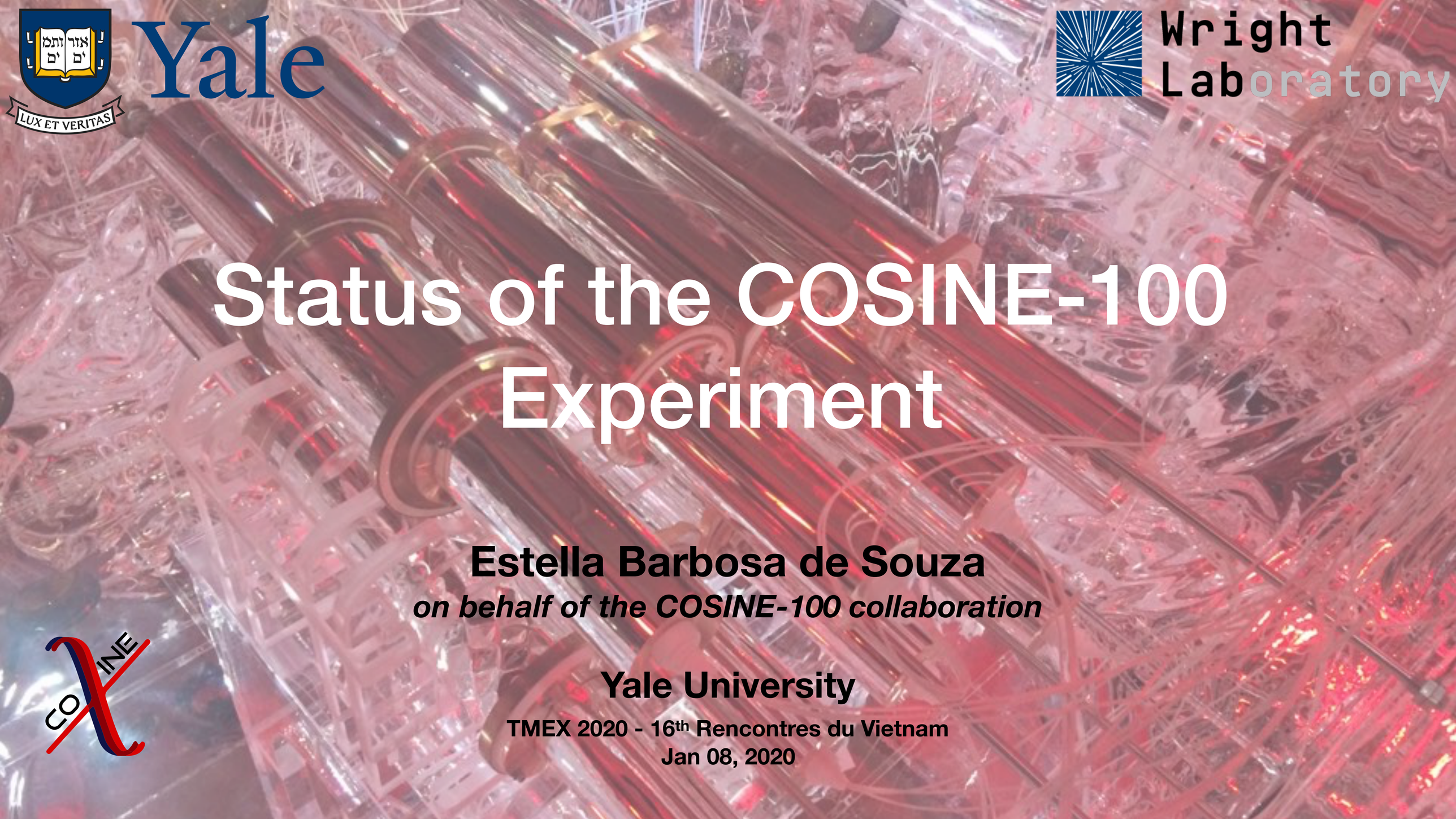


Status of the COSINE-100 Experiment

Estella Barbosa de Souza

on behalf of the COSINE-100 collaboration

Yale University

TMEX 2020 - 16th Rencontres du Vietnam

Jan 08, 2020

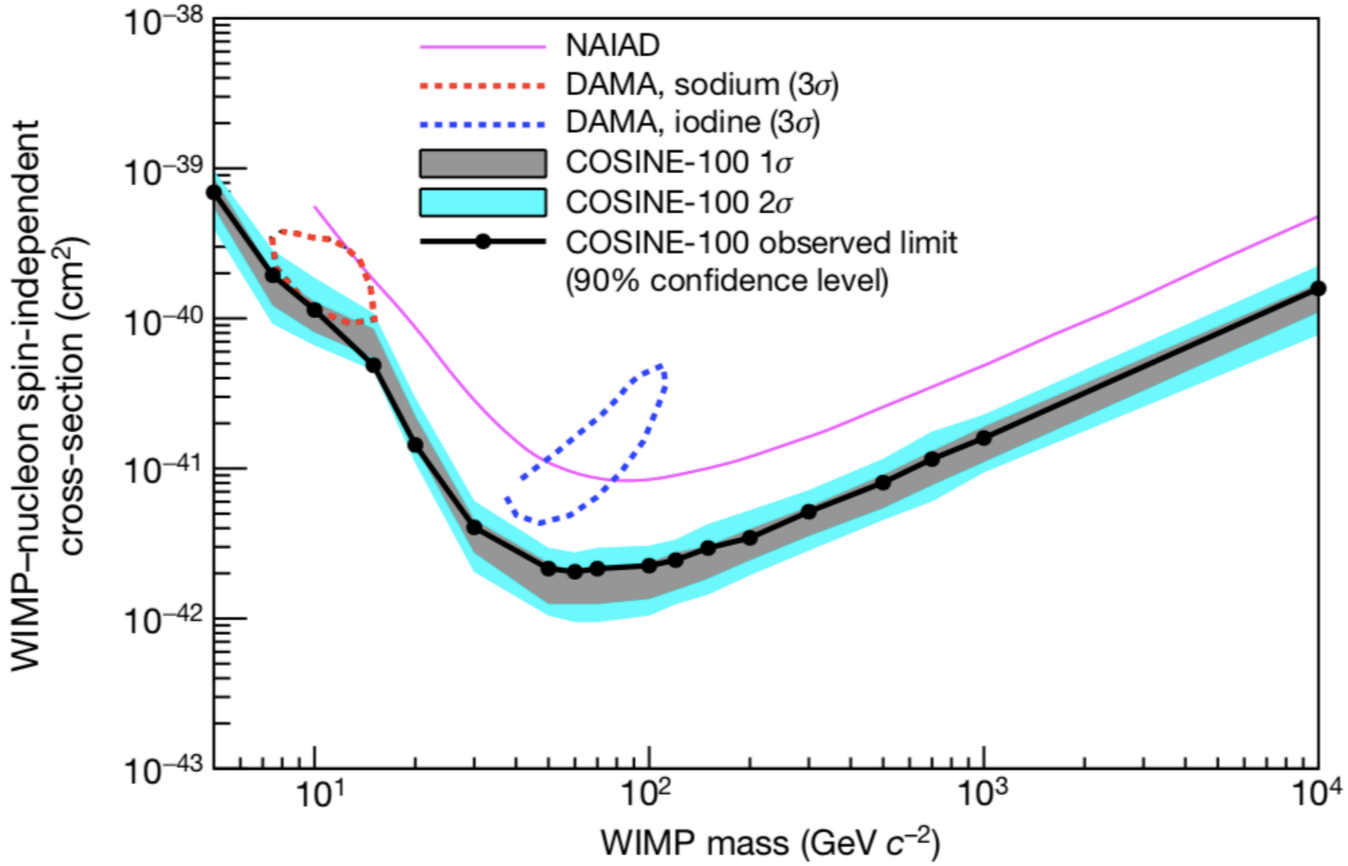
DAMA's Signal Not Spin-Independent WIMPs

LETTER

Nature **564**, 83–86 (2018)

https://doi.org/10.1038/s41586-018-0739-1

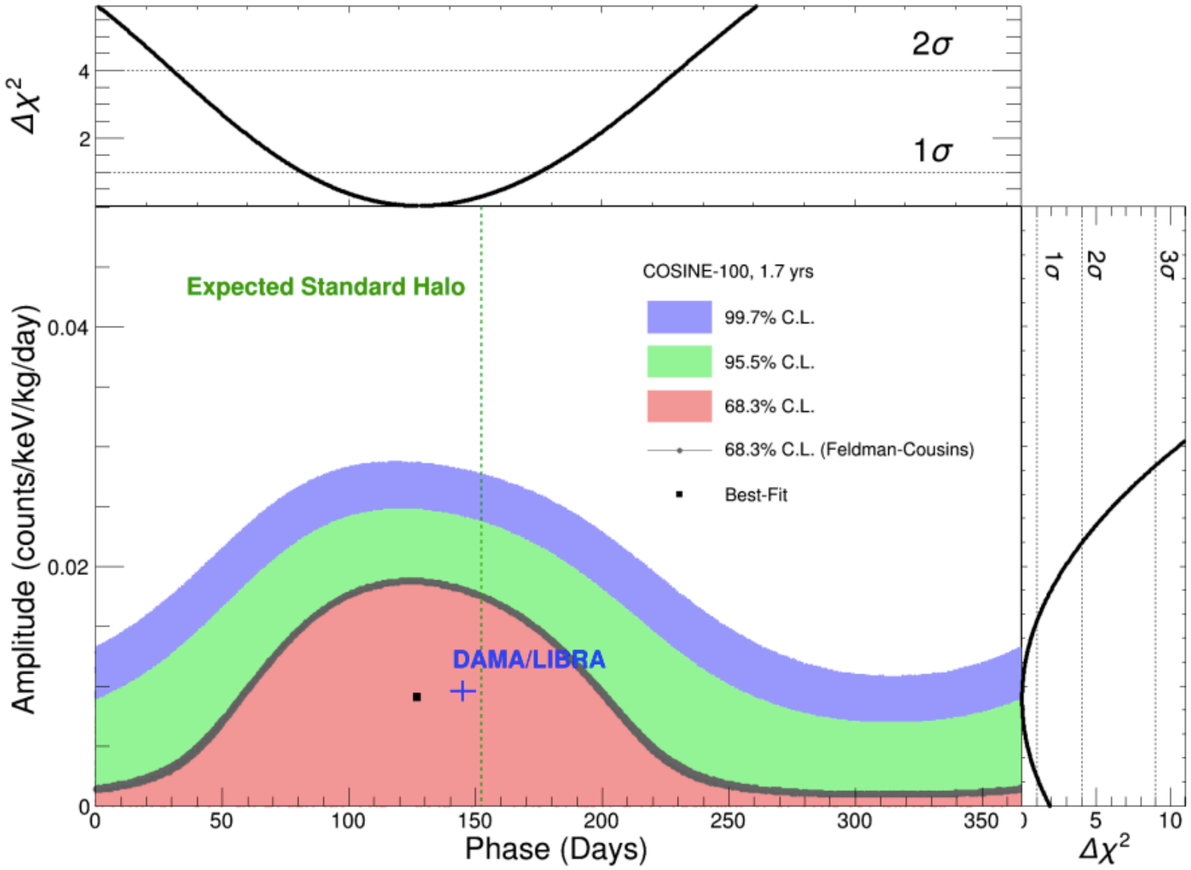
An experiment to search for dark-matter interactions using sodium iodide detectors

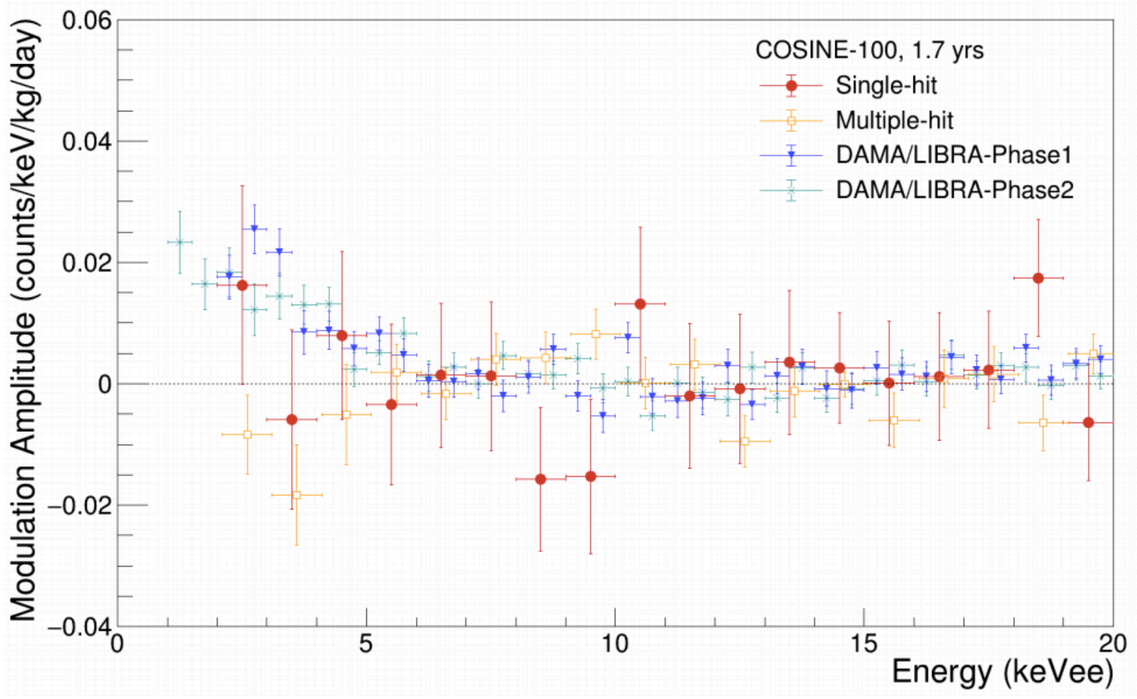


COSINE-100 First Modulation Results

Phys. Rev. Lett. **123**. 031302 (2019)

