COSINUS

Karoline Schäffner

SC meeting, LNGS, 1st April 2019

GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

INFN
Istituto Nazionale di Fisica Nucleare

DARK MATTER

The evidence for dark matter is **overwhelming** and present on all length scales.

Our **cosmological observations** only make sense if the largest fraction of matter is **non-baryonic.**

+ add ($\geqq$1) extra and new ingredient (=Dark Matter)

→ **new physics beyond SM**

→ **explains huge interest in community**

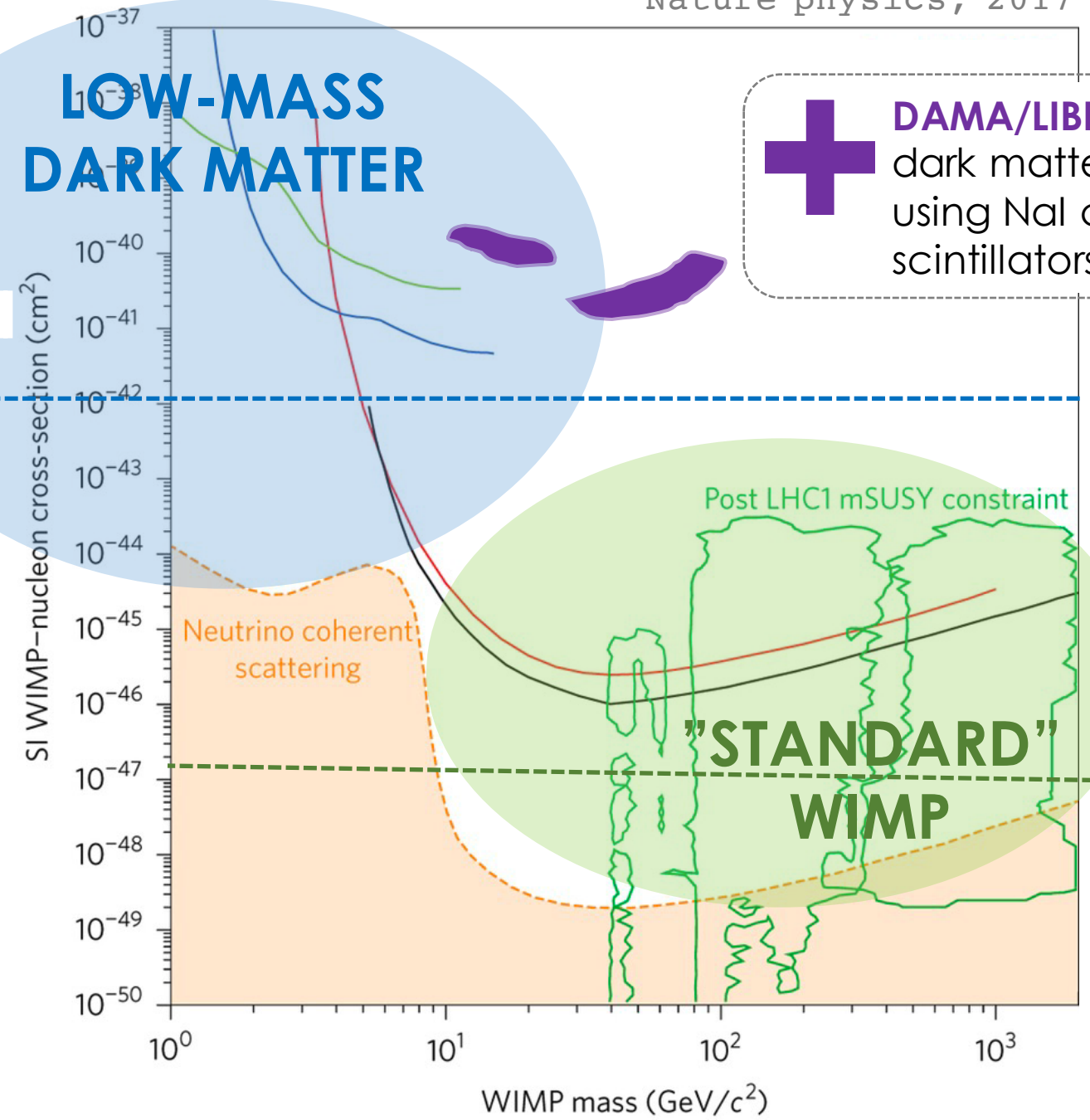
+ add general relativity

"EXOTICS"
far sub-GeV

LOW-MASS DARK MATTER

DAMA/LIBRA
dark matter claim using NaI crystal scintillators

Nature physics, 2017



~ 1 event/ kg-day

low energy threshold

→ performance

diverse technologies

large target

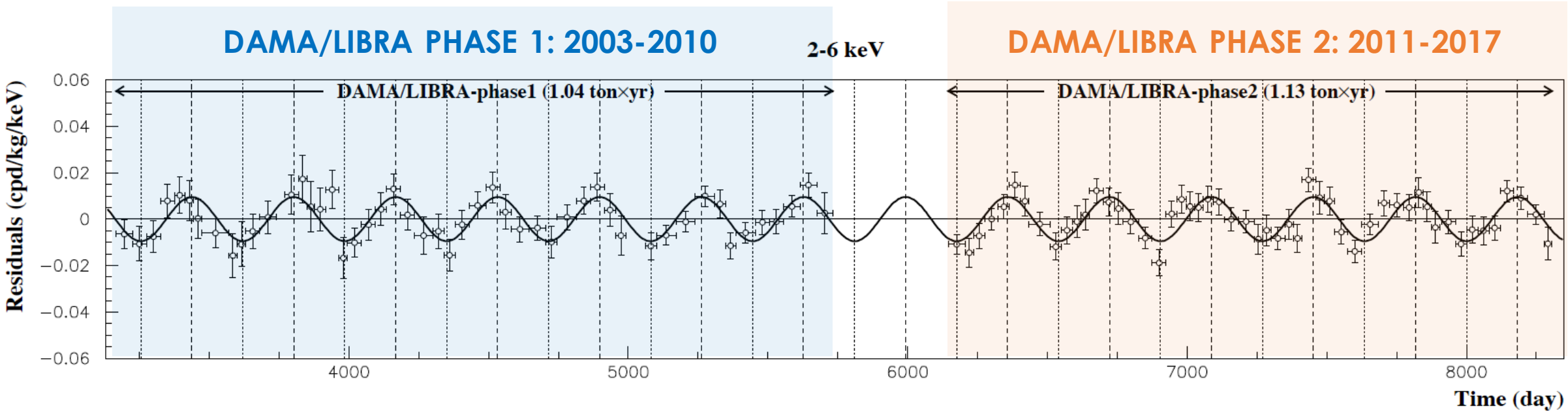
→ exposure

mainly liquid noble gases

~ 1 event/ tonne-year

