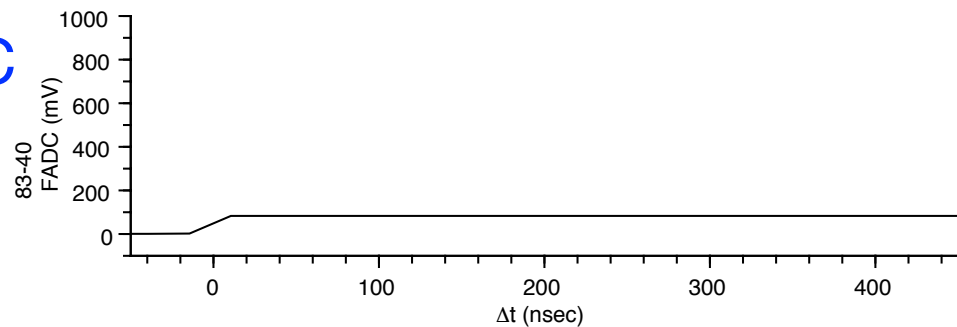
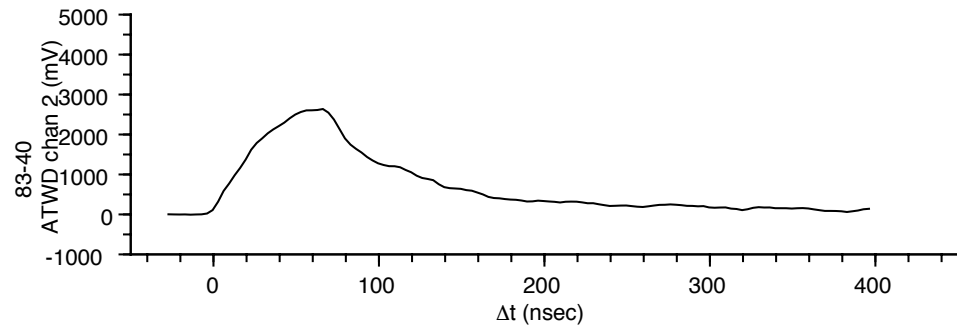
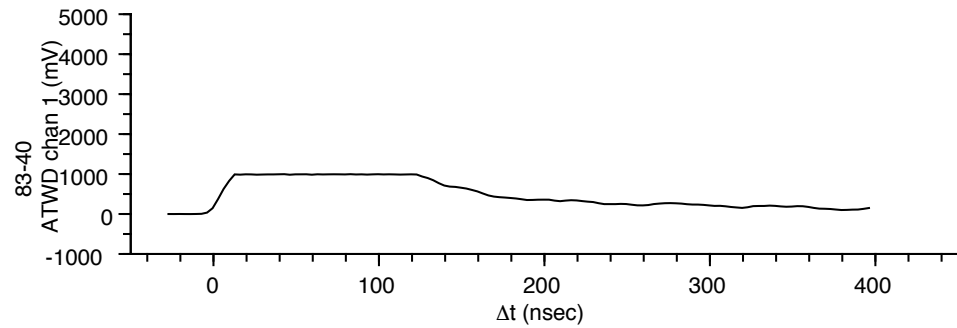
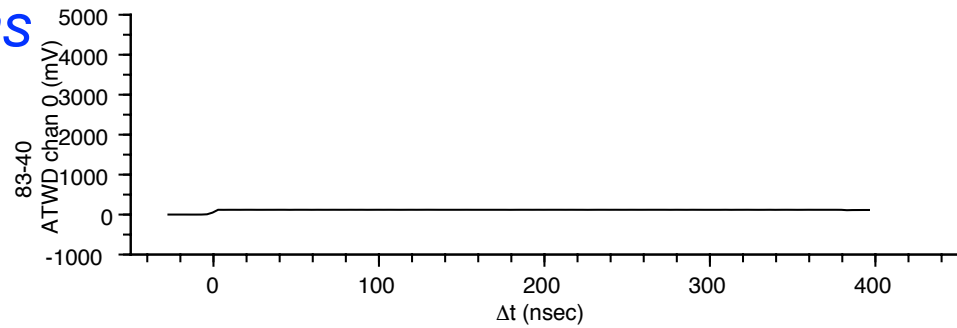
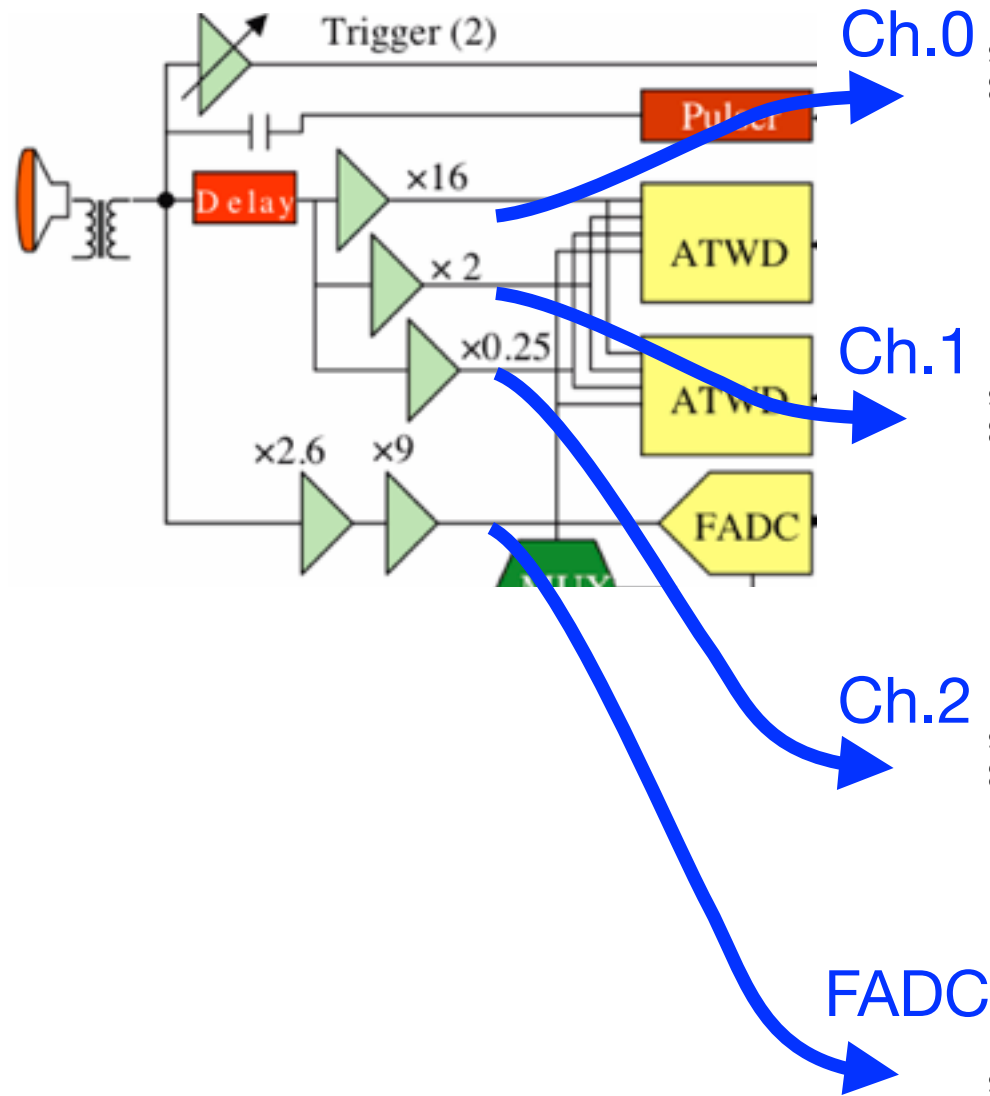
# Waveform digitizers “ATWD” Ch. 0,1,2 and “FADC”

