First Data from DM-Ice17, Prospects for DM-Ice

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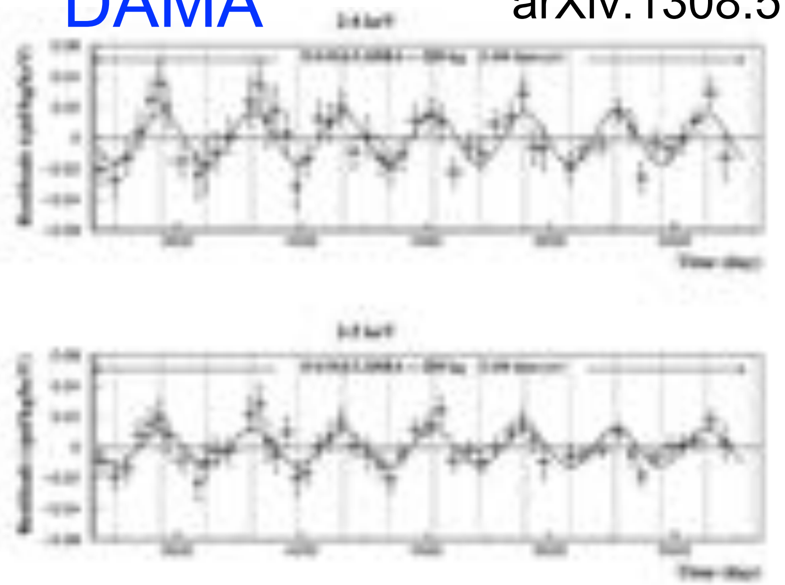
on behalf of the DM-Ice Collaboration

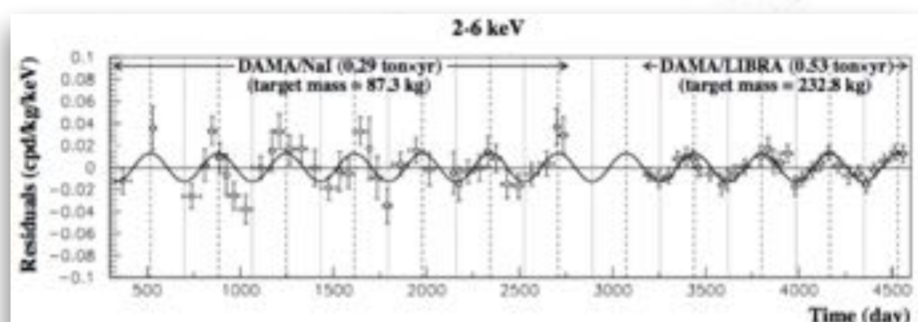
IBS Mini Workshop on Direct Search of Dark Matter
July 7, 2015
Daejeon, Korea

Dark Matter Signal or Background?

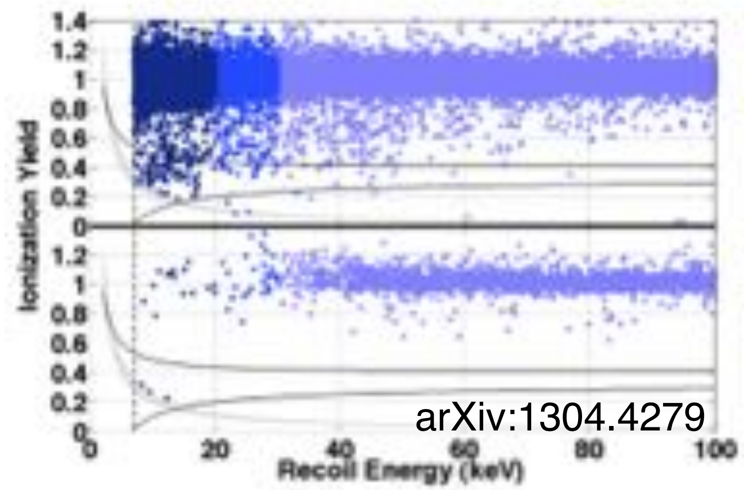
DAMA

arXiv:1308.5109



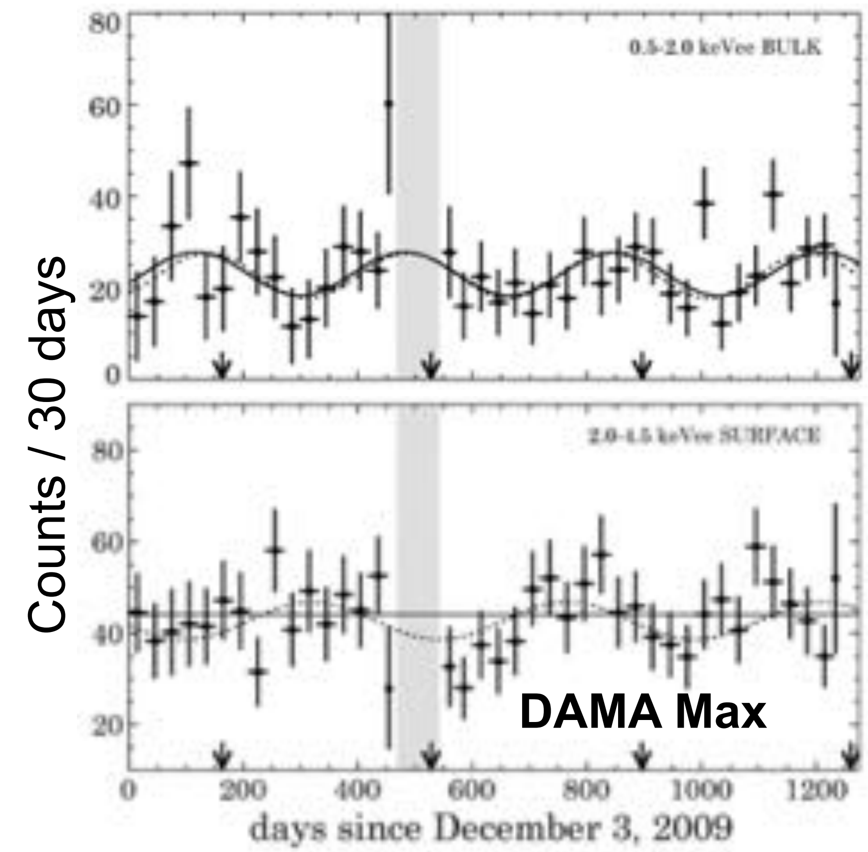


CDMS-Si



arXiv:1304.4279

CoGeNT



arXiv:1401.3295

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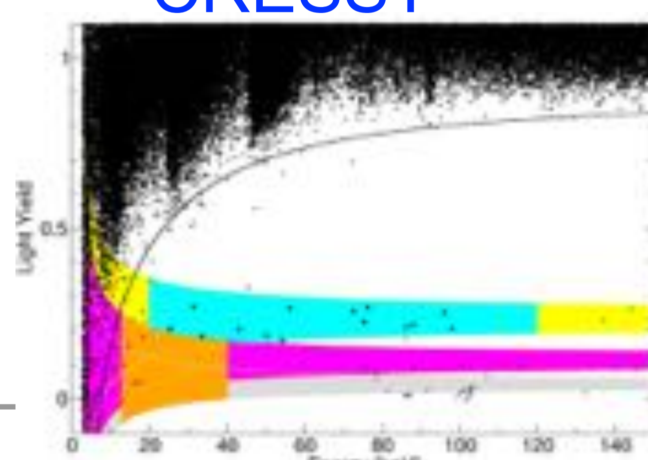
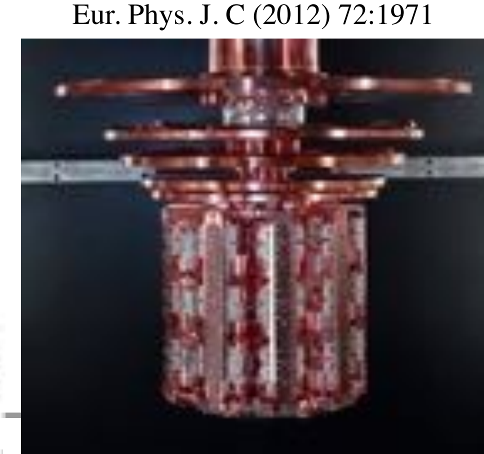


Eur. Phys. J. C (2012) 72:1971



A World of Dark Matter Searches

Annual Modulation Dark Matter Searches with NaI Detectors

Northern Hemisphere	Gran Sasso **DAMA/Libra** 250kg running	Y2L **KIMS** ~200kg	Gran Sasso **SaBRE** R&D	Canfranc **ANAIS** 250 kg	Kamioka **KamLAND-PICO**
Southern Hemisphere	South Pole **DM-Ice** 17 kg running R&D for 250 kg		Stawell Mine, Australia **SaBRE** R&D, lab ready ~ 2018		ice rock

Several Groups conducting ultra-pure crystal with several vendors to go to the full scale

DM-Ice:

- NaI dark matter search in an entirely different environment
- South Pole offers:
  - Ultra-clean and ultra-stable environment
  - Seasonal variation unambiguously different from dark matter modulation
  - IceCube offers muon monitoring and veto as well as experience
  - NSF-run South Pole Station for logistical support

Phased Program for DM-Ice

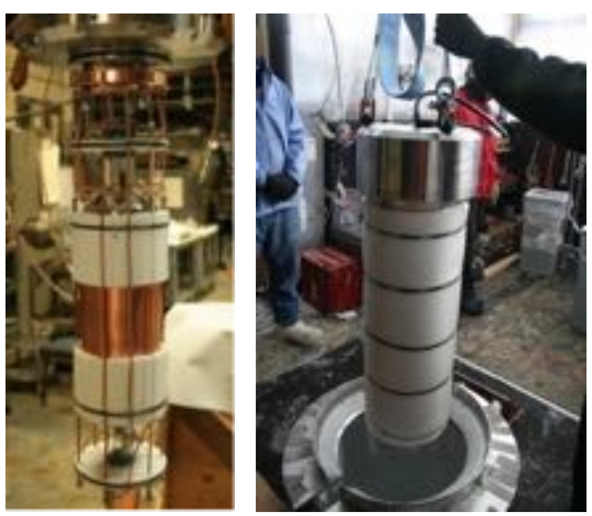
Directly test DAMA's assertion that the observed annual modulation is due to dark matter & understand its origin

- probes longest-standing dark matter claim
- NaI(Tl) target
- aims to understand origin of DAMA's signal
- only experiment with access to both Northern & Southern Hemispheres

DM-Ice 37 North

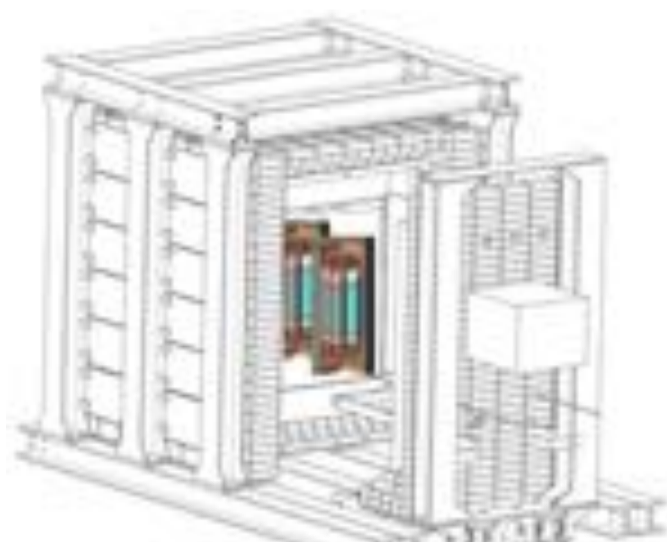
A Phased Experimental Program

DM-Ice17



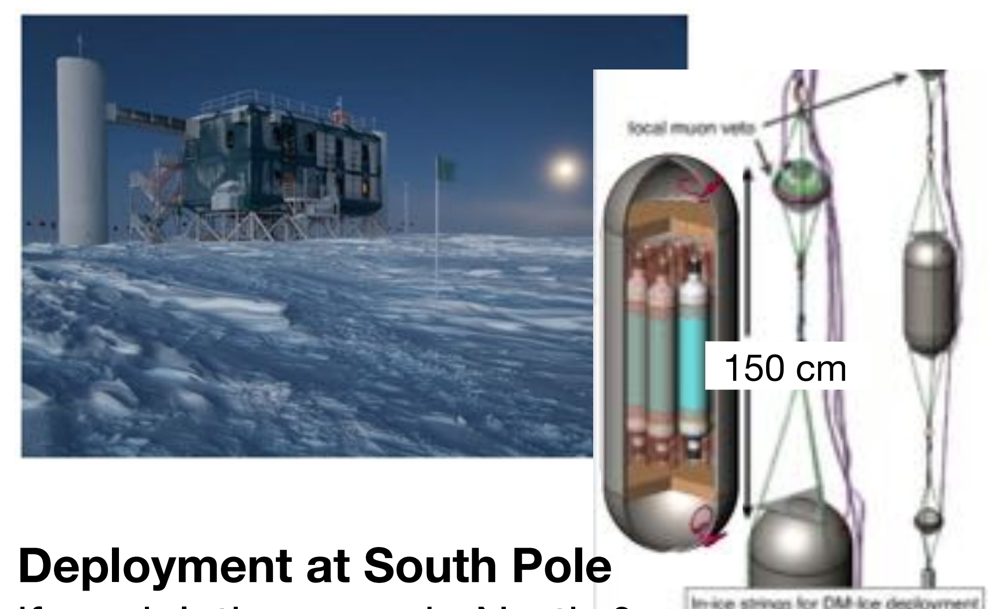
Operating since 2011
17 kg of NaI(Tl) at 2450m depth at South Pole

DM-Ice 250 North



Northern Hemisphere Run
portable 250 kg NaI(Tl) detector, first deployment in the Northern Hemisphere

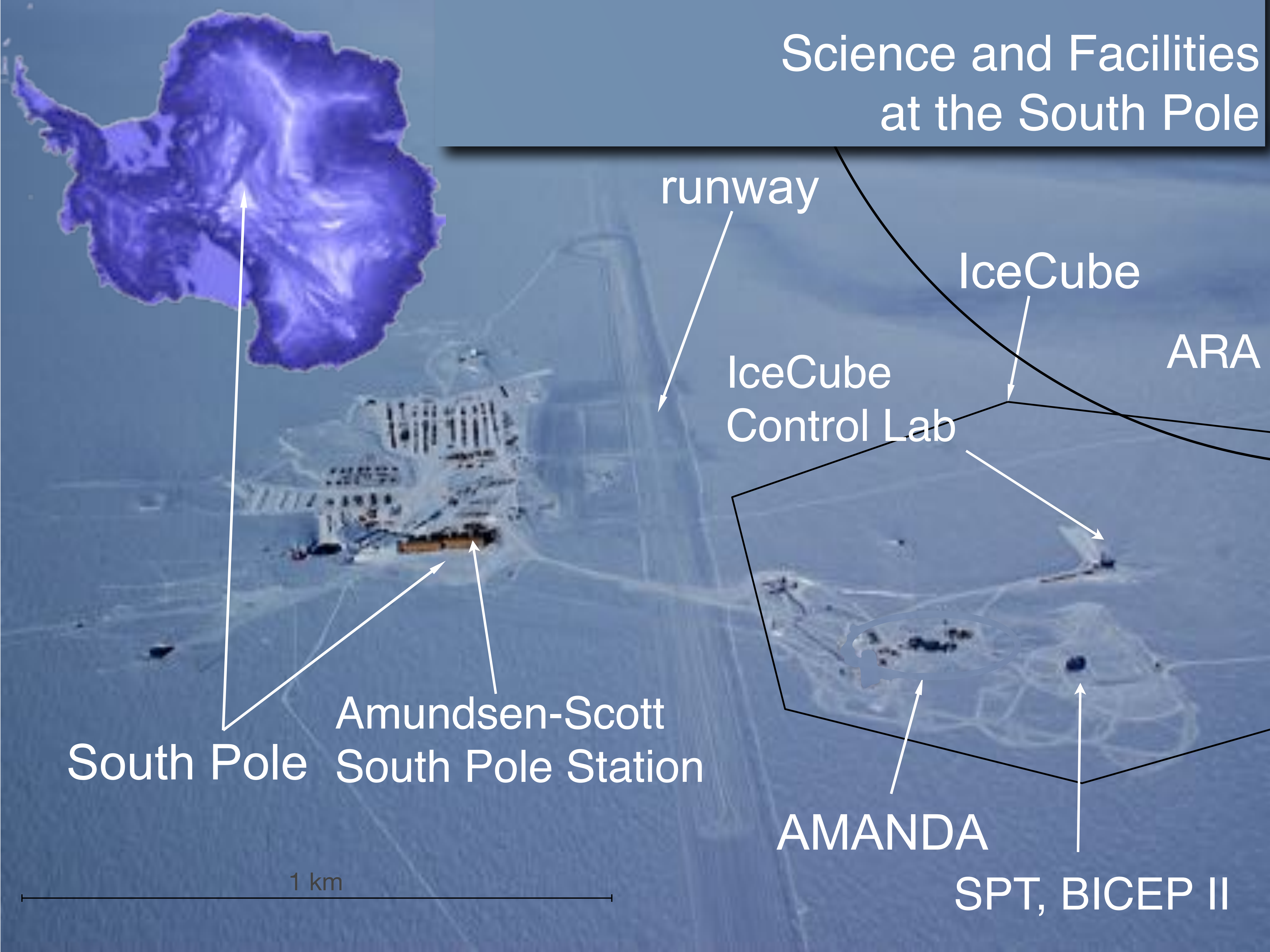
DM-Ice 250 South



Deployment at South Pole
if modulation seen in North & ice drilling becomes available

see also Cherwinka *et al.* Astroparticle Physics **35** (2012) 749

Science and Facilities at the South Pole



Advantages of South Pole

- Same dark matter signal in both hemispheres
- Seasonal variation reversed in phase
  - Muon tagging with IceCube/DeepCore
  - Spallation neutrons moderated by ice
- Overburden: 2450 m ice (2200 m.w.e.)
  - Clean Ice
    - ppt $^{238}U/^{232}Th$, ppb ^{40}K
  - Enclosed space
- Stable environment under ice
- Support infrastructure of Amundsen-Scott South Pole Station

see also Cherwinka *et al.*
Astroparticle Physics **35** (2012) 749

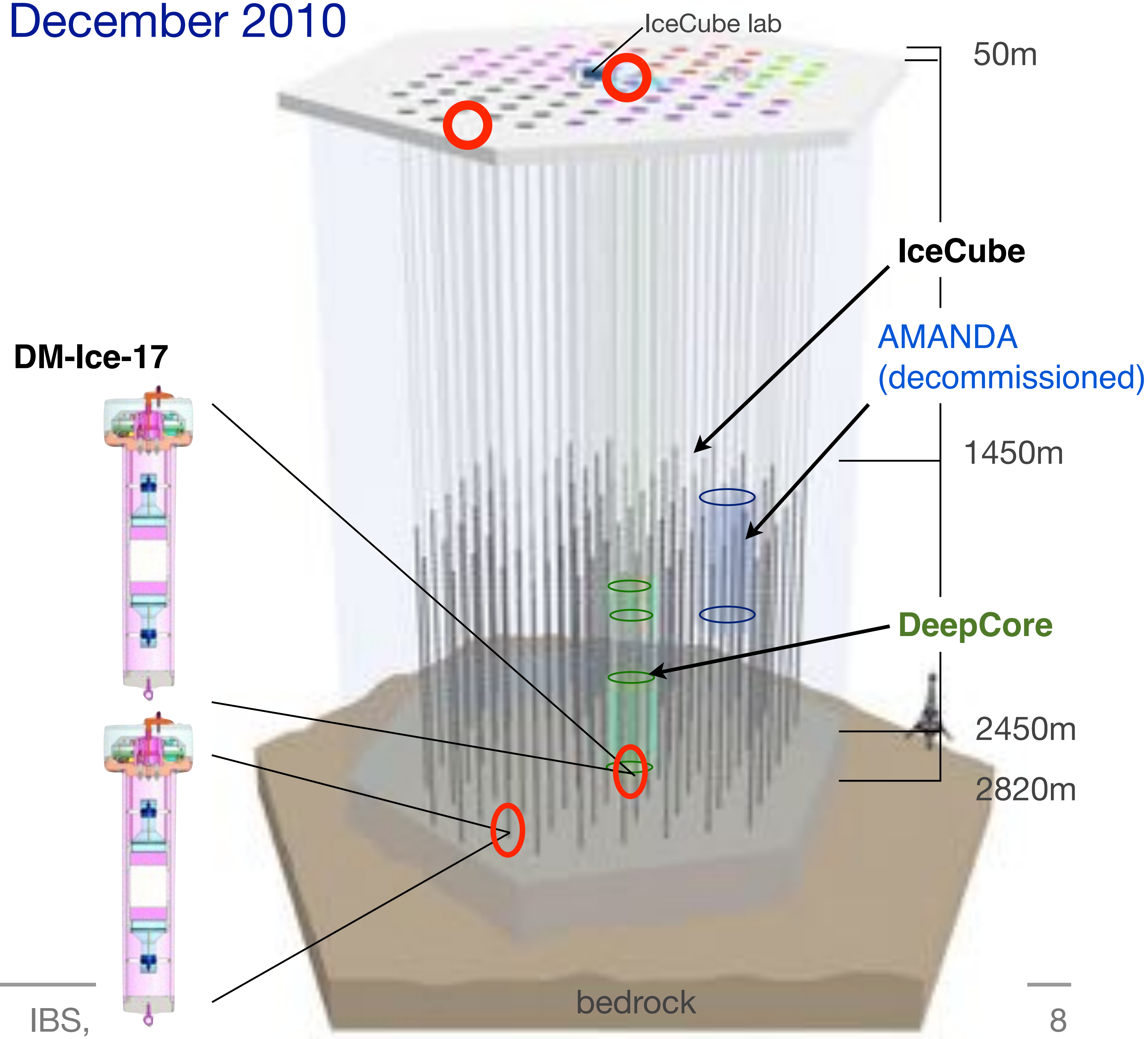
DM-Ice17: An NaI Detector in IceCube/DeepCore

