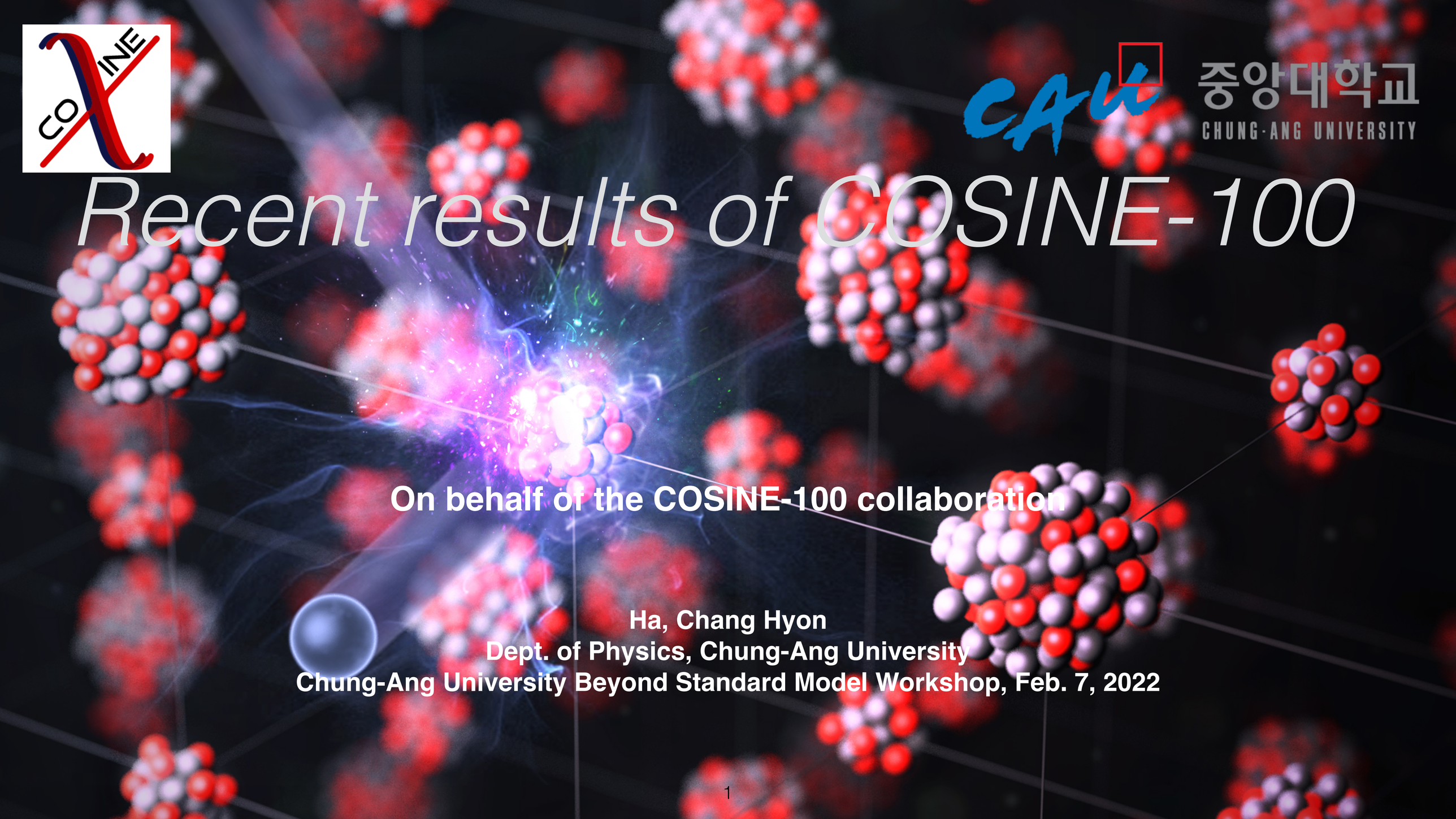


Recent results of COSINE-100

On behalf of the COSINE-100 collaboration

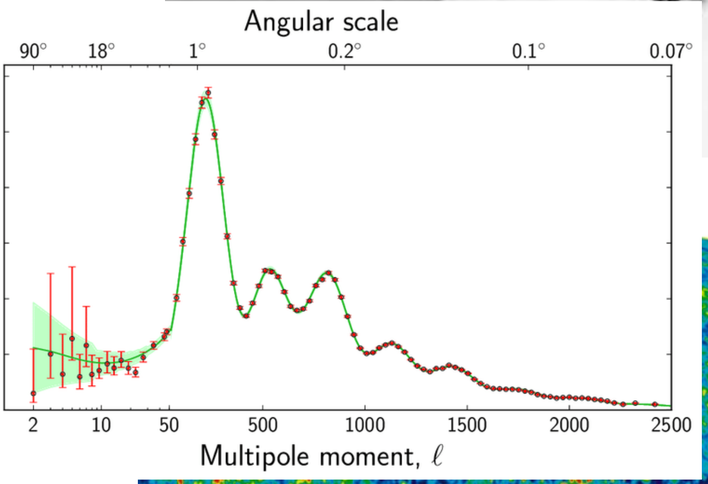
Ha, Chang Hyon
Dept. of Physics, Chung-Ang University
Chung-Ang University Beyond Standard Model Workshop, Feb. 7, 2022

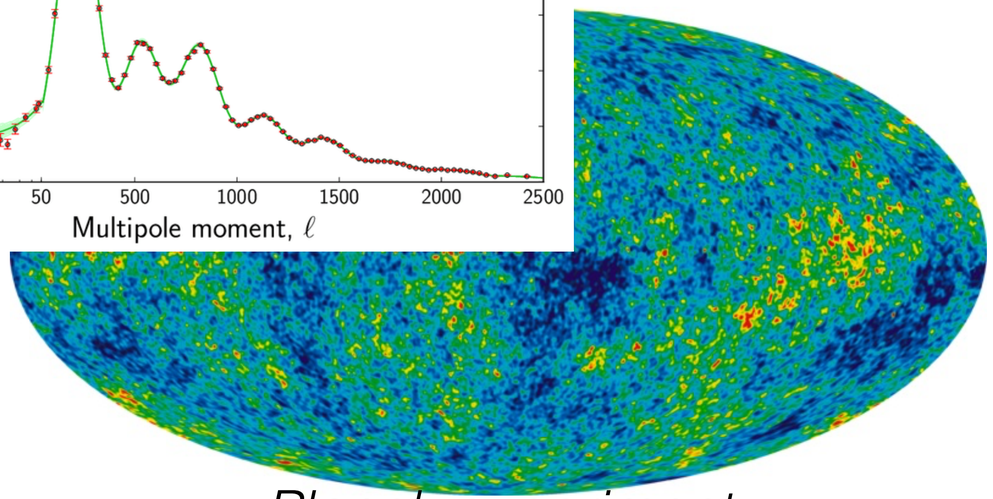
Big Question : What is Universe made of?
Universe is full of Dark Matter!

Zwicky (1933)
Dunkle Materie"

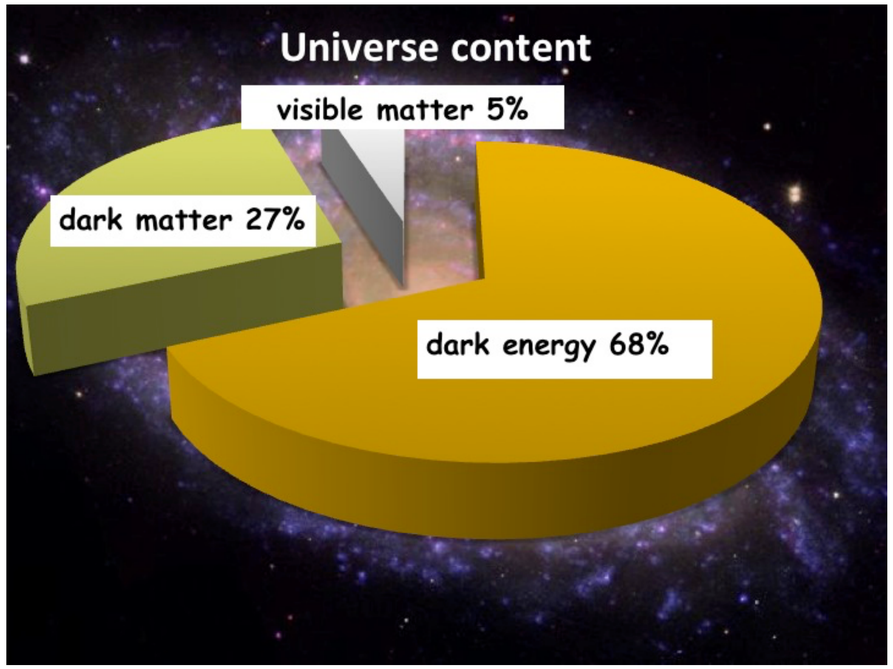
mysterious matter that
holds galaxies together with no light (Coma Cluster)

galaxy velocity curve,
gravitational lensing and
cosmic microwave background



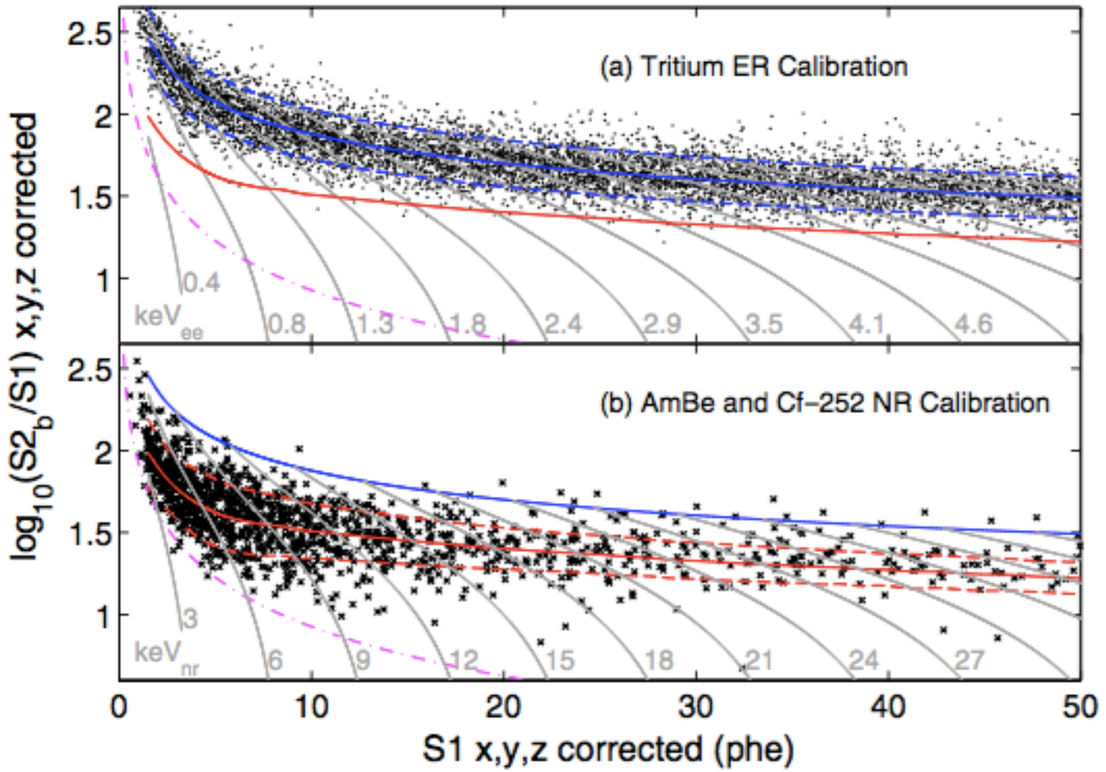


Planck experiment



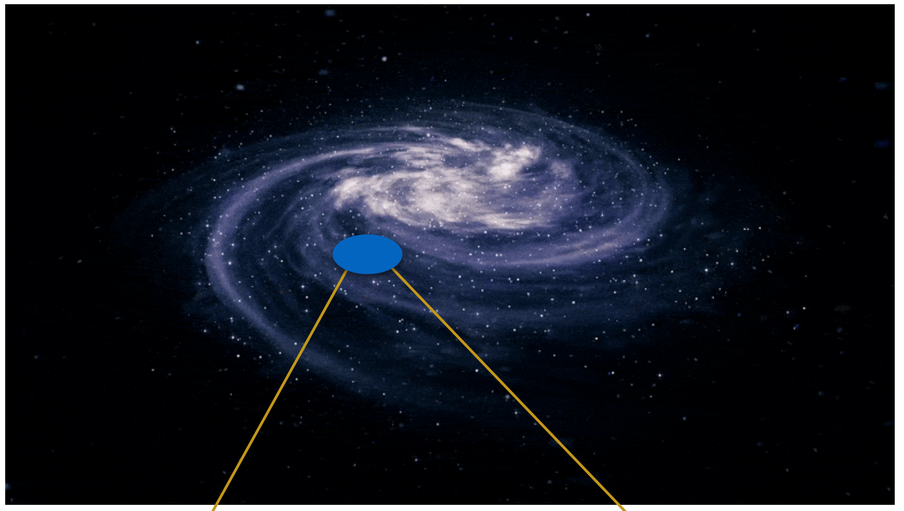
WIMP Signals & Backgrounds

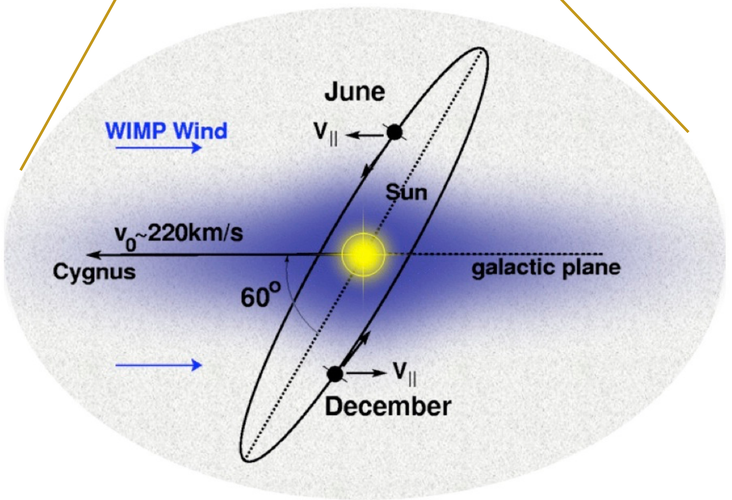
Discrimination of nuclear recoils (Signal) from electron/gamma recoils(Background)



LUX Collaboration, Phys. Rev. Lett., (2014)

Rate Analysis

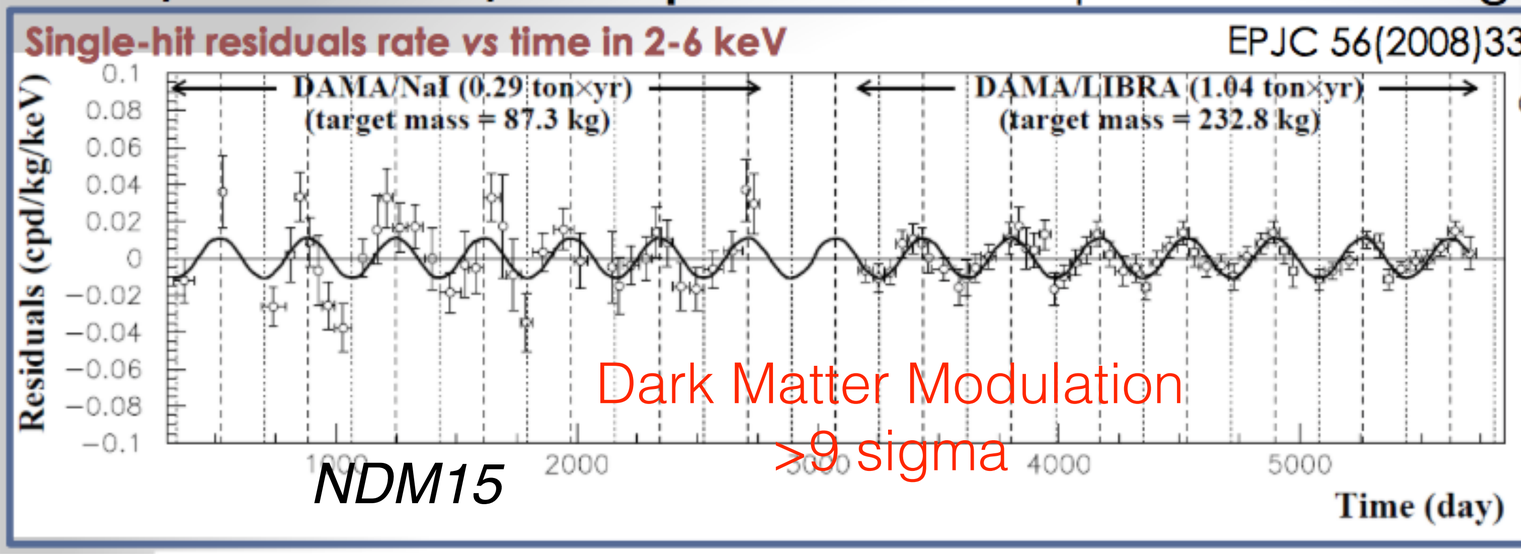




Annual modulation signal

The DAMA annual modulation signal, to be confirmed with independent measurements by the same NaI(Tl) target material

DAMA/NaI + DAMA/LIBRA-phase1 Total exposure: 487526 kg×day = **1.33 ton×yr**



EPJC 56(2008)333, EPJC 67(2010)39, EPJC 73(2013)2648

continuous line: t_0 = 152.5 d, T =1.0 y

A=(0.0110±0.0012) cpd/kg/keV

χ^2/dof = 70.4/86 9.2 σ C.L.

