DM-Ice: A Search for Dark Matter in the Antarctic Ice

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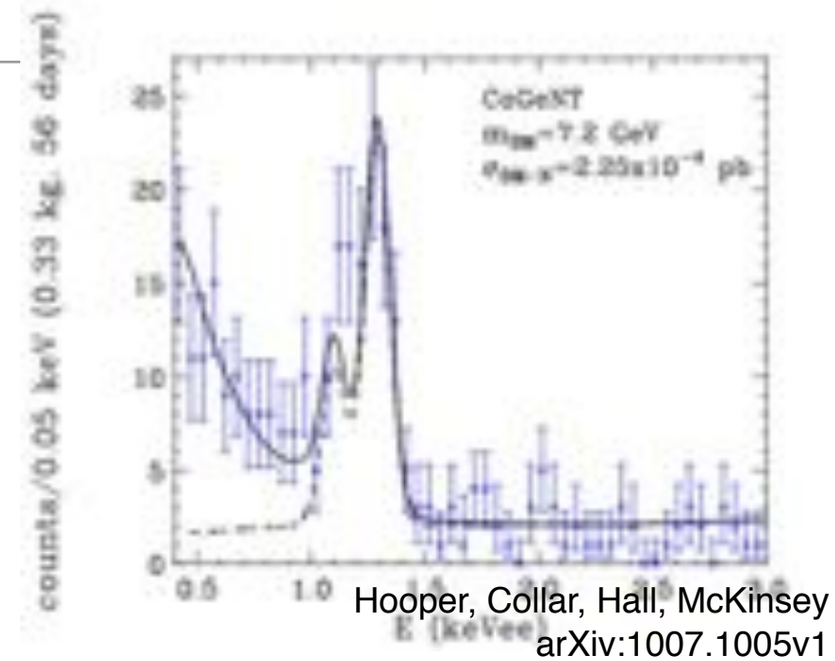
Indirect and Direct Detection of Dark Matter
Aspen Center for Physics
February 6 - 12, 2011

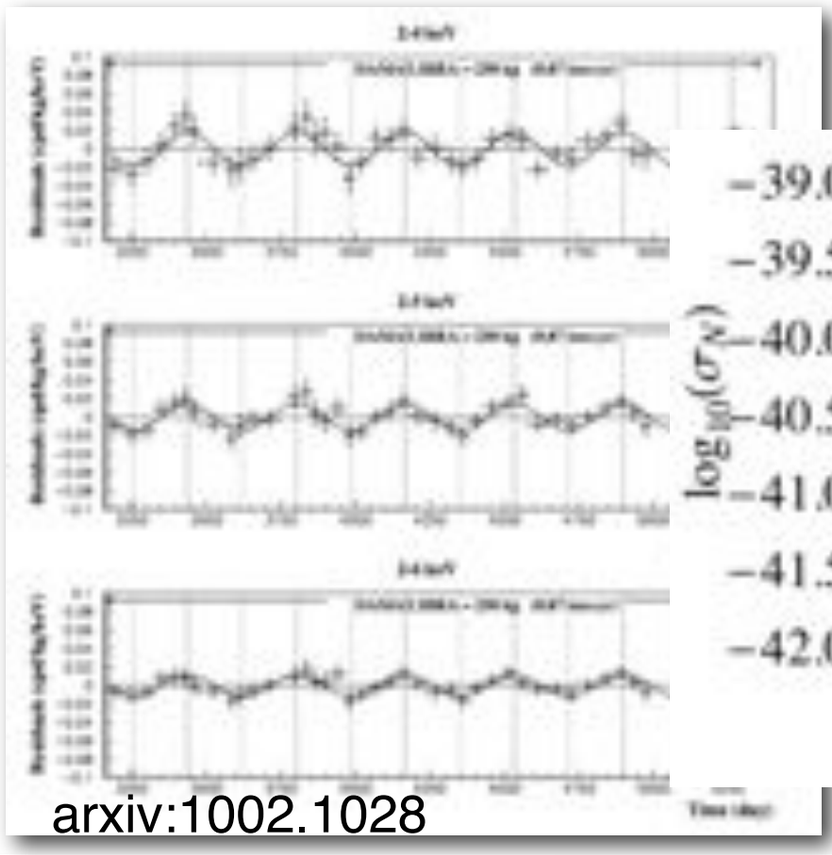
Direct detection of dark matter

Some tantalizing signals...

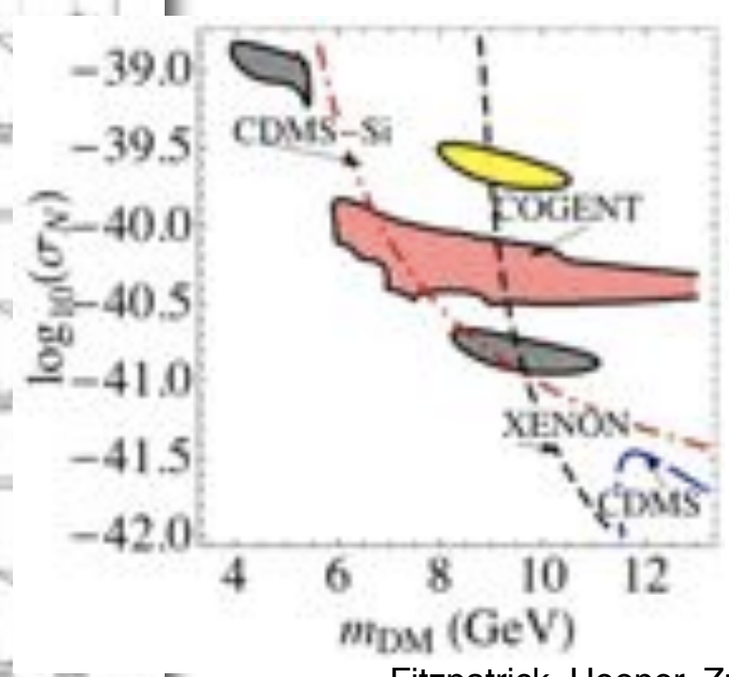
- Recent results, some consistent, some not, from CoGeNT, CRESST, CDMS, XENON 10, XENON 100. DAMA claims DM detection.
- Background? Light WIMPs? ????



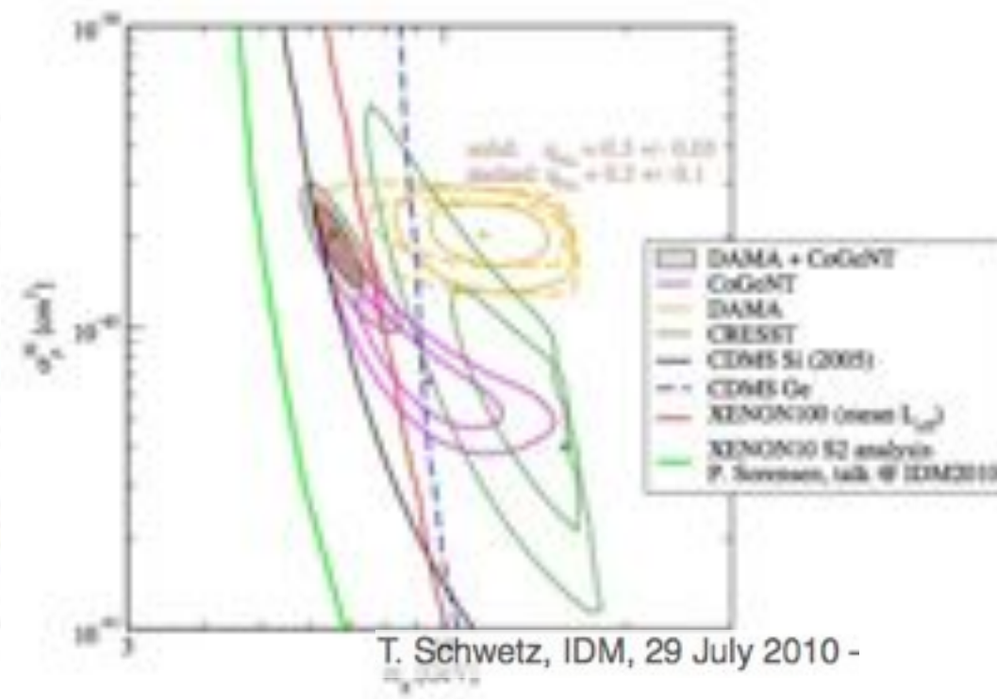
Hooper, Collar, Hall, McKinsey
arXiv:1007.1005v1



arxiv:1002.1028



Fitzpatrick, Hooper, Zurek
arXiv:1003:0014



T. Schwetz, IDM, 29 July 2010 -

What is going on?

- Experimental issues?
  - These experiments are extremely challenging. We need to understand our detectors and uncertainties on quenching factors, energy scale, threshold effects, backgrounds, etc. etc....
  - Build bigger and better experiments or look for annual / daily modulation.
- Modify astrophysics?
  - f(v)? v_{esc}? v_0? co-rotating?
- More exotic particle?
  - spin-dependent, inelastic scattering, momentum-dependent scattering...
- Proposed solution: look for annual modulation with NaI in the Southern Hemisphere.

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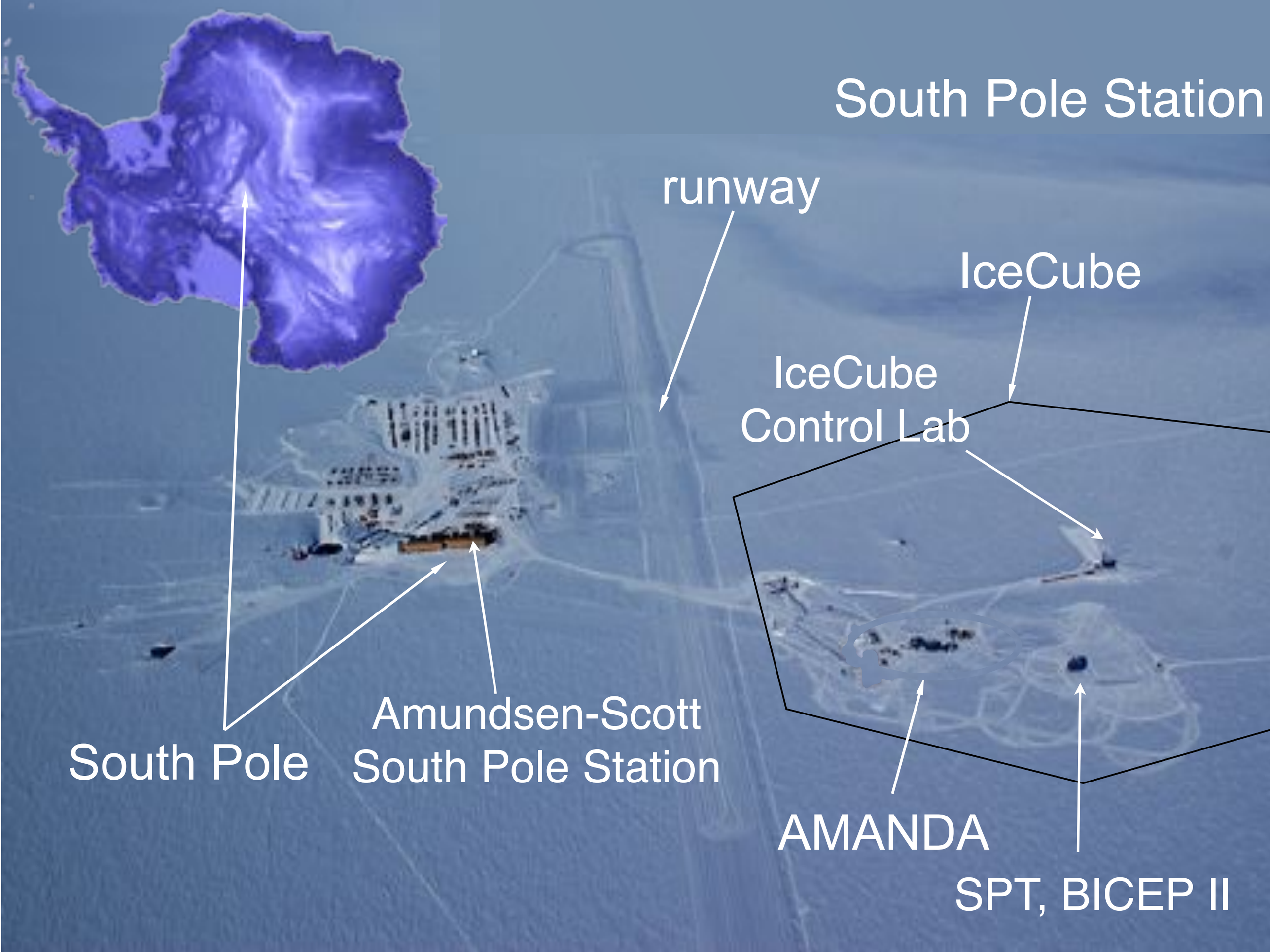
South Pole

Why South Pole?

