DM-Ice

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Closing in on Dark Matter
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WISCONSIN ICECUBE PARTICLE ASTROPHYSICS CENTER

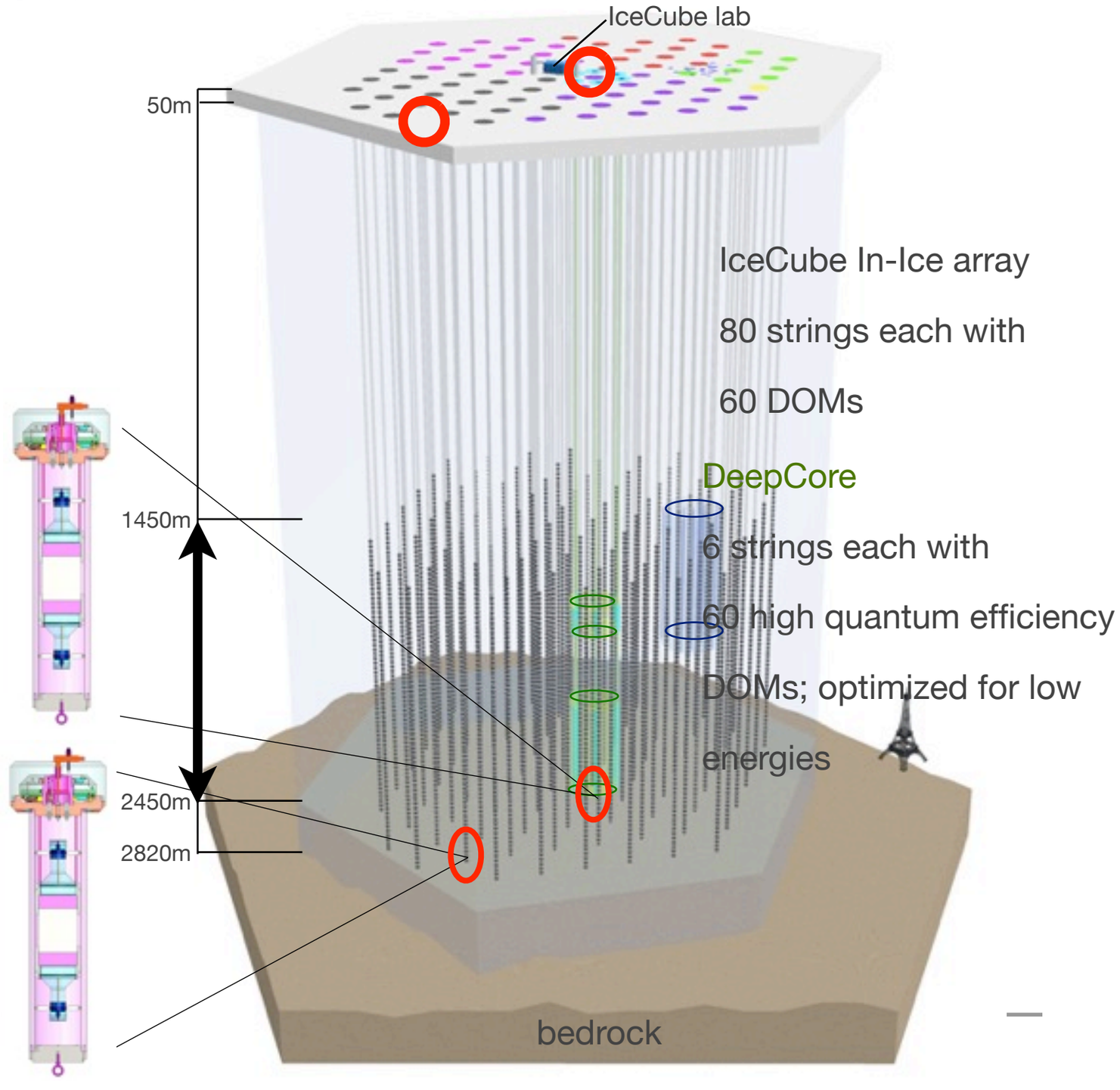
Prototype: DM-Ice-17

Co-Deployed with IceCube at the South Pole in December 2010

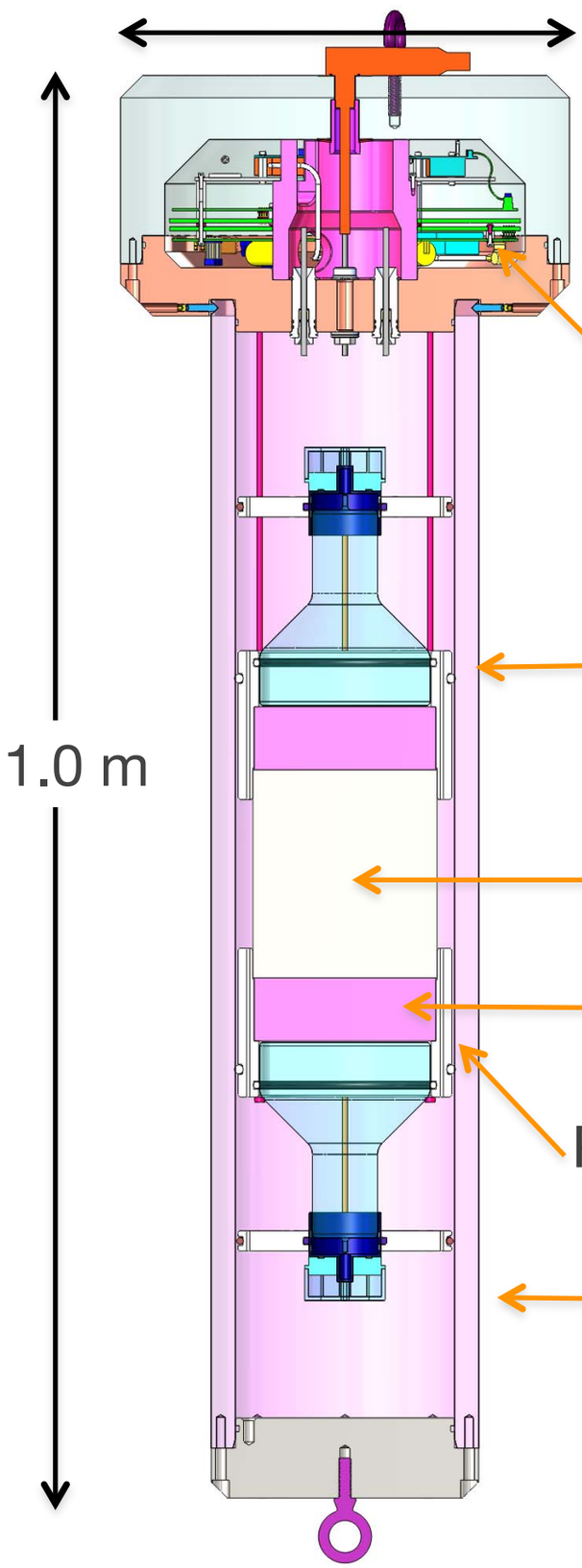
- A 17 kg NaI detector
- Operation since Feb. 2011
- Data run from June 2011
- Data sent over satellite

Goals:

- Feasibility of deploying a remotely-operable dark matter detector in the Antarctic Ice
- Assess the environmental stability
- Establish the radiopurity of the antarctic ice / hole ice
- Explore the capability of IceCube to veto muons
- Look for modulations



DM-Ice-17 Detector



2 IceCube mainboards
+ HV control boards

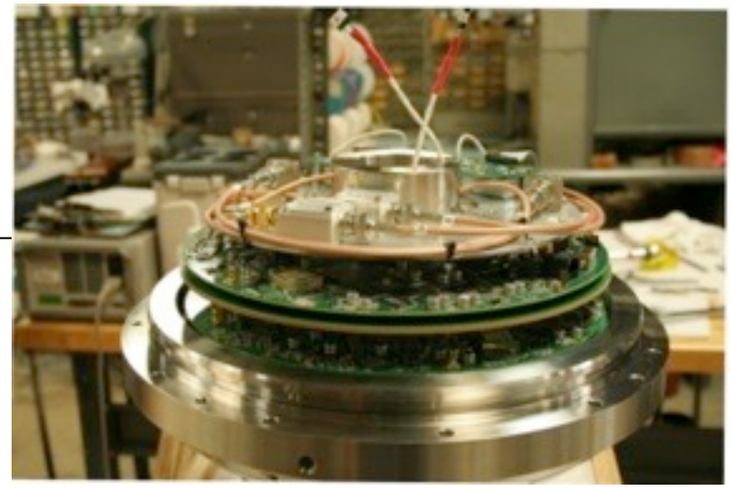
PMTs:
5” ETL 9390UKB

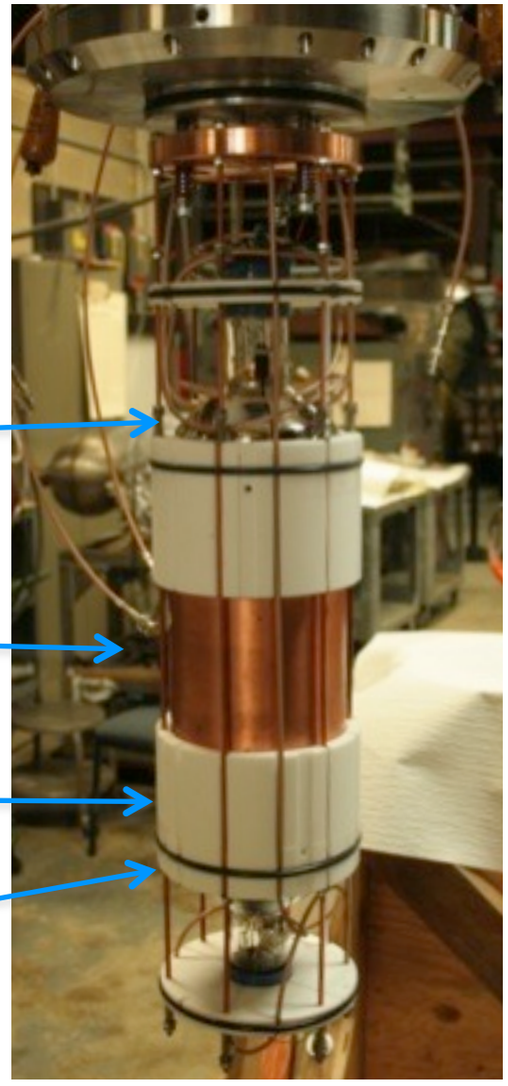
NAIAD NaI Crystal
(5”x5”, 8.5 kg)

