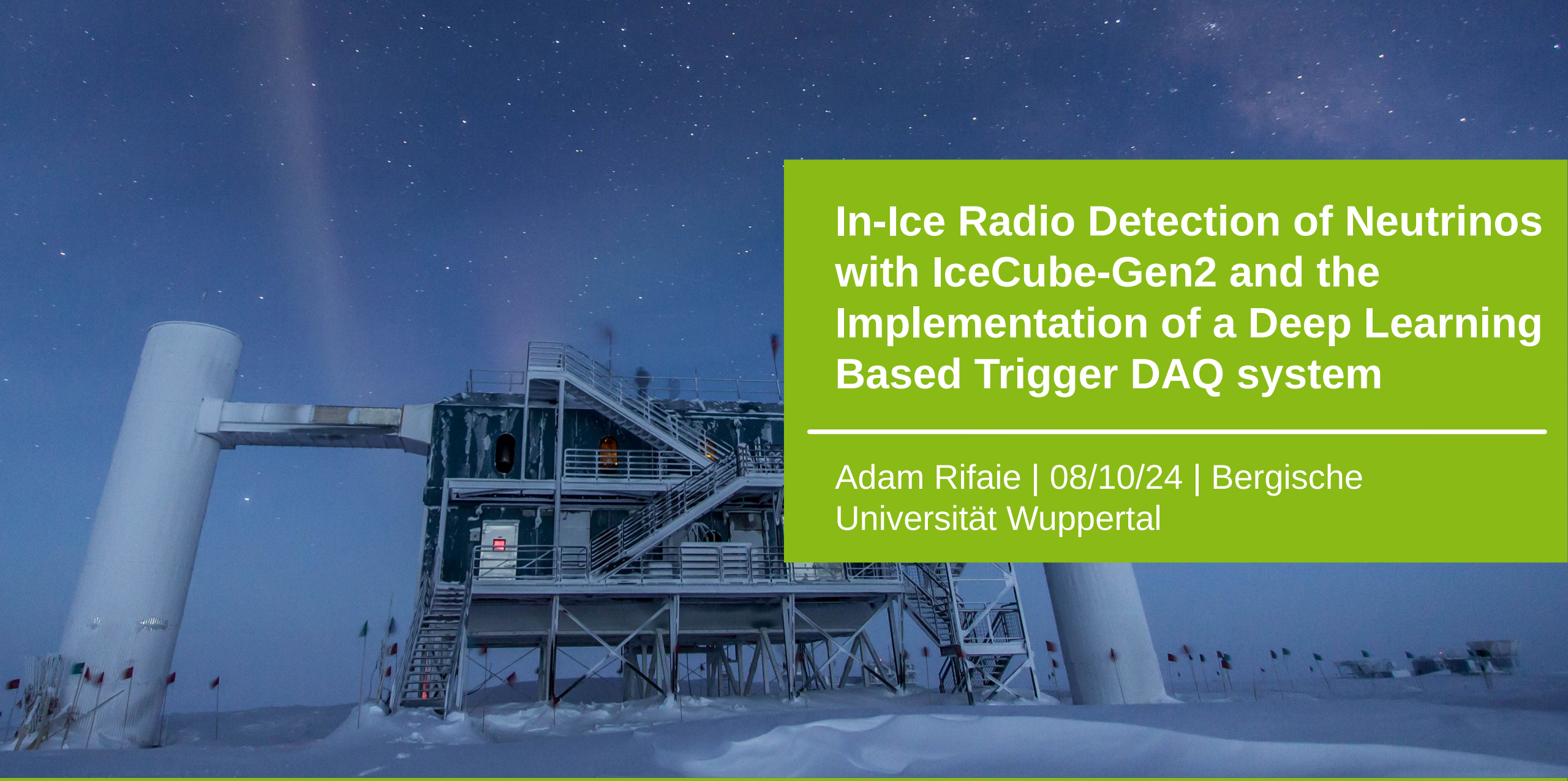

In-Ice Radio Detection of Neutrinos with IceCube-Gen2 and the Implementation of a Deep Learning Based Trigger DAQ system

Adam Rifaie | 08/10/24 | Bergische Universität Wuppertal

IceCube GEN2

RNO-G
Radio Neutrino Observatory - Greenland

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- **The IceCube Neutrino Observatory**
  - IceCube-Gen2
  - Gen2 Radio
    - Radio Emissions from CRs
    - In-Ice detection
- The Radio Neutrino Observatory in Greenland
  - Current DAQ/trigger system
  - Improved DAQ/trigger system
- Planned Contribution

The IceCube Neutrino Observatory

- **In-Ice detection:**
  - ~ 1 km^3 detection volume
  - 5160 **D**igital **O**ptical **M**odules (**DOM**s)
  - Between 1450 and 2450 meters deep in ice
  - Cherenkov light detection induced by charged secondaries
  - Detection of High-Energy neutrinos
- **IceTop:**
  - 162 ice-filled tanks (81 stations) with DOMs
  - Air shower cosmic rays / Veto mechanism

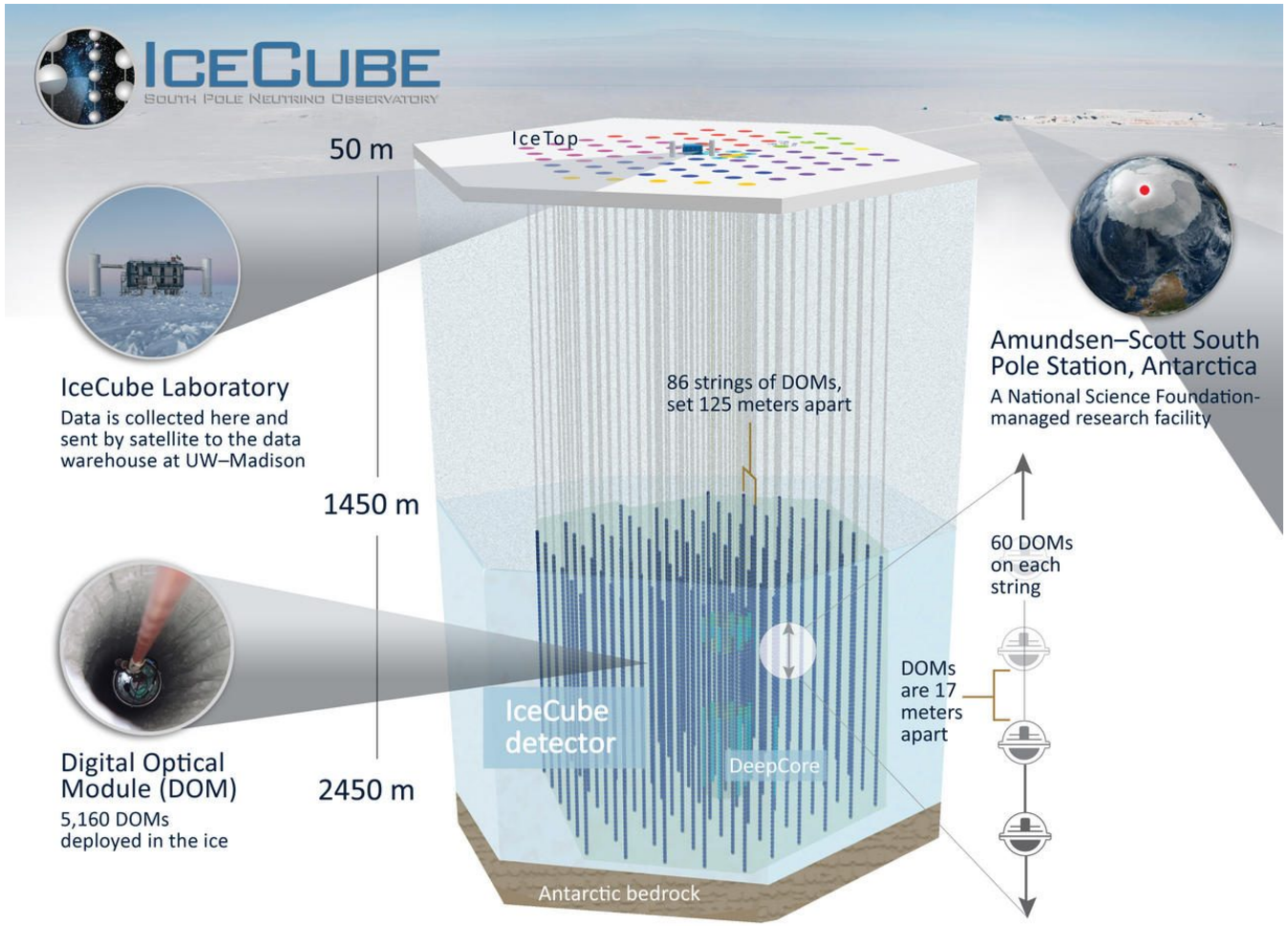

Figure: The IceCube Neutrino Observatory (Credit: DESY)

