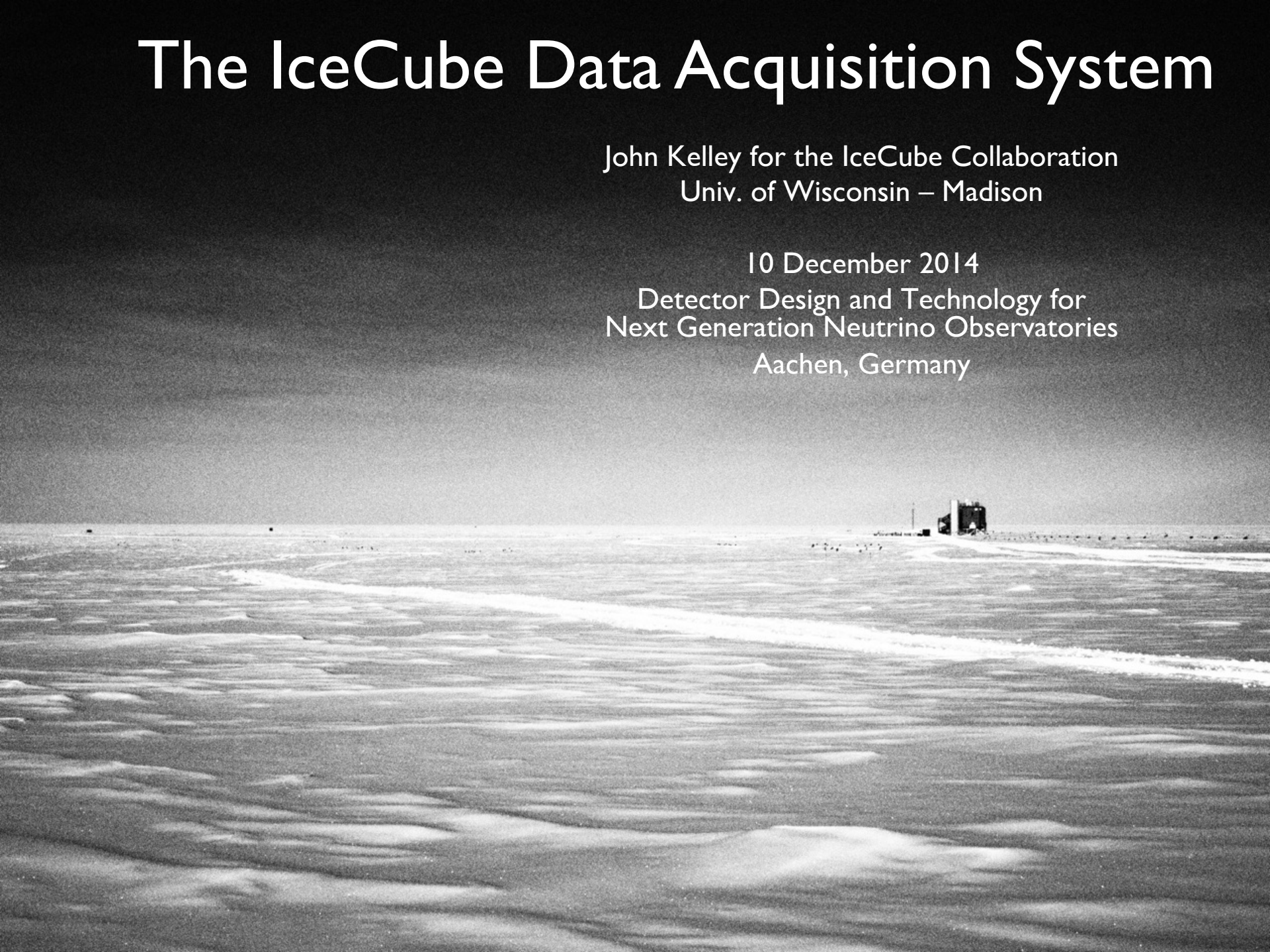
The IceCube Data Acquisition System

John Kelley for the IceCube Collaboration
Univ. of Wisconsin – Madison

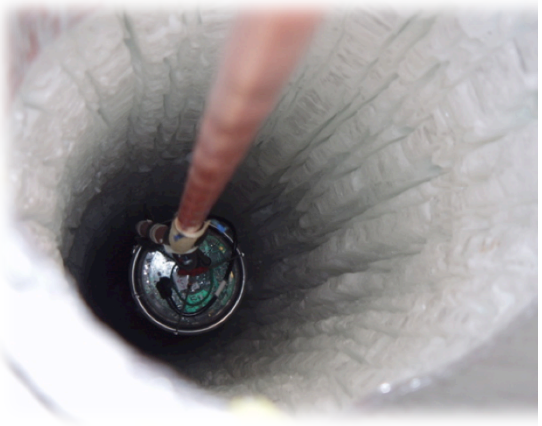
10 December 2014
Detector Design and Technology for
Next Generation Neutrino Observatories
Aachen, Germany

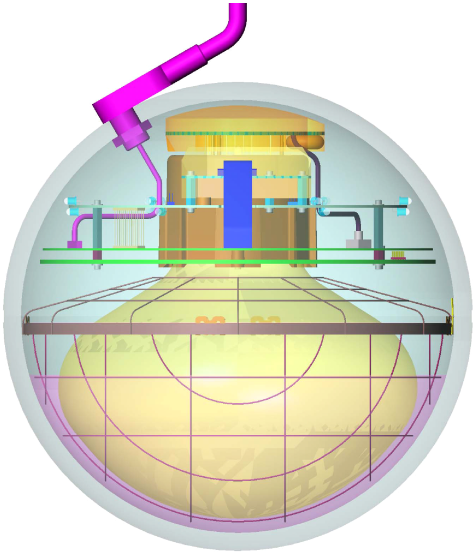


Overview

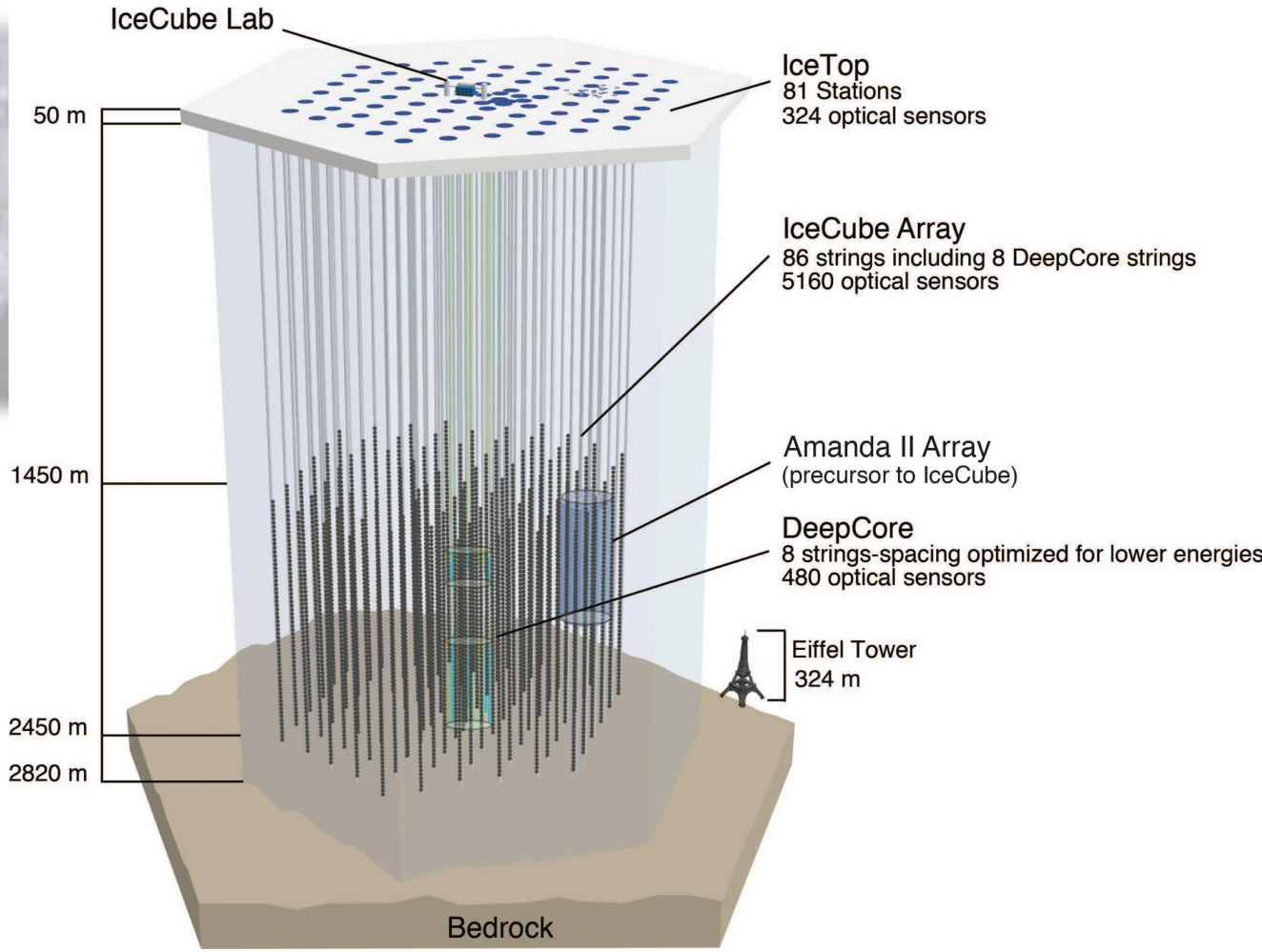
- The IceCube detector
- High-level data flow
- Software DAQ highlights
  - time calibration
  - triggering
  - supernova system
- Recent improvements
  - untriggered data
  - SNDAQ muon subtraction
- Adaptations for next generation

