GNN Monthly
The Global Neutrino Network
60th Edition January/February (February 20, 2022)

News from the GNN partners

ANTARES switched off

At February 14th, 2022, after 16 years of continuous operation, the first deep sea neutrino telescope, ANTARES, was powered down for the last time.

Here some more detailed information taken for the ANTARES webpage:

The adventure of ANTARES started in the late 1990s. A proto-collaboration was formed and first sea operations were carried out to explore potential installation sites, measure the water transparency, the level of sedimentation, bioluminescence and biofouling. In parallel, simulations were done to optimize the detector layout. In 2001 the main cable from the "Les Sablettes" beach at La Seyne-sur-Mer was laid to the chosen site located 40 km offshore at a depth of 2475 m. In 2002 the junction box was installed; it has served for 20 years in the deep sea without interruption. First prototype neutrino detection lines were operated in 2003 and 2005 validating the readout electronics and time synchronization system. On February 14th, 2006 (see picture of Line 1 on Valentin's day) the first 25-storey detector line was deployed, and by May 2008 ANTARES installation was complete with 12 such lines in total.

At the end of 2021 the construction of the two KM3NeT detectors were sufficiently advanced to surpass the ANTARES sensitivity over its full energy range. It was therefore decided to shut down and dismantle the detector in 2022. The EMSO-Ligure campaign of the IFREMER "Pourquoi Pas?" ship offered the first occasion to unplug the cables between junction box and line anchors - a necessary prerequisite to proceed with the actual detector recovery. After the successful installation of various deep sea science equipment at the KM3NeT site, a dive with the "Nautile" submarine at the ANTARES site was performed. During this dive the vast majority of the cables between junction box and line anchors have been successfully unplugged. The Feb 14th 2022 marked the end of ANTARES data taking, 16 years exactly after the deployment of the first detector line. The follow-up steps of the dismantling are already scheduled for the near future.

During its scientific life, the ANTARES Collaboration has published more than 90 papers in refereed journals (including the one co-authored by about 3500 people from about 70 different collaborations on the study of the merging of two neutrons stars on 17 August 2017); about 40 presentations per year were given at international conferences since 2008; and about 100 PhD students (mainly from France, Italy, The Netherlands, Germany and Spain but also neighboring countries such as Morocco) defended their thesis related to the ANTARES telescope.

Congratulations to our ANTARES friends on the many high-quality results obtained over the years (see e.g. the very recent paper on solar atmospheric neutrinos discussed below!)

Good Bye, ANTARES. Well done!

Baikal GVD

In early February, preparations for the expedition have been completed and all material sent to Lake Baikal. Meanwhile (February 18), the early-bird group has arrived at the shore and will start to deploy the ice camp in a few days. The thickness of the ice is already about 40 cm and continues growing.

The plan is to deploy two new clusters and laying the corresponding shore cables, this time (as already last year) at a smaller inter-cluster distance than for the first seven clusters. In addition, a single, isolated string will be placed between clusters in order to improve cascade reconstruction and background rejection outside clusters themselves. A fairly large amount of work is foreseen to repair or upgrade components of a few clusters deployed in the past years

IceCube

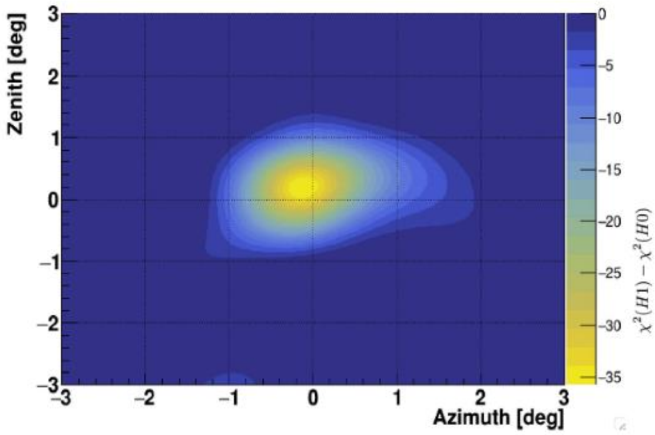
In the first week of February, after quite a few delays, the last 25 members of the South Pole winter crew arrived. It is not typical for half of the crew to arrive so late in the season, but international Covid precautions among other things have complicated the logistics of preparations and travel. The station will be closing soon enough, so there were also goodbyes shared this week, as the summer workers have begun departing. It was a pretty busy week for IceCube's winterovers, including some unexpected detector issues to attend to. They also performed software maintenance and testing tasks, took periodic inclinometer measurements, and had some outdoor adventures as well. Citing from the IceCube Weekly Report 5, 2022 January 31 through February 6: *After more than a week of delays and unsuccessful attempts to reach Pole with an LC-130, affected by the bad weather conditions and multiple mechanical issues, the last 25 members of the Winterover Crew have finally arrived here aboard two Baslers! With the team finally complete, we organized our first all-hands winterover meeting at the "big gym", where for the first time we had the opportunity to meet. We will live together for the next nine months, seeing the same faces every day, whether we like it or not, and we better like it!*