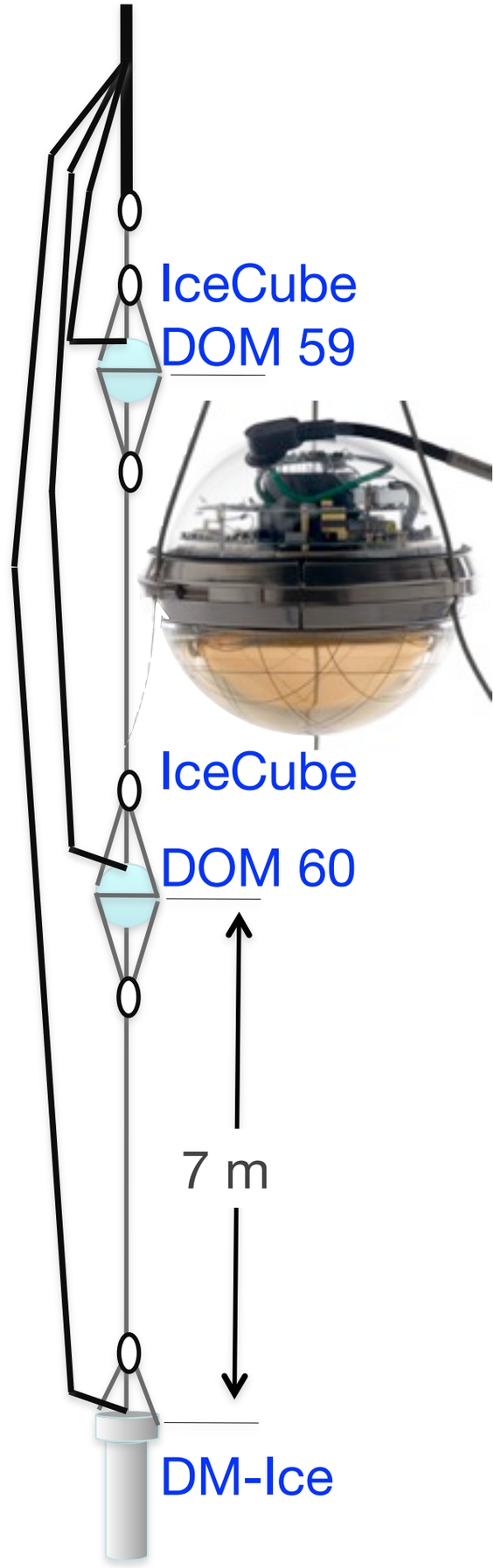
quartz light guides

PTFE light reflectors

Stainless Steel
Pressure Vessel







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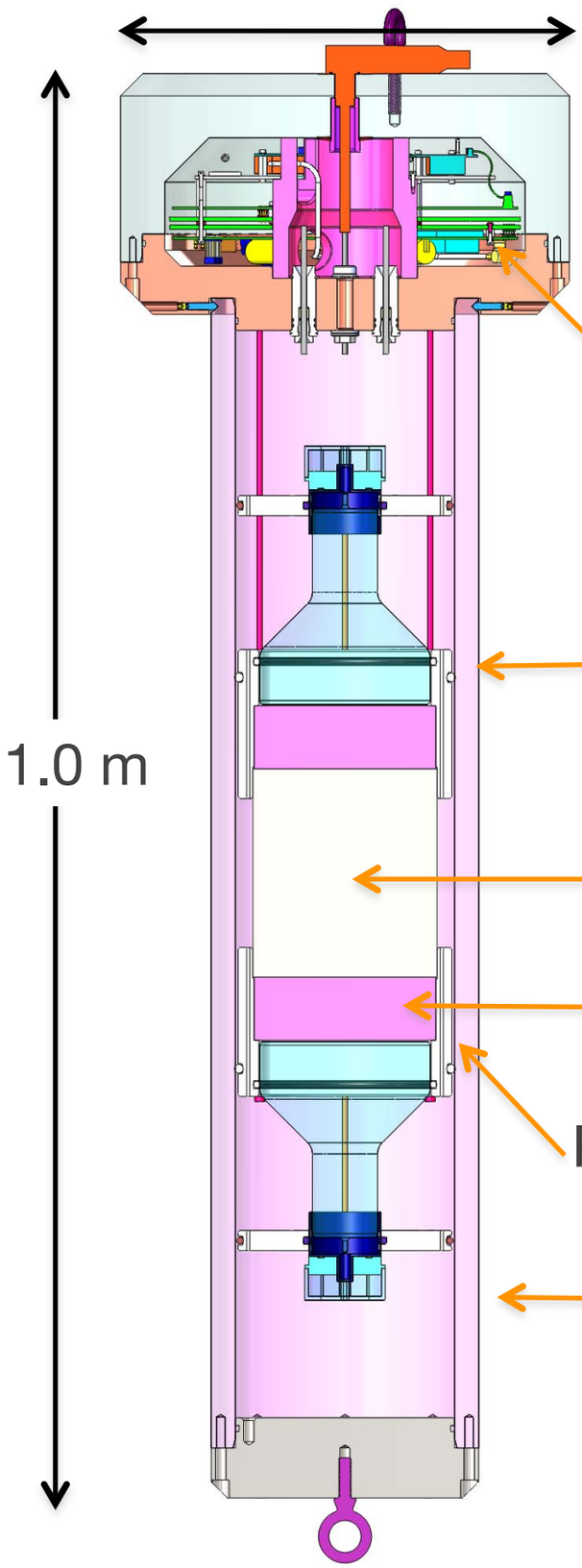
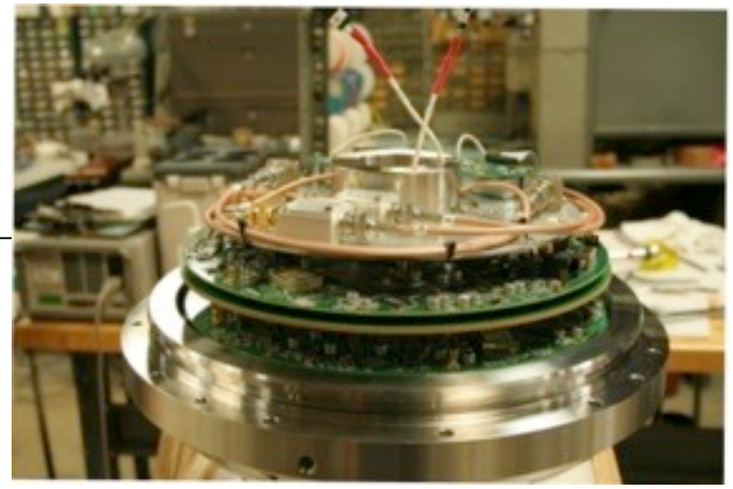
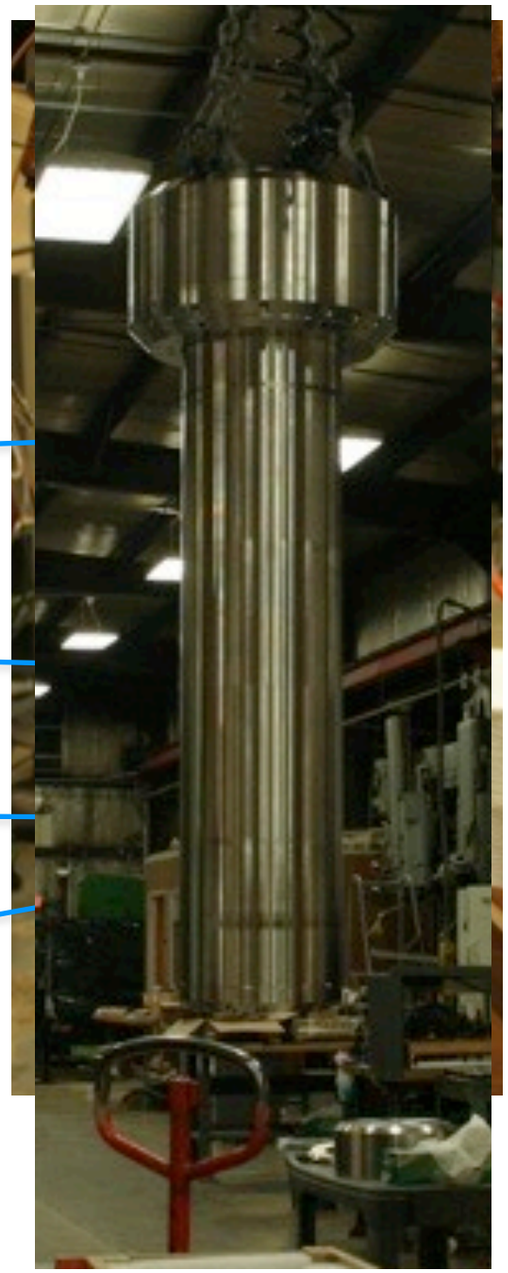
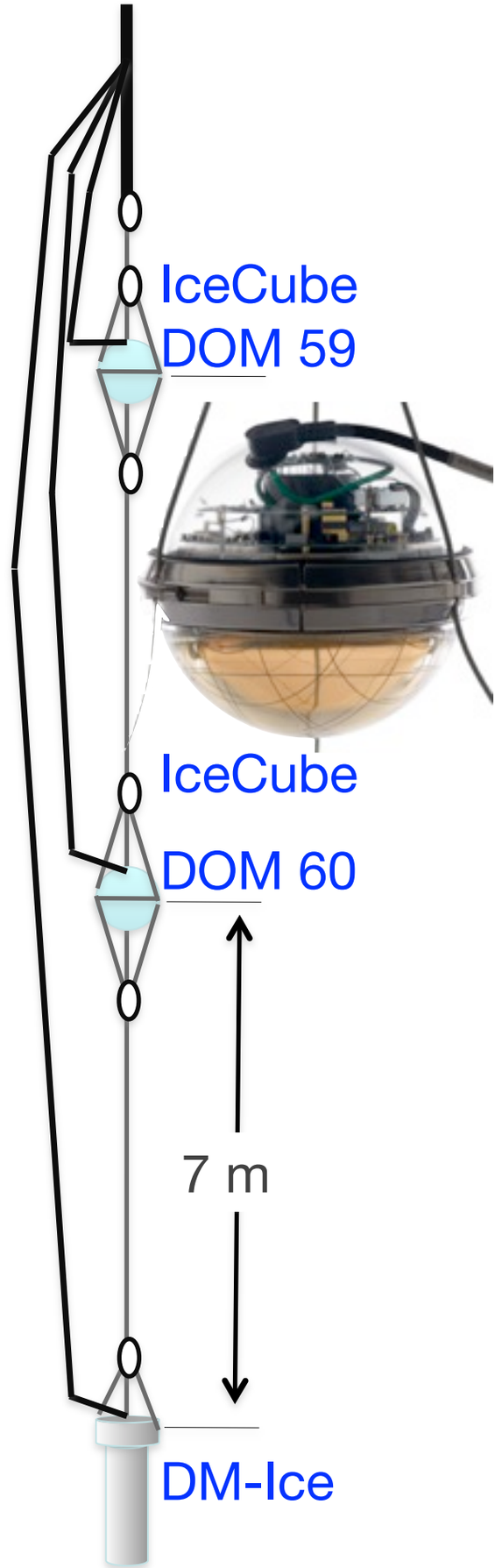








Timeline: DM-Ice17

Autumn 2009

- South Pole considered seriously as a site for NaI(Tl) dark matter search

Spring 2010

- Former NaIAD crystals identified as candidates to be used for prototype, two crystals taken out of underground storage at Boulby for testing
- Preliminary design, identify and purchase materials for detector housing and support structure
- IceCube electronics tested on NaI(Tl) detectors

Summer 2010

- Detectors tested underground at Boulby with NaIAD and IceCube electronics
- Design finalized, materials purchasing continues

Autumn 2010

- parts machined
- Detectors shipped to Wisconsin, tested, and assembled
- Final detector testing and calibration
- **November 5, 2010** Detectors ship out to the South Pole

December 2 - 10, 2010 detectors tested at the South Pole

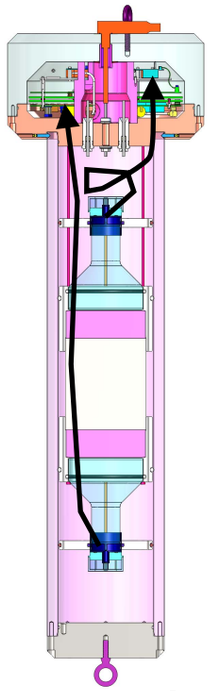
December 11 & 16, 2010 detector deployment

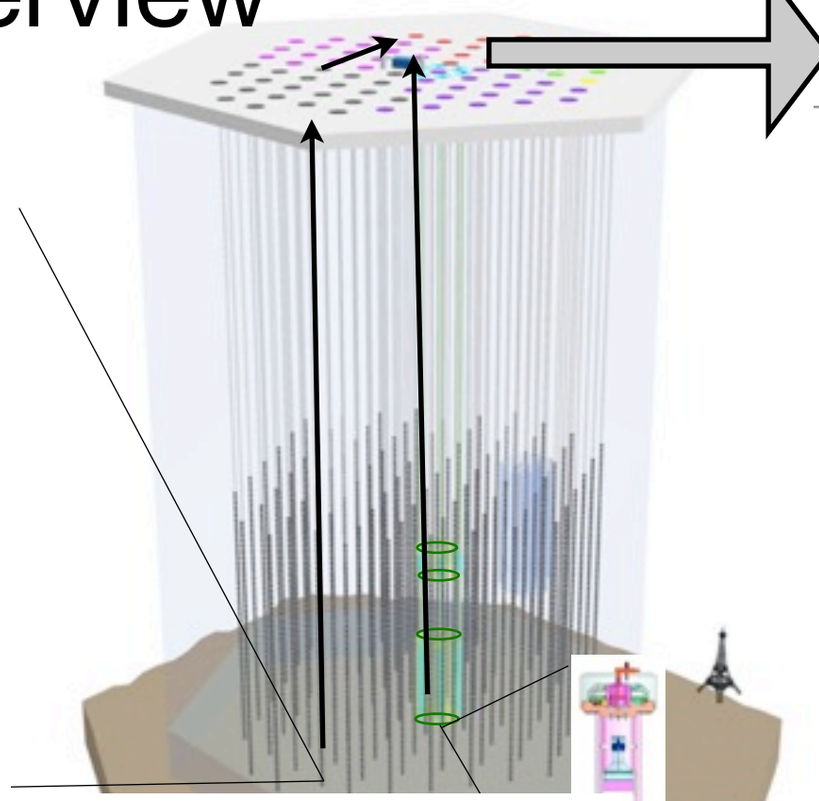
January - March 2011 Detectors freeze in, commissioning

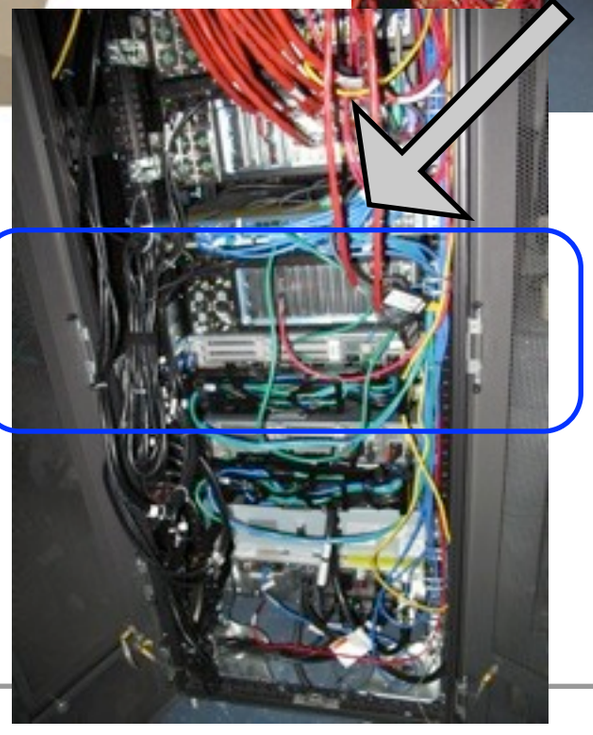
March - June 2011 Detector characterization at different settings

June 2011 - Present Continuous running

DM-Ice17 DAQ Overview



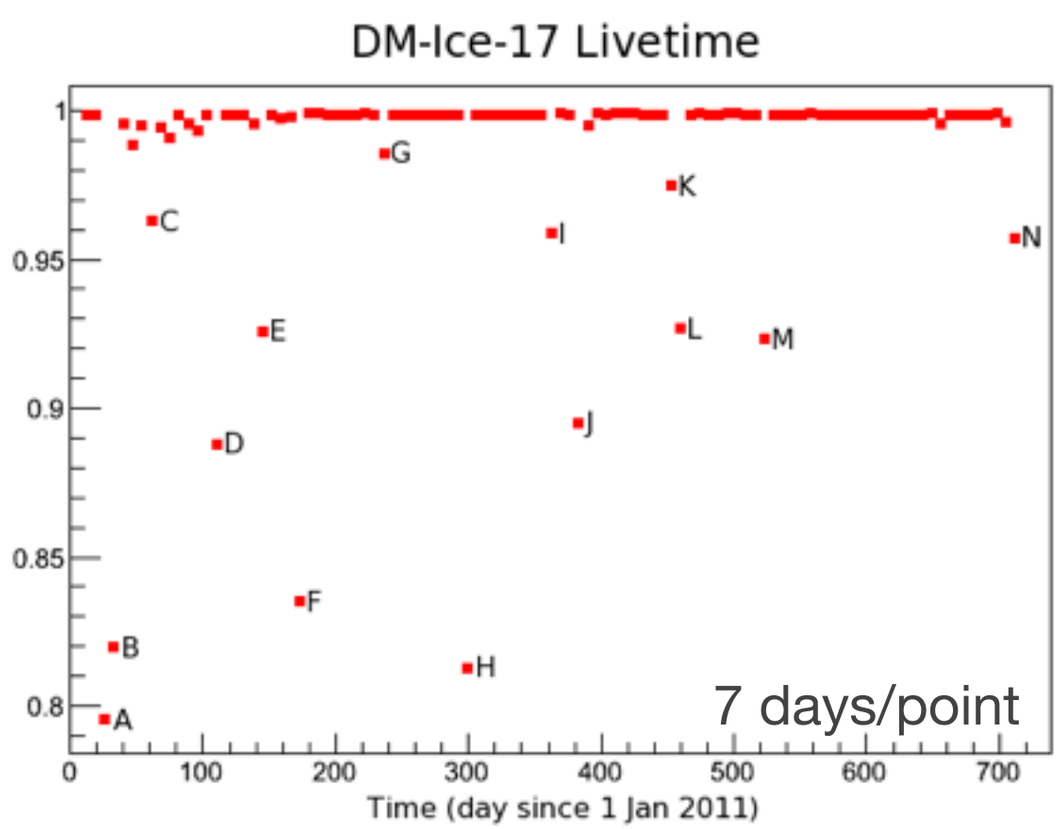




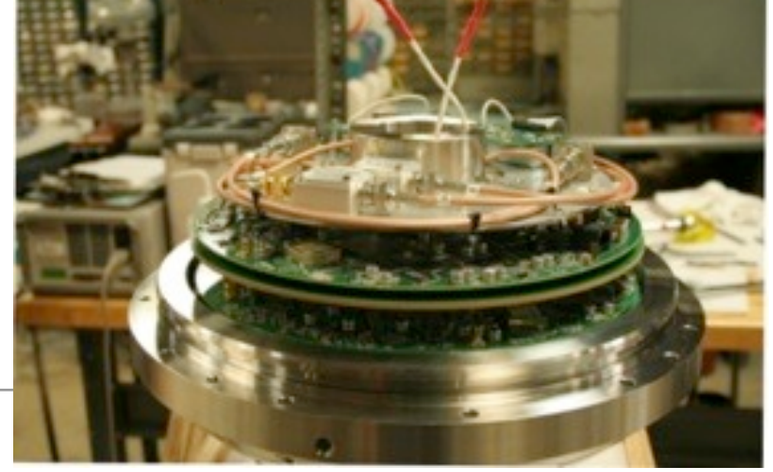
- Remotely programable sample rate, HV & threshold
- Each PMT set to trigger ~1/10 spe
- Waveform recorded only when coincidence between both PMTs w/in 800 ns on a single crystal
- Waveform from each PMT digitized separately in the ice by IceCube mainboards and sent to hub
- Time stamp synchronized to IceCube GPS and calibrated for transit time
- Data sent over satellite to Madison, WI

