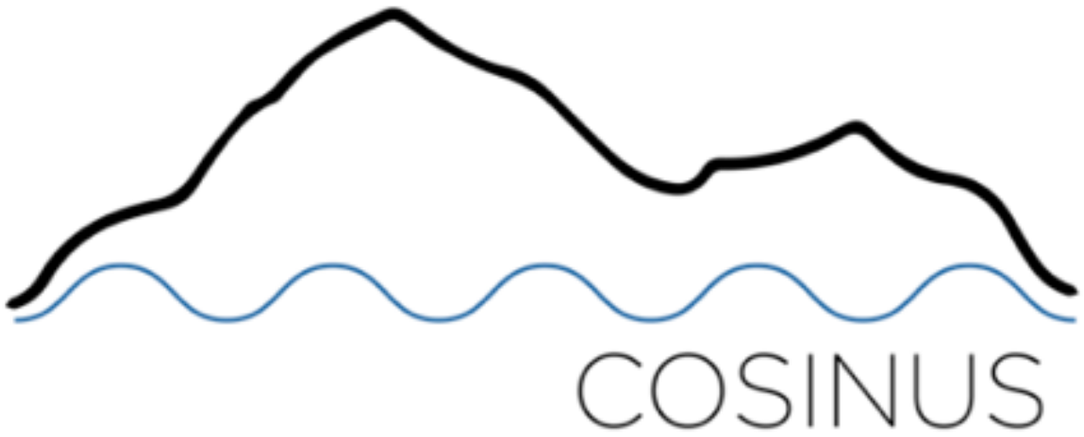
COSINUS @ Gran Sasso: Construction, Setup and Prototype Detector Results

Project Review 2021

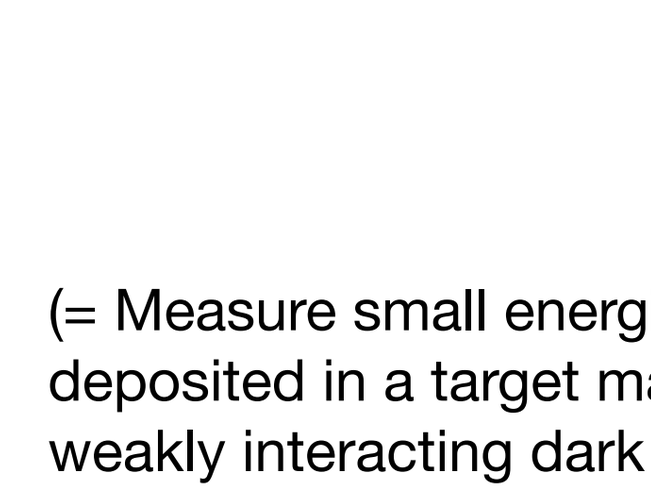
M. Stahlberg



MAX-PLANCK-INSTITUT
FÜR PHYSIK

„Direct“ DM Search Landscape

(= Measure small energies deposited in a target material by weakly interacting dark matter particles)



Ionization Detectors

Targets: Ge, Si, CS_2, CdTe

GENIUS, HDMS, IGEX NEWAGE, CoGeNT, CDEX, DAMIC, SENSEI, DANAE, NEWS-G (noble gas mixture)

Light and Ionization Detectors

Targets: Xe, Ar, CS_2

WARP, ZEPLIN-II, ZEPLIN-III, Panda-X, LUX/LZ, DRIFT-I, DRIFT-II, XENON100, XENON1T, XENONnT, DarkSide-50, DarkSide-20k, ARDM, DARWIN

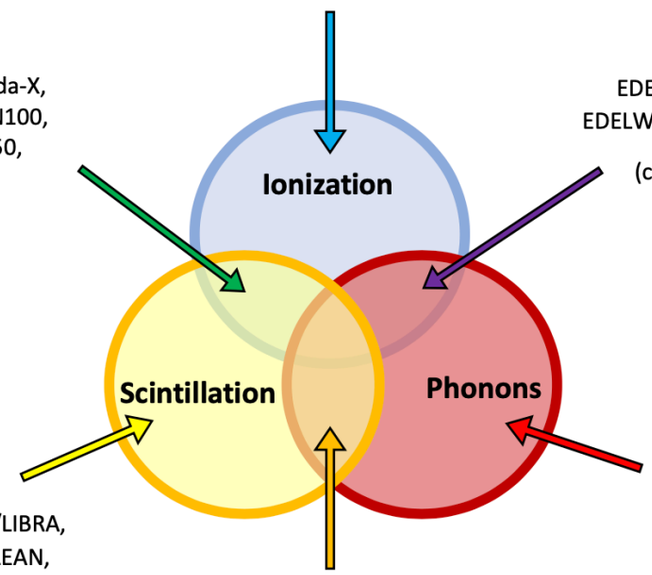
(cold, ~LN_2 temperature)

Heat and Ionization Bolometers

Targets: Ge, Si

EDELWEISS-I, EDELWEISS-II, EDELWEISS-III, CDMS, SuperCDMS

(cryogenic, T<50mK)



Scintillators

Targets: NaI, CsI, Xe, Ar

ZEPLIN-I, KIMS, NAIAD, DAMA/LIBRA, ANAIS, DEAP-3600, XMASS, CLEAN, SABRE, COSINE, KIMS, DM-Ice, PICO-LON

Bolometers

Targets: Al_2O_3, TeO_2

CRESST-I, CUORE

(cryogenic, T<50mK)

Light and Heat Bolometers

Targets: $CaWO_4$, BGO, Al_2O_3, NaI, CsI, Li_2MoO_4

ROSEBUD, CRESST-II, CRESST-III, COSINUS, CUPID

(cryogenic, T<50mK)

Emulsion

Targets: NIT (silver halides)

NEWSdm

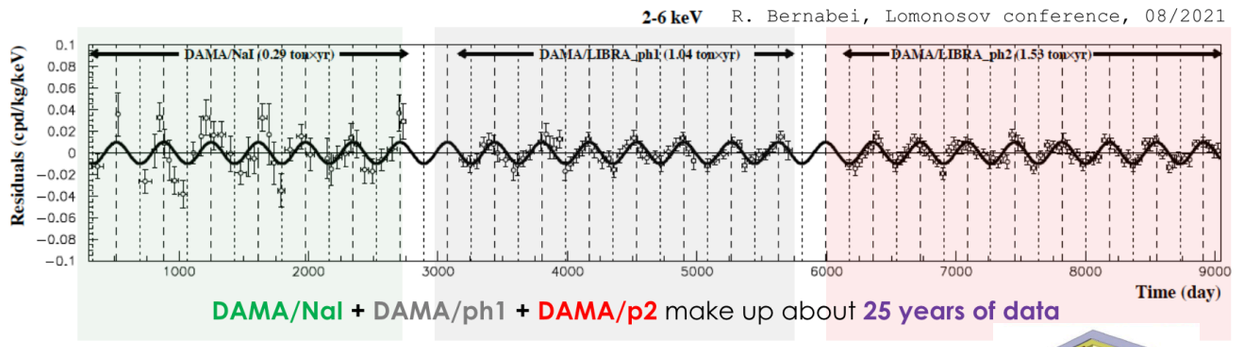
Bubbles and Droplets

Targets: CF_3Br, CF_3I, C_3F_8, C_4F_{10}

COUPP, PICASSO, SIMPLE, PICO-2L, PICO-60, PICO-250

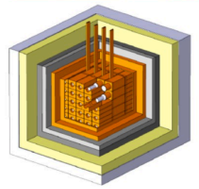
COSINUS

Why COSINUS?



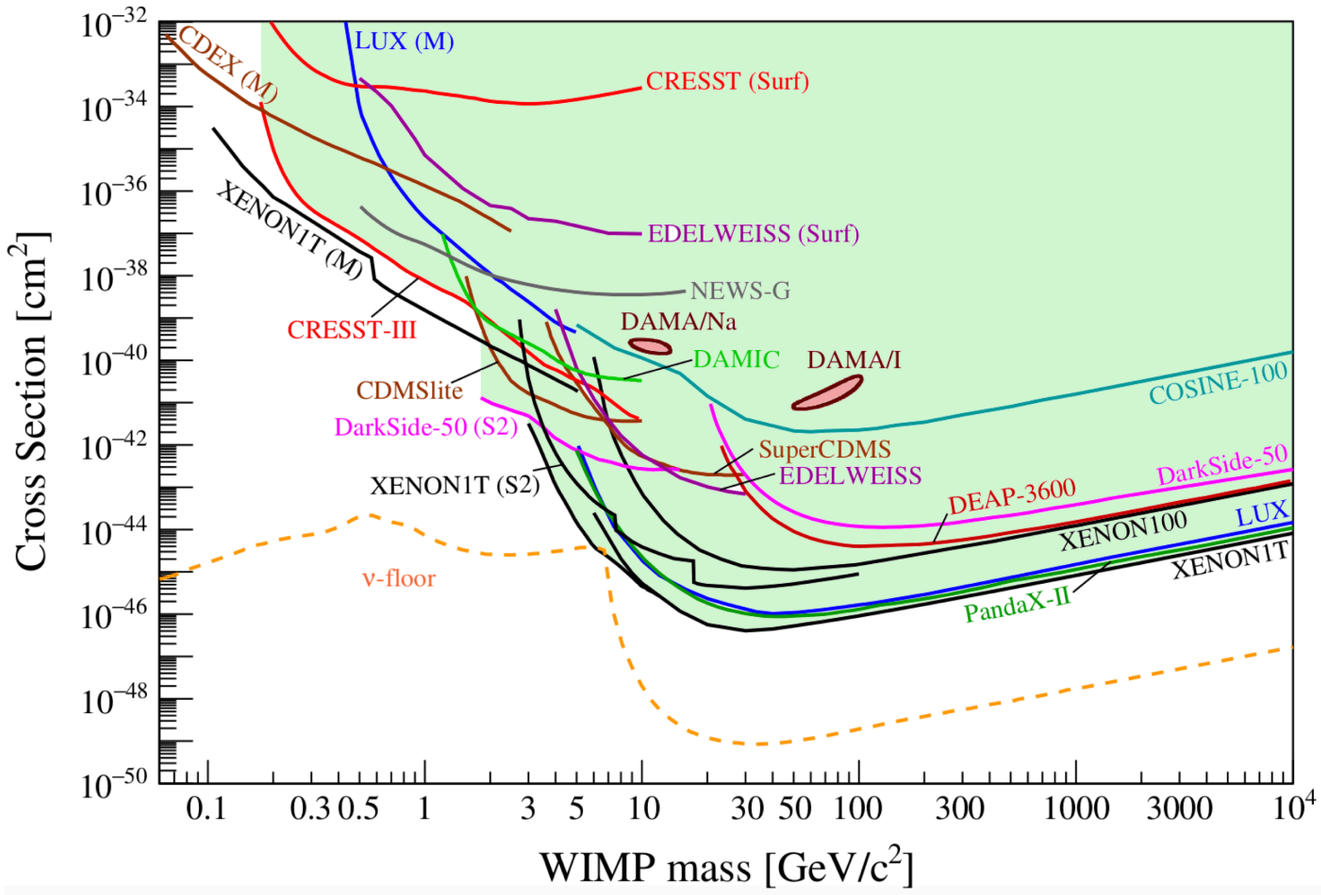
DAMA/NaI + DAMA/ph1 + DAMA/p2 make up about 25 years of data

Total exposure: 2.86 tonne years
Statistical significance: 13.7 σ



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

- Long-standing disagreement between „DAMA-modulation“ and null-results from other experiments
- So far, few experiments with same target material; constraints from COSINE & ANAIS
- COSINUS is the only experiment with event-by-event separation (!)



Billard, Julien, et al. *arXiv: Direct Detection of Dark Matter--APPEC Committee Report*. No. arXiv: 2104.07634. 2021.

Scenario: Spin-independent elastic DM-nucleus scattering, „standard“ DM halo

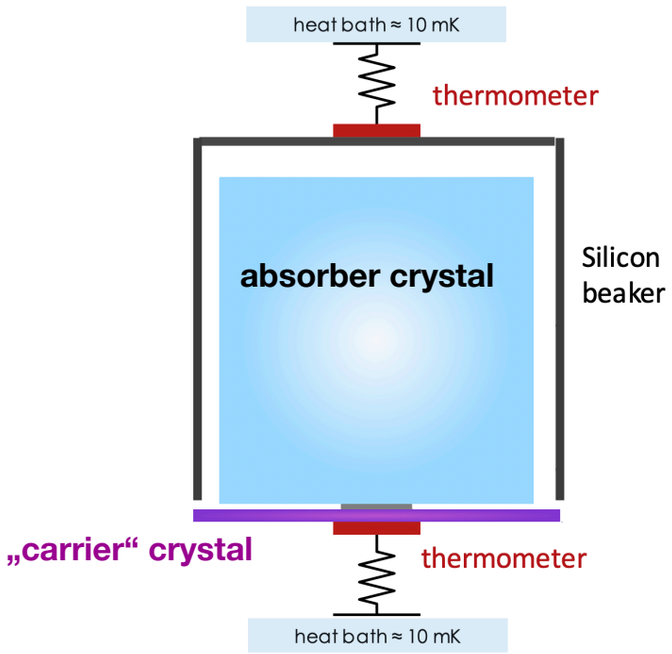
COSINUS

Project Review 2021

COSINUS Detectors

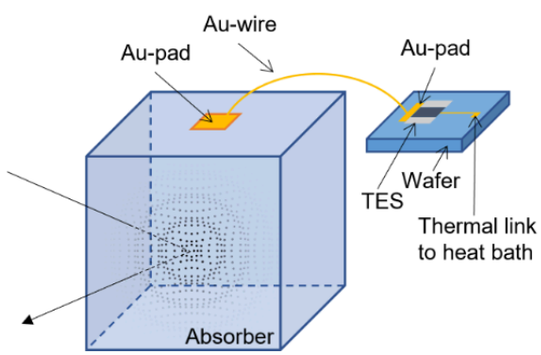
„Cryogenic Observatory for SIgnatures seen in Next-generation Underground Searches“

„Baseline“ design



Angloher, G., et al. "COSINUS: Cryogenic Calorimeters for the Direct Dark Matter Search with NaI Crystals." *Journal of Low Temperature Physics* 200.5 (2020): 428-436.