The first photo of (most of) the winterover crew 2022, among them the two for IceCube.

KM3NeT

Based on the 1-year ORCA dataset that was already used for measuring neutrino oscillations, two more results have been unblinded that probe new physics in the neutrino oscillation pattern, in the form of neutrino decay and so-called non-standard interactions. Both analyses show the data are compatible with the null hypothesis to an excellent degree, and limits have been put on the parameters describing the neutrino decay and on coupling constants non-standard interaction parameters.

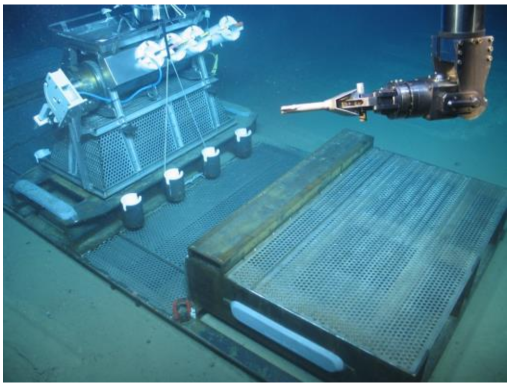
Another recent analysis detects the shadows of the Sun and Moon in downgoing cosmic muons. Both signatures are seen with high significance (5.7 sigma for the Sun and 4.4 sigma for the Moon).



ORCA significance plot of the Sun shadow.

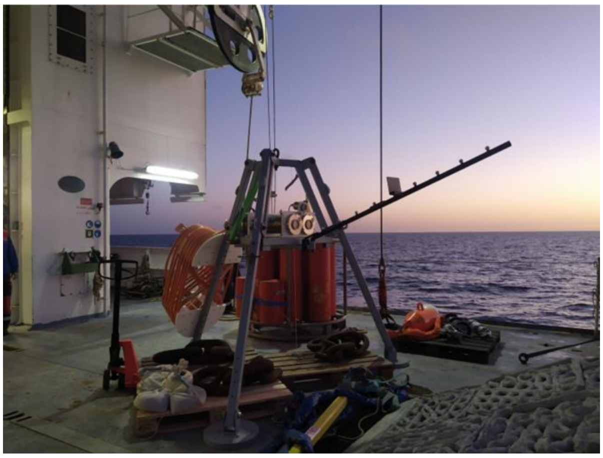
These results confirm the absolute orientation of the detector as measured by the acoustic alignment system. Moreover, the fitted width of the deficit is consistent with expectation and thus validates the direction resolution of the ORCA detector.

From January 31 to February 14, 2022, a sea operation took place aboard the oceanographic vessel the *Pourquoi pas?* operated by *Ifremer* (see https://www.mio.osupytheas.fr/fr/mers-et-oceans-changement-global/emso-lo-bathycruise. During this mission various new marine sensors were connected to the LSPM (Laboratoire Sous-marin Provence Mediterranée), the deep-sea platform which hosts the KM3NeT/ORCA detector. The instrumentation included a seismograph (GeoAzur, Nice), stereo biocameras (Univ. Lyon), a Germanium detector to measure the ambient radioactivity (CPPM, Marseille) and BathyBot (Mediterranean Institute of Oceanography). The BathyBot is a mobile seafloor crawler and can explore the environment around the scientific junction box. It is equipped with sensors and ultra-sensitive cameras and along with the biocameras will allow to study bioluminescence, biogeochemical dynamics and biodiversity.



