



KM3NeT: UHE neutrinos & more

Piotr Kalaczyński

Work supported by:

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**European
Funds**
Smart Growth



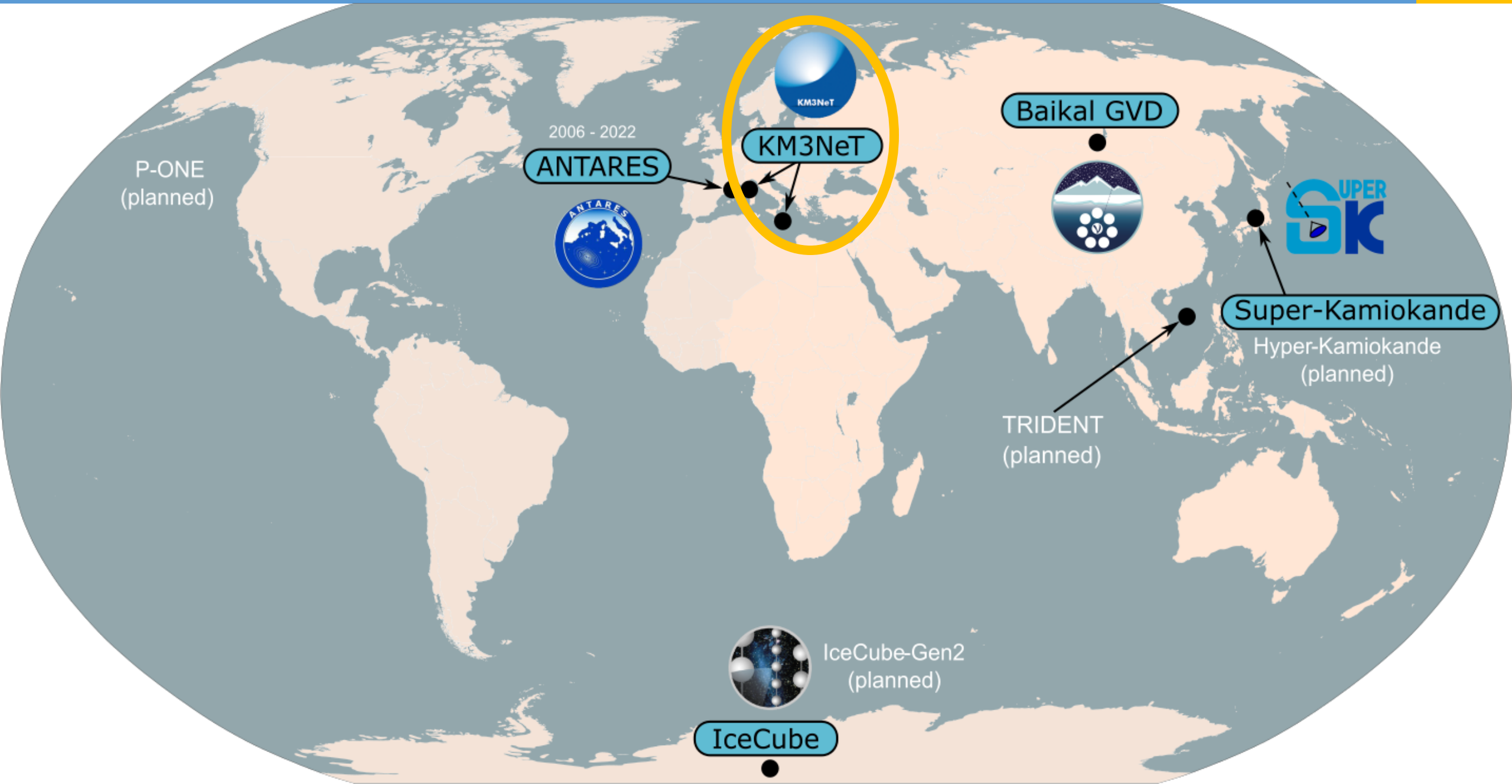
**Republic
of Poland**



**Foundation for
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European Union
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- CNRS Nucléaire et Particules
- Astroparticle and Cosmology Laboratory, Université Paris Cité, CNRS
- Centre for Particle Physics of Marseille, Aix-Marseille Université, CNRS
- Laboratoire d'Astrophysique de Marseille
- Mediterranean Institute of Oceanography, CNRS Terre et Univers, Marseille
- Université de Toulon
- Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, CNRS
- Subatech, IMT Atlantique, Nantes Université
- Laboratoire Univers et Particules de Montpellier
- Laboratoire de Physique Corpusculaire de Caen, Université de Caen, CNRS

United Kingdom

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- Université Libre de Bruxelles

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- Universiteit van Amsterdam
- Universiteit Leiden
- NIOZ, Texel
- TNO, Technical Sciences, Delft

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- Universität Würzburg
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- Universität Münster

Italy

- INFN Laboratori Nazionali del Sud, Sezione di Catania
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- INFN Sezione di Roma, Sapienza Università di Roma
- INFN Sezione di Bari, Politecnico di Bari
- INFN Sezione di Bologna, Università di Bologna
- INFN Sezione di Padova, Università di Padova
- Università degli Studi di Salerno, INFN Gruppo Collegato di Salerno

Slovakia

- Univerzita Komenského v Bratislave
- Slovenská akadémia vied, Košice

Czech Republic

- Czech Technical University in Prague, Institute of Experimental and Applied Physics

Poland

- AGH University of Krakow
- NCBJ - National Centre for Nuclear Research, Warsaw
- Nicolaus Copernicus Astronomical Center, Particle Astrophysics Science and Technology Centre, Warsaw

Romania

- Institute of Space Science - INFLPR Subsidiary, Magurele

Greece

- Institute of Nuclear and Particle Physics, NCSR Demokritos, Athens
- National and Kapodistrian University of Athens

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- University of Cyprus, Nicosia

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- Consejo Superior de Investigaciones Científicas (CSIC)
- Instituto de Física Corpuscular, Universitat de València, CSIC
- Universitat Politècnica de València, IGIC, Gandia, València
- Universidad de Granada
- Centro Oceanográfico de Murcia (IEO-CSIC)
- Laboratori d'Aplicacions Bioacústiques, Universitat Politècnica de Catalunya, Vilanova i la Geltrú
- Instituto de Ciencias del Mar, CSIC, Barcelona

United States of America

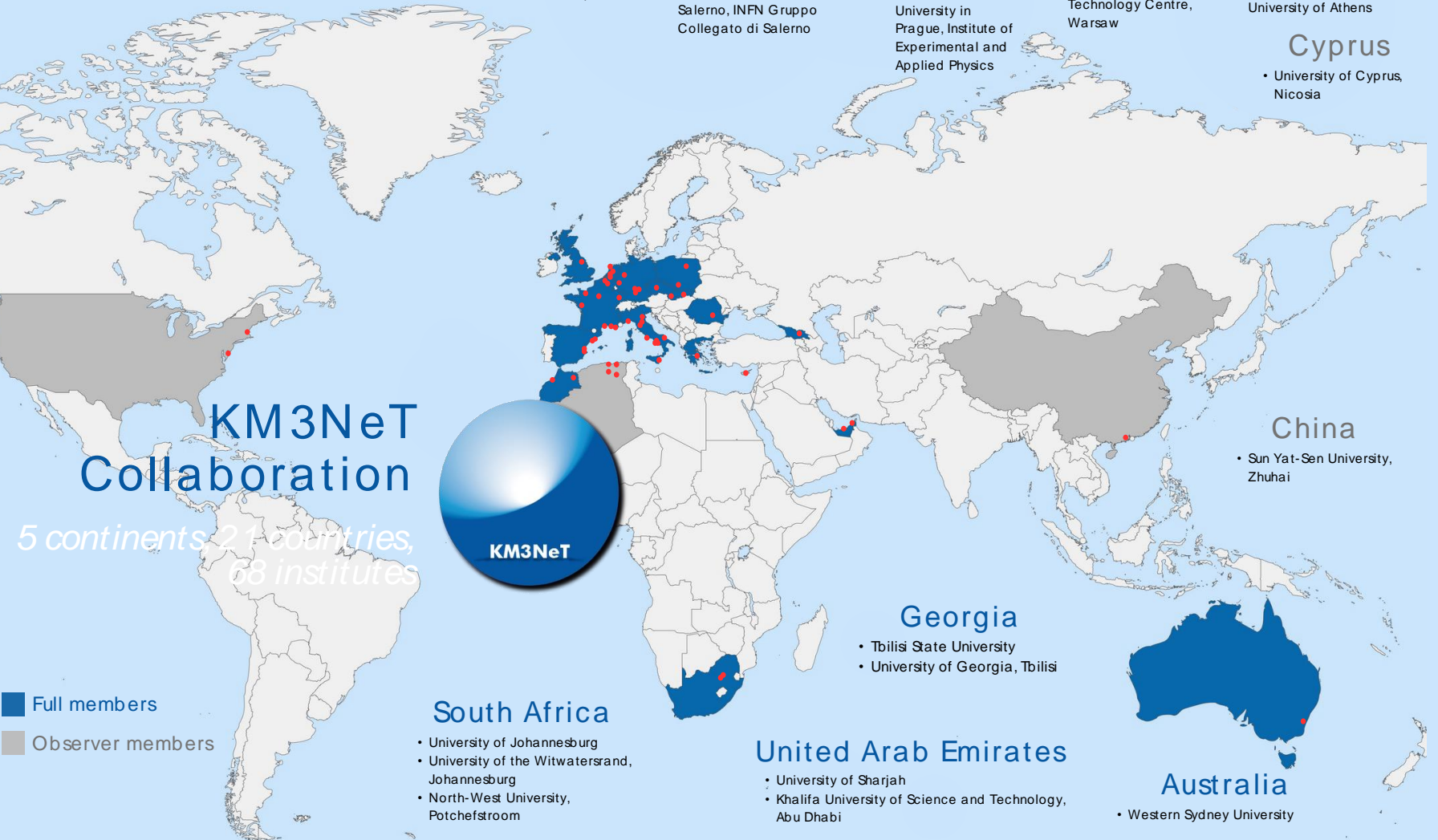
- Harvard University, Cambridge
- Drexel University, Philadelphia

Morocco

- University Mohammed V, Rabat
- National Center of Energy of Sciences and Nuclear Techniques, Rabat
- University Mohammed Ier, Oujda
- Cadi Ayyad University, Marrakesh
- Mohammed VI Polytechnic University, Ben Guerir

Algeria

- Center of Research in Astronomy, Astrophysics, and Geophysics, Bouzaréah
- Université Badji Mokhtar, Annaba
- University of Constantine
- Mohamed Boudiaf University, M'sila



KM3NeT Collaboration
5 continents, 21 countries, 68 institutes

■ Full members
■ Observer members

South Africa

- University of Johannesburg
- University of the Witwatersrand, Johannesburg
- North-West University, Potchefstroom