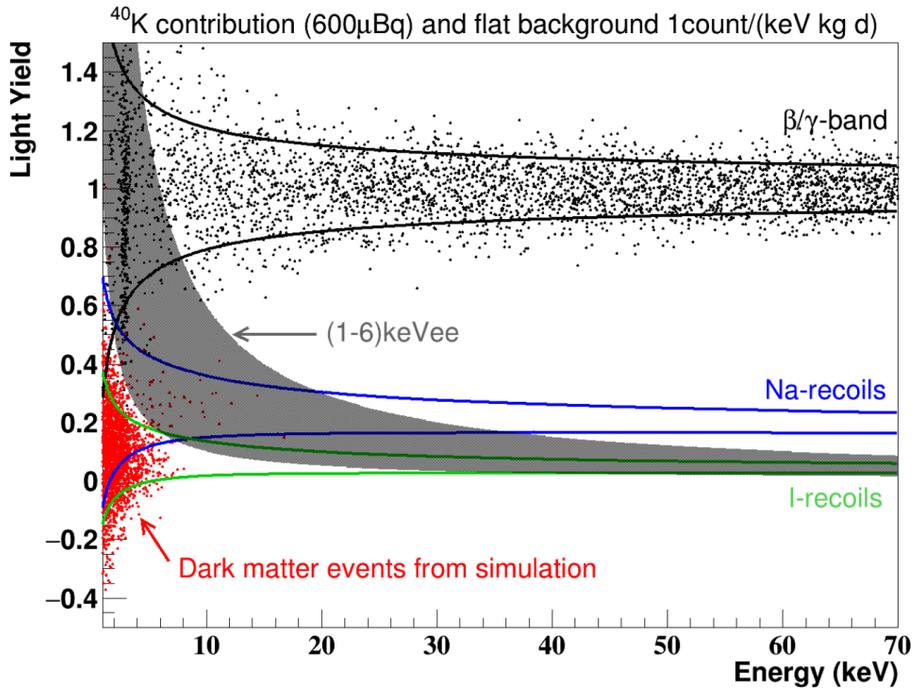
„remoTES“ design



Angloher, G., et al. "First measurements of remoTES cryogenic calorimeters: easy-to-fabricate particle detectors for a wide choice of target materials." *arXiv preprint arXiv:2111.00349* (2021).

COSINUS

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



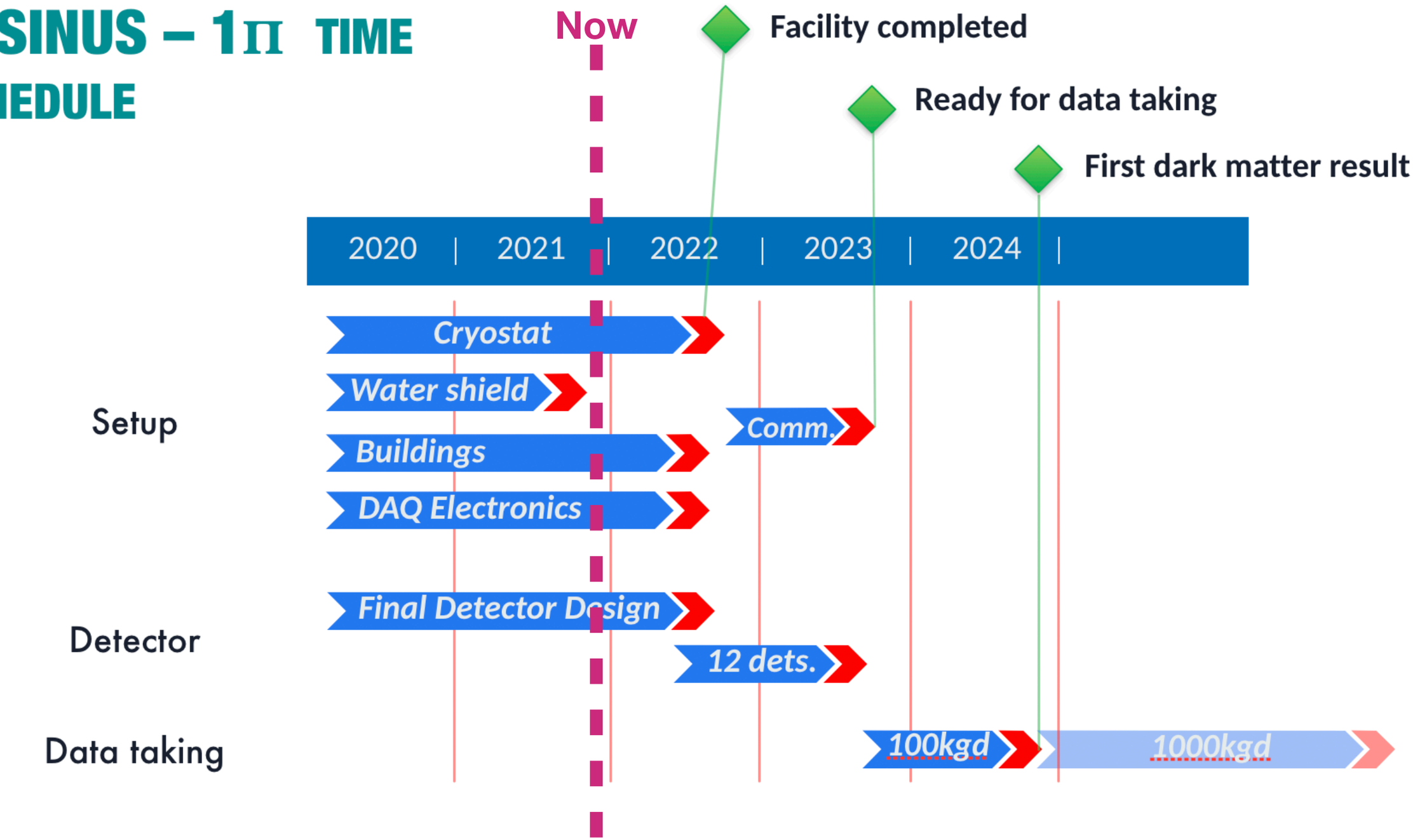
Simulation with 100 kg day exposure and 1 keV threshold

Gütlein, A., et al. "The COSINUS project: Development of new NaI-based cryogenic detectors for direct dark matter search." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 845 (2017): 359-362.

Phonon (~90%) + Scintillation (~10%) signal

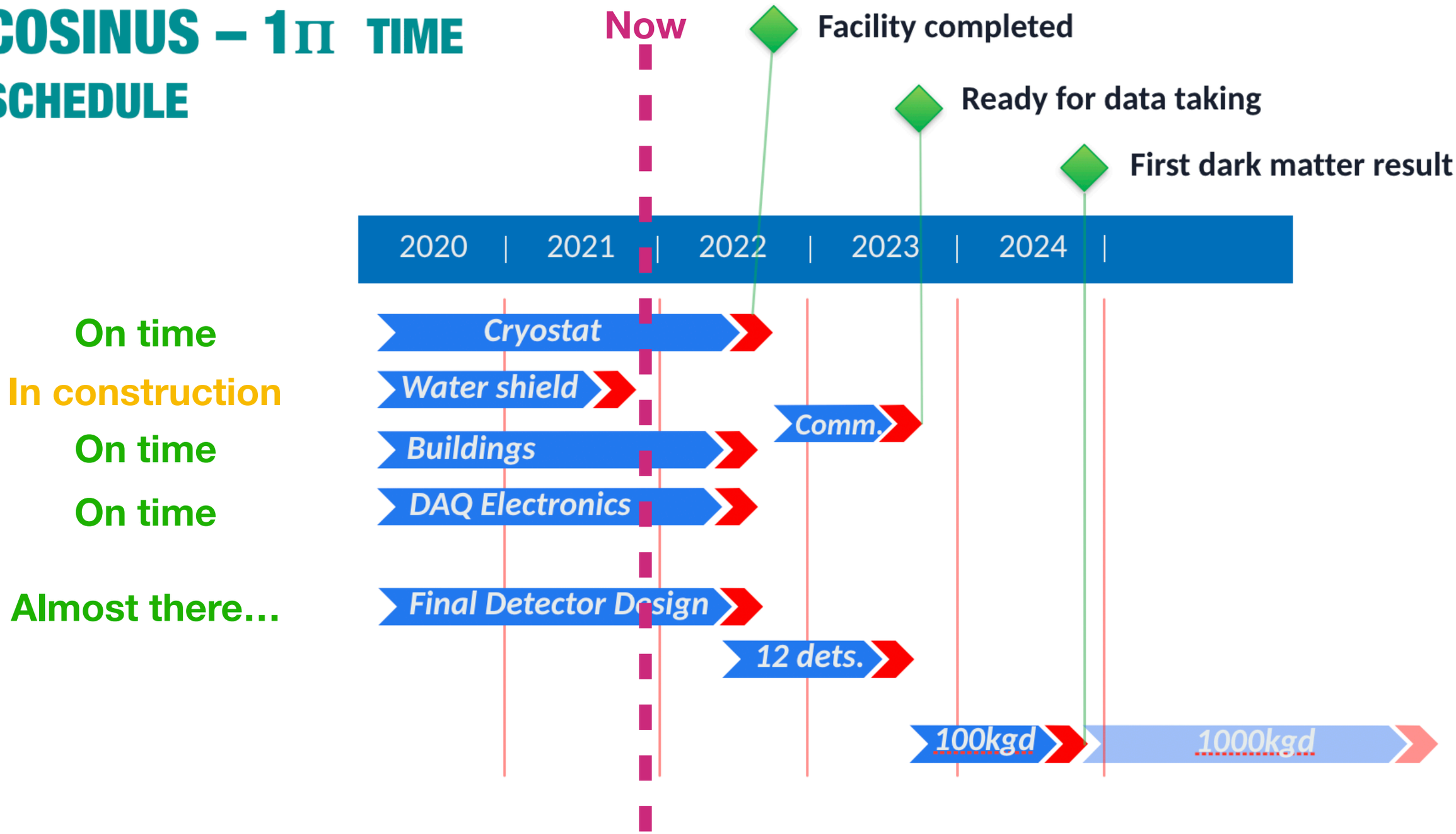
-> Factor 10 improvement over light only (e.g. DAMA)
-> Nuclear recoil energy threshold instead of electron equivalent
-> Use cryogenic sensor technology and know-how from CRESST

COSINUS – 1π TIME SCHEDULE



COSINUS

COSINUS – 1π TIME SCHEDULE



On time

In construction

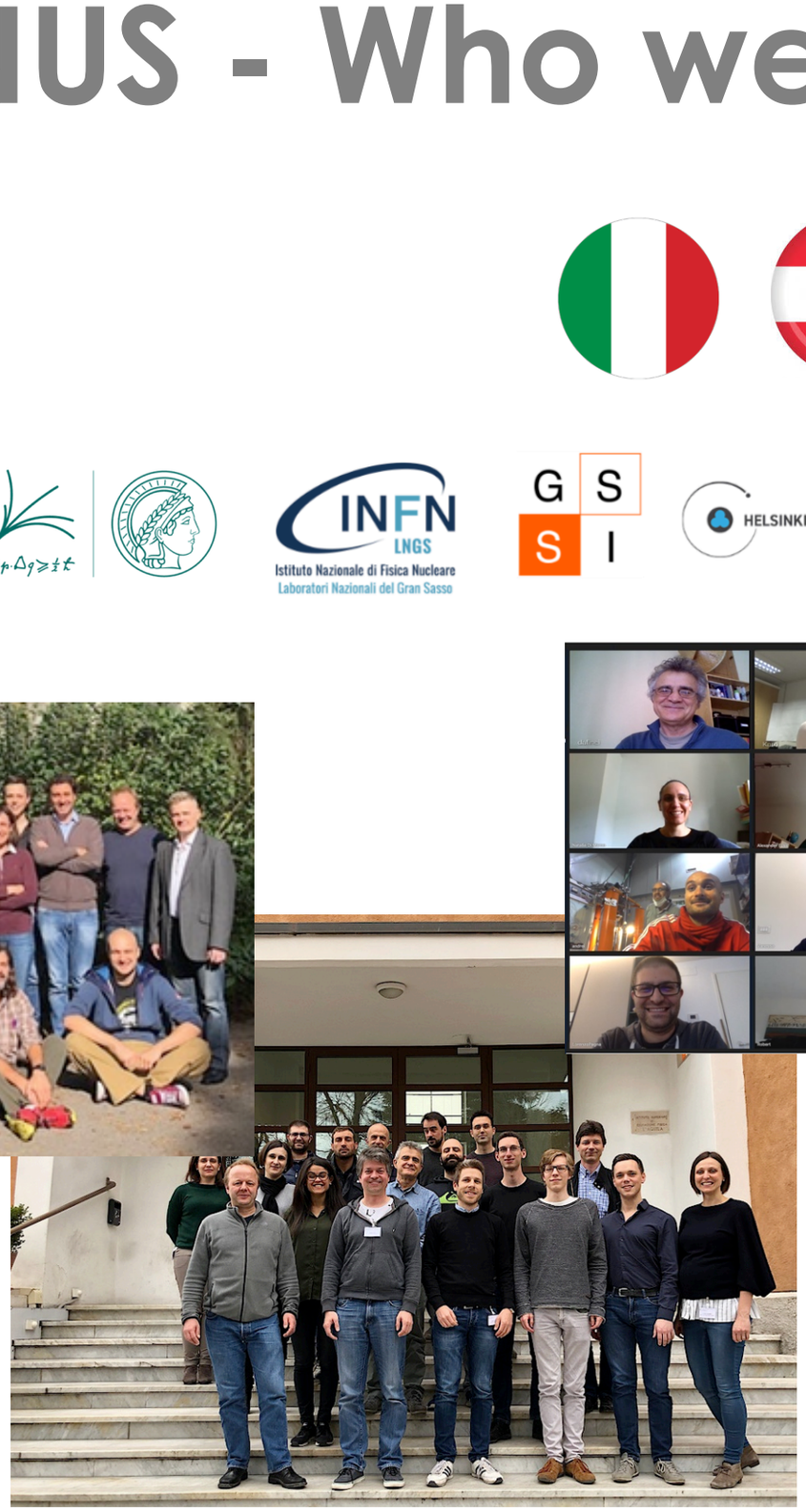
On time

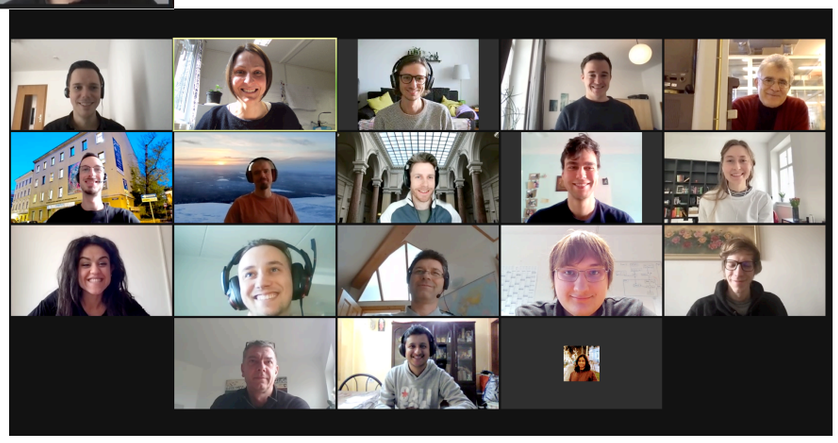
On time

Almost there…

COSINUS

COSINUS - Who we are





Collaboration Meeting 10/2021 @LNGS

COSINUS

COSINUS group at MPP, 12/2020

MAX-PLANCK-INSTITUT FÜR PHYSIK

Karoline Schaeffner **(Group Leader)**

Support from CRESST

Federica Petricca
(Senior scientist)