DAMA/LIBRA: **TIME DISTRIBUTION**

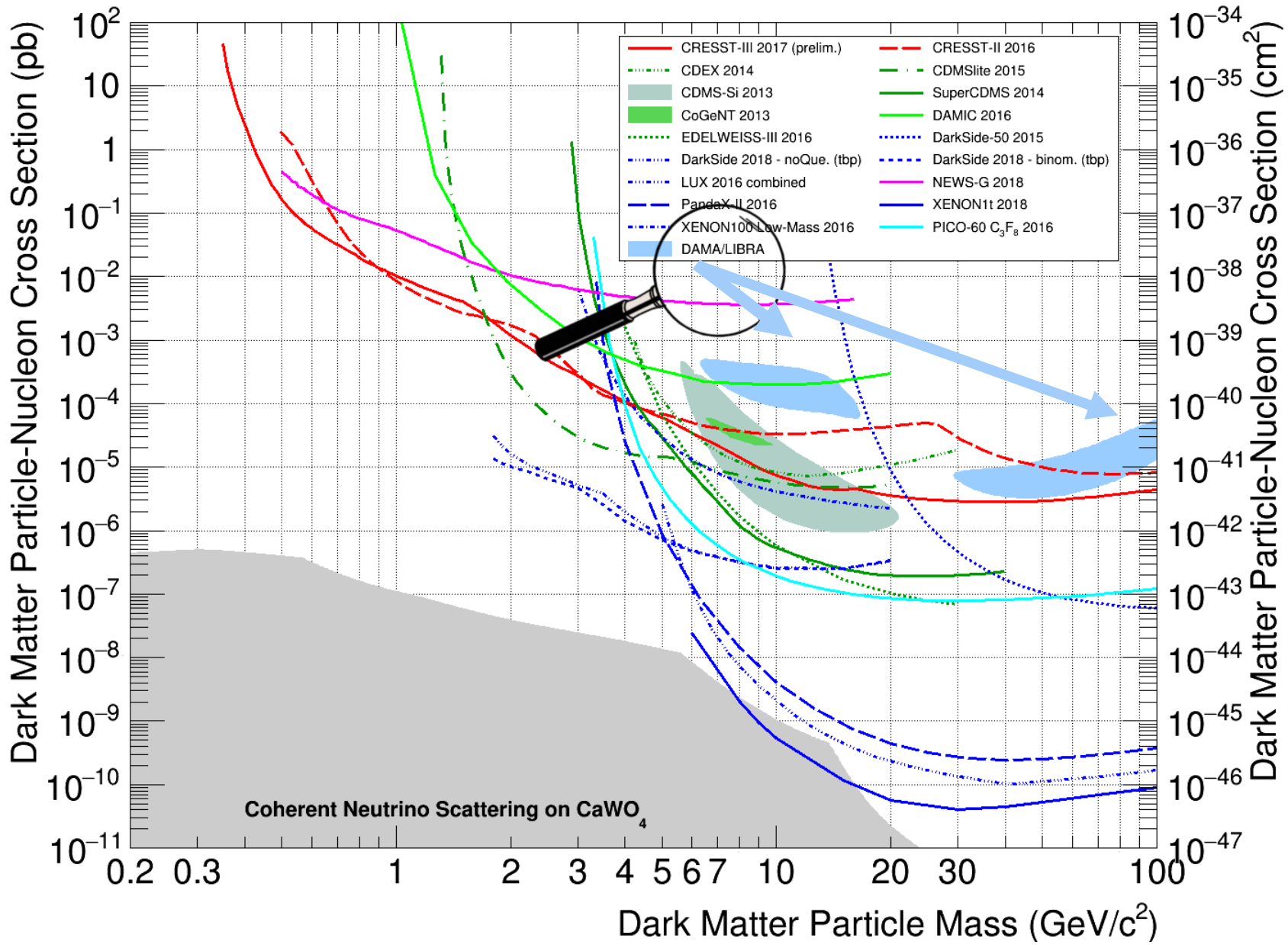
arXiv:1805.10486v1 [hep-ex] 26 May 2018



Total exposure: 2.17 tonne years (phase 1 + 2)
Statistical significance: >11.9 σ

combined with DAMA/NaI: 2.46 tonne years and 12.9σ !!!!

positive evidence for the presence of DM particles in the galactic halo


CRESST-III 2017 (prelim.)
CRESST-II 2016
CDEX 2014
CDMSlite 2015
CDMS-Si 2013
SuperCDMS 2014
CoGeNT 2013
DAMIC 2016
EDELWEISS-III 2016
DarkSide-50 2015
DarkSide 2018 - noQue. (tbp)
DarkSide 2018 - binom. (tbp)
LUX 2016 combined
NEWS-G 2018
PandaX-II 2016
XENON1t 2018
XENON100 Low-Mass 2016
PICO-60 C_3F_8 2016
DAMA/LIBRA
Coherent Neutrino Scattering on $CaWO_4$
Dark Matter Particle-Nucleon Cross Section (pb)
Dark Matter Particle-Nucleon Cross Section (cm^2)
Dark Matter Particle Mass (GeV/c^2)

only valid for standard assumptions!!!

