COSINE-100 and Tests of DAMA

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Yale University

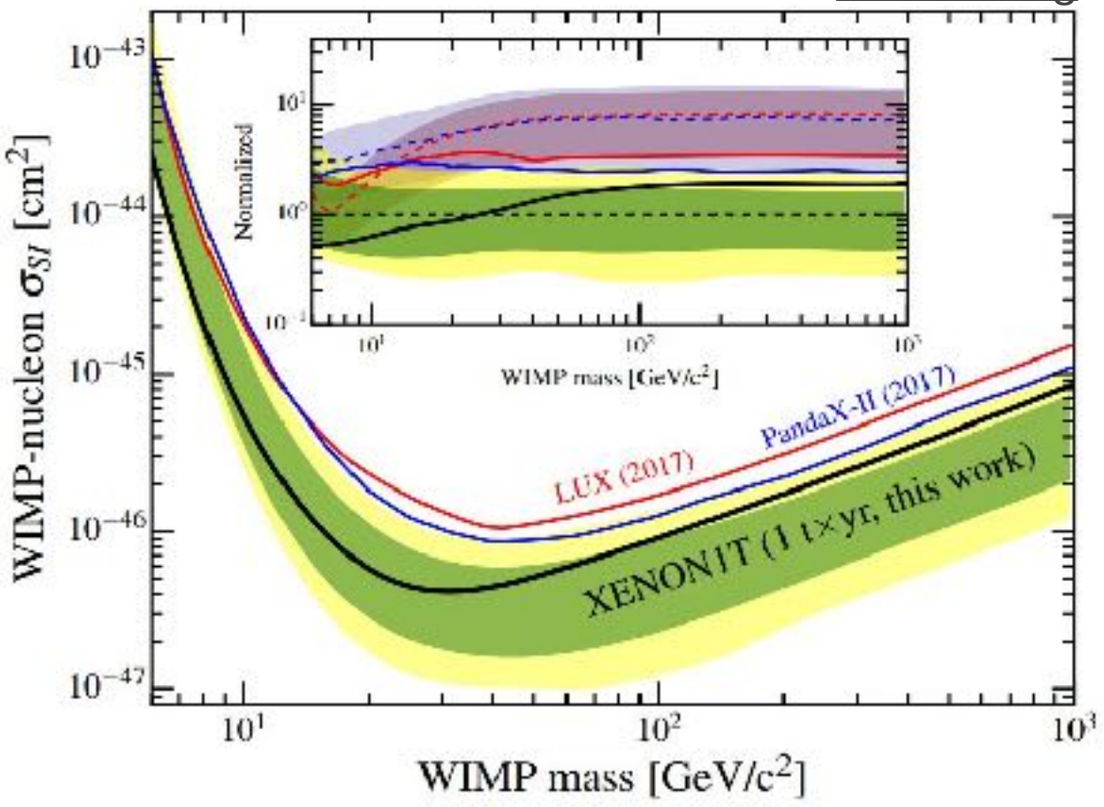
CIPANP 2018
29 May – 3 June, 2018

Yale

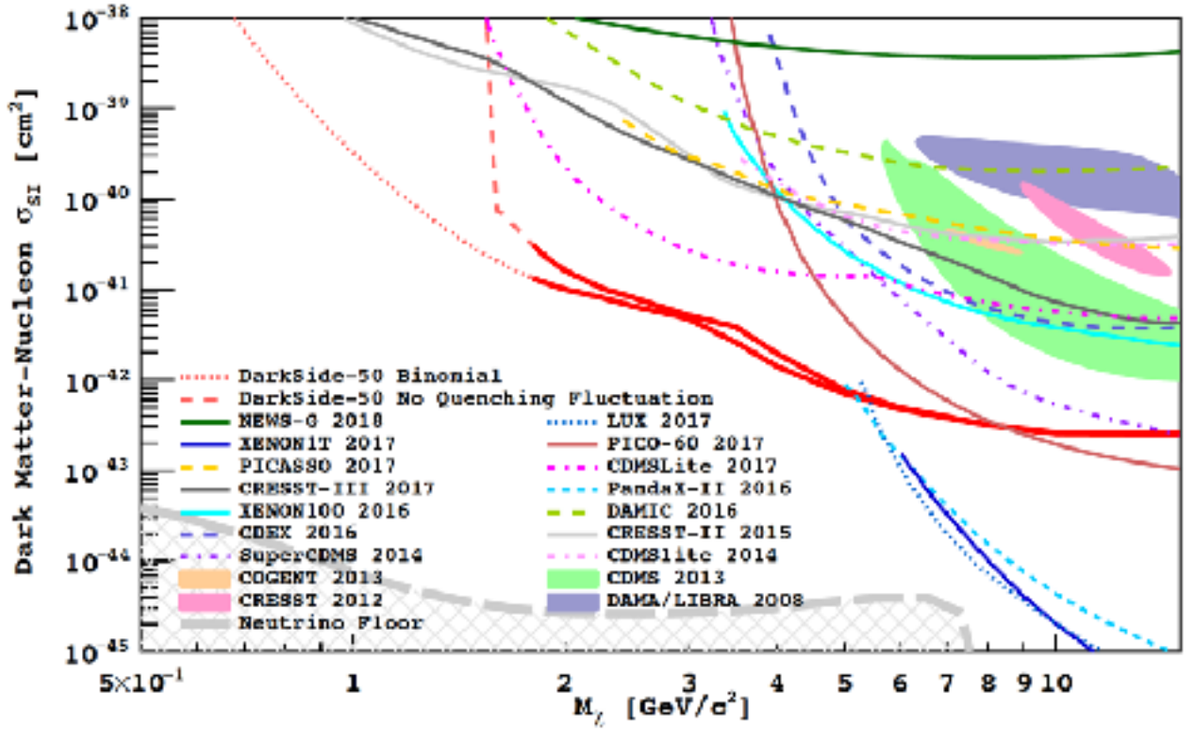
Wright Laboratory

Current status of Direct Dark Matter Searches

xenon1t.org

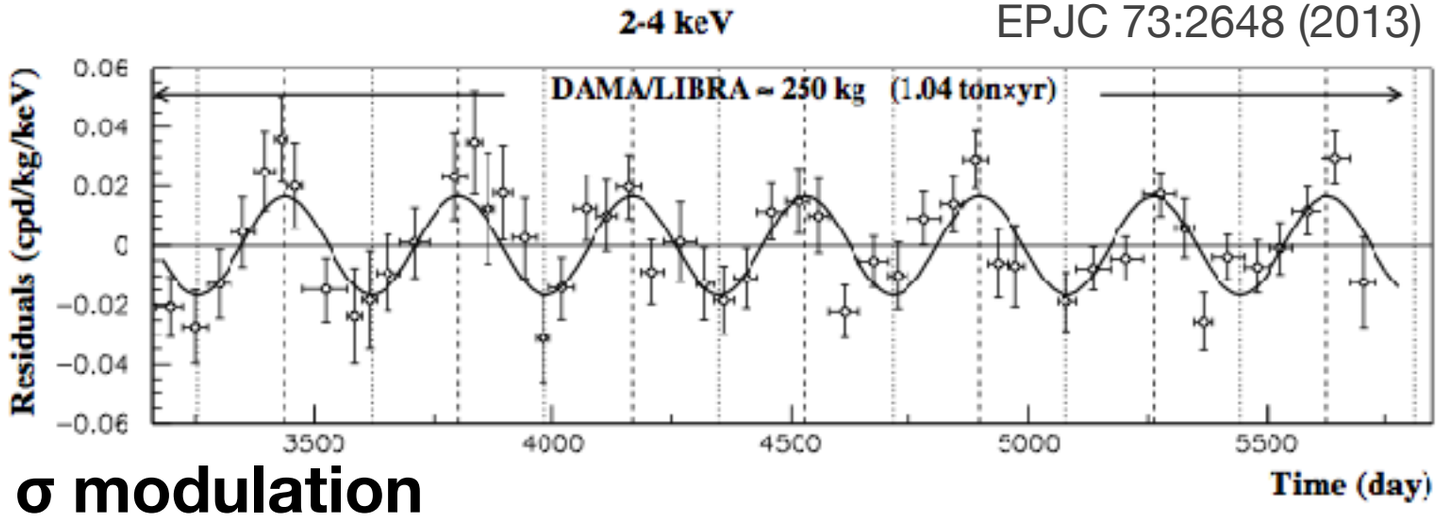


arXiv:1802.06994



- No sign of WIMPs down to >10^{-46} cm^2 @ 30 GeV from XENON1t, LUX, Panda X
- Experiments driving innovations toward low mass dark matter searches
- DAMA's signal remains unresolved

DAMA Phase 1

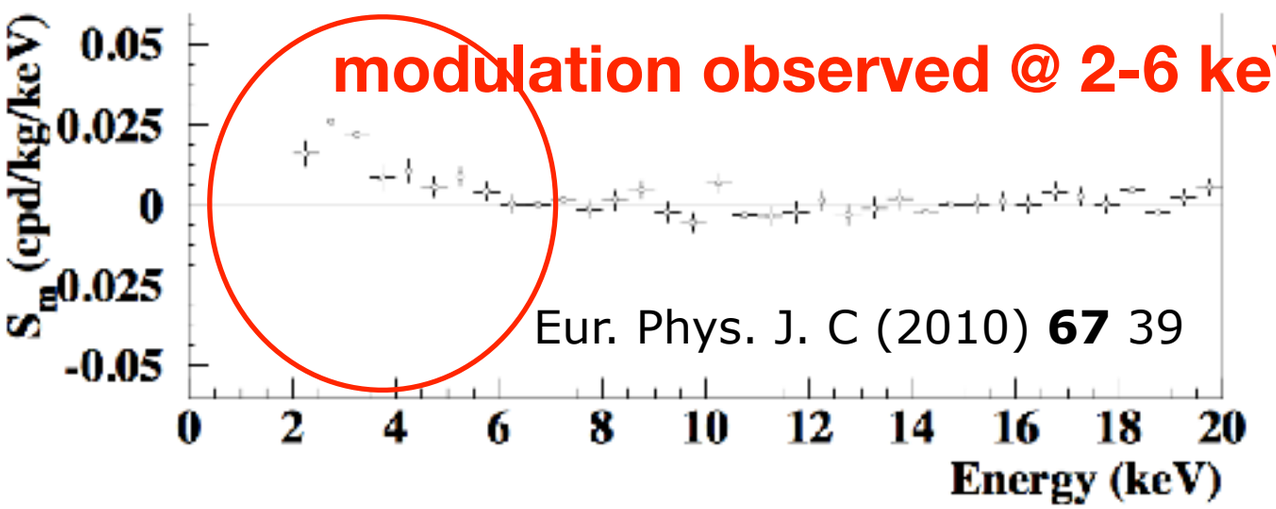


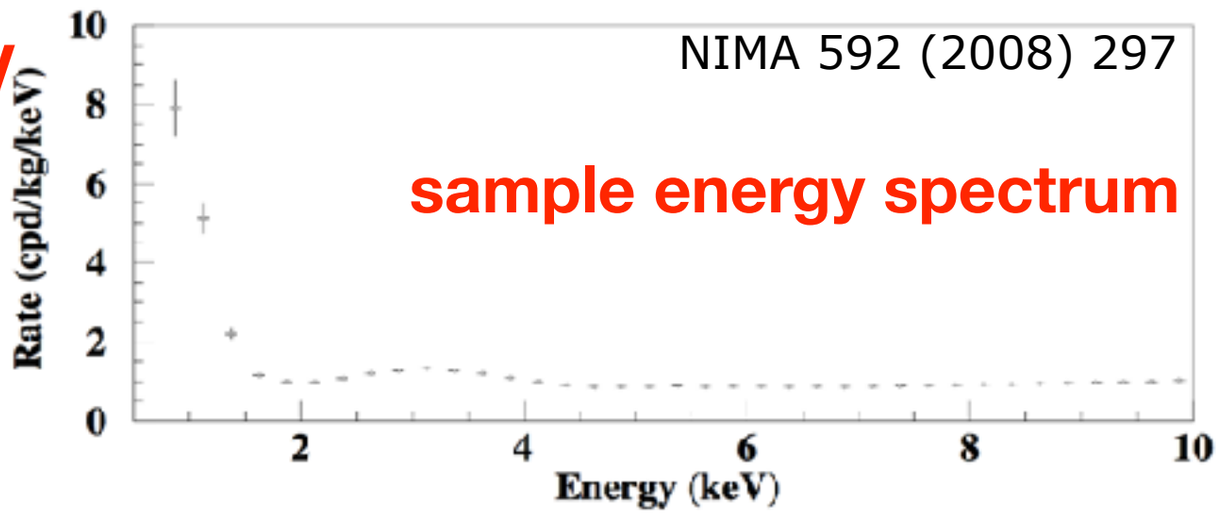
EPJC 73:2648 (2013)

Test DAMA's observation of 9.3 σ modulation

- Phase & Period consistent with dark matter
- Two generations:
  - DAMA/NaI: 100 kg (1996 - 2003)
  - DAMA/LIBRA-phase1: 250 kg (2003 - 2010)
    - Background: ~ 1 count/keV/kg/day
- 1.33 ton-yr over 14 annual cycles

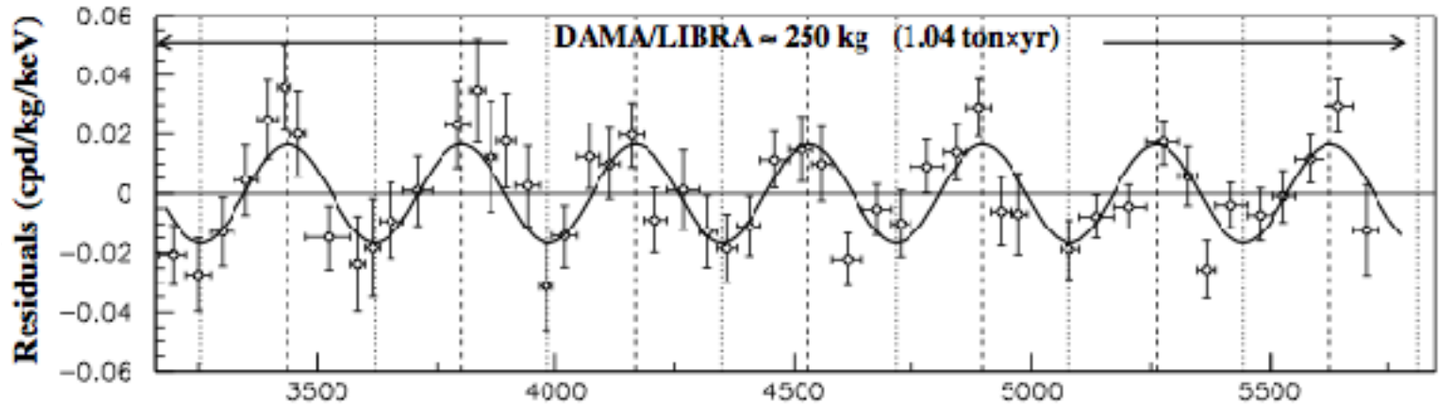
Outdated





DAMA Phase 1

EPJC 73:2648 (2013)



Test DAMA's observation of 9.3 σ modulation

Phase & Period consistent with dark matter

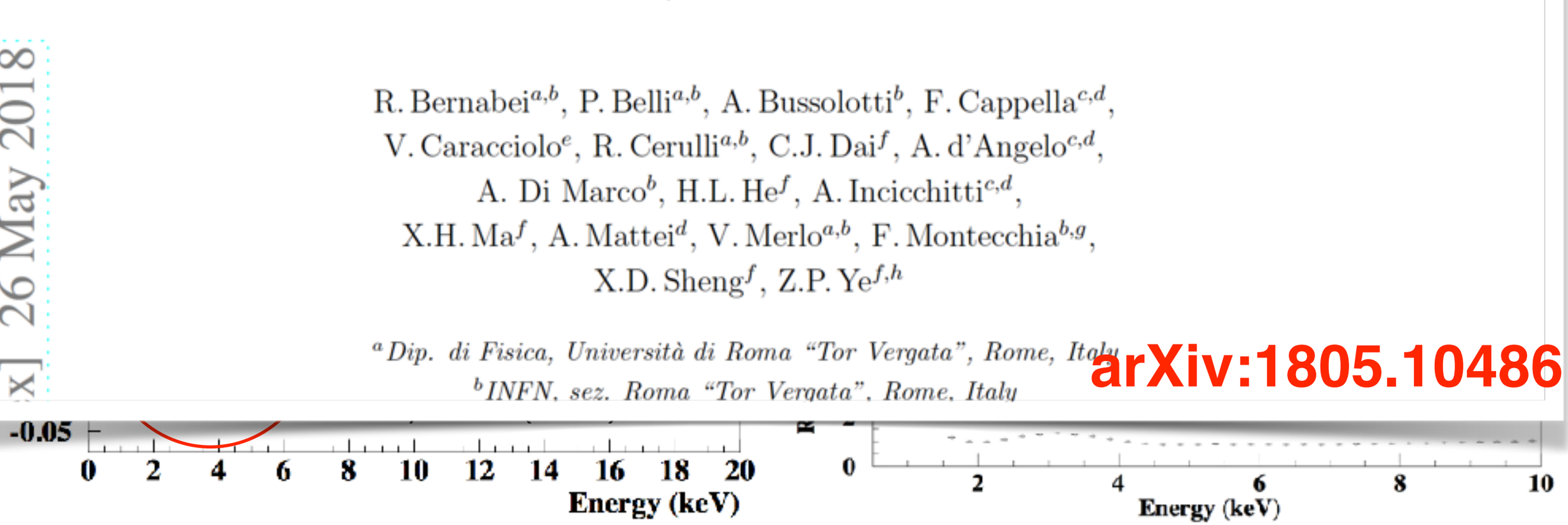
New Paper from DAMA

First model independent results from
DAMA/LIBRA–phase2

R. Bernabei[a,b], P. Belli[a,b], A. Bussolotti[b], F. Cappella[c,d], V. Caracciolo[e], R. Cerulli[a,b], C.J. Dai[f], A. d'Angelo[c,d], A. Di Marco[b], H.L. He[f], A. Incicchitti[c,d], X.H. Ma[f], A. Mattei[d], V. Merlo[a,b], F. Montecchia[b,g], X.D. Sheng[f], Z.P. Ye[f,h]

