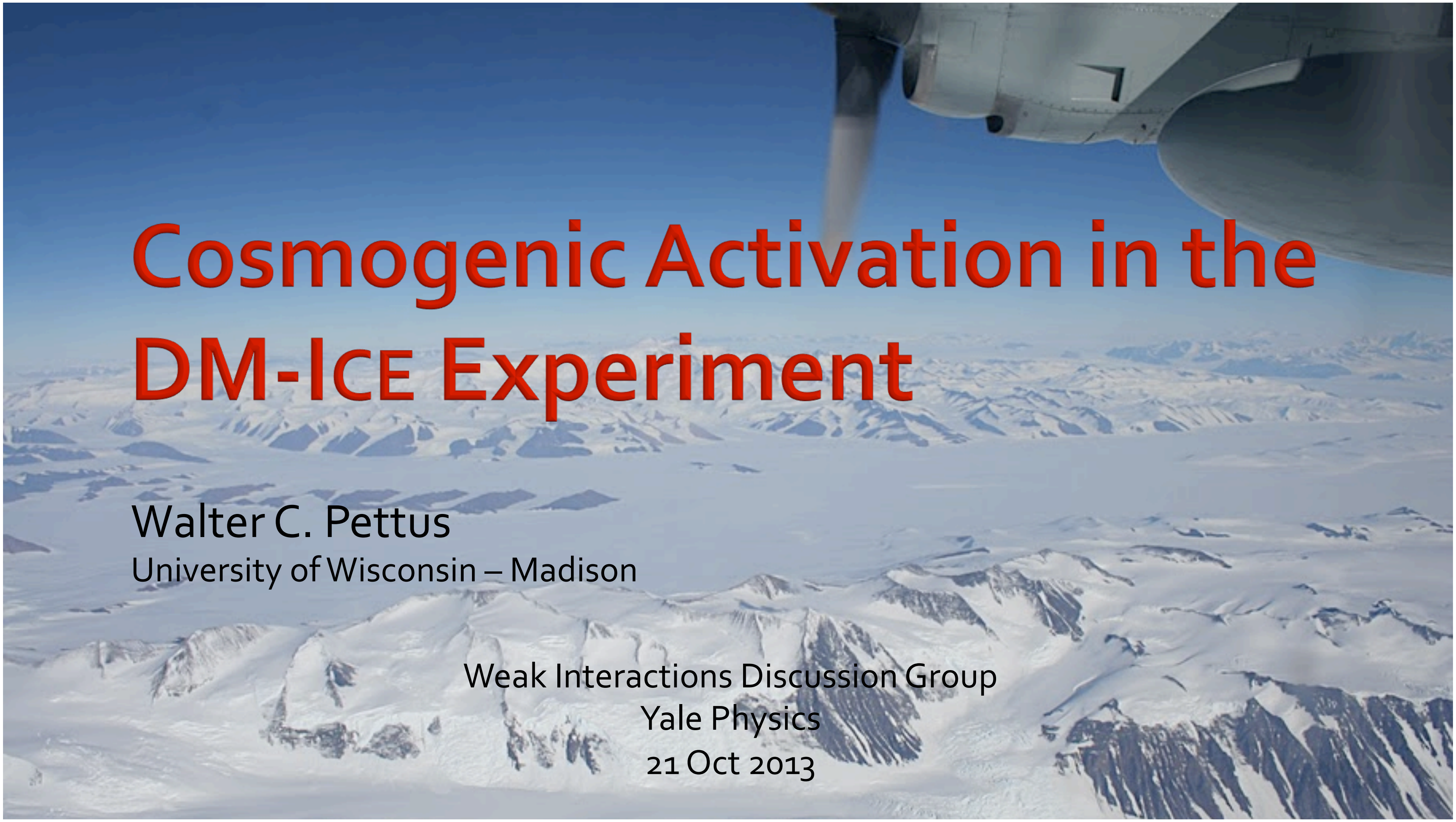

Cosmogenic Activation in the DM-ICE Experiment

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Weak Interactions Discussion Group
Yale Physics
21 Oct 2013

STEWARDSHIP SCIENCE GRADUATE FELLOWSHIP

NSF

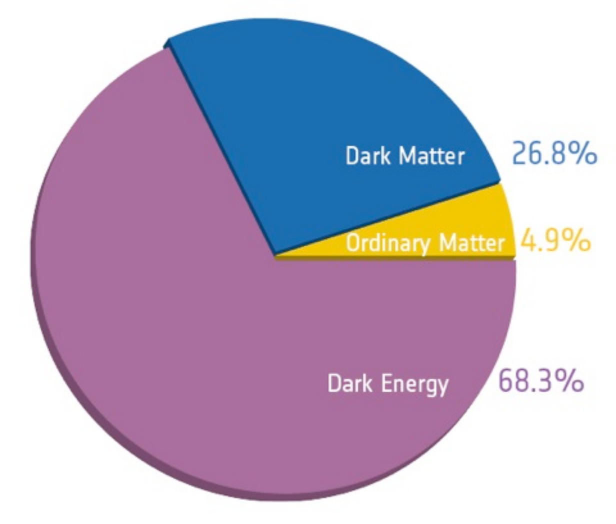
WIPAC
WISCONSIN ICECUBE PARTICLE ASTROPHYSICS CENTER

THE UNIVERSITY of WISCONSIN MADISON

Outline

- Dark Matter and DM-ICE
- Cosmogenic Activation in DM-ICE
  - O(50 – 1000 keV_{ee}) Calibration
- Pulse Shape Discrimination
  - O(>2500 keV_{ee}) Calibration
- Noise Discrimination
  - O(<20 keV_{ee}) Calibration

The Dark Side of the Universe

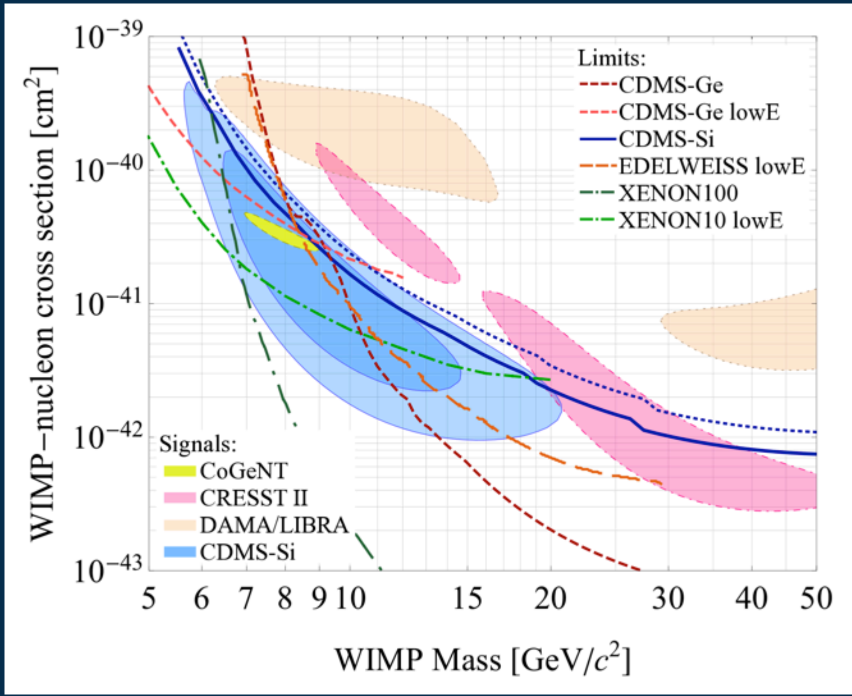


Planck collaboration, arXiv: 1303.5062 (2013)

- 26.8% of Universe is dark matter
  - Cosmic Microwave Background
  - Baryon Acoustic Oscillations
  - Distance Measurements (H_0)
  - Type Ia Supernovae
  - Gravitational Lensing
  - Cluster Measurements
  - Lyman Alpha Forest
  - Large Scale Structure
  - Galactic Rotation Curves