Detector Uptime

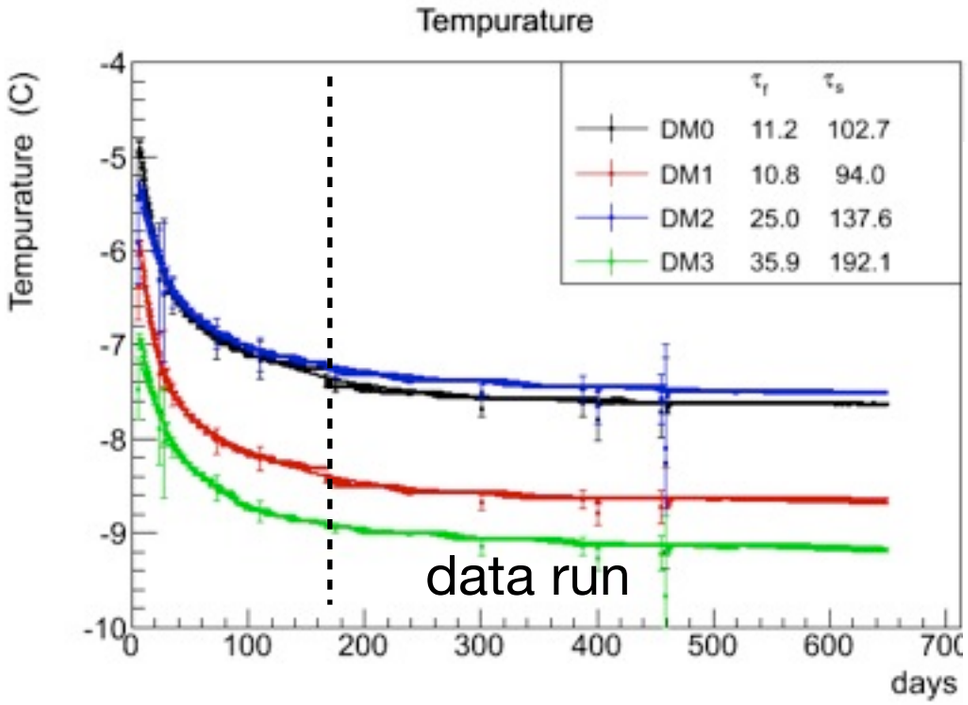
- Commissioning and optimization from Feb - June 2011
- Data run since June 2011
- 99.8% uptime for most weeks with well defined down time for occasional power cycling + pedestal and dark noise runs

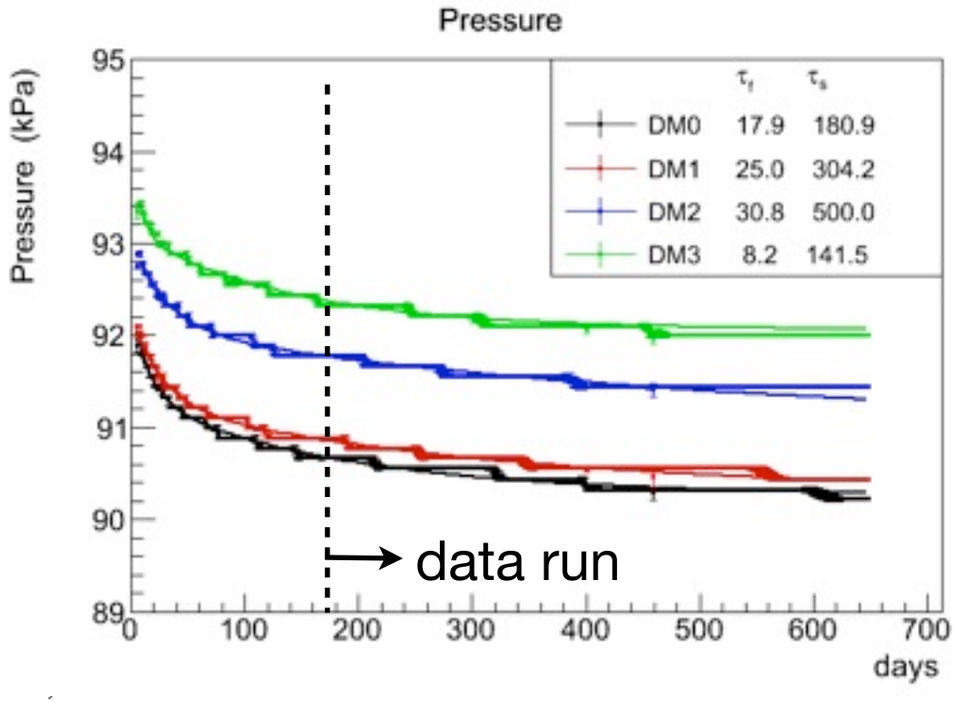


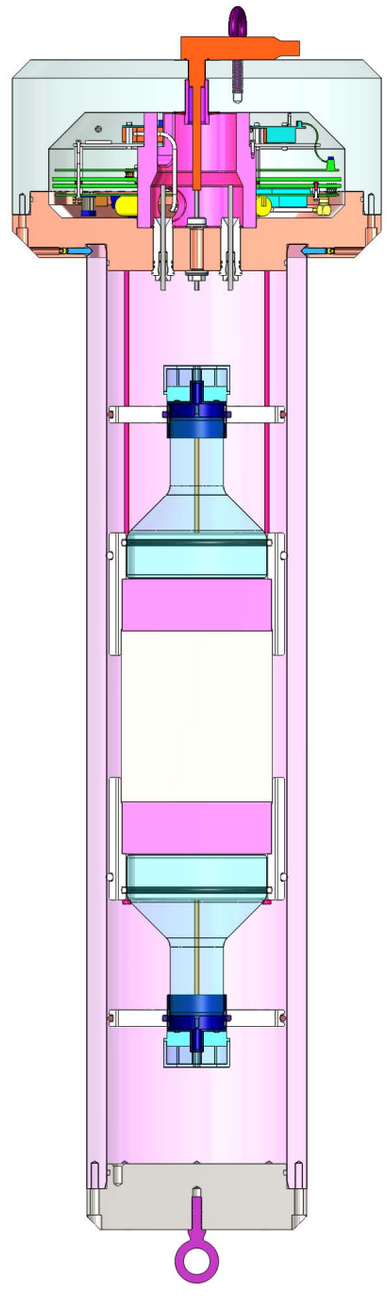
Detector Monitoring



- 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 April 2012. Every 60 sec. since April 2012.

