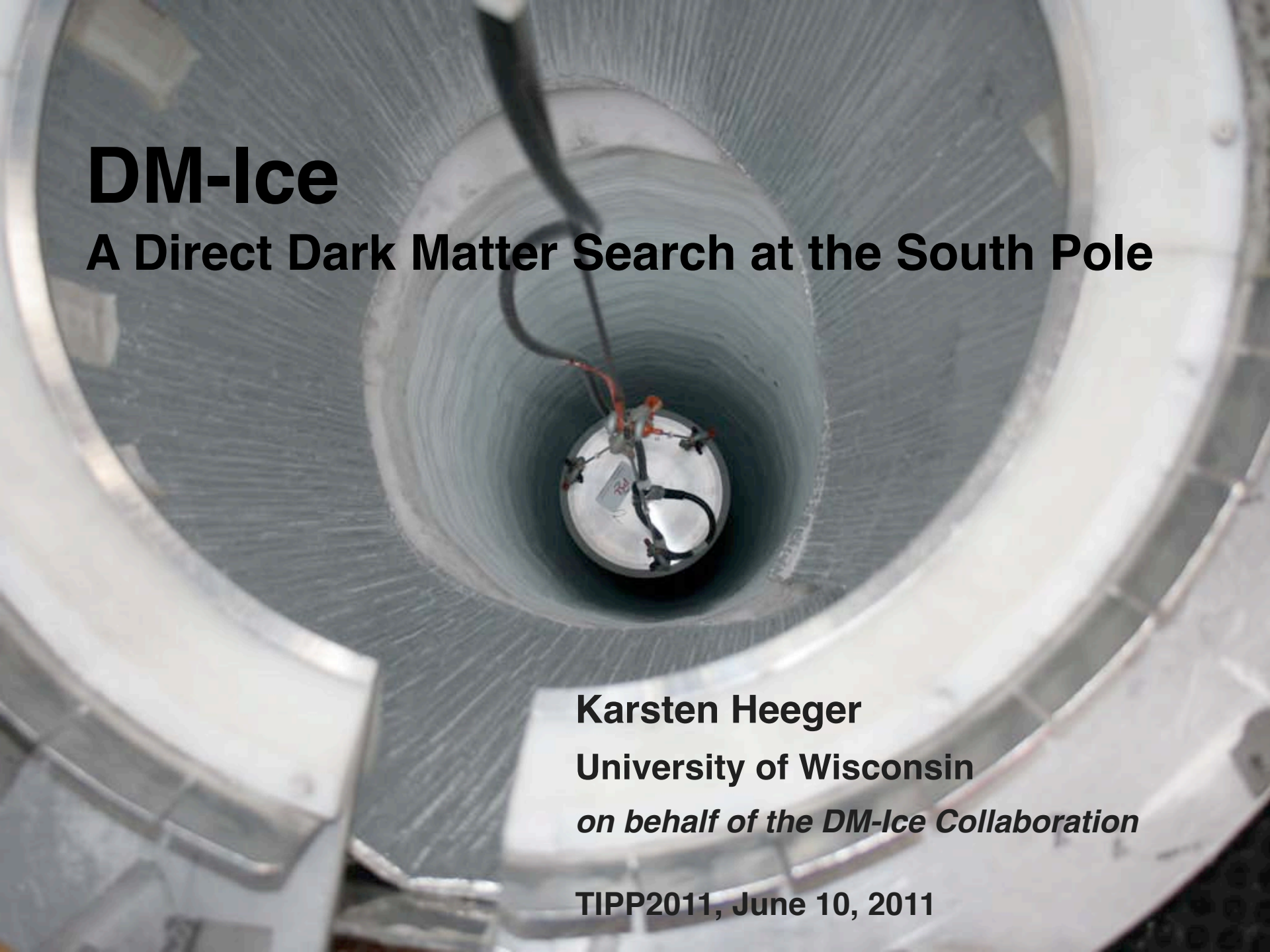


DM-Ice

A Direct Dark Matter Search at the South Pole

Karsten Heeger

University of Wisconsin

on behalf of the DM-Ice Collaboration

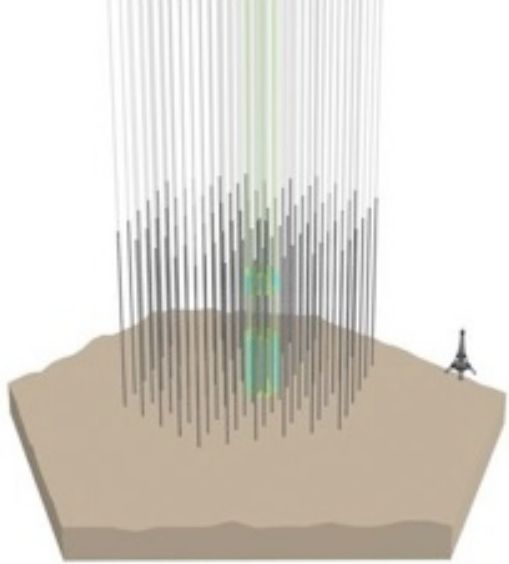
TIPP2011, June 10, 2011

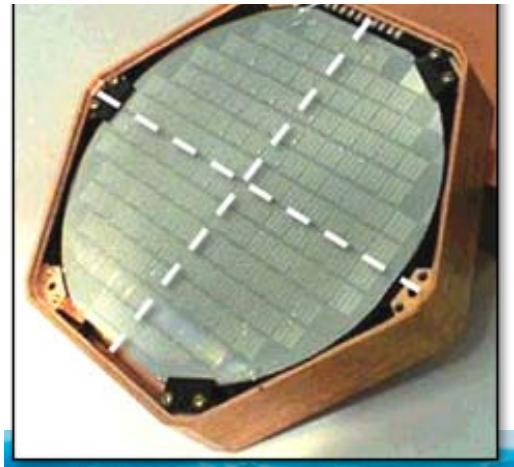
Techniques for Detecting Dark Matter

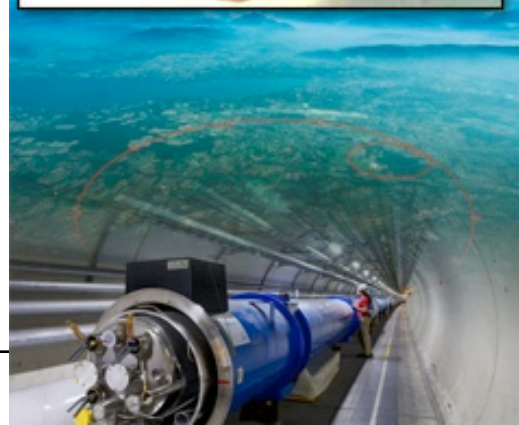
- Indirect detection
  (IceCube, etc.)
  - observe products of WIMP annihilation/decay in terrestrial or space based detectors

- Direct detection
  (CDMS, XENON, DEEP, LUX, DAMA, etc.)
  - observe WIMPS through scattering with matter in terrestrial detectors

- Colliders
  - produce WIMPs directly at the LHC

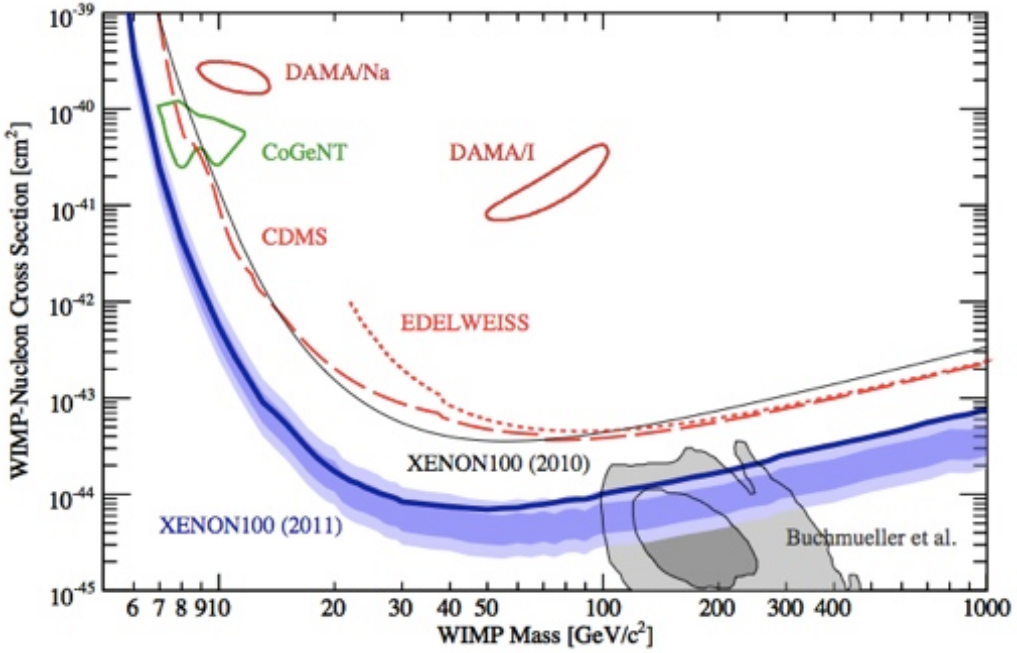




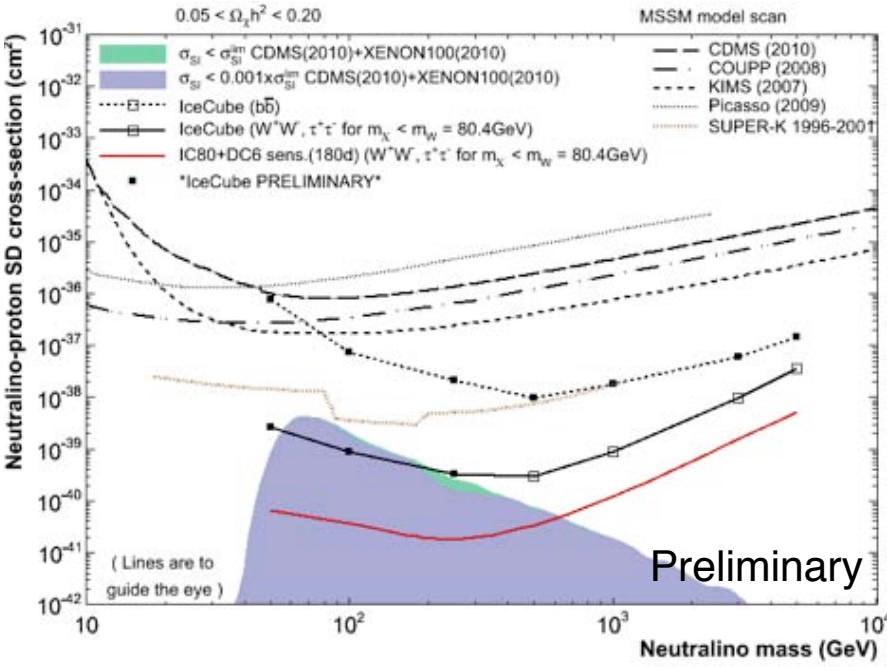


Dark Matter Bounds from Terrestrial Experiments

Spin-Independent



Spin-Dependent



One, maybe two signals.

One claim for discovery: DAMA

Hints of Dark Matter in Direct Experiments?

