GNN Monthly

The Global Neutrino Network | 84th Edition | March 30, 2024

MANTS Meeting

GNN's 2024 MANTS meeting took place on March 24/25 at the Ruhr University Bochum, excellently set up and organized by Anna Franckowiak and her group. The meeting started with project status reports (IceCube, KM3NeT, Baikal-GVD, P-ONE as GNN members, and TRIDENT and HUNT with invited contributions). The other talks have been grouped in thematic blocks (galactic plane, point sources, diffuse fluxes, neutrino oscillations, optical modules etc.), mostly with one talk from each collaboration (IceCube, KM3NeT/ANTARES, Baikal-GVD). These jointly agreed talks were partially framed by an introduction and a summary – very helpful to understand the differences and to discuss ways to converge. There was plenty of time for questions & answers after the talks, and for discussion during long coffee breaks. The slides of the talks are available at https://indico-sfb1491.epp.physik.tu-dortmund.de/event/41/

News from the Experiments

KM3NeT

Already in January, the ORCA team has relocated the control room from the Institute Michel Pacha to the Ifremer Campus. This required the extension of the on-shore optical fibers by about 9 km and commissioning of the new control room.

For the upcoming ORCA sea operation, 11 DUs ("strings") are waiting on shore to be deployed. The present single junction box (JB) can host 24 DUs. 18 DUs are operating at the moment, so another six can be connected to this JB. A second JB will be available after summer. For the fall ARCA sea operation, it is planned to deploy two new junction boxes and up to 20 new DUs.

IceCube

The Spring Meeting of IceCube Collaboration took place on March 18-22 in Münster, Germany. Münster was one of the two cities where the Peace of Westphalia was signed, ending the Thirty Years' War from 1618 to 1648. With 90 percent of the city destroyed during the Second World War, its rebuilt center again breathes the spirit of a great past (and makes one despair that there are still wars).

The meeting was excellently hosted by Alexander Kappes' Münster group. 238 participants attended in person and 21 online.

During the collaboration dinner, the results of the eleventh edition of the IceCube Impact Awards were announced. Here are the awardees:

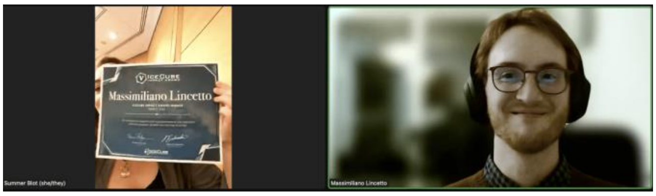
Lasse Halve (RWTH Aachen) for key contributions to D-Egg and mDOM PMT testing with significant impact on OM production for the IceCube Upgrade.

Massimiliano Lincetto (U.Würzburg/DESY) for exceptional support and improvements to two real-time software projects ("SkyMist" and "Skymap Scanner").

Nora Valtonen-Mattila (U.Würzburg), for significant contributions to supernova monitoring operations, including the readout of HitSpool data in response to supernova alerts and introducing a novel application of the supernova data acquisition system.

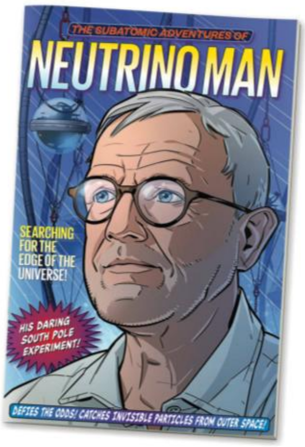
[Erik Ganster](#) (RWTH Aachen) and [Richard Naab](#) (DESY) earned the Group Impact Award for leadership in enabling and supporting a wider use of the NNMFit analysis software tool in the collaboration.

From left to right: Erik Ganster, Richard Naab, Nora Valtonen-Matilla, Lasse Halve, and IceCube Spokesperson Ignacio Taboada after the awards ceremony in Münster.



Connected online: Massimiliano Lincetto

At March 23, Francis Halzen turned 80 – I guess this was the only the second collaboration meeting over all the years which he missed. We celebrated the birthday (and at the same time about 30 years of ice-based astronomy) with a speech by Olga Botner and by singing altogether "Happy Birthday" (filmed and sent to Francis on March 23).



