

The COSINUS project: development of new NaI-based cryogenic detectors for direct dark matter search

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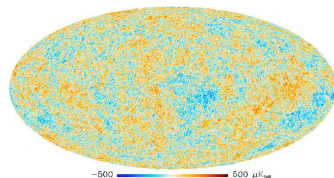
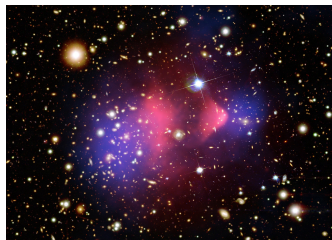


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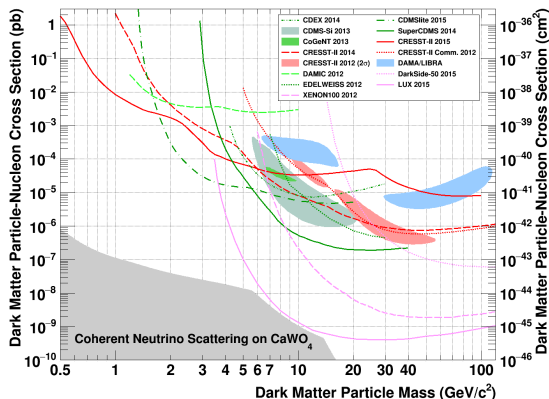


Hints for the existence of dark matter

- Hints for the existence of dark matter (DM) on several length and time scales
 - Precise measurement of temperature fluctuations of cosmic microwave background
- Dark matter contribution: $\sim 27\%$
- Nature of DM remains unknown
 - Several candidates on different mass scales and with different interactions:
- WIMPs, axion-like particles, asymmetric DM, ...
- Direct search: observation of DM interacting with detector material

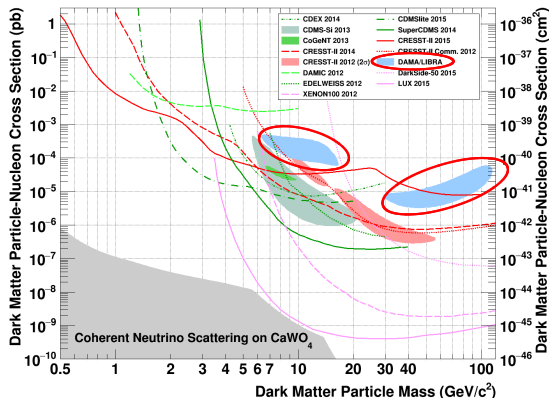


Current results of direct dark matter searches



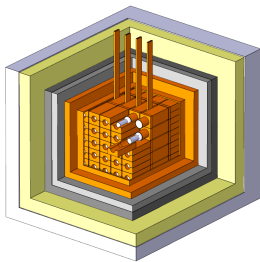
- Filled regions: dark matter interpretations of excesses over expected backgrounds
- Lines: Exclusion limits based on null results

Current results of direct dark matter searches



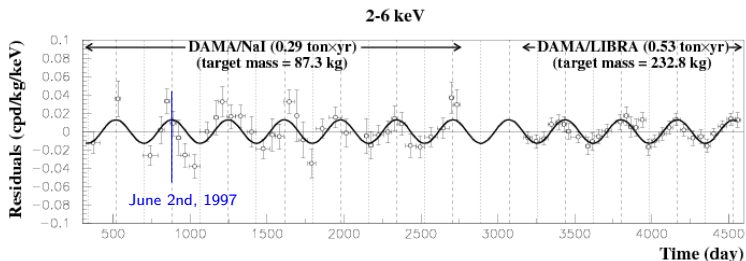
- Long standing claim from DAMA/LIBRA
 - Excluded by null results of other experiments?
- Comparison of experiments is model dependent

DAMA/LIBRA experiment (\rightarrow arXiv:1308.5109)



- Target material: ~ 250 kg NaI(Tl)
- Detection of scintillation light by PMTs
- \rightarrow Less scintillation light for nuclear recoils (\rightarrow dark-matter signal)
 - Single channel read-out: no active suppression of β/γ backgrounds
- \rightarrow Annual modulation of dark-matter signal

DAMA/LIBRA claim



Eur.Phys.J. C **56** 333 (2008), arXiv:0804.2741

- Robust modulation signal over several annual cycles ($\sim 9.3\sigma$)
 - Frequency and phases match expectation for dark matter
 - Dark-matter interpretation is in (strong) tension to null results
- But: comparison of different materials is model dependent
- ⇒ **Detectors based on NaI for model-independent cross checks**

