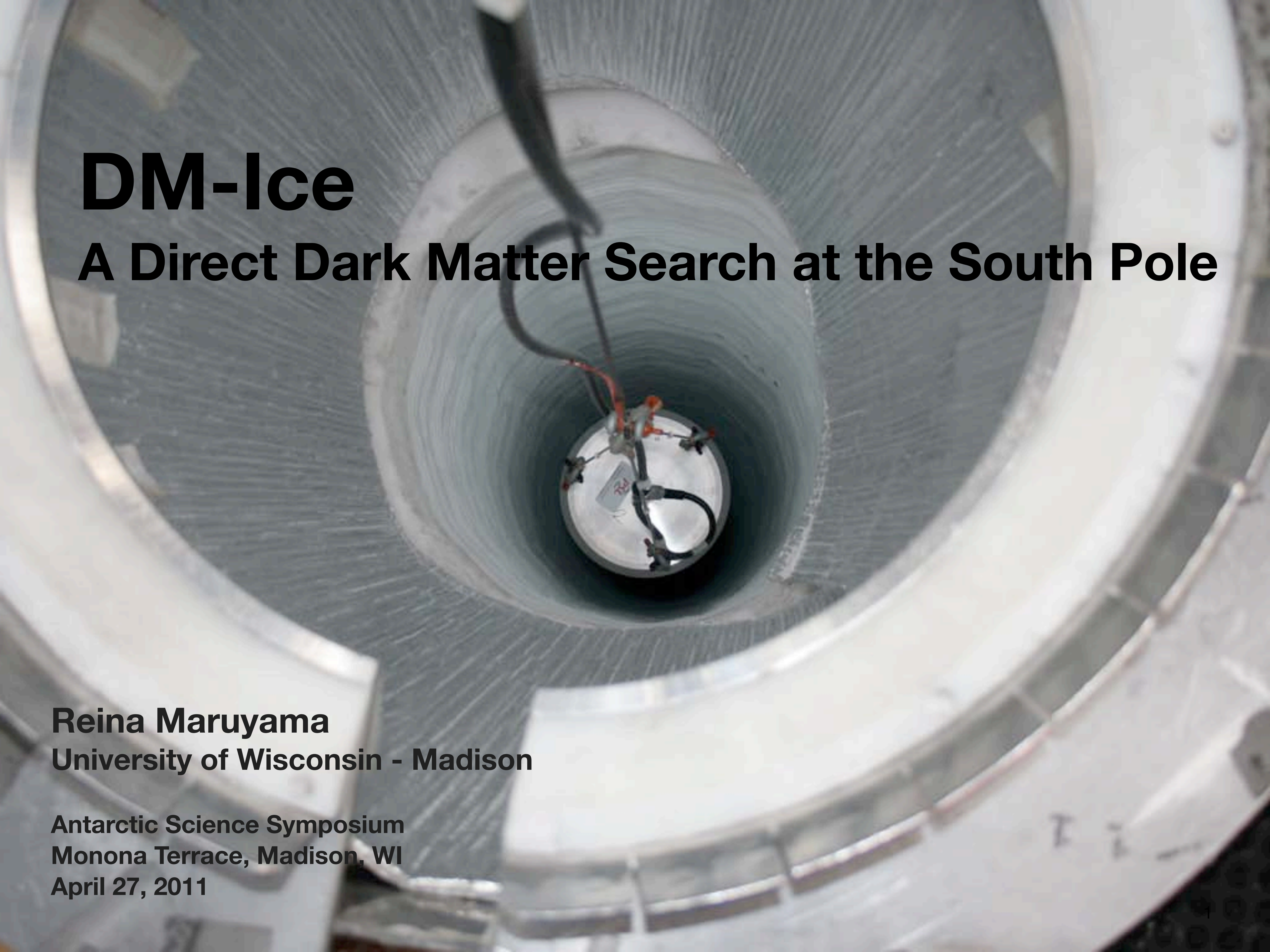


DM-Ice

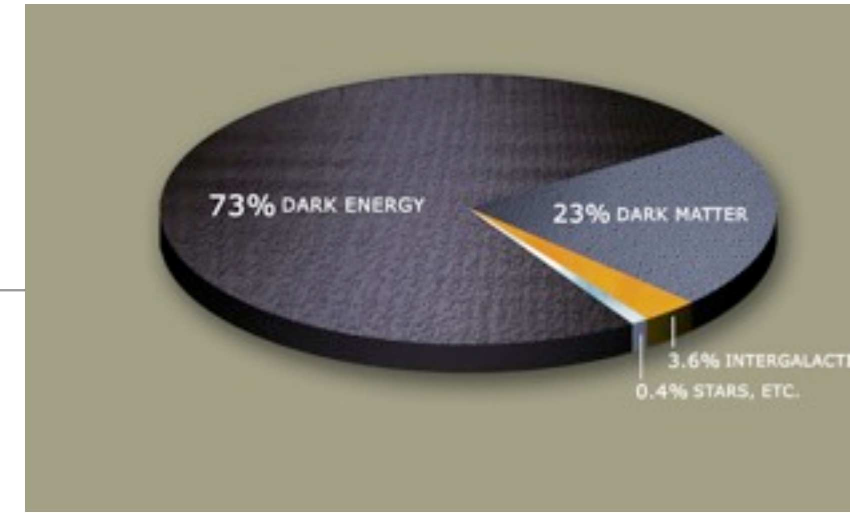
A Direct Dark Matter Search at the South Pole

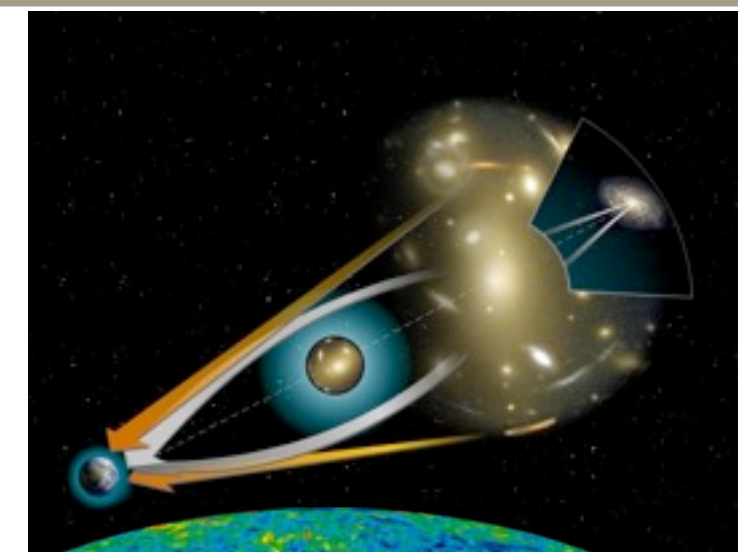
Reina Maruyama
University of Wisconsin - Madison

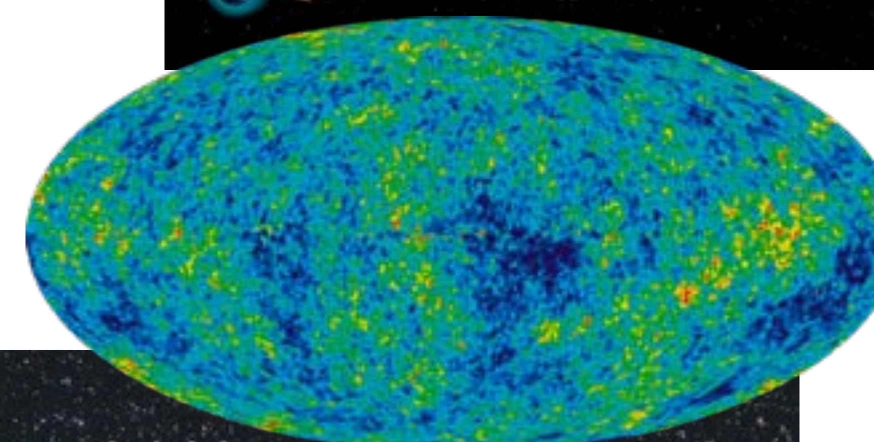
Antarctic Science Symposium
Monona Terrace, Madison, WI
April 27, 2011

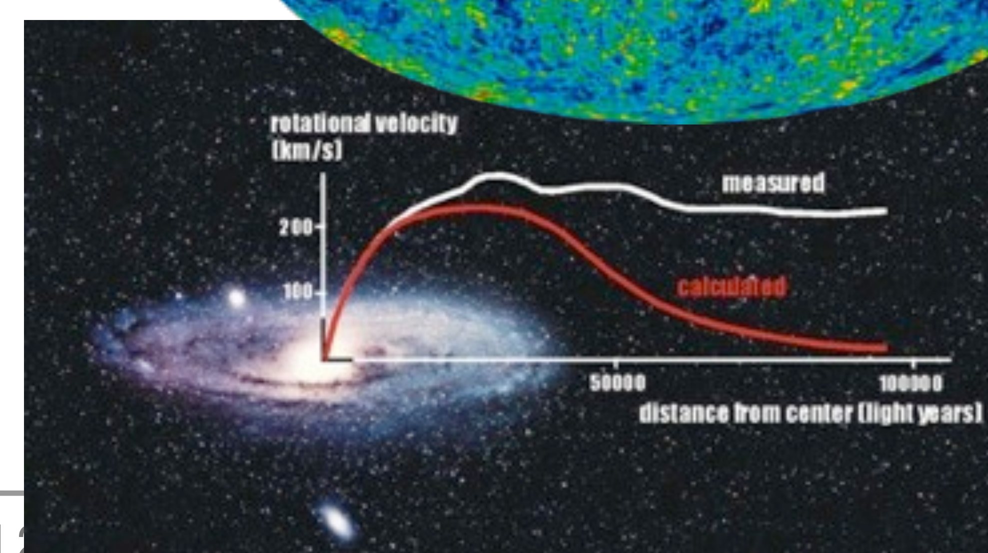
Evidence for Dark Matter

- There is more stuff out there that exerts gravity than we can see!
    - Galactic rotation curves
    - Galaxy clusters and gravitational Lensing
    - Velocity dispersions of galaxies
    - Cosmic microwave background
    - Baryon Acoustic Oscillation clustering
    - Type Ia supernovae distance measurements
    - Lyman alpha forest
    - Structure formation
- All consistent with 23% dark matter content.









Current picture and detection of Dark Matter

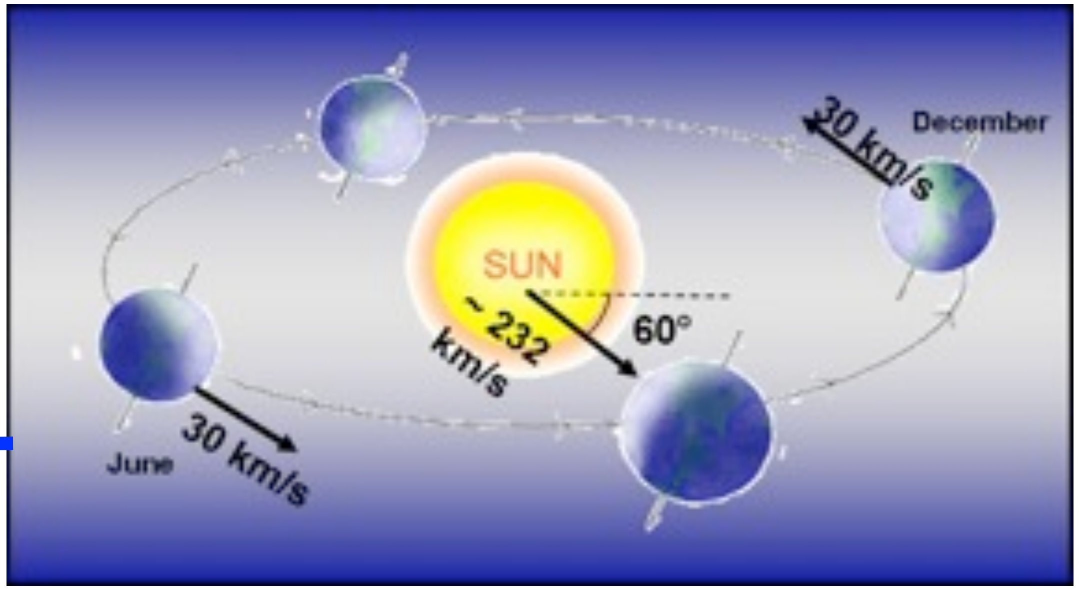
- Isothermal, spherical dark matter halo around the galaxy, with Maxwell-Boltzmann velocity distribution

$$f(v)dv = \frac{4v^2}{v_0^3\sqrt{\pi}} e^{-v^2/v_0^2} d^3v$$

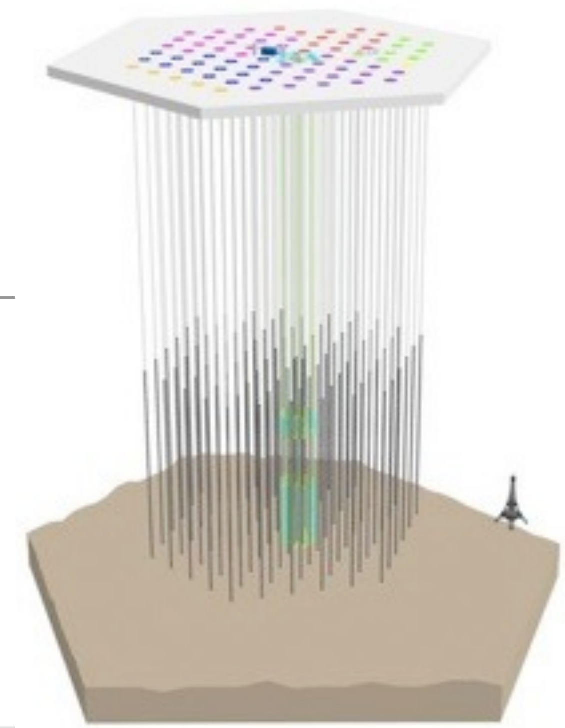
  - $v_0 \sim 230$ km/s, $v_{esc} \sim 550$ km/s, $\rho_\chi = 0.3$ GeV / cm^2

