COSINUS

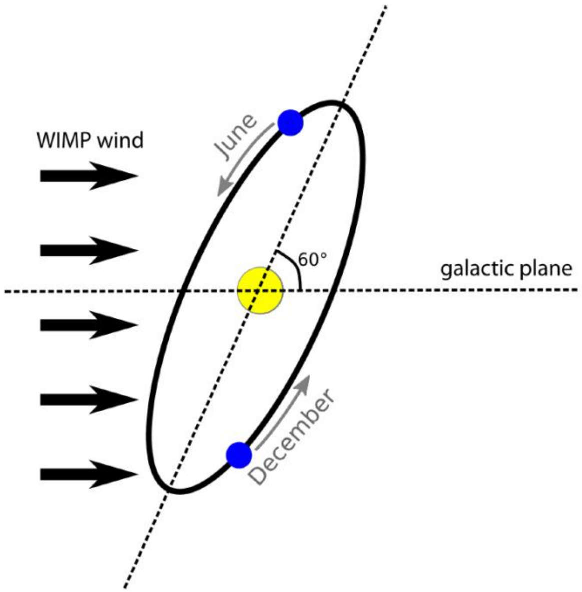
A NaI-based cryogenic scintillating calorimeter: status and results of the COSINUS project

Natalia Di Marco for the COSINUS Collaboration

LNGS - INFN

Dark Matter direct searches

D. N. Spergel, Phys. Rev. D37 (1988)



Assumption

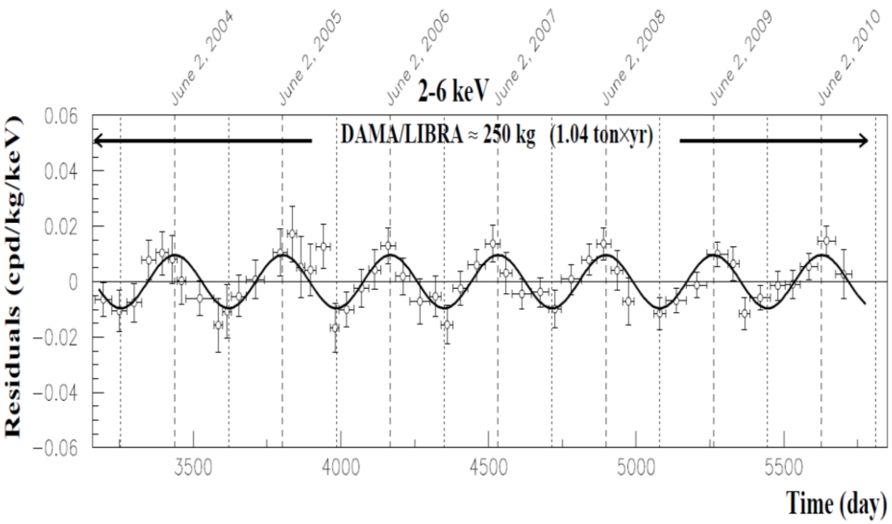
Dark matter particles (WIMPs) scatter off the nucleus and induce nuclear recoils

Signature

- Earth revolution gives ***seasonal modulation*** with a period of 1 year and a phase peaking at June the 2nd
- Due to the solar system movement in the galaxy, the WIMP flux is expected to be **not isotropic @earth** (directionality)

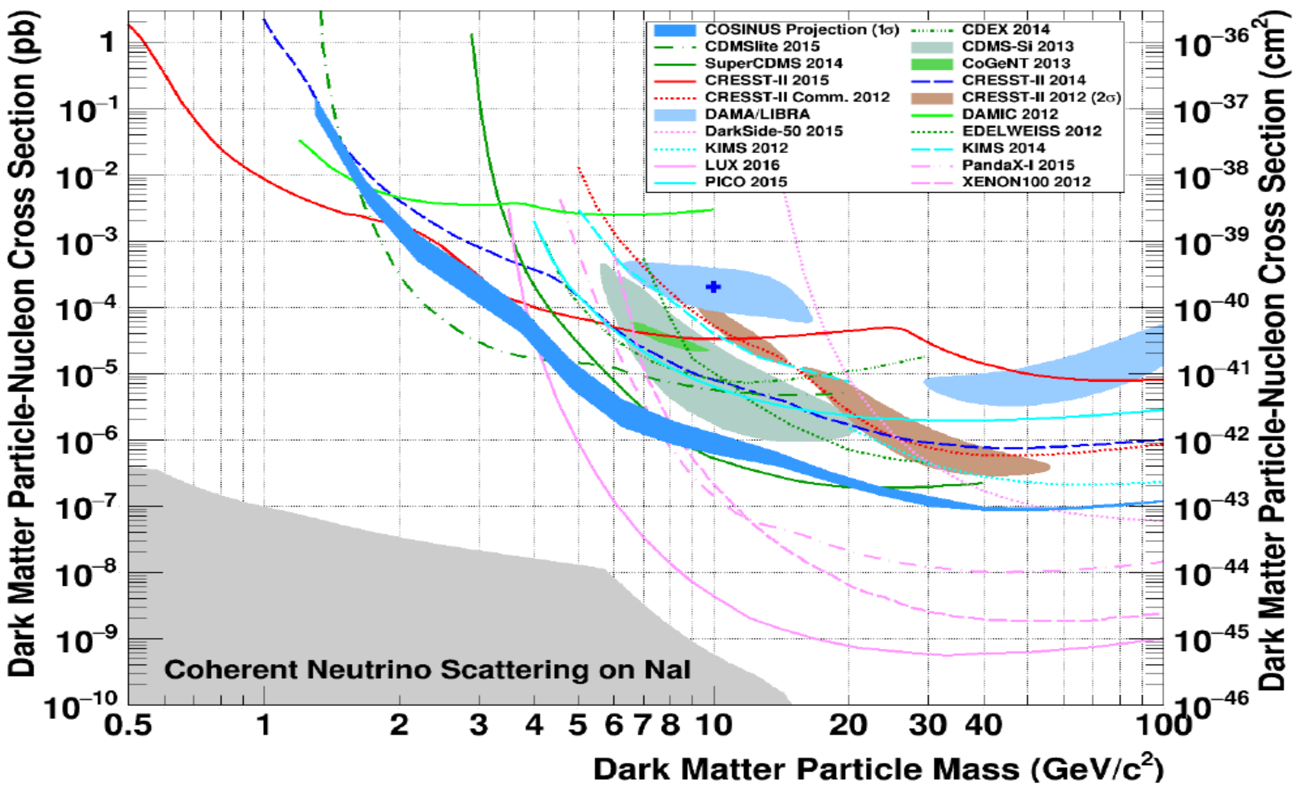
DAMA/LIBRA CLAIM

- 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



Bernabei et al. arXiv:1612.01387

Dark Matter direct searches



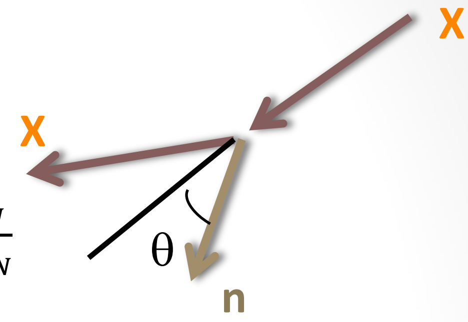
Angloher et al., 2016, EPJ C V76

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.

