Ice modelling & station calibration at the RNO-G neutrino detector

Bob Oeyen

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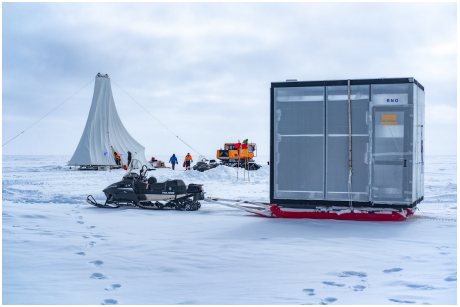
GHENT UNIVERSITY

EPPg$^{\mu\nu}$ Ghent University Experimental Particle Physics and gravity

RNO-G
Radio Neutrino Observatory - Greenland

Ice modelling & station calibration at the RNO-G neutrino detector



Calibration of the detector

Ice, position & system response

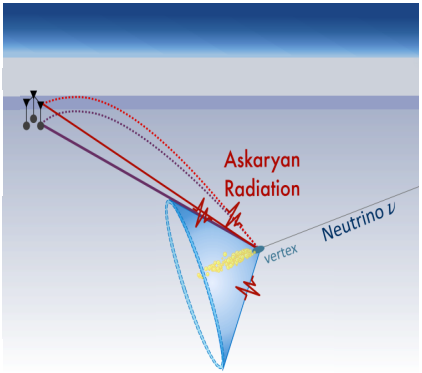
Signal propagation in ice

Ice models & calibration pulses

Measuring ice properties

Surfaces pulses & weather balloons

The reconstruction of neutrino events relies on the ice & position calibration



Neutrino event

Ray path ◀ vertex position
antenna position
refractive index ice

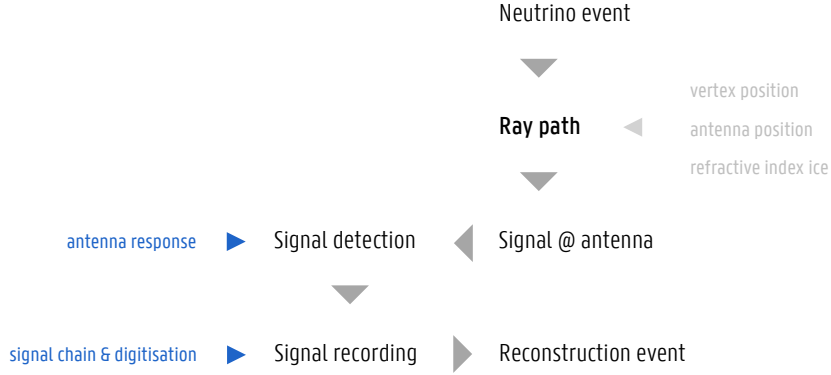
Signal @ antenna

Reconstruction event

The reconstruction of neutrino events

relies on the ice & position calibration

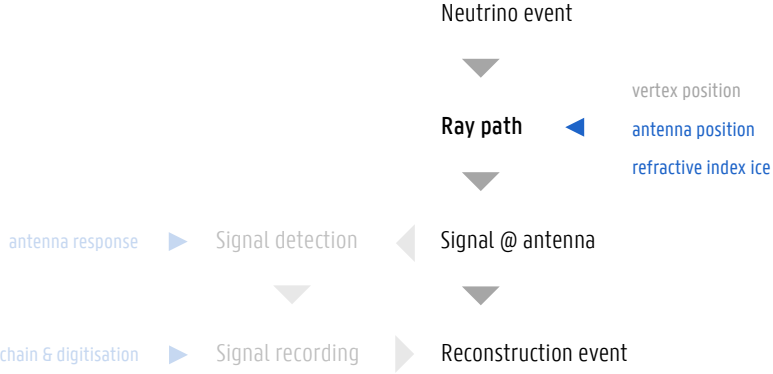
and the system response calibration



The reconstruction of neutrino events

relies on the ice & position calibration ◀ This talk

and the system response calibration



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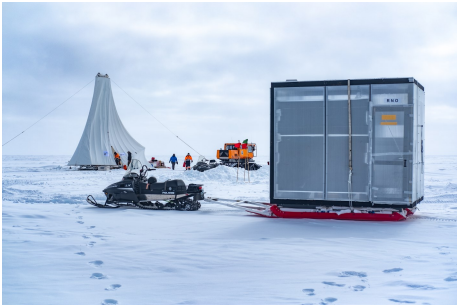

