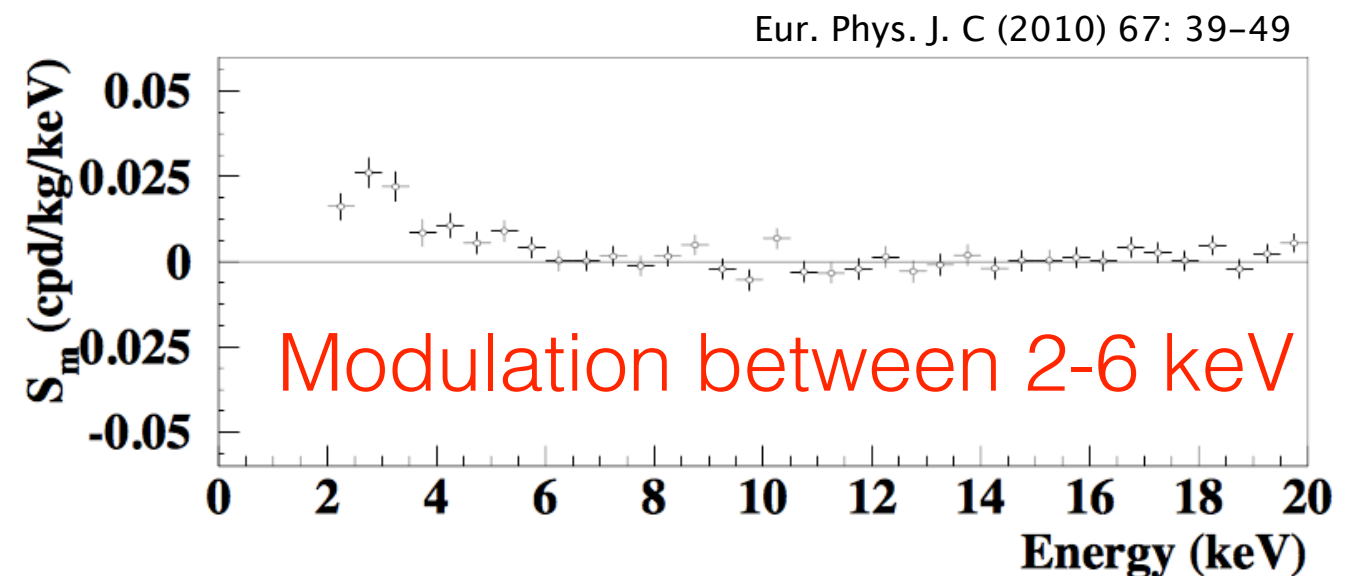
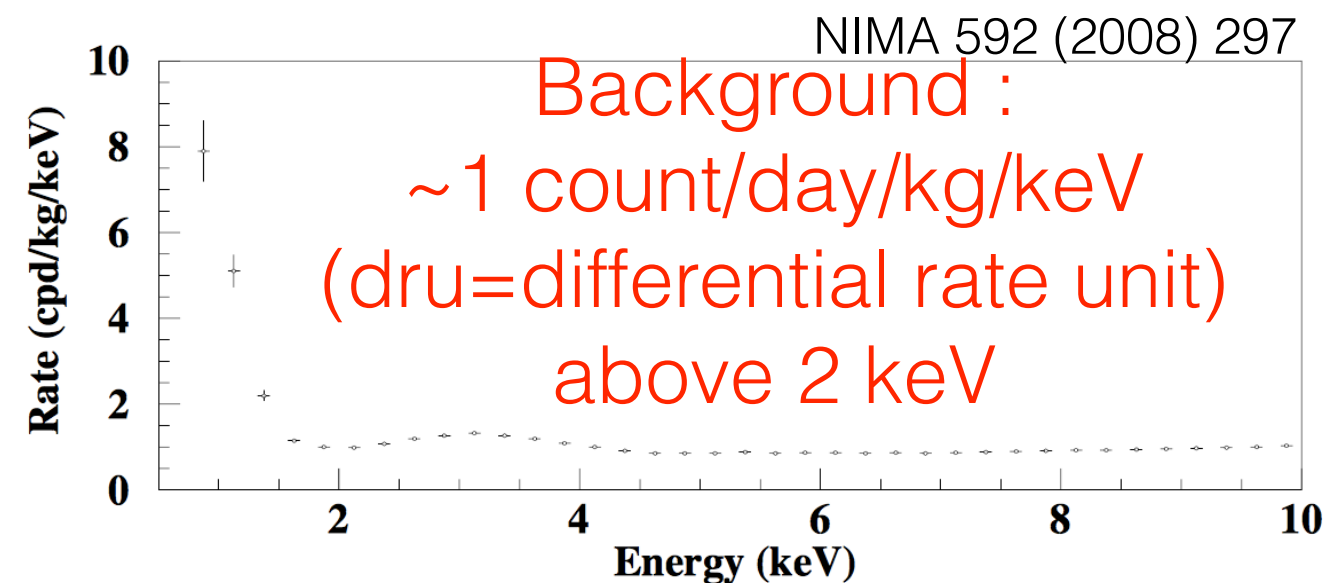
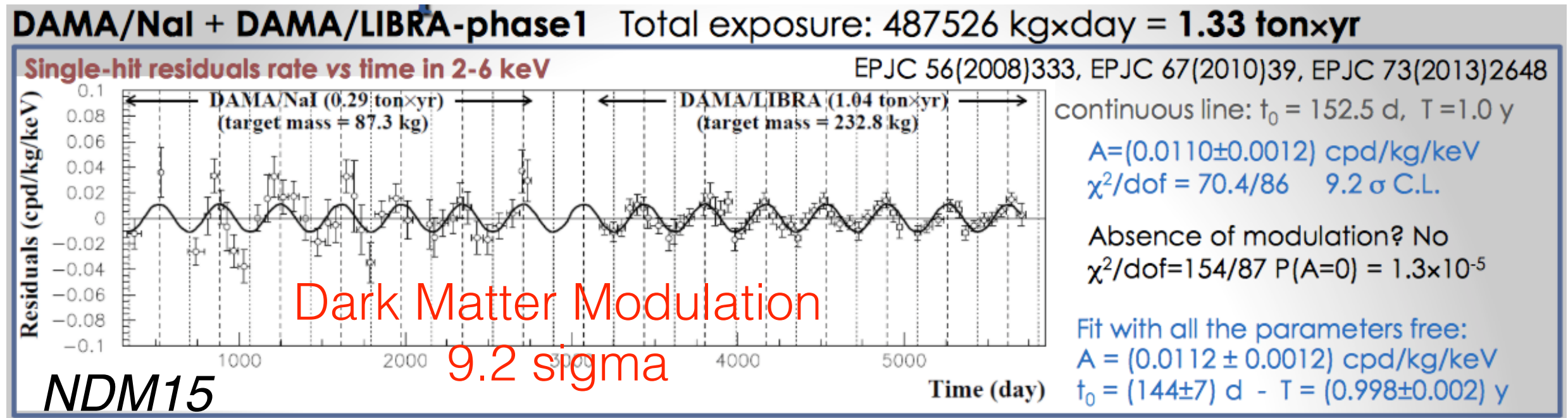


Dark Matter searches with COSINE-100 : present status and perspectives

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

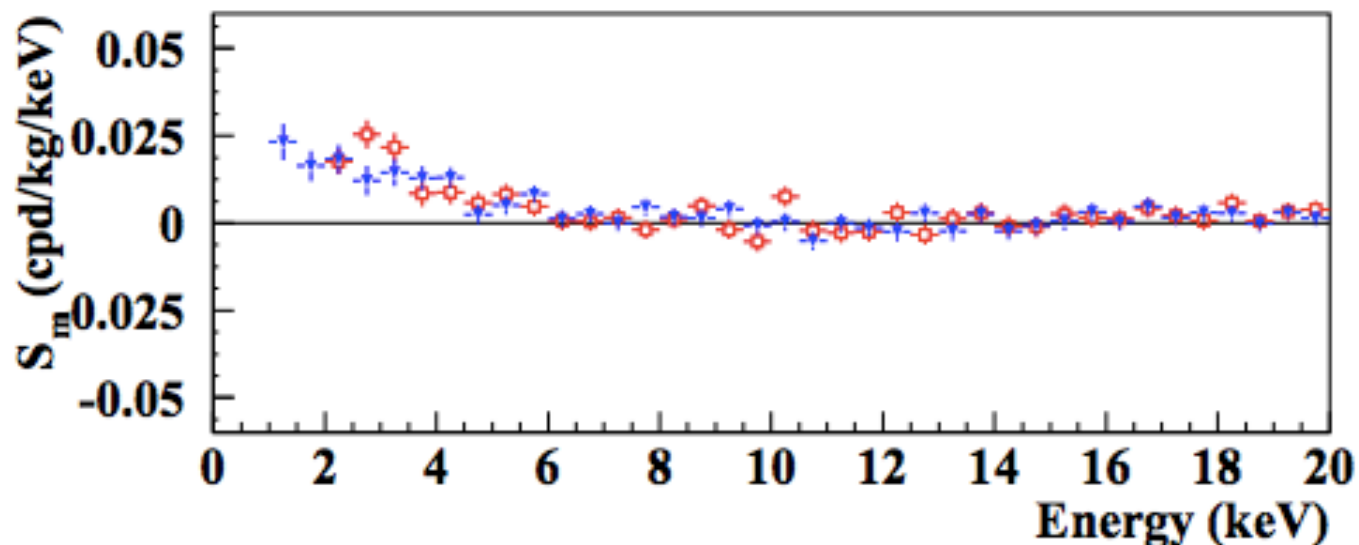


DAMA/LIBRA-phase2

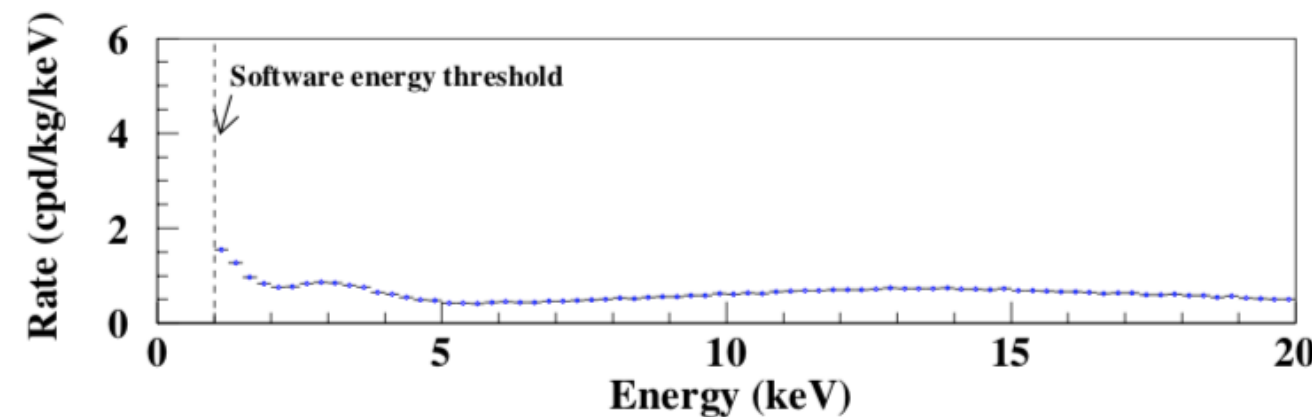
First model independent results from DAMA/LIBRA-phase2

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



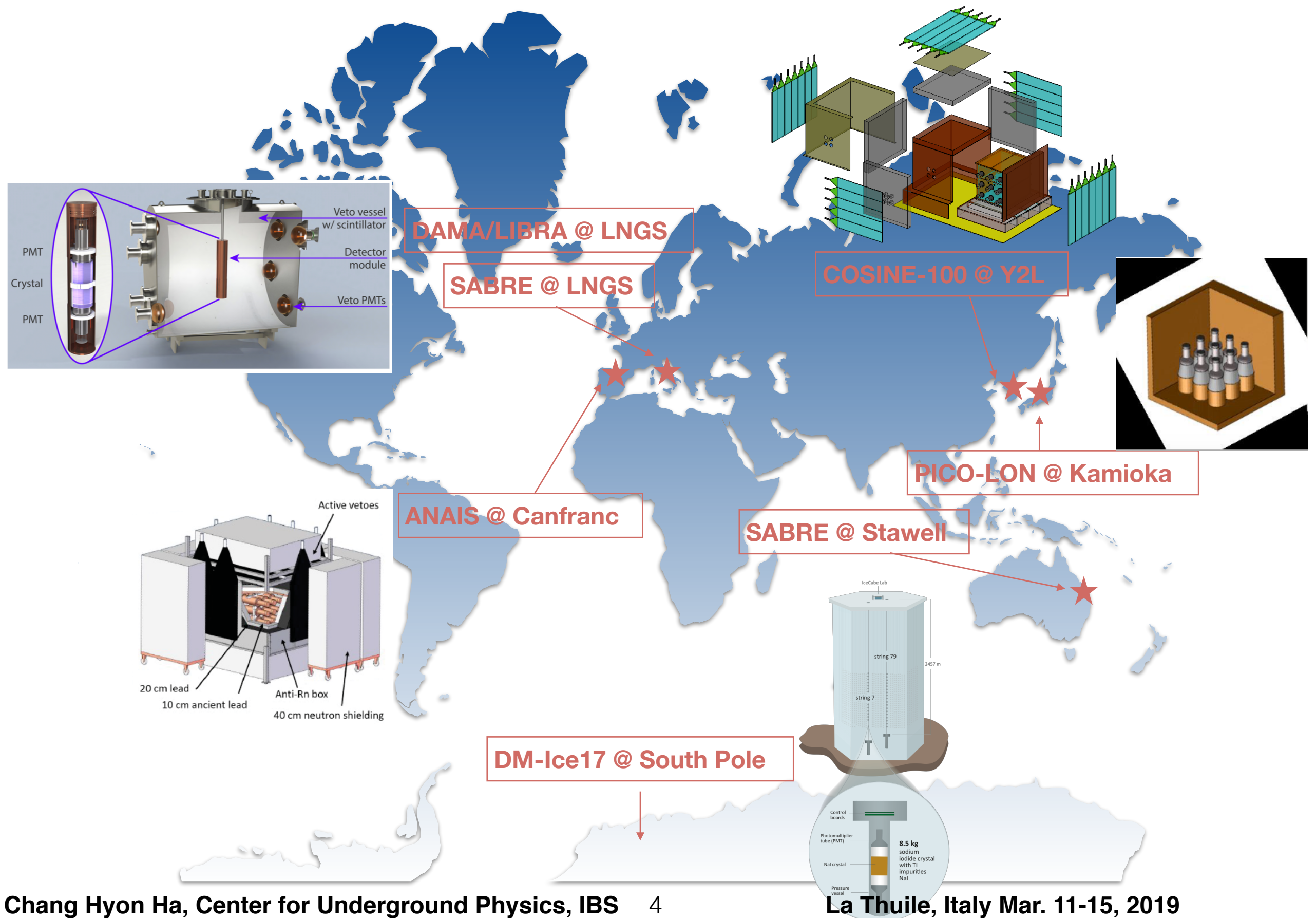
	A (cpd/kg/keV)	$T = \frac{2\pi}{\omega}$ (yr)	t_0 (days)	C.L.
DAMA/LIBRA-phase2:				
1-3 keV	(0.0184 ± 0.0023)	1.0	152.5	8.0 σ
1-6 keV	(0.0105 ± 0.0011)	1.0	152.5	9.5 σ
2-6 keV	(0.0095 ± 0.0011)	1.0	152.5	8.6 σ
1-3 keV	(0.0184 ± 0.0023)	(1.0000 ± 0.0010)	153 ± 7	8.0 σ
1-6 keV	(0.0106 ± 0.0011)	(0.9993 ± 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



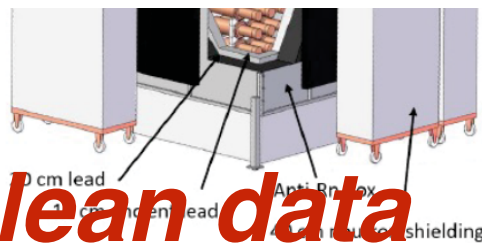
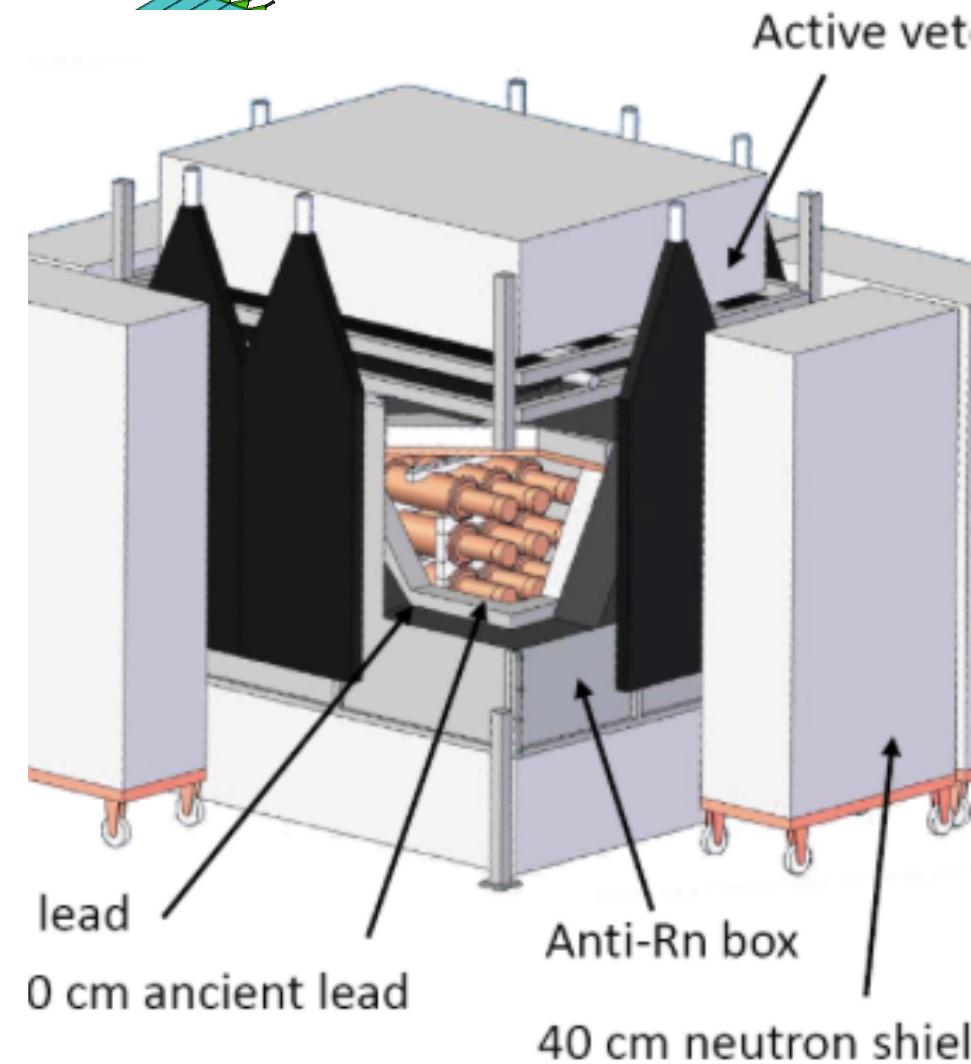
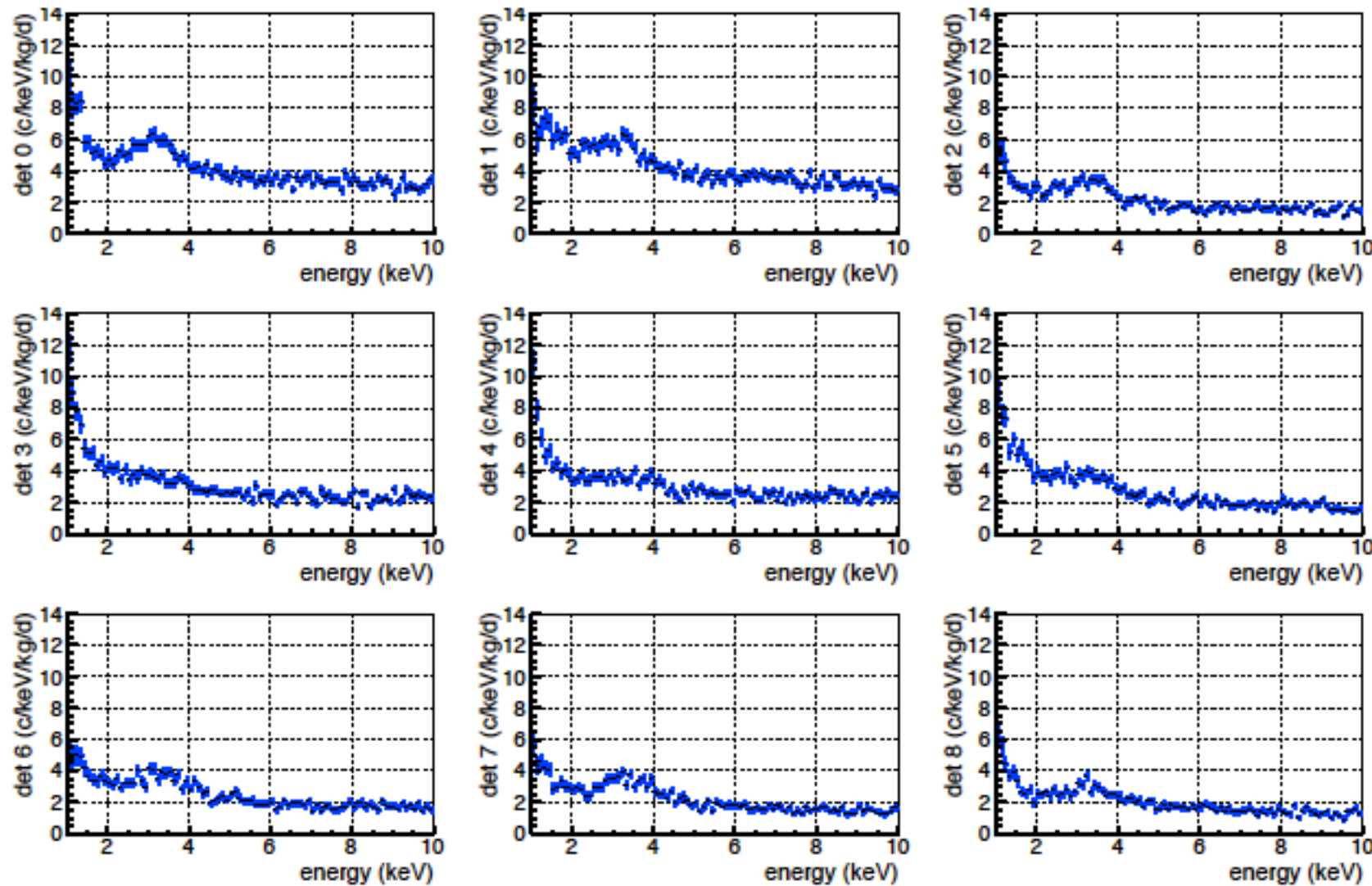
Down to 1 keV region