Search for a Dark Matter-Induced Annual Modulation Signal in NaI(Tl) with the COSINE-100 Experiment

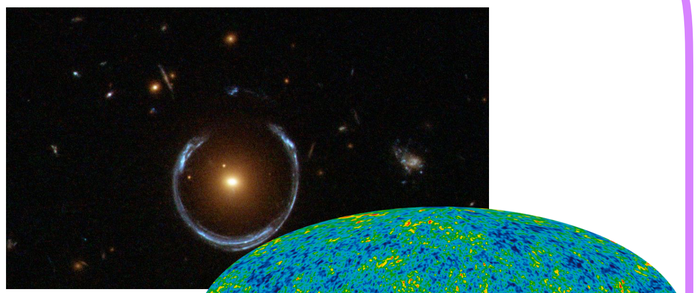


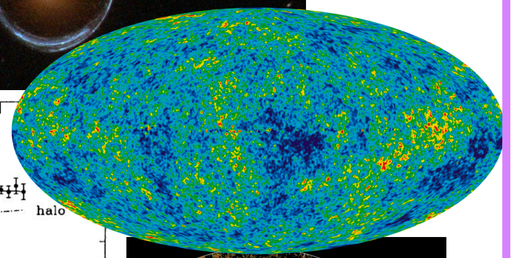


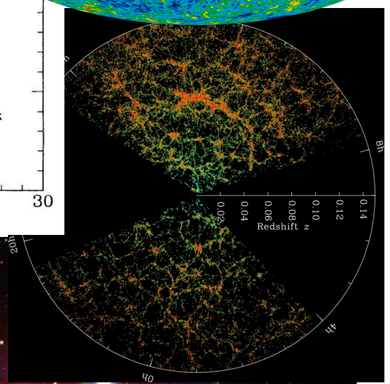
Current Status of the Field

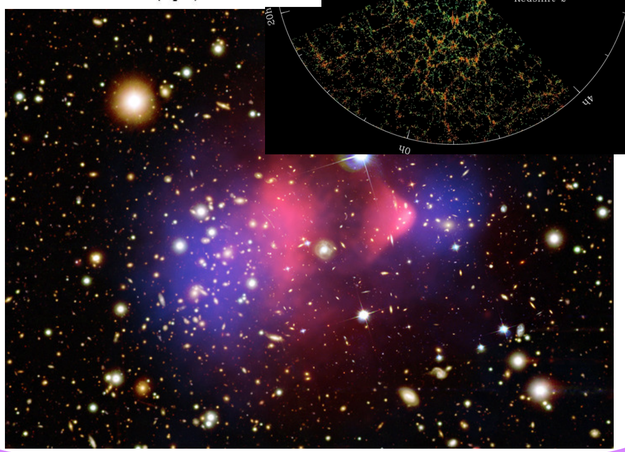
Current Status of the Field

Evidence









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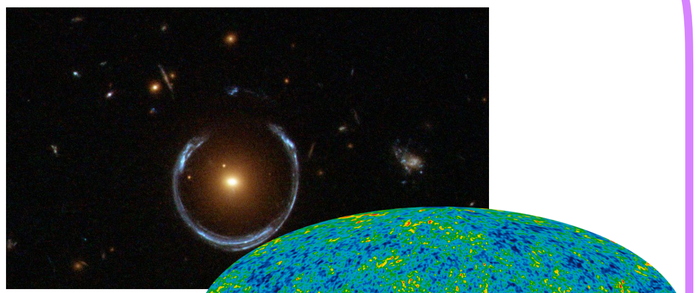
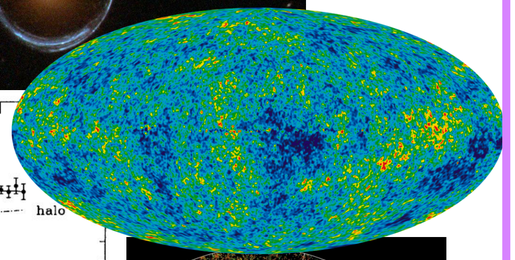
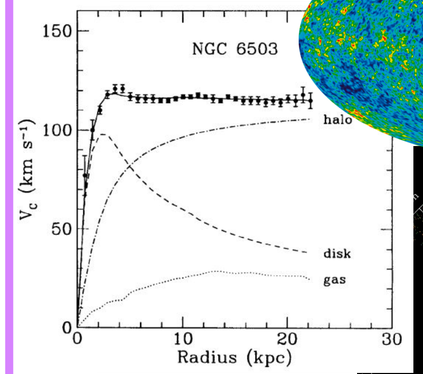
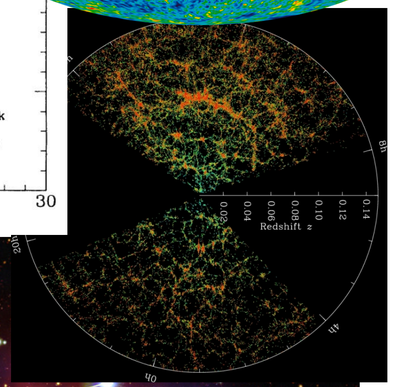
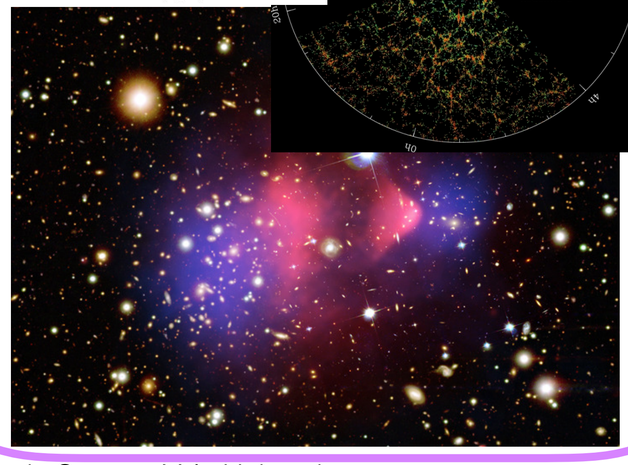