Georgia

- Tbilisi State University
- University of Georgia, Tbilisi

United Arab Emirates

- University of Sharjah
- Khalifa University of Science and Technology, Abu Dhabi

Australia

- Western Sydney University



Nicolaus Copernicus
Astronomical Center
Polish Academy of Sciences



AGH UNIVERSITY
OF KRAKOW

AGH

ASTROCENT

Particle Astrophysics Science
and Technology Centre
International Research Agenda

- ❖ me 😊
- ❖ Mariusz Suchenek

WFIS



AGH

WFIS:

- ❖ Artur Ukleja
- ❖ Tomasz Szumlak
- ❖ Agnieszka Obłąkowska-Mucha
- ❖ Kalyani Mehta (PhD student)
- ❖ Amine Meskar (PhD student)
- ❖ Wiktoria Szewczyk (MSc student)



CEAI

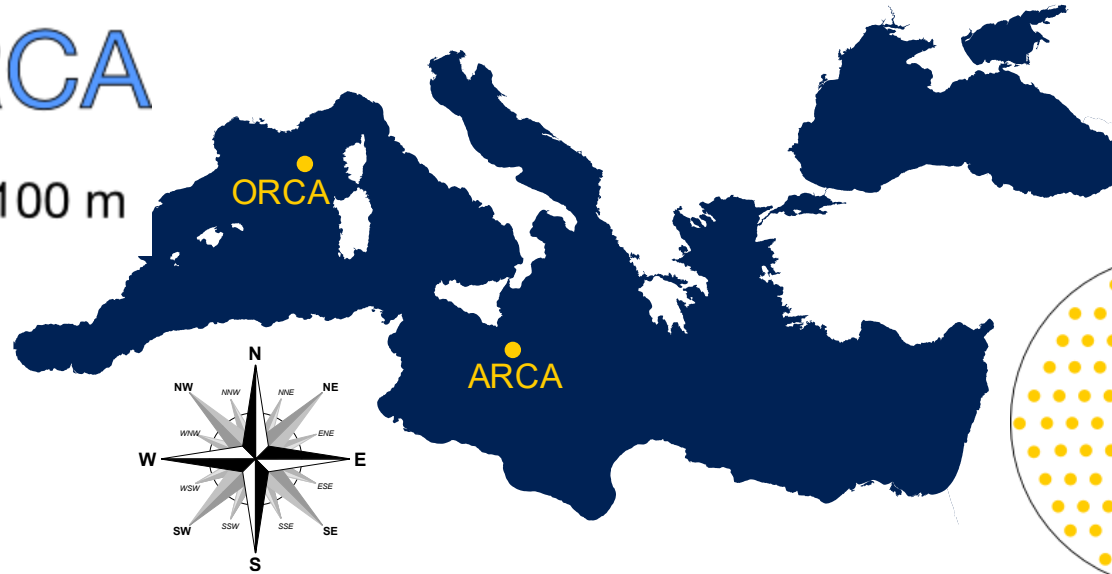
Center of Excellence in Artificial Intelligence

- ❖ me 😊

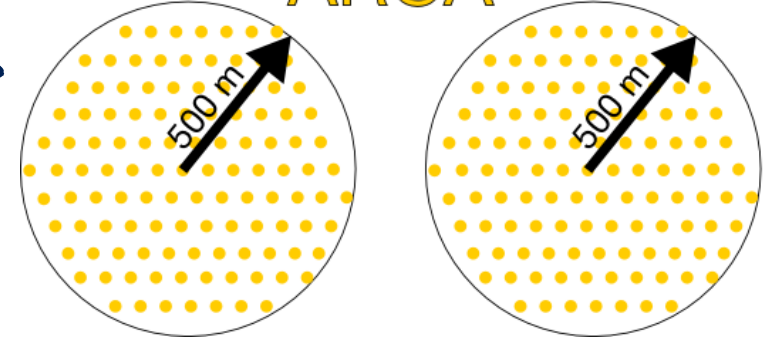
Grants:

Under evaluation: OPUS (NCN)
In preparation: MNiSW grant

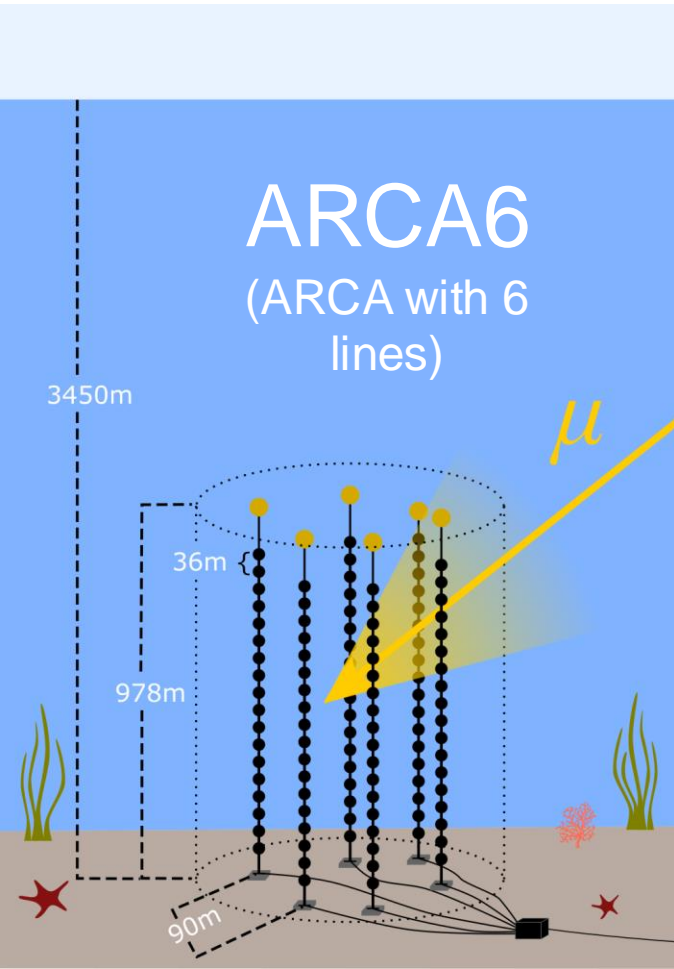
ORCA



ARCA



ARCA6 (ARCA with 6 lines)



Detector	ARCA	ORCA
Depth	3.5 km	2.45 km
Volume	1 km ³ (1Gton)	0.007 km ³ (7Mton)
# lines	28 / 2x115	24 / 115
Topic	Astroparticle RCA*	Oscillation RCA*
Goal	ν_{astro}	m_ν hierarchy

*RCA : Research with Cosmics in the Abyss

DOM:
71 unique components



[DOM production: \(@Nikhef\)](#)



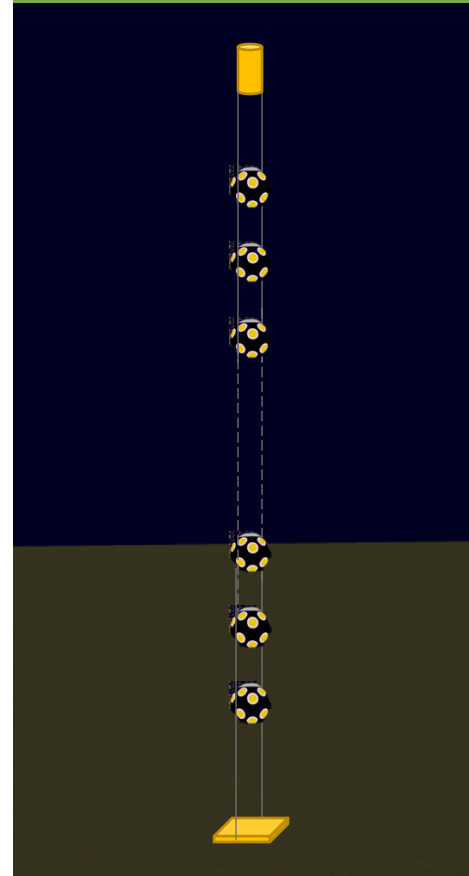
1 DOM:
31 PMTs



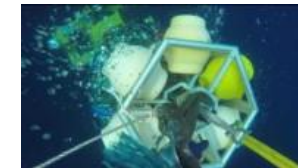
[Preparation for deployment:](#)



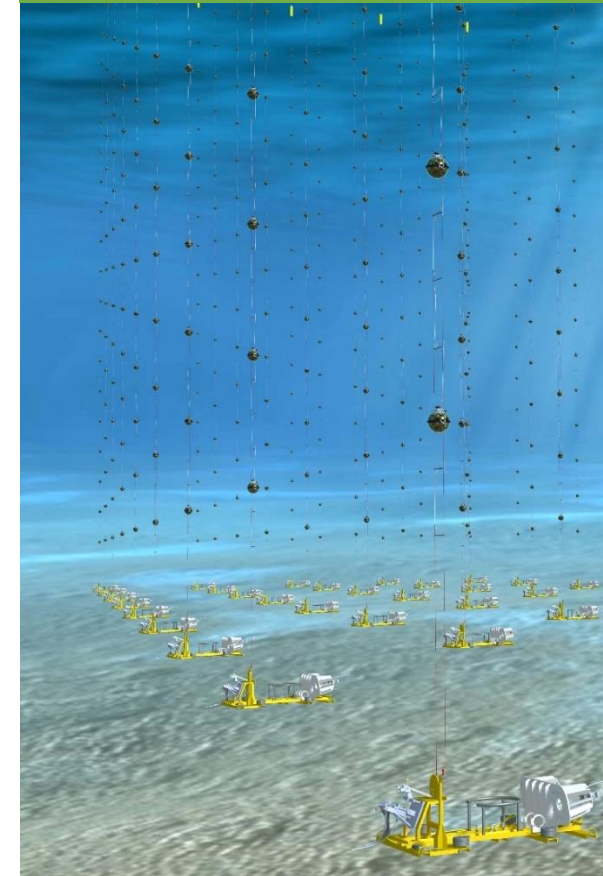
1 string (DU):
18 DOMs



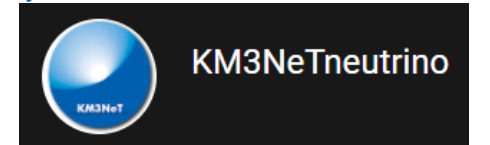
[String deployment:](#)