Modulation is persistent in phase2 data

Global NaI(Tl) efforts

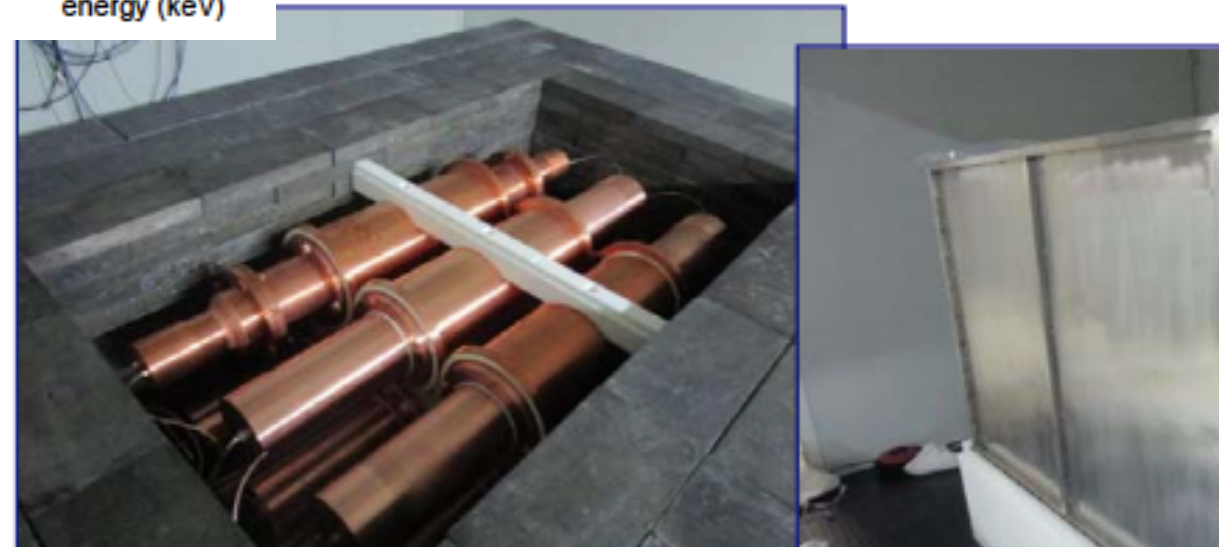


ANAIS-112 (total of 112 kg)



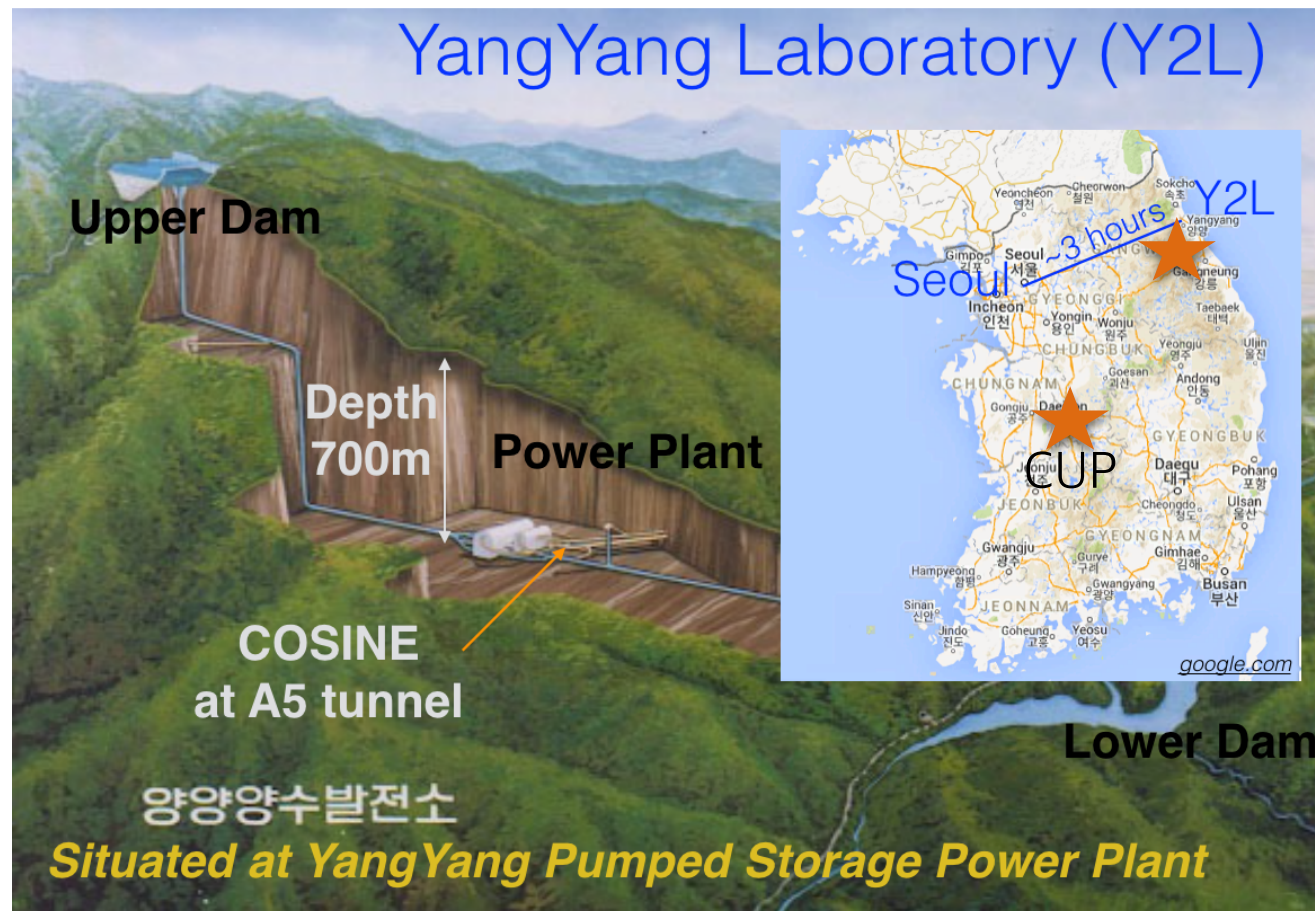
Clean data
1 keV threshold
2-5 dru @ 2 keV

DM-Ice17 @ S



The COSINE-100 experiment

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



COSINE-100 Construction Timeline

Dec. 2015

Jan. 2016

Feb. 2016



Mar. 2016

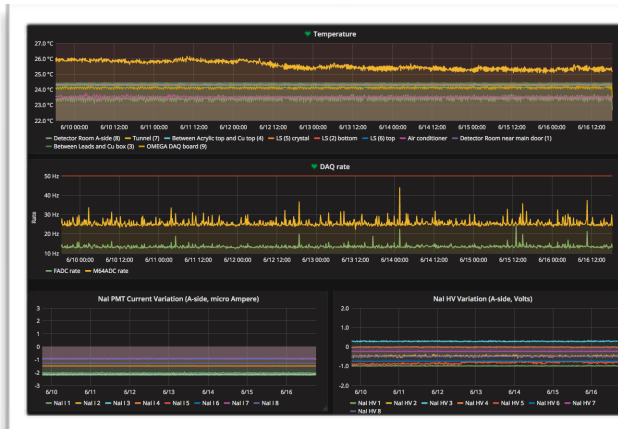
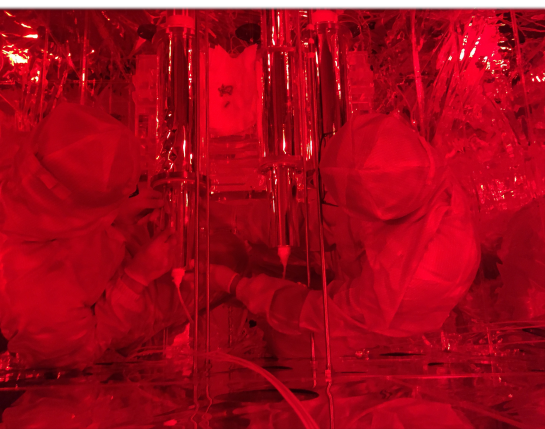
Apr. 2016