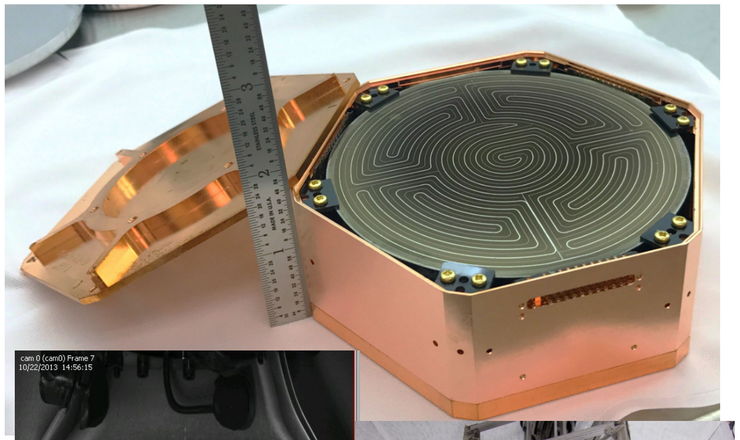






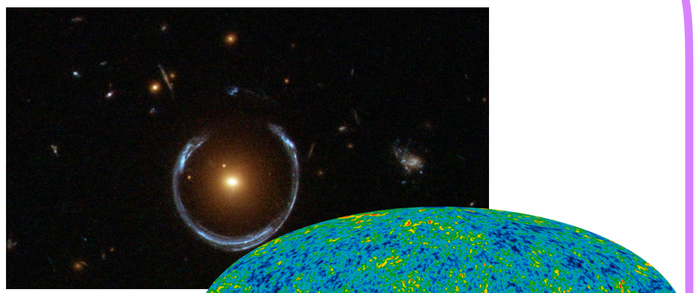


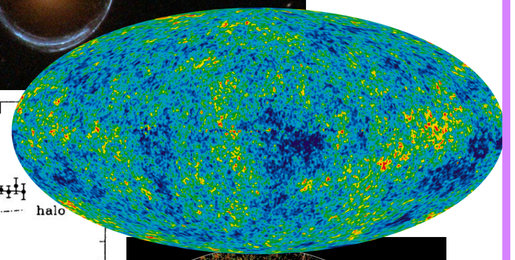
Direct Detection

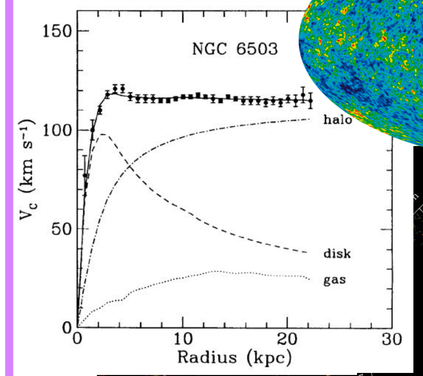


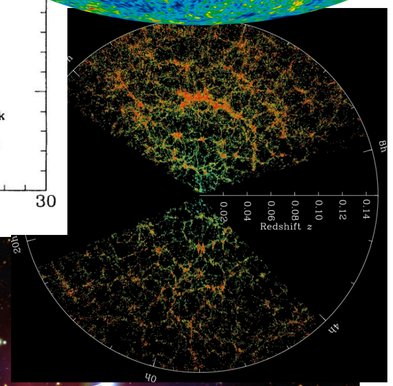
Current Status of the Field

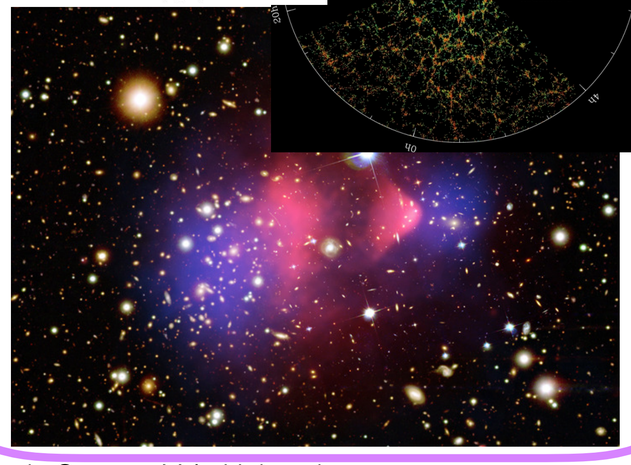
Evidence



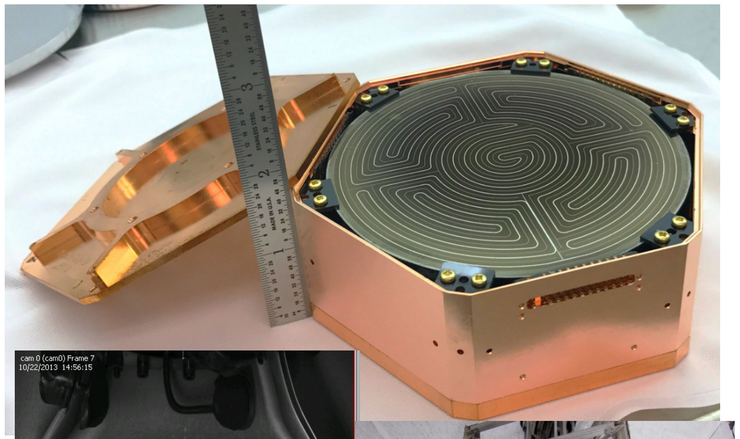




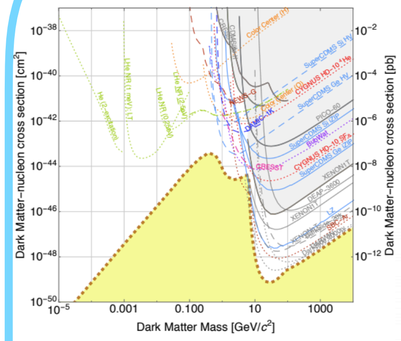


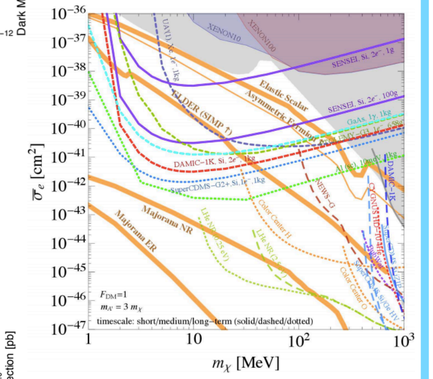


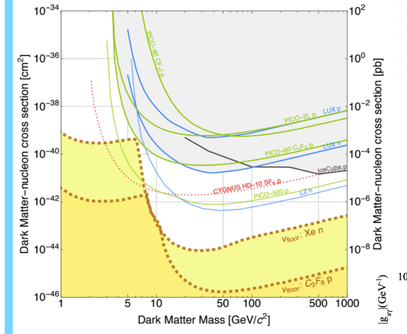
Direct Detection

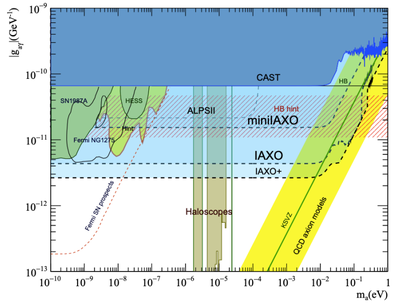


Results



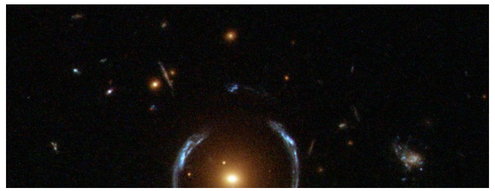






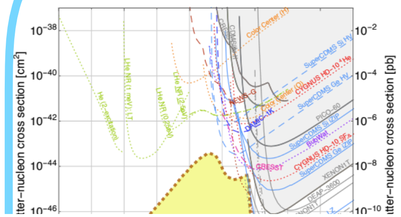
Current Status of the Field

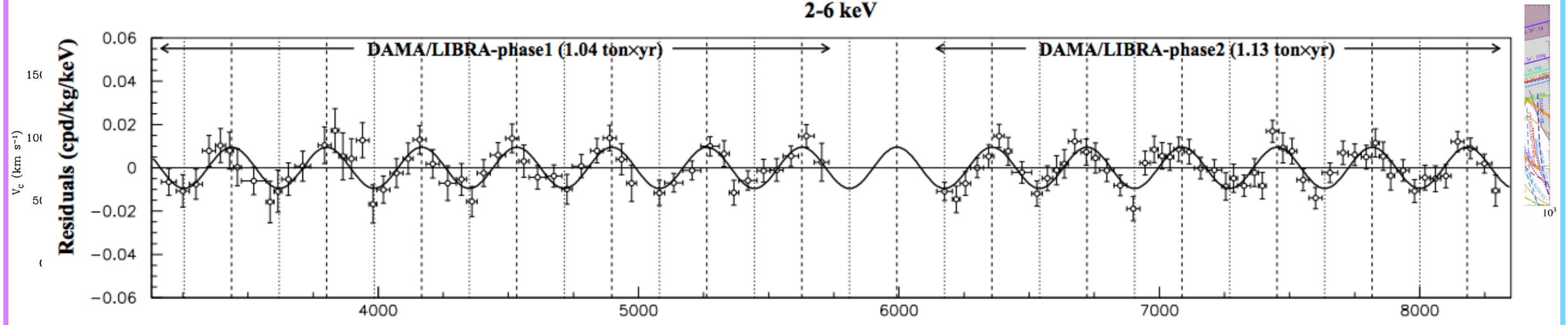
Evidence

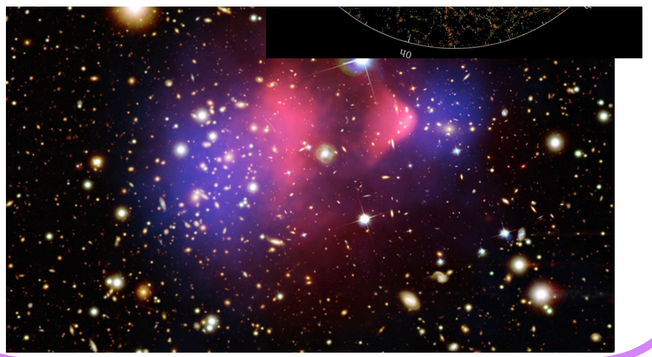


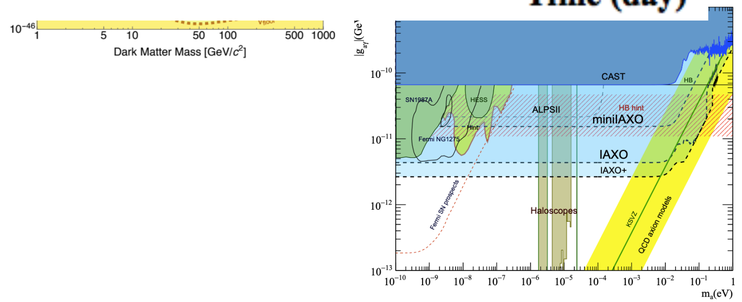
Direct Detection

Results







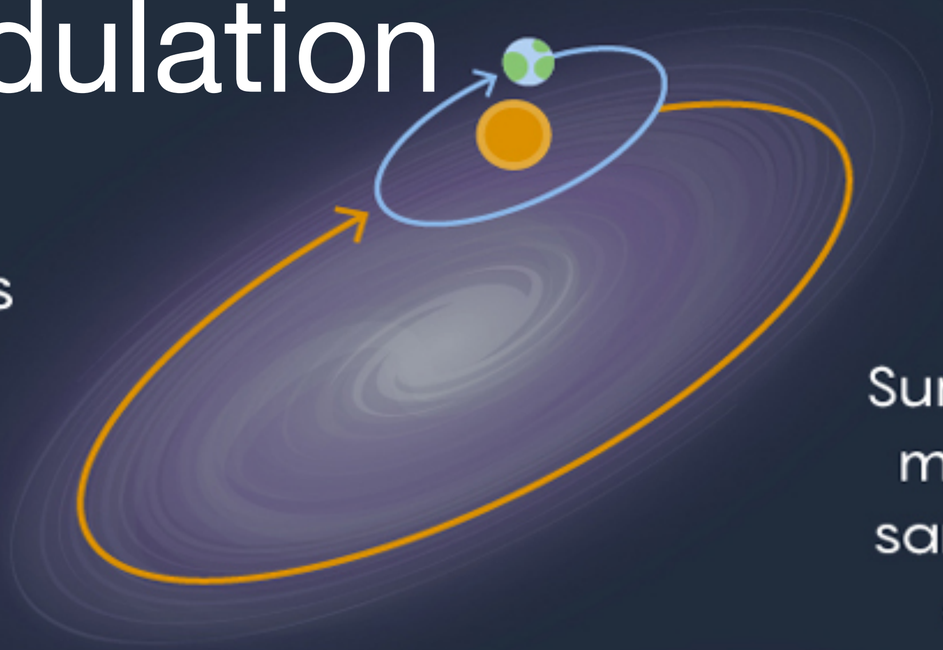


Annual Modulation

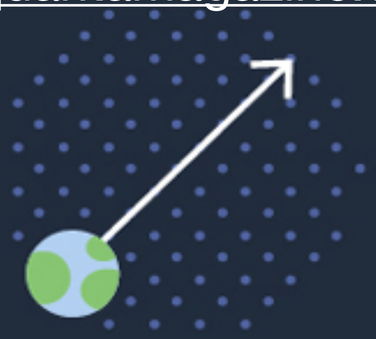
Image Credit: quantamagazine.org

The Highs

In June, Earth moves at its fastest speed through the dark matter halo.



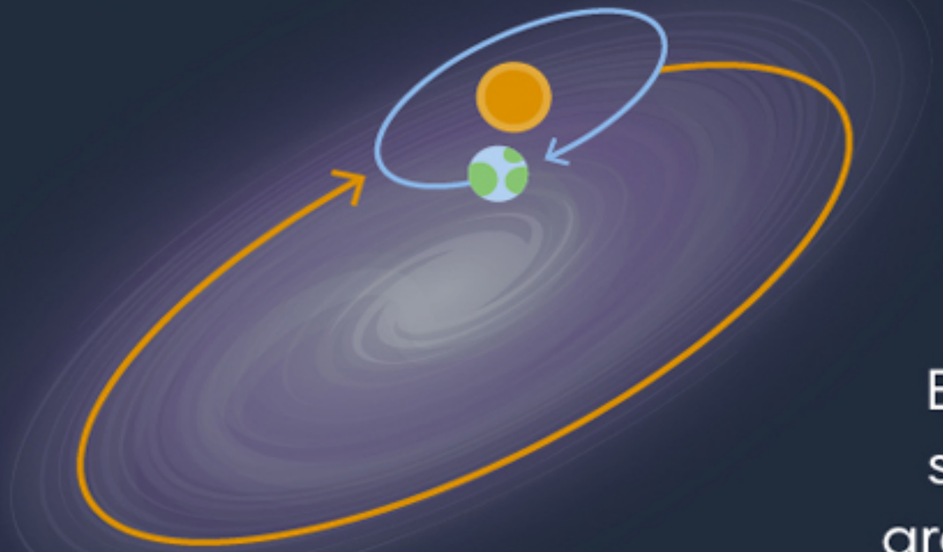
Sun and Earth move in the same relative direction



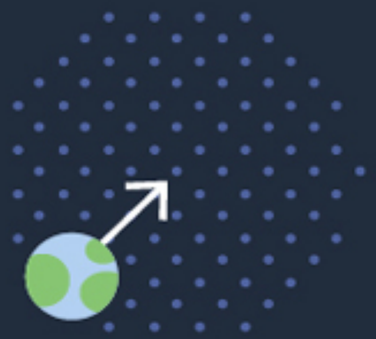
Earth passes through many dark matter particles

The Lows

In December, Earth moves at its slowest speed.



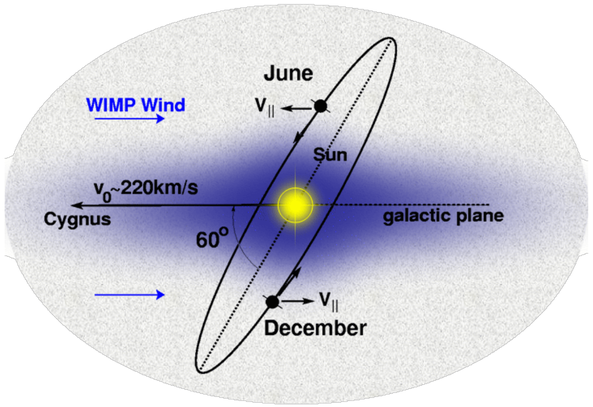
Earth and sun orbits are opposed

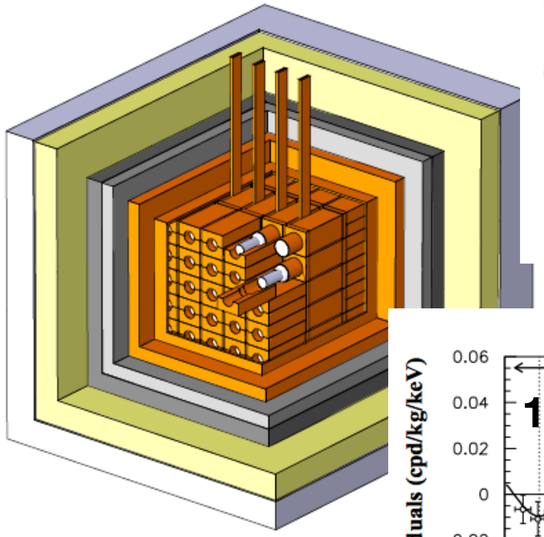


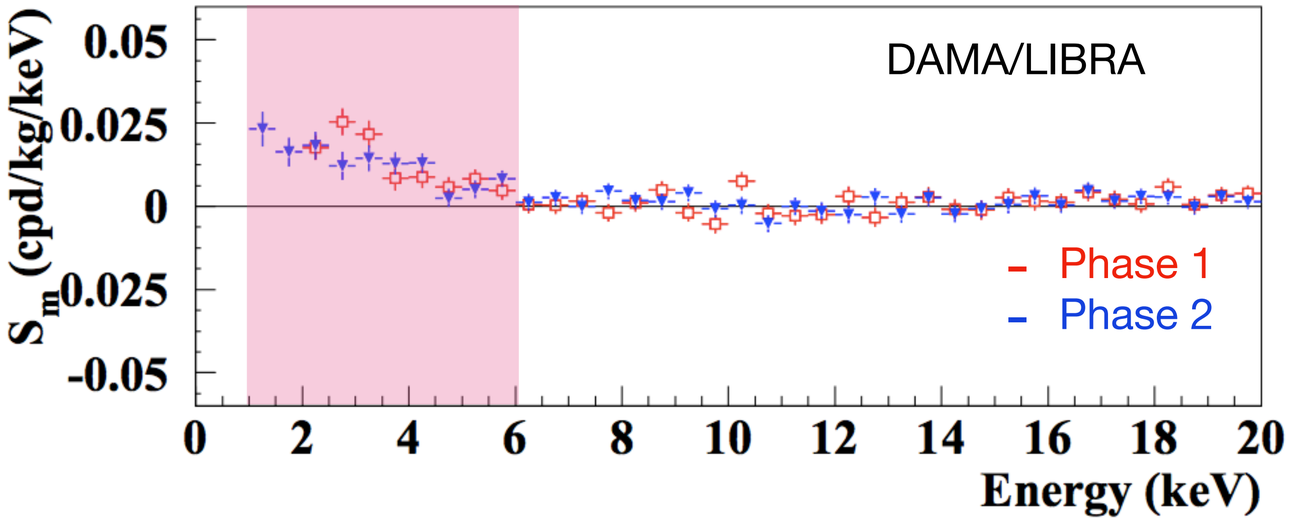
Earth encounters fewer particles

The DAMA Experiment

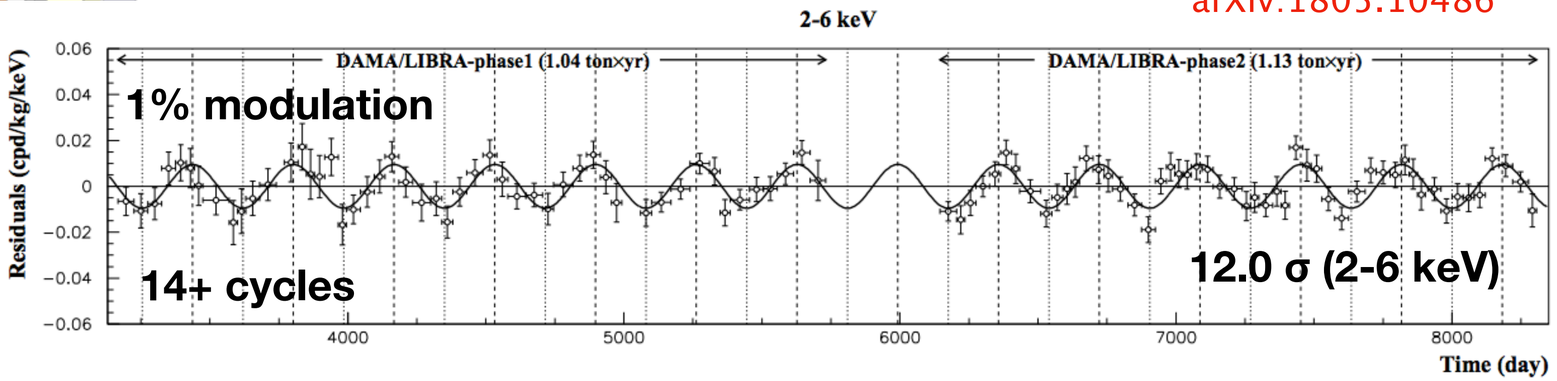
- NaI(Tl) experiment: 250 kg @ LNGS
- Avg background: ~1 count/keV/kg/day
- Looking for annual modulation of rate







arXiv:1805.10486



- How to confirm this signal?
  - Use same target material: NaI(Tl)
  - Have low enough backgrounds: modulation amplitude is small
  - Look for time dependent components in backgrounds

