
hey guys it's over here!
DM-ICE update from the south pole!

# DM-Ice Collaboration

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J. Cherwinka et al. A Search for the dark matter annual modulation in south pole ice, (2011) arXiv:1106.1156

# DM-Ice (250 kg NaI) Concept

**Use NaI(Tl)**

- Eliminate uncertainties due to detector effects and dark matter models
- Crystal Array for sophisticated event tagging

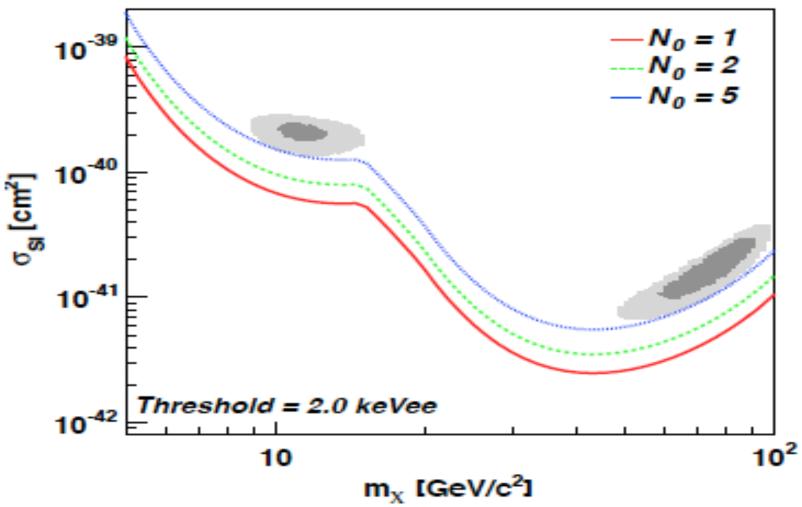
**Detection (5σ) or exclusion**

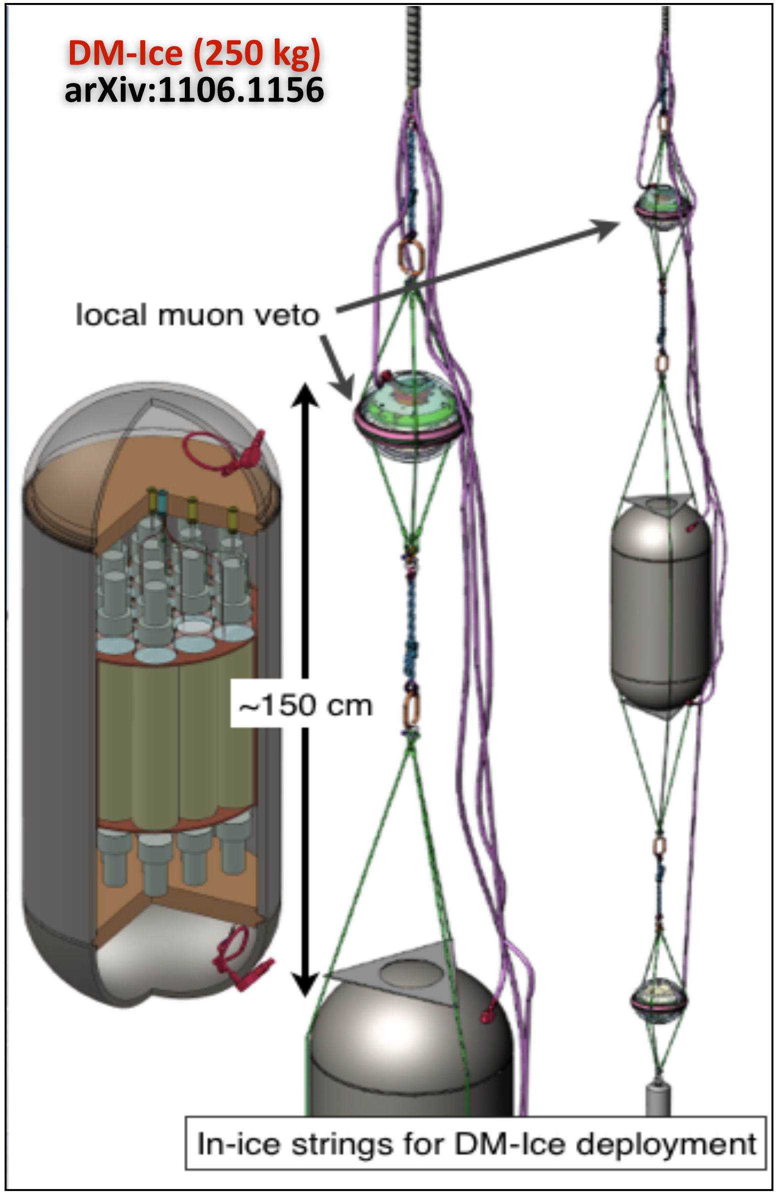
- 500 kg*yr NaI (same scale as DAMA)
- Threshold < 2 $keV_{ee}$
- Background < 5 cpd/kg/keV

**Go to the South Pole**

- Seasonal effects have opposite phase
- 2200 mwe overburden
- Ice < 1 ppt U/Th (radon ~0)
- Ice < 1 ppb K
- Ice == great neutron moderator

**DM-Ice Sensitivity**
**500 kg•yr NaI**
(2 - 4 keV) with 1, 2, and 5 dru bkg



# Muons and Seasonal Modulation

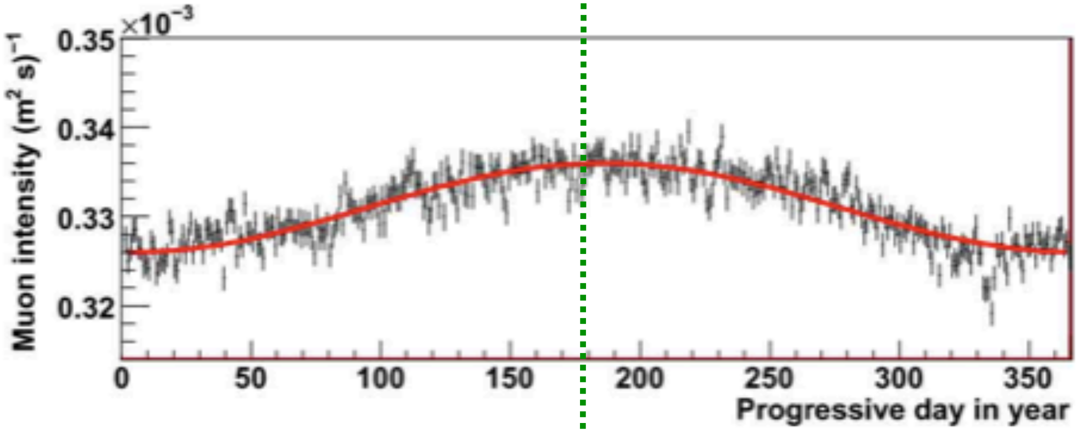
- Overburden 2500 m depth (2200 m.w.e.)
- ~85 muons/m²/day at bottom of IceCube, IceCube/DeepCore veto reduces rate by ~1-2 orders of magnitude, Ice is a good neutron moderator

Gran Sasso

summer

- LVD:

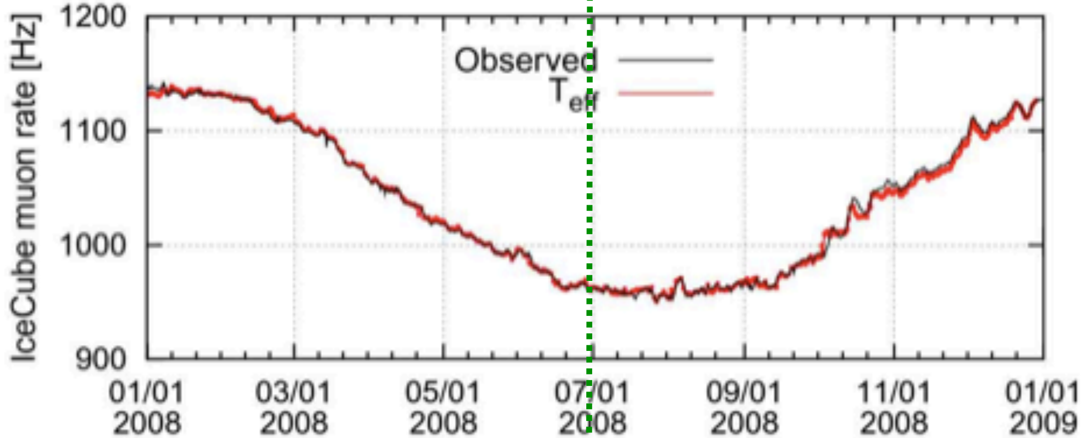
Selvi, Proc. 31st ICRC. (2009)

