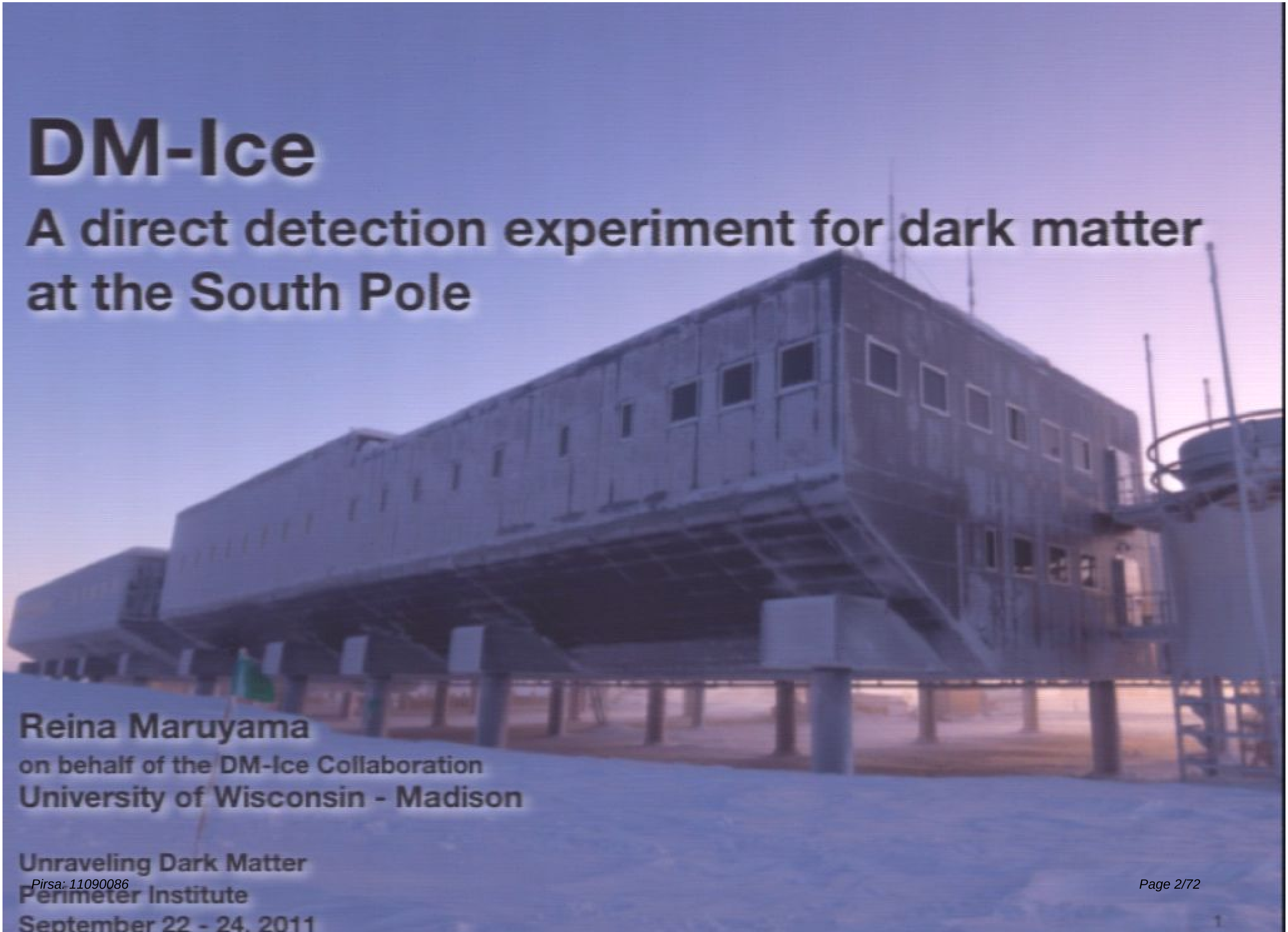
Title: DM-Ice: a Direct Detection Experiment for Dark Matter at the South Pole

Date: Sep 23, 2011 10:20 AM

URL: http://pirsa.org/11090086

Abstract: I will describe DM-Ice, a direct detection dark matter experiment at the South Pole. The aim of the experiment is to test the claim for an observation of dark matter by the DAMA collaboration by carrying out an experiment with the same detector technology, but in the southern hemisphere. By going to the opposite hemisphere, many of the suspected backgrounds would produce annual modulation with the opposite phase whereas the dark matter signature should stay the same. DMIce-17, a 17-kg detector was installed in the Antarctic ice at the South Pole in December 2010 at the depth of ~2200 m.w.e. and is currently taking data. An experiment that can test DAMA's claim is currently being designed. I will report on the status of DMIce-17 and the plans for the full-scale experiment.


DM-Ice
A direct detection experiment for dark matter at the South Pole
Reina Maruyama
on behalf of the DM-Ice Collaboration
University of Wisconsin - Madison
Unraveling Dark Matter
Perimeter Institute
September 22 - 24, 2011
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Current Status of Bounds on Dark Matter from Terrestrial experiments

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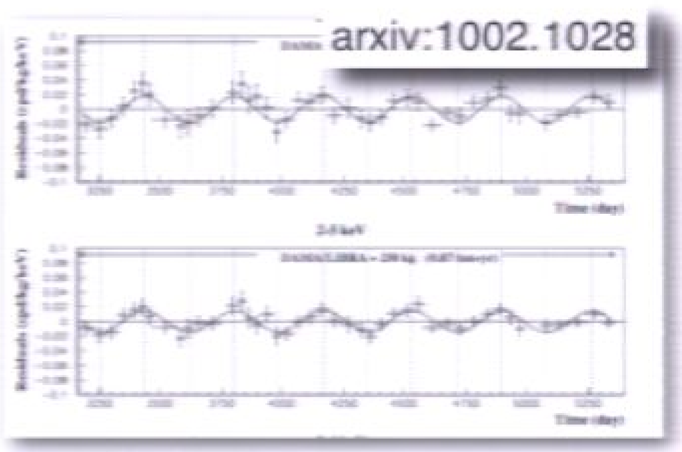

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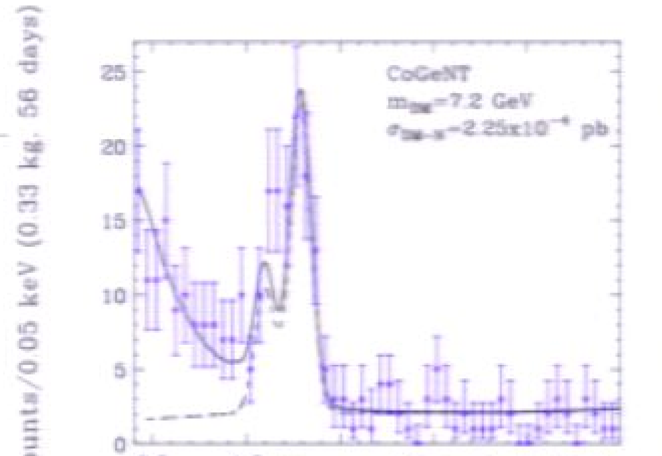
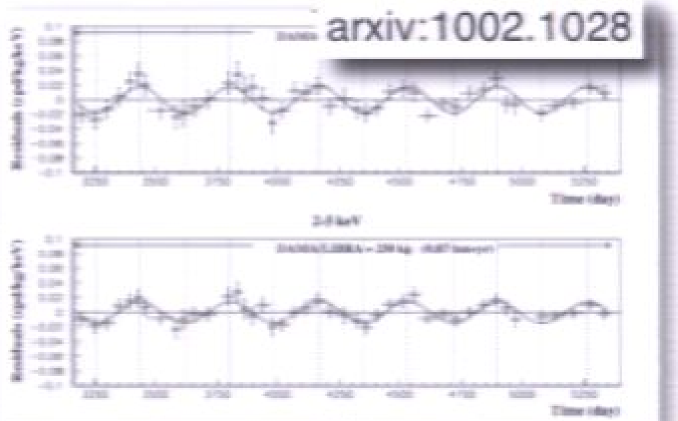


Hooper, Collar, Hall, McKinsey
arXiv:1007.1005v1



arxiv:1002.1028

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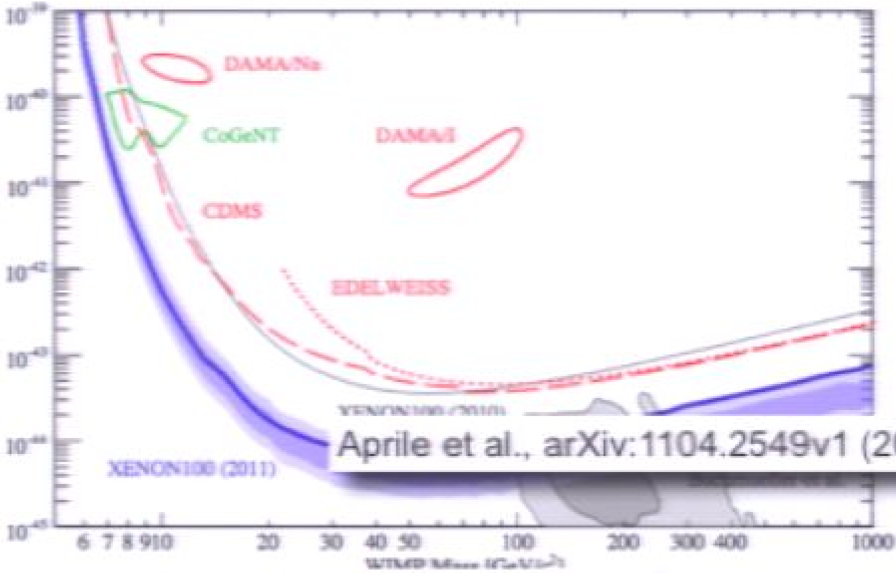
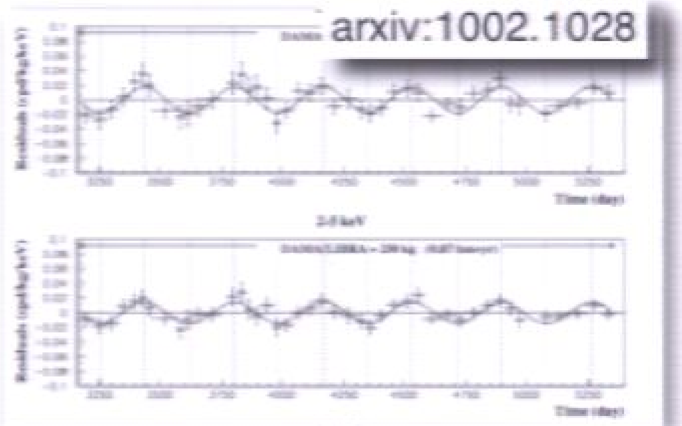


Aprile et al., arXiv:1104.2549v1 (2011)



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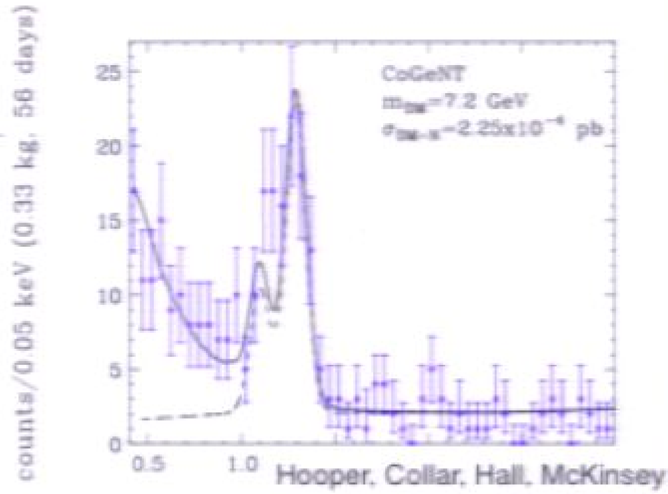

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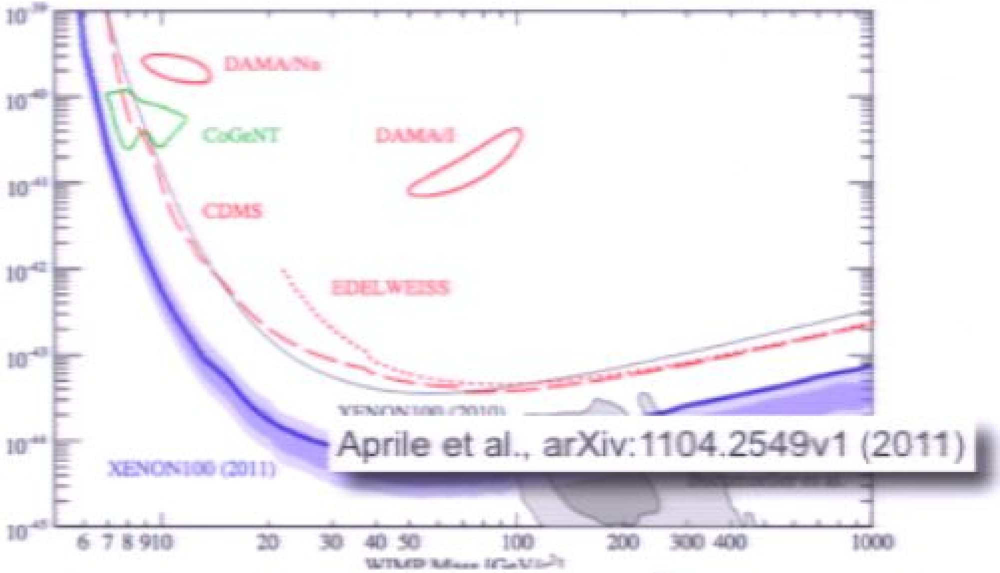

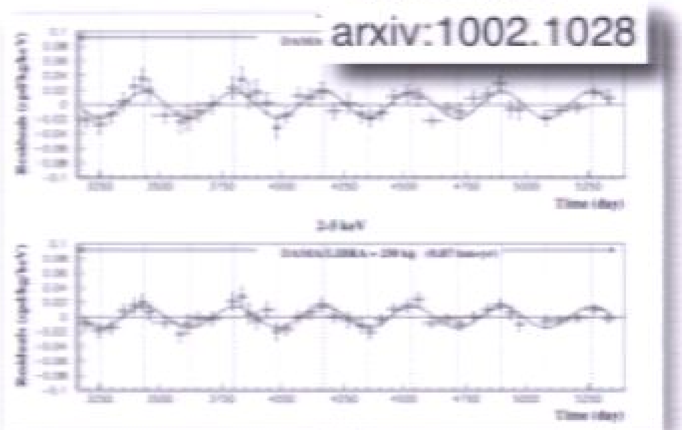

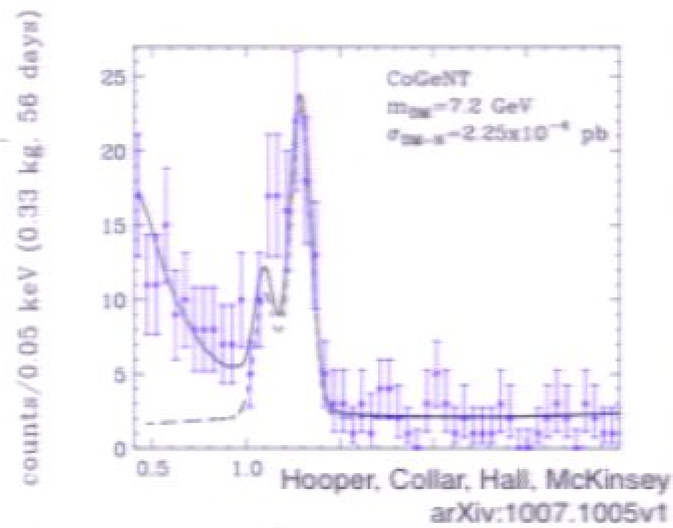

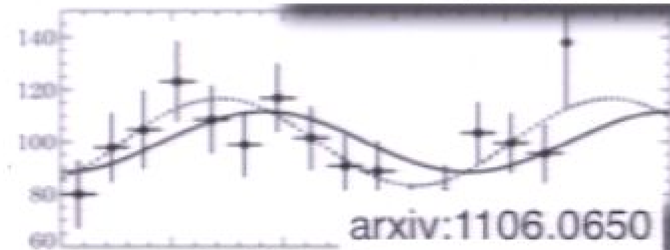

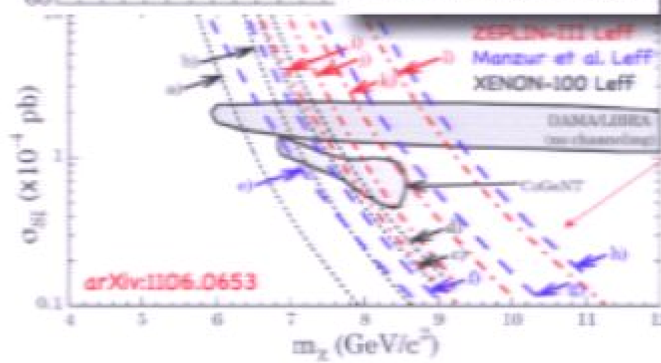

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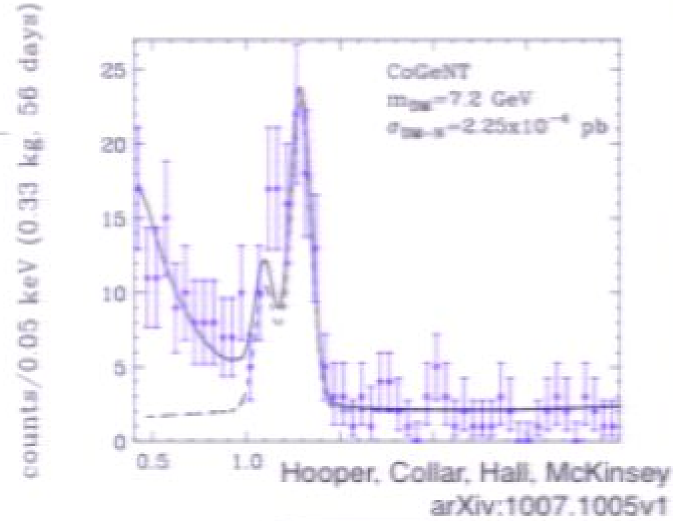

