Progress on the implementation of interferometric air shower reconstruction in astroparticle physics observatories.

OBSERVATORIO PIERRE AUGER

SWGO
The Southern Wide-field Gamma-ray Observatory

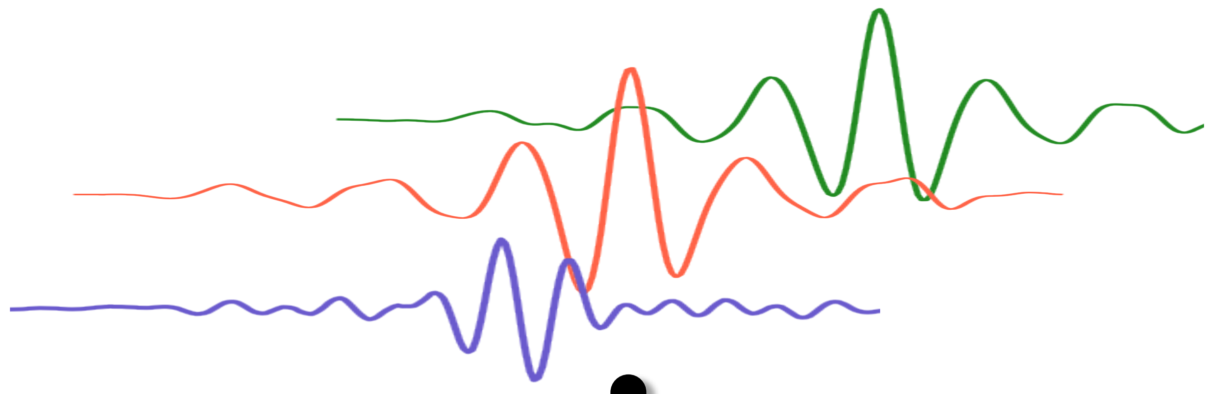
Harm Schoorlemmer

Funded by the European Union
European Research Council
Established by the European Commission

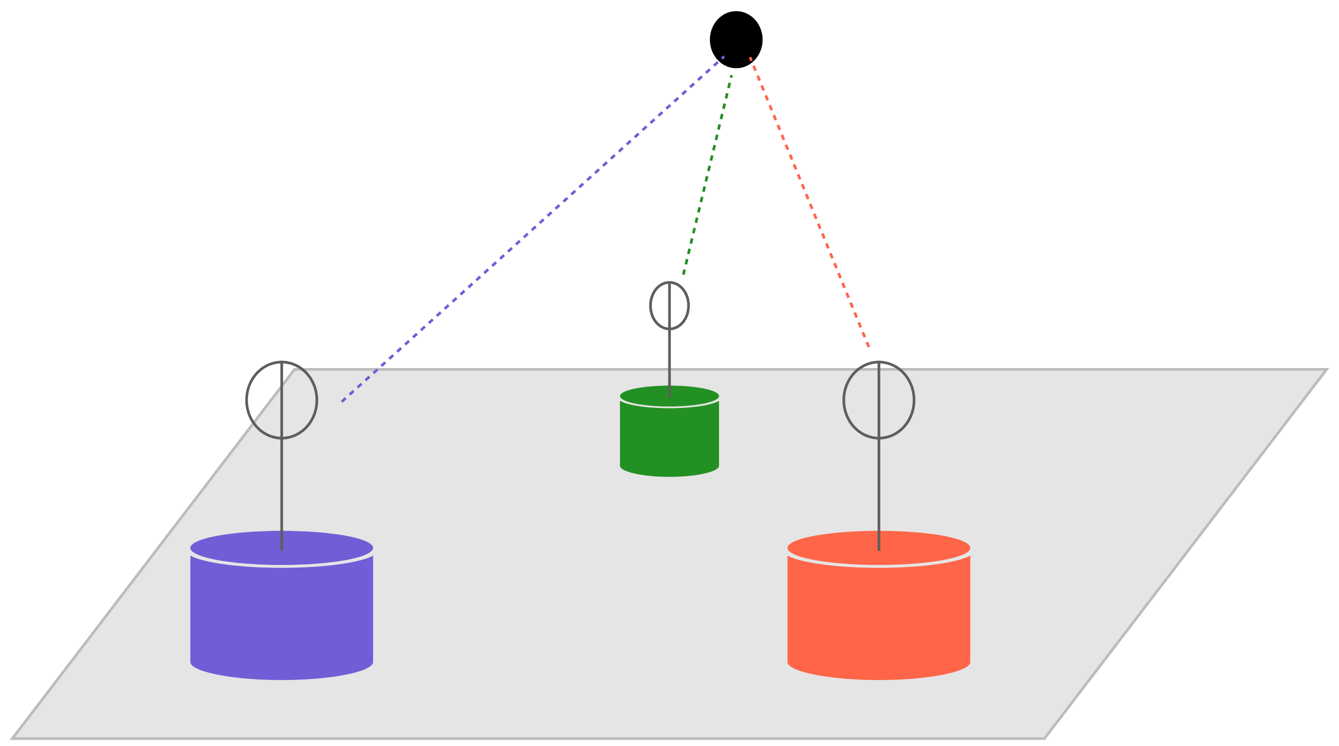
Nikhef
Radboud Universiteit

Inteferometry applied to air showers

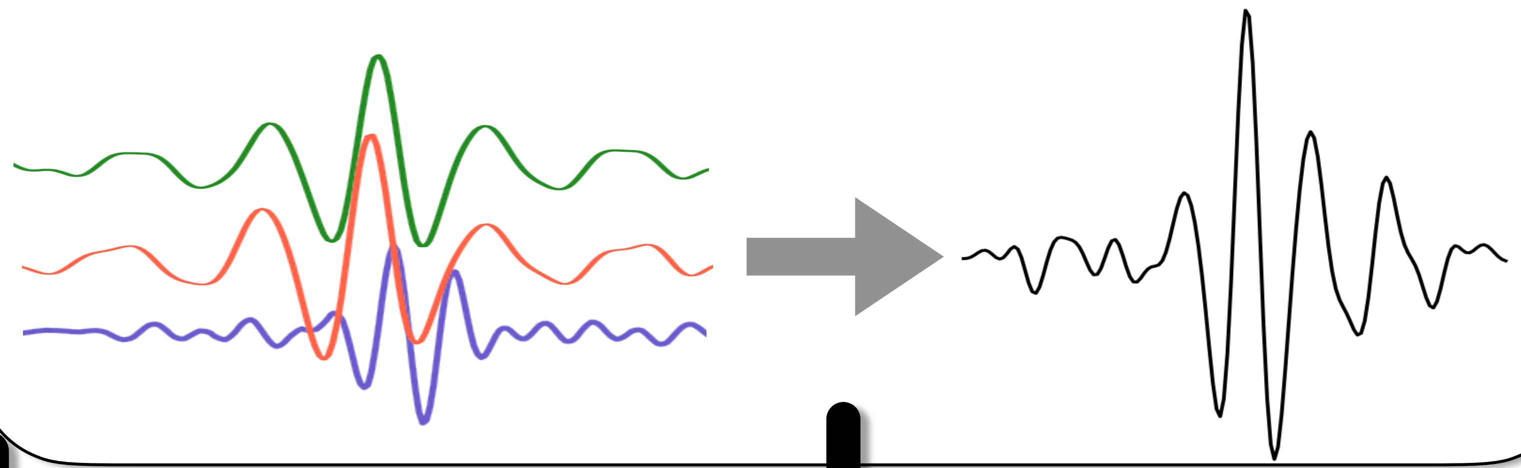
1) Measure radio signals



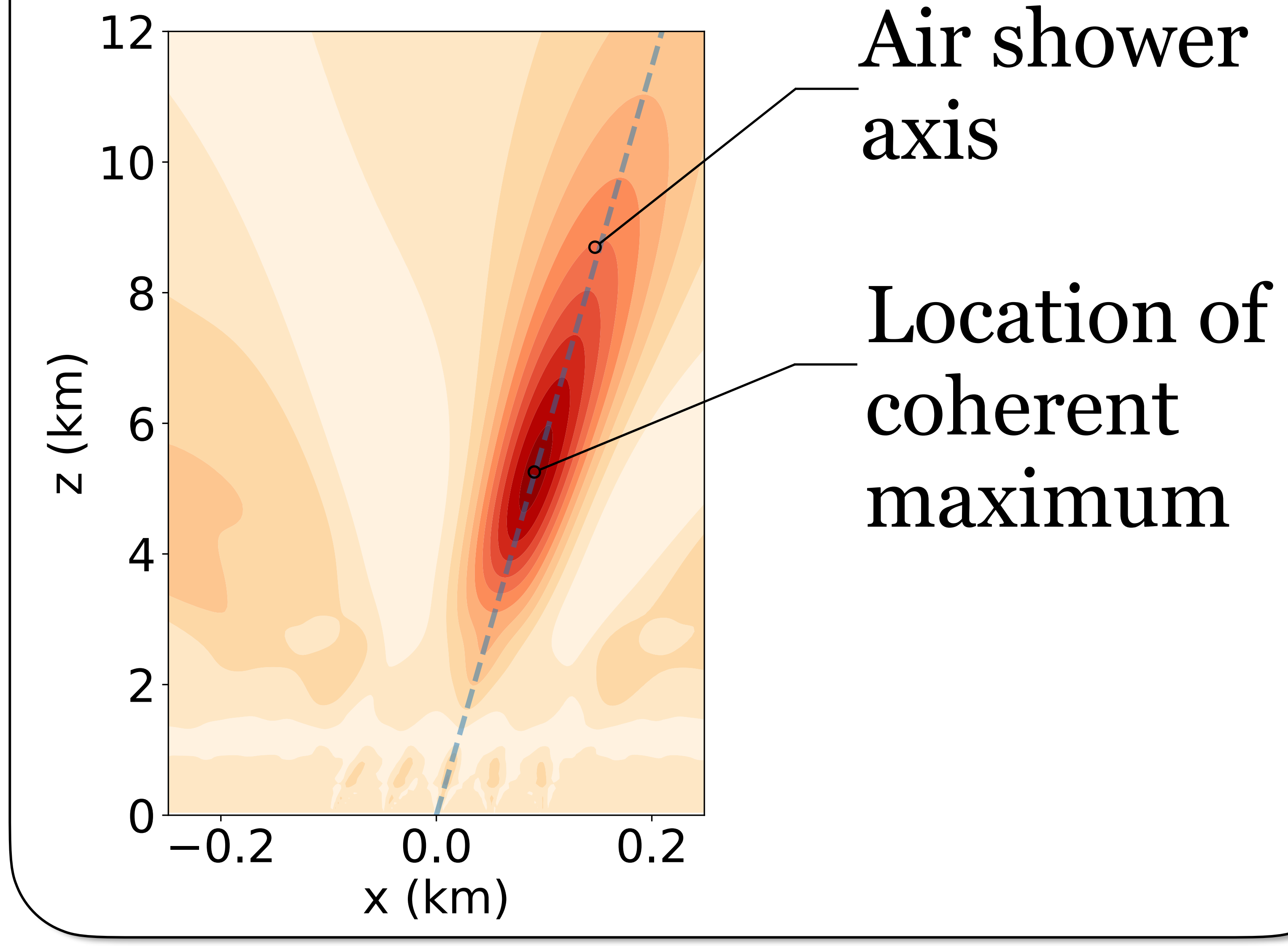
2) Calculate time delay for each antenna to a location in space



3) Delay the signals and sum them



4) Scan through space & time to identify the air shower



Inteferometry applied to air showers

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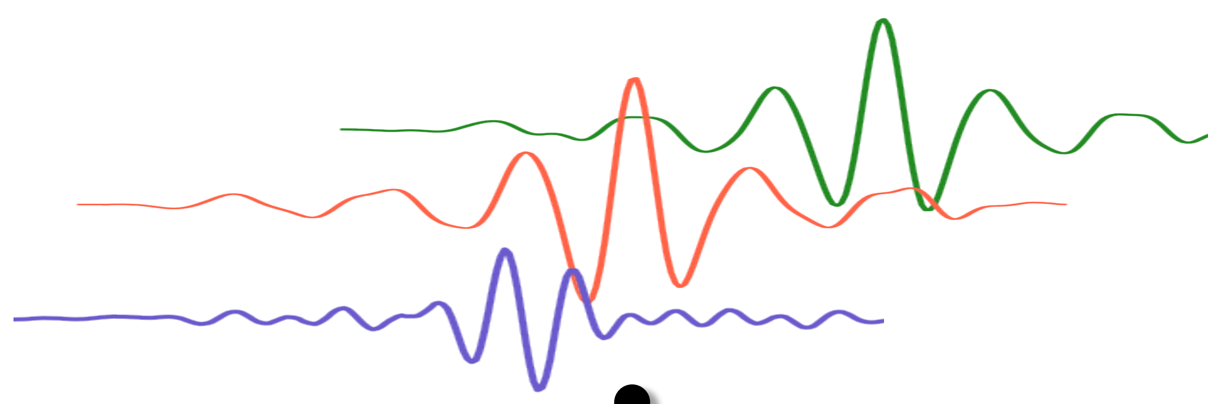