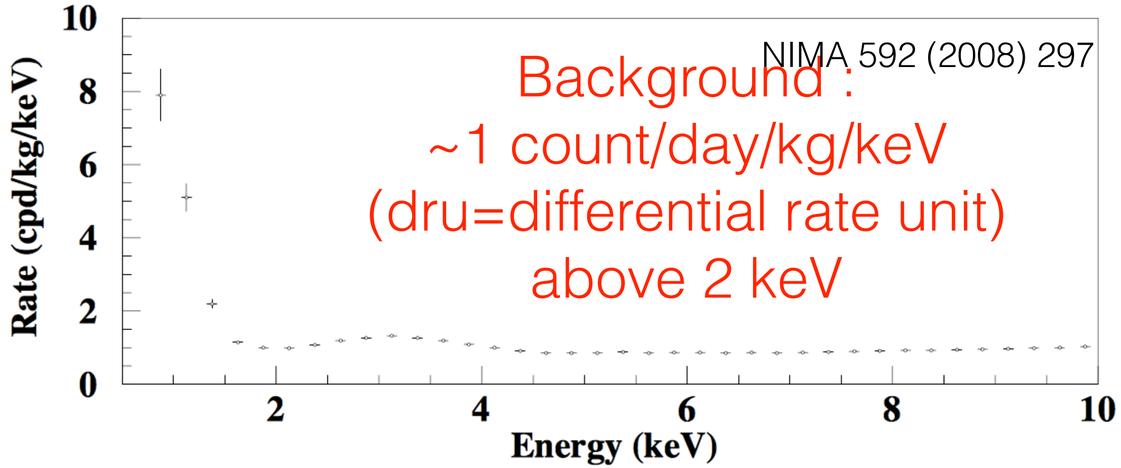
Absence of modulation? No

χ^2/dof=154/87 P(A=0) = 1.3×10^{-5}

Fit with all the parameters free:

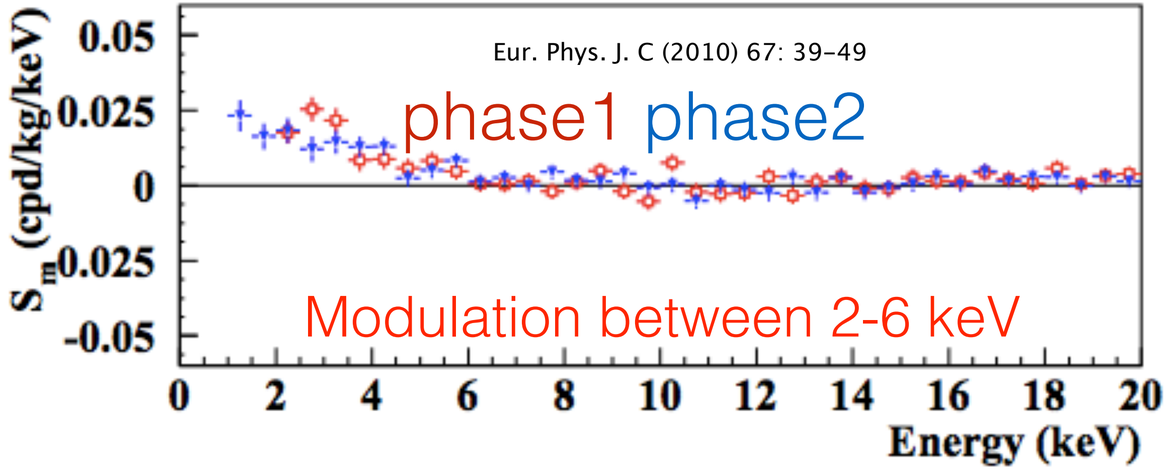
A = (0.0112 ± 0.0012) cpd/kg/keV

t_0 = (144±7) d - T = (0.998±0.002) y



NIMA 592 (2008) 297

Background :
~1 count/day/kg/keV
(dru=differential rate unit)
above 2 keV



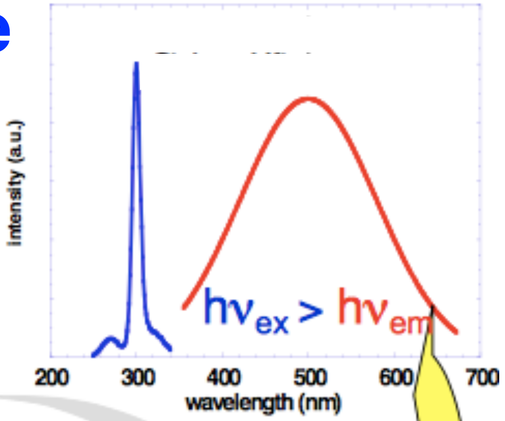
Crystal Scintillator Technology

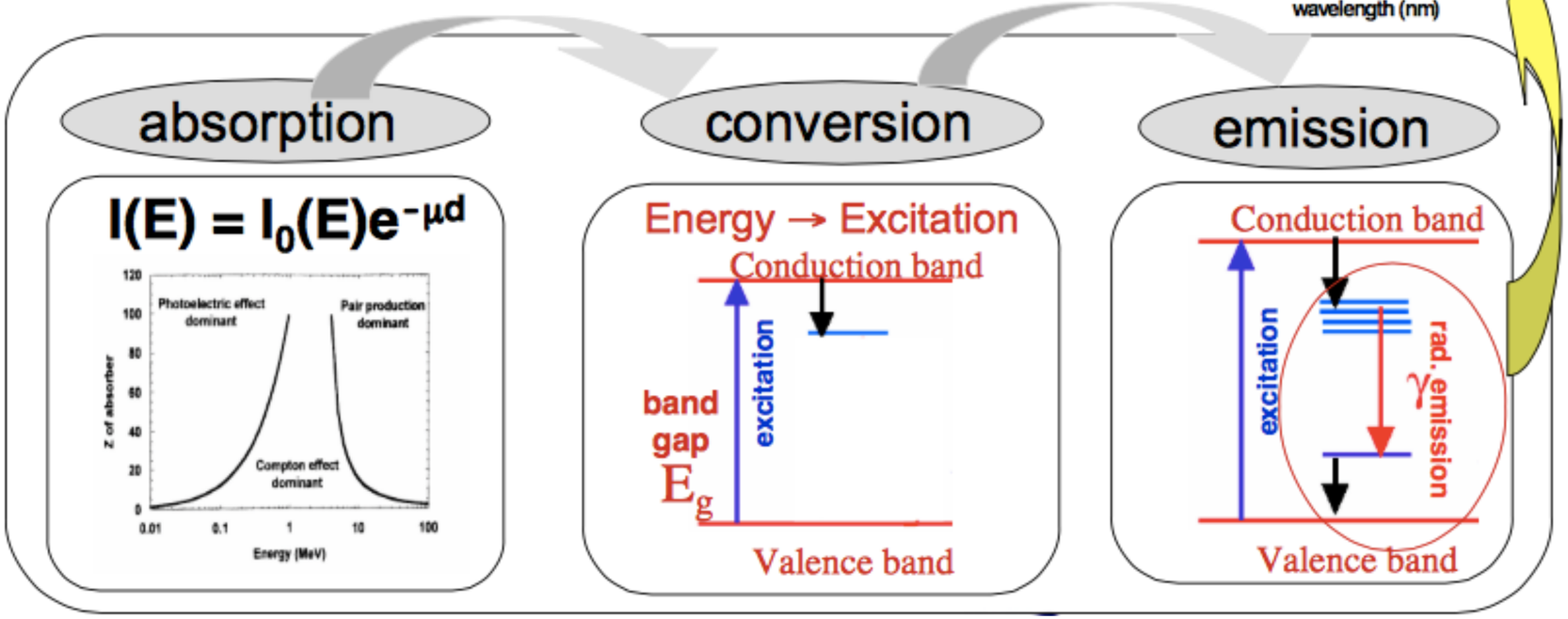
Goal : Collect as much visible light as possible

Scintillator + Photo Detector = Detector

PMT,PD,APD

How does it work

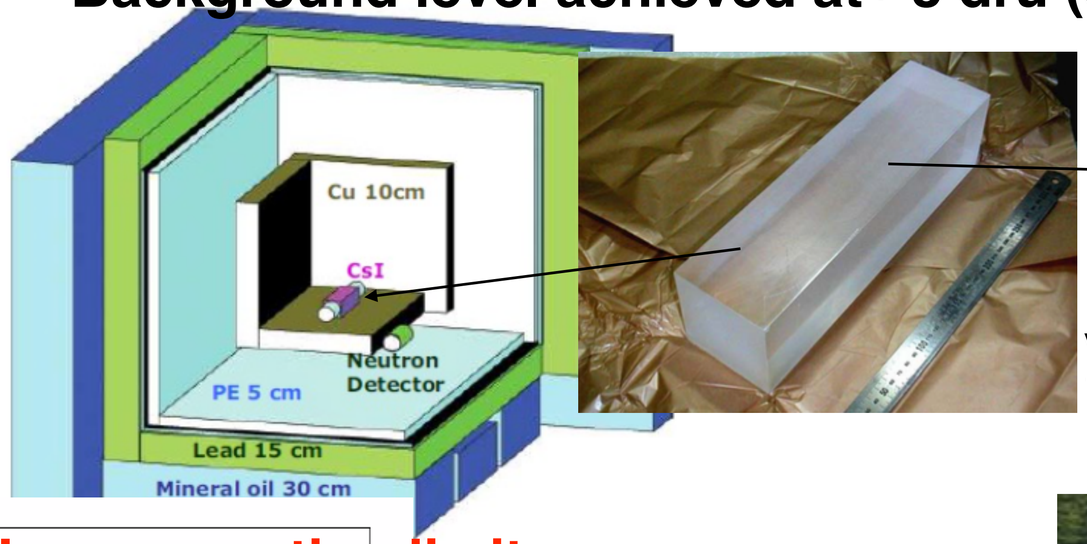




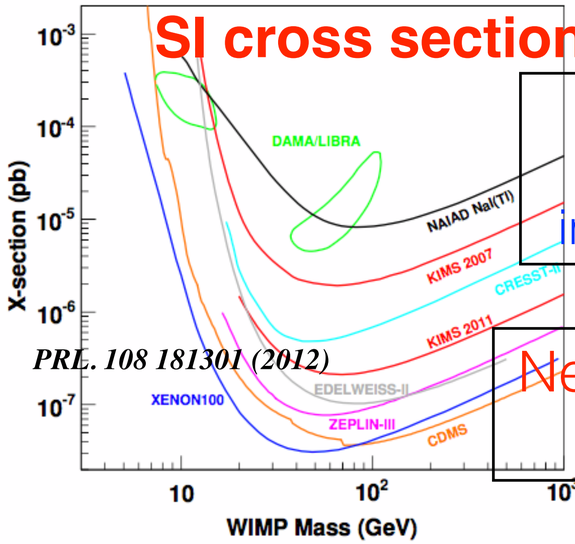
Good Resolution, Good Stopping power, Hygroscopic, Low scalability

Korea Invisible Matter Search : the KIMS experiment

12 CsI(Tl) 8.7 kg crystals (103 kg total)
Background level achieved at ~3 dru (counts/keV/kg/day) at 3 keV



SI cross section limit

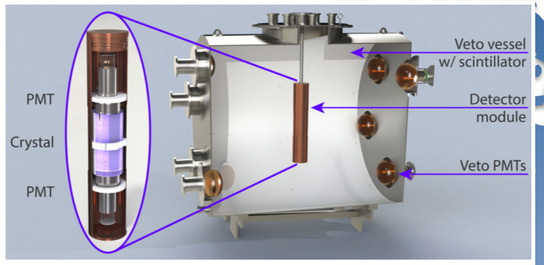


PRL. 108 181301 (2012)

KIMS-CsI results
rejects DAMA signal
in WIMP-Iodine interactions

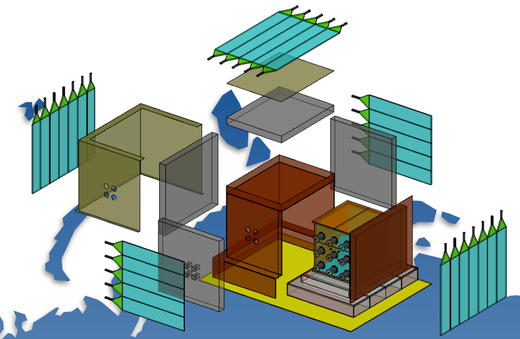
Need to investigate WIMP-Sodium interactions

Global NaI(Tl) efforts

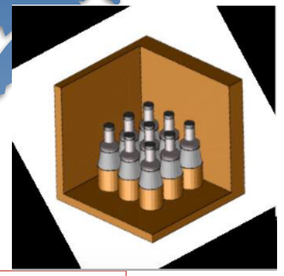


DAMA/LIBRA @ LNGS

SABRE @ LNGS

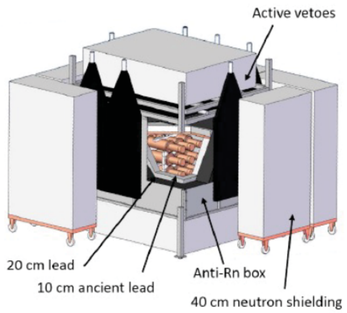


COSINE-100 @ Y2L

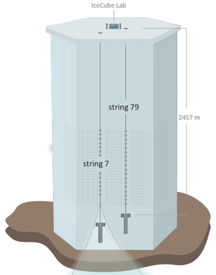


PICO-LON @ Kamioka

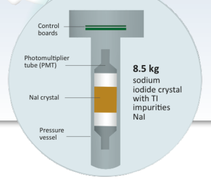
ANAIS @ Canfranc



SABRE @ Stawell



DM-Ice17 @ South Pole

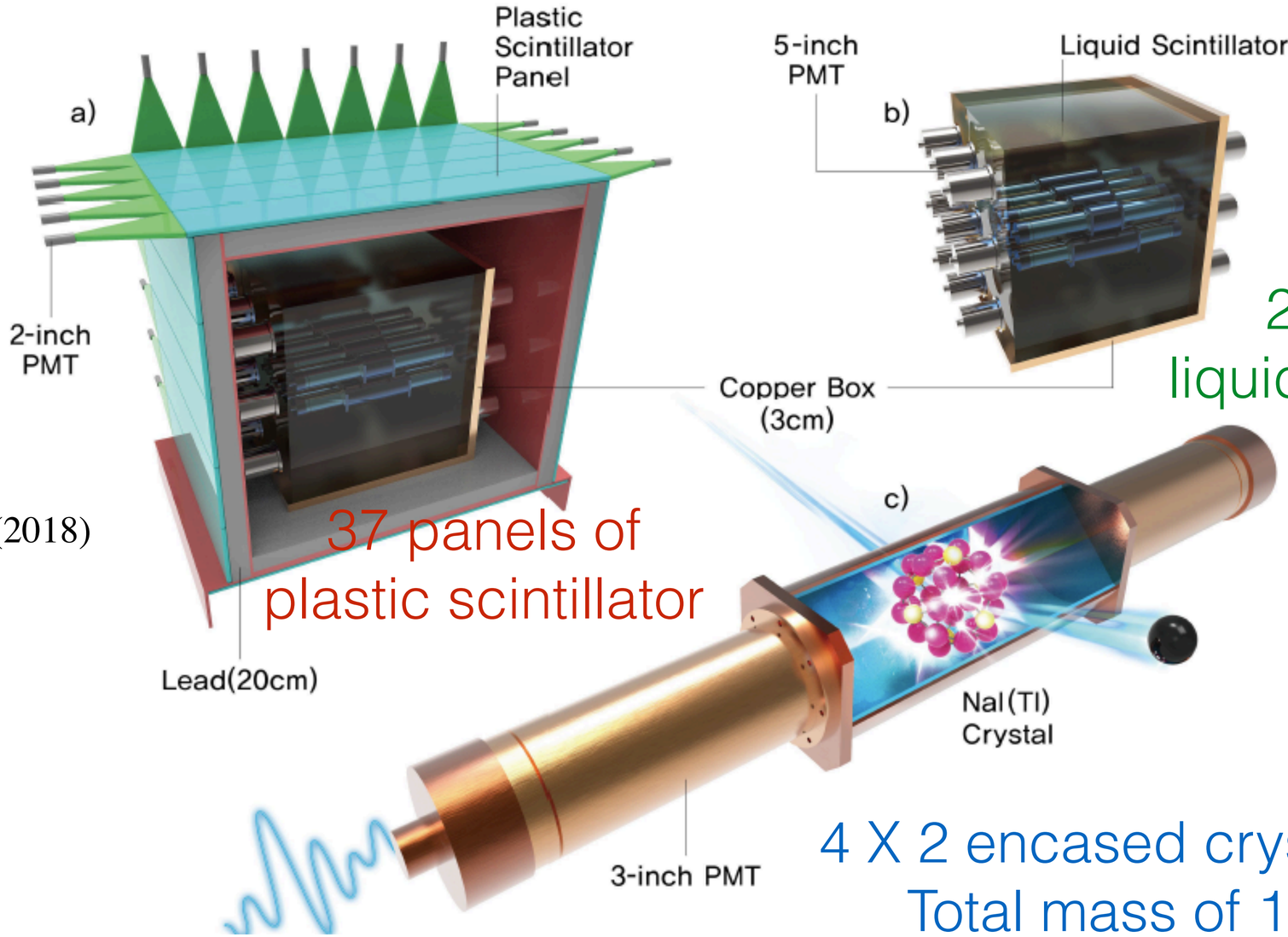


The COSINE-100 Experiment

5 countries,
15 institutes
50 scientists

Joint collaboration between KIMS and DM-Ice to search for dark matter interactions in NaI(Tl) scintillating crystals.

