A NaI-based cryogenic scintillating calorimeter:
status and results from the first COSINUS prototype detectors

COSINUS

Karoline Schaeffner on behalf of the COSINUS collaboration | Gran Sasso Science Institute, Italy

MOTIVATION | DARK MATTER

DIRECT DARK MATTER SEARCH

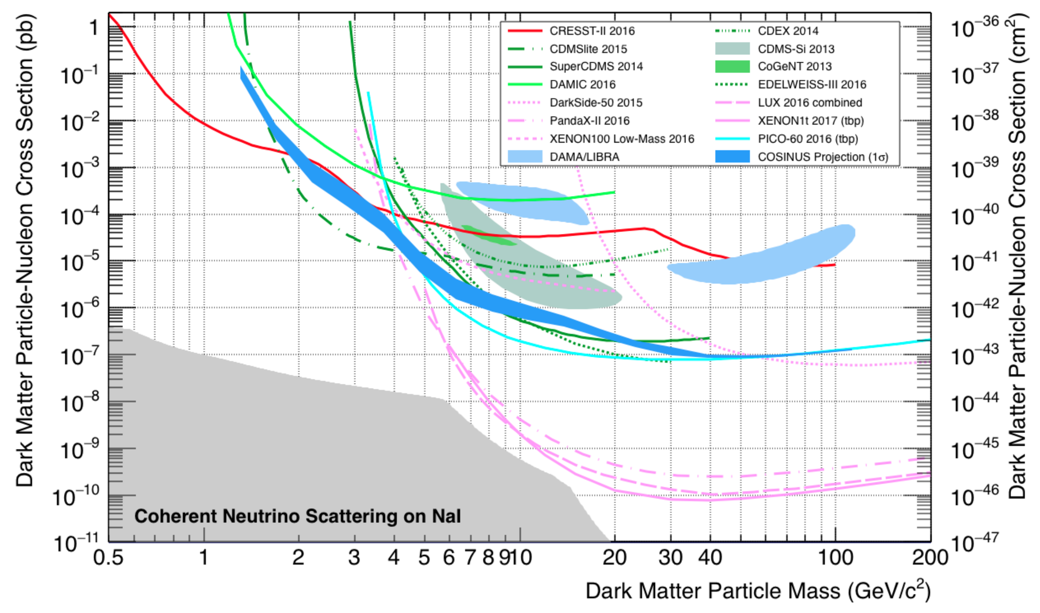
Assumption
Particle-like dark matter which interacts with Standard Model particles

Most common
Dark matter particles scatter off the nucleus and induce nuclear recoils

DAMA/LIBRA CLAIM
Bernabei et al. EPJ (2013) 73:2648

- 250 kg of high-pure NaI (Tl) crystals
- detect scintillation light using dedicated PMTs
  - ~ 5 -7.5 PE/keV
  - nuclear recoils show less light (LIGHT QUENCHING)
- **positive evidence** for the presence of DM particles in the galactic halo via annual modulation signal
  - ~ 1.33 ton-y exposure, statistics > 9σ
  - frequency and phase match expectation for DM

DARK MATTER LANDSCAPE



Long-reigning contradicting situation in the dark matter sector: the positive evidence for the detection of a dark matter modulation signal claimed by the DAMA/LIBRA collaboration is (under standard assumptions) **inconsistent with the null-results** reported by most of the other direct dark matter experiments.

UNKNOWNS ?

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

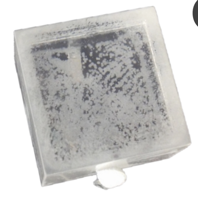
galactic escape velocity; velocity distribution; min. velocity to produce a recoil above threshold; DM-nucleon cross-section

Astro physics
dark matter halo velocity distribution

Particle physics
interaction mechanism

We have a dependence on the target material:
→ cross-check DAMA/LIBRA signal with a NaI-based detector