IceCube-Gen2

- 8 km^3 optical array volume
- 500 km^2 radio array
- Greater sensitivity to neutrinos at Ultra-High Energies (>100 PeV)

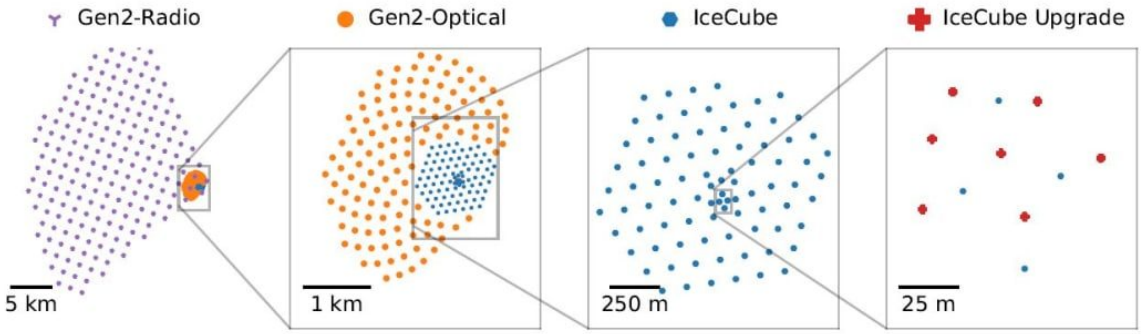

Figure: Footprint of the envisioned IceCube-Gen2 neutrino observatory (Credit: IceCube Collaboration)

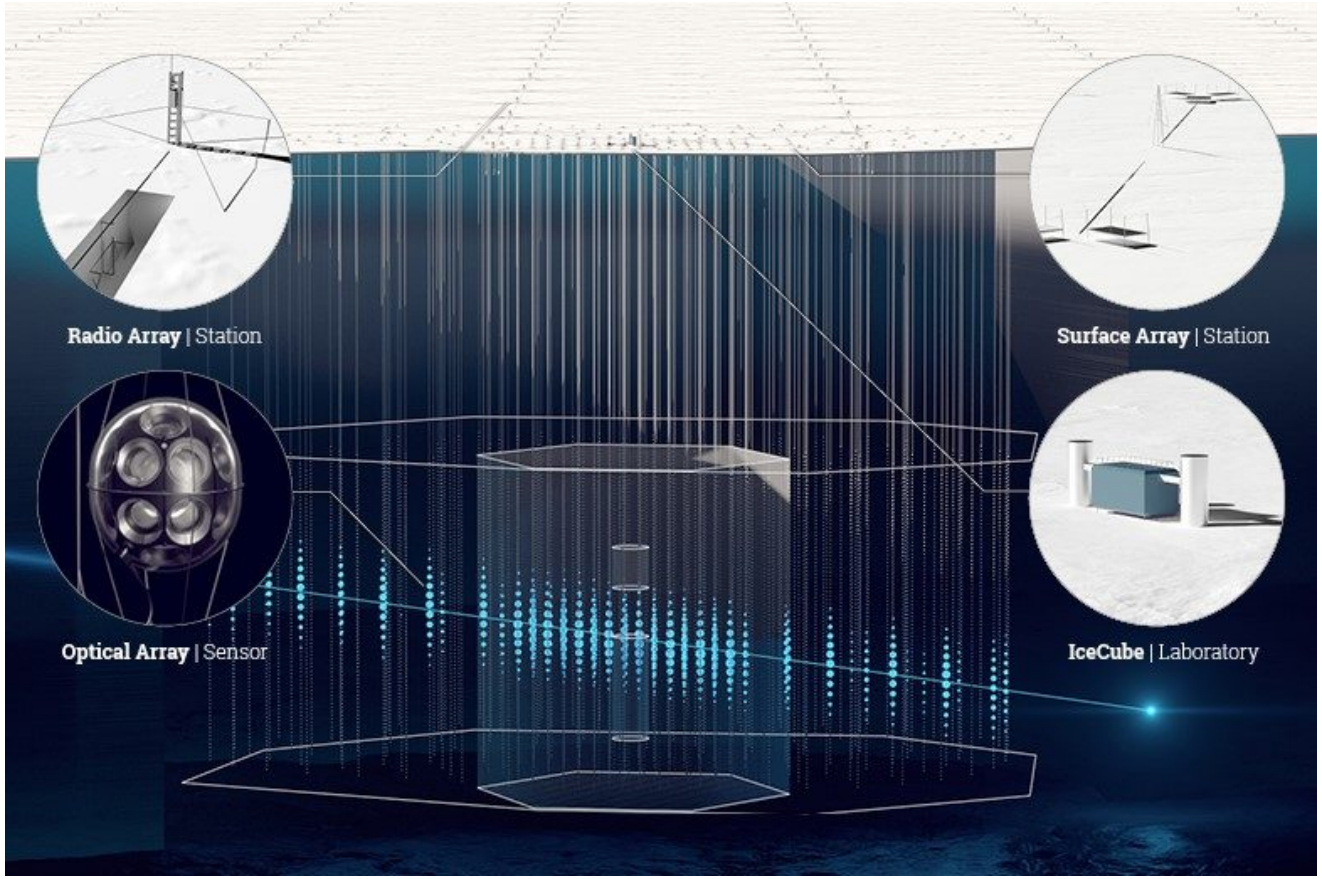

Figure: Visualization of the IceCube Expansion to IceCube-Gen2 (Credit: DESY)

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IceCube-Gen2 Radio Array – Radio Emission from CRs

- **Askaryan Effect:**
  - Development of electromagnetic component of the shower
  - Additional electrons up-scattered through Compton effect
  - Positron depletion by in-flight annihilation
    - → Leads to a relativistic negative charge excess and a charge separation from axis
    - → Dipole formed that changes as shower develops. i.e. emits radiation
- **Geomagnetic Effect:**
  - Electrons and positrons deflected in opposite directions in the earth's magnetic field (Lorentz force)
  - Dipole, i.e. radiation

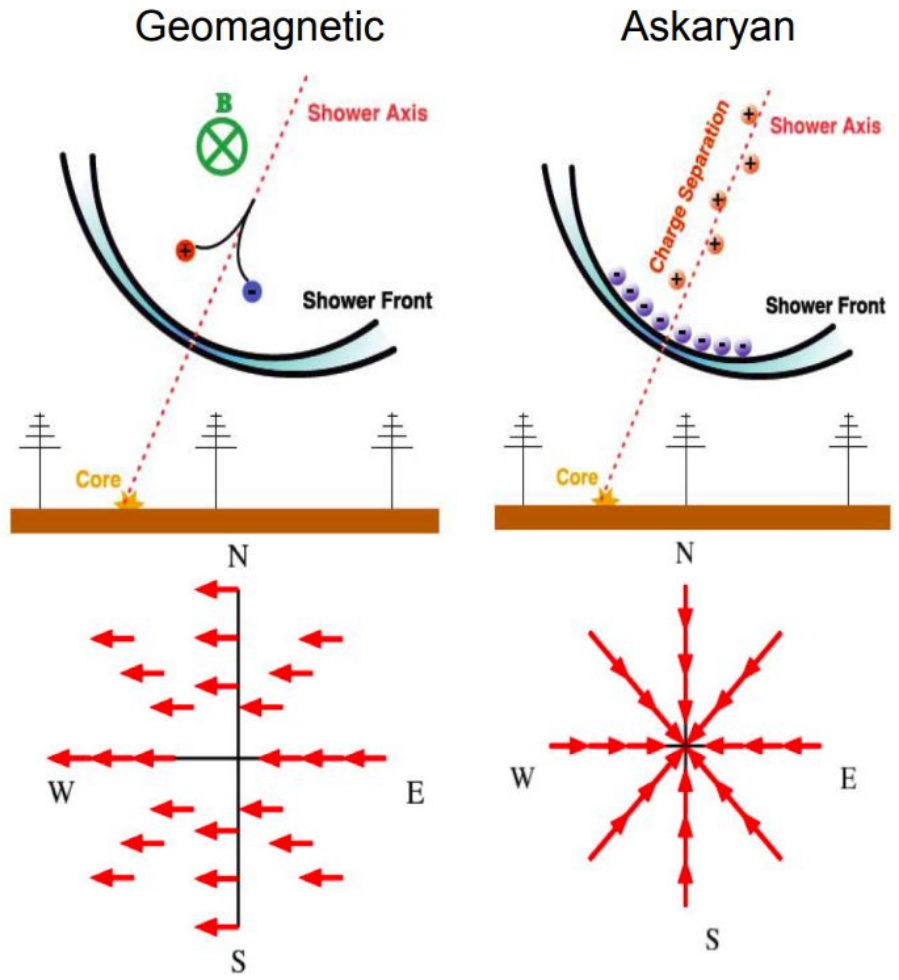

Figure: Radio Emission from T. Huege, ICRC2013

IceCube-Gen2 Radio Array – In-Ice detection

- Preliminary station design
- ~ 300 Independent stations (min separation 2 km)
- 3-strings
  - 1 string for phased array trigger (main trigger)
  - 2 strings for direction reconstruction
- Antennae on surface help veto air showers, trigger and reconstruction information

