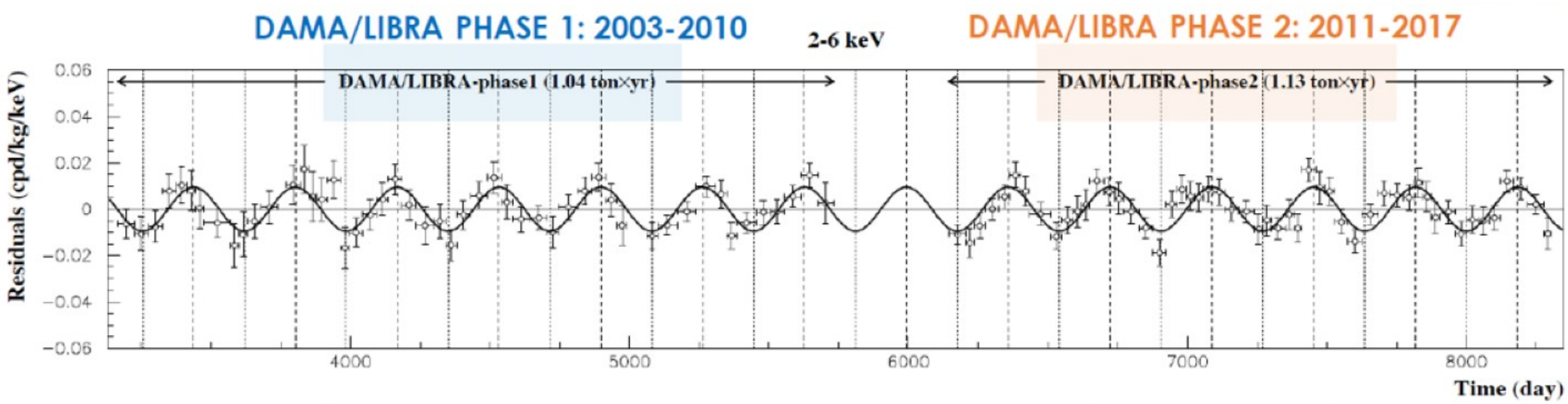
16th Patras Workshop on Axions, WIMPs, and WISPs

COSINUS - Direct Search for Dark Matter with Cryogenic NaI Detectors

Martin Stahlberg for the COSINUS Collaboration

Universe **2018**, *4*(11), 116



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

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

- **Positive evidence** for the presence of DM particles in the galactic halo
- Strong tension with other direct DM detection experiments - but different target materials used
- Up to now, source of the modulation is unknown

