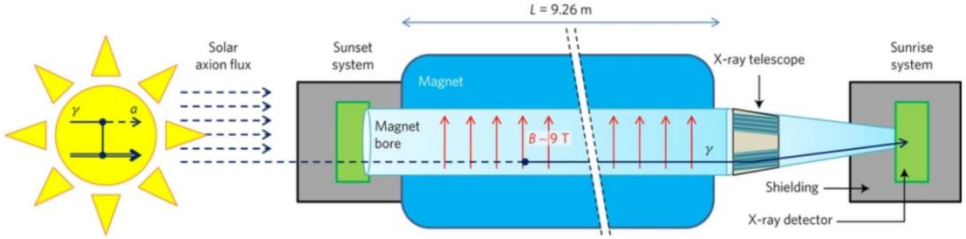
Astroparticle and Neutrino Physics

Christos Markou

Director,
Institute of Nuclear and Particle Physics,
NCSR ‘Demokritos’

The CAST (Cern Axion Solar Telescope) collaboration

2002 - 2018



13 Countries,
20 Institutions,
In Greece:

Aristotle University of Thessaloniki,
NCSR Demokritos,
University of Patras

CAST people in Greece

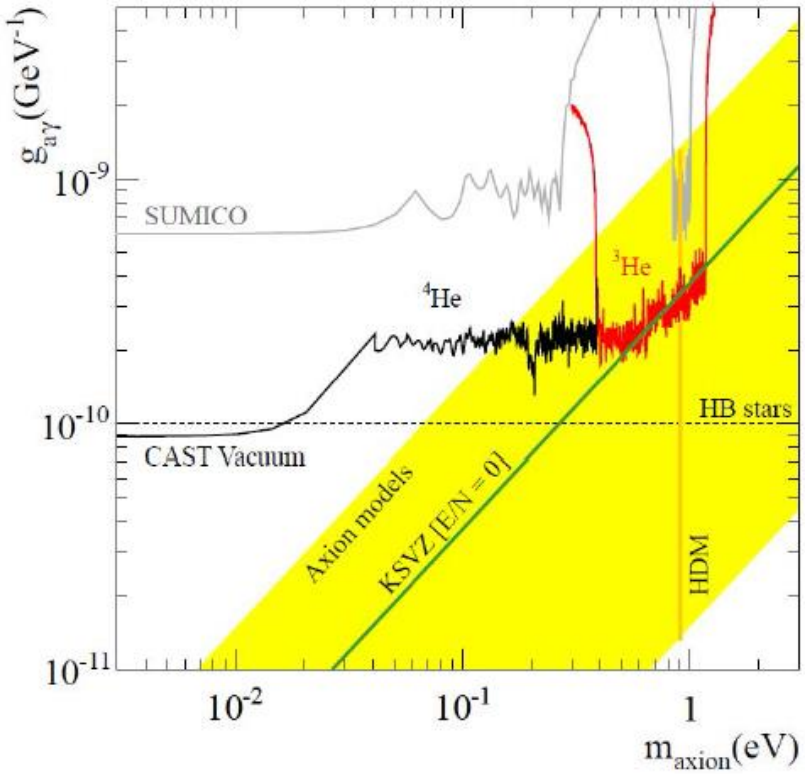
K. Zioutas, V. Anastassopoulos, A. Gardikiotis, A. Liolios, T. Papaevangelou, I Savvidis, T. Vafeiadis, A. Nikolaidis, G. Fanourakis, Th. Geralis, K. Kousouris, K. Zachariadou, E.N. Gazis, A. Liolios.

Funding

About at total 30k €, for the duration of the project from NCSR Demokritos internal funds. GSRT funded the Operating expenses (~30k € / year)

The CAST collaboration

CAST has given quite stringent limits for axion production
(m_a=10^{-11} to ~1 eV)



Greek Involvement in:

Concept – Design
Management
Micromegas detectors
DAQ systems
MC simulations
Novel Analysis Techniques
Setting up and Running the experiment


Co-funded by the
European Union
essνsb
ESS Neutrino Super Beam Plus
The European Spallation
Source as a Neutrino Facility
(in addition to its current mission)
ν

European Spallation Source Neutrino Super Beam

H2020 - INFRADEV

Feasibility Study for employing the uniquely powerful ESS linear accelerator to generate an intense neutrino beam for leptonic CP violation discovery and measurement.

15 Partner Institutions, NCSR Demokritos from Greece

The Conceptual Design Report of ESSnuSB is published in: Eur. Phys. J. Spec. Top. (2022) 231:3779–3955

It Includes:

- Modifications to ESS Linac
- Design of the accumulator, the target/horn system and the decay tunnel to create a powerful Neutrino Super Beam
- Design of a Near detector complex and a Far Water Cherenkov detector
- The choice of the underground mine to house the Far detector such as it sits at the Neutrino Oscillation second maximum, allowing the measurement of the CP violating phase with an unprecedented precision.
- The Physics reach of the proposed facility

Info on : http://essnusb.eu/

Publications:

- The ESSnuSB Design Study: Overview and Future Prospects, A. Alekou et al., Universe 9 (2023) 8, 347
- Updated physics performance of the ESSnuSB experiment, A. Alekou et al., Eur.Phys.J.C 81 (2021) 12, 1130
- The Conceptual Design Report of ESSnuSB, A. Alekou et al., Eur. Phys. J. Spec. Top. (2022) 231:3779–3955

European Spallation Source Neutrino Super Beam

Being followed by a Design Study funded by HORIZON-INFRADEV-2022: **ESSvSB+**

(2023-2025)

Study of the use of the ESS facility to accurately measure the neutrino cross-sections for ESSvSB leptonic CP violation measurements and to perform sterile neutrino searches and astroparticle physics.

20 Collaborating Institutes – 10 Countries (Including NCSR Demokritos and AUTH)

Aims :

- To Design two new facilities to precisely measure Neutrino Cross Sections
- To design a Near-Near detector to form a Short Base Line experiment with the ESSnuSB Near Detector
- To further improve the Physics of ESSnuSB and study the non beam Physics of the far detectors of ESSnuSB

ESSnuSB people in Greece

G. Fanourakis, Th. Geralis, G. Stavropoulos, A. Psallidas, E. Fasoula, S. Tzamarias, E. Kasimi, K. Kordas, A. Leisos, Ch. Petridou, D. Sampsonidis, A. Tsirigotis, O. Zormpa.