WHAT ARE THE **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

DM-nucleus cross-section

minimal velocity to produce a recoil of energy E_r

~ A^2

~ form factor

Astro physics

dark matter halo

velocity distribution

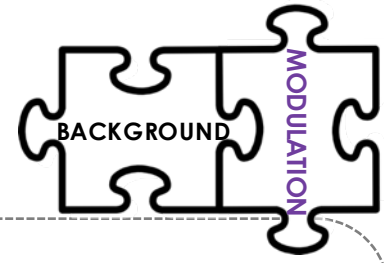
Particle physics

interaction mechanism

We have a dependence on the target material

→ cross-check DAMA/LIBRA signal with **same-target experiment**

NaI EXPERIMENTS *incomplete list!*

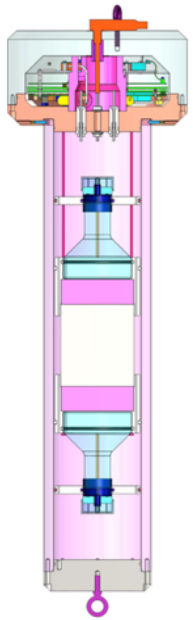


DM-Ice17

South pole
17 kg NaI

energy: 4 keV_{ee}

3.5 y physics run
no hint

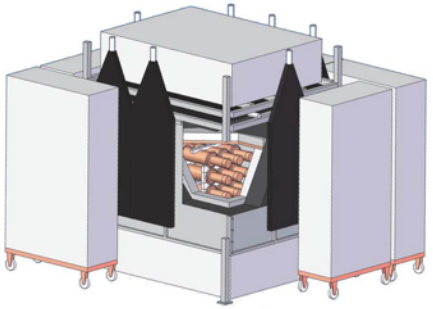


ANAIS-112

LSC - Spain
112.5 kg NaI

energy: < 1 keV_{ee}

spring 2017



COSINE-100

Y2L Korea
KIMS NaI + DM-Ice
106 kg

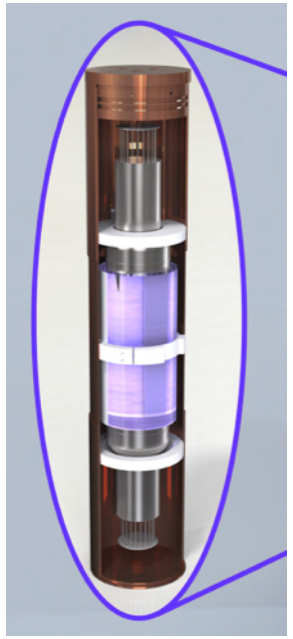
energy: ~ 2 keV_{ee}

since Sept. 2016

SABRE

Gran Sasso/Australia
40-50 kg NaI

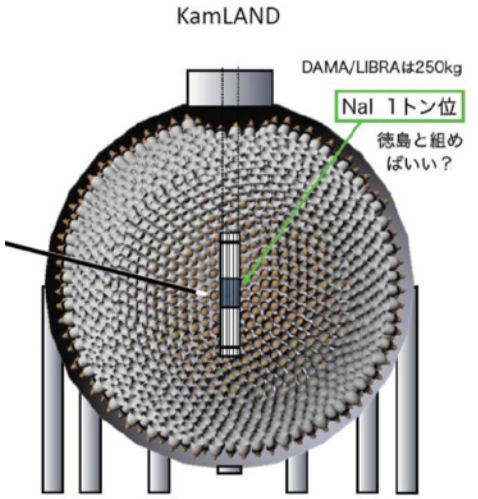
construction phase
PoP in 2019



KamLand-PICO-Ion

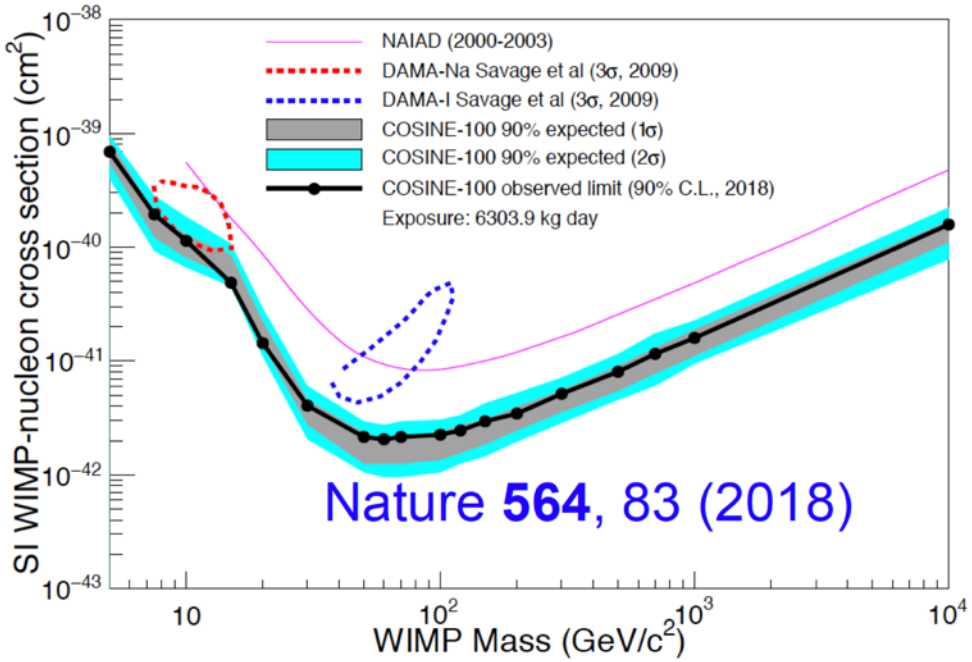
KamLand/Japan
1t NaI

planning/
prototyping phase

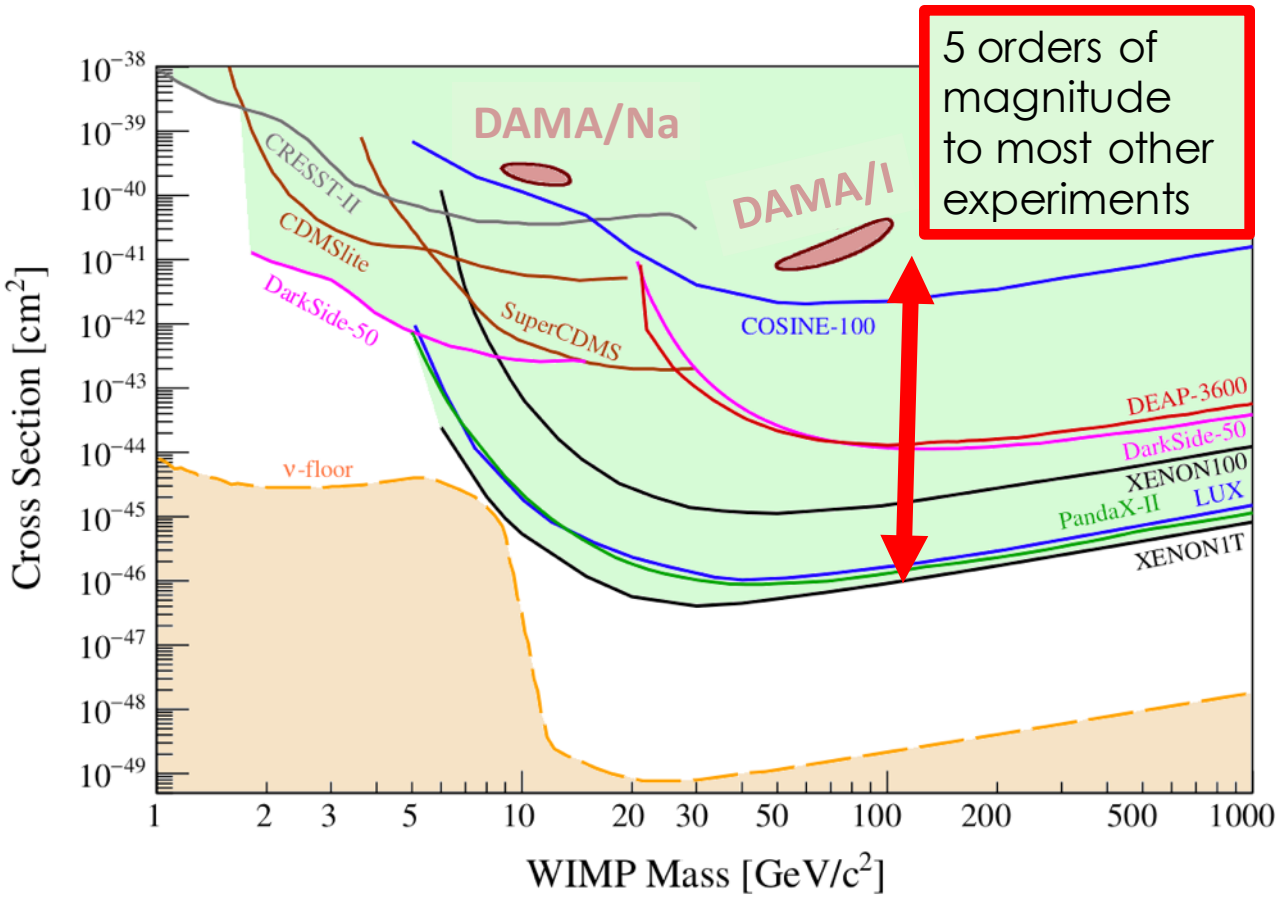


DAMA/LIBRA and STANDARD SCENARIO

COSINE-100



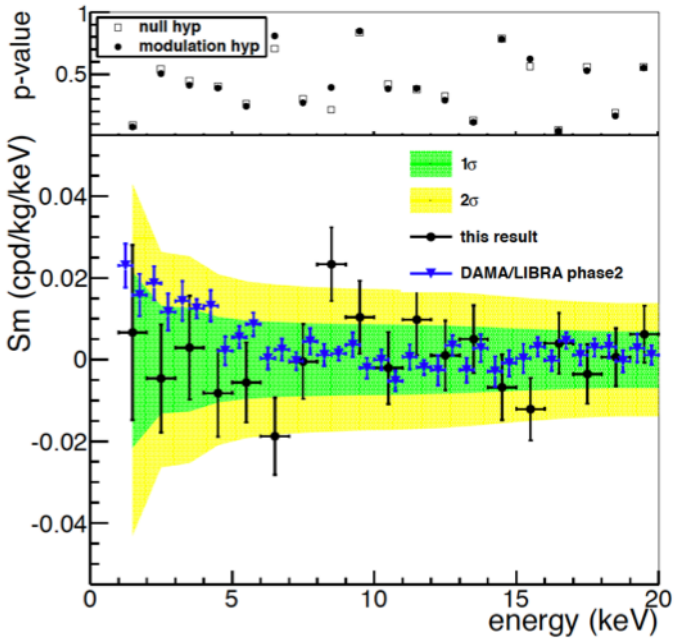
