Dark matter search with COSINE-100 experiment

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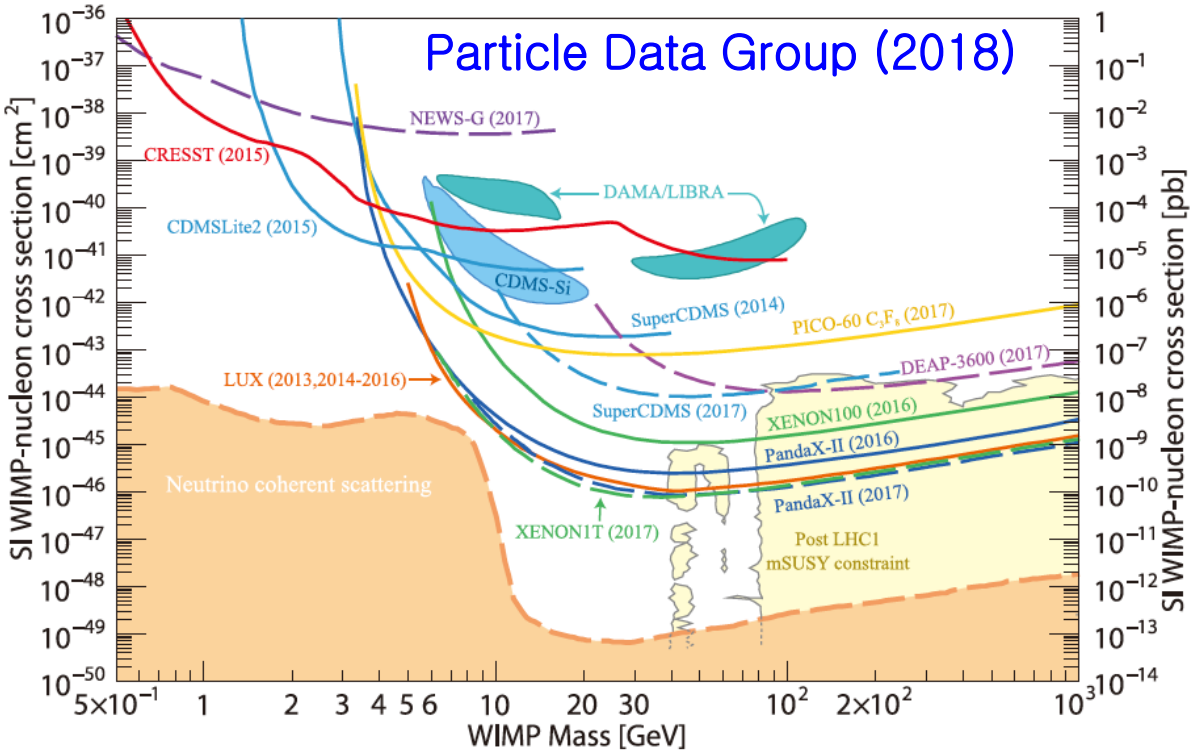
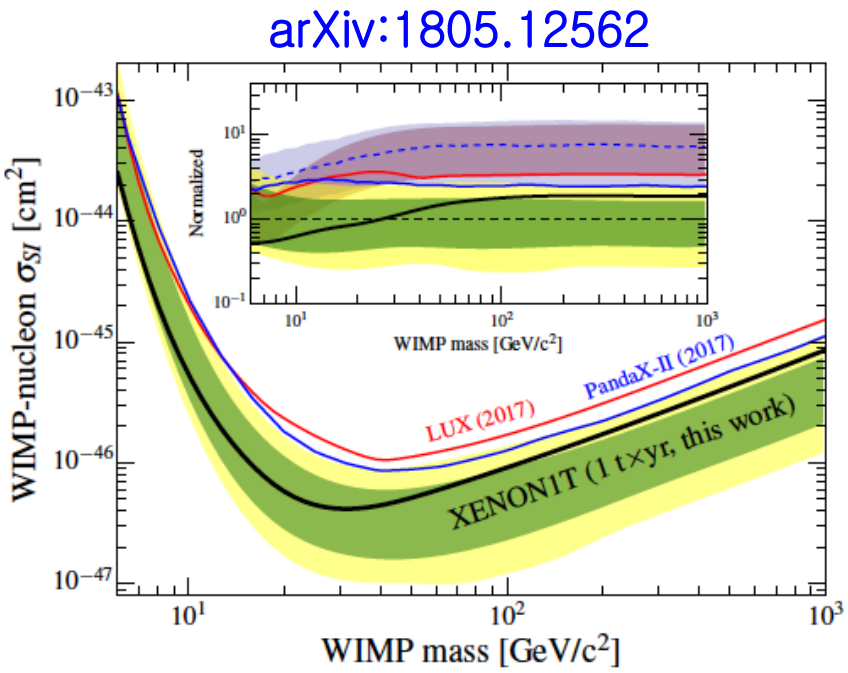
Institute for Basic Science (IBS)

On behalf of the COSINE-100 Collaboration

Current status of direct dark matter searches





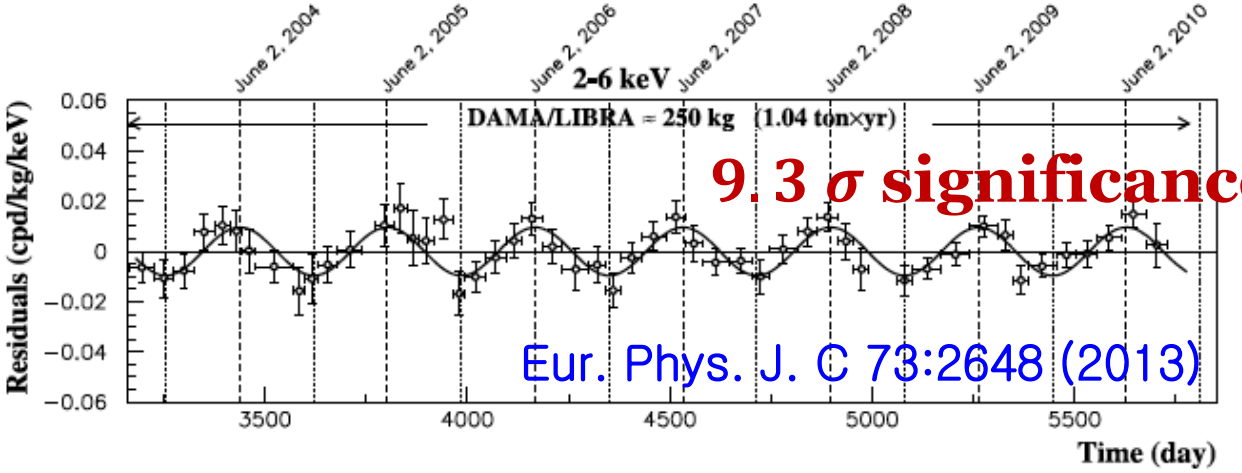
- No sign of WIMP dark matter down to 4×10^{-47}cm^2 @ 30 GeV
- Exploring low-mass dark matter
- Unresolved signal from DAMA

Motivation

DAMA/LIBRA experiment

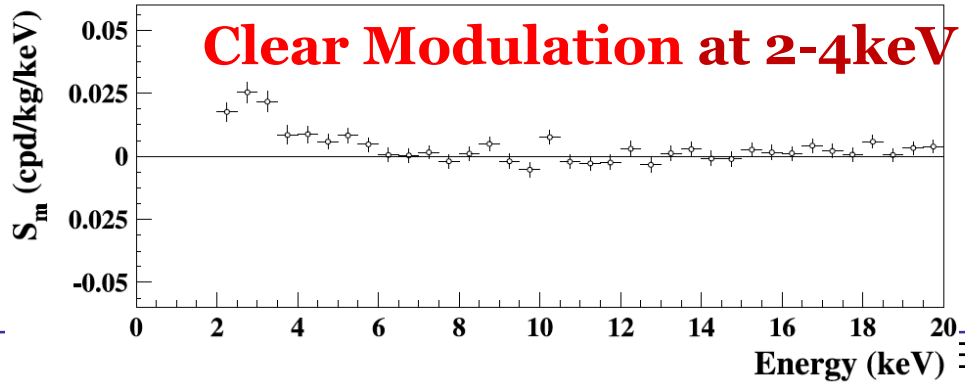
- Annual Modulation Searches with an array of NaI(Tl) crystals

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

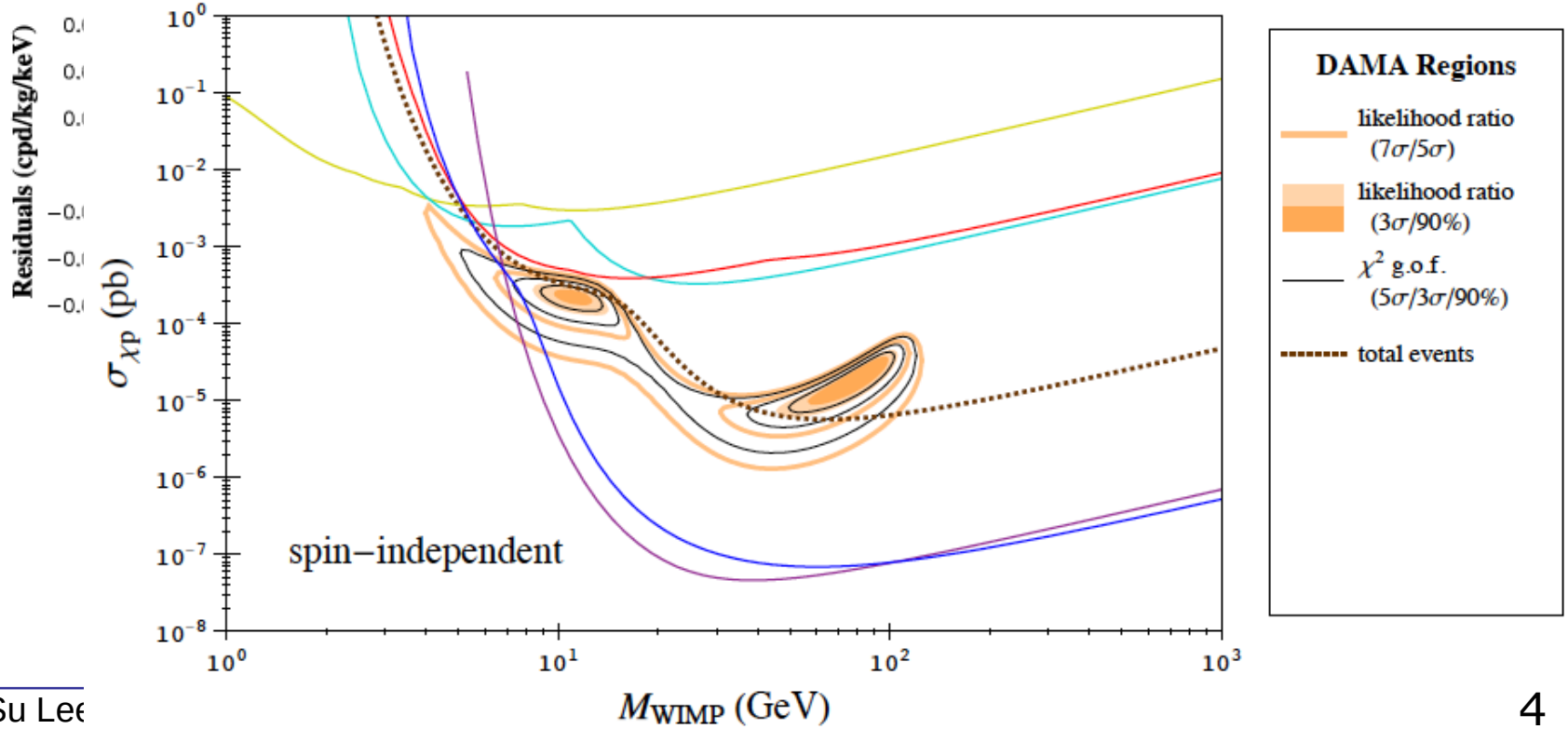
Motivation

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



Motivation

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

Universe 4, 116 (2018)

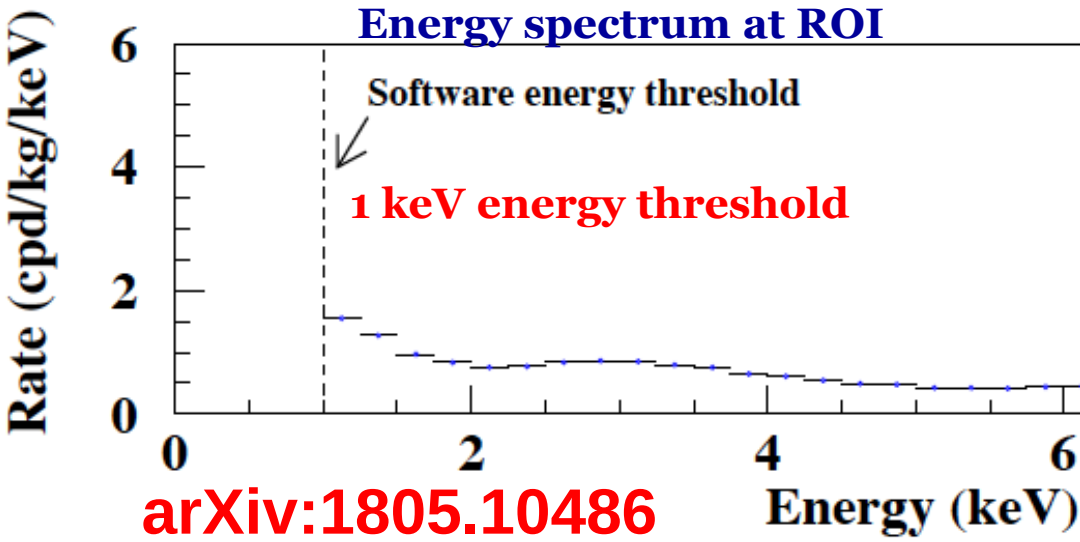
arXiv:1805.10486

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]

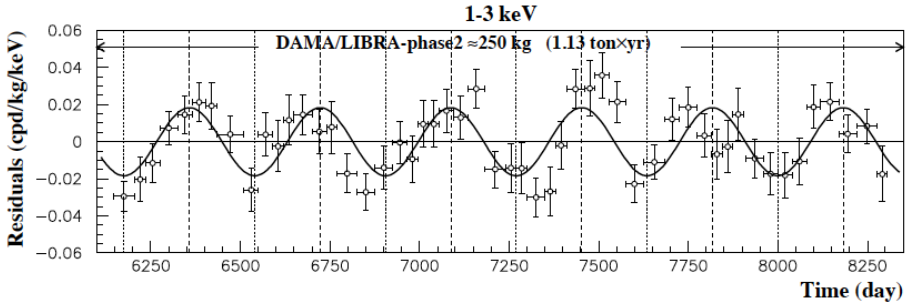
e 1

DAMA/LIBRA phase 2

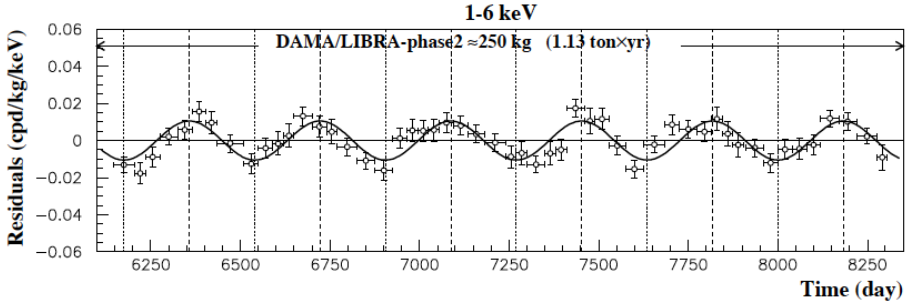
- Energy threshold reached 1keV with better PMTs
- Still there is modulation
- Significance
  - ❖ 1-6 keV : **9.5 σ** (phase 2)
  - ❖ 2-6 keV : **12.9 σ** (phase 1+2)
- Increased modulation amplitude below 2keV

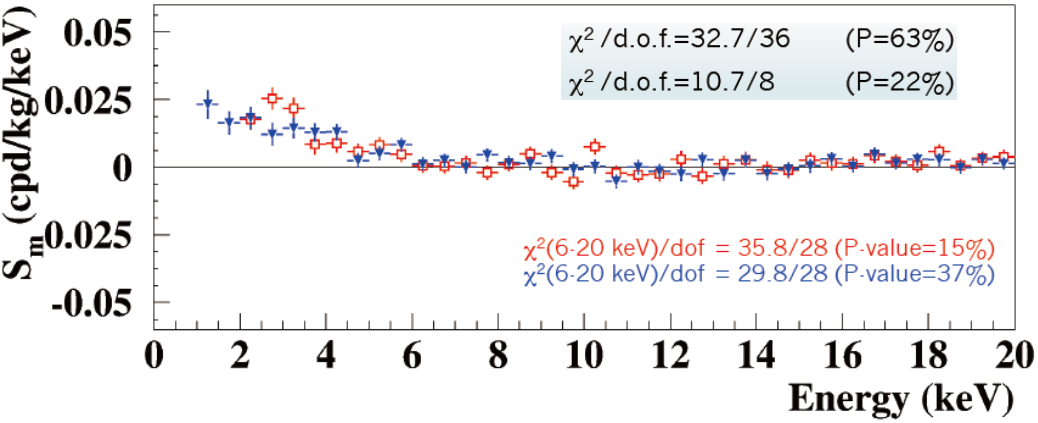


arXiv:1805.10486



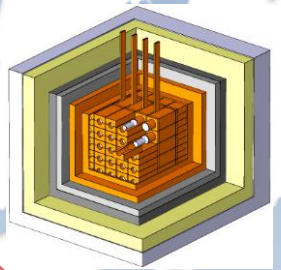
Modulation amplitude





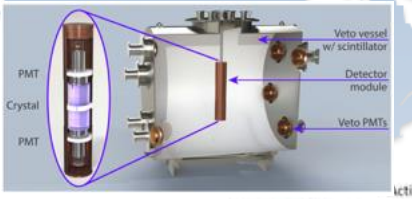
Global NaI(Tl) efforts

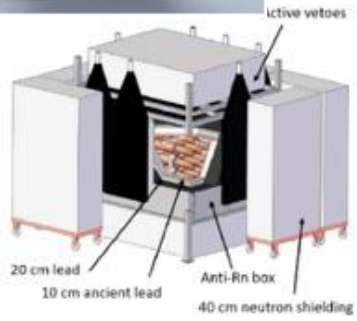
COSINUS
@ LNGS



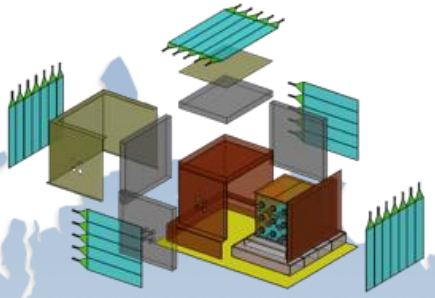
DAMA
@ LNGS

SABRE
@ LNGS



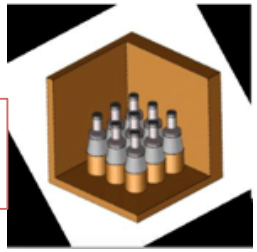


ANAIS
@Canfranc



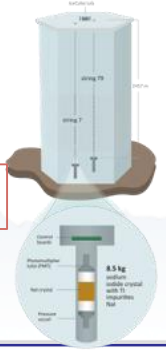
KIMS/COSINE
@ Yangyang

PICO-LON
@ Kamioka



SABRE @
Stawell

DM-Ice @ South Pole



Global NaI(Tl) efforts

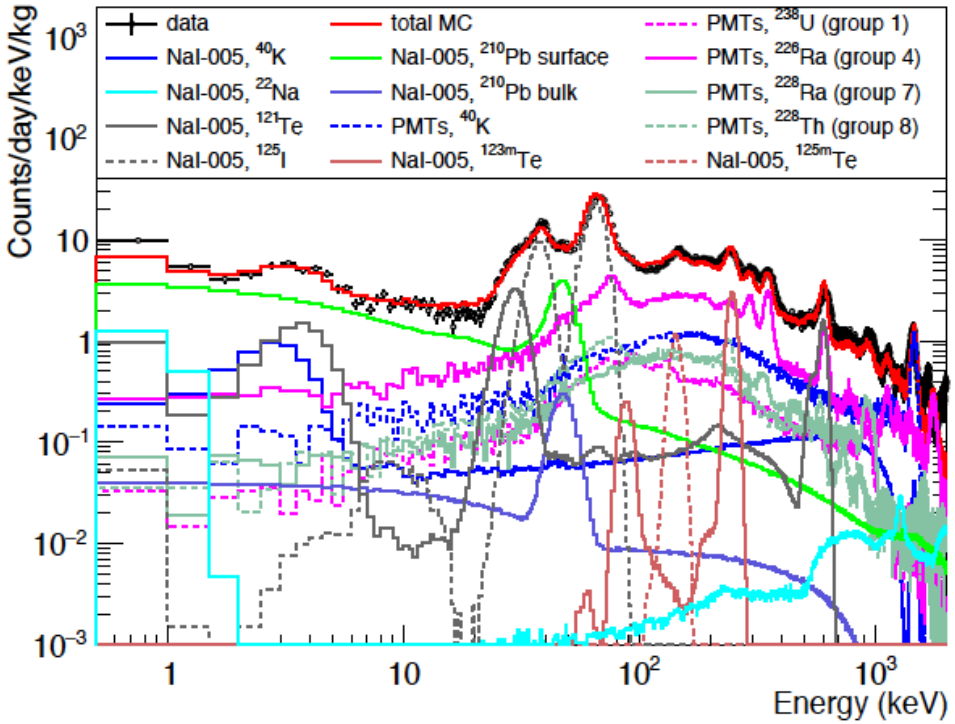
- ANAIS: Taking physics data with 112 kg of NaI(Tl) array since 3rd, August 2017
- COSINE : Taking physics data with 106 kg of NaI(Tl) array since 30th, September 2016
- COSINUS : R&D of cryogenic detector for PID
- KIMS : Various R&D of NaI crystals
- PICO-LON : Careful purification program
- SABRE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

Crystal backgrounds and reduction (KIMS)

K.W. Kim *et al.*, Astropart. Phys. 62, 249 (2015)

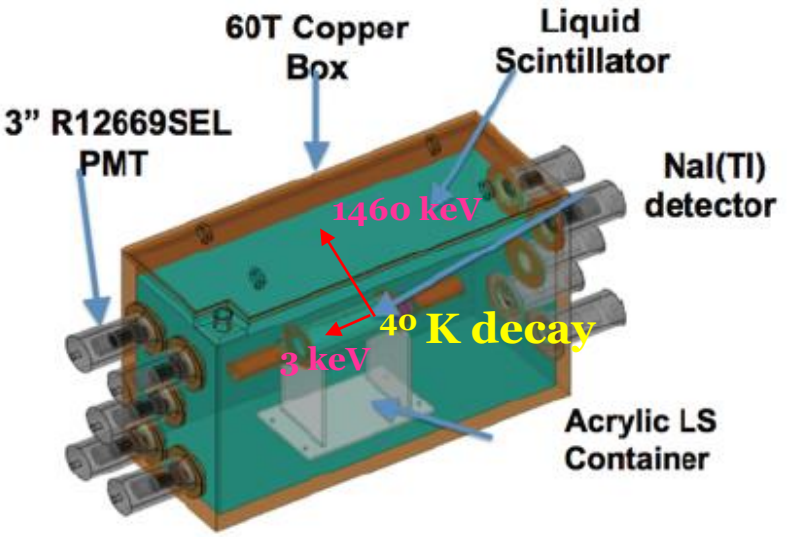
P. Adhikari *et al.*, EPJC 76, 185 (2016)

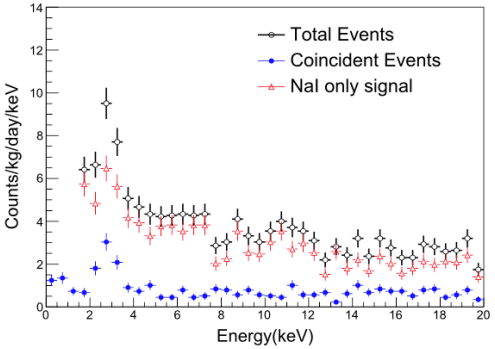
G. Adhikari *et al.*, EPJC 77, 437 (2017)



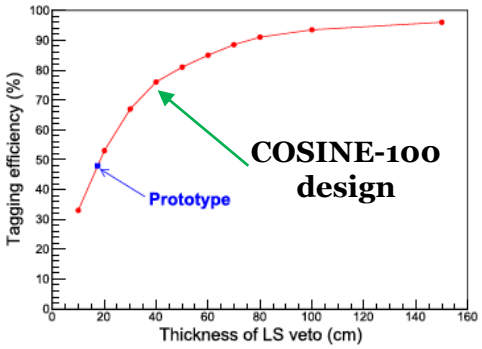
- Internal ^{210}Pb, ^{40}K, and cosmogenics are dominant backgrounds

