Material Radioassay and Background Estimation for COSINUS Run 1

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Motivation, Experiment and Simulation

Scientific Motivation

DAMA/LIBRA reports an annual modulation compatible with dark matter at **13.6** σ, but the signal remains unconfirmed by an independent NaI-based experiment.

COSINUS strategy

- Model-independent test of the DAMA/LIBRA claim using the same target material.
- Eight 34 g NaI crystals operated as cryogenic scintillating calorimeters.
- Event-by-event discrimination between electron recoils and nuclear recoils.

Detection principle: The NaI crystal is operated as a cryogenic calorimeter instrumented with a remoTES. The scintillation light is collected by a surrounding silicon beaker light detector instrumented with a TES.

Particle discrimination: COSINUS uses the light yield, i.e. the amount of scintillation light measured for a given deposited energy. Nuclear recoils in Na and I are quenched relative to electron recoils and therefore populate lower light-yield bands.

Run 1 background challenge: A model-independent DAMA/LIBRA test requires a detailed understanding of radiogenic neutrons, cosmogenic activation and leakage from the electron-recoil band into the nuclear-recoil region of interest.

Neutrons remain the critical irreducible background because they produce nuclear recoils directly.

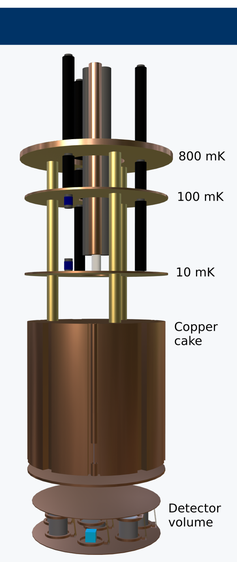
COSINUS Run 1 Setup

Detector

- 8 NaI crystals, 34 g each
- Cryogenic scintillating calorimeters
- Phonon + light readout
- Si beaker light detectors
- NOSV-Cu holders and shields

Shielding

- 7 m×7 m water tank
- Active muon veto, 30 PMTs
- Copper Cake above detectors, ∼200 kg
- Outer Cu shield, ∼2082 kg



Cryostat geometry in ImpCRESST.

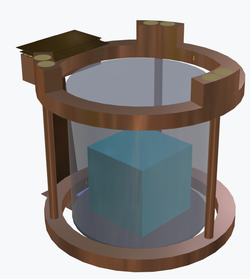
Monte Carlo Background Model

Simulation framework

- ImpCRESST based on Geant4 10.7.3
- EM physics: `G4EmStandardPhysics_option4`
- SOURCES4 for (α, n) and spontaneous-fission neutrons

Detailed detector geometry

The Monte Carlo includes the lower cryostat, copper shielding and near-detector components. Measured assay values are used as radioactive source terms for the dominant components, supplemented by reference values where no screening result is available.



Detector module as implemented in ImpCRESST.

Simulated sources

- EM: γ, β, X-rays, EC
- cosmogenic activation
- radiogenic U/Th neutrons

Simulated spectra are scaled by measured activities or concentrations. Upper limits are treated as conservative inputs; central values are taken as mean +1σ.

Inputs to the Background Model

Material Screening Campaign

Final Run 1 materials were screened with **HPGe gamma spectroscopy** at LNGS and SNOLAB, and with **HR-ICP-MS** at LNGS. The measured activities define the radiogenic source terms in the Monte Carlo model.

Material	Assay result	Role
NOSV-Cu	U/Th at ppt level	Detector holders / cold Cu shielding
OF01-Cu	$<$ 1 ppt U/Th	Outer Cu shield
NaI crystals	$<$ 0.01 ppb U/Th	Target
AISI316L steel	Batch selected	Dry well/support
Si, brass, POM	Screened	Near detector

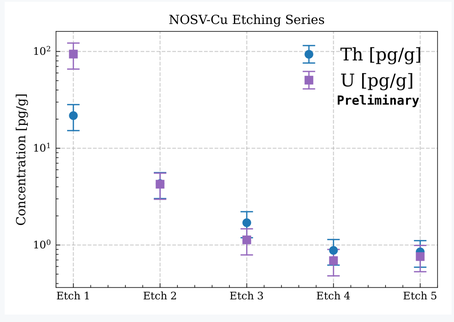
Copper cleaning:

acid soap → HNO_3+H_2O_2 etching → citric acid passivation → TECM.