- WIMPs elastically scatter off nuclei in targets, producing nuclear recoils

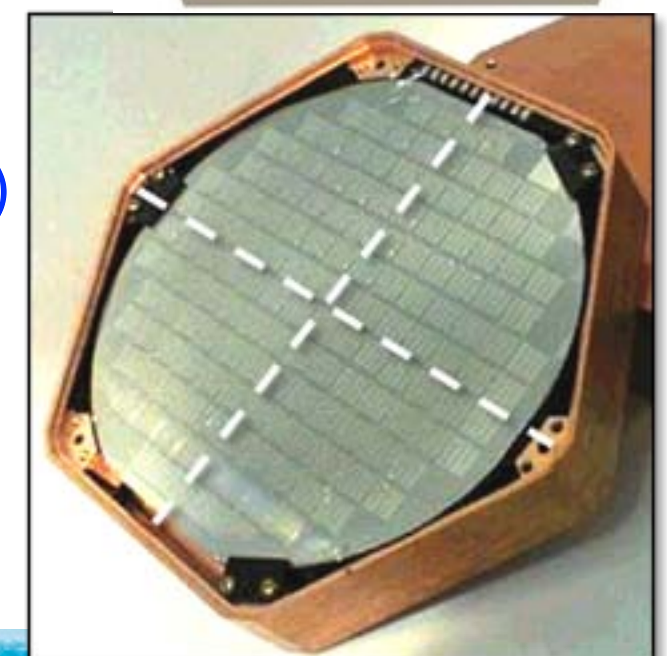
- We can look for
  - individual interactions,
  - annual modulation, or
  - diurnal modulations.



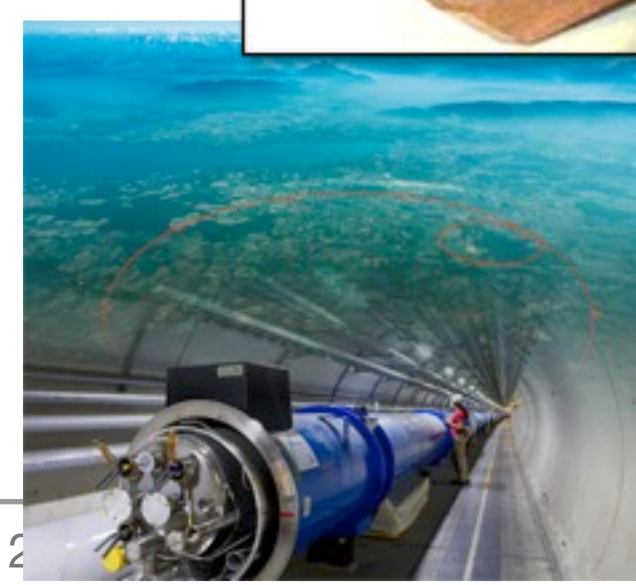
Techniques for Detecting Dark Matter



- Indirect detection (IceCube, etc.)
  - observe products of WIMP annihilation/decay in terrestrial or space based detectors

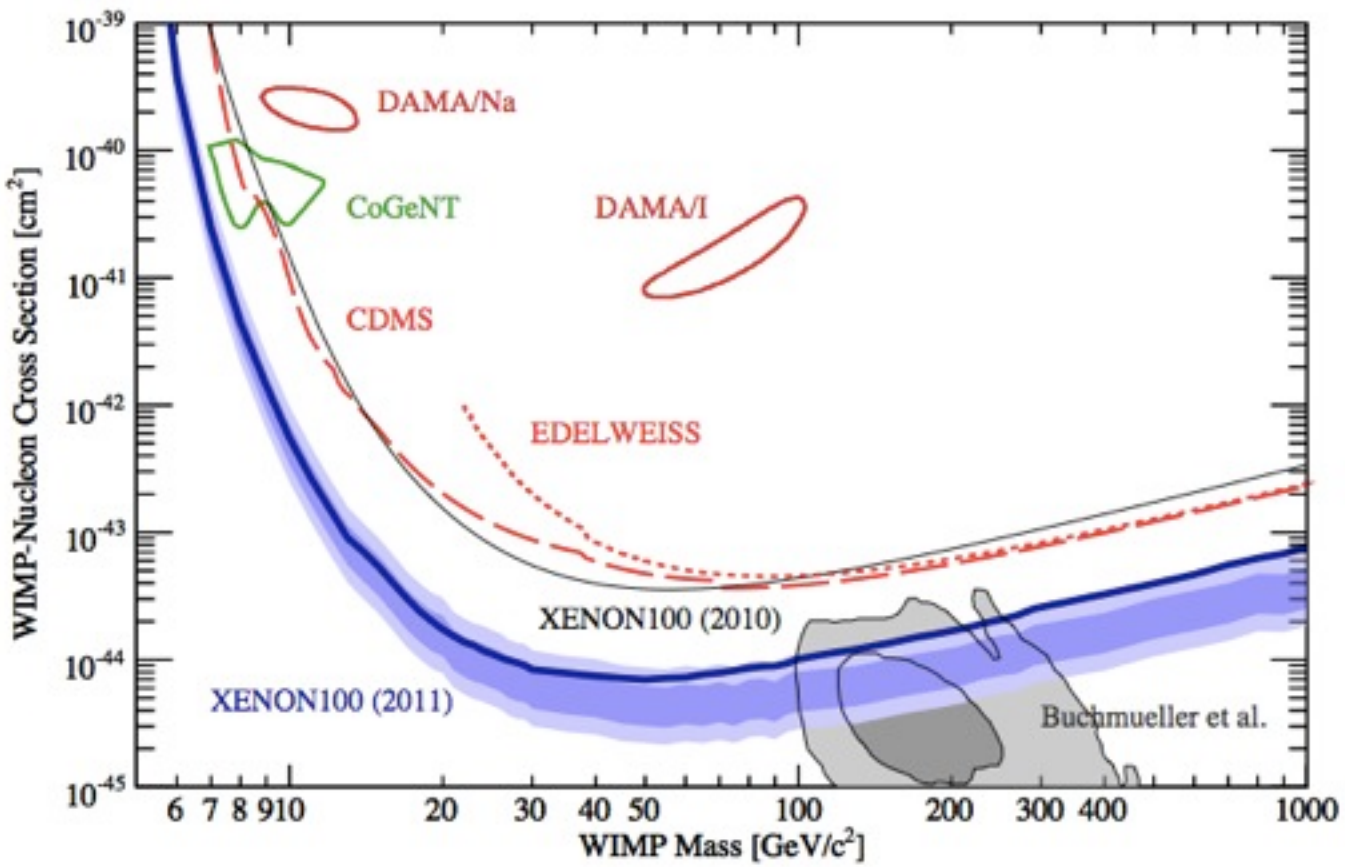


- Direct detection (CDMS, XENON, DEEP, LUX, DAMA, etc.)
  - observe WIMPS through with matter in terrestrial detectors
- Colliders
  - produce WIMPs directly at the LHC



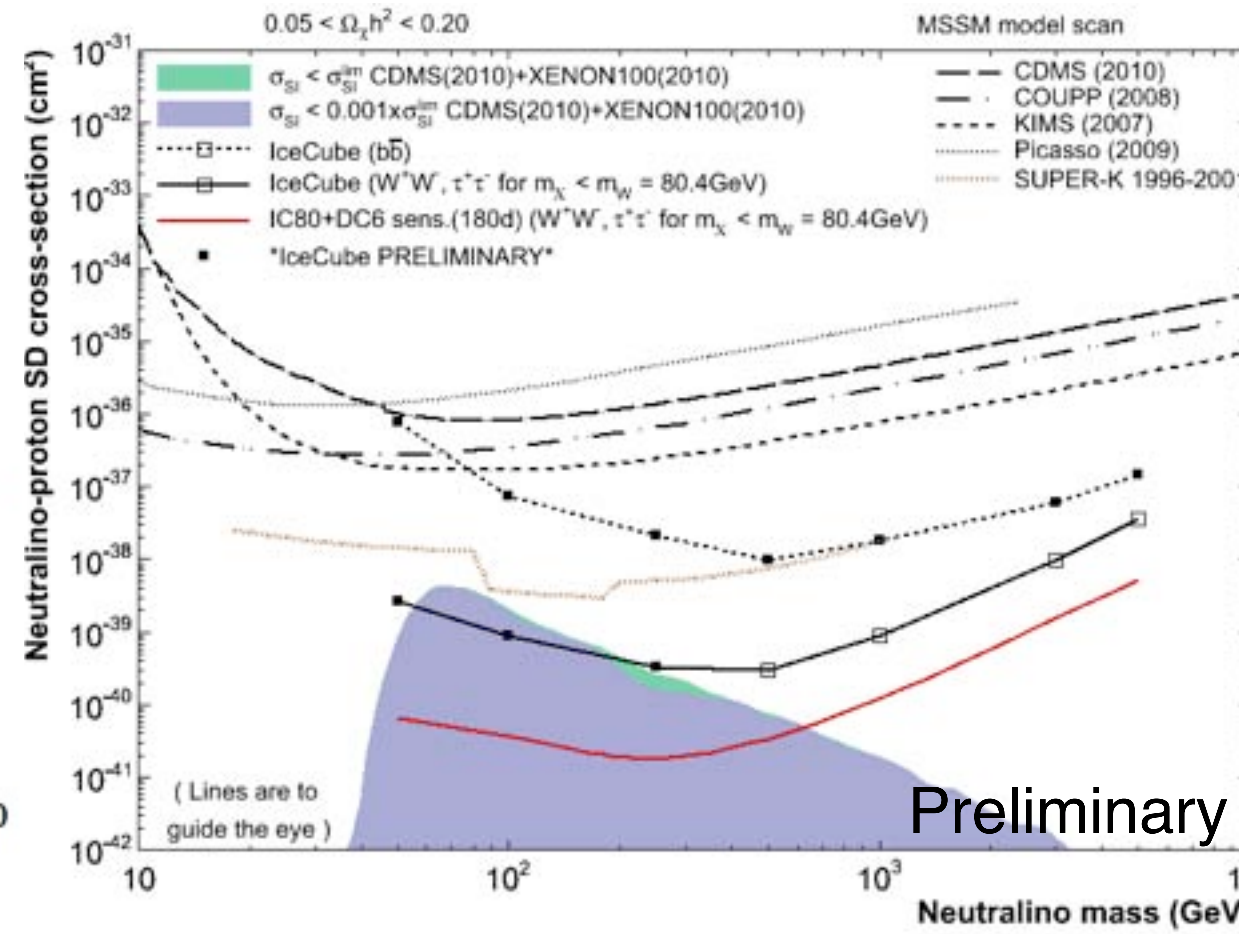
Current Status of Bounds on Dark Matter from Terrestrial experiments

Spin-Independent



Aprile et al., arXiv:1104.2549v1 (2011)