Dark Matter direct searches

The energy transferred to the recoiling nucleus is:

$$E_r = \frac{m^2{}_r v^2}{m_N}\,(1-\cos\theta),\ \ m_r = \frac{m_\chi \cdot m_N}{m_\chi + m_N}$$



Energy deposited in the detector ~ few keV - tens of keV

The differential recoil rate is:

$$\frac{dR}{dE_r} = N_N\,\frac{\rho_0}{m_\chi}\int_{v_{min}}^{v_{max}} d\vec{v}\, f(\vec{v})v\,\frac{d\sigma}{dE_r}$$

N_N → number of target nuclei

ρ_0 → local WIMP density

$f(\vec{v})$ → WIMP velocity distribution

$v_{min} = \sqrt{\frac{m_N E_{th}}{2m^2{}_r}}$, v_{max} → escape velocity

$\frac{d\sigma}{dE_r}$ → WIMP-nucleus differential cross section

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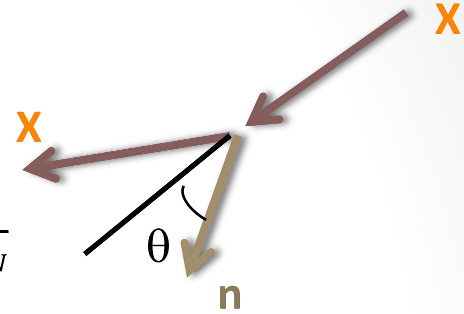

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Astrophysics

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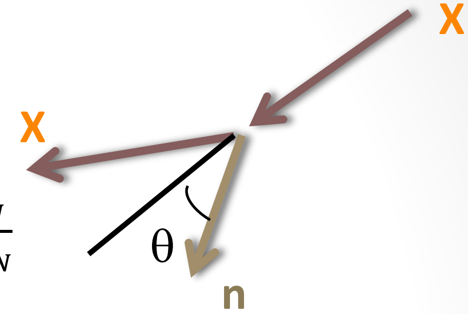

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Astrophysics

Particle/Nuclear Physics

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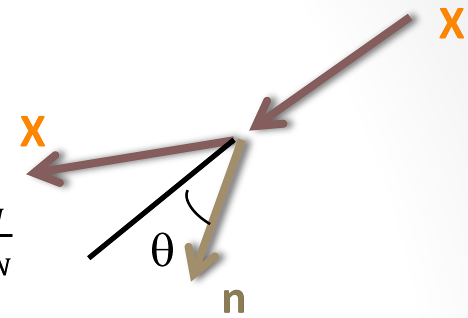

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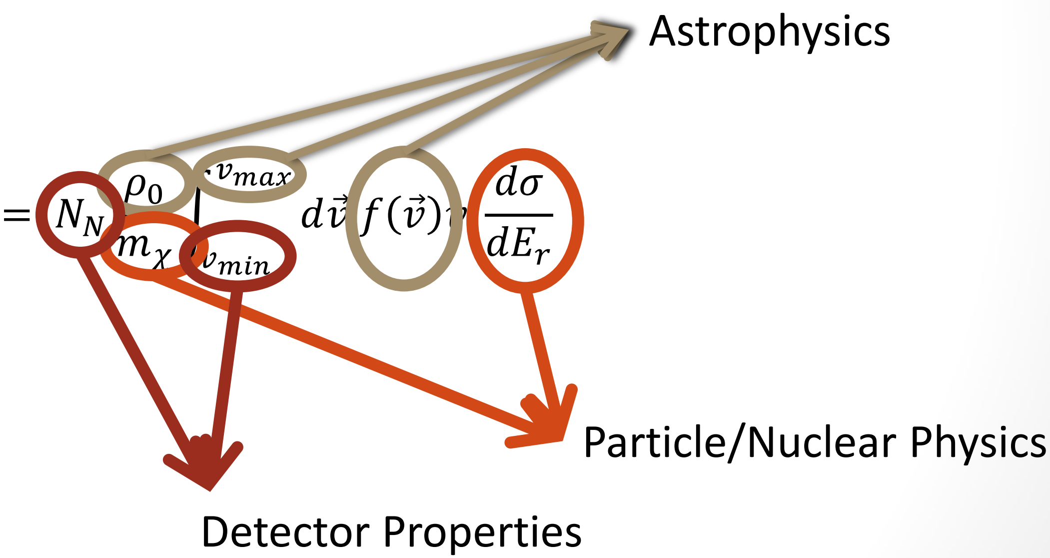

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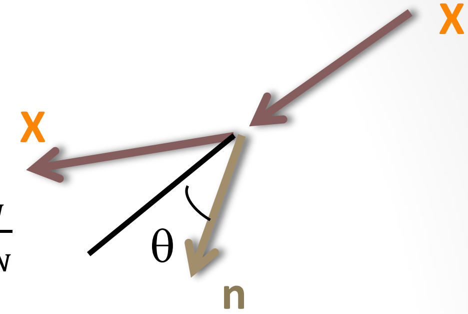

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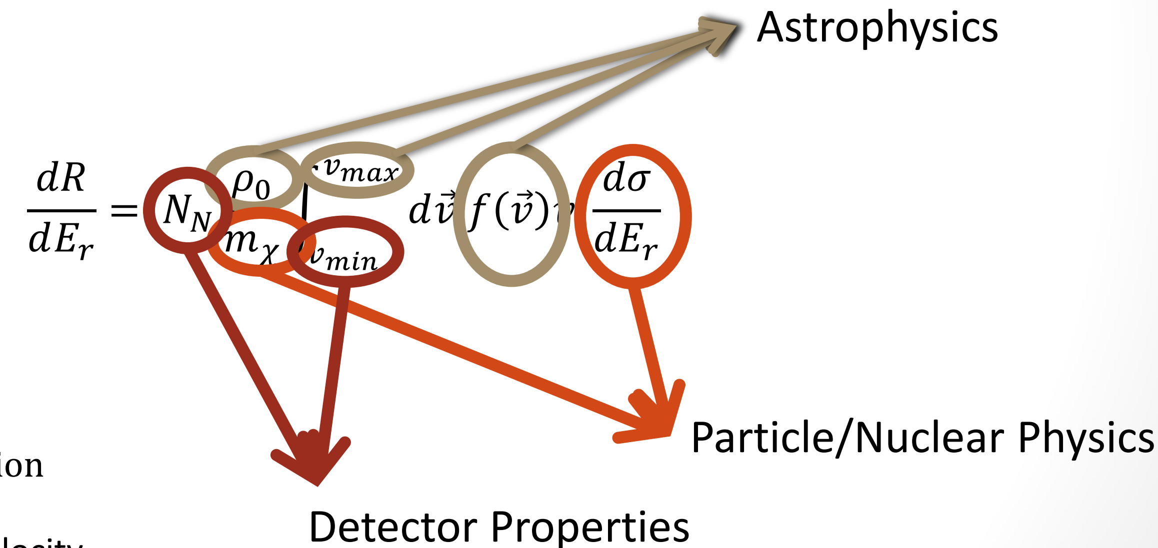

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Target material dependence: test DAMA with NaI experiment(s)

NaI experiments/R&D

DAMA/LIBRA
Running, 1keVee threshold (this year?)