CHALLENGE of NaI



- hygroscopic nature
- low Debye temperature
- high contamination with ^{40}K

DETECTION TECHNIQUE | SCINTILLATING CALORIMETER

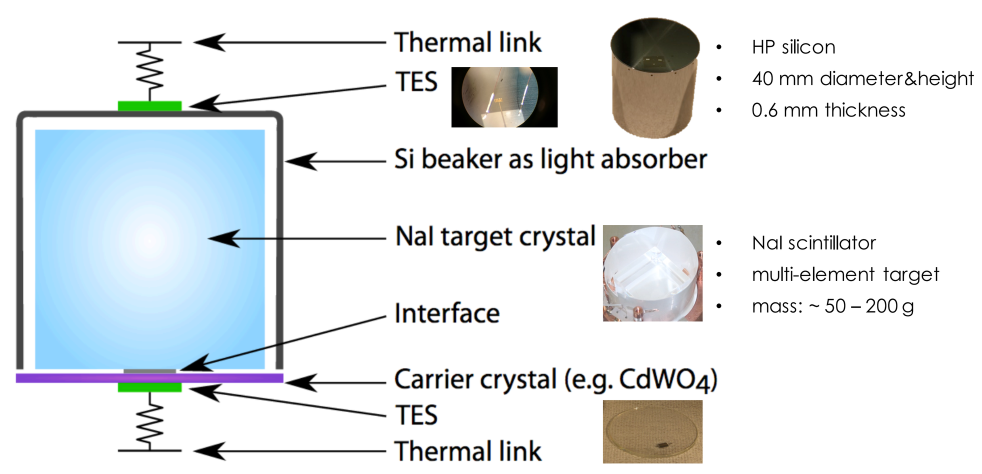
DUAL CHANNEL NaI DETECTOR

PHONON SIGNAL (~ 90 %) $\Delta T = \frac{\Delta E}{C}$

- (almost) independent of particle type
- precise measurement of the deposited energy

SCINTILLATION LIGHT (few %)

- amount of emitted light depends on particle type → LIGHT QUENCHING
- discrimination of interacting particle via the **ratio light to phonon signal** → LIGHT YIELD



ADVANTAGE (DARK MATTER SIGNAL / BACKGROUND)

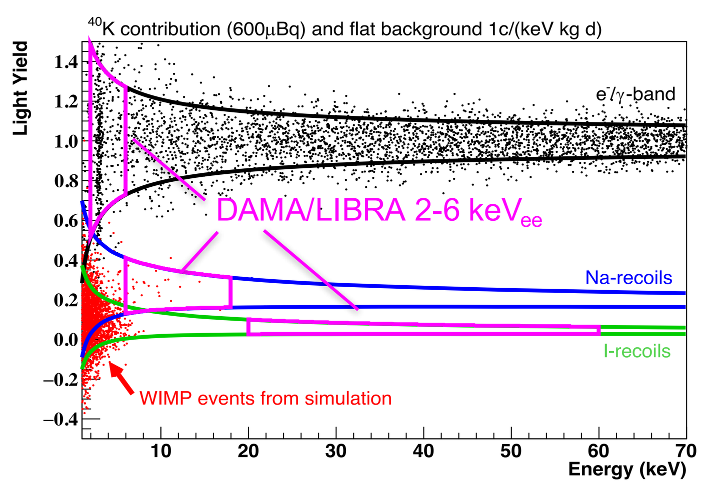
- first NaI detector with β/γ-discrimination
- lower threshold, in particular for nuclear recoils

PERFORMANCE GOAL

- energy threshold of 1 keV (energy resolution σ=200 eV)
- 4% of deposited energy detected in form of light
- light detector baseline noise σ=10 eV

EXPECTED PERFORMANCE

LIGHT YIELD = LIGHT SIGNAL / HEAT SIGNAL



- **black events:** flat background: 1 /(keV kg d) + ^{40}K background: 600uBq/kg
- **pink colored boxes** correspond to DAMA/LIBRA signal regions in the standard elastic scattering scenario
- **red events:** 10 GeV/c² WIMP with 2E-04 pb corresponding to DAMA/LIBRA signal in standard elastic scattering scenario:

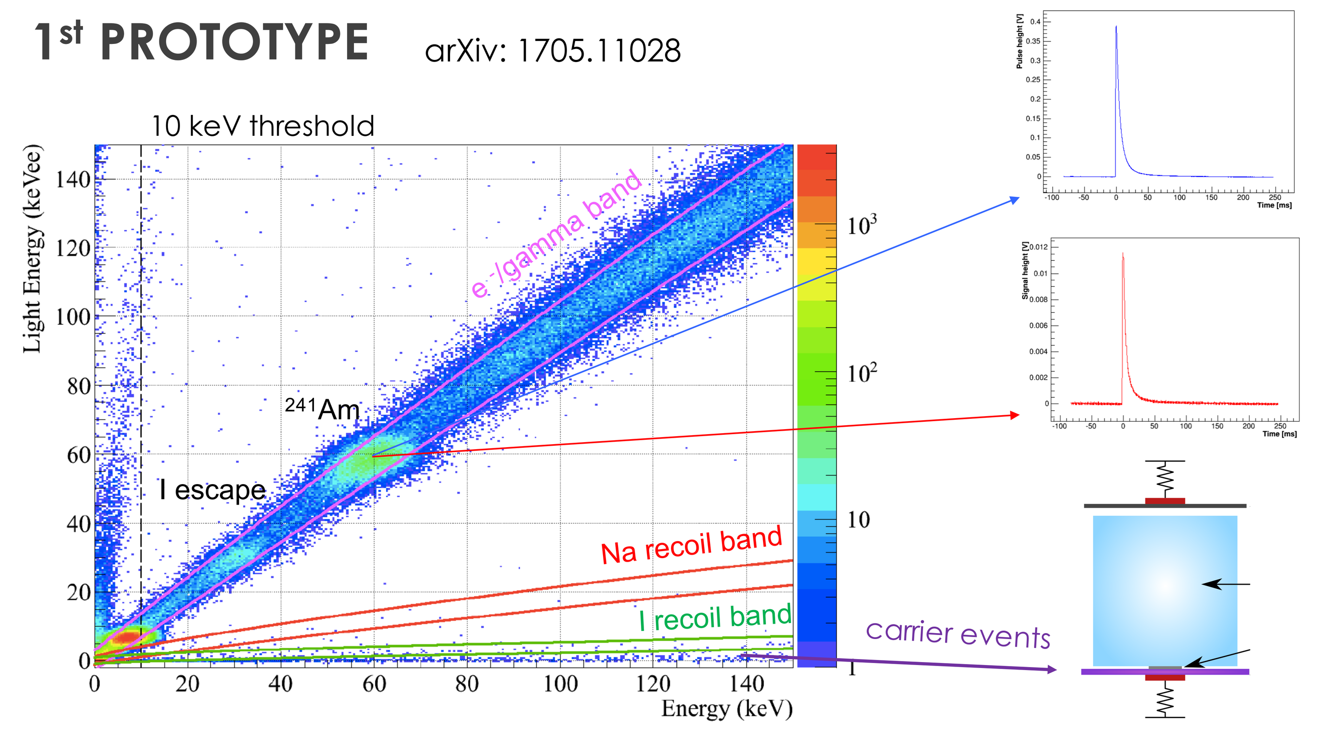
ASSUMPTIONS:
- exposure 100 kg-days
- nuclear recoil threshold of 1keV
- beaker-shape light detector performance as in CRESST-II phase 2

Energy	# Events	Fraction
1-2 keV	1078	45 %
2-6 keV	1262	53 %
> 6 keV	46	2 %
TOTAL	2386	100 %

- **a moderate exposure of few 10 kg-days will be sufficient to confirm or rule out a nuclear recoil origin of the DAMA/LIBRA dark matter claim**
- **increasing the target mass makes the COSINUS technique sensitive for the annual modulation signal**