Congratulations, Francis, and thank you for your leadership and vision. ("*Nothing is guaranteed, but history is on our side!*" 😉). We wish you health, continued fun with physics, and – if any possible – a soon close-by supernova (or whatever you wish yourself)!

Baikal-GVD

The 2024 Baikal-GVD expedition is approaching its end.

The plan for this expedition was to complete cluster #12 with the yet missing three strings, to install cluster #13, to lay two cable communication lines (one for cluster #13 and one for the future cluster #14), to add a third string of the fiber-optic experimental cluster (now using new Chinese-made hybrid cables), to repair some failed components in earlier clusters, and to deploy an experimental string built in IHEP Bejing for a first long-term test. This "Chinese string" carries twelve 23"-spheres, each housing a 20" PMT. Truly a huge working plan!

There is less than a week left until the melting ice will dictate to dismantle the ice camp. As of March 28, most of the above program has been completed. There is even hope to deploy one or two strings of cluster 14.

A final report will follow in the next edition of GNN Monthly.

Baikal veteran Igor Belolaptikov turned 60 during this year's campaign. The event was met with an evening grill party at shore. Congratulation, Igor!

As for previous expeditions, Bair Shaibonov from Dubna documented the campaign with fantastic pictures. Here are some of them:

Excavating an ice hole

The diver who is to pull the cable up from a depth of about thirty meters before diving in.
Right, in full action, Konstantin Konishev (Dubna).

A "must" during every expedition: the group photo on ice

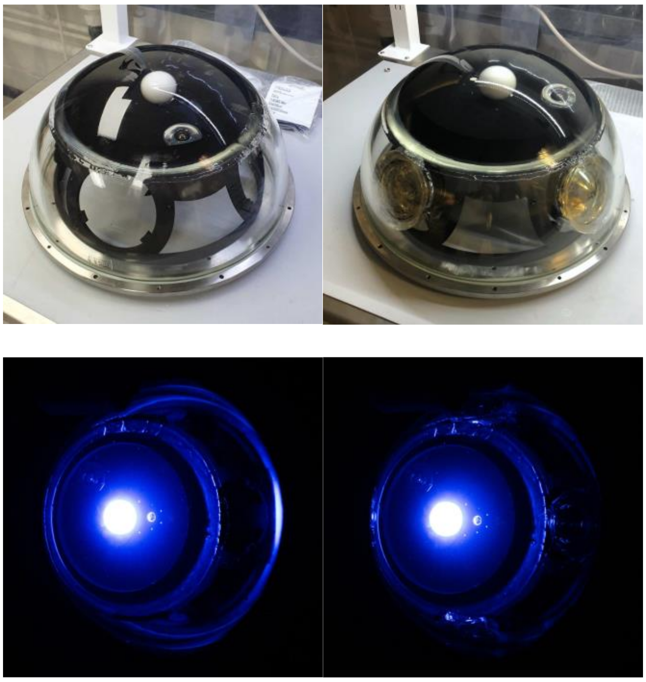
Vladimir Aynutdinov, Vladimir Chadymov and Aleksandr Doroshenko looking to the electronic block of the cluster center for the new "optical fiber cluster". The faster transmission along fibers would allow for much more sophisticated triggers and a substantially better sensitivity. At present, this technology is still in its test phase.

Igor Belolaptikov together with Chinese colleagues from IHEP Bejing. In front of them: boxes with 6 of the 12 optical modules of the "Chinese string".

Top: a Chinese optical module, a 23" glass sphere housing a 20" PMT. Bottom: a GVD module housing a 10" PMT.

P-ONE

The P-ONE team at Simon Fraser University (SFU) has successfully developed and integrated the first P-ONE calibration module – short P-CAL – last week. The P-CAL is a hybrid calibration module with integrated photosensors and isotropic, self-monitored nano-second light pulsers [*PoS ICRC2023 1053 (F. Hennigsen et al.) & 1113 (J. Stacho, F. Henningsen, K. Nell and M. Danninger)*]. It will be used for both optical characterization of water properties and relative positioning within the P-ONE array. Optical gel around the light diffuser in the center corrects for in-water refraction to provide a maximally isotropic light emission into the P-ONE detector volume. The SFU team is further developing the piezo-acoustic receivers for acoustic detection line positioning, which are included in all P-CALs as well as all regular P-ONE optical modules (P-OMs) [*PoS ICRC2023 1112 (D. Ghuman, F. Henningsen, M. Danninger, et al.)*].



