Status of COSINE experiment

Hyun Su Lee

Center for Underground Physics (CUP)

Institute for Basic Science (IBS)

On behalf of the COSINE-100 Collaboration

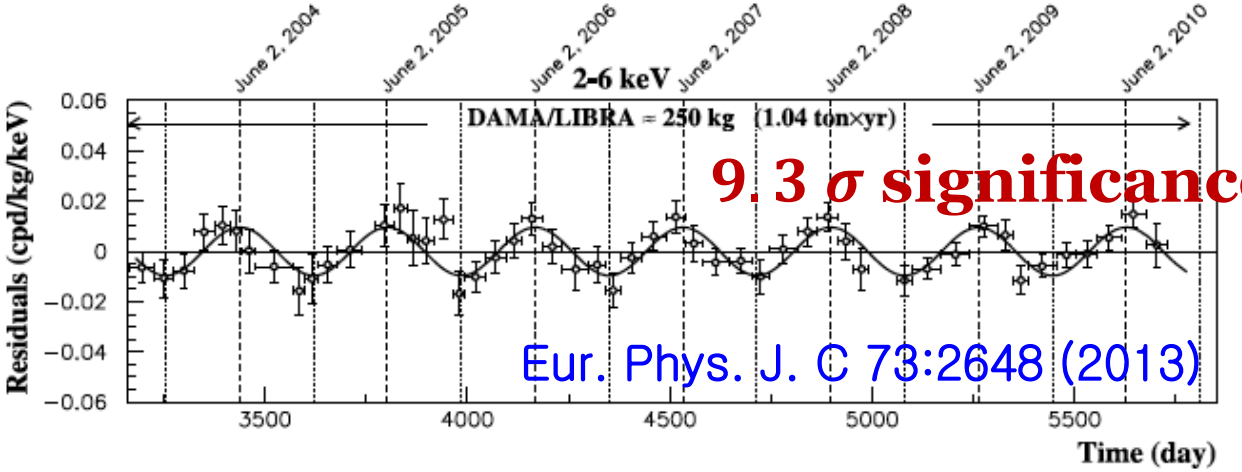
Double Beta Decay and Underground Science (DBD2018)

Hawaii Island November 21-23

DAMA/LIBRA experiment

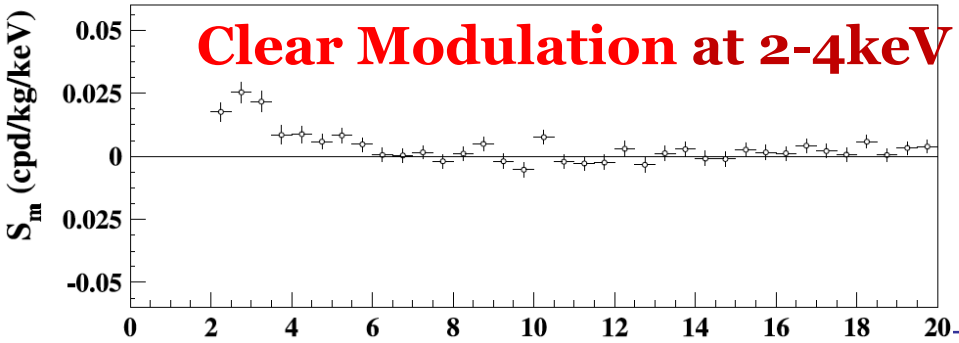
- Annual Modulation Searches with an array of NaI(Tl) crystals

Claimed an observation of the dark matter



9.3 σ significance

Eur. Phys. J. C 73:2648 (2013)



DAMA/LIBRA phase 1

1.33 ton-year

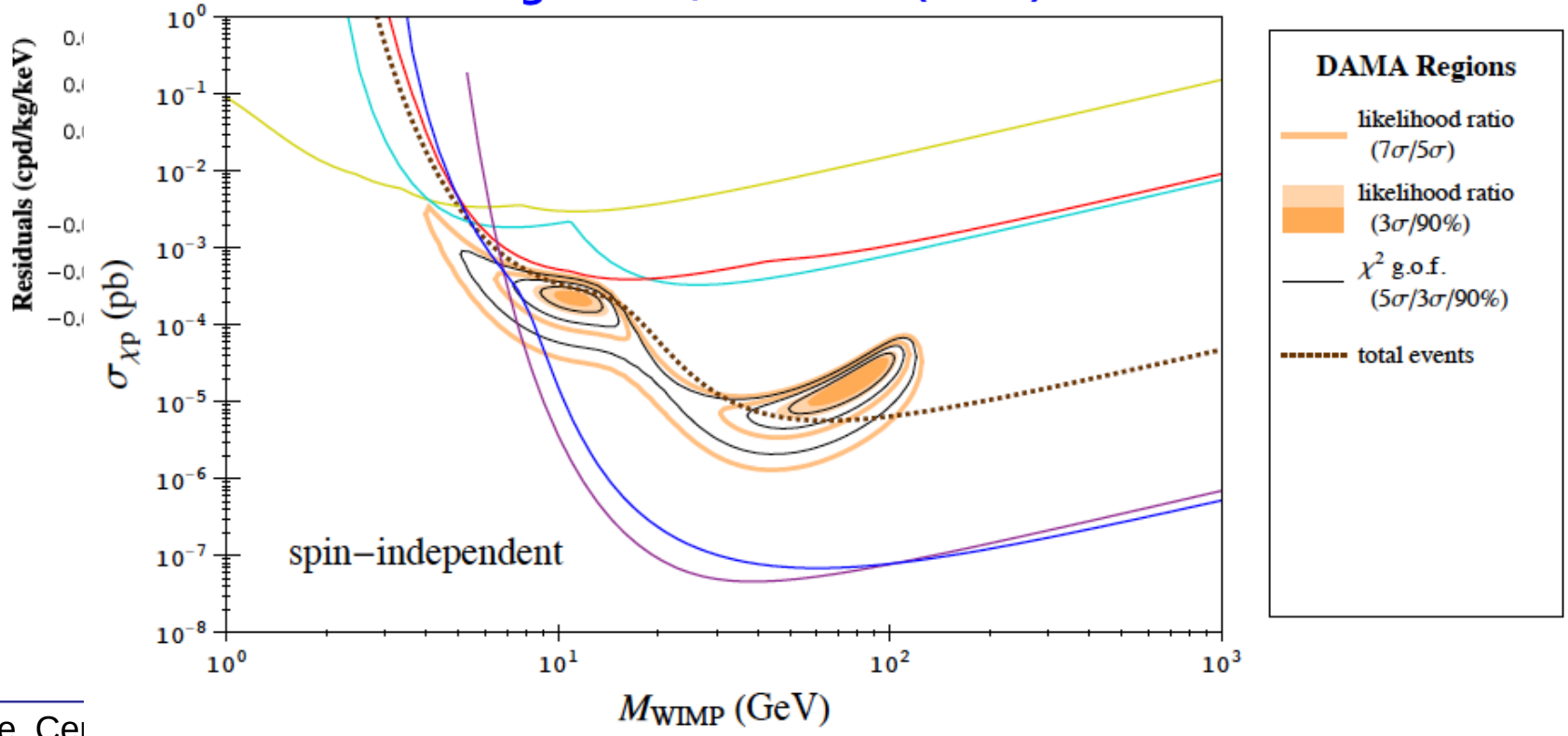
Center for Underground Physics

DAMA/LIBRA experiment

- Annual Modulation Searches with an array of NaI(Tl) crystals

Claimed an observation of the dark matter

C. Savage *et al.*, JCAP 04 (2009) 010



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DAMA/LIBRA experiment

- Annual Modulation Searches with an array of NaI(Tl) crystals

Claimed an observation of the dark matter

First model independent results from DAMA/LIBRA–phase2

New result from DAMA/LIBRA

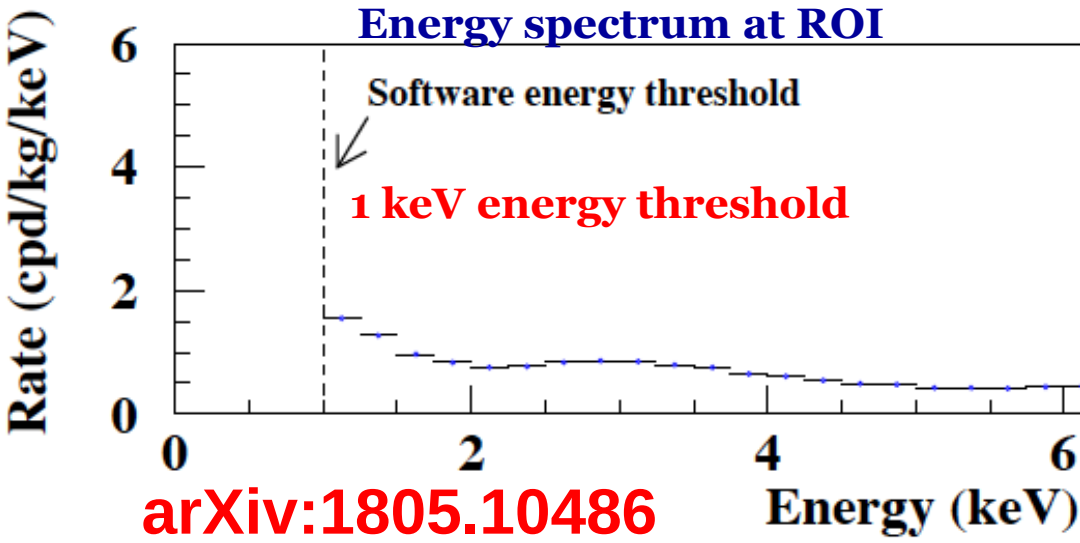
R. Bernabei[a,b], P. Belli[a,b], A. Bussolotti[b], F. Cappella[c,d], V. Caracciolo[e], R. Cerulli[a,b], C.J. Dai[f], A. d'Angelo[c,d], A. Di Marco[b], H.L. He[f], A. Incicchitti[c,d], X.H. Ma[f], A. Mattei[d], V. Merlo[a,b], F. Montecchia[b,g], X.D. Sheng[f], Z.P. Ye[f,h]

arXiv:1805.10486

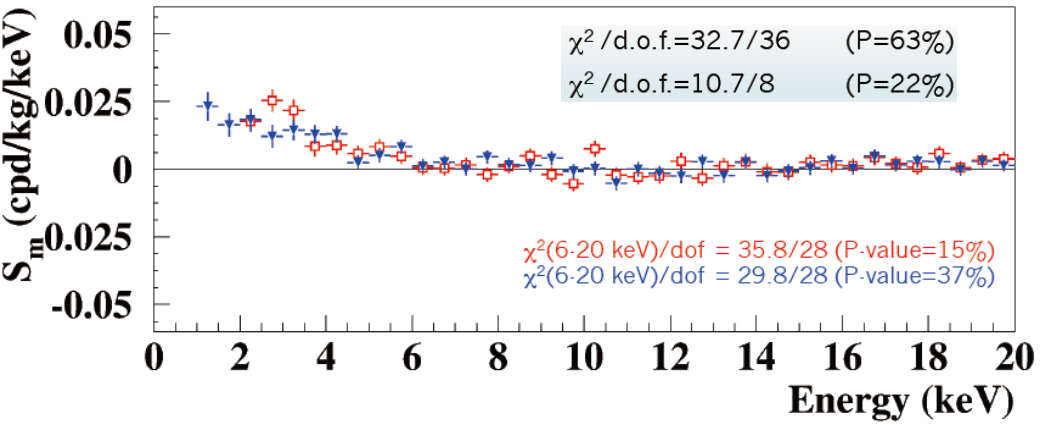
e 1

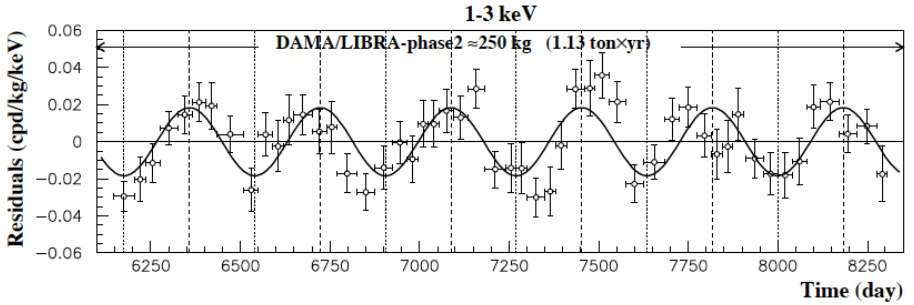
DAMA/LIBRA phase 2

- Energy threshold reached 1keV with better PMTs
- Still there is modulation
- Significance
  - 1-6 keV : **9.5 σ** (phase 2)
  - 2-6 keV : **12.9 σ** (phase 1+2)
- Increased modulation amplitude below 2keV