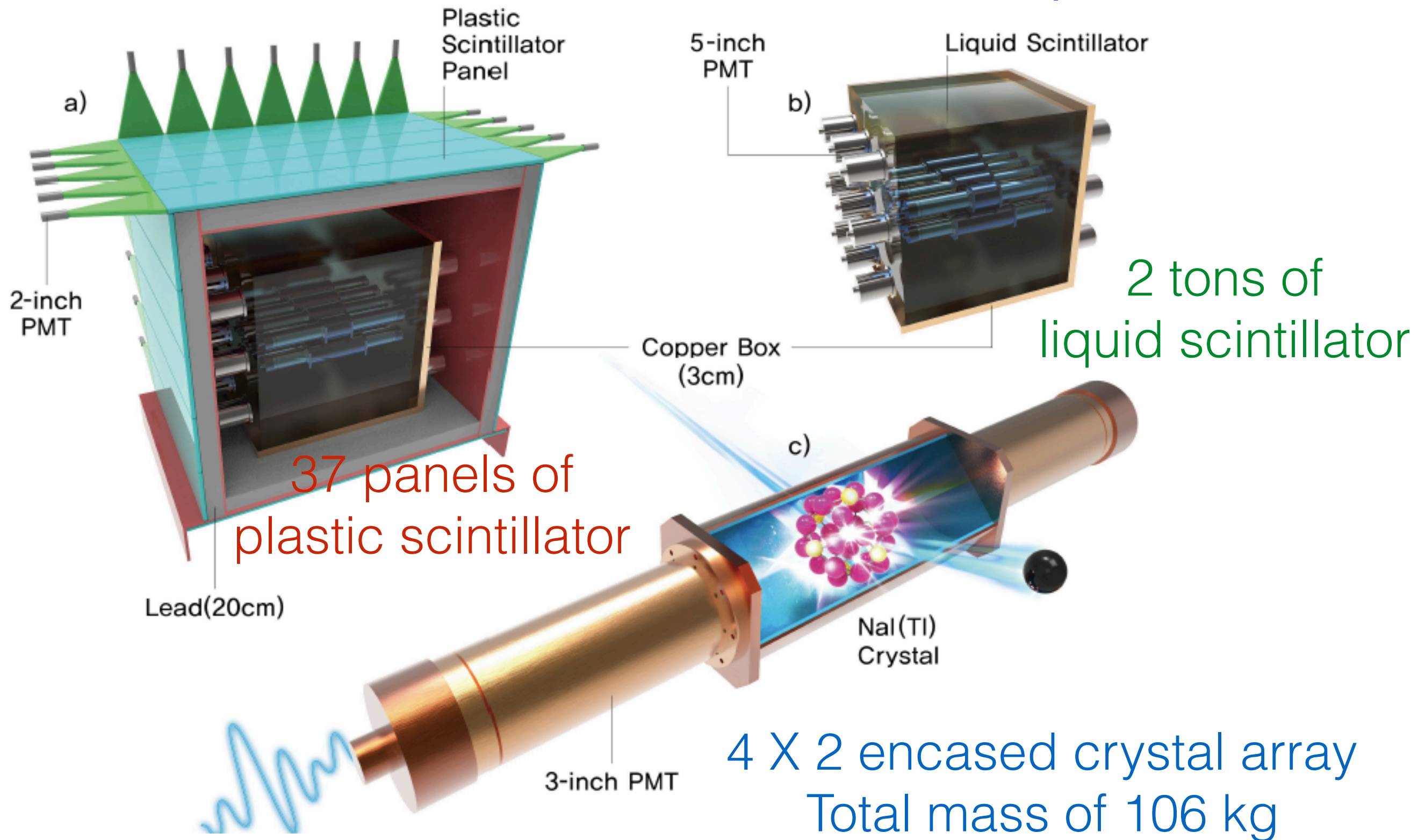
May. 2016

Jun. 2016

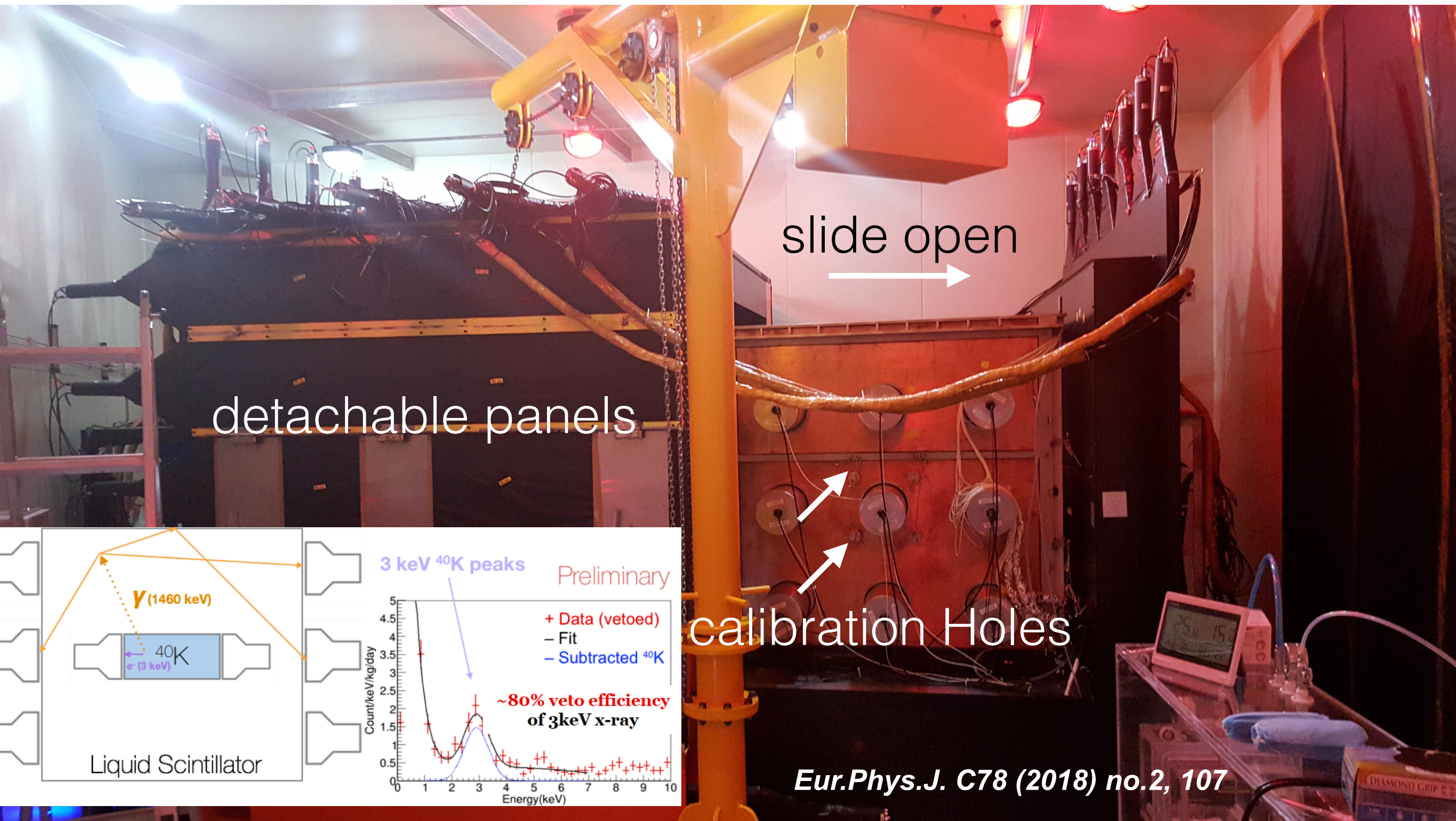
Sep. 2016



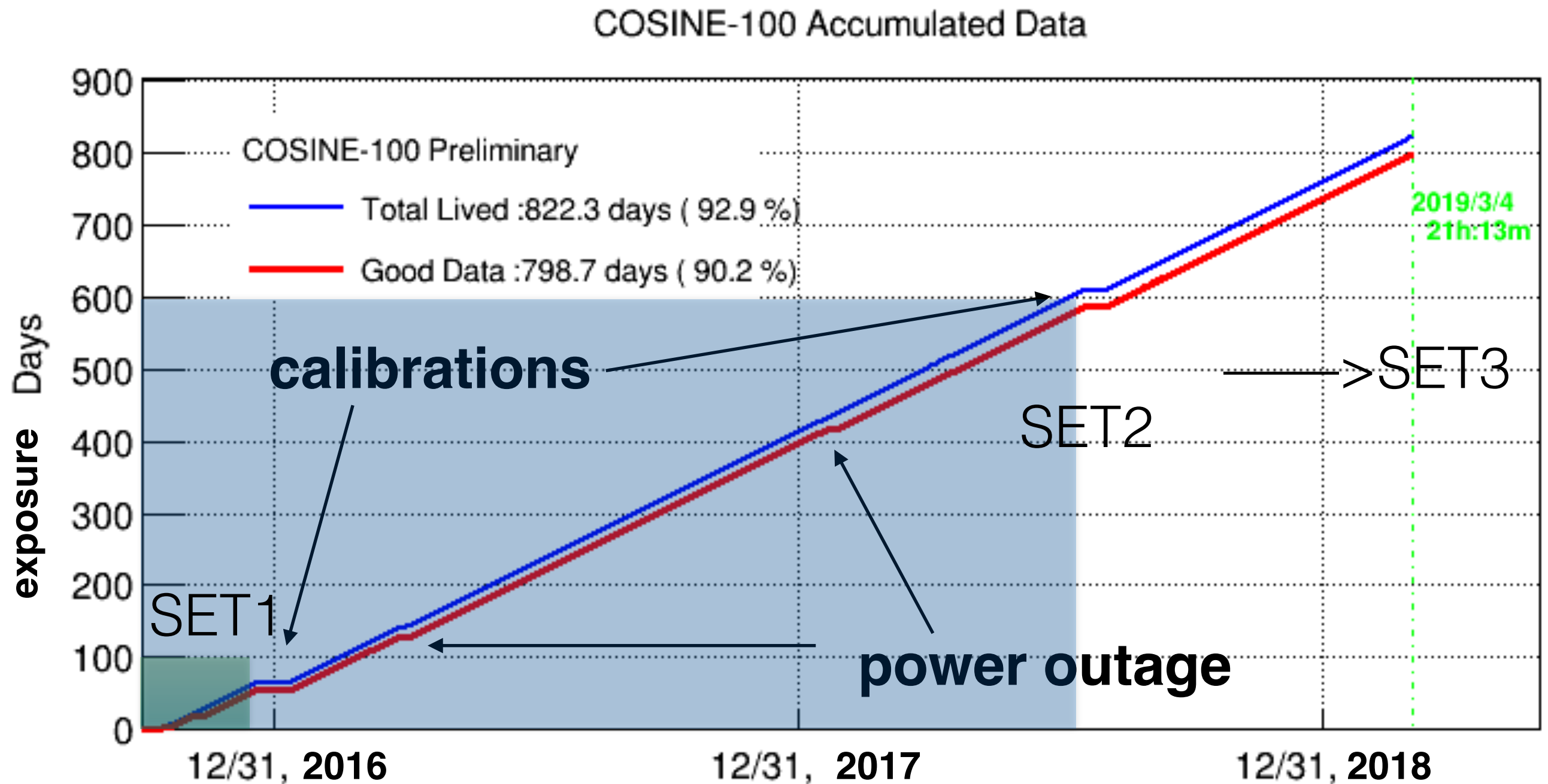
The COSINE-100 detector components



The COSINE-100 detector components

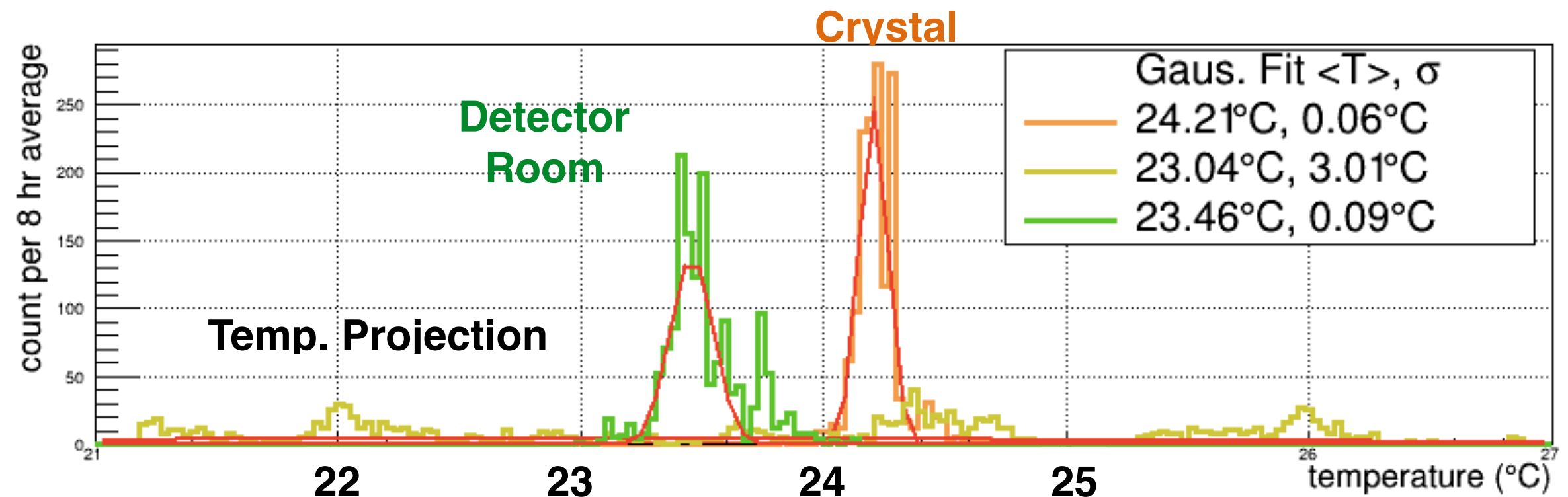
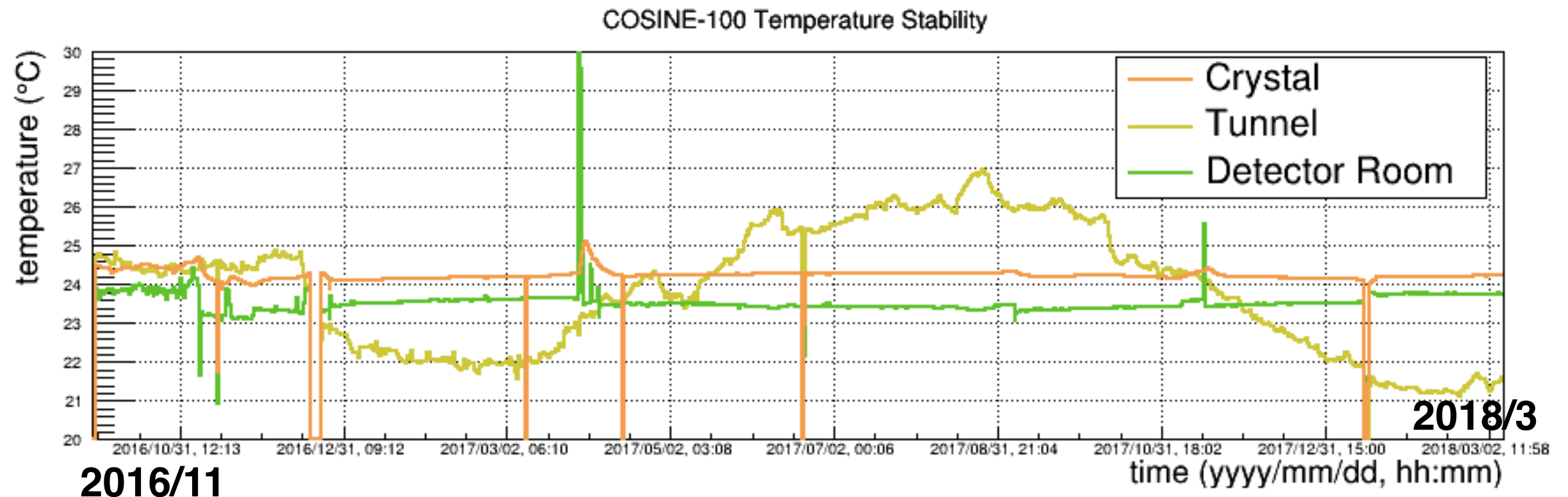


Exposure (Running for 30 months)



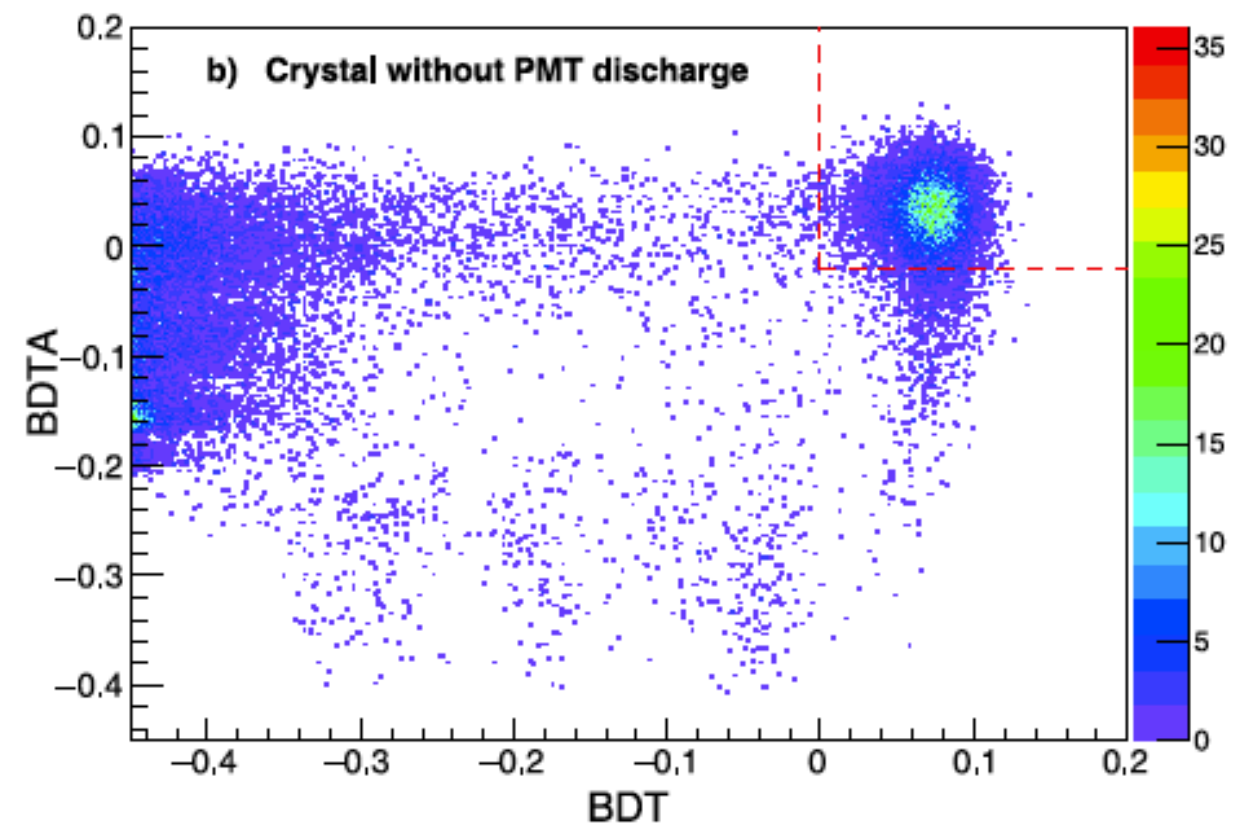
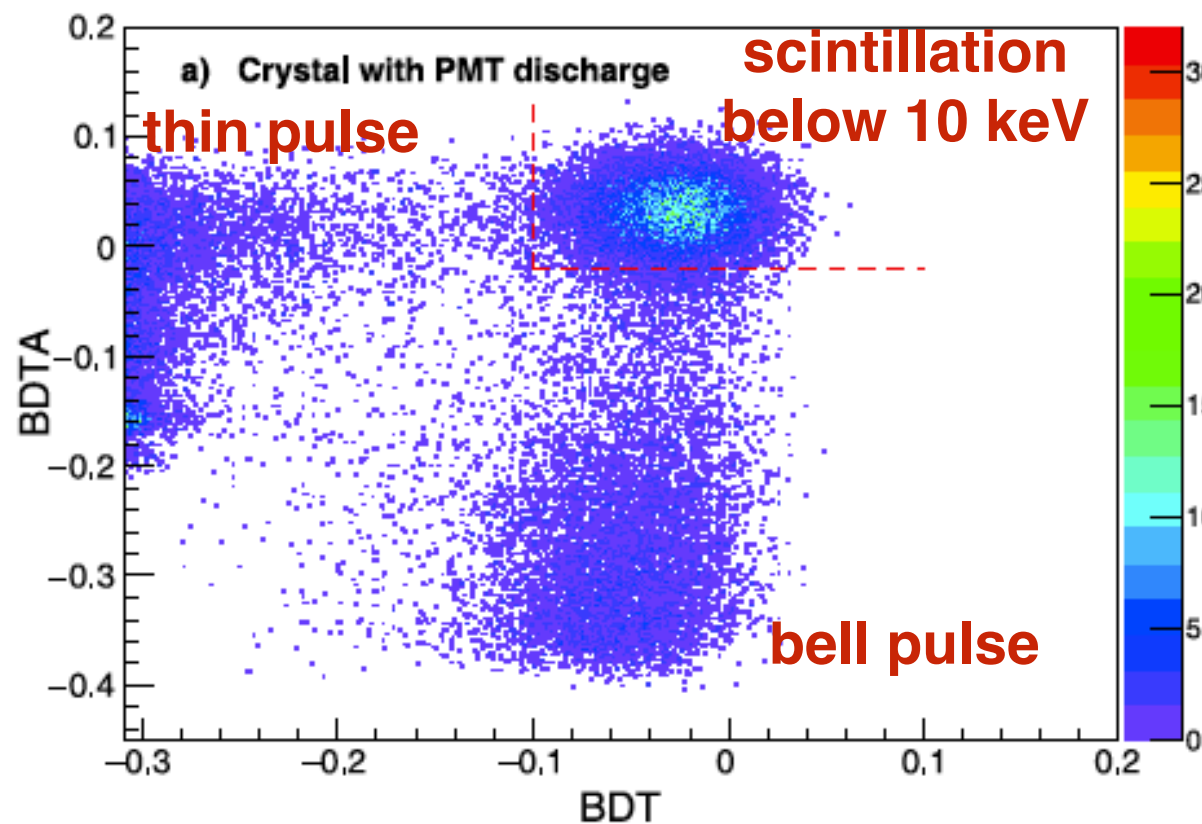
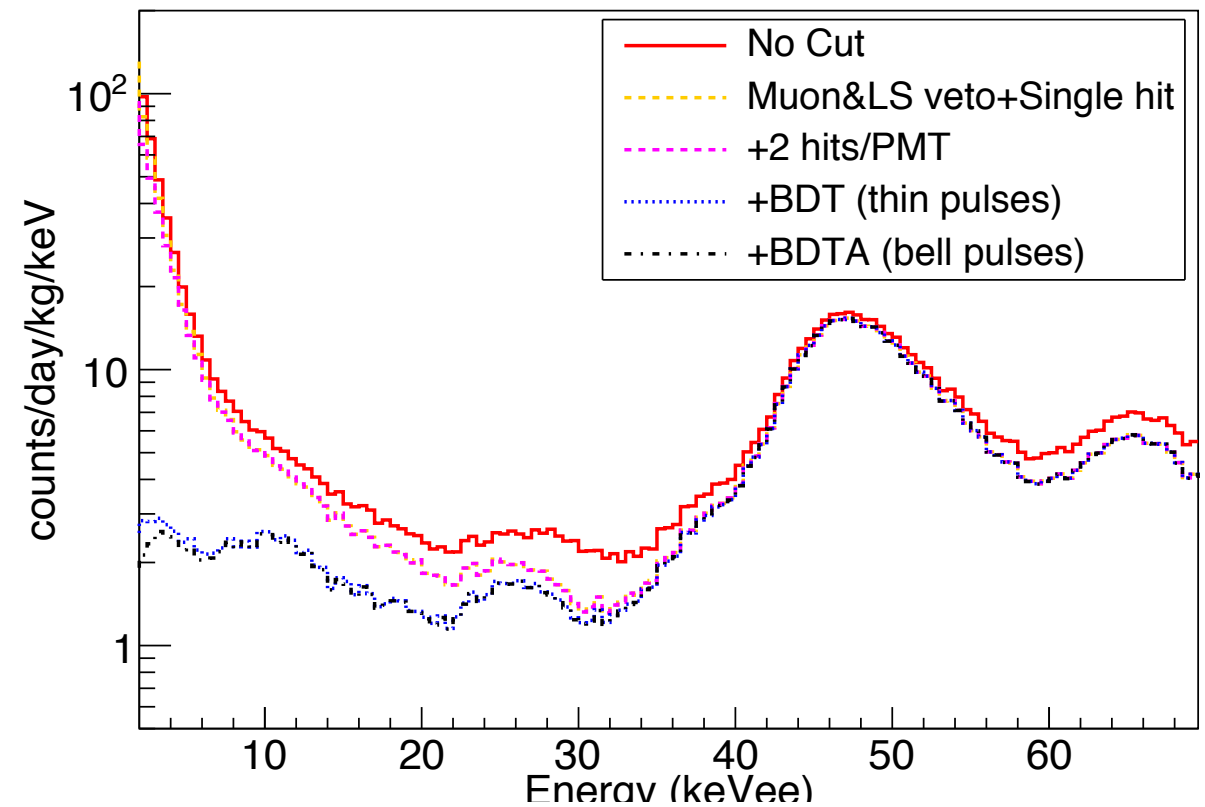
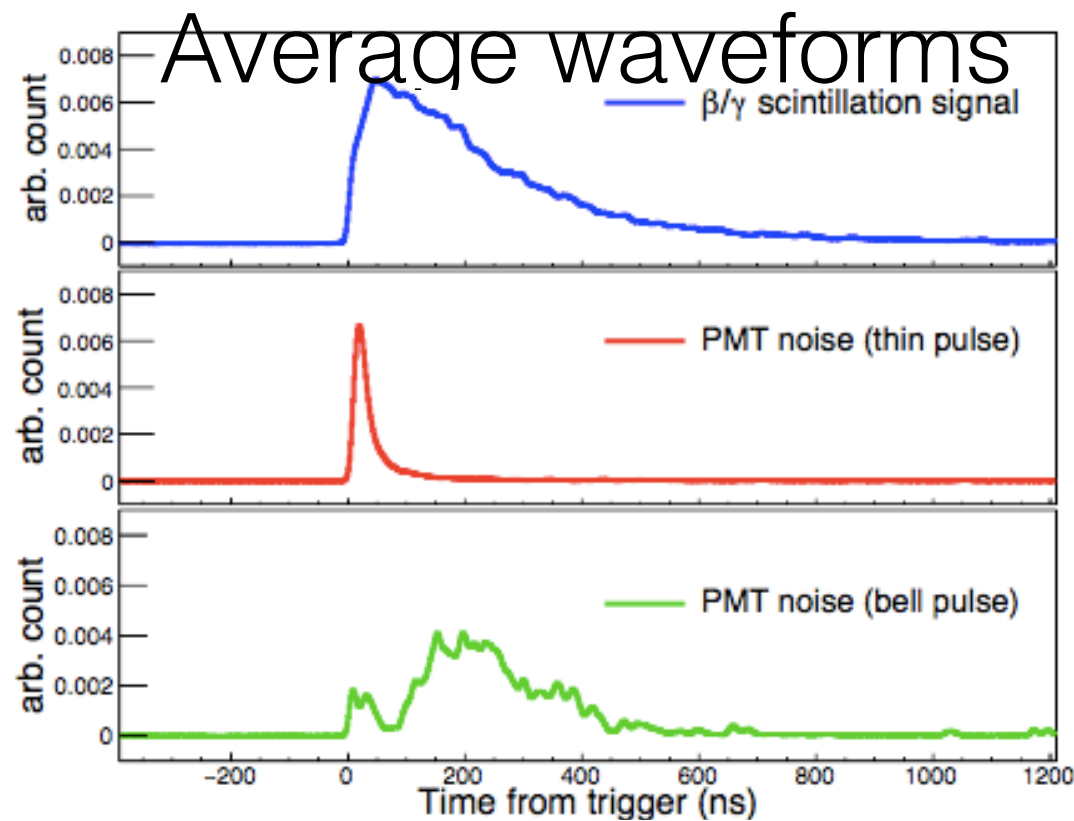
Detector is running smooth (>95% physics data)

