DETECTION OF 5 TEV PHOTONS FROM MRK 421

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The observation of very high energy γ-ray emission of blazars at multi-TeV energies places severe constraints on the production mechanism at the source. In addition, current limits on the infrared extragalactic background radiation can be improved if ground-based γ-ray observations are extended to higher energies ($E \geq$ 5TeV). Here we highlight experimental results regarding the high energy emission from Mrk 421 using a new method, the so-called large zenith-angle technique. We report the detection of γ-ray emission with energies of 5 TeV from Mrk 421.

1 Introduction

The first detection of 500 GeV γ-rays from Mrk 421 by the Whipple Observatory collaboration[11] and the report of an energy spectrum[10] has caused interest for two different reasons: to study the emission process at the source and to probe the interaction of γ-rays with the intergalactic medium. AGN Models in which the production of γ-rays involve inverse Compton scattering of low frequency "seed" photons from high energy electrons in the inner region of a relativistic jet have problems to explain TeV-emission. Some of these AGN models predict a cut-off to the spectrum of some AGNs (3C279) in the range 10 - 100 GeV (Sikora, Begelman & Rees[12]), however in case of Mrk 421 a cutoff in the multi-TeV region is expected. Other models such as the proton-blazar model[8] do predict γ-ray emission well beyond the 10 TeV-regime. It is therefore important to extend ground-based γ-ray observations to higher energies. Observations of TeV γ-ray emission from Mrk 421 can be used to derive constraints on the density of intergalactic starlight. The physical process is: $\gamma\gamma \rightarrow e^+e^-$, the absorption of the high energy radiation through pair production off optical or near infrared photons[5]. Previous observations[10] have been used by a number of authors to derive upper limits on the IR photon density. By making a conservative assumption that appreciable absorption was already taking place at the lowest energies covered by the Whipple Observatory measurements at 400 GeV[10], Biller et al. (1995[1]) derived an upper limit. De Jager, Stecker, & Salamon (1994[3]) in contrast derived a much lower value for the starlight density by integrating a preliminary Whipple Observatory differential spectrum[10]. Those authors[3] made the assumption that absorption was taking place external to the object itself. However, the statistics of the spectrum[10] of Mrk 421 above 1.5 TeV (3.3σ) is limited.

The duty cycle ($\leq$10%) of imaging atmospheric Čerenkov telescopes and the restricted collection area of $\approx 40,000 m^2$ limits the sensitivity for energies above 1 TeV. In this paper we review observational results[7] by the Whipple Observatory collaboration which employ the so-called large-zenith angle technique. This technique increases the sensitivity of Whipple 10m telescope above $\approx$1 TeV and will be discussed in §2. The observations are presented in §3 and summarized in §4.

2 The large-zenith angle technique

Observations reported here utilize the imaging atmospheric Čerenkov technique[14], but with a significant difference from previous observations: the data reported here are taken at large zenith angles. Air showers developing at large zenith angles have their shower maximum further away from the detector and therefore, the Čerenkov light is spread out over a larger area at ground level. Consequently, the detector collection area increases and, as a result, large-zenith angle observations have increased statistics at higher energies. Since the Čerenkov photon density at observation level decreases with increasing zenith angle, the energy threshold increases. This causes the energy region covered by the observations to shift to significantly higher energies relative to standard small-zenith angle observations (figure 1).

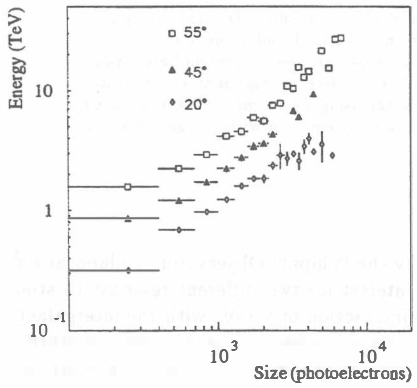

Figure 1. The average energy of γ-ray showers as a function of the total measured light (Size (p.e.)) at different zenith angles (20°, 45° and 55°).

Figure 1 shows the correlation between the average number of photoelectrons (Size = total number of digital counts (d.c.) of an individual Čerenkov image, 1 d.c. = 1 photoelectron (p.e.)) of Čerenkov images from simulated γ-ray showers and their average primary energy at three different zenith angles. It can be seen that the energy coverage of the imaging atmospheric Čerenkov technique can be extended significantly (300 GeV - 30 TeV) by combining small zenith-angle with large-zenith angle observations. The energy threshold at different zenith angles has been derived from Monte Carlo simulations.