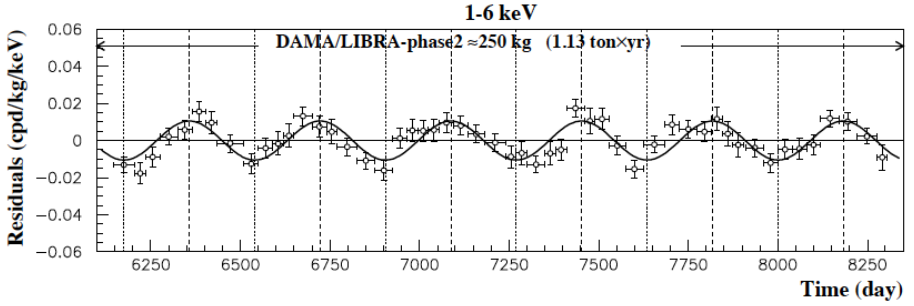


arXiv:1805.10486



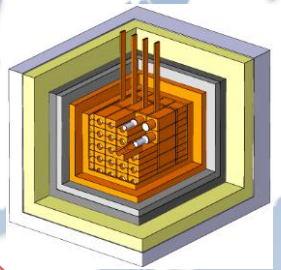


Modulation amplitude



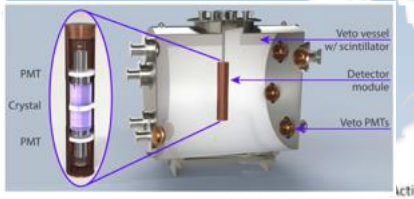
Global NaI(Tl) efforts

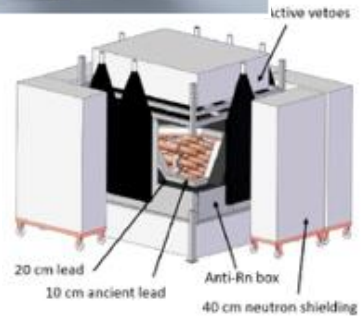
COSINUS
@ LNGS



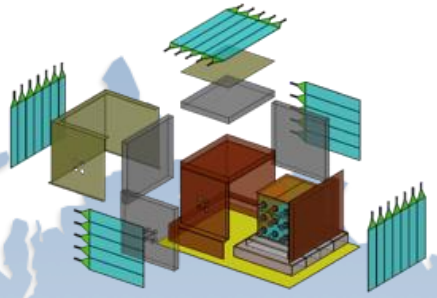
DAMA
@ LNGS

SABRE
@ LNGS



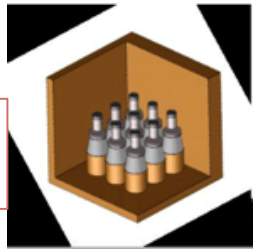


ANAIS
@Canfranc



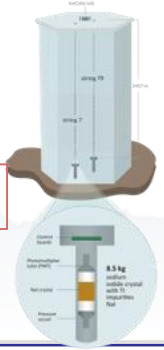
KIMS/COSINE
@ Yangyang

PICO-LON
@ Kamioka



SABRE @
Stawell

DM-Ice @ South Pole



Global NaI(Tl) efforts

- ANAIS: Taking physics data with 112 kg of NaI(Tl) array since 3rd, August 2017
- COSINE : Taking physics data with 106 kg of NaI(Tl) array since 30th, September 2016
- COSINUS : R&D of cryogenic detector for PID
- KIMS : Various R&D of NaI crystals
- PICO-LON : Careful purification program
- SABRE : Crystal R&D growing, proof-of-principle detector under construction at LNGS
- DM-Ice : ~5 years stable data at Ice

COSINE Project (Since 2015)

Center for Underground Physics

KIMS and DM-Ice joint effort to search for dark matter interactions in NaI(Tl) scintillating crystals.
(Goal to **verify DAMA/LIBRA's observation**)

YangYang(Y2L) Underground Laboratory

(Upper Dam) YangYang Pumped Storage Power Plant

Center for Underground Physics

IBS (Institute for Basic Science)

1000m

700m

(Power Plant)

양양양수발전소

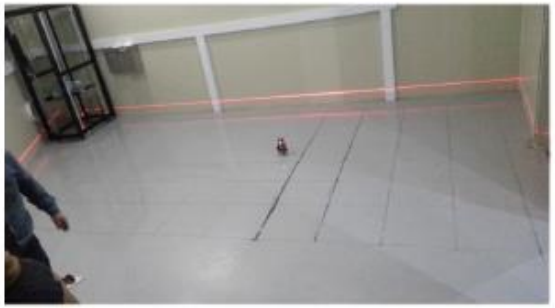
(Lower Dam)

Minimum depth : 700 m / Access to the lab by car (~2km)

COSINE-100 Construction

Center for Underground Physics

Dec. 2015 — Jan. 2016 — Feb. 2016



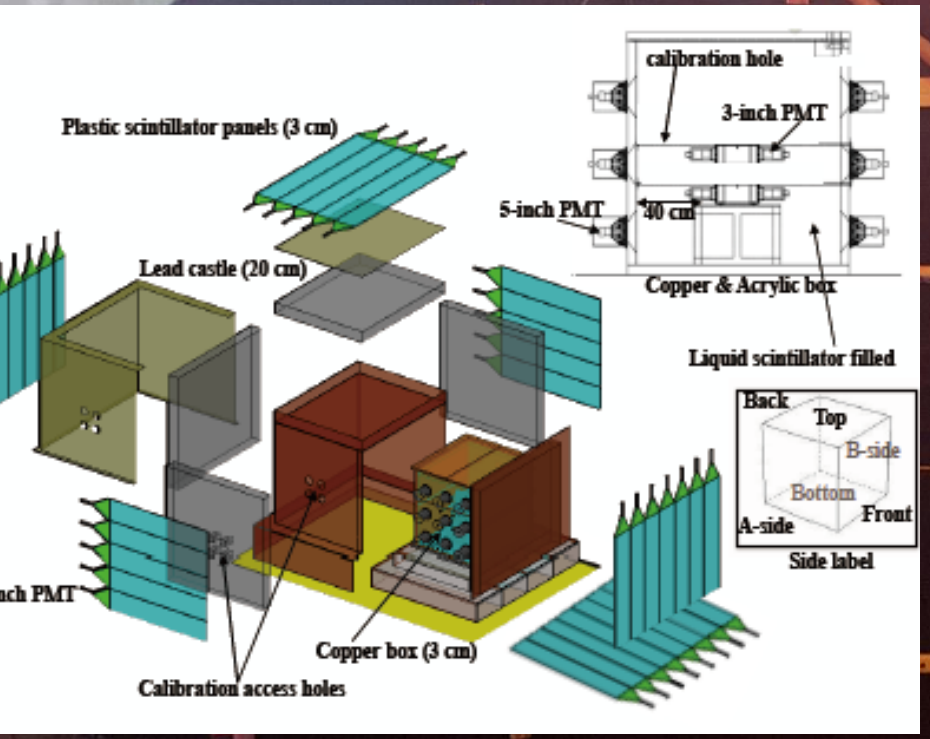

Mar. 2016 — Apr. 2016




May. 2016 — Jun. 2016 — Sep. 2016




COSINE-100 detectors



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

Eur. Phys. J. C 78 (2018) 490

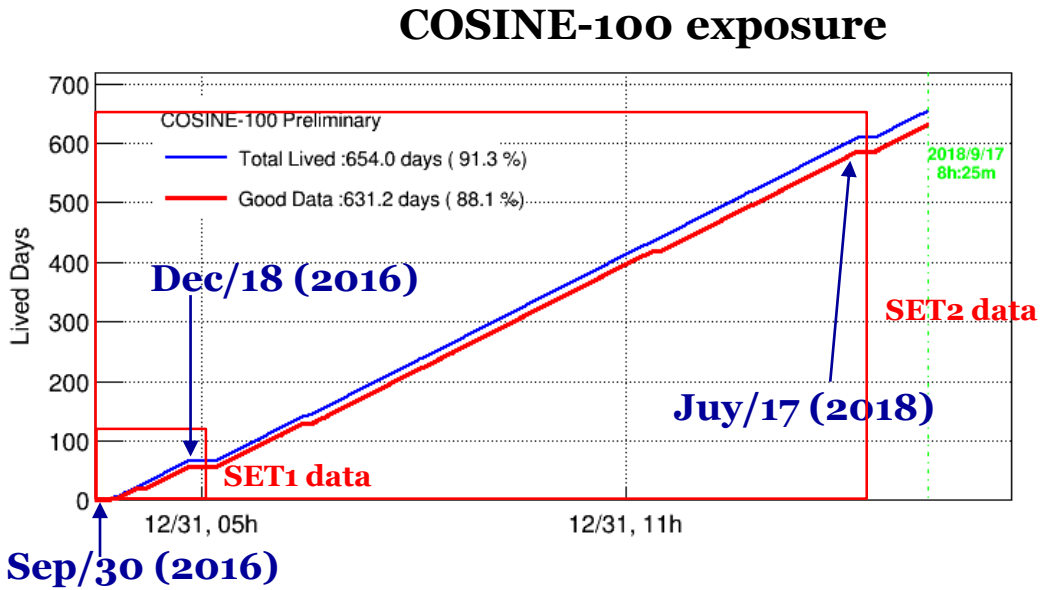
JINST 13 (2018) P09006

JINST 13 (2018) T02007

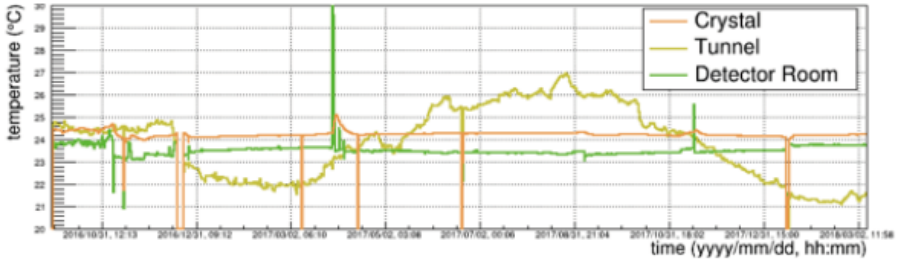
JINST 13 (2018) T06005

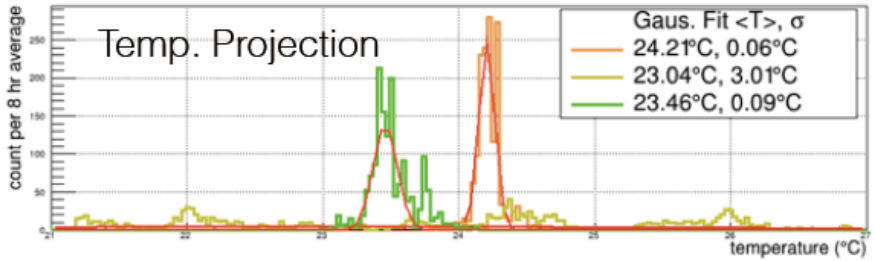
Physics run started since Sept/2016

COSINE-100 operation

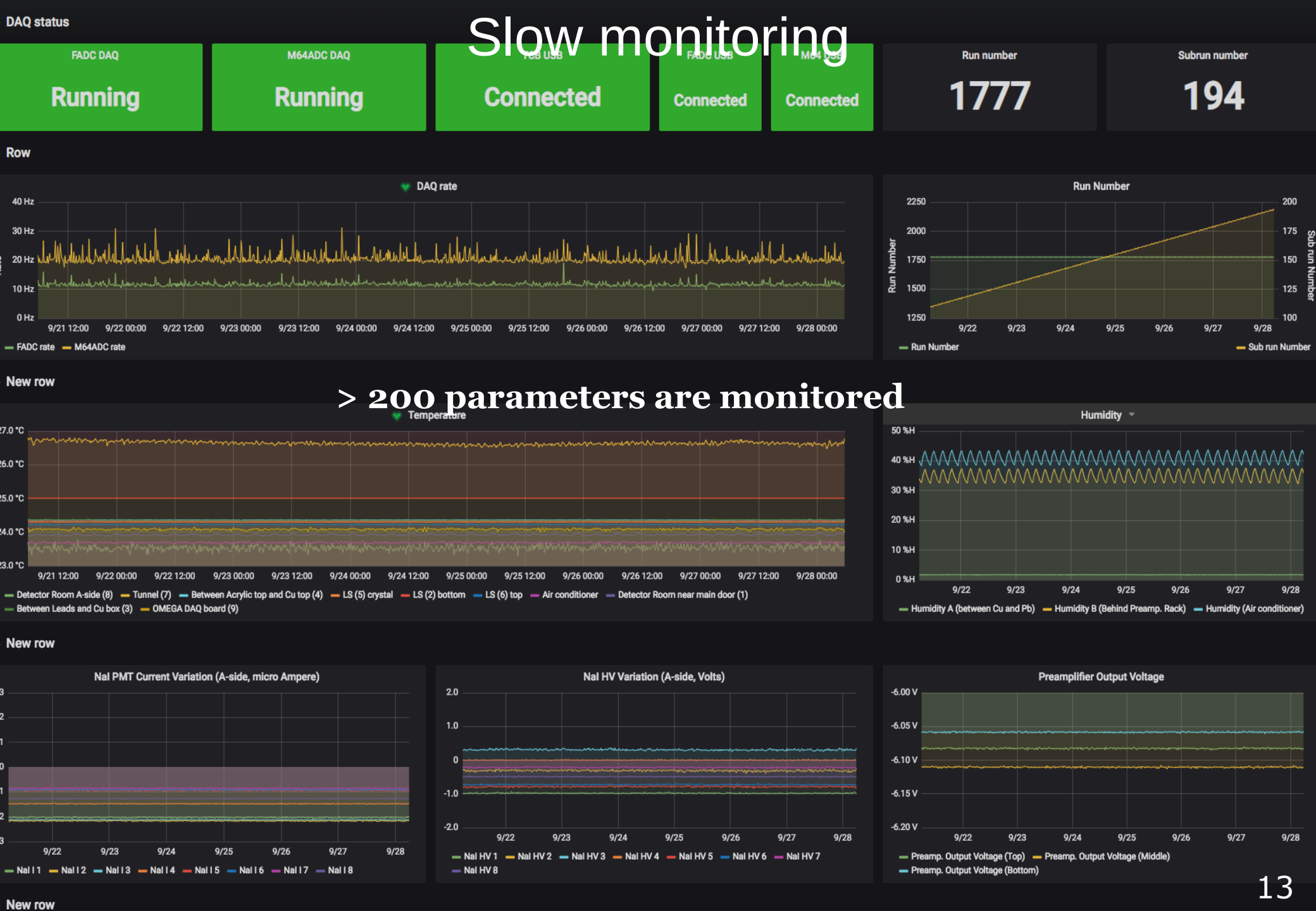


- Stable physics run
  - More than 90% live time!! Most of data are marked as good quality data
- Operating for about 2 years





