

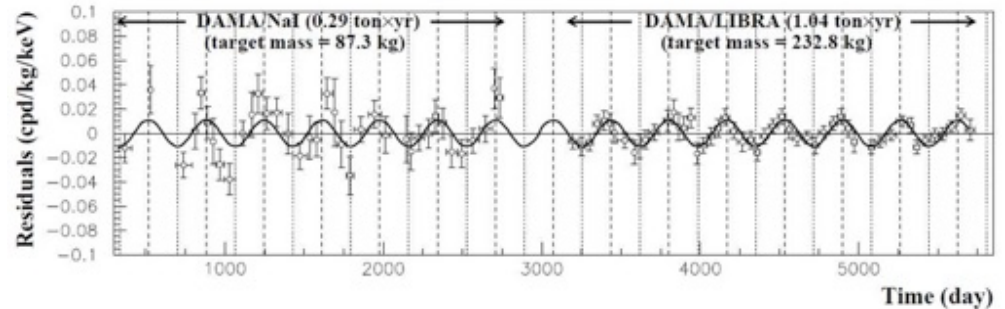
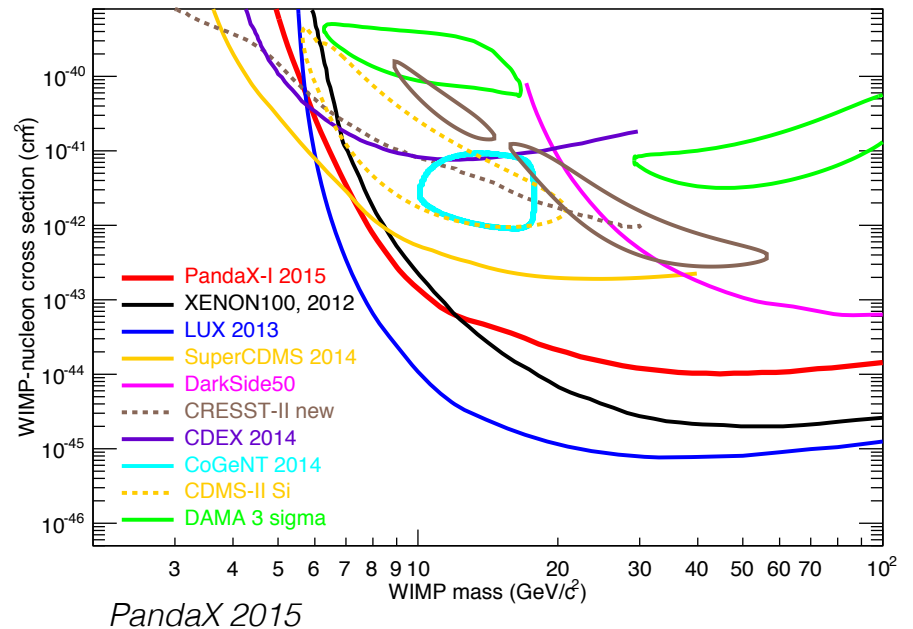


DM-Ice: Results and Prospects

Antonia Hubbard
Northwestern University

Has DAMA found dark matter?

- Bigger and more advanced experiments continue to produce increasingly sensitive limits
- We still have positive signals to explain away
 - CoGeNT, CRESST, CDMS-Si may be the results of backgrounds
- DAMA modulation ($9\sigma+$) remains unexplained
 - Is it dark matter?
 - No compatible background hypothesis
 - More exclusion limits will not answer this question

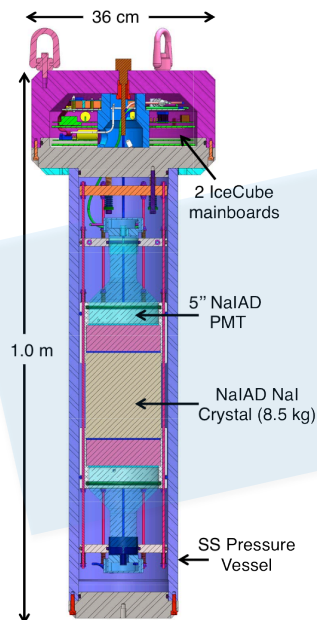


DAMA 1412.6524

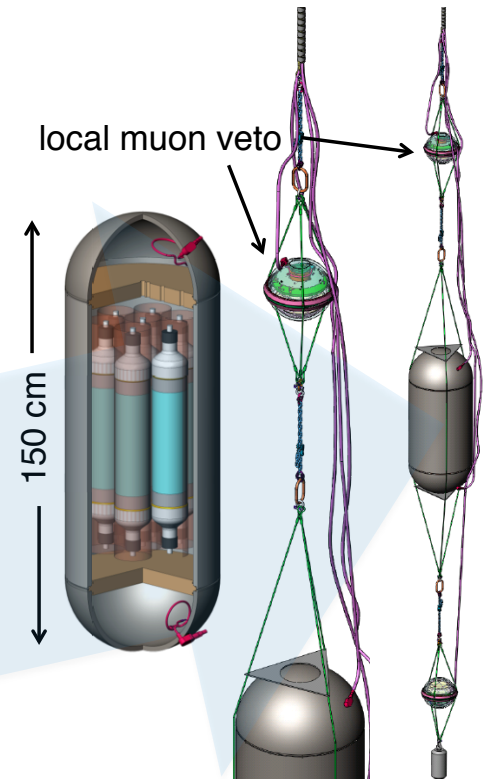
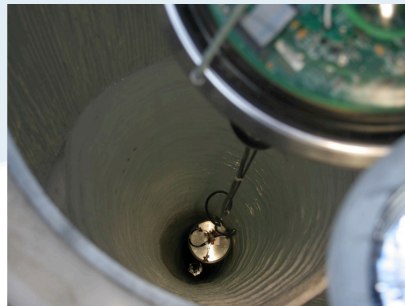
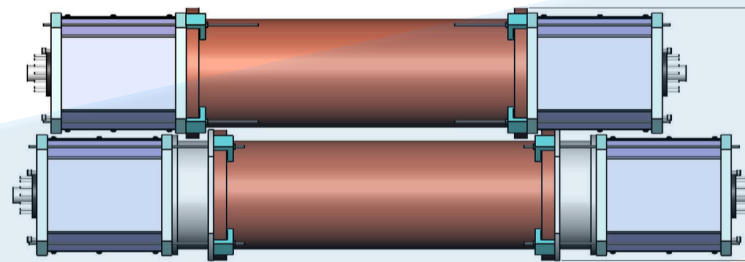
DM-Ice

- Phased program designed to maintain DAMA's sensitivity to dark matter signal
 - NaI(Tl) of similar size, threshold as DAMA
- Run in both hemispheres to decouple WIMP modulation from seasonal backgrounds

DM-Ice17: Feasibility
[Southern Hemisphere]



DM-Ice37: R&D
[Northern Hemisphere]



DM-Ice250: Set limits
[Southern Hemisphere]

Global NaI(Tl) Collaborative Effort

★ **Boulby**
★ **Canfranc**

ANAIS

University of Zaragoza
Canfranc Laboratory
University of Washington

&

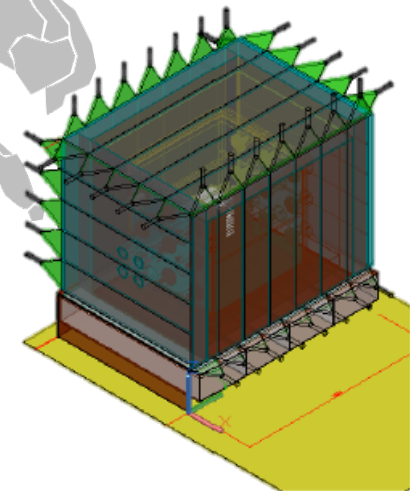
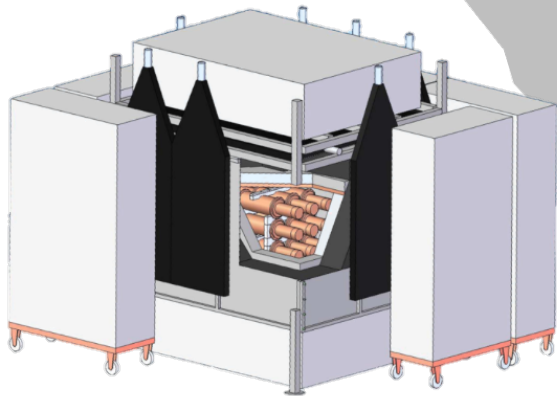
DM-Ice

Yale University
University of Wisconsin
Sheffield University
University of Illinois
University of Alberta
Fermilab NAL
Boulby Laboratory

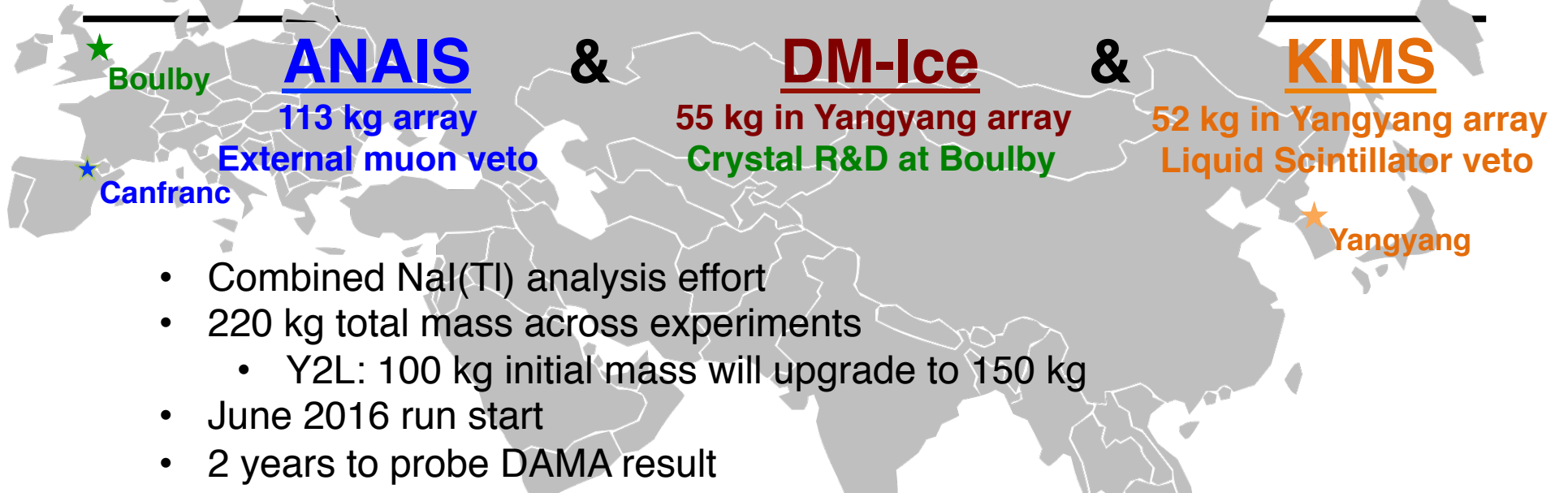
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KIMS

