Energy Reconstruction with the Radio Neutrino Observatory in Greenland (RNO-G).

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Station Design

- 9 LPDAs at surface for cosmic ray identification
- Vertically and horizontally polarized antennas for polarization measurement
- 4-channel phased array used as trigger on main string with many antennas
- Support strings for azimuth reconstruction

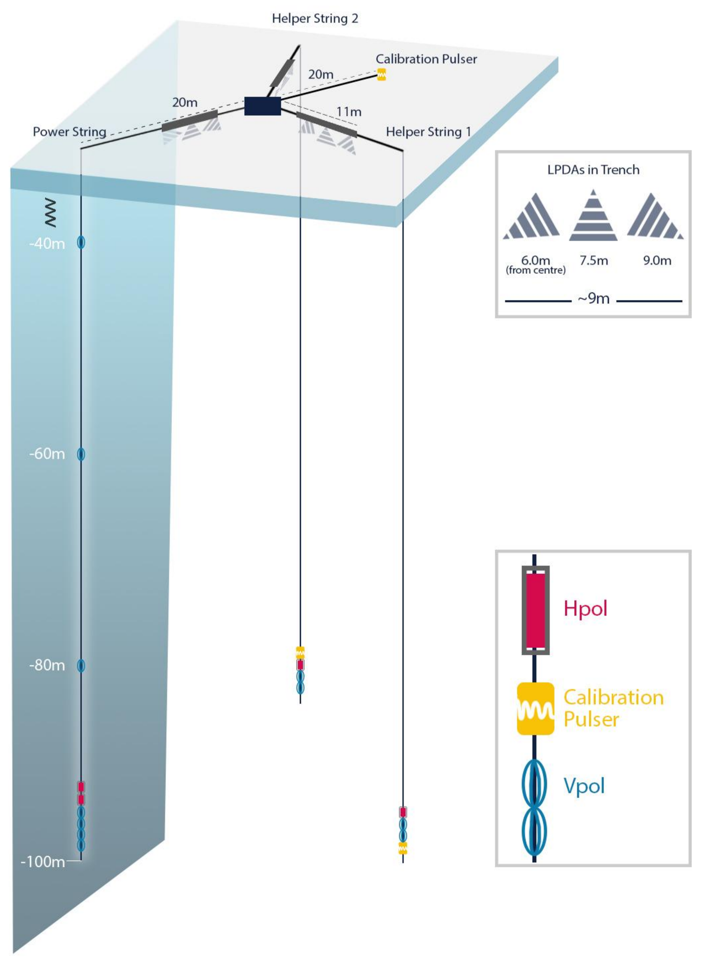


Figure 1: Lay-out for an RNO-G station.

