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Sensitivity of the High Altitude Water Cherenkov Experiment to observe Gamma-Ray Bursts

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Abstract: Ground based telescopes have marginally observed very high energy emission (>100GeV) from gamma-ray bursts(GRB). For instance, Milagrito observed GRB970417a with a significance of 3.7 sigmas over the background. Milagro have not yet observed TeV emission from a GRB with its triggered and untriggered searches or GeV emission with a triggered search using its scalers. These results suggest the needof new observatories with higher sensitivity to transient sources. The HAWC (High Altitute Water Cherenkov) observatory is proposed as a combination of the Milagro tecnology with a very high altitude (>4000m over see level) site. The expected HAWC sensitivity for GRBs is at least >10 times the Milagro sensitivity. In this work HAWC sensitivity for GRBs is discussed.

Introduction

Gamma-Ray Bursts (GRBs) have been studied since 1963. Several experiments such as PROGNOZ [1, 2], GINGA [3], VENERA [4, 5, 2], SIGNE [2], PVO [2], ISEE [2], SMM [6, 7], OSO-6 [8] and OGO-5 [8], observed a few hundreds of GRBs during the 19 years following the publication of the GRB discovery. Most of these experiments were sensitive to a decade of energy in the keV regime. The results from these observations already pointed to some of the now-well-known properties of GRBs. But it was until the BATSE observation of 2704 GRBs that the results on keV emission from GRBs were conclusive. The success of BATSE was in part a result of its full sky coverage.

The next step towards our understanding of GRBs came with the determination of GRB redshifts and the observation of breaks in optical afterglows thanks to the promptly slew of BeppoSax to determine the GRB position and the dissemination of the GRB coordinates through GCN to tens of observatories in other wavelengths around the world.

After 44 years of study and observations, GRB theory is converging on a model that is successfully explaining and predicting GRB emission at different wavelengths, at least for energies below 1MeV. The GRB emission above 1MeV is poorly understood mainly because the existence of a few observations showing different spectral characteristics in single bursts. The GRB spectrum does not seem to have a cut off or a change of the spectral index after the peak energy at least up to 1MeV as BATSE showed. The long-lived GeV emission detected in GRB940217 [9], the average spectra above 100MeV over 200s of 4 bursts observed by EGRET spark chambers [10] and the 175 bursts observed by SMM [7] in the energy range of 0.8-10MeV, were shown to be consistent with a continuation of the spectrum observed at keV-energies. The only two observations that hint to a change in the GRB spectrum are: 1. The 3σ burst observed by Milagrito [11], GRB970417, at energies near 1TeV that suggests the existence of a spectral component possibly explained by self-Compton emission related to the keV-spectrum; 2. The 6σ burst observed by EGRET-TASC [12], GRB941017, in the energy range of 1-200MeV that suggests the existence of a spectral component difficult to explain with the standard synchrotron shock model suggesting the existence of a new phenomena.

GLAST will observe GRB emission up to energies of 100GeV. However, because of the unpredictable GRB direction and the low photon flux at TeV energies, increasing the TeV observations of

GRBs requires to have several tens of TeV observatories along the world or a full-sky and high duty cycle detector. In these paper the capabilities of a High Altitude Water Cerenkov detector, HAWC, to search for TeV emission from GRBs are presented.

HAWC

The HAWC detector is designed as a 150m x 150m x 5m deep reservoir lined with a polypropylene-nylon liner to contain and isolate the $\sim$115 Ml of filtered water from the ground below. Nine hundred 8” Hamamatsu R5912 photomultiplier tubes (PMTs) are secured on a 30 x 30 grid with 5m spacing and 4m deep. Stretching between the PMTs is an opaque curtain designed to optically isolate each PMT. The reservoir is covered with a light-tight building made from prefabricated steel components. The whole observatory will be situated at an altitude of 4100m over sea level in Sierra Negra, Puebla, México. The gain in sensitivity of HAWC over Milagro is result of the higher altitude, larger physical area and the optical isolation of the PMTs.