The energy threshold is defined so that more than 90% of the events which pass a corresponding Size cut do have energies above that energy threshold. This definition ensures that less than 10% of the events are below the stated energy threshold. This definition actually quotes a threshold 30% lower than using the standard definition[15] which corresponds to the energy where the rate has its maximum. The systematic uncertainty of the energy threshold is about 30% and is generally related to the absolute calibration of imaging atmospheric Čerenkov telescopes. The increase in collection area has been determined by Monte Carlo simulations and has been tested with observations of the Crab Nebula[7]. In the 55°-60° zenith angle region the collection area is increased by a factor of 4.2±1.2.

The analysis to suppress the hadronic background developed for images of Čerenkov light flashes[13] from air showers is based on the differences between γ-ray showers and hadronic showers in their lateral and longitudinal structure. For point sources the geometrical orientation of the major axis of the elliptical Čerenkov image can be used as an additional selection criterion usually referred as α-analysis[13]. The same technique can be used for large zenith angle observations with modified selection criteria. The main difference of showers that develop at large-zenith angles is that they are geometrically further away from the detector resulting in narrower images. Monte Carlo simulations have been used to develop efficient cuts as described in Krennrich et al. 1997[7].

3 Observations and Results

We report here observations of Mrk 421 at large zenith angles carried out during 11 nights between June 18 and July 1 1995. The data consists of 17 ON/OFF pairs covering the zenith angle region between 45° and 60°. The data show an excess of 481 events with a significance of 14.3σ. The daily rate variations are shown in figure 2.

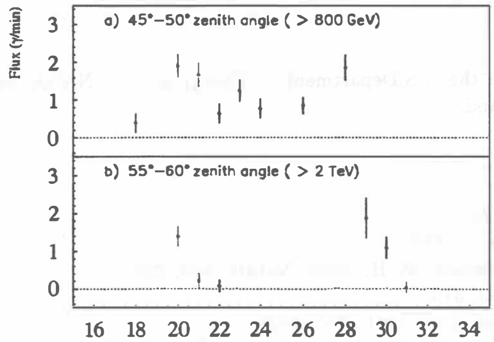

Figure 2. The daily γ-ray rate between 18 June and 1 July 1995 at 2 different zenith angle regions.

The data has been binned into two different zenith angle intervals: 45° - 50° and 55° - 60° zenith angles with a corresponding estimated energy threshold of 800 GeV and 2 TeV. Figure 2b) showing two flares within 11 days demonstrates the potential of large zenith angle observations to study day scale flux variations at energies E$\geq$ 2TeV. In order to study the spectrum of Mrk 421 at energies E$\geq$ 5 TeV, we have used the combined data of 112 minutes from the 2 flares on June 20, 21 and June 28 to search for γ-ray emission at multi-TeV energies.

Data taken at 45° - 50° and 55° - 60° has been analyzed at different energy thresholds (2 TeV, 4 TeV, 5 TeV and 8 TeV). Figure 3. showing the α-distribution (orientation angle of image relative to the γ-ray source) for events with energies E$\geq$ 5 TeV exhibits an excess of 25 events with a significance of 5σ. The numbers at different energy threshold are consistent with a powerlaw spectrum and no evidence for a cutoff is present in the data.

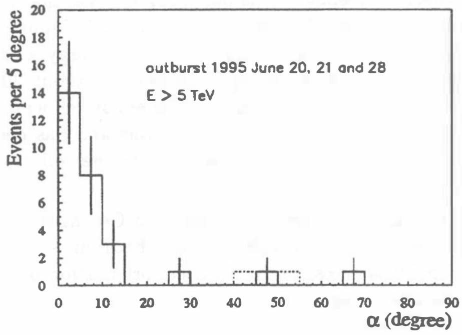

Figure 3. The α-distribution of 112 minutes of ON-source (solid line) and OFF-source (dashed line) observations for events having an estimated energy $E \geq 5$ TeV.

4 Conclusions

Gamma-ray emission of $E \geq 5$ TeV from Mrk 421 has been detected using the large-zenith angle technique and no evidence for a cutoff in the energy spectrum is present in the data. This result conflicts with the interpretation of a previously reported energy spectrum[10] by De Jager, Stecker, & Salamon (1994[3]), where the lack of statistics at 5 TeV has been attributed to a cutoff by extragalactic IR background radiation. It is important to realize that Mrk 421 is a highly variable source as could be seen just recently during the "big flare"[4] when the γ-ray rate increased up to 15 γ rays per minute. A burst in this regime detected at large zenith angles would extend the measurement of the energy spectrum up to 20 TeV and could constrain the intergalactic IR photon density and AGN models most severely.

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