➡ Emergence of several NaI-based direct detection experiments in the last years

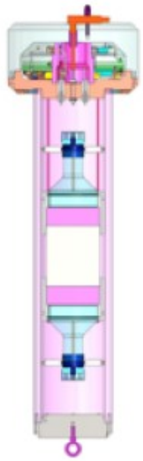
NAI EXPERIMENT LANDSCAPE

DM-Ice17

South pole
17 kg NaI

threshold: 4 keV_{ee}

3.5 y physics run
no hint

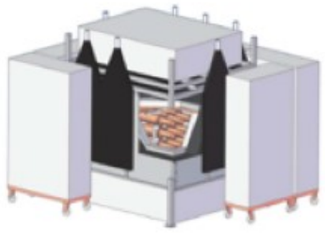


ANAIS-112

LSC - Spain
112.5 kg NaI

threshold: < 1 keV_{ee}

since spring 2017



COSINE-100

Y2L Korea
KIMS NaI + DM-Ice
106 kg

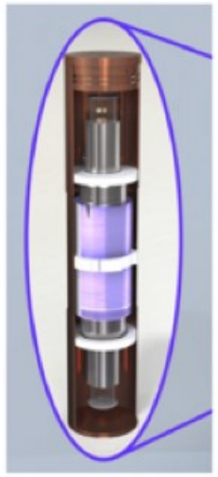
threshold: ~2 keV_{ee}

since Sept. 2016

SABRE

Gran Sasso/Australia
40-50 kg NaI

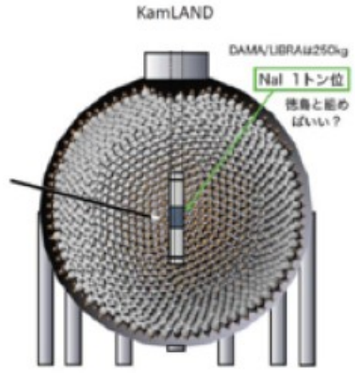
construction phase



KamLand-PICO

KamLand/Japan
1t NaI

planning/
prototyping phase



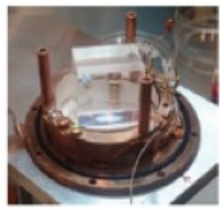
COSINUS

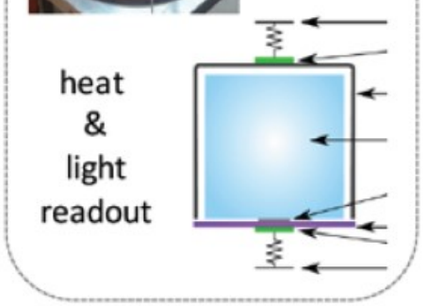
NEW

Gran Sasso
NaI as **cryogenic detector**

only NaI-based experiment with Particle Identification

construction starts ~~2020~~ 2021





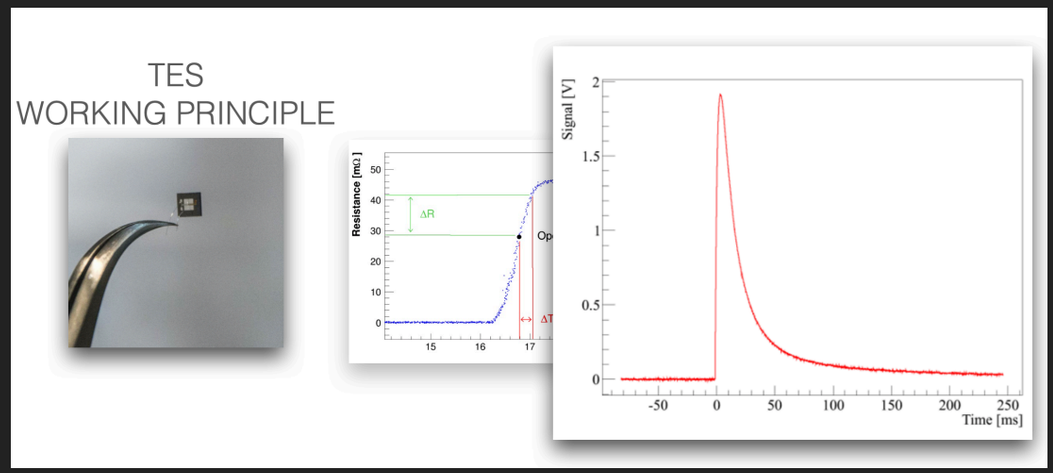
- Results from ANAIS & COSINE also in strong tension with DAMA

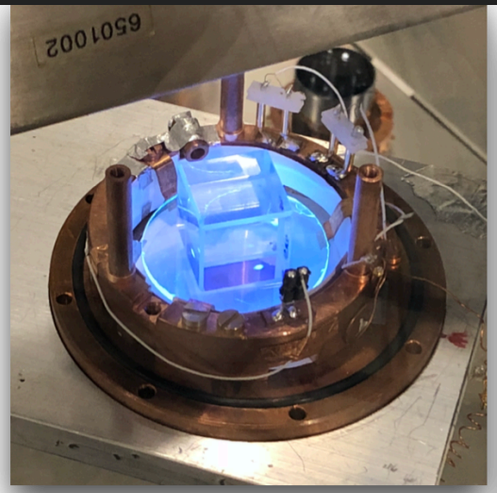
  - Physical review letters 123.3 (2019): 031302
  - Physical Review D 103.10 (2021): 102005

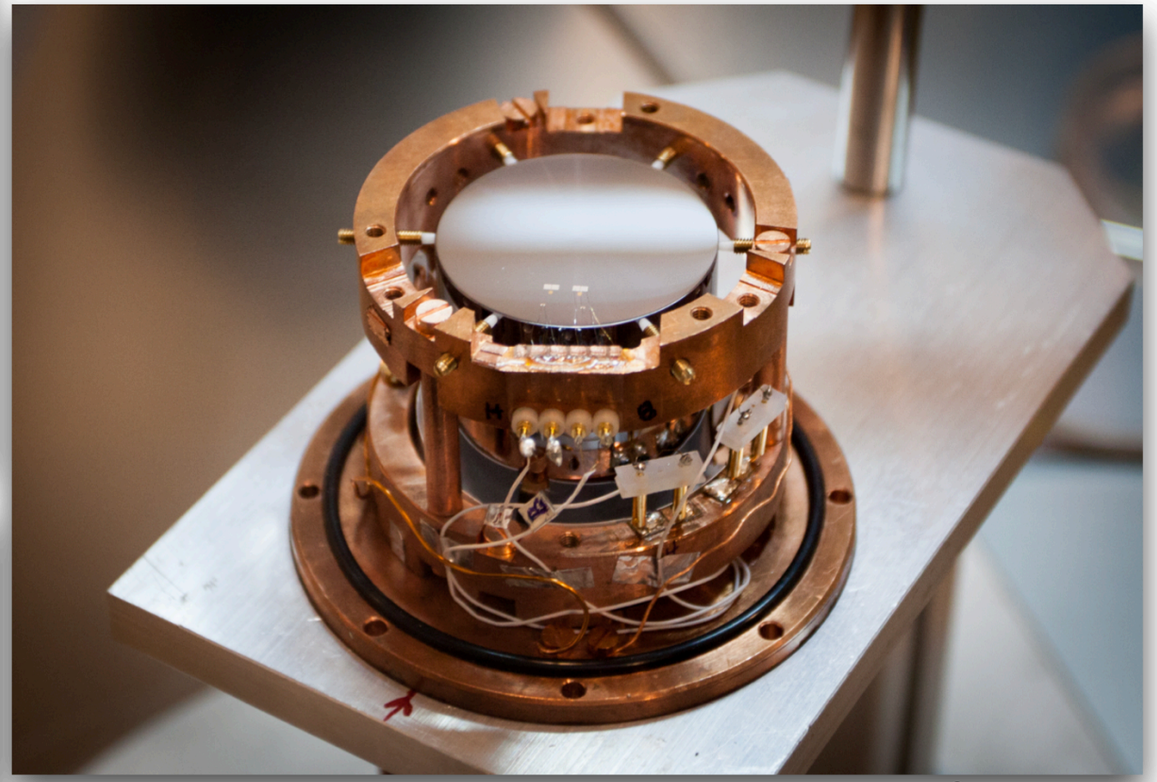
- **Idea: Operate NaI crystals as cryogenic detectors**
- Well-established technique
- Two channels, read out via TES sensors + SQUIDs:

  - Heat (phonons)
  - Scintillation light

- Example: „Beaker“ design - use Si beaker to collect light

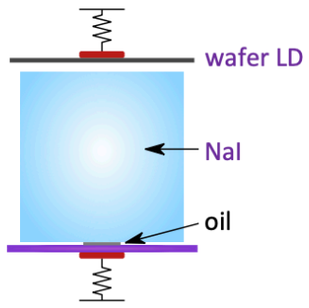






COSINUS

1st PROTOTYPE (2016)



1st measurement of a NaI as cryogenic calorimeter

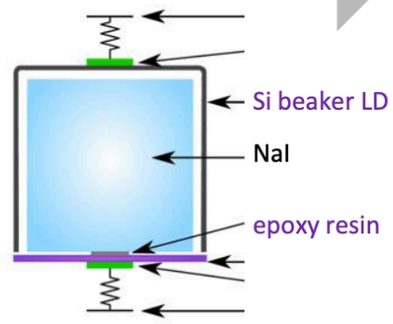
linear relation between light output and deposited energy

