COSINE-100 Results: DAMA's Signal Not Spin-Independent WIMPS

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on behalf of the COSINE-100 collaboration

Yale University

Lake Louise Winter Institute
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DAMA's Signal Not Spin-Independent WIMPs

LETTER

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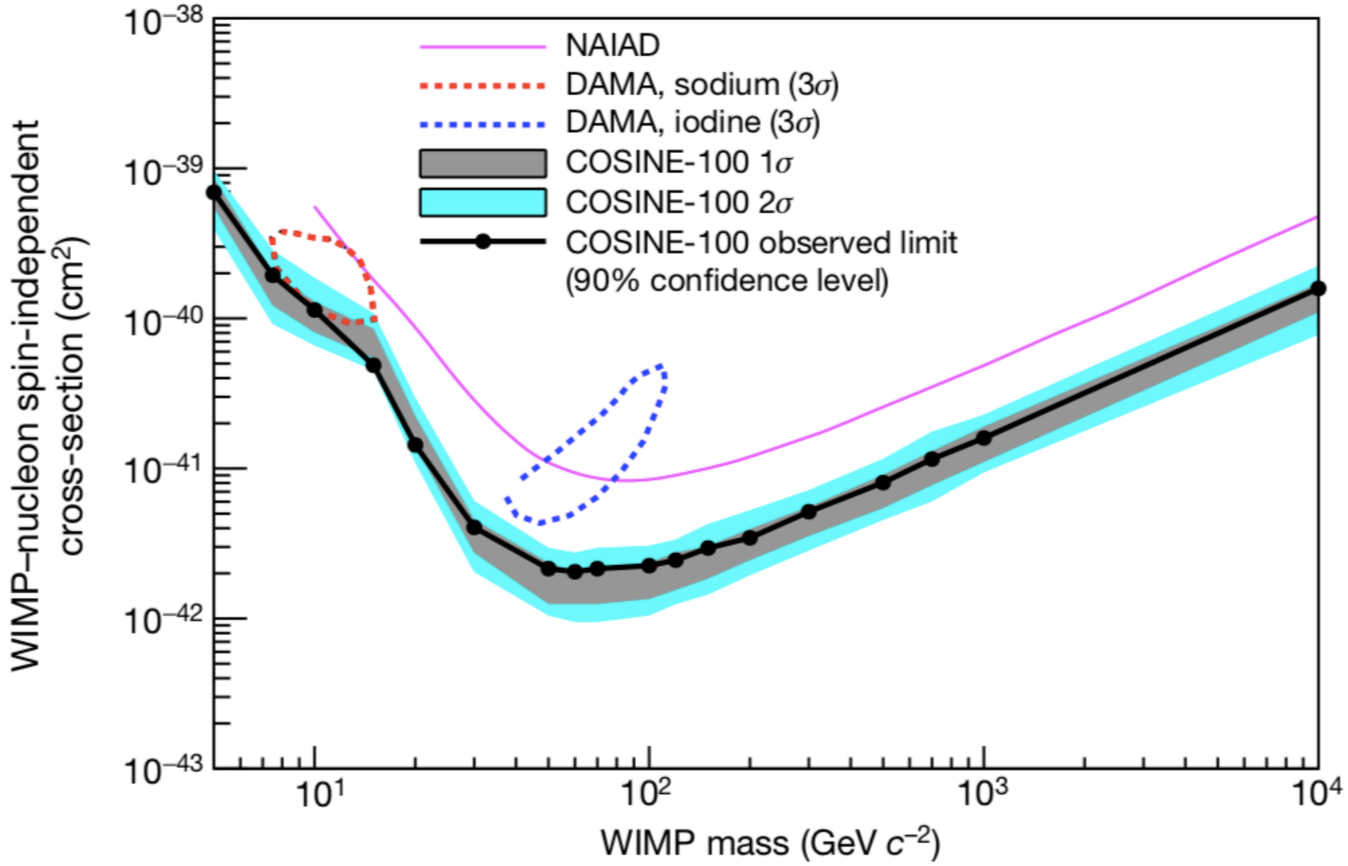
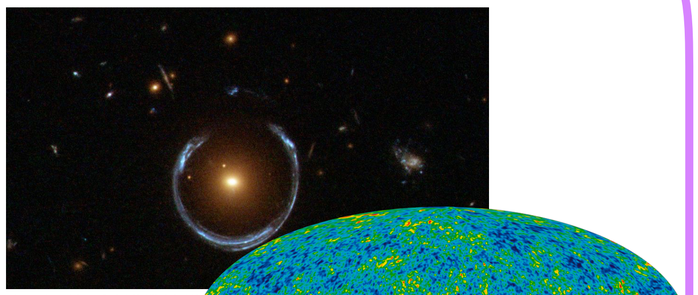
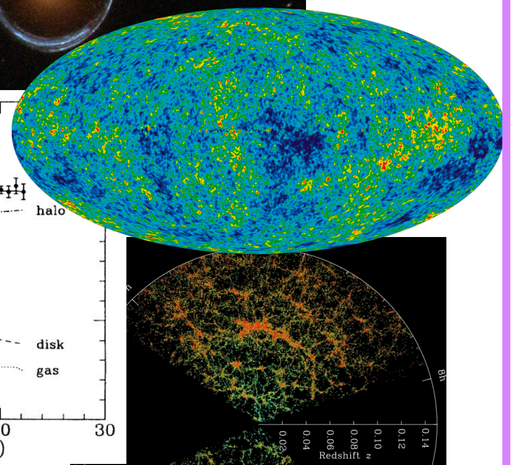
An experiment to search for dark-matter interactions using sodium iodide detectors

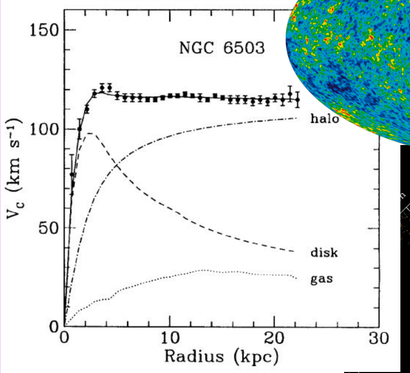


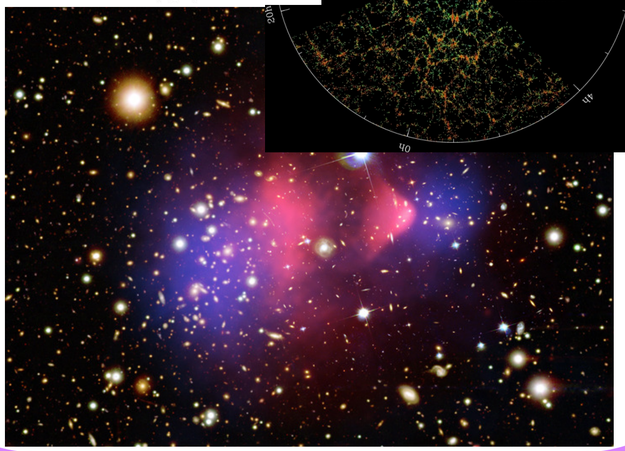
Current Status of the Field

Evidence









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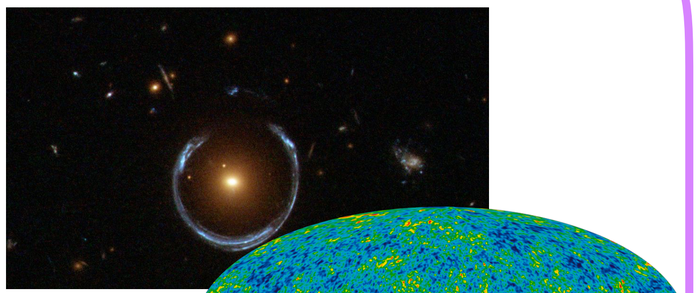
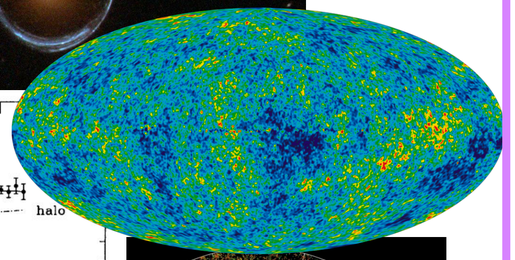
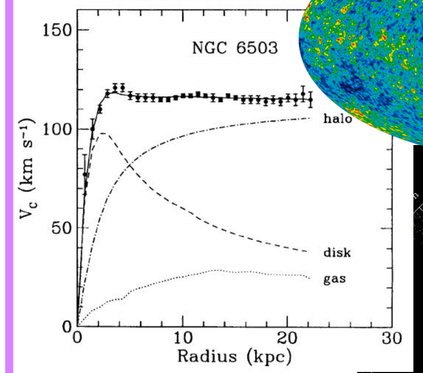
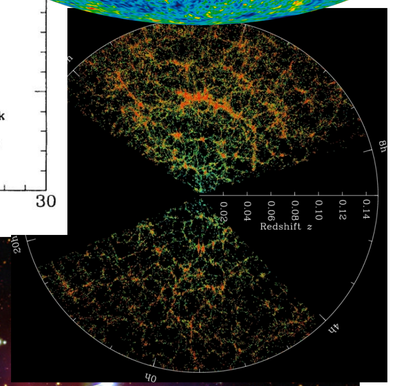
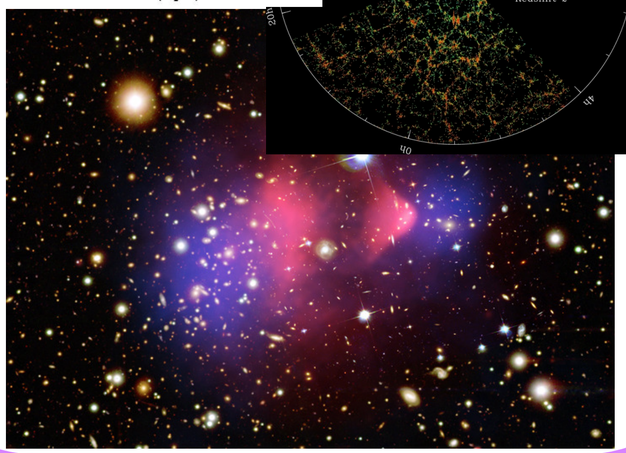


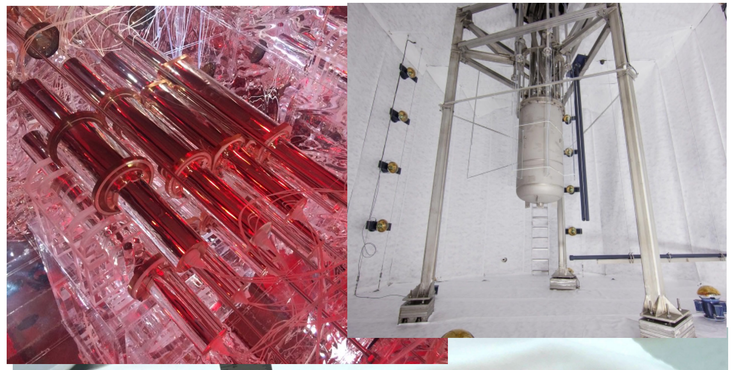


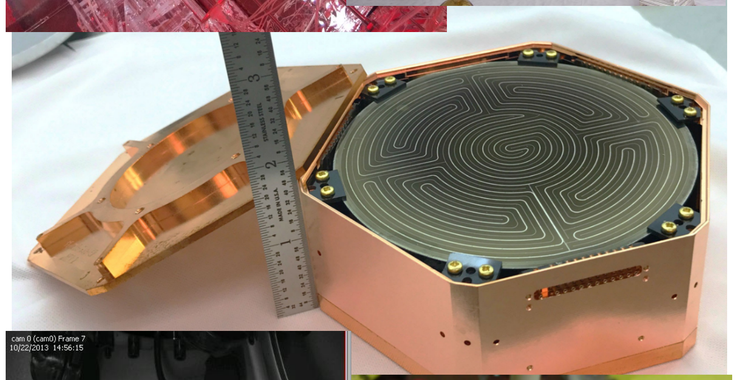


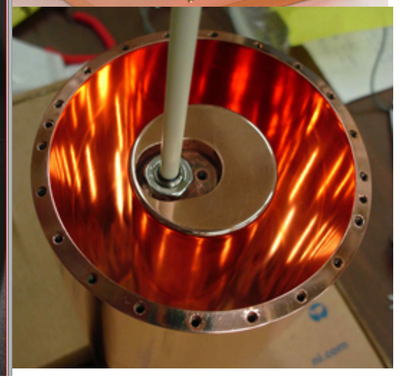




Direct Detection







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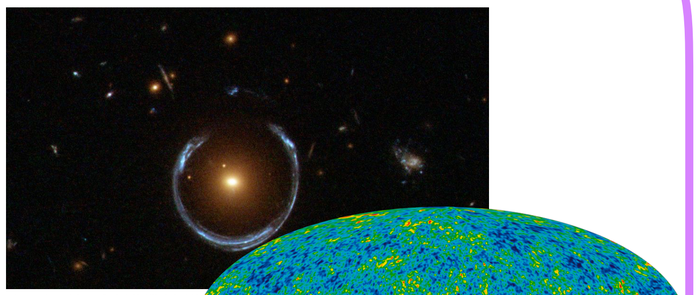

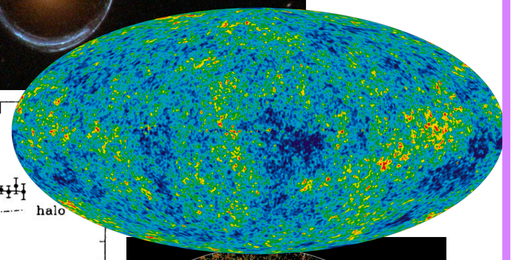

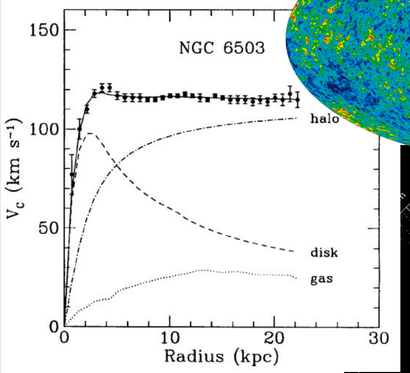

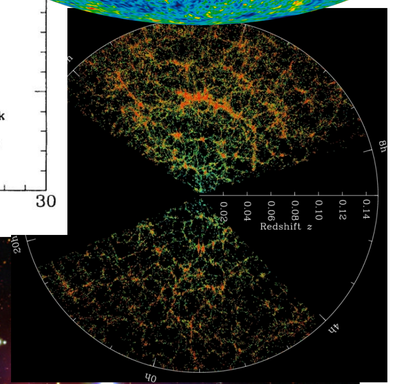

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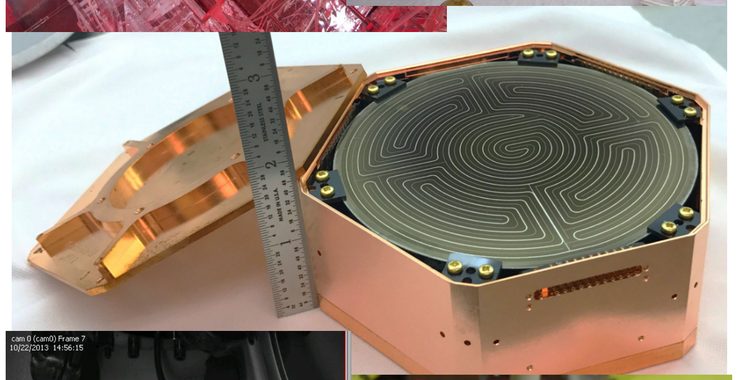
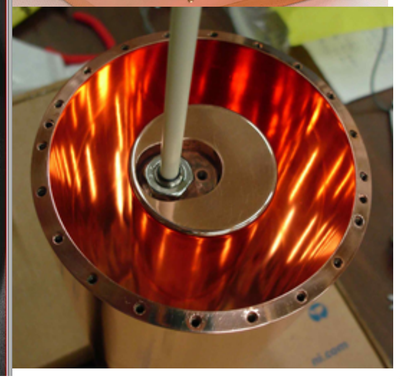
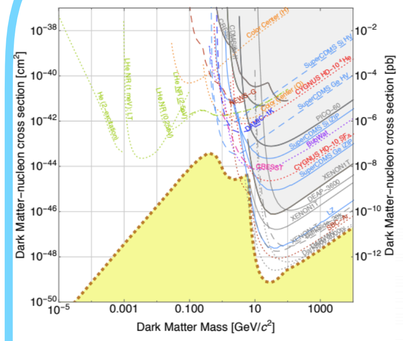
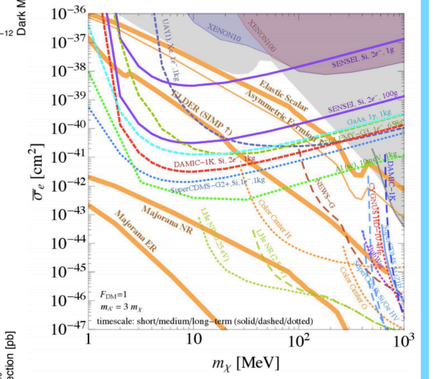
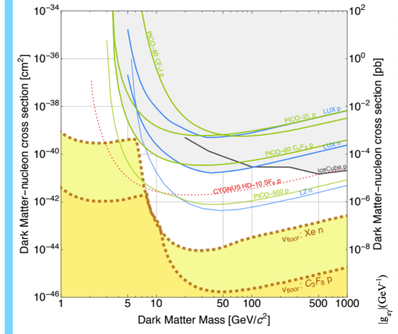


