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Discovery of VHE Gamma Rays from PKS 2005−489

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The high-frequency peaked BL Lac PKS 2005−489 (z=0.071) was observed in 2003 and 2004 with the H.E.S.S. stereoscopic array of imaging atmospheric-Cherenkov telescopes in Namibia. A signal was detected at the 6.7σ level in the 2004 observations (24.2 hrs live time), but not in the 2003 data set (27.3 hrs live time). The integral flux above 200 GeV observed in 2004 is (6.9$\pm 1.0_{stat} \pm 1.4_{syst}$) $\times 10^{-12}$ cm^{-2} s^{-1}, corresponding to ∼2.5% of the flux observed from the Crab Nebula. The 99% upper limit on the flux in 2003, I(>200 GeV) $<$ 5.2 $\times 10^{-12}$ cm^{-2} s^{-1}, is smaller than the flux measured in 2004, suggesting an increased level of activity in 2004. However, the data show no evidence for significant variability on any time scale less than a year. An energy spectrum is measured and is characterized by a very soft power law (photon index of $\Gamma = 4.0 \pm 0.4_{stat}$).

1. Introduction

The relatively nearby (z=0.071), high-frequency peaked, BL Lac PKS 2005−489 was initially discovered as a bright (>0.5 Jy) radio source at 2.7 GHz [18]. It has been the target of several multi-wavelength observation campaigns and is well studied from the radio to the X-ray regime. Marginal detections of PKS 2005−489 at energies greater than 100 MeV [11] and in the GeV regime [10] have also been reported. Based on its SED and its proximity, several publications ([6]; [13]; [16]) have described PKS 2005−489 as a promising candidate for detection as a VHE (>100 GeV) emitter. However, past VHE observations made by CANGAROO (1993-94 [14], 1997 [15], and 1999-2000 [12]) and the University of Durham group (1996-99 [5]) have only yielded upper limits. As upper limits are of limited value for interpreting an SED, the discovery of VHE γ-rays from PKS 2005−489 [3] by H.E.S.S. yields considerable insight into the understanding of this object and VHE AGN in general.

2. H.E.S.S. Observations

The High Energy Stereoscopic System (H.E.S.S.) experiment is used to search for astrophysical γ-ray emission above ∼100 GeV with unprecedented sensitivity (5σ in 25 hours for a 1% Crab Nebula flux source at 20° zenith angle). Located in the Khomas Highlands of Namibia (23° 16’ 18” S, 16° 30’ 1” E, 1800 m above sea level), the detector is an array of four imaging atmospheric-Cherenkov telescopes (diameter 13 m, focal length 15 m, mirror area 107 m^2) in a square of 120 m side. Each telescope is equipped with a camera that provides a 5° field of view (f.o.v.) and contains 960 individual photomultiplier pixels, subtending 0.16° each, with Winston cone light concentrators. A central trigger system [8] is used to require a minimum of two camera images of the Cherenkov light from the same extensive air shower. More details on H.E.S.S. can be found in [4], [9], and [17].

The observations of PKS 2005−489 in 2003 were made prior to the completion of H.E.S.S. Therefore the data were obtained using different instrument configurations. Most observations in 2003 were made using a two-telescope array, with the exception of a small amount of data taken after the addition of the third telescope to the array in September 2003. Another variation arises because the H.E.S.S. central trigger system was installed in July 2003. Before this time two-telescope data were taken with each telescope separately, and the stereo multiplicity requirement was performed off-line (“Offline Stereo”) using GPS time stamps. After the installation of the central trigger system, the stereo multiplicity requirement was imposed in the hardware ("Online Stereo"). As the central trigger system reduced the recording rate considerably, the camera trigger threshold could be lowered (increasing the rates). This resulted in a lower energy threshold, while maintaining a reduced system dead time. All observations made in 2004 use the full four-telescopearray.

Table 1 gives details of the observations of PKS 2005−489 by H.E.S.S. passing quality selection. These criteria remove data for which the weather conditions were poor or the hardware was not functioning properly. The data were taken in 28 minute runs using *Wobble* mode, i.e. the source direction is positioned $\pm 0.5^\circ$ relative to the center of the f.o.v. of the camera during observations, which allows for both on-source observations and simultaneous estimation of the background induced by charged cosmic rays. The calibration of the data is described in [1], and the analysis techniques (image cleaning, geometrical reconstruction, background reduction, background estimation, and spectrum determination) used are described in [2] and [3].

