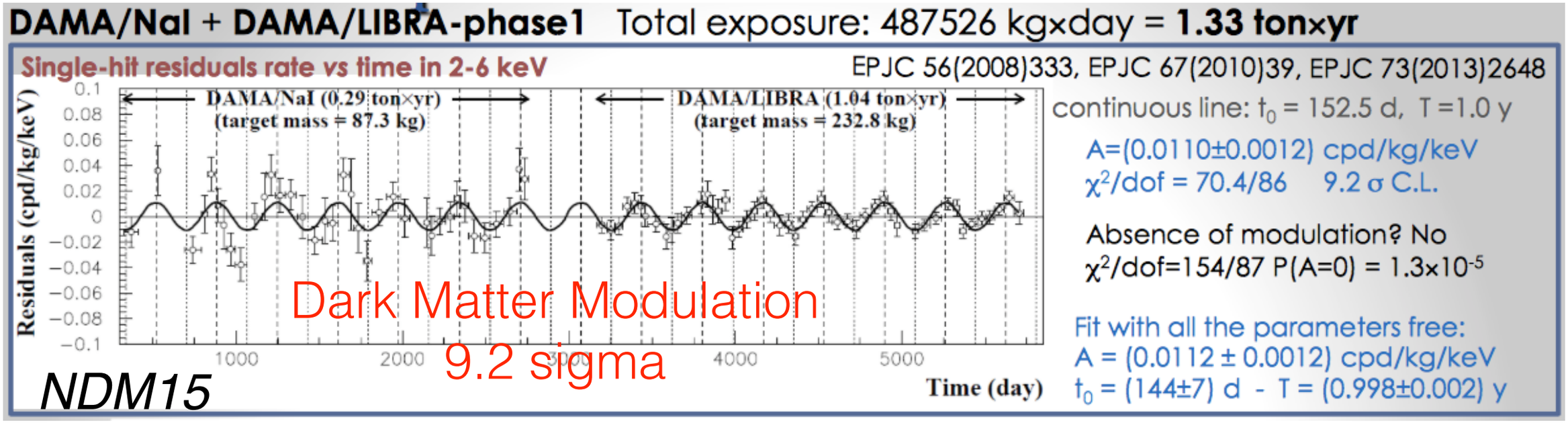
Center for Underground Physics

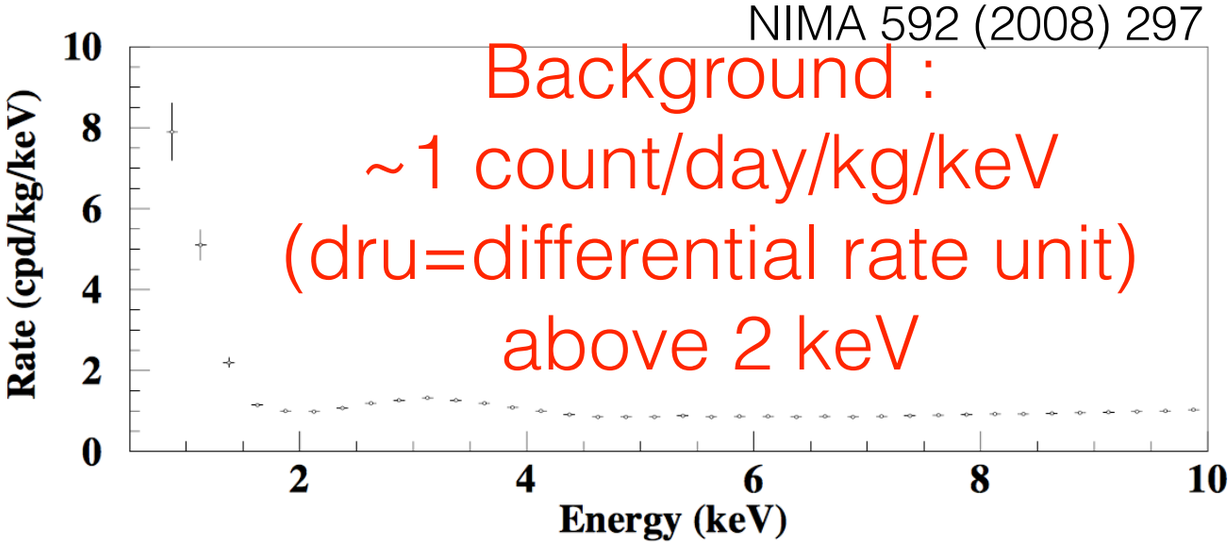
Institute for Basic Science

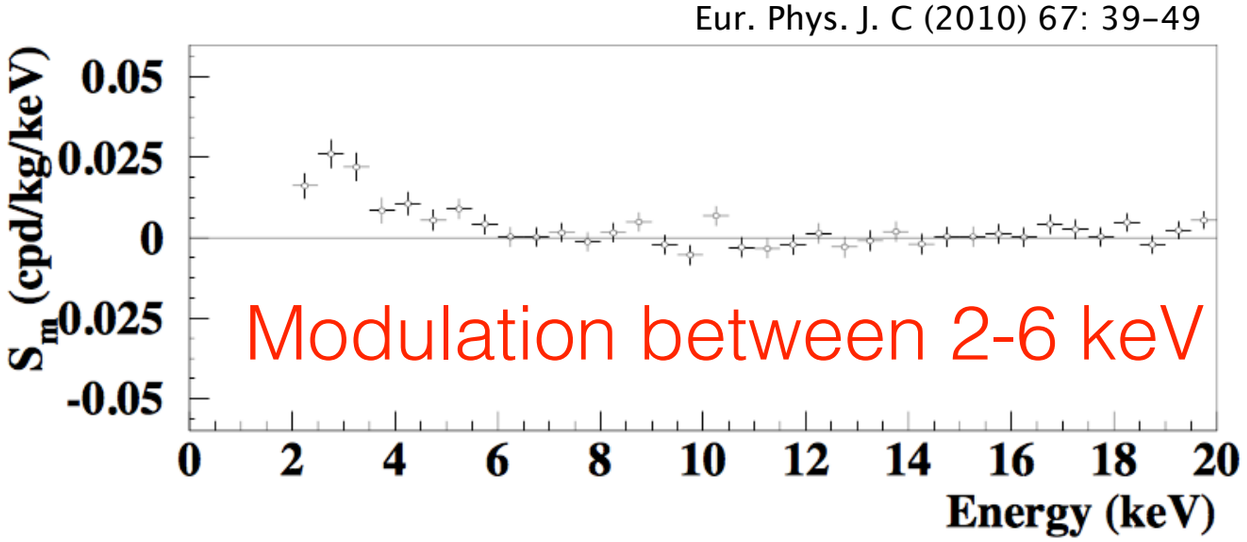
Dark Matter searches with COSINE-100 : Present and Future

Chang Hyon Ha
On behalf of the COSINE-100 collaboration
Center for Underground Physics (CUP), IBS, Korea

Motivation : DAMA annual modulation signal, to be checked with independent measurements using the same NaI(Tl) target material







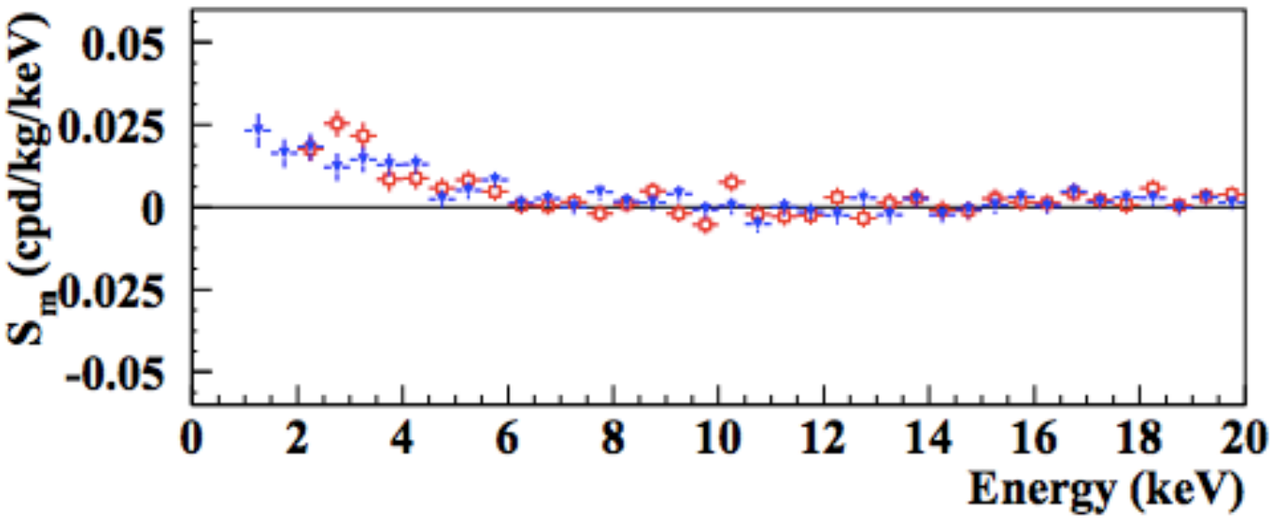
DAMA/LIBRA-phase2

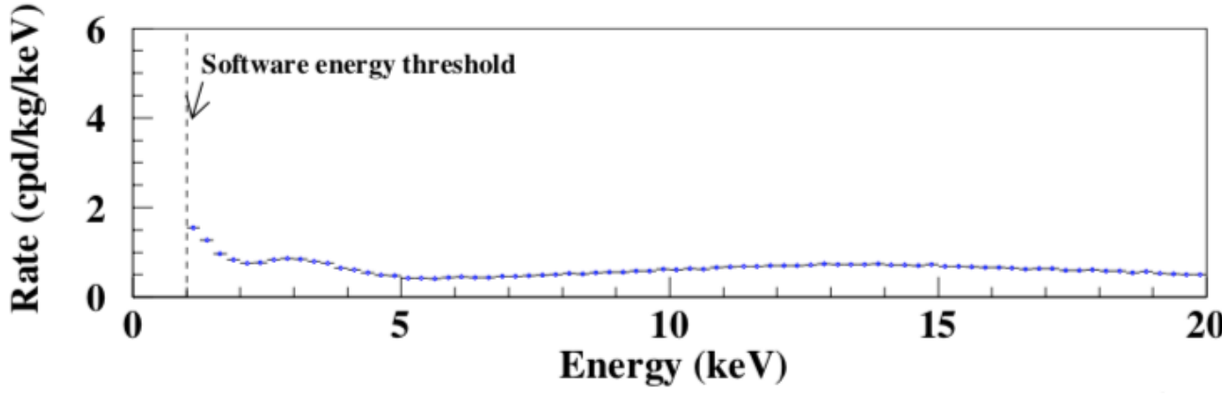
First model independent results from DAMA/LIBRA–phase2

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

Nucl. Phys. At. Energy 19 (2018) 307

	A (cpd/kg/keV)	$T = \frac{2\pi}{\omega}$ (yr)	t_0 (days)	C.L.
DAMA/LIBRA–phase2:				
1-3 keV	(0.0184±0.0023)	1.0	152.5	8.0 σ
1-6 keV	(0.0105±0.0011)	1.0	152.5	9.5 σ
2-6 keV	(0.0095±0.0011)	1.0	152.5	8.6 σ
1-3 keV	(0.0184±0.0023)	(1.0000±0.0010)	153±7	8.0 σ
1-6 keV	(0.0106±0.0011)	(0.9993±0.0008)	148±6	9.6 σ
2-6 keV	(0.0096±0.0011)	(0.9989±0.0010)	145±7	8.7 σ
DAMA/LIBRA–phase1 + phase2:				
2-6 keV	(0.0095±0.0008)	1.0	152.5	11.9 σ
2-6 keV	(0.0096±0.0008)	(0.9987±0.0008)	145±5	12.0 σ
DAMA/NaI + DAMA/LIBRA–phase1 + phase2:				
2-6 keV	(0.0102±0.0008)	1.0	152.5	12.8 σ
2-6 keV	(0.0103±0.0008)	(0.9987±0.0008)	145±5	12.9 σ

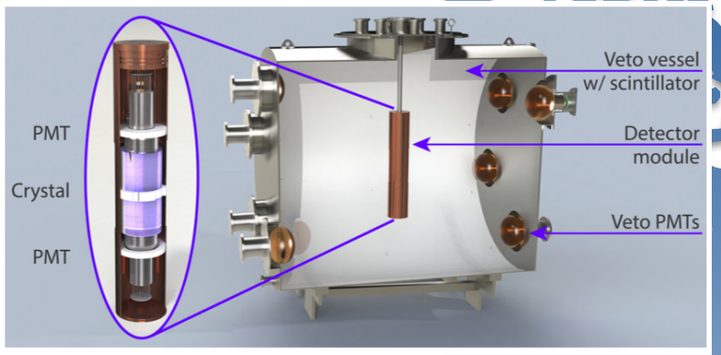




Down to 1 keV region

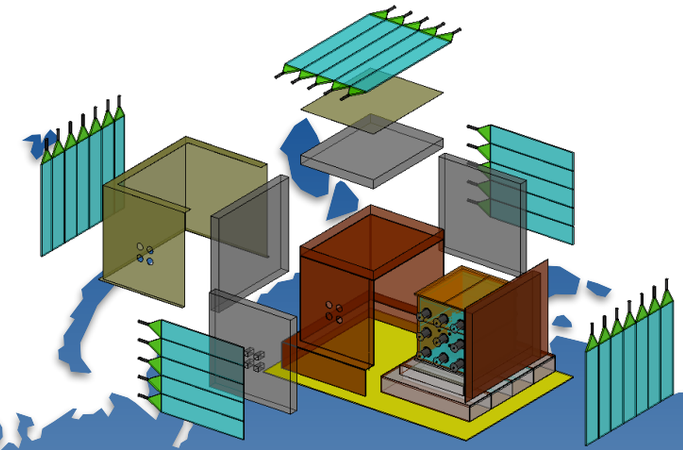
Modulation is persistent in phase2 data

Global NaI(Tl) efforts

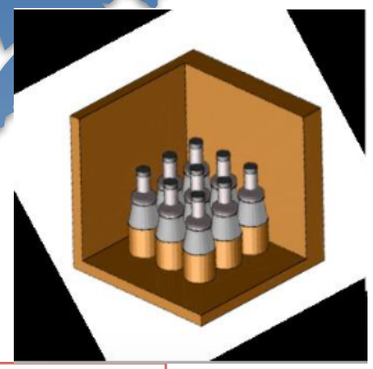


DAMA/LIBRA @ LNGS

SABRE @ LNGS

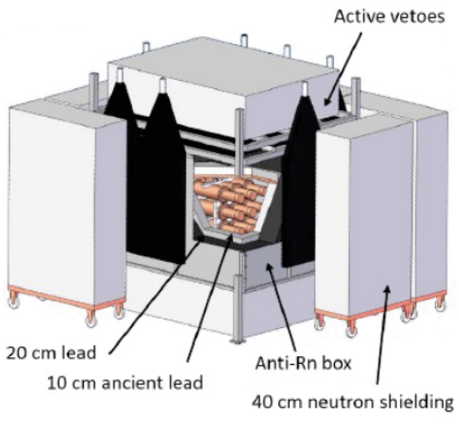


COSINE-100 @ Y2L

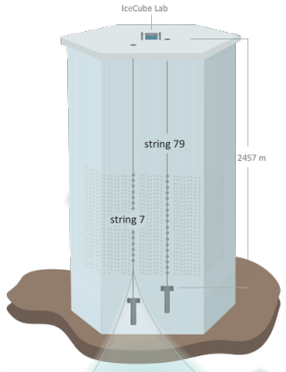


PICO-LON @ Kamioka

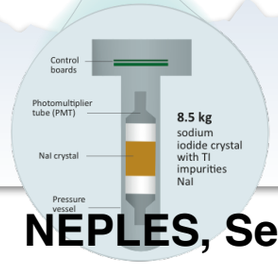
ANAIS @ Canfranc



SABRE @ Stawell

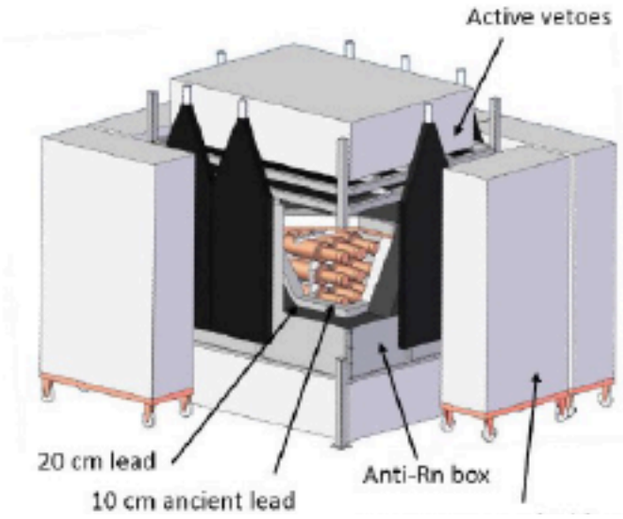


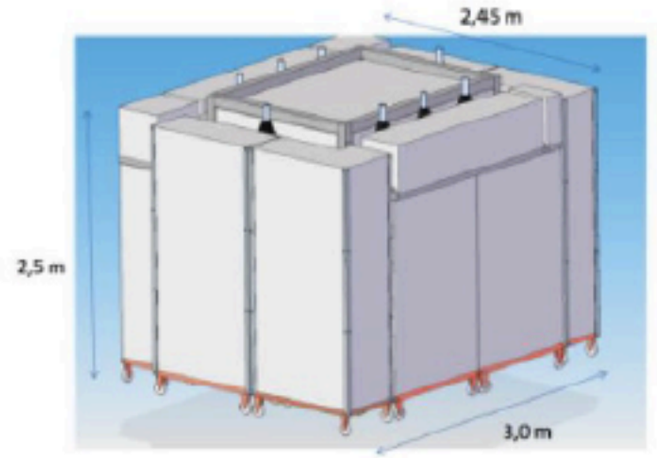
DM-Ice17 @ South Pole



ANAIS (Annual modulation with NAI Scintillators)

- Installed at LSC in a convenient shielding





Null hypothesis is well supported by the χ^2 test (p-values of 0.63 and 0.09 for 2-6 and 1-6 keV energy regions)

Best fits for the modulation hypothesis have p-values slightly lower than for the null hypothesis

NEW !!!

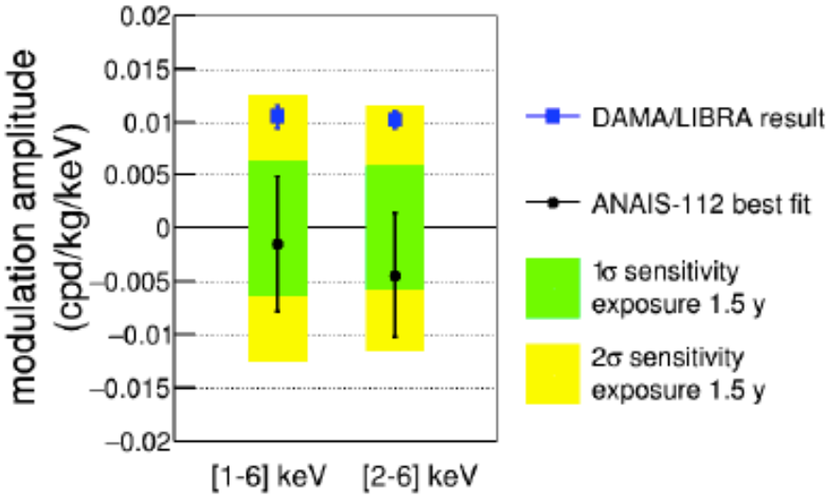
2-6 keV -> $S_m = -0.0029 \pm 0.0050\ cpd/kg/keV$ $(S_m^{DAMA} = 0.0102 \pm 0.0008$ cpd/kg/keV)

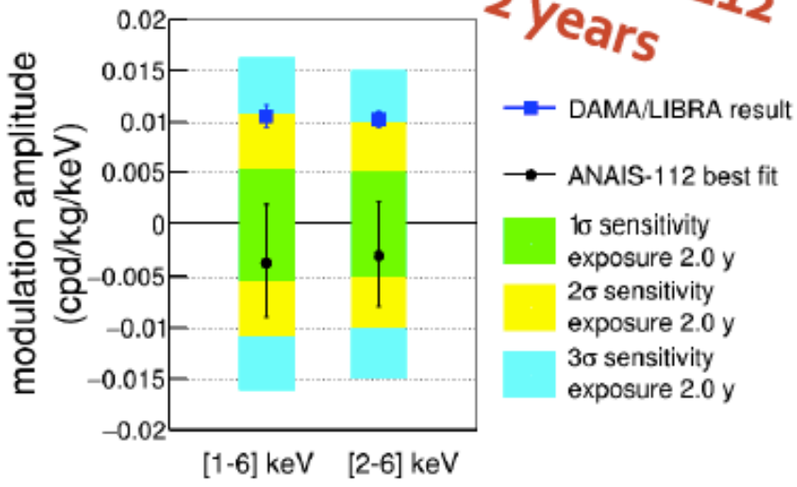
1-6 keV -> $S_m = -0.0036 \pm 0.0054\ cpd/kg/keV$ $(S_m^{DAMA} = 0.0105 \pm 0.0011$ cpd/kg/keV)

PRELIMINARY

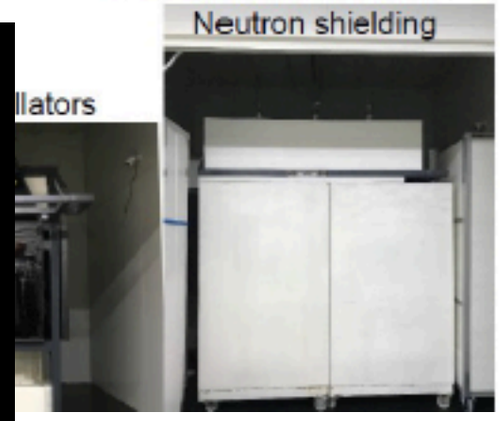
ANAIS-112

2 years





ANAIS-112 annual modulation



113 kg active mass

M.L. Sarsa et al @ TAUP 2019

PICOLON (Pure Inorganic Crystal Observatory for LOw-energy Neutr(al)ino)

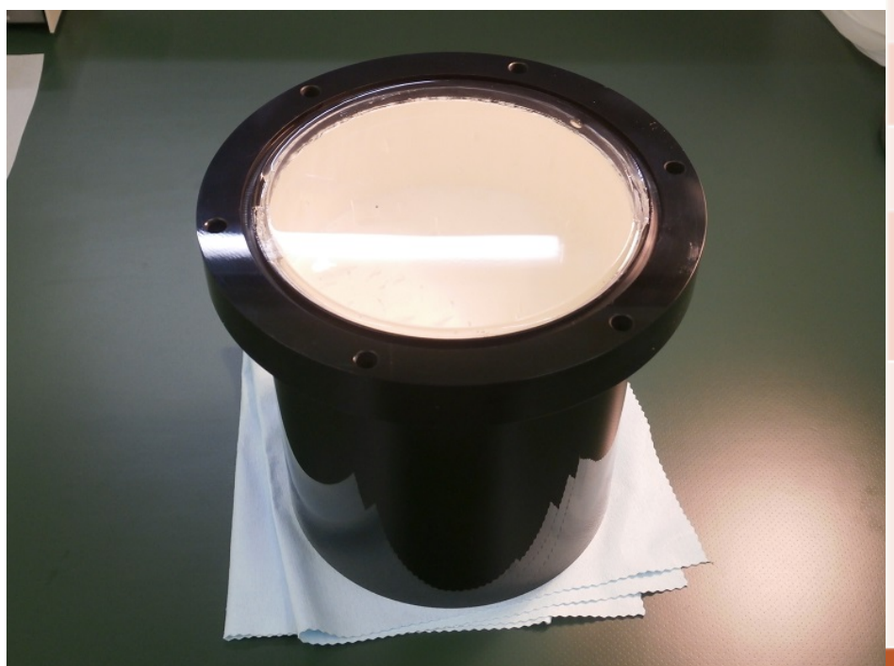
Status of NaI(Tl) purification (~April 2019)

RI	Ingot26 (2015)	Ingot37 (2016)	Ingot71 (2018)	Ingot76 (2019)	Goal
Size	3”ϕX3”	4”ϕX3#	3”ϕX3”	5”ϕX4”(*)	5”ϕX5”
^{40}K (ppb)	2630	120	<20	<20	<20
^{232}Th (ppt)	0.4±0.5	3.7±0.5	1.7±0.2	--	<4
^{238}U (ppt)	4.7±0.3	5.9±0.3	9.7±0.8	4.4±0.2	<10
^{210}Pb (μBq/kg)	30±7	2300	1076	~560	<50
Method	Resin for Pb	I26+cation resin	double re-crystallization	Pb resin + double re-crystallization	

Factory moved.