DM-ICE
KIMS-NaI
} **COSINE**
Taking data since Sep 2016

ANAIS
data taking started in 2017

SABRE
in construction

COSINUS (R&D)
Funded 2016-2018 (INFN CSN V)
Performance test run in 2018

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No β/γ discrimination

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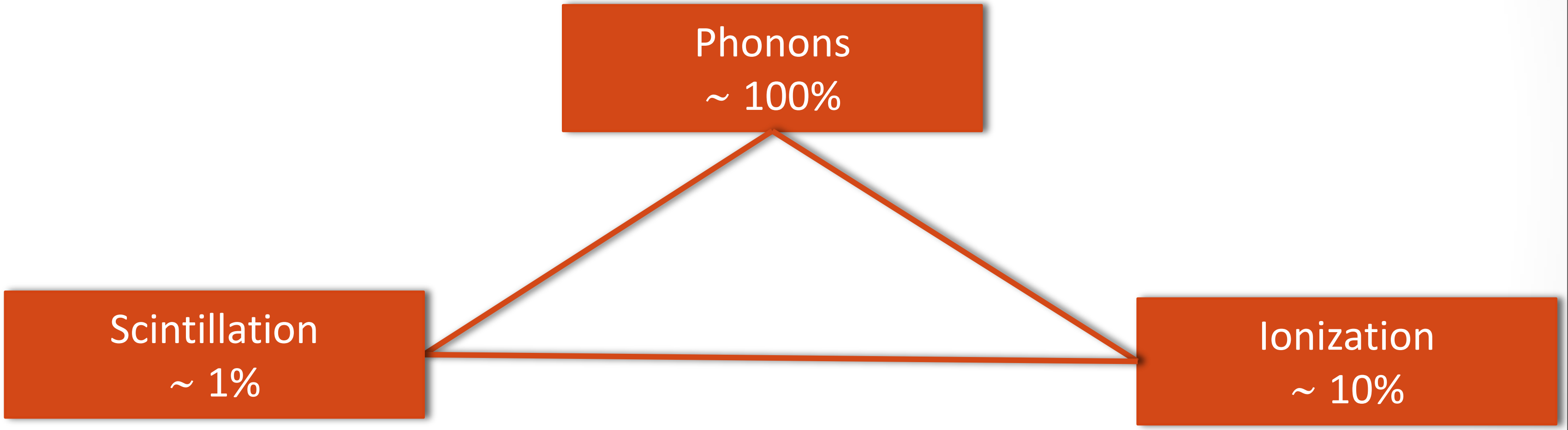
Performance test run in 2018

→ Counting experiment
Particle ID

The COSINUS project

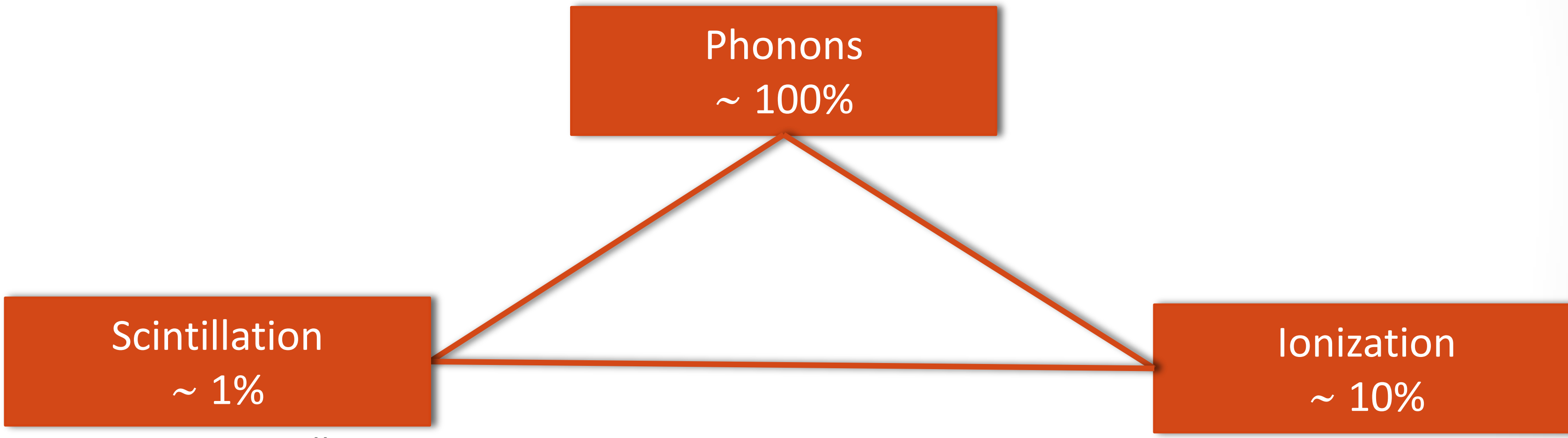
in the panorama of direct search techniques



The COSINUS project

in the panorama of direct search techniques

- <u>Super-heated Liquids</u>
 (COUP, PICASSO, SIMPLE, PICO)



- <u>Inorganic Scintillators</u>
 (**<u>DAMA,KIMS-ANAIS, DM-ICE,SABRE</u>**)

- <u>Single Phase Noble Liquids</u>
 (Xmass, DEAP, MiniCLEAN)

- <u>High purity Ge/Si Detector</u>
 (*CoGeNT, CDEX, Texono, Malbek, DAMIC*)

The COSINUS project

in the panorama of direct search techniques

- <u>Super-heated Liquids</u> (COUP, PICASSO, SIMPLE, PICO)

Phonons ~ 100%

- <u>Scintillating calorimeters</u> (CRESST, ***COSINUS***)
- <u>Super-conducting calorimeters</u> (CDMS, EDELWEISS)

Scintillation ~ 1%

Ionization ~ 10%

- <u>Inorganic Scintillators</u> (**DAMA,KIMS-ANAIS, DM-ICE,SABRE**)
- <u>Dual Phase Noble Liquids</u> (XENON, DARK-SIDE, Panda-X, LUX/LZ)
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The COSINUS project

in the panorama of direct search techniques

1. *Crystals (NaI, Ge, Si)*
2. Cryogenic Detectors
3. Liquid Noble Gases

4. Tracking:
DRIFT, DMTPC
MIMAC,NEWAGE,
D3, NEWS

- Super-heated Liquids
(COUP, PICASSO, SIMPLE, PICO)