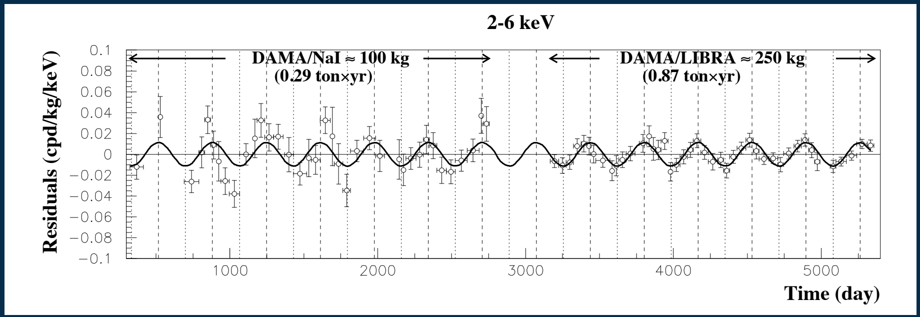
WIMP Dark Matter Field Status

Best Exclusion Limits



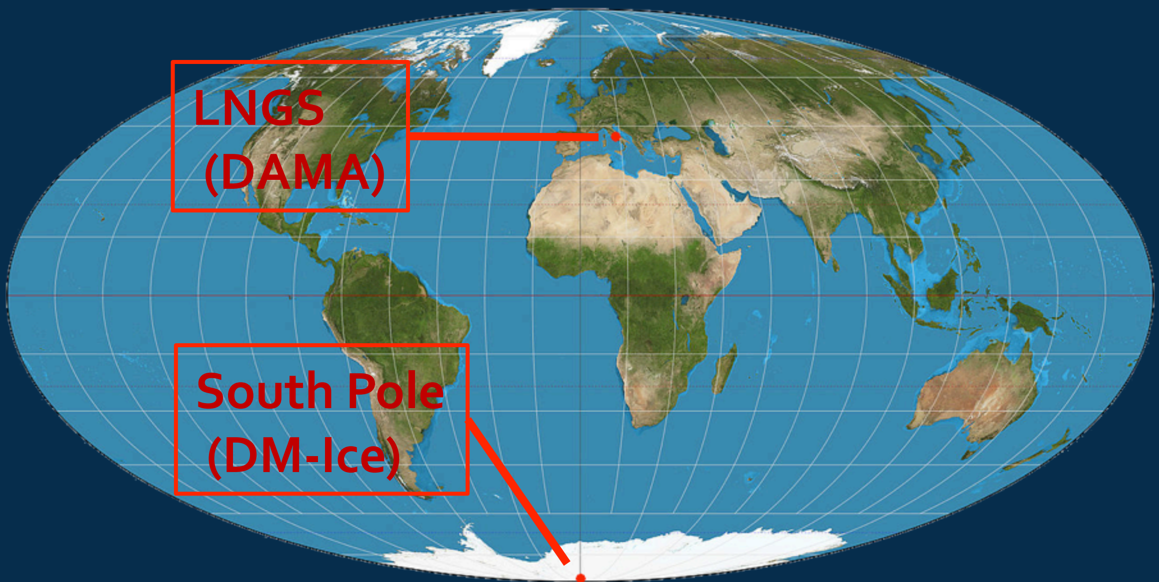
Agnese *et al*. arXiv:1304.4279 (2013)

Nagging Positive Signals



Bernabei *et al*. Int J Mod Phys A (2013)

DM-ICE Concept

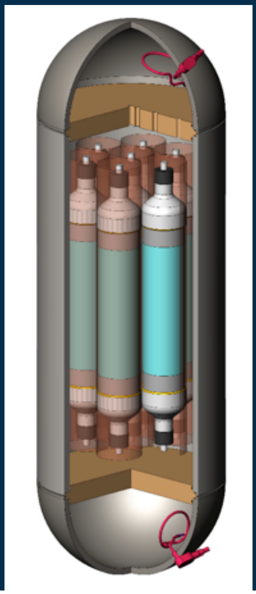


Search for annual modulation with NaI(Tl) crystals in the Southern Hemisphere

DAMA/LIBRA
- 5x5 array
- ~250 kg

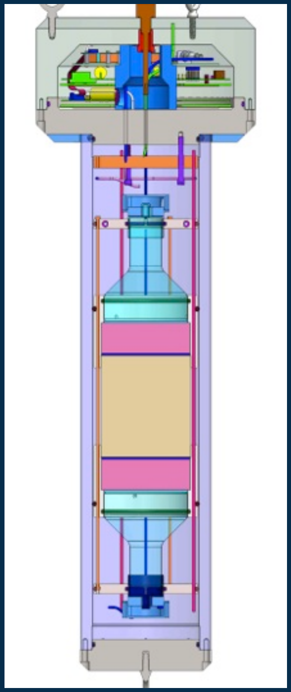
DM-Ice (concept)
- 7 crystal array
- ~125 kg/module
- ~250 kg total

