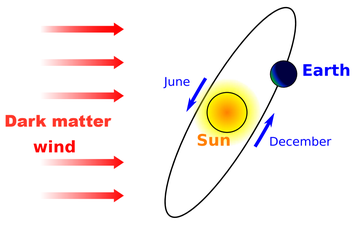
Vanessa Zema for the **COSINUS collaboration**

18th INTERNATIONAL WORKSHOP on LOW TEMPERATURE DETECTORS | July 22-26 2019 Milano, Italy

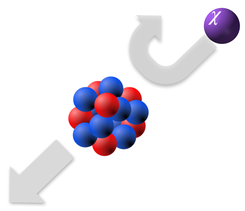
Cryogenic calorimeters for the direct dark matter search with NaI crystals

DIRECT DARK MATTER SEARCH



- Cosmology and astrophysics suggest the existence of dark matter
- The Earth is expected to be constantly hit by a wind of dark matter particles

- Low background detectors on the Earth aim at detecting tiny energy depositions (O(keV)) released in the target material by scatterings of dark matter off nuclei



EVENT RATE

- v: dark matter velocity
- v_{obs}: Earth velocity around the galactic center
- v_{esc}: escape velocity from the galaxy

Number of targets

$$\frac{dR}{dE_R} = N_T \frac{\rho_0}{m_\chi} \int_{v_{min}}^{|\mathbf{v}+\mathbf{v}_{obs}|<v_{esc}} d^3v \; v f(\mathbf{v}) \frac{d\sigma}{dE_R}$$

Differential dark matter-nuclei cross-section

Local DM density over DM mass

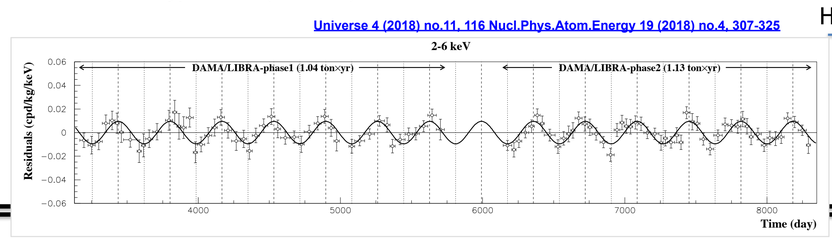
- v_{min}: minimum-dark-matter-velocity visible in the detector (sensitivity limit)

Maxwell-Boltzmann velocity distribution

ANNUAL MODULATION

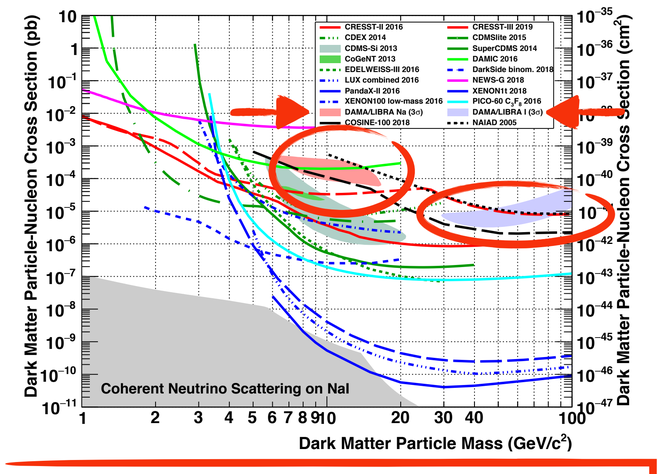
- The composition of the Earth-velocity around the galactic center and the Earth-velocity around the Sun introduces an annually periodic time-dependence in the event rate
- The DAMA/LIBRA collaboration is detecting since 20 years a signal compatible with the DM hypothesis (12.9 σ!!)