Deployed at the South Pole in December 2010

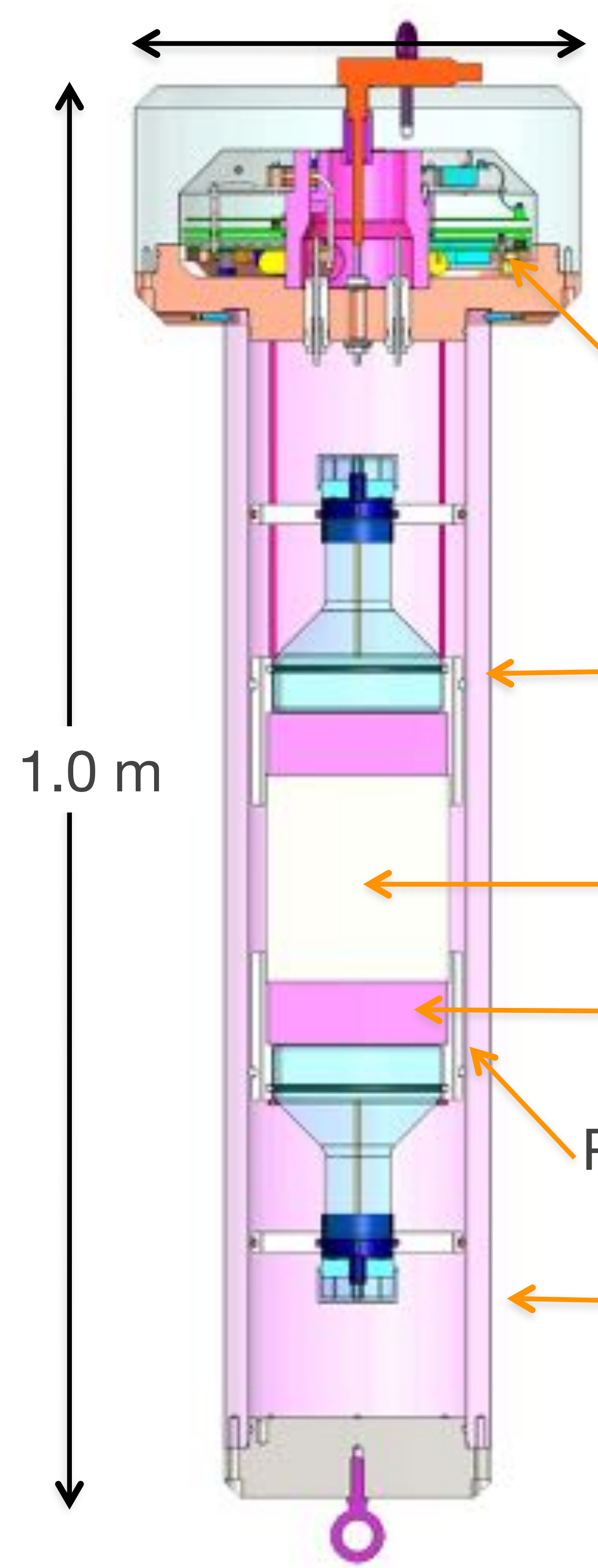
- A 17 kg NaI detector
- Operation since Feb. 2011
- Data run from June 2011

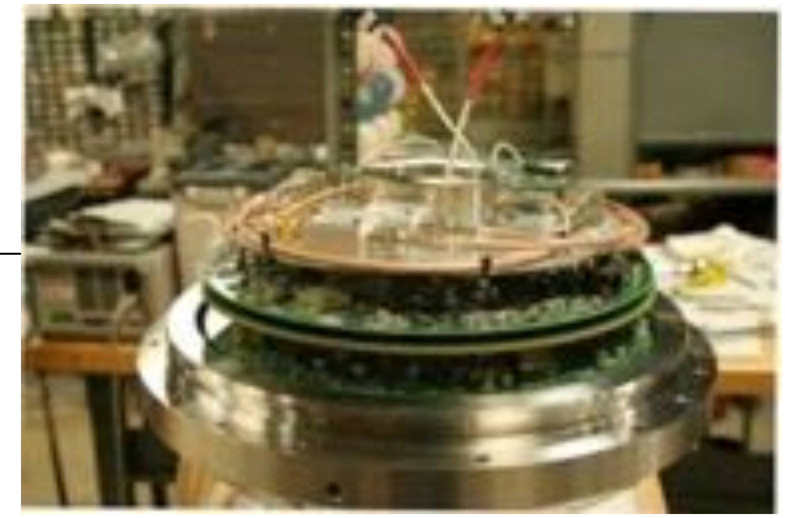
Demonstrated:

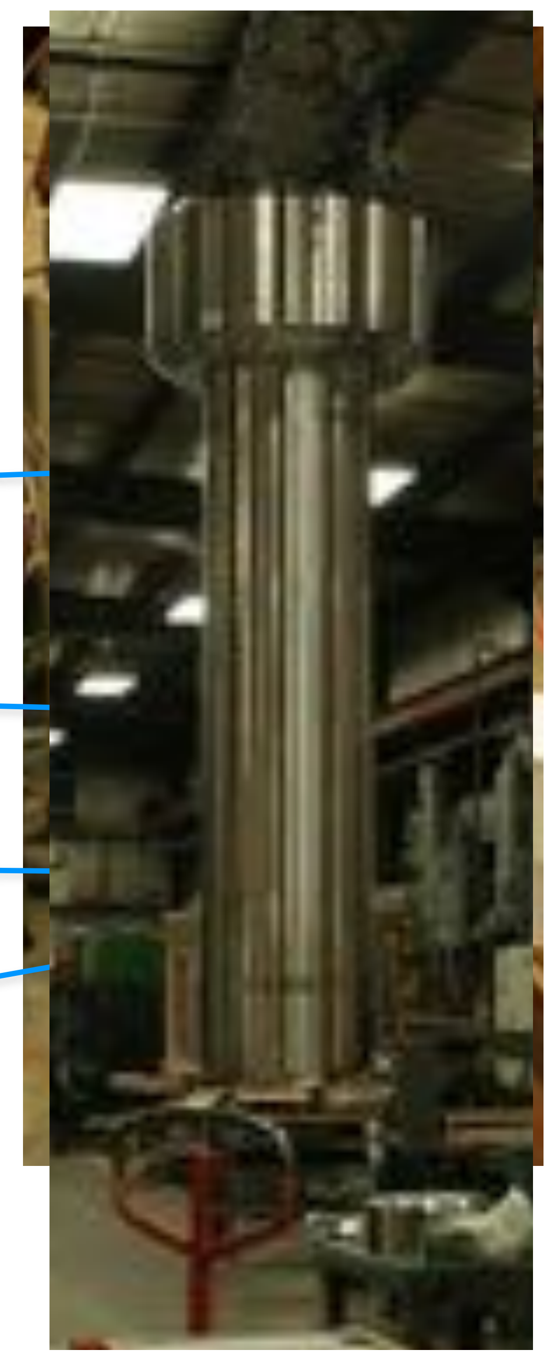
- Feasibility of deploying a remotely-operable dark matter detector in the Antarctic Ice
- Stability of the environment
- Radiopurity of the antarctic ice / hole ice
- Explore the capability of IceCube to veto muons



DM-Ice-17 Detector







2 IceCube mainboards
+ HV control boards

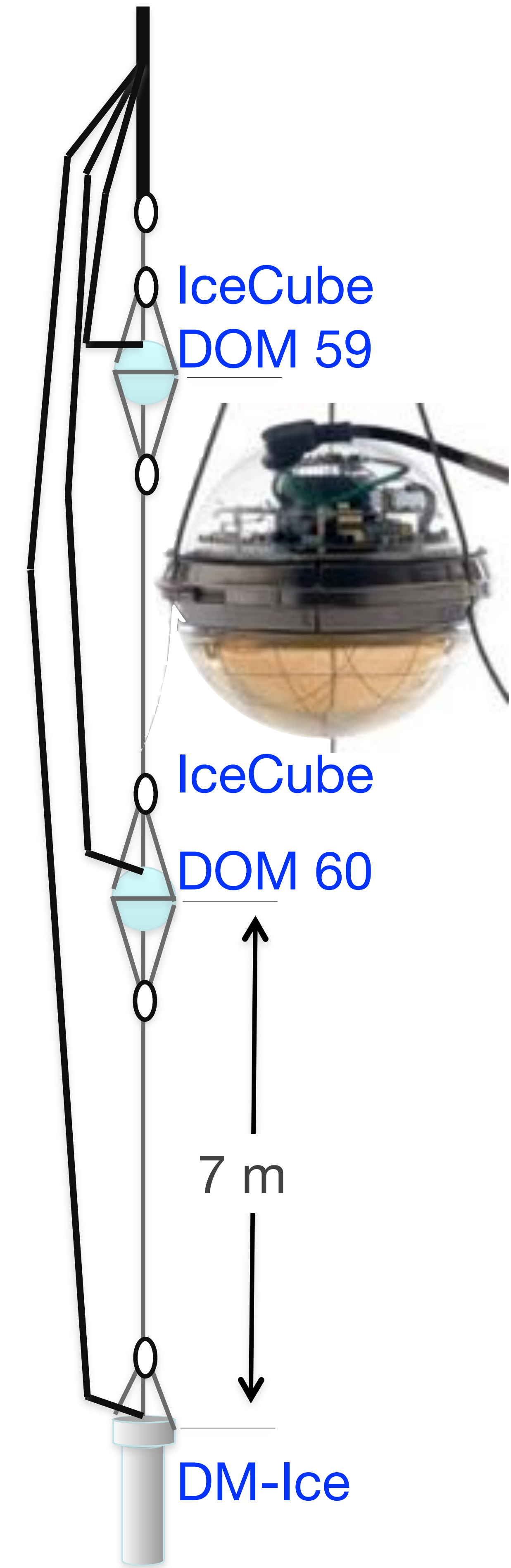
PMTs:
5” ETL 9390UKB

NAIAD NaI Crystal
(5”x5”, 8.5 kg)

quartz light guides

PTFE light reflectors

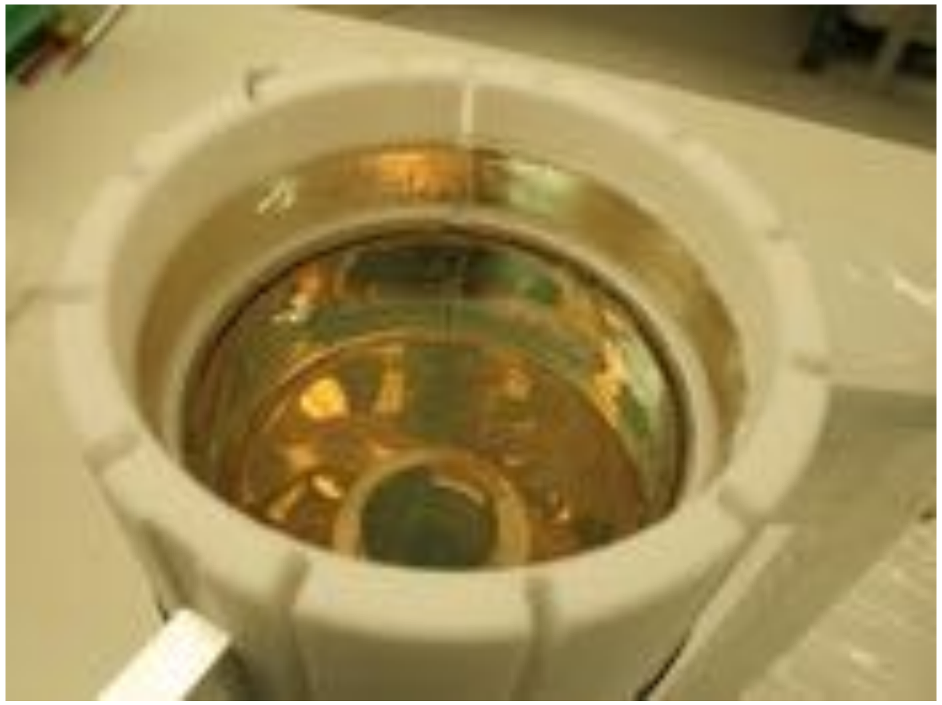
Stainless Steel
Pressure Vessel

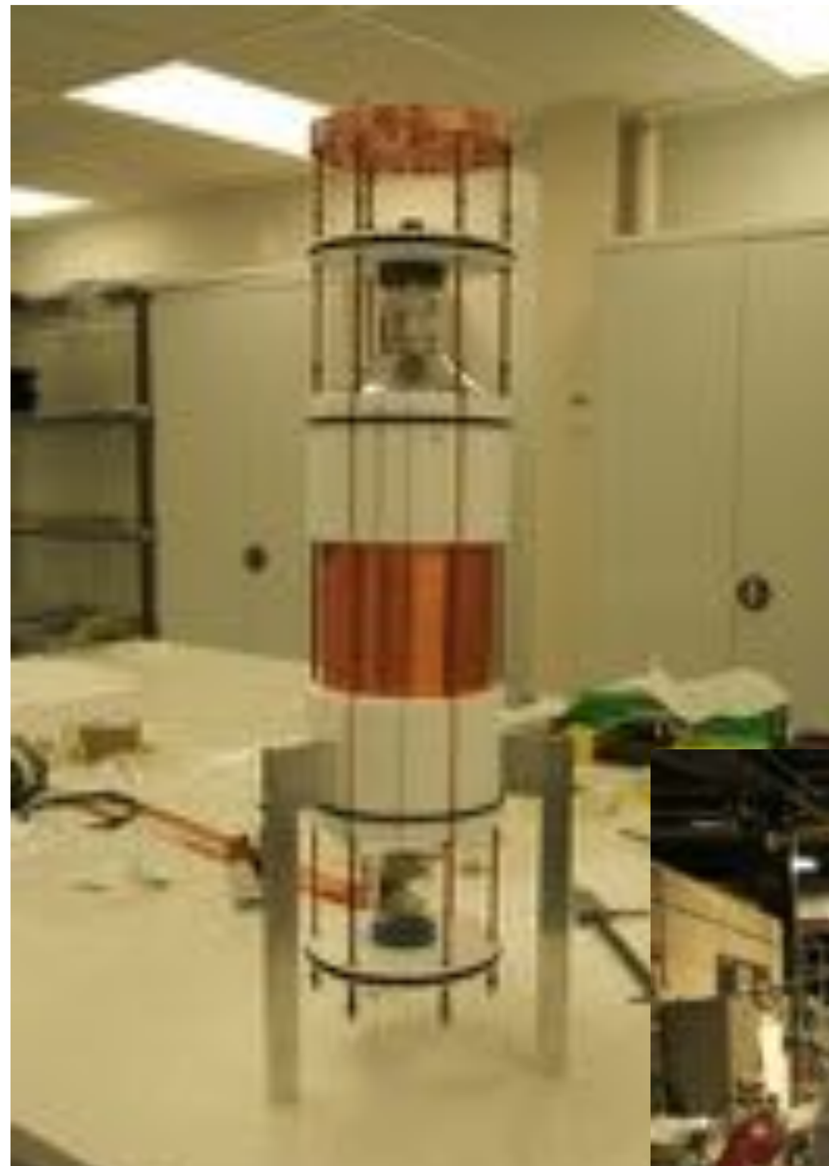


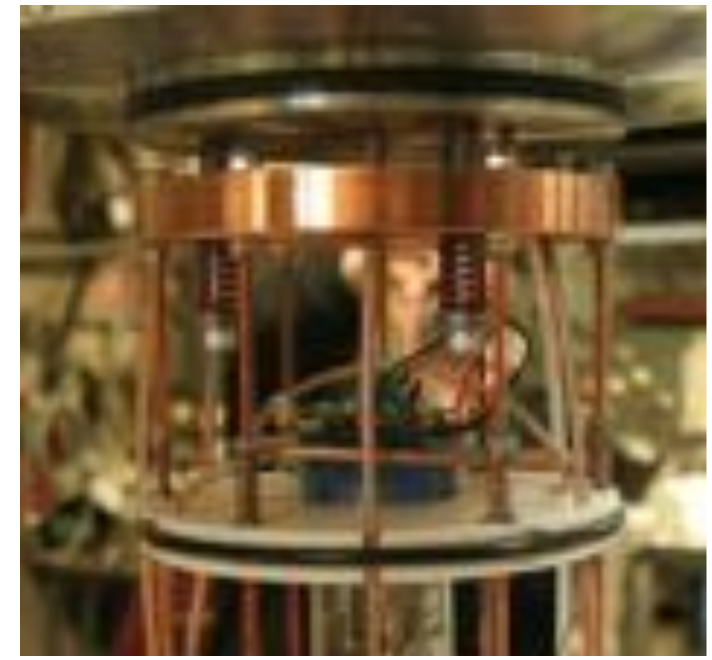
DM-Ice-17 Construction & Deployment

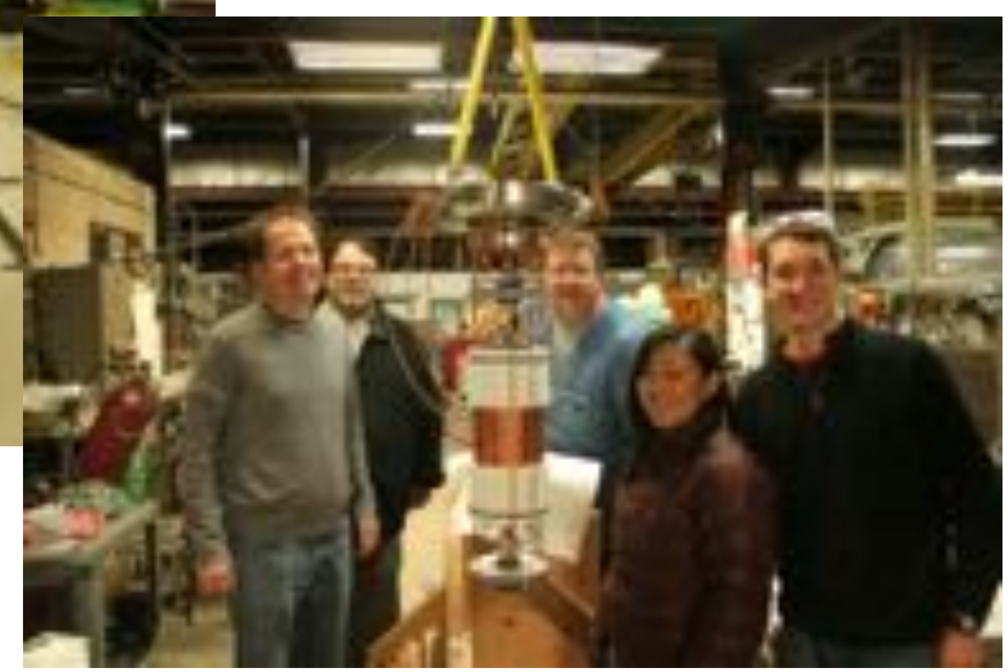
Design begin Feb. 2010

DM-ICE17 Assembly





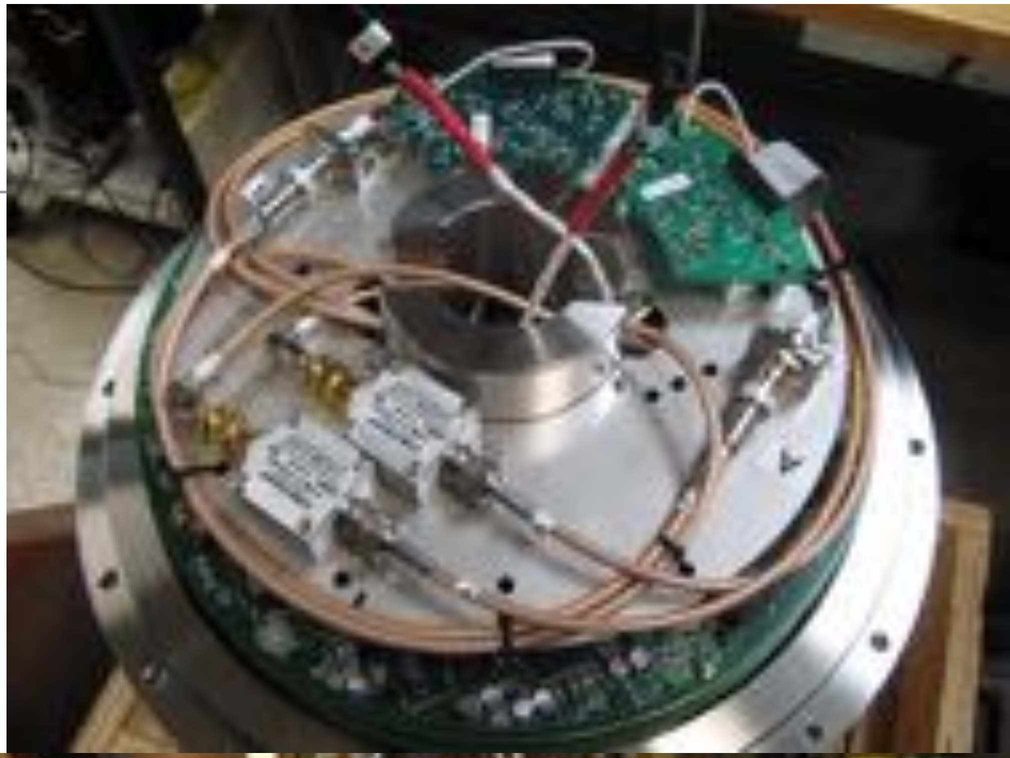




Pressure Vessel Testing

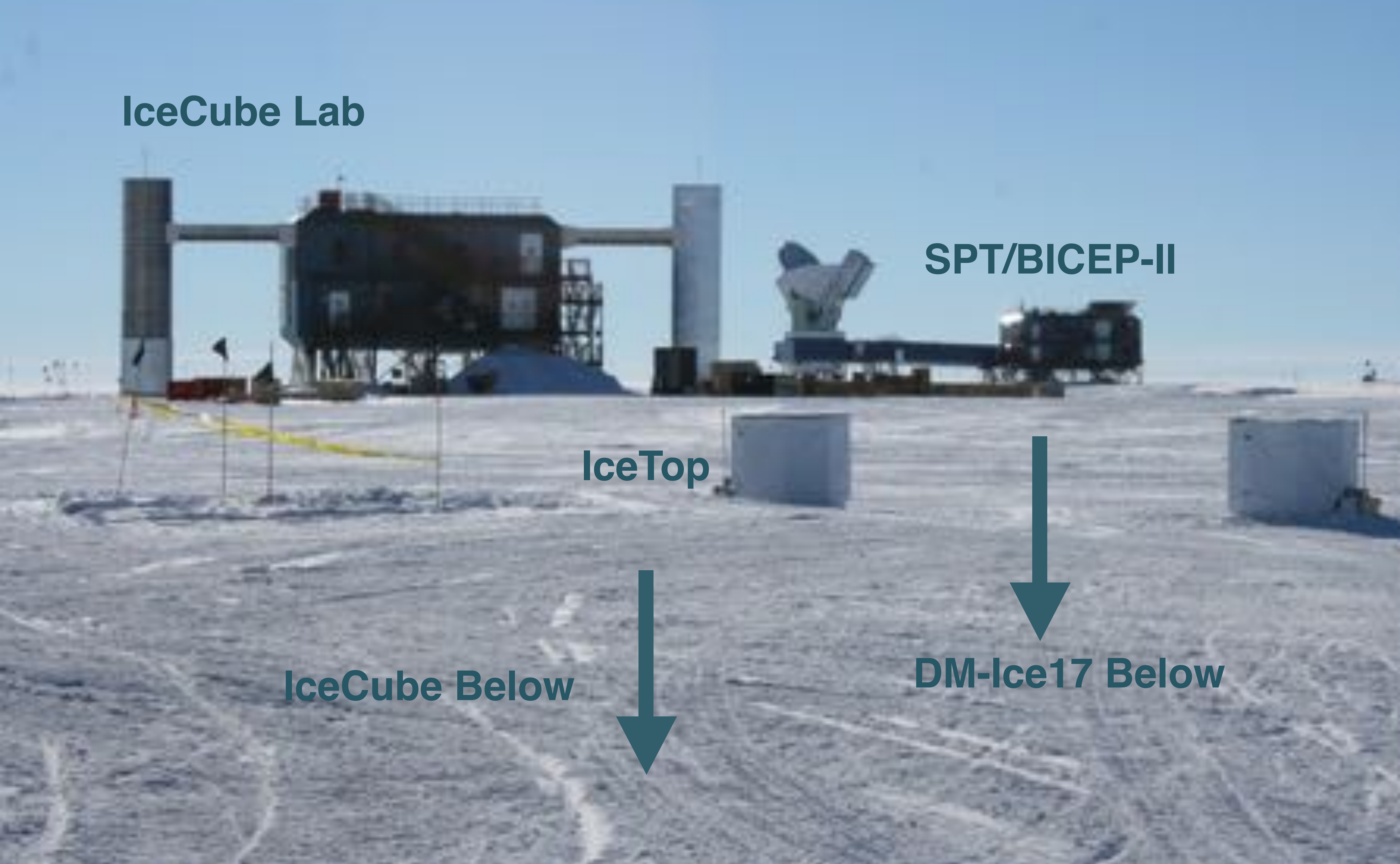
Integrity of steel pressure vessel tested against >7000 psi (freeze-in test)

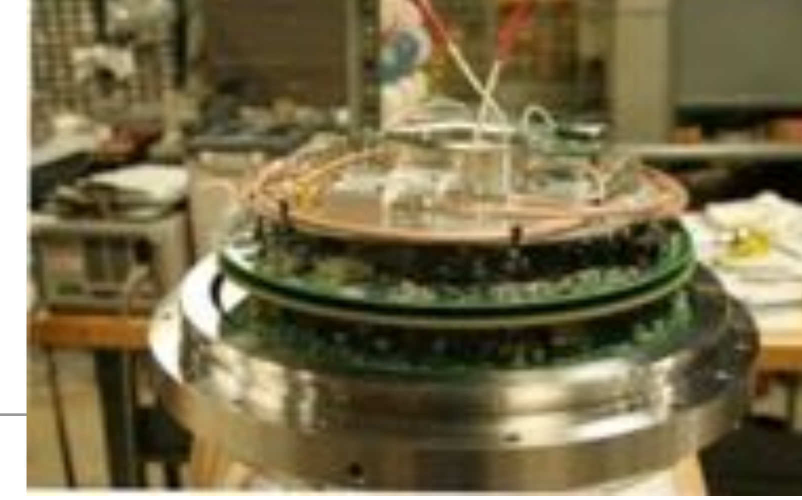
DM-ICE17 Assembly



Final assembly and wiring.
Lower volume purged with nitrogen and sealed from electronics.