Environmental control/monitoring

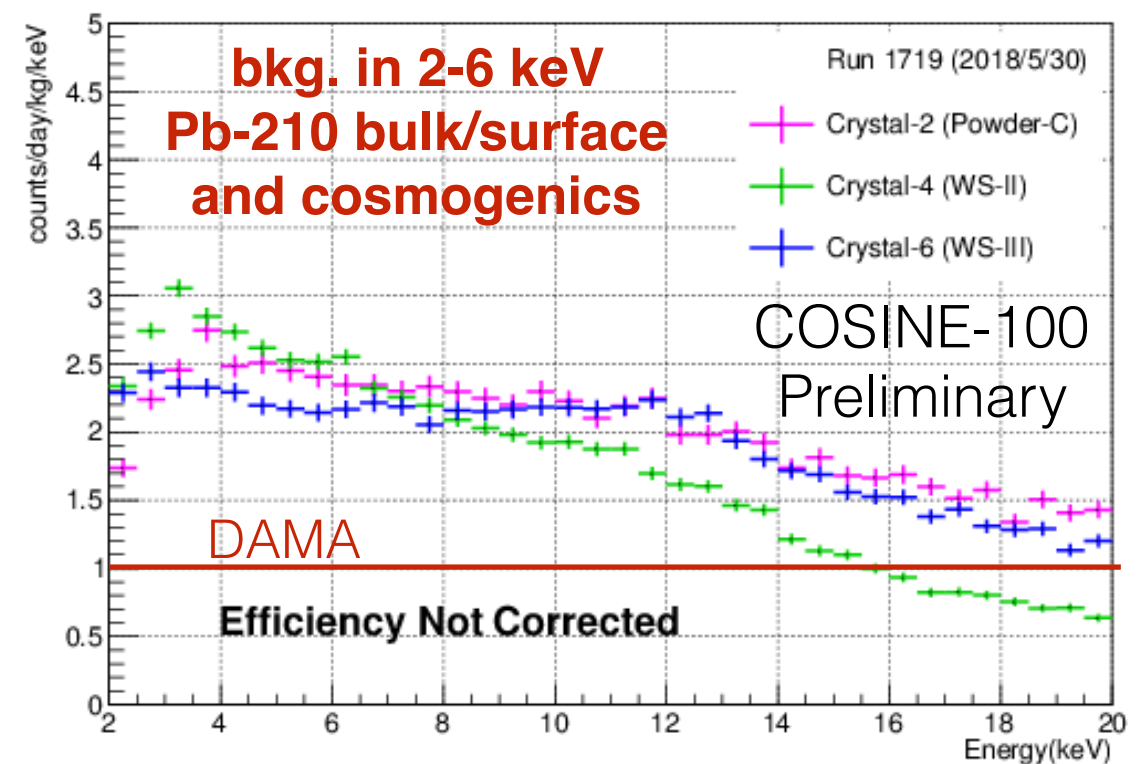
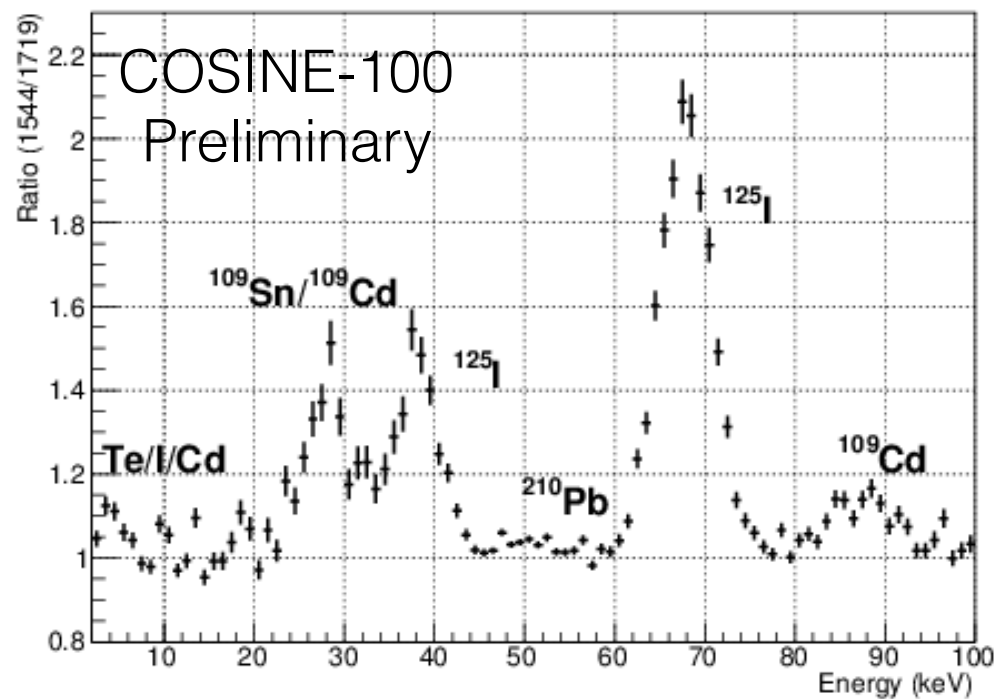
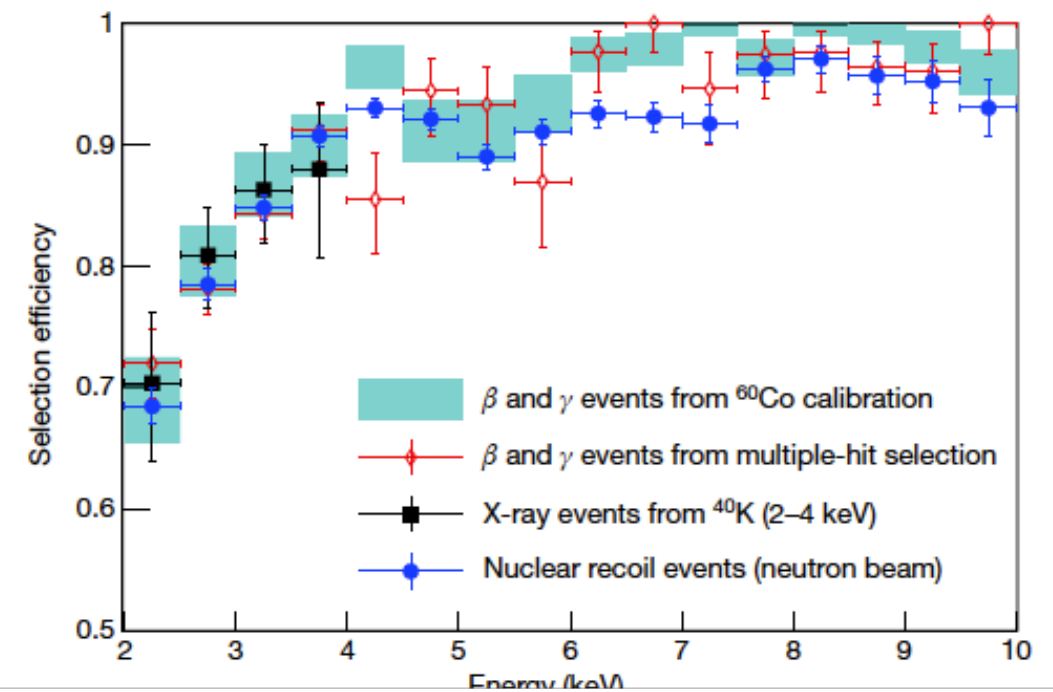
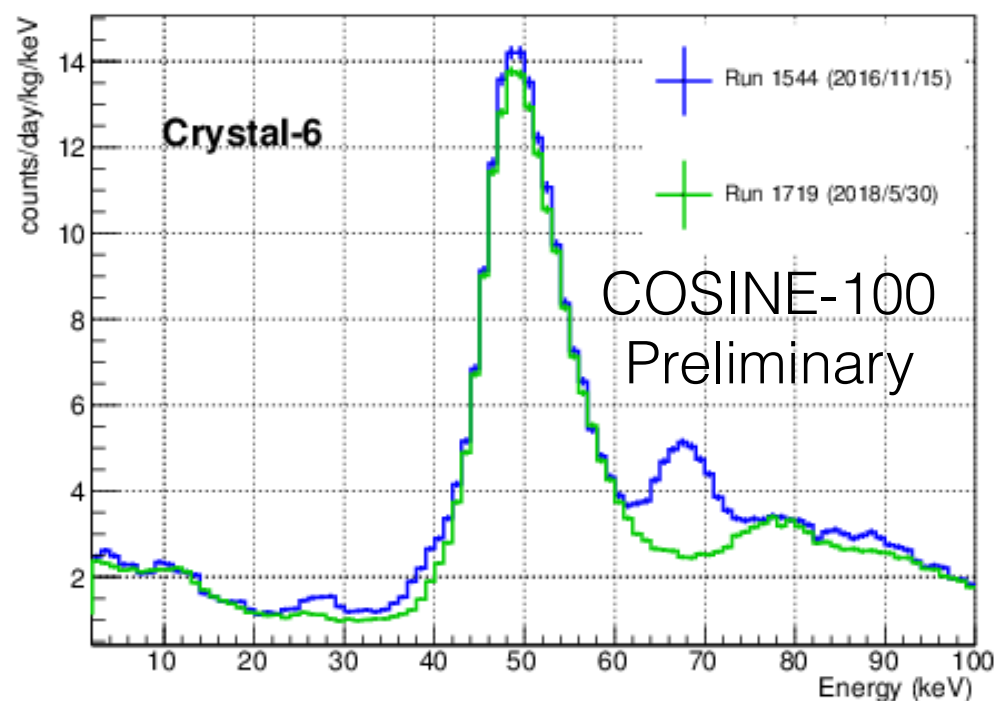


Crystal temperature is maintained better than 0.1 deg. C

PMT noise rejection



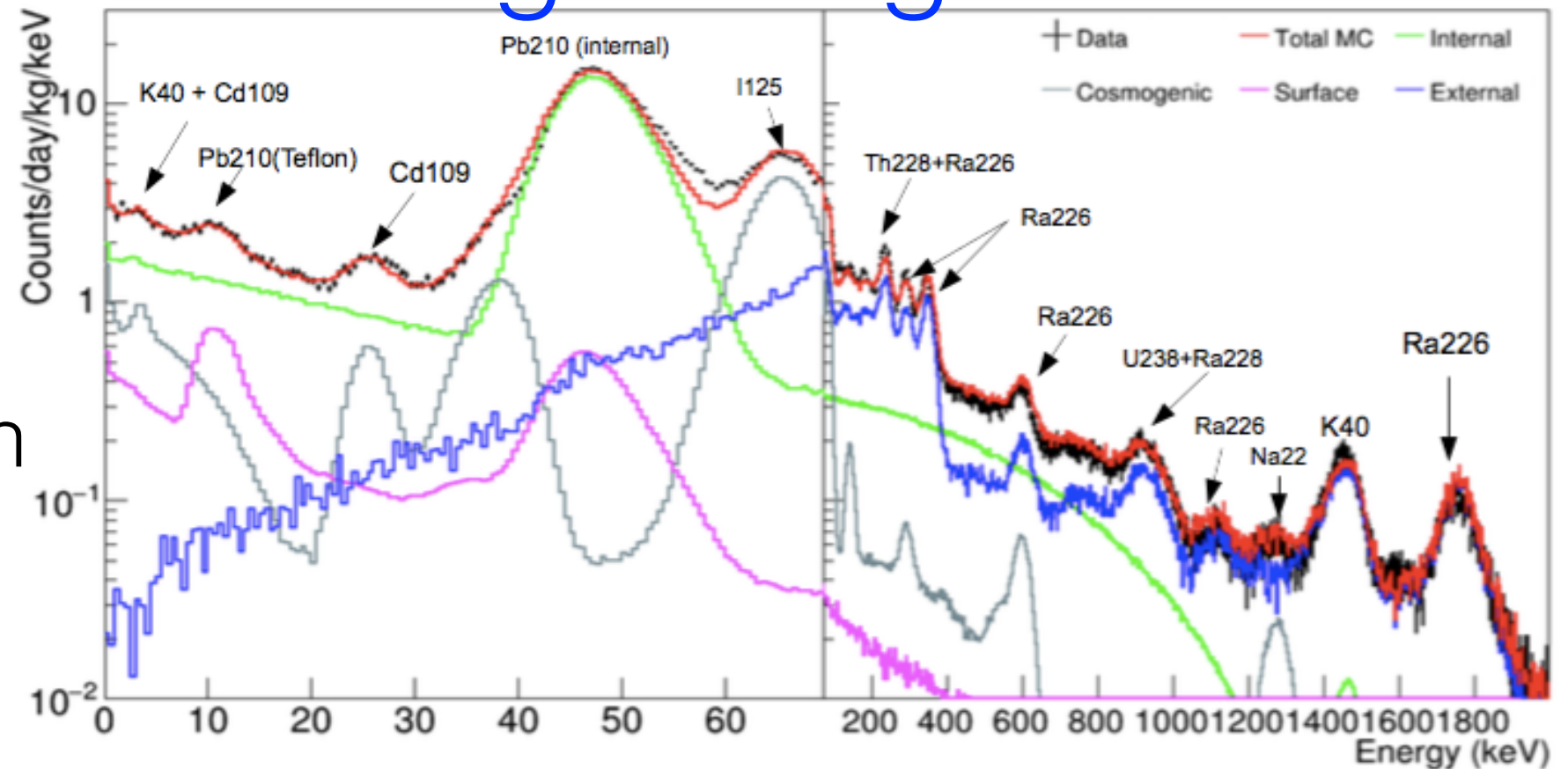
Single-hit Energy spectrum



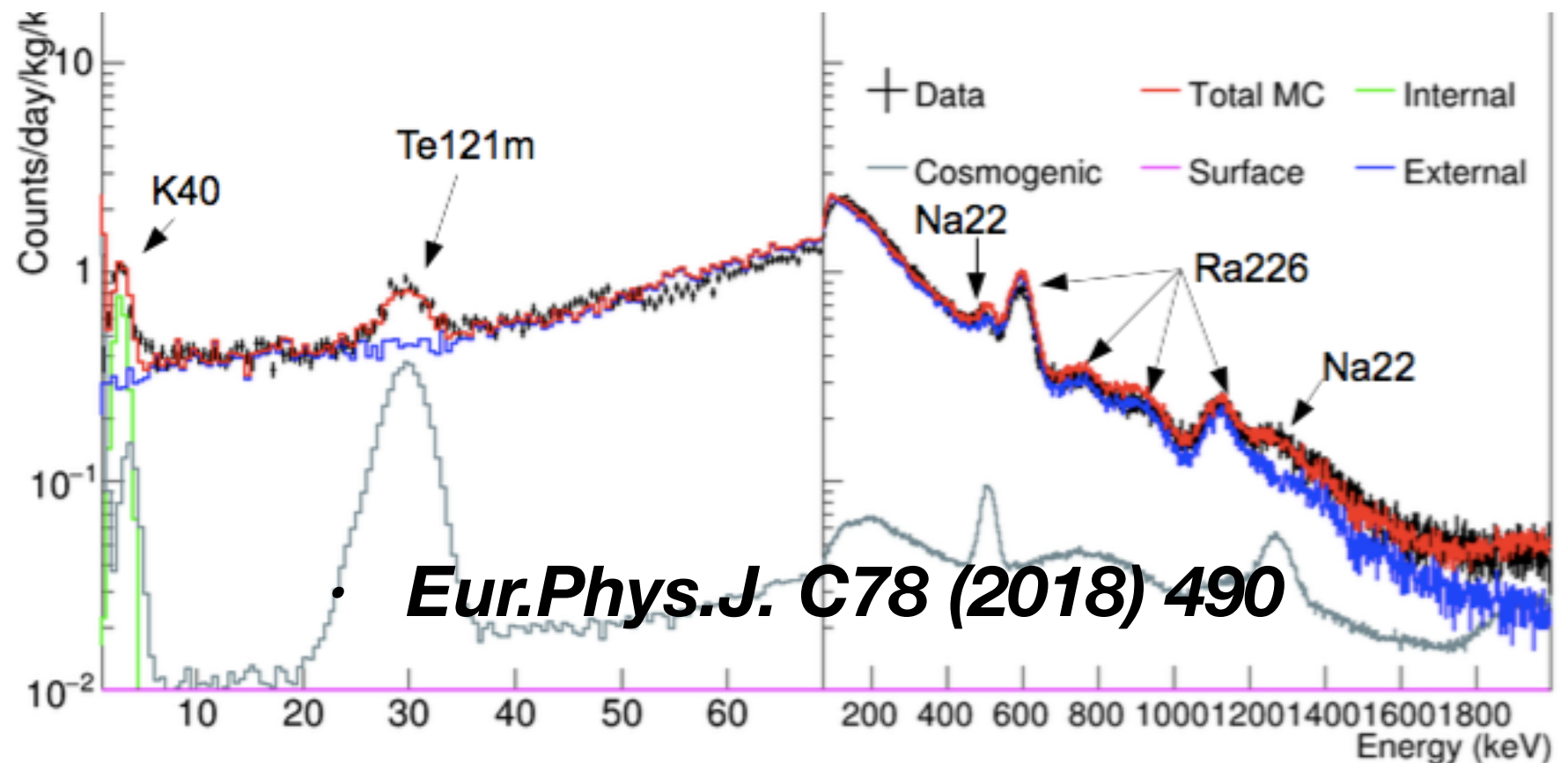
~70% Efficiency at 2 keV, Current bkg. is around 3 counts/day/kg/keV

Understanding Background

Single-Hit
(2-6 keV region
not used)