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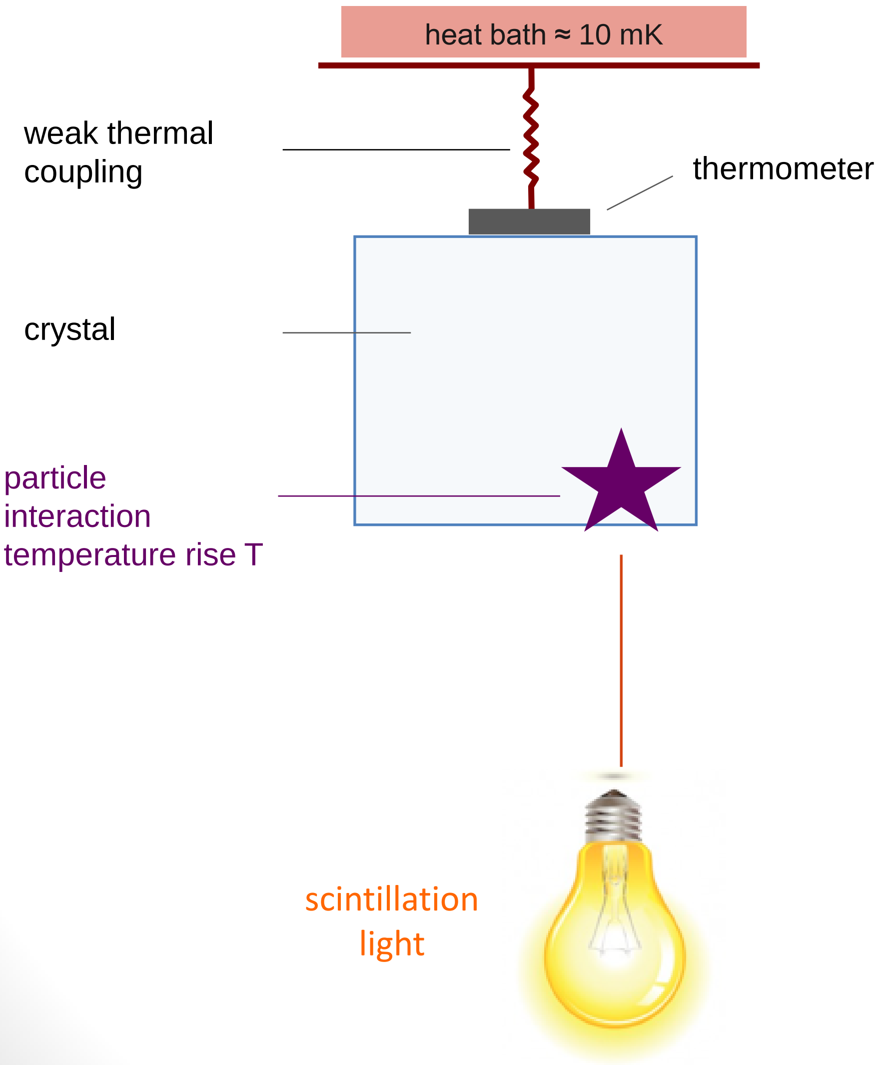
The COSINUS project

Eur. Phys. J. C (2016) 76:441



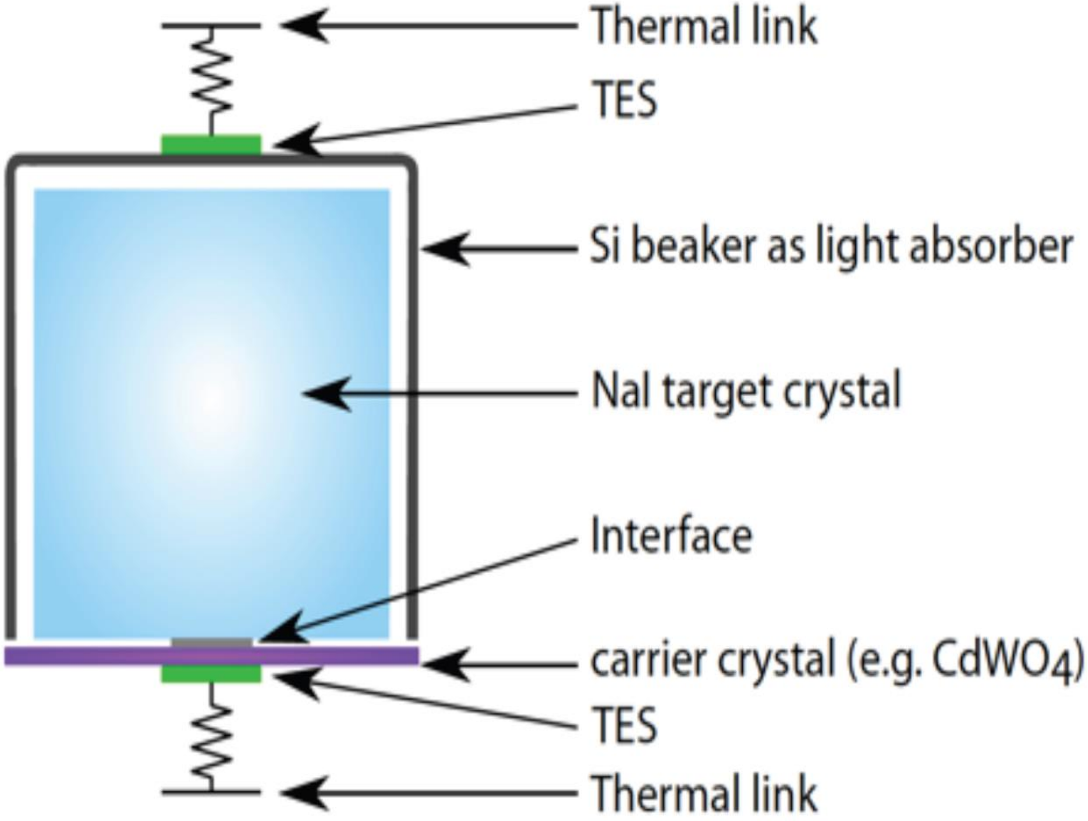
Phonon signal (~ 96 %)

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

Scintillation light (~ 4 %)

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

COSINUS performance goal



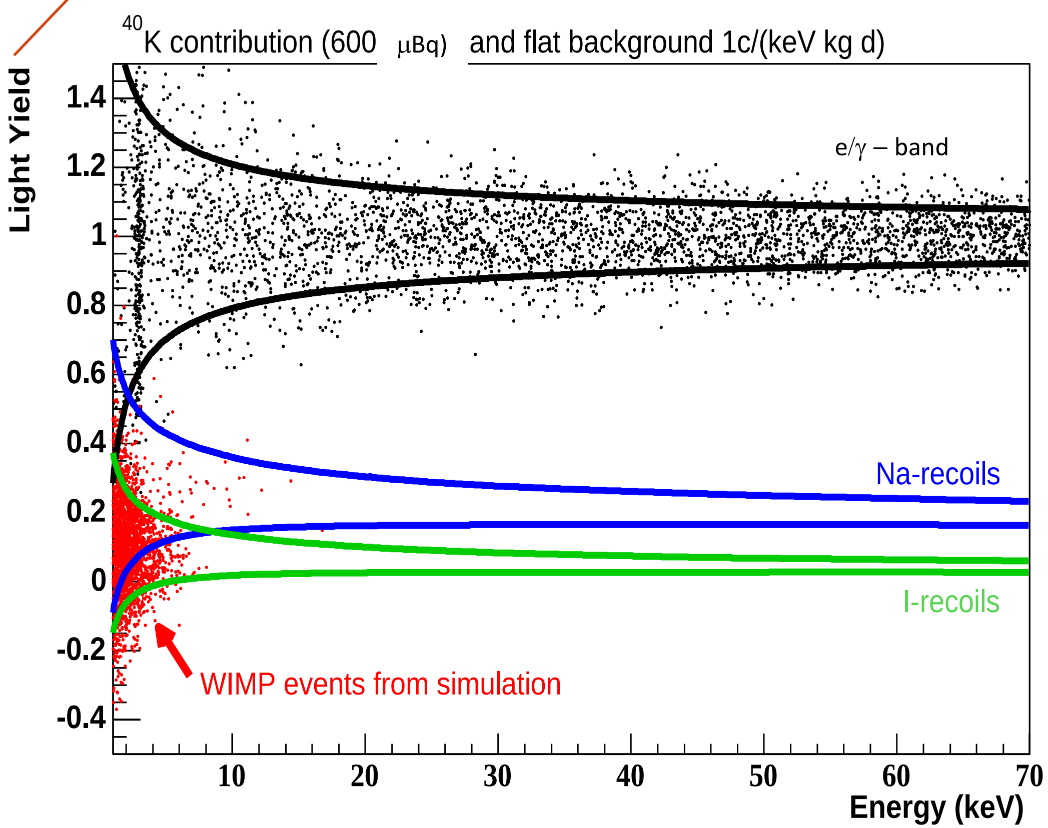
Bring NaI-based cryogenic detectors to level of existing ones (e.g. CRESST-II):

