

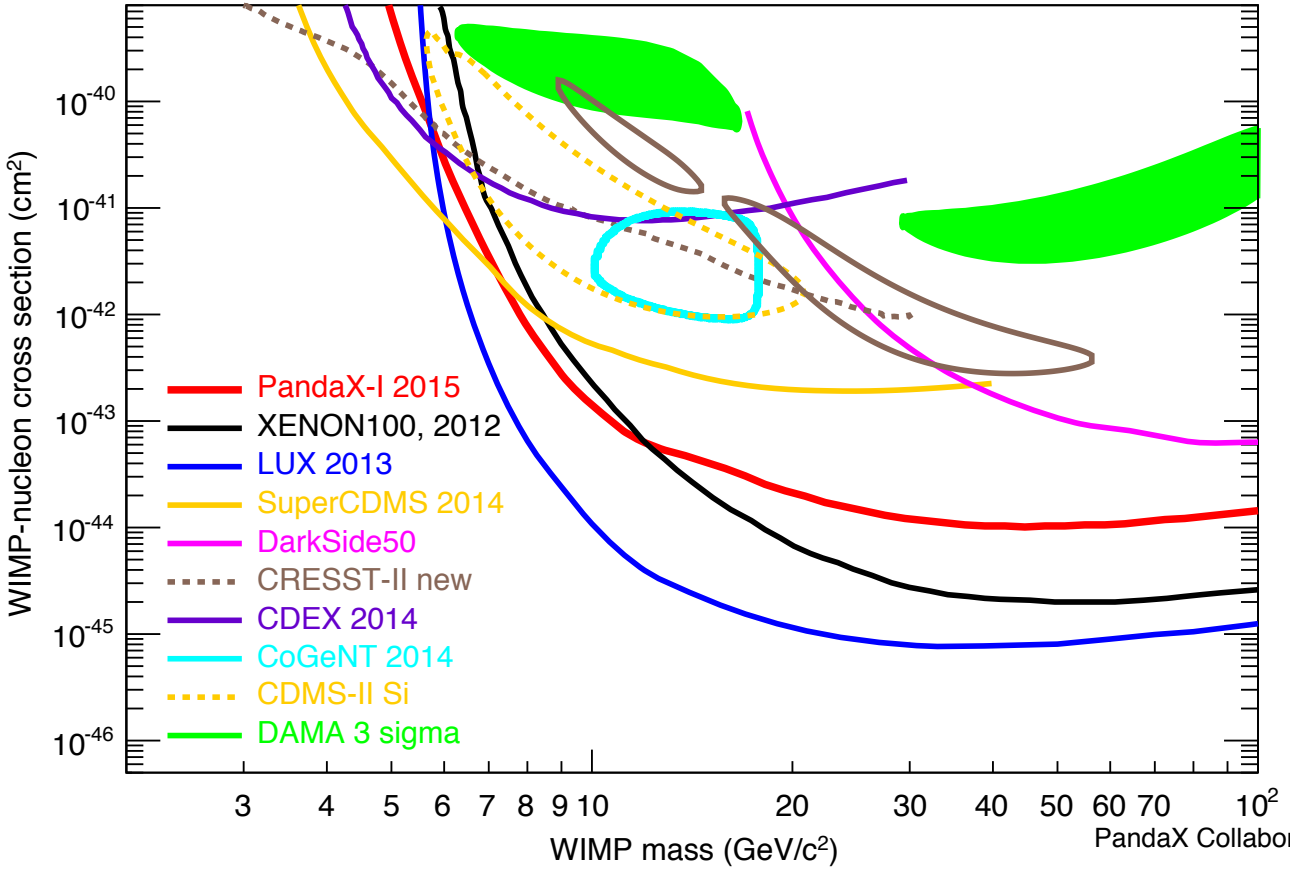
Walter C. Pettus
on behalf of the DM-Ice collaboration
Yale University

CIPANP 2015
19 – 24 May 2015

DM-Ice: Current Status & Future Prospects

Direct Detection Status

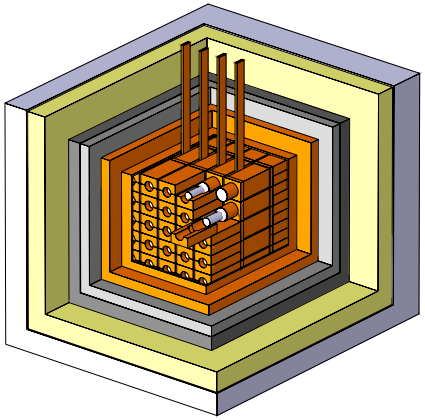
Unresolved tension between leading exclusion limits and low-mass signal hints



PandaX Collaboration, arXiv:1505.00771

DAMA Modulation Signal

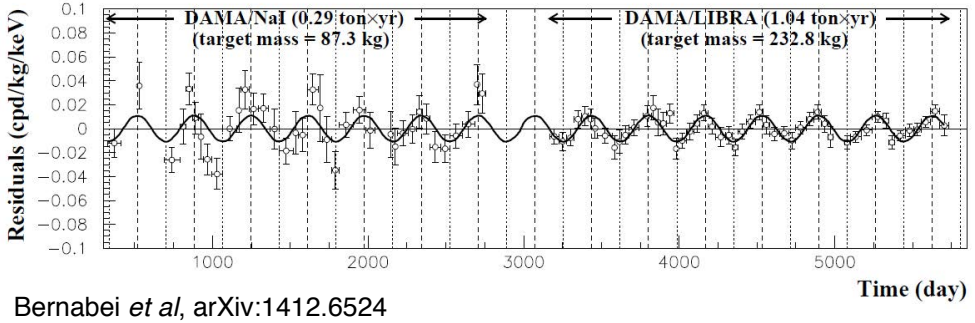
Performed search for dark matter annual modulation with NaI(Tl) crystal array



Bernabei *et al.*, NIM A, (2008)

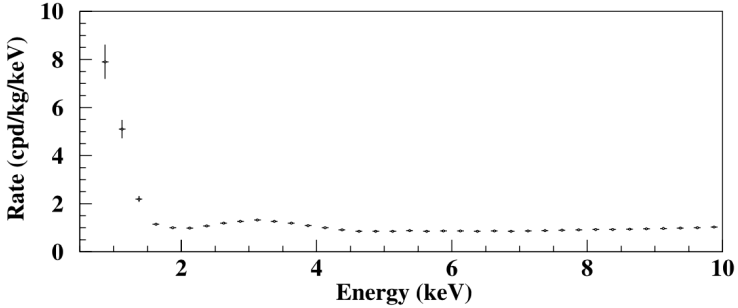
Observe non-zero amplitude at ***9.3-sigma***

- Consistent signal spanning 15 cycles



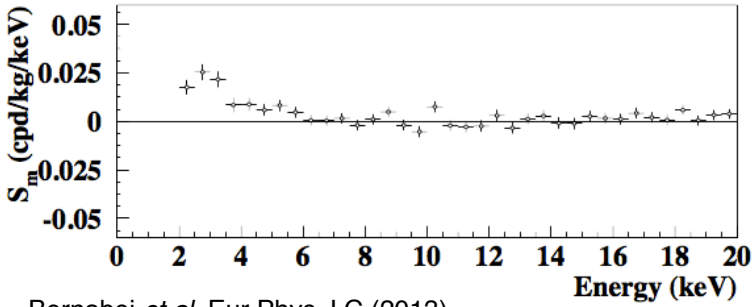
Bernabei *et al*, arXiv:1412.6524

Demonstrated excellent background reduction:



Bernabei *et al*, Eur Phys J C (2008)

Modulation only observed at low-energy:



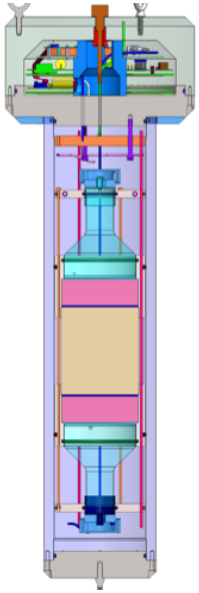
Bernabei *et al*, Eur Phys J C (2013)

No background or environmental effect has been shown to replicate the DAMA signal

DM-Ice Experiments

DM-Ice17

(*January 2011 – present*)

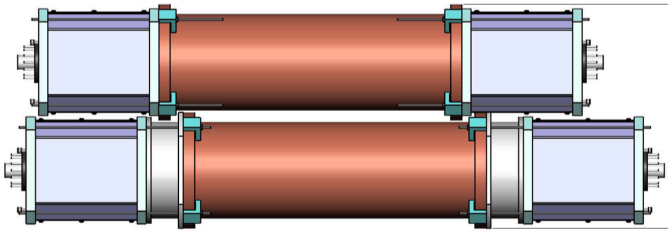


First dark matter experiment in South Pole ice

- Demonstrated viability and advantage of environment

DM-Ice37

(*April 2014 – present*)