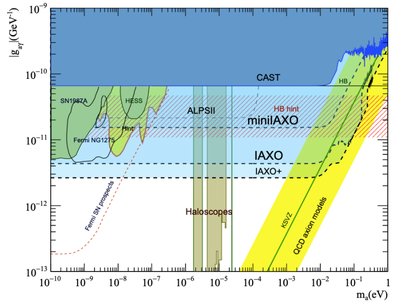


Results









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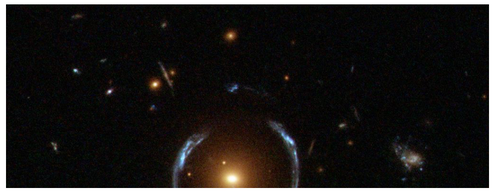
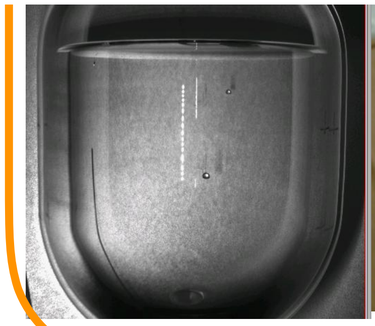
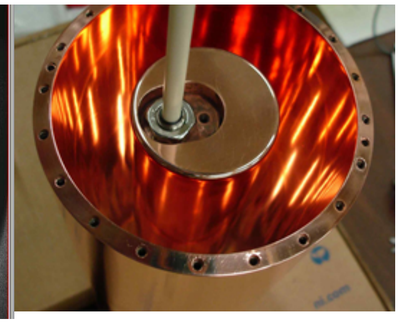


Experiments





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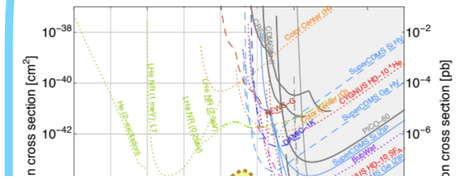
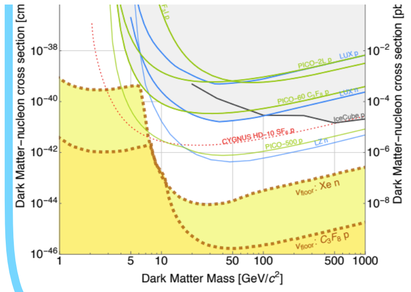
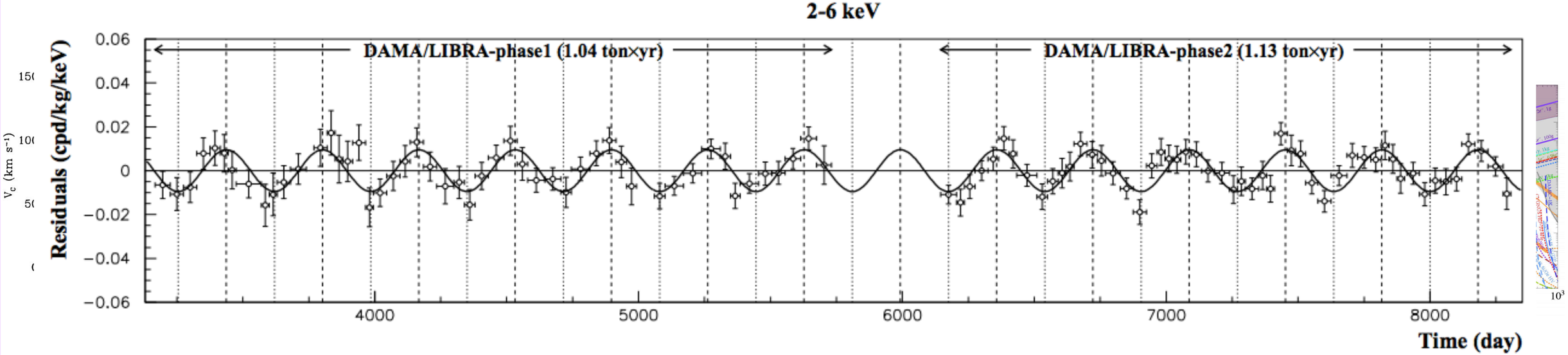
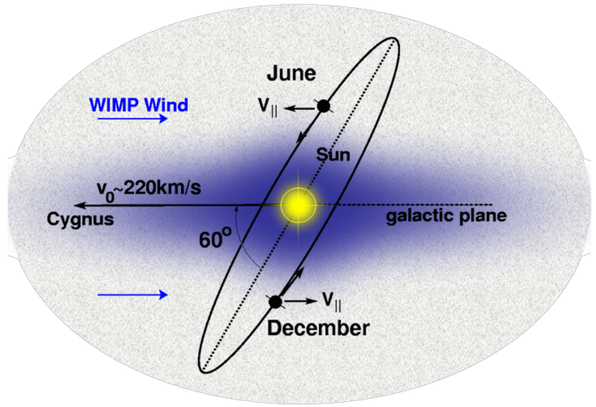


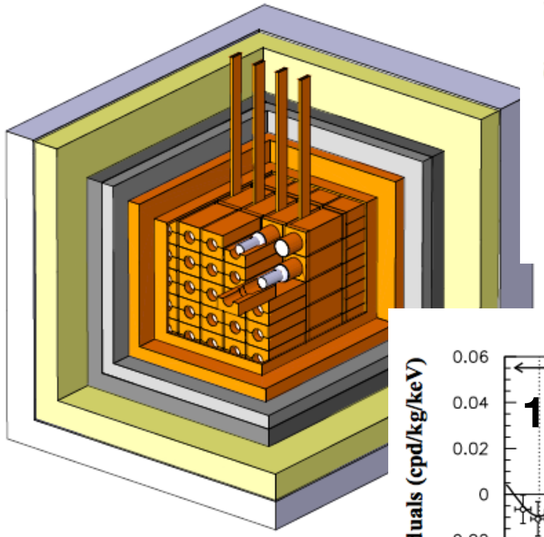


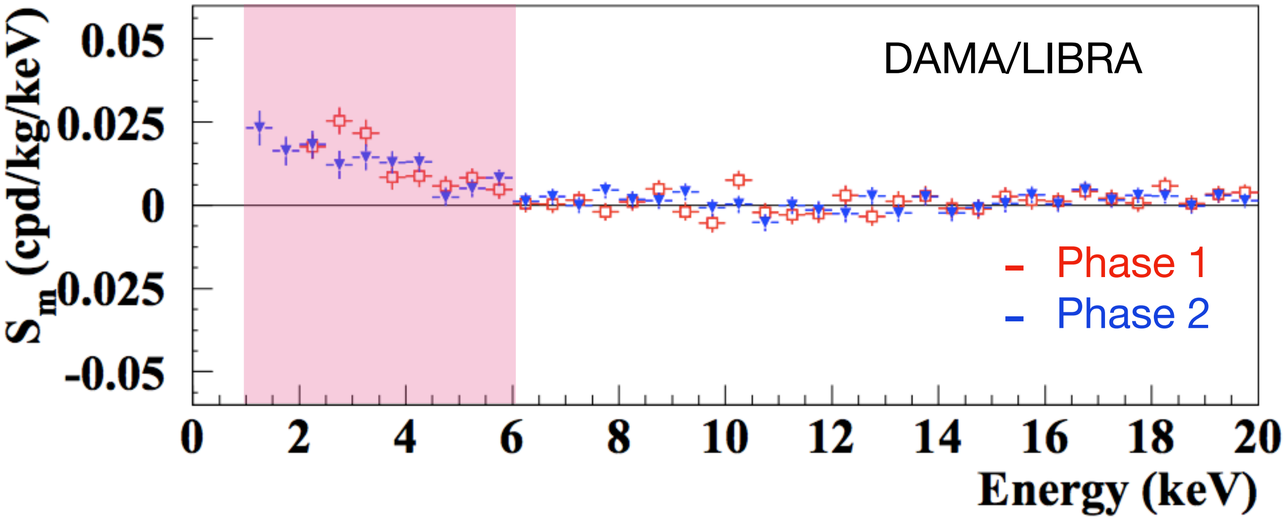


The DAMA Experiment

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







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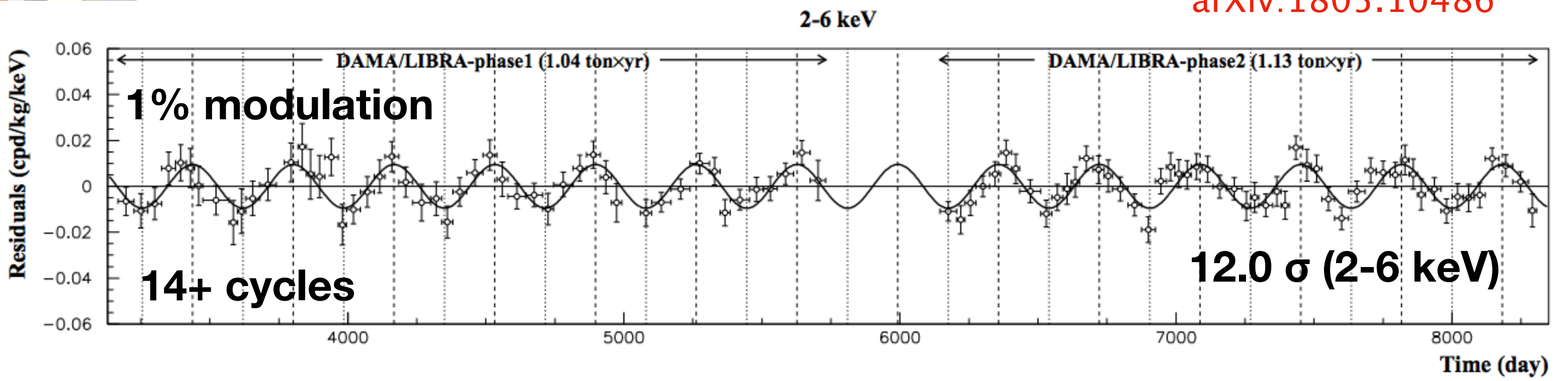


- How to confirm this signal?
  - Use same target material: NaI(Tl)
  - Have low enough backgrounds: modulation amplitude is small
  - Look for time dependent components in backgrounds

NaI(Tl) Global Effort

KIMS (+ DM-Ice)

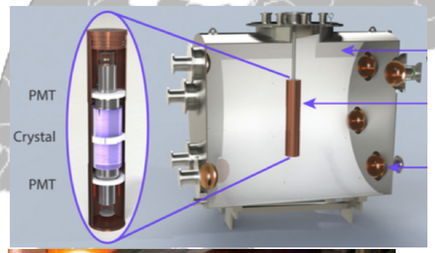
COSINE-100

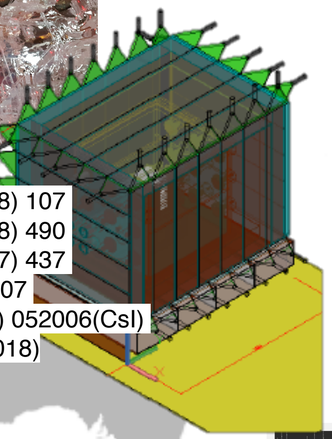
DAMA
SABRE
COSINUS
★ Gran Sasso + Australia

Yangyang ★ ★ Kamioka

PICOLON

ANAIS ★Canfranc





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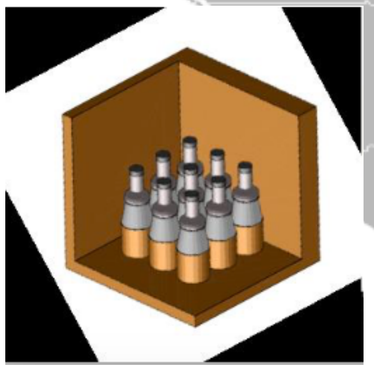
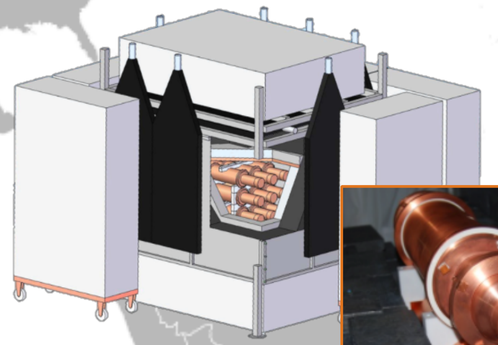
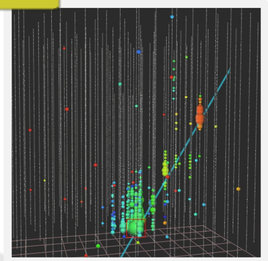
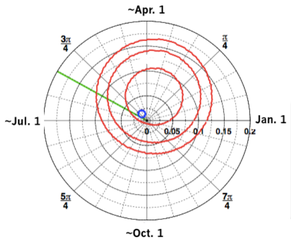
Eur.Phys.J. C **78** (2018) 490
Eur.Phys.J. C **77** (2017) 437
JINST **13** (2018) T02007
Phys.Rev. D **90** (2014) 052006(CsI)
Nature, **564**, 83-86 (2018)