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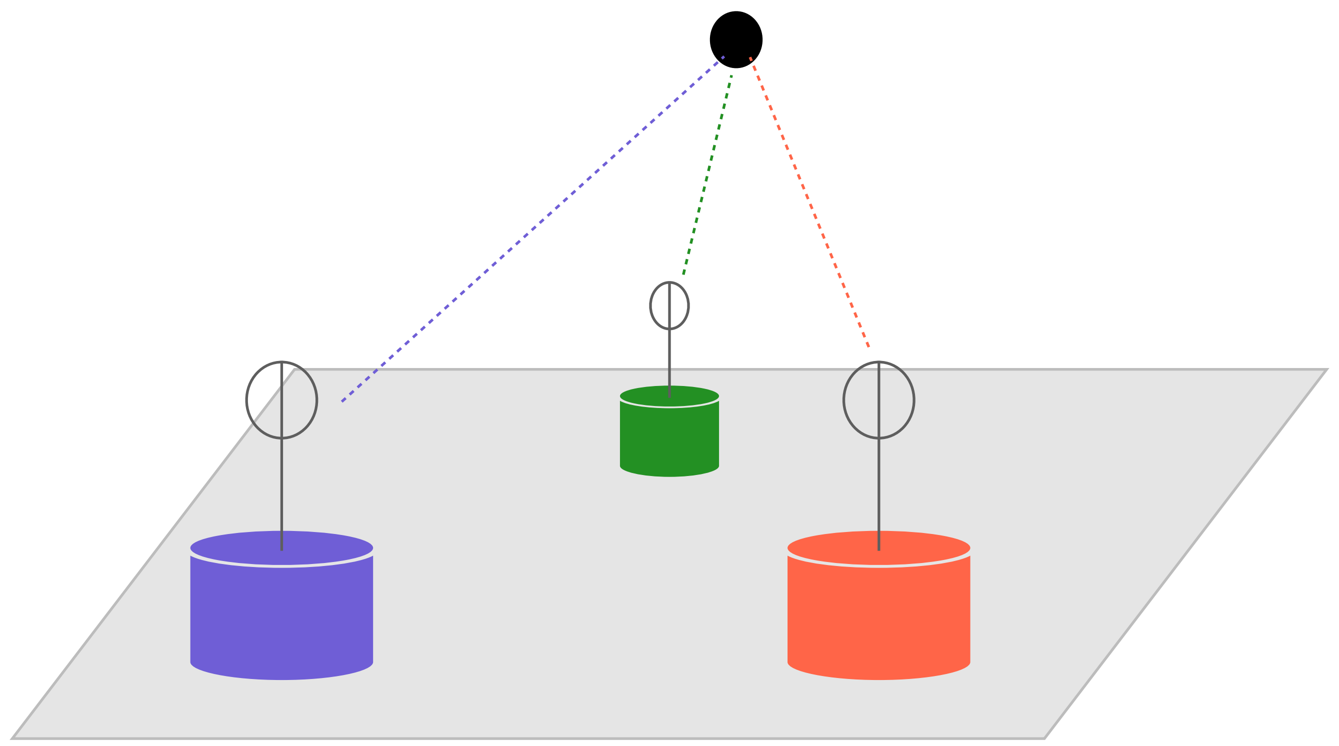

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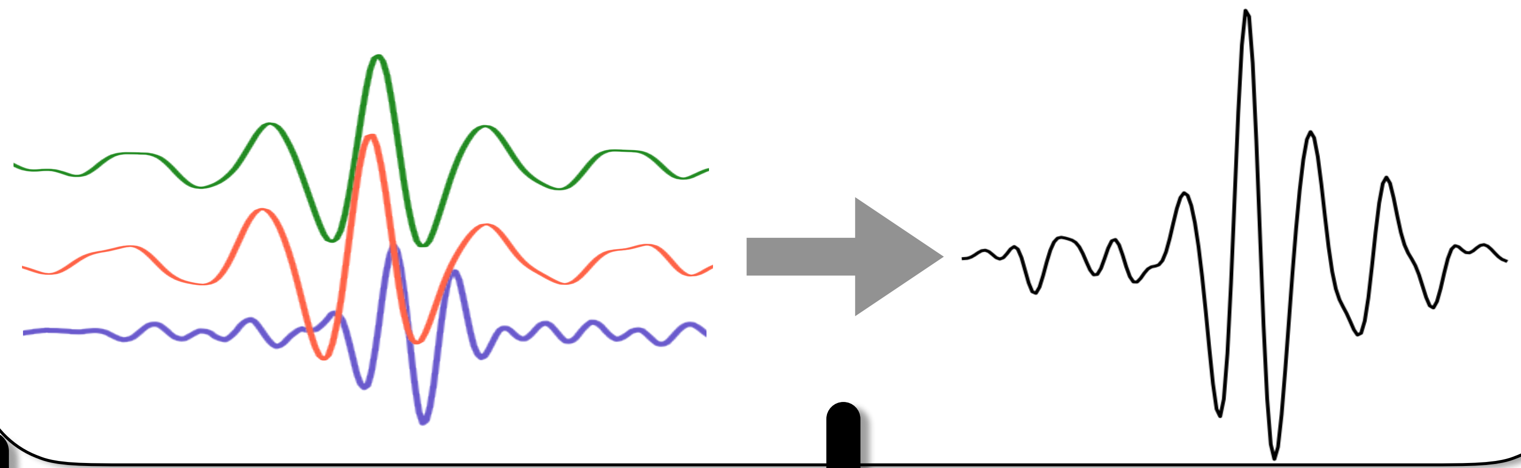

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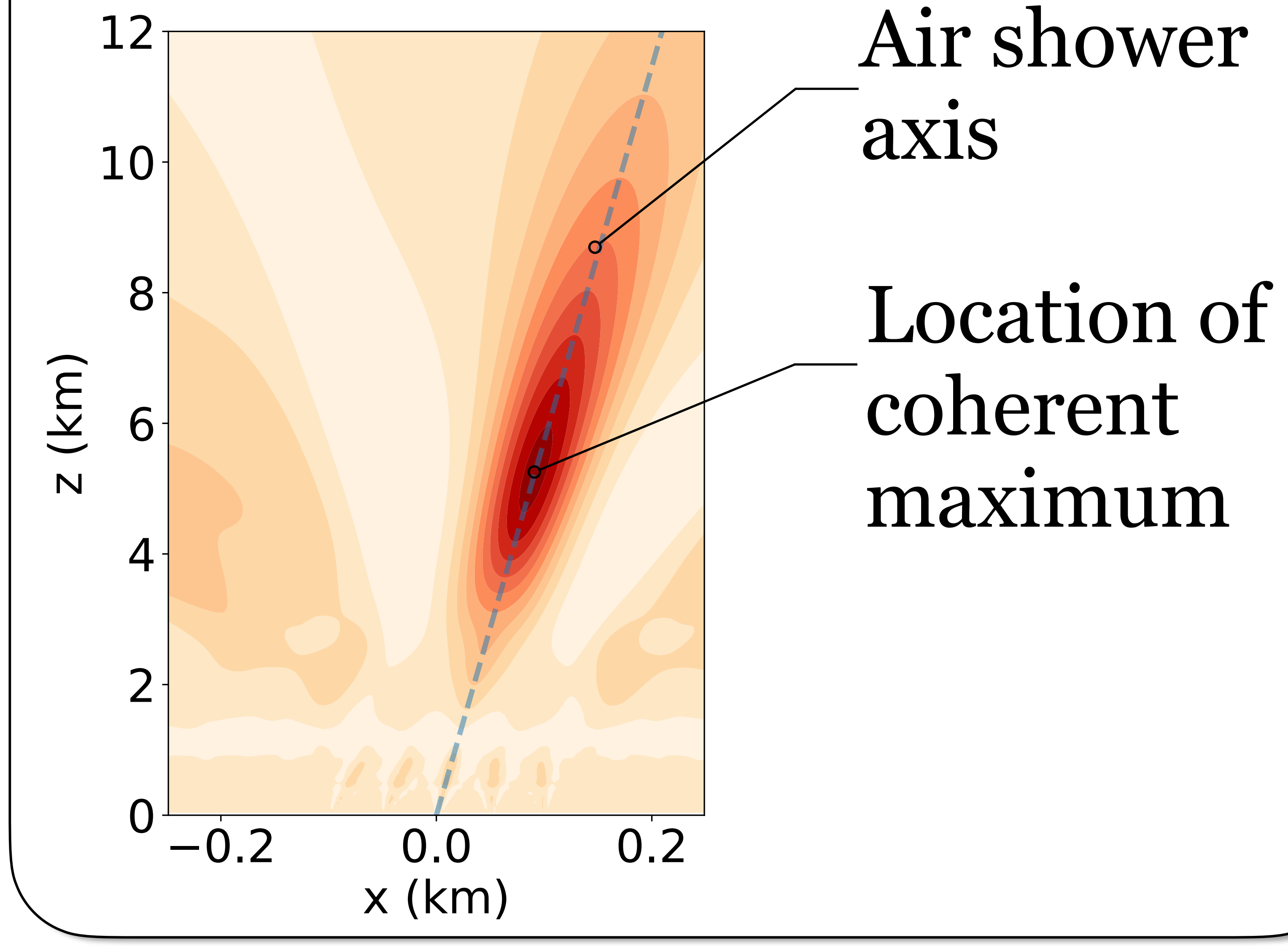
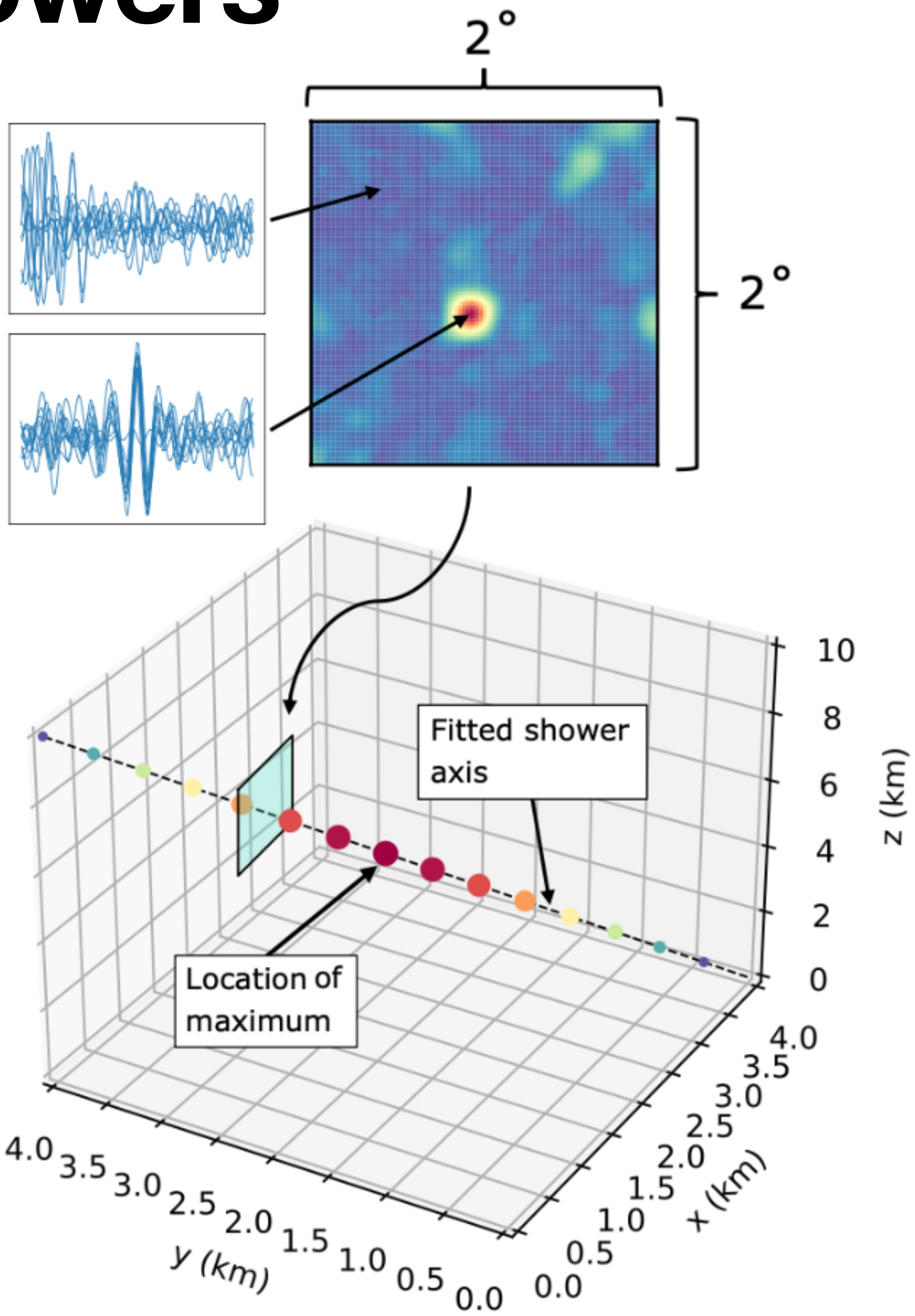
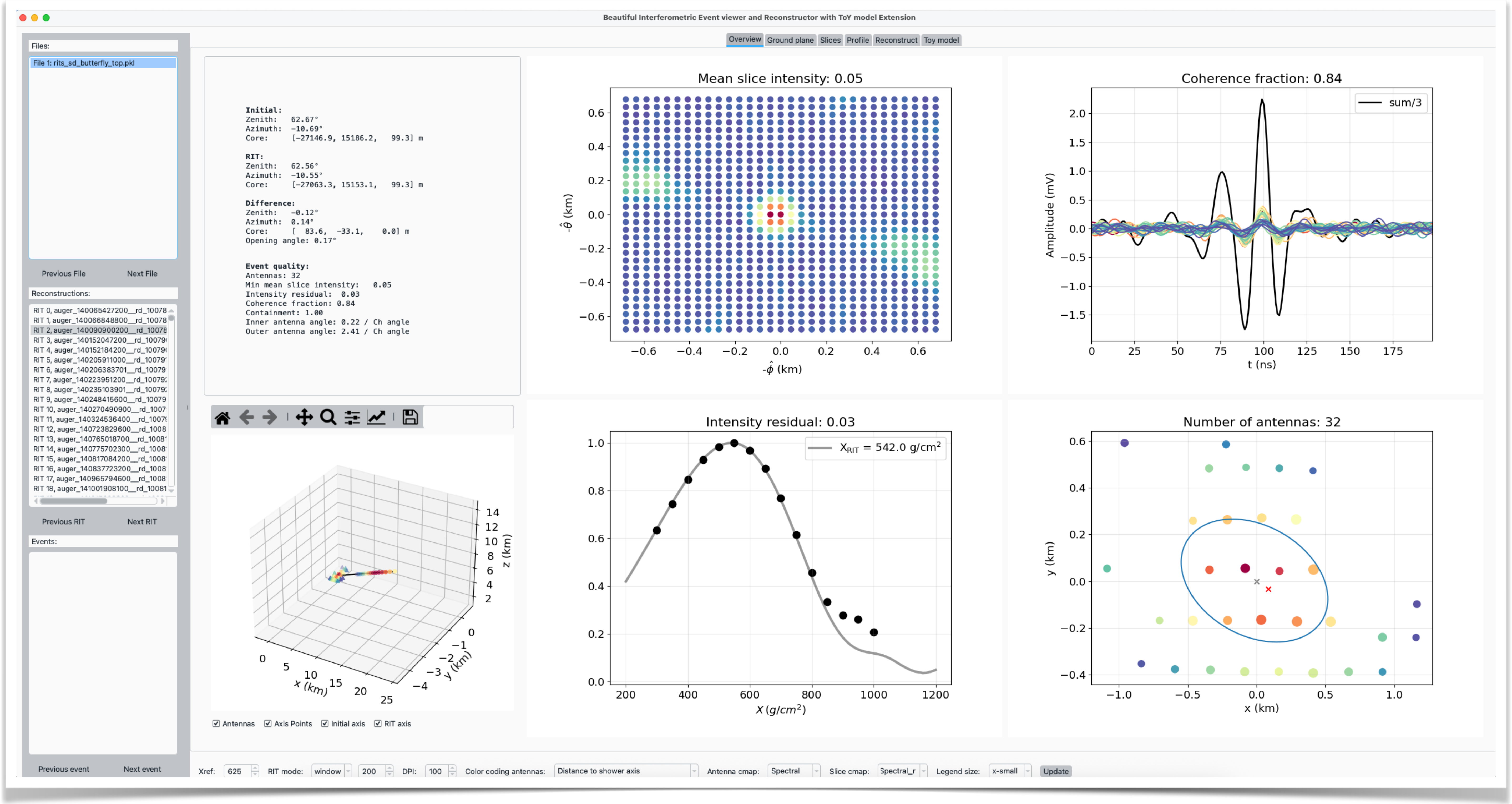


