PROCEEDINGS OF SCIENCE

Status of RNO-G: Radio Neutrino Observatory Greenland

M. Cataldo[a,*] **for the RNO-G Collaboration**

[a] *Erlangen Centre for Astroparticle Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany*

E-mail: maddalena.cataldo@fau.de

Astrophysical hypotheses suggest the existence of neutrinos beyond the energy range currently reached by optical detectors ($>$ 10 PeV). The observation of such particles by capturing the coherent emission of their interaction in ice, i.e. Askaryan radiation, is the aim of the Radio Neutrino Observatory in Greenland (RNO-G). Located at Summit Station, RNO-G represents the first neutrino detector oriented towards the Northern sky, and it will play a role in the future shaping of the larger IceCube-Gen2 Radio Array. The first installed stations of RNO-G are currently active and collecting data, while the full array will reach completion within the next years. The plan includes a grid of 35 radio stations, each designed to be low powered and autonomous. Learning from previous radio detectors, each station includes both shallow antennas mainly for cosmic-ray identification, and in-ice deep antennas with a phased array trigger for detection and reconstruction. We present the motivation, design and current status of the detector.

European Physical Society Conference on High Energy Physics,
21-25 August 2023
Universität Hamburg, Hamburg, Germany

PoS(EPS-HEP2023)076

---

[*] Speaker

1. The Radio Neutrino Observatory Greenland

The deployment of Radio Neutrino Observatory Greenland [1] started in 2021 and is currently ongoing. RNO-G's main aim is the first observation of highly energetic neutrinos, above 10 PeV, and contributing to the multimessenger study by setting new constrains on ultra-high-energy fluxes. The method of detection is through Askaryan radiation. Neutrinos interacting with the atoms of the medium (in this case the greenlandic ice) produce a shower of secondary particles which, propagating in a dense medium, collects a net negative charge on the front part due to the multiple interactions with the ice electrons. The charge that propagates in the ice produces therefore a Čerenkov-like effect with emission in the radio waves. This represents a complementary method of observing neutrinos respect to the optical detection since the attenuation length of radio waves in ice (order of kms) makes possible to cover larger volumes with a minor number of stations and allows therefore to detect higher energies.

RNO-G complete layout includes 35 autonomous low-powered stations located on a grid with 1.2 km spacing. Each station presents a hybrid design with a shallow components buried at ~ 3 m below the ice surface, and a deep component that reaches $\sim 80-100$ m of depth. The surface component is equipped with Log Periodic Dipole Antennas (LPDA), 3 facing upwards and 6 facing downwards. The upward antennas are useful for vetoing cosmic rays and mostly antropogenic backgrounds due to activities occurring on the surface. The deep component consists in three strings to which are attached Vertically and Horizontally polarized antennas (Vpol, Hpol) respectively sensitive to vertical and horizontal signal components. On the power string is located a phased array: a group of 4 Vpols equally spaced from each other which allows to lower the trigger threshold, see Fig. 1. The whole in-ice equipment is predominantly dedicated to event reconstruction (see Section 3), although the vertical cylindrical shape of the boreholes where the antennas are inserted favors the vertical morphology and makes Vpols more efficient than Hpols. The hardware detailed description can be found in [6]. So far 7 of the stations have been deployed. An expedition is scheduled every year to deploy new stations and perform calibration measurements and in-ice studies. Last field season, in Summer 2023, was entirely dedicated to maintenance, calibration and positioning precision measurements [3].

2. Background study and analysis

In order to be able to discern neutrino signals, particular attention has to be dedicated to understand all possible sources of background. Radio frequency emissions can be generated by different sources of either antropogenic or non-antropogenic nature. Man generated RF activity in RNO-G band of detection is mainly produced by GPS signals, airplanes, walkie-talkies, radars, snowmobiles, and so on. In Fig. 2 (*left*) are highlighted the narrowband and broadband backgrounds in the average frequency spectra observed in the upward and downward-facing LPDAs. Some bands, like the narrowband background at 403 MHz given by the weather balloons, or the handheld radio and air-traffic ones, have clear origins, while some other signals, like the continuous transmitter at 200 MHz, are still under investigation. Among non-antropogenic backgrounds we expect cosmic rays, triboelectric events (i.e. wind), galactic and solar activity. A recent analysis has indeed shown a correlation between increased trigger rate and three solar flares in all the stations. A further proof of the relation with solar flares is shown in Fig.2 (*right*) where we observe how accurately the event directions reconstruct the solar position during the solar activity. The galactic activity is also evident in RNO-G data from upward-facing LPDAs. A daily variation of the power in the low frequency band is observed as a function of local sidereal time, and the time variation trend is consistent with the expectation from simulations (Fig. 3 (*right*)) . Both these signals represent both background and calibration sources for RNO-G. An increase of trigger rate is also typically observed during high-wind periods. As observed in other radio detectors in polar regions, the triboelectric effect generated by the wind blowing on the ice surface presents a turn-on effect: the phenomenon is observed above a specific wind speed which in RNO-G is around 10m/s [4]. Another known source of background is given by cosmic rays. The first three cosmic rays candidates were found in the recent analysis performed over the data collected in 2022. It was used a template correlation method in which template waveforms are correlated with waveforms of the data sample and the correlation parameter was used as signal identification. In Fig. 3 (*left*), is shown the plot of the correlation score as a function of SNR where is highlighted one of the the CR candidates with value of correlation close to 1. It is evident how the cosmic ray candidates can be well-discerned from the rest of the background. The three candidates have been found considering the results from burn sample (~ 3% of the full data) of three stations in the time period of 68 days between 07/25/2022 - 10/01/2022 [5], but further searches are being performed as new data are collected.