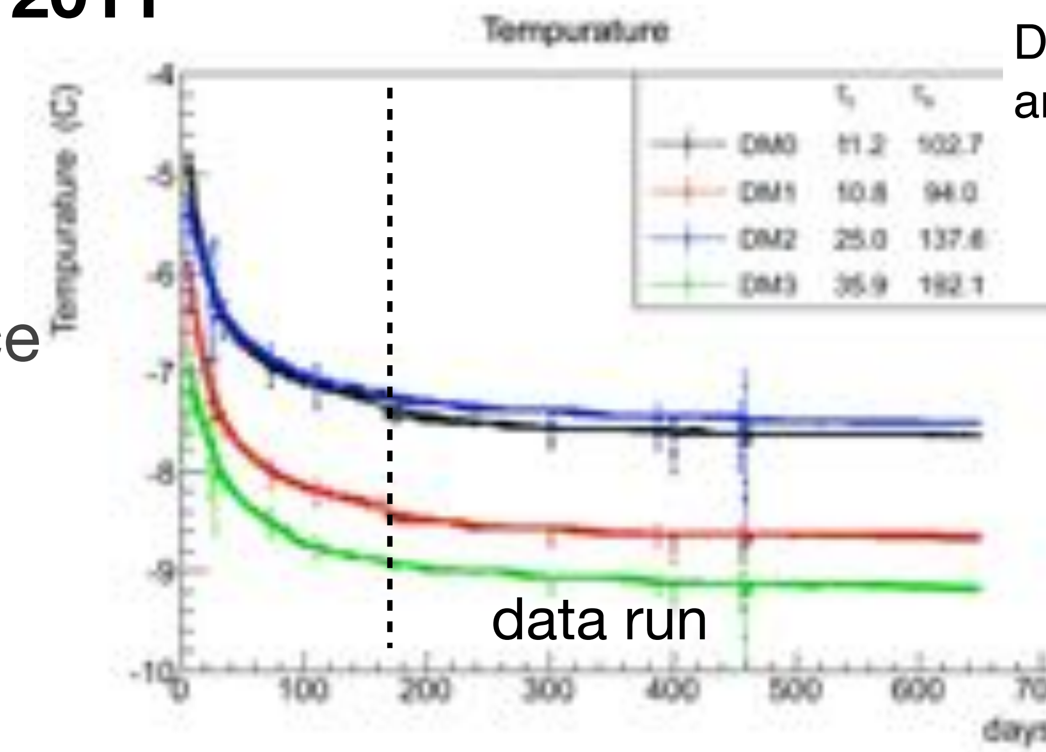
Data from DM-Ice17

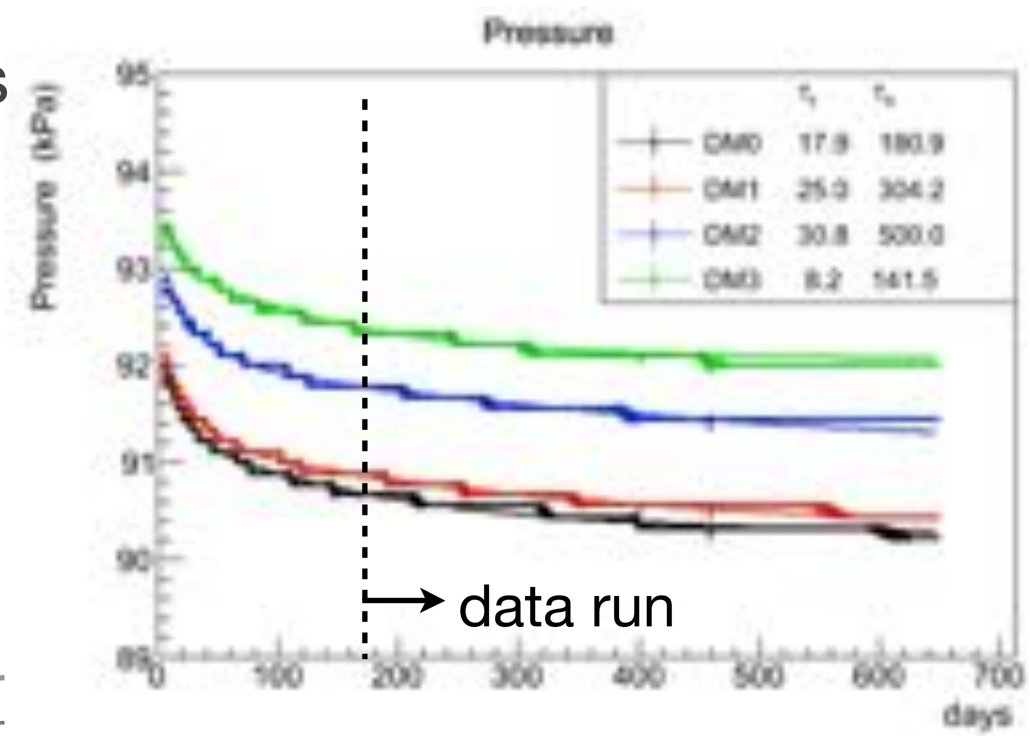




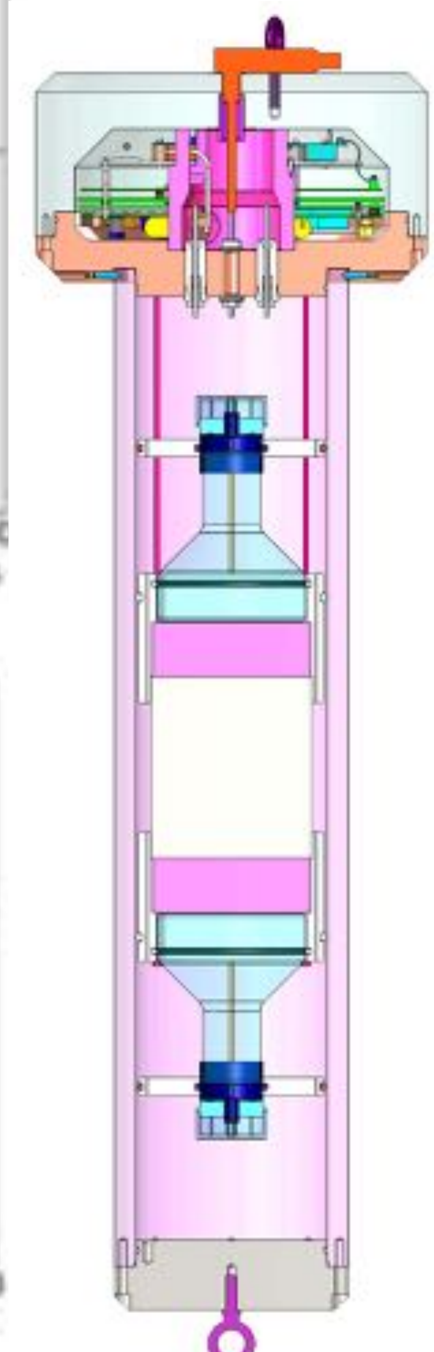
DM-Ice17: Detector Operations

- **Physics data taking since June 2011**
- Monitored quantities:
  - Temperature of the boards
    - ~10°C above surrounding ice
    - Fast (2-3 weeks) decrease during freeze-in
    - slower decrease over a few months after freeze-in
  - Pressure follows similar trend as temperature (ADC resolution limited)
- Values recorded every 2 sec. before March 2012. Every 60 sec. since March 2012.





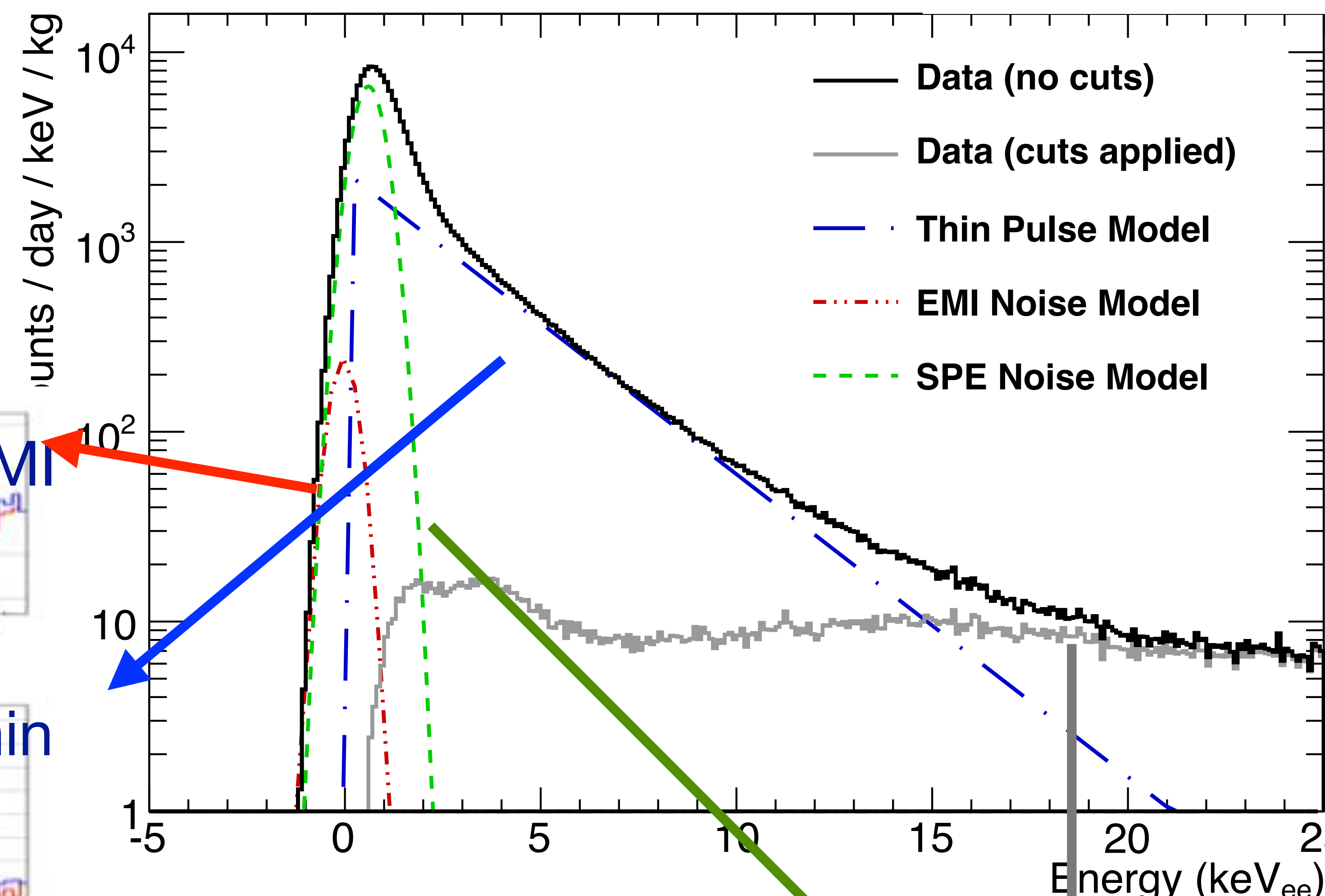
DM-Ice Collaboration
arXiv:1401.4804v1



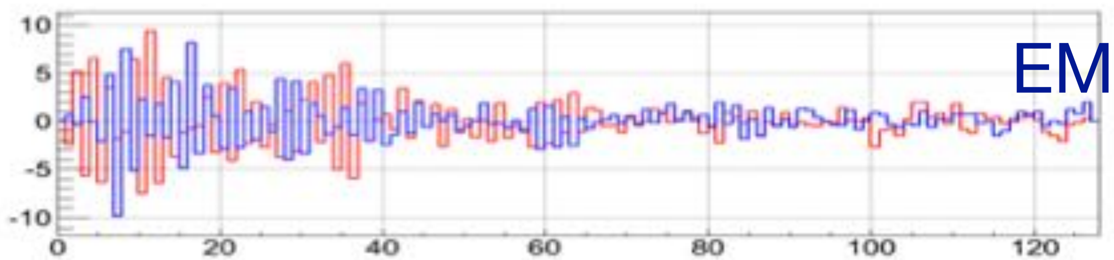
Low Energy Spectrum

- Spectrum below 10 keV dominated by “thin” pulses.
- Below 2 keV: combination of single-photoelectrons & electronics noise

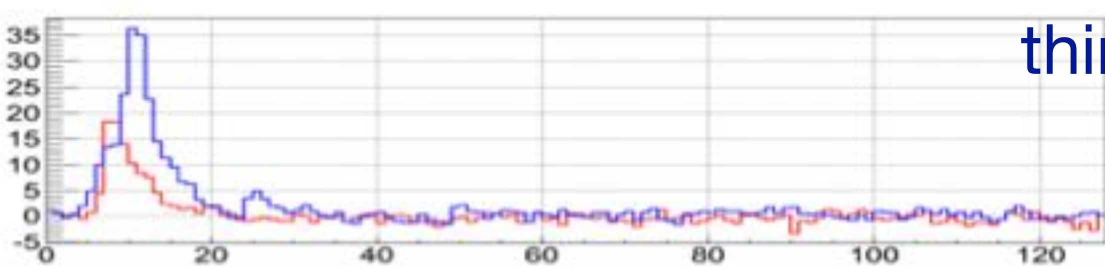
DM-Ice Collaboration
arXiv:1401.4804v1



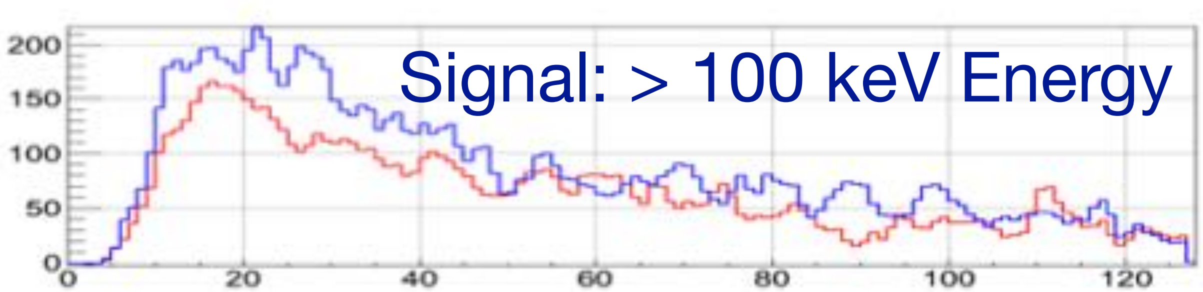
EMI



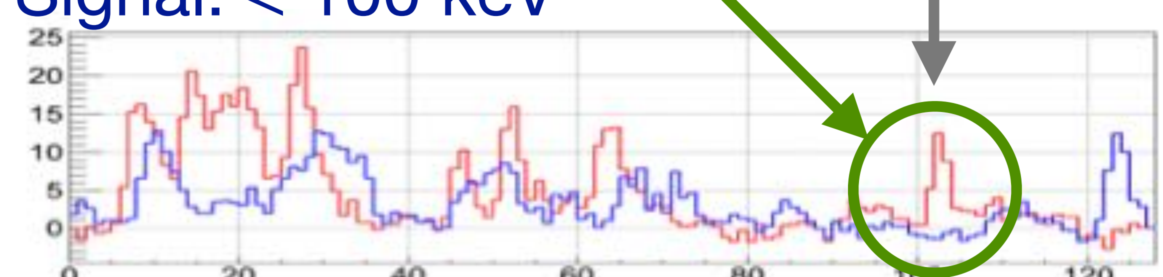
thin



Signal: > 100 keV Energy

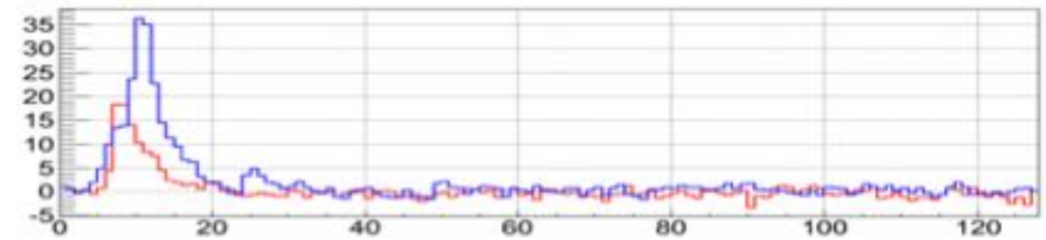


Signal: < 100 keV



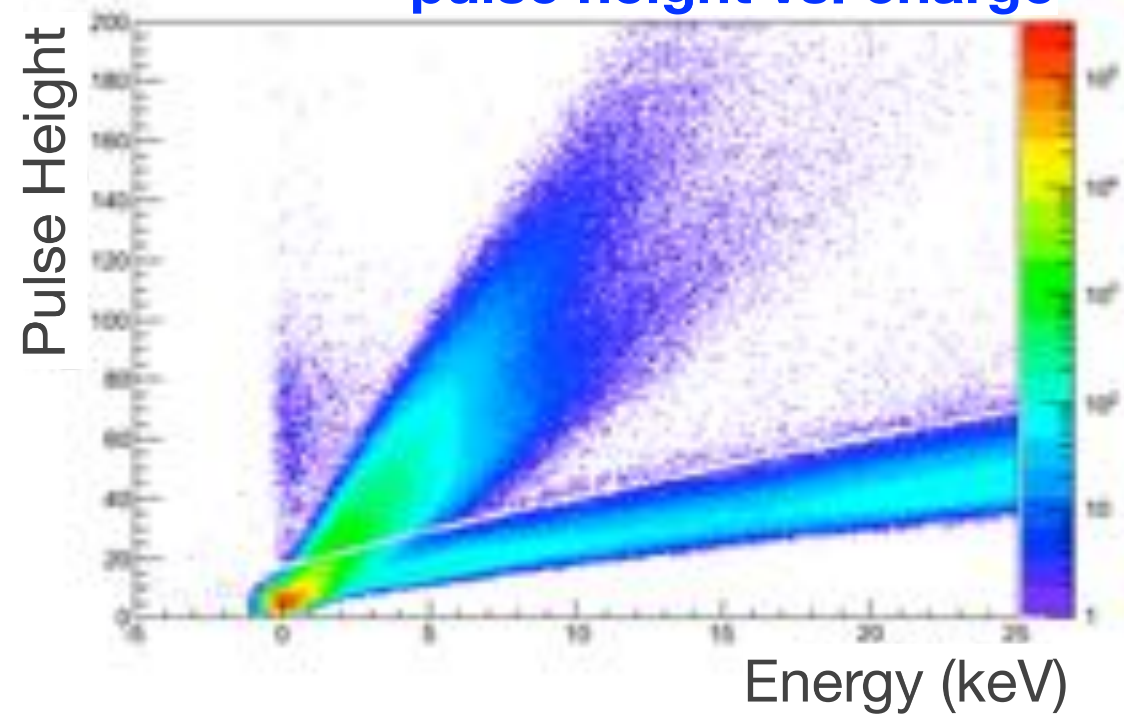
SPE

Event Selection: “Thin” pulses

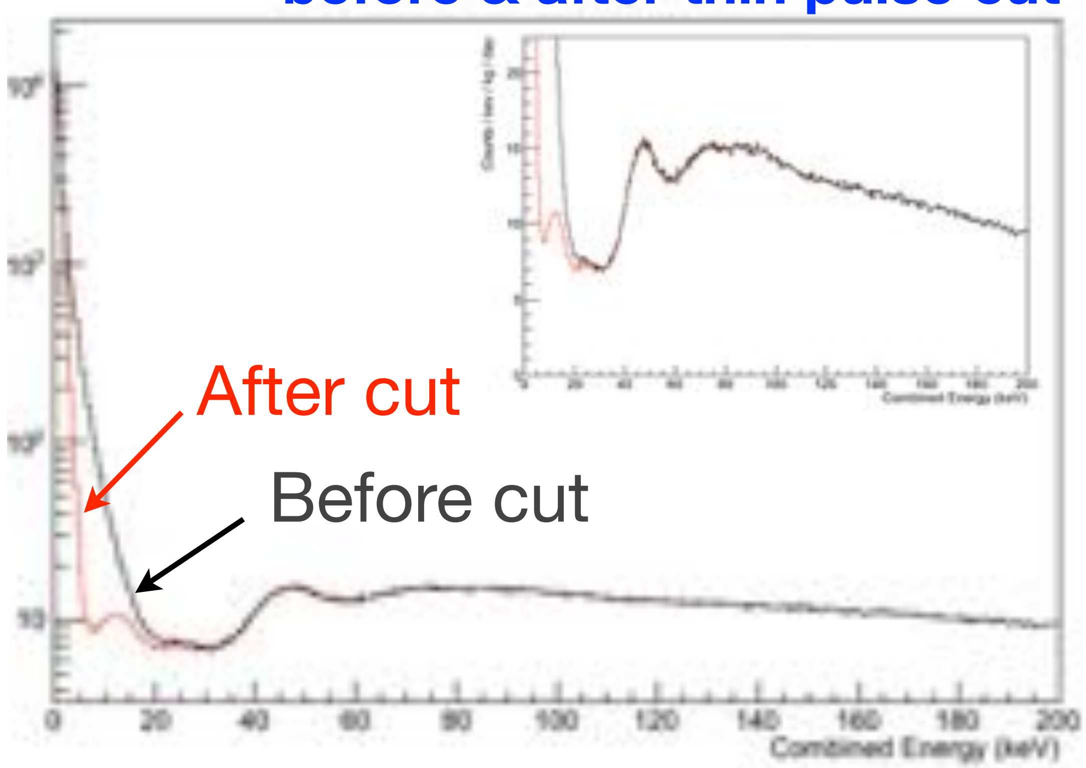


- Characteristics:
  - high pulse-height relative to charge
  - asymmetric between two PMTs
- 90% of events between 5-10 keV are “thin”
- Current cut effective above 7 keV