Radio Signal Properties

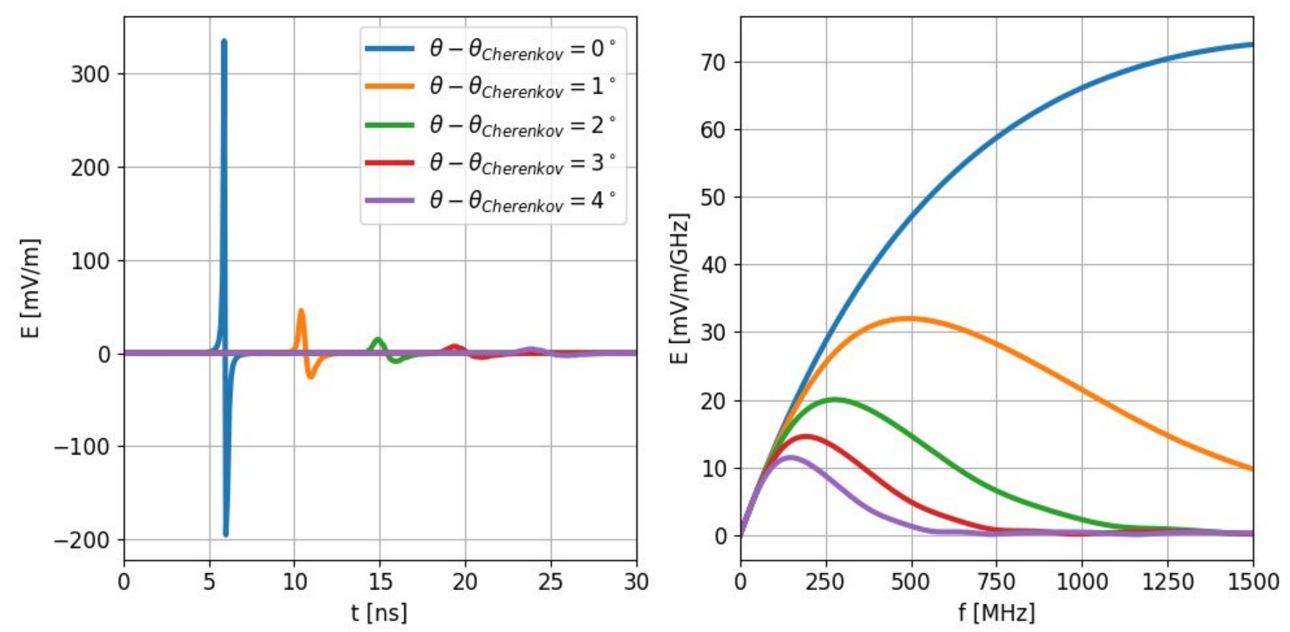
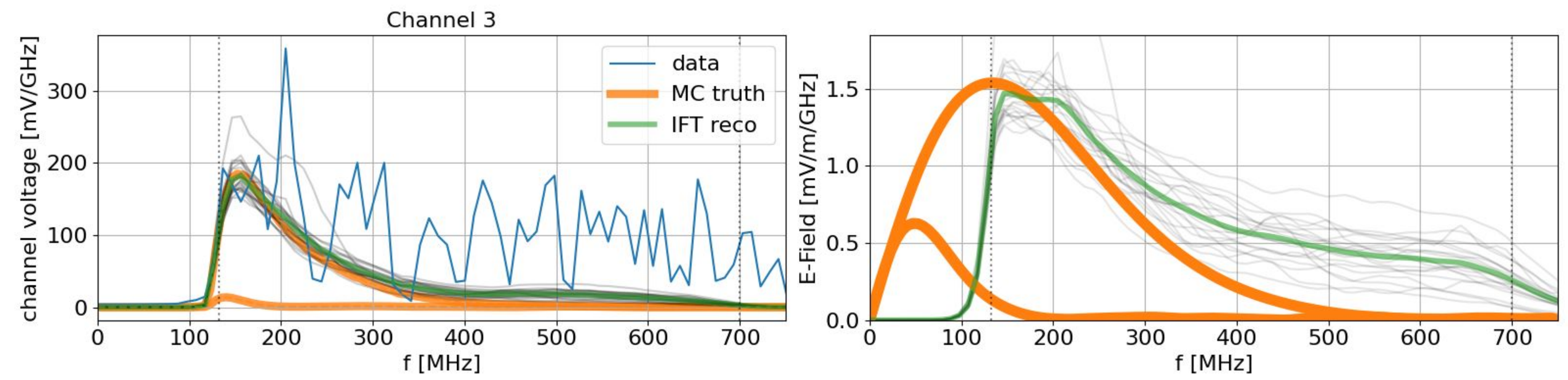


Figure 3: Waveform (left) and spectrum (right) of the radio signal emitted by a 1 EeV shower seen at different viewing angles from 1 km distance. The viewing angle is the angle the signal makes with respect to the shower axis. The radio signal is the strongest near the Cherenkov angle (56°).

To reconstruct the **neutrino energy**, we need:

- Electric field amplitude (is proportional to shower energy);
- Distance traveled by the radio signal (inferred from Vertex Position Reconstruction);
- viewing angle (inferred from Electric Field Reconstruction);
- Inelasticity (from simulations, cannot be reconstructed)

Electric Field Reconstruction



- Information Field Theory: Bayesian inference of signal from data
- Calculate maximum posterior from prior and data
- Can reconstruct shape and amplitude of E-field even at low SNR
- Combine multiple channels for more accuracy

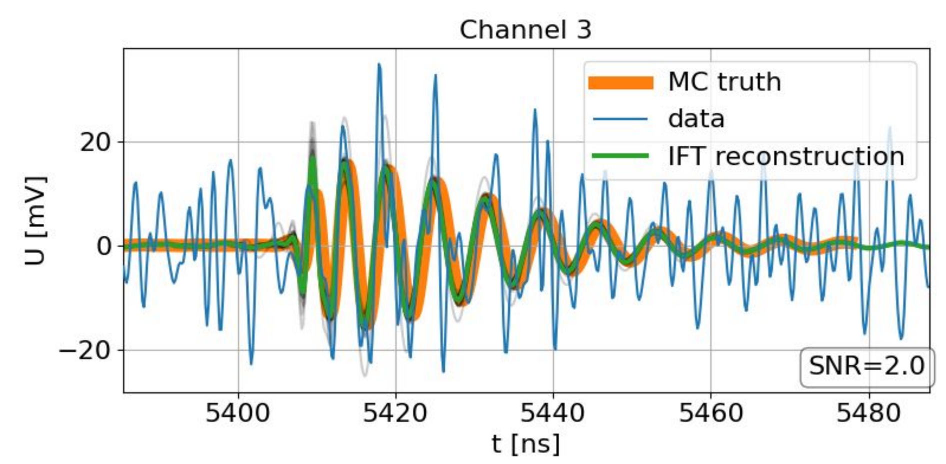


Figure 4: Example of an electric field reconstruction using IFT. Top left: Voltage spectrum in the channel. Top right: Electric field spectrum. Bottom: voltage trace in the channel