*Ch.1 good for medium waveforms*



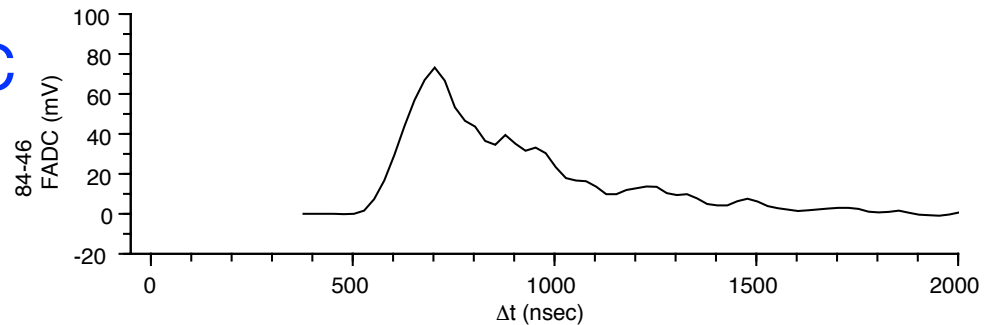
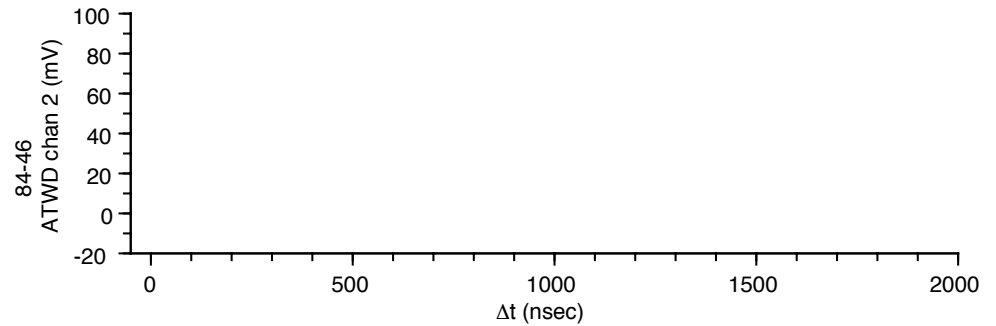
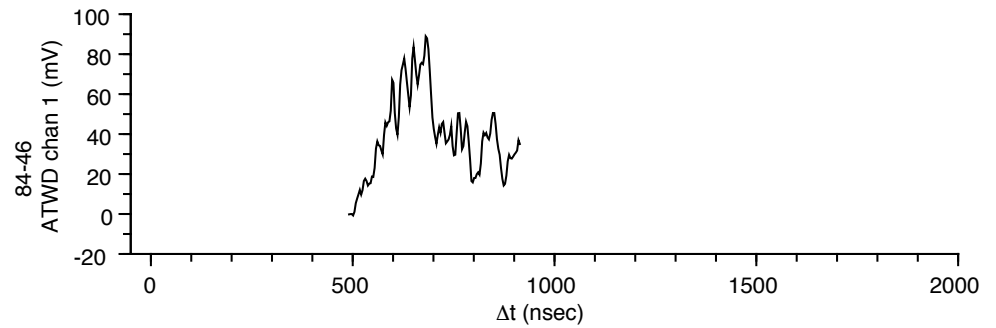
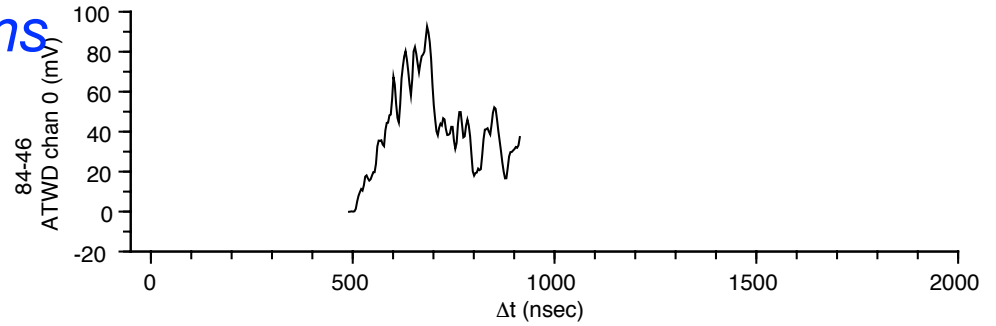
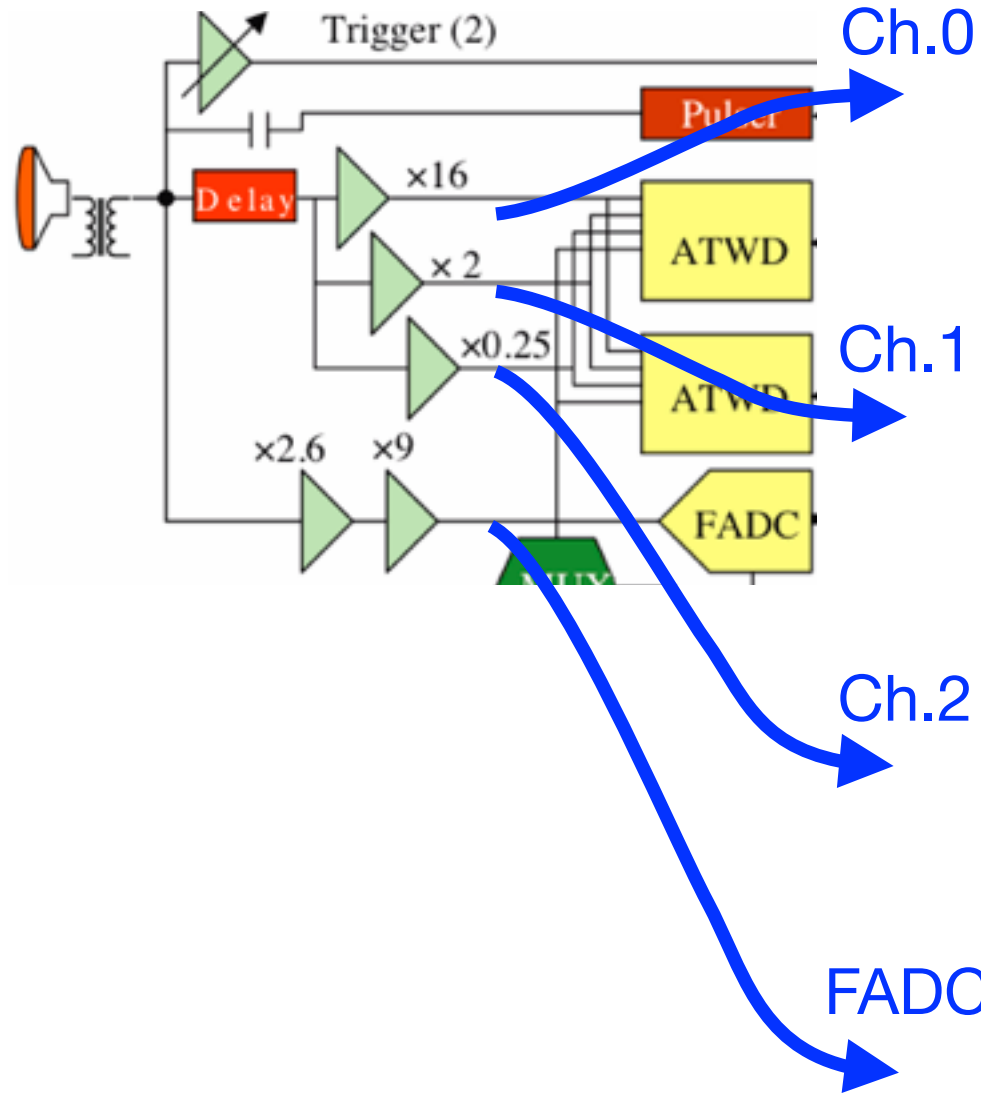
# Waveform digitizers “ATWD” Ch. 0,1,2 and “FADC”

*Ch.2 needed for large waveforms*



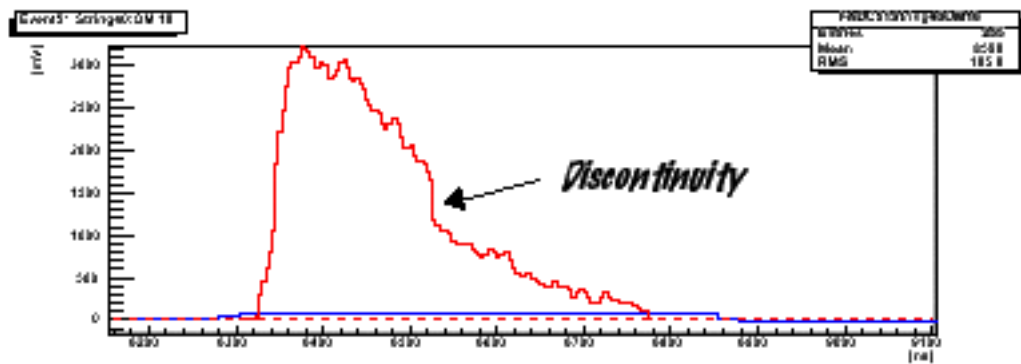
# Waveform digitizers “ATWD” Ch. 0,1,2 and “FADC”

*FADC needed for long waveforms*



# Why so many channels and digitizers?

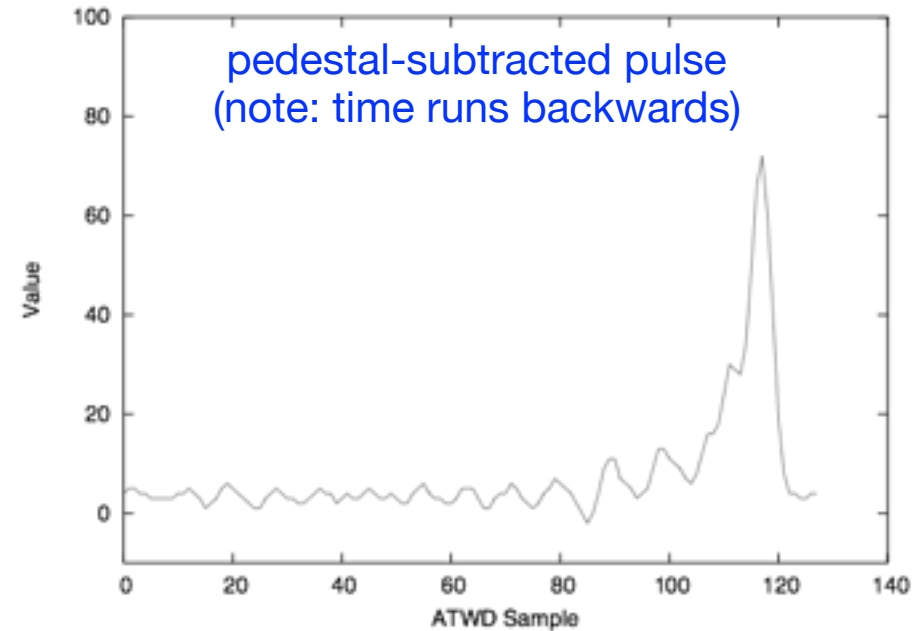
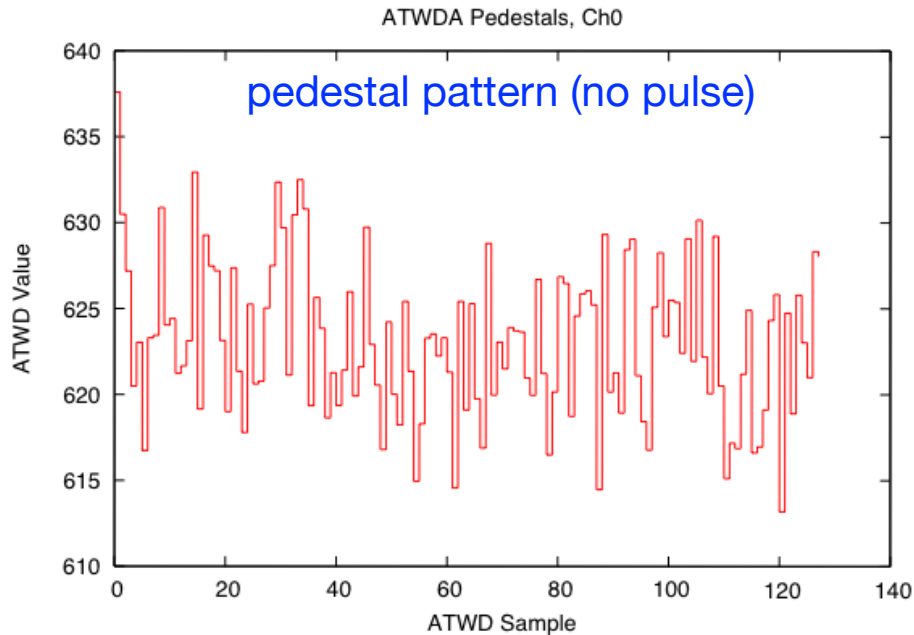
- Fast digitizers are power hungry, and the ATWD design was the alternative
  - When triggered, the ATWD quickly stores 128 samples of waveform, then digitizes these
  - During the digitization period, the ATWD is disabled, so a second one is provided to avoid losing additional hits (“ping-pong”)
- The FADC is a slower digitizer to cover the case of longer waveforms
- Each channel had only 10 bit resolution so could not accommodate the dynamic range from small signals to large signals... thus needed ch.0/1/2
- But we pay a price in complexity and some funky problems when combining information from different gain channels