Spin-Dependent



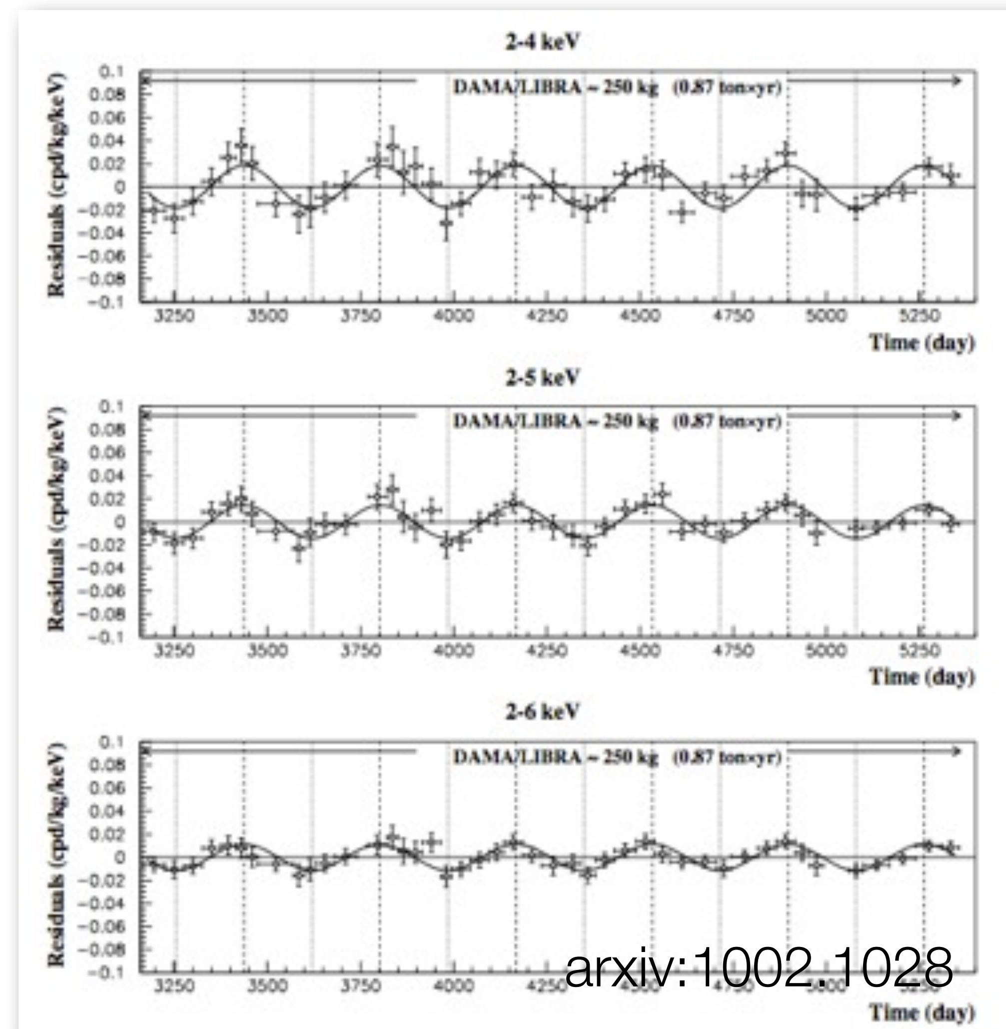
One claim for discovery: DAMA

Modulation Observed by DAMA

DAMA Signal:

- DAMA observes annual modulation in the 2 - 4 keV range at 8.9σ C.L.
- 1.17 ton-yr (13 annual cycles)
- phase: (146 +/- 7) days (peak on June 2)
- period: (0.999 +/- 0.002) yr

★ DAMA attributes the modulation to dark matter.



DAMA Detector:

- 250 kg of clean NaI detectors
- Located at Gran Sasso Underground Laboratory

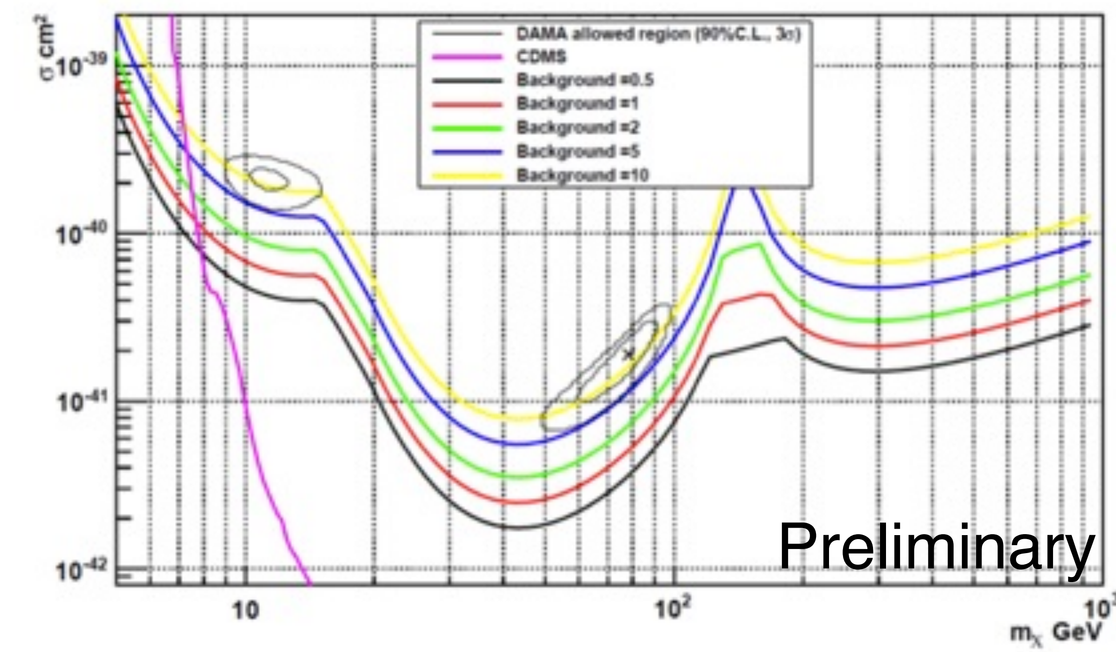
Go to the South Pole to Verify!

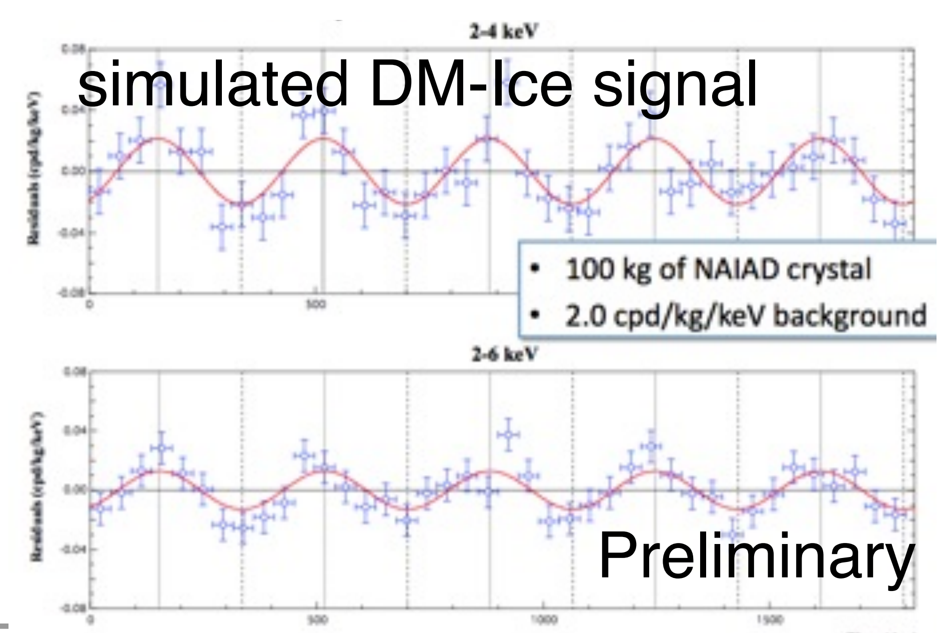
- Phase of the dark matter modulation is the same.
- Opposite seasonal modulation, e.g. muon rate (max in December).
- $>$ 2500 m.w.e. of overburden with clean ice.
    - Many sources of backgrounds either non-existent or different from other underground sites.
    - Clean ice → Very little uranium/thorium. No radon.
    - Ice is a great 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 rates well understood by IceCube/DeepCore
    - Infrastructure for construction, signal readout, and remote operation

Requirements for Testing DAMA

- Environment with different systematics
- Background rates of < 1 event/kg/keV/day
  - Use clean detectors and surrounding materials.
  - Depth of ~2400 m in the Antarctic ice
  - Muon rates well understood by IceCube
- > 250kg of NaI(Tl) detectors
  - 2 - 4 holes, 70 cm diameter
- Long-term stability in operation
- Technical readiness:
  - Drilling and deployment can be ready for the 2013/14 season

5-σ detection of DAMA signal with a 250-kg / 2-year running time (2 - 4 keV)





DM-Ice Concept
Large Pressure Vessel
Segmented Crystals

38 NaI Crystals (each vessel contains 19)

- 95.6 mm Diameter
- 250 mm Long
- 6.5 kg each
- 2 PMTs each

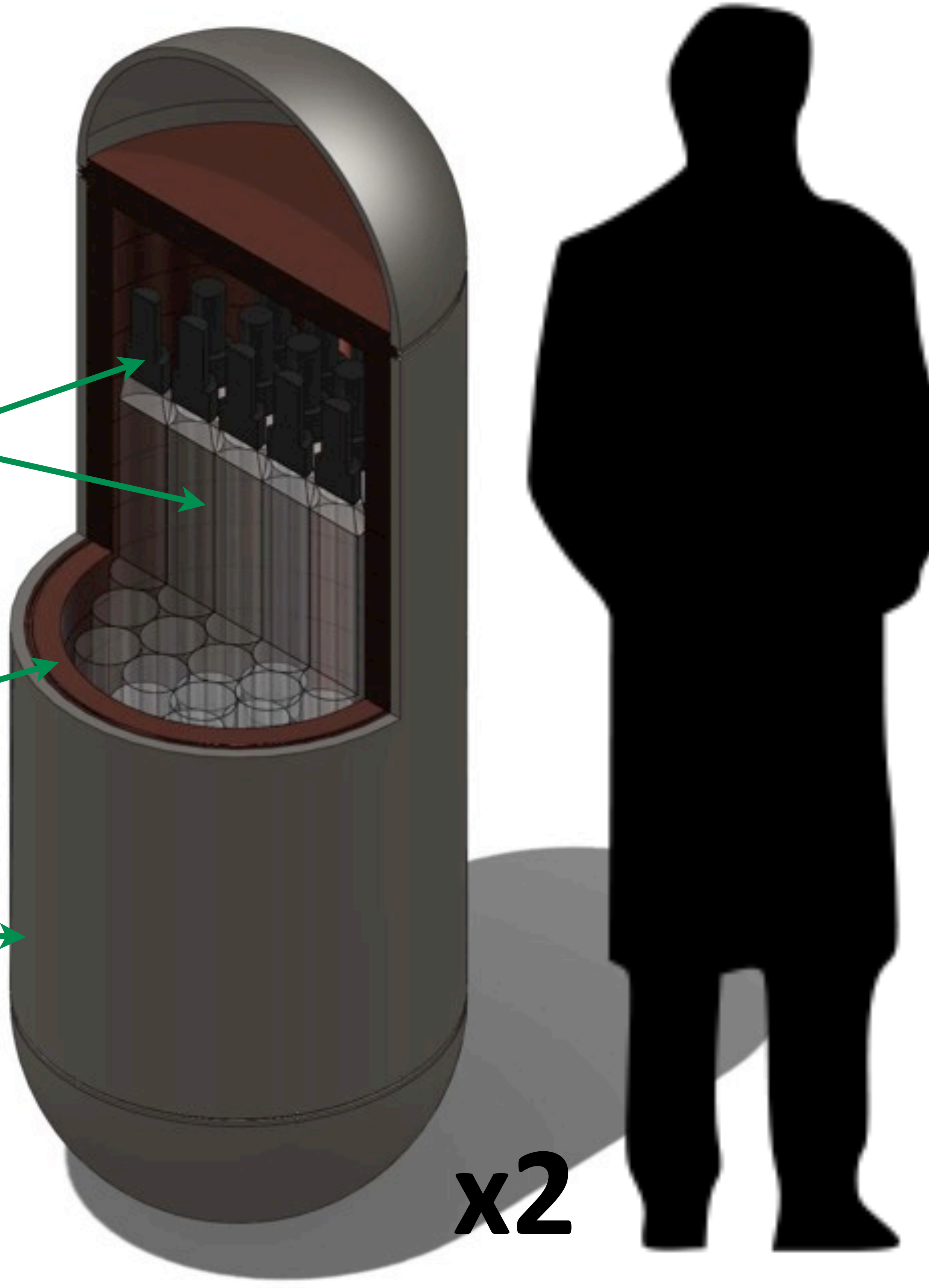
Instrument with few “DOMs” externally for veto

