

Radio-electric fields from cosmic-ray air showers at large impact parameters

La composante électron-positon de grande énergie dans une gerbe atmosphérique de rayon cosmique crée un champ électrique radio-fréquences transitoire. Il est utile pour choisir les caractéristiques du dispositif de détection radio d'avoir une idée des valeurs des impulsions radioélectriques ainsi que de leur forme et de leur échelle de durée. Un modèle simplifié utilisable à grand paramètre d'impact est proposé pour l'estimation de ce champ radioélectrique.

High-energy electrons and positrons in cosmic ray air showers generate transient electric fields in the radio frequency domain. Estimates of pulse magnitudes, together with their time scales and behaviors are useful ingredients for the design of a radio-detection experiment.

For a very large scale experiment it seems unrealistic to expect a sampling of the air shower electric field on a scale much smaller than a kilometre. This defines the typical impact distance at which electric field estimates are needed. At such distances, a simple model of the shower can be used to investigate various aspects of air shower electric field phenomenology.

The formulation of this model is thoroughly discussed in [1]. A preliminary report on this work was given at the 30th International Cosmic-Ray Conference [2].

i. Electric field estimates

Several mechanisms of charge separation in the shower may lead to a radio electric field component. Here the so-called transverse current component is singled out. At large impact parameter b , the electric field for this component received at time t at observation point A reads

$$\mathbf{E}(t,A)=4(ct')^2(N_{ee}(t')+t'N'_{ee}(t'))\mathbf{J}/b^4$$

where N_{ee} is the number of electrons and positrons in the shower at emission time

$$t'=-b/c)^2/(2t),$$

and \mathbf{J} is in proportion of the drift velocity of positrons and electrons as a consequence of their deflection in the geomagnetic field.

A sample of pulse shapes is shown in Fig. 1 for showers with energy 10^{19} eV and $X_{\max}=770$ g/cm². They are coming from the South azimuth with various zenith angle. The field is always EW in this situation and the eastward projection is shown. The observer is located at $b = 1$ km.

The conversion from the emission time t' to the reception time t (Doppler-like effect) distorts the time dependence, early times (corresponding to t' negative and large) getting

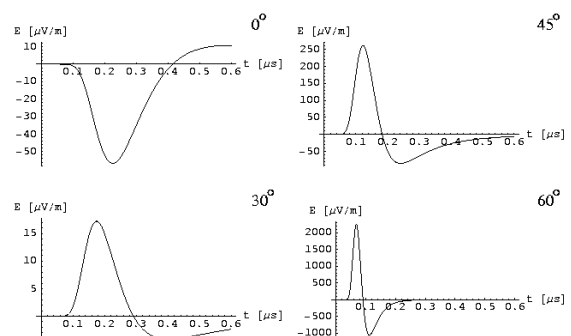


Fig. 1: Electric field pulses simulated at 1 km from the observer.

more contracted than later times. This explains the sharp rise, the slower decay, and the even slower undershoot of the pulse shown in Fig. 1. The variation of rise time with zenith angle θ is

a specificity of radio emission by air showers at large impact parameters. The probing of earlier stages when θ increases affects pulse shape and has the tendency to give larger fields. To get the complete change this increase has to be combined with the overall amplitude modification coming from the variation of the drift velocity, which is proportional to $\sin \alpha(\theta, \phi)$, where α is the angle between the shower axis and the geomagnetic field.

ii. Efficiency

Given a detection criterion it is straightforward to count the number of antennas that see a given cosmic ray shower event, once the distribution of antennas is fixed. The geometry considered is that of a hexagonal array on a horizontal ground located at sea level and the detection efficiency is studied as a function of the antenna spacing. Our detection criterion is that the electric field magnitude is above a threshold to be defined on at least three antennas belonging to the same elementary triangle. The threshold is first fixed to the root mean square of the galactic noise below 100 MHz:

$$E_T = \sigma_{sky} = 30 \mu V/m.$$

A look at Fig. 1 indicates that an antenna located at 1 km receives an electric field magnitude above this threshold for a vertical shower. For such vertical events and an antenna spacing $d = 1.5$ km, Fig. 2 depicts the area spanned by impact parameters of $E_p = 10^{19}$ eV events seen by 3 antennas. The

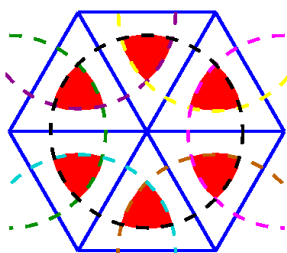


Fig. 2: Hexagonal array and area of detection.

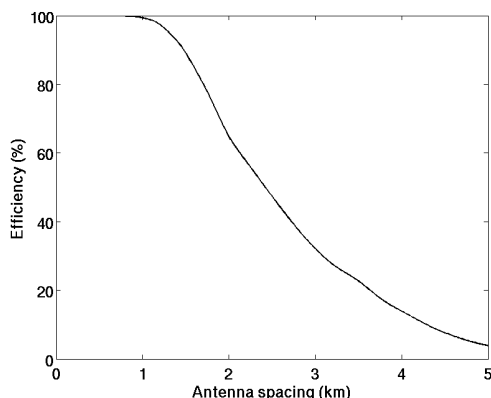


Fig. 3: Efficiency vs antenna spacing.

proportion of detected events is simply given by the ratio of the area of one filled region to that of a basis triangle. For 10^{19} eV vertical shower and $d = 1.5$ km this is about 35 %.

Fig. 3 displays efficiency integrated over arrival directions from vertical to 60-inclined showers with a weight $\sin \theta \times \cos \theta$. As explained in Sect. 1, inclined showers are in general more effective at large impact parameters, making them easier to detect than vertical ones. As a consequence the efficiency for $d = 1.5$ km is now 90 %.

iii. Perspectives

Current investigations are dedicated to small impact parameters. This is the situation of interest for a small antenna array such as CODALEMA. As already mentioned, computations of electric fields are much more difficult in this case.

Ce travail théorique présente l'évaluation du champ électrique créé lors de la traversée de l'atmosphère terrestre par un rayon cosmique de grande énergie, en vue d'aider à la conception d'un système de détection par un réseau d'antennes. La géométrie du réseau est déduite de l'efficacité de détection, calculée pour une antenne sous diverses conditions de distance à la gerbe et d'orientation de celle-ci.

[1] T. Gousset, J. Lamblin, S. Valcares, 2008, internal Subatech publication 2008/03: "Radioelectric fields from cosmic-ray air showers at large impact parameters".

[2] T. Gousset et al., 2007, "EAS radio detection at large impact parameter: the inverse problem and the design of a giant array", in: Proceedings of the XXXth ICRC, July 2007, Merida, Mexico.