Funding: Horizon 2020 and Horizon Europe
ESSnuSB project (2018-2022): ~65k €
ESSnuSB+ project (2023-2026): ~ 115k €

Radio detection of CRs

ASTRONEU

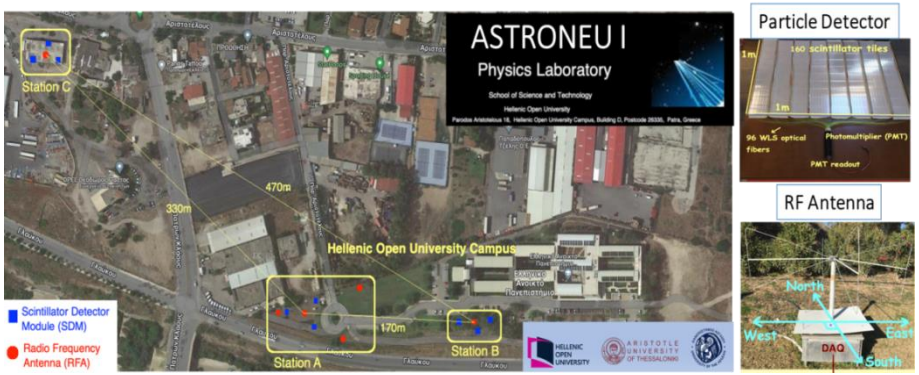
Astroneu I 1st Phase (2014-2016) and 2nd Phase (2017-2022)
Funded by NSRF 2007 – 2013 (540k €) and internal HOU funds (30k €)

Pilot array of autonomous stations to detect Extensive Air Showers in noisy urban environment

4 Staff members (A. Leisos, S. Tzamarias- in AUTH, I. Gialas -in U.Aegean and K. Papageorgiou -in U.Aegean)

2 Post-Docs (A. Tsirigotis and S. Nonis)

https://astroneu.eap.gr/index.php/publications/



Astroneu II (since 2023)
Funded via the Public Investment program with 300k €

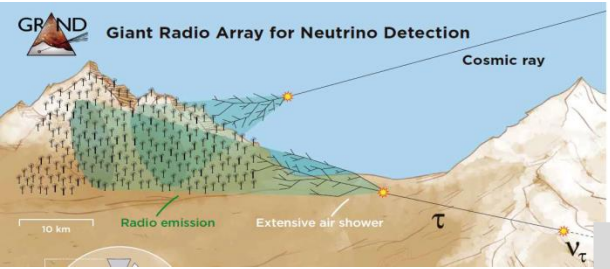
A denser array with 16 stations each one with 3 particle detectors, 1 RF antenna and a large muon counter.

A test bench for R&D developments related to the **GRAND experiment** (antenna characterization, software and analysis algorithms development, DAQ tests etc)

Radio detection of UHE neutrinos

GRAND

Proposal for a telescope for UHE neutrinos with excellent direction resolution, large field of view & sensitivity



9 Countries, 14 Institutions, Hellenic Open University (GR)

2 Staff members:
A. Leisos and K. Papageorgiou (UoAegean),

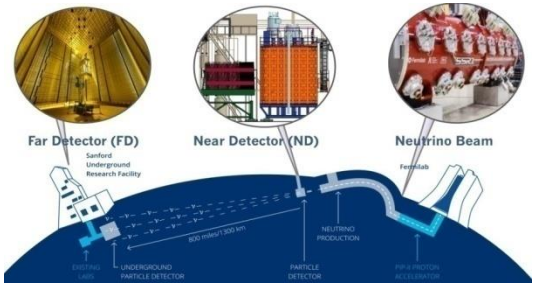
2 Post-docs: A. Tsirigotis, S. Nonis

1 Ph.D. Student: Vittakis

Horizon Antenna in the field

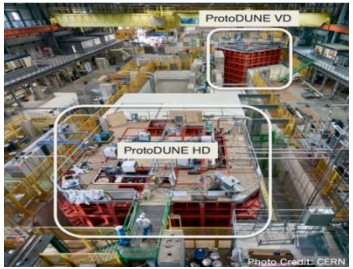
	GRANDProtos	GRAND10k	GRAND200k
	2023	2028	203X
Goals	➢ Autonomous radio detection of very inclined air-showers ➢ Cosmic rays $10^{16.5\text{-}18}$ eV •Galactic/extragalactic transition •muon problem •radio transients	➢ 1st GRAND sub-array ➢ discovery of EeV neutrinos for optimistic fluxes ➢ radio transients (FRBs!)	➢ sensitive all-sky detector ➢ 1st EeV neutrino detection and neutrino astronomy!
Setup	➢ GRANDProto300: 300 antennas over 200 km^2 ➢ GRAND@Auger: 10 antennas for cross-calibration ➢ GRAND@Nançay: 4 antennas for trigger testing	➢ 2 detectors of 5-10k antennas each in each hemisphere: GRAND-North (China) and GRAND-South (Argentina?)	➢ 200,000 antennas over 200,000 km^2 ➢ 20 sub-arrays of 10k antennas on different continents
Budget	2 M€ 100 antennas produced funded by China + ANR-DFG NUTRIG (France- Germany) + Radboud University	13 M€ 1500€/unit	➢ 300 M € in total, 500 €/unit ➢ to be divided between participating countries

Deep Underground Neutrino Experiment (DUNE)



HUMANS OF DUNE

- 1400+ collaborators
- 200+ institutions
- 37 countries (including CERN)



- **Impressive progress** in **several fronts** : **Far and Near site construction**, **Beamline**, **Far and Near detectors for Phase I.**
  - First **neutrino test beam data in 2024.**
  - Start of **DUNE science in 2028, with beam in early 2031**

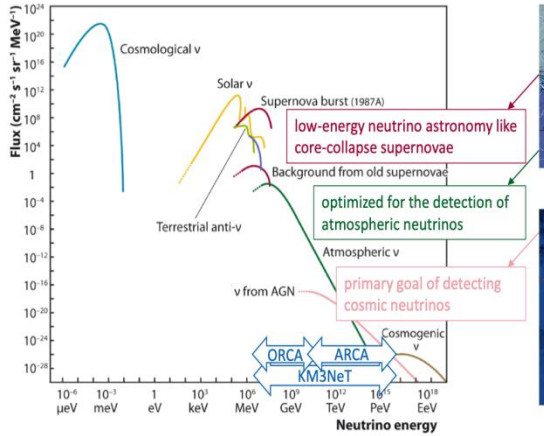
DUNE NKUA Team

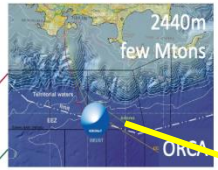
- **Prof. Niki Saoulidou :**
  - Chair of LBNC https://lbnc.fnal.gov/, charged by the Fermilab Director to oversee DUNE in a similar way LHCC oversees LHC experiments.
  - Member of the Scientific/Steering Board of Dr. Papoulias H.F.R.I Grant.
  - Founding member of the Fermilab DUSEL project (2006-2009) which evolved into DUNE.

