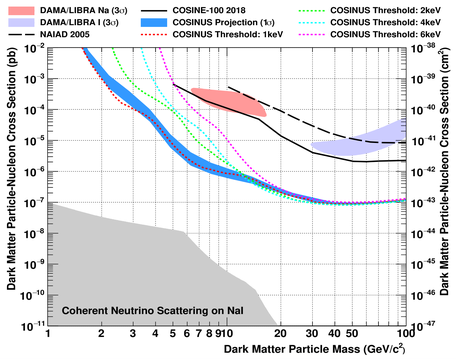
COSINUS:
a NaI-based cryogenic scintillating calorimeter for DARK MATTER search

andrei puiu @ gssi.it

find out more on www.cosinus.it

Dark Matter search

The **DAMA/LIBRA** collaboration claim: detection of dark matter by measuring the expected annually modulated event rate: exposure 2.46 ton × yr, collected in 14 annual cycles (Nucl.Phys.Atom.Energy 19 (2018) 4, 307-325)
Detector: 250 kg of radiopure NaI crystals. Signal: scintillation light at room temperature. Detection: Photomultipliers, 5-10 p.e./keV (quenched light emission for nuclear recoil). Frequency and phase match the expectations for a DM signal.
Cross-check is necessary



The blue band indicates the projection for a 100kg*d (gross exposure) run. Dotted lines are one of the simulated data sets for different thresholds. Only the threshold was changed, the resolution was kept at 0.2keV (sigma) which is conservative. (Angloher et al., Eur. Phys. J. C 76 441, 2016)

COSINUS:
- **NaI crystal:** same target material - eliminates uncertainties and systematics related to the astrophysical parameters and the DM interaction in the detector.
- **Cryogenic calorimeter: lower threshold and better energy resolution**
- **Simultaneous readout** of phonon (heat) and scintillation (light) signal allows event-by-event **discrimination**. We can eliminate the dominant e/gamma background, and also identify recoils off Na and I nuclei, by measuring the two different light yields

(Angloher et al., Eur. Phys. J. C 76 441, 2016)

galactic escape velocity — velocity distribution

$$\frac{dR}{dE_r} = \frac{\rho_\chi}{m_N m_\chi} \cdot \int_{v_{min}}^{v_{esc}} d^3v\, f(\vec{v})\, v \frac{d\sigma(\vec{v}, E_r)}{dE_r}$$

min. velocity to produce a recoil of energy E_r — DM-nucleon cross-section

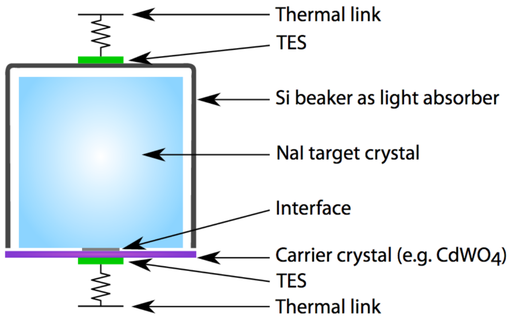
Astro physics
dark matter halo
velocity distribution

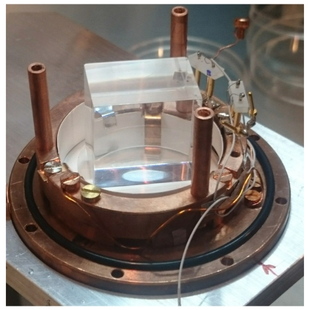
Particle physics
interaction mechanism

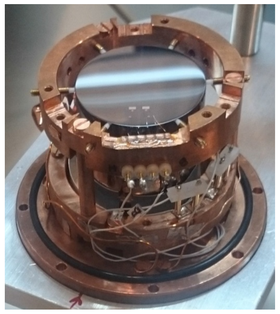
COSINUS 1π (first phase in the next 2 years): clarify if the DAMA signal has a nuclear recoil origin, **independent** of interaction mechanism and dark matter halo model
COSINUS 2π: **modulation search** to investigate other possible DM interactions - electron interaction (in case of no signal in 1π-phase) or confirm dark matter origin (in case of positive signal in 1π-phase)

COSINUS NaI crystal production is starting in Shanghai at SICCAS using ultrapure NaI powder -> Production and testing will take place in Gran Sasso Laboratory. Measurements of Light Yield from room temperature to 10 K is being performed for both NaI and NaI:Tl doped crystals

