Polarization Reconstruction of Cosmic Rays with the ARIANNA Neutrino Radio Detector

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for the ARIANNA Collaboration

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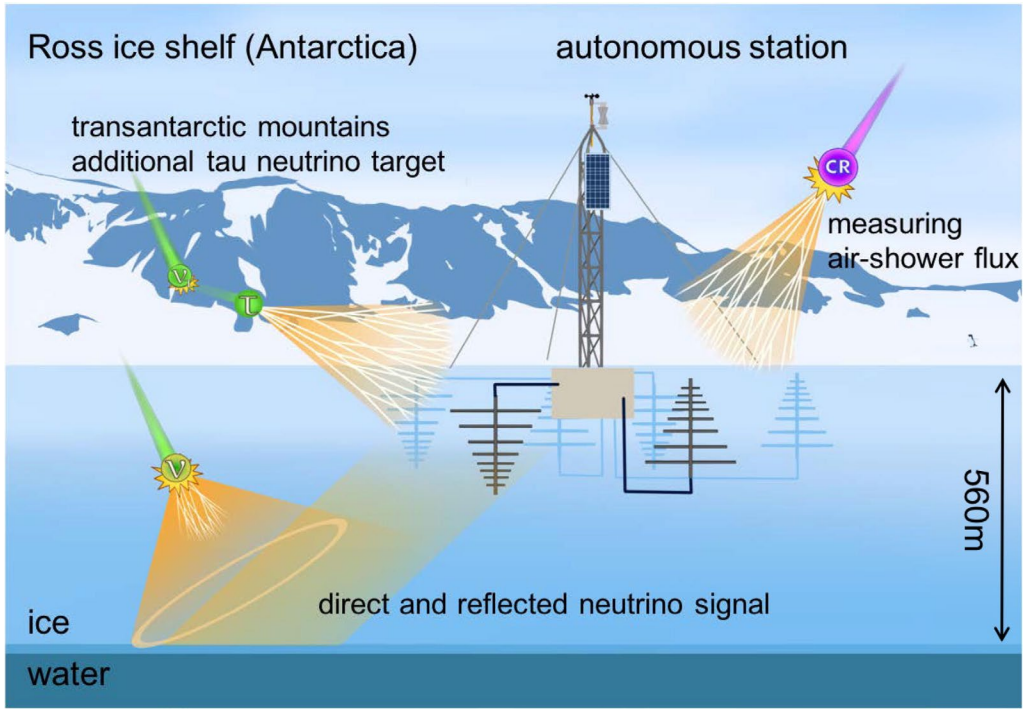
Motivation

- No accelerator beam of ultra-high energy neutrinos to calibrate ARIANNA
- Cosmic rays generate similar radio signals with known polarization properties
- Polarization is required for neutrino direction in ARIANNA
- Use cosmic rays as test beams to assess and verify reconstruction capabilities

Station Design

- 4 upward facing LPDAs
- 2 downward facing LPDAs
- 2 dipole antennas (5m, 10m)



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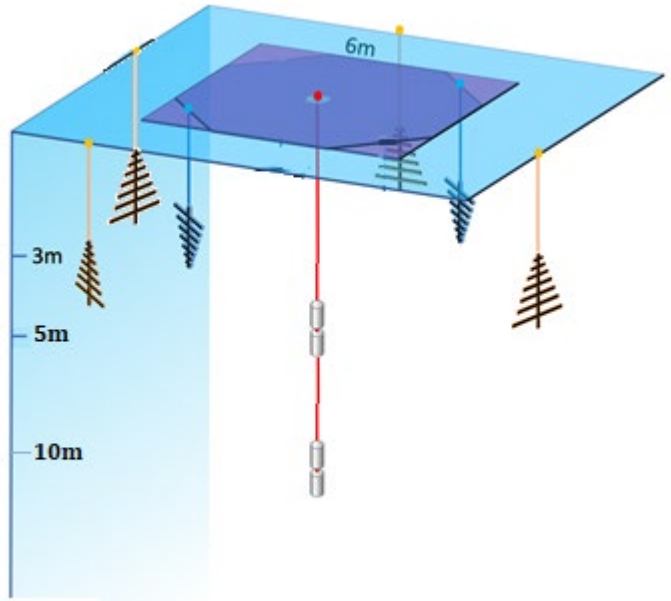