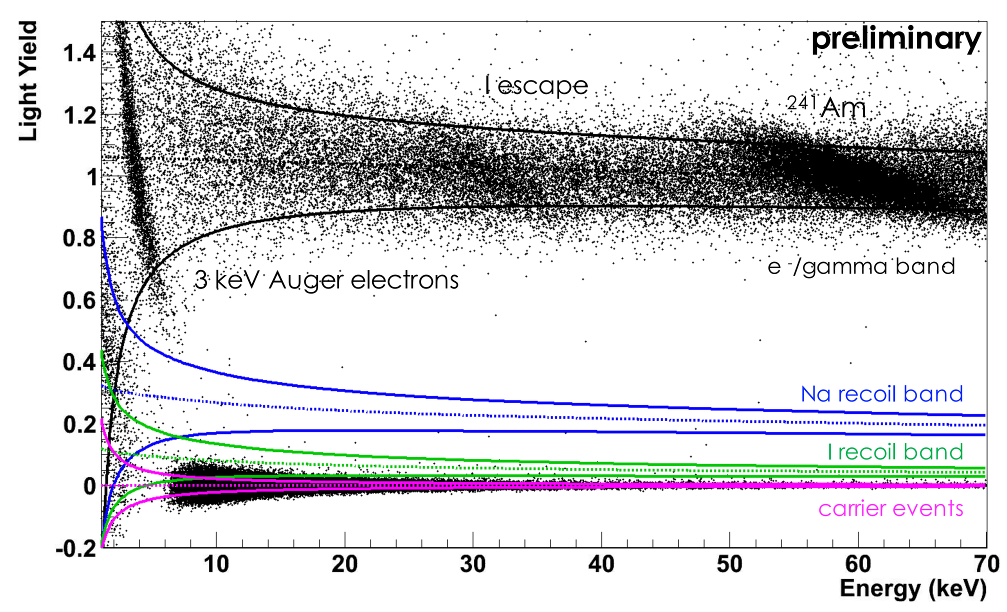
FIRST PROTOTYPE DETECTORS | RESULTS

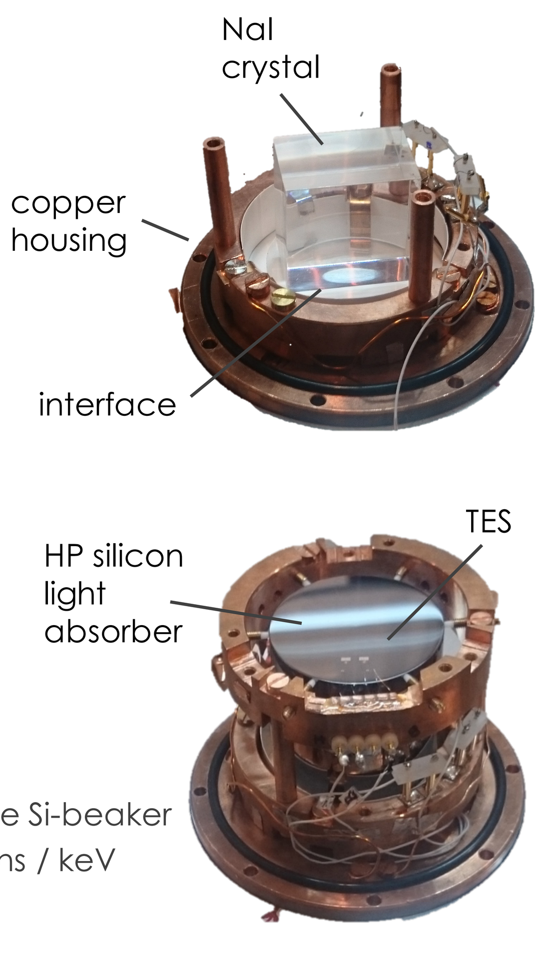
1st PROTOTYPE
arXiv: 1705.11028



- NaI energy threshold is about 10 keV
- width of the ^{241}Am peak is (5.02 ± 0.06 (stat.)) keV
- resolution at zero energy is (1.12 ± 0.01 (stat.)) keV
- 3.7% of the deposited energy is detected as light in a wafer-like light absorber
  → standard CRESST-II silicon on sapphire (SOS) light absorber

2nd PROTOTYPE

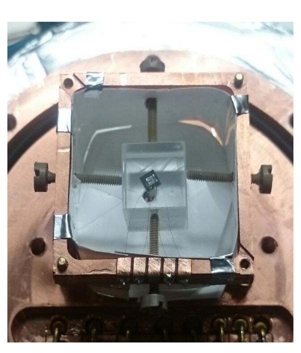


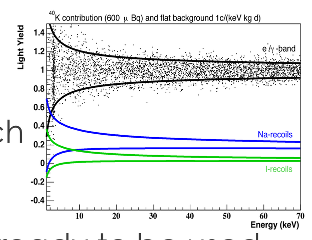


- NaI energy threshold is (8.26 ± 0.02 (stat.)) keV
- width of the ^{241}Am peak is (4.508 ± 0.064 (stat.)) keV
- 13.1 % of the deposited energy is detected in form of light in the Si-beaker in other words: we measure an average number of 39.4 photons / keV for a beta/gamma-event
- **observation**: pulses have a very slow decaying tail

OUTLOOK | ONGOING STUDIES

QUENCHING FACTOR MEASUREMENT





- MLL - Tandem accelerator at TU Munich
- 11 MeV neutron beam
- dilution cryostat available and facility ready to be used
- small NaI scintillating calorimeter mounted

beam-time accepted for September

GOAL:
Determination of QFs using a small NaI scintillating calorimeter operated in identical conditions as later in the experiment. This is an important advantage as the knowledge of the exact QF, in particular its energy dependence in the ROI, is crucial for the particle discrimination power of the detector.

