Search for Cross-Correlation between HiRes stereo events and BL-Lacertae Objects

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Abstract: One of the leading candidate sources of ultrahigh energy cosmic rays (UHECR) are BL-Lacertae (BL-Lac) objects. These are thought to represent Active Galactic Nuclei (AGN) whose jets are aligned with the line-of-sight toward the Earth. Previous experiments have reported small cross-correlation signals with BL-Lac objects with nominal chance probabilities in the 10^{-3}-10^{-4} range. None of these results have been independently confirmed. At the 29th ICRC, the HiRes experiments has also presented an excess of events correlated with BL and HP objects in the Veron Catalog. This result was based on HiRes events with energies in excess of 10^{19} eV, observed before February, 2004, and has been subsequently published in the Astrophysical Journal. The dataset taken after February, 2004, which were not included in the previous study, will provide an independent test of the hypothesis.

Introduction

The High Resolution Fly's Eye (HiRes) Experiment was a fluorescence ultrahigh energy cosmic ray (UHECR) observatory that operated between 1997 and 2006. The HiRes-1 site began monocular observations in 1997. Stereo data was collected after November, 1999.

While monocular data from HiRes-1 and -2 have the advantages of larger exposure and lower energy threshold, respectively, the stereo reconstruction provides a much more accurate determination of the shower trajectory. This leads to better energy and shower maximum depth (X_{max} resolutions. In particular, the stereo dataset also has far superior resolution of air shower arrival directions. Simulation studies have shown that 68% of stereo events above 10^{19} eV are reconstructed within $0.6°$ of their simulated *true* arrival direction (Figure 1). Moreover, using star surveys and reconstruction of Rayleigh-scattered laser light, we estimate systematic uncertainties to be less than $0.6°$, with the dominant contribution coming from uncertainties in mirror pointing directions.

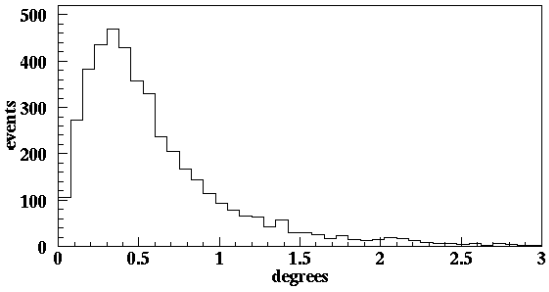

Figure 1: Magnitude of difference between true and reconstructed arrival direction for simulated HiRes stereo events above 10^{19} eV.

The sky-maps for the HiRes stereo data set, taken before Feb. 2005, are shown in Figure 2.

