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Simulation of radio signals from cosmic-ray cascades in air and ice as observed by in-ice Askaryan radio detectors

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To detect the cosmic neutrino flux at the highest energies, Askaryan radio detectors are being deployed in the polar regions. These detectors use the radio detection technique to cover multi-gigaton detection volumes to probe neutrino interactions in the polar ice. Cosmic ray showers can serve as essential calibration sources for in-ice Askrayan radio detectors. However, if not well understood, radio emissions from cosmic ray showers pose an essential background signal in the neutrino search. The neutrino signal is almost perfectly mimicked by cosmic-ray particle cascades moving from air to ice. We present a simulation framework to model the radio emissions from cosmic-ray showers by combining the in-air and in-ice radio emission frameworks to fully characterize the cosmic-ray radio signal as observed by the in-ice antennas. The framework involves a CoREAS-based code to simulate in-air radio emissions and a GEANT4-based code for in-ice radio emissions from cosmic-ray showers as seen by an in-ice antenna. The cosmic-ray shower particles that reach the ice surface at the end of the CORSIKA 7 simulation are injected into the GEANT4-based shower simulation code that takes the cosmic-ray shower particles and propagates them further into the ice sheet. The CoREAS-based and the GEANT4-based codes have been adapted to account for curved ray paths caused by the exponential refractive index profiles of air and ice.

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