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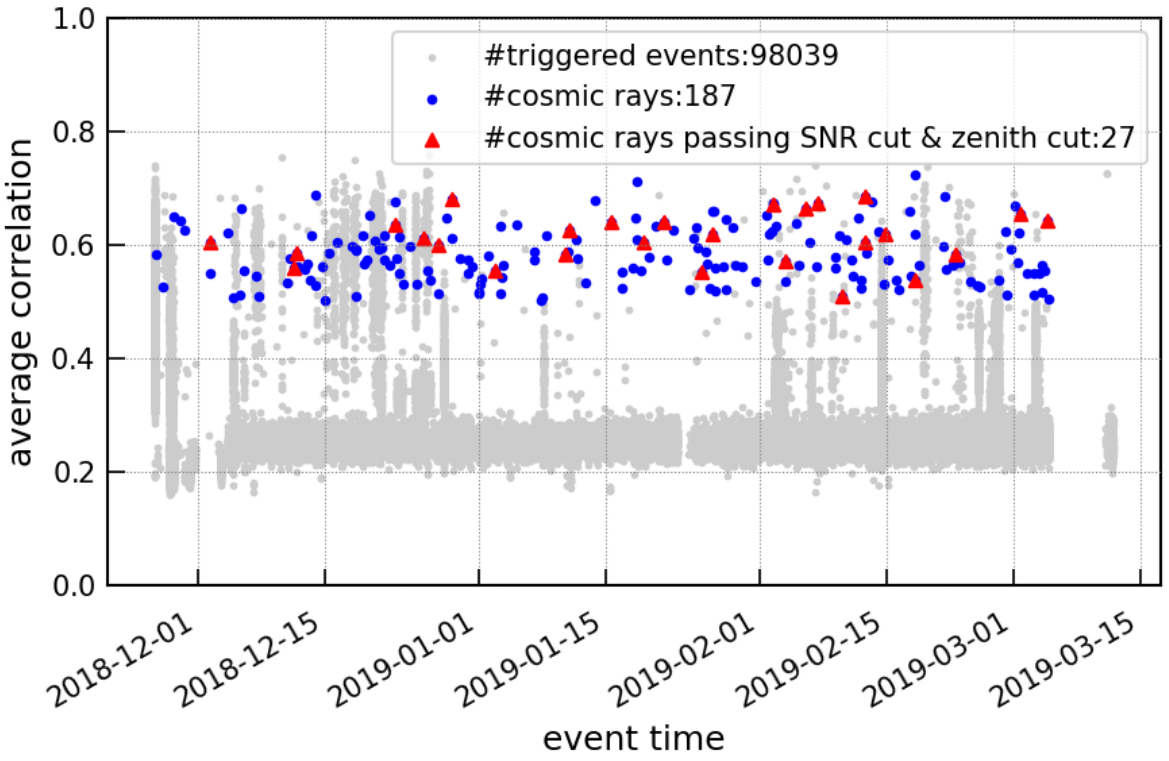
Cosmic rays identification

