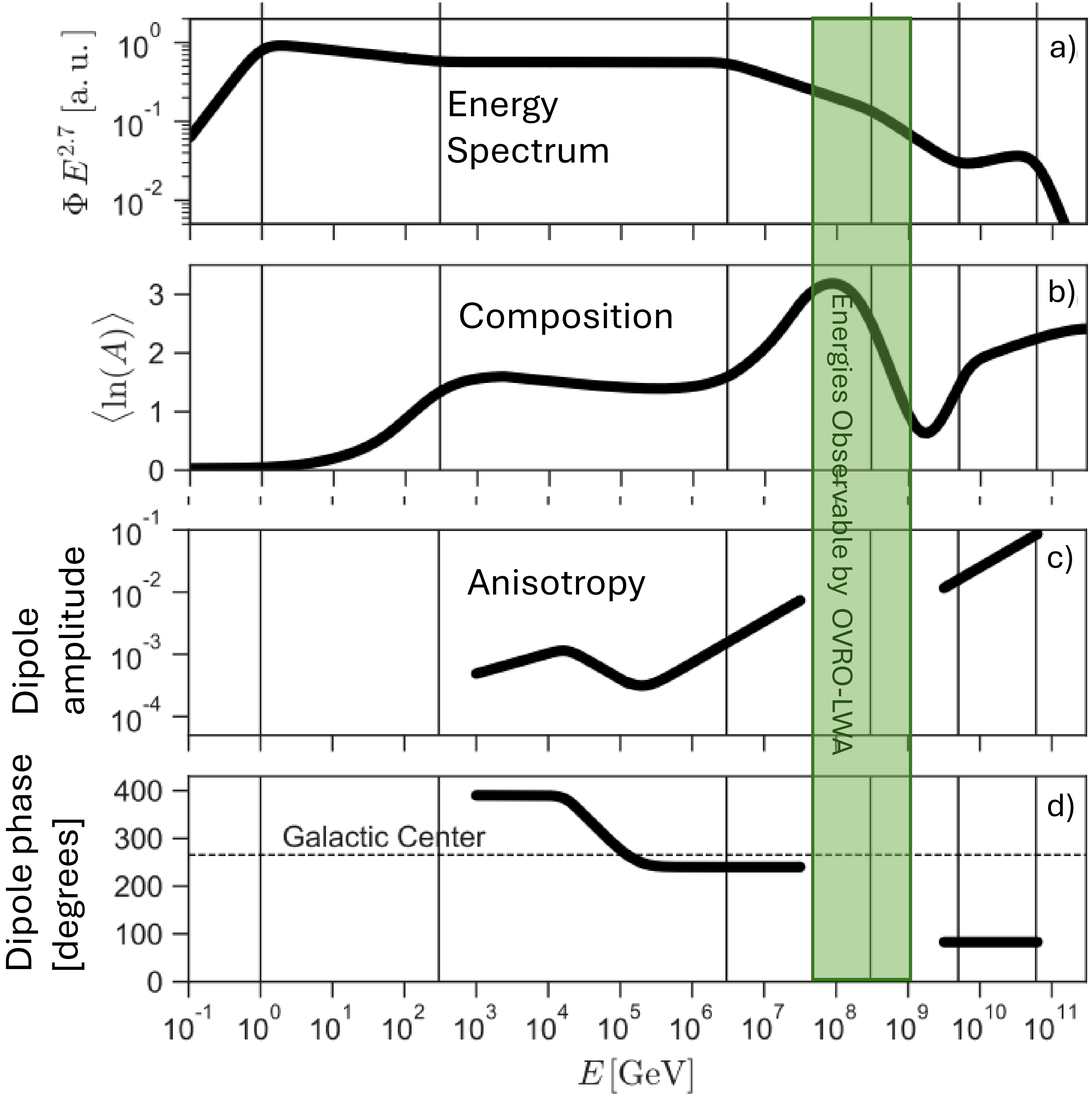
Standalone-radio cosmic ray detection at the OVRO-LWA

Kathryn Plant

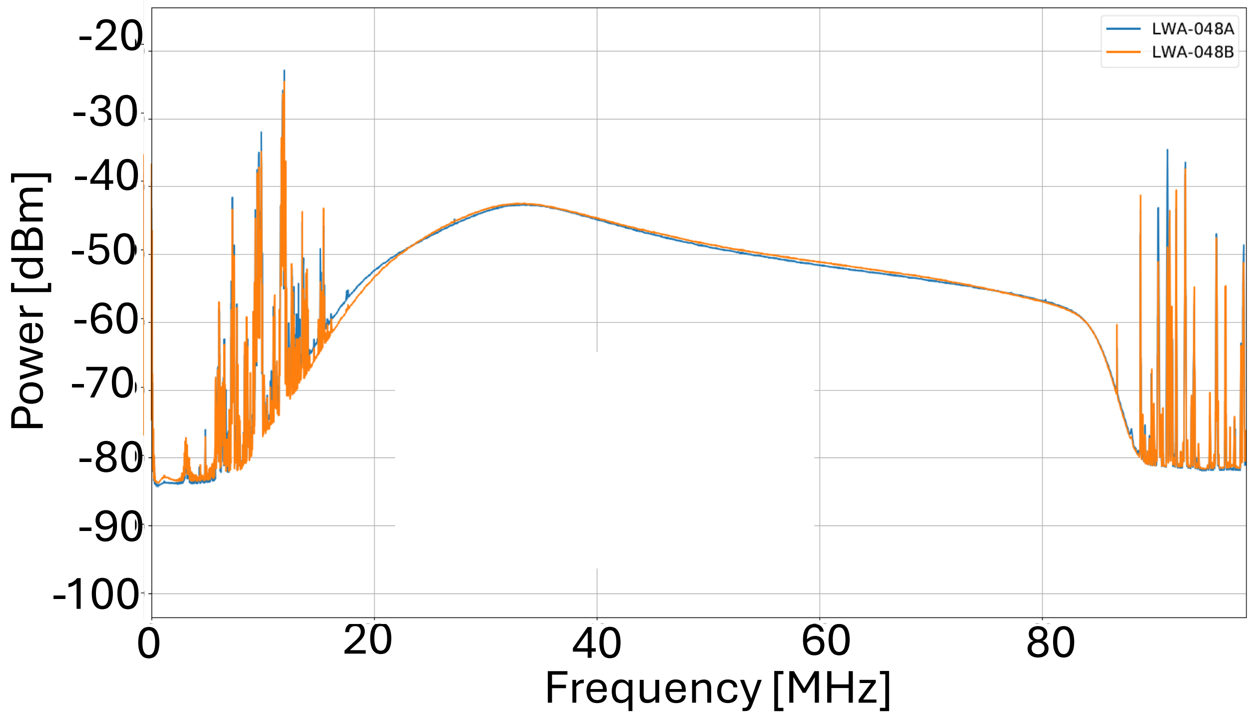
Jet Propulsion Laboratory
California Institute of Technology

The OVRO-LWA will probe the Galactic to extragalactic transition.