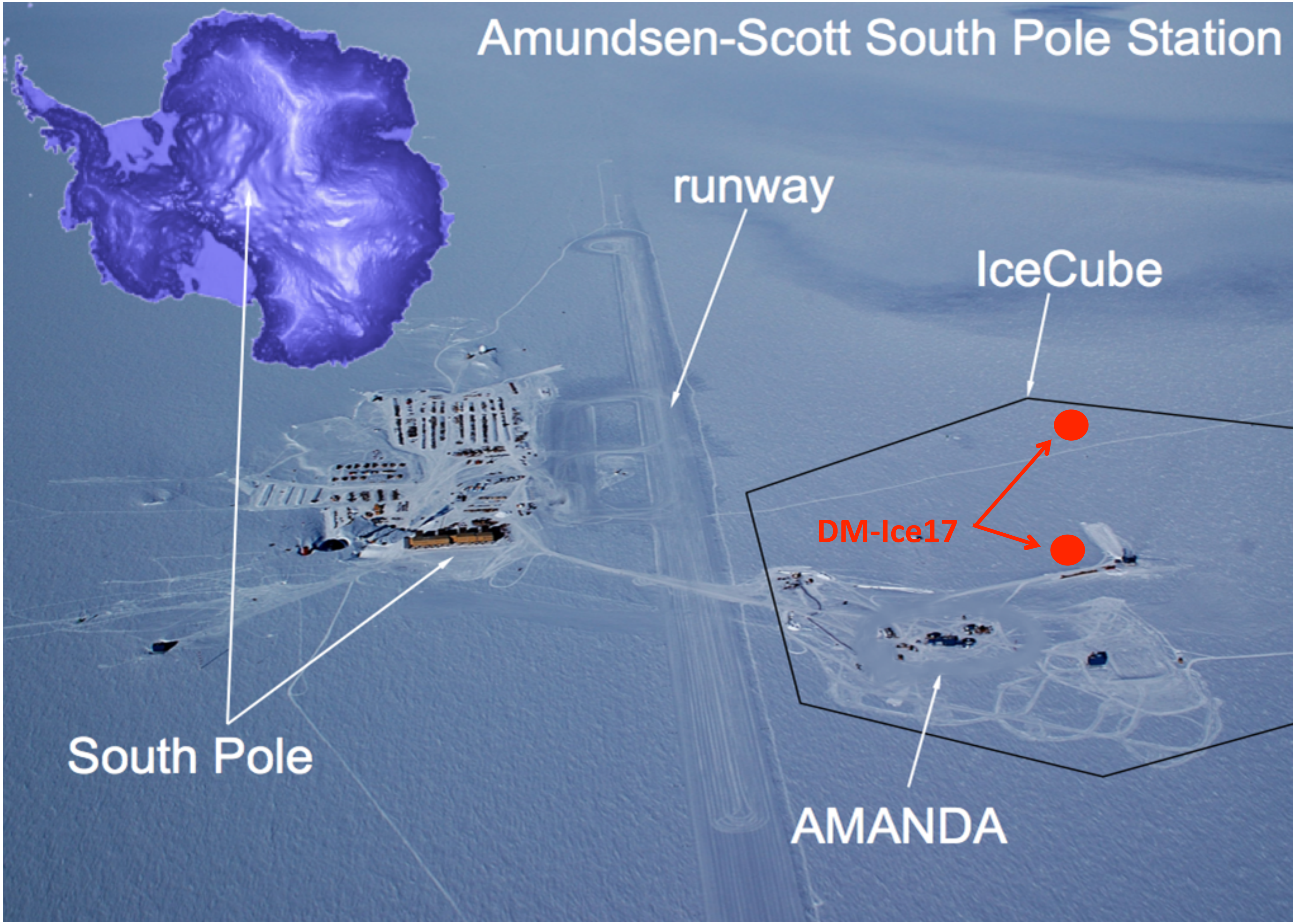



South Pole

- Opposite Muon modulation at the South Pole:

Tilav, Proc. 31st ICRC. (2009)





Amundsen-Scott South Pole Station
runway
IceCube
DM-Ice17
South Pole
AMANDA

# DM-Ice17 Deployment

**Feb 2010**

- a great idea!

10 months →

**Dec 2010**

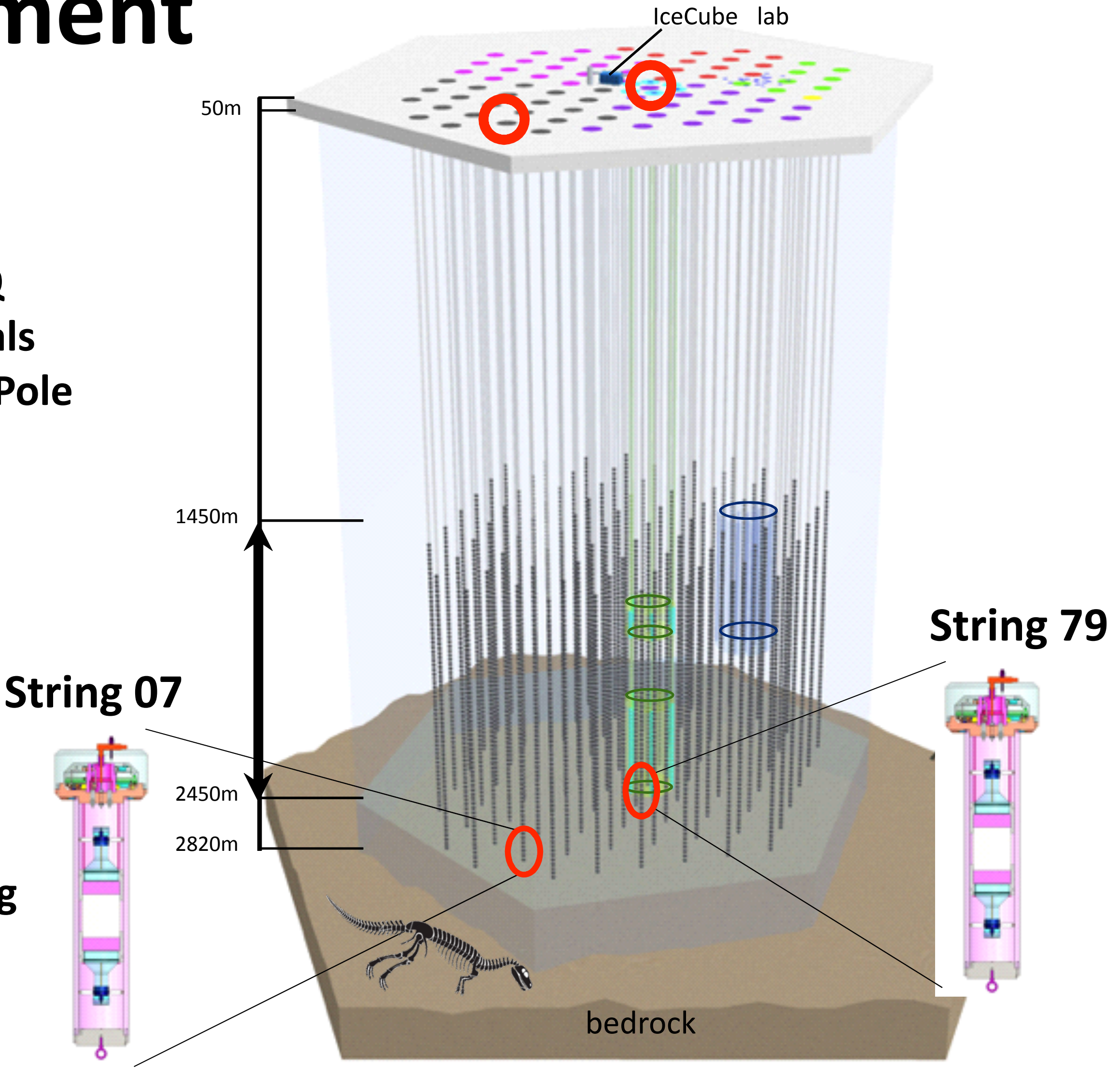
- IceCube DAQ
- NAIAD crystals
- deployed at Pole

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

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

**Goals…**

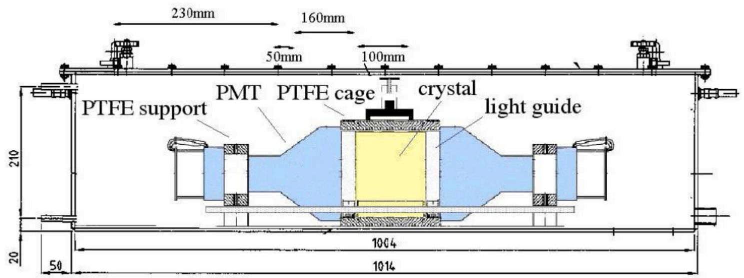
- determine the feasibility of deploying a remotely-operable detector in the Antarctic Ice
- Assess the environmental stability
- Establish the radiopurity of the Antarctic ice / drill ice
- Explore the capability of IceCube to veto muons
- Look for modulations

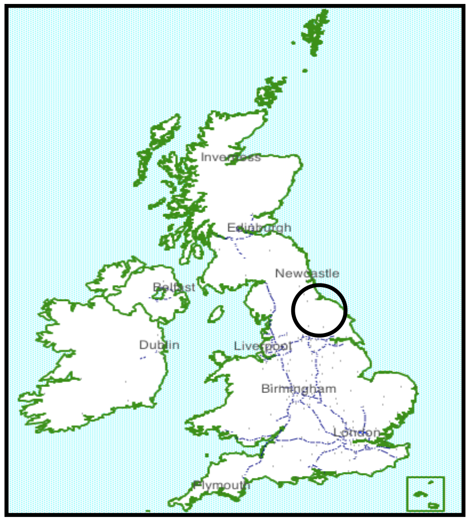


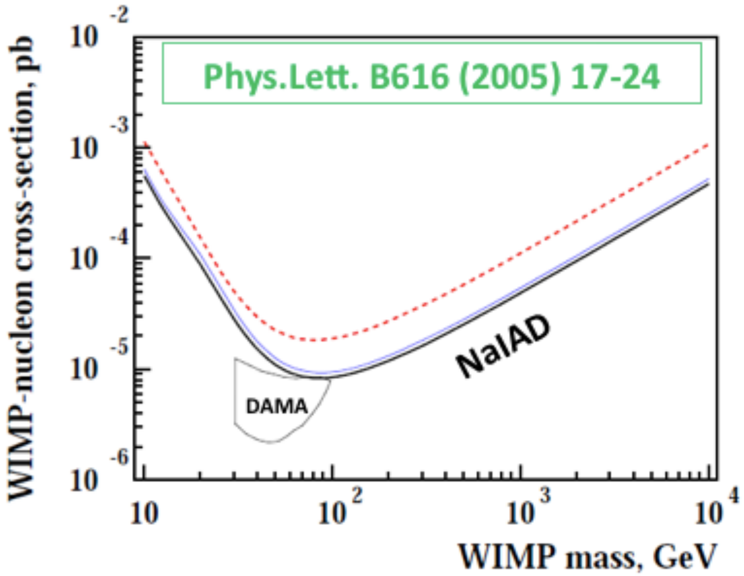

- **2200 M.W.E. overburden**
- **~85 muons/m^2/day**

# Original NAIAD Crystals at Boulby

- NAIAD was an array of encapsulated and unencapsulated NaI(Tl) with high light yield used for early dark matter searches from ~1998-2004
- NAIAD was used to set upper limits on the WIMP-nucleon spin-independent and WIMP-proton spin-dependent cross-sections
- Pulse shape analysis used to discriminate between nuclear recoils, as may be caused by WIMP interactions, and electron recoils due to gamma background