The IceCube Detector

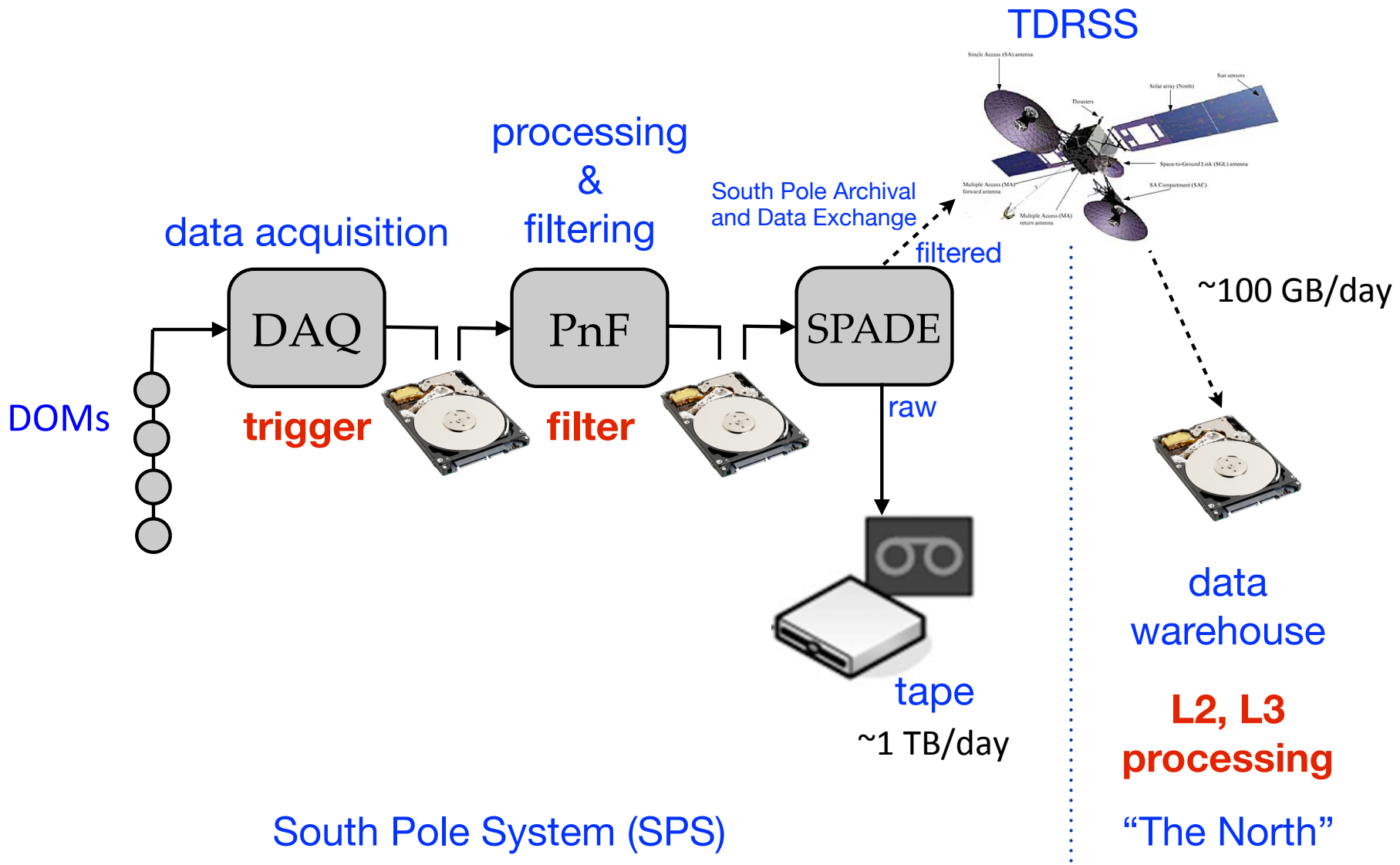




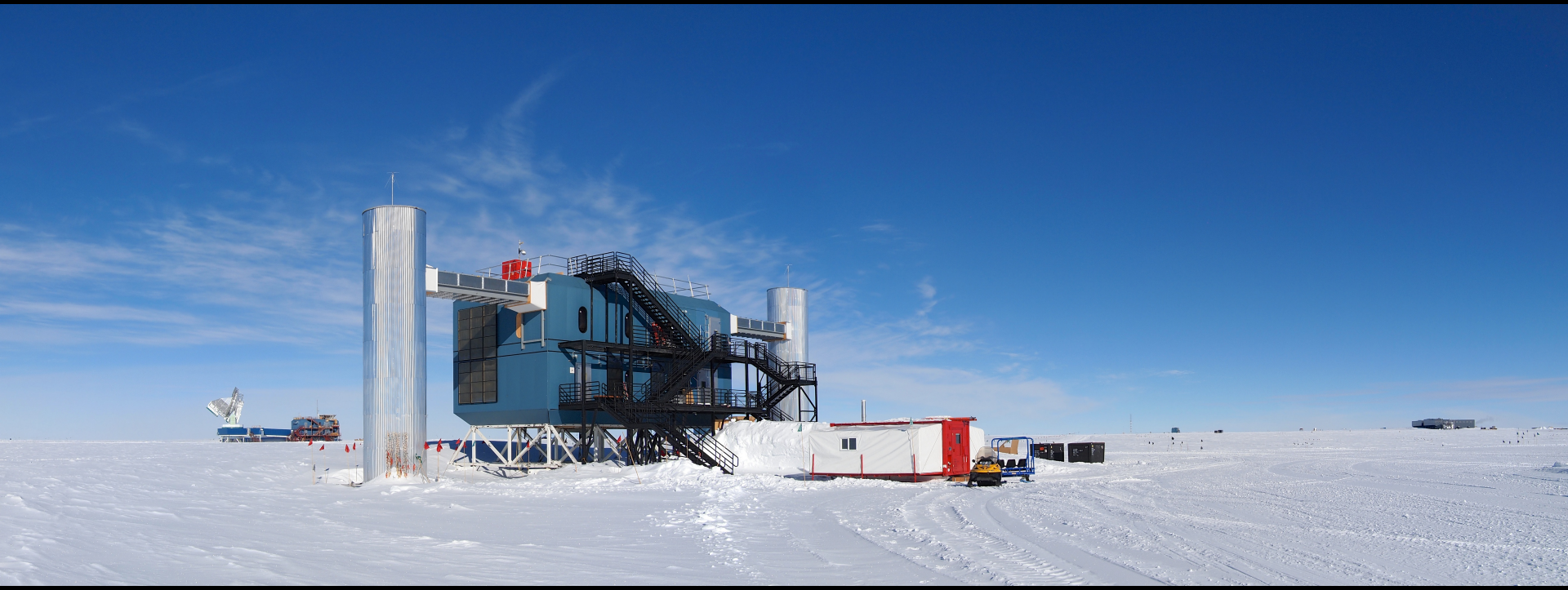
digital optical module (DOM)



IceCube Data Flow



IceCube Lab (ICL)

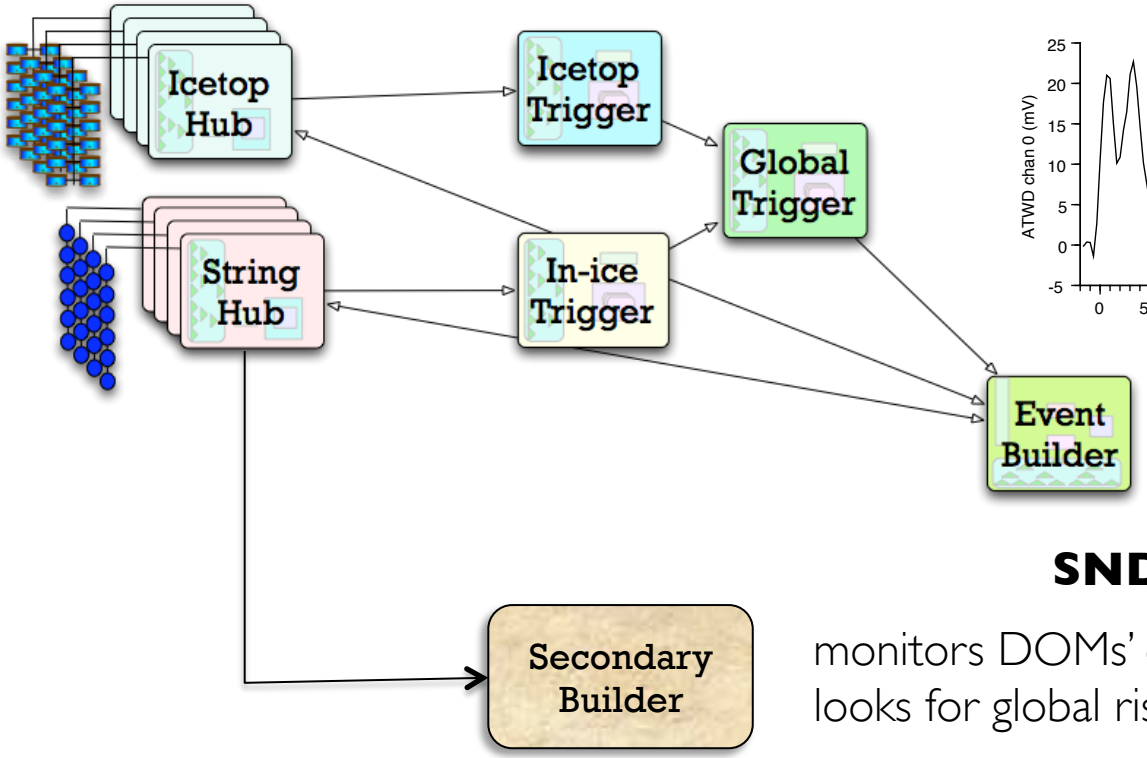


Computing in the IceCube Lab (ICL)

- 18 racks
- 97 DOMHubs
  - Atom D525 SBCs
  - custom PCI readout cards
  - GPS clock fanout
  - in-ice: 1 hub/string
- ~45 Dell PowerEdge R720 servers
  - 4 DAQ
  - 23 filtering
  - 6 monitoring & verification
  - 7 networking, backup, kickstart, NTP, NFS, etc.
  - DB, spares
- GPS receivers + fanouts, switches, UPS, special devices

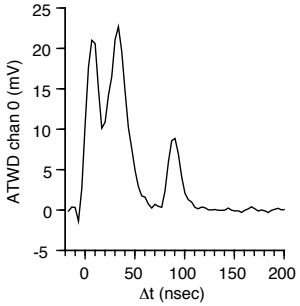
IceCube DAQ

DOMs
n=5404



pDAQ

forms triggers (e.g. 8-fold multiplicity)
stores DOM waveforms + hit times

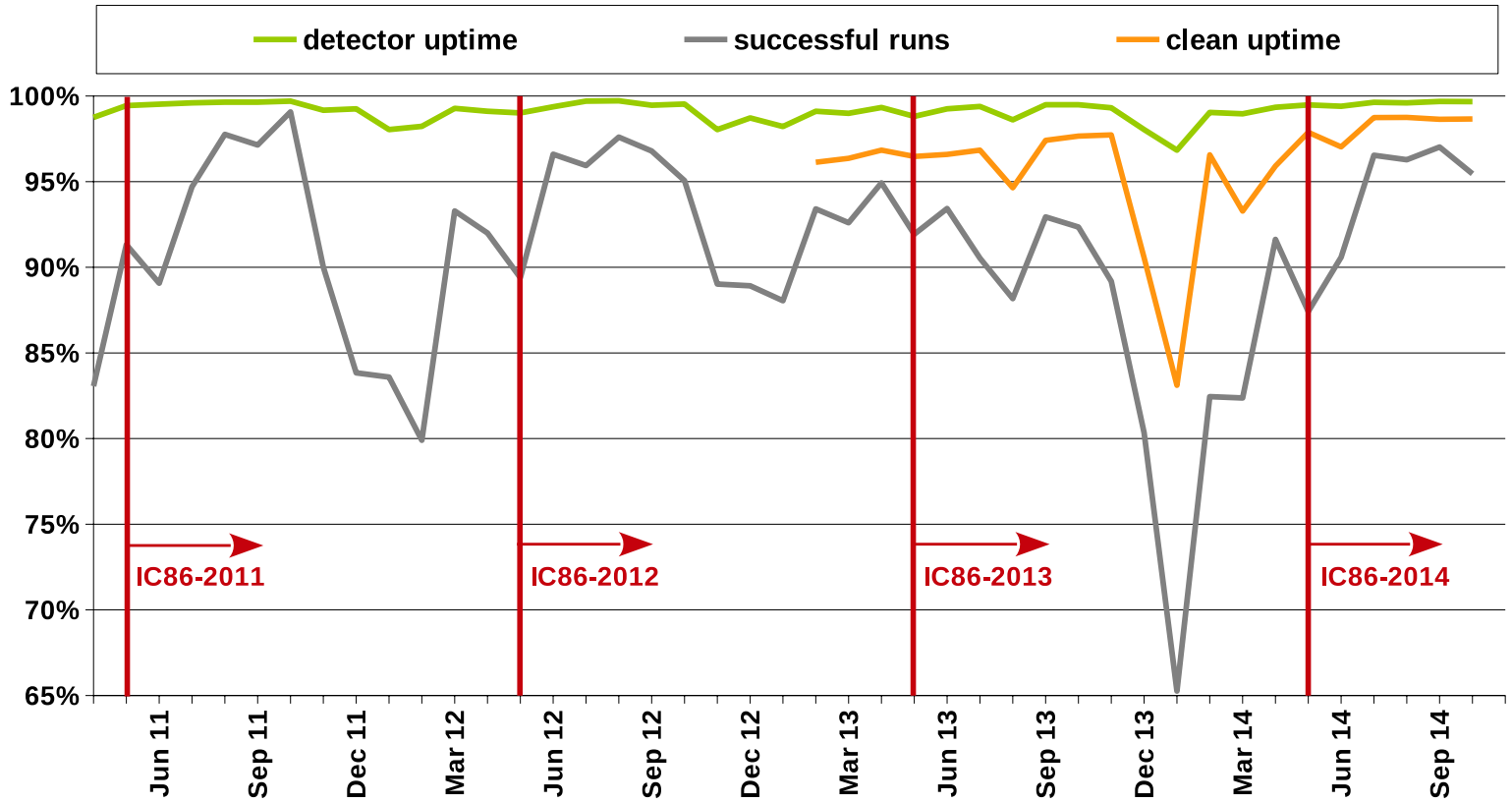


SNDAQ

monitors DOMs' dark noise rates
looks for global rise on short time scale

pDAQ: mostly Java with some C (DOMs) and Python (control)