1 building block:
115 DUs



More at:
youtube.com/KM3NeTneutrino



KM3NeTneutrino



AG 887 LH

AG 887 LH

FUGRO

FUGRO

FUGRO

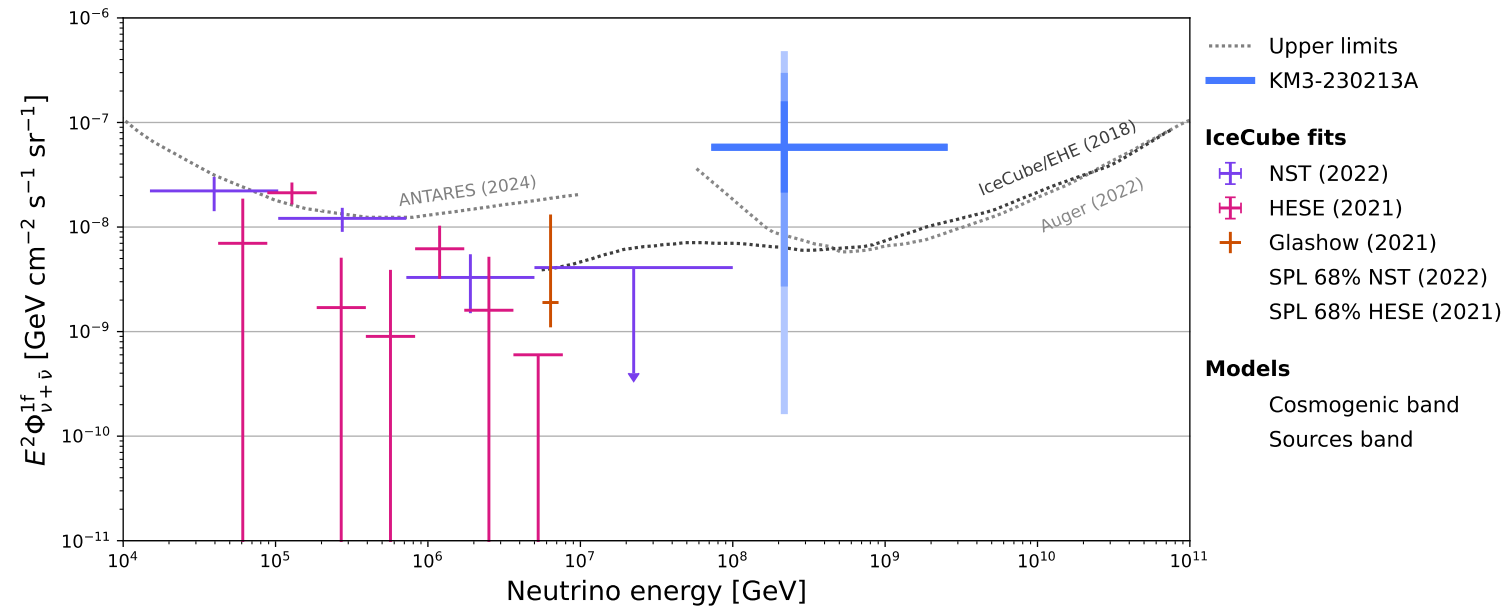
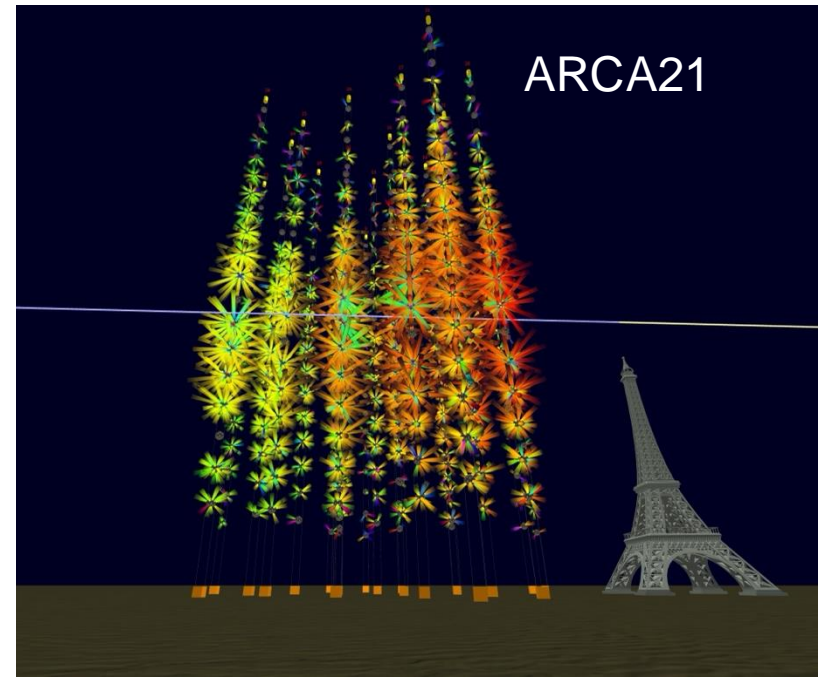
Aggreko

Aggreko

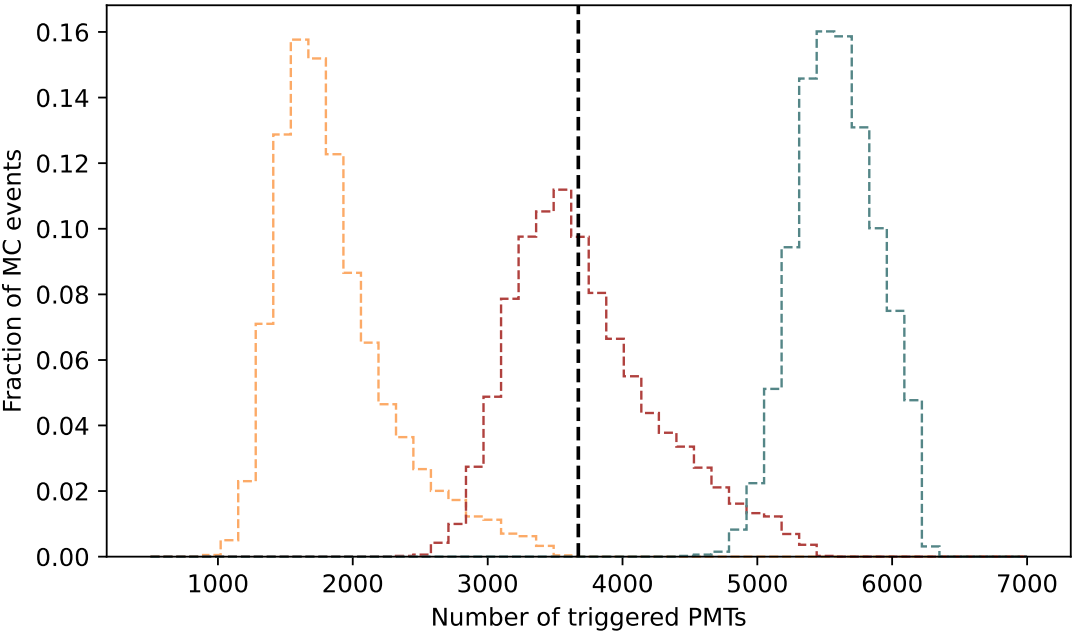


In case you did not follow the news last week ...

We've observed quite a beast of a neutrino



Muon energy
 10 PeV 1000 PeV
 100 PeV --- Measurement



Reco energies:

$$E_{\mu} = (120^{+110}_{-60}) \text{ PeV}$$

$$E_{\nu} = (220^{+570}_{-110}) \text{ PeV}$$

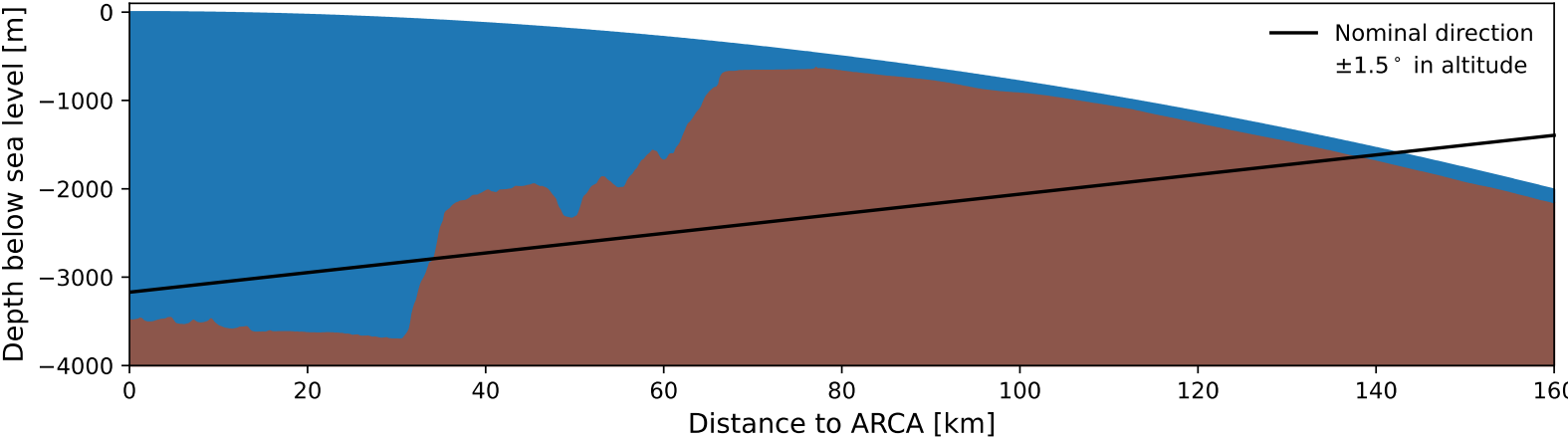
Origin:

- galactic x
- blazar ?
- cosmogenic ?

Companion papers:

- [\[1\]](#) other exp
- [\[2\]](#) cosmogenic
- [\[3\]](#) blazar
- [\[4\]](#) galactic
- ...

(more coming!)



Geometry:

- 104 km of rock
- 38 km of water
- 309 km w. e. in total

[link to the paper](#)
[link to the data](#)

How do we increase the statistics?

We need more datapoints at UHE



Instrument even bigger volume

... but how?

multi-km³ water Cherenkov telescopes very expensive, biggest planned: 7.5 km³ ([TRIDENT](#))

The problem: light range ~ few 100m

The solution: sound range ~ few km

But how do we „hear” a neutrino?

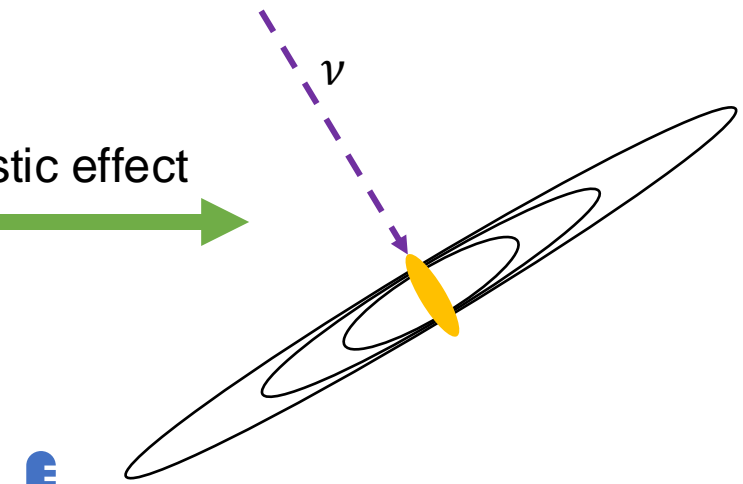


Gurgen A. Askaryan



source: https://en.wikipedia.org/wiki/Gurgen_Askaryan#/media/File:G_Askaryan.jpg

thermoacoustic effect



~ kHz audio signal

Hardware

Hydrophones:

- Piezoelectric (already installed)
- Membrane (already installed)
- Optic fibre + membrane (under development)
- ...?