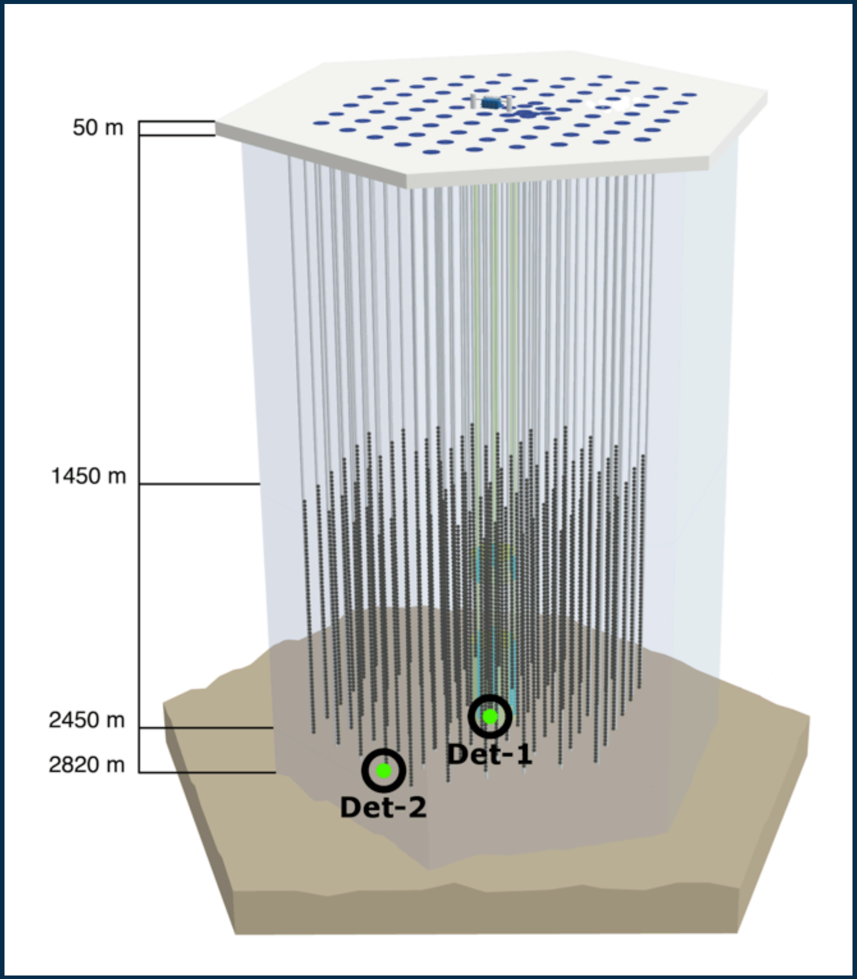
x2



DM-Ice17

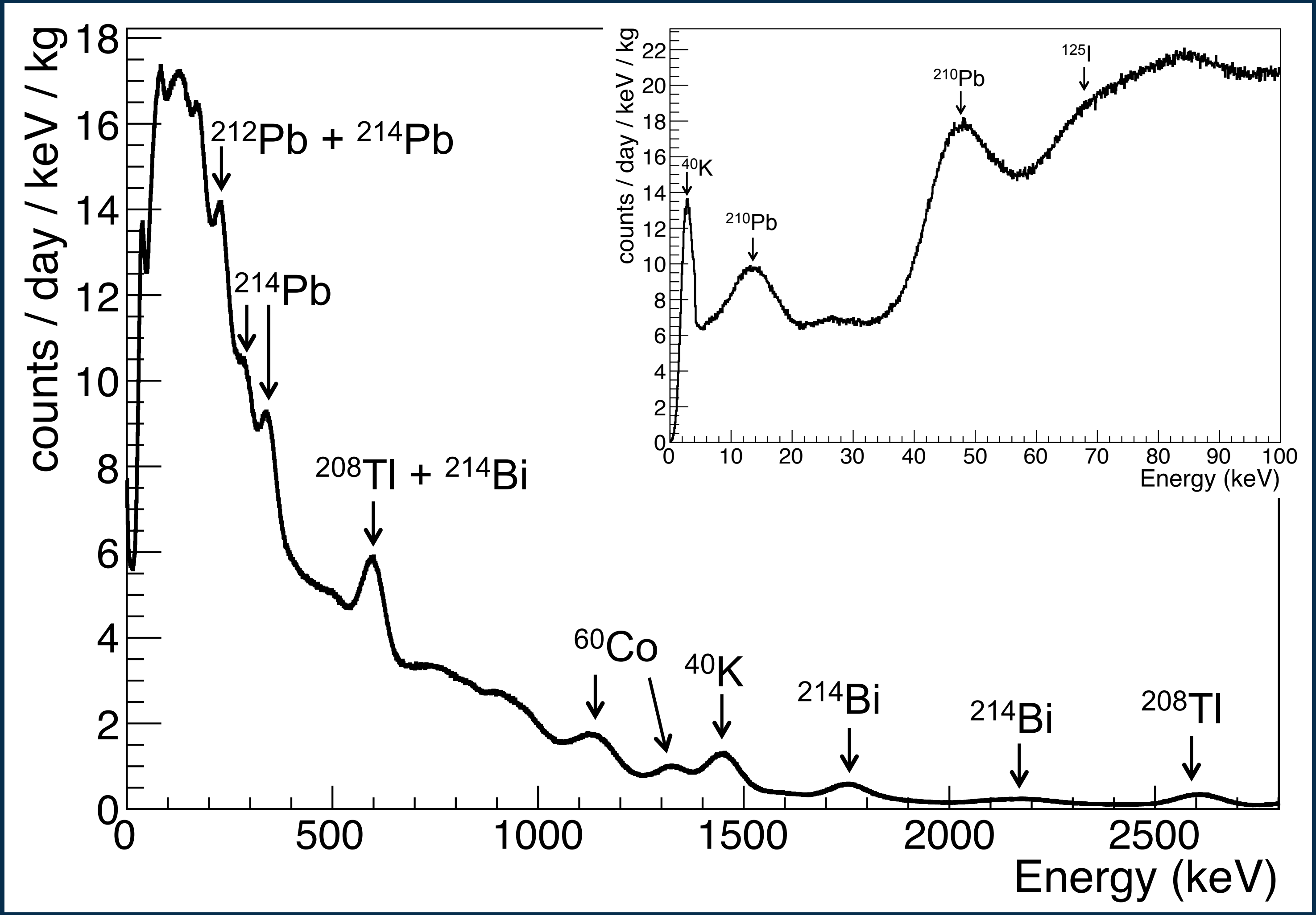
- 2 detectors
- 8.47 kg each
- 2457 m depth
  - 2200 m.w.e.



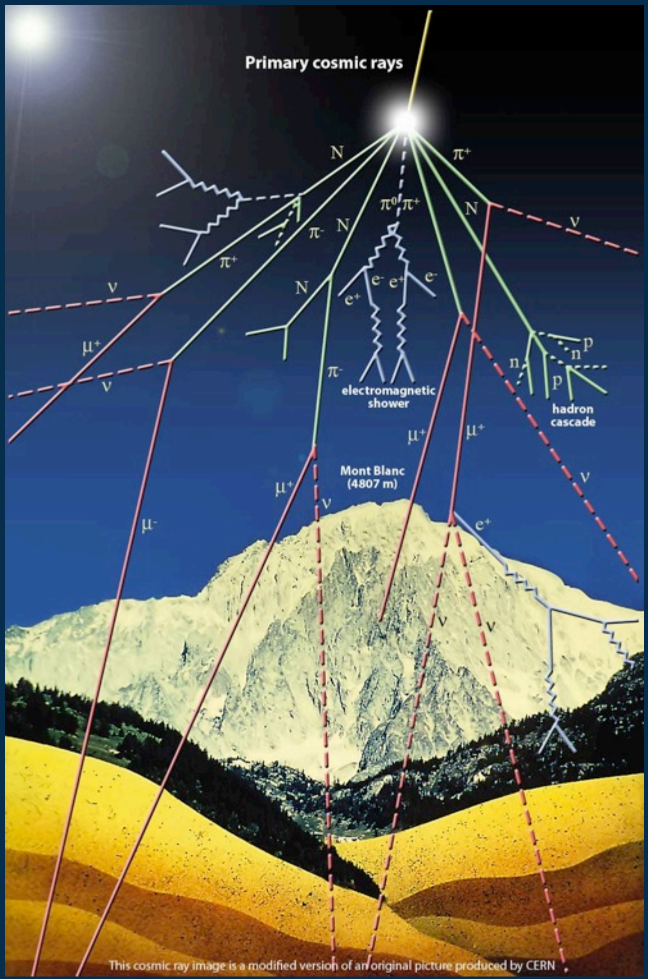


- Deployed Dec 2010
- Stable running since June 2011

DM-Ice17 Energy Spectrum



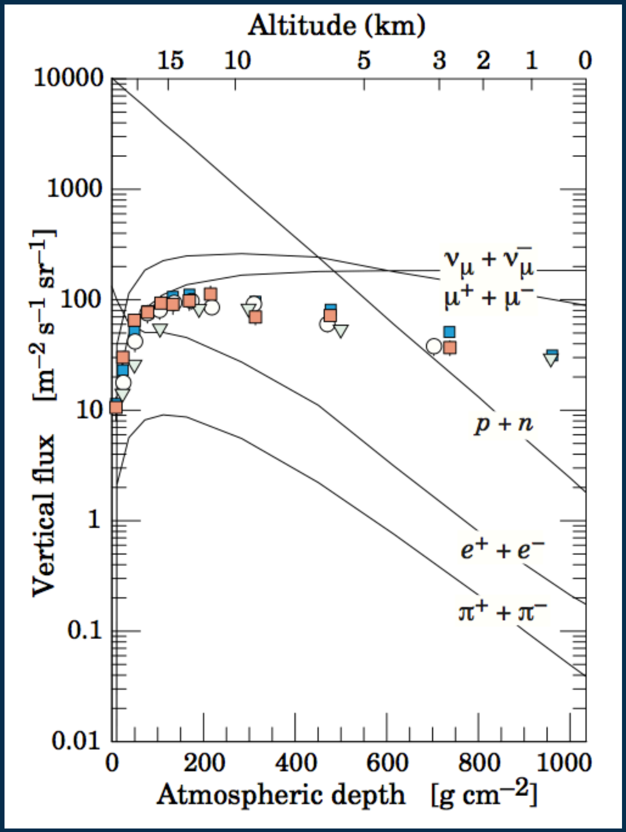
Cosmic Ray Showers



- Cosmic ray shower components can ‘activate’ detector components
  - Muon capture
    - $\mu^- + A(Z,N) \rightarrow \nu_\mu + A(Z-1,N+1)$
  - Hadron capture
    - $n + A(Z,N) \rightarrow A(Z,N+1)$
    - $p + A(Z,N) \rightarrow A(Z+1,N)$
  - Spallation
    - $n + A(Z,N) \rightarrow n + A_1(Z_1,N_1) + A_2(Z_2,N_2)$