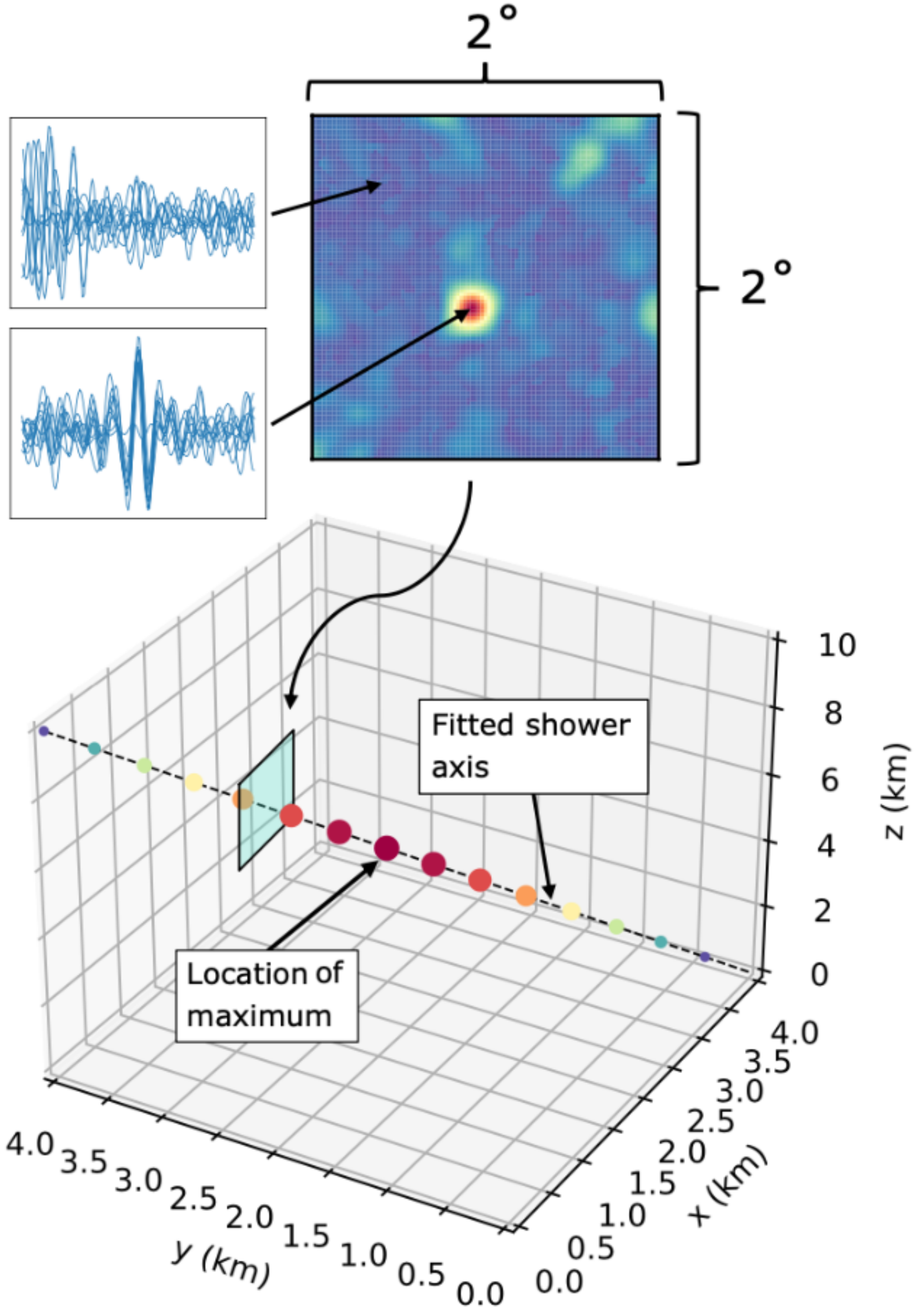


Air Shower Interferometric Reconstruction Algorithm

ASIRA: Toolkit to do interferometric reconstructions

- Simulations and measurements
- Toy model emission
- Interactive reconstructions and result inspection