TAUP2019 TOYAMA 2019/SEP/11 16

K.Fushimi et al @ TAUP 2019



SABRE (Sodium iodide with Active Background REjection)

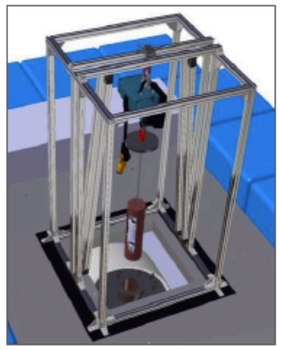
STAWELL UNDERGROUND PHYSICS LAB

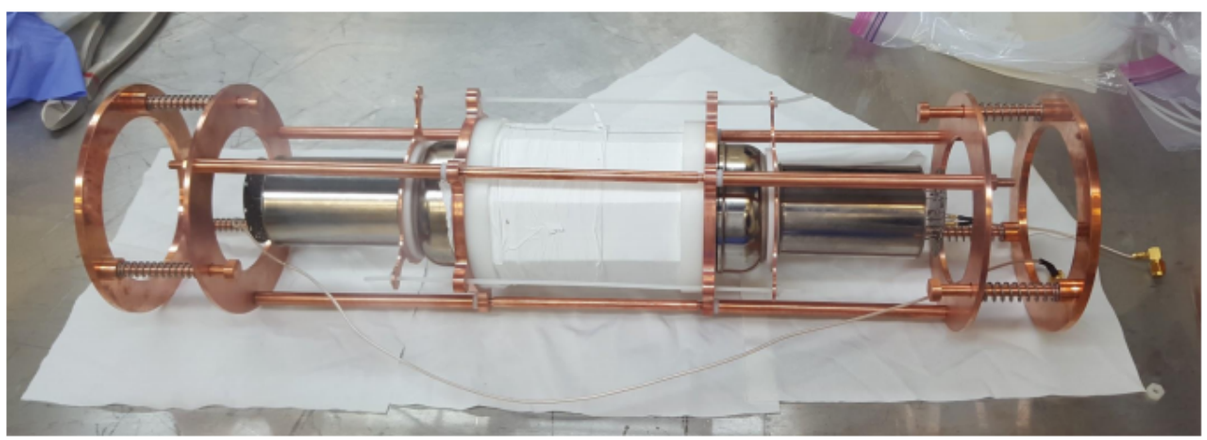
Proof of Principle status

North

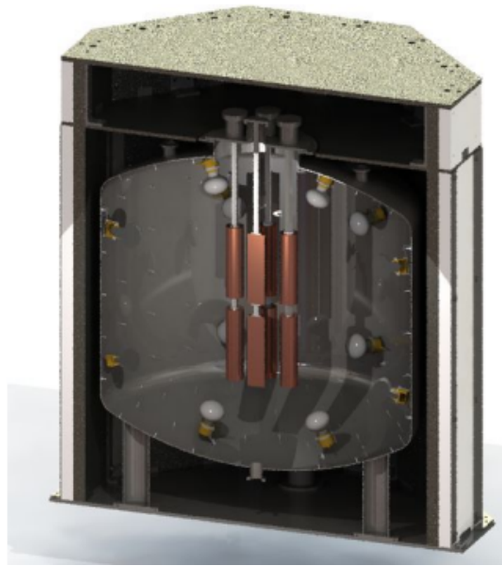
Crystal Insertion System

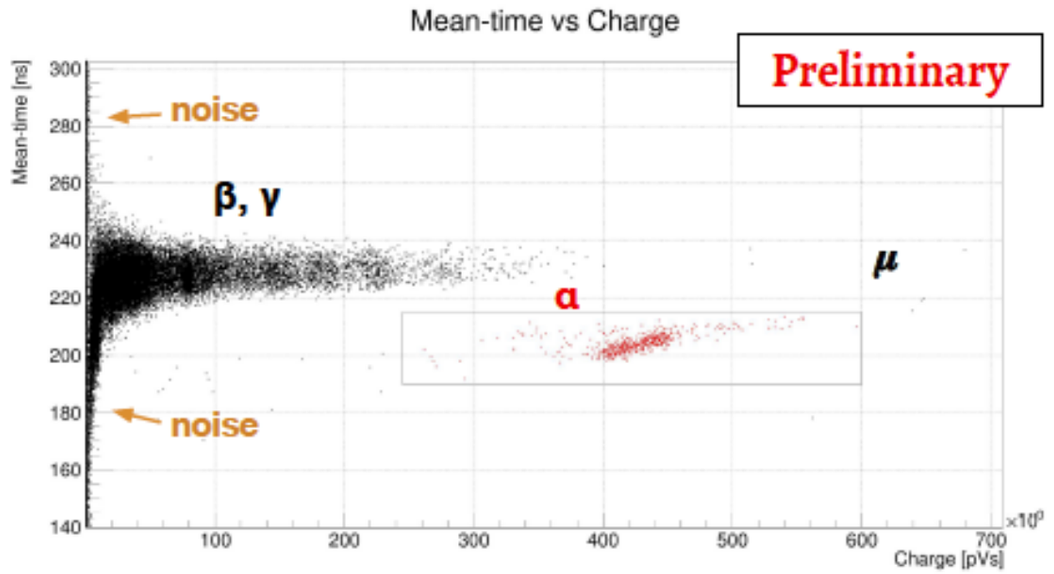
A **frame** is mounted on a steel plate above the vessel. A **motorized pulley** connected to an alignment system, **guides the enclosure into the copper tube**. The enclosure is connected to a flange via a steel bar.





South





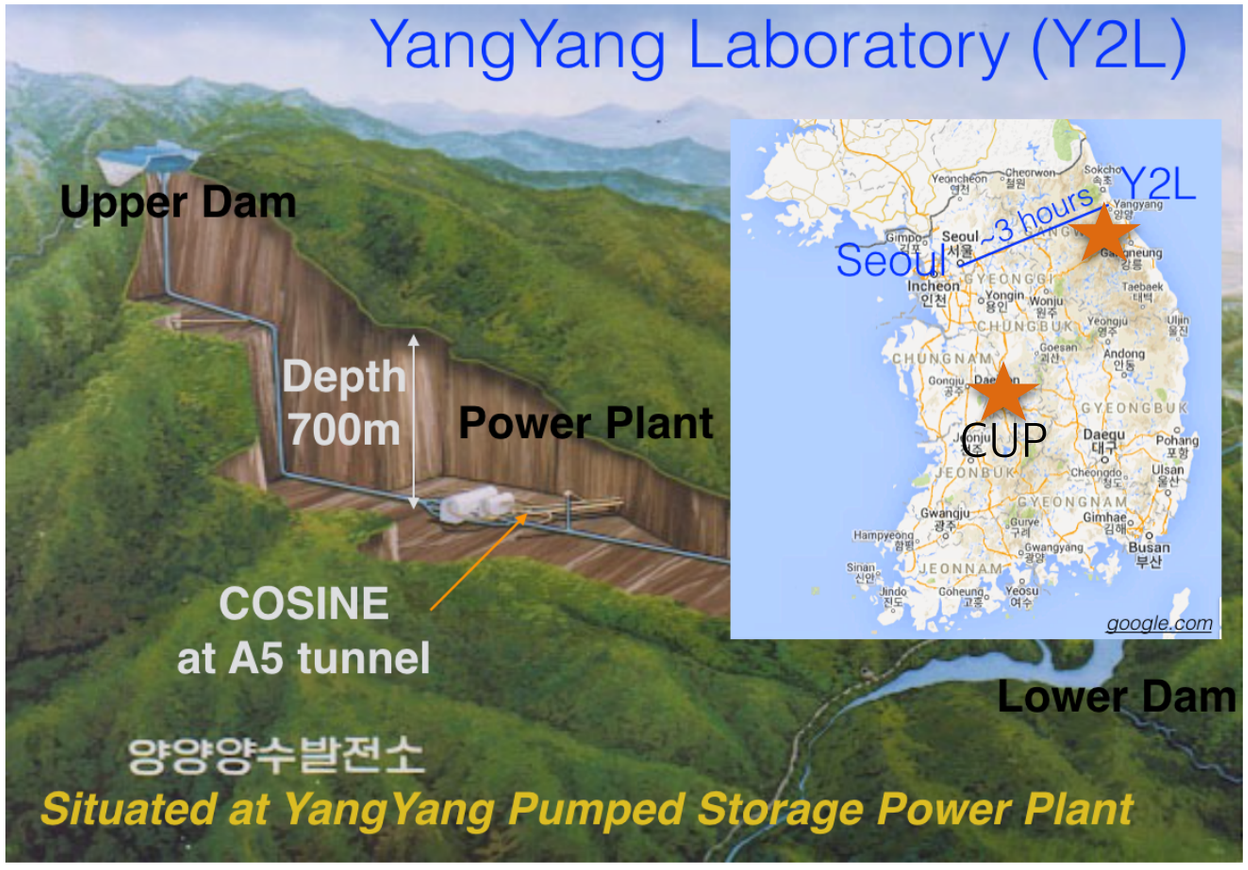
Alpha rate: 0.4 mBq/kg

Higher than DAMA but lower than other competitors,

~ 0.36 mBq/kg is due to ^{210}Po (see next slide)

The COSINE-100 experiment

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



KIMS Korea Invisible Mass Search Experiment + DM-ICE

COSINE

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Institute for Basic Science 기초과학연구원

EWHA W.U. 梨花女大 1945 1886

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The University Of Sheffield.

SUNGKYUNKWAN UNIVERSITY 1398 성균관대학교

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

Yale

KOREA UNIVERSITY 1905



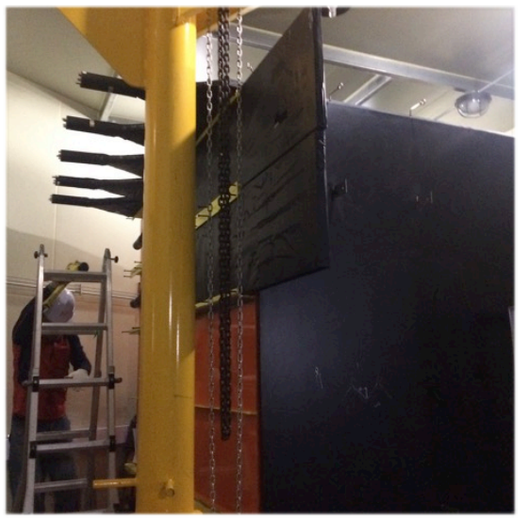


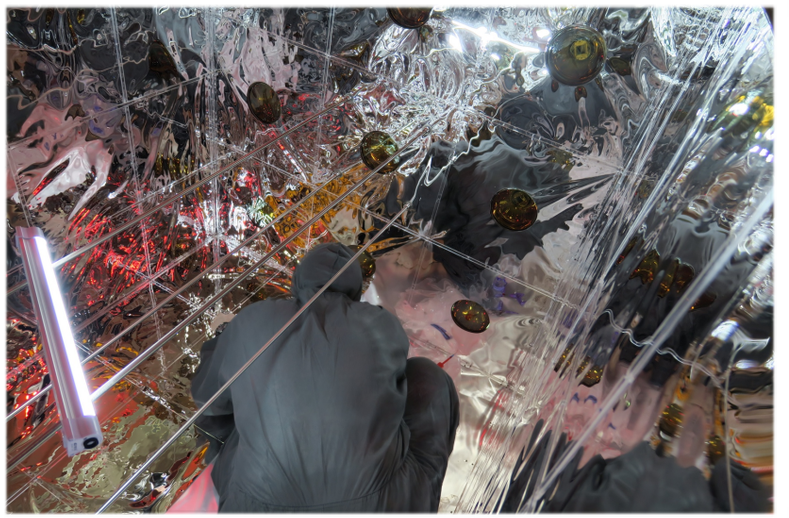
COSINE-100 Construction Timeline

Dec. 2015 — **Jan. 2016** — **Feb. 2016**

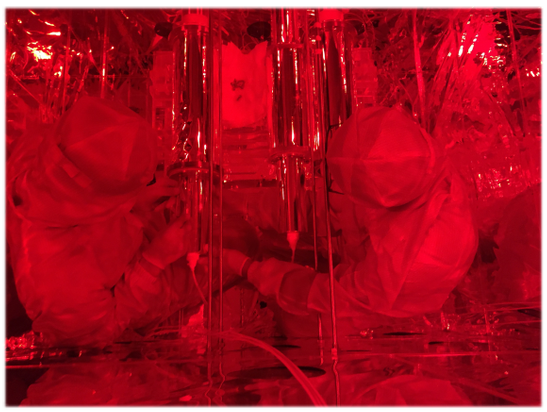



Mar. 2016 — **Apr. 2016**

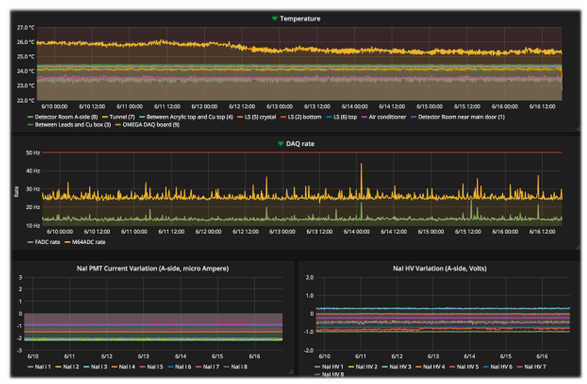




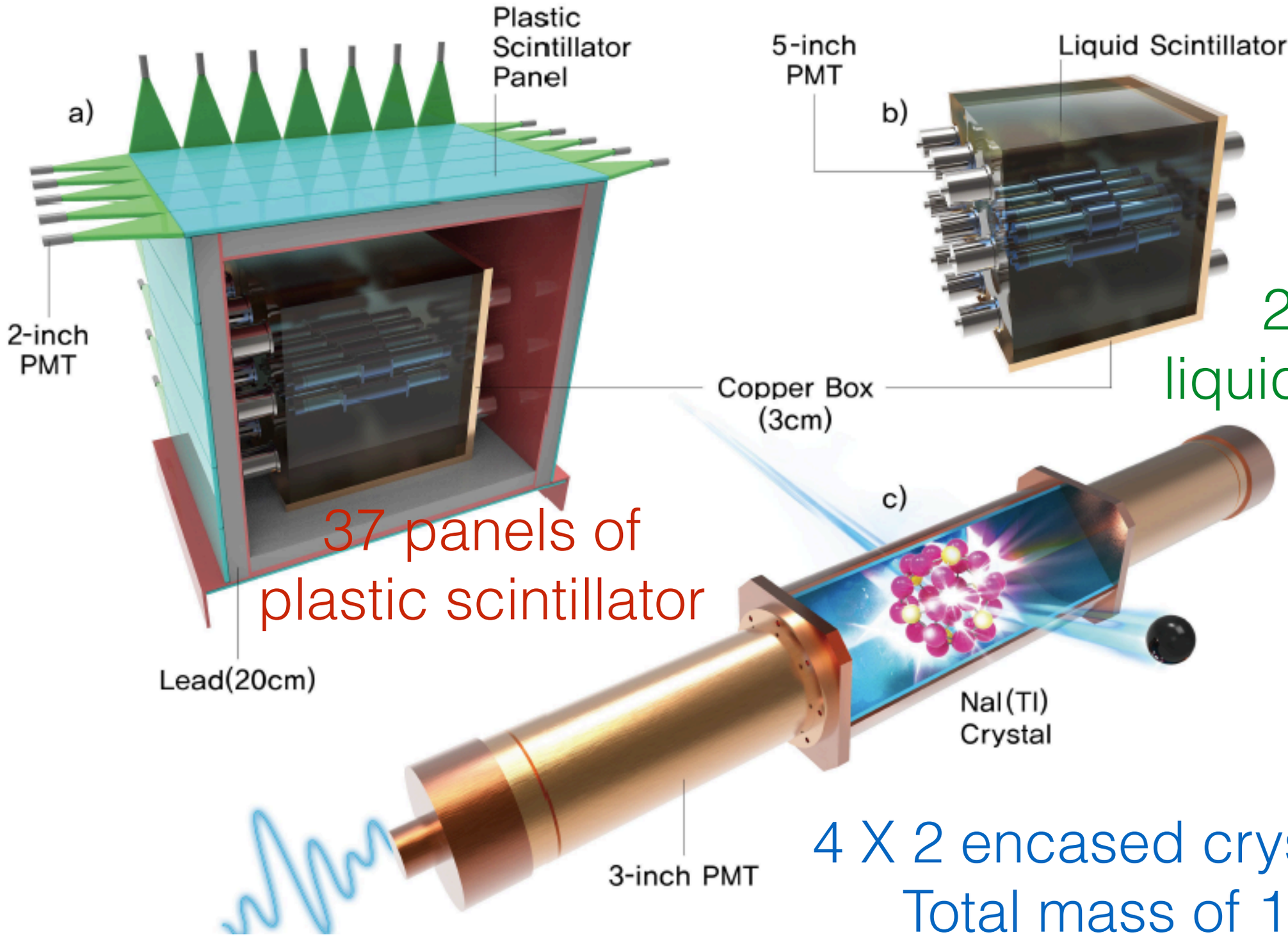
May. 2016 — **Jun. 2016** — **Sep. 2016**







The COSINE-100 detector components



2 tons of
liquid scintillator

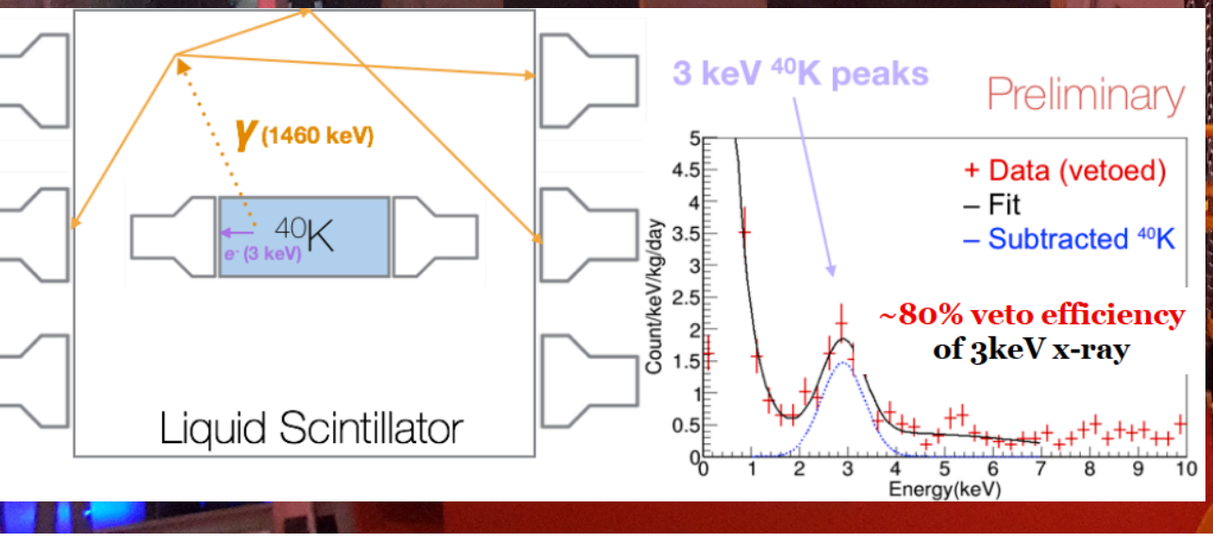
37 panels of
plastic scintillator

4 X 2 encased crystal array
Total mass of 106 kg

The COSINE-100 detector components

slide open

detachable panels



calibration Holes

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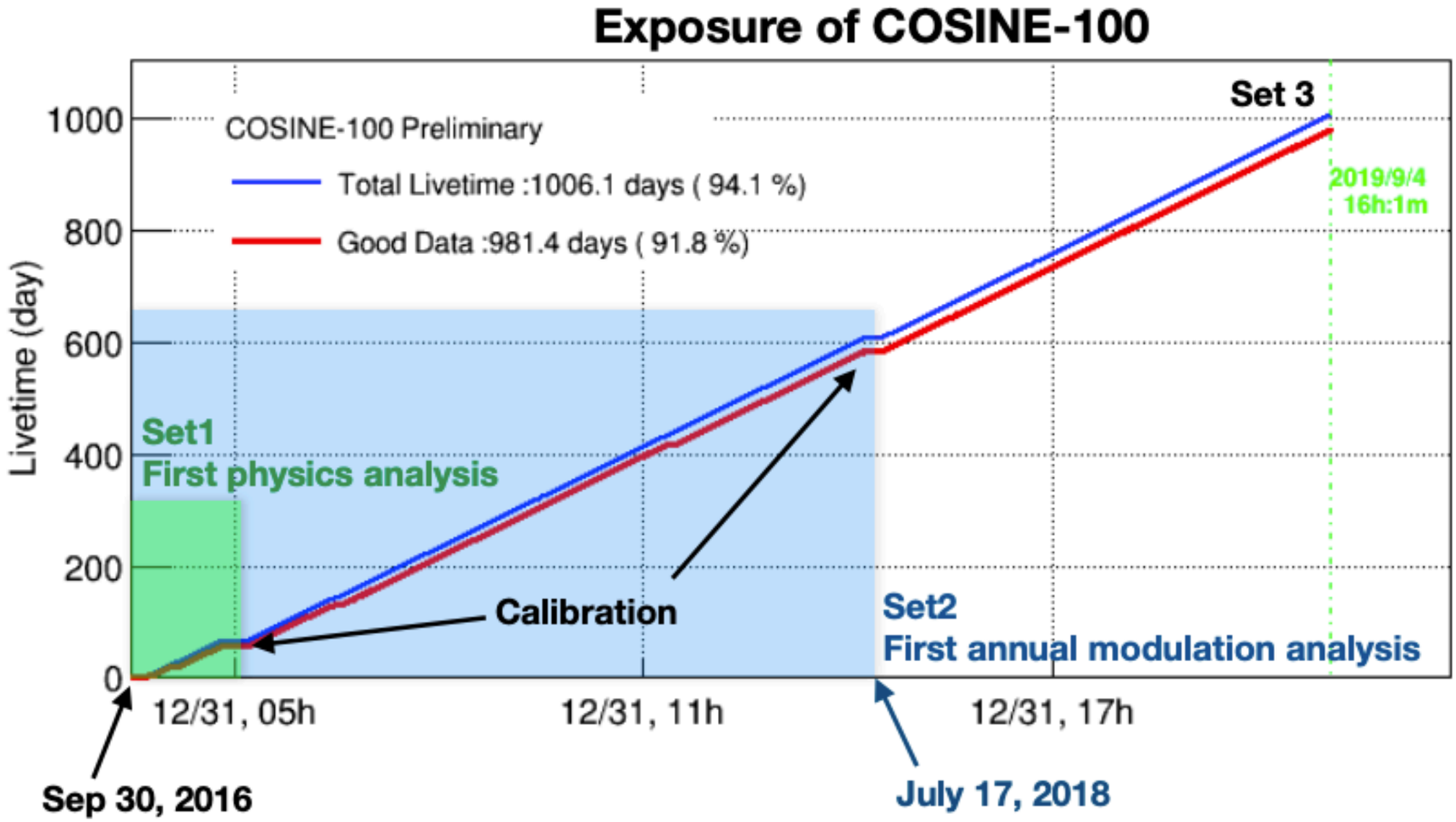
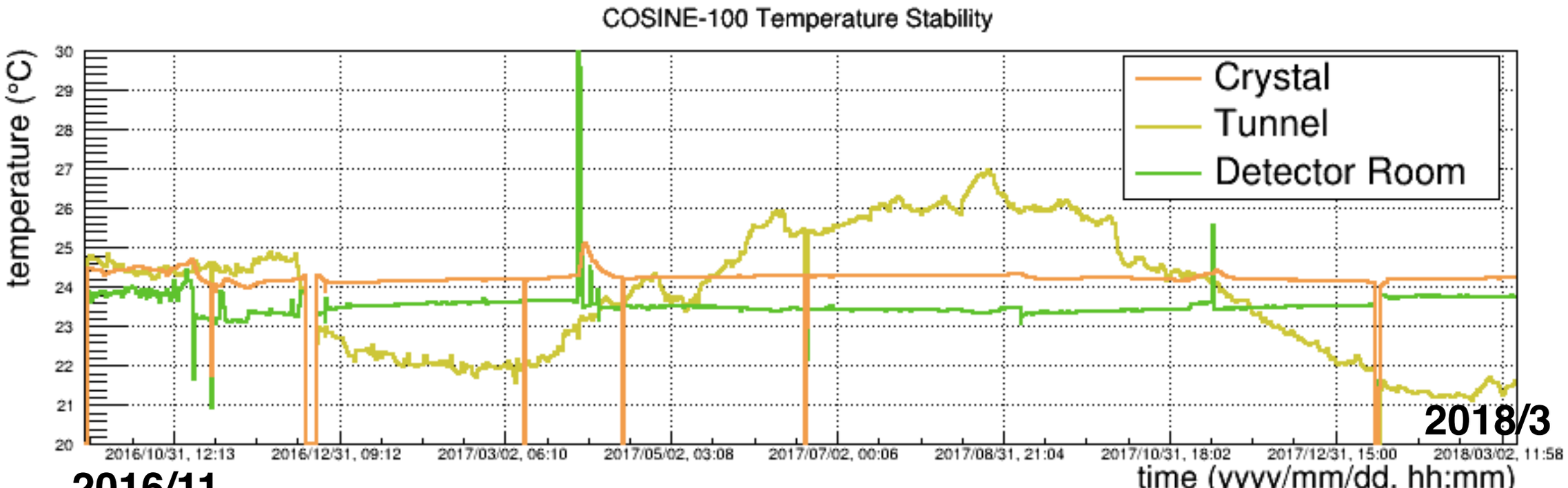
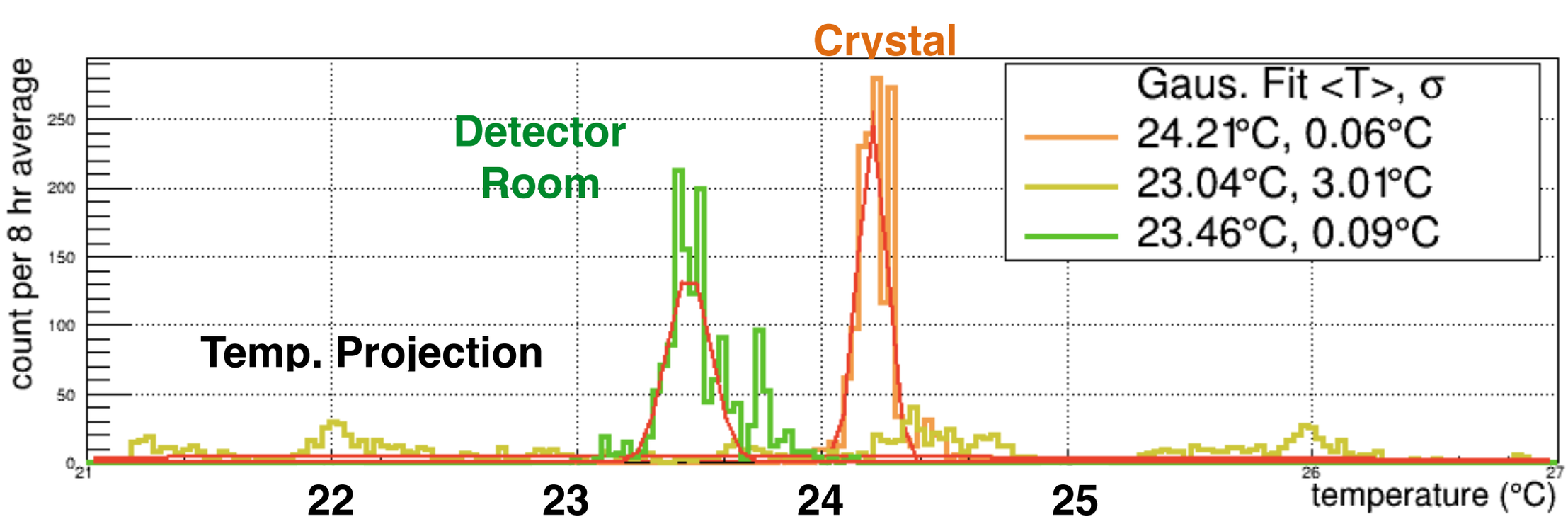
Exposure (Running for 3 years)