J.S. Park *et al.*, NIMA, 851 (2017) 103





~50 % ^{40}K tagging

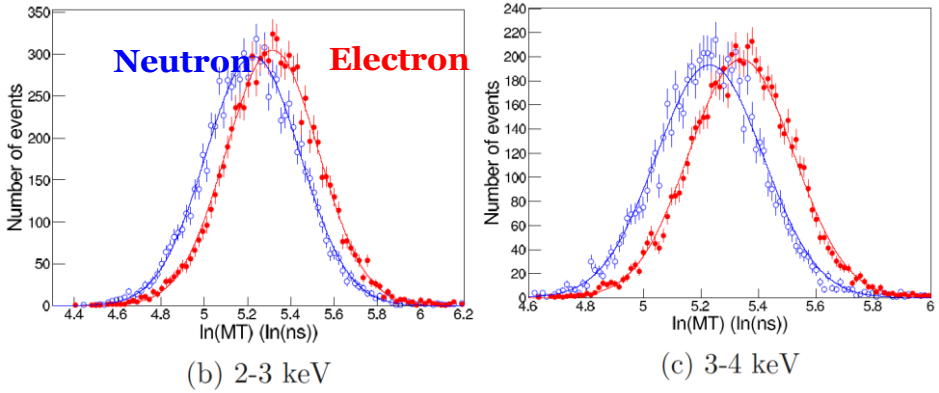


~80% tagging efficiency with 40cm of LS

Pulse shape discrimination of nuclear recoils

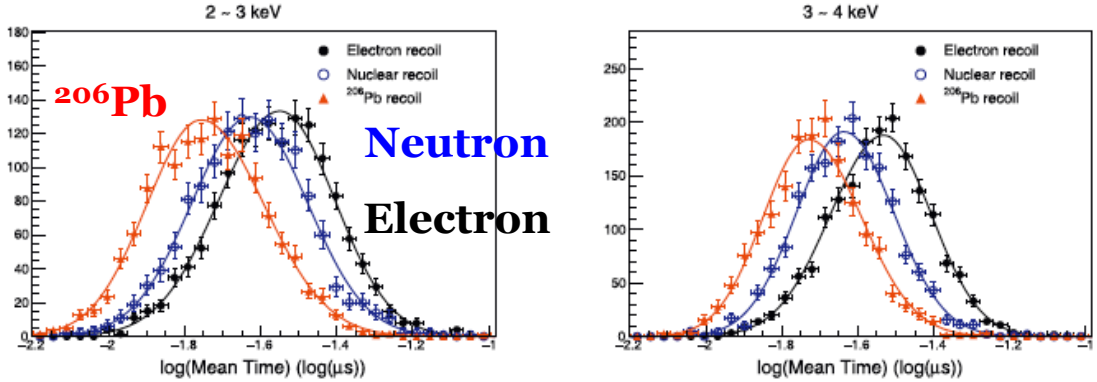
JHEP 08, 093 (2015)

Nuclear recoil discrimination

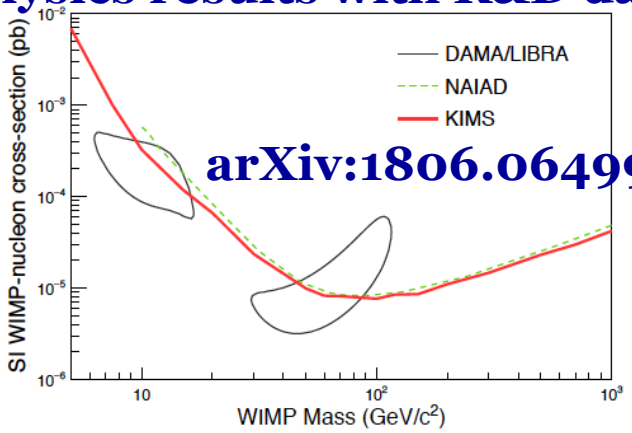


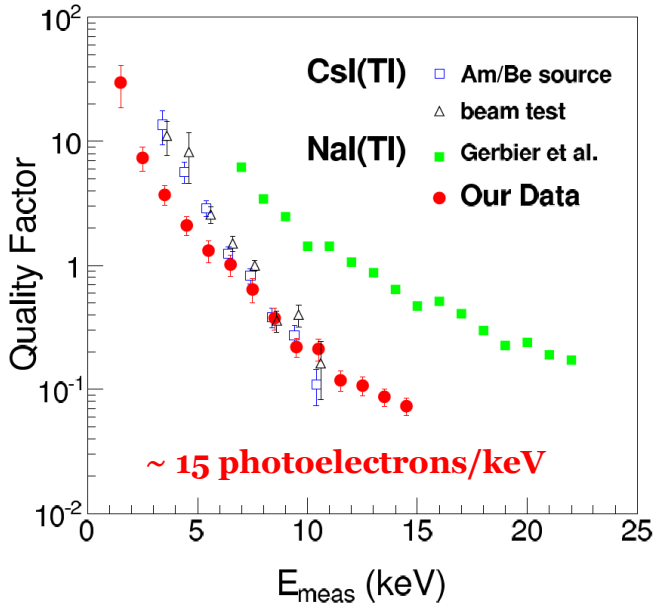
Astropart. Phys. 102, 51 (2018)

Surface alpha recoil discrimination



Physics results with R&D data

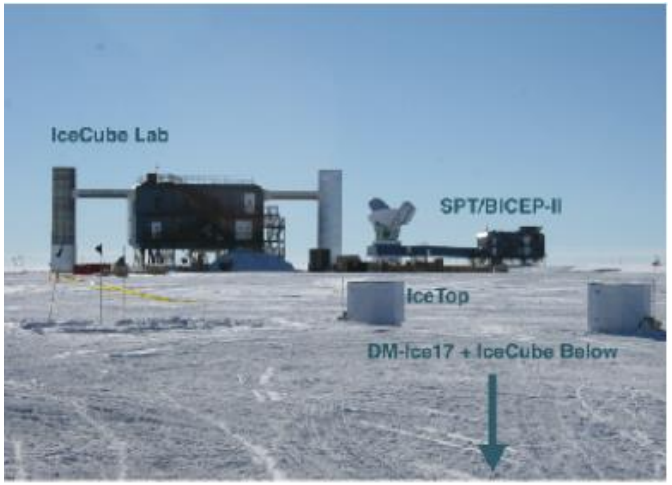




- Demonstrate discrimination of nuclear recoil events
- We can study the annual modulation of the nuclear recoil events

DM-Ice17

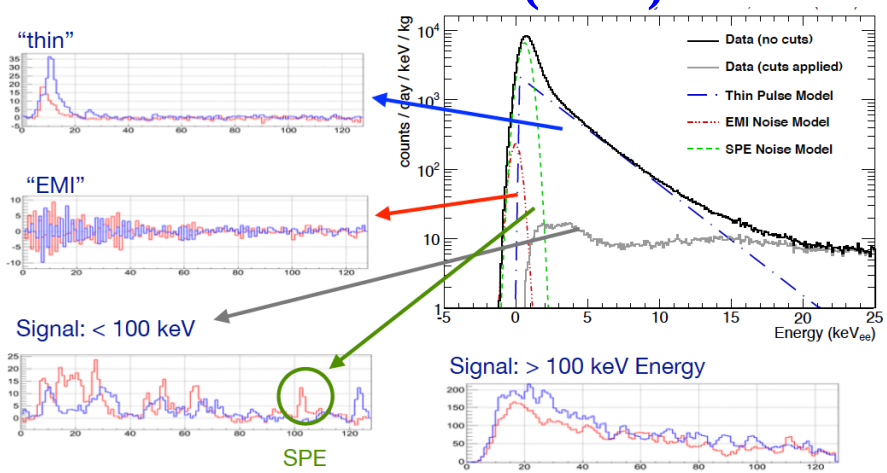
- DM-Ice17 in South pole (Jun.2011 – Jan.2015)



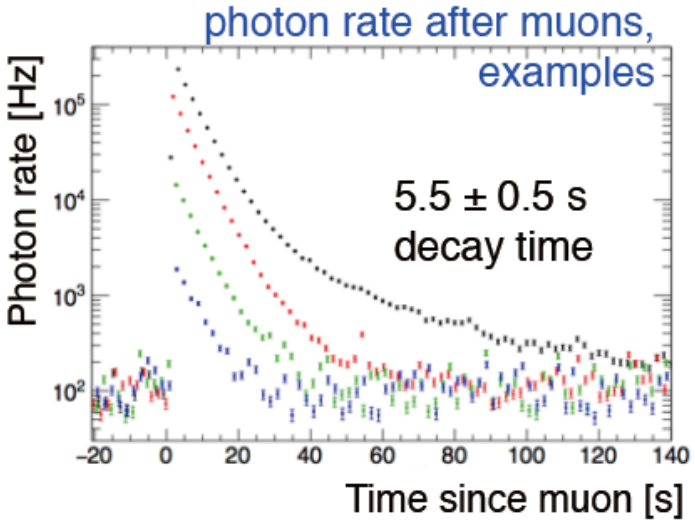
Two 8.47 kg crystal

2200 m.w.e overburden

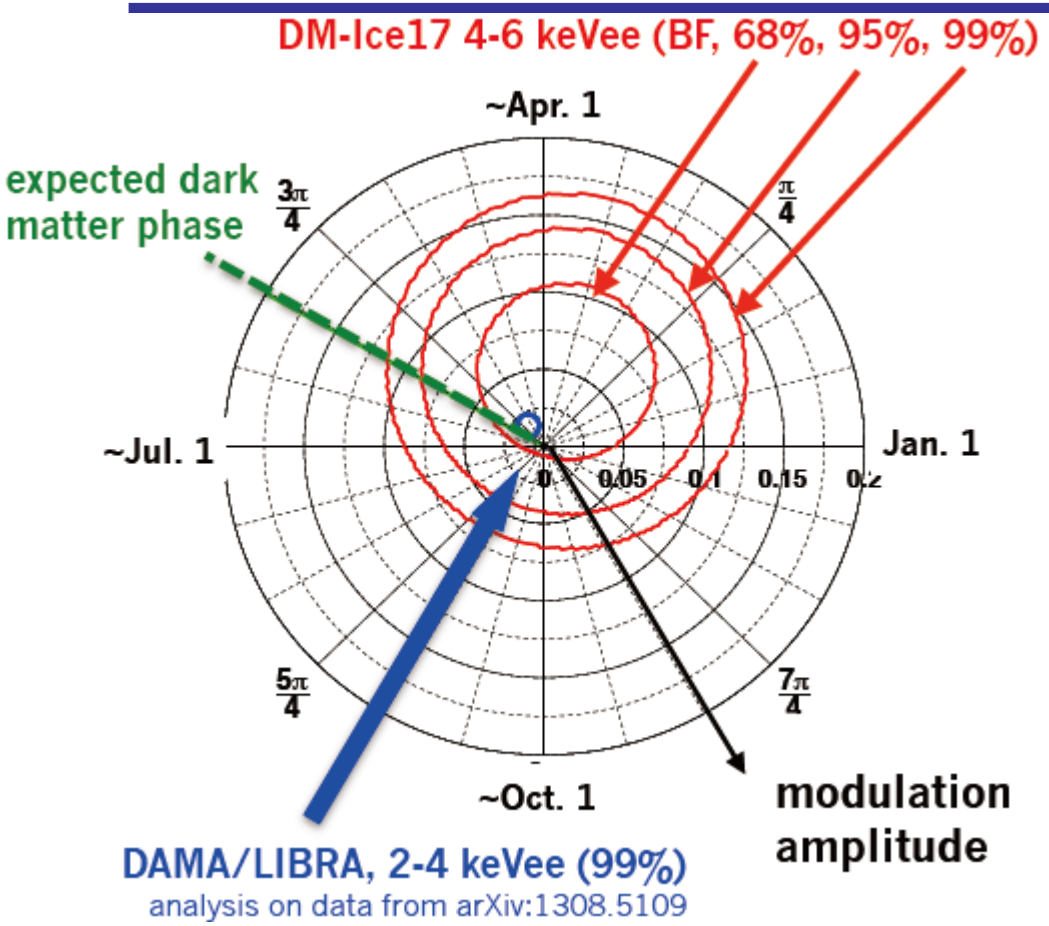
PRD 90 092005 (2014)

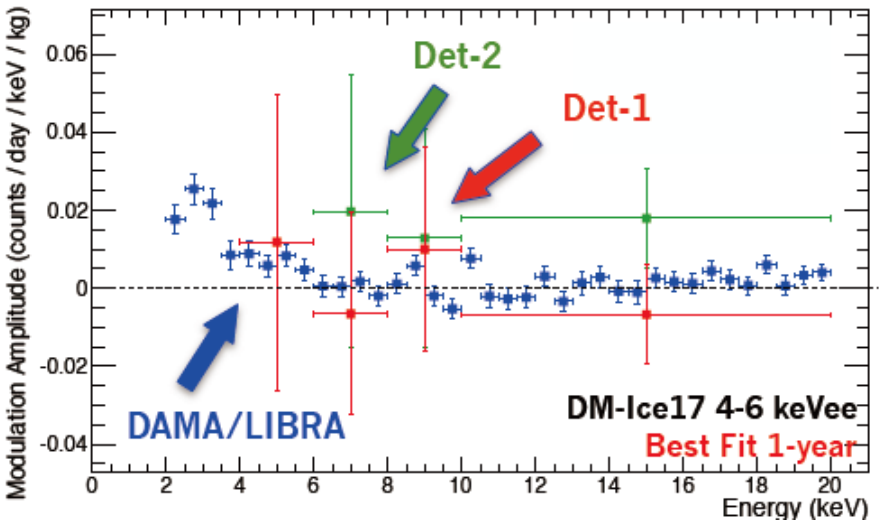


PRD 93 042001 (2016)

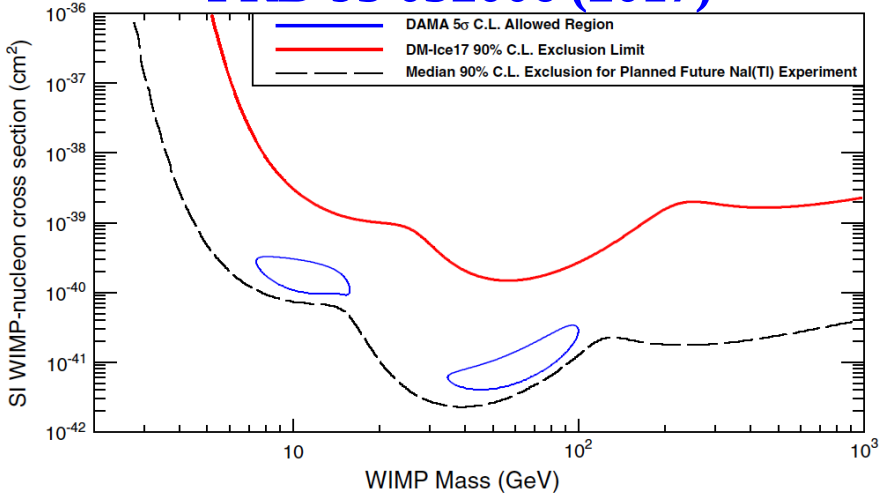


Annual modulation study with DM-Ice17





PRD 95 032006 (2017)



Proof of principle

- Continue to develop low background NaI(Tl) crystals

COSINE project (Since 2015)

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

YangYang(Y2L) Underground Laboratory

(Upper Dam) YangYang Pumped Storage Power Plant

Center for Underground Physics

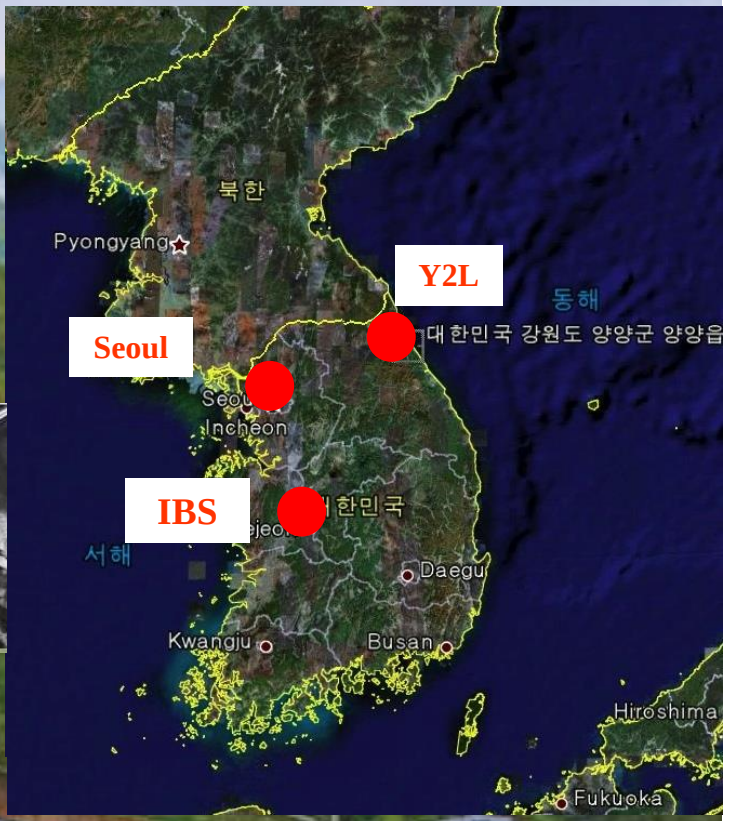
IBS (Institute for Basic Science)

1000m

700m

(Power Plant)

양양양수발전소



(Lower Dam)

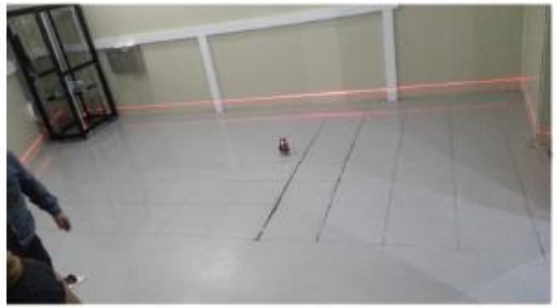
KIMS (Dark Matter Search)

AMoRE (Double Beta Decay Experiment)

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

COSINE-100 construction

Dec. 2015 Jan. 2016 Feb. 2016



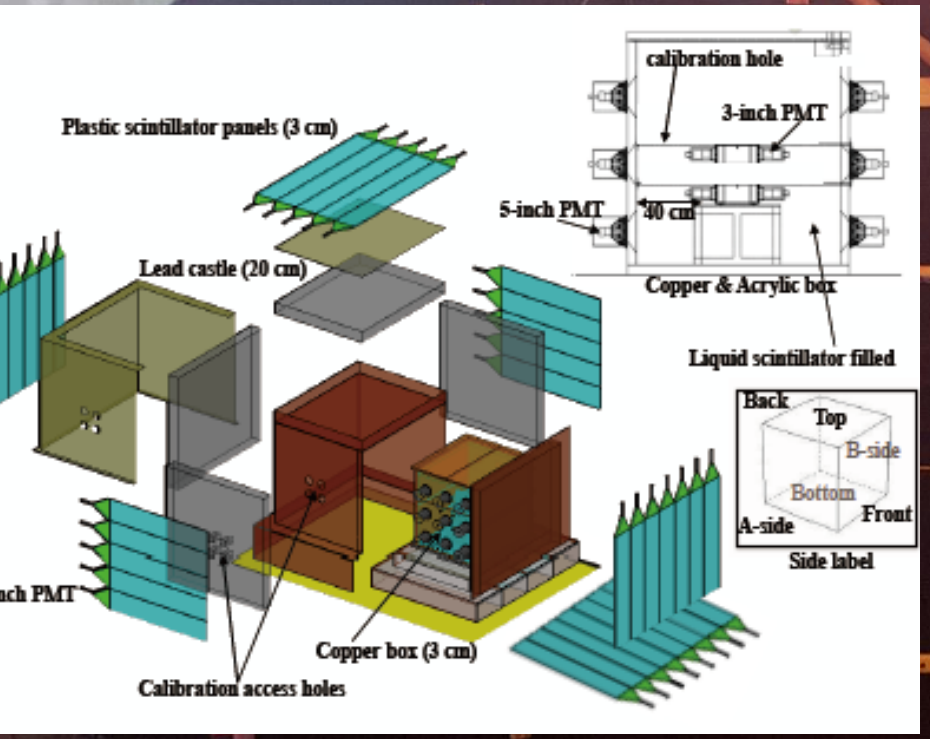

Mar. 2016 Apr. 2016




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

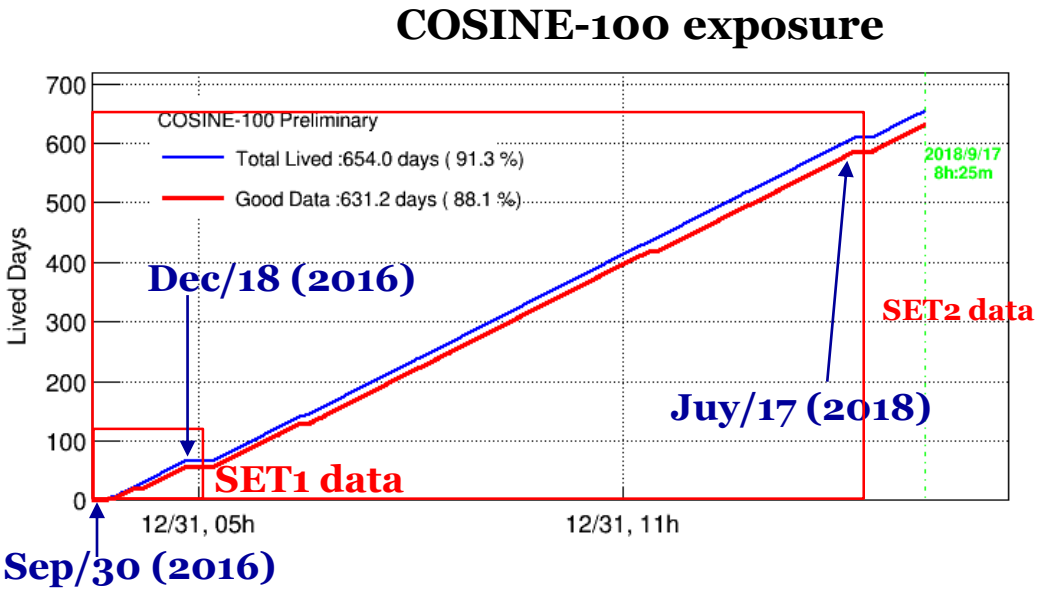
JINST 13 (2018) T06005

Physics run since Sept/2016

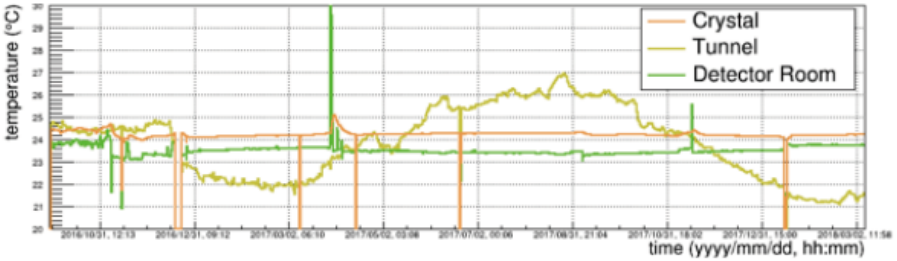
Oct/2/2018

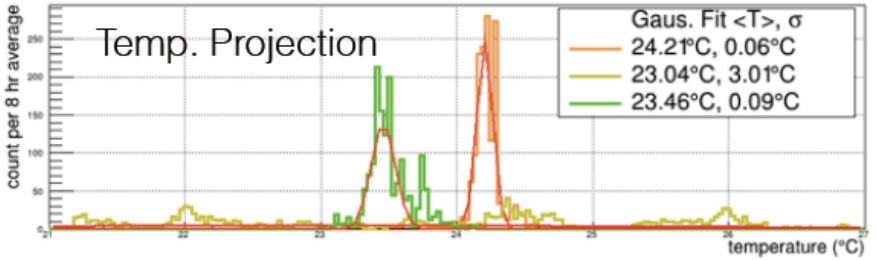
Italian colleagues with COSINE-100 detector