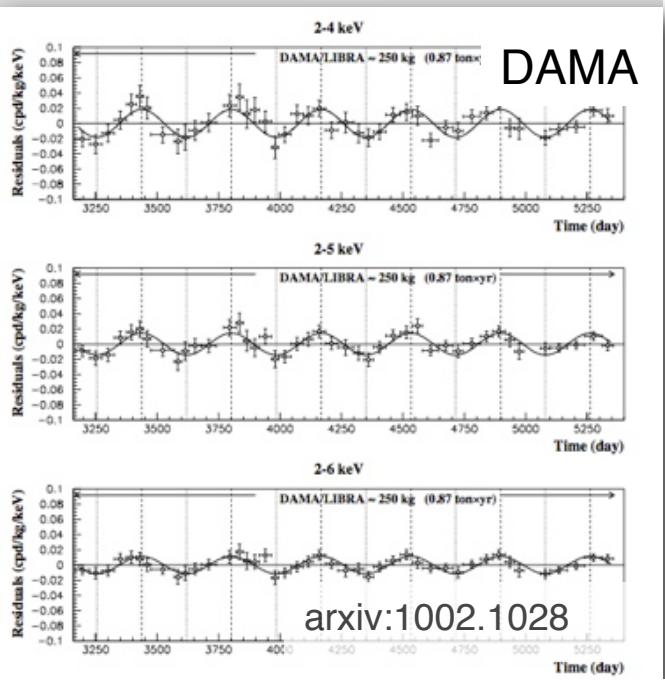
Some tantalizing signals...

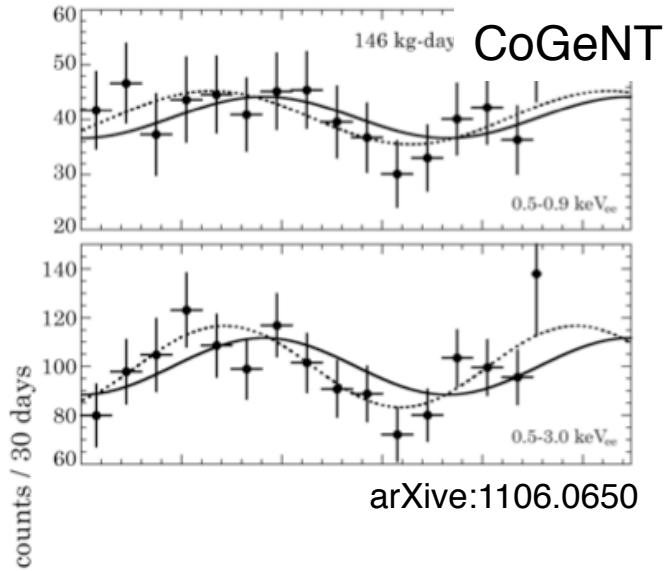
- Observation by DAMA (8.9σ).
- Recent results from CoGeNT show events at low energies and annual modulation (2.8σ)
- Excess events in CDMS (but no observation in their low-energy analysis), null results from XENON 100.

What could it be...?

- Background? Detector?
- Light WIMPs? Asymmetric WIMPs? ????

Requires careful investigation!





What is going on?

- Possible factors that can contribute to an annual modulation
  - Ambient temperature variation
  - Muon flux depend on temperature/pressure in the upper atmosphere
  - Spallation neutrons from muons interaction in rock
  - Radon diffusion from rocks may be varying with time
  - threshold effects
  - detector and lab maintenance timing
  - Many of these factors tend have periodicity of 1 year
- Modify astrophysics?
  - f(v)? v_{esc}? v_0? co-rotating?
- More exotic particle?
  - spin-dependent, inelastic scattering, momentum-dependent scattering..

→ Repeat experiment in different environment. Look for annual modulation with NaI(Tl) detectors in the Southern Hemisphere.

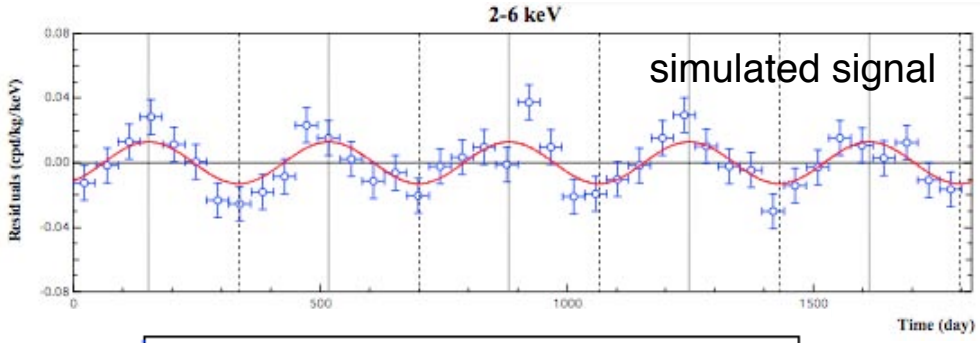
Requirements for Testing Annual Modulation

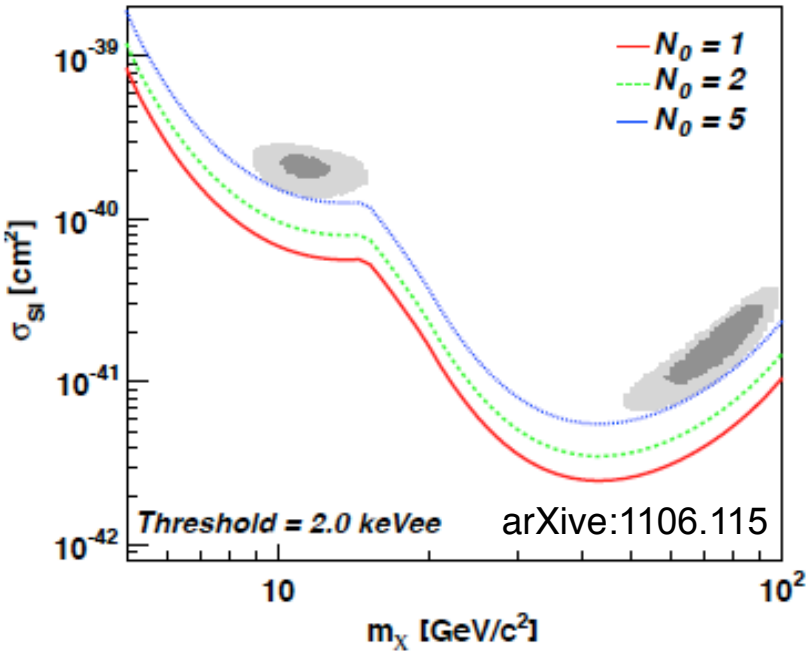
- Environment/location with different systematics
  - Site with different systematics and backgrounds than what might mimic the annual modulation signal from dark matter
- Low background rates (< 1 event/kg/keV/day)
  - Use clean detectors and surrounding materials. Limited by intrinsic NaI(Tl) background.
  - Deep underground site (e.g. depth of ~2400 m in the Antarctic ice)
- > 250kg of NaI(Tl) detectors
  - same or larger size than DAMA to collect sufficient statistics
- Long-term stability in operation (> 2 years)
  - would like to see at least 2 annual modulations if signal is seen

Statistics of DAMA-Like Signal

Sensitivity

- Assume DAMA-like signal, statistics



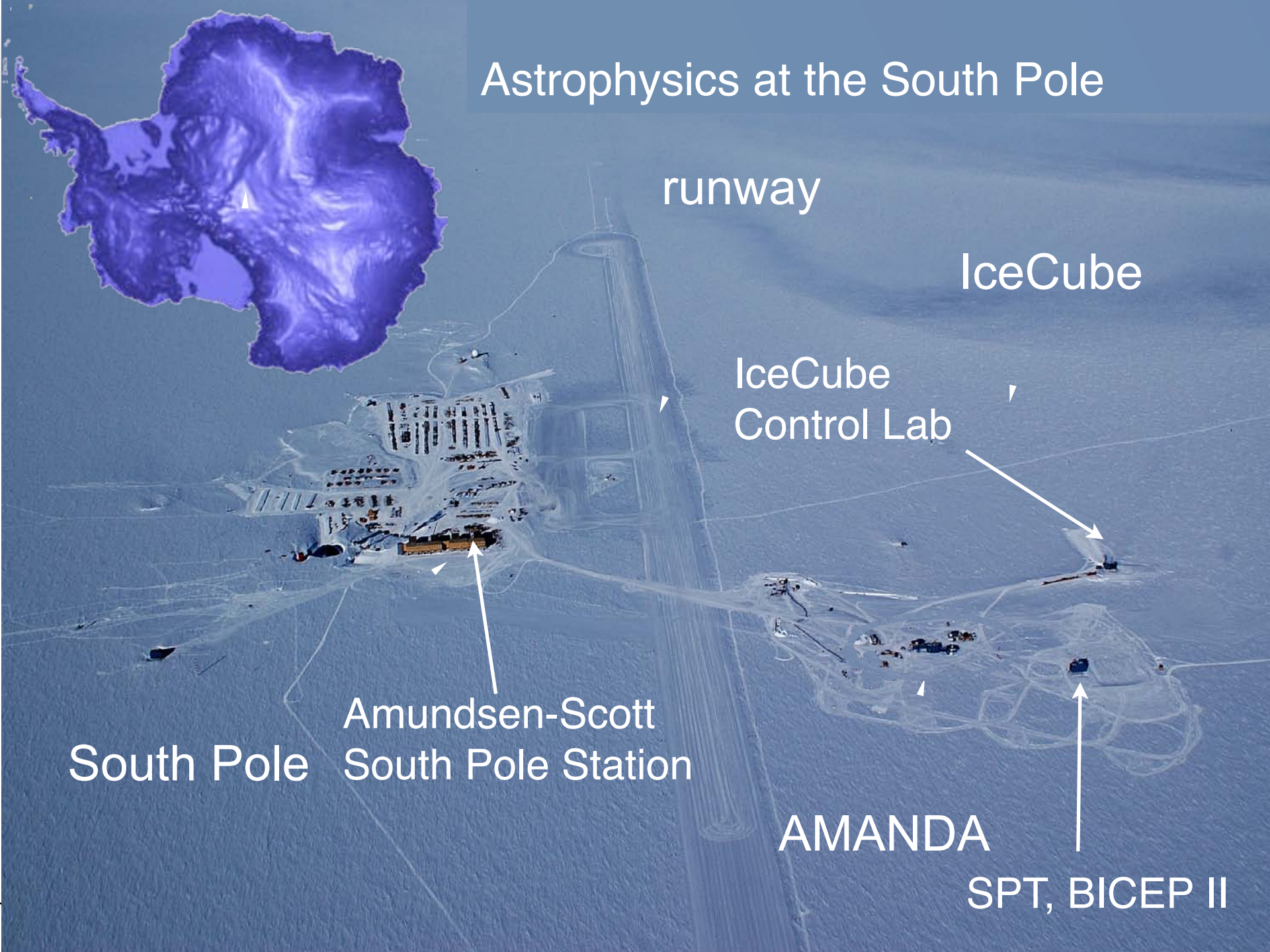


- 5-σ detection of DAMA-like signal with a 250-kg / 2-year running time (2 - 4 keV) and comparable backgrounds to DAMA

	Years	2 NAIAD 17.0 kg	NAIAD size 44.5 kg	DAMA size 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

Going to the South Pole


Neumayer
Esperanza
WEDDELL SEA
INDIAN OCEAN
Mawson
Vernadsky
Rothera
Antarctica
South Pole
Amundsen-Scott
Dome C
Casey
McMurdo
Scott
ROSS SEA
Dumont d'Urville


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

Dark Matter Annual Modulation Search at South Pole

- Annual Modulation Signal
  - Phase of the dark matter modulation is the same.
  - Opposite seasonal modulation, e.g. muon rate (max in December).
- Overburden with clean, radiopure ice (> 2500 m.w.e.)
  - 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

