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Trigger Strategy for Radio Detection in Atmospheric Air Showers with LOPES^{STAR}

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Abstract: In the framework of LOPES (**LO**FAR **P**rototyp**E** **S**tation), a **S**elf-**T**riggered **A**rray of **R**adio detectors ($STAR$) is developed. The challenge of LOPES^{STAR} is to provide an independent self-trigger on radio emission of extensive air showers with primary energies above $5 \cdot 10^{17}$ eV.
Measurements are done with an external trigger and self-trigger in radio loud and quiet areas. Based on these data the self-trigger is optimised and higher level triggers are developed, as well as algorithms for reconstruction of shower observables. The methods and first results from LOPES^{STAR} are described.

Introduction

On site of the Forschungszentrum Karlsruhe (FZK) in a first step 10 and later additional 20 short dipole antennas with an inverted V-shape (LOPES30) with east/west polarisation were installed and triggered by KASCADE [1, 2].
To optimise these techniques and to provide an independent trigger system for radio emission of Ultra High Energy Cosmic Rays (UHECRs) the LOPES^{STAR} detector was developed. Two antenna clusters, each with 4 logarithmically periodic dipole antennas (LPDAs) and two polarisation channels – east/west & north/south (8 channels), were set up on the site of FZK within the area of

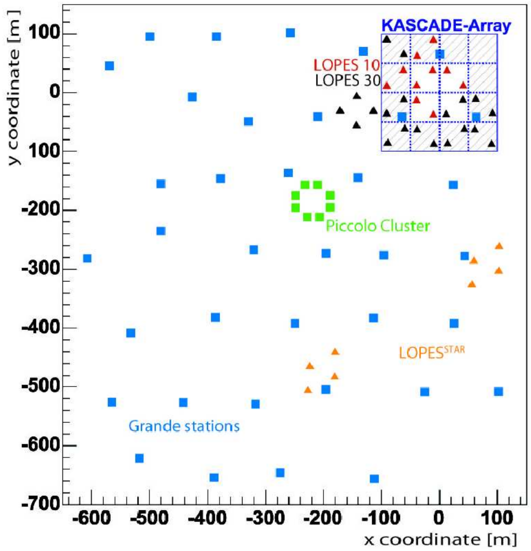

Figure 1: Layout of the KASCADE-Grande and LOPES experiment on site of the Forschungszentrum Karlsruhe.

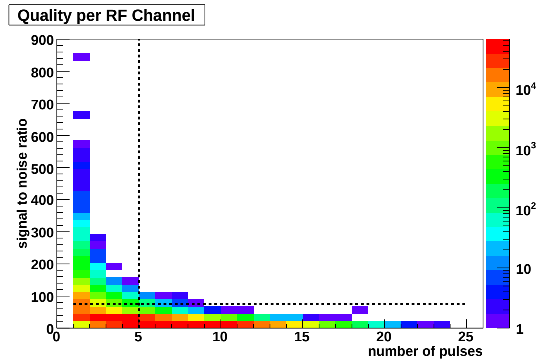

Figure 2: *Signal to noise ratio* versus the detected *number of pulses* with eight entries per event. The dashed lines indicate the Quality Cut.

the air shower experiment KASCADE-Grande [3] (see fig. 1).

First self-triggered measurements have shown, that Radio Frequency Interferences (RFI) are dominating the trigger rate. To improve the self-trigger concept and to develop higher trigger levels an external trigger signal from KASCADE-Grande was provided. LOPES^{STAR} data are recorded whenever a coincidence configuration of seven KASCADE-Grande stations (blue squares in fig. 1) is registered. This corresponds to an energy threshold of $\approx\ 10^{16}$ eV and a trigger rate of $\approx$ 50 mHz.

Signal Chain

The pulsed, coherent radio emission of the cosmic ray shower can be observed by antennas when the UHECRs energy and the electric field strength are large enough [4]. The signal of each channel is raised by a low noise amplifier and transmitted to a 40 – 80 MHz bandpass filter. The Radio Frequency (RF) signal is then split. One part can be used as input signal for the self-trigger analogue electronics while the other is digitised by a 12 bit ADC with a sampling frequency of 80 MHz and stored in ring buffers [5, 6]. Additionally, a timestamp from a GPS clock is stored with the ADC data if an event is triggered.