[a] *Dip. di Fisica, Università di Roma "Tor Vergata", Rome, Italy*
[b] *INFN, sez. Roma "Tor Vergata", Rome, Italy*

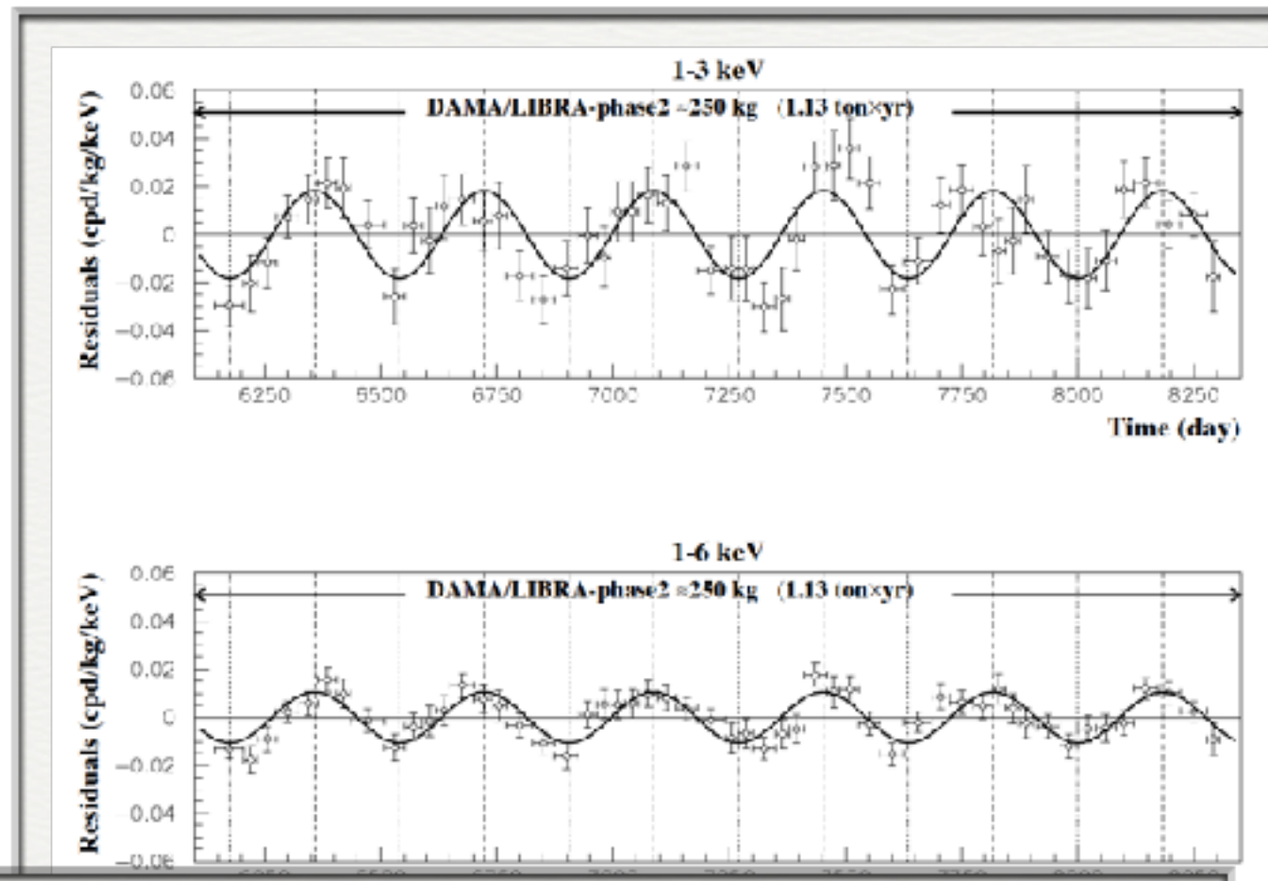
arXiv:1805.10486

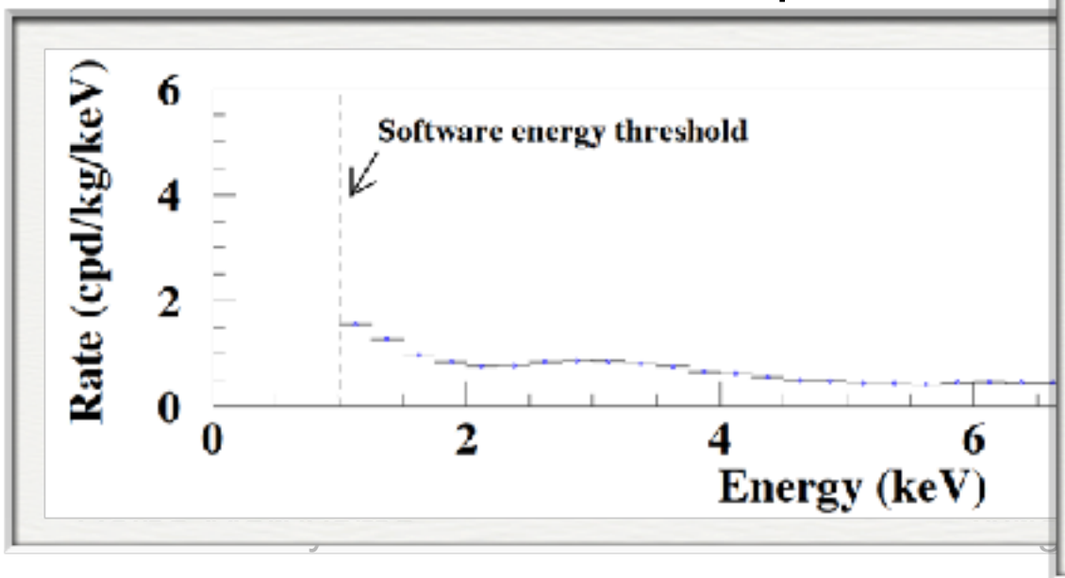


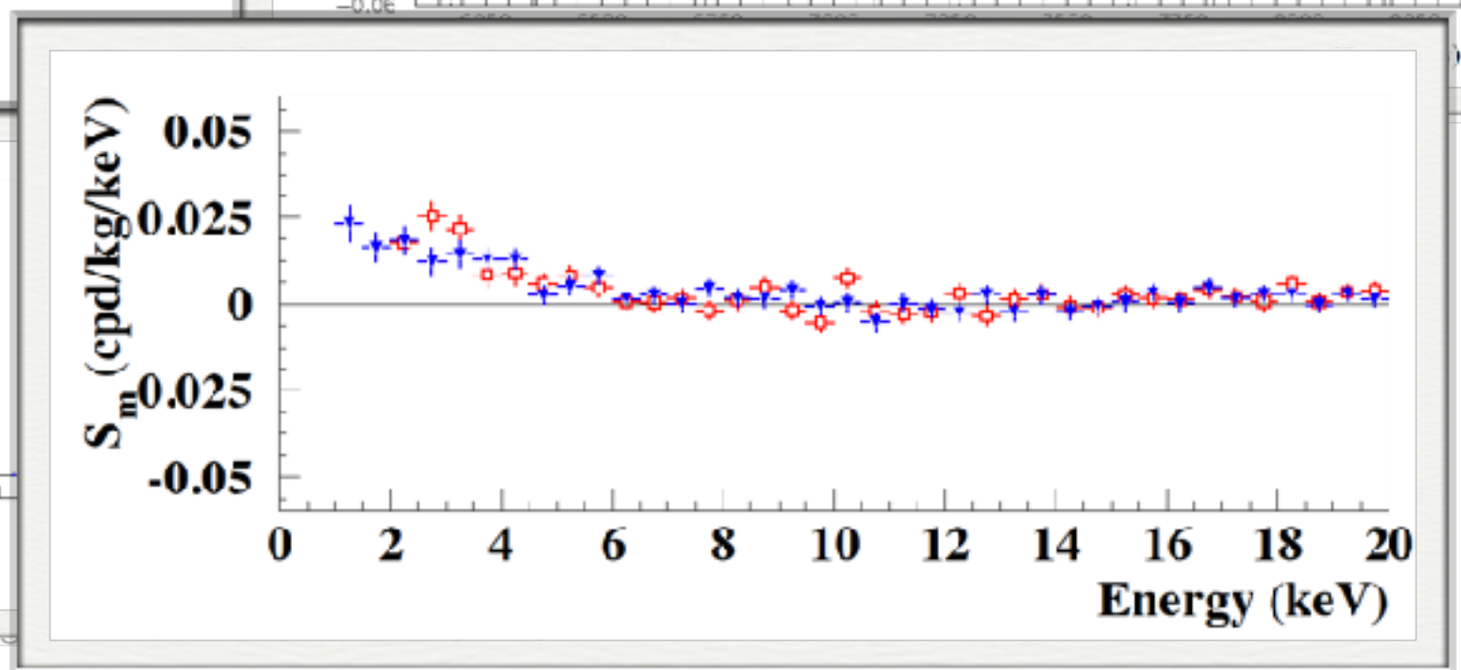
DAMA Sees Annual Modulation

arXiv:1805.10486

- Modulation persists in DAMA Phase 2
  - 6+ additional years / 1.13 ton-year
  - Threshold lowered to 1 keV
- **(1 – 6) keV: 9.5σ from 1.13 ton- year**
- **(2 – 6) keV: 12.9σ from 2.46 ton-year**
- Modulation amplitude: (0.0103 +/- 0.0008) cpd/kg/keV
- Phase: (145 +/- 5) days
- period: (0.999 +/- 0.001) year
- Data from Nov. 2011 - Sept. 2017







NaI(Tl) Experiments

KIMS (+ DM-Ice)

DAMA

SABRE **COSINUS**

★ Gran Sasso + Australia

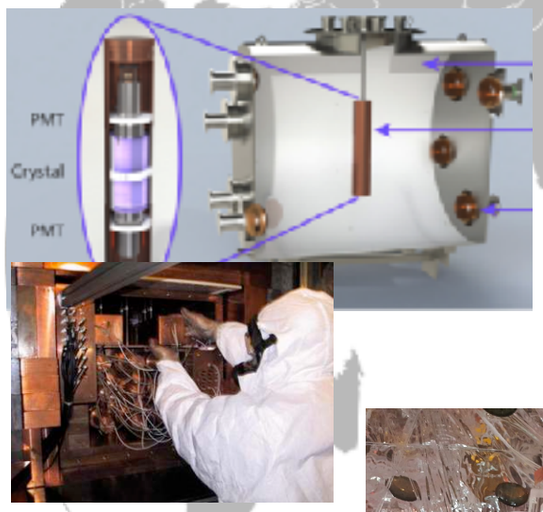
COSINE-100

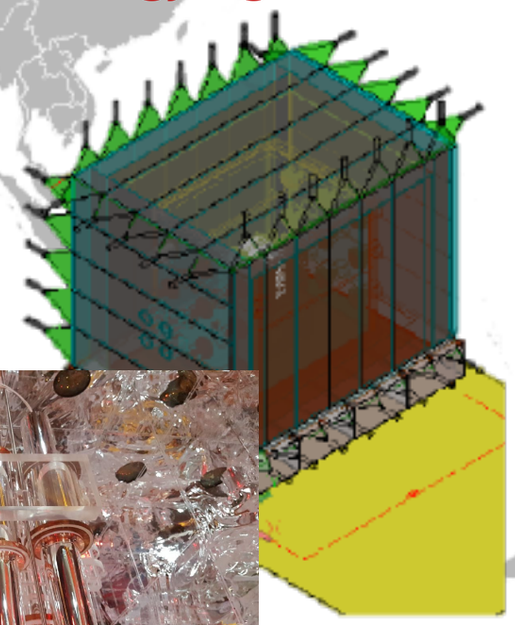
★ Yangyang ★ Kamioka

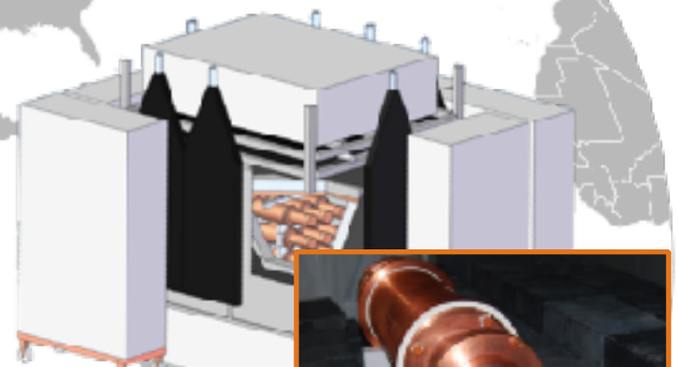
PICOLON

ANAIS

★ Boulby ★ Canfra



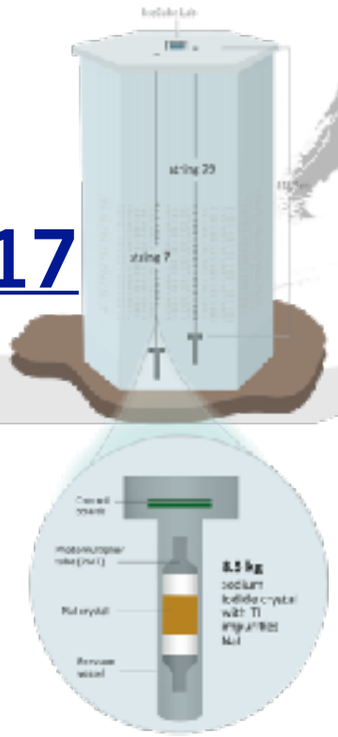


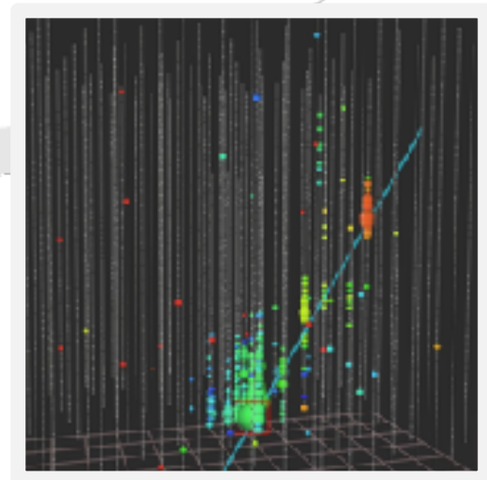


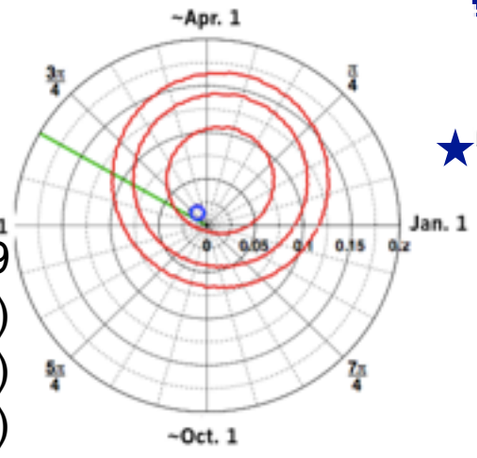
Eur.Phys.J. C **78** 107 (2018)
Eur.Phys.J. C **77** 437 (2017)
JINST **13** T02007 (2018)
Phys.Rev. D **90** 052006 (2014) (CsI)