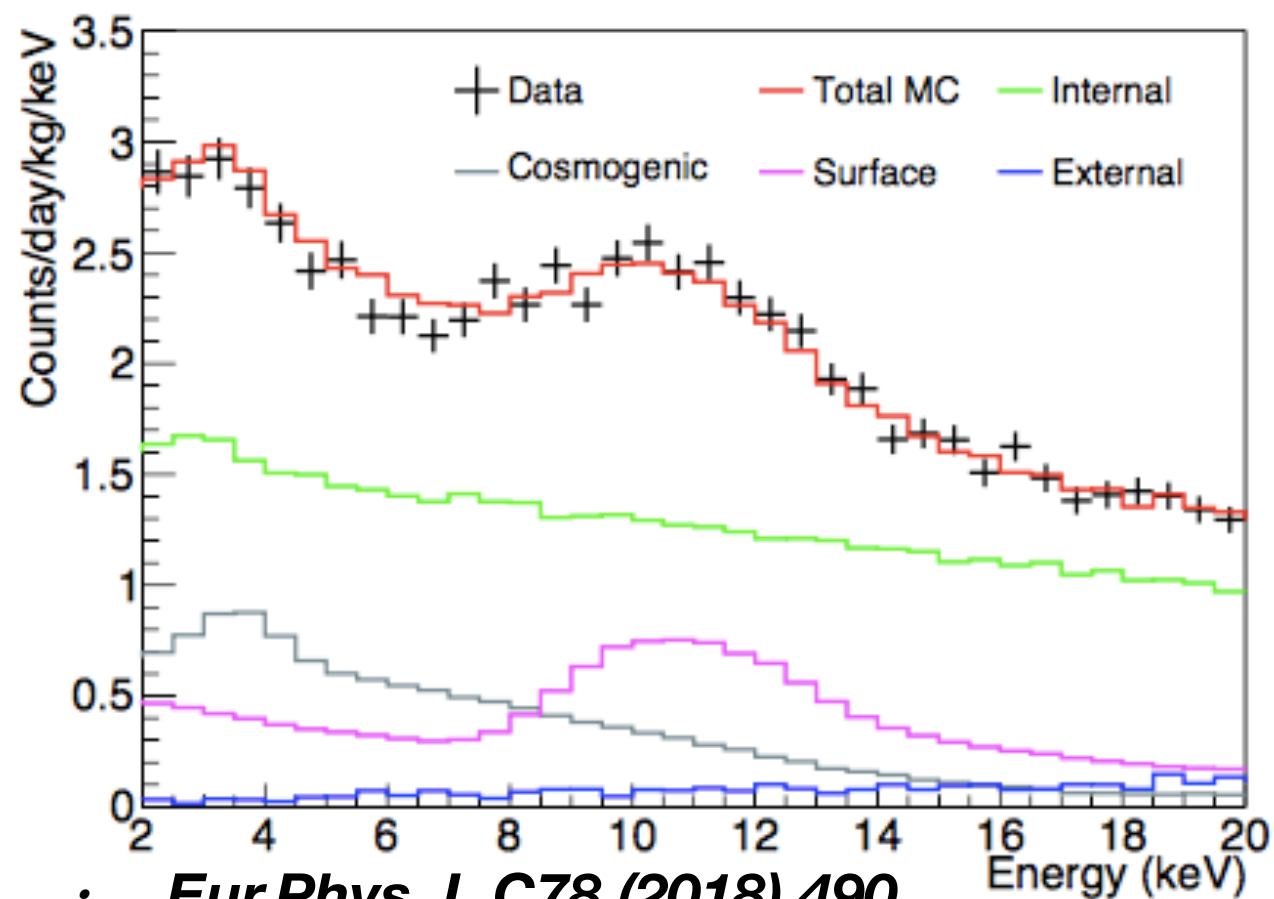


Multiple-Hit

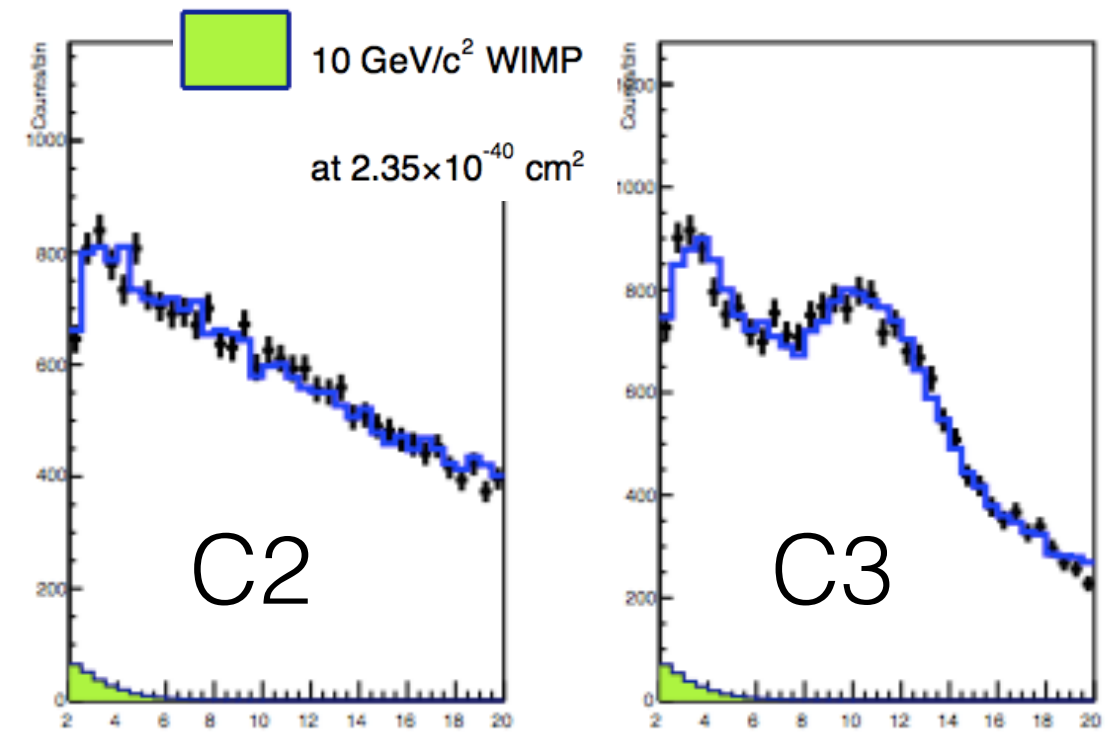


• ***Eur.Phys.J. C78 (2018) 490***

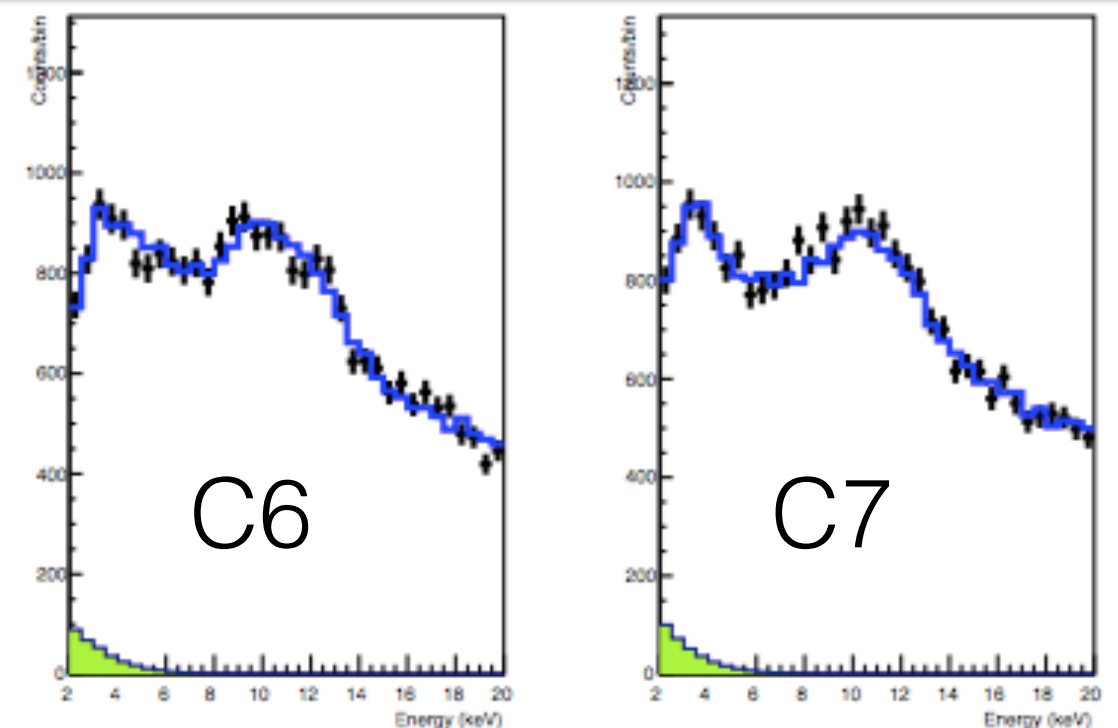
WIMP Search, 59.5 days of Data (until enough modulation analysis data are accumulated)



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

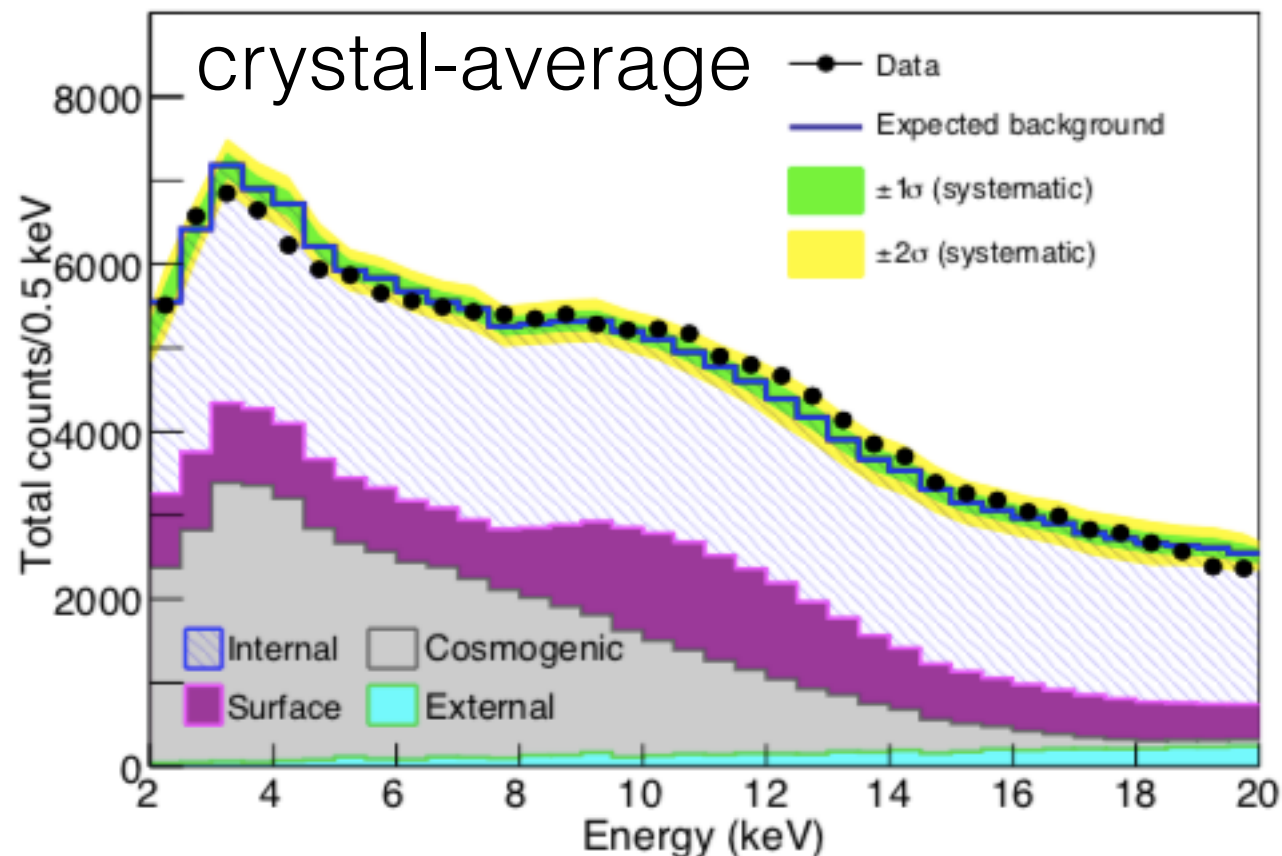


Overlay of DAMA-Na Signal at 10 GeV/c²

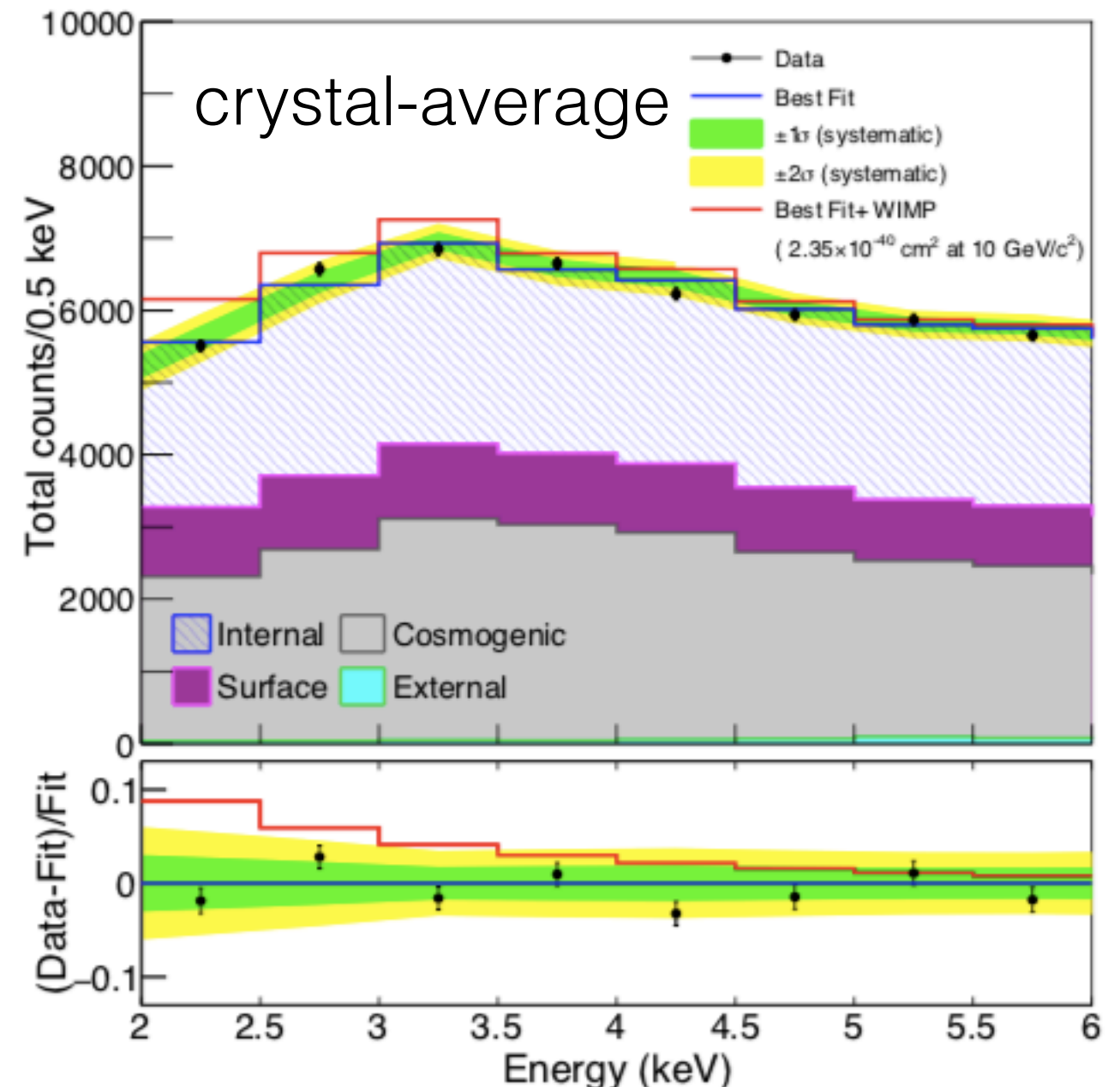


Results for likelihood fits in 2-20 keV region with assumed WIMP signals

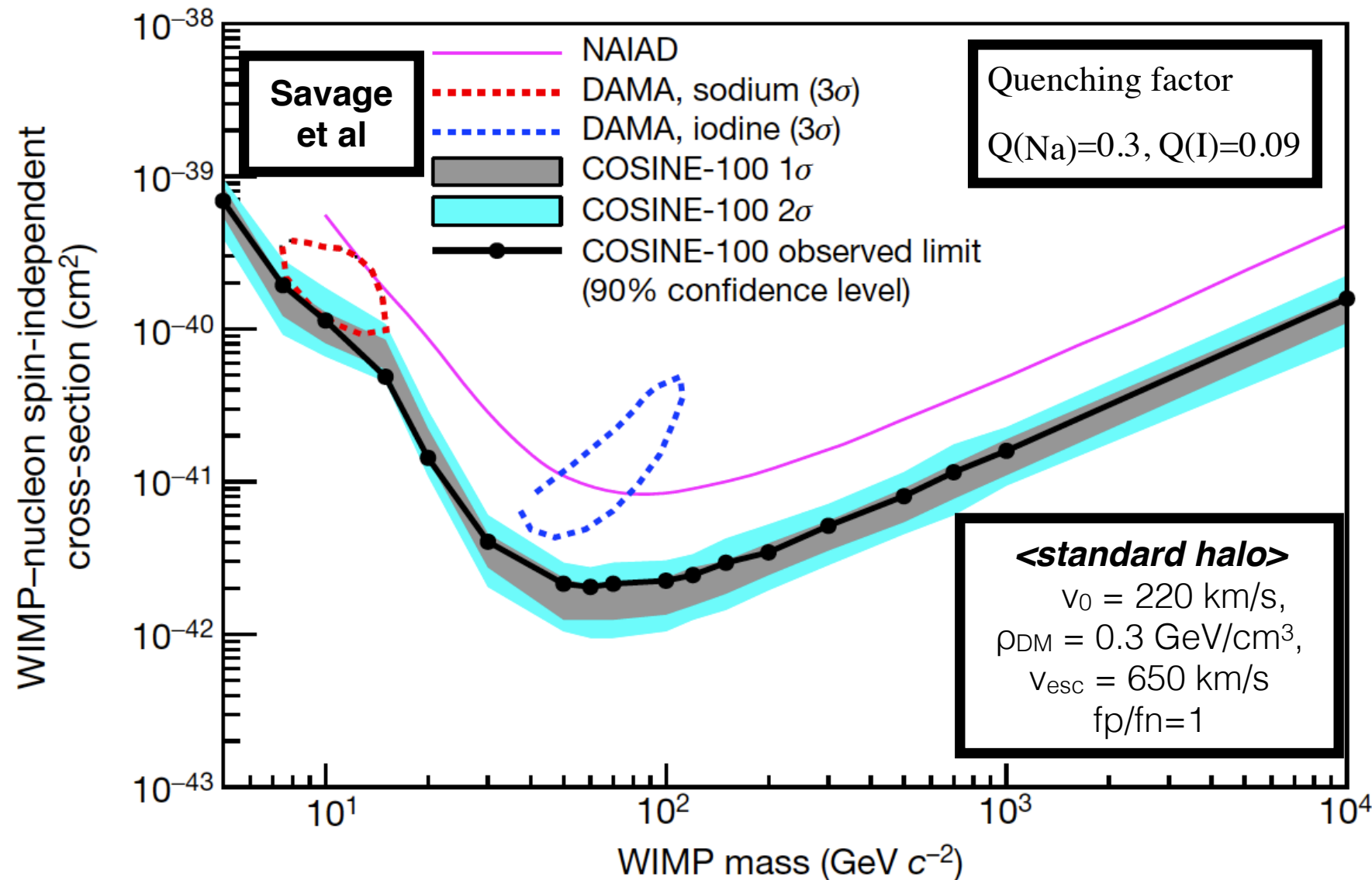
WIMP masses in 5–10000 GeV/c²
 Perform a simultaneous fit with bkg. components and a signal component.
 Nuisance parameters for bkg. and systematics



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)