3. Calibration and Ice Studies

Instrument calibration and ice property studies are performed using in-situ permanent and temporary pulsers. Three pulsers are permanent in each station, two on each helper string and

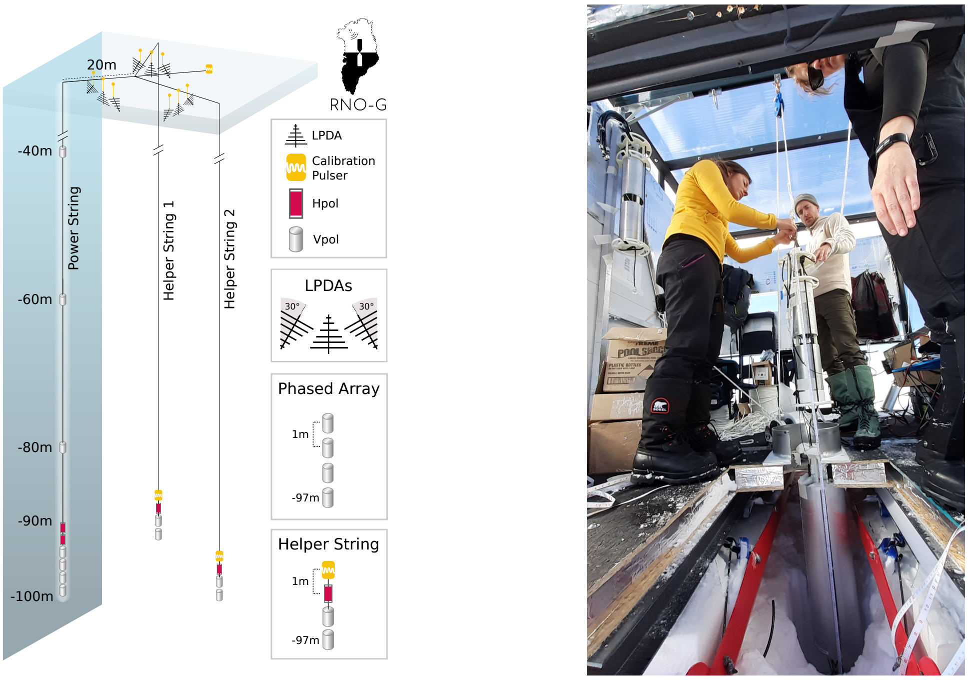


Figure 1: *left* – RNO-G station layout. *right* – Downhole string deployment process.

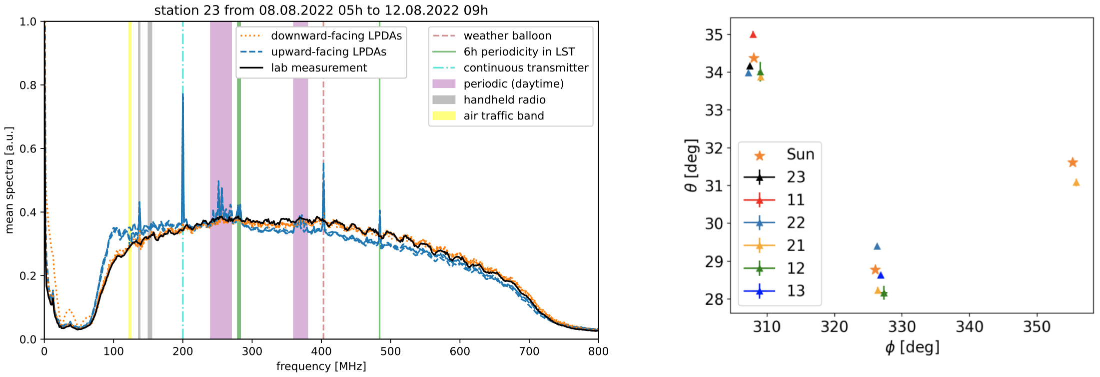
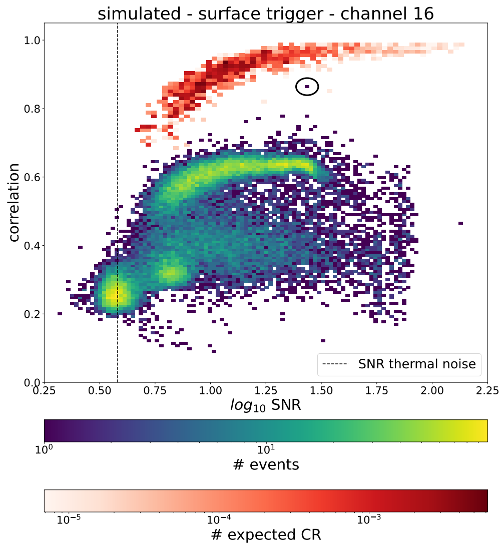