Adapted from Becker-Tjus and Merton 2017

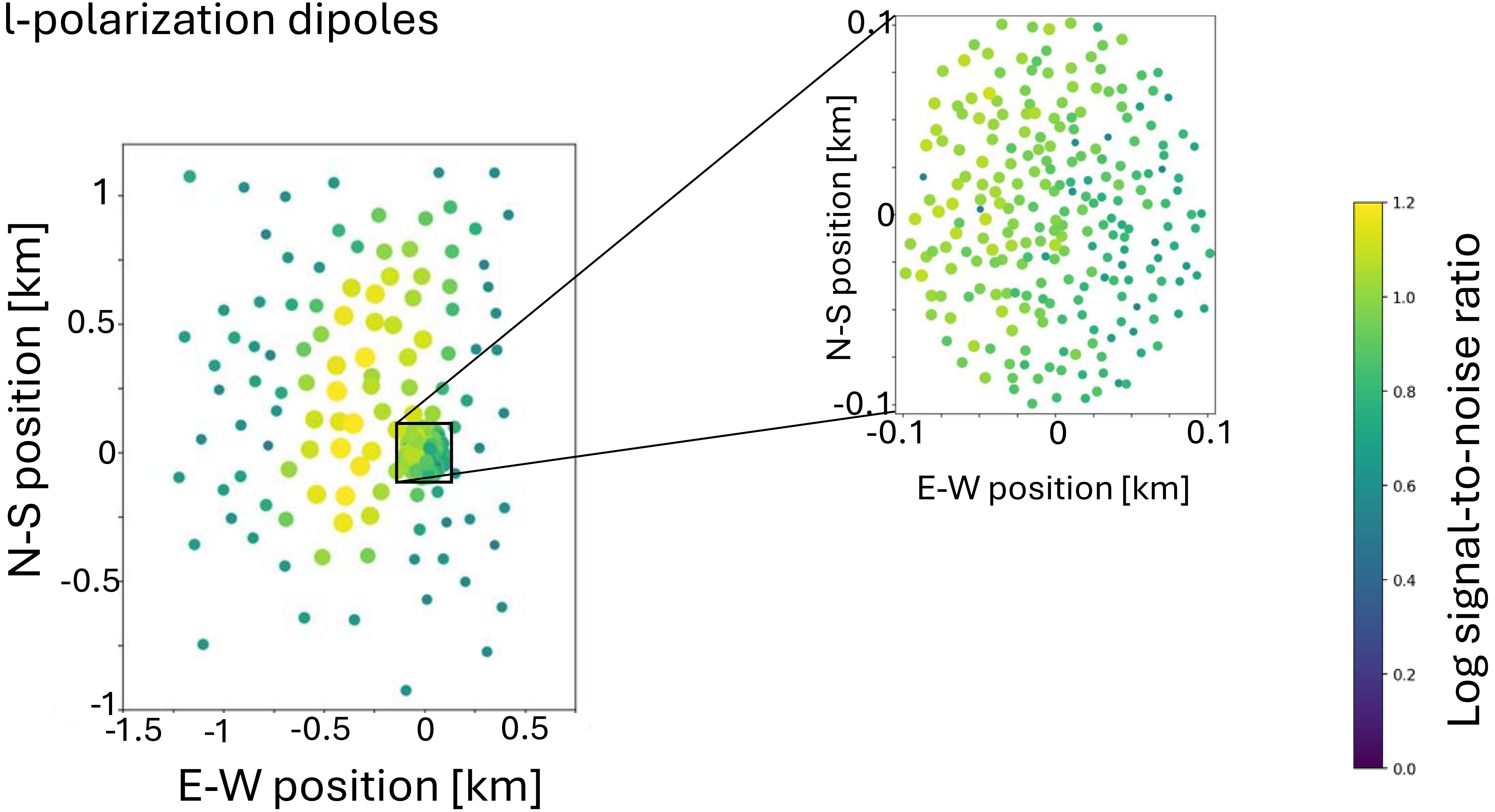
Introduction to the OVRO-LWA



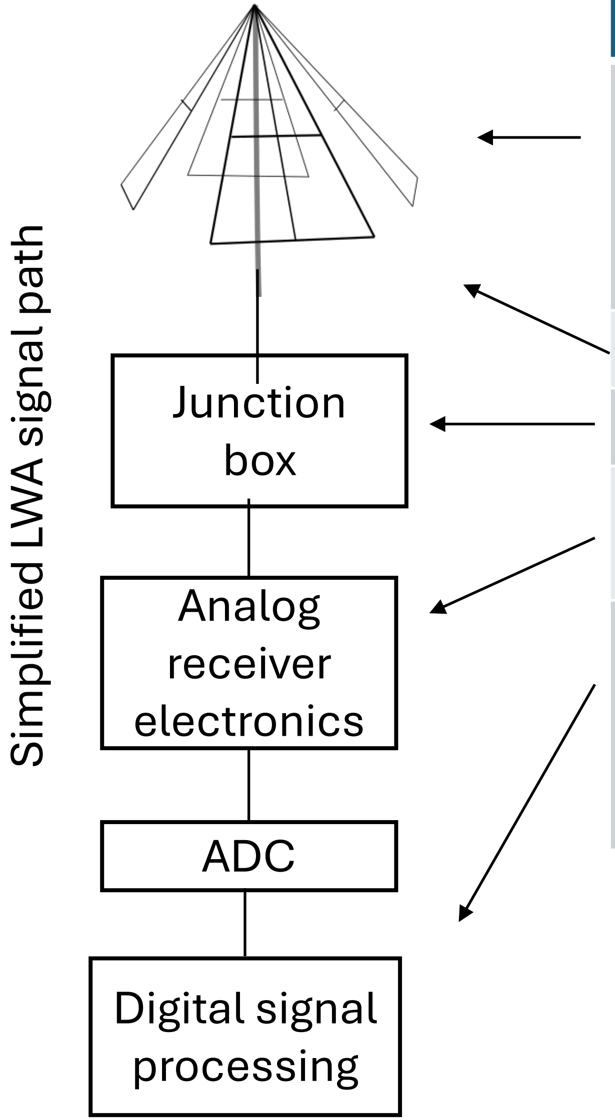
- Extrasolar space weather, epoch of reionization, solar astronomy, cosmic rays and more

Array layout

352 dual-polarization dipoles

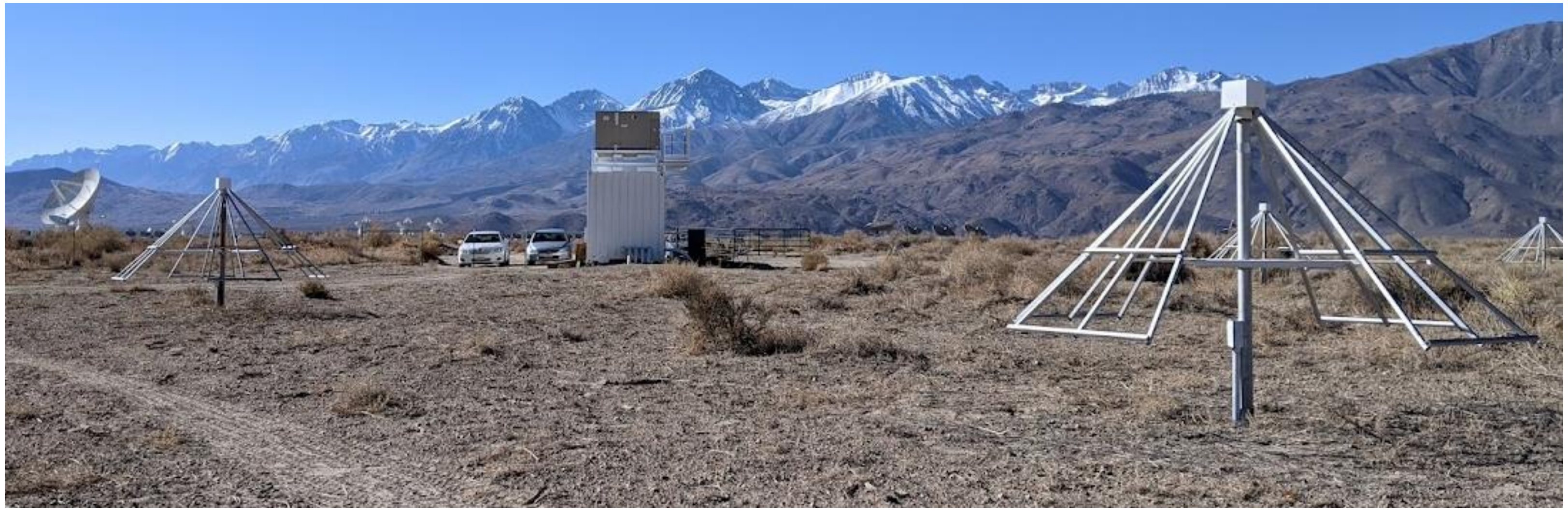


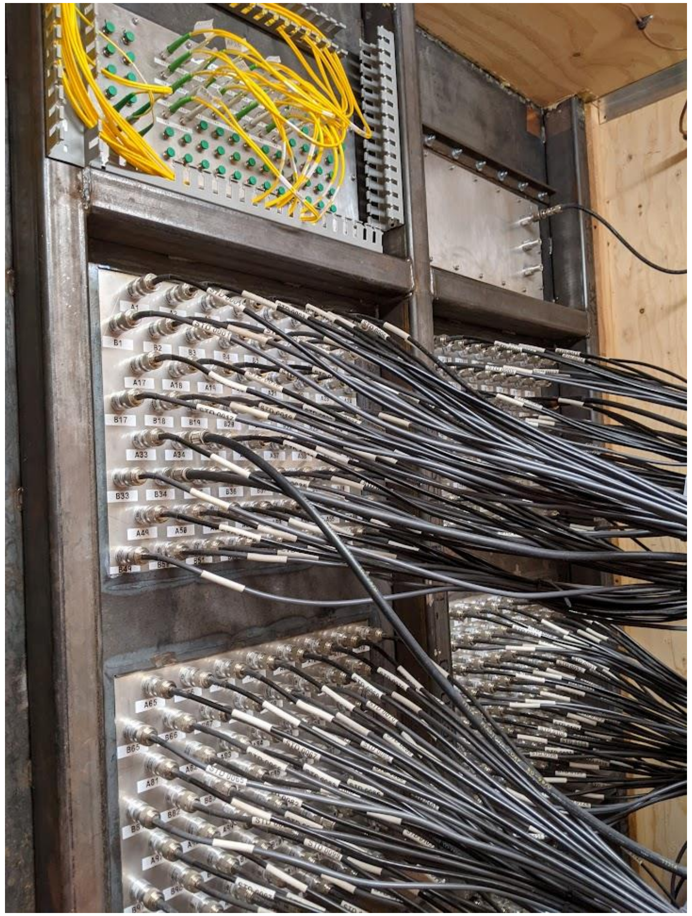
The OVRO-LWA underwent a major upgrade from 2019-2023.