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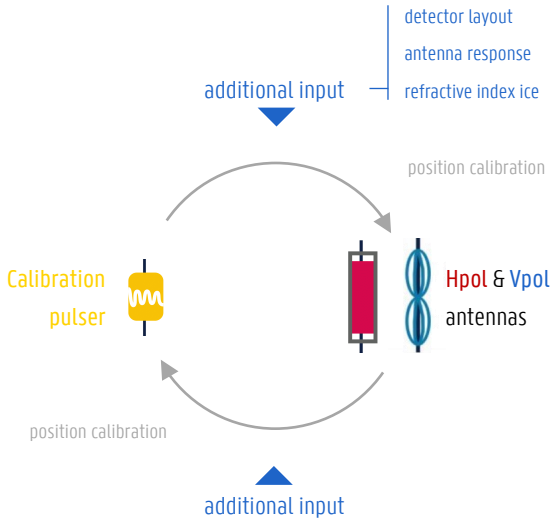
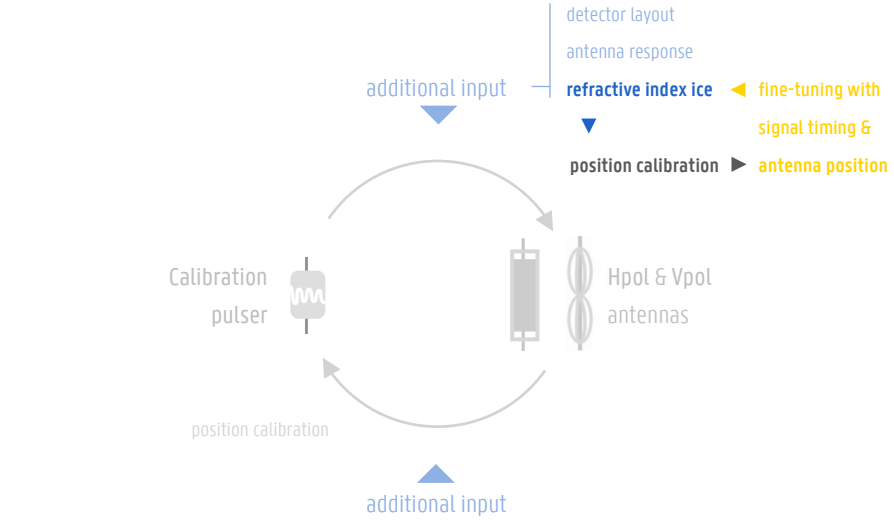
Antenna position calibration depends on the pulser position and vice-versa



Antenna position calibration depends

on the ice model and vice-versa

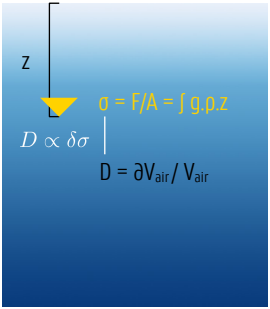


A single exponential description of the ice

is favoured as it allows for fast computation

Simple exponential profile ▶ **Ray paths are analytically solvable**

$$n(z) = n_{ice} - \Delta n \cdot \exp\left(\frac{z}{z_0}\right)$$

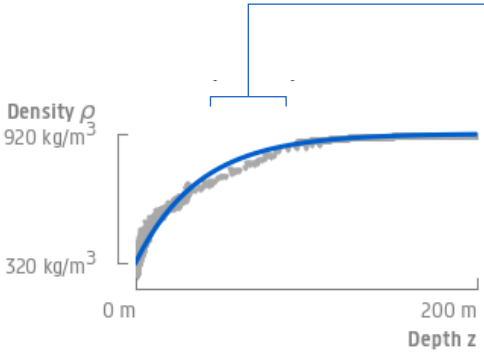


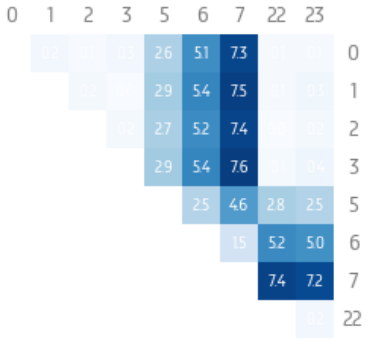
The top layer of the ice sheet is not well