Site

KM3NeT-Gr:

- near Pylos
- depth: 4550m
- noise lvl measured
- seabed mapped:
 - sub-m precision
 - quite flat

Software

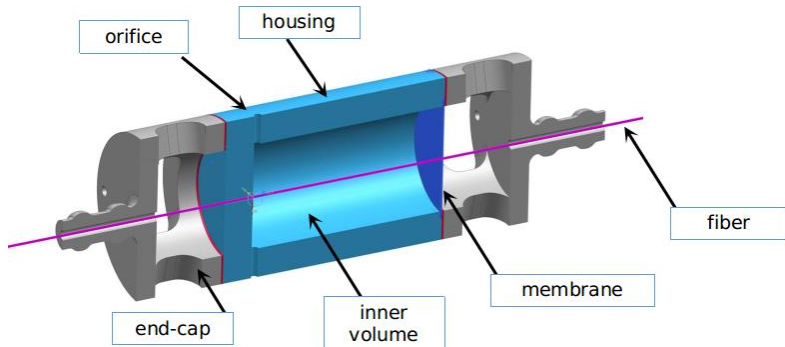
- There once was a MATLAB code from The ACoRNE Collaboration (and it is not available anymore ...)
- well ... and there's nothing else
- that's where we step in!

Simulation studies

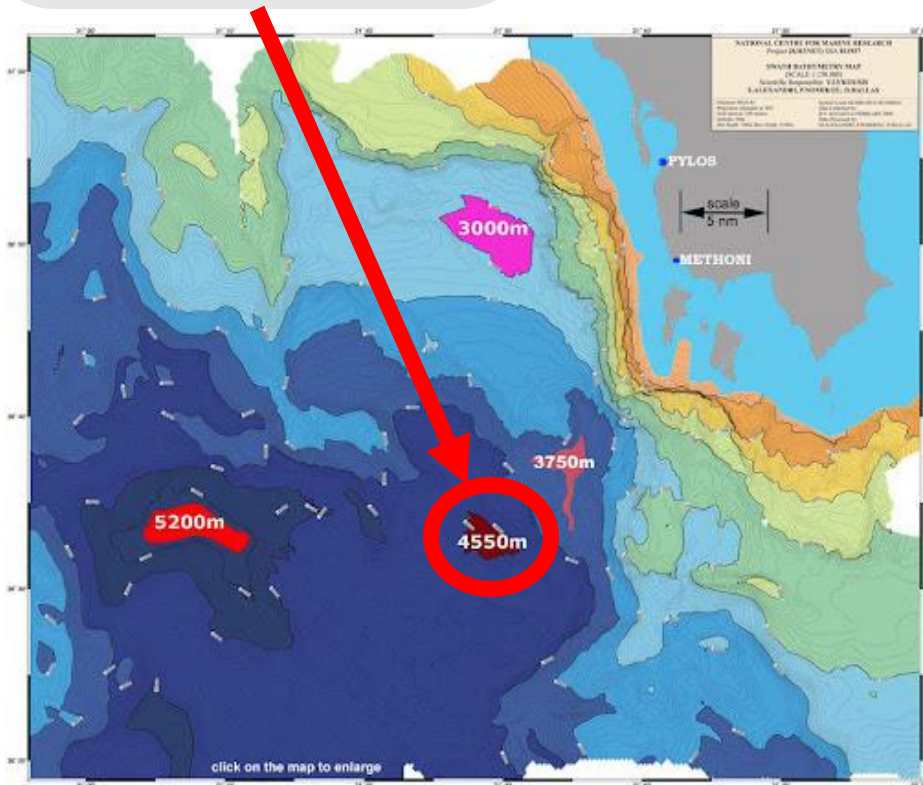
Funding ...



doi.org/10.1051/epjconf/201921602007



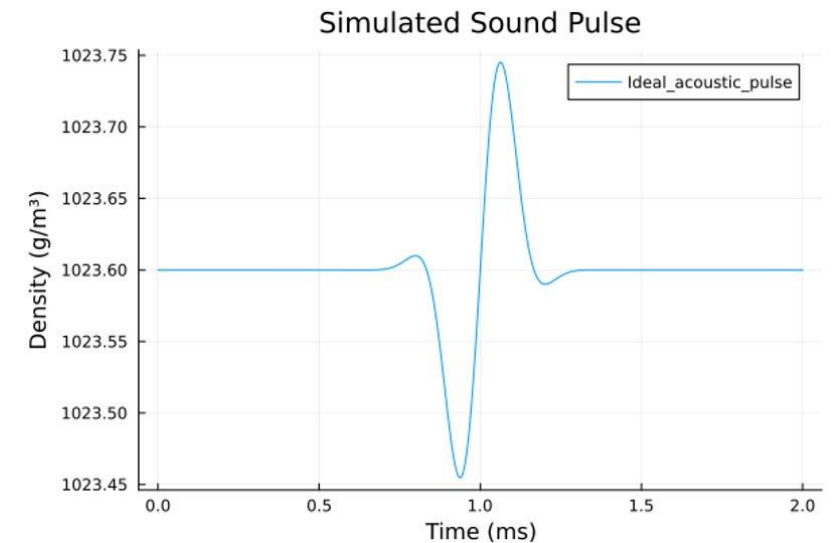
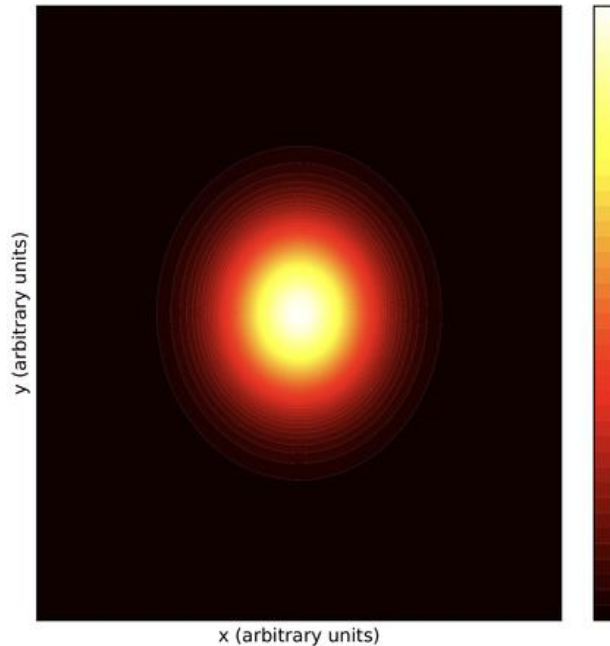
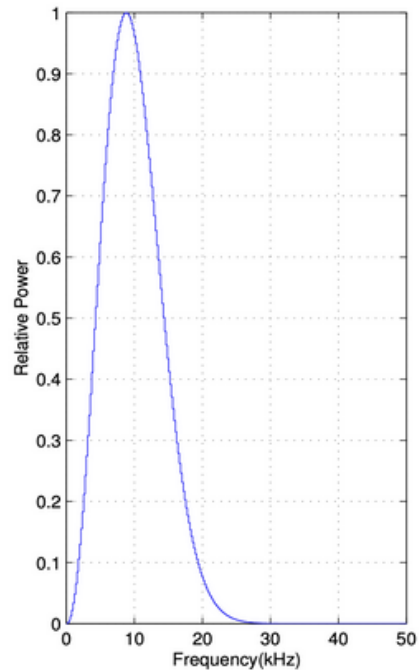
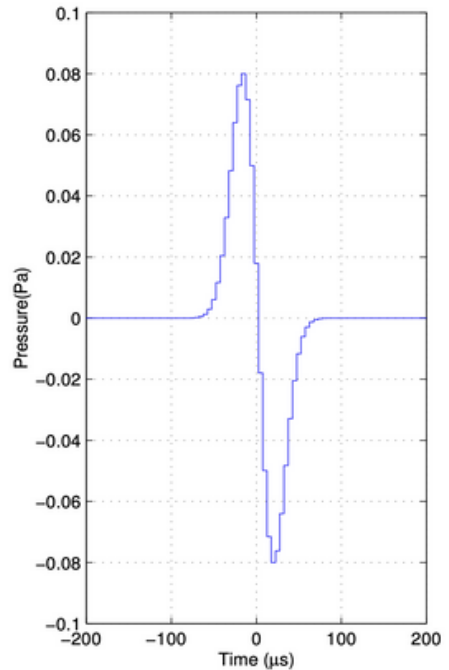
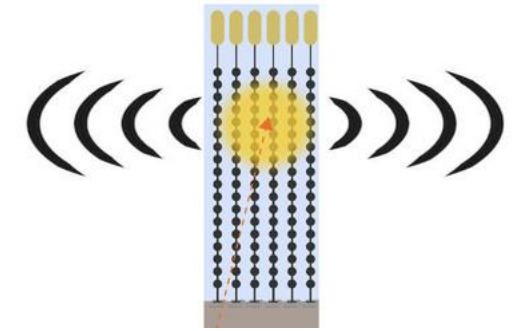
[arXiv:2501.12999](https://arxiv.org/abs/2501.12999)



oceansonics.com

Our focus:

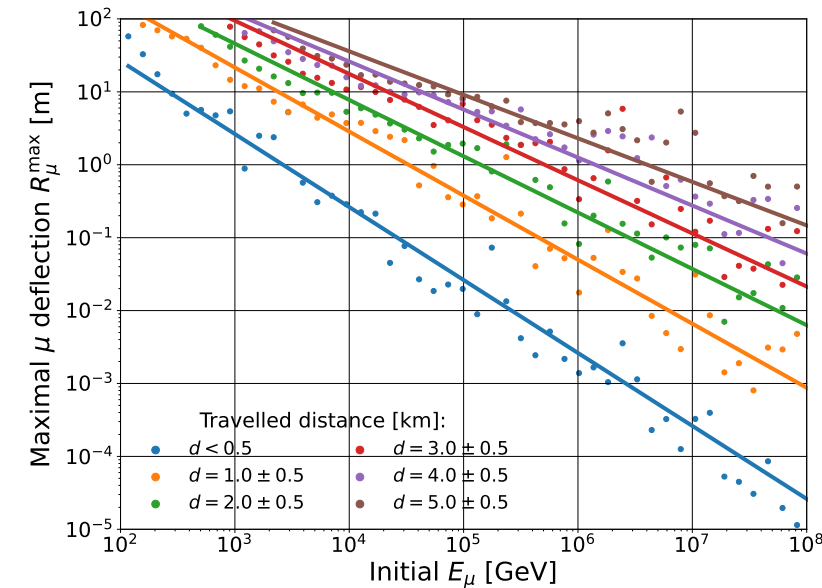
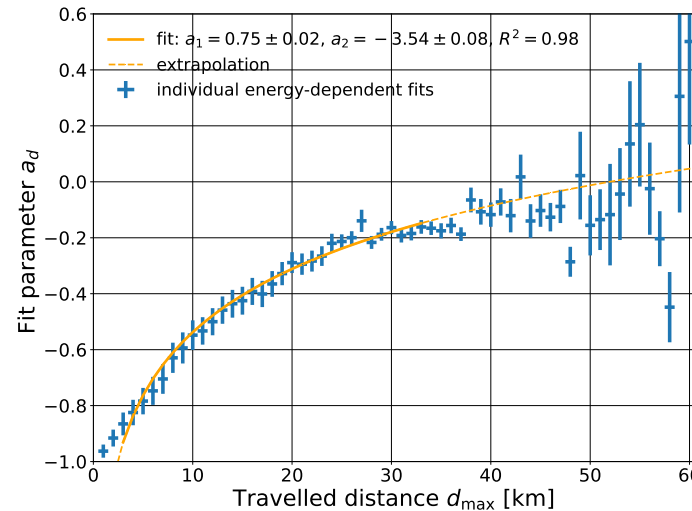
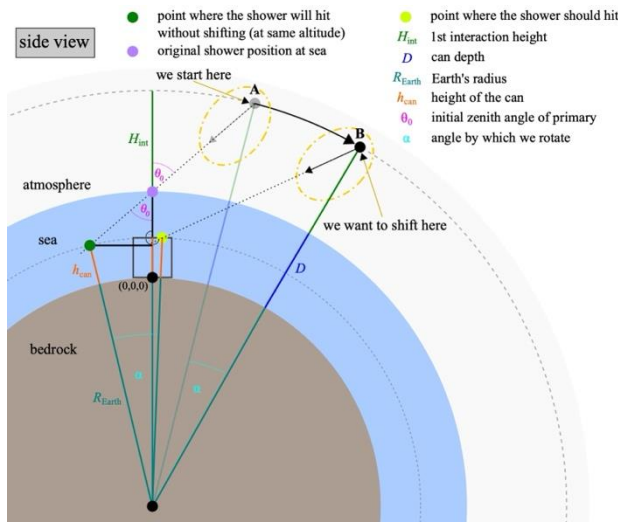
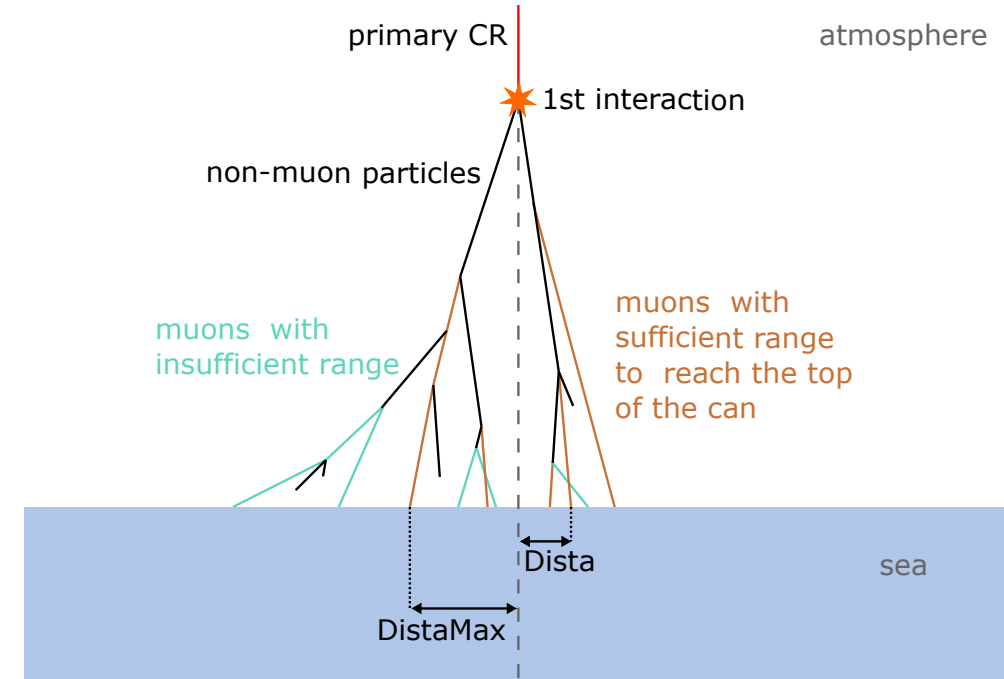
- ❖ Software development & maintenance:
 - new acoustic simulation code: SUNSET [Julia]
 - Acoustic calibration
 - Sound emission by UHE neutrino events



Our focus:

❖ Software development & maintenance:

- new acoustic simulation code: **SUNSET** [Julia]
 - Acoustic calibration
 - Sound emission by UHE neutrino events
 - [gSeaGen](#) [C++]
 - [GENIE](#)-based neutrino events generator
 - Processing of muons simulated with [CORSIKA](#)
- [Paper](#) submitted to Comp. Phys. Comm.



Our focus:

❖ Software development & maintenance:

- new acoustic simulation code: SUNSET [Julia]
 - Acoustic calibration
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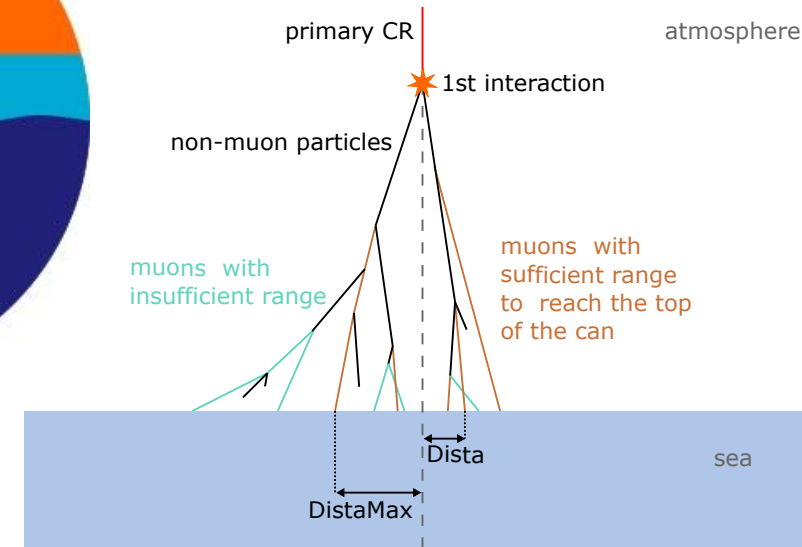
- [gSeaGen](#)

[C++]

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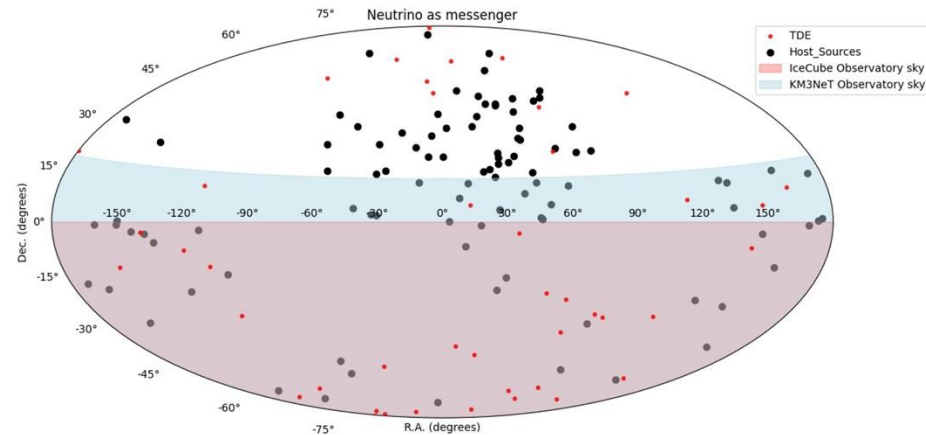
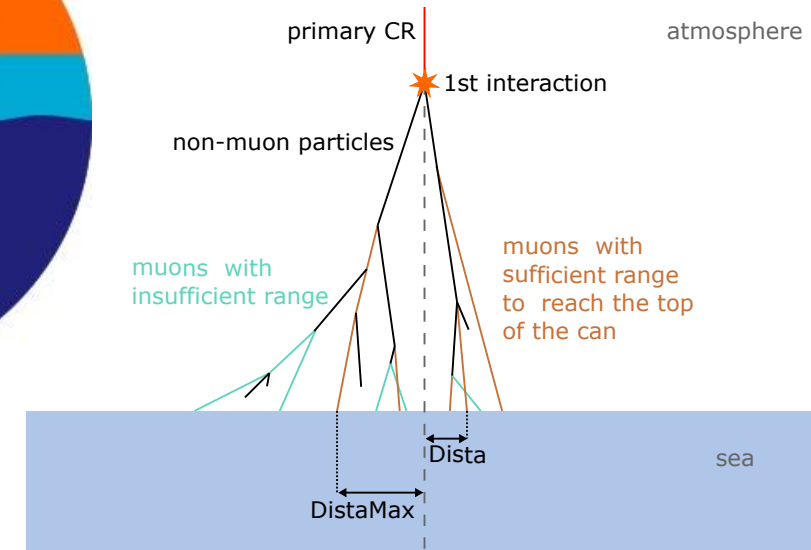
❖ Neutrino energy & direction reconstruction

- Using optical and/or acoustic data
- Using ML & DL



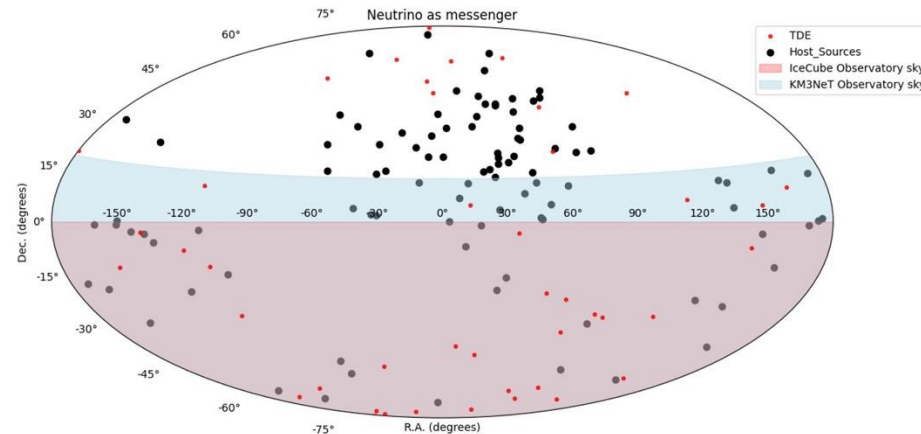
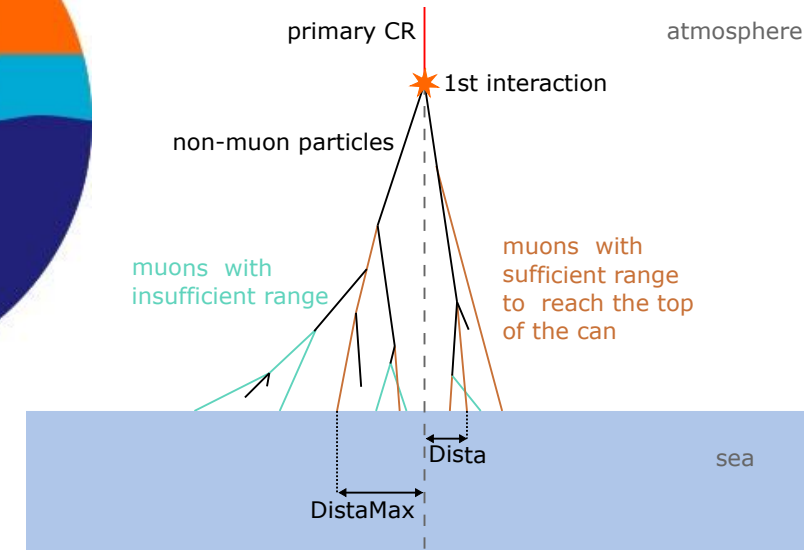
Our focus:

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- ❖ Study of TDEs with neutrinos



Our focus:

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- ❖ Neutrino energy & direction reconstruction
 - Using optical and/or acoustic data
 - Using ML & DL
- ❖ Study of TDEs with neutrinos
- ❖ Muon bundle reconstruction
- ❖ Prompt muon sensitivity study
- ❖ ...

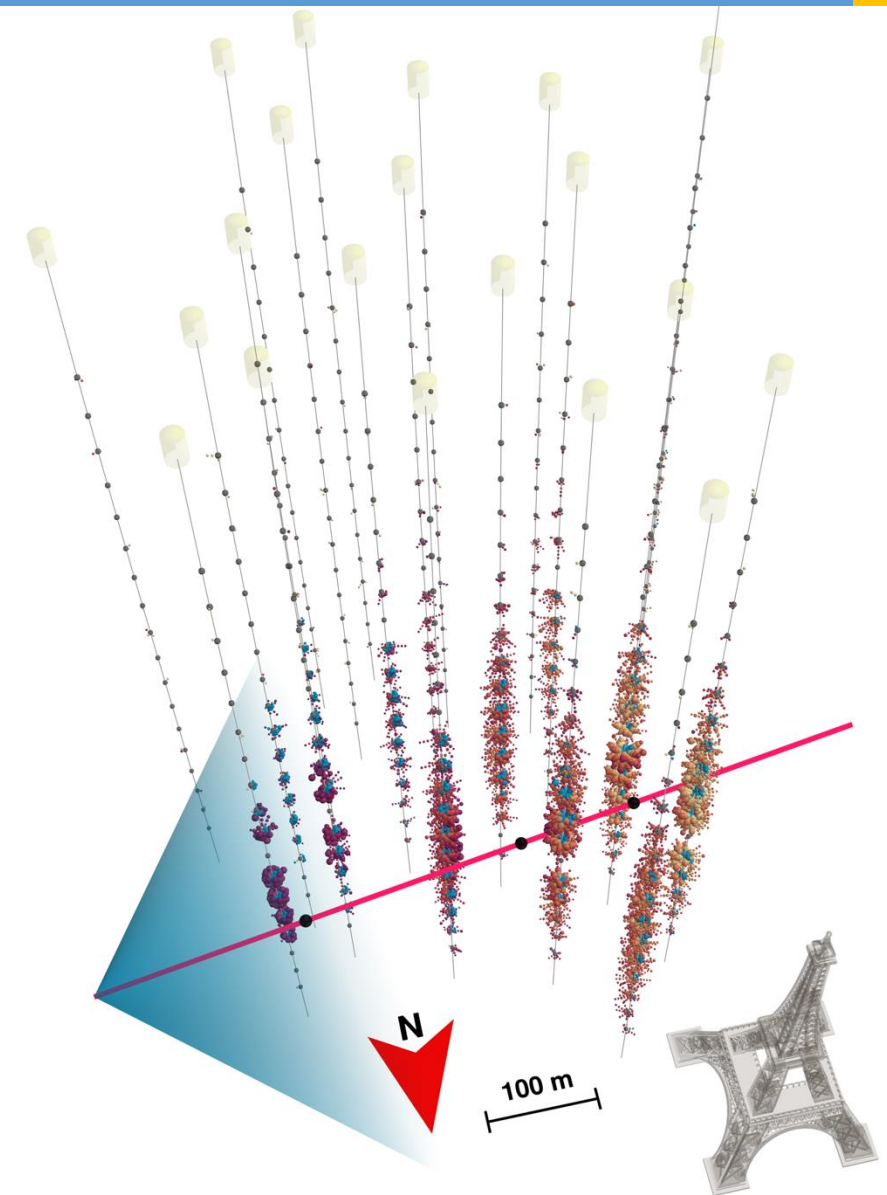




Summary:

- ❖ KM3NeT keeps growing & collecting data
- ❖ Already competitive in astronomy (and beyond)
- ❖ Polish group active in:
 - simulation software development
 - neutrino astronomy
 - cosmic ray physics
 - machine learning
- ❖ Stay tuned for more exciting results! 😊

Thank you for your attention!



Backup

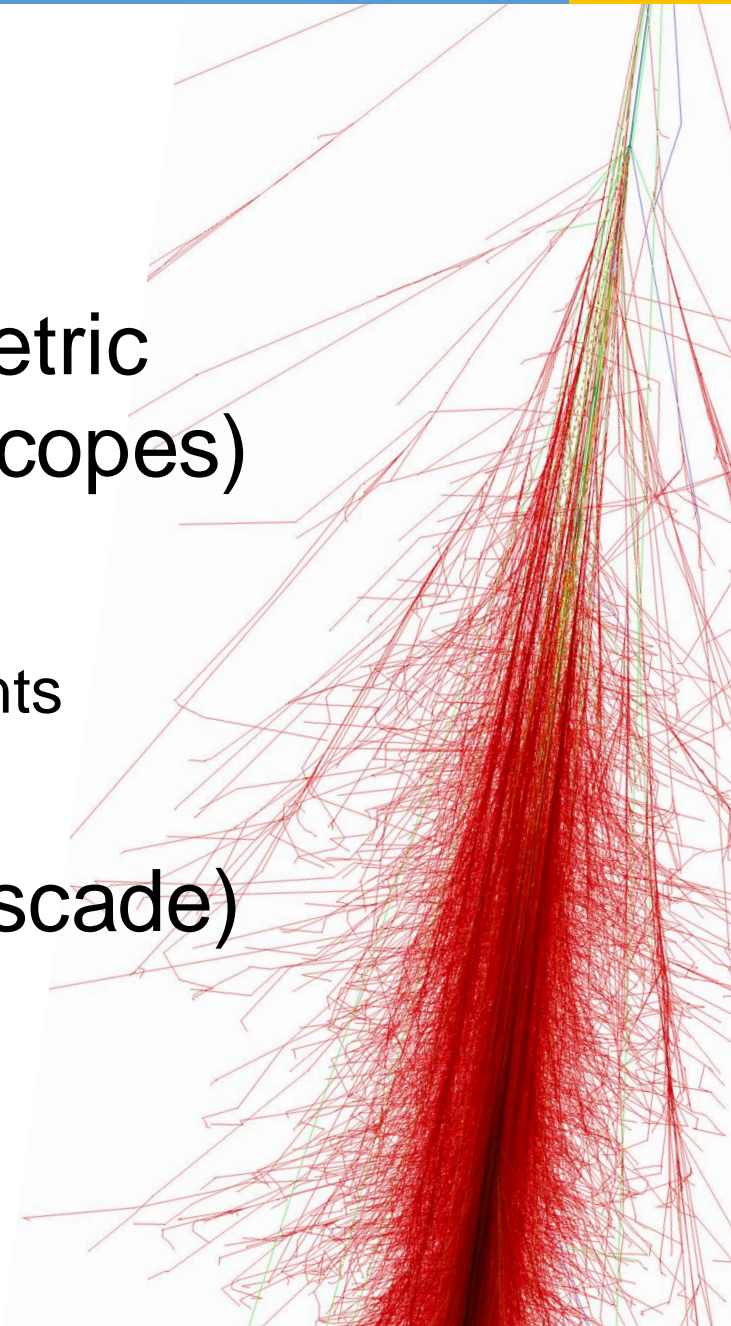
We have 2 options:

1. [MUPAGE](#) (atmospheric **MU**ons from **PA**rametric formulas: a fast **GE**nerator for neutrino telescopes)

- developed for ANTARES
- fast muon MC generator
- based on parametric formulas and MACRO measurements
- parameters can be freely tuned

2. [CORSIKA](#) (**CO**smic **R**ay **SI**mulations for **KA**scade)

- developed for KASCADE
- full simulation of air showers
- customizable (models, primaries, etc.)



Digital Optical Module (DOM)

acrylic glass sphere with:

- 31 3" PMTs,
- readout electronics,
- pressure gauge,
- acoustic sensors,
- ...

2022 JINST 17 P0703

JATIS 7(1), 016001 (2021)