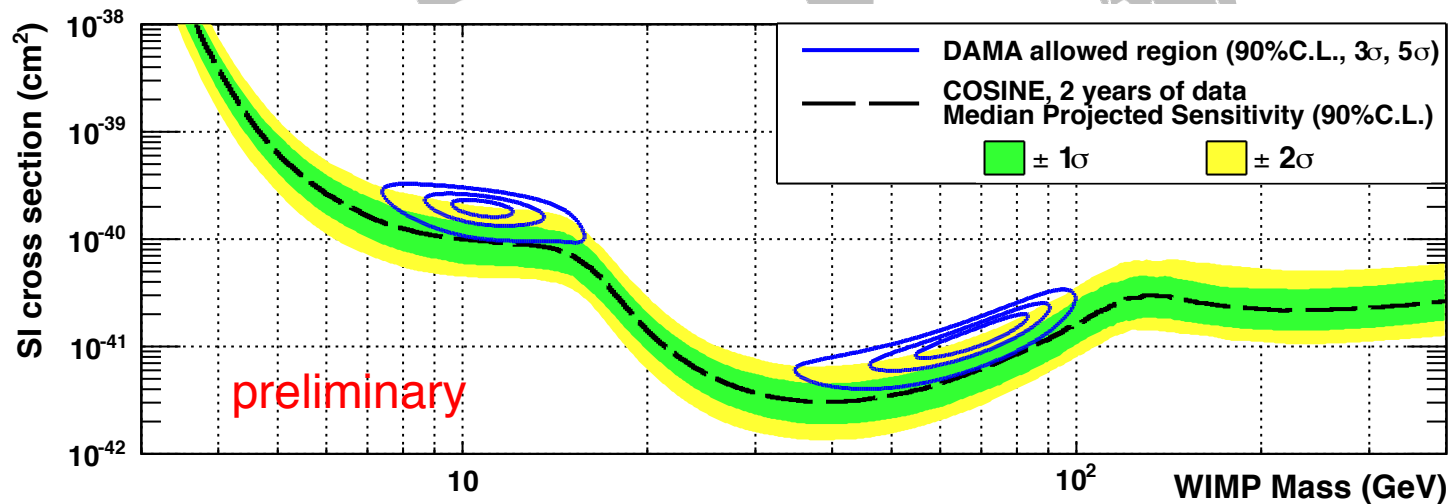
Seoul National University
Sejong University
Kyungpook National University
Yonsei University **Yangyang**
Ewha Womans University
Seoul City University
Korea Res. Inst. of Standard Sci.
Tsinghua University



Global NaI(Tl) Collaborative Effort

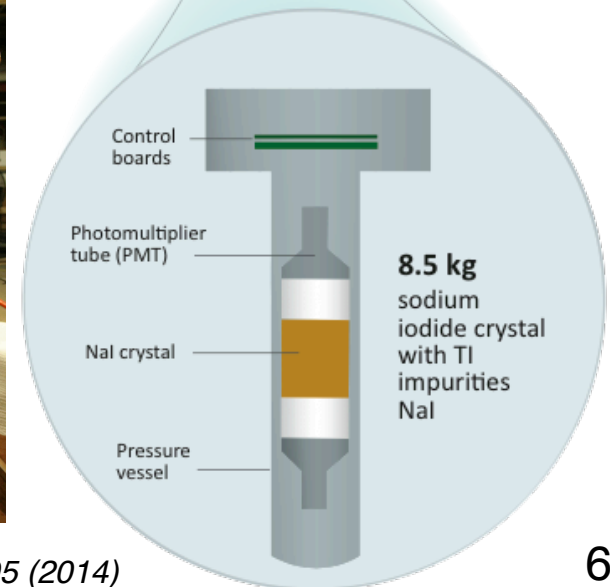
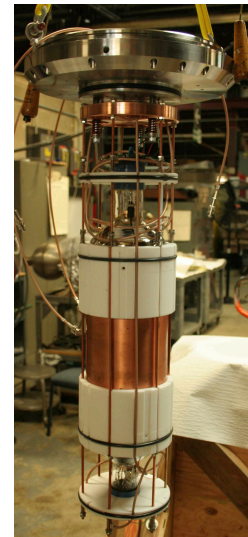
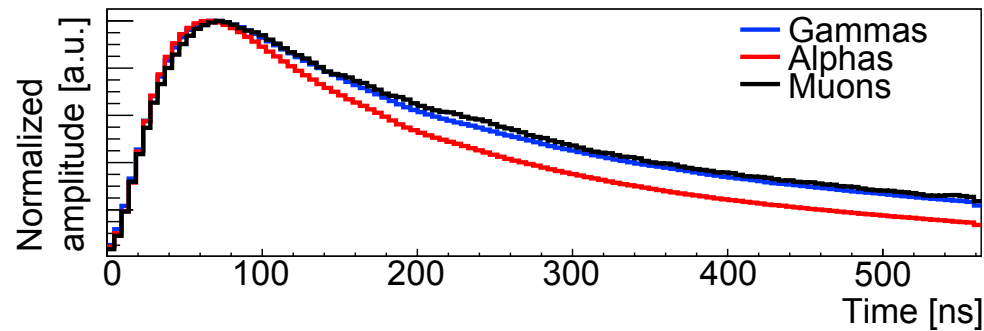
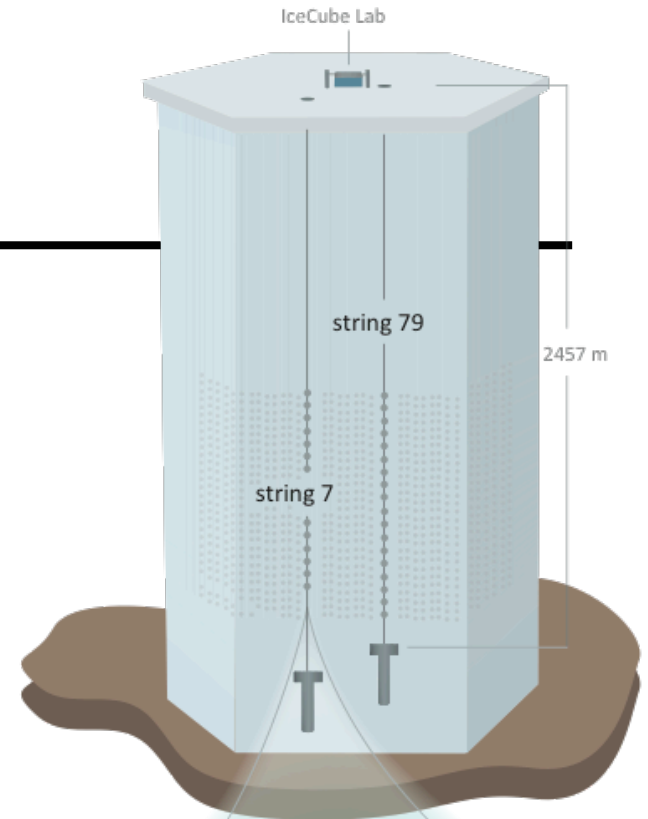


- Combined NaI(Tl) analysis effort
- 220 kg total mass across experiments
 - Y2L: 100 kg initial mass will upgrade to 150 kg
- June 2016 run start
- 2 years to probe DAMA result