The scientific junction box on the seafloor

The BathyBot on the artificial reef in the test pool



The stereo biocameras

The Nautile *submarine on the* Pourqoui pas?, *used to connect the instrumentation to the scientific junction box.*

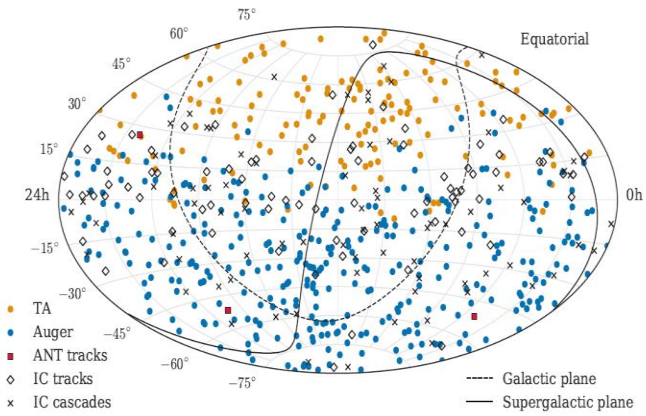
Publications

The ANTARES, IceCube, Pierre Auger and Telescope Array collaborations have posted a paper *Search for Spatial Correlations of Neutrinos with Ultra-High-Energy Cosmic Rays* at 2201.07313.pdf (arxiv.org) (submitted to Astrophysical Journal). The neutrino data are provided by IceCube and ANTARES, while the UHECR data with energies above ~50 EeV are provided by the Pierre Auger Observatory and the Telescope Array. Compared to previous results from 2015, all experiments provide increased statistics and improved reconstructions.

Three different approaches for correlating the arrival directions of neutrinos with the arrival directions of

UHECRs have been chosen. The first analysis uses a high-statistics neutrino sample optimized for point-source searches to search for excesses of neutrinos clustering in the vicinity of UHECR directions. The second analysis searches for an excess of UHECRs in the direction of the highest-energy neutrinos (with high probability to be of astrophysical origin. The third analysis searches for an excess of pairs of UHECRs and highest-energy neutrinos on different angular scales.

The next figure shows the skymap for the neutrino and cosmic ray events.



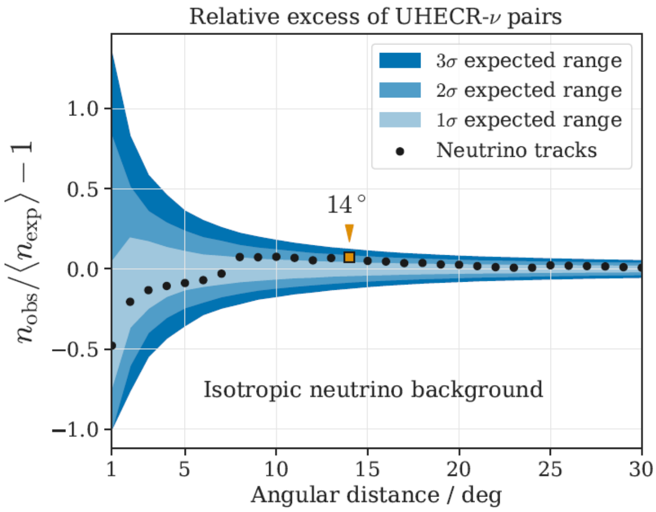
Skymap of the arrival directions of UHECR events and high-energy neutrinos. The high-energy neutrino track-like events from IceCube consists of the HESE, HENU and EHE data sets (see the table for explanations), while the cascade-like events are only of the IceCube-HESE data sets. From ANTARES, only high-energy tracks are selected for the analyses.

Detector	Analysis 1	Analysis 2	Analysis 3
ANTARES	PS	HENU	HENU
IceCube	PS	HESE + HENU + EHE	HESE + HENU + EHE

Data set	Description	Topology
PS	Optimized for point-source searches, ν_μ candidates.	Tracks
HESE	High-energy starting events, all flavors.	Tracks and cascades
HENU	High-energy selection of ν_μ candidates.	Tracks
EHE	Extremely-high energy ν_μ candidates.	Tracks

Table 1. Overview over different neutrino data sets used in the different analyses.

None of the three analyses has found a significant excess (p-values 0.1 or larger) – see as an example the results from analysis 3 in the next figure. Previously reported over-fluctuations are reduced in significance. Based on these results, the paper further constrains the neutrino flux spatially correlated with UHECRs.