- **Postdoctoral Researcher Dr. Dimitrios Papoulias :**
  - Awarded **competitive research grant** by the Hellenic Foundation for Research and Innovation (H.F.R.I) to perform **Beyond the Standard Model searches (BSM) with the DUNE Near and Far detectors.** (110 k €)

- **PhD Student Pantelis Melas, co-supervised by Dr. Papoulias and Prof. Saoulidou**
  - Member of the H.F.R.I research grant of Dr. Papoulias, **currently analyzing ProtoDUNE-HD data**
  - **Awarded Fermilab Neutrino Physics Center (FNC) Fellowship,** to participate and contribute to the **Prototype DUNE ND installation**, **commissioning** and **analysis with neutrino data** from the NUMI Beam.

KM3NeT

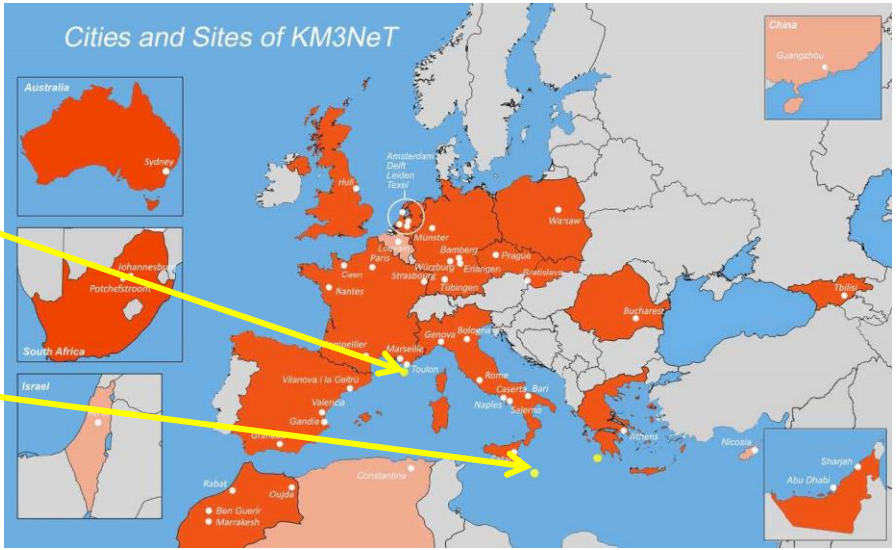




KM3NeT/ORCA
***O**scillation **R**esearch with **C**osmics **I**n the **A**byss*

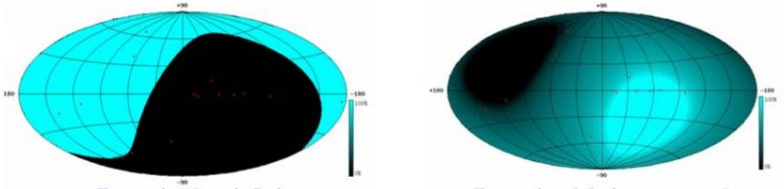
KM3NeT/ARCA
***A**stroparticle **R**esearch with **C**osmics **I**n the **A**byss*

Position in the Northern Hemisphere: optimal view of the Southern sky, including the Galactic Center



- Visibility of the Galactic region ➔ ~ 70 % for the Galactic Centre
- Optical properties of water ➔ Mapping the **Southern sky** with unprecedented angular resolution

The sky in Galactic coordinates



From the South Pole

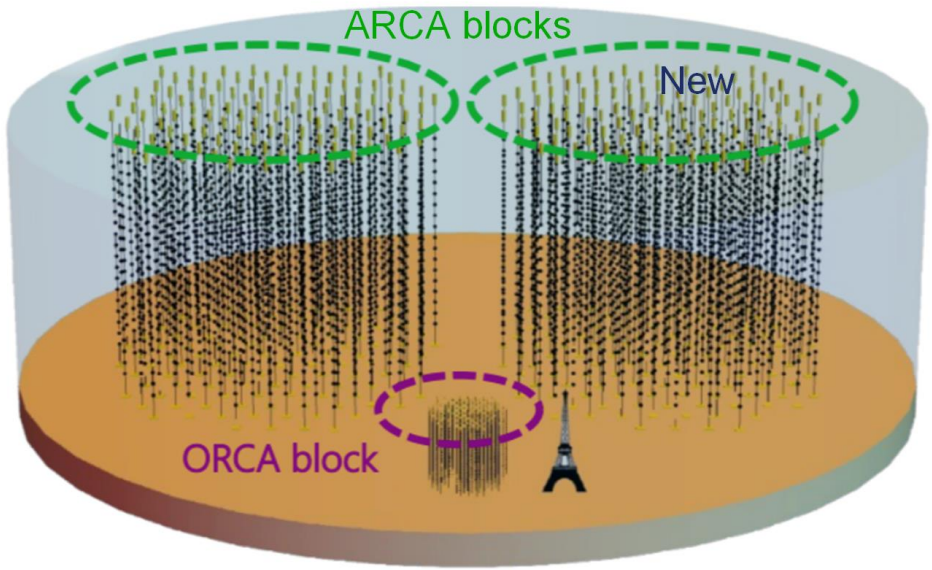
From the Mediterranean Sea

Visibility for up-going neutrinos

21 countries, 57 institutions, 273 physicists

From Gr, Institute of Nuclear and Particle Physics (INPP) NCSR "Demokritos"

KM3NeT



ARCA ✓ **Currently 28 DUs deployed**

ORCA ✓ **Currently 18 DUs deployed**

	ARCA	ORCA
Location	Sicily (IT)	Toulon (FR)
Depth	3450m	2450m
No. of DUs	2 x 115	115
DU horizontal spacing	90 m	20 m
DOM Vertical Spacing	36 m	9 m
DOMs/DU	18	18
PMTs/DOM	31	31
Instrumented water mass	1 Gton	7 Mton
DUs deployed	28	18

KM3NeT – INPP people

- **Ekaterini Tzamariudaki** - Director or Research, Head of the group, Co-chair of the Publication Committee, EDI committee, Management team (2016 – 2020)
- **Evangelia Drakopoulou** - Researcher, Open Science Committee
- **Christos Markou** - Director of INPP, Chair of the KM3NET Institution Board (2016-2020), Chair of the Conference Committee, Management Team (since 2021), Publication Committee, RRB.
- **G. Androulakis** (Deceased) – KM3NeT QA/QC manager (2016 – 2021)
- **L. Kalousis**, Post-Doctoral associate
- **C. Bagatelas, S. Tsagkli** – Scientific Personnel
- **A. Vougioukas, Y. Kiskiras** (part-time) – Technicians

- 3 Ph.D. candidates : **D. Stavropoulos, V. Tsourapis, G. Zarpapis**
- 2 M.Sc. Students
- Several undergraduate students (interns and diploma students)

- 3 Ph.D. theses completed in the previous years (E. Drakopoulou, K. Pikounis, A. Sinopoulou)

Funding

No support on investment from GRSI in the last 10 years for KM3NeT.