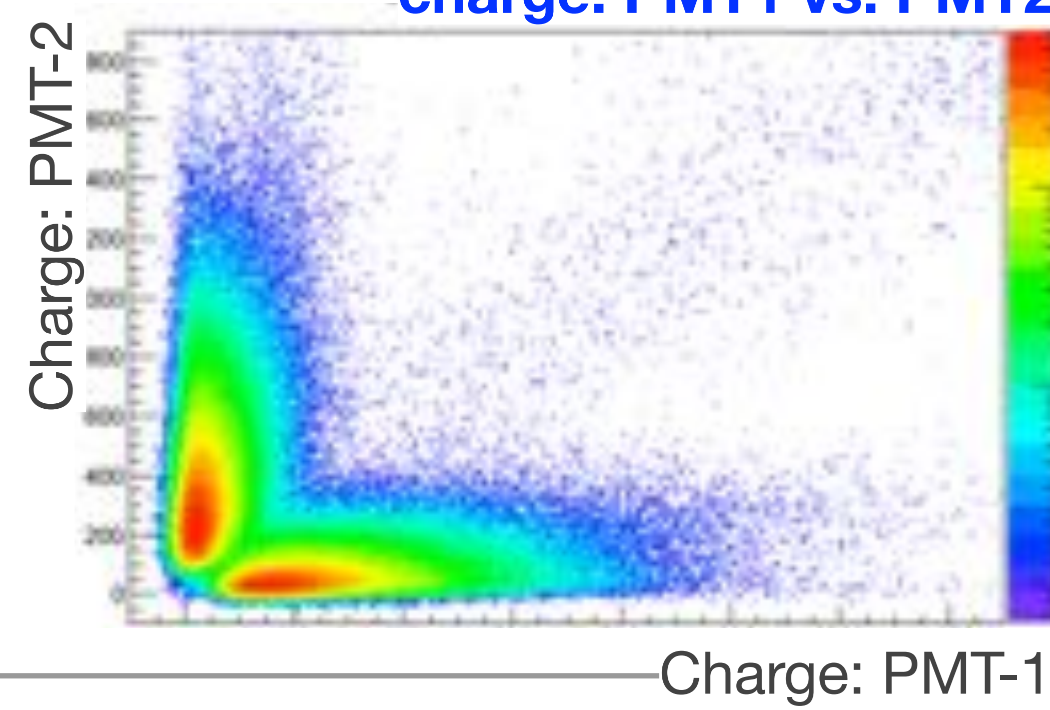
pulse height vs. charge



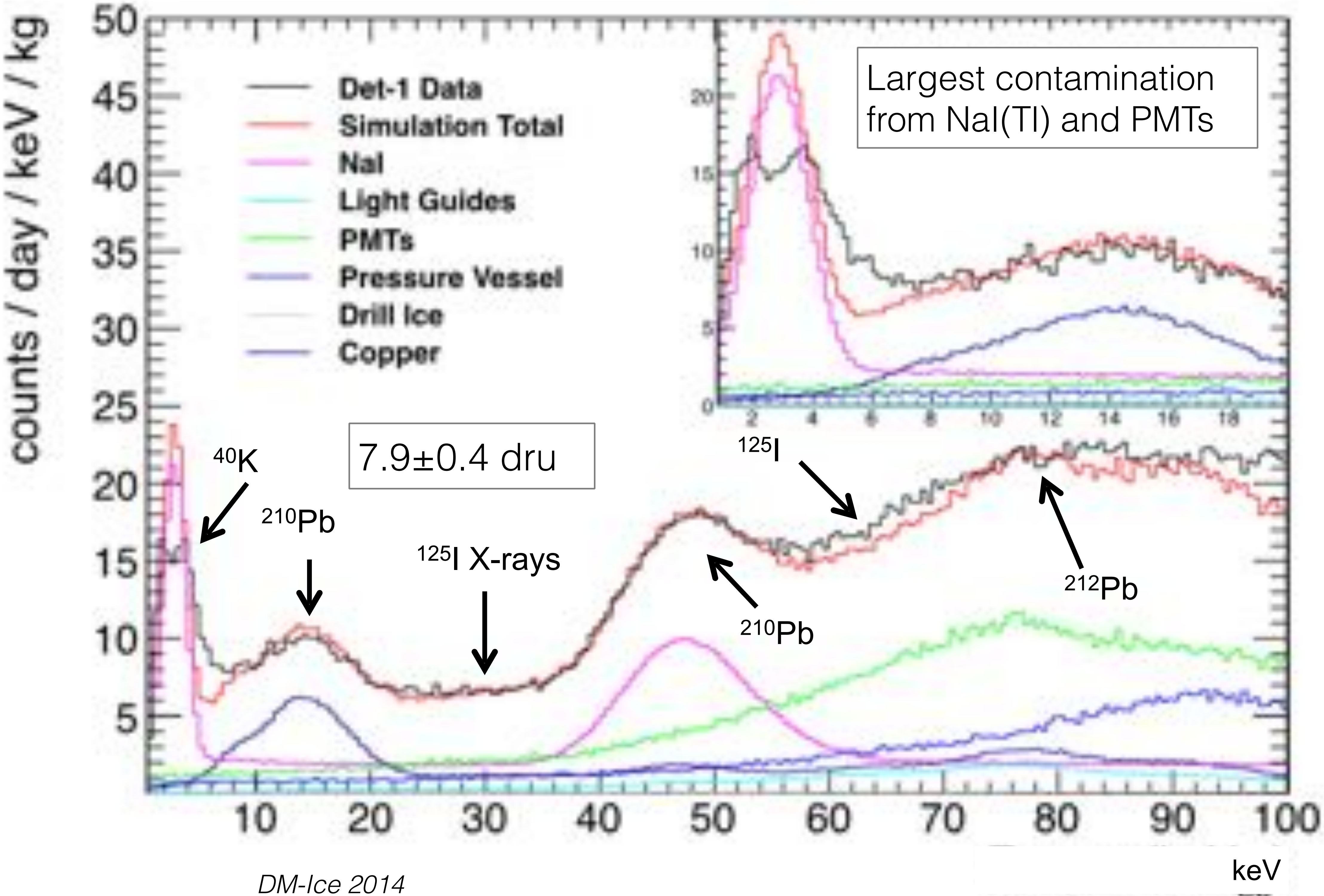
energy spectrum: before & after thin pulse cut



charge: PMT1 vs. PMT2



Low Energy Background Model

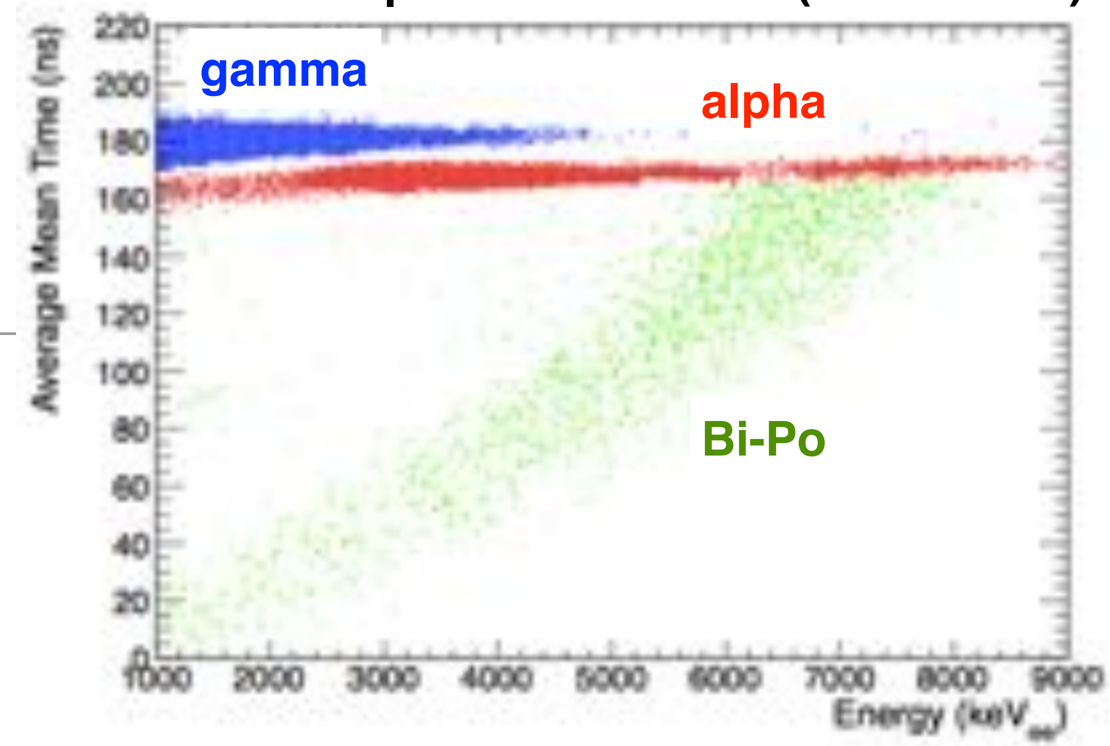


DM-Ice 2014

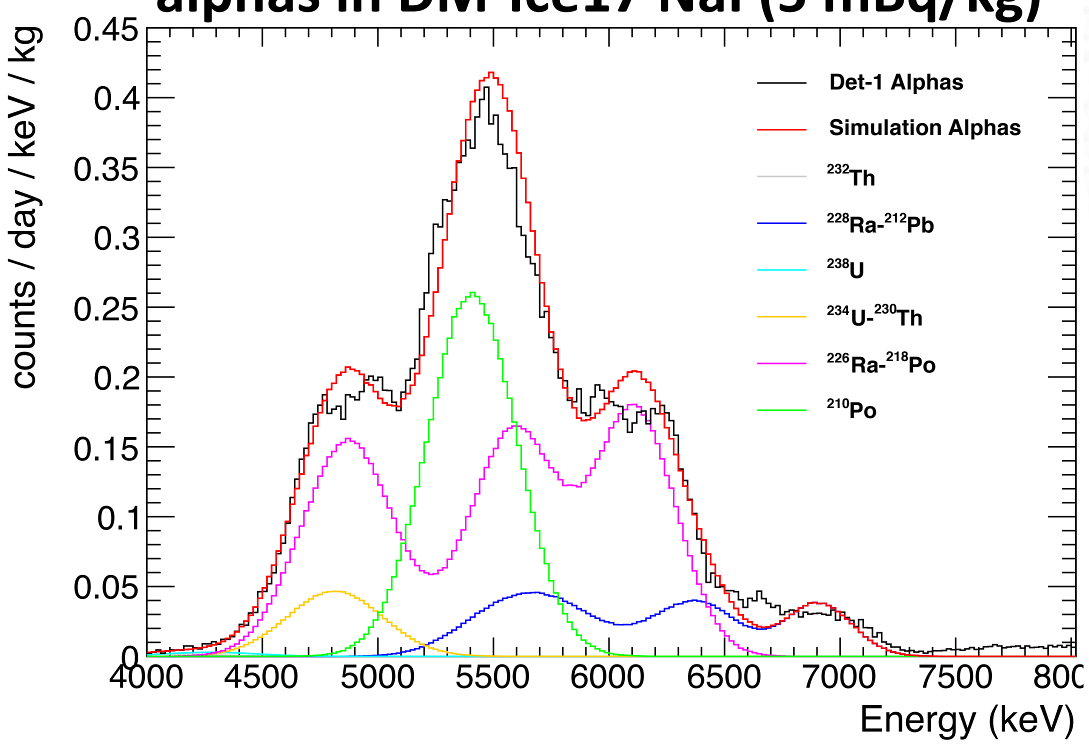
Spectrum vs. Simulation

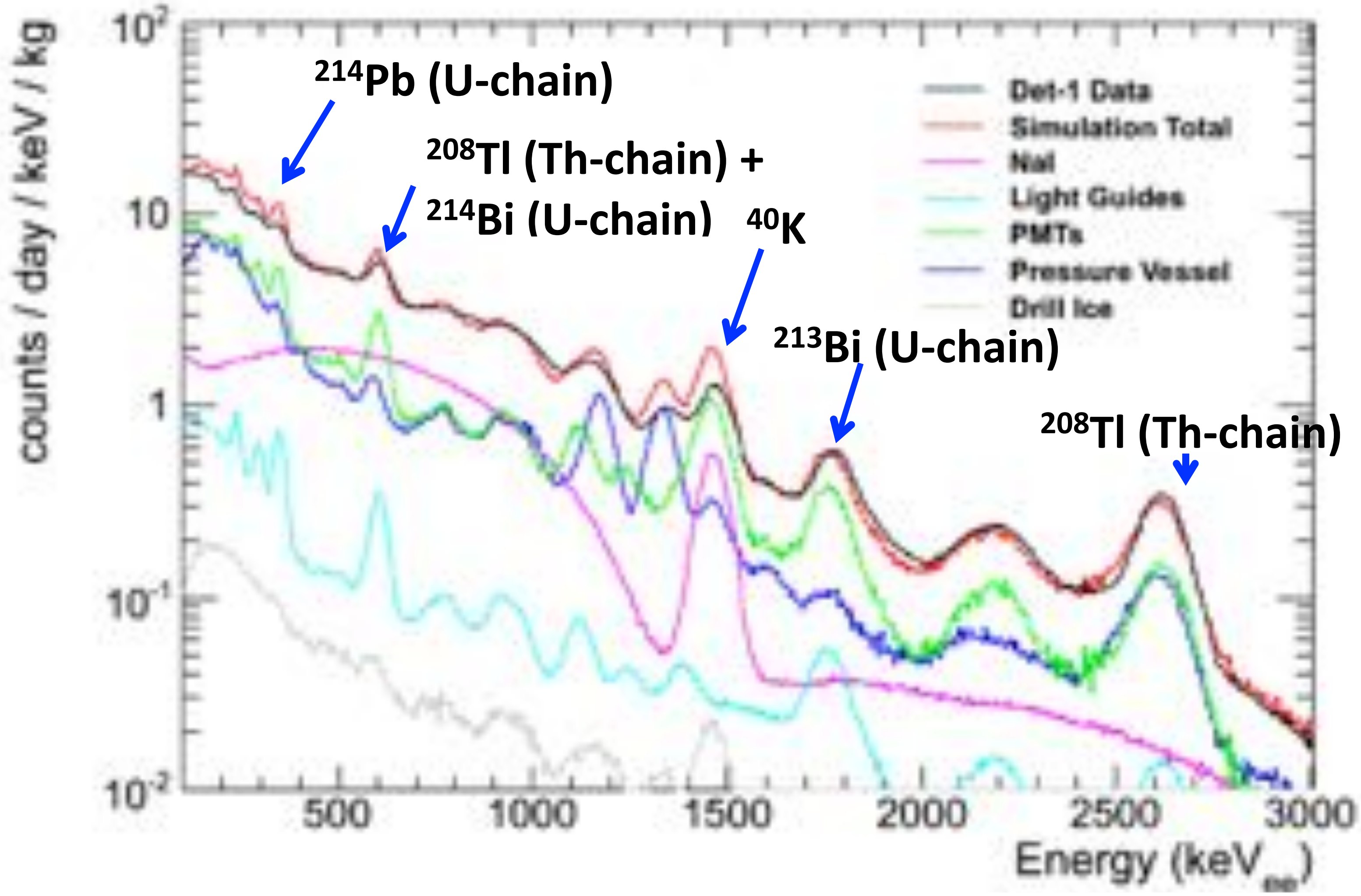
- Good agreement with simulation
- Simulation based on:
  - NaI from alphas and K from data
  - radioassay of spare parts

Pulse-shape discrimination (1 - 9 MeVee)



alphas in DM-Ice17 NaI (5 mBq/kg)

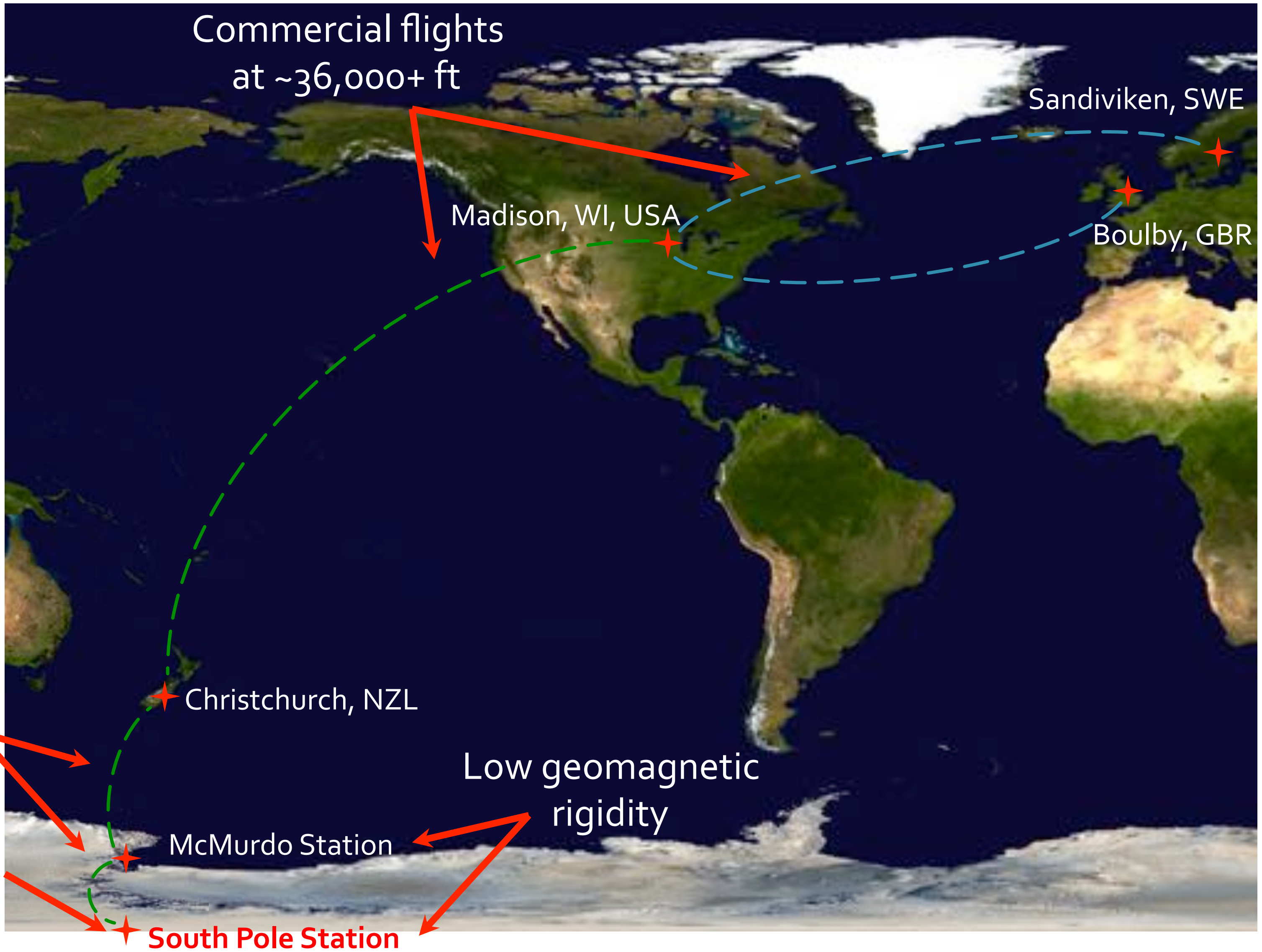




DM-Ice Collaboration
arXiv:1401.4804v1

Cosmogenic Activation for DM-Ice17

Location	Relative Neutron Rate (to sea level)
Madison, WI	1.38
South Pole	11.1
Commercial Flight	100 – 600