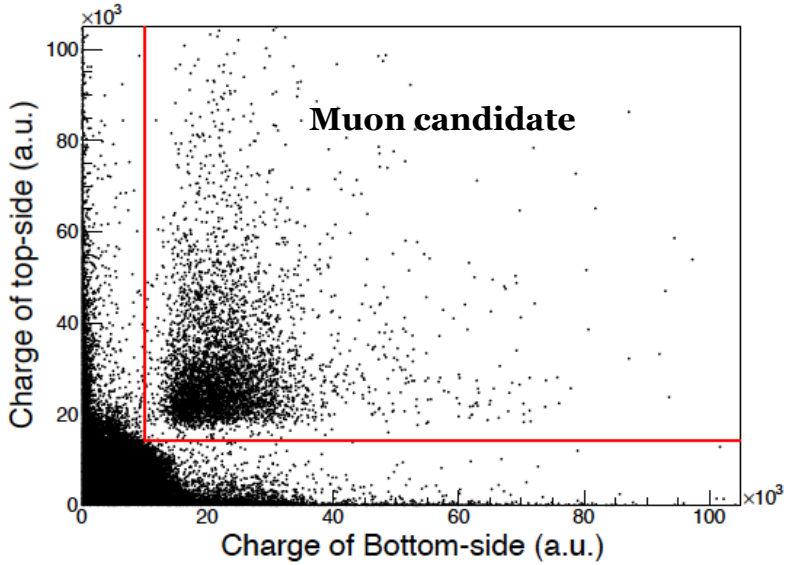
Slow monitoring



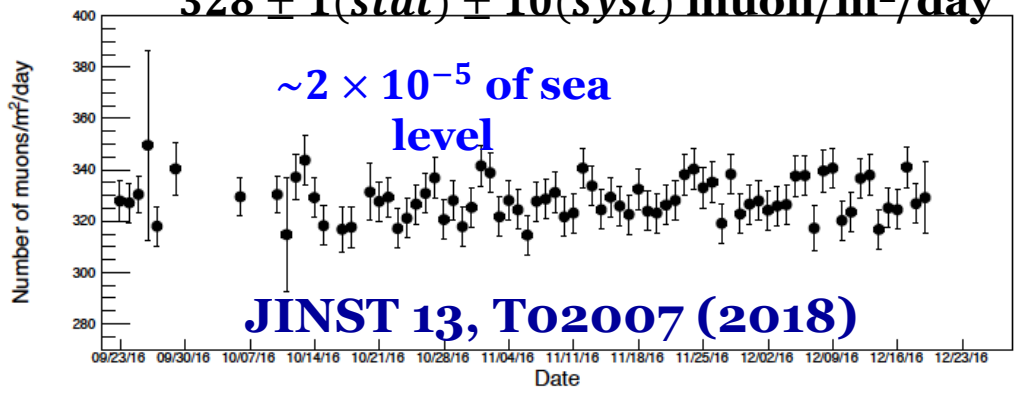
> 200 parameters are monitored

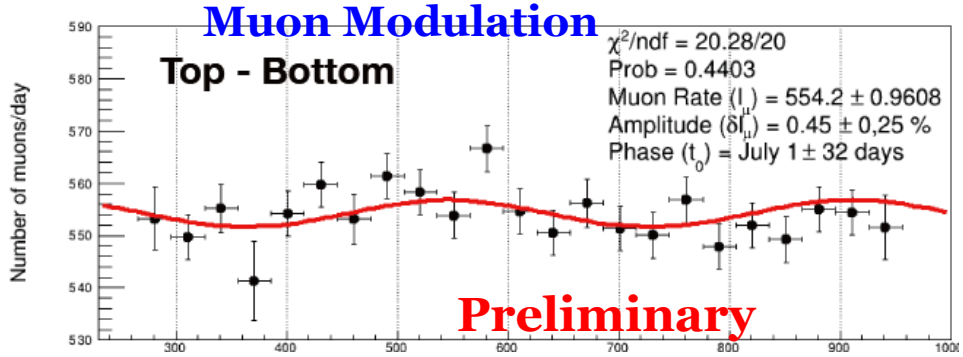
Muon detector

- Outer muon veto consists of 37 plastic scintillator panels



$328 \pm 1(stat) \pm 10(syst)$ muon/m²/day

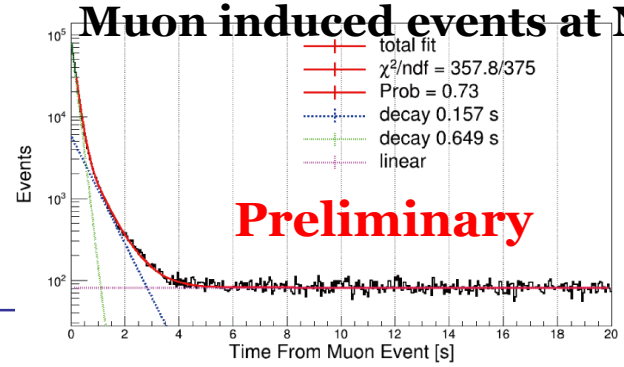




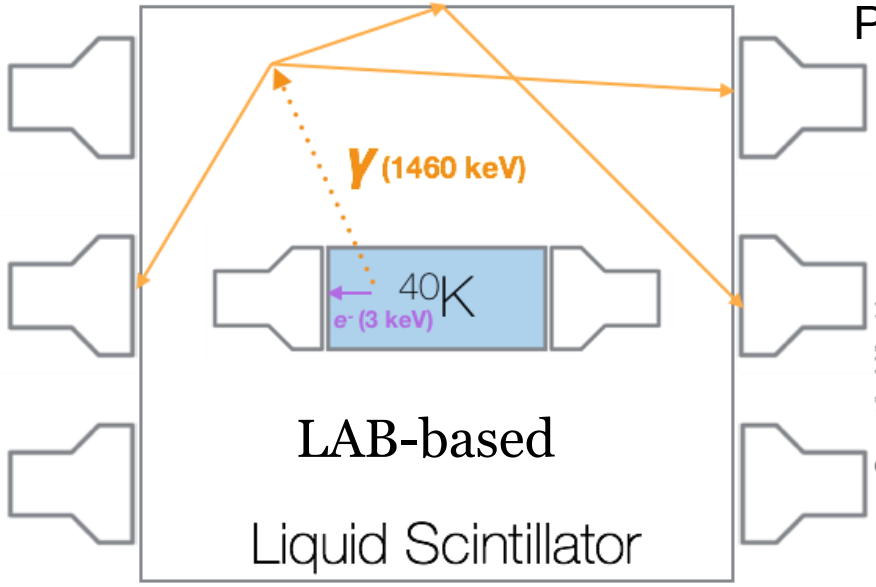
Muon flux has been monitored stably

Vetoing of muon correlated events in NaI(Tl) crystals was implemented

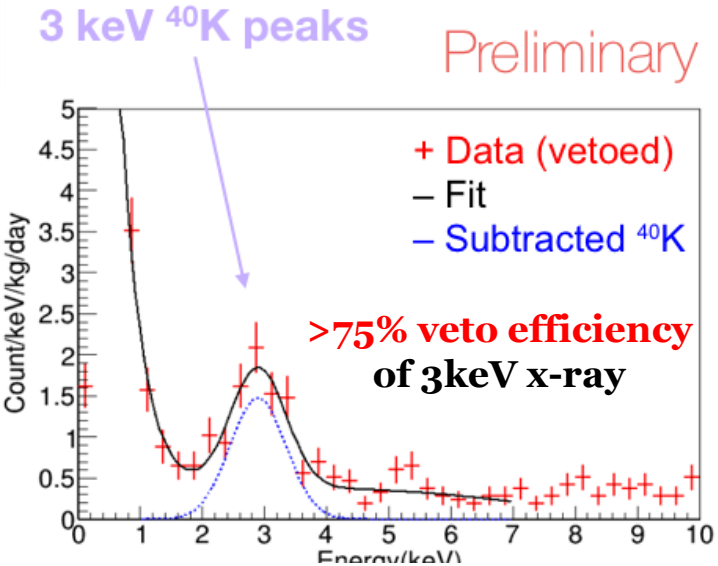
Study on muon induced events with NaI(Tl) and liquid scintillator is ongoing

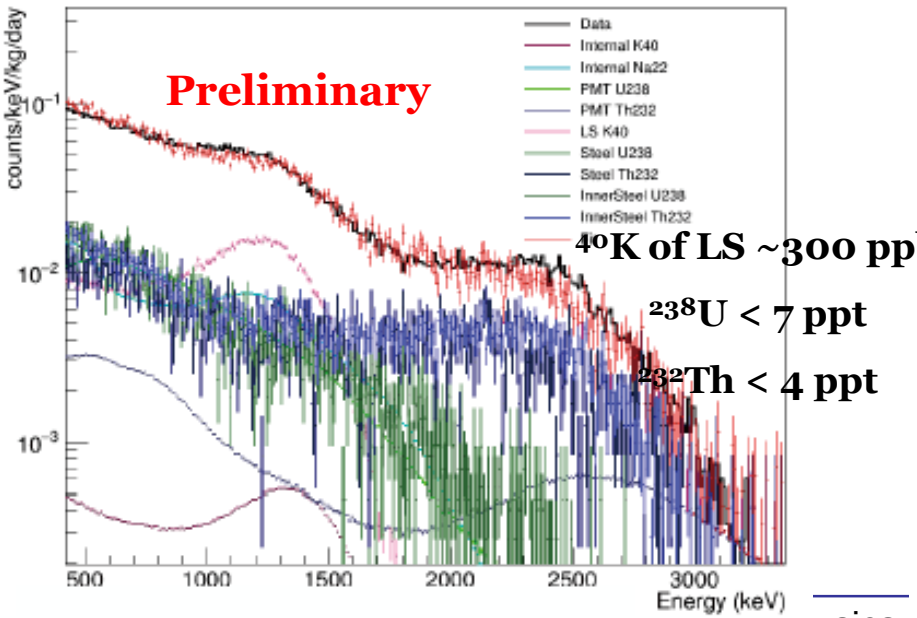


Liquid scintillator veto system



Prototype : **NIMA 851 (2017) 103**



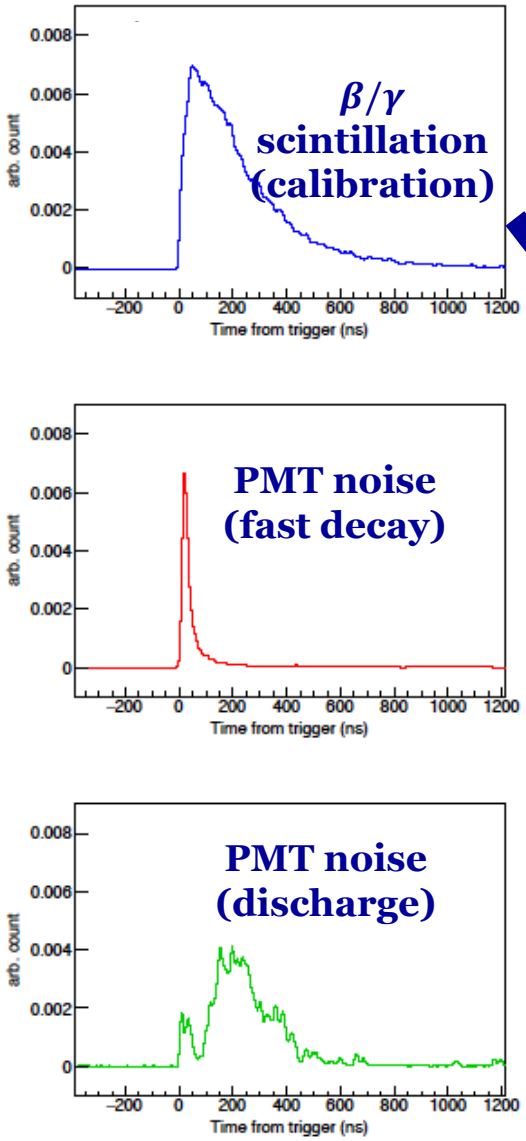


- Tagging rate of ^{40}K is well understood with Geant4-based simulation
- Internal background of LS is well understood and low enough
- 20 keV tagging threshold is achieved