50 - 60 mm Copper Radial Shield

SS External Pressure Vessel Shell

- 65 cm (25.6 inch) Outer Diameter
- 1.7 m (67 inch) Length

250 kg NaI (38@6.5 kg crystals)
1500 kg total including pressure vessel



$D^{ark} M^{atter}$-Ice prototype

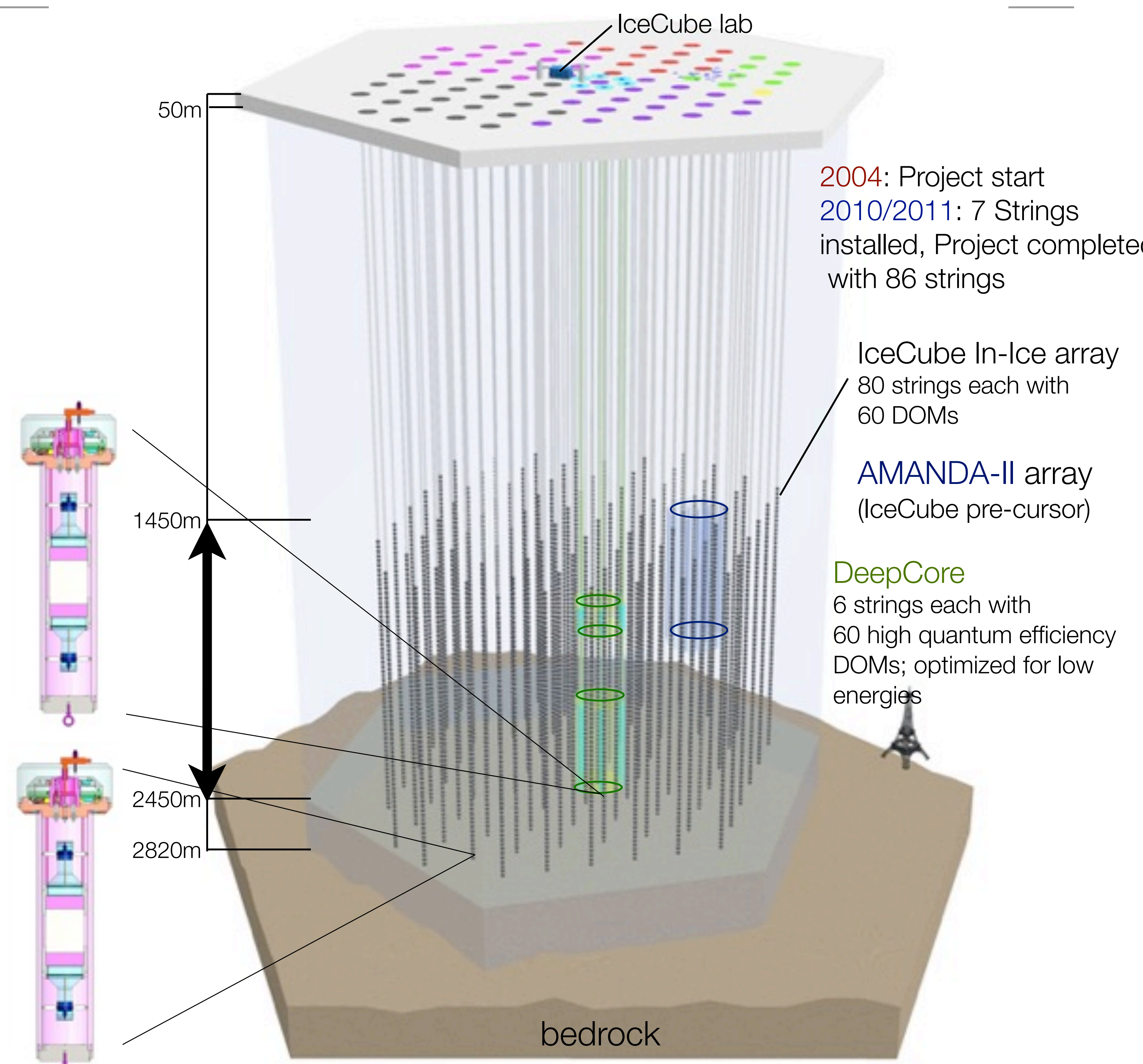
Detectors:

- Two 8.5 kg NaI detectors from NAIAD

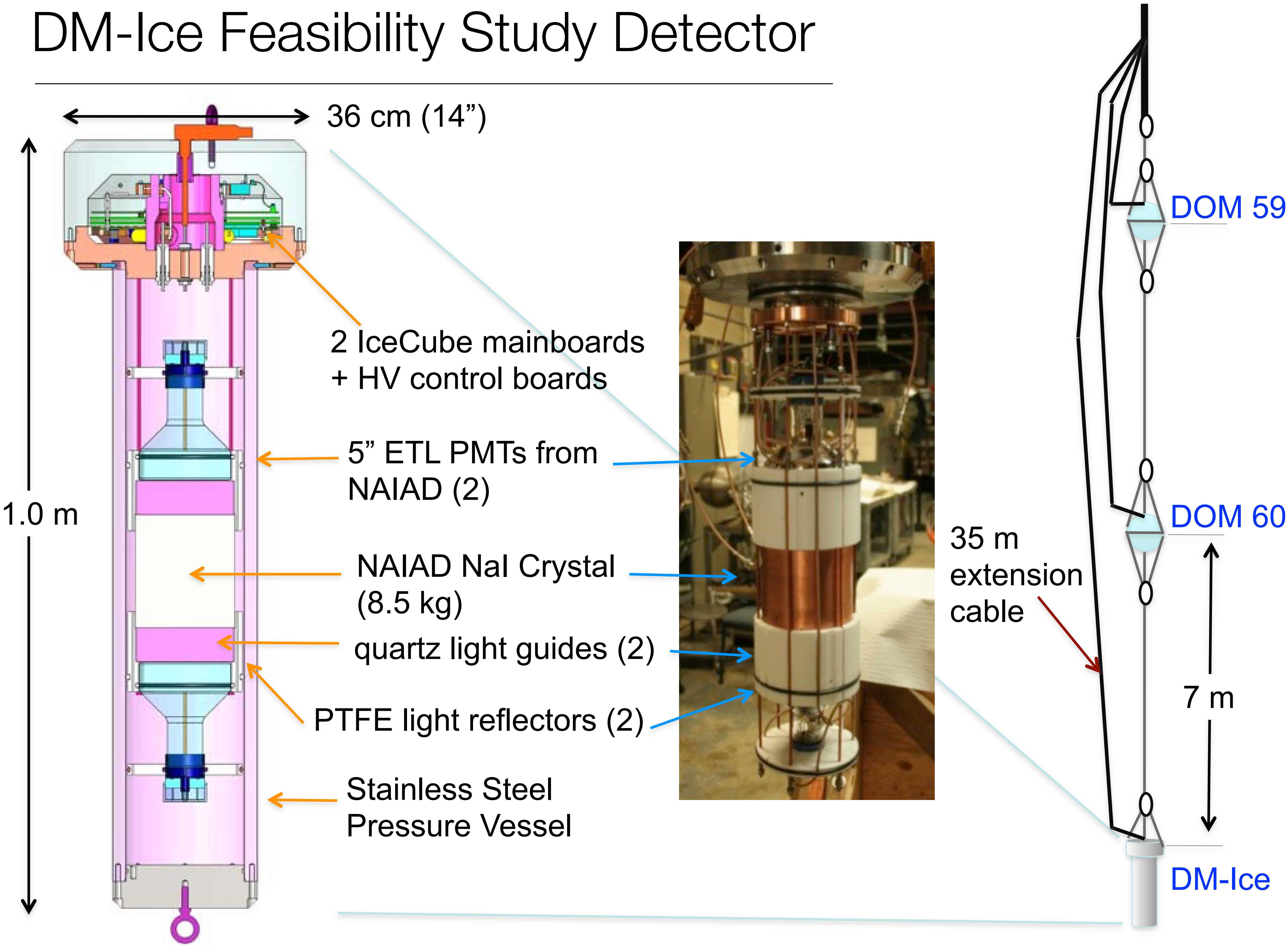
Goals:

- 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

Installed Dec. 2010

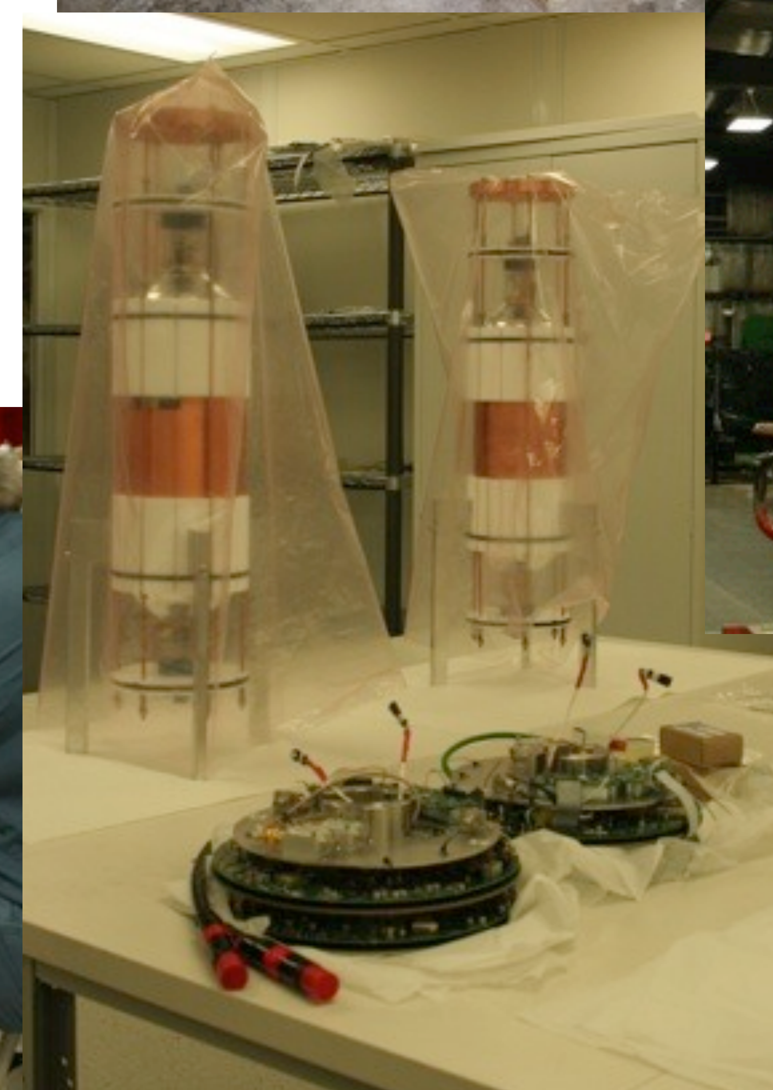


DM-Ice Feasibility Study Detector



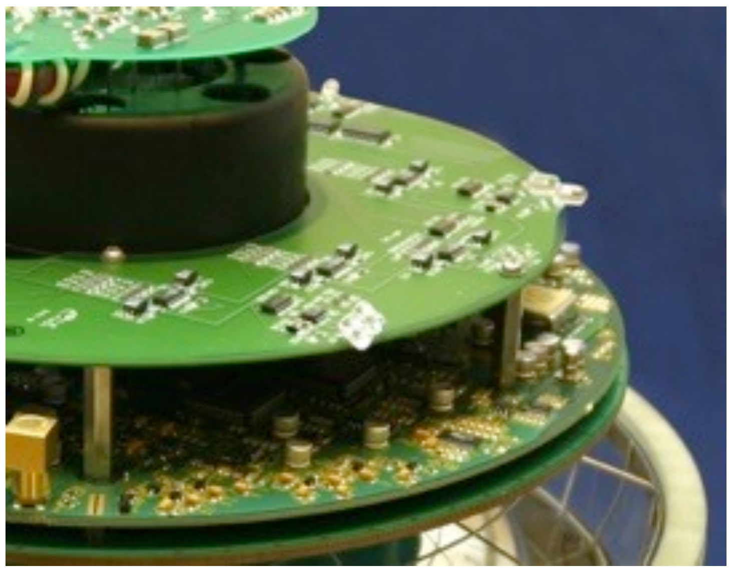
Pressure vessel, support structures, etc