The COSINE-100 detector components



JINST13 T02007 (2018)

37 panels of
plastic scintillator

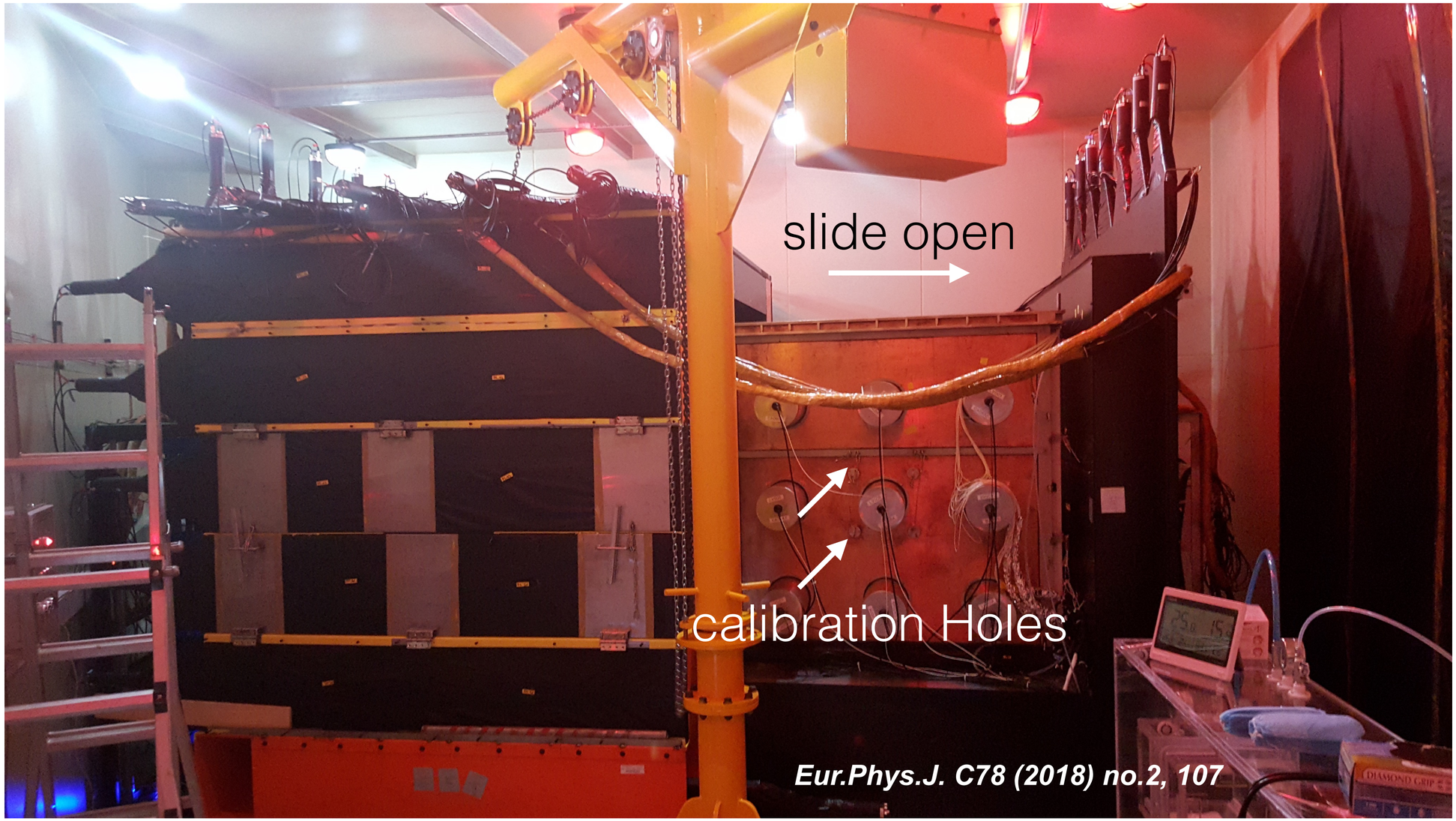
2 tons of
liquid scintillator

Nucl. Instrum. Meth. A 851 102 (2017)

4 X 2 encased crystal array
Total mass of 106 kg

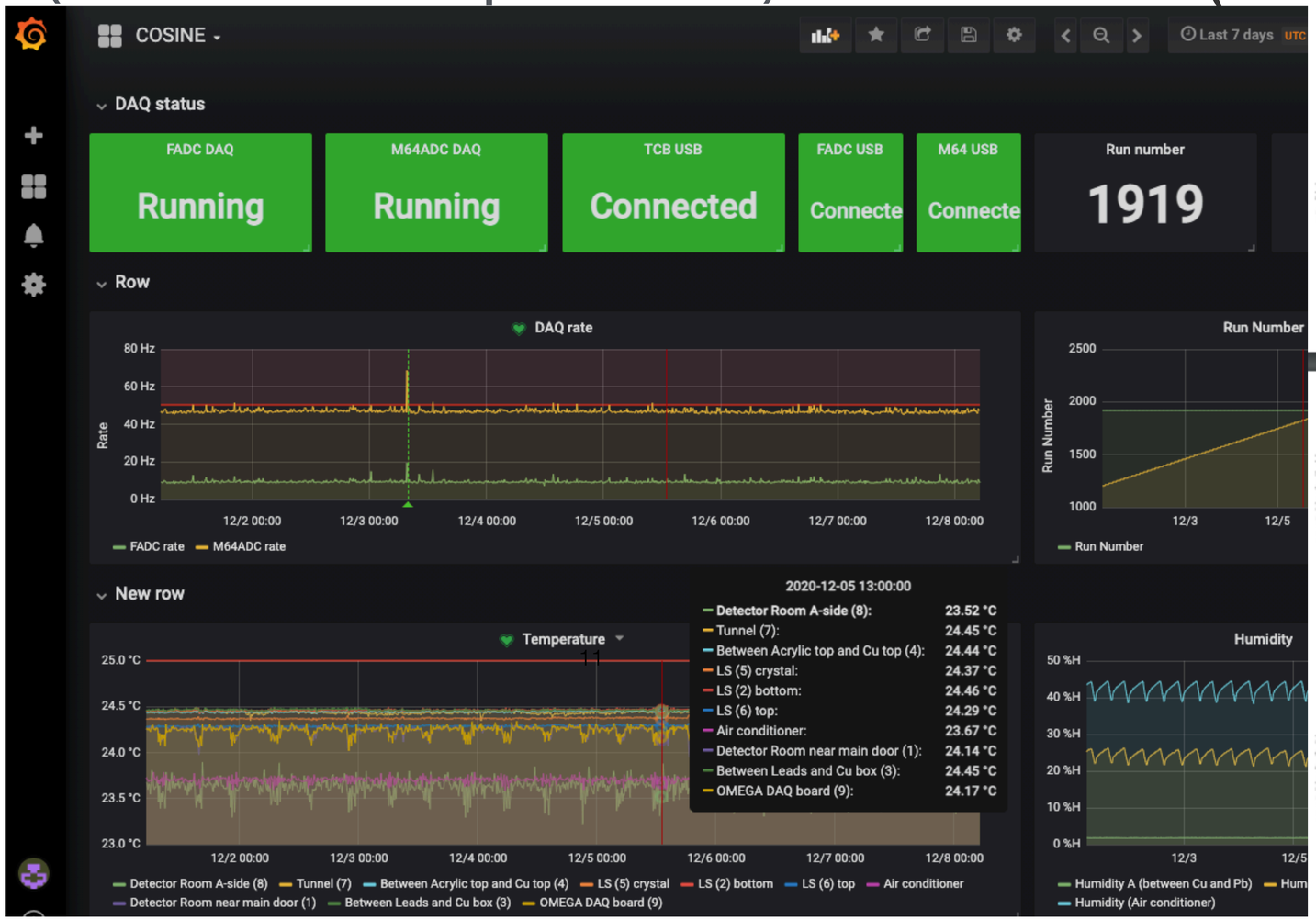
Eur. Phys. J. C. 78 107 (2018)

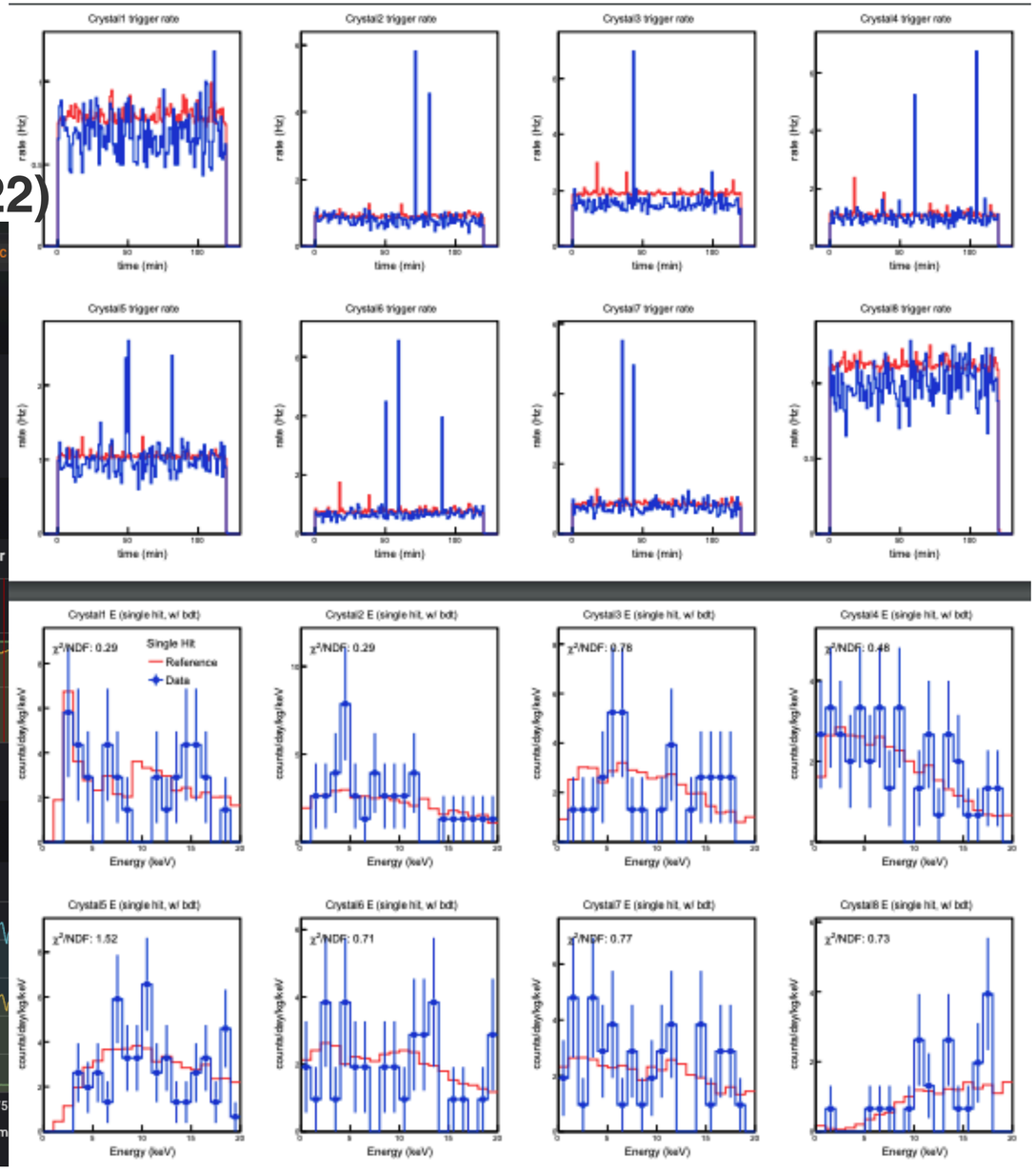
The COSINE-100 Detector



Data Monitoring (via Smartphone)

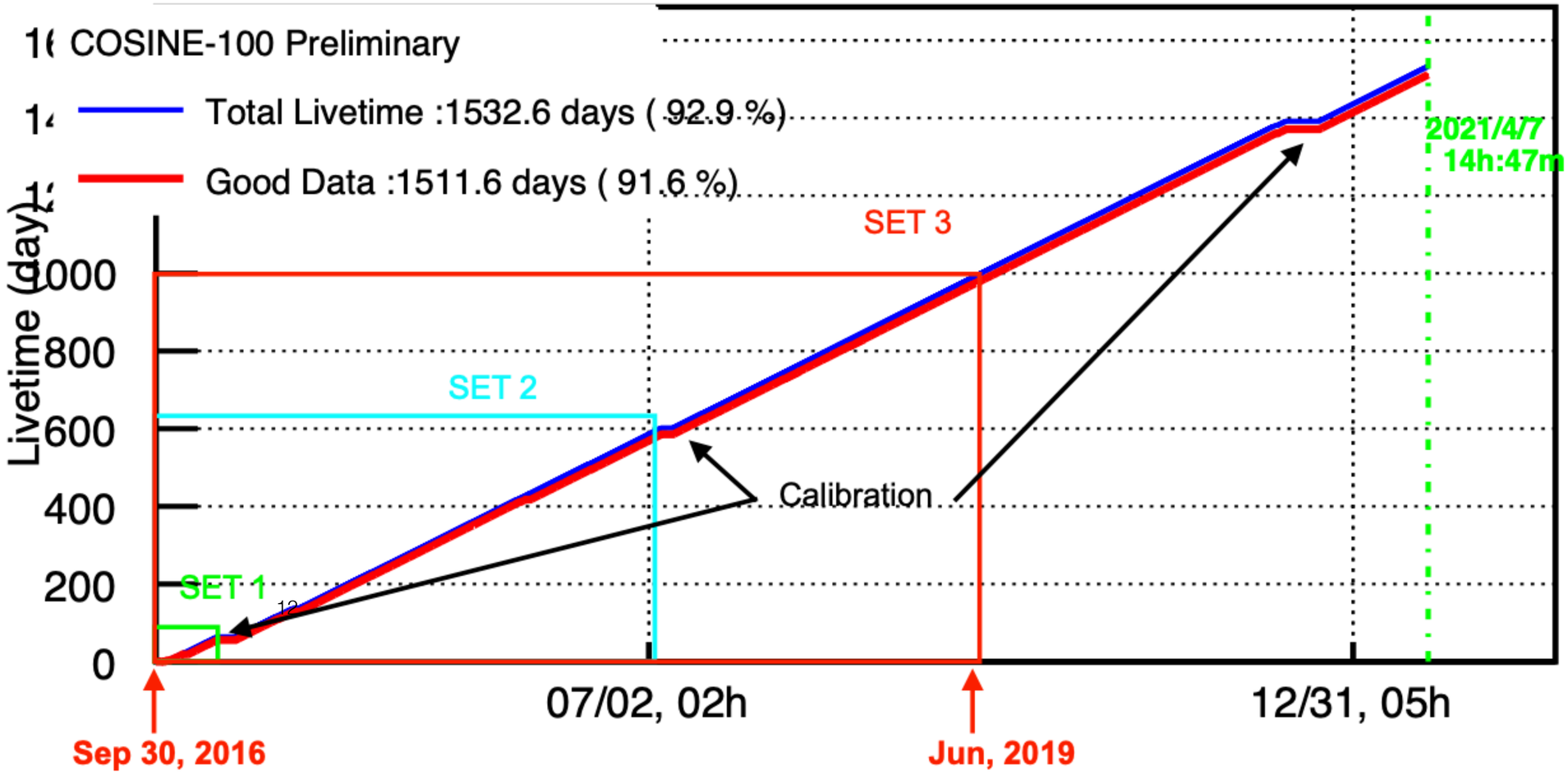
***JINST* 17 T01001(2022)**





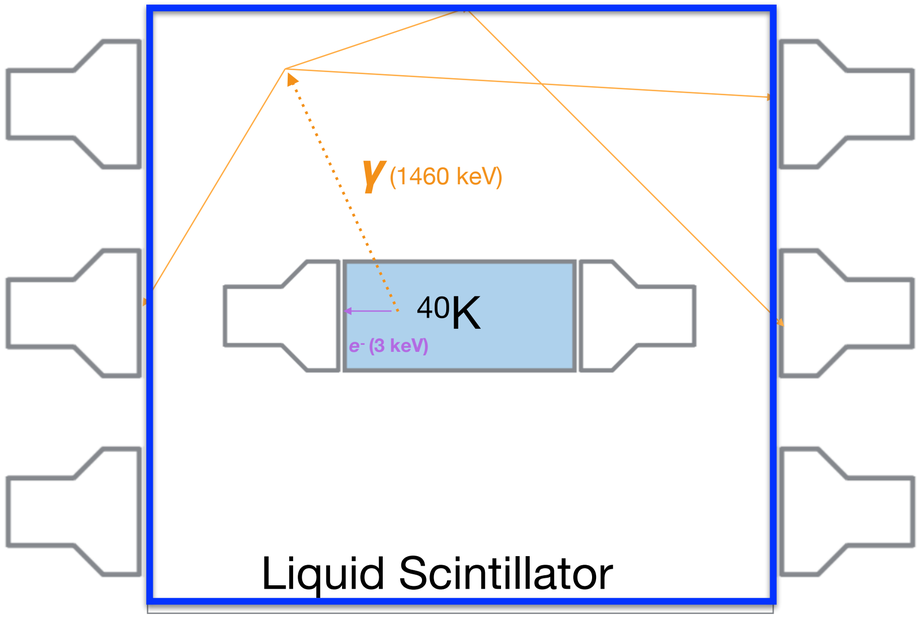
We monitor >100 parameters for the detector and Another 100 variables from data

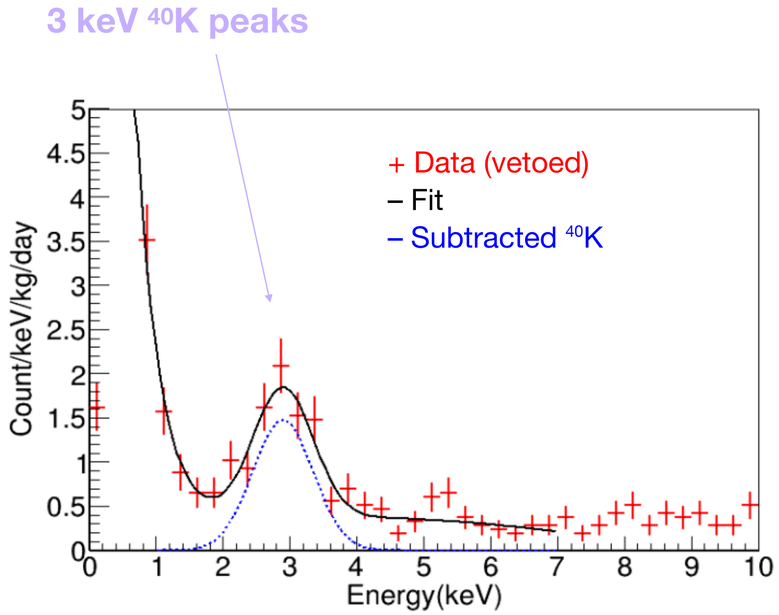
Exposure (Running for more than 5 years)