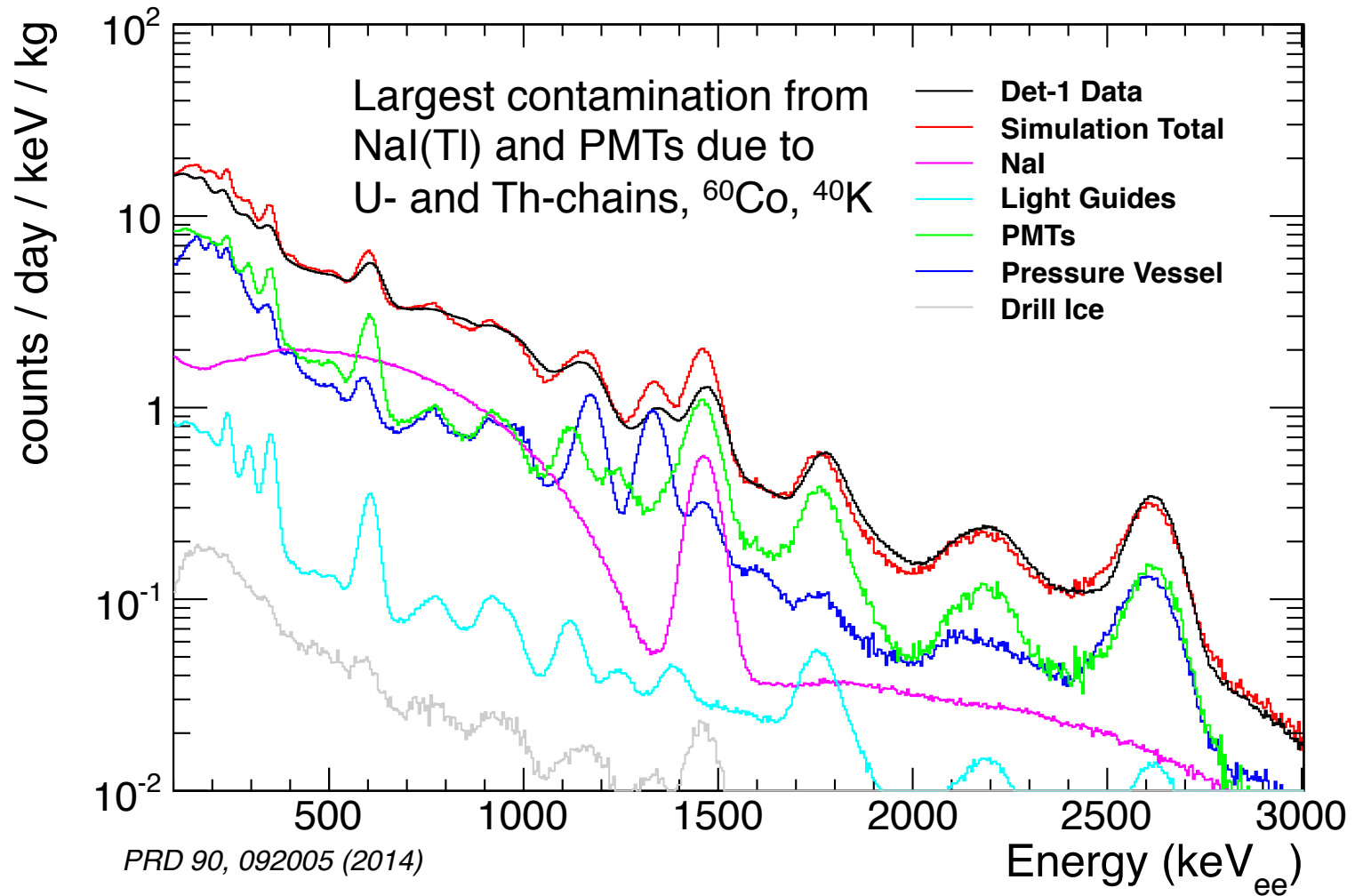


DM-Ice17

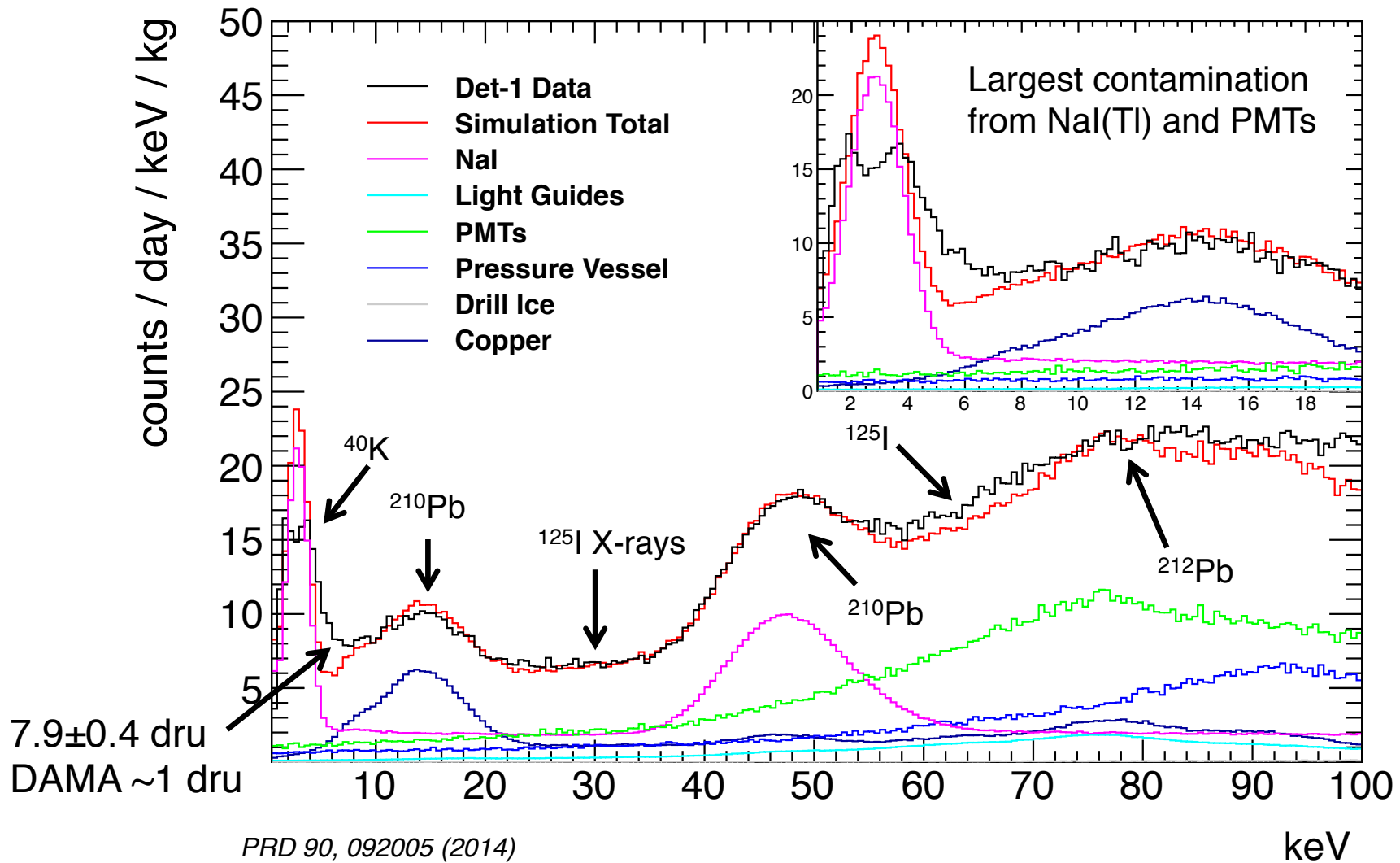
- Deployed December 2010
 - >99% uptime after June 2011
- 2 detectors located 2457 m deep
 - Optically isolated from the ice
- 14 cm dia. x 16 cm NaI(Tl) crystals



DM-Ice17 Background Model

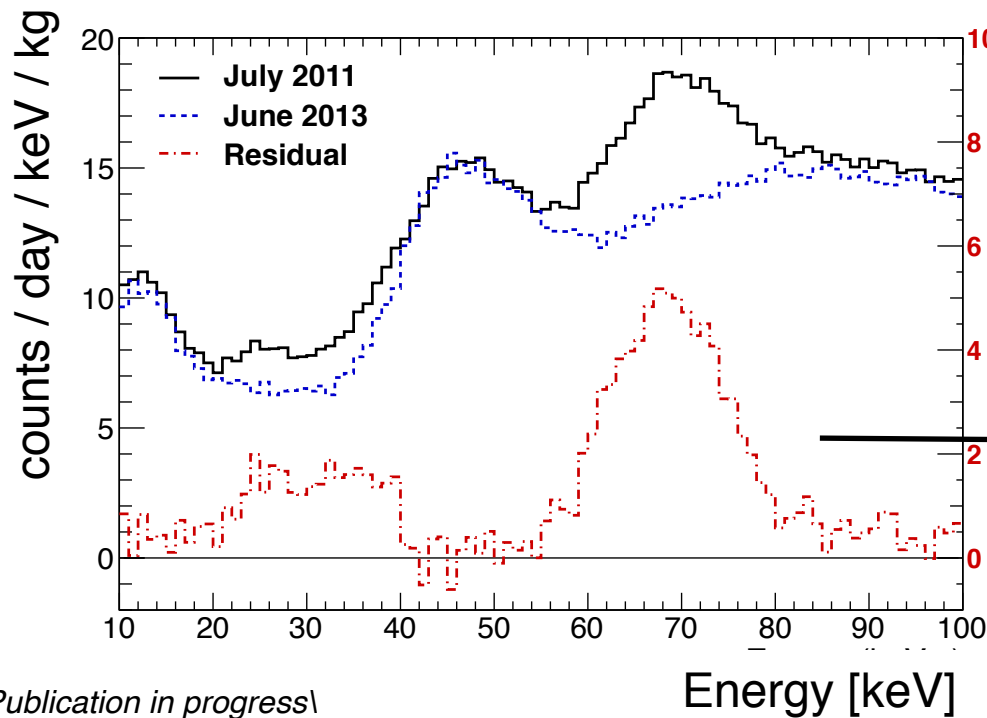


Low Energy Background Model

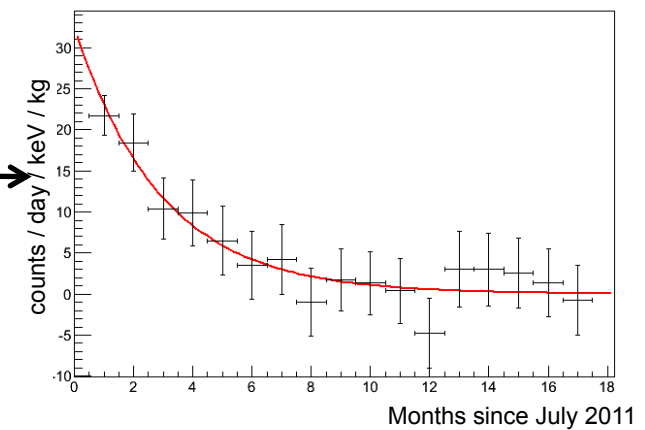


Remote Calibration

- Cosmogenic activation provides a calibration source for the remotely deployed detectors
 - Short-lived isotopes are identified by their energy and decay time



^{125}I half-life measured to be 59.4 ± 2.7 days, consistent with quoted value of 59.40 ± 0.01 days