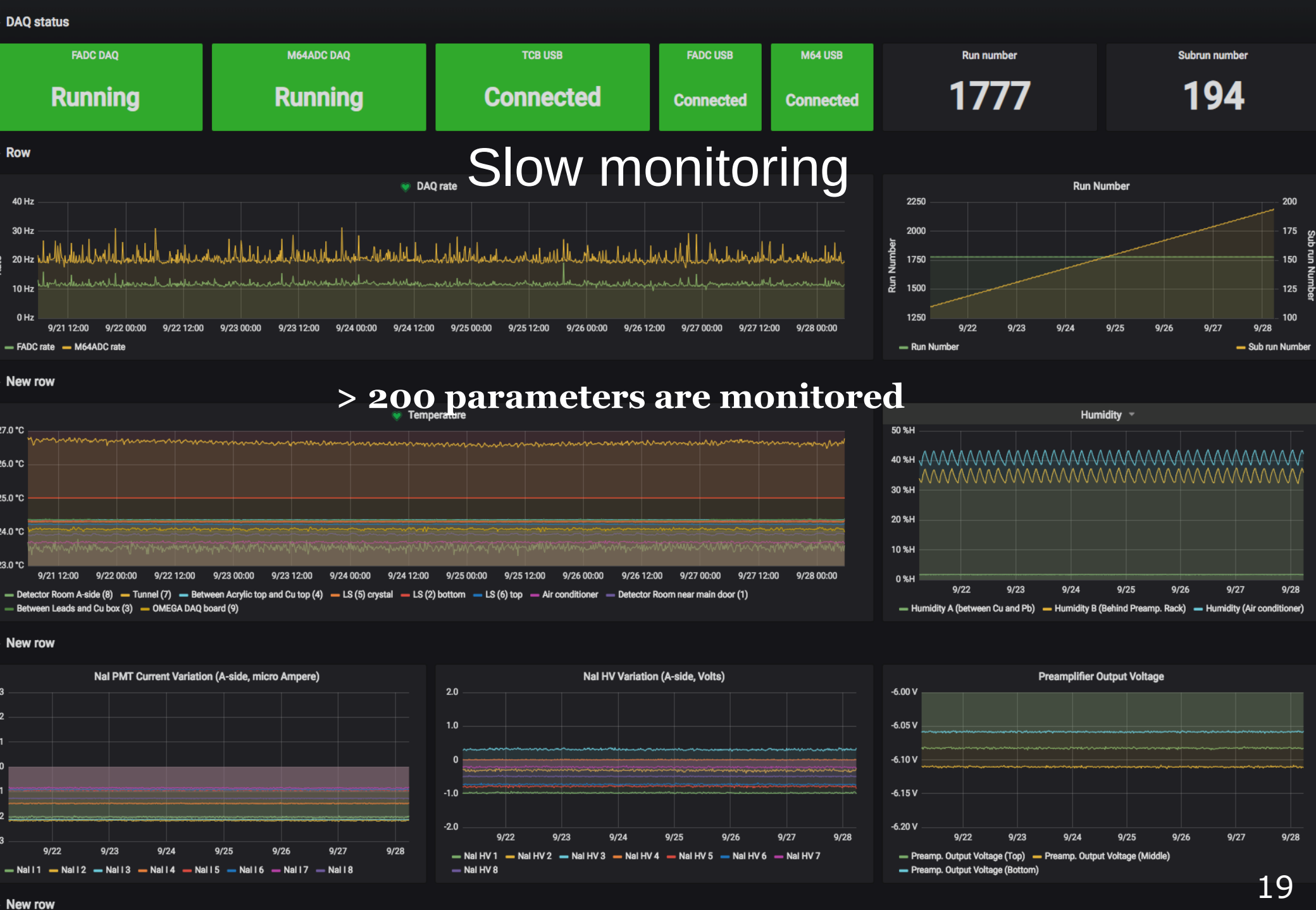
COSINE-100 operation



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






DAQ status
FADC DAQ
Running
M64ADC DAQ
Running
TCB USB
Connected
FADC USB
Connected
M64 USB
Connected
Run number
1777
Subrun number
194
Row
Slow monitoring
DAQ rate
40 Hz
30 Hz
20 Hz
10 Hz
0 Hz
9/21 12:00
9/22 00:00
9/22 12:00
9/23 00:00
9/23 12:00
9/24 00:00
9/24 12:00
9/25 00:00
9/25 12:00
9/26 00:00
9/26 12:00
9/27 00:00
9/27 12:00
9/28 00:00
FADC rate
M64ADC rate
Run Number
2250
2000
1750
1500
1250
200
175
150
125
100
9/22
9/23
9/24
9/25
9/26
9/27
9/28
Run Number
Sub run Number
New row
> 200 parameters are monitored
Temperature
27.0 °C
26.0 °C
25.0 °C
24.0 °C
23.0 °C
9/21 12:00
9/22 00:00
9/22 12:00
9/23 00:00
9/23 12:00
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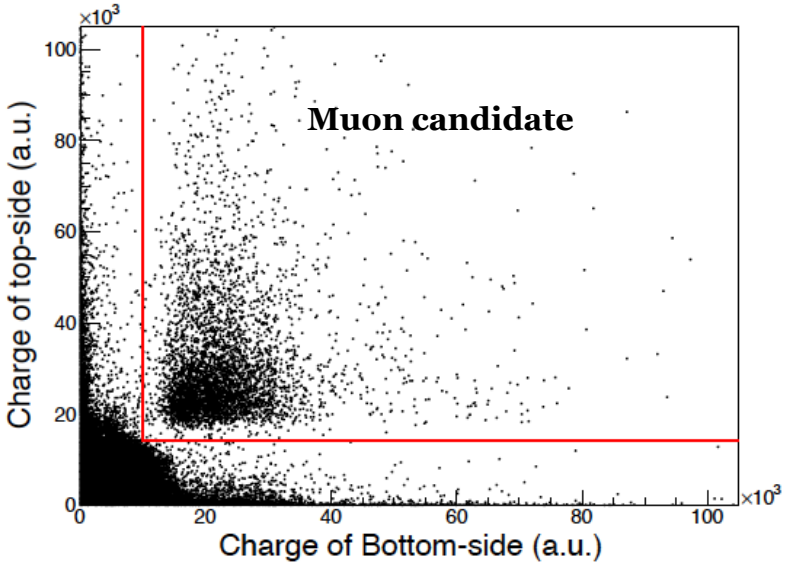
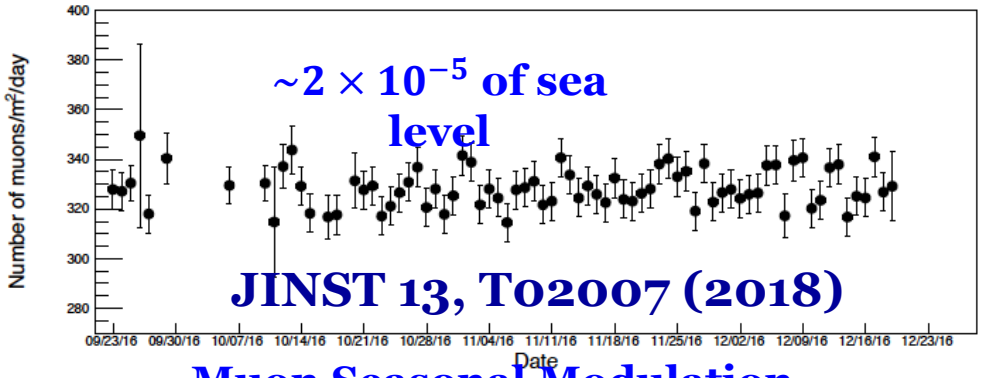
9/24 12:00
9/25 00:00
9/25 12:00
9/26 00:00
9/26 12:00
9/27 00:00
9/27 12:00
9/28 00:00
Detector Room A-side (8)
Tunnel (7)
Between Acrylic top and Cu top (4)
LS (5) crystal
LS (2) bottom
LS (6) top
Air conditioner
Detector Room near main door (1)
Between Leads and Cu box (3)
OMEGA DAQ board (9)
Humidity
50 %H
40 %H
30 %H
20 %H
10 %H
0 %H
9/22
9/23
9/24
9/25
9/26
9/27
9/28
Humidity A (between Cu and Pb)
Humidity B (Behind Preamp. Rack)
Humidity (Air conditioner)
New row
NaI PMT Current Variation (A-side, micro Ampere)
9/22
9/23
9/24
9/25
9/26
9/27
9/28
NaI l 1
NaI l 2
NaI l 3
NaI l 4
NaI l 5
NaI l 6
NaI l 7
NaI l 8
NaI HV Variation (A-side, Volts)
2.0
1.0
0
-1.0
-2.0
9/22
9/23
9/24
9/25
9/26
9/27
9/28
NaI HV 1
NaI HV 2
NaI HV 3
NaI HV 4
NaI HV 5
NaI HV 6
NaI HV 7
NaI HV 8
Preamplifier Output Voltage
-6.00 V
-6.05 V
-6.10 V
-6.15 V
-6.20 V
9/22
9/23
9/24
9/25
9/26
9/27
9/28
Preamp. Output Voltage (Top)
Preamp. Output Voltage (Middle)
Preamp. Output Voltage (Bottom)
New row

Muon detector

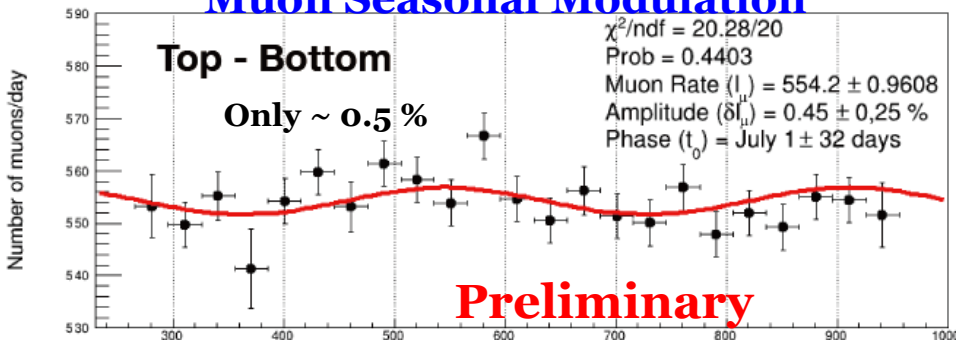
- Outer muon veto consists of 37 plastic scintillator panels



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



Muon Seasonal Modulation

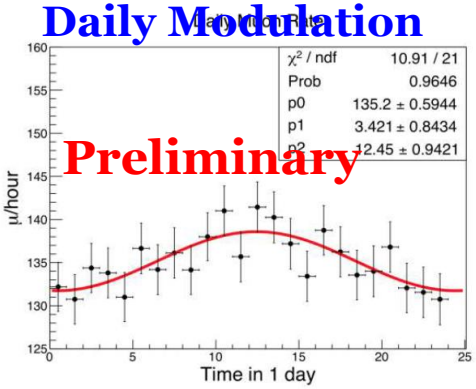


Muon flux has been monitored stably

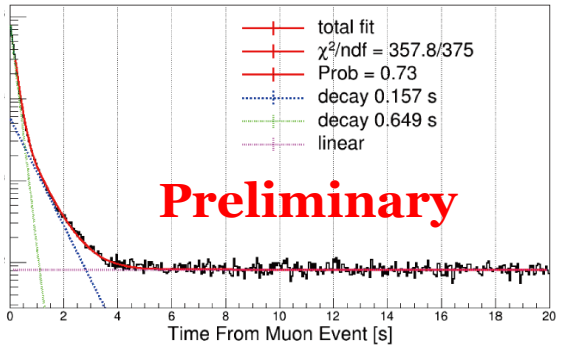
Vetoing of muon correlated events in NaI(Tl) crystals was implemented

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

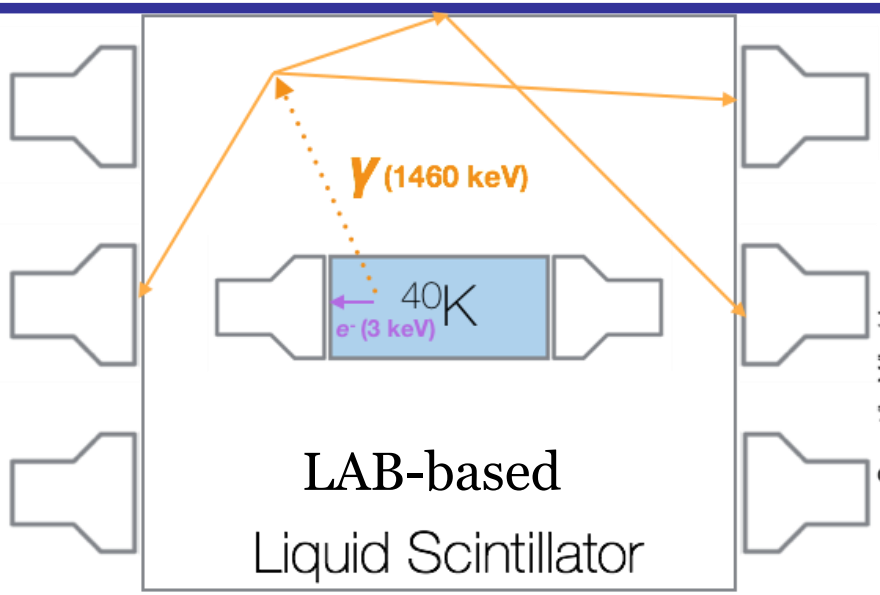
Daily Modulation

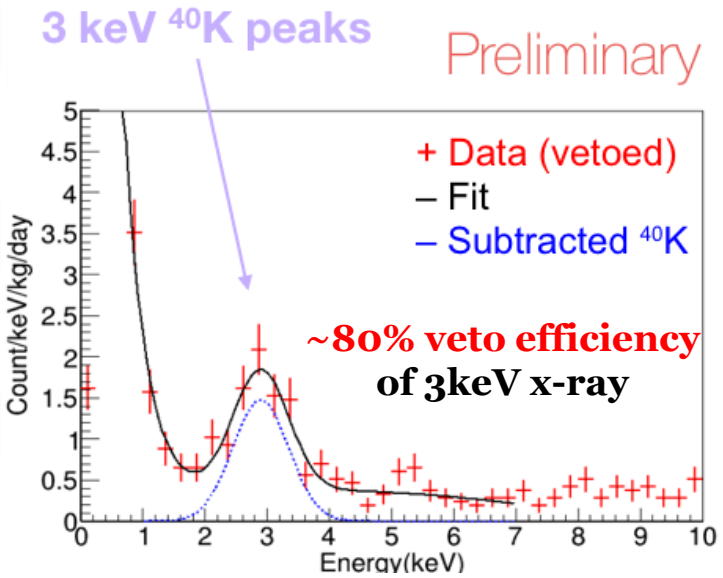


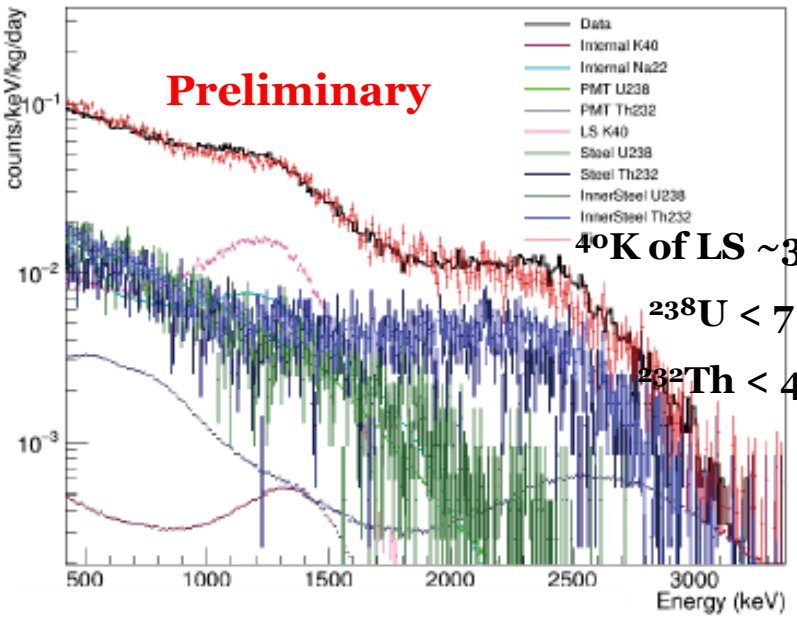
Muon induced events at NaI



Liquid scintillator veto system







- 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


COSINE-100 NaI(Tl) crystals
8 crystals, 106 kg in total

COSINE-100 NaI(Tl) crystals

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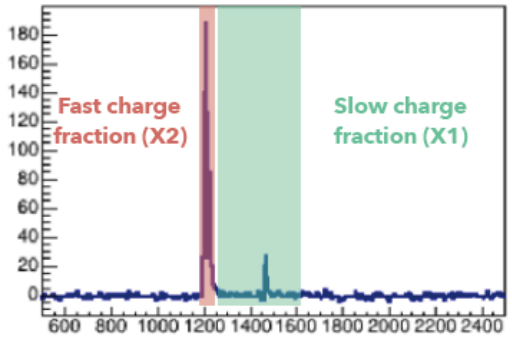
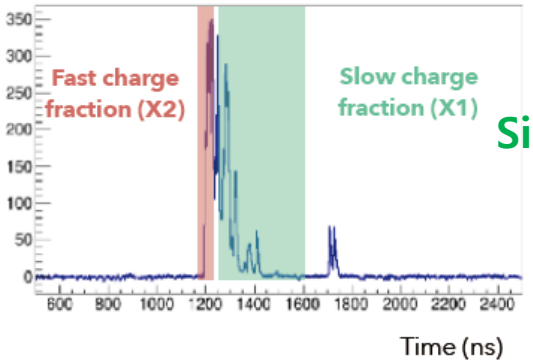
- 8 crystals, total 106 kg
- Different quality crystals from crystal R&D with Alpha Spectra
- For best cases, U/Th/K are lower than DAMA
- Total alphas (~^{210}Pb) are higher than DAMA

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-WS Ⅲ	1.52 ± 0.04	12.2 ± 4.5	< 0.018	0.56 ± 0.19	14.56 ± 1.45
Crystal 7	12.5	AS-WS Ⅲ	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

Fast (mostly PMT induced) event rejection

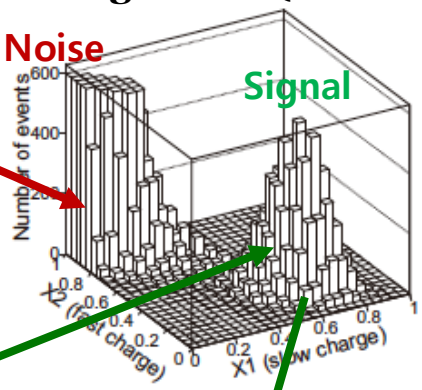




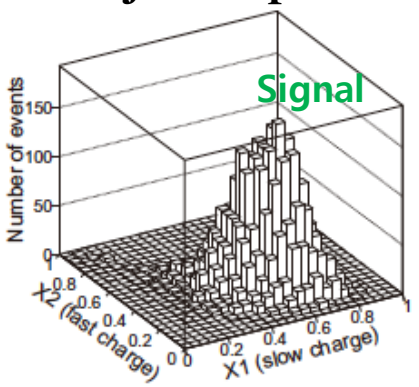
Noise

Signal

Charge Ratio (DAMA noise rejection parameter)

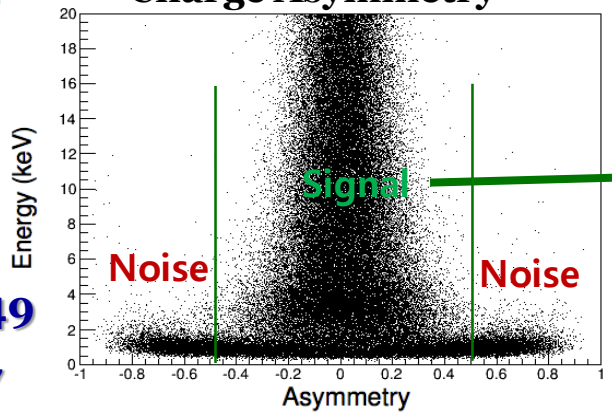


(a) Background data

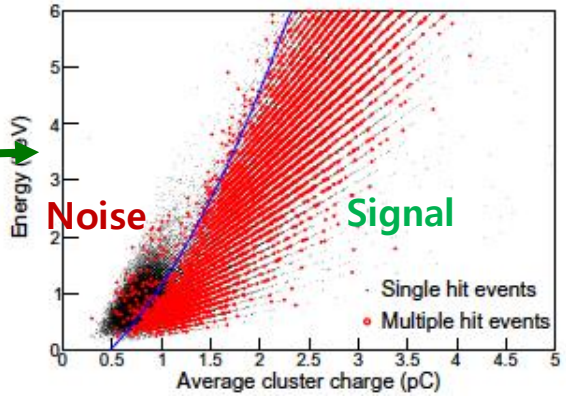


(b) ^{55}Fe calibration data

Charge Asymmetry



Average cluster charge



Astropart. Phys. 62 (2015) 249

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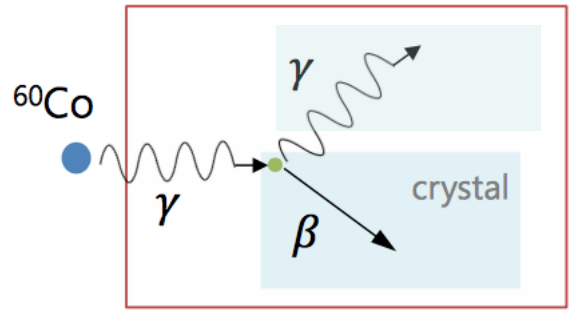
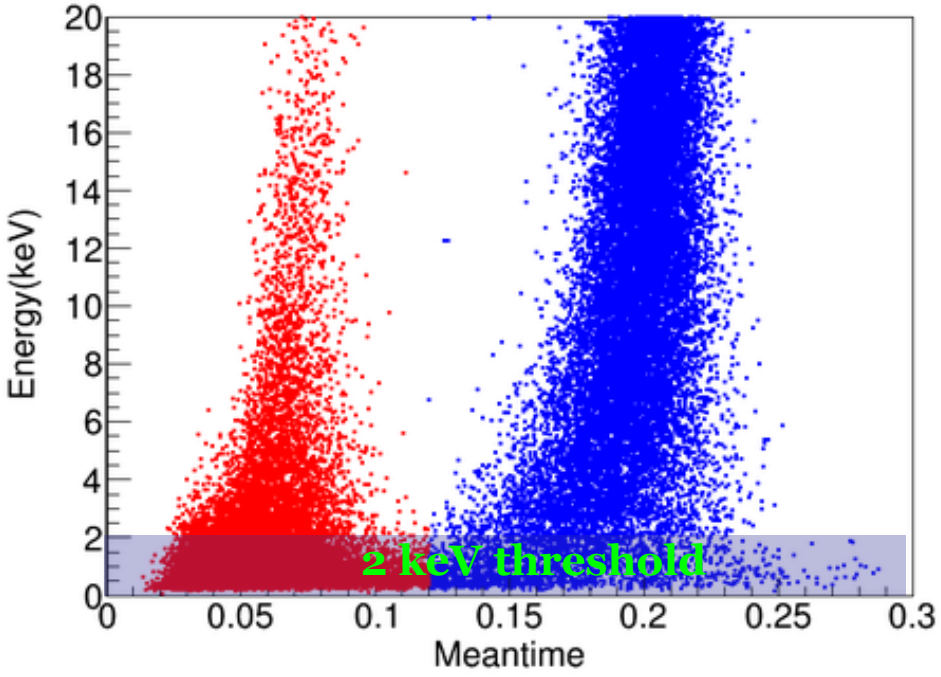
- Charge ratio (DAMA cut) is effective to reject fast noise but, it is not enough to remove all the noise!!

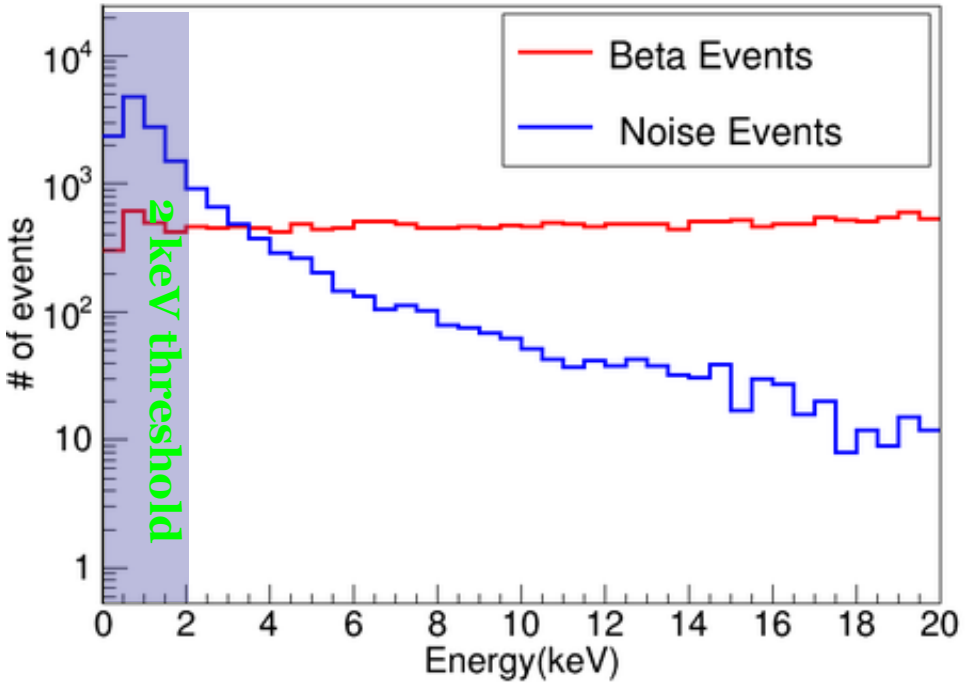
Pure electron recoil samples

- Two weeks long ^{60}Co calibration data



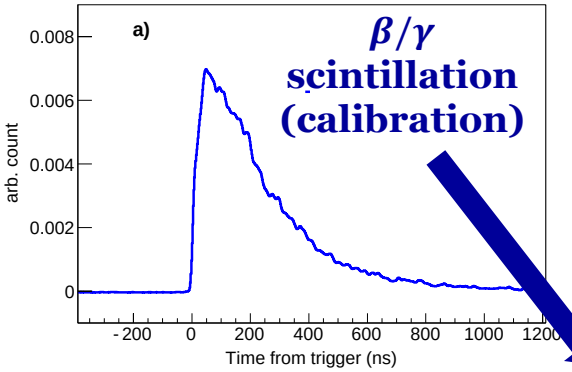
- Used to model scintillating events
- Used to estimate signal efficiency

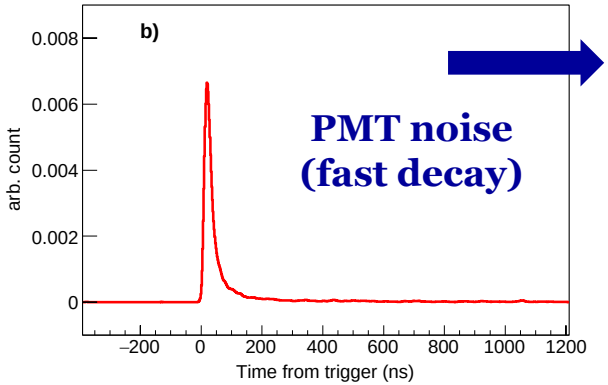




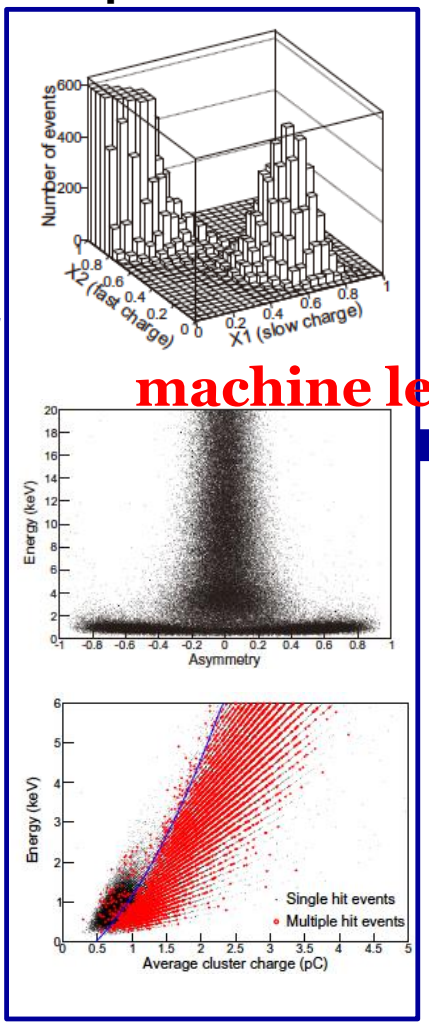
Machine learning to remove PMT induced noise