DM-Ice17

★ South Pole







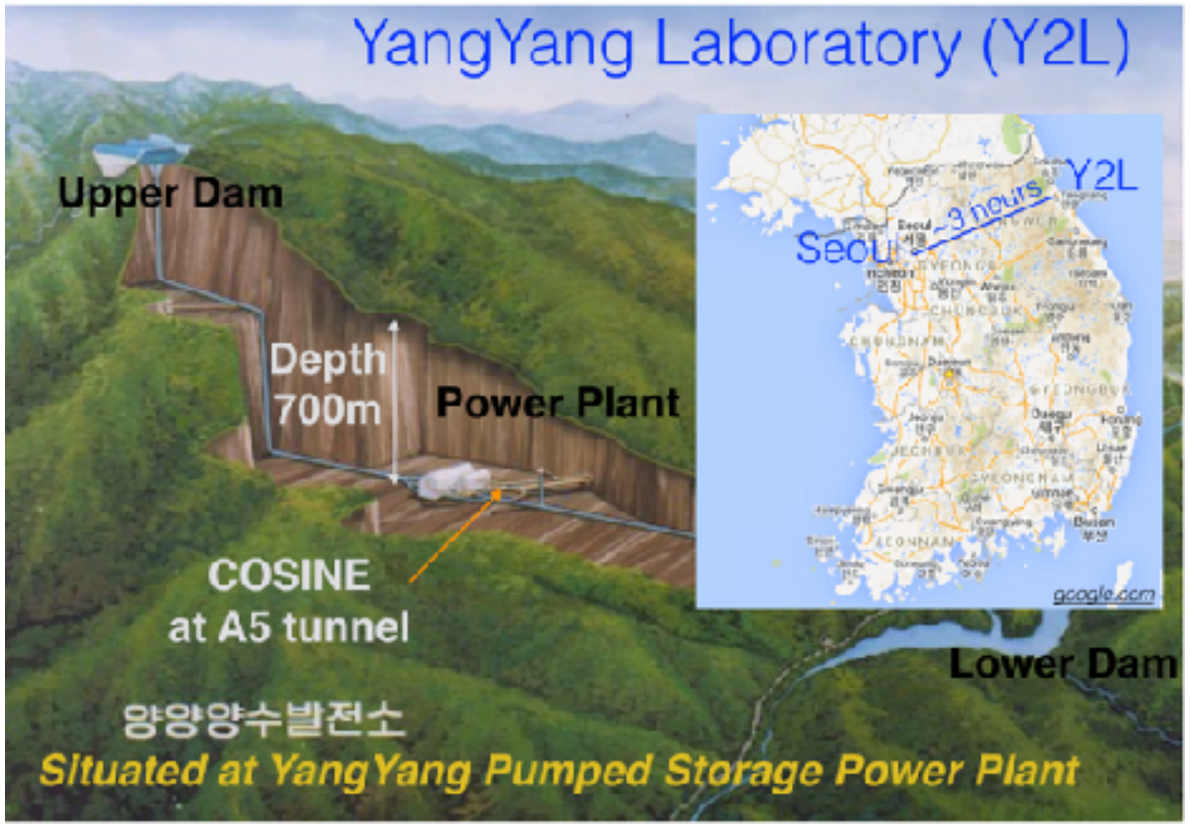
Astropart. Phys. **35** (2012) 749
Phys. Rev. D **90** 092005 (2014)
Phys. Rev. D **93** 042001 (2016)
Phys. Rev. D **95** 032006 (2017)

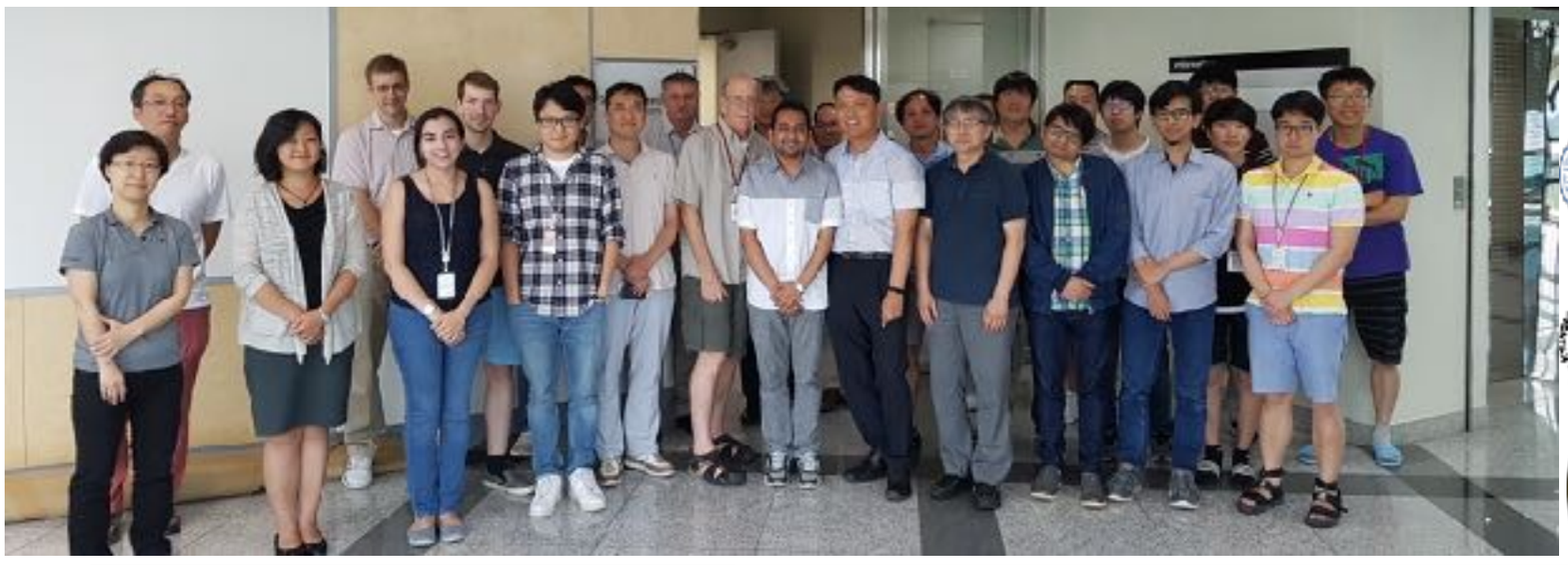
COSINE-100

http://cosine.yale.edu

KIMS (Korea Invisible Mass Search Experiment) + DM-ICE

- Joint effort between KIMS & DM-Ice
- 100 kg NaI detectors of varying sizes
- Operations started in Sept. 2016
- Background in ROI: 2 - 4 cpd/kg/keV
-





The University Of Sheffield.

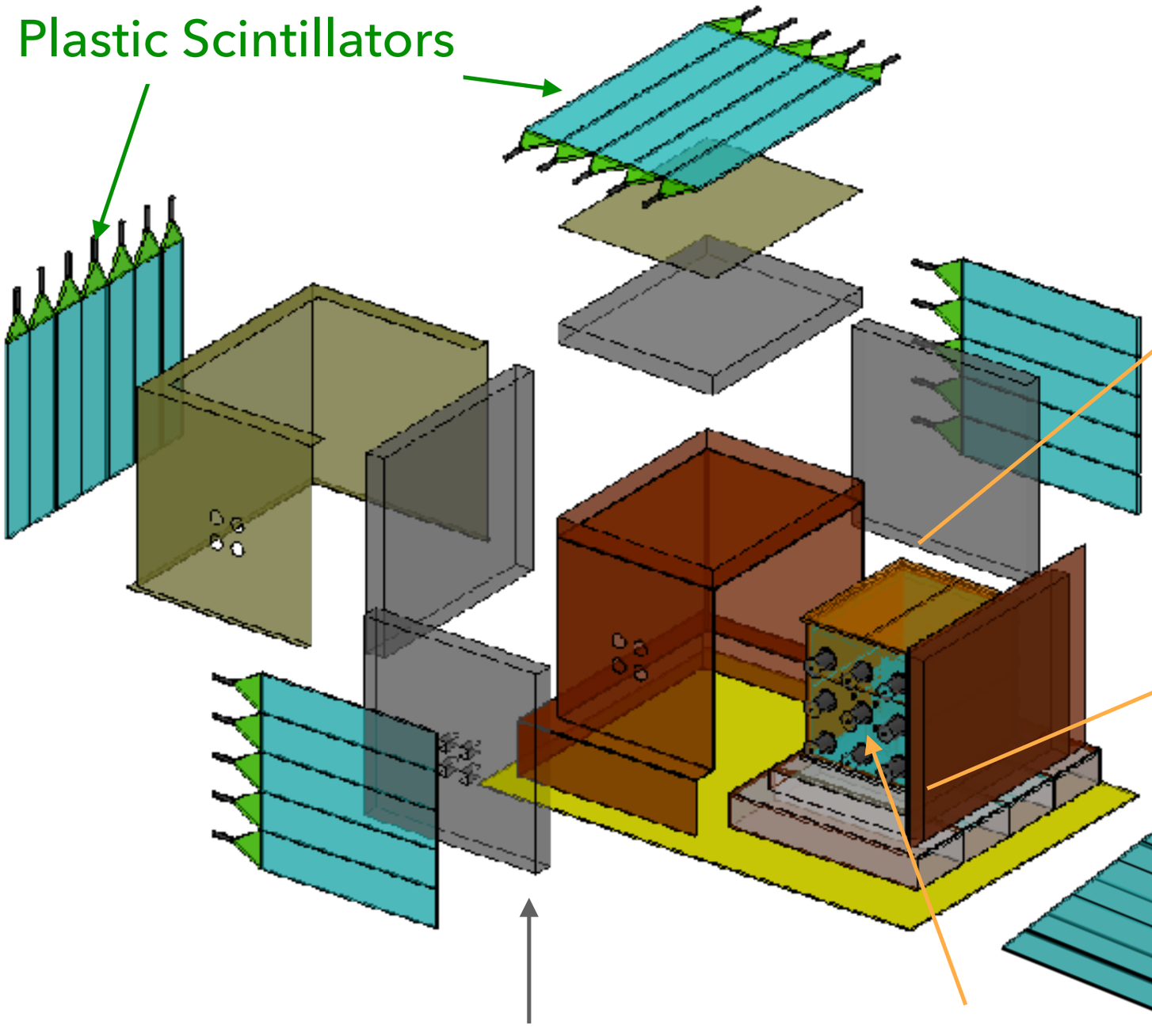
WISCONSIN UNIVERSITY OF WISCONSIN–MADISON Yale

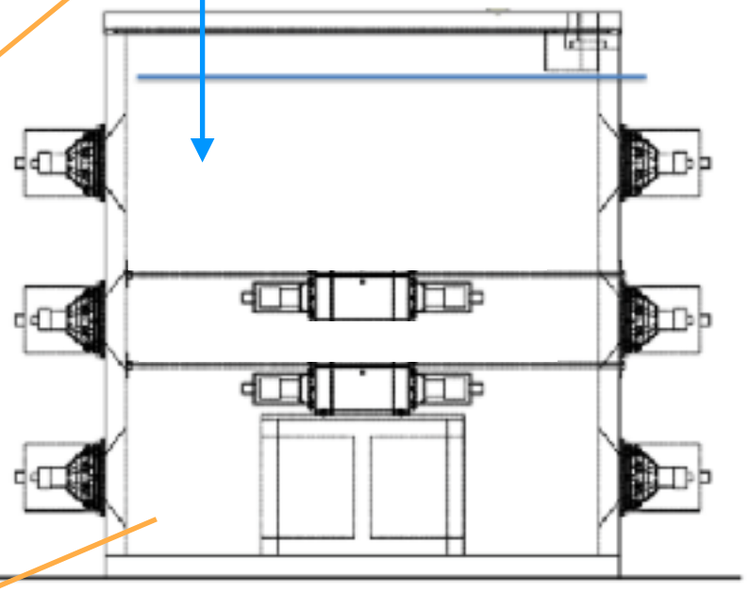
COSINE-100 Shielding

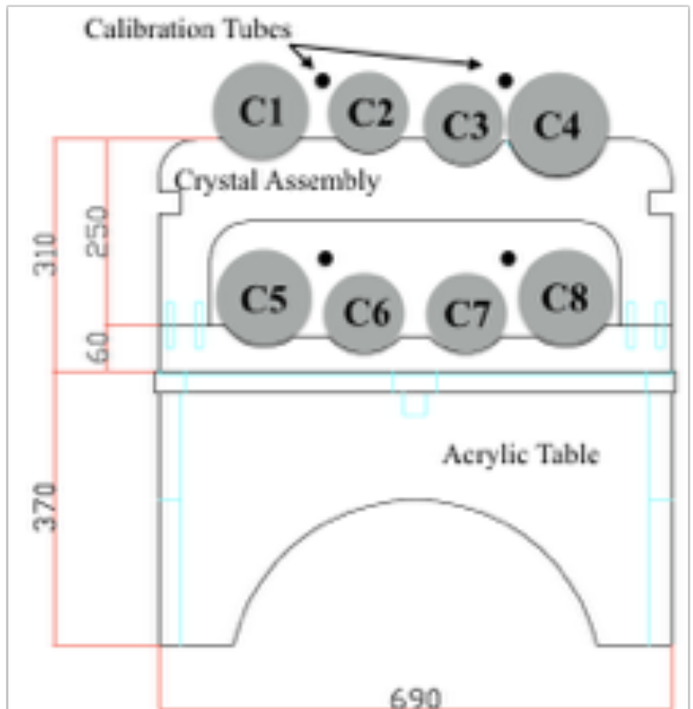
Plastic Scintillators

2000 L Liquid Scintillator

Tag ^{40}K to veto 3 keV background events



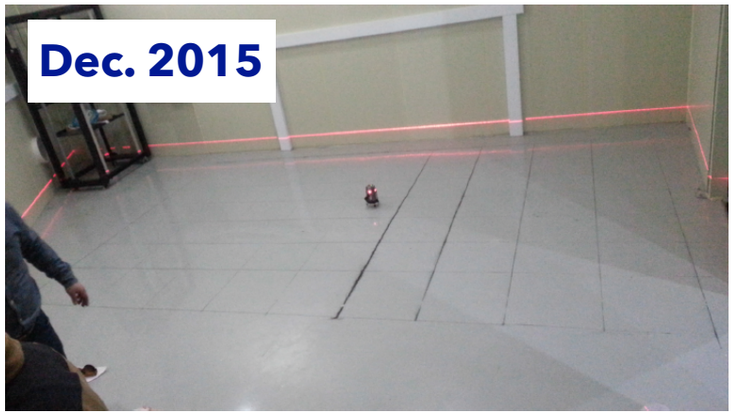


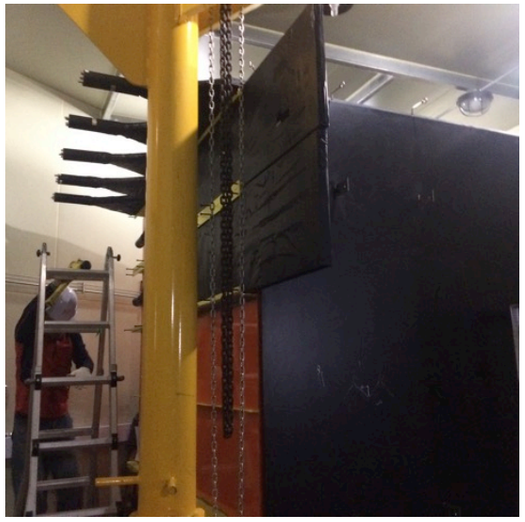


Lead Shielding (20 cm)

Cu Box (3 cm)