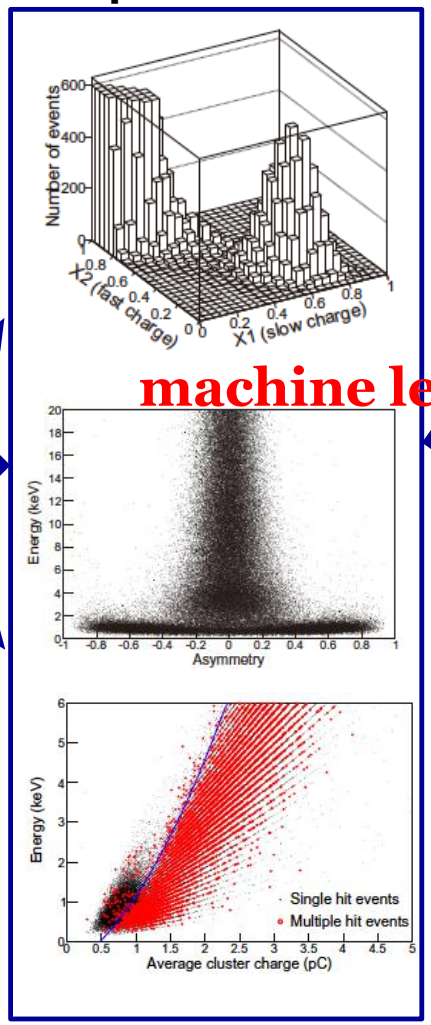
PMT induced noise rejection

Center for Underground Physics

Accumulated waveforms

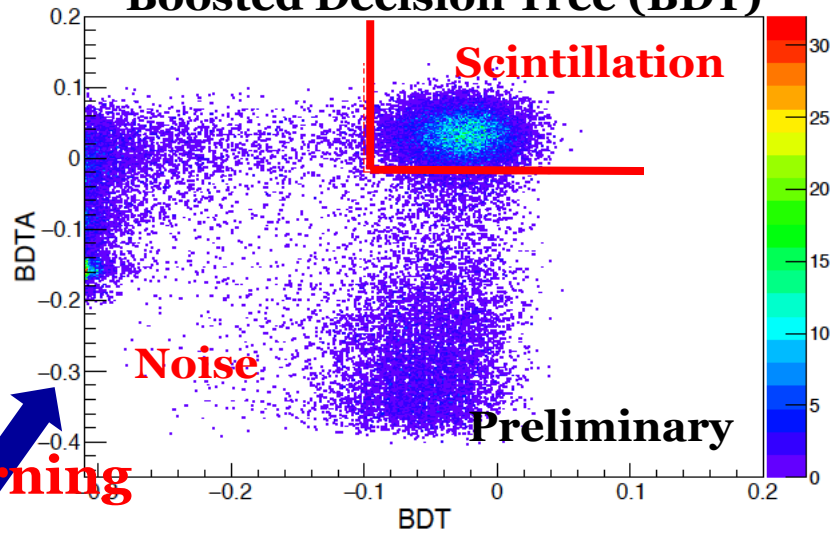


Discrimination parameters

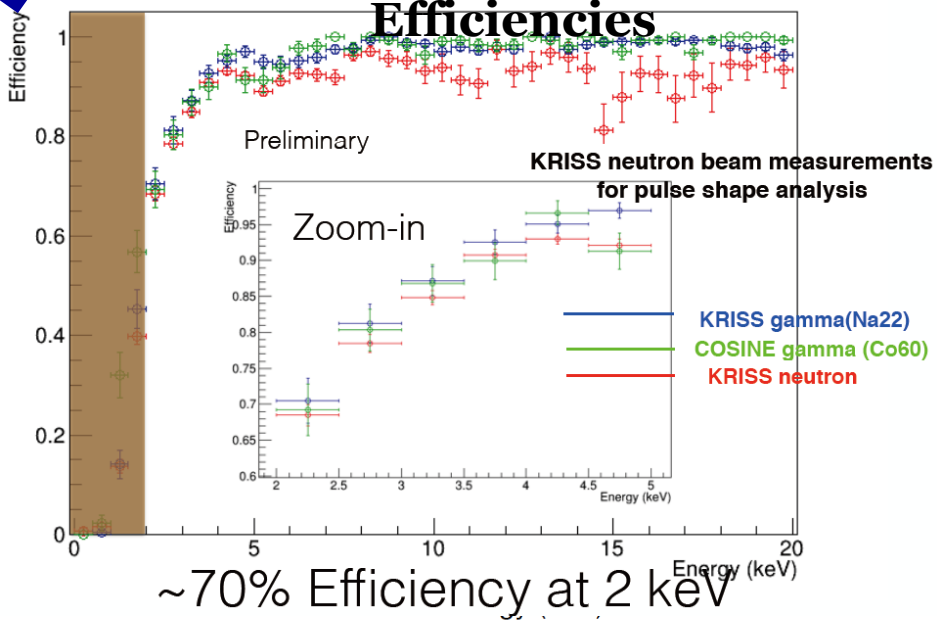


machine learning

Boosted Decision Tree (BDT)

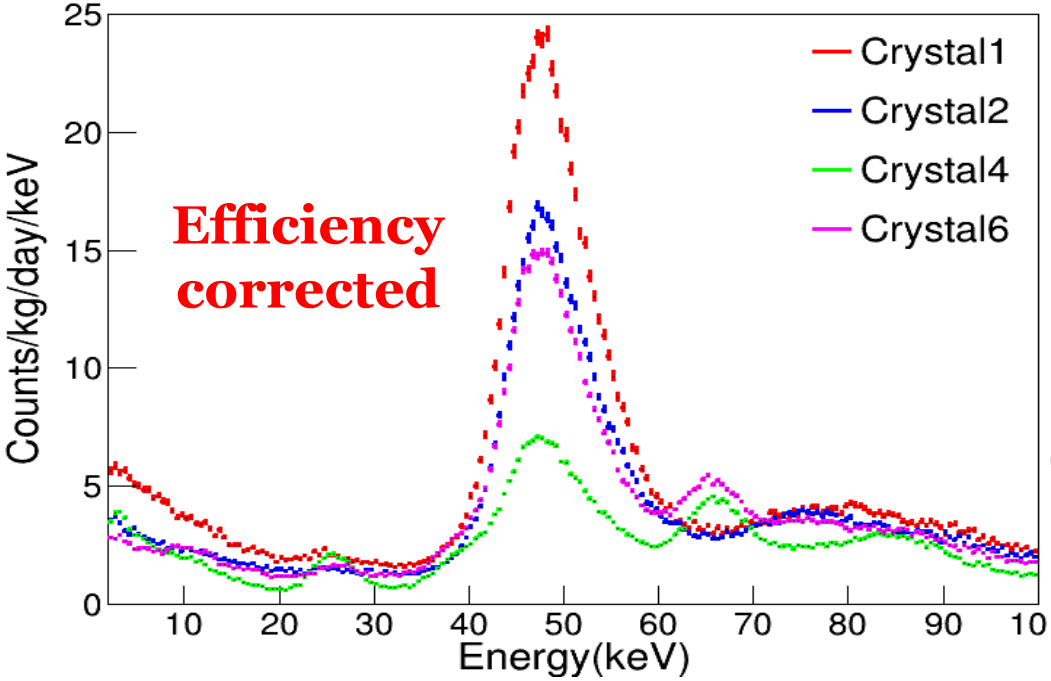


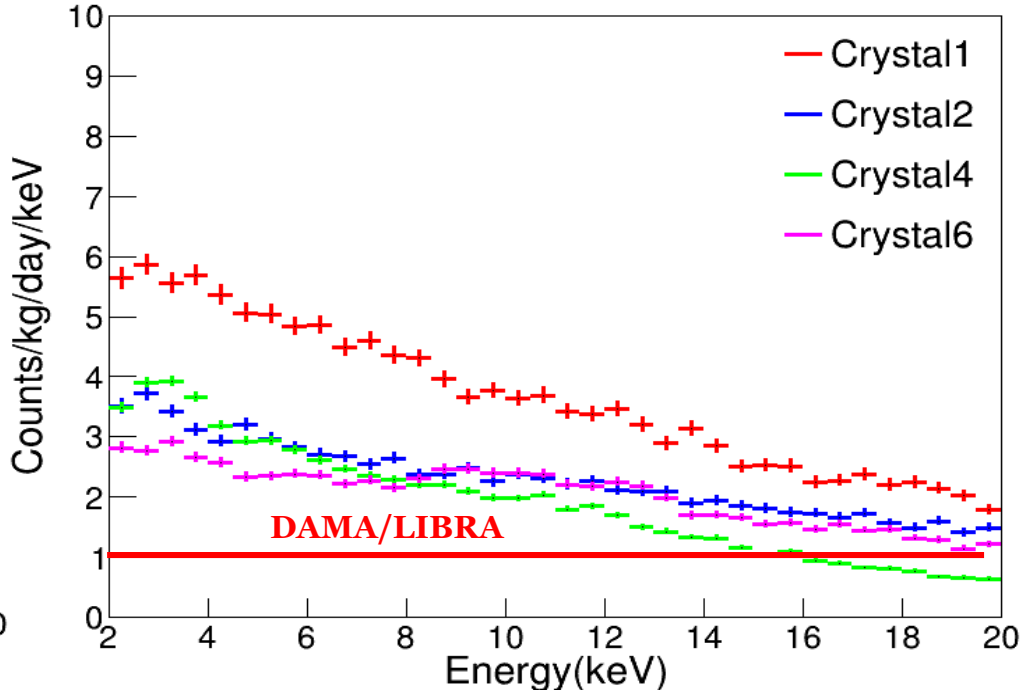
Efficiencies



~70% Efficiency at 2 keV

Crystal data (initial three month)

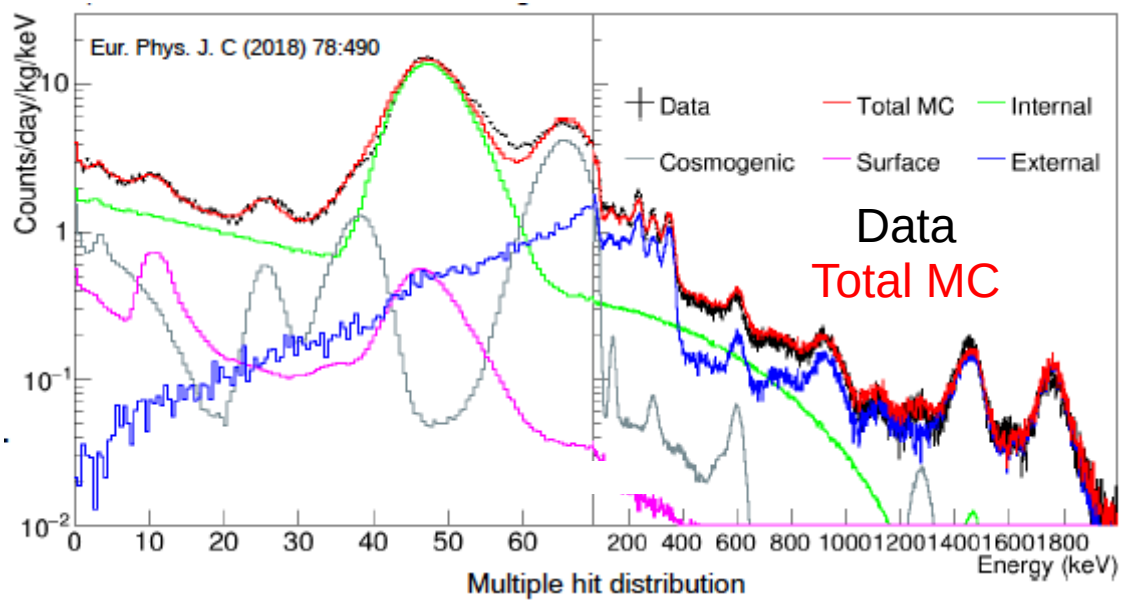




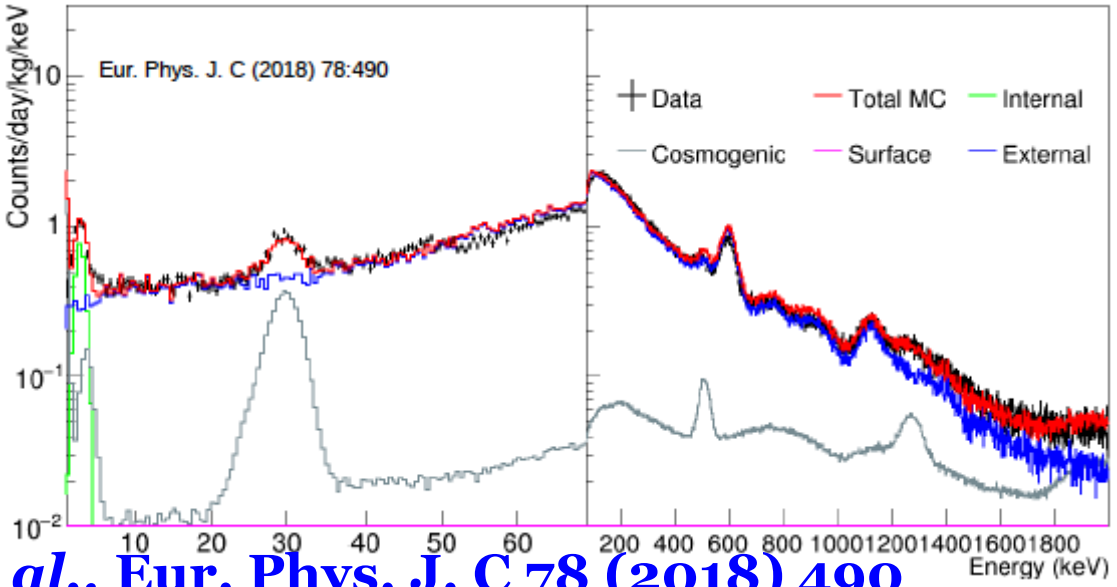
- **Background levels** from 2 to 4 dru (counts/kg/day/keV)
  - Higher than DAMA/LIBRA crystals