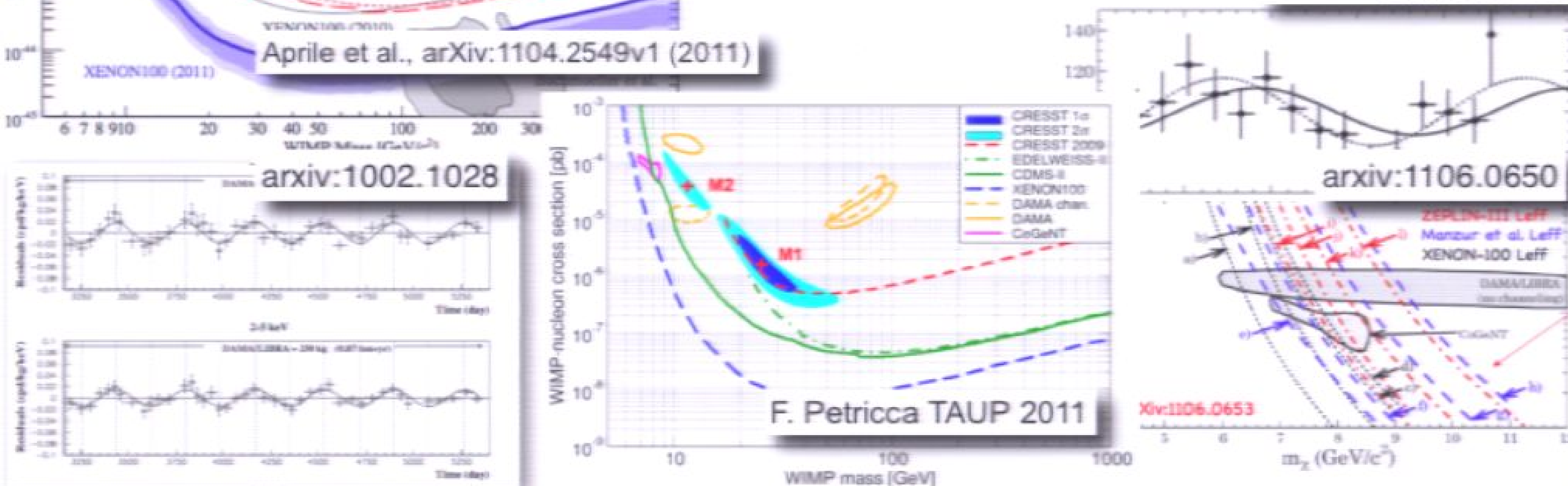

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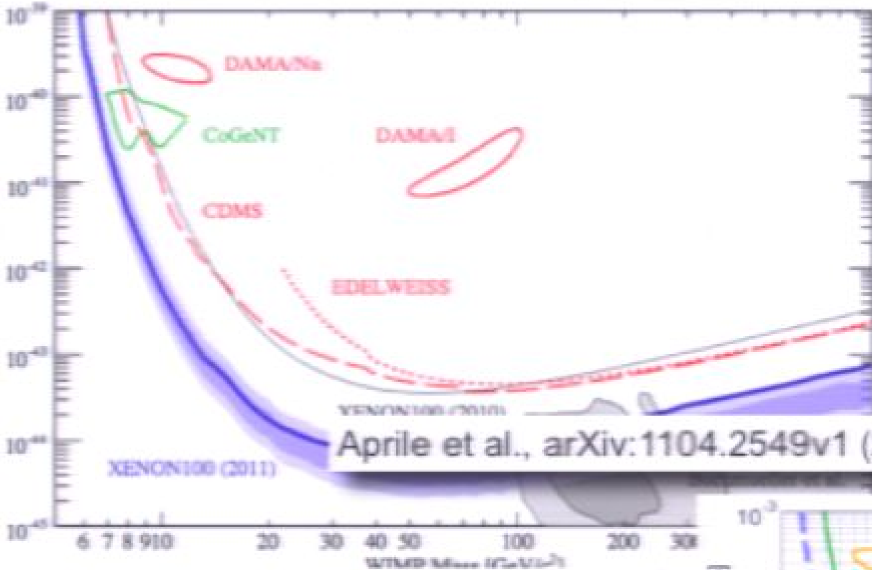

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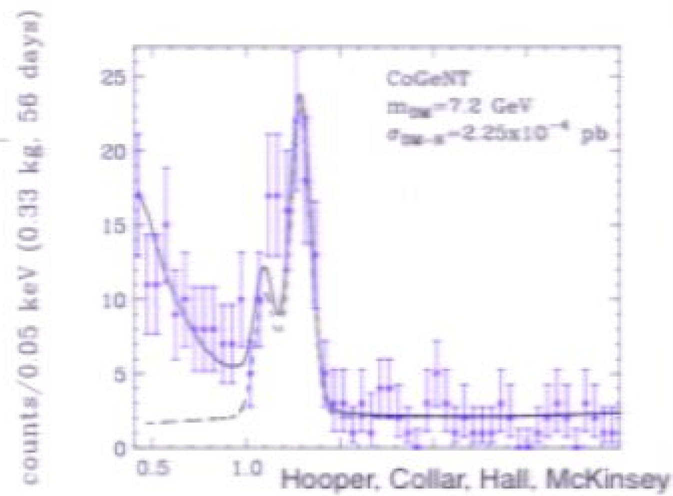

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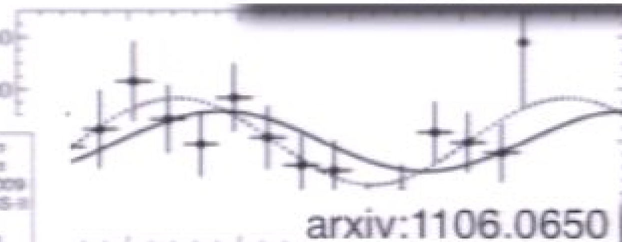
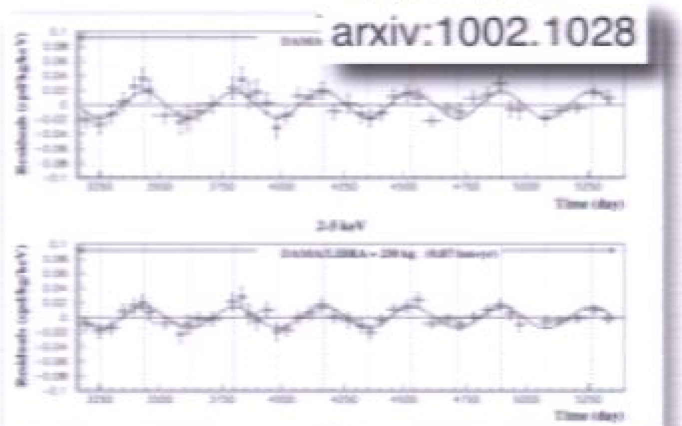


arxiv:1106.0650



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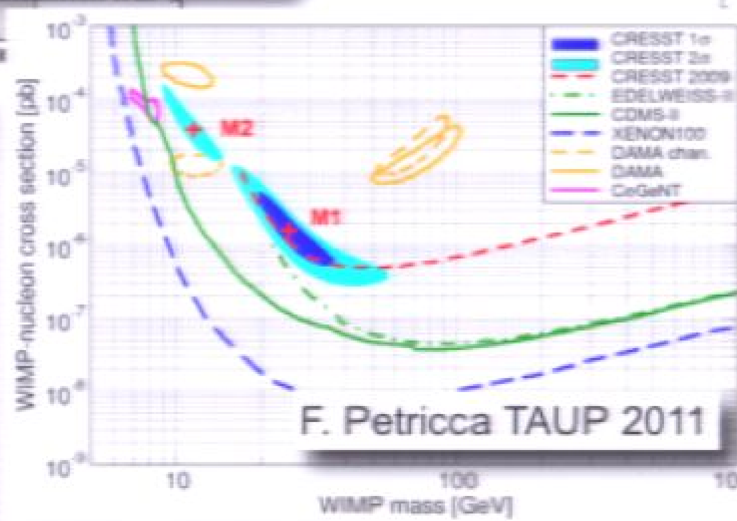
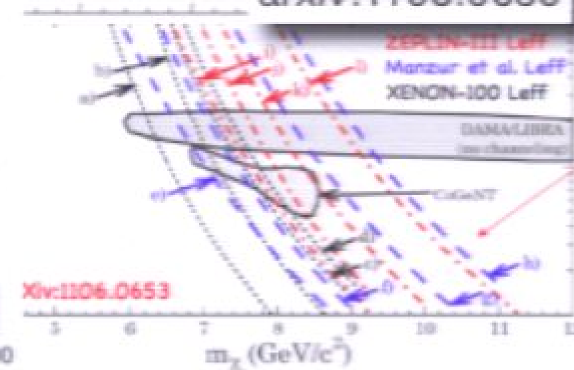


F. Petricca TAUP 2011

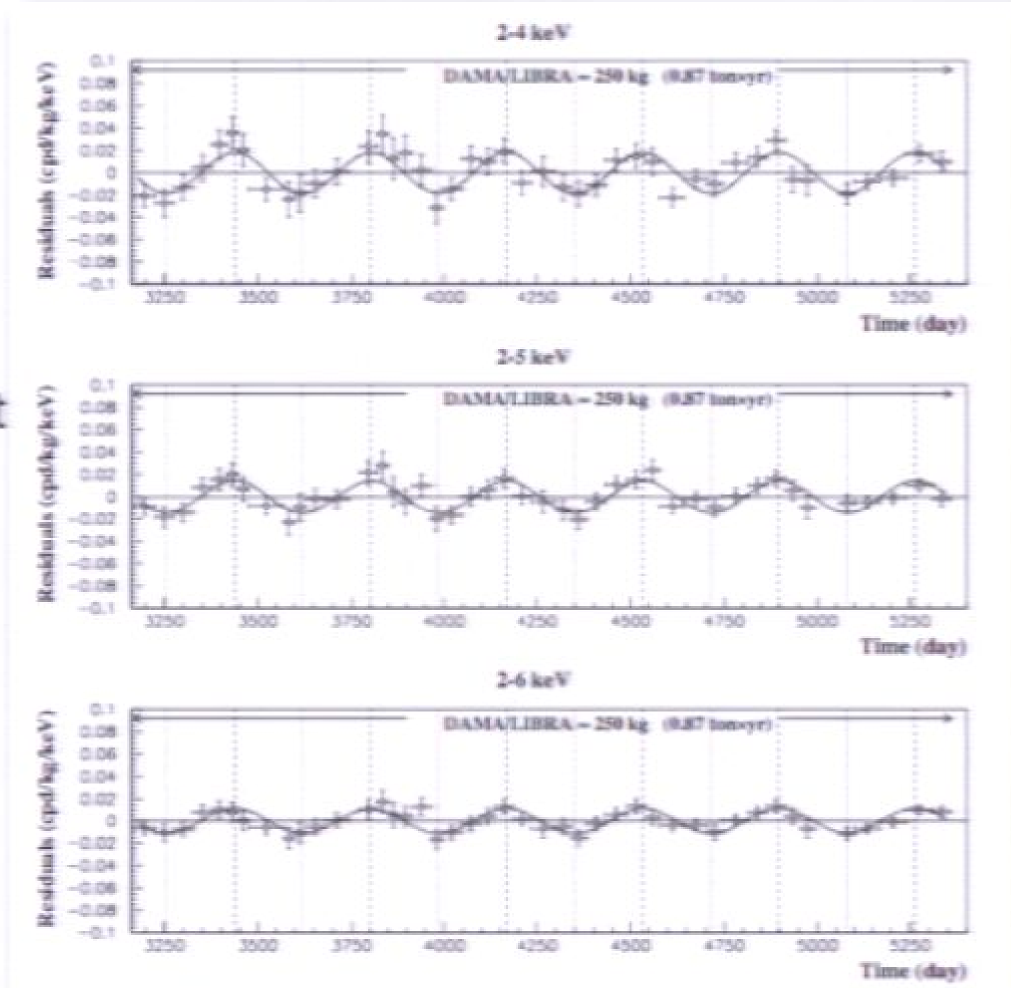


One claim for discovery: DAMA

hints in CoGeNT? CRESST?

Modulation Observed by DAMA

- DAMA/NaI (1996 - 2003)
- DAMA/LIBRA (2003 - present)
- 1.17 ton-yr (13 annual cycles)
- 8.9σ C.L.
- modulation amplitude of the single-hit events in the (2 - 6) keV:
    - (0.0116 +/- 0.0013) cpd/kg/keV
- phase: (146 +/- 7) days (June 2)
- period: (0.999 +/- 0.002) yr



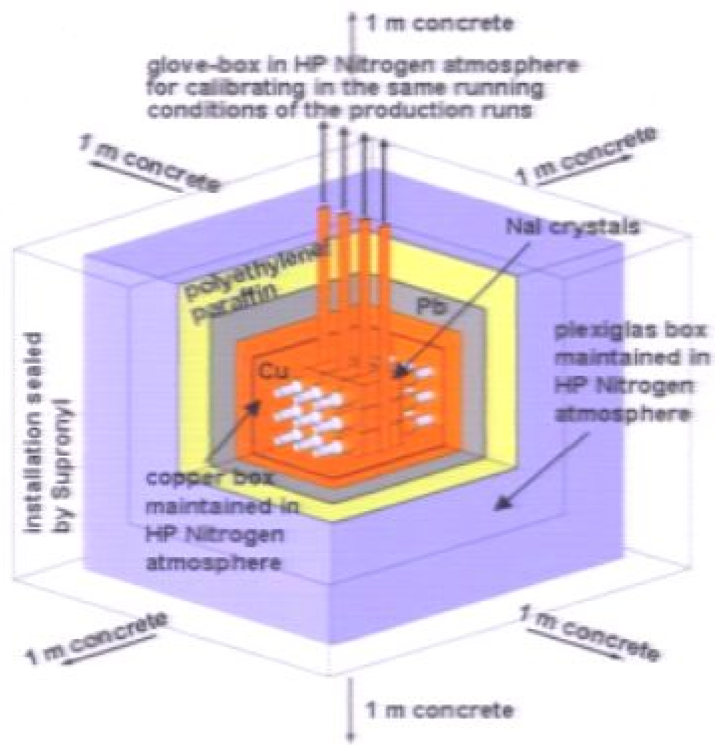
★ DAMA attributes the modulation to dark matter.

arxiv:1002.1028

DAMA/NaI, DAMA/LIBRA

- Gran Sasso, Italy under ~3800 m.w.e of rock.
- DAMA/NaI consisted of ~100 kg of NaI
- DAMA/LIBRA ~250kg
    - 25 xtals (10 x 10 x 25 cm^3, 9.7 kg)
- Look for scintillation in NaI with two PMTs, 5 - 7 p.e./keV
- background: ~1-2 events/kg/d/keV
- $E_{threshold}$: 2 keV_e (25 keV_r)

Claim for 9σ observation of dark matter



Simplified schema of ~ 100 kg NaI(Tl) set-up

Possible Explanations for Annual Modulation Signals

- Environmental Effects/Backgrounds
  - 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
  - detector and lab maintenance timing

Many of these factors tend to have periodicity of 1 year

- Detector Effects
  - quenching factor
  - channeling
  - Xenon scintillation function: L_{eff}
  - Scintillator phosphorescence

- Astrophysical Uncertainties?
  - f(v)? v_{esc}? v_0? co-rotating? streams?
- Dark Matter Physics
  - inelastic scattering
  - iso-spin violation
  - Asymmetric DM

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experimental situation and interpretation unclear

Many of these factors tend to have periodicity of 1 year

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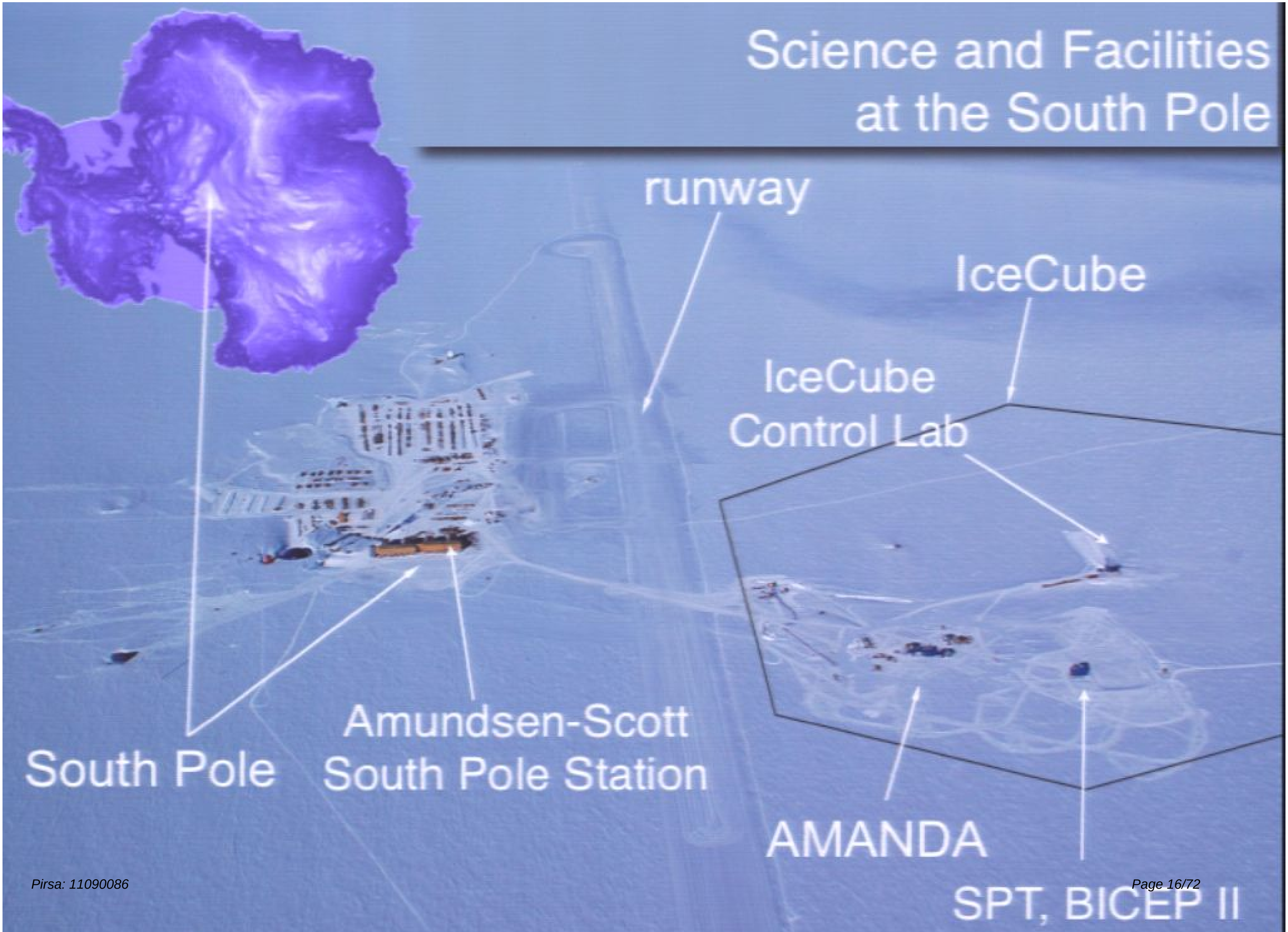
  - Asymmetric DM

