Reply to "Comment on 'Hunting long-lived gluinos at the Pierre Auger Observatory'"

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(Received 14 April 2008; published 17 June 2008)

DOI: 10.1103/PhysRevD.77.128302 PACS numbers: 96.50.sd, 11.30.Pb, 13.85.Tp

In the closing paragraph of [1] we make a speculation connecting the peculiar characteristics of air showers initiated by hypothetical heavy gluinos and the cosmic ray exotic event "Centauro-I" [2]. This very speculative observation was not meant to be the main thrust of the paper.

The Centauro-I event was observed as a bundle of showers in the lower chamber of a two-story type emulsion chamber, which consisted of an upper chamber, a target layer, an air gap, and a lower chamber [3]. The bundle comprised a few tens of showers detected on x-ray films, with detection threshold of about 1 TeV and total energy much higher than events commonly observed in the lower chamber. Extrapolating the shower direction carefully to the upper chamber yielded no sign of a corresponding family of comparable or greater size. A bundle of showers of small total energy was found in the upper chamber, which had an incident direction similar to the shower cluster in the lower chamber, and was identified as the upper part of the showers in the lower chamber. The position of three showers in the respective bundles, found in the upper and lower chambers, were superposed on x-ray films within the possible errors. The upper part was composed of seven showers with detection threshold of 1 TeV. Since most of the showers in the lower chamber were originated by hadrons, the event was remarkably hadron rich. Analyses of the event showed that it was consistent with multiple production of particles without emission of electrons and photons. The event then was called "Centauro," because one could not imagine the upper body from inspection of the lower body. Subsequent to the initial Centauro observation, several other events with similar characteristics were recorded [4].

The energy lost by a gluino during collision with nucleons is primarily through hard scattering. This implies a fractional energy loss per collision $\sim 1\ \text{GeV}/M$, where M is the gluino mass [5]. The very low inelasticity of gluino-air interactions implies the leading particle retains most of its energy all the way to the ground, while the secondary particles promptly cascade to low energies as for any other air shower. This results in an ensemble of minishowers strung along the trajectory of the leading particle. Since the typical distance between minishowers is about 10 times smaller than the extent of a single longitudinal profile, it is not possible to resolve the individual showers experimentally. Instead one observes a smooth envelope encompassing all the minishowers, which extends from the first interaction all the way to the ground. Qualitatively speaking, low-energy gluino showers would be hadron rich since the electromagnetic component (of each minishower) is readily extinguished.

In [6] Kopenkin, Fujimoto, and Sinzi (KFS) criticize our association. Their criticism is based on a reanalysis of the experimental data carried out by KFS, which suggests that the original upper-lower correspondence is incorrect and that the observation in the lower chamber is most likely the result of a narrow family of showers, from a standard atmospheric interaction, that passed through the gap between the emulsion chamber units [7]. In [8] Ohsawa, Shibuya, and Tamada (OST) made a separate reanalysis of the data where they confirmed that the association could be in error. However, OST also quantified the probability for a narrow atmospheric family to pass through a gap in the upper chamber to be $0.5\text{–}3 \times 10^{-4}$. Given that the total sample of the Chacaltaya emulsion chamber experiment contains 156 events, the expected number of events passing through a nonsensitive region of the upper chamber is 0.008–0.04. Based on this, as well as other points raised in the reanalysis of the data [8], OST concluded that the Centauro-I event is indeed hadron rich.

In sum, while the hypothesis of KFS is compelling, numerical estimates indicate that is not sufficient to rule out possible exotic origins [9] of the Centauro-I event. Gluino-induced air showers could eventually constitute such a candidate.

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