GNN Monthly

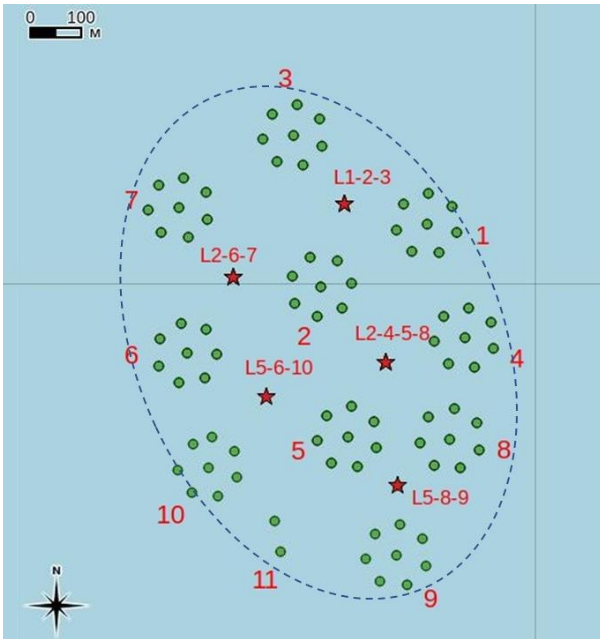
The Global Neutrino Network 62th Edition April 30, 2022

The feeling to write about physics while a brutal war against Ukraine is raging less than 1000 km from Germany is as bizarre and depressing as it was a month ago, when I released the previous GNN Monthly; actually, even worse. A quarter of the Ukrainian population has left their homes and is on the run westward. More than 2 million are in Poland, almost 400.000 in Germany. The war is continuing, thousands of civilians have been killed, not to speak about the soldiers on both sides. Meanwhile many countries have frozen their scientific contacts to Russia. Russia's observer status in CERN has been suspended. The Czech Republic, Poland and Slovakia (all with groups participating in Baikal-GVD) have frozen their participation in all committees of JINR Dubna, have terminated the contracts of their scientists with JINR or will do so in the next months. Needless to say, that this situation strongly affects our friends and colleagues in Baikal-GVD. However, I do not give up to look forward for times when this war is over, hopefully not ending as envisaged by the one who has ordered it, and we can revive our relations of cooperation among <u>all</u> GNN members.
Christian

News from the GNN partners

Baikal GVD

This year, the duration of the period with a sufficiently thick ice cover and the good quality of the ice surface offered best conditions for the GVD deployment campaign. Actually, all planned operations could be completed. A top view of the new configuration is shown in the figure. Two new clusters (9 and 10) have been deployed and connected via their own bottom cables to shore. The red stars in the figure denote single strings with a calibration laser (each linked to one of the neighbored clusters to allow for power supply and control signals). The single string deployed in this season carries not only a laser, but is equipped with 36 optical modules, like a normal string. Like the normal laser strings, also this string has no own shore cable but is linked to a normal eight-string cluster. Strings of this new type are foreseen to fill the “blind” holes between the clusters and allow for better cascade reconstruction and background rejection.



A second “experimental string” has been deployed. It uses optical instead of the present electrical communication along the string (and therefore allows for a much higher data rate and more sophisticated triggers). The two experimental strings are denoted by “11”. Last but not least, significant repair and modernization operations with existing clusters have been succeeded.

Baikal-GVD now consists of 2916 optical modules. With the elliptic envelope shown in the figure and a length of 530 meters of instrumented strings, the geometric volume of the detector is now close to 0.3 km^3. The detector is taking data since April 12.

Optical modules waiting for deployment

Channeling an ice block from a hole through which a string will be lowered.

Dmitry Petukhov and Igor Belolaptikov discussing the route for the shore cable and how to mark it on the ice surface.

IceCube

The Final Design Review of the IceCube mDOM took place on 11-13 April 2022. The prototypes had undergone a successful design verification, and the plan moving forward into a pre-production path of forty modules seems well justified. The mDOM design is one of the two main optical sensor modules for the IceCube Upgrade (the other being the Japanese D-Egg, of which the full number of OMs has already been produced in 2021, see GNN Monthly 52, March 2021).

Prototypes of mDOM (left) and D-Egg (right)

Tests and analysis of prototype mDOMs have shown that the final design fulfills the design requirements in a robust way. The IceCube-internal review panel has a set of recommendations, which reflect a few questions or comments related to the design, and some additional questions or comments related to the upcoming production processes. However, none of these are considered to be critical design issues.