NaI(Tl) Global Effort

KIMS (+ DM-Ice)

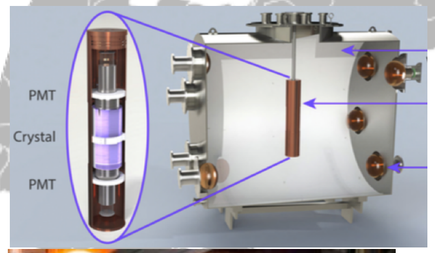
COSINE-100

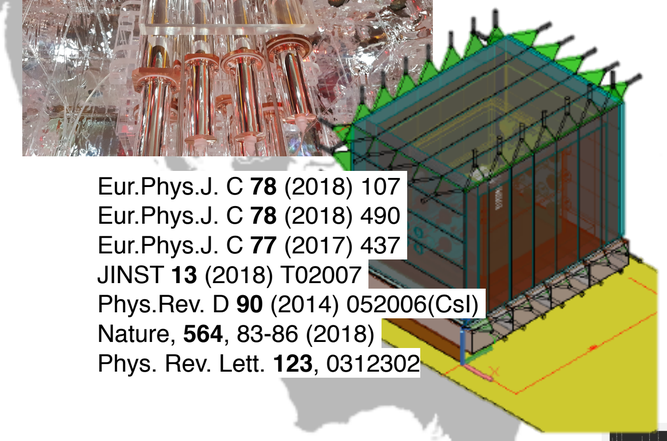
DAMA
SABRE
COSINUS
★ Gran Sasso + Australia

Yangyang ★ ★ Kamioka

PICOLON

ANAIS ★Canfranc





Eur.Phys.J. C **78** (2018) 107
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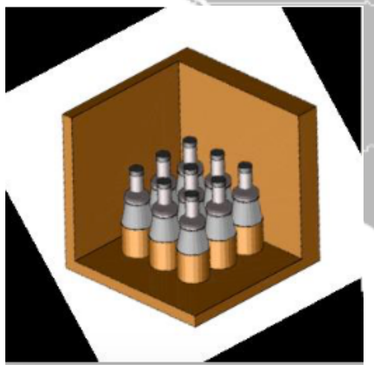
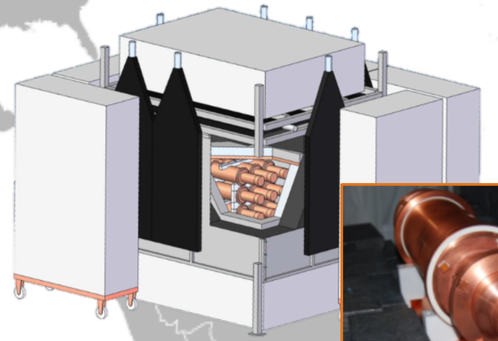
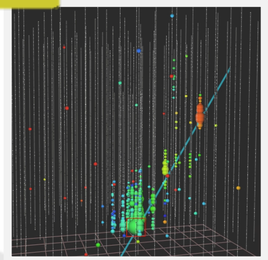
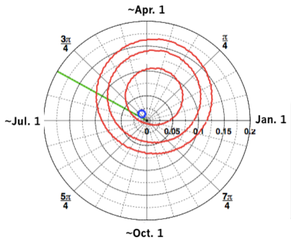
Nature, **564**, 83-86 (2018)
Phys. Rev. Lett. **123**, 0312302

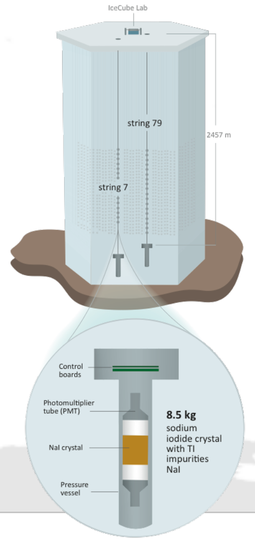








DM-Ice17
★ South Pole



COSINE-100

- DM-Ice + KIMS collaborations = COSINE
- 106 kg of NaI(Tl) from Alpha Spectra
- 2 tons of active liquid scintillator veto for background tagging
- Location: YangYang Underground Laboratory (Y2L), South Korea (~700 m rock overburden)

Physics run:
Since Sept 2016

COSINE-100

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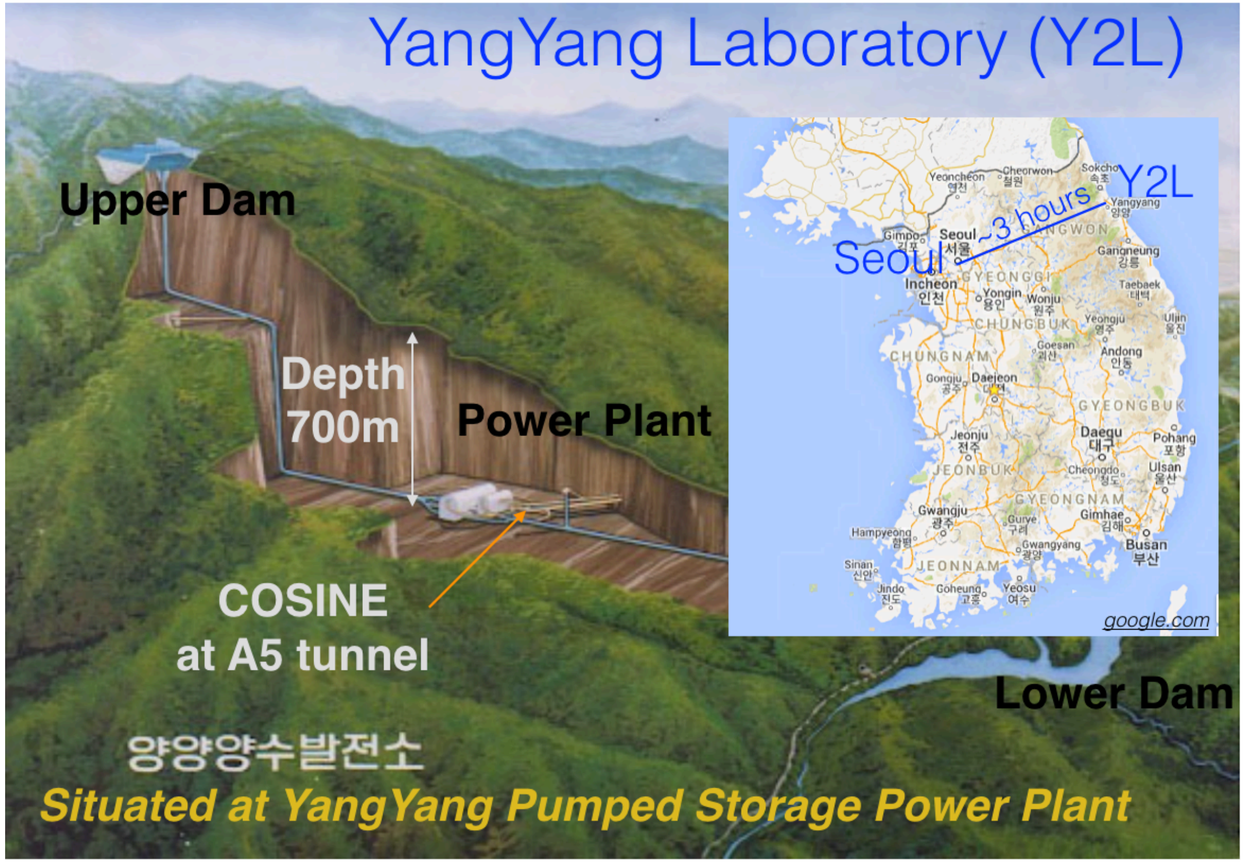
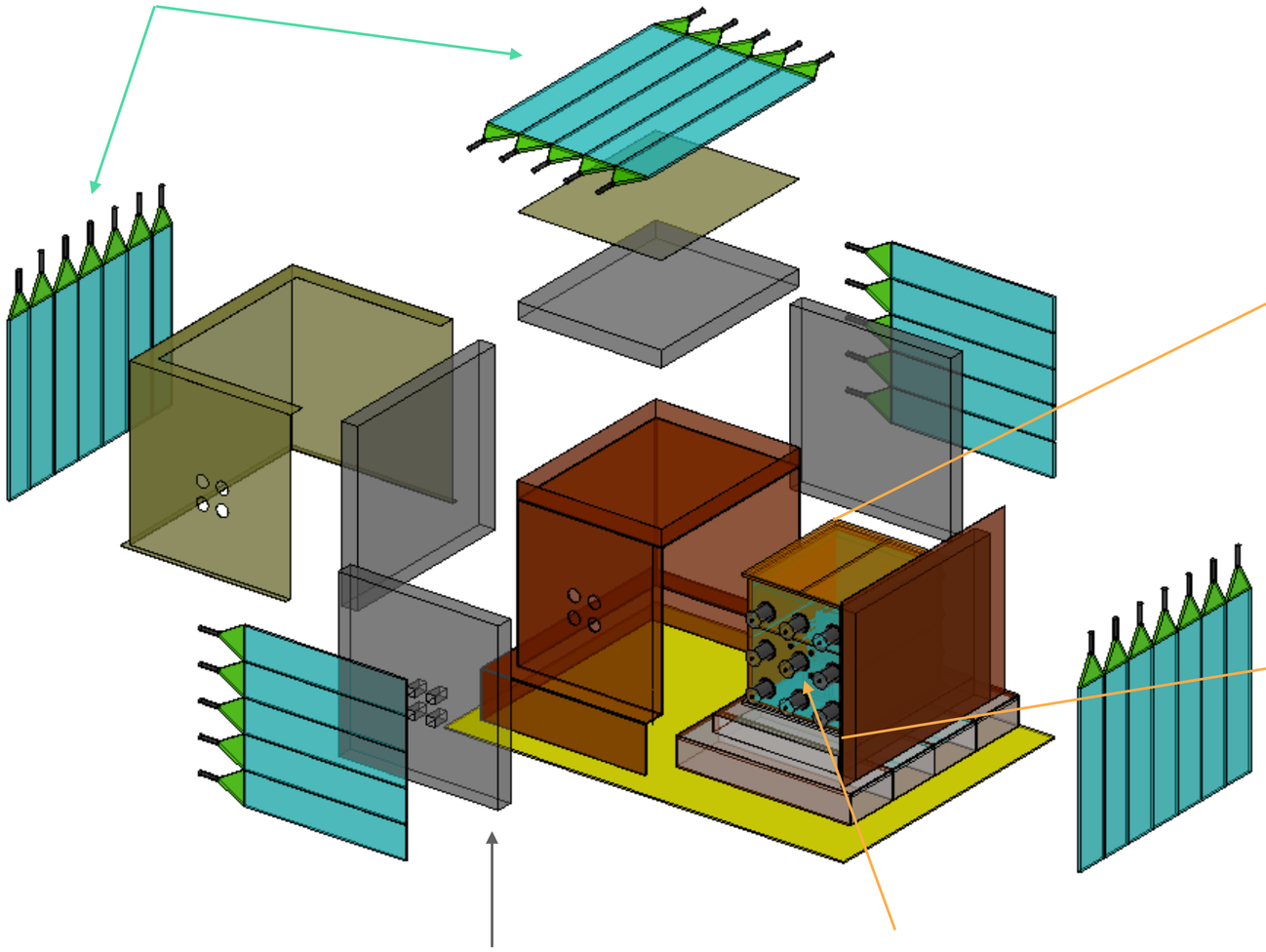


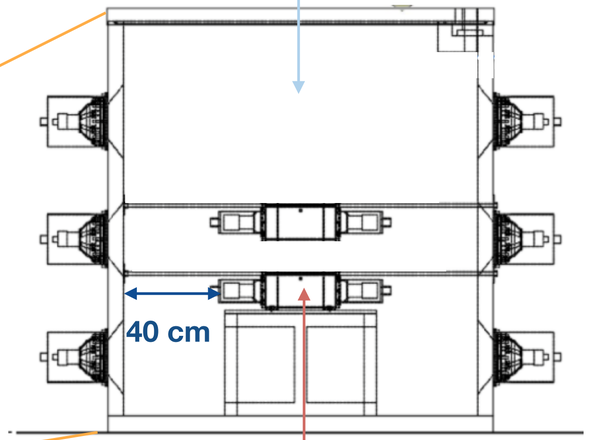
Physics run:
Since Sept 2016

COSINE-100 Shielding Structure

Plastic Scintillators

Filled with Liquid Scintillator (2000 L)