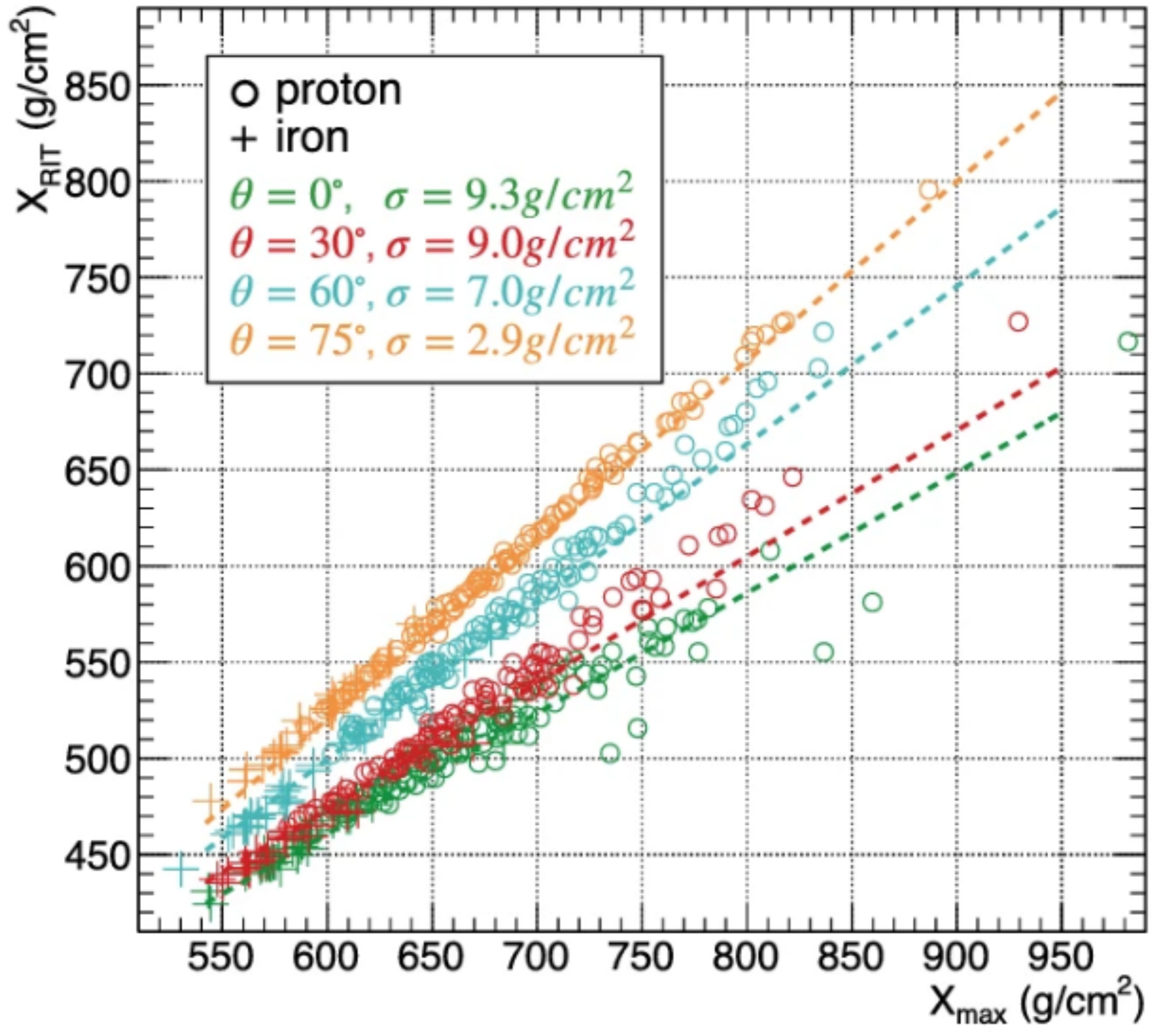


https://gitlab.com/harmscho/asira

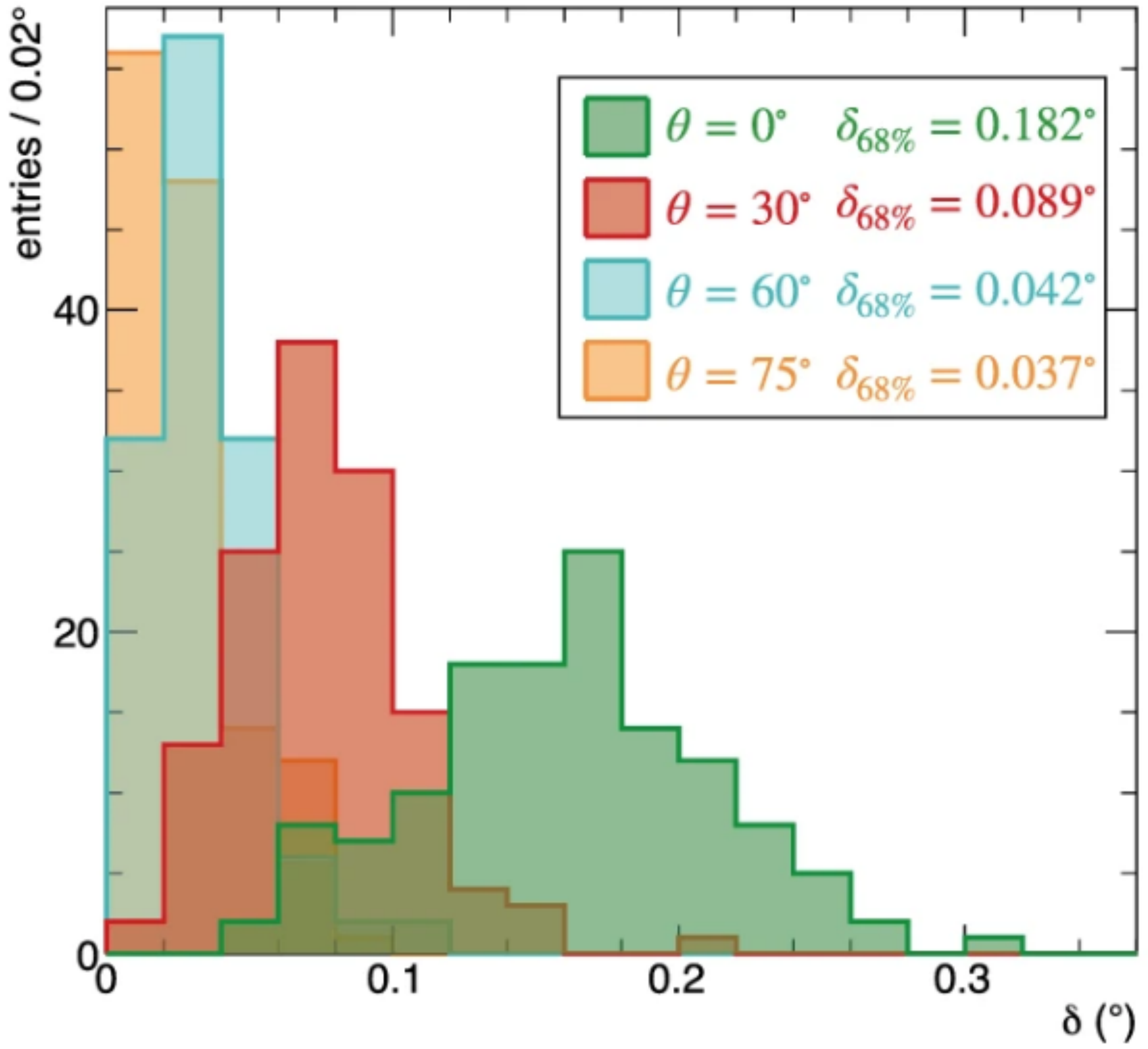
Pim/Juan/HS

Simulation lala-land….

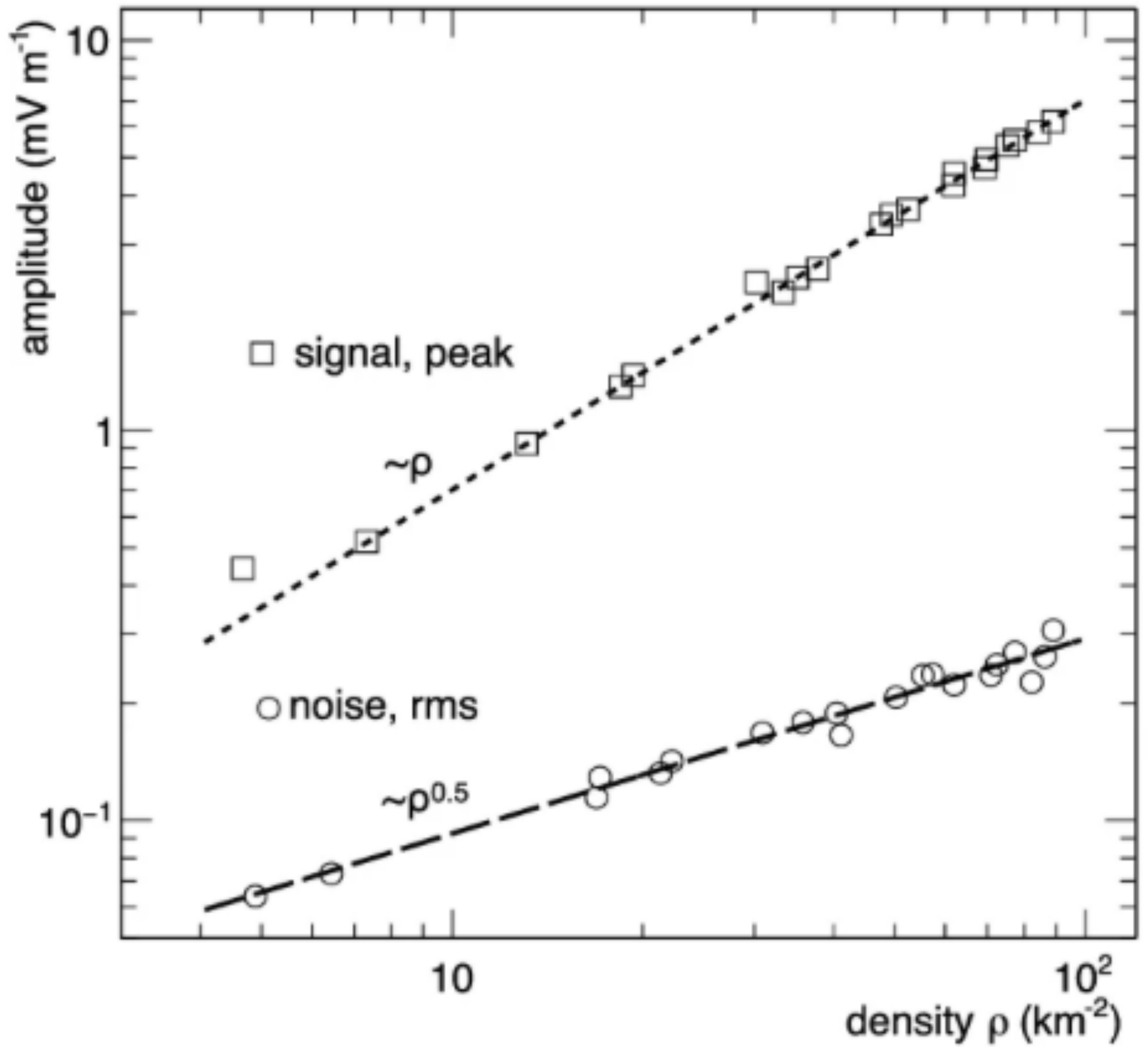
Reconstruct depth of air shower: composition



Direction reconstruction



Dig signals out of the noise

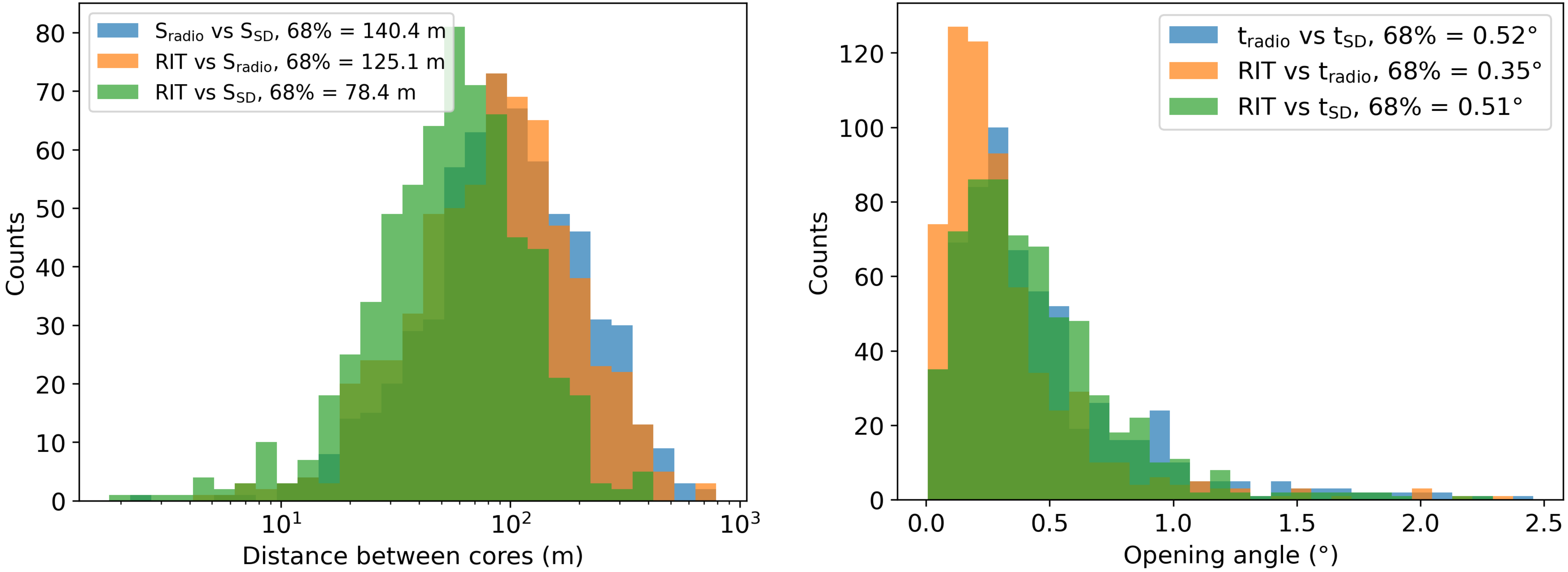


But we need to know the relative timing (and position) in the order of 1ns (1ns * c = 30 cm)

https://gitlab.com/harmscho/asira

Setup 1: The Auger Engineering Radio Array

Geometry reconstruction



- Comparision to traditional methods, where functional shapes are fitted to the signal strength $S_{\text{radio,SD}}$ or the arrival time $t_{\text{radio,SD}}$
- Similar or better preformance as traditional methods.