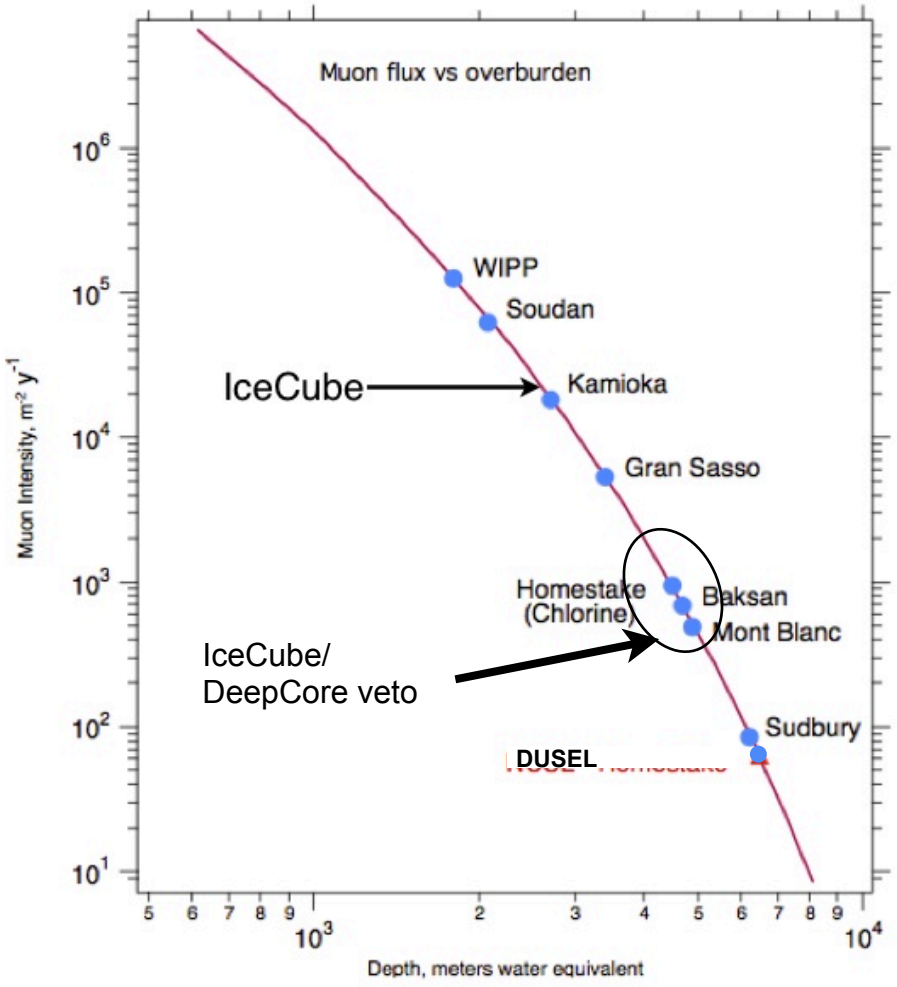
Antarctic Ice Overburden

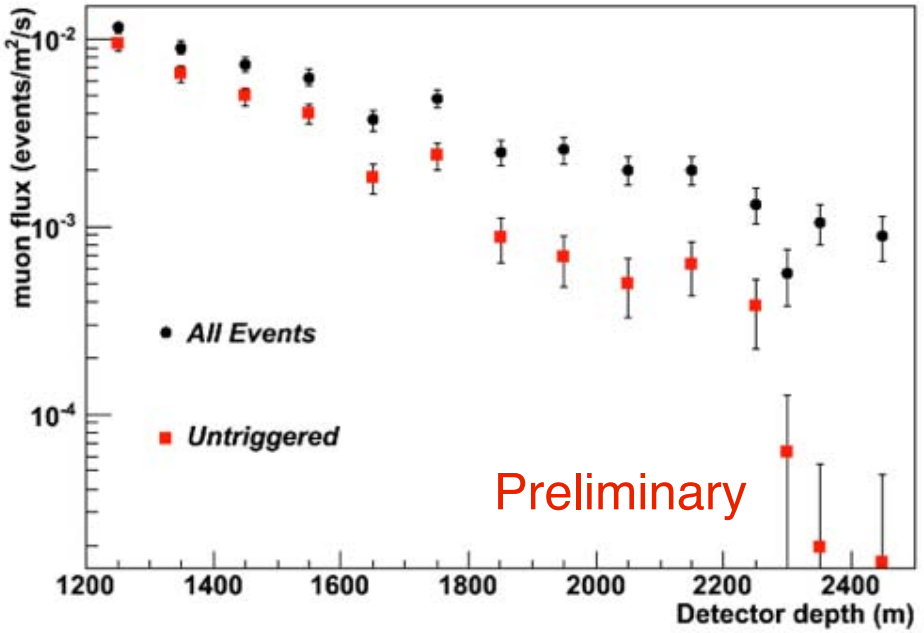
2500 m depth (2200 m.w.e.)

~85 muons/m^2/day at bottom of IceCube

IceCube/DeepCore veto reduces rate by ~1-2 orders of magnitude

Ice is a good neutron moderator



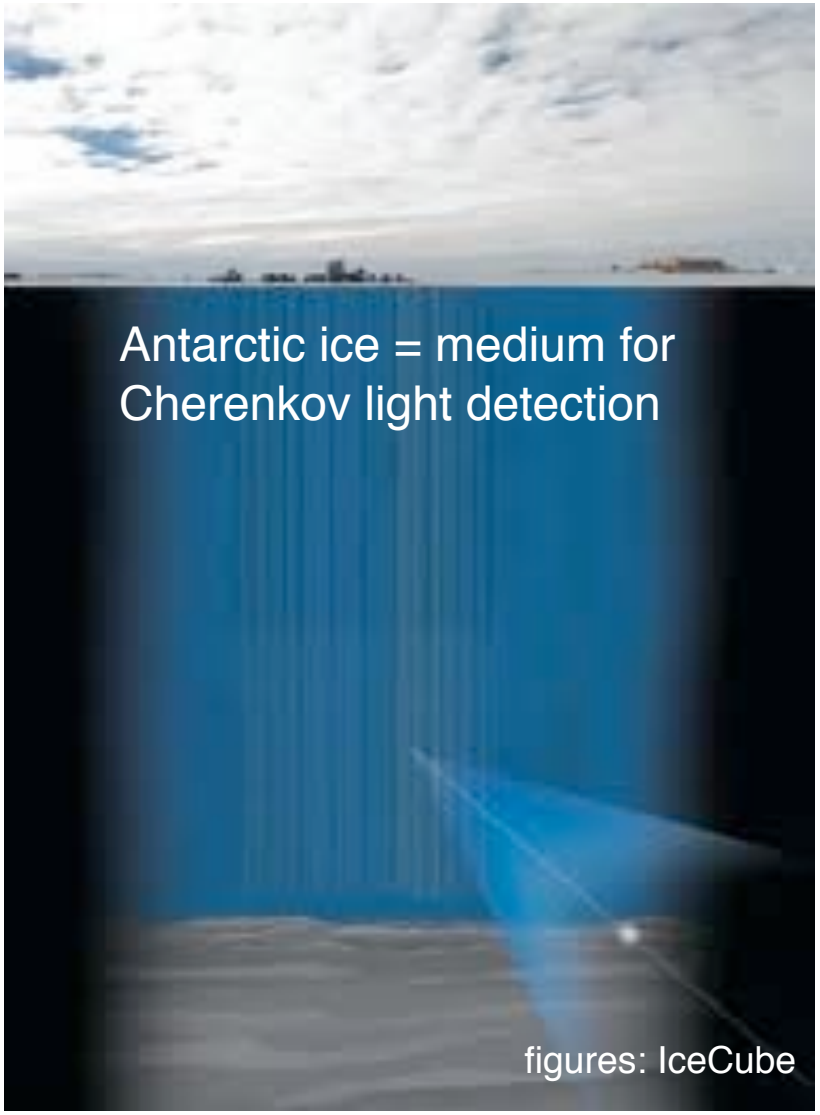


Muon flux vs. depth in the ice, total and those untriggered by IceCube/DeepCore. (Darren Grant)

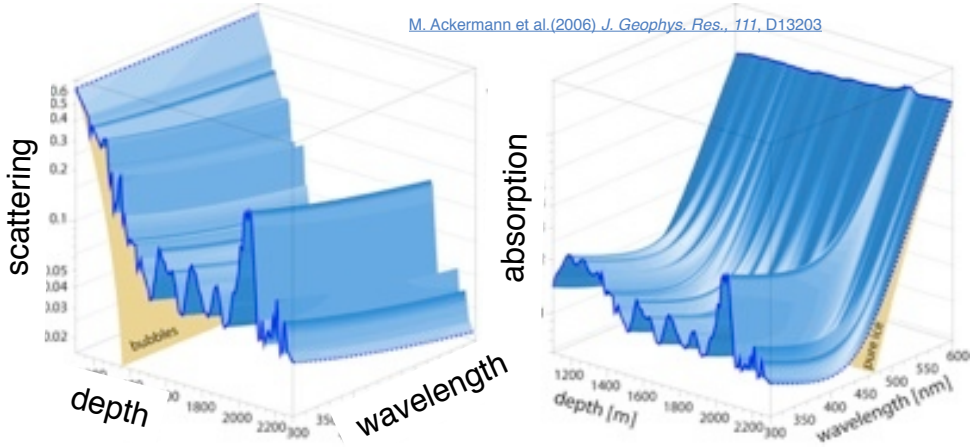
Antarctic Ice

Purity

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



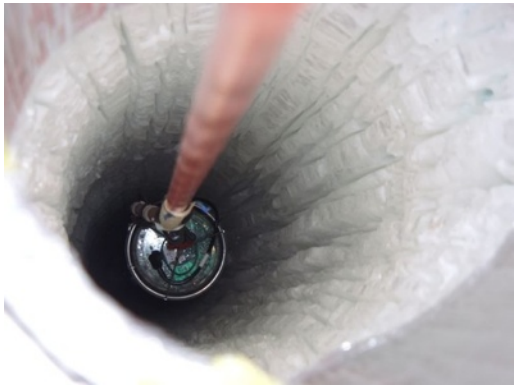
scattering/absorption studies in ice

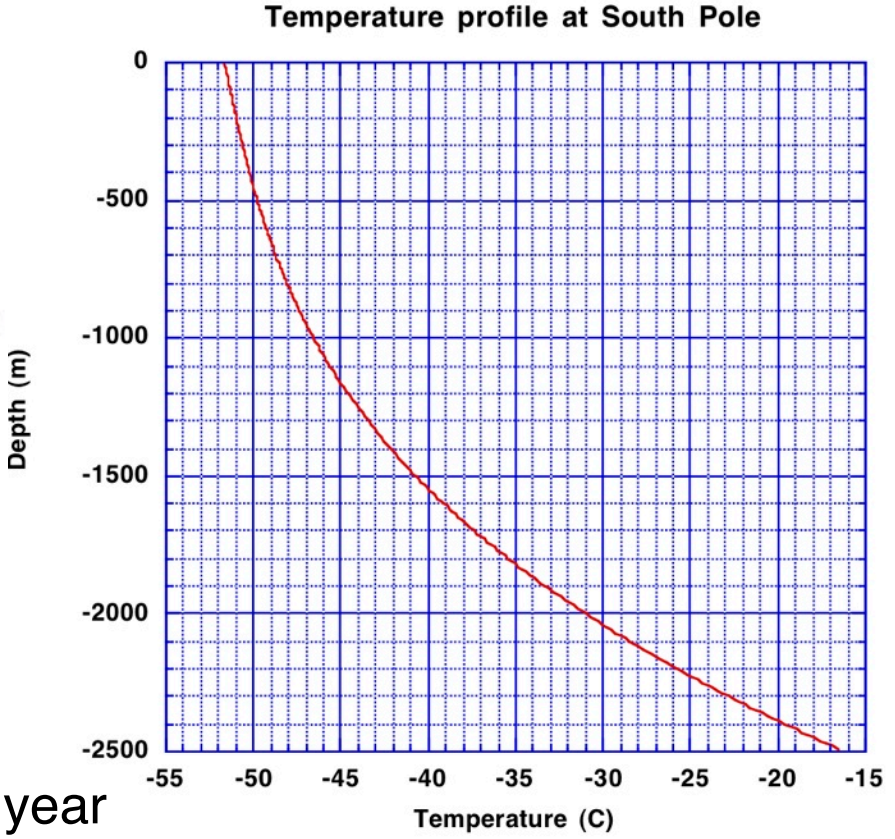


Antarctic Ice

Temperature

- Each IceCube Digital Optical Module (DOM) and deployment cable can measure temperature in the ice





- At -2500 m, ice is -20 °C
- Temperature is stable throughout the year
- at -20°C, NaI pulses are slower than at +20°C but light output is slightly better.