Competitive funding from :

- E.U. in H2020 (480k €) and Horizon Europe (225k €)
- NSRF 2007 – 2013 (540k €)
- NSRF 2015 – 2020 (250k €)
- V. Tsourapis is supported by a research grant by the Hellenic Foundation for Research and Innovation (H.F.R.I)

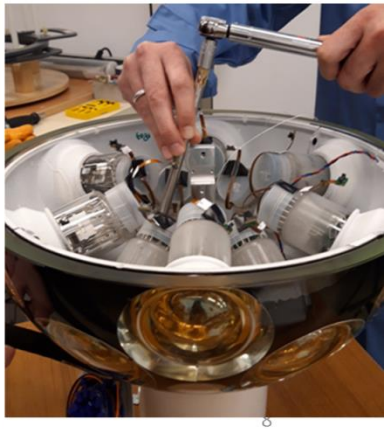
Digital Optical Modules production facility

- **Integrated DOMs:**

✓ DOM production rate: 1.5 - 2 DOMs/week.

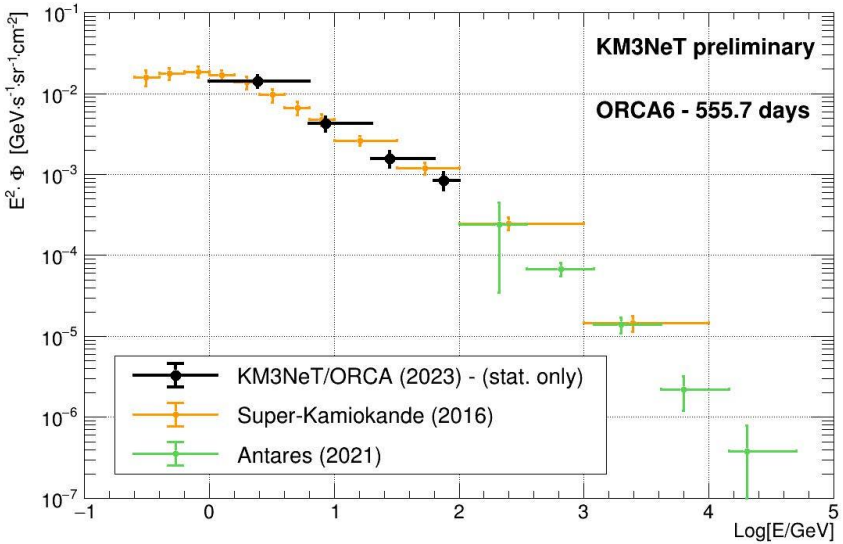
✓ 146 DOMs produced at INPP:

- DOM penetrator high-pressure testing



KM3NeT – a glimpse on recent results

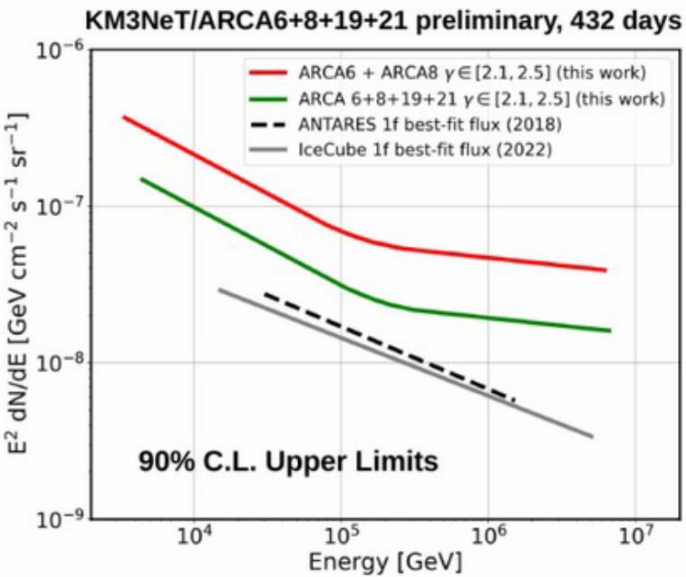
Measurement of atmospheric ν_μ flux with ORCA6



