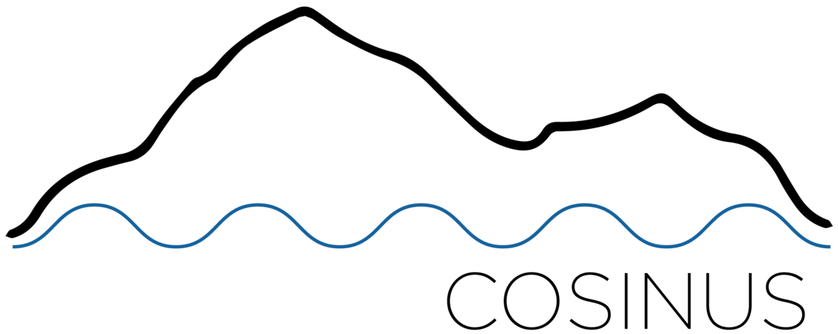
Neutrino flux observation of the next galactic core-collapse supernova in the COSINUS dark matter detector

Presented by: Matthew Stukel
For the 20th International Workshop On Neutrino Telescopes



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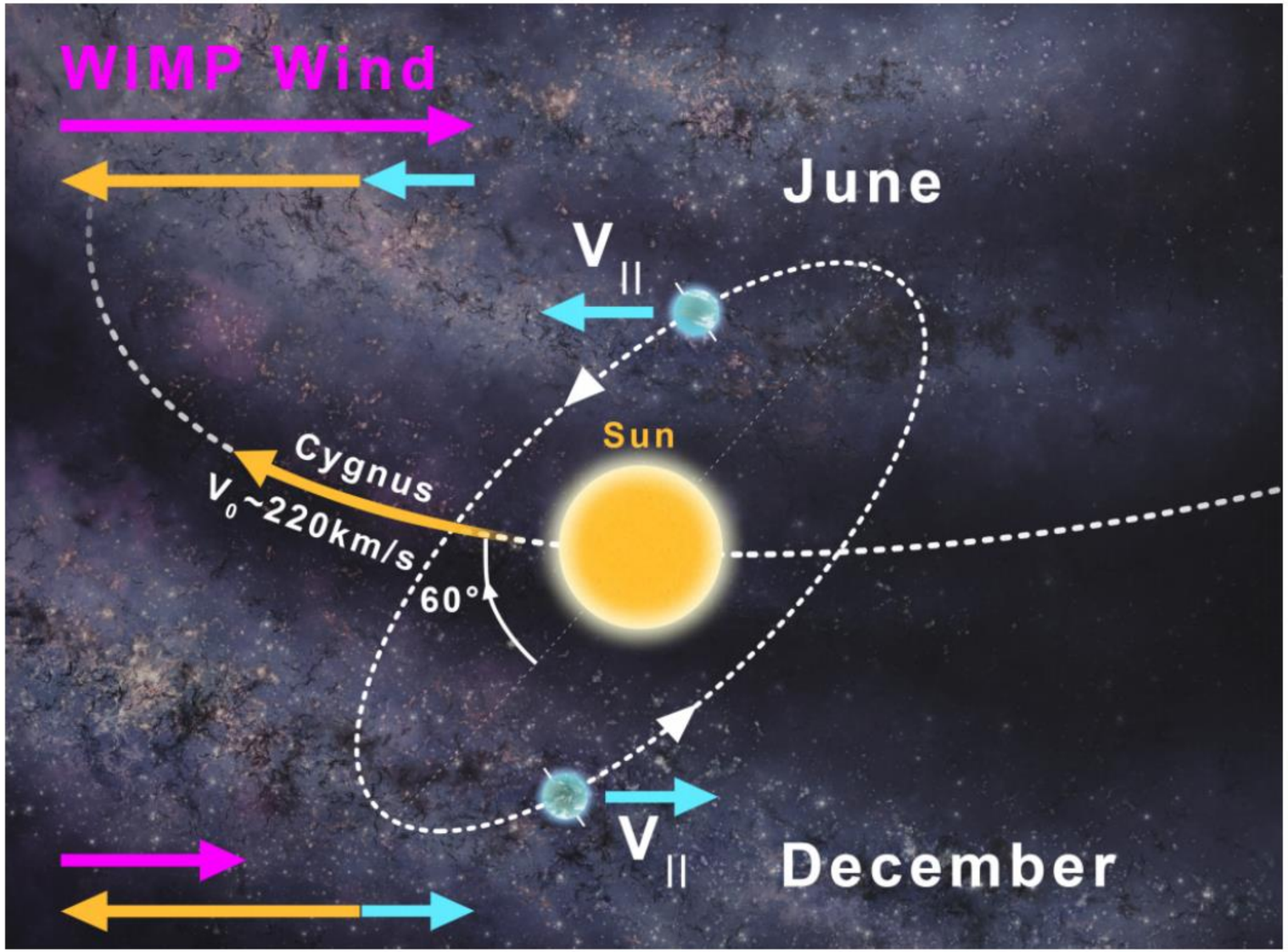
Motivation

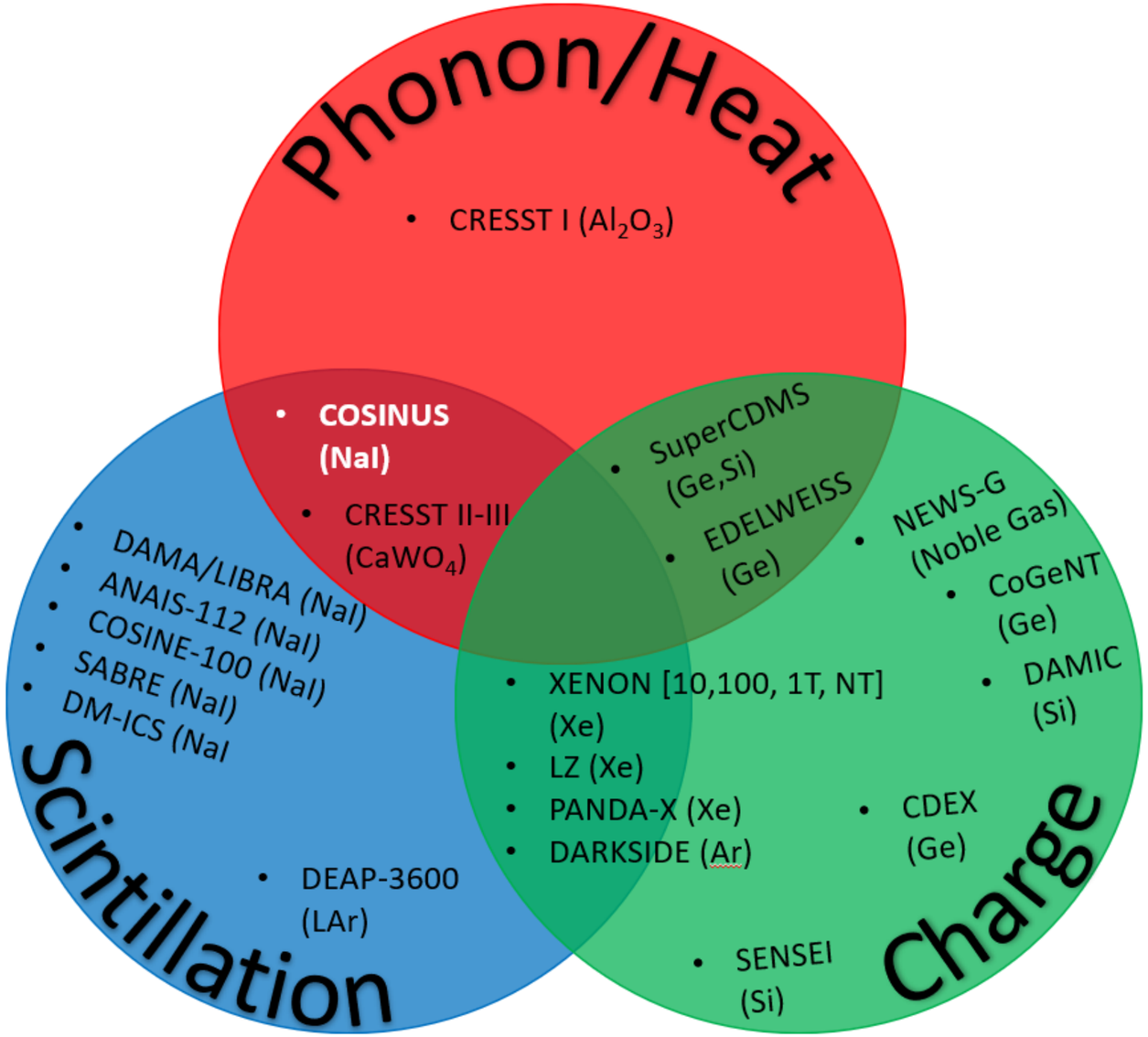
Direct Detection: Annual Modulation



https://iopscience.iop.org/article/10.1088/1361-6471/ab8e93/meta

- The sun moves through the galactic dark matter halo
- The earths rotates around the sun
- Induces a change in the dark matter flux throughout the year
- The DAMA collaboration has detected a peculiar annual modulation signal since 1997
- **Unique** and **detectable** signal for dark matter
  - Period of one year
  - Peaks around June 2nd
  - Signal expected in low energy region (O(keV))