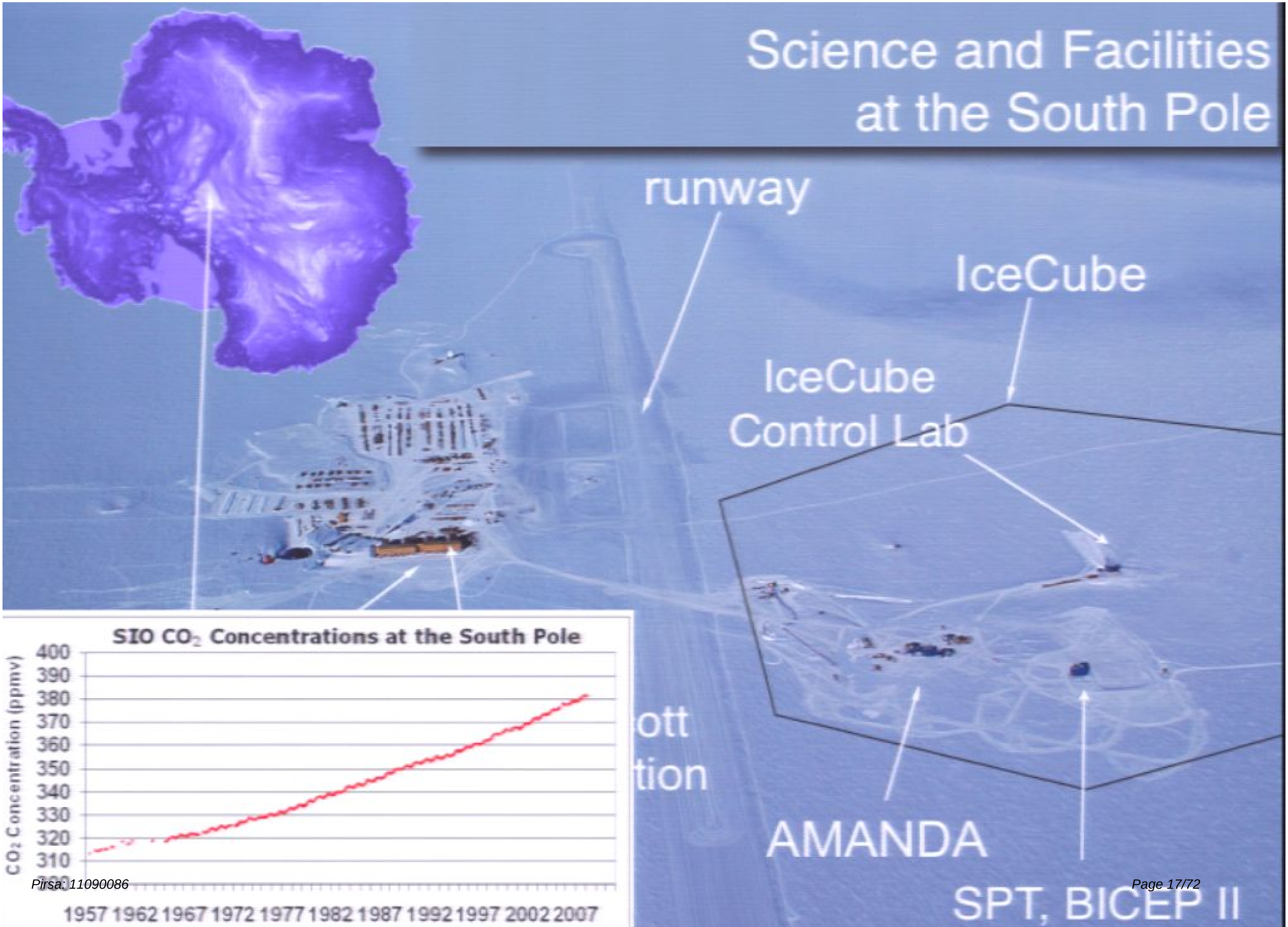
Repeat experiment in different environment. Look for annual modulation with NaI(Tl) in Southern Hemisphere.

Going to the South Pole

Dark Matter Search at the South Pole

- Modulation Phase:
  - The expected phase of the dark matter modulation is the same, but
  - Many environmental variations are either opposite in phase or absent.
- Low background environment
  - > 2500 m.w.e. of overburden
  - Clean ice → no lead/copper shielding necessary. No radon.
  - 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


Science and Facilities
at the South Pole
runway
IceCube
IceCube
Control Lab
South Pole
Amundsen-Scott
South Pole Station
AMANDA
SPT, BICEP II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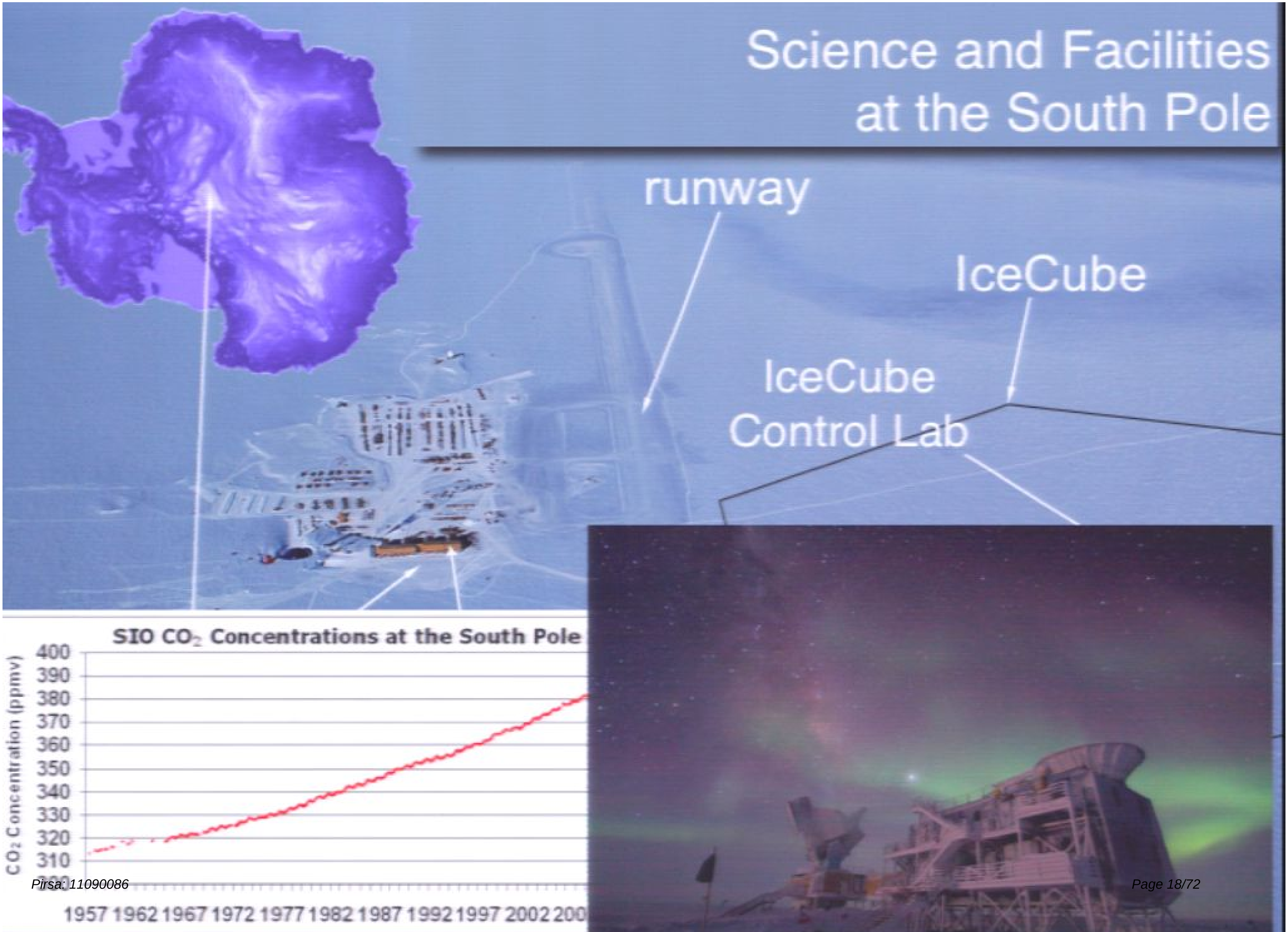
SIO CO2 Concentrations at the South Pole
CO2 Concentration (ppmv)
400
390
380
370
360
350
340
330
320
310
1957 1962 1967 1972 1977 1982 1987 1992 1997 2002 2007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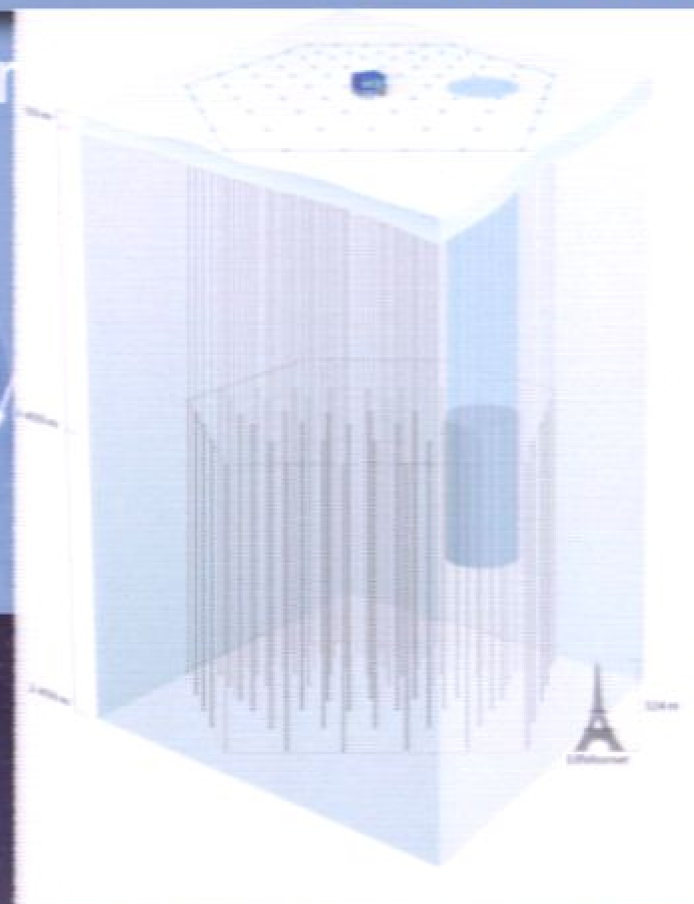
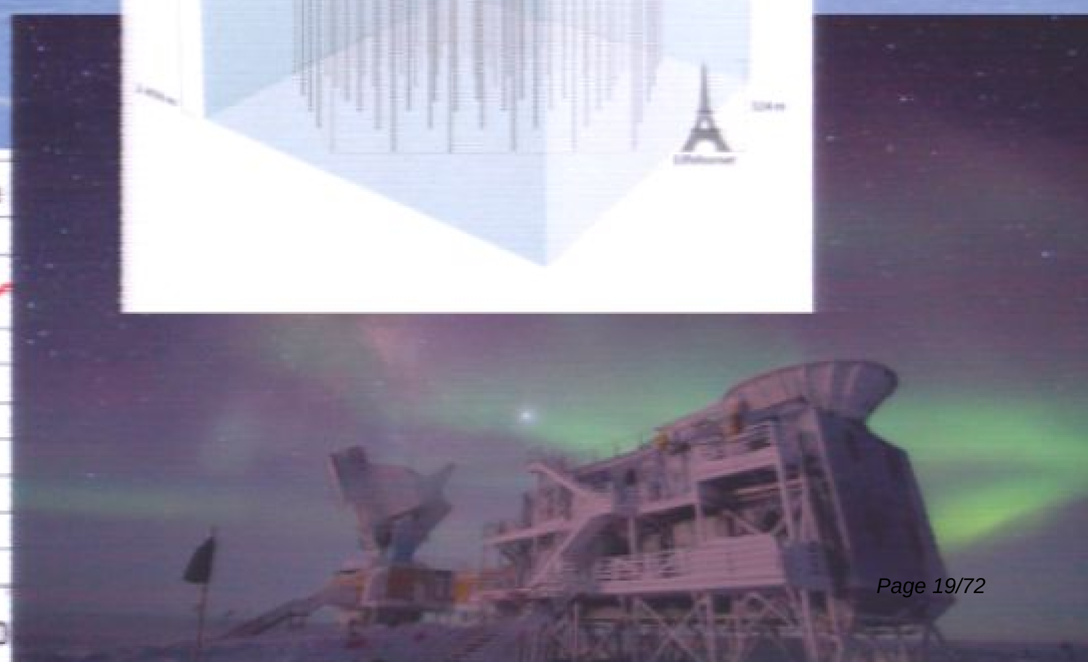
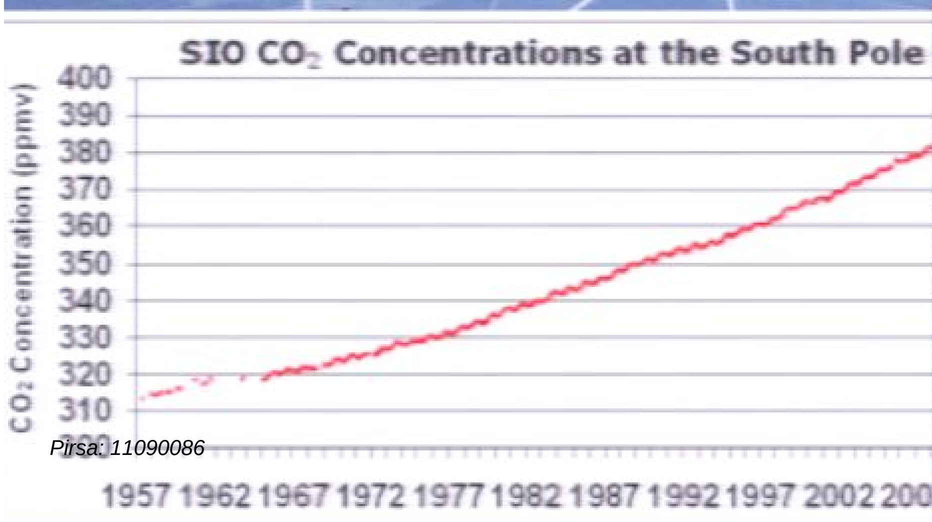
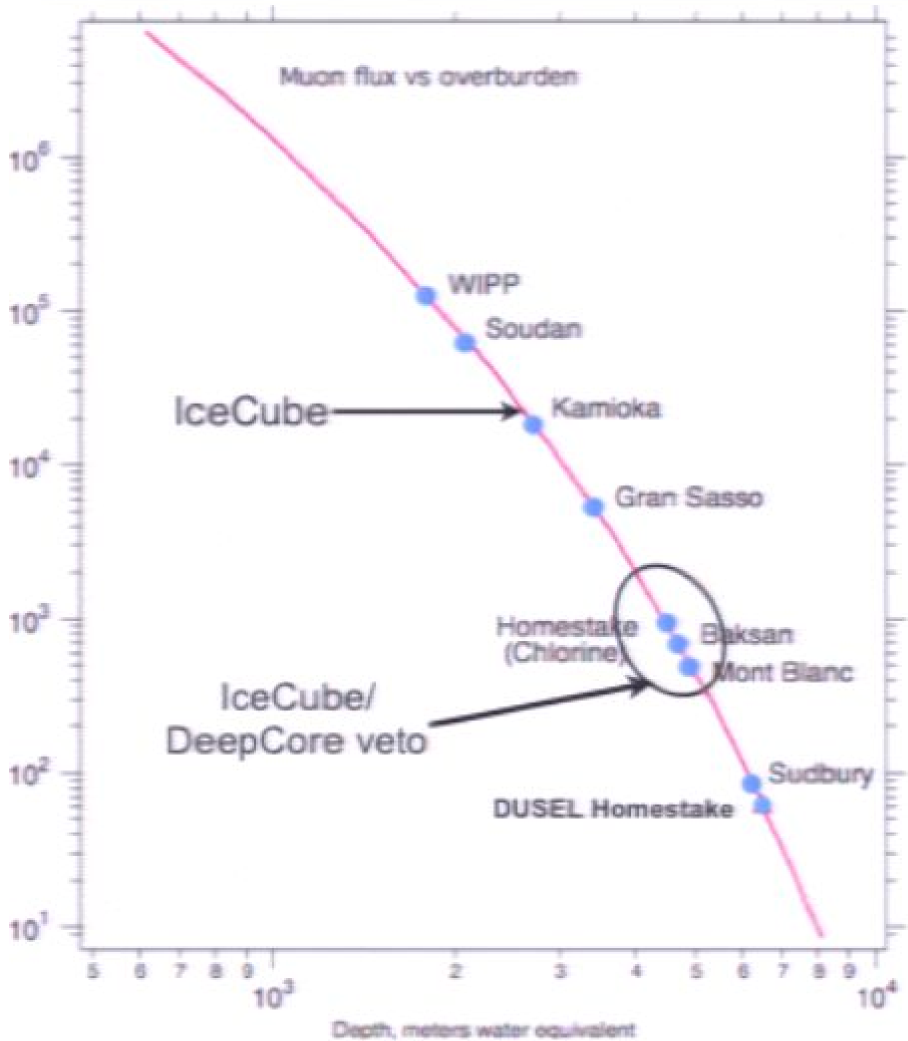


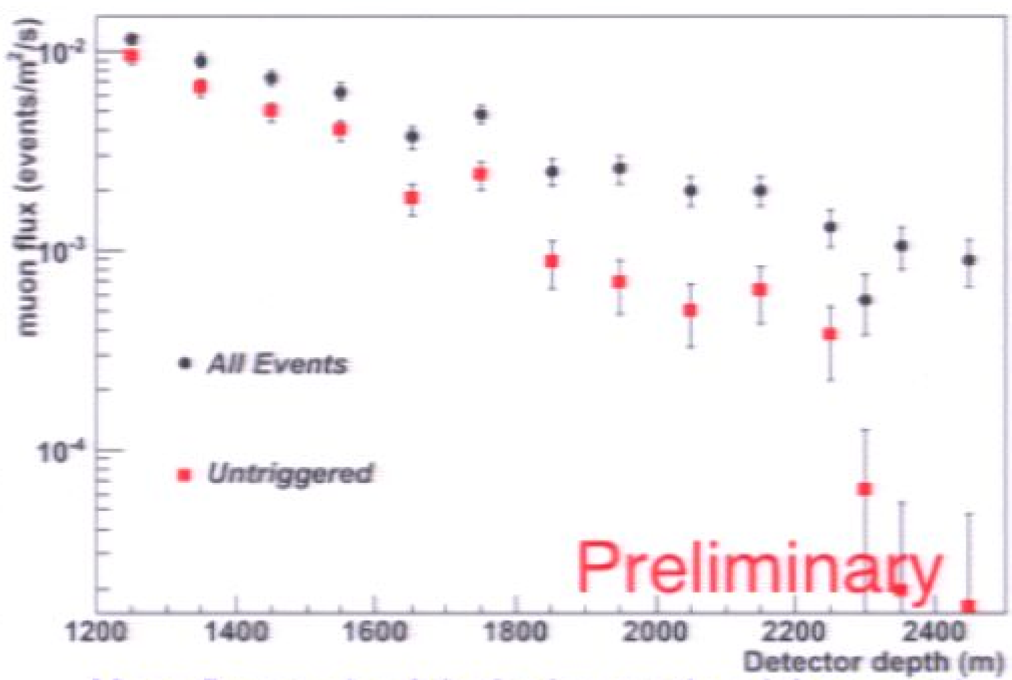




Antarctic Ice: Overburden at -2500 m (2200 m.w.e.)