Kurt Woschnagg (IceCube)

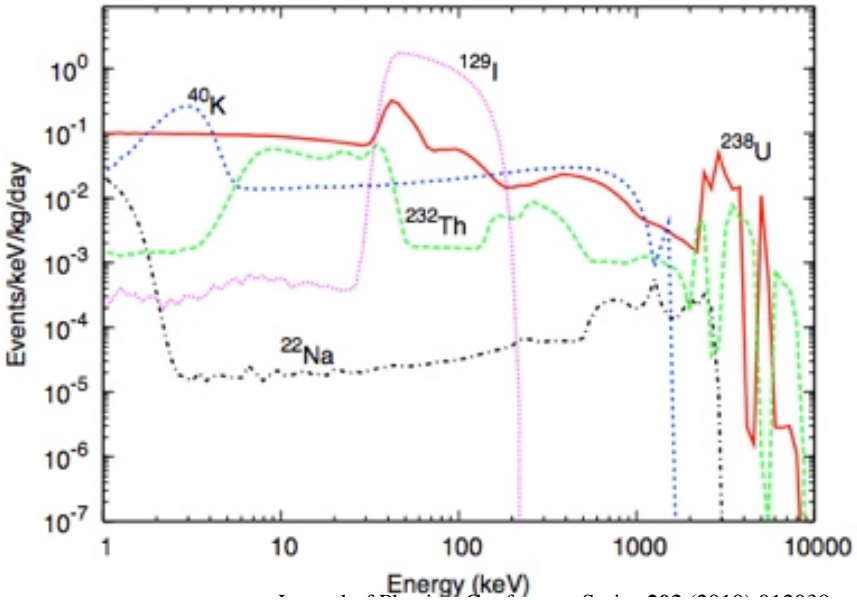
NaI(Tl) Detector Backgrounds

Backgrounds

Likely to be limited by intrinsic backgrounds in NaI crystals

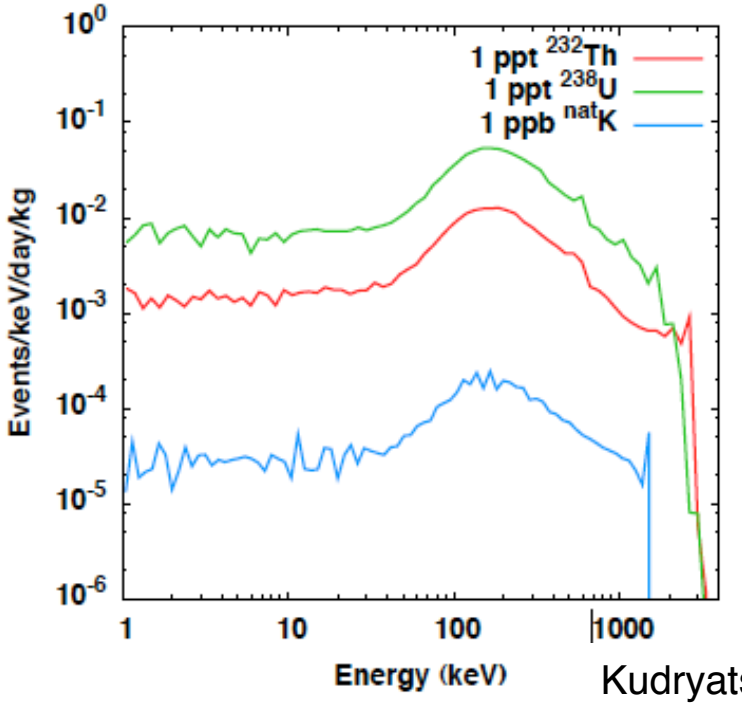
Growing NaI(Tl) crystals: know how to remove U/Th, but K is difficult.

simulated backgrounds from intrinsic contamination in DAMA crystals



Kudryatsev et al.

simulated activity in NaI crystals due to activity in ice



Kudryatsev et al.

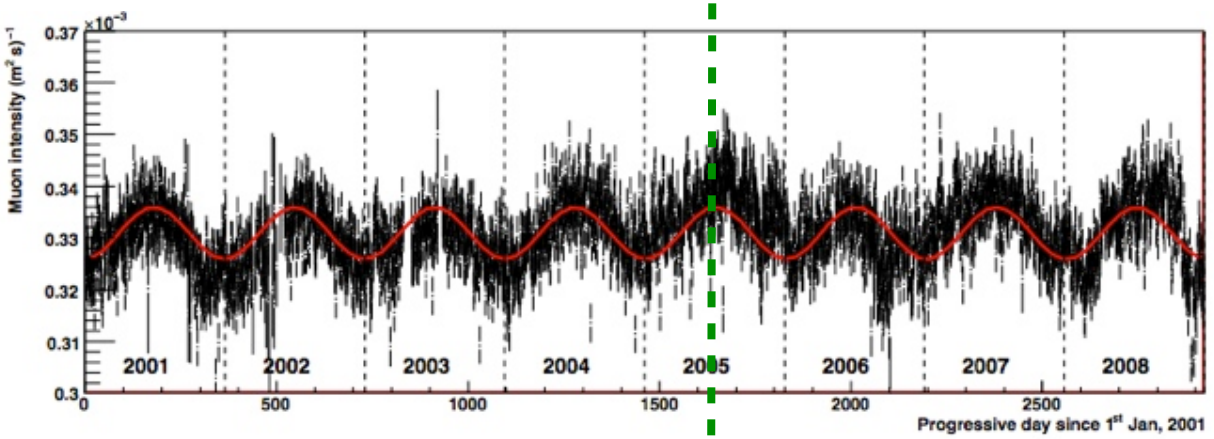
Muon Rate Seasonal Modulation

summer

Gran Sasso

- LVD:

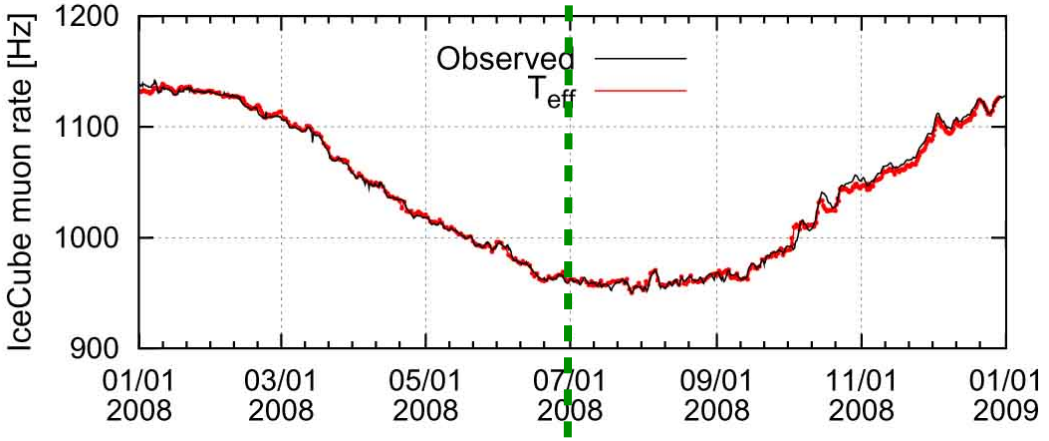
Selvi, Proc. 31st ICRC.



South Pole

- Opposite Muon modulation at the South Pole:

Tilav, Proc. 31st ICRC. (2009)



Muon Rate Seasonal Modulation

South Pole

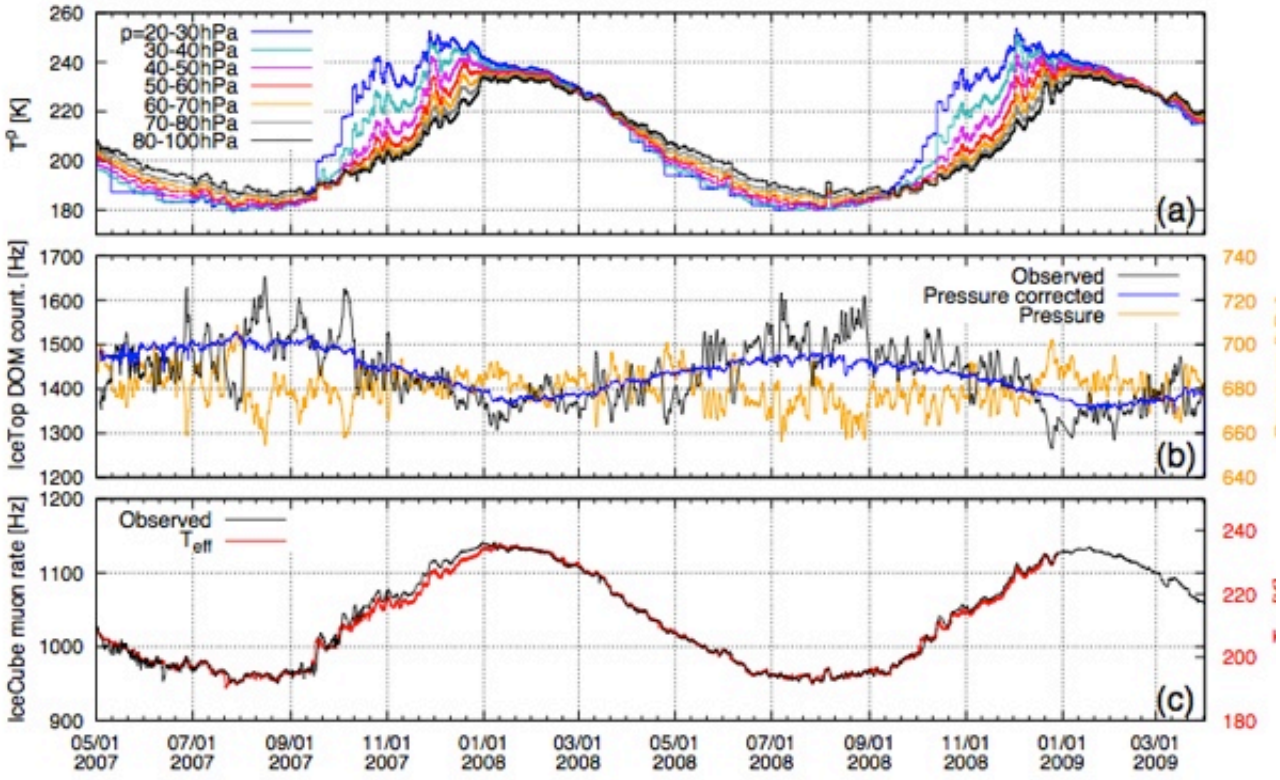
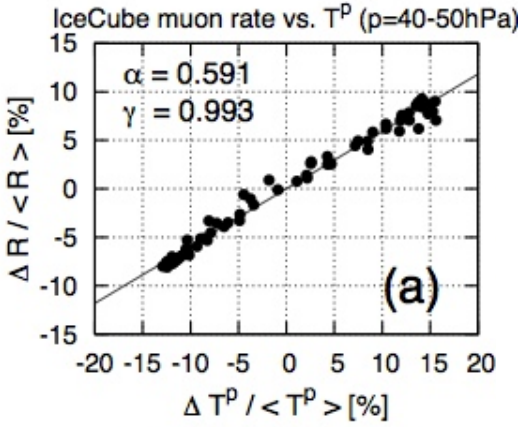
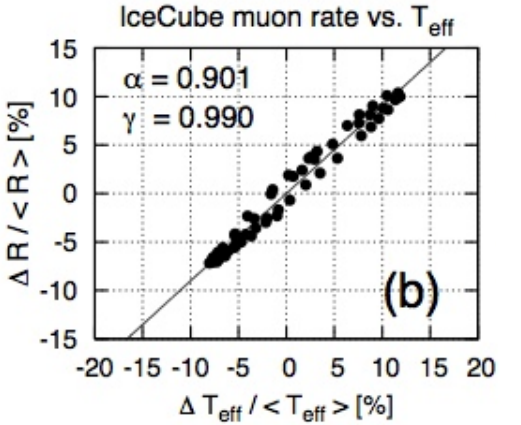