Results (3): Reconstruction around the energy threshold

Event Selection

Zenith angle $75^\circ < \theta < 82^\circ$

Energy: ~1 EeV

Quality SD: $\frac{\sigma_{19}}{N_{19}} < 0.5$

Number of stations in 2xCherenkov cone > 60 (@750g/cm²)

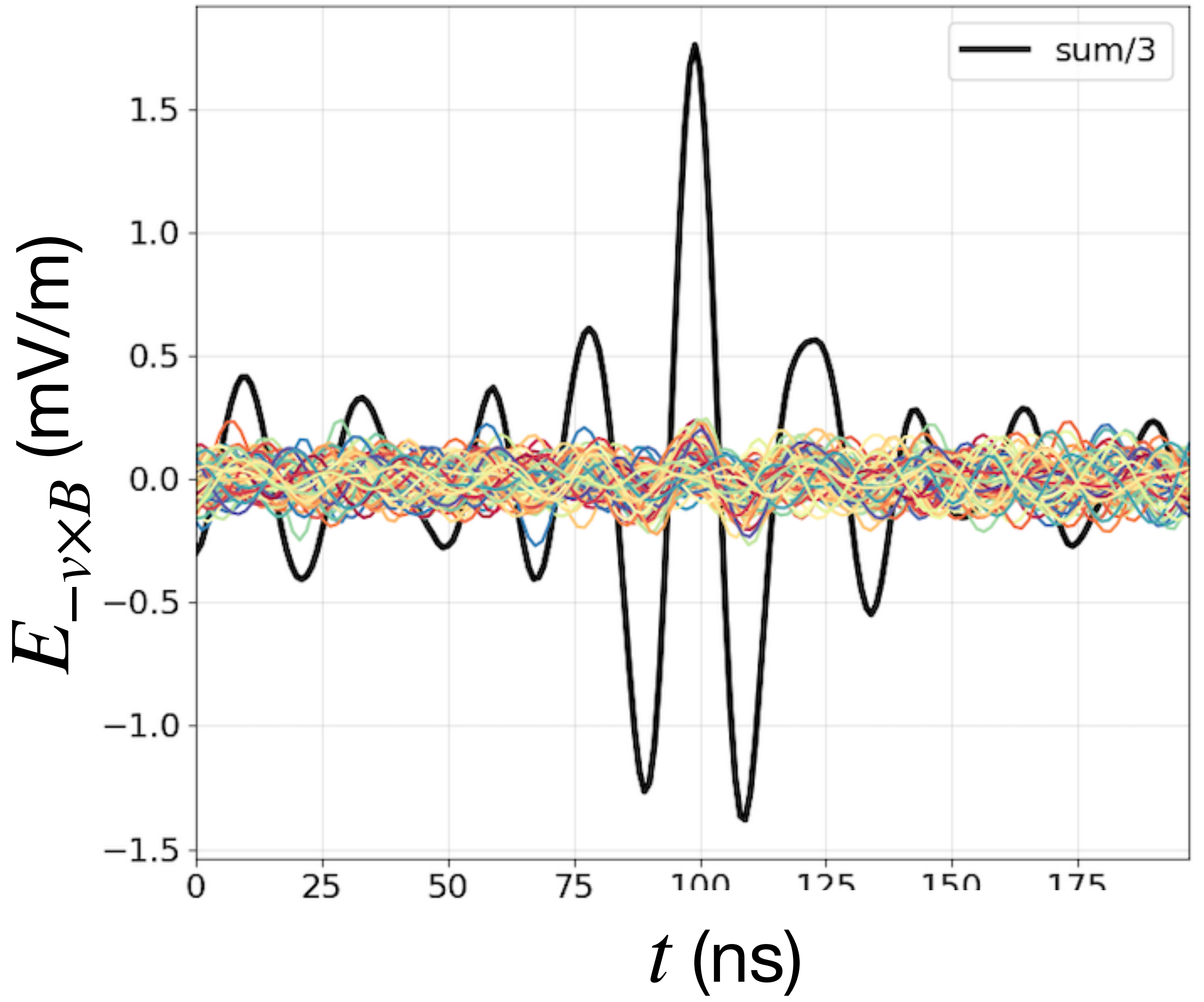
Stats

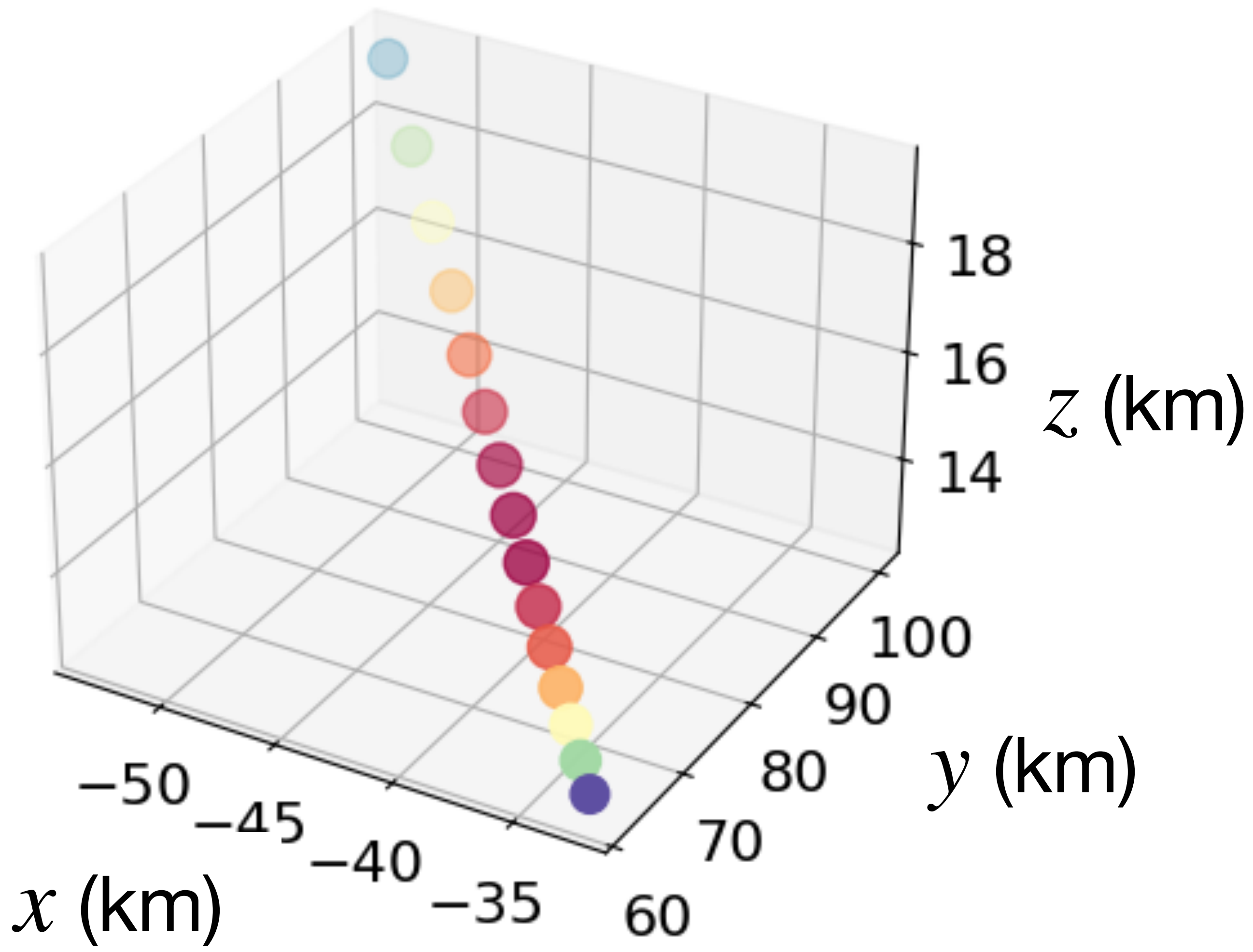
Set: 194 events

Radio standard reco: **17**

Radio inteferometry reconstruction: **57**

Example



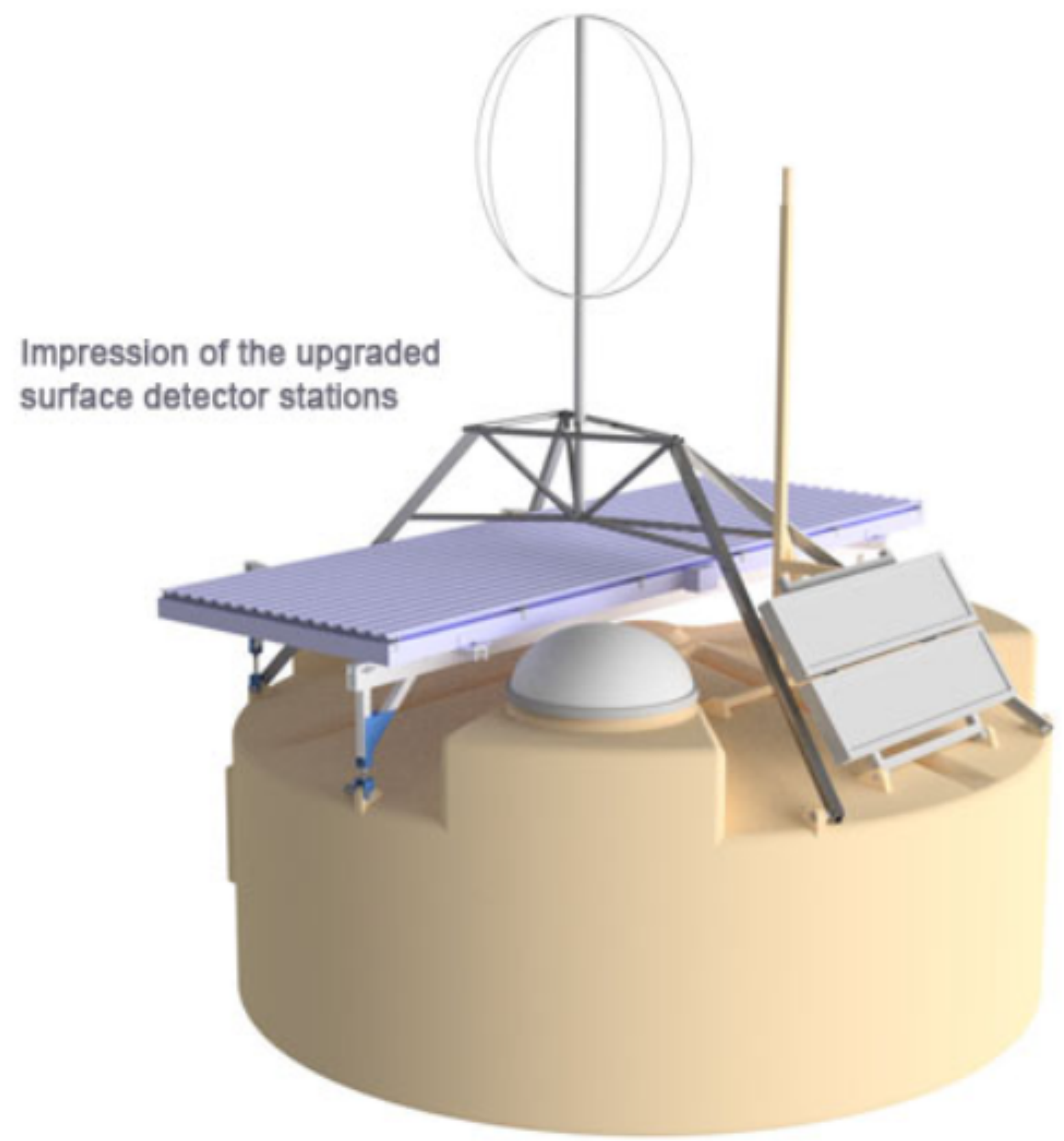


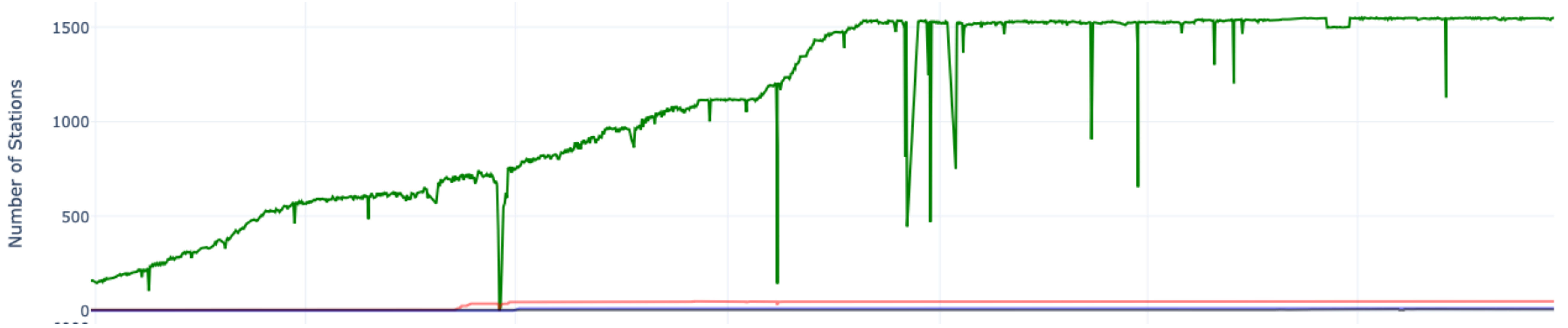
Selection for radio-interferometry: **SNR >7 (max/std) of summed waveform**