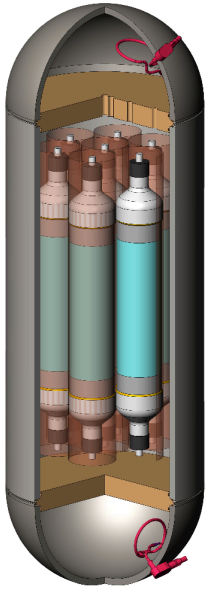


R&D testbed for NaI detectors

- Crystal background
- Light yield
- PMT/lightguide configurations

DM-Ice250

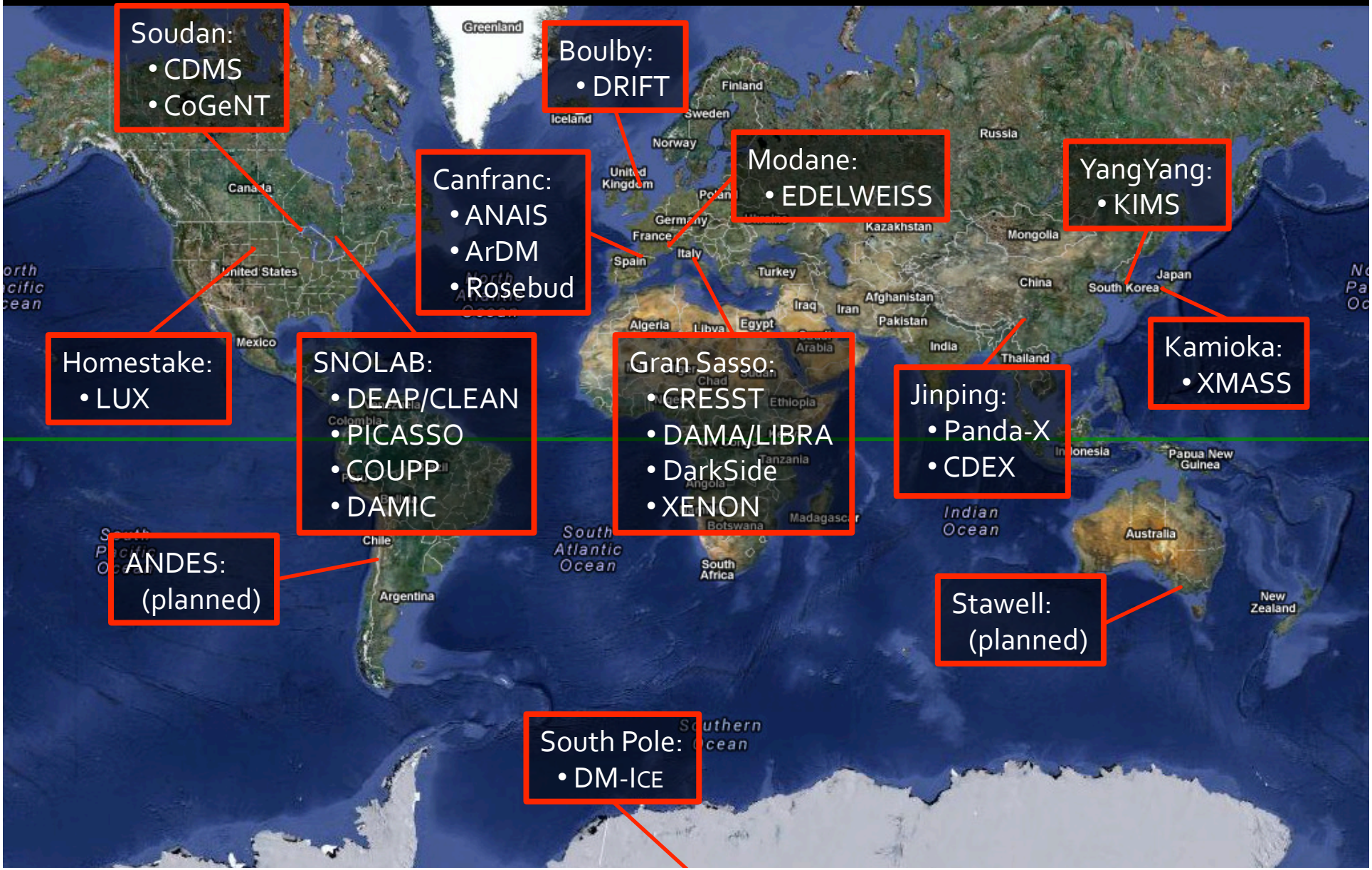
(*future*)



Science result

- Definitive test of DAMA dark matter claim

A World of Dark Matter Searches



DM-Ice17 Experiment

(2x) 8.5-kg NaI(Tl) modules

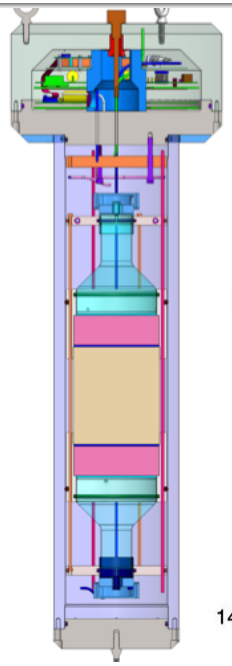
- Installed Dec 2010
- Data run from June 2011 to present

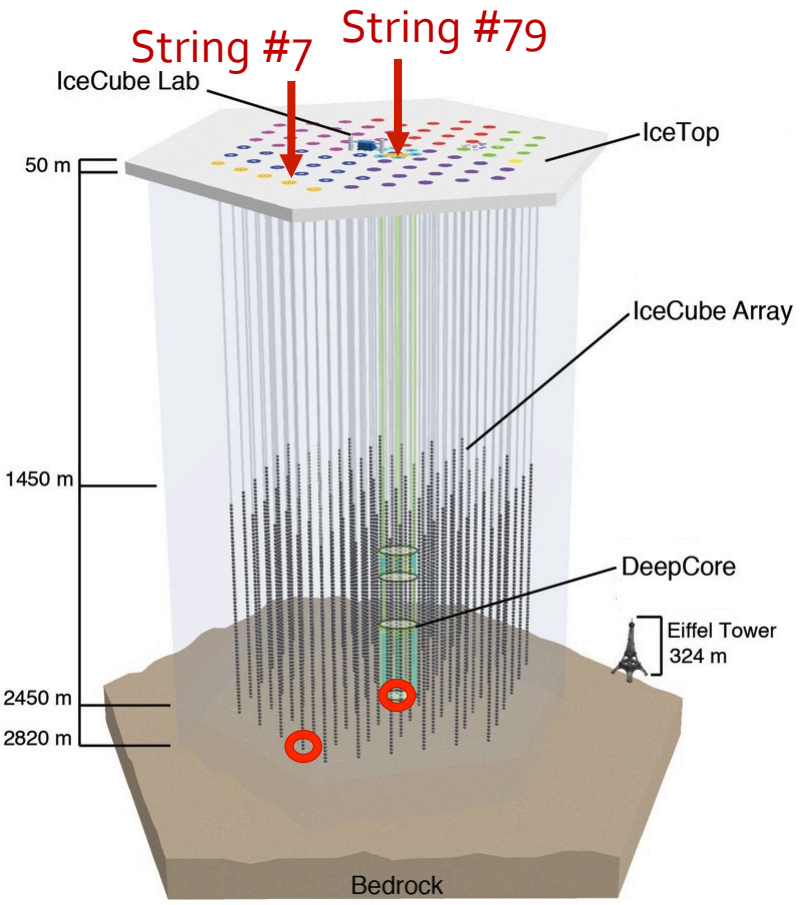
Goals:

- Demonstrate the feasibility of deploying and operating NaI(Tl) detectors in the Antarctic Ice for a dark matter search
- *In situ* measurement of the radiopurity of the Antarctic ice / hole ice at 2450 m depth
- Study environmental stability
- Study the capability of IceCube to veto muons

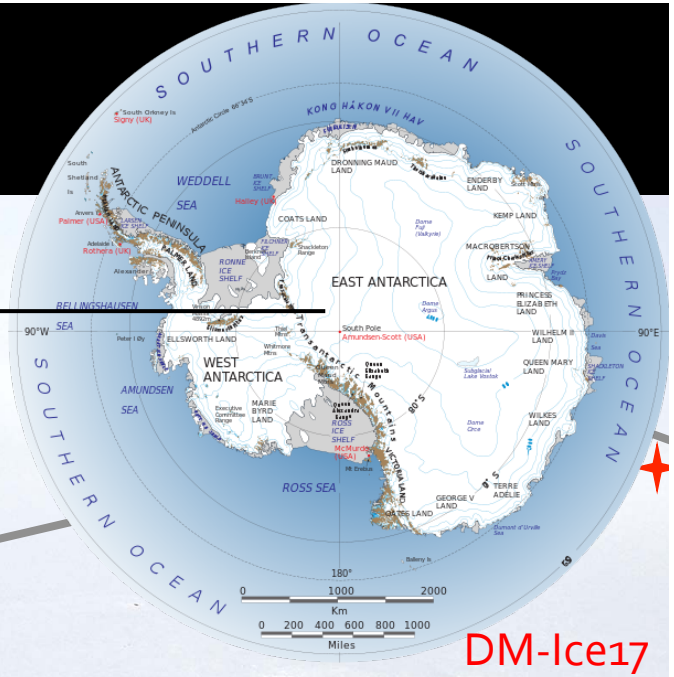
First results published:

Cherwinka *et al.*, Phys. Rev. D **90** (2014)





South Pole Science



Geographic South Pole



Amundsen-Scott South Pole Station

Skiway

DM-Ice17

IceCube
IceTop



Keck Array



BICEP3, SPT

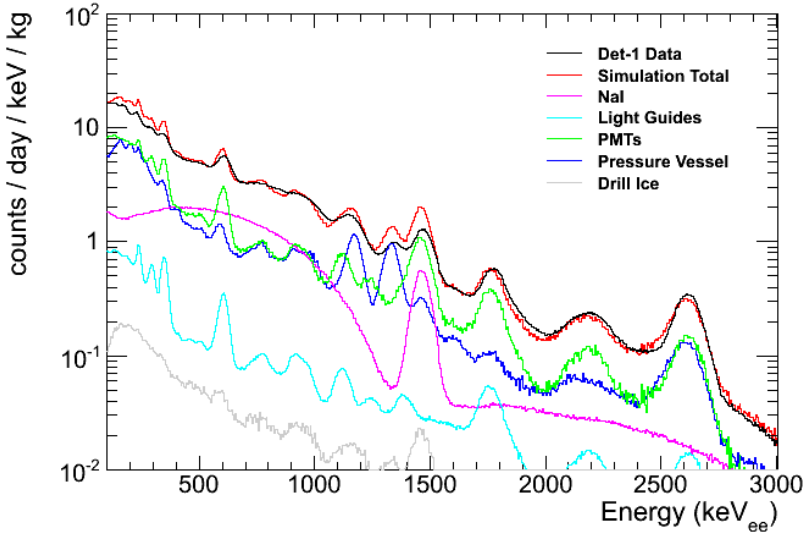
DM-Ice17 Background

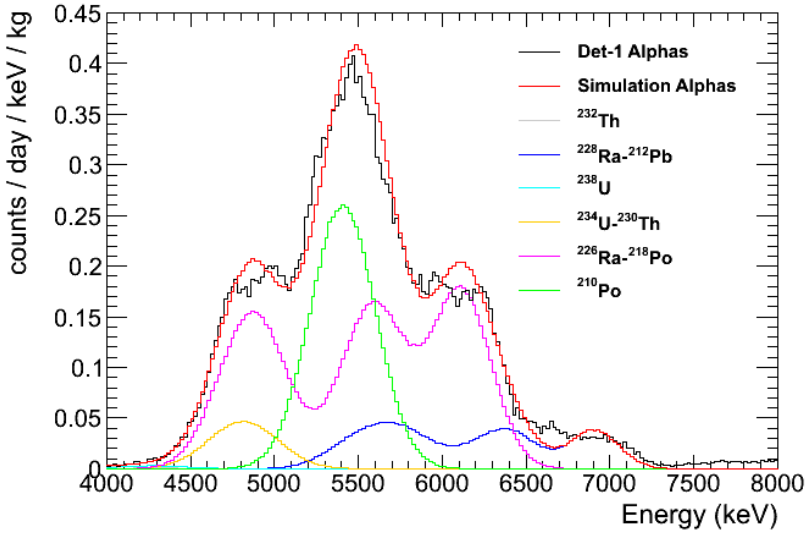
Betas & Gammas:

- Internal contamination lines allow calibration
- Well matched by *a priori* background model
  - Only crystal background unconstrained

Alphas

- Crystal contaminants only
- Constrains ^{232}Th-, ^{235}U-, ^{238}U- and chain levels



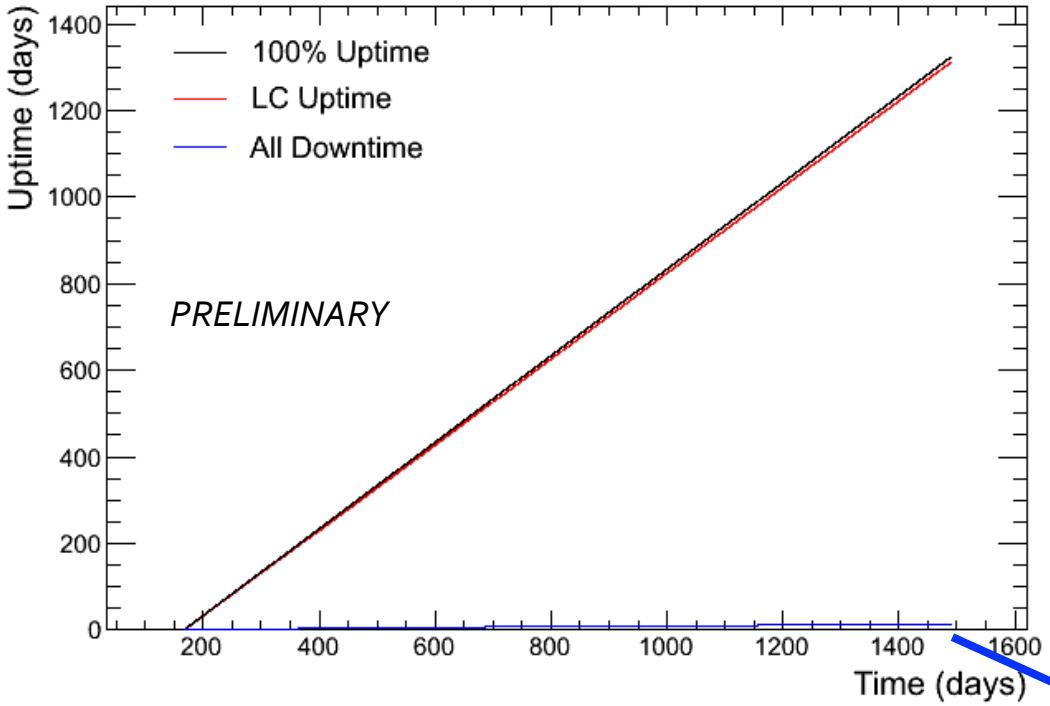


Cherwinka *et al.*, Phys. Rev. D **90** (2014)

Detector backgrounds dominate at all energies;
Negligible contributions from environmental background

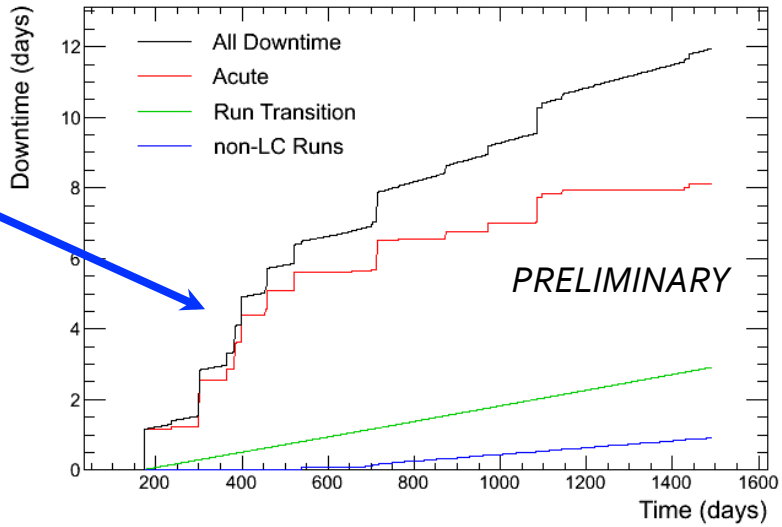
DM-Ice17 Uptime

> 99% uptime



Sources of downtime understood (DAQ, characterization data, satellite issues)