Franz Proebst
(Senior scientist)

Michele Mancuso
(Staff scientist)

Godehard Angloher
(Senior scientist, part time)

Robert Stadler
(Engineer)

Christopher Jablonski
(Engineer)

- Group started in 2019 as Max Planck Research Group

Martin Stahlberg
(Postdoc)

COSINUS

COSINUS group at MPP, 12/2021

MAX-PLANCK-INSTITUT FÜR PHYSIK

Karoline Schaeffner **(Group Leader)**

Support from CRESST

Federica Petricca
(Senior scientist)

Franz Proebst
(Senior scientist)

Michele Mancuso
(Staff scientist)

Godehard Angloher
(Senior scientist, part time)

Robert Stadler
(Engineer)

Christopher Jablonski
(Engineer)

Torsten Frank
(Senior scientist, part time)

Karl-Heinz Ackermann
(Engineer, part time)

Peter Mühlbauer
(Technician, part time)

Moritz Kellermann
(PhD student)

Mukund R. Bharadwaj
(PhD student)

Martin Stahlberg
(Postdoc)

Vanessa Zema
(Postdoc)

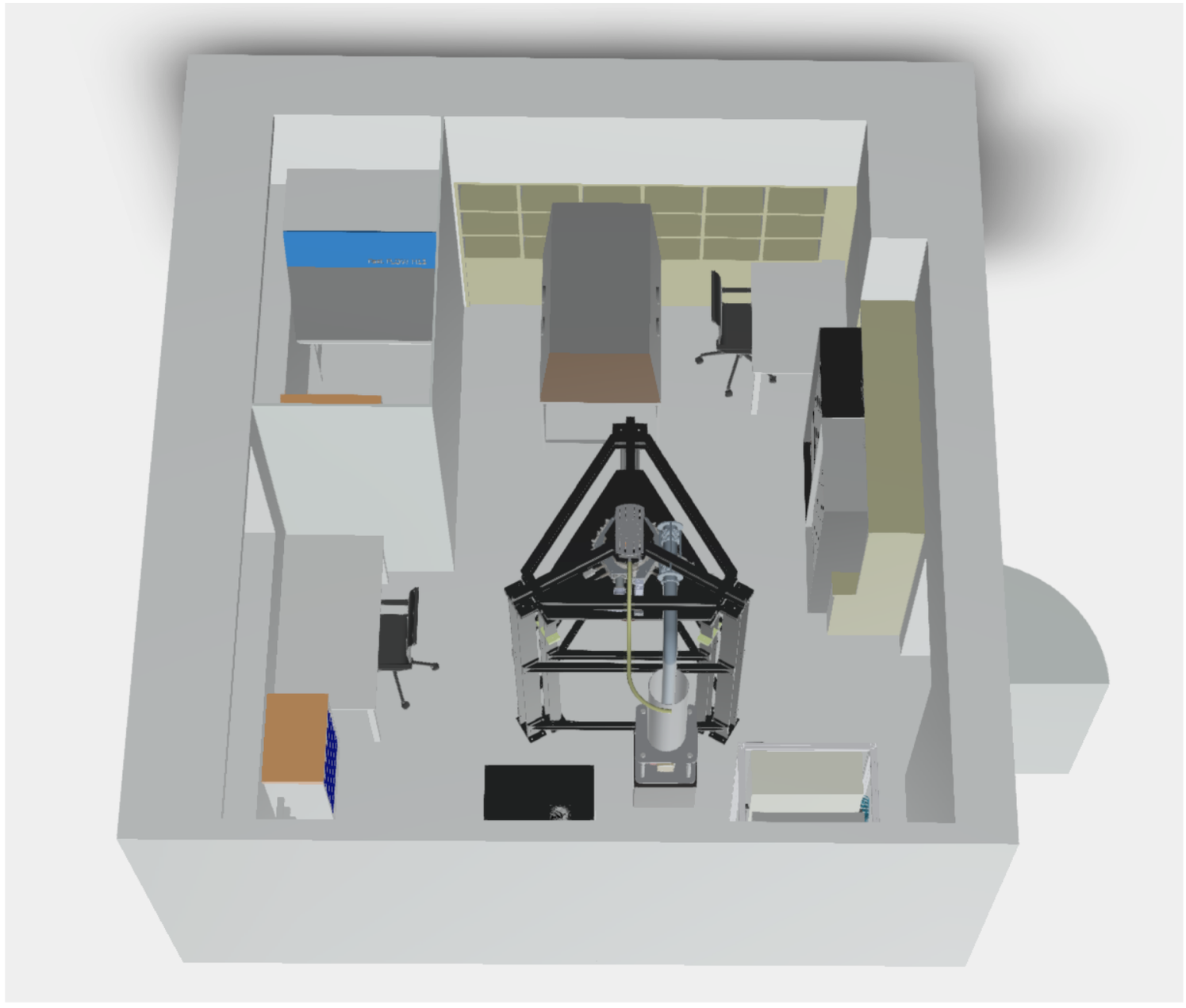
Henrik Ansorge
(Working Student)

COSINUS

COSINUS lab

- Glove box for detector mounting
- Nitrogen cabinet for storage of detector components
- Sealing machine for NaI crystals
- Working tables
- Delivery in March:

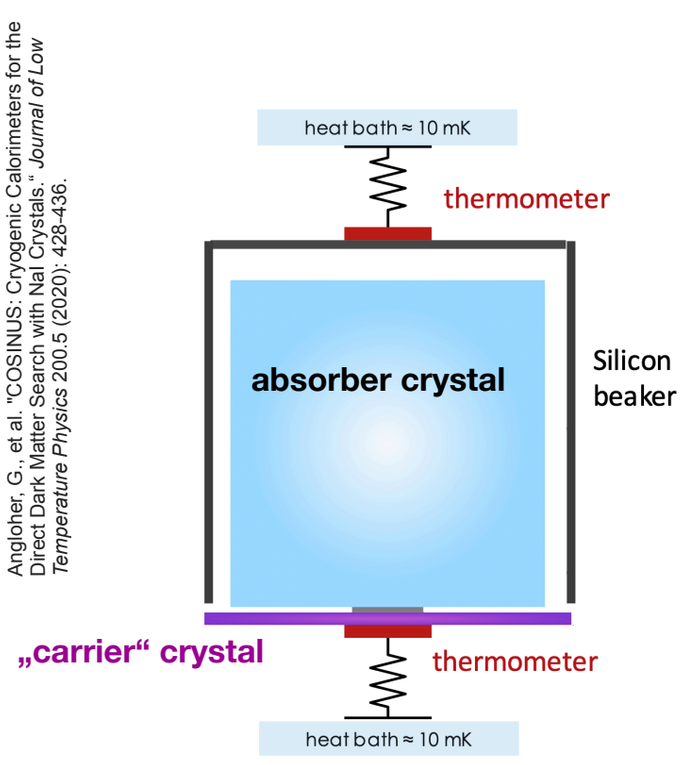
  → Dry cryostat



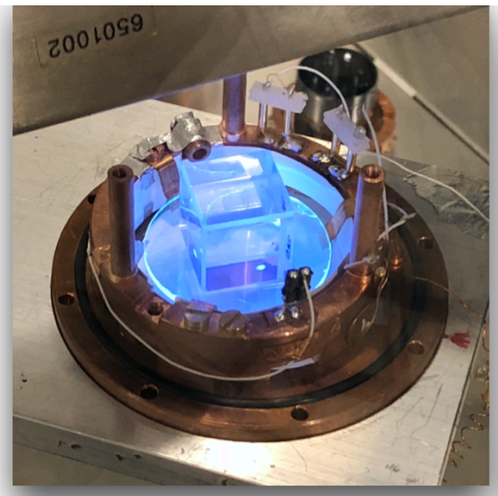
COSINUS

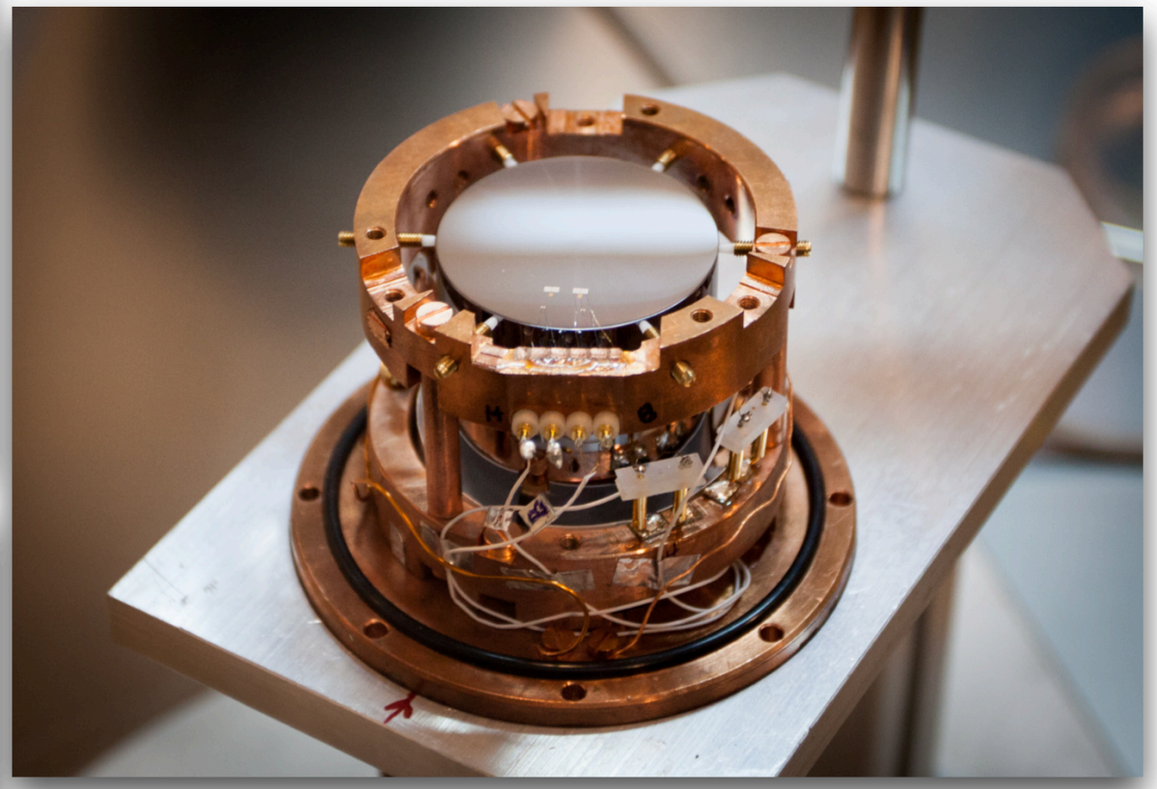
„Baseline“ detector design

- Si beaker encloses NaI absorber, which is interfaced to „carrier“ crystal with Transition Edge Sensor (TES)
- NaI is hygroscopic -> handling difficult, interface problematic
- Carrier can collect light (!)



Angloher, G., et al. "COSINUS: Cryogenic Calorimeters for the Direct Dark Matter Search with NaI Crystals." *Journal of Low Temperature Physics* 200.5 (2020): 428-436.

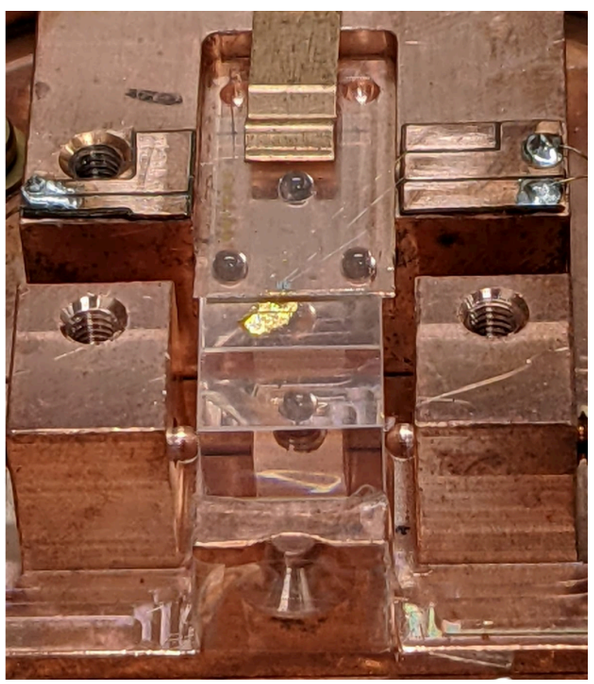


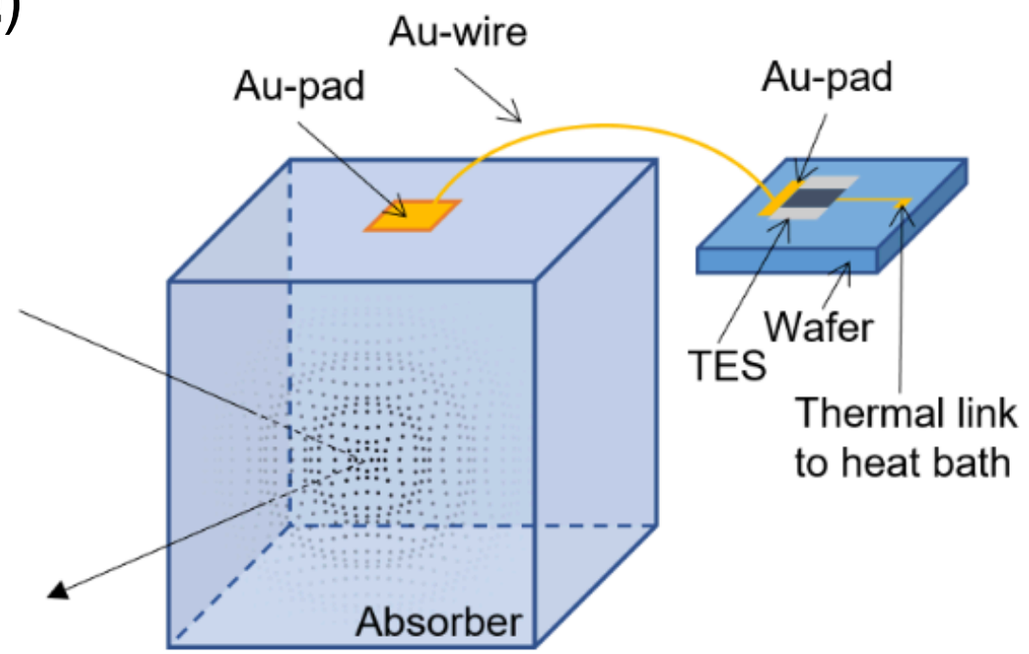


COSINUS

„remoTES“

- Detector concept by Matt Pyle
- First measurements by COSINUS group @MPP
- Idea: avoid problems of attaching TES with carrier to absorber crystal
- Influence of Au link and pads on the signal shape
- Wafer is reusable, easier to fabricate (!)