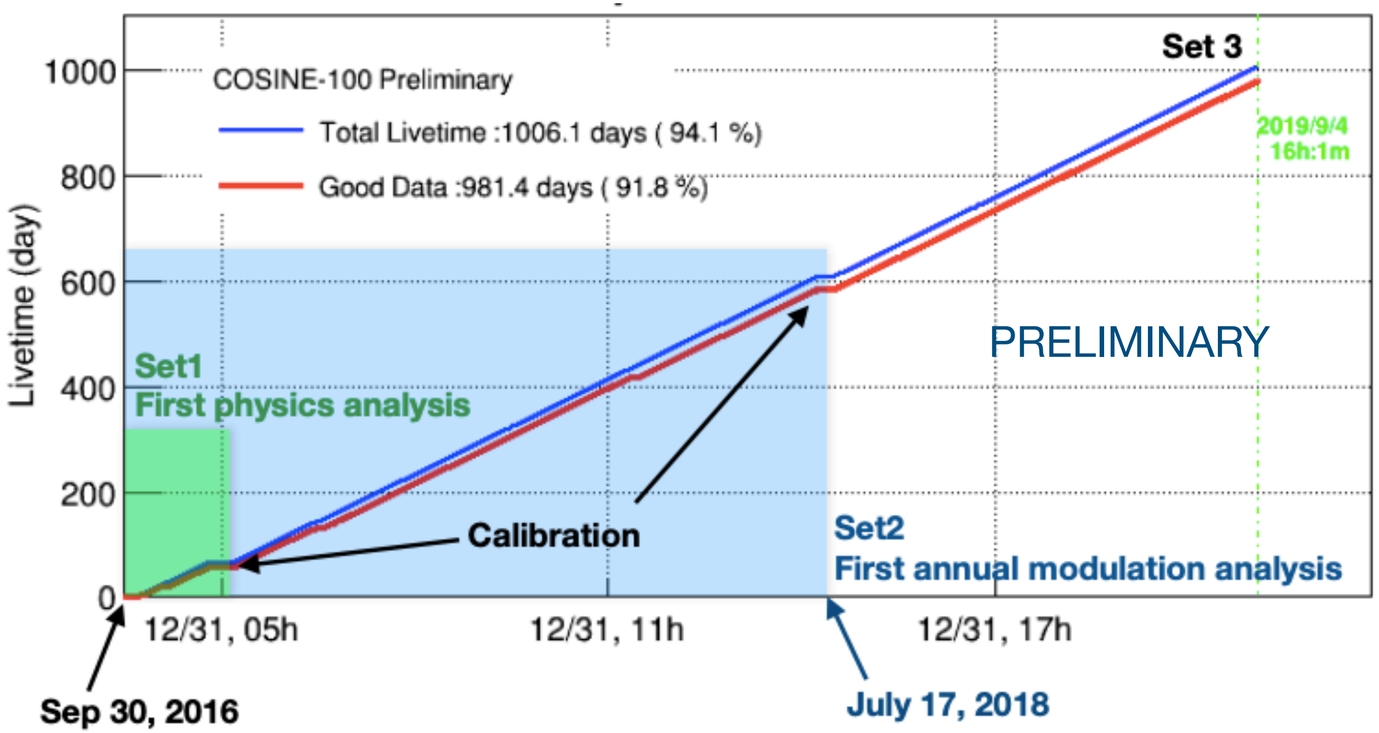


NaI(Tl) Crystals (106 kg)

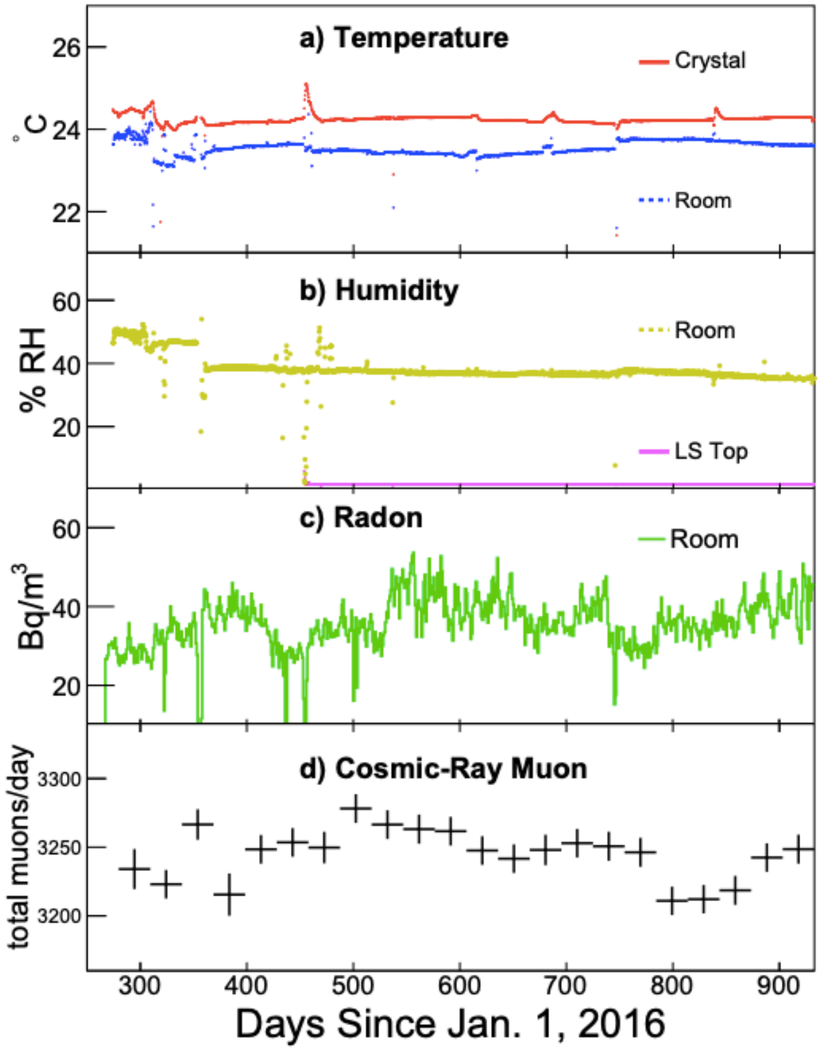
Lead Shielding (20 cm)

Cu Box (3 cm)

Operations and Monitoring

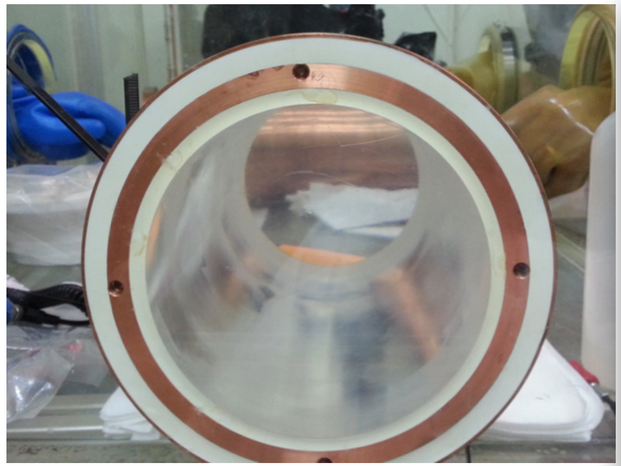


Phys. Rev. Lett. **123**, 031302 (2019)



- Stable environment parameters
- No correlation found between environmental parameter changes and modulation data in SET2 search
- SET3 includes now more than 3yr of data

COSINE-100 NaI(Tl) Crystals



Crystal	Mass (kg)	Size (inches diameter×length)	Powder	α Rate (mBq/kg)	^{40}K (ppb)	^{238}U (ppt)	^{232}Th (ppt)	Light Yield (PEs/keV)
Crystal-1	8.3	5.0 × 7.0	AS-B	3.20 ± 0.08	34.7 ± 4.7	<0.02	1.3 ± 0.4	14.9 ± 1.5
Crystal-2	9.2	4.2 × 11.0	AS-C	2.06 ± 0.06	60.6 ± 4.7	<0.12	<0.6	14.6 ± 1.5
Crystal-3	9.2	4.2 × 11.0	AS-WSII	0.76 ± 0.02	34.3 ± 3.1	<0.04	0.4 ± 0.2	15.5 ± 1.6
Crystal-4	18.0	5.0 × 15.3	AS-WSII	0.74 ± 0.02	33.3 ± 3.5		<0.3	14.9 ± 1.5
Crystal-5	18.3	5.0 × 15.5	AS-C	2.06 ± 0.05	82.3 ± 5.5		2.4 ± 0.3	7.3 ± 0.7
Crystal-6	12.5	4.8 × 11.8	AS-WSIII	1.52 ± 0.04	16.8 ± 2.5	<0.02	0.6 ± 0.2	14.6 ± 1.5
Crystal-7	12.5	4.8 × 11.8	AS-WSIII	1.54 ± 0.04	18.7 ± 2.8		<0.6	14.0 ± 1.4
Crystal-8	18.3	5.0 × 15.5	AS-C	2.05 ± 0.05	54.3 ± 3.8		<1.4	3.5 ± 0.3
DAMA				< 0.5	< 20	0.7–10	0.5–7.5	5.5–7.5

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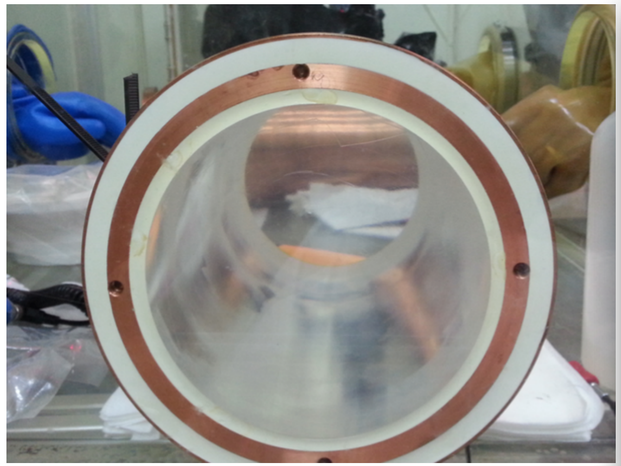
- Intrinsic backgrounds: from crystal powder/growing
- R&D goal: intrinsic background ~DAMA's
- Light yield: up to 15 p.e./keV
- Main challenge: produce crystal with desirable levels of ^{40}K & ^{210}Pb

COSINE-100 NaI(Tl) Crystals



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Eur. Phys. J. C78 (2018) 107

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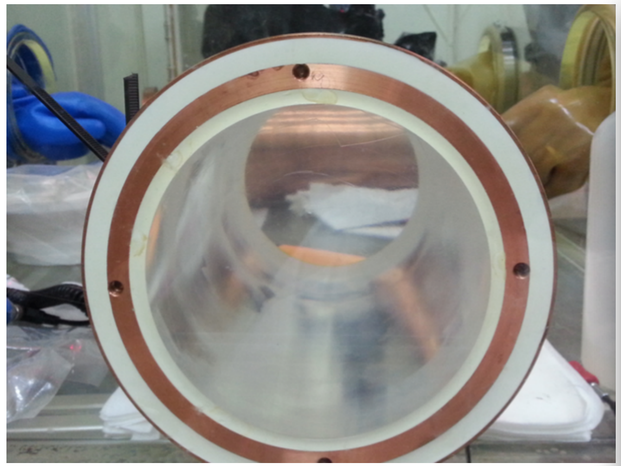

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COSINE-100 Backgrounds

- Full detector simulation with Geant4 + multi-channel fit: **background well modeled**

- Main low energy backgrounds:
  - Internals: crystals' intrinsic contaminants - K/U/Th chains
  - Cosmogenics: dominated by ^{3}H in R.O.I (2-20 keV)
  - Surface: ^{210}Pb in crystals and teflon surfaces