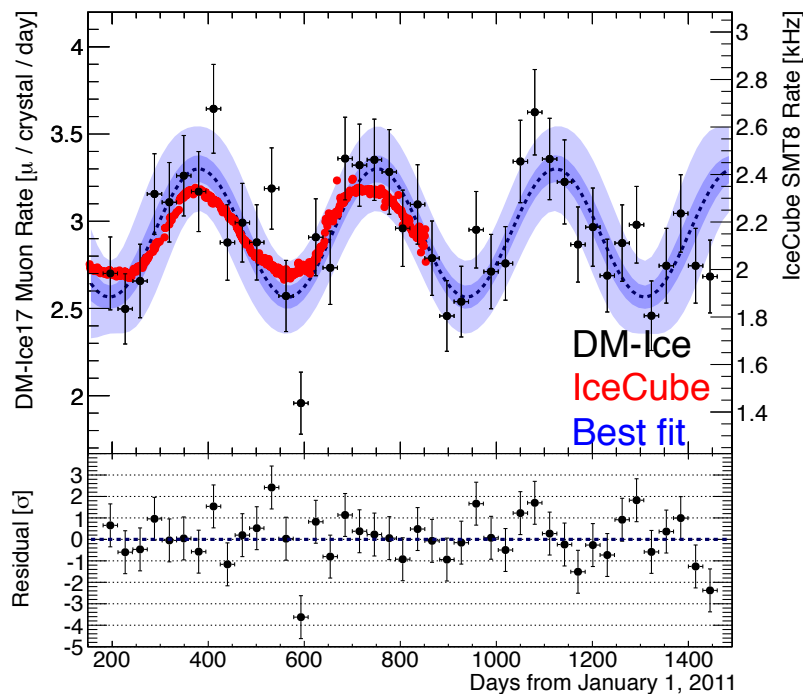


Publication in progress

DM-Ice17 Muon Events

Muon Flux

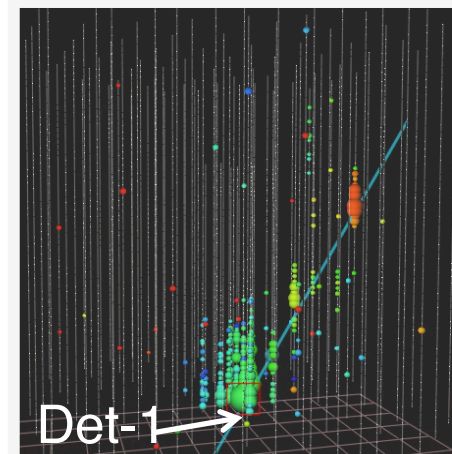
- Flux of 2.93 ± 0.04 muons/crystal/day with a $12.3 \pm 1.7\%$ modulation amplitude



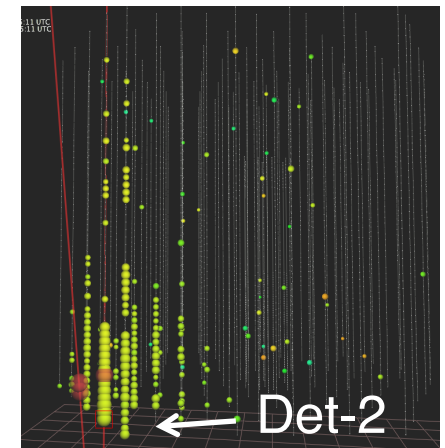
PRD 93, 042001 (2016)

IceCube Coincidence

- 93% of DM-Ice Det-1 muons are coincident with IceCube events
- DM-Ice location information lowers misreconstruction rates and improves location reconstruction through IceCube
 - Little impact on astrophysical parameters

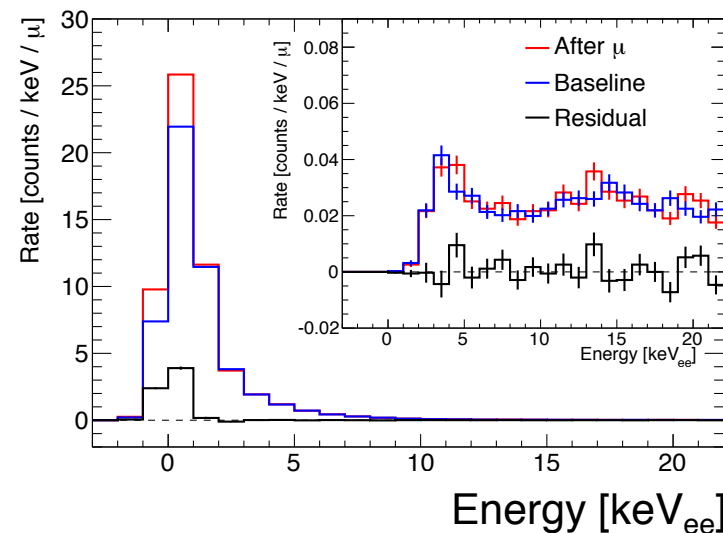
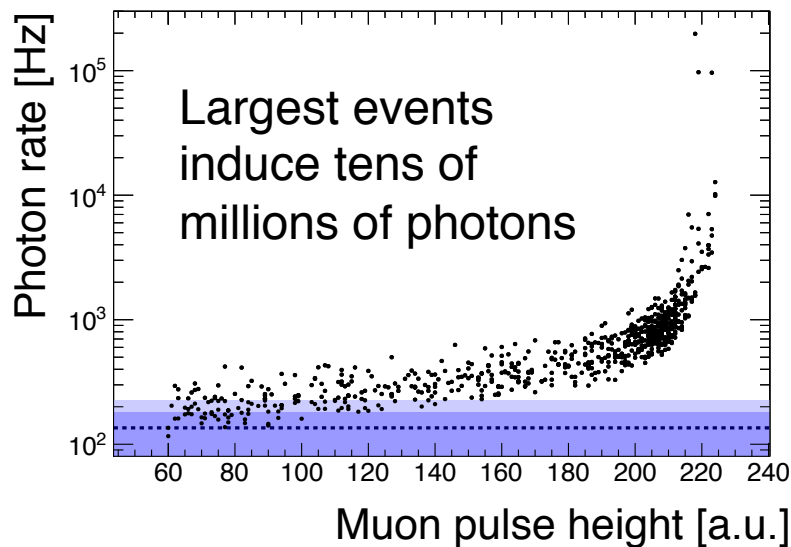
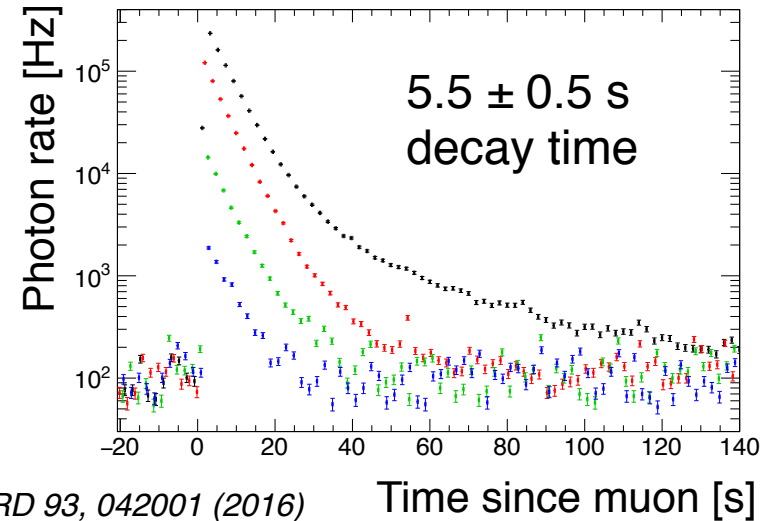


Hubbard



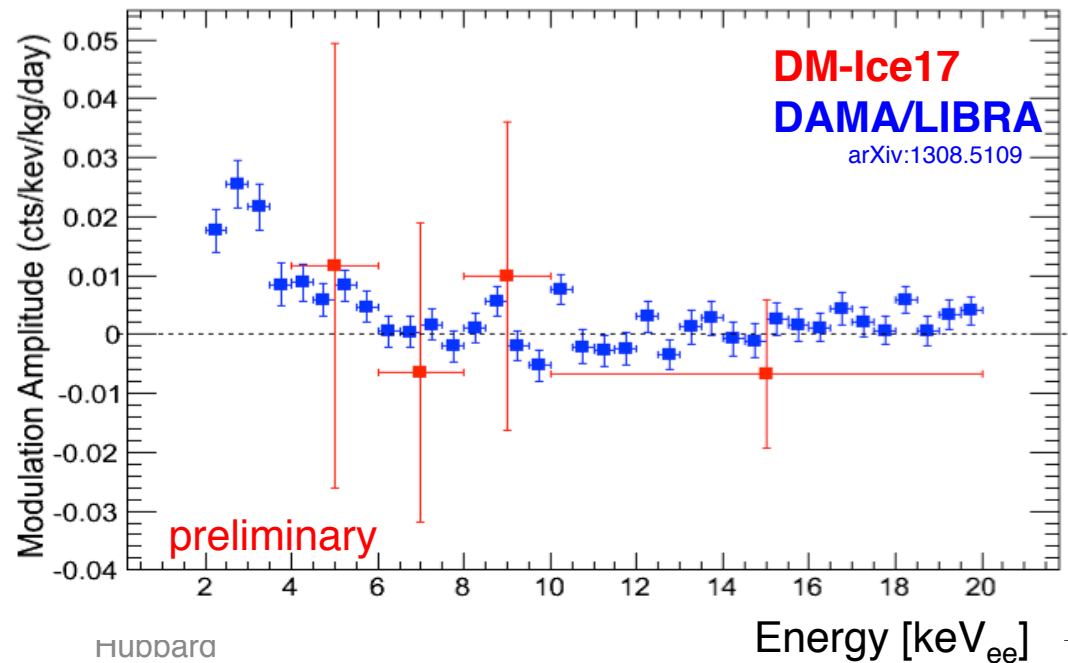
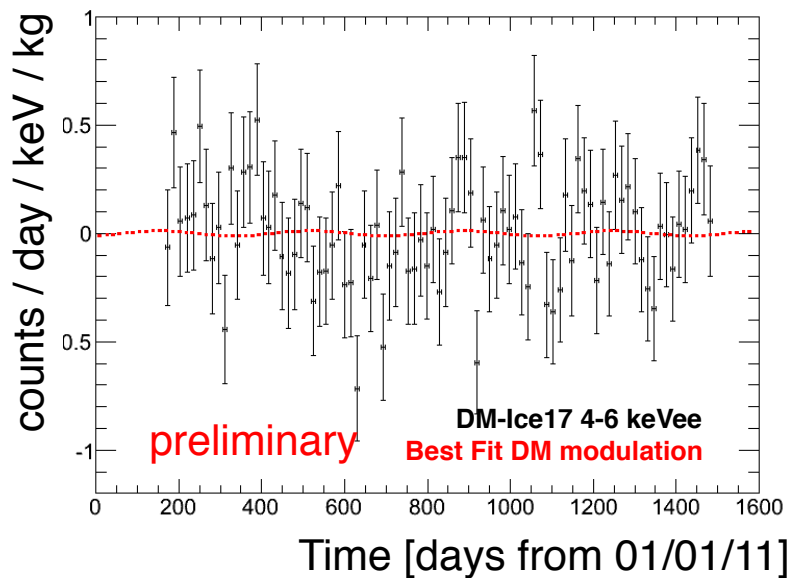
Muon-Induced Phosphorescence