Fig. 1. The temporal behavior of the South Pole stratosphere from May 2007 to April 2009 is compared to IceTop DOM counting rate a the high energy muon rate in the deep ice. (a) The temperature profiles of the stratosphere at pressure layers from 20 hPa to 100 hPa wh the first cosmic ray interactions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





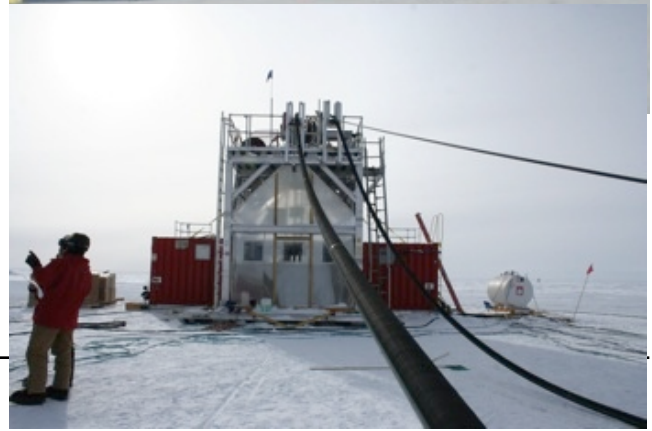
Starting a Dark Matter Experiment at the Pole

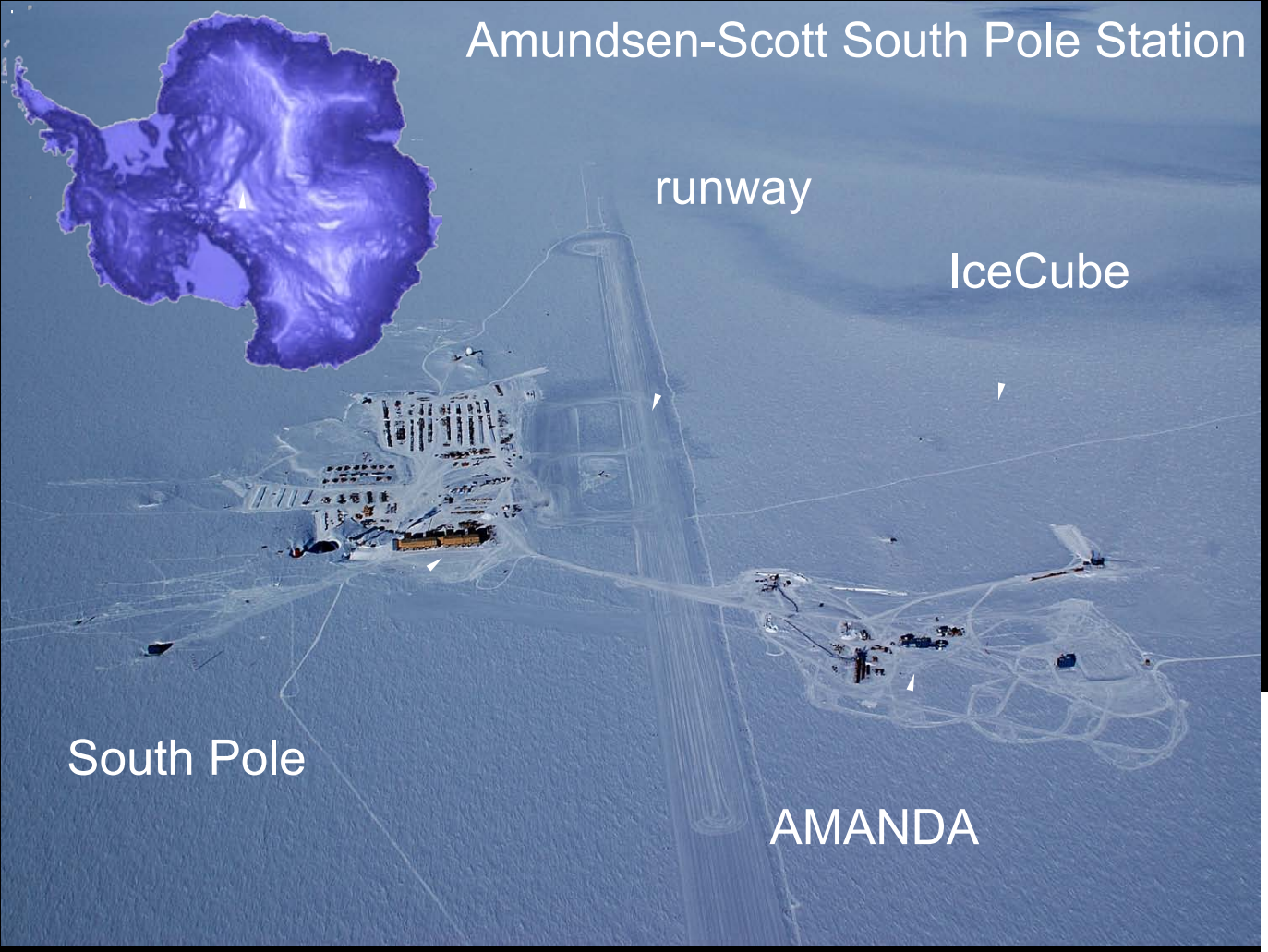
Window of Opportunity

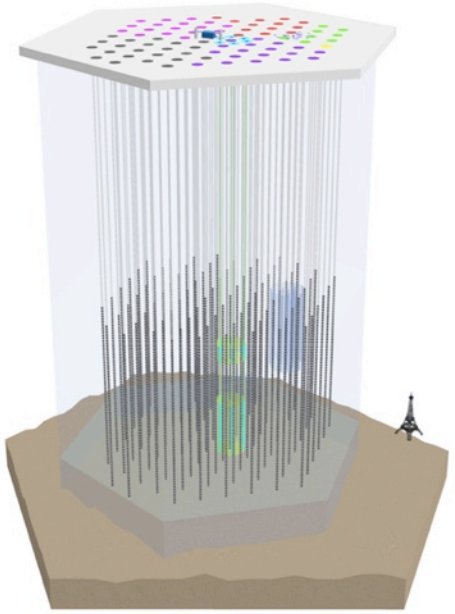
- IceCube construction finished in Dec. 2010
- Infrastructure for deep deployment of instrumentation at South Pole

Challenges

- Extreme environment
- Detector will be inaccessible once deployed.
- But...
  - NaI detectors have been launched into space (e.g. EGRET, Fermi LAT)




Amundsen-Scott South Pole Station
runway
IceCube
South Pole
AMANDA



DM-Ice: A Dark Matter Experiment at the Pole

DM-Ice prototype

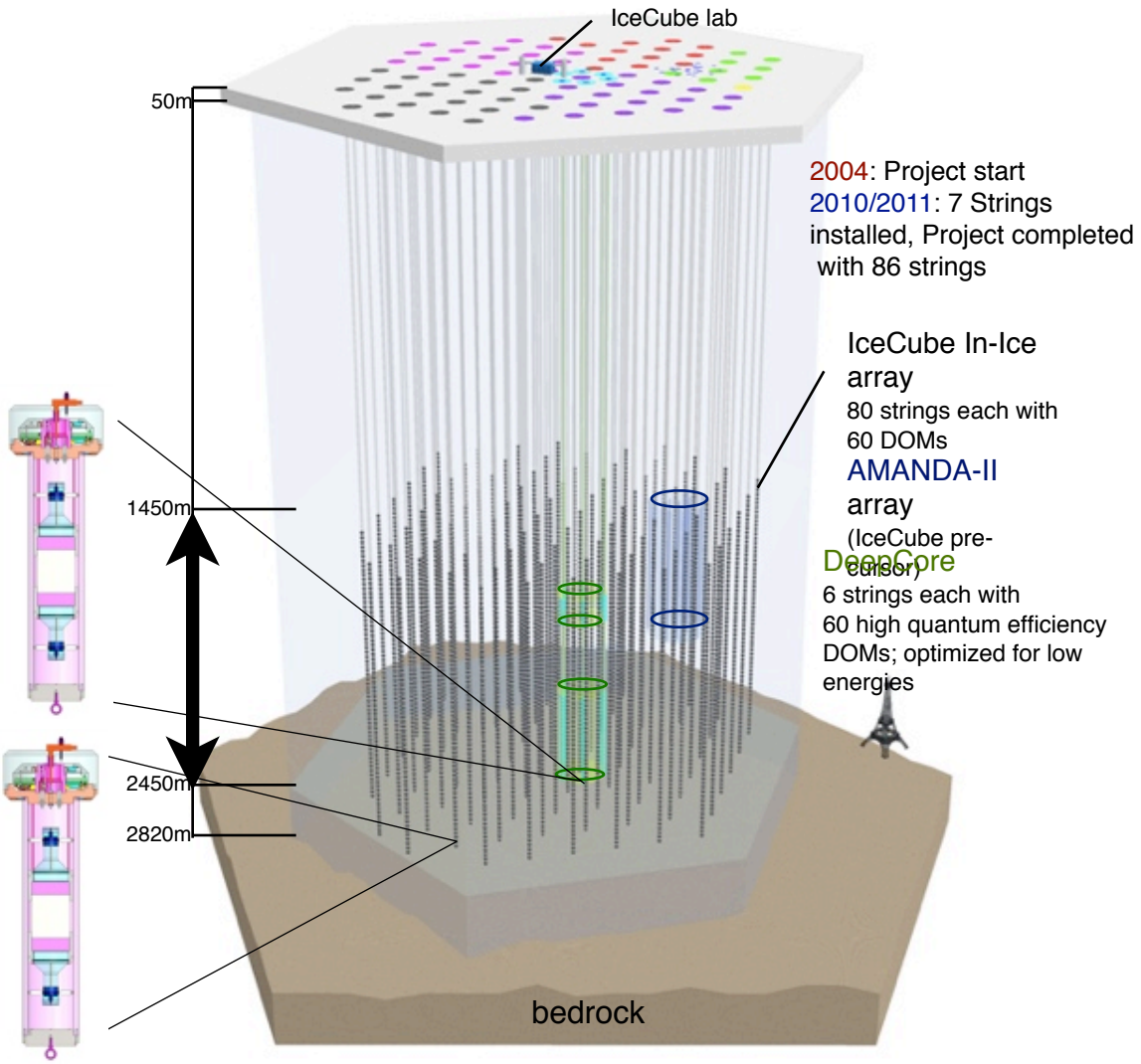
Detectors

- Two 8.5 kg NaI detectors from NAIAD

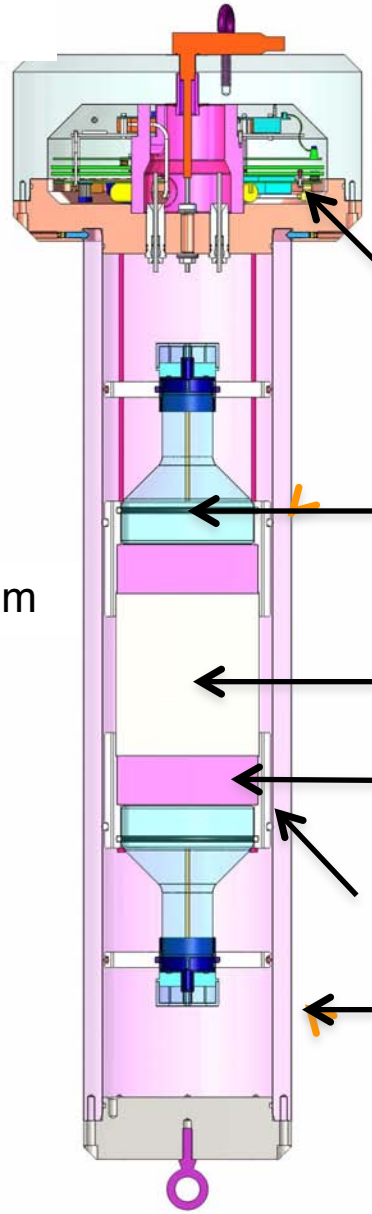
Goals

- 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



36 cm (14”)