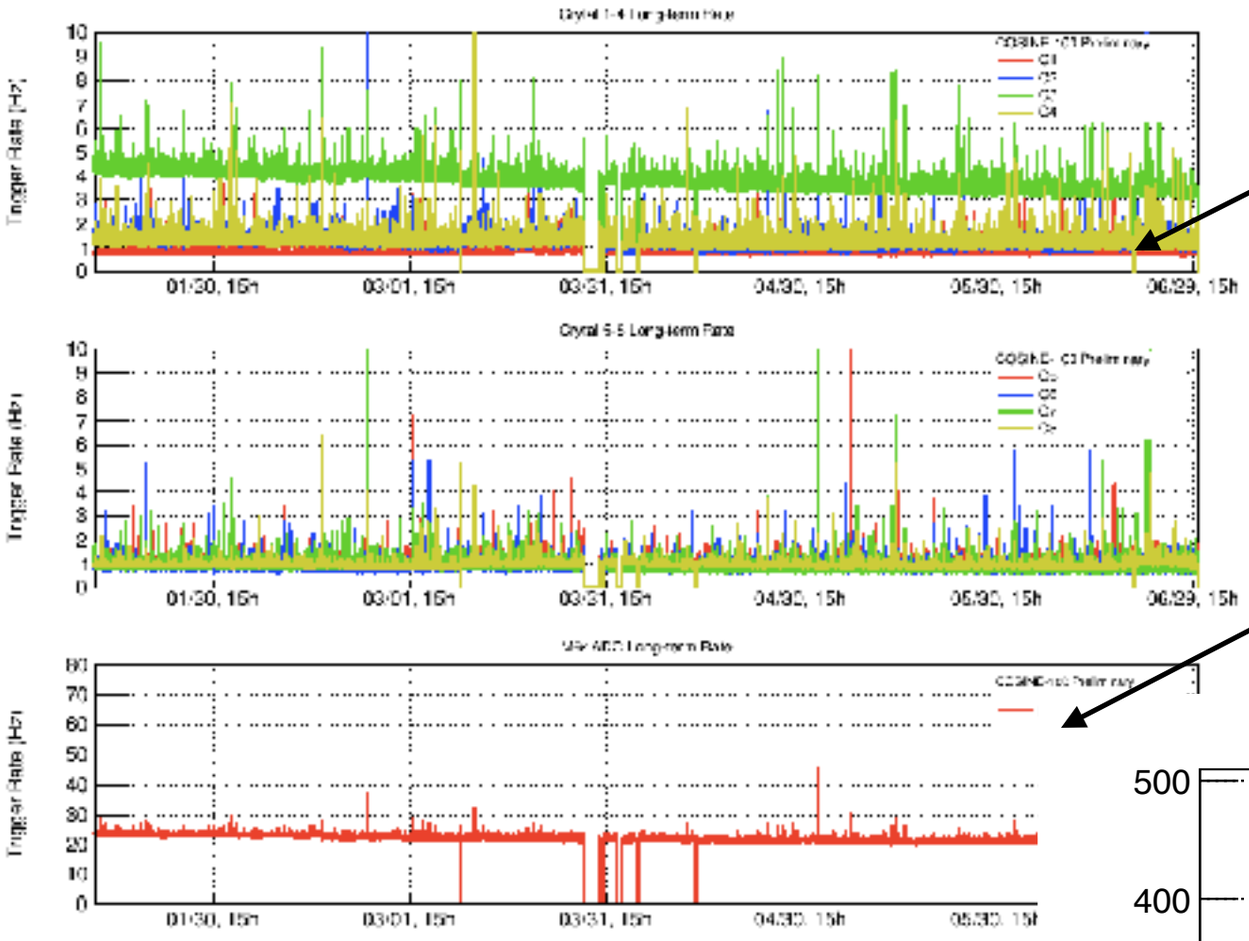
COSINE-100 Construction





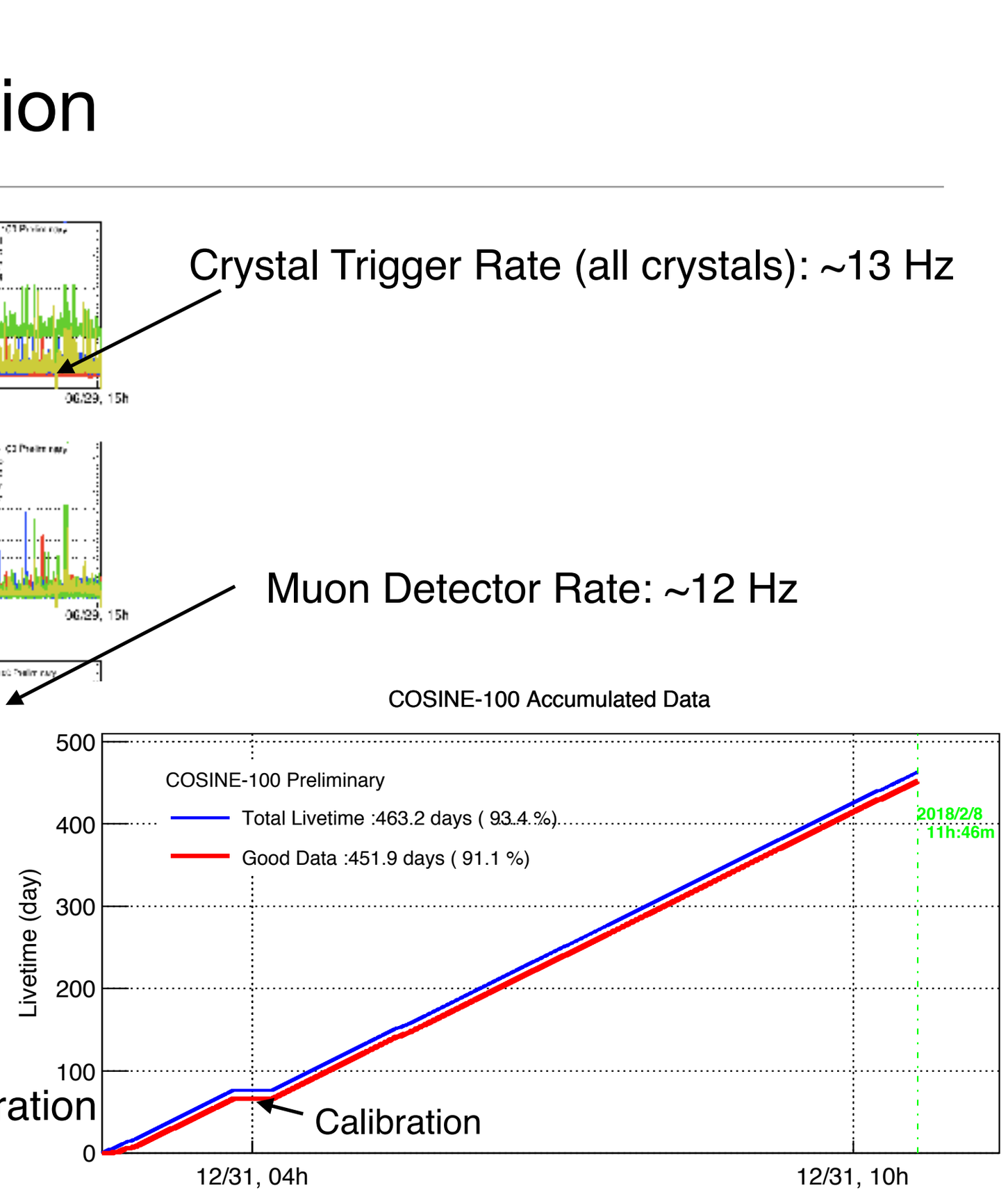
Sep. 2016

COSINE-100 Operation



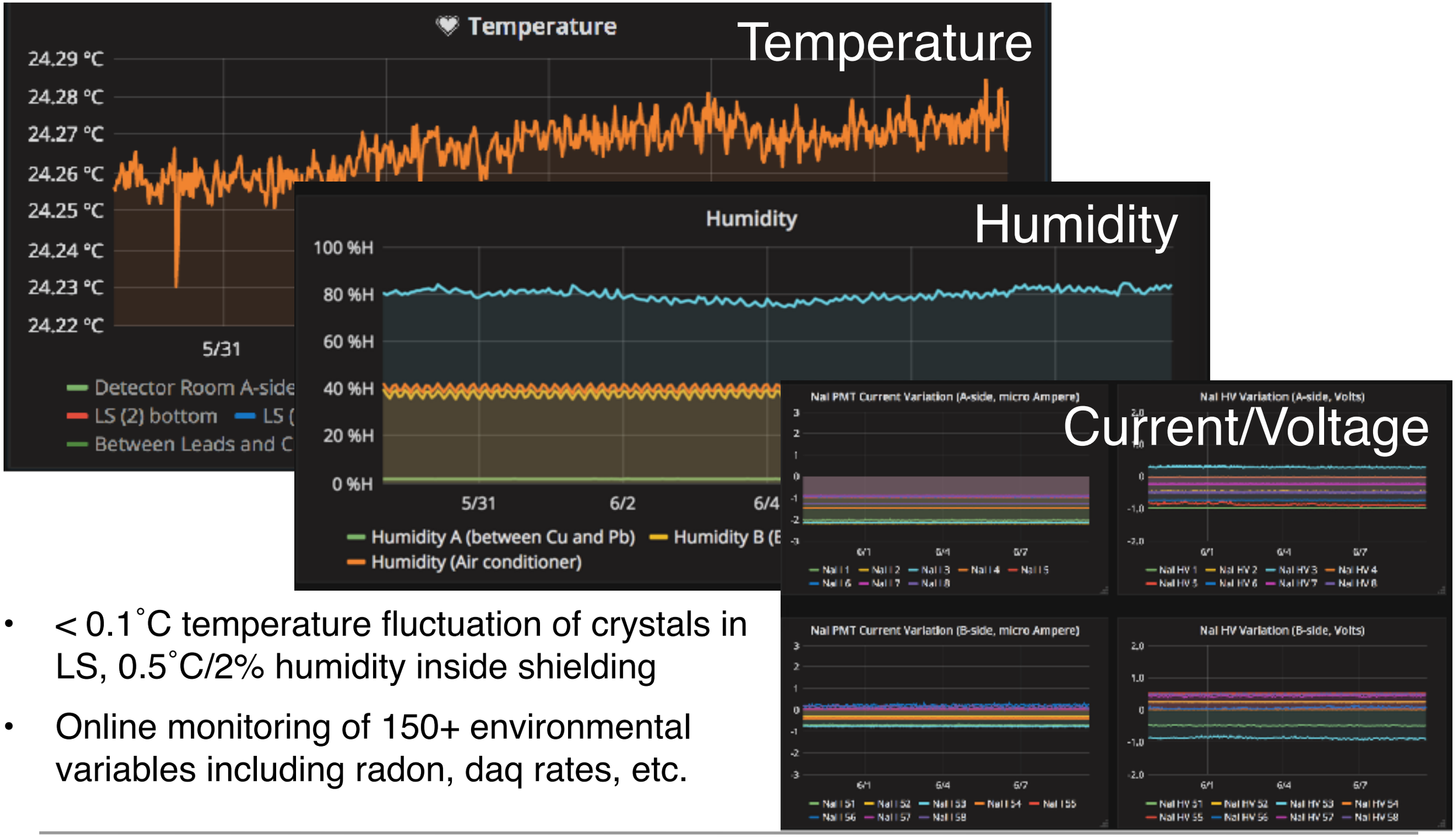
Crystal Trigger Rate (all crystals): ~13 Hz

Muon Detector Rate: ~12 Hz



- Data taking since Sep. 2016
- Stable operation
- ~90% live time
- Near 100% uptime outside of calibration

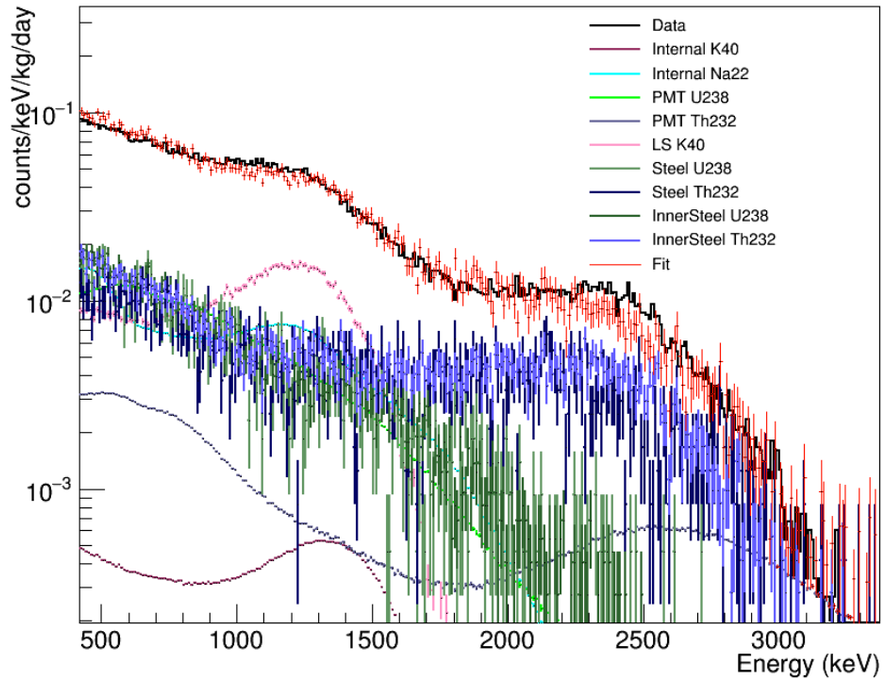
Environmental Control & Monitoring

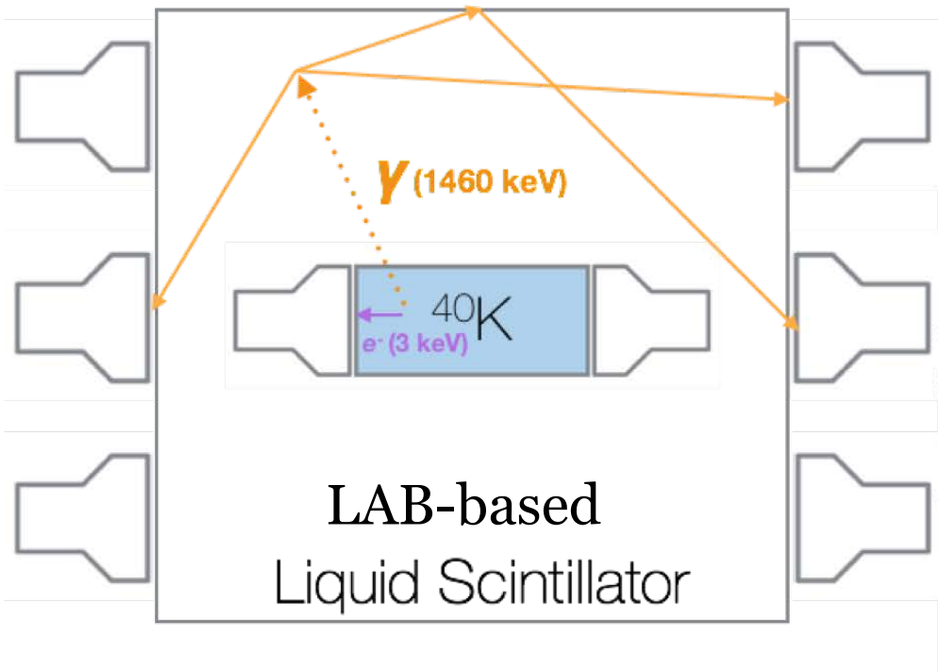


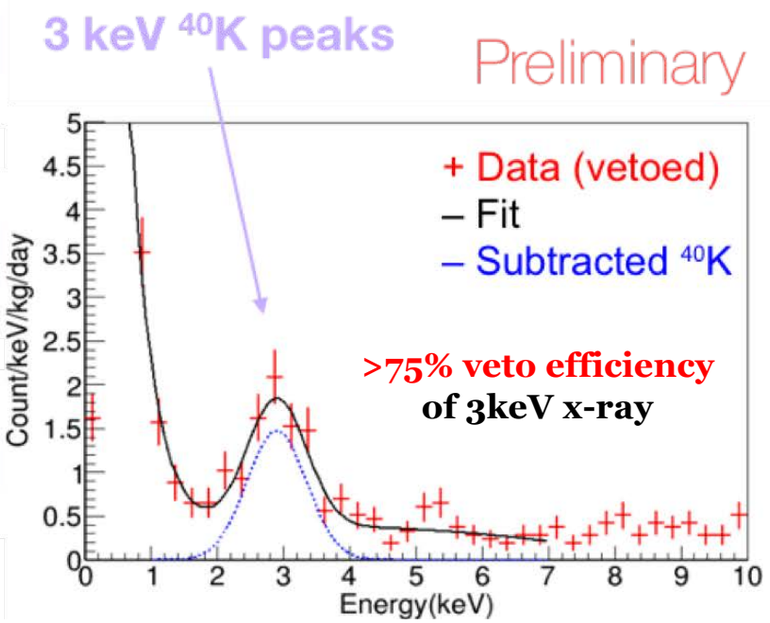
- < 0.1˚C temperature fluctuation of crystals in LS, 0.5˚C/2% humidity inside shielding
- Online monitoring of 150+ environmental variables including radon, daq rates, etc.