Background understanding

Single hit event
(6-2000 keV)

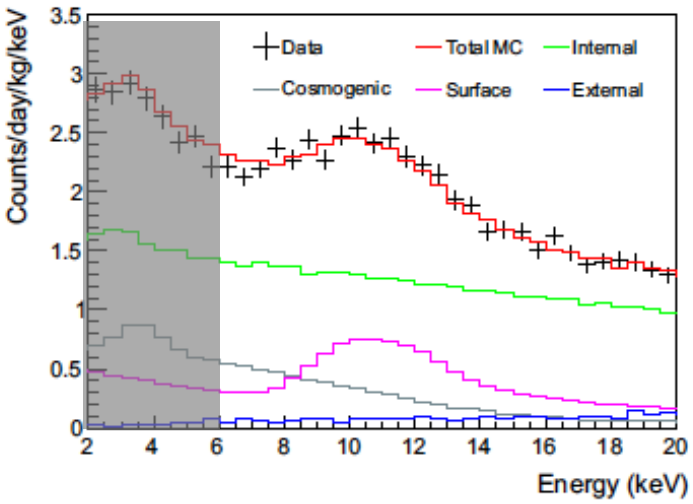


Multiple hit events
(2-2000 keV)



P. Adhikari *et al.*, Eur. Phys. J. C 78 (2018) 490

Expected background (2-6 keV)



Components	Background 2-6 keV (dru)
Internal ^{210}Pb	1.50 +/- 0.07
Internal ^{40}K	0.05 +/- 0.01
Surface ^{210}Pb	0.38 +/- 0.21
^{3}H (Cosmogenic)	0.58 +/- 0.54
^{109}Cd (Cosmogenic)	0.09 +/- 0.09
Other cosmogenic	0.05 +/-0.03
External	0.03 +/- 0.02
Total expected	**2.70 +/- 0.59**
Data	**2.64 +/- 0.05**

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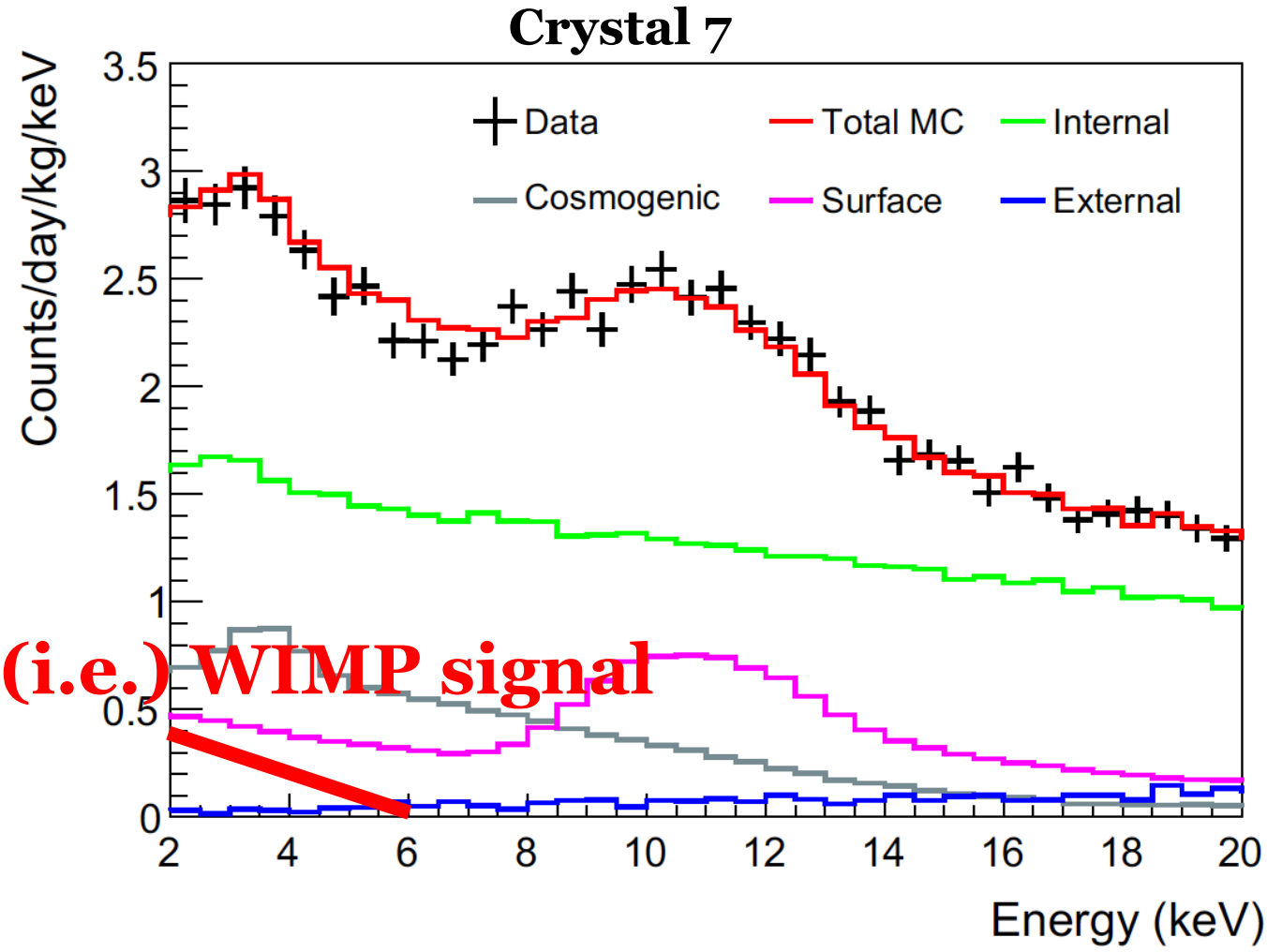
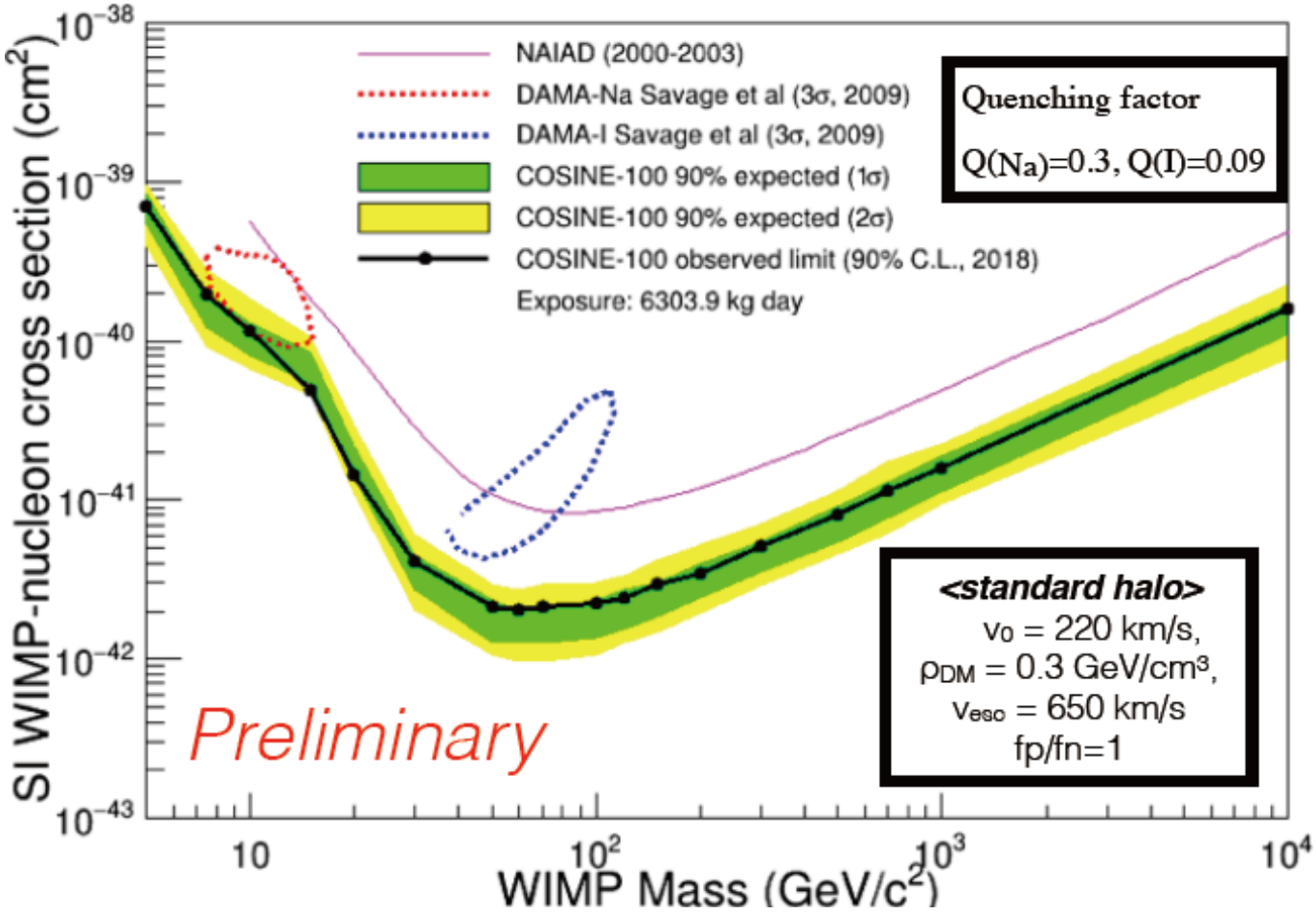
Fit with WIMP signals



Background modeling was done only using 6- 2000keV events

Observed Limits



COSINE-100 excludes DAMA/LIBRA-phase1's interpretation with the spin-independent WIMP interaction in the Standard Halo Model