Work by D. Stavropoulos

PoS ICRC2023 (2023) 1093

All sky diffuse cosmic neutrino flux with ARCA



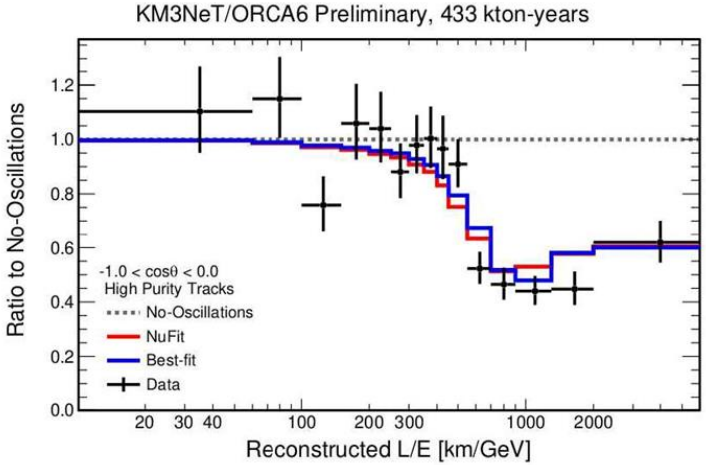
Work by V. Tsourapis

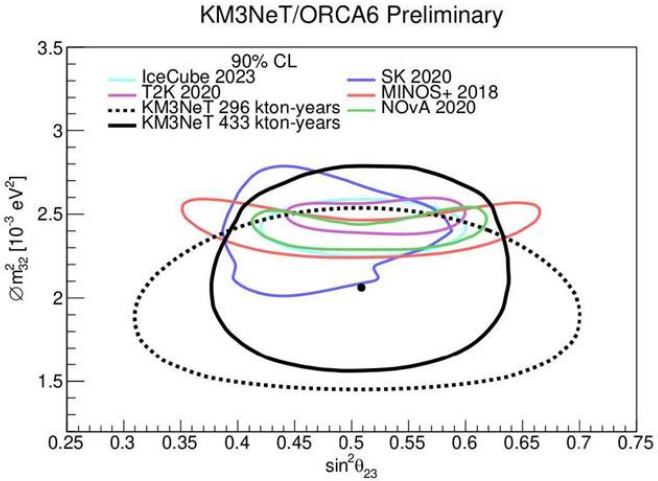
PoS ICRC2023 (2023) 1195

KM3NeT – a glimpse on recent results

The first KM3NeT/ORCA oscillation results with only 6 DUs!

Clear effect of oscillations observed





- Neutrino oscillations preferred with 5.9σ CL over the hypothesis of no oscillations
- Normal mass ordering preferred

PoS ICRC2023 (2023) 996

Best fit

$$\Delta m^2_{31} = 2.14^{+0.36}_{-0.25} \cdot 10^{-3}\text{eV}^2$$

$$\sin^2\theta_{23} = 0.51^{+0.06}_{-0.07}$$

$$-2\log\left(\frac{L_{NO}}{L_{IO}}\right) = 0.9$$

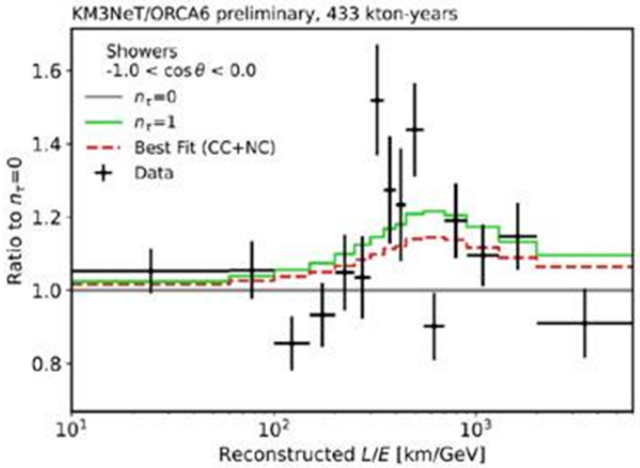
KM3NeT – a glimpse on recent results

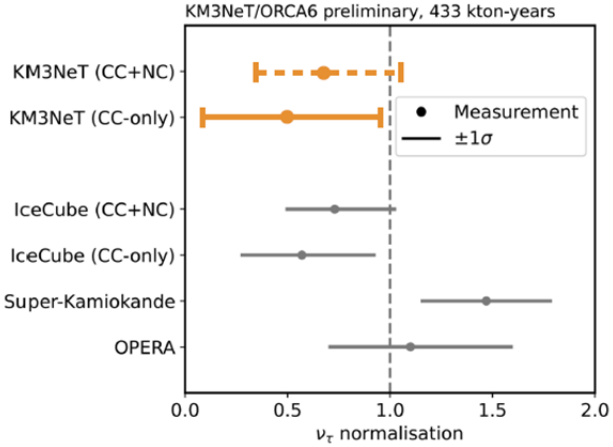
A first measurement of the $\mathbf{n_{\nu_\tau}}$ has been performed in the KM3NeT/ORCA 6 geometry

With only 5% of the final fiducial volume, 169 events in excess observed

→ Already competitive with other experiments

Results compatible with $\mathbf{n_{\nu_\tau} = 1}$

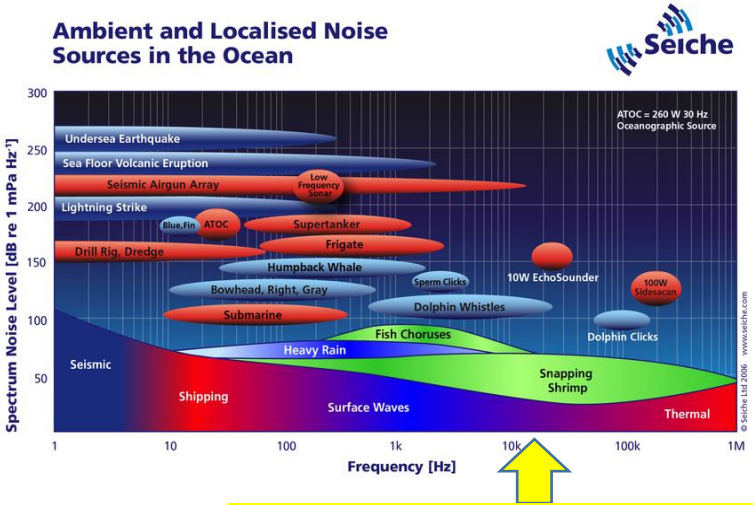




PoS ICRC2023 (2023) 1107

KM3NeT – neutrino acoustic detection

➢ A most promising detection of ultra high energy neutrinos (UHE)



expected signal from neutrino interactions

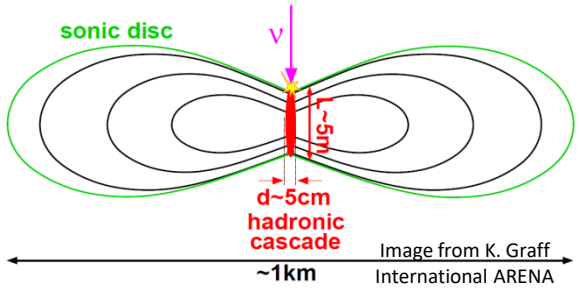
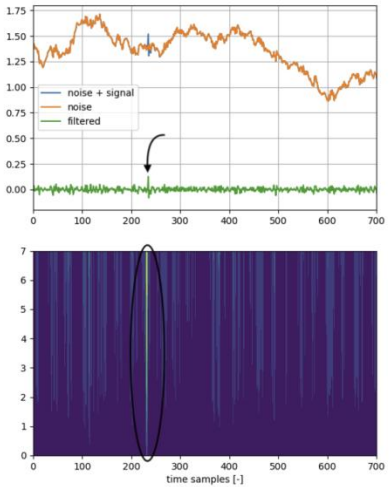
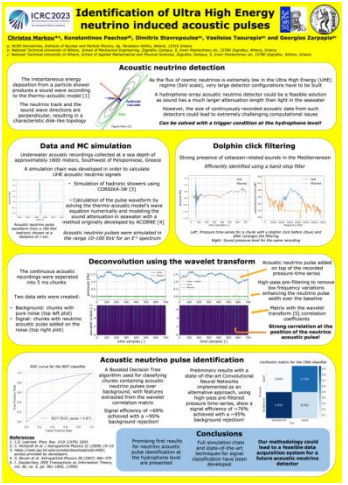