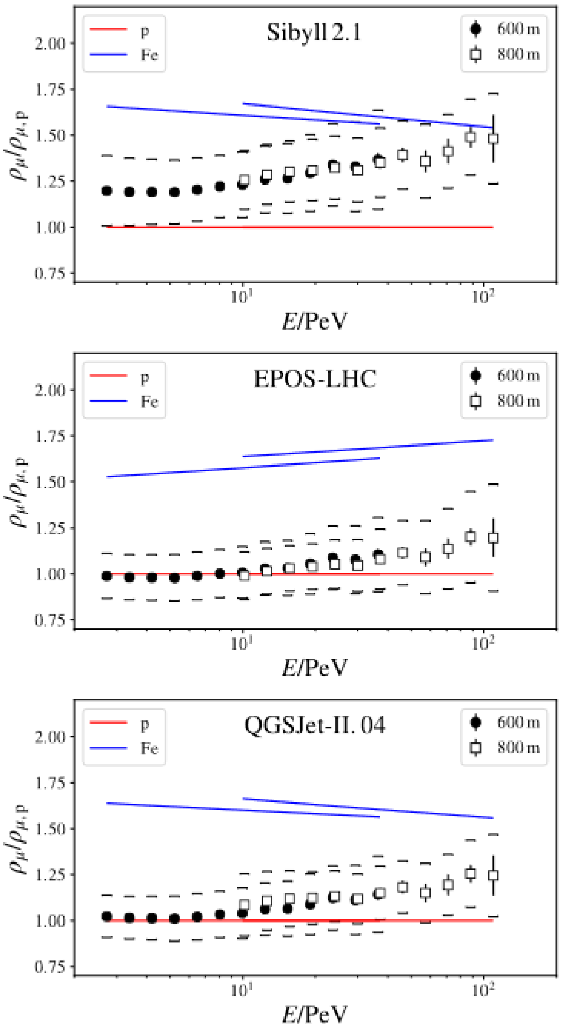


Relative excess of pairs, n_{obs} = ⟨n_{exp}⟩ -1, as a function of the maximum angular separation of the neutrino and UHECR pairs.14° marks the best-fit angular separation for the 2pt-correlation analysis

ANTARES/IceCube contact persons for this paper are Julien Aublin (APC Paris), Lisa Schumacher (TU Munich), Christopher Wiebusch (RWTH Aachen), and Teresa Montaruli (U. Geneva).

The IceCube collaboration has submitted a paper *Density of GeV muons in air showers measured with IceTop* to Phys. Rev. D (posted at [2201.12635.pdf (arxiv.org)]), with the most significant contribution coming from Javier Gonzalez, Hans Dembinski and Dennis Soldin (Bartol Research Institute at the University of Delaware).

Using three years of IceTop data, the density of GeV muons in near-vertical air showers is investigated. Depending on the shower size, the muon densities have been measured at lateral distances between 200 m and 1000 m to the shower core. From these lateral distributions, they derive the muon densities as functions of energy at reference distances of 600 m and 800 m for primary energies between 2.5 PeV and 40 PeV and between 9 PeV and 120 PeV, respectively. The muon densities are determined using, as a baseline, the hadronic interaction model Sibyll 2.1 together with various composition models. The measurements are consistent with the predicted muon densities within these baseline interaction and composition models. The measured muon densities have also been compared to simulations using the post-LHC models EPOS-LHC and QGSJet-II.04. The result of this comparison is that the post-LHC models together with any given composition model yield higher muon densities than observed (see the figure below). This is in contrast to the observations above 1 EeV where all model simulations yield for any mass composition lower muon densities than the measured ones. The post-LHC models in general feature higher muon densities so that the agreement with experimental data at the highest energies is improved but the muon densities are not correctly described in the energy range between 2.5 PeV and about 100 PeV.



See the figure caption in the right column

Measured muon densities at 600 m (solid circles) and 800 m (white squares) lateral distance after applying the corrections, normalized to the muon density obtained from proton simulations. Error bars indicate the statistical uncertainty, brackets the systematic uncertainty. The points are horizontally displaced slightly for better visibility. The consistency of the hadronic interaction models can be examined by checking if the data are bracketed by the expectations given by a cosmic ray flux with 100% proton (red line) and 100% iron (blue lines). In this sense QGSJet-II.04 and Sibyl 2.1 perform *fairly well, since the corresponding proton and iron lines bracket the data. For QGSJet-II.04, the data between 2.5 PeV and about 10 PeV is very close to the expectation for a 100% proton flux. The EPOS-LHC lines do not bracket the data at the lowest energies, requiring an average composition slightly lighter than proton below approximately 6 PeV.*