Accumulated waveforms

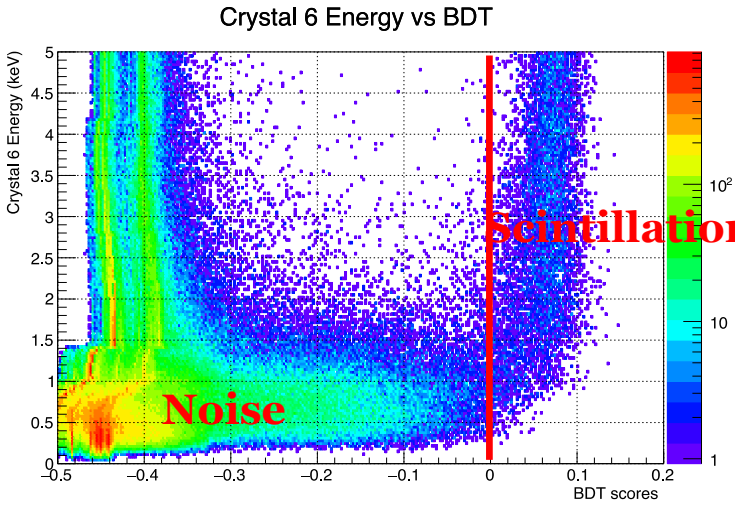


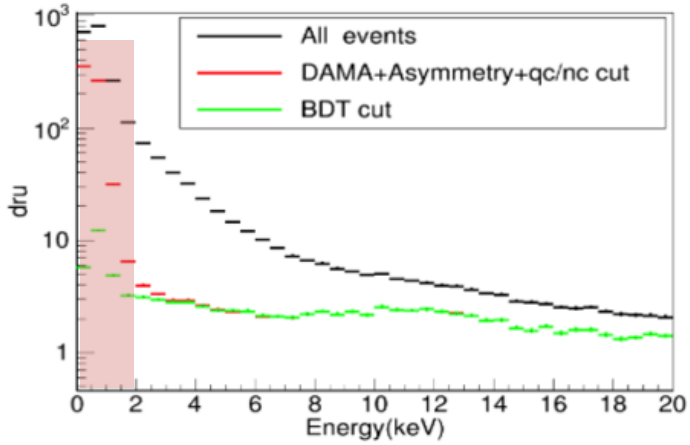


Discrimination parameters



machine learning

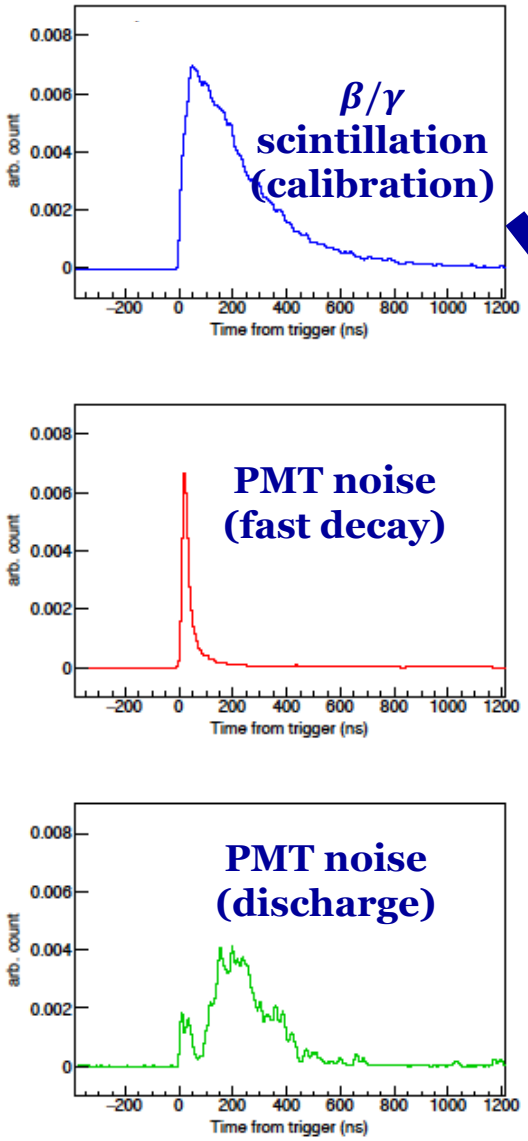




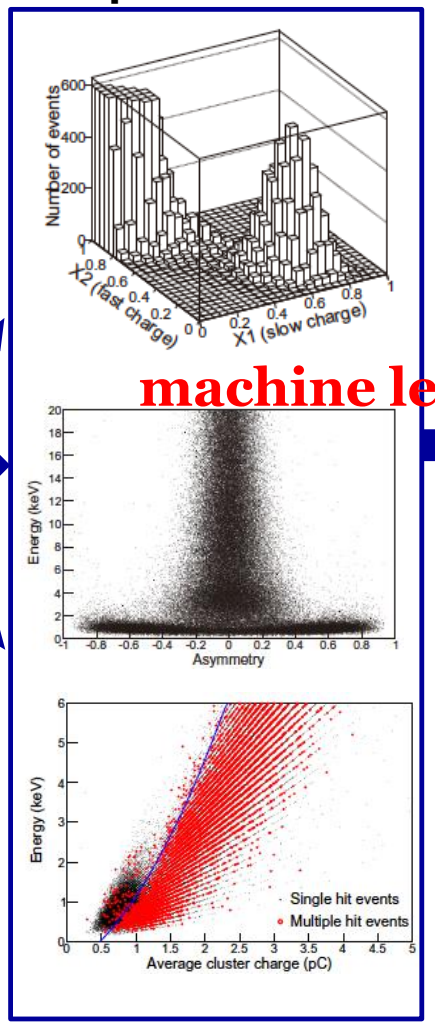
Machine learning (BDT) is more effective at low energy

Machine learning to remove PMT induced noise

Accumulated waveforms

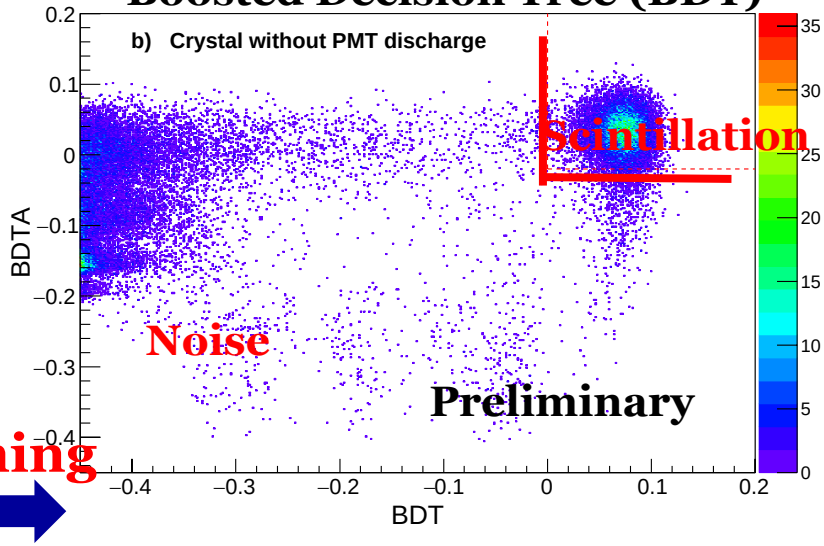


Discrimination parameters

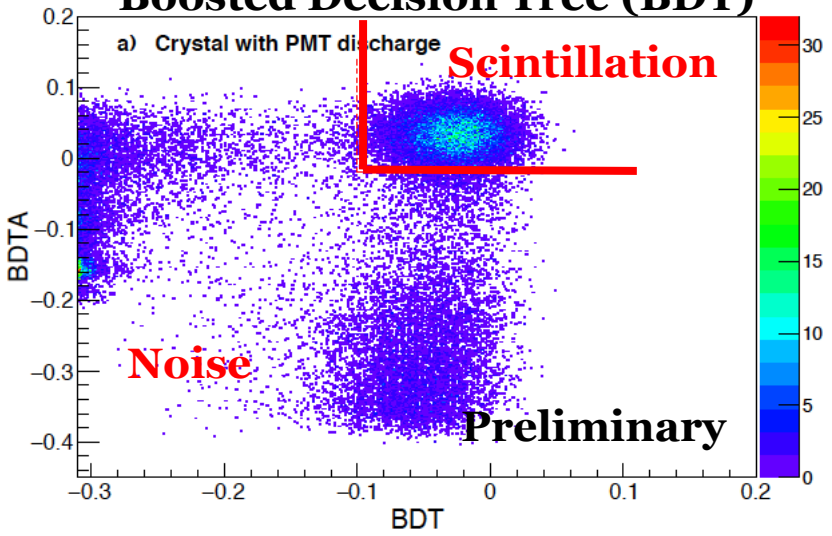


machine learning

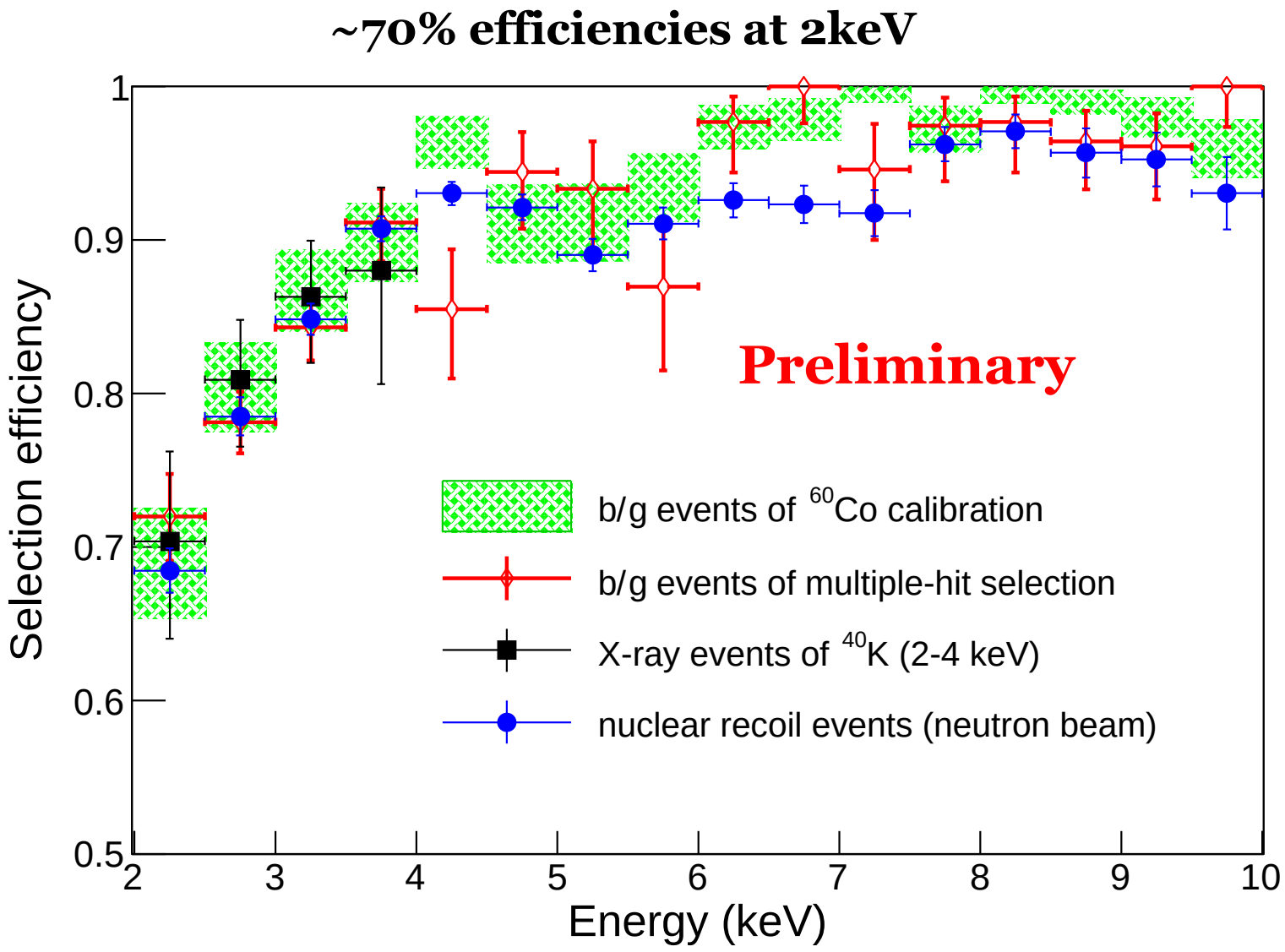
Boosted Decision Tree (BDT)



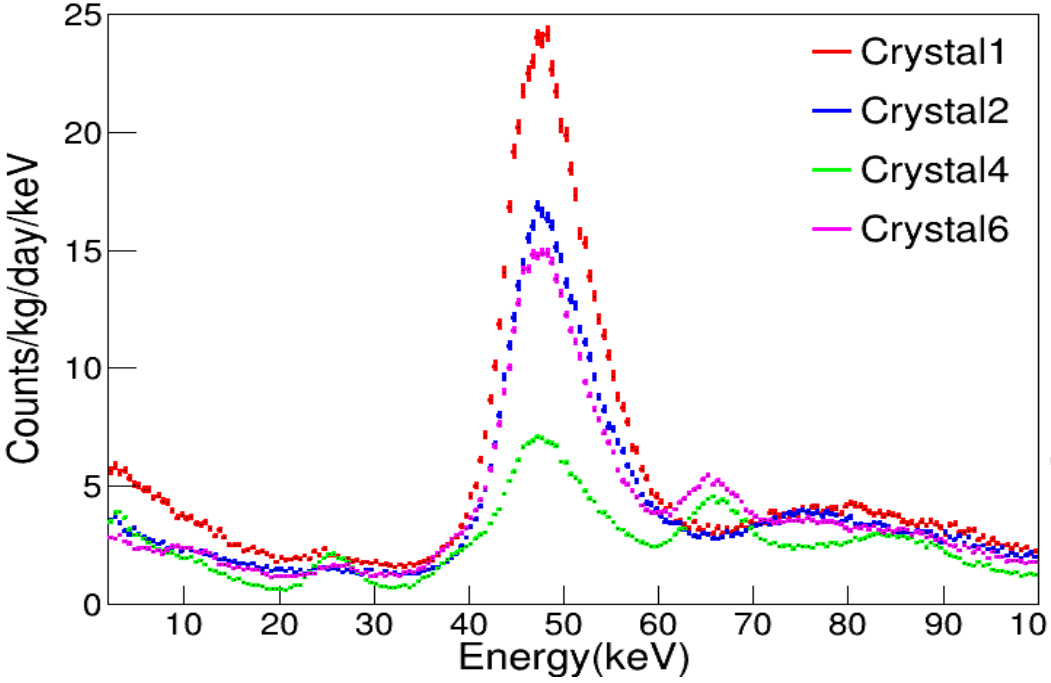
Boosted Decision Tree (BDT)

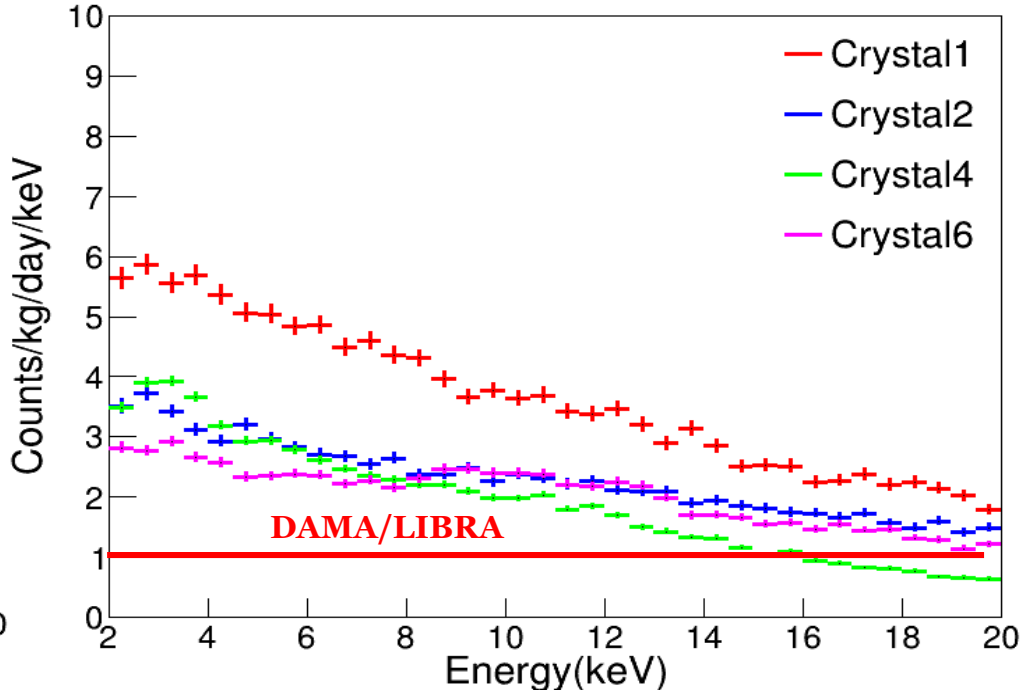


Event selection efficiencies



Crystal backgrounds

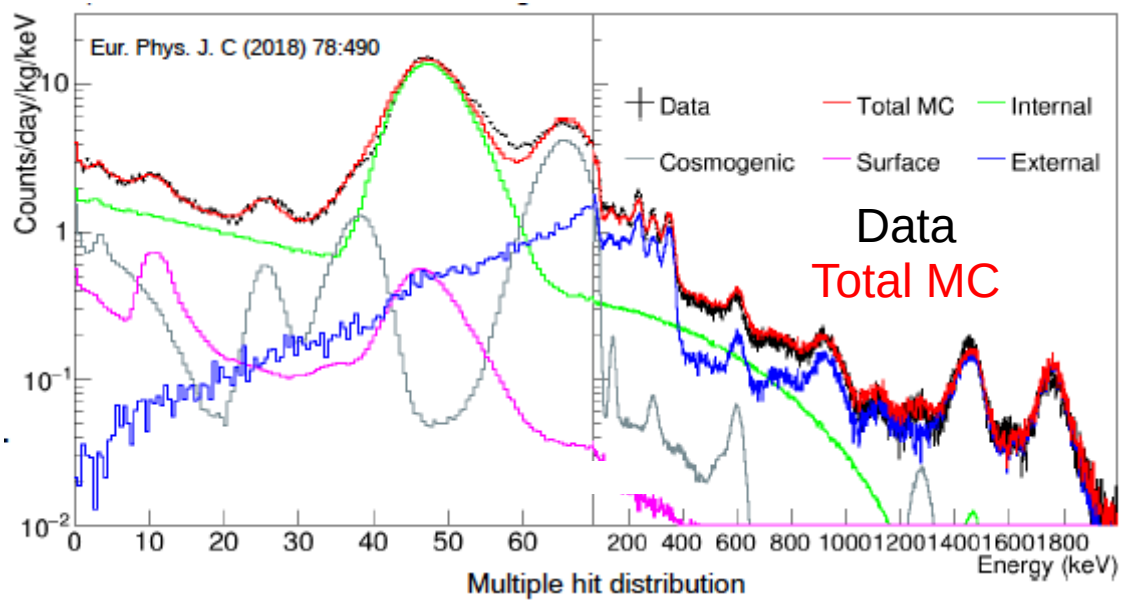




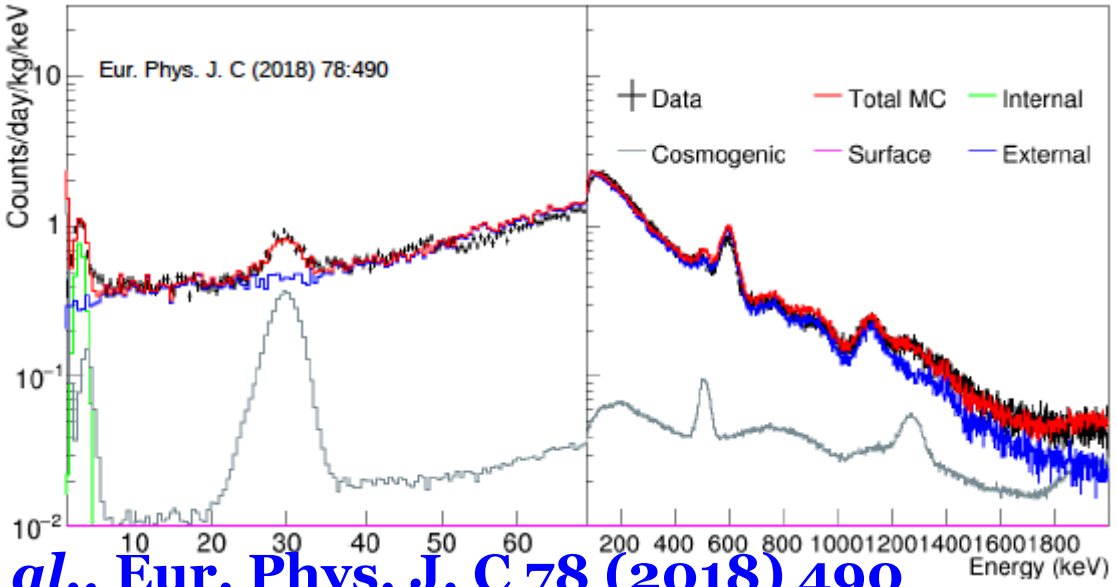
- **Background levels** from 2 to 4 dru (counts/kg/day/keV)
  - ❖ Higher than DAMA/LIBRA crystals
  - ❖ Efficiency corrected spectra

Background understanding

Single hit event
(6-2000 keV)

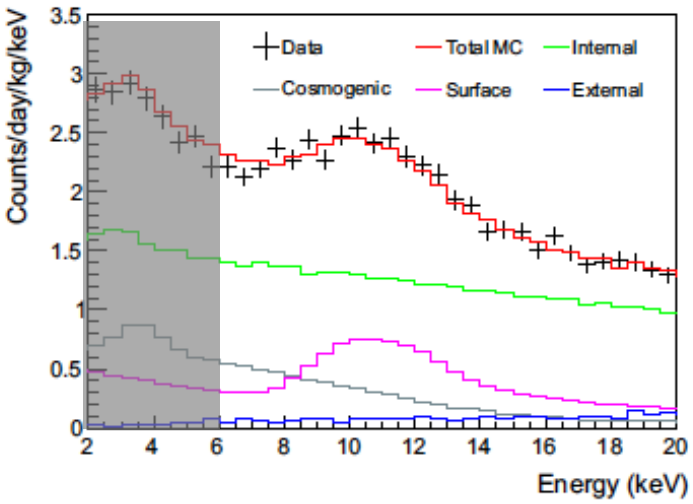


Multiple hit events
(2-2000 keV)



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

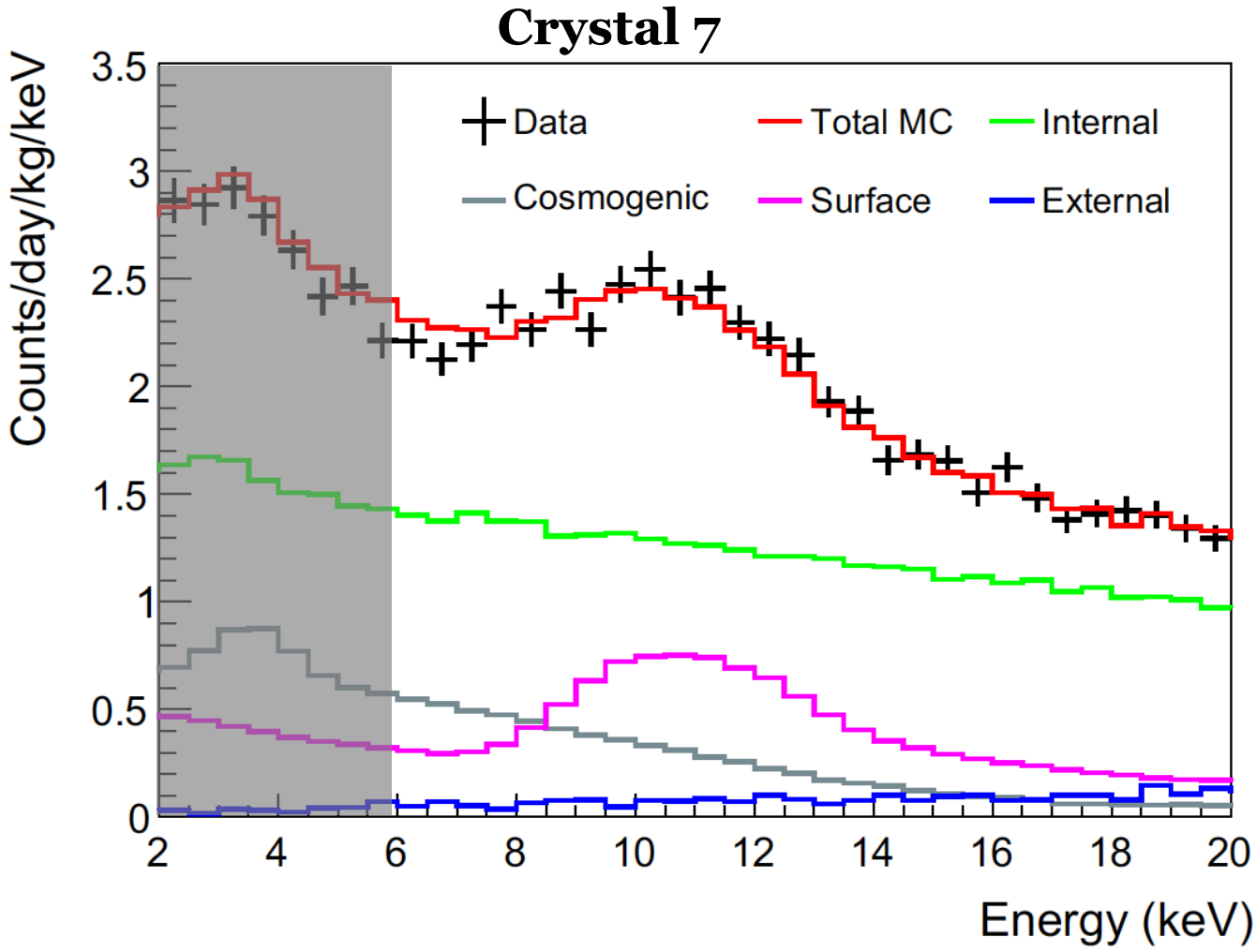
Expected background (2-6 keV)