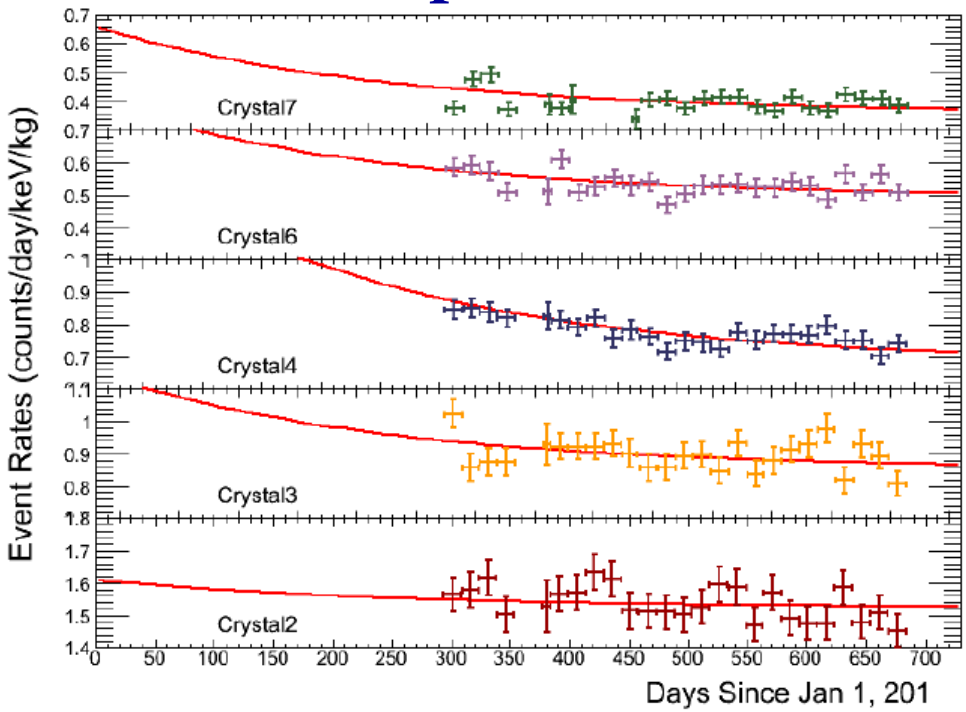
First time with same NaI(Tl) target

Consistent with other null experiments

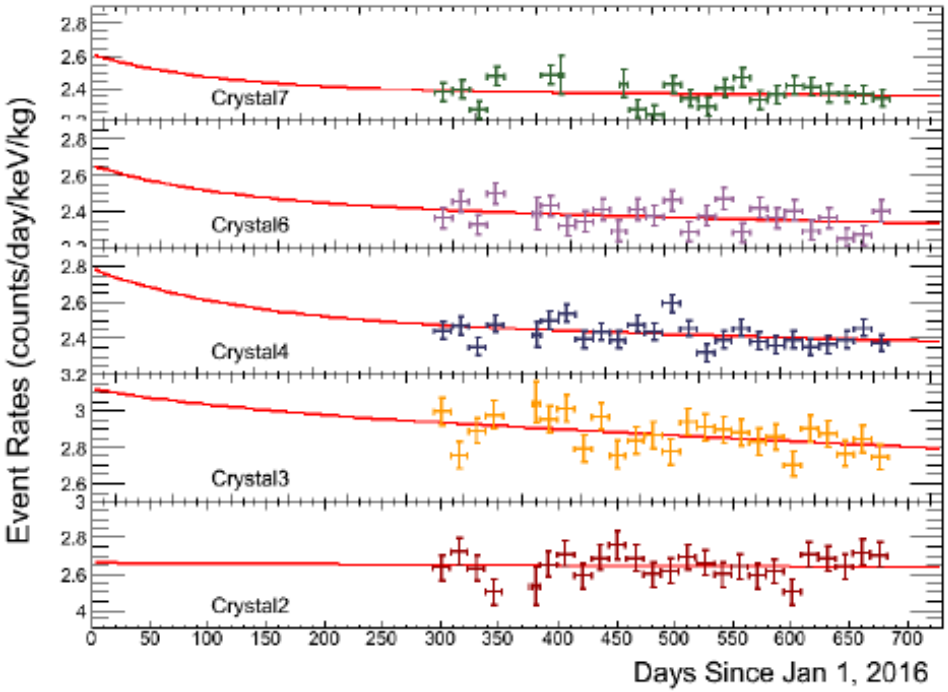
Annual Modulation

- Cosmogenic components were constrained by the measurements
- Floating ^{3}H and **internal background**

Multiple 2-6 keV



Single 6-10 keV



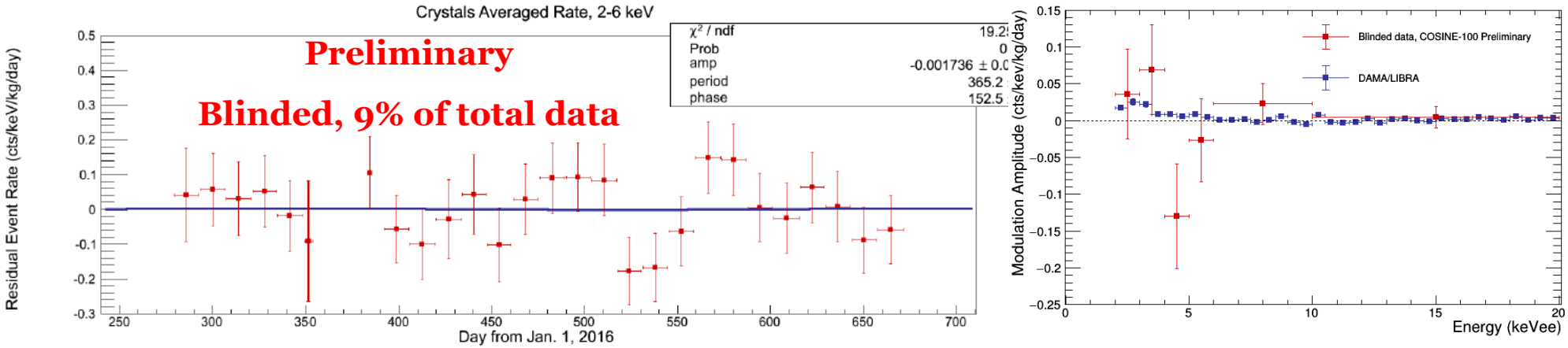
C5 & C8 were excluded due to low light output

C1 was excluded due to uncontrolled PMT induced noise

- Side bands are well explained by known background

~ 9% data opened

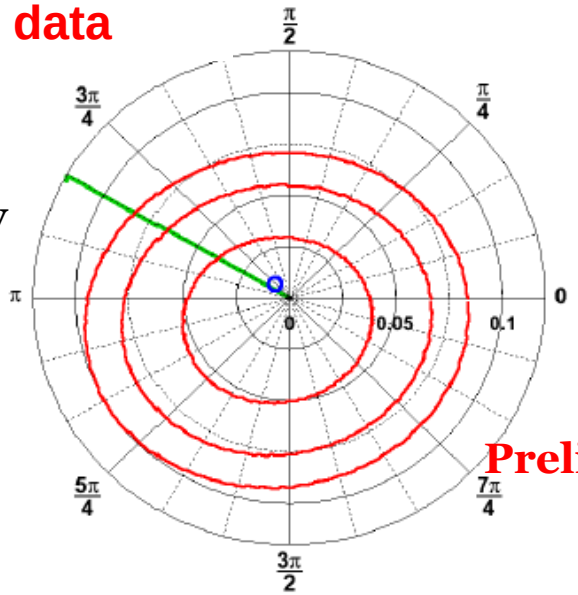
- Current data is blinded



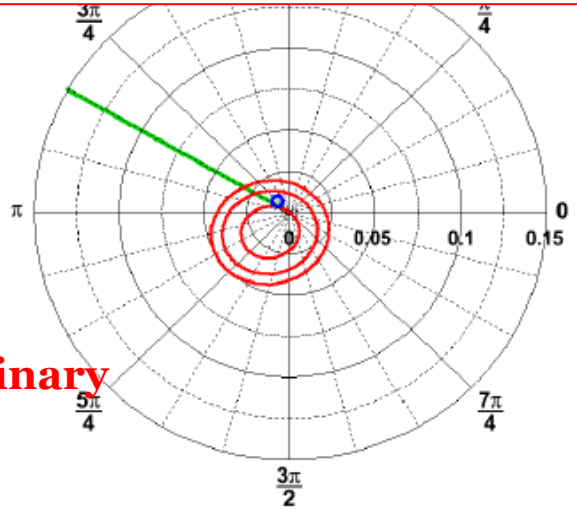
Data quality, cosmogenic component subtraction, and background modeling almost done

9% data

Under evaluating systematic uncertainty

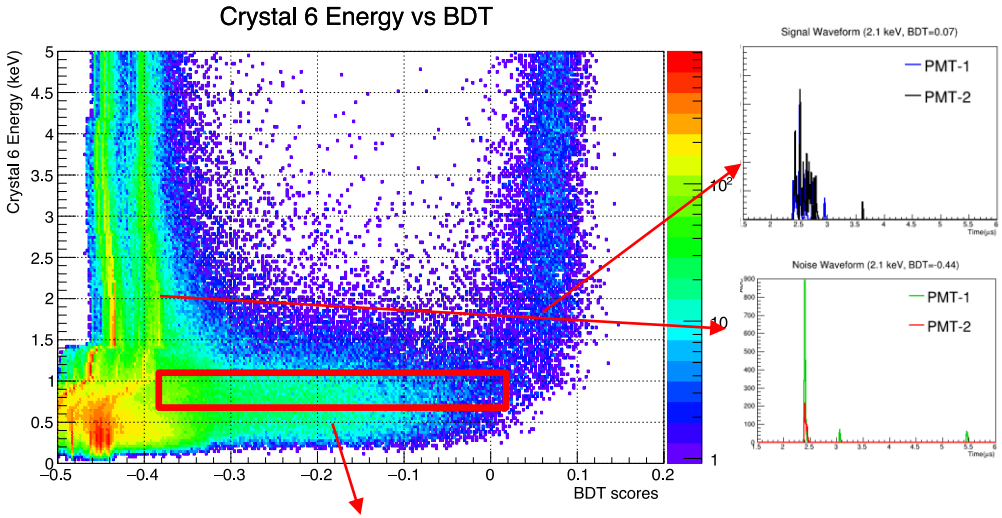


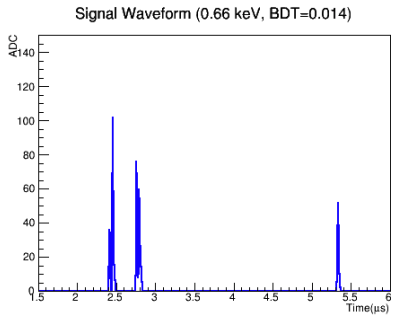
Assuming total SET2 (22 month) data (error reduction only)

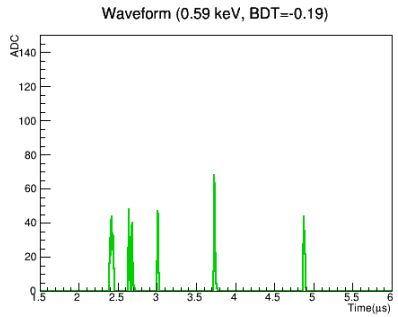


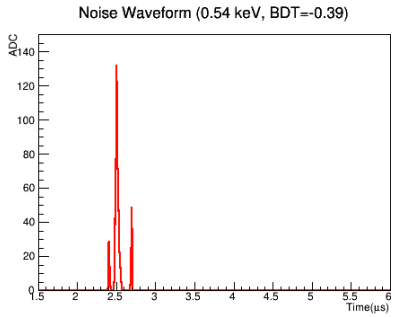
Preliminary

1 keV energy threshold





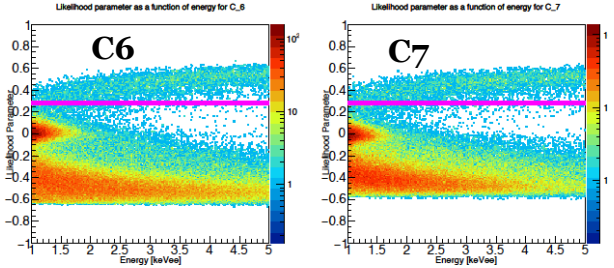




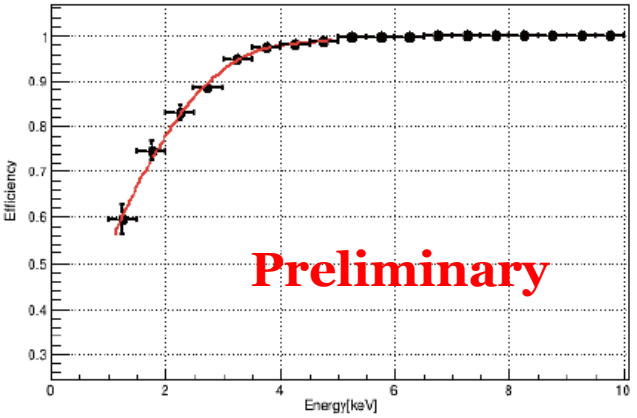
Understand signal-like events and noise-like events at low energy

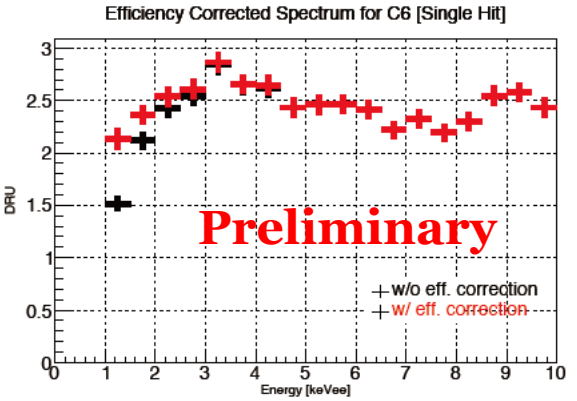
Develop new parameter to reject noise-like events effectively

Likelihood parameters for noise rejection



Efficiency

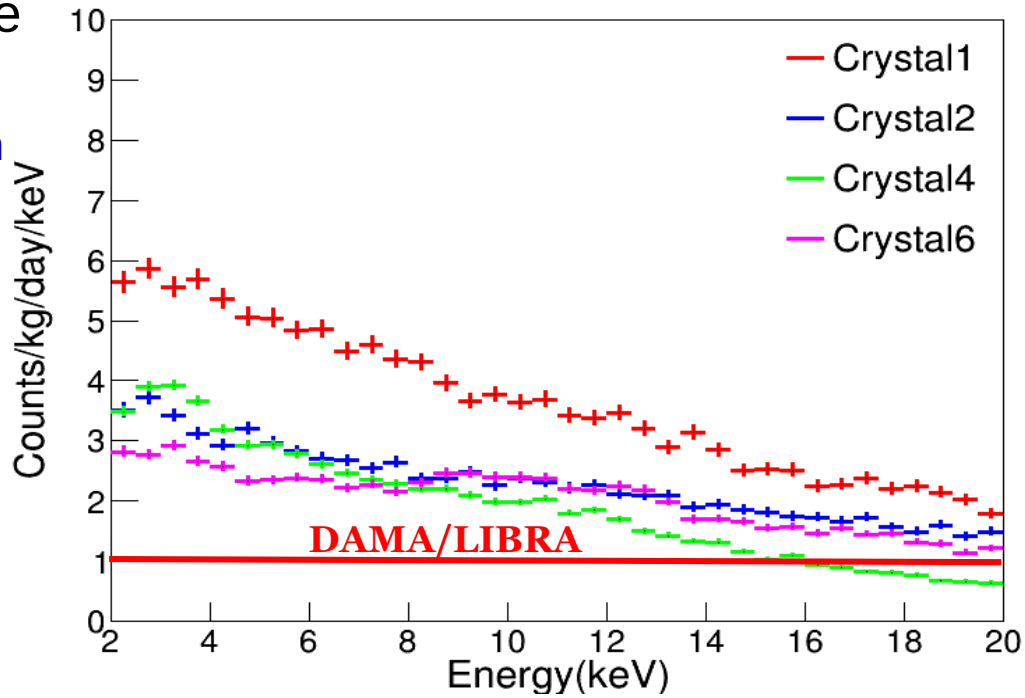




Crystal R&D

- **Background** levels of COSINE-100 are **2-3 times higher** than DAMA/LIBRA
  - We may not resolve all possible scenarios in interpreting DAMA/LIBRA signals
  - Still need to develop better crystals