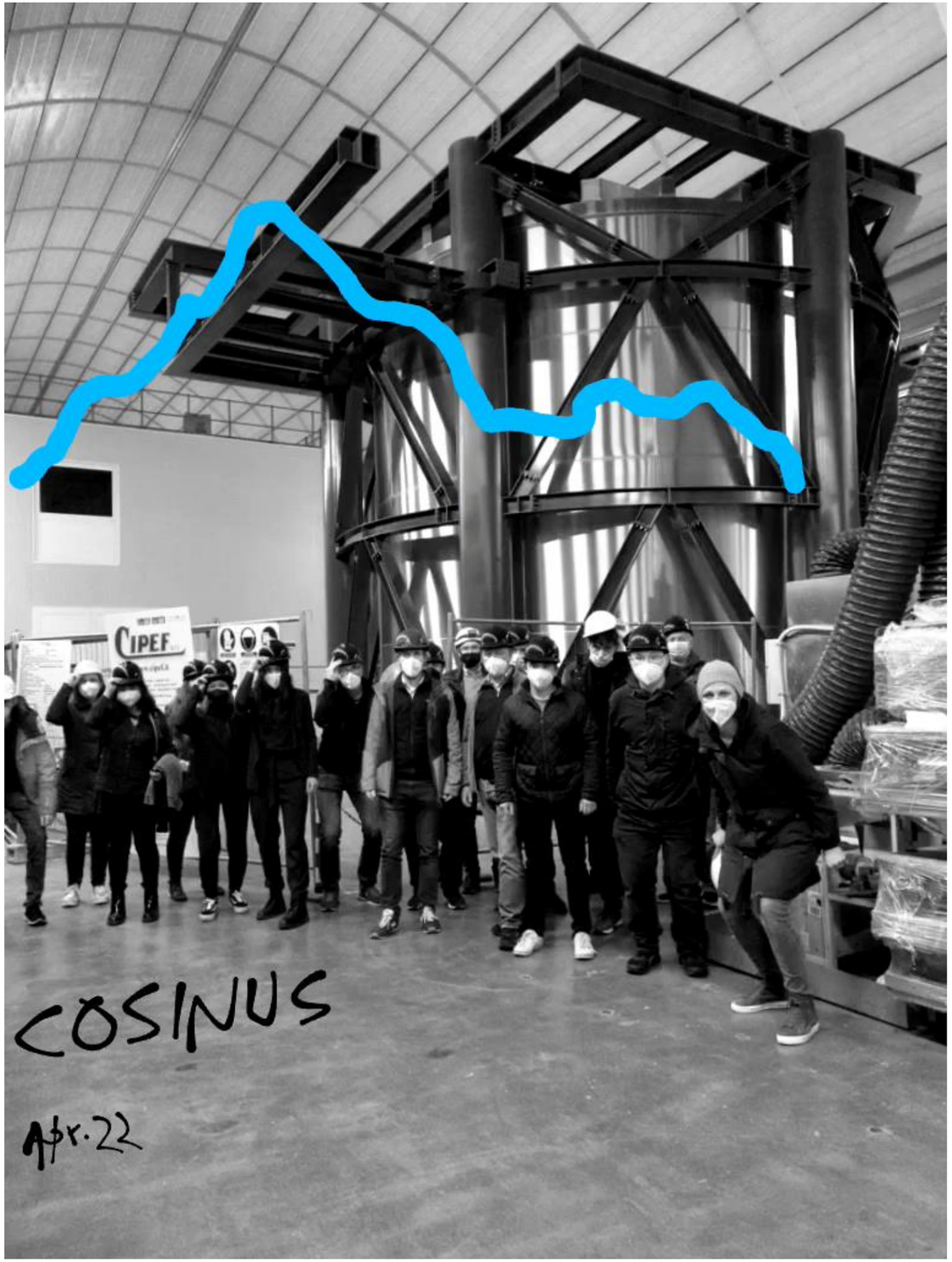
Landscape of Dark Matter Experiments



- **Goal:** Aims at a model independent test of the DAMA/LIBRA experiment
  - Same material (NaI)
  - Same location (LNGS)
  - Need 1000 kg days
- **Unique Technique:** Operate NaI as a cryogenic detector (First ever!!)
  - Dual Channel: Phonon (90%) and Light (10%) signal for **event-by-event particle discrimination**

COSINUS

Cryogenic Observatory for SIgnatures seen in Next-generation Underground Searches



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

Since 1928
SICCAS

TU WIEN

HEPHY
INSTITUTE OF HIGH ENERGY PHYSICS

HELSINKI INSTITUTE OF PHYSICS

$\Delta p \cdot \Delta q \geq \frac{1}{2}\hbar$
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

The Group

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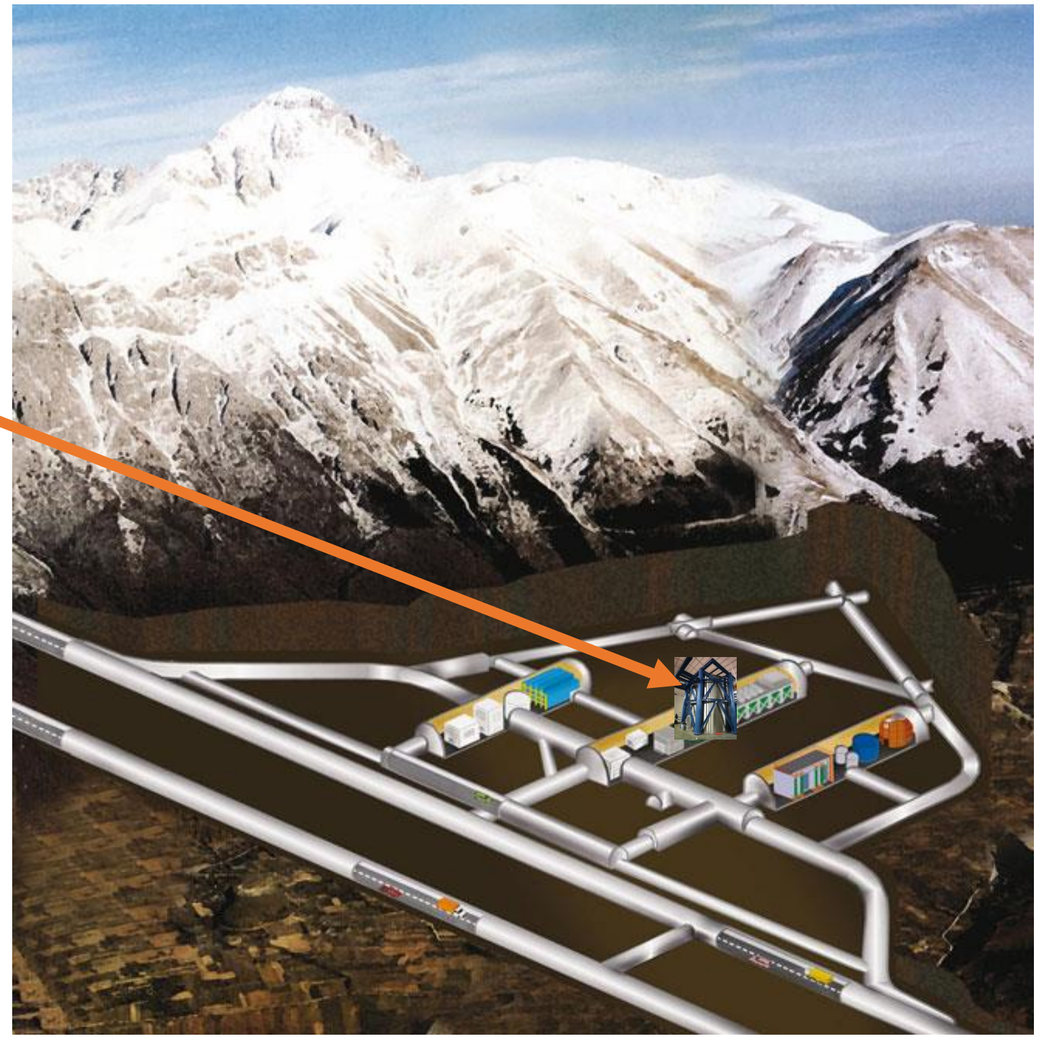
Gran Sasso National Laboratory (LNGS)

https://www.planetware.com/map/italy-italy-republic-map-i-i37.htm

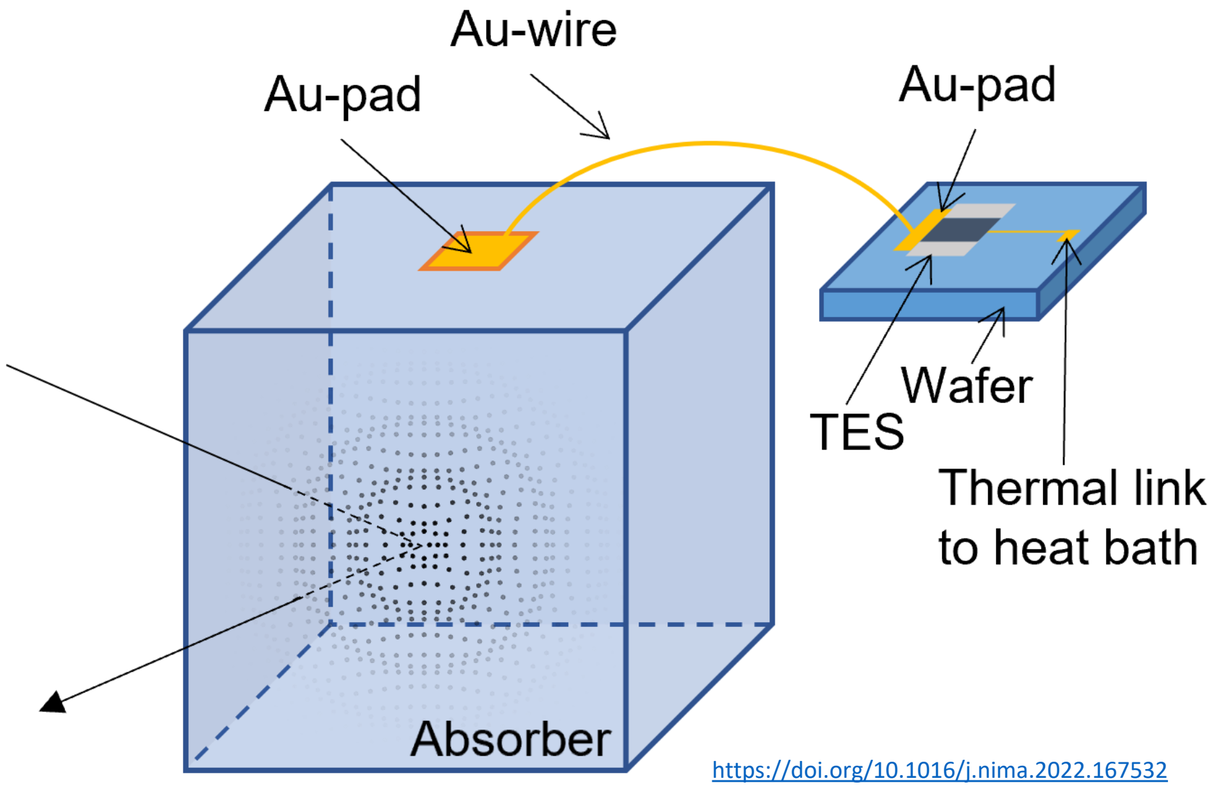
COSINUS Location

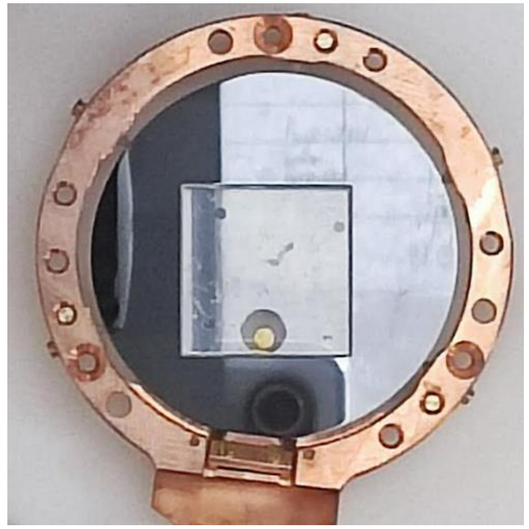


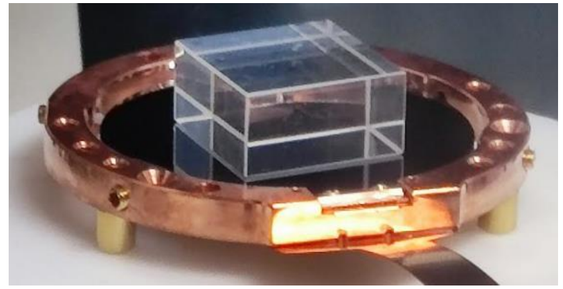
https://www.appec.org/news/hands-on-experimental-underground-physics-at-lngs

