DOMs and the DAQ Demystified
Part II: DAQ, Triggers, Filters, and more

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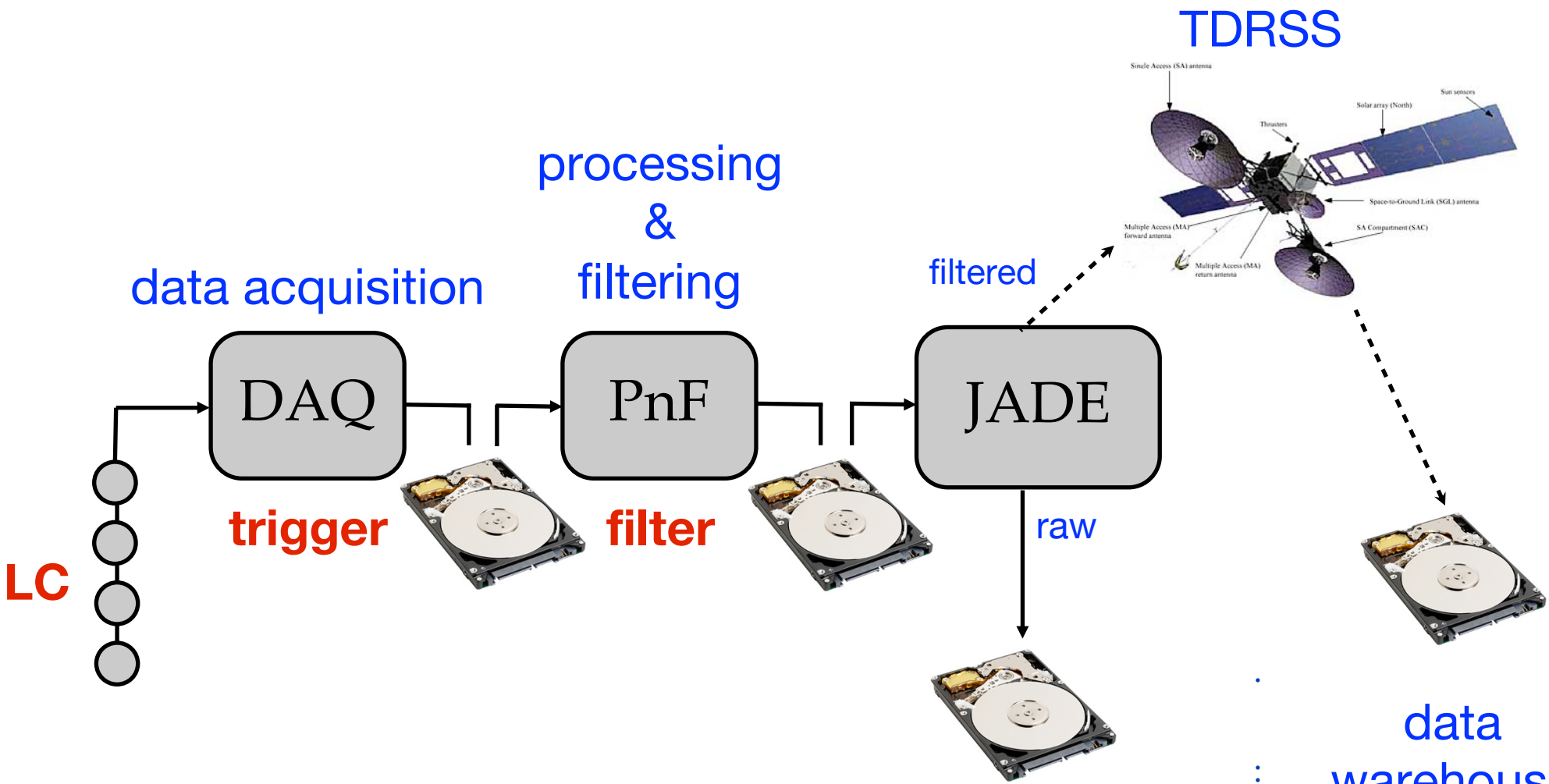
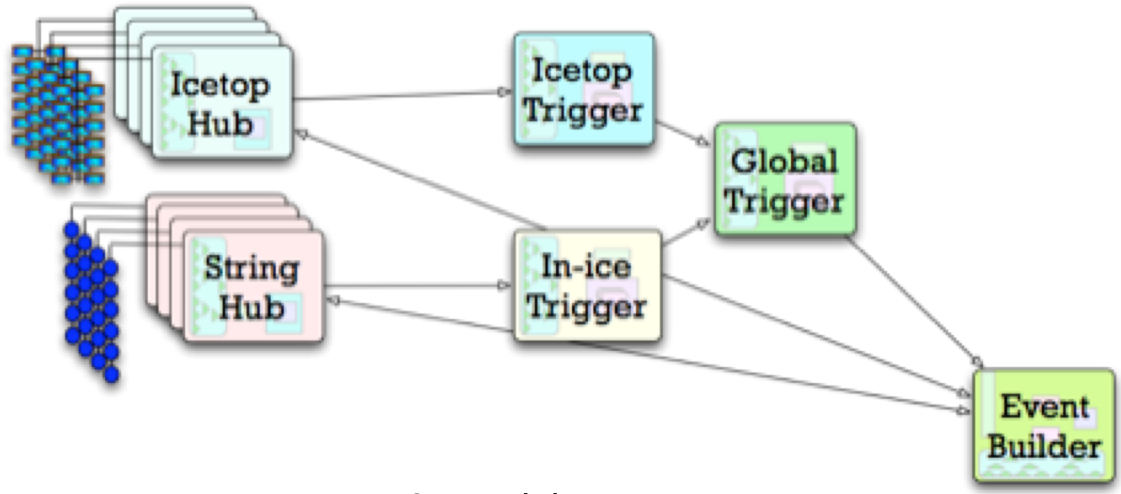
with thanks to Dave Glowacki, Naoko K. Neilson, Erik Blaufuss

Data flow and reduction



DAQ (Data Acquisition System)



- 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

- **S**imple **M**ultiplicity **T**rigger (SMT)
  - *N* HLC hits or more in a time window
  - Example: InIce SMT8 with N_hits ≥ 8 in 5 μs
  - readout window around this captures early and late hits (-4 μs, +6 μs)