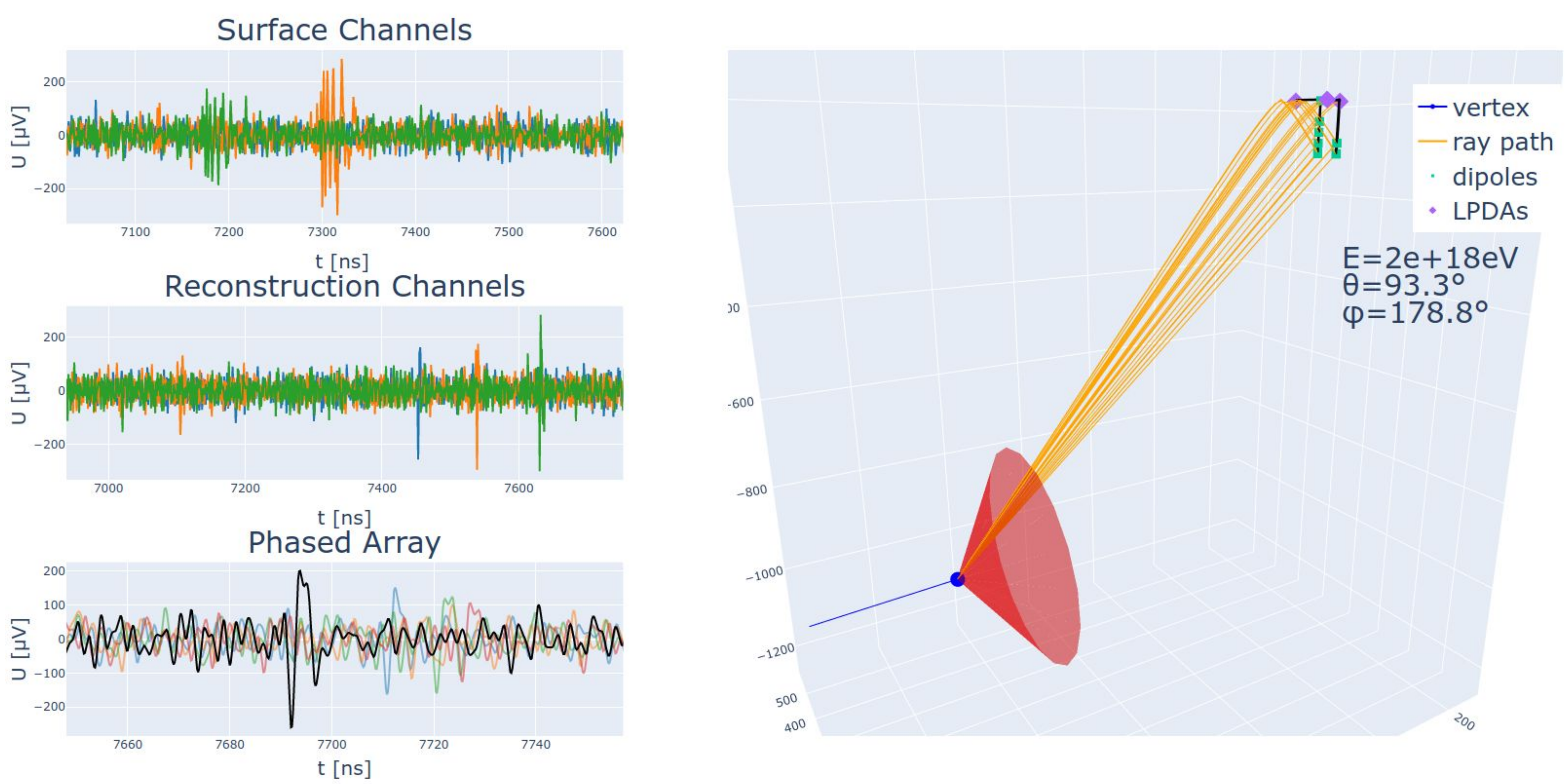


Figure 2: Example of a neutrino event to be detected by RNO-G. Left: Voltage traces from the surface LPDAs (top), signal in the deep vertically polarized antennas (middle) and the phased array (bottom). For triggering, the four channels of the phased array are combined (black curve) to enable triggering at lower thresholds. Right: Visualization of radio signal propagating towards the station. In red the Cherenkov cone is shown. Due to the inhomogeneous density profile of the ice, the signal is refracted during propagation. Note that also reflections from the ice-air boundary are detected.