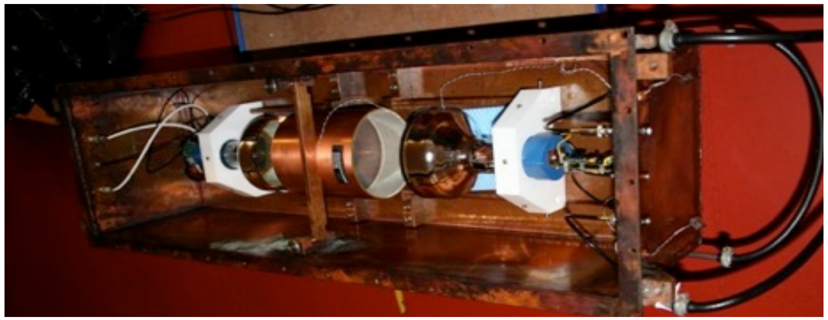


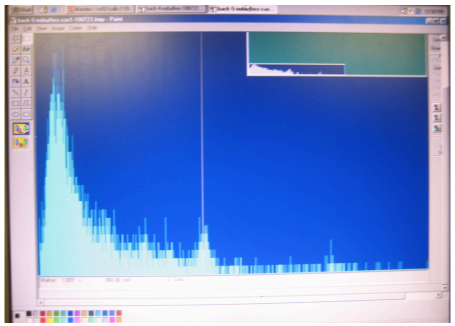




# DM-ICE Prototype Tests at Boulby

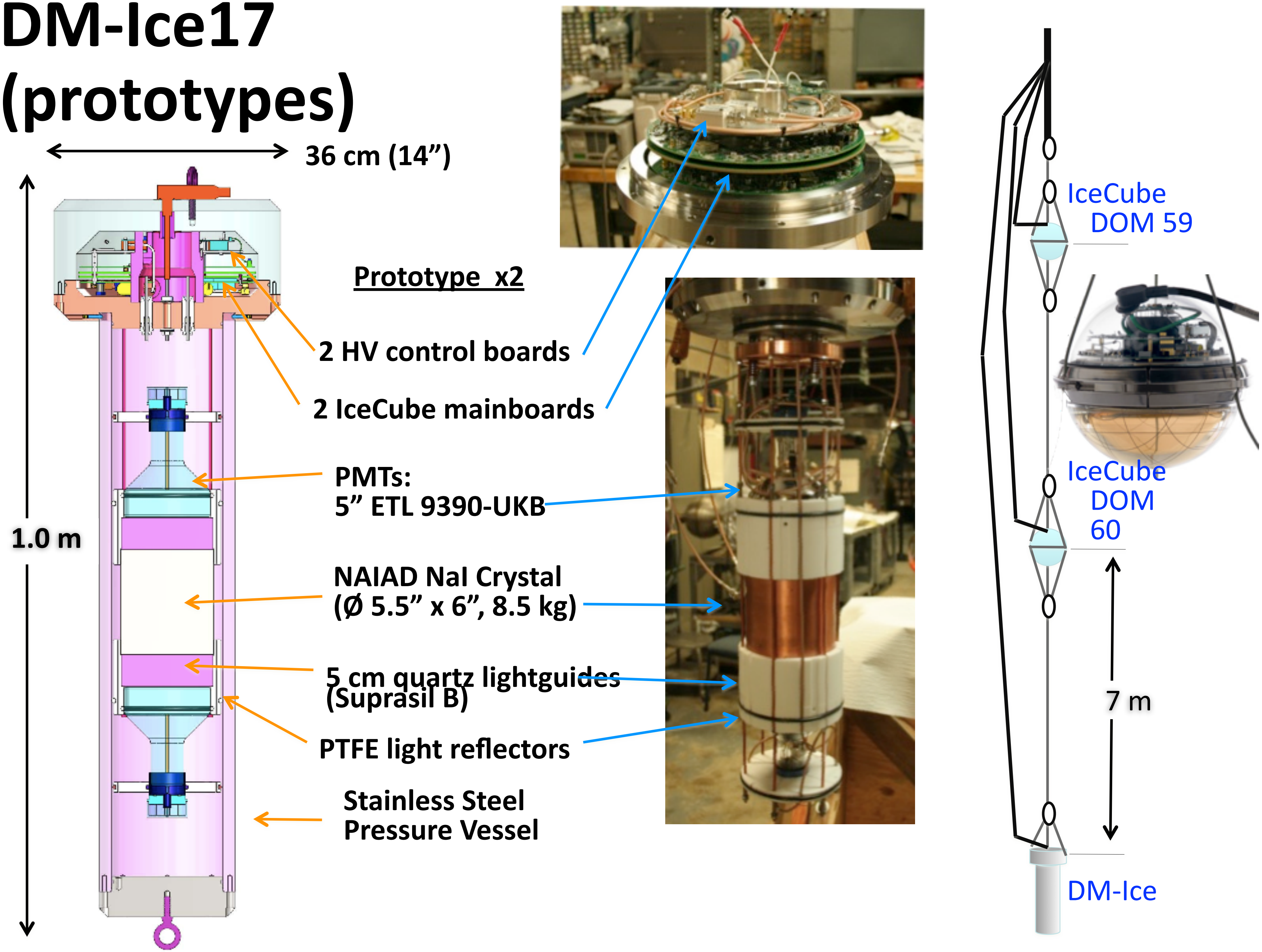
- Boulby Palmer Lab tests at 1.1km depth





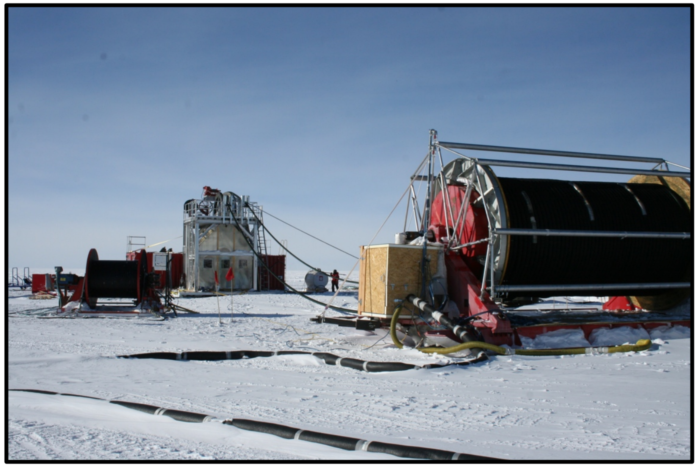
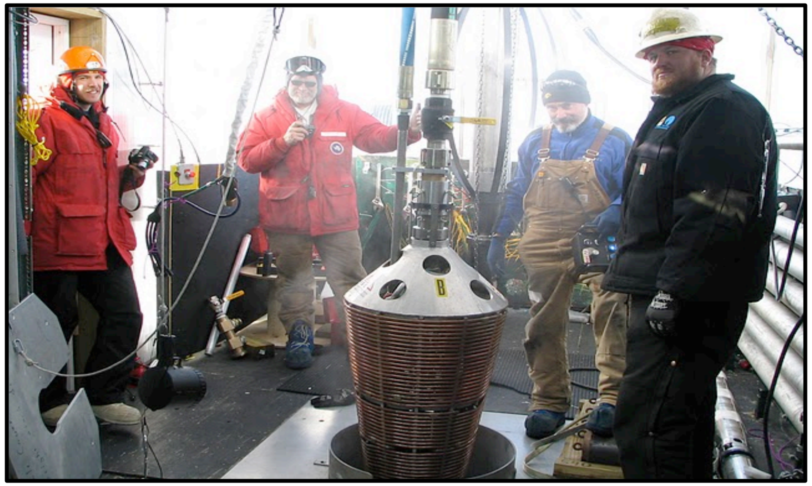
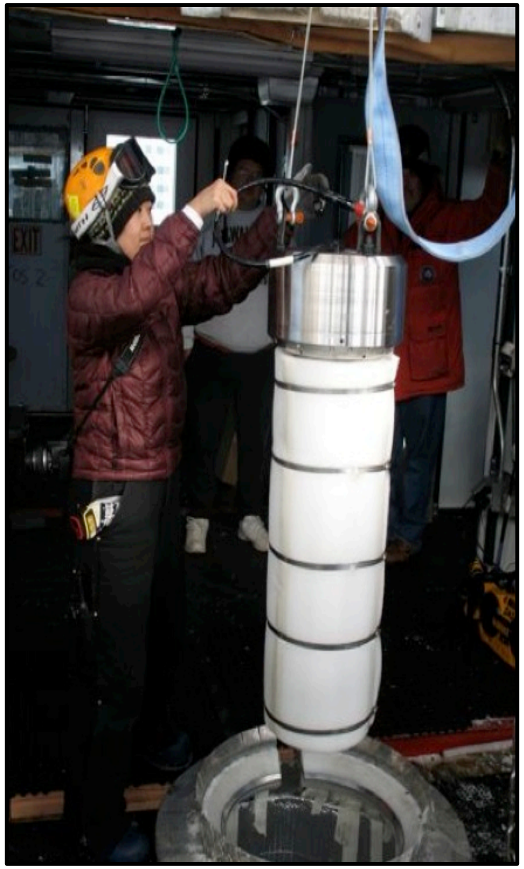
- Both crystals and PMTs tested and found to be in excellent condition
- Packed and shipped to Madison....