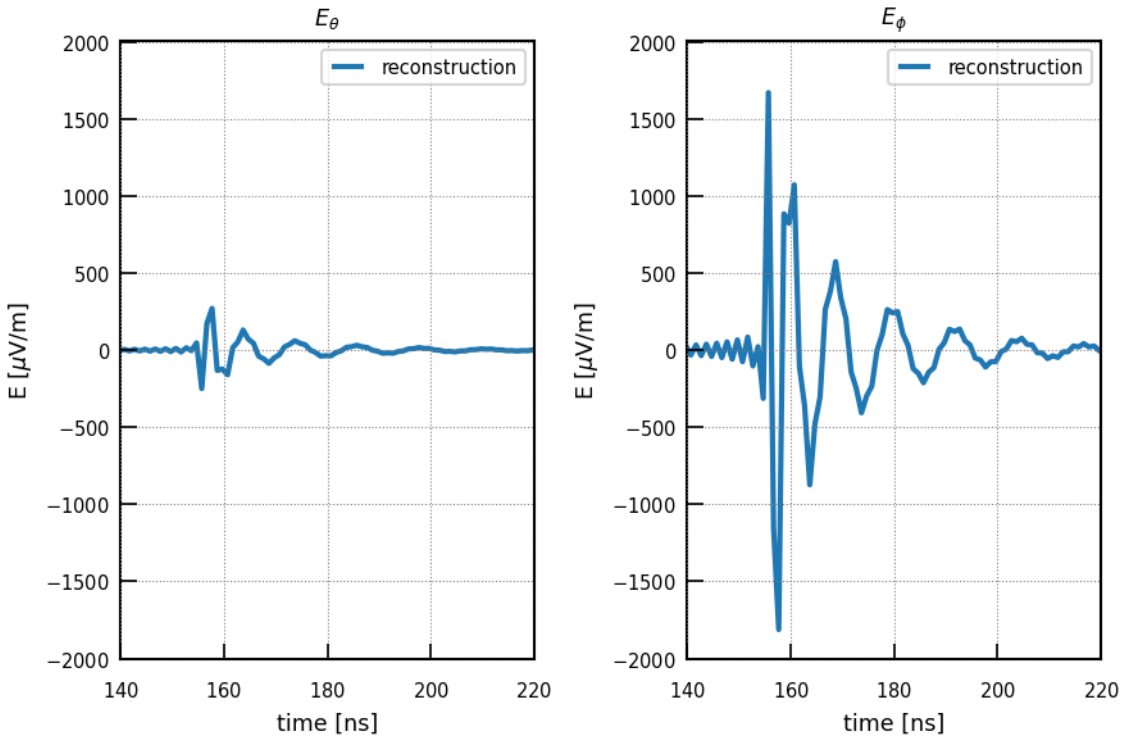
- Data taken from Nov 2018 to Mar 2019
- Correlate voltage traces with simulation
  - Low correlation: thermal events
  - High correlation: cosmic rays, wind events, man-made signals
- Useful characteristics of cosmic ray generated radio signals:
  - Temporally & spatially randomly distributed
  - Plane wave -> similar signal in parallel LPDAs

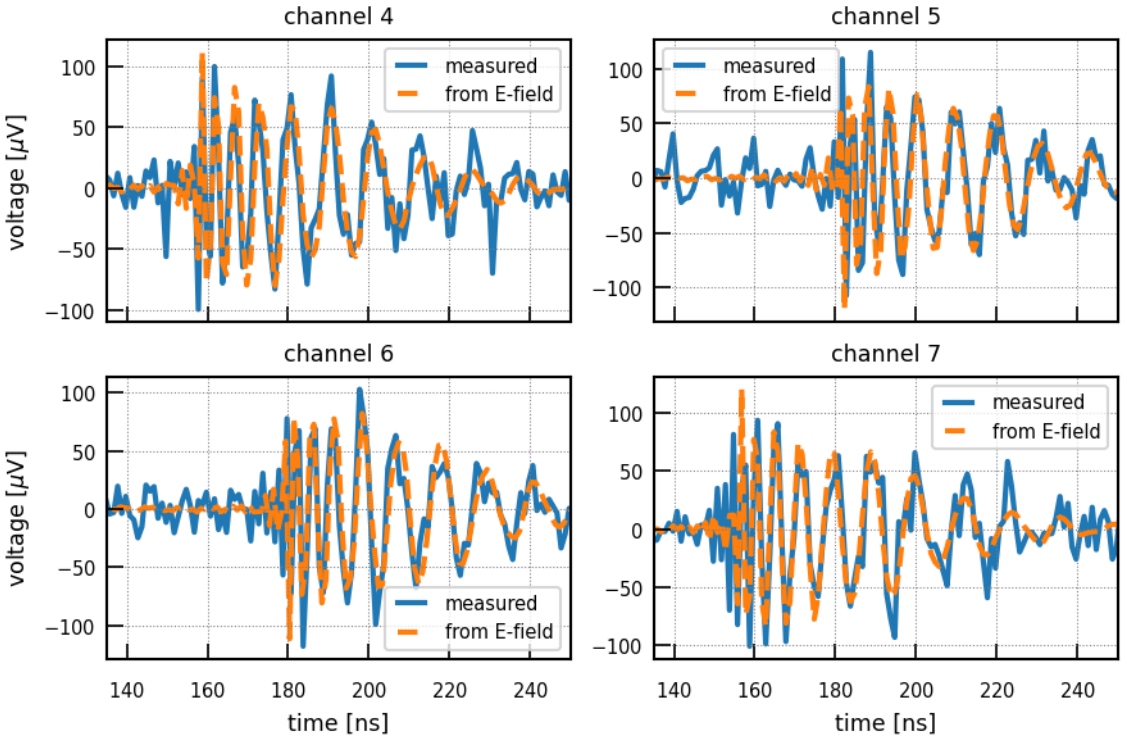


Cut name	Number of events remaining (data)	Cut efficiency from simulation (cosmic rays remaining / total cosmic rays)
Rate cut	33884	N/A
Correlation cut	298	0.97
Parallel channel cut	218	1.00
Downward cut	206	0.99
Dipole cut	192	0.99
Arrival direction cut	187	0.99
SNR cut	35 (0.19)	0.11
Zenith cut	27 (0.77)	1.00