Universe 4 (2018) no.11, 116 Nucl.Phys.Atom.Energy 19 (2018) no.4, 307-325



However

EXPERIMENTAL PANORAMA

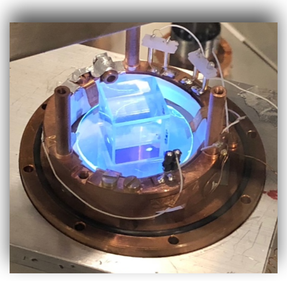


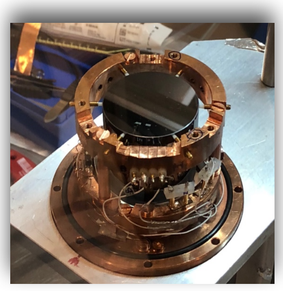
Despite of the extreme efforts, results are still not consistent in the standard scenario

COSINUS: NaI-CRYOGENIC CALORIMETERS

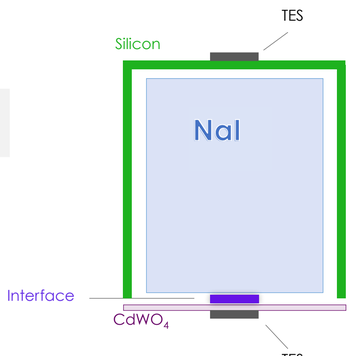
- Material-independent cross-check of the DAMA/LIBRA result
- NaI crystal: hygroscopic, low Debye temperature, ^{40}K contamination
- NaI crystals for the first time operated at mK-temperature as scintillating calorimeters

JINST 12 (2017) no.11, P11007





DUAL-CHANNEL READOUT: PHONON and LIGHT



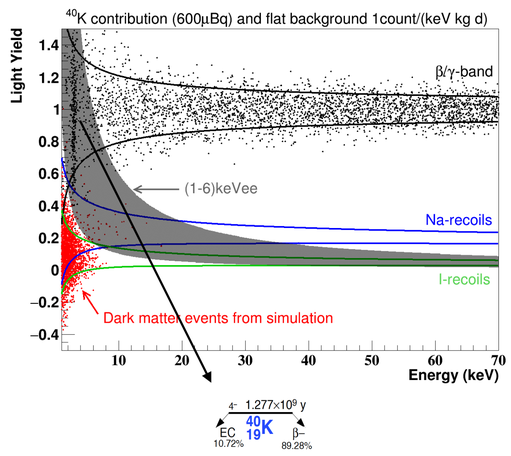
Si-beaker + TES is the light-channel

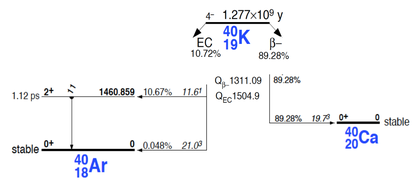
Scintillation light (few %)
amount of emitted light depends on particle type
→ LIGHT QUENCHING

NaI crystal + TES is the phonon-channel

Phonon signal (~ 90 %)
(almost) independent of particle type

PARTICLE-DISCRIMINATION

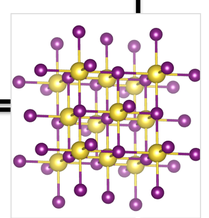




SIMULATION DATA:
- 20 ppb of ^{40}K
- flat background: 1 cpd/(keV kg)
- threshold (NaI): 1 keV
- ε=50%(>2keV), 20%(1-2 keV)
- light energy conversion: 4%
- QF(Na) ~ 0.3
- QF(I) ~ 0.09
- σ^{SI}= 2 x 10^{-4} pb (m_{DM}=10 GeV/c²)

The dark-grey-area indicates the electron-equivalent energy range of 1-6 keVee, where the DAMA experiment observes a positive signal for modulation amplitude

$$\text{Light Yield} = \frac{\text{Light Energy}}{\text{Phonon Energy}}$$



PROTOTYPE DEVELOPMENT: STATUS

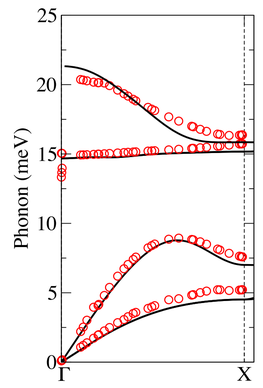
Light yield	~ 13% (~ 30 photons/keV)
Light-energy-threshold	~ 0.6 keV$_{ee}$ (σ ~ 15 eV)
Phonon-energy-threshold	~ 5-6 keV

CRYSTAL PRODUCTION: RESULTS

^{40}K radio-purity: 5-9 ppb at crystals' nose and 22-35 ppb at crystals' tail

Goal achieved!