# DM-Ice17 (prototypes)



# Transfer to South Pole, Installation

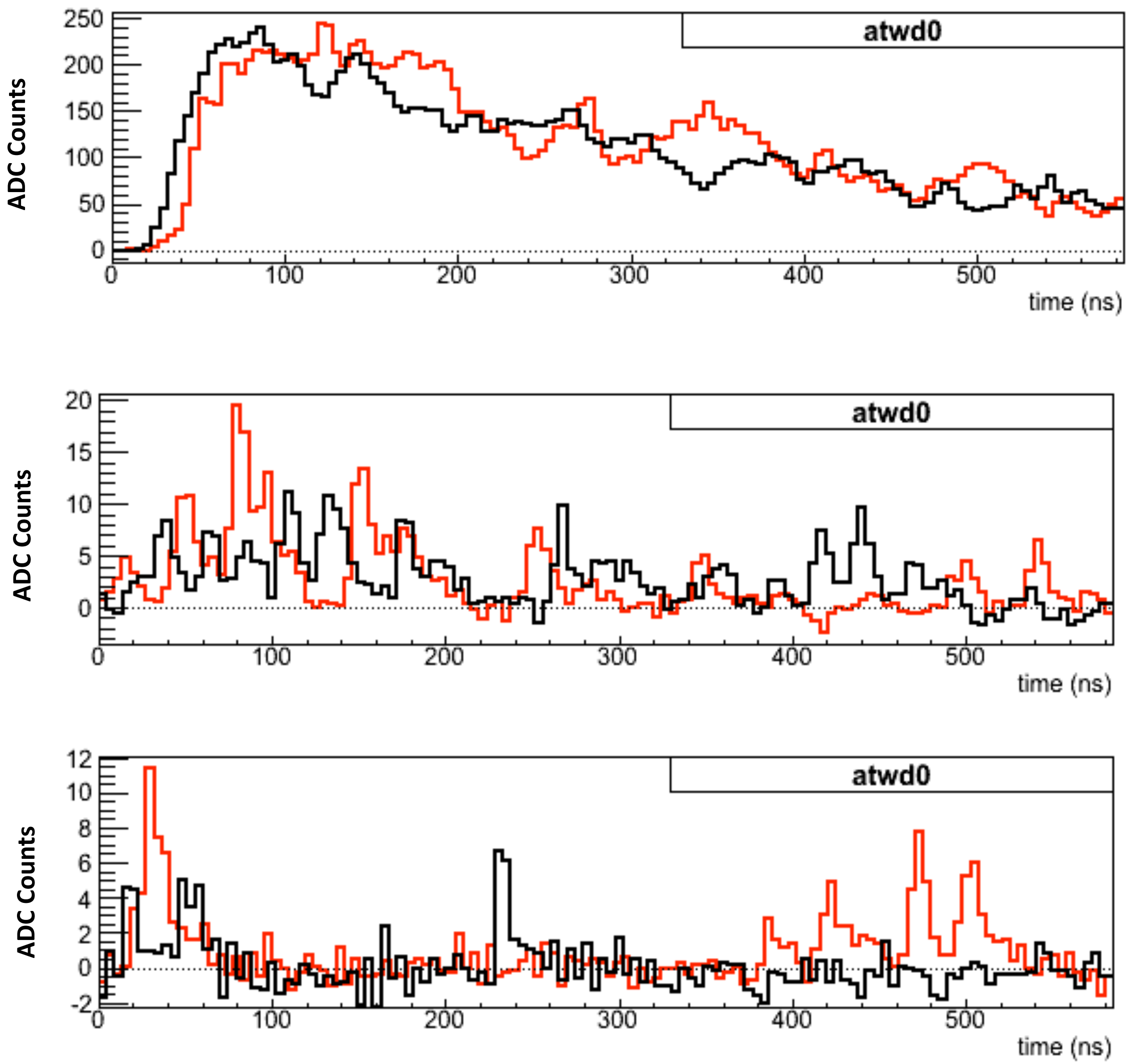


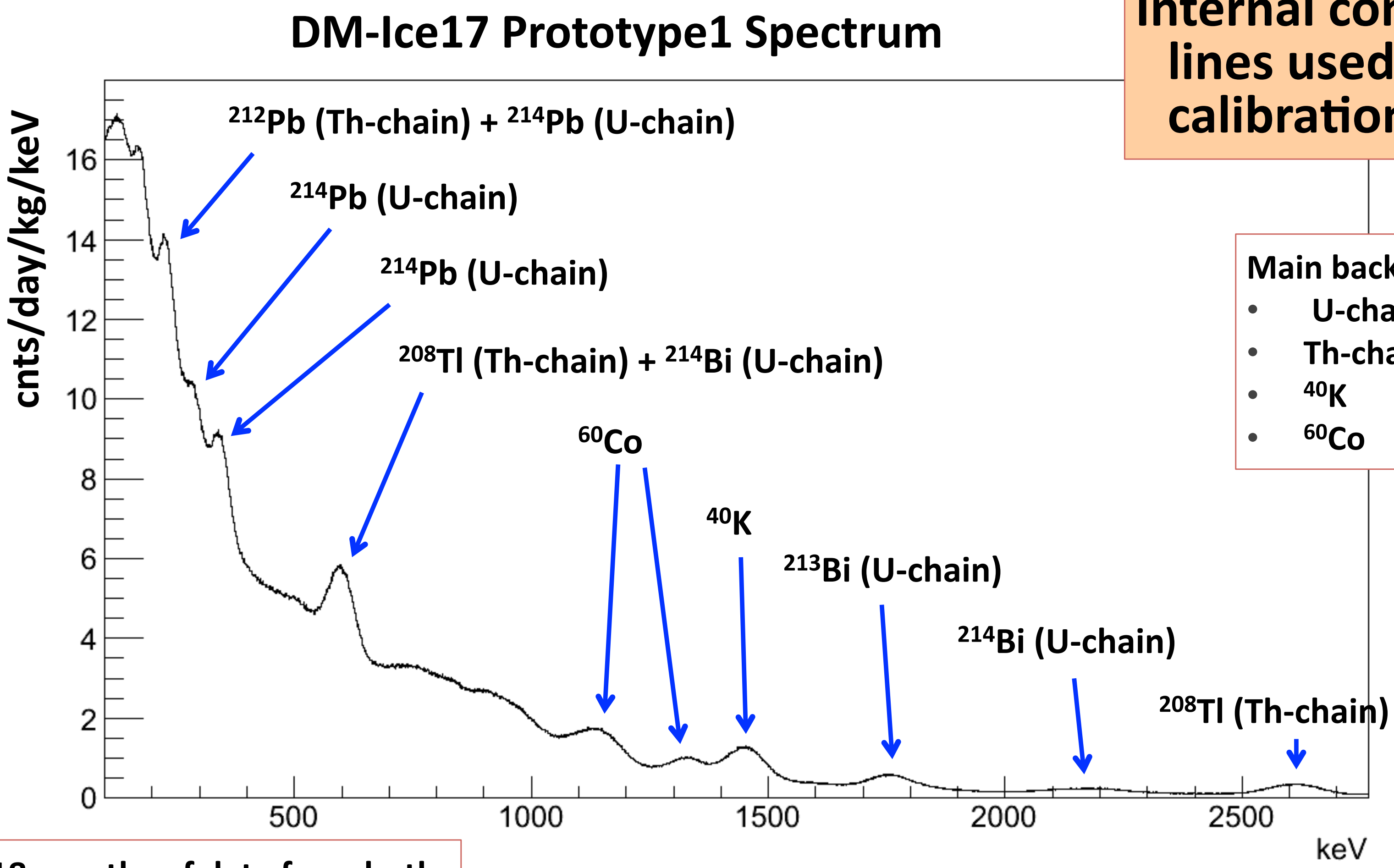

- Transfer by plane to South Pole in Dec 2010
- Installed below last ICECUBE strings
- ***~9 months from idea to deployment in the ice!!!***

# Scintillation Events

- DAQ using slightly modified IceCube motherboardsEach PMT set to trigger ~ 0.3 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
- Signal comes from scintillation in the crystal.
- At high energies, signal has the characteristic scintillation pulse shape.
- At low energies, increasingly events are just a series of single photo-electrons.



# Energy Spectrum: Gammas



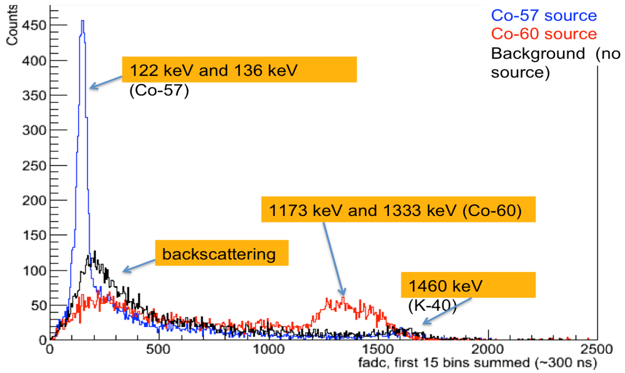

**Internal contamination lines used for calibration**

**Main backgrounds:**
- U-chain
- Th-chain
- $^{40}$K
- $^{60}$Co

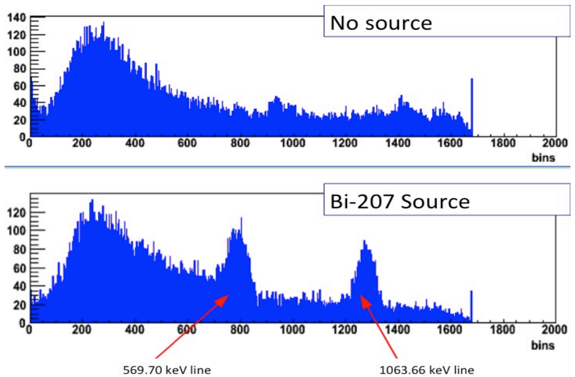
**18 months of data from both PMTs on a single crystal**