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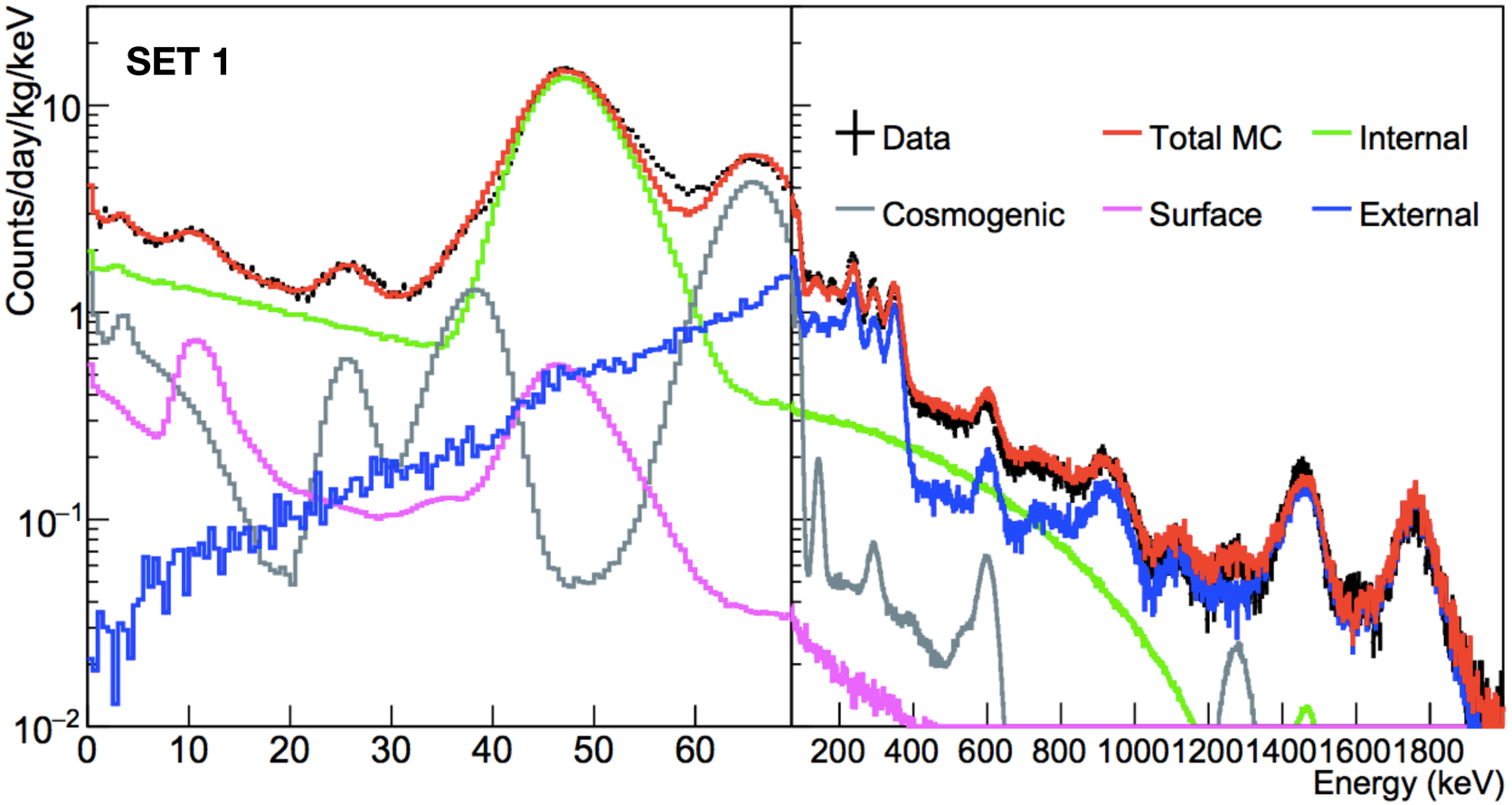
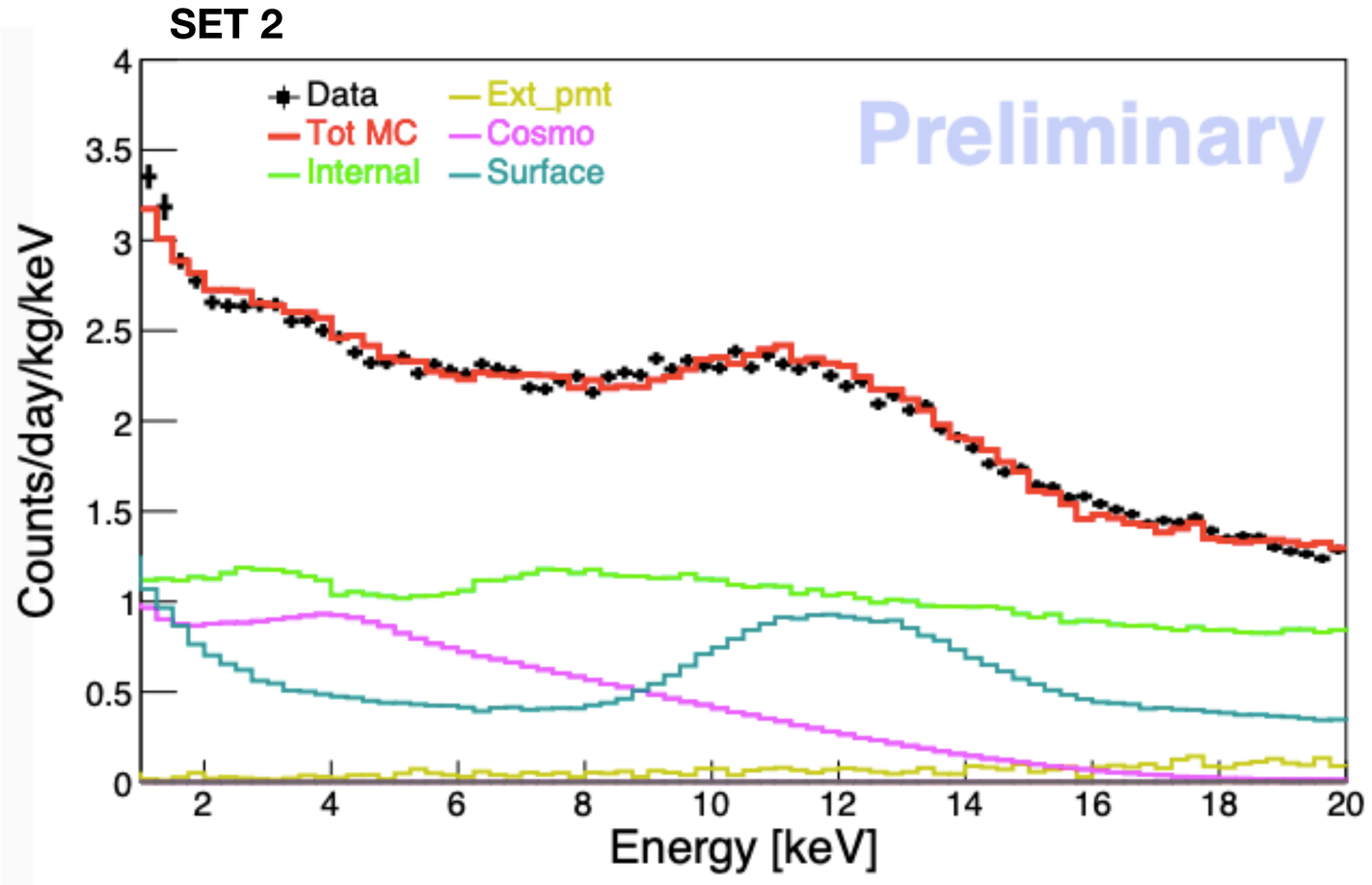


COSINE-100 Backgrounds - Improved

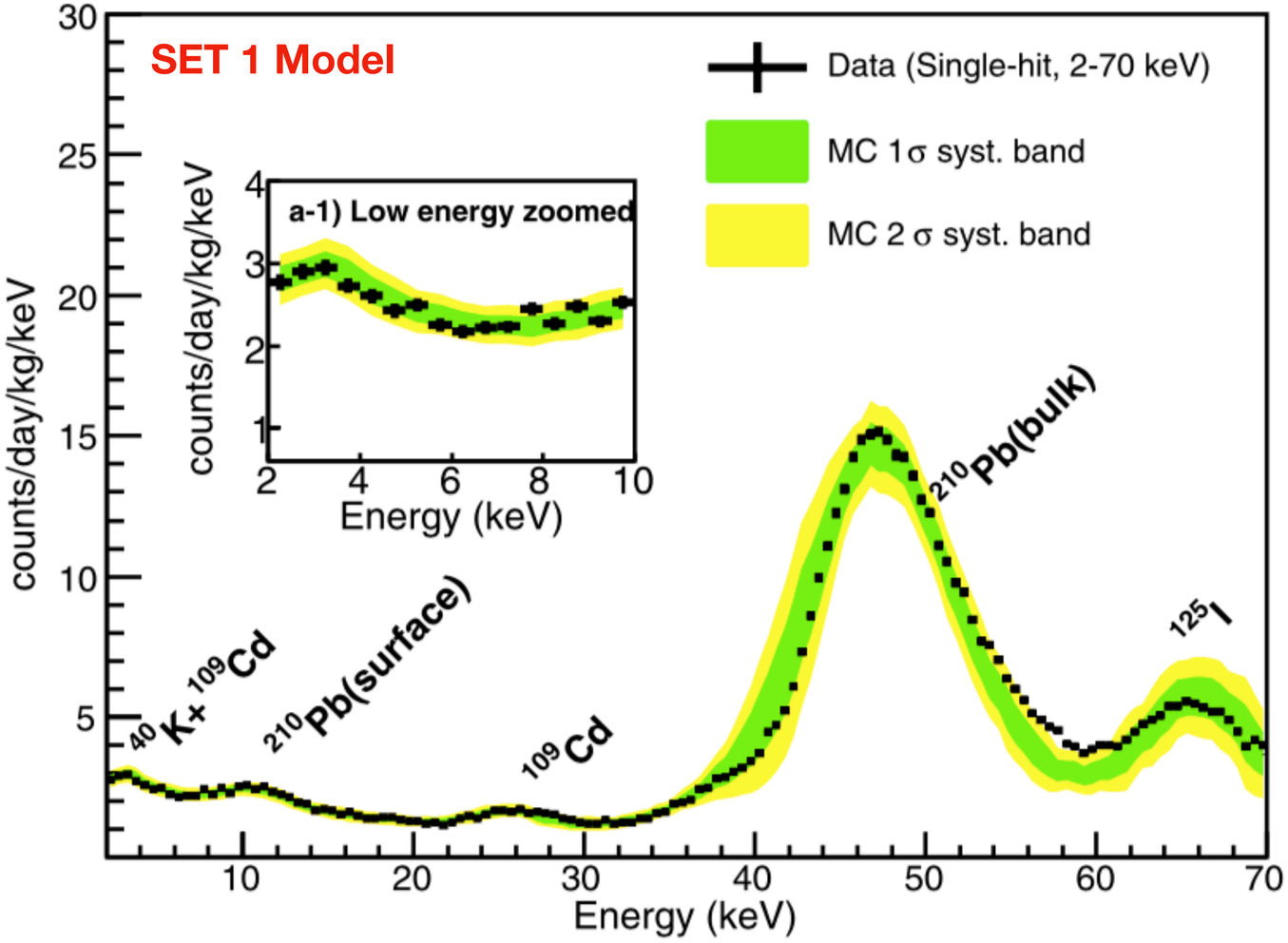
- Full detector simulation with Geant4 + multi-channel fit: **background well modeled**

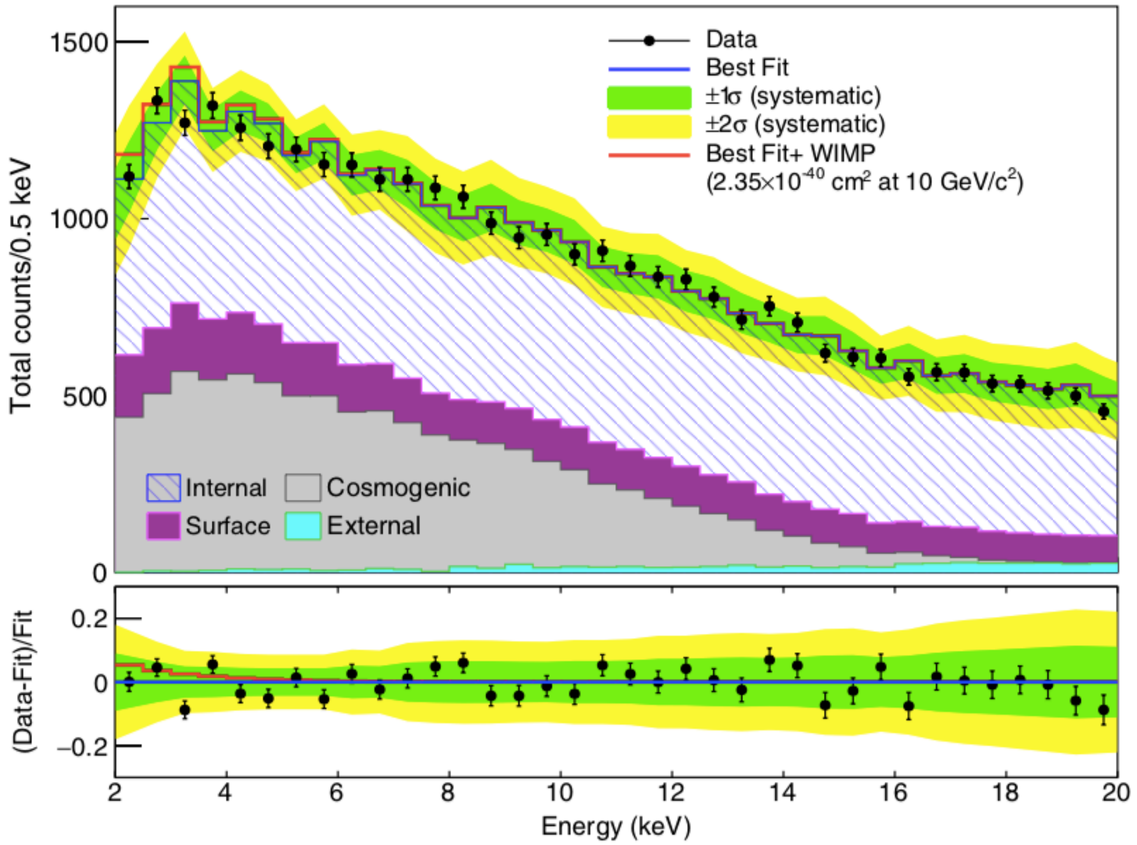
- Updated background modeling:
  - Lower energy threshold, down to **1 keV**
  - Improved event selection and efficiencies
  - Updated simulation package
  - Larger data set: SET2



G. Adhikari, TAUP 2019

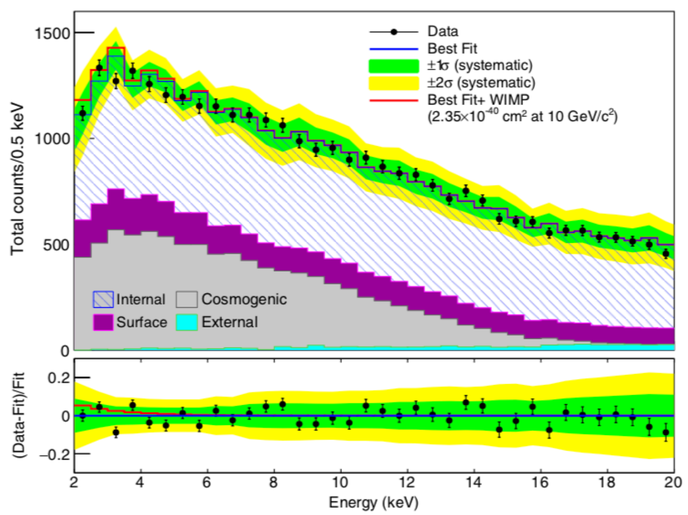
COSINE-100 Backgrounds & Fit



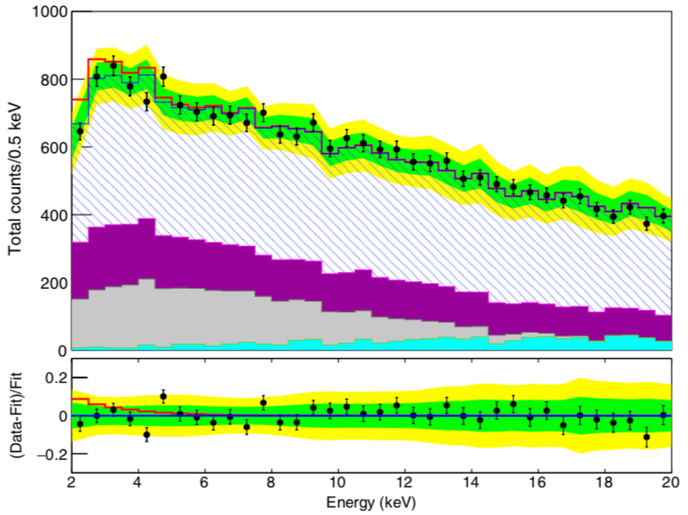


- Estimated systematics: resolution, efficiency, energy scale, simulation package, PMT background
- Crystals are fitted simultaneously to a WIMP-signal model, for different WIMP masses