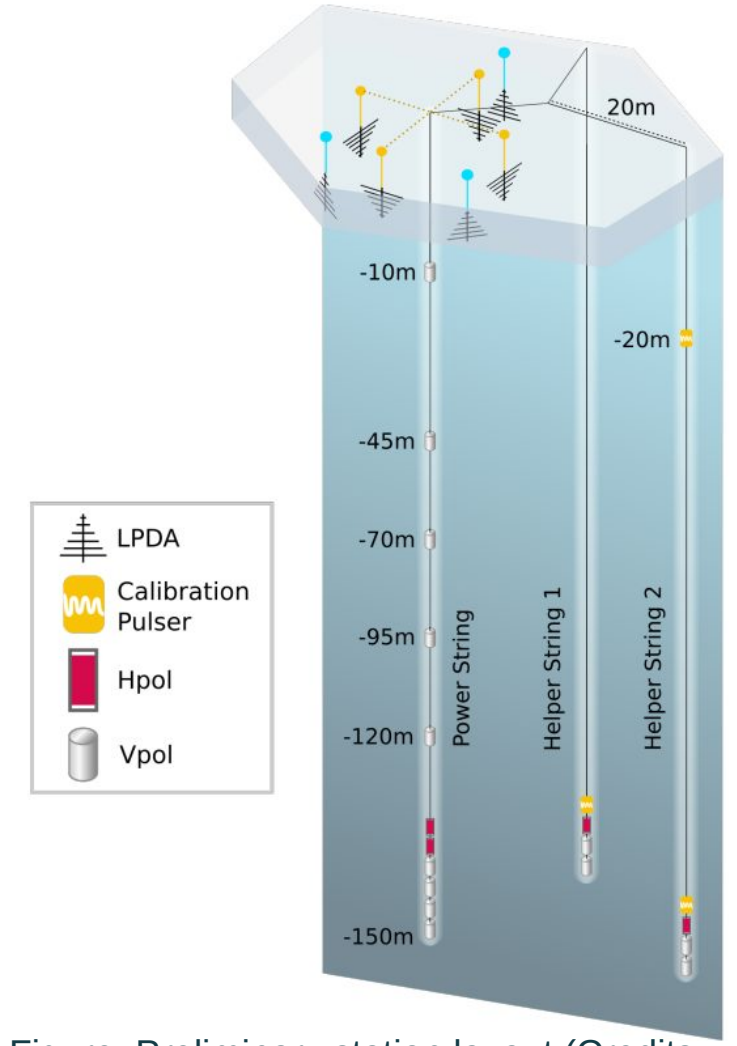

Figure: Preliminary station layout (Credits: IceCube-Gen2 white paper)

- The IceCube Neutrino Observatory
  - IceCube-Gen2
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The Radio Neutrino Observatory in Greenland

- Summit Station Greenland
- ~1 km separation between stations
- Targets astrophysical neutrinos of several PeV to EeV range
- Demonstrates large scale implementation (35 stations) of the in-ice radio neutrino detection technique
- Serves as a smaller scale predecessor to IceCube-Gen2 and enables hardware testing

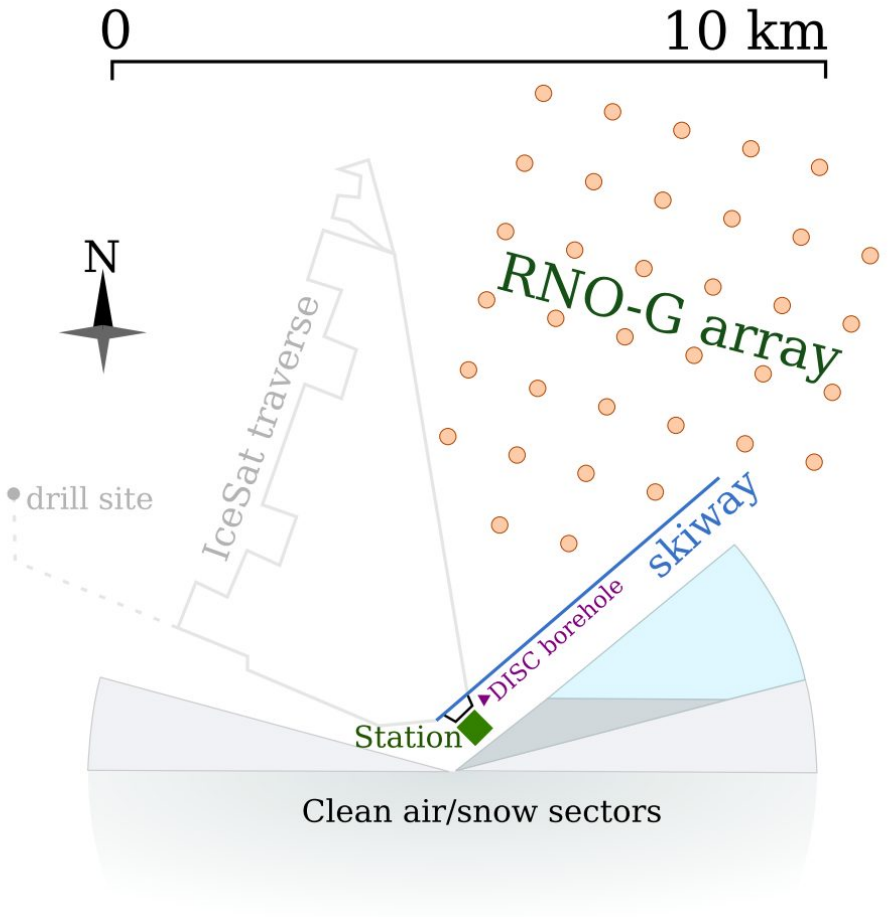


Figure: Planned RNO-G Summit station
(Credits: RNO-G paper)

