Observations of 54 Active Galactic Nuclei with the HEGRA Cherenkov Telescopes

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Abstract

In total 54 Active Galactic Nuclei (AGN) apart from Mrk-421 and Mrk-501 have been observed between 1996 and 2002 with the HEGRA Cherenkov Telescopes in the TeV energy regime. Among the observed 54 AGN are the meanwhile well established BL Lac type objects H 1426+428 and 1ES 1959+650. The BL Lac object 1ES 2344+514 and the radio galaxy M 87 show evidence for a signal on a $4\,\sigma$ level. Fluxes resp. upper limits are given for each of the 54 AGN.

1. Introduction

In the commonly adopted view AGN are powered by a central super massive black hole with $\sim 10^9\,\mathrm{M}_\odot$ surrounded by an accretion disk. Two relativistic plasma outflows (jets) perpendicular to the accretion disk are pointing in opposite directions away from the center black hole [1]. Most detections of extragalactic TeV γ–rays refer to objects of the BL Lac type, i.e. AGN having their jet pointing close to the observers line of sight. In this work the results of an analysis of the observations of 54 AGN with the HEGRA telescope system are presented. The HEGRA collaboration was operating a stereoscopic system of imaging air Cherenkov telescopes (IACT-System) [2] and one stand alone telescope [3] (not used for the present analysis) on the Canary island of La Palma (28.75° N, 17.90° W) at an altitude of 2200 m a.s.l. The stereoscopic reconstruction technique first introduced by HEGRA allows the complete reconstruction of the shower geometry and results in improved angular and energy resolutions as well as a very good γ-hadron separation (hadron rejection up to a factor of 100) using the so called mean scaled width (mscw) parameter. The data set used for this work amounts to a total exposure time before rejection of runs with poor quality of ≈ 1150 hours (without Mkn–421 and Mkn-501) corresponding to more than one year of continuous observations in moonless nights with the HEGRA IACT-System. After quality cuts, 1017 hours remain in the analysis. The applied event cuts are optimized on data of the Crab Nebula which is used as a calibration source in TeV astronomy. The significance of an excess is calculated following [4].

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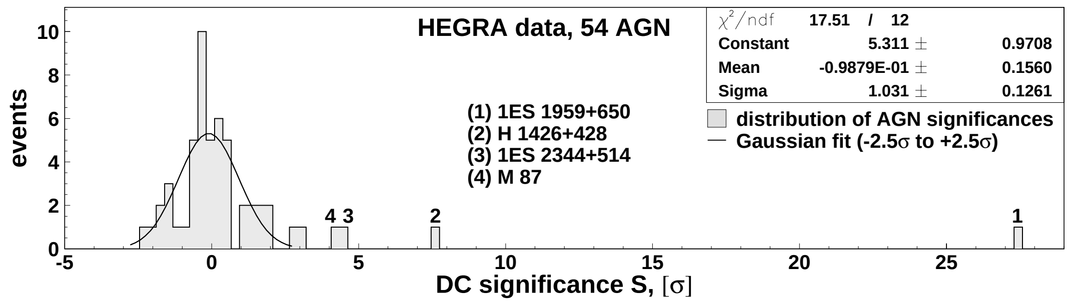

Fig. 1. Distribution of significances for all AGN analyzed in this work. The objects 1ES 1959+650 (1) and H 1426+428 (2) show a clear deviation from the background expectation, represented by a Gaussian fit from -2.5 σ to 2.5 σ. Further two objects, 1ES 2344+514 (4.4 σ, (3)) and M 87 (4.1 σ, (4)) also show a deviation from the background expectation and thus for emission of TeV γ-radiation.

Observed Crab-γ–rates are used to compute integral flux upper limits [5].