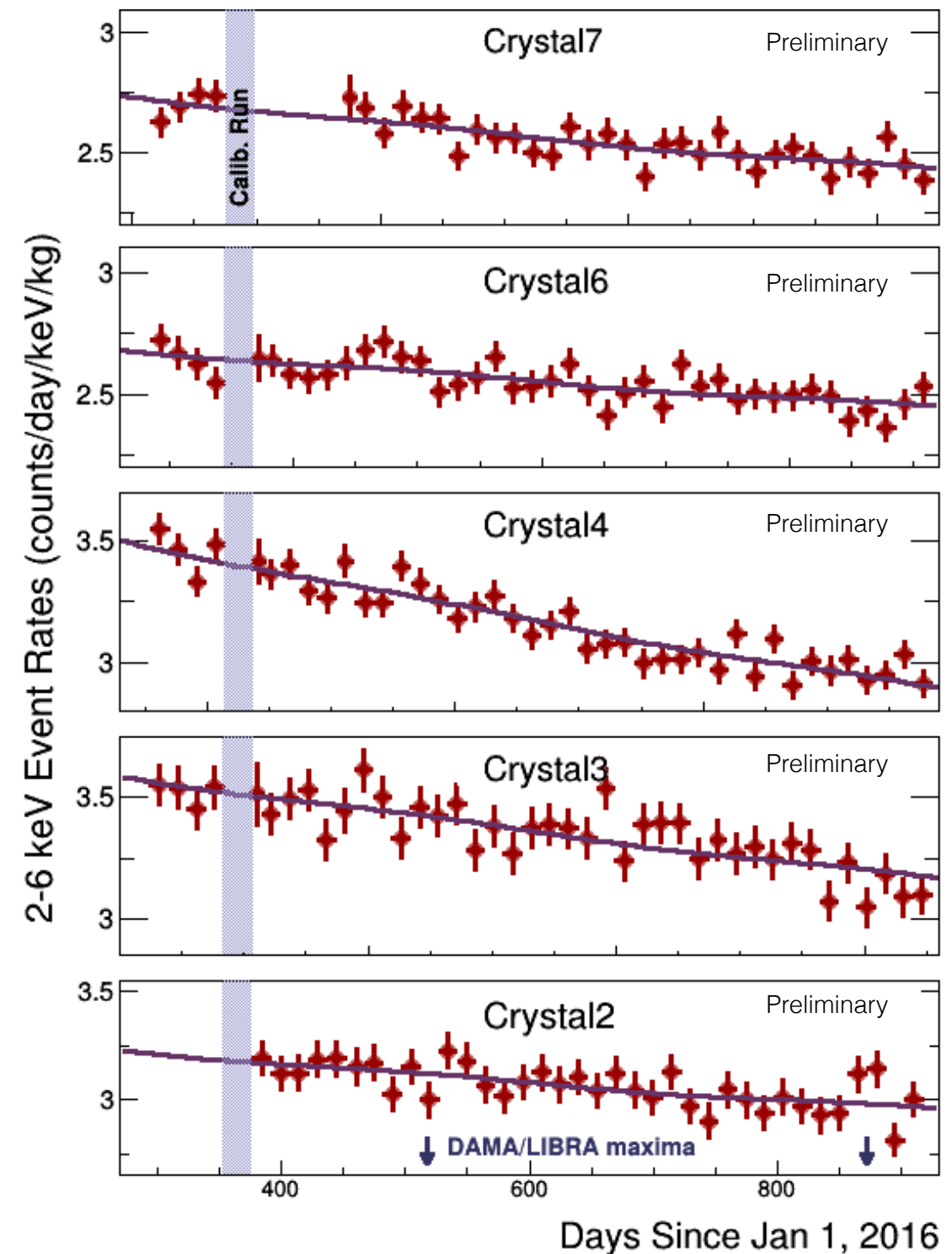
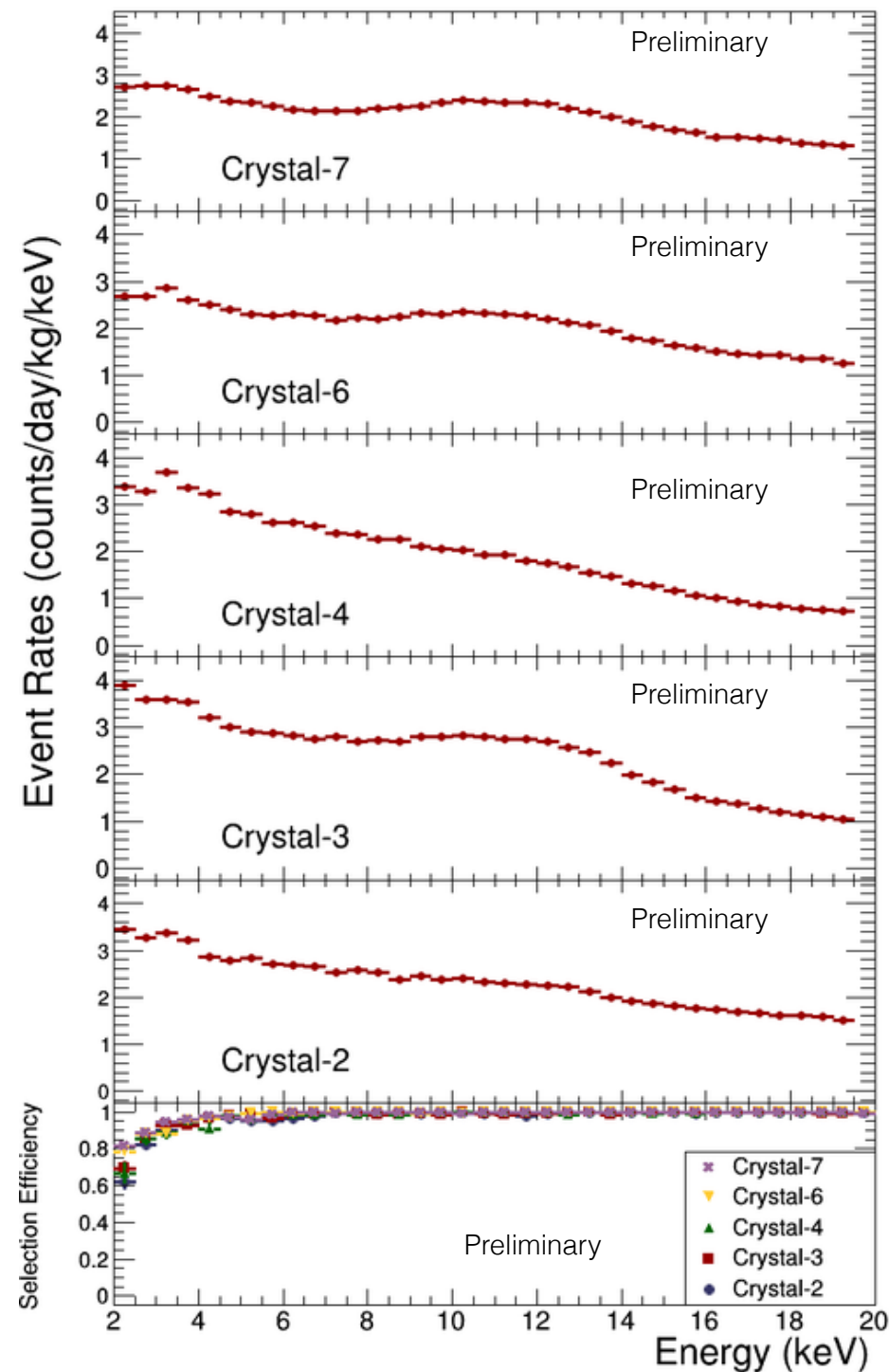
Nature 564, 83 (2018)

- 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.

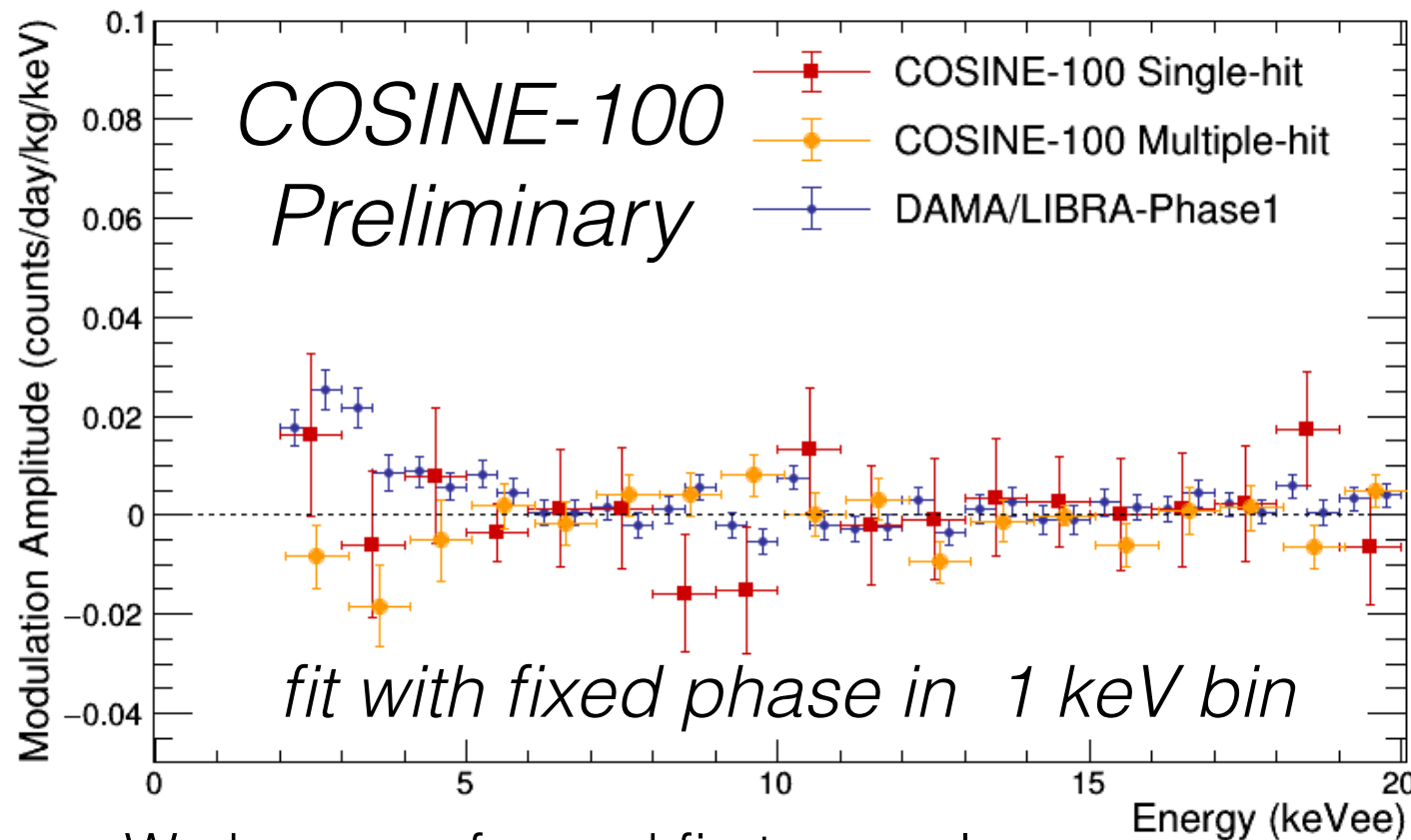
Annual Modulation Analysis (606 days of data, SET2)

Search for oscillatory signature in 2—6 keV region of energy spectrum.

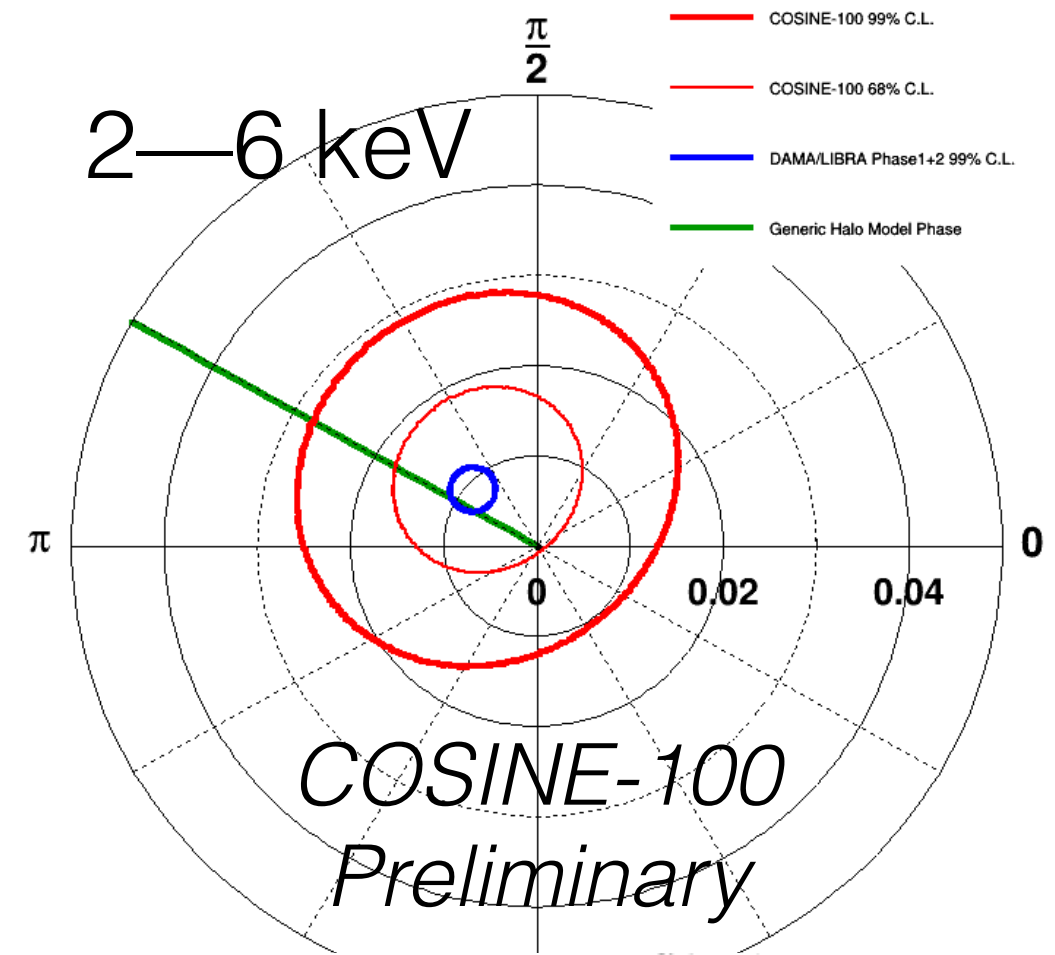


Global fit using cosmogenic and sinusoidal components simultaneously for crystals

Annual modulation analysis : COSINE-100 preliminary results for 1.7 year exposure shows consistency with null modulation and also with DAMA center.



- 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.

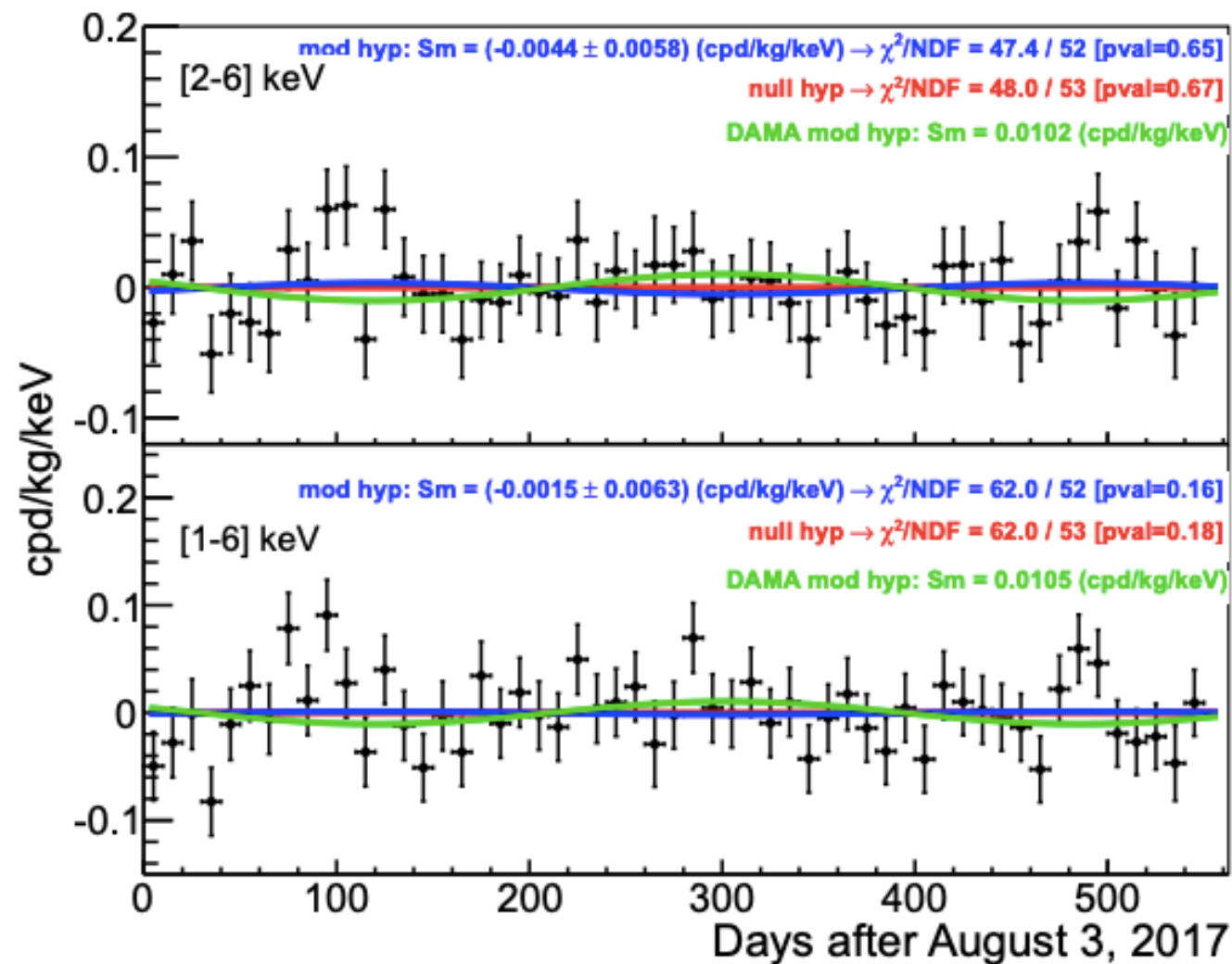


2~6 keV result

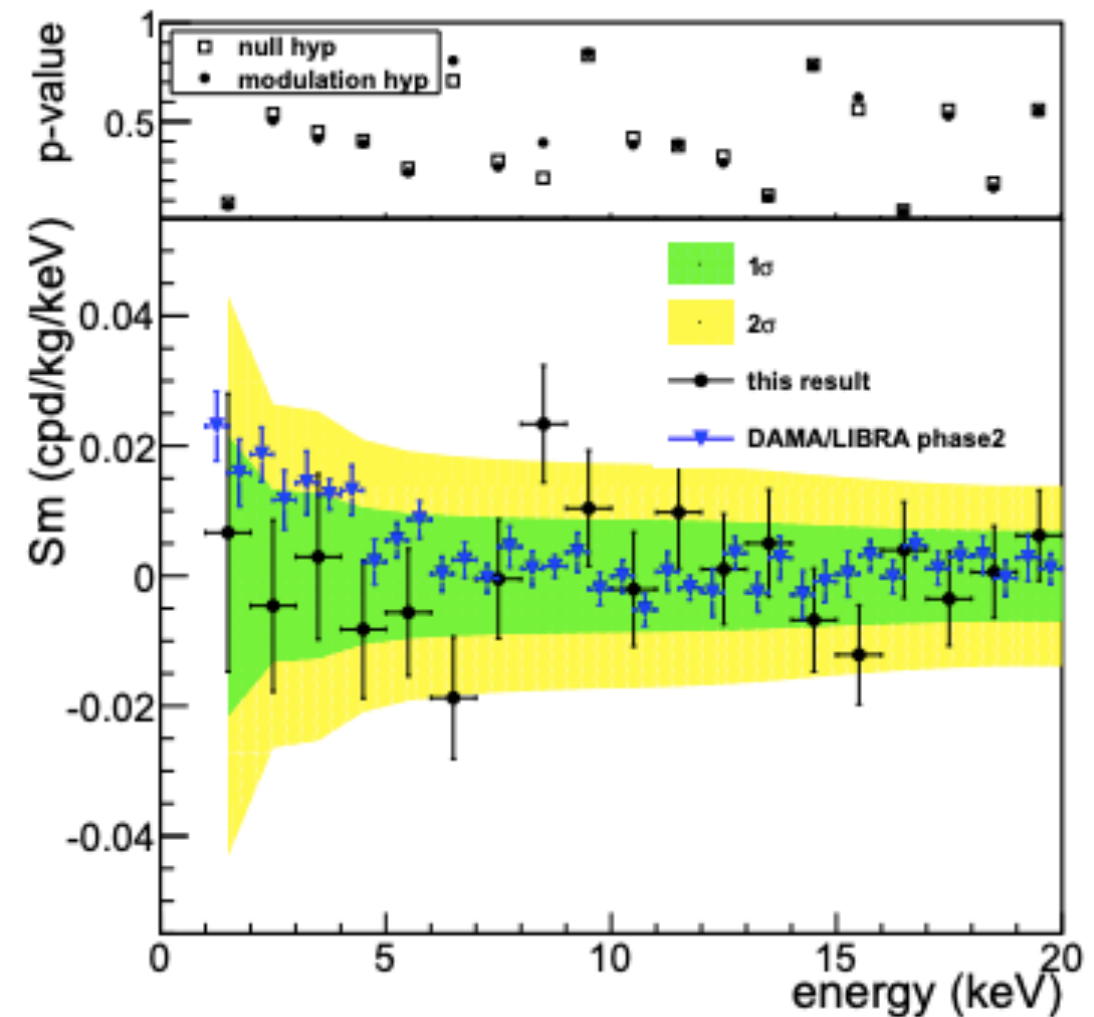
Config	Amplitude	Phase (days)
COSINE-100	0.0083 ± 0.0068	152.5 (fixed)
Without LS	0.0024 ± 0.0073	152.5 (fixed)
DAMA	0.0095 ± 0.0008	152.5 (fixed)
COSINE-100	0.0092 ± 0.0067	127 ± 46
DAMA	0.0096 ± 0.0008	145 ± 5