- Large energy depositions in NaI(Tl) induce long-lived phosphorescent decay
- Sharp increase in photon rate, correlated with muon energy deposition, that produces low energy pulses and slowly decays
 - Pulses are tagged by noise cuts

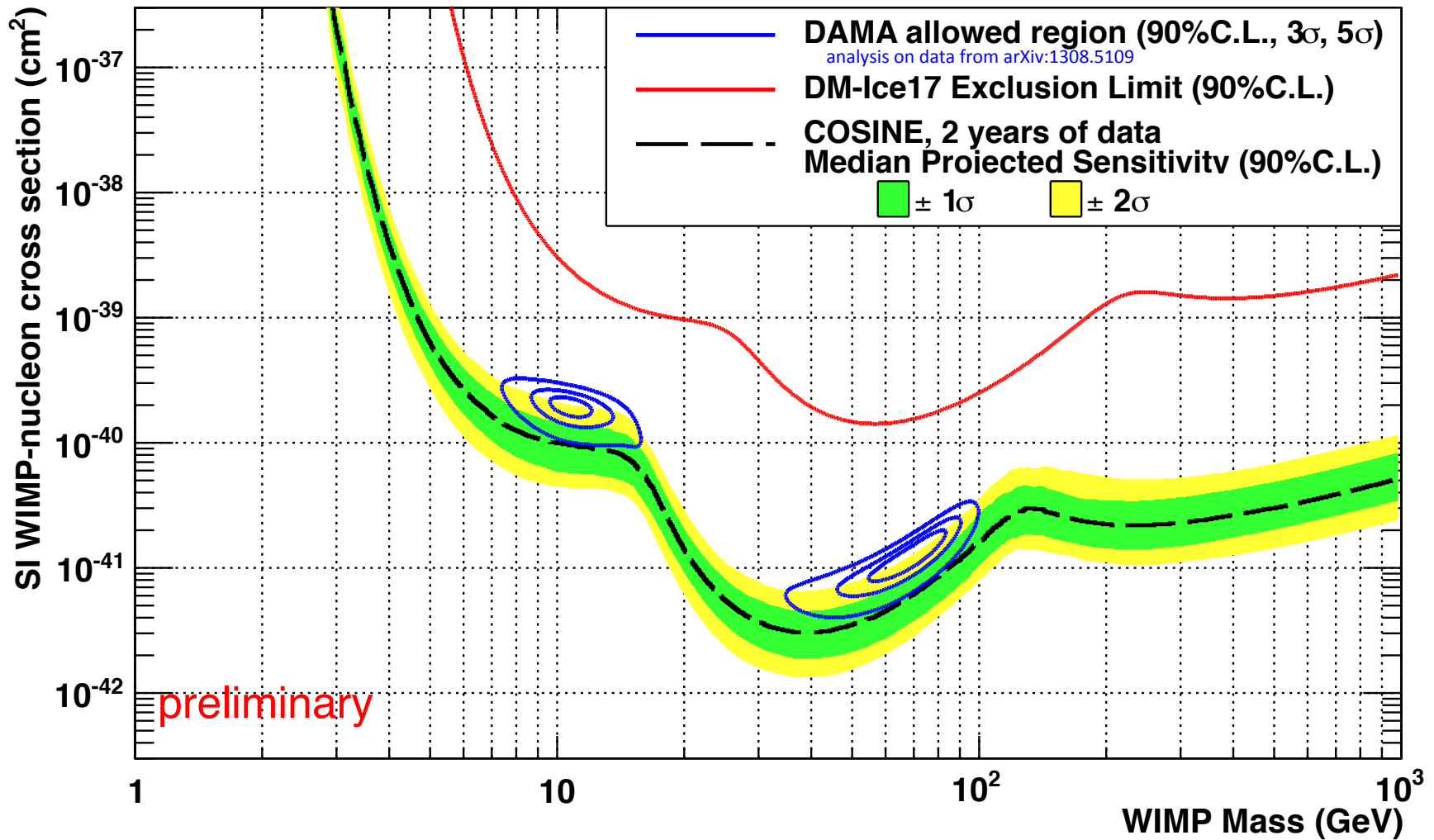


Modulation Analysis

- Modulation amplitude is consistent at all energies with both no modulation and the DAMA/LIBRA signal
 - Fit forces a June 2nd phase; 1 year period
- DM-Ice17 environment is stable
 - Temperature is stable to $<0.3^{\circ}\text{C}$
 - Calibration stable to $<0.2\%$ after accounting for light yield changes
 - No time dependence observed in energy resolution, detector deadtime, cut efficiency, or muon-induced event rate



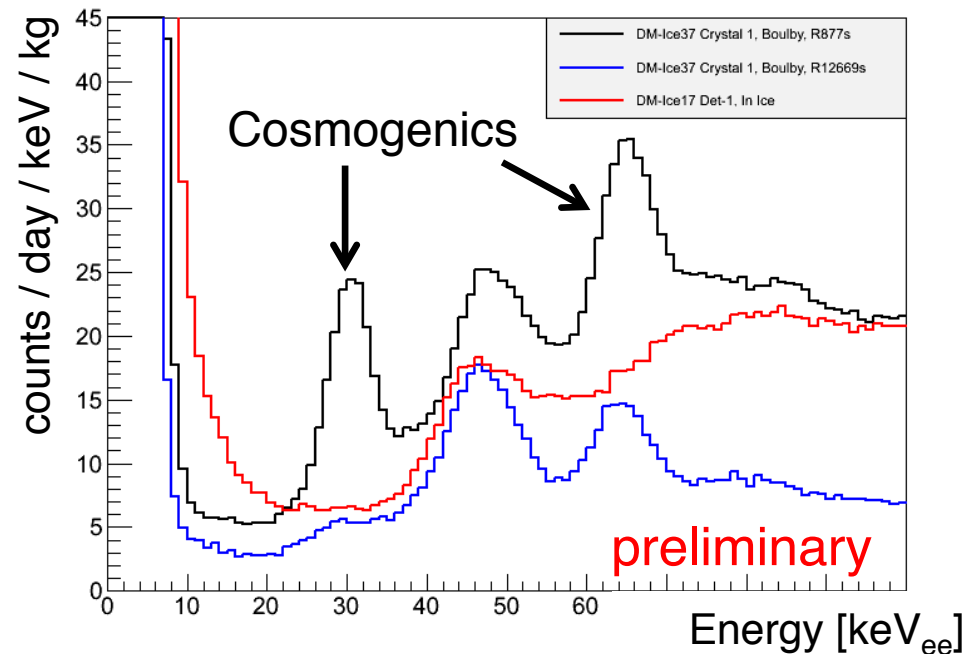
DM-Ice Exclusion Curves



Strongest exclusion limit from a Southern Hemisphere experiment.

Gains from DM-Ice37

- 2-18.3 kg crystals tested at Boulby Underground Lab
- NaI(Tl) improvements
 - 3 dru above noise energies
 - Goal from DAMA: 1 dru
- Significant PMT improvements
- Improved threshold, resolution

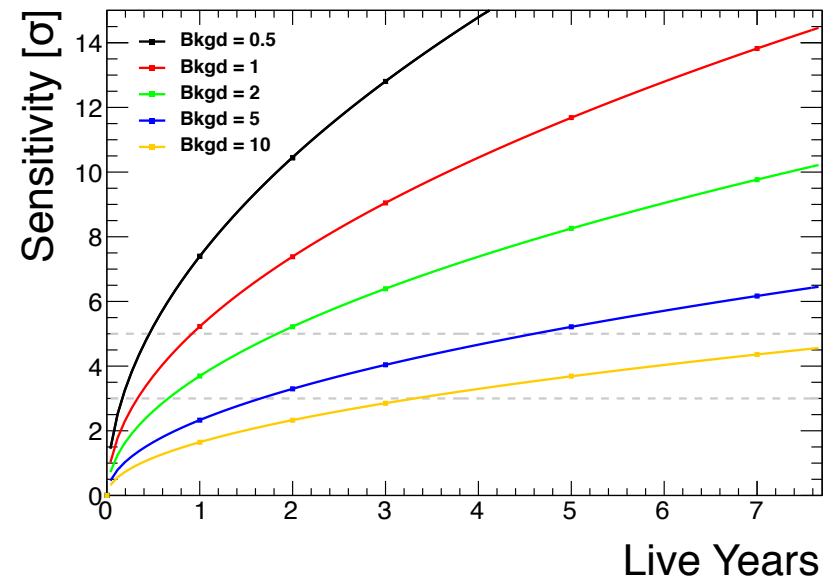
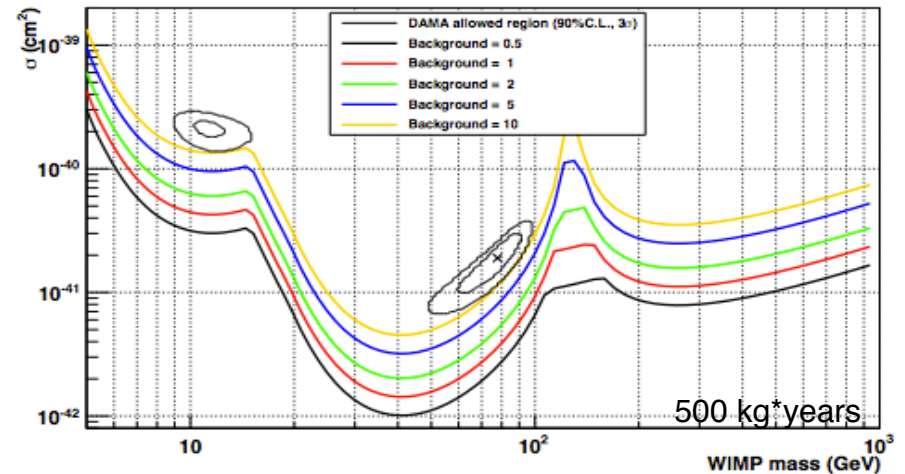