Figure 2: *left* – Average frequency spectra observed in the upward- and downward-facing LPDAs. The spectra are normalised with respect to each other in the 500–650 MHz region. *right* – Preliminary results of reconstructed direction of events for three solar flares for 3 stations.

one at the surface, but other such as temporarily buried pulsers, airplane trackers, radiosonde balloons are also used for calibration. An accurate measurement of antenna positions, signal chain response and ice properties are needed in order to improve the direction reconstruction of events and all these parameters appear to be interconnected. Preliminary Antenna positions are determined through GPS, while more precise measurements were instead obtained in the calibration process of 2023 from time-offset measurements by cross-correlating the waveform of the signals registered in different antennas. However, uncertainty on ice properties also affects the capability of reconstructing the arrival direction of an event because constraining the antenna position is strongly correlated to the ice refraction index. Since the upper layer of the greenlandinc ice (firn) does not have a constant index of refraction the radio waves does not propagate in straight lines but appear to be bent. Hence a good model of the refraction index profile of the firn is needed. Better ice-density



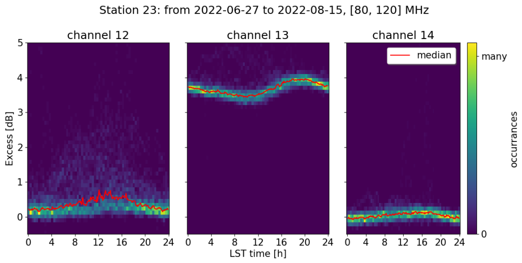


Figure 3: *left* – Correlation score as a function of SNR, the value for thermal noise is represented by the dotted line. The cosmic ray candidate event is circled. *right* – Variation of the power in the frequency spectrum integrated between 80 MHz and 120 MHz for forced trigger data as a function of local sidereal time. The excess is calculated with respect to the hardware thermal noise frequency spectrum normalised to data in the high-frequency range.

measurements were recently performed using a ground penetrating radar (GPR) system. At the moment the interlink between the receiver and antennas positions, and the refraction index of the firn seems to be the largest limitation on the direction reconstruction, hence further effort is being put in increasing the precision of these parameters. Results from the last field season can be found in [3].

4. Conclusions and future perspectives

At the end of its completion, RNO-G will represent the neutrino detector with the largest effective volume in the ultra high energy range and the first neutrino detector at energies above tens of PeV observing the Northern sky. RNO-G's field of view has an optimal overlap with the one of IceCube which is located in Antarctica. This region of the sky appear to include numerous interesting sources already highlighted by IceCube. RNO-G has therefore the potential to provide crucial results regarding multimessenger investigation [7].

Neutrino fluxes at EeV energies are extremely low so their detection is less likely in addition to the already low cross section of these particles. For this reason enhancing the effective volume by increasing the number of radio stations deployed would provide a higher chance of detection. This is specifically the aim of the radio component of the second generation of IceCube: IceCube-Gen2. Its realization is proposed as an extension of the already existing optical array currently active in the South Pole [8] and its effective volume will be order of 10 times larger than RNO-G. In this perspective, RNO-G not only represents the Northern counterpart of a future larger IceCube-Gen2 Radio detector, but it has also the role to inform its future layout based on the performance and upcoming results.

References

[1] J. A. Aguilar *et al.* [RNO-G], JINST **16** (2021) no.03, P03025 [erratum: JINST **18** (2023) no.03, E03001] doi:10.1088/1748-0221/16/03/P03025 [arXiv:2010.12279 [astro-ph.IM]].

[2] J. A. Aguilar *et al.* [RNO-G], PoS **ICRC2021** (2021), 1058 doi:10.22323/1.395.1058

[3] C. Welling *et al.* [RNO-G], PoS **ICRC2023** (2023), 1054 doi:10.22323/1.444.1054

[4] J. A. Aguilar, A. Anker, P. Allison, S. Archambault, P. Baldi, S. W. Barwick, J. J. Beatty, J. Beise, D. Besson and A. Bishop, *et al.* Astropart. Phys. **145** (2023), 102790 doi:10.1016/j.astropartphys.2022.102790

[5] J. Henrichs *et al.* [RNO-G], PoS **ICRC2023** (2023), 259 doi:10.22323/1.444.0259

[6] J. A. Aguilar *et al.* [RNO-G], PoS **ICRC2021** (2021), 1058 doi:10.22323/1.395.1058

[7] M. S. Muzio *et al.* [RNO-G], PoS **ICRC2023** (2023), 1485 doi:10.22323/1.444.1485 [arXiv:2308.07224 [astro-ph.HE]].

[8] IceCube collaboration, 2023. https://icecube-gen2.wisc.edu/science/publications/TDR/