Feature
Expansion: • 288 → 352 dual polarization antennas • 1.5 km →2.4 km longest baselines
Refurbish all front-end electronics
New RF over optical fiber modules
New analog receiver boards for better signal path isolation
All new digital signal processing electronics: opportunity for commensal cosmic ray search

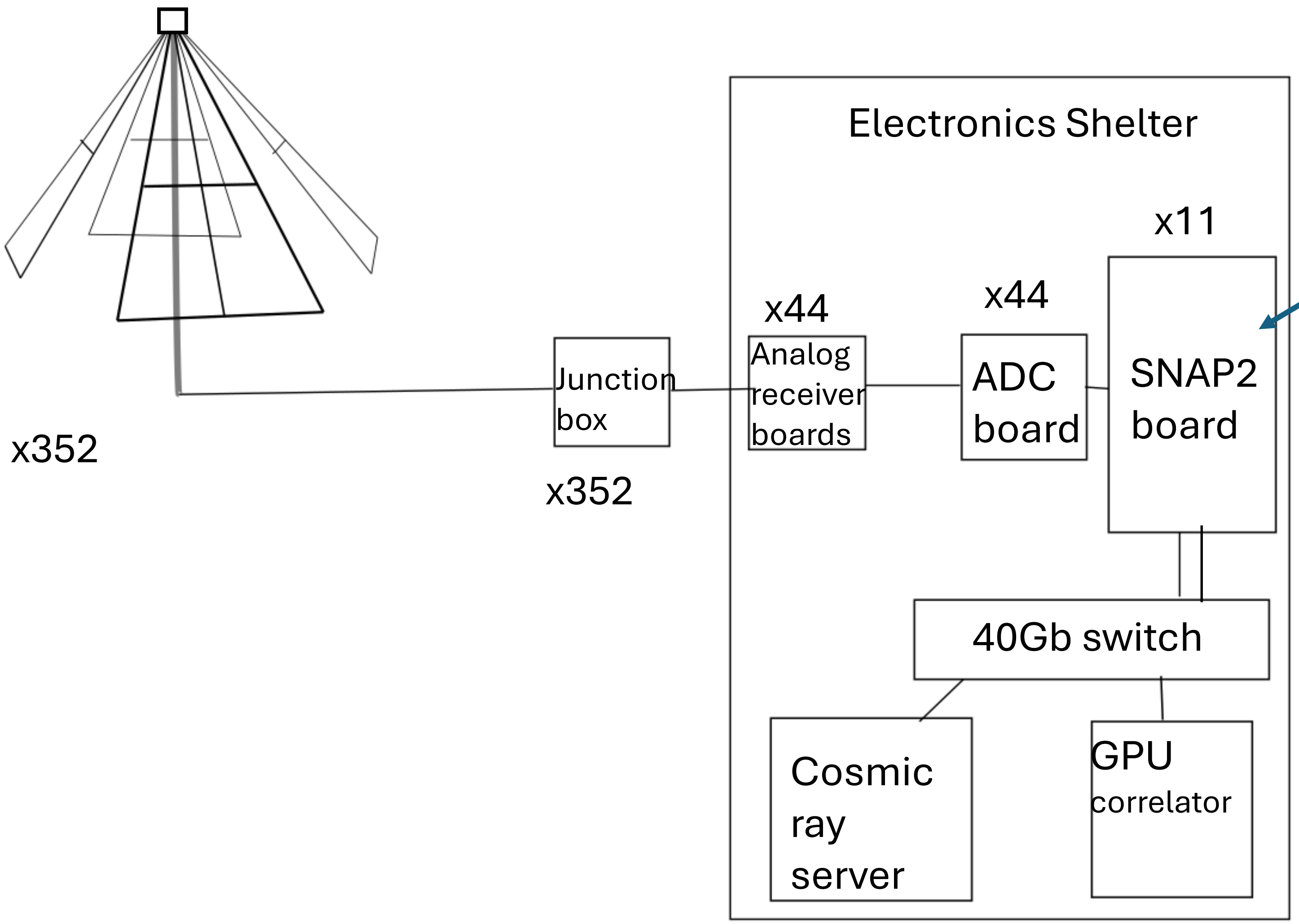
Bringing all signals to a central location is crucial to the cosmic ray detection strategy.





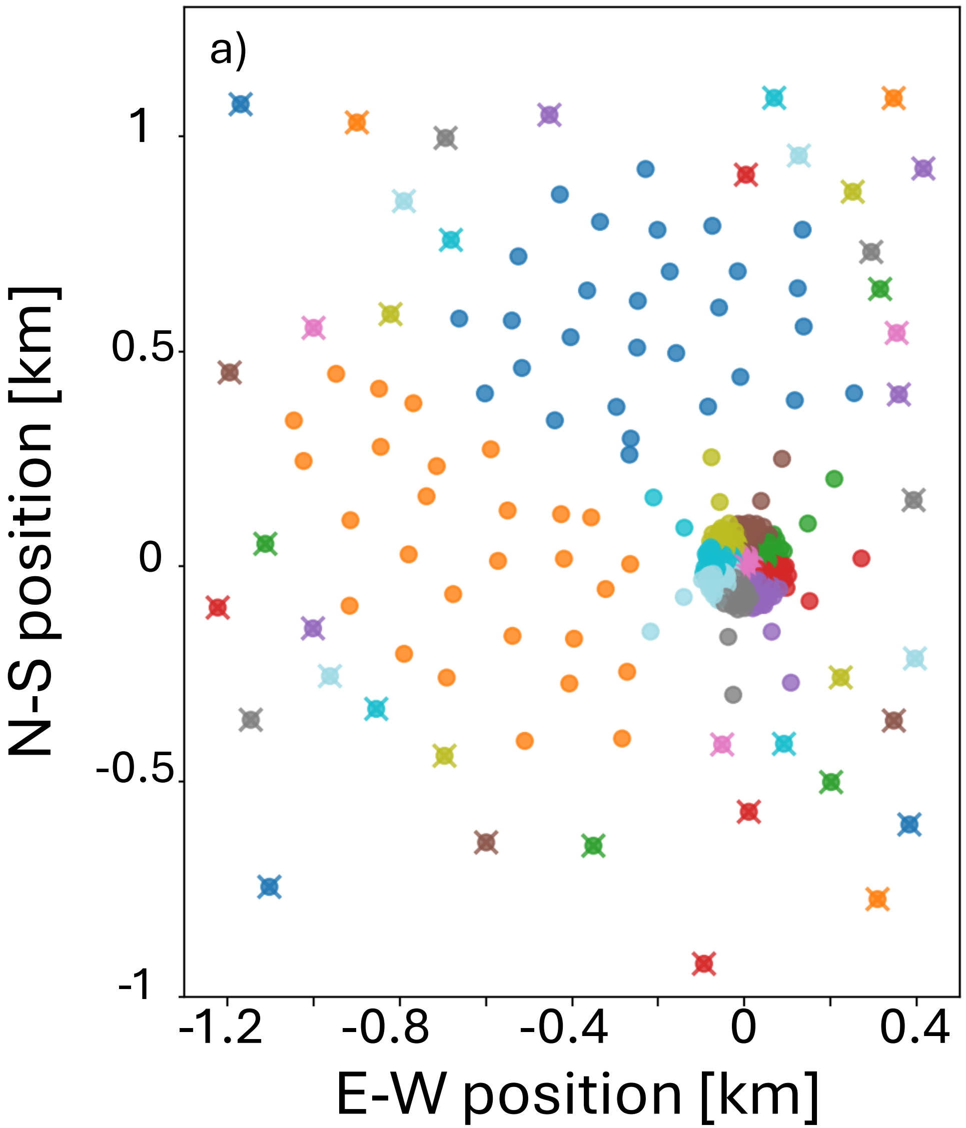
- Requires a combination of:
  - Coaxial cable
  - RF over Fiber optics

OVRO-LWA signal path



Cosmic ray threshold-coincidence trigger firmware runs alongside firmware for other observing modes.

My cosmic ray search strategy leverages the array layout.