Evaluation of the IceCube Upgrade Project: On April 26-28, 2022, the National Science Foundation held a 2½-day panel review "charged with evaluating the IceCube Upgrade current plans to complete the scope that was proposed to NSF" in response to the Upgrade project request for supplemental funds to complete the Upgrade at full scope. The project lost the polar seasons 2020/2021 and 2021/2022, and will not deploy a crew during the upcoming season 2022/2023 due to COVID. In January 2022, the NSF provided the project with a plan for supporting Upgrade cargo in 2022/2023, and personnel deployments to South Pole during the 3 following seasons with the ice drilling and instrumentation installation occurring in 2025/2026.

The project spent the next ten weeks developing a new "bottom-up" plan for completion of instrumentation and delivery of other technical scope in the North and the three field seasons that include drill repair, upgrades, testing, and finally delivery of 7 installed strings of Upgrade instrumentation to IceCube operations. Additional NSF funds of approximately $12 million are sought to realize this plan. Collaborating partners' in-kind support has remained robust throughout the pandemic. The plan and budget were presented to a panel of ten experts in the areas of Antarctic logistics and operations, instrumentation, and project management who evaluated the project's technical progress, logistical plan, cost, schedule, and risk. The panel will provide a recommendation to the NSF in the coming weeks who will provide further direction to the Upgrade project.

ECR Advanced Grant for Elisa Resconi

Elisa Resconi from TUM Munich has been awarded an ERC Advanced Grant for her project NEUTRINOSHOT.

The project aims to build, install, and operate three instrumented strings placed 50 meters apart and equipped with 20 optical modules over one km. The project will act as a demonstrator and pilot phase for P-ONE (see Matteo Agostini et al. The Pacific Ocean Neutrino Experiment. Nature Astron. 4 (2020), 913). The three strings represent about 4% of the P-ONE full telescope.

NEUTRINOSHOT will, for the first time, detect neutrinos in the Pacific Ocean. It shall demonstrate performance and verify all the fundamental operations of a neutrino telescope: spatial and temporal reconstruction of atmospheric muons (about 800/day), neutrinos (about 30/year), and the rejection of ambient background. Three strings compose the minimal unit to overdetermine all these quantities allowing central cross-checks of in-situ performances. In addition to the primary purpose of testing this case, the instrumentation deposited at Cascadia Basin will be equipped with thermometers and pressure sensors to enable studies of oceanography and environmental changes. All data will be made public through the service offered by Oceans 2.0 (a platform to exploit Earth and Ocean science data) and mirrored at the Leibniz Super-computing Centre in Munich (LRZ). The total budget is 3.2 Million Euros over 5 years.

The full project P-ONE is conceived to complement KM3NeT and Baikal-GVD, with the goal to form a distributed Northern network of neutrino telescopes.

Congratulations, Elisa, and good luck!

Publications

The KM3NeT Collaboration has submitted the summary paper on their OM *The KM3NeT multi-PMT optical module* to the Journal of Instrumentation JINST (posted at https://arxiv.org/abs/2203.10048). The corresponding authors are Ronald Bruijn (Nikhef), Marco Circella (INFN Bari), Daniele Vivolo (INFN Napoli).

The optical module of the KM3NeT neutrino telescope is nothing new for GNN readers. Its design served also as the model for the mDOM of IceCube (see above). It contains 31 three-inch photomultiplier tubes in a single 0.44 m diameter pressure-resistant glass sphere. The sphere also houses calibration instruments and electronics for power, readout and data acquisition.

View of an optical module, illustrating its large effective and segmented photon detection area. On the left of the middle PMT, the acoustic piezo sensor used for positioning measurements is visible. The sphere hangs in a titanium collar required for mounting it along a detection unit ("string"). In this picture, the optical module is shown bottom-up.

The design of the module was qualified for the first time in the deep sea in 2013. Since then, the technology has been further improved to meet requirements of scalability, cost-effectiveness and high reliability. Here are the main features of the design:

- A photocathode area of about 1300 cm² in each sphere (three times the area of a single 10" PMT, allowing a sparse distribution of optical modules in the detection volumes),
- Almost uniform and extended angular coverage of the telescope with a field of view above horizon,
- Sensitivity to the incoming direction of detected photons,
- Good photon counting performance, dynamic range from one to thousands of photo-electrons,
- Good position (10 cm) and timing (sub-nsec) calibration,
- Possibility to define local triggers (implemented onshore) based on the pattern of PMT signals,
- Mechanical infrastructure of the detection unit with a small number of pressure housings and barriers as well as electronics, allowing for a significant cost reduction at parity of detector performance,
- Uniformity of this most important component of the detectors, which allows for reliable production and also eases scientific analyses.