The digitisation of a 40 – 80 MHz bandpass signal with a sampling rate of 80 MHz fulfils the extended Nyquist Theorem. The n sub-sampled data have to be up-sampled by a factor k to $k \cdot n$ samples for analysis and reconstruction. For this purpose the signal is transformed to frequency domain, where also the suppression of mono frequent RFI (*RFI suppression*) is done. By putting in $(k-1) \cdot \frac{n}{2}$ zeros in the frequency space we achieve the factor k up-sampled spectra in the time domain [6, 7].

Self-Trigger

The trigger rate per channel at each antenna has to be minimised by controlling the data quality. In a next step, the geometry of the setup is used to check the coincidence constraint. Therefore, the position of each antenna in the illustrated cluster in fig. 1 is part of a vertex of an equilateral triangle with a base length $b = 65$ m. This geometrical configuration of three LPDAs provides the coincidence constraint for the self-trigger. Most RFI sources are located at low elevations. The signals propagate dominantly in parallel to the earth's surface. For this RFI background the typical time dif-

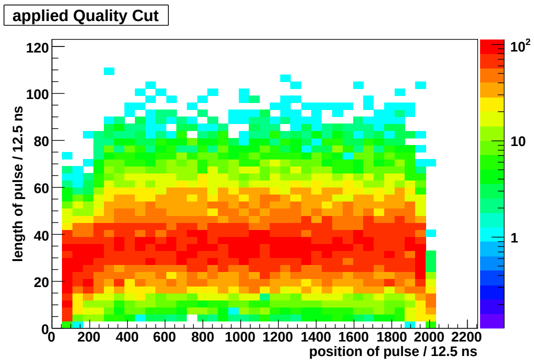

Figure 3: Shown is *length of pulses* versus *position of pulse* of all channels accepted by the Quality Cut.

ference t_{max} of two antennas is $\frac{h}{c} < t_{max} < \frac{b}{c}$, where h is the height of the triangle and c the speed of light. For zenith angles $\theta \leq 60°$ most of the cosmic ray events are detected. The adjusted coincidence time $0 \leq t_c < t_{max}$ is used to suppress horizontal background.

Classification

The analysis is based on a 27d dataset triggered externally by KASCADE-Grande (2006-12-12 to 2007-01-07) in a four antenna array in the lower middle of KASCADE-Grande. More than 102,000 events are recorded with a primary energy $E > 10^{16}$ eV.

RFI suppression is applied to all RF channels. Four classification parameters are calculated: **signal to noise ratio** – The ratio of the peak value and noise in the squared 2048 point sub-sampled data. **number of pulses** – No. of pulses above a dynamically defined threshold counted on base of the sub-sampled data. **length of pulse** – The width of the peak of an envelope in the up-sampled data is calculated. **position of pulse** – The position of the peak in the time domain is calculated in the up-sampled data.

Strategy

The distribution of the *signal to noise ratio* versus *number of pulses* is illustrated in fig. 2 and shows per event eight entries. If the *signal to noise ratio* is > 100 the counted pulses are clearly visible pulses. On the other hand, the expected number of pulses are low, if more than five pulses are detected the broad band RFI is for this channel too high. The quality per RF channel is defined to be *good* by the cut *signal to noise ratio* > 75 AND *number of pulses* < 5.

The *length of pulses* versus *position of pulse* of the accepted RF channels are plotted in fig. 3. RFI signals are distributed randomly over the recorded time window. The maximum *length of pulse* corresponds to the mean length of RFI pulses $t_{\text{mean,RFI}} = 475$ ns at the antenna array. The decreasing mean length of pulses for low and high values of the recorded time are due to the used window function for Fourier transformation. Only 21,000 events (20%) of the given data sample are accepted for further analysis.

Events with at least two accepted RF channels by the Quality Cut are in the next step checked for coincident signals of all channels in one triangle. Therefore, the envelope and a dynamic threshold of each polarisation per antenna are calculated.

The basic idea is to verify all possible coincidences of all RF channels of one triangle and to ensure that at least one RF channel per antenna is included. This also implies a comparison of different polarisations and reduced broad band RFI in several RF channels. The contribution of the signal strength in each polarisation is given by the geomagnetic angle (angle between shower axis and geomagnetic field) but is identical in both polarisations. 269 events (0.026%) of the given data sample are accepted by described method. Due to the dynamic threshold per channel this mechanism is able to detect UHECR events in radio loud environments.