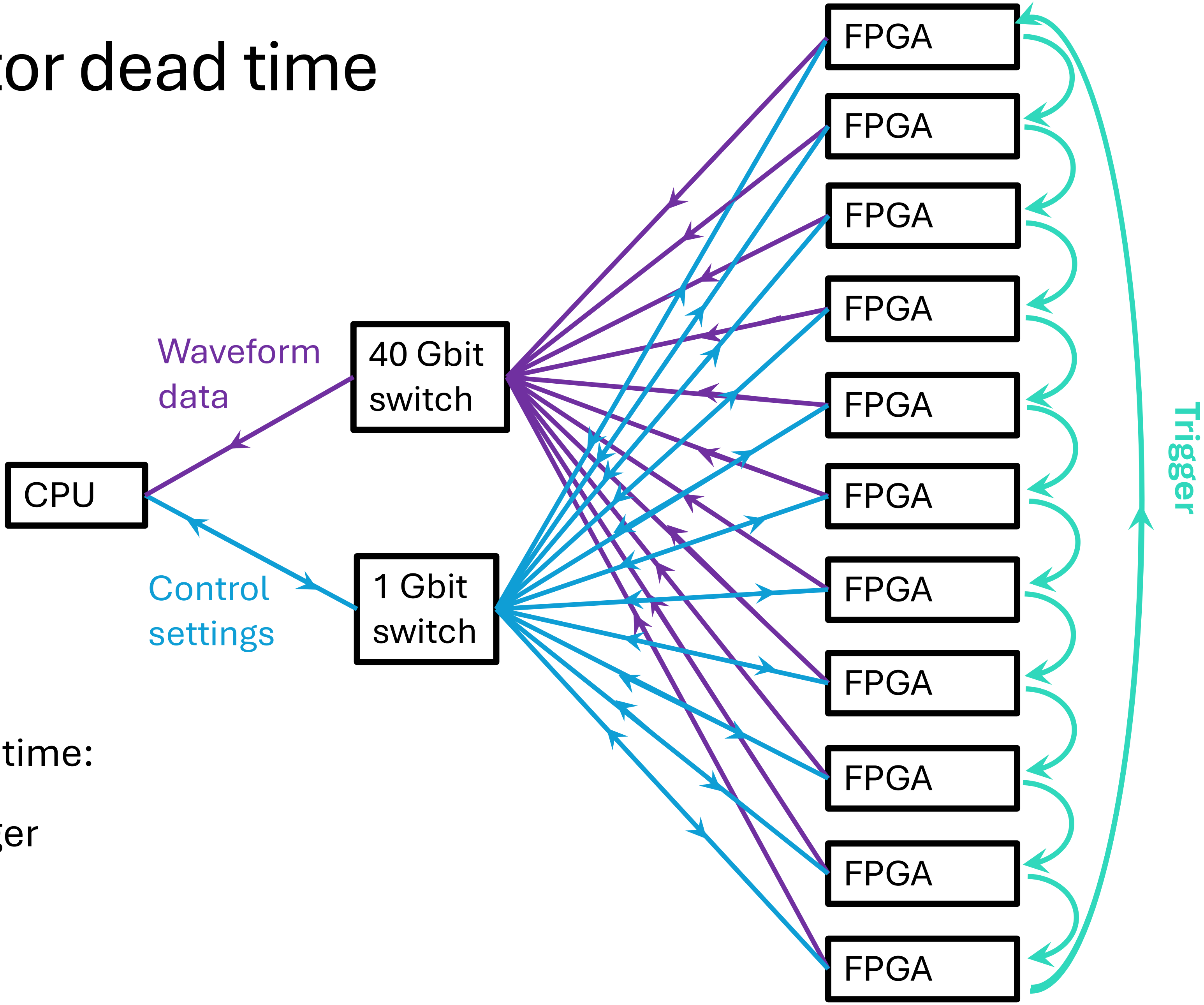


- Array layout color-coded by FPGA
- Distant antennas veto RFI.

Data flow and detector dead time

Design challenges

- Readout firmware strategy
- Inter-FPGA communication



Performance

- Readout time: 0.7ms
- Inter-FPGA communication time: 0.84 microsecond
- Dead time for 20-40 Hz trigger rate: 1.3-2.7%
- Veto dead time 4%
- Total: 5-7%

Event Classification Software: Reject RFI & identify cosmic rays

Example dataset: 19 hours from 2 nights
April 29-30 & May 1-2

Summary statistics for each event

↓ .... **877365 events**

Basic quality criteria

↓ ~1% pass .... **3368 events**

Model fits
- Spherical wavefront fit to arrival times
- 2D Gaussian fit to spatial distribution of SNR