NaI crystal radiopurity from HR-ICP-MS, upper limits:

$U < 0.01$ ppb, $Th < 0.01$ ppb, $K < 30$ ppb.

Equivalently, U/Th are constrained below ∼10 ppt in the grown SICCAS crystals.



Absolute U/Th concentrations measured after successive HNO_3 etching steps of NOSV-Cu.

Screening take-away: The COSINUS Run1 NaI crystals have radiopurity levels compatible with DAMA/LIBRA. For the dominant detector, shielding and cryostat components, measured assay values are used directly; reference values are used only where screening was not available.

Cosmogenic Activation

Cosmic-ray exposure during crystal growth, transport and assembly produces time-dependent EM backgrounds. Activation of NaI, Cu, brass and Si is modeled with ACTIVIA and literature production rates.

Activation history

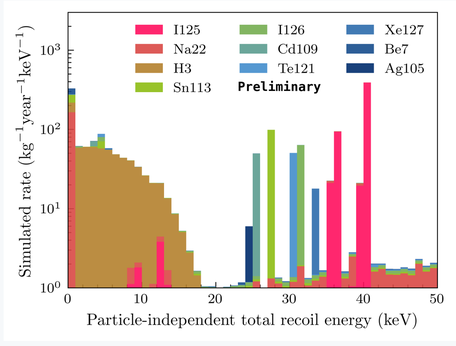
- NaI: crystal growth, transport and detector assembly
- Cu/brass: relevant construction/handling exposure after underground storage
- Si: long above-ground storage included

Production-rate input

- ACTIVIA used where no measured rate is available
- measured literature rates preferred
- if several measurements exist: weighted mean +1σ
- isotopes propagated if residual activity exceeds 1 μBq/kg after cooling

NaI and Cu inputs are mainly measurement-based; brass is treated with composition-weighted elemental rates.

Take-away: The activation model is based primarily on measured production rates with conservative treatment of uncertainties.



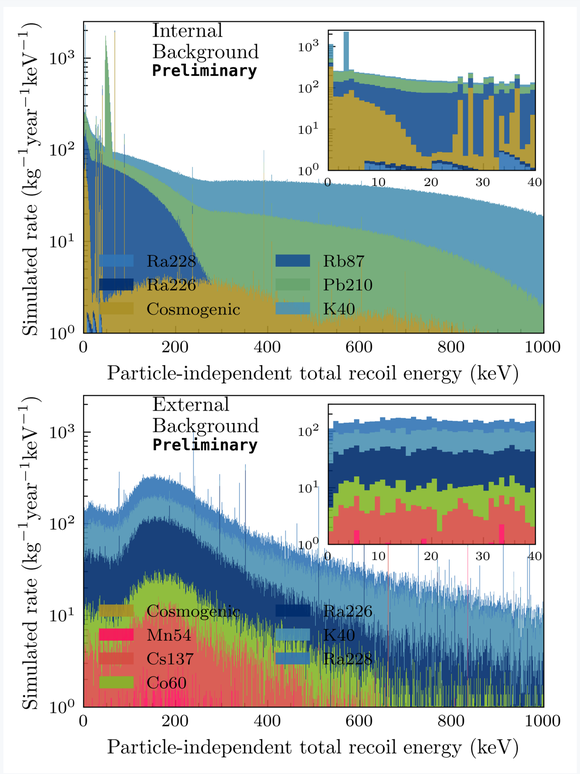
Cosmogenic EM contribution in the first Run 1 year.