Crystals	^{40}K [mBq/kg]	^{210}Pb [$\mu\text{Bq/kg}$]	^{228}Ra - ^{208}Tl
DM-Ice17	17	1500	160
DAMA	0.6	24.2	8.5
In progress	1.5	188	2



Conclusions

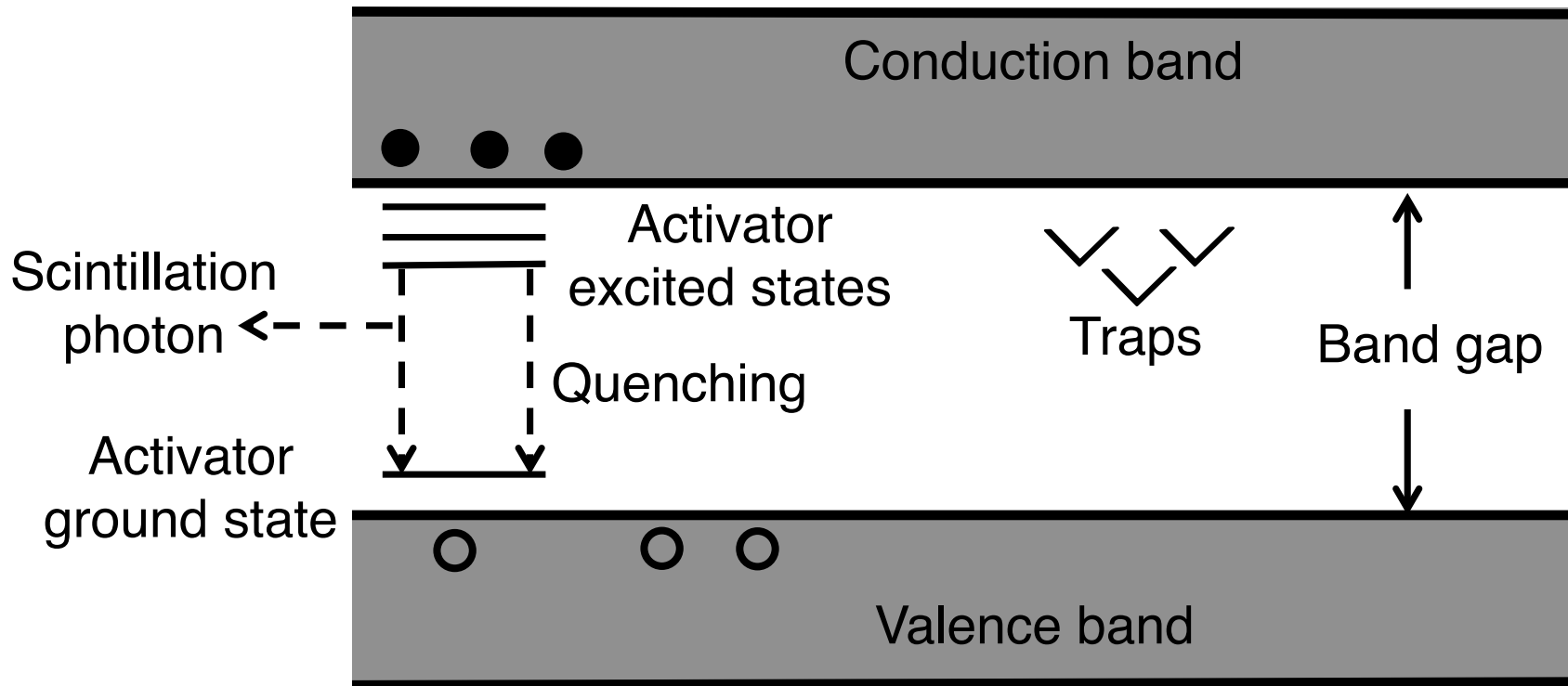
- DM-Ice17 has performed better than expected
 - Established South Pole as a good environment for NaI(Tl) detectors
 - Longest direction detection exposure behind DAMA
 - Measured muon modulation and phosphorescence, cosmogenic activation, and performed modulation analysis
- DM-Ice37 achieved backgrounds to levels able to probe DAMA
- DM-Ice55/KIMS/ANAIS will come online June 2016
 - 2 years to probe DAMA result





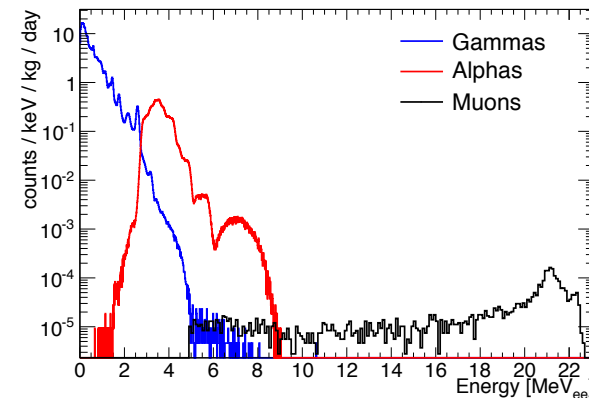
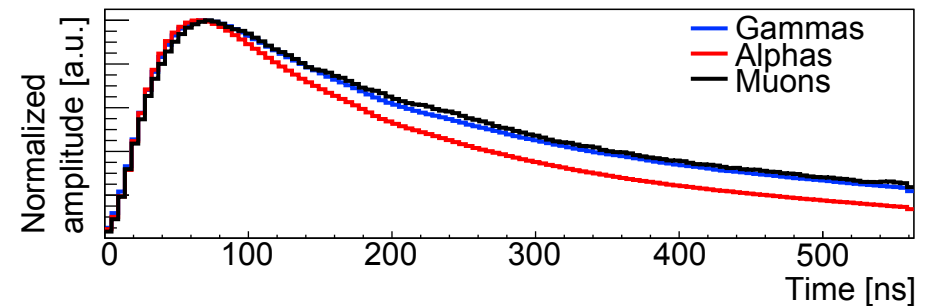
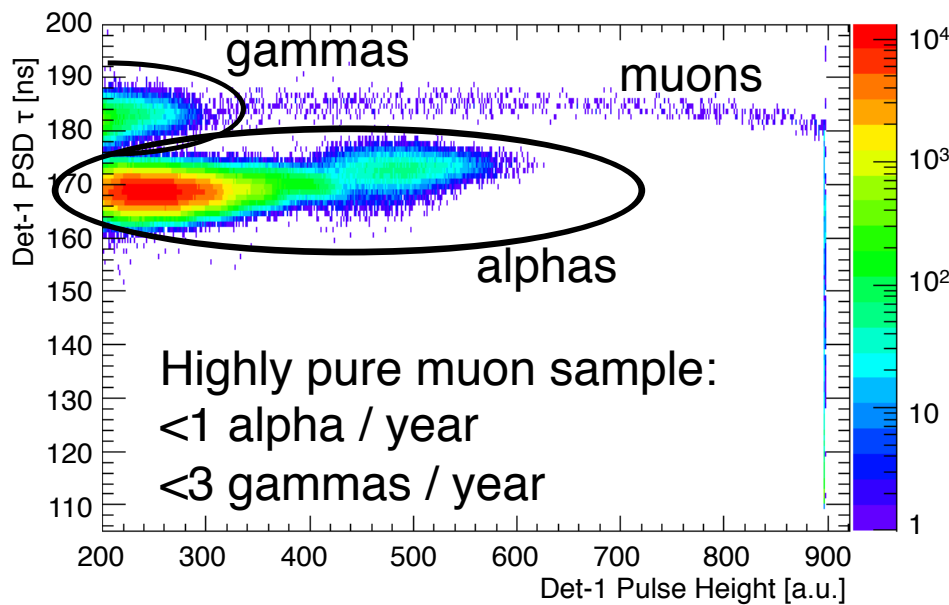
Backup Slides

