The ARGO-YBJ inclusive trigger

Stefano Mastroianni for the ARGO-YBJ Collaboration
Presenter: S. Mastroianni (mastroianni@na.infn.it),
Institution: INFN section of Naples and University Federico II of Naples

ARGO-YBJ is a ground-based cosmic ray telescope presently under construction at the Yangbajing High Altitude Cosmic Ray Laboratory (Tibet, People’s Republic of China, 4300 a.s.l.). The detector will cover \(5800\) m\(^2\) with a single layer of Resistive Plate Counters (RPCs), and will be surrounded by a partially instrumented guard ring. About 2000 m\(^2\) of the central carpet are in data taking for science runs since December 2004. The ARGO-YBJ experiment is devoted to gamma ray astronomy studies at an energy threshold of a few hundreds of GeV. The detection of small size showers is accomplished by means of an inclusive trigger with high rejection capability against the background. The logic of this trigger and its implementation are presented. The response of the trigger system has been studied by using a custom code. It allowed us to estimate the efficiencies, the particle fluxes and the trigger rates at different thresholds. Finally, these calculations are applied to the 42-cluster carpet and the results are compared to the experimental data.

1. Introduction

The ARGO-YBJ experiment (Astrophysical Radiation with Ground-based Observatory at YangBaJing) studies a wide class of phenomena in cosmic rays and astroparticle physics [1]. The apparatus has been designed to observe the secondary particles of the atmospheric showers. The carpet is made of a single layer of RPCs that work in streamer mode and each chamber is read out by means of 80 pick-up strips. The ARGO-YBJ detector is divided into 15600 basic elements, the logic pads, which are defined by the fast-OR of 8 adjacent strips. The detector provides a space-time pattern of the shower front with a very high granularity.

The energy spectra of the showers of interest for the ARGO-YBJ experiment span the GeV to TeV range. All the trigger algorithms validate and select an event on the basis of the time distribution of the fired pads and their multiplicity on the carpet. In this paper we will investigate the trigger to select low energy showers, in the range of a few hundreds GeV, are expected to fire less than 100 pads on the entire carpet. Beside this channel there are others to select showers which have a much higher particle density [2]. In order to build up an inclusive trigger without core selection and with high efficiency to horizontal air showers, a logic correlating the EAS particles in a 400 ns window has been implemented.

Figure 1. The level-n coincidence scheme: level-1 manages up to 4 Clusters (150 ns), level-2 up to 12 Clusters (250 ns), level-3 up to 65 Clusters (350 ns) and level-4 up to 130 Clusters (400 ns).
The DAQ and Trigger basic elements correspond modules made of 12 RPCs, called Clusters. The central carpet includes 130 Clusters. Each Cluster has its own modular read-out and local trigger electronics housed in a Local Station (LS) [3]. The 120 pad signals of each Cluster are stretched to 150 ns in order to guarantee that particles of the same shower are in coincidence. The LS outputs a 6-bit Low Multiplicity (LM) weighted bus (when 1, 2, 3, 4, 5, 6 pads are fired). This read-out produces a saturation effect when the pads fired in coincidence on the same Cluster are greater than 6.

A simple yet powerful algorithm to select shower events is achieved just adding the multiplicities of all Clusters corresponding to the same shower across the entire carpet in ~400 ns. This logic produces an output when the total number of hits exceeds the programmed threshold. The spurious signals of the detector (~400 Hz/pad) represent the noise for the shower events. To keep them as low as possible, a four-level coincidence scheme has been implemented in order to correlate only pad signals pertaining to adjacent areas. This logic offers a good noise rejection. In Fig. 1 the level-n coincidence scheme is shown. In order to guarantee the coincidence across all the input elements even with the worst hit timing case, the algorithm stretches the bit widths to the pertaining time window Δt and then sums them up, handling the bus outputs. The level-n coincidence splits the central carpet in an opportune number of blocks of adjacent Clusters managing their time coincidences. For greater details about its implementation, see [2].

In the following we will describe the response of the inclusive trigger to the selection of the showers, evaluating the trigger probabilities, the particle fluxes and the expected trigger rates. The estimate will be compared with the experimental results for the 42 cluster carpet.