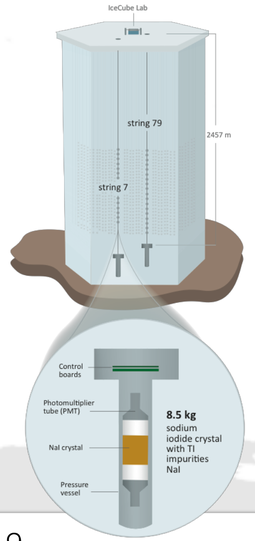








DM-Ice17
★ **South Pole**



COSINE-100

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

Physics run:
Since Sept 2016

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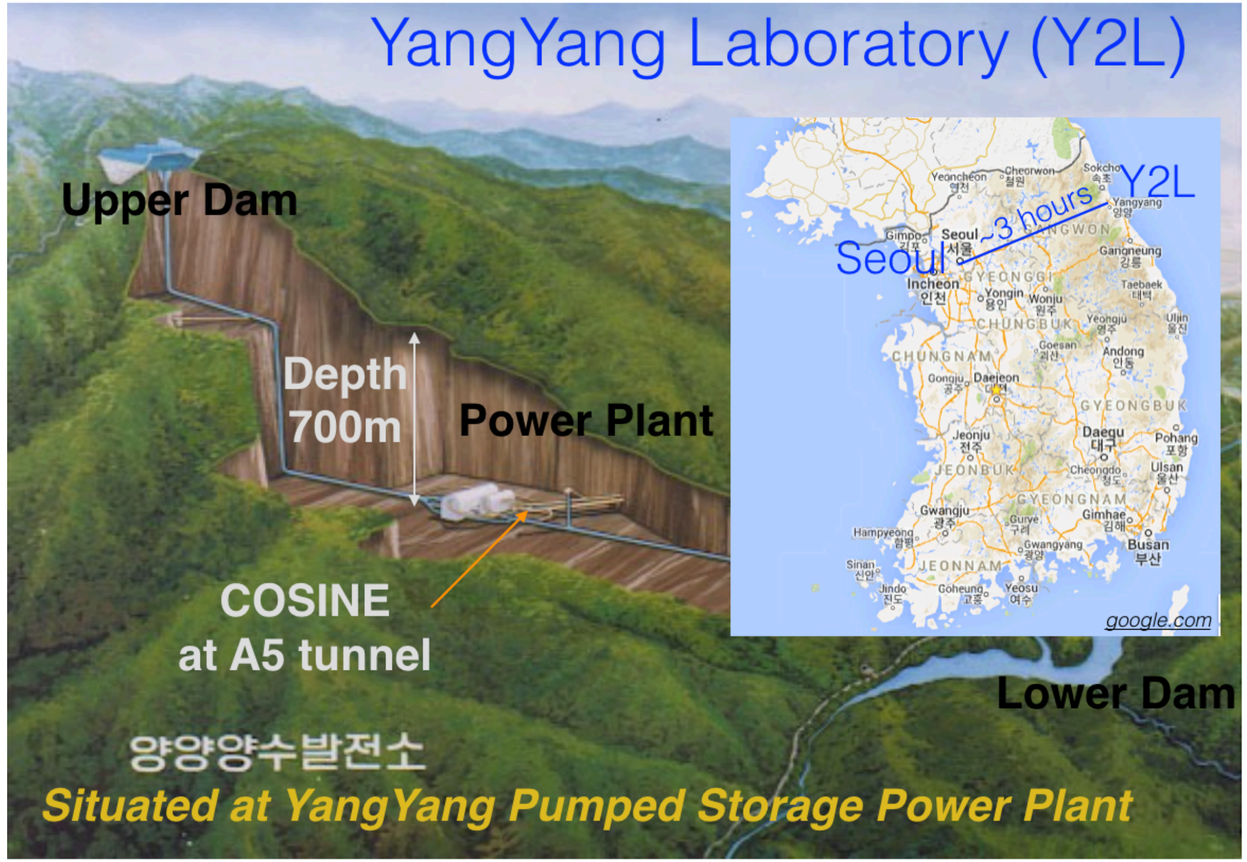
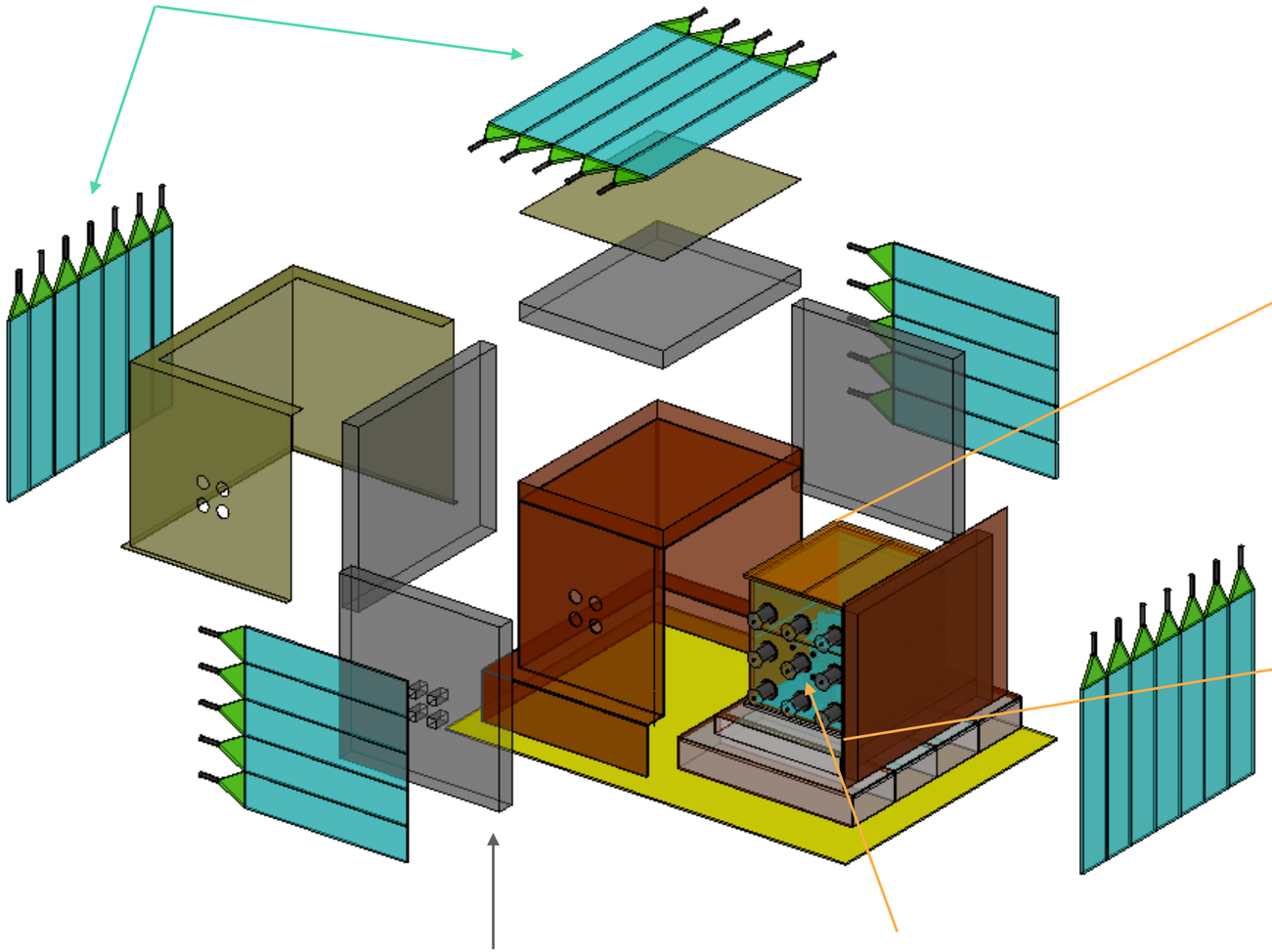


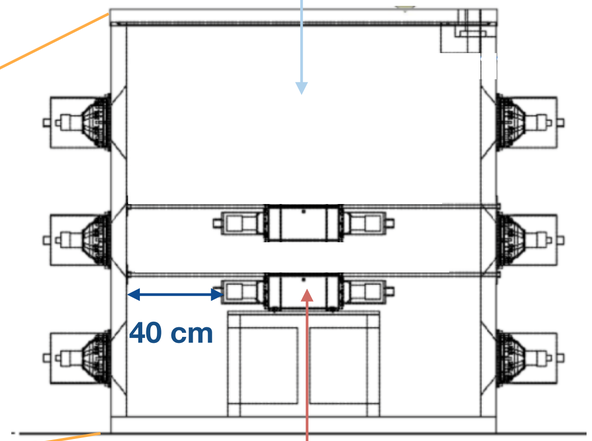
Physics run:
Since Sept 2016

COSINE-100 Shielding Structure

Plastic Scintillators

Filled with Liquid Scintillator (2000 L)



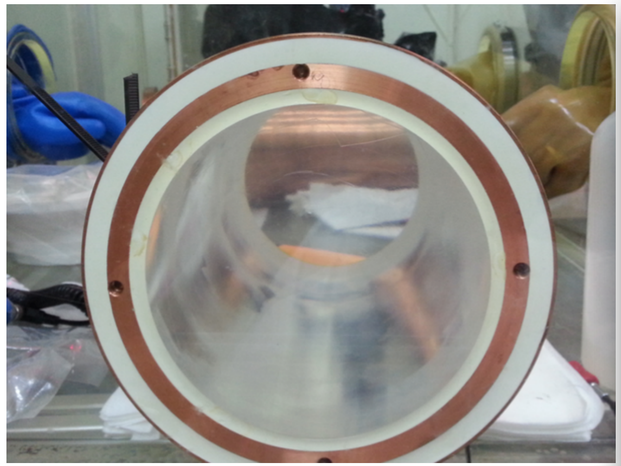


NaI(Tl) Crystals (106 kg)

Lead Shielding (20 cm)

Cu Box (3 cm)

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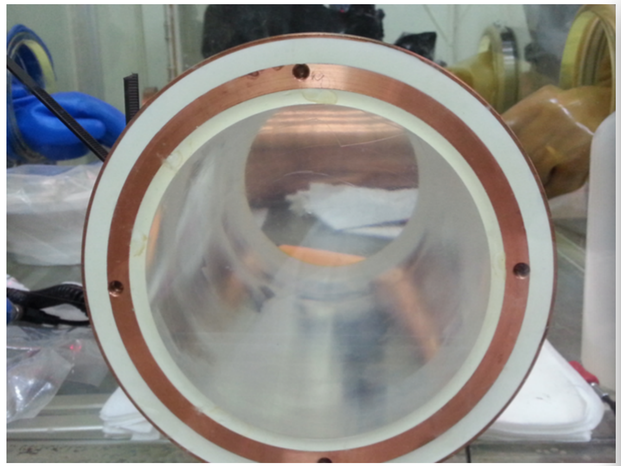
- Intrinsic backgrounds: from crystal powder/growing
- R&D goal: intrinsic background ~DAMA's
- Light yield: up to 15 p.e./keV
- Main challenge: produce crystal with desirable levels of ^{40}K & ^{210}Pb

COSINE-100 NaI(Tl) Crystals



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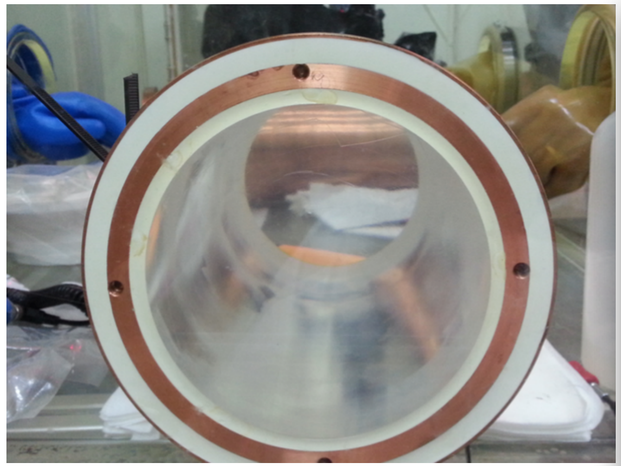

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Crystal-2	9.2	4.2 × 11.0	AS-C	2.06 ± 0.06	60.6 ± 4.7	<0.12	<0.6	14.6 ± 1.5
Crystal-3	9.2	4.2 × 11.0	AS-WSII	0.76 ± 0.02	34.3 ± 3.1	<0.04	0.4 ± 0.2	15.5 ± 1.6
Crystal-4	18.0	5.0 × 15.3	AS-WSII	0.74 ± 0.02	33.3 ± 3.5		<0.3	14.9 ± 1.5
Crystal-5	18.3	5.0 × 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 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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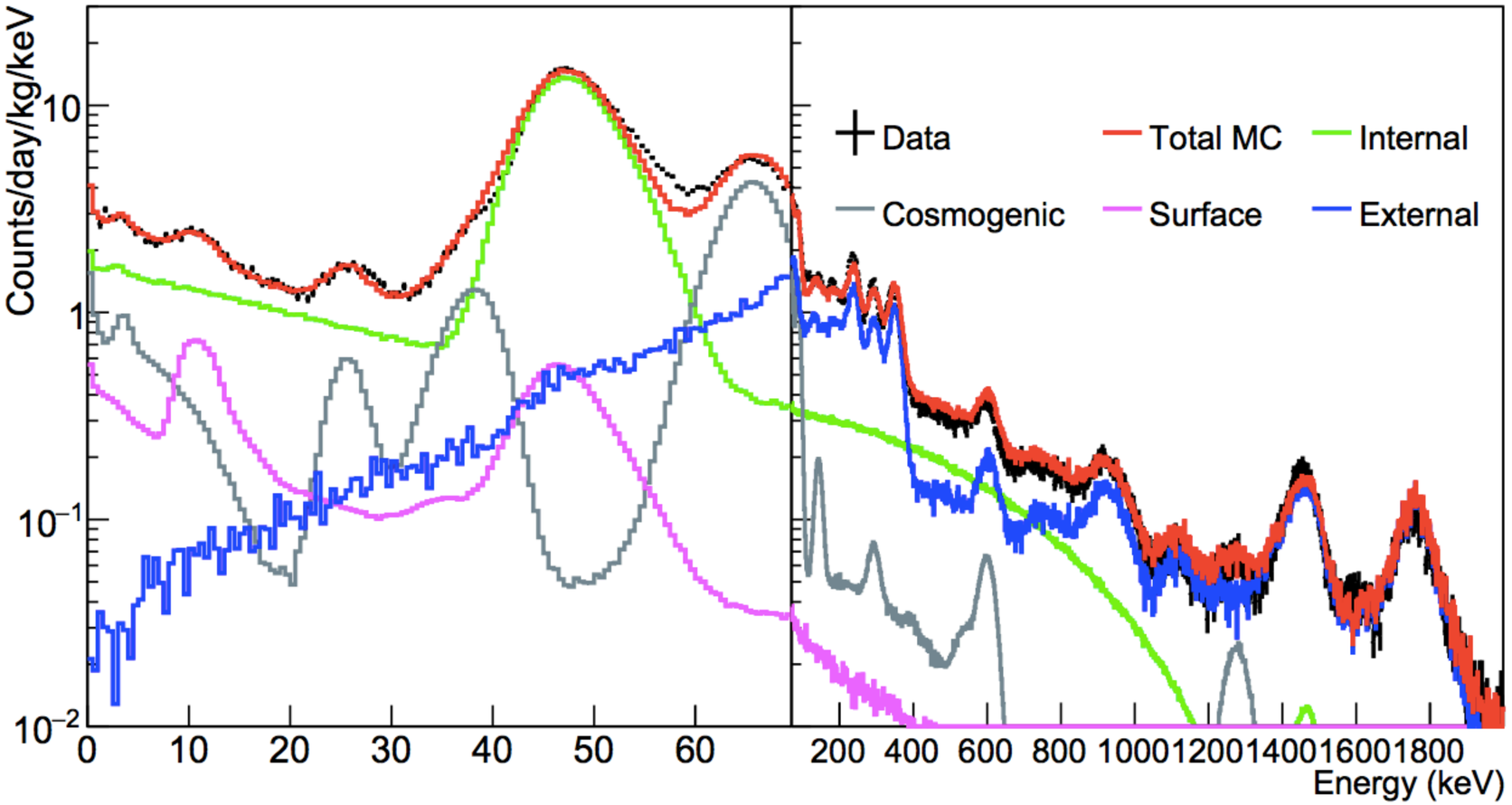
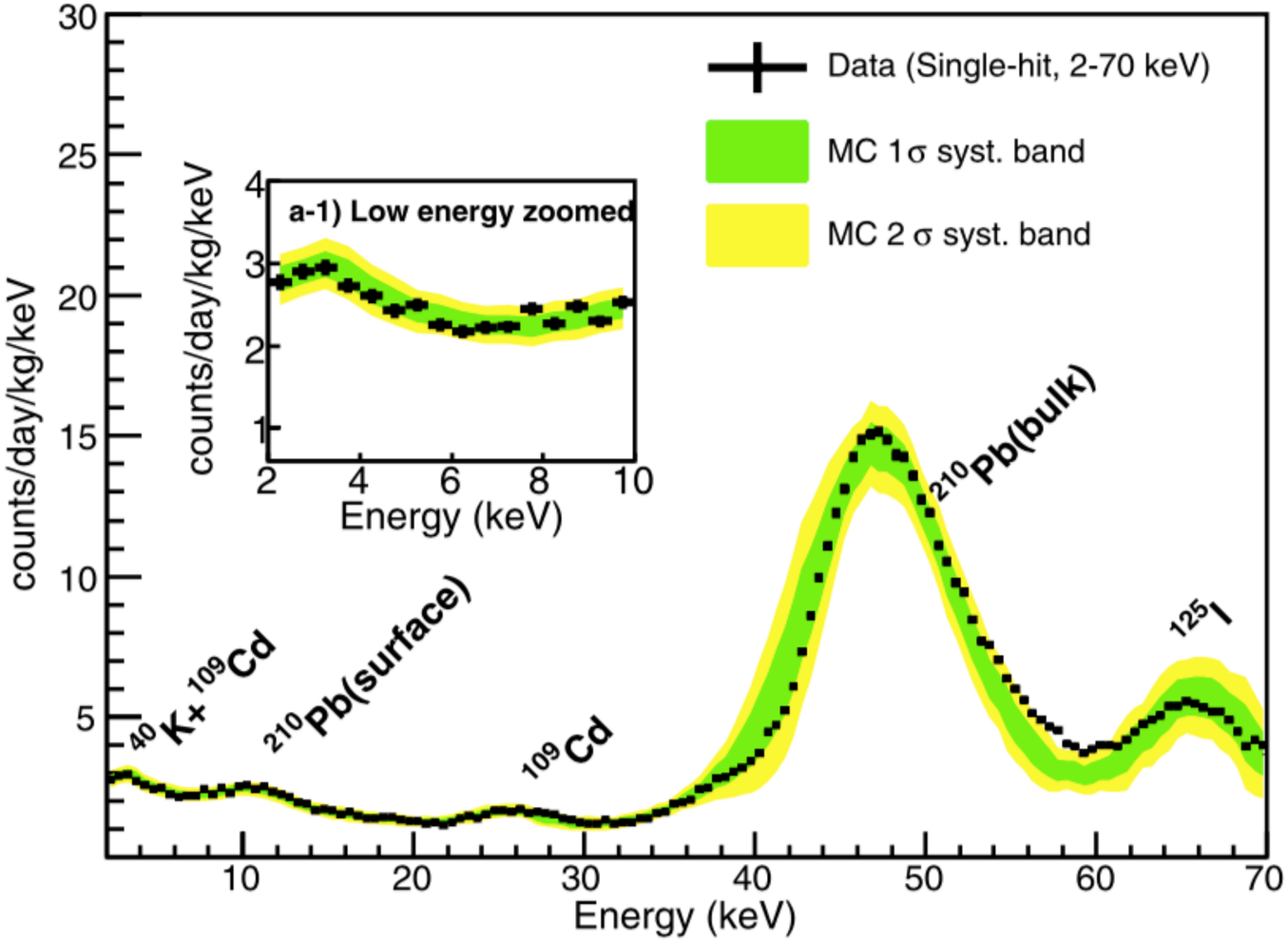
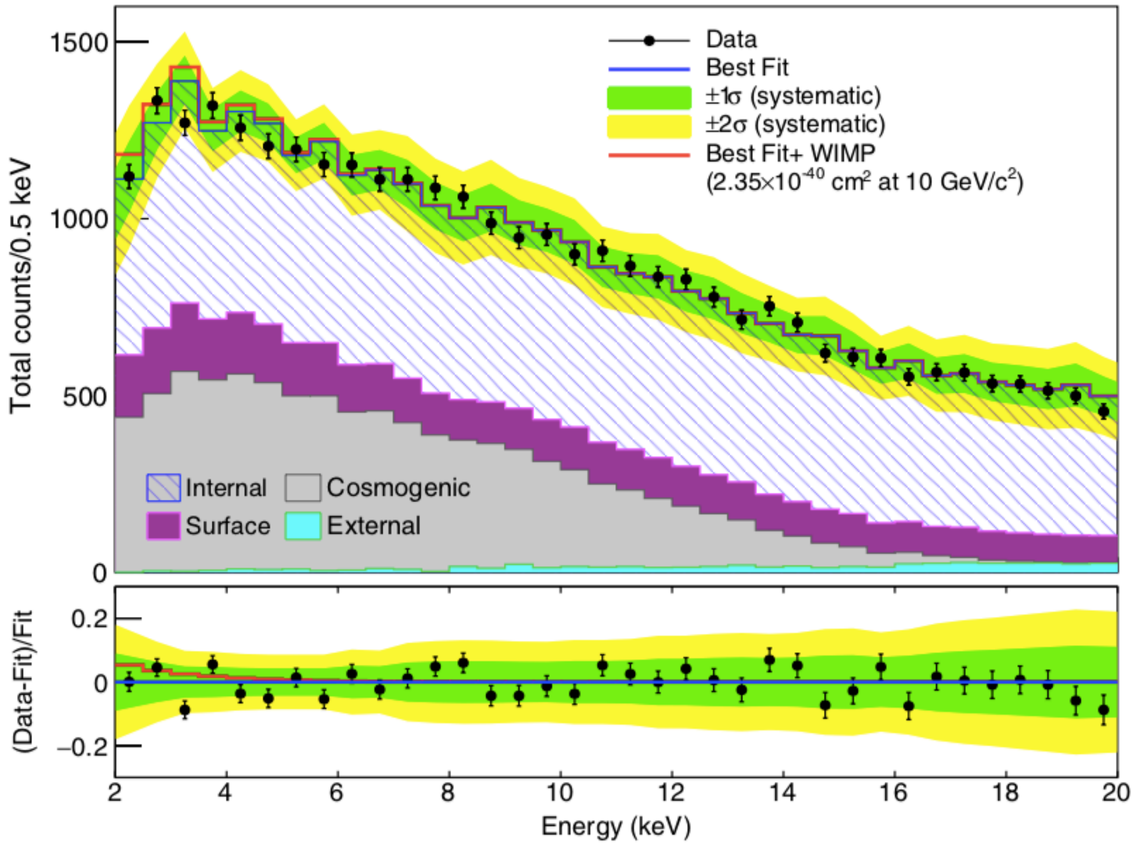