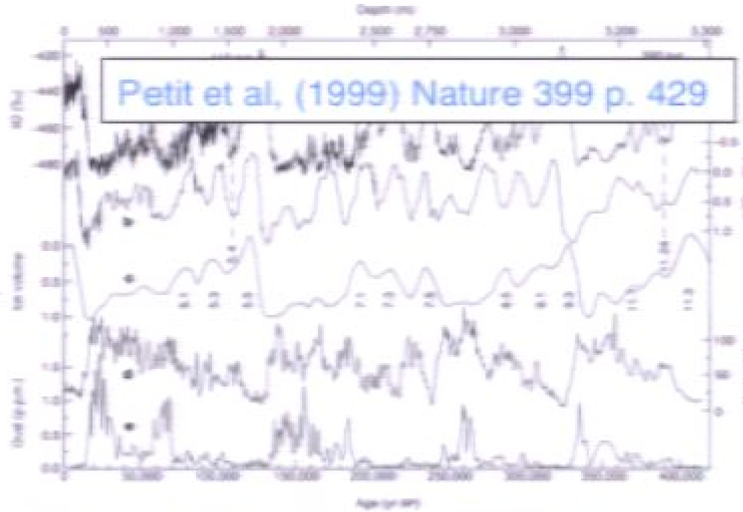
- ~85 muons/m^2/day at bottom of IceCube
- IceCube/DeepCore veto reduces rate by ~1-2 orders of magnitude.

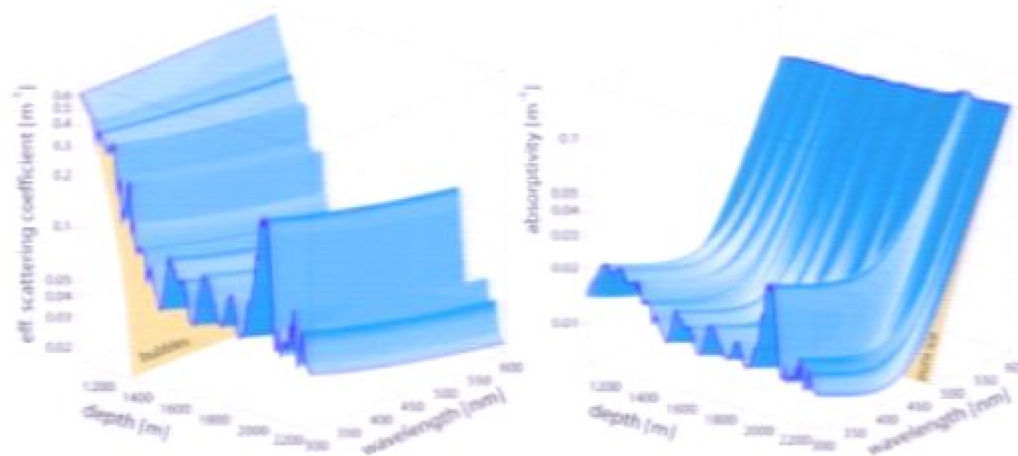


Muon flux vs. depth in the ice, total and those untriggered by IceCube/DeepCore. (Darren Grant)

Antarctic Ice: Radiopurity

- Measurements from ice cores at Vostok.
- Absorption and scattering lengths measured by AMANDA/ IceCube
- -2500 m at South Pole is ~100,000 years old
- Most of the impurities come from volcanic ash, < 0.1 ppm
- Radioactive contaminants in ice:
  - U ~ 0.1 - 1 ppt
  - Th ~ 0.1 - 1 ppt
  - K ~ 0.1 - 1 ppb

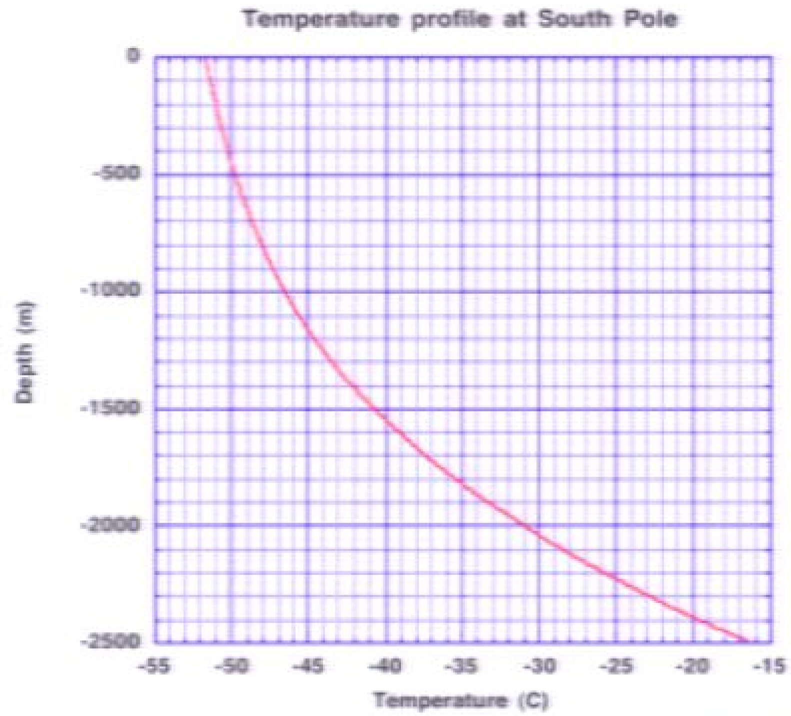




J. Geophys. Res., 111, D13203 (2006)

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)

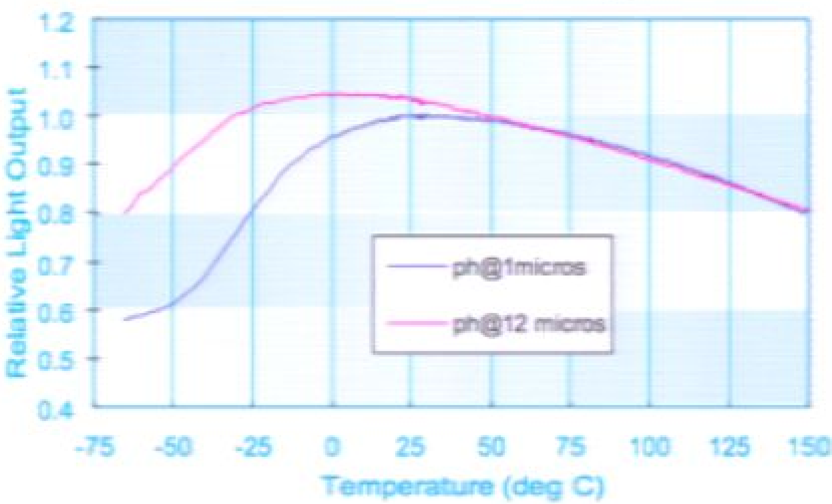


Figure 2. Temperature response of NaI(Tl)

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

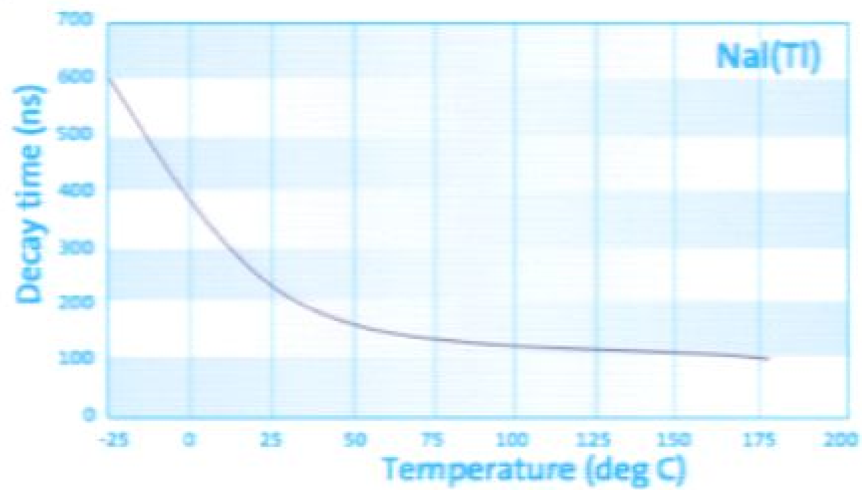


Figure 3. Temperature dependence of the decay time of NaI(Tl)

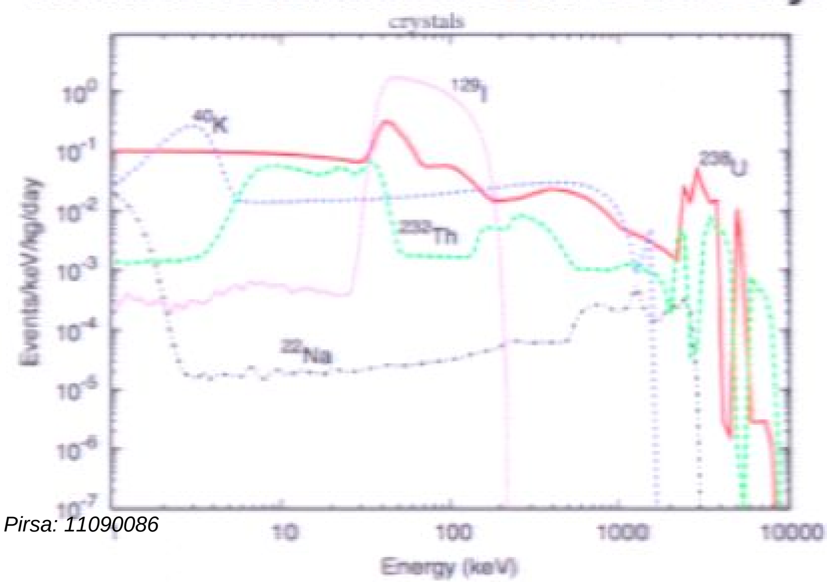
See also: Ianakiev et al., NIM A 607 (2009) 432–438

NaI(Tl) Detector

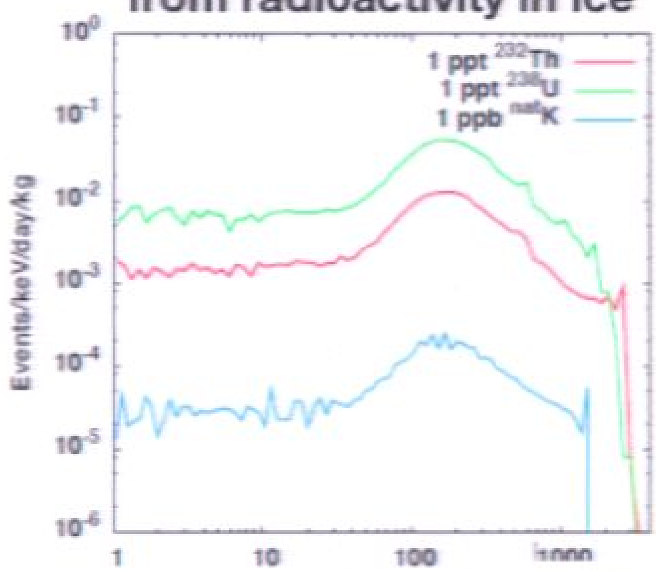
Backgrounds

- Likely to be limited by intrinsic backgrounds in NaI crystals
- Growing NaI(Tl) crystals: know how to remove U/Th, but K is difficult.
- DAMA's crystal: ^{238}U: 5 ppt, ^{232}Th: 5 ppt, ^{nat}K: 20 ppb (NIMA 592 (2008) 297– 315)
- NAIAD crystal: 5 - 10x DAMA bgd in ROI (PLB 616 (2005) 17–24)

simulated backgrounds from
intrinsic contamination in DAMA crystals



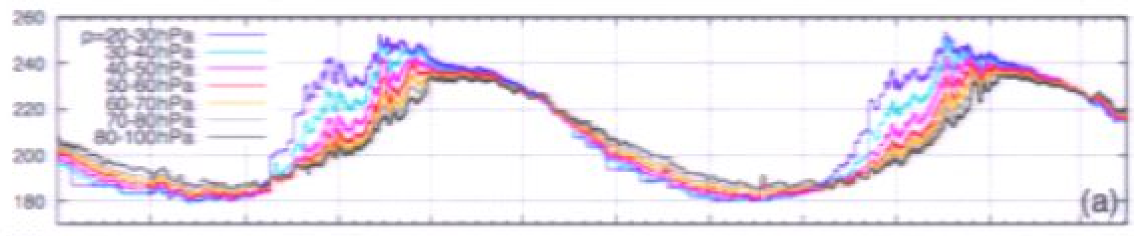
simulated activity in NaI crystals
from radioactivity in ice

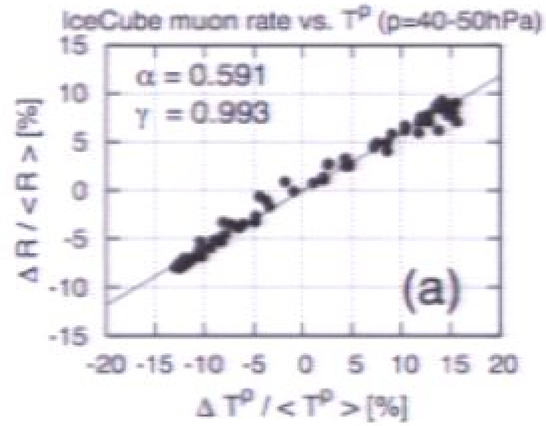


Seasonal Muon Rate Modulation

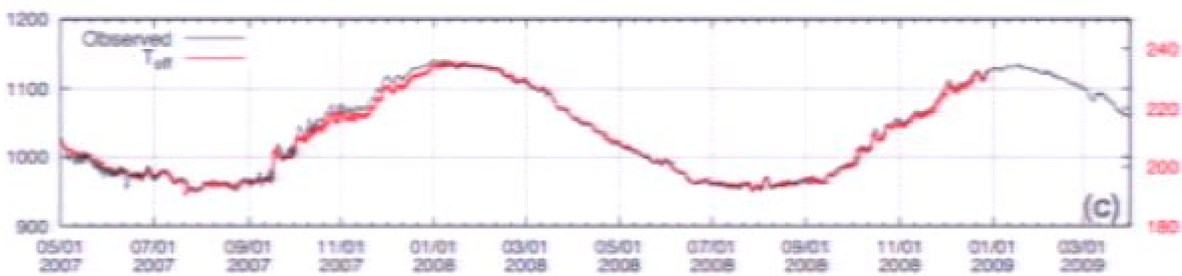
The muon rate at the South Pole well measured by IceCube

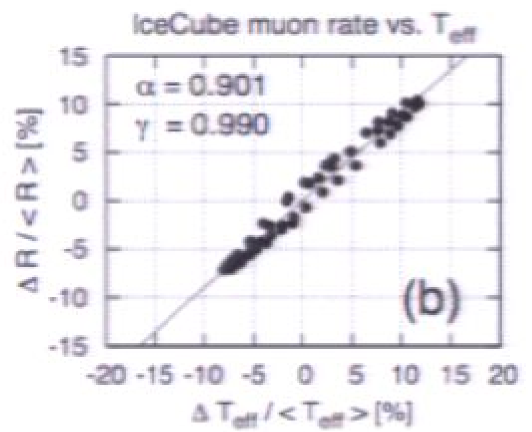
Temperature of the stratosphere in pressure layers, T^P [K]





IceCube muon rate [Hz] (black) & T_{eff} [K] (red)