Polarization reconstruction

- Reconstruct the electric field using forward-folding [A.Nelles *PoS ICRC2019 366 (2020)]*
- *Good agreement with measurement*
- *Not perfect at the highest frequencies at the early times*





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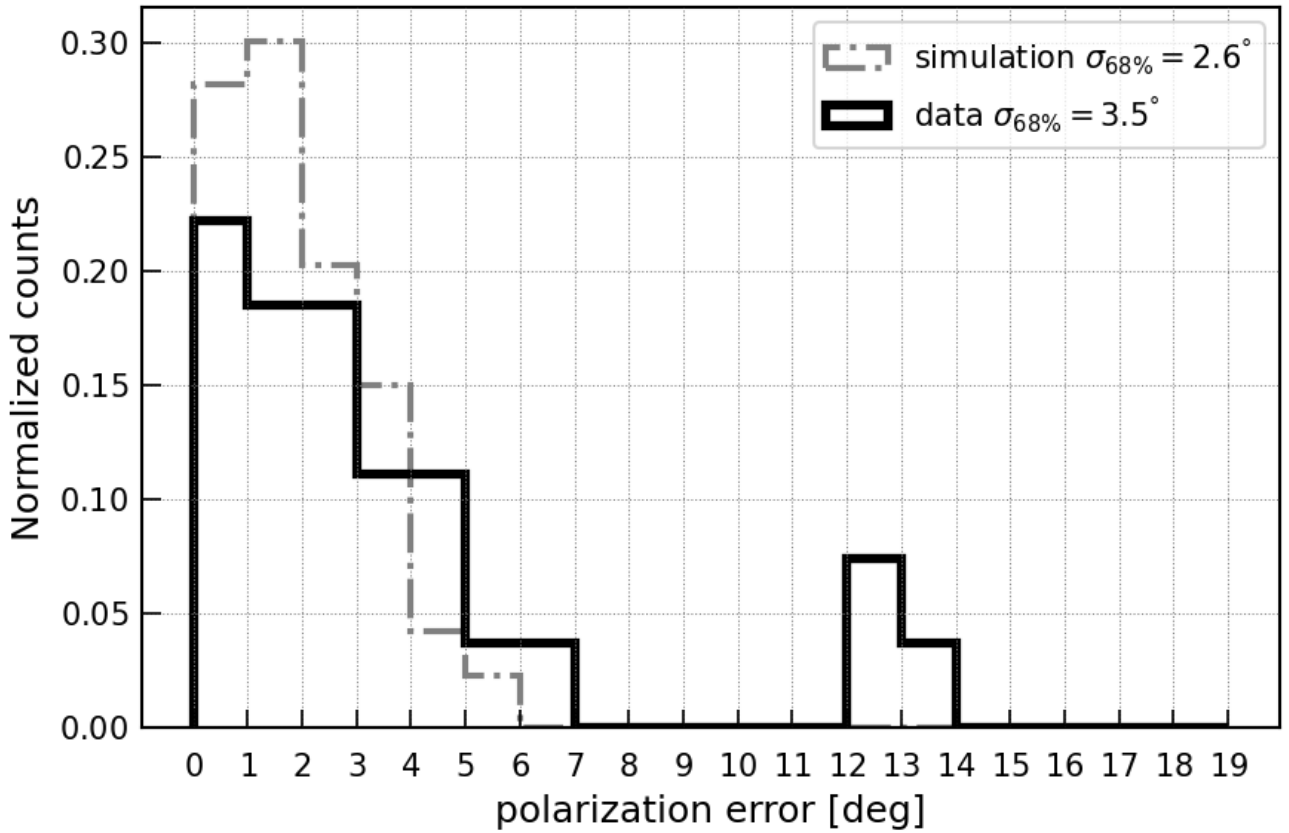
Polarization reconstruction