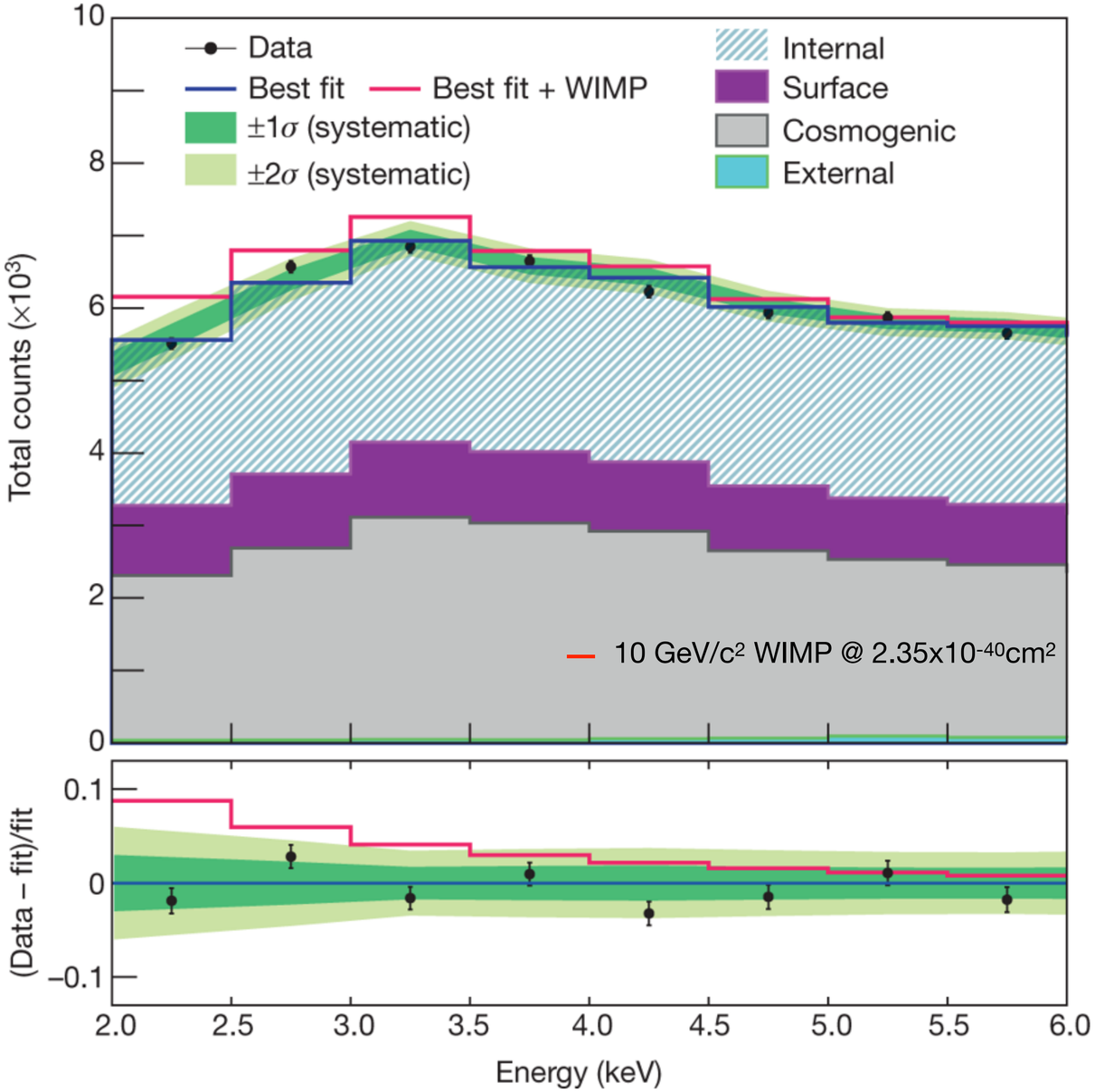
COSINE-100 Backgrounds & Fit

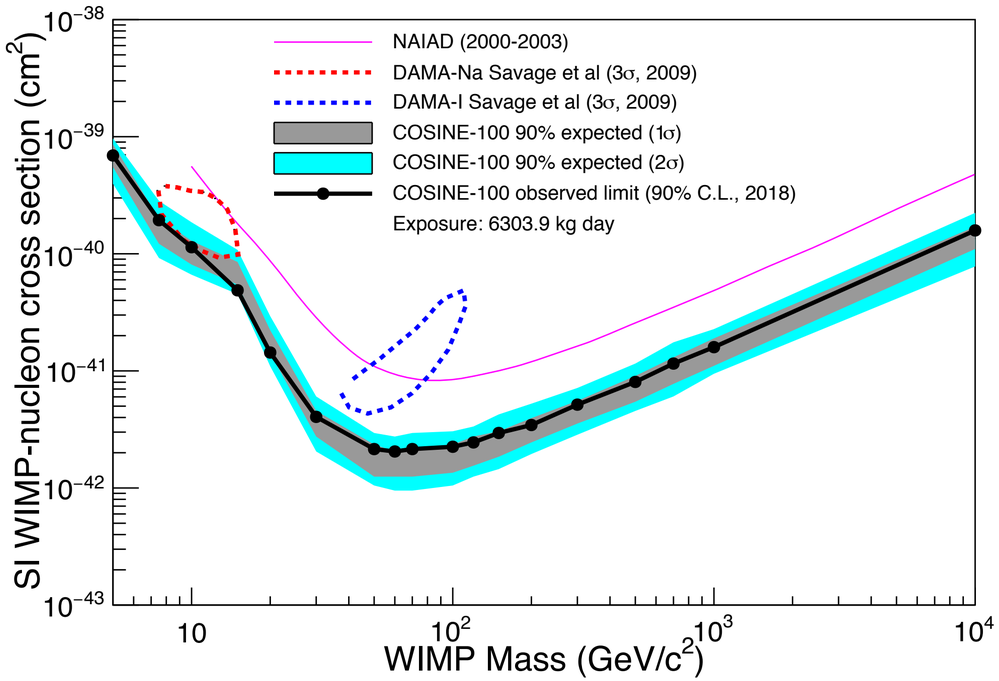




- Estimated systematics: resolution, efficiency, energy scale, simulation package, PMT background
- Crystals are fitted simultaneously to a WIMP-signal model, for different WIMP masses

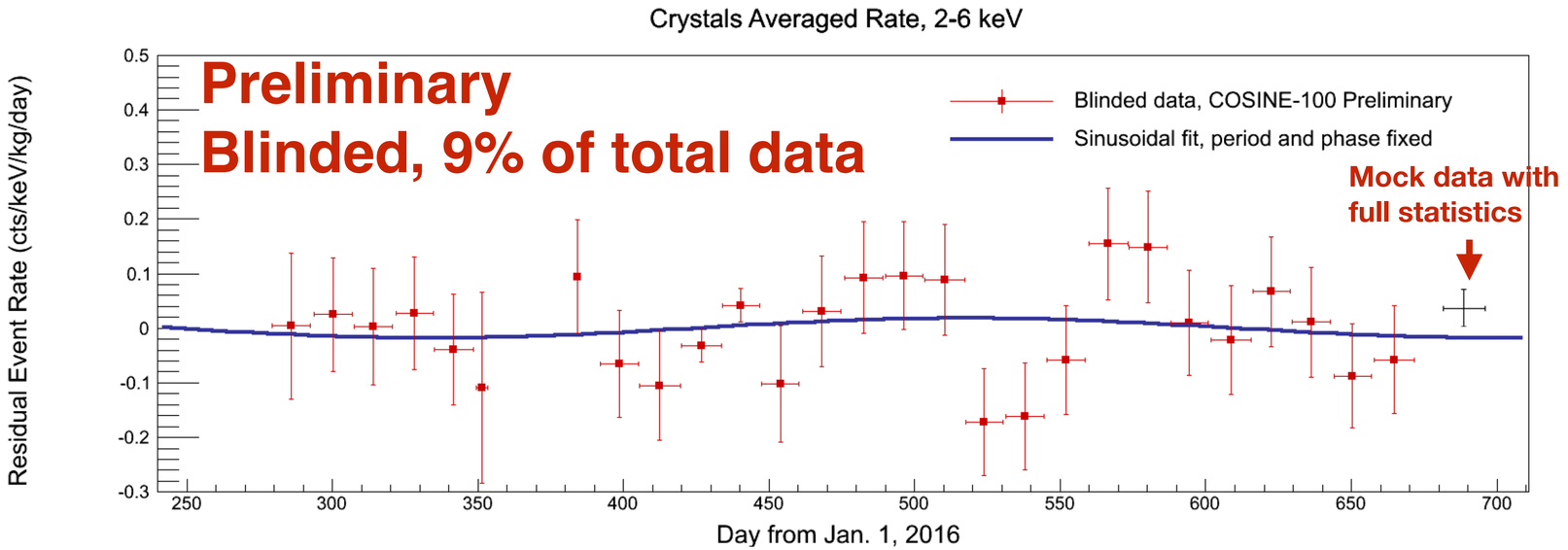
Spin-Independent WIMP Search

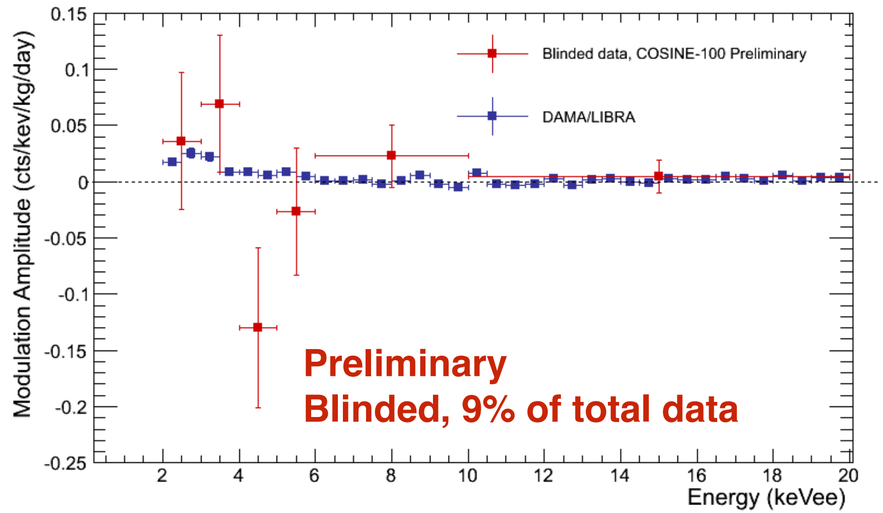




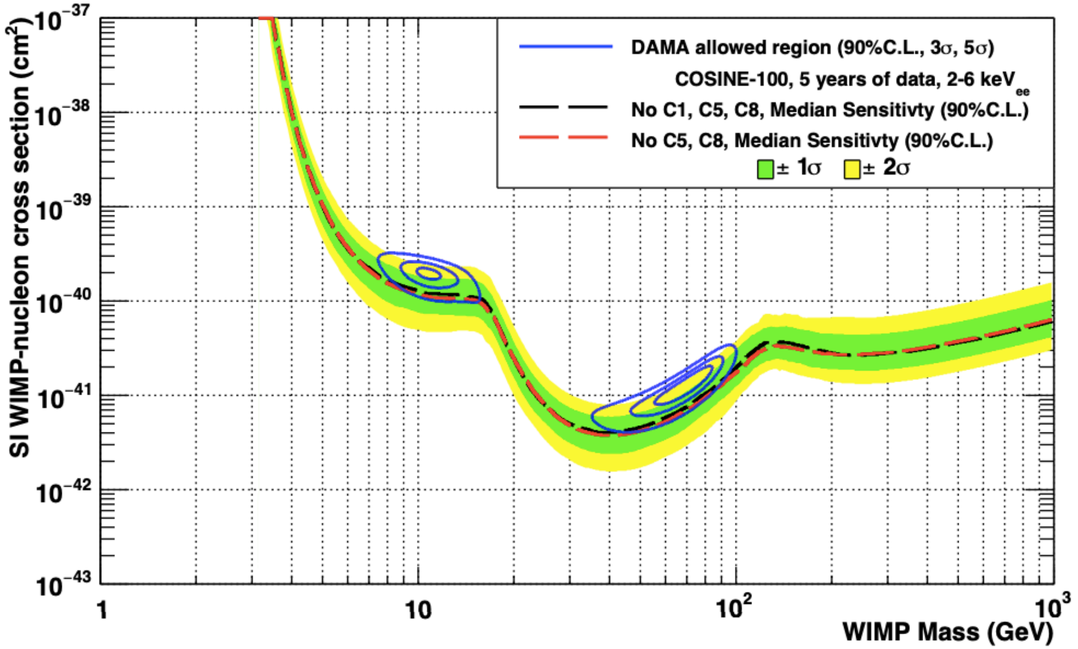
- Exclusion of DAMA/LIBRA-phase1 spin-independent signal, standard halo model interpretation
- First time excluded with same target material