Setup 2: AugerPrime the radio detector

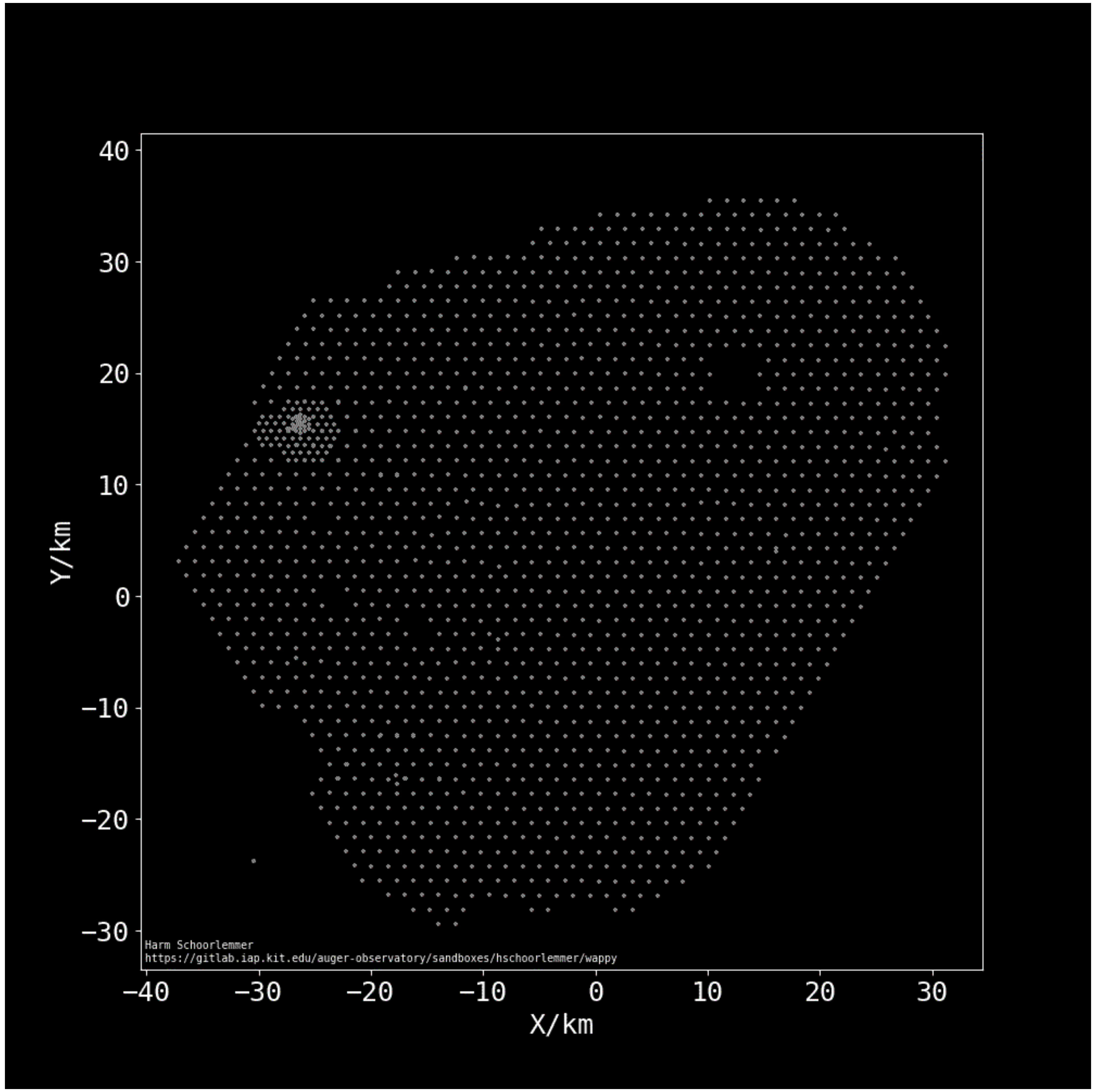
Each particle detector has a radio antenna

Largest cosmic ray observatory: 1660 detectors, 3000 km²





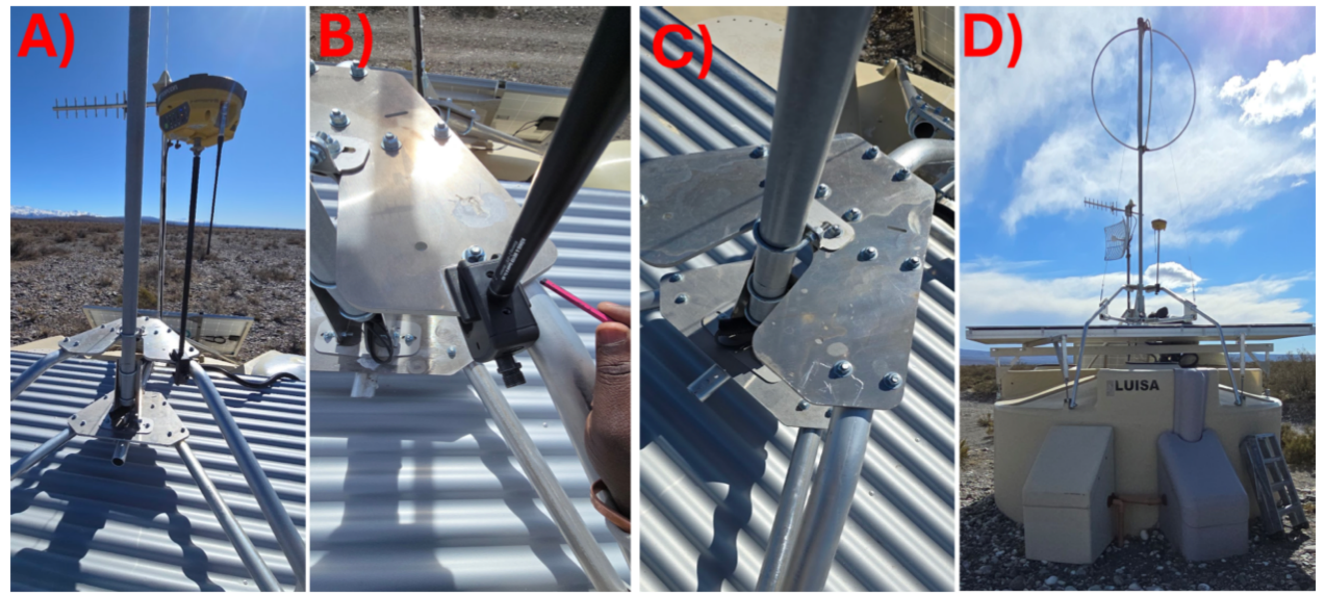
jan 2024 jan 2025 now

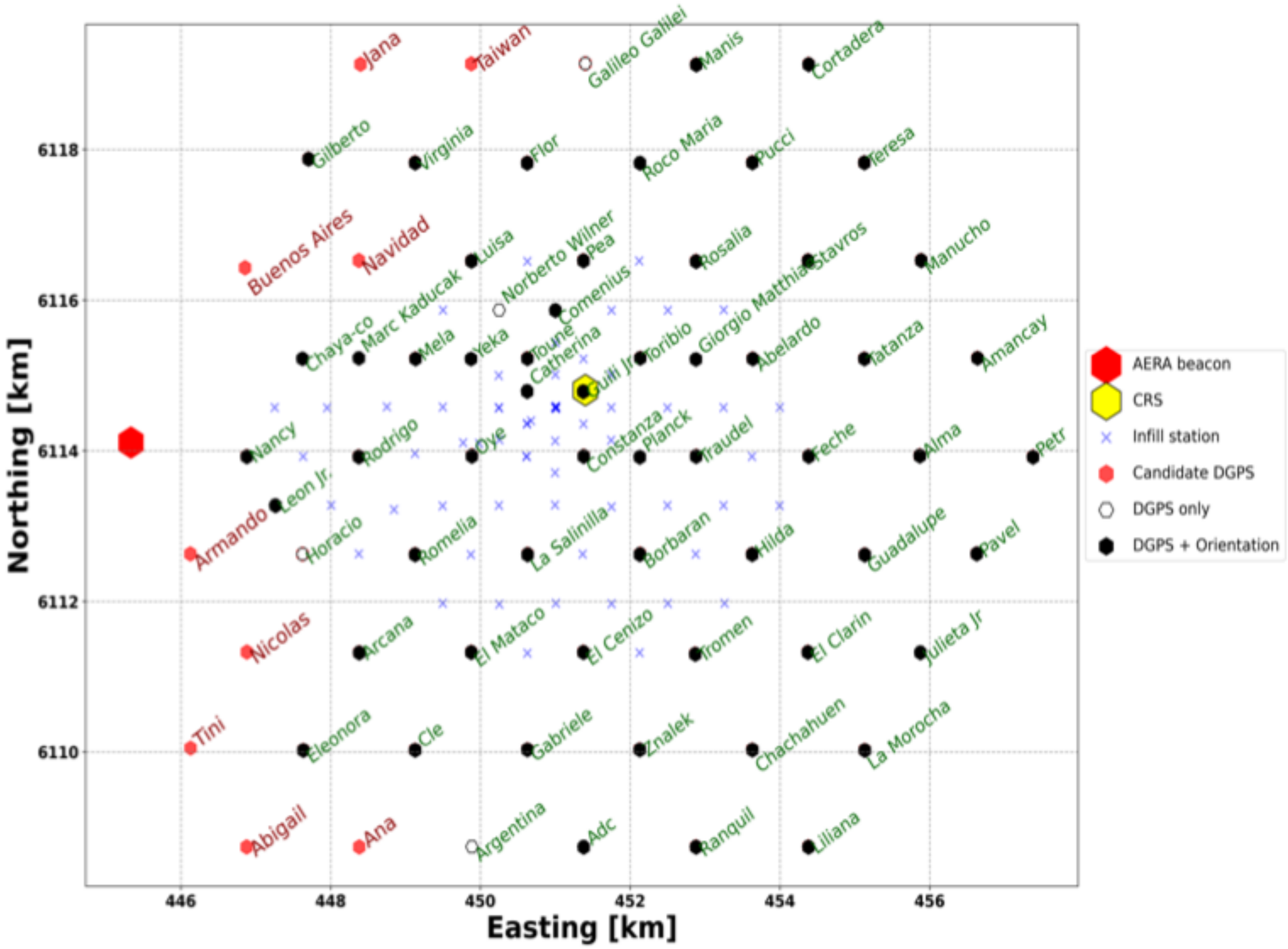


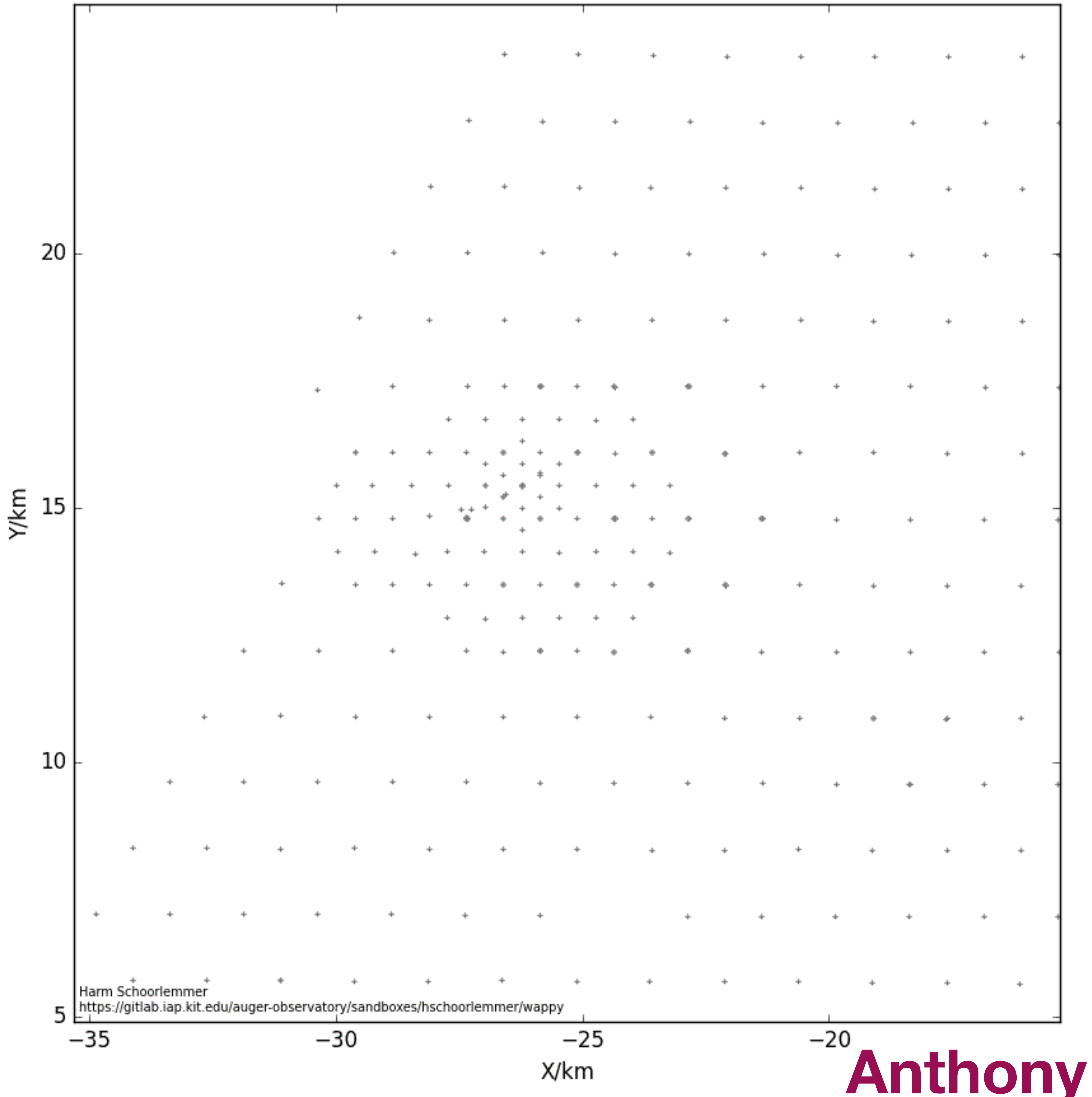
Mohamed

Setup 2: First results

Accurate survey of 60 antennas (~10cm)