3. The trigger probability

The showers development in the atmosphere has been simulated by means of the CORSIKA/QGSjet code [4]. The response of the detector, including its pad noise, has been studied by using a GEANT3-based code, that gives position and time of all the fired pads for every shower hitting the detector. We developed a custom software to simulate the trigger logic that takes account the trigger implementation. A large number of showers induced by gamma, protons and Helium nuclei have been simulated at different
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Figure 4. Trigger probability vs. energy for $\gamma$-primary at different $N_{\text{trg}}$ and zenith angle=20°.

Figure 5. The gamma fluxes for different trigger thresholds. The median energies, calculated with this process, range from 490 GeV for $N_{\text{trg}}=20$ to 1650 GeV for $N_{\text{trg}}=90$.

zenith angles in the energy range from a few GeV to 100 TeV, using a “fiducial area” $A_{\text{fid}} = 800 \times 800$ m$^2$. The core has been sampled all over $A_{\text{fid}}$.

We define $N_{\text{trg}}$ as the number of fired pads required to satisfy the trigger conditions and $n_{\text{pad}}$ as the number of pads fired on the detector when the trigger is issued. These two quantities are generally different because:

- a) the maximum number of pad signals for each Cluster recorded by the trigger system is 6 with respect to a total of 120;
- b) the time coincidences for the trigger purposes are defined in Fig. 1.

The inclusive trigger has in input the LM busses driven by the 130 cluster logic units of the central carpet. For the trigger purpose, 780 pad signals at most come from the carpet: we found a saturation effect that depends on the nature of the primary particle and on its energy. To evaluate this effect we compare $N_{\text{trg}}$ with $n_{\text{pad}}$, which are equal only when in each Cluster the fired pads are always below 6. The results are summarized in Fig. 2, showing that the flattening effect increases with the energy.

The saturation effect reduces with the increase of the zenith angle because of a smaller degradation of the shower in the atmosphere and because the geometric area of the detector decreases by a $\cos$ factor. The behavior of the cosmic ray showers is gamma-like but, at the same energy, they generate a smaller number of particles showing an attenuated saturation effect.

Our greater interest is in $\gamma$ showers: we will study the response of the ARGO-YBJ detector to $\gamma$ sources with respect to the energy and trigger selection. The trigger probabilities versus the energy for different $N_{\text{trg}}$ is shown in Fig. 4. In order to trigger $\gamma$-shower events of energy below a few hundreds of GeV we shall set $N_{\text{trg}} \leq 40$. Therefore, in our set-up (low energy showers) the difference between $n_{\text{pad}}$ and $N_{\text{trg}}$ can be considered negligible, as the 1-TeV $\gamma$ showers show in Fig. 3.

In order to quantify the capability of the ARGO-YBJ detector to trigger a $\gamma$ shower it is convenient to estimate the median energy for different trigger selections. The trigger probabilities are folded with the Crab-spectrum [5] to calculate the $\gamma$-fluxes and the median energies, as shown in Fig. 5. To evaluate the background (or trigger) rate due to cosmic rays for different $N_{\text{trg}}$, we used the proton and Helium fluxes at the top of the atmosphere [6]. At this point, we can calculate the trigger rate $R(\theta, N_{\text{trg}})$ for different zenith angles and trigger thresholds.
Therefore, integrating over the solid angle $\Delta \Omega$ we can evaluate $R(N_{\text{trg}})$ for protons and Helium nuclei. The results are shown in Fig. 6, where it is possible to identify the internal and external components of the showers.

4. Test results

42 Clusters are in data taking since December 2004. The measured trigger rate is shown in Fig. 7 together with the values obtained by MonteCarlo simulation. However, the simulated values are slightly below the measured rate, this could be explained taking into account the contribution of heavy components. According to our model for the 42-cluster carpet, we expect that the inclusive trigger channel provides to the entire carpet a very low energy threshold for the research of $\gamma$-ray sources: the median energies expected range from 490 GeV for $N_{\text{trg}} = 20$ to 1650 GeV for $N_{\text{trg}} = 90$ and the pertaining trigger rates space from $\sim 5 \text{ kHz}$ to $\sim 500 \text{ Hz}$.

References