Image from K. Graff
International ARENA
Workshop 2005





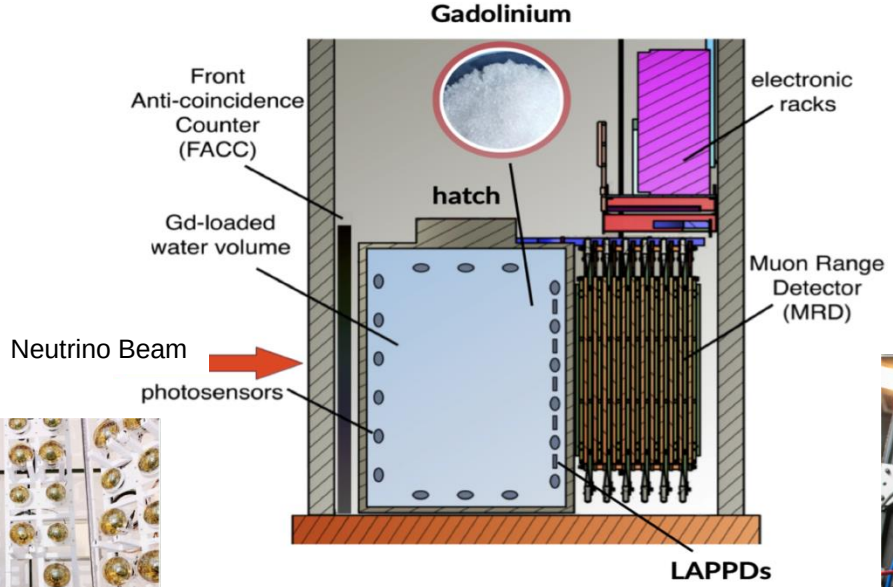
- Machine and Deep learning algorithms were used to classify acoustic recordings containing acoustic neutrino pulses over background.
- First results are promising. Our methodology could lead to a feasible data acquisition system for a future acoustic neutrino detector.

ANNIE

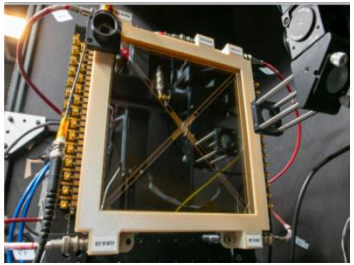
Accelerator **N**eutrino **N**eutron **I**nteraction **E**xperiment (**ANNIE**):

a 26-ton Gd-doped water Cherenkov detector installed in the Booster Neutrino Beam at Fermilab

INPP, NCSR Demokritos joined ANNIE in September 2021.



ANNIE is the first experiment using the fast-timing (~60 psec time resolution) **Large Area Picosecond Photo Detectors** (**LAPPDs**) for event reconstruction.



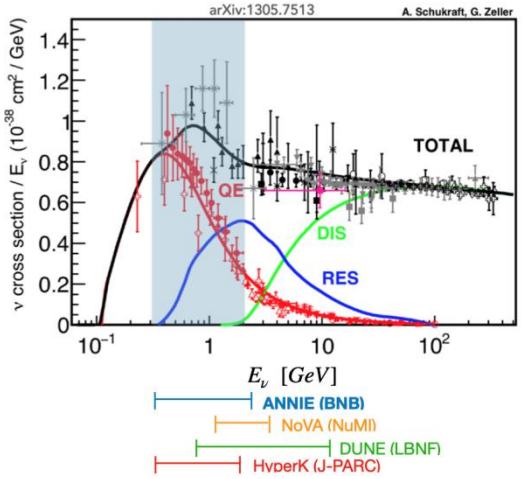
ANNIE is seeing neutrinos with the first LAPPD deployed in the water tank.

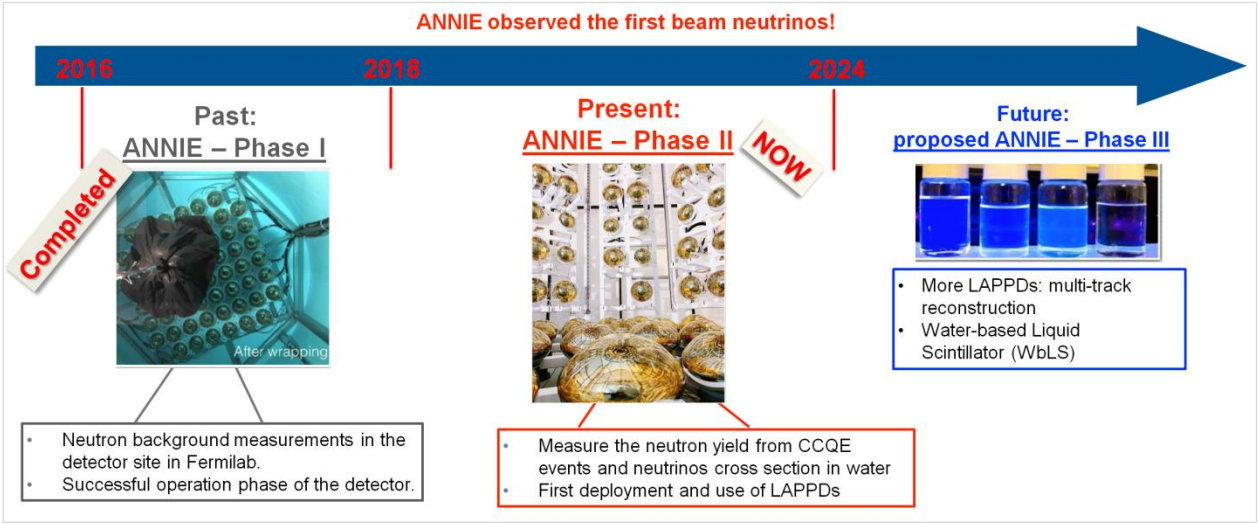
ANNIE

Two main goals:

- Better understanding of neutrino-nucleus interactions.
  - Measure the **neutron yield** from Charged Current neutrino-nucleus interactions in water to reduce the systematic uncertainties in neutrino oscillation experiments (e.g. Hyper-Kamiokande(HK) in Japan)
  - measurement of cross-sections, ν_μ CC and potentially NC

- R&D platform to test new neutrino detection technologies and techniques.
  - Demonstrate the use of fast-timing (~60 psec time resolution) **Large Area Picosecond PhotoDetectors** (**LAPPDs**) for event reconstruction





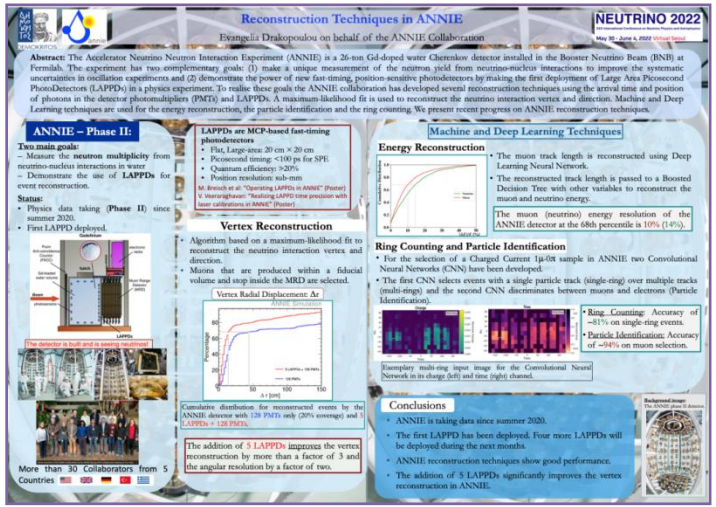
ANNIE people in INPP

- E. Drakopoulou, P. I.

- I. Vitsikanos, G. Stravropoulou, E. Sakkou (Intern students)
  Removing background noise from data using Deep Learning methods

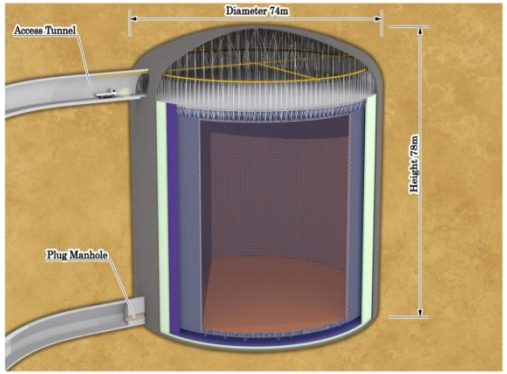
- C. Karagiannis (Intern student, Associate researcher)
  Apply a machine learning-based method to reconstruct the muon energy in ANNIE.

Funded up to now, by internal NCSR D funds



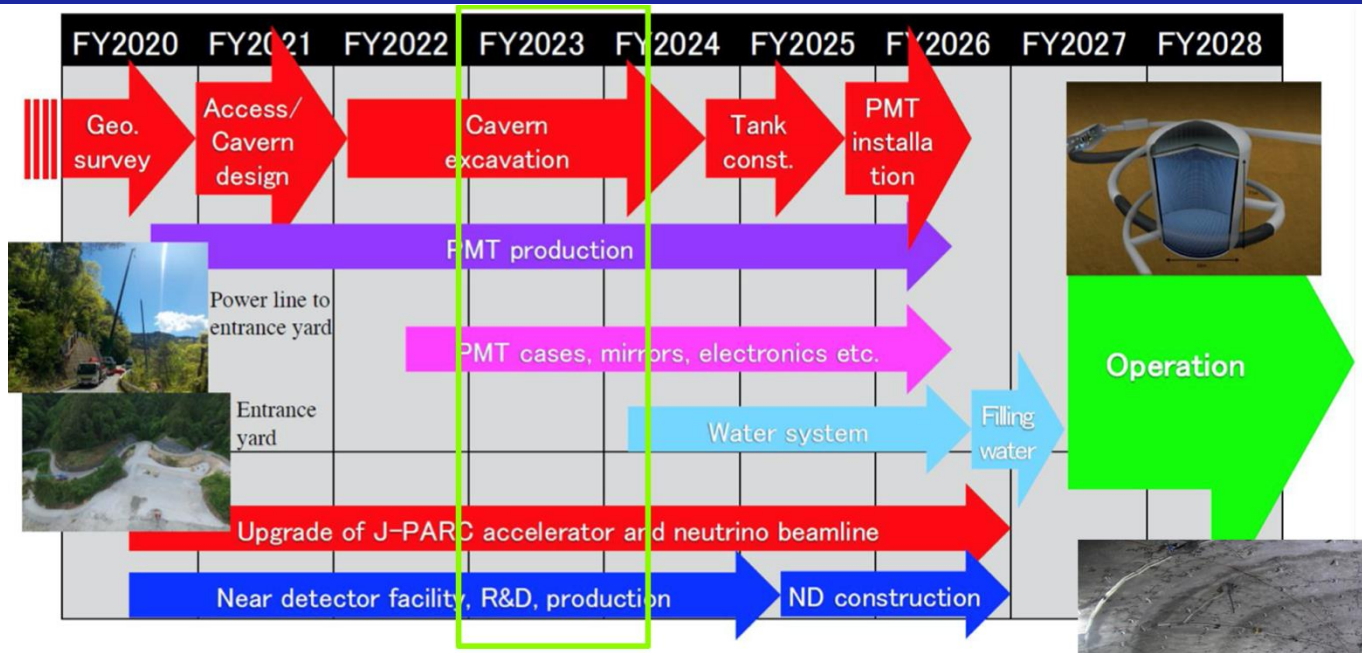
HYPER-K

Hyper Kamiokande (Hyper-K) detector



Upgrade of J-PARC neutrino beam to 1.3 MW beam power

HYPER-K



Oct. 2023:
Hyper-K dome excavation completed
69mdiameter, 21m height

Now:
the excavation of the barrel section is ongoing.

HYPER-K

INPP/Demokritos joined HYPER-K in 2023

Testing and QA/QC on the Far Detector mPMT detector.

Hyper-K database development and maintenance

Funded for the moment by internal NCSR D funds

HYPER-K people in INPP

C.Markou,
E. Drakopoulou,
E. Tzamariudaki,
L. Kalousis (post-Doc)

Summary - Outlook

- Several diverse activities and experiments in Astroparticle and Neutrino Physics
- Participation in high visibility, large, International Collaborations
- Significant contributions to hardware, operations and physics analyses
- Attractive to bright and motivated young physicists

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❖ The evident statement "Lack of funding and limited HR resources are a significant handicap" refers to the effects of more fundamental problems in the Research

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❖ The evident statement "Lack of funding and limited HR resources are a significant handicap" refers to the effects of more fundamental problems in the Research

❖Research and Education overseen by two different government ministries!