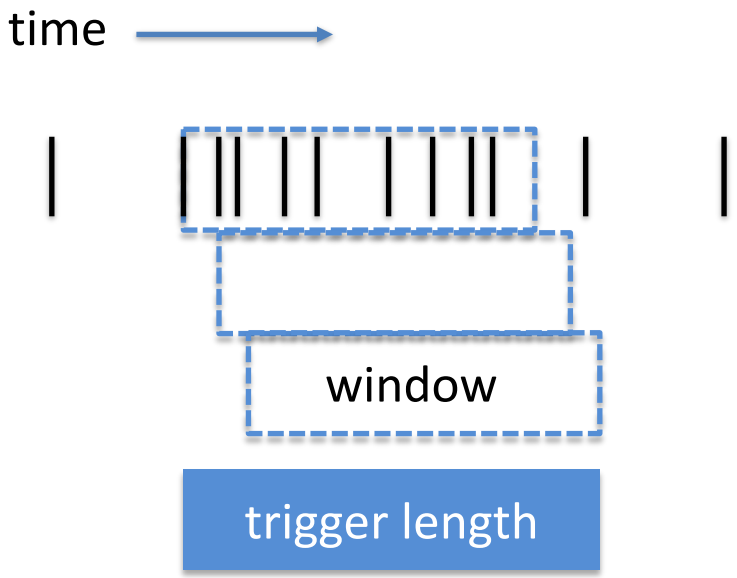
- **String** trigger (a.k.a. Cluster trigger in DAQ-land)
  - *N* HLC hits out of *M* DOMs on a string in a time window
  - Example: 5 hits from a run of 7 adjacent DOMs in a time window of 1500 ns

- **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).

- **Slo**w **P**article trigger (SLOP)
  - slow-moving hits along a track
  - lengths of the order of 500μs and extending up to milliseconds

- **F**ixed **R**ate **t**rigger, **Min**imum **Bias** trigger, **Calibration** trigger

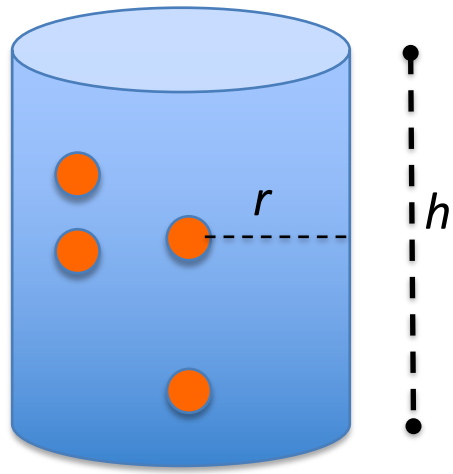
Simple Multiplicity Trigger



- 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 (μs)	Rate (Hz)
In-ice	8	5	2100
DeepCore	3	2.5	250
IceTop	6	5	25

Topological Triggers



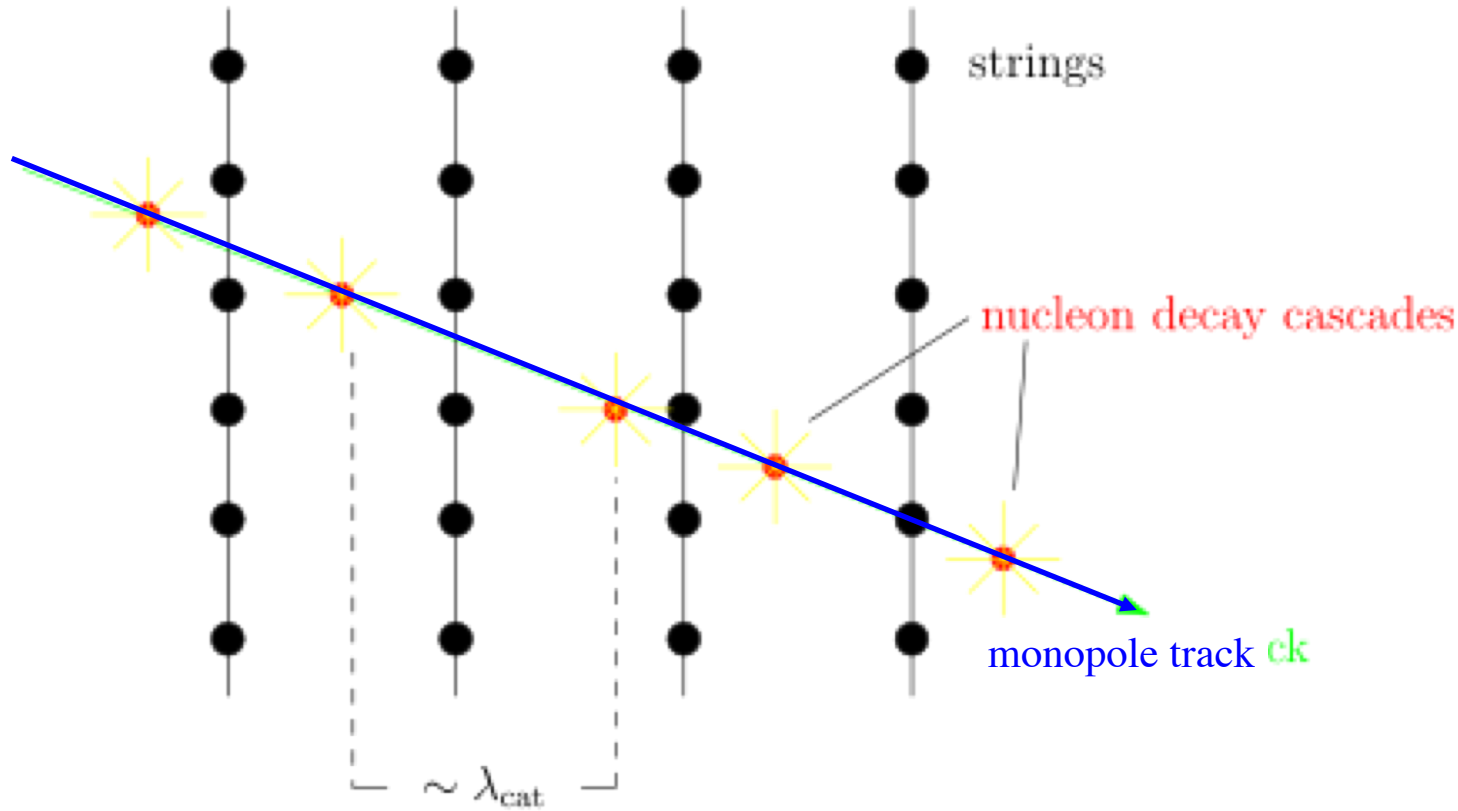
Volume trigger: *N* hits within a cylindrical volume around DOM in a time window