- LNGS provides 3500 m of water equivalent shielding from cosmic radiation

NaI- remoTES design



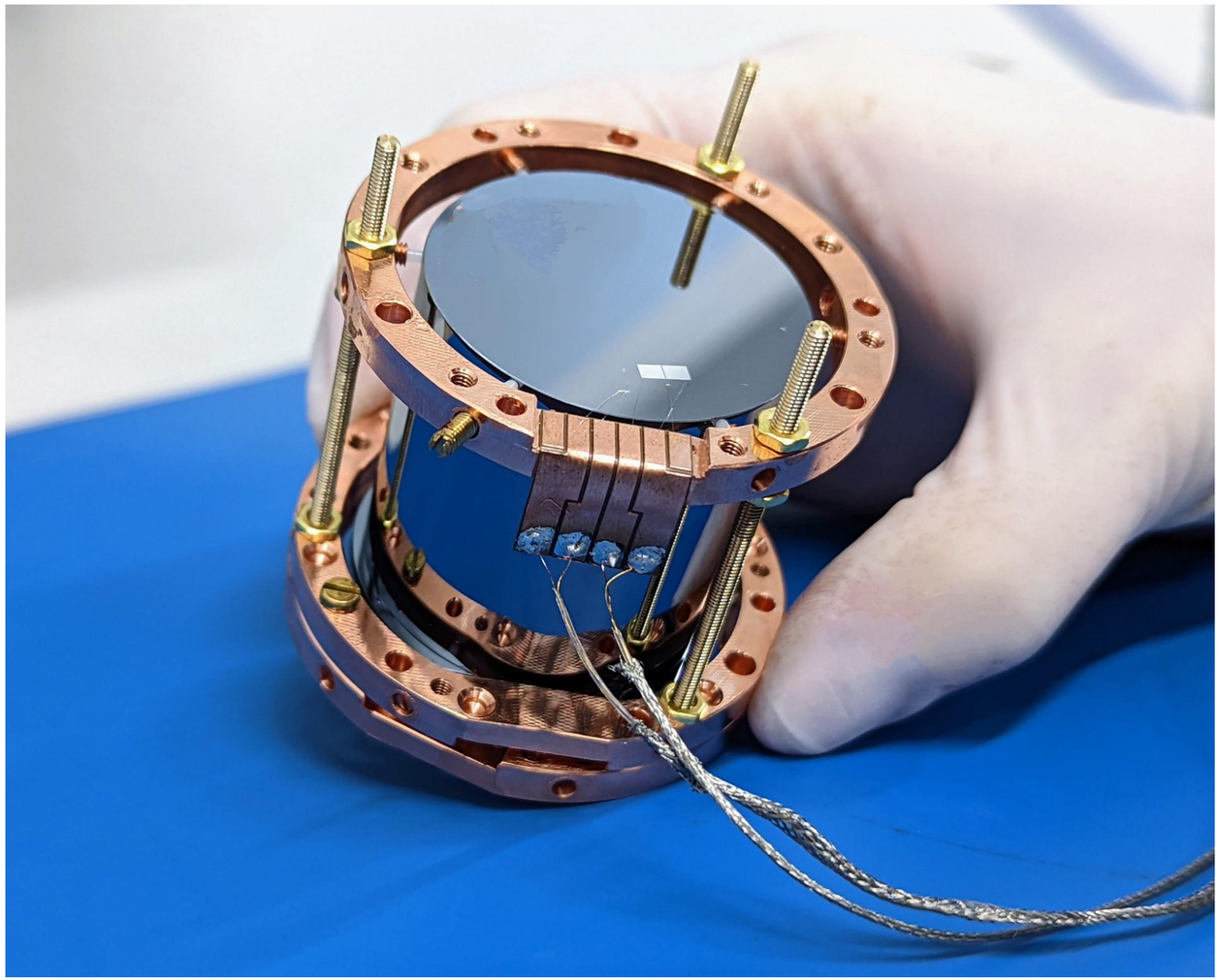




https://doi.org/10.1016/j.nima.2022.167532

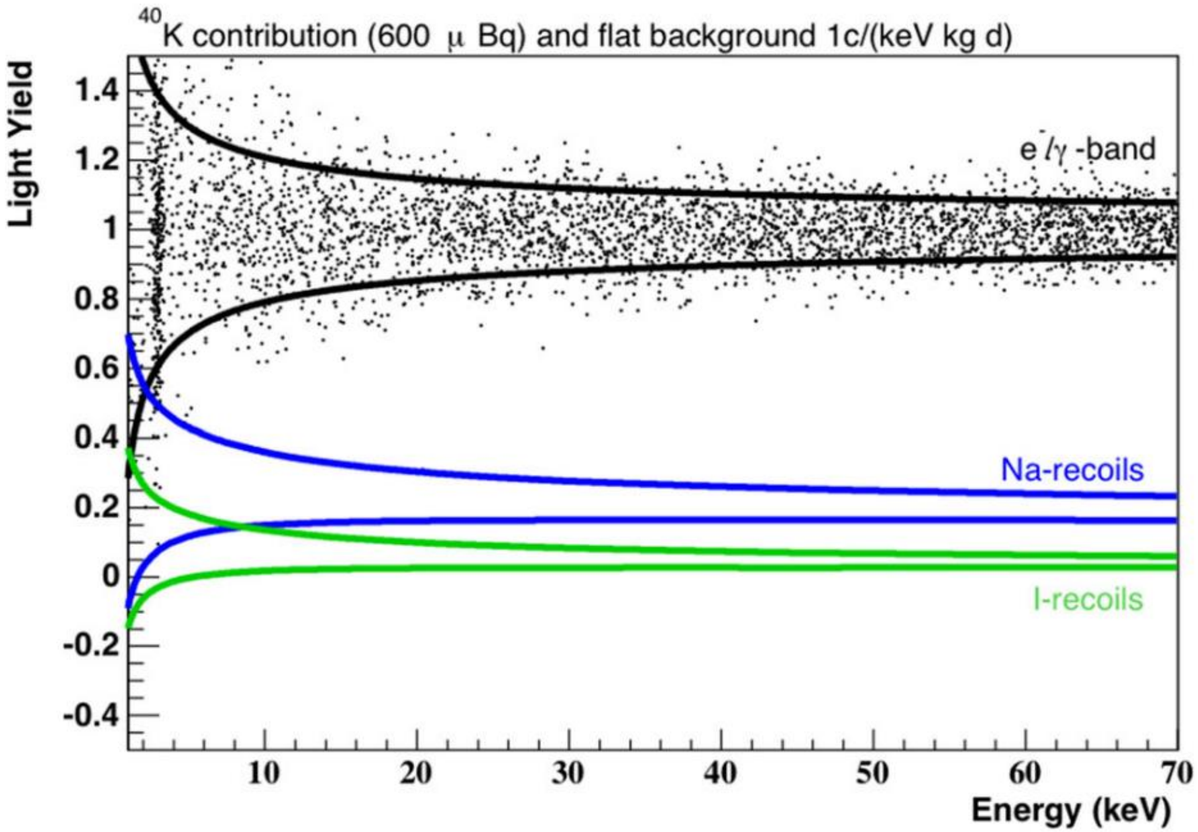
- Implement **remoTES** design, first proposed by Matt Pyle
  - NaI is hygroscopic (cannot come into contact with humid air)
  - Very soft and low melting point (easy to damage when handling)
  - Not suited for traditional thin film deposition
- Separate wafer that holds the TES: Wafer: Al_2O_3
- Gold pad on absorber with a gold bonding wire connected to TES

NaI – Light Detector



- Scintillation light is detected by a surrounding silicon beaker
  - 1mm thick, 40mm in diameter
- 4π coverage to maximize light collection
- TES is evaporated directly onto the silicon
- Resolution: 990 eV_{ee}

COSINUS: Particle Discrimination



Angloher, G., et al. "Simulation-based design study for the passive shielding of the COSINUS dark matter experiment." *The European Physical Journal C* 82.3 (2022): 1-11

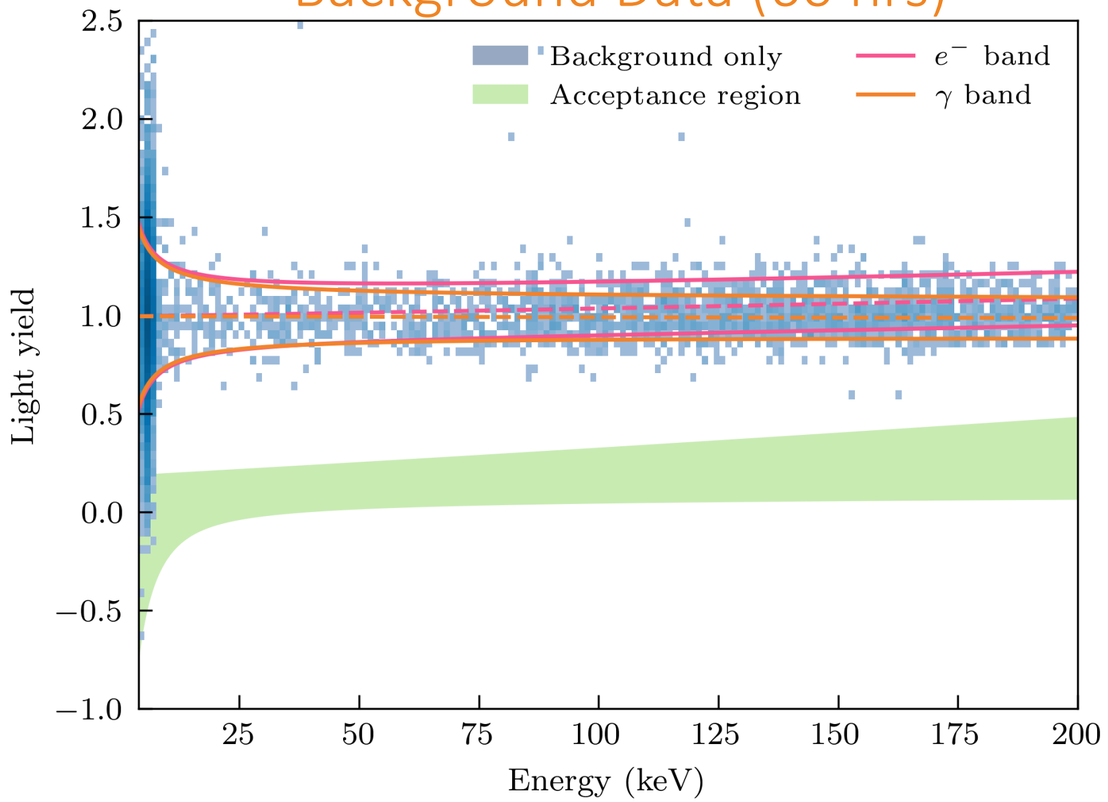
- Particle discrimination is the COSINUS advantage

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

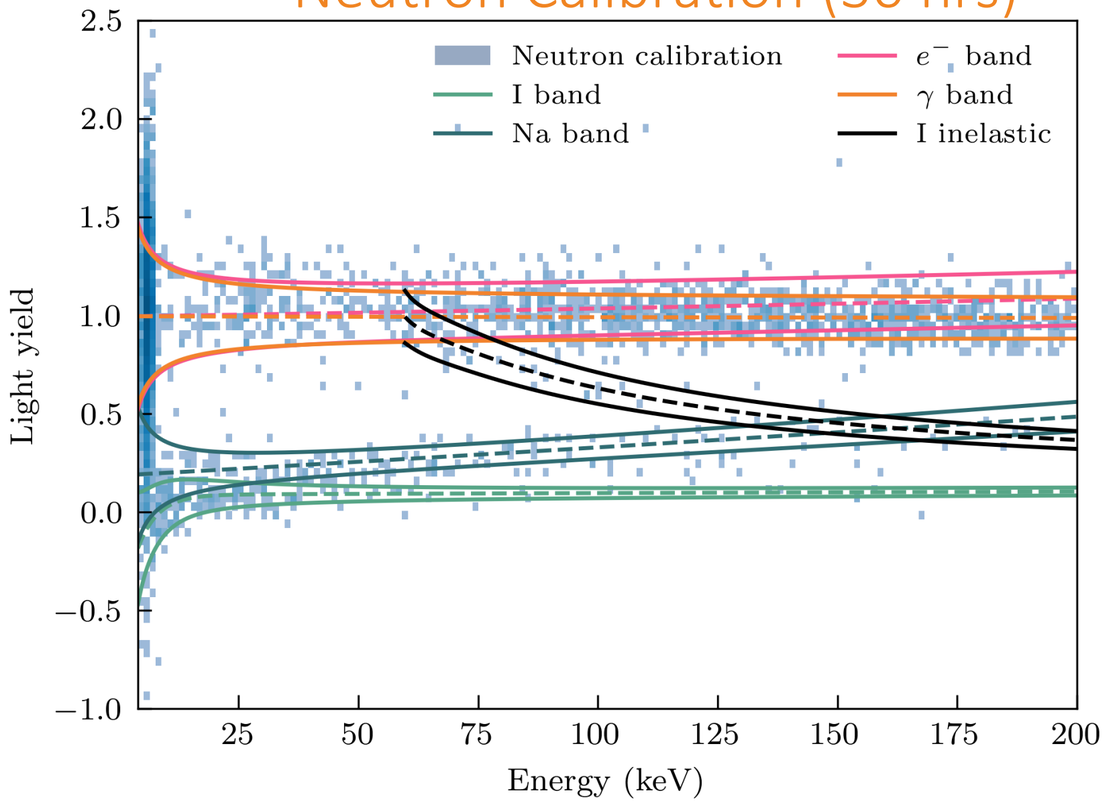
- Electromagnetic interactions will emit more light than nuclear recoils
- Use for **particle discrimination** on an event-by-event basis
- Left is simulated data
- Position of the bands is very dependent on the quenching factor (QF)
  - Dedicated QF performed at TUNL (See backup slide)