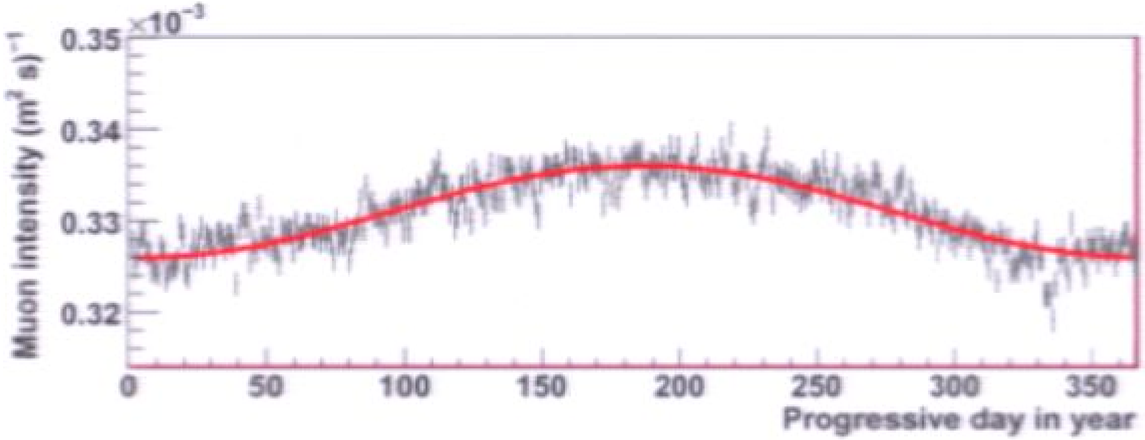


Tilav et al, arXiv:astro-ph/1001.0776

Muon Rate at Gran Sasso vs. South Pole

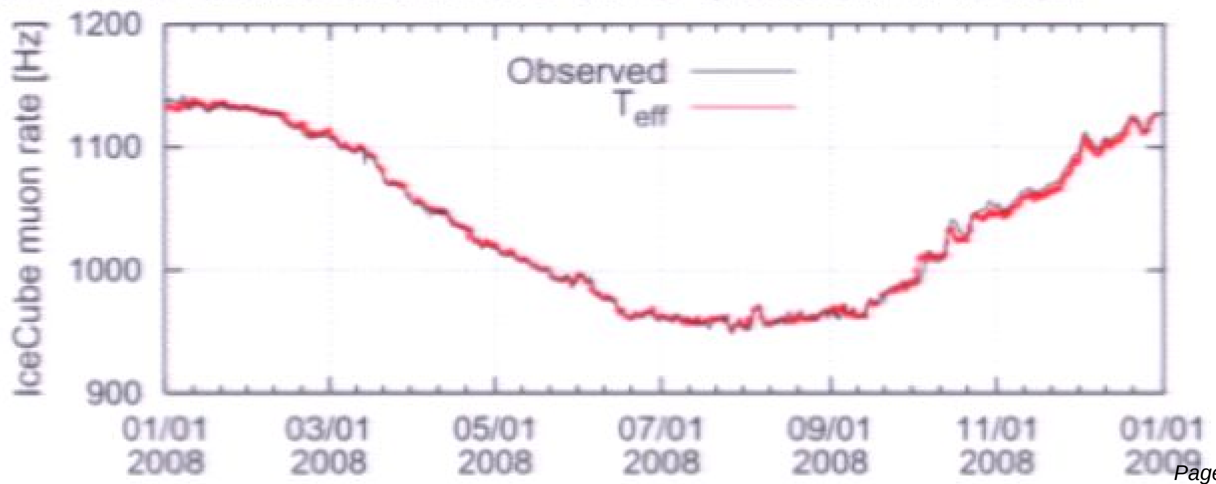
- LVD:

Selvi, Proc. 31st ICRC. (2009)



- Opposite Muon modulation at the South Pole:

Tilav, Proc. 31st ICRC. (2009)



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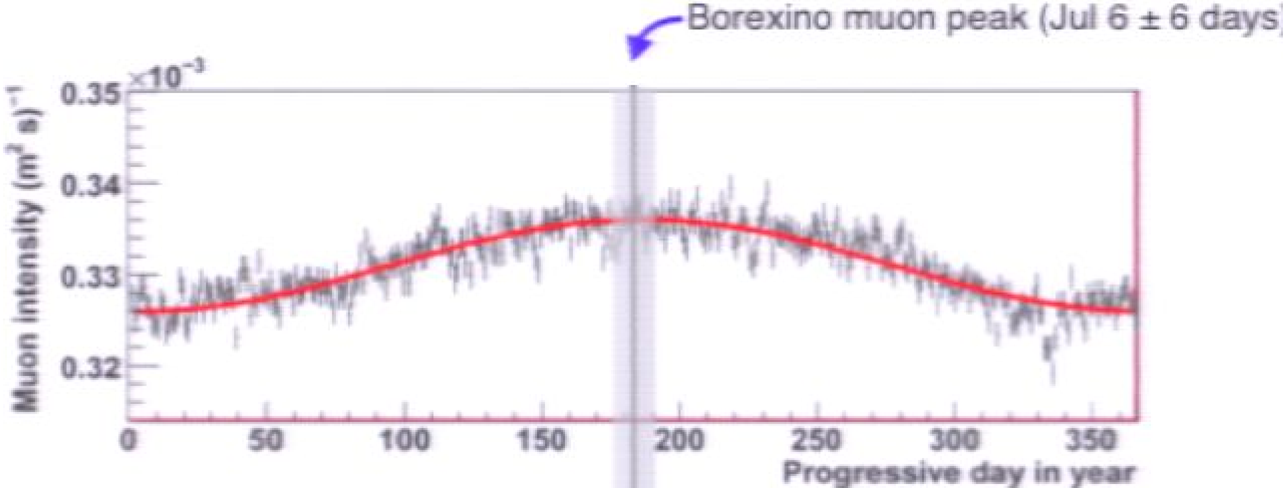

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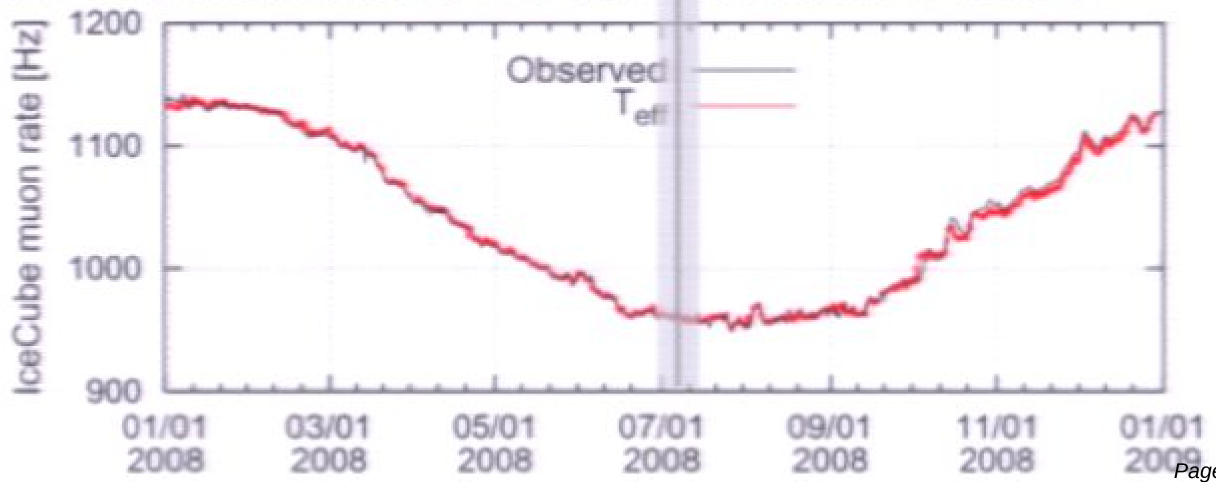

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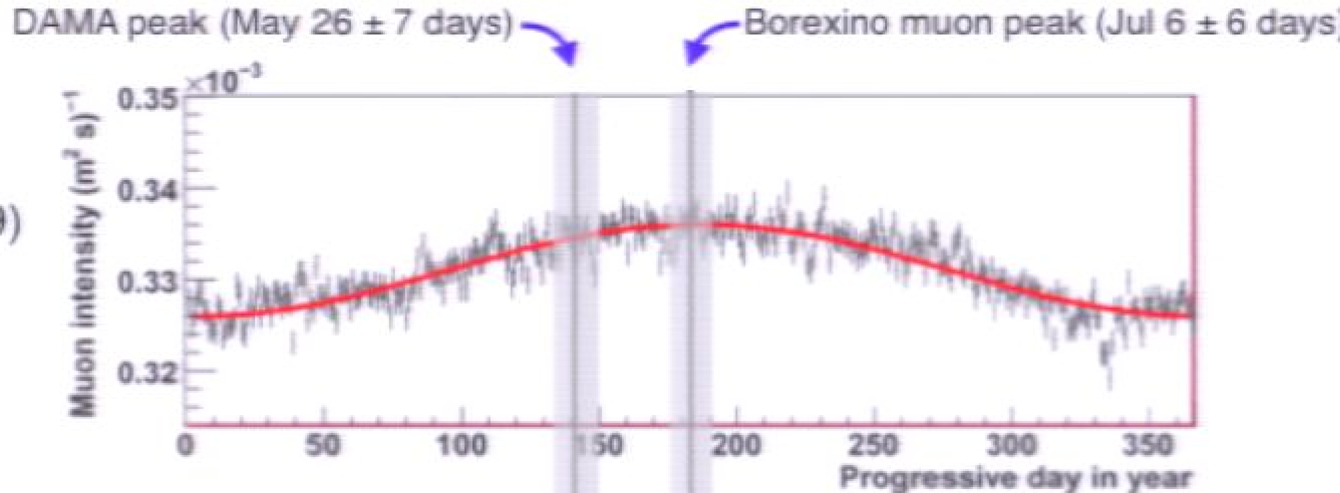

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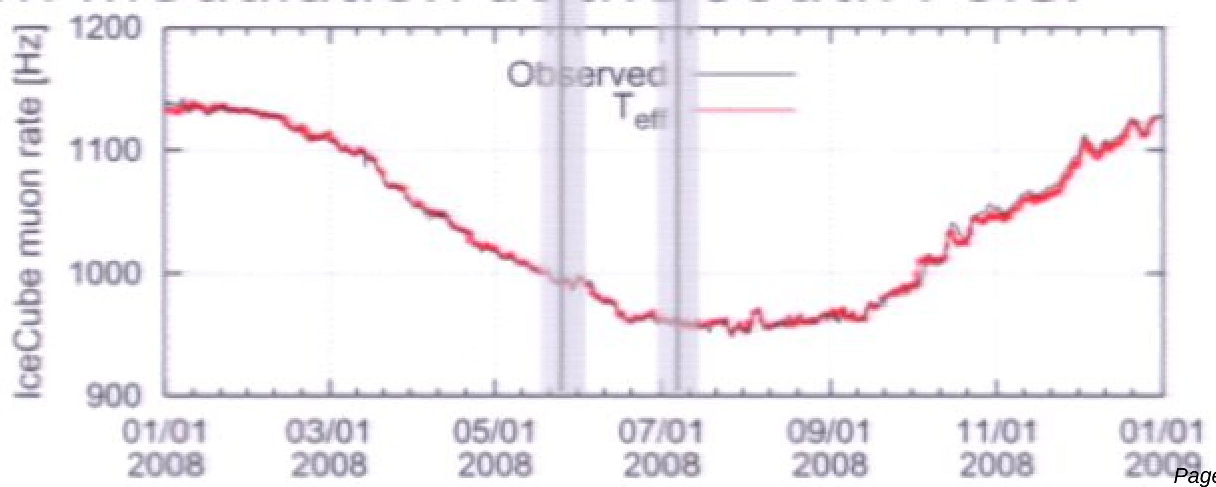
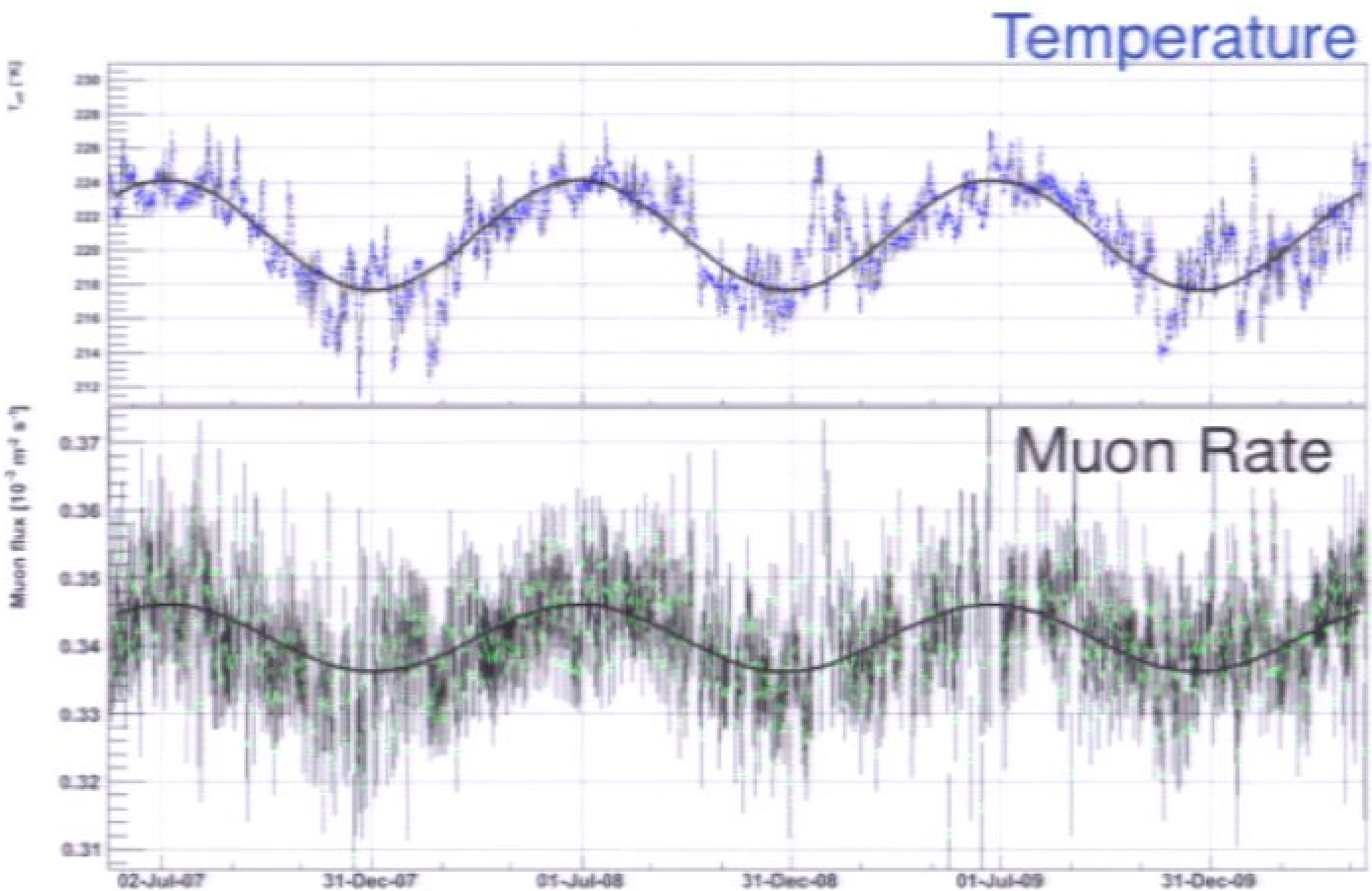


Muons in Borexino



Davide D'Angelo, ICRC 2011

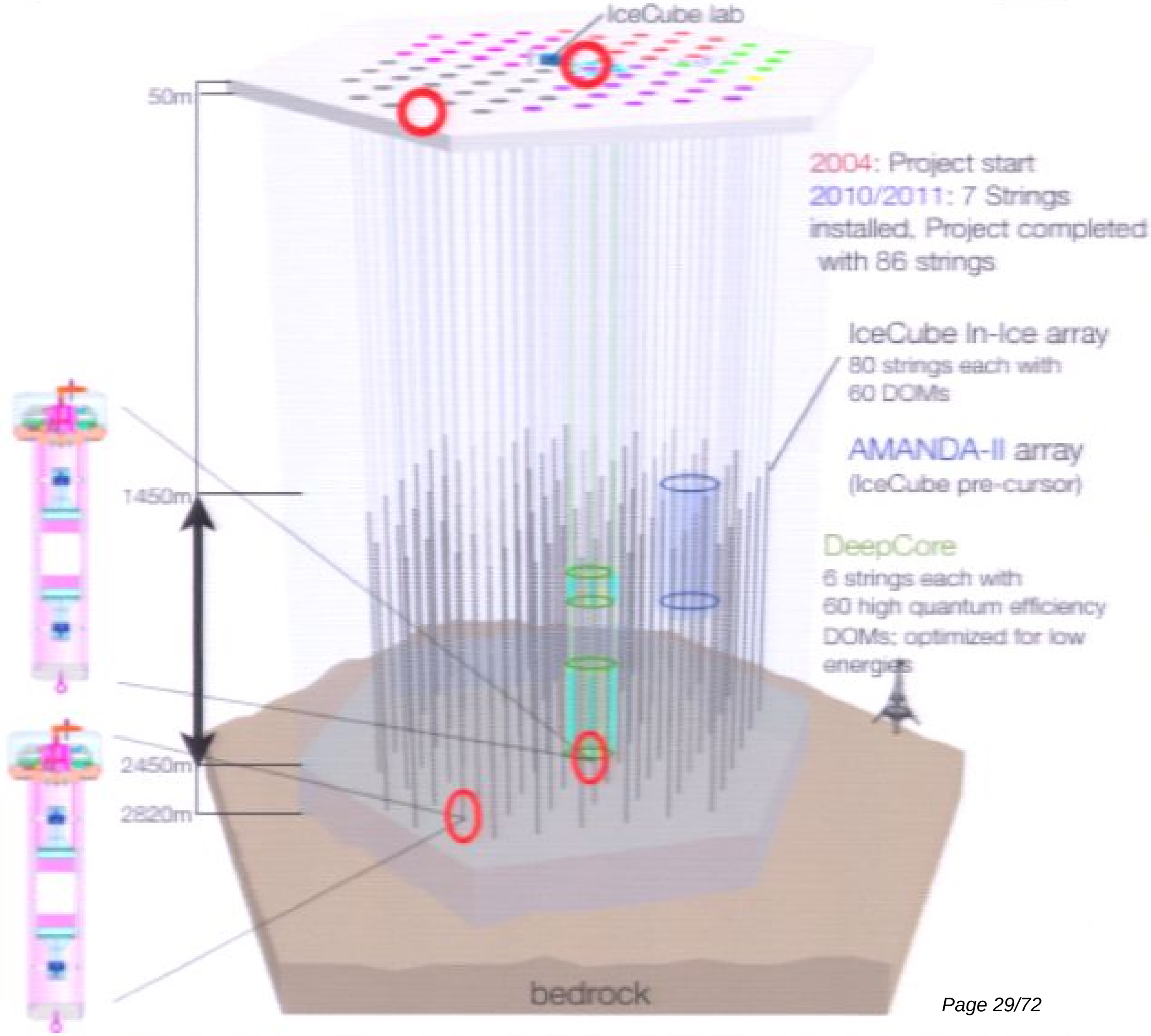
DM-Ice-17: First Step

Detectors:

- Two 8.5 kg NaI detectors from NAIAD (17 kg total)