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**

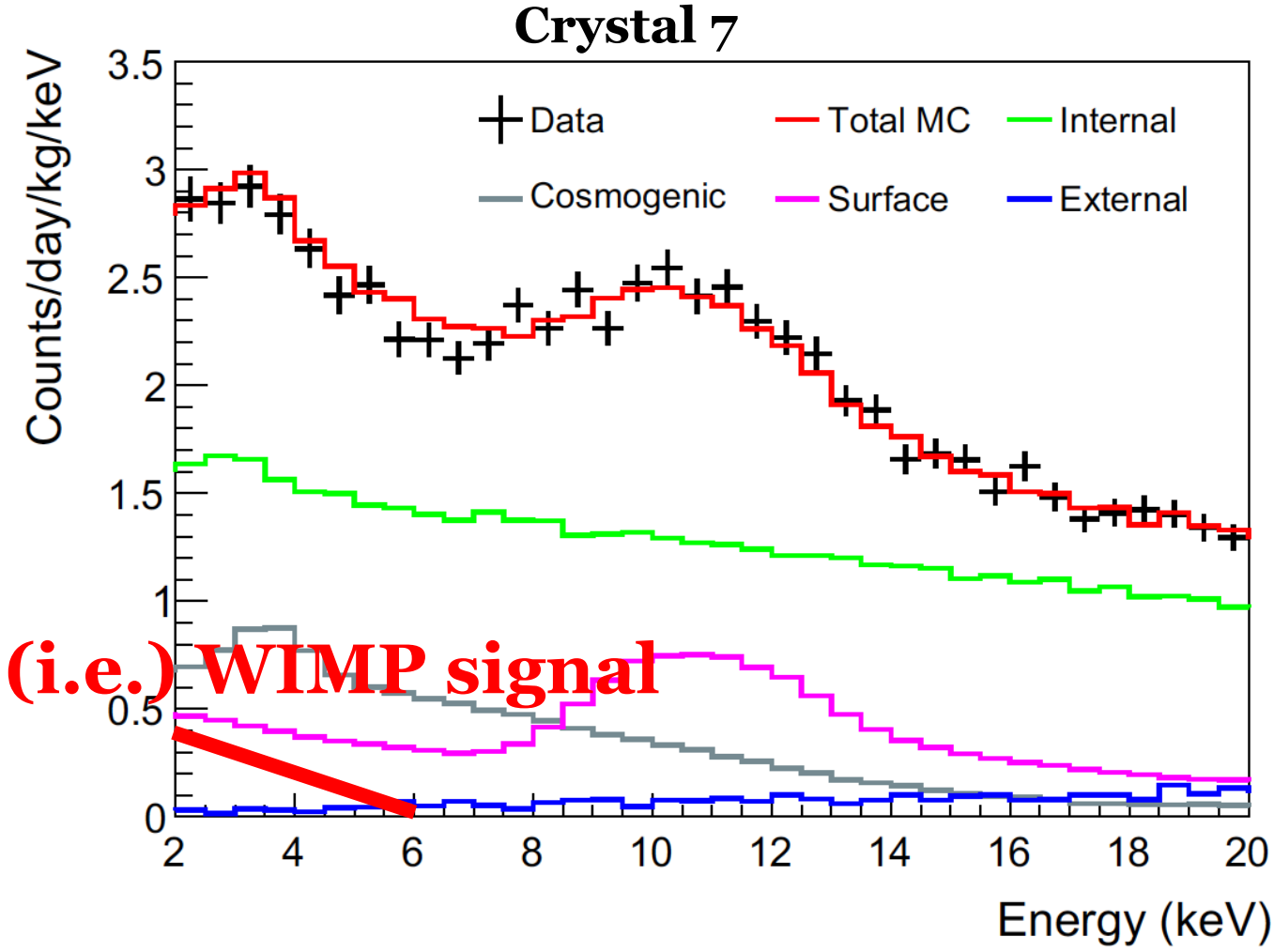
P. Adhikari *et al.*, Eur. Phys. J. C 78 (2018) 490

Fit with WIMP signals



Background modeling was done only using 6- 2000keV events

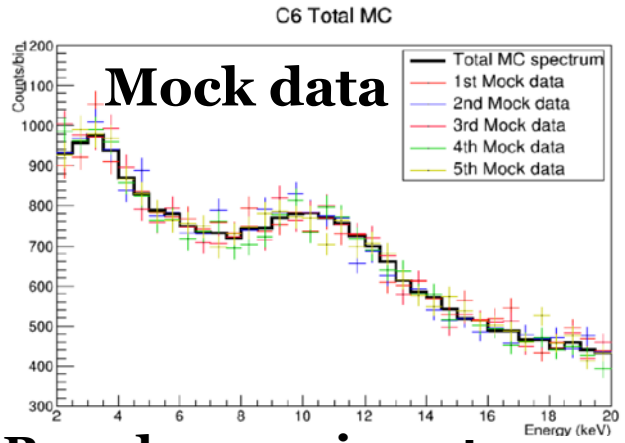
Fit with WIMP signals



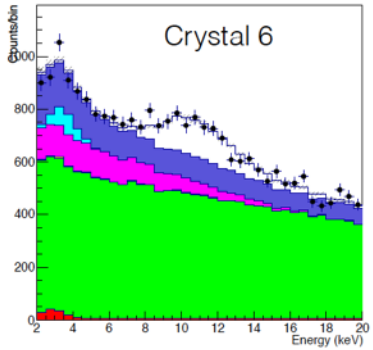
Background modeling was done only using 6- 2000keV events

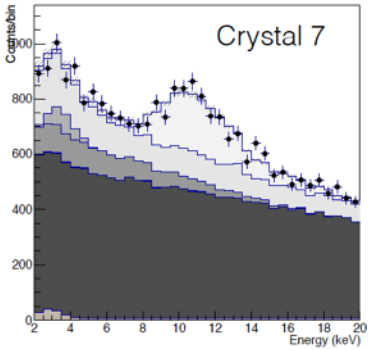
Sensitivity of COSINE-100 59.5 days data

- Generate mock data from MC modeling

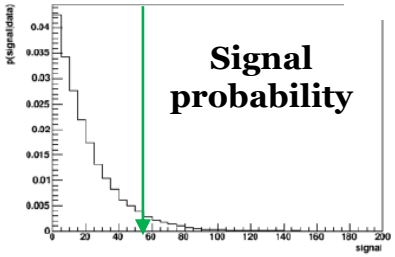


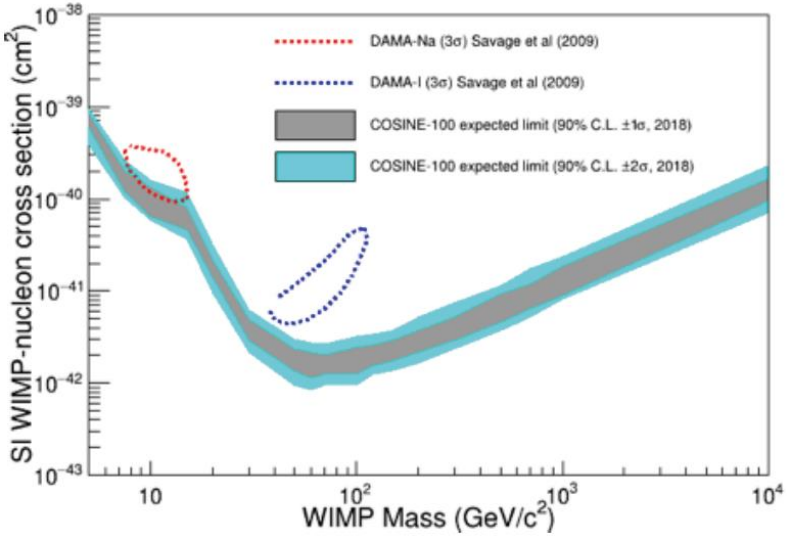
Pseudo experiment





Set 90% CL upper limit





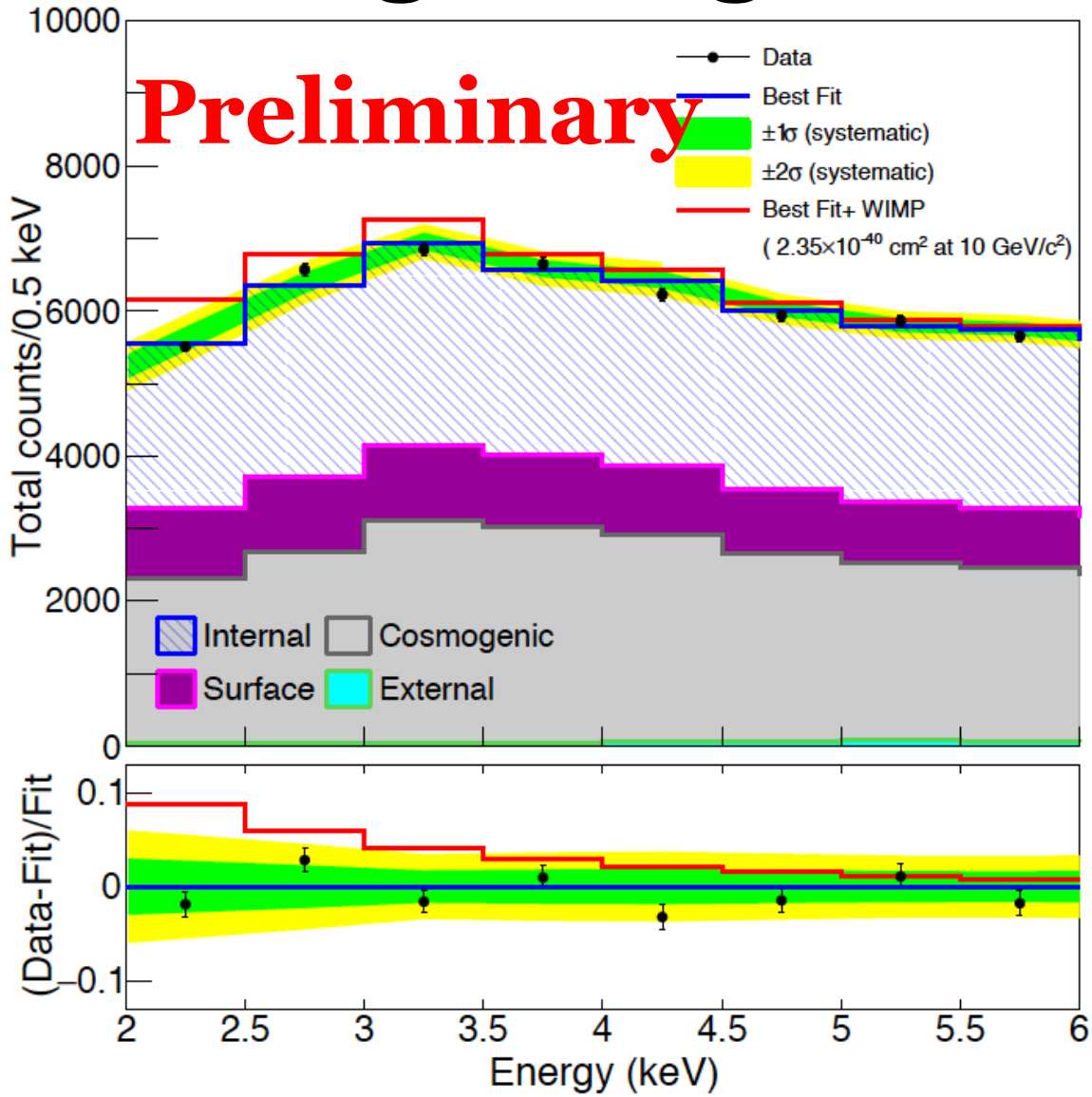
Single hit-spectra from eight crystals are fit simultaneously with an assumed WIMP signal

Same parameters as Savage et al. (2009)

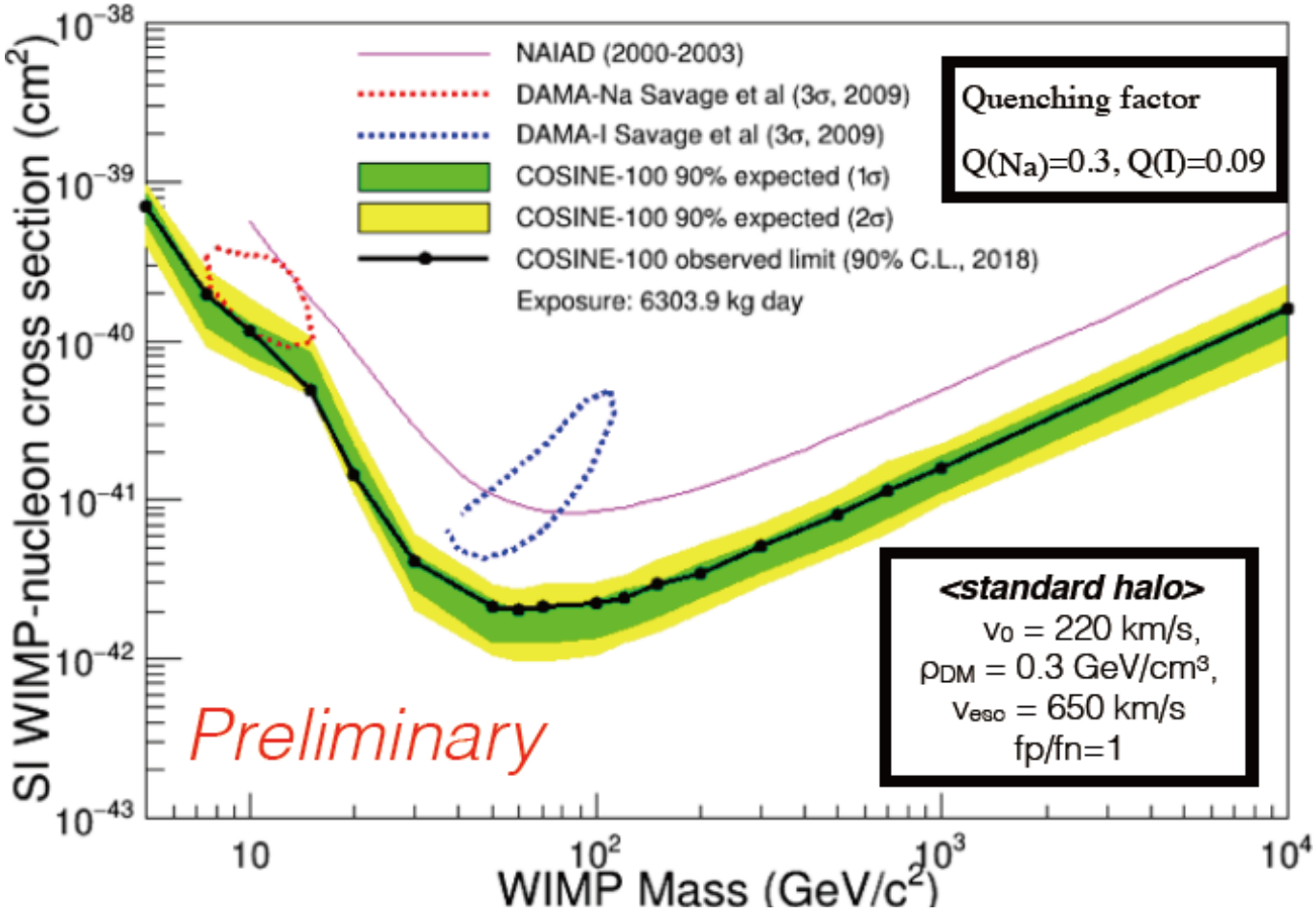
- Sensitivity estimation is done

Data fit (COSINE 59.5 days)

No Sign of signal excess



Limit on WIMP-nucleon cross section



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

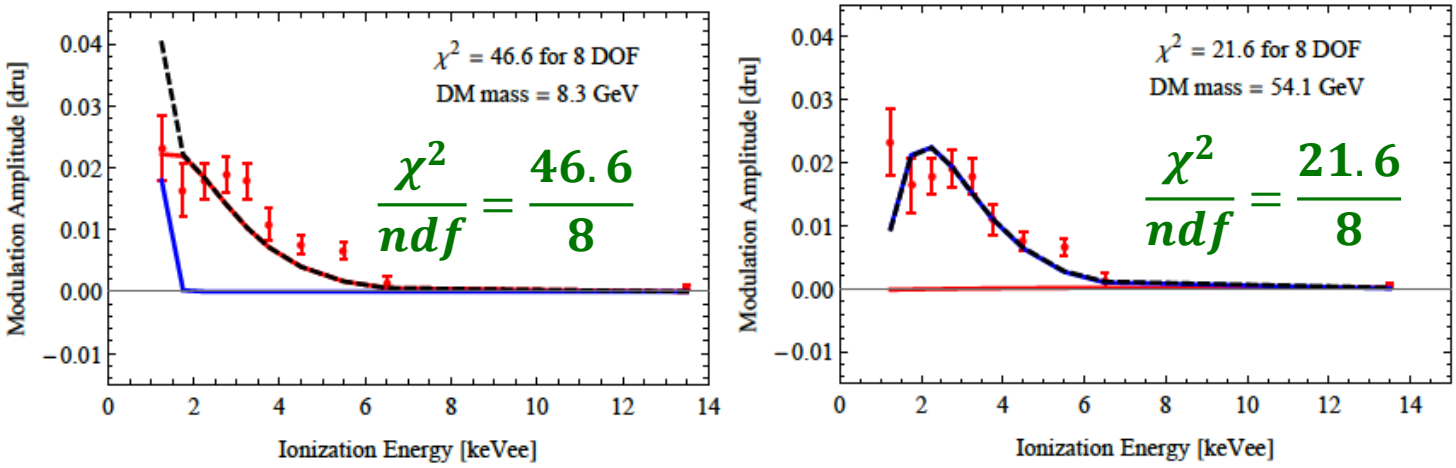
First time with same NaI(Tl) target

Consistent with other null experiments

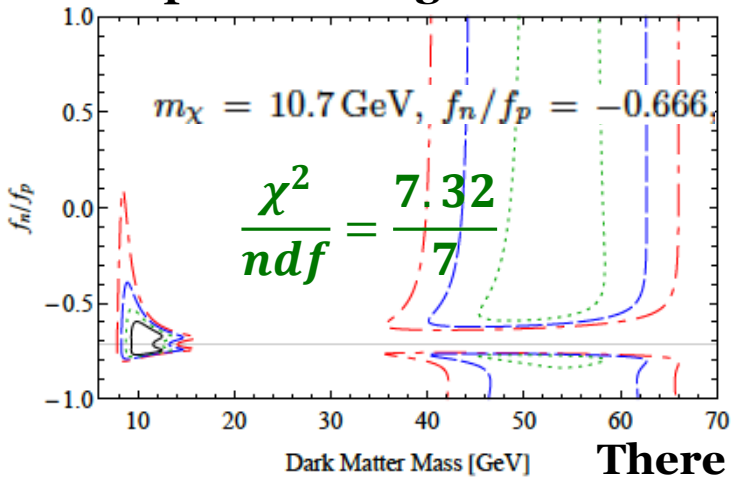
DAMA/LIBRA-phase2 interpretation?

- Typical isospin conserving SI interpretation is not work

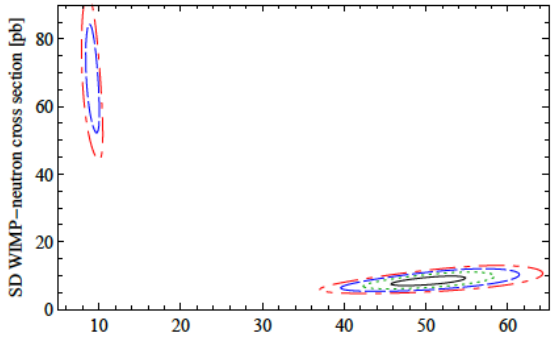
S. Baum, K. Freese, and C. Kelso, arXiv:1804.01231



Isospin violating interaction



Spin dependent interaction

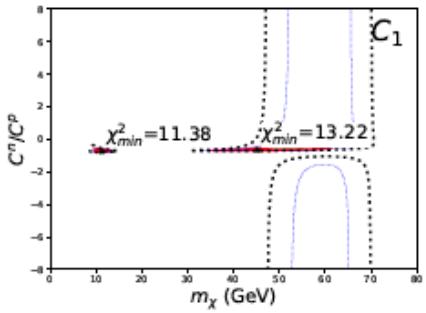


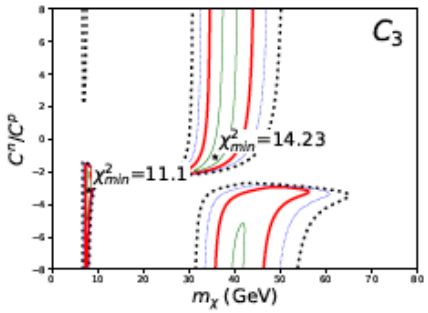
	m_χ [GeV]	σ_i^{SD} [pb]	a_n/a_p	χ^2/dof
n-only	9.3	68.0	∞	24.5/8 (3.1 σ)
	50.2	8.4	∞	12.0/8 (1.4 σ)
p-only	10.8	0.53	0	7.4/8 (0.7 σ)
	41.5	0.38	0	39.8/8 (4.6 σ)
mixed	10.7	1.9	-6.32	7.3/8 (0.7 σ)
	10.8	0.47	0.665	7.3/8 (0.7 σ)
	44.2	0.43	-7.46	9.6/8 (1.0 σ)

There is possible parameter spaces to interpret DAMA/LIBA phase2

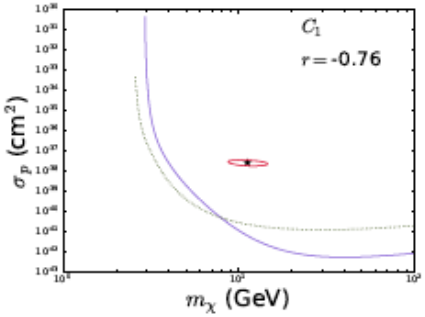
EFT interpretation

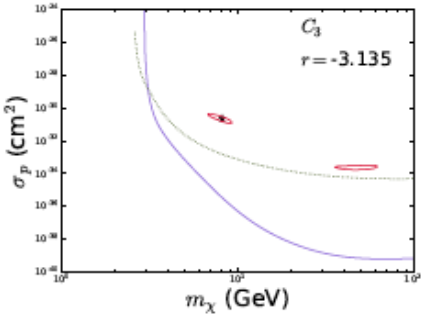
S. Kang, S. Scopel, and G. Tomar, and J.H. Yoon, JCAP 1807, 016 (2018)

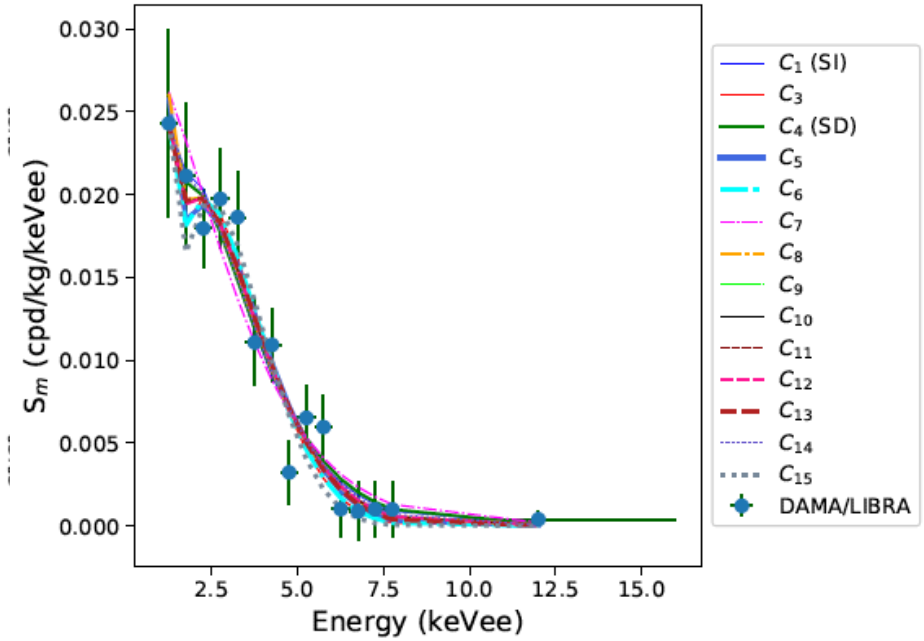


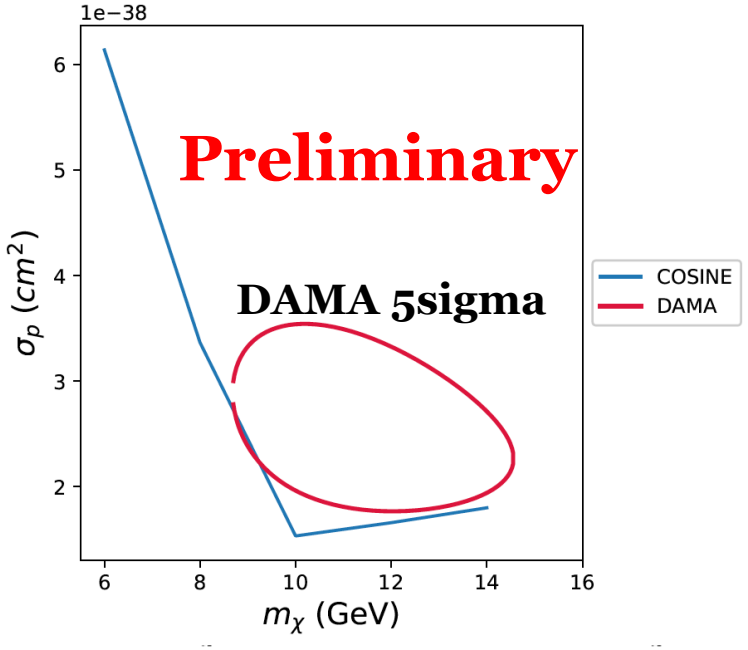


$$r = \frac{c^n}{c^p}$$





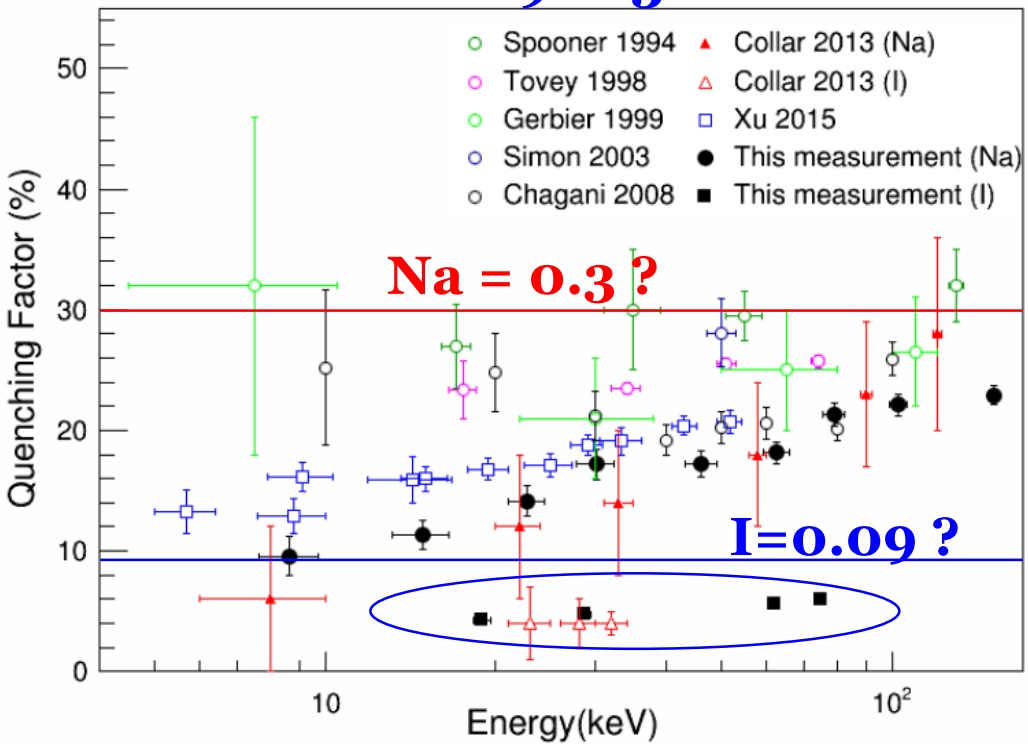




- We are working on this interpretation with COSINE-100 result

Quenching factor of NaI(Tl) crystals

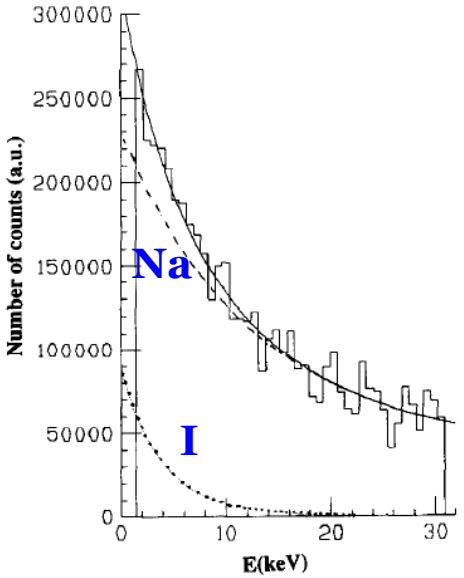
arXiv:1809.10310

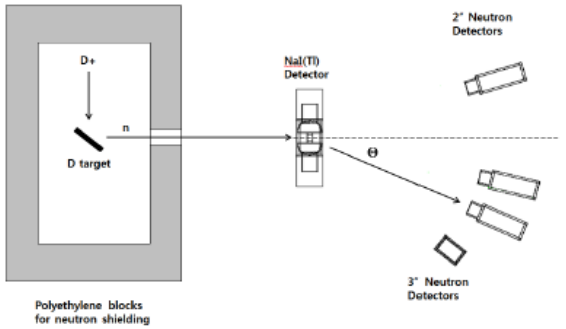


PLB 389, 757 (1996)