COSINE-100 excludes DAMA/LIBRA signal as standard SI WIMP interaction with standard halo model and using **NaI(Tl) crystals**



Most of experiments in exclude standard SI WIMP interaction with standard halo model

RECENT NaI-based MODULATION RESULTS

ANAIS-112



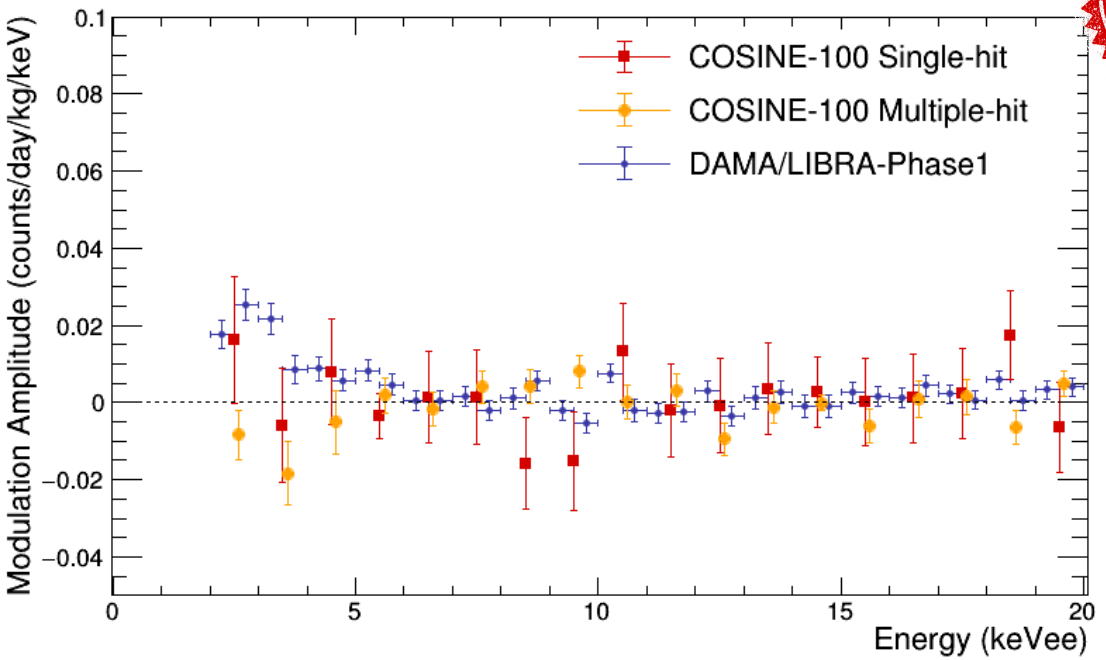
time: 1.5 years of data

exposure: 157.55 kg year

best fits are consistent with the absence of modulation

arXiv:1903.03973

COSINE-100



time: 1.7 years of data

exposure: 97.7 kg year

consistent with both a null hypothesis and DAMA/LIBRA's 2–6 keV best fit value

arXiv:1903.10098v1

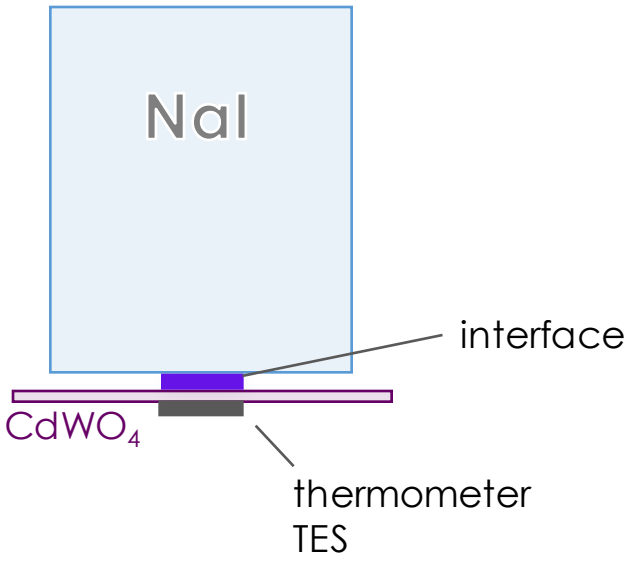
Why we need COSINUS?

www.cosinus.it

- **IDEA**: NaI-based scintillating calorimeter operated at **mK-temperatures**
- **PRINCIPLE:** **Two channel** approach: NaI crystal scintillates
  → simultaneous detection of the HEAT and the LIGHT signal

- first NaI detector with **particle discrimination** → low background
- lower energy threshold for nuclear recoils → high sensitivity
- 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

COSINUS DETECTOR DESIGN



NaI Target Crystal

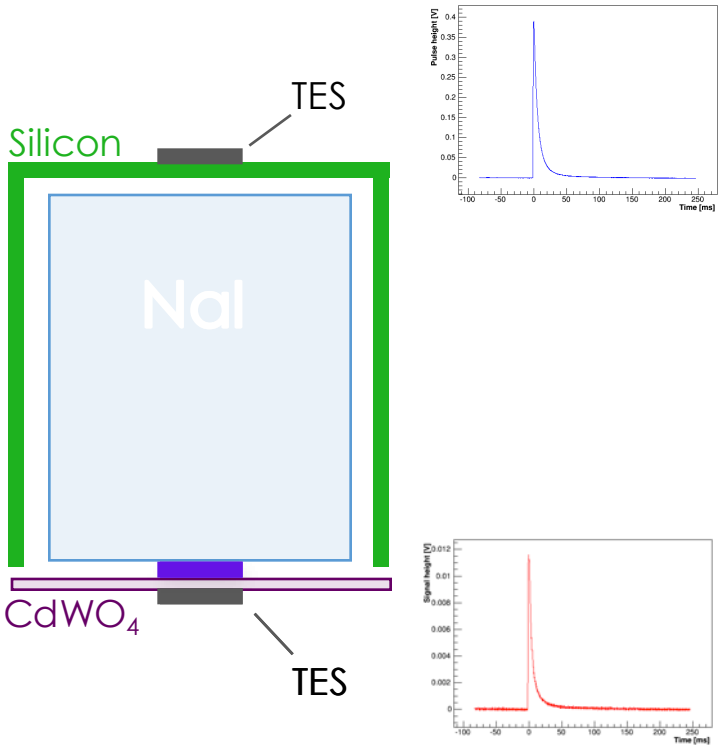
- scintillator
- multi-element target
- mass: ~ 30 – 200 g
- **hygroscopic**

