Available online at www.sciencedirect.com

ScienceDirect

Nuclear and Particle Physics Proceedings 279–281 (2016) 190–197

www.elsevier.com/locate/nppp

Status of the radio technique for cosmic-ray induced air showers

Frank G. Schröder

Institut für Kernphysik, Karlsruhe Institute of Technology (KIT), Germany

Abstract

Radio measurements yield calorimetric information on the electromagnetic shower component around the clock. However, until recently it was not clear whether radio measurements can compete in accuracy with established night-time techniques like air-Cherenkov or air-fluorescence detection. Due to recent progress in the radio technique as well as in the understanding of the emission mechanisms, the performance of current radio experiments has significantly improved. Above 100 PeV, digital, state-of-the-art antenna arrays achieve a reconstruction accuracy for the energy similar to that of other techniques, and can provide an independent measurement of the absolute energy scale. Furthermore, radio measurements are sensitive to the mass composition of the primary particles: First, the position of the shower maximum can be reconstructed from the radio signal. Second, in combination with muon detectors the measurement of the electromagnetic component provides complementary information on the primary mass. Since the radio footprint is huge for inclined showers, and the radio signal does not suffer absorption in the atmosphere, future radio arrays either focus on inclined showers at the highest energy, or on ultra-high precision measurements with extremely dense arrays. This proceeding reviews the current status of radio experiments and simulations as well as future plans.

Keywords: cosmic ray, air shower, radio

1. Introduction

Measurements of cosmic-ray air showers are motivated typically by two different classes of scientific goals: first, a better understanding of the particle physics relevant for the first interaction of the primary particle and the development of the particle cascade; second, a better understanding of the astrophysics relevant for the sources and propagation of the primary cosmic rays. For both goals, the properties of the primary particles have to be known as accurately as possible, i.e., reconstructed from air-shower measurements.

Different techniques for air-shower detection have different strengths and weaknesses (cf. Refs. [1, 2]). Particle detectors at ground can only measure one stage of the shower development and suffer from statistical uncertainties, since for economic reasons detectors in air-shower arrays cover only a small fraction of the total area. A different category of techniques provides an integral, calorimetric measurement of the full air shower, namely air-fluorescence, air-Cherenkov, and radio detection. However, these techniques are only sensitive to the electromagnetic shower component, not to the hadronic or muonic components. Moreover, air-fluorescence and air-Cherenkov techniques are restricted to dark, clear nights. Modern experiments usually combine both classes of techniques in hybrid detectors, to maximize the total accuracy for the type and energy of the primary cosmic-ray particles.

Within the calorimetric techniques, only radio detection has the principal advantage of being available around the clock. Thus, radio detectors would be the ideal supplement for particle detector arrays. Still, in the past, the radio technique suffered from technical difficulties and problems in the understanding of the radio emission by air showers. Recently, these problems have been solved to a large extent, and current radio experi-

http://dx.doi.org/10.1016/j.nuclphysbps.2016.10.027

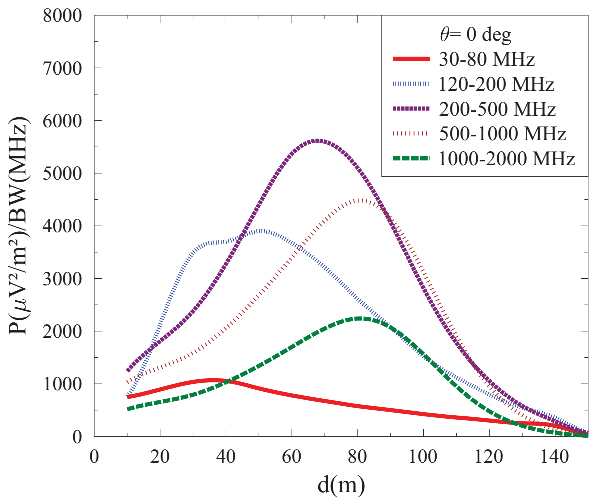

Figure 1: Power of the radio emission over the distance to the shower axis simulated in different frequency bands (from Ref. [3]).

