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LATTES: A new gamma-ray detector concept for South America

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Summary. — In this contribution we discuss the main features and capabilities of a novel hybrid-detector concept for a gamma extensive air-shower array with improved sensitivity towards the lower energies (100 GeV). Preliminary results on its expected perfomance and sensitivity are presented. This wide field-of-view experiment is planned to be installed at high altitude in South America making it a complementary project to the planned Cherenkov telescope experiments and a powerful tool to trigger further observations of variable sources and to detect transient phenomena.

1. – Introduction

The detection of gamma-rays at energies below 100 GeV can be done using instruments placed in artificial satellites, for instance the Large Area Telescope detector onboard the *Fermi* satellite [1]. These have typical collection areas of few square meters and allow for a direct measurement with very good energy and angular resolution. As the gamma-ray energy increases, the flux at Earth decreases steeply, and the collection areas become too small for collecting a sufficient number of events. However, at high energies the interaction of gamma-rays with the Earth's atmosphere produces an Extensive Air Shower (EAS) whose secondaries can be directly detected by detector arrays, or indirectly through the Cherenkov light produced by the relativistic charged secondaries, by using

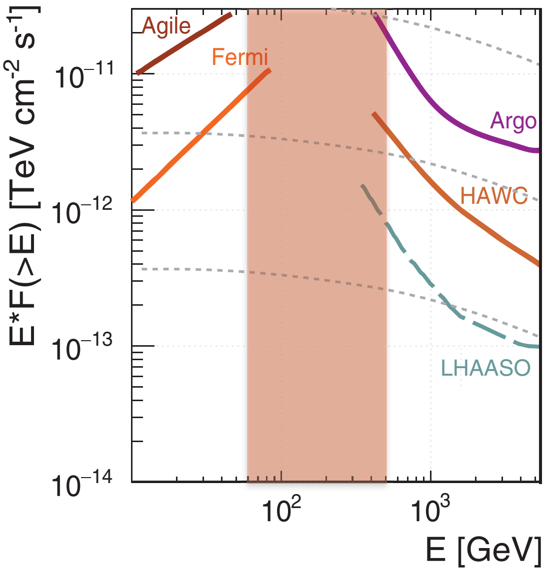

Fig. 1. – Integrated sensitivity for several gamma-ray large field-of-view experiments.

Imaging Atmospheric Cherenkov Telescopes (IACTs). These ground-based detectors have different advantages/disadvantages with respect to each other: IACTs have a lower energy threshold and better angular and energy resolution, as they can image the shower development, but the field of view (FoV) is small, of the order of few tens of square degrees and they can only operate in the dark; on the other hand EAS arrays have significantly wider field of views, covering a large fraction of the sky at once and the duty cycle is typically above 90%; the drawback is that the attainable energy and angular resolutions are several times worse than those of the IACTs [2].

In fig. 1 it is shown the sensitivities of current and future gamma-ray experiments with wide field of views. Two things become evident: there is no wide field-of-view experiment covering the Southern hemisphere sky and the region between several tens of GeV and several hundreds of GeV is not covered by any detector with a good sensitivity. Indeed, this energy region is quite challenging since the number of shower secondary particles that reach the ground becomes too small to trigger and/or reconstruct the shower. In order to cover the present gap between satellite and ground-based observations, a two-fold strategy seems unavoidable: design a novel detector concept, able to trigger at the lowest energies while maintaining a reasonable shower reconstruction capability; increase the altitude to deploy the array in order to collect as many shower particles as possible. However, since the experiment has to be deployed in high-altitude plateaus, this choice is obviously limited. We discuss here a novel hybrid detector concept to be installed at 5200 m a.s.l., to improve the sensitivity to gamma-rays in the 100 GeV energy region. This manuscript is organised as follows: in sect. **2** we describe the detector and the layout of the experiment. In sect. **3** we discuss its performance and in sect. **4** we present the achieved sensitivities.