2. Results

A distribution of the significances for steady state emission (DC) of all analyzed objects is shown in Fig. 1. The objects 1ES 1959+650, H 1426+428, 1ES 2344+514 and M 87 show significances deviating from the expectation of a Gaussian distribution in case of pure background fluctuations. In Tab. 1 a list of all objects analyzed in this work ordered by ascending redshift is shown along with their observation time and the results of this analysis. The results of the observations of the BL Lac objects 1ES 1959+650 and H 1426+428 as well as a tentative detection of a signature of absorption by pair production on the diffuse extragalactic background radiation in the TeV spectrum of H 1426+428 were reported elsewhere [6, 7]. The results of a dedicated analysis of the M87 data are presented separately at this conference and have been published recently [8, 9]. The first TeV detection of 1ES 2344+514 was reported by the Whipple group in 1998 with 6 σ in one night only [10]. The results of the HEGRA observations of 1ES 2344+514 of the year 1997 and 1998 were first reported by [11] with a DC significance of 3.3 σ. The analysis presented here includes the complete dataset (1997 – 2002) and results in an excess of 63 ± 14 γ–like excess events ($N_{on} = 235$, $\langle N_{off} \rangle = 171$) on a significance level of 4.4 σ and no evidence for burst-like behaviour. However, the excess is accumulated almost exclusively in the observation periods of August to November 1998 and September 2002 (61 ± 12 excess events). In Fig. 2. the distribution of the squared angular distance of the reconstructed shower events to the object position as well as a plot of the excess rate vs. observation periods are shown. The observed excess results in a flux of Φ(E>0.80 TeV) $= (0.8 \pm 0.3) \cdot 10^{-12}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ corresponding to 3.3% of the Crab-Nebula flux.

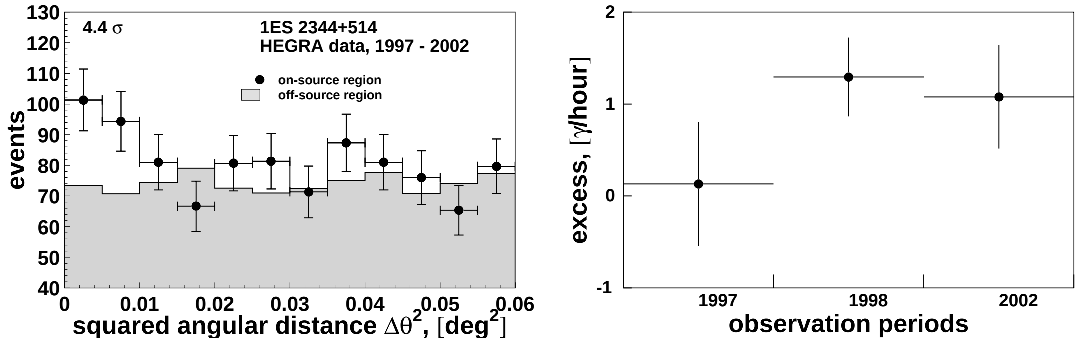

Fig. 2. Left: Distribution of reconstructed squared angular distances of the 1ES 2344+514 data. The distribution of the on–source events is represented by the data points. The background is shown as a shaded histogram. Right: The excess rate in γ/hour for the three observation campaigns on 1ES 2344+514. The excess is accumulated almost exclusively in 1998 and 2002.

3. Summary

The two objects 1ES 1959+650 and H 1426+428 can be considered as well established sources of TeV γ-radiation. The evidence for 1ES 2344+514 being a TeV source is strong taking the detection by the Whipple collaboration into account. The detection of TeV γ–rays from M87, if confirmed, would be the first detection of photons in the TeV energy regime of an AGN not classified as a BL Lac object.

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Table 1. Results of all objects of the HEGRA AGN data sample. The object names are given as well as observation time, number of ON- and OFF-events, energy threshold, upper limits in Crab units and in flux units and fluxes in Crab units.