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

Trigger	HLC hits	Topology	Window (µs)	Rate (Hz)
Volume	4	cylinder r=175m, h=75m	1	3700
String	5	of 7 DOMs on string	1.5	2200

Specialized trigger: monopoles

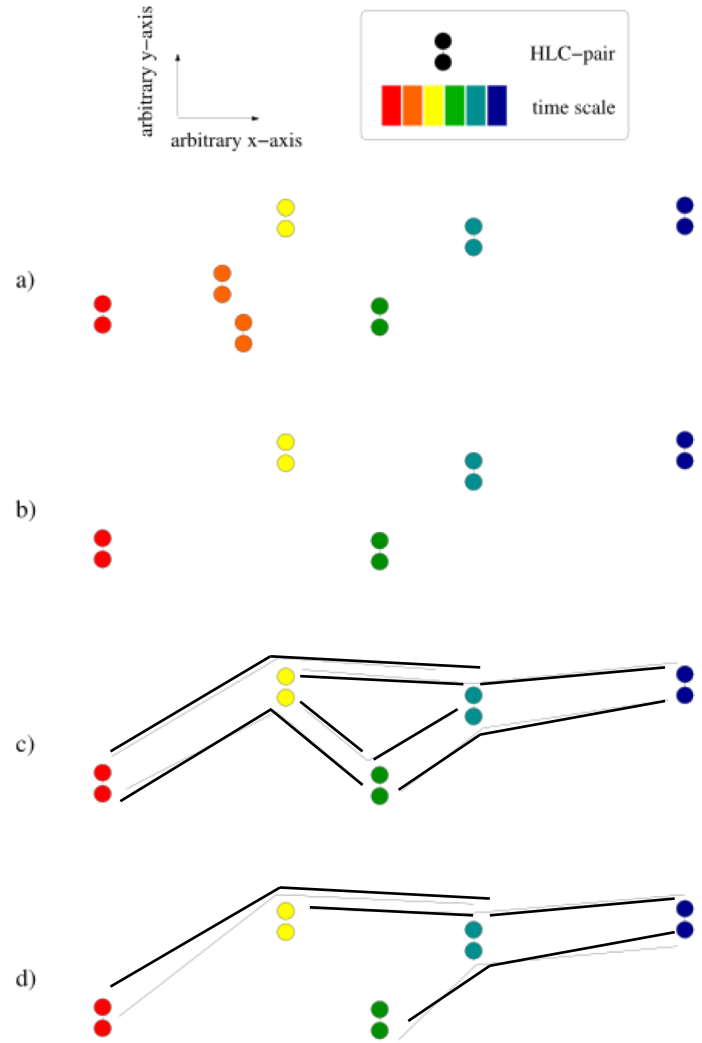
T. Glüsenkamp



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

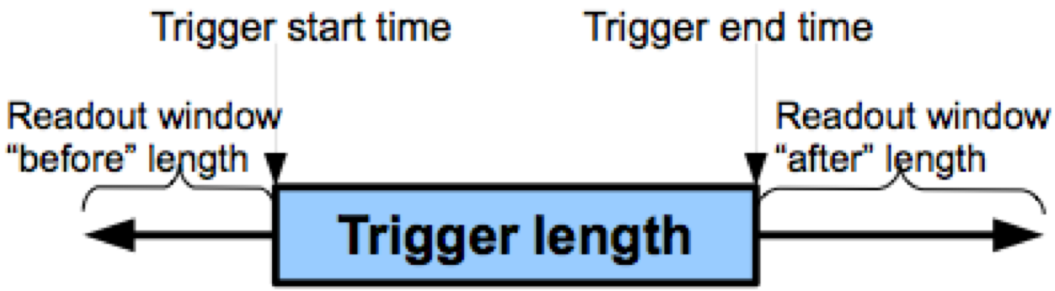
SLOP Trigger

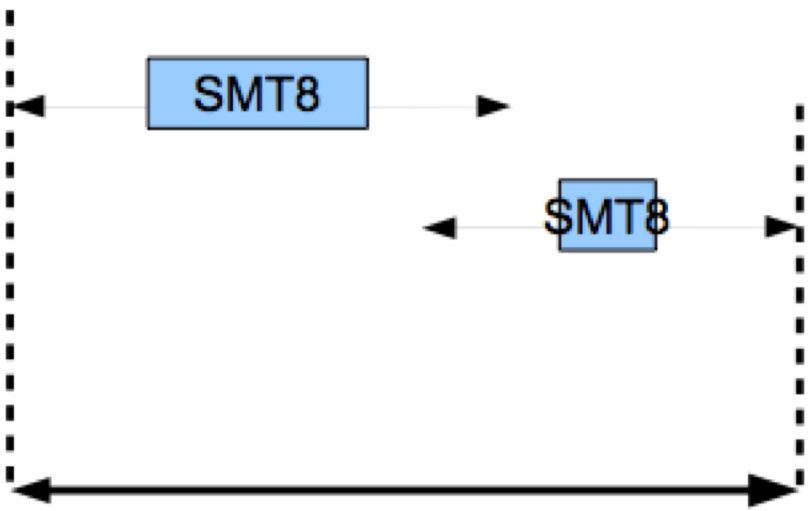
- Consider pairs of hits with LC condition
- Remove pairs if too close in time (T_{prox})
- Form 3-tuples of pairs within time window (T_{min}, T_{max})
- Track-like check on 3-tuples:
  - minimum inner angle α_{min}
  - normalized velocity difference v_{rel}
- Condition on minimum number of 3-tuples