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

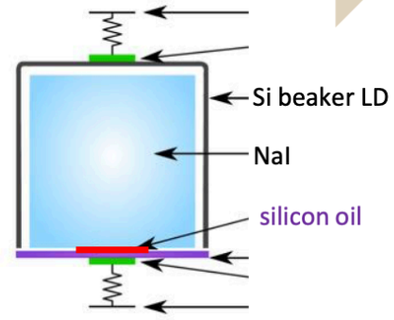
energy resolution at zero energy : 15 eV

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

3rd PROTOTYPE (2017)

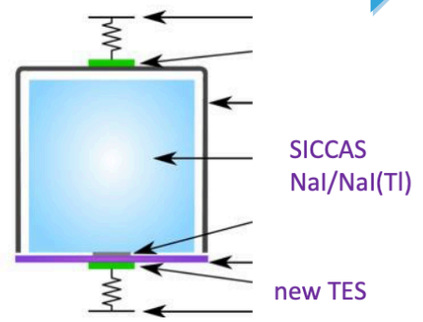


changed interface to thin layer of silicon oil

commissioning of: in-house electronics and DAQ from MIB

NaI threshold: 6.5 keV

4th - 20th PROTOTYPE



tests with high-purity NaI/NaI(Tl) crystals from SICCAS

Tests of different TES-concepts for the NaI crystal, optimization of beaker design

Work ongoing!

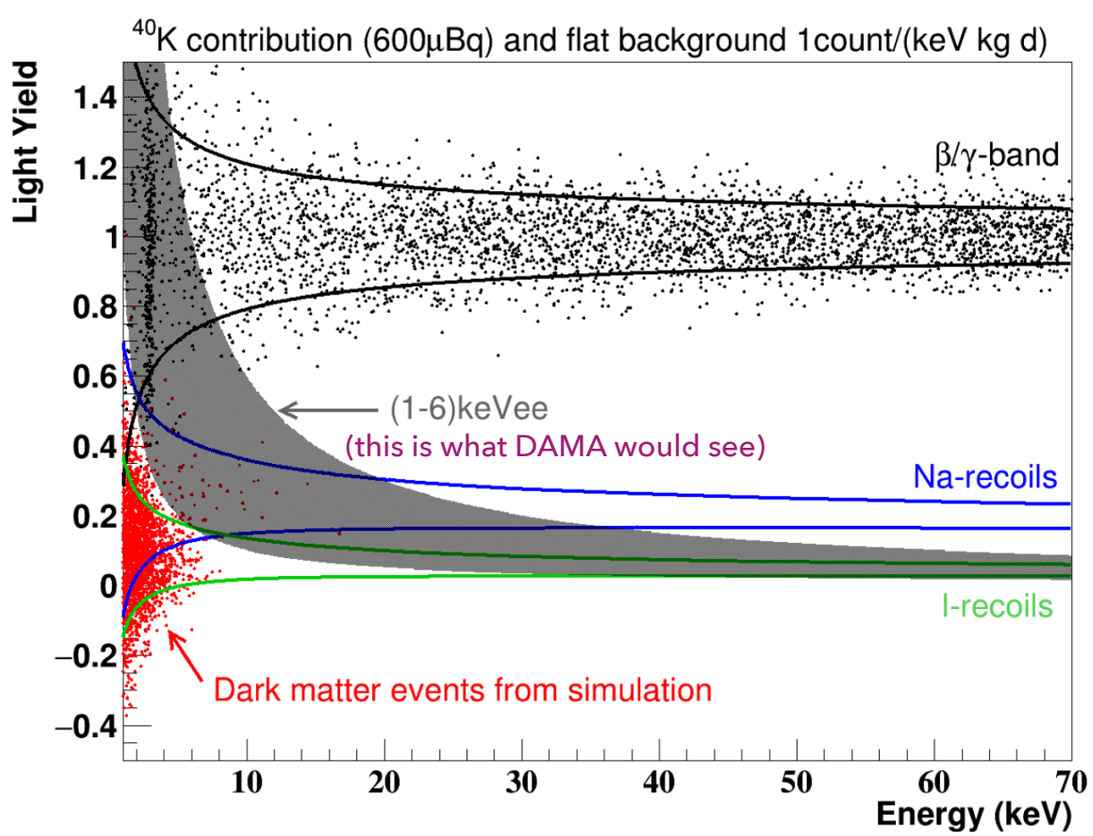
Performance goal: 1 keV

Performance goal: 4 %

- Crystals of few cubic centimeters (10-100g)
- Collaboration with SICCAS; production of high-purity NaI crystals

- With TES, achievable thresholds on the order of a few keV (in recoil energy)
- Additional scintillation light allows for particle discrimination
- ➡ Quenched bands