Integrated P-CAL instruments before testing (top row) and during testing (bottom row). The module is shown with and without integrated PMTs (right and left column, respect-tively). Optical gel is used in the volume around the diffuser to correct for refraction when deployed in water. The various reflections seen in the testing images are expected and arise from light-guide and back-scatter effects of the glass pressure sphere only when tested in air.

Publications

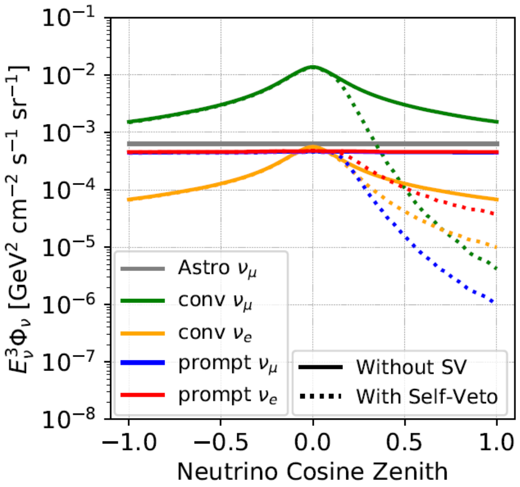
End of February/March, the IceCube Collaboration has posted three papers:

Characterization of the Astrophysical Diffuse Neutrino Flux using Starting Track Events in IceCube (2402.18026.pdf (arxiv.org)), submitted to Phys.Rev.D, with lead authors Sarah Mancina, Jesse Osborn, and Manuel Silva, all UW Madison (Sarah Mancina now Univ. Padua),

Improved modeling of in-ice particle showers for Ice-Cube event reconstruction (2403.02470.pdf (arxiv.org), submitted to JINST, with lead author Tianlu Yuan (UW Madison),

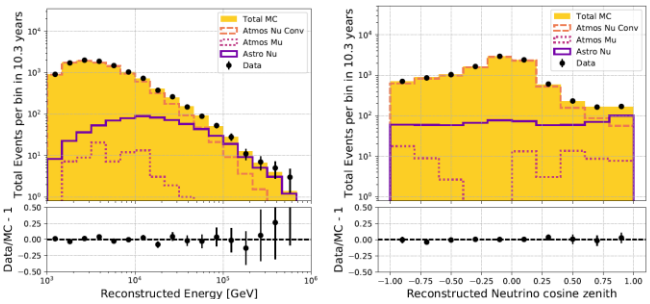
Observation of Seven Astrophysical Tau Neutrino Candidates with IceCube (2403.02516.pdf (arxiv.org), accepted by PRL, with several Penn. State authors involved in the analysis: PhD student Daria Pankova, postdocs Philipp Eller (now at TUM), Timothée Grégoire (now in France) and Aaron Fienberg (now with Blackberry) and PI Doug Cowen. There was also additional support from the Aachen group.

Characterization of the Astrophysical Diffuse Neutrino Flux using Starting Track Events in IceCube
The analysis uses data collected from 2011-2022 (10.3 years). It presents novel detection techniques to search for events with a contained vertex and an exiting muon track. For the southern sky, this allows not only to reject more effectively atmospheric muons, but also atmospheric neutrino backgrounds, opening a new window to the sub-TeV astrophysical neutrino sky. The event selection is constructed using a dynamic starting track veto (“self veto” against accompanying downward muons) and machine learning algorithms – see the paper for the tricky veto procedure, known as *Enhanced Starting Track Event Selection* (ESTES). The dataset contains 10798 neutrino events of which about 1000 were assigned to the southern sky. The next figure shows the expected atmospheric neutrino fluxes with and without accounting for the self-veto, resulting in a strong suppression of down-going atmospheric neutrinos.



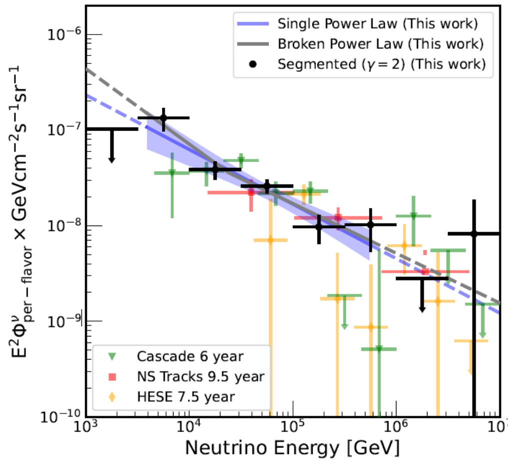
Atmospheric and astrophysical neutrino fluxes with and without accounting for the self-veto. Note that with the self-veto and for cosine zeniths greater than 0.2, the astro-physical neutrino rate at E> 50 TeV is higher than the atmospheric neutrino flux.