Vertex Position Reconstruction

- Expected time differences in channels can be calculated for given vertex position
- Perform beamforming by cross-correlating channels
- Add up correlation for multiple channel pairs
- Location with highest correlation is likely the vertex position

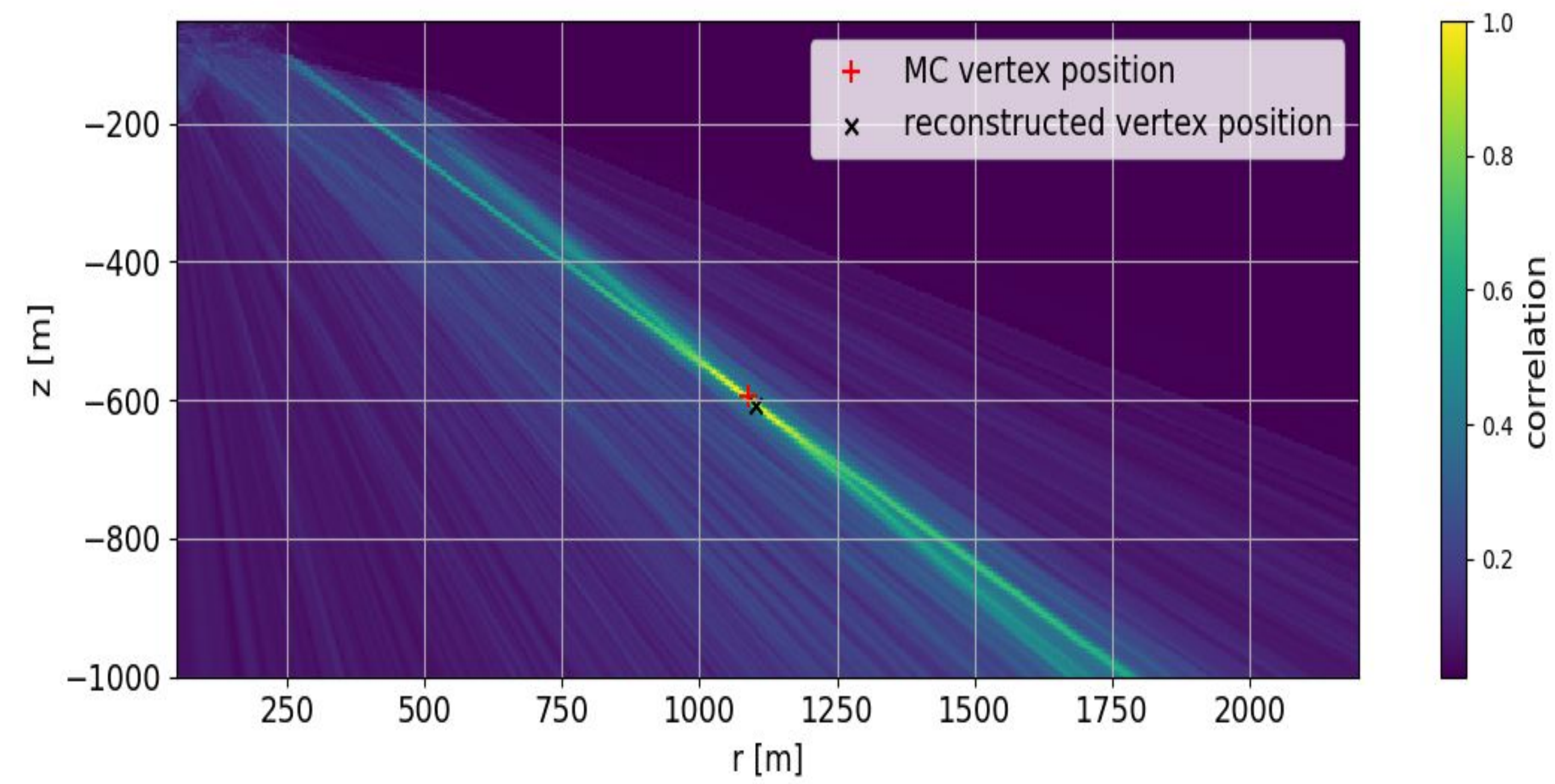


Figure 5: Correlation between channels for a given vertex position.

References

C. Glaser et al. "NuRadioReco: a Reconstruction Framework for Radio Neutrino Detectors." EPJ-C 79.6 (2019)
C. Glaser et al. „NuRadioMC: Simulating the radio emission of neutrinos from interaction to detector" EPJ-C 80 (2020)
T. A. Enßlin, "Information theory for fields" Annalen Phys. 531 (2019) 3, 1800127

All simulation and reconstruction software is available on https://github.com/nu-radio
A whitepaper on RNO-G is available at https://arxiv.org/abs/2010.12279