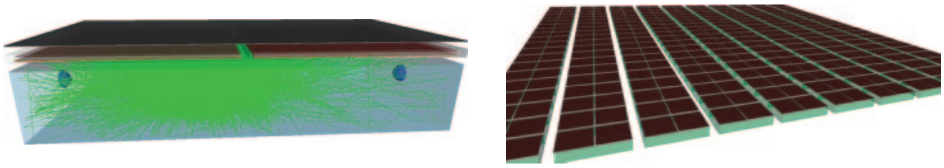

Fig. 2. – Left: Basic detector station, with one WCD covered with RPCs and a thin slab of lead. The green lines show the tracks of the Cherenkov photons produced by the electron and positron from the conversion of a photon in the lead slab. Right: Layout of the detector array.

2. – Detector description

The present detector concept is based on a dense array of hybrid detector units. Each station is composed by two low-cost Resistive Plate Chambers (RPC) on top of a Water Cherenkov Detector (WCD), as shown in fig. 2 (left). Each RPC has 16 charge collecting pads covering a total area of $1.5 \times 1.5\,\text{m}^2$. The WCD has a rectangular horizontal surface of $3\,\text{m} \times 1.5\,\text{m}$ and a depth of 0.5 m, with signals read by two photomultipliers (PMTs) at both ends of the smallest vertical face of the block. On the top of the RPCs a thin lead plate (5.6 mm) is used to convert secondary photons. The conversion of the photons is important to improve the geometrical reconstruction as photons have a stronger correlation with the primary direction with respect to secondary shower electrons. The success of such detector lies on the fact that the RPCs contribute with its high segmentation and time resolution while the WCD provides a calorimetric measure of the shower secondary particles allowing to lower the energy threshold. Moreover, with this hybrid detector concept, it is possible to trigger in the WCD only, which allows the RPCs to operate at a low threshold while minimising several sources of noise (detector, electronics, environment).

The full detector is deployed as an array of individual stations set in long lines with each touching the other on their largest dimension. The row of lines of detectors are separated by a small distance (roughly 0.5 m) to allow access to service the PMTs and the RPCs, as illustrated in fig. 2 (right). This arrangement allows for a compact array and for a scaling of the full detector. The performance results presented herein are based on a baseline configuration with 60 rows and 30 lines, covering an effective geometrical area of about $10000\,\text{m}^2$.

3. – Detector performance

The performance of the present detector concept was assessed using an end-to-end realistic Monte Carlo simulation. The EAS have been simulated using CORSIKA (COsmic Ray Simulations for KAscade) and the detector response was treated by a Geant4 dedicated simulation. We generated 10000 CORSIKA simulations for gammas and protons between 10 GeV and 5 TeV. Each simulated shower is then reprocessed 100 times through the detector simulation, with a new core position randomly set in each realization. To save computational times, the simulations were generated using a power law differential energy spectrum with an index -1.0, and afterwards were properly weighted for the corresponding energy-dependent fluxes. The zenith angle for gammas was fixed to 10°, while for protons the range was between 5° and 15° degrees. At the first level of the event selection, we required that at least 3 stations have been triggered, with

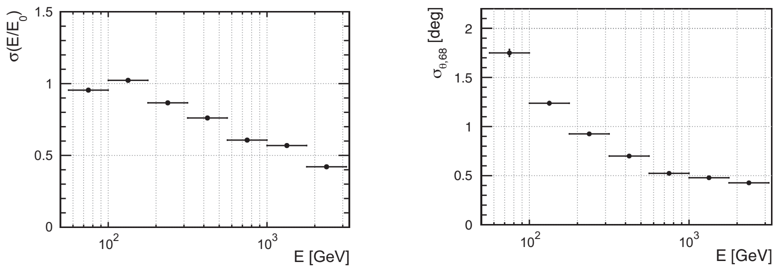

Fig. 3. – Left: Reconstructed energy resolution as a function of the reconstructed energy for photon-initiated showers. Right: Angular resolution for gamma-ray primaries as a function of the reconstructed energy.