Scintillation Mechanism



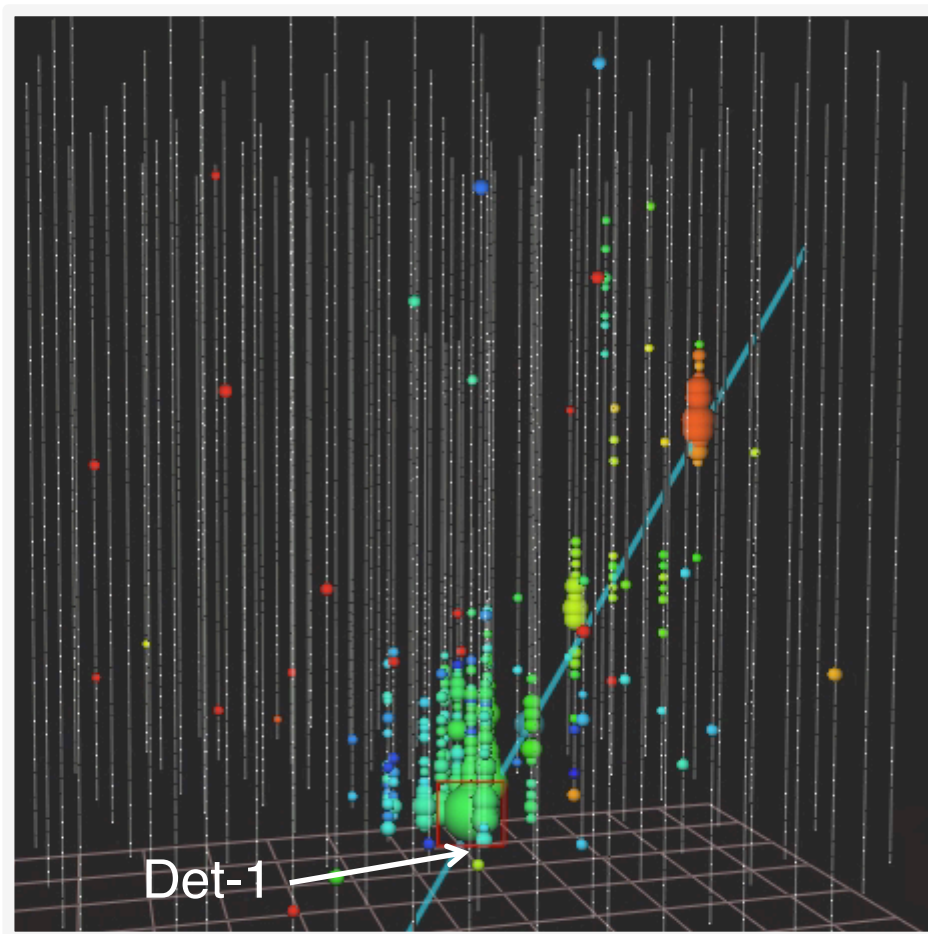
Muon Identification

- Muons are identified through pulse shape discrimination and energy deposition
 - Alphas decay faster than gammas and muons
 - Muons exhibit a MIP energy deposition

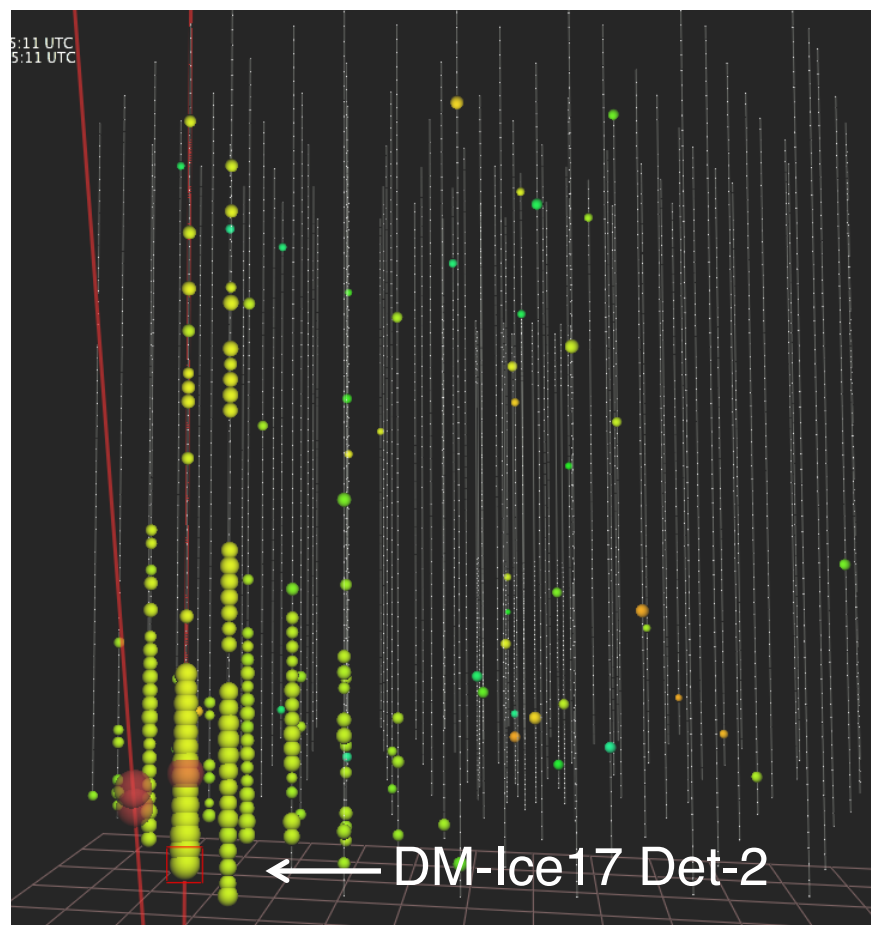


Coincident Events

Det-1

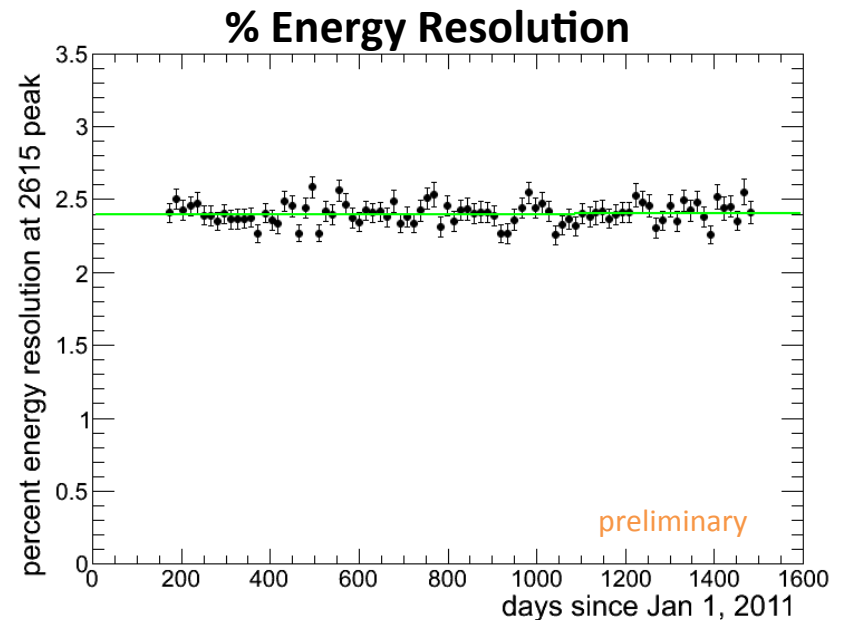
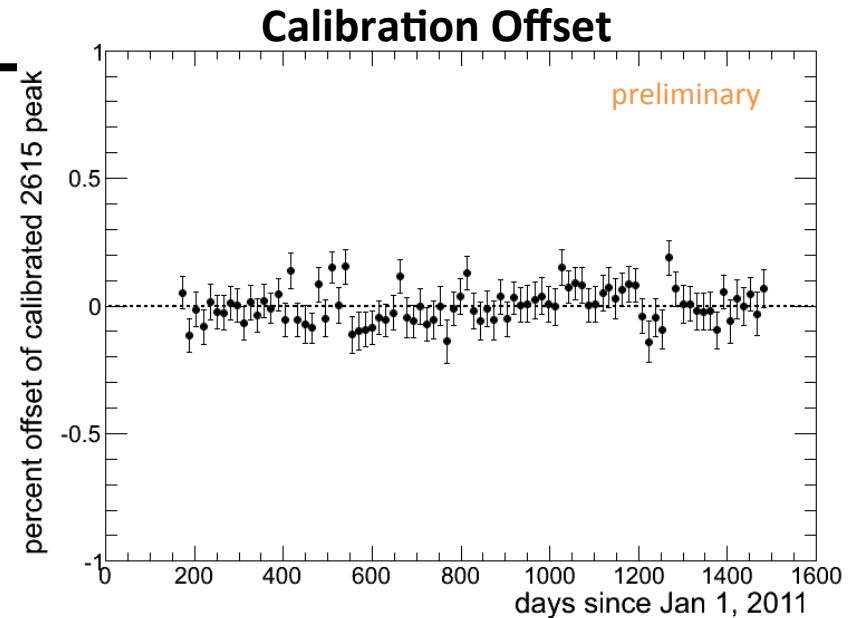
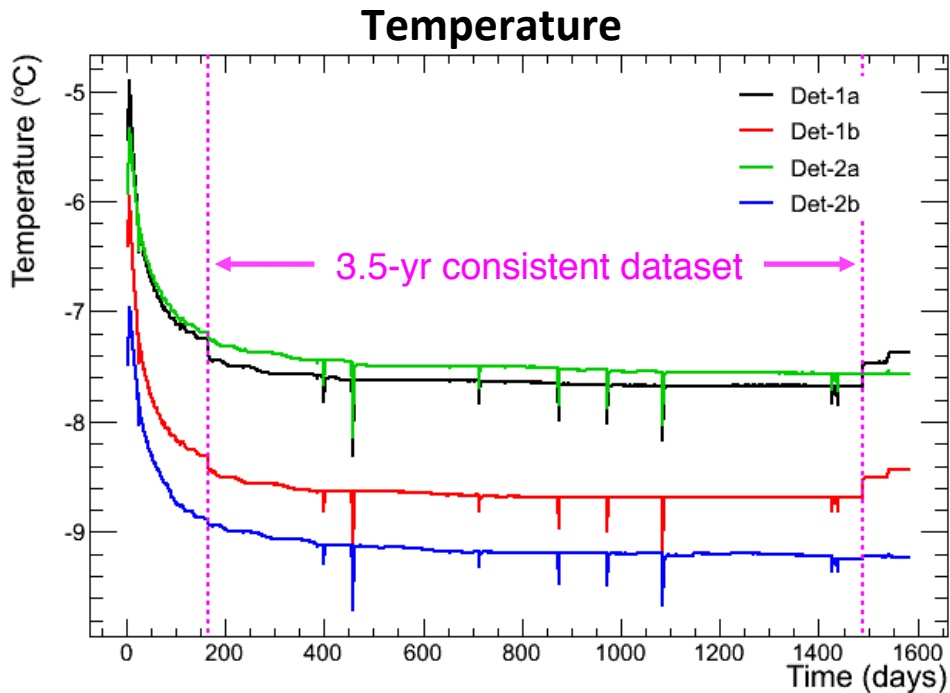