Liquid Scintillator Veto

- Tagging efficiency for ^{40}K consistent with simulation
- Liquid scintillator internal contamination well modeled with simulation
- LS tagging threshold = 80 keV

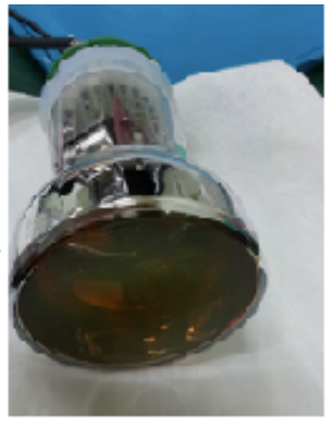




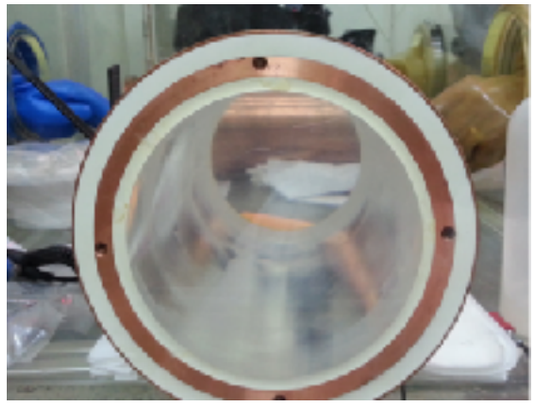


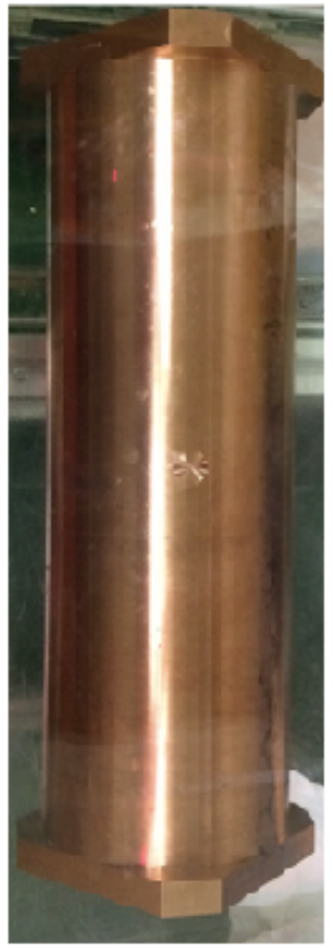
COSINE-100 NaI(Tl) Crystals

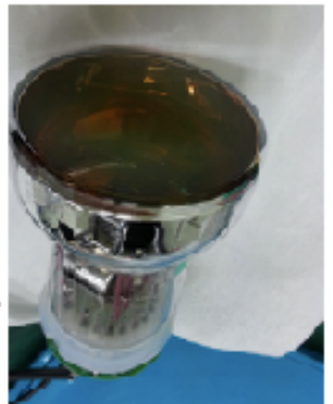
Eur.Phys.J. C **78** 107 (2018)



- 8 crystals, total 106 kg
- Culmination of R&D program with Alpha Spectra
- U/Th/K below DAMA, ^{210}Po very close
- High Light yield
- Challenge: putting it all together
- Total Background: 2 - 4 x DAMA's avg.
- Crystal 5 & 8 used primarily for veto due to low light yield







Crystal	Mass (kg)	Powder	Alpha rate (mBq/kg)	^{40}K (ppb)	^{238}U (ppt)	^{232}Th (ppt)	Light yield (p.e./keV)
Crystal 1	8.3	AS-B	3.20 ± 0.08	43.4 ± 13.7	< 0.02	1.31 ± 0.35	14.88 ± 1.49
Crystal 2	9.2	AS-C	2.06 ± 0.06	82.7 ± 12.7	< 0.12	< 0.63	14.61 ± 1.45
Crystal 3	9.2	AS-WS Ⅱ	0.76 ± 0.02	41.1 ± 6.8	< 0.04	0.44 ± 0.19	15.50 ± 1.64
Crystal 4	18.0	AS-WS Ⅱ	0.74 ± 0.02	39.5 ± 8.3		< 0.3	14.86 ± 1.50
Crystal 5	18.0	AS-C	2.06 ± 0.05	86.8 ± 10.8		2.35 ± 0.31	7.33 ± 0.70
Crystal 6	12.5	AS-WSⅢ	1.52 ± 0.04	12.2 ± 4.5	< 0.018	0.56 ± 0.19	14.56 ± 1.45
Crystal 7	12.5	AS-WSⅢ	1.54 ± 0.04	18.8 ± 5.3		< 0.6	13.97 ± 1.41
Crystal 8	18.3	AS-C	2.05 ± 0.05	56.15 ± 8.1		< 1.4	3.50 ± 0.33
DAMA			< 0.5	< 20	0.7 - 10	0.5 – 7.5	5.5 – 7.5

Event Selection: Fast Event Rejection

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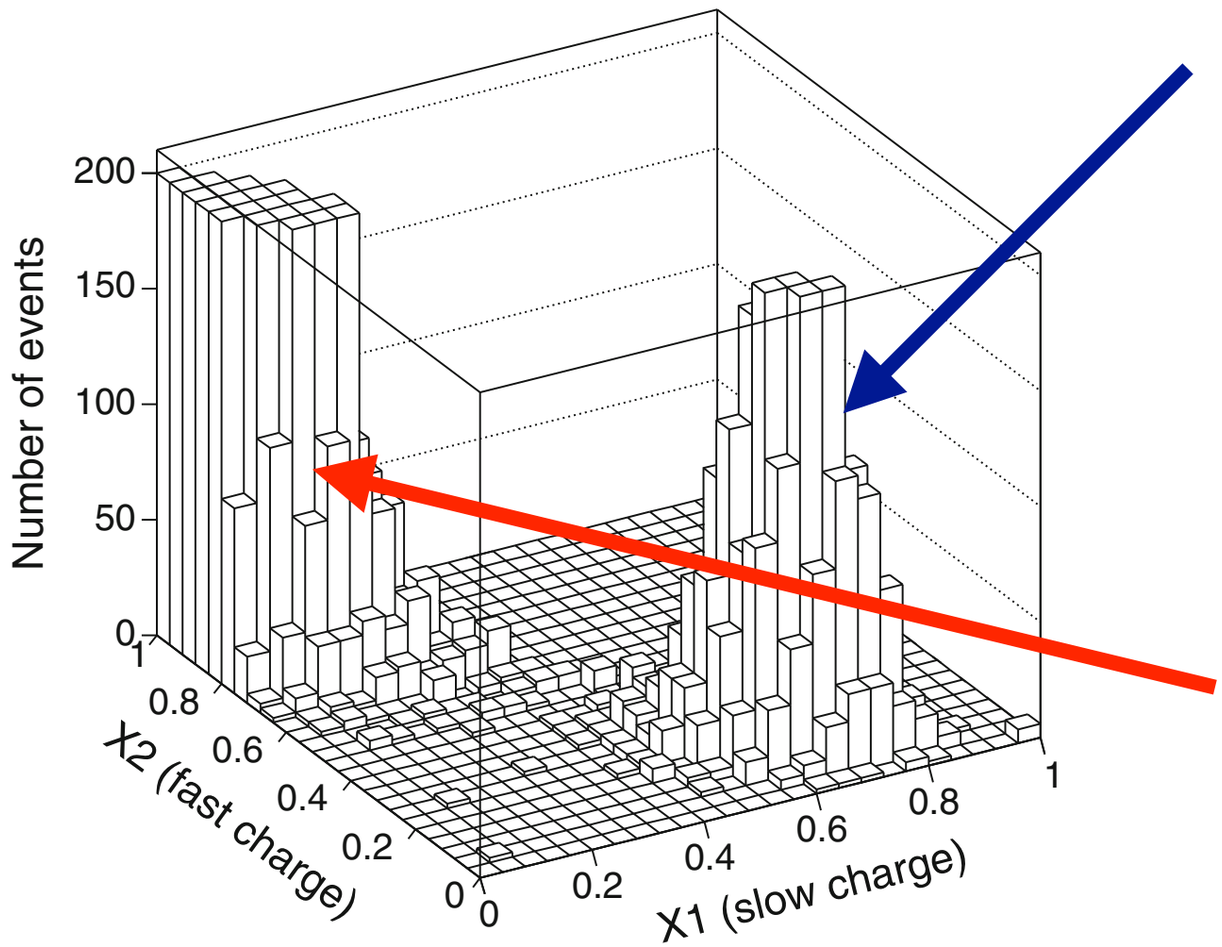
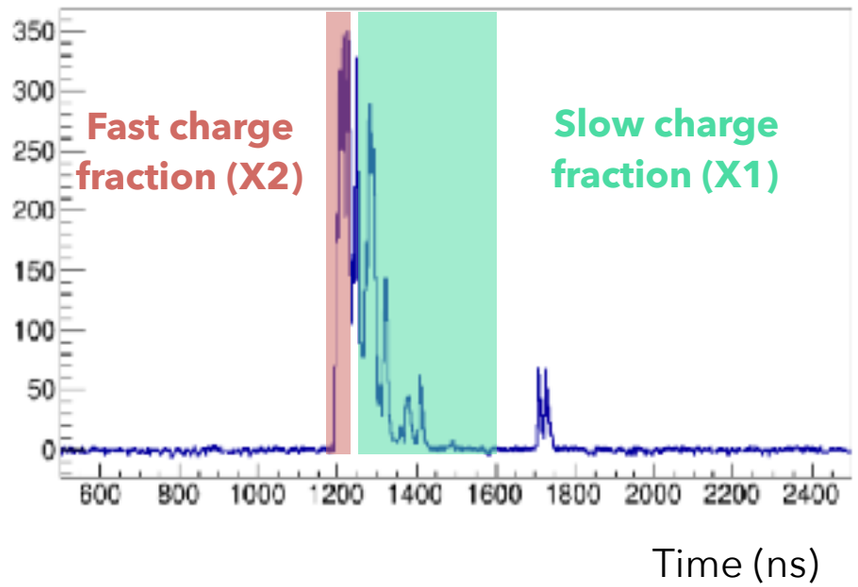
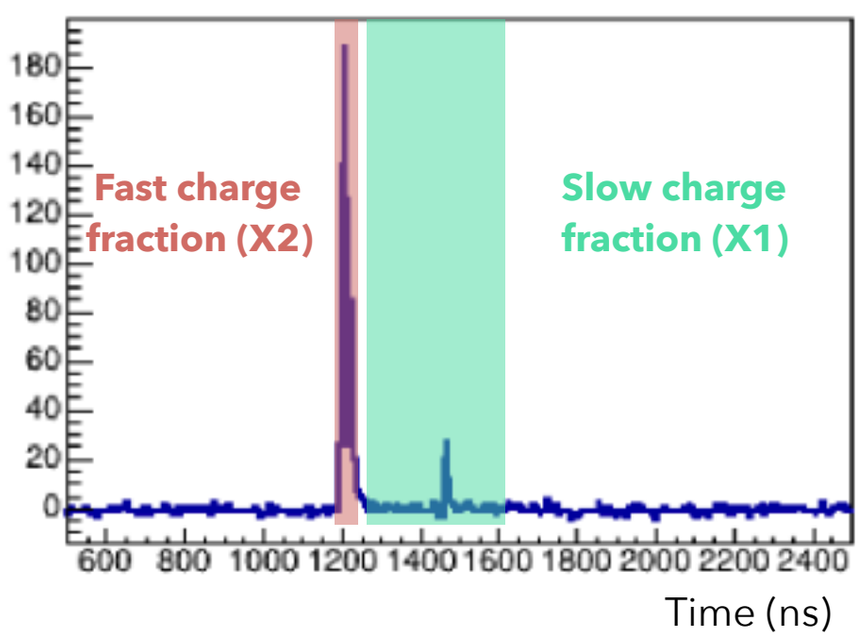
- Separate noise via charge ratio of rising edge vs. falling edge



Signal

Noise





Low Energy Spectrum

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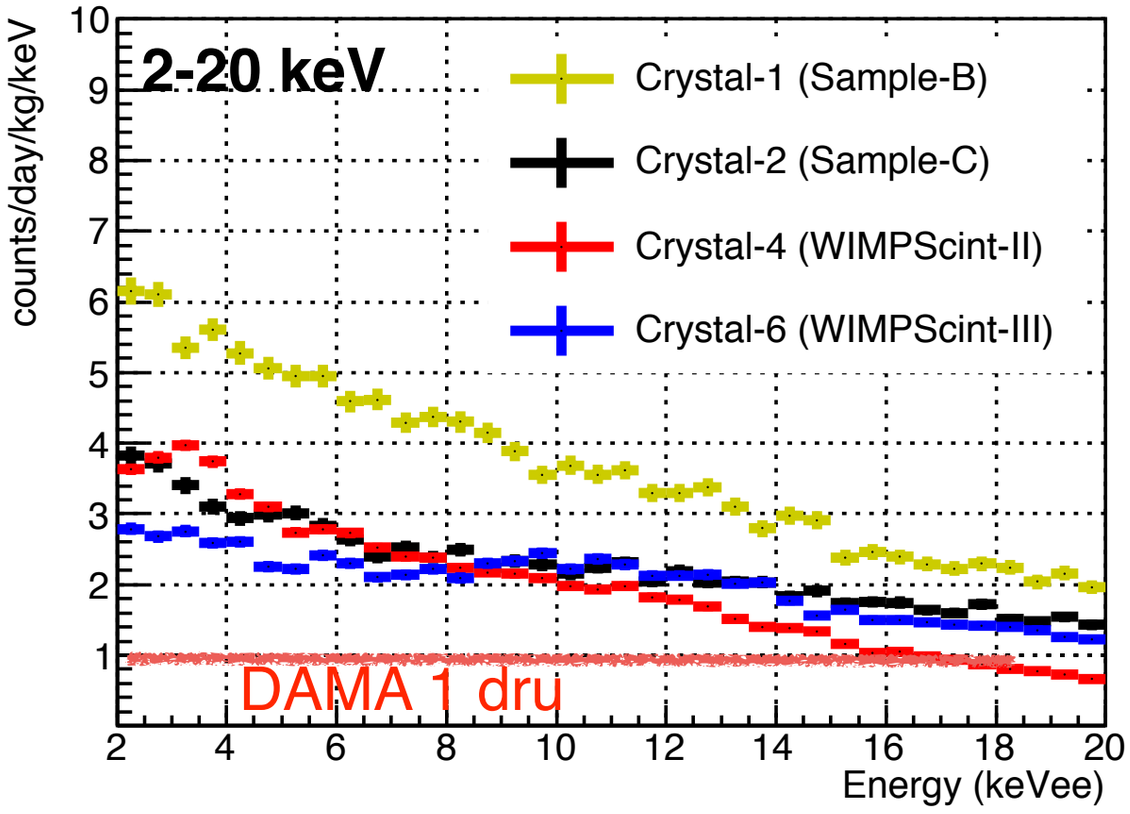
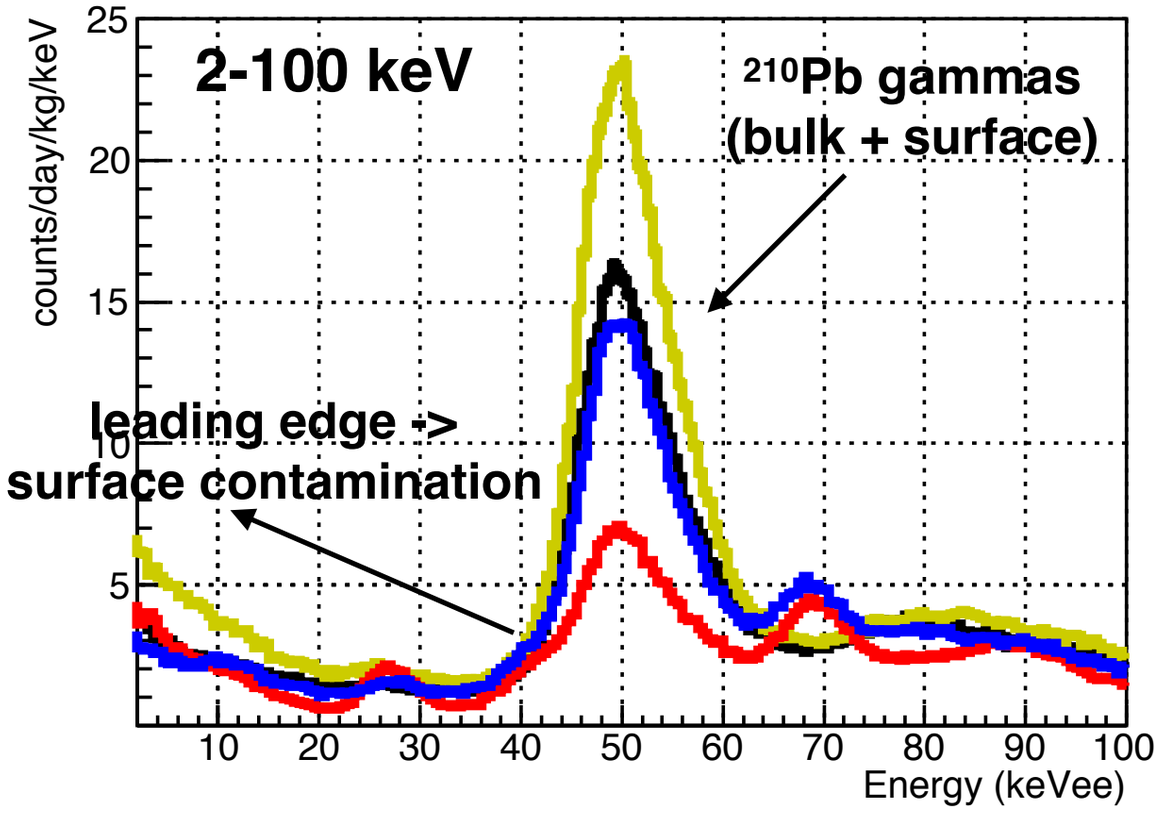
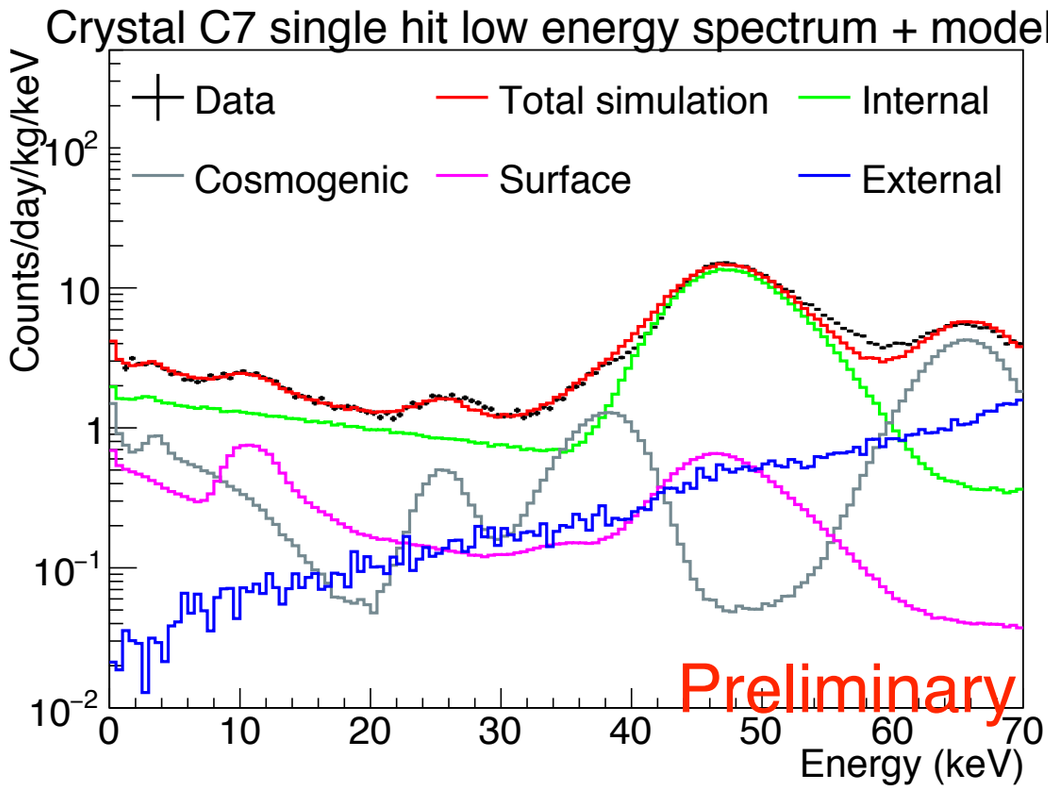