the trigger condition for the station requiring at least 5 photoelectrons in each PMT. The effective area for this array was computed using simulations. The effective area at trigger level, *i.e.*, the integral of the surface times the trigger efficiency, is of the order of 20000 m^2, for gamma-initiated showers with an energy of 100 GeV. Considering all event selection quality cuts described below, we still have an effective area of the order of 2000 m^2 for 100 GeV primary photons. The energy estimation has been done using the total signal recorded in the WCD stations for each event. A calibration curve was derived and used to get the reconstructed energy for each event from the total signal. The estimated energy resolution that one could achieve with this detector, as a function of the reconstructed energy is shown in the left plot of fig. 3. As expected, the energy resolution improves as the shower energy increases. At the lowest energies, one still has a reasonable energy resolution of 100%, mostly dominated by shower-to-shower fluctuations. The reconstruction of the direction of the primary particle was performed by taking advantage of the RPC segmentation and fast timing (a time resolution of 1 ns was considered in the simulations). The position and time of the hits recorded in the RPC were fitted to a plane shower-front model. The quality of the reconstruction is improved by requiring that the event has at least 10 hits. The reconstructed angle was compared to the simulated one, and we calculate the 68% containment angle, $\sigma_{\theta,68}$. The result is shown in the right plot on fig. 3. As can be seen, even at energies as low as 100 GeV, a reasonable resolution can be achieved, better than 2°.

4. – Detector sensitivity

The sensitivity of this detector to steady sources was also computed. The effective area after selection cuts, the energy and angular resolution were taken into account. Meanwhile, algorithms for discriminating between gamma and hadron initiated showers, are currently being optimised. The goal is to explore the hybrid nature of the detector, in order to combine background rejection techniques used previously by HAWC [3] and ARGO [4], which could lead to an improved background rejection. For now we conservatively assumed no background rejection below 300 GeV while above 300 GeV we took HAWC gamma/hadron capabilities as an ansatz for the highest energies. We compute the sensitivity as the flux of a source giving $N_{\mathrm{excess}}/\sqrt{N_{\mathrm{bkg}}} = 5$ after 1 year of effective observation. It was assumed that the source is visible one fourth of the time, which is roughly the time that the galactic centre is visible in the Southern tropic. In fig. 4 the obtained differential sensitivity for this detector is compared with the 1 year sensitivities

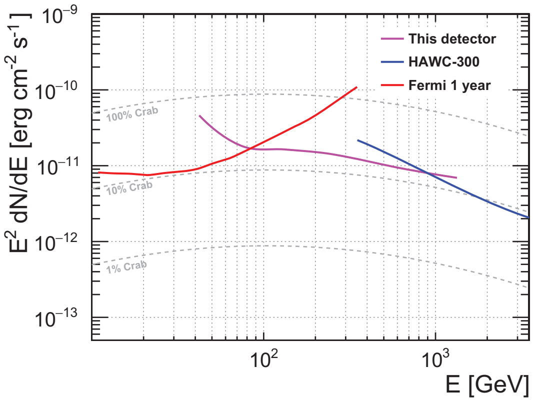

Fig. 4. – Differential sensitivity for steady sources after one year of effective time. 4 bins per decade in estimated energy are used. For comparison, fractions of the Crab Nebula spectrum are plotted with the thin dashed gray lines.

of *Fermi* and HAWC. One can clearly see that this detector would be able to cover the gap between the two most sensitive experiments in this energy range.

5. – Summary

We have presented a novel hybrid detector concept able to extend the sensitivity of large field-of-view gamma-ray experiments down to the energy region of 100 GeV (more information can be found in [5]). It is based on compact and modular low-cost detector units. Each unit combines a low-energy-threshold calorimetric measurement provided by a water Cherenkov detector, with the fast, high segmentation and high time resolution charged-particle detection, using robust and low-cost resistive plate chambers. The results presented here were based on a 10000 m^2 baseline array. While the obtained results are already rather encouraging, the final detector design should consist of a larger, 20000 m^2 core array, complemented by an outrigger of sparse detectors, with a total area of about 100000 m^2. Such wide-FoV experiment with a low energy threshold and a large duty cycle would be fully complementary to the powerful narrow-FoV Cherenkov Telescope Array, as it would be able not only to issue alerts of transient phenomena but would also enable long-term observations of variable sources.

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