COSINUS: Particle Discrimination

Background Data (60 hrs)



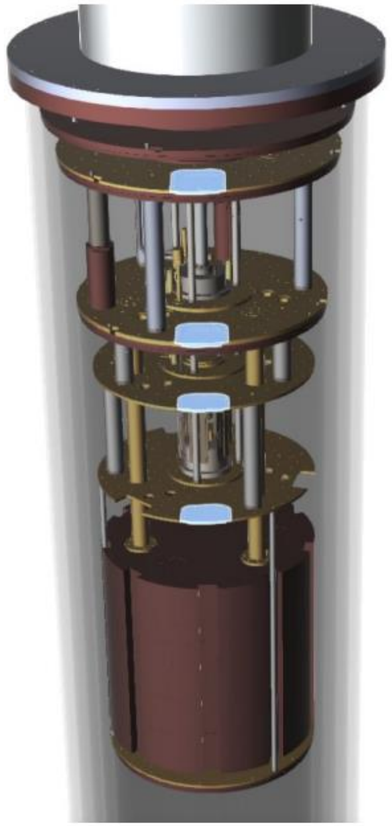
Neutron Calibration (30 hrs)

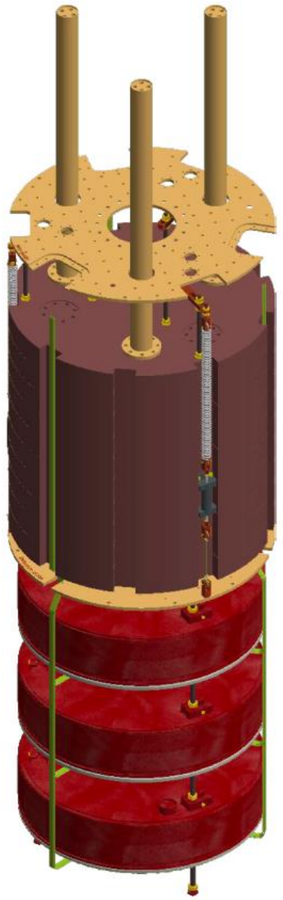


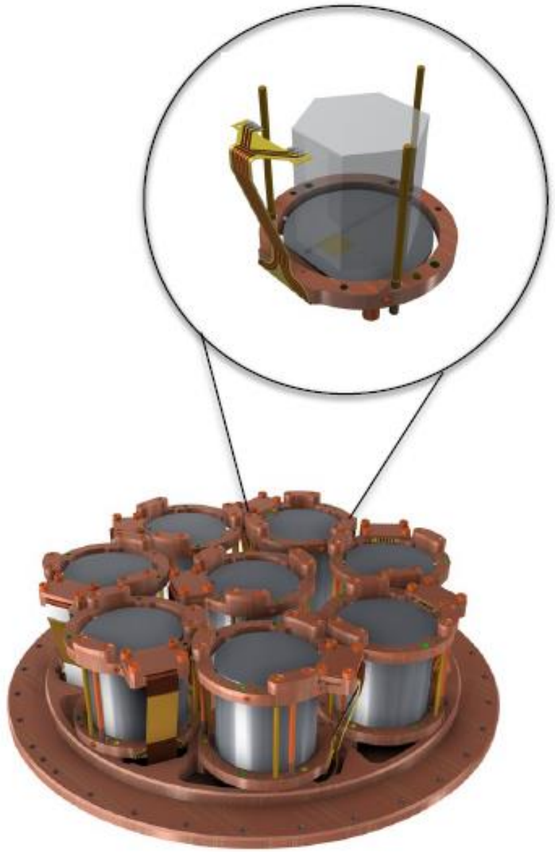
- December 2021: Demonstrated the first particle discrimination in NaI at a surface setup
- June 2022: Measurement was carried out using a CRESST test facility at the Gran Sasso National Laboratory (underground)
- Plots by Leonie Einfalt, publication on arXiv
- NaI phonon resolution: 440 eV_{nr}
- Neutron band is clearly visible, **proof of particle discrimination in NaI**

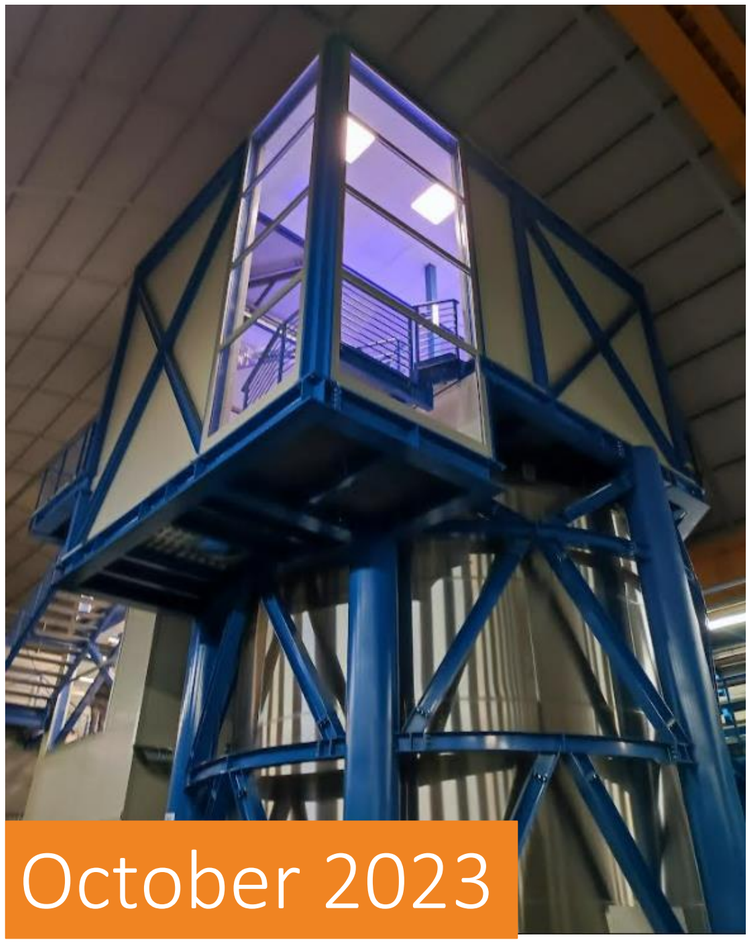
https://doi.org/10.48550/arXiv.2307.11139

COSINUS: Dry Dilution Refrigerator









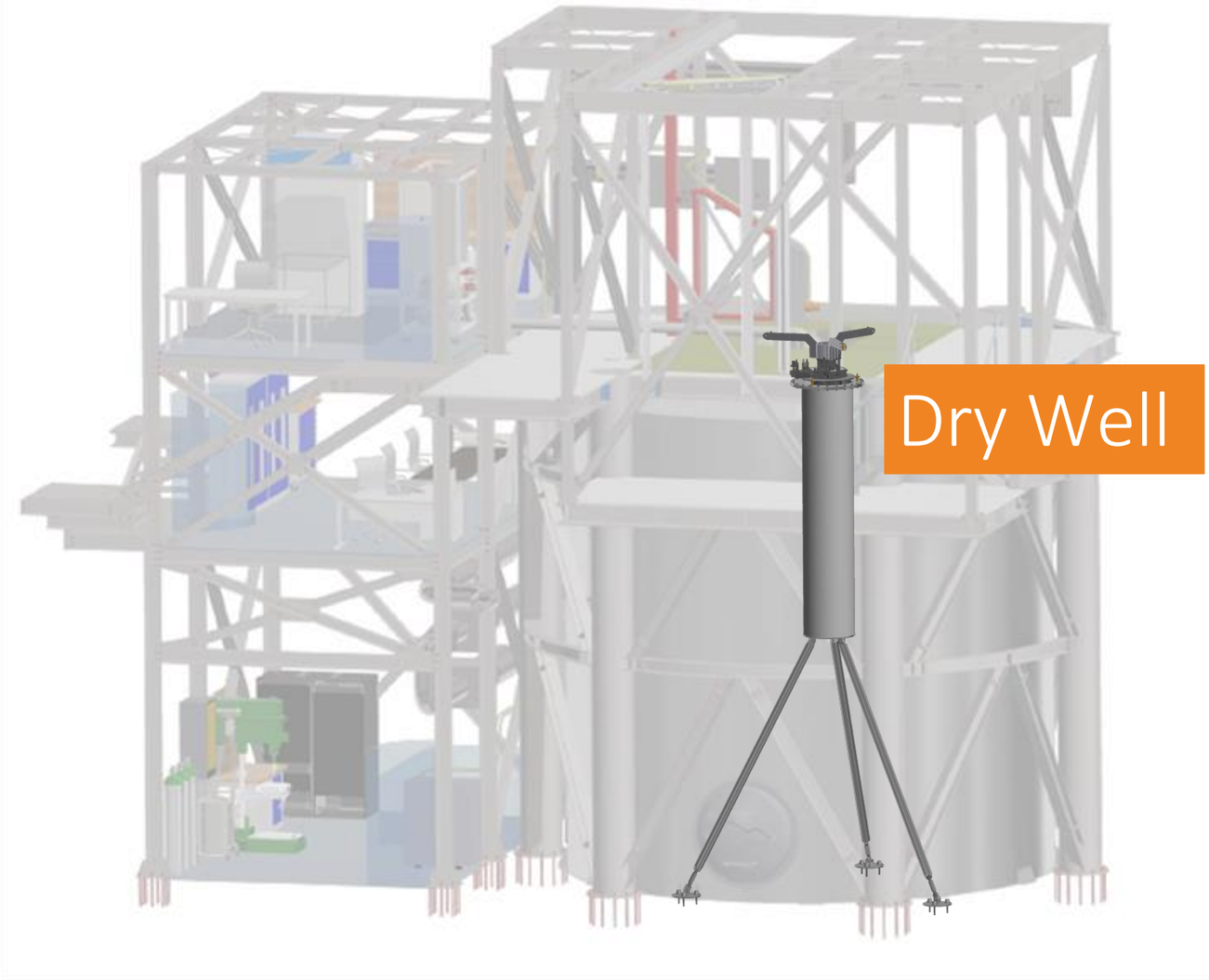
- Detectors housed in a pulse tubed assisted dilution refrigerator (mK)
  - Each detector is expected to house a 117g NaI crystal
- Vibration decoupling: Two different stages, spring-based passive decoupling system
- Ultra-pure copper for shielding the detectors from cryostat radiogenics