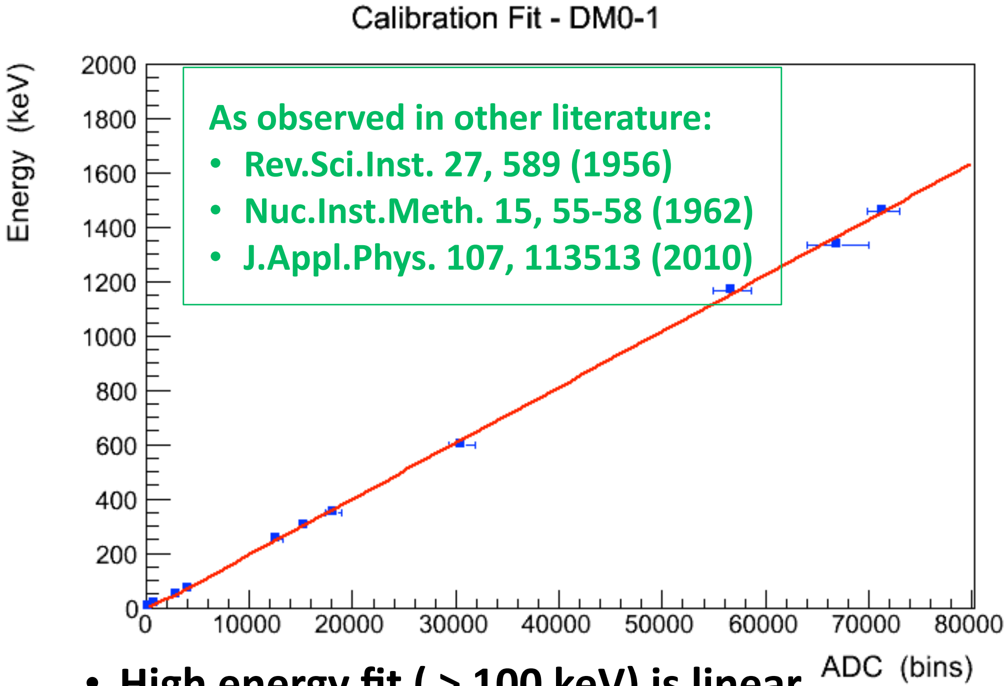
# Energy Calibration

## Calibration at Boulby



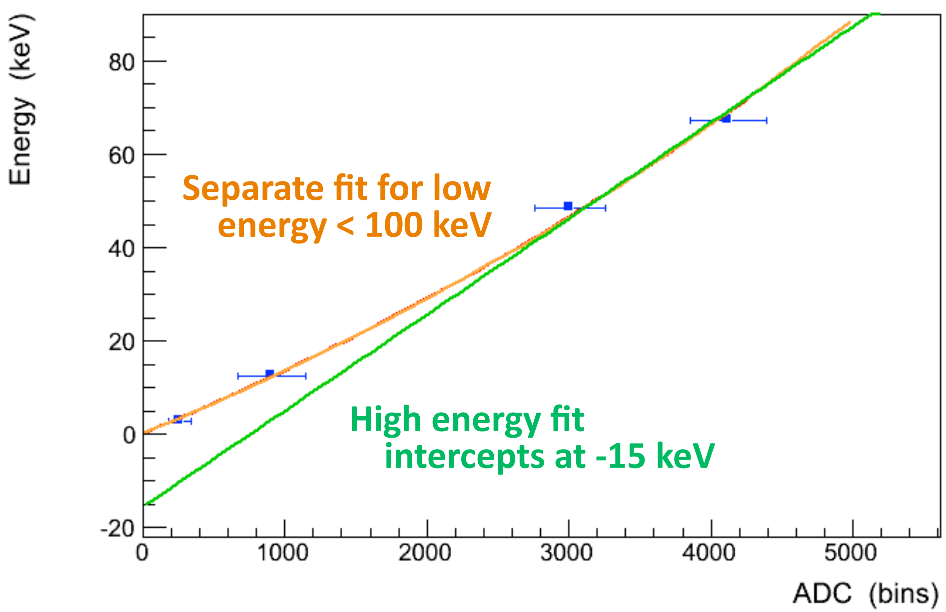

## Calibration at Madison



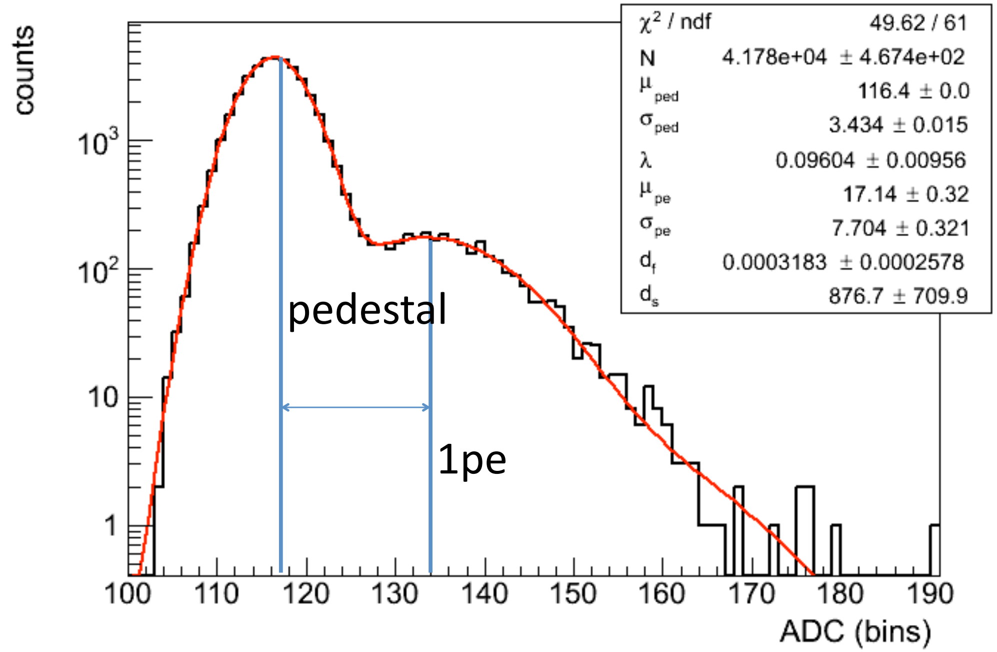

- **High energy fit ( > 100 keV) is linear**
- **Low energy fit ( < 100 keV) deviates from linearity**

Calibration Fit - DM0-1



# NaI Light Yield

- **Obtain 1pe-ped separation from dark noise runs (ie no coincidence requirement)**
- **Normalize the energy to keV using the energy calibration**



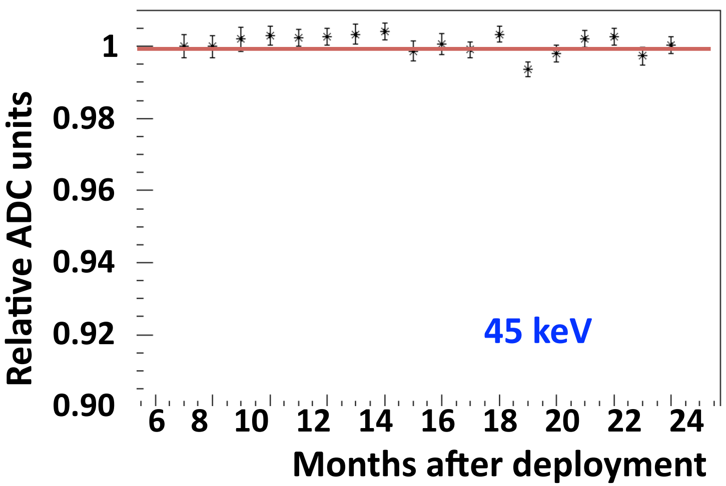

**xtal-1 = 6.1 +/- 0.07 pe/keV**
**xtal-2 = 4.9 +/- 0.05 pe/keV**

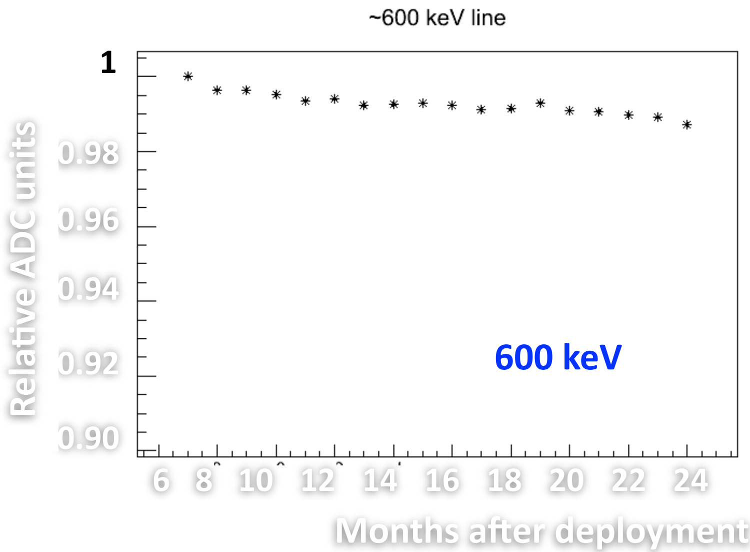
**Consistent with:**

- **DAMA = 5.5 – 7.5 pe/keV**
- **NaiAD = 5 – 8 pe/keV**

# Detector Stability

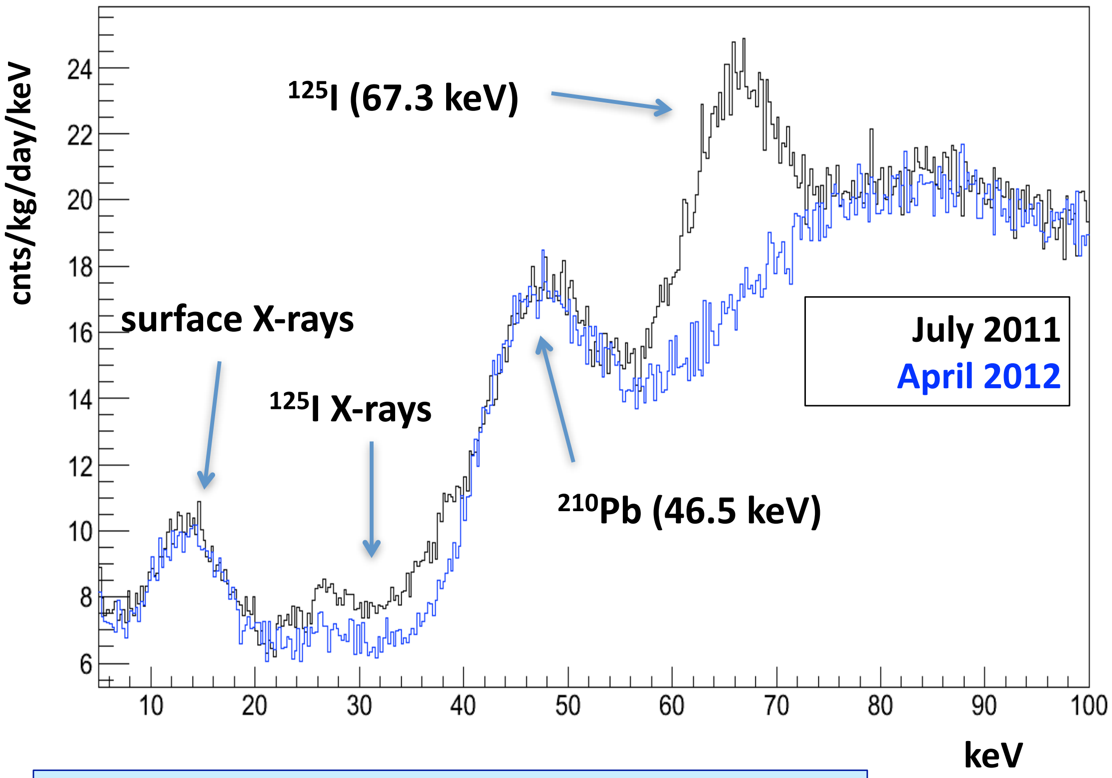
- Detector calibration is stable to 1.3% over 18 months.
  - 1.3% decrease over 18 months in light collection (peak position) observed at 600 and 1460 keV
  - No observable change in calibration at 45 keV
  - We have not had to change our calibration with time
    - Any changes at higher energies are smaller than our resolution



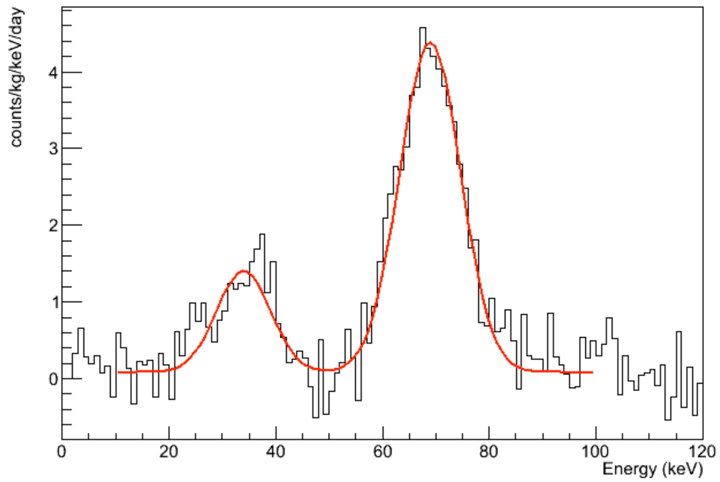



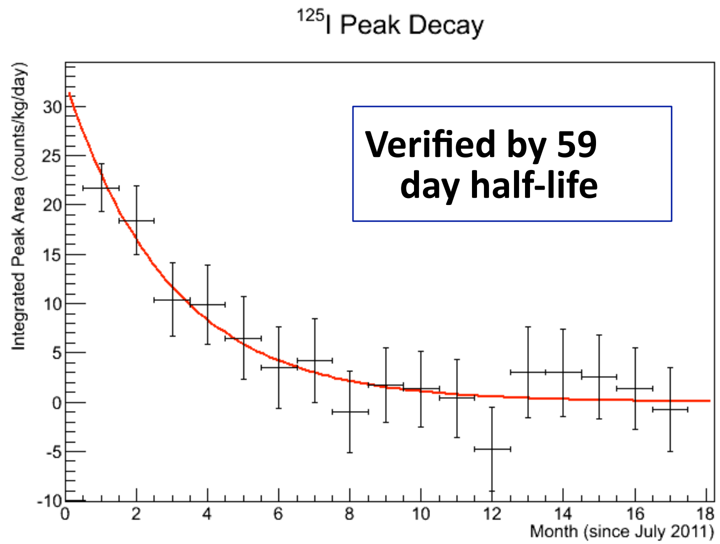
# Cosmogenic $^{125}$I (in the NaI crystal)