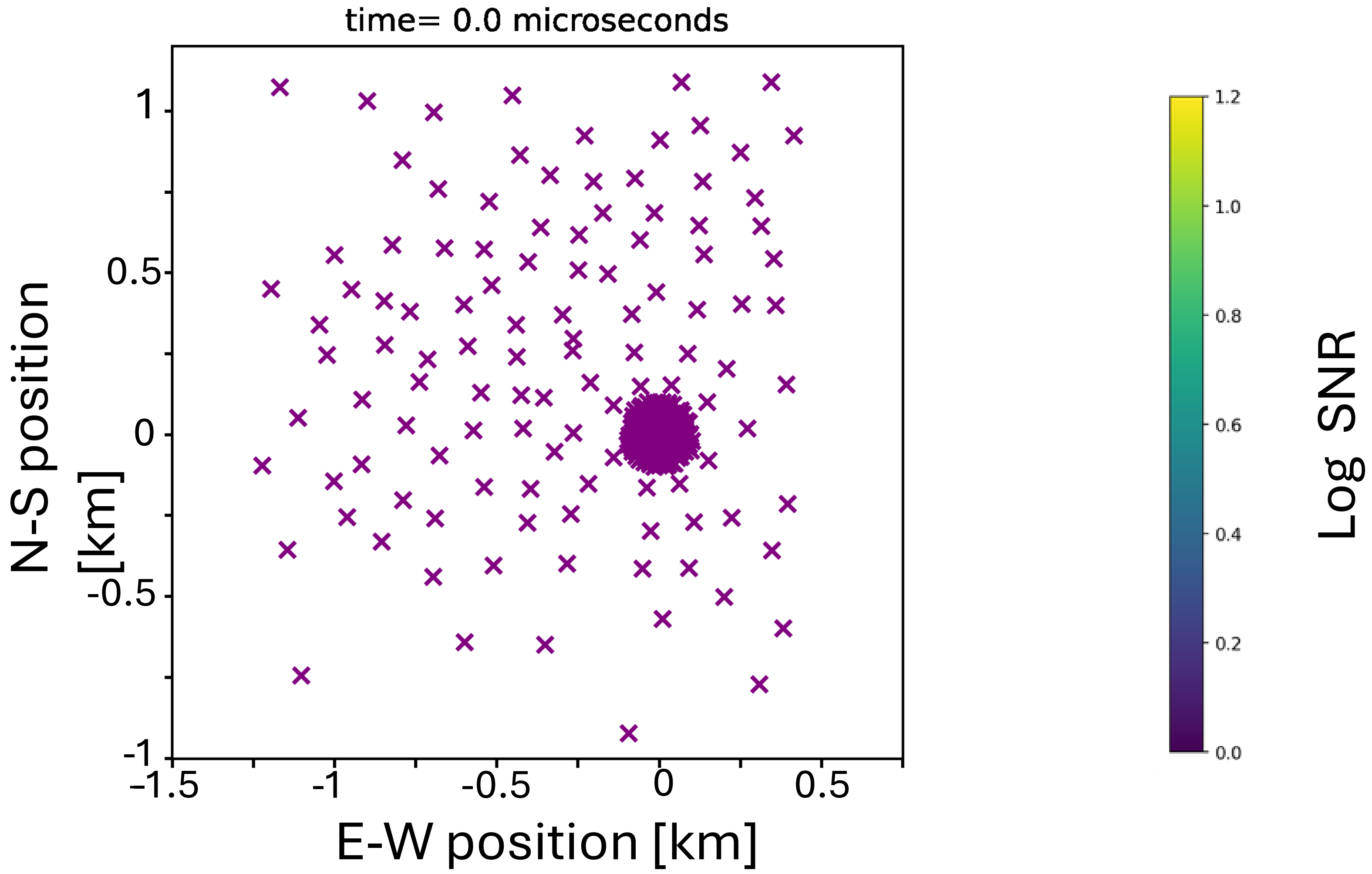
↓

Apply selection criteria on model fits

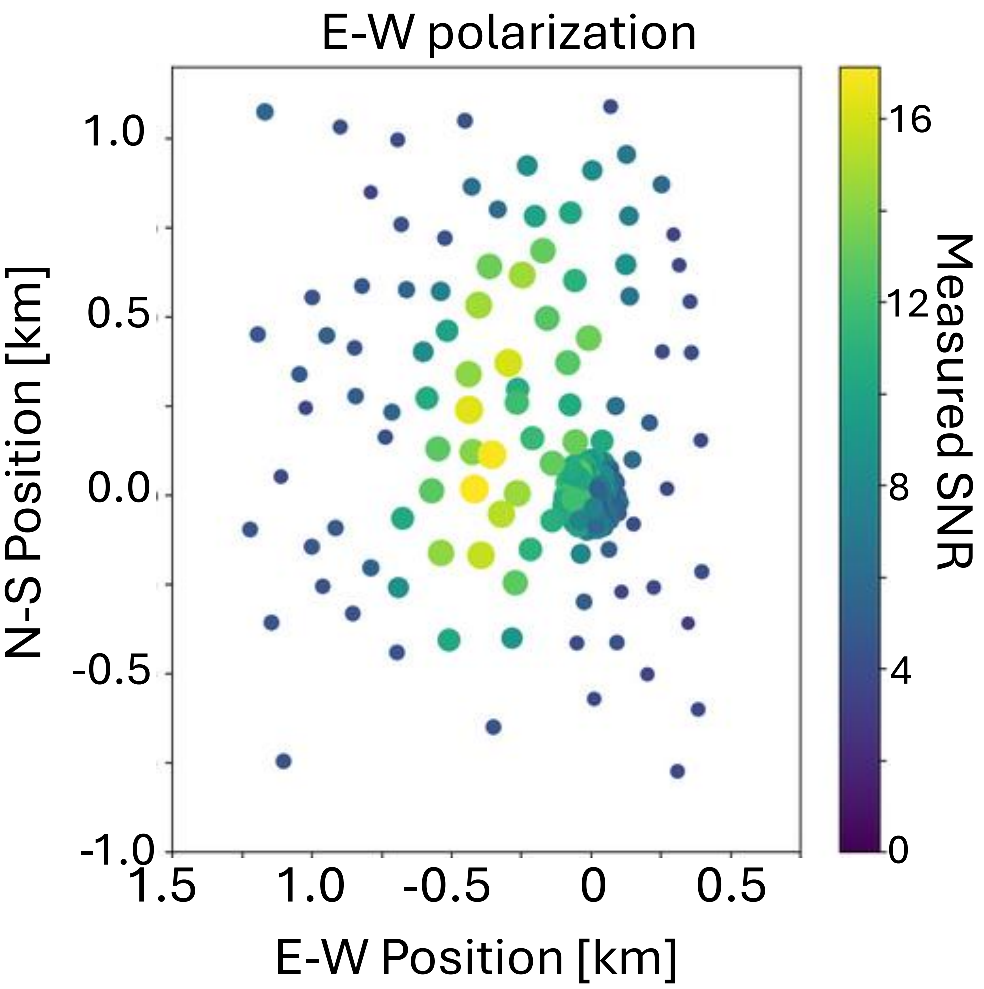
↓ ~0.1% pass .... **4 candidate cosmic rays**

Cosmic ray candidates

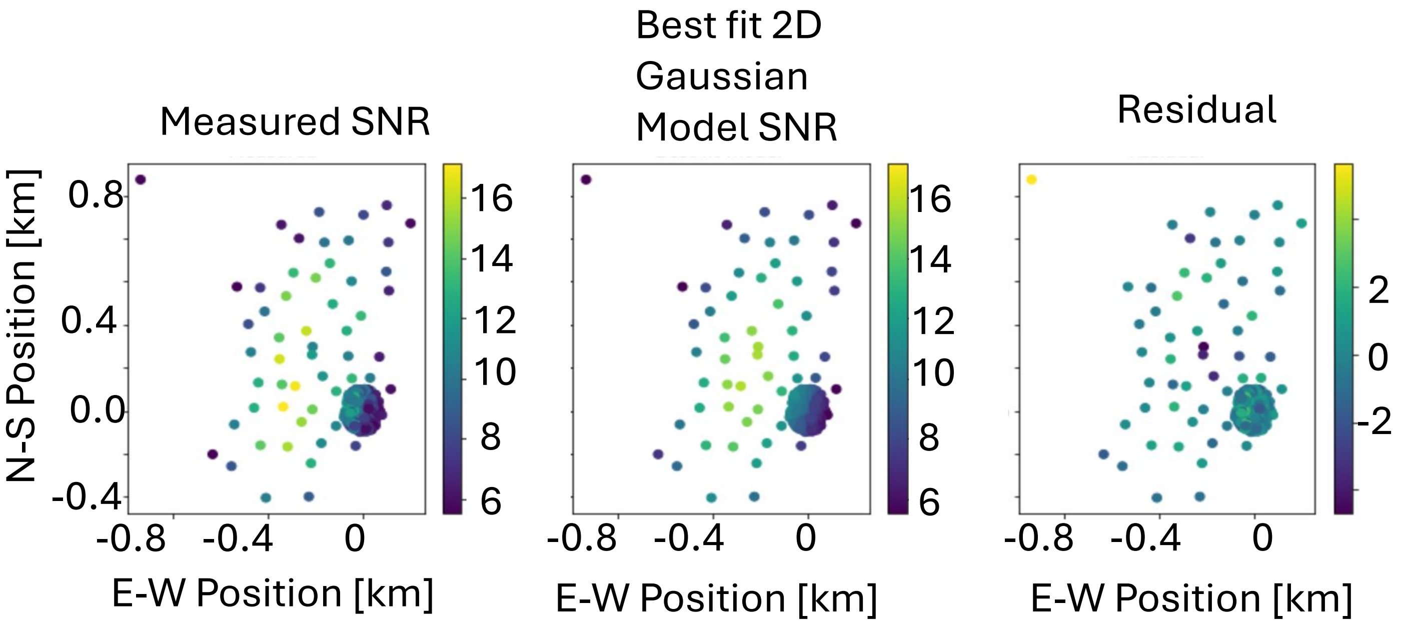
Example Event– Arrival time & signal to noise ratio