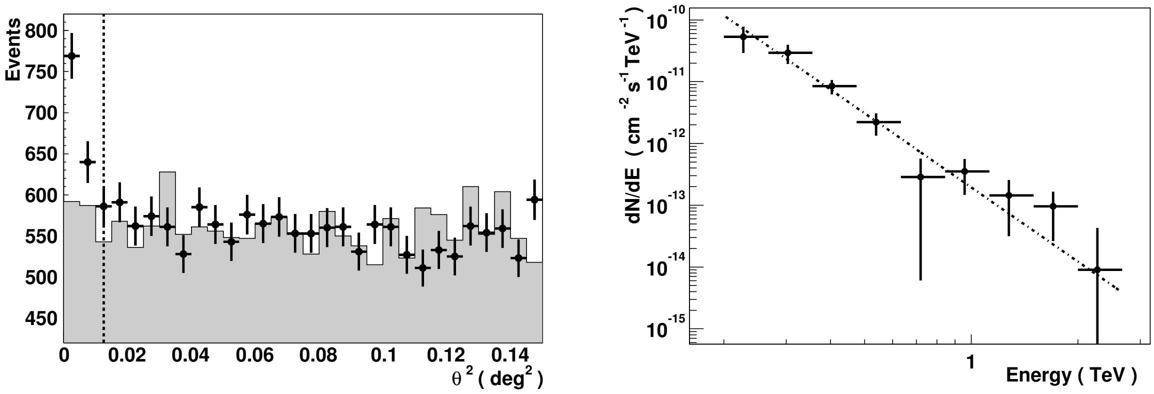
Table 1. Shown are the configurations of H.E.S.S. with which PKS 2005−489 was observed, the number of observation runs, the dead time corrected observation time, the mean zenith angle of the observations (Z_{obs}), the post-cuts energy threshold at Z_{obs}, the observed excess from PKS 2005−489, and the significance of the excess.

Dark Periods	Configuration	$N_{\rm tel}$	$N_{\rm runs}$	Obs. Time [hrs]	$Z_{\rm obs}$ [°]	$E_{\rm th}$ [GeV]	Excess	Sig. [σ]
6/2003	Offline Stereo	2	22	7.9	28	340	10	0.7
7 & 8/2003	Online Stereo	2	43	18.6	29	250	39	1.5
9/2003	Online Stereo	3	2	0.8	26	240	-4	-0.5
6, 7, 9 & 10/2004	Online Stereo	4	57	24.2	38	300	288	6.7
Total								6.3

3. Results

The results of the H.E.S.S. observations for each of the detector configurations are shown in Table 1. A significant excess (6.7σ) of events is detected from the direction of PKS 2005−489 in 2004, but not in 2003 (1.4σ). The total significance of the excess for all observations is 6.3σ. The distributions of θ^2, the square of the angular difference between the reconstructed shower position and the source position, for all observations in 2004 is shown in Figure 1 for the on-source (i.e. the area centered on the source location) and normalized off-source regions. The background is flat in θ^2 as expected, and there is a clear excess at small values of θ^2 corresponding to the observed signal. A two-dimensional fit of the excess observed finds the shape to be characteristic of a point source, located (J2000) at (α=$20^{\rm h}9^{\rm m}29.3^{\rm s}\pm2.7^{\rm s}_{stat}\pm1.3^{\rm s}_{syst}$, δ=$-48^\circ49'19''\pm36''_{stat}\pm20''_{syst}$). The excess, named HESS J2009−488, is consistent with the position of the blazar (α=$20^{\rm h}9^{\rm m}25.4^{\rm s}$, δ=$-48^\circ49'53.7''$) as expected, and is therefore assumed to be associated with PKS 2005−489.