Detector is running smooth (>95% physics data)
More than 3 years of running and collecting 2.5 years of good data currently analyzing

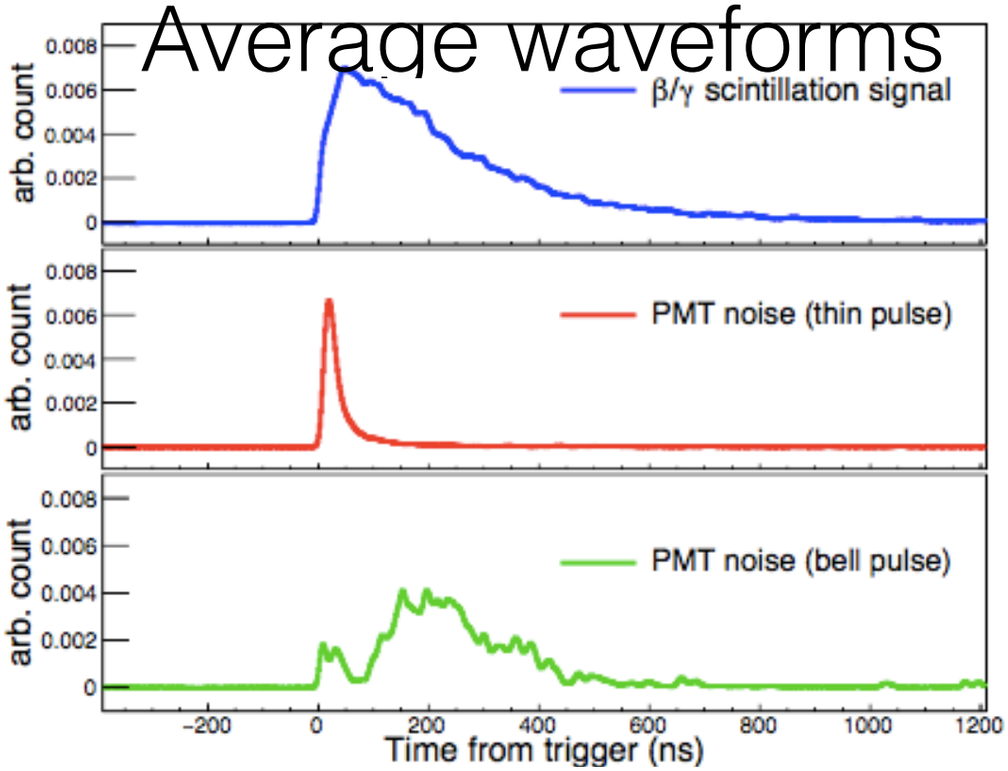
Environmental control/monitoring

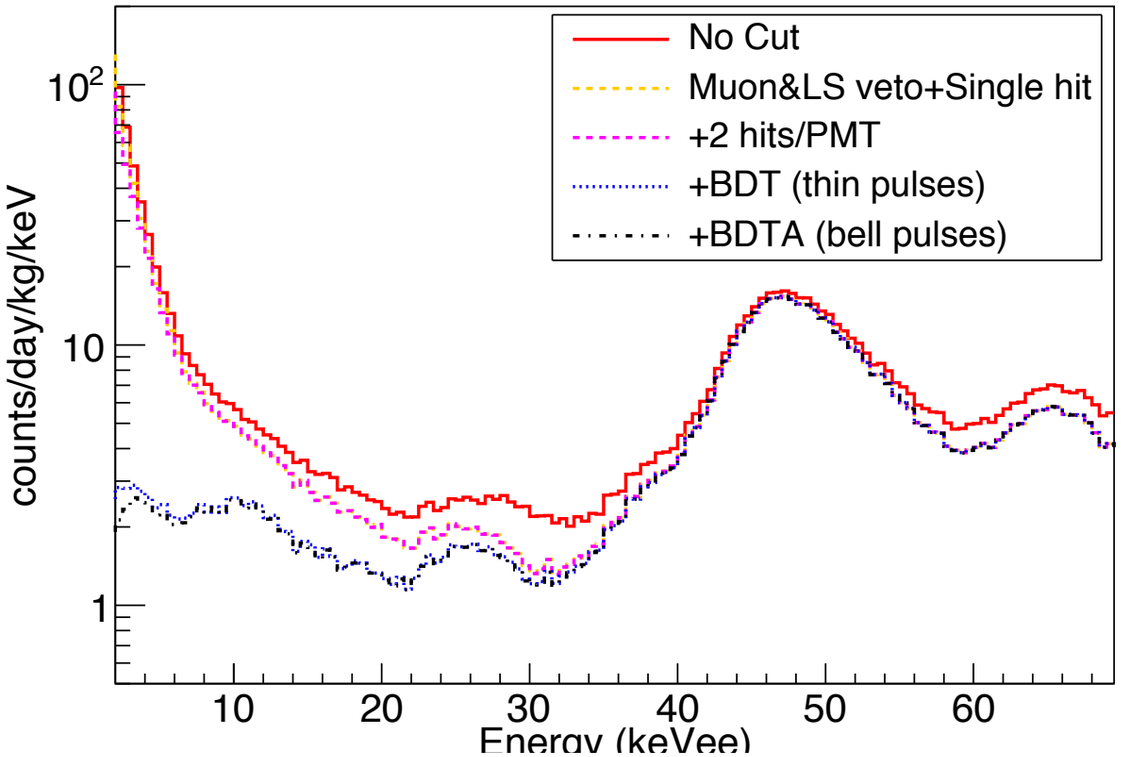


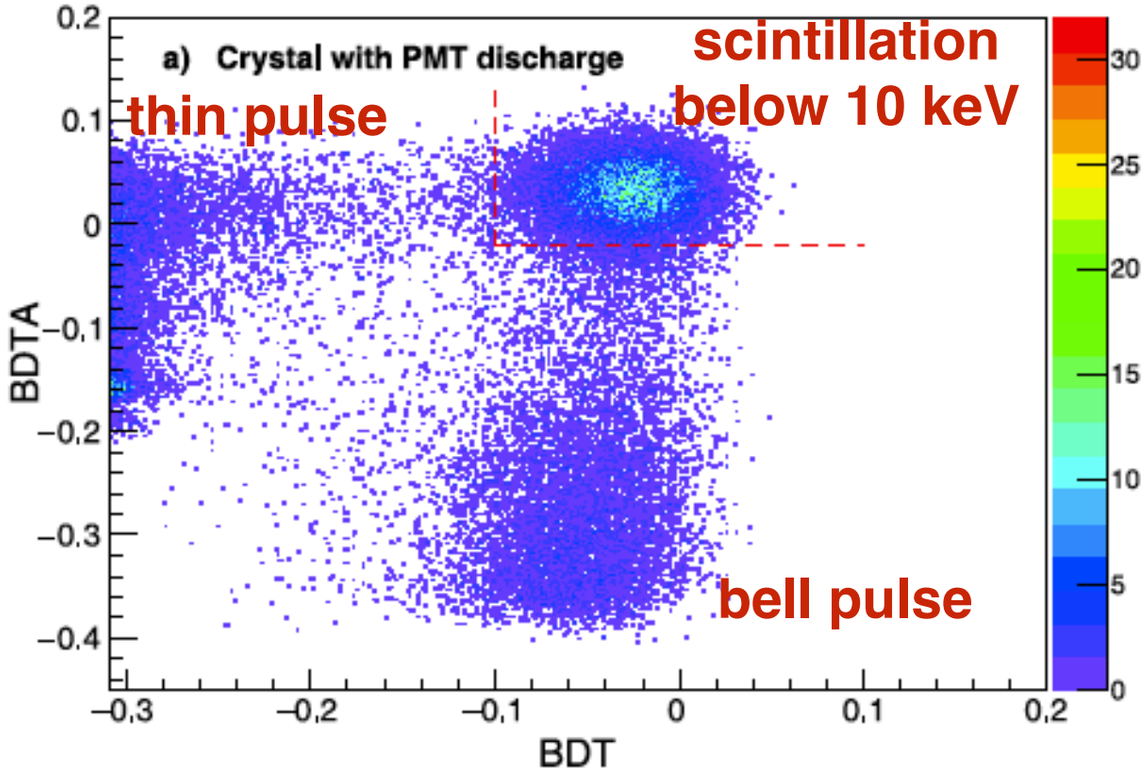


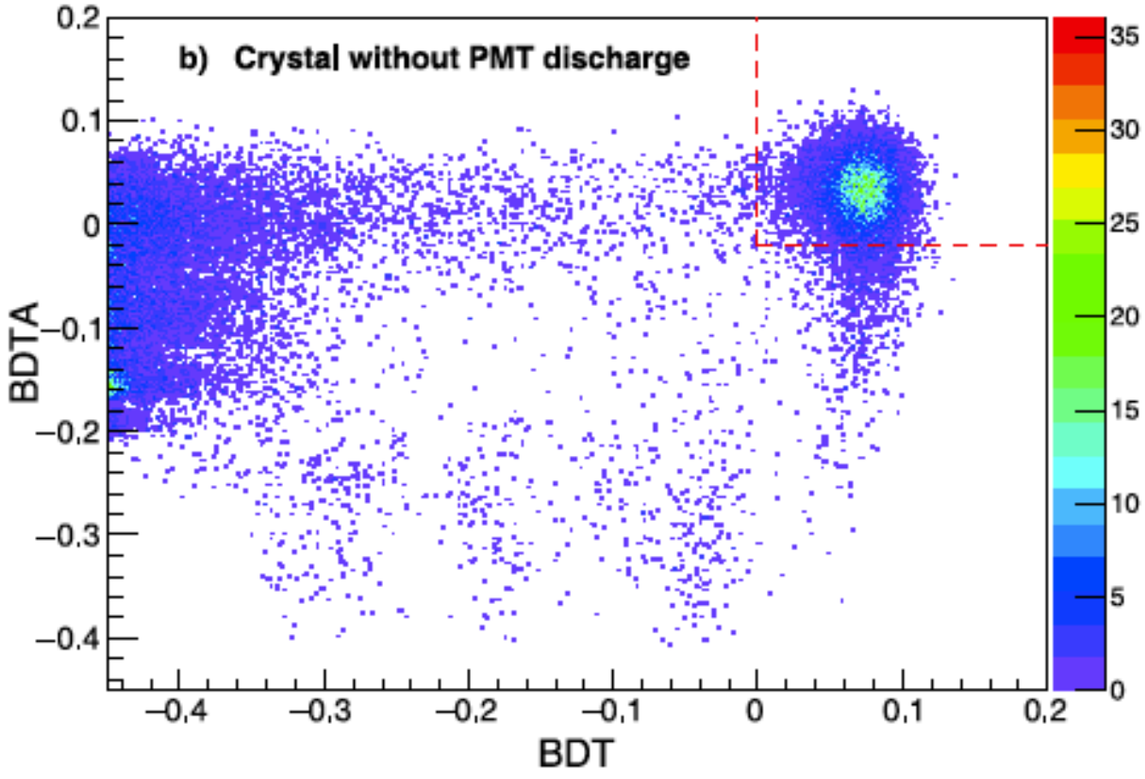
Crystal temperature is maintained better than 0.1 deg. C