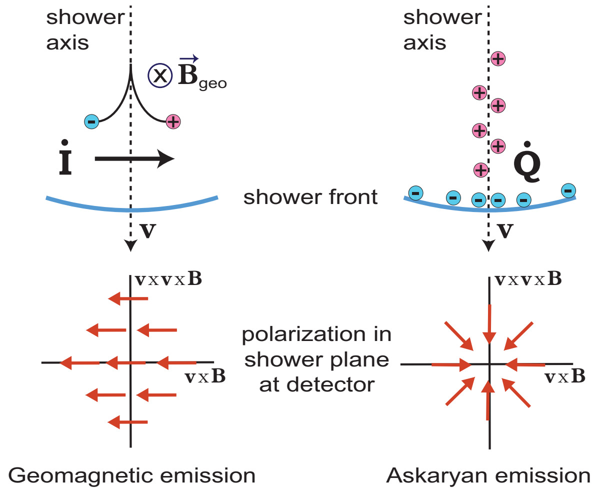

Figure 2: Two emission mechanisms are experimentally confirmed: The geomagnetic deflection of electrons and positrons causes linearly polarized radio emission (left), the time-variation of the charge excess in the shower front causes radially polarized radio emission, known as Askaryan effect (right). In case of a vertical shower, the **v** x **B** axis corresponds to the east-west axis, and the **v** x **v** x **B** axis corresponds to the north-south axis [8].

ments start to become competitive with the established air-Cherenkov and air-fluorescence techniques.

2. Radio emission from air showers

Like air-fluorescence and air-Cherenkov emission, the radio signal is also generated by charged particles in the shower, mainly by the electrons and positrons. While air-fluorescence light is emitted isotropically by nitrogen molecules excited by the air-shower particles, air-Cherenkov light and radio signal are emitted by the air-shower particles themselves. Since the air-shower particles are highly relativistic, their emission is not isotropic but strongly beamed in the direction of the shower axis with an opening angle on the order of 2°. Since the shower front has a typical thickness on the order of meters, the emission is generally coherent at wavelengths of that order or larger.

Thereby the exact coherence conditions depend on the observer position, since the refractive index of air causes the radio waves to propagate slightly slower or faster than the particles, depending on altitude [4, 5]. Therefore, at the Cherenkov angle the emission from all shower stages arrives simultaneously, and is coherent for wavelengths as short as centimeters [3]. Consequently, radio emission can be observed in a wide distance range at frequencies of several 10 MHz, and only at the Cherenkov angle also at much higher frequencies up to a few GHz (see figure 1). The Cherenkov angle corresponds to a distance to the shower axis on the order of 100 m for vertical showers at typical observation altitudes. This is why the lateral distribution features a kind of bump in this distance range, where the exact bump position depends on the observation altitude and the position of the shower maximum [6, 7].

Two different mechanisms have been confirmed experimentally to contribute significantly to the total emission (see figure 2), which makes the observed radio signals more complicated compared to all the other techniques relying on a single mechanism. The stronger of the two effects is the geomagnetic deflection of the electrons and positrons inducing a time-varying transverse current [9, 10]. This basically converts the shower front into a kind of simple Hertz dipole. The amplitude of the geomagnetic emission is proportional to the Lorentz forces and, thus, to $\sin\alpha$ (with α being the geomagnetic angle between the shower axis and the geomagnetic field). The geomagnetic emission is linearly polarized like the emission by a dipole orthogonal to the shower axis and the geomagnetic field.

The second mechanism is the Askaryan effect [11]: the shower front accumulates a time-varying net charge due to electrons kicked out from air atoms, and due to annihilation of positrons in the shower. This time-varying net charge causes radially polarized emission. The Askaryan effect dominates in dense media (and sometimes is confused with Cherenkov radiation), but is less strong in air, typically an order of magnitude weaker than the geomagnetic effect [12, 13, 14, 15]. Nevertheless, the relative strength depends strongly on