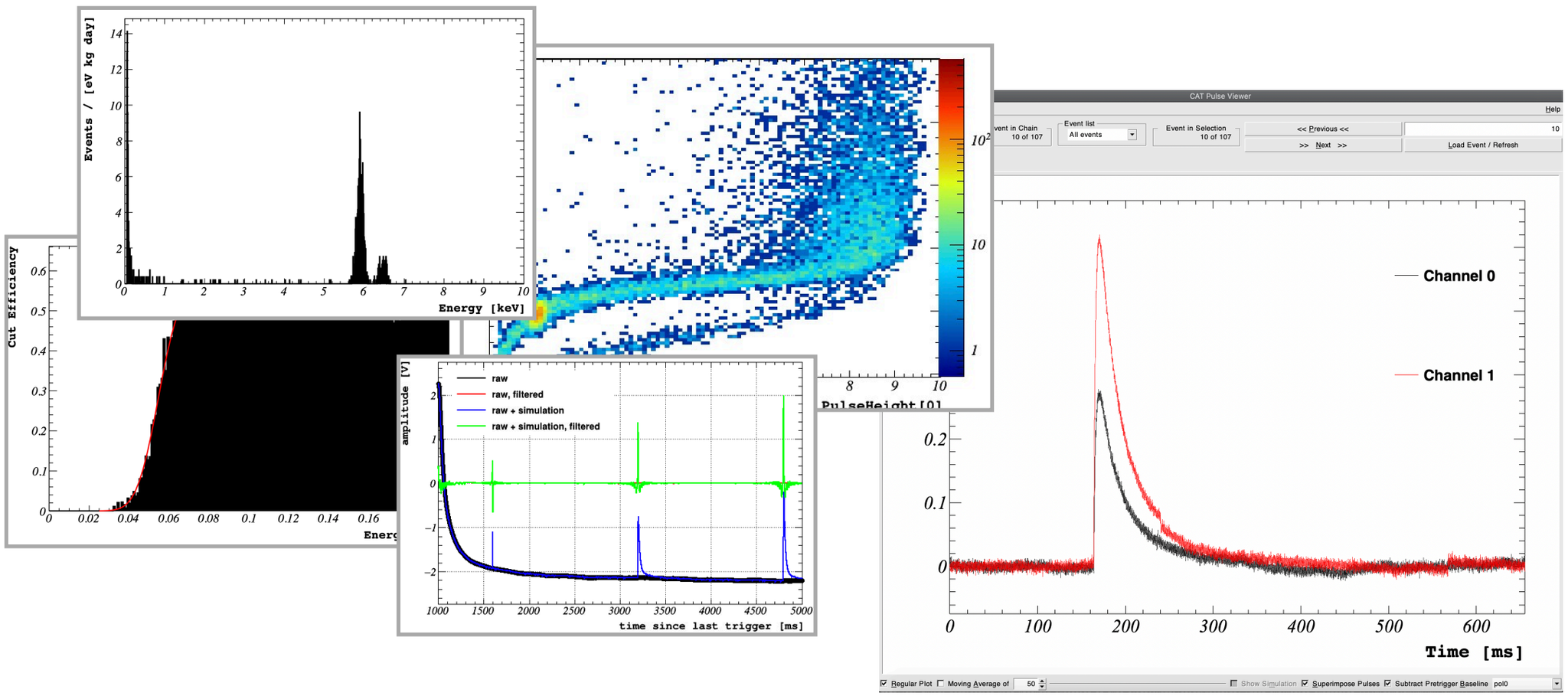


https://arxiv.org/abs/2111.00349

COSINUS

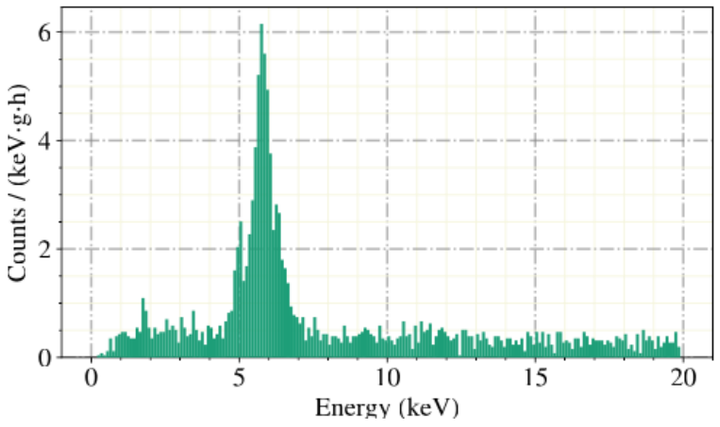
DAQ & Software

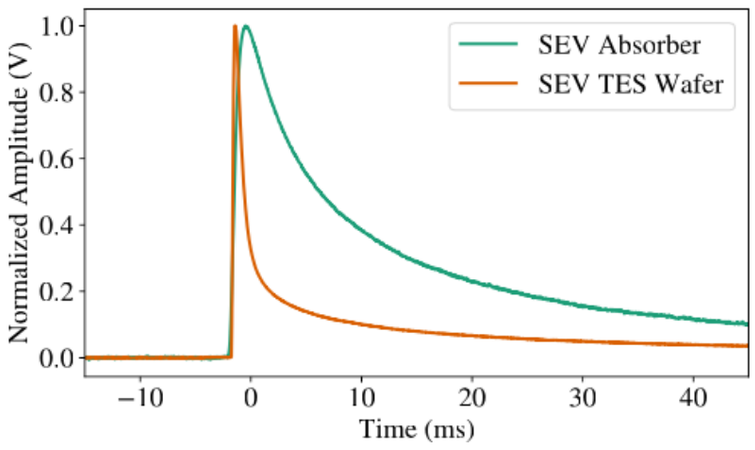
- DAQ electronics & readout software developed by HEPHY INSTITUTE OF HIGH ENERGY PHYSICS
- Analysis Software developed at MPP in collaboration with HEPHY INSTITUTE OF HIGH ENERGY PHYSICS
- All of this used also in CRESST



COSINUS

remoTES - first results





https://arxiv.org/abs/2111.00349

Many thanks to the CRESST group for their support and access to their facility!

COSINUS

Run	Absorber material	Absorber size [mm]	Au-pad properties	Au wire properties	TES-type	Energy threshold [eV]
557	$CdWO_4$	20x10x5	200nm sputtered	17 µm wedge bond	LD type on Al_2O_3	600*
561	Si	20x10x5	200nm sputtered	17 µm wedge bond	LD type on Al_2O_3	900*
561	Si	20x10x5	200nm sputtered	17 µm wedge bond	istick-TES on Si	900*
562	Si	20x10x5	200nm sputtered	10 µm wedge bond	istick-TES on Si	770
564	CsI	∅=20 h=2	300nm sputtered	17 µm wedge bond	LD type on Al_2O_3	18000*
564	CsI	∅=20 h=2	600nm sputtered	17 µm wedge bond	istick-TES on Si	100000*
566	Si	20x10x5	200nm sputtered	17 µm glued on pad	LD type on Al_2O_3	323
567	Si	20x10x5	200nm sputtered	17 µm, bigger glue spot on pad	LD type on Al_2O_3	800*
569	Si	20x10x5	no pad sputtered	17 µm, glued directly on Si	LD type on Al_2O_3	40000*
569	Si	20x10x5	400nm foil RRR=15 glued on Si	17 µm glued on pad	istick-TES on Si	665
571	Si	20x10x5	400nm foil RRR=15 glued on Si	17 µm wedge bond	istick-TES on Si	735
571	TeO_2	20x10x5	400nm foil RRR=15 glued on TeO_2	17 µm wedge bond	LD type on Al_2O_3	<4000*
573	TeO_2	20x10x5	400nm foil RRR=15 glued on TeO_2	17 µm 2 wedge bonds	LD type on Al_2O_3	1100
574	TeO_2	20x10x5	400nm foil RRR=15 glued on TeO_2	17 µm 6 wedge bonds	LD type on Al_2O_3	3760
577	TeO_2	20x10x5	400nm foil RRR=15 glued on TeO_2	17 µm 4 wedge bonds	LD type on Al_2O_3	2989

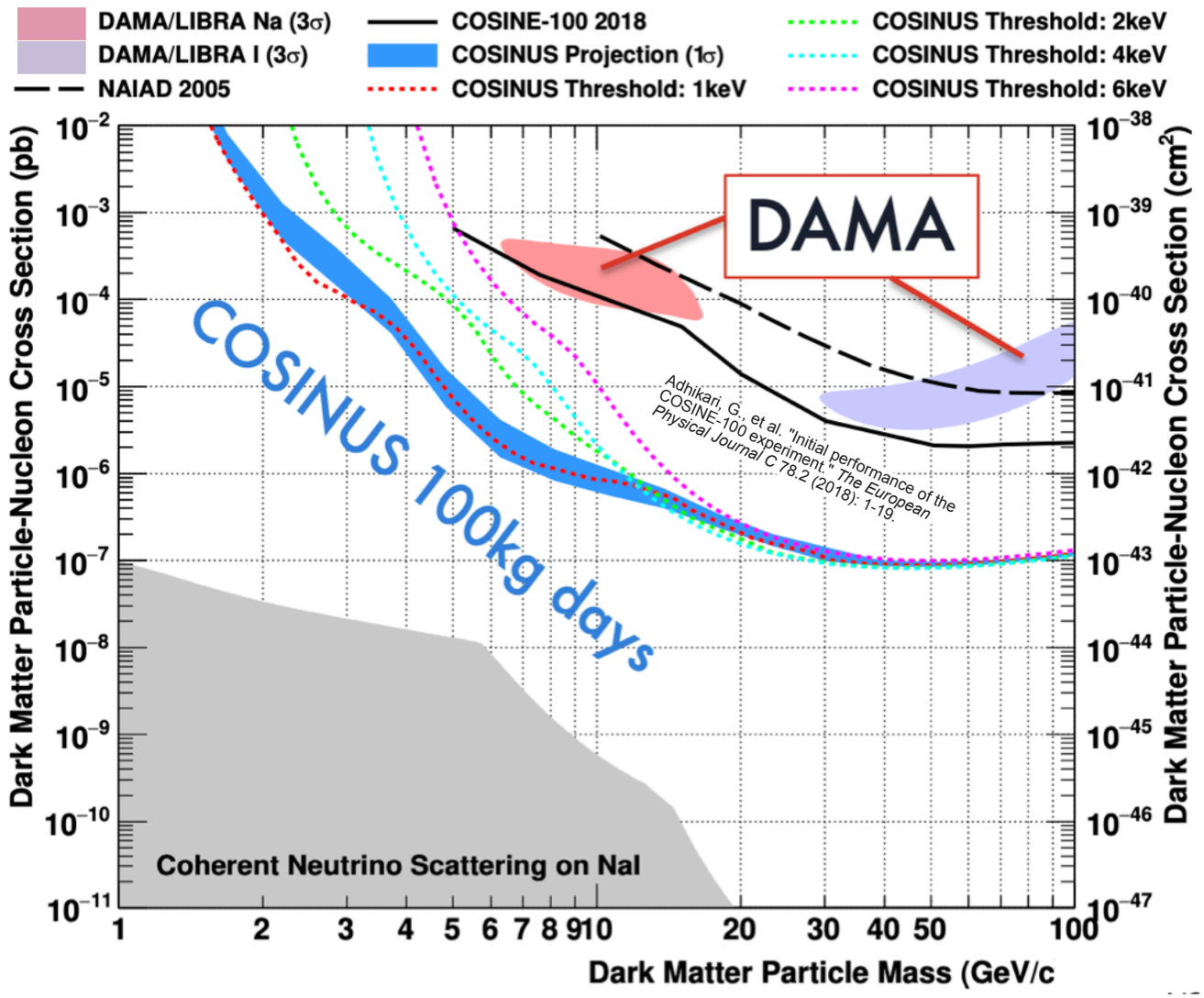
2020 | 2021

Physics Reach

- NaI absorber mass: ~100g

  -> 10 detectors x 100days = 100kg days

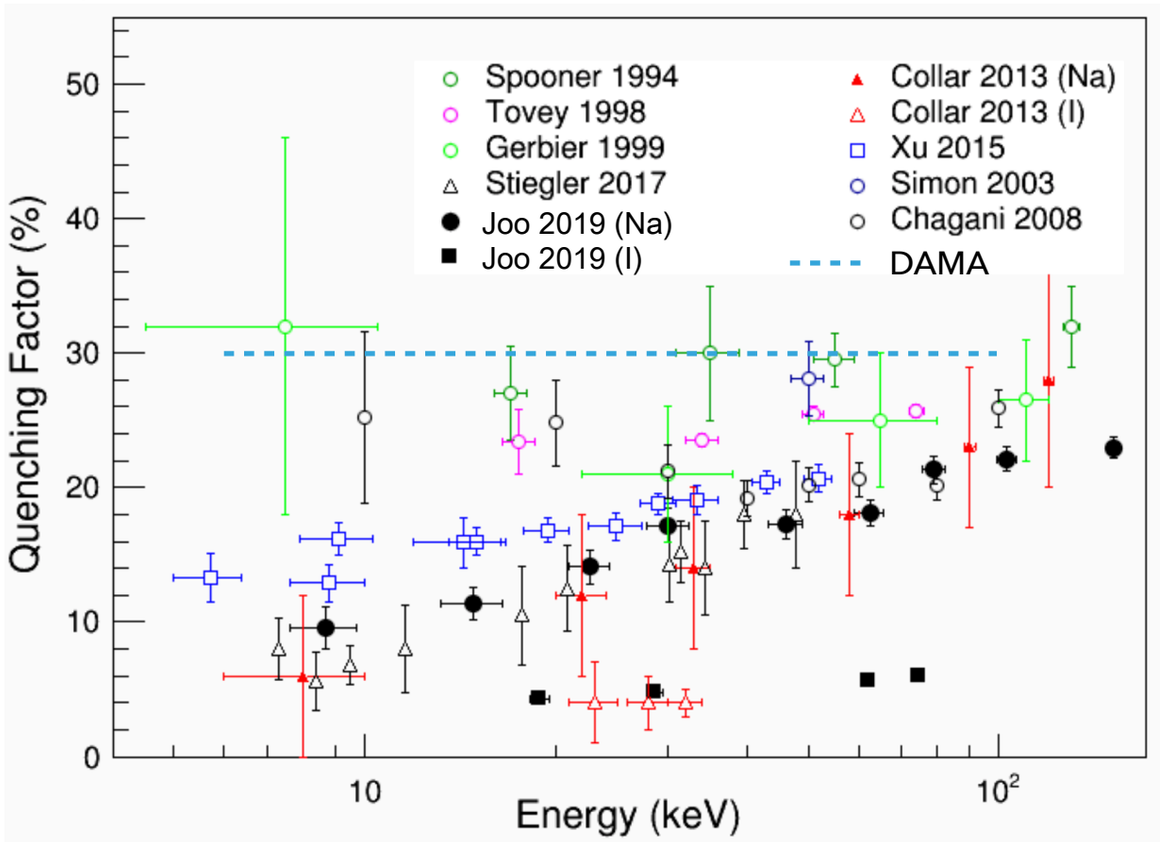
- No rate -> no modulation (!)