Two papers on non-standard neutrino interactions *have been submitted during the last 2 months, one by the ANTARES collaboration and one by the IceCube collaboration.*

Both papers investigate atmospheric neutrinos which have passed through the Earth and have been subject to nonstandard interactions (NSI) in the interior of the Earth. They assume that the Standard Model Hamiltonian for CC coherent interaction can be written as

$$H_{\mathrm{mat}}(x) = V_{CC}(x)\begin{pmatrix}1 & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{pmatrix}$$

which is replaced by

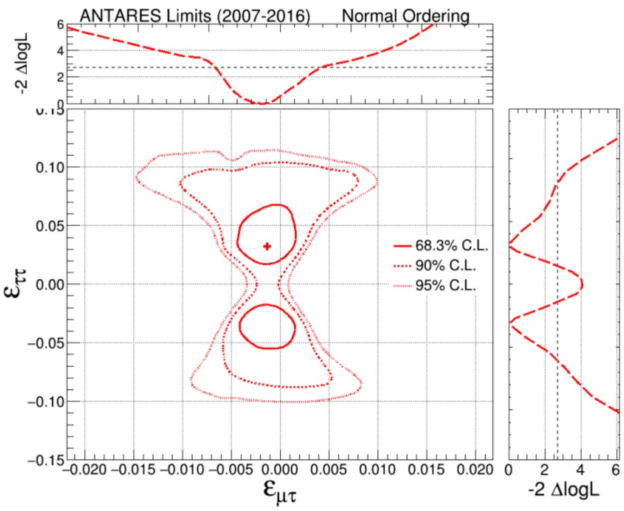
$$H_{\mathrm{mat+NSI}} = V_{CC}(x)\begin{pmatrix}1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau}\\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau}\\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau}\end{pmatrix}$$

for the NSI case, where the $\varepsilon_{\alpha\beta}$ (complex conjugate $\varepsilon^*_{\alpha\beta}$) characterize the NSI. Various assumptions can be made on the $\varepsilon_{\alpha\beta}$. They can be assumed real (as for the ANTARES paper or for the corresponding IceCube paper from 2018, PRD 97, 072009) or complex (the present IceCube paper and the IceCube paper from June last year, PRD 104 072006, see also my delayed report in GNN Monthly from December 2021). The NSI can be assumed to couple with down quarks only (the ANTARES paper) or with nucleons and electrons (the

IceCube paper). All that makes a comparison difficult. In any case: both experiments impose new strong constraints on a real $\varepsilon_{\mu\tau}$, ANTARES also on $\varepsilon_{\tau\tau}$.

The ANTARES collaboration has submitted the paper *Search for non-standard neutrino interactions with 10 years of ANTARES data* to Journal of High Energy Physics (2112.14517.pdf (arxiv.org)). Corresponding authors are N.R.K. Chowdhury, T. Thakore and J.J. Hernández-Rey from IFIC Valencia.

As explained above, the analysis looks for matter effects in atmospheric neutrino propagation through the Earth which might be altered non-standard interactions. Ten years of atmospheric neutrino data collected from 2007 to 2016, with energies in the range from~5 to 10^4 GeV, have been analyzed. As a result, a log-likelihood ratio test yields best-fit values of the dimensionless coefficients that quantify the strength of NSI between the neutrino flavors, namely, $\varepsilon_{\mu\tau}$ and $\varepsilon_{\tau\tau}$, the second of them being non-zero at the 1.7σ and 1.6σ level for normal (NO) and inverted (IO) mass ordering, respectively. The 90% CL limits for $\varepsilon_{\mu\tau}$ are $-0.0047 < \varepsilon_{\mu\tau} < 0.0029$.