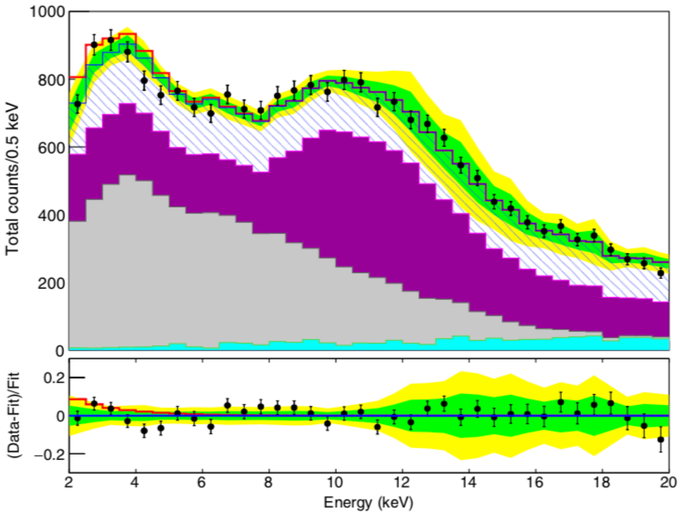
WIMP Analysis: Backgrounds + WIMP



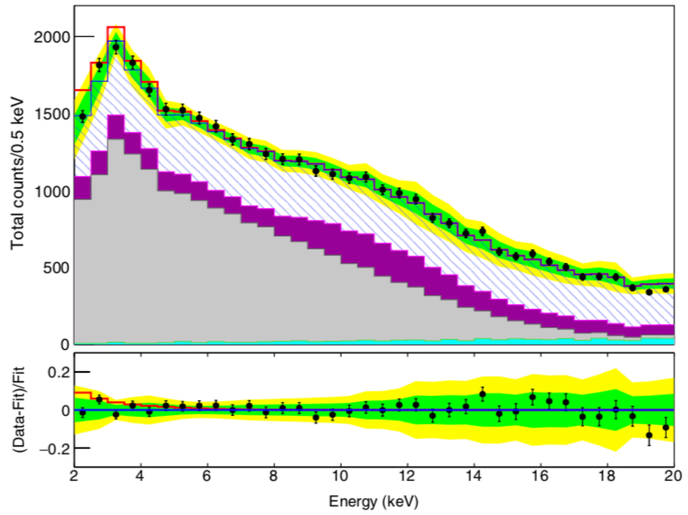
a) Crystal 1



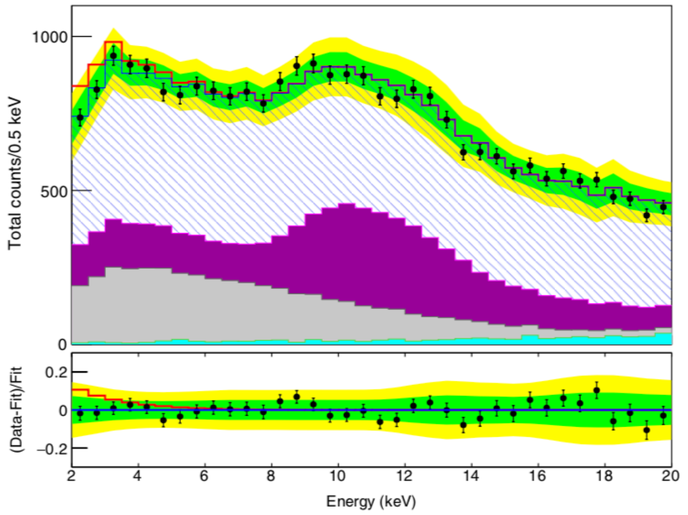
b) Crystal 2



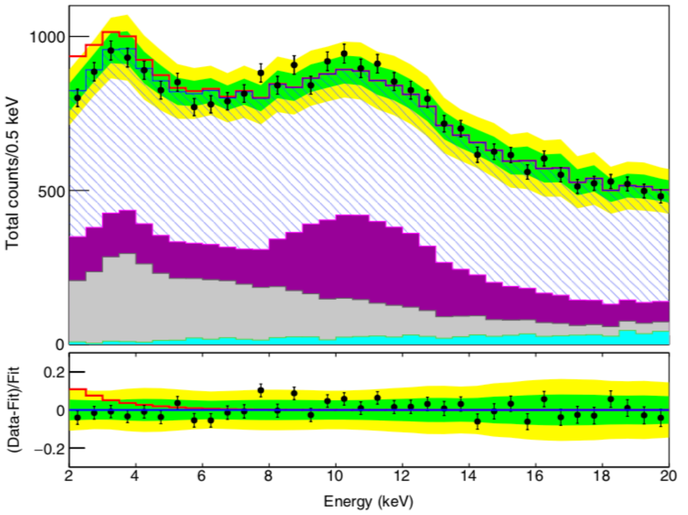
c) Crystal 3



d) Crystal 4

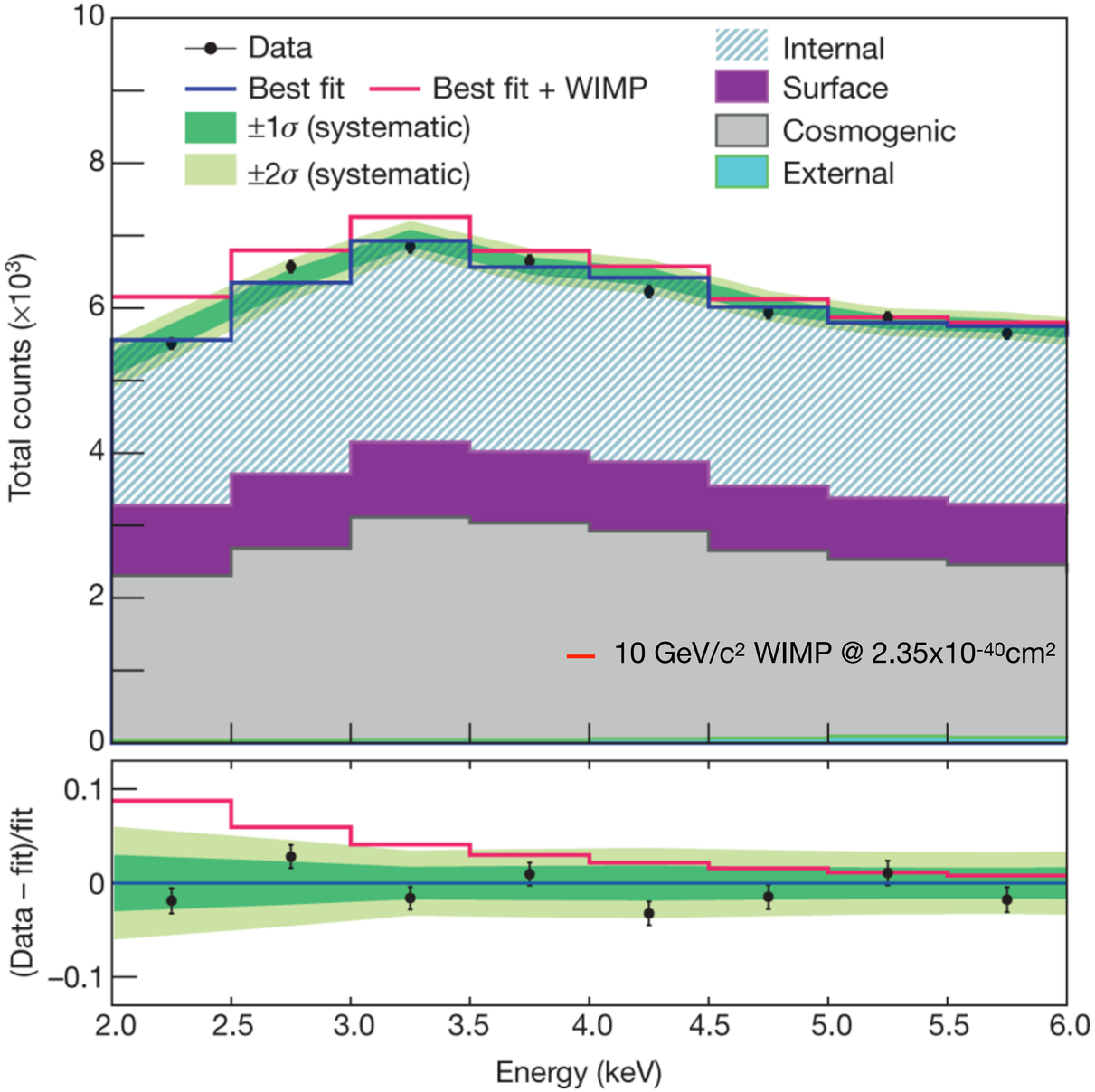


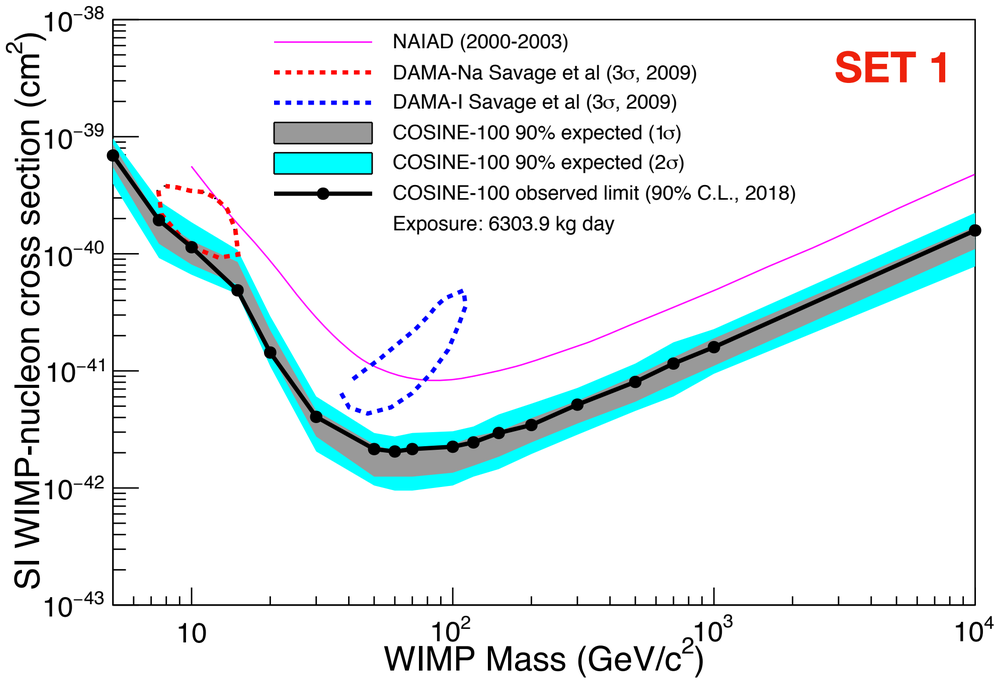
e) Crystal 6



f) Crystal 7

Spin-Independent WIMP Search





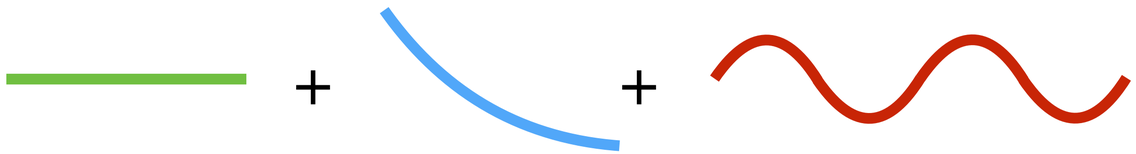
- Exclusion of DAMA/LIBRA-phase1 spin-independent signal, standard halo model interpretation
- First time excluded with same target material

Annual Modulation Search

Phys. Rev. Lett. **123**, 031302 (2019)

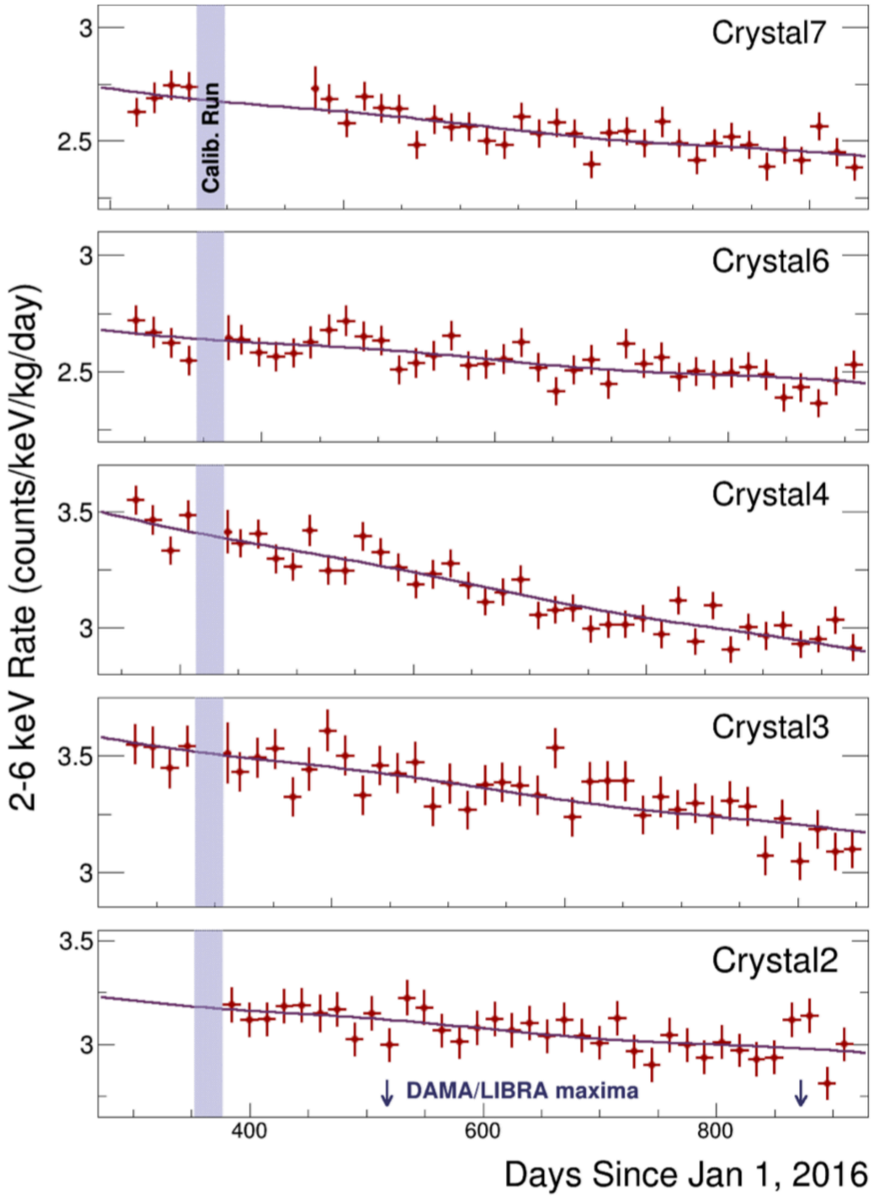
Backgrounds, constrained:
Different for each crystal