- 1keV nuclear recoil threshold
- 4% of deposited energy

measured as scintillation light

Simulated data

$$LY = \frac{light\ signal}{phonon\ signal}$$



ASSUMPTIONS:

- exposure 100 kg-days
- nuclear recoil threshold of 1keV
- beaker-shape light detector

performance as in CRESST-II phase 2

Black: β/γ-background
flat 1c /(keV kg day)
+ 40K: 600μBq/kg

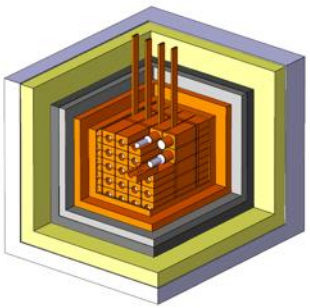
Recoils off Na
Recoils off I

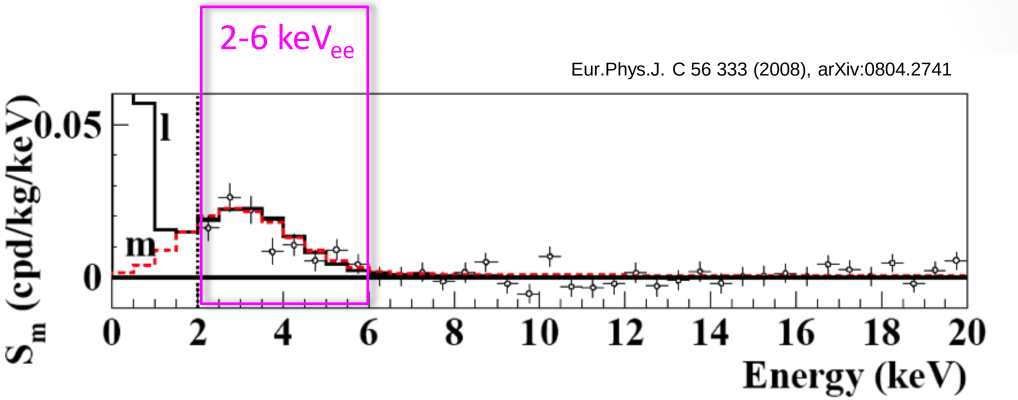
Quenching factors by V. Tretyak, Astropart. Phys. 33, 40 (2010)

Red: 10 GeV/c^2 WIMP with 2E-04 pb as from Savage et al.

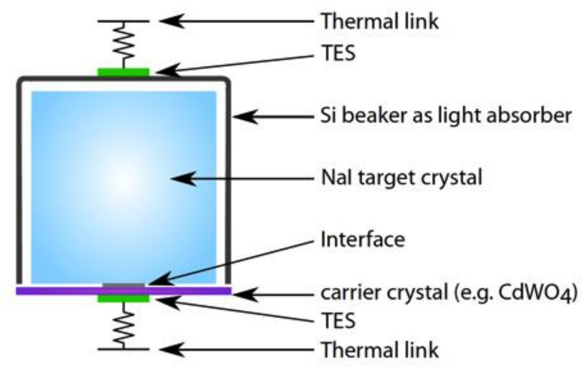
Compare DAMA to COSINUS

DAMA/LIBRA





COSINUS



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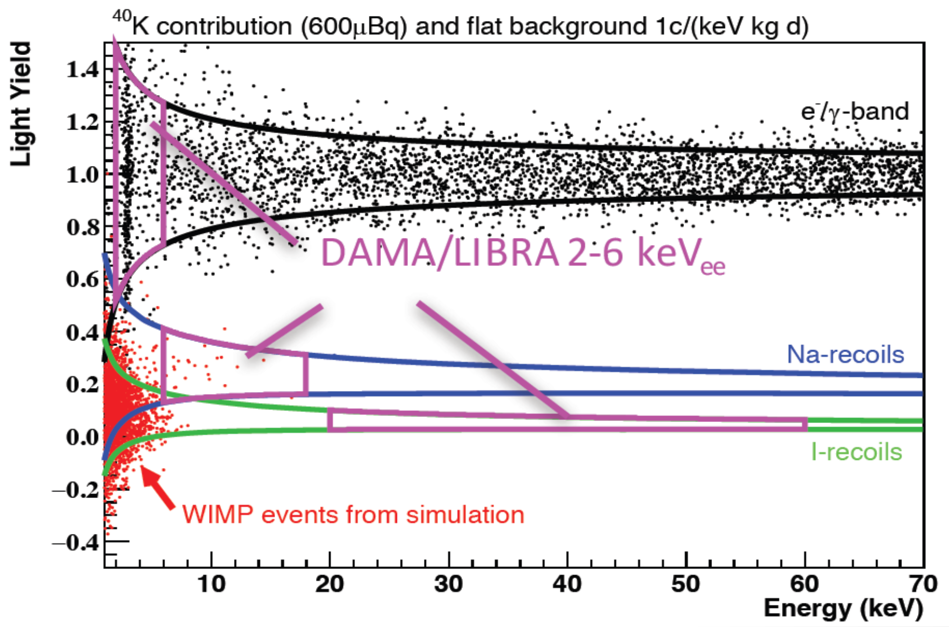
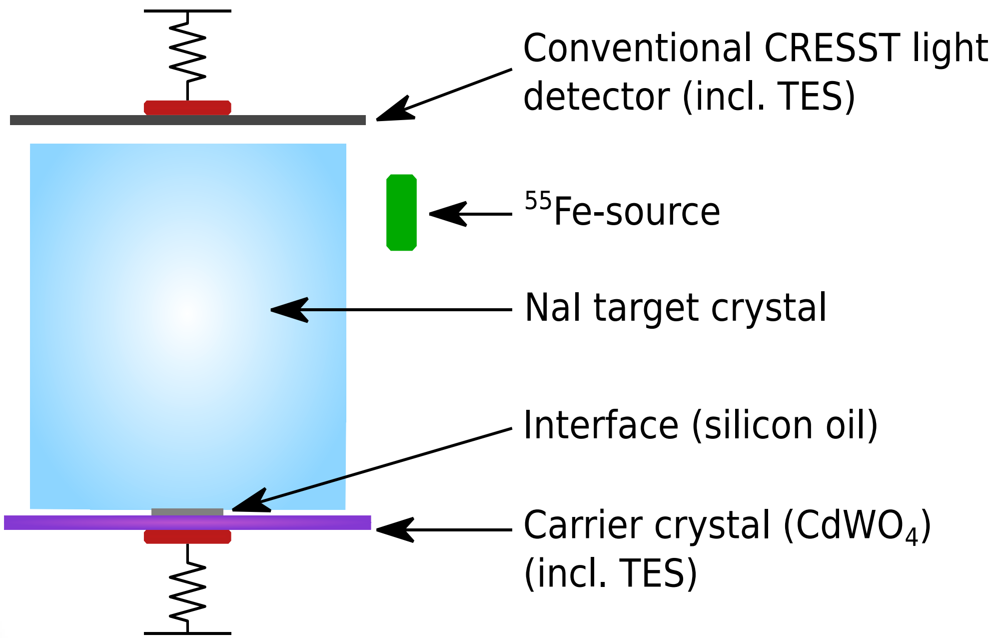
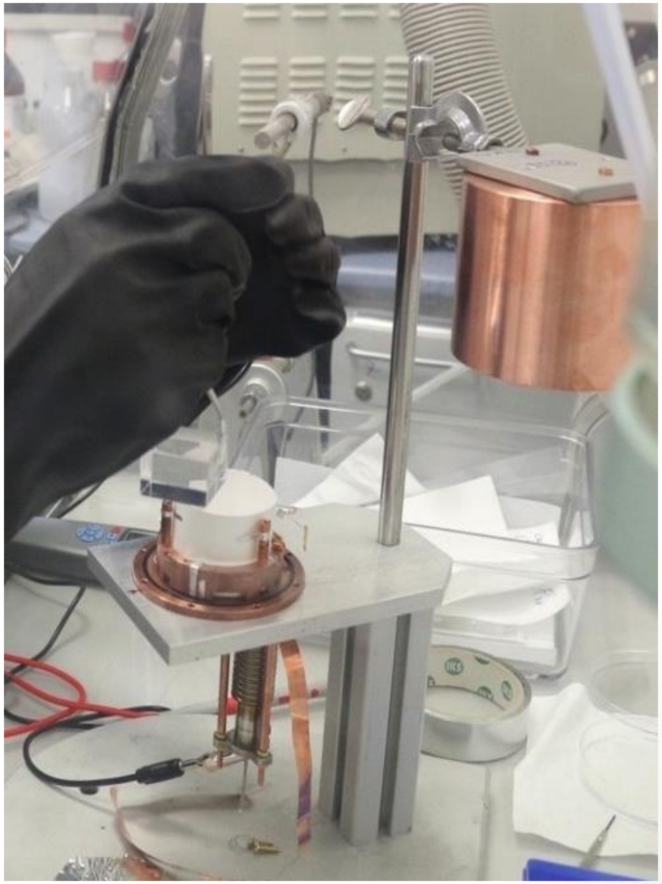
DOI 10.1140/epjc/s10052-016-4278-3