# ATWD peculiarities

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- Each ATWD has a “fingerprint” or pedestal pattern which much be subtracted from the waveform (happens automatically in the software)



- Baseline voltage is very sensitive to DOM conditions; baselines are measured from previous runs and subtracted before pulses analyzed

- ATWD documentation:

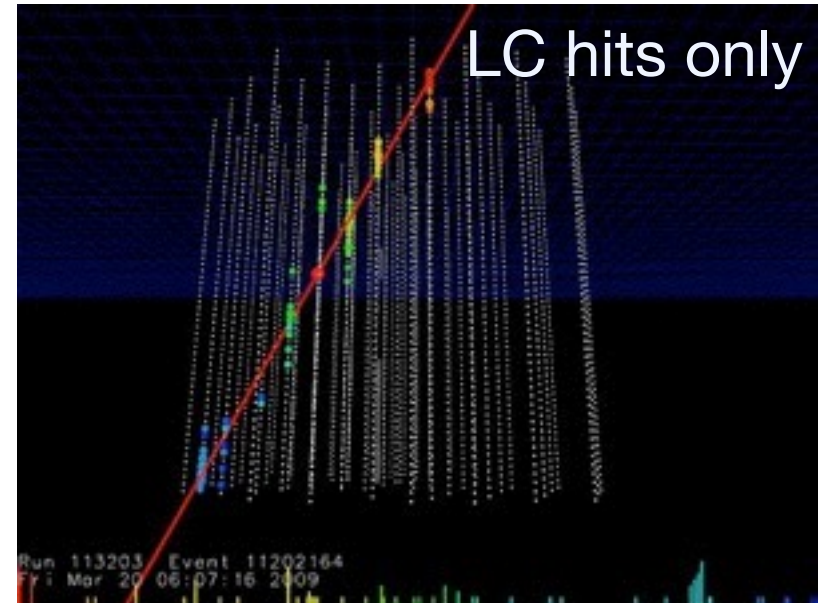
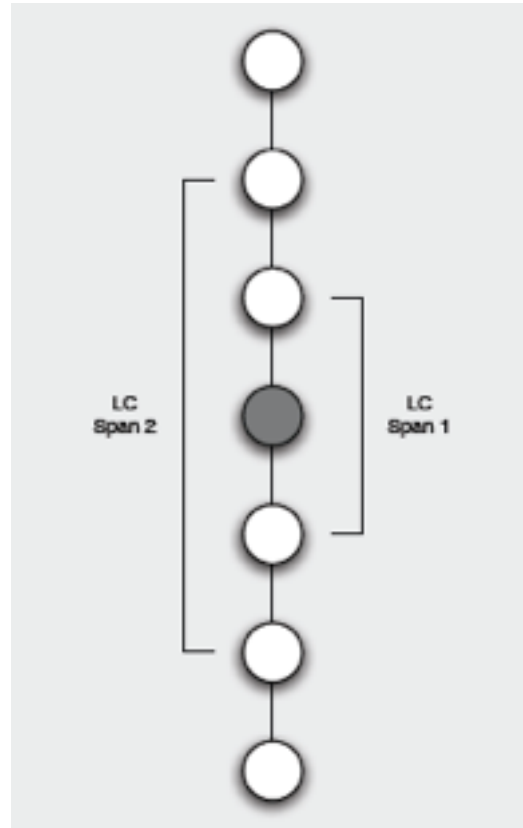
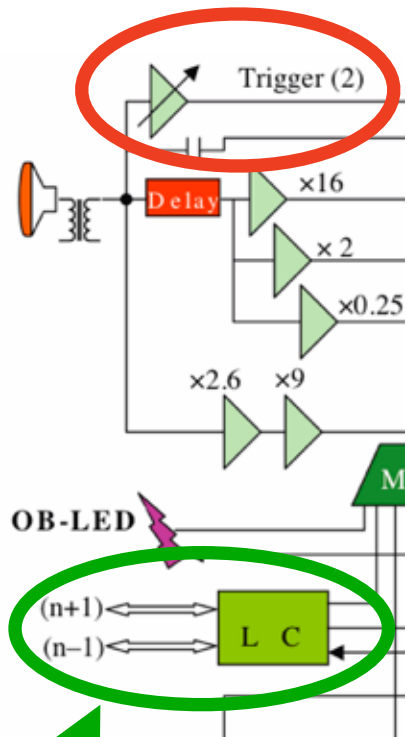
[http://docushare.icecube.wisc.edu/docushare/dsweb/Get/Document-21613/atwd\\_manual.pdf](http://docushare.icecube.wisc.edu/docushare/dsweb/Get/Document-21613/atwd_manual.pdf)

<http://glacier.lbl.gov/~thorsten/ATWD/>





# Local Coincidence



“Local coincidence”

- looks at whether a neighboring DOM also recorded an SPE
- 1  $\mu$ sec time window implemented in FPGA
- Many no-LC hits are from PMT dark noise, others are isolated signal photons

# Sending waveforms to surface

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- Readouts *with* local coincidence “HLC Readouts”

- Ch.0 + FADC
- Ch.0 + Ch.1 + FADC
- Ch.0 + Ch.1 + Ch.2 + FADC

*Include enough channels to accommodate peak amplitude*

*Highly compressed ~150 bytes/record  
but all information is saved*

- Readouts *without* local coincidence “SLC Readouts”

*Only three samples of FADC are saved  
so time of SPE can be determined*

- All readouts are grouped into big chunks and transmitted to surface
- Must stay below 40kB/sec for each DOM, otherwise chunks of data get thrown away (“LBM overflows”)

# DOMs and the DAQ Demystified

## Part II: DAQ, Triggers, Filters, and more

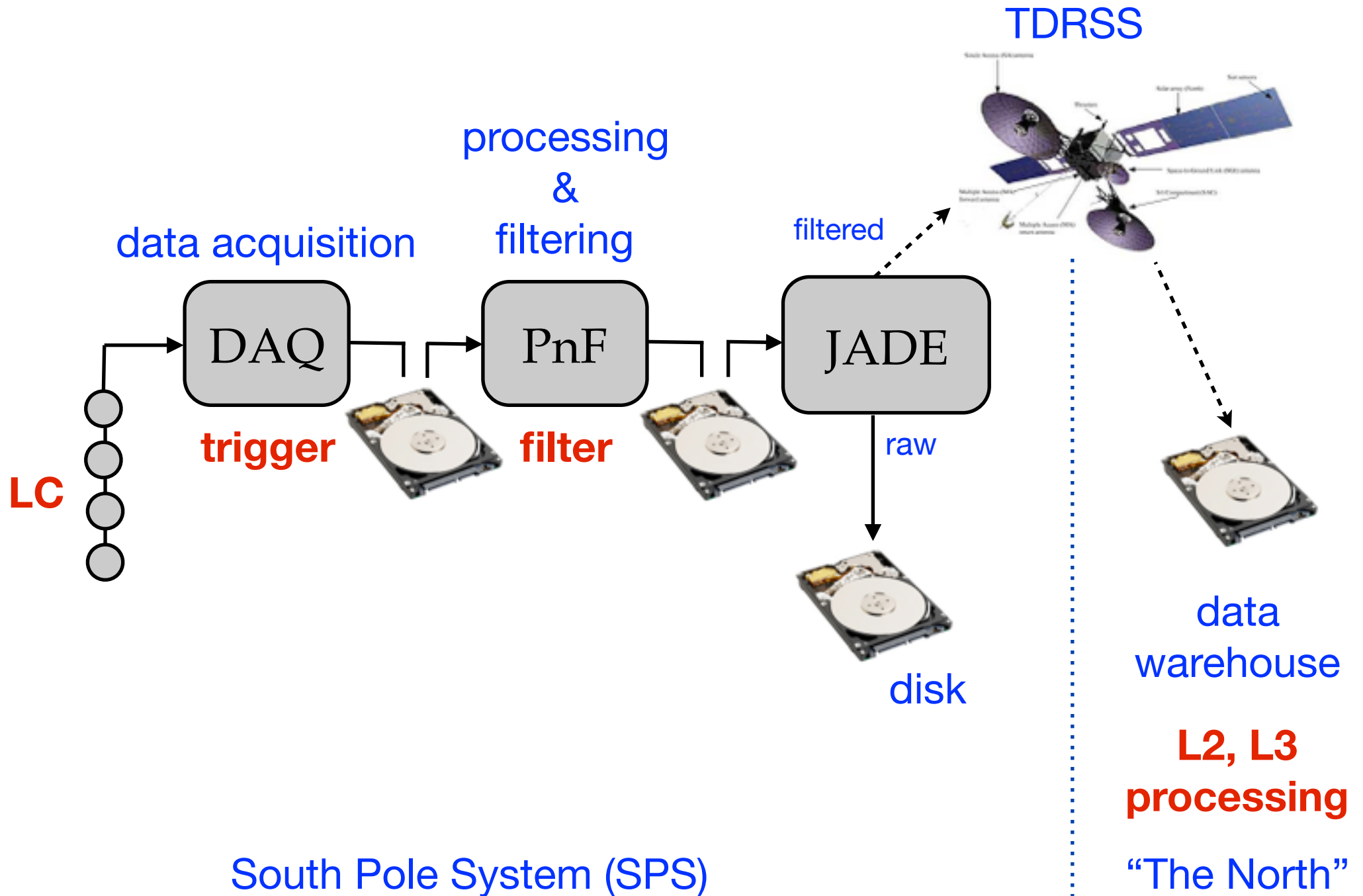
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UW-Madison