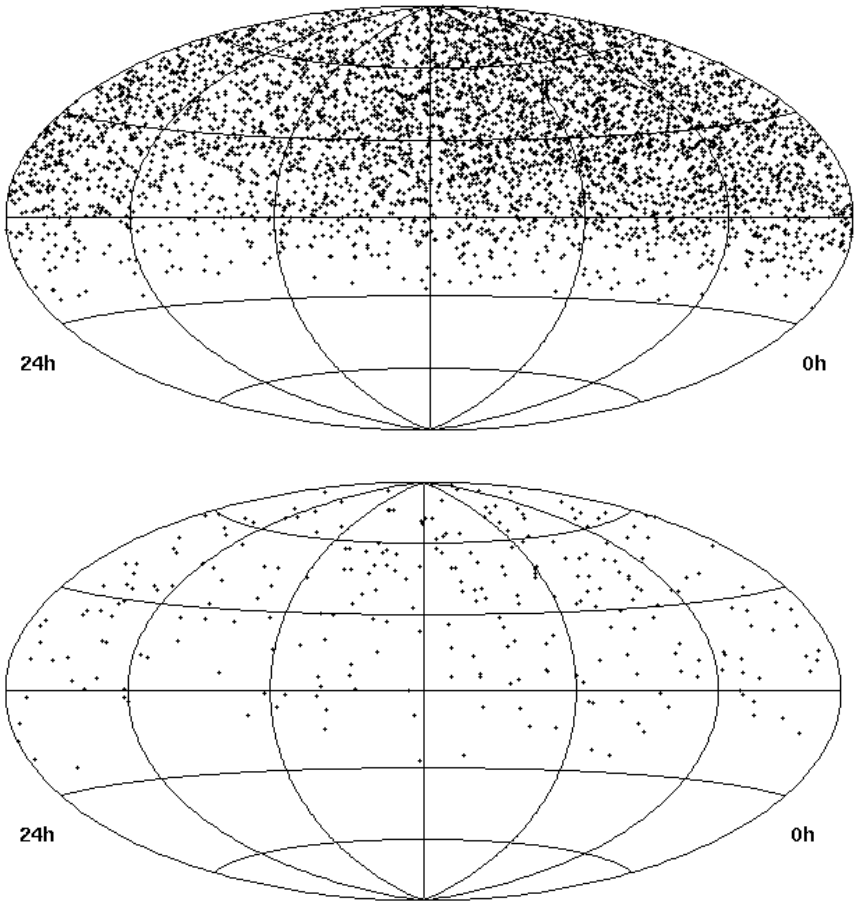

Figure 2: *Top:* The sky-map for the HiRes stereo data set, including air showers of all energies above $10^{18.2}$ eV collected between December 1999 and January 2004 (4495 events). *Bottom:* The sky-map for the HiRes stereo data set, including air showers of energies above 10^{19} eV (271 events).

Correlations with BL-Lac Objects

BL Lacertae objects are thought to be a special subclass of blazars, in which the jet axis of the active galaxy is parallel with our line of sight. Blazars are an established source of TeV γ-rays, which may be produced in the acceleration of UHECR. Recently, a series of reports have claimed evidence for correlations between UHECR and BL-Lac objects [1, 2, 3, 4, 5, 6, 7].

Table 1 lists the results of BL-Lac correlation searches made against UHECR data from the AGASA and Yakutsk arrays. While these searches reported apparently low chance probability of arising from isotropic background, an identical analysis performed with the HiRes stereo data shows no significant correlation above background expectations.

More recently, Gorbunov *et al.* [6] have made a similar search with the HiRes stereo data (taken before Feb., 2004) above 10^{19} eV (Figure 2). Using all BL-Lacs with magnitude $m < 18$ in the 10th Veron Catalog [10] (156 objects) and an optimized bin size of $0.8°$, they found 10 correlated BL-Lac cosmic ray pairs, with a reported chance probability of 0.001.

Table 1: BL Lac Correlation: Testing Previous Claims with HiRes Stereo

Mag.	z	6 cm Flux	Obj	Sample	CRs	Bin	Pairs	Prob.
$m < 18$	> 0.1 or unknown Source: Ref. [8]	> 0.17 Jy	22	AGASA > 48 EeV Yakutsk > 24 EeV	65	$2.5°$	8	$< 10^{-4}$
				HiRes > 24 EeV	66	$2.5°$	0	1.00
no cut	no cut Source: Ref [9]	no cut	14	AGASA > 48 EeV Yakutsk > 24 EeV	65	$2.9°$	8	$< 10^{-4}$
				HiRes > 24 EeV	66	$2.9°$	1	0.70
$m < 18$	no cut Source: Ref [10]	no cut	156	AGASA > 40 EeV	57	$2.5°$	12	0.02
				HiRes > 40 EeV	27	$2.5°$	2	0.78

AGASA and Yakutsk correlation analyses carried out in References [1, 2, 3]. HiRes analysis carried out by the HiRes collaboration [11].

The HiRes group subsequently carried out an unbinned, maximum-likelihood analysis. This same technique was used in a previous HiRes publication [12], modified for a multiple-source hypothesis [11]. Our result indicates an excess of $n_s = 8.0$ events correlating with BL Lacs. Only 2×10^{-4} of isotropic Monte Carlo data sets score a stronger signal.

This chance probability, however, does not take into consideration any tuning in the selection of the BL-Lac sample used to make the search. The apparent correlation therefore constittues a new claim that needs to be tested against an independent data set. Since Feb., 2004, the HiRes experiment has accumulated additional data equivalent in exposure to 70that of the data used in the previous report [11]. The analysis of this additional, independent data set is in progress and will be reported in the near future.

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References

[1] Tinyakov and Tkachev, JETP **74** 445 (2001).
[2] Tinyakov and Tkachev, Astropart. Phys. **18** 165 (2002).
[3] Gorbunov *et al.*, ApJ **577**, L93 (2002).
[4] Evans, Ferrer and Sarkar, Phys. Rev. **D67** 103005 (2003).
[5] Torres *et al.*, ApJ **595** L13 (2003).
[6] Gorbunov *et al.*, JETP Lett **80** 145 (2004).
[7] Stern and Poutanen ApJ **623** L33 (2005).
[8] M. P. Véron-Cetty and P. Véron, ESO scientific report (2000).
[9] M. P. Véron-Cetty and P. Véron, Astron. Astrophys. **374** 92 (2001). BL Lacs correlated with EGRET sources were considered.
[10] *ibid.* All BL Lac objects were considered.
[11] R.U. Abbasi *et al.* ApJ **636**, 680 (2006).
[12] R.U. Abbasi *et al.*, ApJ **623**, 164 (2005).