Experimental Setup I

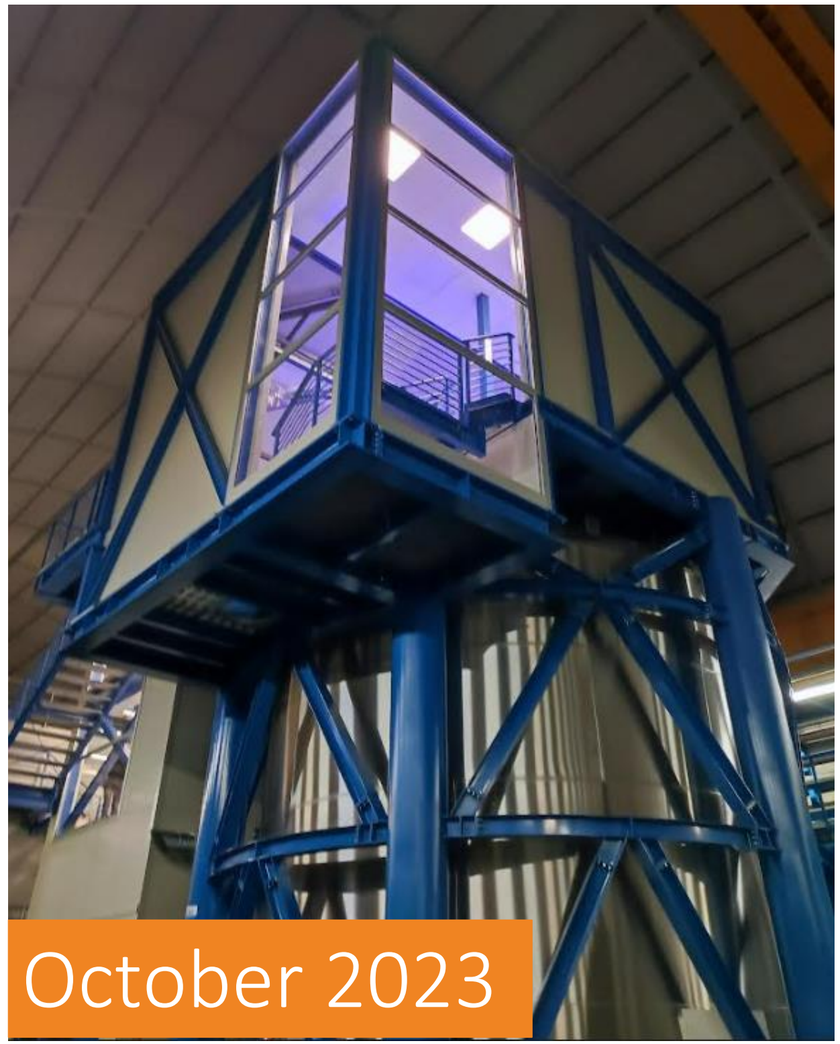
Cryostat

October 2023

Experimental Setup II



Dry Well



October 2023

Experimental Setup III

Control Room

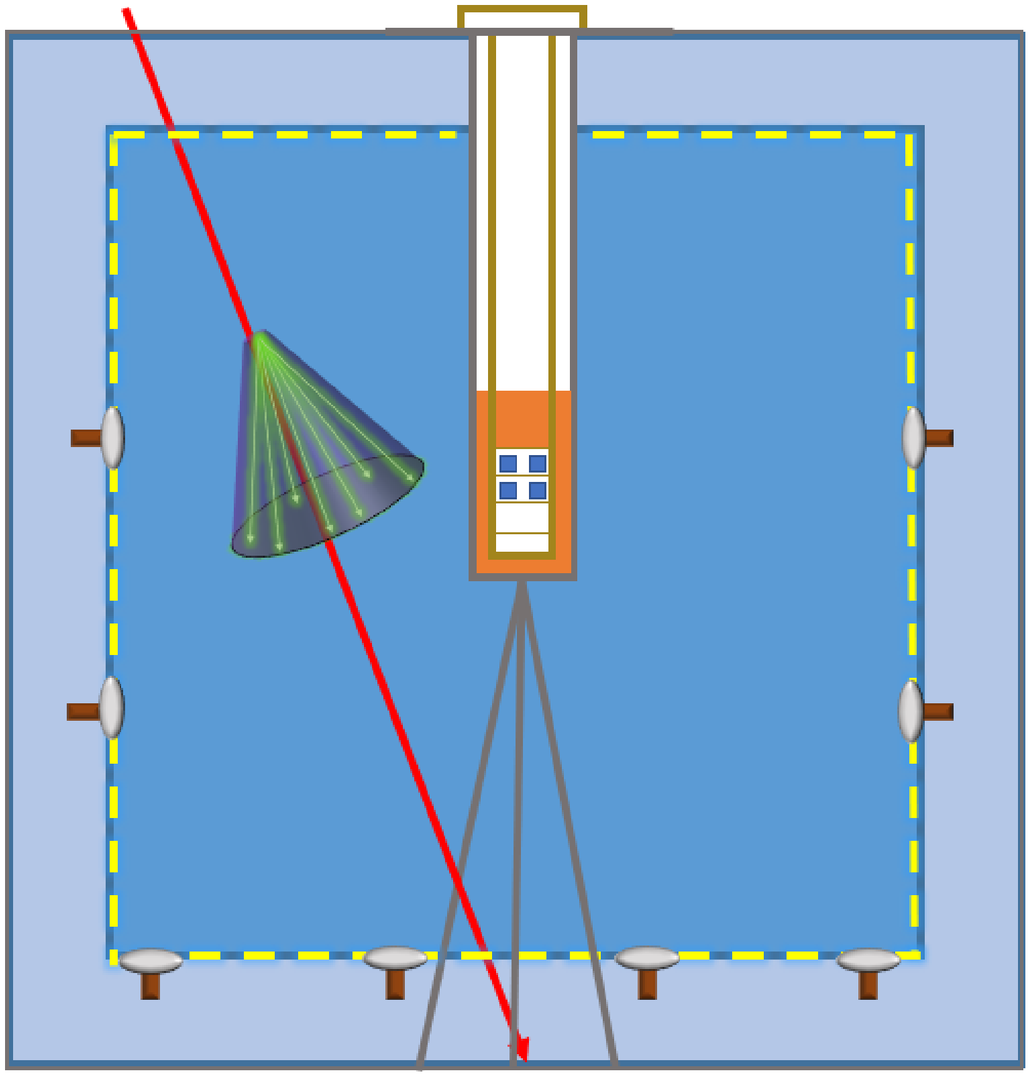
Clean Room

Water Tank

October 2023

COSINUS Water Tank I

- 230 tonne water tank (7x7 m^2 cylinder)
- Instrumented with 28, 8-inch R5912-30 PMTs from Hamamatsu
  - 18 along the bottom and 10 along the wall
- Optical dead layer for the muon veto
  - Reduce the spurious triggers of PMT from ambient background and triggers
  - Need a trigger rate less then 1 Hz to be viable
- Detailed optical simulation created with ImpCRESST to optimize PMT placement, detector efficiency and background rate
- Achieve a total muon veto efficiency of 97(2)%
- Paper in progress



COSINUS Water Tank II

- 230 tonne water tank (7x7 m^2 cylinder)
- Instrumented with 28, 8-inch R5912-30 PMTs from Hamamatsu
  - 18 along the bottom and 10 along the wall
- Optical dead layer for the muon veto
  - Reduce the spurious triggers of PMT from ambient background and triggers
  - Need a trigger rate less then 1 Hz to be viable
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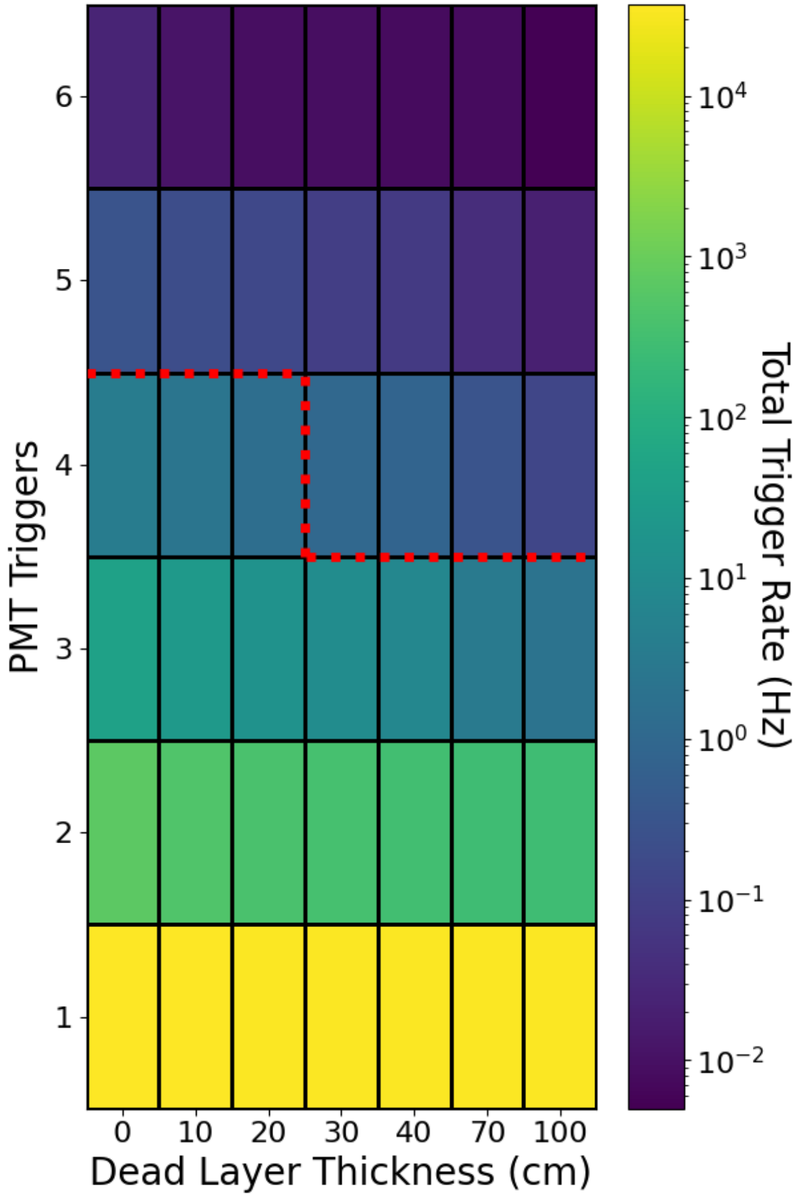
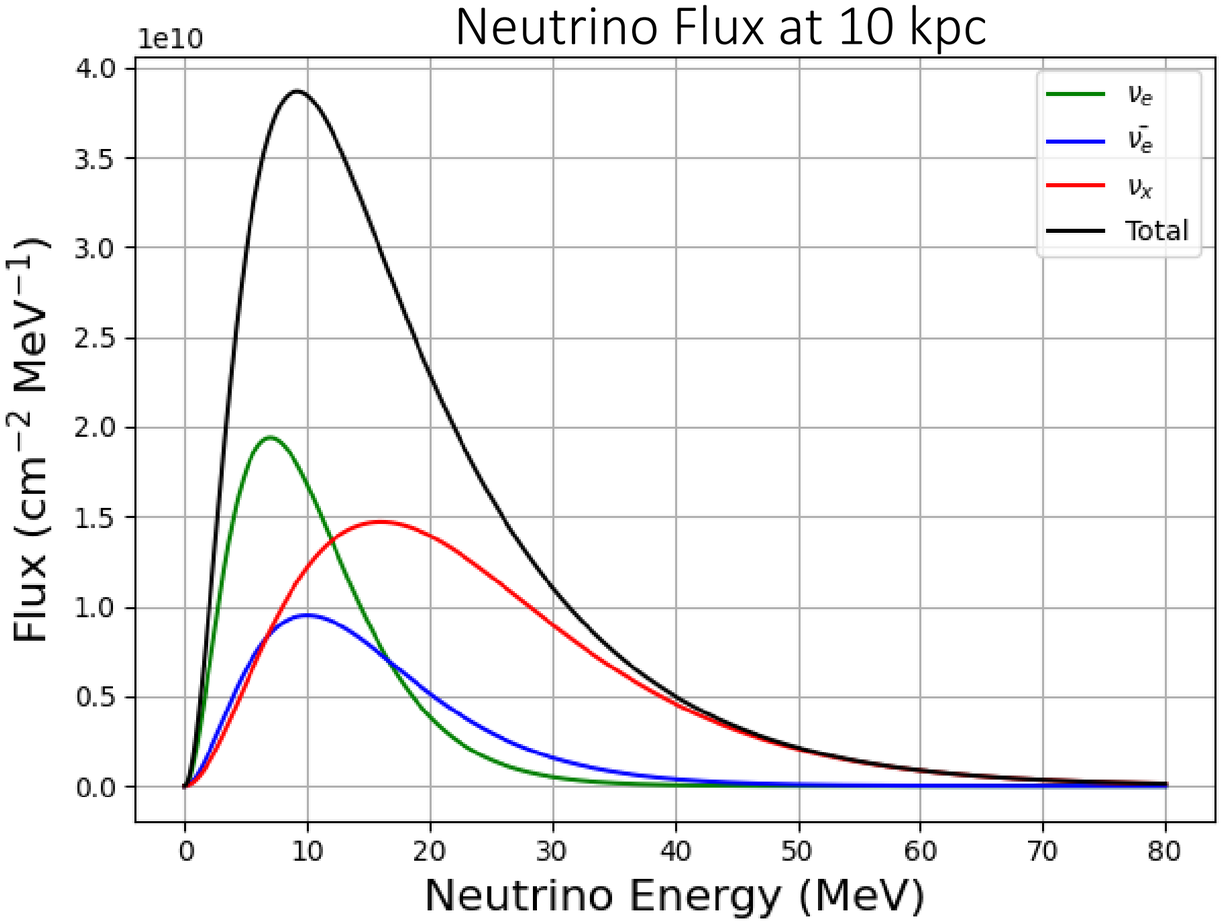