- The phase of the dark matter modulation is the same.
- Opposite seasonal modulation, e.g. muon rate (max in December).
- > 2500 m.w.e. of overburden with clean ice.
  - Many sources of backgrounds either non-existent or different from other underground sites.
  - Clean ice → no lead/copper shielding necessary. No radons.
  - Ice → neutron moderator.
  - Ice as an insulator → No temperature modulation.
- Existing infrastructure
  - NSF-run Amundsen-Scott South Pole Station
  - Ice drilling down to 2500 m developed by IceCube
  - Muon veto by IceCube/DeepCore
  - Infrastructure for construction, signal readout, and remote operation


South Pole Station
runway
IceCube
IceCube
Control Lab
South Pole
Amundsen-Scott
South Pole Station
AMANDA
SPT, BICEP II

DM-Ice prototype deployment in 2010

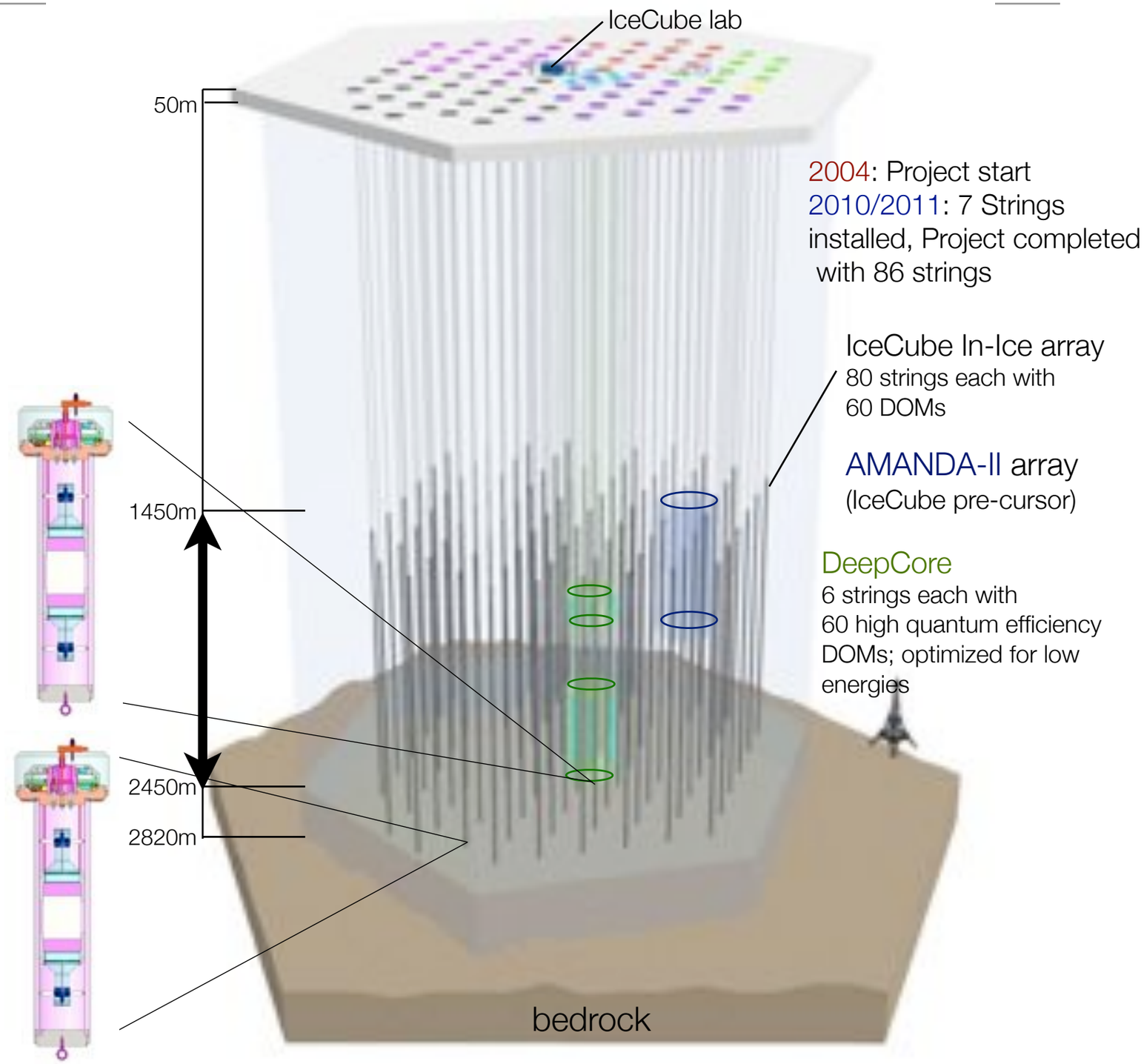
Detectors:

- Two 8.5 kg NaI detectors from NAIAD

Goals:

- Assess the feasibility of deploying NaI(Tl) crystals in the Antarctic Ice for a dark matter detector
- Establish the radiopurity of the antarctic ice / hole ice
- Explore the capability of IceCube to veto muons

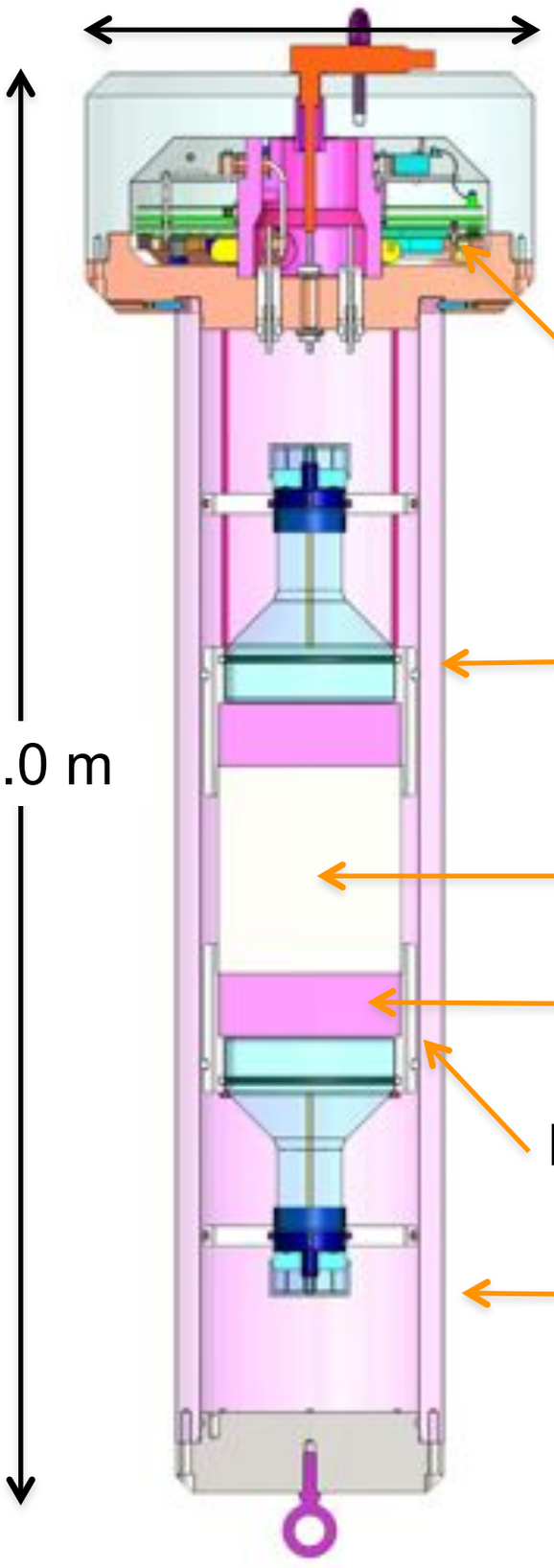
Installation in Dec. 2010



Prototype schedule and design criterion

- Schedule
  - Start design in Feb. 2010. Funding through UW-Madison.
  - Small funding via NSF Rapid in August 2010.
  - Ship to the South Pole by November 5, 2010 to meet IceCube construction schedule.
  - Deployment along with the last 7 IceCube strings: December 5 - 20, 2010.
- Design
  - Find the cleanest possible crystals, PMTs & surrounding materials.
  - Enclose detector in a pressure vessel to withstand 6000 psi from 2500 m of water above + water refreeze process.
  - Record waveforms from NaI pulses, transmit data North.
  - No interference with IceCube operation, minimal impact on construction schedule.

DM-Ice Feasibility Study Detector



2 IceCube mainboards
+ HV control boards

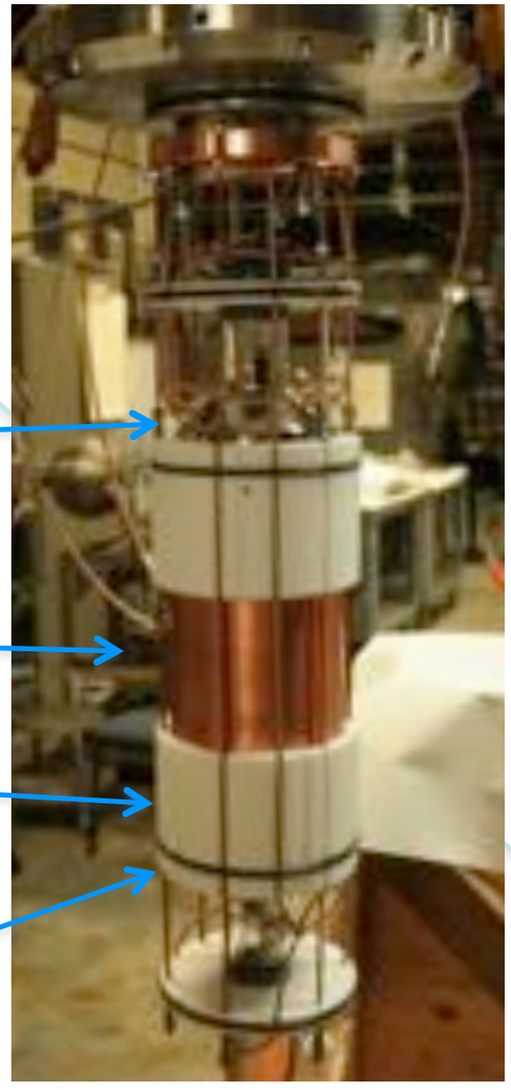
5” ETL PMTs from
NAIAD (2)

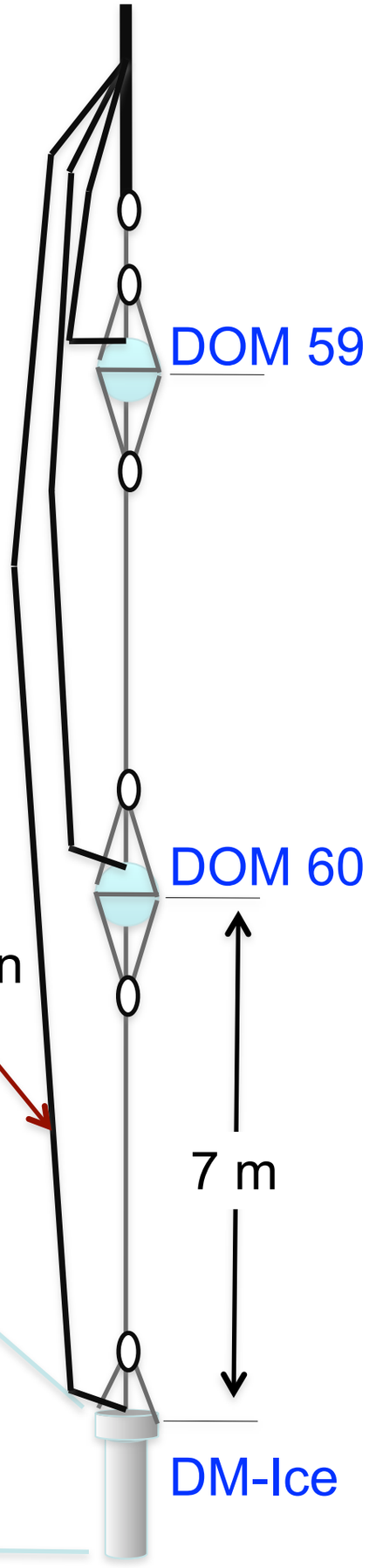
NAIAD NaI Crystal
(8.5 kg)

quartz light guides (2)

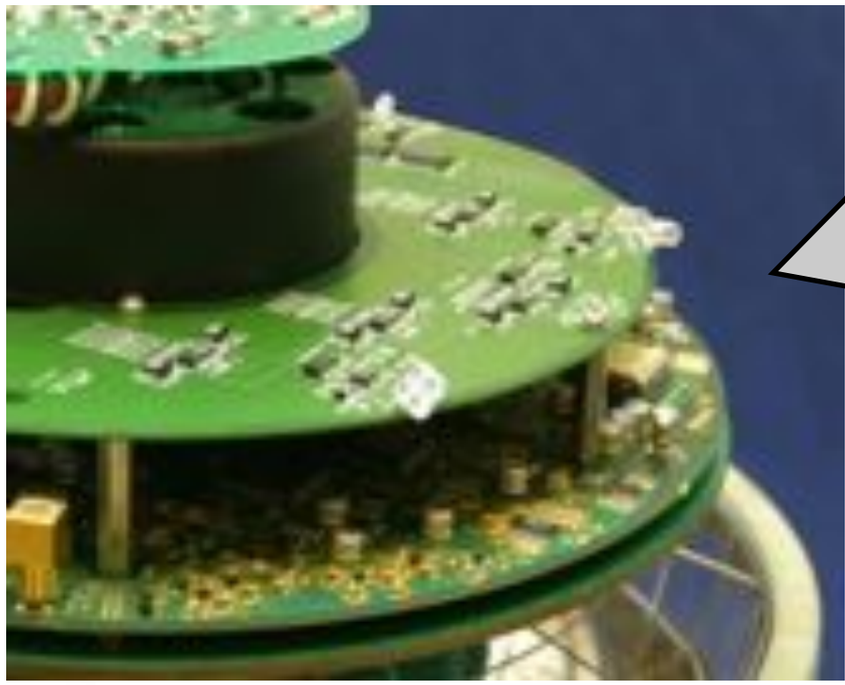
PTFE light reflectors (2)