$$\text{Light Yield} = \frac{\text{Light Energy}}{\text{Phonon Energy}}$$

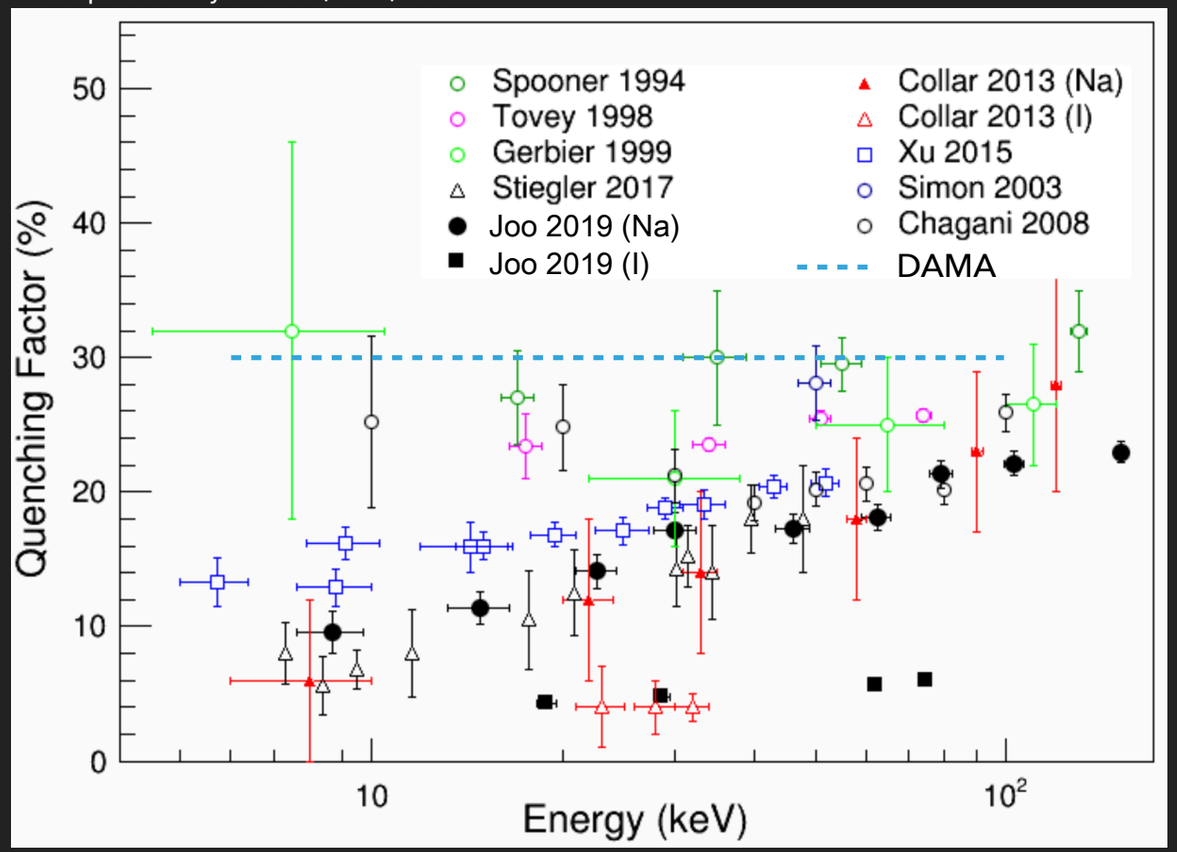


Simulation with 100 kg day exposure and 1 keV threshold

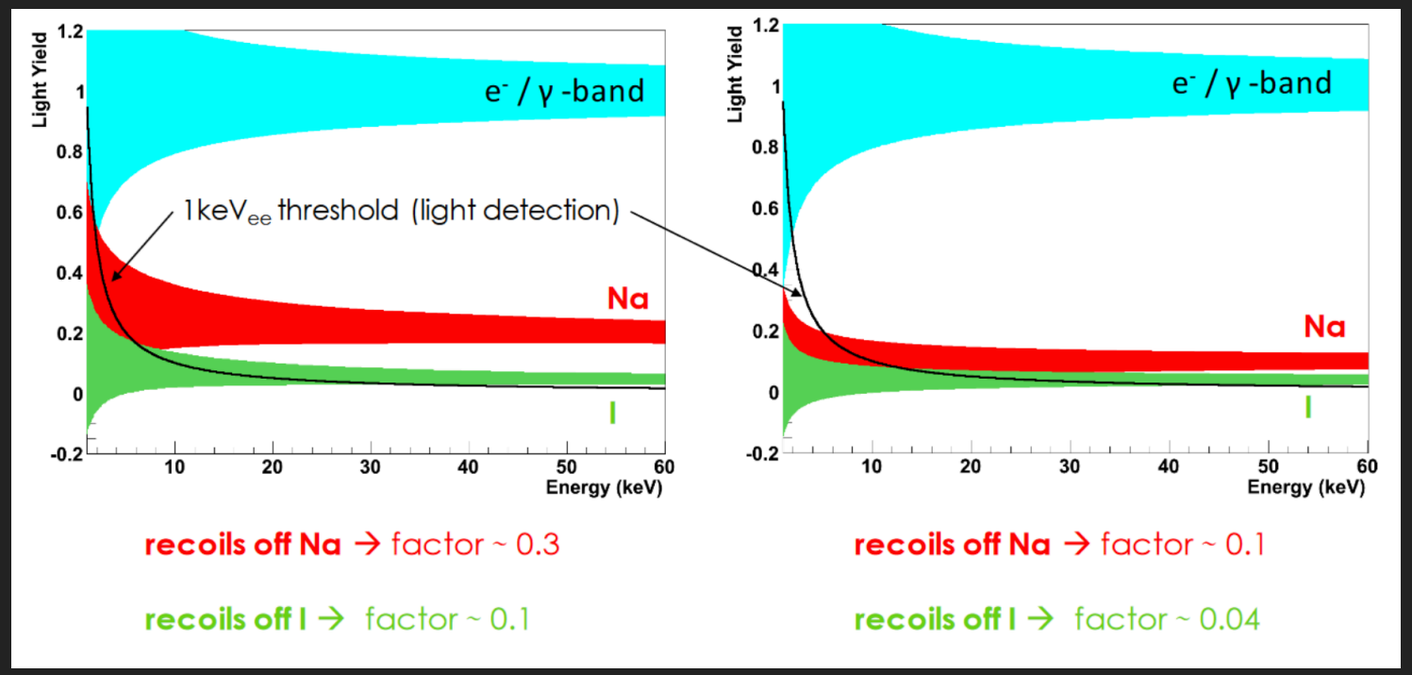
"The COSINUS project: perspectives of a NaI scintillating calorimeter for dark matter search."
The European Physical Journal C 76.8 (2016): 1-7.