Due to the expected *pulse length*, *number of pulses* per channel, and *detected channels* further cuts are applied to the data to reduce the amount of background events. The resulting 12 events are accepted out of 102,000 events. 5 of these events are in good agreement with the reconstructed shower direction by a plane fit compared with the reconstructed direction of KASCADE-Grande (see fig. 4).

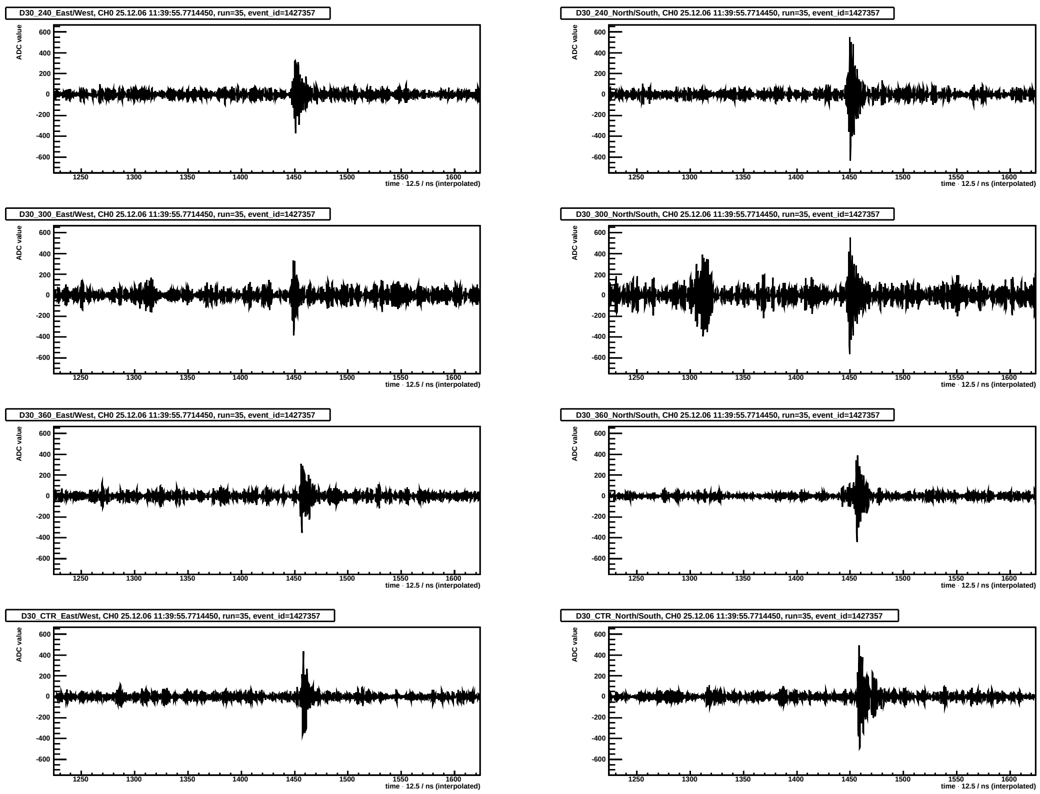

Figure 4: Radio emission of an observed air shower with an energy $E \approx 6 \cdot 10^{17}$ eV (derived from KASCADE-Grande) is shown and re-detected by the self-trigger. The reconstructed direction of LOPES^{STAR} results to an azimuth angle $\varphi = 195°$ and a zenith angle $\theta = 44°$, which is in good agreement with KASCADE-Grande.

Conclusion

The detection of coherent radio emission of UHECR with an independent and self-triggered detector is provided by LOPES^{STAR}. Data are taken in coincidence with the air shower experiment KASCADE-Grande. Based on this data sample a self-trigger strategy was developed. On the one hand the data quality of each channel is monitored and on the other hand coincidence constraint is check by using the triangle geometry. The introduced algorithm detected 12 shower candidates out of 102,000 triggered events in the radio loud environment. With the benefit of the KASCADE-Grande reconstruction 5 UHECR events with a reconstructed energy $E > 2 \cdot 10^{17}$ eV are detected.

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