PMT noise rejection

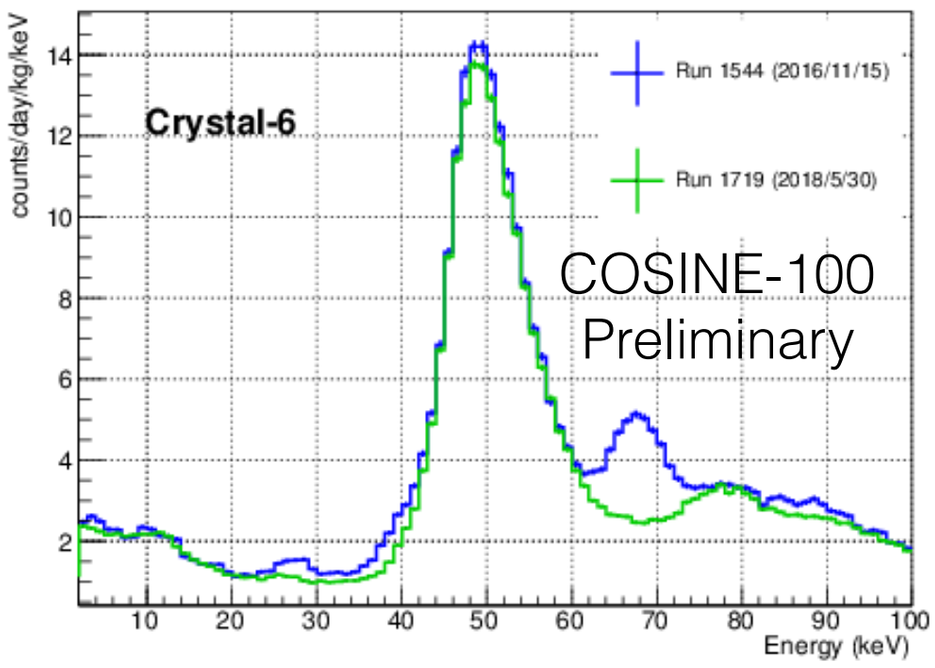


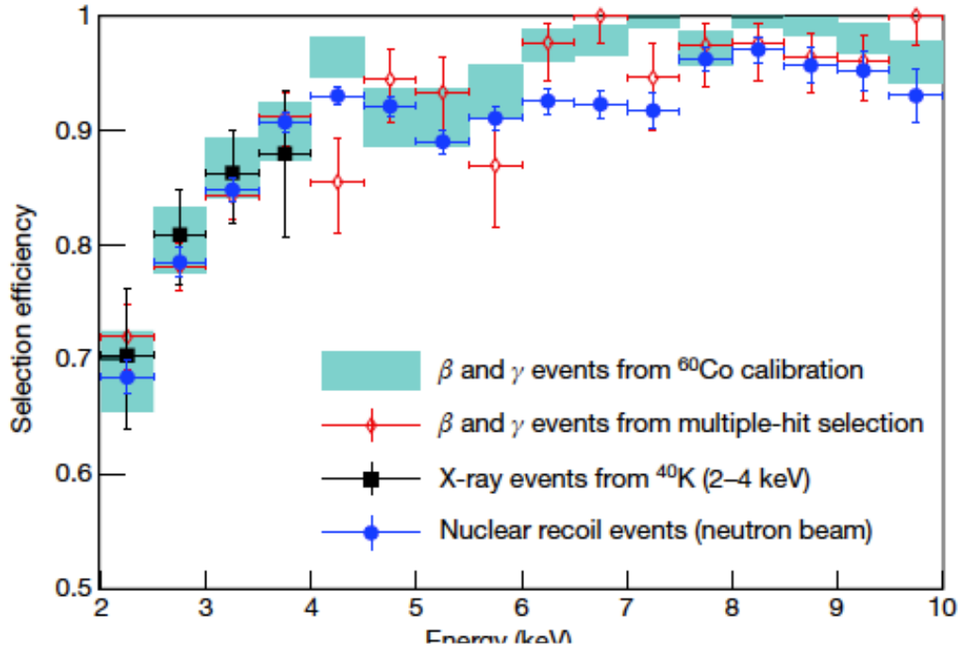


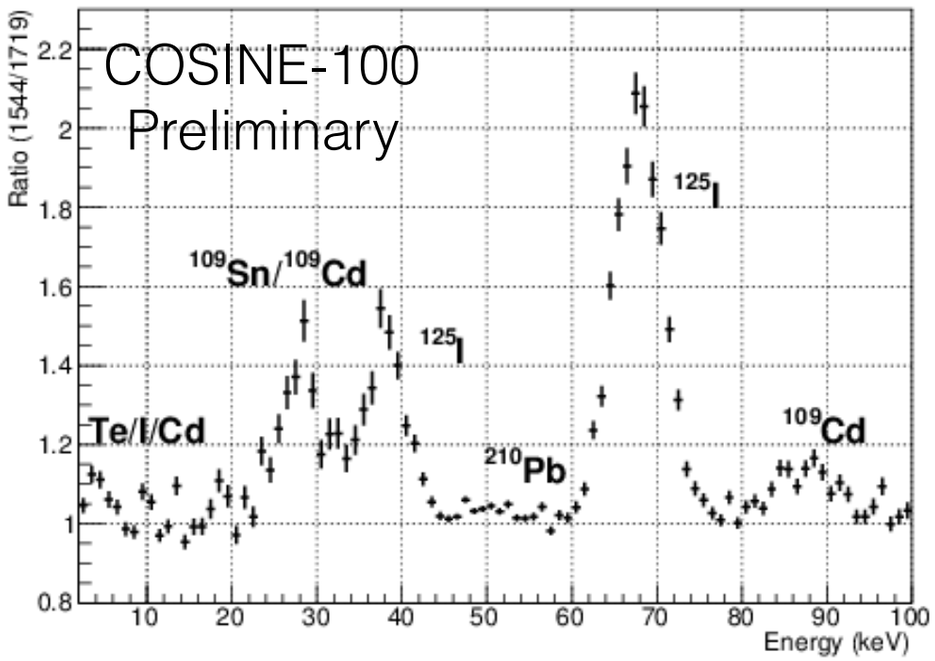


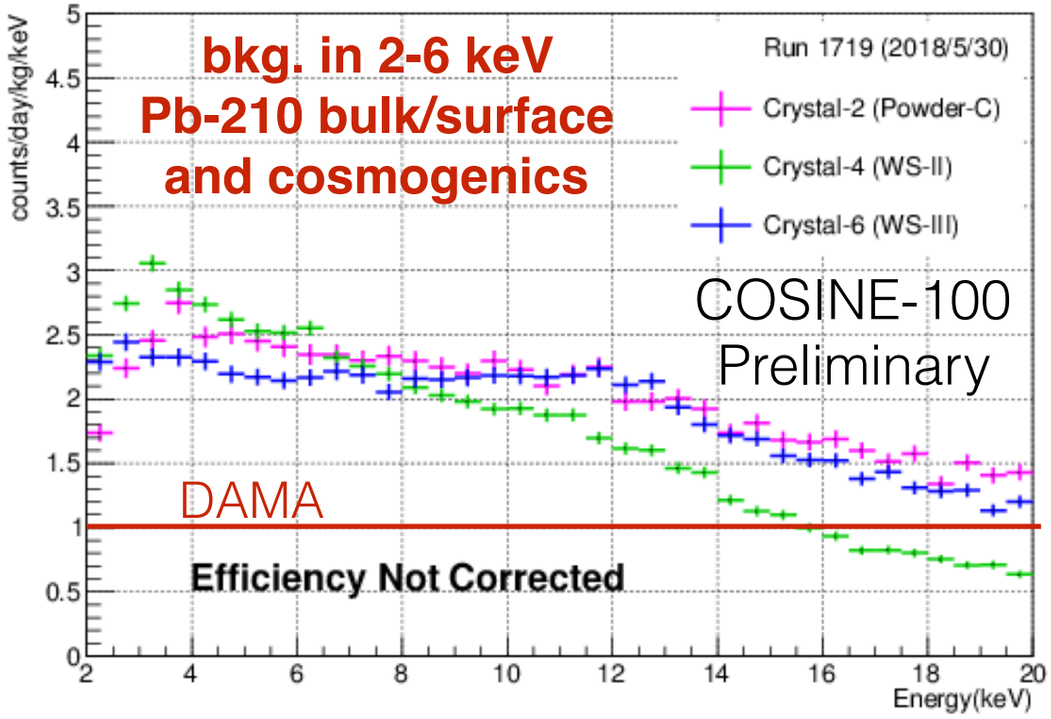


Single-hit Energy spectrum







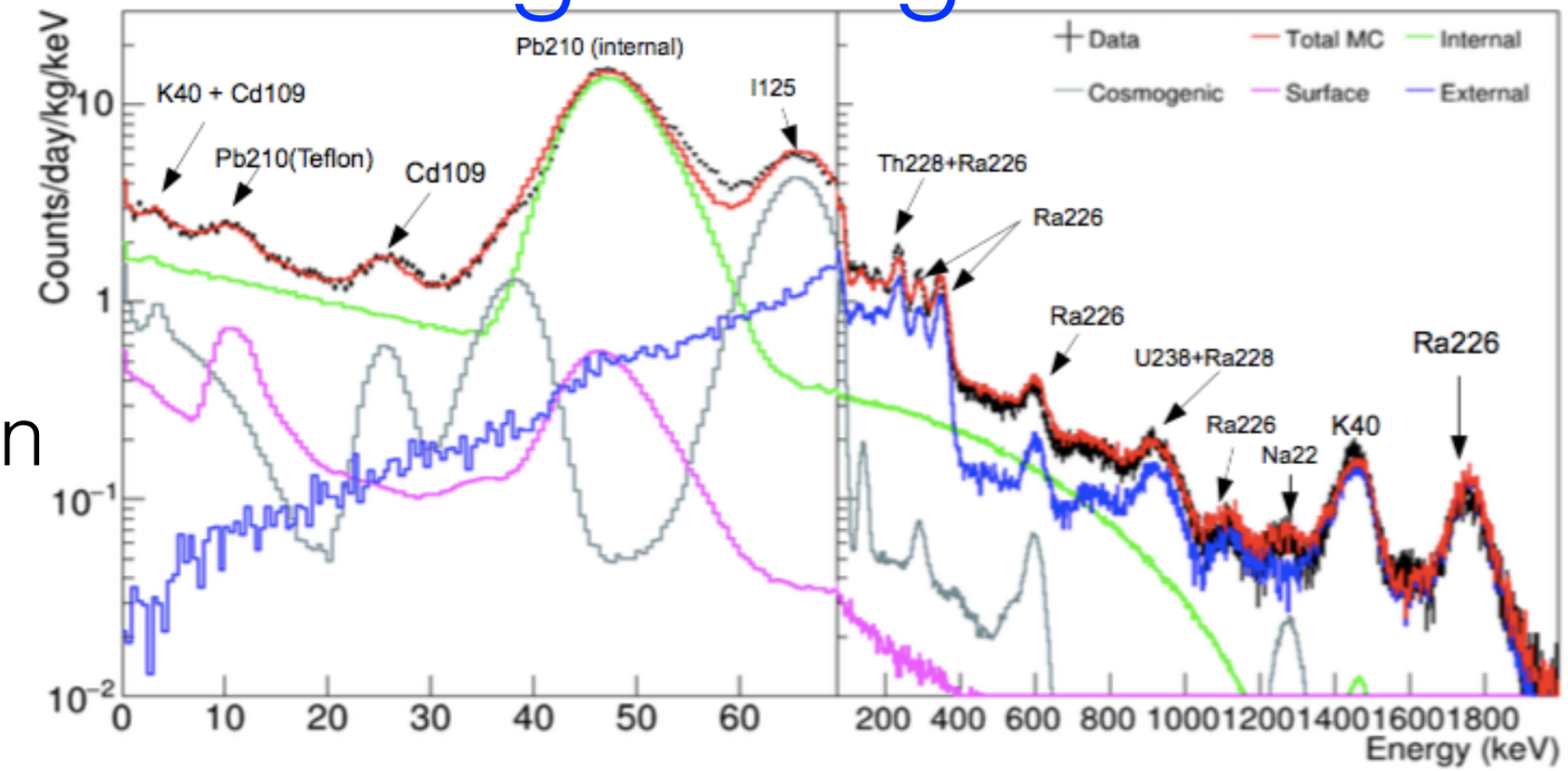


~70% Efficiency at 2 keV, Current bkg. is around 3 counts/day/kg/keV

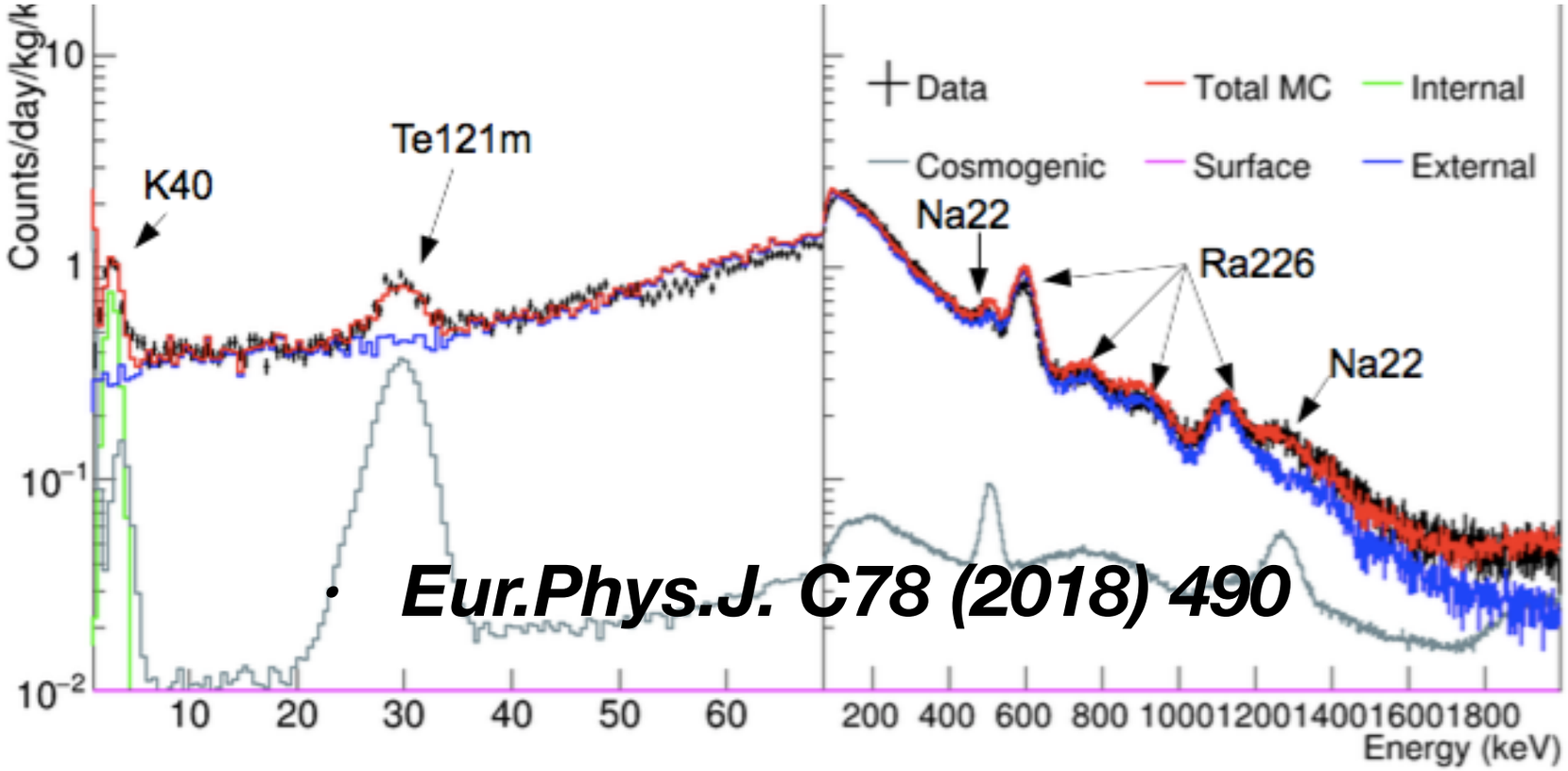
Understanding Background

Single-Hit

(2-6 keV region not used)



Multiple-Hit



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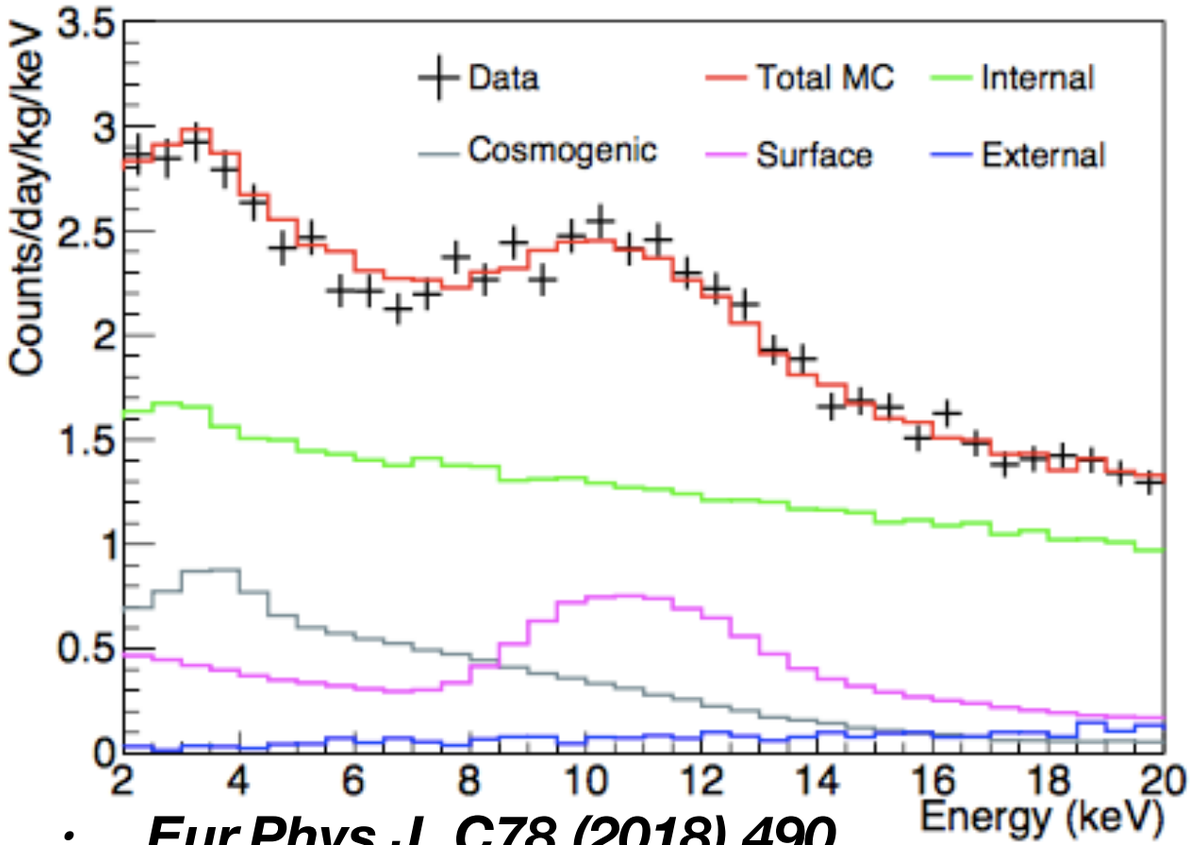
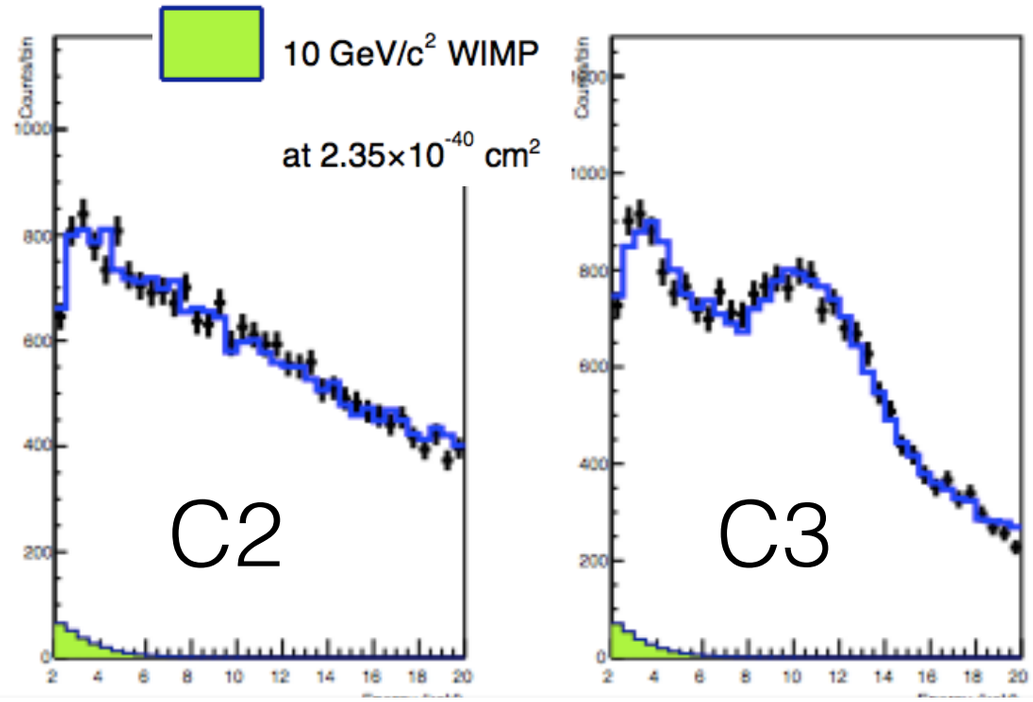
WIMP Search, 59.5 days of Data
(until enough modulation analysis data are accumulated)

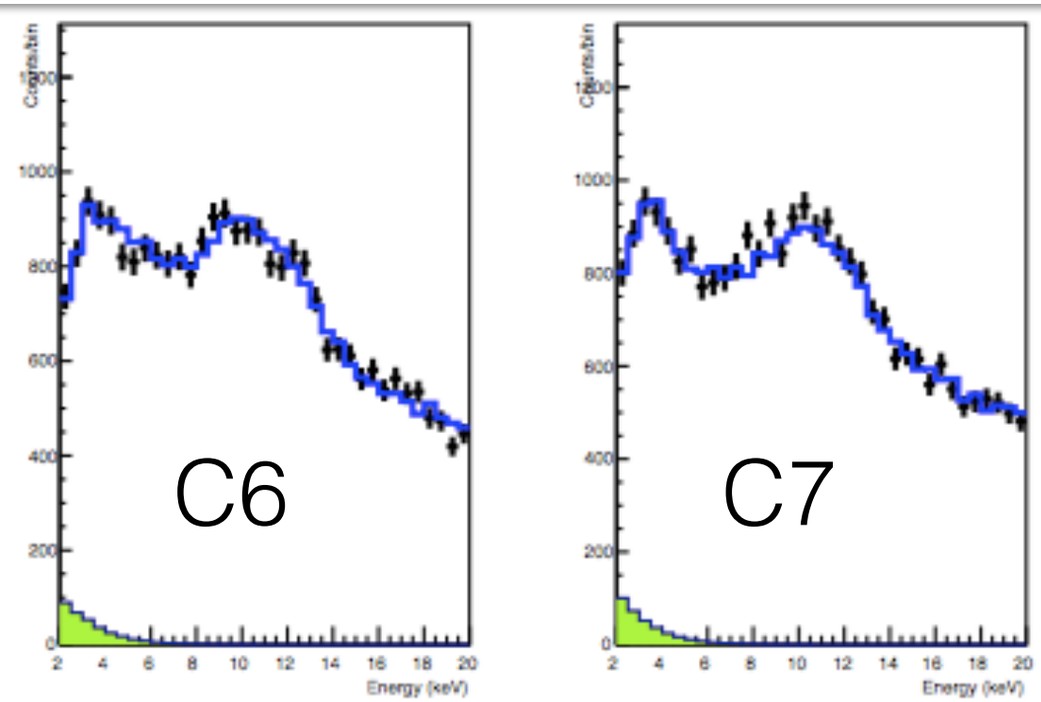


- ***Eur.Phys.J. C78 (2018) 490***

With bkg. understanding, 8 single-hit spectra are fit simultaneously with an assumed WIMP signal (SHM as described in Savage et al., Jounal of cosmology and astrophysics), Note that bkg. understanding consideration from Kudryavtsev et al. Astropart.Phys. 33 (2010) 91

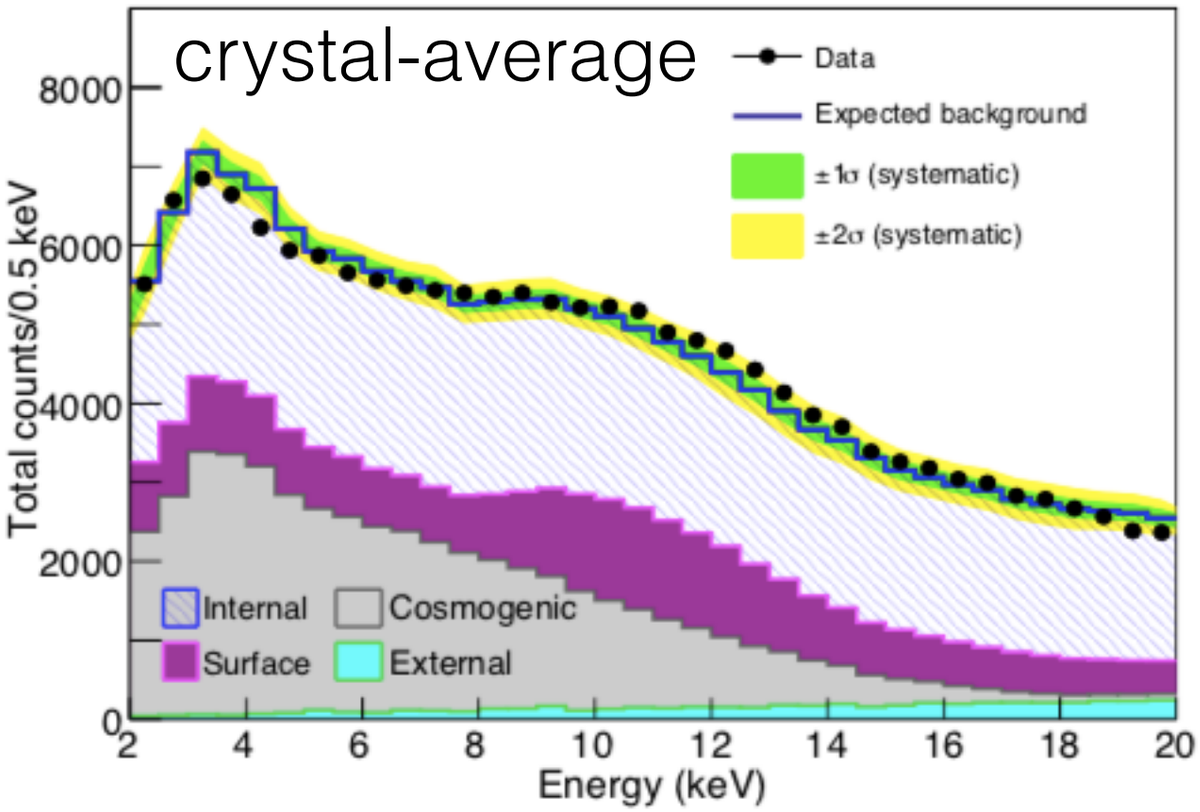


Overlay of DAMA-Na Signal at 10 GeV/c2

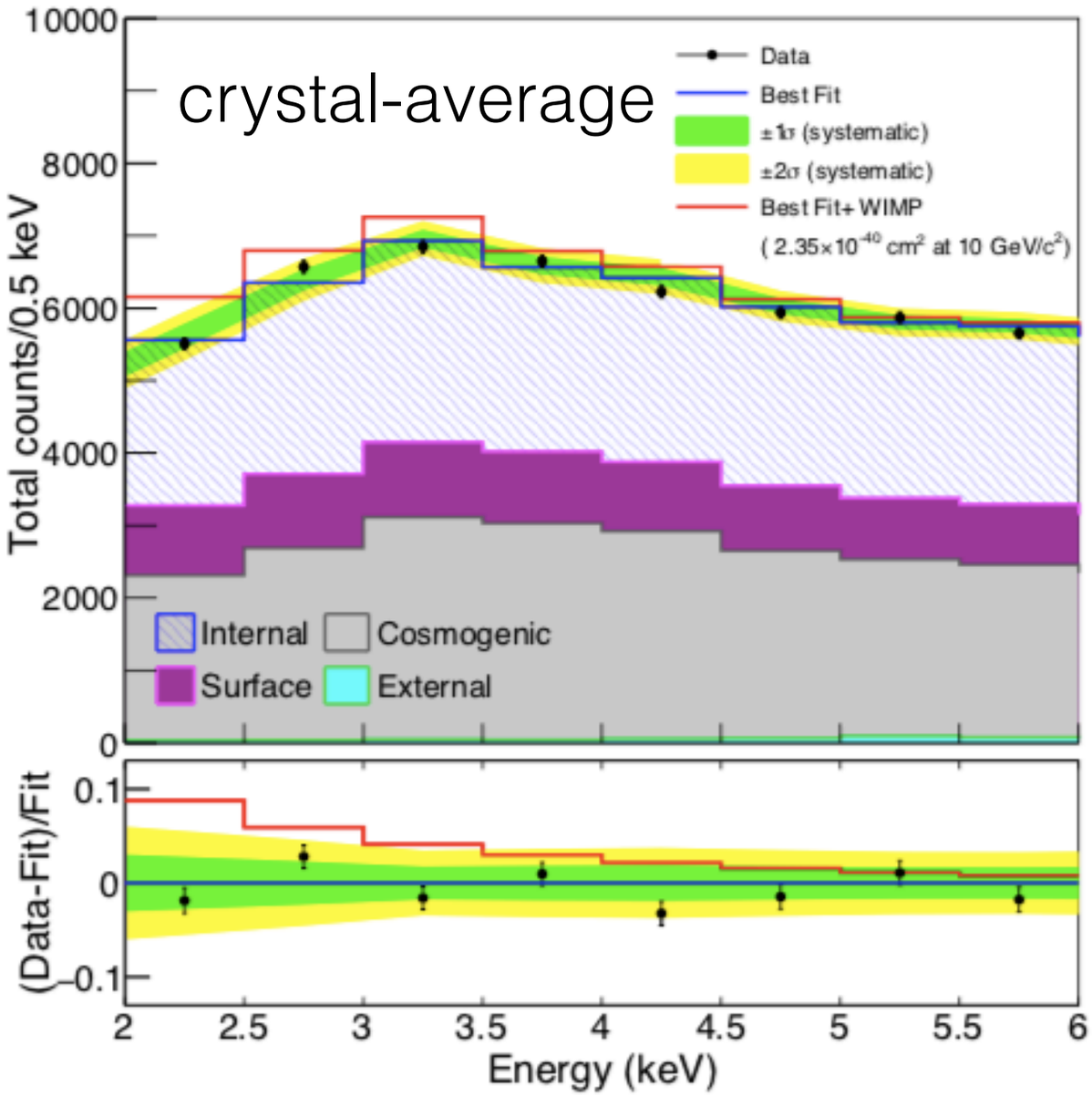


Results for likelihood fits in 2-20 keV region with assumed WIMP signals

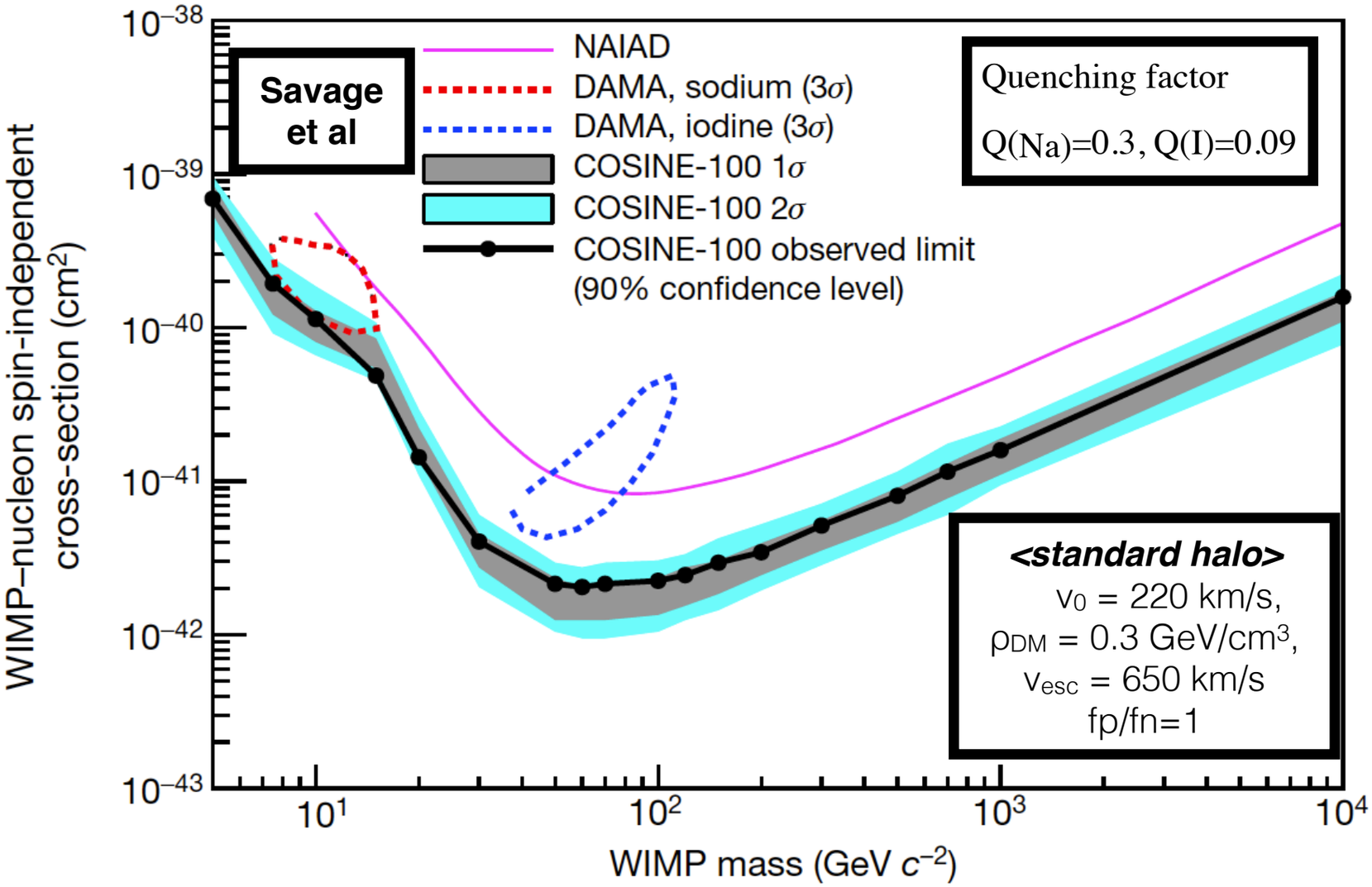
WIMP masses in 5–10000 GeV/c2
Perform a simultaneous fit with bkg. components and a signal component.
Nuisance parameters for bkg. and systematics



Best fit in 2—6 keV zoomed



Spin independent WIMP-nucleon cross section limit with same NaI(Tl) target (59.5 days of the COSINE-100 data)