IceCube Bootcamp, 2018-06-19

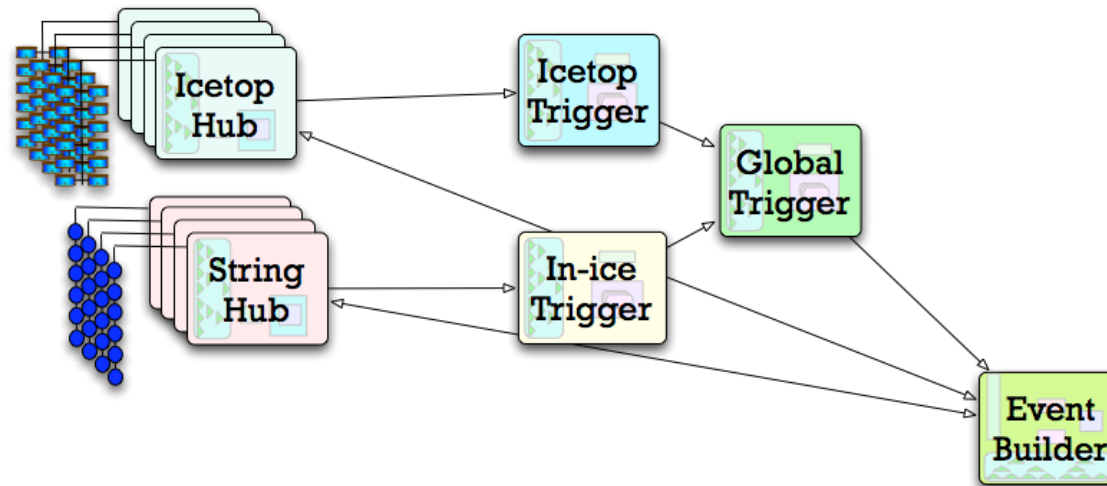
with thanks to Dave Glowacki, Naoko K. Neilson, Erik Blaufuss

# Data flow and reduction



# DAQ (Data Acquisition System)

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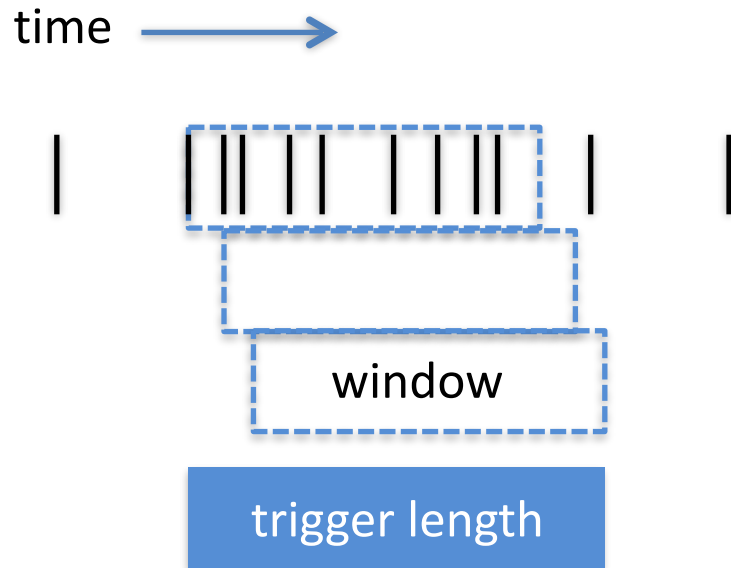
- DOMs generate **hits**: PMT waveform(s) + a timestamp
- We don't want to (and can't) save every hit from every DOM all the time
  - but we do save them for ~6 days in *hitspool* buffers
- The DAQ forms **triggers** when a pattern of hits looks interesting
  - many definitions of "interesting": muons, cascades, air showers, monopoles...
- Individual triggers are combined into a global readout window, or "event"

# Trigger Types

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- **Simple Multiplicity Trigger (SMT)**
  - $N$  HLC hits or more in a time window
  - Example: InIce SMT8 with  $N_{\text{hits}} \geq 8$  in  $5 \mu\text{s}$
  - readout window around this captures early and late hits ( $-4 \mu\text{s}$ ,  $+6 \mu\text{s}$ )
- **String** trigger (a.k.a. Cluster trigger in DAQ-land)
  - $N$  HLC hits out of  $M$  DOMs on a string in a time window
  - Example: 5 hits from a run of 7 adjacent DOMs in a time window of 1500 ns
- **Volume** trigger (a.k.a Cylinder trigger in DAQ-land)
  - simple majority of HLC hits (SMT4) with volume element including one layer of strings around a center string
  - cylinder height is 5 DOM-layers (2 up and down from the selected DOM).
- **Slow Particle** trigger (SLOP)
  - slow-moving hits along a track
  - lengths of the order of  $500\mu\text{s}$  and extending up to milliseconds
- **Fixed Rate** trigger, **Minimum Bias** trigger, **Calibration** trigger

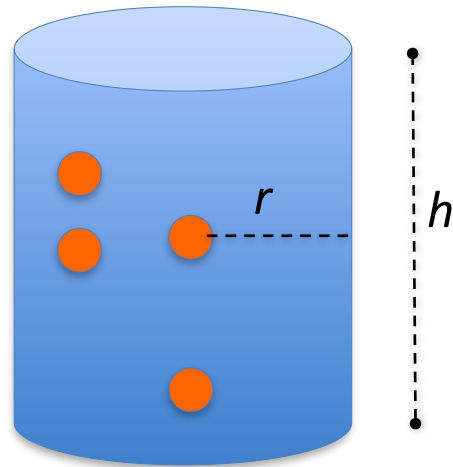
# Simple Multiplicity Trigger



- At least N HLC hits in a sliding time window
- Trigger is extended as long as majority condition satisfied
- Readout windows extend both sides; capture early, late light and SLC hits

Sub-detector	HLC hits	Window ( $\mu\text{s}$ )	Rate (Hz)
In-ice	8	5	2100
DeepCore	3	2.5	250
IceTop	6	5	25

# Topological Triggers



**Volume trigger:**  $N$  hits within a cylindrical volume around DOM in a time window



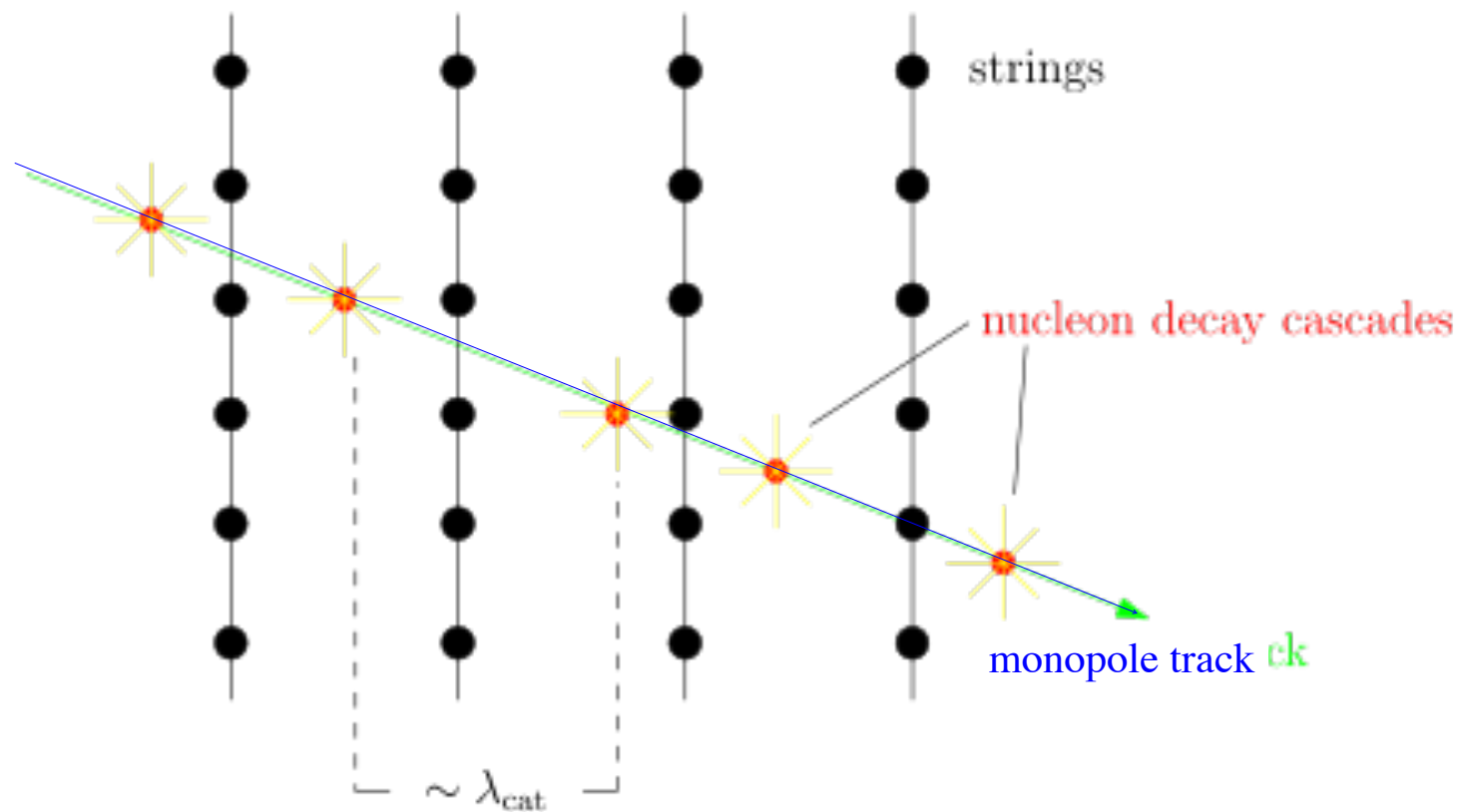
**String trigger:**  $N$  hits of  $M$  DOMs on a string in a time window