Current DAQ/trigger system

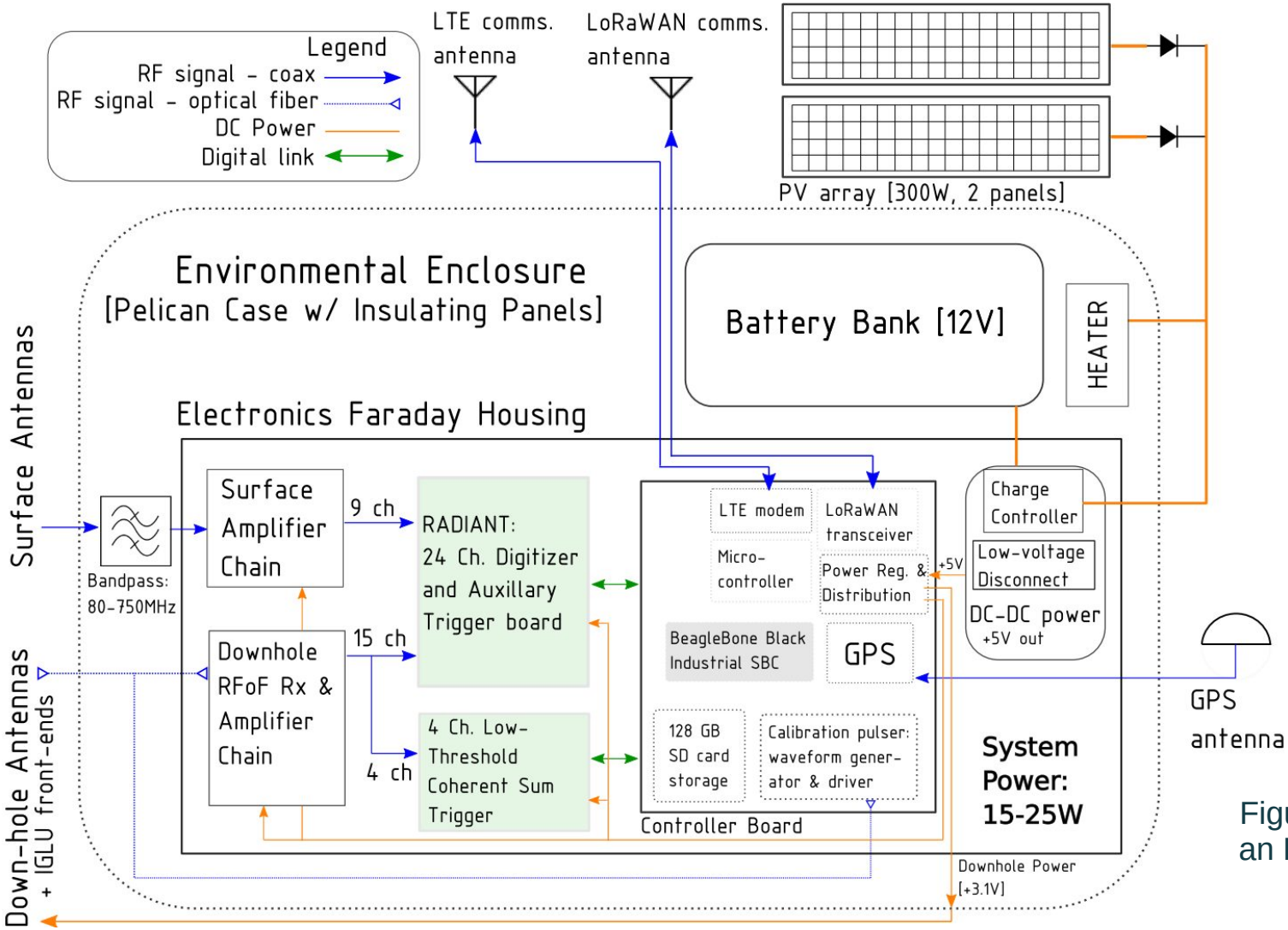
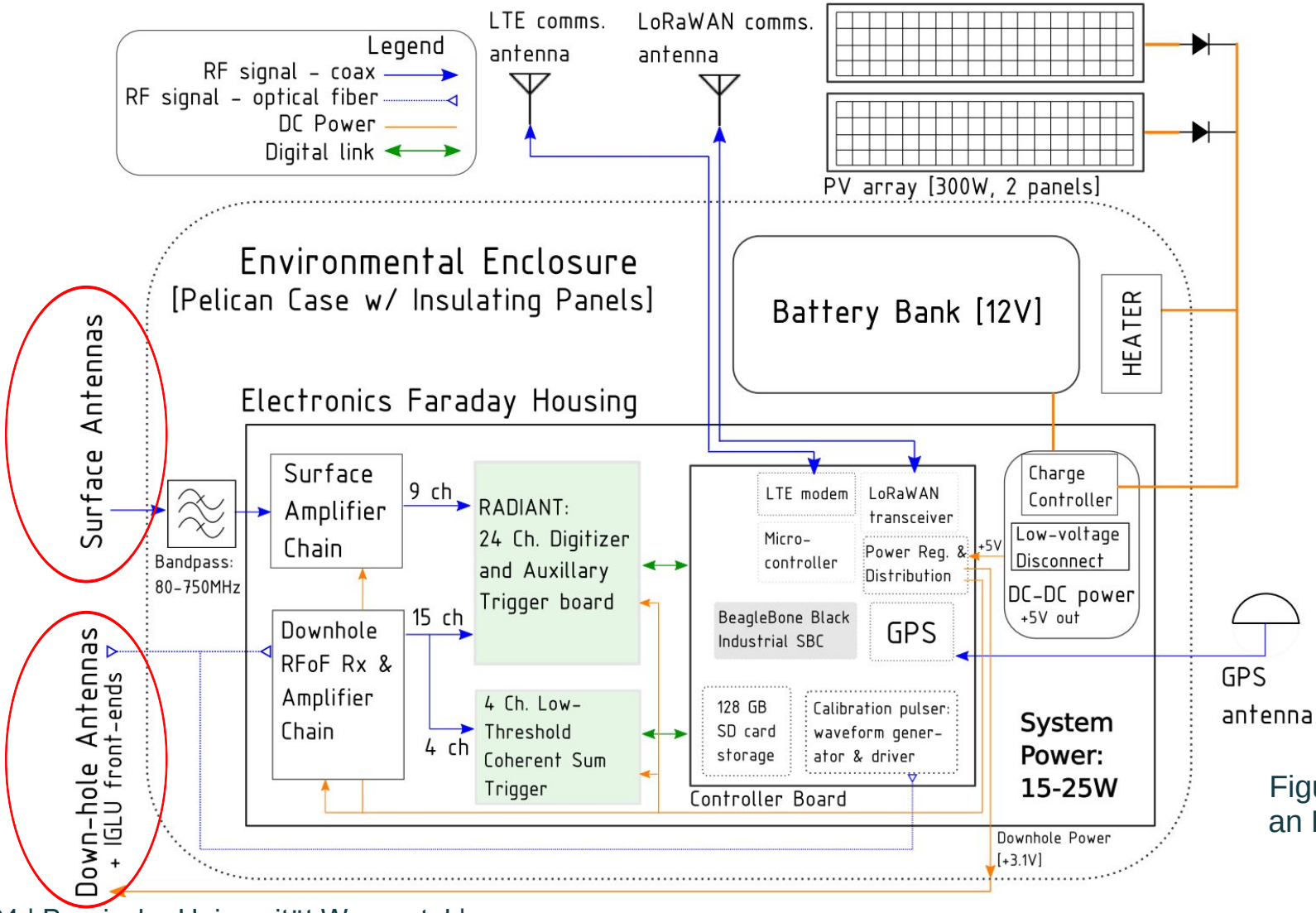


Figure: System Diagram for an RNO-G station (Credits: RNO-G paper)

Current DAQ/trigger system



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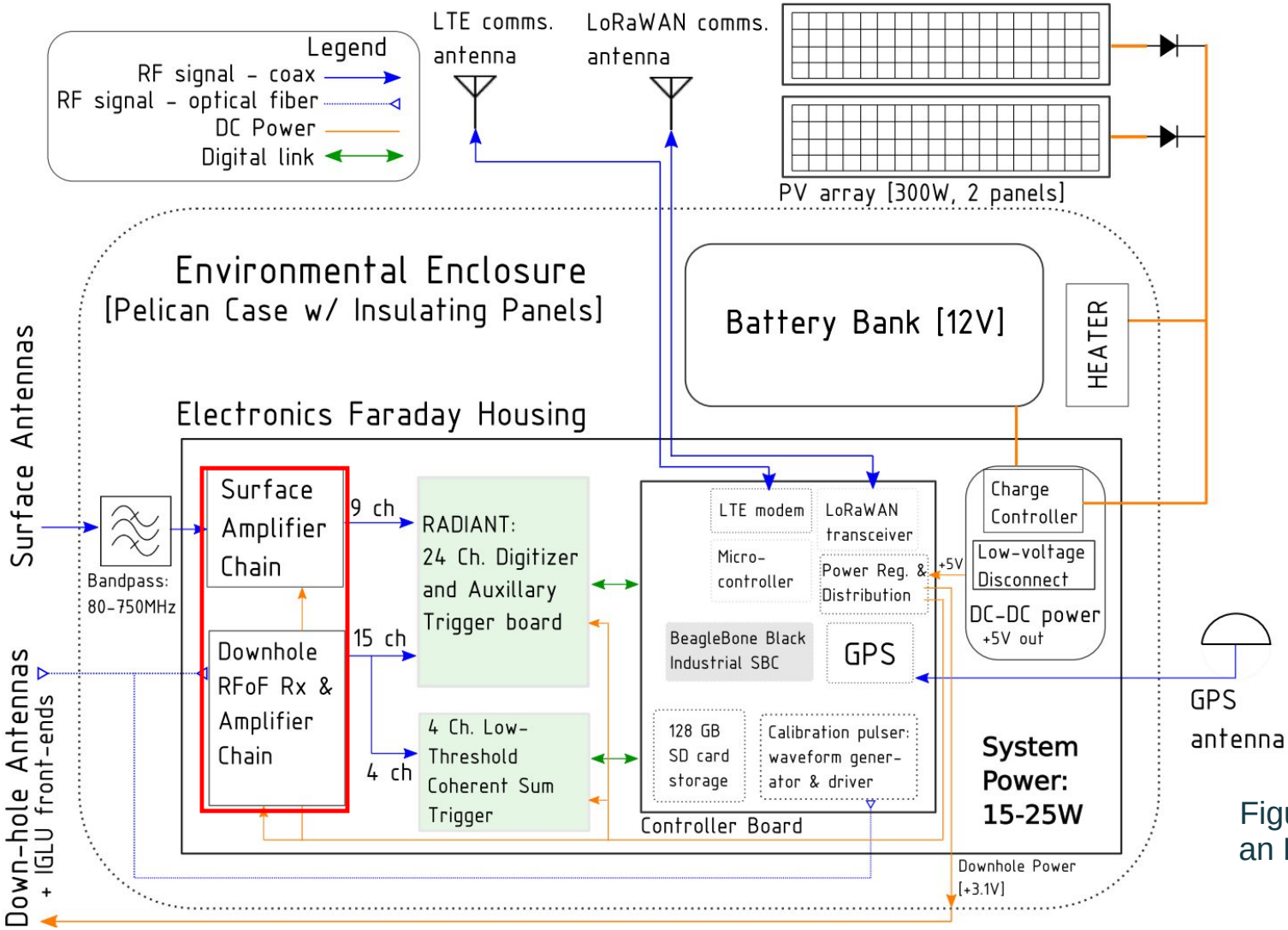