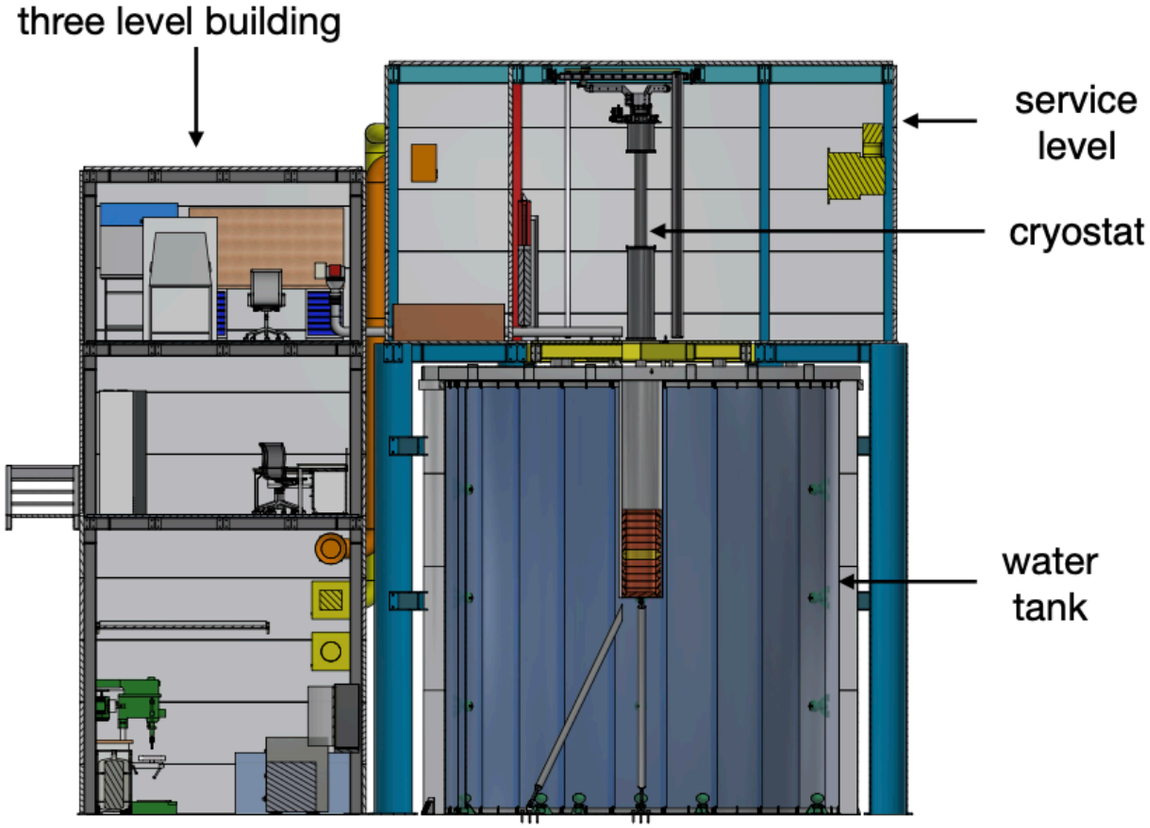
„QUENCHING FACTOR MYSTERY"

Modified from: Joo, H. W., et al. "Quenching factor measurement for NaI (Tl) scintillation crystal." Astroparticle Physics 108 (2019): 50-56.



- Measurements of quenching factors (QF) at room temperature do not agree
- In particular, role of Tl is unclear (usually crystals are doped)
- Strong influence of QF on signal interpretation
- COSINUS will provide the first cryogenic QF measurement for NaI