Photomultiplier Tube (PMT)

converts light into electric signal

JINST13 (2018) P05035



Detection Unit (DU):
vertical string with 18 DOMs

Eur. Phys. J. C 76 (2016) 76:54

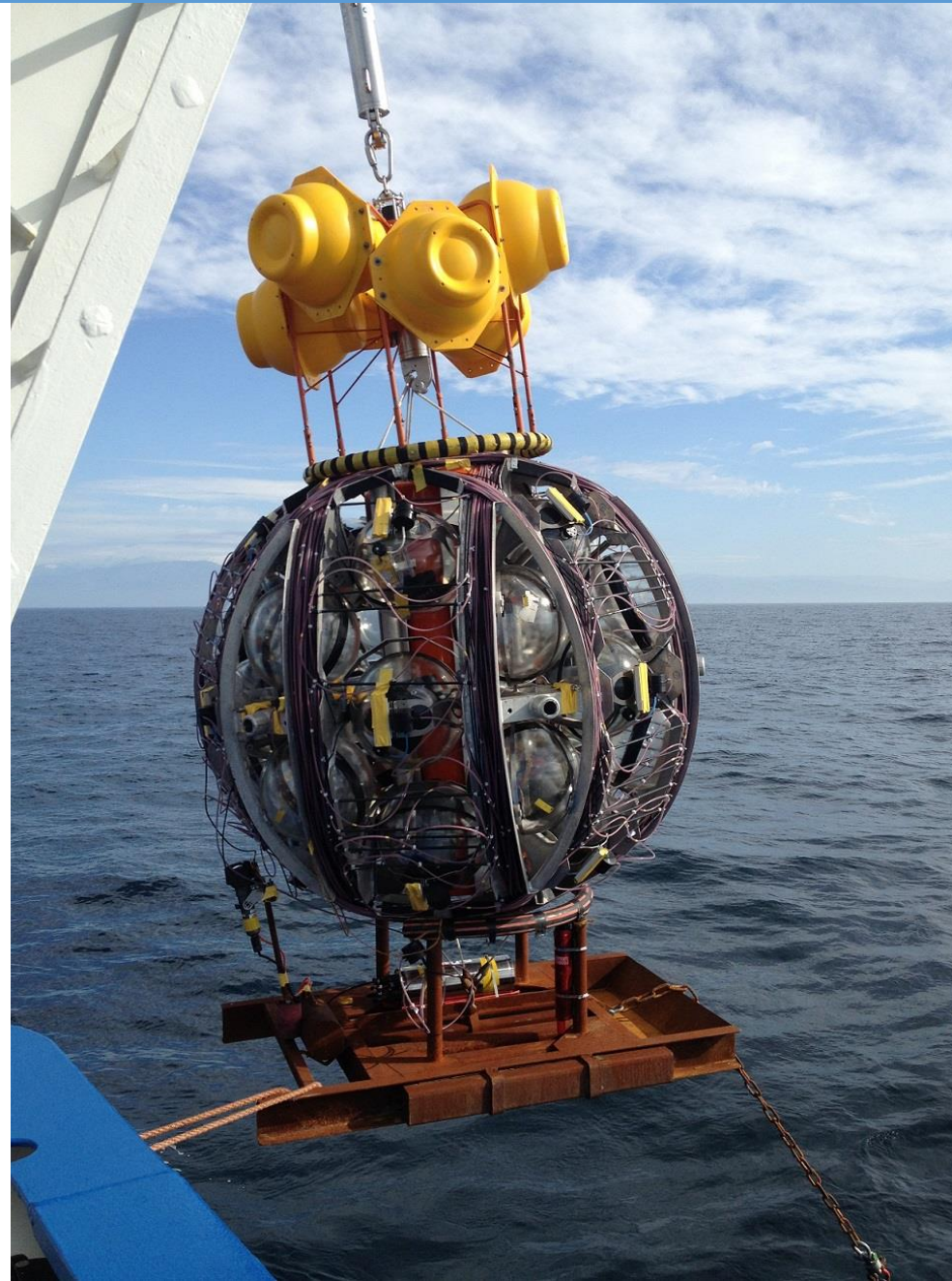
Naming:

ORCA6 ↔ ORCA with 6 strings

ARCA2 ↔ ARCA with 2 strings

etc.

2020 JINST 15 P11027



Detection Unit (DU):
vertical string with 18 DOMs

Eur. Phys. J. C 76 (2016) 76:54

Naming:

ORCA6 ↔ ORCA with 6 strings

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etc.

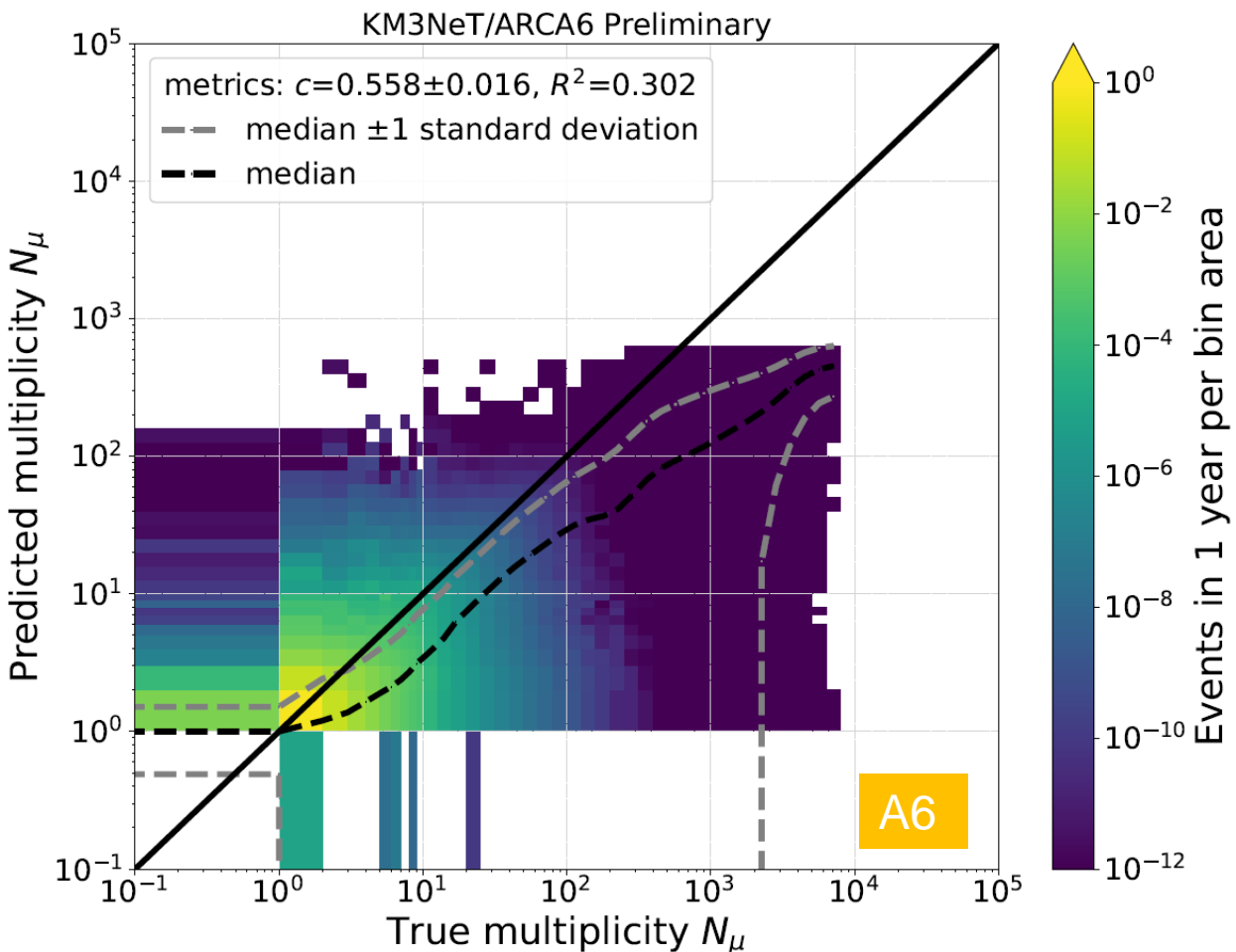
2020 JINST 15 P11027



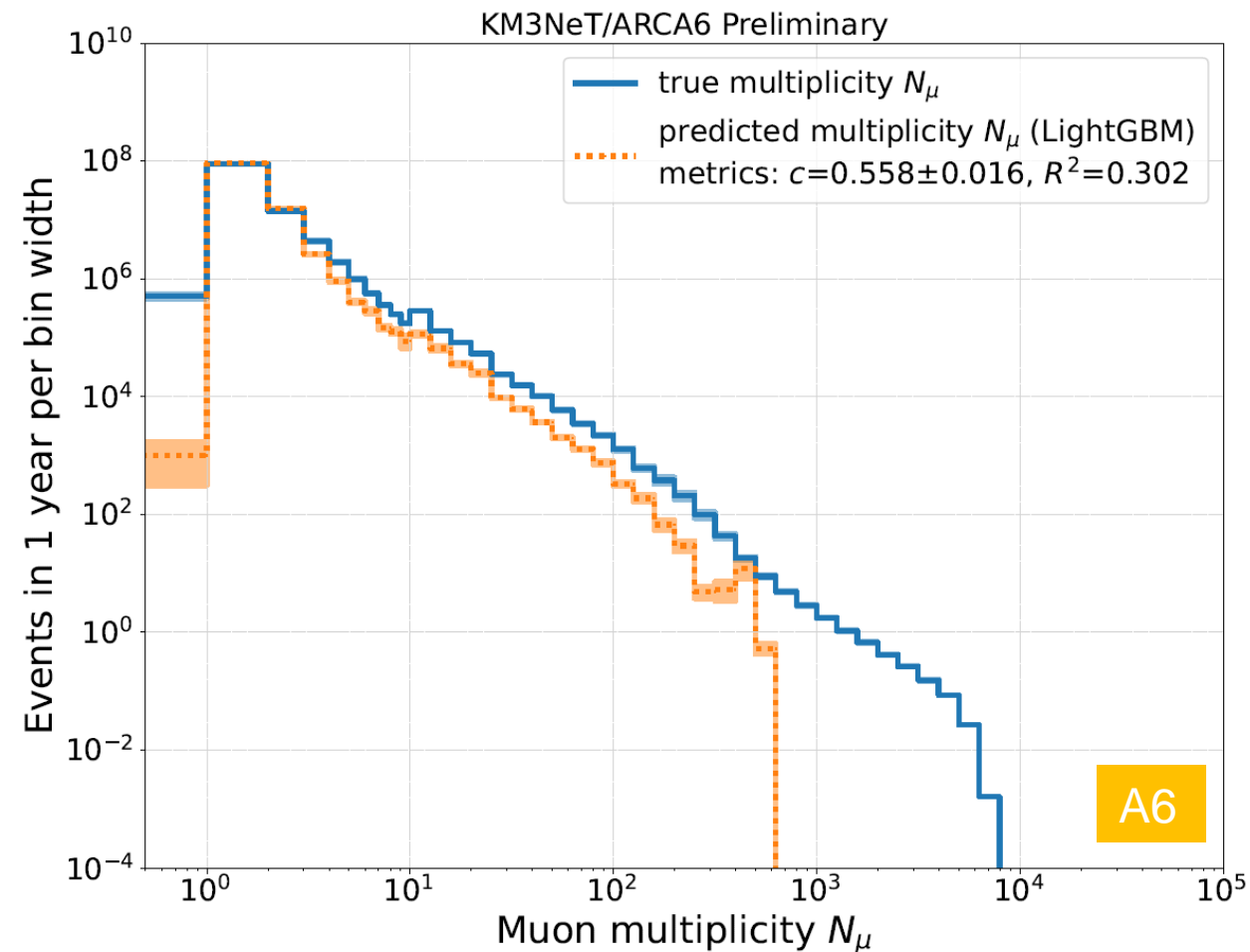
Analogical results obtained for ARCA115, ORCA115 and ORCA6

Example of the results for ARCA6:

2D: pred vs true



1D histograms

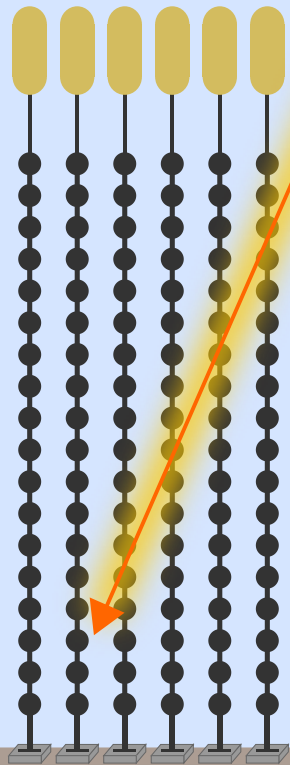


Examples of basic event topologies:

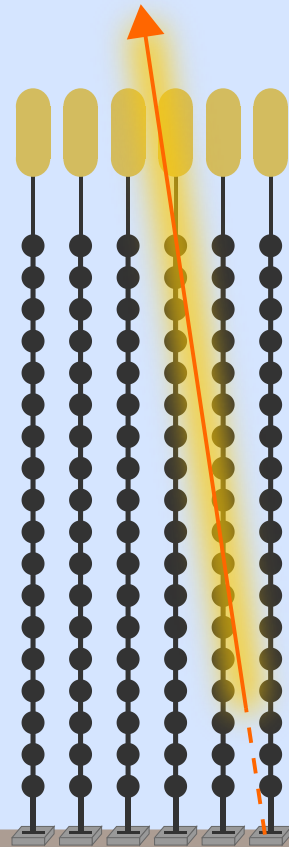
Classes based on combinations of:

- ❖ Direction
- ❖ Shape

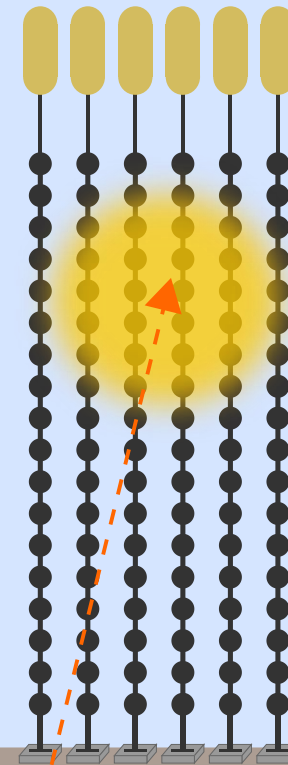
down-going track
(typically atm. μ)



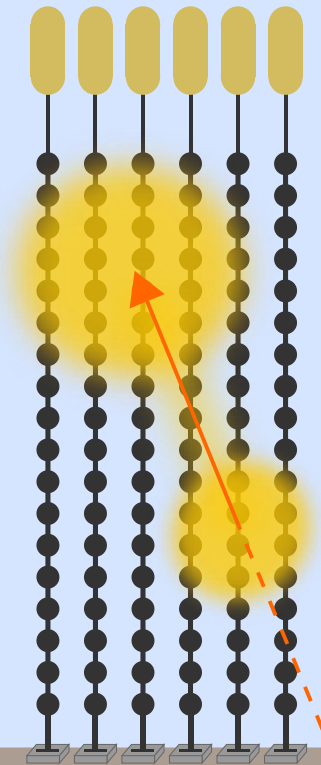
up-going track
(typically atm. ν_μ)



single cascade
(typically atm. ν_e/ν_τ)



double cascade
(typically atm. ν_τ)

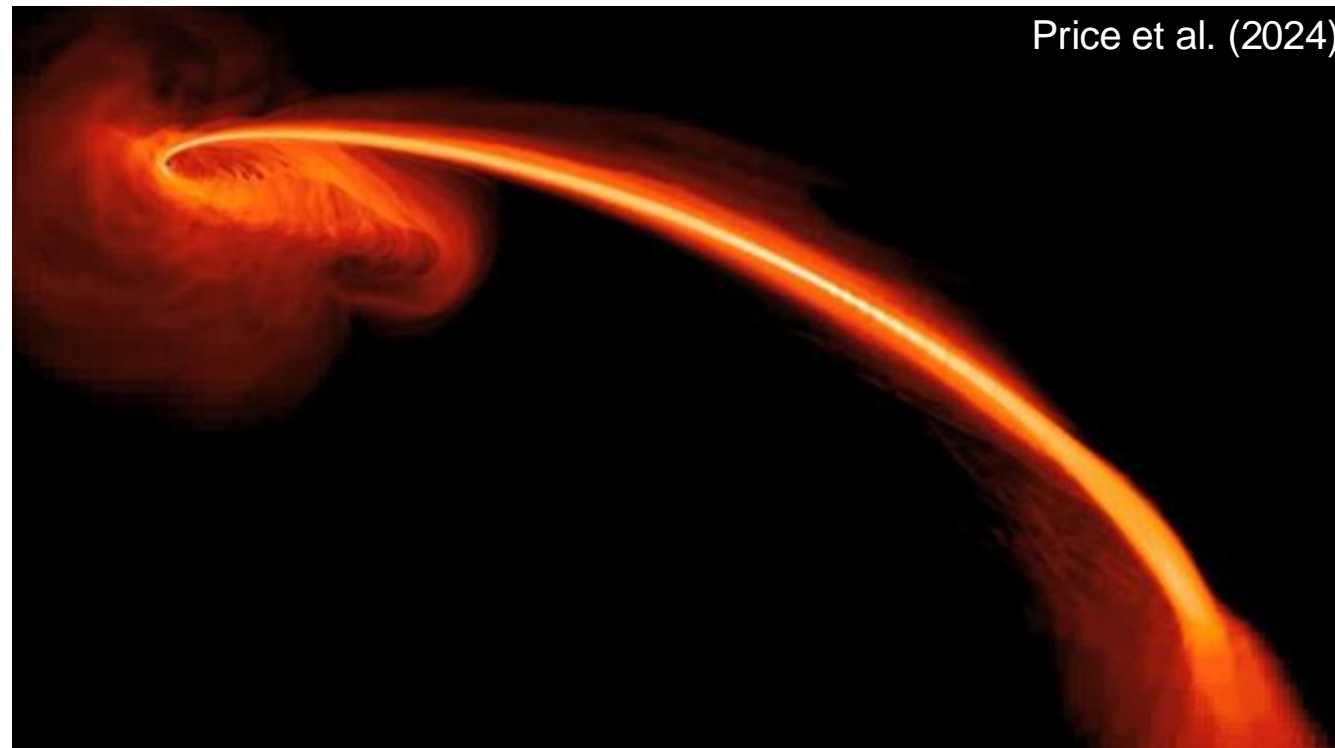


High-energy neutrinos

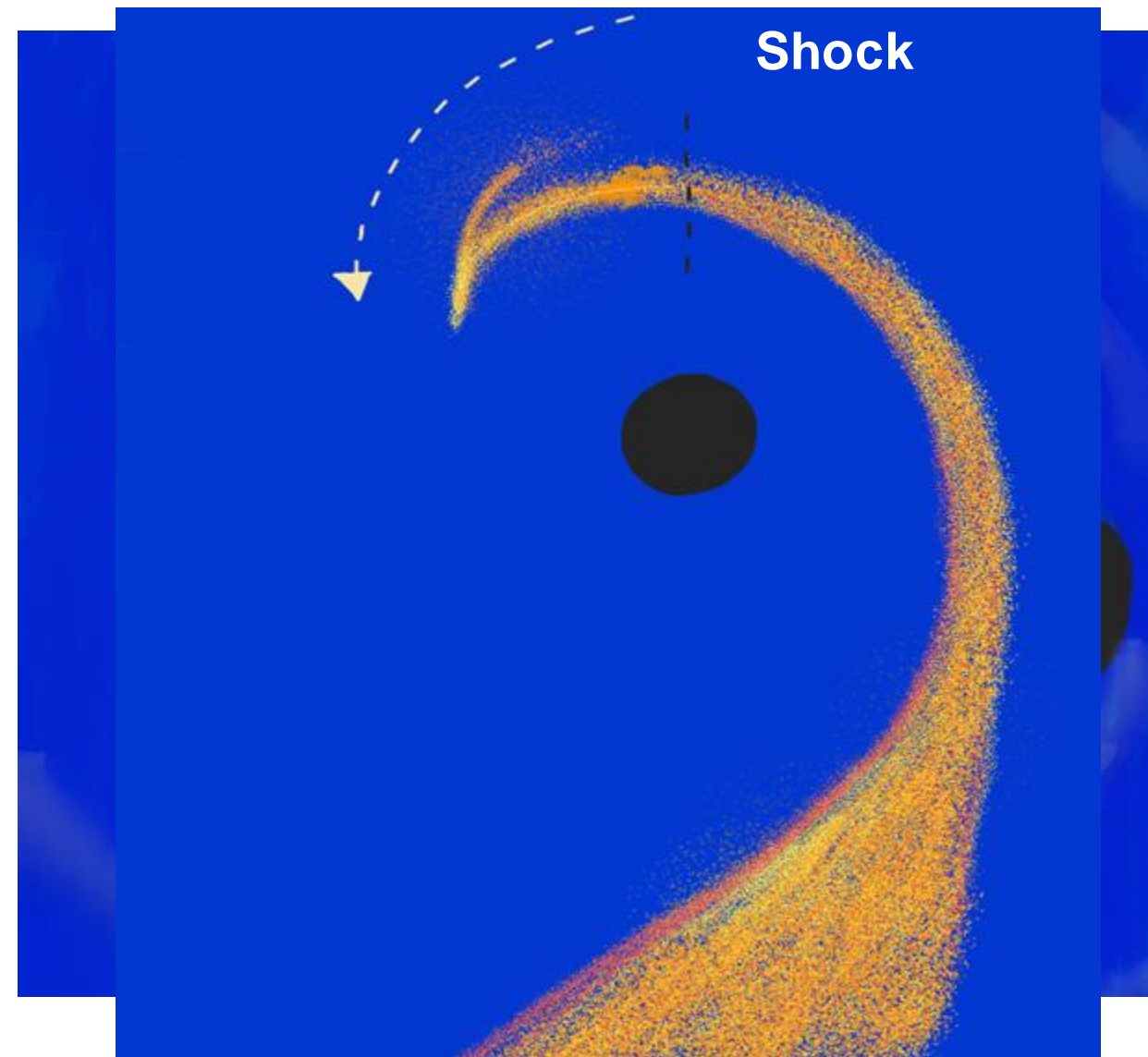
Tidally disrupted events

Strategy

- High-energy neutrino emission is correlated with temporal and spatial emissions across all the multi-messenger
- Tidally disrupted events are one of the potential candidates of high energy neutrinos



- Tidally disrupted events (TDE): Theoretical concept of massive black holes and star system reaching Roche limit
- Main sequence stars of mass $1 - 10 M_{\odot}$ and black hole mass $10^6 - 10^{12} M_{\odot}$
- TDE comprises of jet and fallback accretion system



- Multi-messenger properties:
 - Spectral classification by UV - optical color diagram into TDE-H, TDE-H+He, and TDE-He
 - At X-ray and radio energies non-thermal emissions
 - Very high-energy neutrinos of TeV and PeV
 - Gravitational waves candidate up to 10 Hz