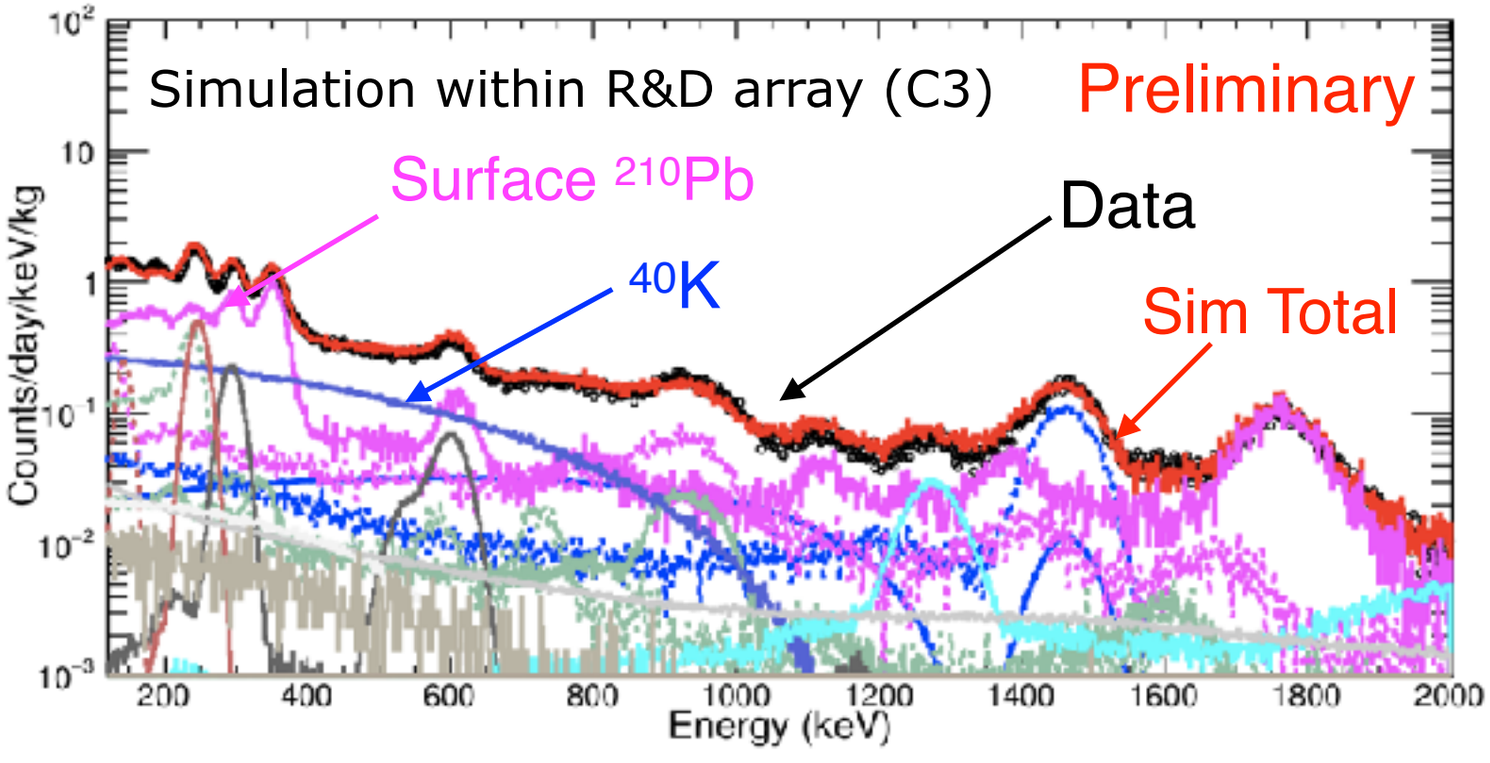


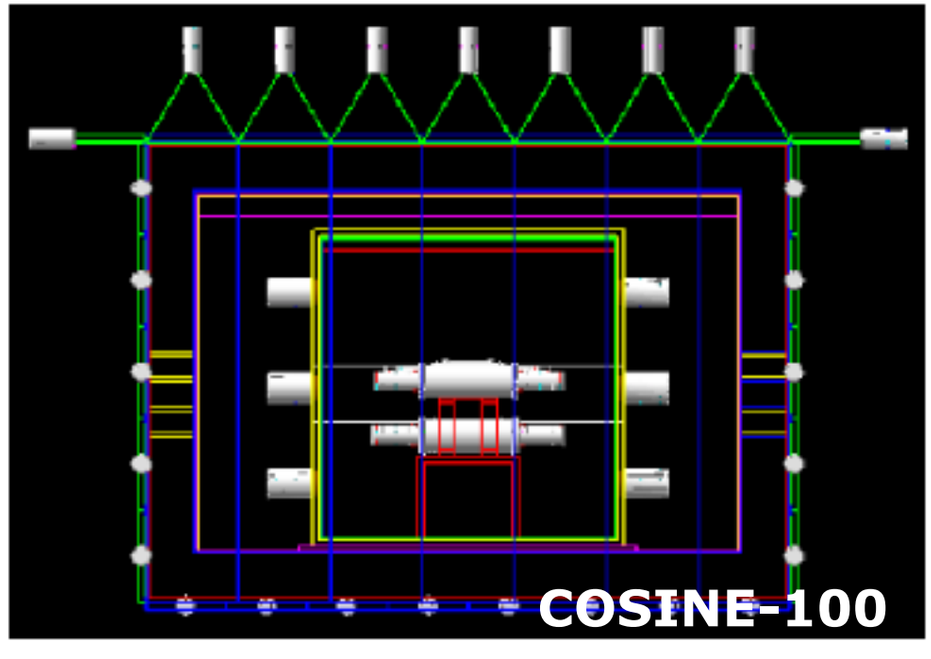
- **2 to 4 cnts/keV/kg/day** in region of interest depending on the crystal
- ^{210}Pb ($t_{1/2}$ = 22 yr), U/Th in Internal components (crystal growing/raw material)
- ^{210}Pb on crystal & PTFE surface
- Cosmogenic components: ^{125}I (59 d), ^{109}Cd (460 d), ^{3}H (12 yr)
- Blind analysis on annual modulation underway.

Background in Data vs. Simulations

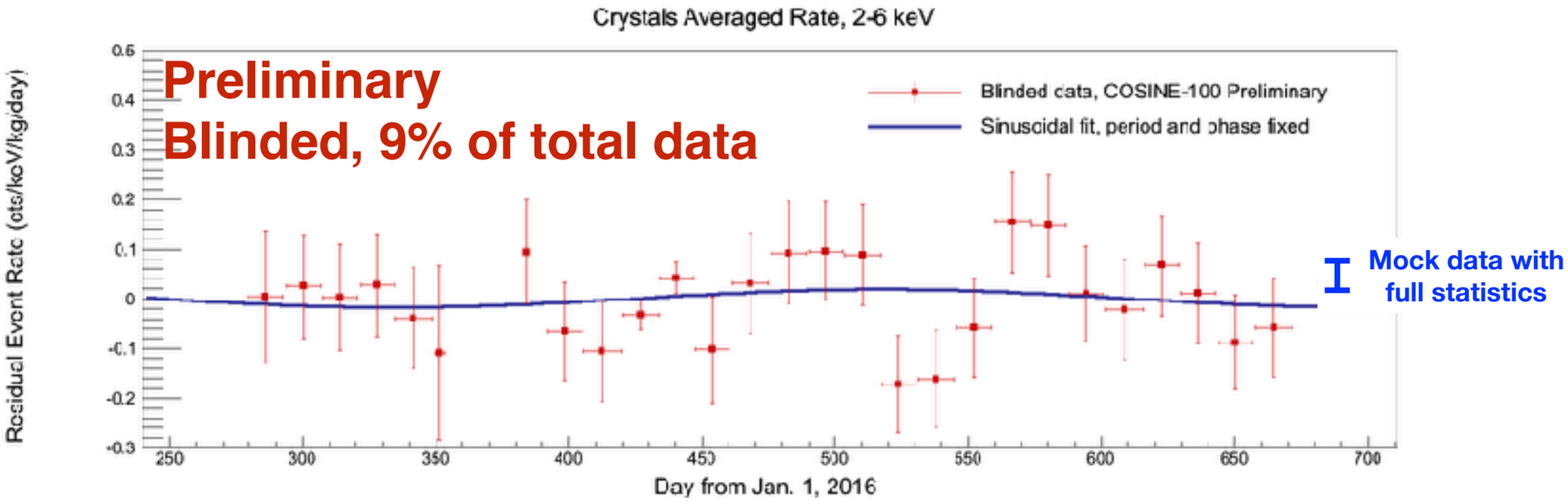
- Data reproduced well with Geant4 simulation
- Dominant backgrounds from ^{210}Pb & ^{40}K



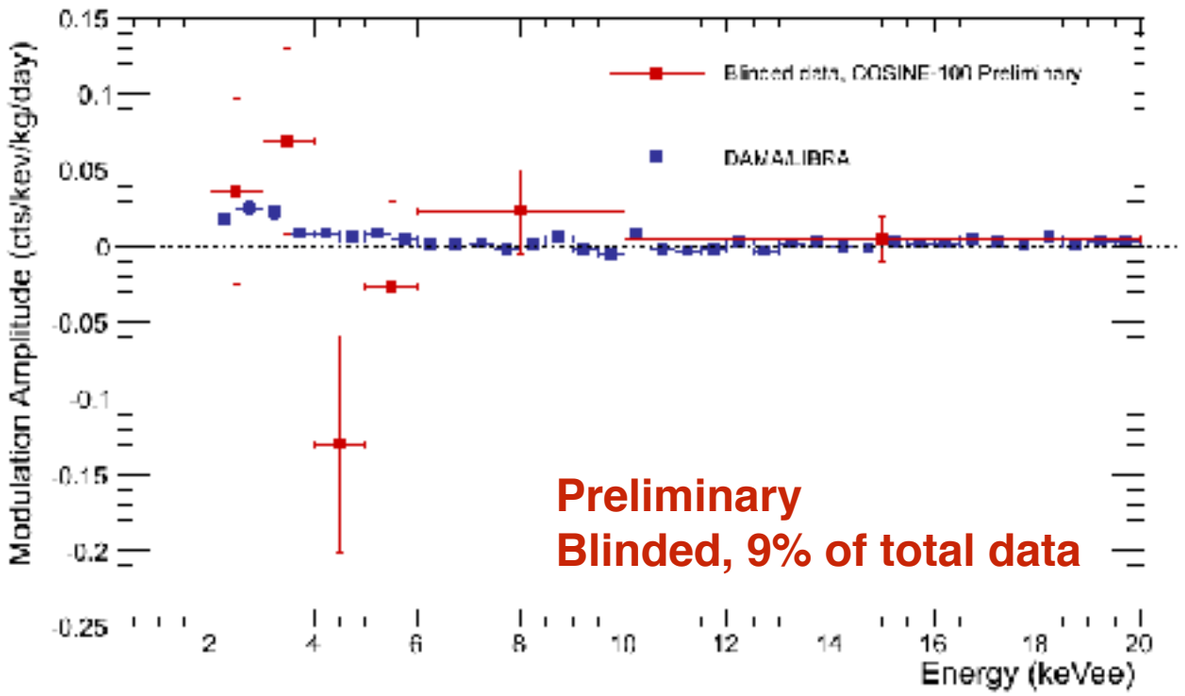




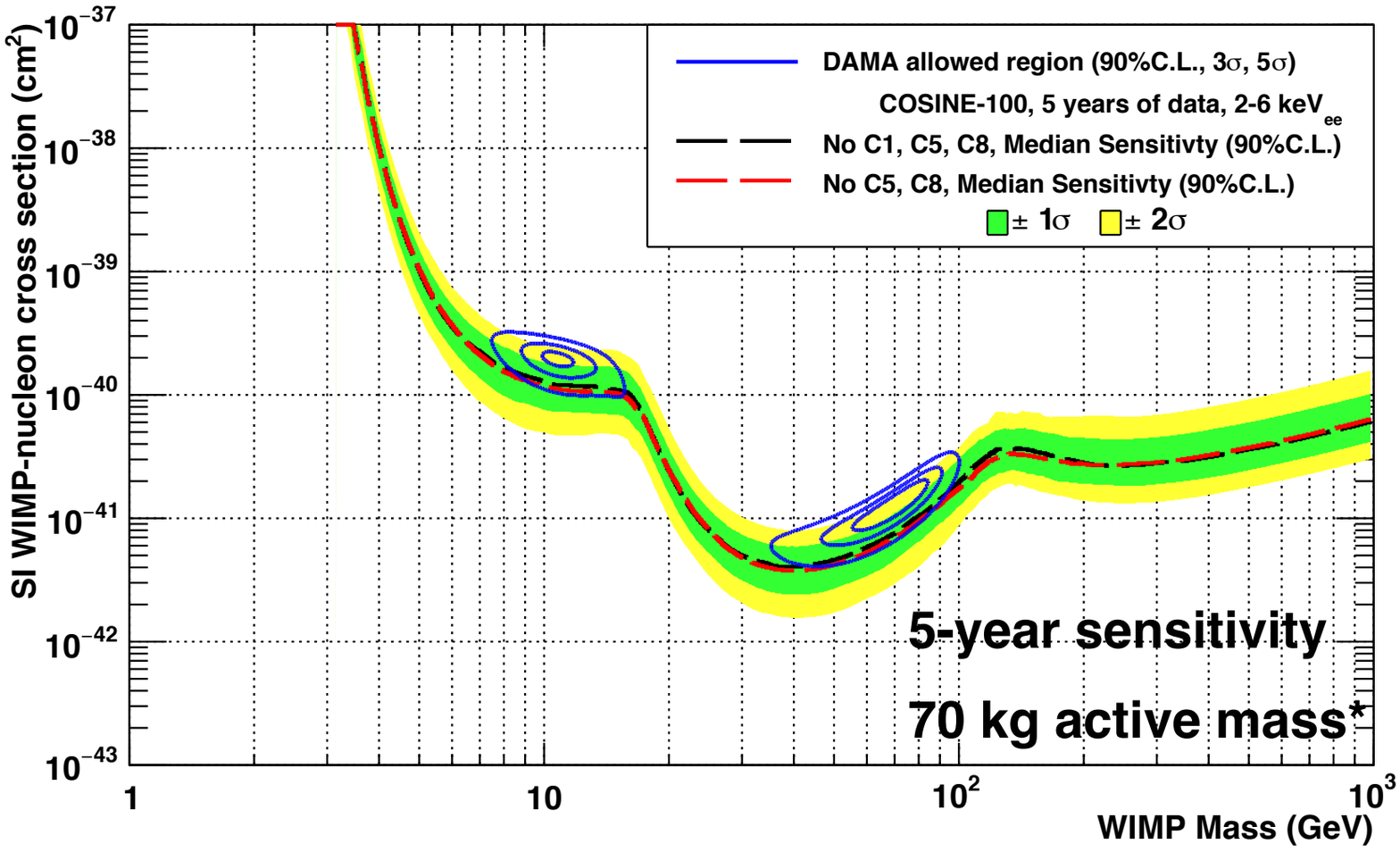
Annual Modulation Search



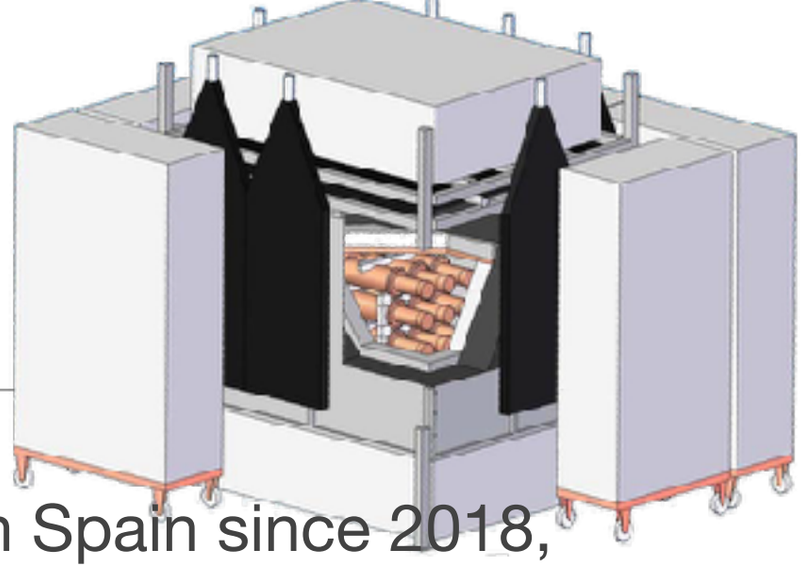
- **Blinded data w/ 9 % of total data**
- 406 days of data available: 24896
- Data quality, background modeling underway
- **Result soon to be finalized with the data unblinded**