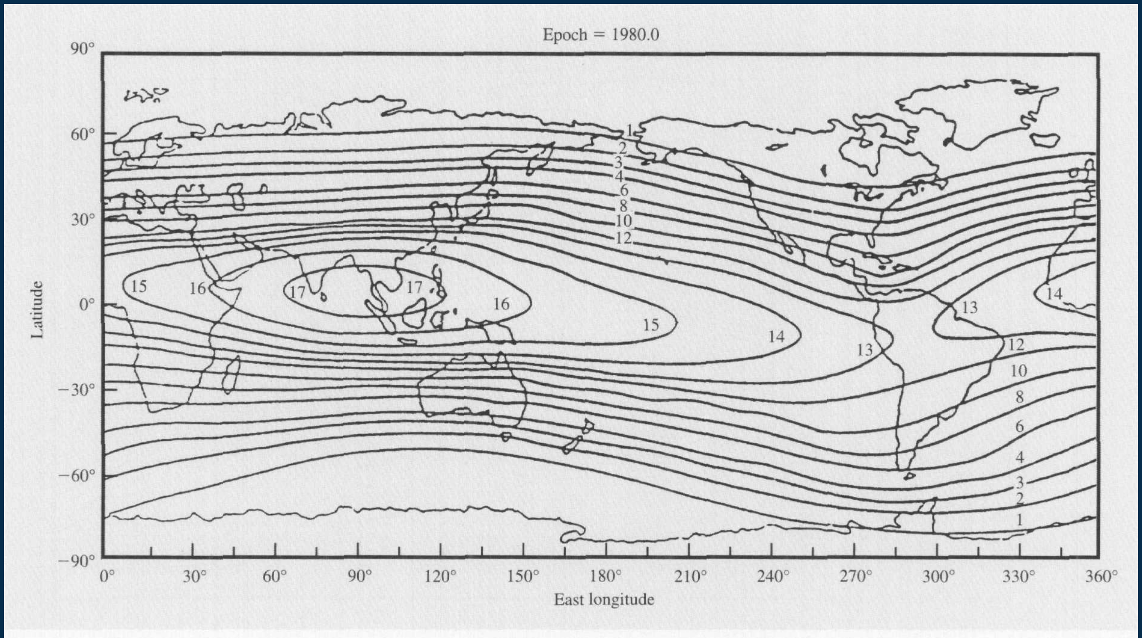
Cosmic Ray Scaling

Altitude Dependence:



Beringer *et al*. (PDG) Phys Rev D (2012)

Latitude Dependence:



Ziegler. IBM J R&D (1998)

Cosmic ray rates depend on altitude (atmospheric depth) and geographic coordinates (geomagnetic rigidity)

DM-Ice Logistics

Before running a dark matter experiment at the South Pole . . .

DM-Ice17 Component Sources
- Crystals: Boulby, UK
- Steel: Sandviken, SWE

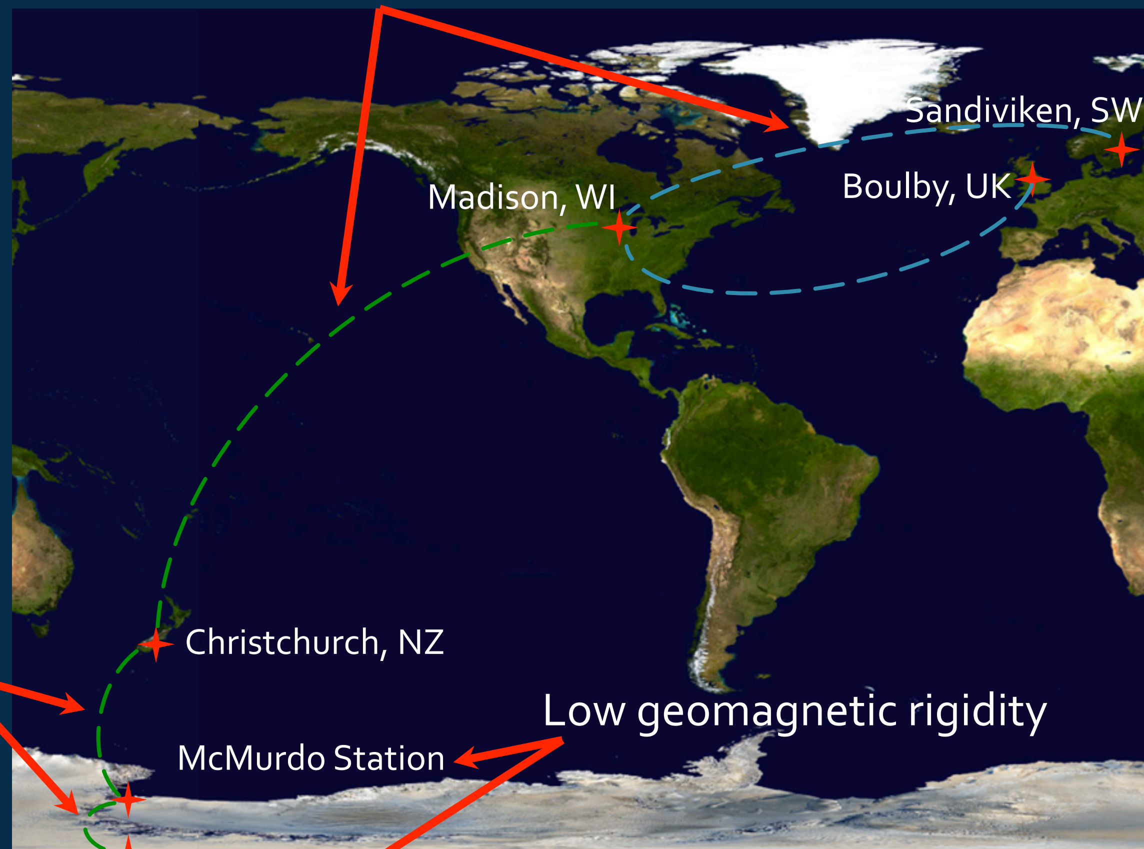
DM-Ice17 Construction
- Madison, WI, USA

Polar Program Waypoints
- Christchurch, NZ
- McMurdo Station
- South Pole Station

Cosmogenic Activation Hazards

Location	Relative Neutron Rate (to sea level)
Madison, WI	1.26
South Pole	9.7
Commercial Flight	130

Commercial flights
at ~35,000+ ft



South Pole Station

Polar program
flights

Storage
at 9,301 ft

Cosmogenic Isotopes

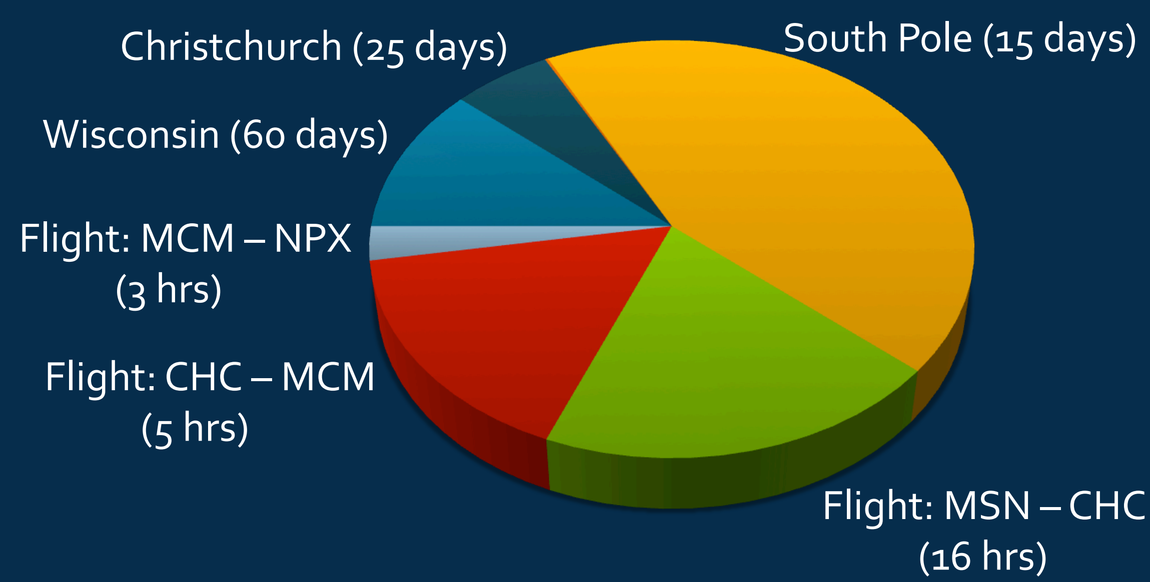
- Activity of cosmogenic isotopes simulated by:
  - ACTIVIA code for NaI crystals
  - Literature values for Steel (and Copper)