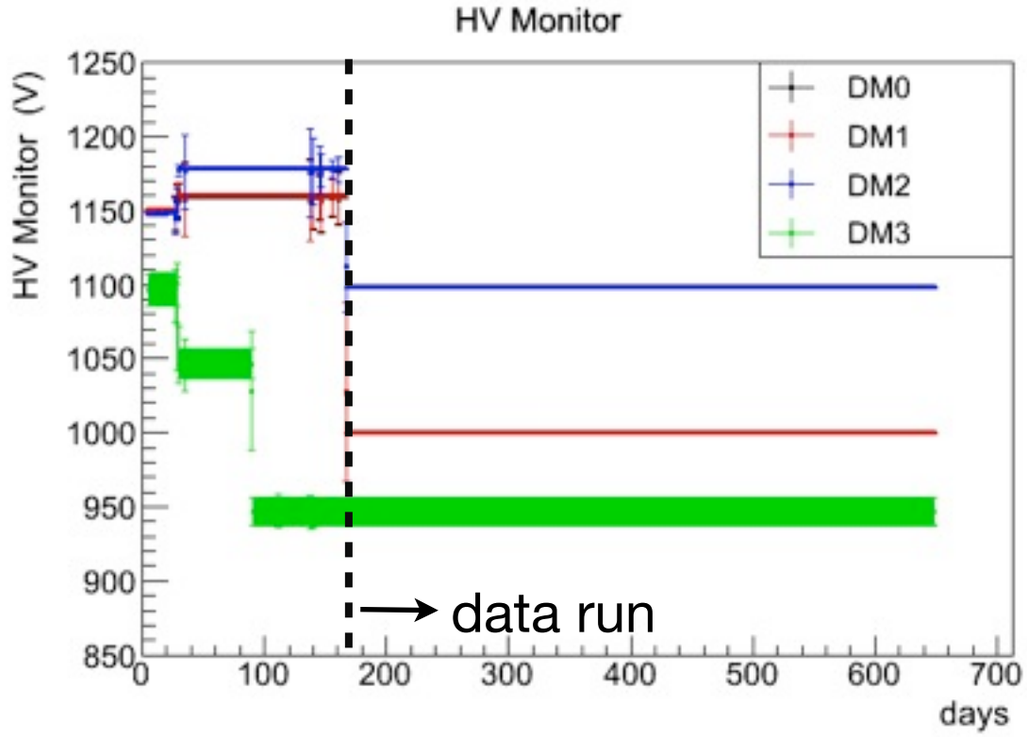


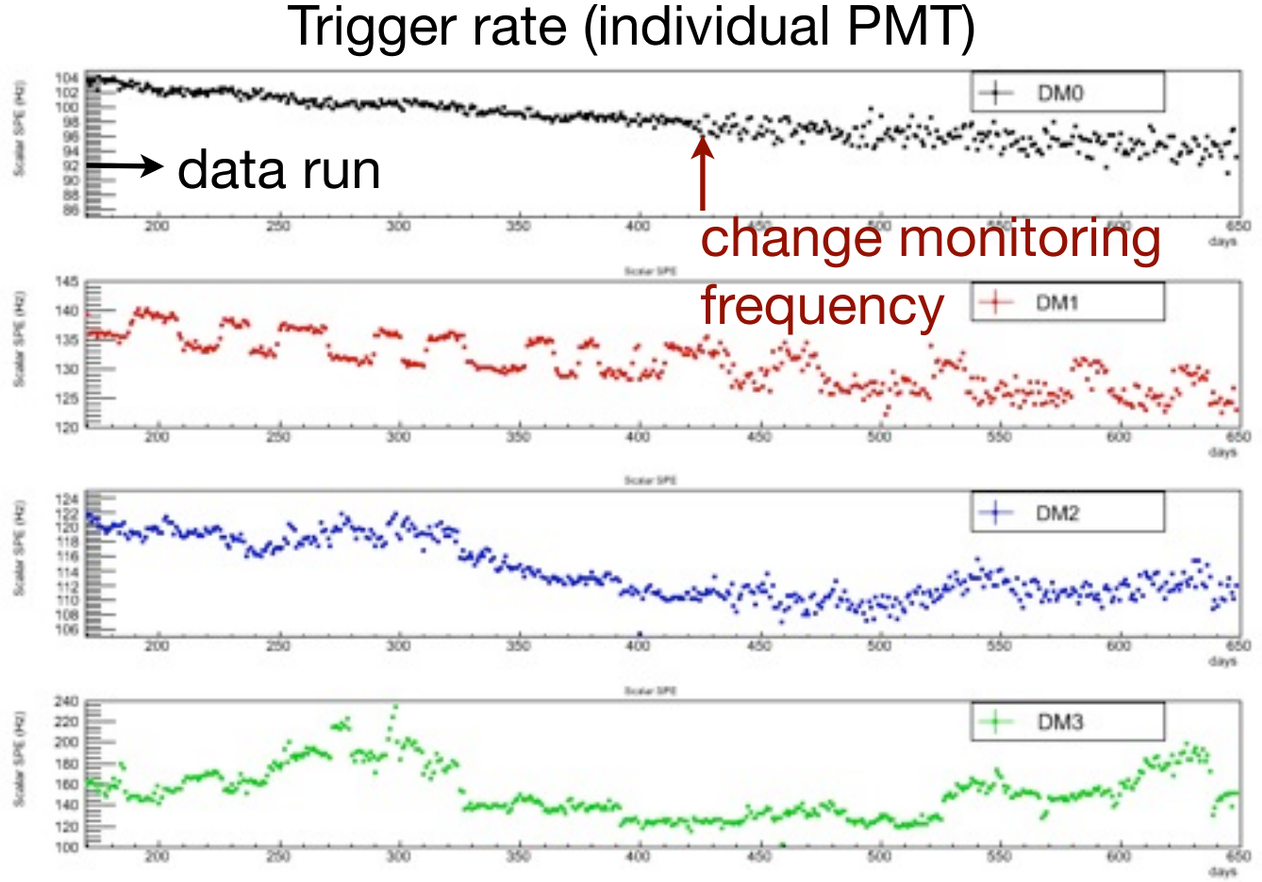




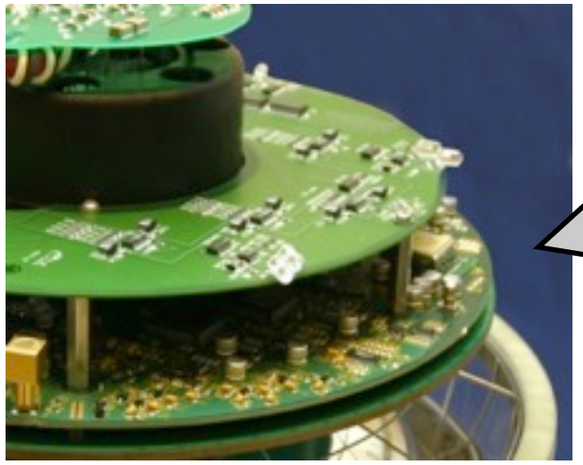
Detector Monitoring

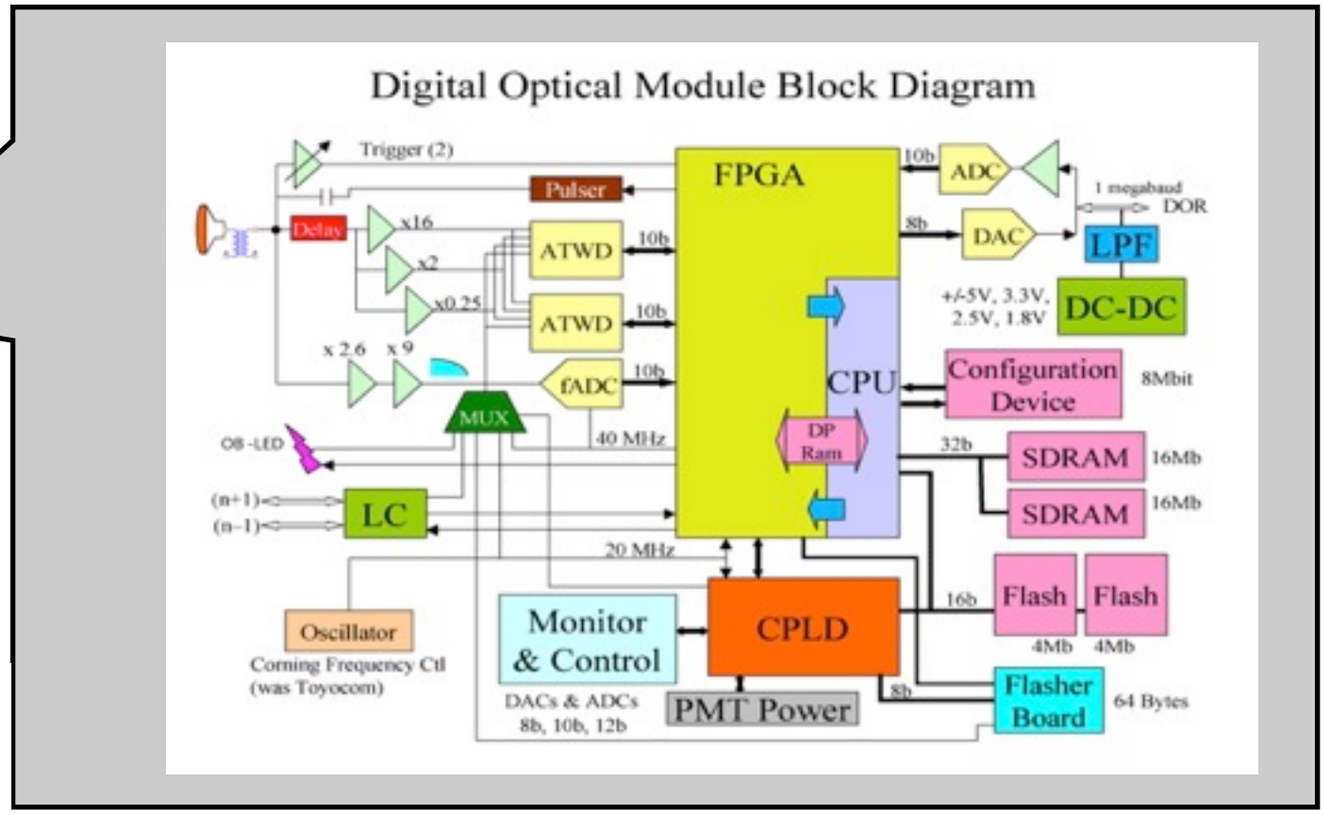
- High voltage of each PMT
  - commissioning until day 167
- Single PMT total trigger rate
  - General decay over time
  - single trigger rate variation seems mostly in the noise (not observed in coincidence data after cuts)



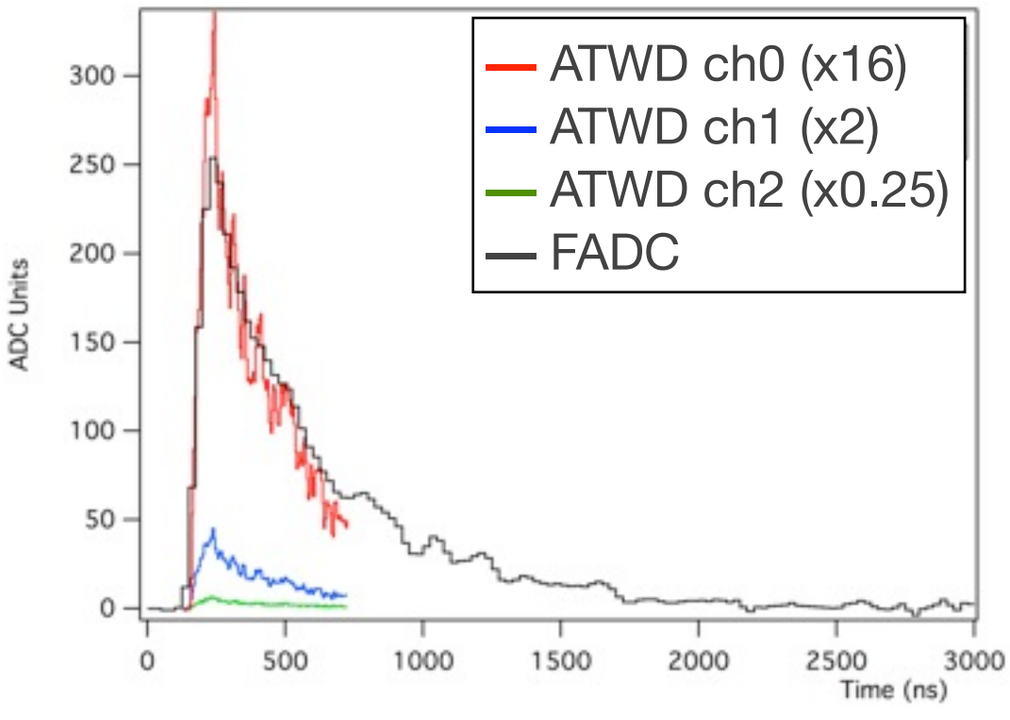


Capturing Waveforms with IceCube Mainboards





Example waveform from all channels



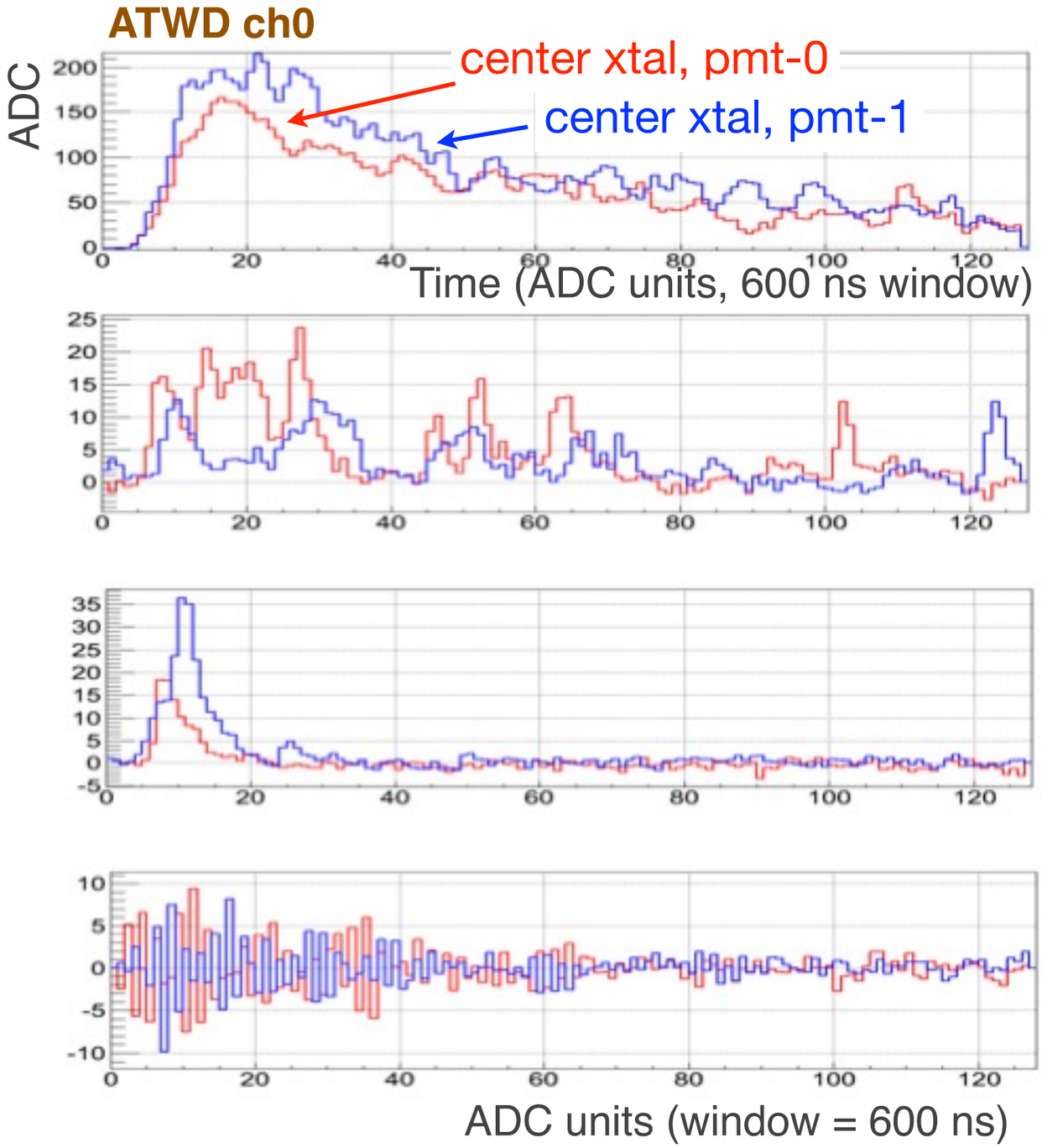
ATWD:

- 213 MS/sec x 128 samples = 600 ns window
- 3 gains:
  - channel-0: high gain
  - channels-1 & 2: useful for > 1500 keV where ch-0 is saturated

FADC: slower sampling rate, wide time window

- 40 MS/sec x 256 samples = 6.4 μsec time window (3 μs shown)

Waveform Examples



high energy events (>100 keV)

Typical scintillation pulses with decay time ~350 ns

low energy events (<100 keV)

single photo-electrons visible

"thin" pulses

Fast pulses with large amplitudes

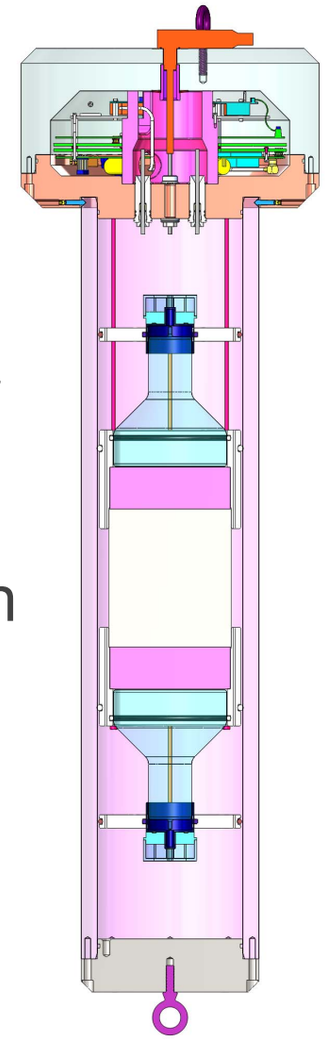
"flashers"?

"EMI" events

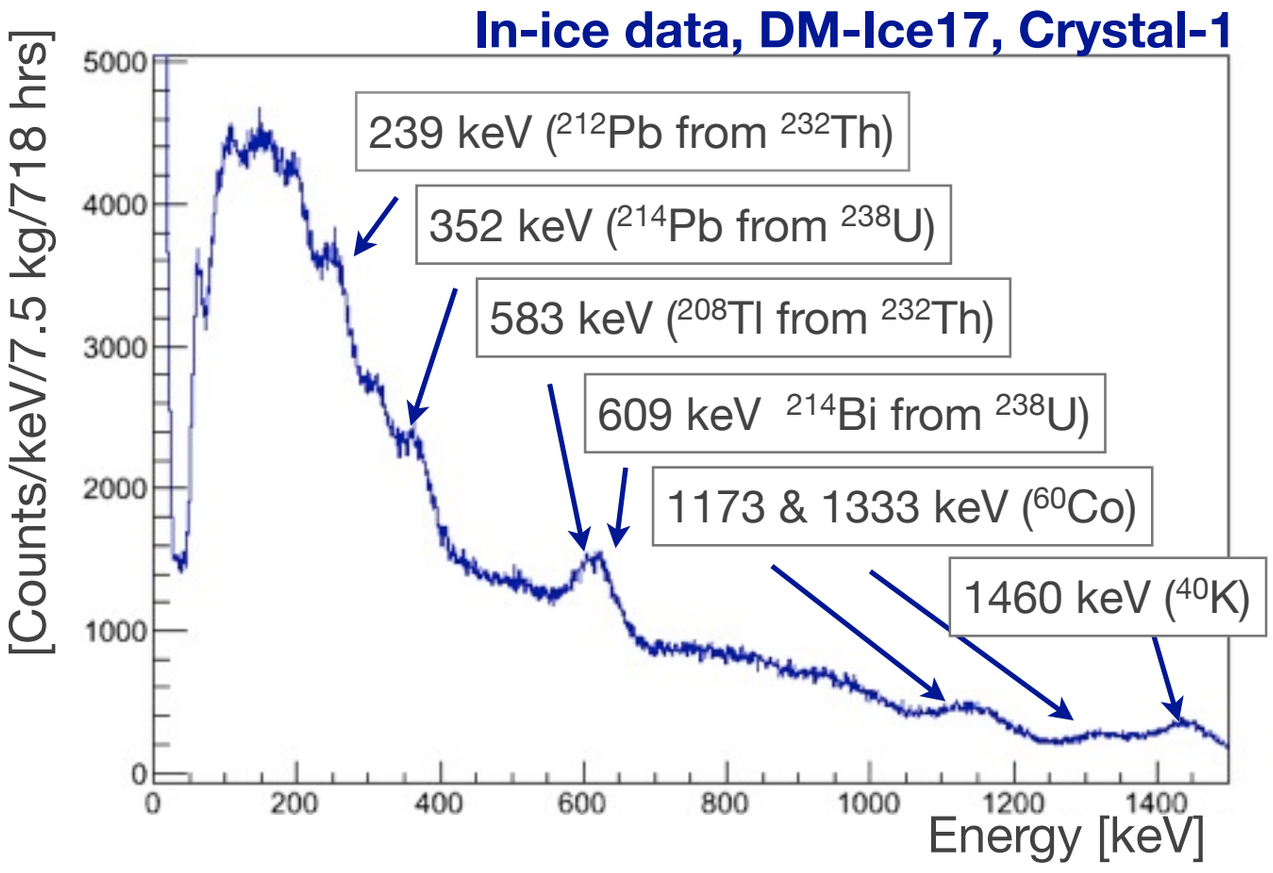
Interference with detector monitoring.