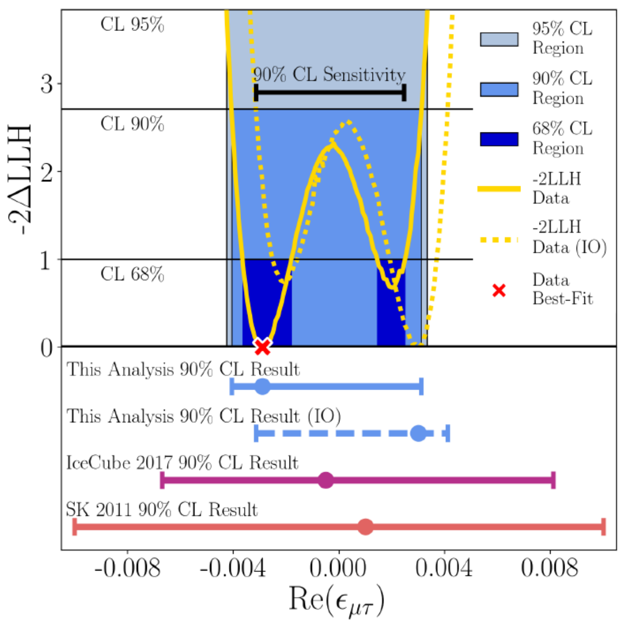


Contours of 68.3% (solid), 90% (dashed) and 95% (dotted) confidence level on the $\varepsilon_{\mu\tau} - \varepsilon_{\tau\tau}$ plane, after 10 years of ANTARES livetime for normal ordering. The cross indicates the best-fit point. The lateral plots show the 1D profile likelihood of the respective NSI parameters under study, when the other parameter is fitted over. The dashed straight lines in lateral plots indicate the 90% C.L. for one degree of freedom.

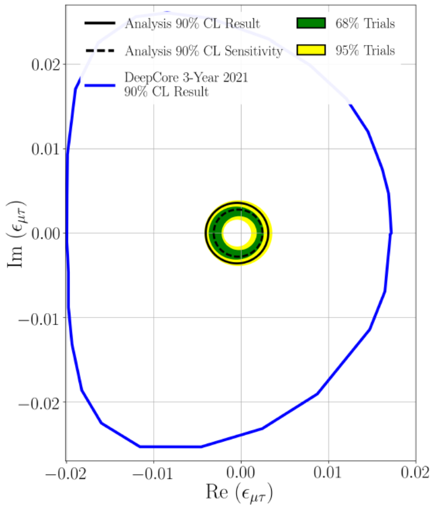
The IceCube Collaboration has submitted the paper *Strong constraints on neutrino nonstandard interactions from TeV-scale ν_μ disappearance at IceCube* to Phys. Rev. Letters (posted at 2201.03566.pdf (arxiv.org)). The analysis was performed at the University of Texas at Arlington, the Massachusetts Institute of Technology, and Harvard University groups, in particular by Grant Parker and Ben Jones.

The paper uses eight years of atmospheric neutrino data, with energies between 500 GeV to ~ 10 TeV (different to the 2021 paper which has used DeepCore data with energies between 5.6 GeV and 100 GeV). It focuses on the disappearance of atmospheric muon neutrinos, while the 2021 paper had looked for simultaneous effects in all oscillation channels.

The parameter of interest is solely $\varepsilon_{\mu\tau}$, since atmospheric neutrinos are mostly muon neutrinos which for energies > 20 GeV predominantly oscillate into tau neutrinos. The best-fit value is consistent with no NSI at a p-value of 25.2%. Besides a 90% confidence interval of $-0.0041 \leq \varepsilon_{\mu\tau} \leq 0.0031$ along the real axis (see the next figure) there is a similar constraint in the complex plane (see second figure).

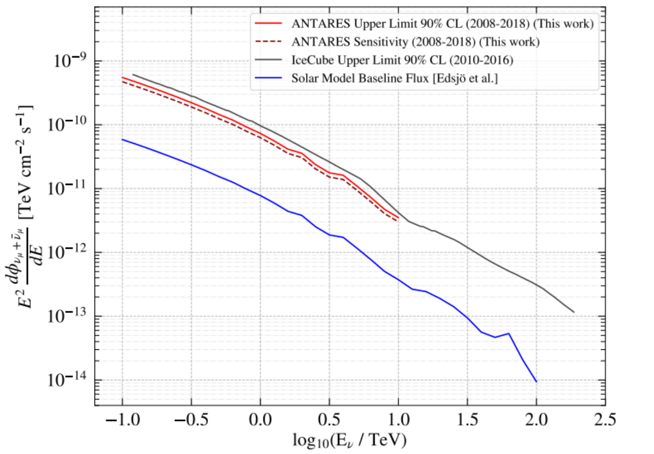


Top: The test statistic profile from the fit to data. Blue-shaded regions correspond to the Confidence Level (CL) regions determined from the value of the test statistic. Bottom: Comparison of the 90% CL limits from this analysis to IceCube's previous real-only $\varepsilon_{\mu\tau}$ search and the Super-Kamiokande constraints.