A ^{252}Cf source

A spectrum fit for residual spectrum with single quenching factor

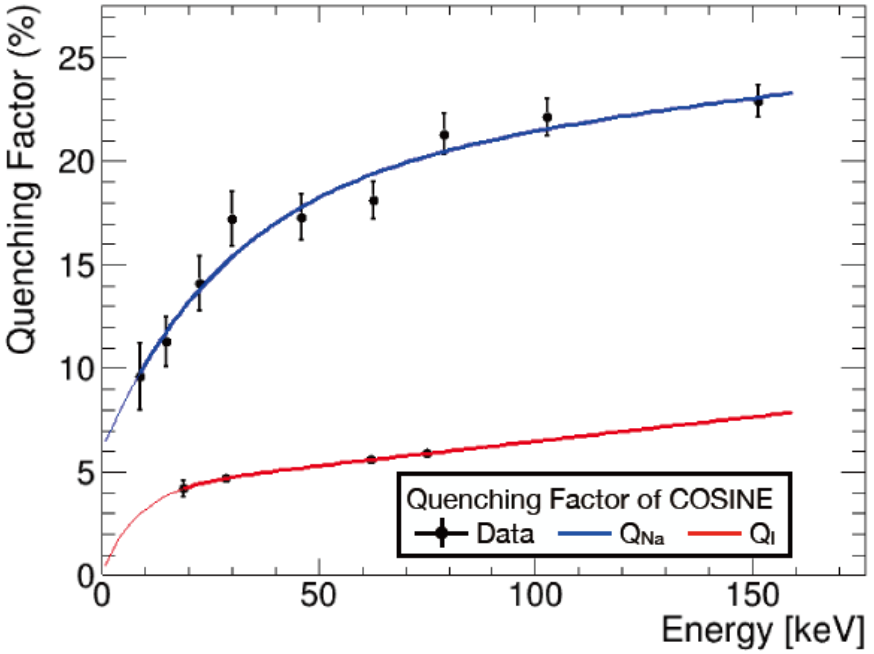


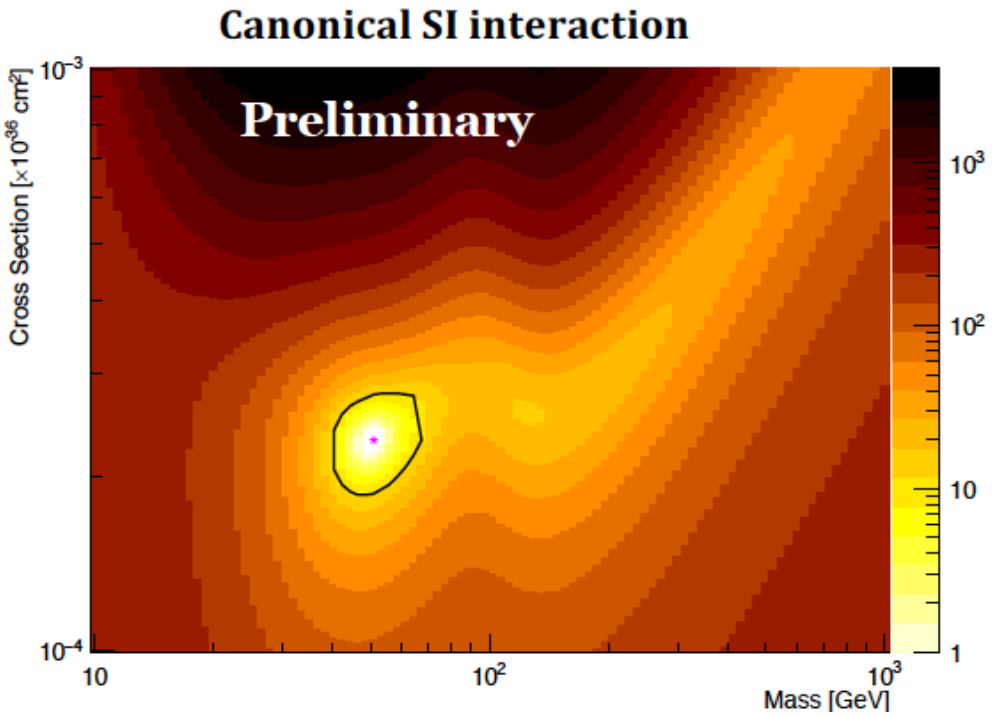


- Recently measured QFs are quite different with those used for DAMA signal interpretations

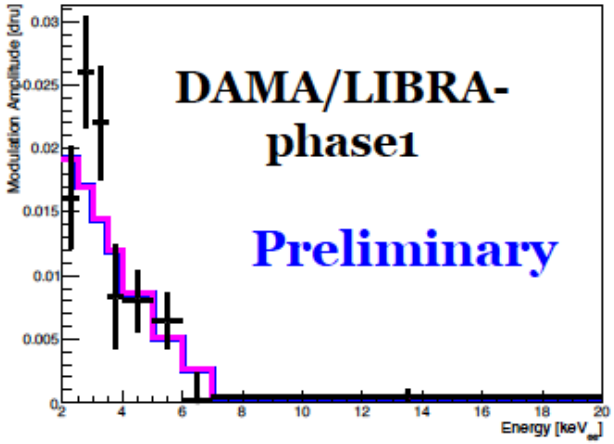
If we use our measured QF…

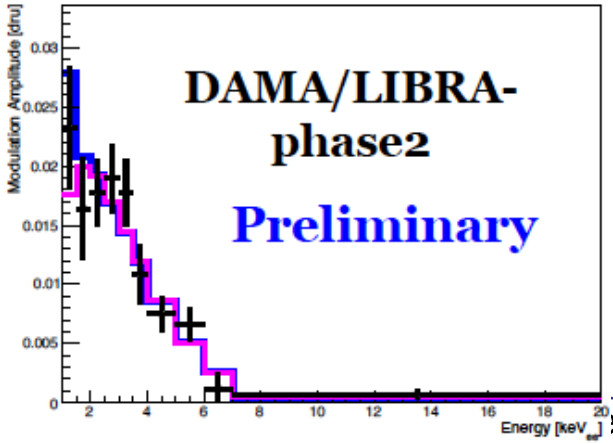
$$f(E) = p_0 + p_1 \cdot E - p_2 \cdot e^{-p_3 \cdot E}$$





$v_0 = 232\ km/h$ $v_{esc} = 544\ km/h$

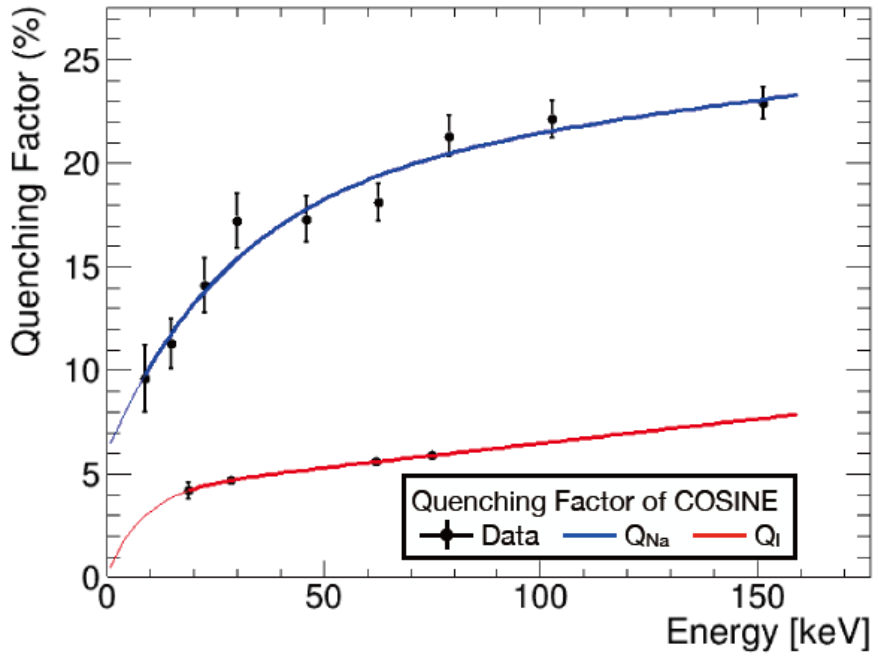




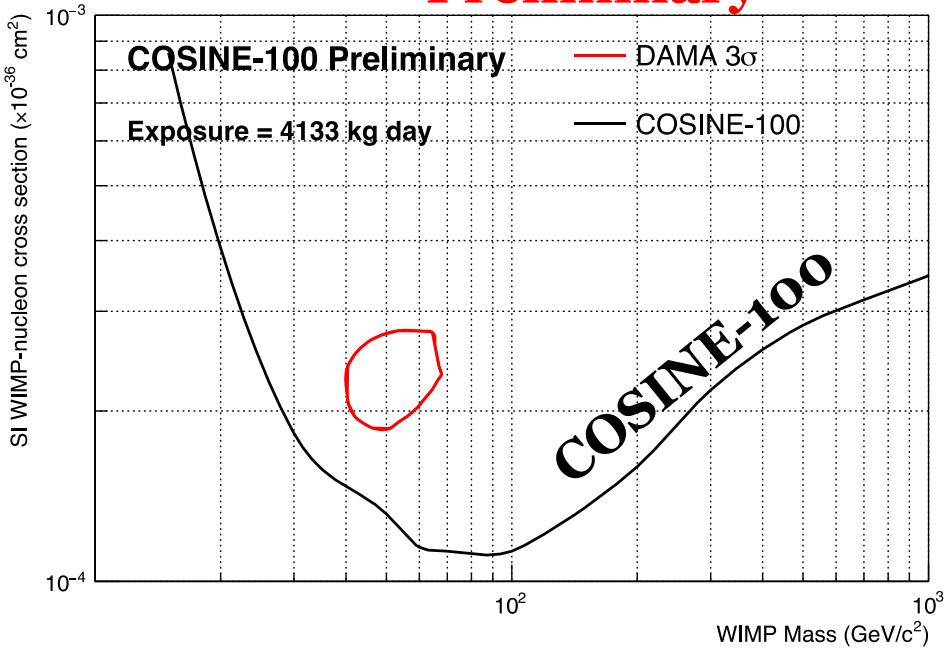
$$m_\chi = 50.9\ \text{GeV}$$
$$\sigma = 2.31 \times 10^{-40}\text{cm}^2$$
$$\frac{\chi^2}{ndf} = \frac{17.9}{16}$$

If we use our measured QF…

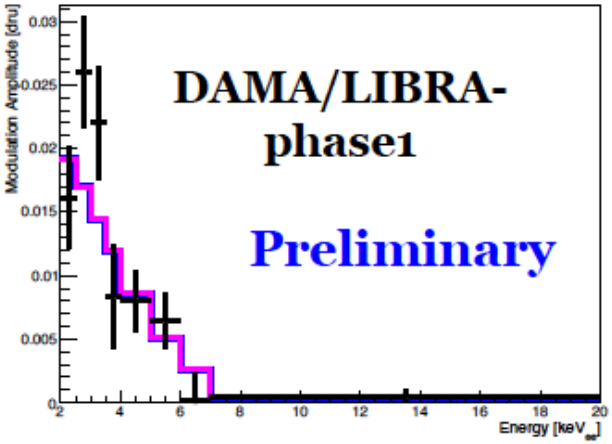
$$f(E) = p_0 + p_1 \cdot E - p_2 \cdot e^{-p_3 \cdot E}$$

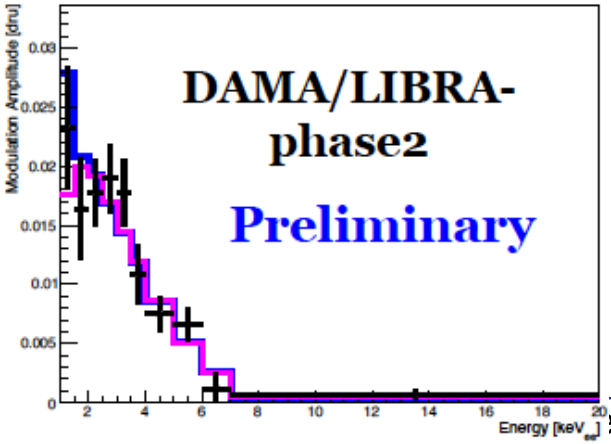


Preliminary



$v_0 = 232\ km/h$ $v_{esc} = 544\ km/h$

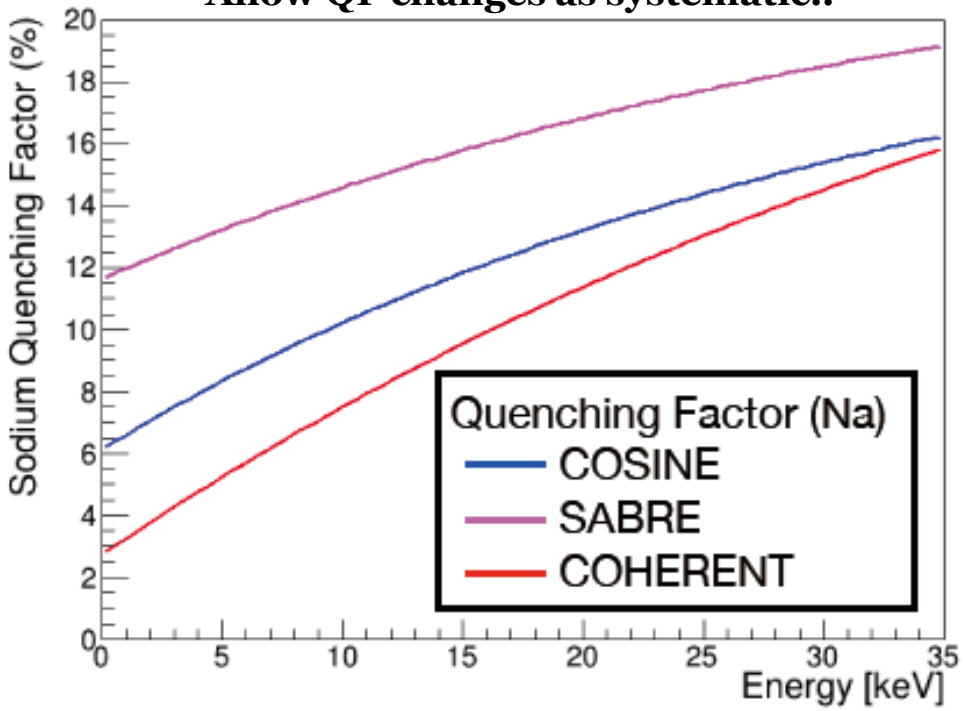




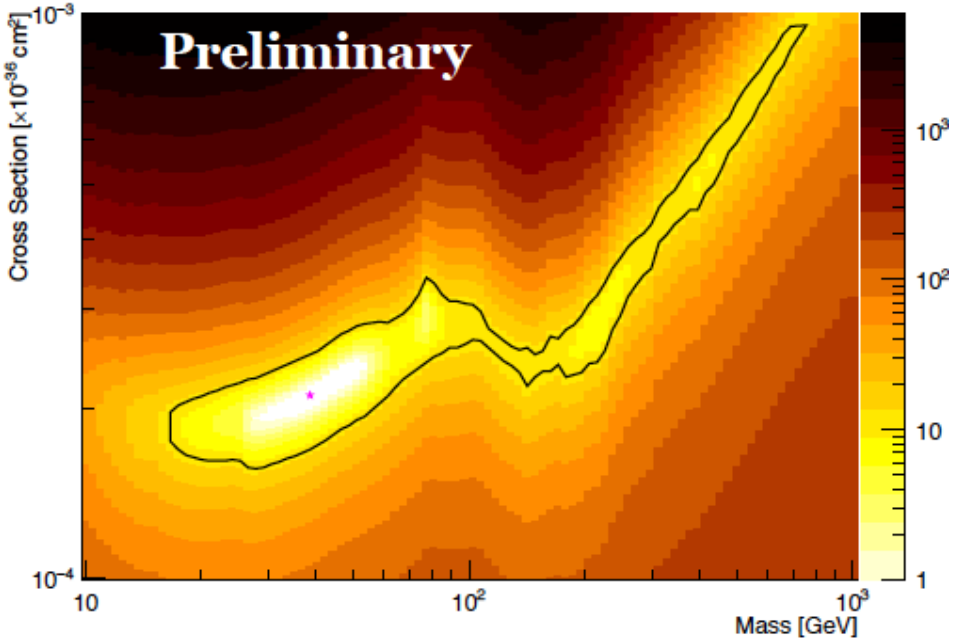
$$m_\chi = 50.9\ \text{GeV}$$
$$\sigma = 2.31 \times 10^{-40}\text{cm}^2$$
$$\frac{\chi^2}{ndf} = \frac{17.9}{16}$$

If we use recently measured QF…

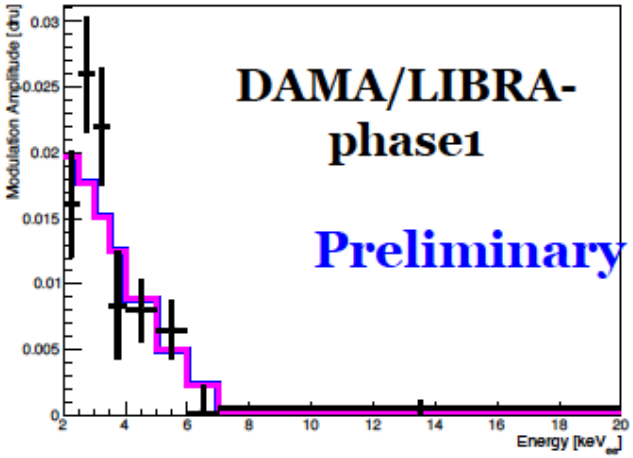
Allow QF changes as systematic..

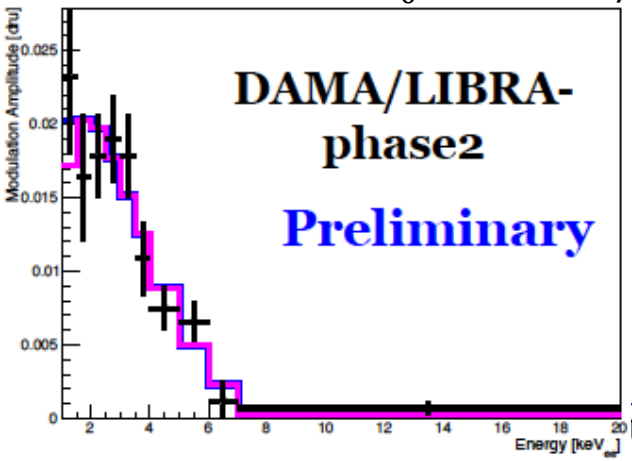


Canonical SI interaction



$v_0 = 232\ km/h$ $v_{esc} = 544\ km/h$



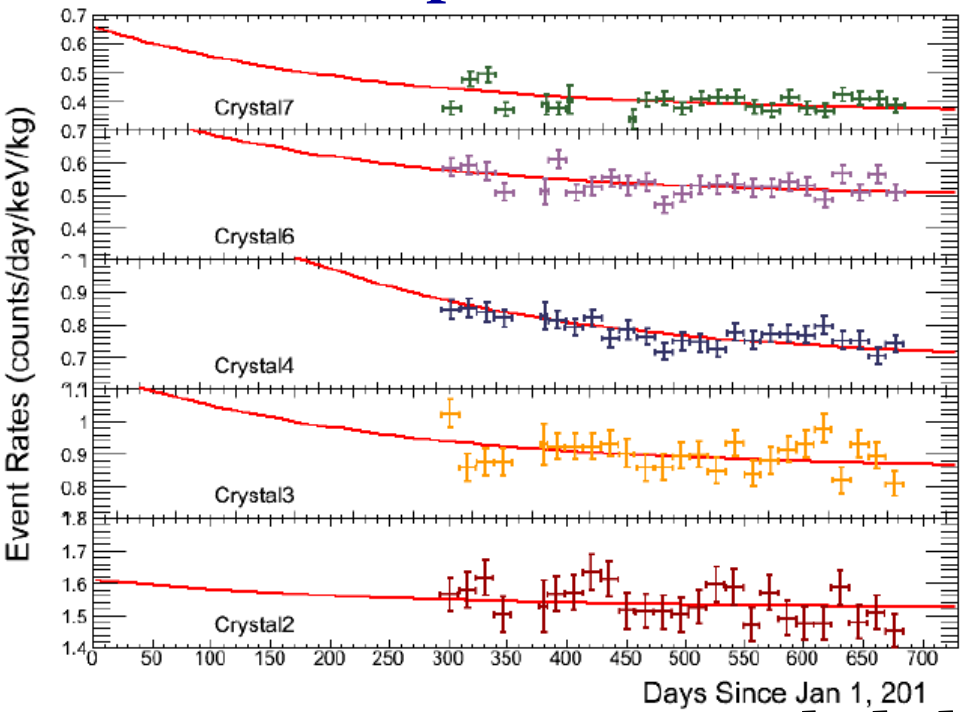


We are evaluating COSINE-100 result as well

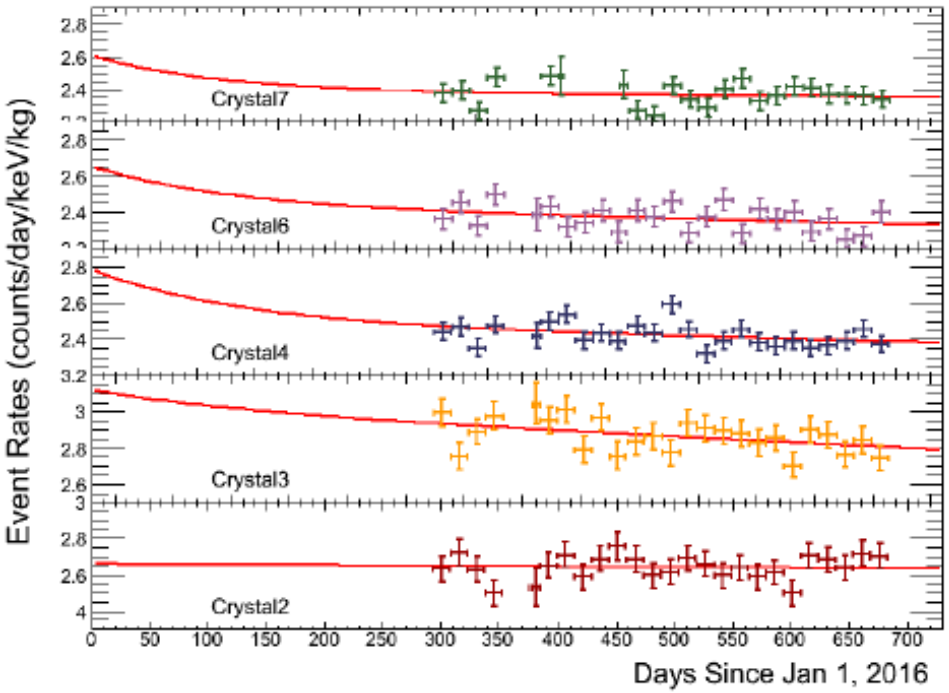
Annual Modulation

- Cosmogenic components were constraint by the measurements
- Floating **^{3}H** and constant (**internal background**)