Figure 1 shows the observed energy spectrum for the 2004 data set along with the best χ^2 fit of a power law ($dN/dE \sim E^{-\Gamma}$) to these data. The fit has a good χ^2 (5.6 for 7 degrees of freedom), and yields a photon index of Γ=4.0$\pm0.4_{stat}$. The systematic error on the photon index is small compared to the statistical error. Although each of the five highest energy points (E $>$ 0.64 TeV) in Figure 1 have statistical significance less than 2σ, removing these points from the fit does not change Γ significantly. Further, the use of alternative background estimation techniques and/or independent analysis chains yields consistent results. The observed energy spectrum shows no evidence for significant features, such as a cutoff, break or curvature.



(a) **(b)**

Figure 1. **(a)** The distribution of θ^2 for on-source events (points) and normalized off-source events (shaded) from observations of PKS 2005−489 in 2004. The dashed line represents the cut on $\theta^2 < 0.125$ applied to the data. **(b)** The energy spectrum of the excess named HESS J2009−488. The dashed line represents the best χ^2 fit of a power law.

Assuming the measured photon index of Γ=4.0, the integral flux above 200 GeV measured in 2004 is I(>200 GeV) = (6.9$\pm 1.0_{stat} \pm 1.4_{syst}$) × 10^{-12} cm^{-2} s^{-1}. This corresponds to ∼2.5% of I(>200 GeV) determined by H.E.S.S. from the Crab Nebula. The 99% confidence limit [7] on the flux, I(>200 GeV) $<$ 5.2× 10^{-12} cm^{-2} s^{-1}, in 2003 is slightly less than the flux in 2004 suggesting that PKS 2005−489 was in a higher state during the 2004 observations. The flux upper limit in 2003 and the flux in 2004 are well below all previously published upper limits for this object.

Although the overall statistics are low, a search for VHE flux variability within 2003 or 2004 was performed. No short time scale variability is found, as all fits to the integral flux versus time on time scales of less than a year are consistent with being constant. This is the case whether the data are binned by dark period (months) within each year, by nights within each dark period or or runs (∼30 min) within individual nights. The χ^2 probability, P(χ^2), for the monthly fit is 0.57 in 2003 and 0.98 in 2004. For each of the four dark periods in 2003 and 2004, the nightly flux fits have P(χ^2)$>$ 0.2 and 0.6, respectively. The run-by-run flux fits have P(χ^2)$>$ 0.05 and 0.1 for all nights in 2003 (mean P(χ^2) = 0.45) and 2004 (mean P(χ^2) = 0.53), respectively.

4. Conclusions

PKS 2005−489 has been detected by H.E.S.S. at energies greater than 200 GeV in 2004. It is the first AGN independently discovered by H.E.S.S. as an emitter of VHE photons. The measured VHE flux is quite low (∼2.5% of the Crab Nebula flux) and the observed VHE spectrum is the softest (Γ=4.0) ever measured from a BL Lac. Given the proximity (z=0.071) of PKS 2005−489, the softness cannot be explained completely by the absorption of VHE photons on the extragalactic background light (for a wide range of EBL fluxes); therefore, it is most likely intrinsic to the blazar. A multi-wavelength observation campaign (including optical, X-ray, and VHE energies) performed in October 2004 will provide information on the overall shape of the spectral energy distribution in that epoch. Analysis of these data is ongoing.

No evidence supporting variability of the observed VHE flux from PKS 2005−489 on time scales of less than a year is found. However, the upper limit resulting from the lack of a detection in 2003 suggests that the flux from PKS 2005−489 was lower than in 2004. This inference is supported by the behavior of this blazar in the X-ray regime. Quick-look results provided by the ASM/RXTE team show the average count rate from PKS 2005−489 was a factor of ∼3 higher in 2004 (0.116±0.025 s^{-1}) than in 2003 (0.039±0.026 s^{-1}). Interestingly, the average ASM count rate in 1998 (0.39±0.02 s^{-1}) is considerably higher than that in 2004, suggesting that PKS 2005−489 was in a low state during the H.E.S.S. observations. Should the VHE flux increase comparably to the historical (1998 vs 2004) X-ray count rate, a significant signal will quickly accumulate (∼1 hour) in H.E.S.S. observations allowing for more detailed studies of the VHE behavior to be performed.

Due to its low flux and soft spectrum, PKS 2005−489 was not detectable by previous generations of VHE instruments. This demonstrates the ability of H.E.S.S. to detect faint soft-spectrum sources of VHE gamma-rays, such as AGN.

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