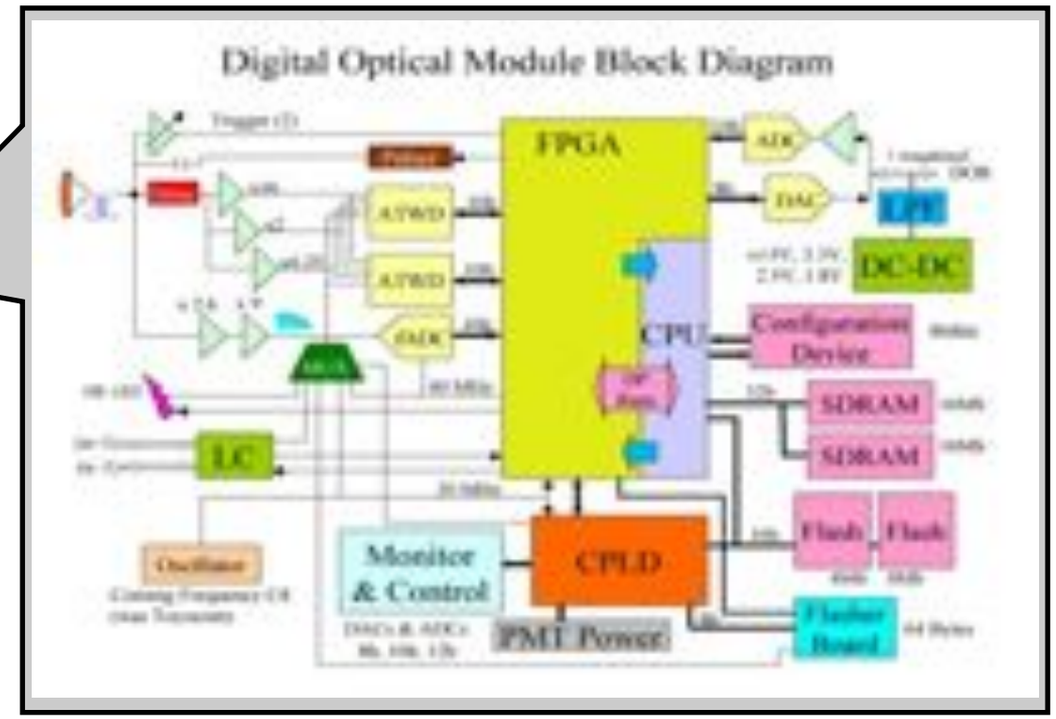
Stainless Steel
Pressure Vessel

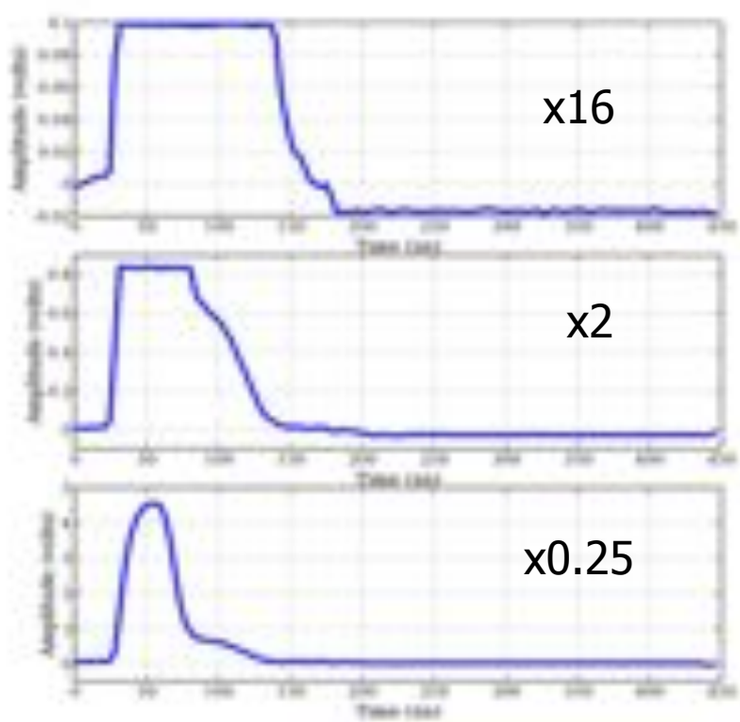




IceCube DOM mainboards







- 40 MHz 10-bit flash ADC for slow high energy events
- 2 parallel Analog Transient Waveform Digitizer (ATWD) chips, 10-bit resolution and programmable sampling speeds from 250 MHz to 1 GHz
- Each ATWD contains 3 gain paths: x16, x2, x0.25 (giving effectively 14-bits)
- Coincidence trigger capabilities
- Controls a separate HV board
- Programmable from surface

IceCube DOMs in Production

DOM Assembly

DOM sealing station

DOM testing freezer

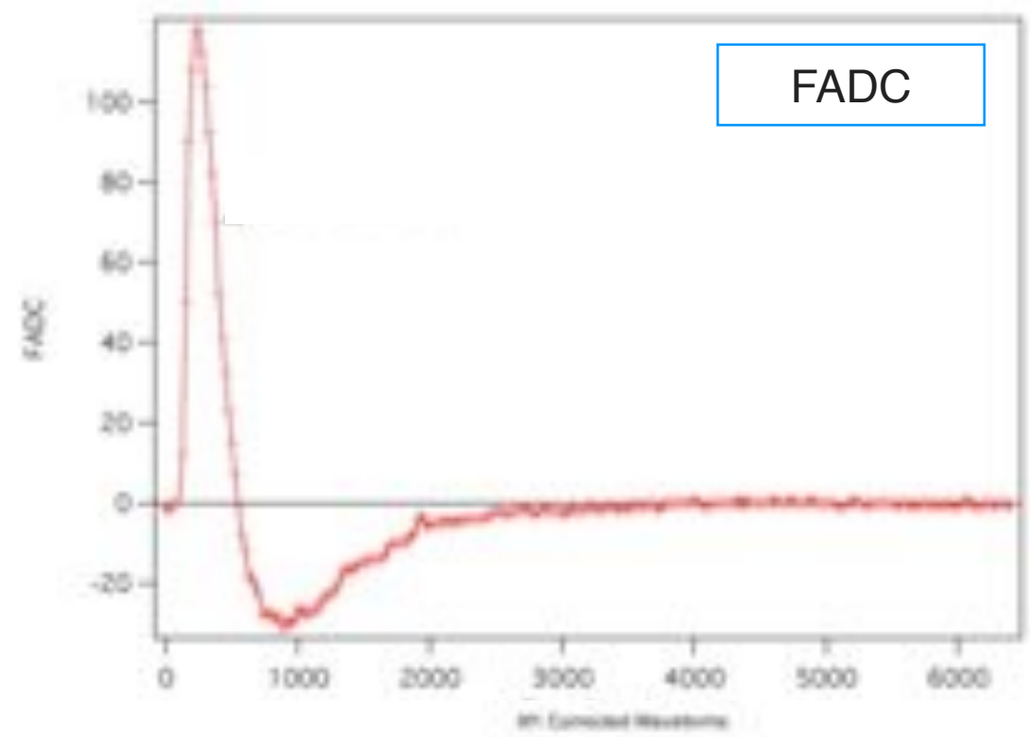
Modular Dark Freezer Lab

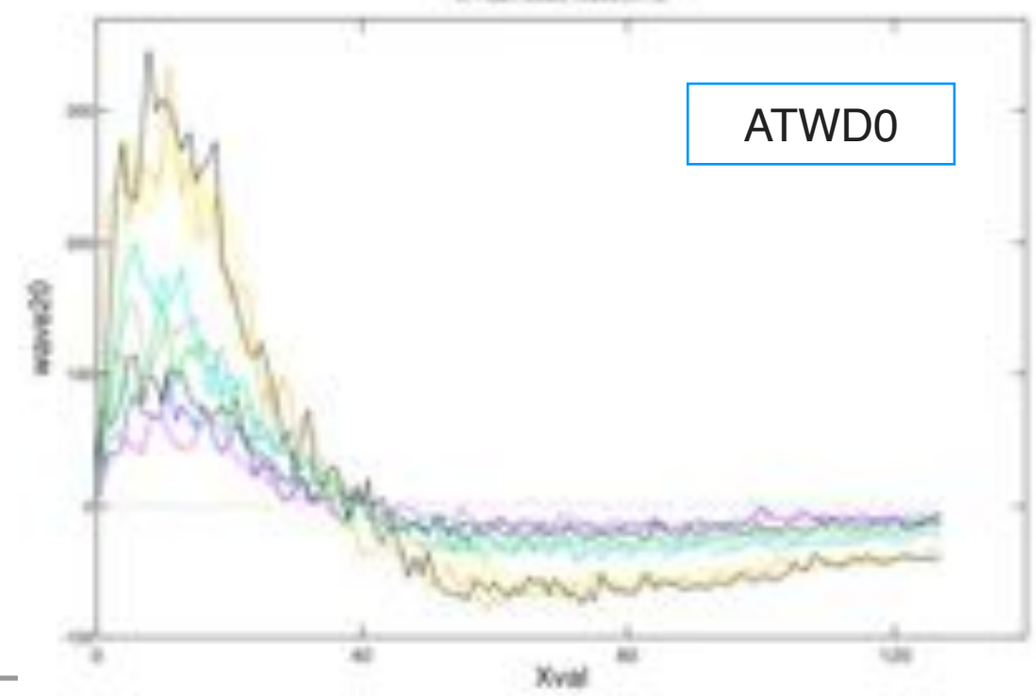
2 NAIAD Crystals from Boulby

- 2 crystals (17 kg) from the NAIAD experiment (2000 - 2003)
- Intrinsic background 5 – 10 times the reported DAMA background
- Boulby Underground Laboratory (1100 m deep)
- Revived and tested two NaI crystals (Bicron) with two 5-inch ETL PMTs each.

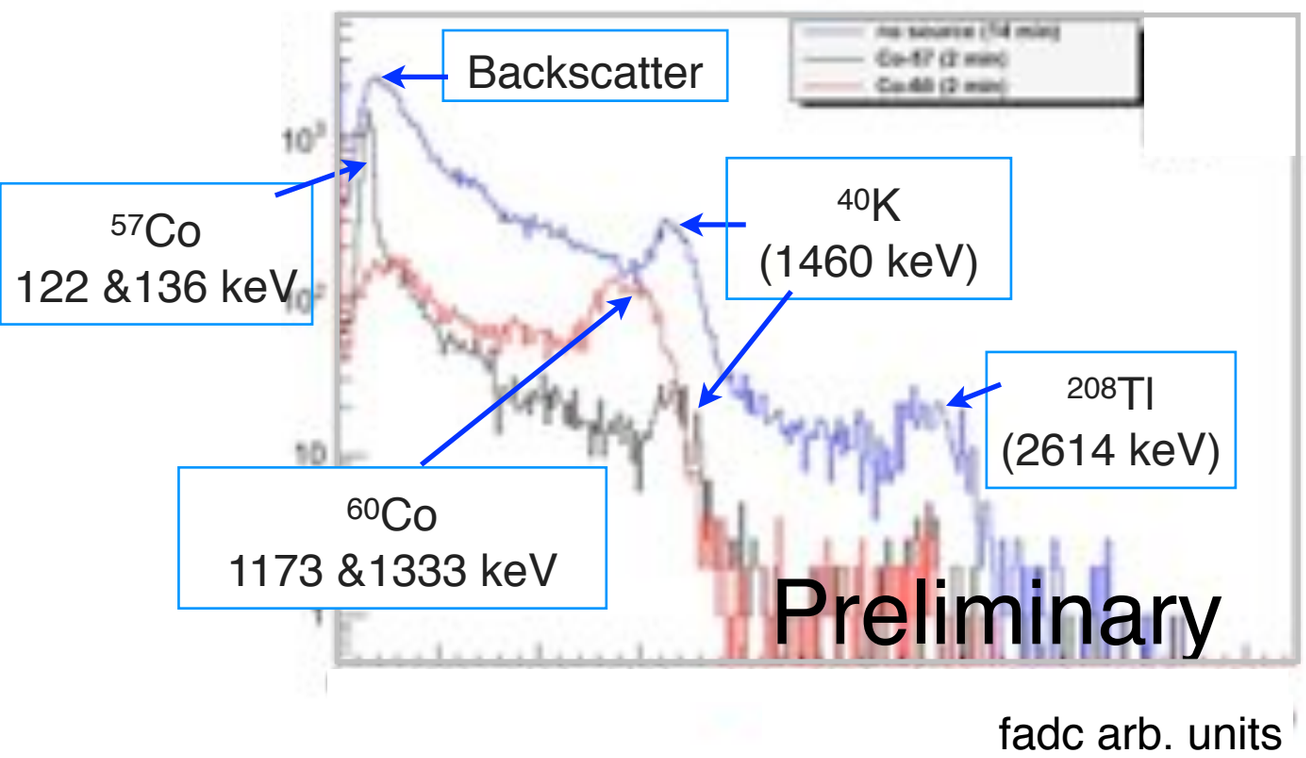
NaI Waveforms from IceCube DOM Mainboards

- Scintillation pulses have time constants of ~ 100 us
- Waveforms recorded with multiple gains (FADC, 3 gains w/ ATWD)
- FADC: 10 bit, 40 MHz, 6.4 μs window,
- ATWD is highly programable with large dynamic range. Pedestal calibration required.