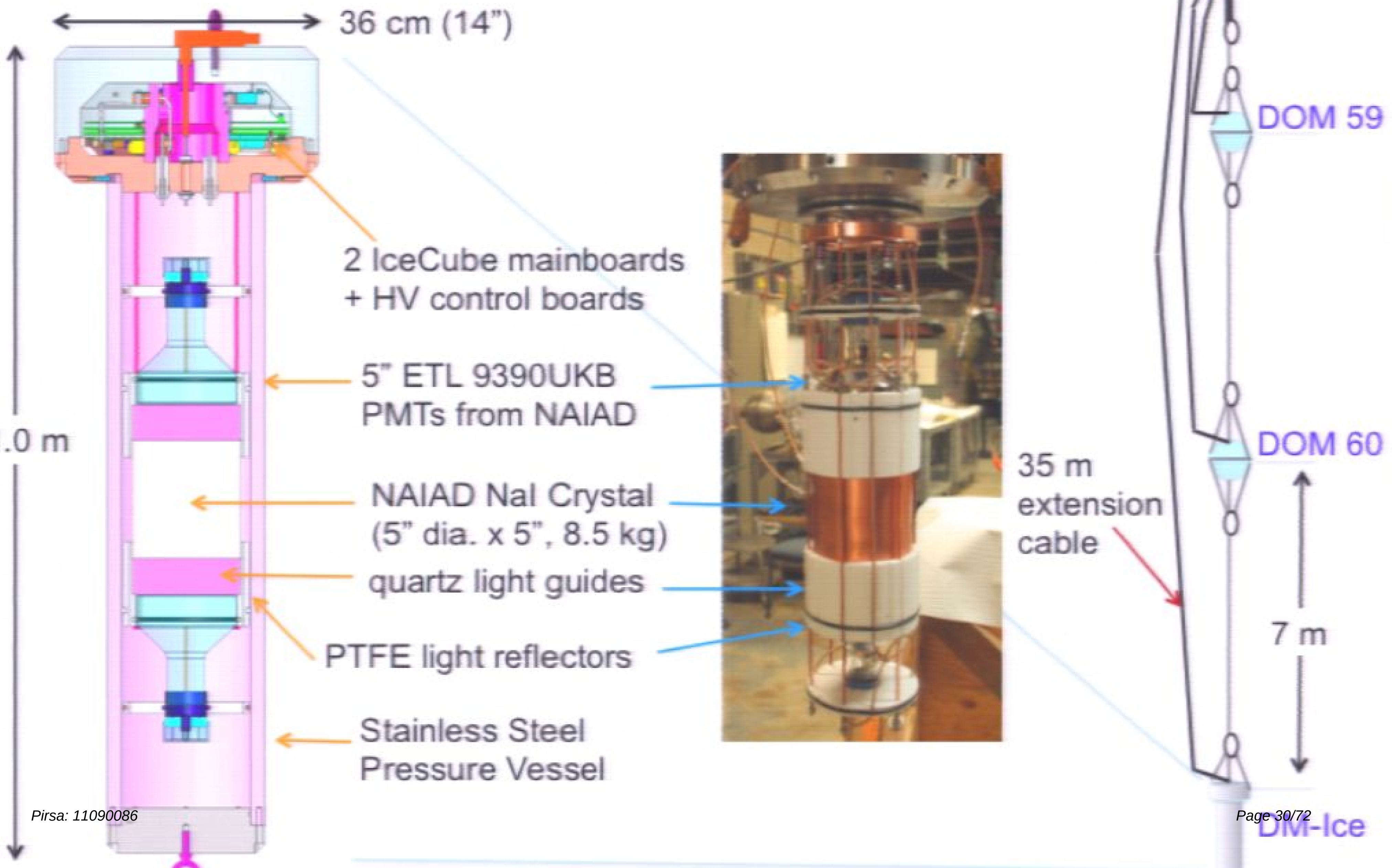
Goals:

- 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-17 Detector

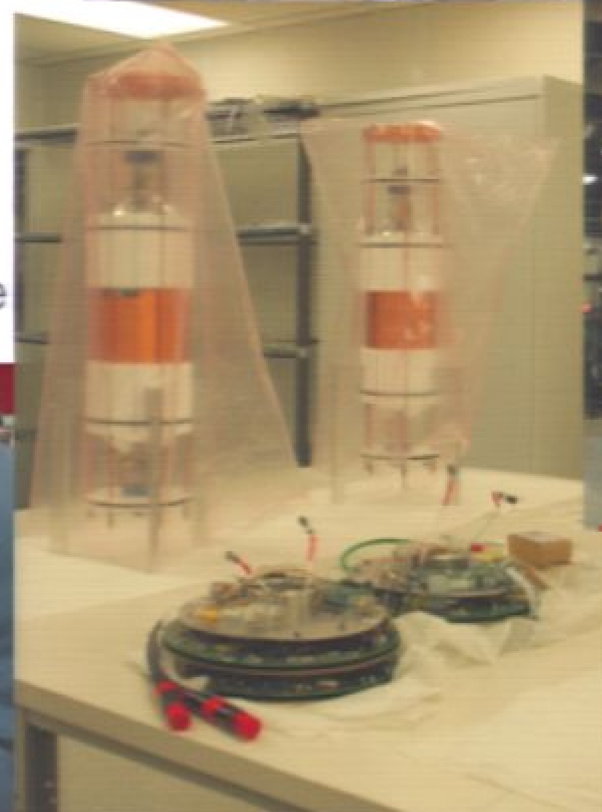


2 NAIAD Crystals from Boulby

- 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.

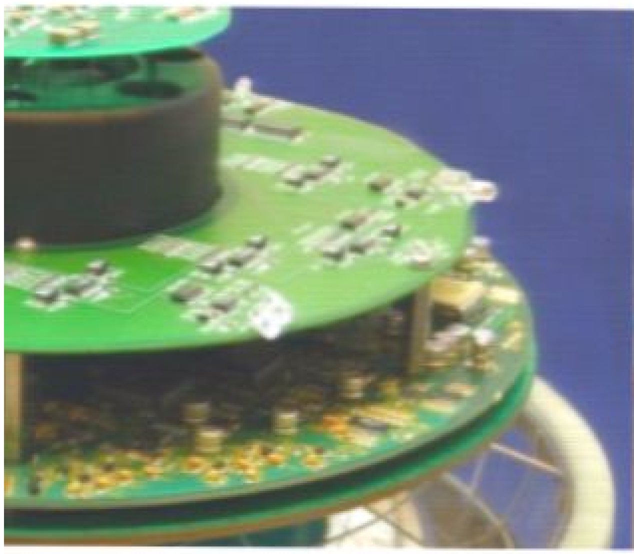
Pressure vessel, support structures, etc

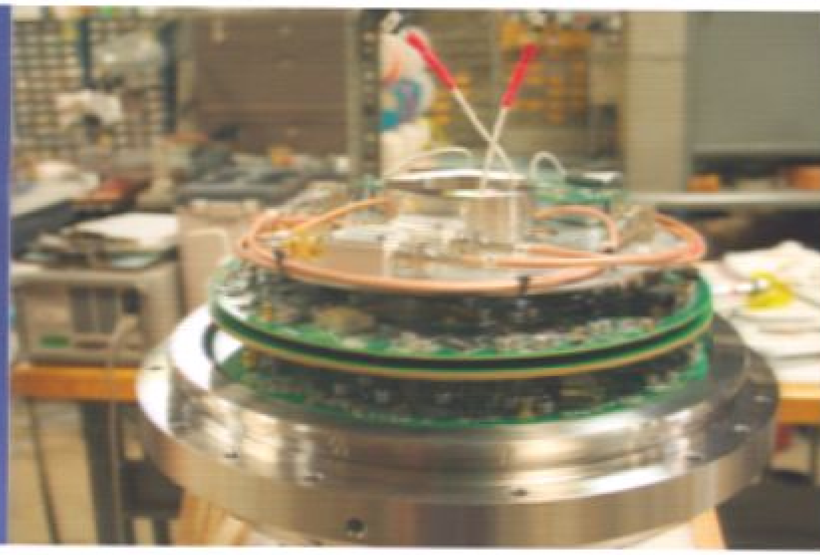
- Stainless, Teflon, etc. selected from vendors known to produce clean material.
  - measurements currently underway at LBNL & SNOLAB.
- Pressure vessel tested to 6200 psi
  - static pressure of water ~ 3500 psi
  - 6000+ psi during ice refreeze in the hole

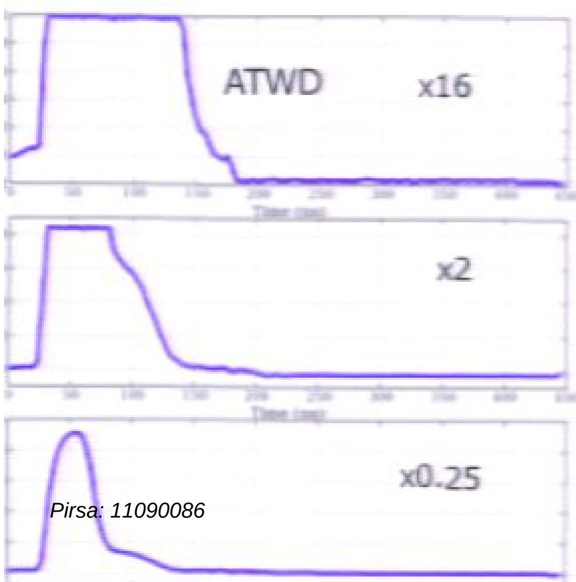


DM-Ice 17kg Prototype

ceCube DOM Mainboards in DM-Ice







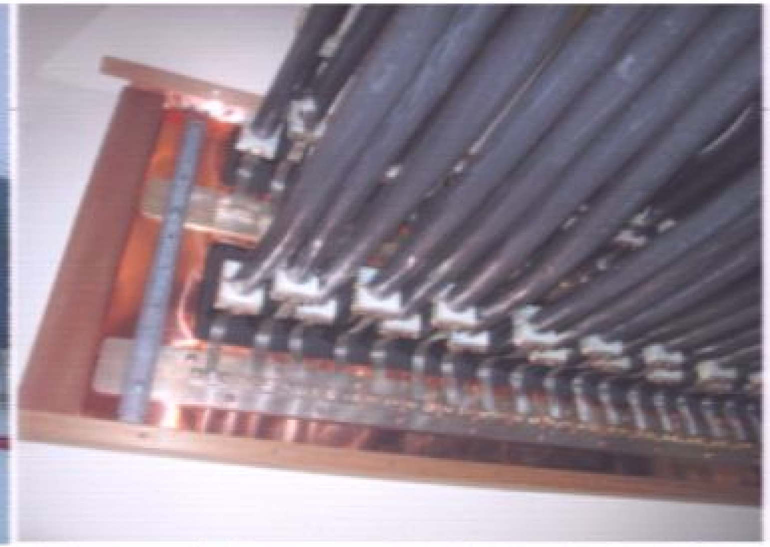
- 40 MHz 10-bit flash ADC for slow high energy events
- ATWD: 10-bit resolution, programmable sampling speeds from 250 MHz to 1 GHz, 3 gain paths: x16, x2, x0.25 → eff. 14-bits
- Coincidence trigger capabilities
- Controls a separate HV board
- Programmable from surface
- Established reliable technology

IceCube Counting Laboratory (ICL)

DM-Ice Electronics in IceCube Counting Lab

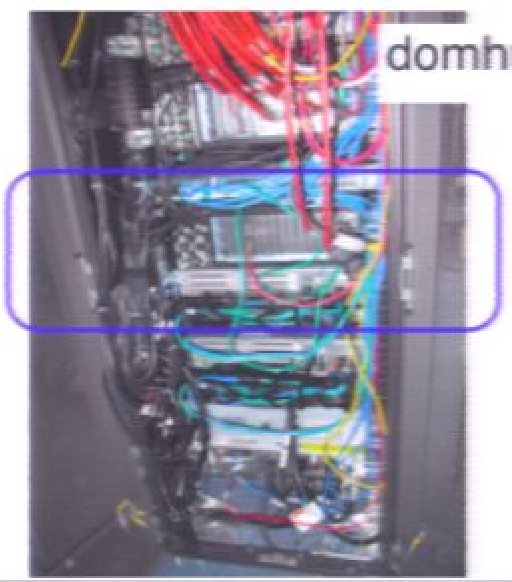
ICL

“beer can” with string cables



string cable penetrations into ICL

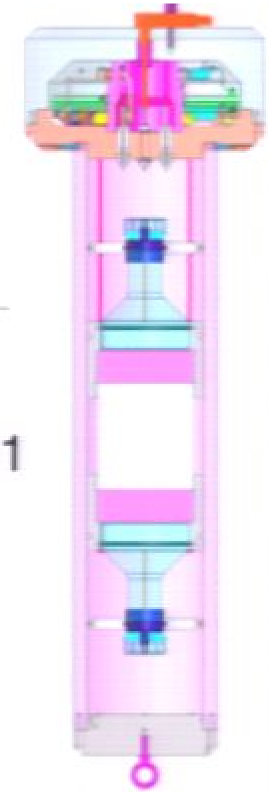
patch panels



domhubs

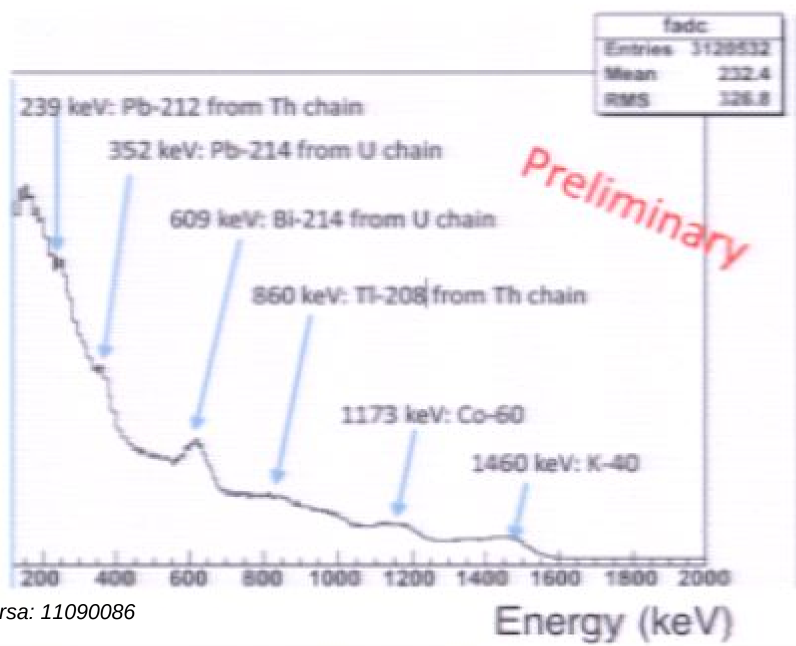
event building

DM-Ice-17 Status



DM-Ice-17 functioning well

- taking data, continuous operation since Jan. 2011
- data transmitted over satellite
- Analysis underway... stay tuned for background levels, pulse shape discrimination, light collection efficiency, threshold ...



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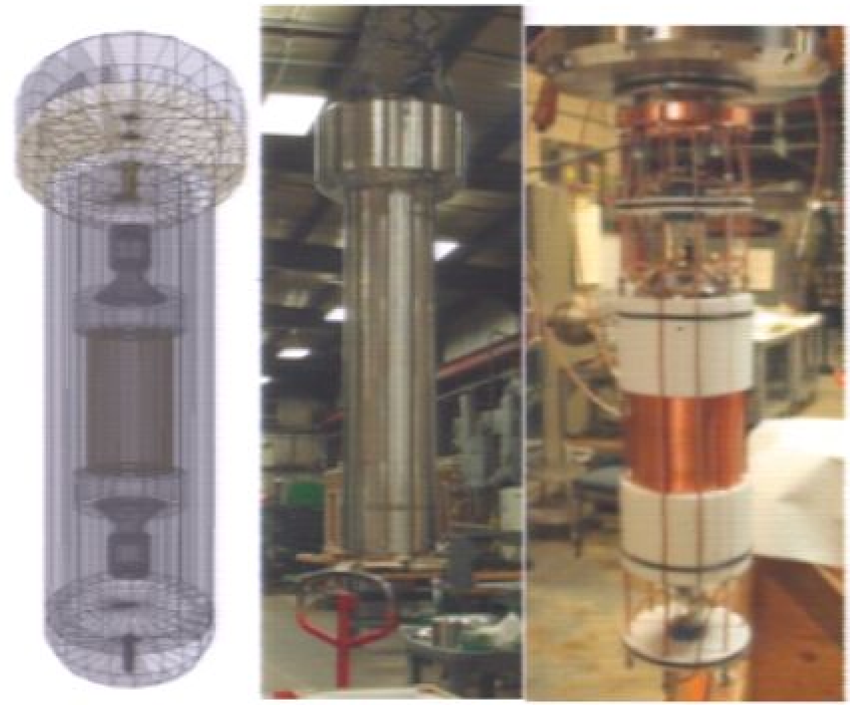

Background Simulations

assumed U, Th, and K concentrations

Material	^{238}U	^{232}Th	^{nat}K
drill ice [27]	0.076±0.046	0.47±0.14	<262
Antarctic ice	10^{-4}	10^{-4}	0.1
PMT [26]	30	30	60000
steel PV [27]	0.2	1.6	442
NaI	0.005	0.005	10

note: these are DAMA numbers, scale for DM-Ice-17

estimated contributions to event rate

Material	event rate in NaI ($cpd/kg/keV_{ee}$)
drill ice	0.8
Antarctic ice	< 0.001
photomultiplier tubes	0.01-0.02
steel PV	0.2-0.6
NaI crystal	~0.3

ptimizing analysis, background studies
vith radio-assay & Monte Carlo simulation

Goal: ~ 1 cpd/kg/keV

Reducing the backgrounds

drill water/ice
- won't reuse, circulate water
- minimize volume of drill ice around detector

steel pressure vessel (PV)
- can use better material, custom steel
- may be able to use Cu or Ti for full detector