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Current DAQ/trigger system

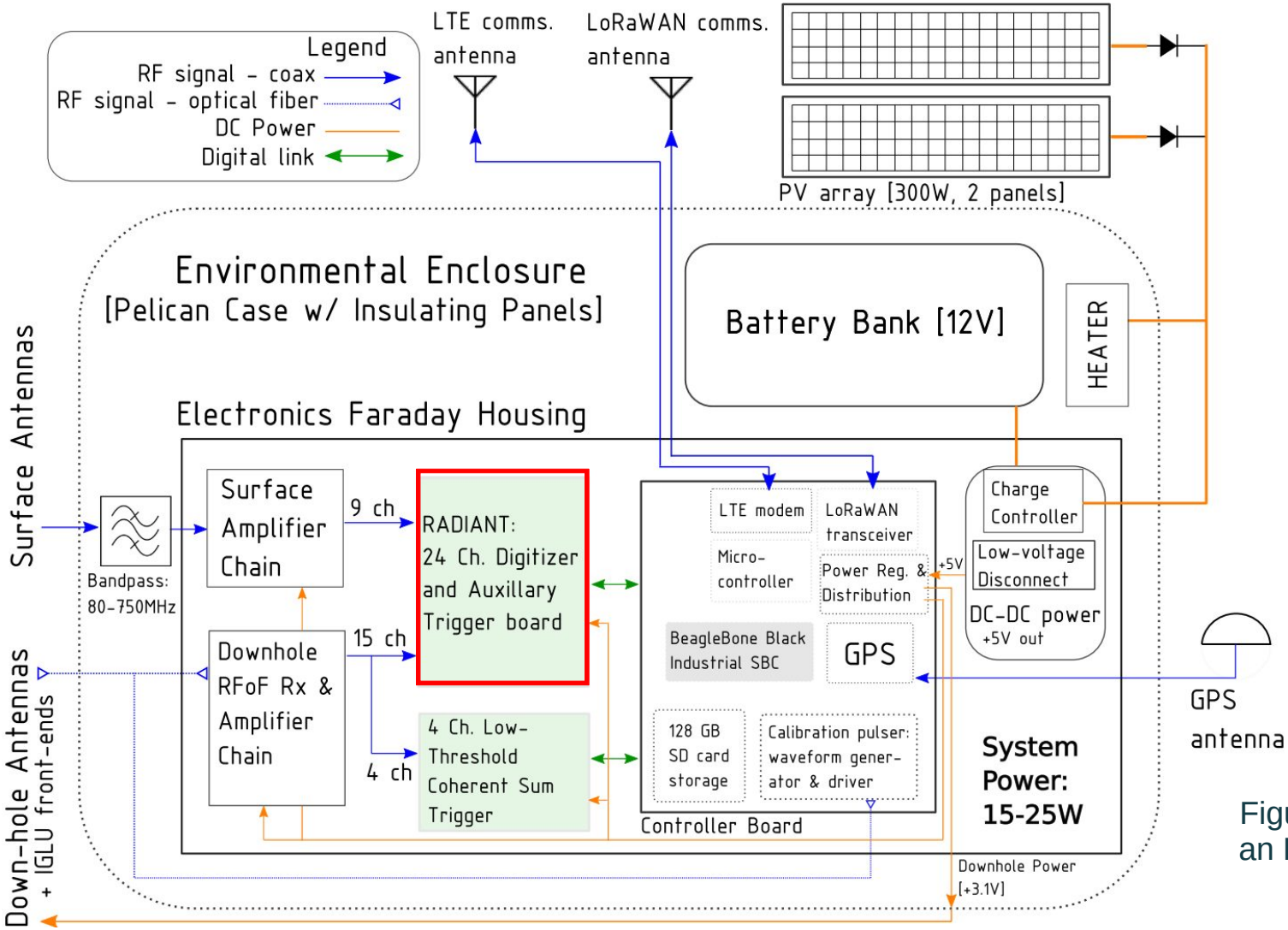

Figure: System Diagram for an RNO-G station (Credits: RNO-G paper)

Current DAQ/trigger system

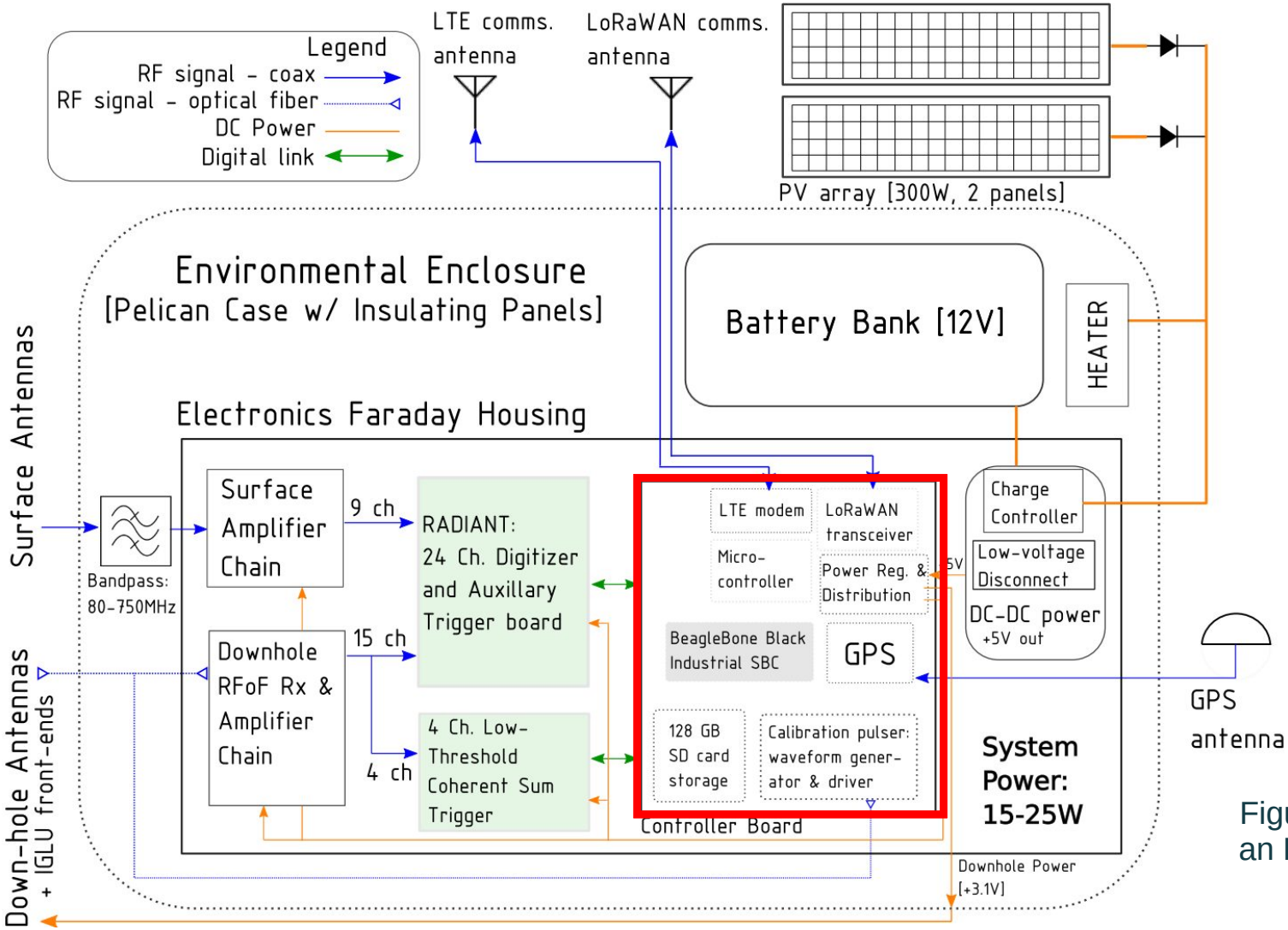

Figure: System Diagram for an RNO-G station (Credits: RNO-G paper)