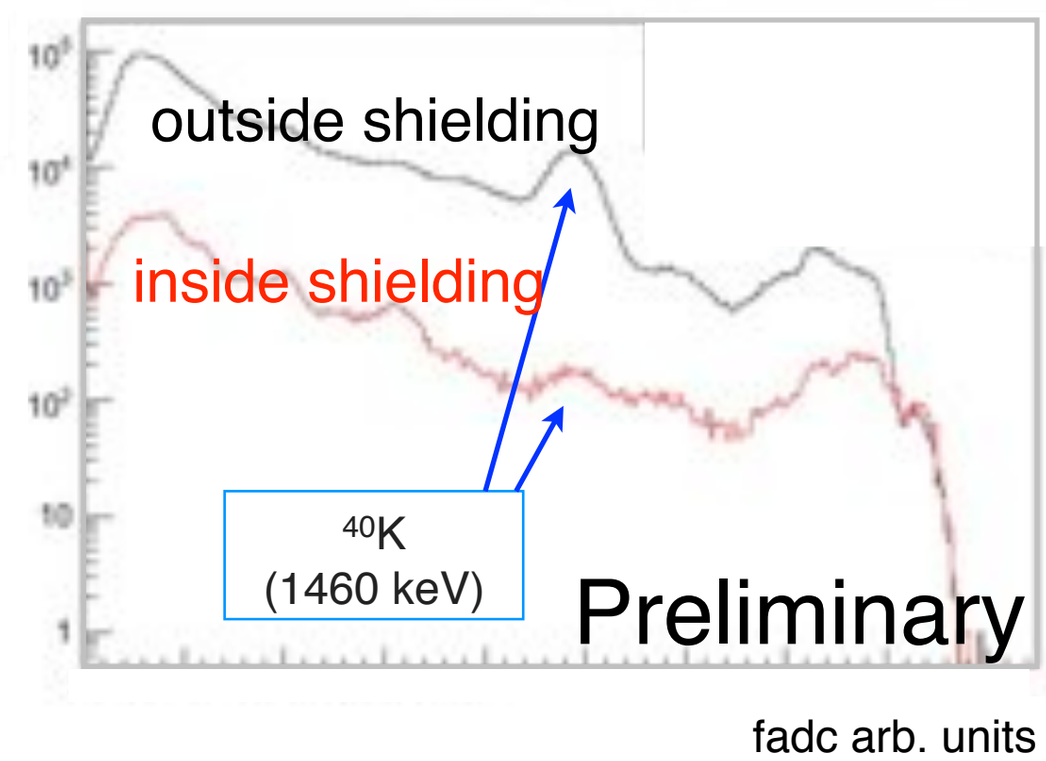




First look at the detectors at Boulby



^{57}Co & ^{60}Co calibration outside shielding



Background measurement inside and outside the shielding

- Detectors seem to be working as well as they did while NAIAD was in operation, background rates reasonable.

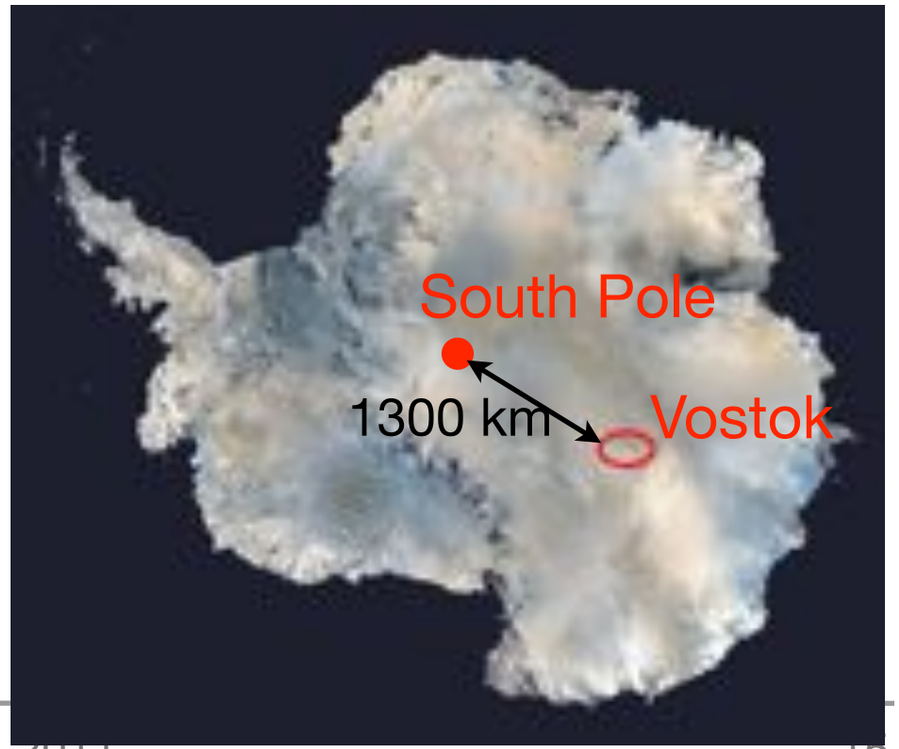
Pressure vessel, support structures, etc

- Stainless, Teflon, etc. selected from vendors known to produce clean material.
  - measurements currently underway at LBNL & SNOLAB.
- Pressure vessel tested to 6200 psi
  - static pressure of water ~ 3500 psi
  - 6000+ psi during ice refreeze in the hole

The Antarctic Ice

- 60 - 70% of all of Earth's fresh water is frozen here.
- Radio-purity available data:
  - Measurements from ice cores at Vostok.
  - Absorption and scattering lengths with lasers and LEDs from AMANDA/ IceCube
- Glacial ice is moving ~10m/year along the 40° west meridian
- Depth (and contaminant concentration) versus age estimated by correlating Vostok/IceCube measurements

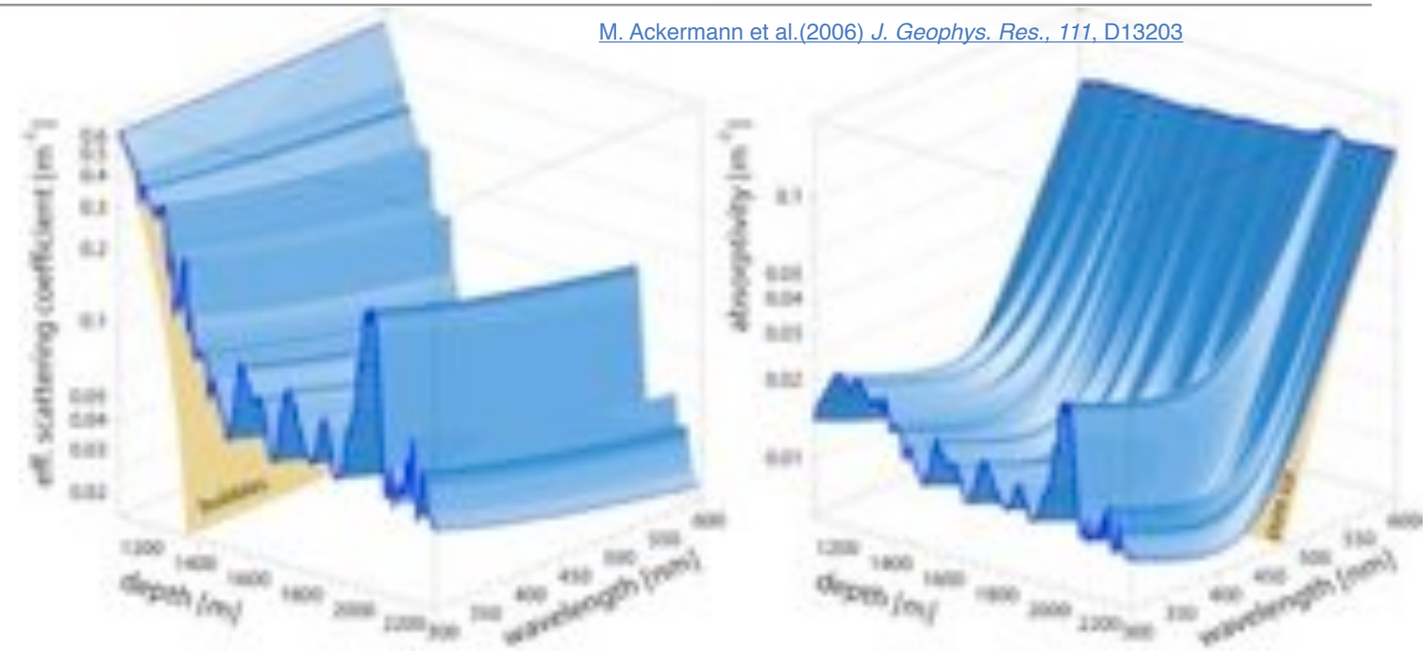
http://en.wikipedia.org/wiki/Vostok_Station



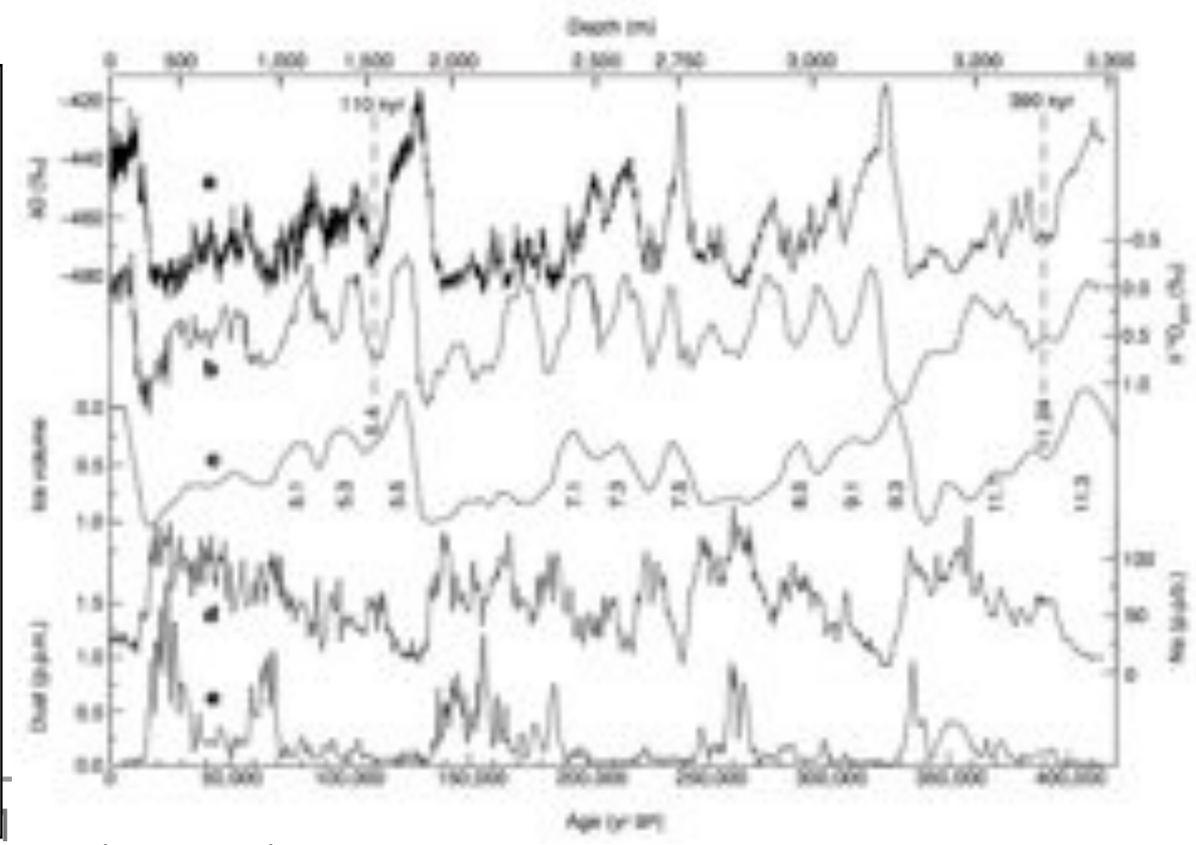
Radiopurity of Antarctic Ice

- -2500 m at South Pole is ~100,000 years old
- Most of the impurities come from volcanic ash, < 0.1 ppm
- Ice is nearly as clean as the cleanest materials used for ultra-low background experiments.
  - U ~ ppt
  - Th ~ ppt
  - K ~ ppb

M. Ackermann et al.(2006) *J. Geophys. Res., 111*, D13203



Petit et al, (1999) Nature 399 p. 429



Enhanced Hot Water Drill - EHWD

Firn Drill

Deep Drill

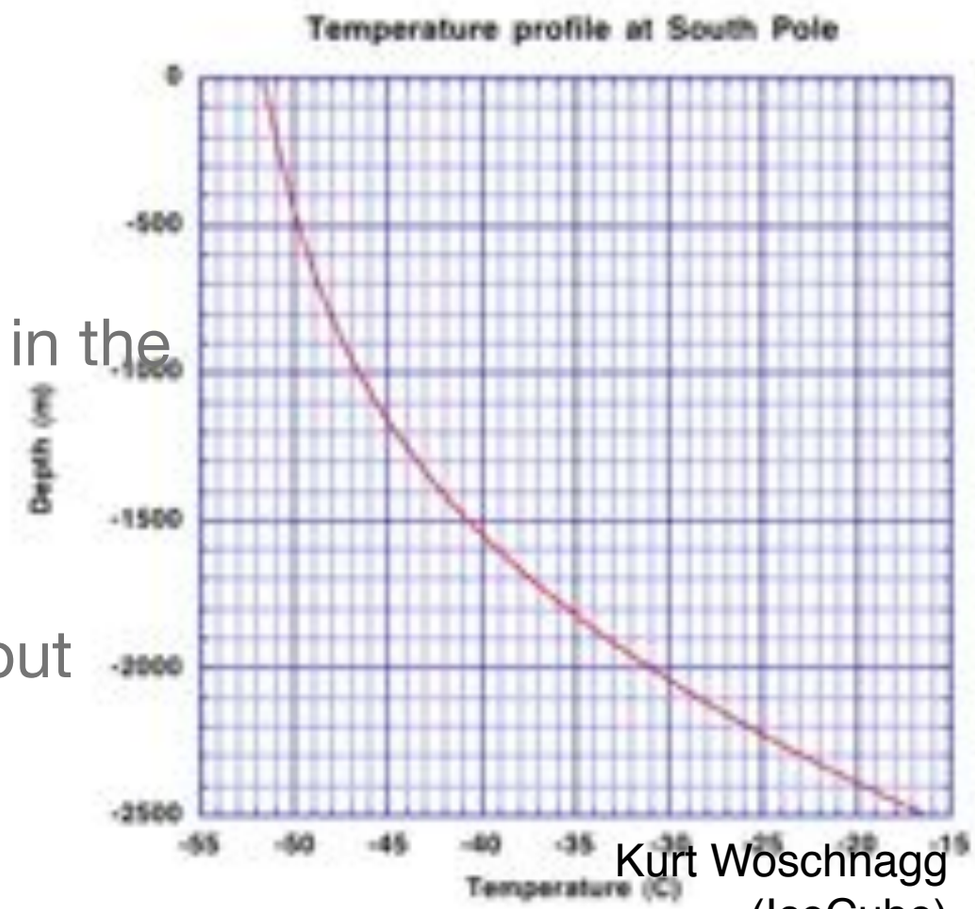
Enhanced Hot Water Drill

Water Purity Analysis

- Drill water may introduce impurities in the water
- Water samples from 3 holes taken during 2009 - 2010 season for IeCube
- Additional analysis from 2010/11 holes
- Samples taken from return from the inlet in to “Tank-1” as water is pumped out from the hole
- Samples counted at SNOLAB look very promising
  - < ppb of U/Th
  - < 200 ppb K-40
- Currently carrying out a more sensitive counting

