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

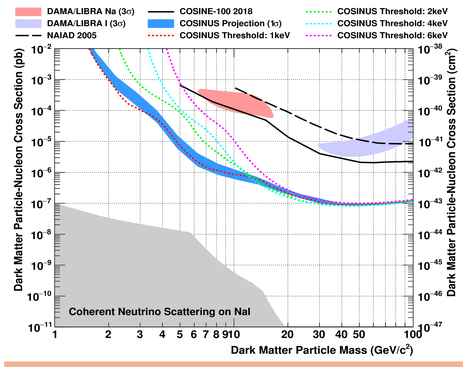
andrei puiu @ gssi

find out more on www.cosinus.it

## Dark Matter searches

The **DAMA/LIBRA** collaboration claim: 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 statistical fluctuation 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 higher energy resolution**
**- Simultaneous readout** of phonon (heat) and scintillation (light) signal allows event-by-event **discrimination**. Not only we can identify and eliminate the dominant e/gamma background, but also identify events on Na and on I nuclei, due to different light yeld.
*(Angloher et al., Eur. Phys. J. C 76 441, 2016)*

*galactic escape velocity* — *velocity distribution*

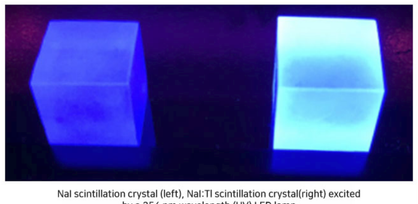
$$\frac{dR}{dE_r} = \frac{\rho_\chi}{m_N m_\chi} \cdot \int_{v_{min}}^{v_{esc}} d^3v\, f(\vec{v})\, v \frac{d\sigma(\vec{v}, E_r)}{dE_r}$$

*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

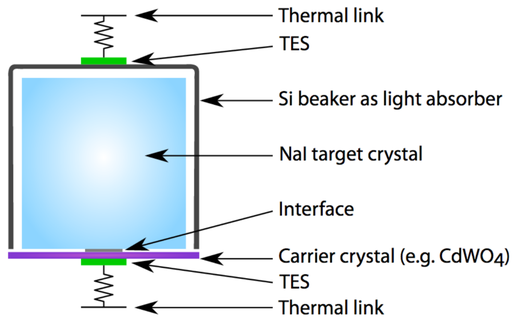
**COSINUS 1π** (first phase in the next 5 years): clarify if the DAMA signal has a nuclear recoil origin, **independent** of interaction mechanism and dark matter halo model
**COSINUS 2π**: **modulation search** to clarify dark matter - electron interaction (in case of no signal in 1π-phase) or confirm dark matter origin (in case of positive signal in 1π-phase)

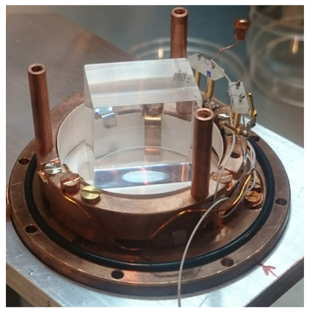


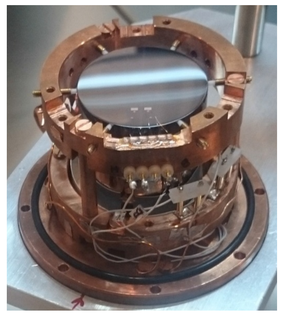
NaI scintillation crystal (left), NaI:Tl scintillation crystal(right) excited by a 254 nm wavelength (UV) LED lamp

Tl-doped NaI has a higher light output at room temperature. We will investigate the low temperature scintillation properties (QF) of NaI:Tl and NaI in order to choose pure or doped crystals and the most suitable Tl concentration. NaI:Tl (100-4000 ppm) will be measured at Diamond Synchrotron Radiation facility (Oxford, UK).