- Uptime has improved over physics data run

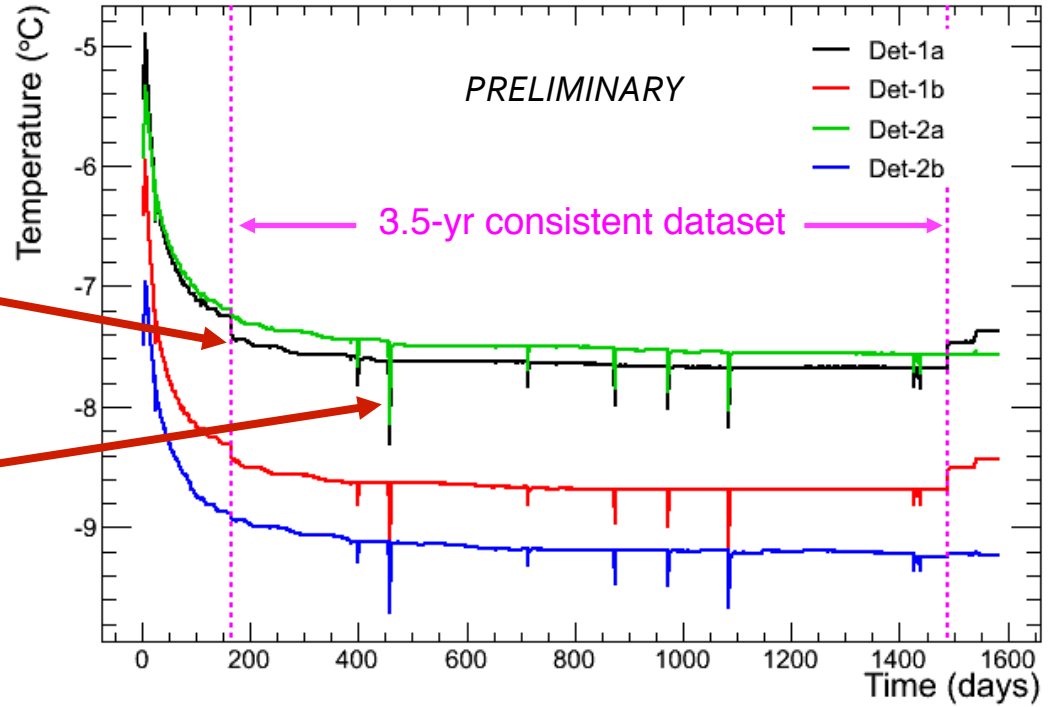


Temperature Stability

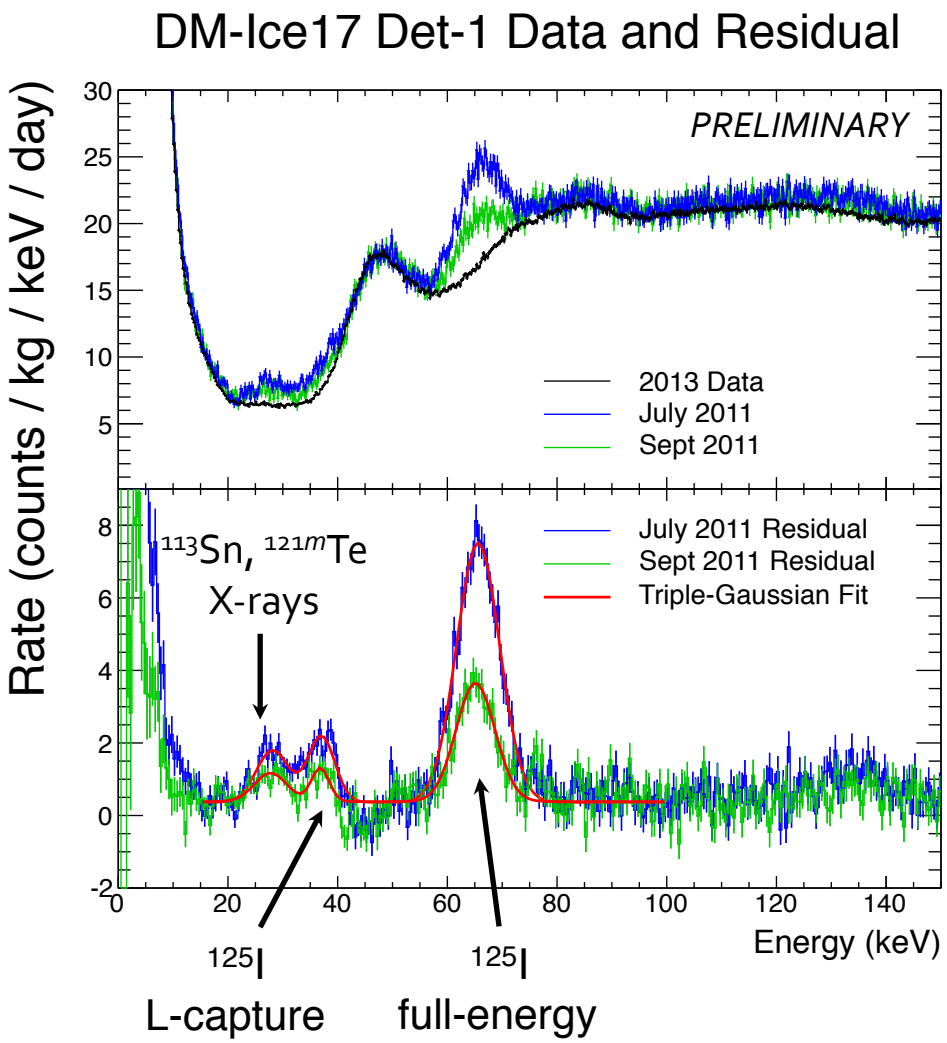
- Ice environment provides stable temperature
  - 0.3°C cooling over 3.5 years measured at mainboard
  - < 0.025°C daily RMS

Changing PMT HV setting affects MB temperature

Power outages affect MB temp, not crystal temp

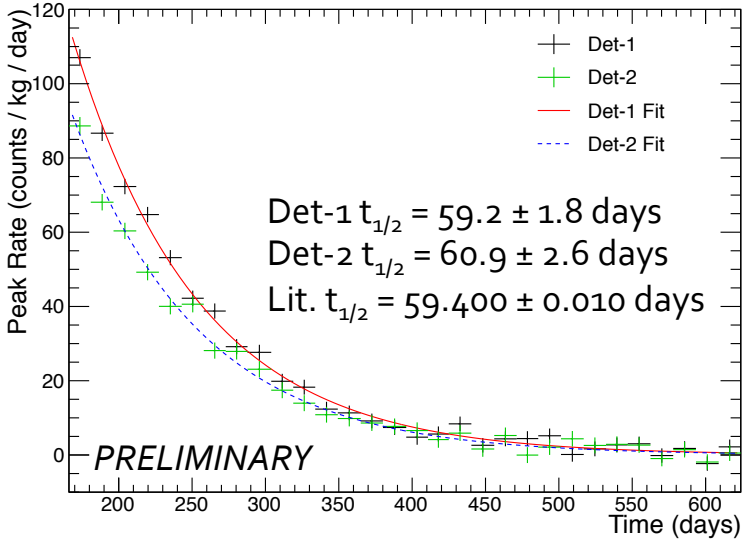


Cosmogenic Decay Peaks



Confirm identity of cosmogenic peaks:

- Match simulated spectral features
  - Expect 65.3 keV full-energy and 37.6 keV L-shell capture peaks for ^{125}I
- Measuring decay time
  - Expect 59.4 day half-life for ^{125}I