^{11}Na 53I

Carrier Crystal

- carries the thermometer (Transition Edge Sensor)
- glue/oil as interface and link for phonons

COSINUS DETECTOR DESIGN



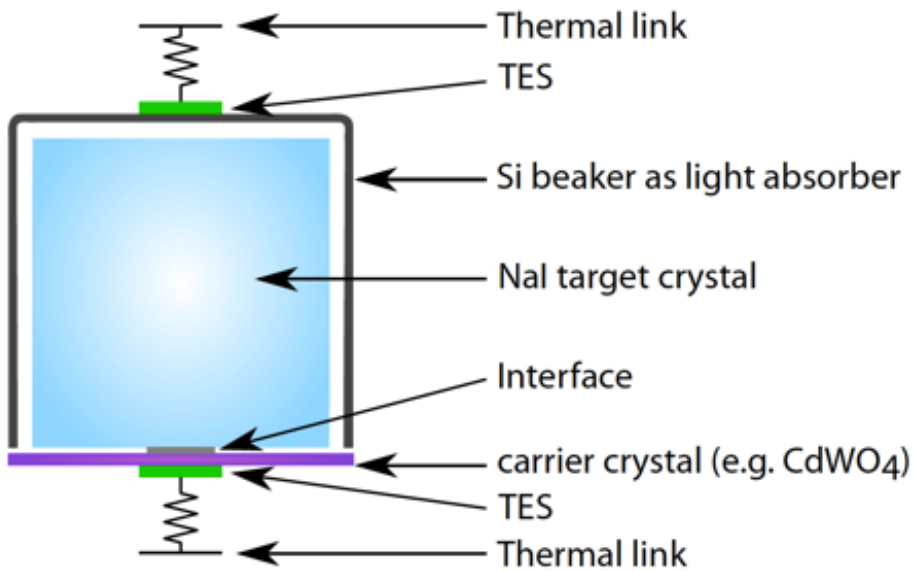
Light absorber

- beaker-shaped HP silicon
- 40 mm diameter & height
- equipped with TES optimized for light detection

→ high light collection efficiency

→ fully active veto to reject surface backgrounds (e.g. alpha-induced nuclear recoils)

PERFORMANCE GOAL



NaI nuclear recoil energy threshold of 1 keV

~ 4% of deposited energy detected in form of light

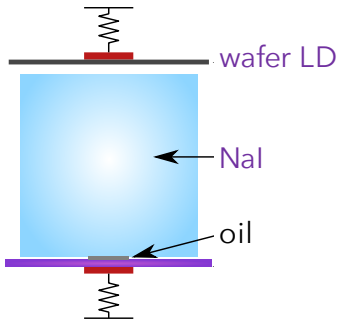
light detector baseline noise σ =10 eV

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

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

DETECTOR STATUS

1st PROTOTYPE (2016)



1st measurement of a NaI as cryogenic calorimeter

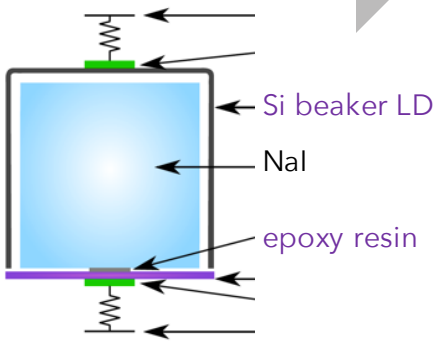
linear relation between light output and deposited energy

NaI threshold: 10 keV

3.7% detected in light

G. Angloher et al. JINST 12 P11007 (2017)

2nd PROTOTYPE (2016/17)



successful test of complete COSINUS detector design

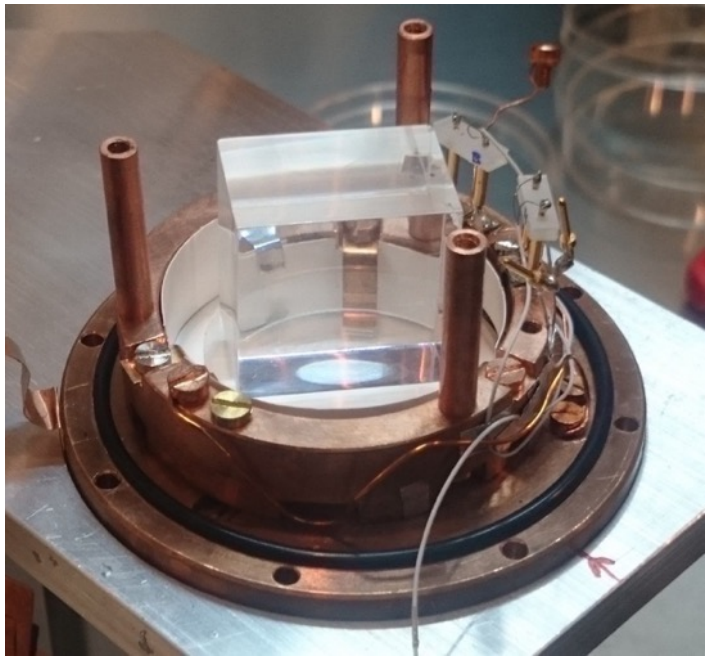
light energy resolution at zero energy: 15 eV

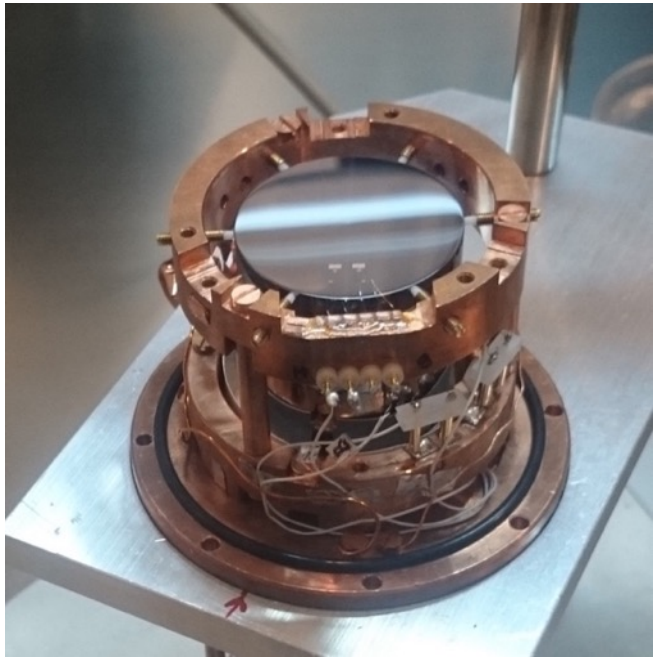
NaI threshold: 8.3 keV

13 % detected in light

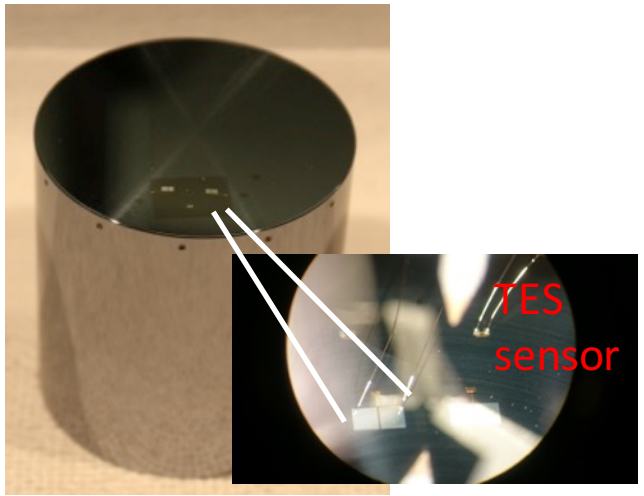
Schäffner, K. et al. J Low Temp Phys (2018). https://doi.org/10.1007/s10909-018-1967-3