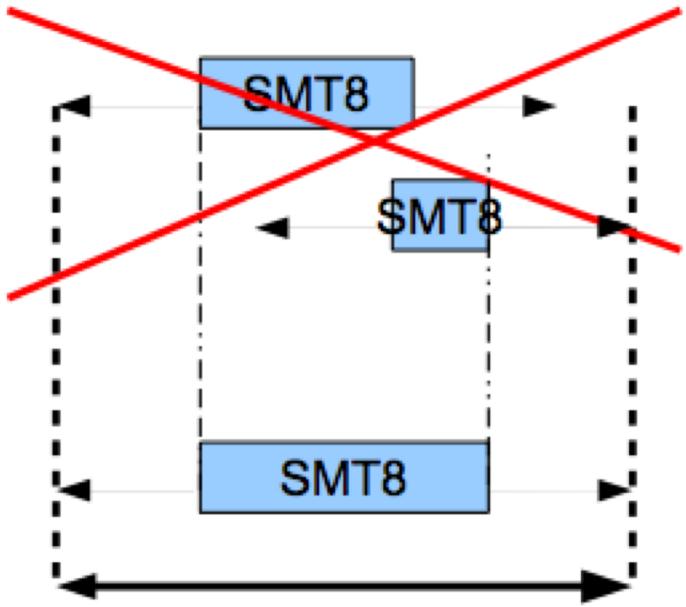
Trigger	N_{tuple}	T_{prox} (µs)	T_{min}, T_{max} (µs)	α_{min}	v_{rel}	Rate (Hz)
SLOP	5	2.5	[0, 500]	140°	0.5	12