Well characterized by timing and shape.

(no interference with IceCube or ARA seen)



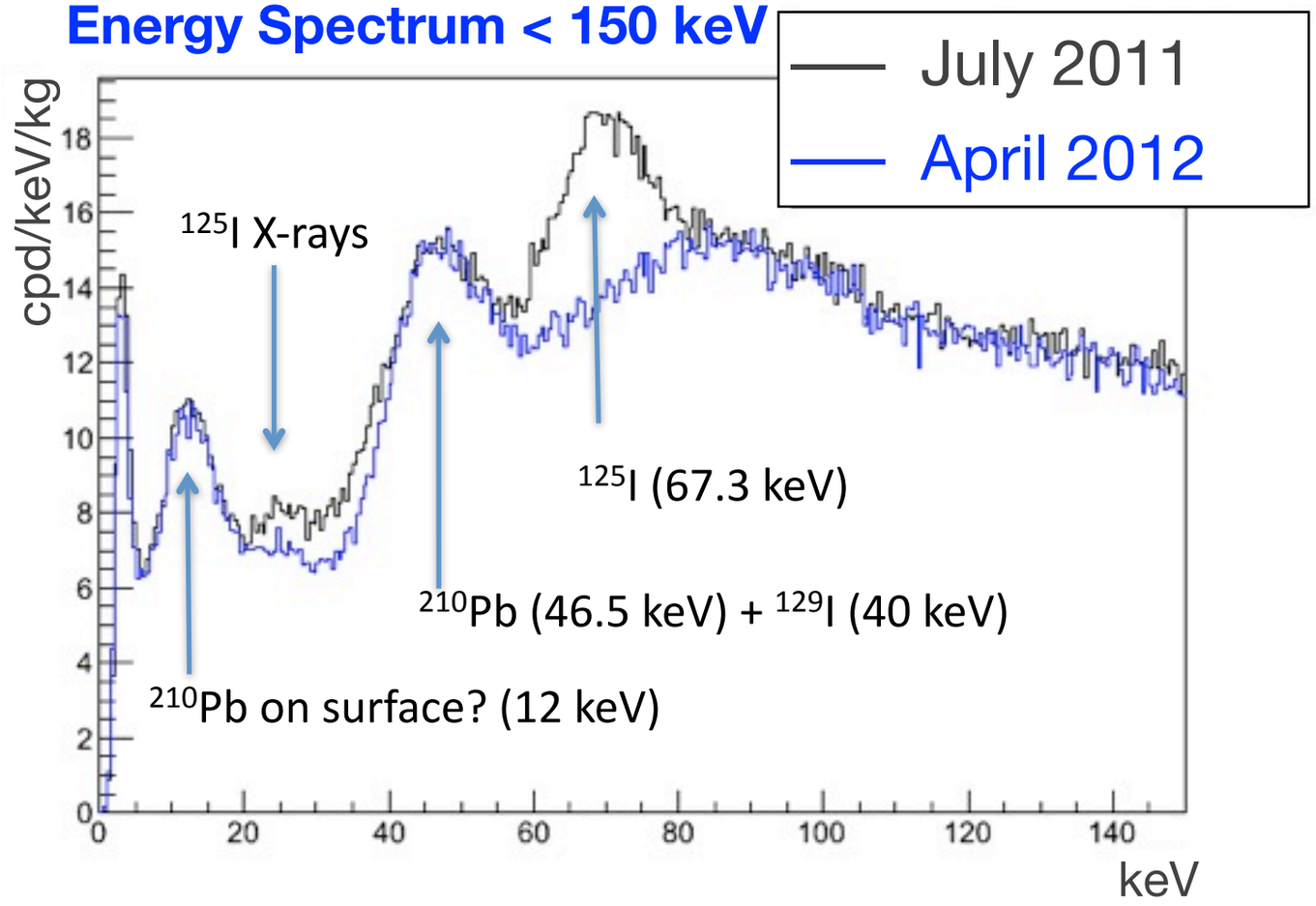
DM-Ice17 Energy Spectrum



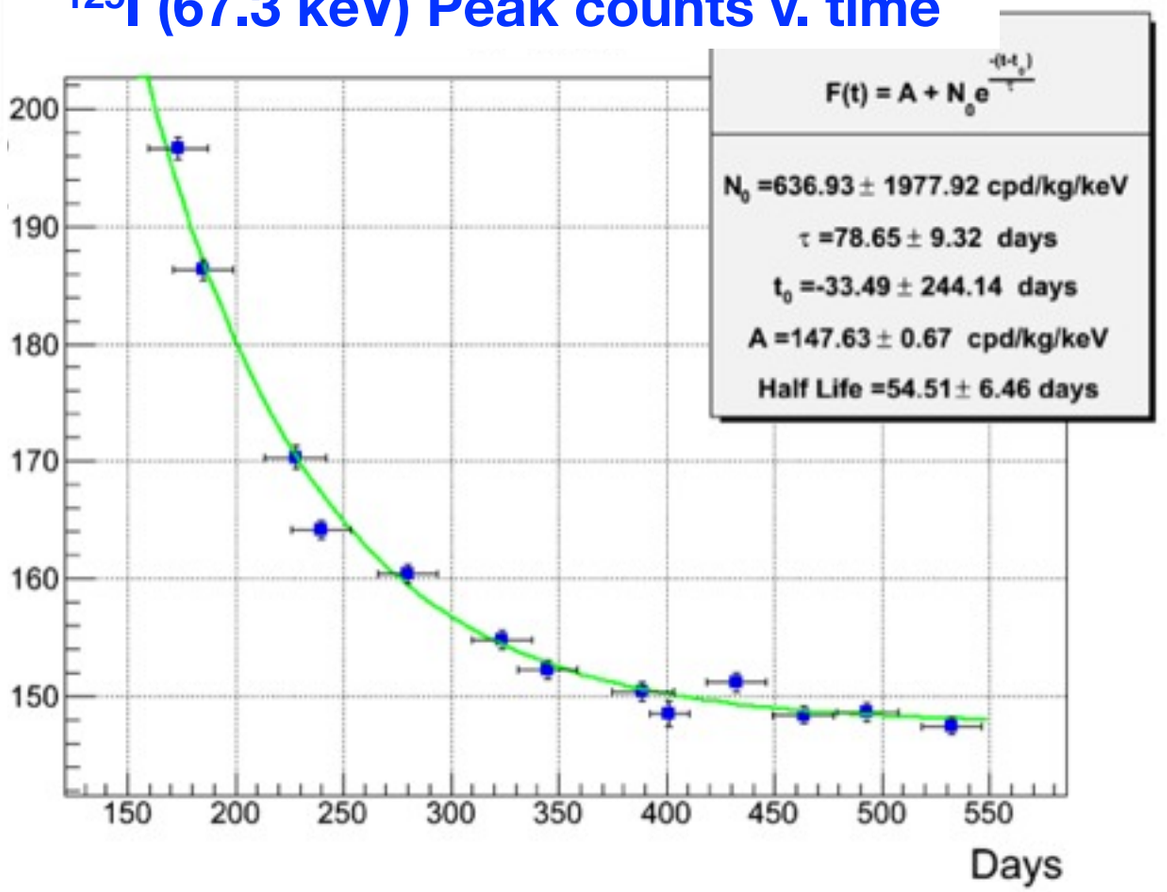
- Energy = integral(waveform)
- Detectors calibrated using internal lines
- Spectra compared & verified with source calibration at Madison and Boulby
  - ^{207}Bi (569.7 & 1063.66 keV)
  - ^{60}Co (122.06 & 136.5 keV),
  - ^{57}Co (1173.34 & 1332.50 keV)
- Calibration stable over >18 months

Low Energy Spectrum

Energy Spectrum < 150 keV

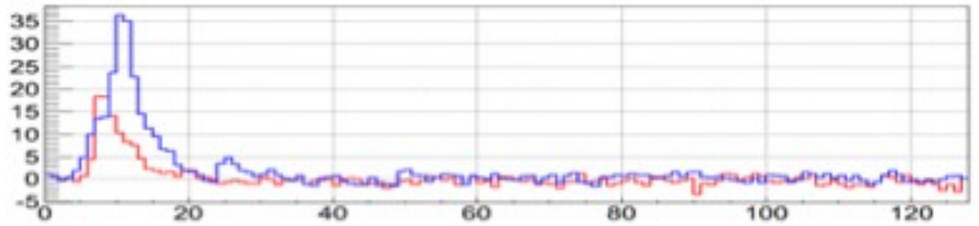


^{125}I (67.3 keV) Peak counts v. time



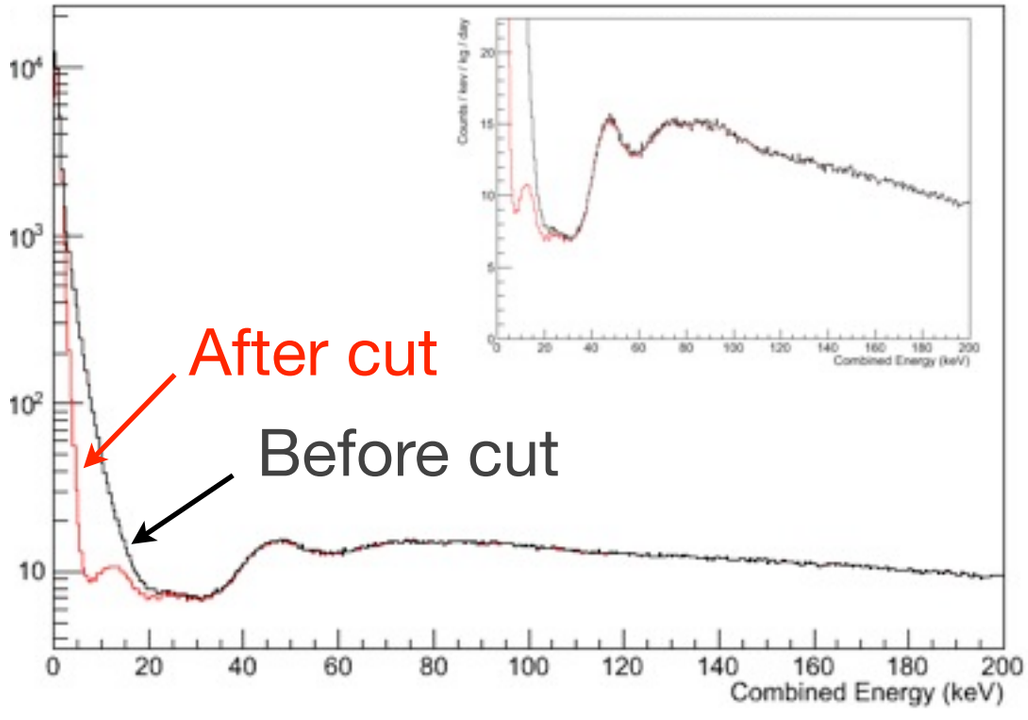
- Spectrum well understood down to 8 keV
- Low energy region calibrated with several lines
- Cosmogenic activation of ^{125}I observed with $T_{1/2}$ = 59.4 days

Event Selection: “Thin” pulses

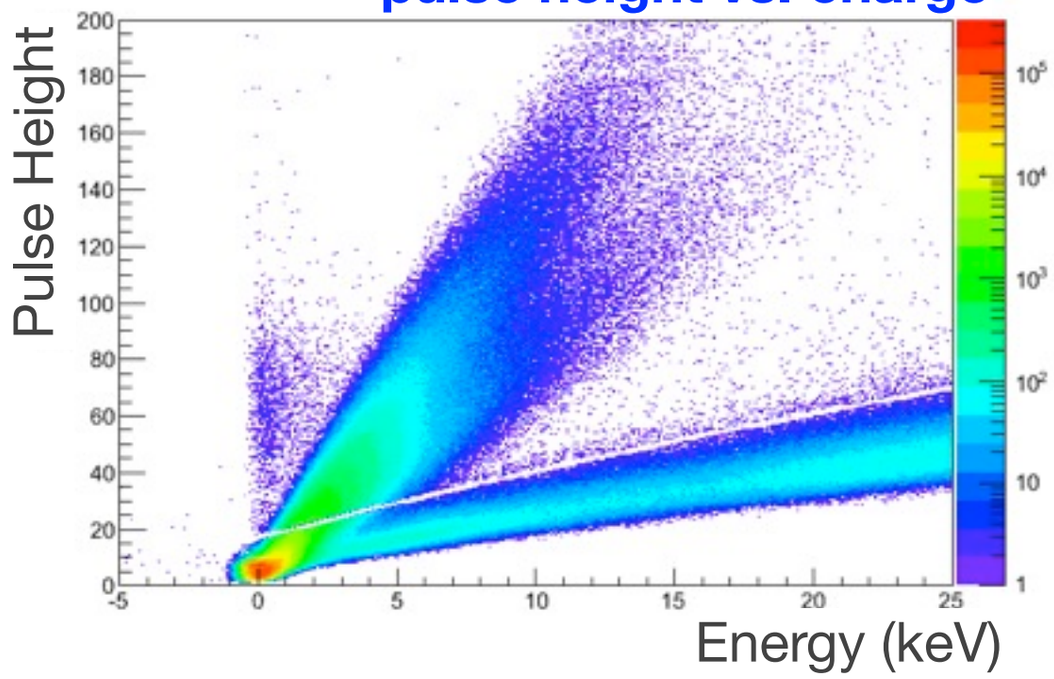


- Characteristics:
  - high pulse-height relative to charge
  - asymmetric between two PMTs
- 90% of events between 5-10 keV are “thin”
- Current cut effective above 7 keV