Crystal	
Isotope	Half-Life
^{3}H	12.3 yr
^{22}Na	2.6 yr
^{109}Cd	461 d
^{113}Sn	115 d
^{121}Te	19.2 d
^{121m}Te	164 d
^{123m}Te	119 d
^{125m}Te	57.4 d
^{127m}Te	106 d
^{125}I	59.4 d
^{126}I	12.9 d
^{127}Xe	36.3 d

Steel	
Isotope	Half-Life
^{7}Be	53.2 d
^{46}Sc	83.8 d
^{48}V	16.0 d
^{51}Cr	27.7 d
^{52}Mn	5.59 d
^{54}Mn	312 d
^{56}Co	77 d
^{56}Ni	70.9 d
^{58}Co	6.08 d

Cosmogenic Isotopes

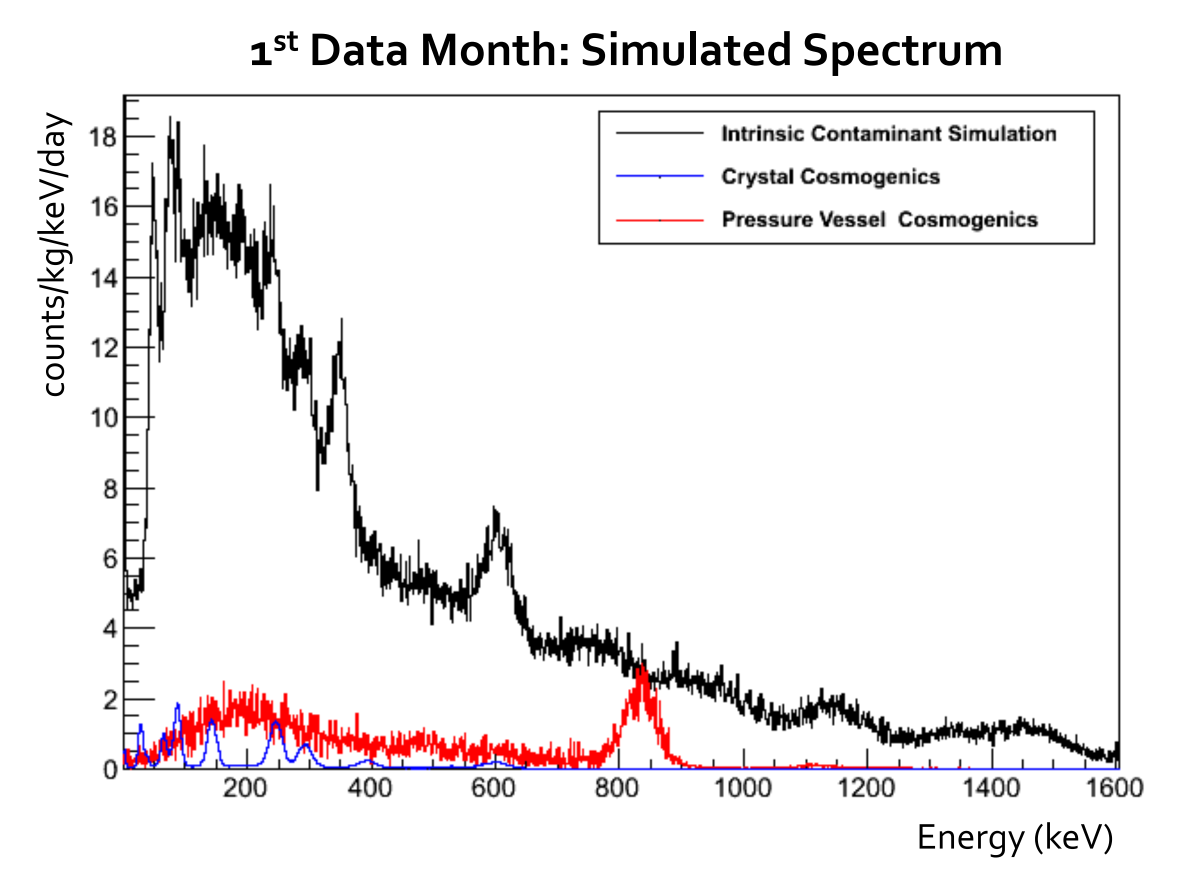
- Breakdown of crystal activation by travel stage:



Cosmogenic Simulation Effects

Long-lived cosmogenic isotopes from crystal and pressure vessel are expected to persist into data taking

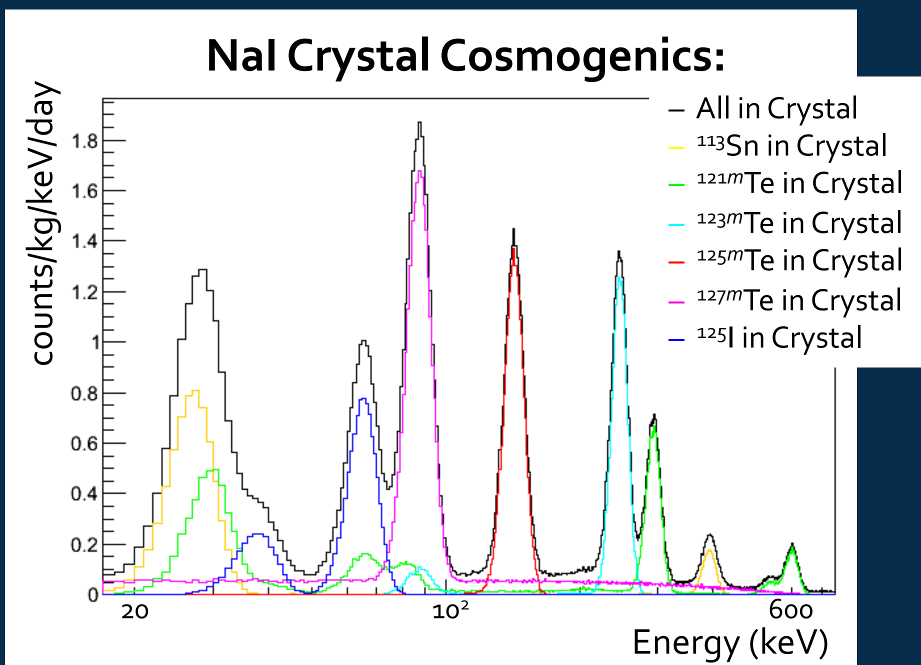
Crystal	Steel
^{3}H	^{7}Be
^{22}Na	^{46}Sc
^{109}Cd	^{48}V
^{113}Sn	^{51}Cr
^{121m}Te	^{52}Mn
^{123m}Te	^{54}Mn
^{125m}Te	^{56}Co
^{127m}Te	^{56}Ni
^{125}I	^{58}Co
^{127}Xe	

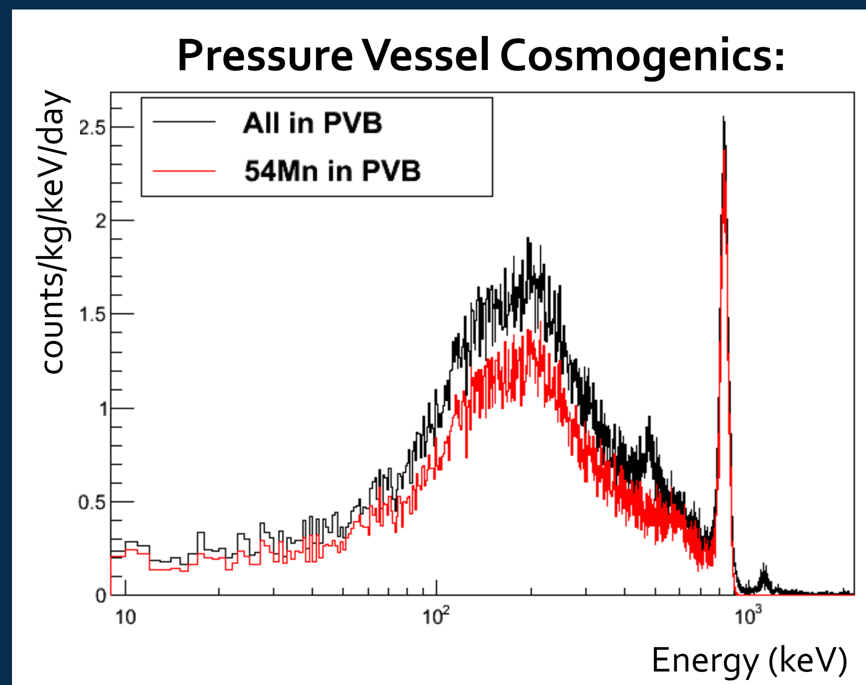


Cosmogenic Signals in July 2011*

* (6.5 months after deployment, first month of data run)