ANAIS-112 results (today@Arxiv:1903.03973)

$$R(t) = R_0 + R_1 \cdot \exp(-t/\tau) + S_m \cdot \cos(\omega \cdot (t + \phi))$$



157.55 kg.year exposure

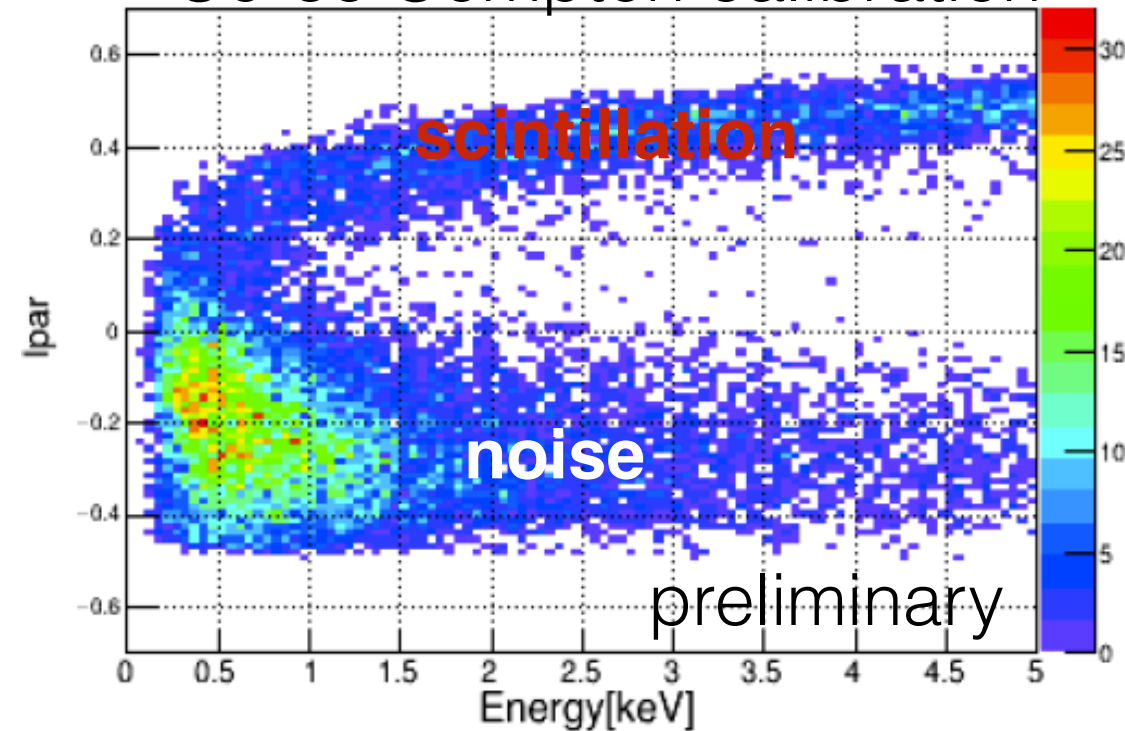


-0.0044+/-0.0058 for 2–6 keV
 -0.0015+/-0.0063 for 1–6 keV

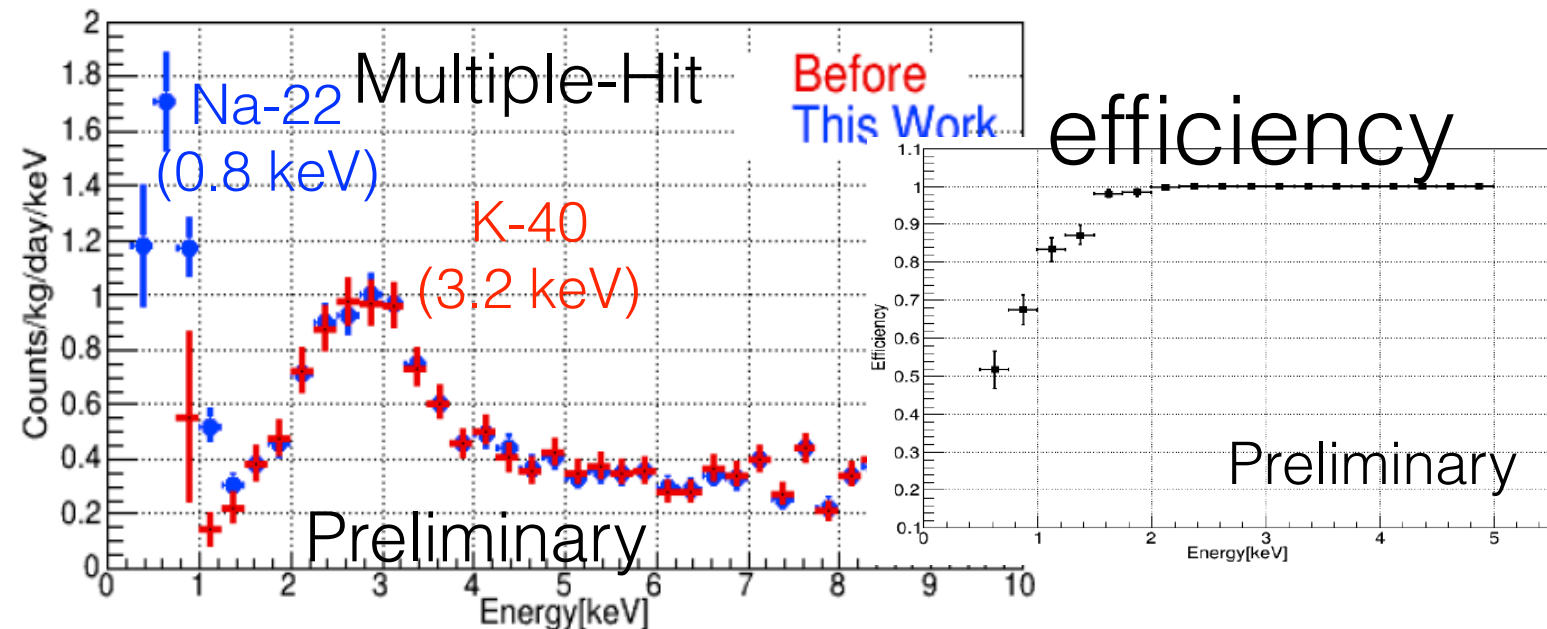
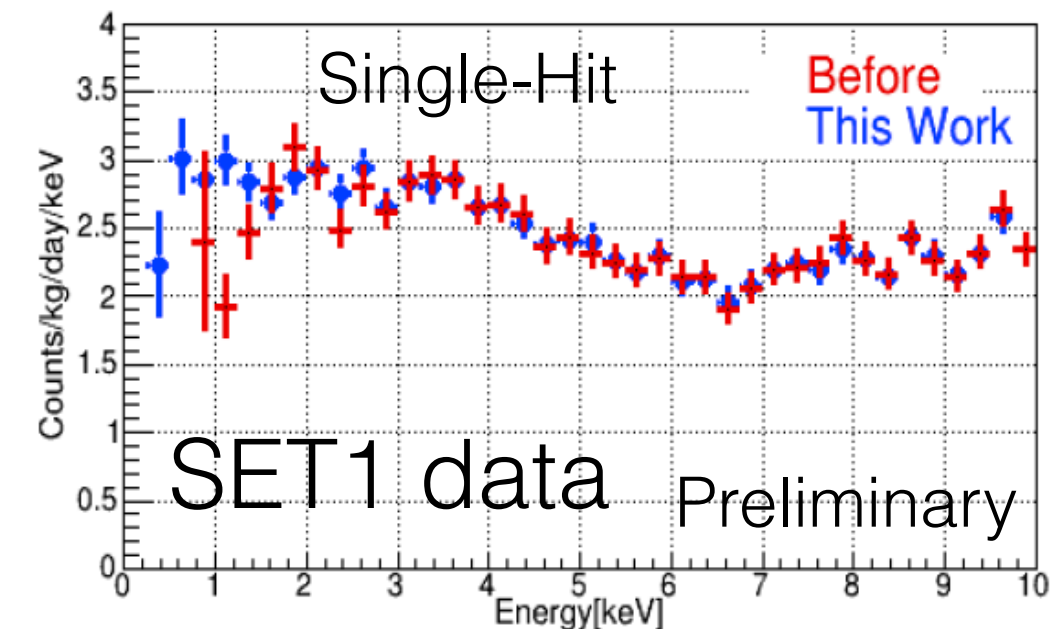
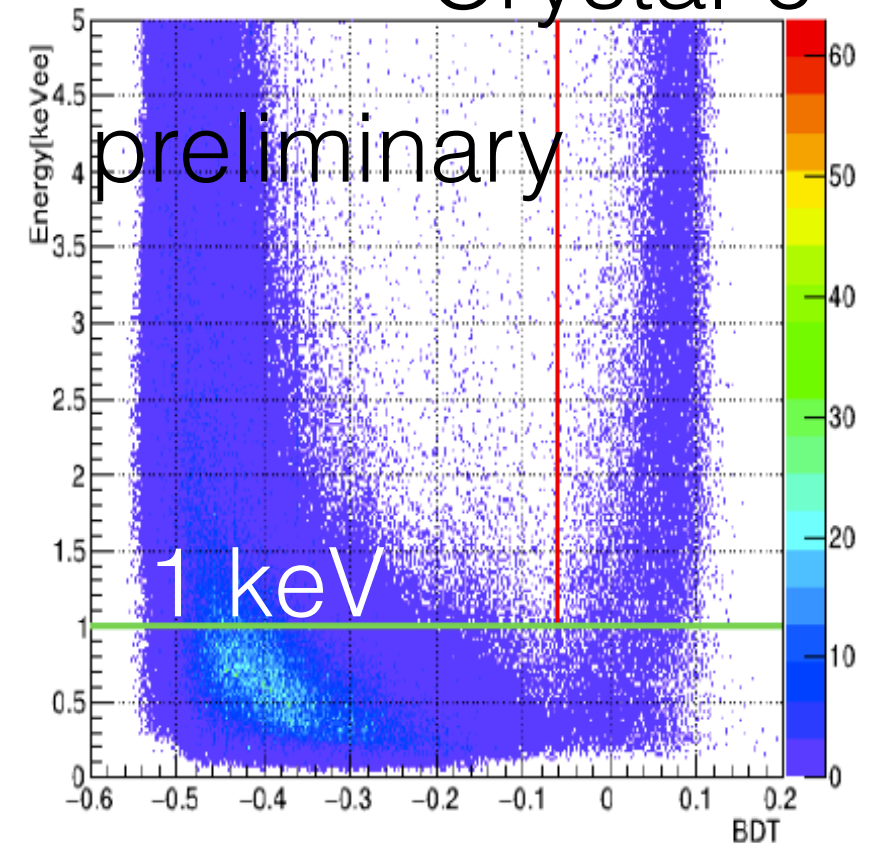
Down to 1 keV threshold

Crystal-6

Co-60 Compton calibration

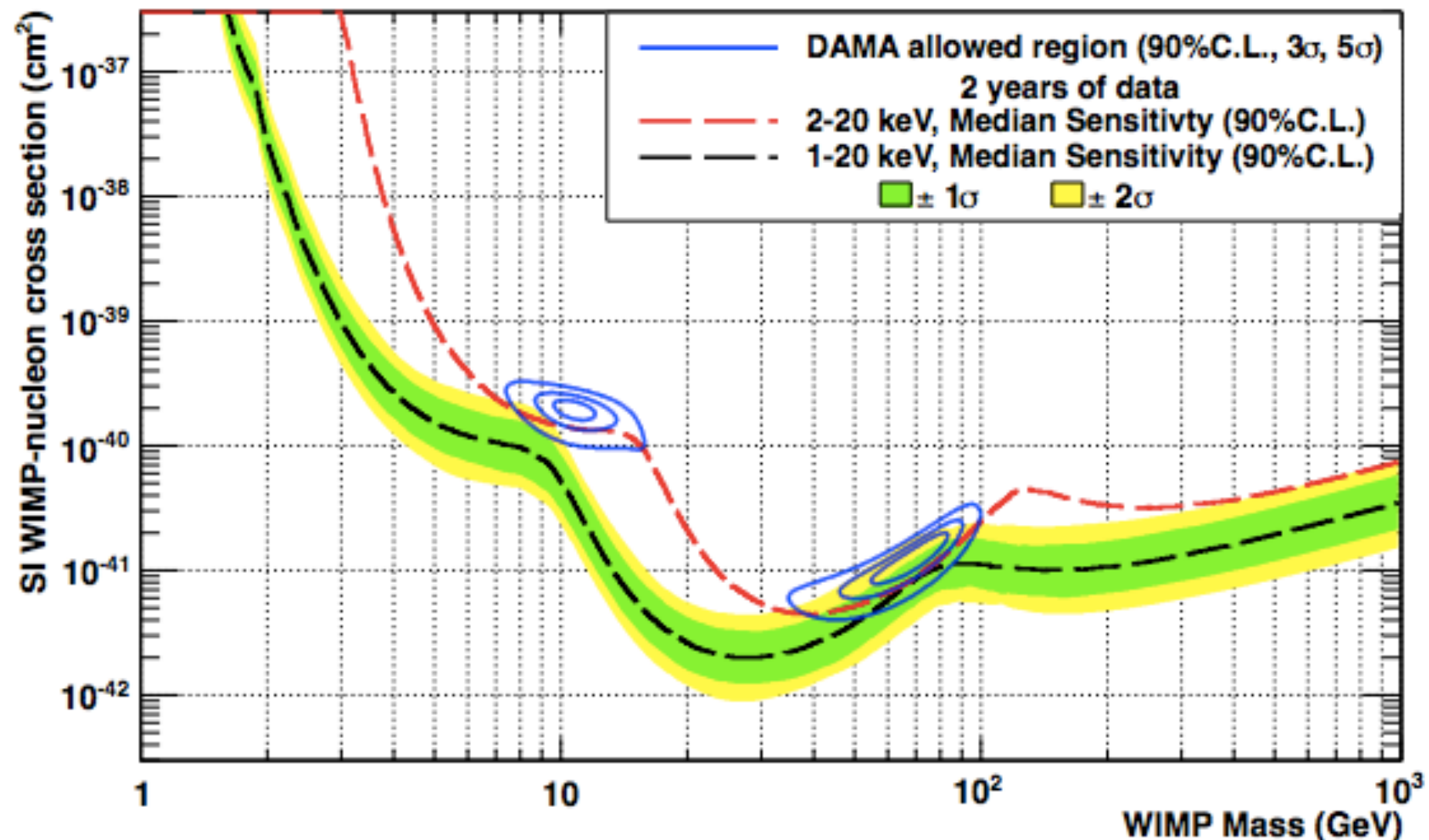


Calibration data
is trained for
noise rejection.



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

Expected Sensitivity for COSINE-100



**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

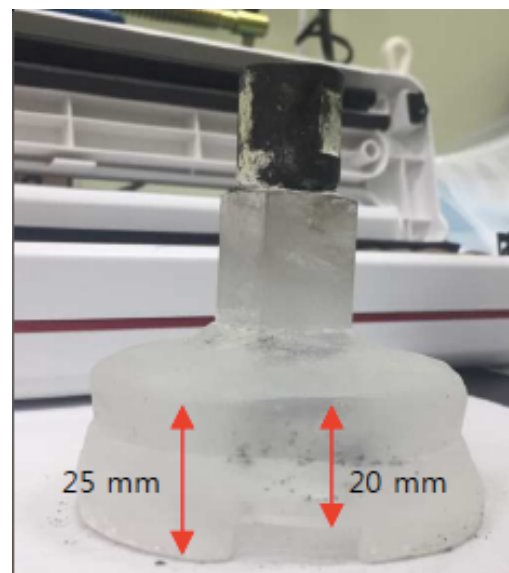
Powder purification (Recrystallization)

Crystal growing & Handling

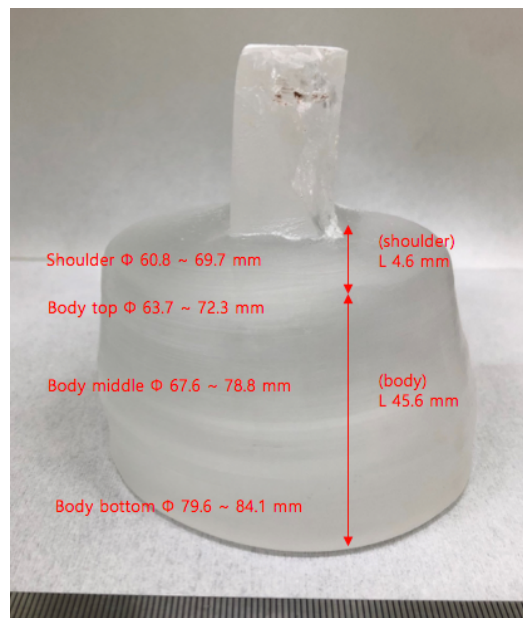
Established a facility at our
center

Powder purification

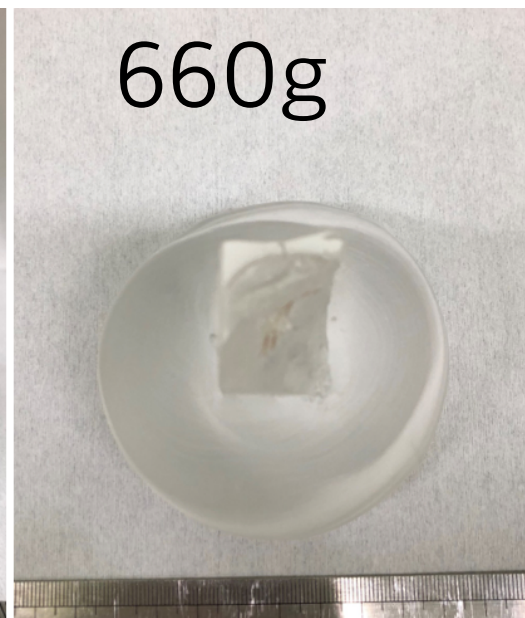
(mass production facility for
purification under
construction)