Det-2

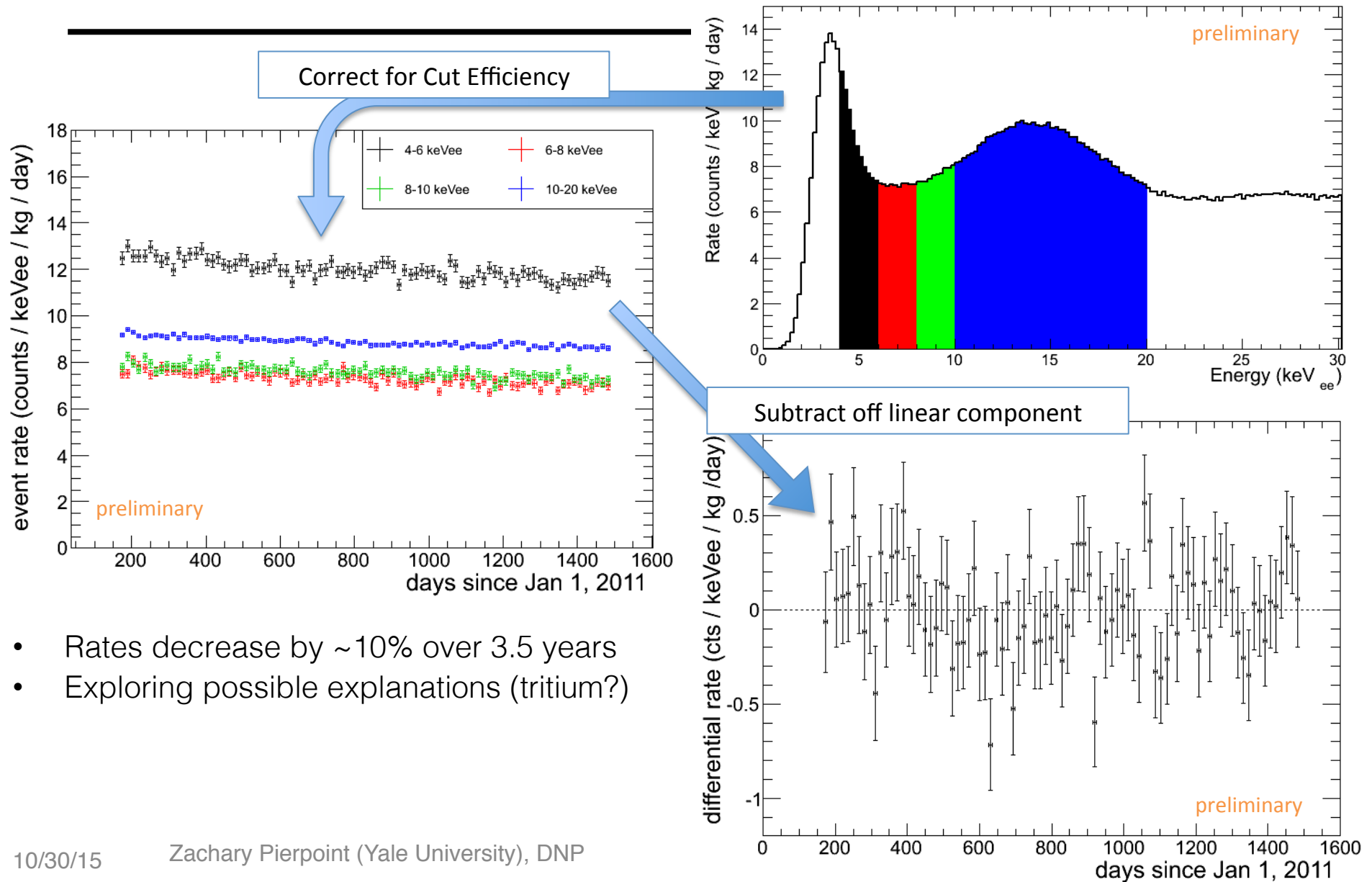


Detector Stability

- ~~Temperature stable to $<0.3^\circ\text{C}$~~
- Calibration stable to $<0.2\%$
- No evidence for time dependence in:
 - energy resolution
 - detector deadtime
 - cut efficiency
 - muon induced event rate



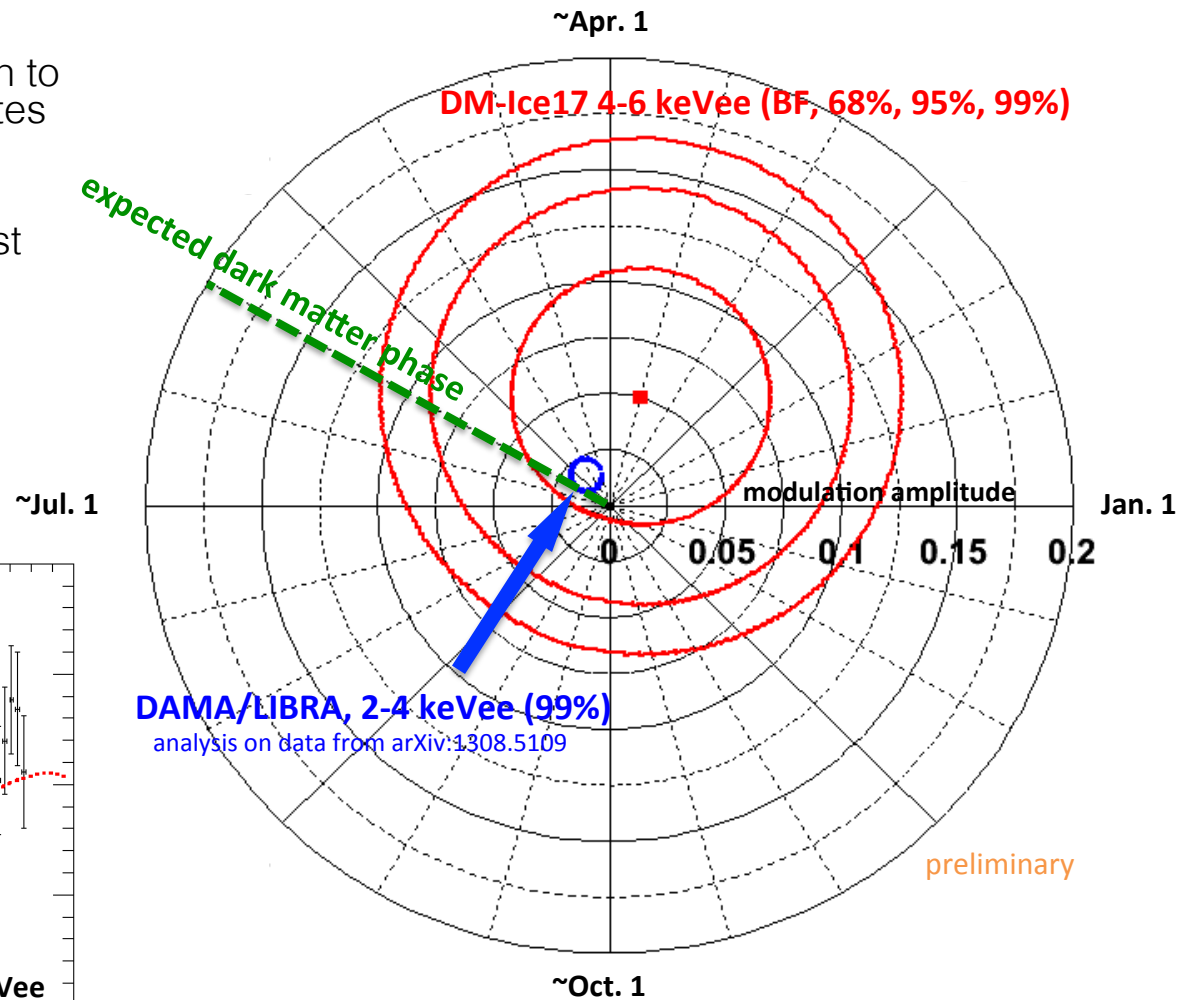
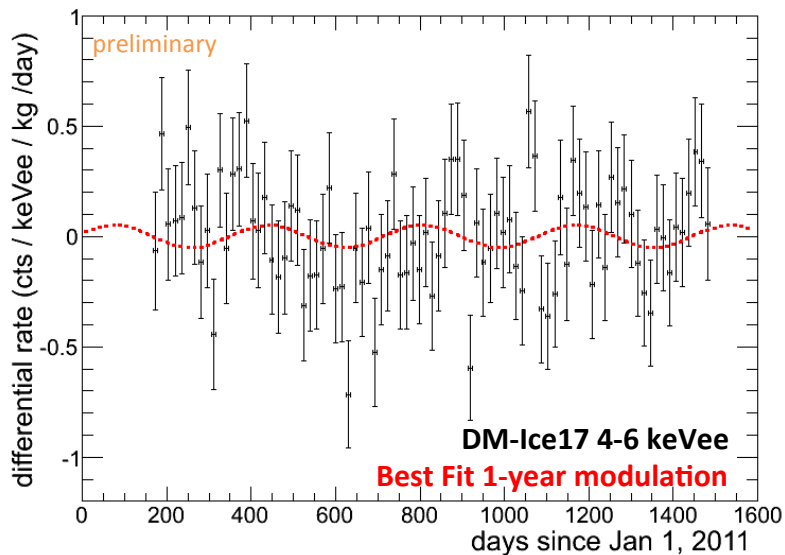
Event Rates in the Region of Interest



- Rates decrease by $\sim 10\%$ over 3.5 years
- Exploring possible explanations (tritium?)

Annual Modulation Allowed Regions

- Comparing sinusoidal modulation to background subtracted event rates
- *Phase fixed to 1 year*
- Log-likelihood comparison to best fit produces likelihood contours
- Same procedure on the DAMA region with maximal modulation provides a scale



DM-Ice37 Background Reduction

