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ANOMALOUS AIR SHOWERS FROM POINT SOURCES*

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Abstract

Several groups have reported "anomalous" air showers associated with point sources in the sky, such as CYG-X3, HER-X1, etc. These showers are induced by apparently massless primaries, such as γ -s and ν -s. Theoretical arguments based on probability conservation and an analysis of the absorption on the $3^\circ K$ background indicate that not all primaries are photons. In many composite models of quarks and leptons, neutrinos acquire a residual strong interaction at sufficiently high energies: we suggest that this can explain the "anomalous" showers. Here we report on a search for additional observable properties of such showers which should distinguish them from either γ or p - induced showers.

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1 Introduction

There is now growing evidence in favour of the existence of “anomalously” muon-rich extensive air showers (EAS) associated with point sources in the sky, see e.g. [1] for a recent review and references quoted there.

Even though the statistical significance of each individual observation is rather low, all existing data appear to exhibit the same qualitative features.

1. The primary can be associated with a “point” source, such as CYG-X3, HER-X1, the CRAB nebula, *etc.* using directional information.
2. Timing information gives an upper limit on the mass of the primary. (Fourier analyses of the data exhibit the orbital period of the source when applicable and in some cases a pulsar period too.) Currently, a conservative upper limit is $m \leq 60 \text{ MeV}$, see [1].
3. Considerations based on the average magnitude of interstellar magnetic fields clearly indicate that the primaries are neutral. (The sources are *many* magnetic diffusion lengths away from us in the relevant energy range.)
4. The primaries interact with a non-negligible cross section in the atmosphere (of the order of a few mb/nucleon), the exact value depending on how one extrapolates the fluxes from lower energies.
5. The muon content of the EAS is comparable with that of ordinary hadron-induced showers.
6. The absorption of the primaries on the $3^\circ K$ background exhibits an anomaly [2]: in the absorption line centred around 2 PeV, the absorption is considerably less than expected under the assumption that all primaries are photons. (See below.)

Items 2, 3 and 4 above indicate that, most probably, the primary is one of the known neutral particles; in the mass range available, only ν and γ are acceptable as candidates. If the Standard Model is valid, however, ν -s of any generation are excluded: their interactions are too weak compared with the value cited in item #4 (by about 7 orders of magnitude). The muon content and the absorption anomaly (the last two items above) seem to exclude γ as a candidate too. (For a more detailed analysis of the evidence, the reader should consult, e.g. ref.[3].)

One faces the following interesting alternative:

- *either* one declares that all the results concerning a muon excess and the absorption anomaly are **WRONG**; in that case one has to provide a rational explanation for the fact that several independent groups of physicists committed the same type of error in analyzing their data
- *or* one accepts the fact that there is a real effect present, albeit at a – so far – low level of statistical significance.

If one chooses the second alternative, one has to play a ‘*what if...*’ type of game, i.e. work out further physical consequences of the “new physics” one has allegedly discovered. We have been playing the ‘*what if...*’ game for a while (see [3] for a list of references): in fact, that’s how the absorption anomaly [2] was discovered in the first place. Having two interesting facts, one starts looking for more. In particular, if the absorption anomaly is real, it hints at an interaction cross section of the non-absorbed component which is somewhere between the weak and strong scales. This has to have then some profound consequences on the development of the muon rich EAS.

Here we report on our first attempt at exploring those consequences. The model described here is a very crude one – intentionally so. It was designed in order to explore the qualitative consequences of some “new physics” taking place at the first stages of development of an EAS induced by a particle (we believe it is a neutrino) at high energies. A more detailed description will be published elsewhere, [4].

2 The Model

Consider the following scenario.

- An incoming primary particle (*a neutrino?*) has a vanishing interaction cross section in the atmosphere below a critical energy, E_c in the LAB frame. (For the sake of definiteness, take $E_c \approx 1\text{PeV}$, corresponding to $\sqrt{s} \approx 1\text{TeV}$, as suggested by the analysis reported in [2].) Above that energy, the interaction cross section is constant, σ_0 . (Take $\sigma_0 \approx 2\text{mb/nucleon}$, see [2].)
- The primary interaction results mostly in hadrons, with an initial multiplicity n_0 .
- After the first interaction, the EAS develops according to the rules of known hadron physics, with each of the n_0 hadrons initiating an independent, “normal” hadronic cascade. Also, for the sake of definiteness, we assume that *all* the hadrons produced in the primary interaction are pions.

For the primary interaction we assume an equipartition of the energy: each of the hadrons produced in the first interaction of primary energy, $E_0 > E_c$, carries an energy $E = E_0/n_0$.

This scenario is compatible with the rapid turn-on of the “new physics” suggested by some model calculations, [5, 6]. Furthermore, we simplify the treatment of the development of the “normal” hadronic cascade by assuming:

1. equipartition of the energy at each stage,
2. energy-independent cross sections and multiplicities,
3. energy independent transverse momentum distributions of the hadrons,
4. each muon produced as a result of π -decay has a vanishing transverse momentum with respect to the parent pion and carries 1/2 of its energy.