Antarctic Ice: Temperature

- Each IceCube DOM can measure temperature in the ice
- At -2500 m, the ice is -20 °C
- at -20℃, NaI pulses are slower than at +25℃ but light output is slightly better.
- Temperature is stable throughout the year



Kurt Woschnagg (IceCube)

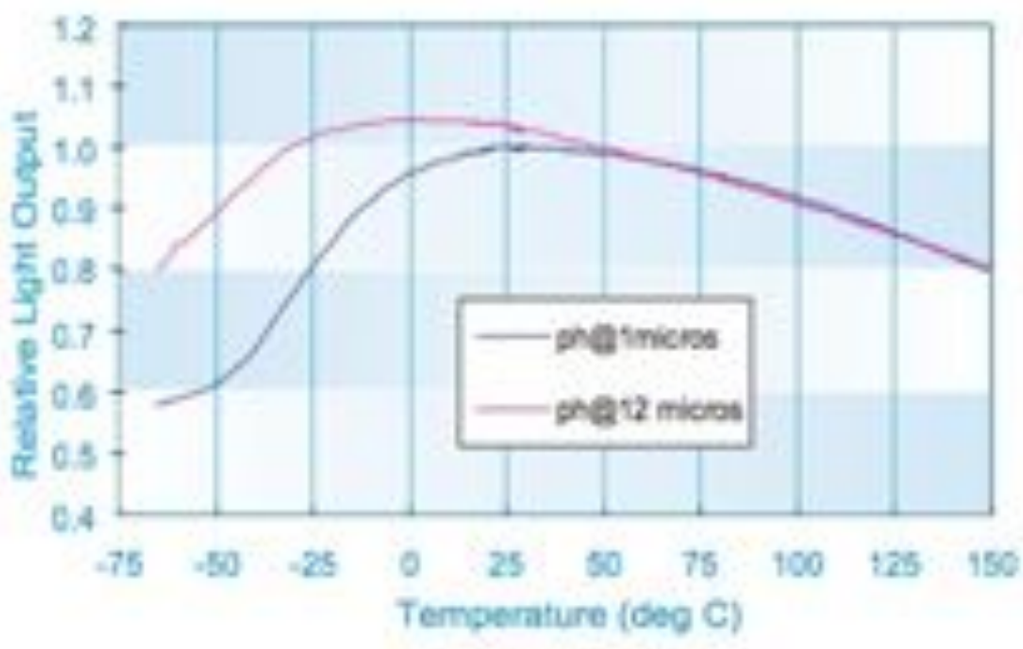


Figure 2. Temperature response of NaI[Tl]

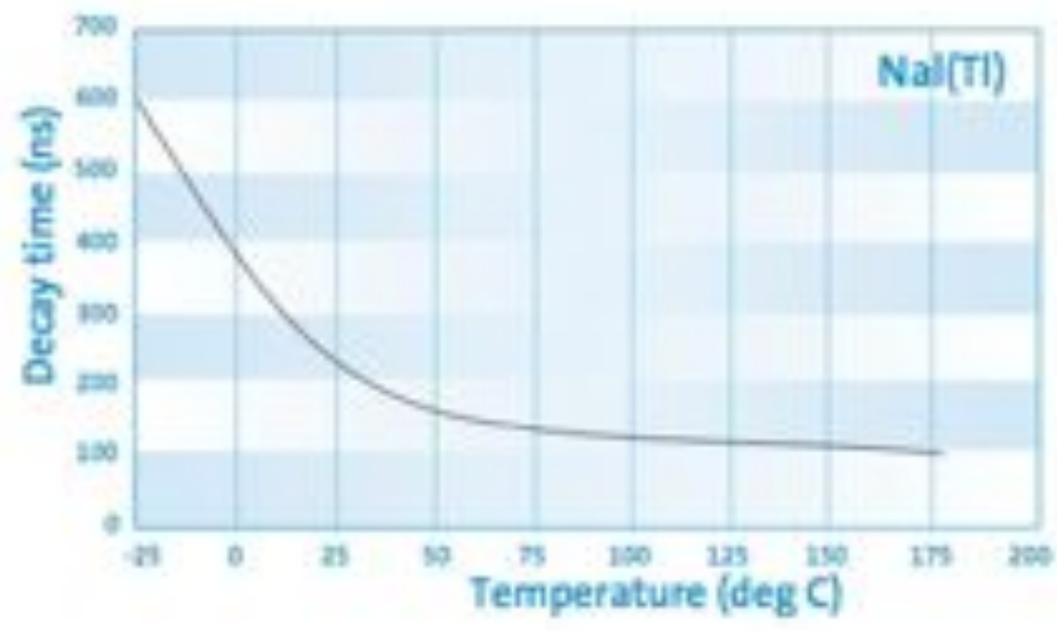
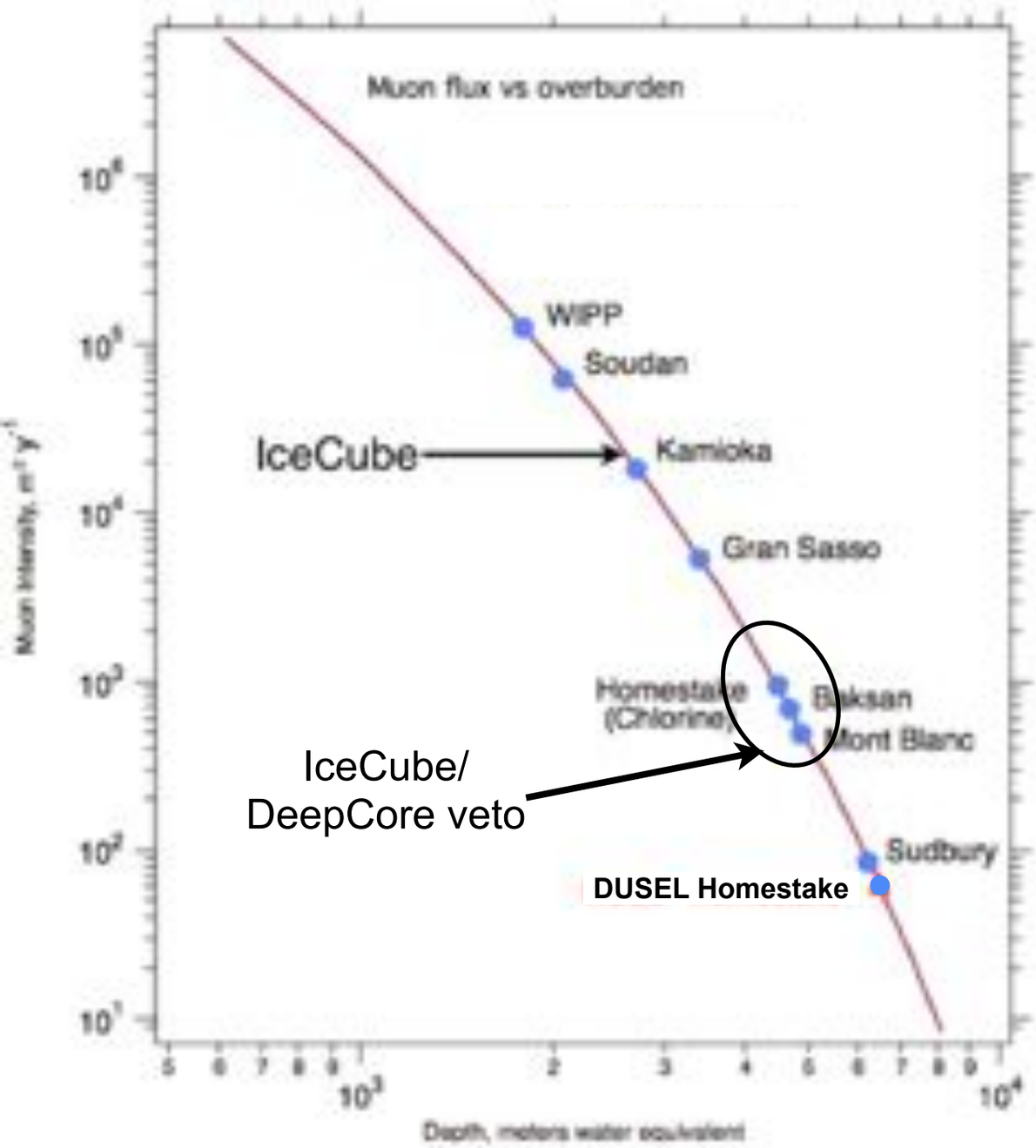


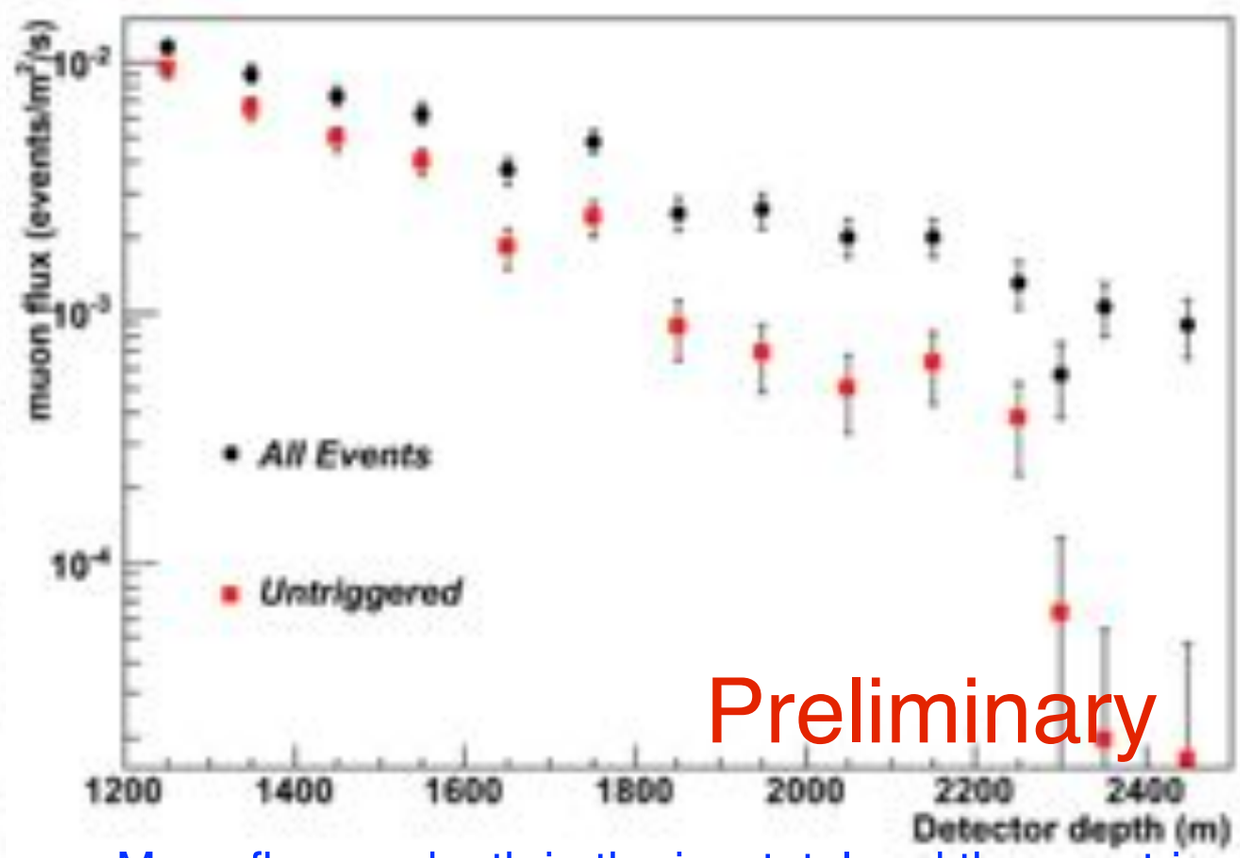
Figure 3. Temperature dependence of the decay time of NaI[Tl]

http://www.detectors.saint-gobain.com

Antarctic Ice: Overburden at -2500 m (2200 m.w.e.)



- ~85 muons/m^2/day at bottom of IceCube
- IceCube/DeepCore veto reduces rate by ~1-2 orders of magnitude.