SuperNova

ν-detection Channels in COSINUS

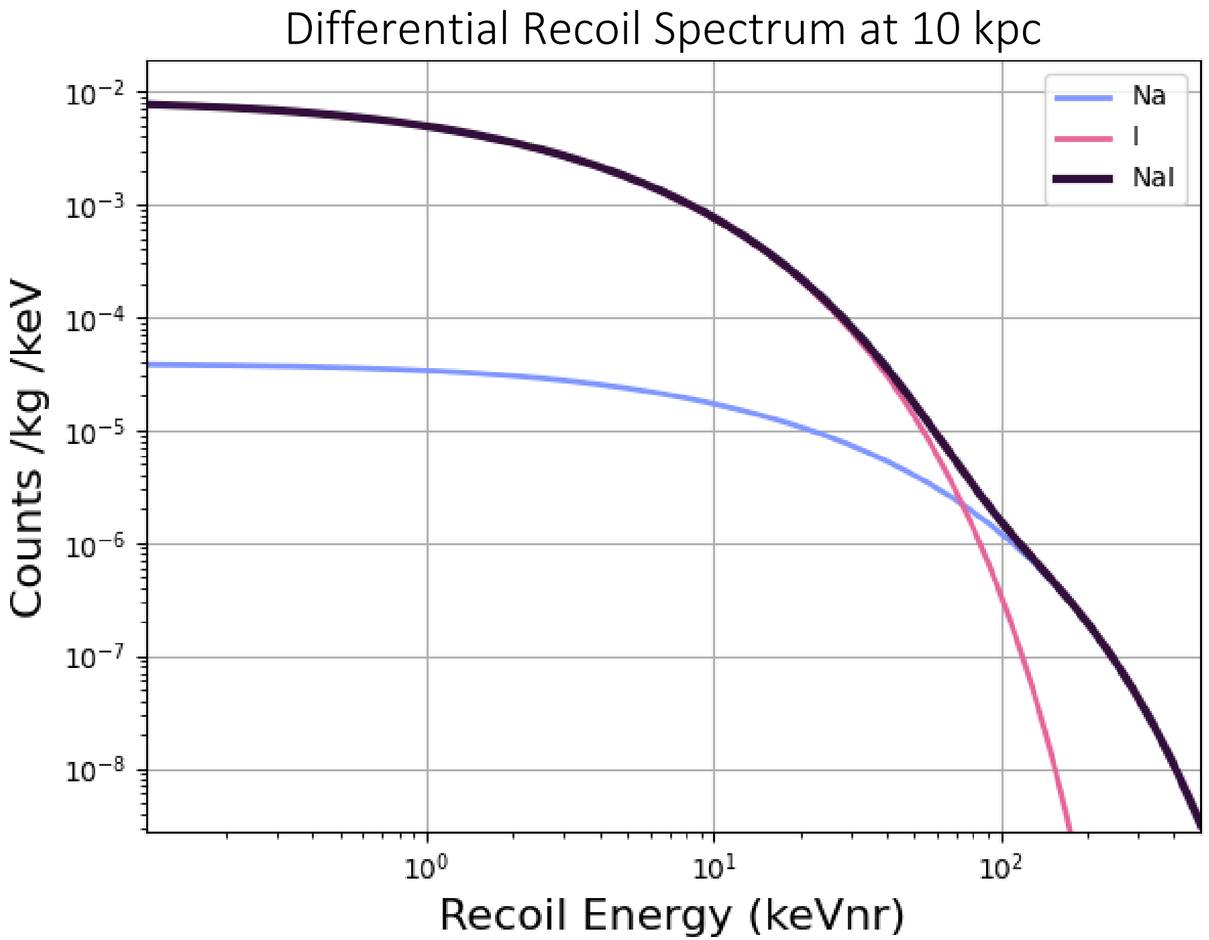
- The COSINUS experiment has two primary detection channels for Supernova neutrinos
  - CEvNS in the NaI detector
  - Inverse beta decay (IBD) in the water tank
- **<u>Advantages:</u>**
  - Direct determination of nuclear recoil event
  - Low background environment
    - For the duration of a Supernova
  - Coincidence capabilities between water tank and cryogenic calorimeters

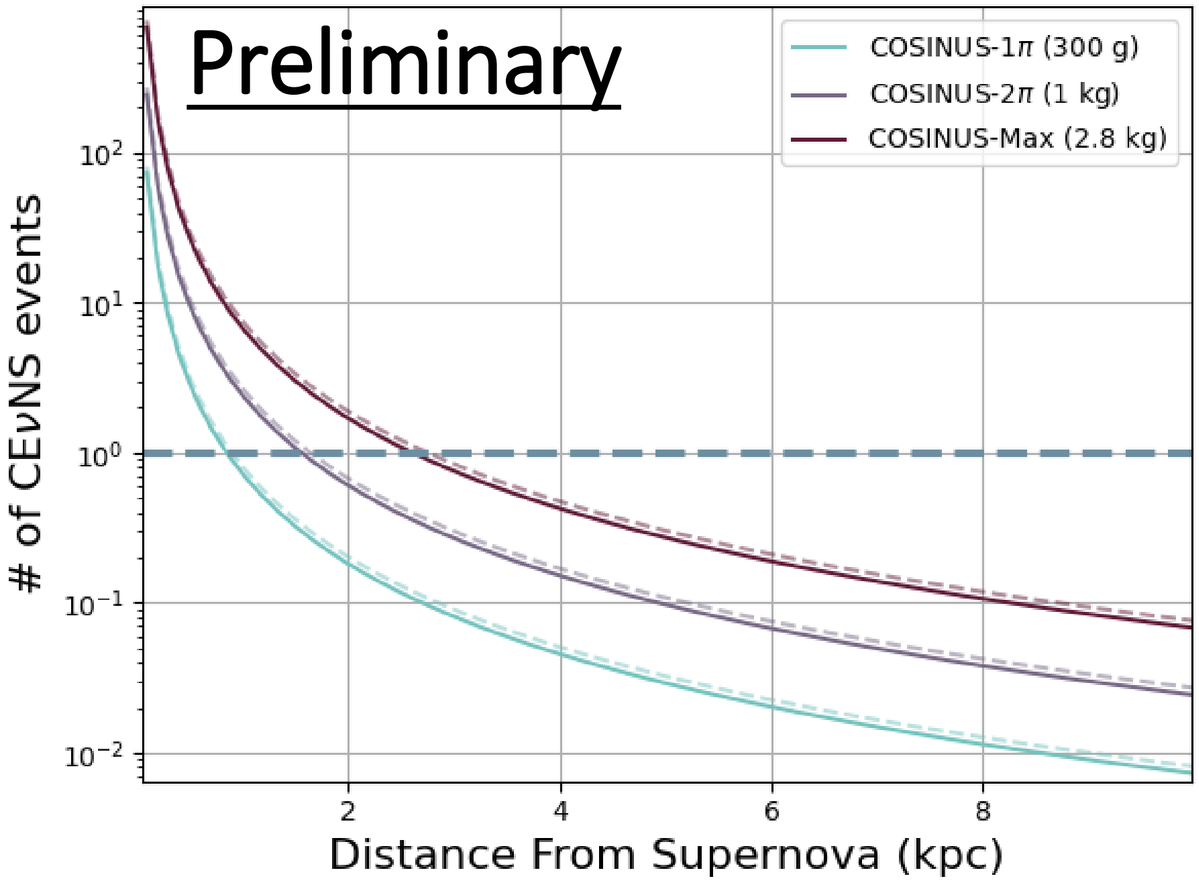


$$\Phi_i = \frac{1}{4\pi D^2} \frac{N_i}{2T_i^3} E_\nu^2 e^{(-\frac{E_\nu}{T_i})}$$