Annual Modulation Search



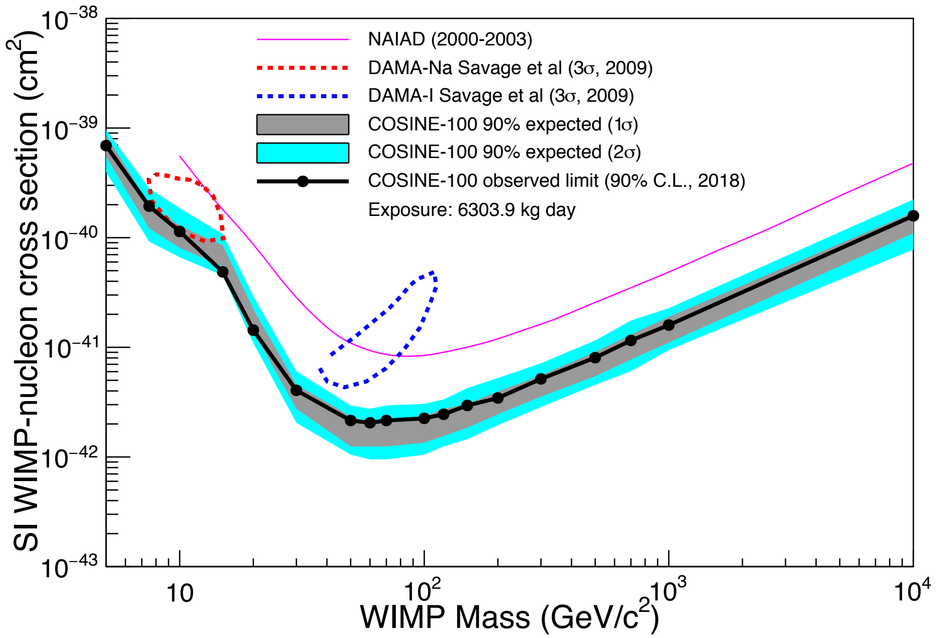


- Data blinded: only 9% of total data
- Full data analysis will be using 585+ days of data
- Stay tuned!



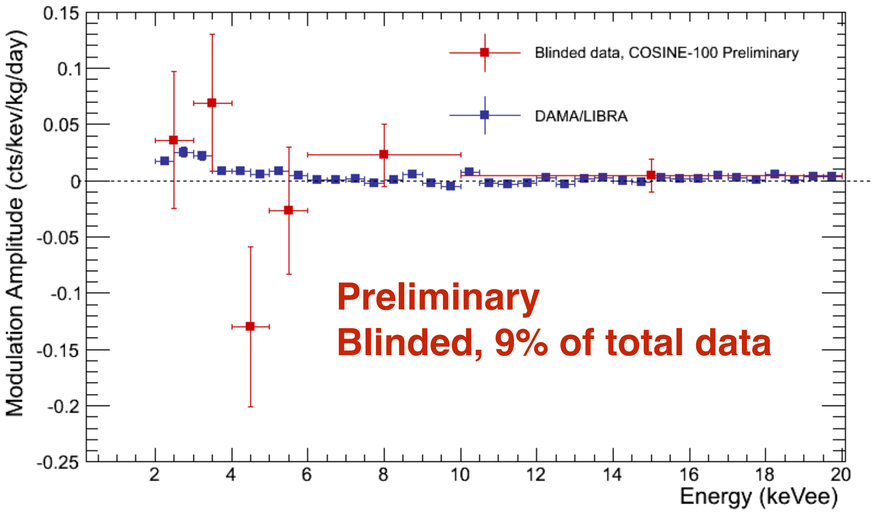
Summary

- COSINE-100 has been running since September 2016.
- 60 days of data strongly disfavors spin-independent WIMPs as the cause for DAMA's signal.
- Modulation model independent test: need for 5-year data anticipated. Analysis of 2 years of data on the way.



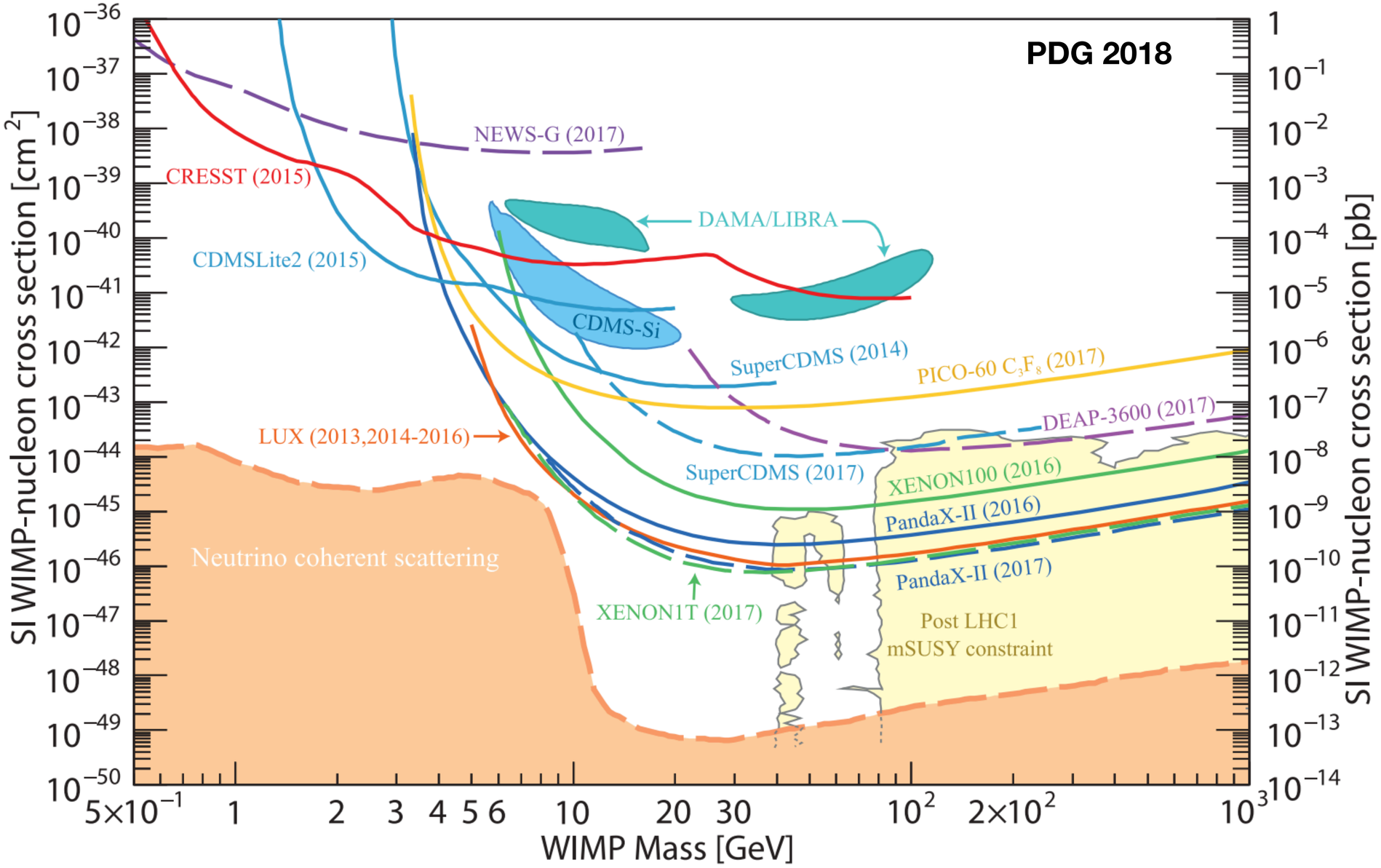
Stay tuned!

Thanks!

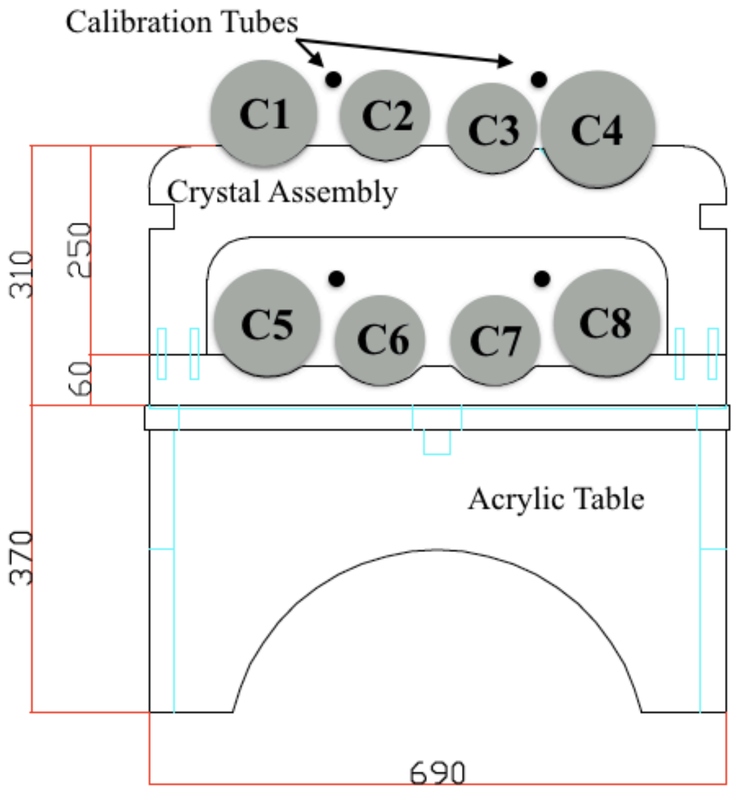


Backup

Status of the Field



Crystal Configuration



Low Energy Spectrum

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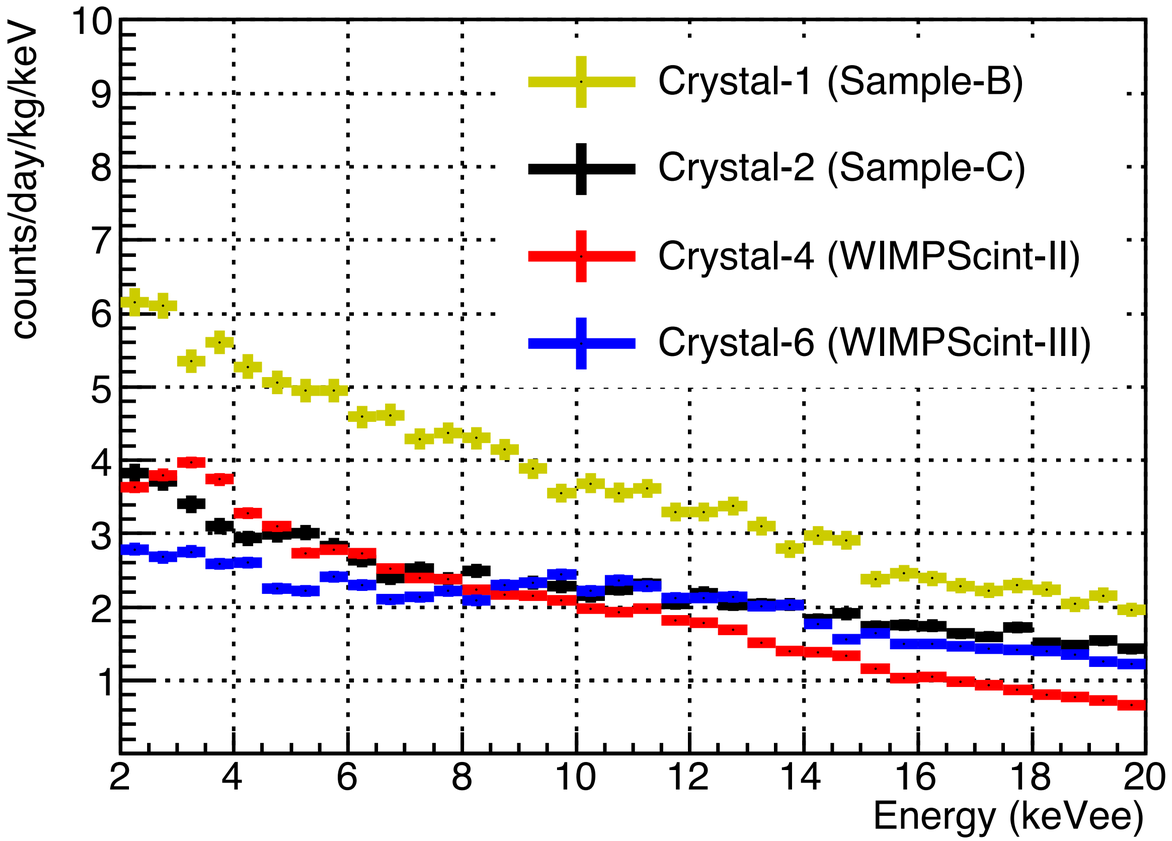
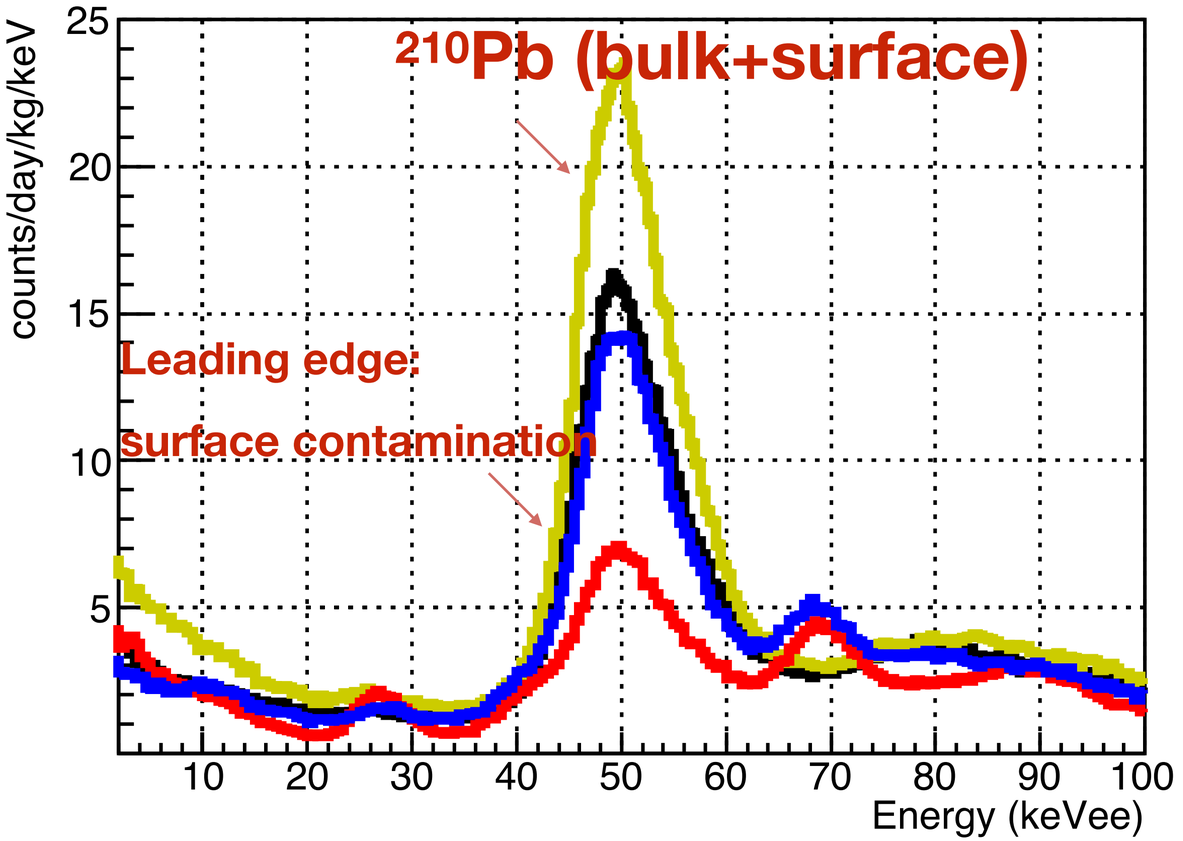
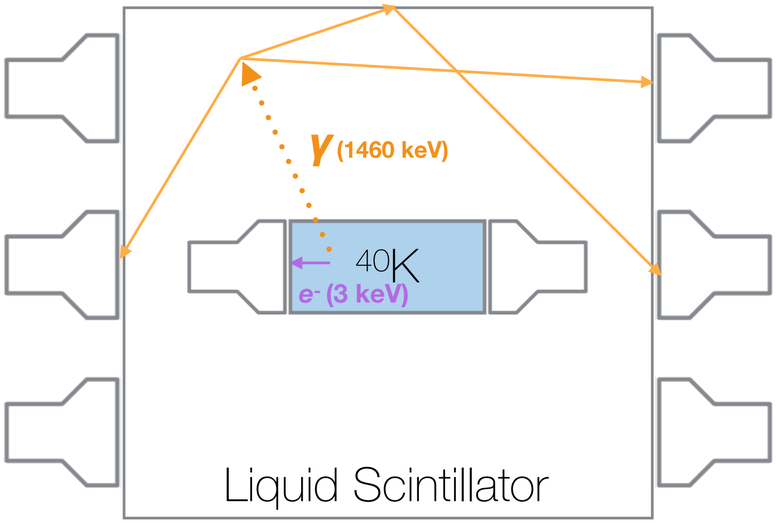
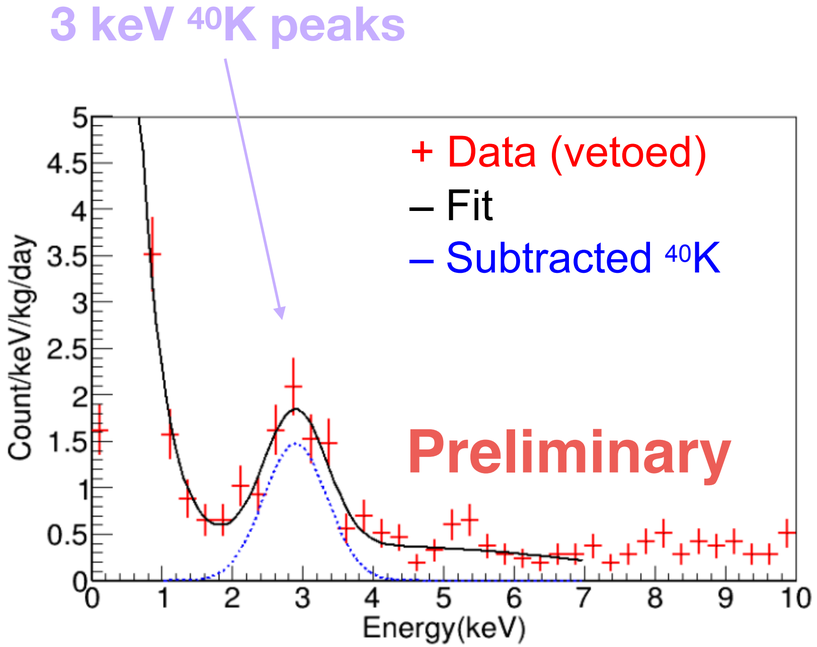