Trigger Readout



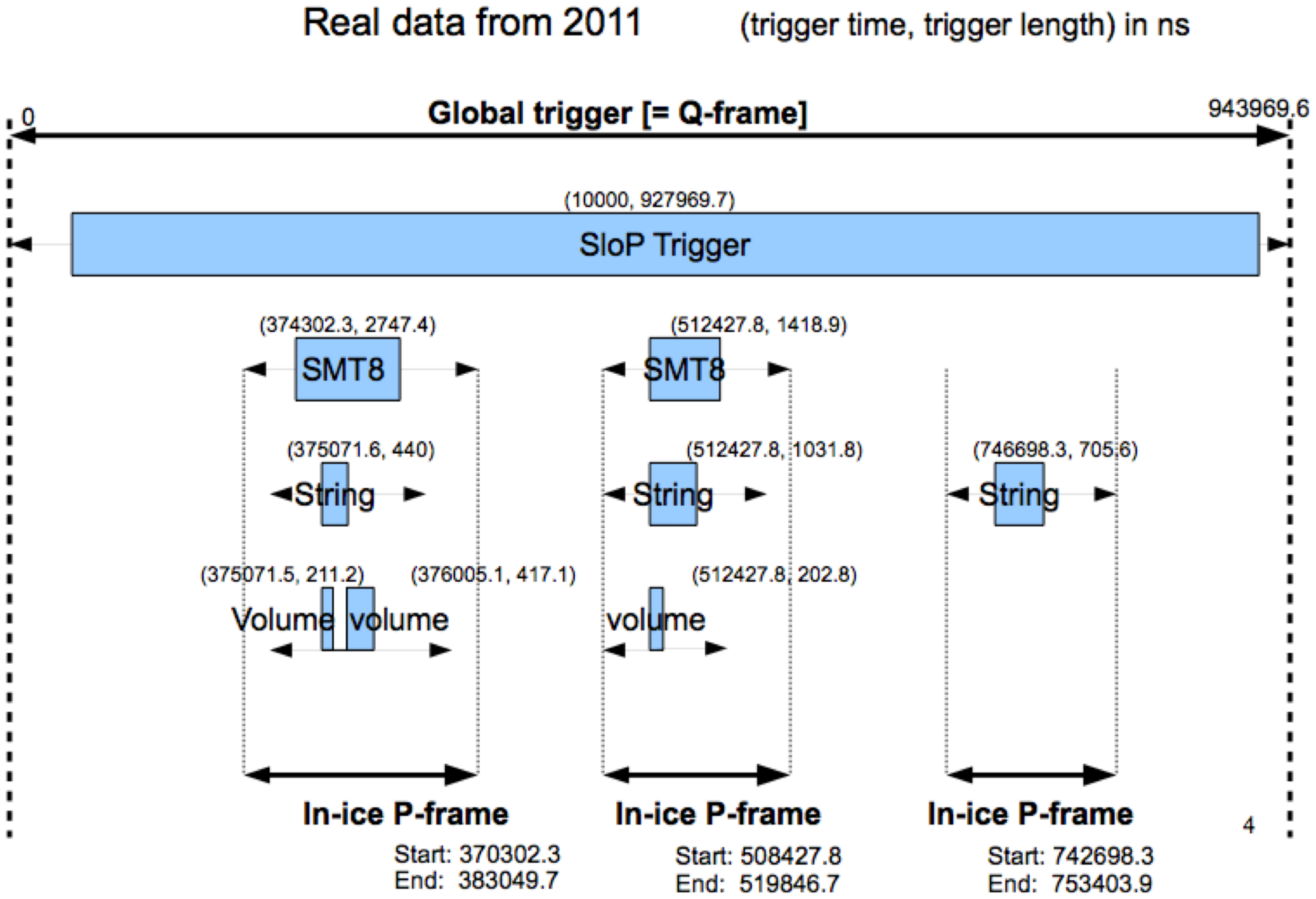


Global Trigger Readout = one Frame



Global Trigger Readout = one Frame

Example global trigger

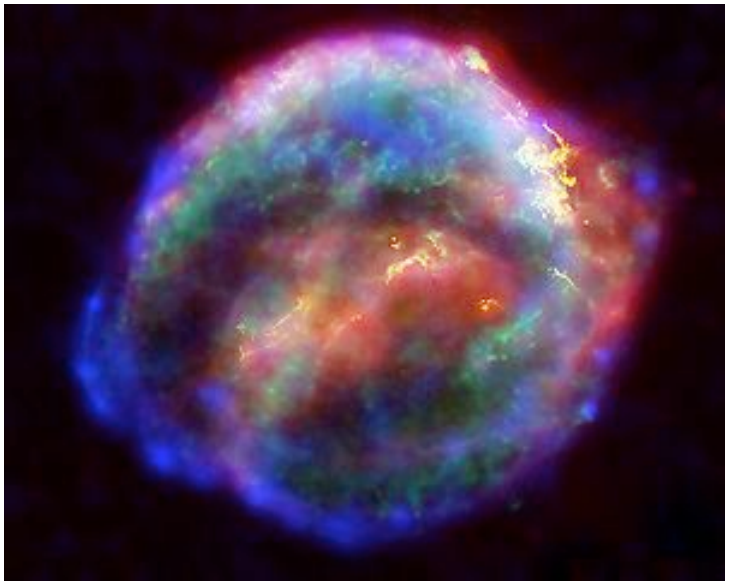


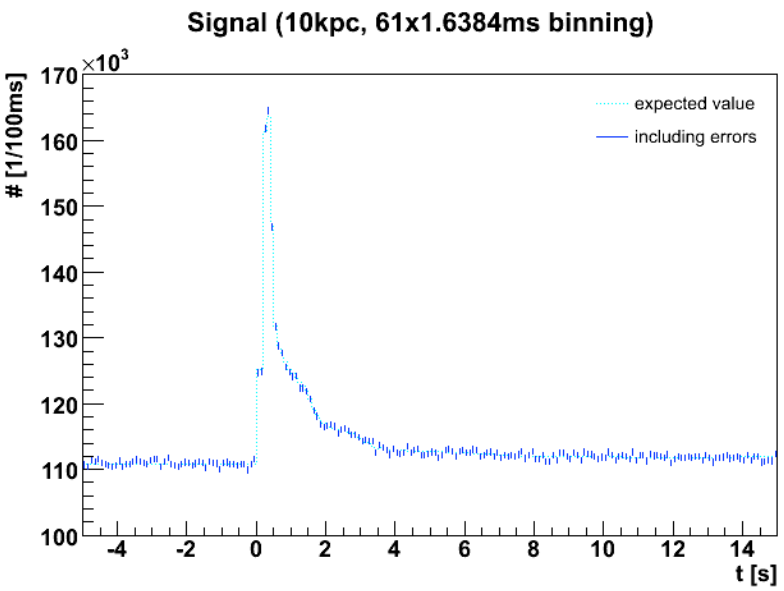
Trigger rate example

Trigger	Rate (Hz)
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





- IceCube can also detect nearby supernovae: detection method very different
- The **S**uper**n**ova **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

- 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?

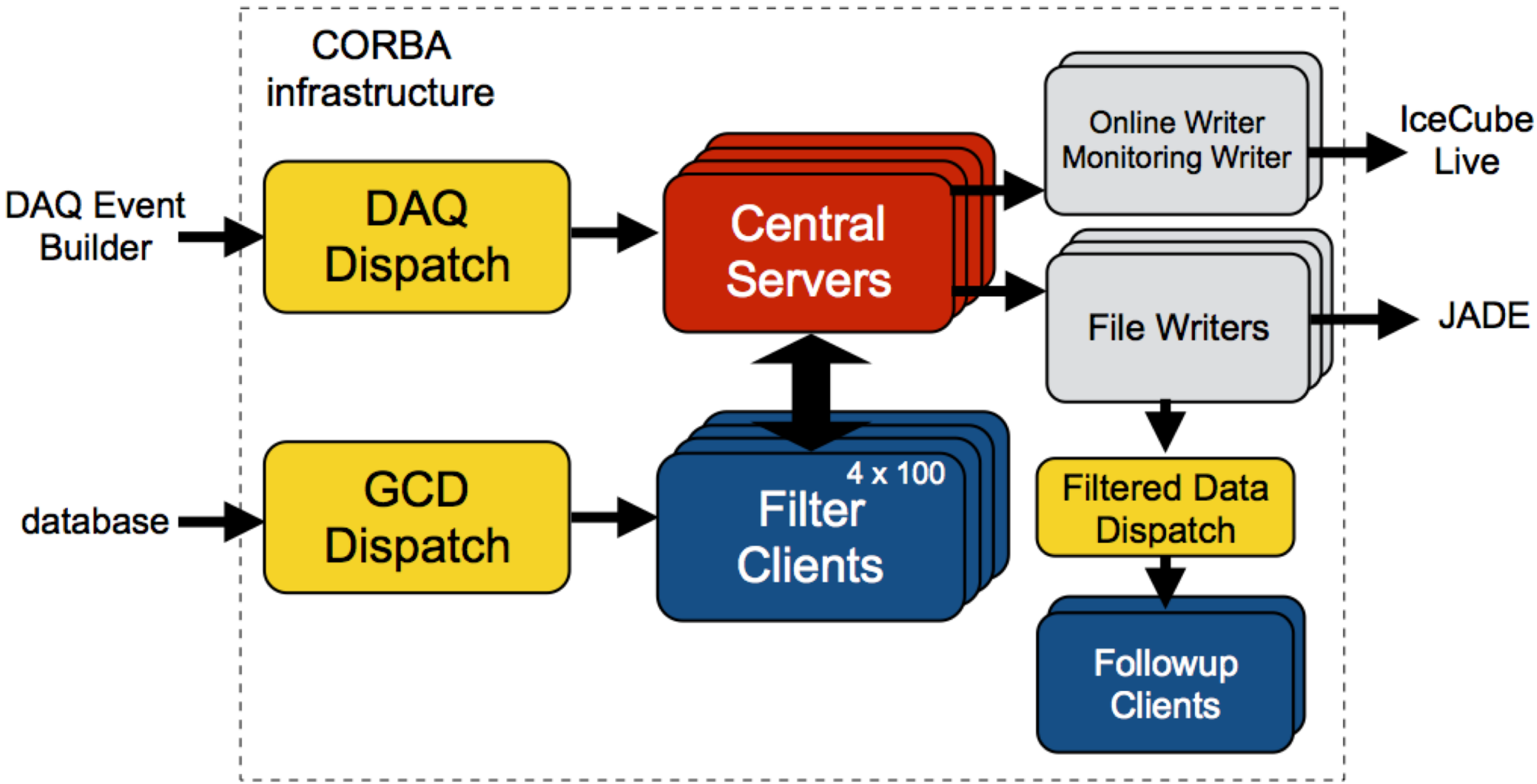
- A **filter** is the first stage of analysis that looks for a type of physics event at SPS, to send over the satellite