- Issues are internal ^{40}K, ^{210}Pb, and ^{3}H
  - ^{40}K : Powder purification
  - ^{210}Pb : Any part of powder, crystal growing, and crystal handling can make it
  - ^{3}H : Cosmogenic activation



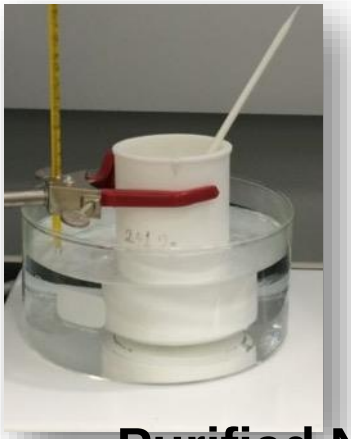
- **Extremely pure crystal** development
  - From initial materials to detector assembly, we need **very careful handling**
  - These are very **difficult jobs** for a private **company**
  - We decided to do our own development for the entire process

Cosmogenic activation will be naturally reduced if we grow the crystals in Korea

NaI powder purification

- Recrystallization

Saturated NaI solution @ 25 ° C



T↑ 110 ° C

Evaporation of 40 % of H_2O under vacuum

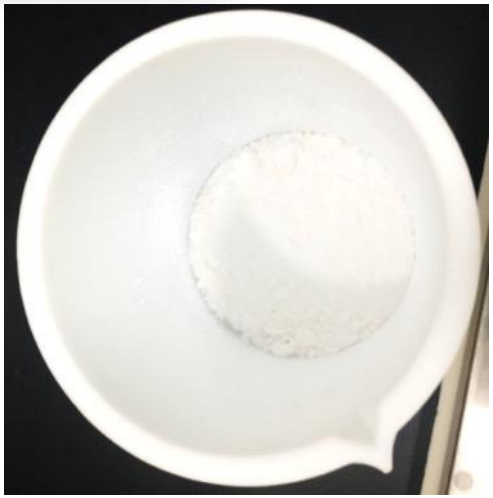
T↓ 25 ° C

Crystallization: Cooling down with stirring

NaI crystal

Drying crystal under vacuum @ 130 ° C

Purified NaI powder



NaI powder purification

- Recrystallization three times for normal grade while one time for the other pure grade powders

ICP-MS results

Powder	^{39}K (ppb)		^{208}Pb (ppb)		^{232}Th (ppb)		^{238}U (ppb)	
	initial	After	Initial	After	Initial	After	Initial	After
Astro grade	5	< 1	0.9	<0.4	<0.1	<0.1	<0.1	<0.1
Crystal grade	45	6	3.3	0.8	<0.1	<0.1	<0.1	<0.1
Normal grade	240,000	210	6.9	0.2	<0.1	<0.1	<0.1	<0.1

- **Efficiency: 40% – 50%**
- **Mother solution can be reused for next recrystallization.**

Reduction for K and Pb after one recrystallization

- K : factor of 10 reduction
- Pb: factor of 3 reduction

K.A. Shin et al., J. Rad. Nucl. Chem. 317, 1329 (2018)

Goal : K less than 20 ppb

Purification factory

70 kg NaI powder can be loaded

Feed tank

Mixing tank

Filter unit

Receiver tank 1, 2

Conical dryer

Goal : K less than 20 ppb

~ 30 kg of purified NaI powder

	K (ppb)	Pb (ppb)	U (ppb)	Th (ppb)
Initial NaI	248	19.0	<0.01	<0.01
Purified NaI	<16	0.4	<0.01	<0.01

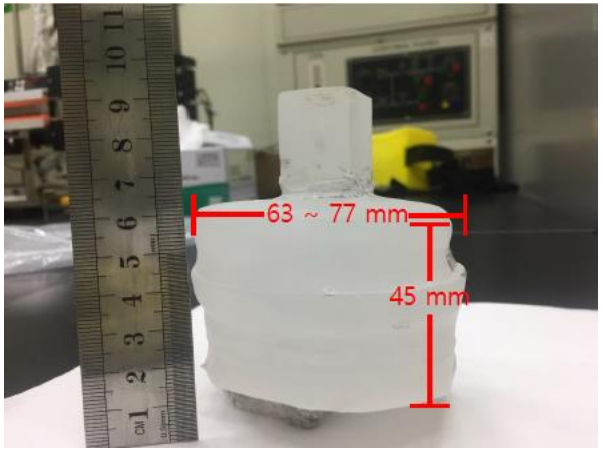
This system is more effective than small experiment

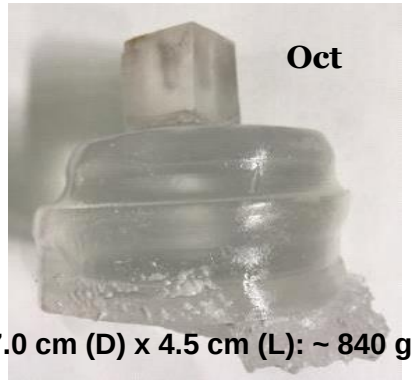
Crystal growing

- Small crystal grower was installed in 2017

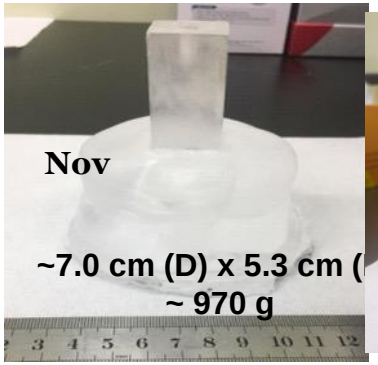
Crucible diameter is $\phi = 15$ cm; **1~2 kg** test crystal can be grown

Sept/2017 **Pure NaI**

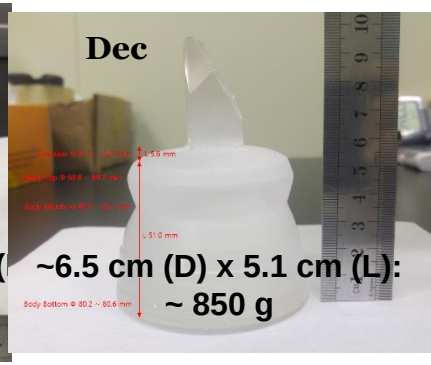




~ 7.0 cm (D) x 4.5 cm (L): ~ 840 g



~7.0 cm (D) x 5.3 cm (
~ 970 g



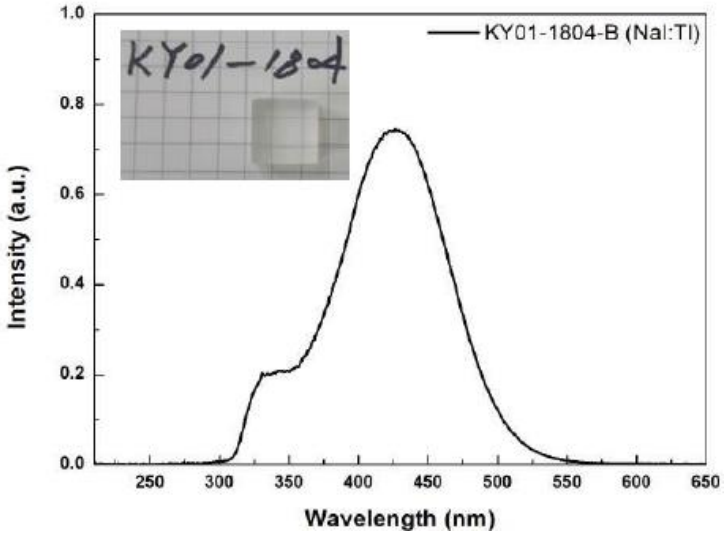
~6.5 cm (D) x 5.1 cm (L):
~ 850 g

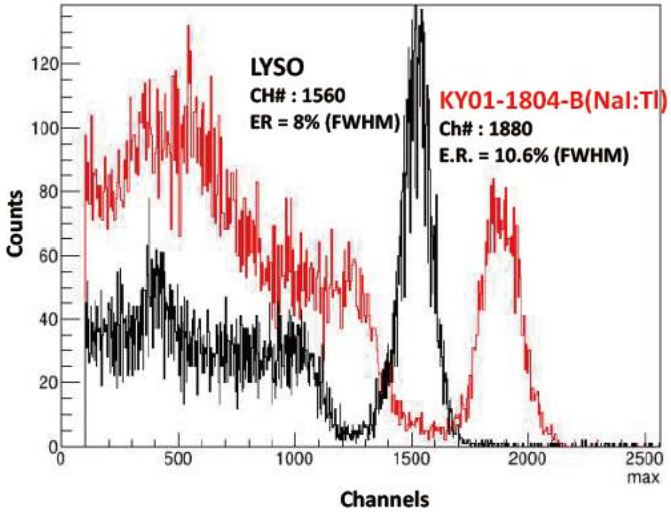
NaI(Tl) detector

Center for Underground Physics

Feb/2018

Crystal grade

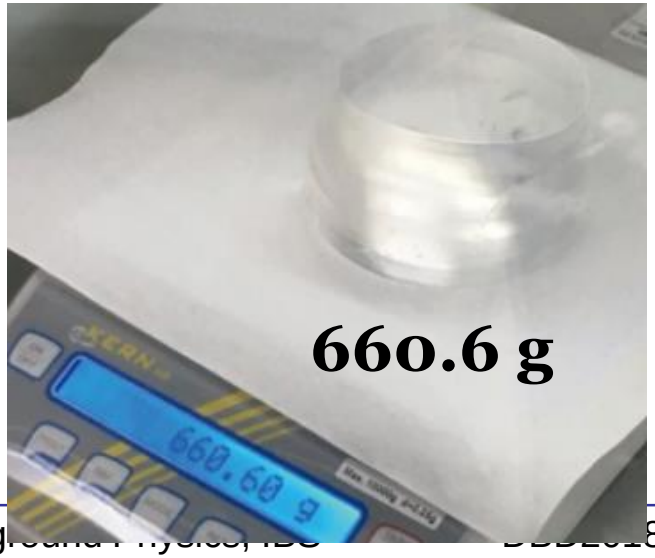


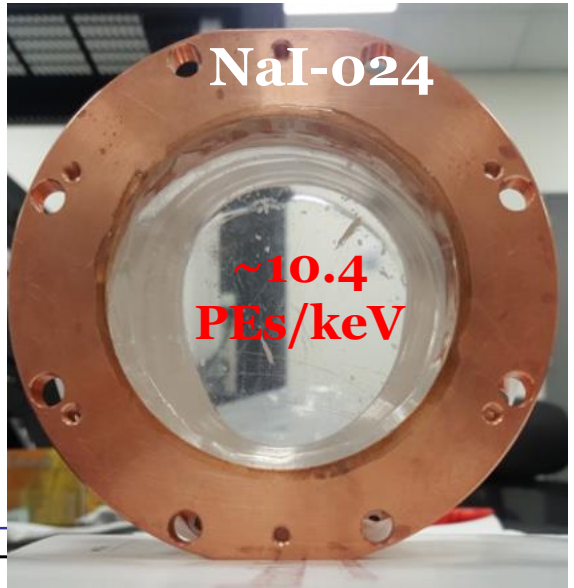


~40,000 Photons/MeV

May/2018

Astro grade





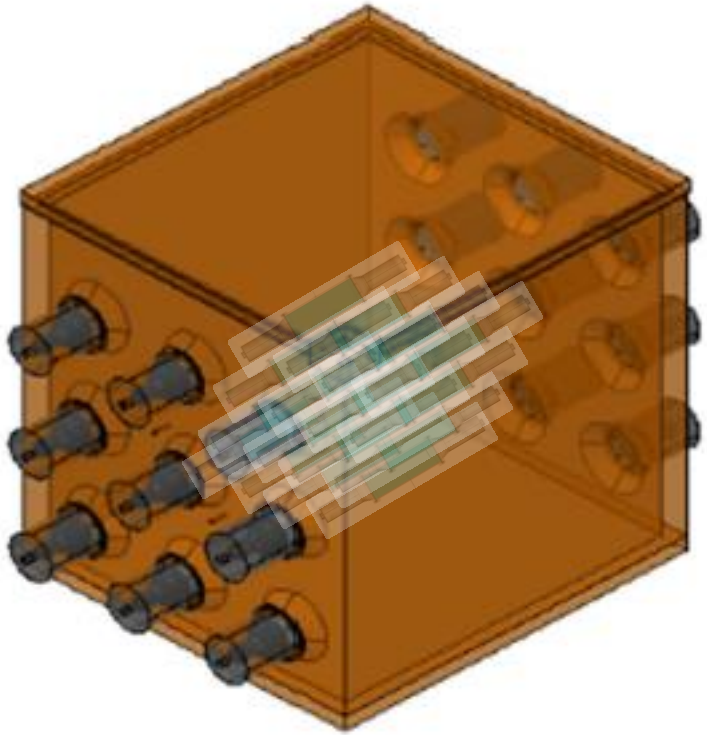
A full size grower

- Full size grower & annealing furnace were installed ($\phi = 60$ cm)
  - ❖ Similar growing machine for the DAMA/LIBRA crystals
  - ❖ Maximum powder loading :120 kg
    - ❑ About three full size detectors (12.5 kg) per ingot