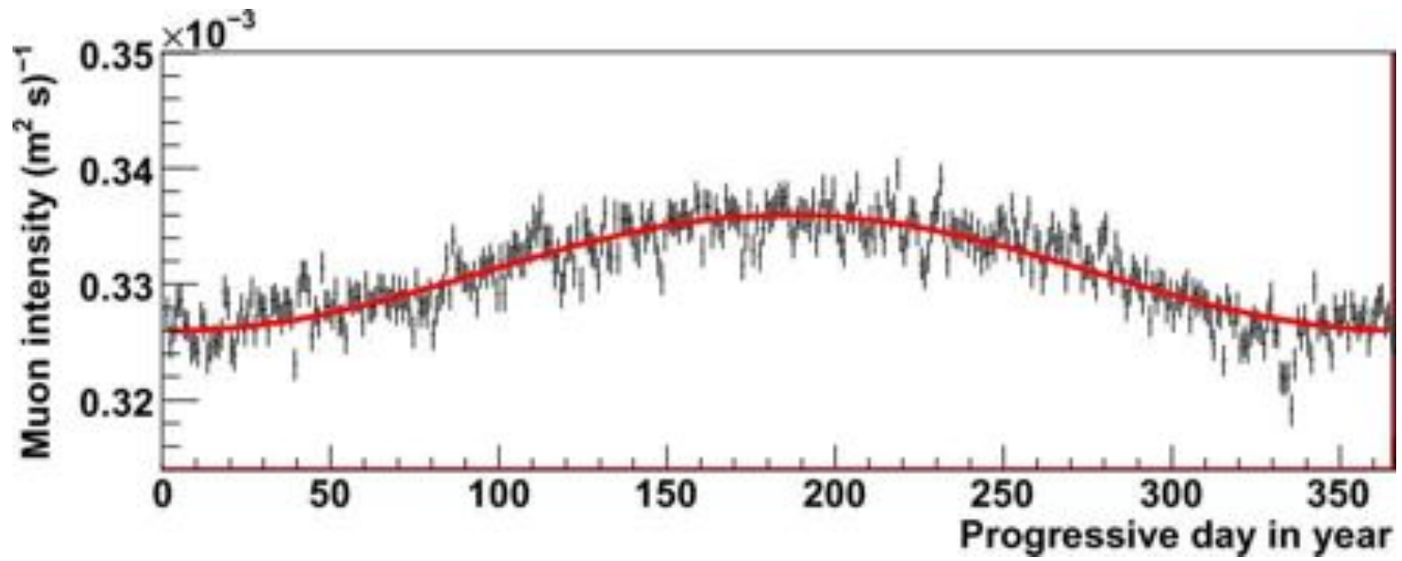


Muon flux vs. depth in the ice, total and those untriggered by IceCube/DeepCore. (Darren Grant)

Muon Rate at Gran Sasso vs. South Pole

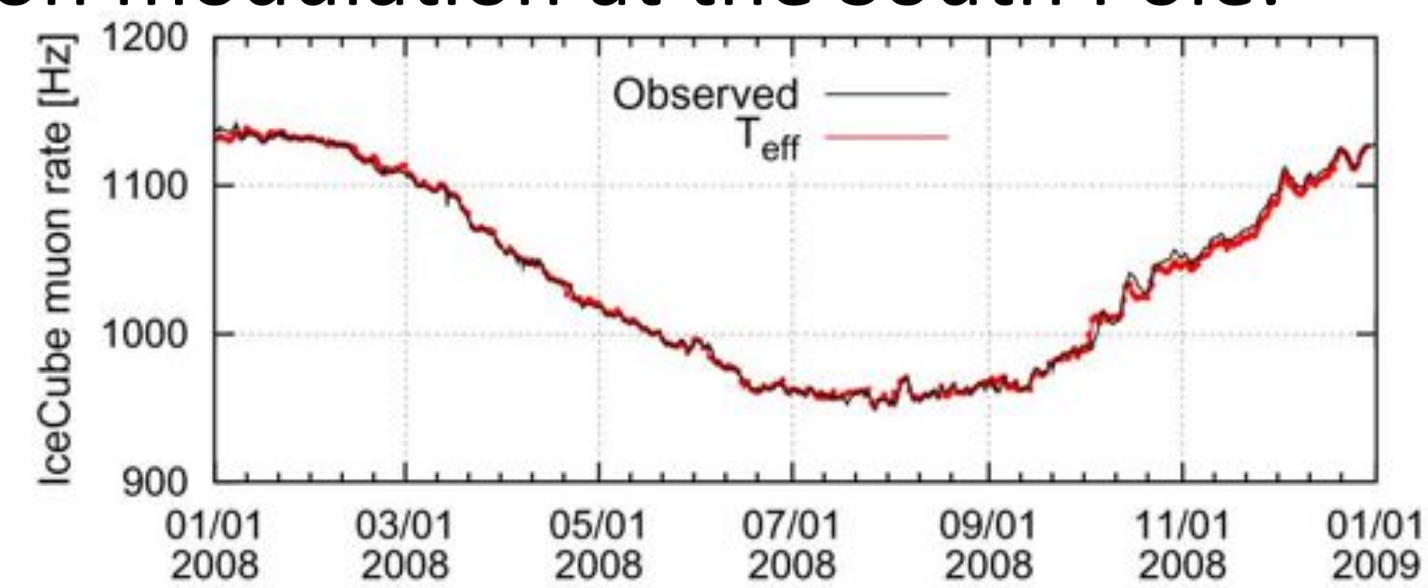
- LVD:

Selvi, Proc. 31st ICRC. (2009)



- Opposite Muon modulation at the South Pole:

Tilav, Proc. 31st ICRC. (2009)



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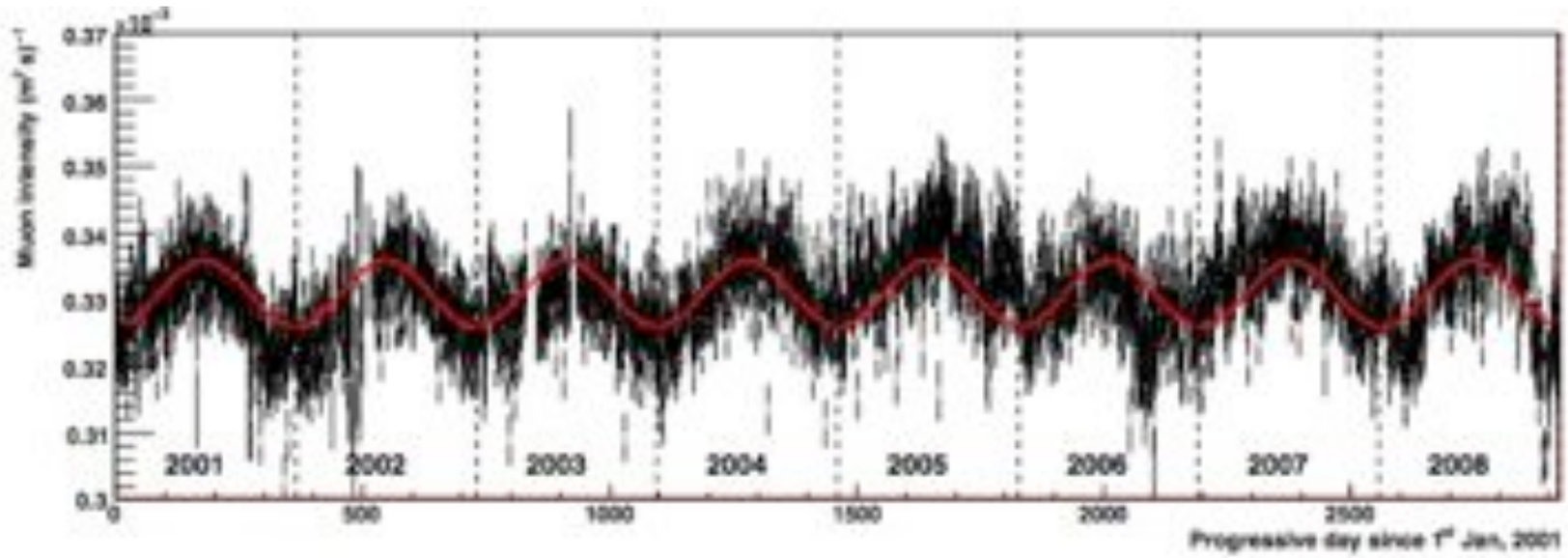

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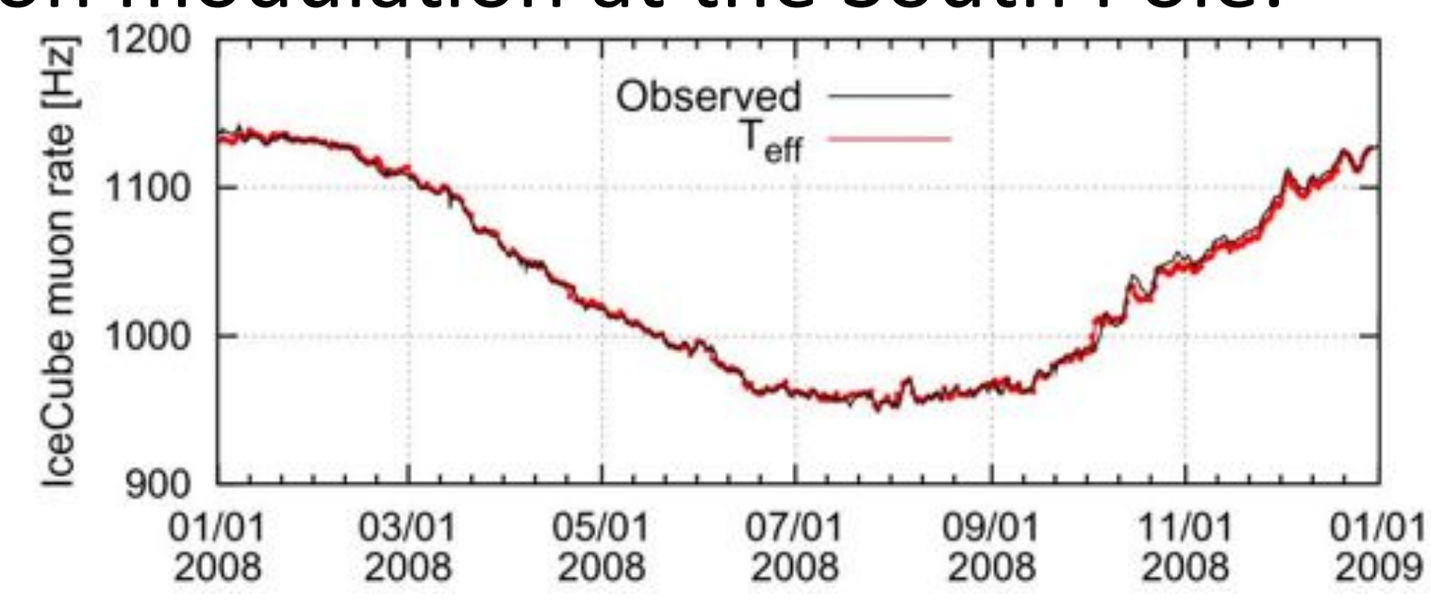


Seasonal Muon Rate Modulation

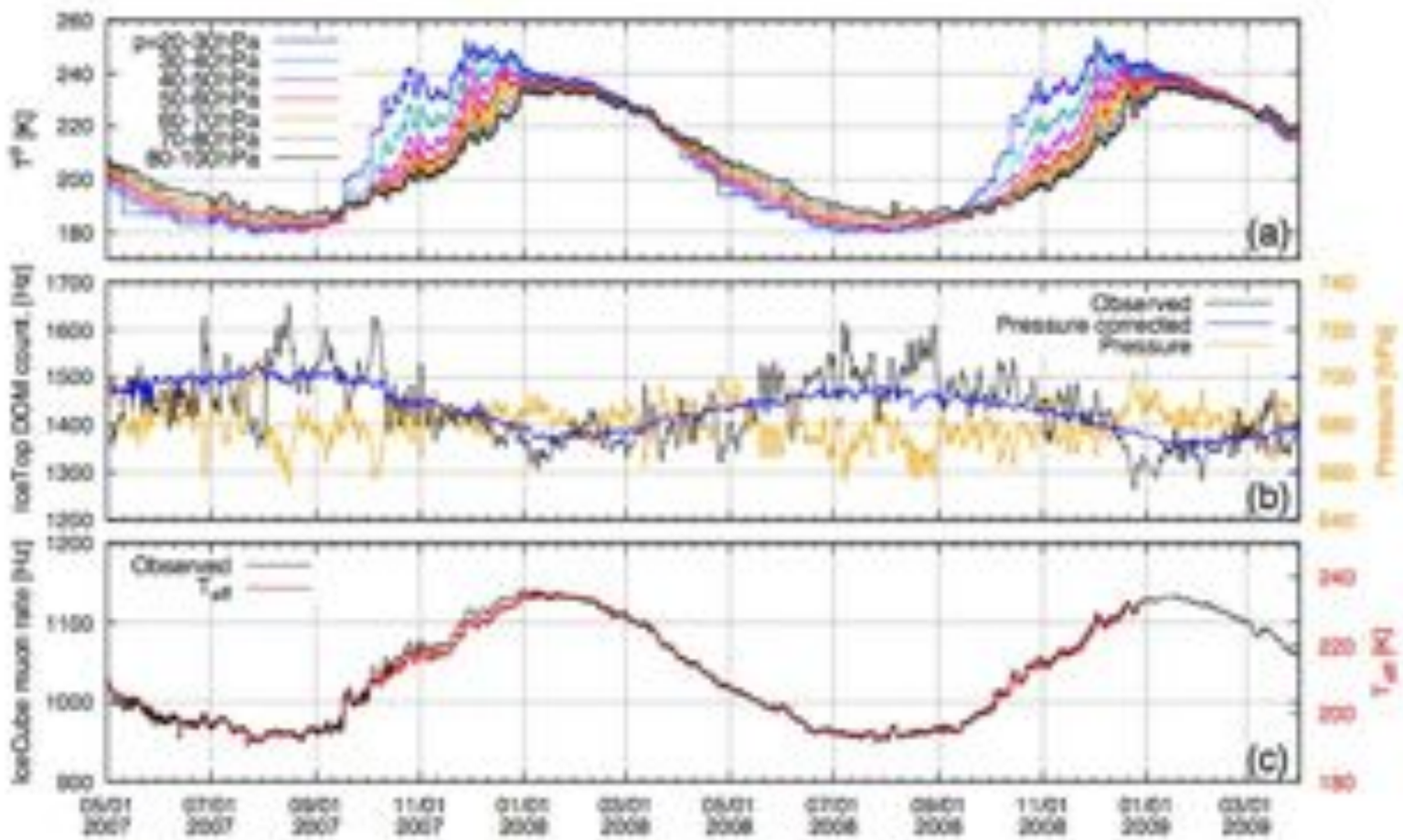
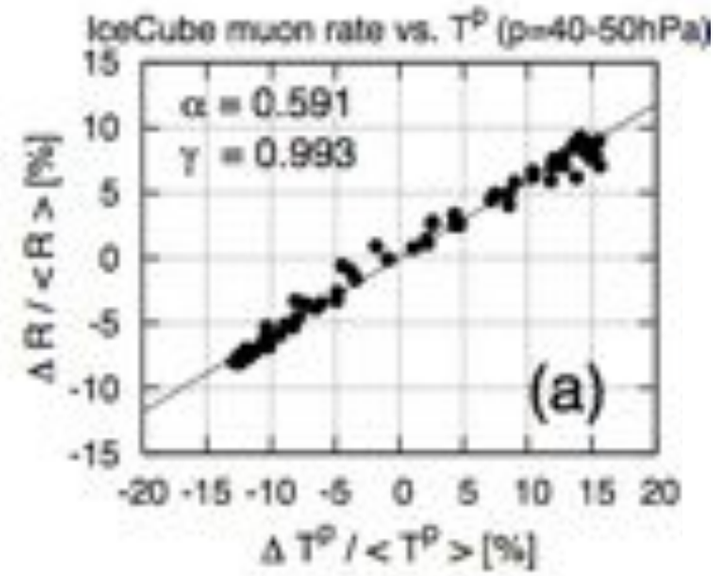
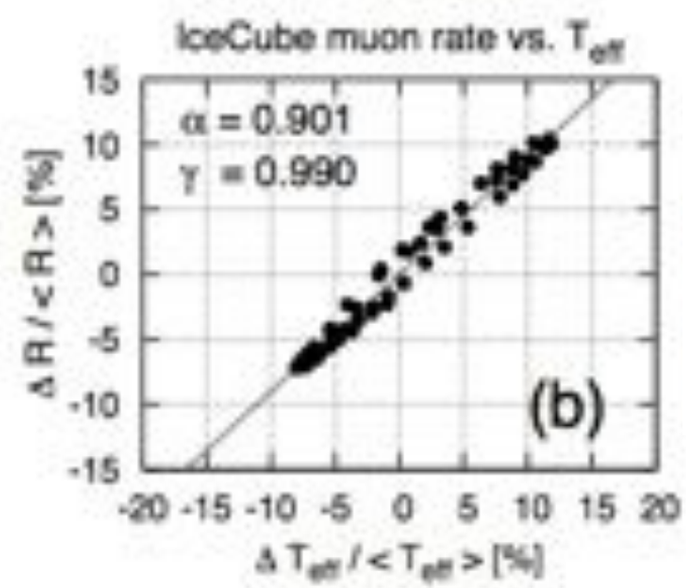