Detection technique

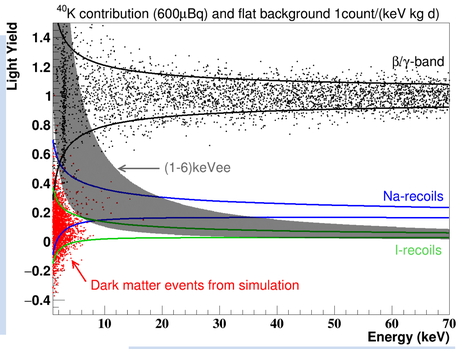


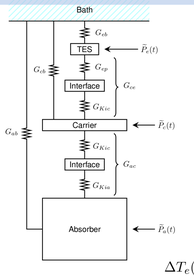


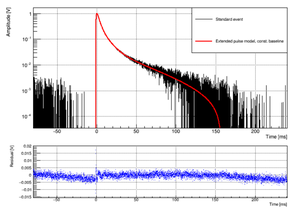


The NaI crystal is coupled to a carrier crystal (e.g. $CdWO_4$) onto wich a very sensitive **Transition Edge Sensor** (TES) is evaporated, since NaI can not withstand the temperature at which the TES film is evaporated. Such TES is used for the phonon channel readout (90% of deposited energy). A **Si beaker** encapsulates the NaI crystal and it is used as a calorimetric light detector read out by a TES as well

BLACK events: flat e/gamma background (1 count/keV/kg/day)+ ^{40}K contribution (600 uBq)
BLUE band: recoils off Na nuclei
GREEN band: recoils off I nuclei
RED: Simulated dark matter events compatible to DAMA in the standard scenario
(K. Schäffner et al. J Low Temp Phys 193, pages1174–1181(2018))



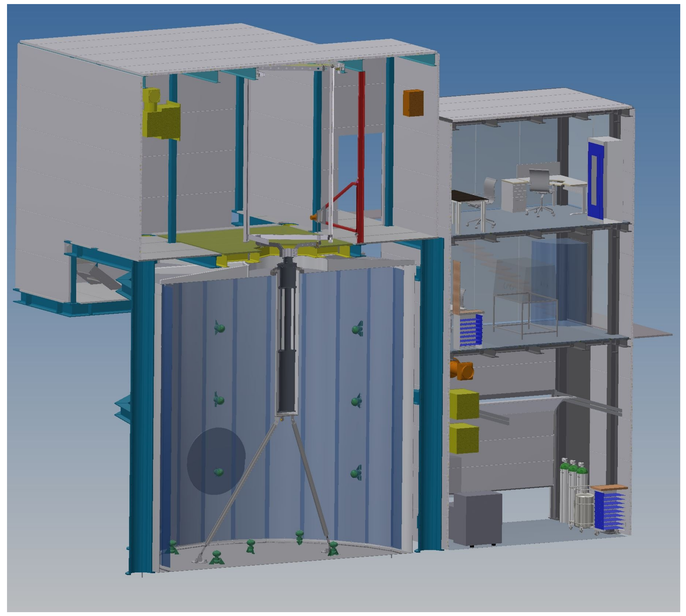




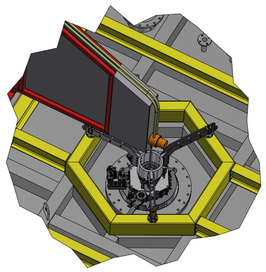
$$\Delta T_e(t) = \sum_{i=1}^{3} \underbrace{A_i\,[e^{\lambda_i t} - e^{-t/\tau'_n}]}_{\text{A-components}} + \sum_{i=1}^{3} \underbrace{B_i\,[e^{\lambda_i t} - e^{-t/\tau_t}]}_{\text{B-components}}$$

A dedicated thermal model that describes the different power inputs on the detector elements has been developed. We can now separate the thermal pulses of the TES into two separate components from which the light and heat amplitudes are extracted (V. Zema, Ph.D. thesis 2020 GSSI & Chalmers)

Experimental status



COSINUS will start to be built in **Hall B of LNGS this autumn**.
A 270 m^3 **water tank** (7 m tall, 7 m diameter) will provide shielding against cosmogenic neutrons, environmental gammas and neutrons. It will act as an **active veto** for tagging muons and muon-induced showers.



The dry dilution refrigerator will be strongly **decoupled** from the detector frame.
The Pulse-Tube cryocooler will be mechanically isolated from the rest of the dilution refigerator in order to reduce the vibrations induced on the detectors

NEXT STEPS:
- reach 1 keV threshold and demonstrate discrimination ability
- finalise the design of the custom dilution refrigerator (i.e. SQUID readout, cabling, radiation shielding)
- design the final detector module
- test the crystal production