Uptime



M. Kauer

- Total detector uptime, including partial-detector and failed runs: **~99%**
- Clean ("golden") uptime: no missing strings, no problems found: **~95%**
- "Good" run start/stop times recover data even from runs that may crash

IceCube Live

SPS Status

Data Acquisition

Current run: **122346** (8h:12m:41s)
Run config: sps-IC86-adios-Skorpionen-again-V228
DAQ release: Capital_14431:103430M
Total events: 75480758
Active DOMs: 5406

Light mode: **dark** Change: LID

Control Details

pdaq RUNNING

Other Components

DB	RUNNING	stop
GammaFollowUp	UNKNOWN	waiting
I3DAQDispatch	RUNNING	stop
I3MoniDomMon	RUNNING	stop
I3MoniDomSn	RUNNING	stop
I3MoniDomTcal	RUNNING	stop
I3MoniMover	RUNNING	stop
I3MoniPhysA	RUNNING	stop
OpticalFollowUp	RUNNING	stop
PFFiltDispatch	RUNNING	stop
PFFiltWriter	RUNNING	stop

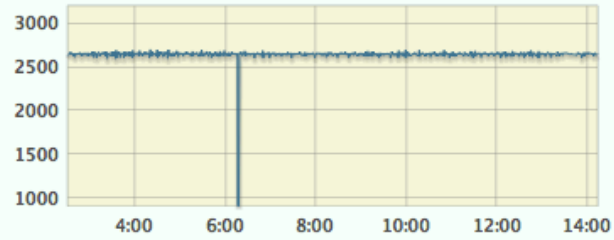
Currently Watched Alerts

multirunfail	OK
runfail	OK
ICL overtemp max2	OK
/mnt/data/pdaqlo...n.tar file count	OK
Detector not taking data	OK
ICL overtemp max1	OK
ICL overtemp min2	OK
ICL temperature too high	OK
Lots of LBM overflows	OK
Max WXGoose 3 Temp	OK
Max WXGoose 3 Temp (pages)	OK
Max WXGoose 6 Temp	OK
Min WXGoose 1 Temp	OK
Minimum Active DOMs	OK
OFU latency too high	OK
PnF latency too high	OK
PnF rate too low	OK
SERIOUS SN alert triggered!	OK
Supernova DAQ state check	OK
Test Alert	OK
Time since SNDAQ...in running state	OK

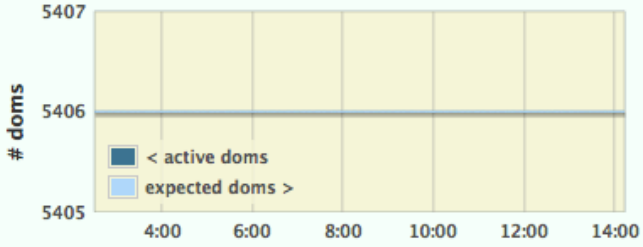
Graphs

(Detailed rates page)

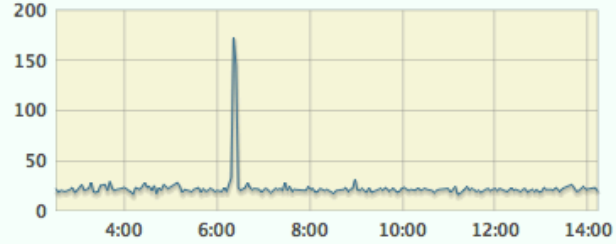
pDAQ Event Rate (Hz)



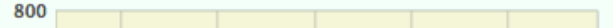
Active DOMs



PnF Latency (sec)

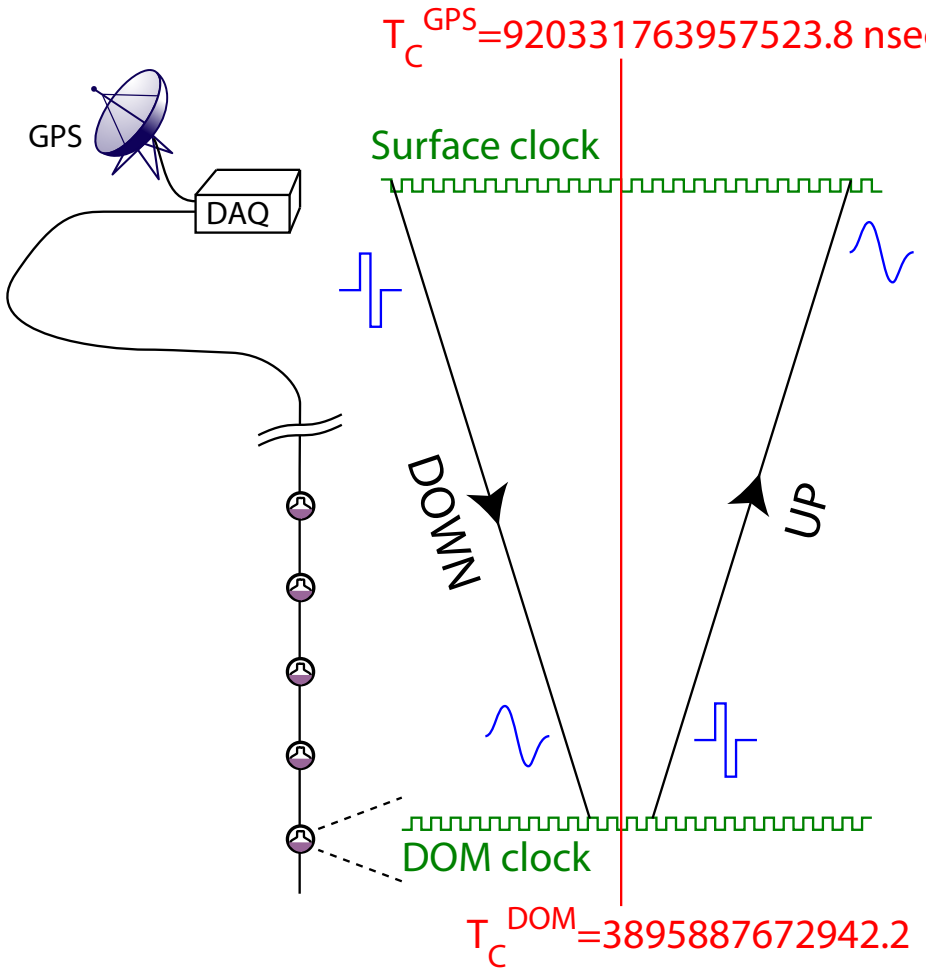


SNDAQ Processing Latency (sec)



DOM Time Synchronization

Reciprocal **A**ctive **P**ulse **Cal**ibration (RAPCal)



- Pulses degraded over 3km cable but reciprocal so errors cancel
- Don't need to know cable delays
- Automatic process every 1-2 secs

Surface DAQ can correct hit times before recording

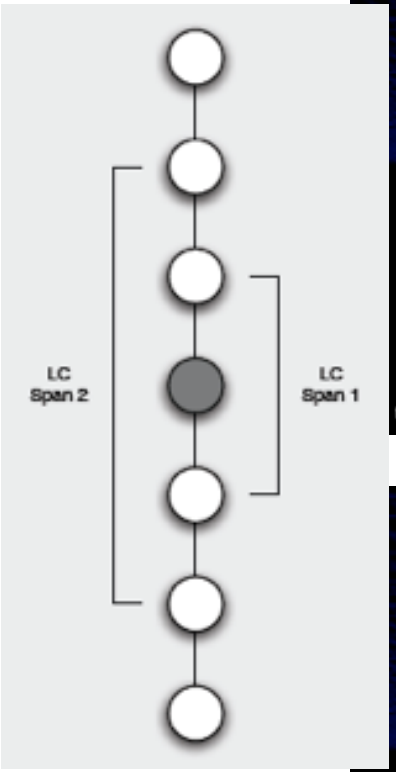
$$T^{GPS} = k\,T^{DOM} + T^{offset}$$

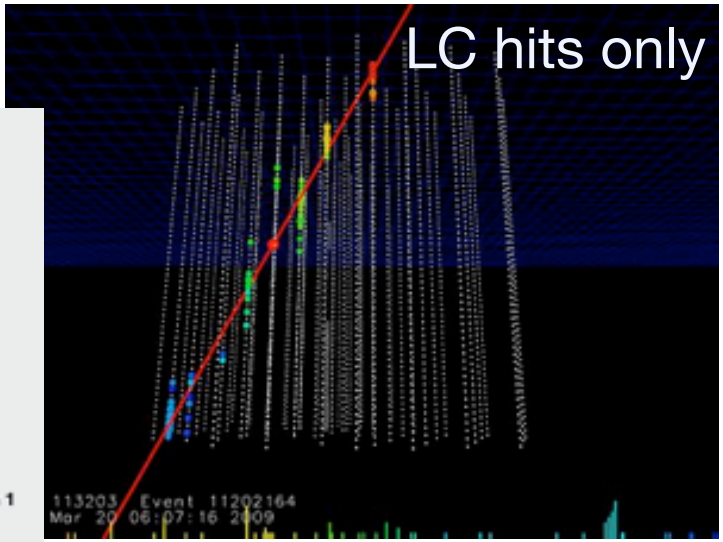
rms of ~2 ns

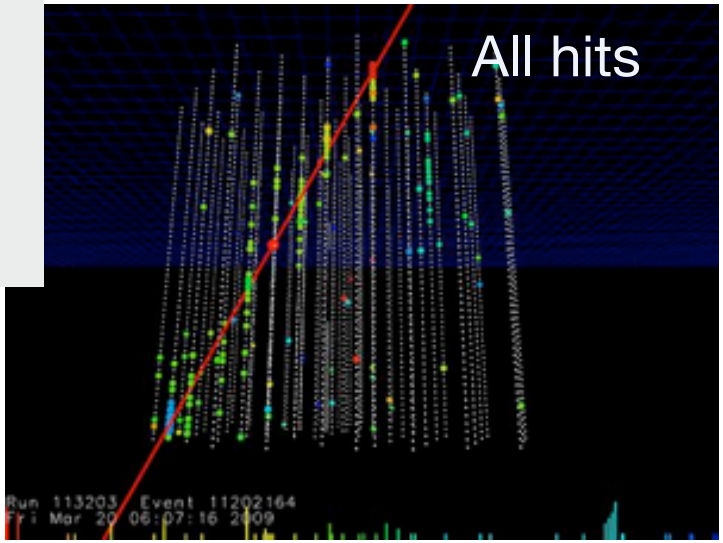
R. Abbasi *et al.*, NIM A **601** 294 (2009)