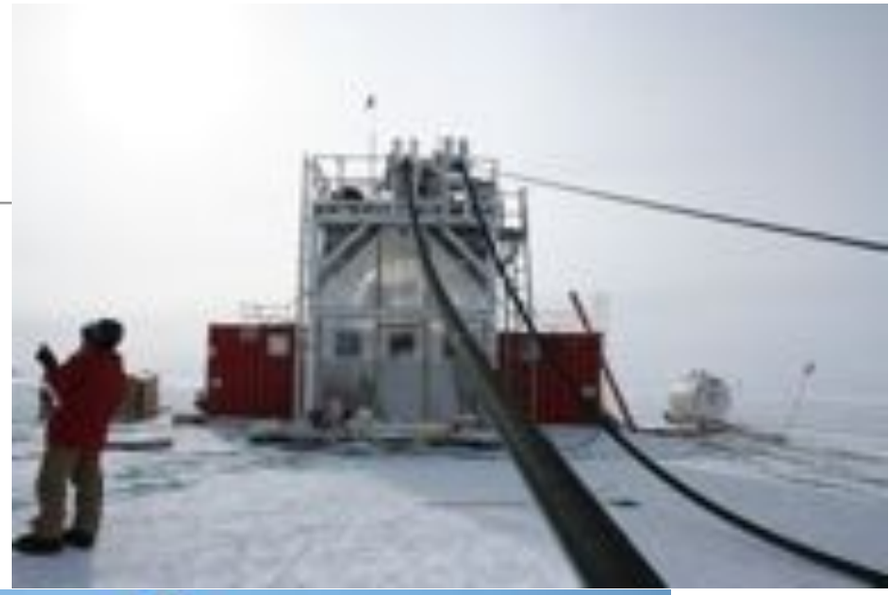
Fig. 1. The temporal behavior of the South Pole stratosphere from May 2007 to April 2009 is compared to IceTop DOM counting rate and the high energy muon rate in the deep ice. (a) The temperature profiles of the stratosphere at pressure layers from 20 hPa to 100 hPa where the first cosmic ray interactions happen. (b) The IceTop DOM counting rate (black -observed, blue -after barometric correction) and the surface pressure (orange). (c) The IceCube muon trigger rate and the calculated effective temperature (red).





Tilav et al, ArXiv:astro-ph/1001.0776

Challenges of going to the Pole

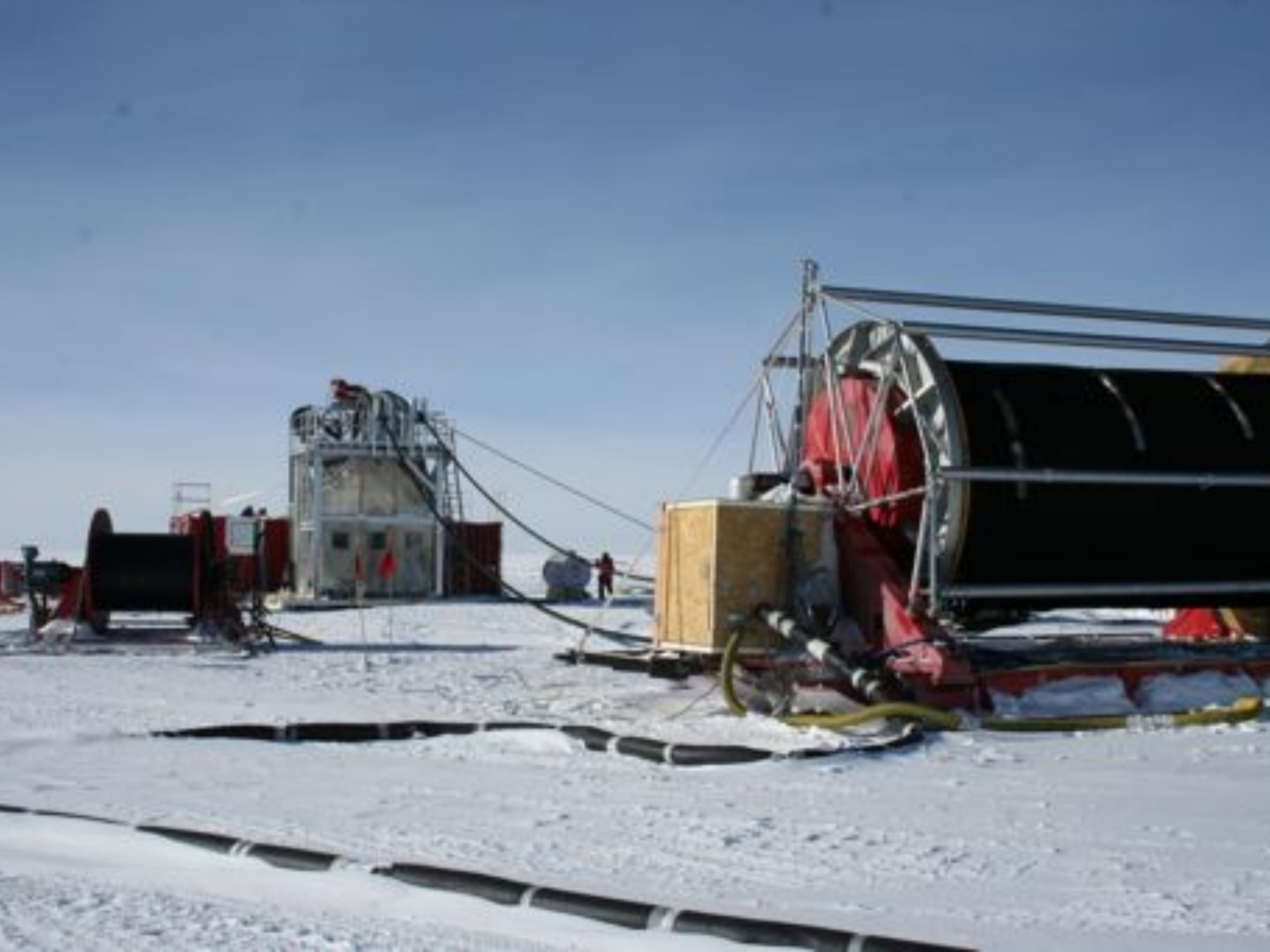


- IceCube construction finished in Dec. 2010.
  - new holes will need to be drilled after this year.
- Detector will be inaccessible once deployed.
  - NaI detectors have been launched into space (e.g. EGRET, Fermi LAT)
- DAMA uses NaI(Tl) crystals grown with proprietary process to achieve low U/Th/K content.
  - U/Th is exuded out during crystal growing. K is more difficult.
  - R&D to grow clean NaI crystals underway by several groups
  - ...but DAMA has done it!