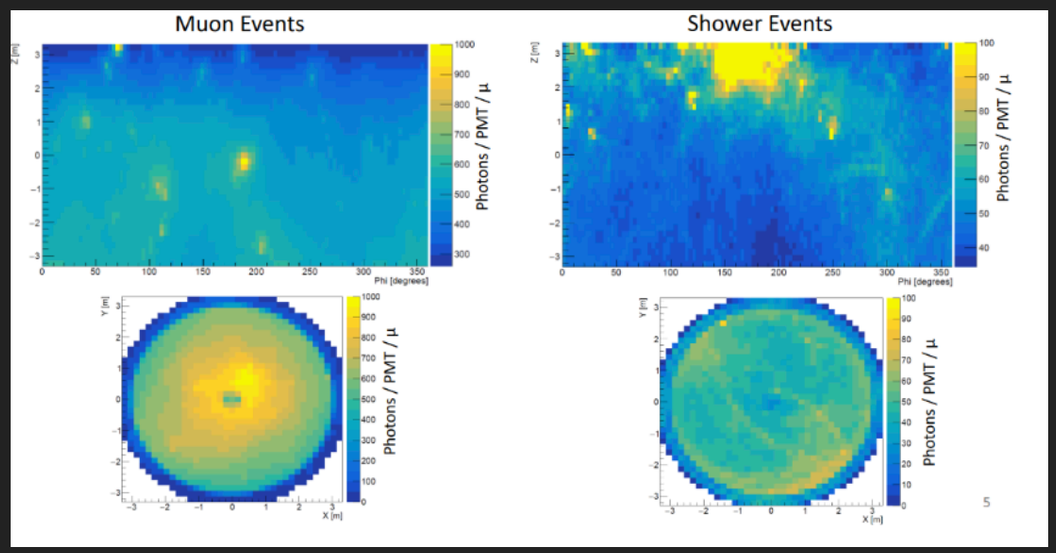


<u>Construction site:</u>

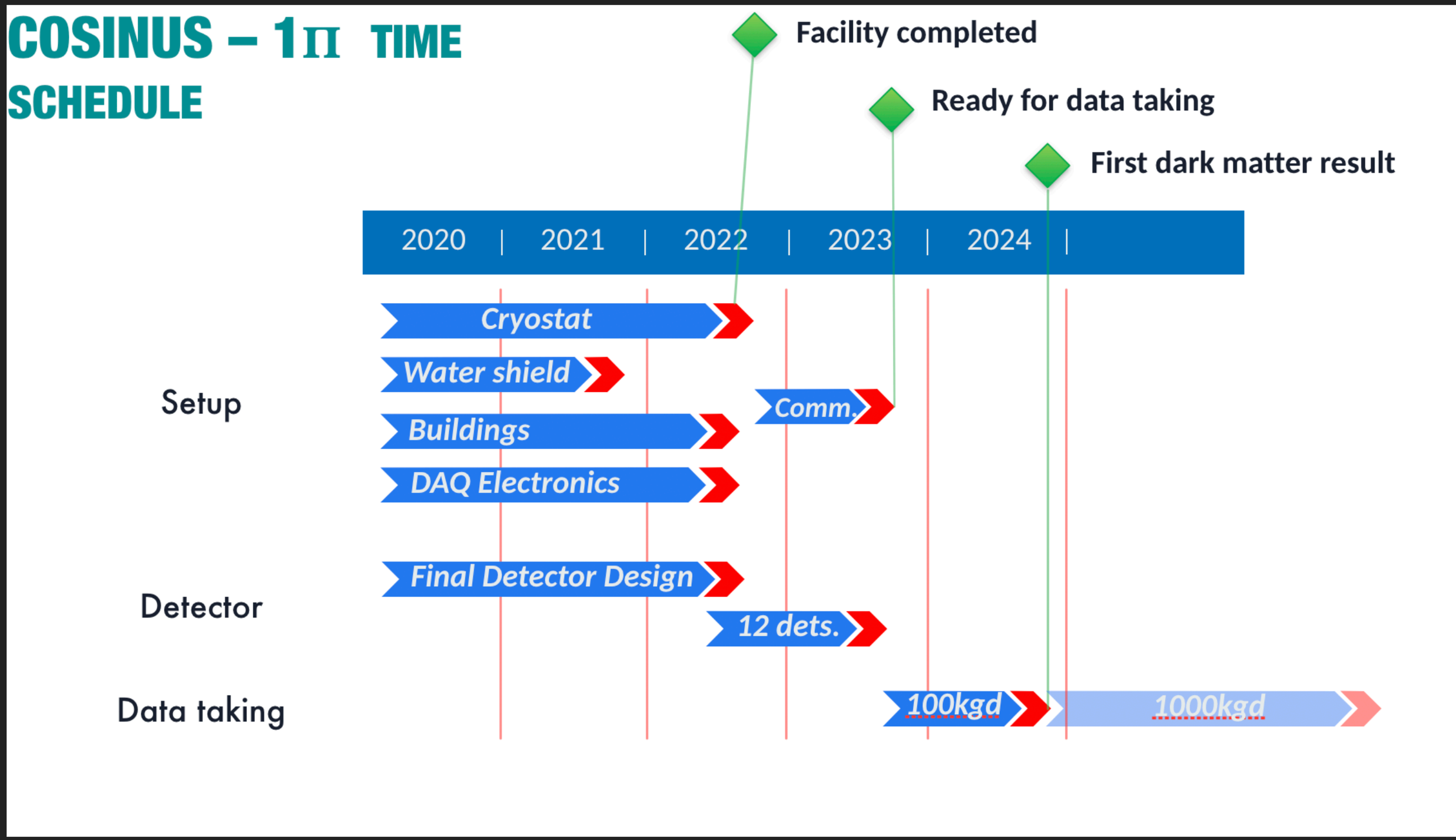
Laboratory Nazionali del Gran Sasso (Italy)

<u>Planned facility:</u>

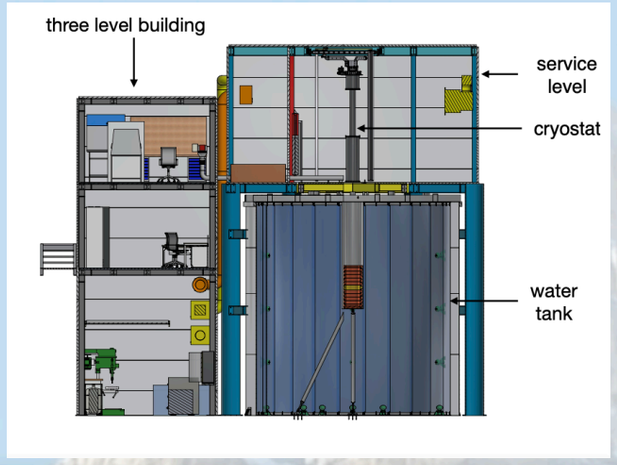
- („Dry“) cryostat with detector modules
- Cu shielding
- Water Cherenkov veto for active muon tagging
- Decoupling system to reduce vibrations
- Clean room for detector assembly

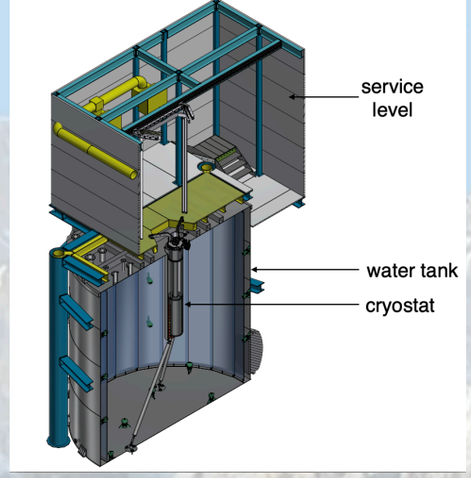


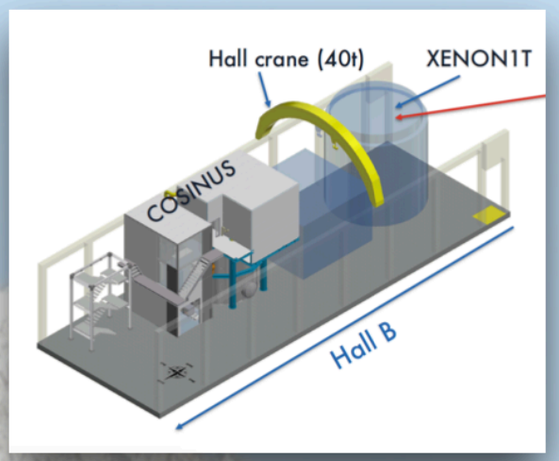
(GEANT simulation for muon veto)