Local Coincidence

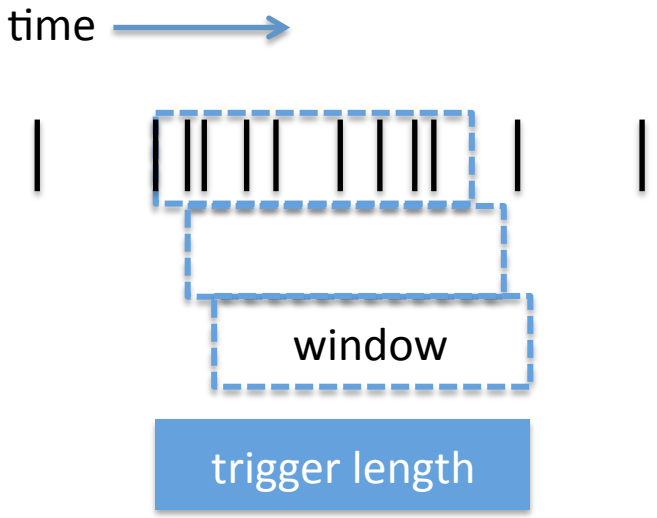
- Physical connection along in-ice cable and between IceTop tanks
- DOM firmware flags hits that have neighbor hits within 1 μs
- DOMs can forward LC signal (current span = 2)
- Only LC hits "HLC" are used in triggering
- Rate (per DOM): reduces 600 Hz darknoise to 5-15 Hz LC







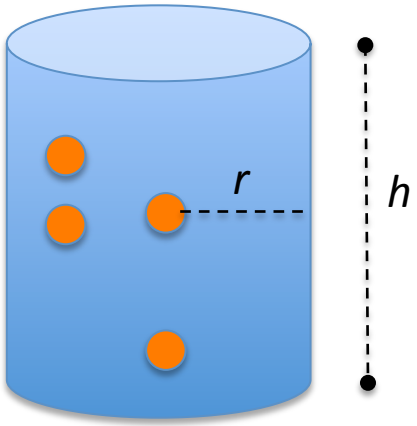
Simple Multiplicity Trigger



- 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

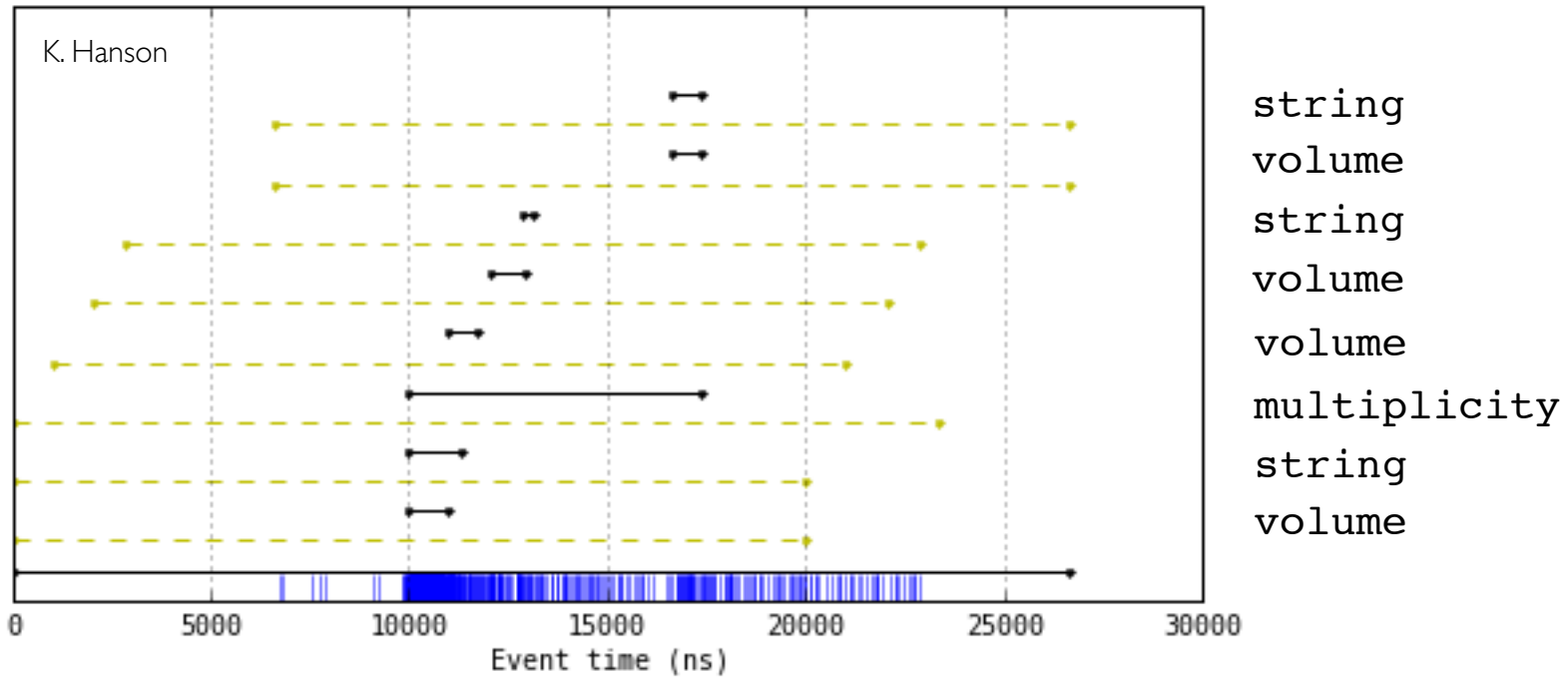


Volume trigger: *N* hits within a cylindrical volume around DOM in a time window

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

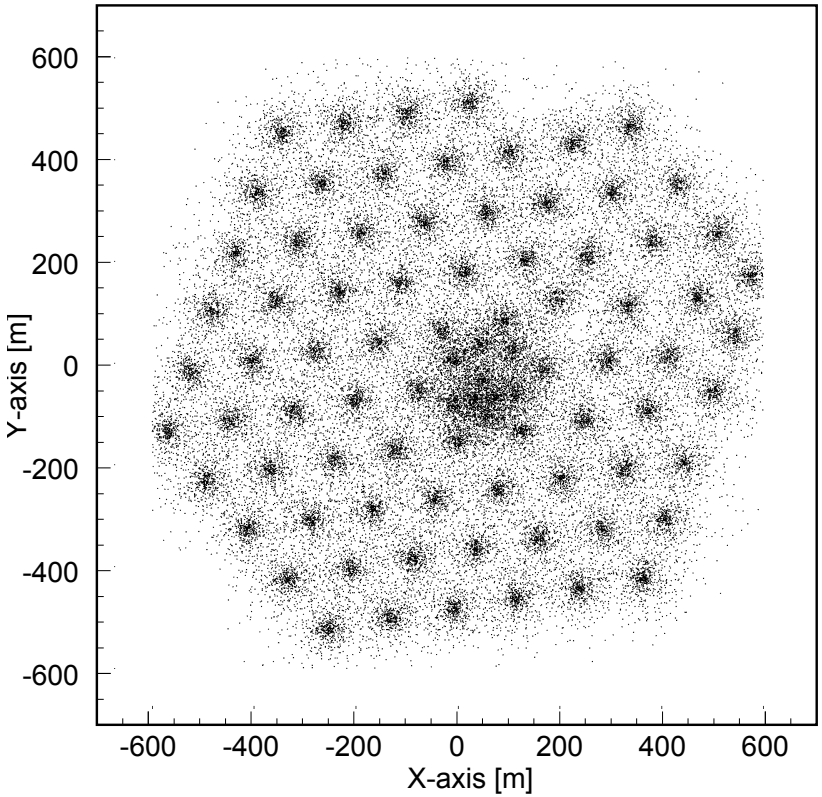
Trigger	HLC hits	Topology	Window (μs)	Rate (Hz)
Volume	4	cylinder r=175m, h=75m	1	3700
String	5	of 7 DOMs on string	1.5	2200

Global Trigger / Merging



- Design goal: avoid overlapping events!
- Combine individual triggers into event if readout windows overlap
- Retain individual trigger information