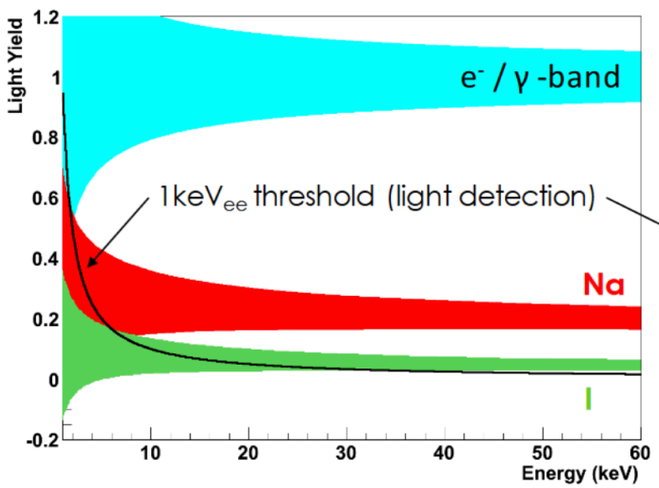
COSINUS

„QUENCHING FACTOR MYSTERY"

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

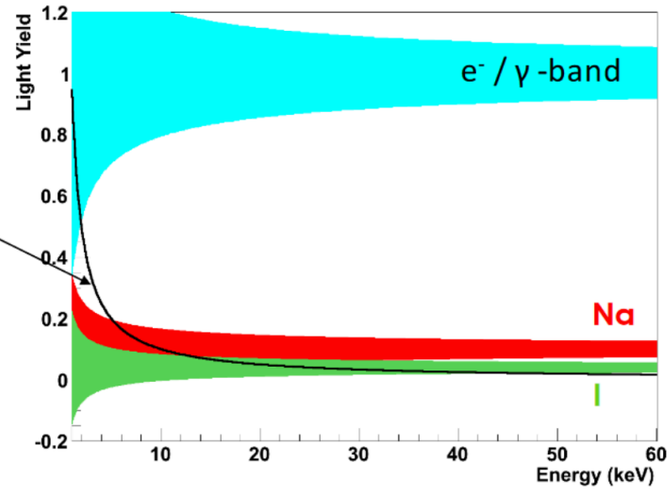


- Measurements of quenching factors (QF) at room temperature do not agree
- In particular, role of Tl is unclear (usually crystals are doped)
- Strong influence of QF on NR energy scale -> comparability of modulation studies (!)
- COSINUS will provide the first cryogenic QF measurement for NaI



recoils off Na → factor ~ 0.3

recoils off I → factor ~ 0.1



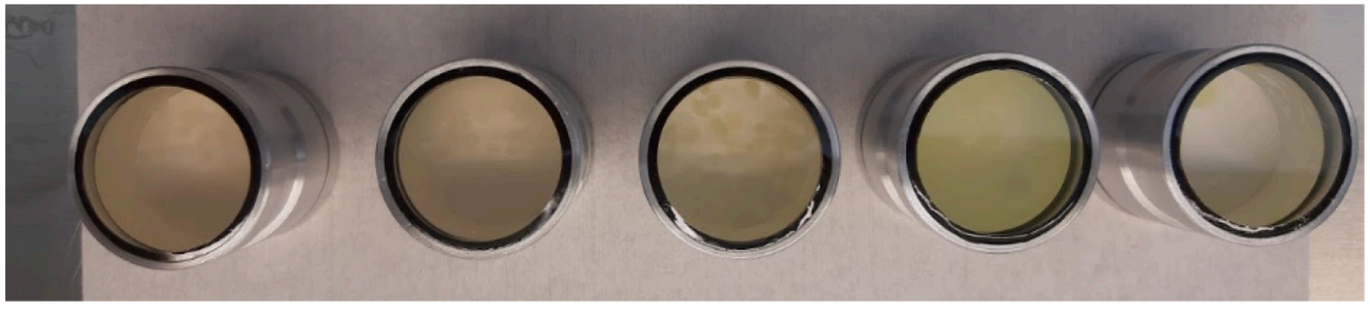
recoils off Na → factor ~ 0.1

recoils off I → factor ~ 0.04

COSINUS

„QUENCHING FACTOR MYSTERY"

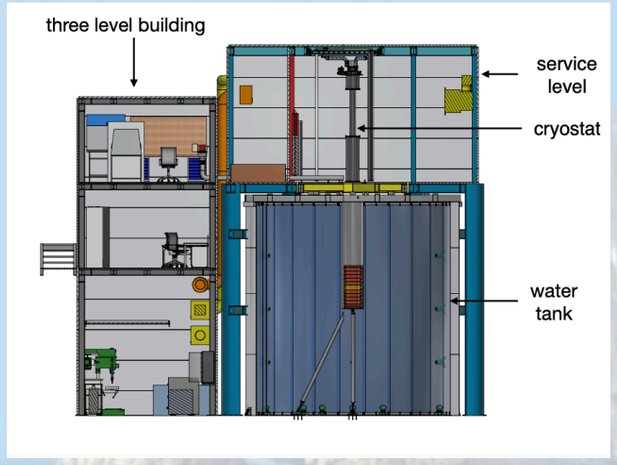
- Initiated QF Measurement at TUNL (Triangle Universities Nuclear Laboratory), performed in September 2021 by the Barbeau group
- Monoenergetic neutron beam (~3.3MeV) , detectors at different scattering angles
- Five ultrapure crystal samples from SICCAS with different Tl dopant levels tested
- Analysis ongoing!

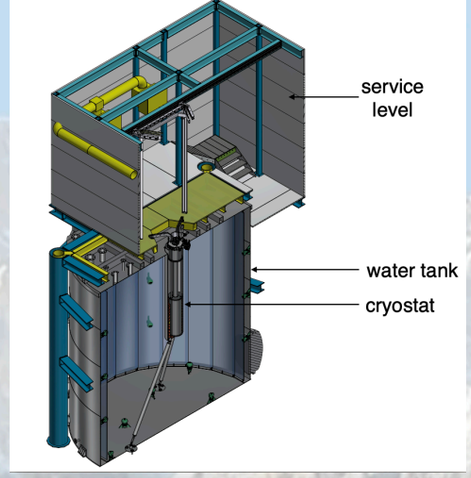


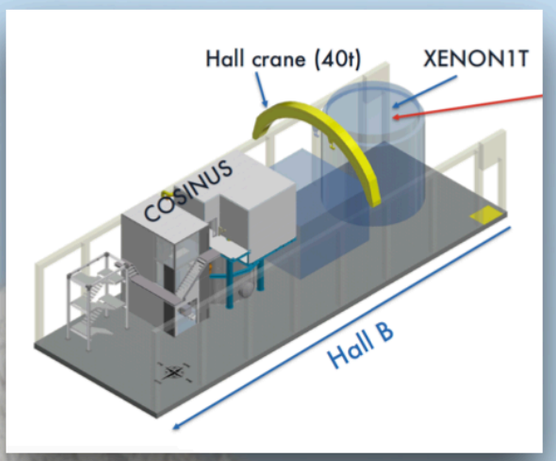
Since 1928 SICCAS

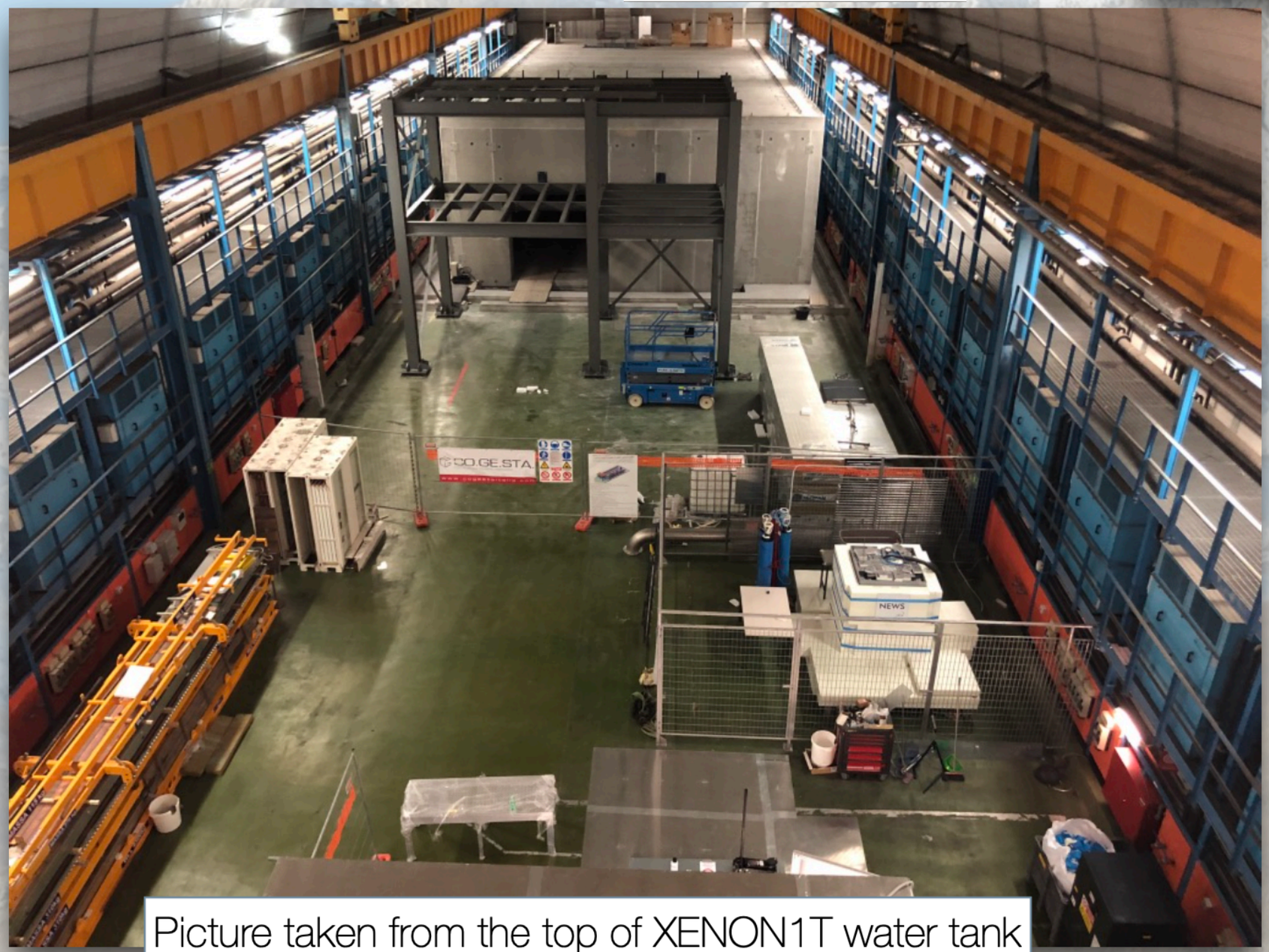
COSINUS

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





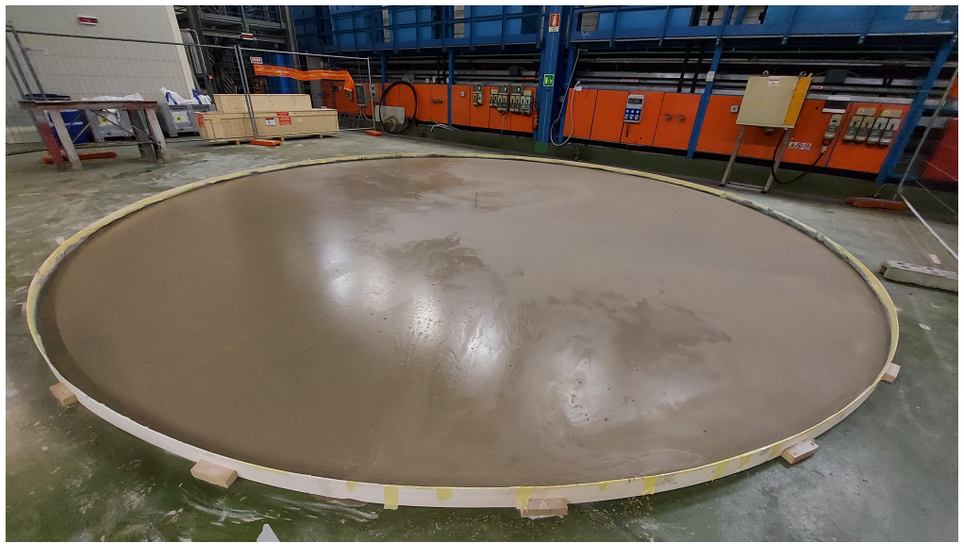


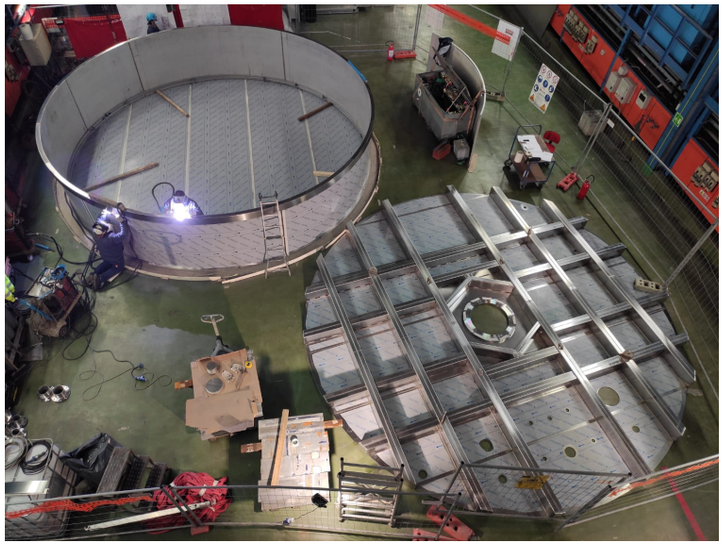


Picture taken from the top of XENON1T water tank

Construction progressing…

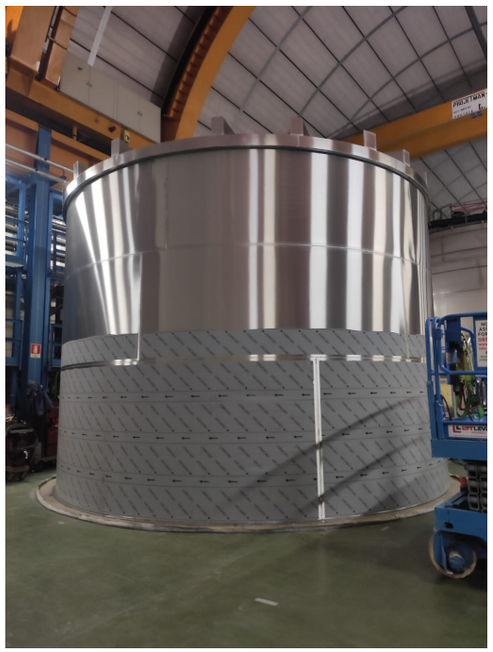
October 10 - Screed installation ("Estrich")