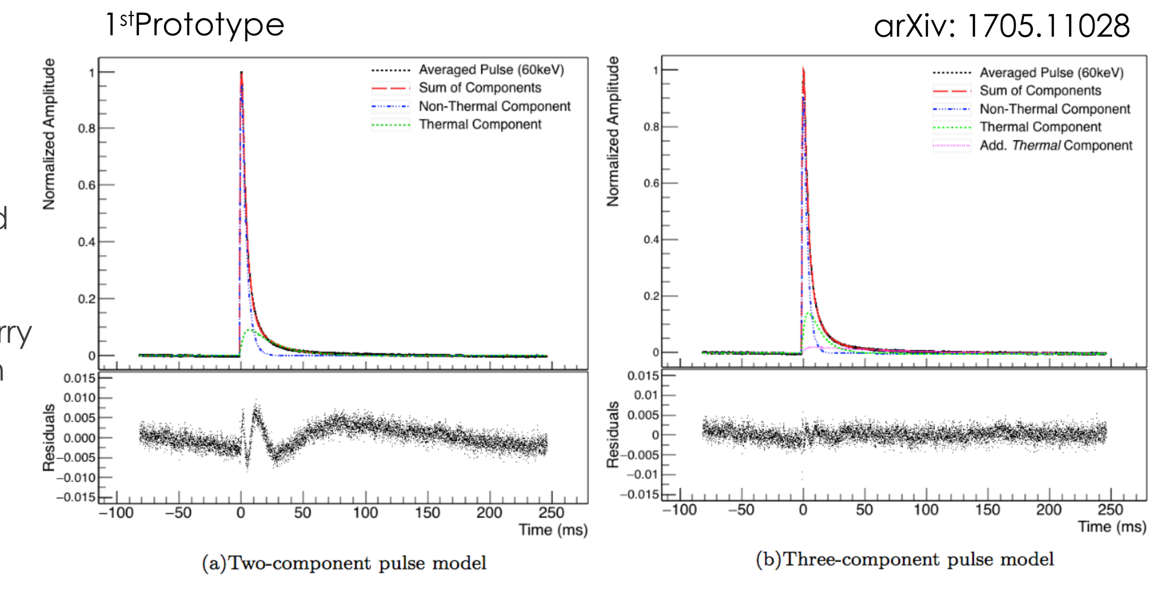
PULSE SHAPE - NaI EVENTS

F. Pröbst et al., J. Low Temp. Phys. 100, 69 (1995):

$$\Delta T_e(t) = \Theta(t)[A_n(e^{-t/\tau_n} - e^{-t/\tau_{in}}) + A_t(e^{-t/\tau_t} - e^{-t/\tau_n})]$$

- the two components do not allow for a good description of the pulse
- fit result looks like a compromise trying to marry the fast rise of the pulse with the quite longish thermal decay constant
- by adding a **third thermal component** to the model, the fit result can be significantly improved over the whole range

1stPrototype — arXiv: 1705.11028



References
Angloher et al., Eur. Phys. J. C (2016) 76:441
DOI 10.1140/epjc/s10052-016-4278-3
Angloher et al., submitted to JINST
arXiv:1705.11028

www.cosinus.it

COLLABORATION
INFN - Sezione Milano Bicocca, Milano, Italy
INFN - Laboratori Nazionali del Gran Sasso, Assergi, Italy
Max-Planck-Institut für Physik, München, Germany
HEPHY: Institut für Hochenergiephysik der Österreichischen Akademie der Wissenschaften, Wien, Austria

FUNDING
Istituto Nazionale di Fisica Nucleare (INFN)
Commissione Scientifica Nazionale 5 (CSN5)
3 years for prototype development [2016 – 2018]

GRAN SASSO SCIENCE INSTITUTE — SCHOOL OF ADVANCED STUDIES — Scuola Universitaria Superiore

17th INTERNATIONAL WORKSHOP on LOW TEMPERATURE DETECTORS | July 17-21 2017 **KURUME, FUKUOKA, JAPAN**

INFN — Istituto Nazionale di Fisica Nucleare