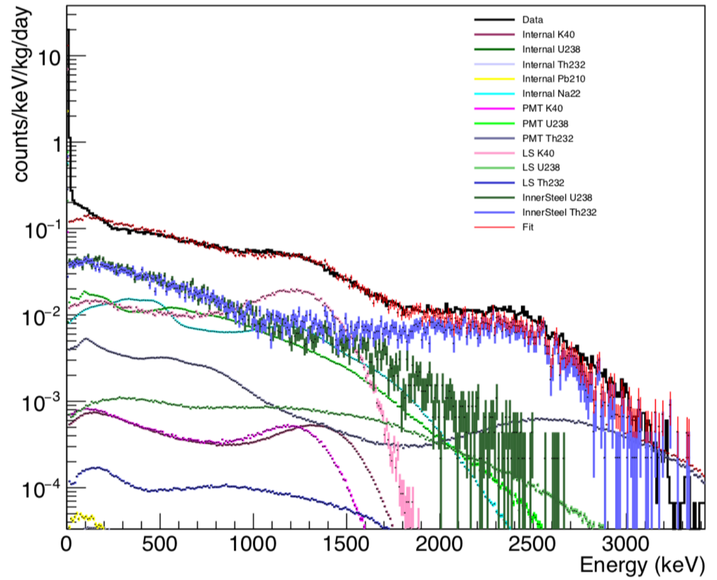


Stable running of the detector for 5 years. Good runs are more than 90%

Crystal-LS coincidence



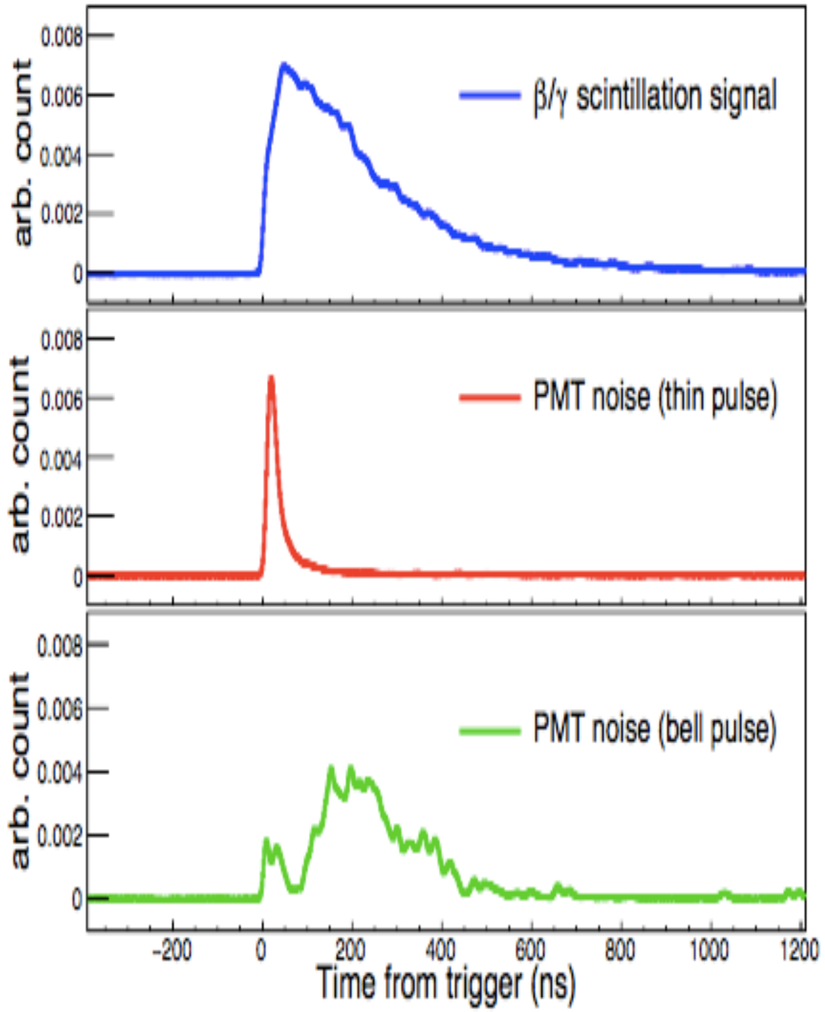


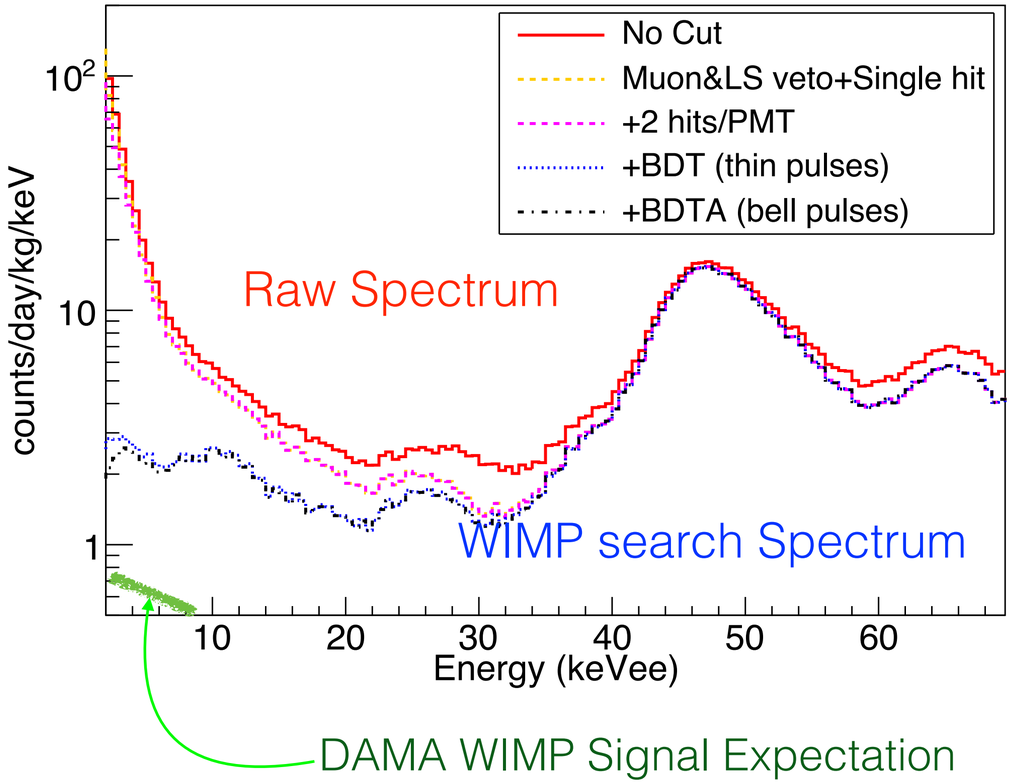


Nucl. Instrum. Methods A 1006, 165431 (2021)

- Liquid scintillator light is passively read out when there is a trigger in a crystal.
- A crystal trigger with LS energy deposit larger than 80 keV is defined as multiple hit events.
- ^{40}K emits 1460 keV gamma with 3 keV Auger electron energy deposition in NaI crystal
- Tagging 1460 keV events with LS enables **vetoing of 3 keV background events (70-80%)**
- Liquid scintillator internal contamination well modeled with simulation

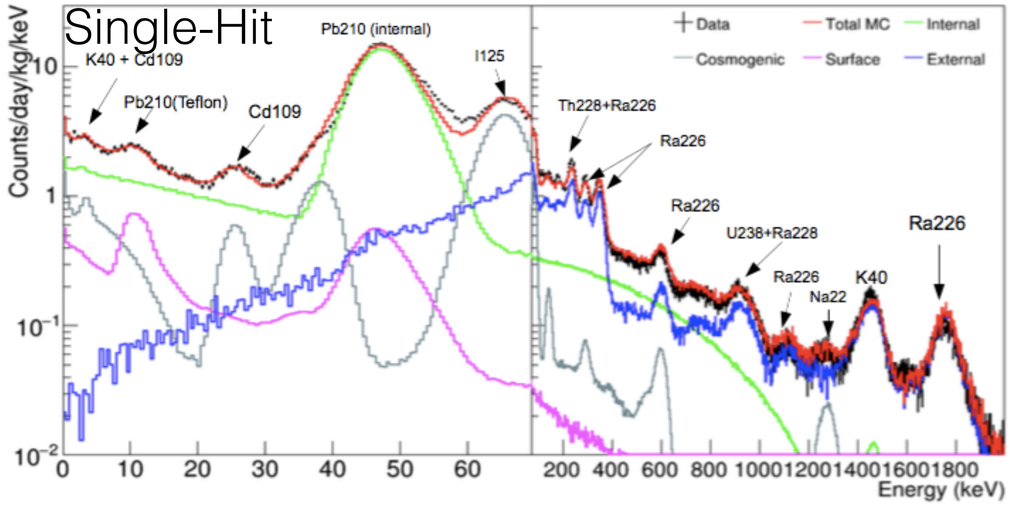
PMT noise reduction
Every experiment has noise and WIMP search=Noise Reduction

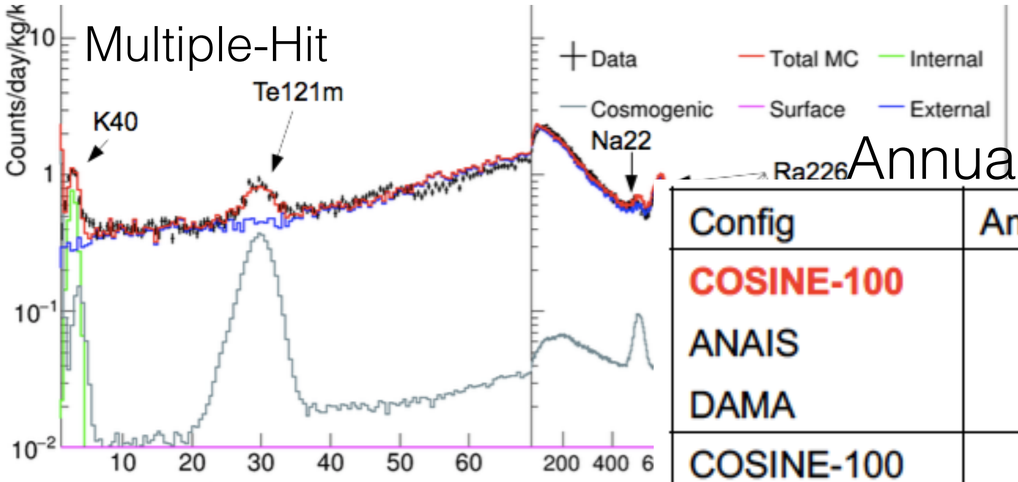




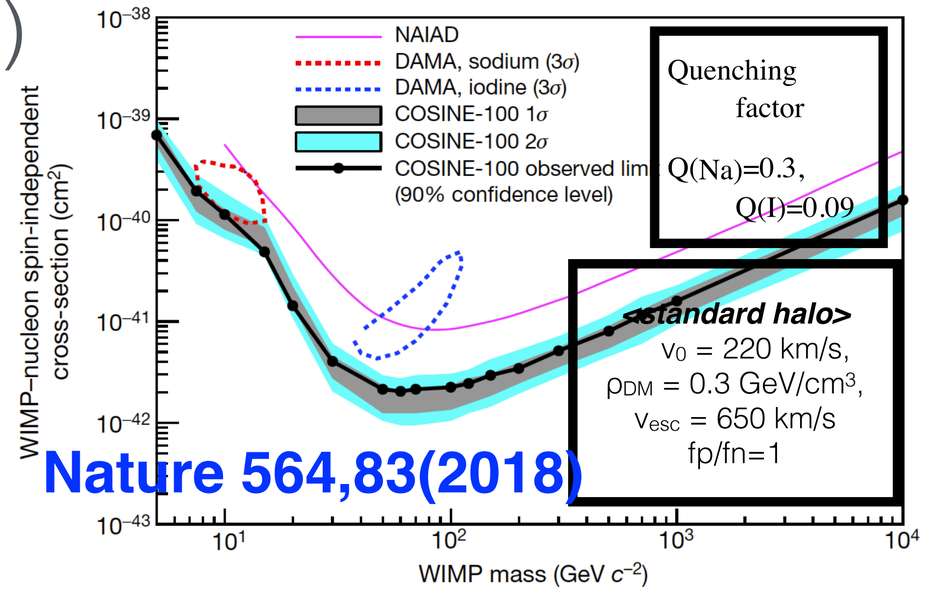
1. Constant Rate Analysis
2. Annual Modulation Analysis

COSINE-100 (2-keV Threshold Analyses)



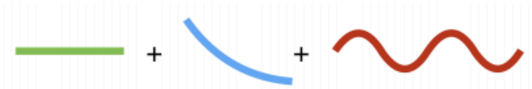


EPJC 78, 490 (2018)



Nature 564,83(2018)

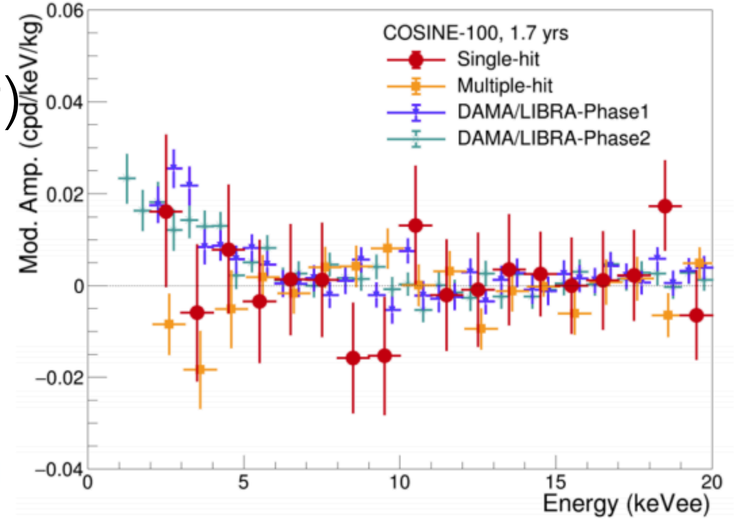
Offset + Exponential + Cosine is fit to data at 2-6 keV.



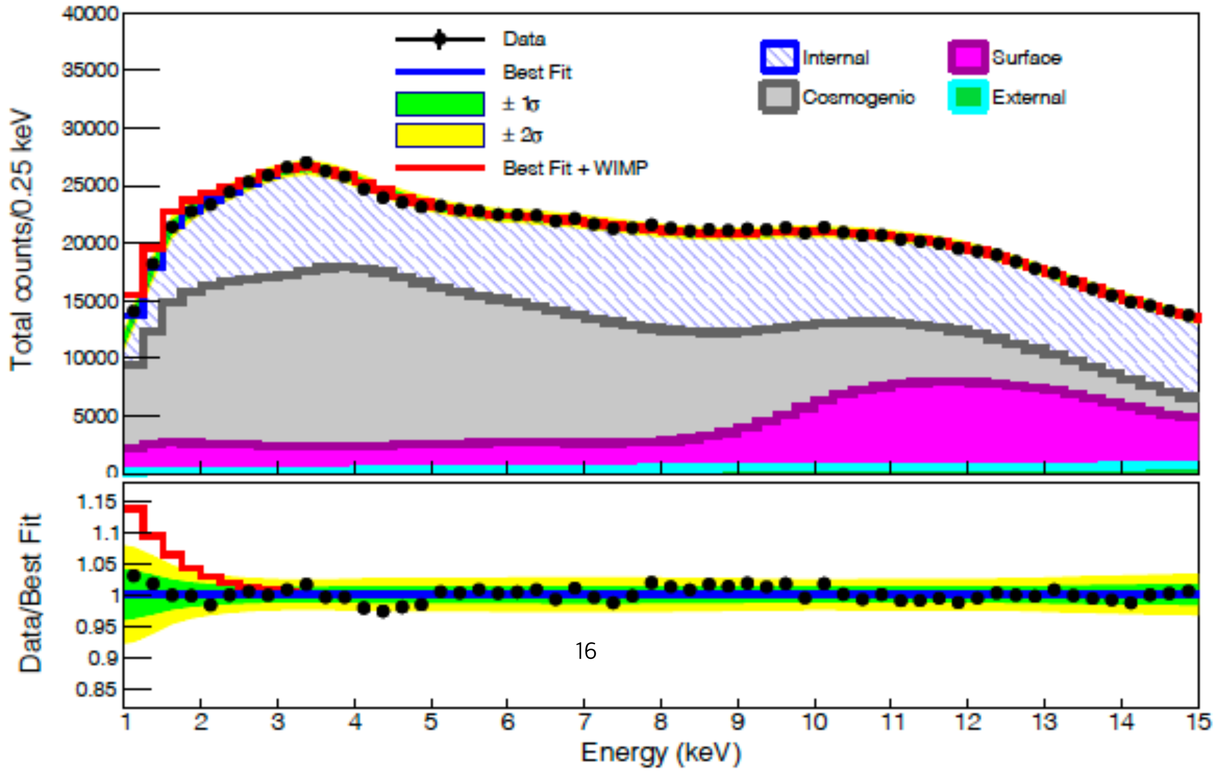
PRL 123,031302 (2019)

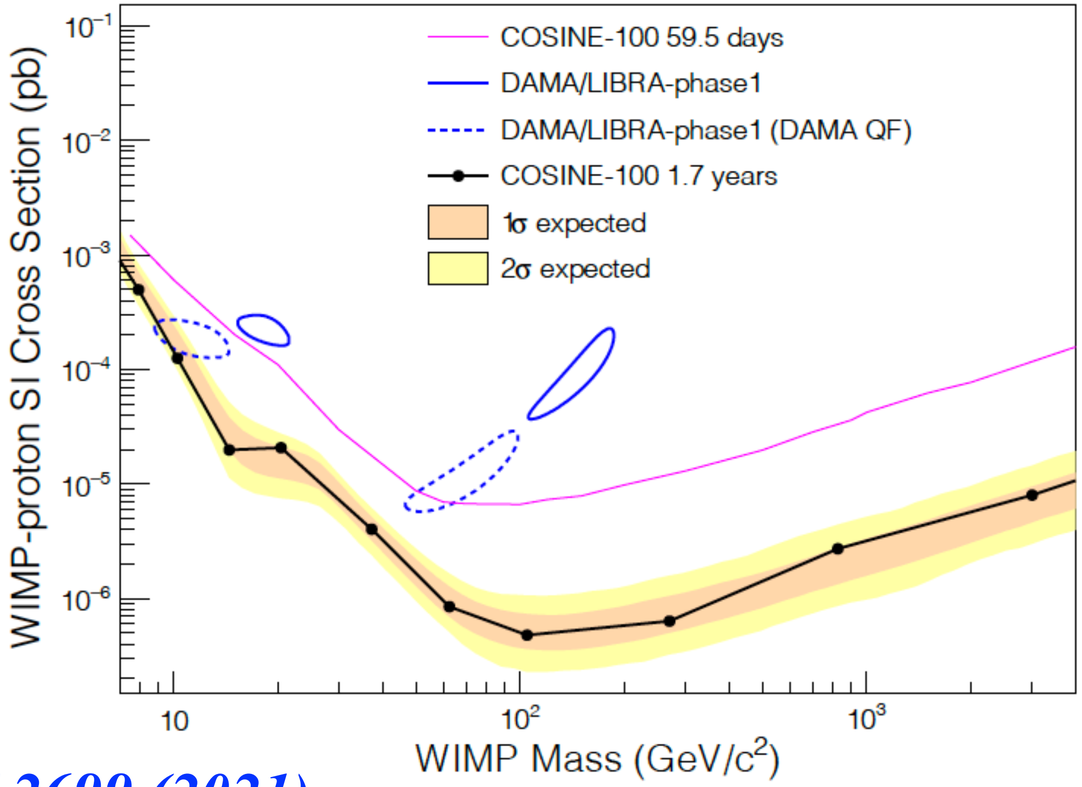
Annual Modulation Analysis(1.7 yr)