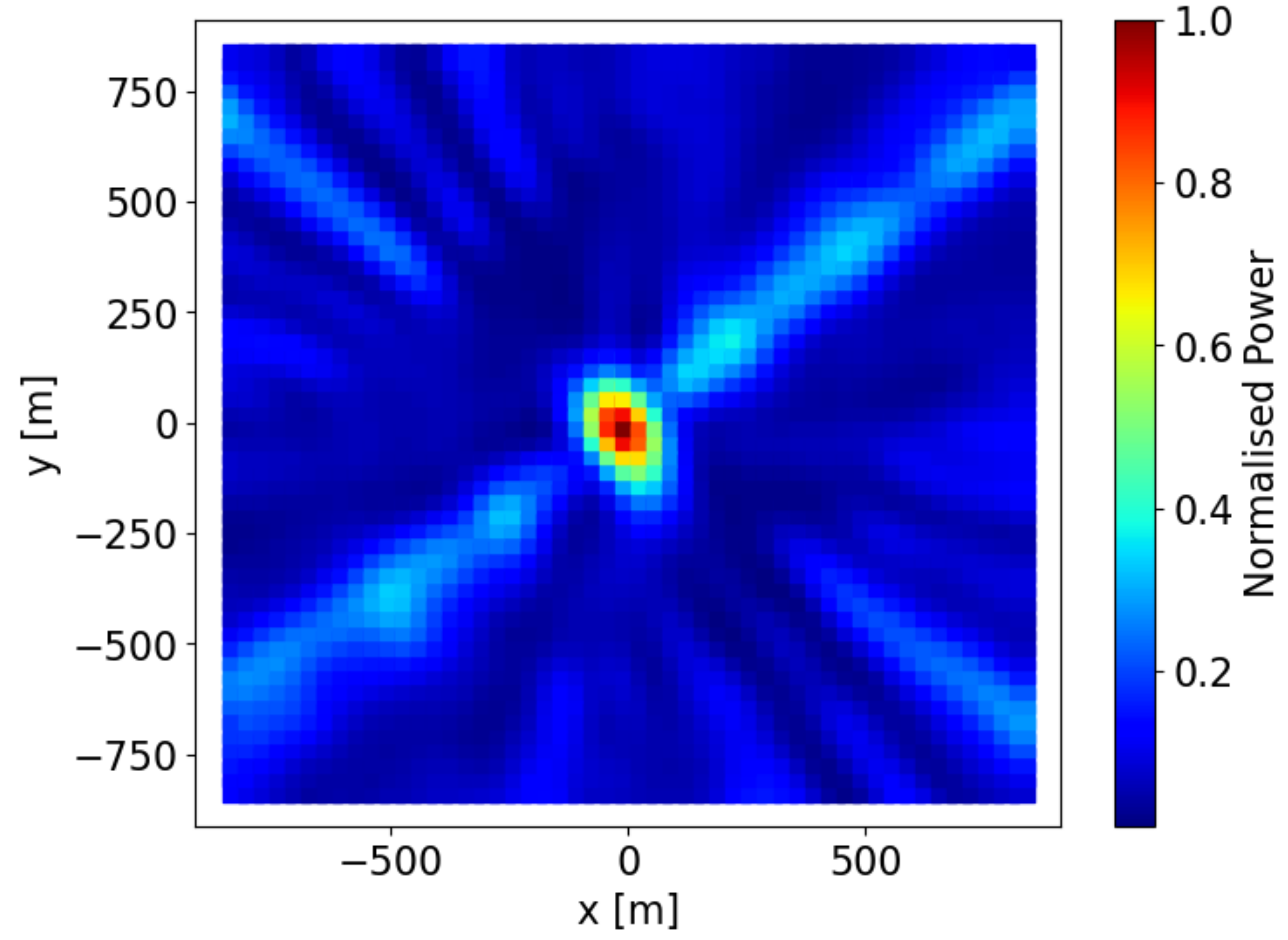


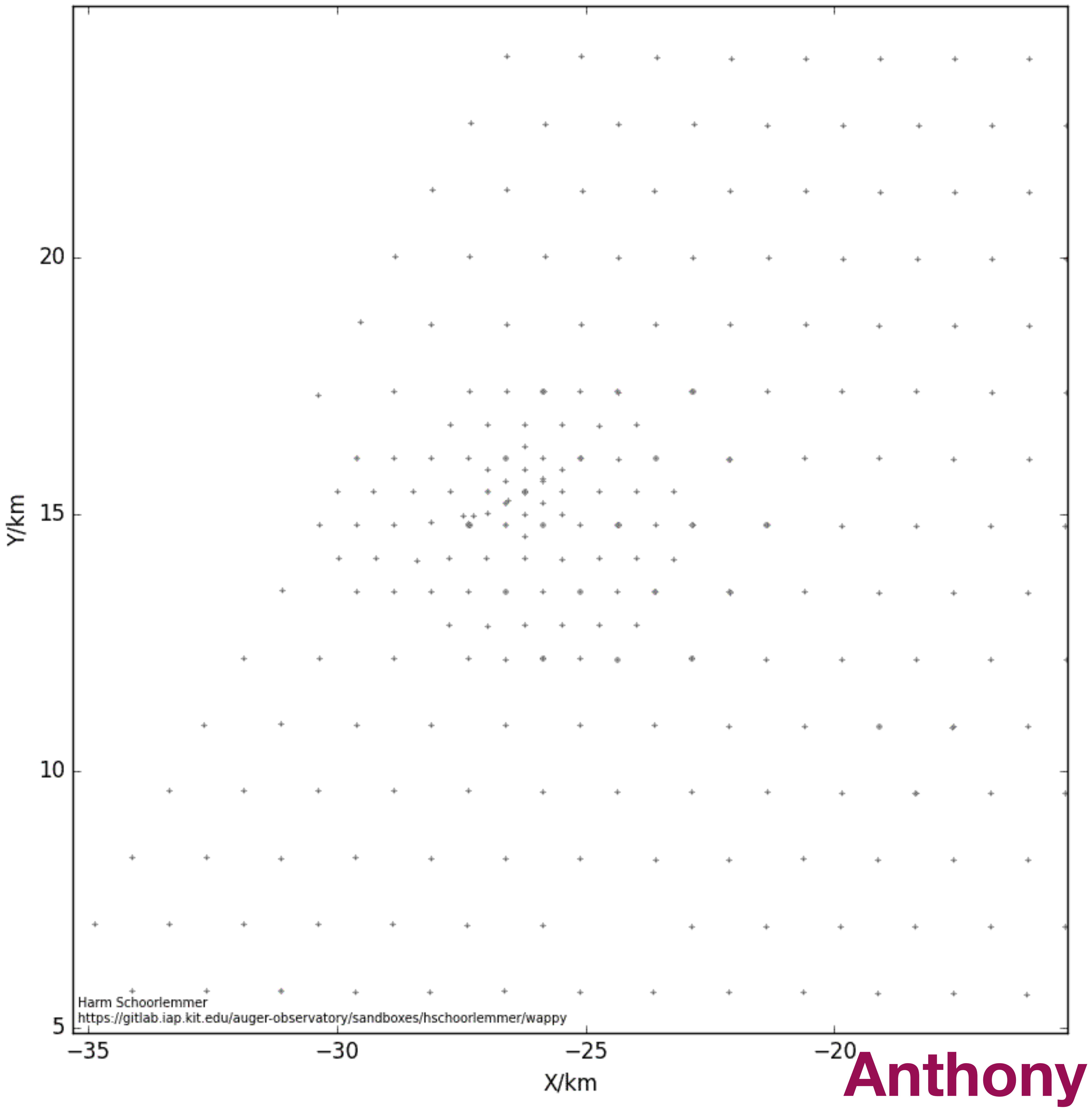


Anthony

Setup 2: First results

Perform interferometric reconstruction





Anthony

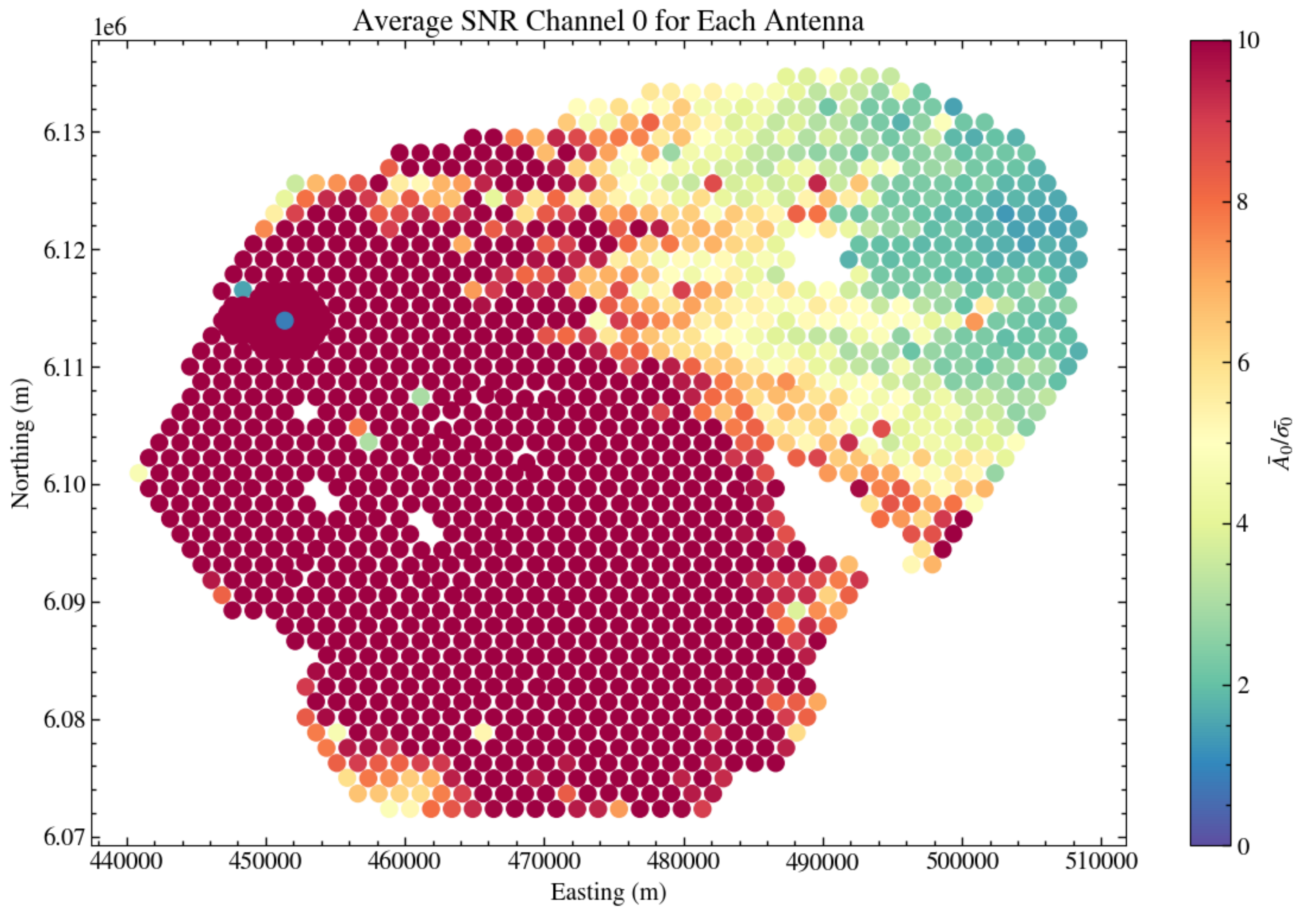
Setup 2: Next steps

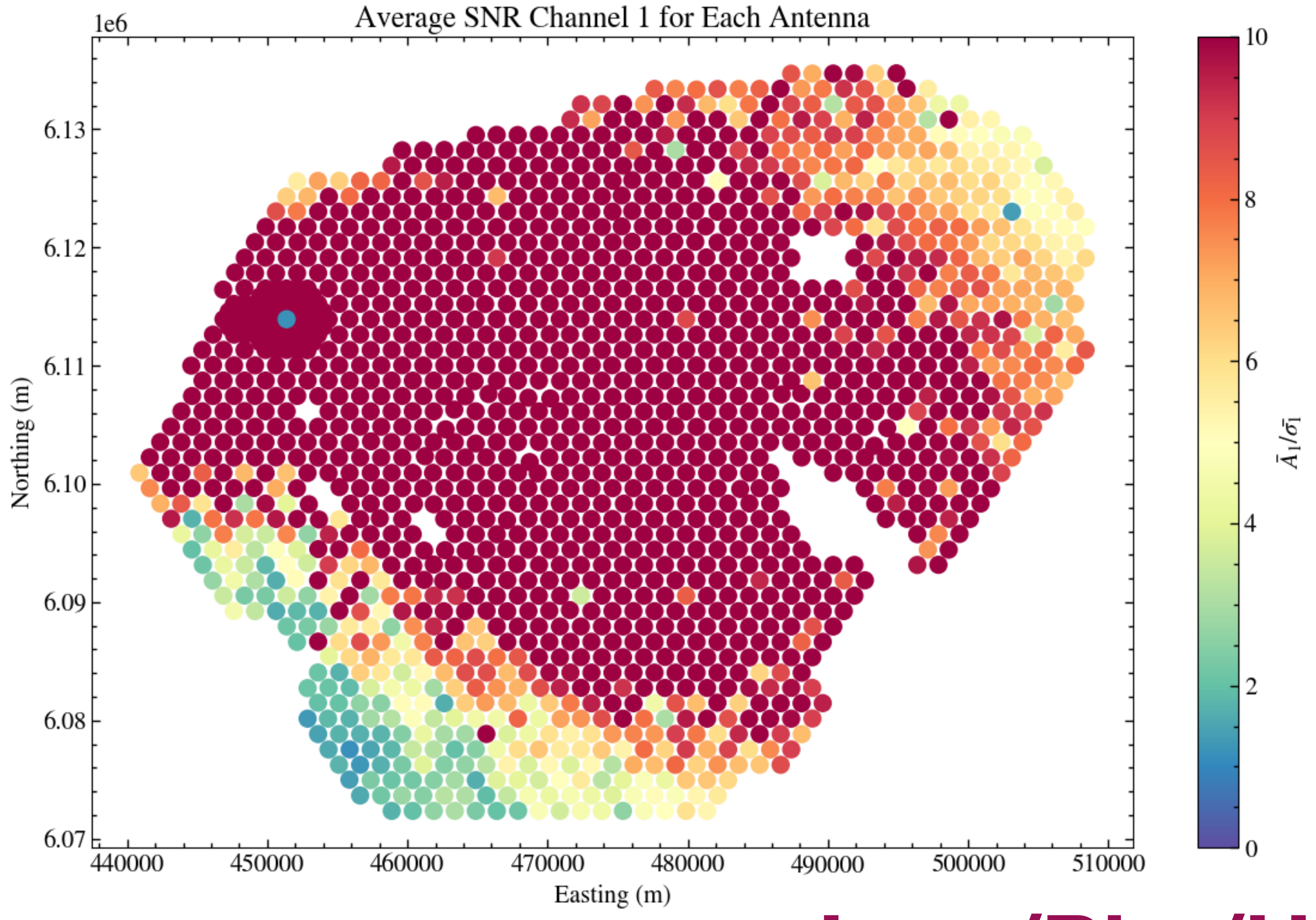
Beacon setup for the full array:

- Currently prototyping and testing configurations
- Aim for permenant solution within the coming year

Differential GPS survey full array

- Purchasing equipment
- Start early 2026





Juan/Pim/HS

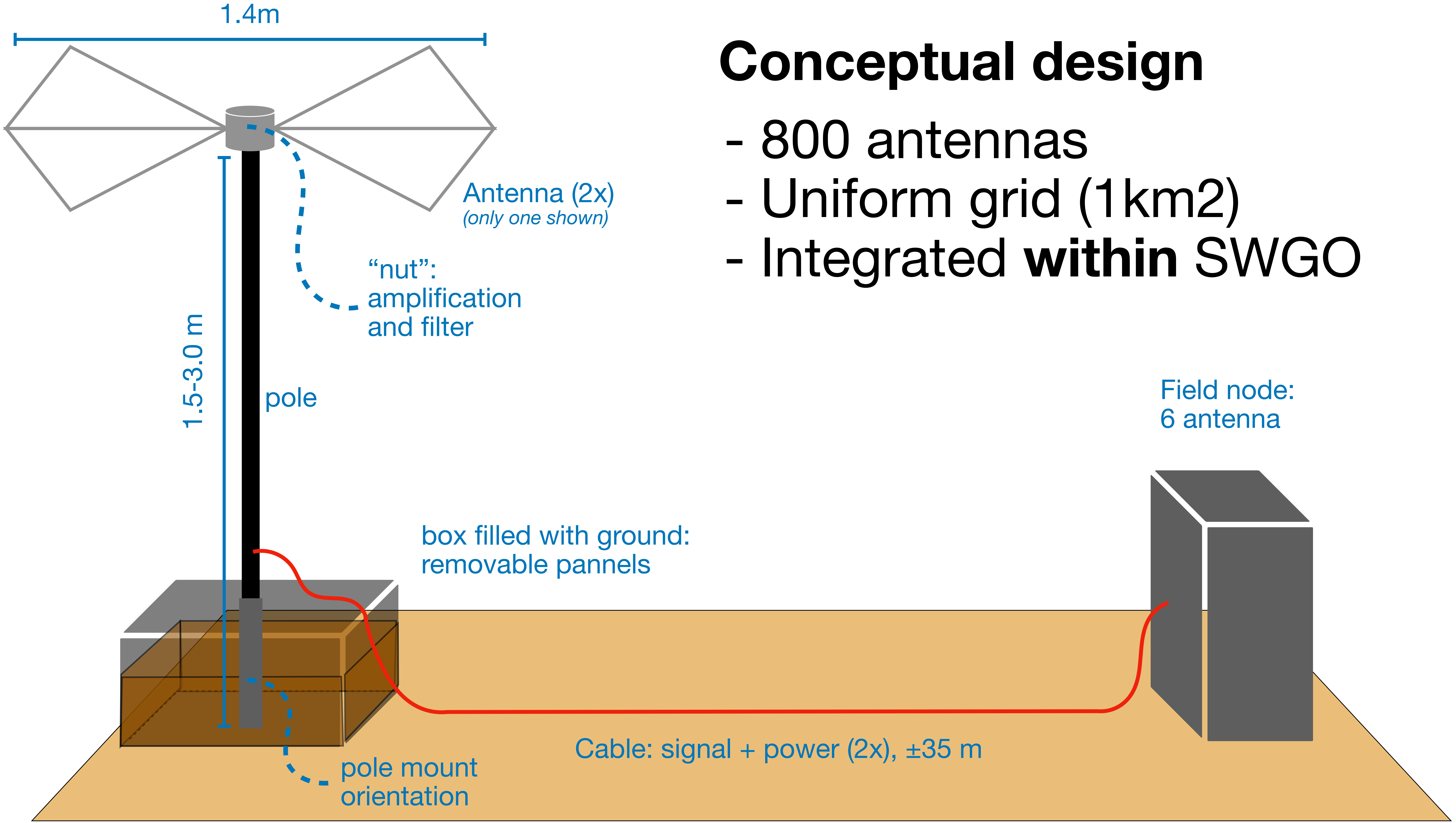