The next figure shows the energy and the cosine zenith distribution for experimental data, compared to MC simulations.



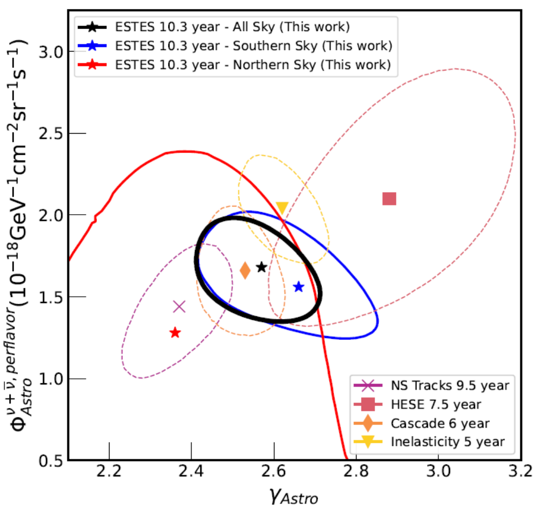
The reconstructed energy and cosine zenith distributions for experimental and simulated data using the best-fit para-meters from the single power law flux measurement. The astrophysical neutrinos are shown as a solid purple line, the atmospheric neutrino and muon expectations are shown as dashed and dotted lines respectively. The error bars shown for experimental data are due to Poisson statistics only.

Fitting the astrophysical diffuse flux as a single power law flux (SPL), one gets a best-fit spectral index of γ = 2.58 (+0.10 −0.09) and a per-flavor normalization of φ_{Astro} = 1.68 (+0.19−0.22) × 10^{-18} × GeV^{-1} cm^{-2} s^{-1} sr^{-1} (at 100 TeV). The sensitive energy range for this dataset is 3 - 550 TeV under the SPL assumption (the measured flux goes down to an impressively low value of 300 GeV for the astrophysical component). These data were also used to measure the flux under a broken power law, however no evidence of a low energy cutoff was found – see the next figure.



Per flavor astrophysical neutrino flux as a function of energy. The black points are the segmented power law flux measurement assuming a spectral index of -2 per segment. The blue line with error bands corresponds to the SPL measurement. The blue shaded region is the 90% sensitive energy range. The gray line is a fit to data assuming a broken power law flux. Included are also results from recent IceCube publications.

The next figure shows the flux vs. spectral index plot for the various IceCube analyses.



Summary of the SPL 68% confidence intervals for the All-Sky, Southern-Sky, and Northern-Sky SPL measurements.

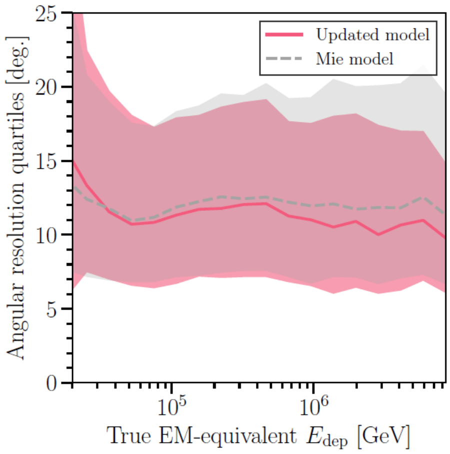
Note the inferior precision for upgoing (Northern sky) events, when compared to the contours for down-going (Southern sky) events. The latter profit from the self-veto rejecting most of the atmospheric neutrino events.

Last but not least, no evidence for a prompt atmospheric neutrino flux was found and upper limits were set of 3.2 times the prediction of the Gaisser H4a-GST cosmic ray model plus Sibyll 2.3c for the prompt flux).