Config	Amplitude (2-6 keV)	Phase (days)
COSINE-100	0.0083 ± 0.0068	**152.5 (fixed)**
ANAIS	-0.0044 ± 0.0058	152.5 (fixed)
DAMA	0.0095 ± 0.0008	152.5 (fixed)
COSINE-100	0.0092 ± 0.0067	127 ± 46
DAMA	0.0096 ± 0.0008	145 ± 5



Constant Rate Analysis with 1-keV threshold (1.7 yr)

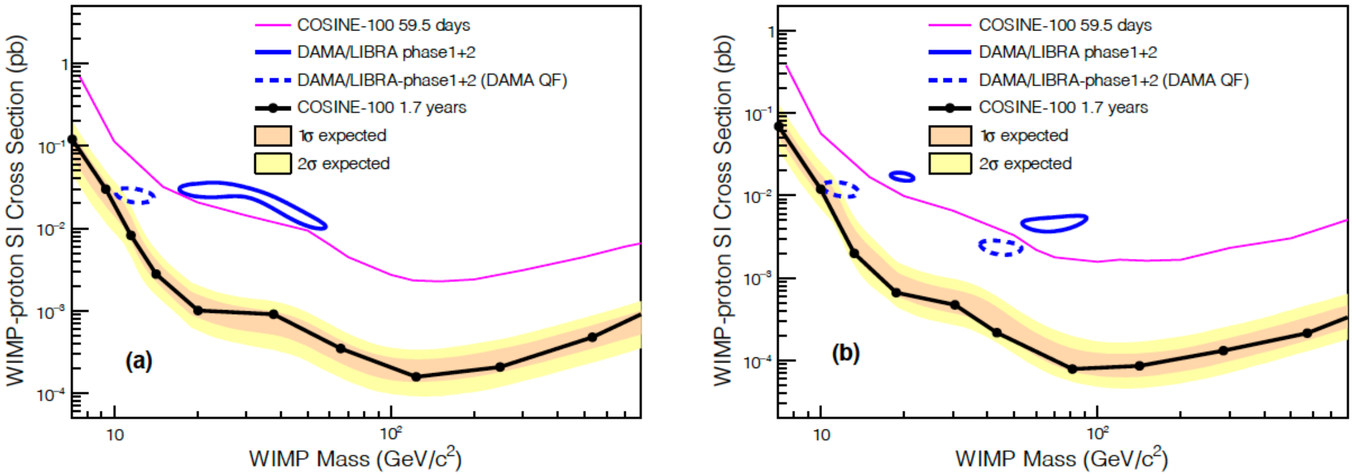


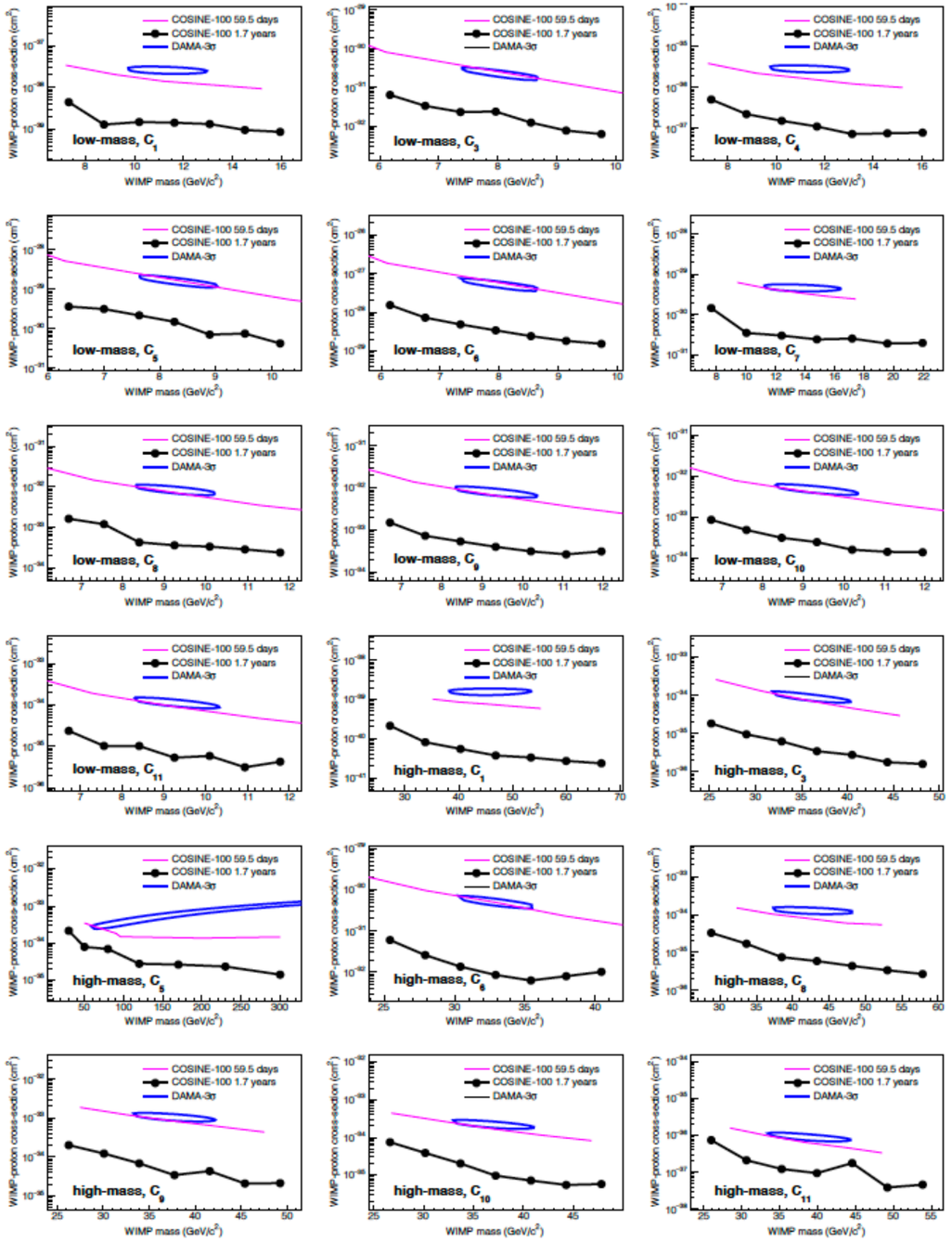


Sci. Adv. 7, eabk2699 (2021)

A factor of 10 improved result compared to the first result

Constant Rate Analysis with 1-keV threshold (1.7 yr)



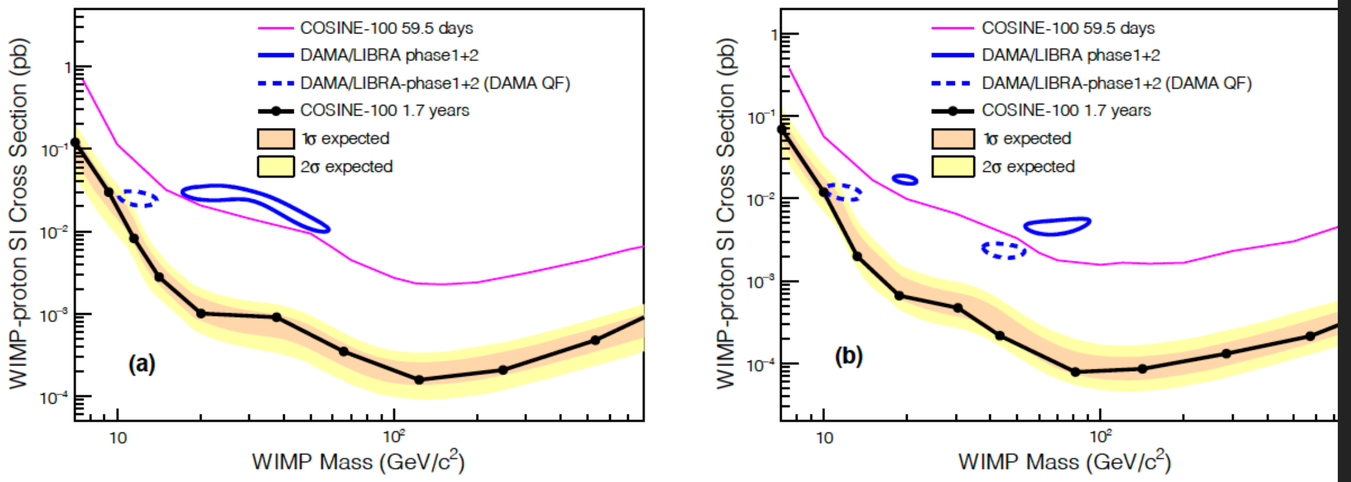


Sci. Adv. 7, eabk2699 (2021)

Additionally, we checked alternative hypotheses for isospin-violating cases and EFT operators with the same threshold and the updated quenching factors as DAMA/LIBRA.

We find, in general, those are incompatible with COSINE-100 data. There is no excess of events over the expected background, that can be interpreted as DAMA's annual modulation signal under the assumption of dark matter interactions based on the Standard Halo Model.

Constant Rate Analysis with 1-keV threshold (1.7 yr)



Sci. Adv. 7, eabk2699 (2021)

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We find, in general, those are incompatible with COSINE-100 dat There is no excess of events over the expected background, that can be interpreted as DAMA's annual modulation signal under th assumption of dark matter interactions based on the Standard Halo Model.

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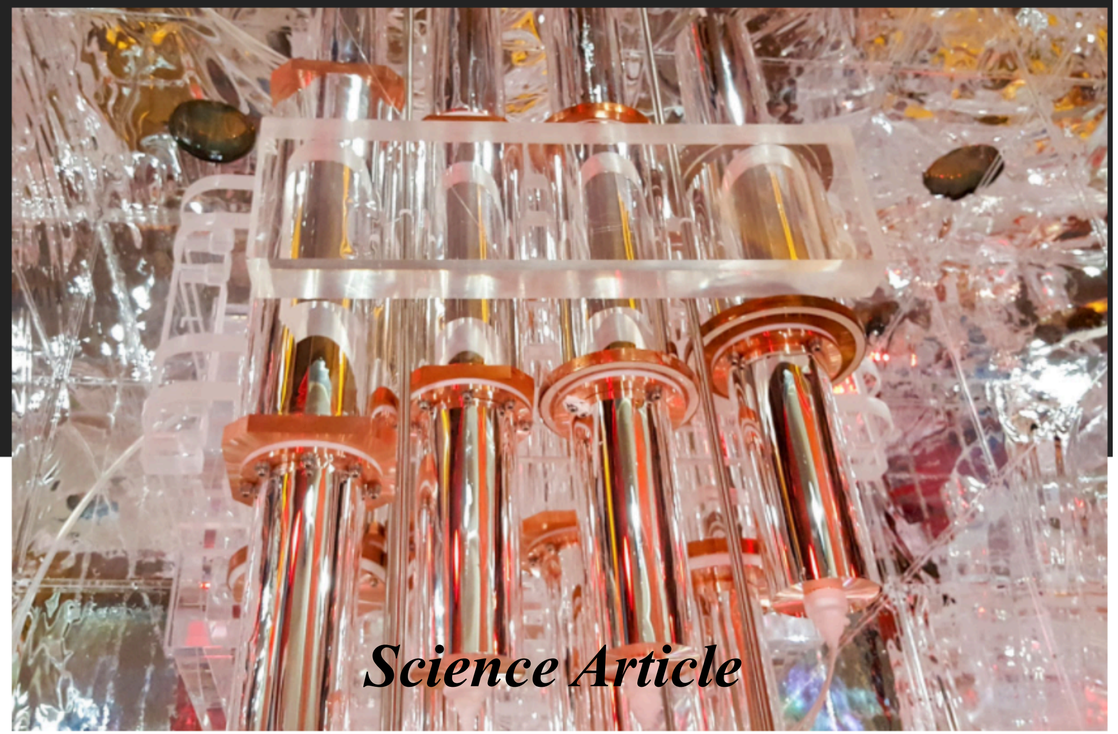
HOME > NEWS > ALL NEWS > IS THE END IN SIGHT FOR FAMOUS DARK MATTER CLAIM?

NEWS | PHYSICS

Is the end in sight for famous dark matter claim?

New data cast more doubt on controversial result from the DAMA experiment and an alternative explanation of it emerges

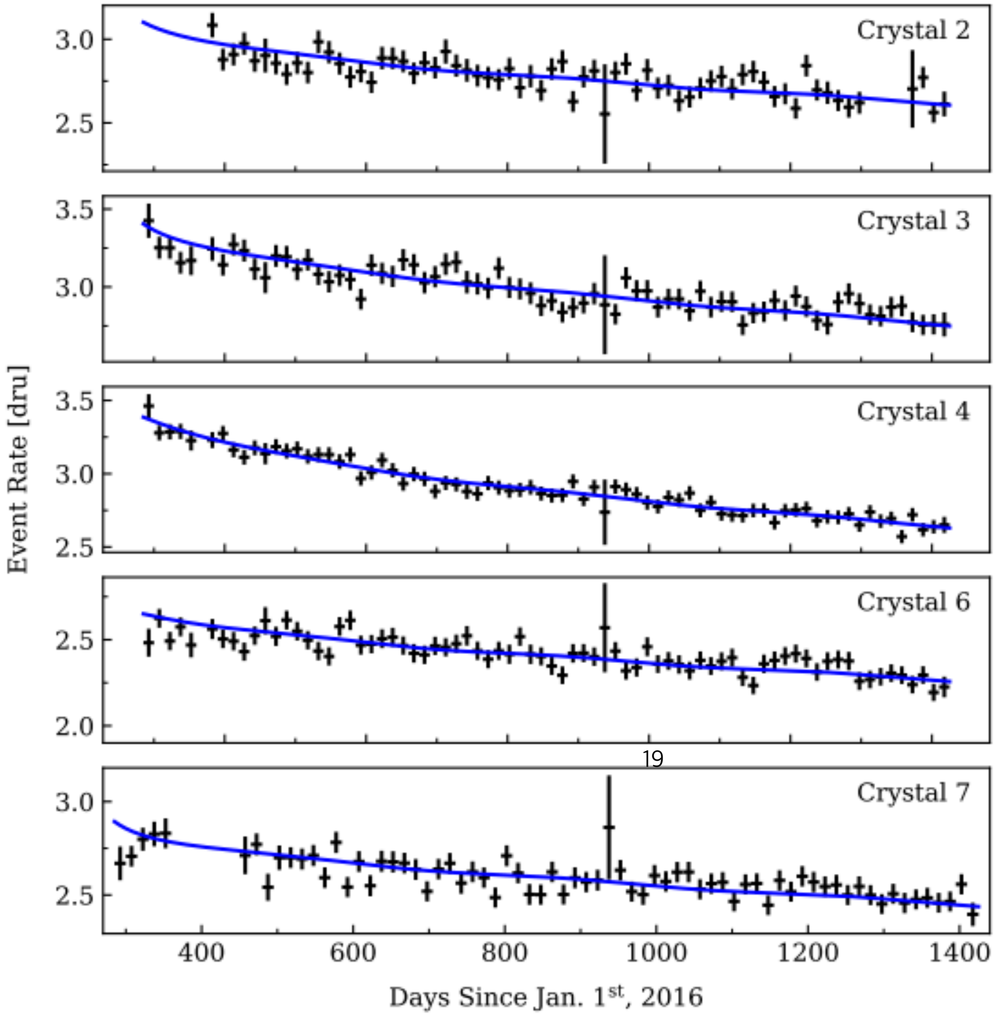
10 NOV 2021 · 2:00 PM · BY ADRIAN CHO



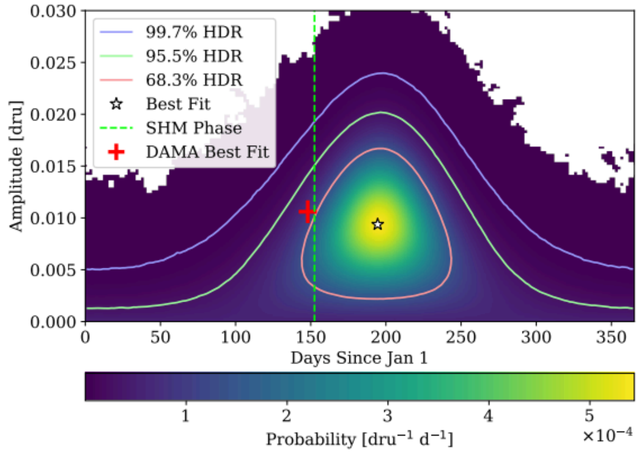
Science Article

Dark matter particles should generate flashes of light in the COSINE experiment's sodium iodide crystals. It aims to test a similar experiment's dark matter claim. CHANG HYON HA

Annual Modulation Analysis with 1-keV threshold (2.82 yr)