- 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

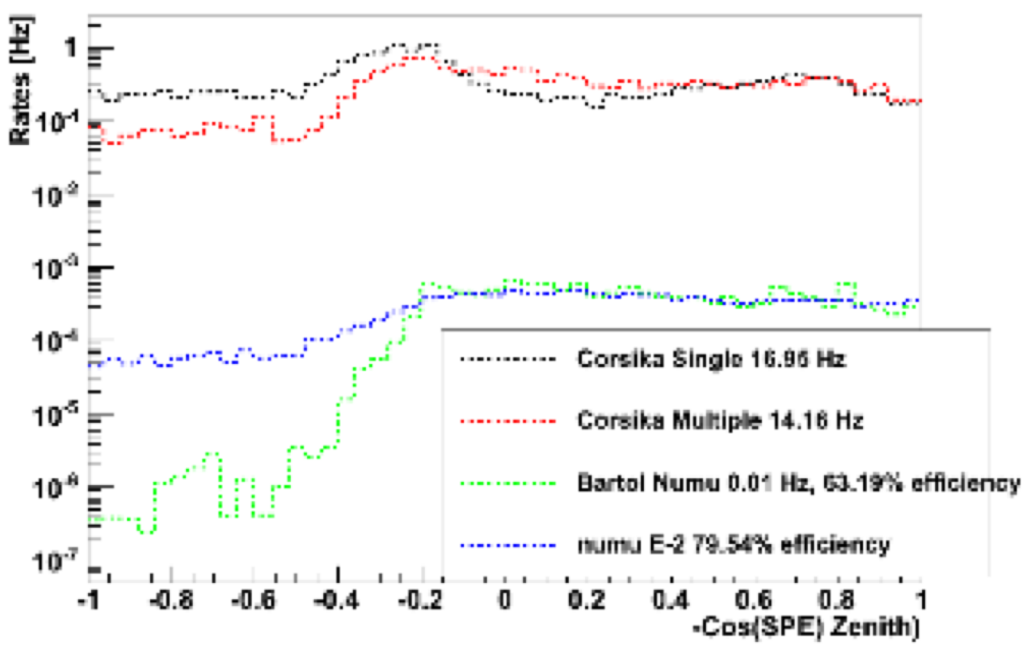
Processing and Filtering (PnF)



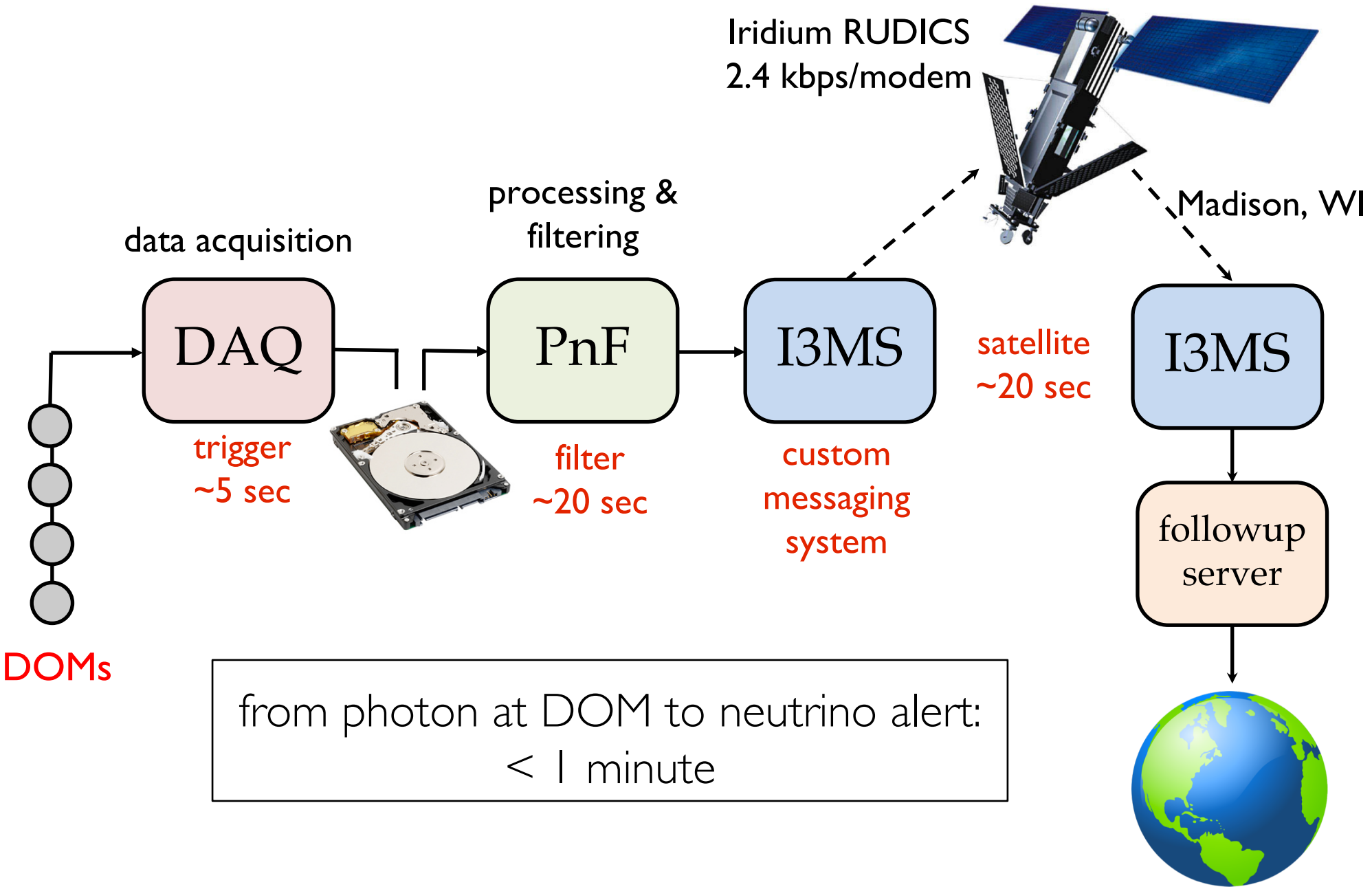
Filter Examples (not exhaustive!)