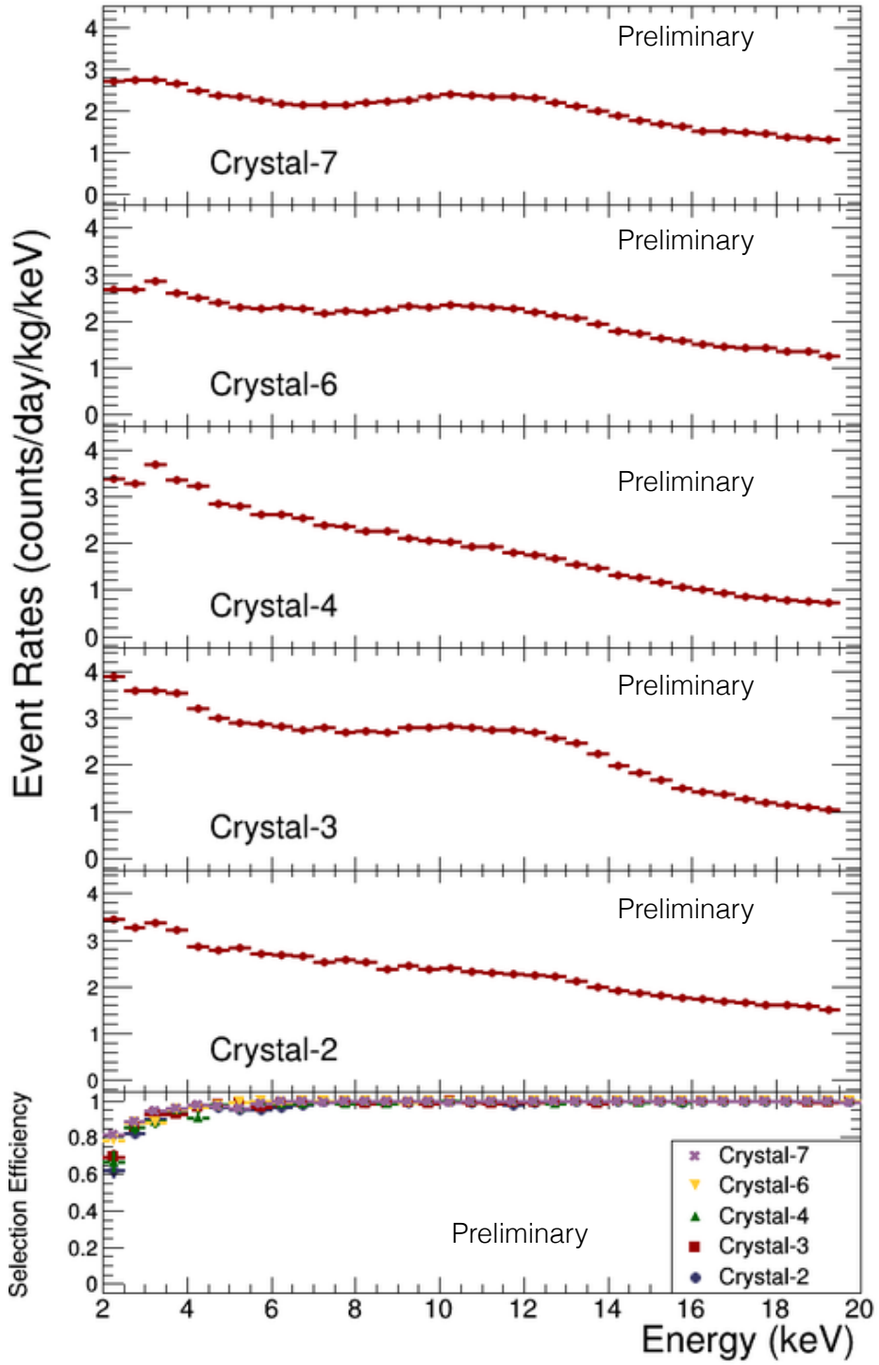


Nature 564, 83 (2018)

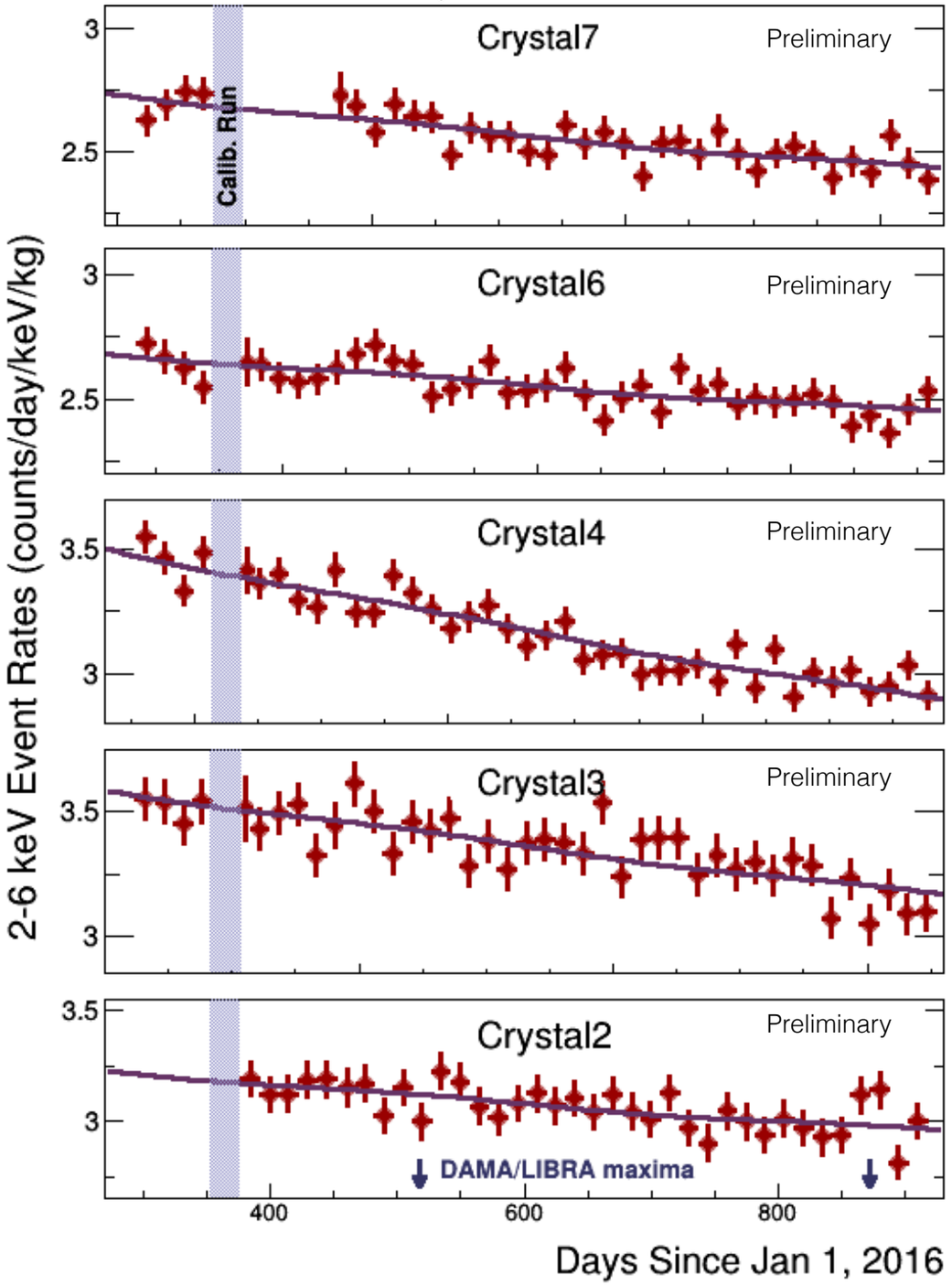
- Spectrum with known sources of backgrounds
- COSINE-100 excludes DAMA/LIBRA-phase1's signal as spin-independent WIMP with Standard Halo Model in NaI(Tl)
- Consistent with null results from other direct detection experiments with different target medium

Results with SD case and effective field theory with measured quenching are forthcoming.

Annual Modulation Analysis (606 days of data, SET2)
Search for oscillatory signature in 2—6 keV region of energy spectrum.



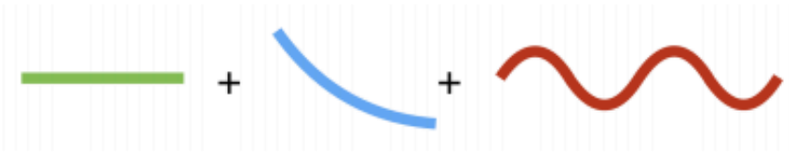
Phys. Rev. Lett. 123 031302 (2019)

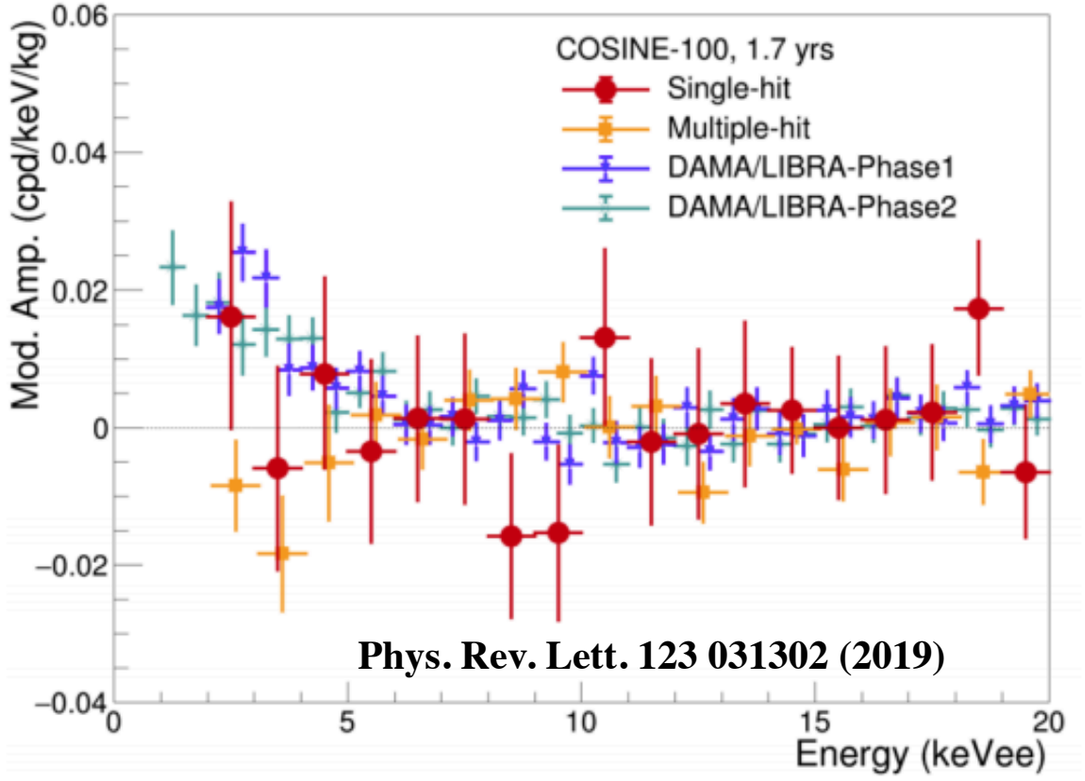


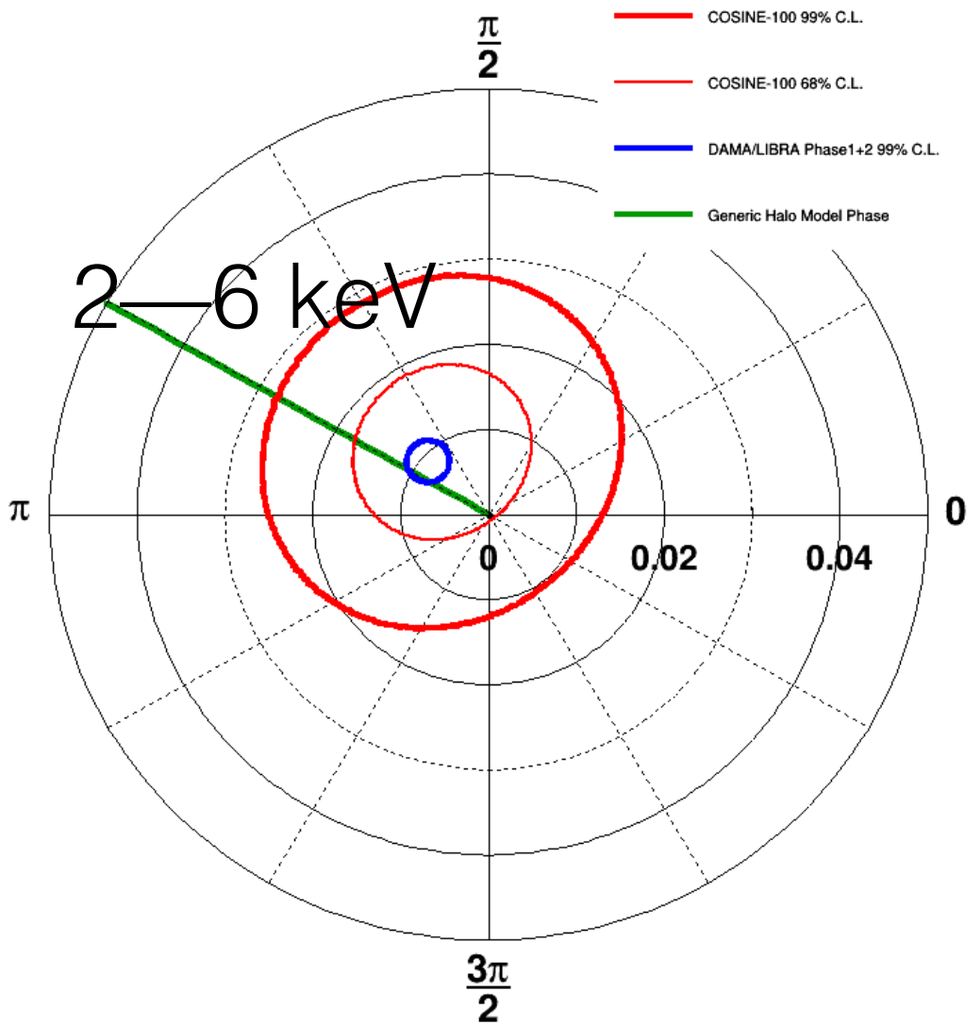
Global fit using cosmogenic and sinusoidal components simultaneously for crystals

Annual Modulation Results

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







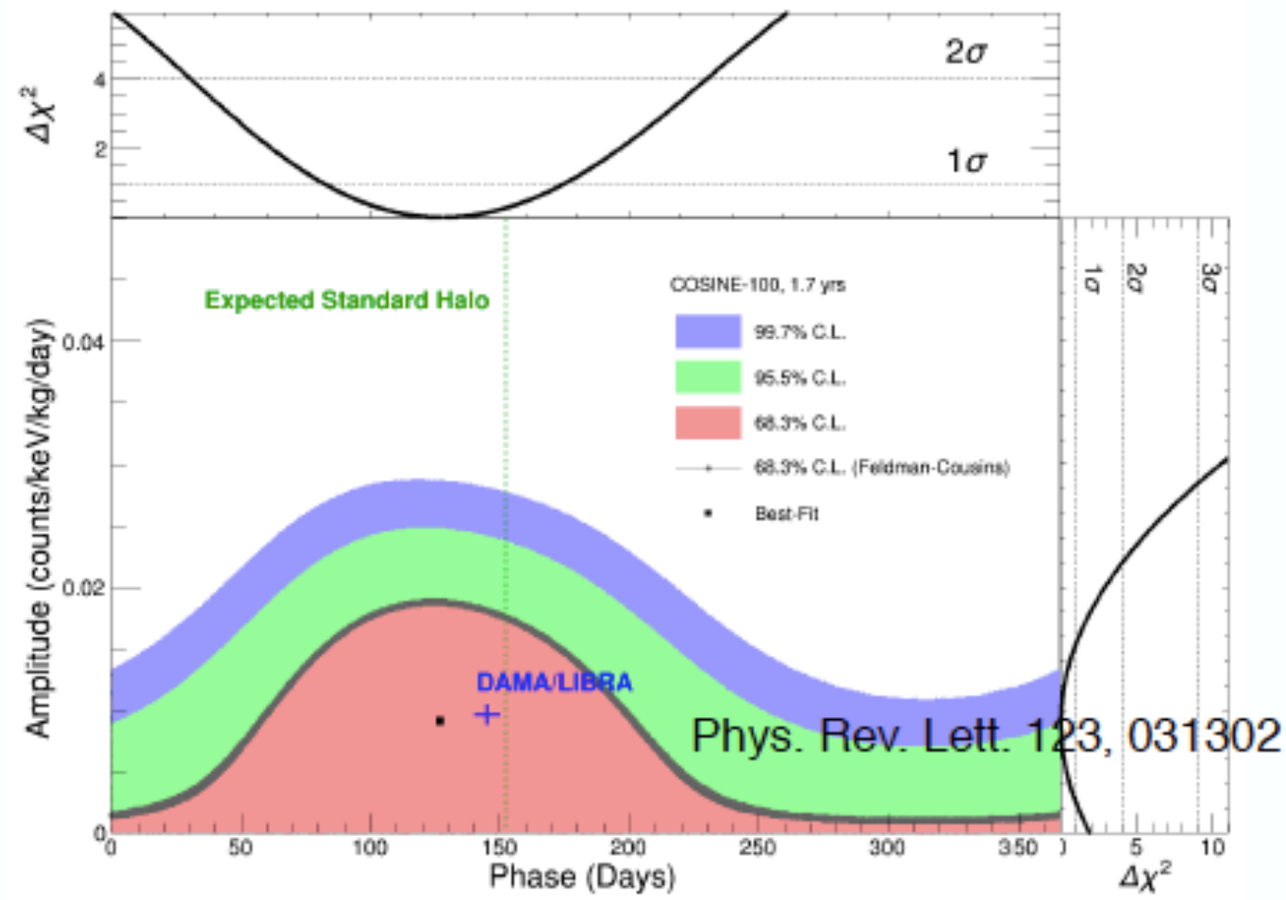
- We have performed first annual modulation analysis with 1.7 years of data (exposure 97.79 kg.year)
- No significant modulation is found between 2—6 keV region of interest.
- The analysis is currently statistically limited and it will improve with upcoming data.

Configuration	Amplitude [cpd/kg/keV]	Phase (Days)
COSINE-100	0.0092 ± 0.0067	127.2 ± 45.9
DAMA/LIBRA (Phase1 + Phase2)	0.0096 ± 0.0008	145 ± 5
COSINE-100	0.0083 ± 0.0068	152.5 (fixed)
COSINE-100 (Without LS)	0.0024 ± 0.0071	152.5 (fixed)
ANAIS-112	-0.0044 ± 0.0058	152.5 (fixed)
DAMA/LIBRA (Phase1 + Phase2)	0.0095 ± 0.0008	152.5 (fixed)

Upcoming data analysis projected sensitivity

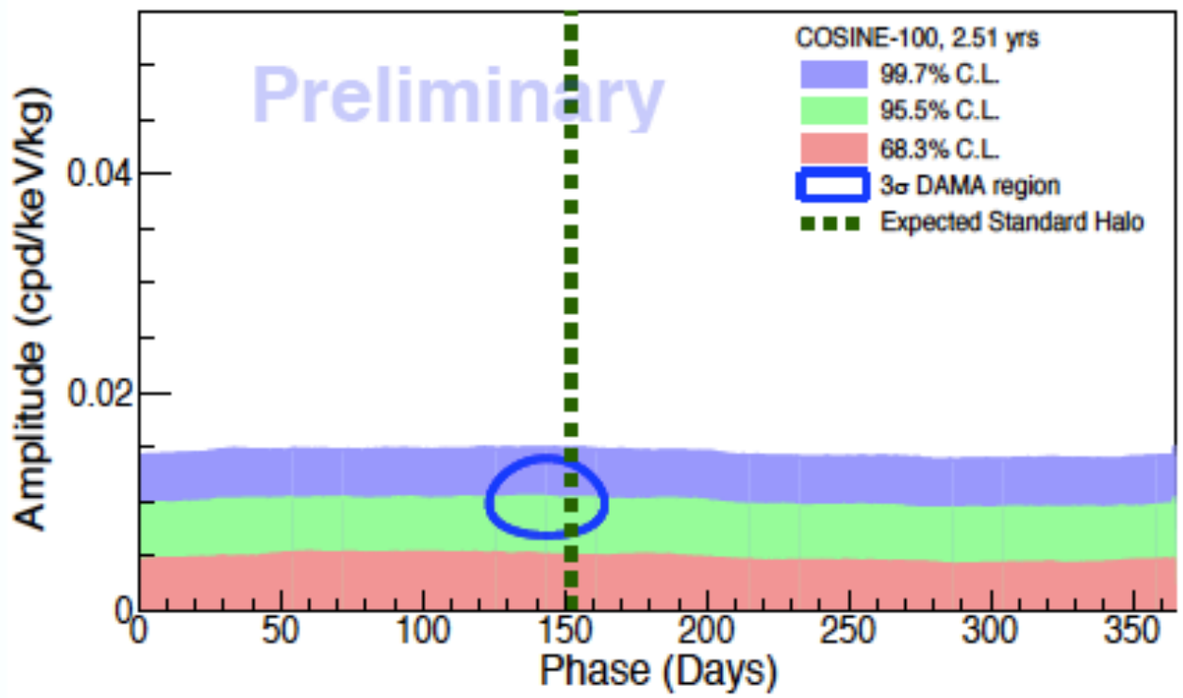
SET2 result

dama data : Nucl. Phys. At. Energy 19 (2018) 307



SET3 Predicted Sensitivity

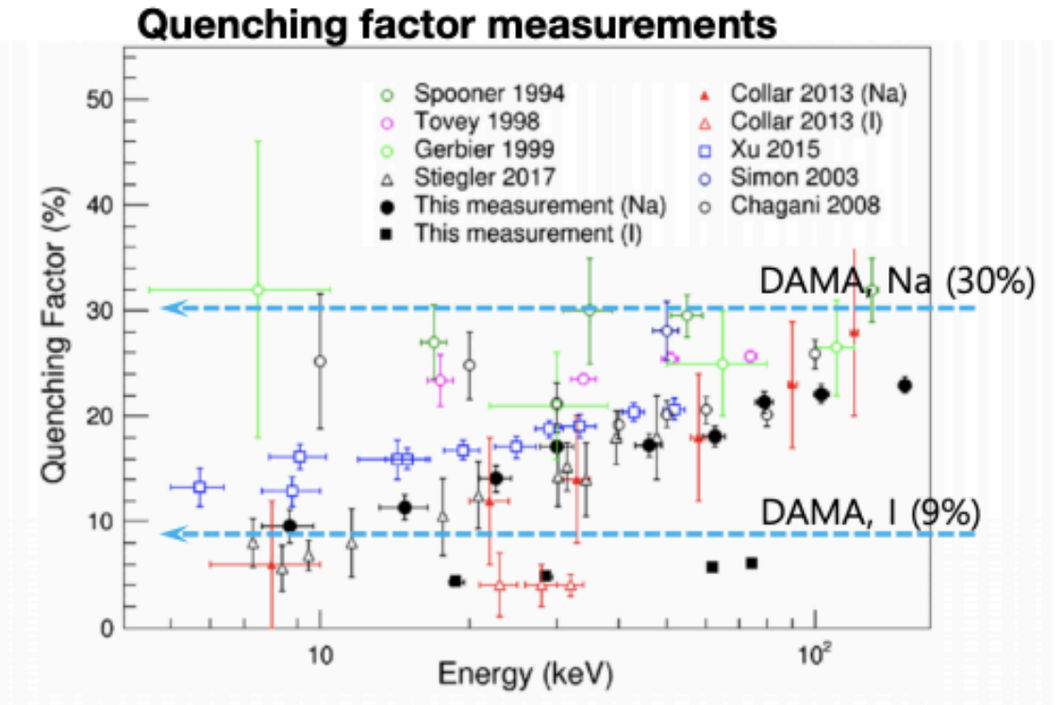
Assuming no modulation case

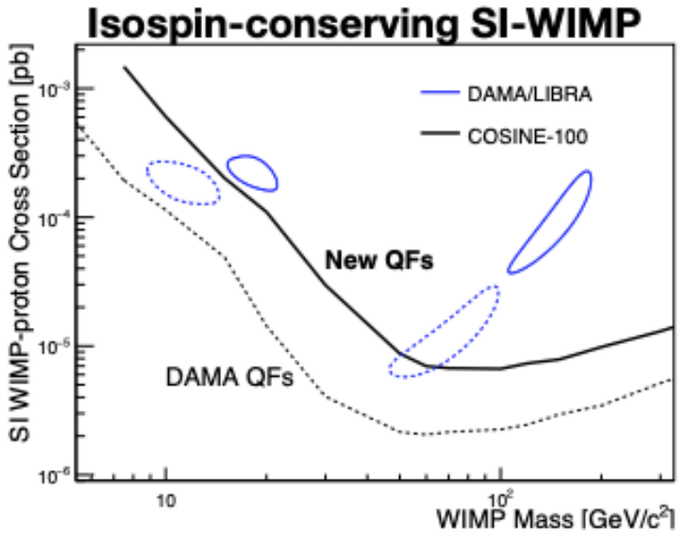


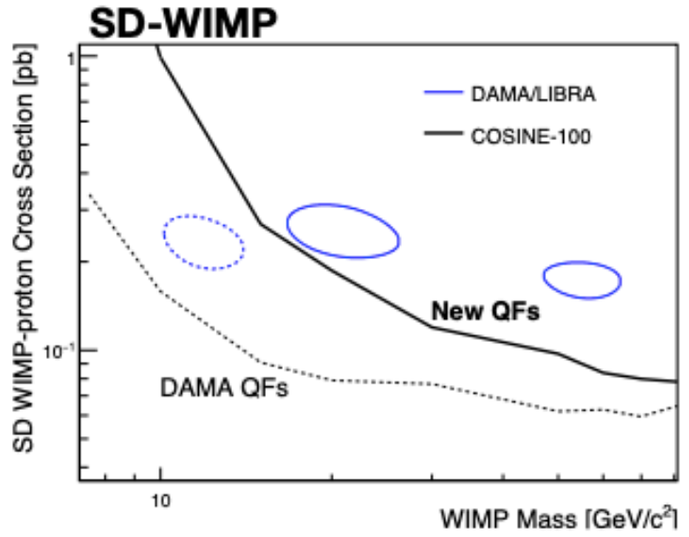
- New data (SET3) uses 153.7 kg year (2.5 yr) exposure with improved event selection (1 keV threshold) and better background understanding.
- Plan to unblind near the end of this year.