Comparison of the analysis 90% CL sensitivity and actual result to the DeepCore 3-year, 5.6-100 GeV result of last year. Green and yellow regions represent 90% CL sensitivity envelopes of the 68% and 95% (respectively) regions.

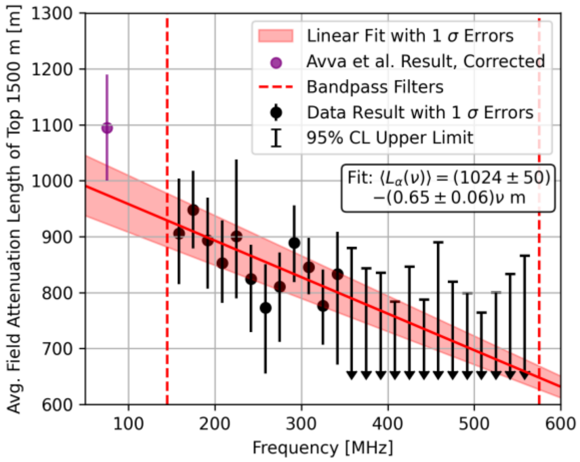
The ANTARES collaboration has submitted a paper *Search for solar atmospheric neutrinos with the ANTARES neutrino telescope* to JCAP (posted at 2201.11642.pdf (arxiv.org)). Solar Atmospheric Neutrinos (SAvs) are produced by the interaction of cosmic rays with the solar medium. The detection of SAvs would provide useful information on the composition of primary cosmic rays as well as the solar density. These neutrinos represent an irreducible source of background for indirect searches for dark matter towards the Sun. The measurement of their flux would allow for a better assessment of the uncertainties related to these searches. The paper reports results from an analysis based on an un-binned likelihood maximization, using muon neutrino data collected over 11 years. No evidence for a solar atmospheric neutrino signal has been found. An upper limit at 90% confidence level on the flux of solar atmospheric neutrinos has been obtained, equal to 7×10^{-11} TeV^{-1} cm^{-2} s^{-1} at $E_\nu = 1$ TeV for the reference cosmic ray model assumed. As can be seen from the figure next column, both the ANTARES and the IceCube limit are still about an order of magnitude higher than the prediction of the baseline model assumed in this analysis. Note also, that despite the smaller size of ANTARES, the ANTARES limit is slightly tighter than that from IceCube, due to its better angular resolution (significantly decreasing the number of Earth atmospheric neutrinos entering in the angular search window) and energy estimation of the neutrino candidates (taking into account the different ν_μ energy fluxes for SAv and Earth atmospheric neutrinos).



ANTARES upper limit (solid red) and sensitivity (dashed red) for 11 years of data, assuming the Sun as a point-like source for the baseline model H3a-Ser+Stein (solid blue line). For comparison, the current 6 years IceCube upper limit is also shown (solid black line). The ANTARES limit and sensitivity lines expand in the energy range which contains 90% of the expected number of events.

The RNO-G collaboration has submitted an article *In situ, broadband measurement of the radio frequency attenuation length at Summit Station*, Greenland to the Journal of Glaciology (posted at 2201.07846.pdf (arxiv.org)).

Radiowave detection of neutrino-generated signals in cold polar ice has emerged as perhaps the most promising technique for detection of extragalactic neutrinos with energies above 100 PeV. During the summer of 2021 and in tandem with the initial deployment of the Radio Neutrino Observatory in Greenland (RNO-G, see GNN Monthly of October 2021), radio-glaciological measurements have been conducted at Summit Station, Greenland to refine the understanding of the ice target. The paper reports the result of one such measurement, the radio-frequency electric field attenuation length L_α. It is found to depend approximately linearly on the frequency, see the figure.



Measured average electric field attenuation for the top 1500 m of the ice sheet, as a function of frequency at Summit Station, derived from the measured bulk field attenuation and the relationship between attenuation and temperature. Overlaid is the ±1σ confidence interval of a linear fit of the data.