**Decay of $^{125}$I**




**July – April Residual**

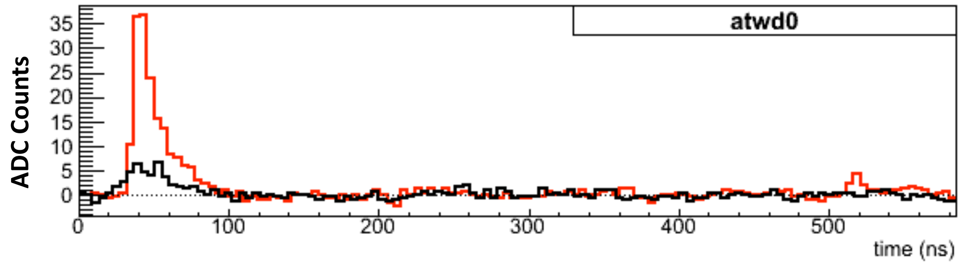


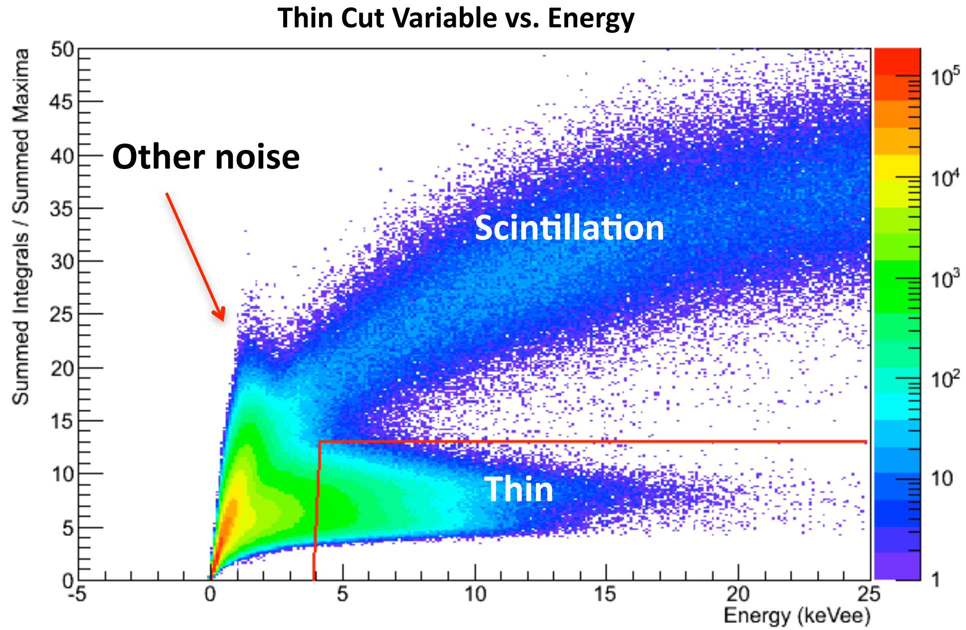




Cosmogenic lines verify our energy calibration; this is particularly useful for the prototype since we do not have an in-ice source.

# Cuts: e.g. “Thin Pulse” Events (Madison)

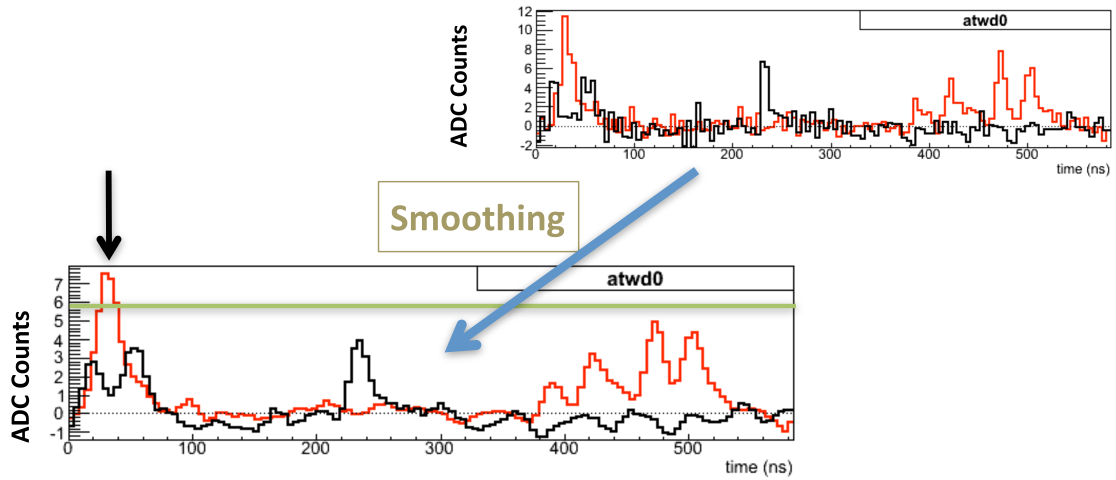
- **Interactions within the light guides and/or PMTs can also trigger the detector.**
- **These events are referred to as thin events due to their characteristic pulse shape.**
- **Current cut variable :**
  - **Pulse Integral / Pulse Maximum**
- **Current cut value chosen to preserve 75% of signal with a signal to noise ratio > 10 in cut region.**
- **Current Energy Threshold : 4 keV**



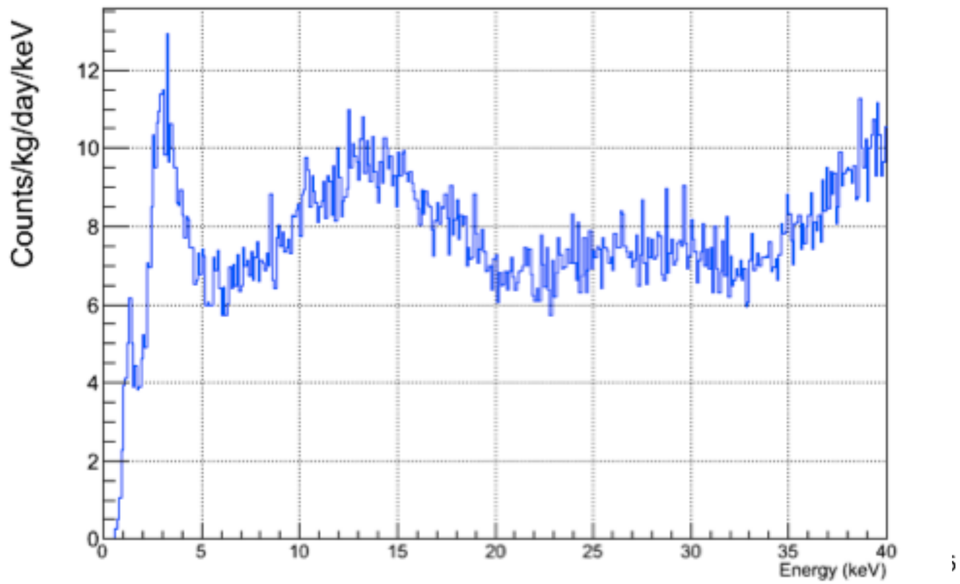



# Cuts: e.g. Steppiness Cut (Sheffield)

- **Steppiness in essence requires multiple SPEs to occur in quick succession in at least one PMT.**
- **This is achieved by requiring a smoothed waveform to break a threshold.**
- **Steppiness is not a good cut of thin pulses so a series of cuts is required to remove them.**
  - **Energy symmetry between the two PMTs**
  - **Mean time symmetry between the two PMTs**
  - **Mean time**
  - **Tail energy fraction**

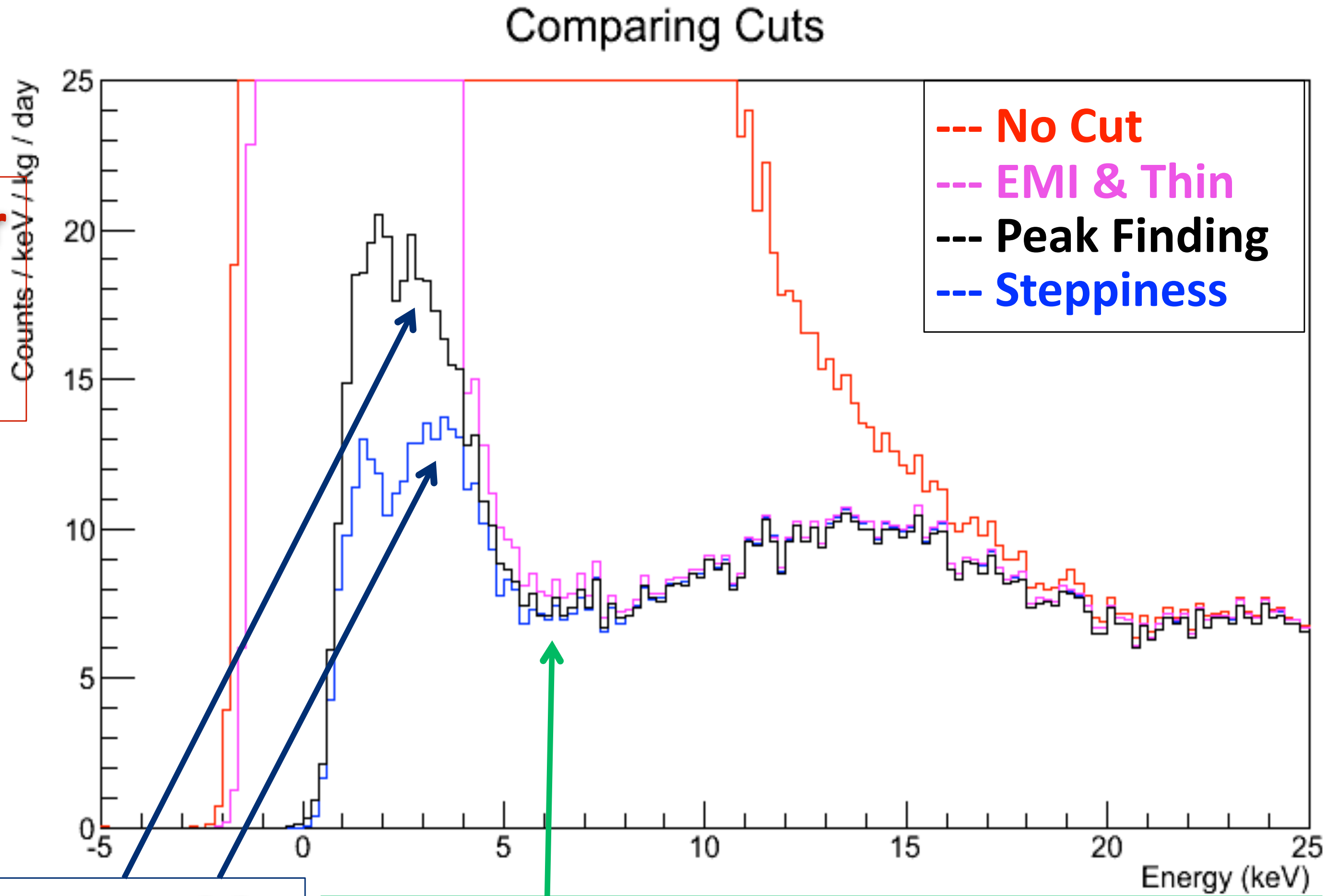



**Energy Spectrum after Sheffield Cuts**



# 3 keV $^{40}$K Peak

We understand our spectrum well down to 4 keV.