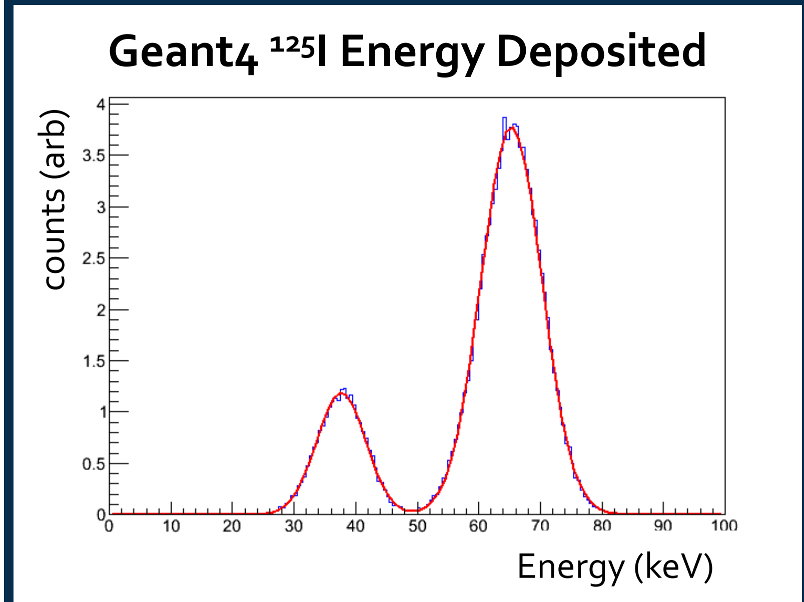
- NaI Crystal
  - Still expect clear peaks from multiple isotopes
- Steel Pressure Vessel
  - ^{54}Mn is only significant isotope

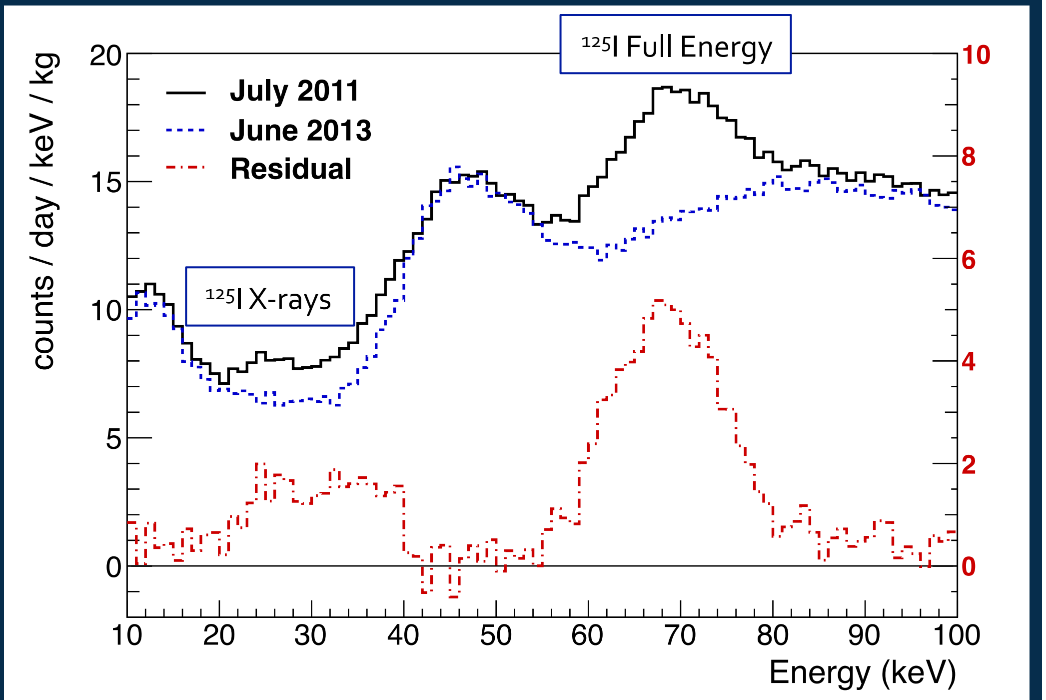




^{125}I in DM–Ice17 Spectrum

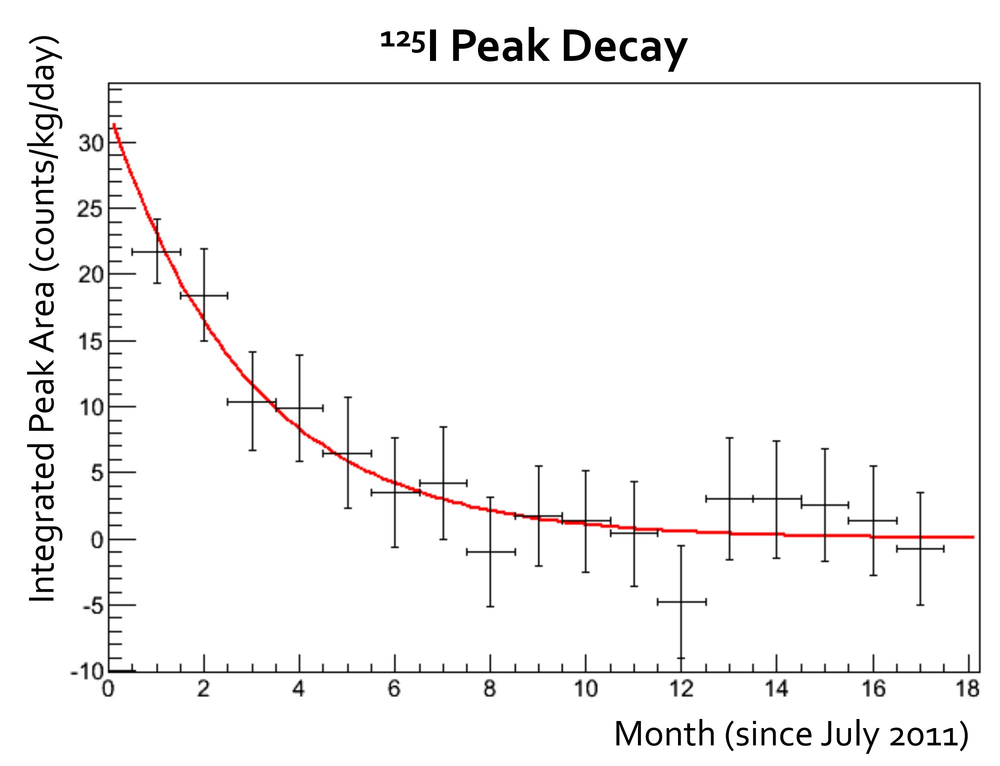
- ^{125}I ($t_{1/2}$ = 59.4 days) is good candidate for search in early data months