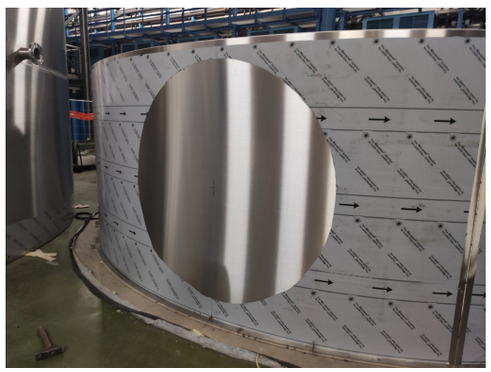


November 17 - Tank roof

December 07 - Third ring



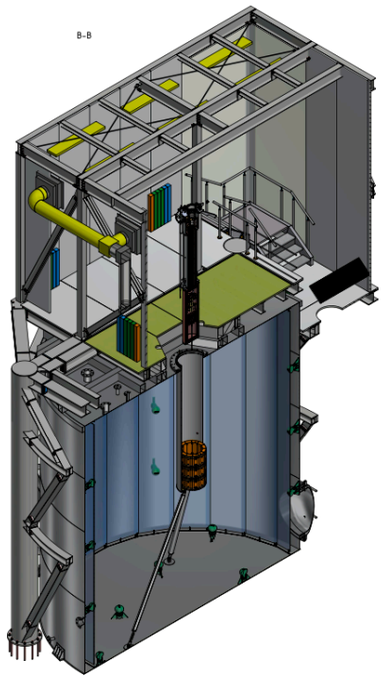
Today: Fourth ring & manhole

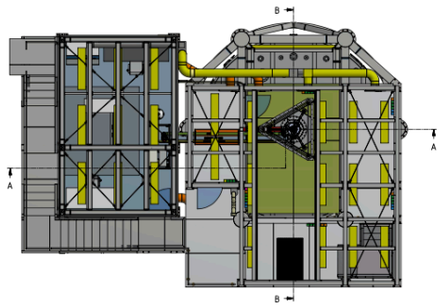


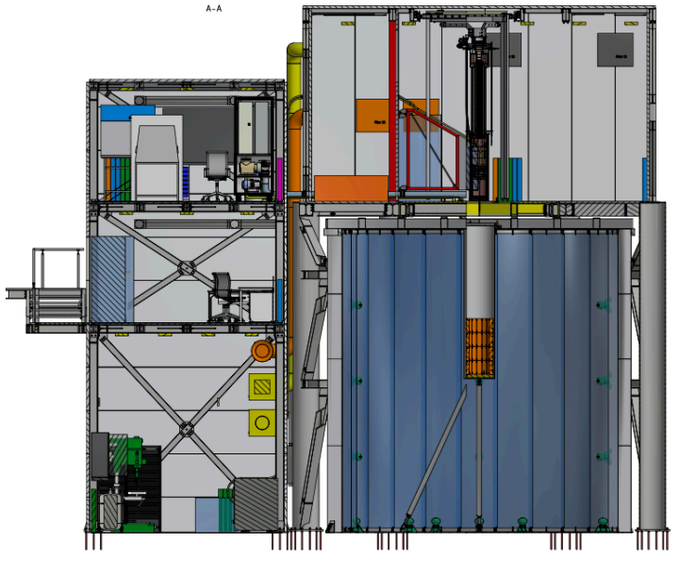
Tank will be completed by Christmas!

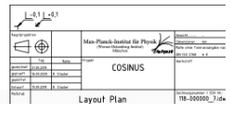
COSINUS

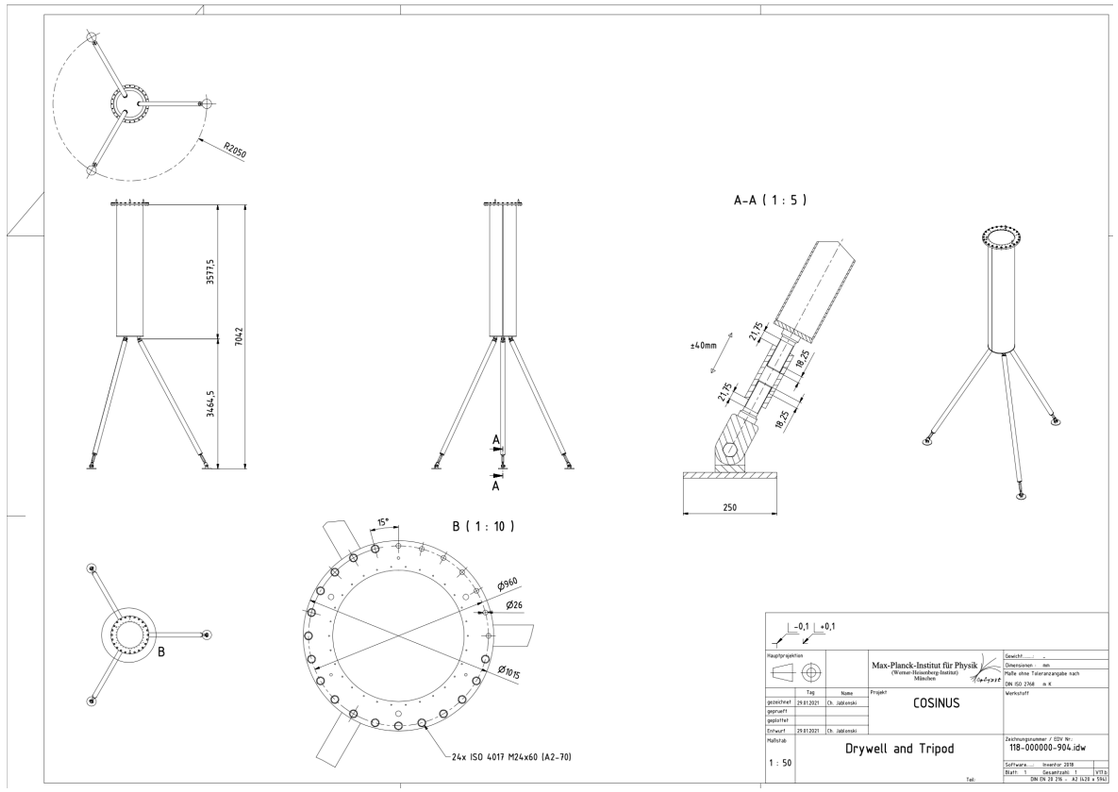
Lifting system, Drywell & Tripod





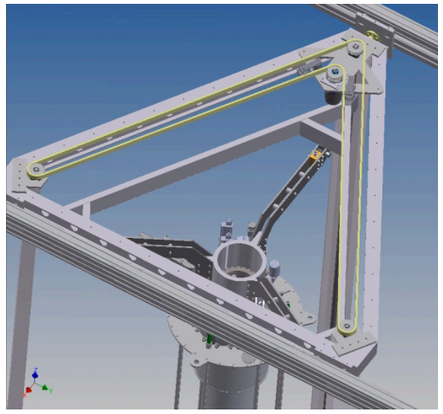


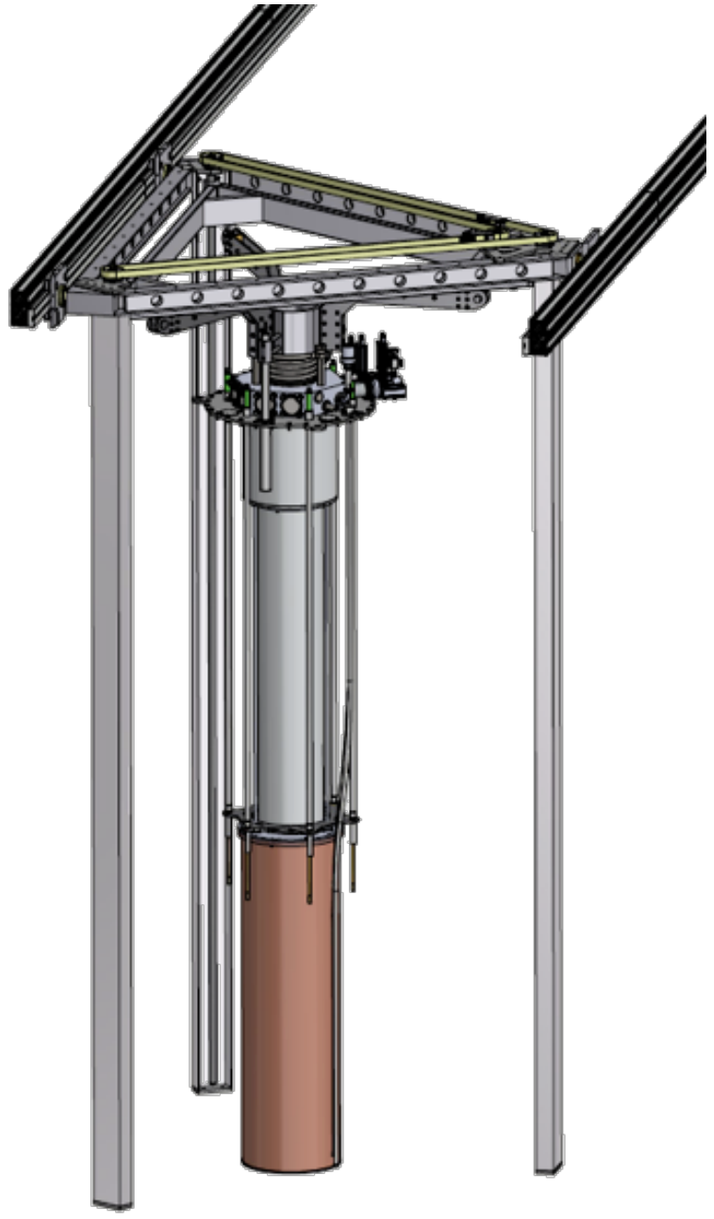




COSINUS

Lifting System

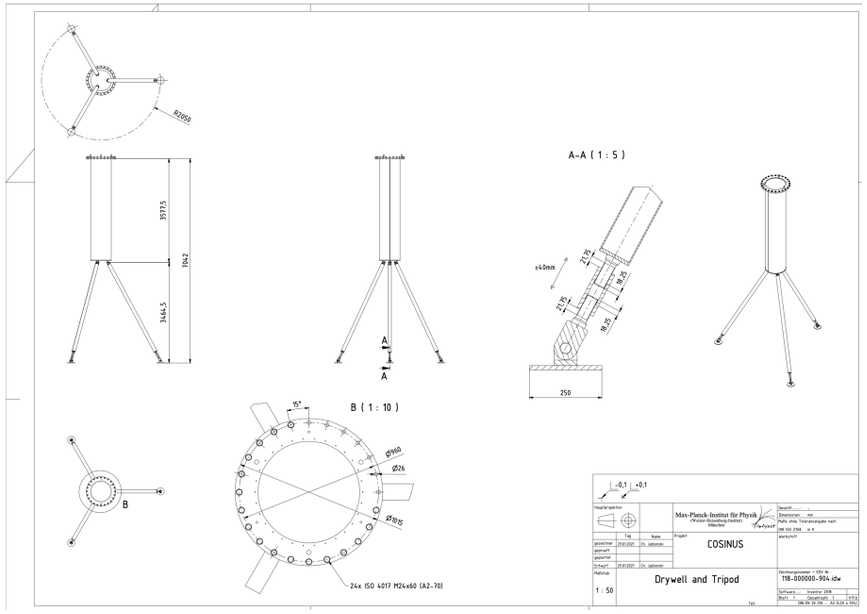




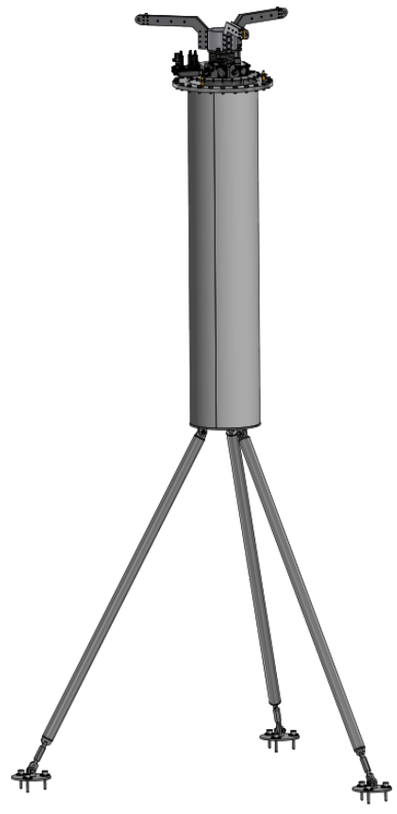
- Designed at MPP
- Motor-drive delivered
- Control unit in preparation
- System will be tested and commissioned at MPP