Example cosmic ray candidate 21-Feb-2024



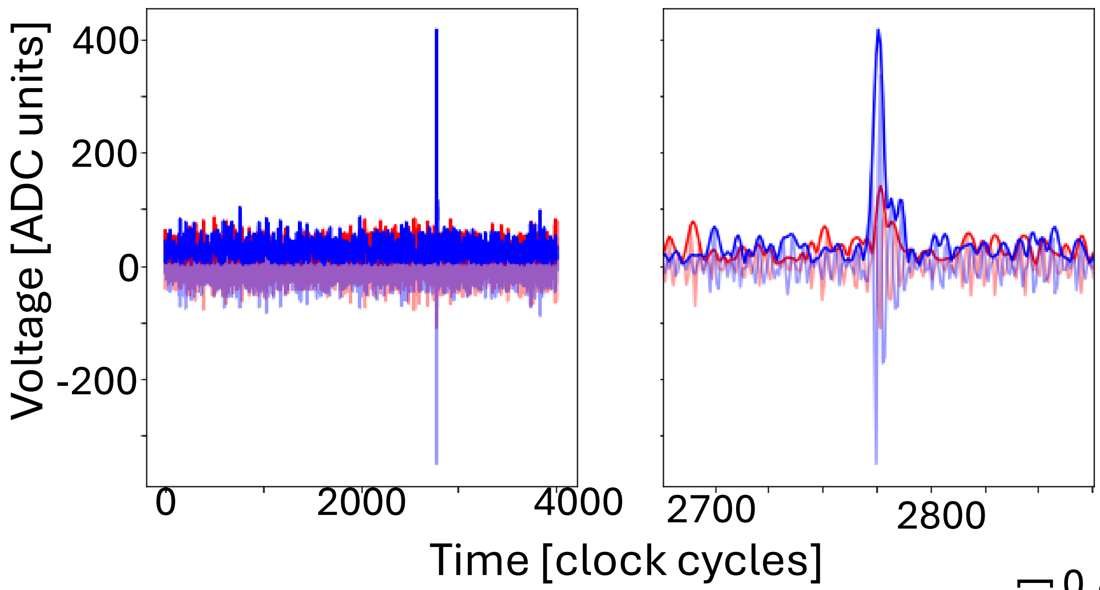
Gaussian fit RMS residual ~ 1.18



SNR=(Peak of Hilbert envelope)/rms
Mean SNR of background noise ~3.8

Example cosmic ray candidate 21-Feb-2024

Waveform of highest-SNR antenna



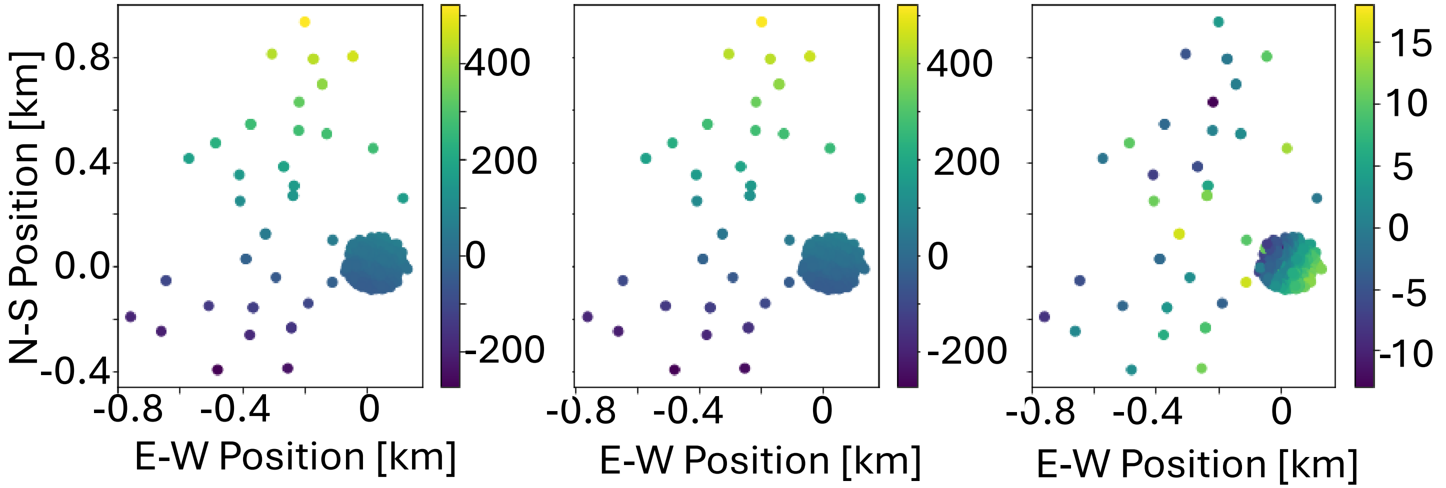
--E-W polarization
--N-S polarization

Best-fit arrival direction:
Azimuth 190.0 +- 0.2 degrees
Zenith angle 63.7 +- 0.4 degrees