Trigger	HLC hits	Topology	Window ( $\mu\text{s}$ )	Rate (Hz)
Volume	4	cylinder $r=175\text{m}$ , $h=75\text{m}$	1	3700
String	5	of 7 DOMs on string	1.5	2200



# Specialized trigger: monopoles

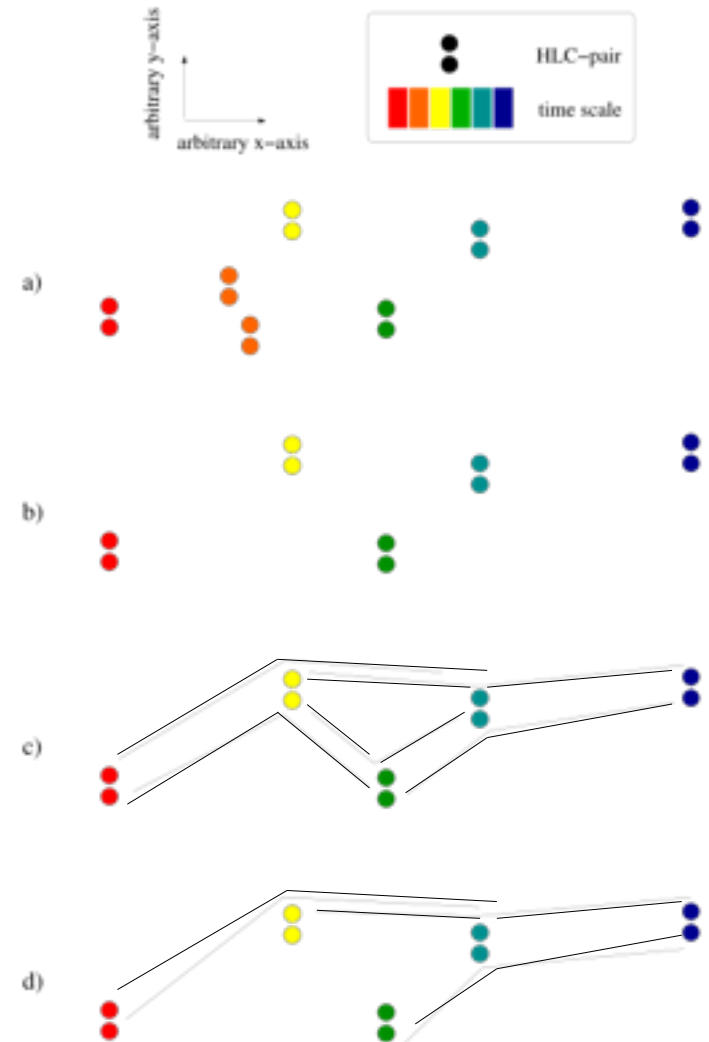
T. Glösenkamp



Signature of some exotic particles (magnetic monopoles, Q-balls, etc.):  
slow ( $v \sim 0.001-0.01c$ ) tracks with intermittent cascades

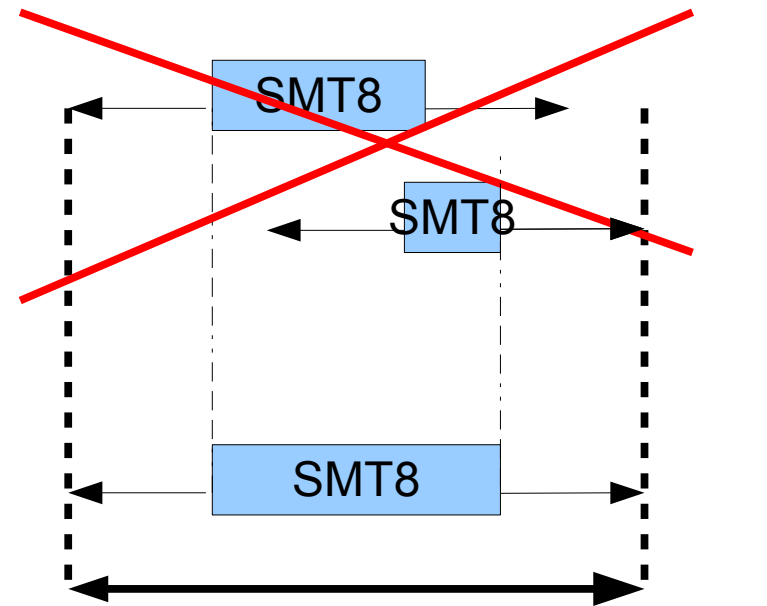
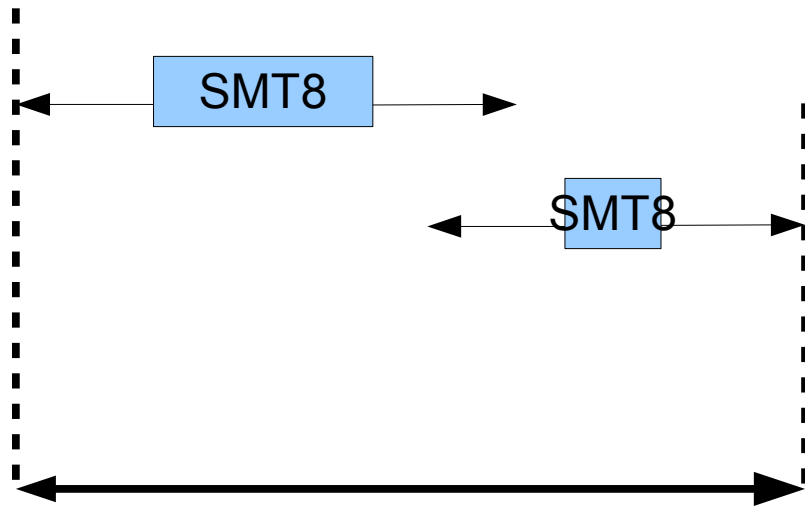
# SLOP Trigger

- Consider pairs of hits with LC condition
- Remove pairs if too close in time ( $T_{\text{prox}}$ )
- Form 3-tuples of pairs within time window ( $T_{\text{min}}, T_{\text{max}}$ )
- Track-like check on 3-tuples:
  - minimum inner angle  $\alpha_{\text{min}}$
  - normalized velocity difference  $v_{\text{rel}}$
- Condition on minimum number of 3-tuples



Trigger	$N_{\text{tuple}}$	$T_{\text{prox}} (\mu\text{s})$	$T_{\text{min}}, T_{\text{max}} (\mu\text{s})$	$\alpha_{\text{min}}$	$v_{\text{rel}}$	Rate (Hz)
SLOP	5	2.5	[ 0, 500 ]	140°	0.5	12