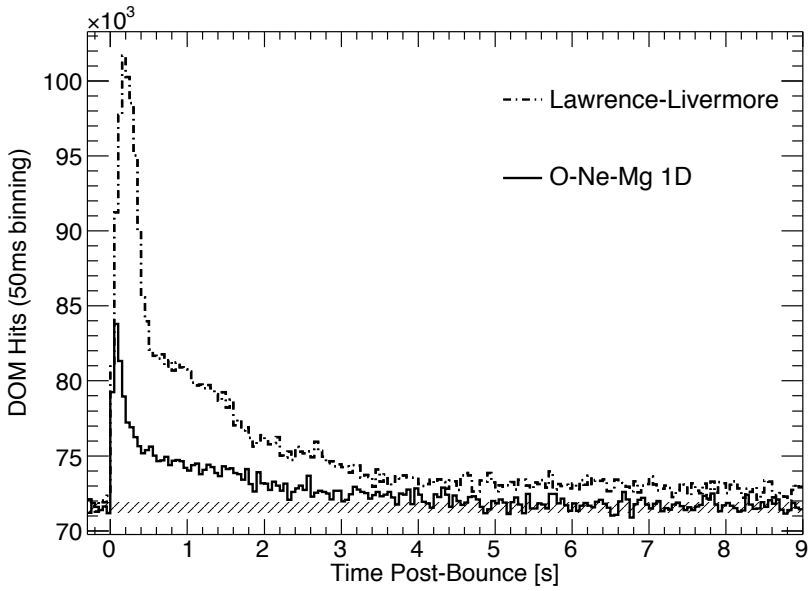
Supernova (SN)DAQ



GEANT simulation of detected inverse beta decay events

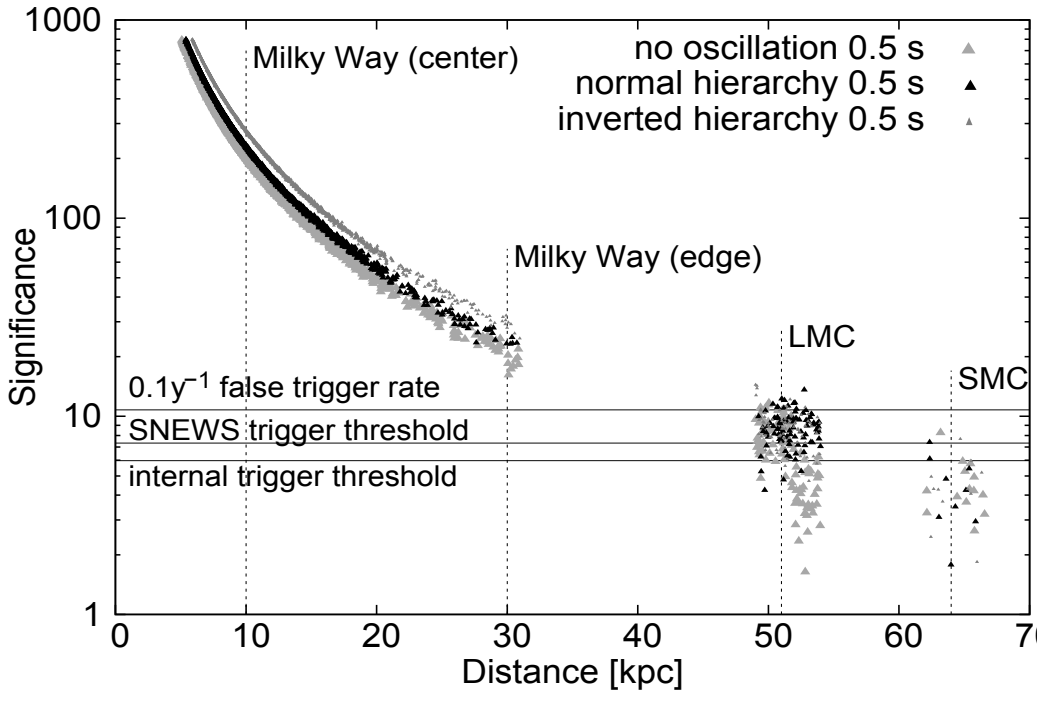
- Detection principle: global noise rate increase from many ~10 MeV neutrino interactions
- Scaler dark noise counts from in-ice DOMs (4b count / 1.6 ms)
- Artificial dead-time introduced
  - reduces bursts of correlated noise hits
  - avg. rate lowered: 540 Hz to 290 Hz
- Real-time significance of any global rise estimated

Sensitivity



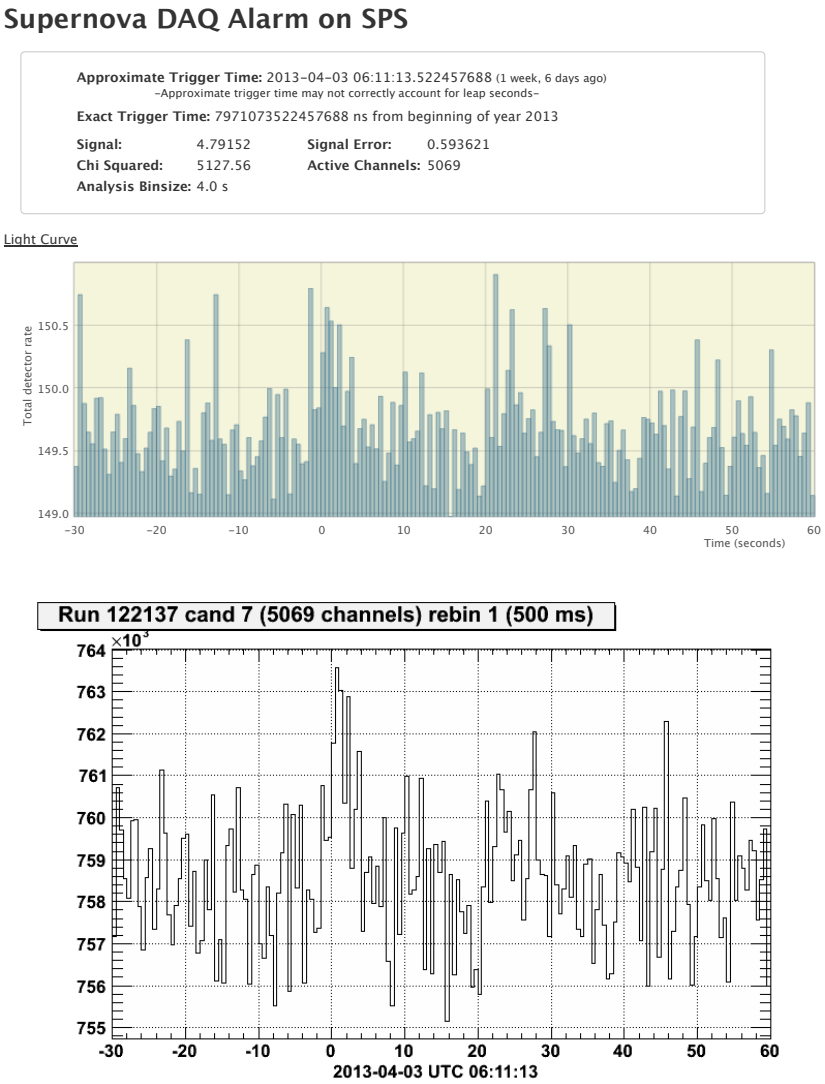
Simulated summed signal
(10 kpc distance)

Detection significance vs. distance
(LL model)



see Abbasi et al., A&A **535** A109 (2011)

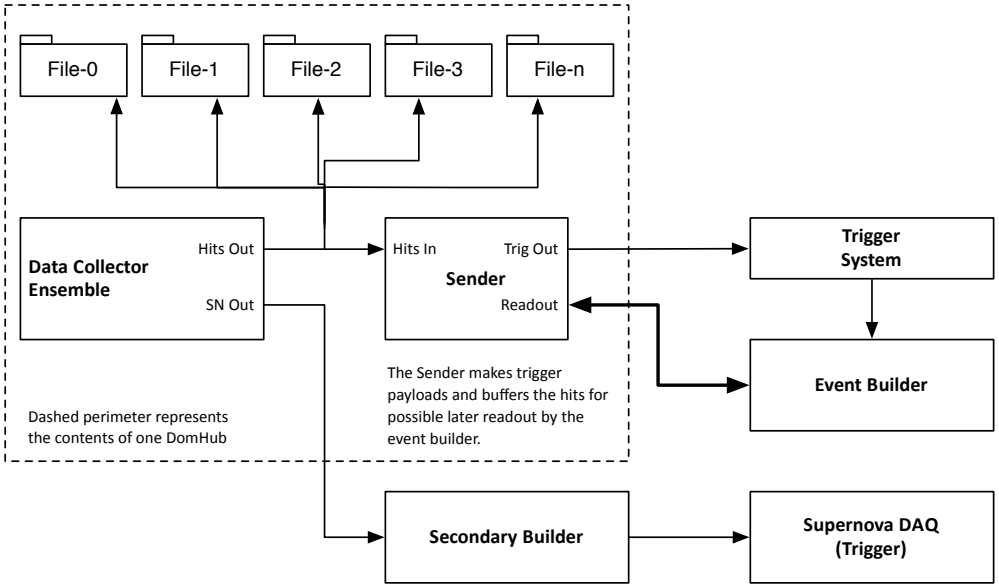
Alerts + SNEWS



- Iridium link allows:
  - near real-time monitoring of SNDAQ light curve
  - e-mail, SMS in case of high-significance alert
  - forwarding of alarms to SuperNova Early Warning System (SNEWS)
- Automated fast (+0:10) follow-up analysis at Univ. of Mainz

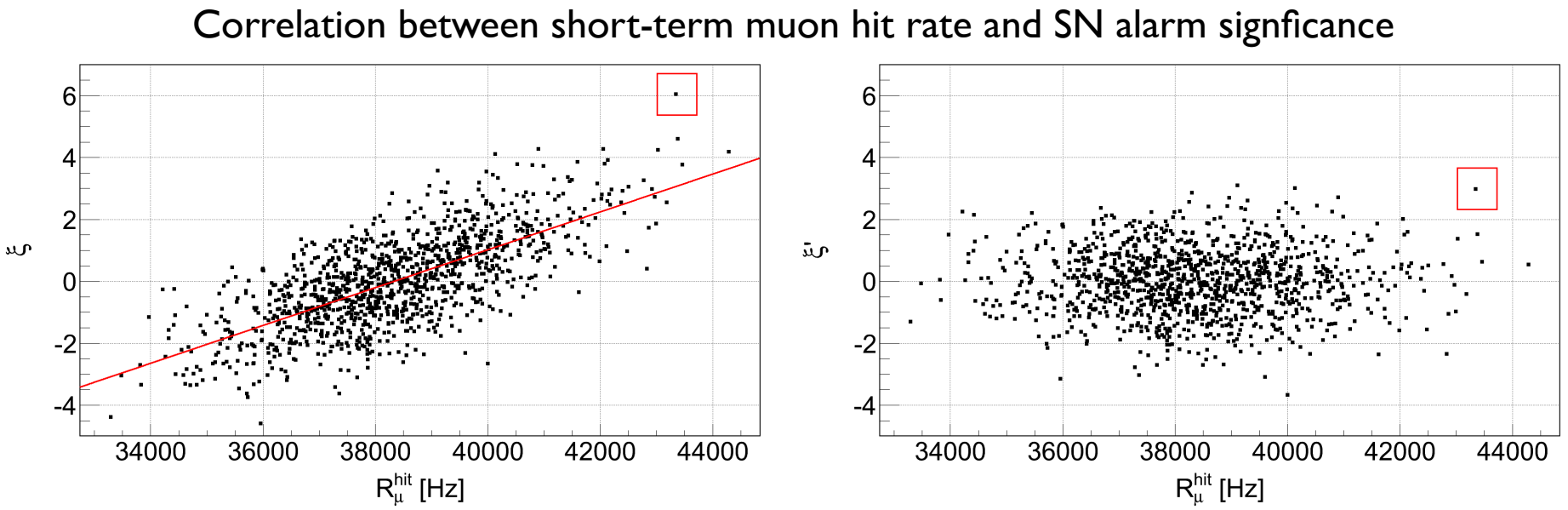
New Feature: Hitspooling

- Some analyses can take advantage of sub-threshold hits
- Hitspooling: save all DOM hits to hub disks
  - 2 MB/s per string
  - ring buffering in files on hubs
  - 16-hour buffer
- Interfaced to supernova DAQ
  - raw data stored if significant alarm
- Link active since mid-April 2013
- Still to do:
  - longer buffers (~5 days)
  - daemonize hubs