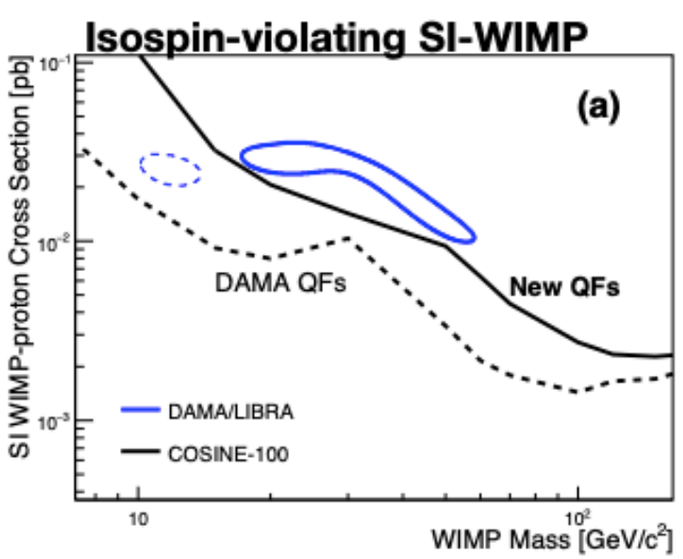
Quenching factors and COSINE-100

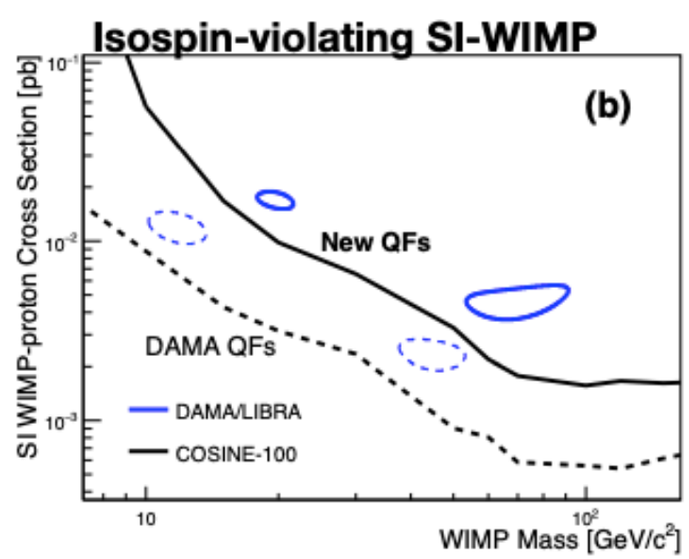
Astropart. Phys. 108 50-56 (2019)
arXiv:1907.04963v2 [hep-ex]





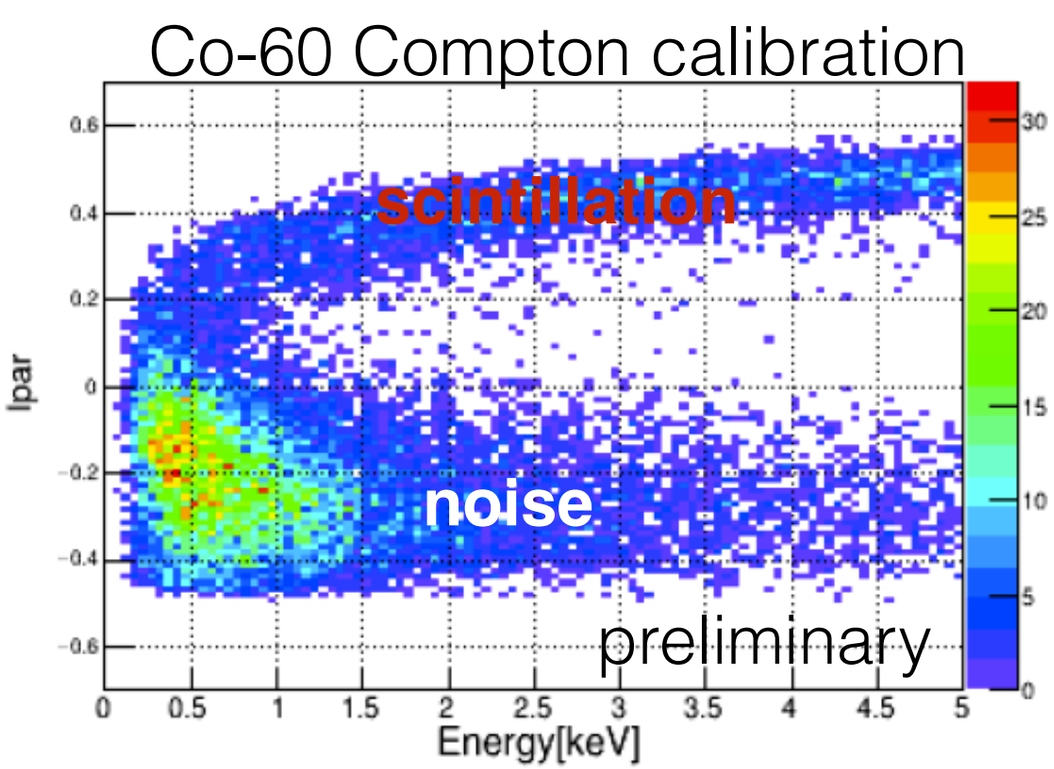




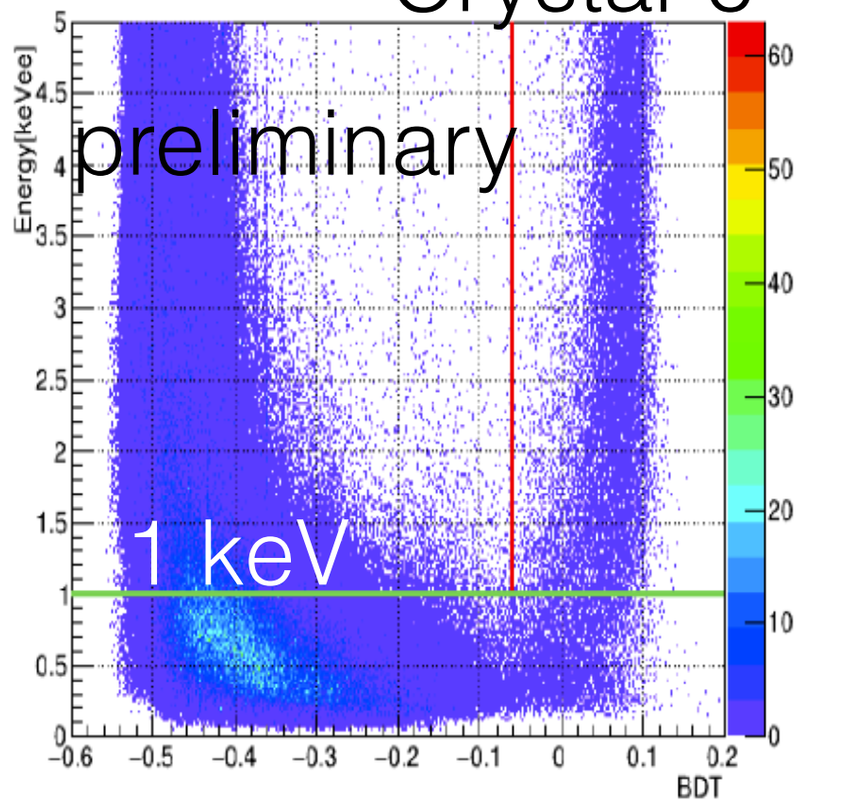


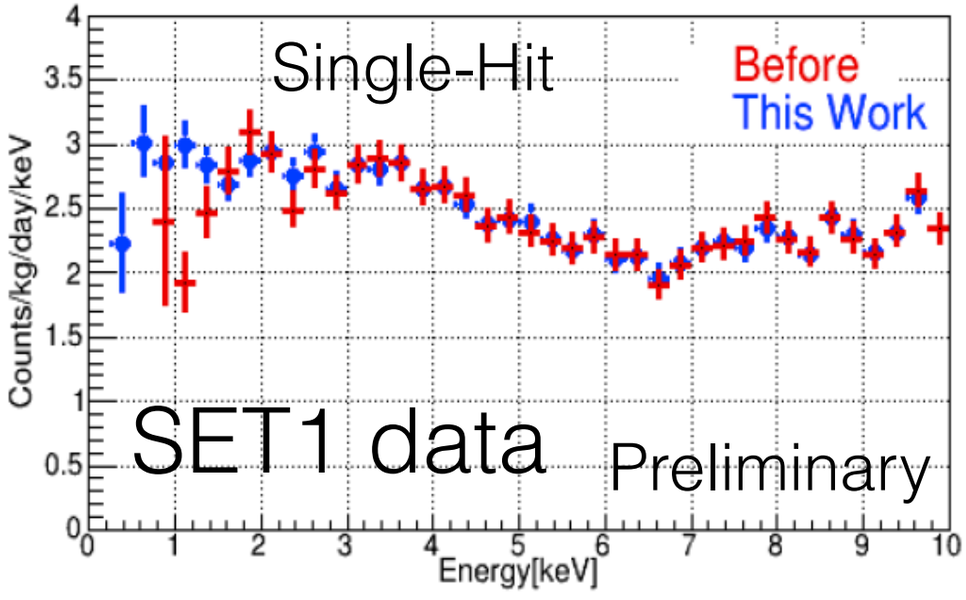
- Interpretation with SI and SD WIMP in SHM via new QF measurements.
- The region of mass and cross-section are moved to higher region by new QF.
- COSINE-100 data incompatible with DAMA signal region.

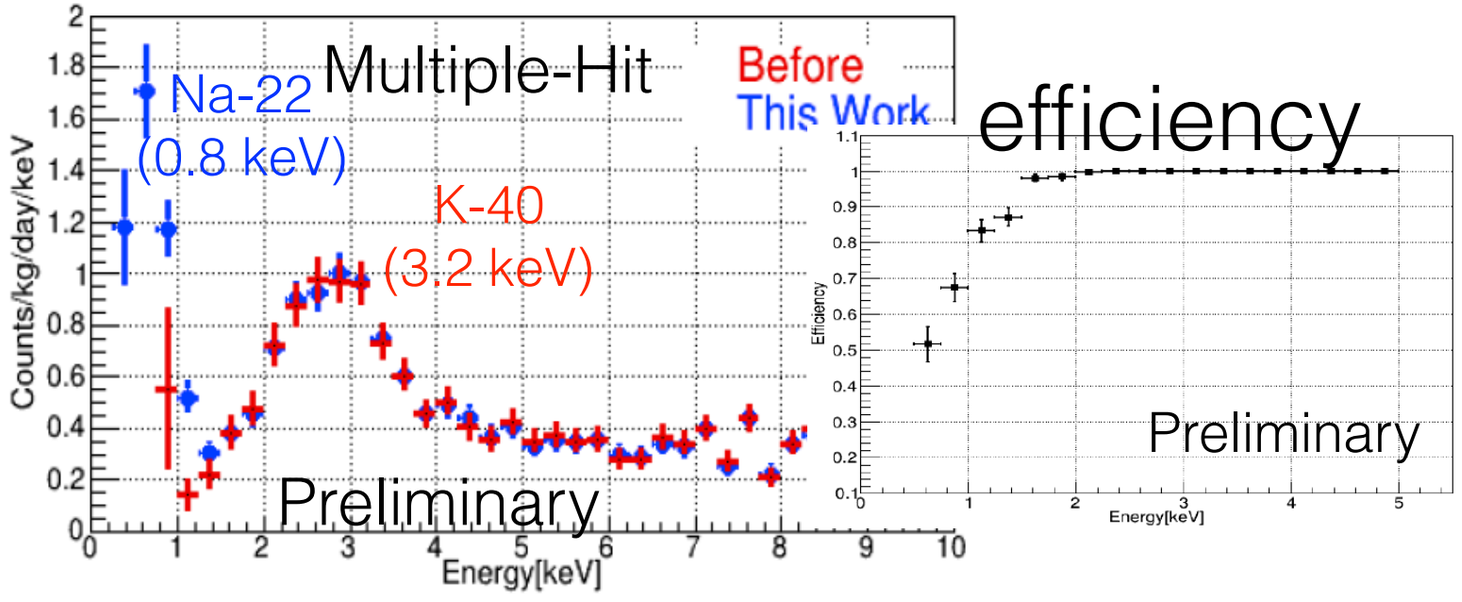
Down to 1 keV threshold



Calibration data is trained for noise rejection.

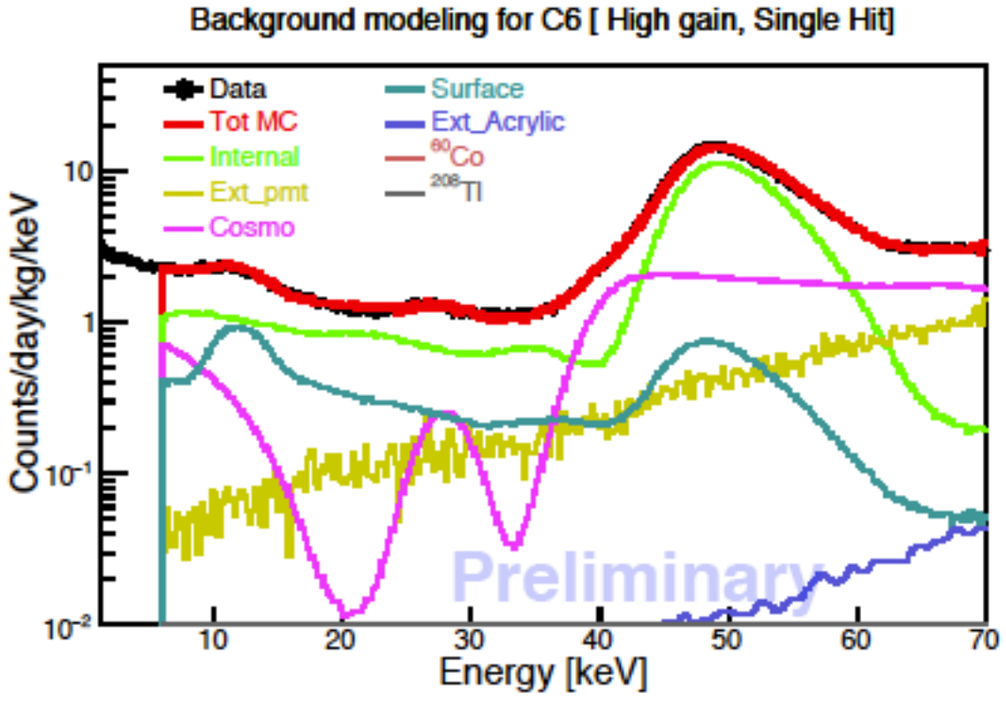


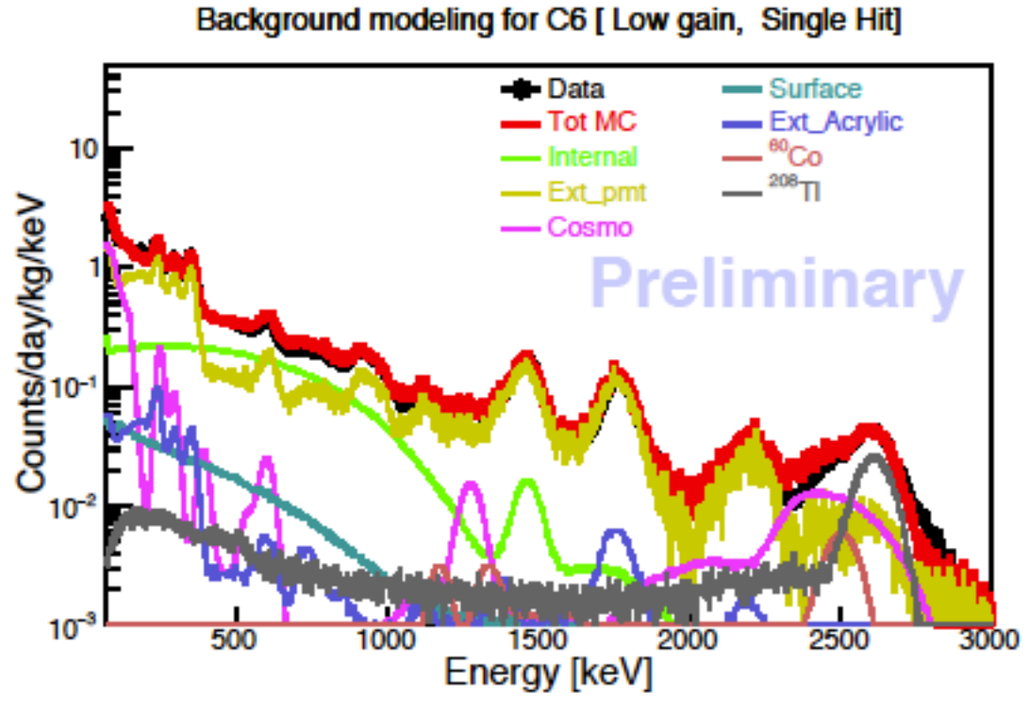


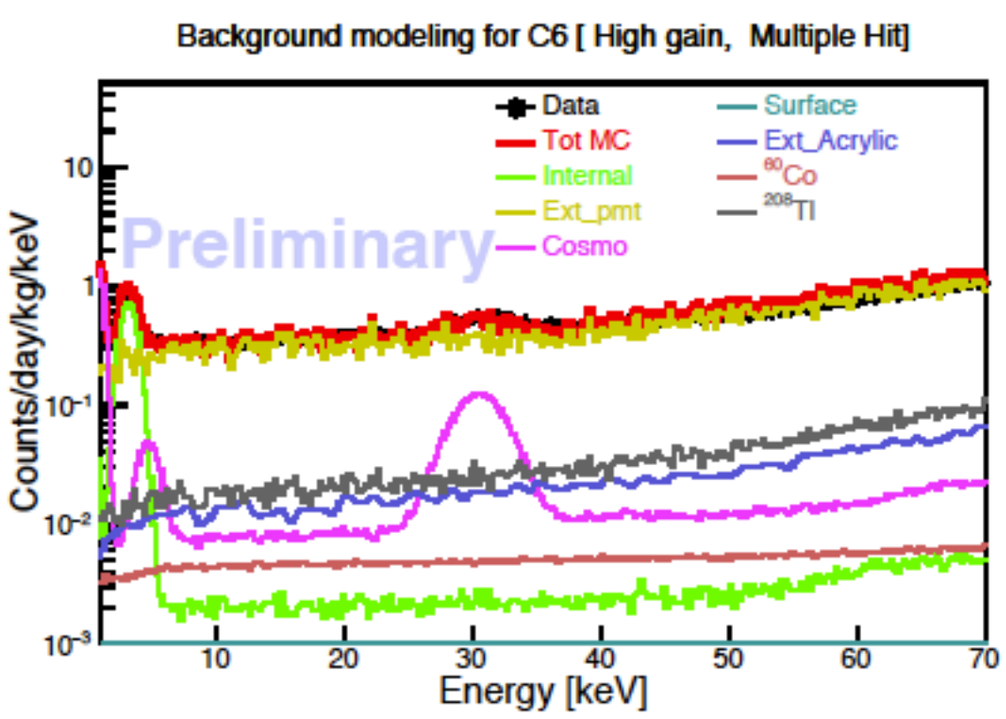


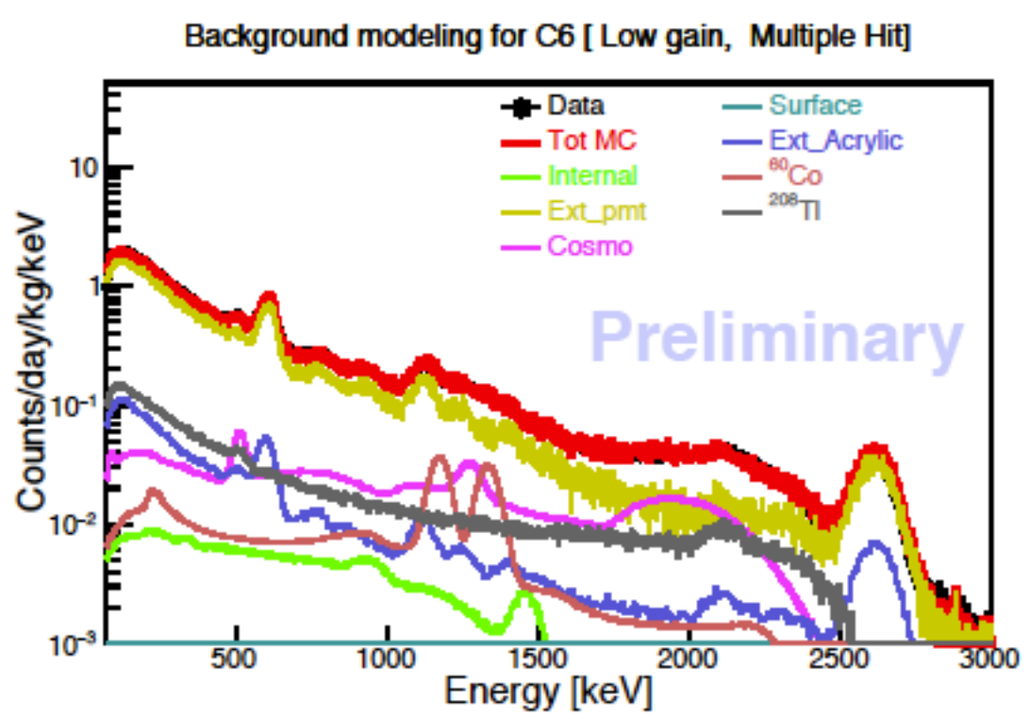
In near future, we expect to have 1 keV threshold analyses.