Relevant products: ^{22}Na, ^{7}Be, ^{113}Sn, ^{105}Ag, ^{109}Cd, ^{125}I, ^{126}I, ^{127}Xe.

Short-lived isotopes may be visible in early Run 1 data.

Background Simulation Results

Electromagnetic Background



Simulated EM spectrum for the first year of COSINUS Run 1. Top: internal NaI background. Bottom: external components.

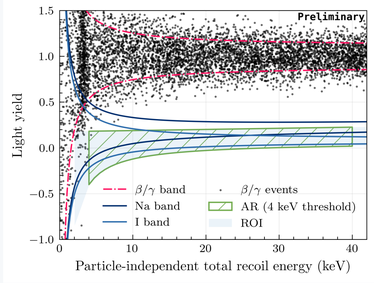
- Internal NaI contributes up to **75%** of the total EM background.
- Dominant low-energy features are ^{40}K electron-capture lines: **0.3 keV** and **3.2 keV** from ^{40}Ar de-excitation.
- External materials mainly contribute a Compton-like continuum.
- No significant Cu fluorescence peak is observed near 8 keV, indicating effective shielding/vetoing by the detector geometry.

Electromagnetic background take-away: The 3.2 keV ^{40}K line dominates potential leakage from the electron-recoil band into the nuclear-recoil ROI. Cosmogenic activation is subdominant overall, but can modify the early low-energy spectrum during the first months of Run 1.

ER-band Leakage into NR ROI

Concept: Electron-recoil background events are mapped into the light-yield–energy plane. Leakage occurs when the β/γ band overlaps the nuclear-recoil acceptance region close to threshold.

Benchmark LY–energy population (One detector-response scenario)

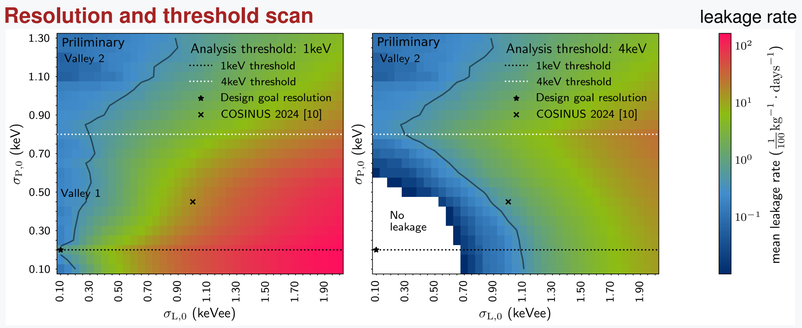


LY–energy plane for 99.3 kg days. The β/γ band, Na/I recoil bands and ROI are shown.

The 3.2 keV ^{40}Ar line from ^{40}K electron capture is the dominant feature that can leak into the nuclear-recoil ROI.

Fixed benchmark response ⟹ vary $\sigma_{P,0}$, $\sigma_{L,0}$ and threshold

Resolution and threshold scan



Mean leakage rate versus phonon and light baseline resolution. Left: 1 keV; right: 4 keV threshold.

Response parameters

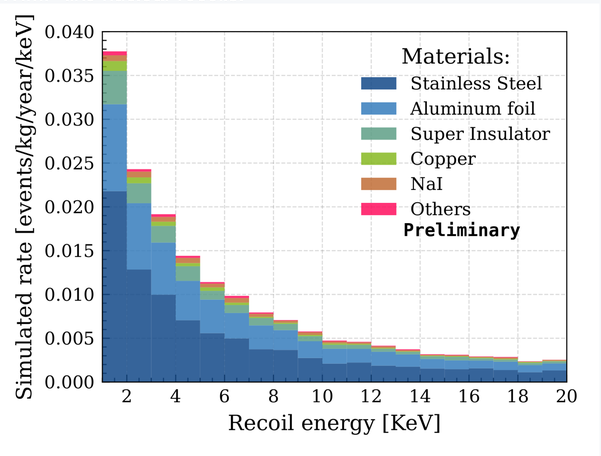
- $\sigma_{P,0}$: phonon-channel baseline resolution
- $\sigma_{L,0}$: light-channel baseline resolution
- E^{an}_{thr}: lower analysis threshold

Threshold choice $E^{an}_{thr} = \max(X, 5\sigma_{P,0})$ with X = 1 or 4 keV. The 4 keV threshold suppresses the dominant 3.2 keV ^{40}K leakage.