described by a single exponential profile

▲

First principles on compression & densification

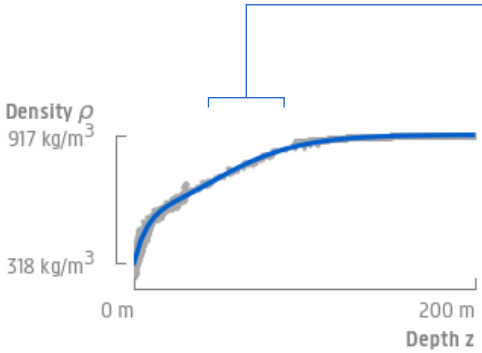


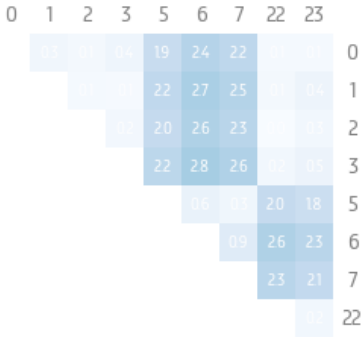


The top layer of the ice sheet is better

described by an exponential polynomial

First principles with higher order corrections





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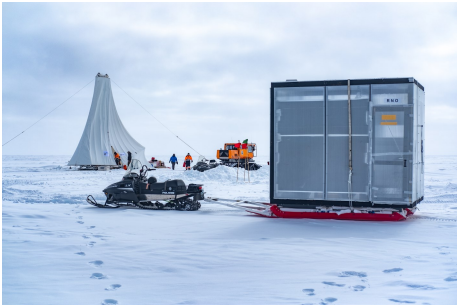


Calibration of the detector

Ice, positions & system response

Iterative calibration procedure

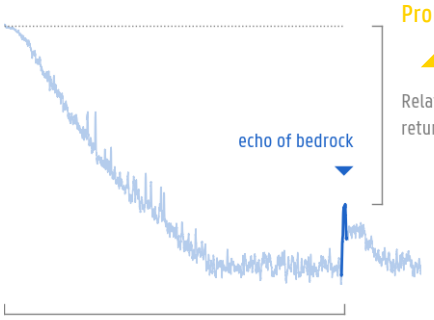
Antenna positions vs ice models

Measuring ice properties

Surfaces pulses & weather balloons

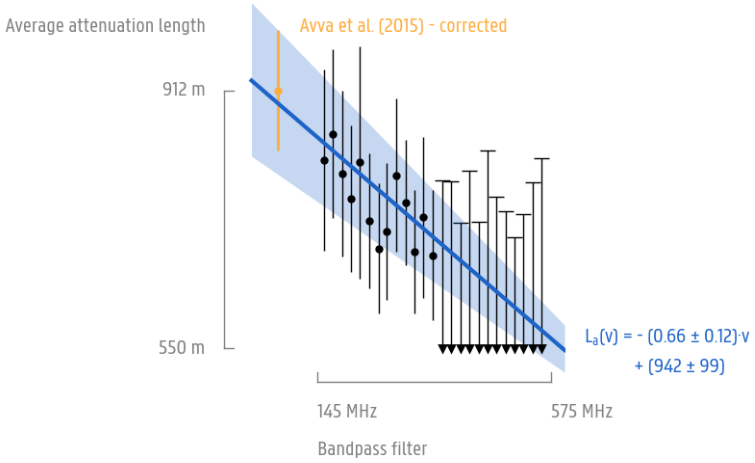
The bedrock echo of a surface pulse gives information on the glacier thickness & attenuation length in ice

Aquilar et. al. (2022) - arXiv:2201.07846



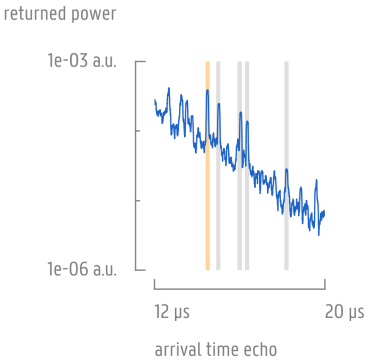
The attenuation length of radio waves in ice is of kilometre scale & decreases with higher frequency

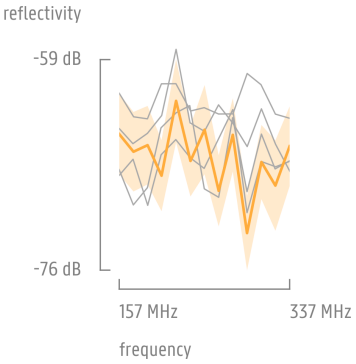
Aquilar et. al. (2022) - arXiv:2201.07846



Peaks in the time series of a surface pulse indicate reflective layers with –70 dB to –60 dB reflectivity