Current DAQ/trigger system

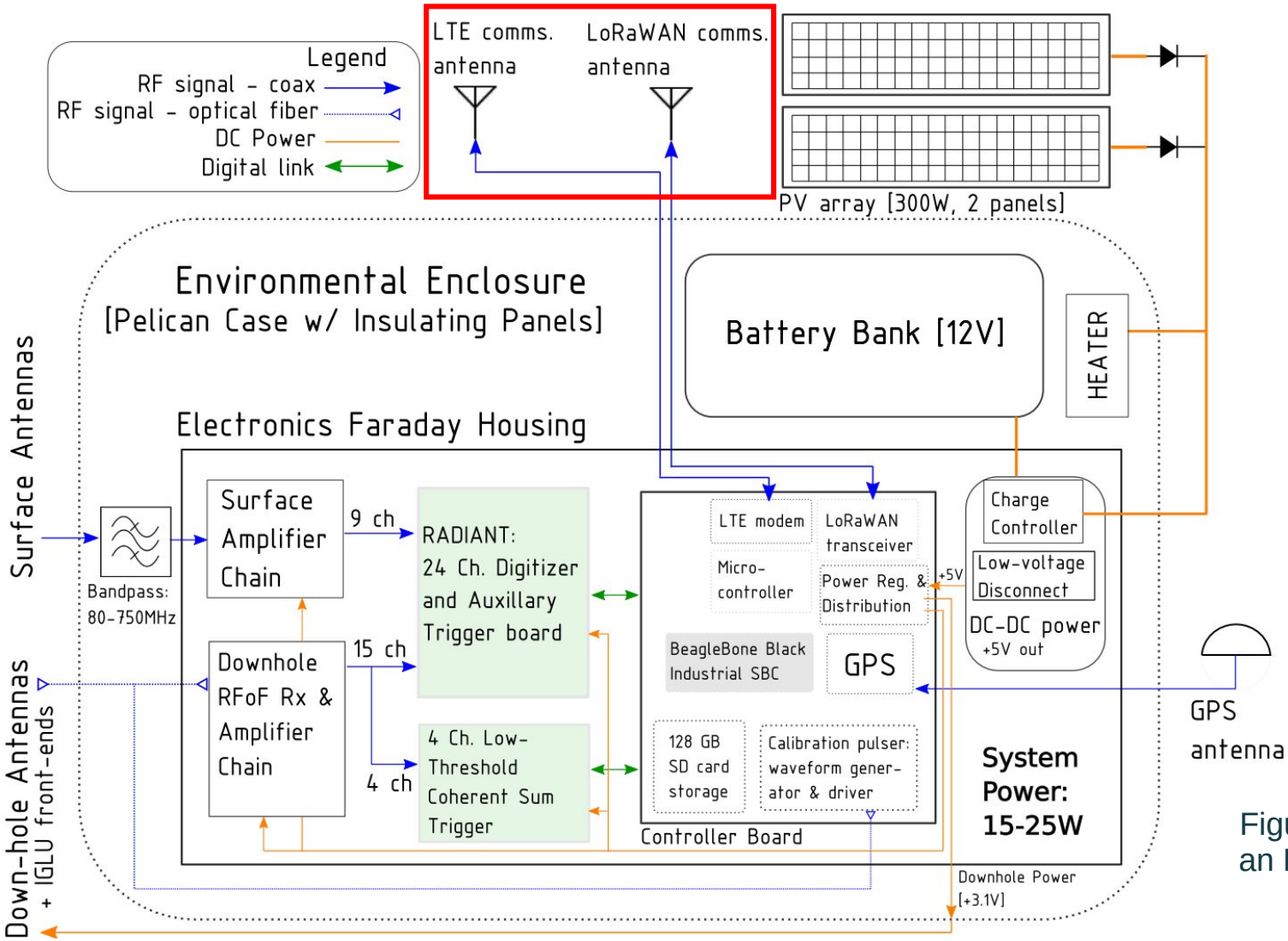

Figure: System Diagram for an RNO-G station (Credits: RNO-G paper)

Current DAQ/trigger system

- Phased array trigger
- Simulated event
- Red is Cherenkov cone
- Blue is interaction vertex
- Black line shows the improved Signal to Noise ratio when all signals are in phase

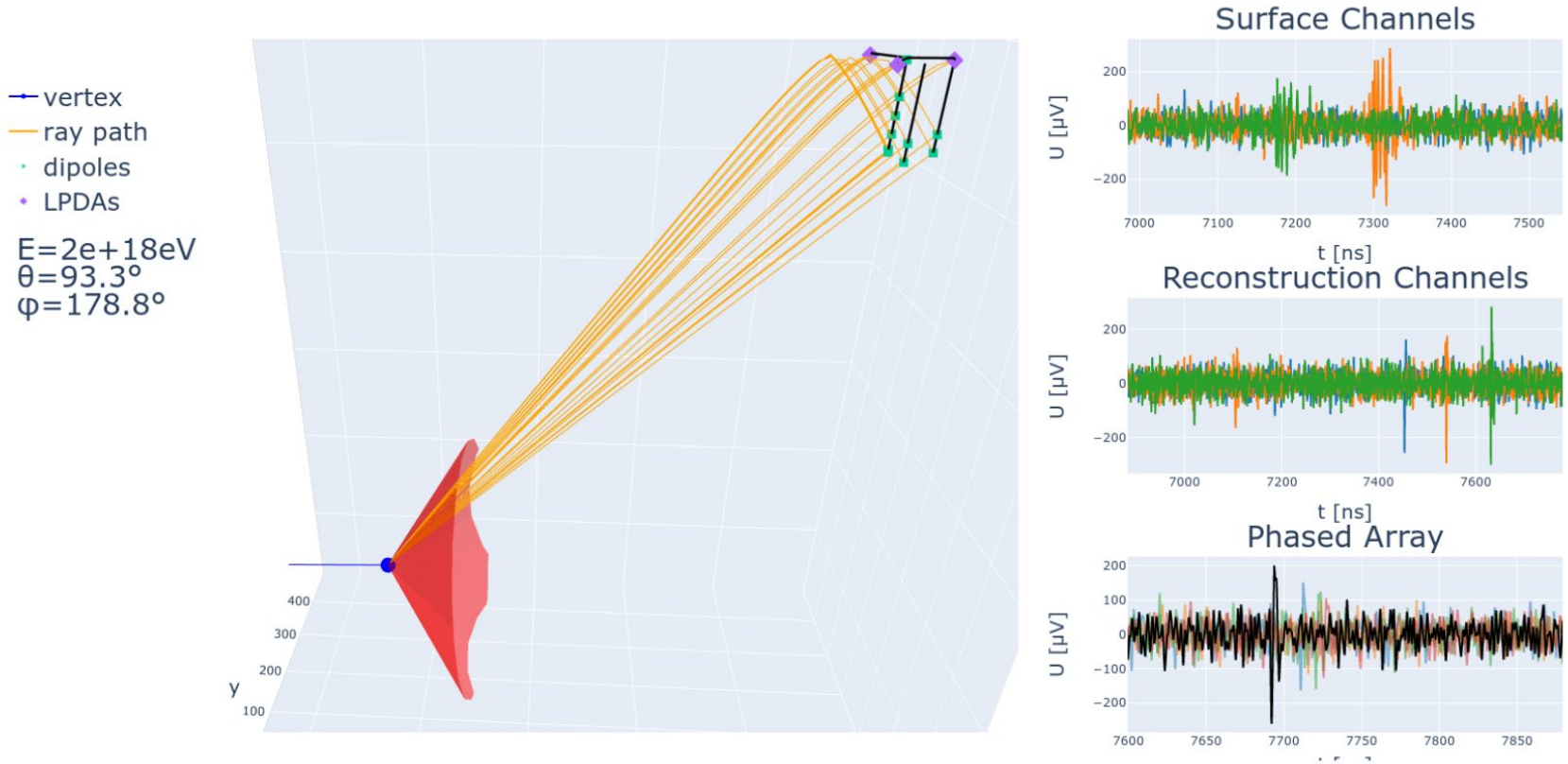

Figure: Simulated RNO-G neutrino event (Credits: RNO-G paper)