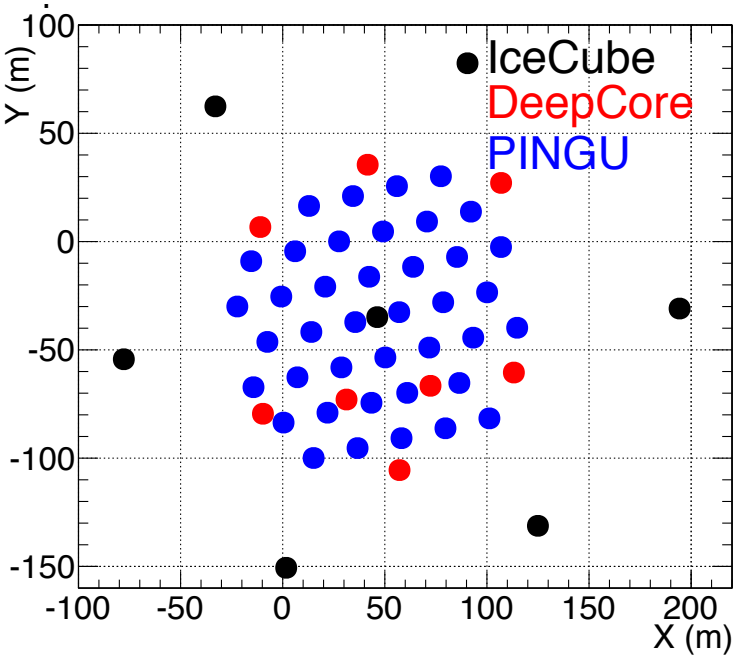
New Feature: SNDAQ Muon Subtraction

V. Baum



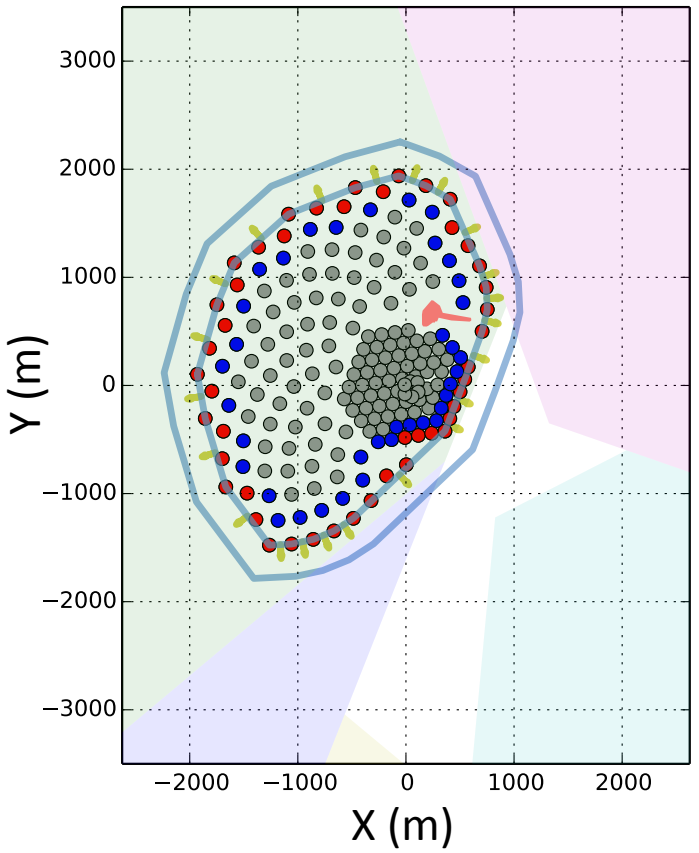
- Near-real-time link from trigger system to SNDAQ to reduce impact of muon rate fluctuations
- Example: significance corrected from 6.04 to 2.97

DAQ R&D for Gen2 Arrays



talk by D. Cowen

High-energy extension

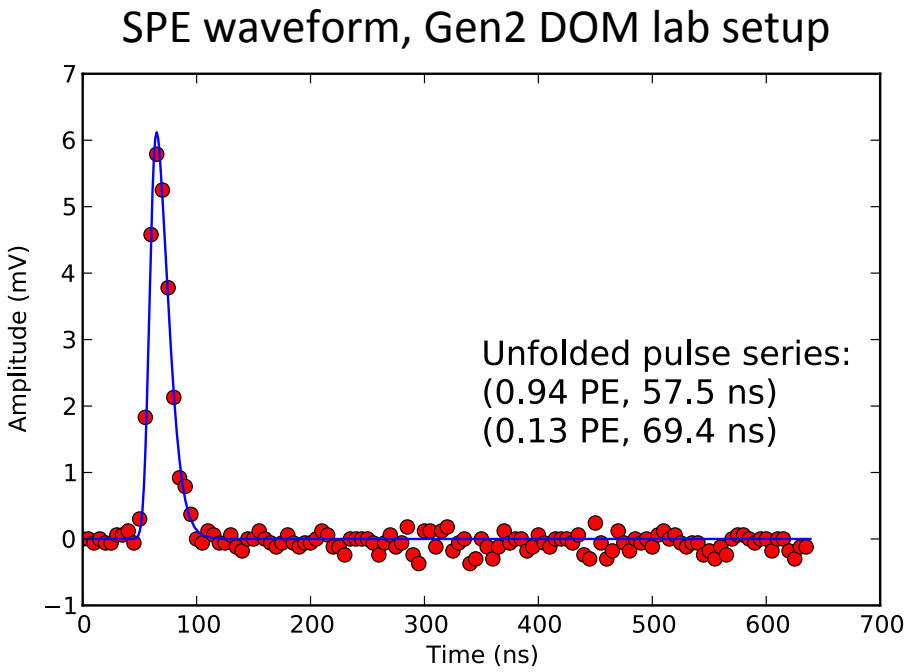


talk by C. Kopper

Low-energy and high-energy extensions in development phase

No Hardware Local Coincidence

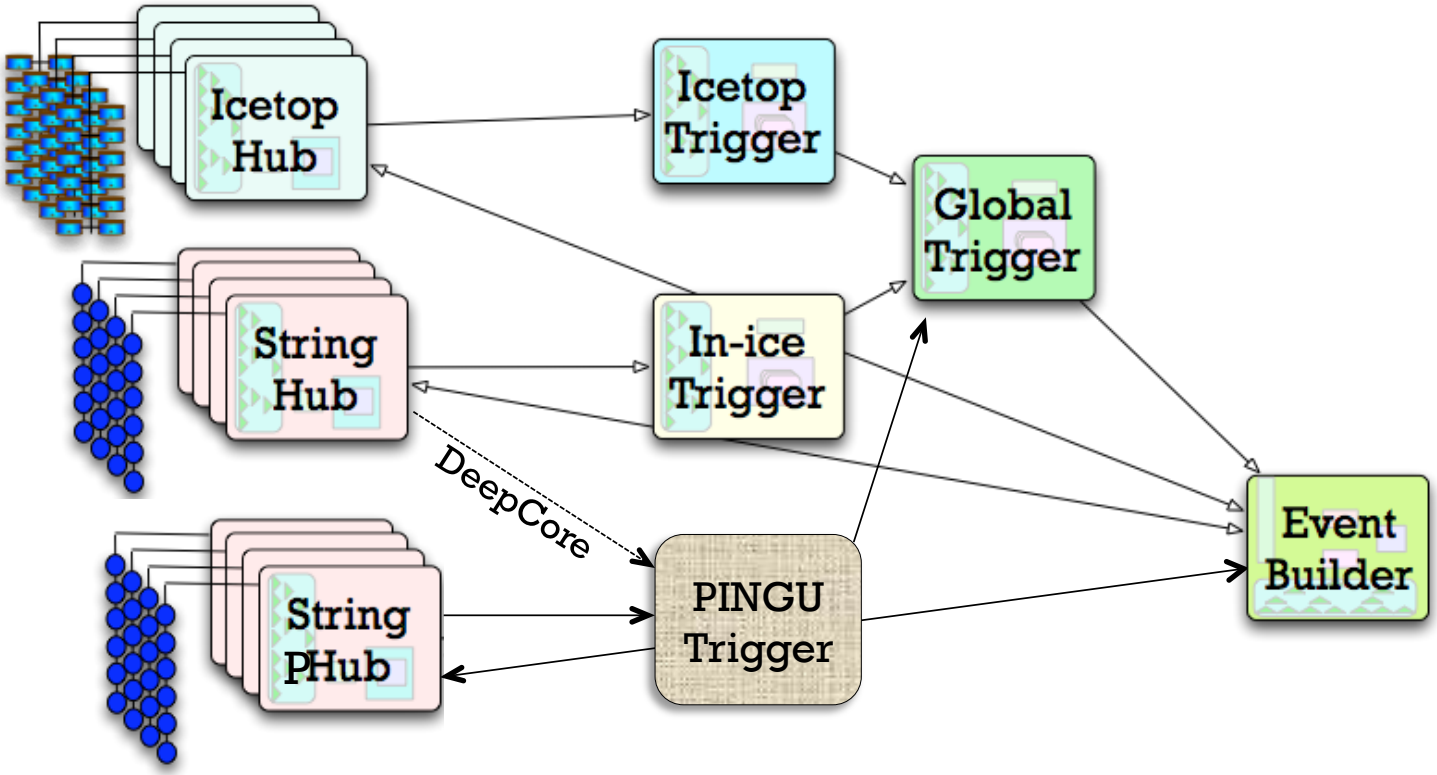
- Simplifies in-ice cable
- Compression of dark noise (800 Hz) becomes more important
- Investigating in-DOM feature extraction (SPE pulse template unfolding*)



*M. G. Aartsen *et al.* 2014 *JINST* **9** P03009

IceCube+PINGU Triggering

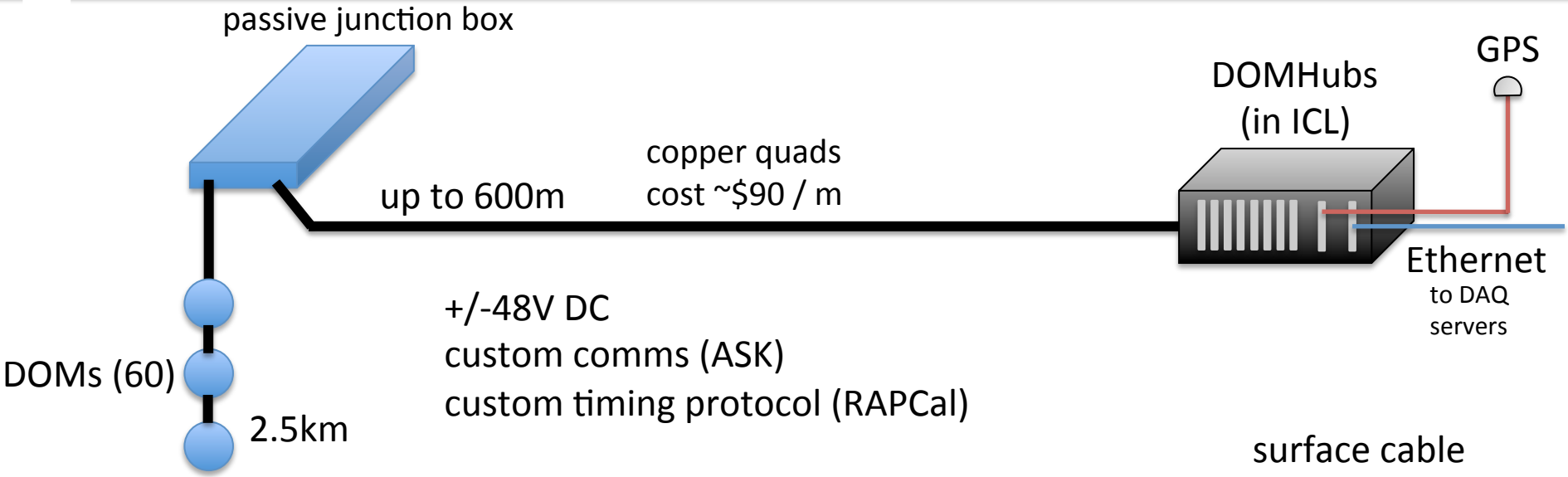
D. Glowacki



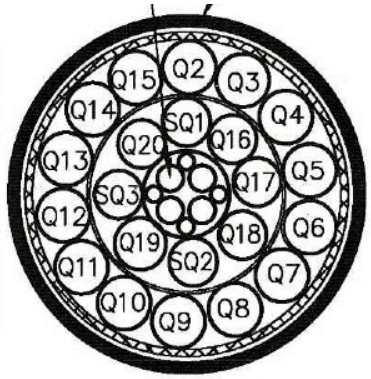
Separate PINGU trigger component

- trigger on PINGU DOMs and possibly DeepCore; readout both detectors
- modular design: architecture can be used as-is

DOM Readout (IceCube)