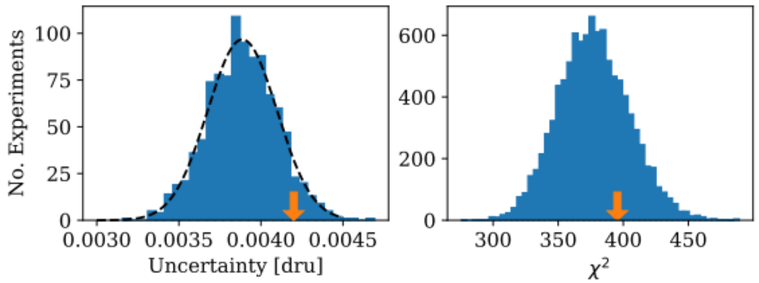


Better Modeling of Backgrounds
Better Pseudo experiments



Configuration	Amplitude [dru]	Phase [days]
COSINE-100 1–6 keV (This result)	0.0067±0.0042	152.5 (fixed)
COSINE-100 2–6 keV (This result)	0.0050±0.0047	152.5 (fixed)
COSINE-100 2–6 keV (2019 result [14])	0.0083±0.0068	152.5 (fixed)
ANAIS 1–6 keV (2021 result [16])	-0.0034±0.0042	152.5 (fixed)
ANAIS 2–6 keV (2021 result [16])	0.0003±0.0037	152.5 (fixed)
DAMA/LIBRA 1–6 keV (phase2 [7])	0.0105±0.0011	152.5 (fixed)
DAMA/NaI+LIBRA 2–6 keV [7]	0.0102±0.0008	152.5 (fixed)
COSINE-100 1–6 keV (This result)	$0.0094^{+0.0073}_{-0.0072}$	$194.5^{+49.0}_{-50.5}$
COSINE-100 2–6 keV (This result)	$0.0061^{+0.0064}_{-0.0061}$	Unconstrained
COSINE-100 2–6 keV (2019 result [14])	0.0092±0.0067	127.2±45.9
DAMA/LIBRA 1–6 keV (phase2 [7])	0.0106±0.0011	148±6
DAMA/NaI+LIBRA 2–6 keV [7]	0.0103±0.0008	145±5

PRD submitted (arXiv:2111.08863)

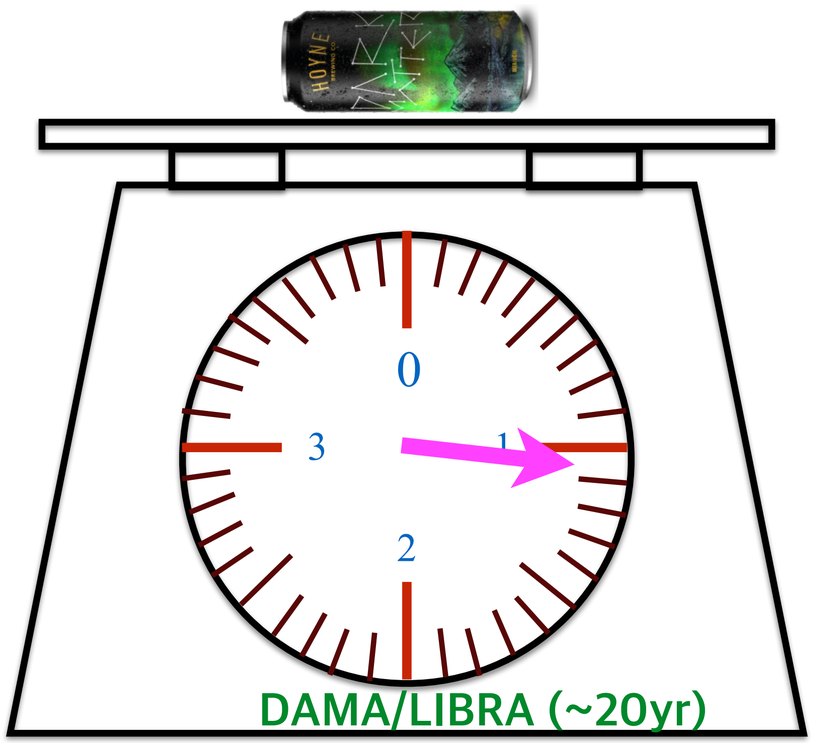


This Results (1–6 keV) : 0.0067 ±0.0042 dru

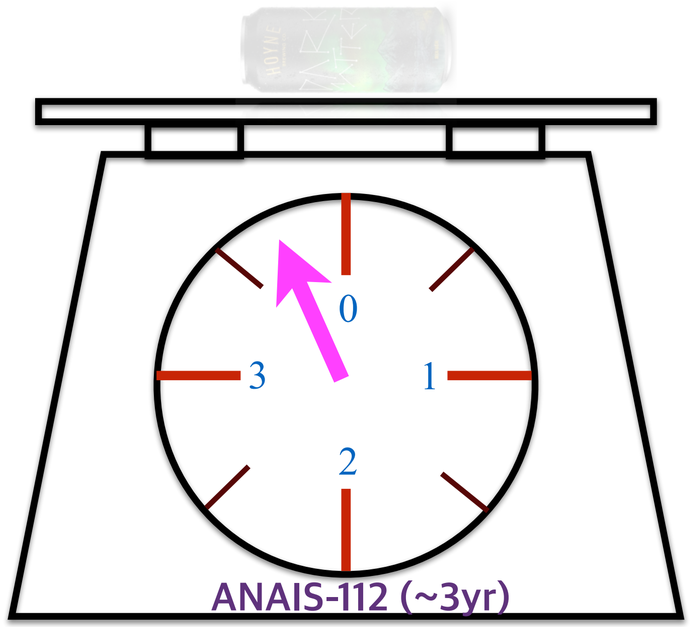
DAMA/LIBRA : 0.0105 ±0.0011 dru

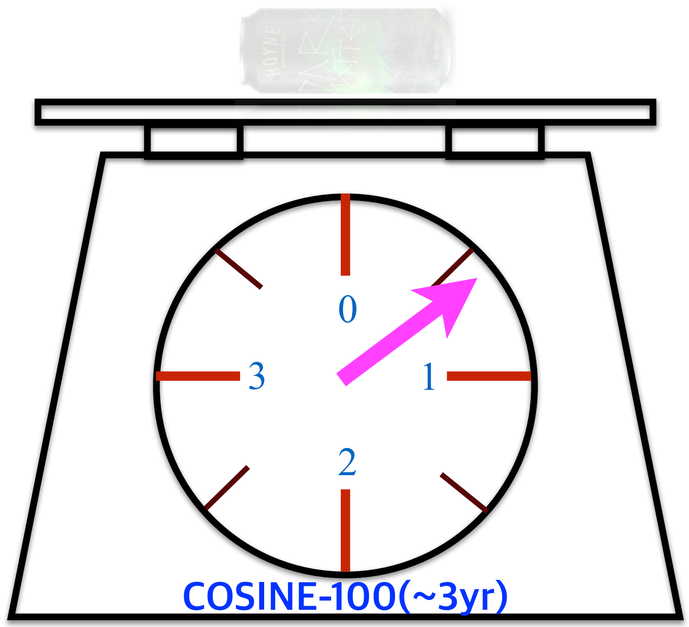
Current results are statistics-limited. Need a better detector!

What does this mean? : Weighing a WIMP



VS





$(1.05 \pm 0.11) \times 10^{-2}$ $[dru]$

$(-0.34 \pm 0.42) \times 10^{-2}$ $[dru]$

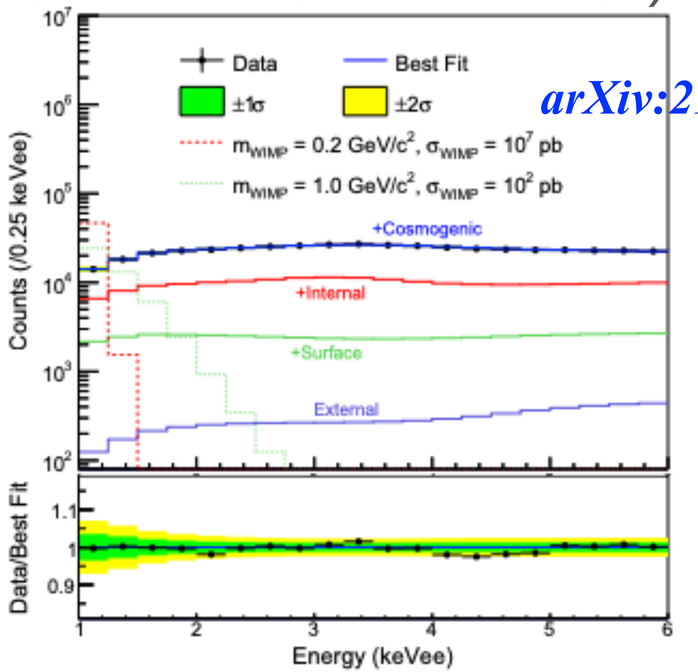
$(0.67 \pm 0.42) \times 10^{-2}$ $[dru]$

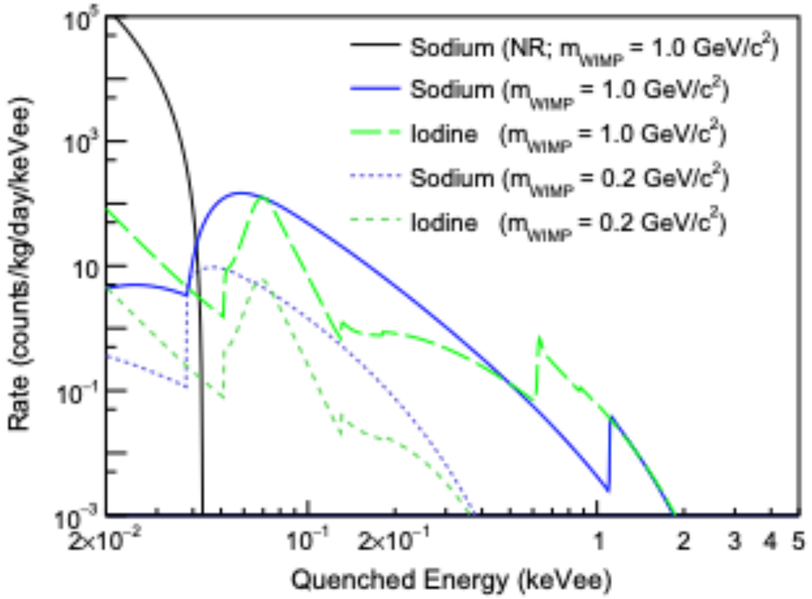
With the current setup, it is hard to reach 5σ test to the DAMA exp.

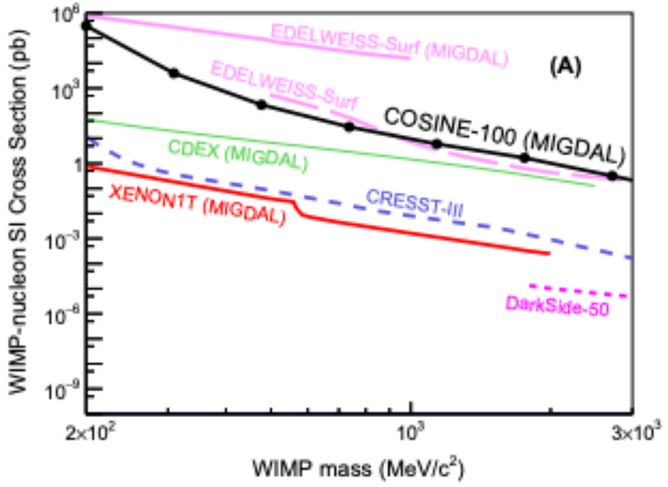
Search for the Migdal Effect (Look for ~GeV nuclear recoils)

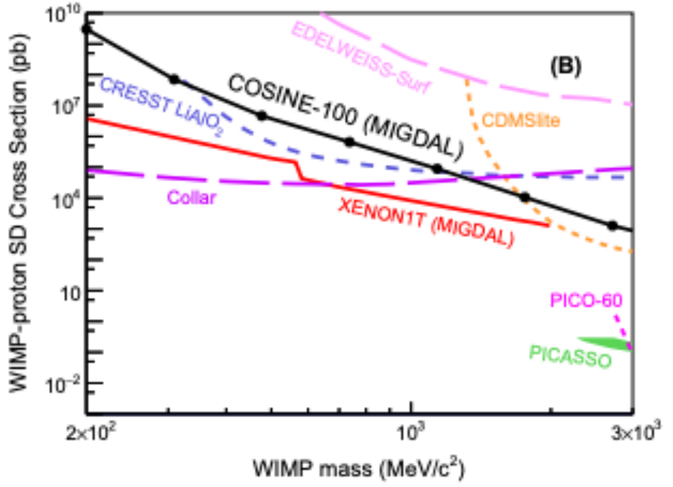
When a Nuclear Recoil by a Low Energy WIMP is small (a few keV), the recoil signal is not easy to detect directly. However, after the recoil, due to the lagging (excitations) of surrounding electrons, some energies come out as e/γ