Improved Trigger System

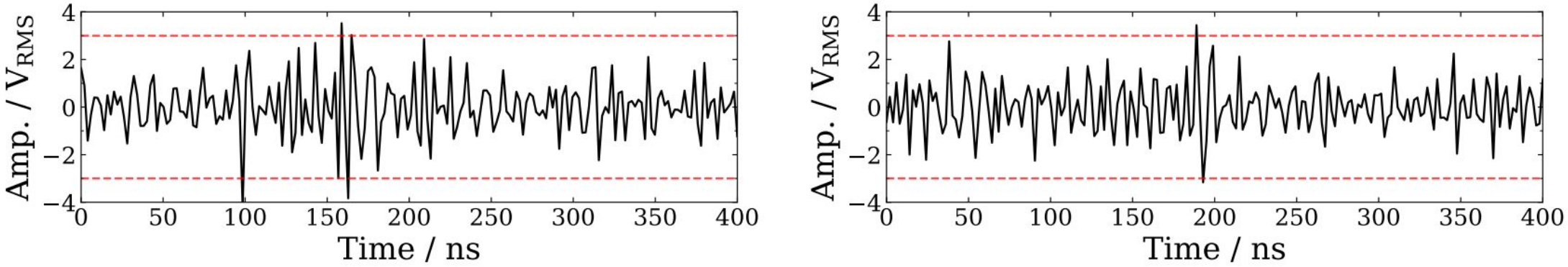

Figure: Test signal pulse-form (left) and noise pulse-form (right) measured by an LPDA antenna (Credits: NuRadioOpt proceedings ICRC2023)

- Use a deep-learning-based trigger
- Analyzes data stream in real-time
- Improve sensitivity of detecting UHE neutrinos

Improved Trigger System

- Moderate assumption:
  - All signals above 3 RMS noise can be identified (already achieved)
- Optimistic assumption:
  - All signals above 2 RMS noise can be identified
- Effectively increase the “volume” of the detector by 3 (optimistically)

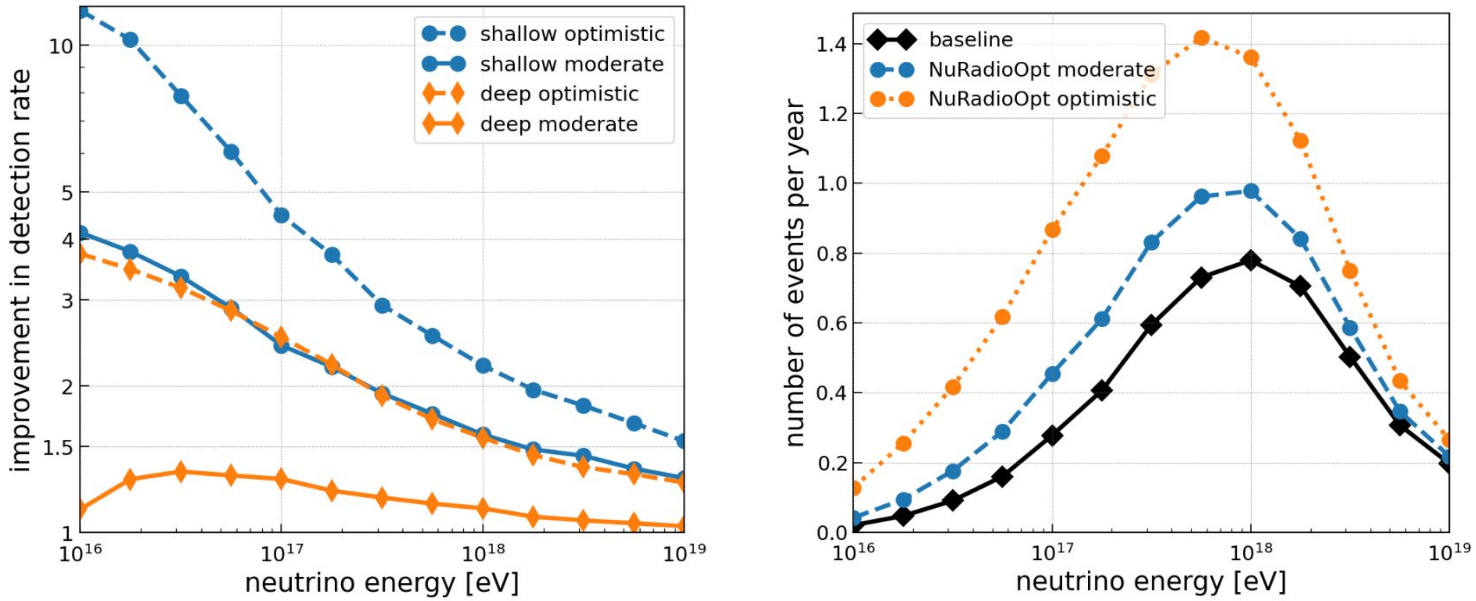

Figure: (left) Increase in detection rate due to deep-learning trigger. (right) Number of neutrinos detectable per year with IceCube-Gen2 (Credits: NuRadioOpt proceedings ICRC2023)

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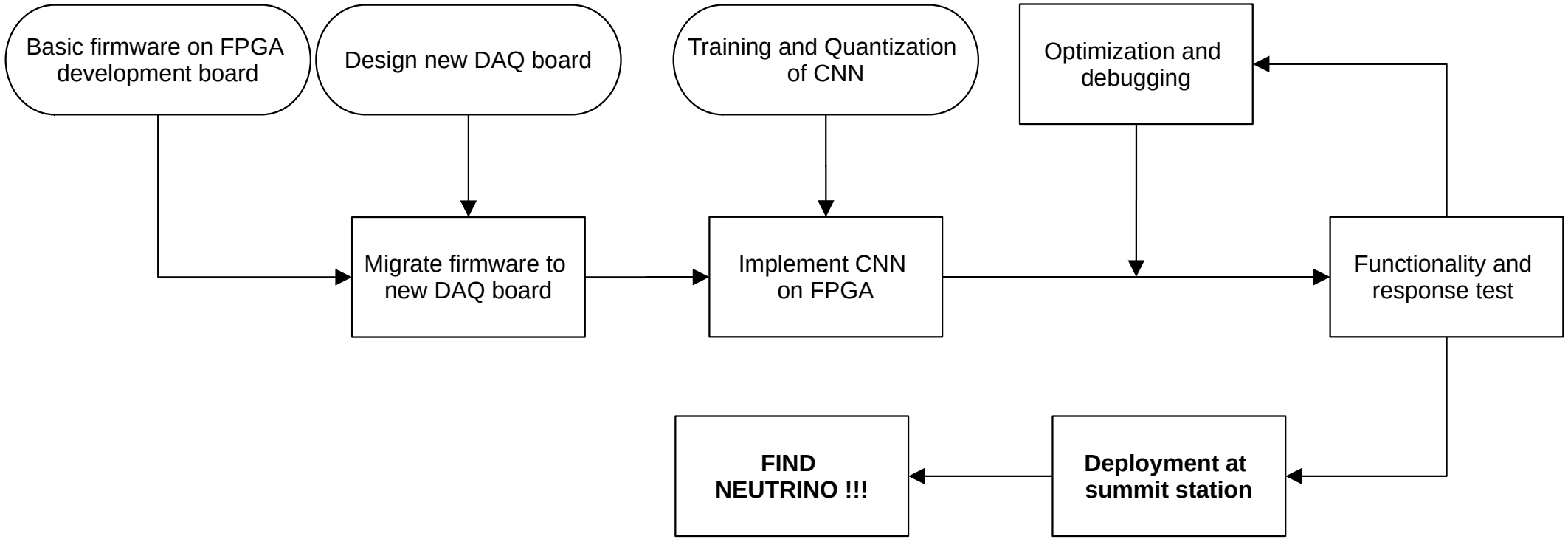
Planned contribution