Setup 3

SWGO
The Southern Wide-field
Gamma-ray Observatory

TURBO
The Utility for Radio
Beamformed Observations

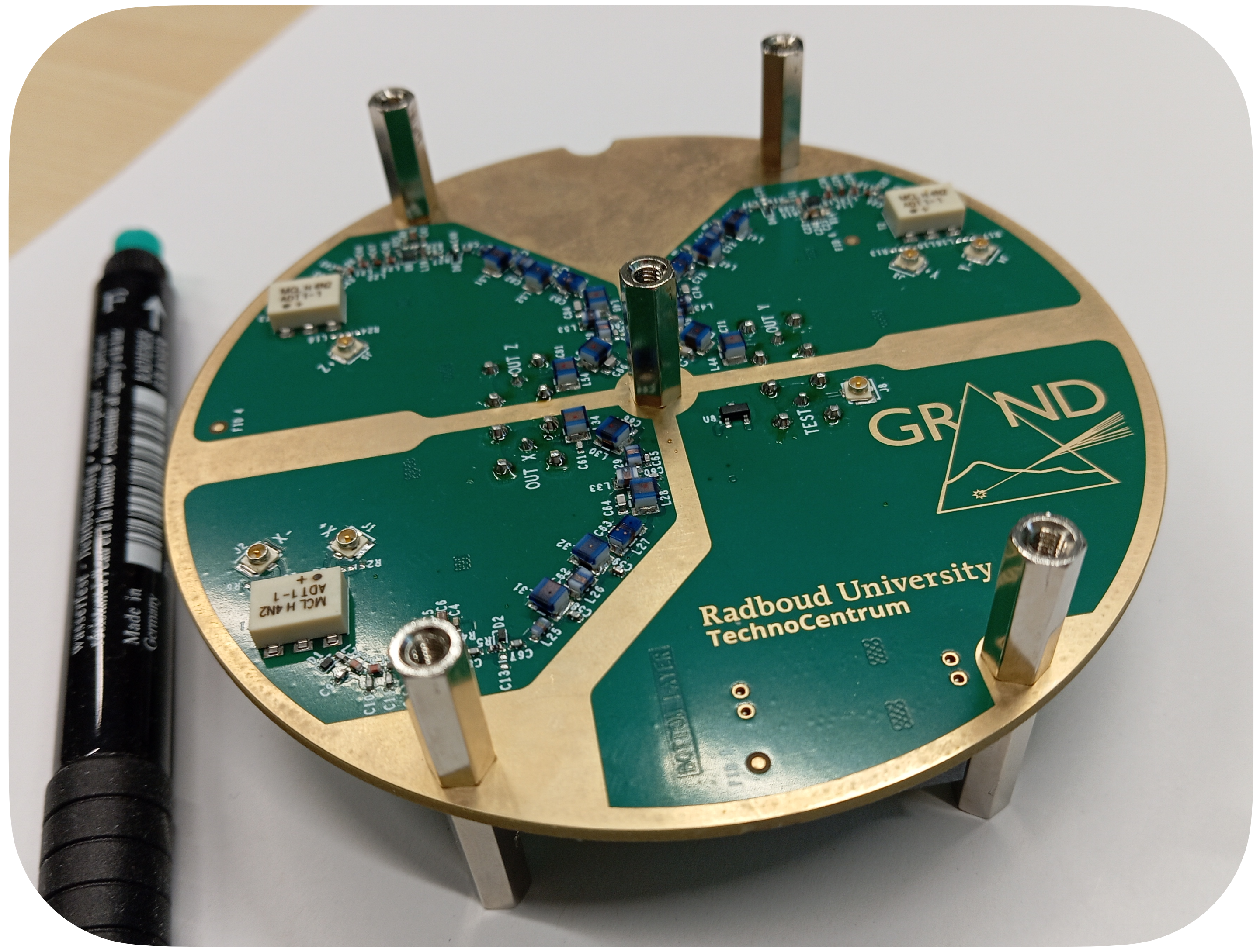
Conceptual design

- 800 antennas
- Uniform grid (1km2)
- Integrated **within** SWGO



Towards actual design: Build on hardware development for GRAND and SWGO

Amplification at
the antenna



Testing digitizer:
24 channels, 250 MHz => 12 channels, 500 MHz

Aim to have a full proto-type within one year

Postdoc starts in mid-February, looking for a PhD student to start before April

Daniel/Charles/HS