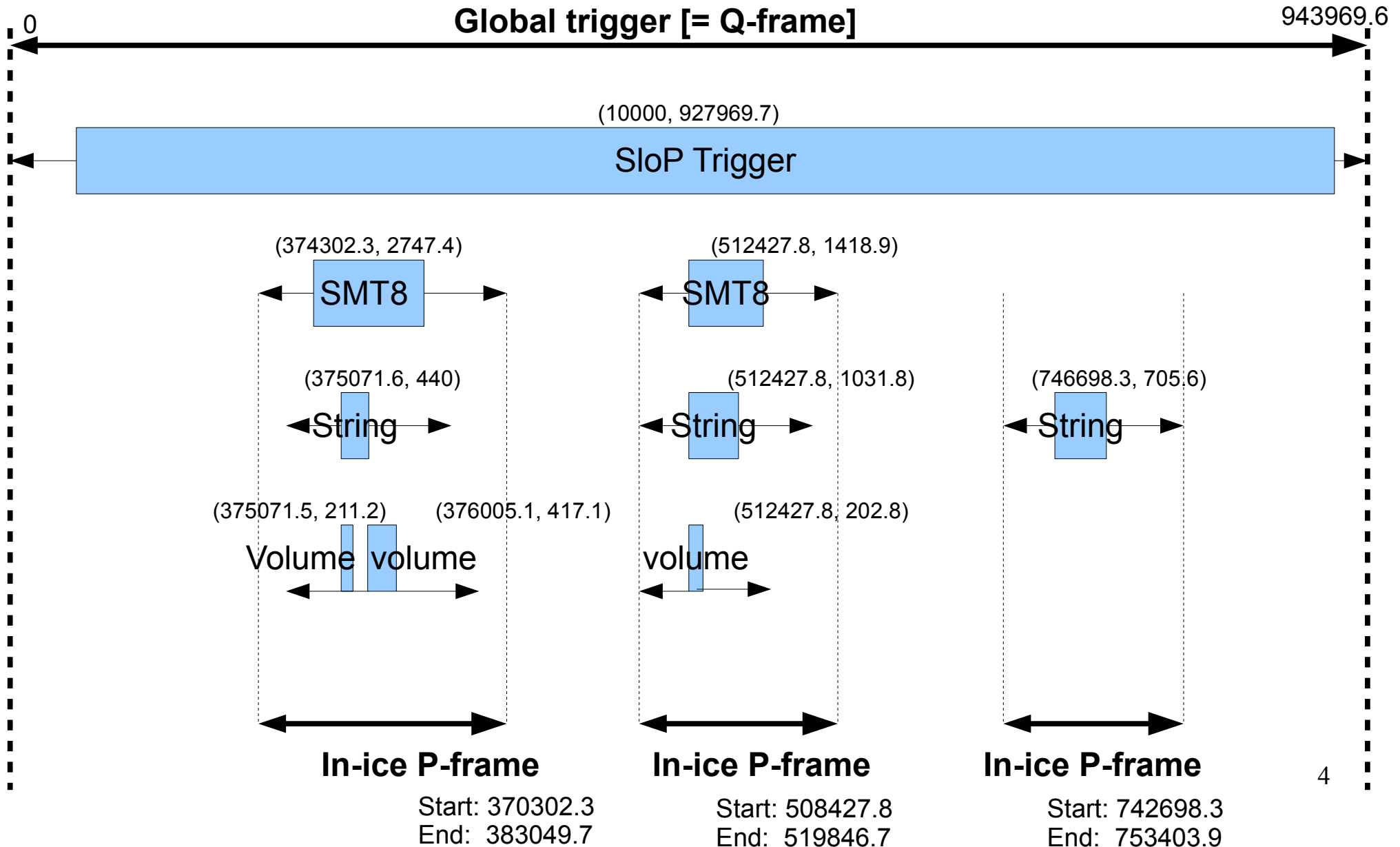
# Trigger Readout



# Example global trigger

Real data from 2011

(trigger time, trigger length) in ns



# Trigger rate example

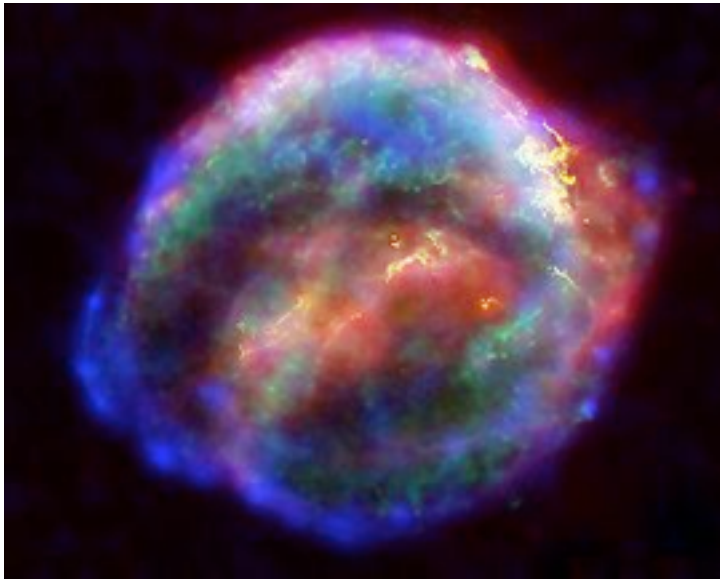
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<b>Trigger</b>	<b>Rate (Hz)</b>
InIce SMT8	2113
DeepCore SMT3	256
SLOP	13.3
FRT	0.0333
String	2240
Volume	3727
MinBias	59.4

**Event** rate from Run 120029: 2742 Hz

# SNDAQ

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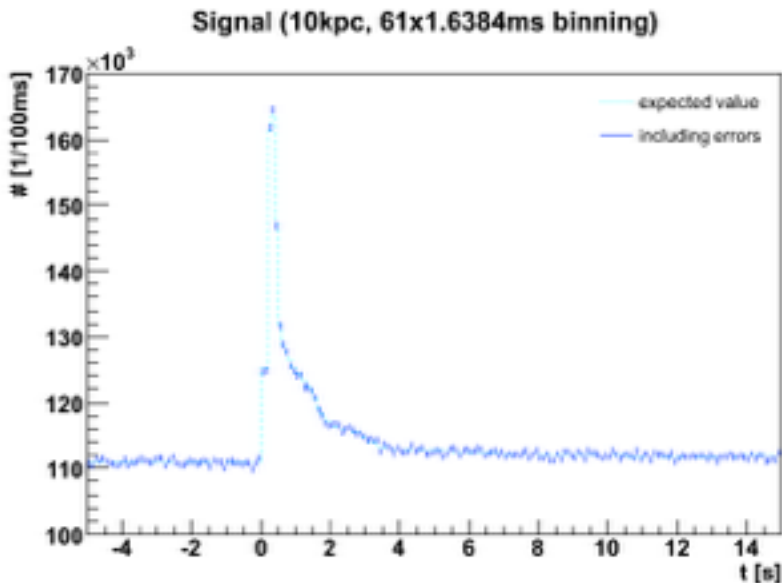


- IceCube can also detect nearby supernovae: detection method very different

- The **Supernova DAQ** runs in parallel to the “normal” DAQ after the StringHubs

- Collects noise rates vs. time for all in-ice DOMs

- looks for global rise in noise rates across detector
- sends alerts over Iridium satellite constellation to SNEWS
- sends SMS alerts and e-mails



# Online Filtering

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- DAQ “raw” output: almost 1 TB/day
  - recall: vast majority of these are cosmic-ray muons
- TDRSS (satellite) bandwidth allocation for IceCube: 105 GB/day
- Options:
  - wait until we can fly the disks out (what if there’s a problem with the data?)
  - run **filtering** online to look for interesting events; send subset of data over satellite
- **Bonus!** Can trigger other experiments for near-real-time followup
  - HESE, EHE, optical / gamma-ray followup alerts

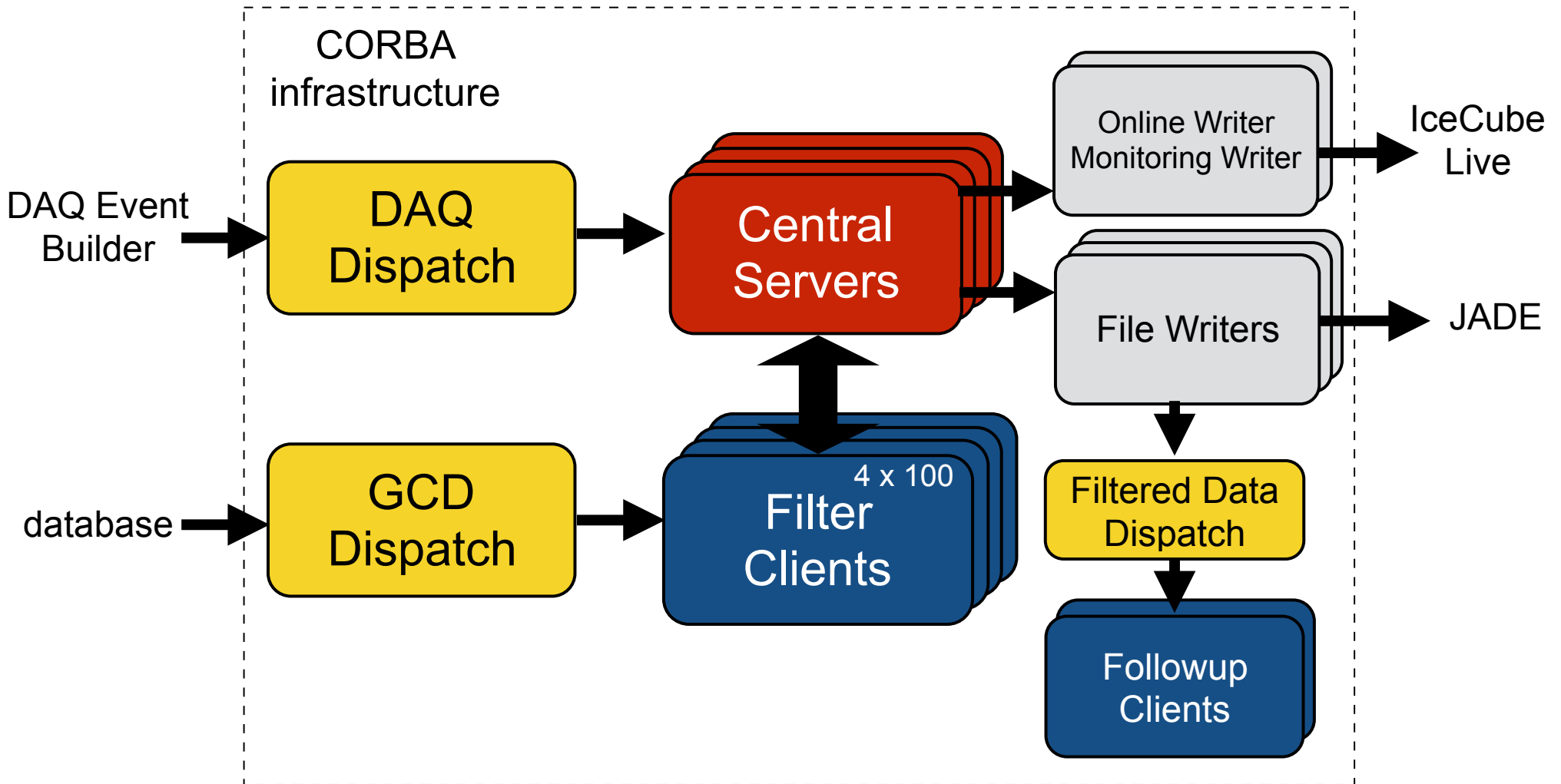
# What is a filter?

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- A **filter** is the first stage of analysis that looks for a type of physics event at SPS, to send over the satellite
- Each working group proposes its own filter(s): muon, cascade, etc.
- The filters are run by **PnF**, which calibrates and cleans the data, looks for events containing triggers that the filters are interested in
  - fast, first-guess algorithms run on most events
  - loose “quality cuts” throw away the junk
- PnF then farms the events out to a computer cluster at pole



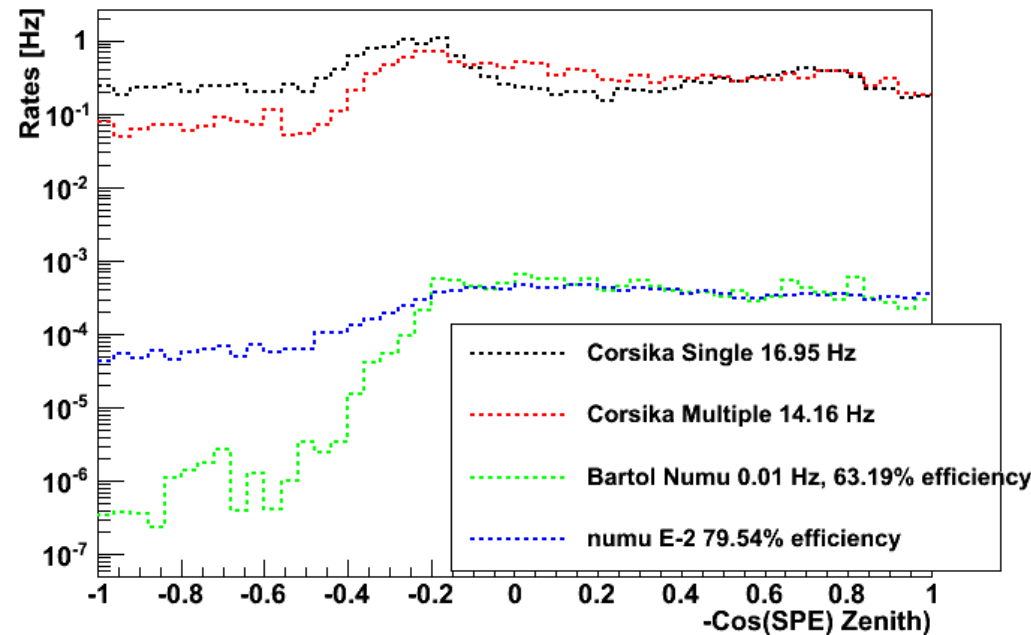
# Processing and Filtering (PnF)