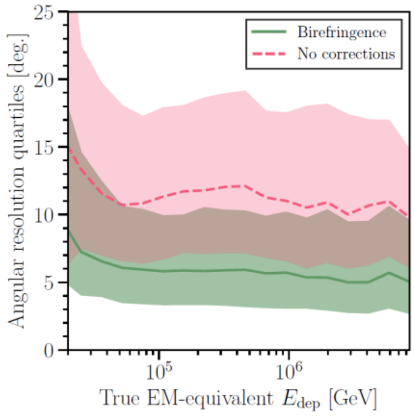
Improved modeling of in-ice particle showers for IceCube event reconstruction

IceCube data analyses depend on an in-depth characterization of the glacial ice, and on novel approaches in event reconstruction that utilize fast approximations of photoelectron yields. In this paper, a more accurate model is derived for event reconstruction that better captures the current knowledge of ice optical properties across the IceCube volume. When evaluated on a Monte Carlo simulation set, the median angular resolution for in-ice particle showers improves by over a factor of three compared to a reconstruction based on a simplified model of the ice. The following figures show the subsequent improvement after 1) refining the old "Mie model" (see section 3 of the paper for details), 2) including birefringence effects due to the poly-crystalline structure of the ice, 3) taking into account the ice layers are not exactly horizontal but undulated and 4) approximating the shower longitudinal extension by simulating double cascades (instead of point-like cascades).

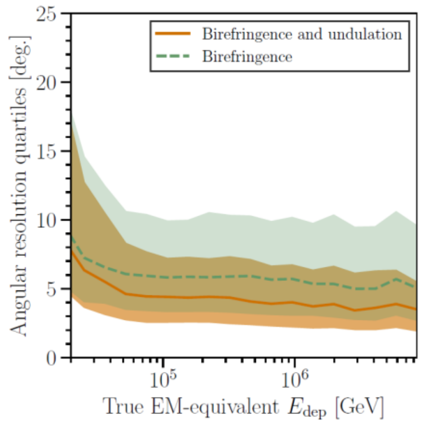
The most substantial improvement is obtained when including effects of birefringence. When evaluated on data classified as particle showers in the high-energy starting events sample, a significantly improved description of the events is observed.



Quartiles of the distribution between reconstructed and true directions, δΨ, as a function of deposited EM-equivalent energy for a benchmark MC sample. Results obtained using the old Mie model are shown in gray. Results obtained with a newer ice model are shown in red. The solid red and dashed gray lines indicate their respective median angular resolutions. Lower (upper) cut offs for each color band show the respective 25 (75) percentile levels of the δΨ distribution.



Same as the previous figure but now including birefringence corrections. The red intervals are identical to those in the previous figure.



Same as the previous figure but now additionally including ice layer undulations. The green intervals are identical to those in the previous figure.

Corrections applied	50 TeV	100 TeV	1 PeV	5 PeV
None (Mie model)	11.0°	11.9°	12.0°	12.6°
None	10.7°	11.3°	11.0°	11.0°
Birefringence	6.1°	5.8°	5.7°	5.7°
Birefringence + undulations	4.6°	4.4°	4.0°	3.9°
Birefringence + undulations + shower extension	4.4°	4.2°	3.5°	3.5°

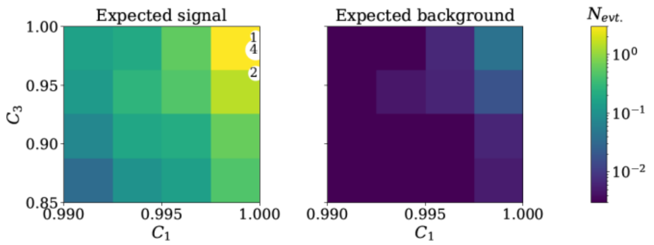
The median angular resolution at the energies listed for the given models. Compared to models that do not include any corrections, the angular resolution is improved by more than a factor of three at 1 PeV.