https://doi.org/10.48550/arXiv.1110.3536

CEvNS in COSINUS



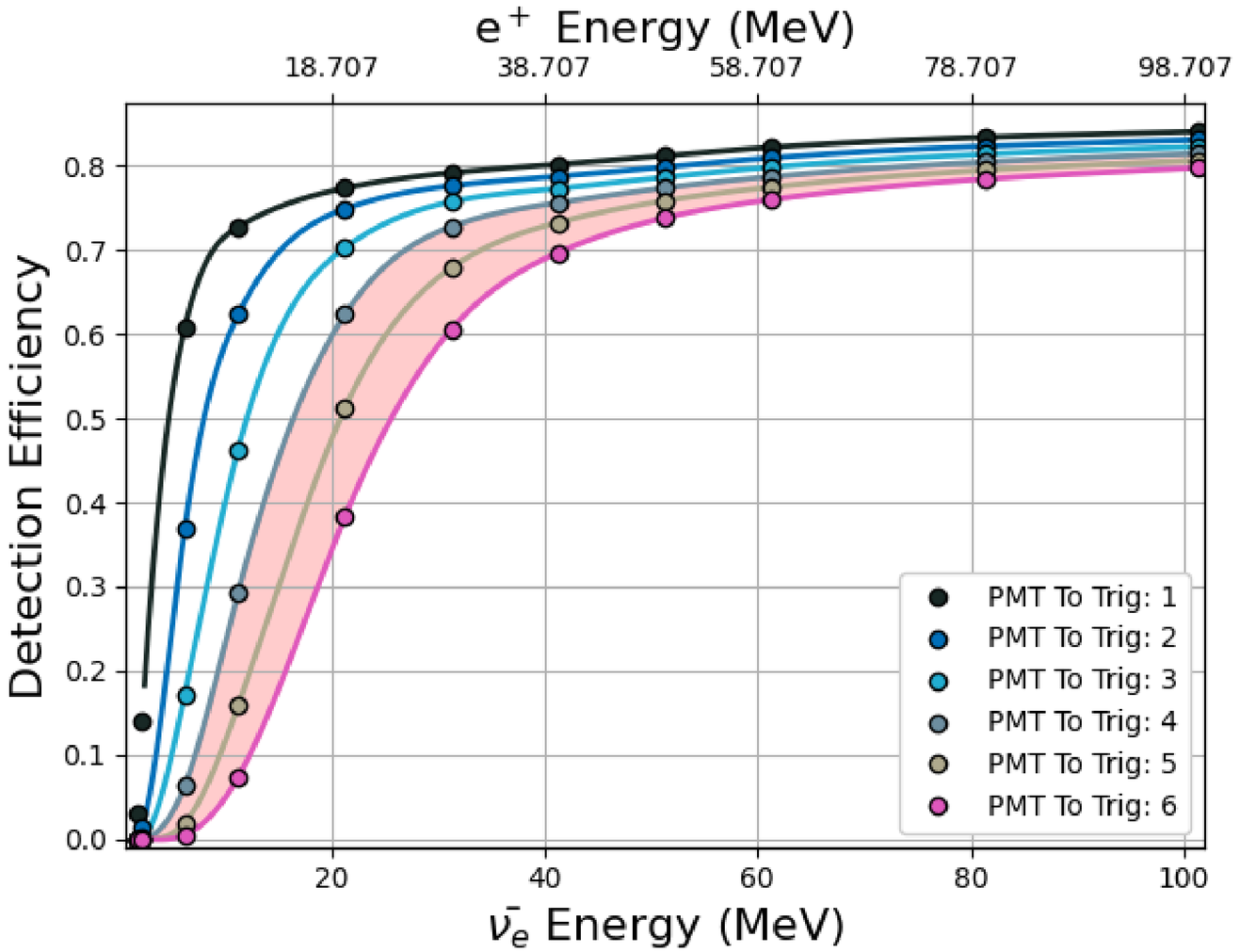


- Klein-Nystand form factor used to determine differential recoil rate
- Over the length of a supernova the NaI detectors should be background free, so just a few events will be significant
- Depending on the mass deployed COSINUS will be sensitive to Supernova in the <u>< 2.5 kpc range</u>
  - Solid lines (1 keV threshold) Dashed lines (0.5 keV)

IBD in COSINUS

$$\bar{\nu}_e + p \rightarrow n + e^+$$

$$N = N_p \int_{E_{thresh}} \Phi_{\bar{\nu}_e}(E_\nu)\sigma_{IBD}(E_\nu)\epsilon(E_\nu)dE_\nu$$



Inverse beta decay is the primary detection channel of neutrinos for the water tank

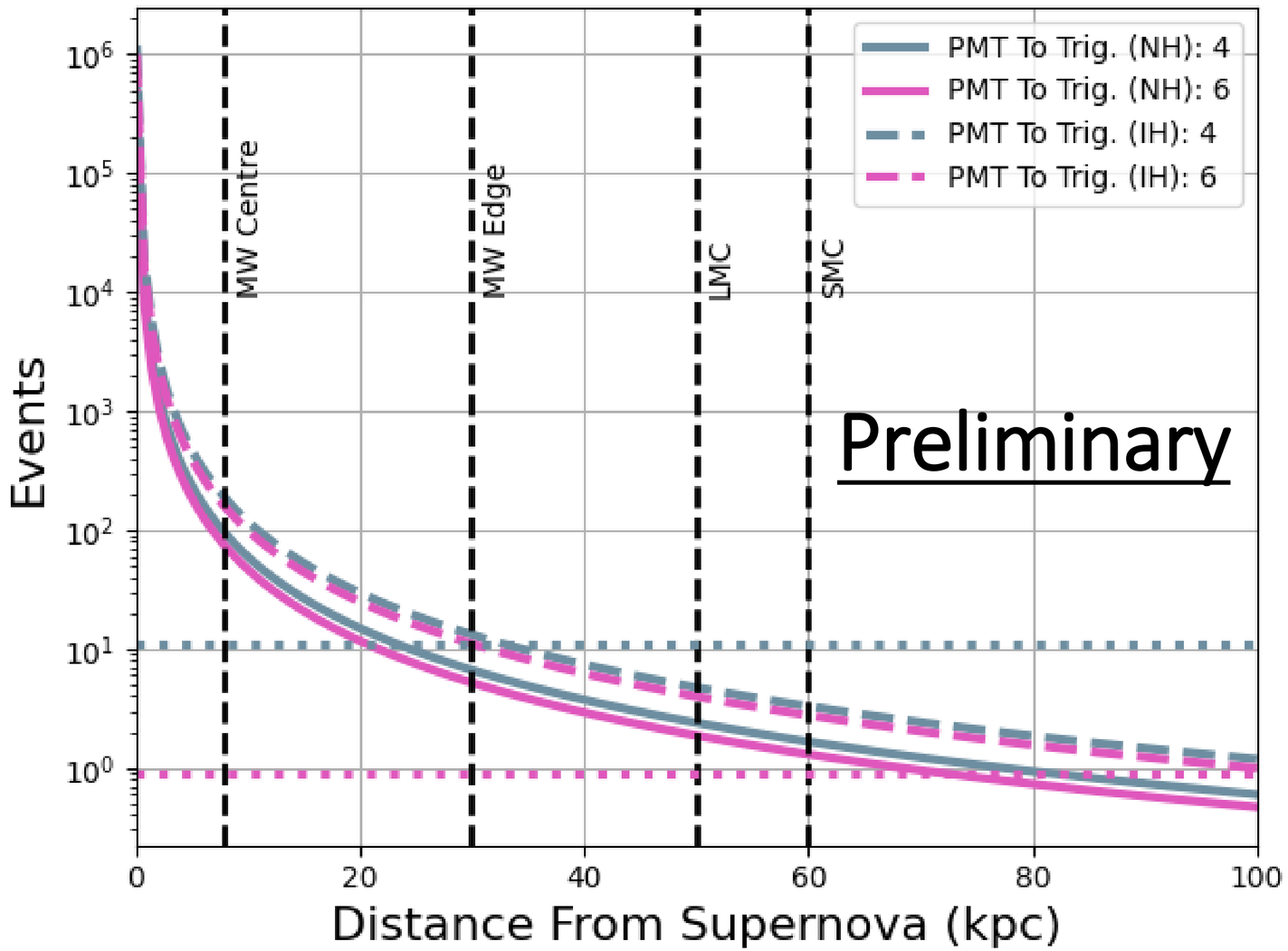
- Water tank is 230 tonnes with 28, 8’ PMTs

Efficiency of positron detection was studied using the ImpCRESST optical simulation code.

Efficiency is dependent on the configuration used (i.e. how many PMTs are required to trigger)

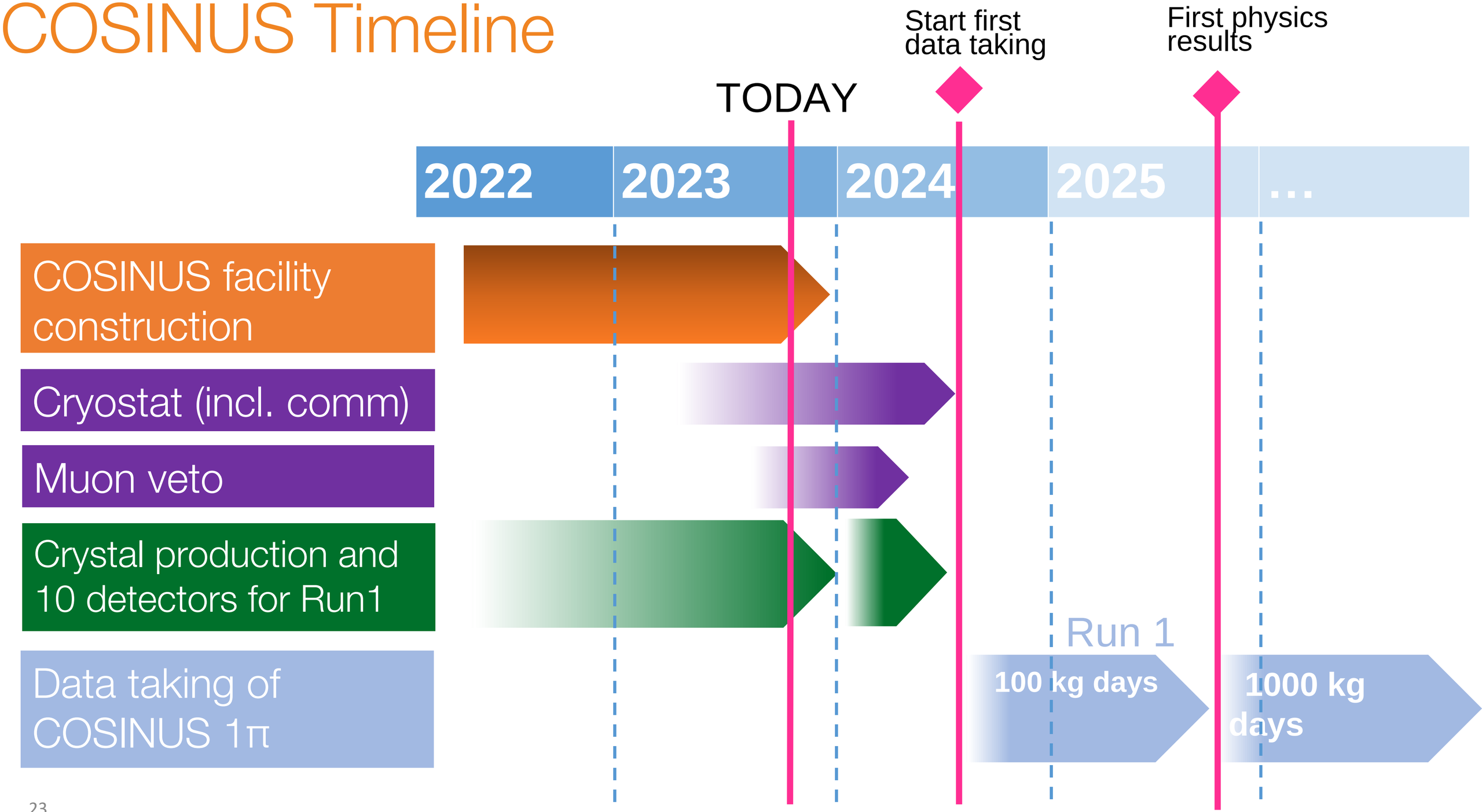
IBD cross-section used

IBD in COSINUS



- Number of detected events for a Supernova when considering different trigger conditions of the COSINUS water tank
- Approx. 50 events at a Supernova 10 kpc away (NH)
- Background events in the water tank for the average length of a Supernova are the dashed lines.
  - BKG Includes: Muon events, Dark counts and ambient background triggers
- Overlap with the background
  - 4 PMT Trig.(NH) = 25 kpc
  - 4 PMT Trig. (IH) = 32 kpc
  - 6 PMT Trig. (NH) = 72 kpc
  - 6 PMT Trig. (IH) = > 100 kpc