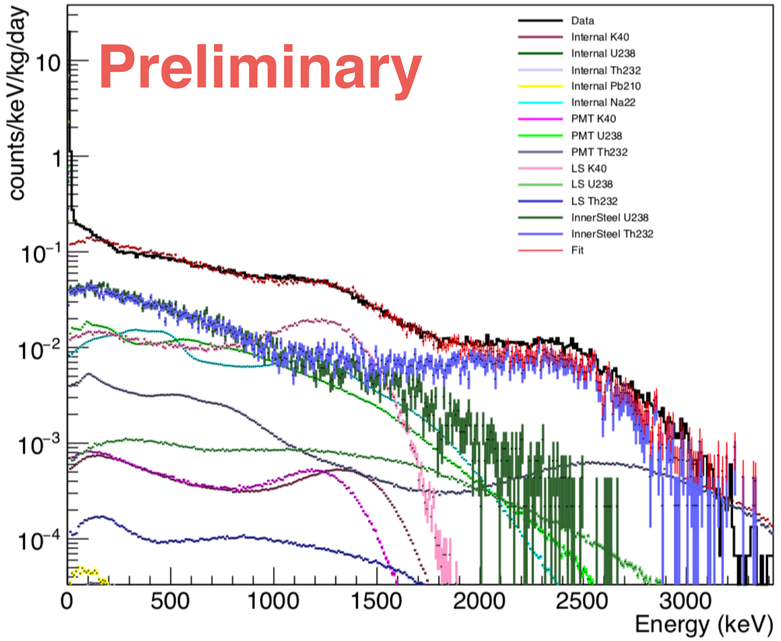


- 2 - 4 counts/keV/kg/day in R.O.I

Liquid Scintillator Veto

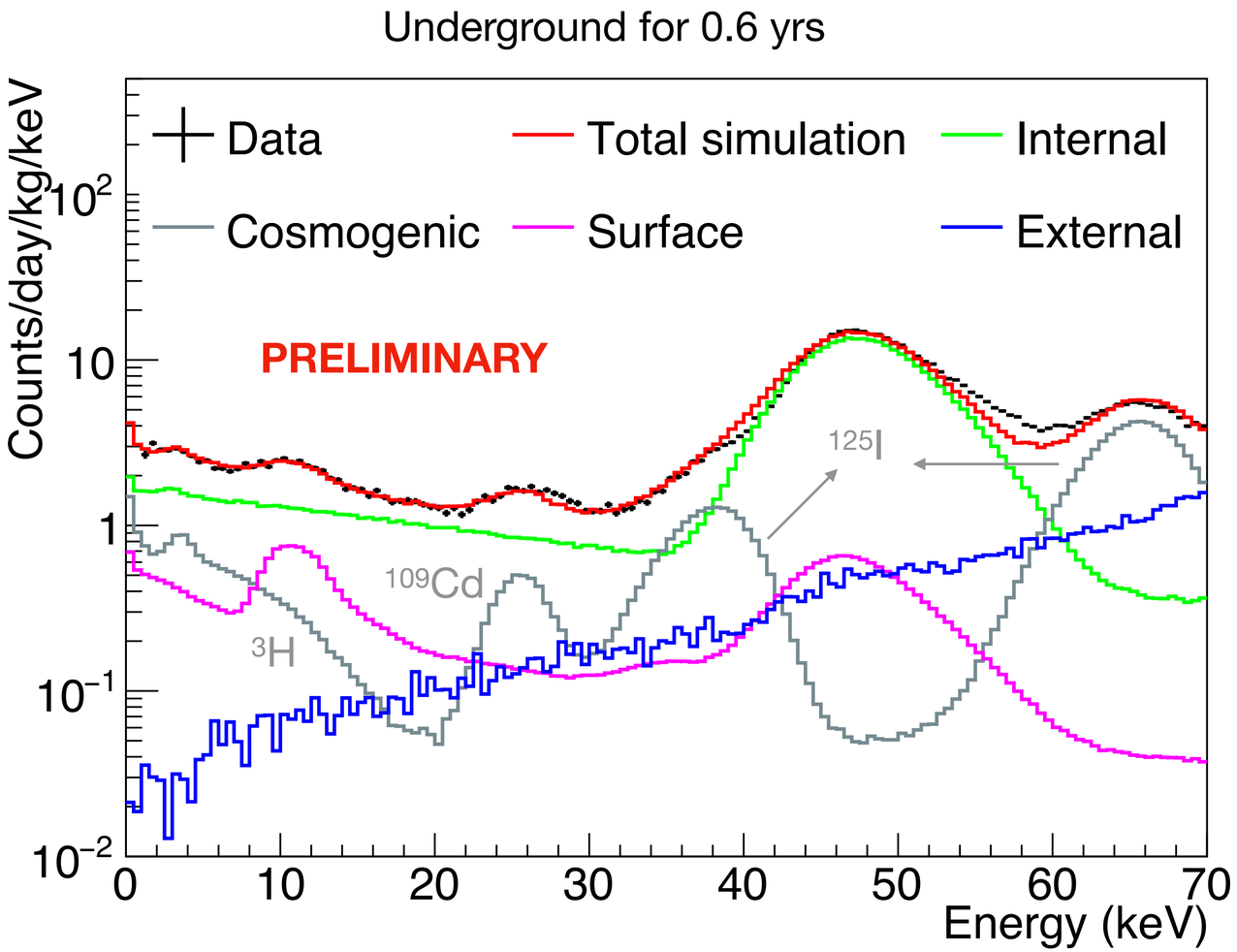


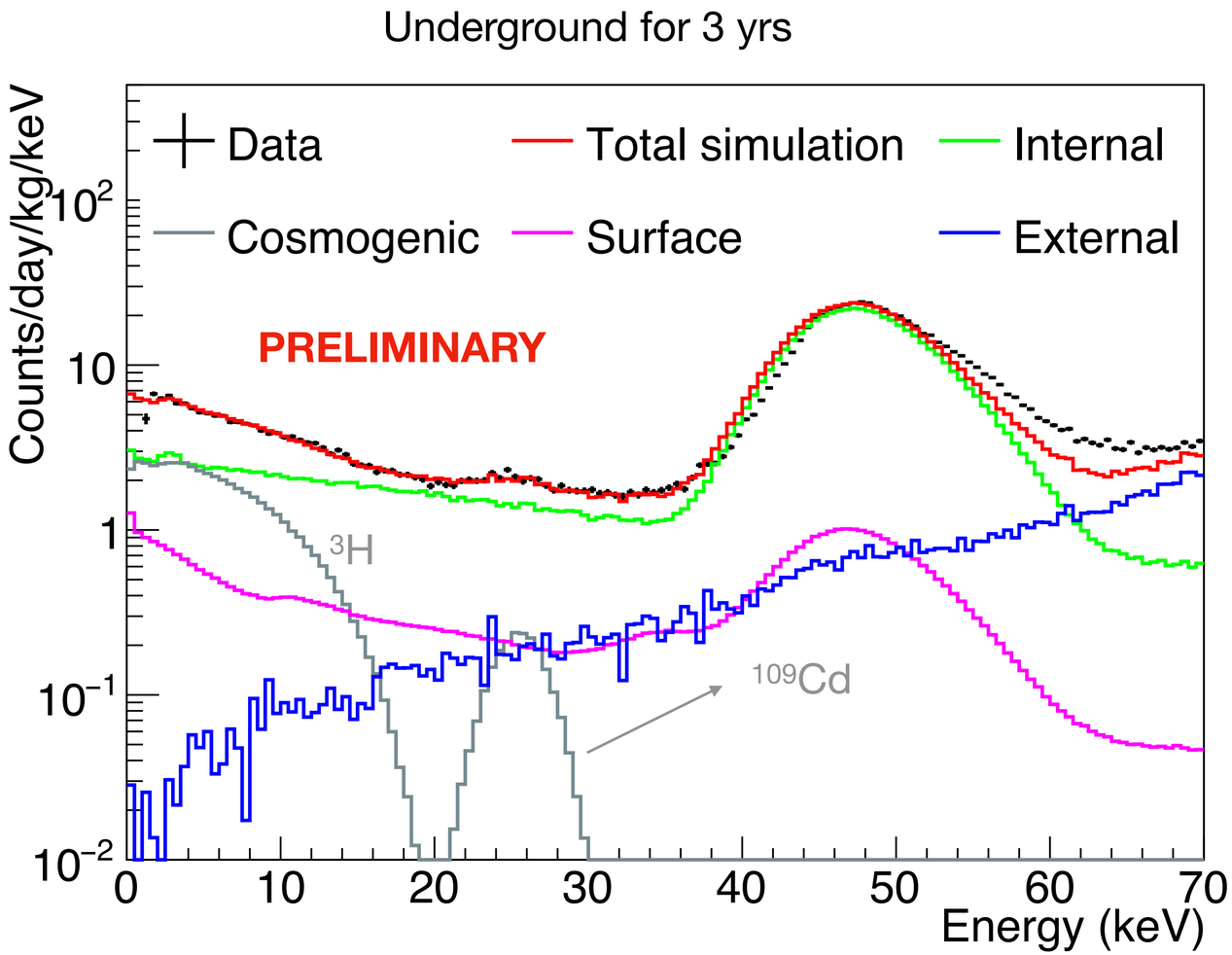




- ^{40}K emits a 1460 keV gamma with 3 keV Auger electron energy deposition in the crystal
- Tagging the 1460 keV events with LS enables to **veto the ^{40}K 3 keV background events**
- The liquid scintillator background is well modeled with simulation

Cosmogenics





Muon Detector

- Muon veto with 37 plastic scintillator panels
- Events correlated with muon tagged
- Muon-induced events in NaI(Tl) under investigation