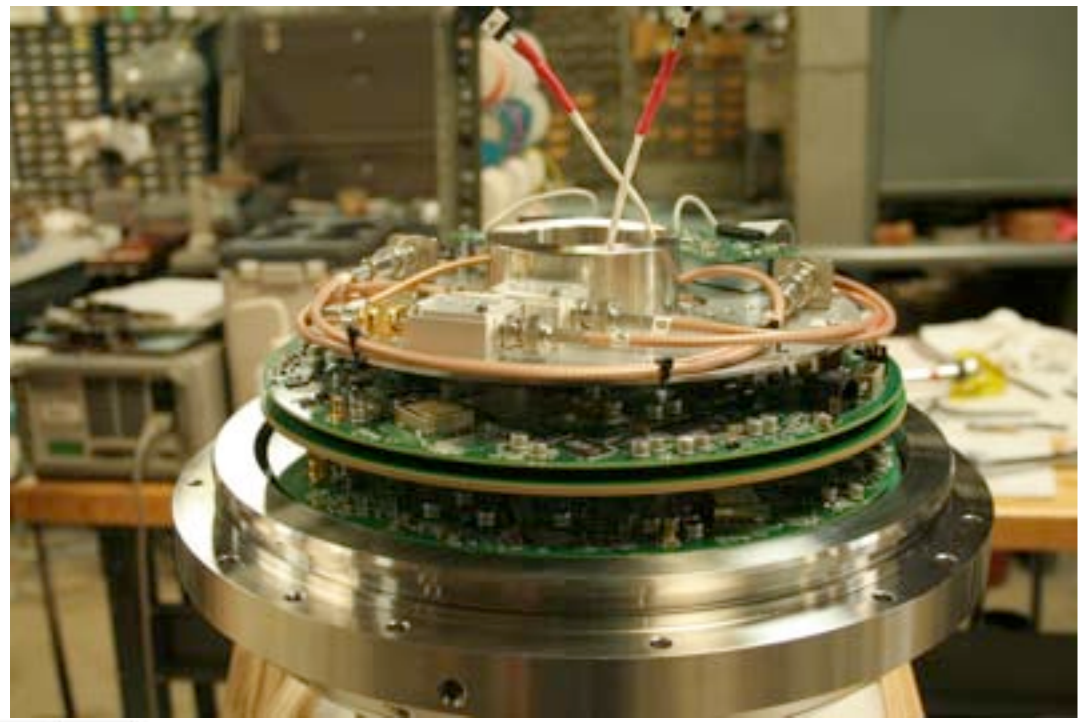
- Stainless, Teflon, etc. selected from vendors known to produce clean material.
  - measurements currently underway at LBNL & SNOLAB.
- Pressure vessel tested to 6200 psi
  - static pressure of water ~ 3500 psi
  - 6000+ psi during ice refreeze in the hole

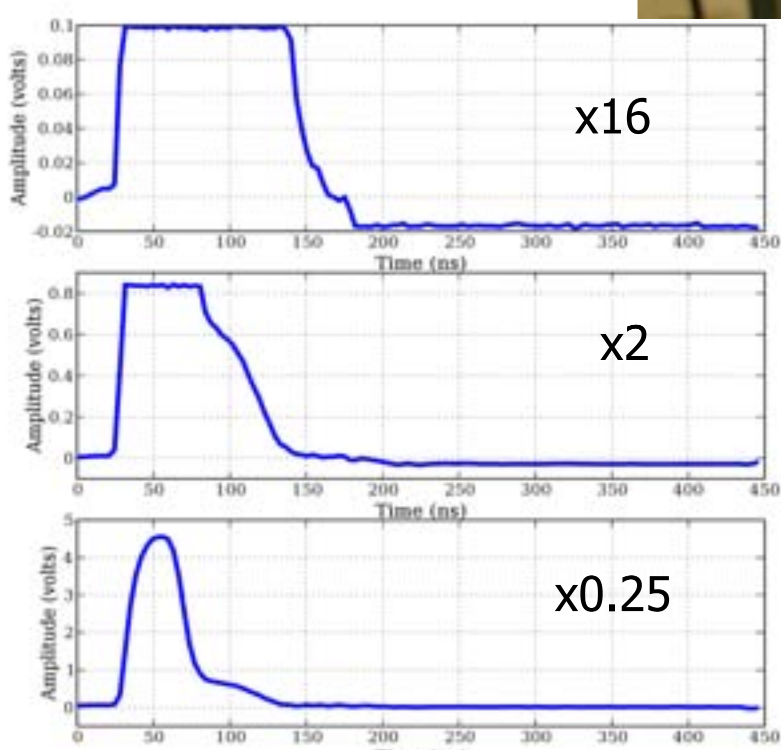


Physical Sciences Laboratory
University of Wisconsin-Madison

IceCube DOM mainboards in DM-Ice



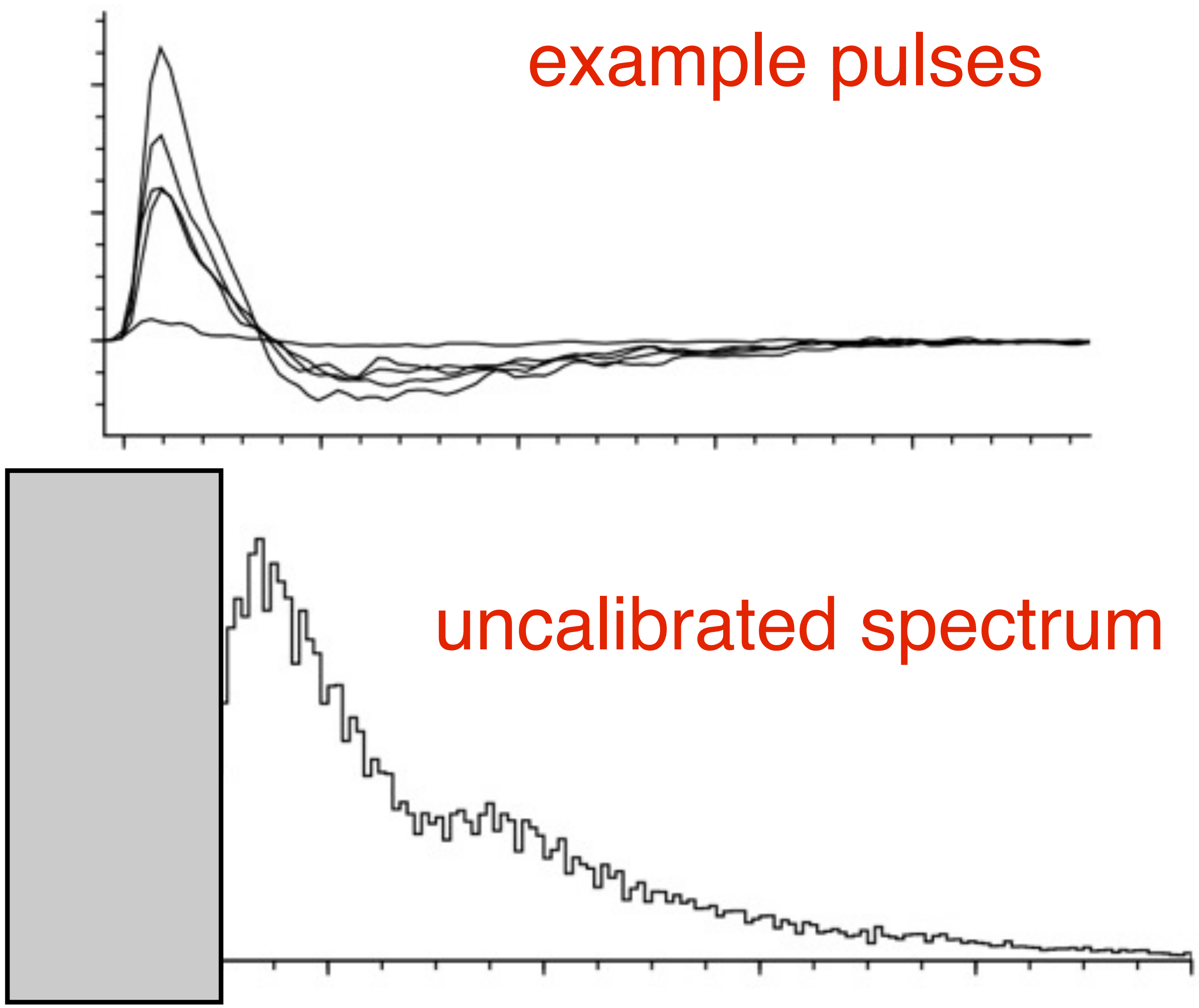


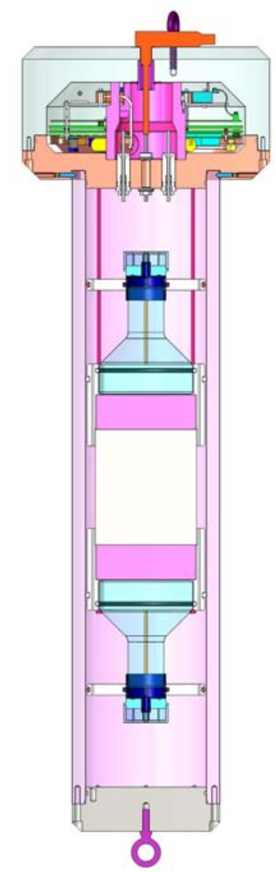


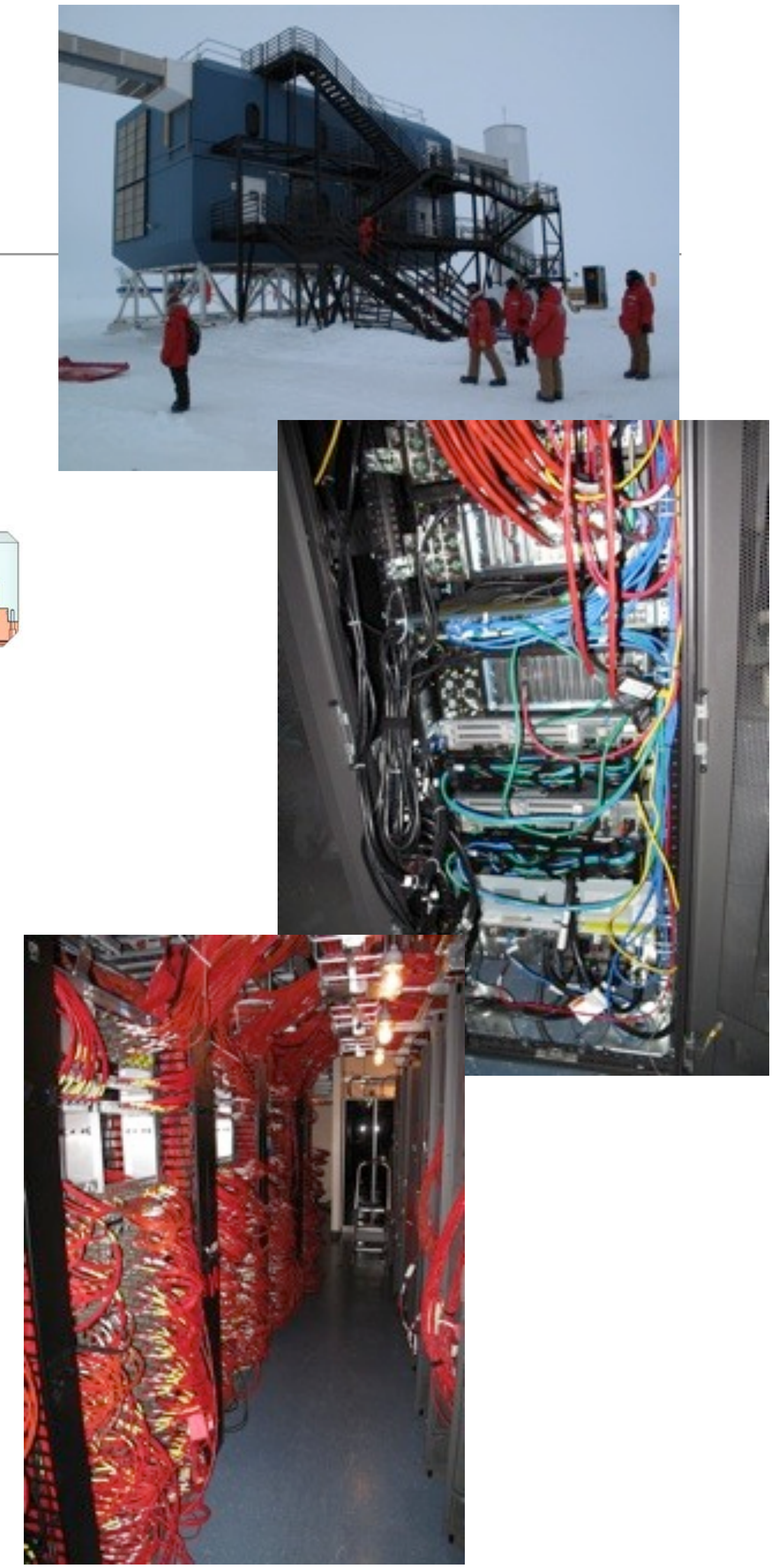
- Each ATWD contains 3 gain paths: x16, x2, x0.25 (giving effectively 14-bits)
- Coincidence trigger capabilities
- Controls a separate HV board
- Programmable from surface
- Established reliable technology

Data from the South Pole

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








EDELRID
Arbuckle

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
- Designing 250-kg scale DM-Ice detector
  - Developing drilling and deployment plan for 2013/14
  - Starting R&D on low background crystals
  - Investigating low background PMTs
  - Designing pressure vessels, etc.