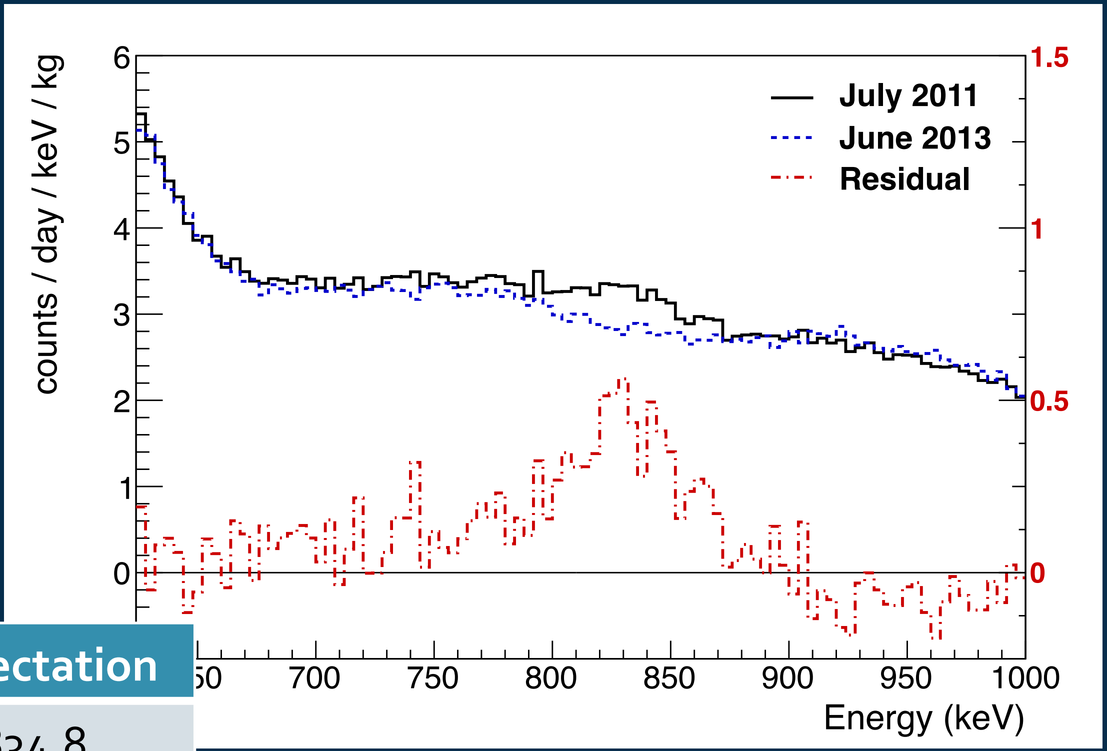
^{125}I Peak Decay

- $\lambda = 0.3500 \pm 0.0157$ month^{-1}
  - $t_{1/2} = 59.41 \pm 2.66$ days
  - (59.4 days)
- Deploy activity:
  - 1151 ± 118 cpd/kg



^{54}Mn in DM-Ice17 data

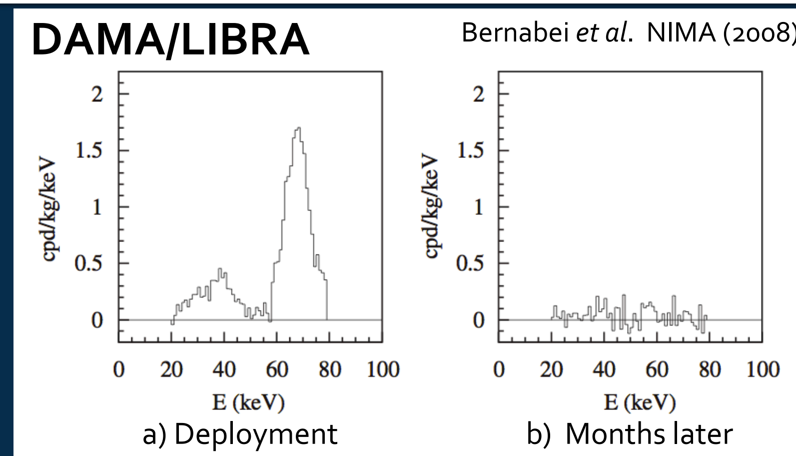
- γ-line expected from ^{54}Mn
  - E_γ = 835 keV
  - $t_{1/2}$ = 312.03 days

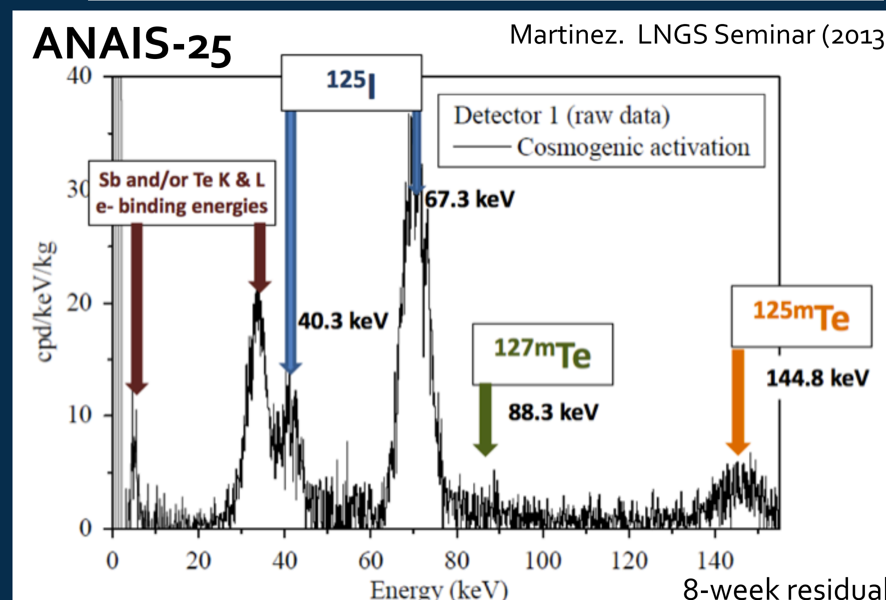


	Fit	Expectation
Energy (keV)	836.1 ± 3.0	834.8
Sigma (keV)	36.9 ± 3.7	23.3
Deploy Rate (decays/day)	51,700 ± 6,500	135,800

Other NaI Experiments

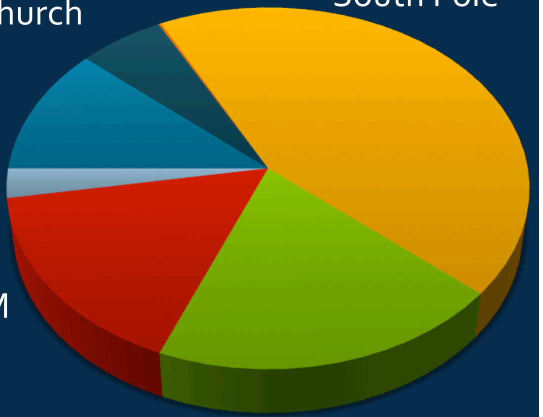
- Both ANAIS and DAMA observe ^{125}I peak
- ANAIS also looking into presence of other NaI cosmogenics (esp. Te states)





Cosmogenic Mitigation at Pole

- Time on surface at South Pole can be most damaging stage for cosmogenics:



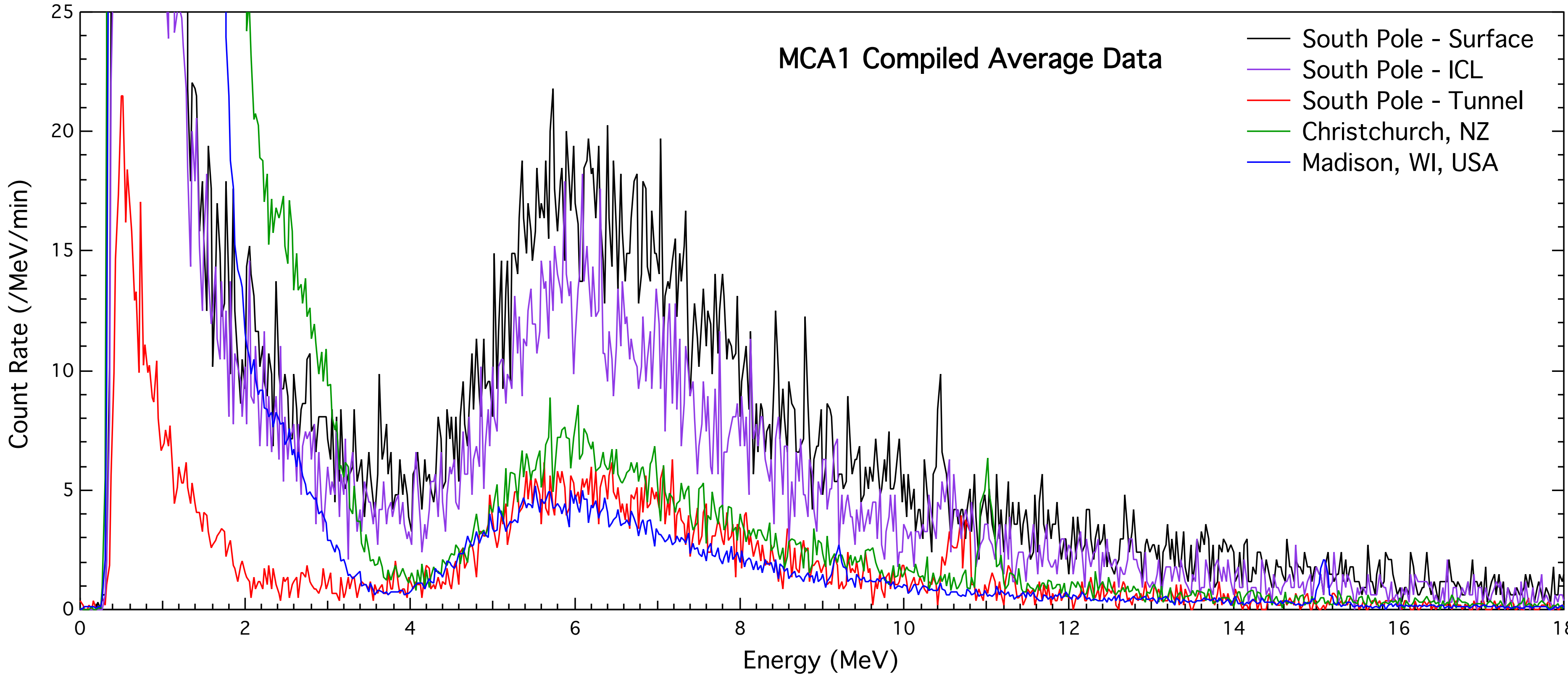
South Pole is topographically flat and station buildings provide minimal overburden

