

Signatures of air showers induced by gluinos within the context of split-SUSY

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It has been proposed recently that, within the framework of split Supersymmetry, long lived gluinos generated in astrophysical sources could be detected using the signatures of the air showers they produce, thus providing a lower bound for their lifetime and for the scale of SUSY breaking. We present the longitudinal profile and lateral spread of G -hadron induced extensive air showers and consider the possibility of measuring them with a detector with the characteristics of the Pierre Auger Observatory.

1. Introduction

A novel beyond-SM-model proposal to break the GZK barrier is to assume that ultrahigh energy cosmic rays are not known particles but a new species of particle, U [1]. The meager information we have about super-GZK particles allows a naïve description of the properties of the U . The muonic content in the atmospheric cascades suggests U 's should interact strongly. At the same time, if U 's are produced at cosmological distances, they must be stable, or at least remarkably long lived, with mean-lifetime $\tau \gtrsim 10^6 (m_U/3 \text{ GeV}) (d/\text{Gpc}) \text{ s}$, where d is the distance to the source and m_U , the uhecrion's mass. Additionally, since the threshold energy increases linearly with m_U , to avoid photo-pion production on the CMB $m_U \gtrsim 1.5 \text{ GeV}$. Within the Minimal Supersymmetric (MS) extension of the SM, the allowed range for gluino masses is $m_{\tilde{g}} \leq 3 \text{ GeV}$ and $25 \text{ GeV} \leq m_{\tilde{g}} \leq 35 \text{ GeV}$. In this direction, it was noted in [2] that light Supersymmetric baryons (made from a light gluino + the usual quarks and gluons, $m_U \lesssim 3 \text{ GeV}$) would produce atmospheric cascades very similar to those initiated by protons.

Recently, Arkani-Hamed and Dimopoulos [3] proposed an alternative to the MSSM in which the mass spectrum of the super-partners is split in two. In this theory, all the scalars, except for a fine tuned Higgs, get a mass at a high scale of supersymmetry breaking while the fermion's masses remain near the electroweak scale protected by chiral symmetry. Additionally, all corrections that involve loops of supersymmetric bosons are suppressed, thus removing most of the tunings required to reproduce $(g-2)_\mu$, $B - \bar{B}$ mixing and $b \rightarrow s\gamma$ [4]. At the same time it allows for radiative corrections to the Higgs mass.

An important feature of split SUSY is the long life of the gluino due to the high masses of the virtual scalars (m_s) that mediate the decay. Indeed, very strong limits on heavy isotope abundance require the gluino to decay on Gyr time scales, leading to an upper bound for the scale of SUSY breaking $\mathcal{O}(10^{13}) \text{ GeV}$. Additionally, it has been pointed out that the detection of gluinos coming from astrophysical sources (with $m_{\tilde{g}} \sim 500 \text{ GeV}$) leads to a lower bound on their proper lifetime of the order of 100 yr, which translates into a lower bound on the scale of SUSY breaking, $\mathcal{O}(10^{11}) \text{ GeV}$ [6]. Some bounds have been recently set on the mass on the gluino and the scale of SUSY breaking [7] leaving a window around $M_G = 500 \text{ GeV}$.

In light of this, it is of interest to explore the potential of forthcoming cosmic ray observatories to observe gluino-induced events. Some signatures of the air showers initiated by these long lived gluinos have been presented in [6, 8, 9]. In this Brief Report, we carry out a more detailed analysis by generating gluino air showers through Monte Carlo simulations and pave the ground for a future study on the actual feasibility of measuring them at the Pierre Auger Observatory [10]. The outline is as follows. In Sec. II we review the relevant aspects of cosmic ray air showers. In Sec. III we first carry out Monte Carlo simulations of gluino

induced showers and then show their distinct signatures in the air shower profile and lateral spread at ground level. Section IV contains a summary of our results.