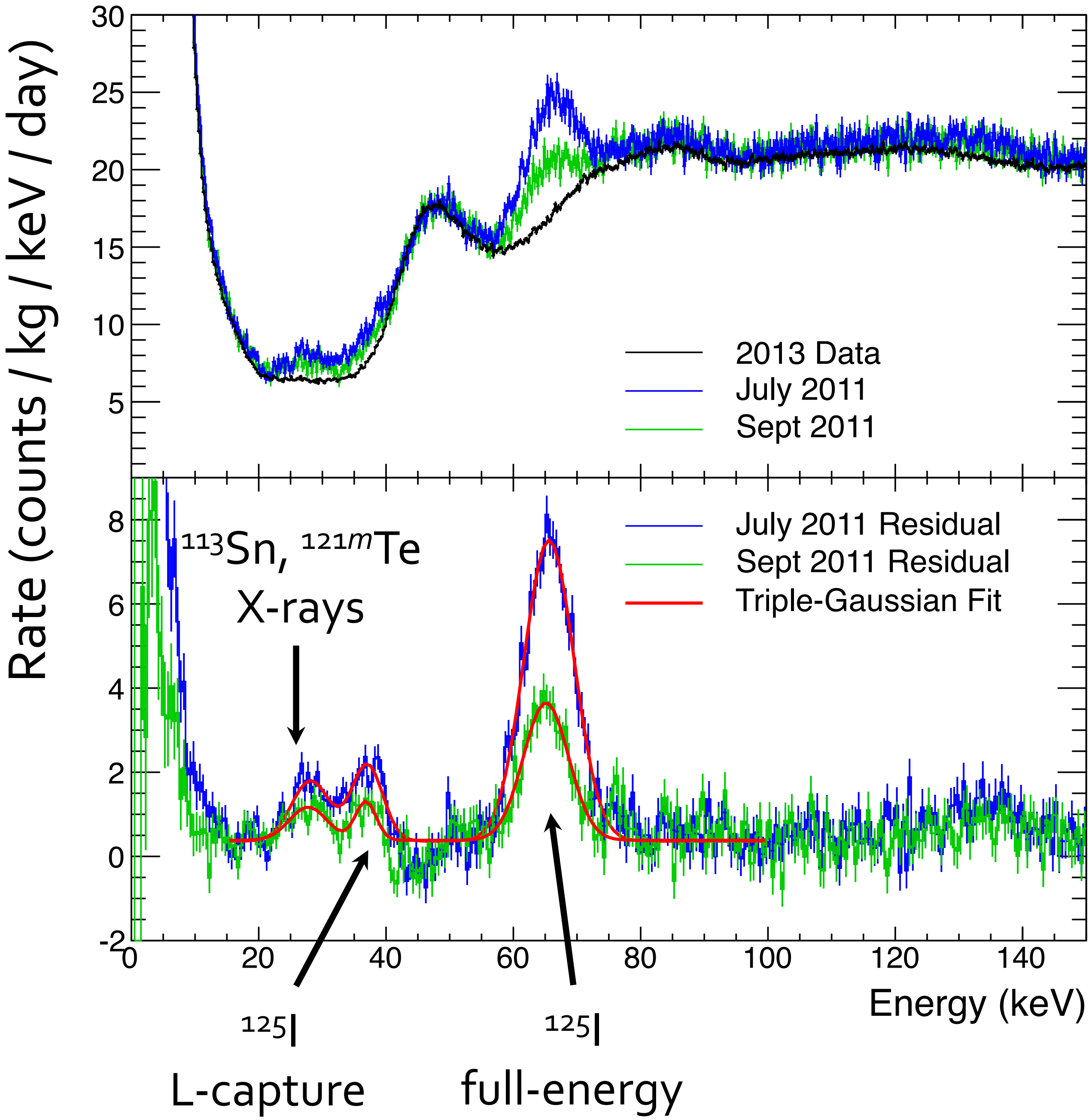
Polar program flights

Storage at 9,301 ft

44

Cosmogenic Decay Peaks

DM-Ice17 Det-1 Data and Residual



Confirm identity of cosmogenic peaks:

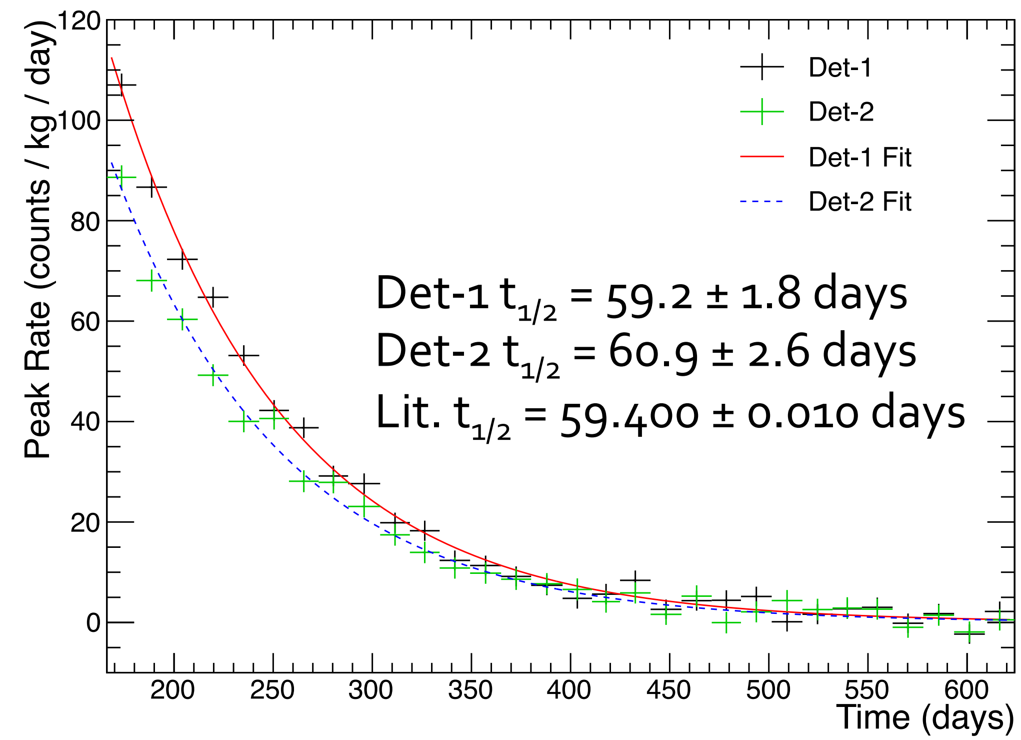
Match simulated spectral features

- Expect 65.3 keV full-energy and 37.6 keV
  - L-shell capture peaks for ^{125}I

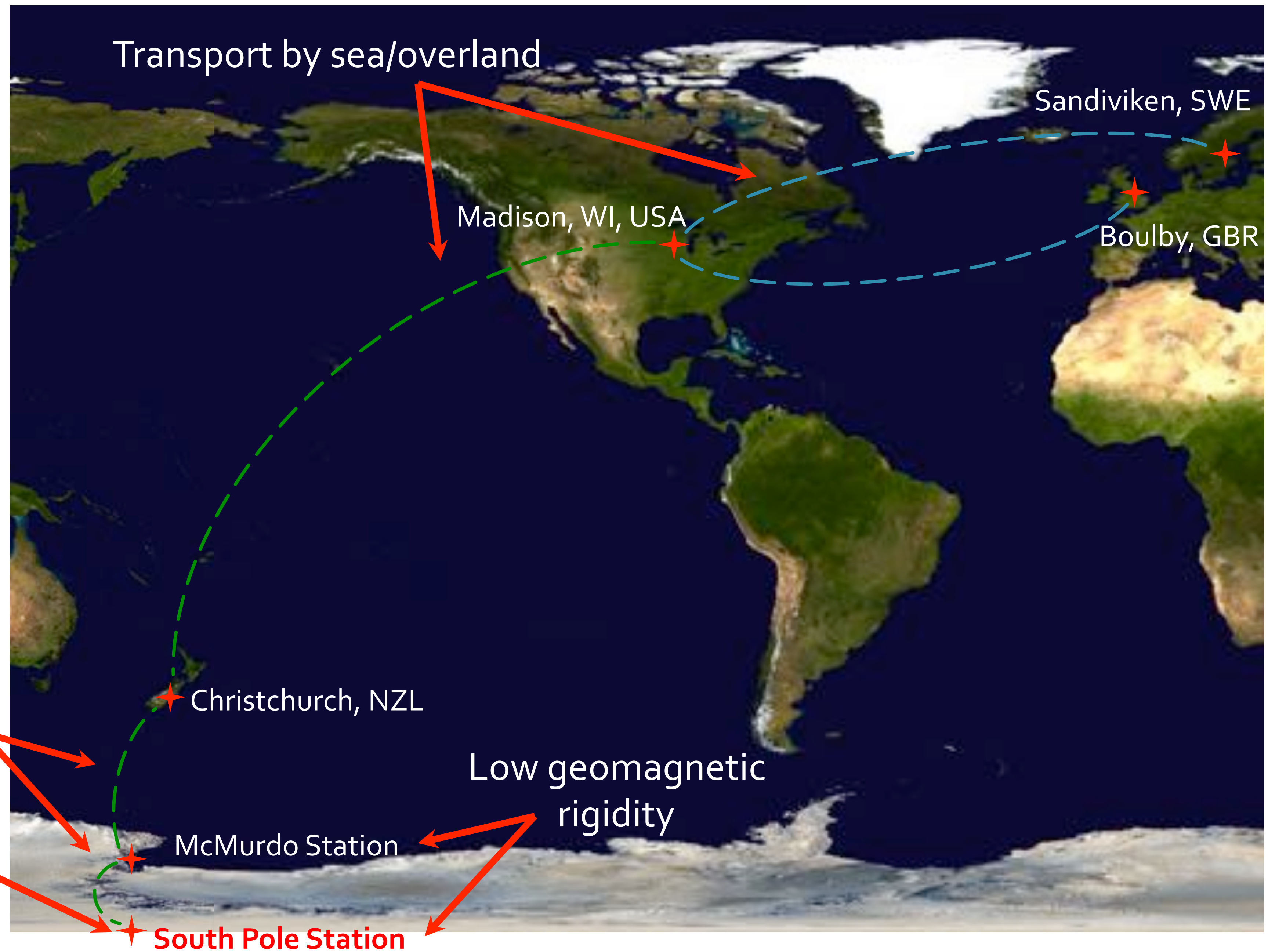
Measuring decay time

- Expect 59.4 day half-life for ^{125}I

Count Rate for ^{125}I Peak

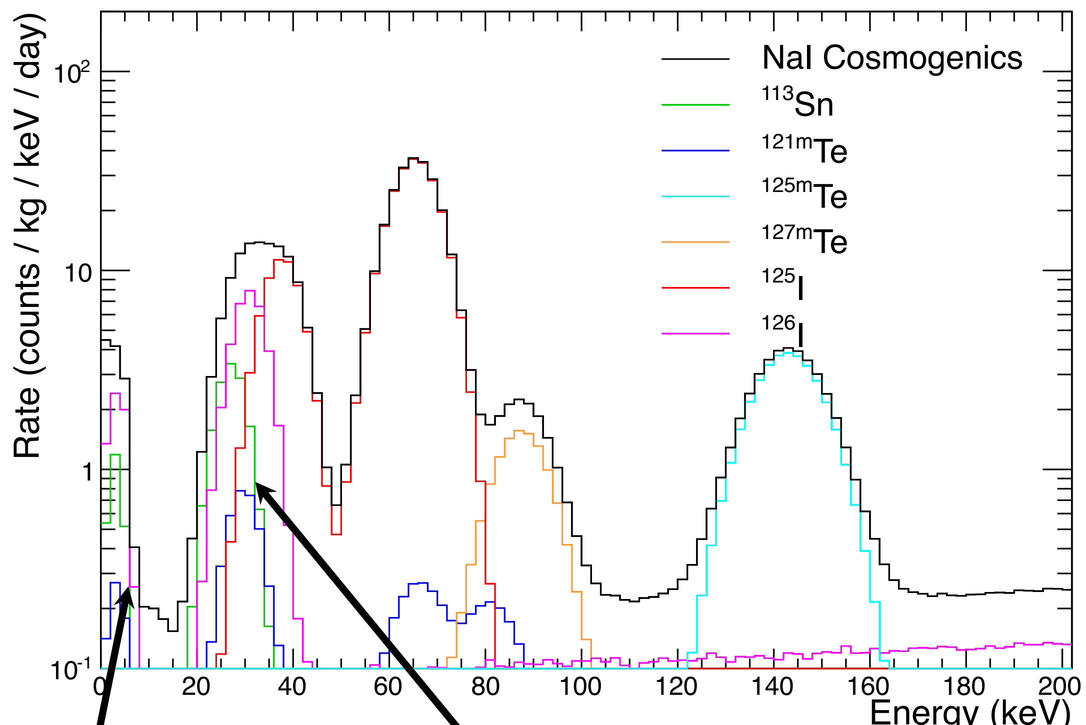


Looking Ahead: Activation for DM-Ice



Simulated Activation Event Rate

Event rate one month after deployment



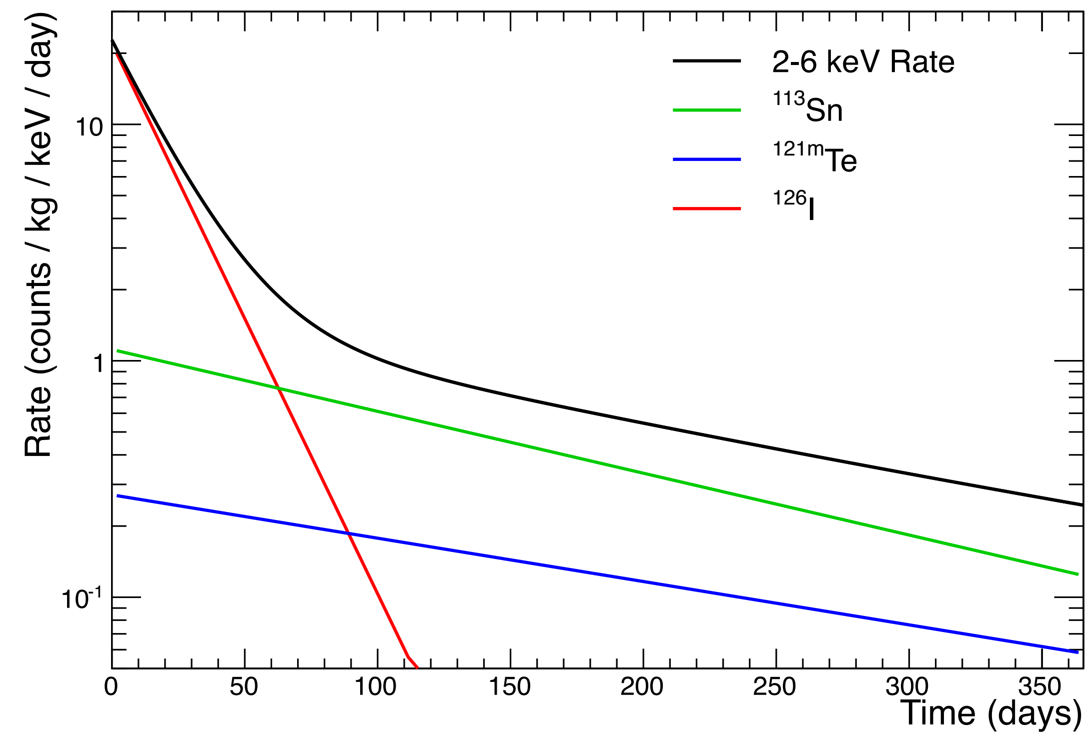
L-shell X-ray or Auger e⁻

K-shell X-ray or Auger e⁻

^{126}I, ^{113}Sn, ^{121m}Te

- Multiple strong cosmogenic lines
- Significant contributions to 2 – 6 keV region of interest & must be minimized

Event rate vs. time



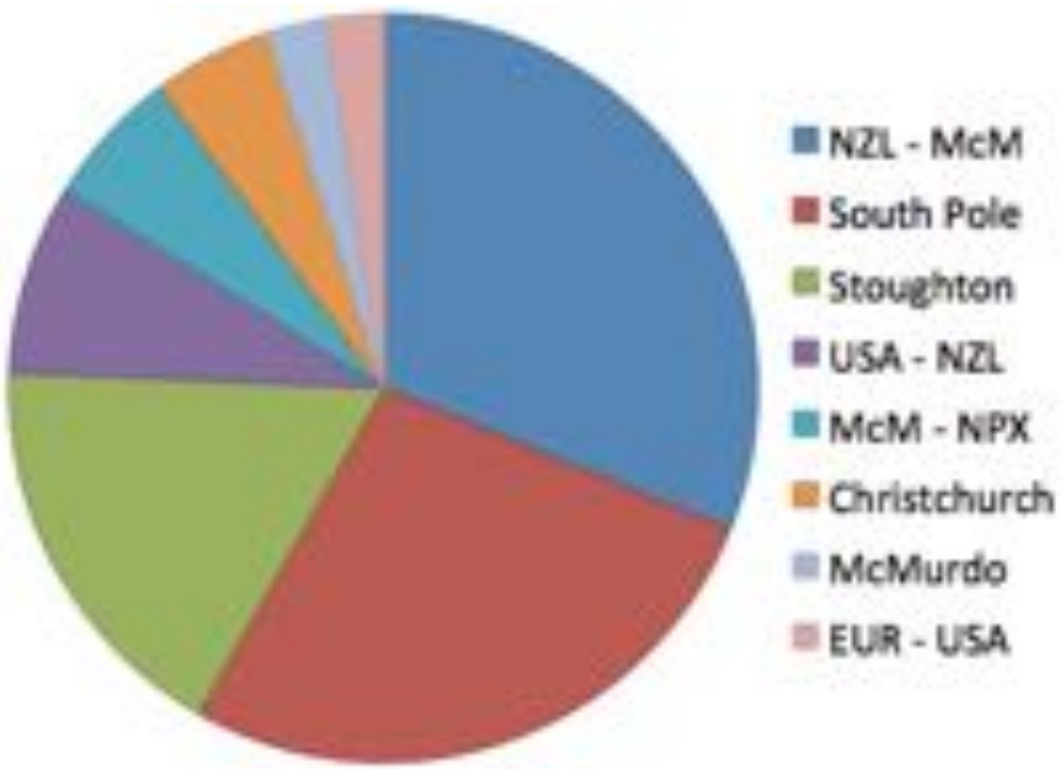
Cosmogenic contribution to ROI:

- ^{126}I ($t_{1/2}$ = 13 days)
  - lead contribution at deployment
- ^{113}Sn ($t_{1/2}$ = 115 days)
  - dominates rate over physics run

Cosmogenic Mitigation

“Exposure budget” for ^{113}Sn in DM-Ice250S:

- After “easy” 40% reduction
- Major contributions remain from NZL-McM flight and South Pole

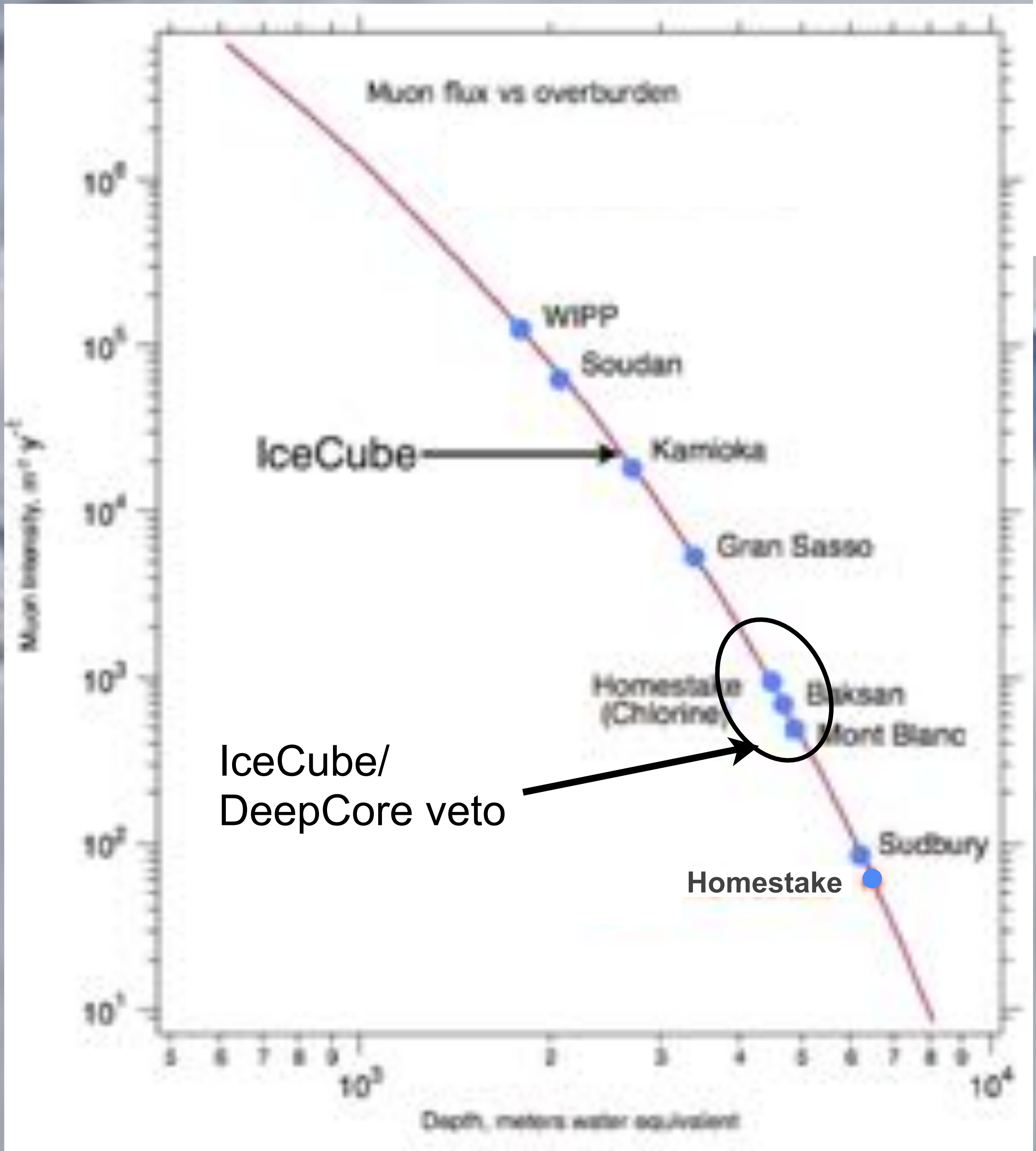


Further reductions:

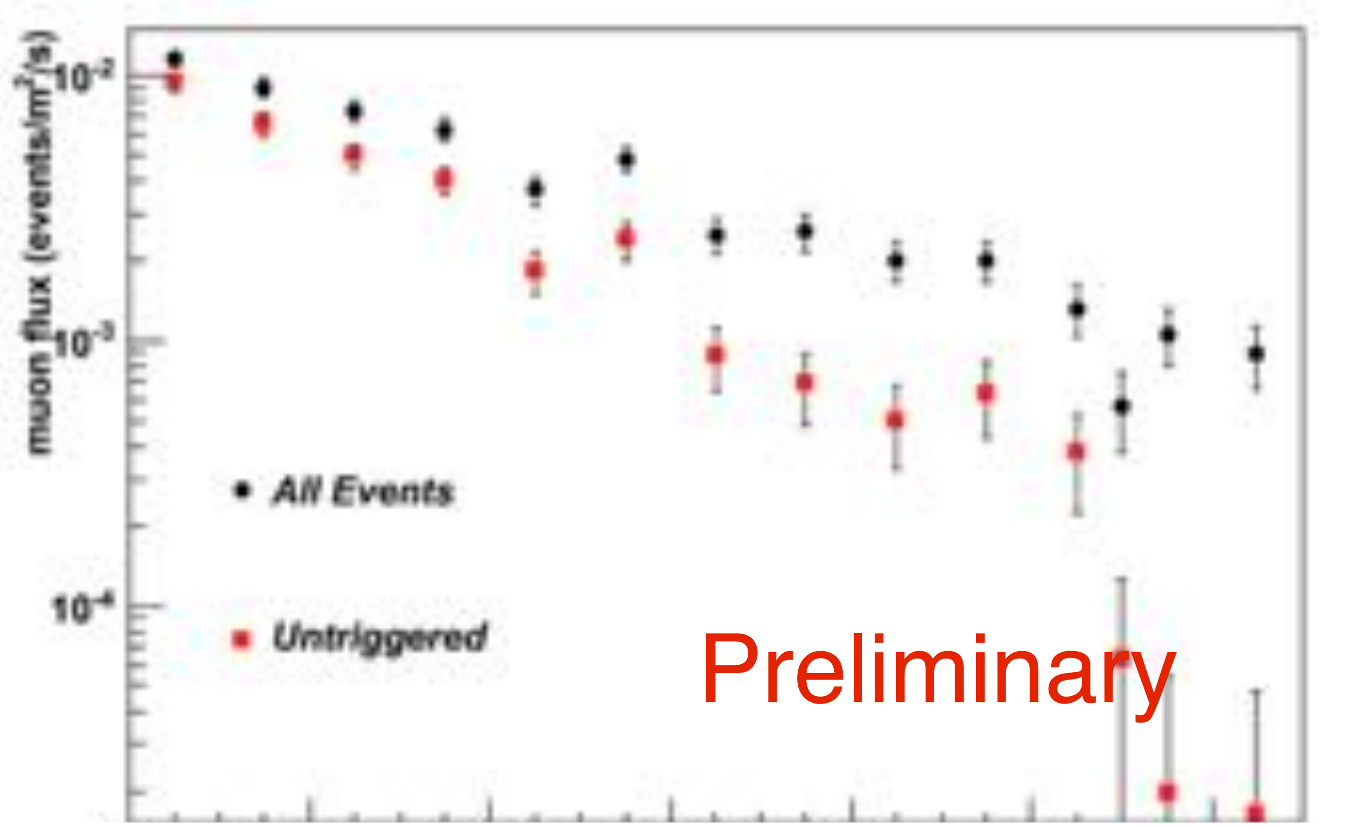
- 50% reduction in low-altitude NZL-McM cargo flight (15% of total)

- 90% reduction in South Pole activation from under-ice storage:

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

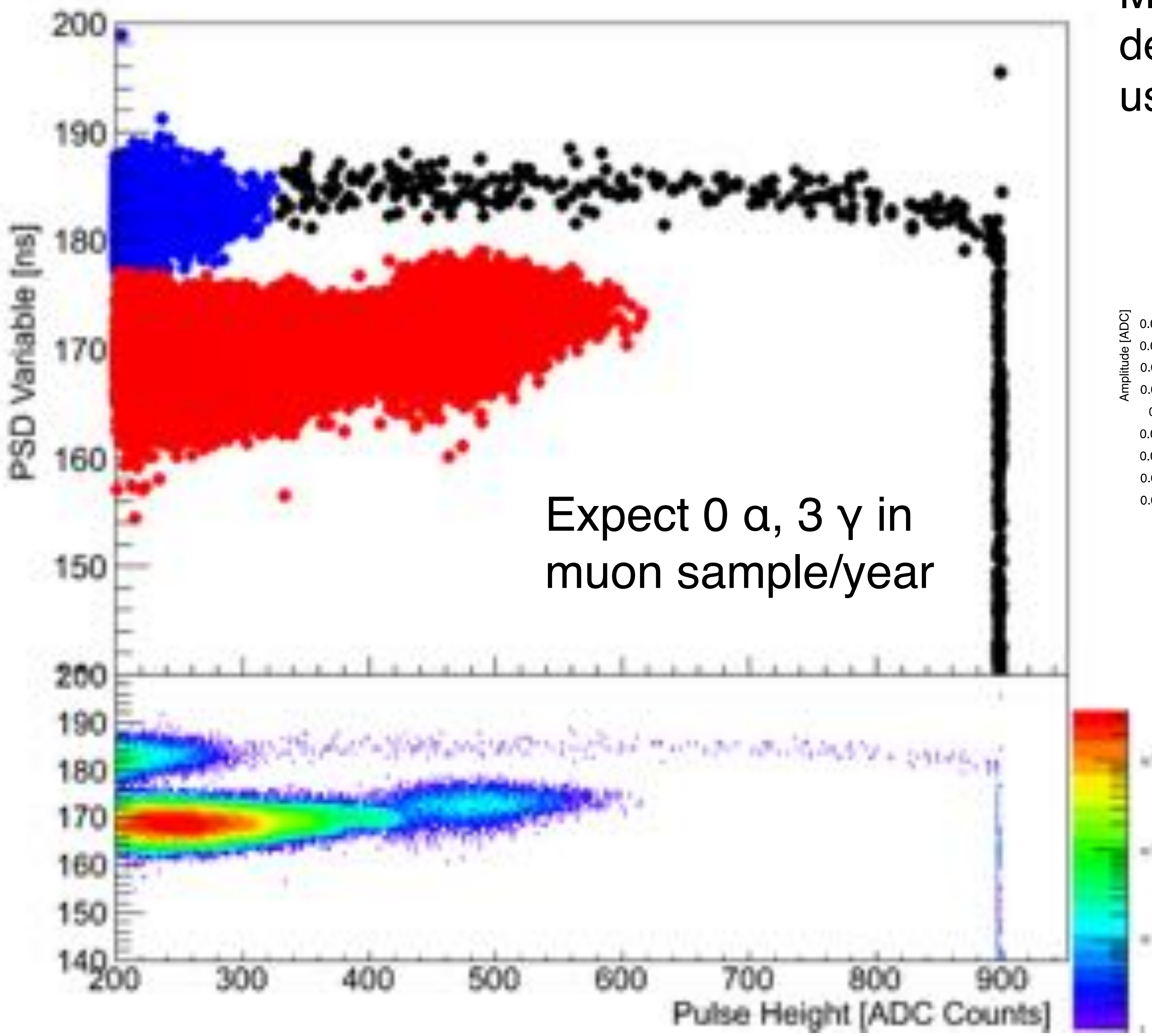


- ~85 muons/m^2/day at bottom of IceCube (2/day for DM-Ice17)
- IceCube/DeepCore veto reduces rate by ~1-2 orders of magnitude.



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

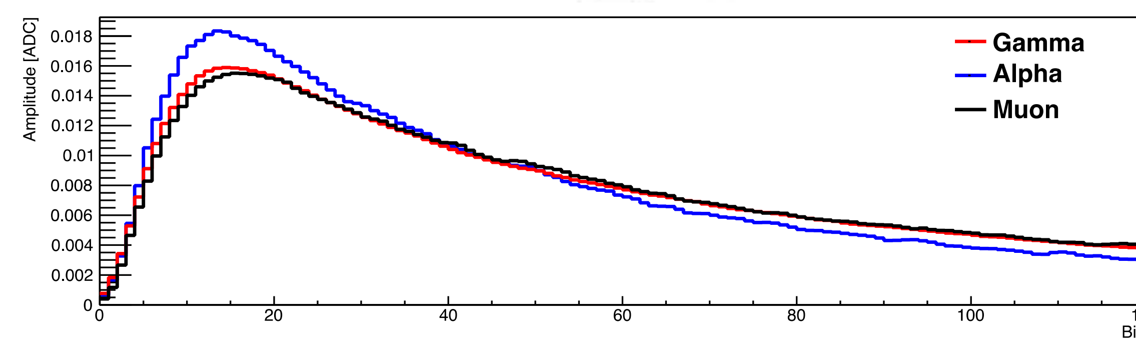
Identifying Muons in DM-Ice

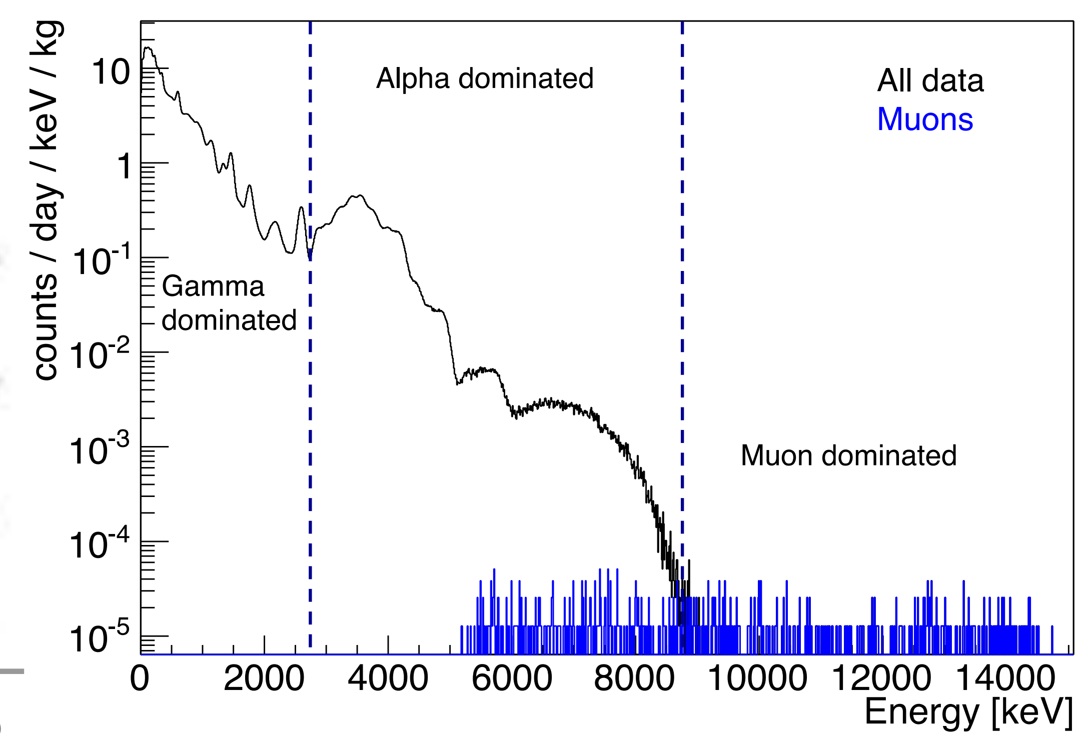


Expect 0 α, 3 γ in muon sample/year

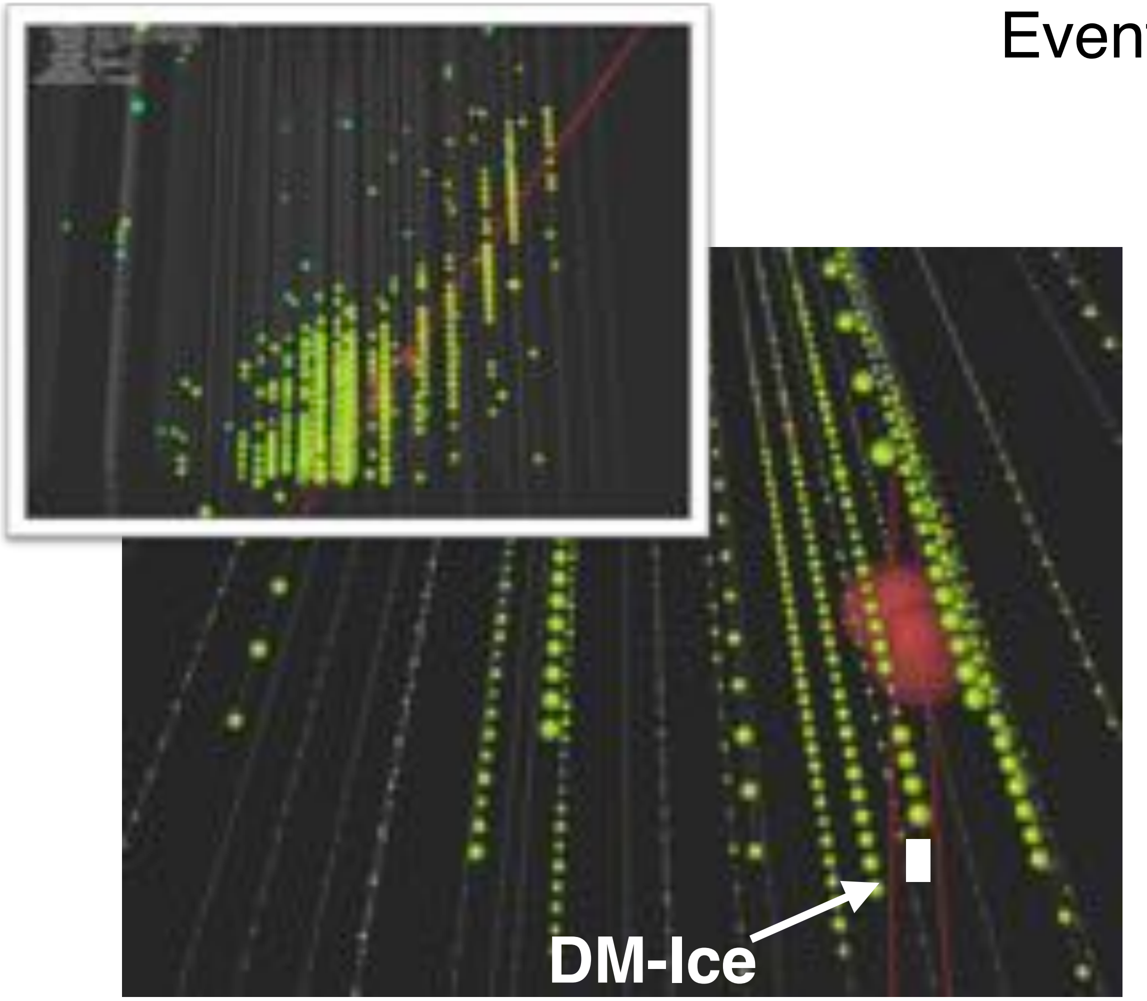
Muons are identified with their high energy depositions and pulse shape variable using the pulse height (h_i) at time (t_i):

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





IceCube - DM-Ice Coincidence



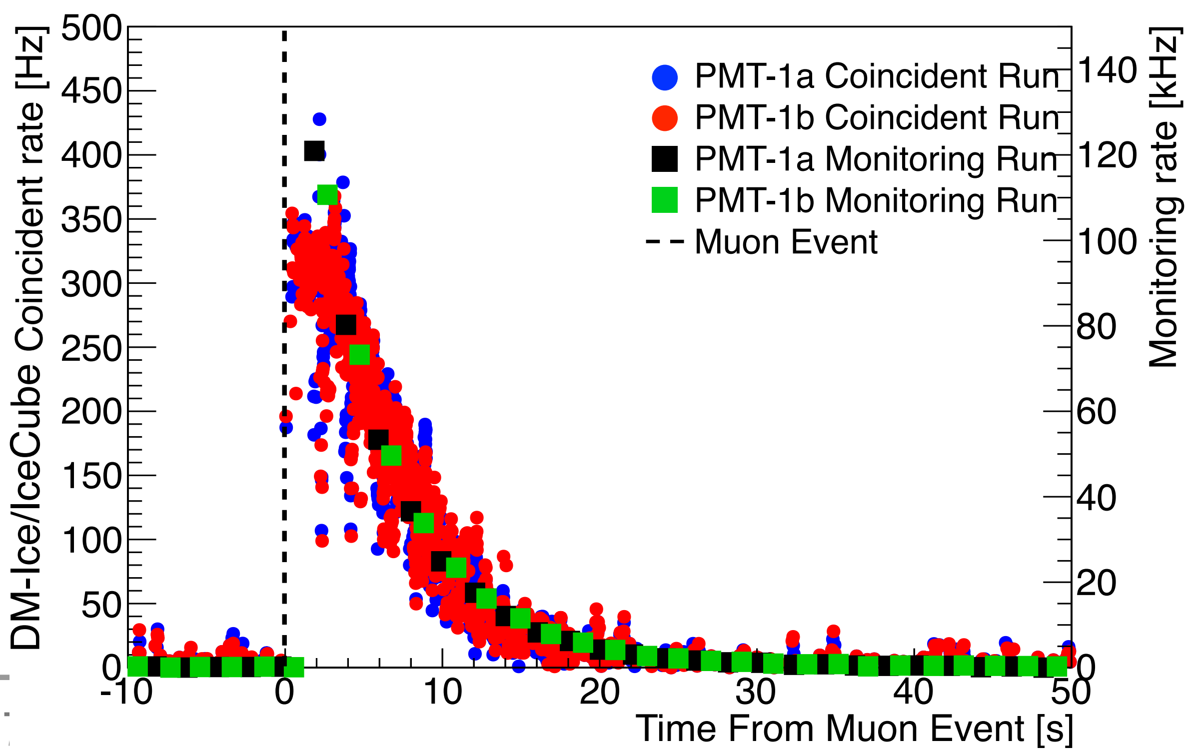
Events that trigger both DM-Ice and IceCube Found!

Muon rate in DM-Ice (appear as mip): 2/day

81 events in 11 months pass IceCube's muon trigger. (expect more events in less stringent triggers)

Muon events result in elevated event rate at low energies in DM-Ice17 persisting for > 10 sec.

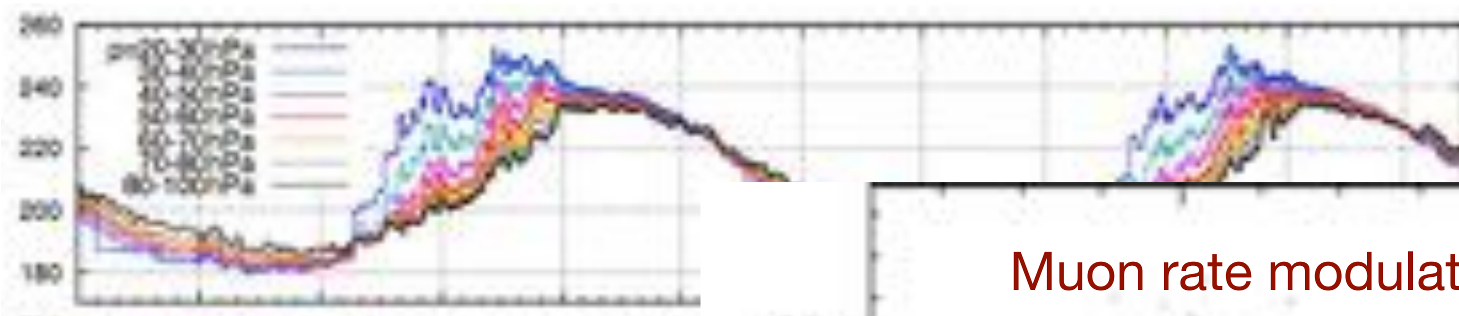
December 2012 – Event #14
2012-12-21 RunID: 121431, EventID 79868923

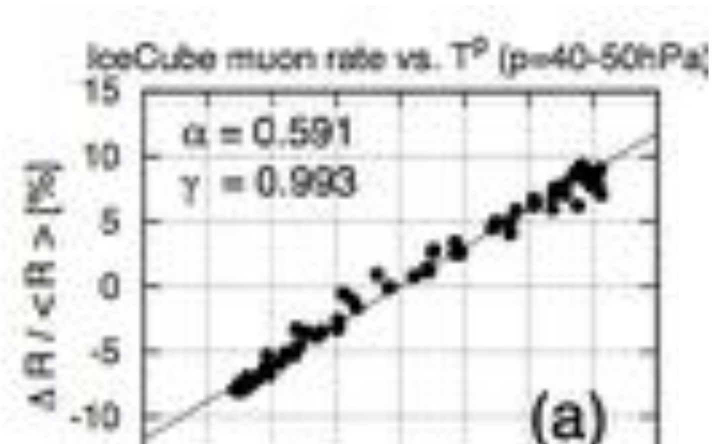


Seasonal Muon Rate Modulation

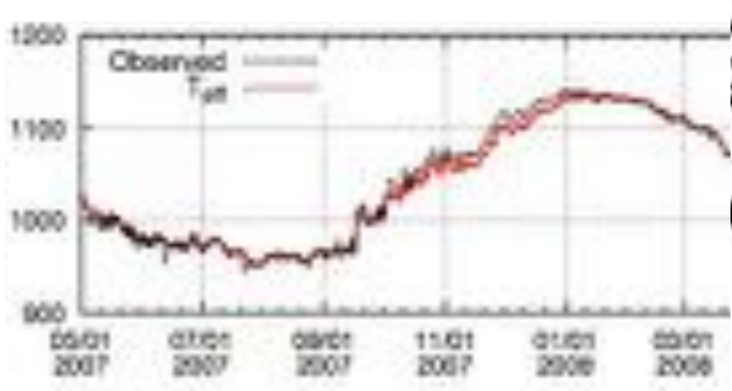
The muon rate at the South Pole well measured by IceCube