The exploded view of the OM components has often been shown. Here instead a photo of a selection of components:

Most details are self-explaining. 5. is a tray for routing of optical fibers, 6. the cooling and support mechanics (shell with rod mounted), 7. the power board, 8. the Central Logic Board, 10. the pressure gauge 11. the two signal collection boards, 12. the nanobeacon (led flasher) on driver board, 14. the piezo hydrophone and 15. the laser transceiver.

At the end of 2021, more than 700 modules have been produced, of which more than 340 are already installed in the ARCA and ORCA detectors. A total of more than 6000 modules will be assembled at eight production sites in the KM3NeT Collaboration.

The IceCube Collaboration has submitted a paper *First Search for Unstable Sterile Neutrinos with the IceCube Neutrino Observatory* to Phys. Rev. Lett. (posted at 2204.00612.pdf (arxiv.org)). The main author is Marjon Moulai (MIT, Cambridge).

The longstanding anomalies in short-baseline (SBL) neutrino experiments have been interpreted in the standard oscillation framework of three known flavors and one or more hypothetical sterile neutrinos (3+N models). The 3+1 model with only one sterile neutrino has been extensively studied through global fits to data sets sensitive to vacuum oscillations involving a dominant mass splitting of ~1 eV². These fits find a preference for 3+1 over the 3+0 hypothesis. However, the allowed regions from these fits suffer from tensions between datasets. In particular, no experiment has found evidence of ν_μ disappearance, which is expected in a 3+1 model. An extension to the basic 3+1 model are models where the sterile neutrino is unstable ("3+1+decay") where theses tensions seem to be reduced.

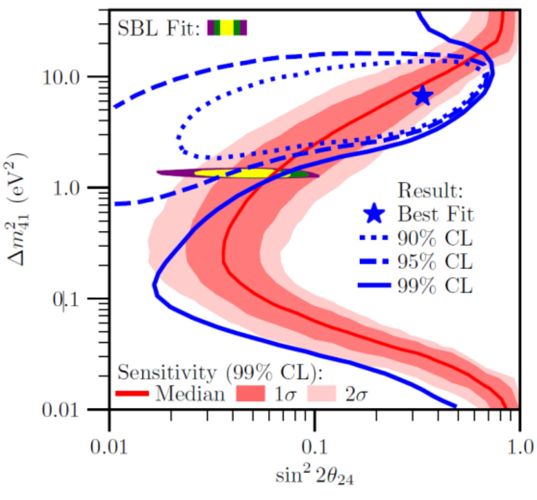
In order to be seen as a well-motivated improvement, the 3+1+decay model should be tested through entirely different processes than vacuum oscillations (as all the experiments mentioned above). This can be done with IceCube. Here, the existence of an eV-scale sterile neutrino can manifest itself as a resonant, matter-enhanced flavor transition for muon (anti)-neutrinos traversing the core of the Earth. This causes a deficit of up-going muon (anti)neutrinos at TeV-scale energies. A search in the framework of the 3+1 model using eight years of IceCube data has been published in 2020 (arXiv:2005.12942 and 12943). The same data set offers a good platform to test whether the 3+1+decay hypothesis provides a better description of the data than the 3+1 model.

In addition to the parameters of the 3+1 scenario, a decay parameter is g introduced, defined via

$$\tau = \frac{16\pi}{g^2\ m_4}$$

with τ being the lifetime and m_4 the mass of the fourth neutrino.

Two analyses have been performed, a frequentist and a Bayesian. Both describe the data better than the 3+1 model without decay. The frequentist analysis gives a best fit for g^2 around 2.5π, that of the Bayesian analysis around 1.5π. The best fit for the oscillation parameters are $\Delta m_{41}^2 = 6.7\ (+3.9/-2.5)\ \text{eV}^2$ and $\sin^2 2\theta_{24} = 0.33\ (+0.20/-01.7)$. The figure below shows the results for the frequentist analysis, after fixing g^2 to 2.5π. The preferred regions from SBL oscillation searches are excluded at 90% C.L. Both the three-neutrino and the 3+1 models are disfavored relative to the 3+1 +decay, with p-values of 2.5% and 0.81%, respectively.