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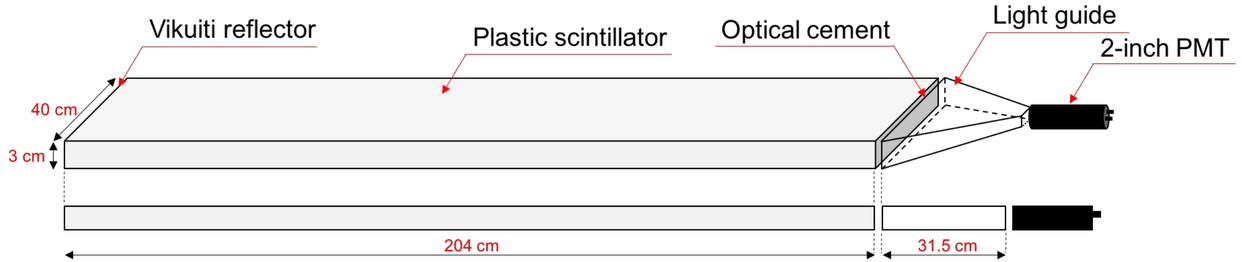
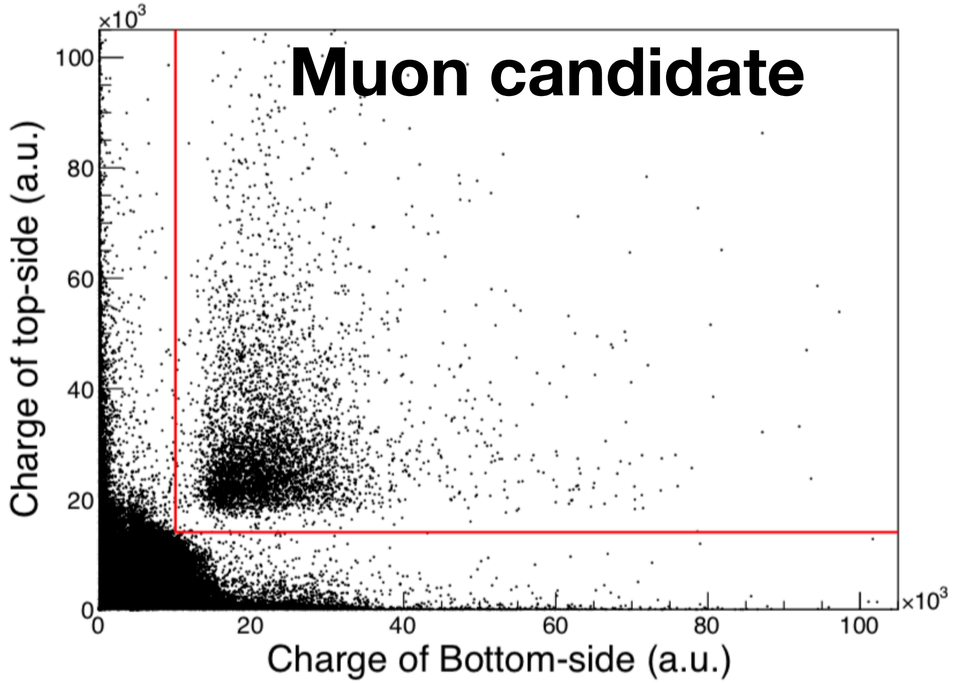
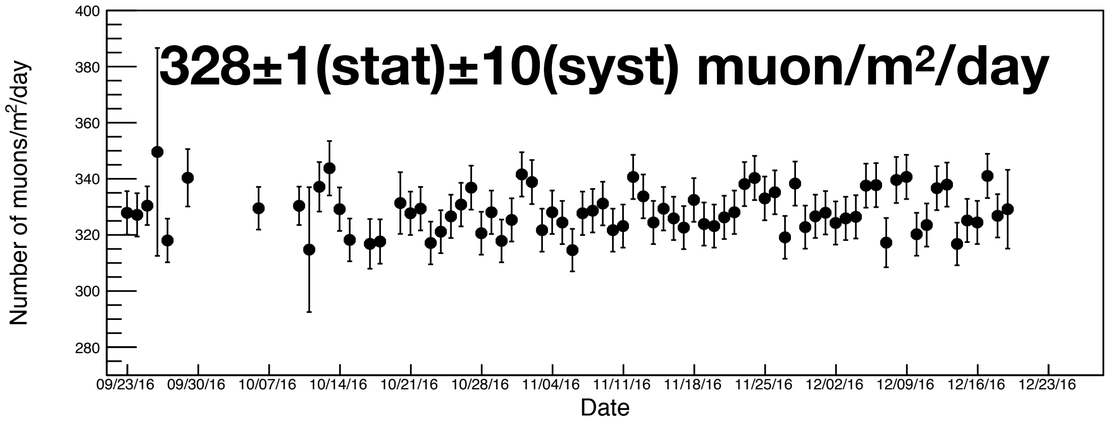
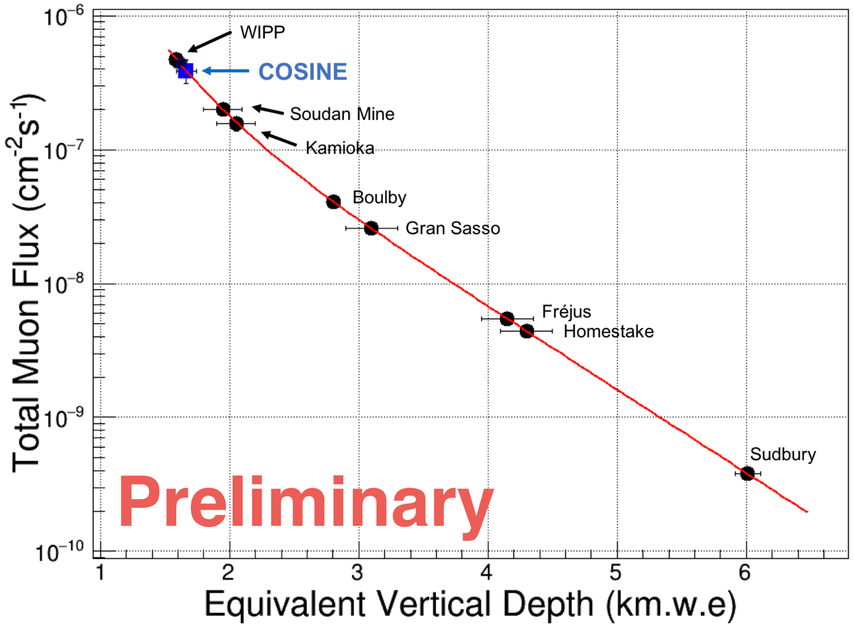
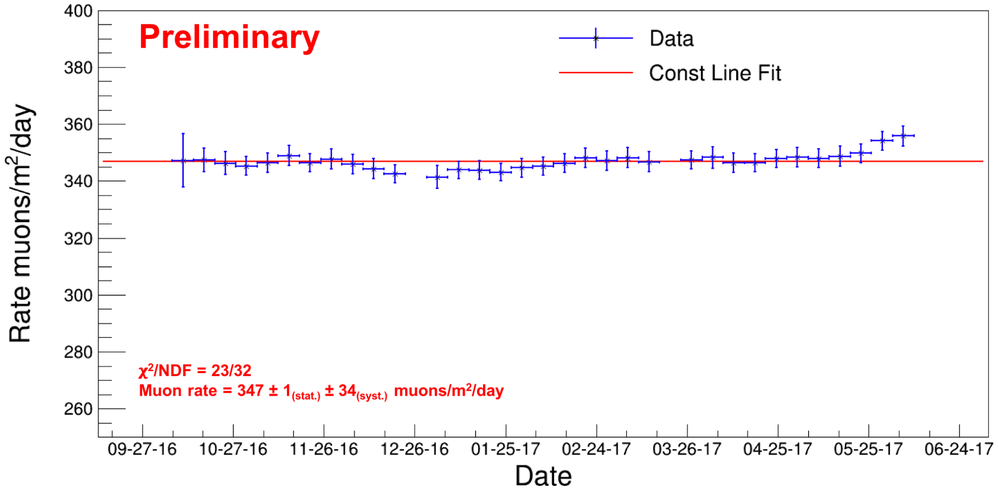






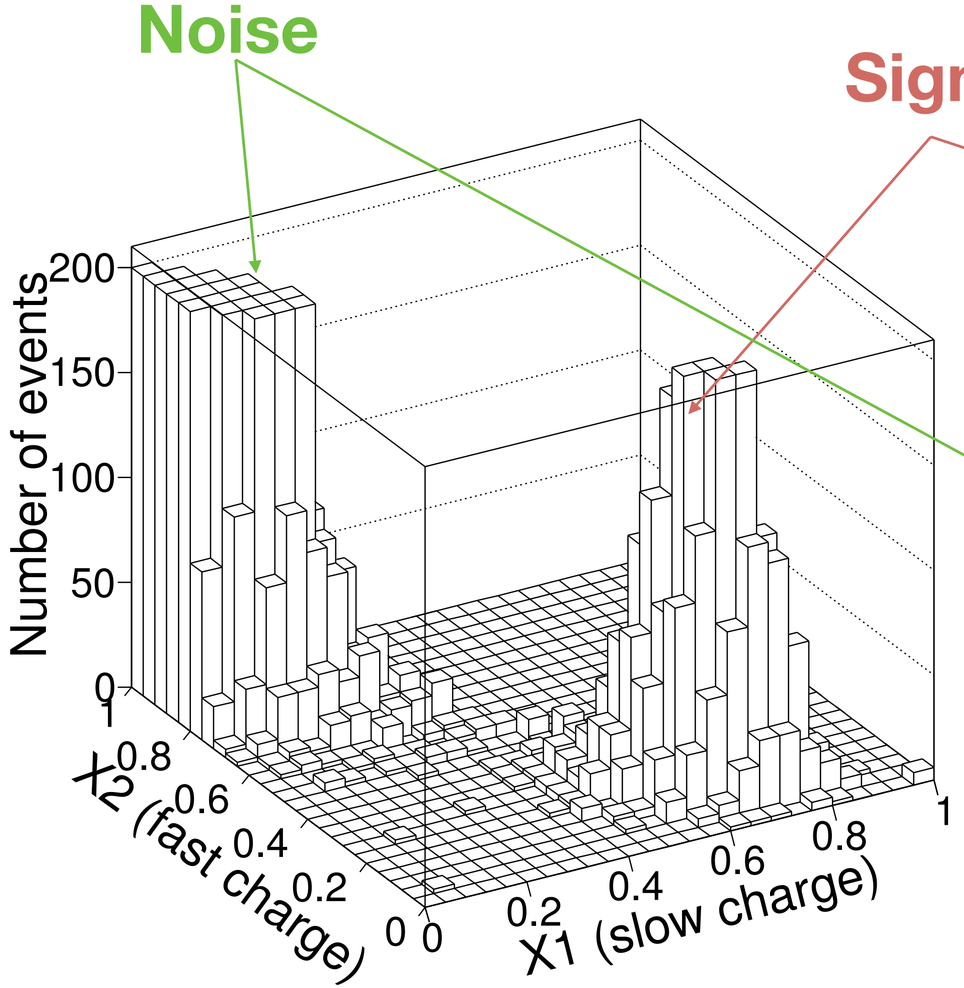
COSINE-100 Muon Background

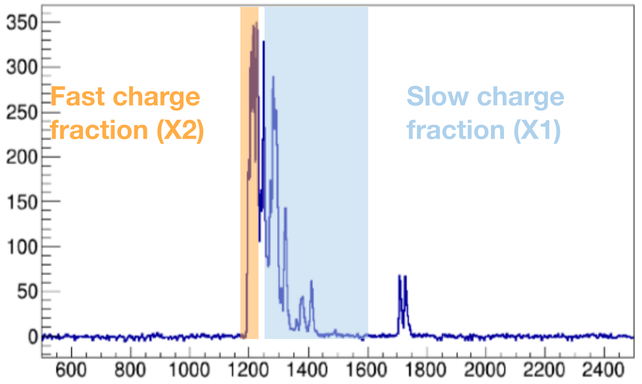


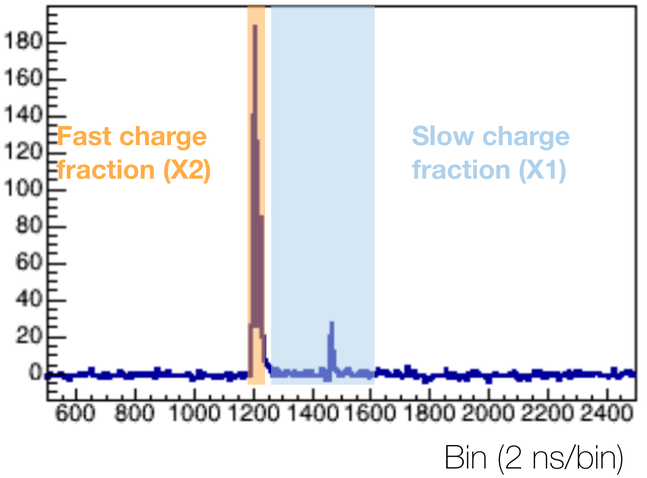


- Muon flux at COSINE-100 is ~3.98 x 10^{-7}/cm^2/s (344.29 muons/m^2/day)
- Rate has been consistent throughout the physics run
- Muon selection used to veto muon-induced crystal events

Event Selection: Charge Ratio







- Looking at charge ratio between rising edge and falling edge of a pulse gives good noise separation power

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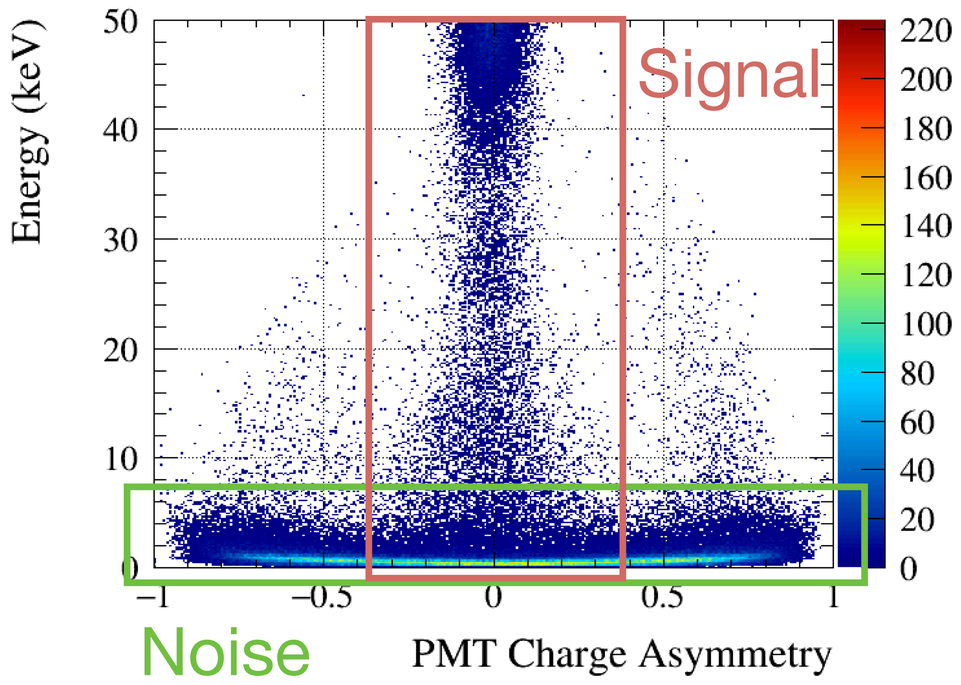
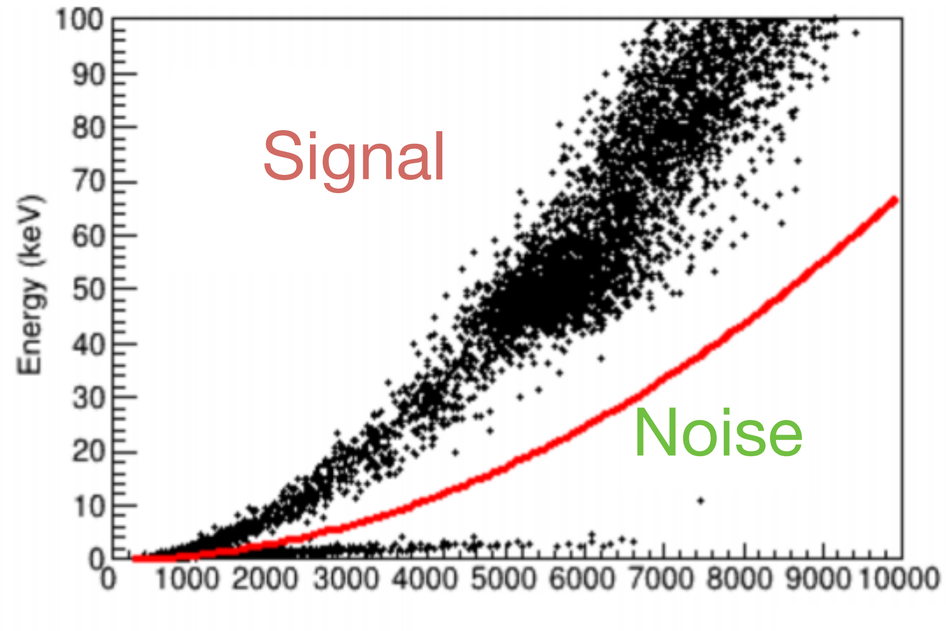
Event Selection: Asymmetry and Charge/Peak