A very special paper

In arXiv:2112.11375 , an association was claimed between fast radio bursts and Ice-Cube neutrino events at a quoted significance level of 21 sigma. Citing from their abstract: "*Utilizing recently released IceCube neutrino and CHIME FRB catalogs, we examine the possibility of an association between neutrinos and FRBs for both the entire FRB population and individual FRBs using the directional matching method. We report an association between FRBs and low-energy IceCube neutrinos with energies 0.1 – 3 TeV at a significance level of 21.3σ*". An independent analysis in arXiv:2112.13820 found no signal. The first paper was withdrawn from arXiv.

Miscellaneous

IceCube in space

As mentioned above, the IceCube Neutrino Telescope is negatively affected by COVID. Not so another IceCube: The first COVID-19 drug research in space started operations in the European commercial ICE-Cubes facility in December on the International Space Station – see the picture next column.

See more under https://www.icecubesservice.com/

Dark Ghosts Workshop

The third *GNN Workshop on Indirect Dark Matter Searches with Neutrino Telescopes* (Dark Ghosts) will be hold at March 31 and April 1 as a full in-person meeting in Granada, Spain. The goal of the workshop is to bring together experts on indirect detection of dark matter with neutrinos from different experi-ments: IceCube, KM3NeT, ANTARES, GVD... as well as phenomenologists and theoreticians to discuss the latest advances and future avenues on the indirect detection of dark matter with neutrinos. The deadline for the submission of abstracts is February 28. See https://indico.cern.ch/event/1075227/ for more information.

2022 GNN Dissertation Prize: Call for Nominations

The GNN Board announces the call for the 2022 GNN Dissertation Prize. This is the eighth year the prize will be awarded.

The conditions are:

1) All involved in supervising PhD theses can send nominations.
2) Only one candidate can be nominated per proposer.
3) The thesis must have been successfully defended.
4) The date of the defense must have been in the period April 1, 2021 to March 31, 2022.

5) The proposer should submit a short laudation detailing why she/he proposes the thesis for the Dissertation Prize.
6) Accepted languages are, to a certain degree, defined by the availability of reviewers from other countries and institutes. The standard case is that the theses are written in English. Please contact Uli Katz if this is not the case.
7) If not contained in the thesis, a 2-page English summary written by the candidate is required.
8) The main criterion will be the quality of the thesis, not just the best limit or most spectacular result. It is thus also possible to receive the prize for a technical thesis or e.g. for a thesis on improving the event reconstruction.
Nominations, including an electronic version of the thesis in PDF format and the documents specified above, should be sent by email until April 15, 2022 to Uli Katz (katz@physik.uni-erlangen.de)

Obituary

On December 28, 2021 Buford Price, one of the founding fathers of AMANDA, passed away.

Buford was a member of the group demonstrating in 1990 the detection of muons using Greenland ice as a detector (Lowder, Miller, Price, Westphal, Barwick, Halzen, Morse, Nature 353 (1991) 331) (https://www.nature.com/articles/353331a0).

P. Buford Price was born in Memphis, Tennessee on November 8, 1932. After having received his PhD in 1958, he moved to the University of Bristol, England. In 1960 he was recruited to do research at the General Electric Laboratory in Schenectady, New York. In 1969 he was offered a professorship at the Department of Physics, UC Berkeley, which he held until his retirement in 2002. He remained a Professor of the Graduate School from 2002 until his death in 2021.

His scientific accomplishments contributed to a wide range of disciplines. At General Electric, he developed the nuclear track-etch technique for which he received the Ernest Orlando Lawrence Award and which continues to find widespread application in geology, geophysics, anthropology, high-energy nuclear physics, exotic radioactivity, planetary science, and high-energy astrophysics, as well as commercial applications. He was one of the first scientists to analyze lunar samples returned by the Apollo astronauts, and later developed cosmic-ray detectors that were deployed on the Russian Space Station.

Buford's membership in AMANDA an IceCube led to highly productive work in glaciology, paleoclimatology (https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2000GL011351), and the study of extremophile bacteria living in Antarctic ice (https://academic.oup.com/femsec/article/59/2/217/2908360).

Buford was elected to the National Academy of Sciences in 1975 as a result of his early work, and he contributed to many other fields during his research career spanning more than five decades. He trained several generations of students who went on to productive scientific careers, a testament to his highly collaborative approach to doing science. All who worked with Buford knew him to be a delightful colleague, peer and mentor.

Buford left his mark on many lives both professionally and socially. Most of all, his limitless curiosity and enthusiasm was a constant source of inspiration for his students and collaborators.

We will miss his sparkling eyes and trademark smile.