An air-shower in HAWC is defined as an event with a prescribed number of hit PMTs within the trigger window. This prescribed number of hit PMTs defines the trigger multiplicity. Since there are about $\sim$6 times more electromagnetic particles in an extensive air shower (EAS) at 4100m than at 2600m (Milagro altitude), the shower plane can be reliably reconstructed for events with a few as 20 hits lowering the HAWC energy threshold, see Figure 1. Below $\sim$50PMTs the background grows rapidly, but it can be reduced by shrinking the trigger time window or by making geometric cuts requiring that the hit PMTs are concentrated, indicating the presence of a shower core. The larger size of HAWC results in an improved angular resolution of 0.25^o-0.4^o depending on the trigger multiplicity because of a better determination of the shower front curvature and core location. The background rejection and efficiency also improves significantly, especially at low energies, because penetrating particles such as muons can be detected over a much larger area. Finally, the optical isolation decreases the number of PMTs hit by light traveling horizontally across the reservoir. Then, the number of PMTs hit not related to the shower decreases resulting in a better angular resolution and a lower trigger multiplicity. The ability to trigger at low multiplicity greatly increases the area of HAWC below 100GeV, see Figure 2, which increases the instrument’s sensitivity to distant sources with intrinsic cutoffs such as GRBs.

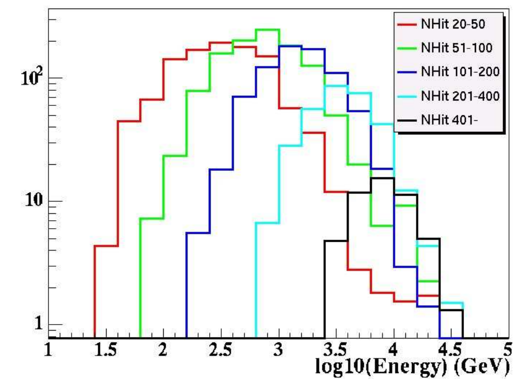

Figure 1: Energy of gamma-ray events for a Crab-like spectrum and different multiplicities in HAWC.

Figure 3 demonstrates the ability of HAWC to observe shorter time scale variations than GLAST and to extend the energy range of observations beyond those of GLAST. The instantaneous field-of-view of HAWC is approximately 2π steradians and HAWC duty cycle is expected to be at least the 95% value obtained for Milagro.

The HAWC sensitivity to the prompt emission from gamma-ray bursts is unique. Preliminary calculations of HAWC sensitivity for GRB emission is shown in Figure 4 and compared with Milagro sensitivity. With HAWC low energy threshold, GRBs with a TeV fluence comparable to their keV fluence will be detectable to a redshift of $\sim$1, while for closer GRBs much lower fluences can be detected.

Observations of TeV emission from GRBs

There have been several reports of TeV counterparts to gamma ray bursts. however, the most compelling such evidence has come from Milagrito.

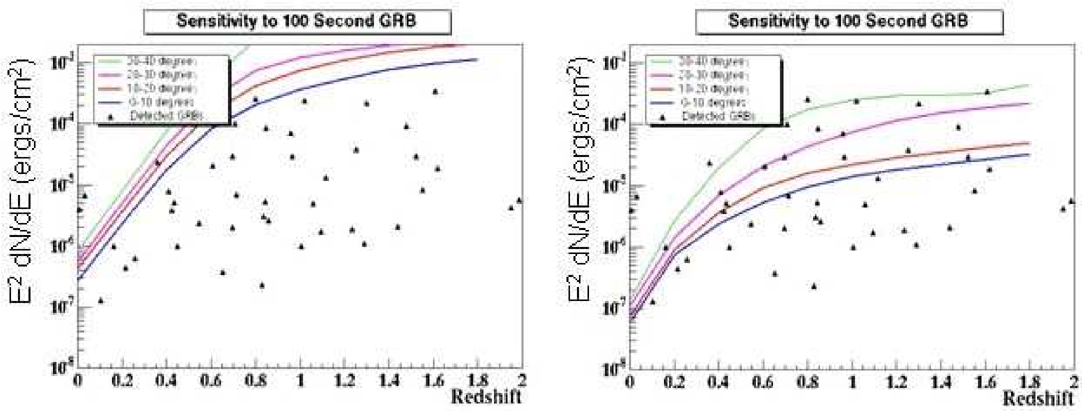

Figure 4: Fluence sensitivity as emitted at the source for a 5σ detection of a 10s GRB vs. redshift for HAWC (right) and Milagro (left). The different color lines indicate the sensitivity for GRBs at different zenith angles. The superimposed triangles indicate the keV-MeV fluence and redshift of satellite detected GRBs.