1st Prototype: detector setup





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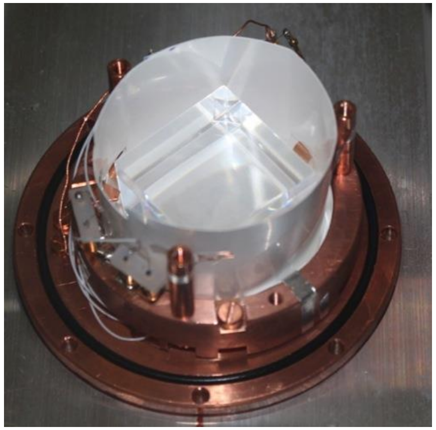
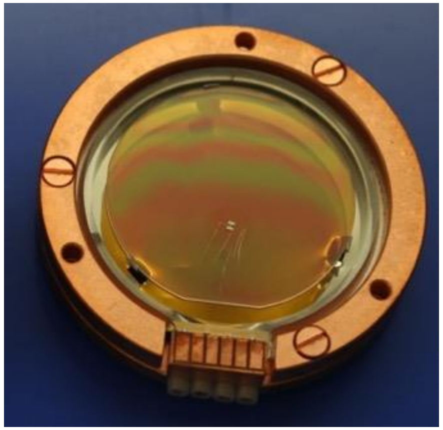
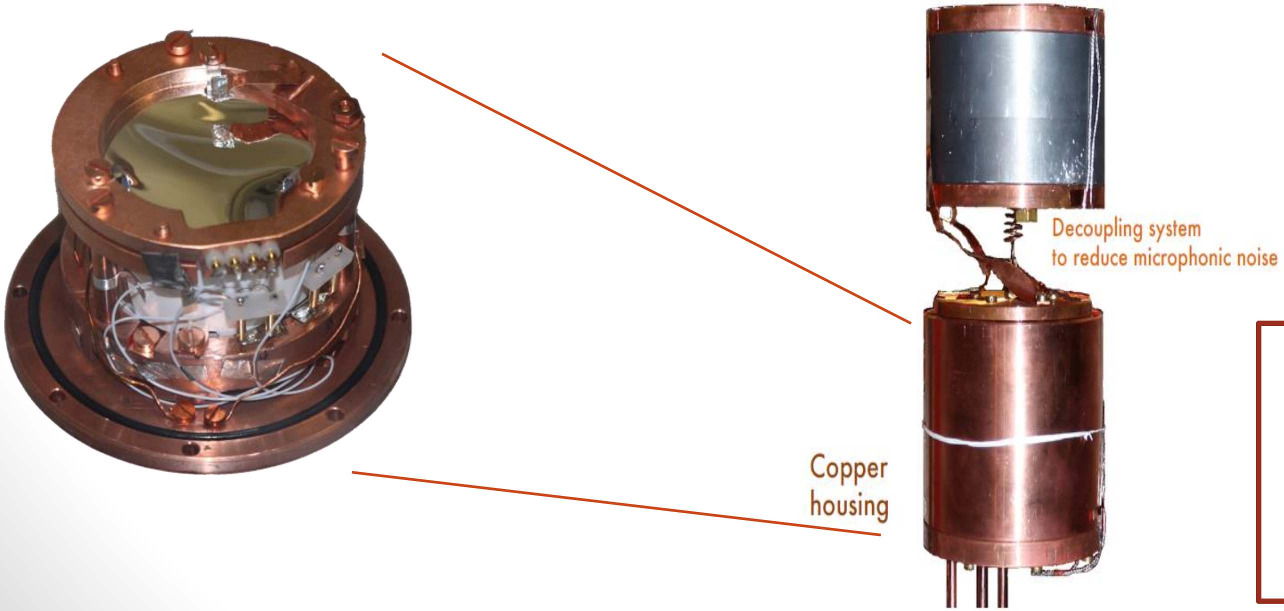


NaI:
- (20x30x30) mm^3, 66 g
- all sides perfectly polished
- Hilger crystal company

$CdWO_4$ carrier crystal:
- small standard TES
- 1.5 mm thickness, 40 mm diameter
- about 13 g