arXiv:2110.05806



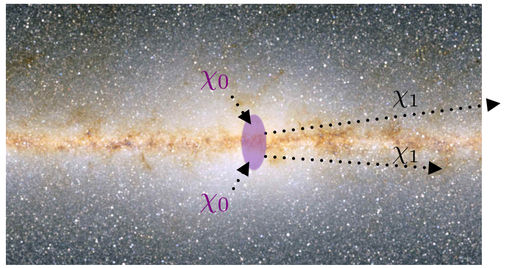


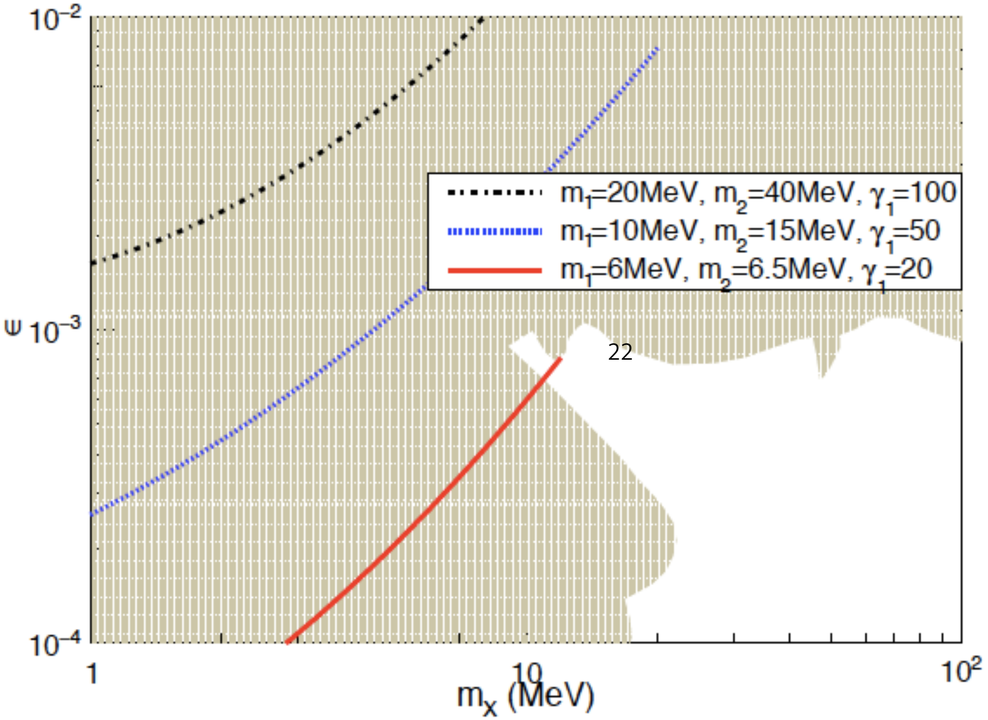


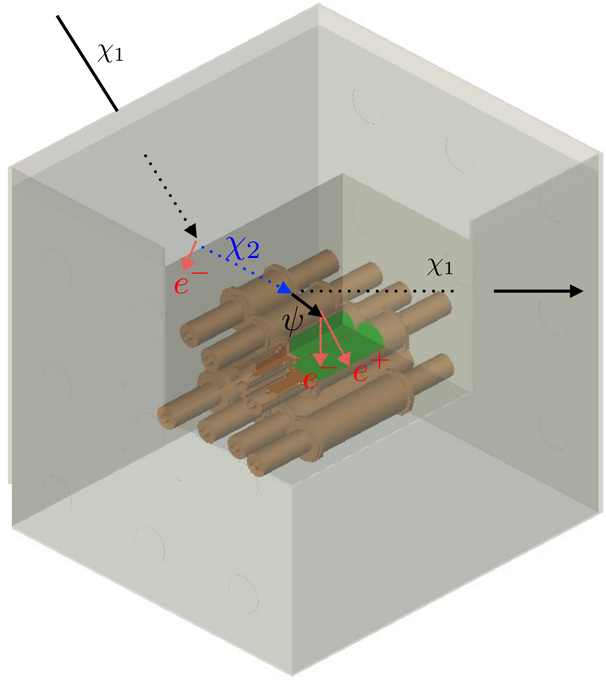


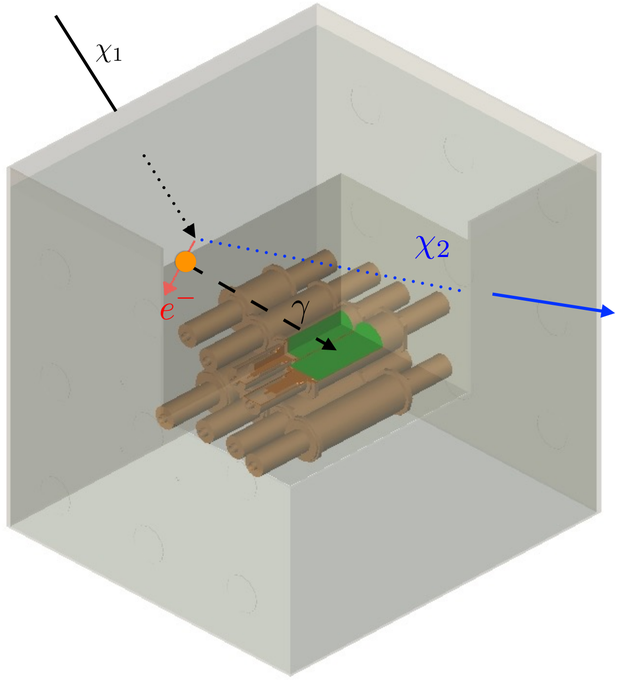
Inelastic Boosted Dark Matter

Physics Letters B 780 (2018) 543–552





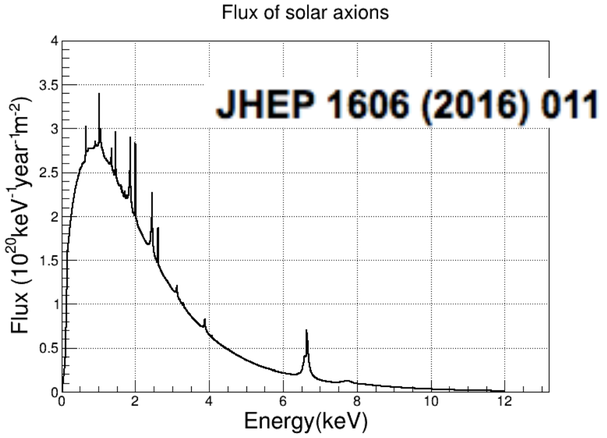


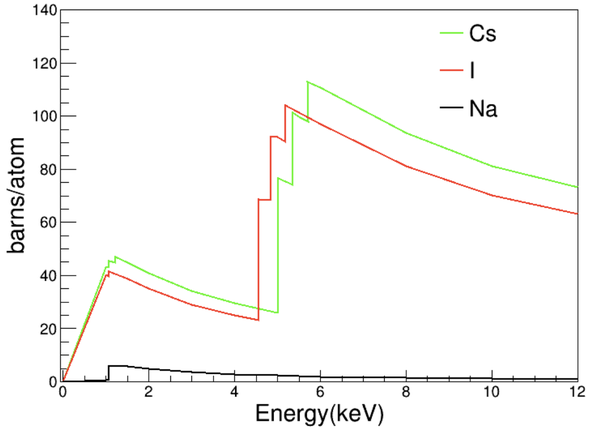


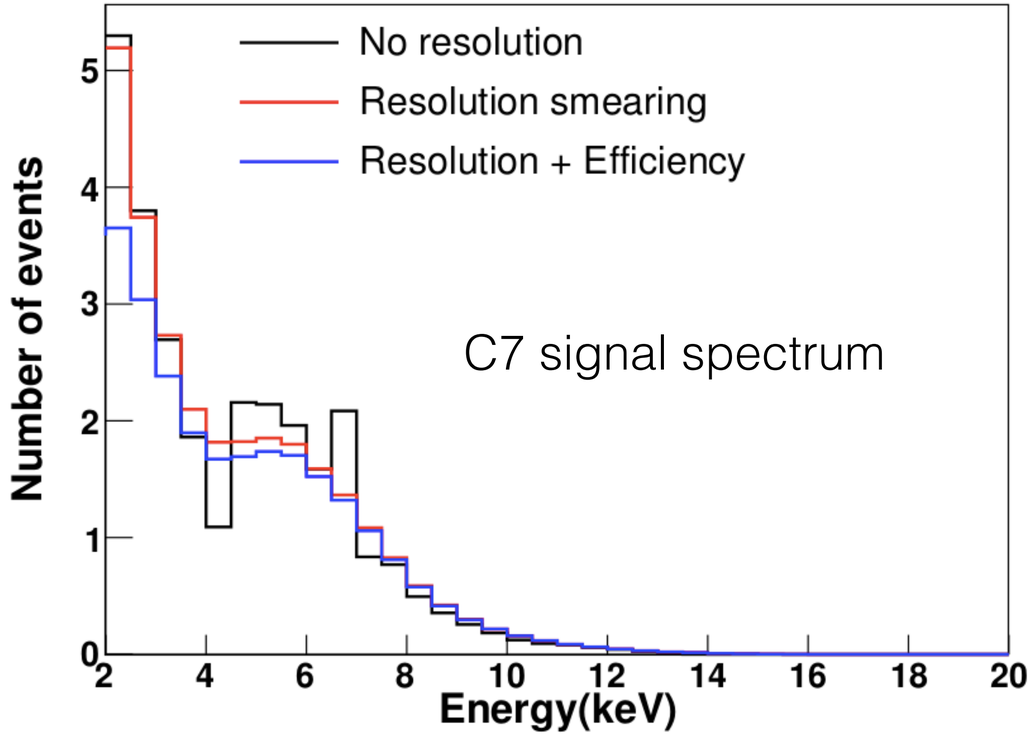
PRL 122,131802 (2019)

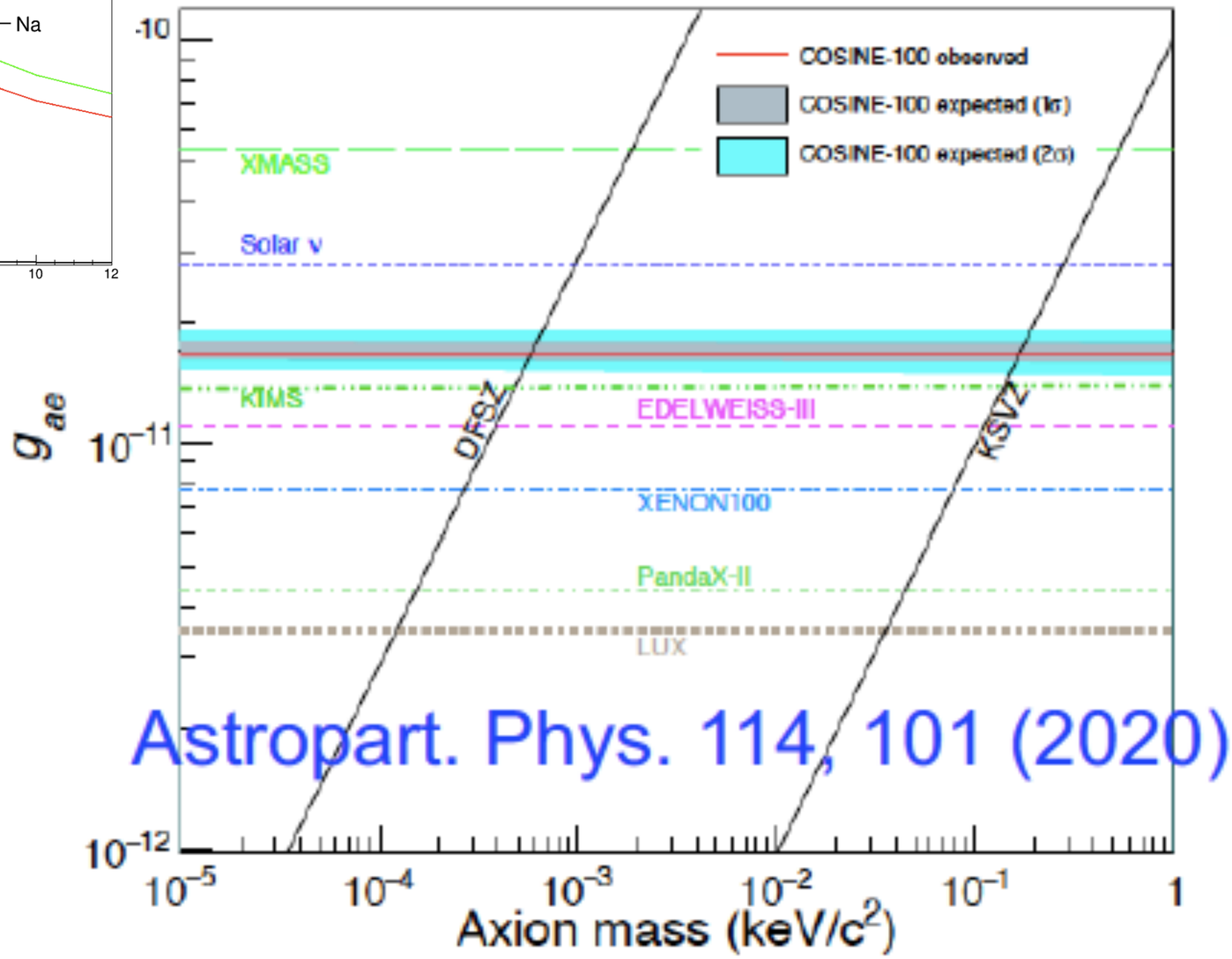
Using 2 tons of the LS volume as a crystal-LS combined target, we search for dark matter signals that could be displaced in a volume.

Solar Axion Search









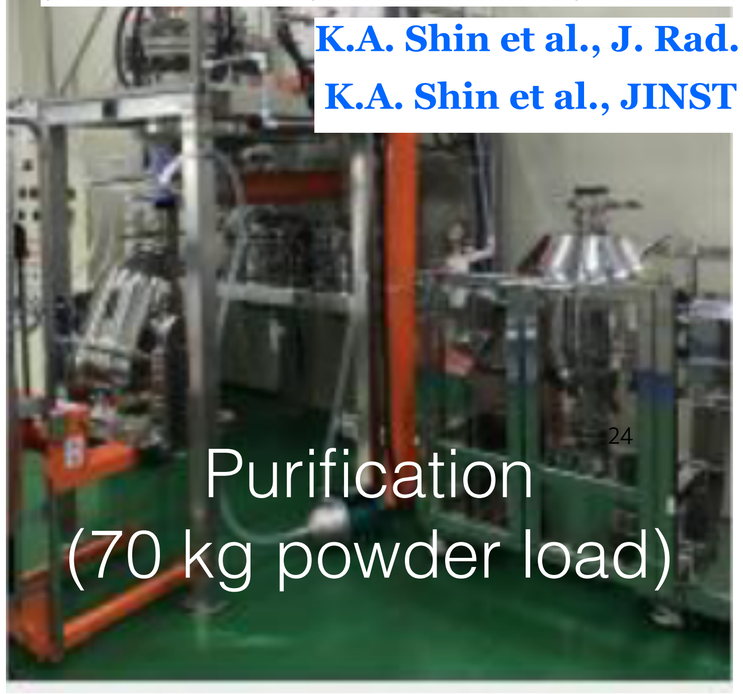
Astropart. Phys. 114, 101 (2020)

COSINE-200 Preparations (much work done in Korea)

Powder Purification

	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

K.A. Shin et al., J. Rad. Nucl. Chem. 317, 1329 (2018)
K.A. Shin et al., JINST 15, C07031 (2020)



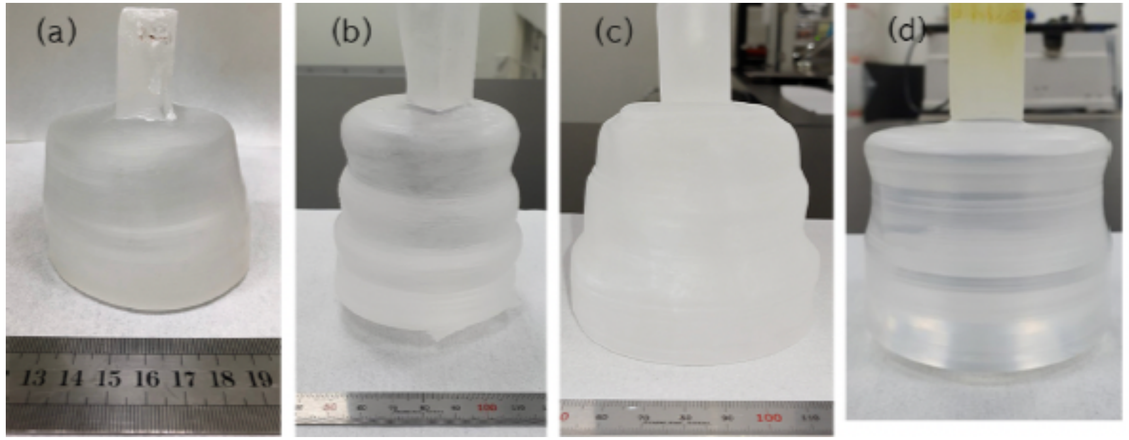
Purification
(70 kg powder load)

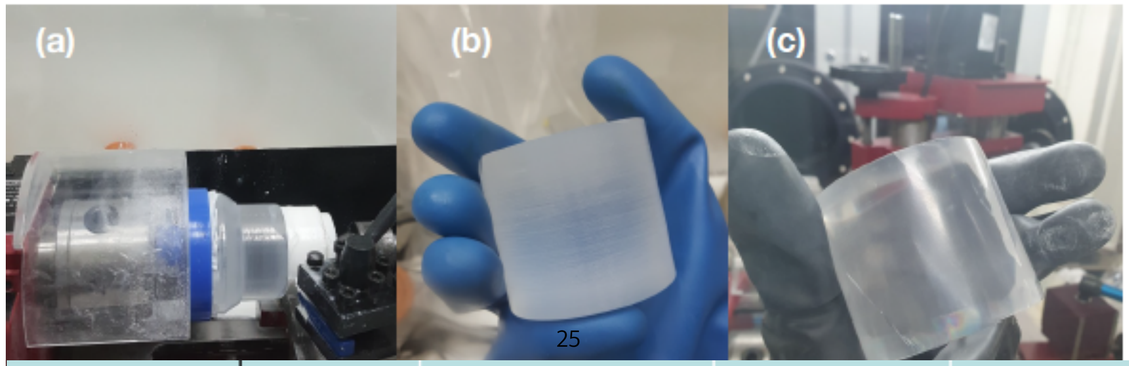
Small Grower
(1 kg crystal ingot)

Full-sized Grower
(100 kg crystal ingot)

Background rate should be less than 1 dru (DAMA)

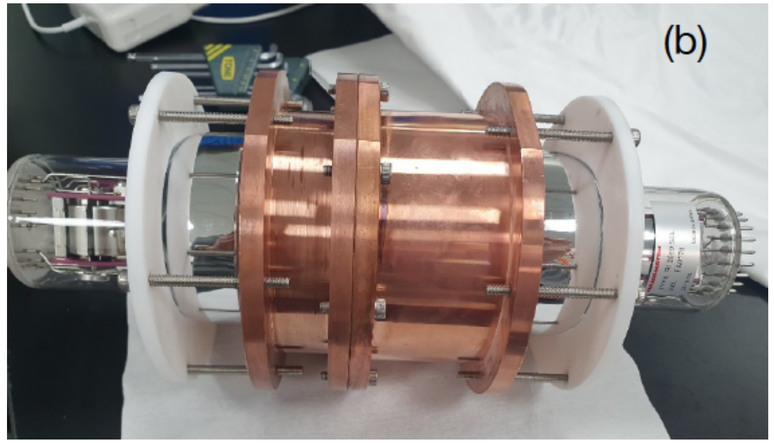
Prototype NaI(Tl) crystal detector

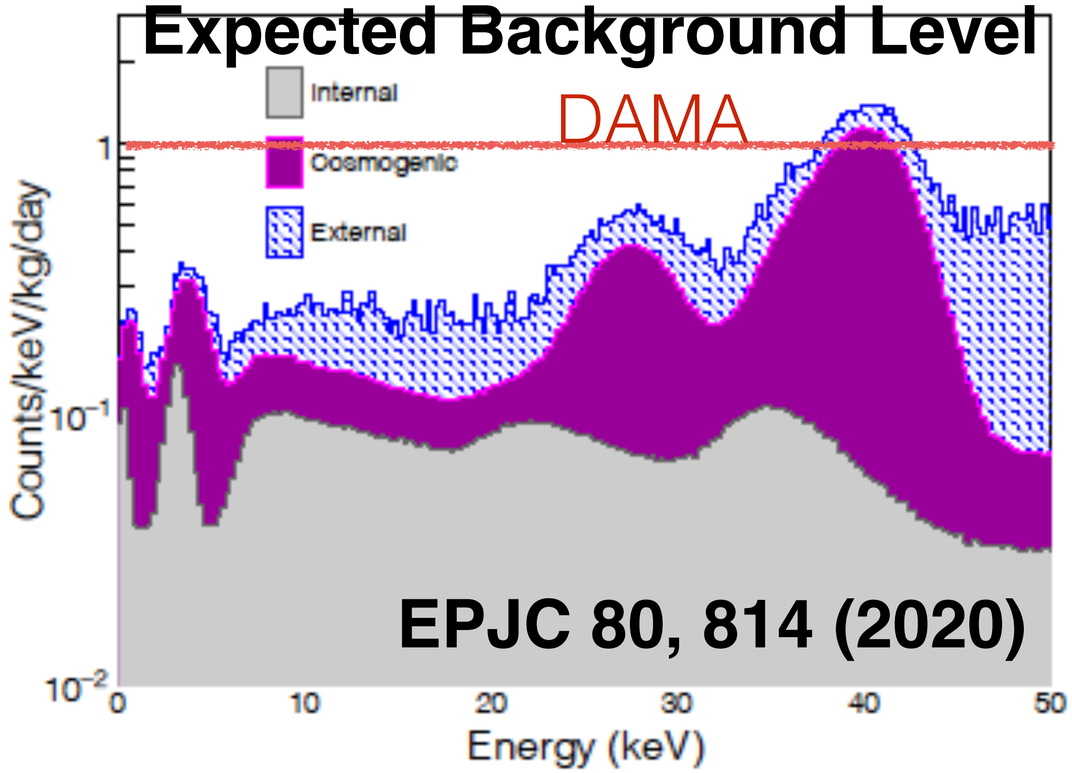




25

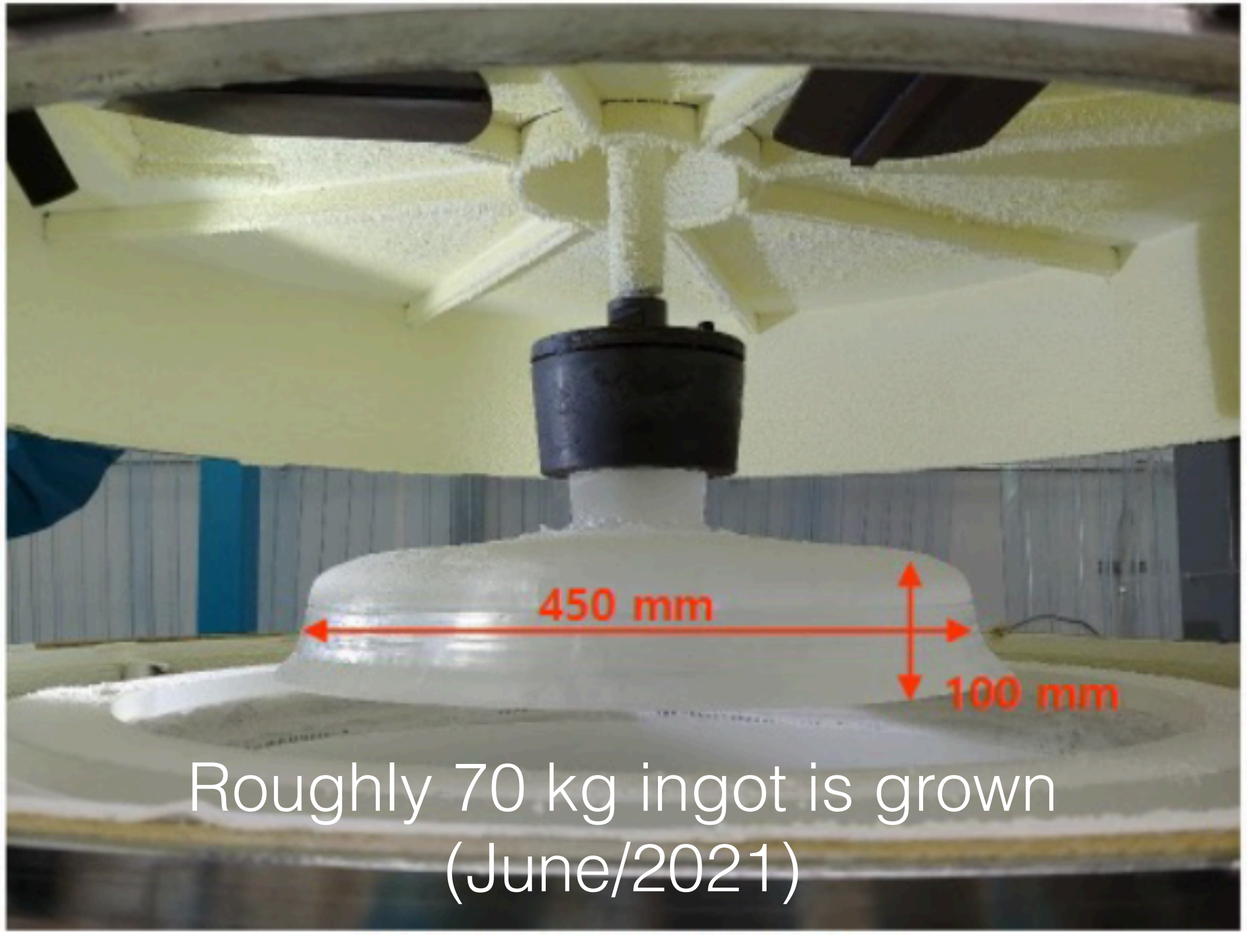
	K (ppb)	^{210}Pb (mBq/kg)	^{238}U (μBq/kg)	^{232}Th(μBq/
Powder	5	-	<20	<20
Aug/2018	684	3.8+/-0.3	26+/-7	<6
Sept/2019	**8**	**0.01+/-0.02**	**11+/-4**	**7+/-2**
DAMA	<20	0.01~0.03	8.7~124	2~31