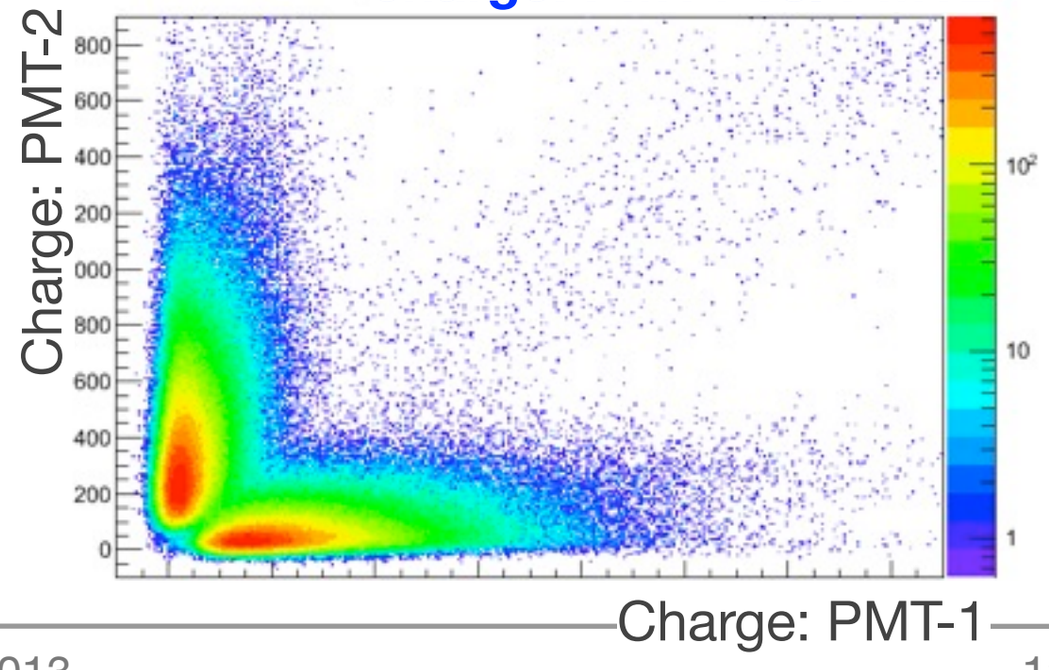
energy spectrum: before & after thin pulse cut



pulse height vs. charge

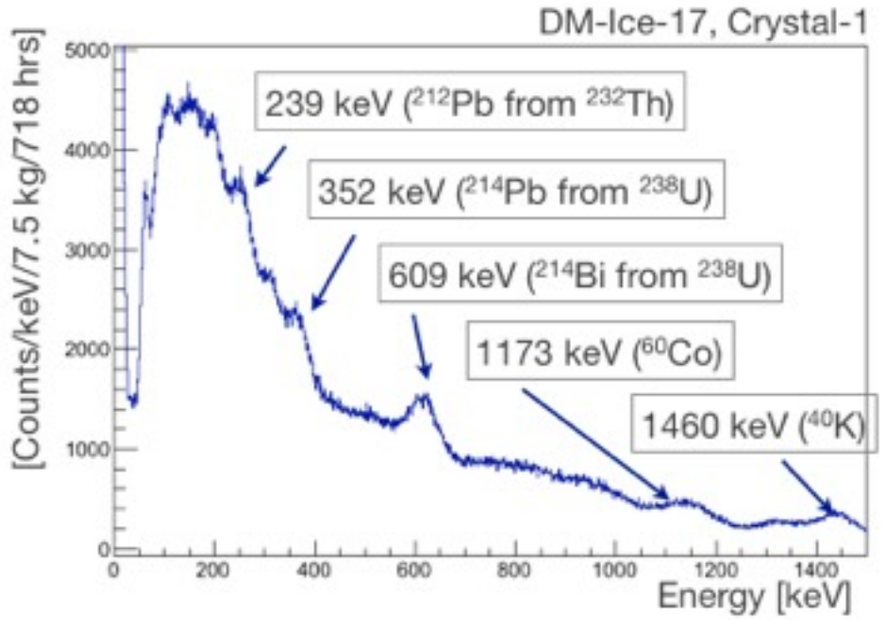


charge: PMT1 vs. PMT2



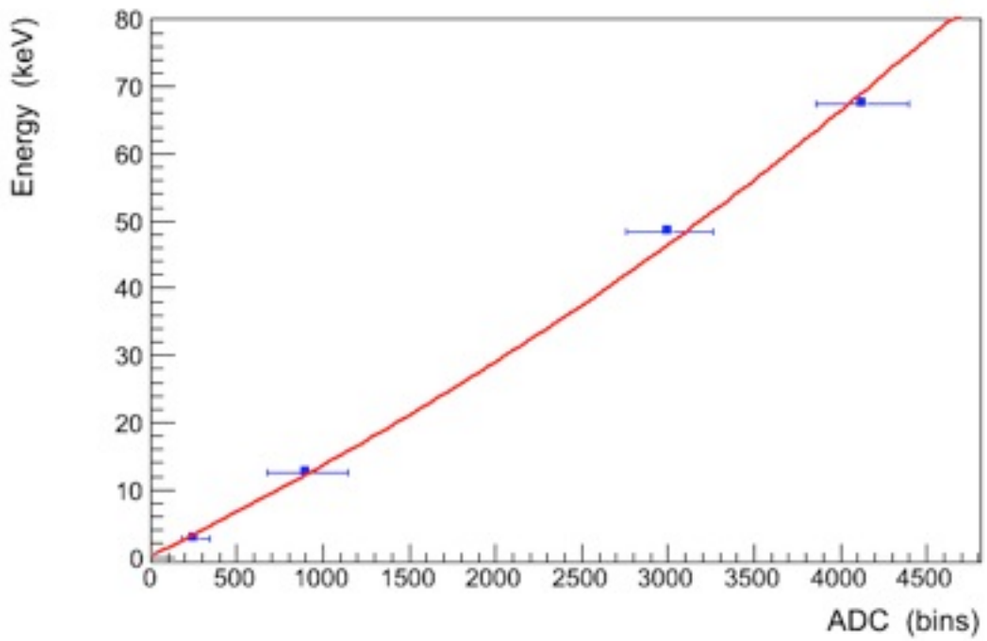
Energy Calibration

- power law < 100 keV
- linear >100 keV

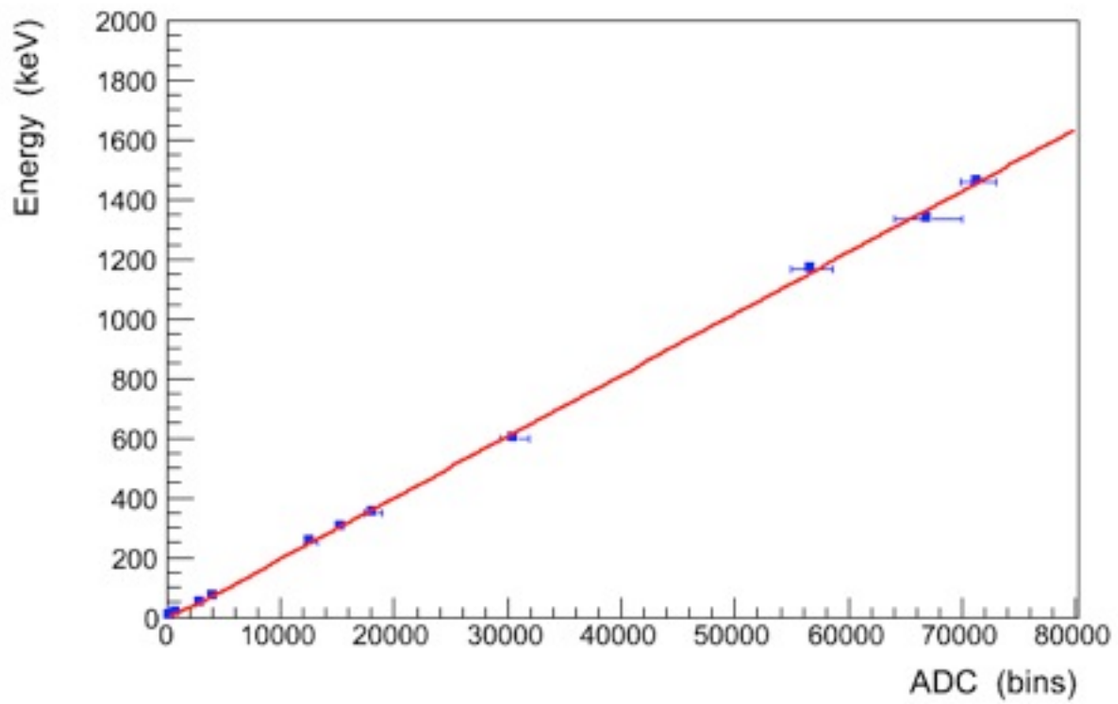


Energy (keV)	source
3.2	K-40
12.5	Pb-210
46.5	Pb-210
67.3	I-125
252	Pb-212, Pb-214
301	Pb-212
352	Pb-214
599	Tl-208, Bi-214
1166	Bi-214, Co60
1333	Co-60
1460	K-40