Tunnel Storage

- 40-50 ft firn overburden
  - ~ 10 m.w.e.
  - ~ 30% of surface muon rate

Muon Flux Reduction

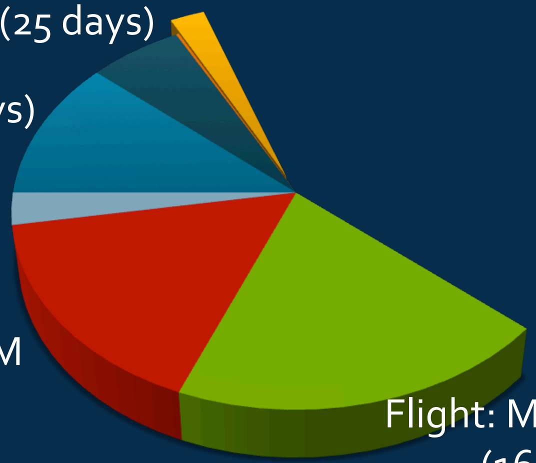
- Muon spectra comparison of South Pole sites with Christchurch and Madison data



Muon Flux

Location	Elevation (ft)	Relative Intensity*
South Pole - Surface	9190	2.60
South Pole – ICL	9190	1.89
South Pole – Tunnel	9190	0.795
Christchurch, NZ	120	1.00
Madison, WI, USA	880	0.669

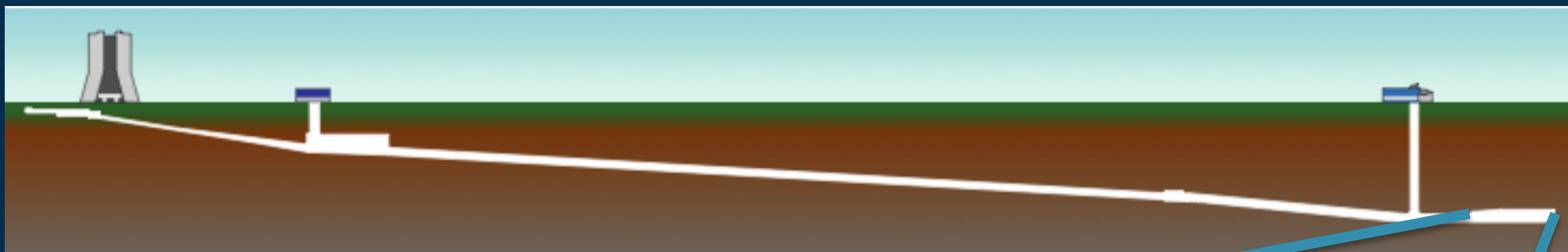
*Relative to Christchurch – approximately sea level



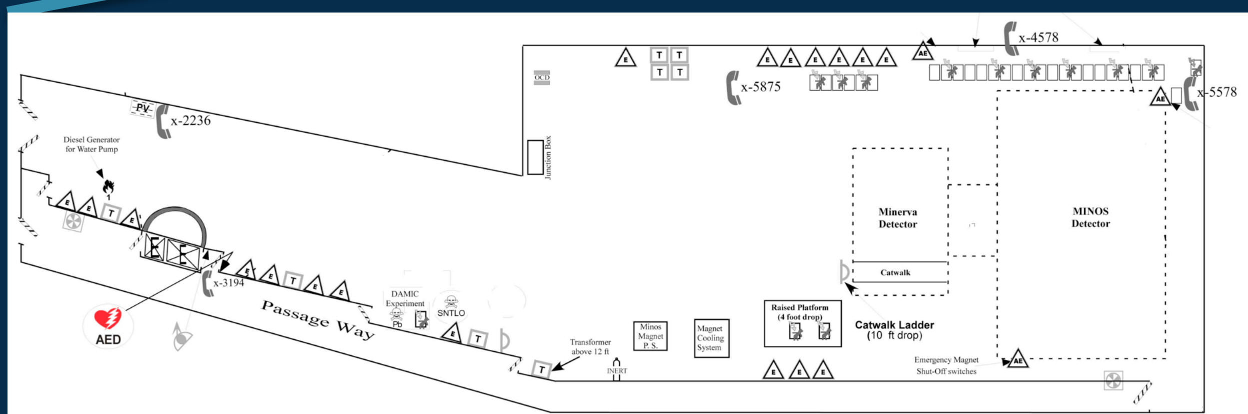
Towards DM-ICE: Crystal Growing

- Growing crystals with Alpha Spectra Inc. (Grand Junction, CO) for next phase
  - 4,600 ft above sea level
- What cosmogenic products can we measure in these crystals?

MINOS Underground @ FNAL

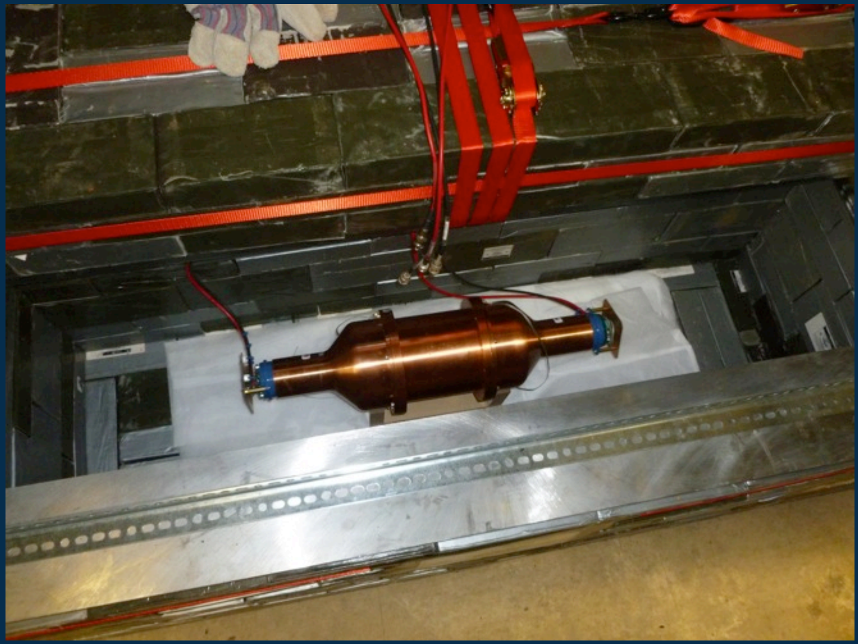


- 330 ft overburden



Fermilab Test Setup

Test Crystal in Castle



Castle (closed) with DAQ

Cosmogenic Outlook

- Cosmogenics allow energy calibration in 50 – 1000 keV range
- Testing underway to investigate cosmogenic effect on next-phase DM-ICE