Object	z	time [h]	N_{on} #	N_{off} #	E_{thr} [TeV]	$F^{99\%}_{UL}(> E_{thr})$ [*Crab*]	$\Phi^{99\%}_{UL}(> E_{thr})$ $[10^{-12}cm^{-2}s^{-1}]$	$F(> E_{thr})$ [*Crab*]
1ES 0647+250	—-	4.1	12	10	0.74	0.13	3.65	
MG 0509+0541	—-	15.8	60	50	0.79	0.11	2.61	
M87	.004	70.0	241	184	0.76			0.033
NGC 315	.016	14.6	31	33	0.75	0.05	1.29	
NGC 1275	.018	87.6	231	236	0.75	0.03	0.84	
H 1722+119	.018	5.1	21	14	0.76	0.21	5.51	
PKS 2201+04	.028	17.8	59	46	0.79	0.08	1.89	
V Zw 331	.029	4.1	9	9	0.75	0.09	2.44	
NGC1054	.032	57.9	134	155	0.75	0.02	0.46	
3C 120	.033	25.4	64	70	0.78	0.05	1.14	
NGC 4151	.033	7.0	16	18	0.74	0.07	1.99	
UGC01651	.037	14.3	44	36	0.74	0.07	1.79	
UGC03927	.041	6.3	7	16	0.86	0.09	1.93	
1ES 2344+514	.044	72.5	235	171	0.80			0.033
Mkn0180	.046	9.8	29	32	1.38	0.12	1.24	
1ES 1959+650	.047	163.7	1202	454	1.17			0.053-2.200
3C 371.0	.050	5.4	16	18	1.40	0.19	1.88	
B2 0402+37	.054	6.7	9	17	0.74	0.05	1.32	
I Zw 187	.055	16.0	44	32	0.78	0.09	2.21	
Cyg-A (3C 405.0)	.057	59.0	159	161	0.77	0.03	0.83	
1ES 2321+419	.059	22.3	53	66	0.76	0.03	0.86	
3C 192.0	.060	2.9	8	7	0.78	0.20	5.01	
4C+31.04	.060	3.0	8	9	0.74	0.14	4.01	
BL Lacertae	.069	26.7	94	67	0.87	0.28	5.97	
1ES 1741+196	.083	10.2	28	26	0.78	0.07	1.88	
4C+01.13	.084	7.7	30	31	0.81	0.10	2.45	
PKS 2155-304	.116	1.8	4	4	4.62	0.27	0.39	
1ES 1118+424	.124	2.0	5	4	0.79	0.24	5.88	
1ES 0145+13.8	.125	3.2	2	1	0.75	0.06	1.73	
EXO0706.1+5913	.125	33.7	81	85	0.86	0.06	1.32	
H 1426+428	.129	258.5	796	624	0.77			0.024-0.060
3C197.1	.130	15.0	22	24	0.79	0.05	1.17	
1ES 1212+078	.130	2.4	6	8	0.78	0.17	4.26	
1ES 0806+524	.138	1.0	2	2	0.86	0.29	6.19	
1ES 0229+200	.139	3.0	11	8	0.78	0.17	4.25	
RBS 0958	.139	3.8	18	9	0.75	0.28	7.57	
1ES 1255+244	.140	5.9	14	14	0.79	0.12	2.88	
MS1019.0+5139	.141	17.5	44	43	0.78	0.07	1.78	
1ES 0323+022	.147	14.3	24	32	0.81	0.04	1.00	
OQ 530	.152	9.4	32	30	0.89	0.10	2.05	
3C 273.0	.158	12.2	44	46	0.91	0.09	1.82	
1ES 1440+122	.162	13.1	35	41	0.77	0.08	1.95	
PKS 0829+046	.180	18.0	59	55	0.81	0.06	1.35	
PG 1218+304	.182	3.9	7	8	0.75	0.12	3.22	
1ES 0347-121	.185	1.9	13	7	1.34	0.56	5.90	
1ES 0927+500	.186	13.3	30	29	0.79	0.06	1.44	
PKS 2254+074	.190	16.3	44	48	0.77	0.05	1.27	
MS0317.0+1834	.190	2.7	5	6	0.74	0.12	3.30	
1ES 1011+496	.200	2.0	1	3	0.81	0.11	2.58	
1ES 0120+340	.272	18.9	36	44	0.75	0.04	1.03	
2E 0414+0057	.287	4.5	18	15	0.81	0.13	3.07	
S5 0716+714	.300	1.7	6	4	1.46	0.38	3.54	
3C 066A	.444	1.3	3	3	0.75	0.17	4.70	
PKS 0219-164	.698	1.7	5	10	1.67	0.27	2.04	