Core Members of DM-Ice

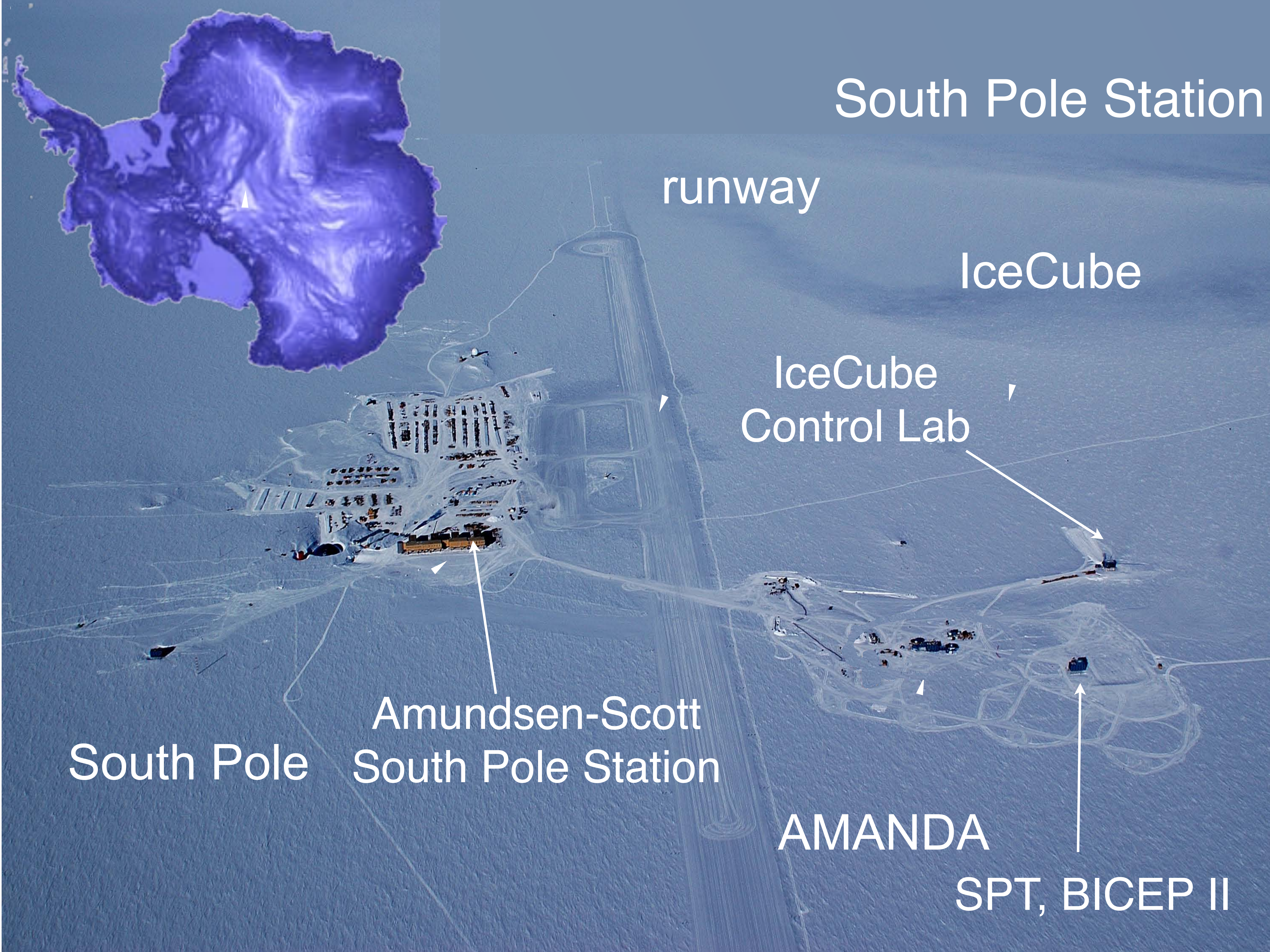
- UW-Madison
  - Francis Halzen*, Karsten Heeger, Albrecht Karle*, Reina Maruyama*, Walter Pettus, Antonia Hubbard*, Bethany Reilly
- University of Sheffield
  - Neil Spooner, Vitaly Kudryavtsev, Dan Walker, Sean Paling, Matt Robinson
- University of Alberta
  - Darren Grant*
- Penn State
  - Doug Cowen*
- Fermilab
  - Lauren Hsu
- University of Stockholm
  - Seon-Hee Seo*

working closely with IceCube

*members of IceCube Collaboration

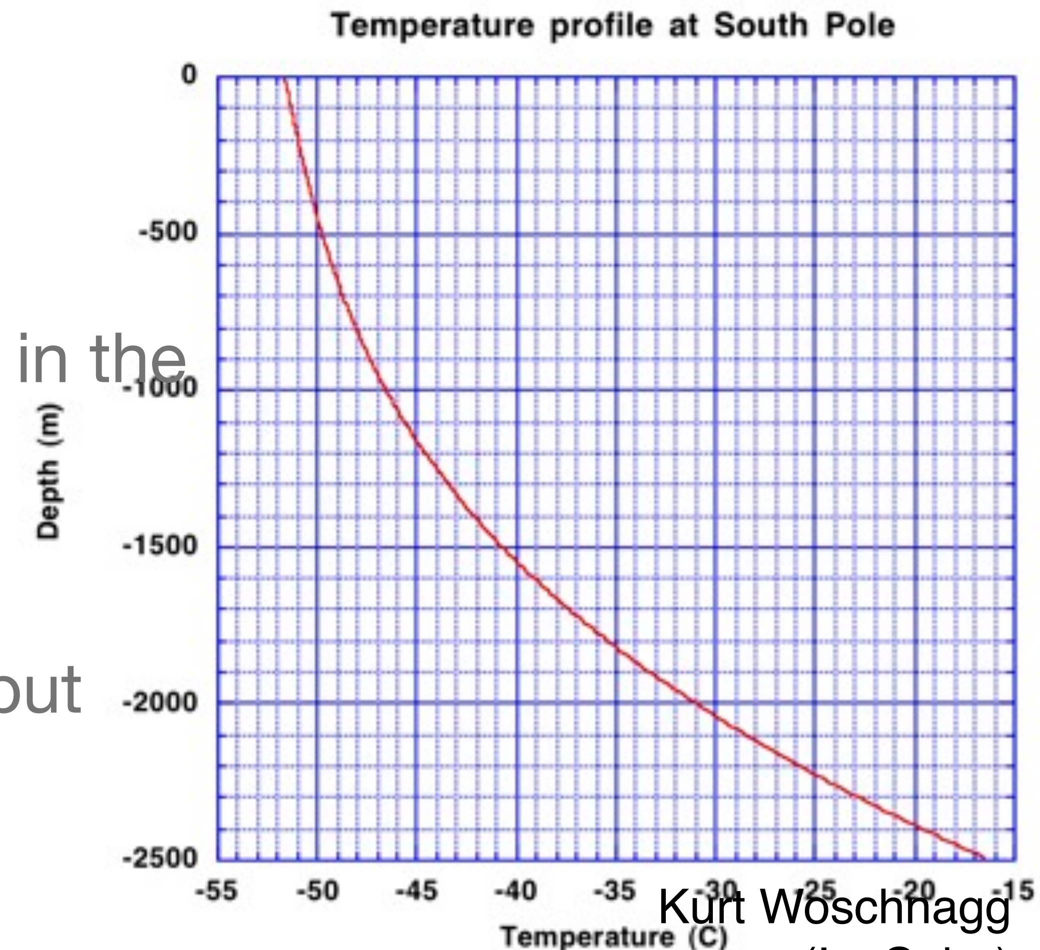
Thank you!!

Backup


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

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)

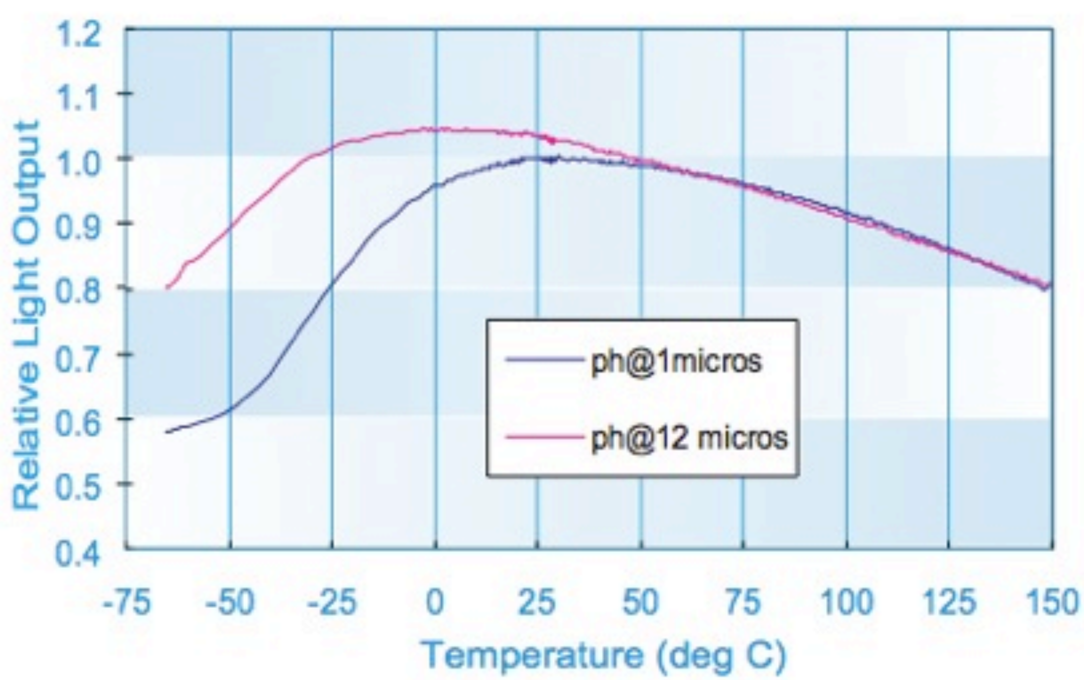


Figure 2. Temperature response of NaI(Tl)