Multiple 2-6 keV



Single 6-10 keV



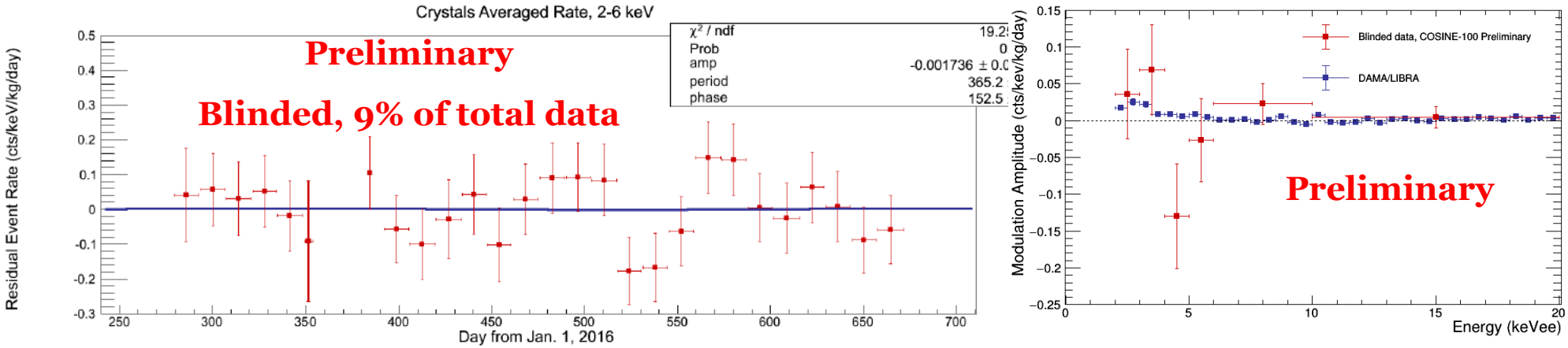
C5 & C8 were excluded due to low light output

C1 was excluded due to uncontrolled PMT induced noise (discharge)

- Side bands are well explained by known background

~ 9% data opened (blinded analysis)

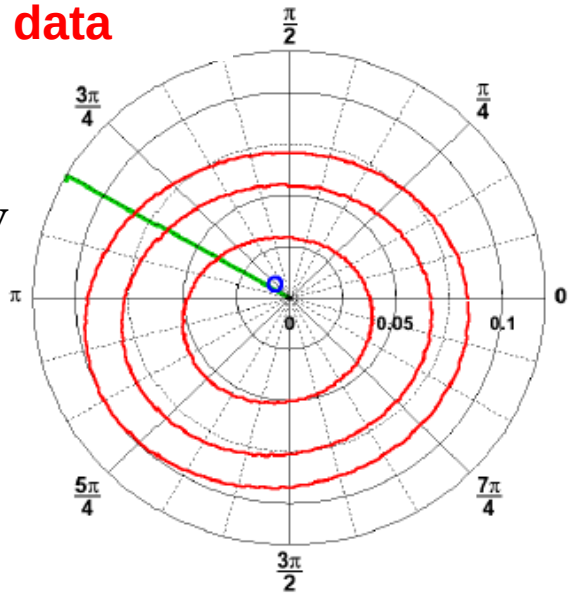
- Current data is blinded, only 9% of total data



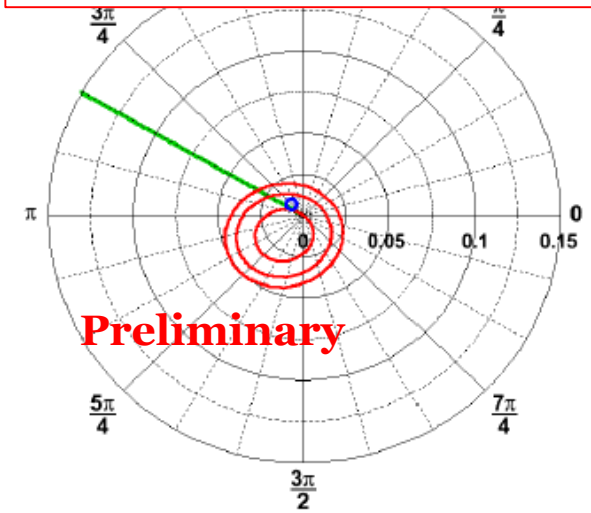
Data quality, cosmogenic component subtraction, and background modeling almost done

Under evaluating systematic uncertainty

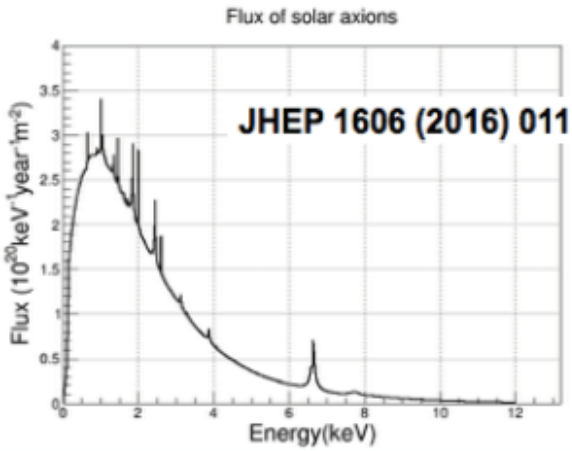
9% data

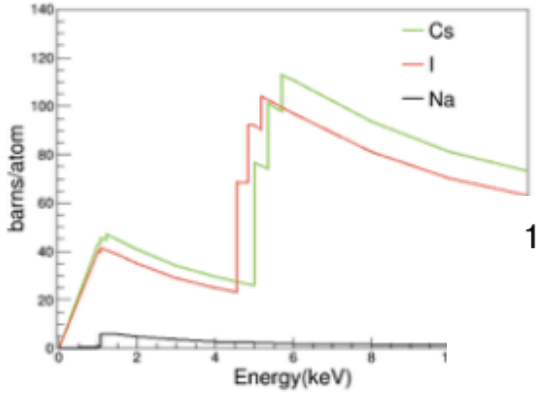


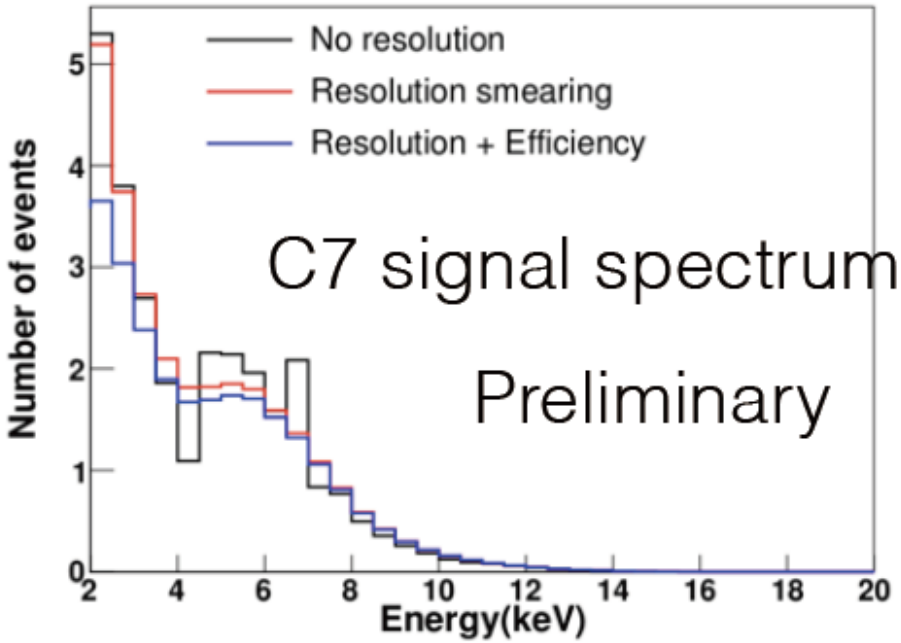
Assuming total SET2 data (error reduction only)

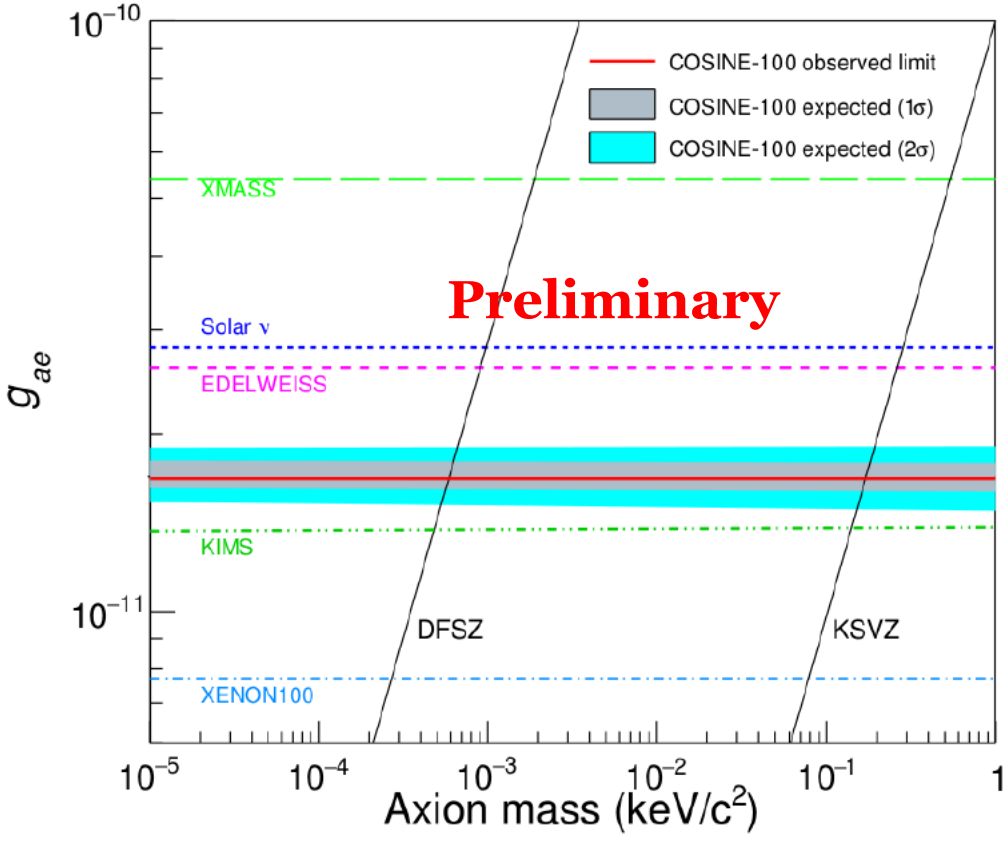


Solar axion search



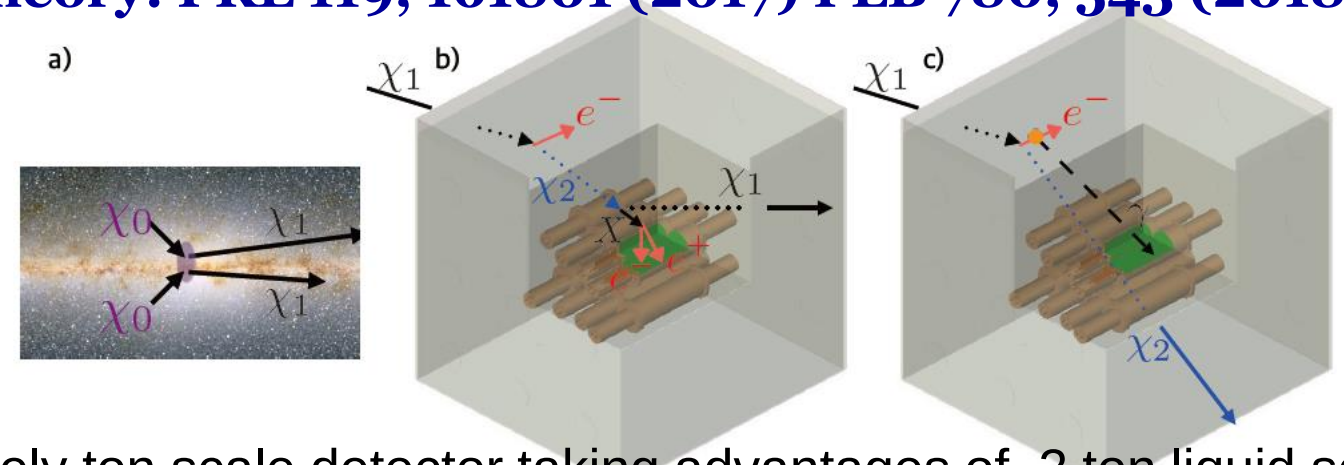




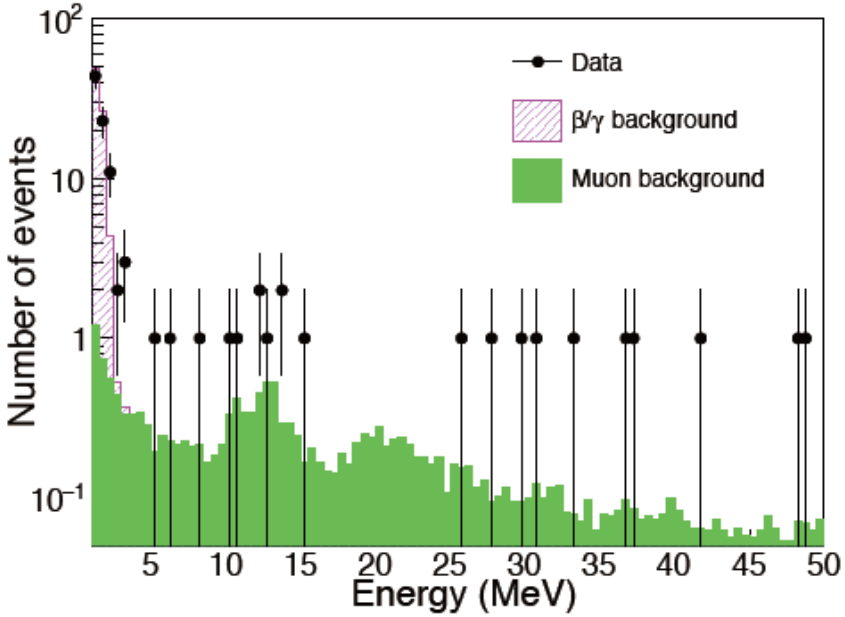


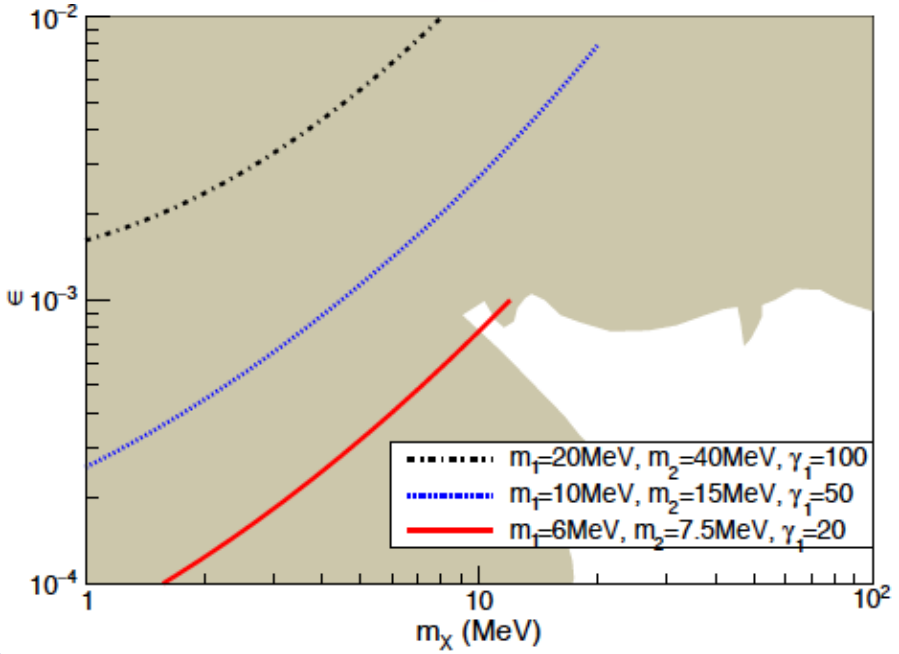
Boosted inelastic dark matter search

Theory: PRL 119, 161801 (2017) PLB 780, 543 (2018)

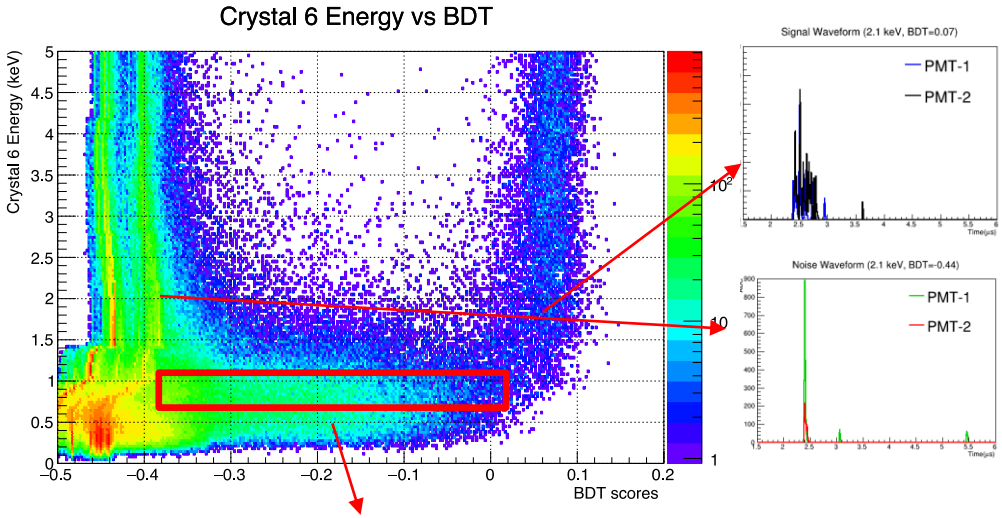


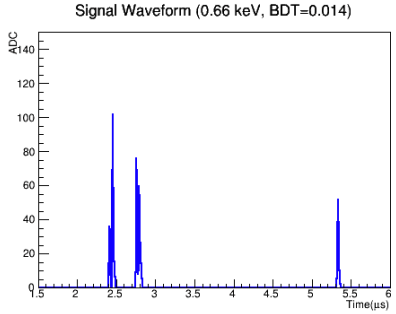
Effectively ton scale detector taking advantages of 2 ton liquid scintillator

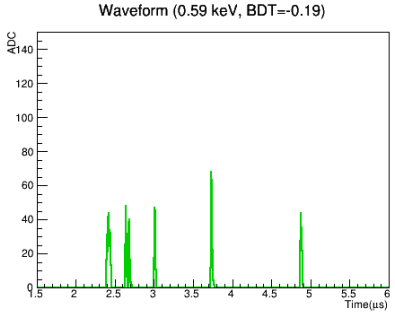


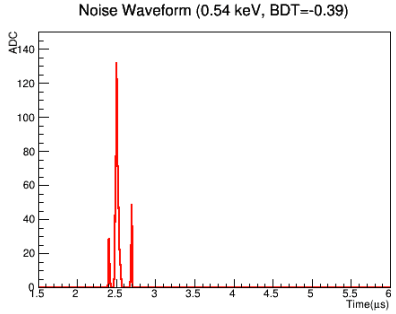


Analysis with 1 keV energy threshold





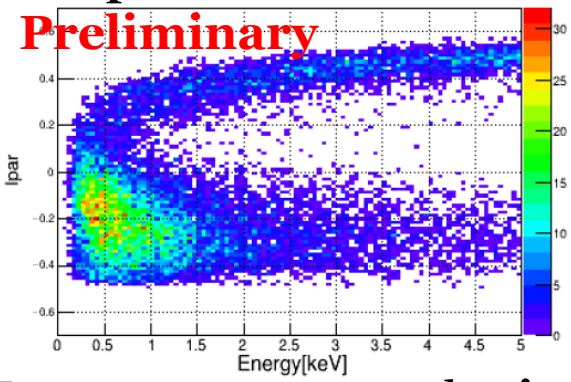




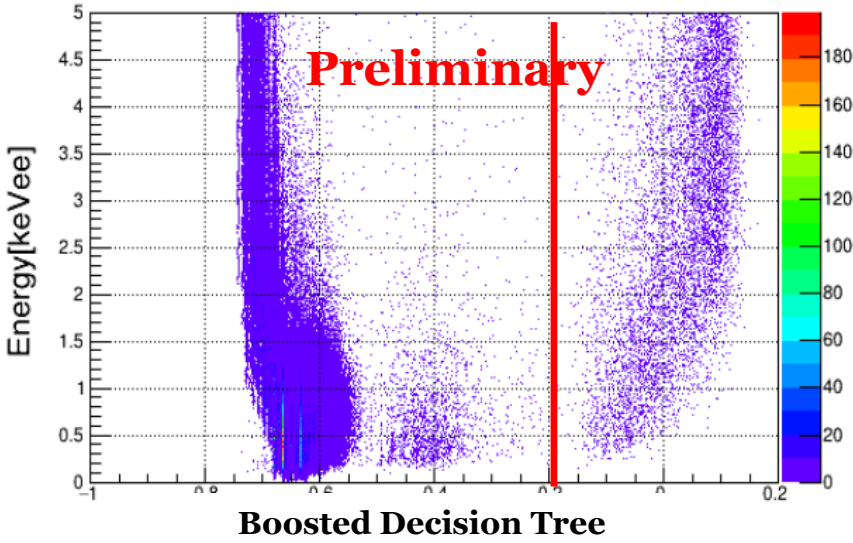
Understand signal-like events and noise-like events at low energy

Develop new parameter to reject noise-like events effectively

Likelihood parameters for noise rejection

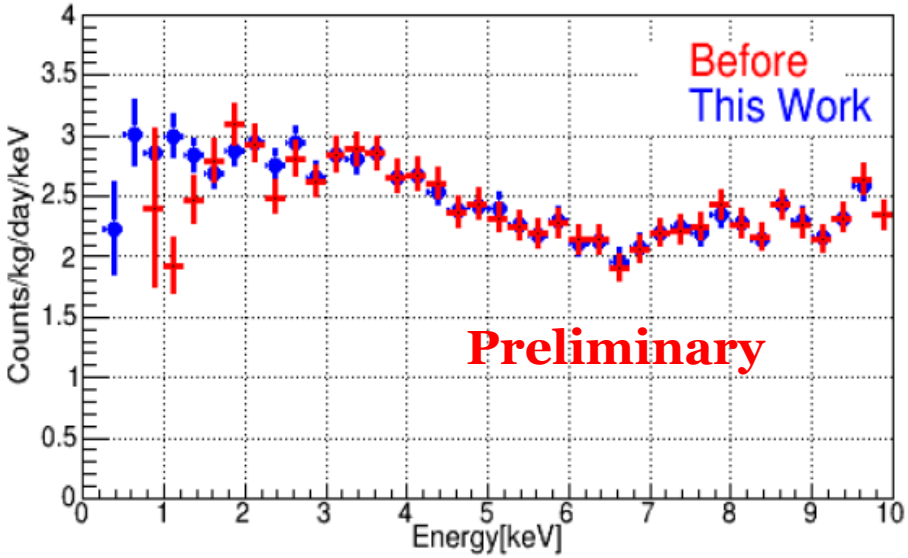


New parameters are used as **inputs for multi-variable technique** (boosted decision tree)

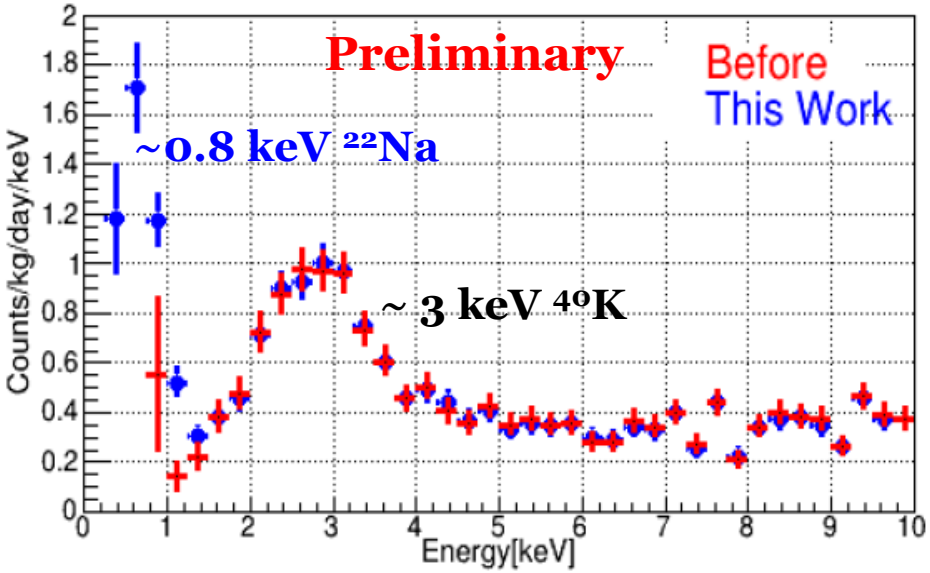


Analysis threshold < 1keV

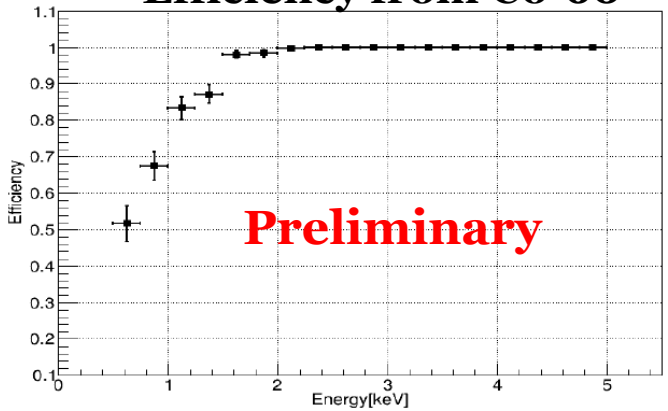
Single hit spectrum



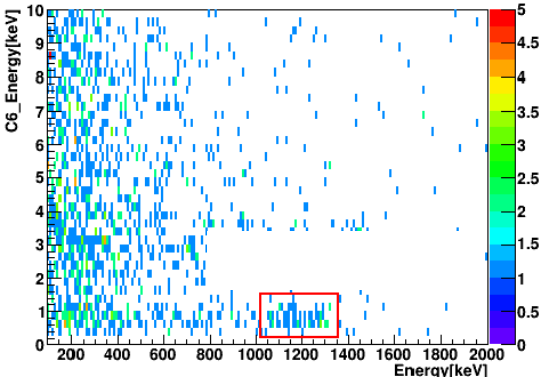
Multiple hit spectrum

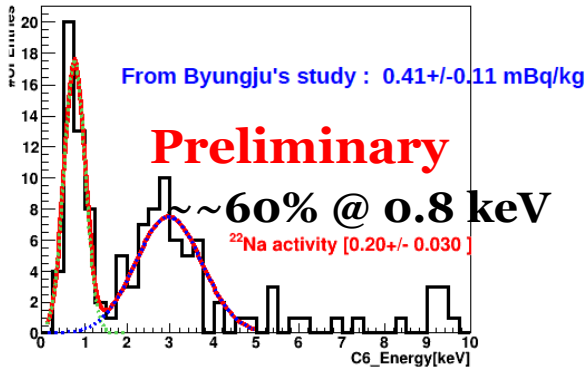


Efficiency from Co-60



Efficiency of Na-22 (0.8 keV)