Leakage take-away: At the Run 1 design goal, $\sigma_{P,0}$ = 0.2 keV and $\sigma_{L,0}$ = 0.1 keV$_{ee}$, a 4 keV threshold suppresses leakage from the ^{40}K EC feature.

Radiogenic Neutron Background

Neutrons are the critical irreducible background because elastic neutron scatters in NaI mimic WIMP-like nuclear recoils.



Simulated neutron-induced recoil spectrum in NaI. The low-energy rise reflects neutron-scattering kinematics and transport through surrounding detector materials.

Material contribution and rates

Material	Share	1 keV	4 keV
Stainless steel	∼51%	0.11	0.06
Al flux-trapping foil	∼31%	0.06	0.04
Superinsulator	∼10%	0.02	0.01
NaI crystals	∼3.5%	0.01	0.01
Total		**0.21**	**0.13**

Units: events kg^{-1} yr^{-1} in the 1–40 keV and 4–40 keV ROIs.

Chains and selected topology

Quantity	Fraction
^{238}U chain	∼75%
^{232}Th chain	∼25%
^{235}U chain	negligible
Pure elastic events	96.3%
I-only scatters	55.9%
Na-only scatters	38.5%
Multi-scatter events	5.6%

NR-like selection rejects inelastic scatters, captures and coincident gammas.

Uncertainty budget:

- SOURCES4 neutron-yield uncertainty ∼20%
- neutron-transport modeling $\lesssim$20%
- screening upper limits make the rate estimate conservative.

Neutron take-away:

0.21 (0.13) events kg^{-1} yr^{-1} for thresholds of **1 (4) keV**

The simulated radiogenic neutron background is nearly two orders of magnitude below the DAMA/LIBRA modulation scale and is subdominant for the Run 1 exposure needed for a model-independent test.

Summary and Run 1 Impact

Neutron background
0.21 (0.13)
events kg^{-1} yr^{-1}
for 1 (4) keV thresholds
Nearly two orders of magnitude below the DAMA/LIBRA modulation scale.

ER-band leakage
4 keV
analysis threshold
suppresses the ^{40}K leakage line
At design resolution, leakage is negligible for the 4 keV ROI; at 1 keV, residual leakage is dominated by the 3.2 keV ^{40}K EC line.

DAMA/LIBRA test
265 kg days
1 keV threshold scenario
310 kg d required for 4 keV threshold
Exposure needed for a model-independent 3σ exclusion.

Dominant handles
NaI ^{40}K EC
drives low-energy EM leakage
U/Th neutrons
set the irreducible NR background

Main conclusion:

COSINUS Run 1 can test the DAMA/LIBRA claim with low expected background and modest exposure. The screened material inventory, detector-response model and Geant4/SOURCES4 simulations indicate that the simulated backgrounds are sufficiently low for the planned Run 1 exposure.

✓ final materials screened with HPGe and HR-ICP-MS ✓ neutron background below DAMA/LIBRA scale ✓ 4 keV threshold suppresses ^{40}K leakage

Selected references

Bernabei et al., Universe 4, 116 (2018); Angloher et al., EPJC 84 (2024); Angloher et al., PRD 110 (2024); Angloher et al., arXiv:2504.18263 (2025); Geant4 Collaboration, NIM A 506 (2003).

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COSINUS.it

Poster contribution:

COSINUS Run 1 radioassay, cosmogenic activation and background simulation.

Results to be published in a forthcoming COSINUS paper.