Improving Background Understanding





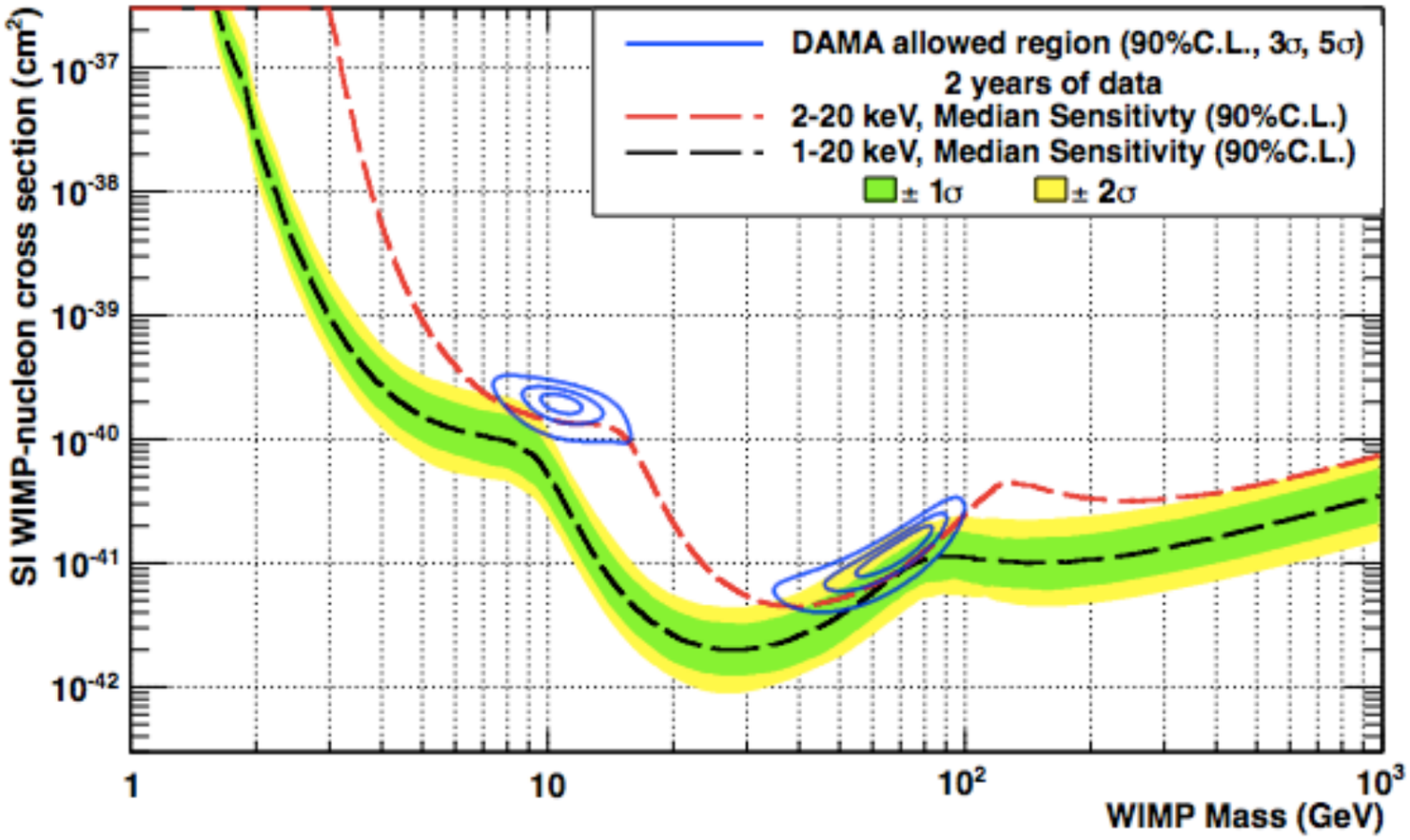




with 1 keV threshold

Expected Sensitivity for COSINE-100

Annual Modulation Sensitivity



**Assumed 2 dru or 4 dru flat backgrounds depending on crystals.*

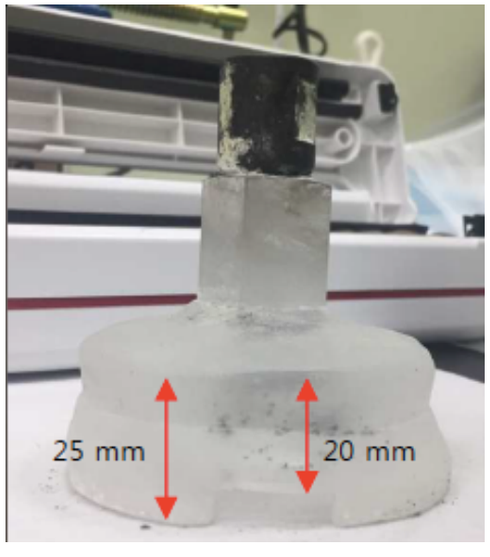
The sensitivity should be comparable with the DAMA allowed region.

COSINE-200 (Phase-II)

Goal : Reaching background lower than DAMA (1 dru).
a factor two or more improvement is needed.

Powder	^{39}K (ppb)		^{208}Pb (ppb)	
	Initial	After	Initial	After
Astro grade	4.5	<1.0	0.9	<0.4
Crystal grade	45.1	6.0	3.3	0.8
Cian (99.5%)	180000	1305	5.7	<0.4

Powder purification (Recrystallization)



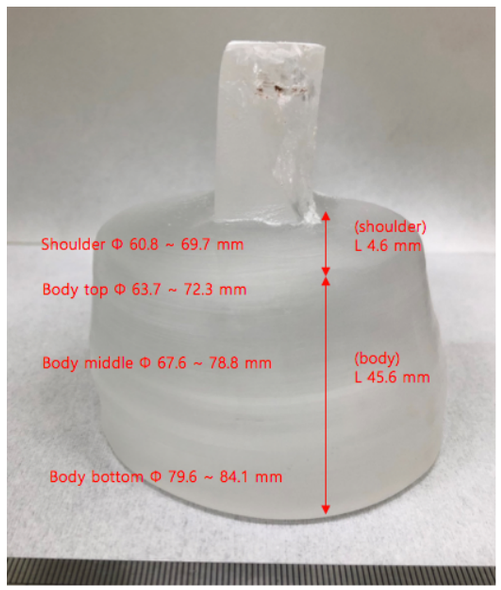
Crystal growing & Handling

Established a facility at our center

Powder purification

(mass production facility for purification under construction)

Growing low radioactive NaI(Tl) Crystals at our center



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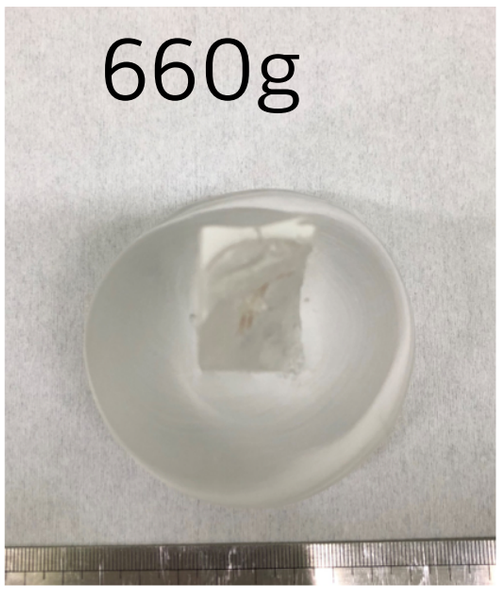
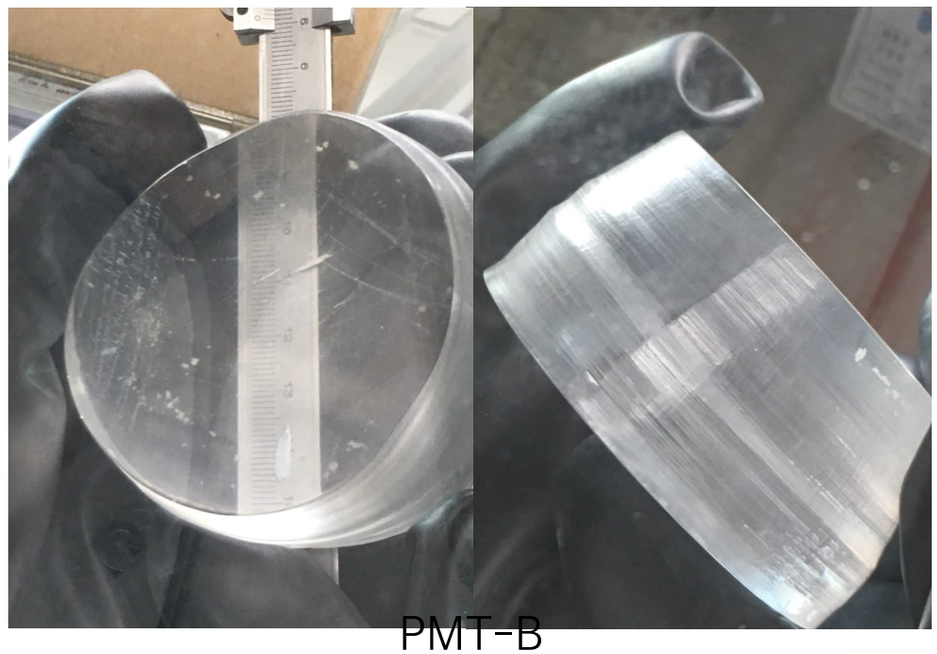


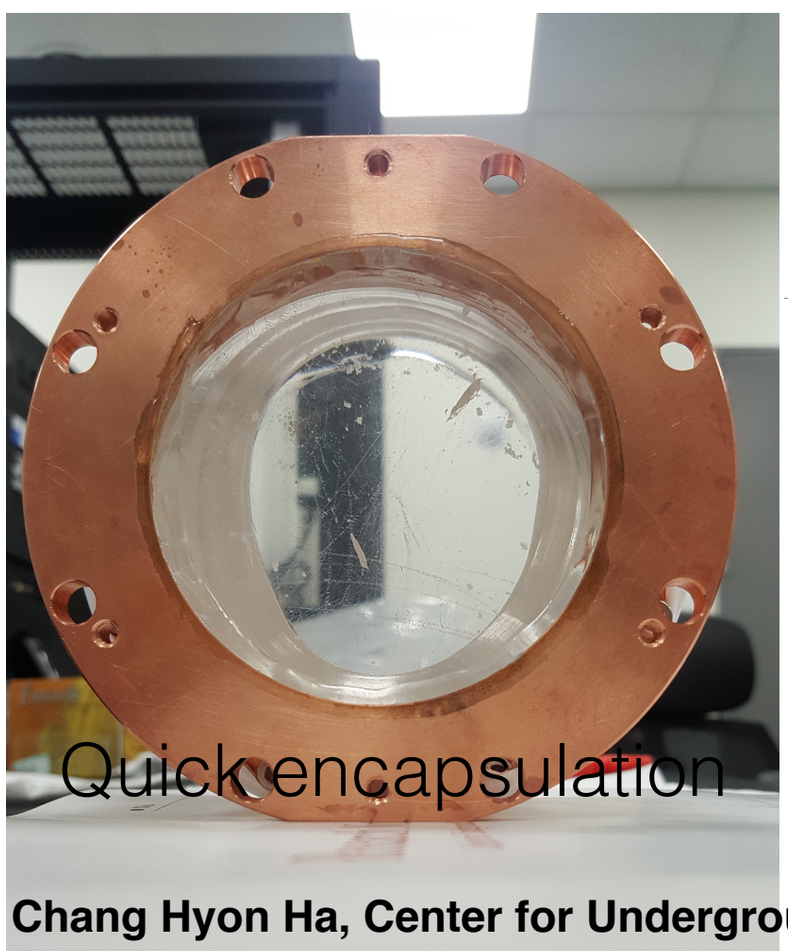
<결정 모양>

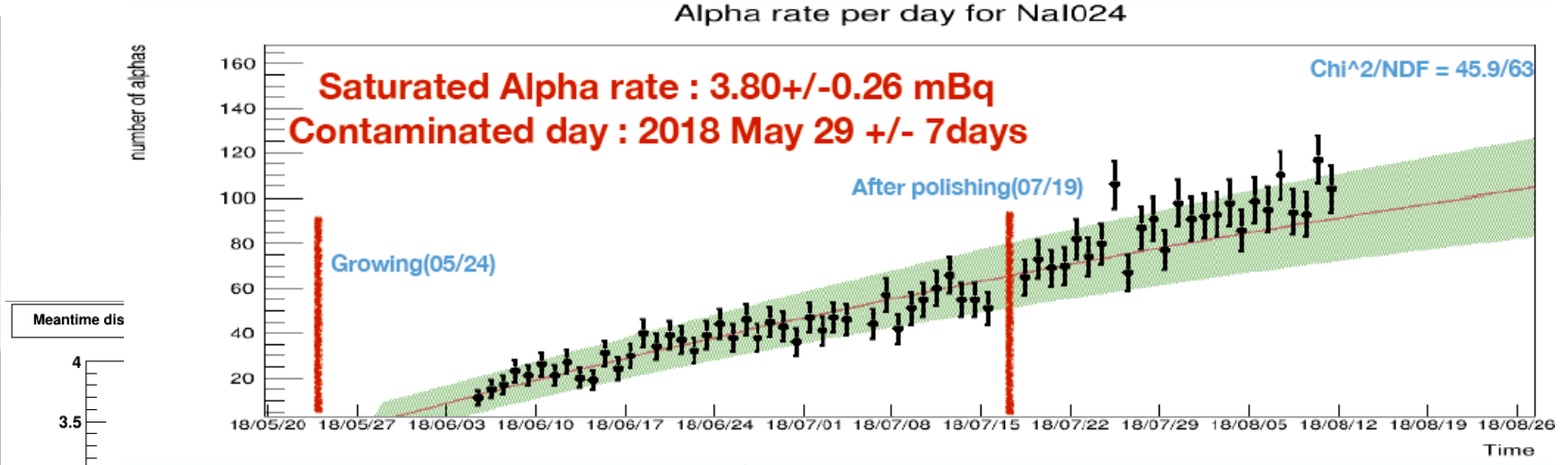

<결정 내부 이물질>

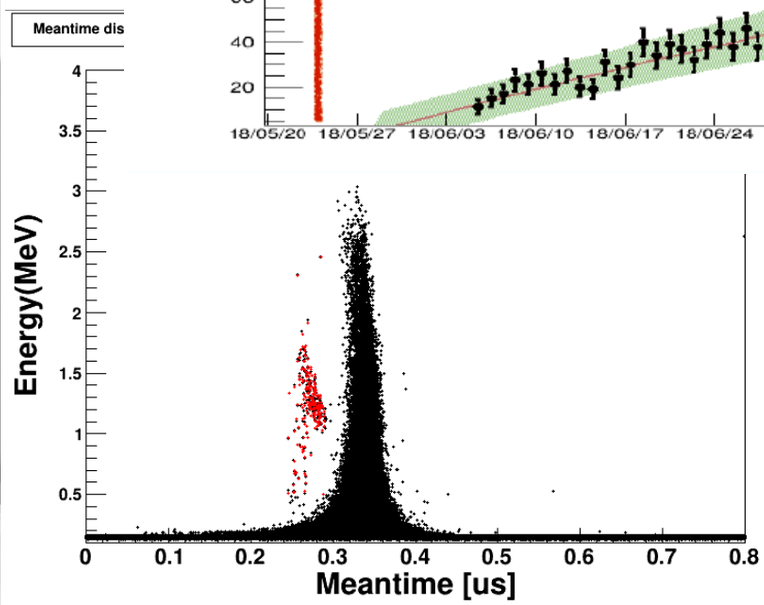
PMT-A



PMT-B





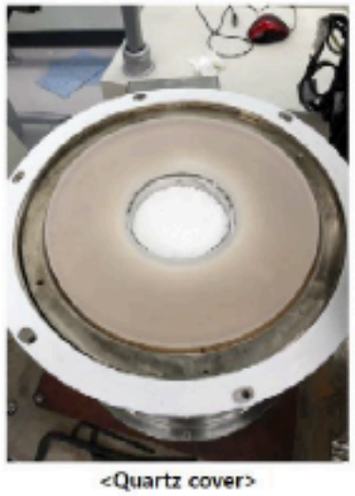


- A few NaI(Tl) Crystals are grown, encased, and measured at CUP.
- L.Y. ~ 10.4 p.e./keV, Stable
- Alpha rate is increasing, indicating that internal Pb-210 contamination

COSINE-200 Crystal Development

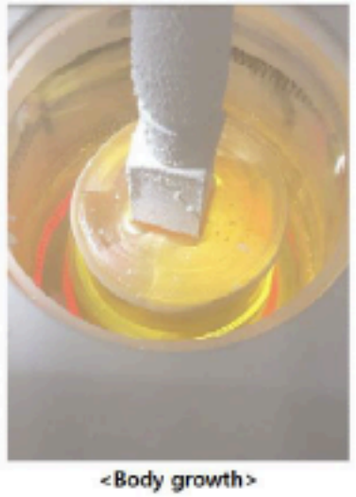
Aug/2019

Pure NaI

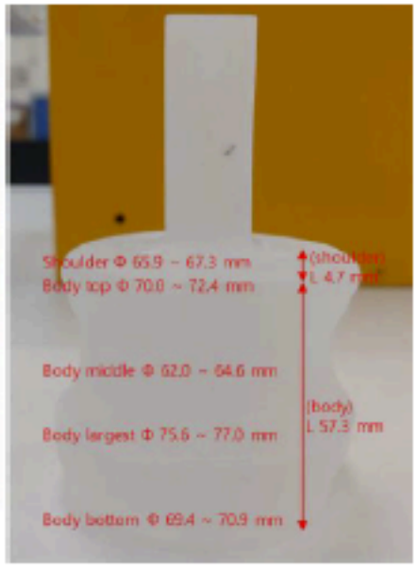


<Quartz cover>

<Impurity>



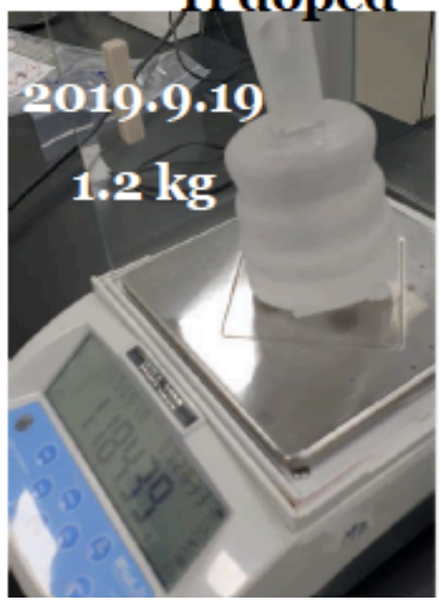
<Body growth>



	K (ppb)	Pb (ppt)	U (ppt)	Th (ppt)
Powder	<14	<300	<5.2	<4.6
Aug/2018	300	9000	<5.2	<4.6
Mar/2019	100	17000	<4.3	<2.6
Aug/2019	**100**	**<240**	**<4.3**	**<2.6**

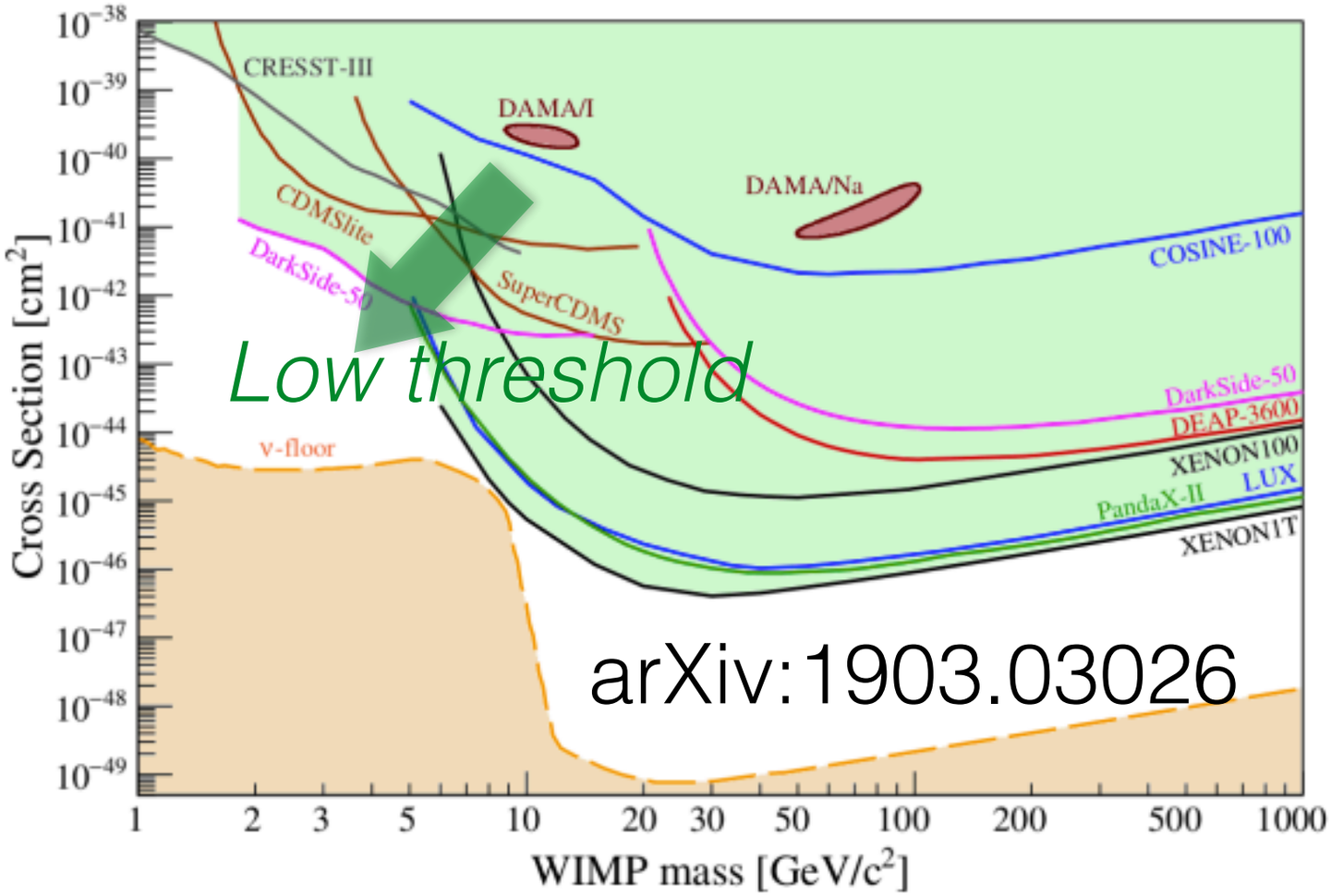
To understand ^{210}Pb, we need underground measurement

Tl doped

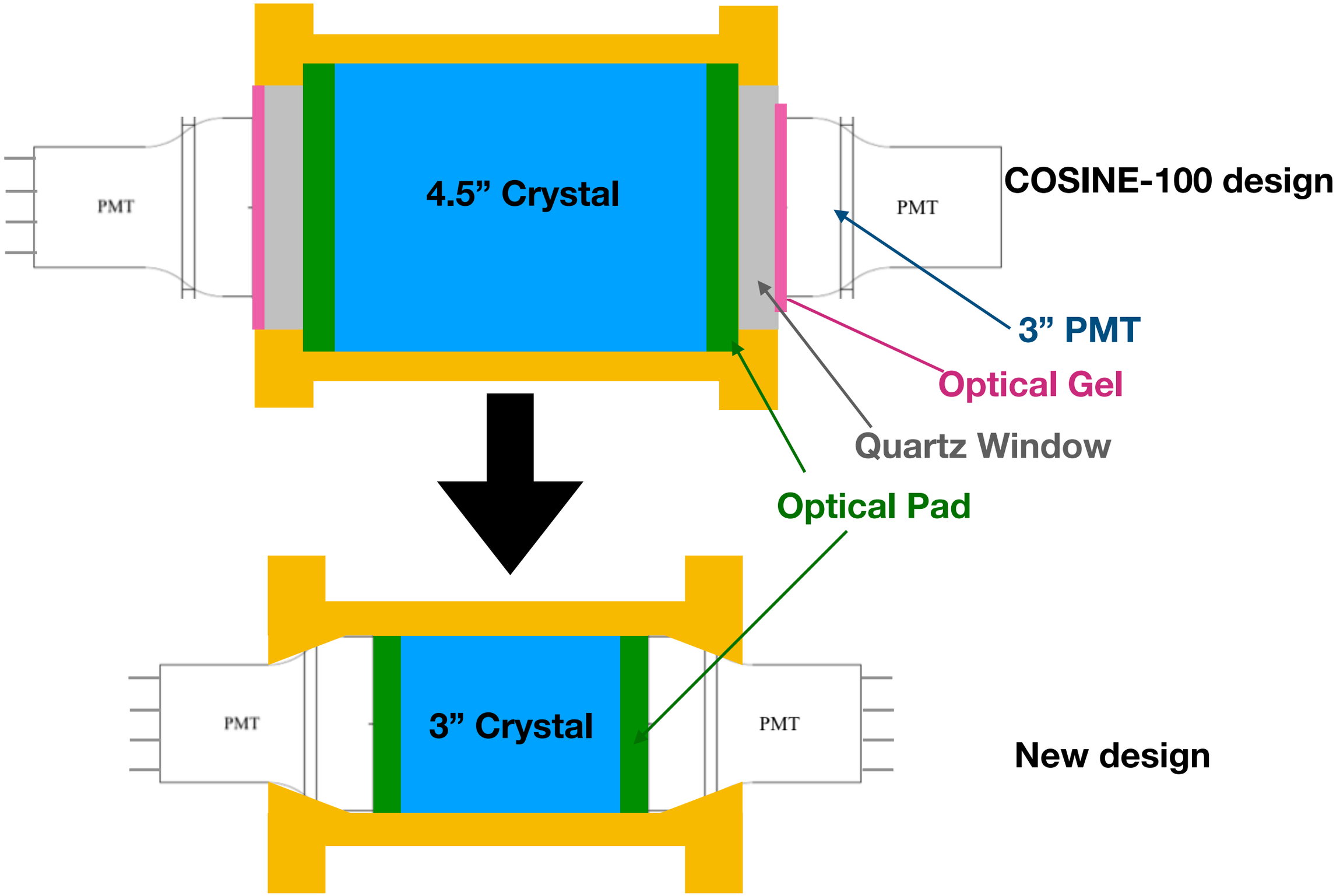


High Light Yield ~ Better sensitivity to low mass dark matter

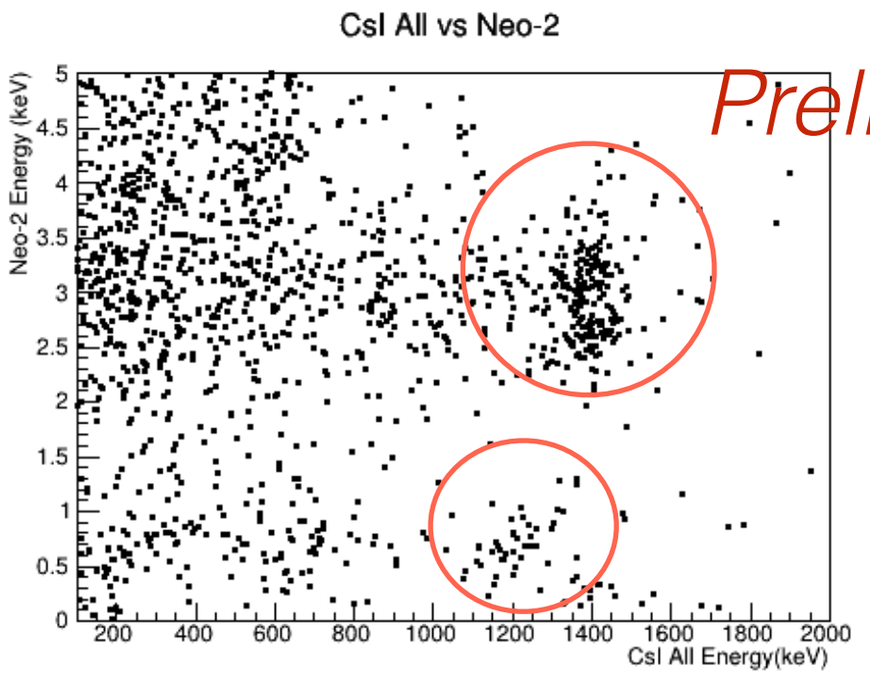
- Higher Light Yield : Lowering threshold in hardware
  - PMT : light coupling, no quartz guide
    - More material, more loss
  - Crystal window size matching with PMT size. (3-inch)
    - No loss due to reflection.
- High light yield crystal can be used in Coherent Scattering.
- R&D step towards COSINE-200 encapsulation development