Model independent cross check of DAMA/LIBRA results

- Production of DAMA/LIBRA-like detectors is challenging:
 - Very low threshold (less scintillation light for nuclear recoils)
 - Very low radiopurity due to single channel read-out
 - Cryogenic detectors based on NaI crystal with two channel read-out:
 - Simultaneous measurement of phonons and scintillation light
 - Measurement of deposited energy independent of interaction type
 - Discrimination between scatterings off electrons and nuclei
 - Background suppression
 - For dark matter discovery: more details on interactions
 - Successfully operated in CRESST-II (CaWO_4)
- ⇒ The COSINUS project:
- Development of cryogenic detectors based on undoped NaI crystals with two channel read-out
 - R&D project at Laboratori Nazionali del Gran Sasso, Italy
 - Funded by CSN5 of Istituto Nazionale di Fisica Nucleare (INFN)

The COSINUS project

Cryogenic Observatory for Signatures seen in Next-generation Underground Searches

Collaborating institutes:

- Max-Planck-Institut für Physik- D-80805 München - Germany
- INFN - Sezione di Milano-Bicocca, I-20125 Milano - Italy
- Dipartimento di Fisica, Università di Milano-Bicocca, I-20126 Milano - Italy
- Institut für Hochenergiephysik, Österreichische Akademie der Wissenschaften, A-1050 Wien - Austria
- Atominstitut, Technische Universität Wien, A-1020 Wien - Austria
- INFN - Laboratori Nazionale del Gran Sasso, I67010 Assergi (AQ) - Italy
- Gran Sasso Science Institute, I-67100 L'Aquila - Italy

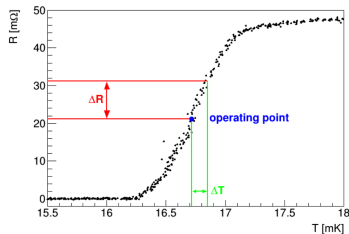


Energy deposition in NaI



- Energy deposition in NaI
- Generation of phonons (heat) and scintillation light
- Majority of energy is converted into phonons
- Small fraction (few percent) is converted into scintillation light

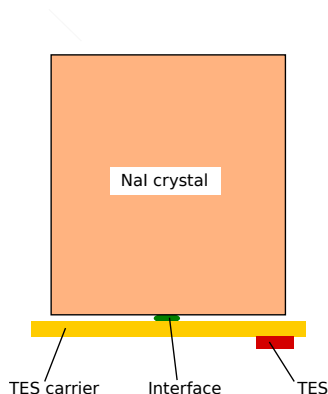
Phonon detector - Transition Edge Sensor



Phase transition of a tungsten TES

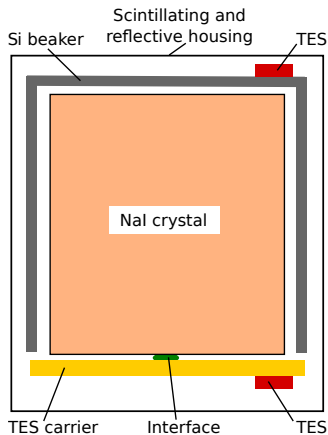
- Precise measurement of deposited energy
- Sensitive thermometer to measure phonon signal
- **Transition Edge Sensor (TES)**
 - Superconducting metal-film operated in steep phase transition between super and normal conducting phase
 - Attached to absorber crystal
 - Phonons enter TES
 - Small temperature rise of the TES
 - ⇒ Measurable change of resistance due to steep phase transition
- Detector operated at mK temperatures

Phonon detector - TES carrier



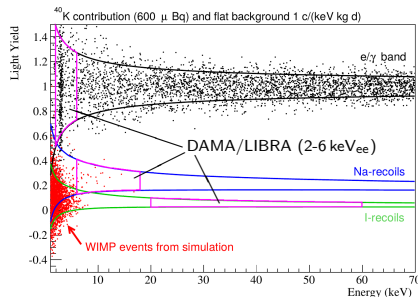
- NaI is hygroscopic
- TES can not be directly evaporated on NaI crystal
- ⇒ TES is evaporated onto carrier disk (e.g. CdWO_4)
- Carrier disk is thermally coupled to NaI
- Events in carrier disk can be identified via different pulse shapes
- Successfully applied to CRESST-II detectors (EPJ C **74** 3184 (2014), arXiv:1407.3146)