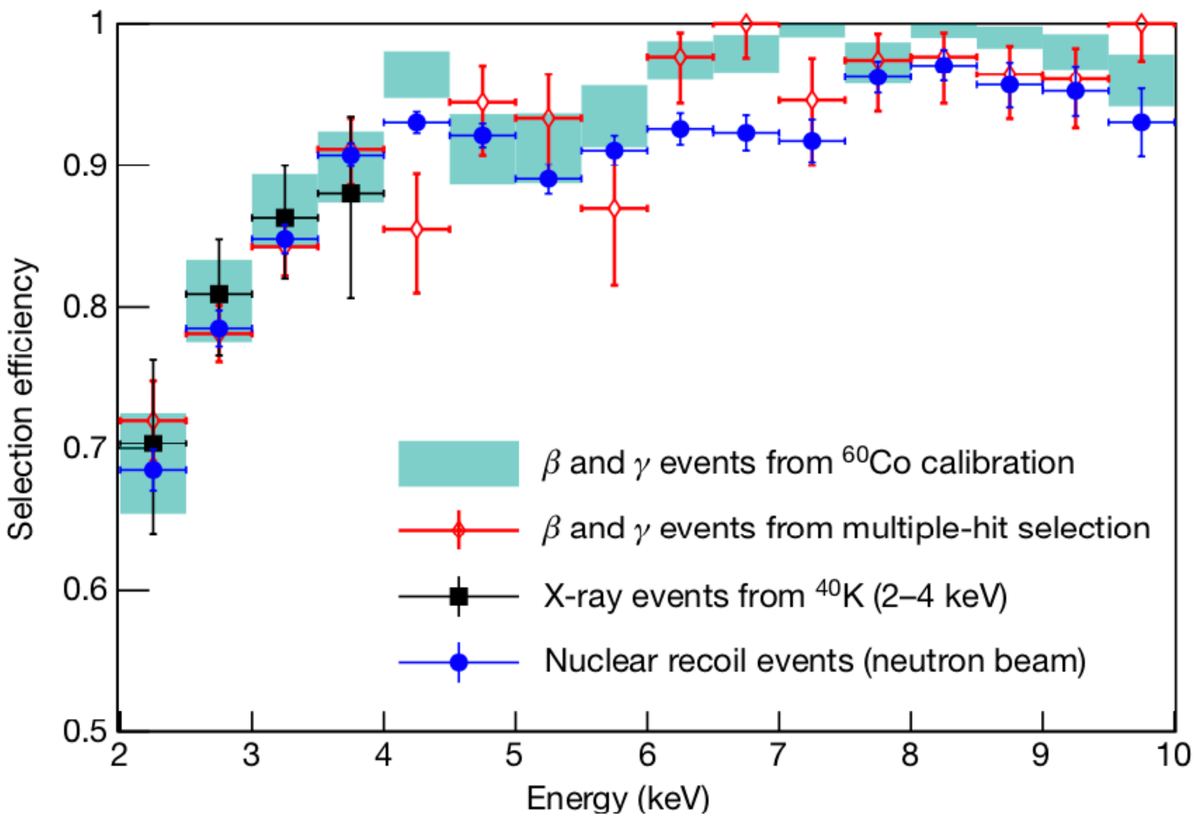


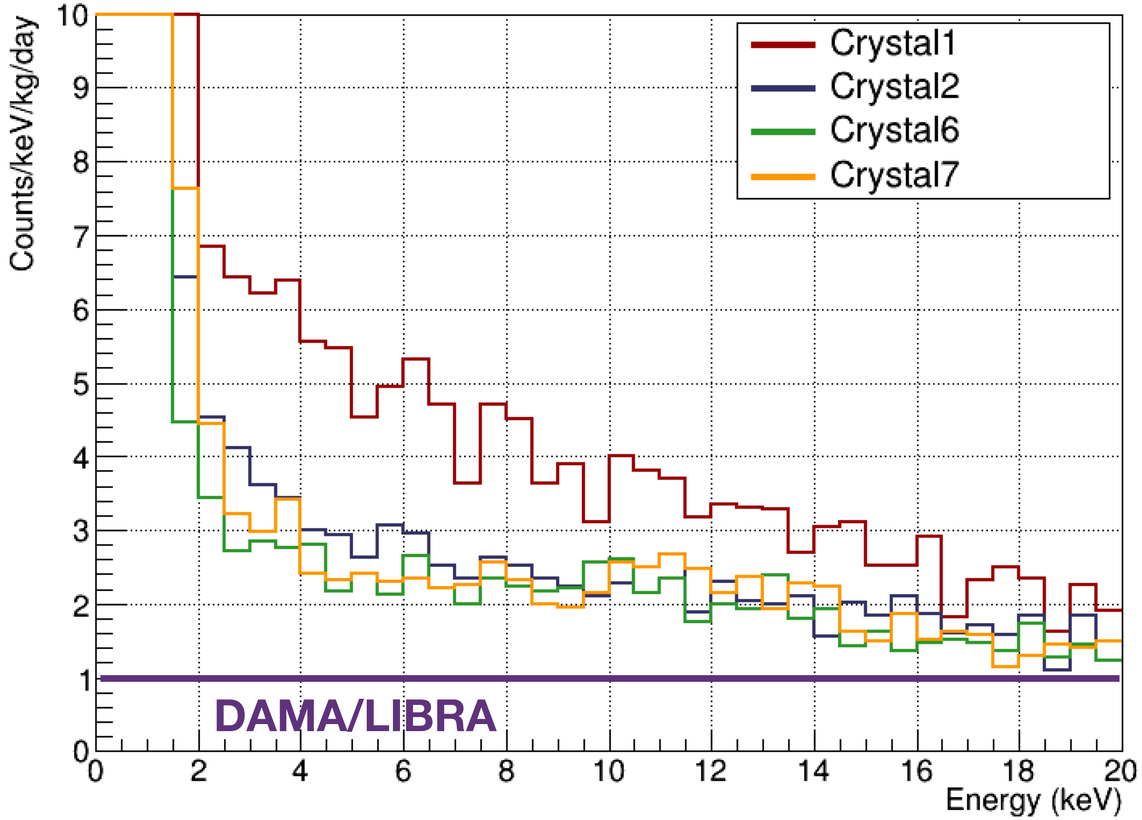


Average charge per SPE

- Additional noise reduction cuts have been developed:
  - Charge asymmetry between 2 PMTs in each crystal
  - Charge/peak: Average charge per SPE
- New development of event selection criteria based on multivariate analysis on going

Selection Efficiency/Low Energy Spectrum

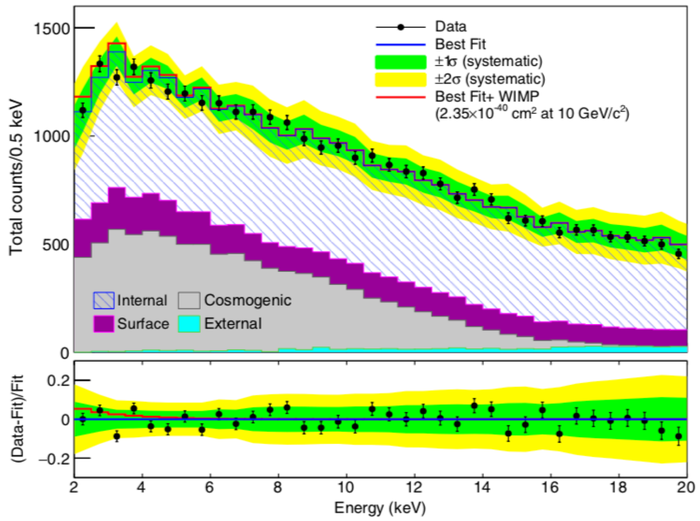




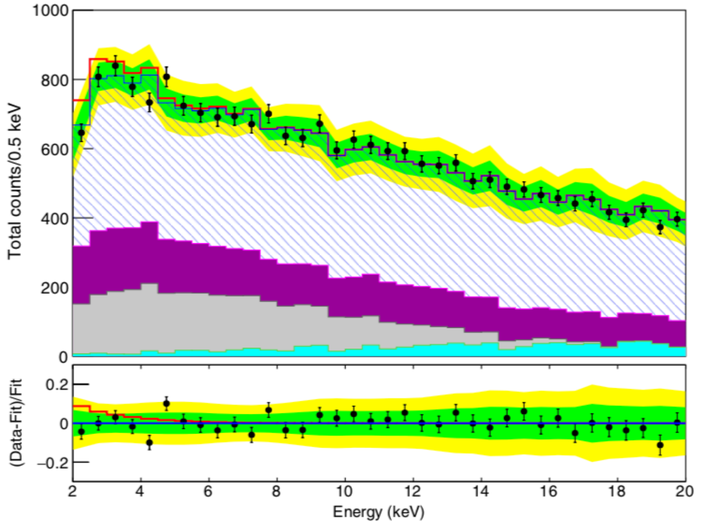
- ~70% efficiency at 2 keV

- 2 - 4 counts/keV/kg/day in region of interest depending on the crystal

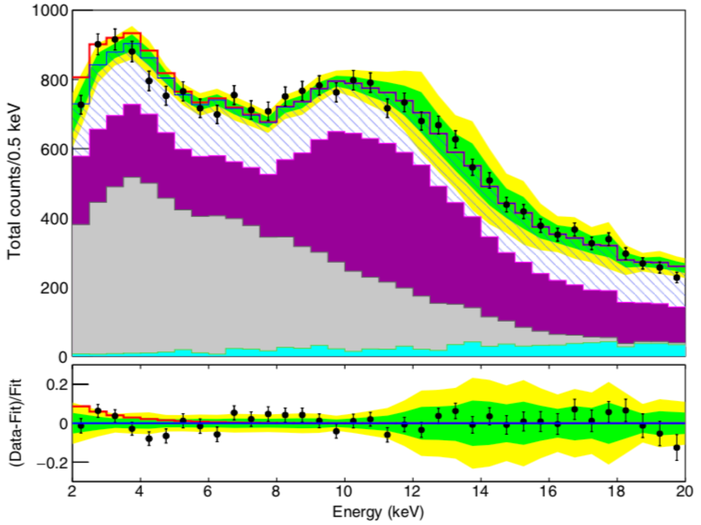
WIMP Analysis



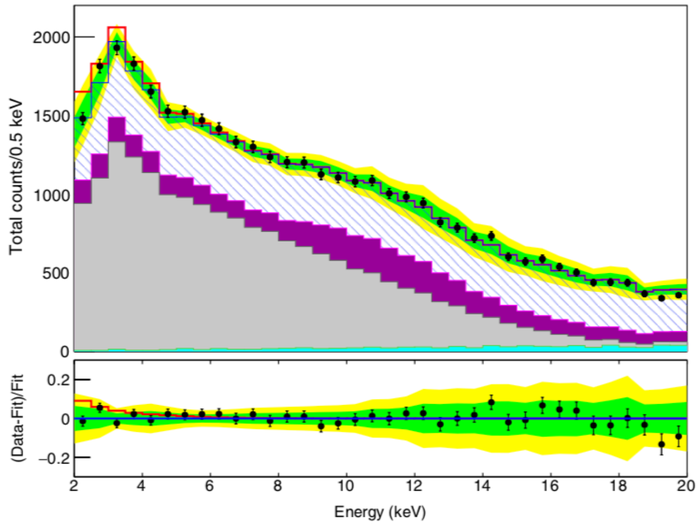
a) Crystal 1



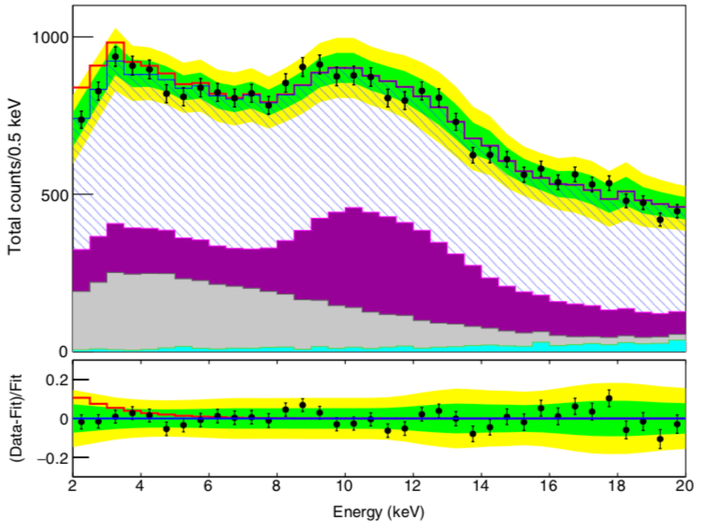
b) Crystal 2



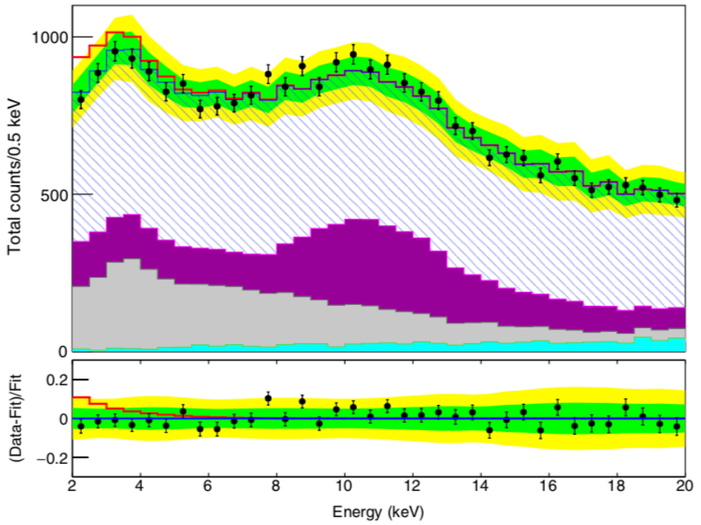
c) Crystal 3



d) Crystal 4



e) Crystal 6



f) Crystal 7

Crystal Growing R&D

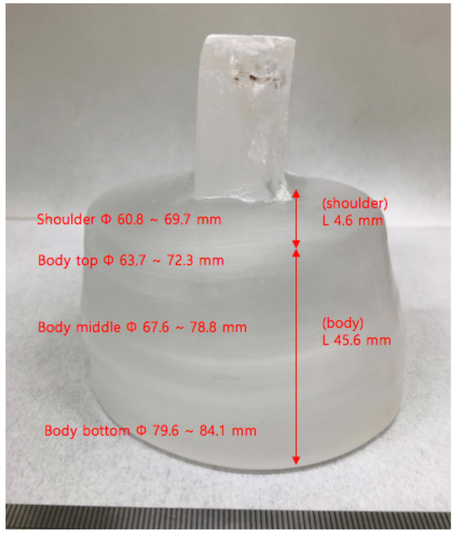
- Needs to grow our own crystal with low(er) background and better understanding of the crystal

- Powder purification system and crystal growers are available at IBS facility

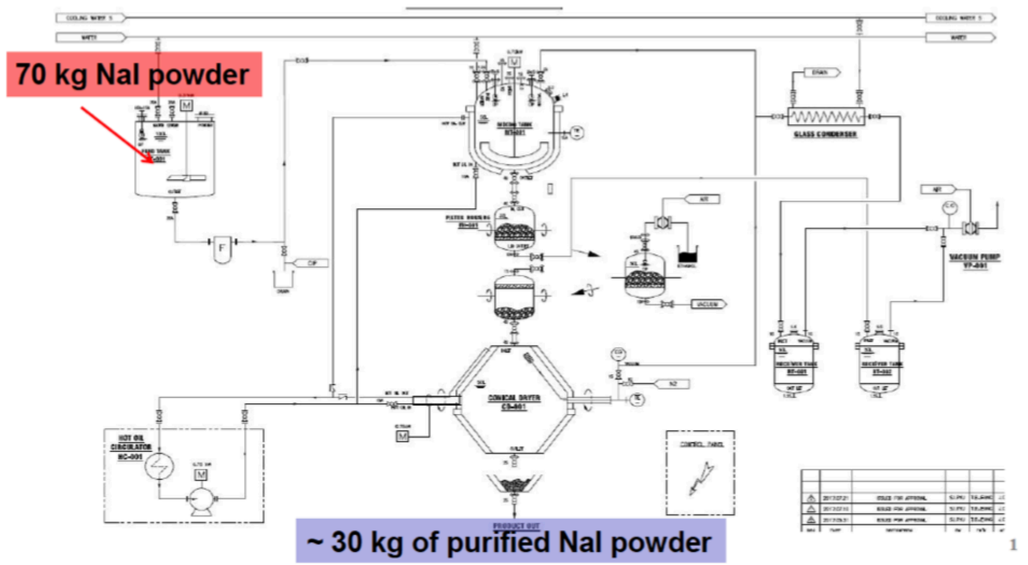
- Went through many trials and errors, found ways to reduce background contamination in powder & improve growth condition of NaI(Tl) crystals

- Current measurements show great improvements!

~ 100 kg NaI crystal (ingot) grower



Piping & Instrument Diagram



Possible Joint Analysis: COSINE-100 + ANAIS