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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 energies 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 livetime 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 spectral 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$10^{-11} cm^{-2}s^{-1}.
b) The Supernova Remnant MSH 15-52. Its image [3] reveals an elliptically shaped emission region around the pulsar PSR B1509-58. The overall energy spectrum from 280 GeV up to 40 TeV can be fitted by a power law with spectral index α=2.27$\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 $\mathrm{d}N/\mathrm{d}E = N_0 \cdot (E/TeV)^{-\alpha}$ with a spectral 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 Corsika [5] with the 2.1 version of the 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^2 value that contains 68% of all events is $(2.1^o)^2$. For showers of $S_{30} < 3$ m^{-2} this number is $(3.3^o)^2$. Proton showers in both energy ranges show slightly worse angular resolution.

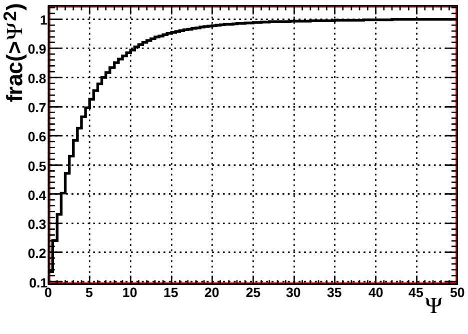

Figure 1: Integral distribution of the Ψ^2 values (in square degrees) derived from simulation of γ-induced showers.

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. Initially our data set was *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.

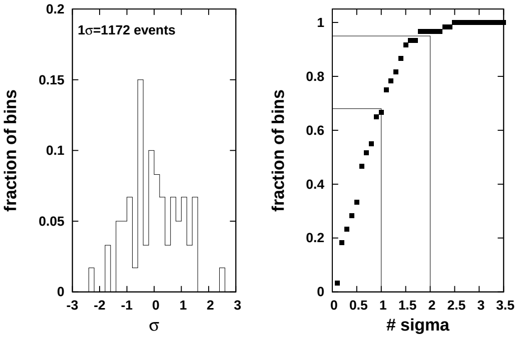

Figure 2: Left-hand panel: Distribution of the deviation from the average for 60 6^o RA bins. Right-hand panel: Integral distribution in number of σ.

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.

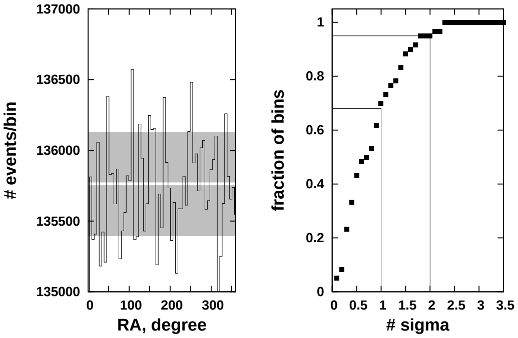

Figure 3: Left-hand panel: Number of events per bin in the declination band 41^o- 47^o. The average is shown with a white line and the shaded area represents $\pm 1\sigma$. Right-hand panel: Integral distribution in number of σ for the declination band.

Angular bins

The angular bins recommended for source search with air shower arrays [7] correspond to an elliptical region with axes equal to $1.59\sigma_0$ where σ_0 is the angular resolution of the detector. We decided to use equal solid angle which means that the major axis of the ellipses are bigger at low zenith angles. We will search separately for showers with S_{30} higher and lower than 3 m^{-2} The angular resolution for $S_{30} > 3\ \mathrm{m}^{-2}$ is 2.1^o and is about 3.3^o for lower energy showers. The search ellipses would be correspondingly wider for lower energy showers. The search ellipses for the three sources and the two S_{30} values are plotted in relative RA units in Fig. 4. 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.

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. We will first look at the 2005 data set. Assuming conservatively the area of SPASE2 to be 10^8 cm^2 and its livetime in 2005 was $2.65.10^7$ s, we expect to have 321 (149) 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}. There may be some contribution from lower energy gamma ray showers but the array efficiency below 100 TeV is less than one and we need further Monte Carlo studies to estimate it.