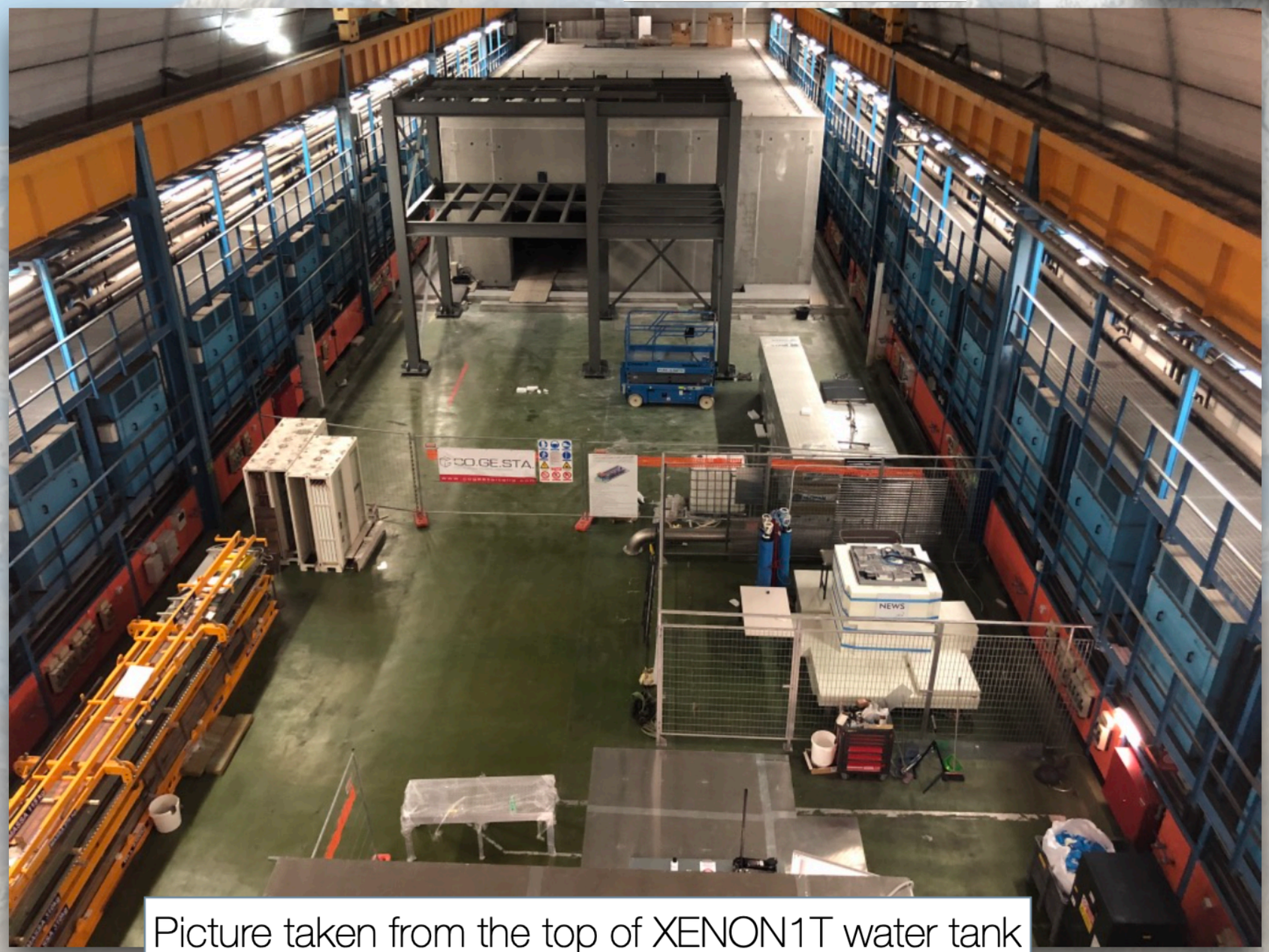

COSINUS – 1π TIME SCHEDULE
Facility completed
Ready for data taking
First dark matter result
2020 | 2021 | 2022 | 2023 | 2024 |
Setup
Cryostat
Water shield
Buildings
DAQ Electronics
Comm.
Detector
Final Detector Design
12 dets.
Data taking
100kgd
1000kgd