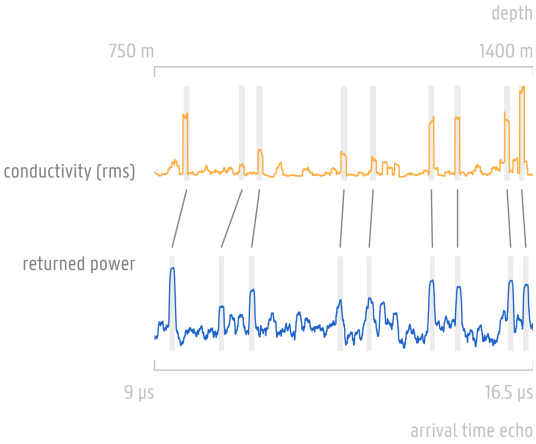
Aguilar et. al. (2022) - arXiv:2212.10285





Depth information from conductivity layers allow us to calculate the refractive index of the bulk ice

Aguilar et. al. (2022) - arXiv:2304.06181

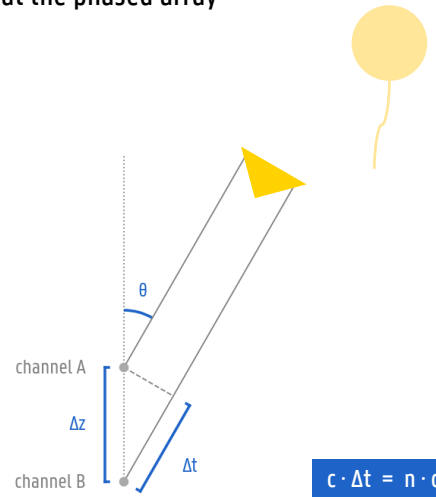


Align peaks by horizontal:

- scaling (varying n)
- shifting (varying Δt)

$n = 1.778 \pm 0.006$

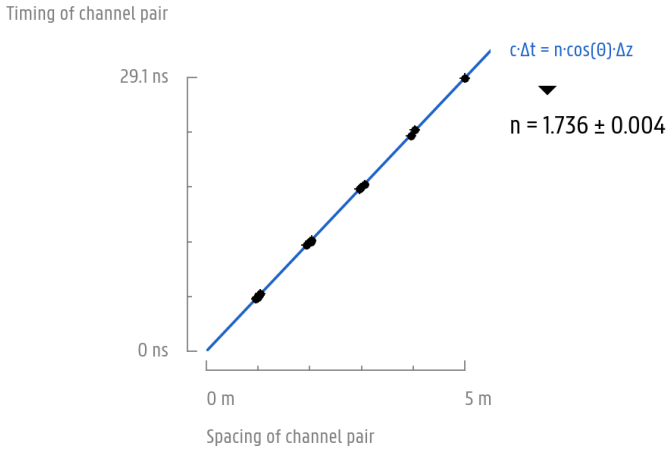
Over-flying weather balloons can be used to probe the refractive index of ice at the phased array



$$c \cdot \Delta t = n \cdot \cos(\theta) \cdot \Delta z$$

Over-flying weather balloons can be used to probe the refractive index of ice at the phased array

RNO-G preliminary



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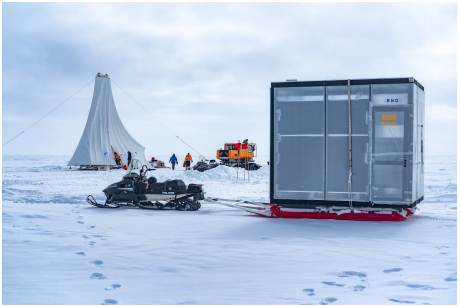

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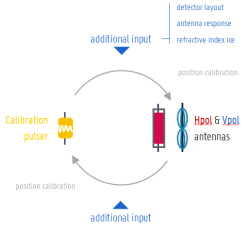
Calibration of RNO-G detector convoluted task

but progress is made by several people

Calibration tasks

- Antenna position & timing
- Ice modelling
- Signal chain
- Digitalisation



Glacier ice complex with lots of open question,

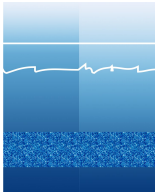
but we progress towards a better understanding

Continuous 1D profiles

Exponential polynomial profile

- Attenuation length: ± 750 m
- Refractive index bulk ice: 1.778 ± 0.006
- Refractive index deep firn: 1.736 ± 0.004

More complex ice properties ?



- 1D-profile depending on location ??
- Birefringence → not significant in vertical direction
- Reflective layers → -70 dB to –60 dB
- Dispersion







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