❖ Lack of specific, short, medium or long term scientific plan in the country, coupled with budgets which are respected and followed.

❖ No interlocutor in the overseeing agency, able to assess and respond to the needs of the research community.

❖No methodology/rules/procedures to participate to any international research structure (ERIC, RI, etc) with the support/backup/commitment of the Greek State.

Thank you for your attention!

Additional material

The CAST collaboration

13 Countries,
20 Institutions

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Politecnico di Milano, Italy
Universidade de Lisboa Lisboa, Portugal
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Tel Aviv University, Ramat Aviv, Tel Aviv Israel
Max-Planck-Institut für Physik, Werner-Heisenberg-Institut 80805 Muenchen, Germany
University of Patras

The CAST collaboration

CAST publications

1. Improved Search for Solar Chameleons with a GridPix Detector at CAST, V. Anastassopoulos et al. *JCAP* 01 (2019) 032
2. New CAST Limit on the Axion-Photon Interaction, V. Anastassopoulos et al. Nature Phys. 13 (2017) 584-590
3. Search for chameleons with CAST, V. Anastassopoulos et al., Phys.Lett.B 749 (2015) 172-180
4. New solar axion search using the CERN Axion Solar Telescope with ^{4}He filling, M. Arik et al., Phys.Rev.D 92 (2015) 2, 021101
5. Search for Solar Axions by the CERN Axion Solar Telescope with ^{3}He Buffer Gas: Closing the Hot Dark Matter Gap, M. Aric et al., Phys.Rev.Lett. 112 (2014) 9, 091302
6. CAST search for sub-eV mass solar axions with ^{3}He buffer gas, S. Aune et al., Phys.Rev.Lett. 107 (2011) 261302
7. Search for solar axion emission from ^{7}Li and D(p,γ)^{3}He nuclear decays with the CAST γ-ray calorimeter, S. Andriamonje et al., JCAP 03 (2010) 032
8. Search for 14.4-keV solar axions emitted in the M1-transition of Fe-57 nuclei with CAST, S. Andriamonje et al., JCAP 12 (2009) 002
9. Probing eV-scale axions with CAST, E. Arik et al., JCAP 02 (2009) 008
10. An Improved limit on the axion-photon coupling from the CAST experiment, S. Andriamonje et al., JCAP 04 (2007) 010
11. Prospects for the CERN Axion Solar Telescope Sensitivity to 14.4-keV Axions, K. Jakovcic et al., Nucl.Instrum.Meth.A 580 (2007) 37-39
12. First results from the CERN Axion Solar Telescope (CAST), K. Zioutas et al., Phys.Rev.Lett. 94 (2005) 121301

LBNF/DUNE-US: Status and recent achievements

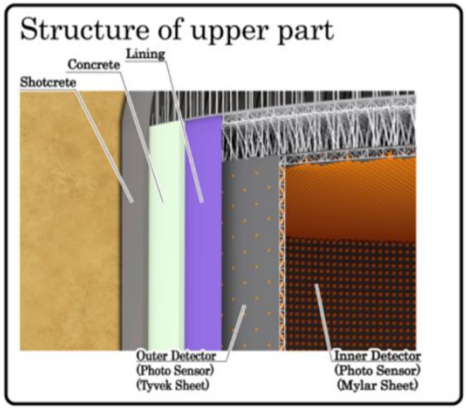
From Lia Merminga, RRB, March 30th 2023

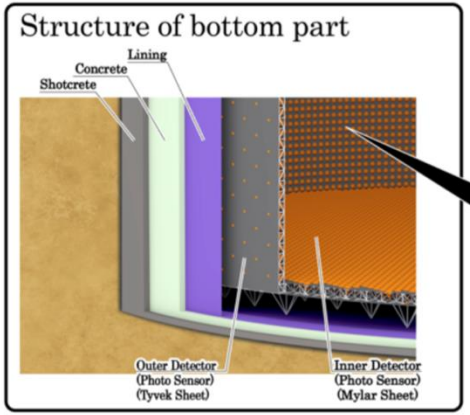
- **Far site excavation ~60% complete** proceeding **on time** and **on budget**
- DOE approved the **CD-1R "Reaffirmation" milestone**, reaffirming **strong commitment** to the **project**
- **DOE approved the CD-2/3** milestone for the buildings and site infrastructure (BSI) subproject in SD
- **Detector installation begins 2024**; **fabrication** by **CERN and partners is underway**
- **Science starts in 2028, "beam on date" in early 2031**
- **First draft of DUNE Host Lab Plan completed**, final in June
- **Next major milestone: FDC CD-2/3 approval**

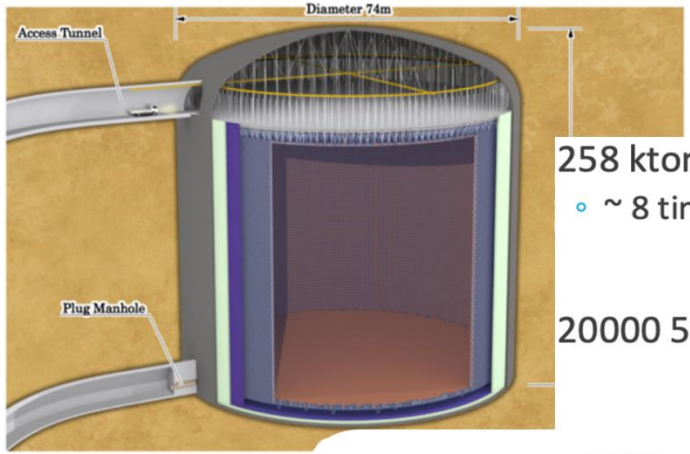


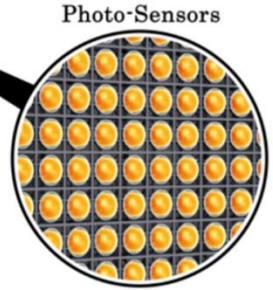

Source: N. Saoulidou

HYPER-K









258 kton Water Cherenkov detector
- ~ 8 times larger than Super-Kamiokande

20000 50 cm PMTs

~1000 mPMTs

7200 OD units
- 8 cm PMT
- Wavelength shifting plate