COSINUS

Tripod & Drywell



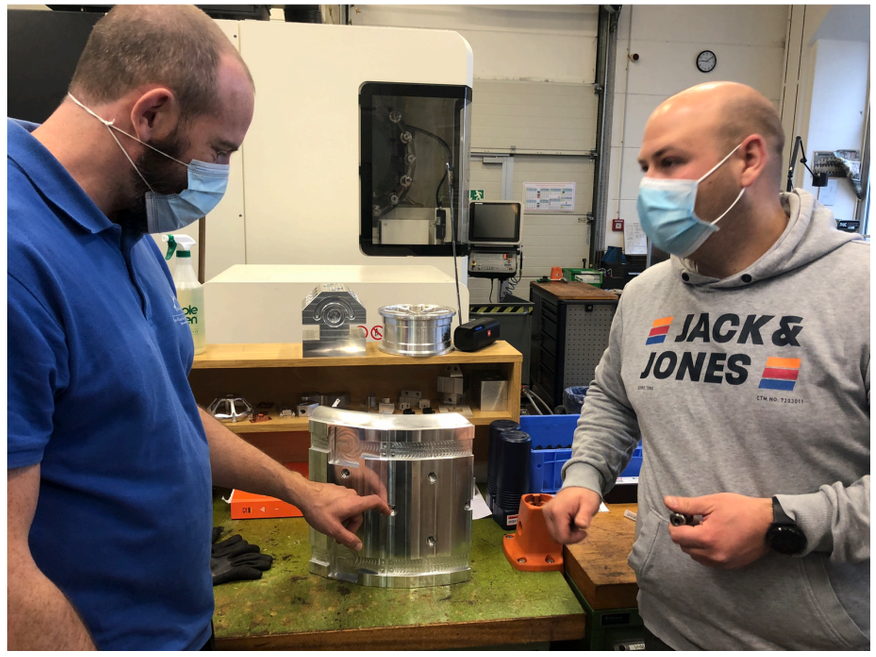
- Designed at MPP
- Screening and careful selection of material
- Manufacturing started
- Delivery to LNGS planned for 2021



Copper (external) shield

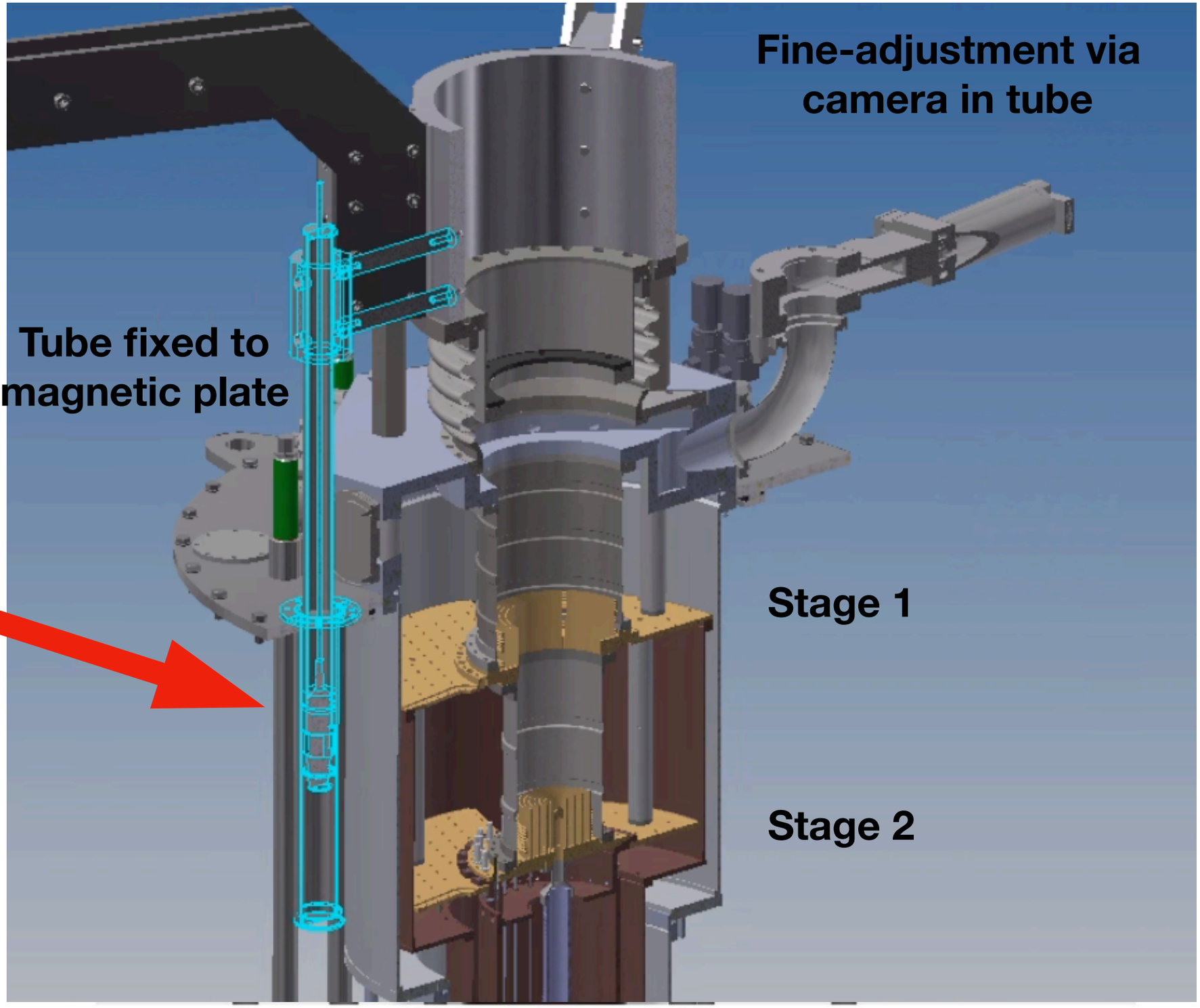
Design & materials screening

Aluminum prototype



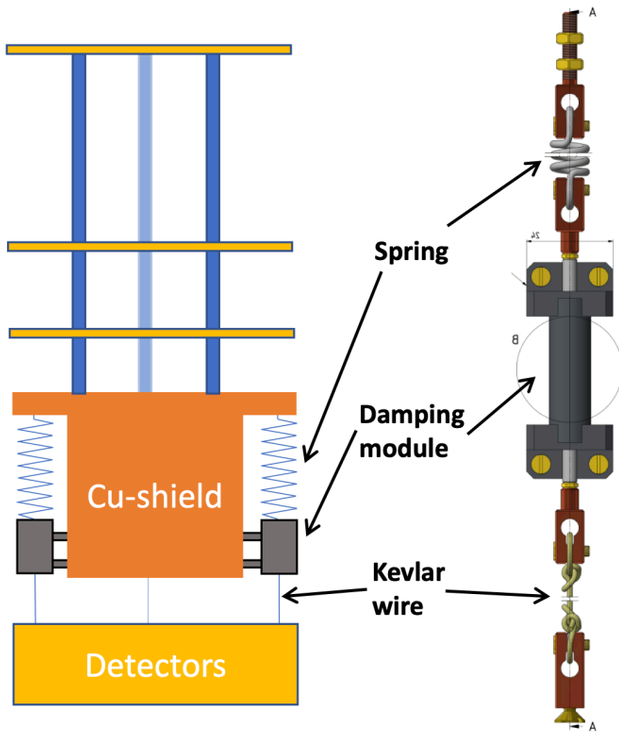
Interior: Finalized design for alignment

USB Camera

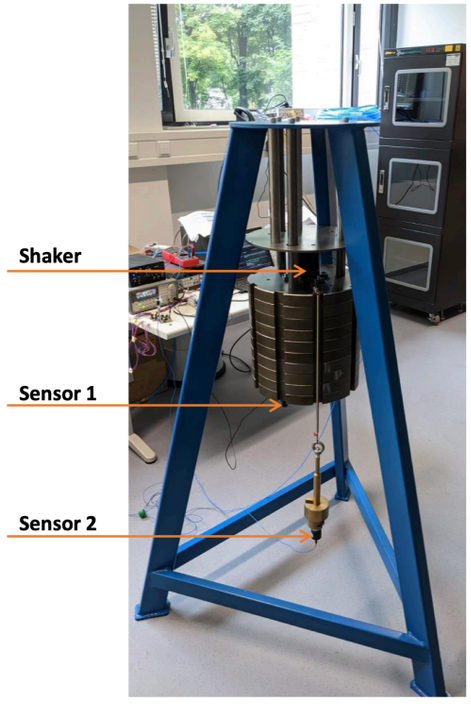


COSINUS

Decoupling at the detector stage



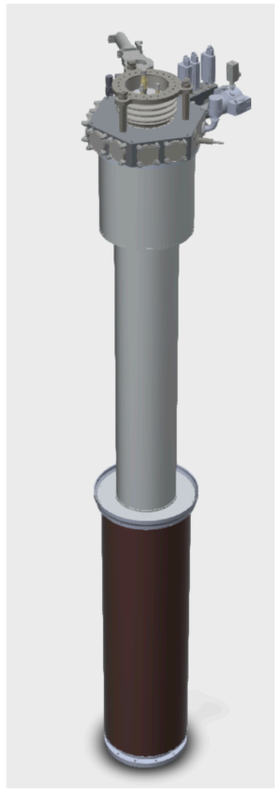
- **Optimize spring & resonance frequency of damping modules**
- **Magnetic eddy current damping**



Mockup system

Cryostats: Visit to Cryoconcept in 11/2021

LNGS system



MPP system

Dilution units

Summary

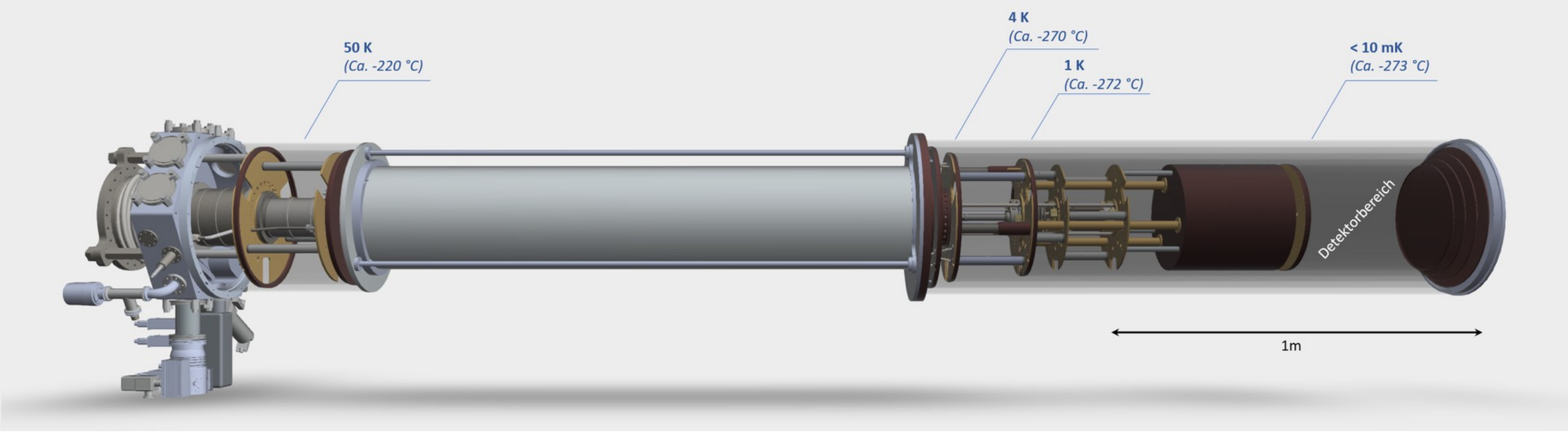
- COSINUS Facility construction has started at LNGS
- „remoTES“ solves several problems
  -> approaching final detector design
- Cryostats will be delivered in March & June 2022
- Designs for water & air systems
- Prototype for shielding ready; production starts in January
- Construction of Drywell, Tripod and Lifting System almost done
- Group at MPP growing!

COSINUS

- Building a new experiment of this size would not be possible without the help and support of a lot of people

- Many thanks especially to the CRESST group, the mechanical and electronics workshop, the construction team, the procurement department, D.Werner and the directors!

COSINUS



www.cosinus.it

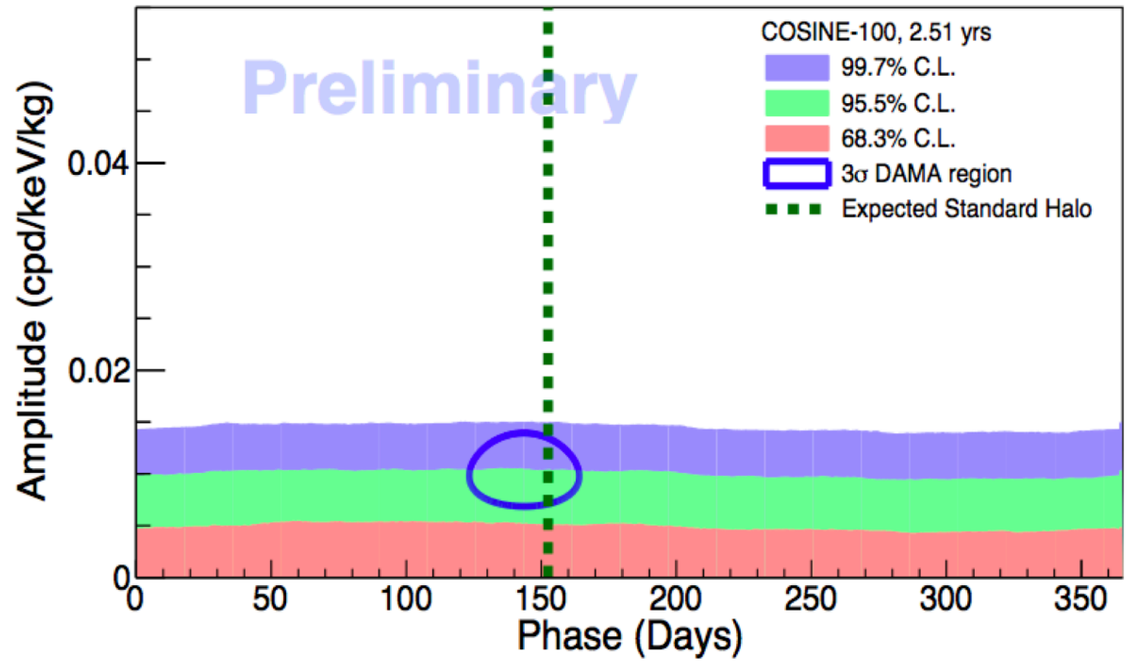
Thank you!