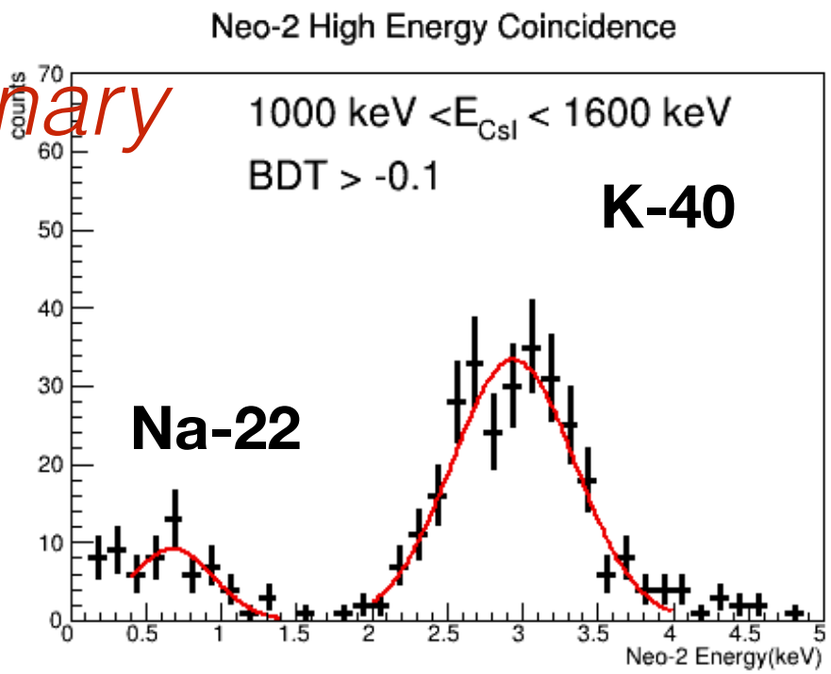
New in-house encapsulation tests



Test setup with new encapsulation

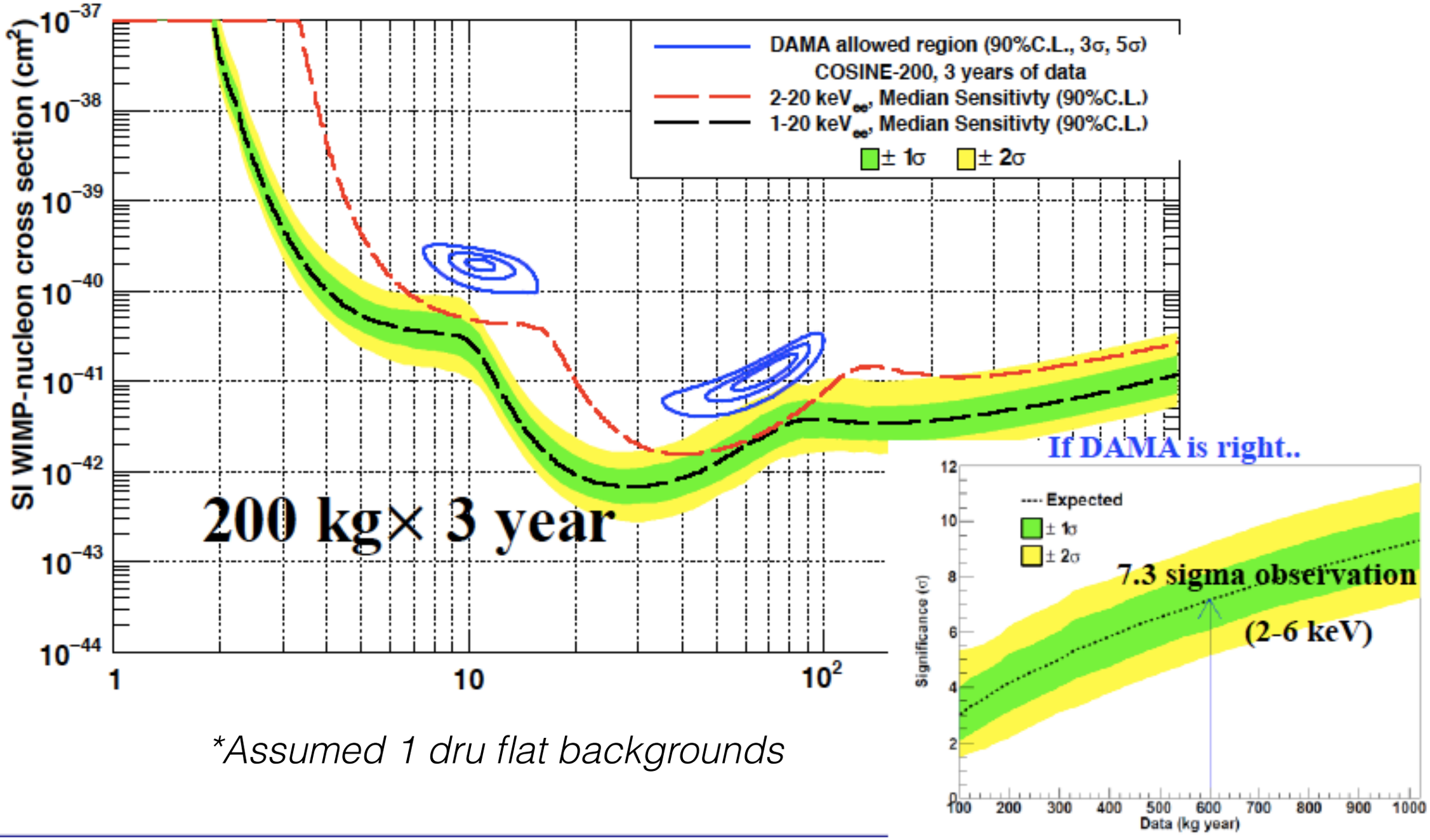


Preliminary



Light Yield of >20 pe /keV!

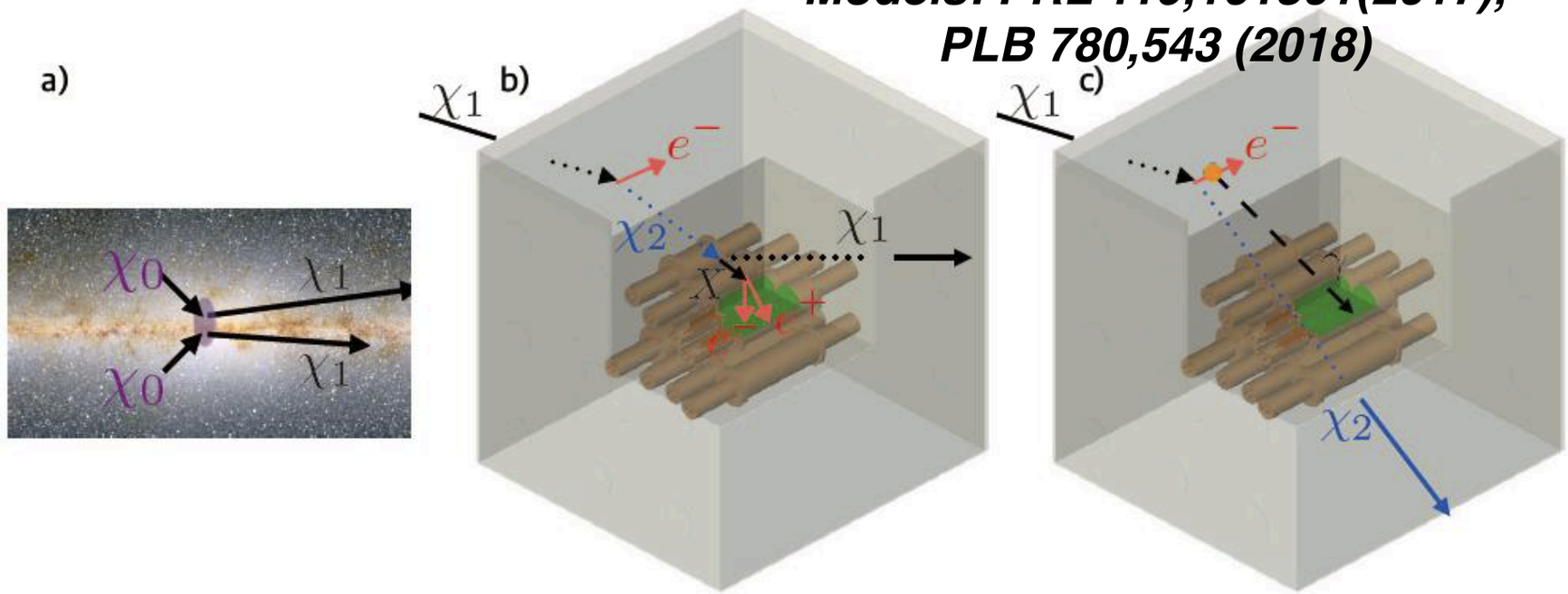
Expected sensitivity for COSINE-200 (Phase-II)

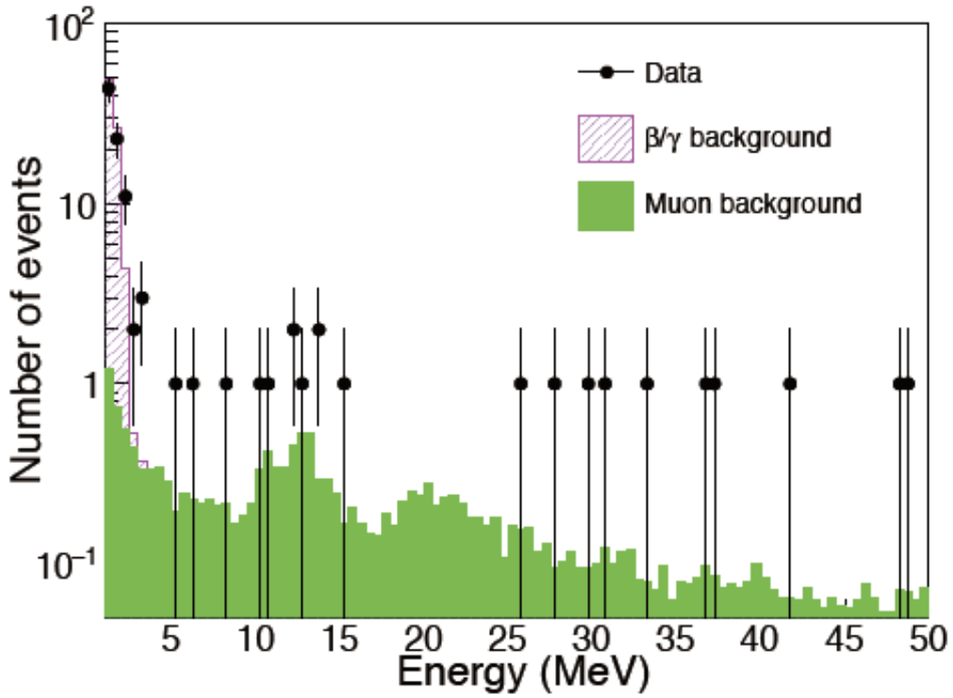


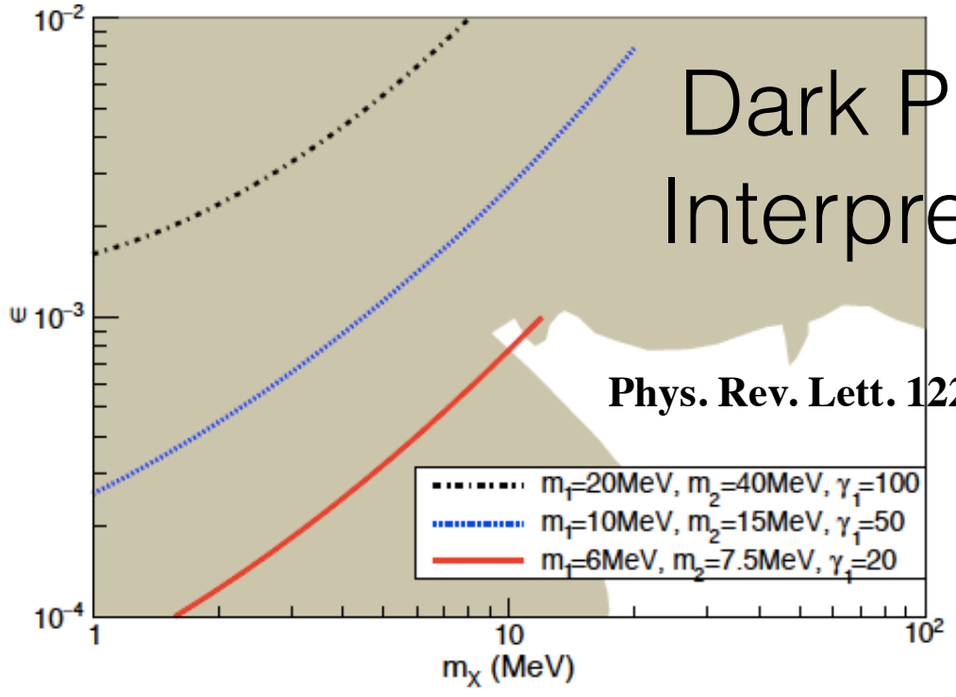
**Assumed 1 dru flat backgrounds*

Boosted Dark Matter search using 2 tons of liquid scintillator

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



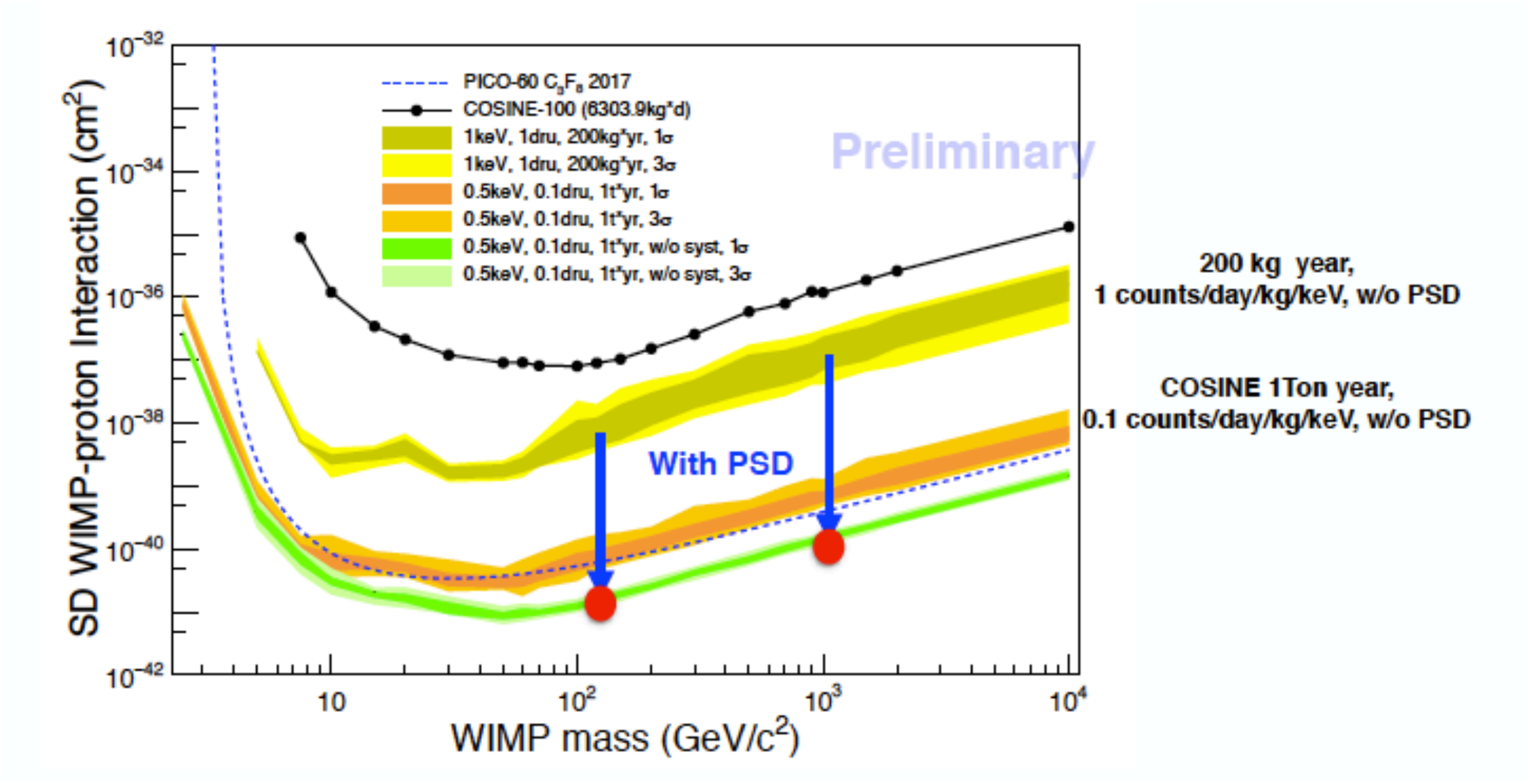




Dark Photon Interpretation

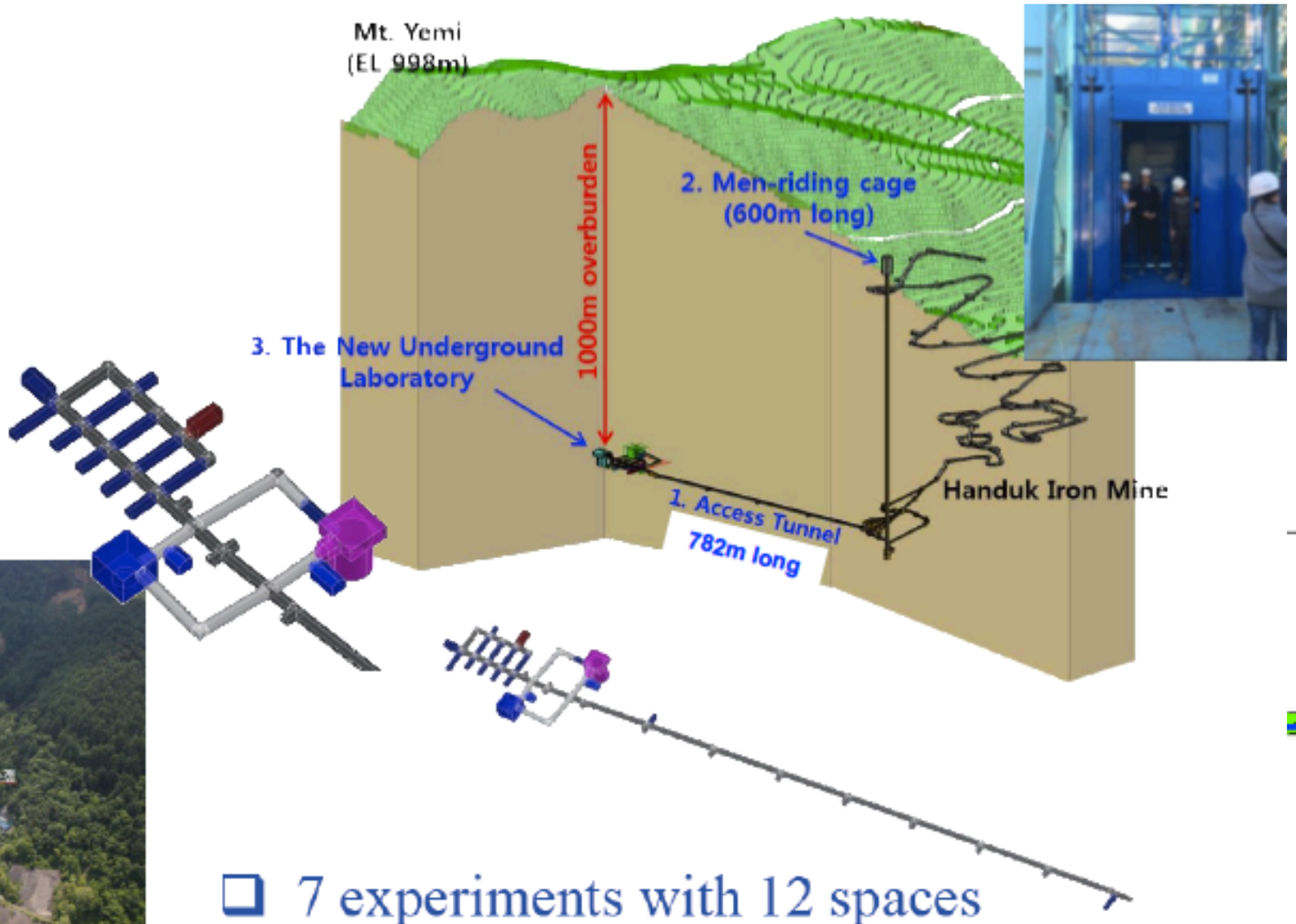
Phys. Rev. Lett. 122 131802 (2019)

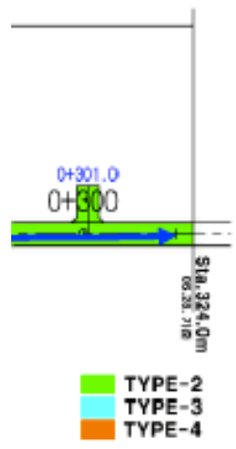
COSINE-1T



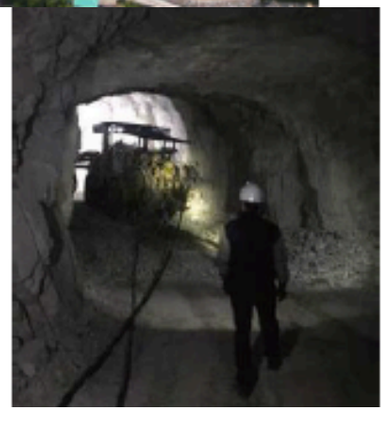
COSINE-1Tonne can be competitive in SD cross section measurements!

COSINE-1T @ Yemilab





- 7 experiments with 12 spaces
- 10 utility spaces



Summary & Outlook

- The COSINE-100 experiment was installed at Y2L and runs smoothly for 3 years.
- In the COSINE-100 early data, on average, bkg. 3.5 counts/day/kg/keV with 2 keV thresholds was achieved.
- COSINE-100 confirms that DAMA's modulation signal cannot be from standard WIMP & SHM with NaI(Tl).
- First modulation analysis with 1.7 years exposure shows consistency with null signal and with DAMA signal.
- The modulation analysis is currently statistics limited and the next analysis is developing.
- Currently, the bkg. rate has been lowered to about 3.0 counts/day/kg/keV due to cosmogenic components decaying and we are improving the analysis threshold down to 1 keV.
- Much progress has been made in developing the capabilities to grow and encapsulate more radio-pure NaI(Tl) crystals at IBS-CUP towards COSINE-200 which will answer to the DAMA anomaly.