VIBRATIONAL PROPERTIES OF NaI-CRYSTALS



PHYSICAL REVIEW VOLUME 119, NUMBER 3 AUGUST 1, 1960

Lattice Dynamics of Alkali Halide Crystals*

A. D. B. Woods, W. Cochran,† and B. N. Brockhouse
Physics Division, Atomic Energy of Canada Limited, Chalk River, Ontario, Canada

(Received March 11, 1960)

The paper comprises theoretical and experimental studies of the lattice dynamics of alkali halides. A theory of the lattice dynamics of ionic crystals is given based on replacement of a polarizable ion by a model in which a rigid shell of electrons (taken to have zero mass) can move with respect to the massive ionic core. The dipolar approximation then makes the model exactly equivalent to a Born-von Kármán crystal in which there are two "atoms" of differing charge at each lattice point, one of the "atoms" having zero mass. The model has been specialized to the case of an alkali halide in which only one atom is polarizable, and computations of dispersion curves have been carried out for sodium iodide. We have determined the dispersion $\nu(\mathbf{q})$ relation of the lattice vibrations in the symmetric [001], [110], and [111] directions of sodium iodide at 110°K by the methods of neutron spectrometry. The transverse acoustic, longitudinal acoustic, and transverse optic branches were determined completely with a probable error of about 3%. The dispersion relation for the longitudinal optic (LO) branch was determined for the [001] directions with less accuracy. Frequencies of some important phonons with their errors (units 10^{12} cps) are: TA[0,0,1] 1.22 ± 0.04, LA[0,0,1] 1.82 ± 0.06, TA[½,½,½] 1.52 ± 0.05, LA[½,½,½] 2.32 ± 0.06, TO[0,0,0] $3.0_0\pm0.1$, TO[0,0,1] $3.8_0\pm0.1$, TO[½,½,½] $3.5_0\pm0.1$. The agreement between the experimental results and the calculations based on the shell model, while not complete, is quite satisfactory. The neutron groups corresponding to phonons of the LO branch were anomalously energy broadened, especially for phonons of long wavelength, suggesting a remarkably short lifetime for the phonons of this branch.

BUILDING CONSTRUCTION: PROJECT ONGOING!

Background budget evaluation and shielding concept investigated using GEANT4 simulations (paper in preparation):

Shielding Concept

- 7 x 7m water tank, as neutron moderator and active Cherenkov veto
  - efficient muon veto using 18 - 28 PMTs and defining a 5-fold PMT coincidence with a trigger on the single photoelectron within a time window of a few 100 ns.
- Internal shielding (from out- to in-side):
  - dry-well = 0.4 cm (stainless)
  - 8 cm of copper
- Top shielding: 30 cm of copper

Clean room

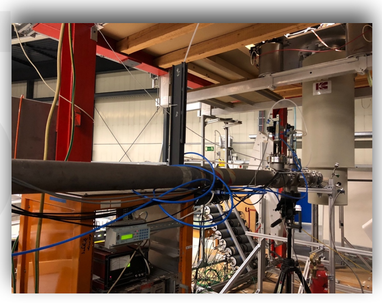
- On top of the structure surrounding the water tank, a clean room for detector mounting will be built

Control room

- Close to the water tank, a three level control room will host the DAQ and the electronics, the cryostat-related infrastructure and a working area

COSINUS will be located under the Gran Sasso mountain (Italy):
~ 3600 wme (water meter equivalent)

QUENCHING FACTOR MEASUREMENTs



- **Room-temperature measurements** are planned to be done at TUNL in U.S., for different concentrations of Tl-dopant
- **Low-temperature measurements** can be done with AmBe source in the underground R&D facility of CUPID-0 in Hall-C in LNGS or at Max-Planck-Institute (MPP). At the Meier-Leibnitz Laboratorium - Tandem accelerator (photo, facility now closed), two beam-time with pure NaI and NaI(Tl) were already performed and data-taking was successfully run. Data analyses are ongoing.

PLAN FOR THE FUTURE

www.cosinus.it

- COSINUS will provide a model-independent cross-check of the DAMA/LIBRA result
- Light-energy-threshold (0.6 keVee) already below the one of DAMA/LIBRA, which is ~ 1keVee
- Phonon-energy-threshold ~ 5-6 keV
- Studies on the properties of NaI on a more fundamental level started
- Room- and low-temperature quenching factor measurements planned
- Building construction project under preparation, according to new GEANT4 simulation results

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