2nd PROTOTYPE DETECTOR

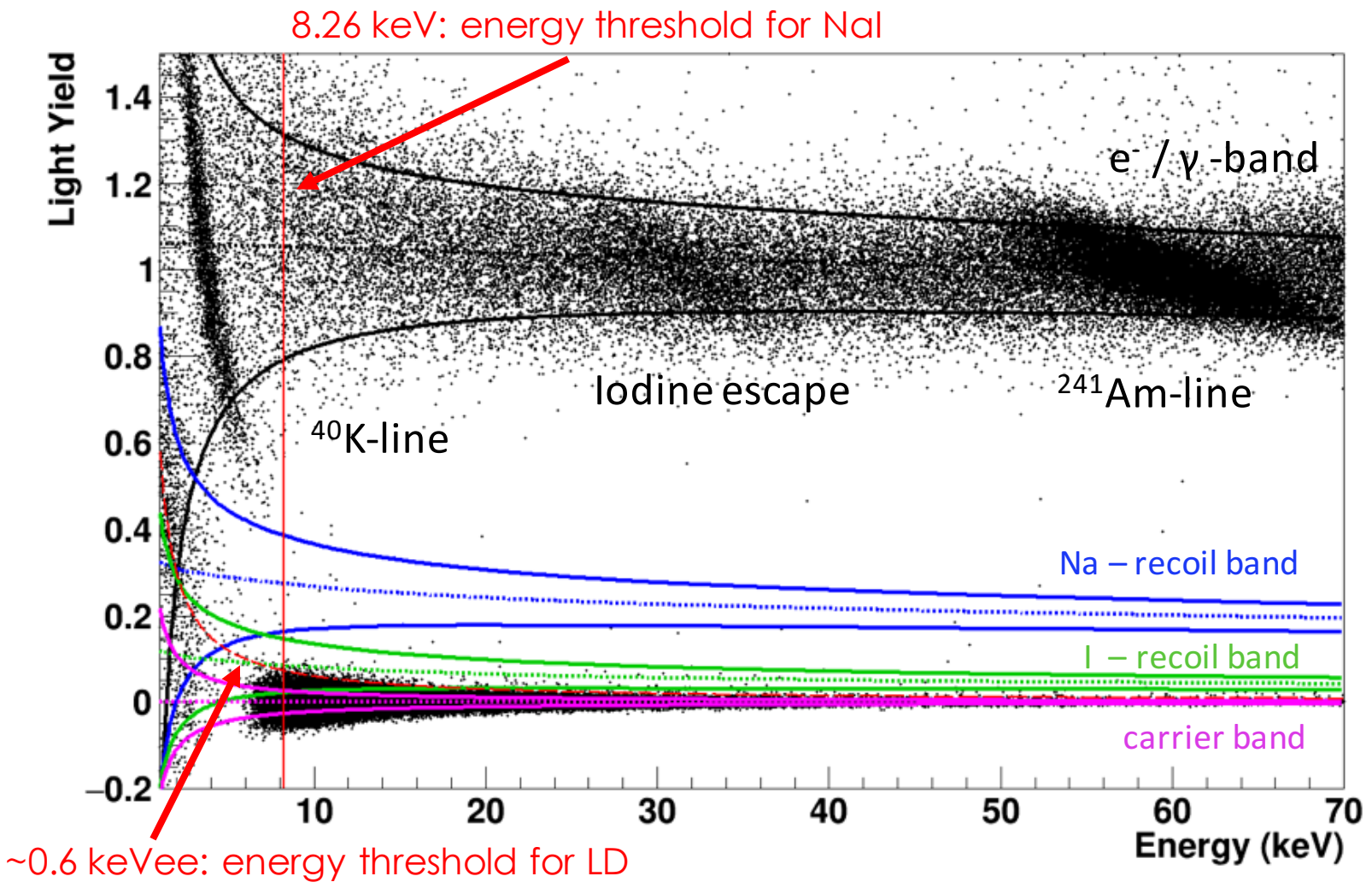




- interface: epoxy resin
- beaker-shaped Si light absorber
- NaI crystal: 66 g



2nd PROTOTYPE DETECTOR



- NaI energy threshold is (8.26 ± 0.02 (stat.))keV
- width of the ^{241}Am peak is (4.508 ± 0.064 (stat.)) keV
- carrier events identified by pulse shape

Schäffner, K. et al. J Low Temp Phys (2018). https://doi.org/10.1007/s10909-018-1967-3

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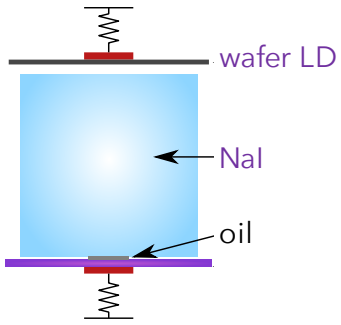

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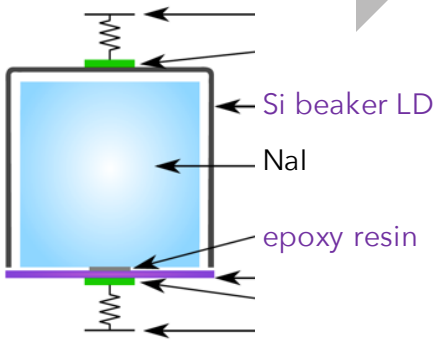

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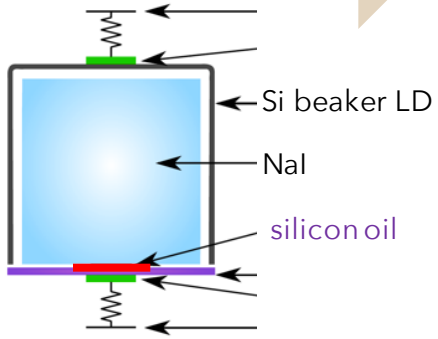
3rd PROTOTYPE (2017)



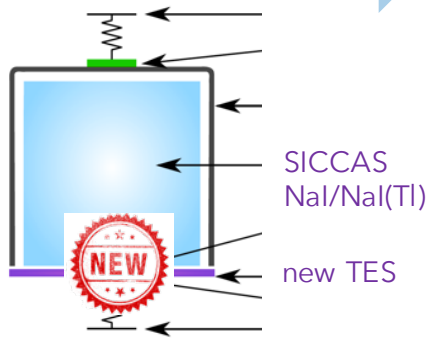
changed interface to thin layer of silicon oil

commissioning of:
in-house electronics
and DAQ from MIB

NaI threshold: 6.5 keV

AmBe calibration campaign

4th → 12th PROTOTYPE (2018/19)