2. Cosmic Ray Air Showers

When a high energy particle hits the atmosphere it generates a roughly conical cascade of secondary particles, an air shower. At any given time, the shower can be pictured as a bunch of particles, the shower front, traveling toward the ground at nearly the speed of light. The number of particles in the shower multiplies as the front traverses the atmosphere, until the particles' energy fall below a threshold at which ionization losses dominate over particle creation, after this point the number of particles decreases. By the time the front hits the ground, its shape is similar to that of a "saucer" with a radius that can range from a few meters to a few kilometers. The shape of the shower front is actually closer to that of a spherical shell, with a curvature of a few kilometers for almost vertical showers to more than a hundred kilometers for inclined ones. The number of particles as a function of amount of atmosphere traversed is the "longitudinal profile" of the shower.

The general properties of the longitudinal profile can be understood with a simple model and it usually can be parameterized by a Gaisser-Hillas function [11],

$$N_e(X) = N_{e,\max} \left(\frac{X - X_0}{X_{\max} - X_0} \right)^{\frac{X - X_{\max}}{\lambda}} e^{-\frac{X - X_{\max}}{\lambda}} \quad (1)$$

where $N_{e,\max}$ is the number of particles at shower maximum, X_0 is the depth of the first observed interaction, X_{\max} is the depth at the maximum, and $\lambda = 70 \text{ g/cm}^2$. The position of the maximum, X_{\max} , depends on the energy as well as on the nature of the primary particle. With cosmic ray showers however, there are fluctuations, associated mainly with the point where the primary first interacts, as well as statistical fluctuations in the development of the shower.

When the shower front reaches the ground it is spread over an area of up to a few kilometers. It is then possible to study the density of energy deposited (or particle densities), on the ground as a function of time and position. There are a number of parameterizations for such distributions but they are mostly modified power laws like the following [11]

$$S(r) = C \left(\frac{r}{r_M} \right)^{-\alpha} \left(1 + \frac{r}{r_M} \right)^{-\eta+\alpha} \quad (2)$$

where r is the distance to the point where the core hits the ground, r_M is the Moliere radius at two radiation lengths above the observation level, α is another empirical parameter and η is the free parameter that depends on the angle. The normalization constant C will depend on the energy.

3. Gluino air showers

To carry out this study we use AIRES, a set of programs specifically designed to simulate the extensive air showers generated by ultra high energy cosmic rays interacting with the atmosphere. The AIRES system is described elsewhere [13, 12] and takes into account the relevant interactions, including electromagnetic and hadronic interactions and transport processes. The hadronic model used is SIBYLL.

We use a feature of AIRES that allows for the definition of special primaries by providing a program that handles the first interactions of each primary until the main program (AIRES) can take over and simulate the rest of the shower until it strikes ground. To model the gluino induced showers we first determine where there

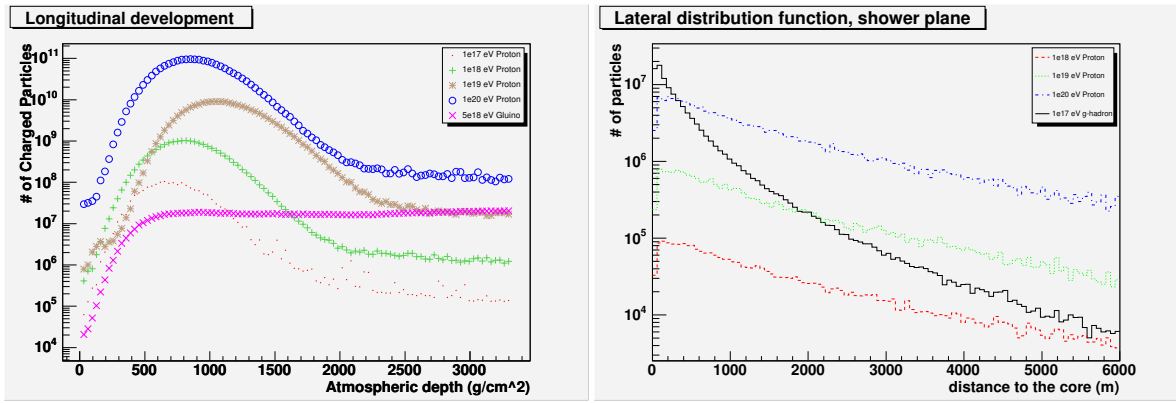


Figure 1. Longitudinal profile for protons at 1e17, 1e18, **Figure 2.** Lateral spread for 1e18, 1e19, 1e20 eV proton showers and 5e18 eV gluino showers.

will be a major interaction and then inject a proton with energy equal to the energy deposited by the gluon. We then force each proton to have its first interaction at its corresponding point, giving rise to a series of hadronic showers that are then simulated by the standard AIRES program.