Observation of Seven Astrophysical Tau Neutrino Candidates with IceCube

The paper describes the identification of astrophysical tau neutrinos with 9.7 years of IceCube data. The analysis uses three separate convolutional neural networks (CNN), trained on images which are derived from simulated events. The CNNs were used to distinguish the ν_τ signal from remaining backgrounds produced by:

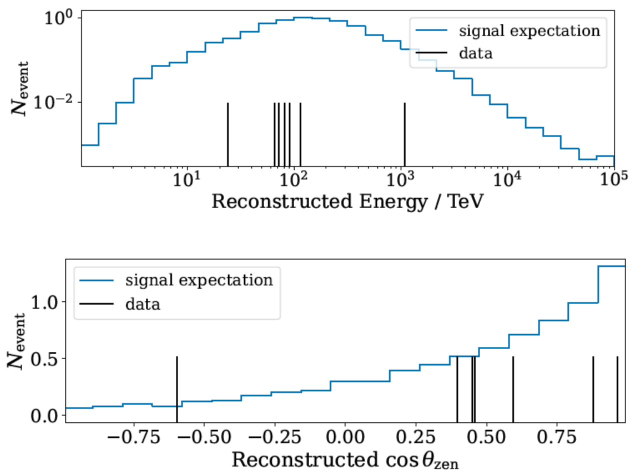
1) single cascade interactions such as $\nu_{e,\mu,\tau}$ neutral current (NC) and ν_e charged current (CC),
2) downward-going muons ($\mu_\downarrow$), and
3) ν_μ interactions producing μ tracks, plus $\mu_\downarrow$.

The associated CNN scores are denoted C_1, C_2 and C_3, respectively, with ranges [0,1]. Seven ν_τ candidates were found, with their positions in the $C_3 - C_1$ plane shown in the next figure, compared to the parameter space population for expected signal (left) and background (right).



Histogram of the C3 vs. C1 CNN scores with all selection criteria applied. The color in each bin gives the expected number of signal (left) and background (right) events in that bin, assuming the IceCube "GlobalFit" flux. The approximate (C1, C3) values of the seven observed candidate $\nu_{astro,,\tau}$ are shown by white circles, with the number inside each circle indicating the number of candidate events.

The visible energies of the seven candidates range from about 20 TeV to 1 PeV, in concordance with the expected energy distribution (next figure top; median expected parent ν_τ-energy ~200 TeV).



Reconstructed visible energies (top) and cos ϑ_{zen} (bottom) for simulated ν_τ CC (solid histogram) and the 7 candidate events (vertical lines) for the diffuse astrophysical flux measured by IceCube flux. The one upward going event with cos $\vartheta_{zen} \simeq -0.6$ has a reconstructed energy of ~90 TeV.

Considering backgrounds from astrophysical and atmospheric neutrinos, and from down-going muons from π/K decays in air showers, a total estimated background of about 0.5 events is obtained, dominated by ν_e and ν_μ astrophysical neutrinos. From this, the absence of astrophysical ν_τ is ruled out at the 5σ level. The corresponding astrophysical ν_τ flux is consistent with expectations based on previously published IceCube measurements of the diffuse astrophysical neutrino flux, taking neutrino oscillations into account.

The paper has a detailed appendix discussing the spatial distribution of the events. Confusingly, all seven events are in a 300 m thick layer around the so-called dust-layer ("z-clustering"). Loosening the cut in C1 a bit yields 9.4 signal and 2.9 background events (i.e. together 12.3 events), which is consistent with 12 observed events, while the z-clustering is tendentially washed out. Other tests also do not reveal anything wrong. So, it is the wisdom of the CCN which has chosen this region to be the best to clearly identify ν_τ events 😉.

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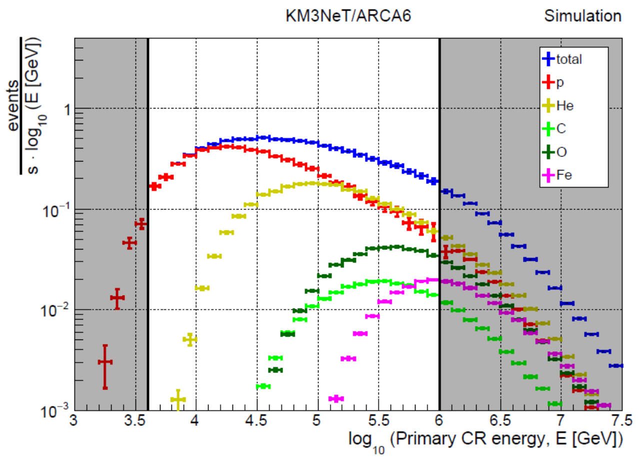
The KM3NeT collaboration has posted a paper *Atmospheric muons measured with the KM3NeT detectors in comparison with updated numeric predictions* (https://arxiv.org/pdf/2403.11946.pdf, submitted to EPJ C) with Andrey Romanov (INFN Genova and Catania), Vladimir Kulikovskiy (INFN Genova) as corresponding authors.