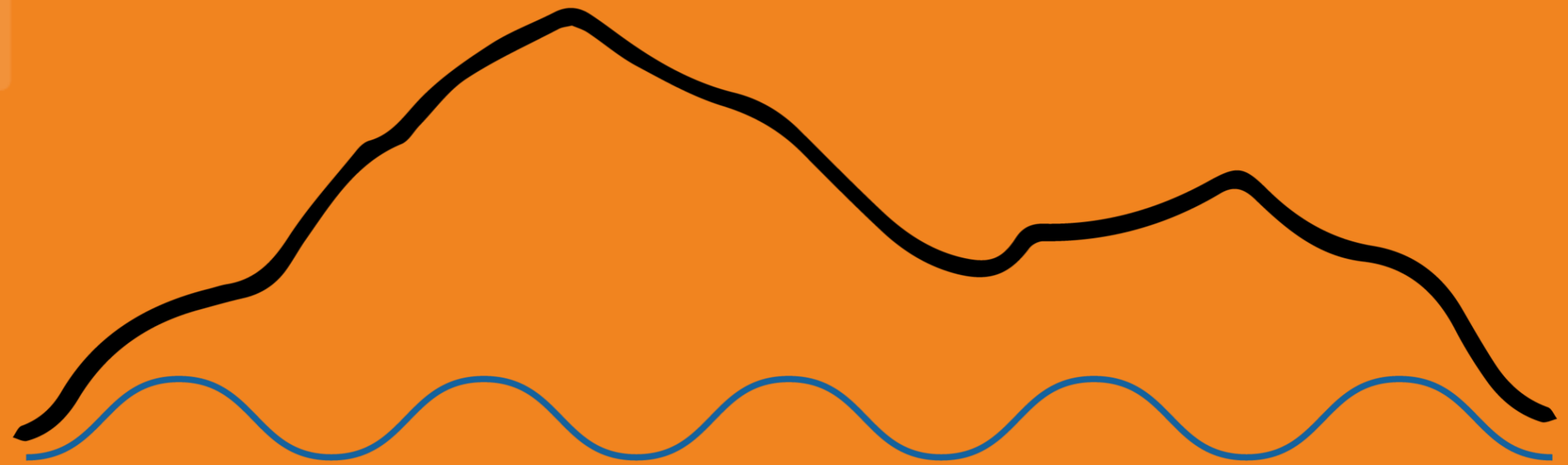
COSINUS Timeline



Conclusion/Future Work

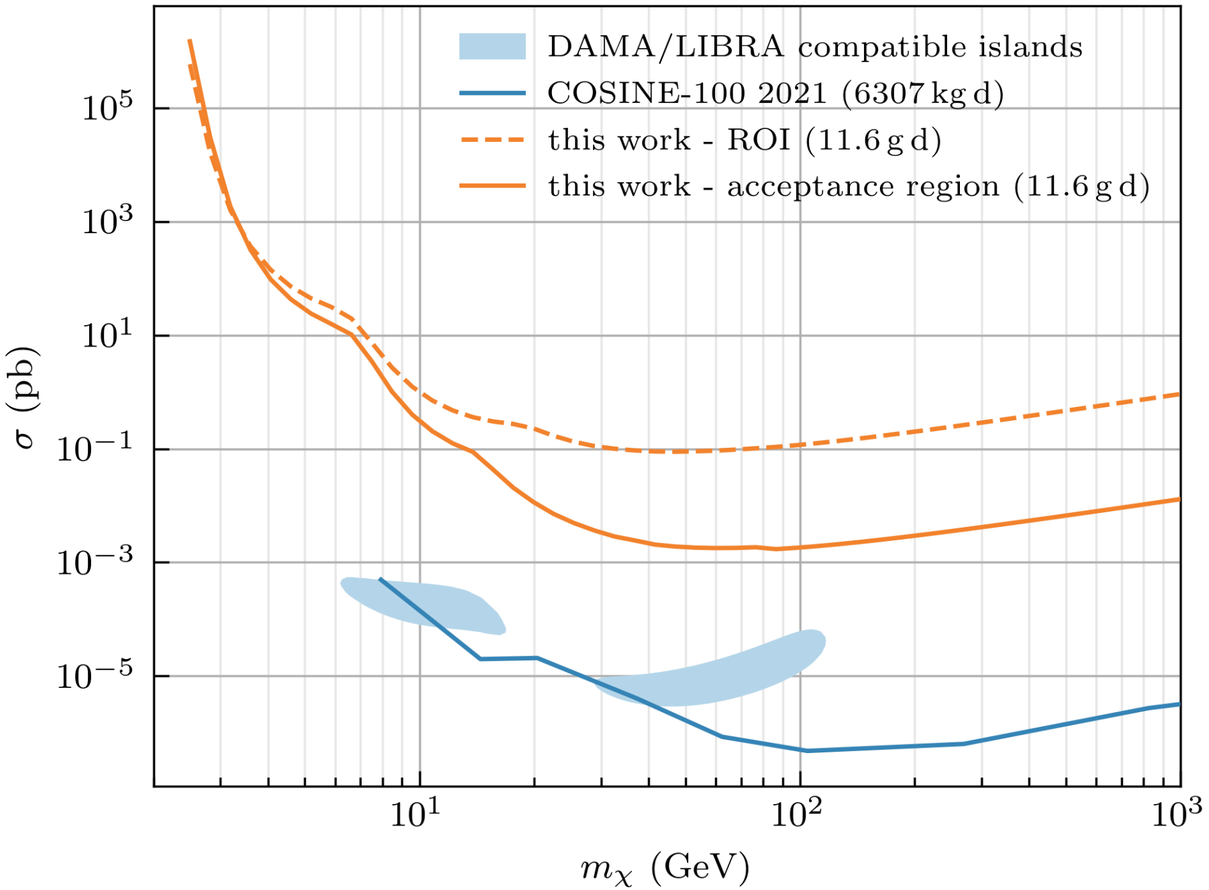
- COSINUS is a cryogenic NaI dark matter experiment whose goal is to verify the longstanding DAMA/LIBRA dark matter claim
- Multiple detections channels are available for Supernovas at varying distances
  - CEvNS: 0 - 2.5 kpc
  - IBD: 2.5 - 70 kpc
- Future Work
  - Include more detailed neutrino flux models (ex: time dependent models)
  - Determine detector significance (in terms of distance)
  - Investigate other channels: NC, CC etc..
  - Combine with other detectors at LNGS
- COSINUS will begin commissioning in 2023 and we look forward to great results!!
- Follow us on Twitter: @COSINUSdm
- Special thank you to Giulia Pagliaroli for guidance and help.

Thank You!



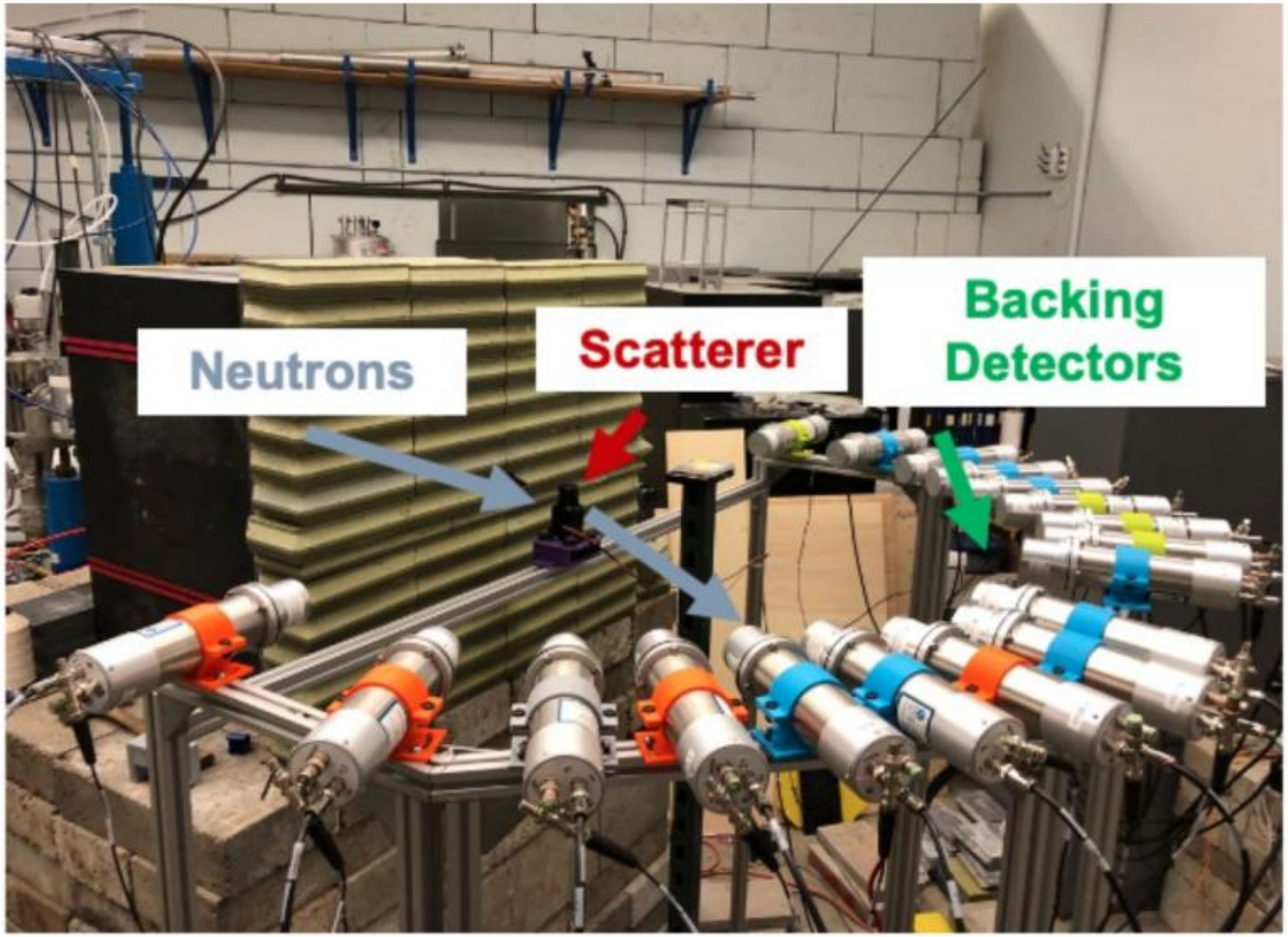
COSINUS

COSINUS: Current Status



- 1 module (3.6g) of NaI
- 11.6 g·d exposure
- 1 order of magnitude away from DAMA/LIBRA
- 3 order of magnitude lower then COSINE-100
  - They have 10^5 times larger exposure

Quenching Factor Measurement



- Performed at TUNL (Triangle Universities Nuclear Laboratory)
- 5 NaI crystals with different Tl doping (0.1-0.9%)
- Neutron beam scatters in the crystal and arrives at backing detector
- Based on the angle we know the actual energy of the recoil
- Can then compare to energy measured and determine the <u>QF!!</u>

Crystal Growth

- Crystals are grown in collaboration with SICCAS using Astrograde (MERCK) powder in a modified Bridgeman technique
- Keep isotope contamination down (K, Th, U)
- First sample hexagonal crystals have been made and will be tested soon