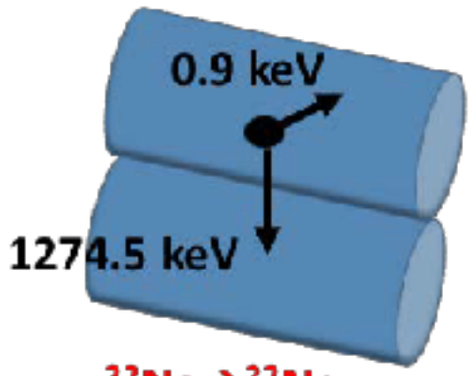
COSINE-100 Expected Sensitivity



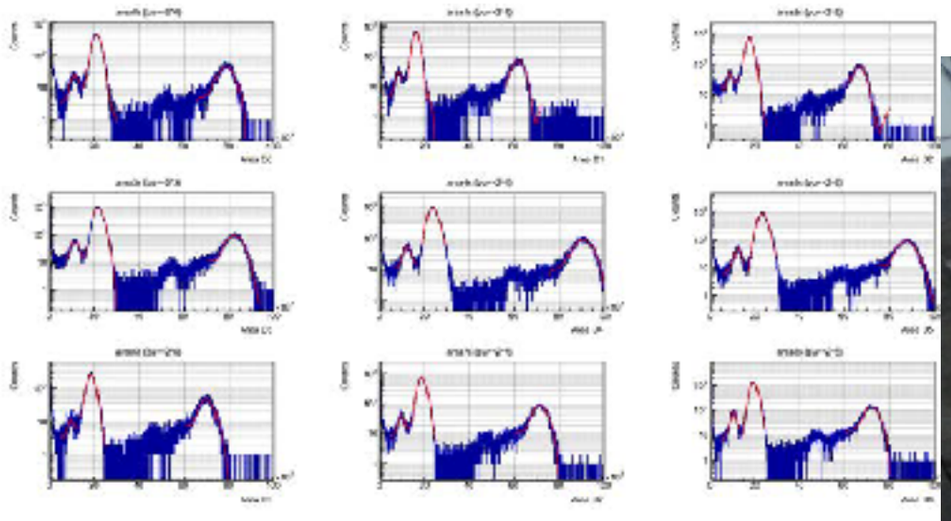
ANAIS-112

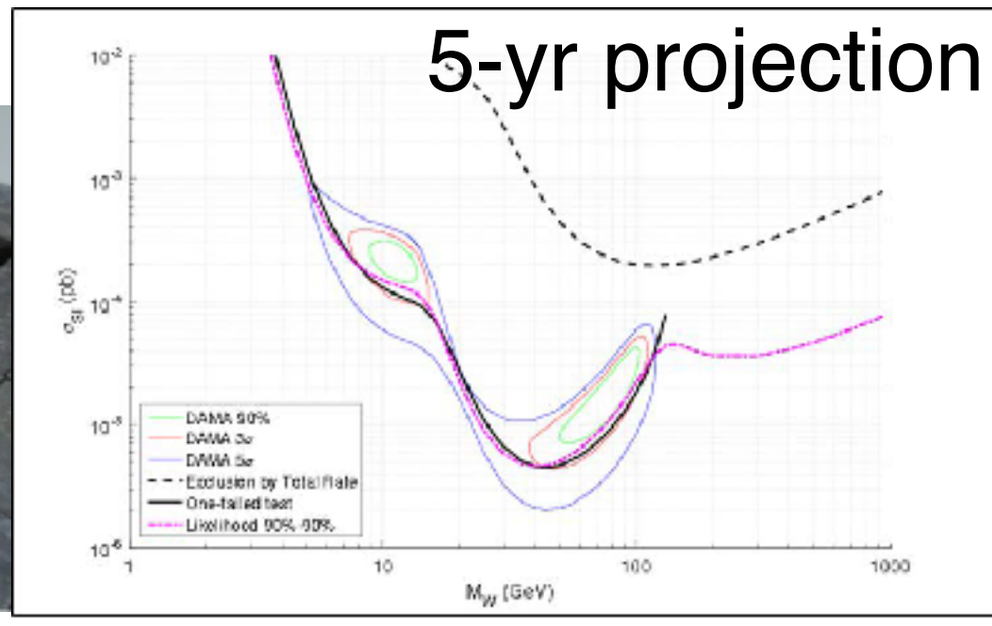


- Taking data at the Canfranc Underground Laboratory in Spain since 2018, August 3
- 3x3 matrix of 12.5 kg NaI(Tl) = 112.5 kg of active mass
- High uptime, muons vetoed w/ plastic scintillators
- ~15 phe/keV light collection in all the modules



- Trigger <1 keV_{ee} with bulk ^{22}Na and ^{40}K (at 3.2 and 0.9 keV, respectively)
- Good understanding of backgrounds

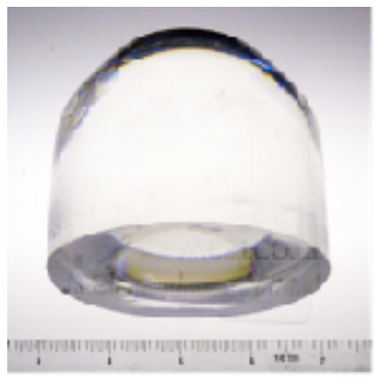




SABRE: Dark Matter Annual Modulation Detection in the Northern and Southern Hemisphere

A Dark Matter experiment based on NaI(Tl) scintillating crystals and focused on the achievement of a **very low background via crystal purity and active rejection** through liquid scintillator veto.

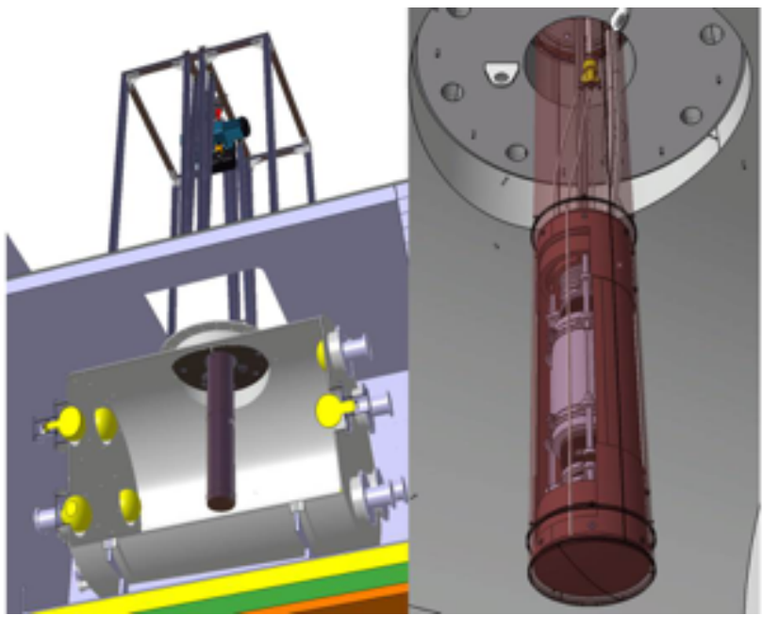
The full SABRE experiment will be installed underground at LNGS and Stawell gold mine (a future underground site in Australia). In the southern hemisphere **seasonal modulations have opposite phase: an effective way to disentangle** this kind of background.



2kg and 3.5” diameter crystal (same diameter foreseen for the ~5kg SABRE crystals) grown from **Astrograde powder**

[K] in crystal: 9 ± 1 ppb
K in crystal below the DAMA level

A **SABRE Proof Of Principle (PoP)** phase is under construction at LNGS. The PoP will be a test stand to evaluate the radio-purity of SABRE crystals as well as the efficiency of the LS veto prior to the full scale experiment, and demonstrate that internal backgrounds are low enough to allow a reliable test of the DAMA/LIBRA result and further high-sensitivity dark matter measurements in the full scale experiment.

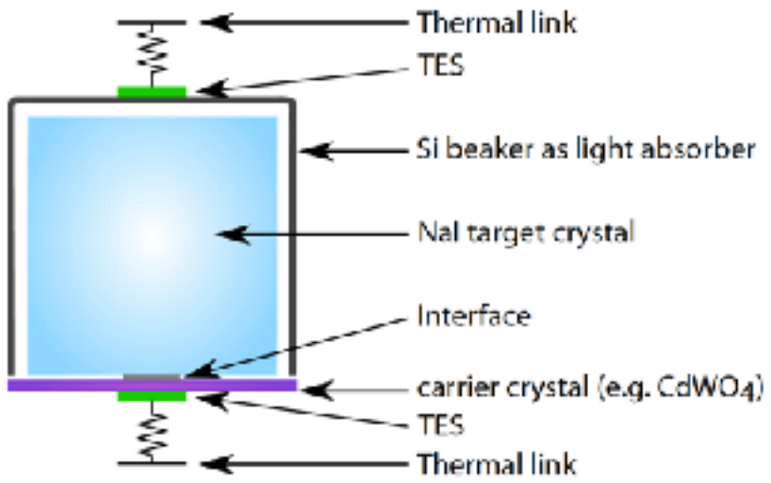


Data-taking expected in 2018

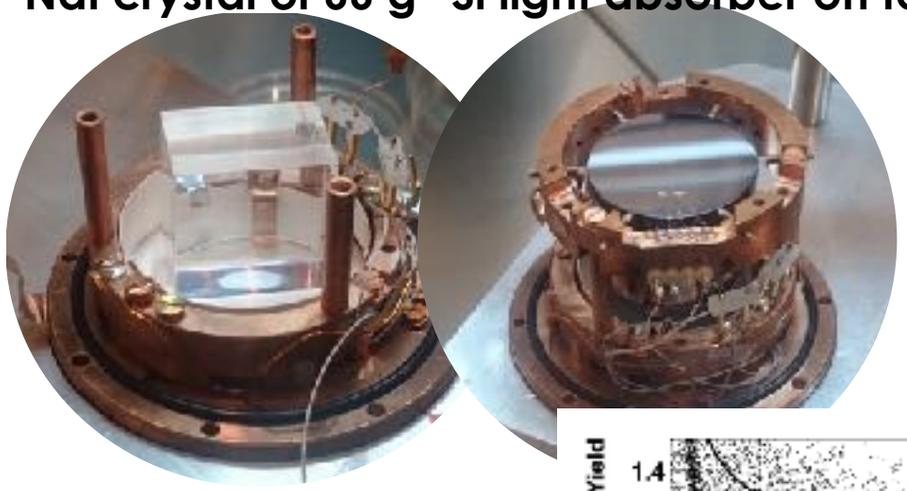
SABRE vessel and passive shielding in Hall C @ LNGS

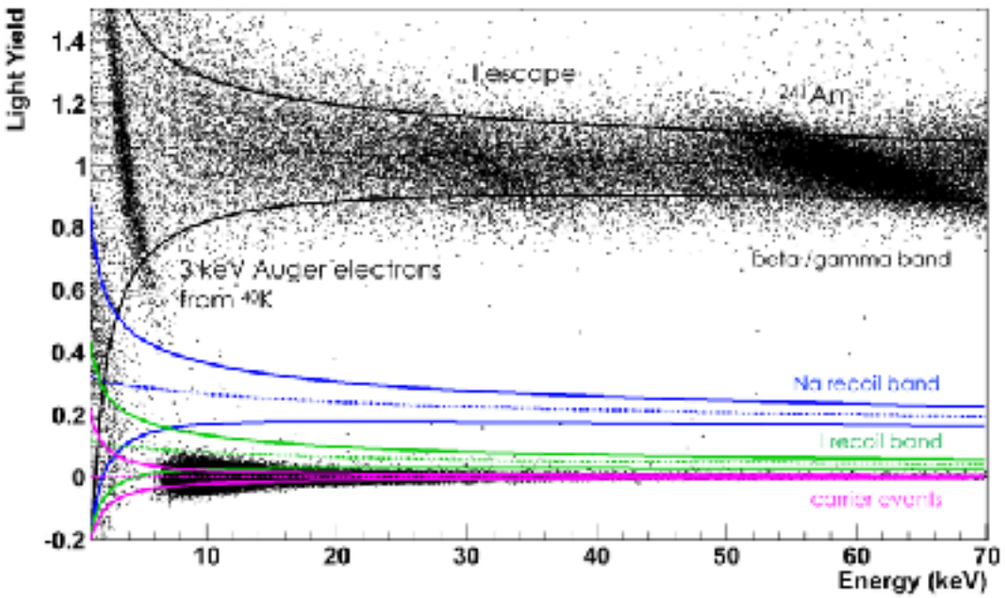
COSINUS project

J Low Temp Phys (2018); EPJC (2016) 76:441; arXiv:1802.10175



NaI crystal of 66 g **Si light absorber on top**





proof-of-principle of final detector design

- Energy threshold is (8.26 ± 0.02 (stat.))keV
- absolute light yield for a β/γ-event: 13 %

- R&D project
- 3 years for prototype development [2016 – 2018]
  → recently received a MPRG grant [2019-2023]

- Production of first radiopure NaI crystal from SICCAS promising
- better low-background cryostat are in the pipeline