- 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

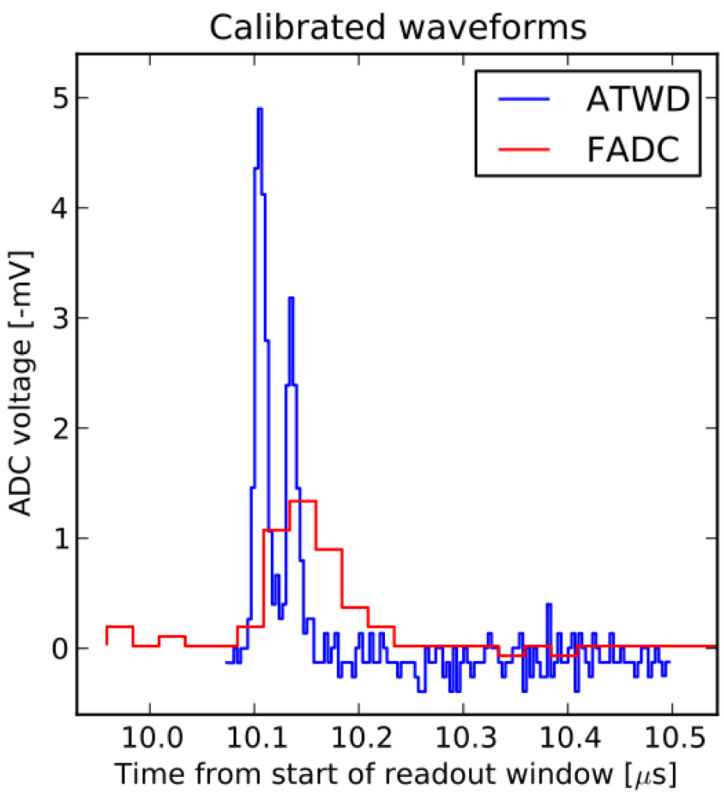


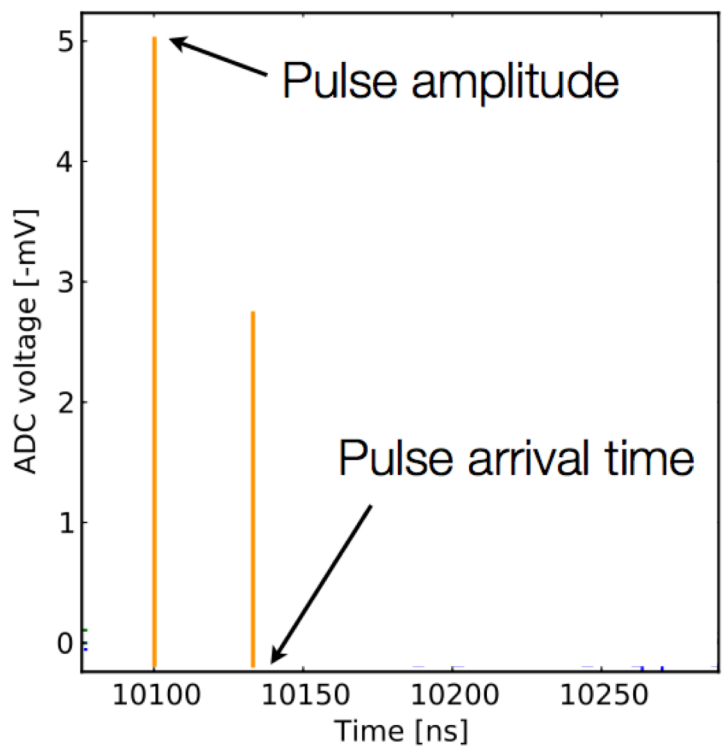
from photon at DOM to neutrino alert:
< 1 minute

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!