INFN
LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso



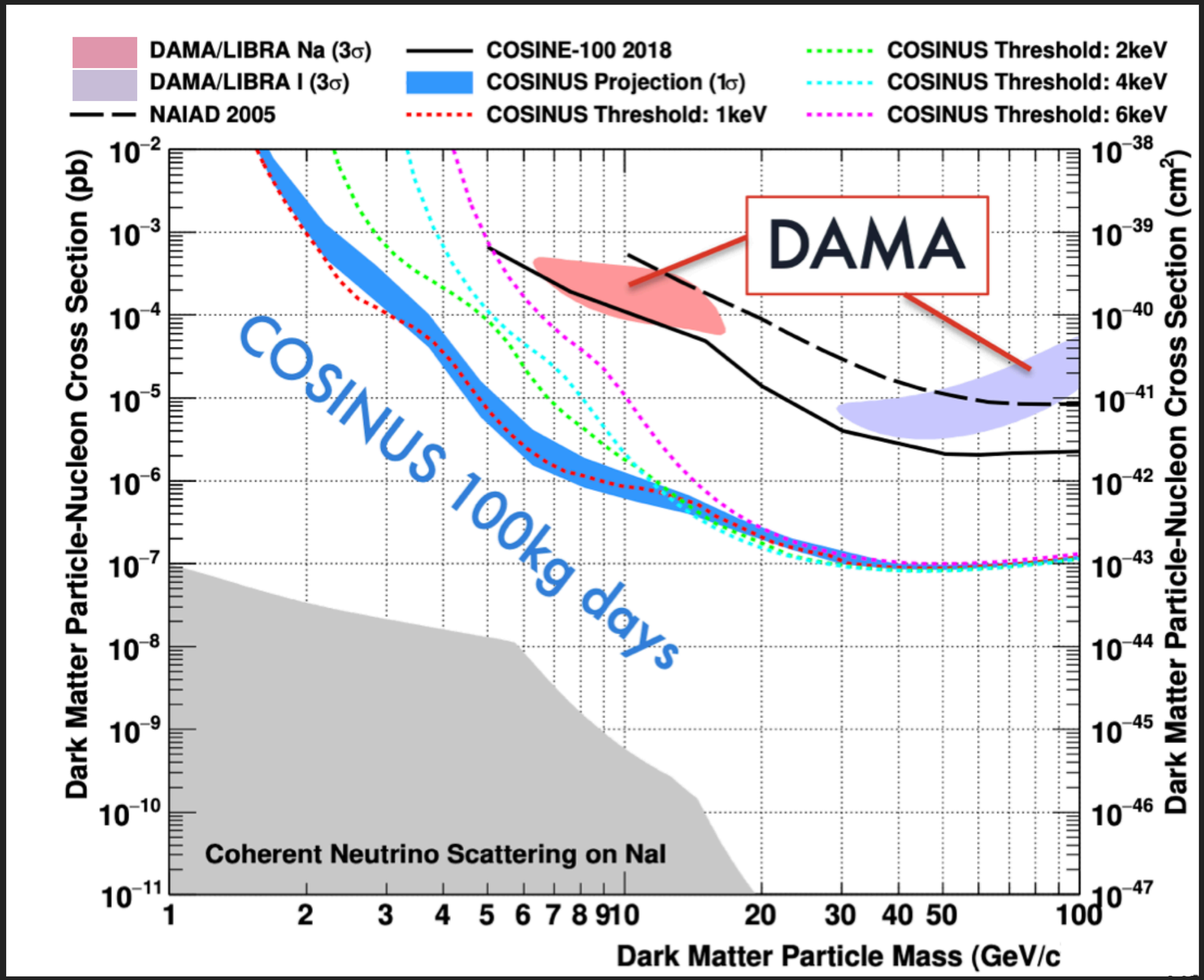






Picture taken from the top of XENON1T water tank

COSINUS SENSITIVITY PROJECTION



COSINUS will provide:

- Cross-check of DAMA modulation using same target material (NaI) and highly radiopure crystals
- Dual-channel readout, threshold of few keV
- Model-independent check (with sufficient exposure)
- First application of NaI as cryogenic detector

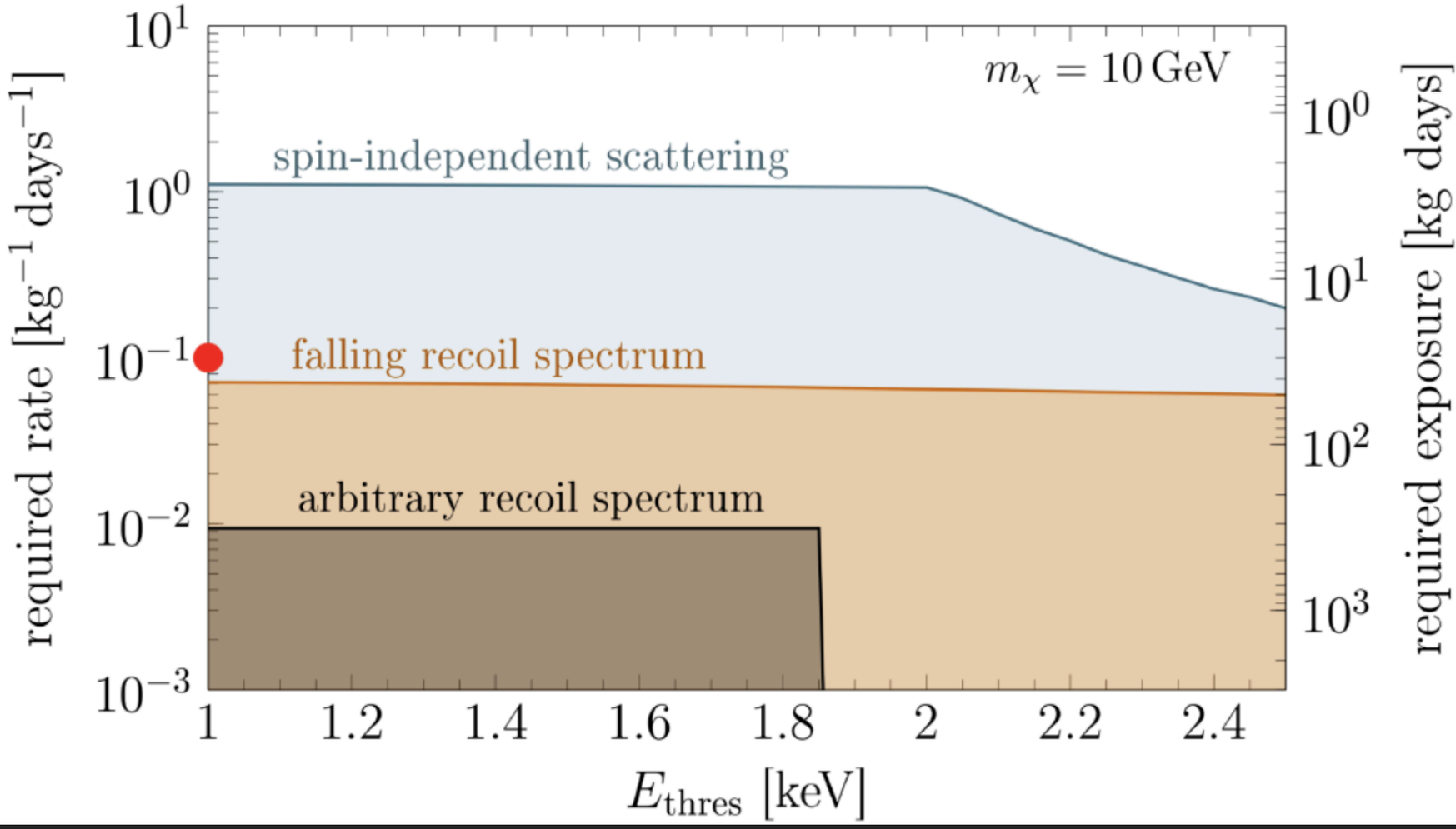
- Construction of COSINUS facilities started
- Expecting first data in 2023

- Thank you!

MODEL-INDEPENDENT CONSIDERATIONS

- COSINUS detectors provide background discrimination on event-by-event basis!

F. Kahlhöfer, K. Schmidt-Hoberg, K. Schäffner, F. Reindl and S. Wild , JCAP 1805 (2018) no.05, 074



- Modulation amplitude cannot exceed total rate!
- No assumption on dark matter halo
- For model-independent cross-check would need ~1.8keV nuclear recoil threshold, ~300kgd exposure

NAI EXPERIMENT LANDSCAPE