The gluino containing hadron (hereafter G) cross section is about half the pion-air cross section and the inelasticity is $K \propto 1 \text{ GeV}/M_G$ [6, 2]. The gluino mass range is not constrained so we could, in principle, study it at different scales. According to [8], the masses accessible to neutrino detectors are $\leq 170 \text{ GeV}$. In our case we try to probe for higher masses, while keeping the fluxes within reach. In our simulations we adopt a gluino mass of 500 GeV, which yields an inelasticity of 0.002 [6]. This small inelasticity is precisely what allows one to model a G shower as a series of proton sub-showers separated according to the G mean free path, with each proton having about 0.002 of the original G energy.

In our case, this program takes the G -hadron of a given energy, mean free path and inelasticity. The nature of the particle chosen to be injected at each vertex will determine the amount of energy channeled into the hadronic shower and the amount of energy going into the electromagnetic shower. For a detector like the surface array of the Pierre Auger Observatory, the hadronic part (the muons) are enhanced over the electromagnetic part (also considering a great part of the electromagnetic part has died away in flight). This means that, by injecting a proton in each vertex we are underestimating the number of muons that can be sampled in the ground.

In figure 1 we present the average longitudinal profile for 100 G -hadron induced Air Showers, along with the longitudinal development of a proton with different energies. It should be clear that the development of a G -hadron shower can not be fitted by function similar to eq. 1, a Gaisser-Hillas function. One of the biggest sources of fluctuations in Air Showers is the first interaction point. That means that, in our case, the longitudinal development of any particular shower will show small fluctuation in the shape, since one of these is composed by about ten proton showers. This was taken at a zenith angle of 75° . It should be noted, that it might be possible to tell these events from their background even for zenith angles as low as 60 degrees, where the atmospheric depth is around 2000 g/cm , still more than three times the point where the shower reaches its maximum.

The lateral distribution function (LDF) for all particles also shows a distinct behaviour. In Fig. 2 the total LDF on the shower plane is plotted, along with the corresponding ones for protons of different energies. A distinct feature of the LDF from G -hadrons is that the slope depends on the distance to the core, as opposed to proton generated ones. It is due to the fact that G -hadron induced showers are just a superposition of lower energy

showers with different ages (hence different slopes). The younger showers, that are spread over a smaller area, show a steeper LDF. The particle densities are on the order of the densities from proton showers. These densities need to be scaled according to the detector response. Also, for very inclined showers, the steepness of the LDF depends strongly on the zenith angle so a search for these has to take into account the angular resolution of the experiment.

4. Summary

Using a simple model to simulate the interaction of G -hadrons hitting the top of the atmosphere, we have shown that the longitudinal development of a G -hadron induced air shower is very distinct from that of protons and gamma rays that compose the main background. Thanks to the low inelasticity of G -air interactions, the G -hadron will produce a sequence of smaller showers of almost the same energy, and the value for the cross-section, in agreement with previous works, gives a separation between them that makes it impossible to resolve them.

It should then be possible to differentiate between G -hadron induced showers and those of the background, since they display such a unique profile. In order to assess how difficult it will be to actually measure these showers we need to consider the characteristics of the detector. In the case of fluorescence techniques, a careful study of the signal to noise ratio for the intensities associated with these showers will be needed in order to correctly estimate the correct aperture.

It was also shown that the lateral distribution of particles at ground level is such that it should be measurable with a ground array. The LDF does show a varying slope, due to the superposition of different age showers. A more detailed study also needs to be done in order to study the aperture and the discrimination power, since these will depend strongly on the characteristics of the detector.

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