- $polarization = tan^{-1}(\sqrt{E_\varphi}/\sqrt{E_\theta})$
  - E_φ, E_θ: energy fluence of the electric field
- $expected\ polarization = \vec{v} \times \vec{B}_{geo}$
  - $\vec{v}$: reconstructed direction of the cosmic ray
  - Accounts for geomagnetic Cherenkov effect
  - Does not account for Askaryan effect
- $polarization\ error = |polarization - expected\ polarization|$
- Significant improvement compared to A.Nelles *PoS ICRC2019 366 (2020)*
  - 7.0 deg -> 3.5 deg
  - Increase in purity of data set



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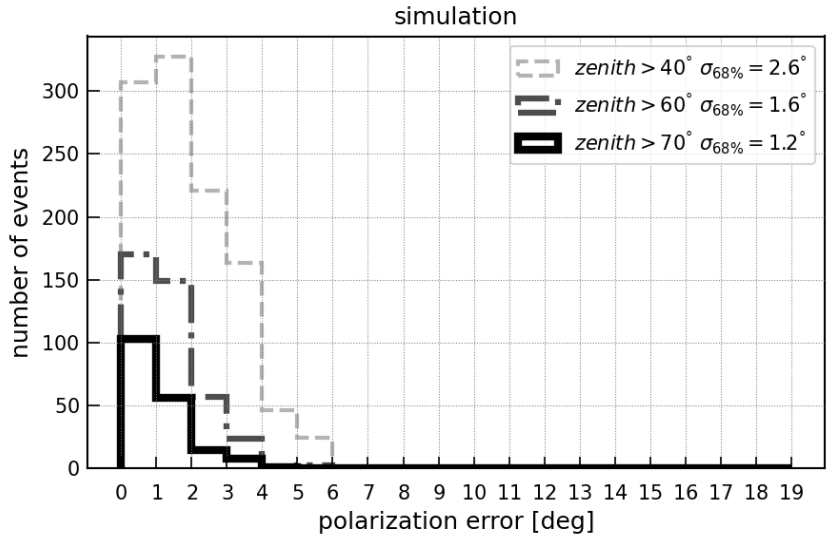
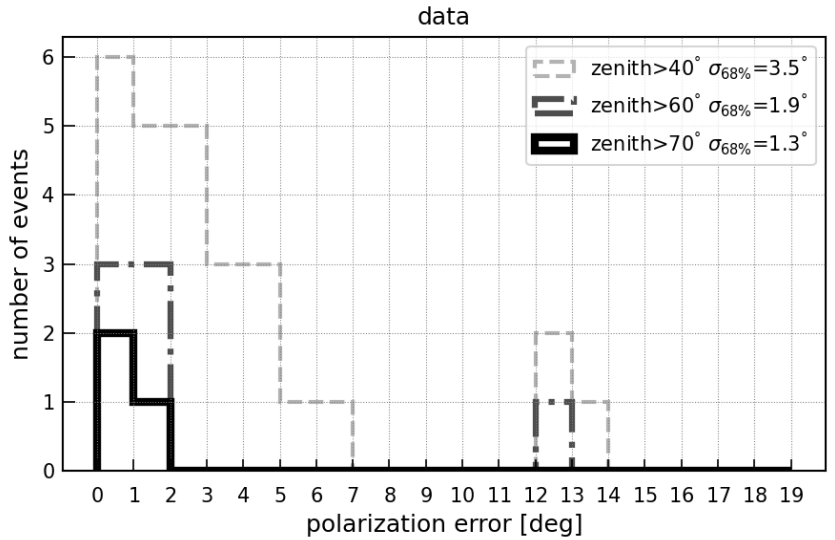
Error in expected polarization dominates

- Expected polarization does not account for Askaryan effect -> is not perfectly accurate
- $polarization\ error = |reconstructed\ polarization - expected\ polarization|$
- Askaryan effect weakens with increasing zenith angle
  - Horizontal cosmic rays travel through less dense air -> long air shower -> effect of geomagnetic field increases
  - Large zenith -> large angle with respect to geomagnetic field -> stronger geomagnetic effect
- 3.5 degree is the upper bound of the 'true' reconstruction resolution
- Simulation indicates the polarization resolution is 1 degree





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Conclusion

- Cosmic rays can be used to measure the polarization reconstruction capabilities
- Data from other seasons/ future detector arrays can be added to improve statistics
- This technique can be used to calibrate detectors in future arrays

- Polarization reconstruction resolution is measured to be 3.5 degree
- The error is dominated by the error in expected polarization due to Askaryan effect, 3.5 degree is the upper bound of the ‘true’ reconstruction resolution
- More data is needed for a more accurate measurement