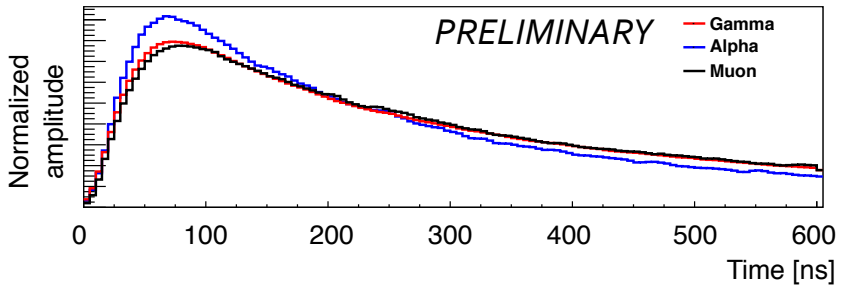
Muon Identification

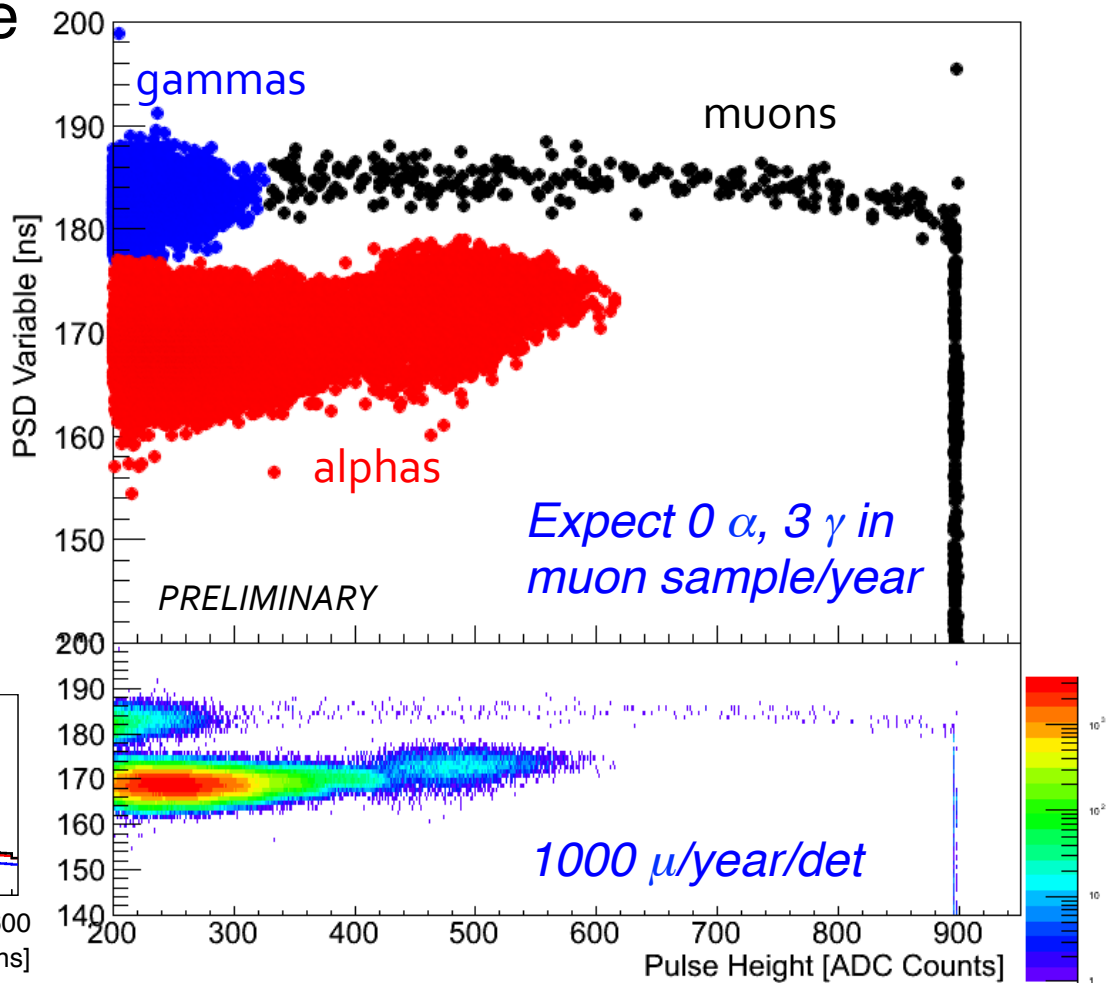
Muons are identified by their large energy deposition and "gamma-like" pulse shape

Pulse-shape discrimination (PSD) variable uses the pulse height (h_i) at time (t_i):

$$PSD = \frac{\sum h_i t_i}{\sum h_i}$$

Longer than decay tail than "alpha-like" events:

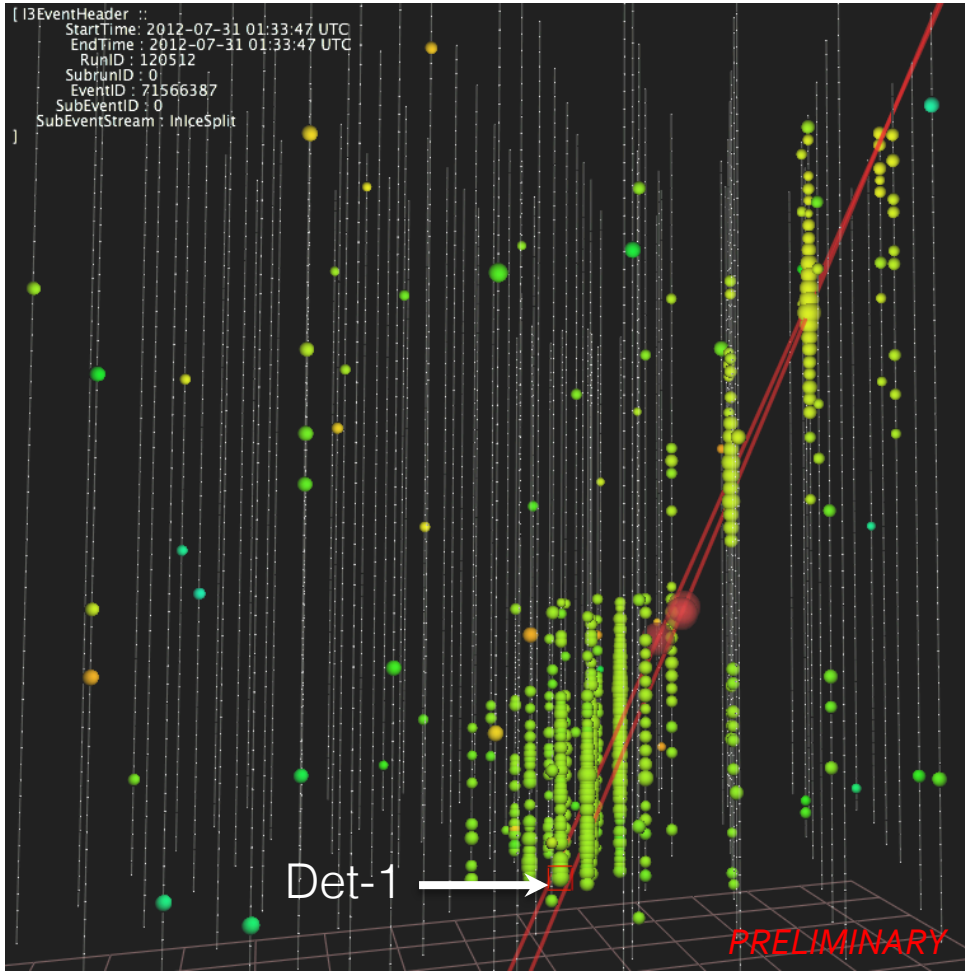




Muon Coincidence in IceCube

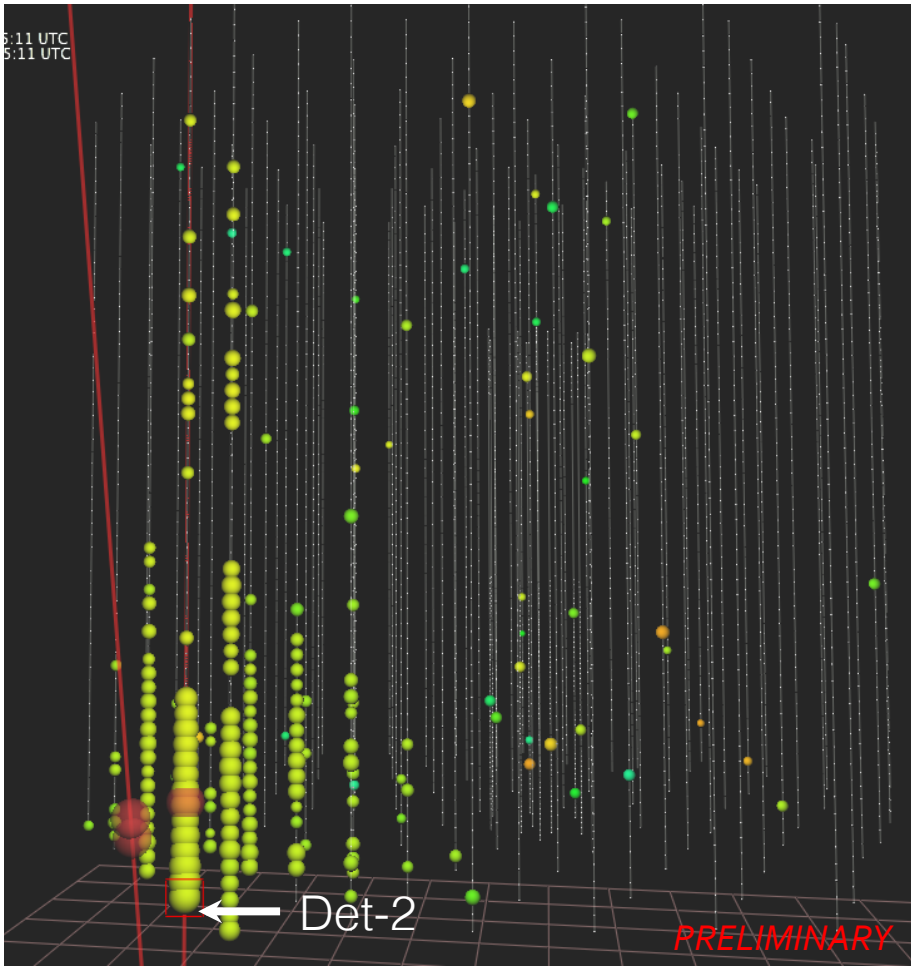
DM-IceCube17 Det-1

93% coincidence



DM-IceCube17 Det-2

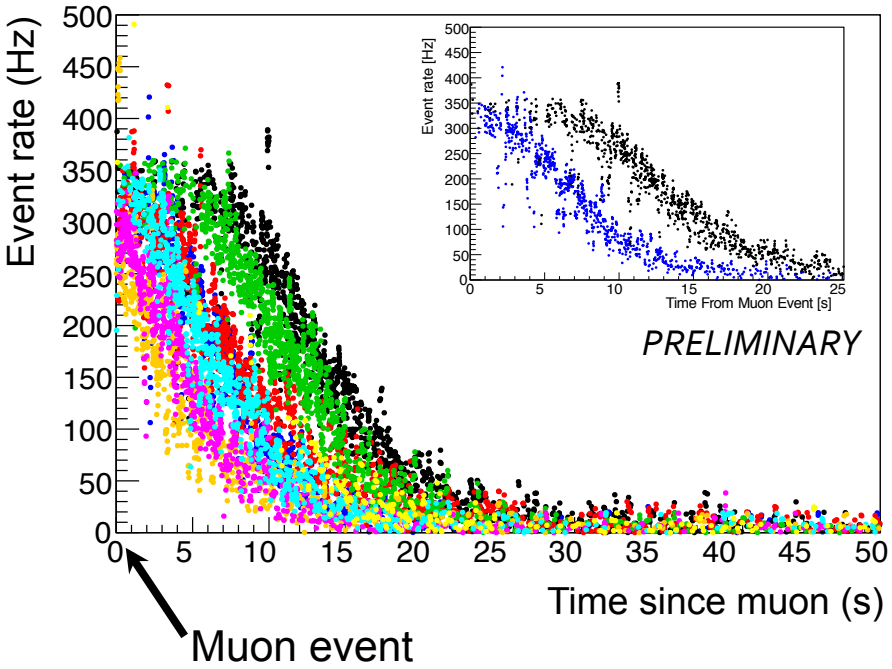
33% coincidence



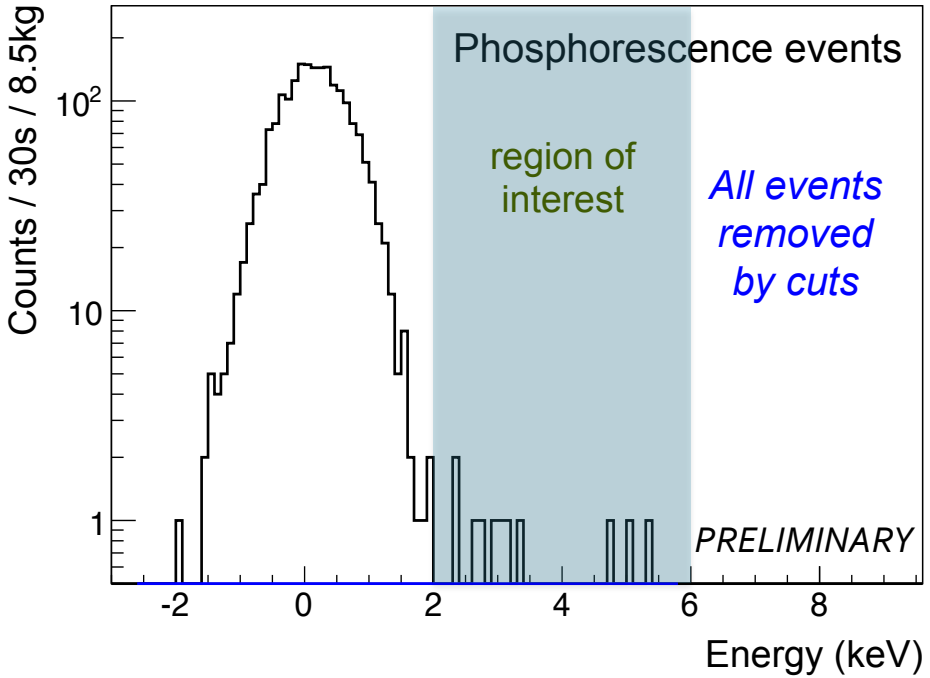
Muon-Induced Phosphorescence

The 2% highest energy muons each induce 100s of low energy events following the muon event

Timing characteristics: 9±2s decay
Normal rate: 2.5 Hz
DAQ saturation visible ~300 Hz



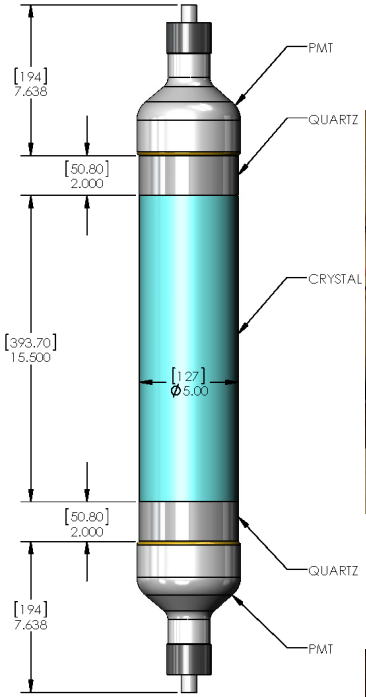
Energy characteristics:
- predominantly <2 keV
- no events pass noise cuts



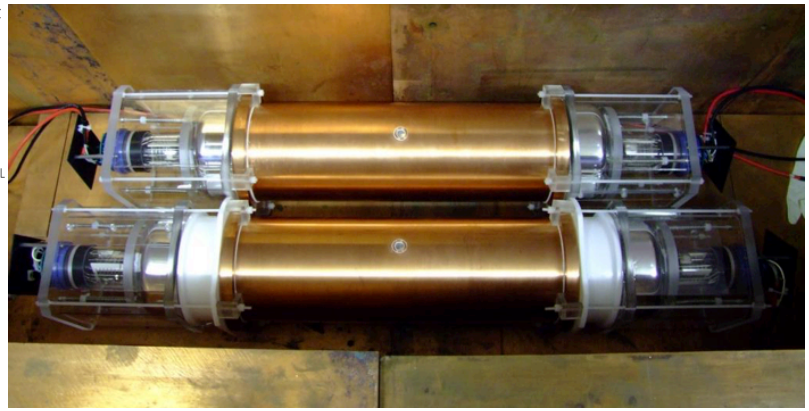
DM-Ice37 Objectives

Open Questions:

- Crystal purity
- Light yield
  - Energy resolution
- PMT background
  - *Lightguides?*
- Photon collection
  - Photocathode coverage
  - *Lightguides?*