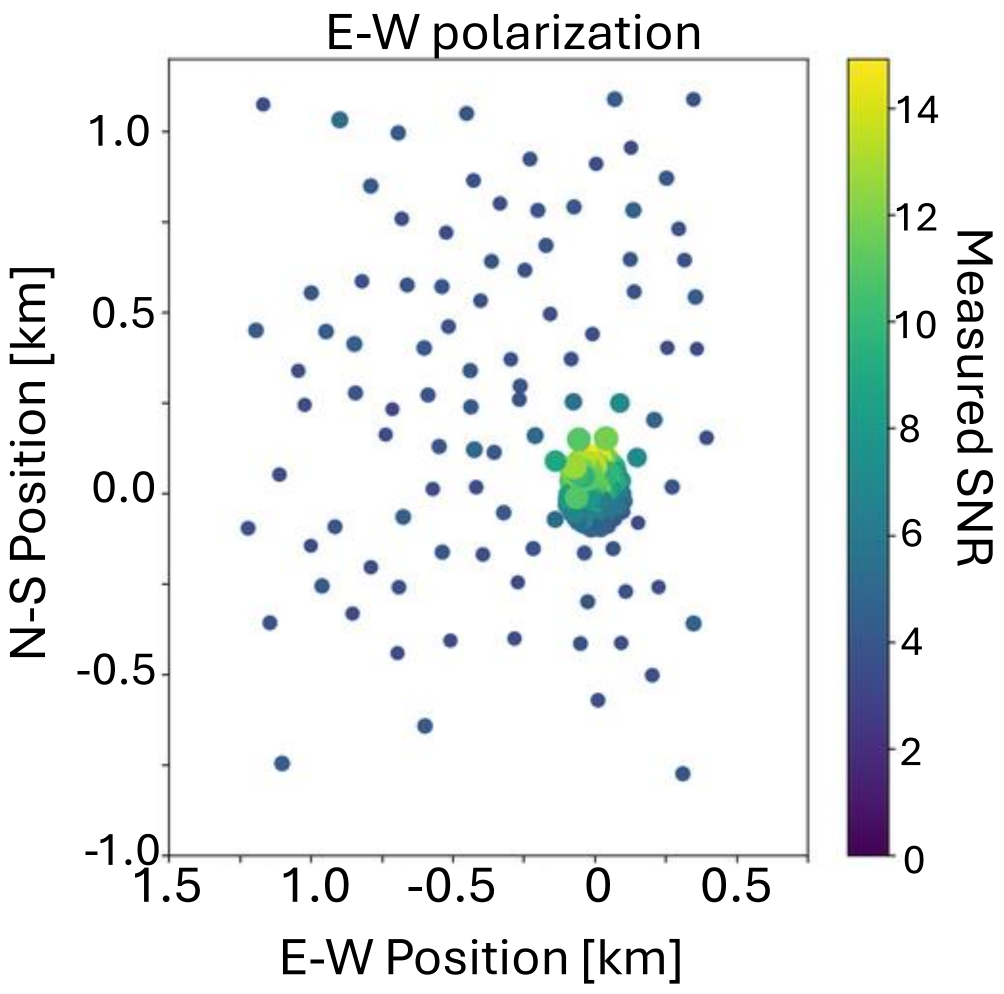
Measured relative arrival times

Best fit spherical wavefront model arrival times

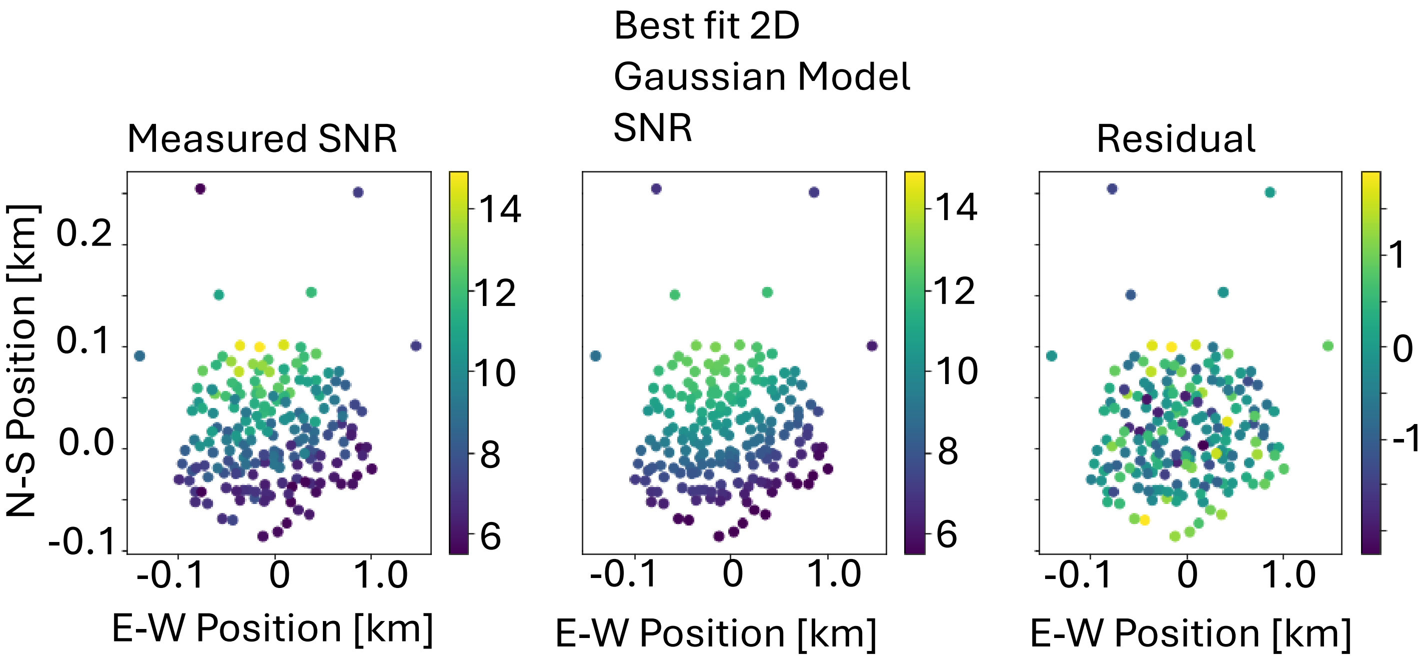
Residual



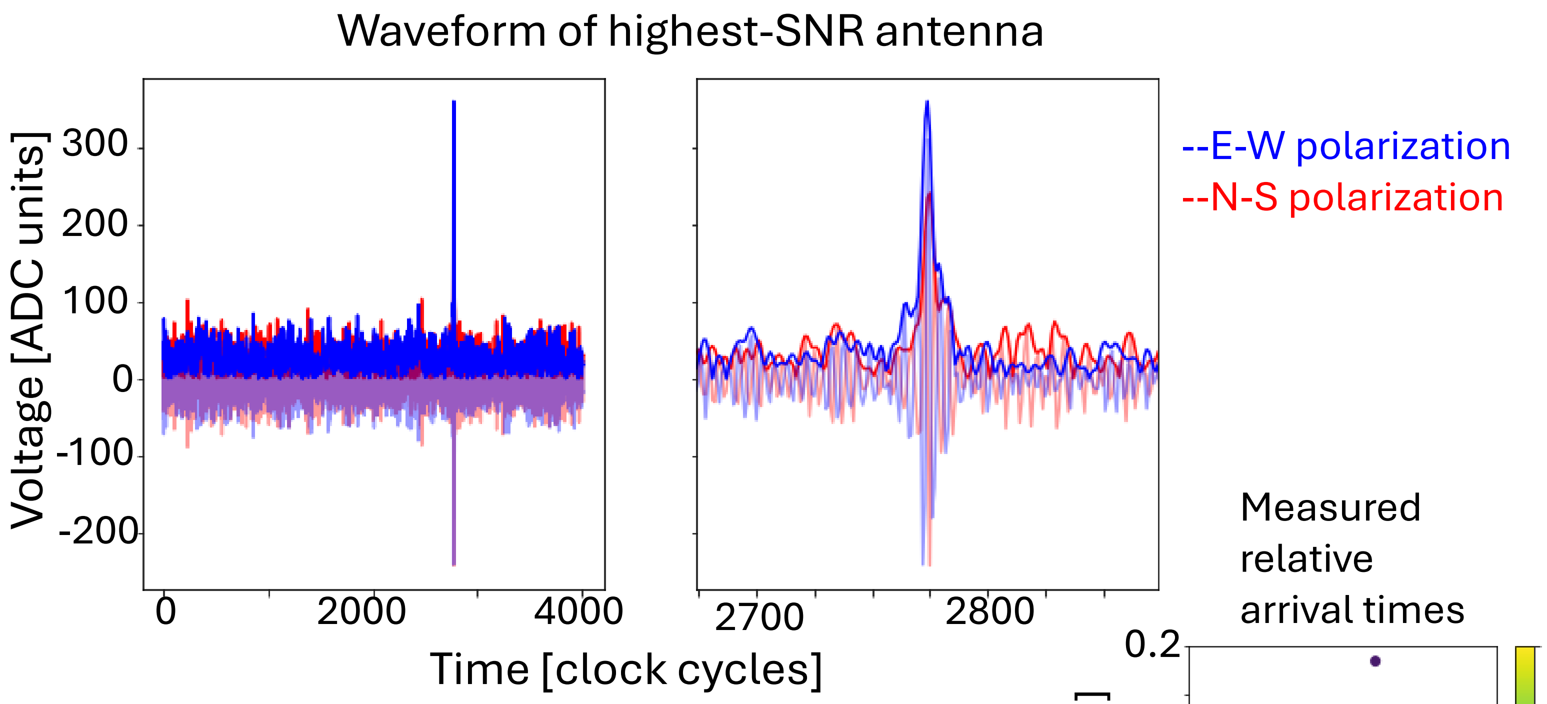
Example cosmic ray candidate 01-May-2024



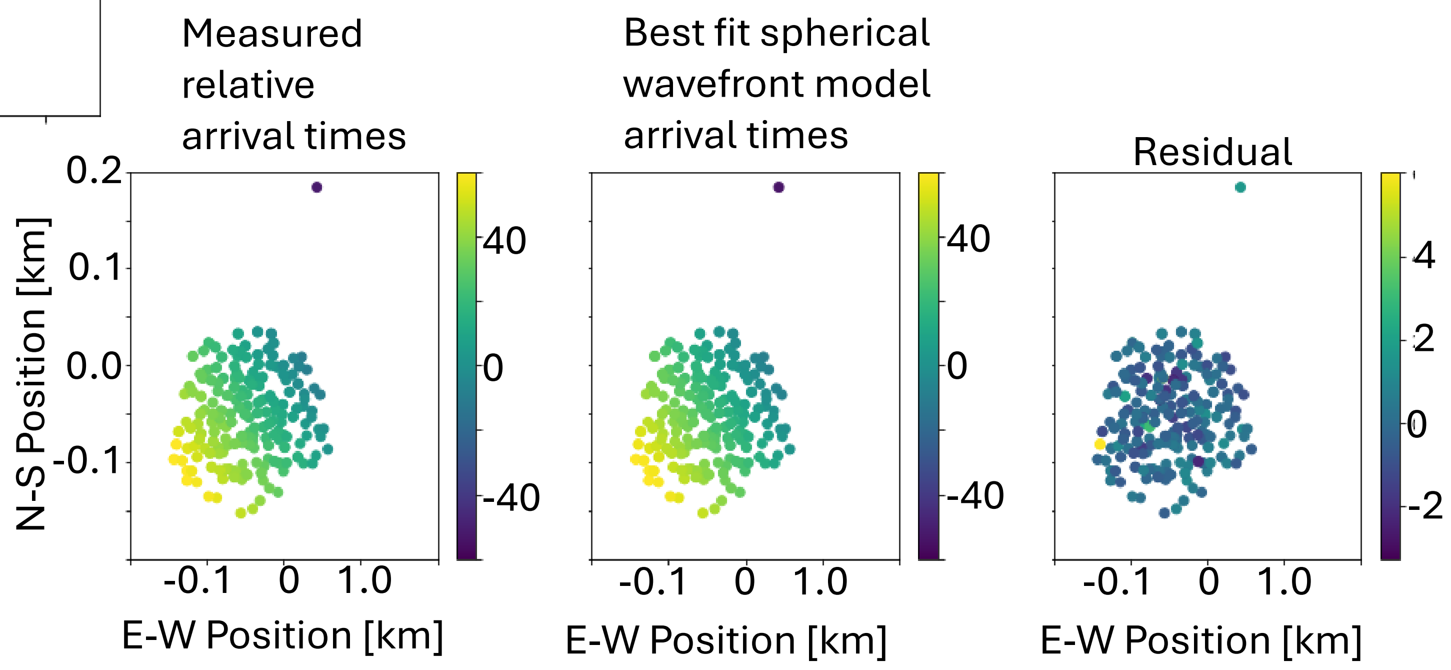
Gaussian fit RMS residual ~ 0.92



Example cosmic ray candidate 01-May-2024



Best-fit arrival direction:
Azimuth 52.0 +- 0.2 degrees
Zenith angle 33.4 +- 0.1 degree



Next steps

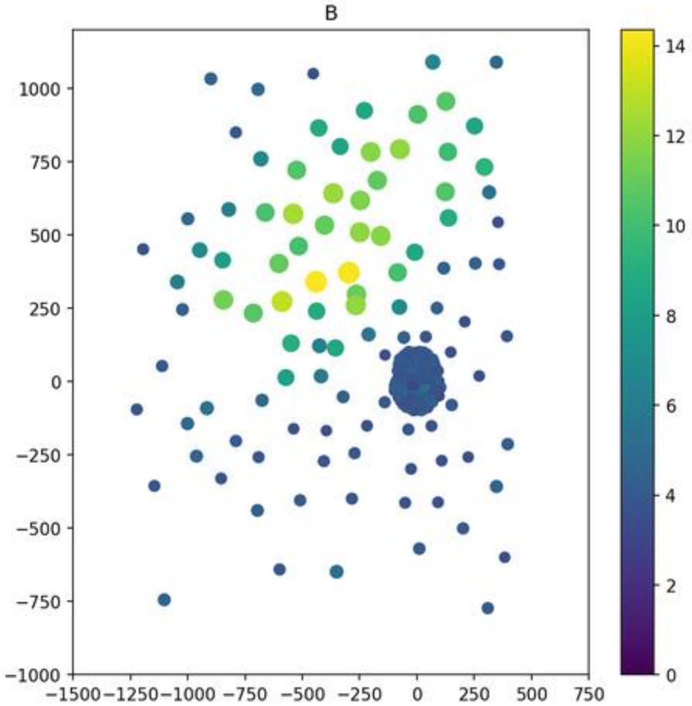
- Refine calibration
- X-max reconstruction
- Explore interferometric reconstruction
- Cross-comparison with muon detector

Conclusions

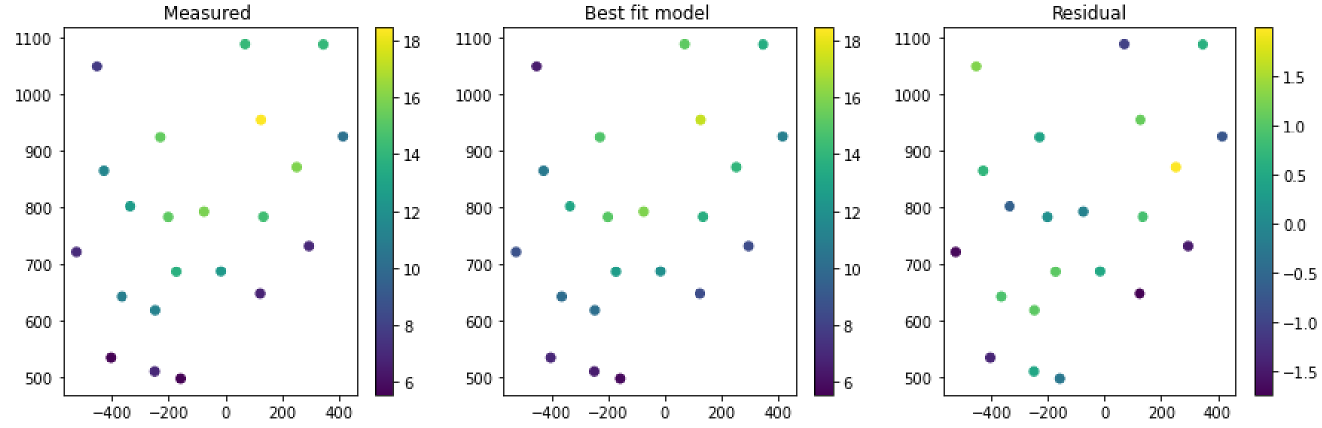
- The standalone-radio cosmic ray detector for the OVRO-LWA is complete and cosmic ray searching has begun.
- Detector dead time 5-7%
- Detailed spatial sampling of cosmic ray footprints supports goals of precise air shower reconstruction, and testing interferometric techniques.