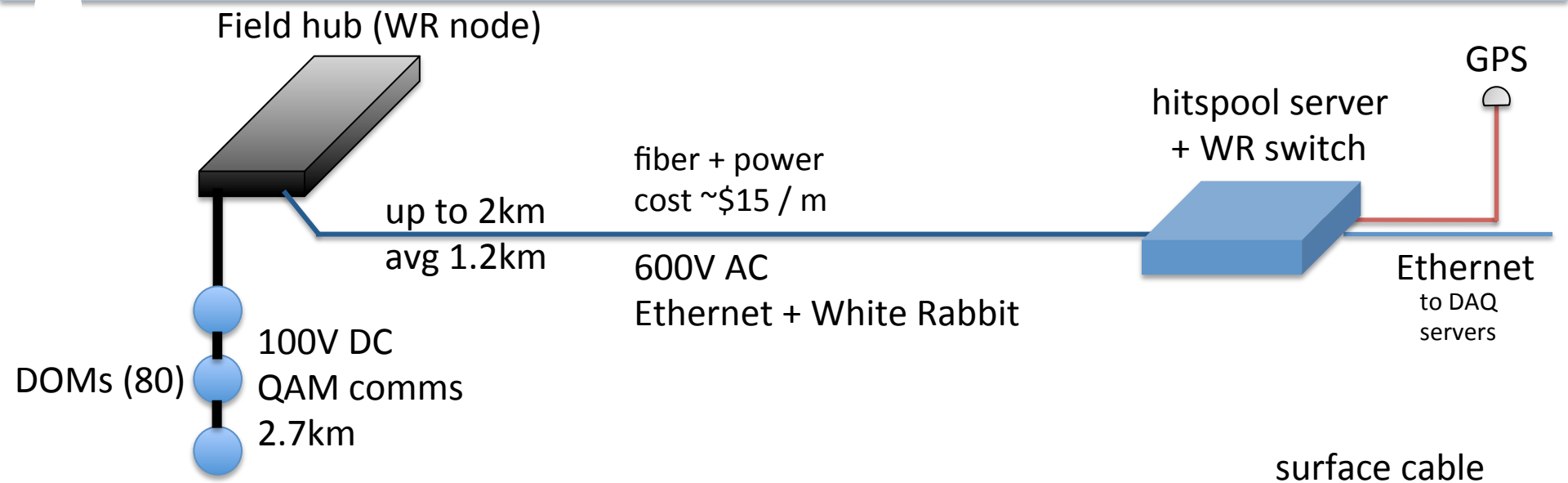
surface cable
cross-section



5 cm OD

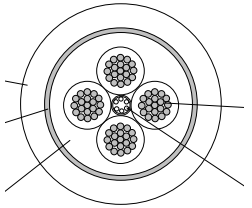
- IceCube scheme:
  - passive junction box at hole top
  - surface cable very similar to down-hole cable
  - readout computers (DOMHubs) in ICL
- Pros: easy to service DOMHubs; warm
- Cons: expensive; resistive losses add up; limited scalability

DOM Readout (Extension)



- Hubs at top of hole for HEX
  - simplified DOM-to-Ethernet functionality (+timing)
  - AC high voltage + fiber to counting house
  - White Rabbit* to synchronize hubs

surface cable
cross-section



1.5 cm OD

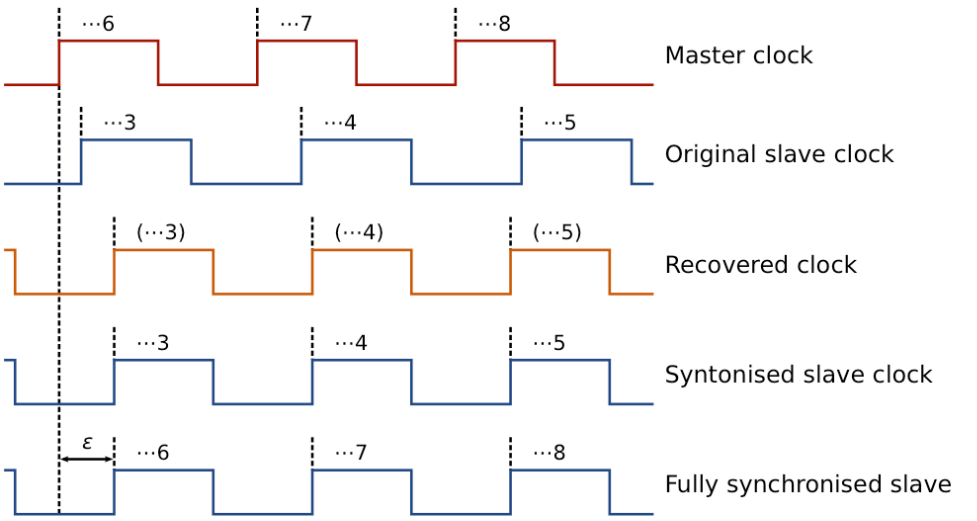
- Pros: reduced cable costs, power; higher-speed comms
- Challenges: cold; hubs not easily serviceable during winter

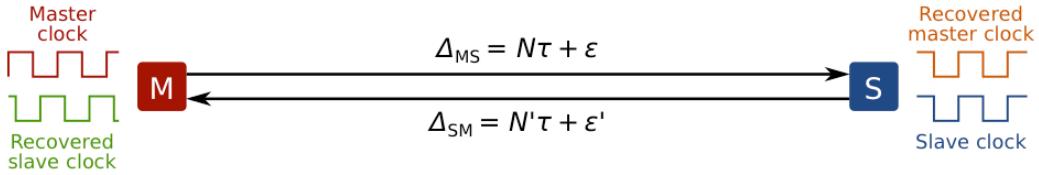
*J. Serrano *et al.*, ICALEPCS 2013 (San Francisco).

Gen2 Timing Calibration

S. Vanheule

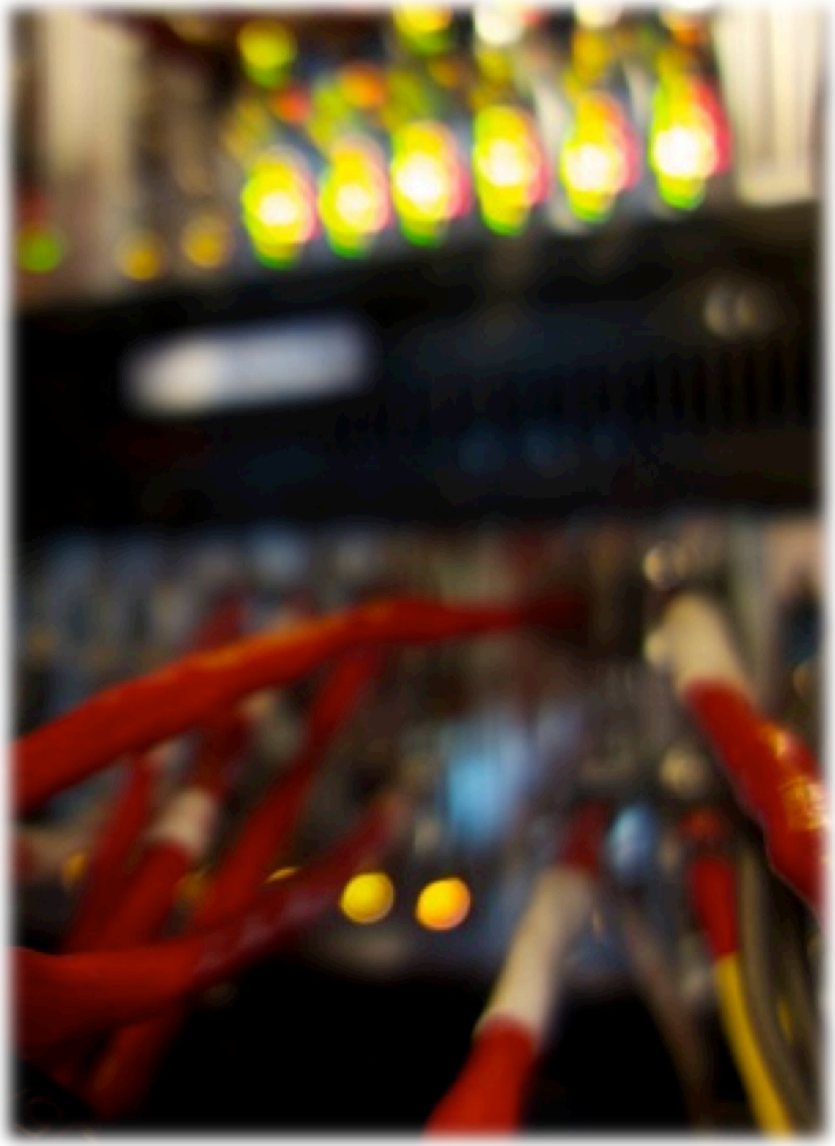
- White Rabbit to readout hubs
  - eliminates custom GPS fanout tree
- Down-hole DOM synchronization
  - QAM carrier phase recovery
  - dispersion could be an issue
  - RAPCal strategy still an option





Conclusions

- IceCube DAQ mature and stable
  - 99% average uptime
  - development still active with new features improving physics capability
- Modifications under investigation for Gen2 extensions
  - updated DOM (P. Sandstrom) and readout hub design
  - investigating new comms, timing calibration
  - software architecture likely to be very similar

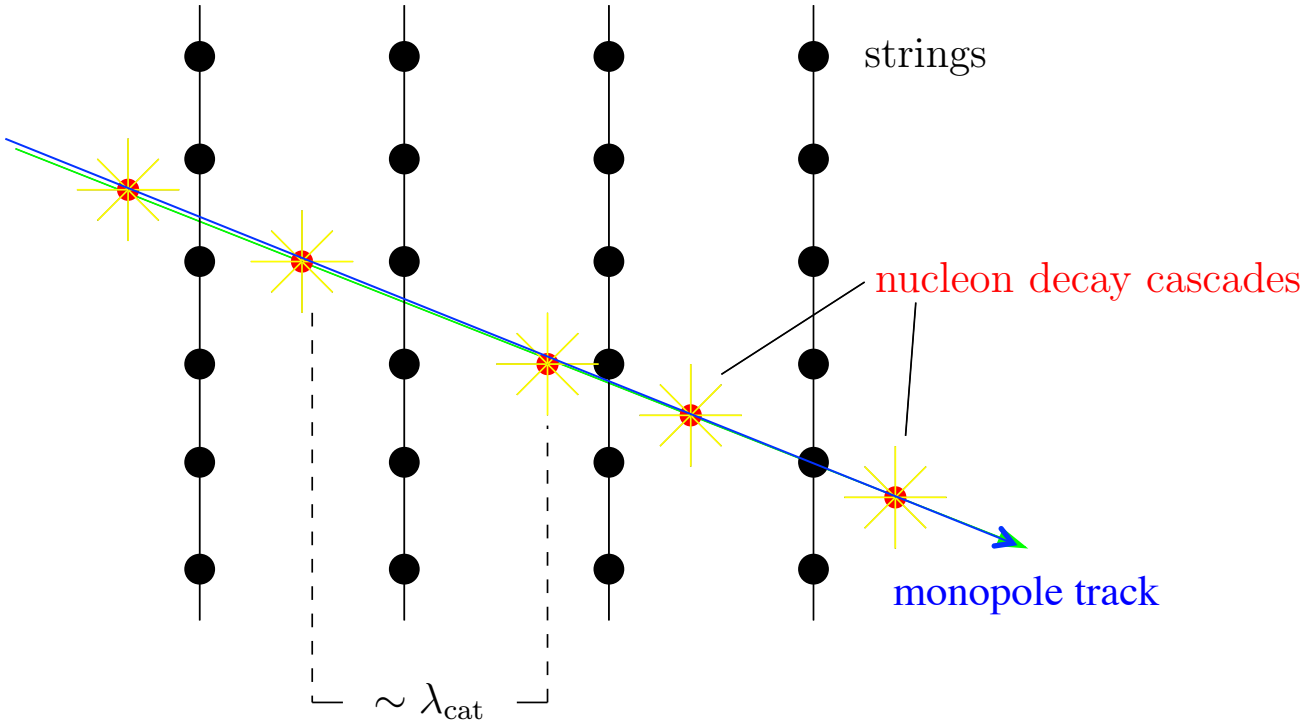


Thank you!