Light detector - Beaker design



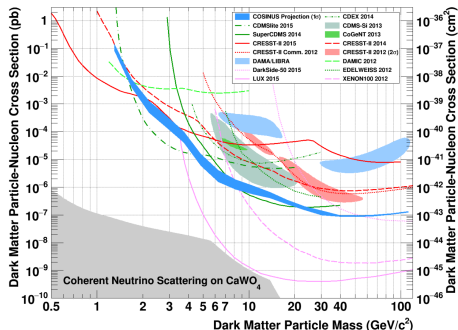
- Cryogenic light-detector based on Si
- TES to read out scintillation-light signal
- Beaker-shaped Si crystal
 - Efficient light absorption
 - Veto for external β/γ backgrounds
 - Veto for decays close to surfaces
- Without veto from light detector: important background source for nuclear recoils (EPJ C **72** 1971 (2012), arXiv:1109.0702)
 - Operated successfully in CRESST-II phase 2
- Scintillating and reflective housing to further increase light-absorption efficiency

Simulated data corresponding to 100 kg-days



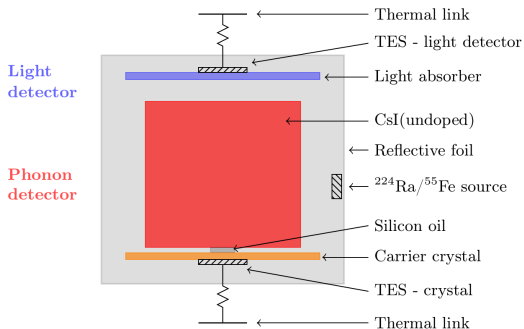
- Light yield: Ratio of scintillation light and deposited energy
- Solid lines: central 80 % bands
- Black events: background (constant + ^{40}K) from DAMA/LIBRA
- Red events: Dark matter signal from DAMA/LIBRA claim
- Exposure: 100 kg-days (about 1 year with two COSINUS detectors)
- Threshold 1 keV for nuclear recoils

Estimated sensitivity



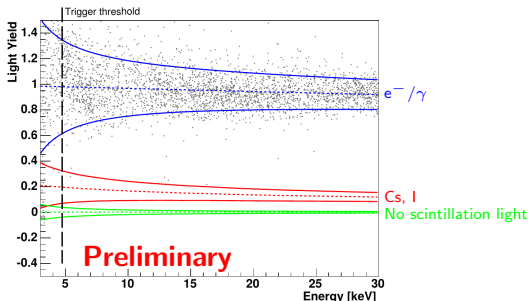
- Background-only simulation
- Projected limit for spin-independent elastic scattering off nuclei
- Exposure of 100 kg-days is enough to test the DAMA/LIBRA claim under standard assumptions
- **Large variety of models predicting nuclear recoils also excluded**

First tests with CsI



- Handling of NaI is challenging (hygroscopic)
- First tests using CsI
- Similar setup as for NaI

First tests with CsI - Preliminary results



- Threshold of ~ 4.7 keV for nuclear recoils (can be further optimized)
- Events below threshold triggered by light detector (→ ^{55}Fe source)
- Good discrimination between electron and nuclear recoils
- Dedicated paper soon ($\mathcal{O}(\text{days})$) on arXiv

Conclusions and outlook

Conclusions

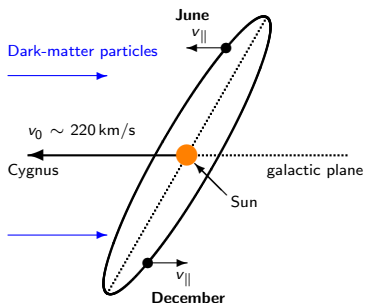
- Long standing DAMA/LIBRA claim is in tension with null results from other experiments (\rightarrow model dependent!)
- COSINUS R&D project: cryogenic calorimeters based on NaI
- Unique feature: simultaneous measurement of heat and scintillation
 - Energy measurement independent of interaction/particle type
 - Particle identification and background suppression
- First tests with CsI very promising

Outlook

- Infrastructure for transport and handling of hygroscopic NaI
- Development of detectors based on NaI
- Long-term measurement with NaI detector

Backup slides

Annual modulation of dark-matter rate



- Motion of the earth around the sun
- ⇒ Modulation of relative velocity between earth and dark matter
- ⇒ Annual modulation of dark-matter signal
- Maximum in June; minimum in December