Summary

- IceCube-Gen2 is the next generation extension that aims to detect UHE neutrinos/CRs.
- As a predecessor to IceCube-Gen2, RNO-G is a large scale astrophysical neutrino detector. It detects radio emissions from neutrino induced particle showers.
- Current DAQ system of an RNO-G station was discussed followed by the limitations of a threshold based trigger system.
- The potential of a Deep-Learning based trigger system and its planned implementation was presented

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Multi-Messenger Astronomy

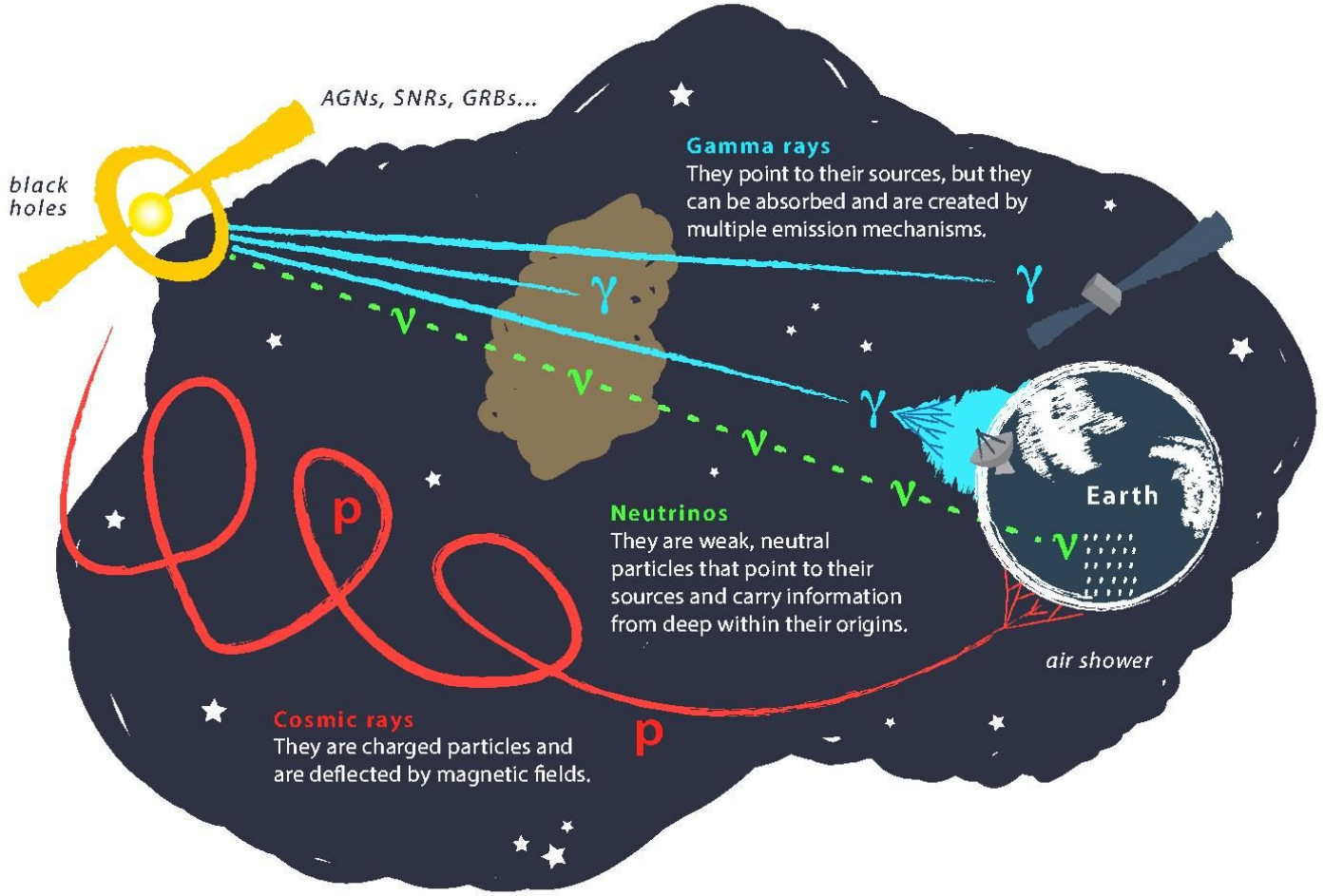
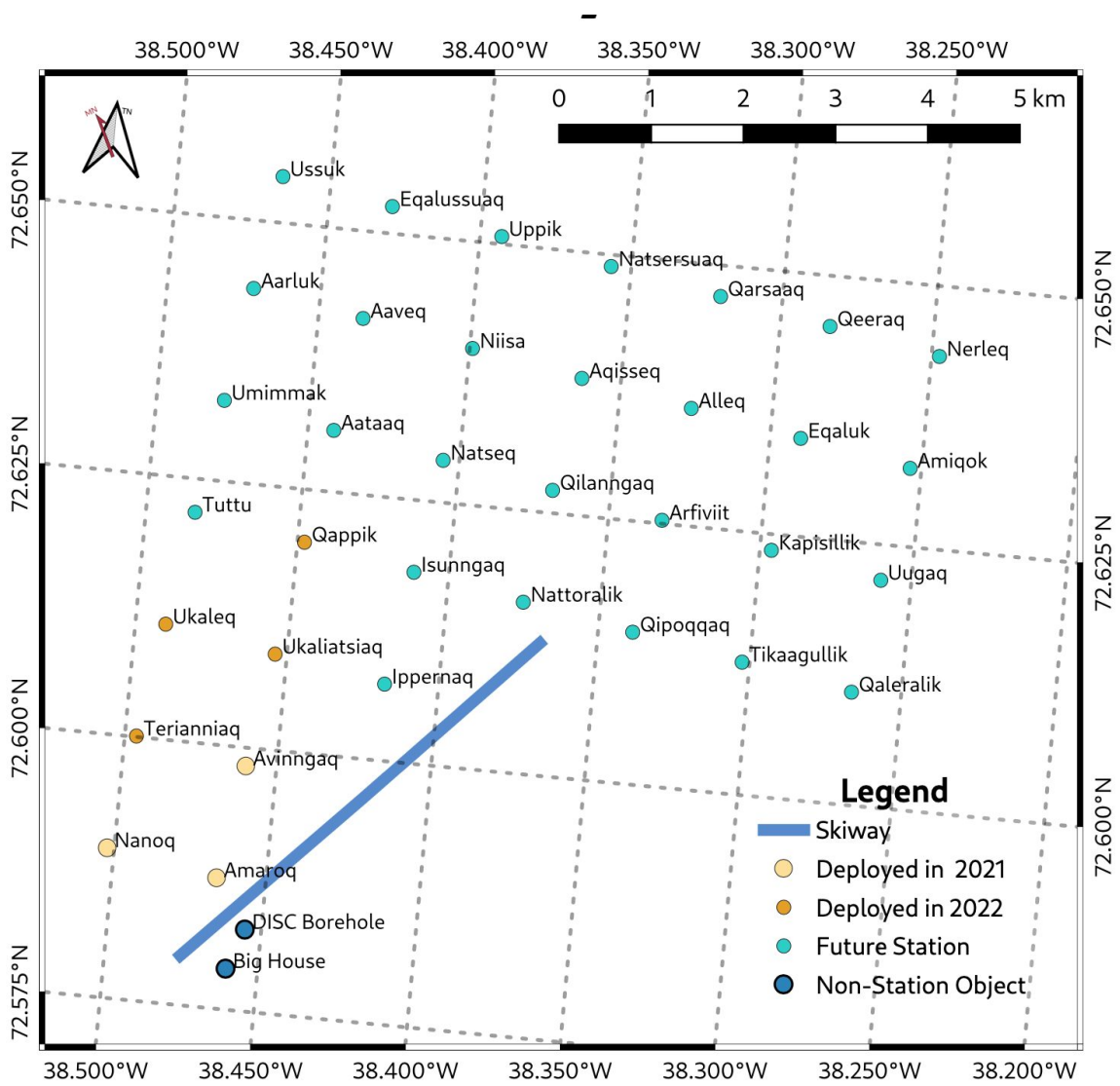


Figure: Multi-messenger astronomy (Credit: IceCube Internal Gallery)

RNO-G Array



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