Growing low radioactive NaI(Tl) Crystals at our center



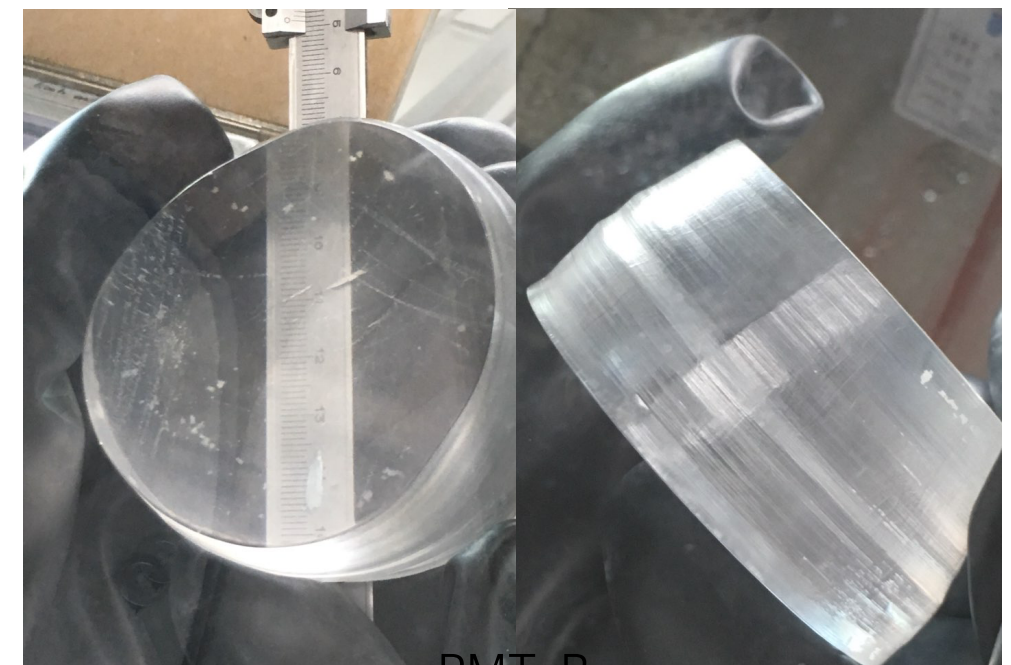
<결정 사이즈>



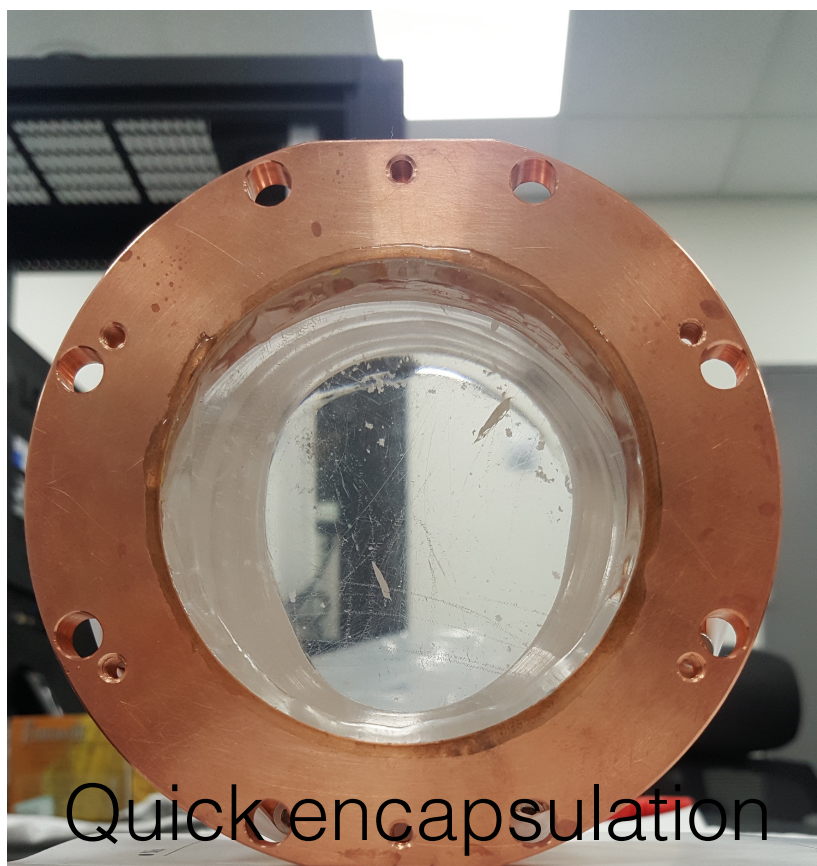
<결정 모양>



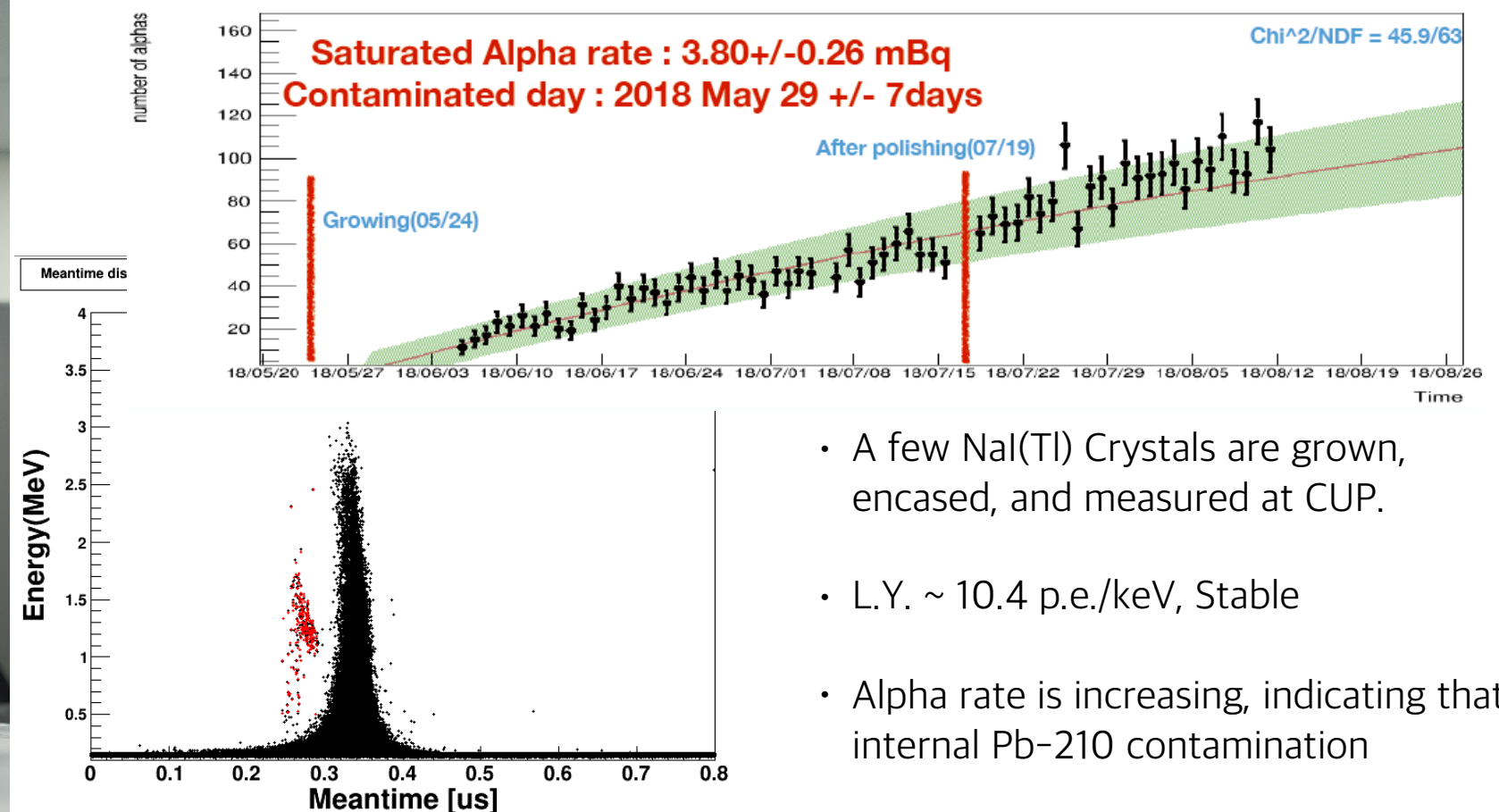
<결정 내부 이물질>
PMT-A



PMT-B

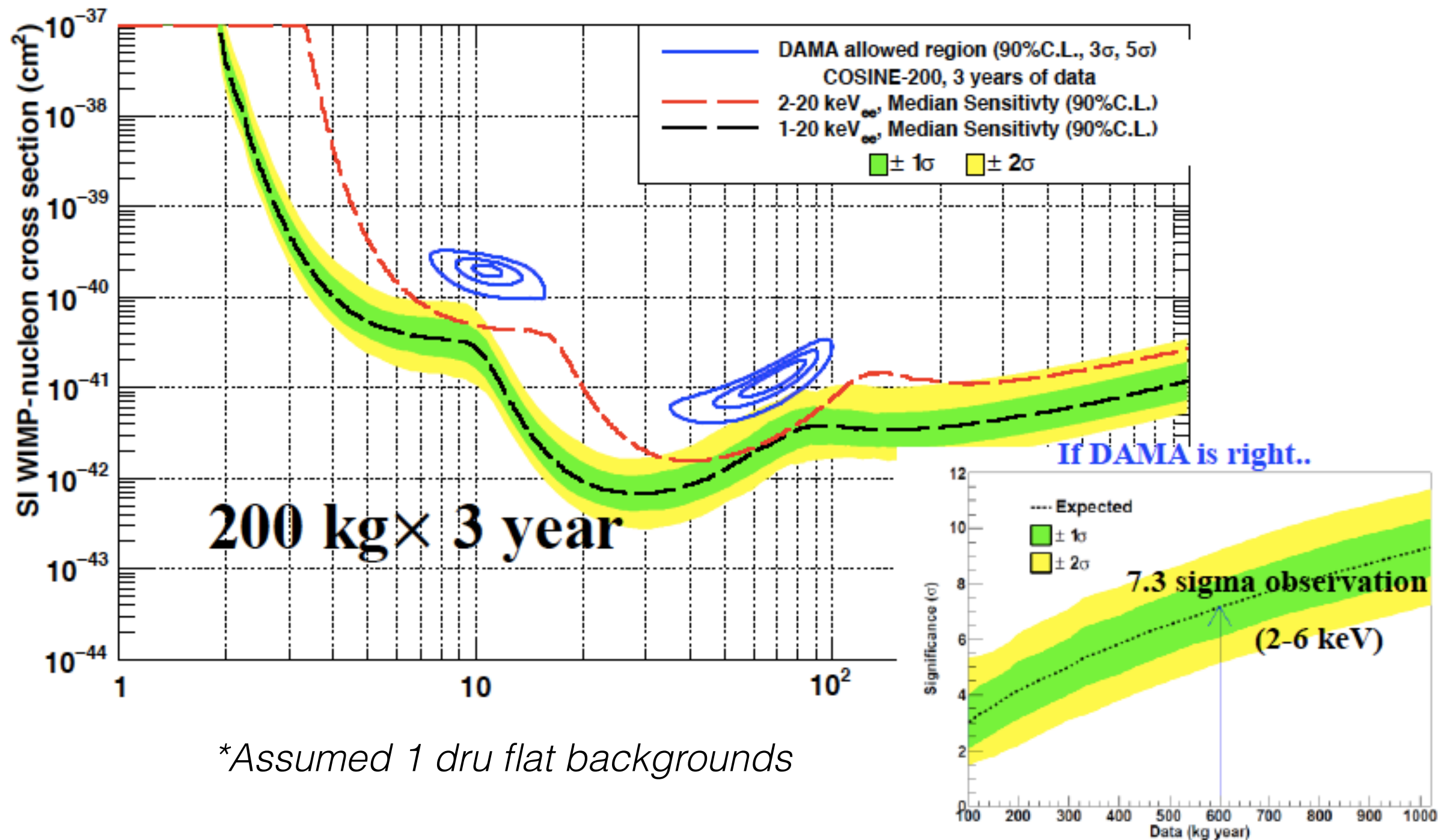


Quick encapsulation



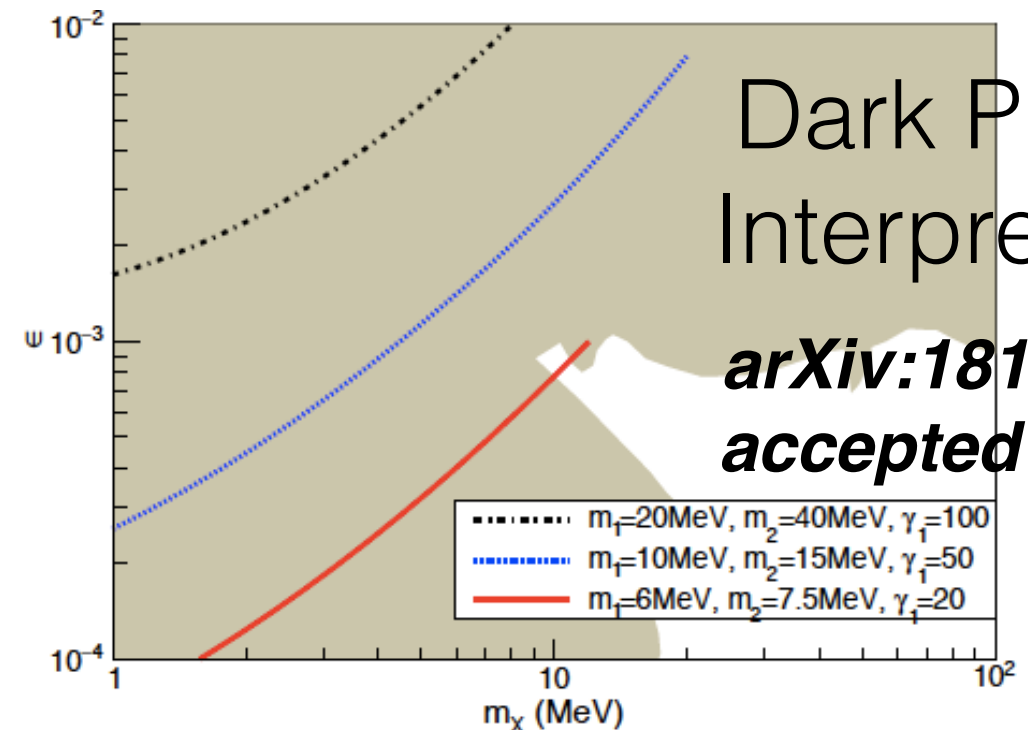
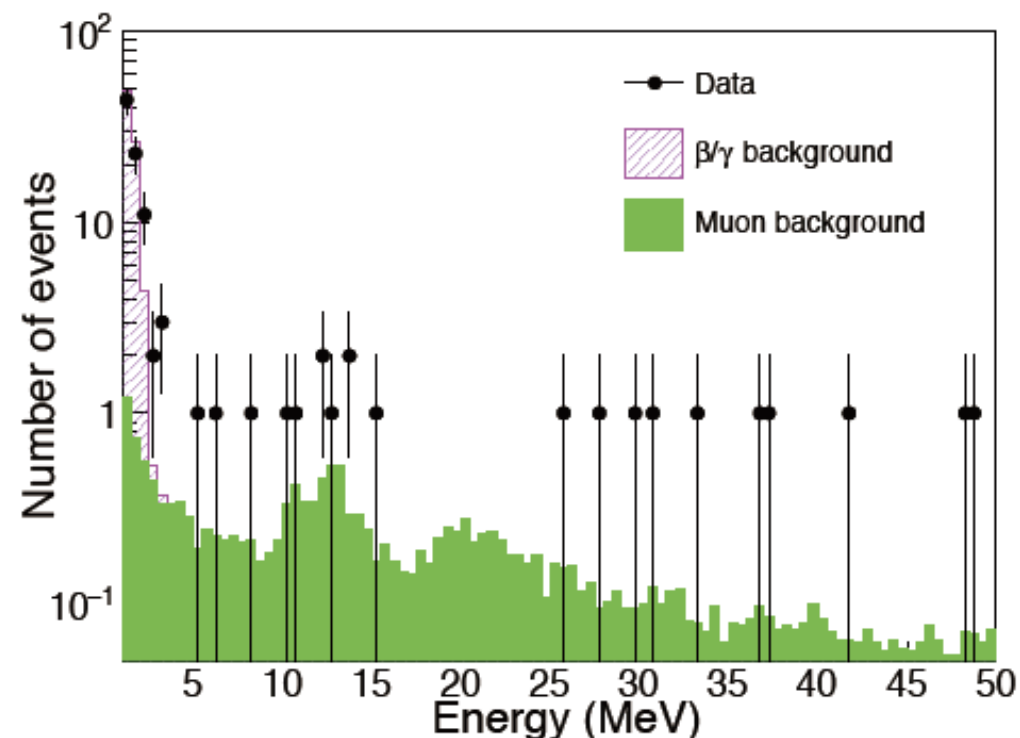
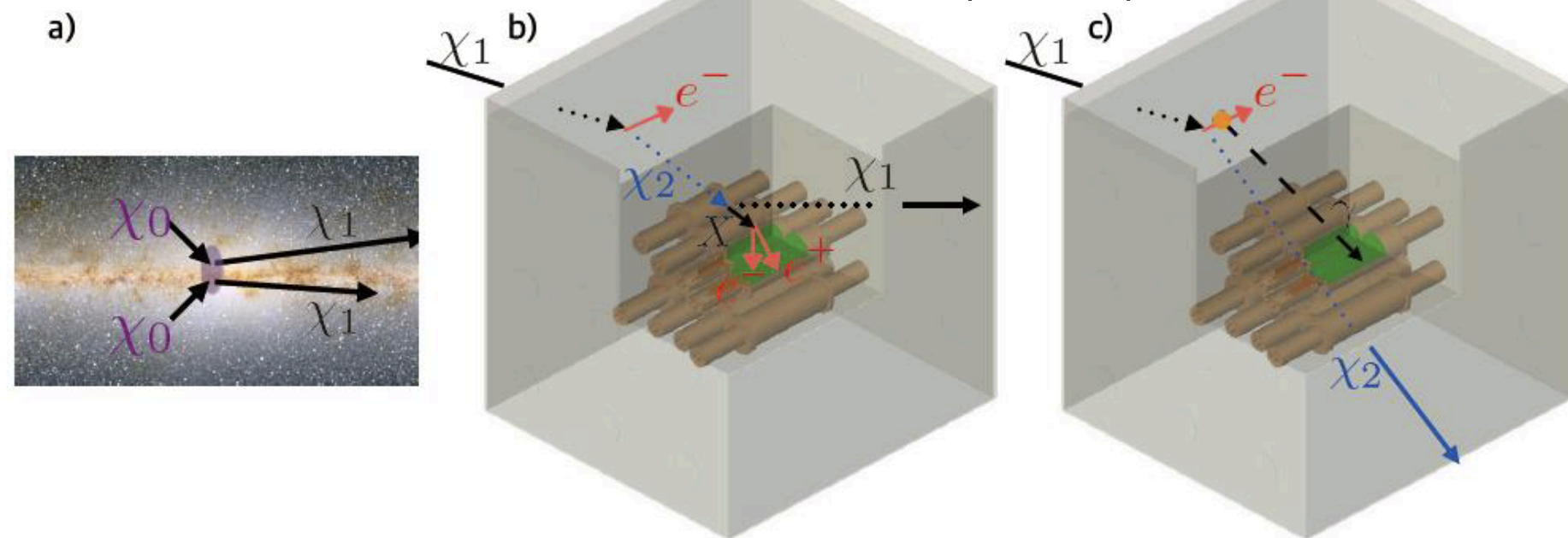
- A few NaI(Tl) Crystals are grown, encased, and measured at CUP.
- L.Y. ~ 10.4 p.e./keV, Stable
- Alpha rate is increasing, indicating that internal Pb-210 contamination

Expected sensitivity for COSINE-200 (Phase-II)



Boosted Dark Matter search using 2 tons of liquid scintillator

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



Summary & Outlook

- The COSINE-100 experiment was installed at Y2L and runs smoothly for 2.5 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.