Result of the frequentist analysis for $g^2 = 2.5\pi$. The 90%, 95%, and 99% C.L. contours are shown as blue dotted, dashed, and solid curves, respectively. The best-fit point is marked with a blue star. The median sensitivity at 99% C.L., determined from 300 simulated datasets, is shown as a red curve. The medium and light pink bands indicate the 1σ and 2σ regions for the sensitivity. The 2D projection of the SBL fit results for the range $2.25\pi < g^2 < 2.75\pi$ at 90% C.L., 95% C.L., and 99% C.L. are shown as the solid yellow, green, and purple islands around $\Delta m_{41}^2 = 1.3\ \text{eV}^2$. See the paper for more explanations.

Miscellaneous

First GNN Machine Learning Meeting

The first meeting of the machine learning (ML) WG under the Global Neutrino Network took place on 8 April 2022 via Zoom. The material can be found at https://indico.cern.ch/event/1141191/ (password ml4gnn). Read the report from Andreas Søgaard:

The meeting was very well-attended by researchers from all GNN experiments. This first meeting included three presentations and was intended to provide an overview of ML activities at the different experiments, and thereby set the scene for future more focused meetings.

The first presentations, by Thorsten Glüsenkamp (ECAP, Erlangen), was an overview of ML activities at IceCube. Thorsten covered recent work on two types of ML in IceCube: Posterior-type predictions (i.e., traditional ML, predicting a point estimate of, or a probability distribution over, some target variable for each event) and likelihood-type predictions (i.e., using ML to estimate individual likelihood factors or functions, which in turn can be used in a traditional maximum-likelihood setting each event). The posterior-type methods ranged from well-established high-energy cascade reconstruction using convolutional neural networks to work-in-progress on graph neural network reconstruction and normalising flows. The likelihood-type methods provide ways of including, e.g., domain knowledge and systematic uncertainties into the "machine" and thereby improve performance of traditional ML models, at the cost of increased computational complexity.

The second presentation, by Daniel Guderian (WWU, Münster), was an overview of ML activities at KM3NeT. Daniel gave a comprehensive account of the evolution of ML methods in use at KM3NeT, from the first boosted decision trees used for particle identification (PID), over the first deep learning studies using convolutional neural networks for PID and reconstruction, to the latest graph neural networks which are already being applied to real data from ORCA6. In general, KM3NeT is pursuing an impressive program of advanced graph neural network-based applications across physics tasks — from neutrino *reconstruction and identification, over muon multiplicity reconstruction, to anomaly detection and estimation of the Bjorken variable in GeV-scale neutrino interactions — which it will be exciting to follow as the work progresses.*

The third and final presentation, by Stephan Meighen-Berger (TUM, Munich), was a presentation of Prometheus, an open-source neutrino telescope simulation framework. The project combines existing, open-source codes (LeptonInjector, PROPOSAL, PPC, and Olympus) and exposes a simulation suite that covers particle propagation, light production, and light propagation in an ice or water medium. This allows for standardized MC simulation of events across detectors (IceCube, KM3NeT, Baikal-GVD, P-ONE, etc.), energies, and particle types, with resulting truth and "reco." data stored in a generic, experiment-independent format (Apache Parquet and Awkward Array). Hopefully, open-source simulation code and open data can help pave the way for even closer collaboration on, and even more open discussion about, ML techniques across experiments.

The next ML WG meeting is being planned for May 2022, with an announcement to follow closer to the date.

RICAP 2022 in Rome

The registration for the eight edition of the Roma International Conference on Astroparticle Physics (RICAP-2022) is now open. The Conference will be held in the Physics Department of University "La Sapienza", in Roma, Italy, on September 6th-9th. See

https://agenda.infn.it/event/29838/

where you can also find all the relevant information to attend the Conference.

The Conference program is in preparation. As for the previous editions the Conference will be organized with plenary and parallel sessions. A poster session is also foreseen.

The Conference, as in the previous editions, in a multi-messenger contest, will be dedicated to discussions on experimental results and theoretical predictions in the field of Astroparticle, Cosmic Ray physics and Dark Matter search.

The organizers invite to submit abstracts, starting from April 1st, for oral presentation and posters following the instructions on the web site of the conference.

The Deadline for submission of abstracts is July 15th, 2022.

GNN Dissertation Prize

The deadline for the submission of nominations for the GNN dissertation prize has been prolonged until May 20. Uli Katz will send out reminder next week.

First in-presence collaboration meetings after a long time

The IceCube and KM3NeT collaborations will held their first in-presence collaboration meetings after more than two years: May 16-20 in Brussels (IceCube) and Athens (KM3NeT/ANTARES).