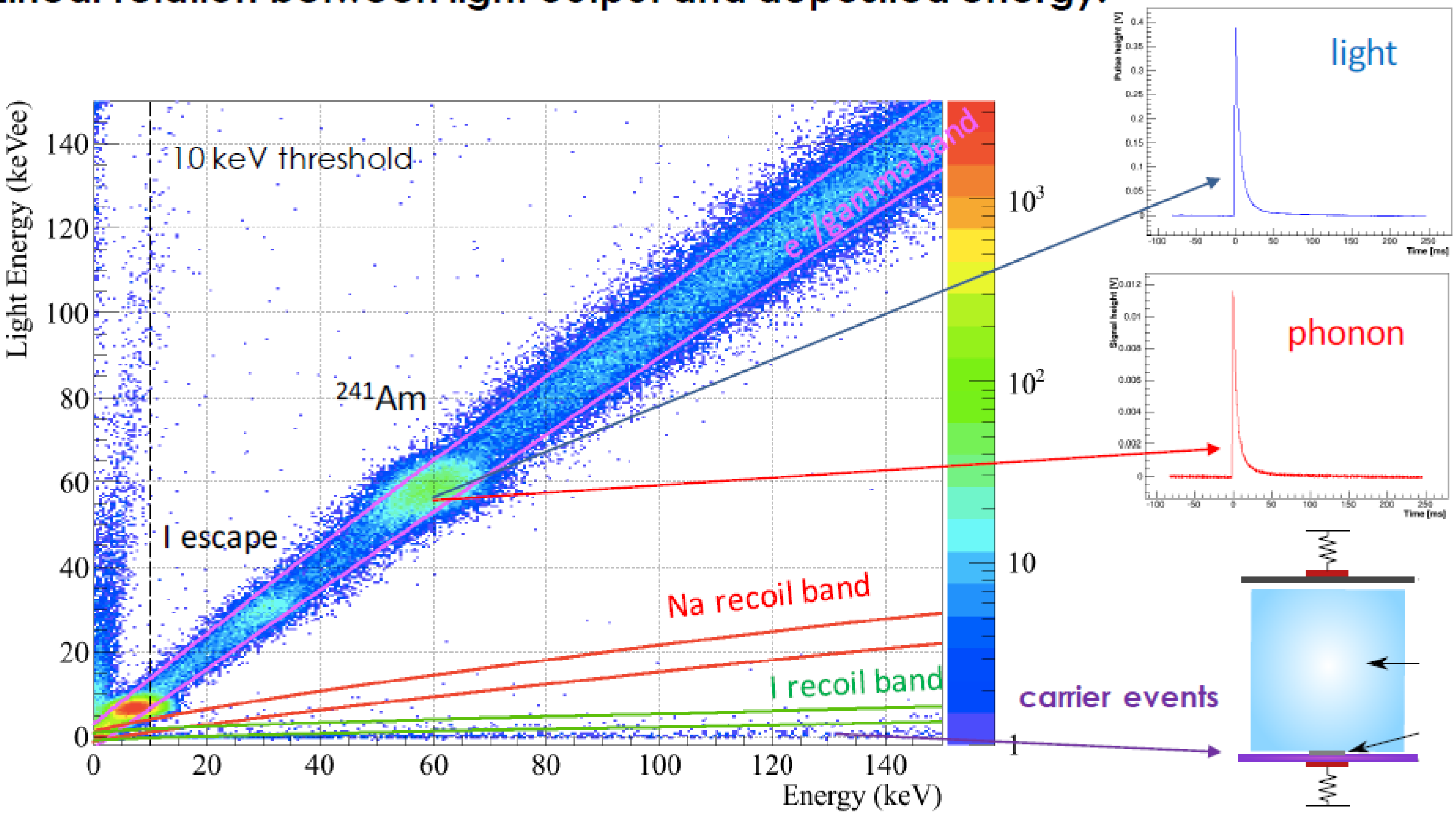
Light detector:
- SOS light absorber a là CRESST
- sep. heater and ^{55}Fe source



cryostat cold from 19.4.2016 to 29.7.2016

1st Prototype: results

Linear relation between light output and deposited energy!



plot: arXiv: 1705.11028, accepted at JINST
QF from Tretyak, Astropart. Phys. 33, 40 (2010)

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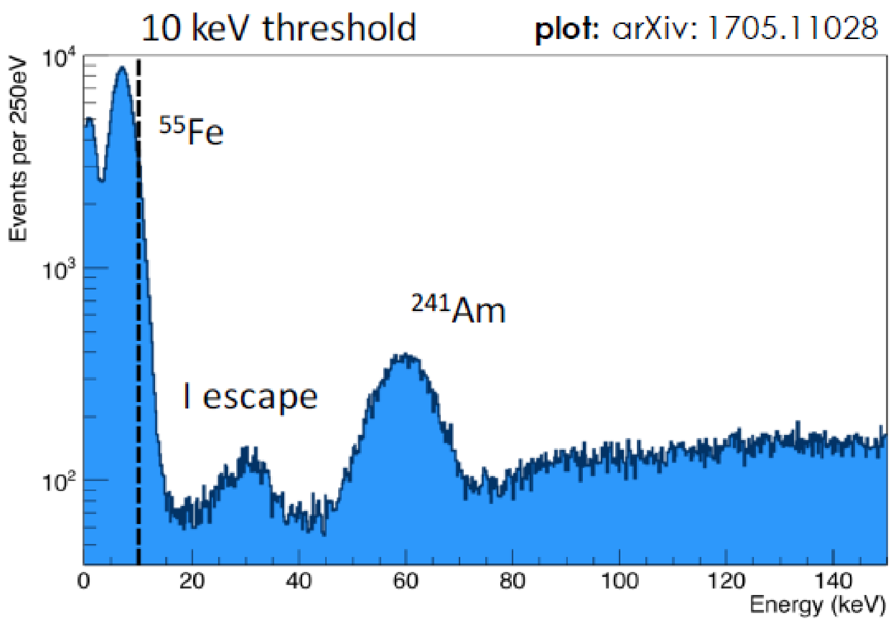


- **energy threshold**: 10 keV

- **for β/γ-events:**

3.7% of the energy deposited in the NaI crystal is measured by the light detector (design goal 4%)

=

11.2 detected photons per keV of energy deposition

✓ first successful measurement of a NaI crystal as cryogenic detector

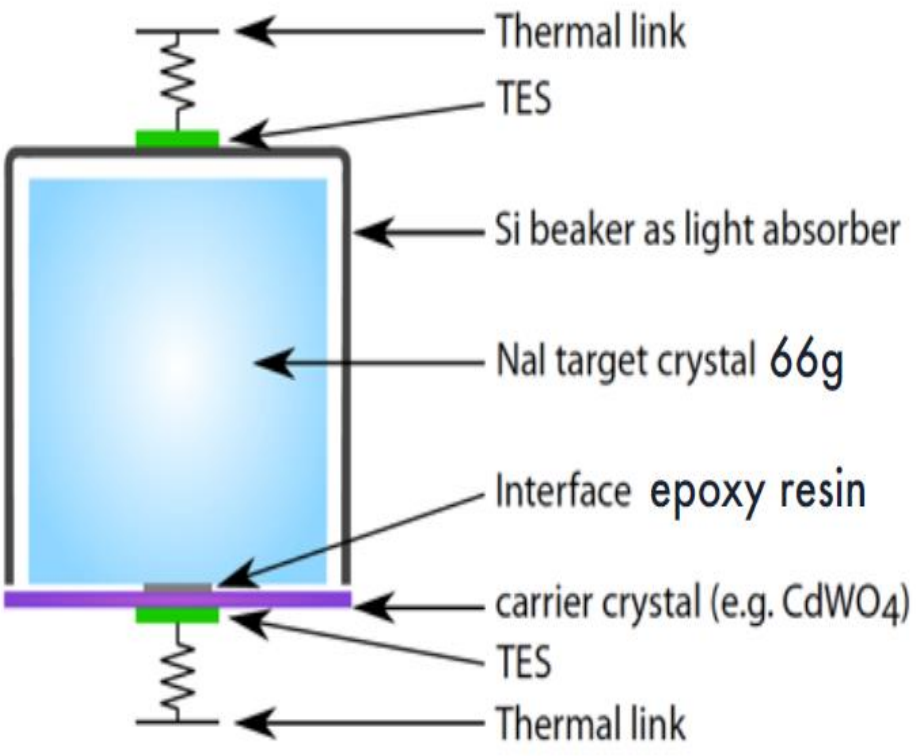
✓ publication accepted at JINST arXiv: : 1705.11028