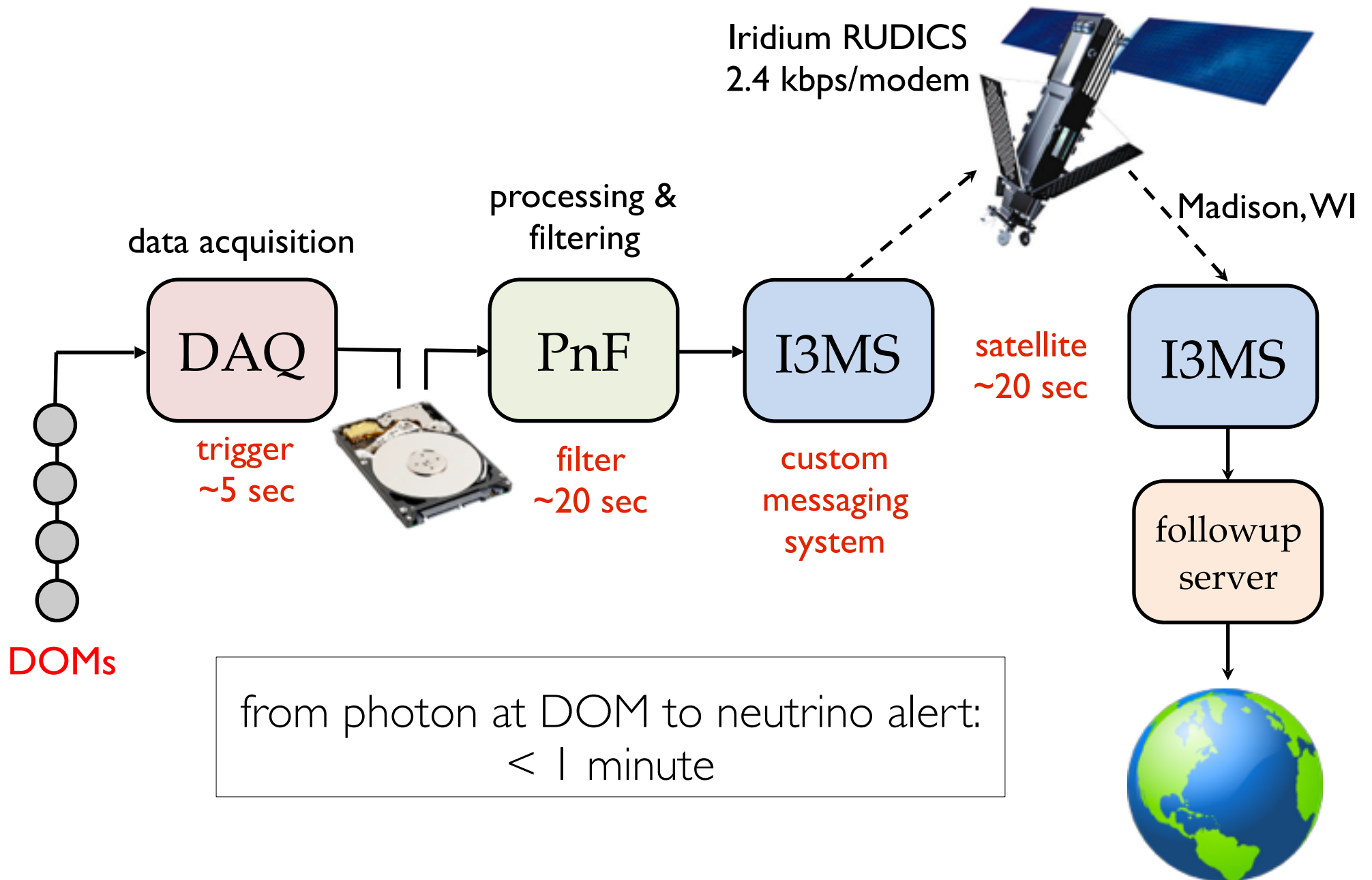
# Filter Examples (not exhaustive!)

- Muon filter
  - hit cleaning -> calibration -> pulse extraction -> fast track reconstruction -> direction-dependent quality cuts
- Cascade filter
  - events that look more blob-like than track-like (tensor of inertia ratio)
- EHE filter
  - high-energy events (total NPE)
- Sun & Moon filter
  - events coming from current Sun and Moon position (WIMPs, moon shadow)
- IceTop filter
  - quality air shower events (also: in-ice coincidences)
- quite a few others for specific analyses

## Muon Filter Passing Rate (simulation)

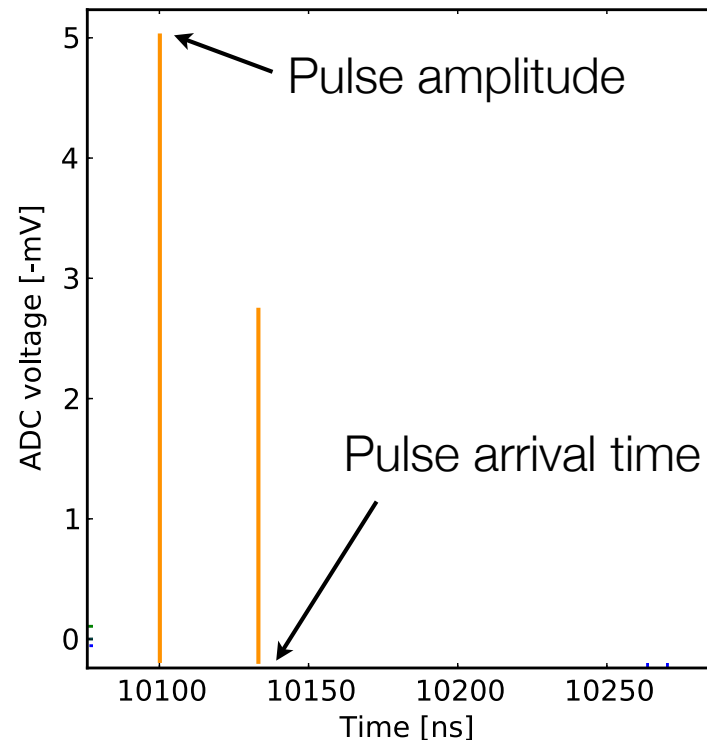
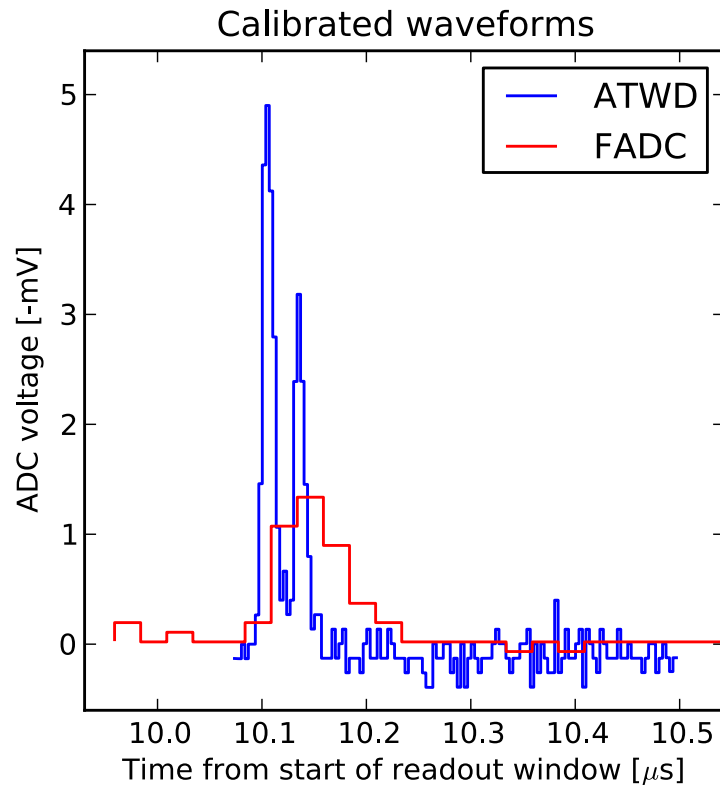


# Real-time Alert System



# SuperDST / WaveDeform

- Basic idea: send highly compressed version of almost every triggered event
  - send reconstructed pulses, not raw waveforms
  - unfold based on template SPE waveforms
- Deployed large-scale in 2012; unfolding is called WaveDeform



all you need for  
many events!