NaI crystal
- purify raw materials

arXiv:1106.1156

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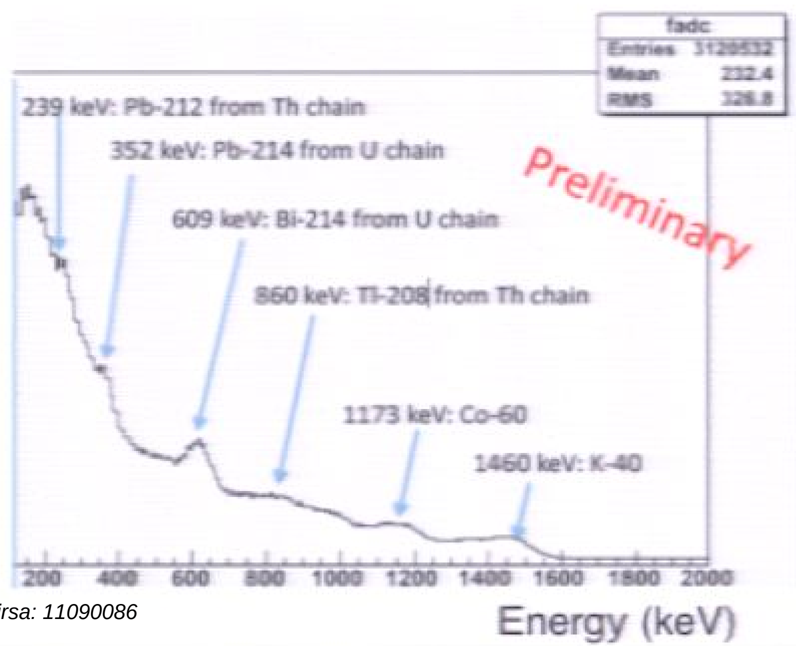

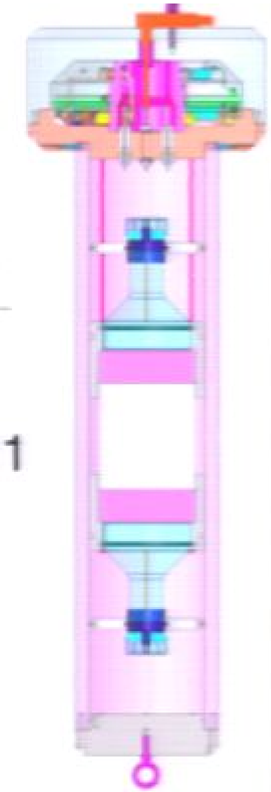

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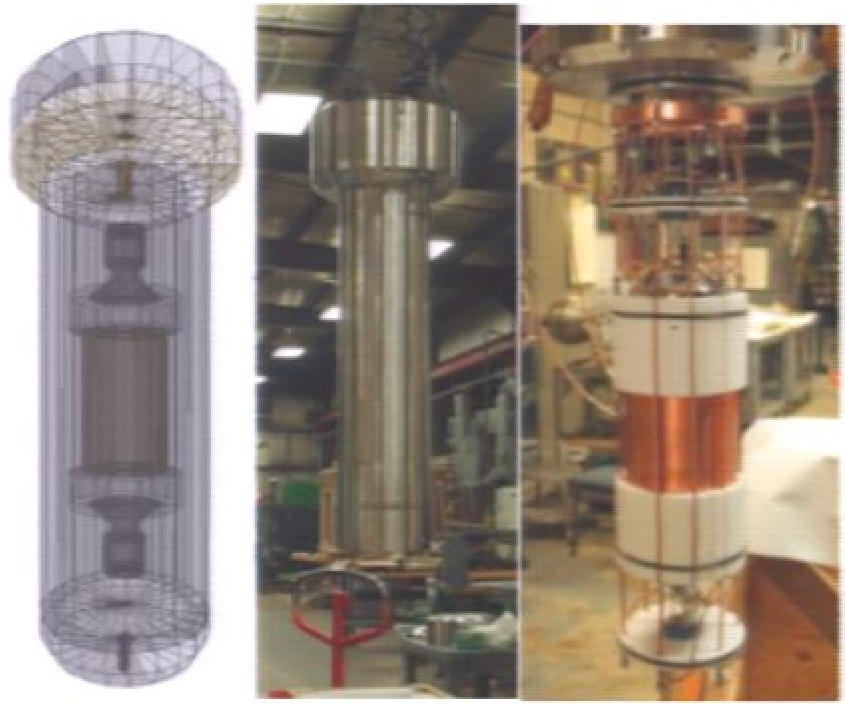

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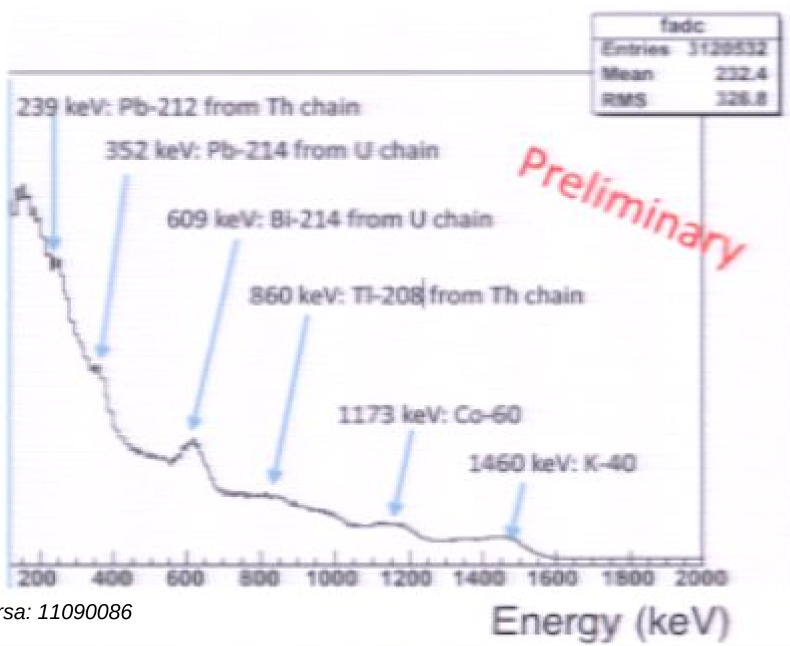

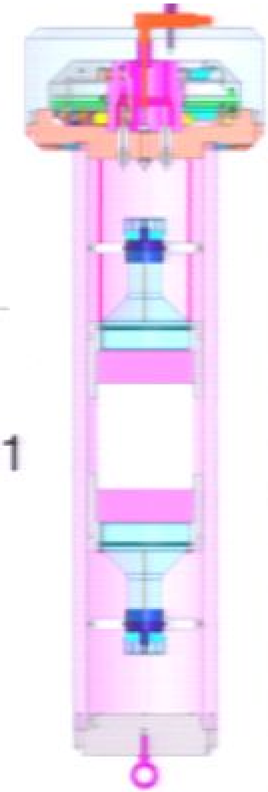

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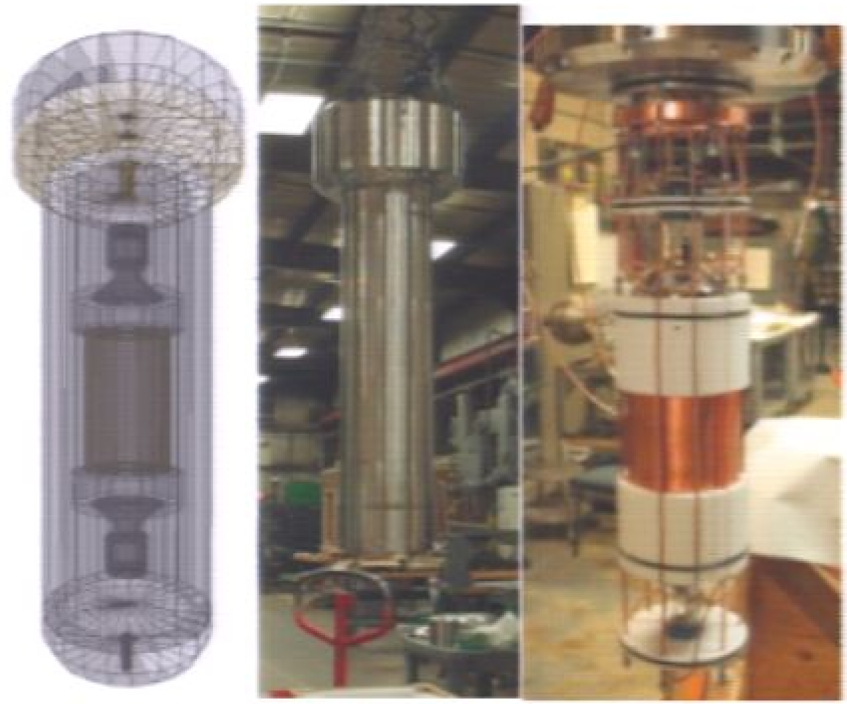

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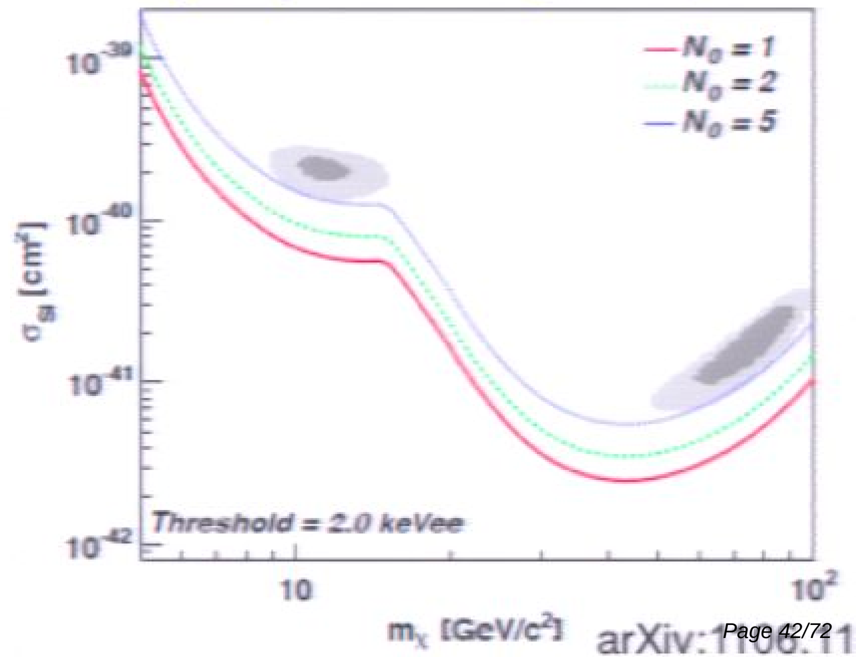
DM-Ice Objectives

- 5-σ measurement of the annual modulation signal in 2 years
  - 2 years w/ DAMA size and backgrounds... or
  - 2 years, 500 kg, x2 NAIAD background... or
  - Additional gain by lowering threshold

		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

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



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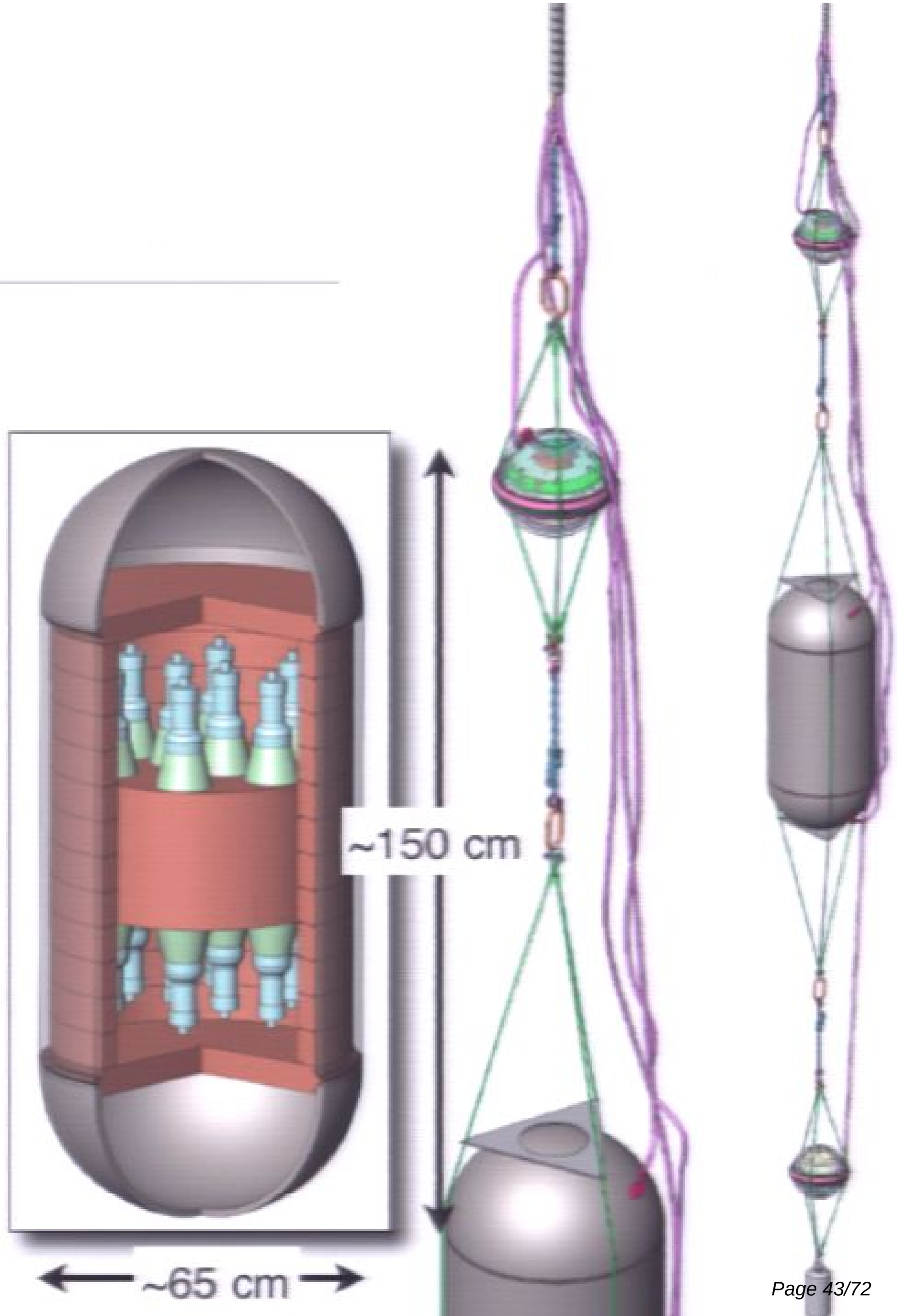
DM-Ice Concept

- Segmented 20" diameter x 10" long NaI detector (~200 kg) (x 2 - 3)
- ~ 2500 m deep in the ice
- Local muon veto
- Stainless steel pressure vessel
    - Copper shielding if needed
- Electronics & pulse digitization in the vessel
- Location: near the center of IceCube for additional veto
- Calibration concepts under consideration