Configuration 1:
- 5” PMTs, lightguide test



Configuration 2:
- 3” PMTs, reflector test

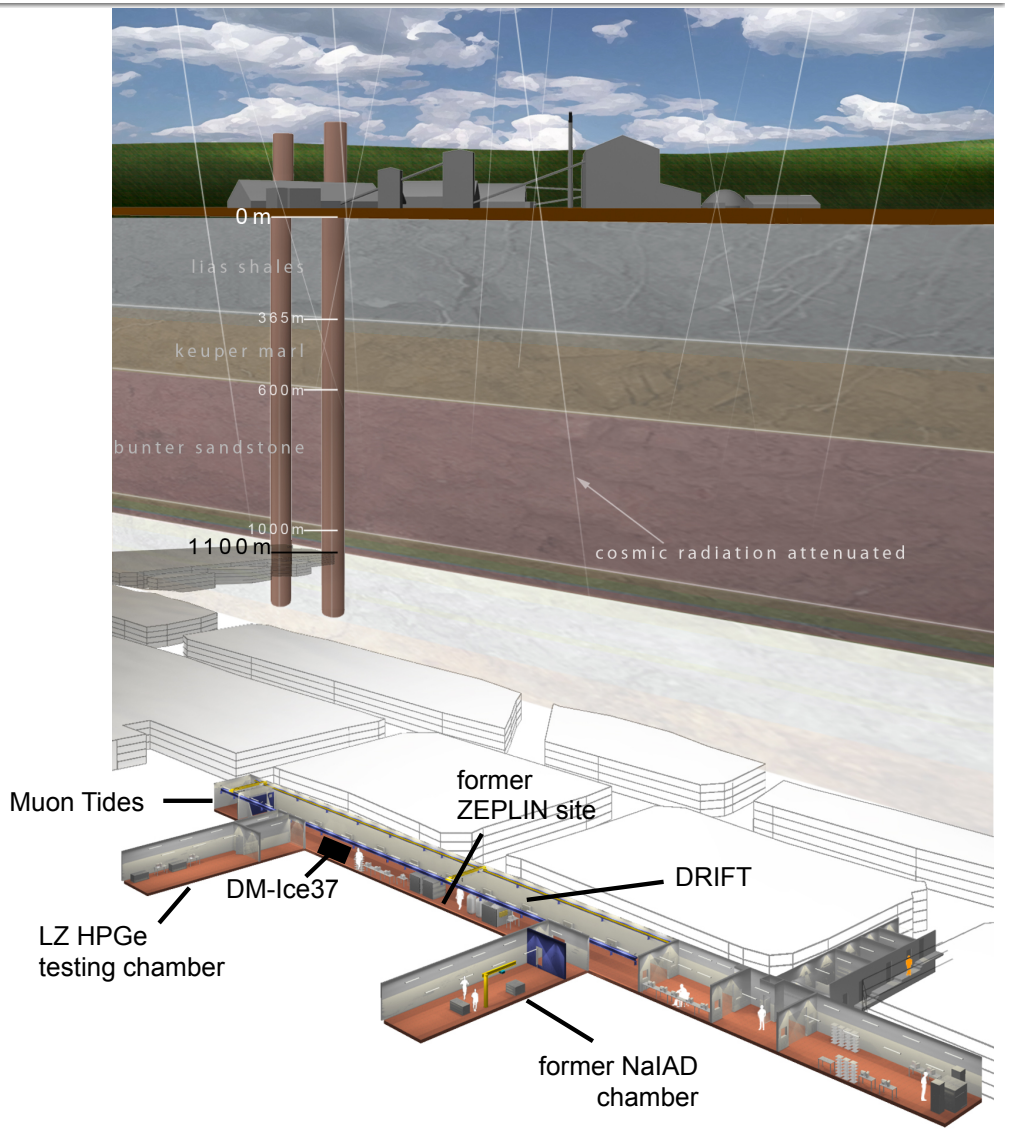


DM-Ice37 : R&D Work

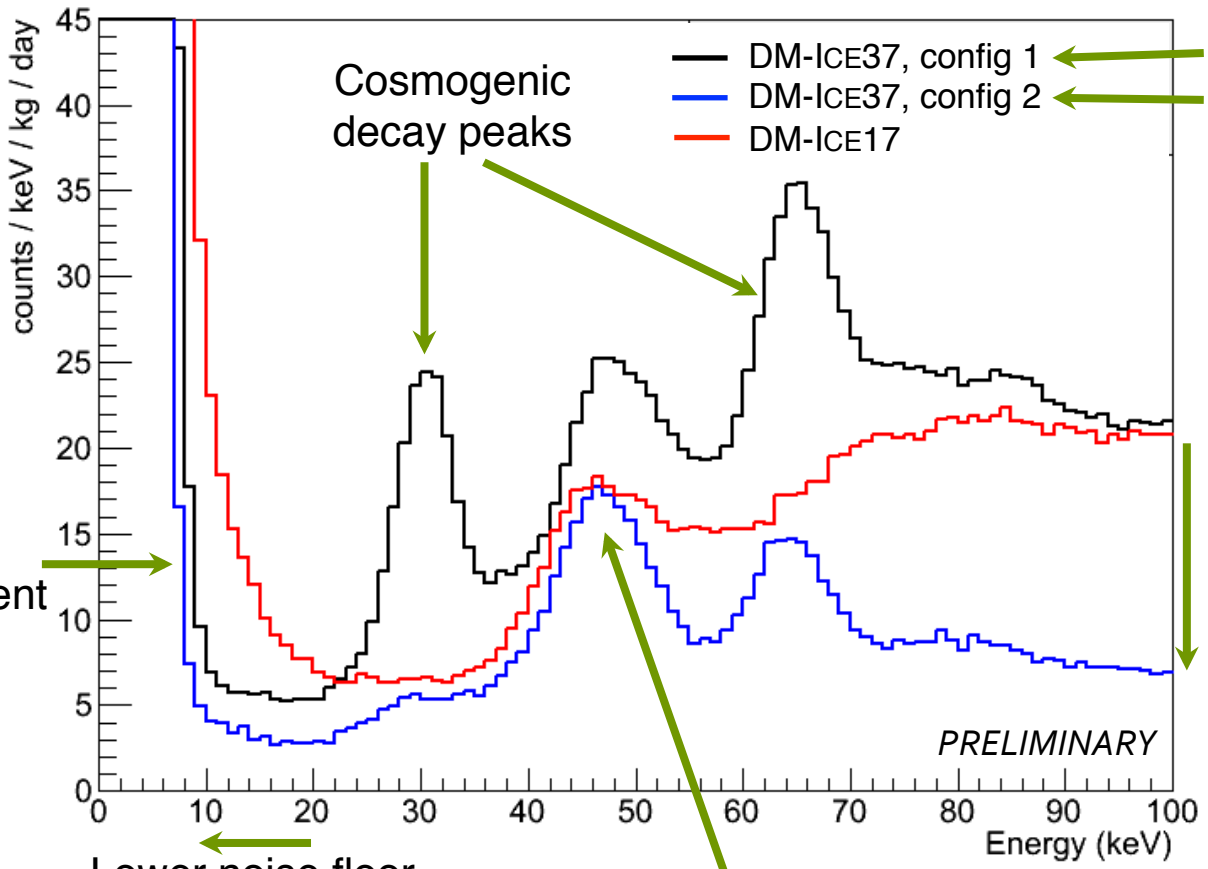
Operating newly-grown NaI crystals at Boulby Lab (UK)

- 2850 m.w.e. overburden
- Low radon environment
- Copper-lined lead castle





DM-Ice37 Spectrum



Also coming:

- Background Monte Carlo
- Muons & phosphorescence

NaI Crystal Background

Worldwide effort of NaI dark matter experiments (ANAIS, DM-Ice, KIMS) working with crystal grower (Alpha Spectra) to produce low-background crystals

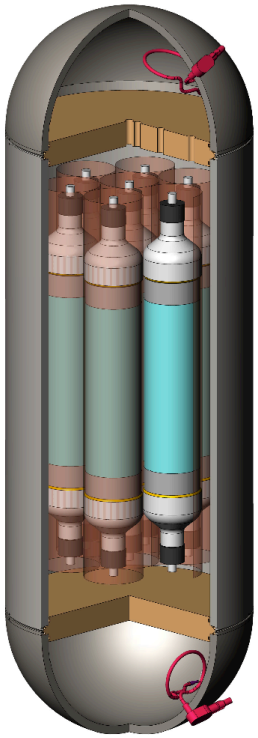
(all rates in μBq/kg)

Decay	DM-Ice17[A]	ANAIS-0[B]	DAMA[C]	ANAIS-25[D]	KIMS-001[E]	KIMS-002[E]	DM-Ice37[F]
^{40}K	17000	12700	600	1250	1250	1490	<2000
^{232}Th	10	13		2	<12	2	
^{228}Ra – ^{208}Tl	160	35	2-30	2	<13	2	
^{238}U	17	75	4.4	10	<7	<12	
^{234}U, ^{234}Th	140	75, 23	15.8				
^{226}Ra – ^{214}Po	900	98	21.7	10	<0.3	<1.5	
^{210}Po	1500	188	24.2	3150	3280	1760	2100

A – Cherwinka *et al.*, Phys. Rev. D **90** (2014)
B – Cebrián *et al.*, Astropart. Phys. **37** (2012)
C – Bernabei *et al.* NIM A **592** (2008)
D – Amaré *et al.* NIM A **742** (2014)
E – Kim *et al.* Astropart. Phys. **62** (2014)
F – *PRELIMINARY*

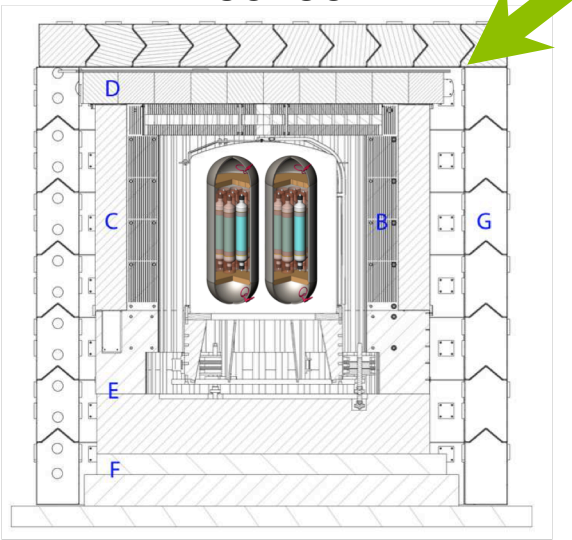
DM-Ice250 Experimental Program

Modular detector supporting deployment in both hemispheres

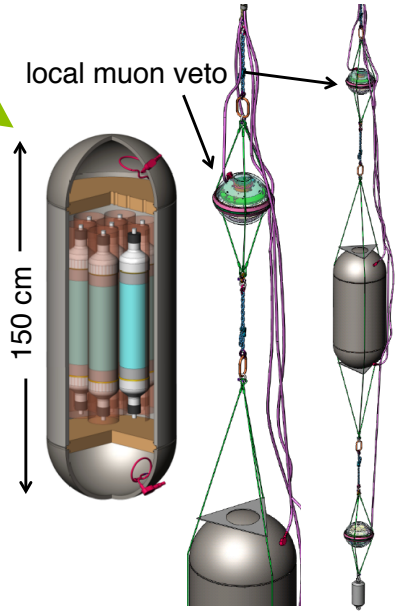


- 125 kg NaI(Tl) / module
- 7-crystal array
  - Coincidence between PMTs
  - Anti-coincidence between crystals