2137


MANTIS


GUS
CAT



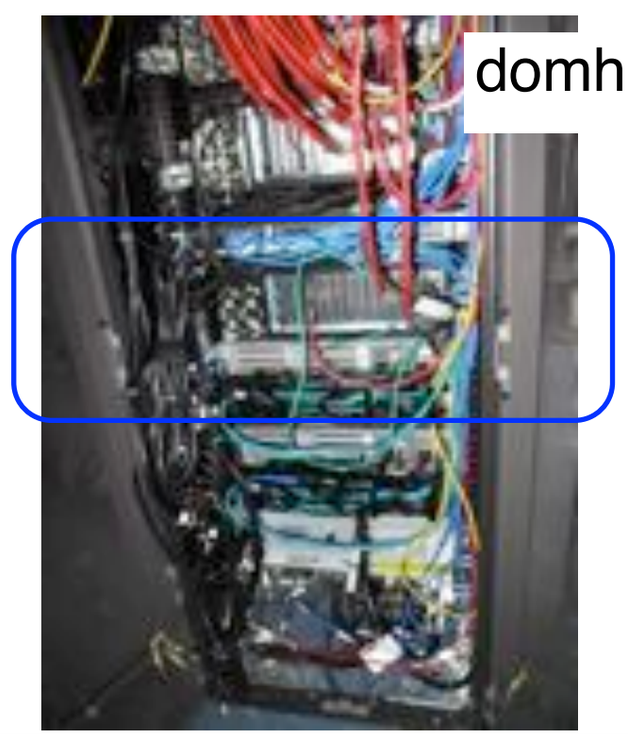
DM-Ice Electronics in ICL

ICL

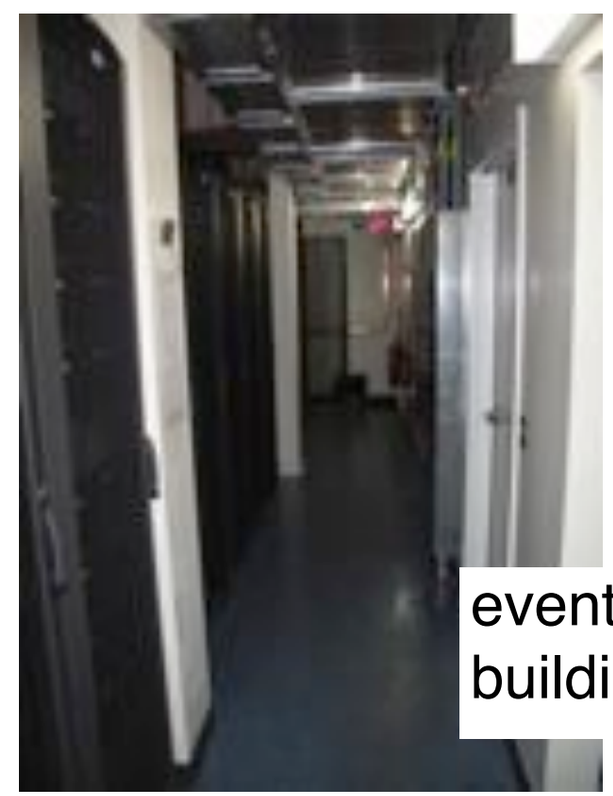
"beer can" with string cables

string cable penetrations into ICL

patch panels



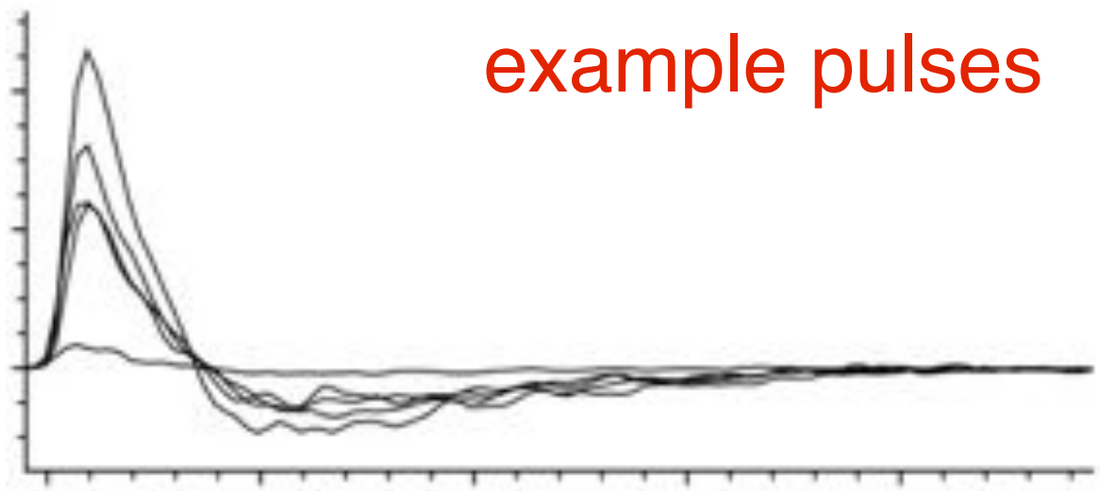
domhubs



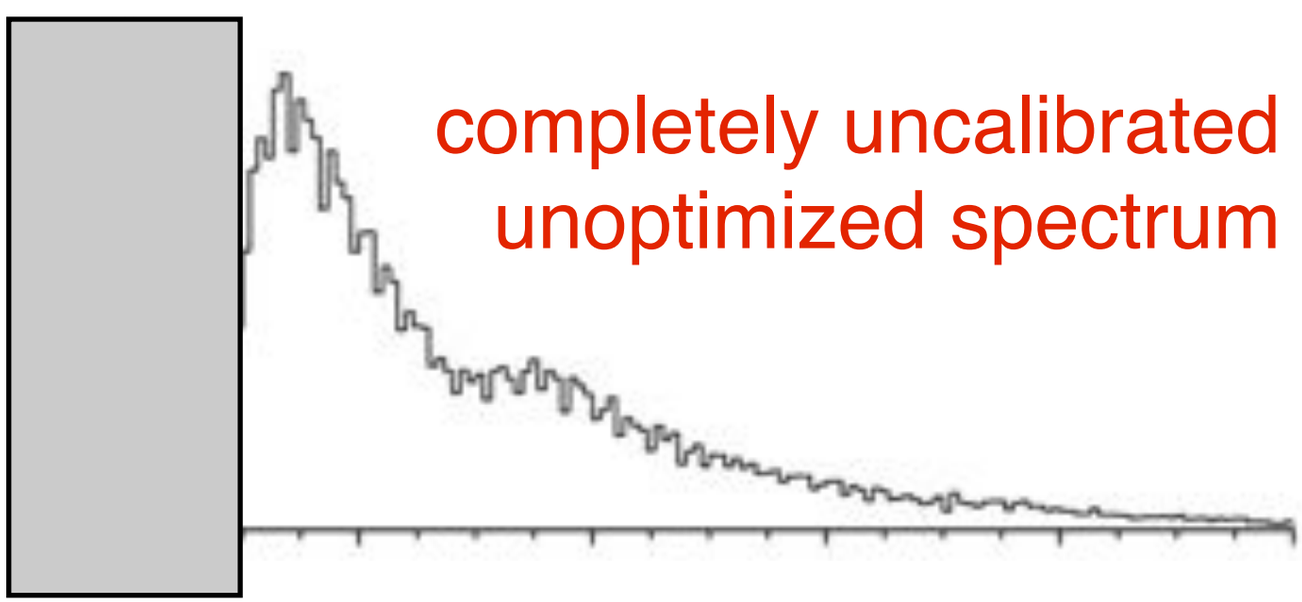
event building

Data from the South Pole

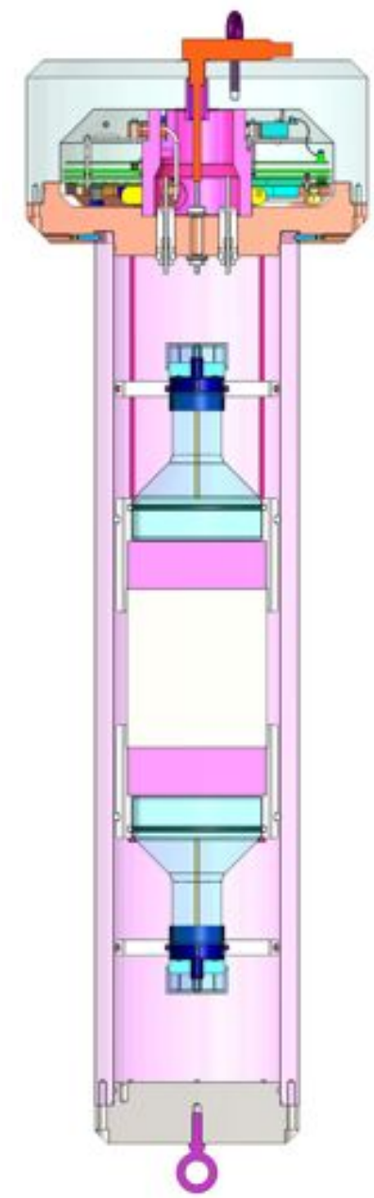
- Preliminary look at the data from one of the PMTs in the ice using IceCube pulse viewing tools



example pulses



completely uncalibrated
unoptimized spectrum

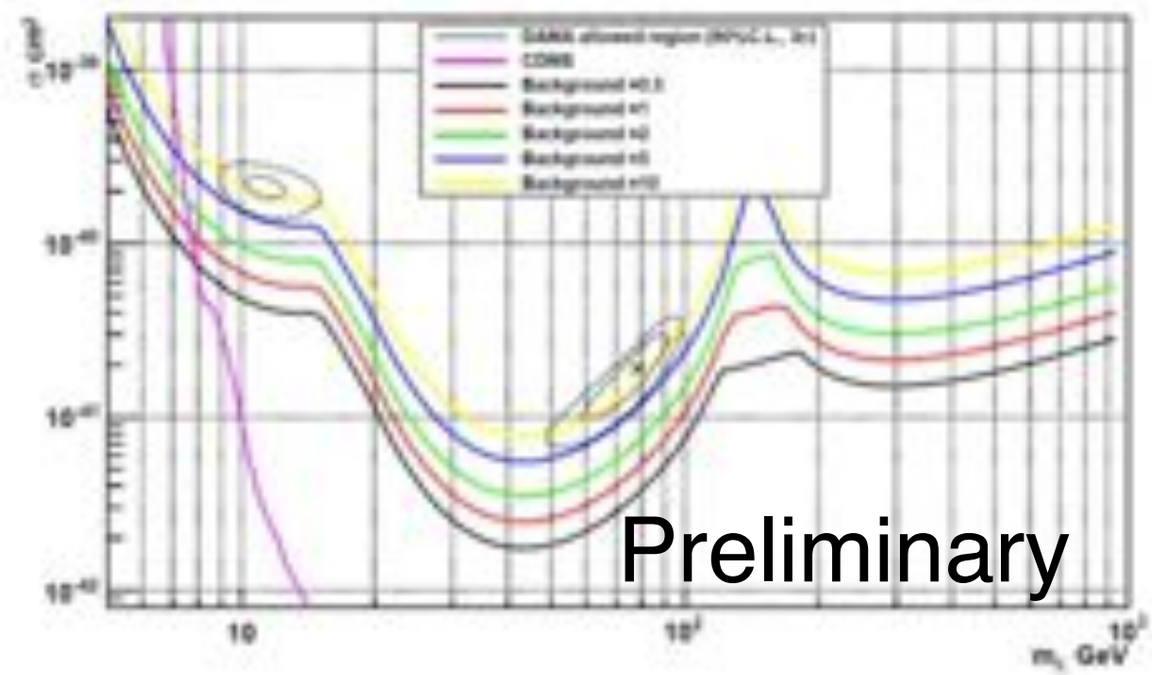


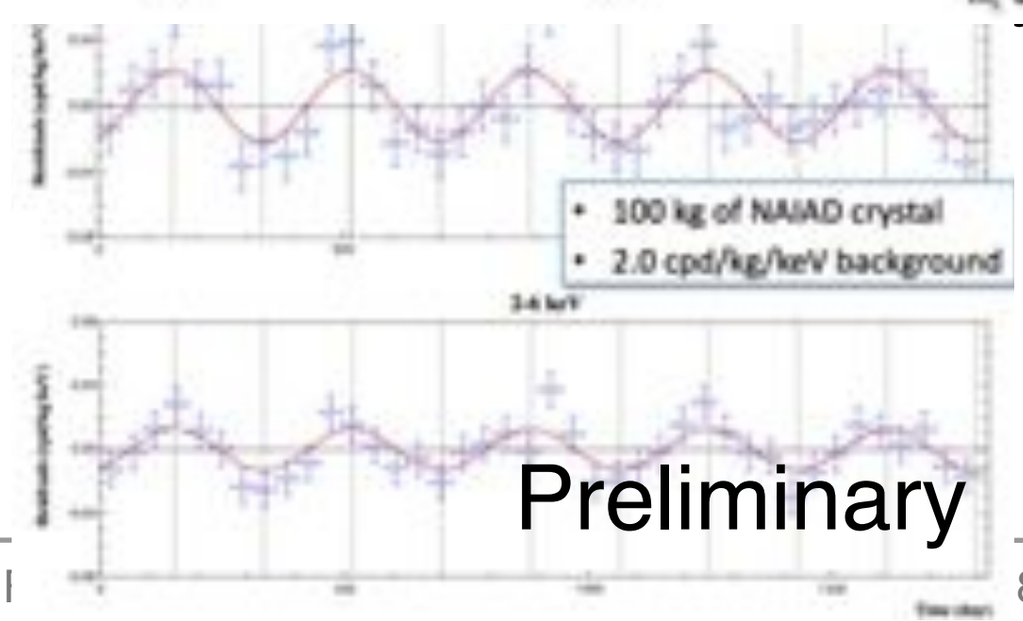
Testing DAMA

- If DAMA signal is there, we can do a 5-sigma measurement in 2 years with 250 kg and comparable background as DAMA.

		2 NAIAD	NAIAD size	DAMA size
	Years	17.0 kg	44.5 kg	250 kg
NAIAD background	1	0.45	0.72	1.71
	3	0.77	1.25	2.96
	5	1.00	1.61	3.82
	7	1.18	1.91	4.52
50% NAIAD background	1	0.63	1.02	2.42
	3	1.09	1.77	4.18
	5	1.41	2.28	5.40
	7	1.67	2.70	6.39
Double DAMA background	1	0.85	1.37	3.26
	3	1.47	2.38	5.64
	5	1.90	3.07	7.29
	7	2.25	3.64	8.62
DAMA background	1	1.20	1.94	4.61
	3	2.08	3.37	7.98
	5	2.69	4.35	10.31
	7	3.18	5.14	12.19
1/10 DAMA background	1	3.80	6.15	14.57
	3	6.58	10.65	25.24
	5	8.50	13.75	32.59
	7	10.06	16.27	38.56

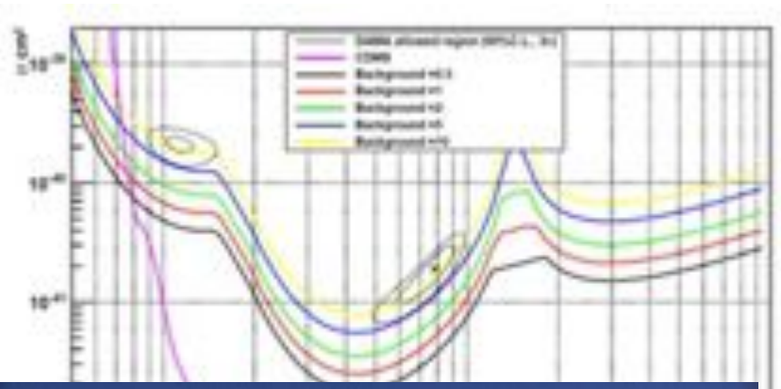
For a 250 kg NaI detector with 2-year running time (2 - 4 keV)

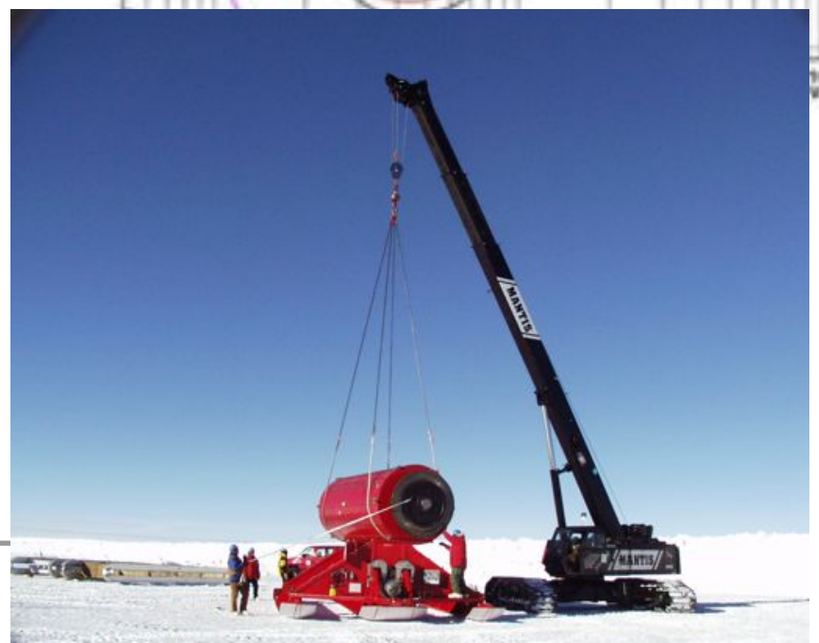




Current Status & Future Outlook

- DM-Ice prototype (17 kg) deployed in December 2010
  - Currently taking data, tweaking operating parameters
  - data transmitted over satellite
  - optimizing analysis, background studies with radio-assay & monte carlo simulation
- >250-kg scale detector under consideration
  - R&D for low background crystals
  - low background PMTs, pressure vessel
  - Calibration
  - Optimize (simplified) daq board and electronics
  - IceCube drill moth-balled at SP





DM-Ice

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