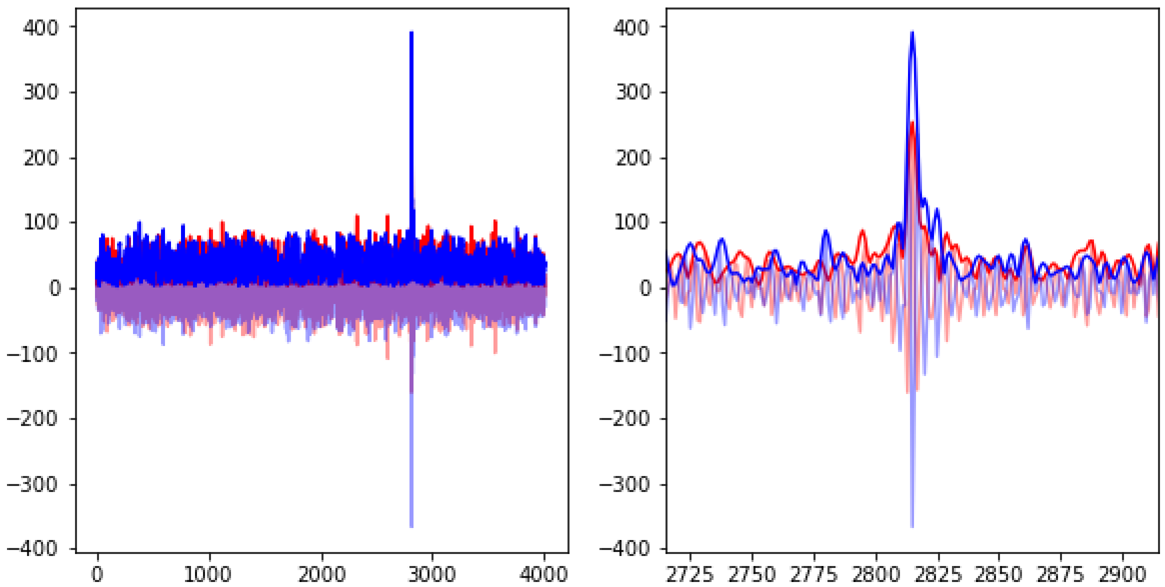
Extra slides

01-May-2024

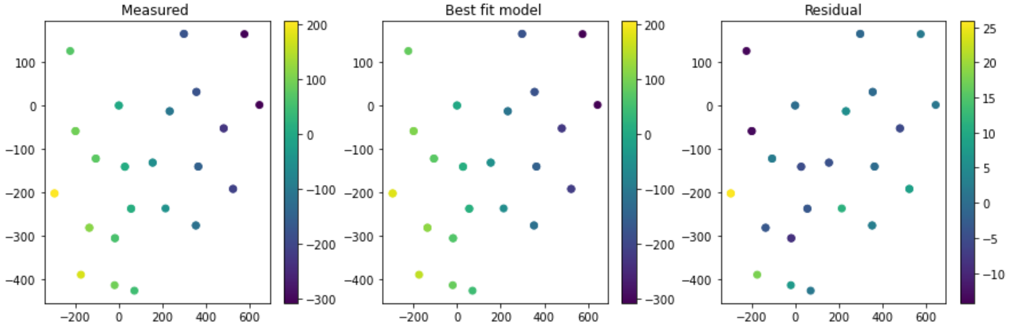


2D Gaussian





Arrival direction



Summary of cosmic ray system design goals

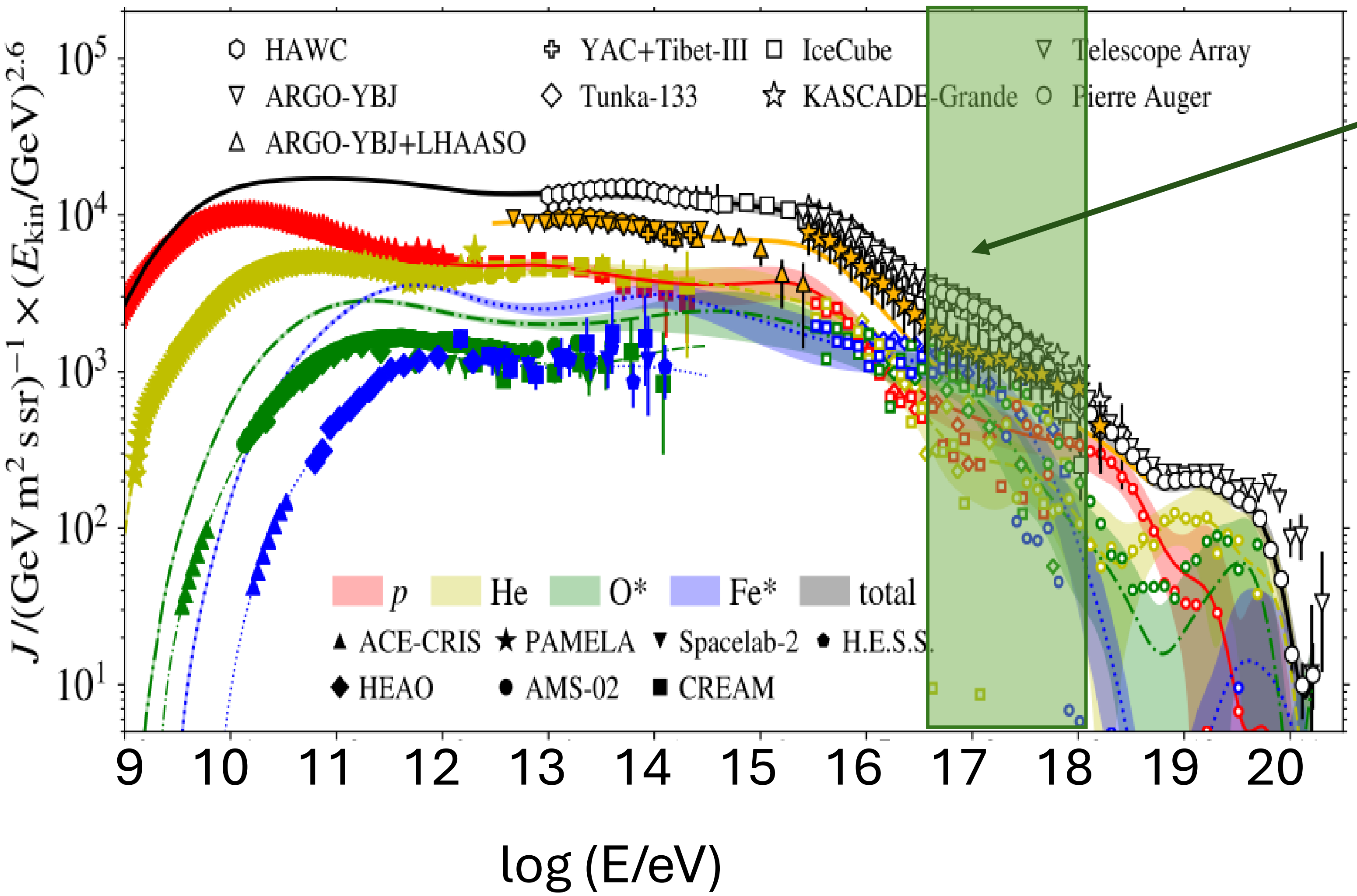
Observable	Instrument Functional Requirement
Band-limited radio impulse	5ns time resolution, 1ns timing synchronization
Polarized emission	Search 2 polarizations
Beamed emission	Subsets of antennas can trigger full-array readout
Expected flux: 5 events per day over OVRO-LWA core	Detector dead time <10%

Engineering constraint	Instrument Functional Requirement
Total data rate of OVRO-LWA is ~terabit per second	Buffer data, and trigger readout
Array spans 2.4 km	Buffer should be 20 microseconds to sample background before event

Cosmic ray composition measurements are the key.

Only accessible via ground-based experiments

Observable by OVRO-LWA



Schroeder 2019

Individual sources may have rigidity-dependent cutoff energies.

Hence shifts in composition are clues to shifts in source classes.