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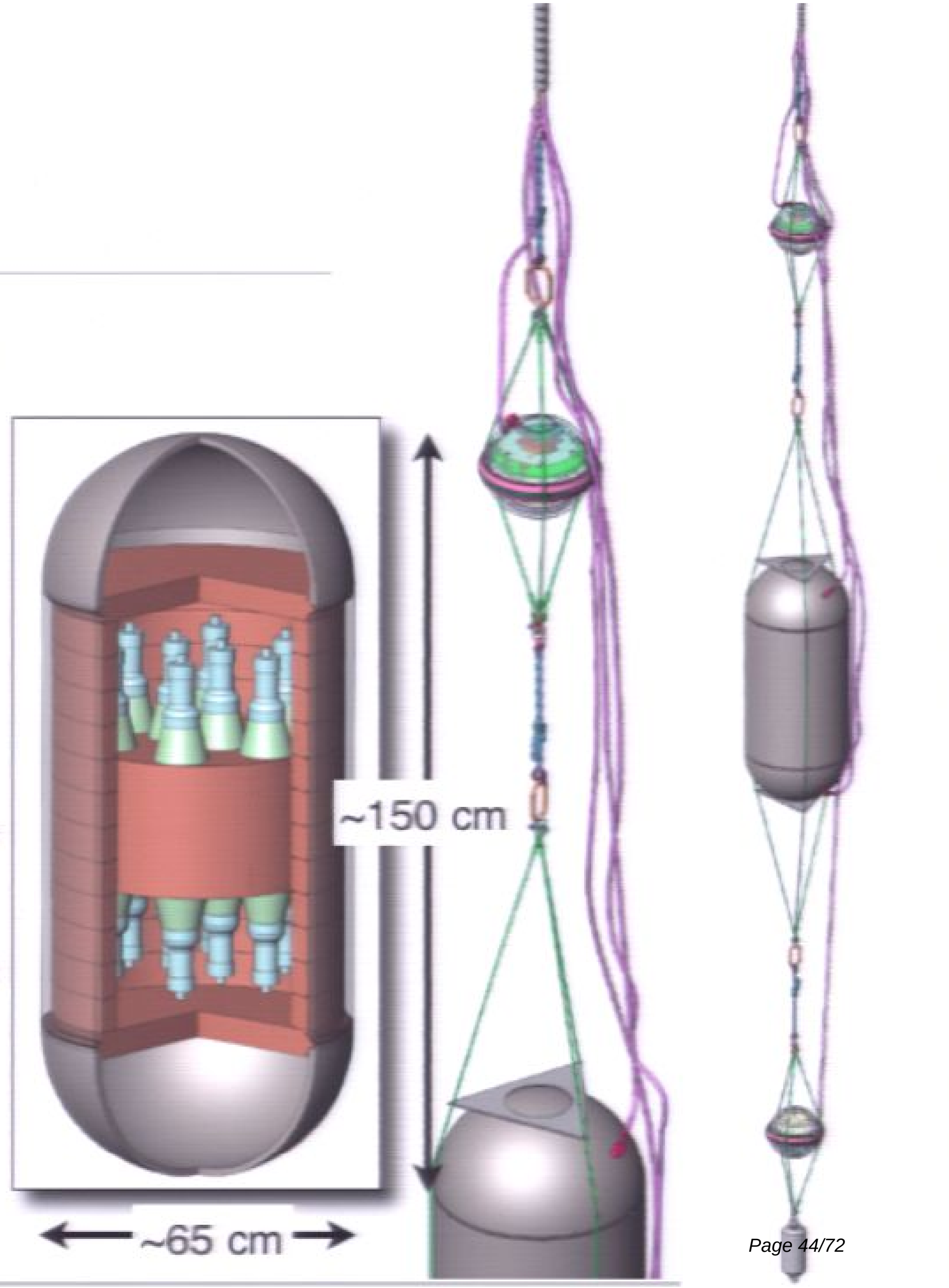
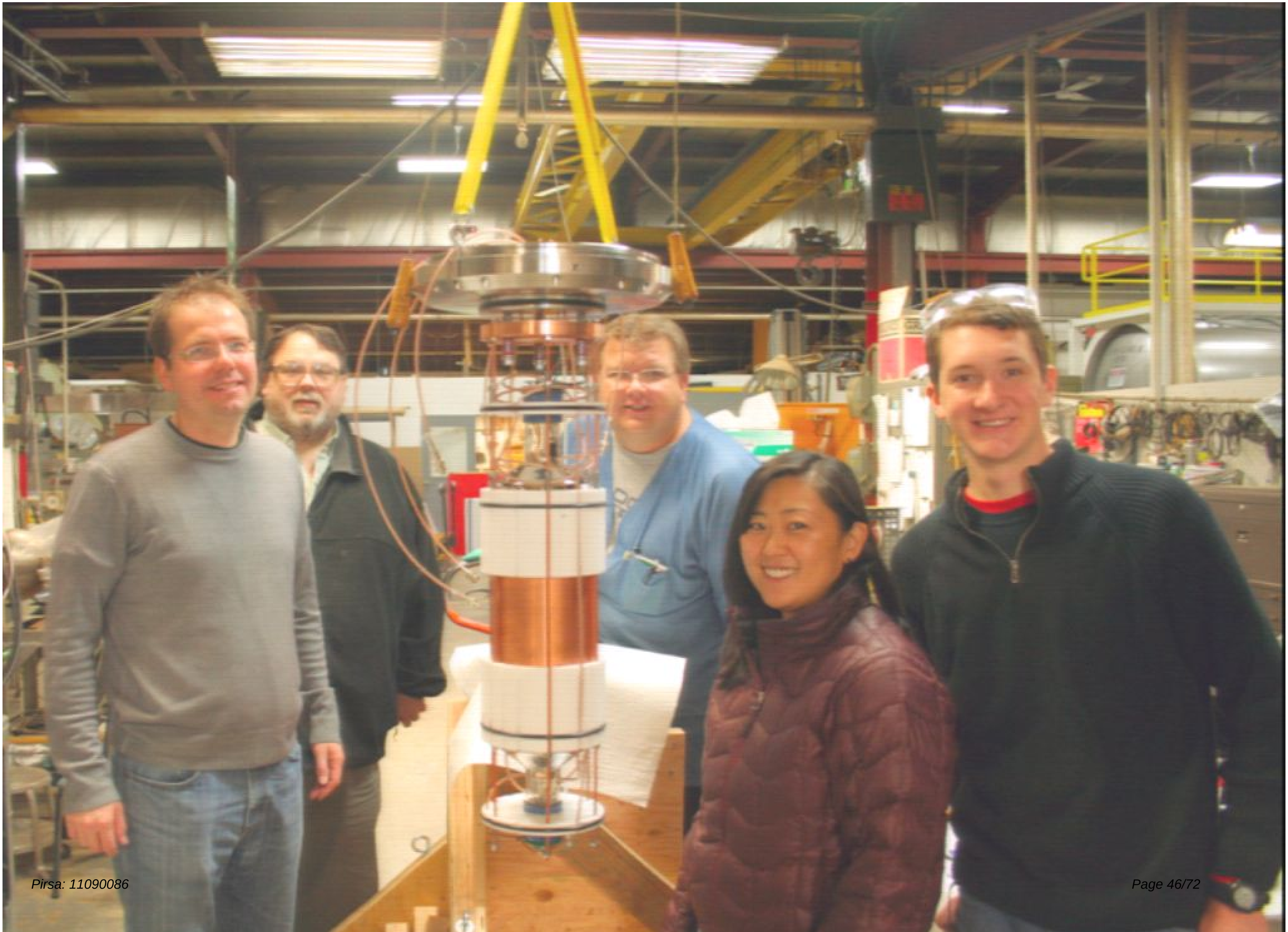
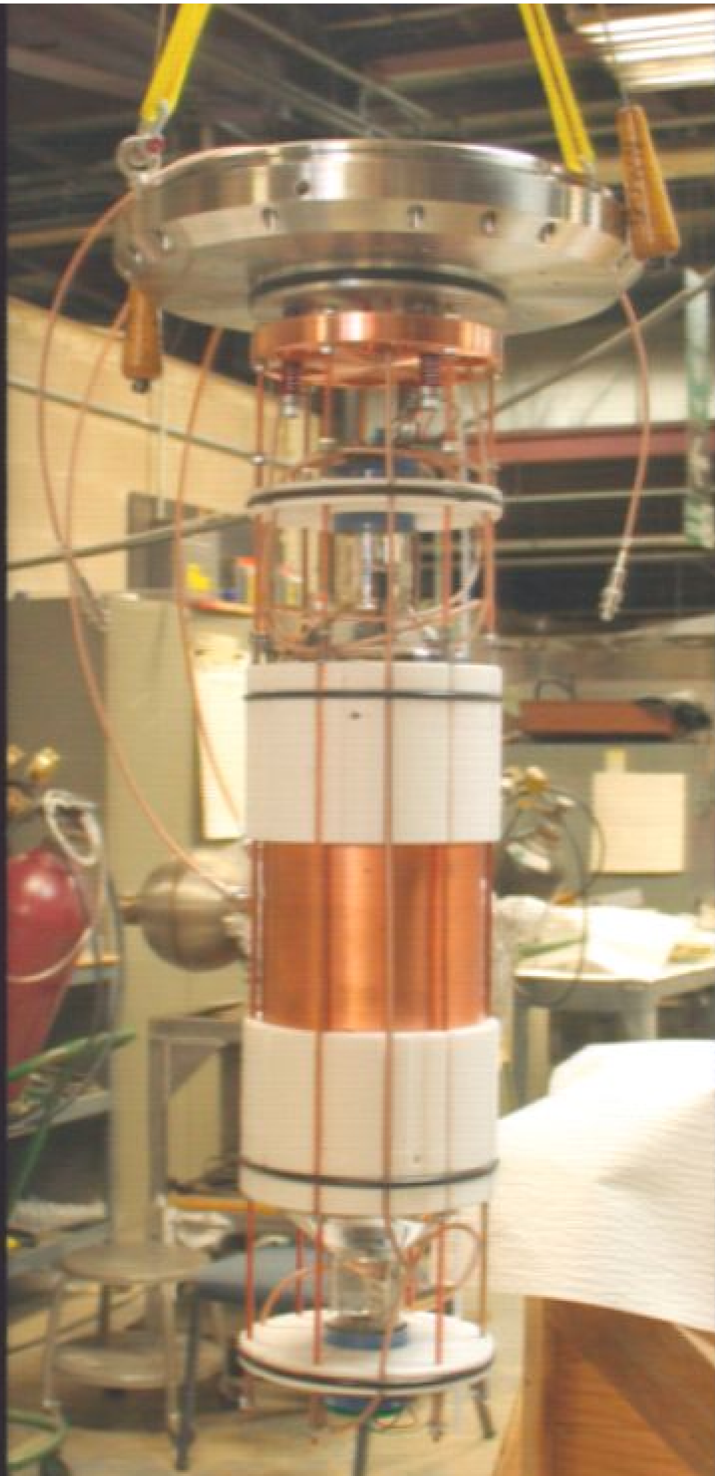
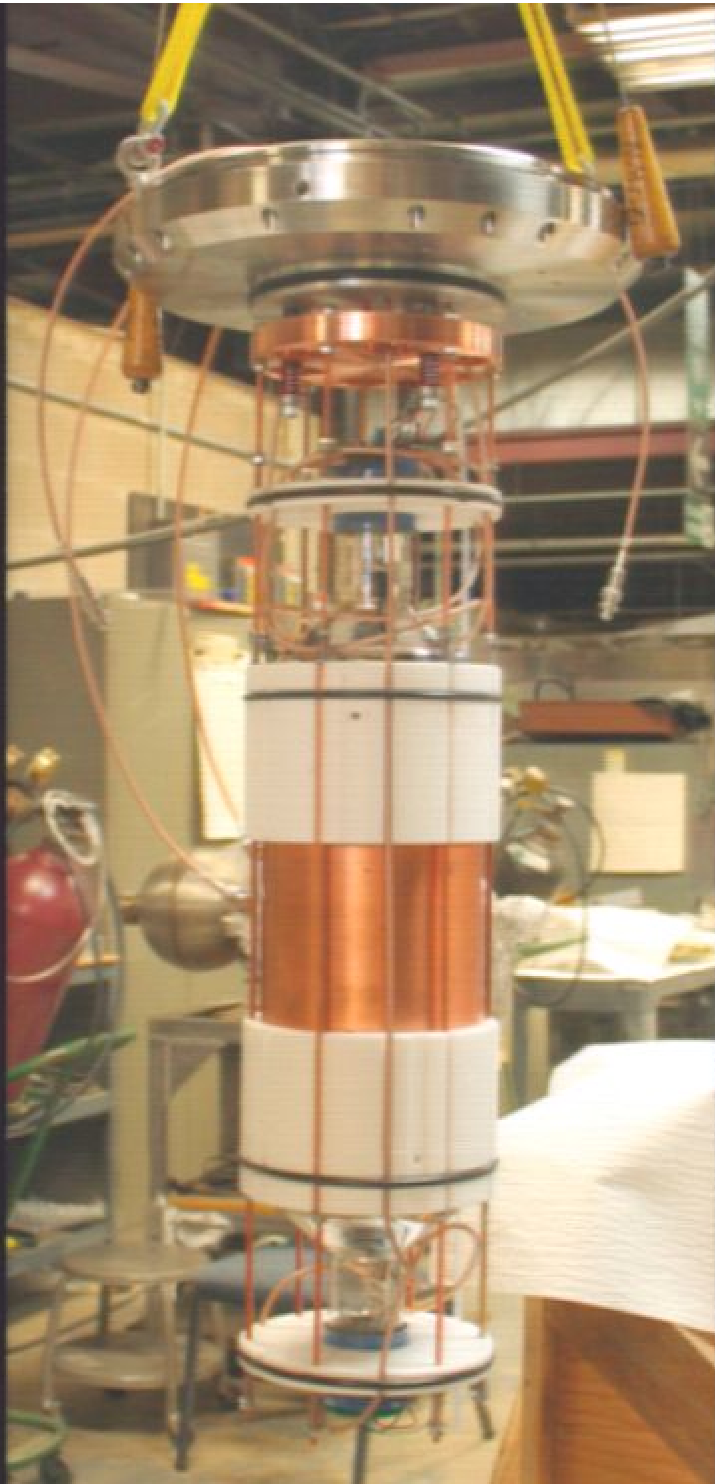




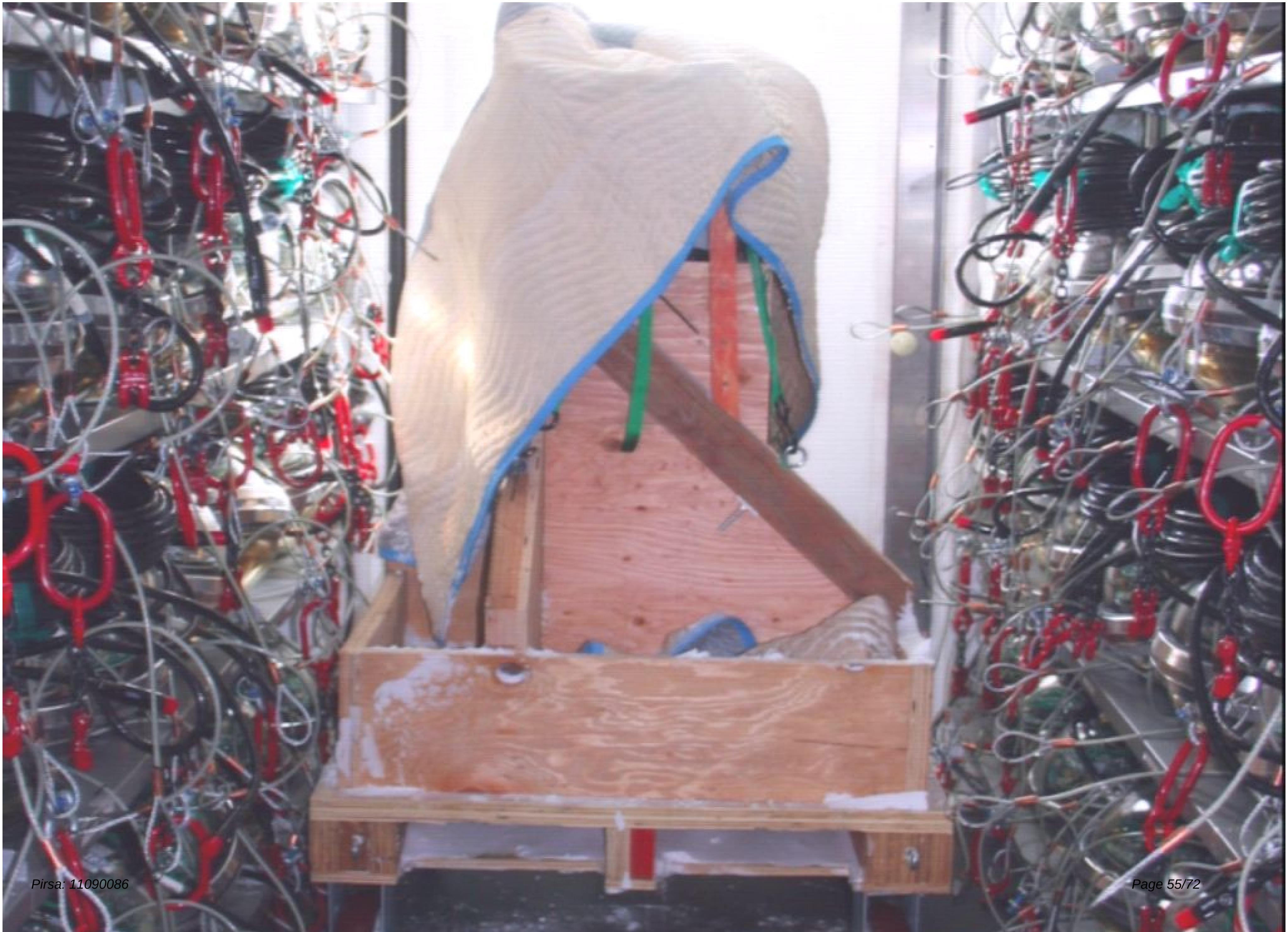





DW3
P137 NPX


63302
SCIENCE FOUNDATION

On-Ice Detector Storage and Testing




GUS
LD30011
CAT

Hot Water Drilling into the Ice


Seasonal Equipment Site
Drill Camp

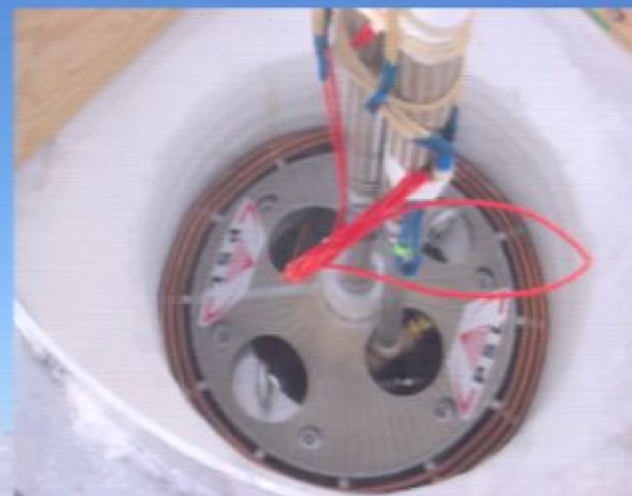
Tower Operations Site

TOS Delivers Water to Hole

Hot Water Drilling into the Ice

Hot Water Drilling into the Ice

Firn Drill



Hot Water Drilling into the Ice

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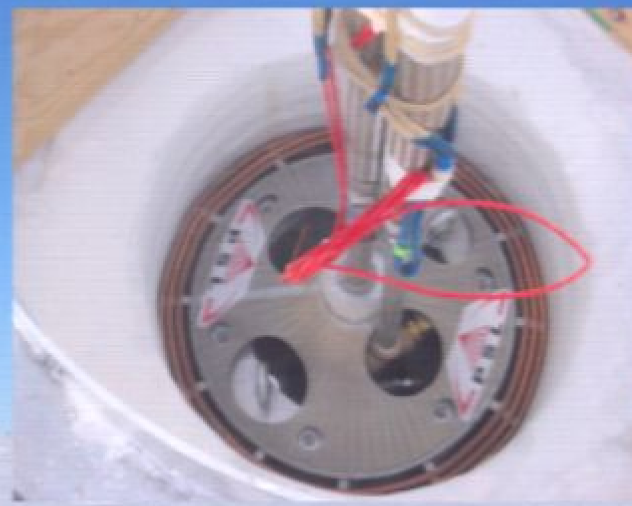
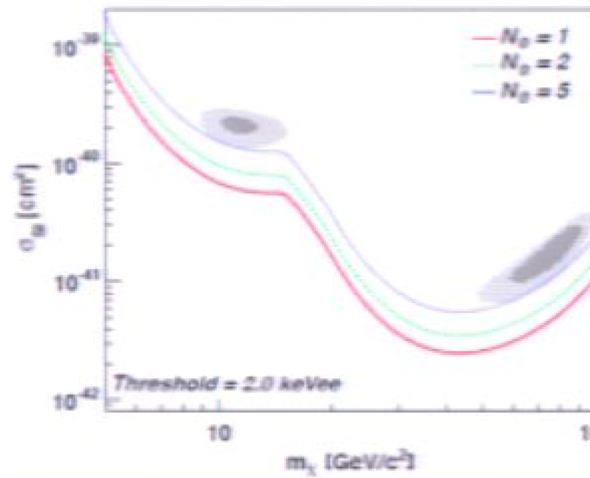


Deep Drill


B


Current Status & Future Outlook

- DM-Ice-17 deployed in December 2010
  - Currently taking data
  - optimizing analysis, for energy, pulse shape cuts, coincidence between PMTs, etc.
  - background studies with radio-assay & monte carlo simulation
- DM-Ice full-scale aims for rapid deployment
  - Unique window of opportunity for an experiment at the South Pole
    - IceCube drilling expertise
    - Opportunity to run simultaneously with DAMA
  - Optimization of detector size, geometry, and backgrounds
  - R&D for low background crystals, calibration, pulse shape discrimination



DM-Ice Collaboration

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Francis Halzen, Karsten Heeger, Albrecht Karle, Reina Maruyama, Carlos Pobes, Walter Pettus, Antonia Hubbard, Bethany Reilly, Moriah Tobin

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

University of Washington – Seattle
Sanshiro Enomoto, Jarek Kasper, Andreas Knecht, Michael Miller

DigiPen
Charles Duba, Eric Mohrmann

Special thanks to the IceCube team!