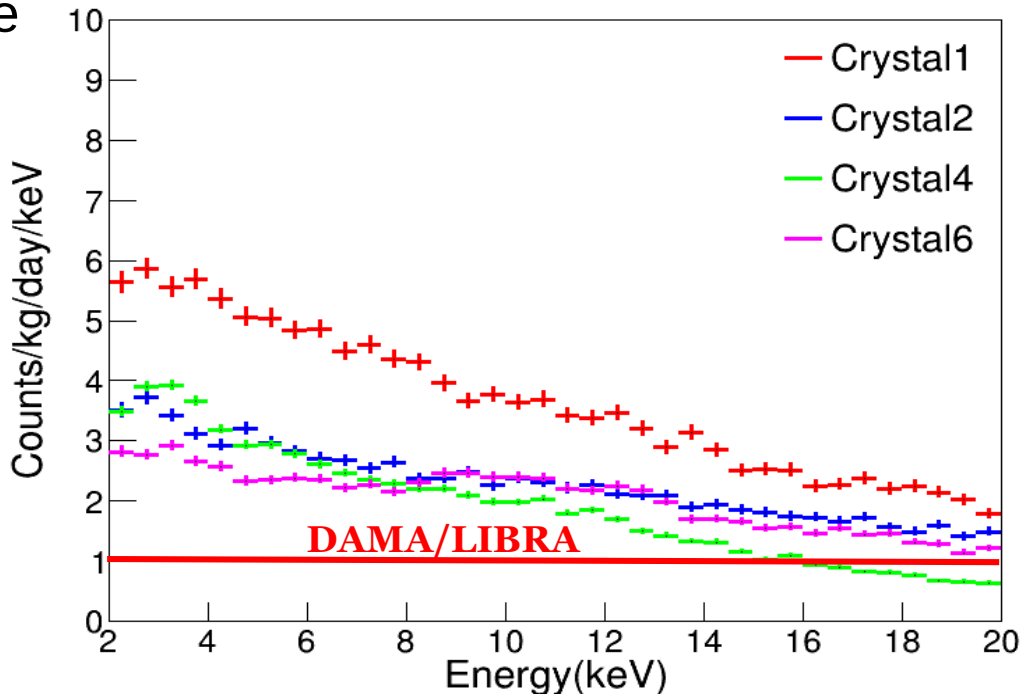


- We can reduce our threshold below 1keV
- Better comparison with DAMA/LIBRA-phase2

Next phase of COSINE (COSINE-200)

- **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



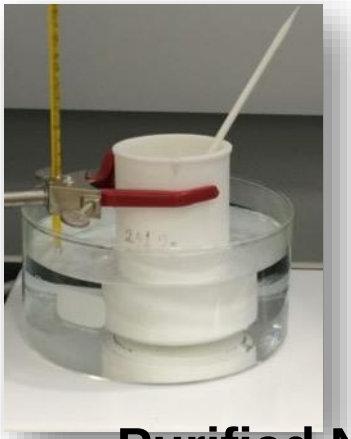
- **Extremely pure crystal** development
  - From initial materials to detector assembly, we need **very careful handling**
  - These are very **difficult jobs** for a private **company**
  - We decided to do our own development for the entire process

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

NaI powder purification (Lab experiment)

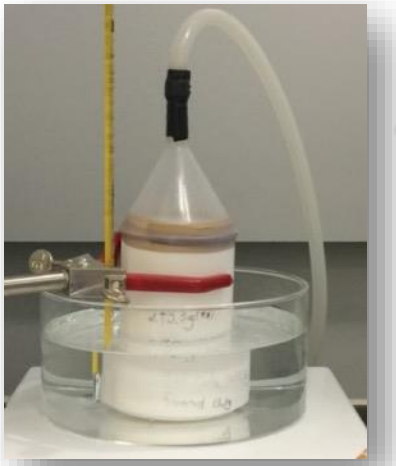
- Recrystallization

Saturated NaI solution @ 25 ° C



T↑ 110 ° C

Evaporation of 40 % of H_2O under vacuum



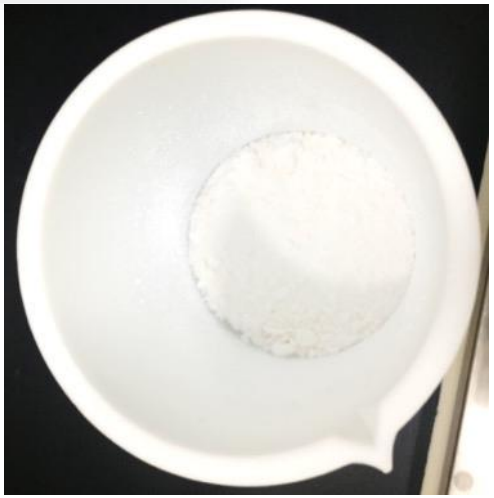
T↓ 25 ° C

Crystallization: Cooling down with stirring

NaI crystal

Drying crystal under vacuum @ 130 ° C

Purified NaI powder



Purification of NaI powder

- Recrystallization three times for normal grade while one times 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 : ~ 10 reduction
- Pb: ~ 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

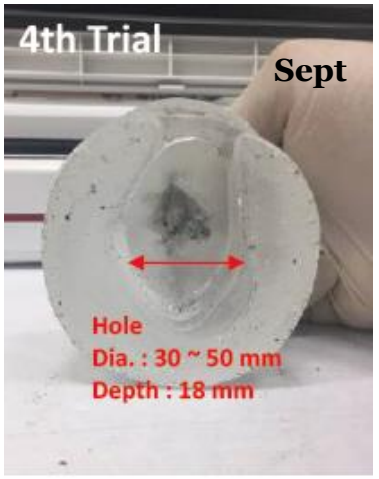
Our system is more effective than small experiment

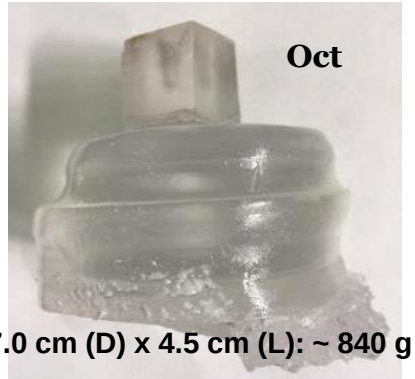
Crystal growing

- Small crystal grower was installed at 2017

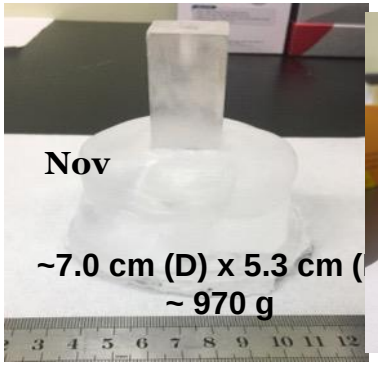
Crucible diameter is $\phi = 15$ cm;
1~2 kg test crystal can be grown

2017 summer

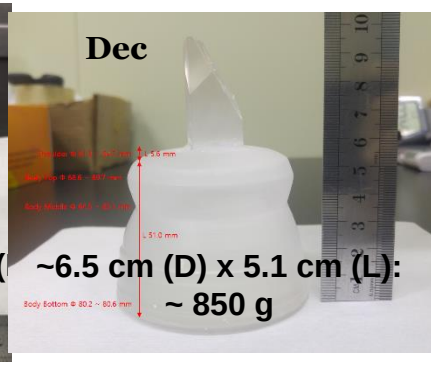




~ 7.0 cm (D) x 4.5 cm (L): ~ 840 g



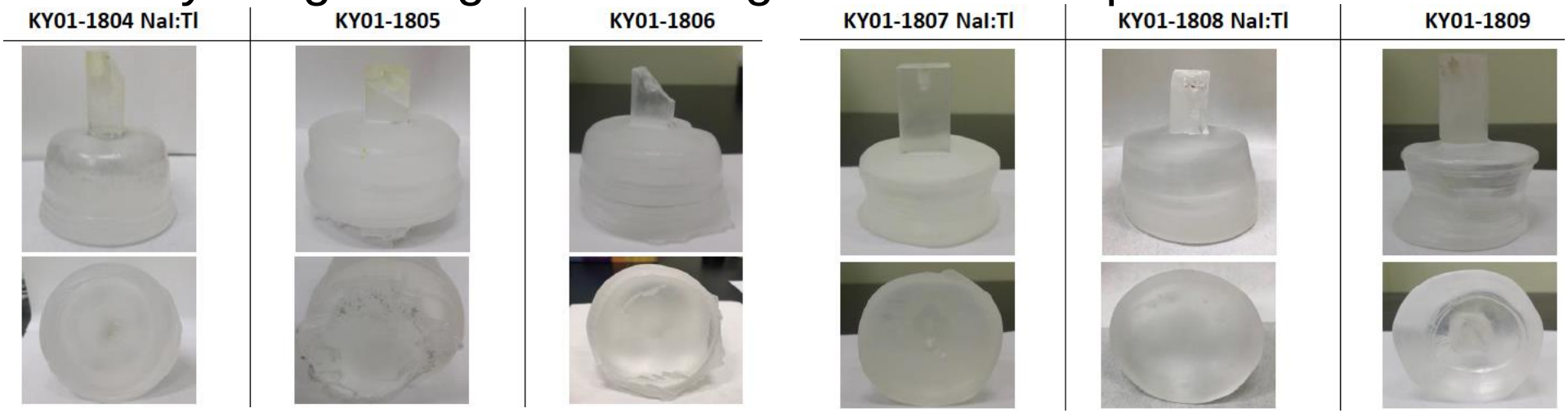
~7.0 cm (D) x 5.3 cm (
~ 970 g



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

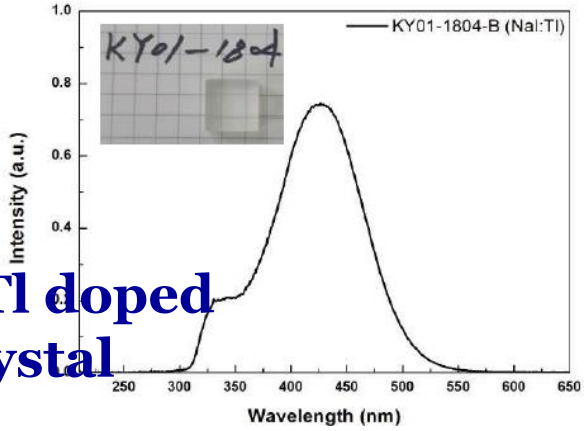
NaI growing @ 2018

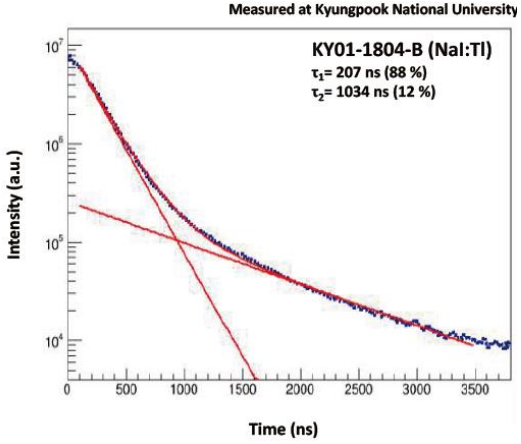
- Crystal growing with small grower is well optimized

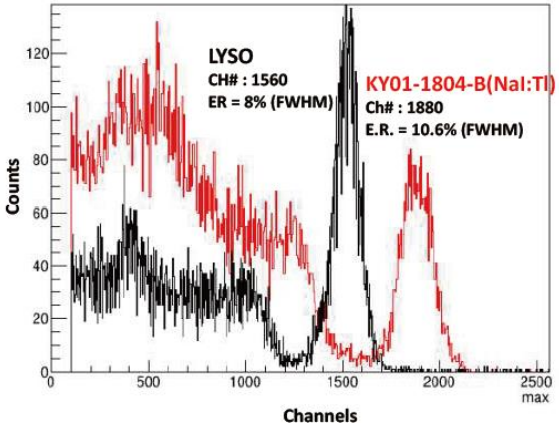


Feb/2018

First Tl doped crystal



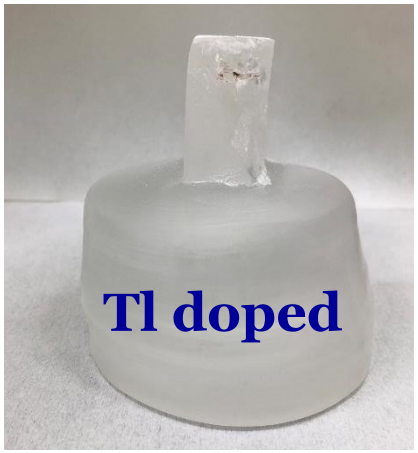


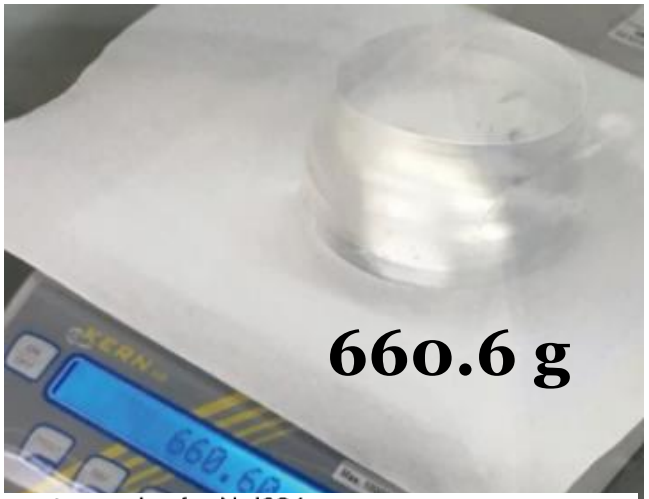


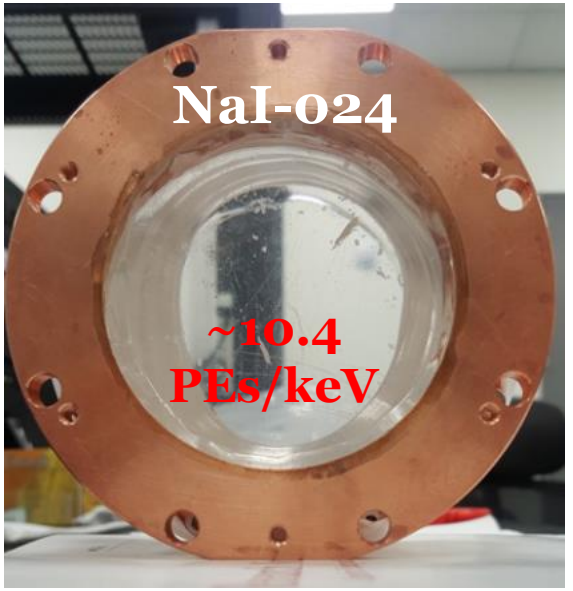
~40,000 Photons/MeV

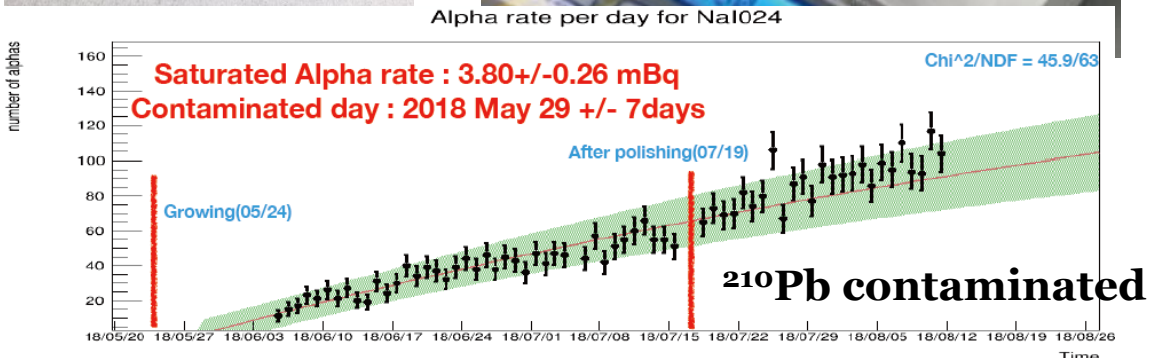
Detector assembly with small crystal

May/2018









- Demonstrated quick detector assembly and underground measurements!!
- Need to prove low background crystal.
- Due to IBS HQ laboratory movement, NaI growing was stopped last six months. It will be resumed from mid-December.

A full size grower

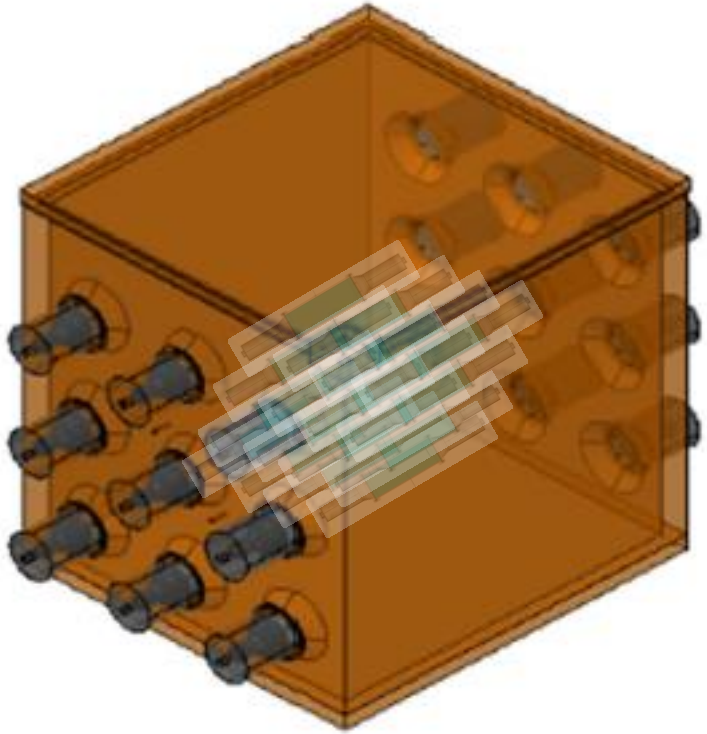
- Full size grower & annealing furnace were installed ($\phi = 60$ cm)
  - ❖ Similar growing machine as the DAMA/LIBRA crystals
  - ❖ Maximum powder loading :120 kg
    - ❑ About three full size detectors (12.5 kg) per ingot

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

COSINE-200

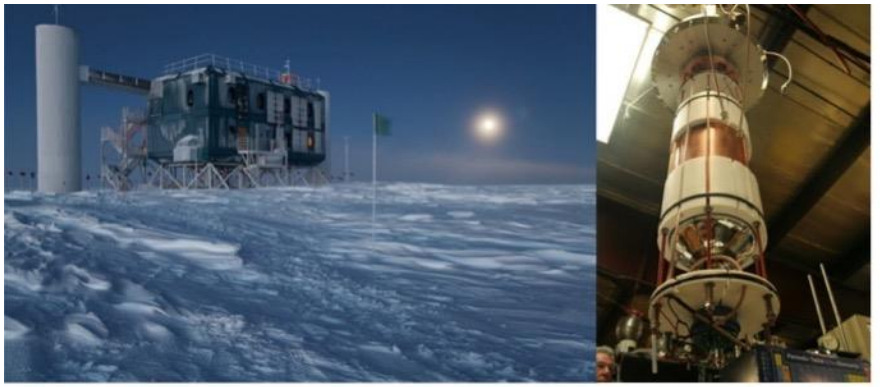
- Current COSINE-100 shield designed to accommodate 16 of 12.5 kg crystals = 200 kg

Total 200 kg



Y2L

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

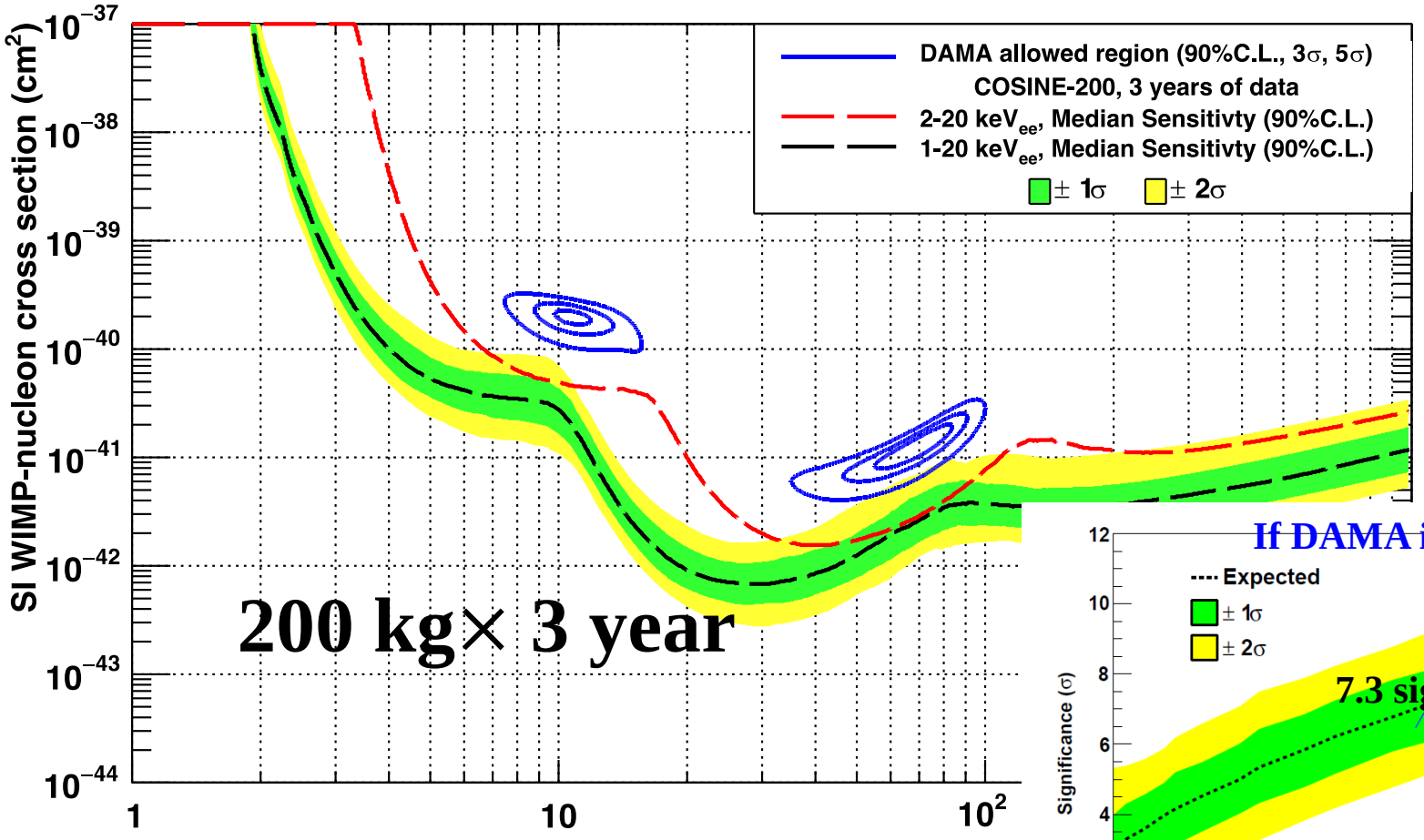


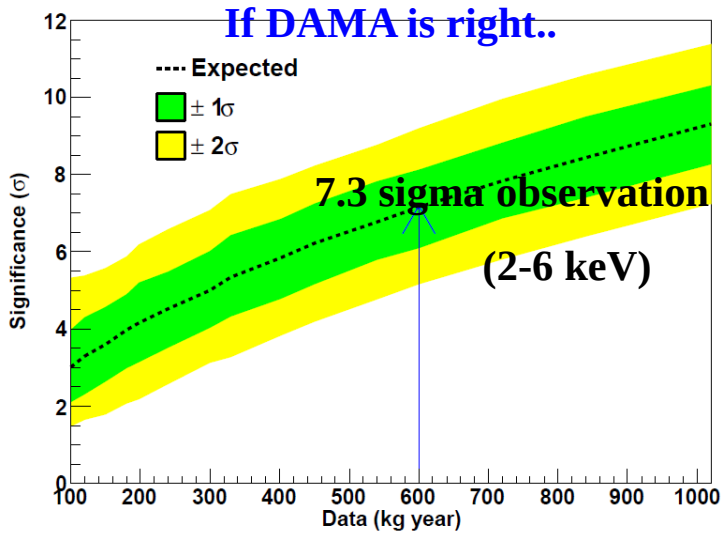
Under consideration

2022-2023 (IceCube upgrade)

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 runs smoothly for more than 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 with same NaI(Tl)
  - Comparison with DAMA/LIBRA-phase2 are ongoing
- Modulation analysis of COSINE-100 is ongoing
- Preparing 1keV threshold (or below) analysis

- COSINE-200 is under preparation
  - Unambiguous conclusion for the DAMA/LIBRA signals
  - Goal to start ~200 kg experiment at 2020 with less than 1dru background