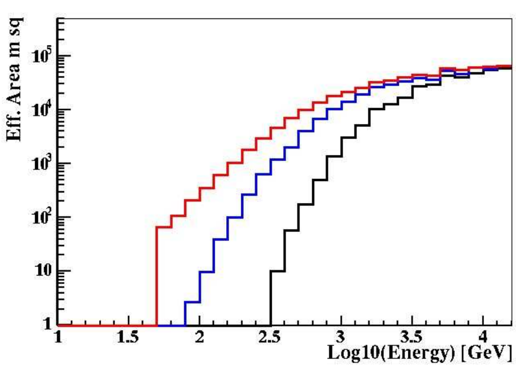

Figure 2: HAWC effective area versus gamma-ray energy for three different levels of trigger multiplicity (20(upper red line), 80(blue line) and 200(lower black line) PMT trigger) for a zenith angle $< 30^o$ after applying the cosmic ray background rejection cut and requiring a reconstructed direction within 1^o

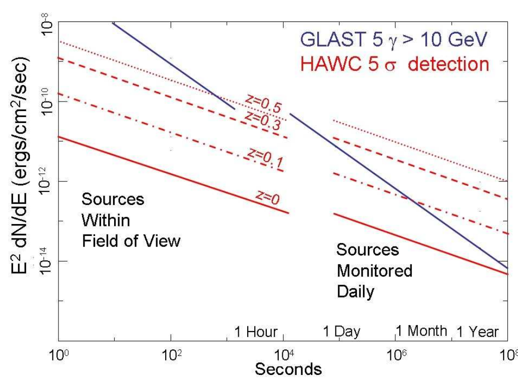

Figure 3: Comparison of the flux necessary for a GLAST detection of 5 γ-rays above 10 GeV with the HAWC 5σ detection threshold for a source differential photon flux of spectral index -2 that is cut off due to extragalactic background absorption. The absorption is calculated assuming the model of Kneiske [13], and the energy at which the flux is attenuated by 1/e is 700, 260, and 170 GeV for z=0.1, 0.3, and 0.5, respectively. The gap between the lines on the left and right is due to the Earth blocking the view of the source.

Milagrito operated for about 1year from February 1997 to May 1998. During this time the BATSE satellite was operational and detected 54 GRBs that were within the field-of-view of Milagrito. There was significant excess of events observed from GRB970417 but because of a poor localization capability of BATSE, a large number of trials had to be performed to scan the BATSE error box. After trials and the fact that 54 GRBs were examined, the observation became marginal.

During Milagro operational time there has not been a satellite detector comparable to BATSE. The number of GRBs within Milagro field-of-view after SWIFT launch is comparable with the number of GRBs examined by Milagrito. However, the average redshift of these bursts is about twice that of the BATSE detected bursts because the increased sensitivity of SWIFT and its smaller field of view. Therefore, Milagro has not found evidence of TeV emission from GRBs concluding, under the assumptions that produce the largest TeV flux, that no more than 30% of all GRBs have a TeV luminosity greater than the observed keV luminosity.

Because the low cost of HAWC (6M dollars) and its relatively fast construction (3 years), HAWC will overlap with GLAST and be able to immediately search for TeV counterparts for every burst in its 2πsteradians field-of-view.

HAWC can also self-trigger and behave as monitor to TeV emission for half of the sky to inmediatly or offline notify other observatories such as IceCube [14]. Although the big cost on significance because of trials factor, it will still be sensitive to the brightest TeV bursts.

Conclusions

Gamma-ray astrophysics is a scientifically rich and growing field. The wide field of view TeV gamma-ray HAWC observatory will have a dramatic impact on the scientific return of the GRB field. HAWC is the most suitable detector to search transient TeV emission because of the combination of its large field-of-view, high duty cycle and broad energy range (down to 100GeV).

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