- Tests on temperature control & mechanical operation were done
- Real experiments will be started soon

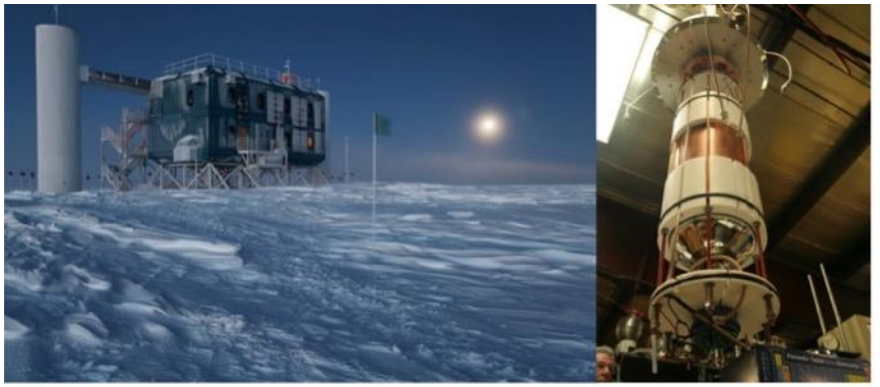
- Current COSINE-100 shield designed to accommodate 16 12.5 kg crystals = 200 kg

Total 200 kg



Y2L

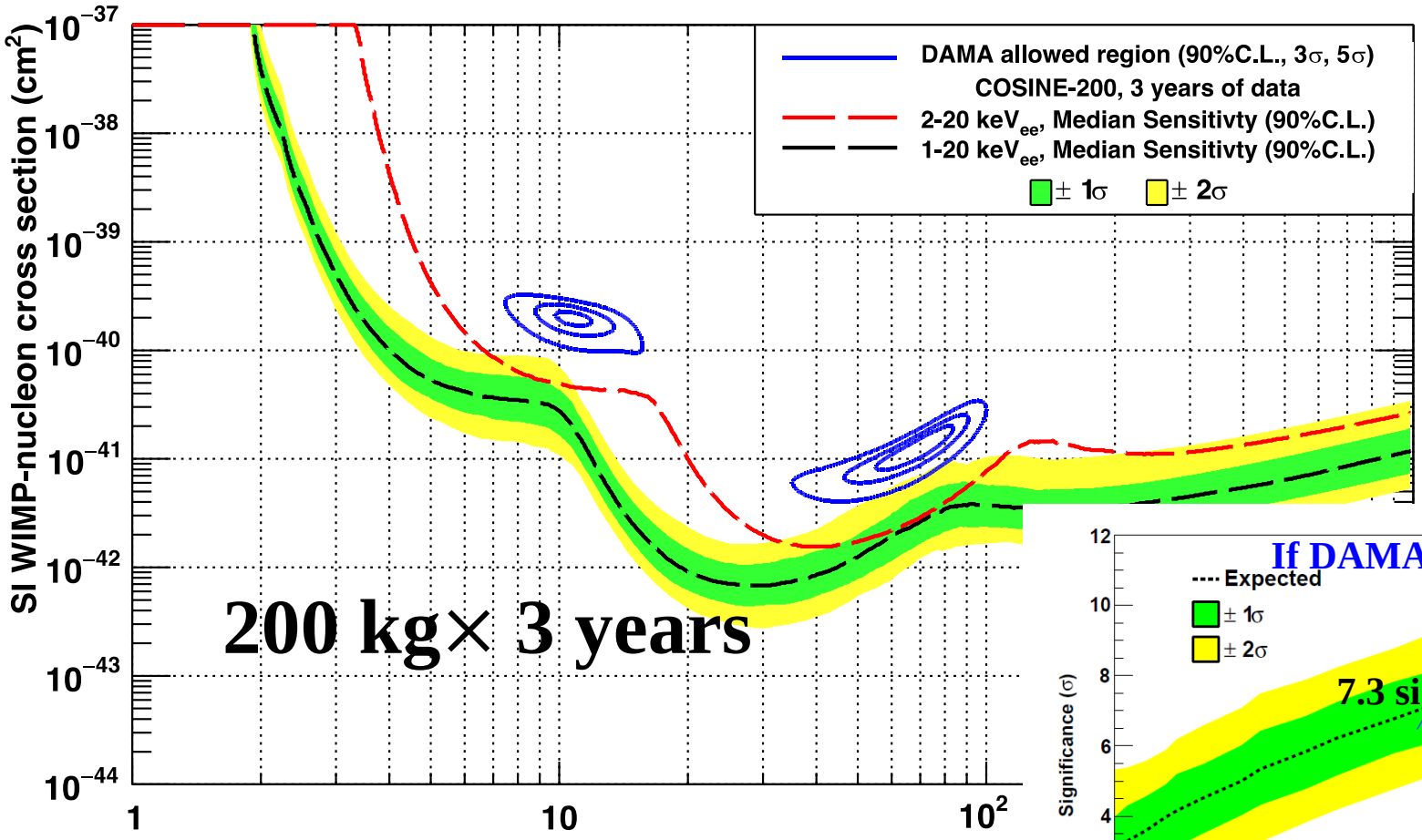
Another 200 kg in south pole ? If we have the same modulation..

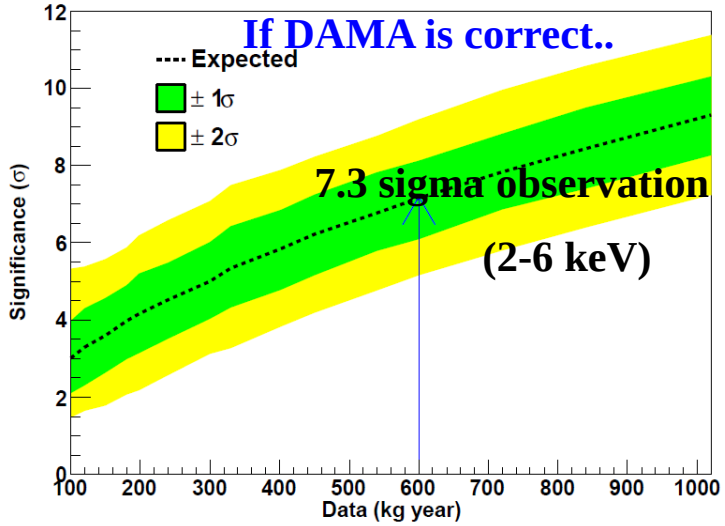


2022-2023 IceCube upgrade is under consideration

COSINE-200 sensitivity (Modulation)

- 1 dru background (same as DAMA/LIBRA)





Model independent comparison of the modulation amplitude at 2-6 keV will be performed

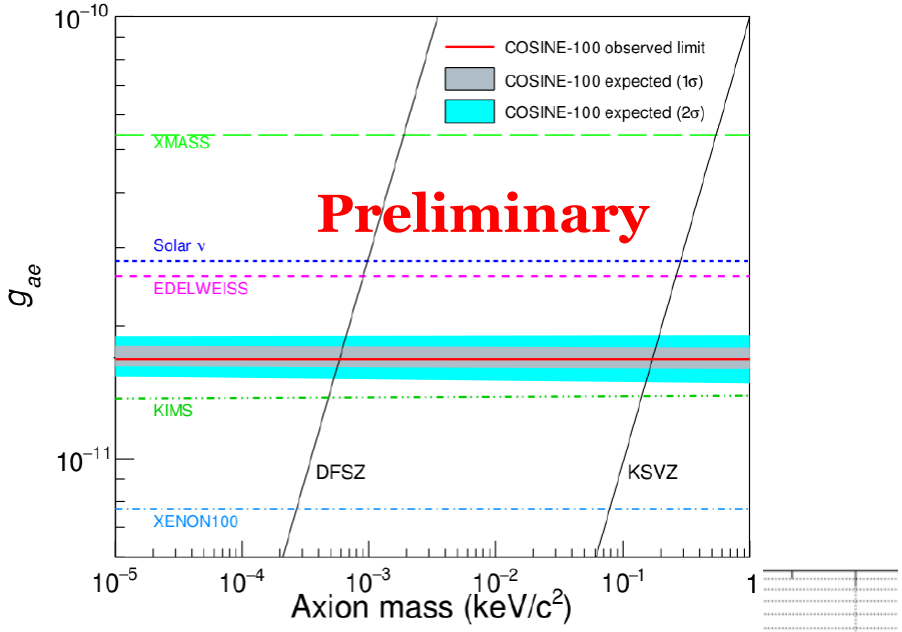
Summary

- COSINE-100 detector was installed at Y2L and has been running smoothly for about two years
- COSINE-100 detector is well understood
  - ~ 2.7 counts/day/kg/keV with 2 keV threshold for best crystal
- COSINE-100 confirms that DAMA's modulation signal cannot be from standard WIMP in SHM using same NaI(Tl) target for the first time
- Modulation analysis of COSINE-100 is ongoing
- Preparing 1keV threshold analysis

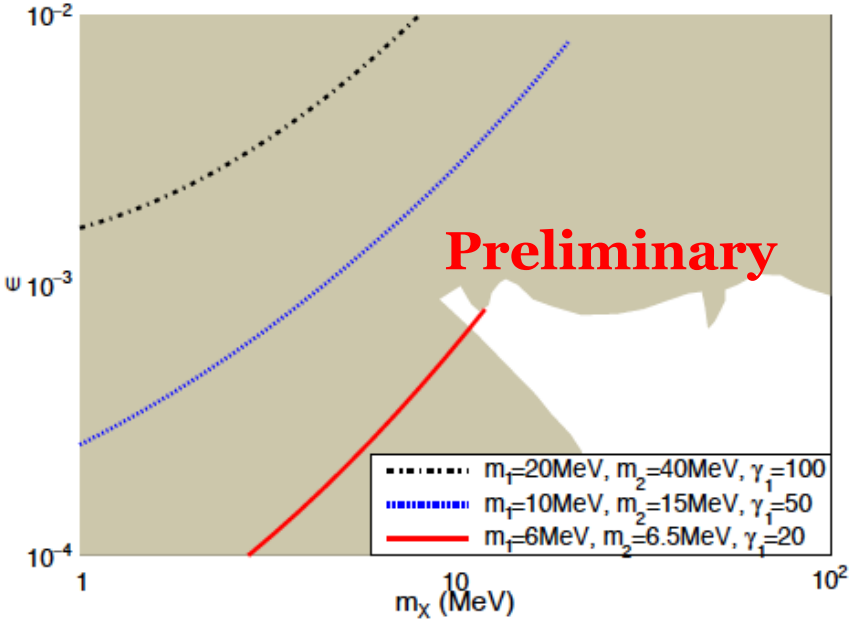
- COSINE-200 is under preparation
  - Unambiguous conclusion for the DAMA/LIBRA signals
  - Goal to start ~200 kg experiment in 2019 with less than 1dru background

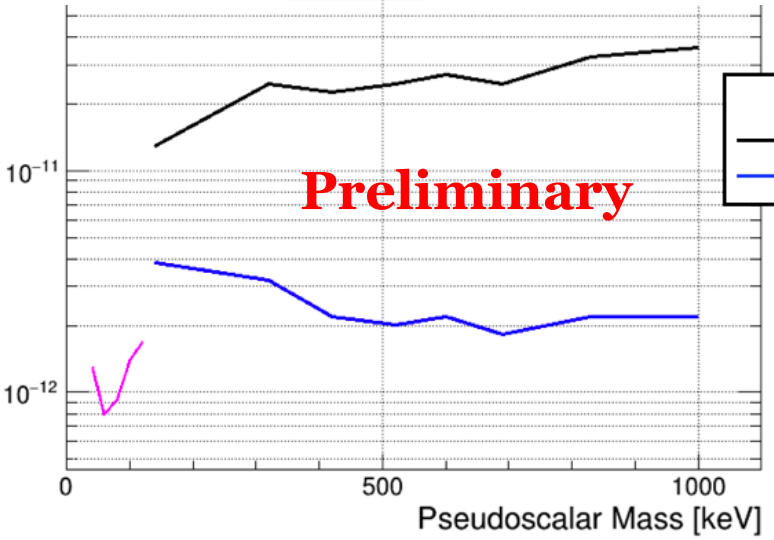
Other physics analysis

Solar Axion Search



Inelastic Boosted Dark Matter





Calculate Compton process