## Detection technique

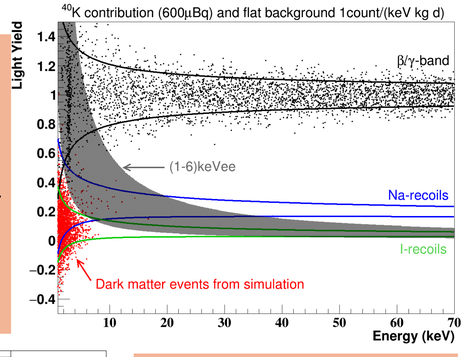


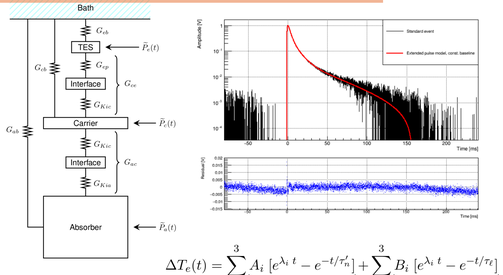





**The NaI crystal** is coupled to a carrier crystal (e.g. $CdWO_4$) onto wich a very sensitive **Transition Edge Sensor** (TES) is evaporated, since NaI can not whitstand the temperature at which the TES film is evaporated. The TES is used for the phonon channel readout (90% deposited energy). A **Si 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: nuclear recoils:** ~keV energy deposit in the phonon channel, very few photons emitted
(*K. Schäffner et al. J Low Temp Phys 193, pages1174–1181(2018)* )

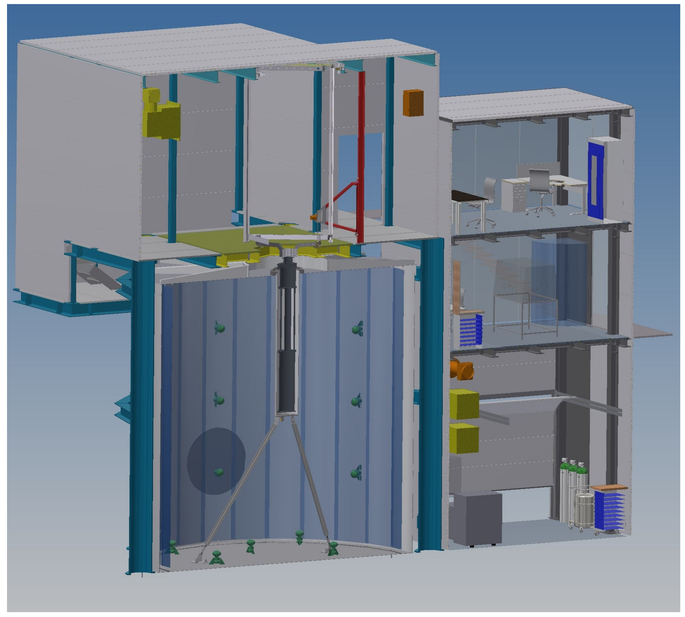


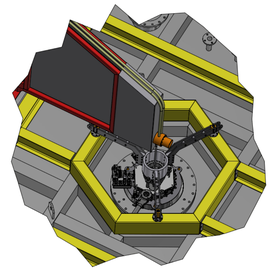

$$\Delta T_e(t) = \sum_{i=1}^{3} A_i \underbrace{\left[e^{\lambda_i t} - e^{-t/\tau_n}\right]}_{\text{A-components}} + \sum_{i=1}^{3} B_i \underbrace{\left[e^{\lambda_i t} - e^{-t/\tau_t}\right]}_{\text{B-components}}$$

**A new thermal model** has been developed to take into account the heat transport and light absorption inside the carrier.
The very good agreement with experimental data allows to design and tune new detectors (*V. Zema, Ph.d thesis 2020 GSSI & Chalmers)*

## Experimental status



**COSINUS** has been approved by the Laboratori Nazionali del Gran Sasso Director and Scientific committee. It will be hosted in **Hall B**. 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 Pulse-tube based dilution refrigerator will be strongly **decoupled** from the detector frame. There are ongoing tests to study mechanical decoupling at different stage. It is crucial to damp the dangerous vibrations which can spoil the perfromance of the cryogenic calorimeters

**NEXT STEPS:**
- reach 1 keV threshold and demonstrate discrimination ability
- finalising the design of the muon veto
- designing the internal copper shield close to the detector volume
- start the tank construction at LNGS and service buildings (under final approval)