~1.0 m

2 IceCube mainboards +
HV control boards

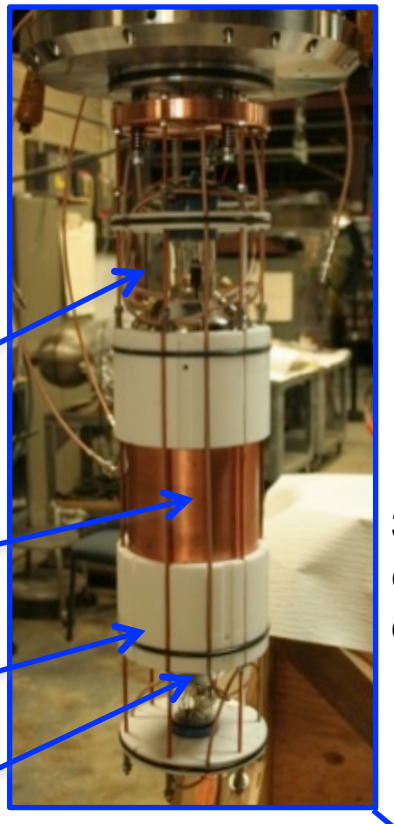
5” ETL PMTs from
NAIAD (2)

NAIAD NaI Crystal
(8.5 kg)

quartz light guides (2)

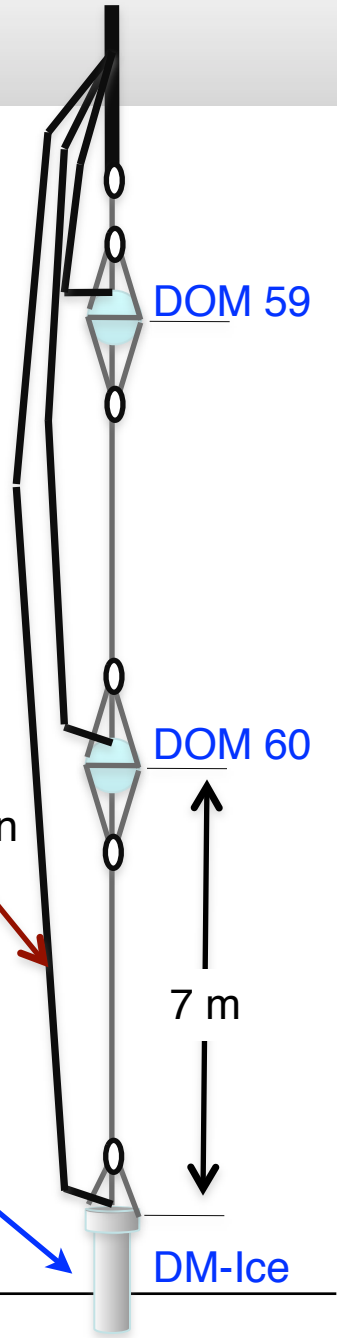
PTFE light reflectors (2)