J. van Santen

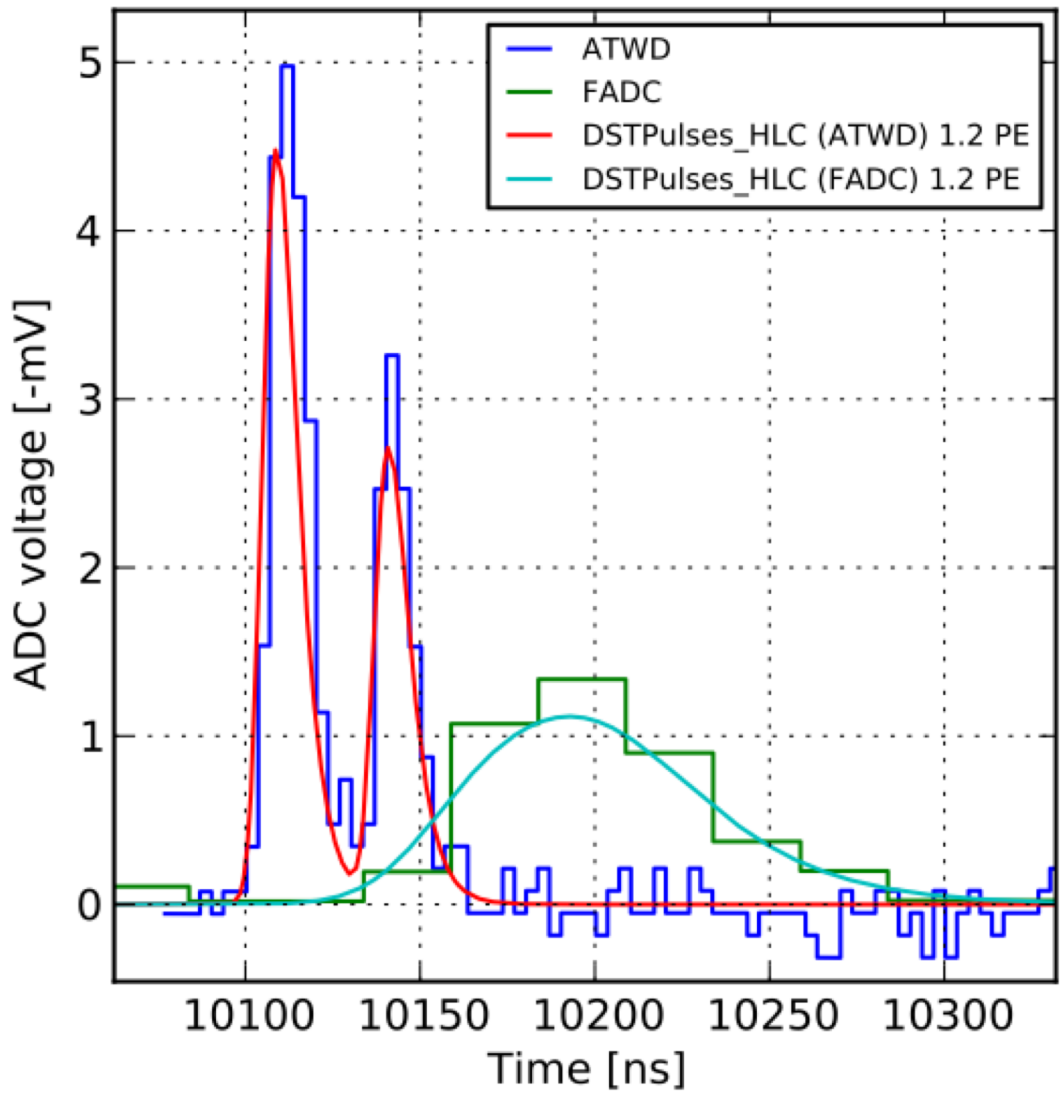
SuperDST reconstructed waveforms

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, **F**iltering, and **T**ransmission Board

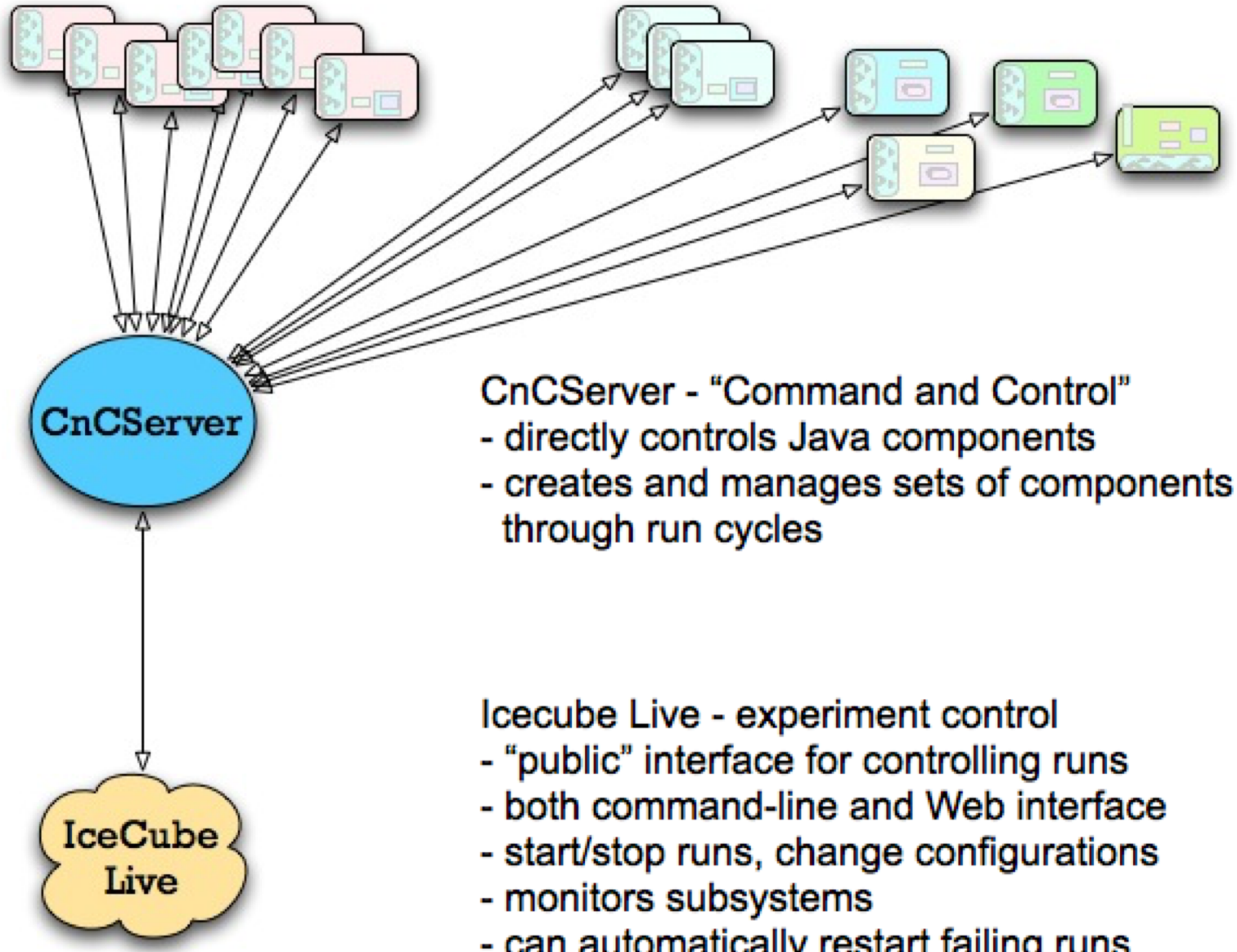
- How to balance needs of everyone wanting:
  - special DAQ trigger
  - special physics event filter
  - lots of satellite bandwidth

- 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

Experiment Control and I3Live



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

For real-time detector status:

http://live.icecube.wisc.edu

Some sources for more information

- 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
  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

- I3Live documentation:
  https://live.icecube.wisc.edu/doc/main/

- TFT proposals:
  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/
  http://wiki.icecube.wisc.edu/index.php/Problem_DOMs (historical)