0 - 80 keV

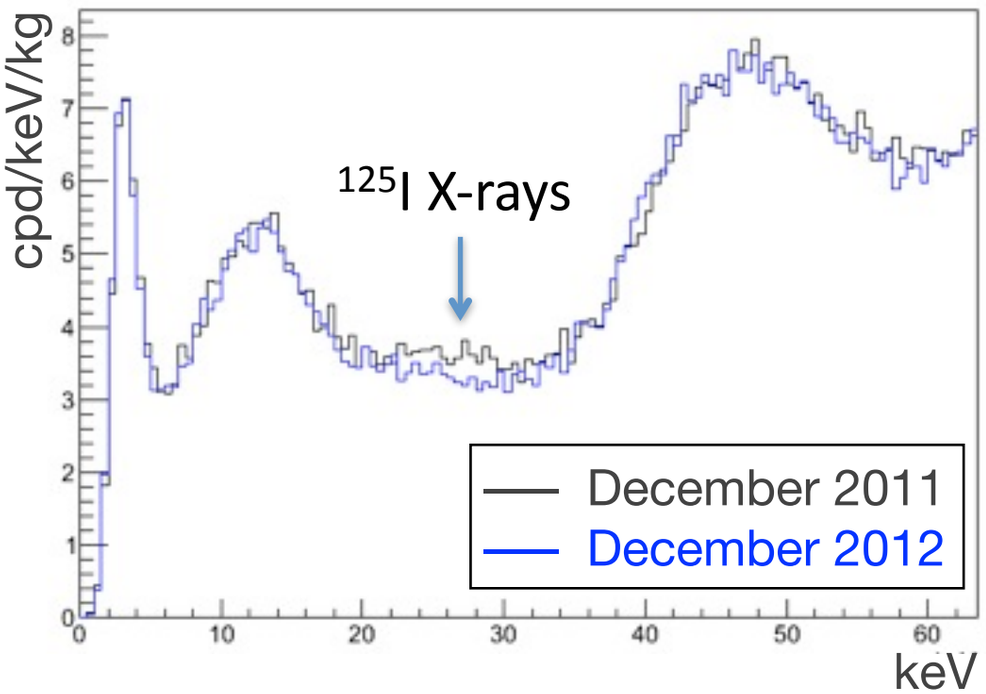


0 - 2000 keV

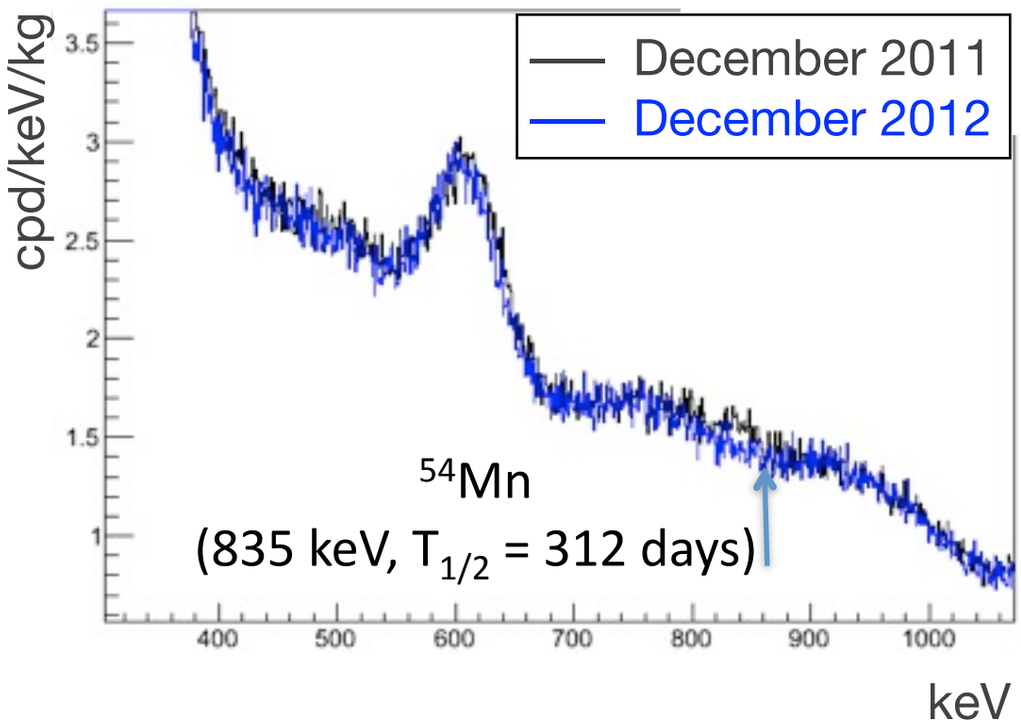


Detector Stability

< 60 keV



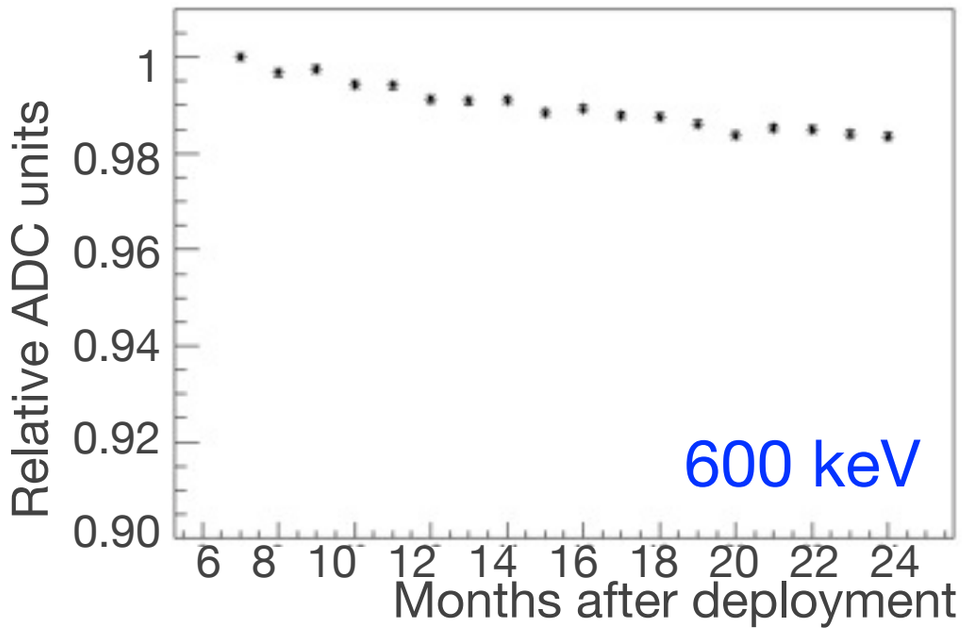
300 - 1100 keV

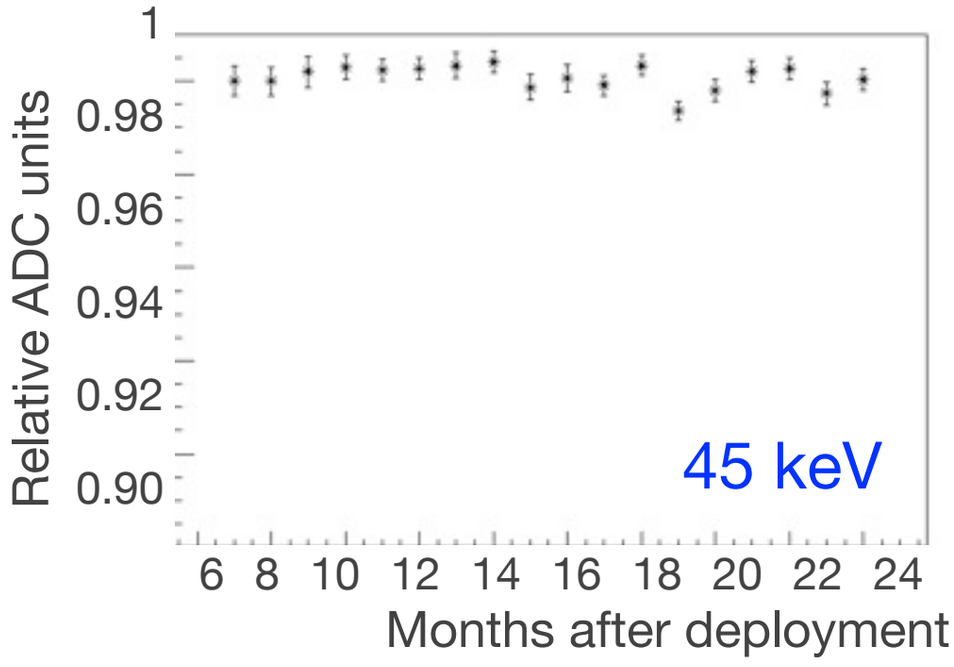


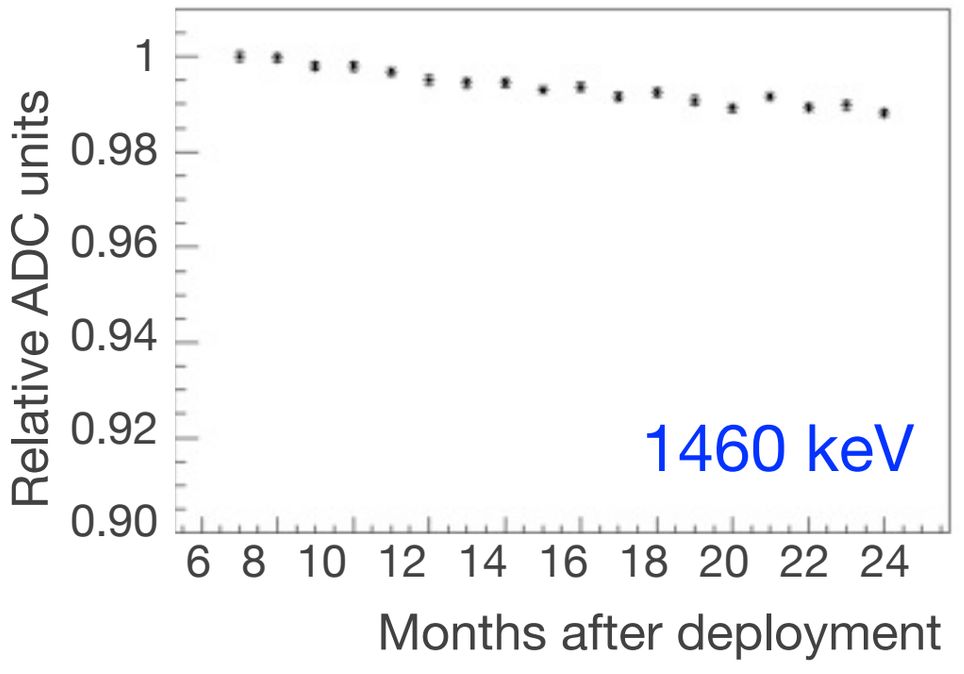
- Spectra are nearly identical over the course of one year
- Longer half-life cosmogenic lines also visible (^{54}Mn, ^{125}I x-rays)

Gain Stability

- Detector calibration is stable to 1% over 18 months.
- 1% decrease over 18 months in light collection (peak position) observed at 600 and 1460 keV
- No observable change in calibration at 45 keV

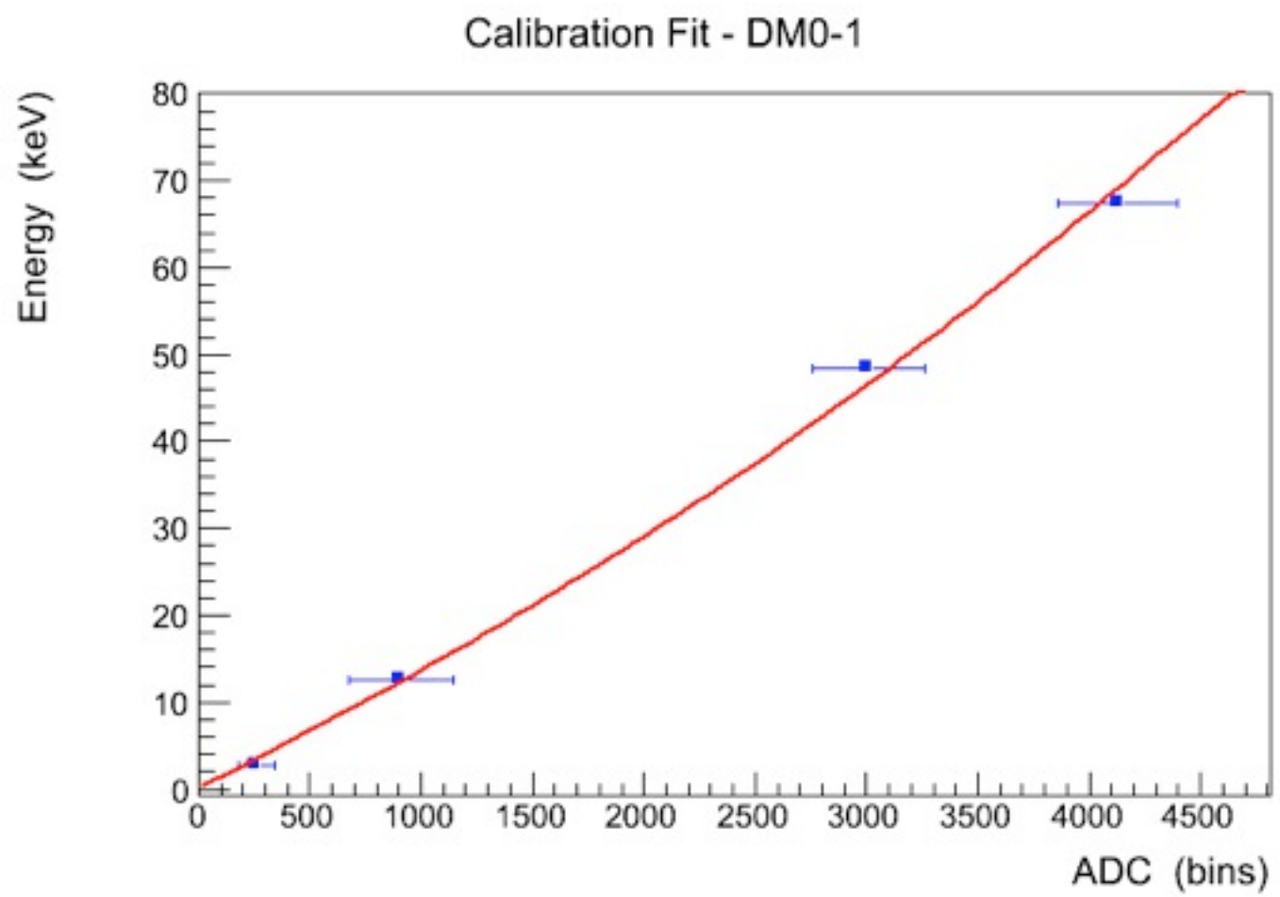


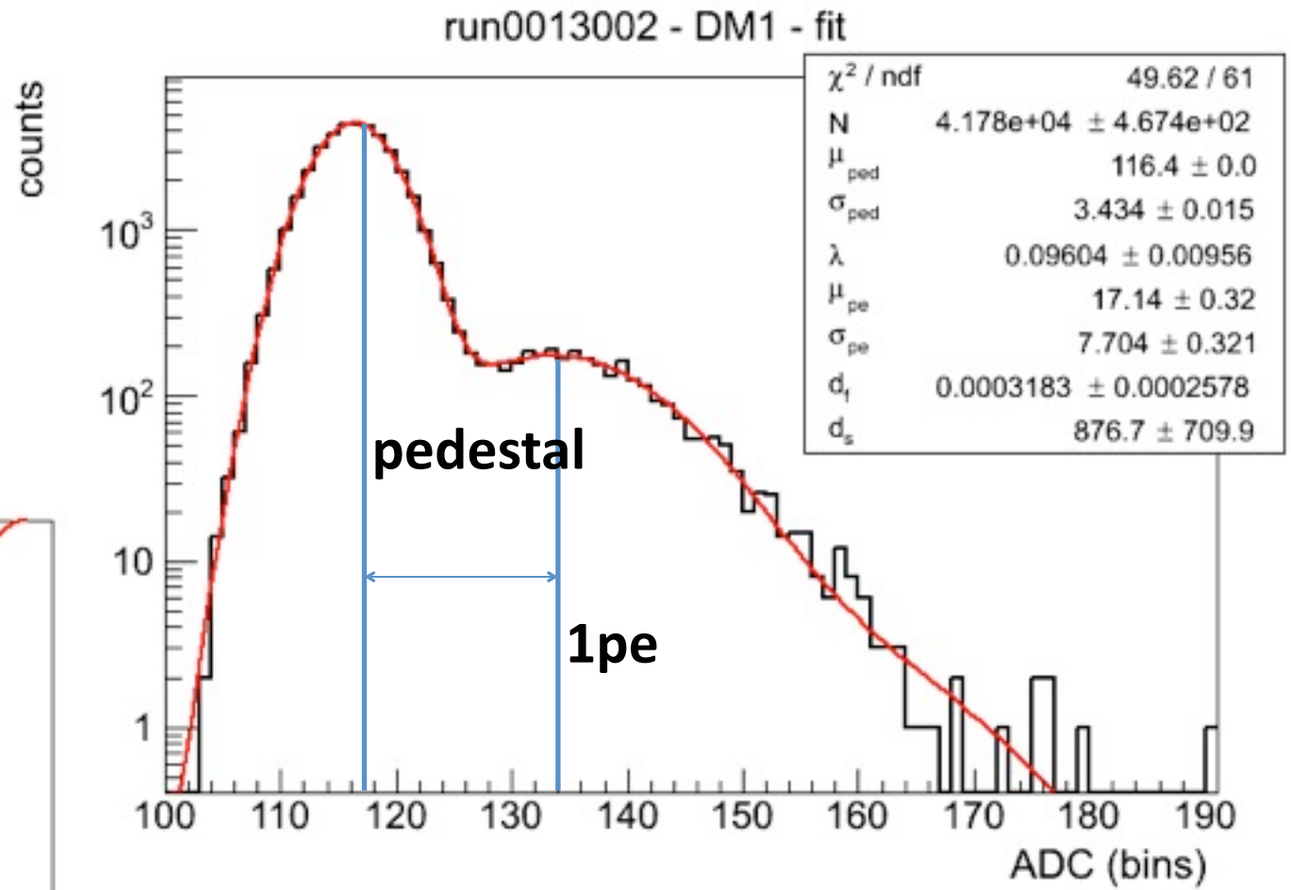




Number of Photoelectrons / keV

Obtain 1p.e.-ped separation from dark noise runs (ie no coincidence requirement)