DM-Ice250N



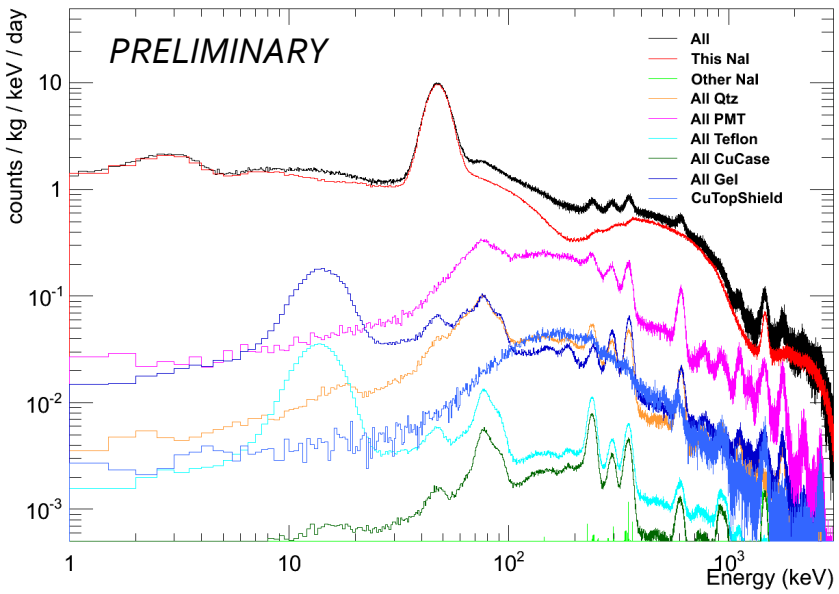
DM-Ice250S



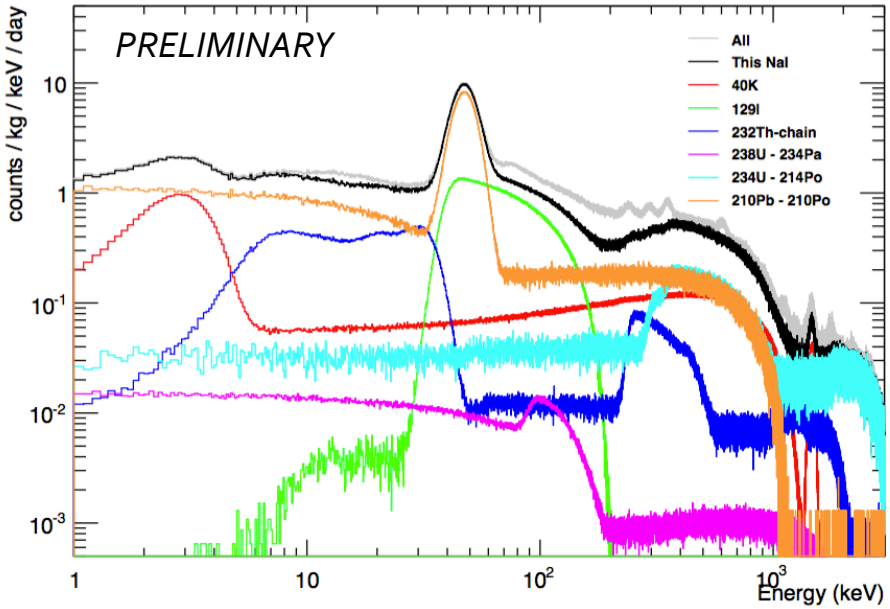
Background Simulation

- Multi-crystal anticoincidence veto effectively reduces all backgrounds except from NaI crystal
  - Low-energy spectrum dominated by ^{40}K and ^{210}Pb (^{238}U-chain)
- Background of 2 counts/kg/keV/day achievable in 2 – 6 keV region of interest

Outer Crystal, Full Sim, Vetoed

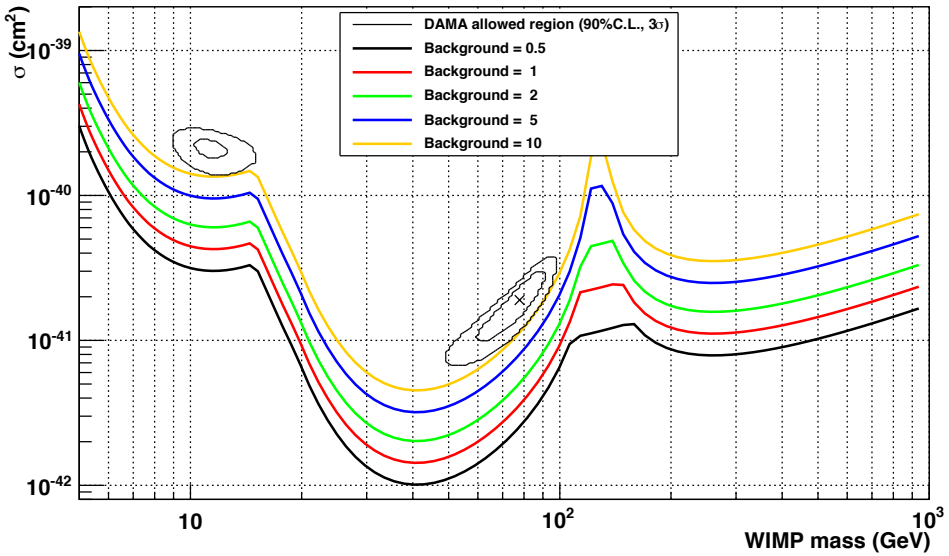


Outer Crystal, NaI Sim, Vetoed

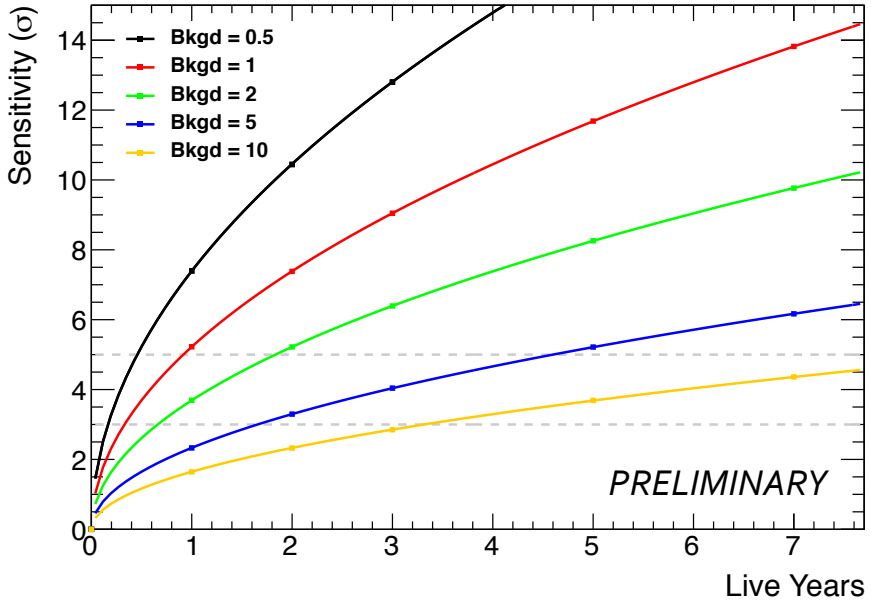


Sensitivity Projection

Null Hypothesis:
(90% CL contours, 500 kg*yr exposure)



Signal Hypothesis:
(250 kg detector)



DAMA dark matter claim can be definitively tested with 500 kg*yr exposure

- 5-sigma test possible with background of 2 dru
  - *cf.* DAMA background of ~1 dru

DM-Ice Collaboration

Yale University

Reina Maruyama, Karsten Heeger, Kyungeun Lim, Antonia Hubbard, Walter Pettus, Estella de Souza, Field Rogers

University of Wisconsin – Madison

Francis Halzen, Michael DuVernois, Albrecht Karle, Matt Kauer, Zachary Pierpoint

University of Sheffield

Neil Spooner, Vitaly Kudryavtsev, Anthony Ezeribe, Frederic Mouton, Matt Robinson, Sam Telfer, Lee Thompson, Dan Walker

Boulby Underground Science Facility

Sean Paling

Fermilab

Lauren Hsu

University of Illinois at Urbana-Champaign

Liang Yang

University of Alberta

Darren Grant

Pennsylvania State University

Doug Cowen, Ken Clark

NIST-Gaithersburg

Pieter Mumm

University of Stockholm

Chad Finley, Per Olof Hulth, Klas Hultqvist, Chistian Walck

SNOLAB

Bruce Cleveland

Physical Sciences Lab

Jeff Cherwinka, Perry Sandstrom