x improve detector performance

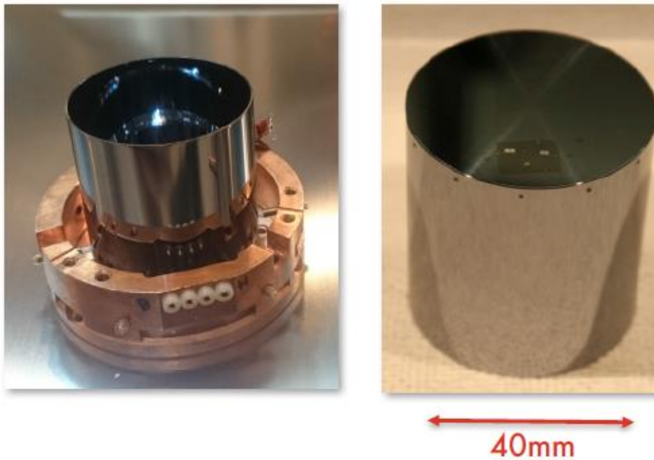
x no beaker-shaped light detector

2^{nd} Prototype: detector setup

PROOF-OF-PRINCIPLE OF FINAL DETECTOR DESIGN



Final design with beaker-shaped light absorber



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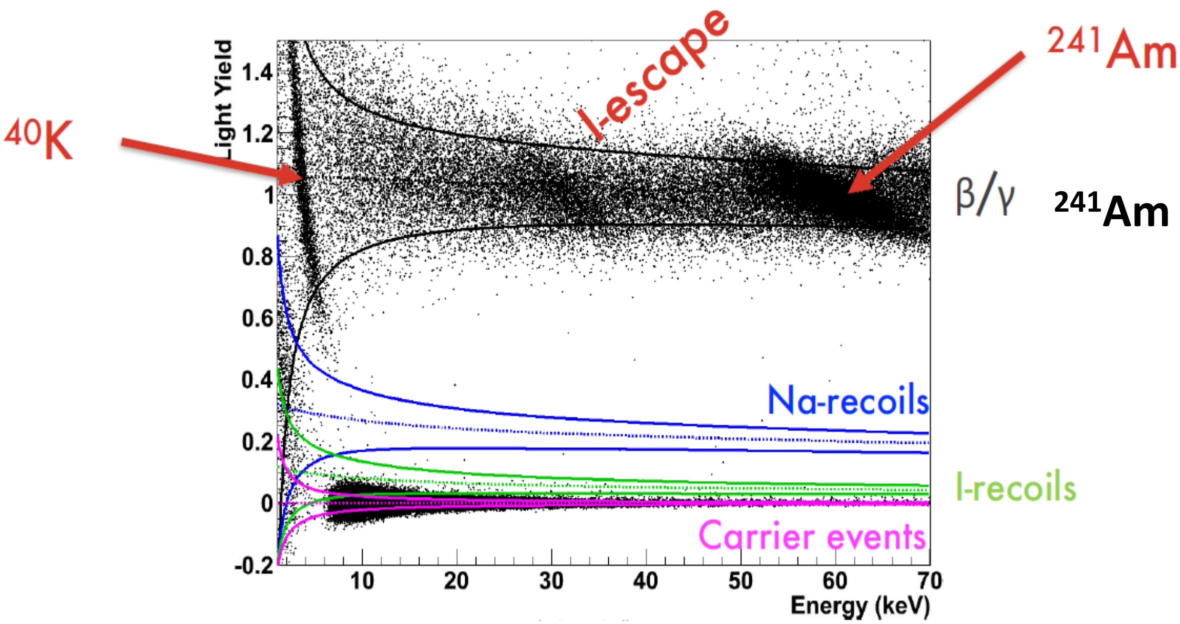


^{241}Am GAMMA CALIBRATION DATA

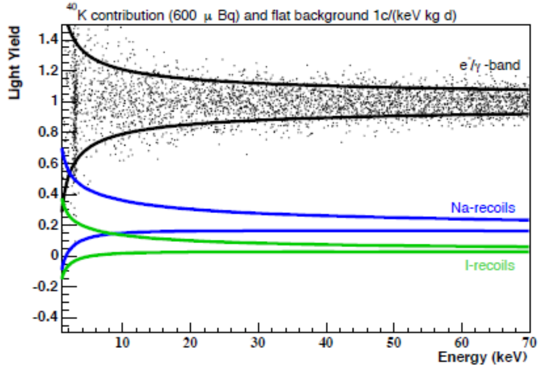
- ✓ successful test of final detector concept
- ✓ NaI is an excellent scintillator at low temperatures
- ✓ beaker-shaped light detector exceeds performance goal

- x improve detector performance of NaI calorimeter to reach 1keV energy threshold

- x 205 ppm of 40K in the HILGER crystal

Next steps

- Quenching factors measurement@MLL - Tandem accelerator at TUM/LMU in Munich



11 MeV neutrons

Dilution cryostat available and ready to be used
Smaller version of the COSINUS detector module

GOAL:
Precise determination of light quenching factor for Na and I at mK-temperatures

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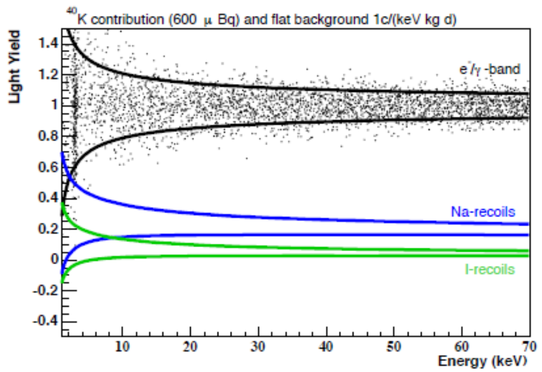

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- 3rd Prototype Detector: first measurement in a low background cryostat (CUPID/CUORE R&D cryostat, hall C at LNGS)

- ✓ installed SQUIDs and dedicated heater / bias lines in the cryostat
- ✓ COSINUS DAQ commissioned
- ✓ NaI crystal: 30 g (cubic)

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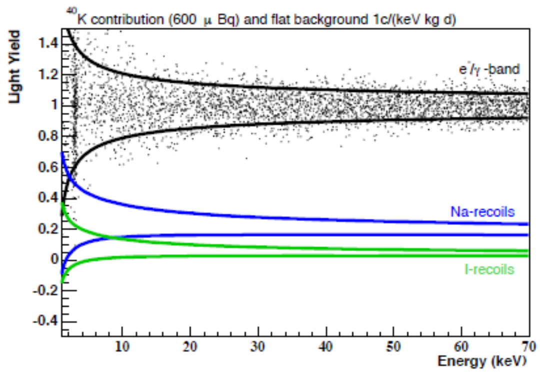

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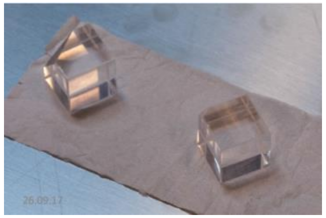
- 4th Prototype Detector:



- ✓ test of first SICCAS radiopure crystal (CHINA)
- ✓ first measurement with Milano heater/ bias electronics modules

Conclusions

- 1st successful measurement of a NaI-based cryogenic calorimeter now published
- 2nd measurement: proof-of-principle of final detector design (incl. beaker-shaped light absorber)
- 3rd measurement in lower background cryostat, analysis ongoing
- 4th measurement of first radiopure NaI crystal, first run with COSINUS DAQ and MIB electronics

A moderate exposure of few O(100 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 also sensitive for the annual modulation signal detection.