Backup

Specialized trigger: monopoles

T. Glüsenkamp

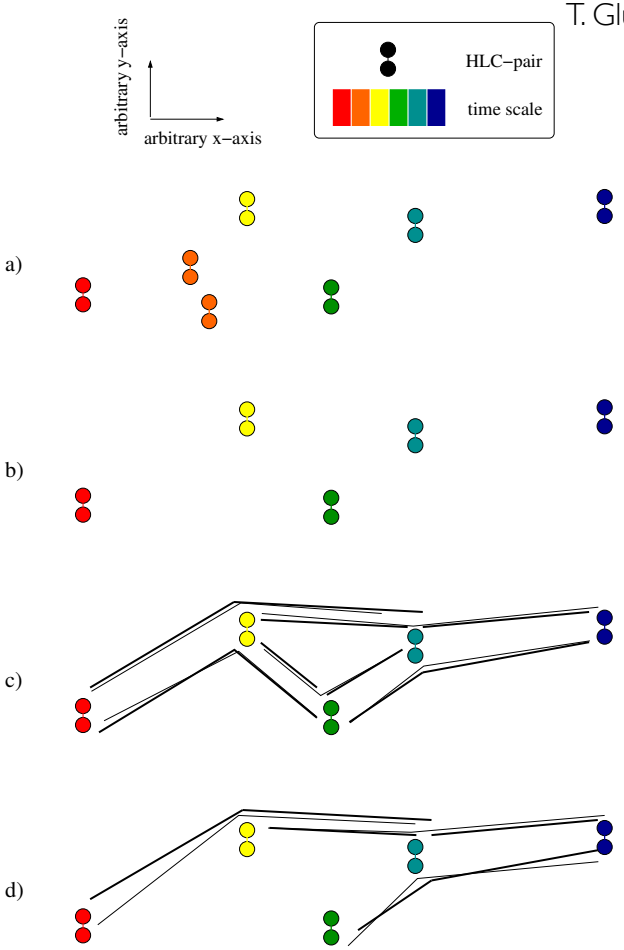


Signature of some exotic particles (magnetic monopoles, Q-balls, etc.):
slow ($v \sim 0.001$–$0.01c$) tracks with intermittent cascades

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

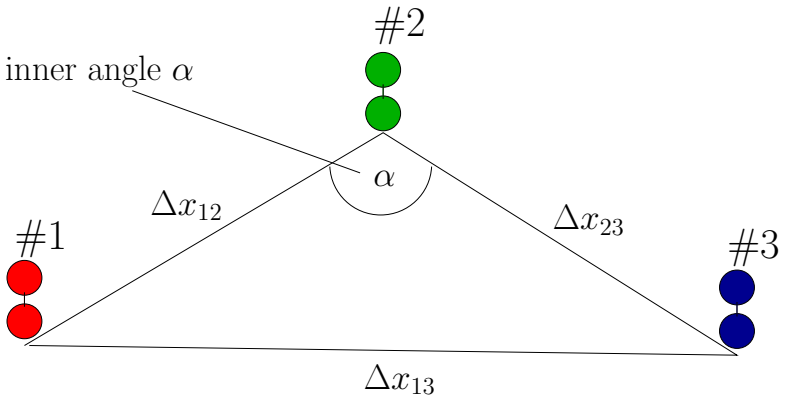
T. Glüsenkamp



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

SLOP Trigger Details

Defining parameters of a 3-tuple



time scale

$\Delta t_{12} = t_2 - t_1$

$\Delta t_{23} = t_3 - t_2$

$\Delta t_{13} = t_3 - t_1$

$$\texttt{rel\_v} = \frac{\Delta v_{\text{inverse}}}{v_{\text{mean/inverse}}} = \frac{\frac{1}{v_{12}} - \frac{1}{v_{23}}}{\frac{1}{v_{12}} + \frac{1}{v_{23}} + \frac{1}{v_{13}}} \cdot 3.$$

Various Trigger Rates

- Simple Multiplicity Trigger (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)

In-ice: 2100 Hz
DeepCore: 250 Hz
IceTop: 26 Hz

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

2230 Hz

- 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).

3700 Hz

- Slow Particle trigger (SLOP)
  - slow-moving hits along a track
  - lengths of the order of 500 μs and extending up to milliseconds

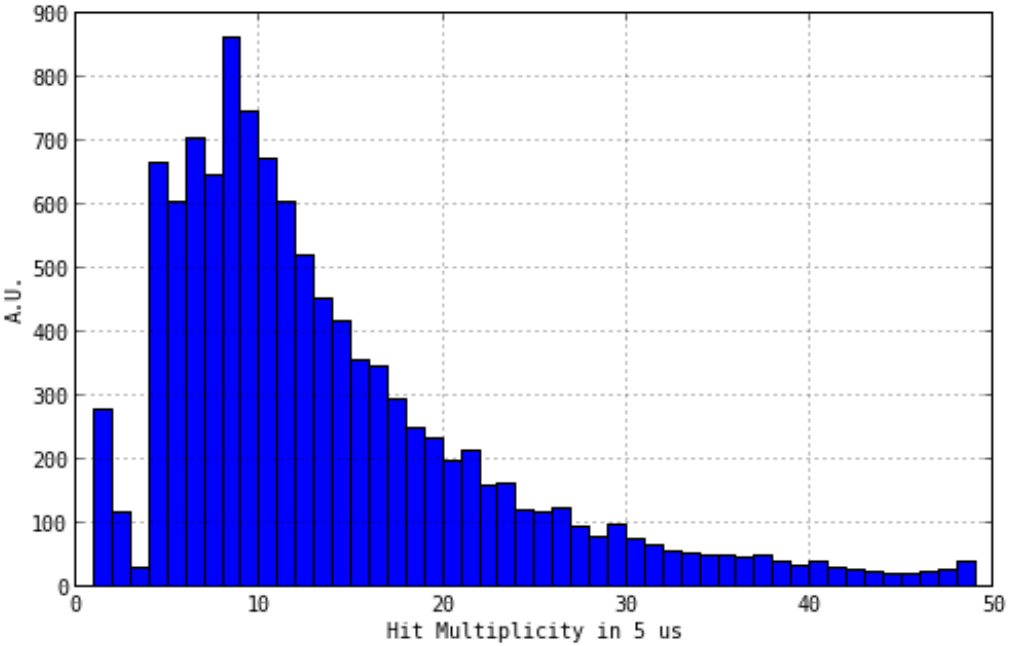
12 Hz

- Fixed Rate trigger, Minimum Bias trigger, Calibration trigger

FRT: 0.003 Hz

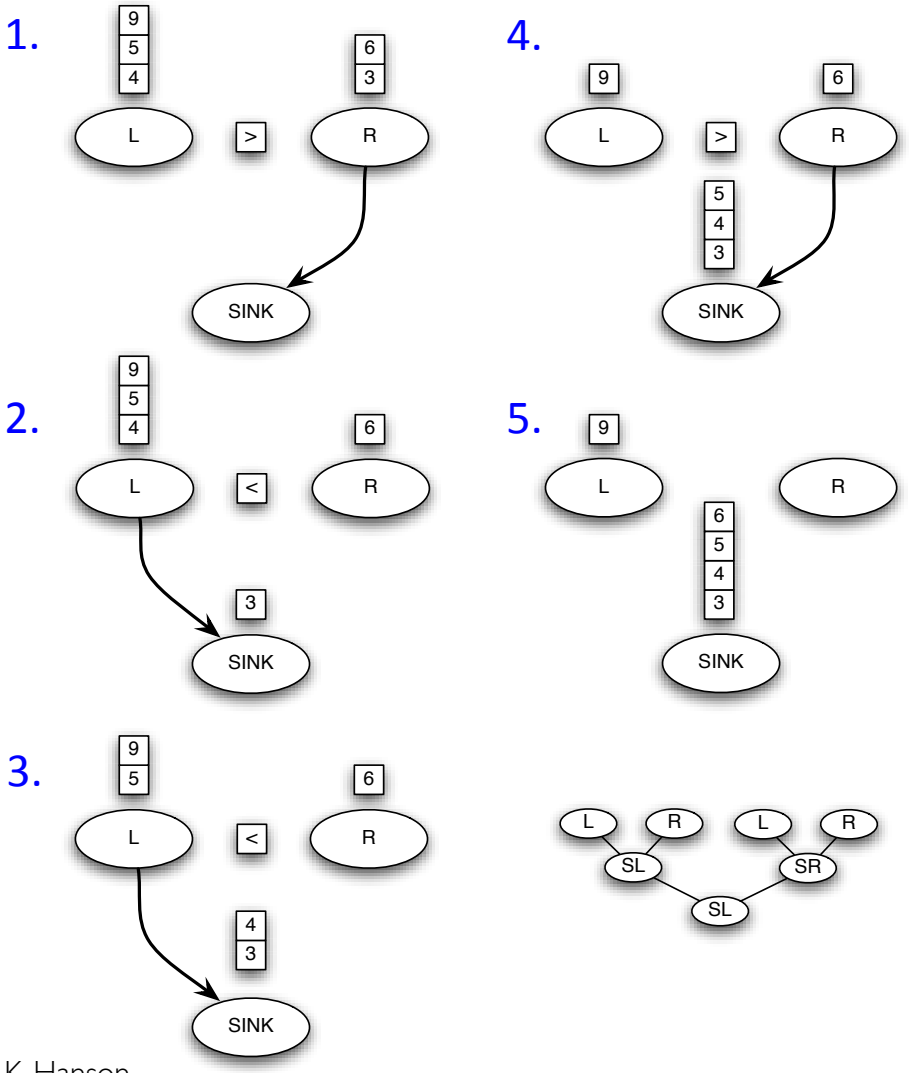
Global: 2700 Hz

Multiplicity and Exclusive Rates



Trigger Condition	Rate (Hz)
SMT8 + Volume + String	1200
Volume	330
Volume + SMT8	330
Volume + String	240
SMT8 + SMT3 + Volume + String	180
SMT8	100

DOM Hit Time Sorting



K. Hanson

- Cascaded binary merge "HKN1" of in-order input streams (DOM hit times)
- Fundamental node: two input linked lists, a comparator, and output list
- Cascade tree to handle many inputs
- Pushing into L or R:
  - if peer is not empty, compare and push into sink
  - continues through tree

Future Improvements

- Multithreaded sort using built-in Java min-heaps
  - performance +300% in initial tests on 4-core system
  - integration pending
- Trigger system modified to use multiple threads (complete)
- Server and DOMHub single-board computer January 2014
  - SBC: Atom D525 dual-core
  - servers: Dell PowerEdge R720