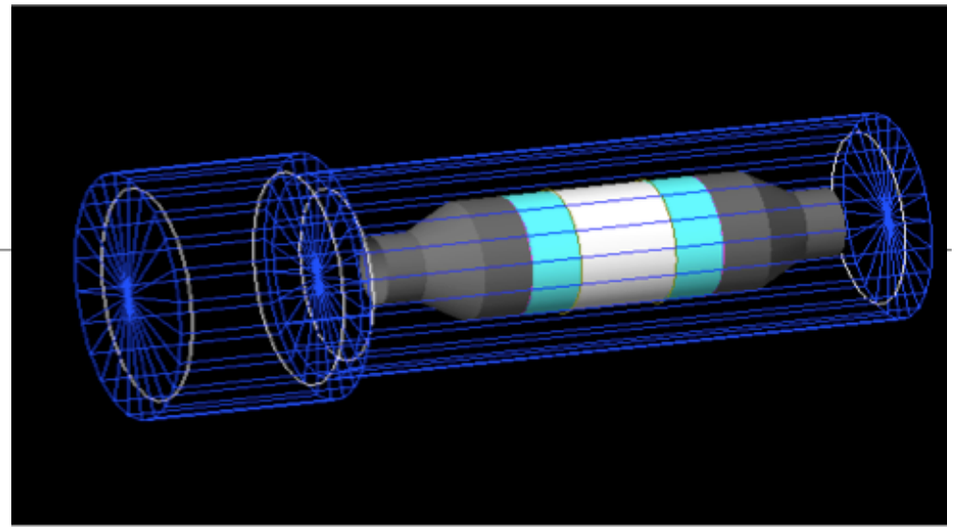


Normalize the energy to keV using the energy calibration

xtal-1 = 6.1 pe/keV

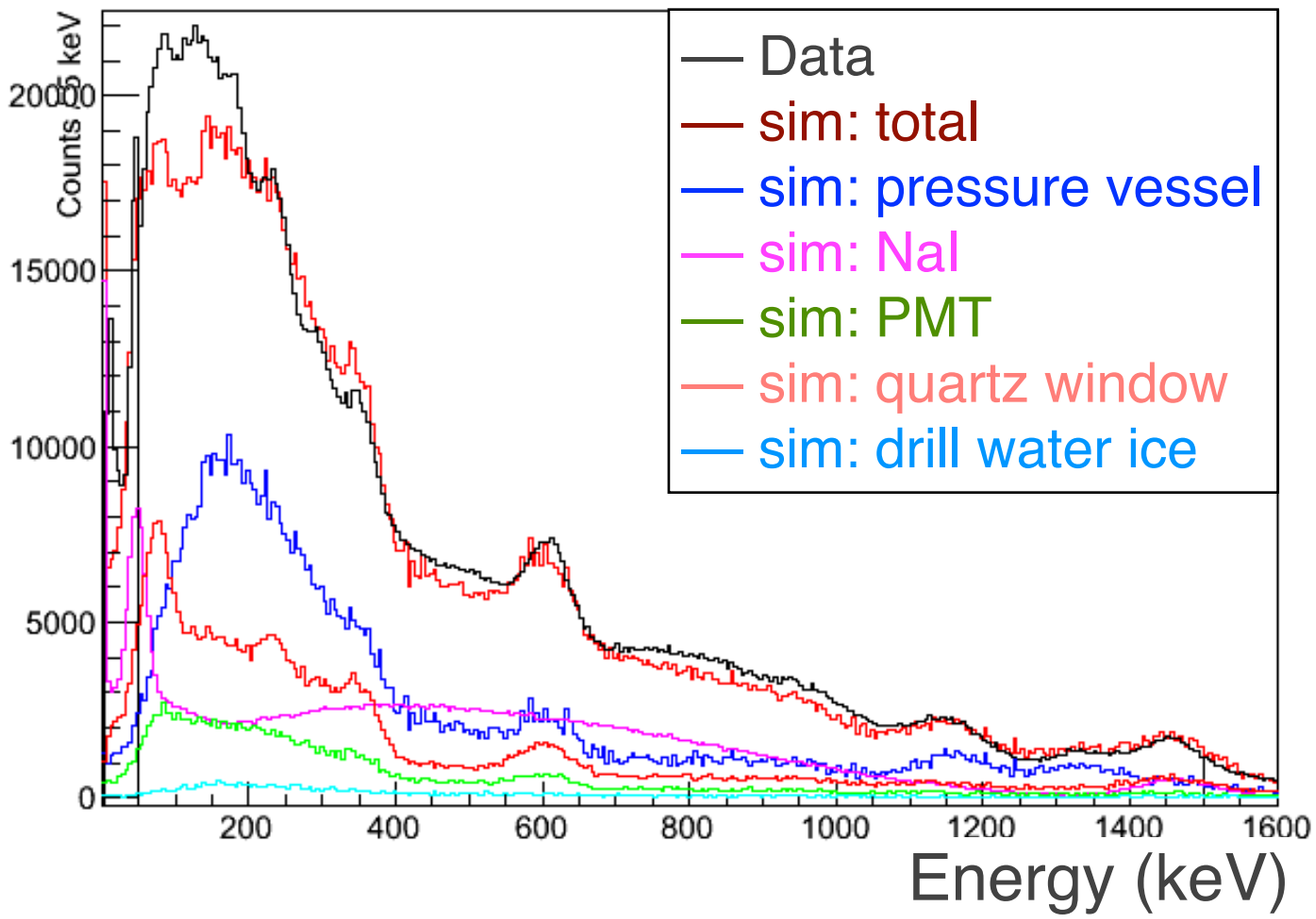
xtal-2 = 4.7 pe/keV

Background Simulation



- Measurements of contaminants in nearby components were used as a starting point
- Largest contributors:
  - NaI(Tl): U/Th measured with alpha events, K from 1460 & 3 keV
  - Pressure vessel: extra sections were γ-counted
  - Measurements from other experiments used for quartz and PMTs
  - Drill water was pumped out during construction & γ-counted
- Simulation in general agreement above 400 keV.

Data vs. simulation



^{238}U & ^{232}Th in the Crystals

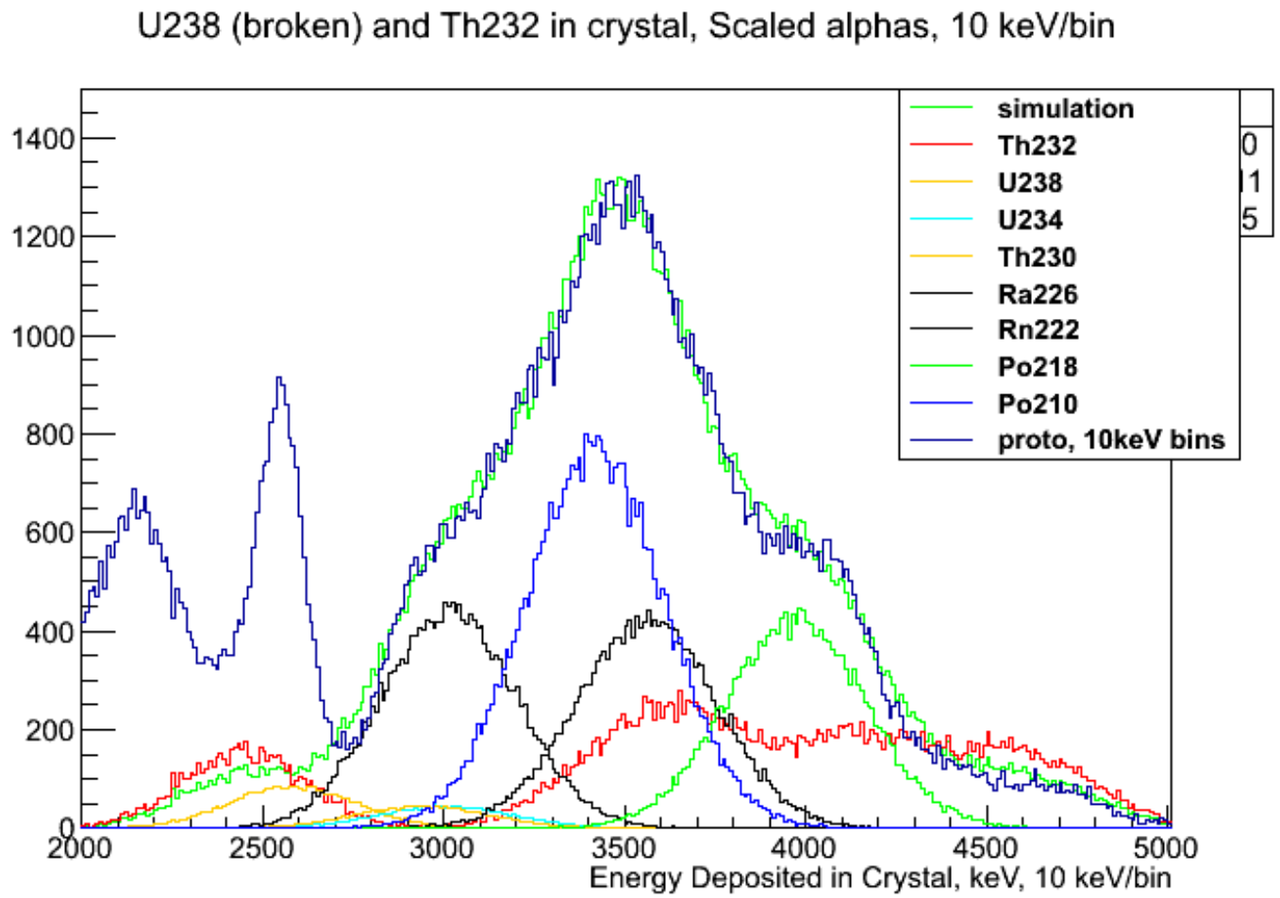
In Progress

Determine U/Th content using α lines

alpha-gamma light ratio

$$\alpha/\gamma = 0.5 + 0.0245*E_\alpha(\text{MeV})$$

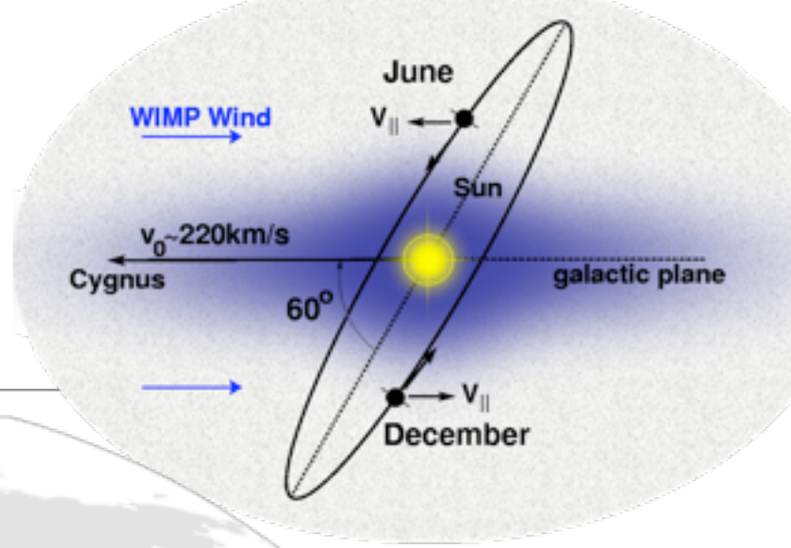
DAMA: $\alpha/\gamma = 0.467(6) + 0.0257(10)*E_\alpha(\text{MeV})$



	DM-Ice-17	Average DAMA		DM-Ice-17/DAMA ratio
U238	No info	2	uBq/kg	-
U234	93	12	uBq/kg	7.8
Th230	93	12	uBq/kg	7.8
Ra226-Pb210	933	18	uBq/kg	52
Bi210-Pb206	1680	33	uBq/kg	51
Th232	214	6	uBq/kg	36

Resolution: 7% (~ x2 DAMA)

Annual Modulation Dark Matter Searches with NaI Detectors



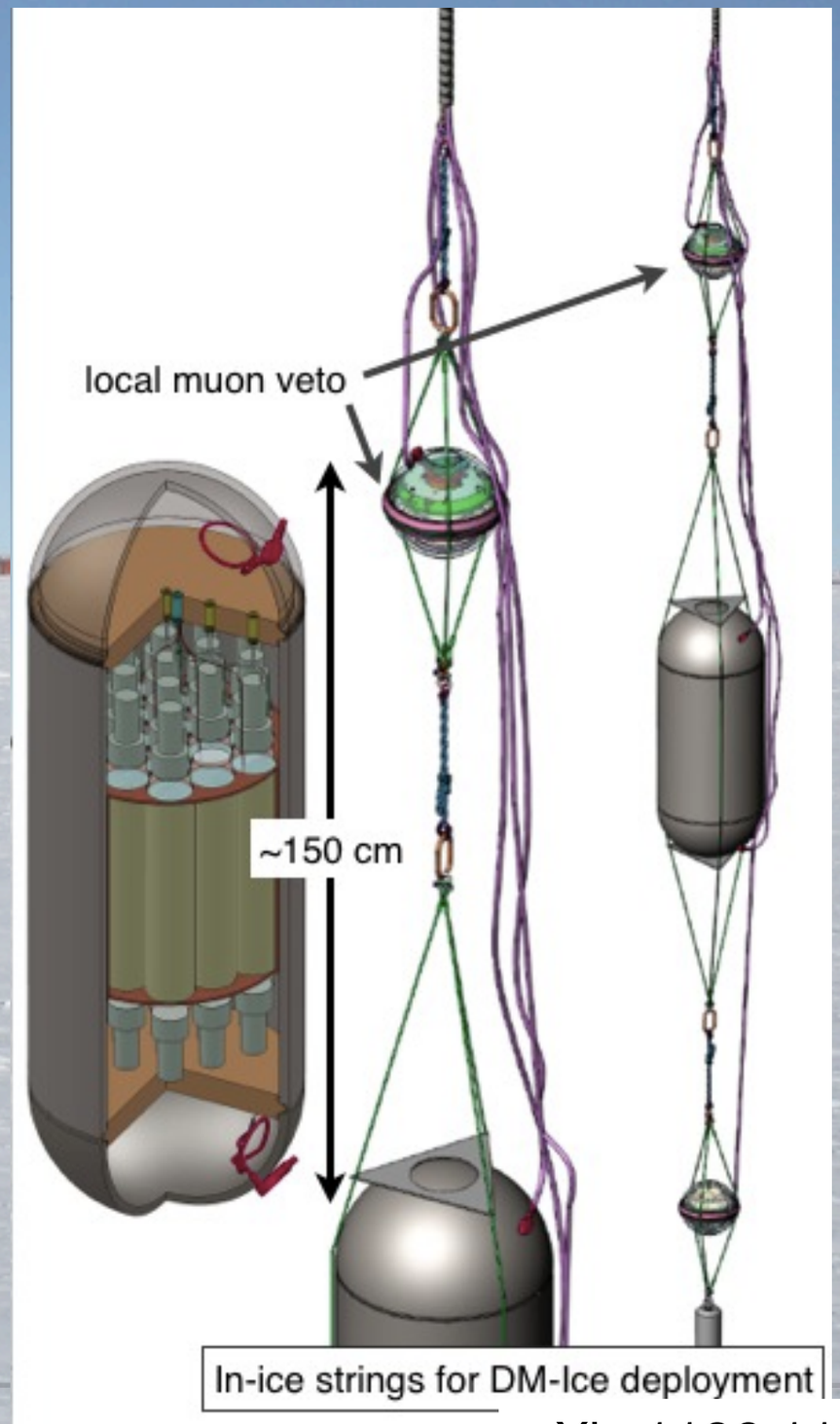
Northern Hemisphere	Gran Sasso **DAMA/Libra** 250kg running	Gran Sasso **Princeton-NaI** R&D	Canfranc **ANAIS** ~100kg starting in 2014?	**PICO-LON** **KIMS** etc...
Southern Hemisphere	South Pole **DM-Ice** 17 kg running R&D for 250 kg	**ANDES** Lab (proposed) expected start 2018		ice rock

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

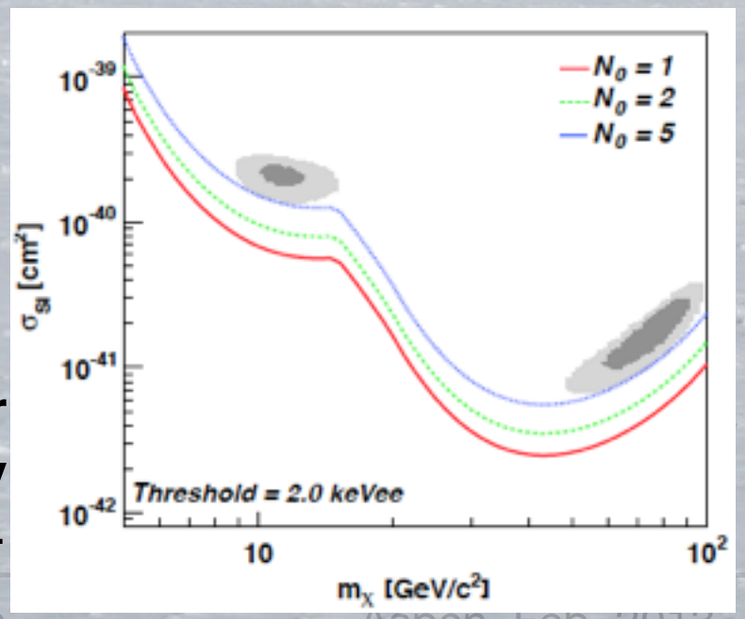
Only experiments in the Southern Hemisphere can definitively confirm DAMA.

DM-Ice Outlook

- DM-Ice17 installed along with IceCube and running stably
- Background level nominally as expected
- R&D and design for the full-scale experiment underway



In-ice strings for DM-Ice deployment



500 kg•year NaI detector sensitivity
(2 - 4 keV) with 1, 2, and 5 dru bgd.

arXiv:1106.1156

DM-Ice Collaboration

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