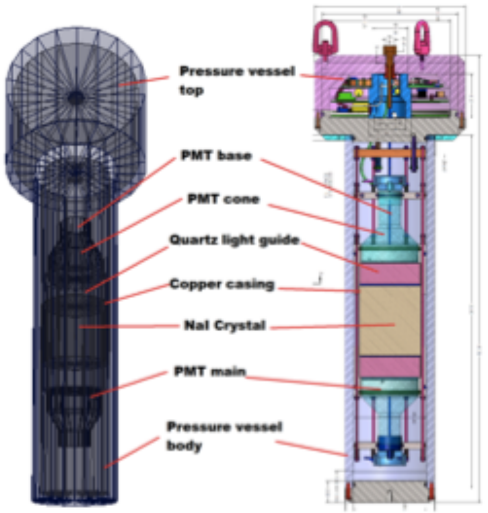



Below 4 keV, we are capable of revealing the $^{40}$K peak despite the difficulties of single crystal analysis.

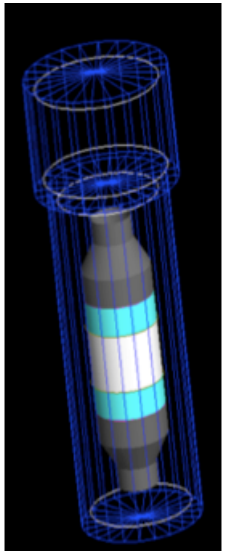
At 6 keV we see 7.2 ± 0.4 cpd/kg/keV. Simulations for the full scale DM-Ice give 1-2 cpd/kg/keV @ 5 keV (not including multi-crystal "hit" rejection)

# Two Geant4 Simulations

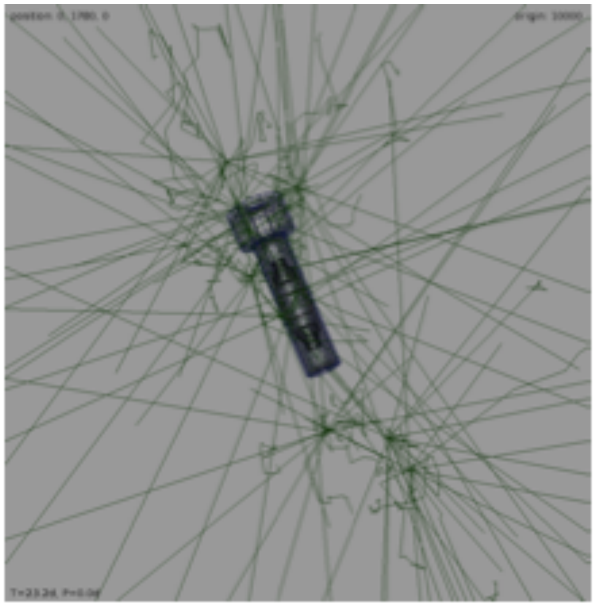
- **Sheffield**



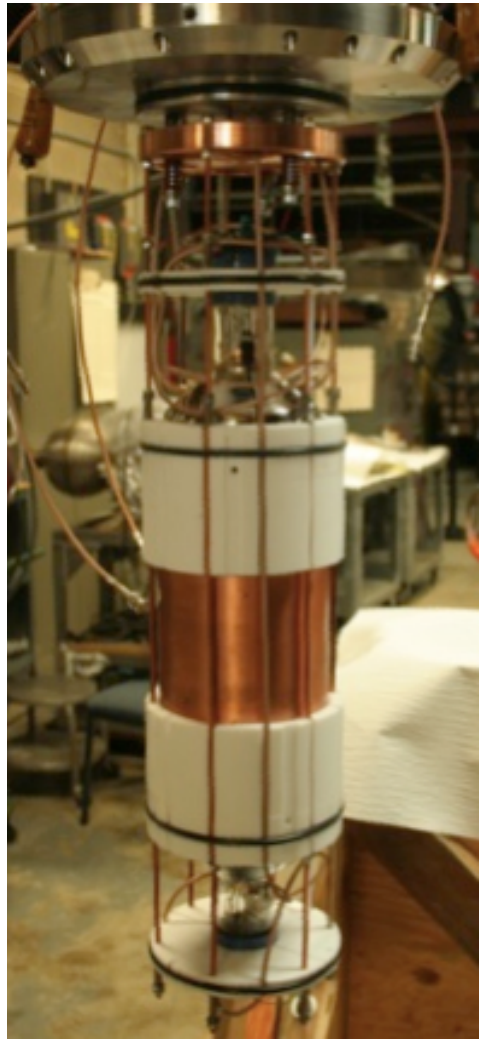

- **Madison**



- **e.g. events from ice**

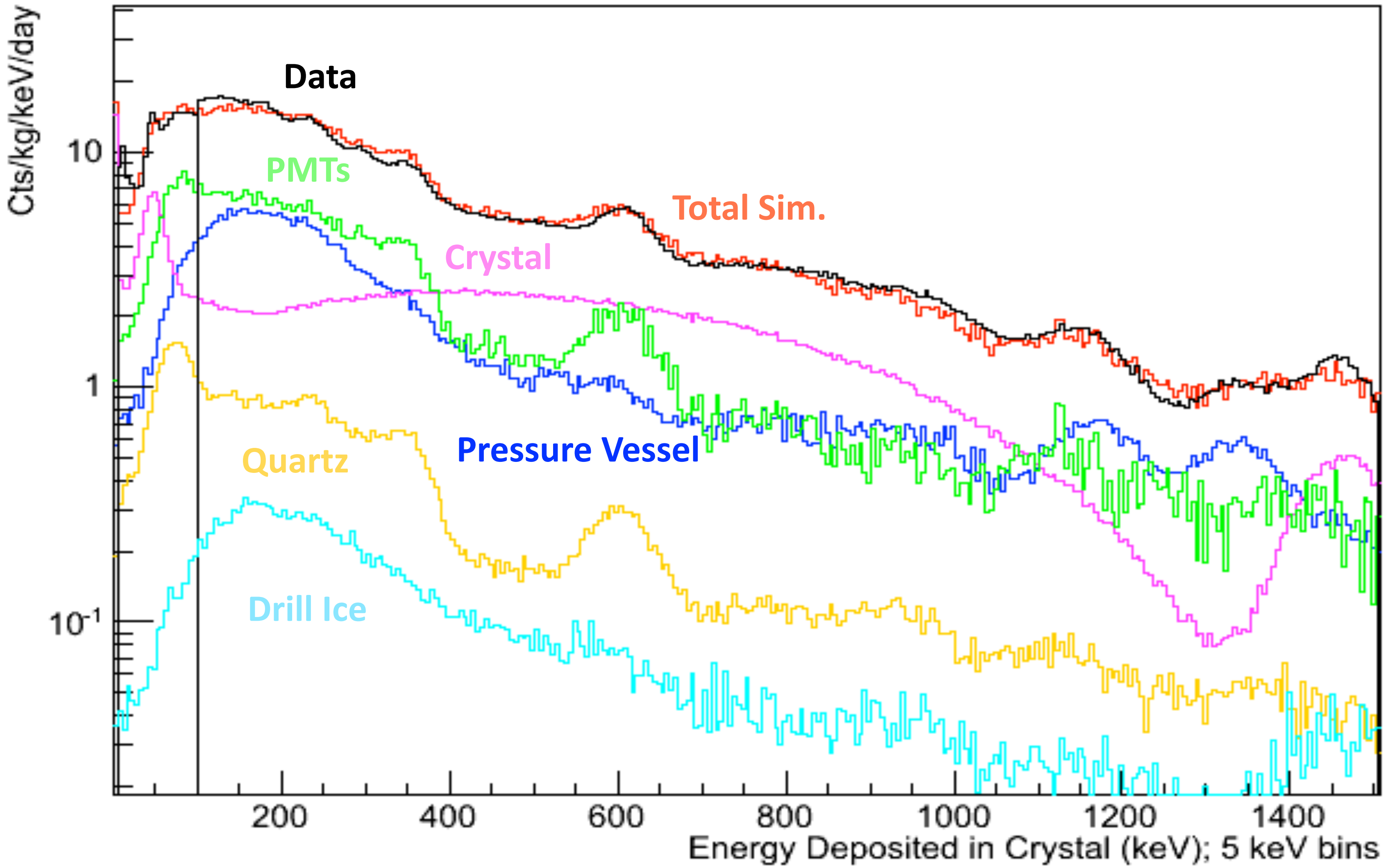


- **Crystal**
  - $^{238}$U, $^{232}$Th, $^{40}$K, $^{129}$I
- **Quartz Light Guide**
  - $^{238}$U, $^{232}$Th, $^{40}$K
- **PMTs**
  - $^{238}$U, $^{232}$Th, $^{40}$K
- **Pressure Vessel**
  - $^{238}$U, $^{232}$Th, $^{40}$K, $^{60}$Co, $^{235}$U
- **Drill Ice**
  - $^{238}$U, $^{232}$Th, $^{40}$K, $^{235}$U
- **Antarctic Ice**
  - $^{238}$U, $^{232}$Th, $^{40}$K