Stainless Steel
Pressure Vessel

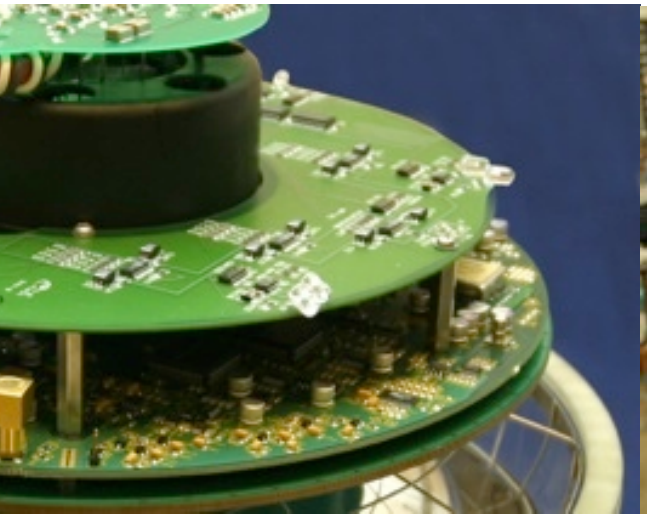


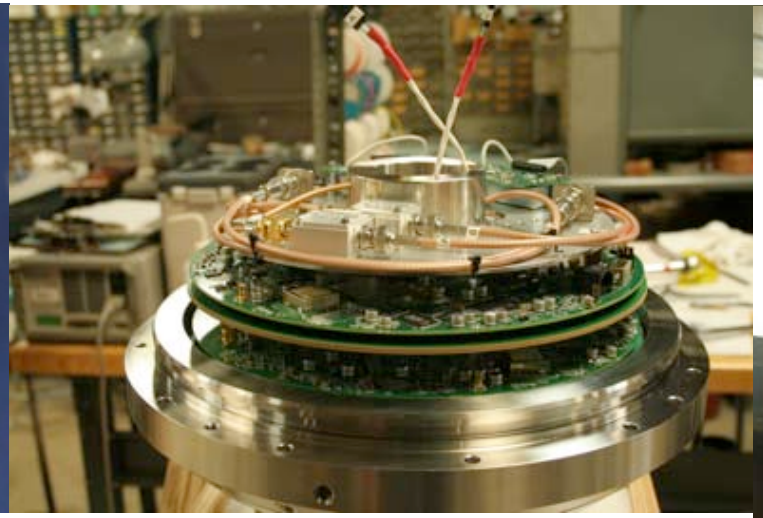
attached to end of
IceCube strings

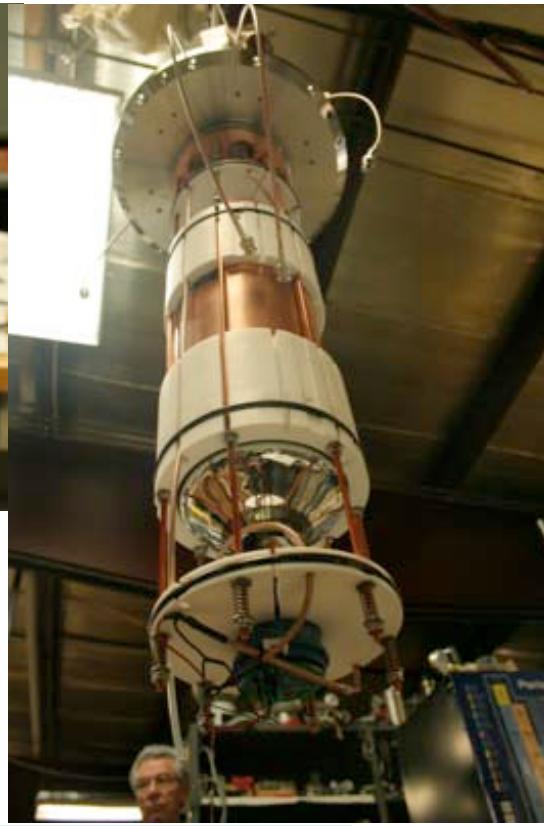
35 m
extension
cable

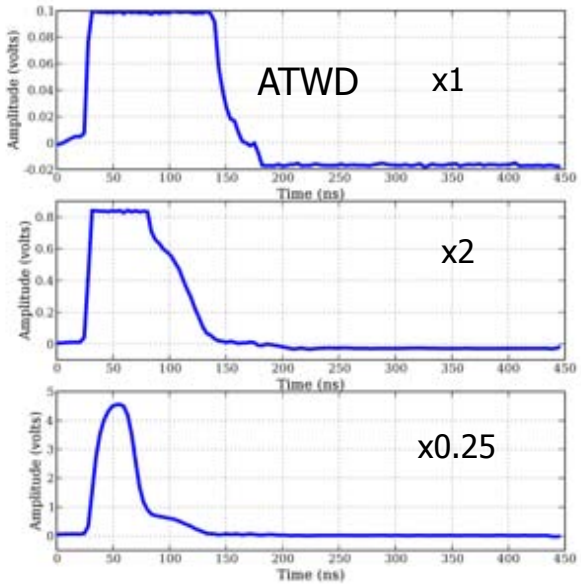


IceCube DOM Mainboards in DM-Ice

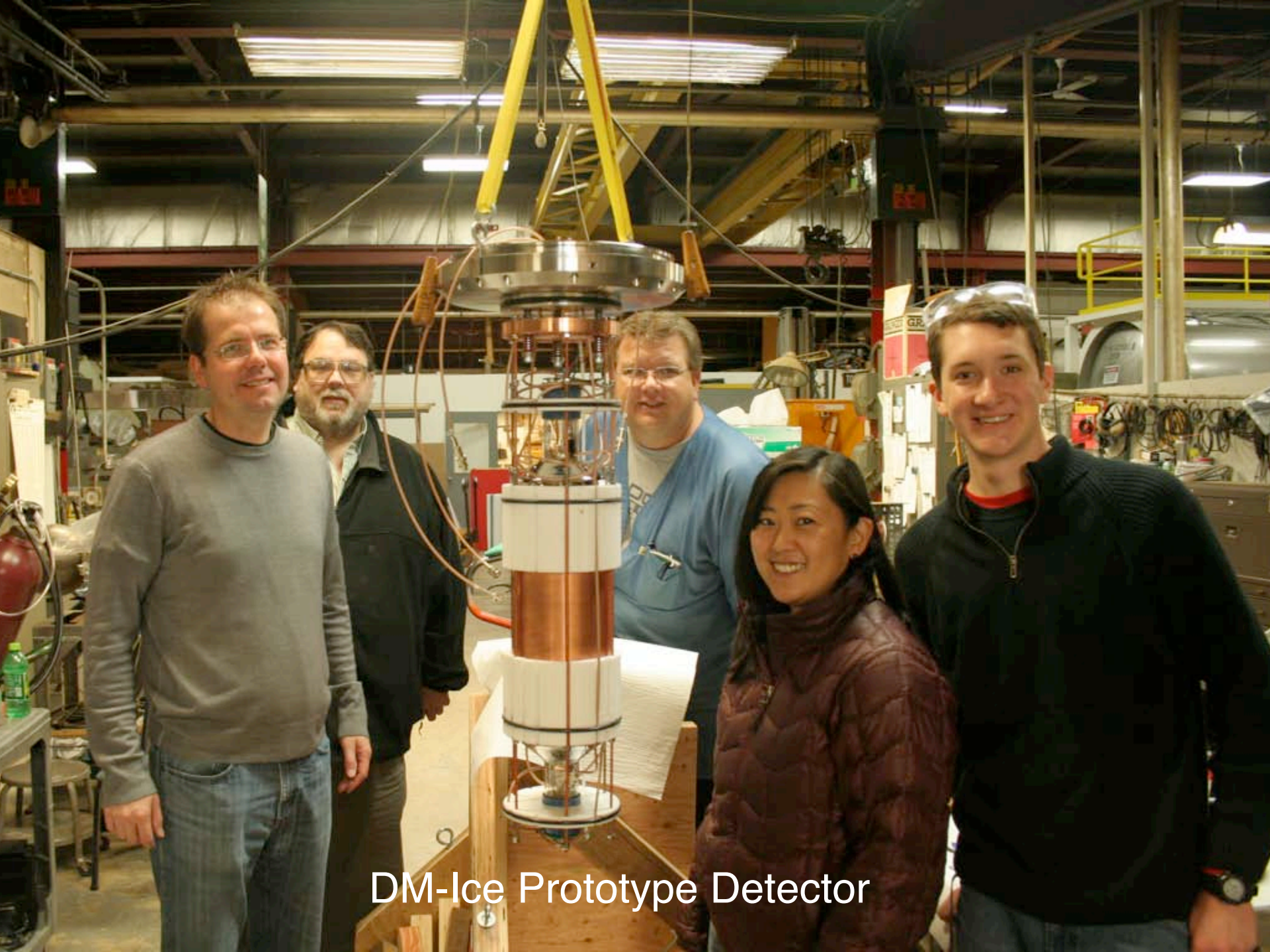






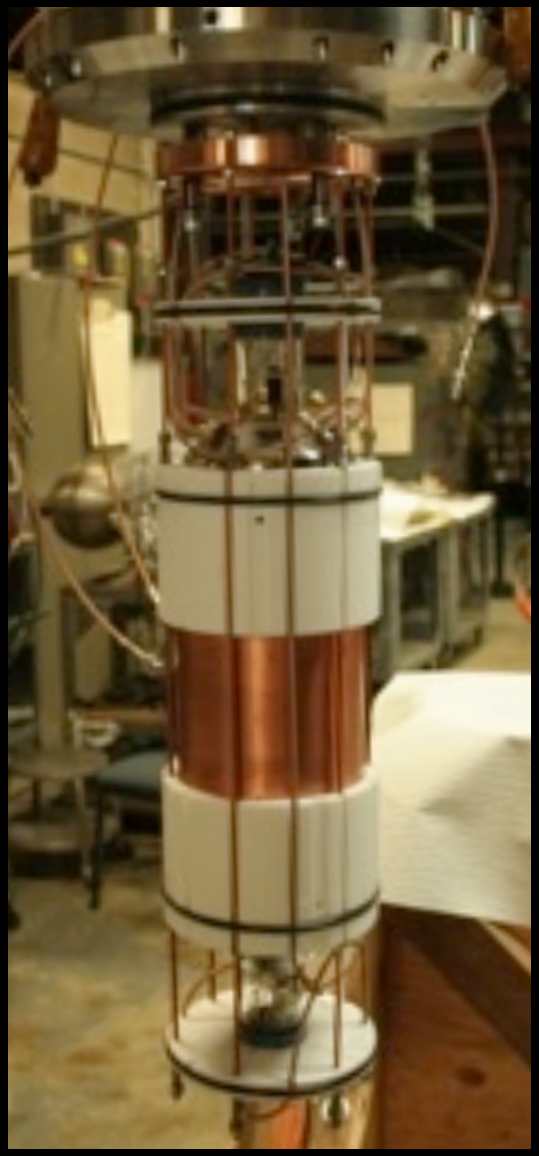


- Each ATWD contains 3 gain paths: x16, x2, x0.25 (giving effectively 14-bits)
- Coincidence trigger capabilities
- Controls a separate HV board
- Programmable from surface
- Established reliable technology



DM-Ice Prototype Detector

DM-Ice Prototype Detector

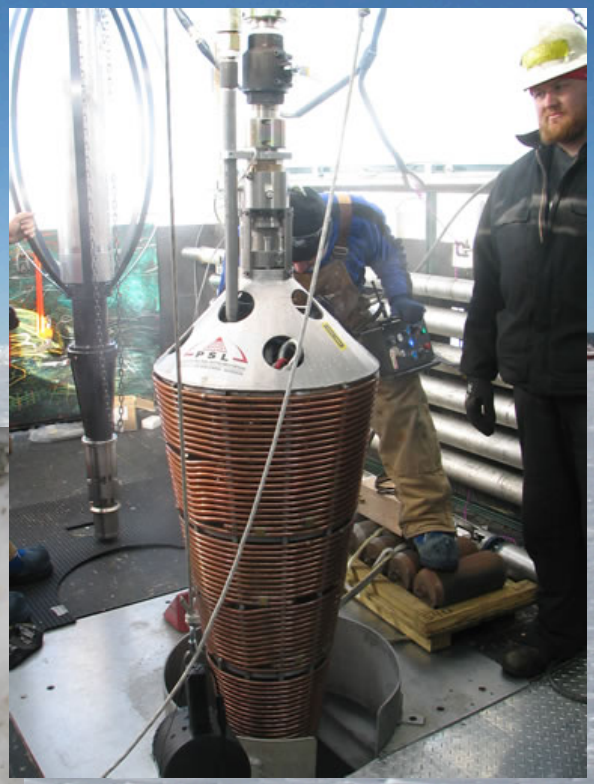


Transport to the South Pole

Transport to the South Pole

Hot Water Drilling into the Ice

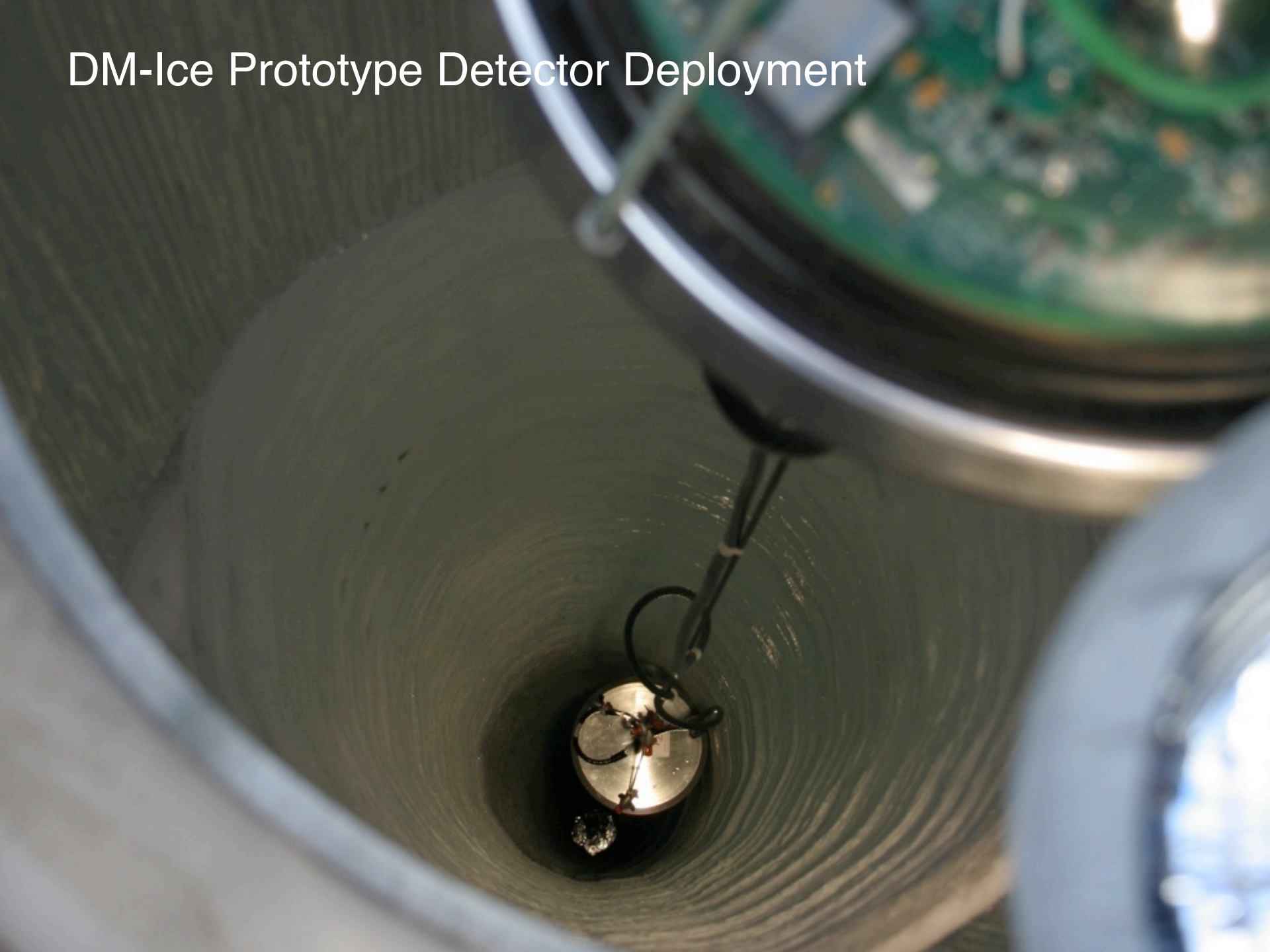
Firn Drill



Deep Drill

DM-Ice Prototype Detector Deployment

DM-Ice Prototype Detector Deployment

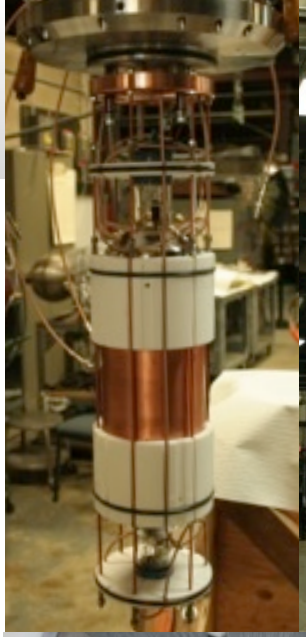


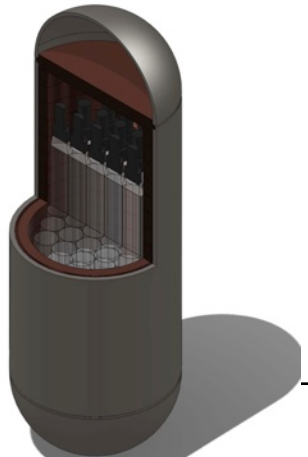
DM-Ice Status & Outlook

- DM-Ice prototype (17 kg) deployed in December 2010
  - Functioning well
  - Currently taking data
  - Data transmitted over satellite
  - Optimizing analysis, background studies with radio-assay & Monte Carlo simulation