1.
validate new batch of NaI/**NaI(Tl)** crystals from **SICCAS**

2.
test of new **TES-concept** for the NaI crystal

CYRSTAL PROGRAM

- collaboration with **I. Dafinei** from INFN, Roma 1 in Italy
- **Yong Zhu** from SICCAS joined the COSINUS collaboration
- NaI / NaI(Tl) grown from **Astrograde-powder** at SICCAS:

→ **very promising radiopurity**:

5-9 ppb of K at crystals' nose and 22-35 ppb at crystals' tail

(3-inch crystal @ SICCAS)

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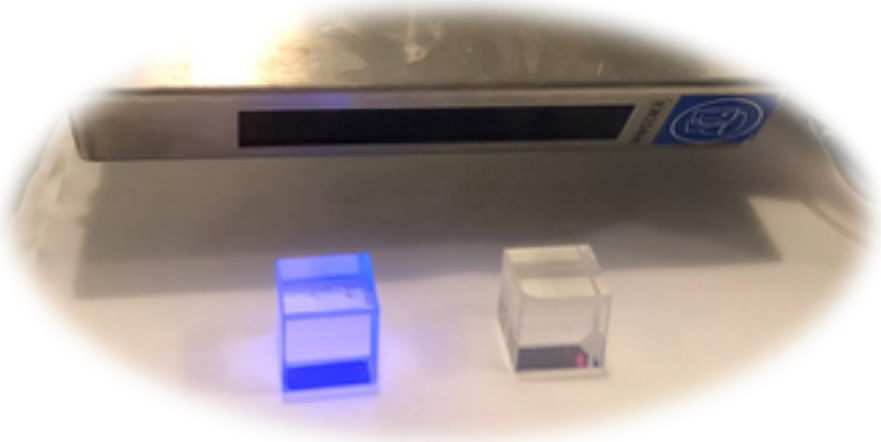
(3-inch crystal @ SICCAS)

IN THE QUEUE:

- NaI(Tl) grown with internal samarium "contamination" to study alpha quenching factor
- NaI(Tl) with different amount of thallium dopant to study nuclear quenching factors



TO DO LIST FOR DARK MATTER MODULE

- ✓ operate NaI as cryogenic detector
- ✓ beaker-shaped light detector
- ✓ radiopure NaI crystals

- ❑ phonon threshold of 1keV: 10keV→8.5 keV→6.5keV→ …
- ❑ particle discrimination: under investigation

Prototype measurement results:
G. Angloher et al. JINST 12 P11007 (2017)
F. Reindl et al., arXiv 1711.01482
Schäffner, K. et al. J Low Temp Phys (2018)

COSINUS COLLABORATION @ present

www.cosinus.it

Karoline Schäffner
Natalia di Marco
Stefano Pirro
Vanessa Zema

Detector development

R&D measurements

Theoretical framework

MC simulation

Data analysis

Setup design

Jochen Schieck
Florian Reindl
Christoph Schwertner
M. Friedl
S. Fichtinger
Martin Stahlberg
Alexander Fuss
Daniel Schmiedmayer

Data analysis

Electronics

MC simulation

Software development

Federica Petricca
Godehard Angloher
Michele Mancuso
Franz Pröbst

Sensor production

Gianluigi Pessina
Paolo Carniti
Claudio Gotti
Lorenzo Pagnanini

Heater/bias electronics

Yong Zhu

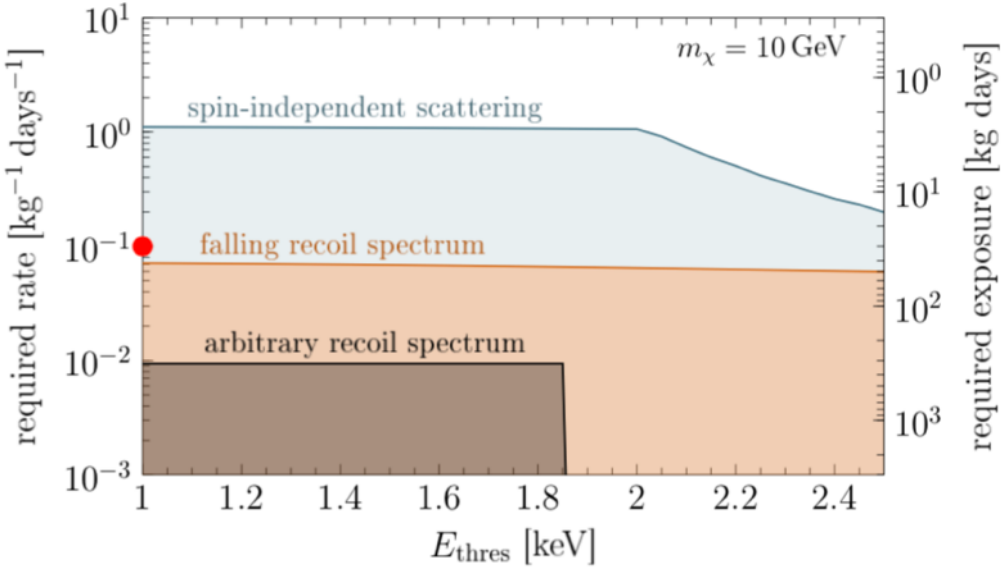
Radiopure NaI production

TWO PHASES: COSINUS 1π and 2π

COSINUS 1π: initial phase

- 1st measurement with 10 modules for 100kg days
- Setup planned with 25 modules for 1000kg days

GOAL: confirm or rule out nuclear origin of DAMA



F. Kahlhöfer, KS et al., JCAP 1805 (2018) no.05, 074

COSINUS 2π:

- increase in target mass, upgrade facility

GOAL: modulation search

COSINUS: INFRASTRUCTURE

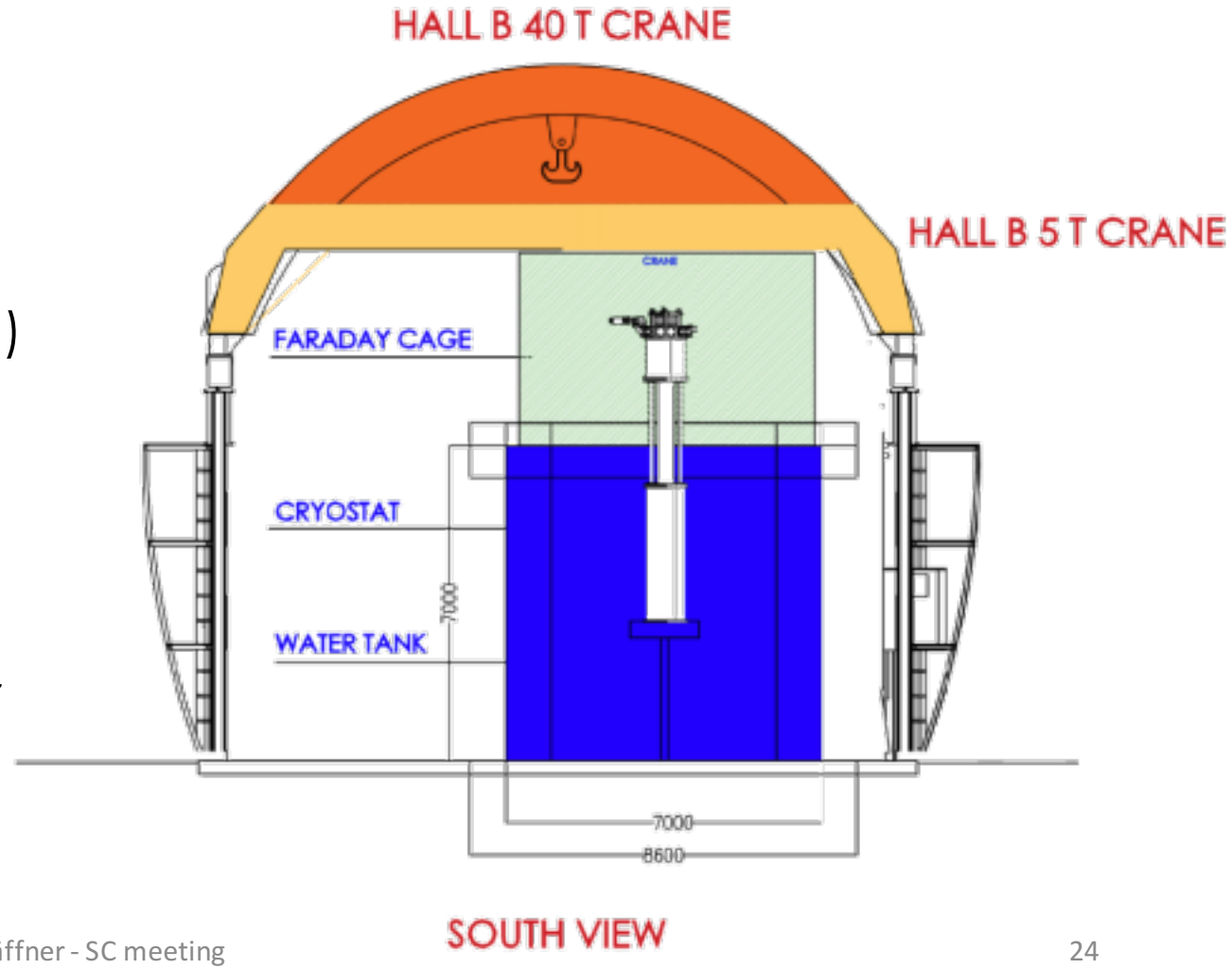
- underground site
- water tank
- $^3He/^4He$- dilution refrigerator
- "dry well" to host the cryostat in the tank
- utility building (platform and service area)
- Faraday cage and clean room

- **Funding granted:**

  MPRG grant, MPP: 3.115 Mio. Eur

  HEPHY, Vienna: 100k Eur

  INFN – CSN5 (2019): 28k Eur

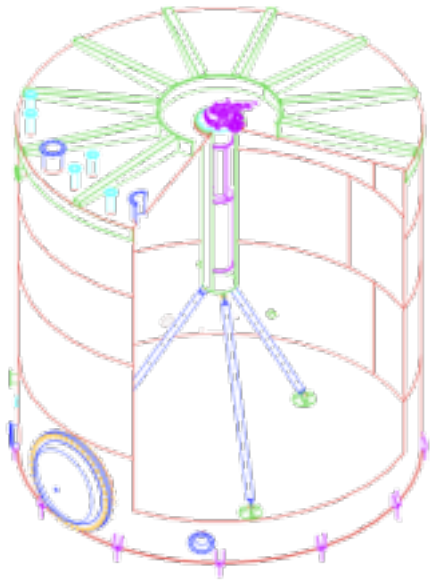


COSINUS: EXPERIMENTAL SETUP

Water tank dimensions:

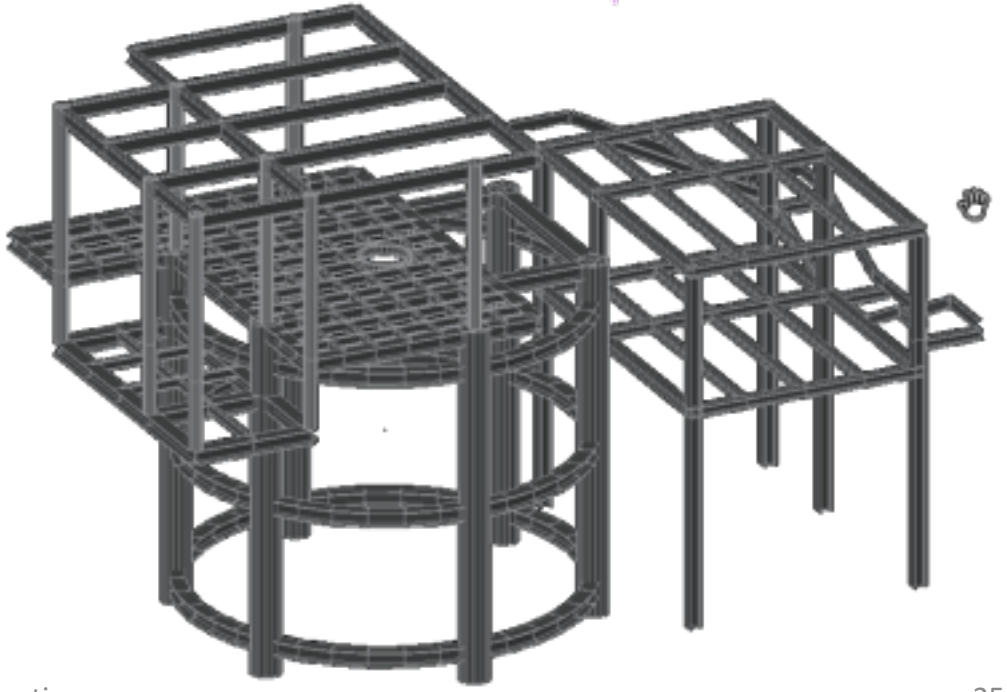
- GEANT 4 MC simulations
  → final design almost completed

- Optical simulation for muon veto in progress



Utility building:

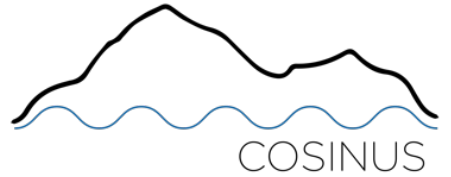
Design studies ongoing



PRELIMINARY TIMELINE

• CDR	submitted to SC of LNGS
• TDR	Q1 2020
• final executive construction plan	Q1 2020
• construction	Q2 2020 – Q3 2020
• cryostat commissioning	Q2 2020
• final detector design	Q3 2020
• installation and commissioning	Q3 2020 – Q1 2021
• start data taking	Q2 2021

SUMMARY



- 1997: DAMA presents at TAUP first evidence for the modulation
  → after more than 20 years the DAMA/LIBRA observation is still not cross-checked by a same-target experiment

- numerous NaI-based experiments *à la DAMA* in data taking or being set up
  → radiopure NaI crystals is the key-issue

- COSINUS develops the first NaI dark matter detector with particle discrimination

- Detector R&D to meet performance goals is ongoing

- CDR submitted and experimental setup design is in progress

- COSINUS-1π provides an opportunity to an early start of COSINUS and to obtain important physics results


Thank you for your attention
@Maurizio Verdecchia Photography