Search for TeV gamma-rays from point sources with SPASE2

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Abstract: The South Pole Air Shower Experiment (SPASE2) began operation in 1996 and took data until it was decommissioned in December 2006. We are currently analyzing those of the 205 million reconstructed events that were taken during the last five years. In this paper we report on a search for 100 TeV gamma-rays from three specific Southern hemisphere point sources discovered by HESS. that may have gamma-ray spectra extending to energy higher than 50 TeV.

Introduction

The SPASE2 scintillator array at the Amundsen-Scott South-Pole station is at an altitude of 2835 m.a.s.l., corresponding to a year-round average atmospheric overburden of $695\,gcm^{-2}$. The total area within the perimeter of the array is $16,000\,m^2$ [1]. For this search we use data taken during the last five years with lifetime of 171+167+204+307+322=1171 days = 3.21 years.

In this work, we focus on the following three HESS sources:
a) The shell-type supernova remnant RX J0852.0-4622 [2]. It has a spectrum observed in the energy range between 500 GeV and 15 TeV, which can be well described by a power law with a photon index of 2.1$\pm$0.1$_{stat}\pm$0.2$_{syst}$ and a differential flux at 1 TeV of (2.1$\pm$0.2$_{stat}\pm$0.6$_{syst}$)$\times 10^{-11}$ cm^{-2}s^{-1} TeV^{-1}. The corresponding integral flux above 1 TeV was measured to be (1.9$\pm$0.3$_{stat}\pm$0.6$_{syst}$)$\times 10^{-11}$ cm^{-2}s^{-1}.
b) The Supernova Remnant MSH 15-52. Its image [3] reveals an elliptically shaped emission region around the pulsar PSR B1509-58. The overall energy spectrum from 280 GeV up to 40 TeV can be fitted by a power law with photon index α=2.27$\pm$0.03$_{stat}\pm$0.20$_{syst}$ and a differential flux at 1 TeV of (5.7$\pm$0.2$_{stat}\pm$1.4$_{syst}$) $\times 10^{-12}$ TeV^{-1}cm^{-2}s^{-1}.
c) The unidentified TeV γ-ray source close to the galactic plane named HESS J1303-631 [4] is an extended source with a width of an assumed intrinsic Gaussian emission profile of σ = (0.16$\pm$0.02)^o. The measured energy spectrum can be described by a power-law $\mathrm{d}N/\mathrm{d}E = N_0 \cdot (E/1TeV)^{-\alpha}$ with a photon index of α=2.44$\pm$0.05$_{stat}\pm$0.2$_{syst}$ and a normalization of N_0=(4.3$\pm$0.3$_{stat}$)$\times 10^{-12}$ TeV^{-1}cm^{-2}s^{-1}.

Energy estimate

The particle density at 30 meters from the shower core, S_{30}, is used by the SPASE2 experiment to estimate the primary particle energy. Monte Carlo simulations tell us that the S_{30} for 100 TeV γ-rays is higher than for 100 TeV proton. The Monte Carlo simulates cascades as well as the response of the air shower array using Cosrsika with the Sibyll2.1 version of Sibyll [6] interaction model.

Currently a Monte Carlo estimate is available for all showers with zenith angles between 20^o and 50^o. For example, at S_{30} of 3 m^{-2}, E_γ is about 120 TeV, while E_p is 180 TeV. We will perform more simulations to determine the energy dependence as a function of the zenith angle.

Angular resolution

The angular resolution of an air shower array is much worse that that of an air Cherenkov telescope. We have estimated the SPASE2 angular resolution in two different ways - using the experimental data with sub-array comparison and with Mote Carlo calculations.

In the sub-array approach the SPASE2 array is divided into two parts. For each one the shower angle is estimated separately. The space angle between the two sub-arrays is used to study the angular resolution.

Monte Carlo events after the standard shower reconstruction were also used to determine the angular resolution. The results from both methods fully agree with each other at higher energy. At threshold the sub-array approach suffers from statistical fluctuations because there are not enough detectors that respond to the showers.

Fig. 1 shows the integral distribution of the square of the space angle difference between the true direction of the simulated shower and the reconstructed direction Ψ^2 for γ-ray showers with $S_{30}>$ 3 m^{-2}. The Ψ value that contains 68% of all events is 2.1^o. For showers of $S_{30} < 3$ m^{-2} this number is 3.3^o. Proton showers in both energy ranges show slightly worse angular resolution.

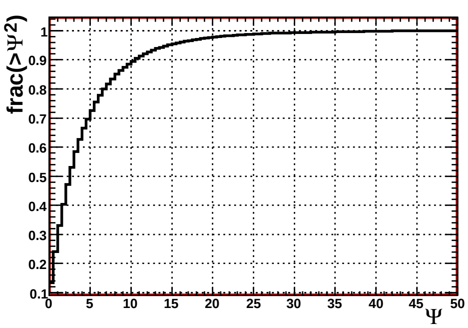

Figure 1: Integral distribution of the Ψ^2 values (in square degrees) derived from simulation of γ-induced showers.