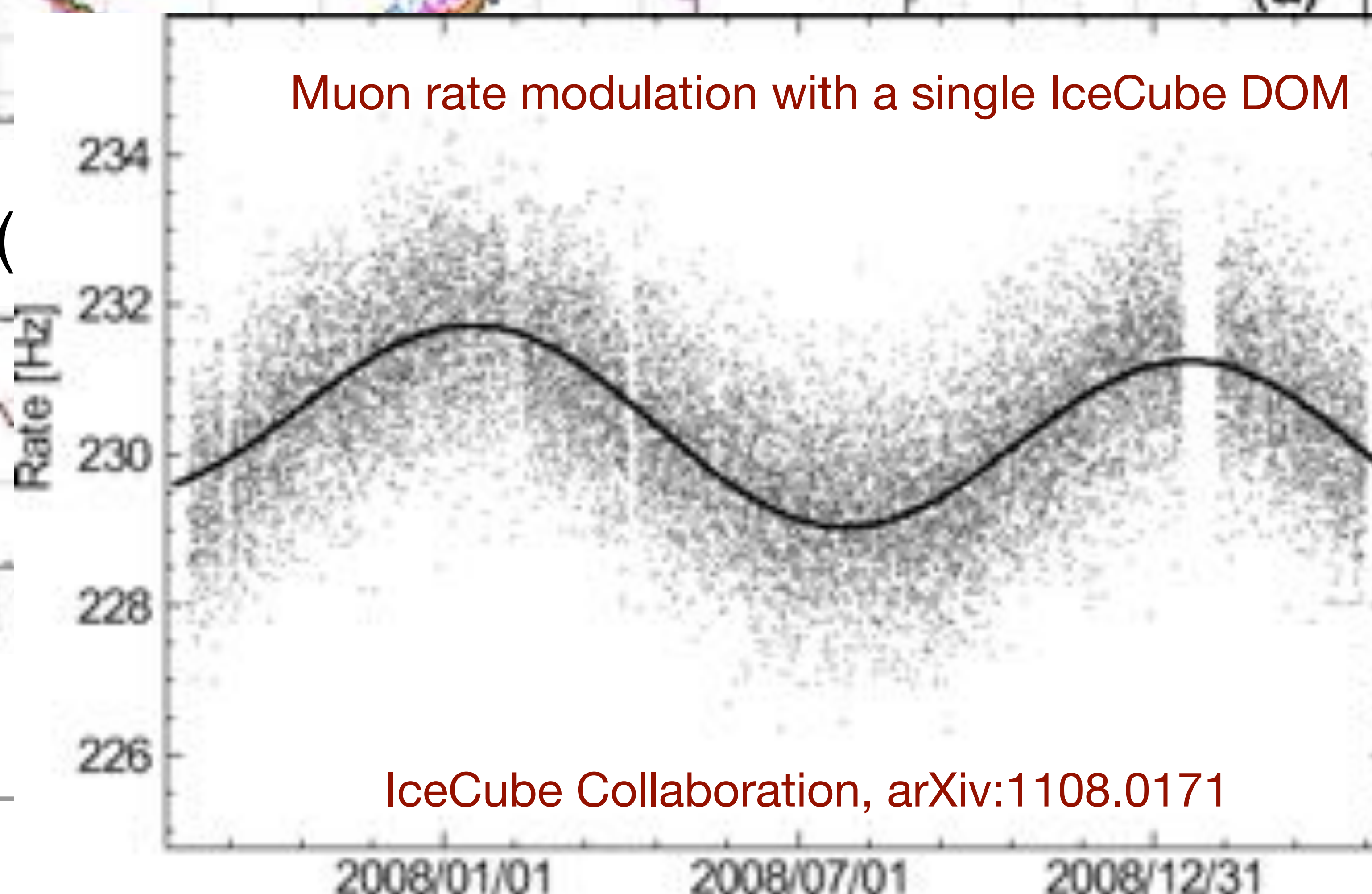
Temperature of the stratosphere in pressure layers, T^P [K]





IceCube muon rate [Hz] (





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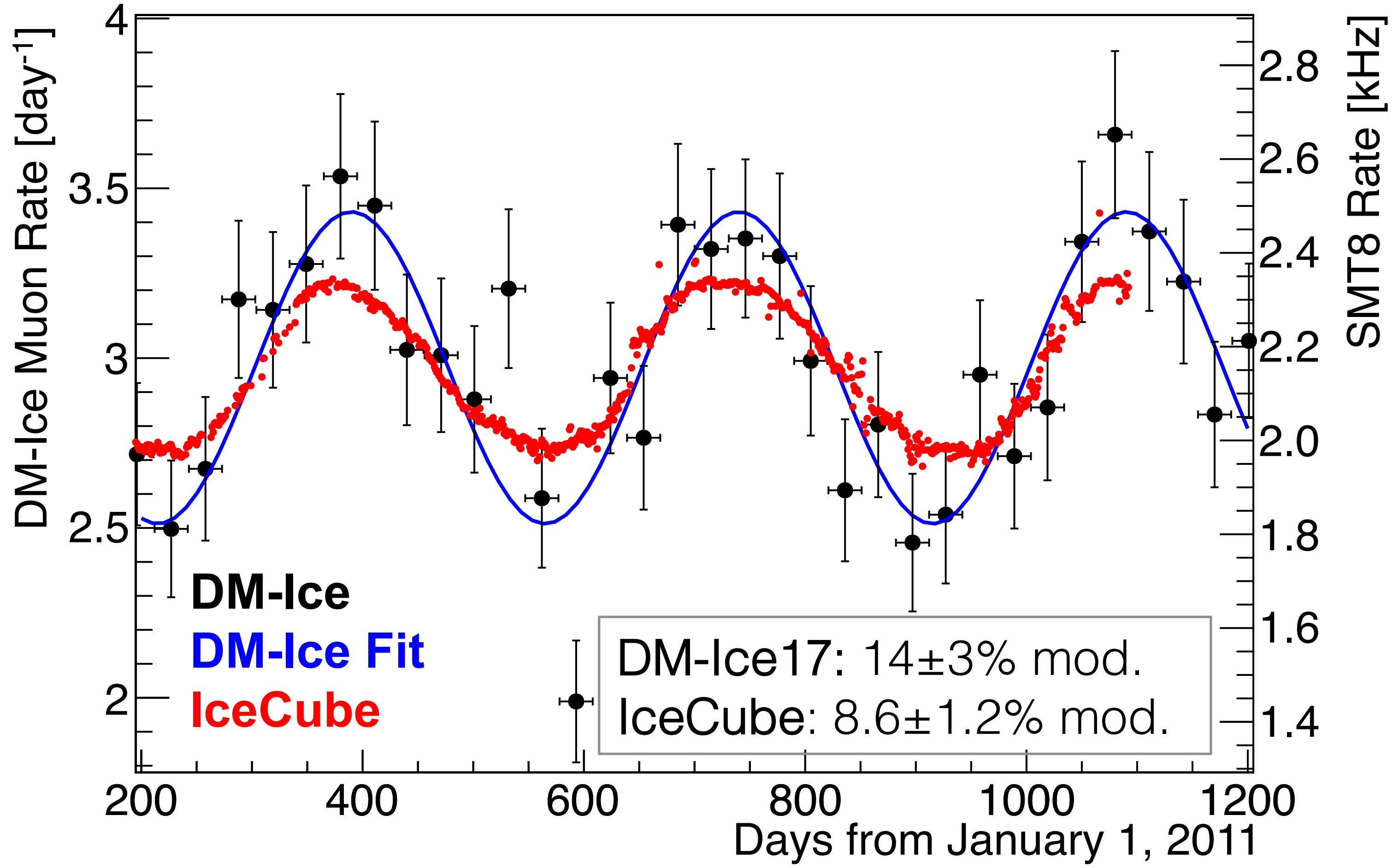
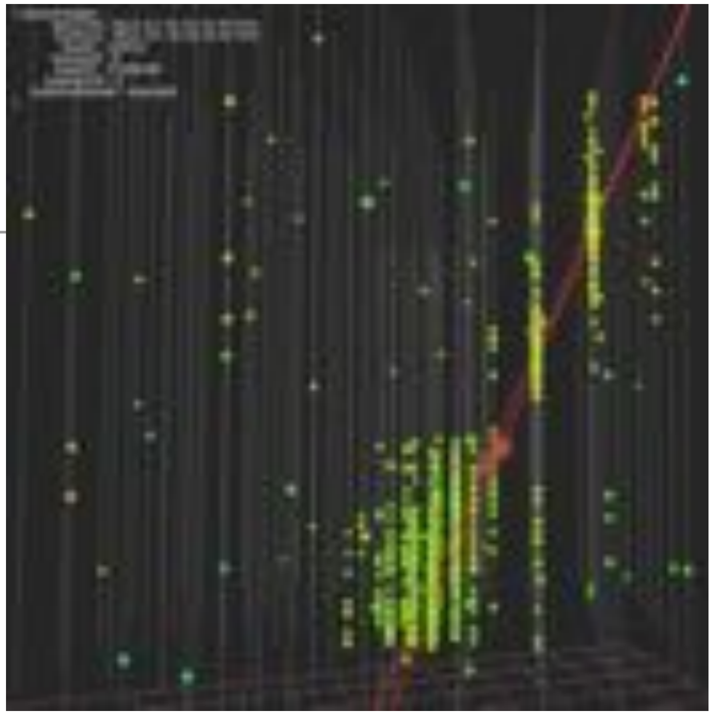
Muon Rate in DM-Ice and IceCube

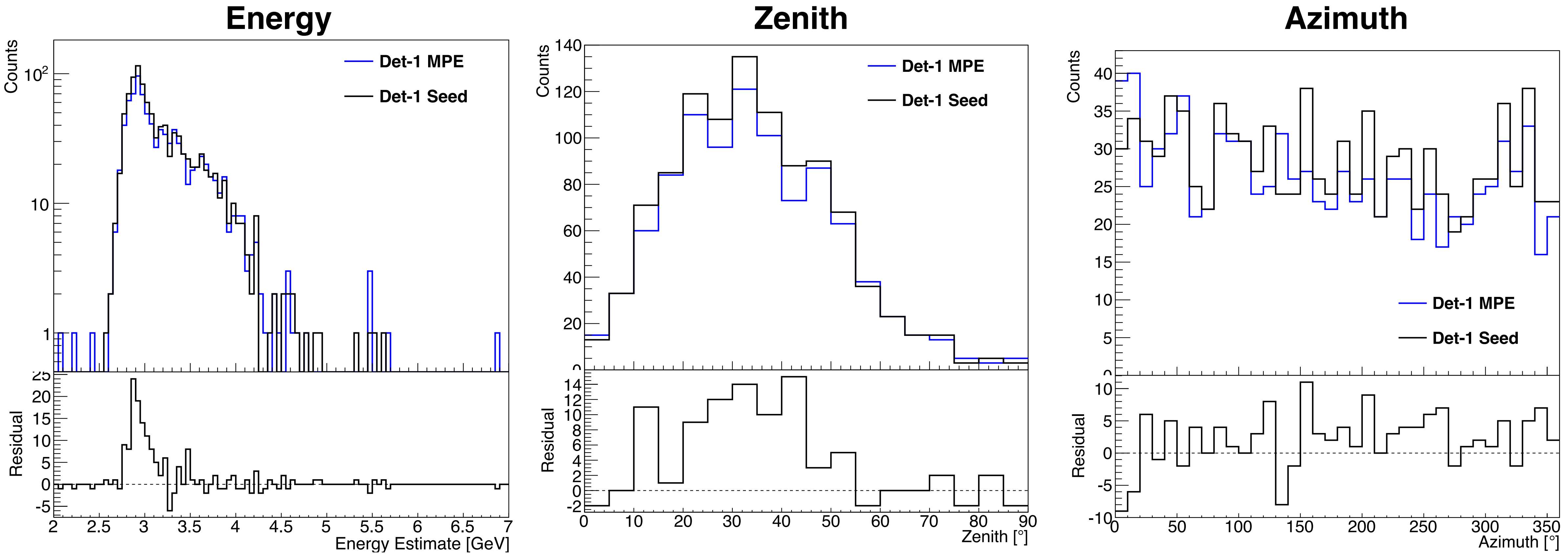
- The muon rate observed in DM-Ice tracks IceCube's rate



Muon Energy Distribution

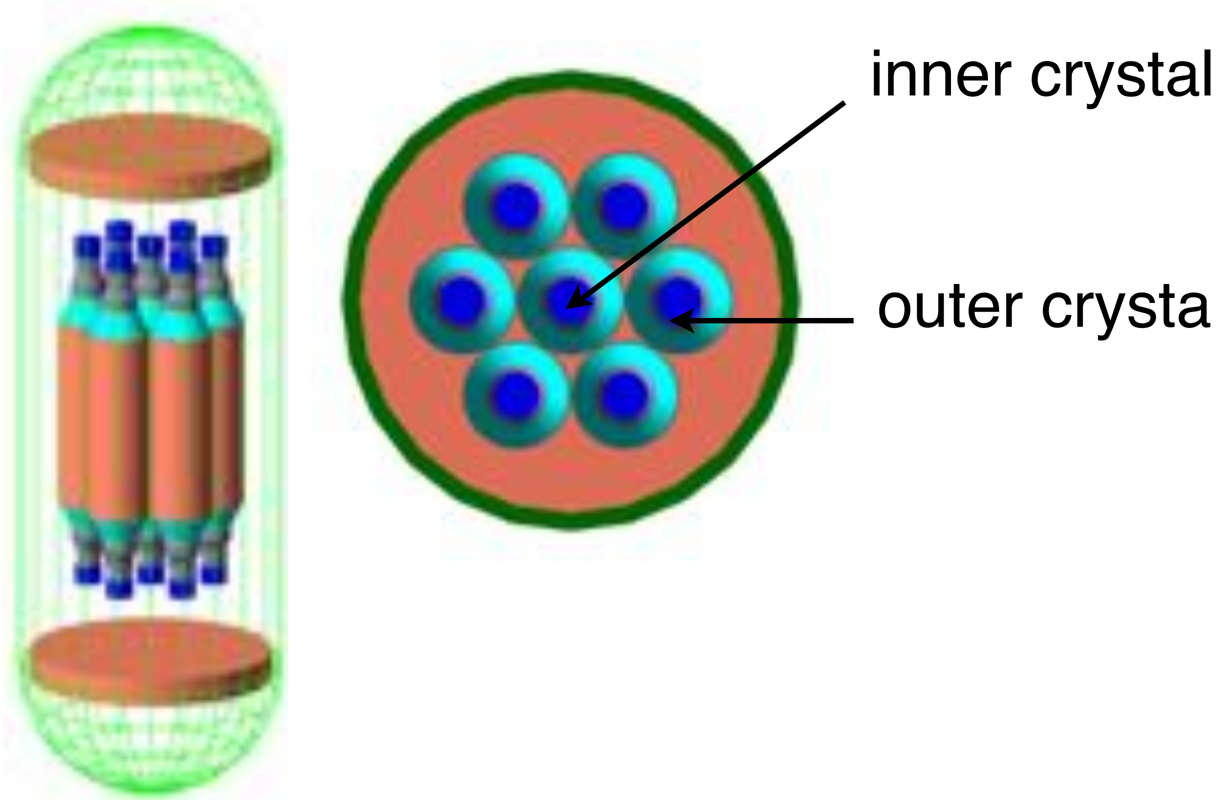


- Energy & direction of the muons measured by IceCube
- DM-Ice anchors muons in IceCube to 13 cm
- Studies underway to help improve IceCube reconstruction

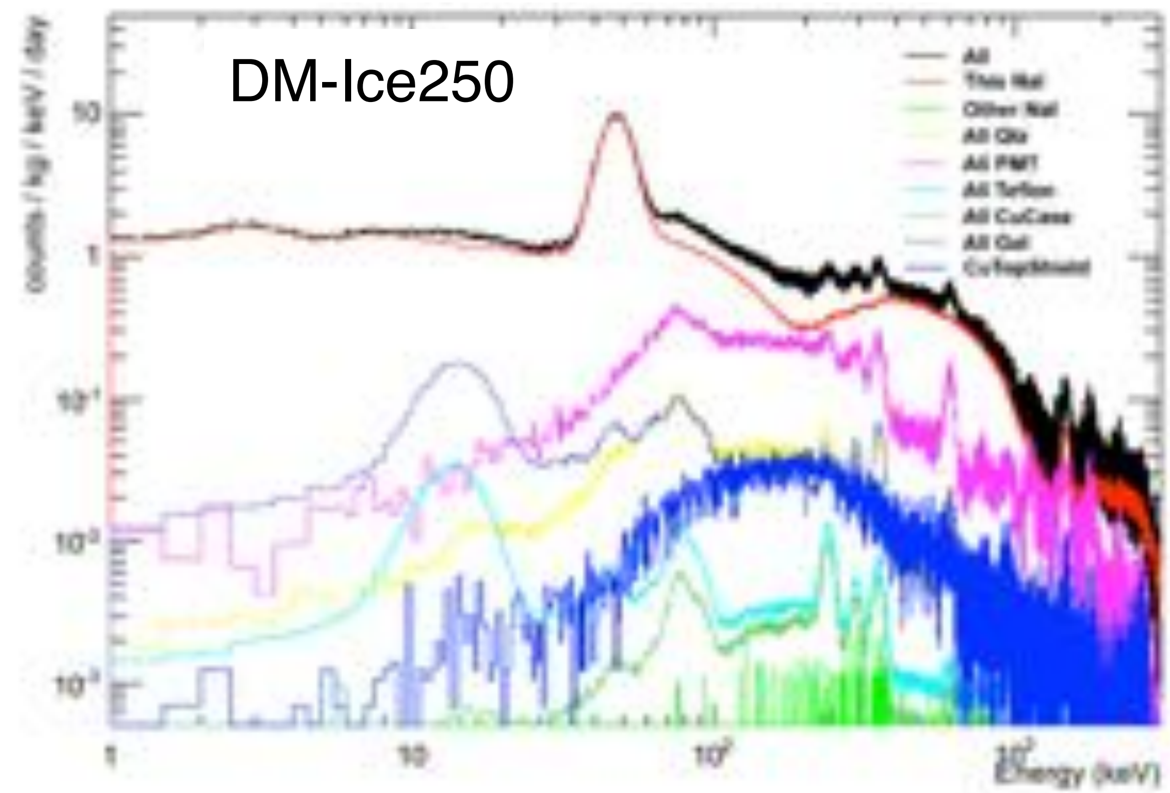


DM-Ice250 Simulations

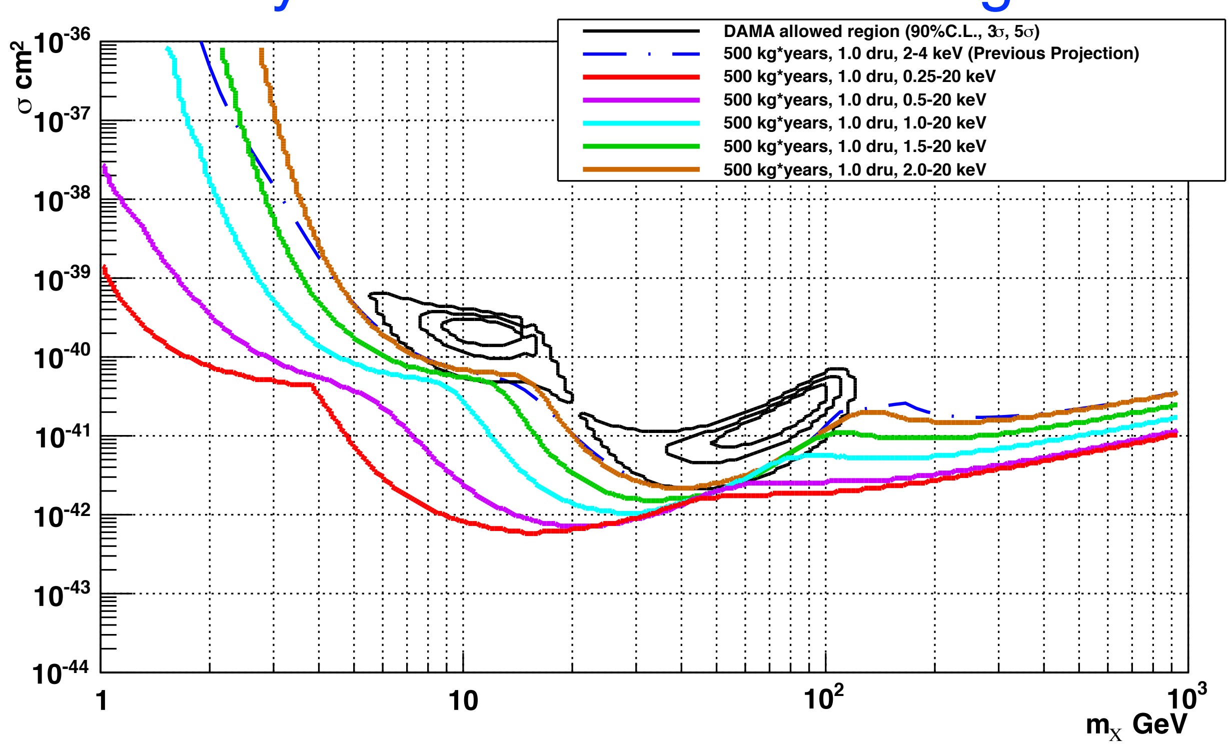
Close-Packed Detector Array



Inner Crystal Vetoed Spectrum

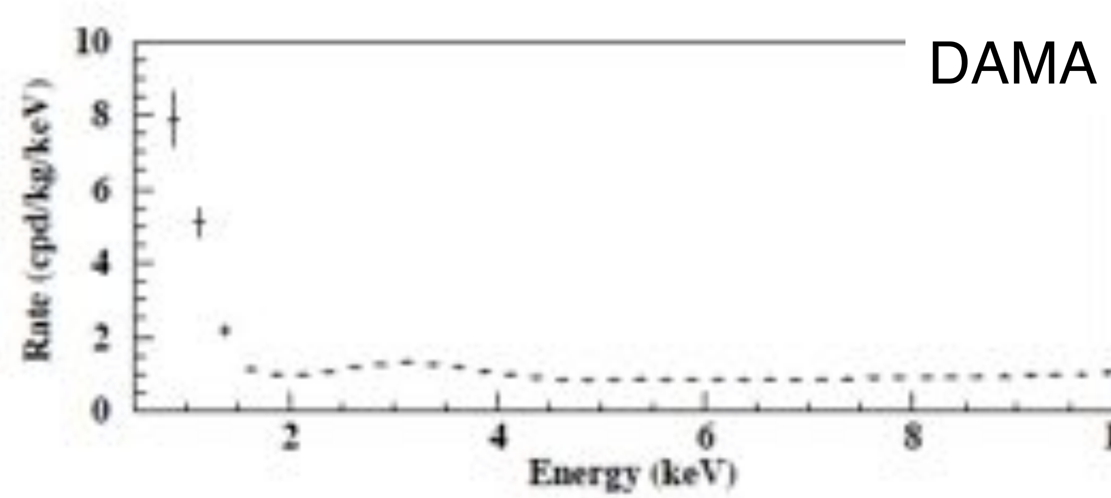


Sensitivity to DAMA Modulation Signal



DM-Ice250 Background

2-6 keV region: 3 dru w/o xtal-xtal veto, 1.75 dru average with veto



New Low-Background NaI(Tl) Crystals

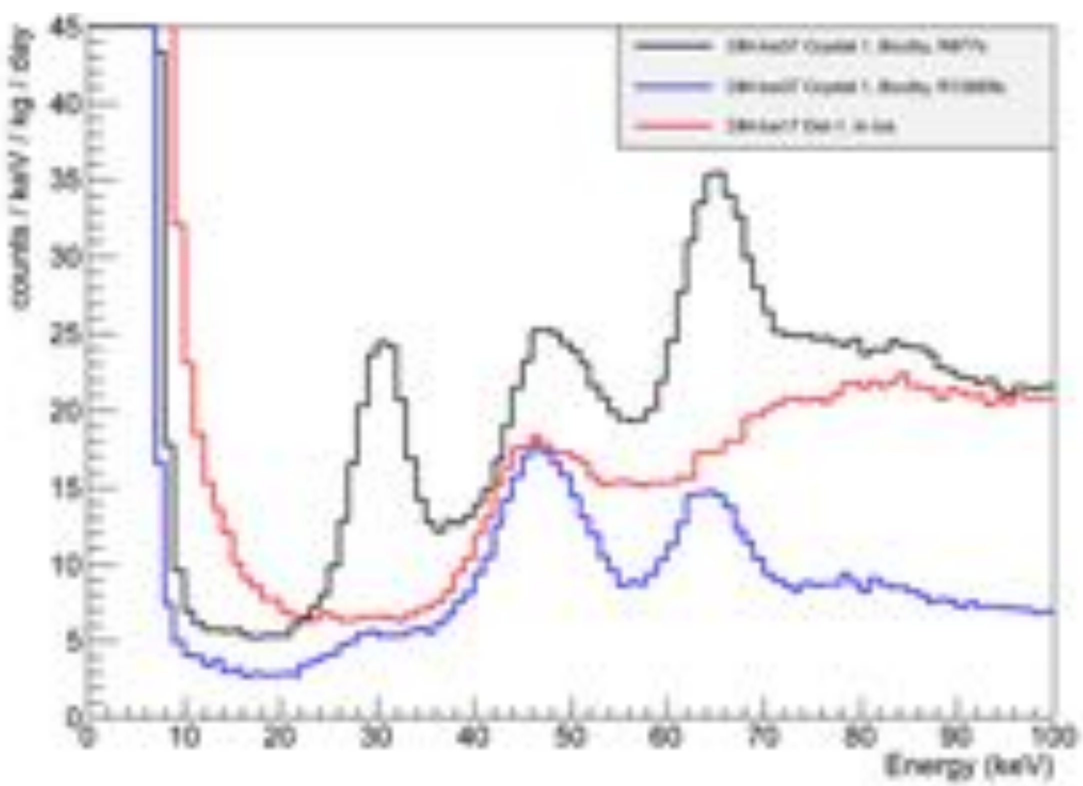
Development of NaI(Tl) detectors with Alpha Spectra, Inc (ASI) in CO, USA
Three groups work with Alpha Spectra: DM-Ice, ANAIS, KIMS.
Communication and sharing of R&D results