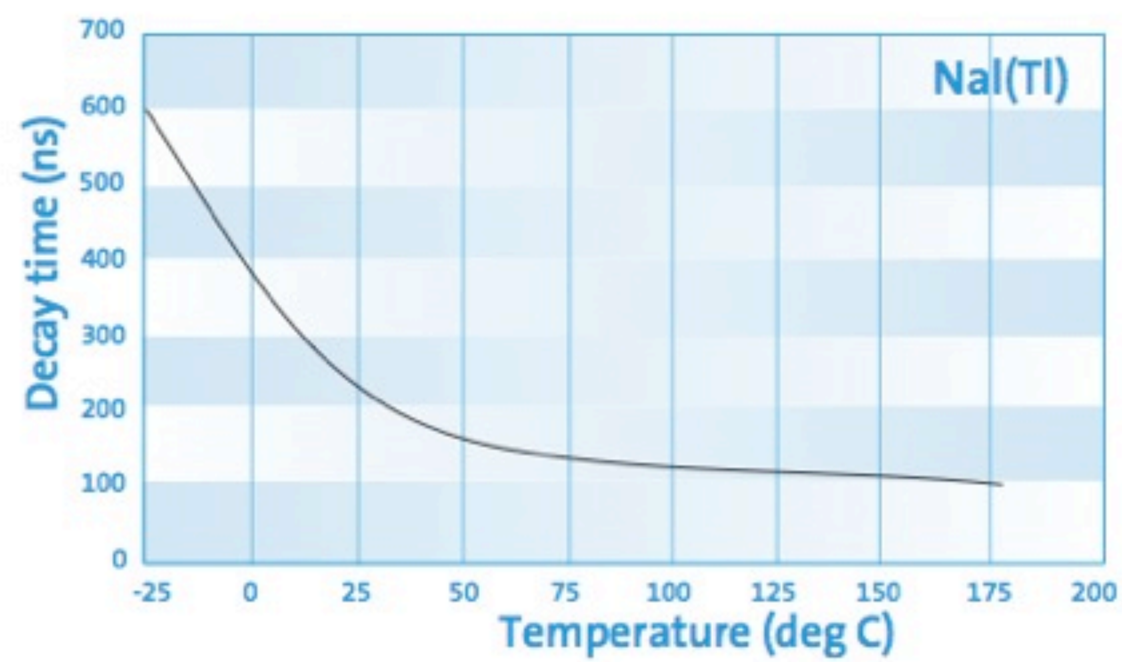


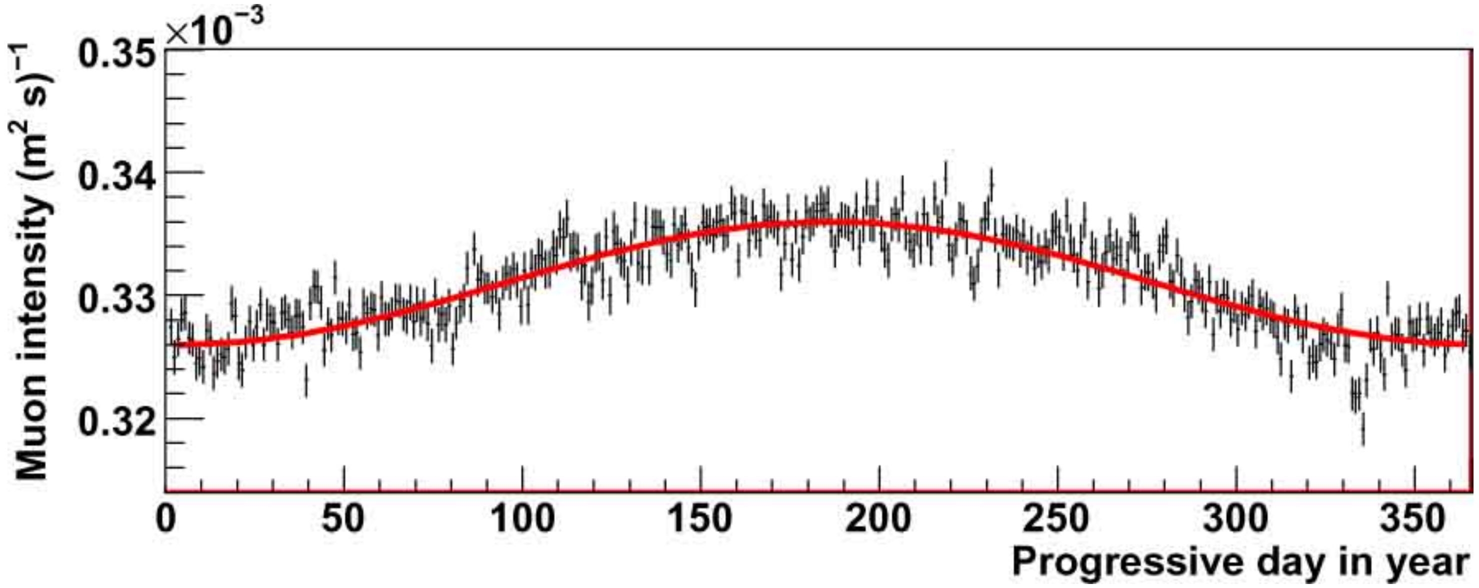
Figure 3. Temperature dependence of the decay time of NaI(Tl)

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

Muon Rate at Gran Sasso vs. South Pole

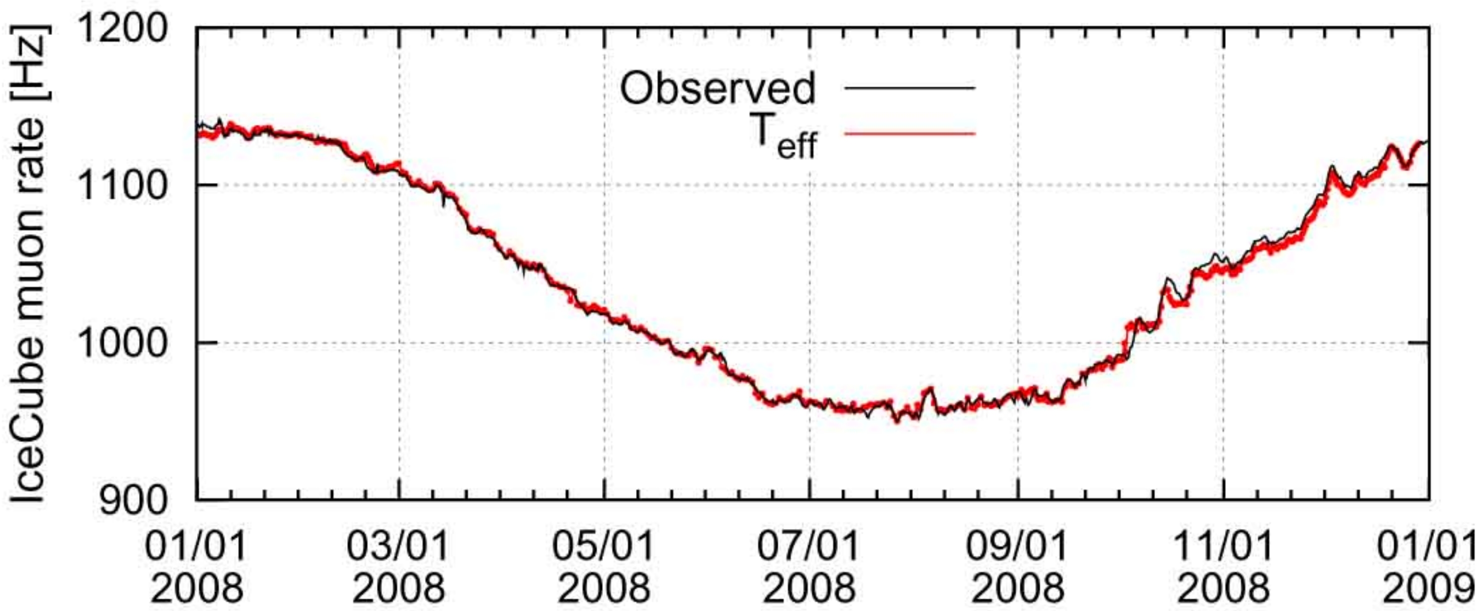
- LVD:

Selvi, Proc. 31st ICRC. (2009)



- Opposite Muon modulation at the South Pole:

Tilav, Proc. 31st ICRC. (2009)



Muon Rate at Gran Sasso vs. South Pole

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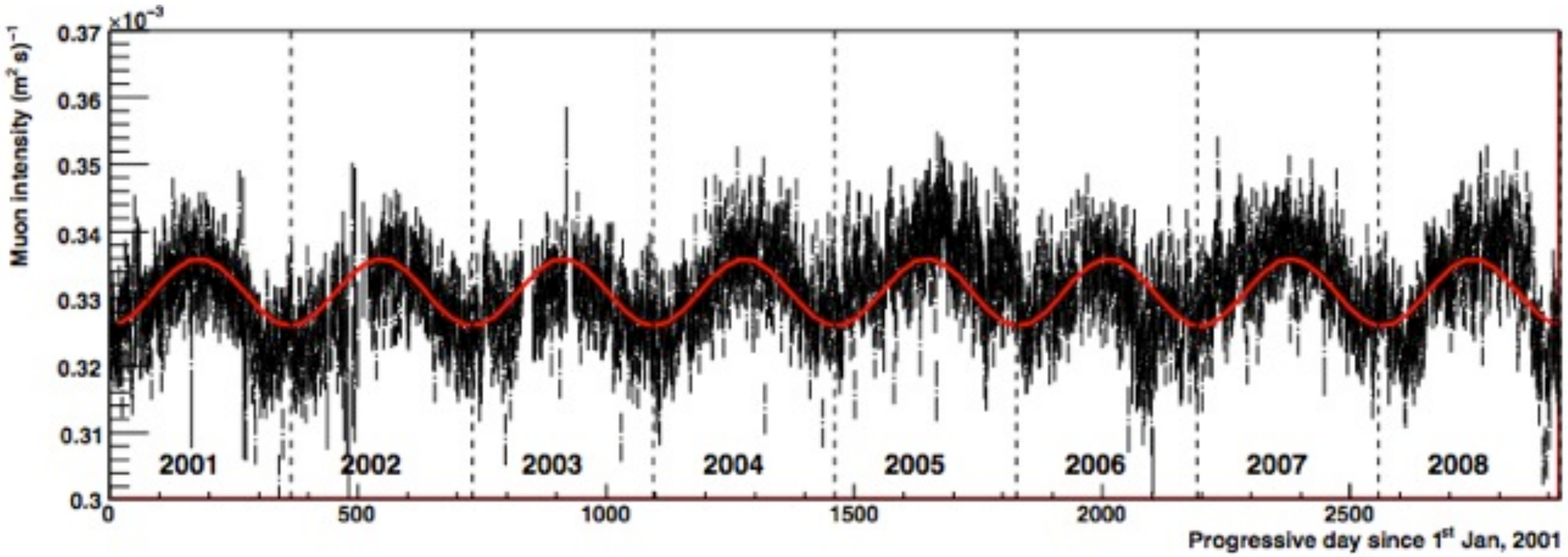
Selvi, Proc. 31st ICRC.



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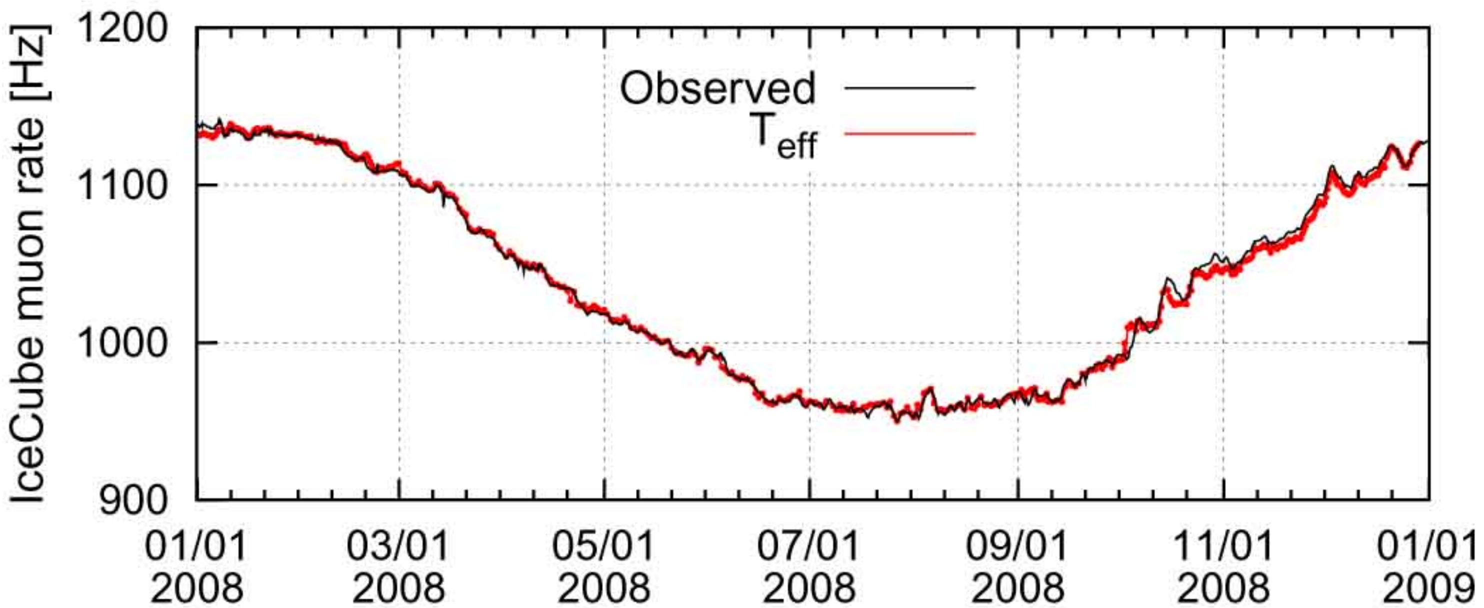