Obviously, this caricature of a shower theory is constructed in the same spirit as Heitler’s model of an electromagnetic cascade was a long time ago, see [7]. It also has the same advantages and disadvantages as that model does.

- *On the positive side*, the transport equations are ordinary differential equations, instead of integro-differential equations. Their solutions for any given initial condition, specified by σ_0 and n_0 , can be reduced to quadratures. (If one assumes Feynman scaling, the transport equations of a mixed hadronic-electromagnetic cascade in ‘*Approximation A*’ can be handled by Mellin transform techniques. However, for typical — “realistic” — energy distributions, the inversion of the Mellin transforms cannot be done analytically.)
- *On the negative side*, a lot of potentially important physics may be missed by making such a crude approximation to shower development. (Leading particle effects, effects of the transverse momentum distribution in the primary interaction, *etc.*)

We do not bother to write down the transport equations for a “ ν ”-induced “anomalous” EAS in the approximation we just described: anyone can reproduce them on the basis of the assumptions stated above — and, at any rate, they are described in our forthcoming article in all the details anyone cares to see (and more ...), see [4]. The real advantage of such a “*Heitleresque*” model of shower development is that one can try out various hypotheses about the primary interaction and get an almost instantaneous response about the effects of changing the parameters, with a minimal amount of computing effort.

3 Results and Discussion

Let us concentrate upon one of the observable quantities — presumably, one that carries important information about the early stages of development of an EAS — the *lateral distribution of muons*. Within the framework of the model described, one computes it under the assumptions stated in the previous Section and then averages it over the primary spectrum. First of all, it is important to know whether the distribution calculated for normal, hadron-induced EAS bears any resemblance to the observed data. For this reason, we took some “typical” values, e.g. $\sigma_0 \approx 100mb$ and $n_0 \approx 30$ per nucleon (the same as used in evolving the “normal” part of the shower) and averaged it over a primary spectrum obeying a power law with a spectral index ≈ 2.5 .

In all the calculations we used a Gaussian p_T distribution with a mean p_T around 250 MeV. The result was compared to a standard empirical fit to the lateral distribution of muons, the “Nishimura-Kamata-Greisen” (NKG) curve, cf. [8], known to describe the shape of the lateral distribution quite well, see for instance Sokolsky [9]. It turned out that even this crude model did a creditable job in producing a lateral distribution of muons: the computed distributions follows the NKG curve quite well for hadron induced showers. It was also found that the calculated distribution is rather *robust*: its shape does not depend in a sensitive way on the spectral index of the primary spectrum, the interaction cross section, the width of the p_T distribution or on the multiplicity. In the calculations reported here, we made no attempt at optimizing the fit to the NKG distribution by varying the parameters.

Next, we modeled ν -induced, “preonic” EAS ([5, 6]) by inserting $E_c \approx 1TeV$, $\sigma_0 \approx 5mb/\text{nucleon}$, a spectral index ≈ -2 and varying the initial multiplicities around normal, hadronic ones. (The value of σ_0 was inferred from ref. [2].) (As in the case of the hadron-induced showers, the results are quite robust; hence, for the purposes of this talk, we do not

Figure 1: Typical muon lateral distributions. Left: the calculated distribution is compared with the NKG curve for a hadron induced shower. Right: comparison of lateral distributions in ‘normal’ and ‘preonic’ showers. The lateral distribution in ‘preonic’ showers is markedly narrower, see text.

have to worry about fine details of how the parameters were chosen.) One clearly recognized that the “anomalous” showers have a noticeably narrower lateral distribution of muons than the normal ones. At least in this approximation, the narrower lateral distribution is due to the fact that “preonic” EAS originate deeper in the atmosphere than hadron induced ones. Moreover, on taking a smaller multiplicity in the initial interaction, the energy remains concentrated on fewer particles than in the “normal” showers. Thus, the narrower lateral distribution is basically an effect of the kinematics. Since the p_T distribution is taken to be energy independent, the width of the *angular* distribution goes as $1/E$ and – using elementary geometry – so does the lateral distribution. One concludes that a careful measurement of the lateral distribution of muons, combined with an absorption analysis on the $3^\circ K$ background should yield some insight into the nature of muon-rich EAS associated with point sources. One also suspects that there are other observables in such EAS distinguishing them from the background. In particular, on behalf of the CYGNUS collaboration, Steve Biller presented some preliminary observational evidence at this meeting [10] indicating that muon-rich EAS associated with point sources may have arrival time distributions which distinguish them from hadron-induced ones.

Future detectors designed for the purpose of observing point sources in the sky will thus yield not only valuable information about what is happening in distant star systems, but also about what is awaiting us at small distances not yet explored at current accelerators.

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