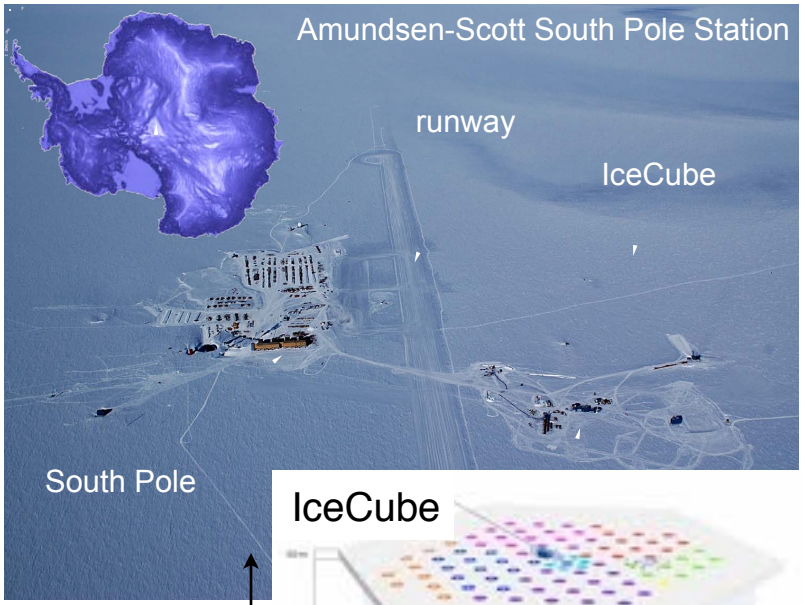
- Designing 250-kg scale DM-Ice detector
  - Developing drilling and deployment plan for 2013/14
  - R&D on low background crystals
  - Designing pressure vessels, etc.
  - Investigating low background PMTs

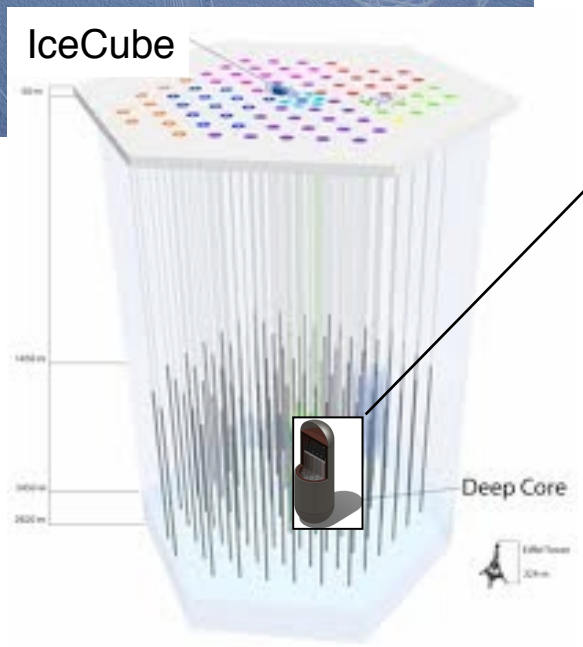
see arXiv:1106.1156



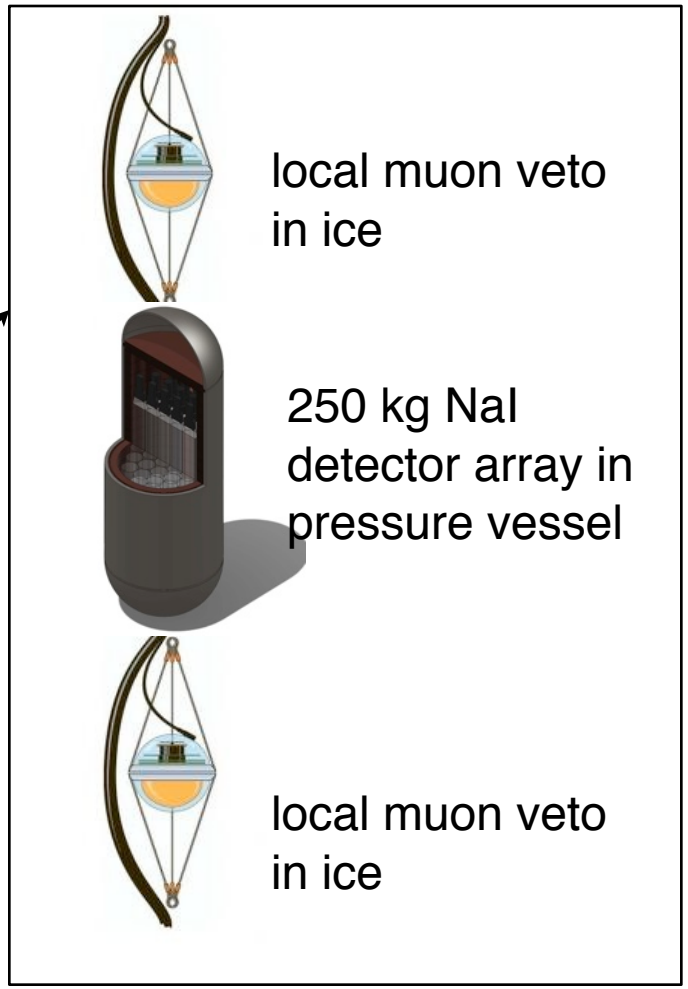
DM-Ice Concept





~2500m

~ 250kg NaI Detector Array Deep int the Ice



arXiv:1106.115

DM-Ice Conceptual Design

DM-Ice Concept
- Large Pressure Vessel
- Segmented Crystals

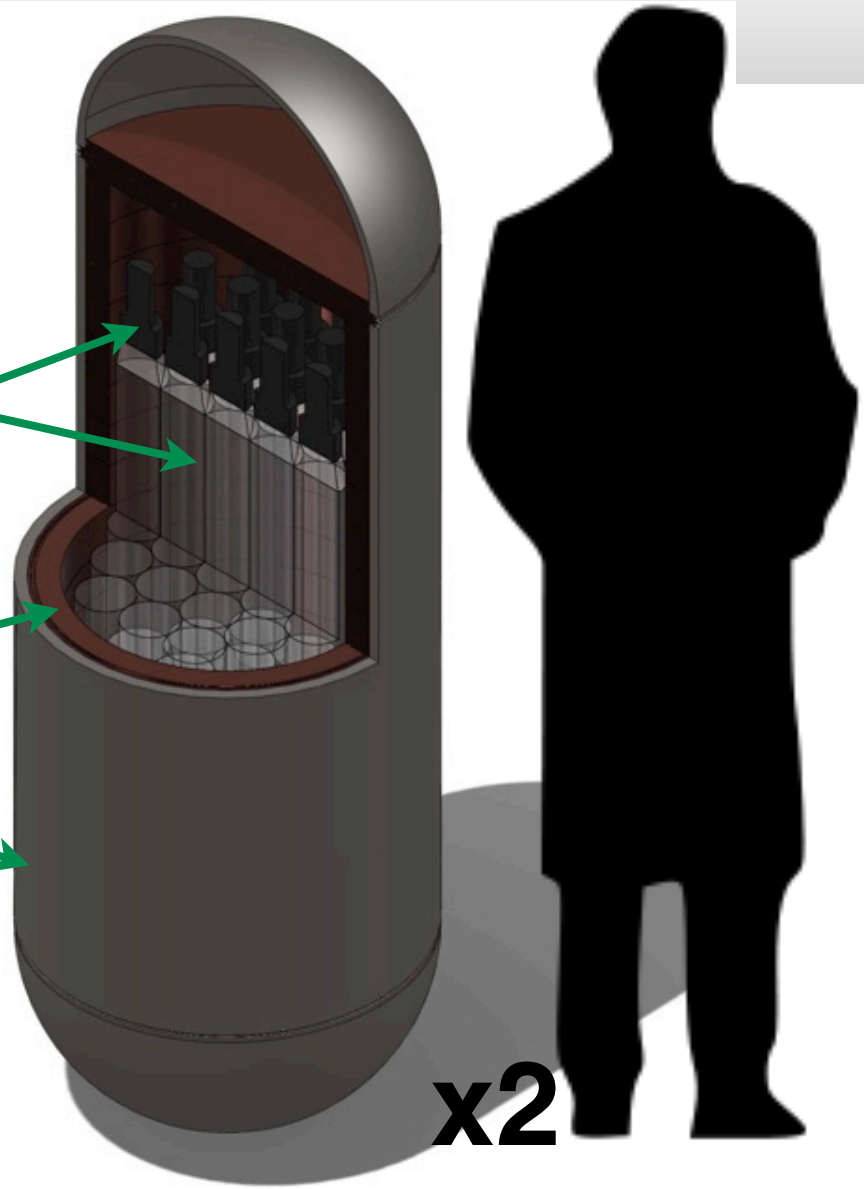
38 NaI Crystals (each vessel contains 19)
- 95.6 mm Diameter
- 250 mm Long
- 6.5 kg each
- 2 PMTs each

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

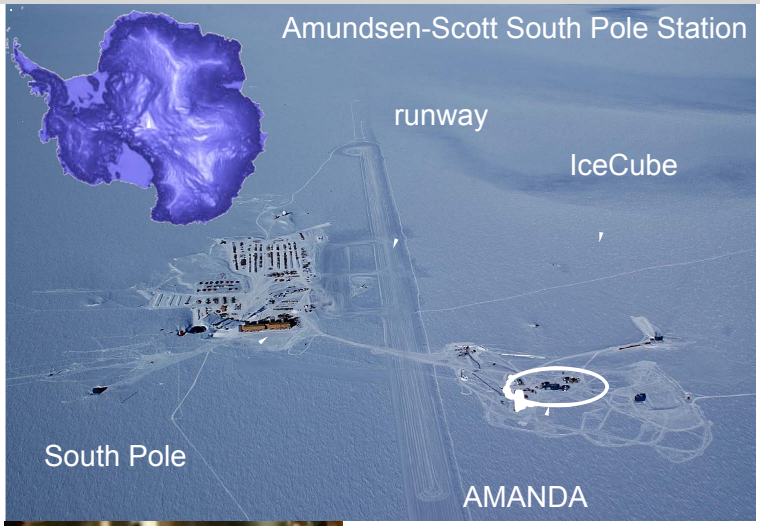
250 kg NaI (38@6.5 kg crystals)
1500 kg total including pressure vessel

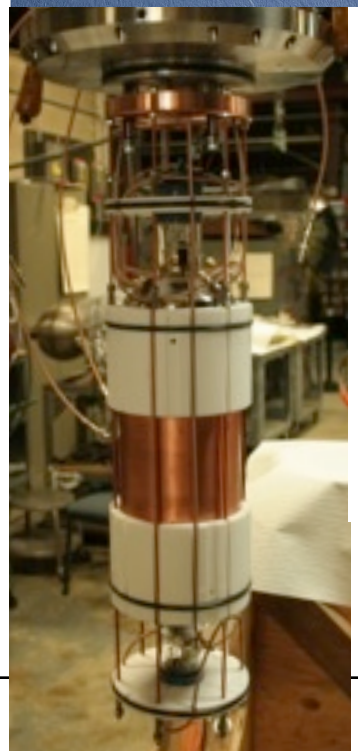


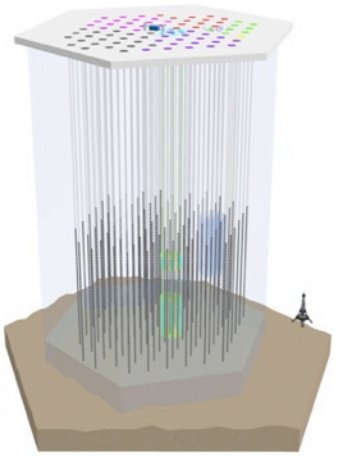
DM-Ice: A Dark Matter Experiment at the Pole

Summary&Conclusions

- We have opportunity for a unique annual modulation experiment in Southern Hemisphere.
- Backgrounds very different from any other underground location.
- Two prototype NaI(Tl) detector installed in the South Pole ice in 2010
- Full-scale experiment currently under design







see arXiv:1106.1156

DM-Ice Collaboration

see arXiv:1106.1156

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... and we are working closely with the IceCube collaboration

Thank you!