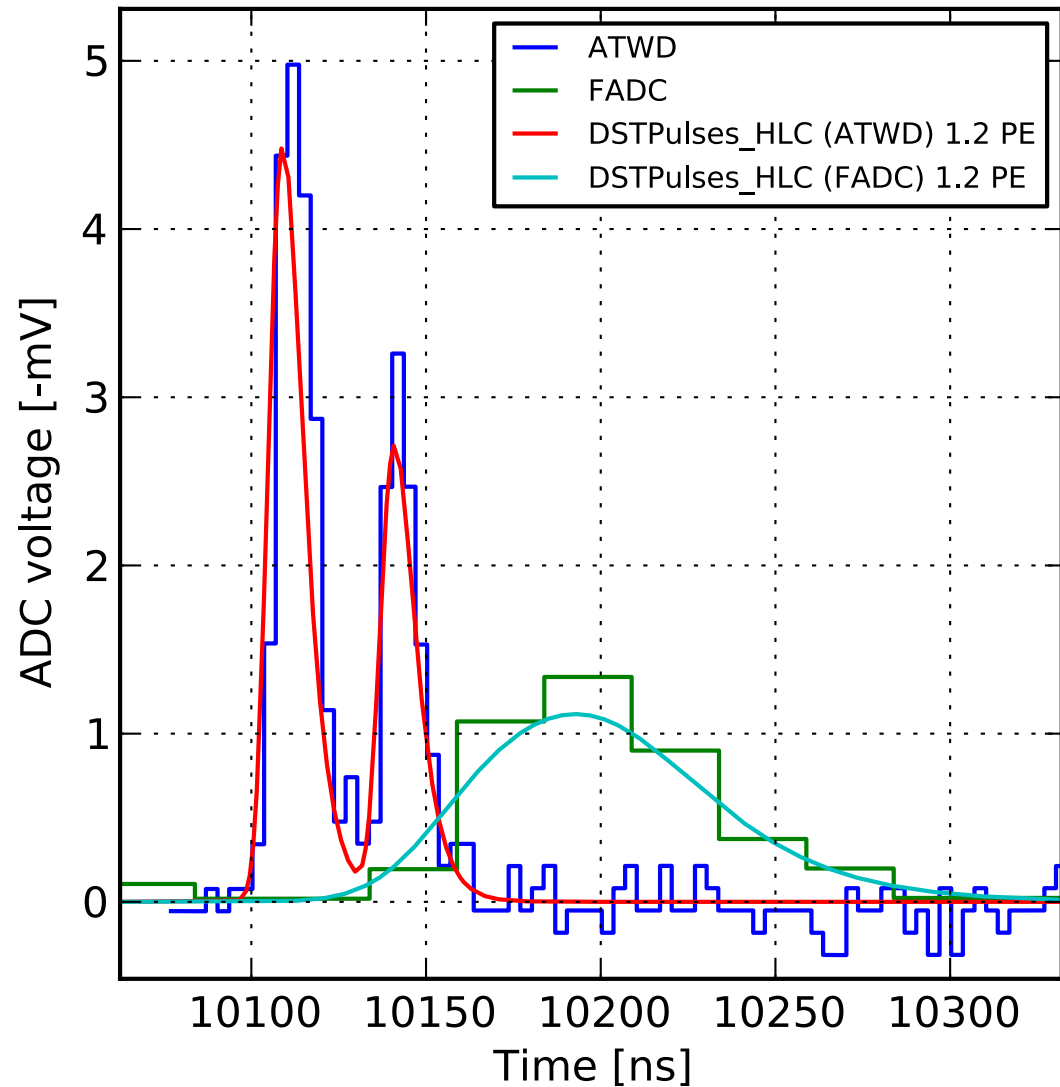
# SuperDST reconstructed waveforms

Raw payload: **4394 bytes**

SuperDST: **414 bytes**

Raw waveforms (“seatbelts”)  
are still sent for

- multichannel hits
- events where the unfolding is bad
- high charge



# Triggering, Filtering, and Transmission Board

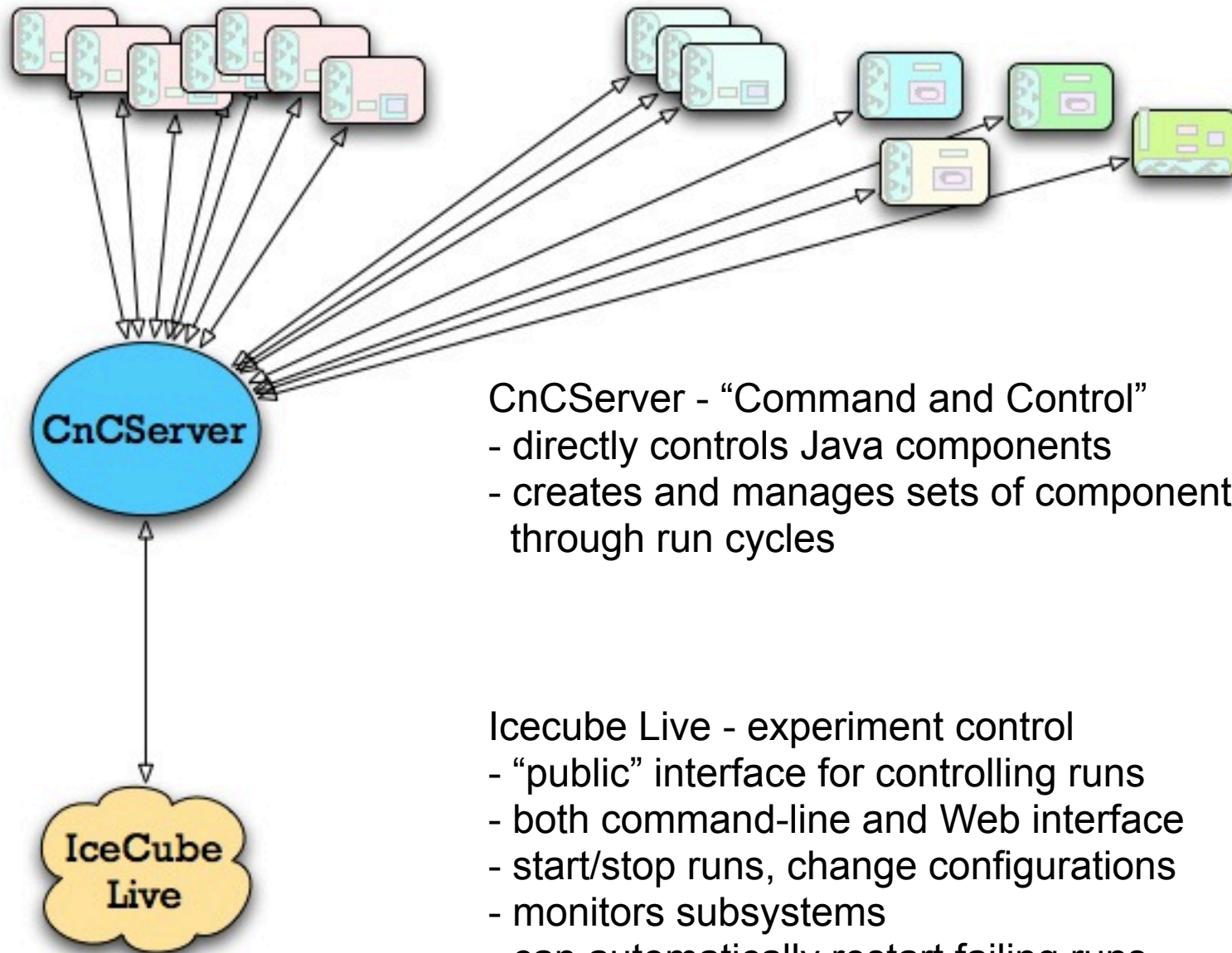
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- How to balance needs of everyone wanting:
  - special DAQ trigger
  - special physics event filter
  - lots of satellite bandwidth
- TFT board reviews proposals once a year
  - changes are made at the “physics run start”, typically in May
- Wiki is a good place to start for trigger / filter descriptions

[http://wiki.icecube.wisc.edu/index.php/Trigger\\_Filter\\_Transmission\\_Board](http://wiki.icecube.wisc.edu/index.php/Trigger_Filter_Transmission_Board)

# Experiment Control and I3Live

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**CnCServer** - “Command and Control”

- directly controls Java components
- creates and manages sets of components through run cycles

**Icecube Live** - experiment control

- “public” interface for controlling runs
- both command-line and Web interface
- start/stop runs, change configurations
- monitors subsystems
- can automatically restart failing runs

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For real-time detector status:

<http://live.icecube.wisc.edu>



# Some sources for more information

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- Previous years' boot camp presentations  
<http://wiki.icecube.wisc.edu/index.php/Bootcamp>
- IceCube PMT Paper  
<https://docushare.icecube.wisc.edu/dsweb/Get/Document-53922/>
- IceCube DOM-DAQ Paper  
“The IceCube Data Acquisition Subsystem: Signal Capture, Digitization, and Time-Stamping”  
Nuclear Instruments and Methods in Physics Research A 601 (2009) 294–316  
<https://docushare.icecube.wisc.edu/dsweb/Get/Document-48249/>
- IceCube Detector Paper  
“The IceCube Neutrino Observatory: instrumentation and online systems”  
Journal of Instrumentation **12** (2017) P03012  
<https://arxiv.org/pdf/1612.05093.pdf>
- Wiki page for LED flashers  
<http://wiki.icecube.wisc.edu/index.php/Flashers>
- Docushare areas and personal websites  
Docushare: <https://docushare.icecube.wisc.edu/dsweb/View/Collection-410>  
Jerry Przybylski: [http://icecube.lbl.gov/~gtp/site\\_map.html#ForIceCube](http://icecube.lbl.gov/~gtp/site_map.html#ForIceCube)  
Thorsten Stezelberger: <http://glacier.lbl.gov/~thorsten/ATWD/>  
Nobuyoshi Kitamura: <http://icecube.wisc.edu/~kitamura/>
- N.B. many more details being taken care of like “toroid droop”, baseline offsets, channel non-matching, PMT saturation, afterpulses, more precise optical sensitivity measurement, ...

# Some sources for more information

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- I3Live documentation:

<https://live.icecube.wisc.edu/doc/main/>

- TFT proposals:

[http://wiki.icecube.wisc.edu/index.php/Trigger\\_Filter\\_Transmission\\_Board](http://wiki.icecube.wisc.edu/index.php/Trigger_Filter_Transmission_Board)

- SuperDST:

<http://software.icecube.wisc.edu/documentation/projects/dataclasses/superdst.html>

<http://wiki.icecube.wisc.edu/index.php/SuperDST>

<https://events.icecube.wisc.edu/indico/contributionDisplay.py?contribId=140&sessionId=4&confId=33>

- Supernova DAQ:

<http://wiki.icecube.wisc.edu/index.php/Supernova>

- Monitoring:

<http://wiki.icecube.wisc.edu/index.php/Monitoring>

- Problem DOMs:

[https://live.icecube.wisc.edu/dom\\_problems/](https://live.icecube.wisc.edu/dom_problems/)

[http://wiki.icecube.wisc.edu/index.php/Problem\\_DOMs](http://wiki.icecube.wisc.edu/index.php/Problem_DOMs) (historical)