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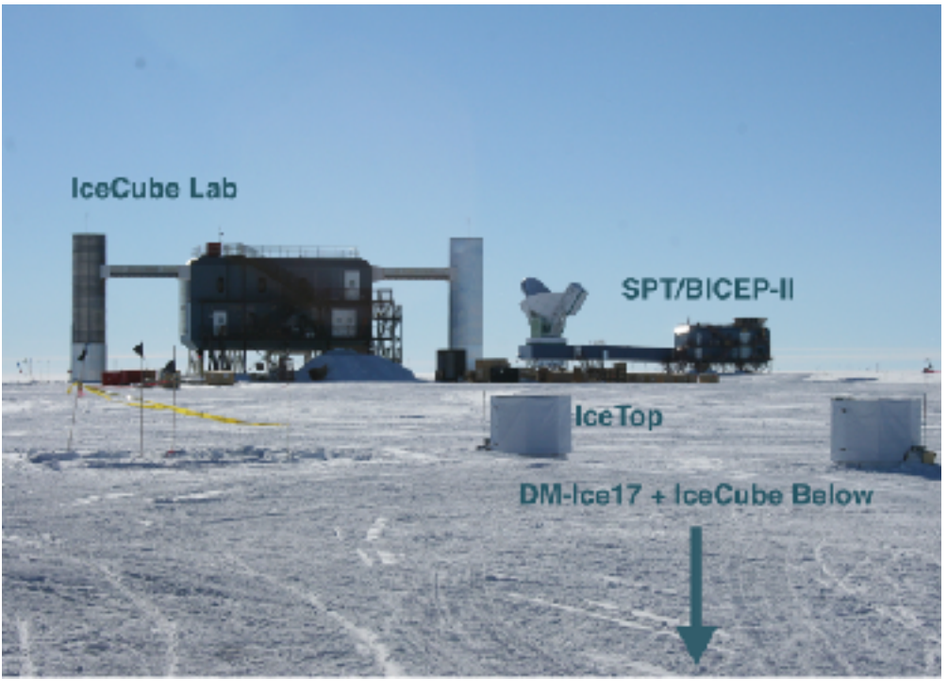
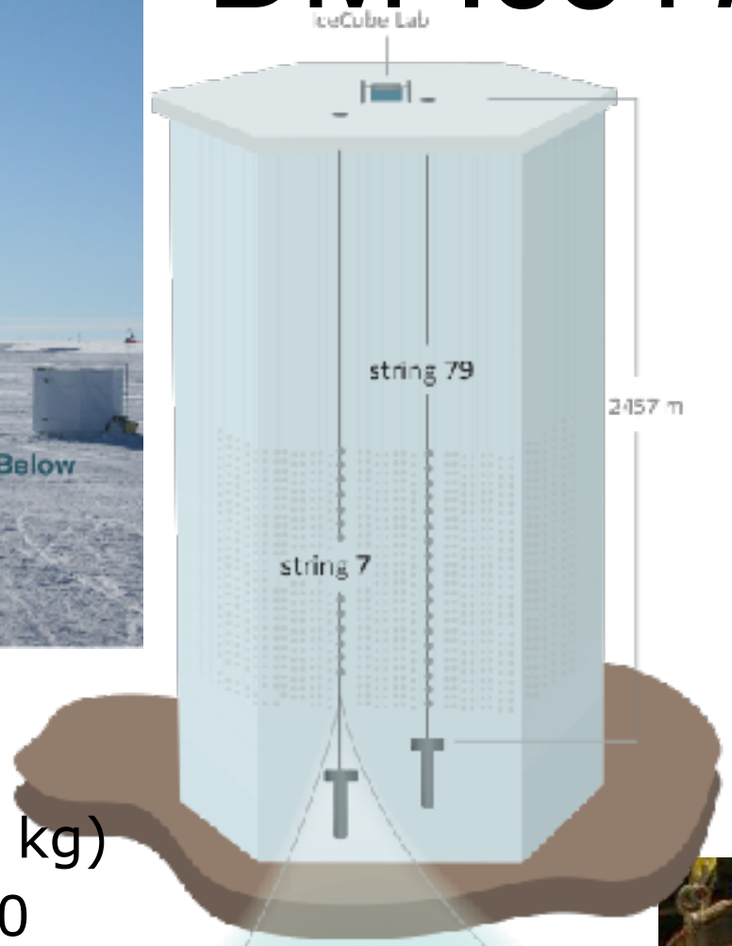
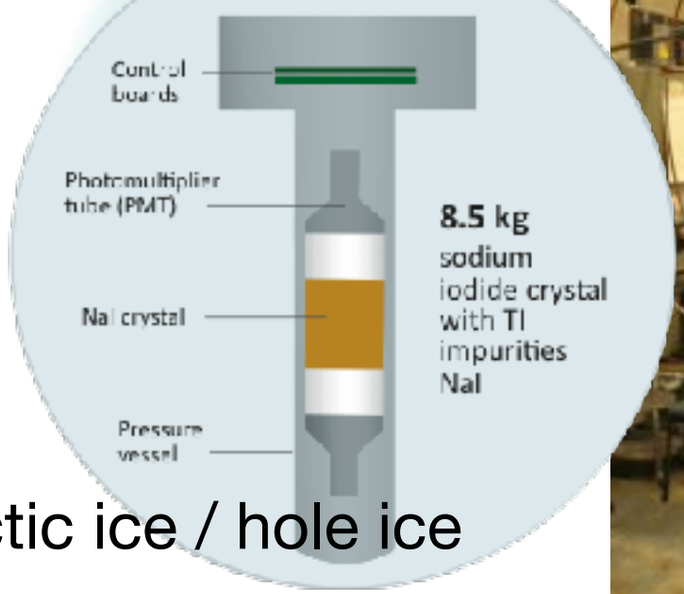
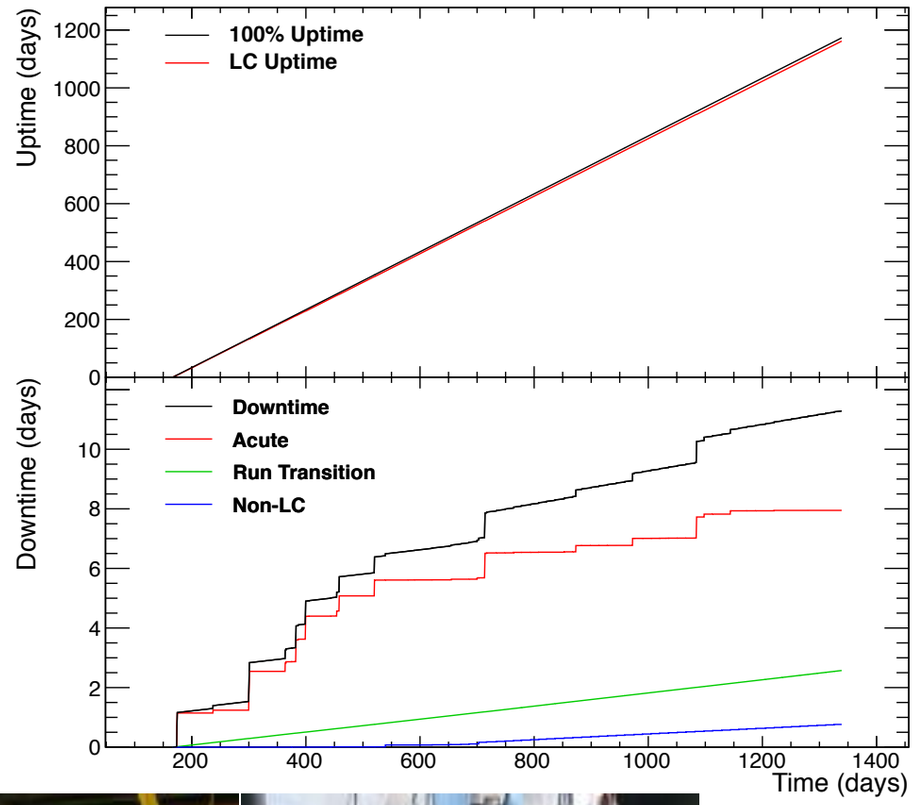
DM-Ice17



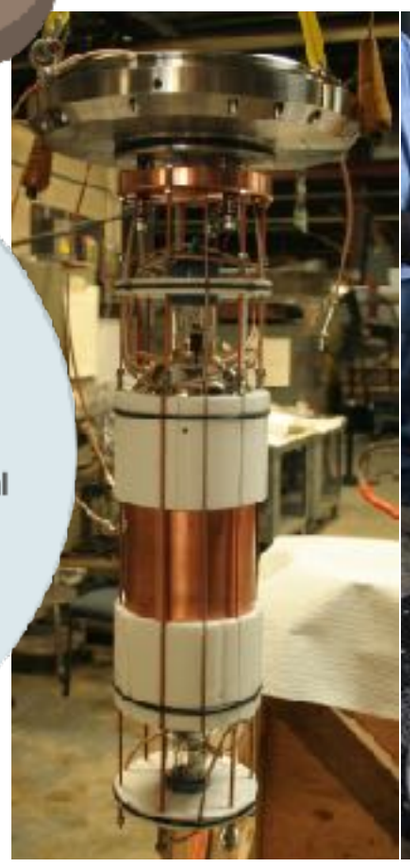




Phys. Rev. D 90, 092005 (2014)



- Two 8.47 kg crystals (17 kg)
- Deployed December 2010
- 2200 m.w.e. overburden
- >99% uptime
- 3.5 years physics data

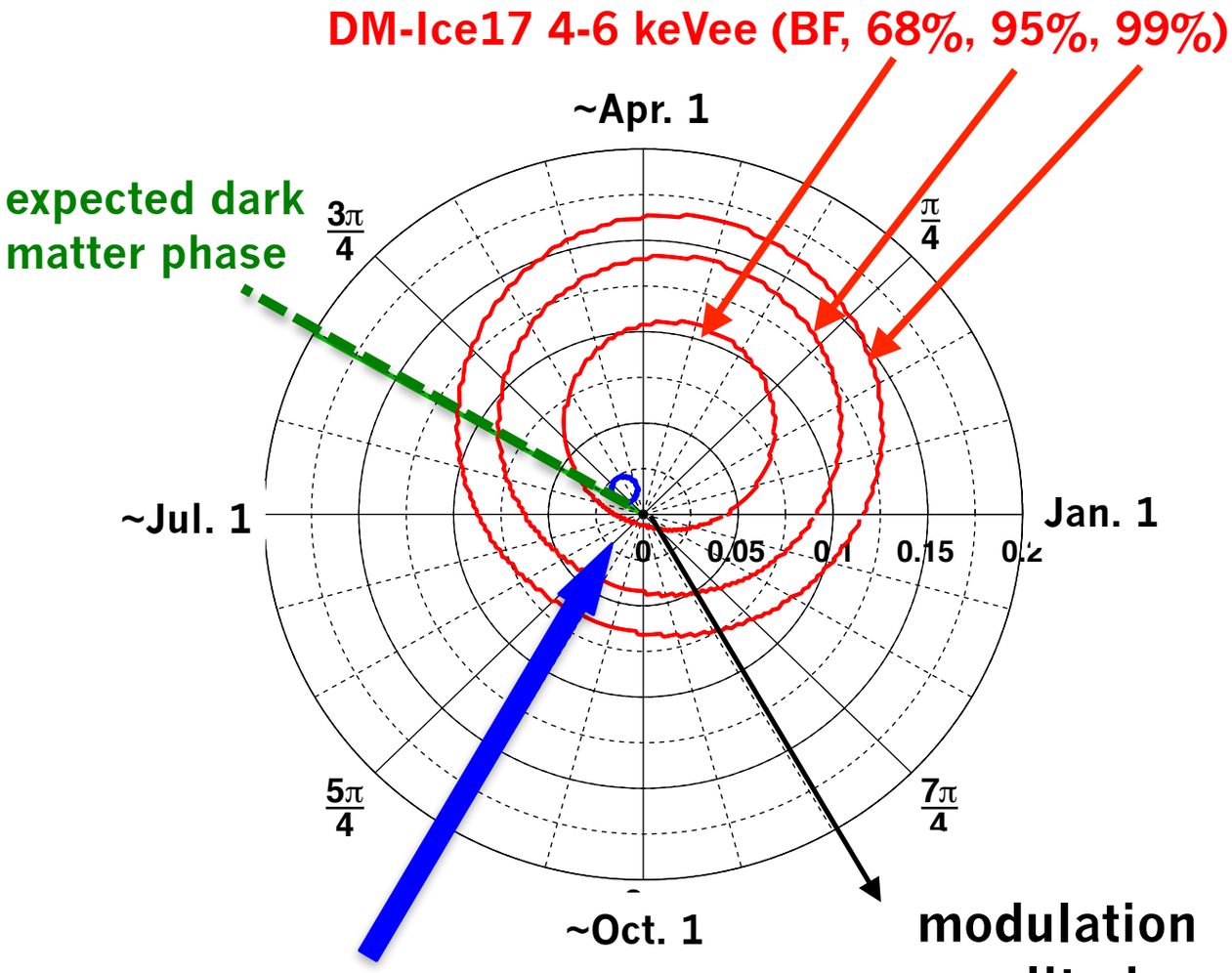


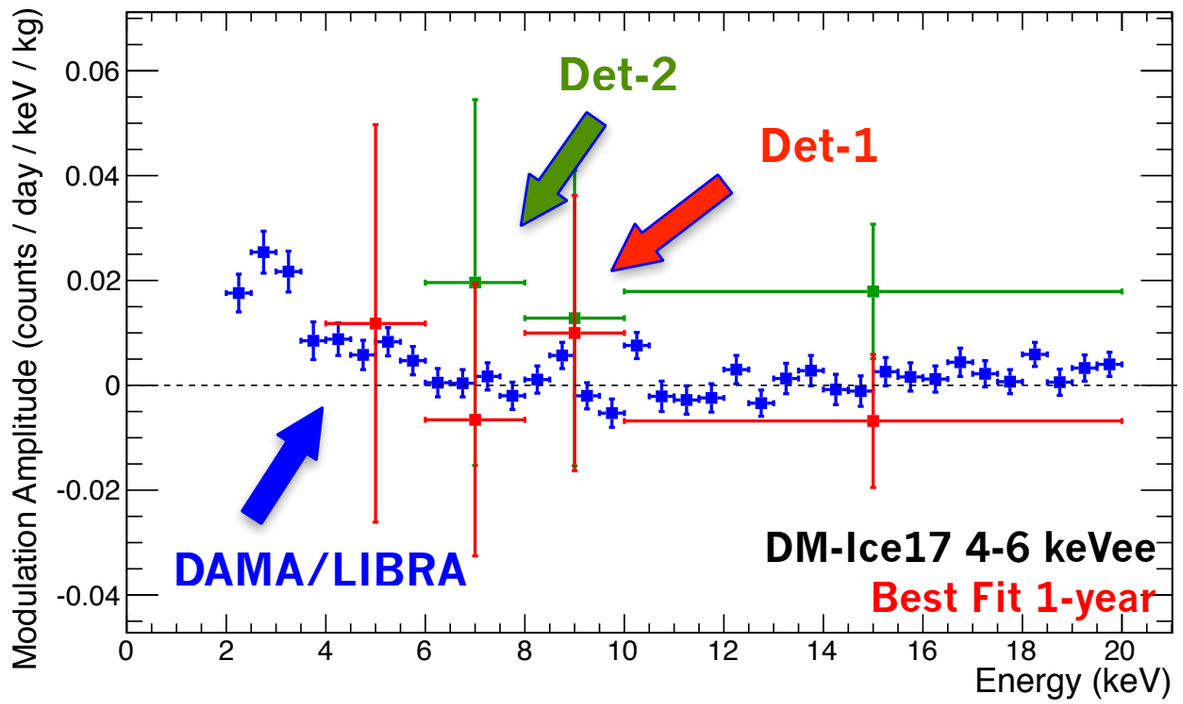
DM-Ice17 establishes…

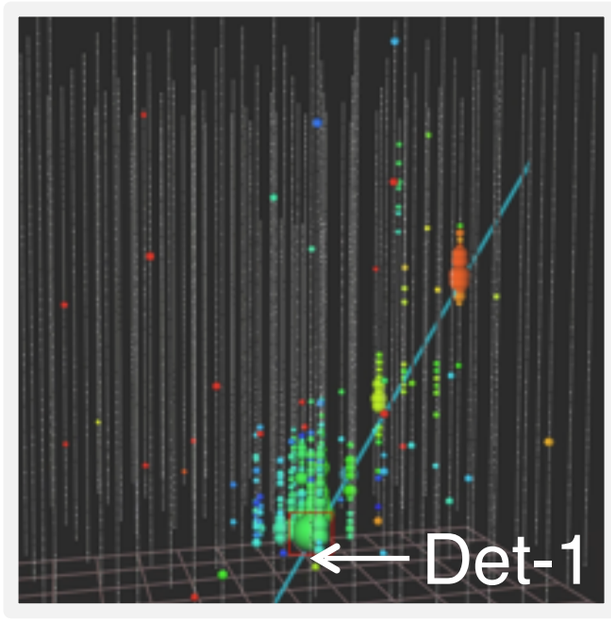
- Feasibility
- Environmental Stability
- Radiopurity of the antarctic ice / hole ice

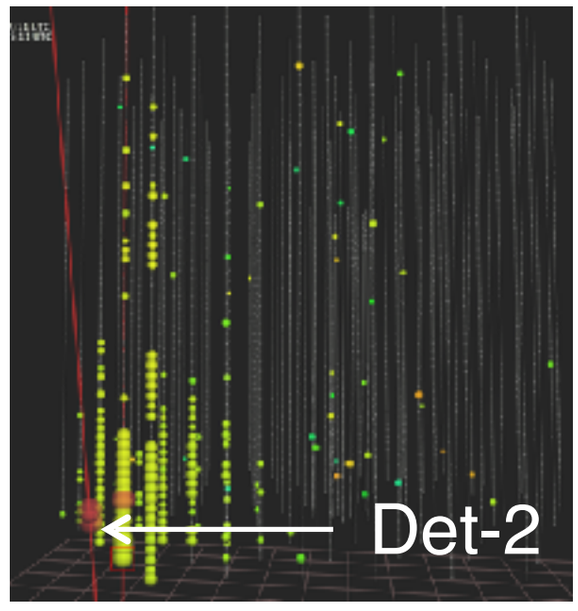
DM-Ice17

Astropart. Phys. **35** (2012) 749
Phys. Rev. D **90** 092005 (2014)
Phys. Rev. D **93** 042001 (2016)
Phys. Rev. D **95** 032006 (2017)





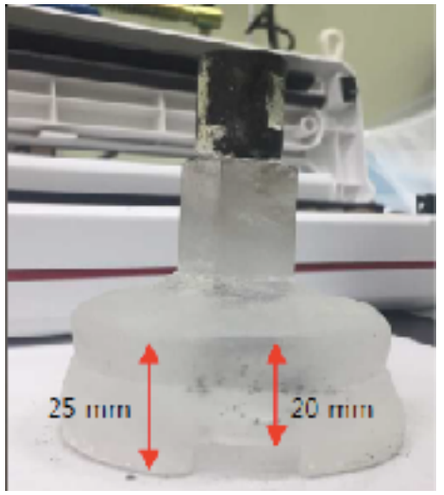




- Proof of principle
- Strongest limit in the Southern Hemisphere
- Awaiting for IceCube upgrade

Summary



- No sign of WIMPs down to 10^{-46} cm^2 @ 30 GeV
- many new ideas for low-mass DM experiments
- World-wide effort to verify DAMA/LIBRA's annual modulation signal
- COSINE-100 started running September 2016
- Initial performance of COSINE-100 is promising. Stay Tuned!
- Continued R&D for higher purity crystals for COSINE-200 (Phase-II)