Project Review 2021

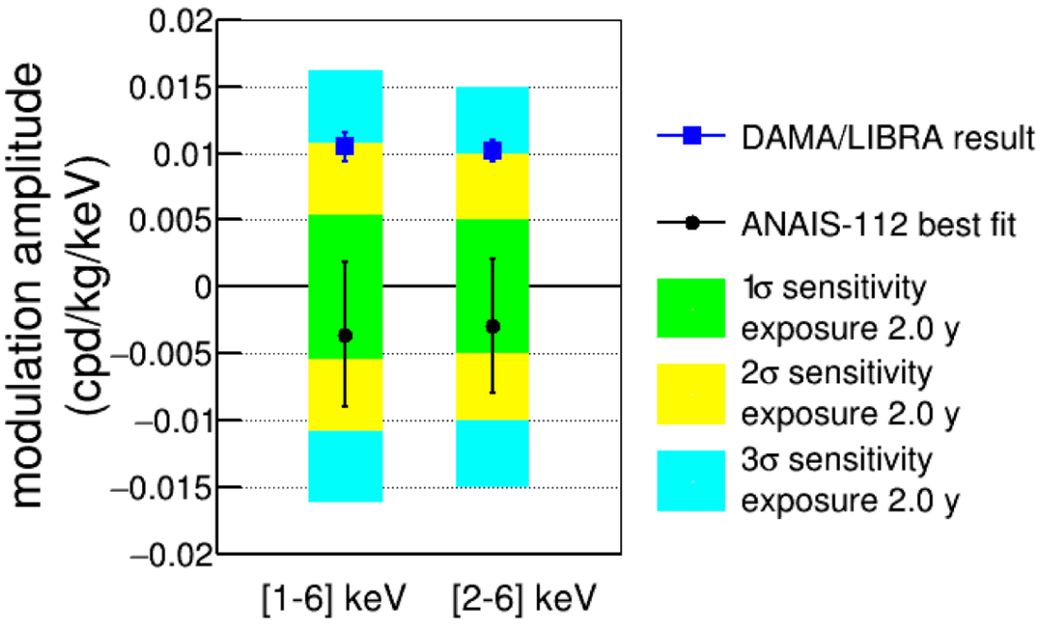
COSINUS

Backup: COSINE-100 and ANAIS modulation results

Govinda, Adhikari, and COSINE-100 collaboration. "Dark Matter Searches with the COSINE-100 Experiment." *Journal of Physics: Conference Series*. Vol. 1468. No. 1. IOP Publishing, 2020.



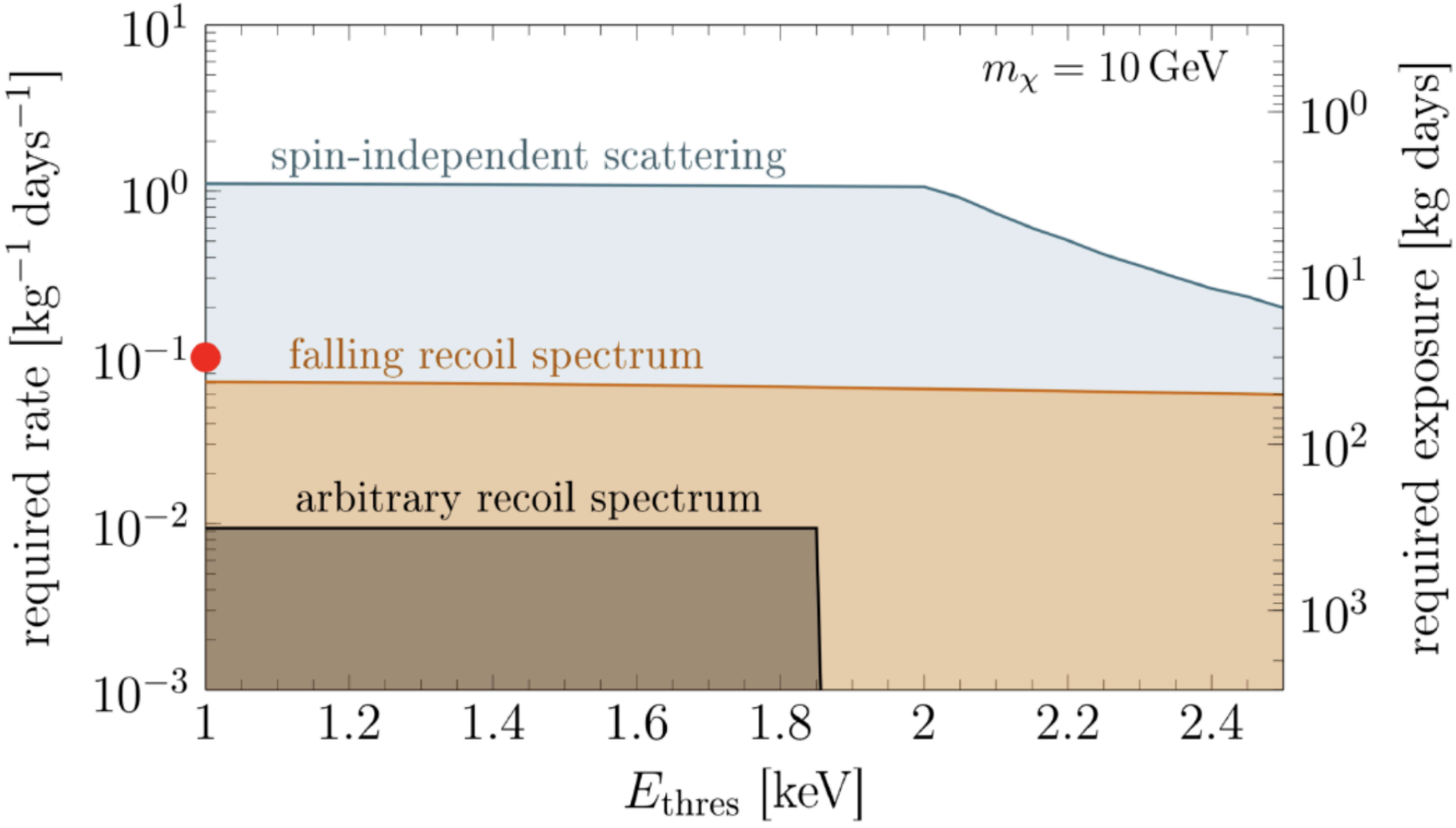
Amaré, J., et al. "ANAIS-112 status: two years results on annual modulation." *Journal of Physics: Conference Series*. Vol. 1468. No. 1. IOP Publishing, 2020.



COSINUS

Backup: Model-Independent Tests

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

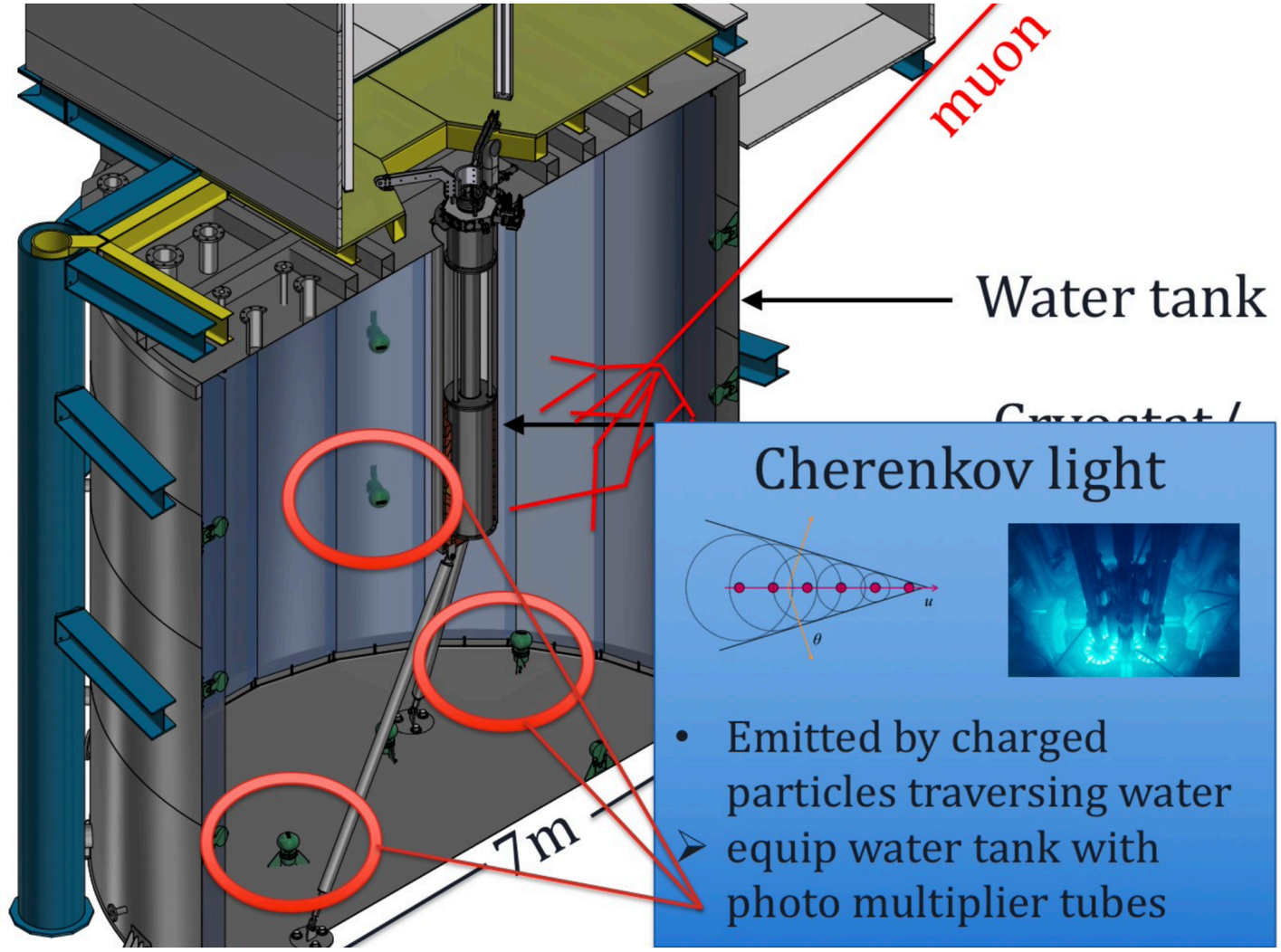
COSINUS

Backup: Muon Veto

Muons create secondary particles: most dangerous are neutrons
R ≃ 4 cts / (kg year)

→ Too high: Veto mandatory

Neutrons from radioactive processes:
R ≃ 0.05 cts / (kg year)

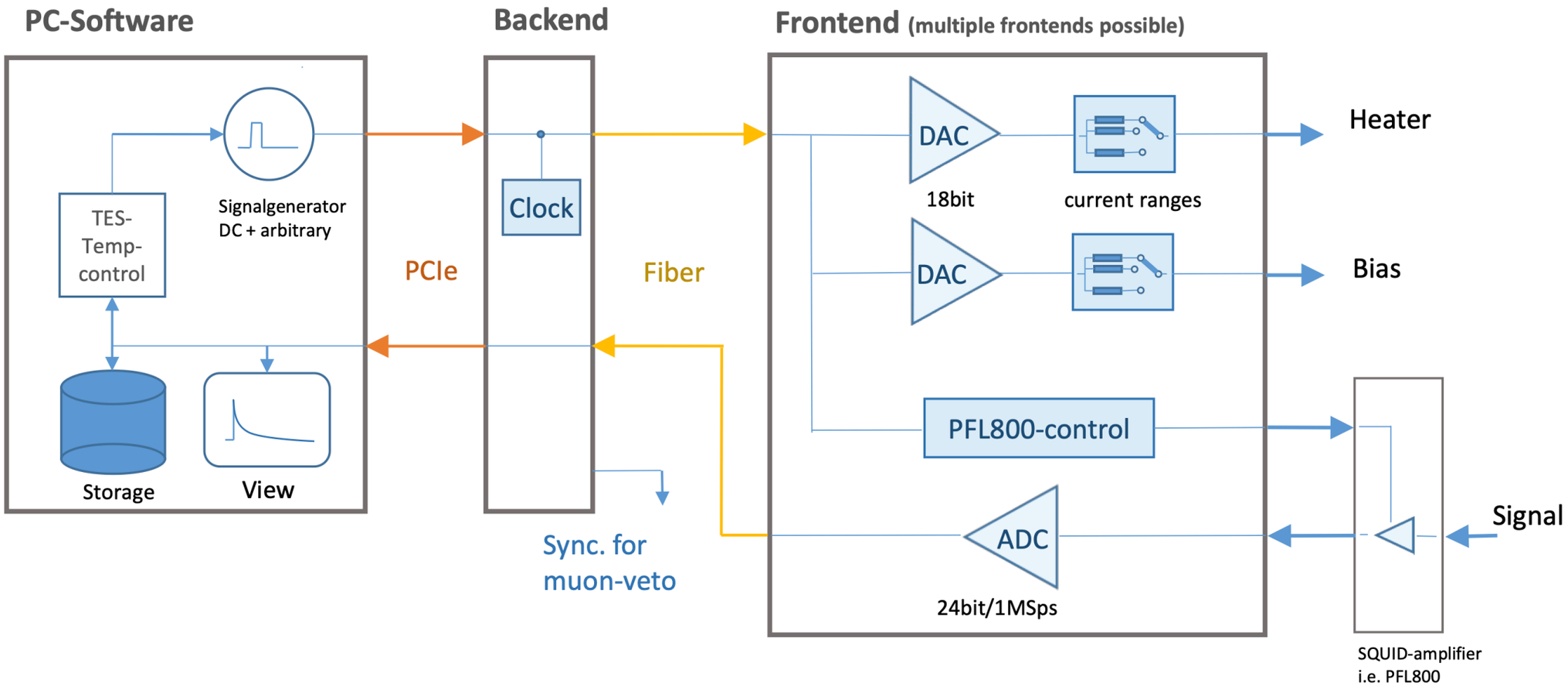


- **From the start or not?**
- **Technical specifications of veto clear; design mostly finished**

COSINUS

Backup: DAQ Electronics

- **„Versatile Data AcQuisition“ combining several electronic parts**
- **Developed at HEPHY in Vienna, two prototypes so far**



VDAQ-Devices:
- Backend: Ready available PCIe-FPGA-card
- Frontend: 19“- crate. Plug-in cards for analog out (heater, bias) and analog in (signal).