I remember our twofold conclusion from the 2016 IceCube paper about down-going muons (Characterization of the Atmospheric Muon Flux in IceCube (arxiv.org)): Firstly, we need data from a different detector, preferentially with a better sensitivity to down-going particles and with less light scattering, and secondly, simulations would profit from more recent LHC results. The present paper meets these hopes, although both underlying KM3NeT configurations still comprise only 6 strings: ARCA6 and ORCA6.

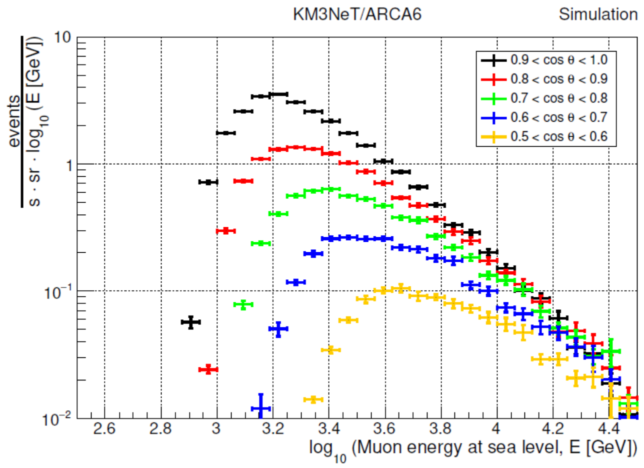
The measurement of the flux of muons produced in cosmic ray air showers is essential for the study of primary cosmic rays. Such measurements are important in extensive air shower detectors to assess the energy spectrum and the chemical composition of the cosmic ray flux, complementary to the information provided by air shower detectors. Even though the knowledge on hadronic interaction has been significantly improved by the LHC measurements, the lack of accelerator data in the forward interaction region does not allow to describe CR air showers accurately. This leaves space for discrepancies, such as observed recently in EAS shower measurements.

In this paper, detailed simulations of the cosmic ray air showers are carried out, using codes such as CORSIKA to extract updated parameters for the underwater muon flux generator MUPAGE, namely using recent input for the hadronic interaction model (Sybil 2.3d) and the CR flux (the GSF model) to estimate the muon flux at sea level. These simulations are based on the choice of hadronic interaction models, for which improvements have been implemented in the post-LHC era.

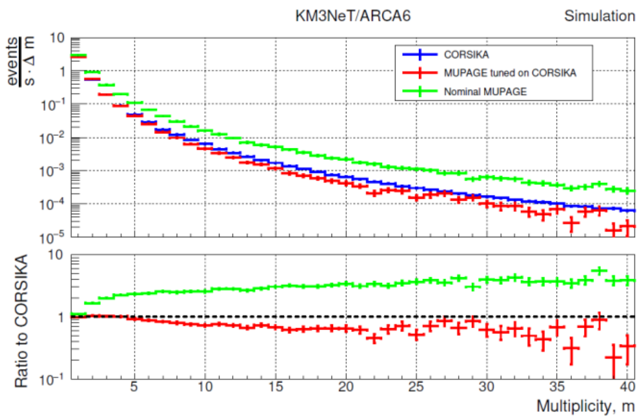
The following two figures show the rate of simulated atmospheric muon events as a function of the primary cosmic ray energy and of the energy of the muons at sea level (here only shown for ARCA6), while the third figure indicates the differences for simulations with different software versions. A strong difference is seen for simulations based on the “nominal MUPAGE” and the “MUPAGE tuned on CORSIKA” (see paper for details).



Rate of simulated atmospheric muon events reconstructed with the ARCA6 as a function of the primary CR energy. The unshaded area corresponds to the 90% fraction of events. Statistical uncertainties are shown as vertical error bars.