Seasonal Muon Rate Modulation

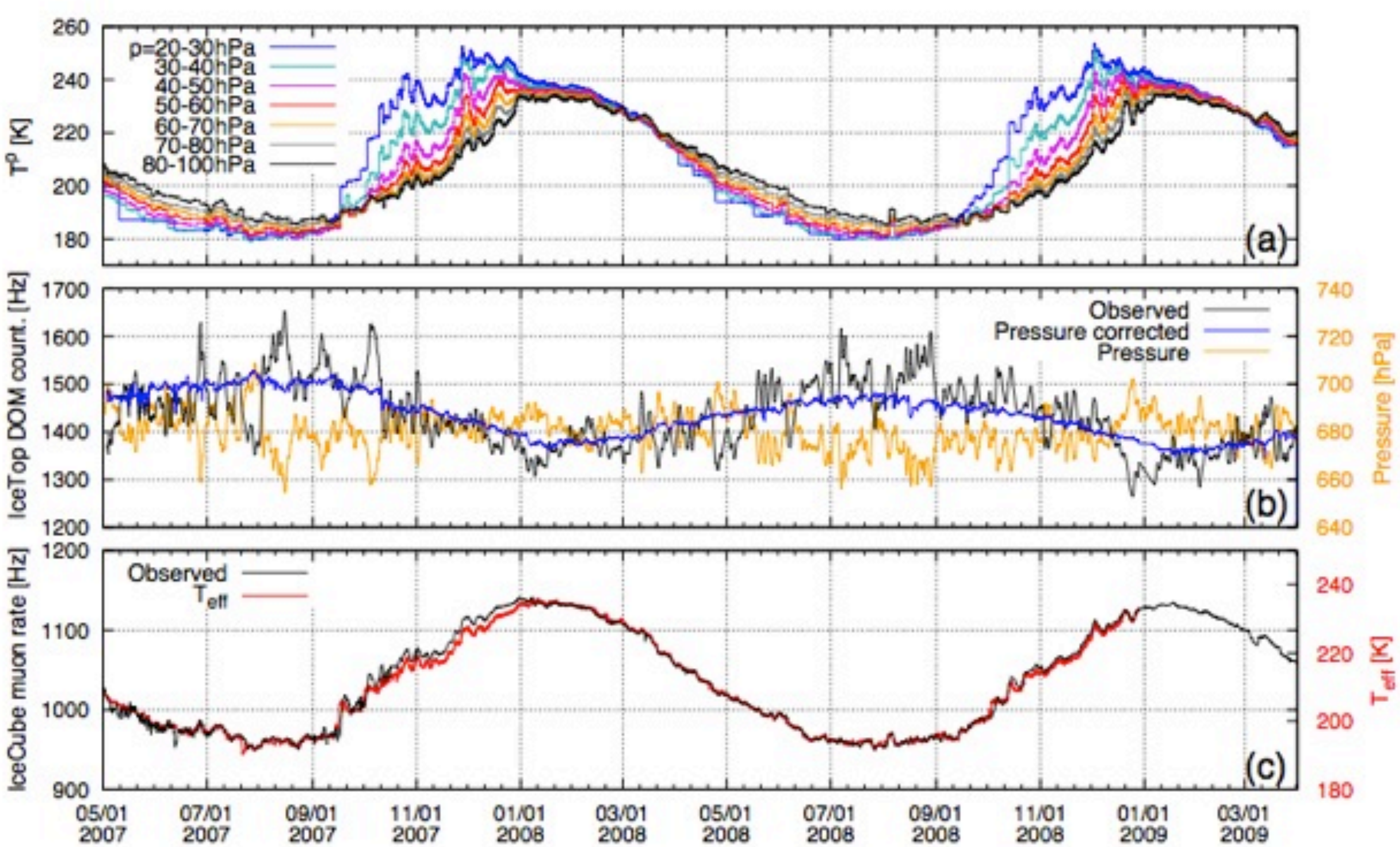
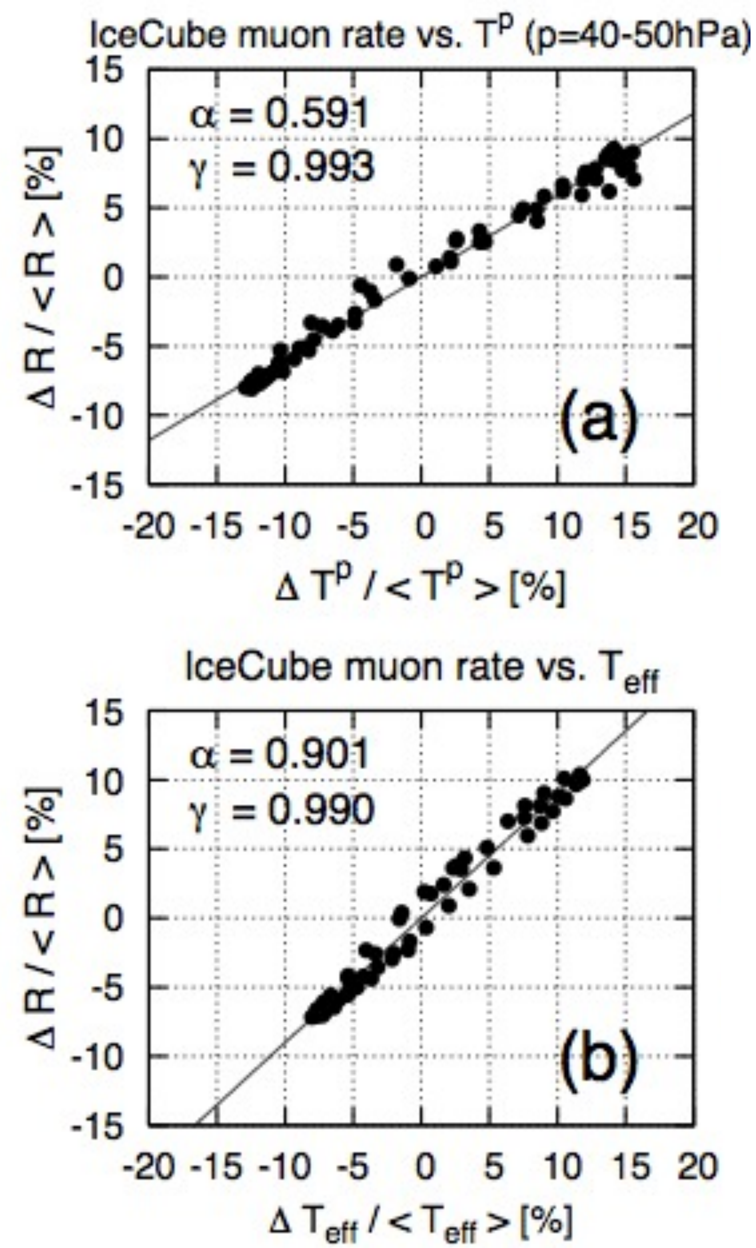


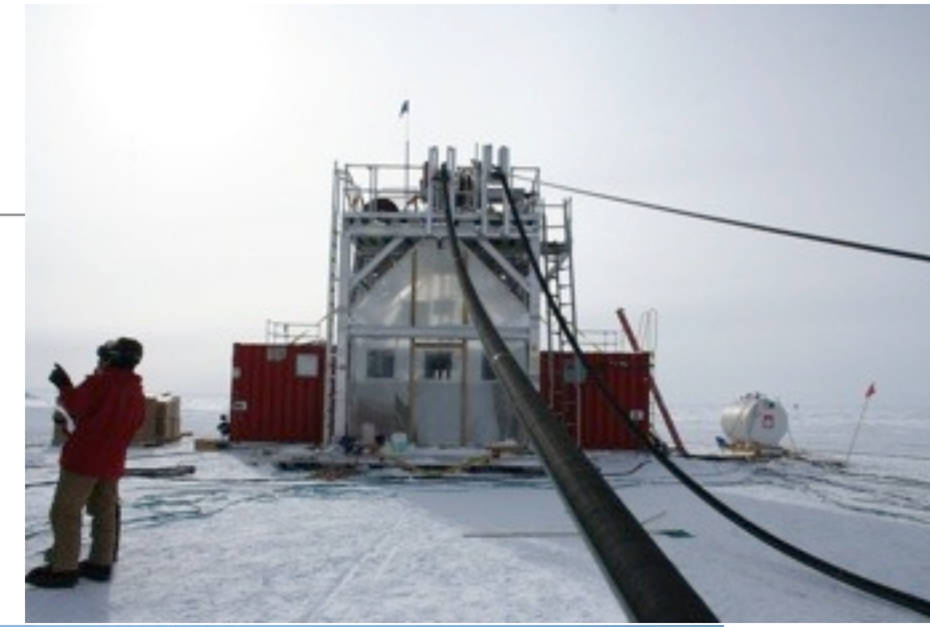
Fig. 1. The temporal behavior of the South Pole stratosphere from May 2007 to April 2009 is compared to IceTop DOM counting rate and the high energy muon rate in the deep ice. (a) The temperature profiles of the stratosphere at pressure layers from 20 hPa to 100 hPa where the first cosmic ray interactions 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

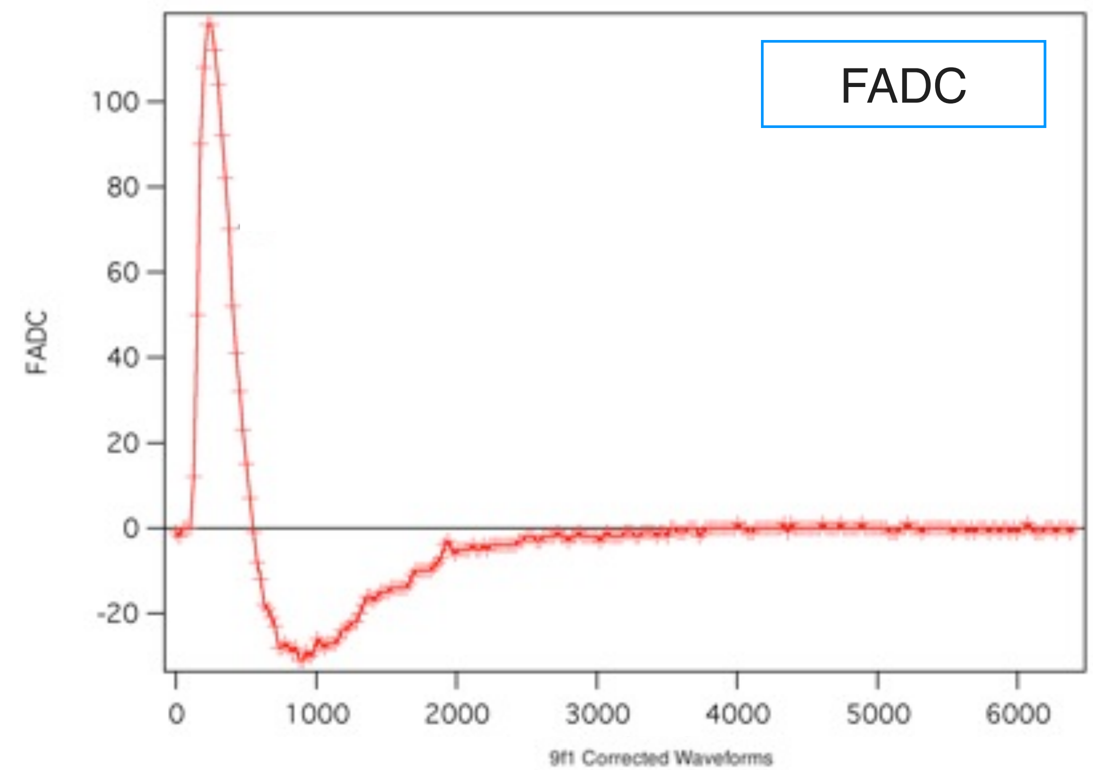
Challenges of going to the Pole

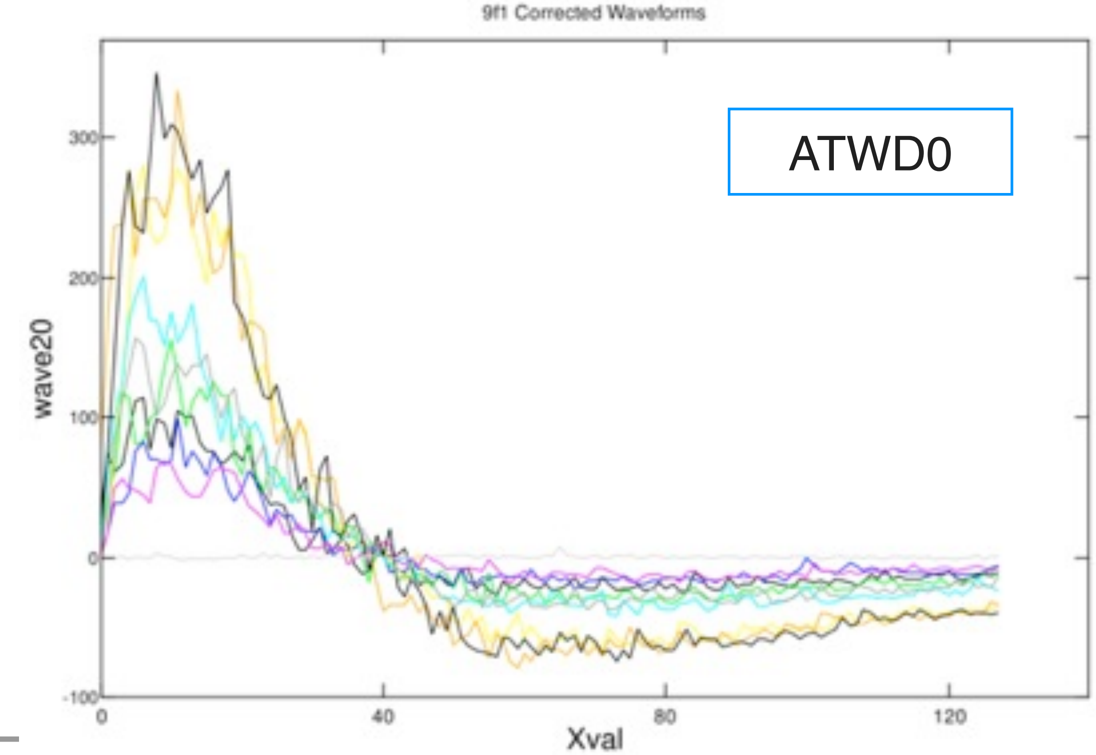
- IceCube construction finished in Dec. 2010.
  - new holes will need to be drilled after this year.
- Detector will be inaccessible once deployed.
  - NaI detectors have been launched into space (e.g. EGRET, Fermi LAT)
- DAMA uses NaI(Tl) crystals grown with proprietary process to achieve low U/Th/K 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!



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.





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