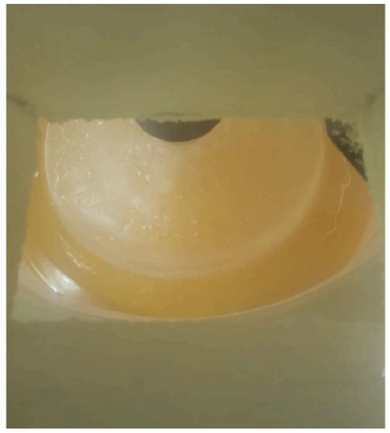
Large Size NaI(Tl) crystal growth at CUP

Test growing without Thallium doping



Roughly 70 kg ingot is grown (June/2021)

195 kg NaI Merck Powder loaded

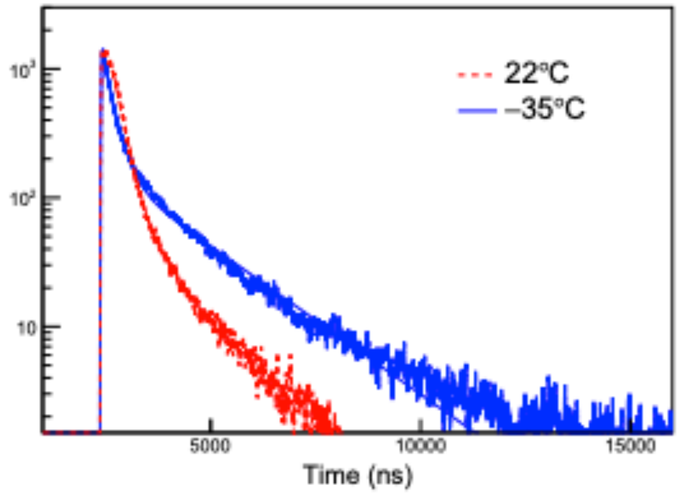


Sequence of crystallization

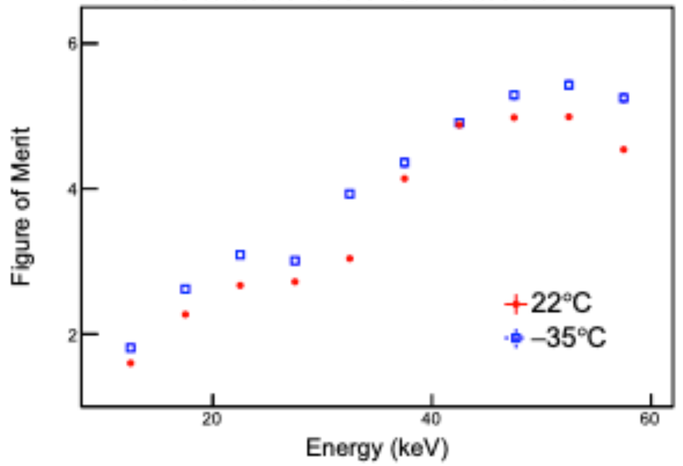
In-house Crystal growing starts working. Large-size Tl-doped and low-bkg crystal growth is the next step.

NaI(Tl) crystal at $-35^{\circ}C$

waveforms

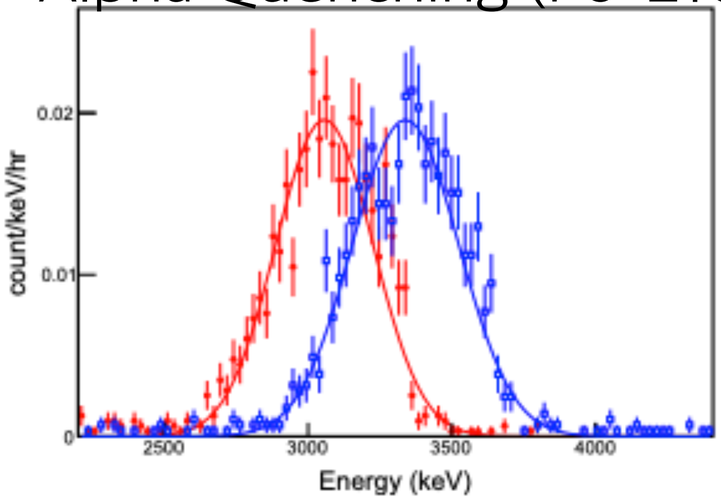


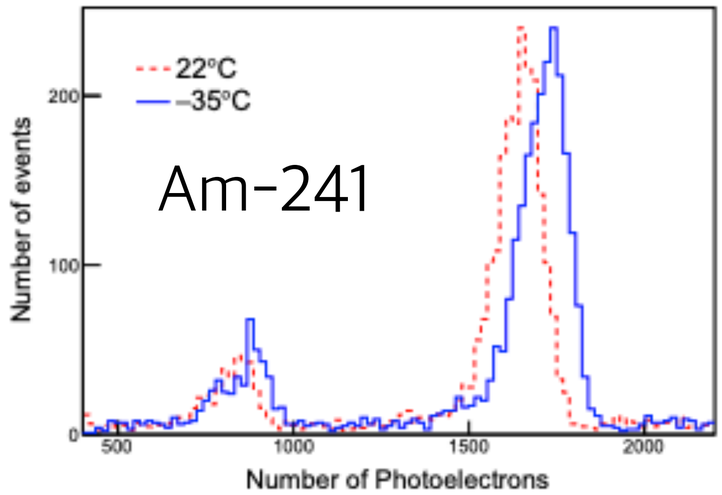
Neutron Source

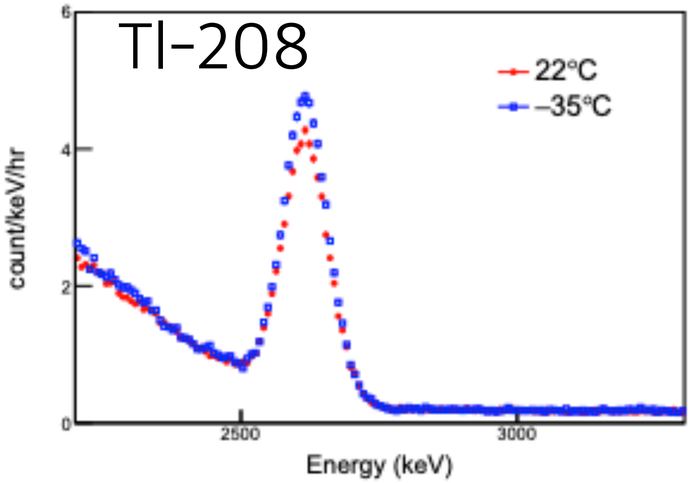


arXiv:2111.03328

Alpha Quenching (Po-210)







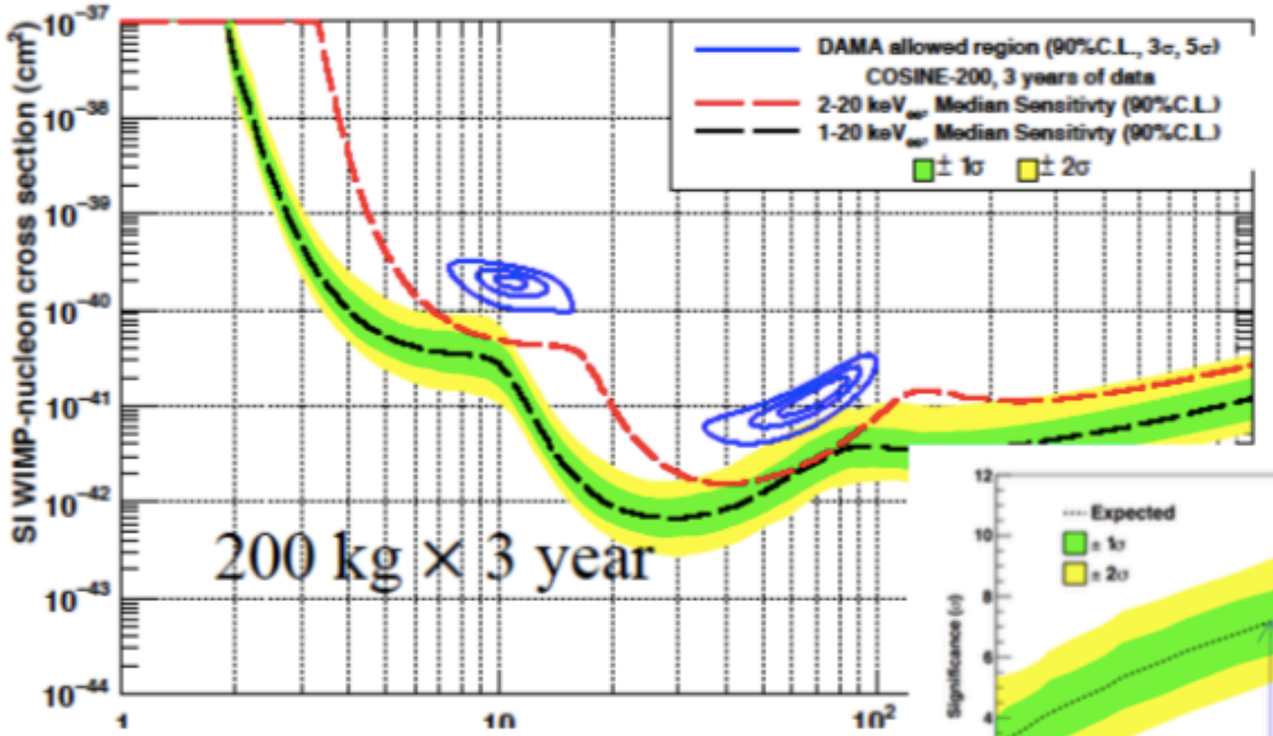
Temp. (°C)	LY (PEs/keV)	σ/mean (%)
22	27.6 ± 0.3	3.8 ± 0.1
−35	28.9 ± 0.2	3.7 ± 0.1

NaI(Tl) crystal produces more light as temperature decreases.

COSINE-200 (starting 2023)

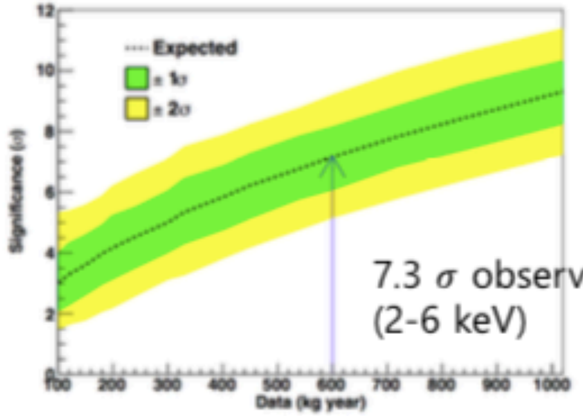
- 1 counts/day/kg/keV background assumed (same as DAMA/LIBRA)

Annual Modulation Analysis



← Null hypothesis

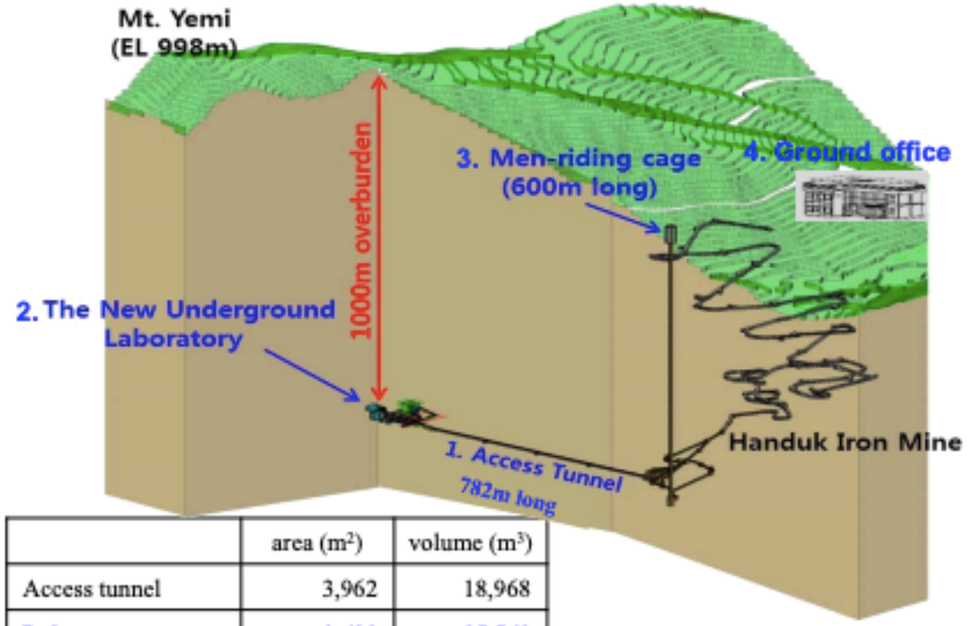
↓ Signal hypothesis



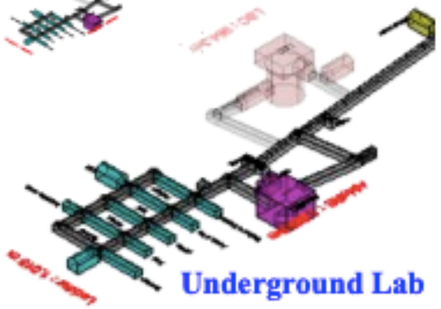
We have been preparing 200 kg experiment (COSINE-200) using better crystals with lower background, possibly operating at $-35^{\circ}C$

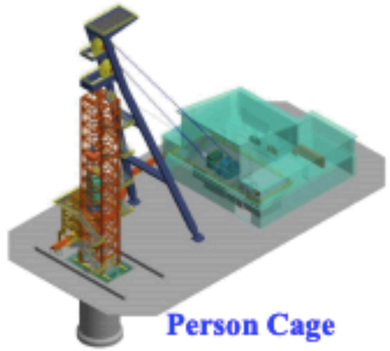
COSINE-200 (starting 2023 @ Yemilab)

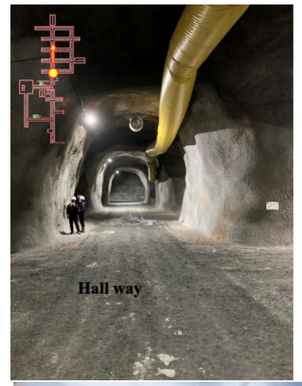
1. **Access Tunnel**, 782 m long with 12% down slope
2. **Underground Lab.** with 2600 m^2
3. **Person Cage**, running vertical 587 m
4. **Ground Office** with 2500 m^2

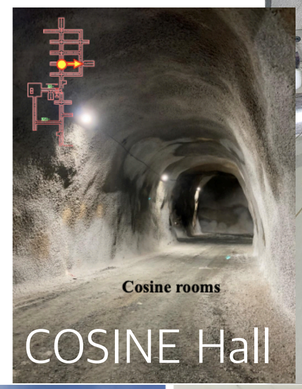


	area (m^2)	volume (m^3)
Access tunnel	3,962	18,968
Lab space	**2,600**	**25,562**
Connecting tunnel	4,847	14,161
amount	**11,525**	**58,691**









The ground office exterior

The reinforcement

Summary and Outlook

- Dark Matter direction detection aims at detecting nuclear recoils by WIMP.
- There is one claimed detection of WIMP from the DAMA experiment that uses annual variation phenomenon.
- Among various efforts, Korea is specialized in using the crystal scintillator target with the same material as DAMA. So, the reproduction of the experiment is possible.
- We have ruled out a theory that explains the DAMA signal as a dark matter particle but we, then, need to figure out where the modulation comes from with better detection sensitivity.
- We also search for other dark matter candidates such as Low-mass WIMPs with Migdal effect, solar Axion and iBDM, and other interaction signatures.
- COSINE-200 is under preparation. We will use high purity, low-background, house-produced crystals. Plan on operating at $-35^{\circ}C$.
- Yemilab construction is well underway. Space for COSINE-200 has been prepared already. Currently finishing up the pavement. Moving of experiments from Y2L to Yemilab will start mid-2023. Stay tuned.