Systematic errors

There are several possible sources of systematic errors in the data set. One is that at the beginning of 2002 the electronics of the shower ray was updated with a consequent increase of its threshold. For this reason we will first use the five years data taken after 2001.

A second source is that the response of SPASE2 has 2% variation with azimuth. Since the array typically has a lower duty cycle in the antarctic summer this could lead to a background that is not completely uniform in right ascension.

The background

We studied the possible anisotropies by looking at the scrambled RA distribution in different declination bins. Currently our data set is blinded. Scrambling was performed by shifting the real RA by a random amount. Figure 2 shows the rms value over the Gaussian expectation in Gaussian standard deviations σ for zenith angles from 20^o to 50^o. In this case the average number of entries per bin is 1.37 million and the standard deviation of Fig. 2 is 1.17×10^3 showers. Out of 60 bins 38 bins show deviation by less than 1σ and 3 bins have deviations of more than 2σ which fully agrees with a Gaussian distribution.

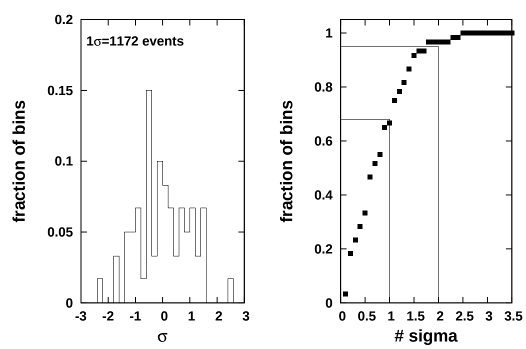

Figure 2: Left-hand panel: Distribution of the deviation from the average for 60 6^o RA bins. Right-hand panel: Integral distribution in number of σ.

We also looked at these distributions for smaller zenith angle bins similar to those that we will use in the source search. Fig. 3 shows the scrambled

RA distribution in $6^o \times 6^o$ bins for the zenith angle band of 41^o to 47^o, which almost coincides with one of the sources. The results are very similar to those for the wider zenith angle band.

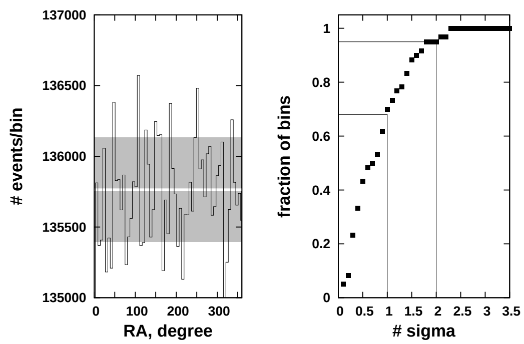

Figure 3: Lef-thand panel: Number of events per bin in the declination band 41^o- 47^o. The average is shown with a white line and the shaded area represents $\pm 1\sigma$. Righthand panel: Integral distribution in number of σ for the declination band.

Signal expectations

Because of its flat energy spectrum the source RX J0852.0-4622 offers the highest chance for detection if its spectrum does not cut off. It is, however at the highest zenith angle of the 3 sources studied. Assuming conservatively the area of SPASE2 to be 10^8 cm^2 and its lifetime to be 10^8 s, we expect to have 870 (400) events above E_γ^{thr} 100 (200) TeV. At zenith angle of 43.8^o this would roughly correspond to S_{30} values of 1 and 3 m^{-2}. For $6^o \times 6^o$ bins the average background per bin is 135,000 (74,000) events, and the signal events correspond to excesses of 2.4σ and 1.6σ. SPASE2 is not, by far, the best detector for γ-ray astronomy, but the chance of detection is reasonable for a flat source spectrum with no cut off.

Angular bins

The angular bins recommended for source search with air shower arrays [7] correspond to an elliptical region with minor axis equal to $1.59\sigma_0$ and a major axis $1.59\sigma_0 / \cos\theta$ where σ_0 is the angular resolution of the detector and $\cos\theta$ corresponds to the declination of the source. We will search separately for showers with S_{30} higher and lower than 3 m^{-2} The angular resolution for S_{30} $>$3 m^{-2} is 2.1^o and is about 3.3^o for lower energy showers. At higher energy the major axis of the ellipse should be 4.6^o and the minor one 3.3^o. The angular bin would be correspondingly wider for lower energy showers. Since the angular area of these bins (and correspondingly the number of background events in them) is higher than those used in the previous section the expected detection probability is slightly different.

Conclusion

The search for 100 TeV γ-ray signal in the SPASE2 data set is work in progress. We continue working on the array sensitivity as a function of the γ-ray energy and the zenith angle of the source. We will present at the conference the results of the search for the three point sources after unblinding of the data set.

Acknowledgments

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