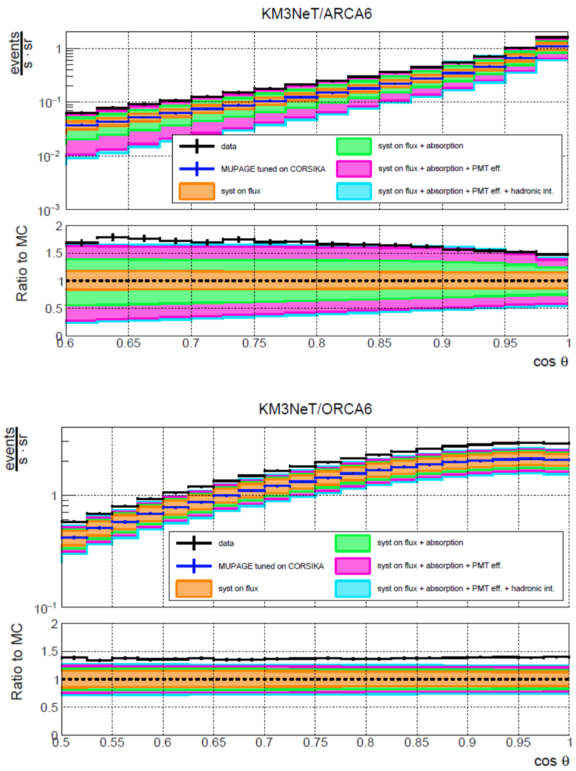


Sea level rate of generated muons from the reconstructed bundles as a function of the muon energy, with different colors for different zenith angle ranges; vertical muons have cos ϑ = 1. Statistical uncertainties are shown as vertical error bars.



Comparison of the CORSIKA simulations (blue) with the MUPAGE tuned on CORSIKA (red) and the nominal MUPAGE (green) for muons on the can from events which passed the trigger condition. For ARCA6 (shown here), the lifetime of the MUPAGE simulations is about 52 hours for the tuned MUPAGE and 43 hours for the nominal one. Here, the comparison is shown for the muon bundle flux as a function of the bundle multiplicity.

As shown in the next two figures, the analysis reveals a deficit of ~40% in simulations that use state-of-the-art QCD models with respect to the KM3NeT measurement. The deficit with respect to the data is constant in zenith angle; no dependency on the water overburden is observed. The observed deficit at a depth of several kilometers is compatible with the deficit seen in the comparison of the simulations and measurements at sea level.



Reconstructed muon rate as a function of the cosine of the zenith angle for ARCA6 (top) and ORCA6 (bottom). The data points are shown in black, the simulations are in blue. Different systematic uncertainties are summed linearly and plotted as colored bands. The lower panels show the ratio between the data and the simulations. Statistical uncertainties are shown as vertical error bars.

The authors note that the observed deficit of simulated TeV muons may indicate that the neutrino production in cosmic sources might be under-estimated with respect to the flux of the accelerated nuclei and with respect to the gamma ray flux. Once the new hadronic interaction model is obtained as a solution to the observed atmospheric muon deficit, the gamma ray and neutrino production in cosmic ray accelerators could be revisited.

This work also provides additional inputs to the Muon Puzzle observed in the measurement of GeV muons from ultra-high energy CR air showers. The recent attempts to solve the discrepancies in the Muon Puzzle should be extended to describe a broader phase space region where the issue is observed. Other muon kinematic properties important for understanding the discrepancy origin include muon bundle multiplicity, lateral spread, and underwater energy spectrum. Proper reconstruction of these observables is expected with the completed KM3NeT detectors.

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Francis Halzen and Paolo Lipari have published an article in APP, commemorating the late Tom Gaisser and his pioneering contributions to astroparticle physics:

Thomas K. Gaisser, a pioneer of particle astrophysics, available at https://authors.elsevier.com/a/1iqoa3Ix5tzN2P (access until May 27 free of charge)

Here is the abstract:

We describe the pioneering contributions of Thomas K. Gaisser to the birth and development of particle astrophysics, a new field of research at the intersection of cosmic ray physics, astronomy, astrophysics, and particle physics that has emerged in the last few decades. We will especially focus on his studies of natural beams of neutrinos: those generated by the interactions of cosmic rays in the Earth's atmosphere and those emitted by astrophysical sources. Tom actively participated in the discovery of these cosmic neutrinos as well. His contributions also extend to gamma-ray astronomy, the study of the cosmic ray spectra and composition, and the modeling of cosmic ray interactions in the atmosphere and in astrophysical environments. Tom invariably focused his research on the theoretical and phenomenological problems of greatest interest at the time, producing frameworks that transparently interpreted often complex data. These studies have been very influential and have shaped the development of the field.

Impressum
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