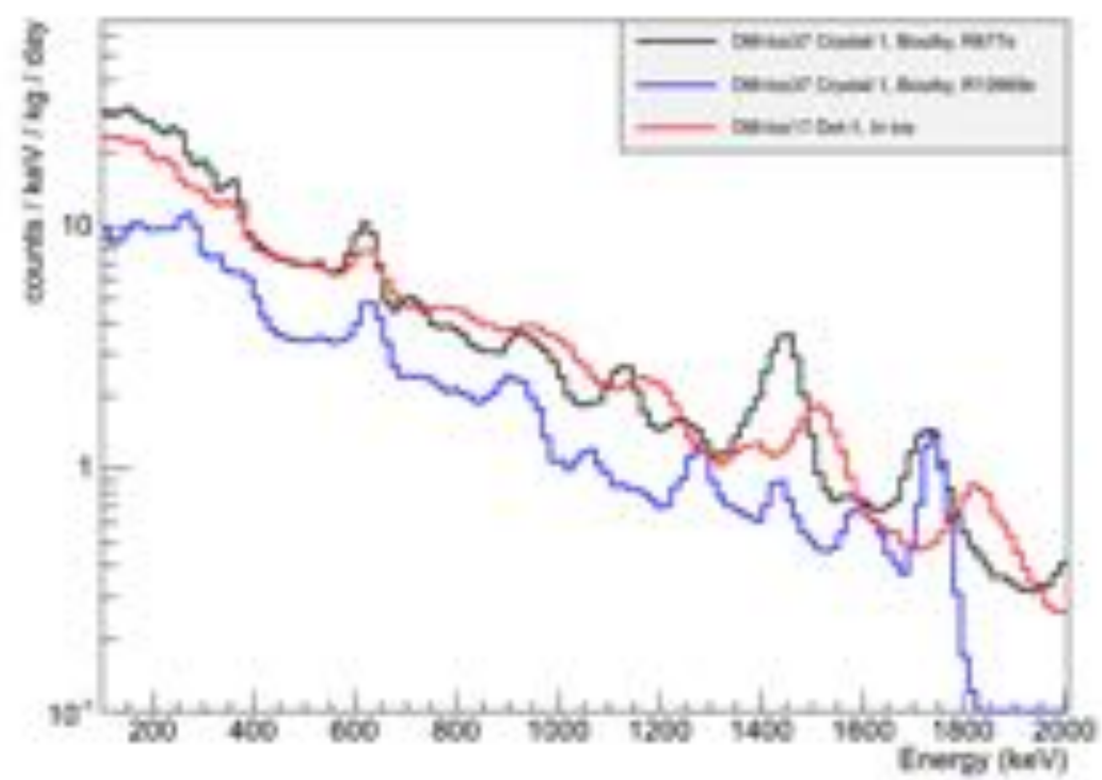
- 2 x 18 kg crystals from Alpha Spectra, first ran at Fermilab MINOS near hall for testing, then moved to Boulby

Backgrounds are within acceptable levels for an experiment with 2 counts/day/keV/kg.

DM-Ice37 Contamination

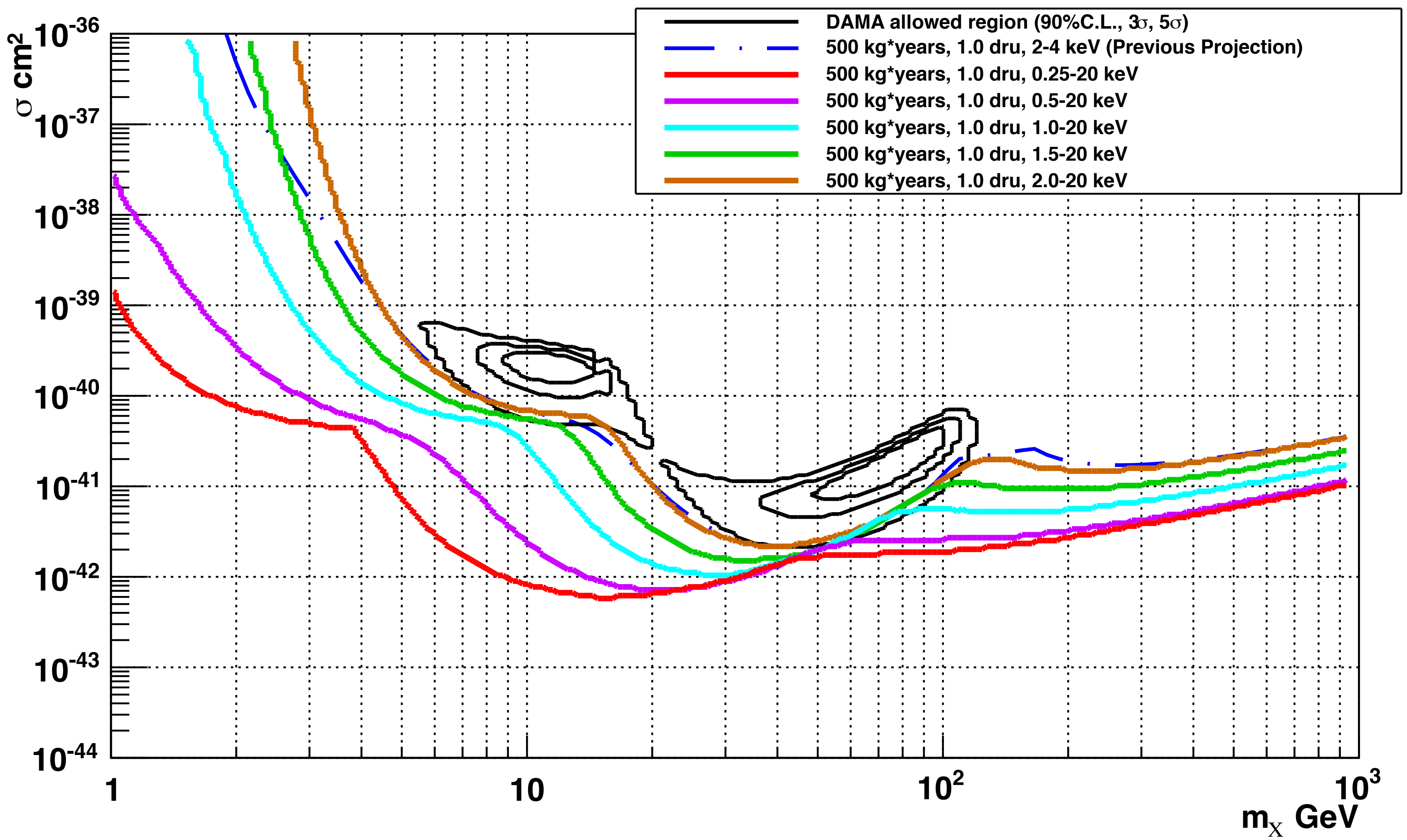
- Collective NaI(Tl) effort (DM-Ice, ANAIS, KIMS)
  - Goal set by DAMA: 1 dru in ROI
  - Currently: 3 dru above noise energies
    - Noise removal in progress
    - DM-Ice17: 8 dru
  - 2 mBq/kg alphas





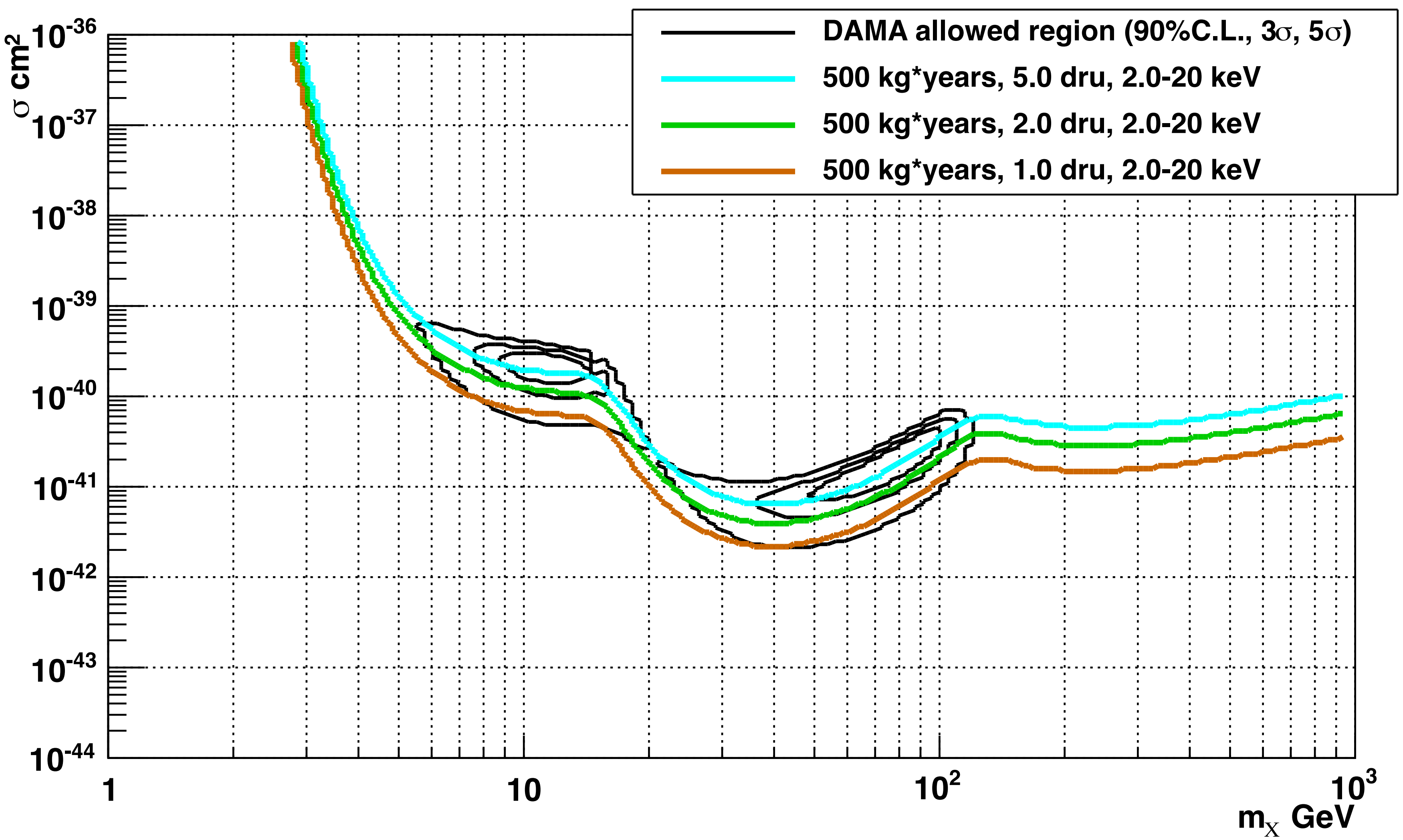
What do we need to test DAMA?

- 500 kg-yr, 1 cnt/keV/kg/day at various thresholds



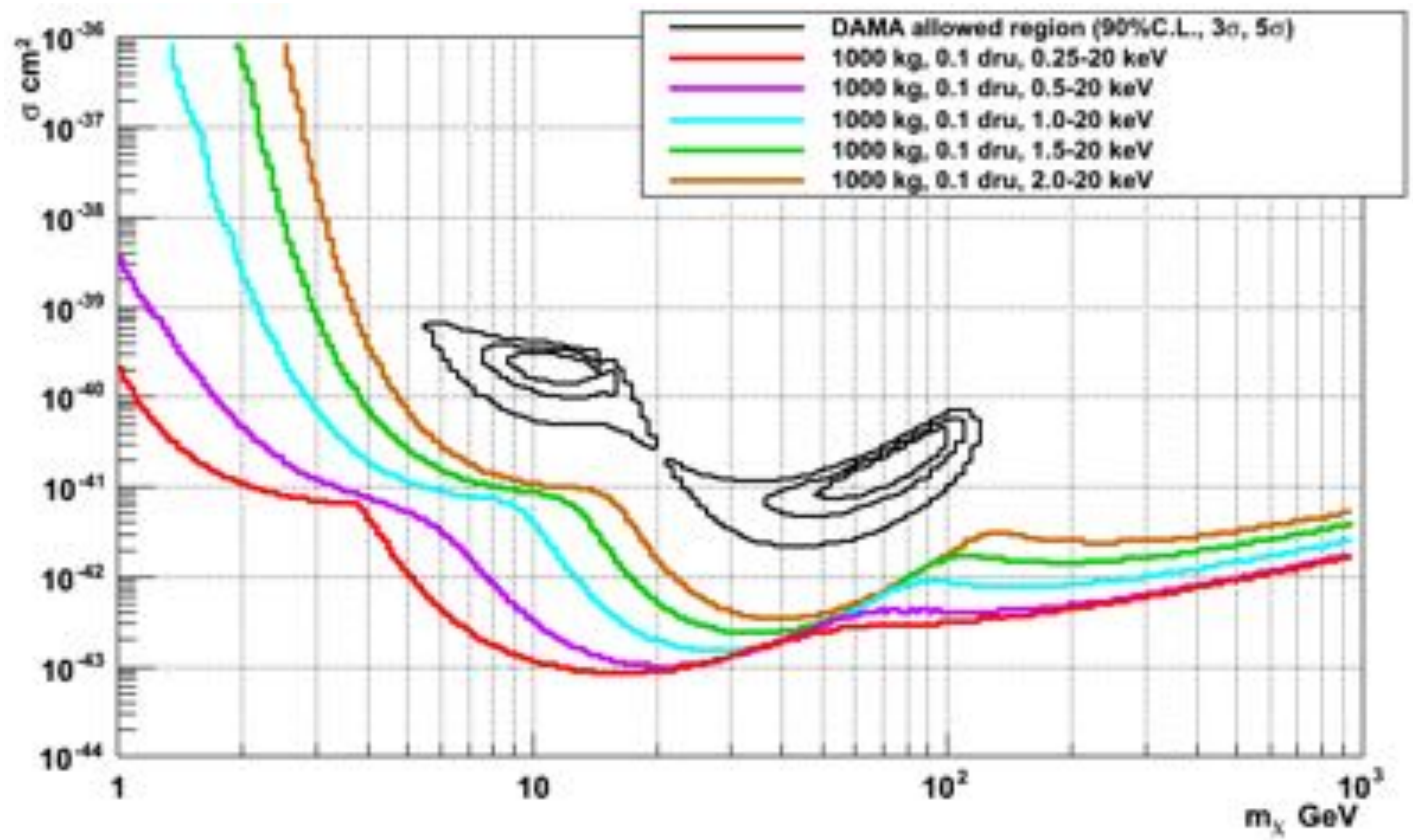
What do we need to test DAMA?

- 500 kg-yr, 1, 2 & 5 cnt/keV/kg/day, 2 - 20 keV



What If…

- 1000 kg-yr, 0.1 cnt/keV/kg/day

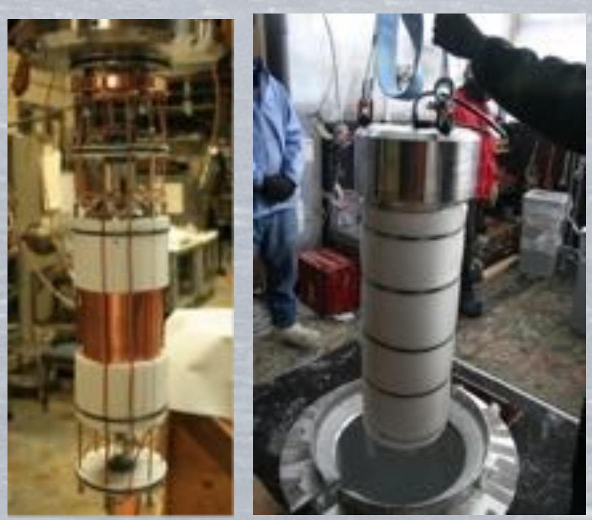


Summary

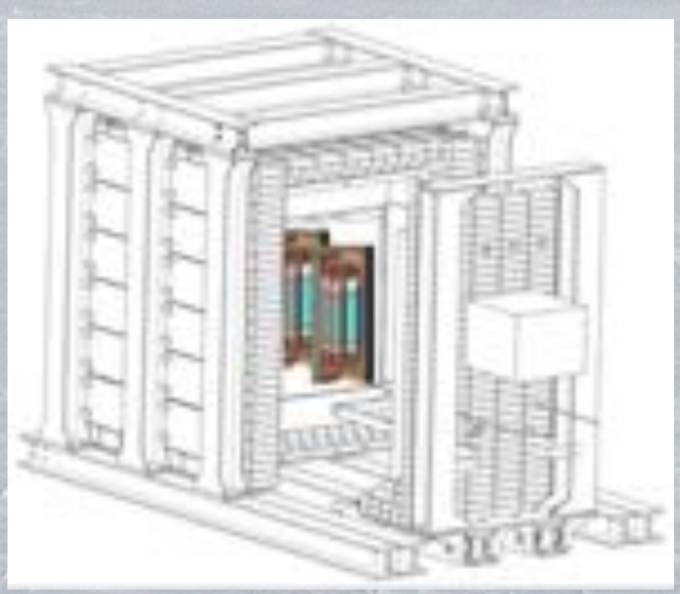
Directly test DAMA's assertion that the observed annual modulation is due to dark matter & understand its origin

- Successful installation and running of DM-Ice17 at the South Pole
- IceCube gives additional information on muons in DM-Ice, DM-Ice may help IceCube's reconstruction
- DM-Ice37 at Boulby, crystal R&D going forward
- 11x reduction in 40K, 8x in 210Pb
- DM-Ice250: unique position in global effort to definitively test DAMA

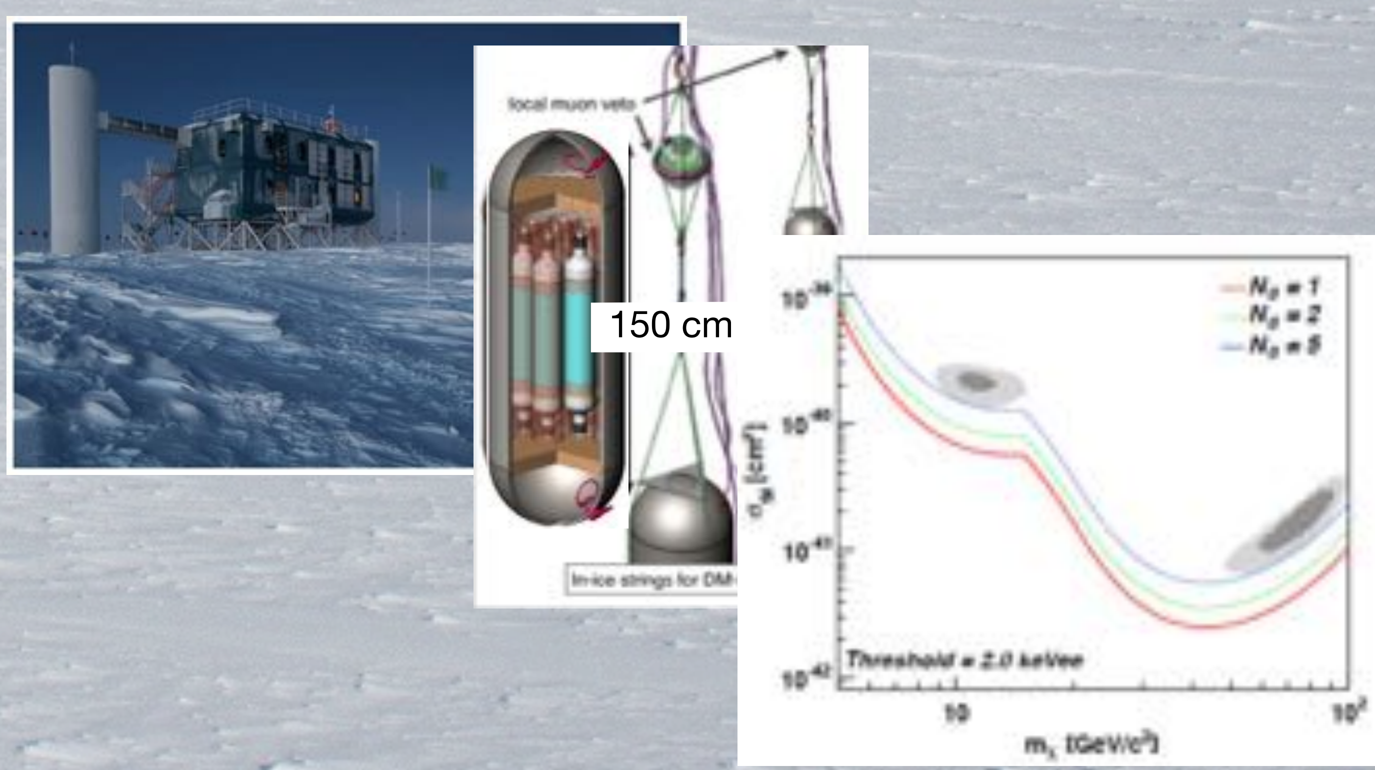
DM-Ice17



DM-Ice 250 North



DM-Ice 250 South



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