Signal, floated:
Same for all the crystals



$$\text{Rate} = C + p_0 \cdot \exp\left(-\frac{ln2 \cdot t}{p_1}\right) + A \cdot \cos\frac{2\pi(t - t_0)}{T}$$

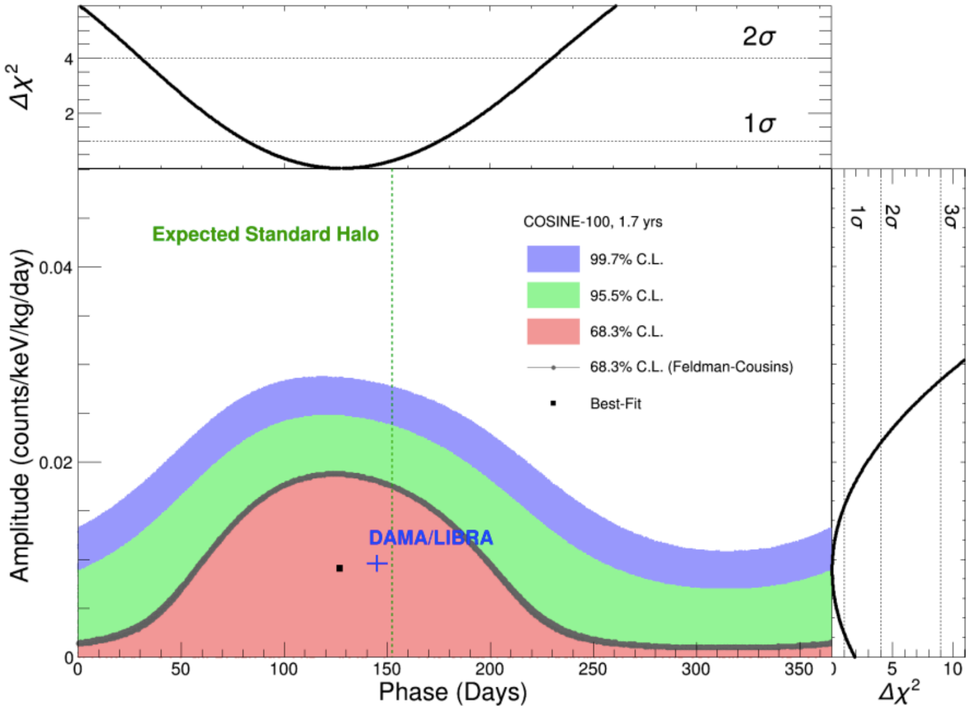
- 1.7 yr of data, 97.7 kg·yr of exposure
- Fitting an offset + exponential component + cosine function
- 15-day bins, with data starting in Oct 2016
- Backgrounds constrained based on background modeling



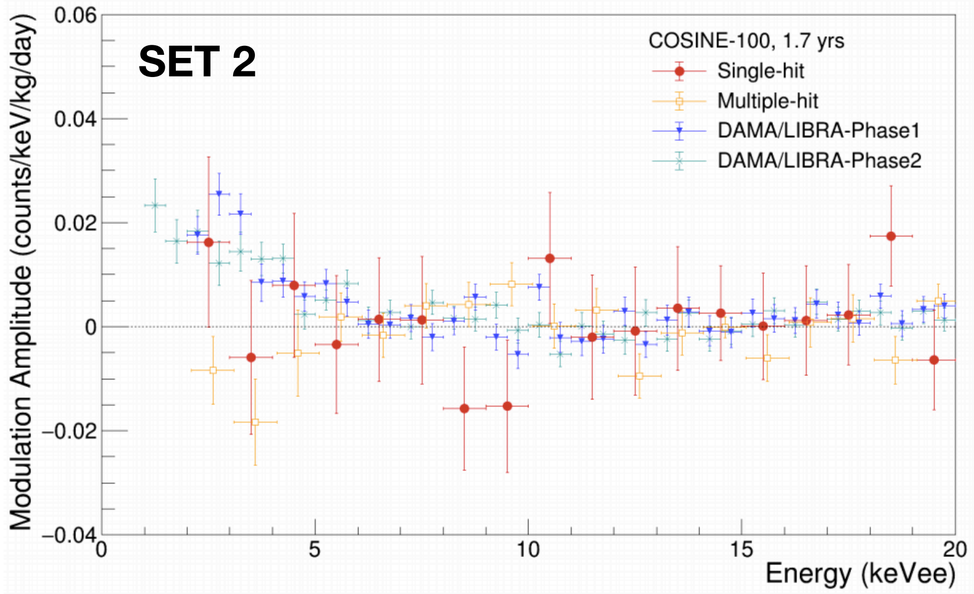
First Annual Modulation Results

- Results in 2-6 keV region agree with null hypothesis and DAMA/LIBRA results, due to statistical limitations
  - **Amp: 0.0092 ± 0.0067 counts/keV/kg/day; Phase: 127.2 ± 45.9 days**

- A lower threshold, improved event selection, and larger data set are in the pipeline

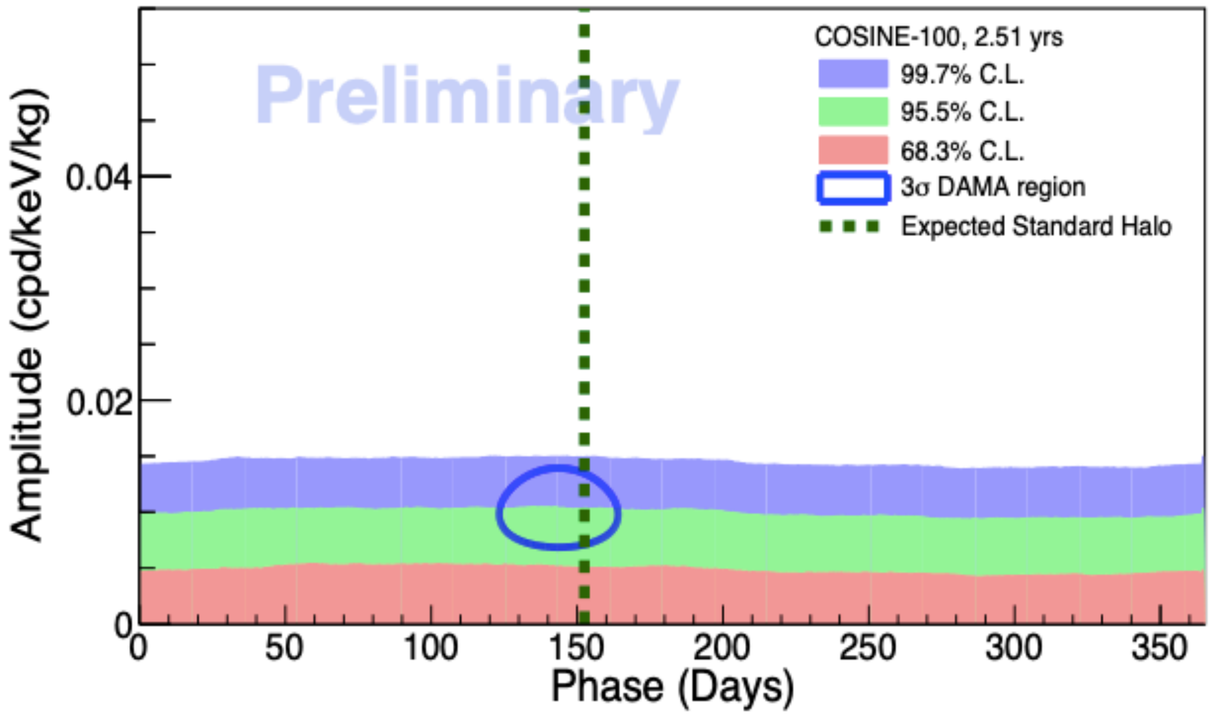


Phys. Rev. Lett. **123**, 031302 (2019)



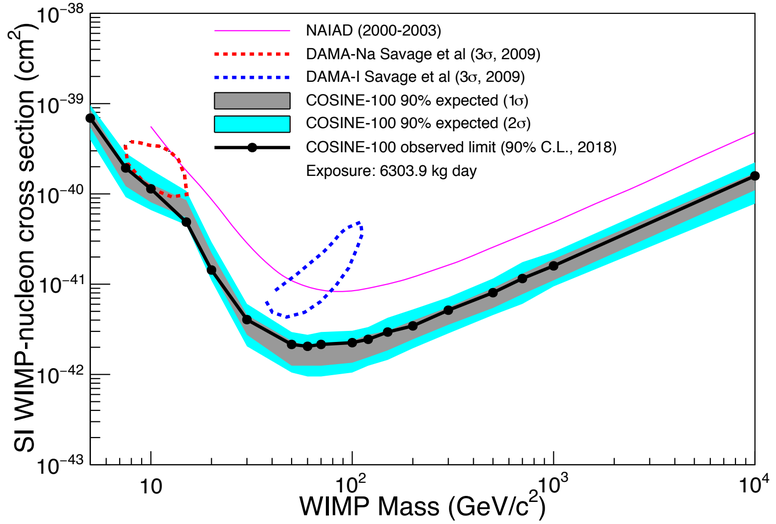
Next Annual Modulation Search Sensitivity

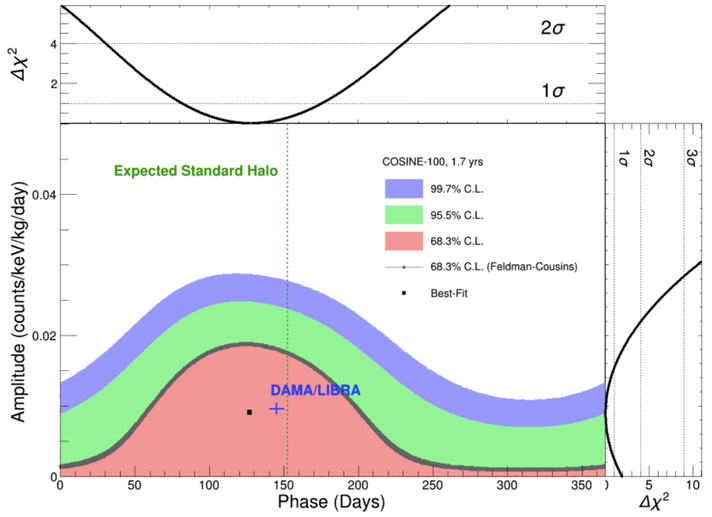
- Larger data set: SET 3 with ~ 154 kg·yr exposure, 2.5 yr of data
- Improved event selection down to 1 keV threshold
- Improved background modeling, with updated simulation package and better understanding of surface components
- Expected sensitivity (for null hypothesis) shows that we will still be statistically limited

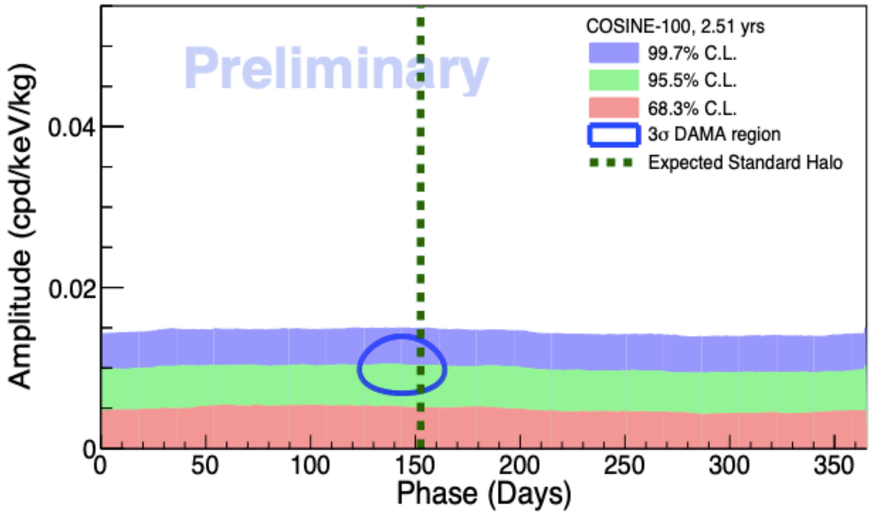


Summary and Outlook

- COSINE-100 has been running since September 2016.
- 60 days of data strongly disfavors spin-independent WIMPs as the cause for DAMA's signal.
- First annual modulation results with 1.7 yr are consistent with DAMA signal and no modulation hypothesis
- A second batch of analyses with lower threshold, larger data set, and improved background modeling is underway
- Stay tuned for more exciting results!







Thanks!