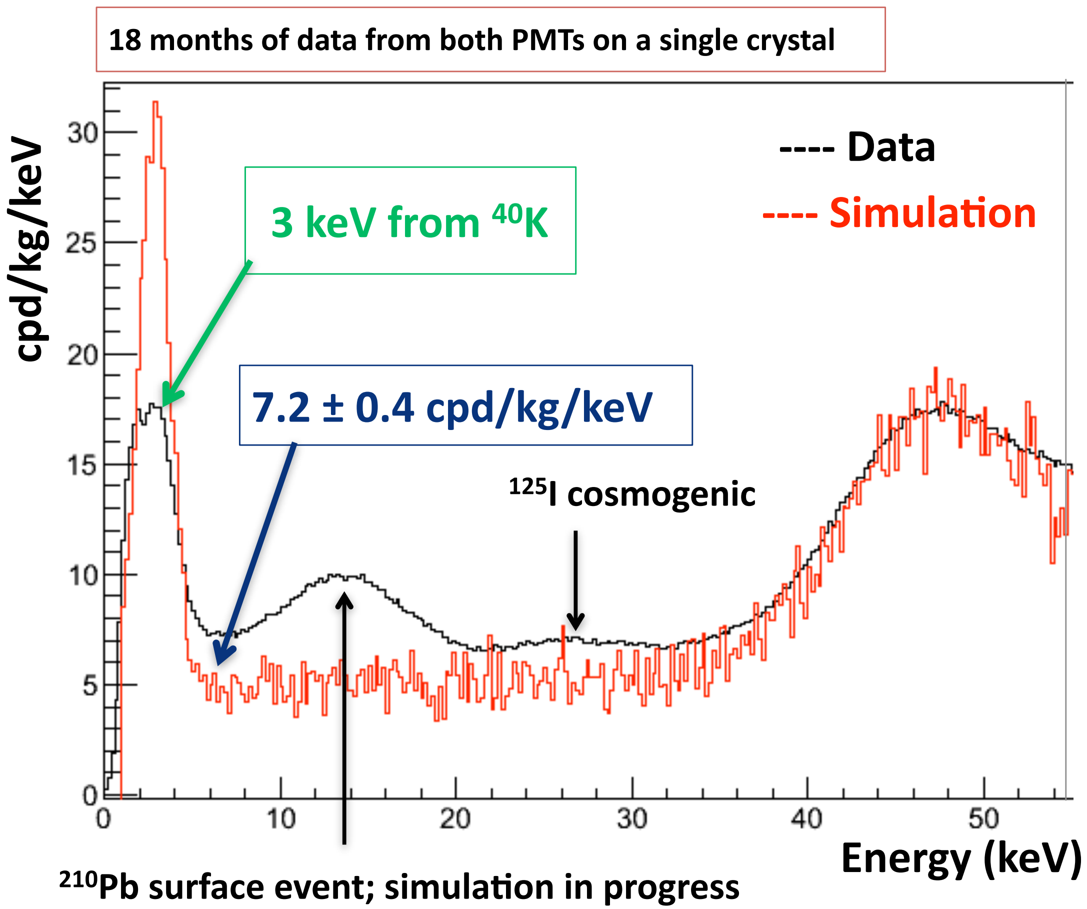


# Background Model

All components measured/ estimated and simulated



# Region of Interest



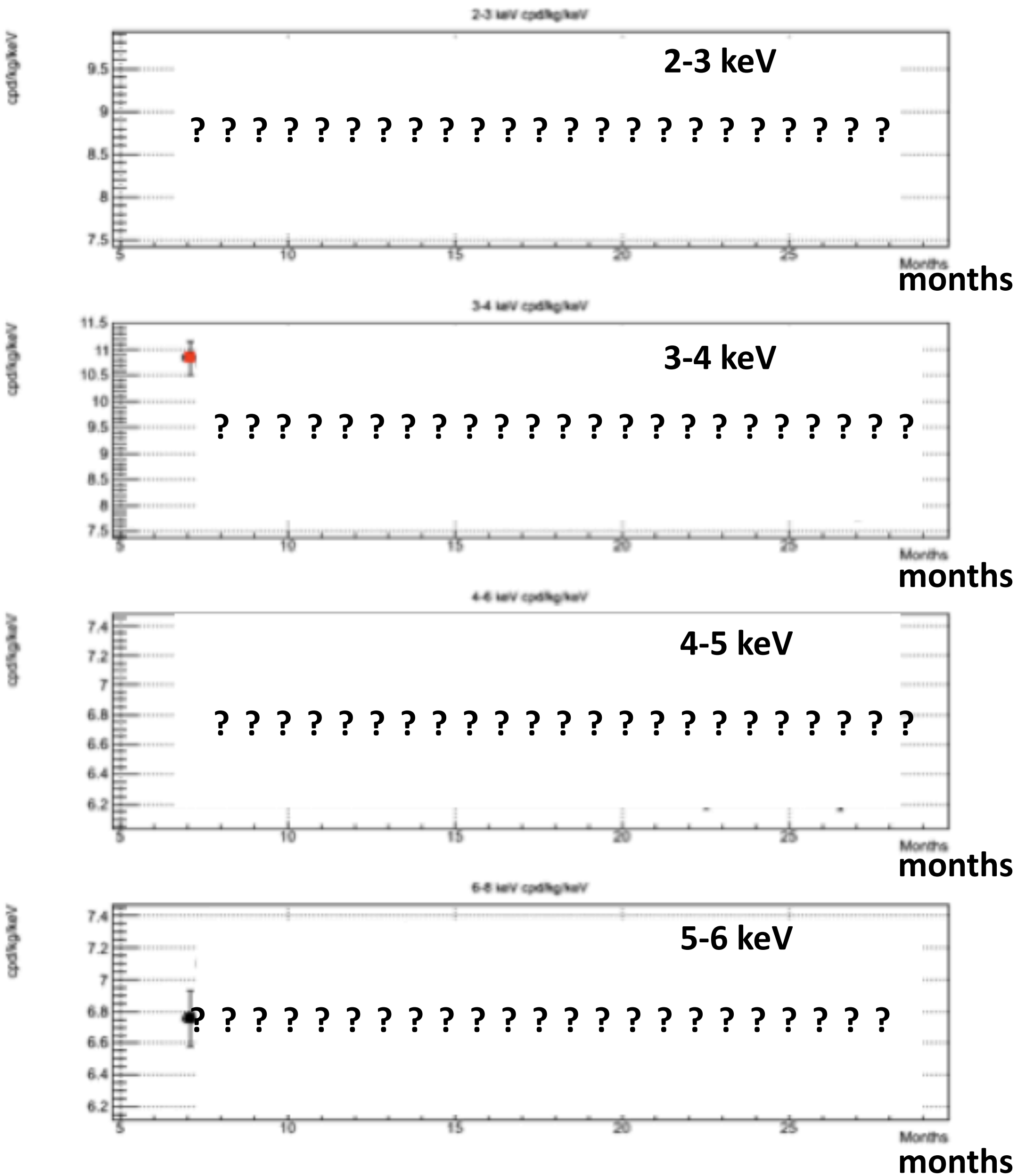

- Good agreement with simulation above 20 keV
  - Surface event simulation at 12 keV in progress
- We understand our detector to 4 keV
  - NAIAD published to 4 keV; we are pushing lower
- We model our 3 keV peak to within a factor of 2 of simulation
  - Understanding efficiencies

**Looking ahead:**

- Backgrounds in ROI 5x higher than simulated for full scale DM-Ice
- Multi-crystal veto will suppress 3 keV events

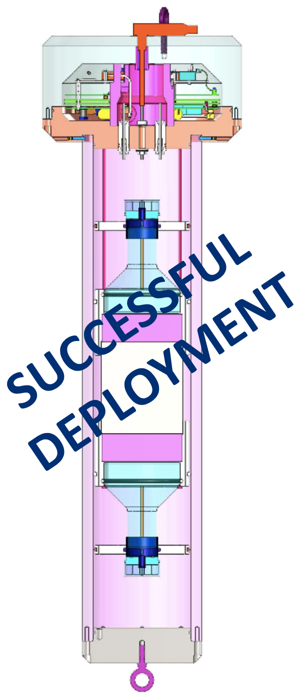
# Analysis Result

- 24 months data analysed for modulations
- Results coming soon!
- Remember this is for 17 kg NaI, with background ~x7 DAMA in low enery region



# Conclusions

- successfully deployed two detectors 2450 meters in the ice
- incredibly stable environment
- calibration from internal/external backgrounds (no calib sources)
- Geant4 background model in agreement with data
- good understanding down to 4 keV ( ~ 7 cpd/kg/keV)
- pushing our energy threshold < 2 keV




DM-Ice Sensitivity
500 kg•yr NaI
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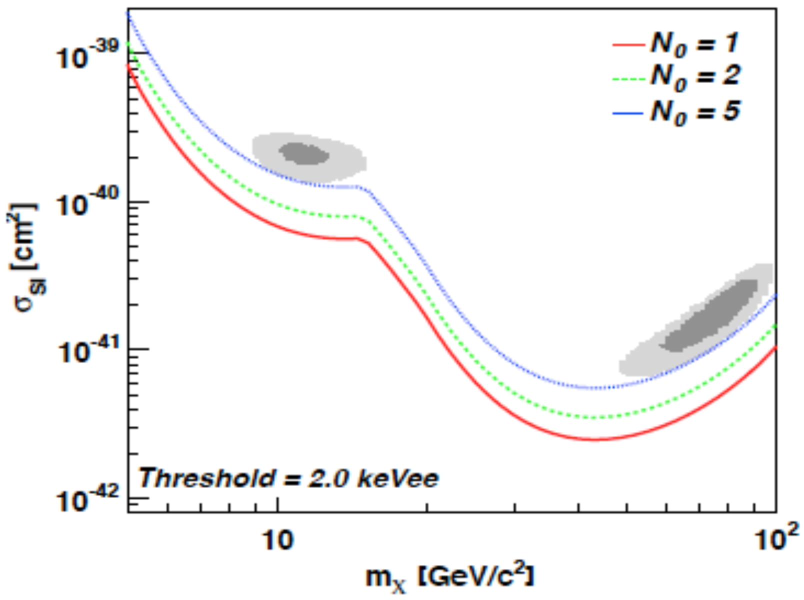


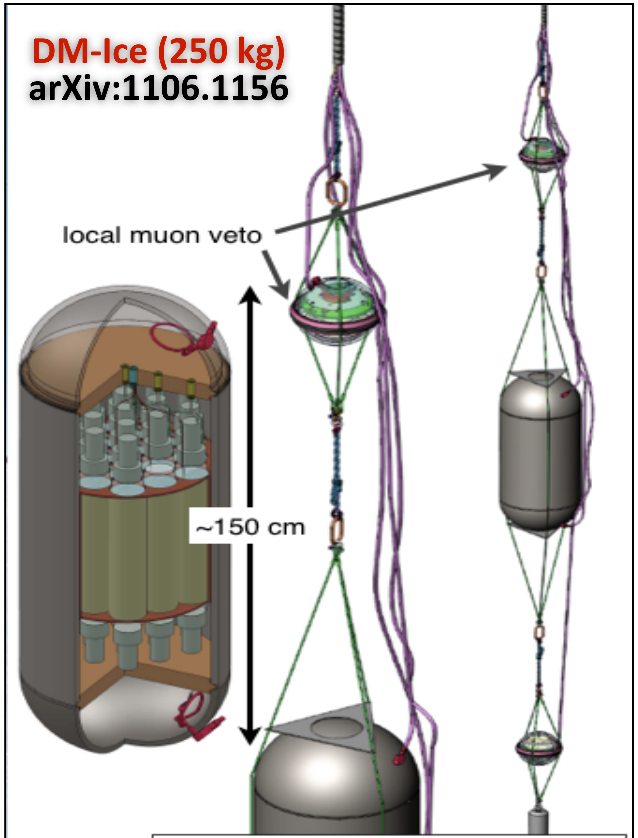


In-ice strings for DM-Ice deployment