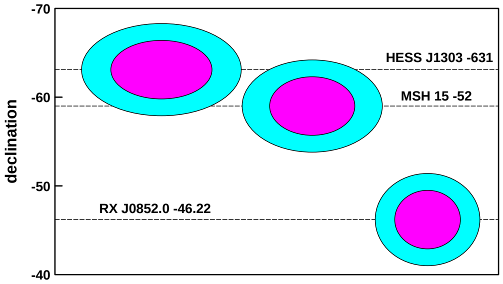

Figure 4: Relative sizes of the search ellipses for the three sources and the two S_{30} values - light shading is for $S_{30} < 3$ and the dark shading is for $S_{30} > 3$.

The backgrounds estimated from the two search ellipses for RX J0852.0-46.22 (excluding the source bins) are respectively 38656 (13739) per bin for $S_{30} < 3$ ($S_{30} > 3$). The background for the lower energy showers is higher because of the much steeper cosmic ray spectrum compared to the γ=1.1 for the source. The expected number of gamma showers thus corresponds to 0.88σ for $S_{30} < 3$ and 1.27σ for $S_{30} > 3$. SPASE2 is not, by far, the best detector for γ-ray astronomy, but the chance of detection is reasonable for a flat source spectrum and no cut off.

The other two γ-ray sources are less intense and can produce not more than several tens of events even if their spectra do not cut off. For this reason we will present only the results for RX J0852.0-46.22.

Results from the 2005 search

Figure 5 shows the observed number of showers from the direction of RX J0852.0-46.22 in the 2005 data set (which we unblinded first) for the two S_{30} values. Note that the bins do not cover the whole 24 hours of RA in the zenith angle band because of the requirement for equal space angle bins. The missing phase space is always less than one bin width. Both searches give negative results. In the S_{30} <3 sample we see -1.5σ from the average expected background. In the higher energy range the lack of events is smaller (-0.5σ).

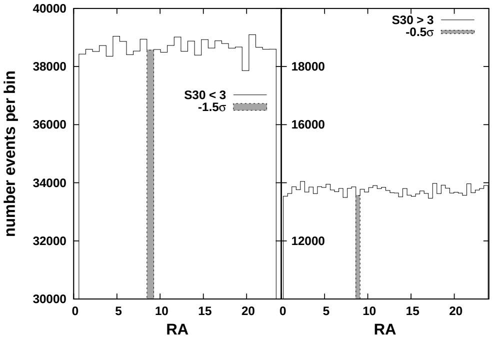

Figure 5: Observed number of showers from the position of the source RX J0852.0-4622 for the two energy bins.

Conclusion

The search for 100 TeV γ-ray signal from RX J0852.0-46.22 in the SPASE2 data set for 2005 gave negative results - we did not observe any showers above the expected cosmic ray background. However, based on the preliminary simulation used here to relate S_{30} to primary energy, we find a limit based on one year data that is nearly inconsistent with the continuation of the spectrum of RX J0852.0-46.22 to 100 TeV without a steepening of its spectrum. We therefore plan to pursue this analysis and to search separately in all five years data and then combine the results, possibly using a more sensitive unbinned search. We will use a detailed simulation of γ-ray and cosmic ray showers appropriate for the declination of this source which corresponds to a zenith angle of 43.8^o.

Acknowledgments

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References

[1] J.E. Dickinson et al. The SPASE Collaboration Nuclear Instruments & Methods A 440:95 (2000)
[2] F. Aharonian, et al. HESS Collaboration, A&A 437, L7-L10 (2005)
[3] F. Aharonian, et al. HESS Collaboration, A&A 435, L17-L20 (2005)
[4] F. Aharonian, et al. HESS Collaboration, A&A 439, 1013-1021 (2005)
[5] D. Heck et al., Report FZKA-6019, Forschungszentrum Karlsruhe
[6] R.S. Fletcher et al., Phys. Rev. D50, 5710 (1994); R. Engel et al., in Proc. 26th Cosmic Ray Conference, Salt Lake City, **1**, 415 (1999)
[7] D.E. Nagle, T.K. Gaisser & R.J. Protheroe, Ann.Rev.Nucl.Part.Sci. 38, 609-657 (1988)