

# SUSY Scaling Violations and UHECR

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*Dedicated to the Memory of Prof. Nathan Isgur*

## Abstract

Advancing QCD toward astroparticle applications generates new challenges for perturbation theory, such as the presence of large evolution scales with sizeable scaling violations involving both the initial and the final state of a collision. Possible applications in the context of Ultra High Energy Cosmic Rays (UHECR) of these effects are discussed.

## 1. INTRODUCTION

Nowadays intriguing theoretical extensions of the Standard Model are being explored, while the experimental results continue to confirm the validity of the model and constrain its extensions. Given the limited energy range available at colliders, it is therefore vital to

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\*presented by C. Corianò at the Intl. Workshop “QCD @ work”, Martina Franca, Italy 16-20 June 2001

develop experimental probes that can climb up the energy ladder. A complementary way to analyze these extensions while waiting for colliders of the next generations is provided by cosmic rays, which exceed the energy scales currently attainable.

We have undertaken the preliminary steps in a program that aims to utilize cosmic rays as an experimental probe of theoretical generalizations of the Standard Model. We have in mind possible applications of cosmic rays for the study of supersymmetry. The first is in the context of top-down models of Ultra-High-Energy Cosmic Rays (UHECR), around and above the Greisen-Zatsepin-Kuzmin cutoff. In these models the primary cosmic rays originate from the decay of a metastable superheavy particle which decay at rest, fragmenting into ordinary hadrons and photons. The dynamics of these decays can be modelled using standard QCD tools on which we elaborate below. We propose to analyze supersymmetric effects in the decay of these metastable states using 2 scales:

A High Energy  $\Lambda_F$  fragmentation Scale  $\approx 10^{11}$  (decay of a metastable state  $\rightarrow$  primary protons)

A collision scale  $\Lambda_{coll}$  due to the interaction of surviving primaries with air-nuclei ( $E_{CoM} \approx 10 - 400$  TeV)

At both scales supersymmetric scaling violations should be included and the multiplicities of the spectrum analyzed.

## 2. Numerical Results

As an illustration of the procedure we adopt in our studies, let's consider the decay of a hypothetical massive state of mass 1 TeV into supersymmetric partons. The decay can proceed, for instance, through a regular  $q\bar{q}$  channel and a shower is developed starting from the quark pair. The  $N = 1$  DGLAP equation describes in the leading logarithmic approximation the evolution of the shower which accompanies the pair, and we are interested in studying the impact of the supersymmetry breaking scale ( $m_\lambda$ ) on the fragmentation. In

our runs we have chosen the initial set of Ref.<sup>2</sup>.

We parameterize the fragmentation functions as

$$D(x, \mu^2) = Nx^\alpha(1-x)^\beta \left(1 + \frac{\gamma}{x}\right) \quad (1)$$

Typical fragmentation functions in QCD involve final states with  $p$ ,  $\bar{p}$ ,  $\pi^\pm$ ,  $\pi^0$  and kaons  $k^\pm$ . We have chosen an initial evolution scale of 10 GeV and varied both the mass of the SUSY partners (we assume for simplicity that these are all degenerate) and the final evolution scale. In general the effects of supersymmetric evolution are small within the range described by the factorization scales  $Q_f$  and  $Q_i$  ( $Q_f = 10^3$  GeV,  $Q_i = 200$  GeV). We mention that  $Q_f$  is the starting scale (the highest scale) at which the decay of the supersymmetric partons starts.  $Q_i$  is fixed by the gluino/squark masses and coincides with them.

The situation appears to be completely different for the gluon fragmentation functions (f.f.'s) (Fig. 1). The regular and the SQCD evolved f.f.'s differ largely in the diffractive region, and this clearly will show up in the spectrum of the primary protons if the decaying state has a supersymmetric content. As we raise the final evolution scale we start seeing more pronounced differences between regular and supersymmetric distributions. We have shown in Fig. 2 the squark f.f.'s for all the flavours and the one of the gluino for comparison. The scalar charm distribution appear to grow slightly faster than the remaining scalar ones. The gluino f.f. is still the fastest growing at small- $x$  values.

### 3. Summary

In a few years several experiments, including the Pierre Auger experiment<sup>3</sup>, will start collecting data from cosmic rays. The issue of the origin of UHECR will be -hopefully- clarified. While the link of UHECR to AGN's has been disfavored on the basis of a quite homogeneous distributions, the local origin of these events remains an open possibility. Potential meta-stable superheavy string relics have been suggested as dark matter candidates, as well as potential sources for the UHECR<sup>4</sup>. A QCD/SQCD analysis of these events is in progress.

With the forthcoming experimental data<sup>3</sup>, and improved theoretical analysis, along the lines discussed here, cosmic ray physics enters an exciting new era, with potentially groundbreaking discoveries.

## FIGURES

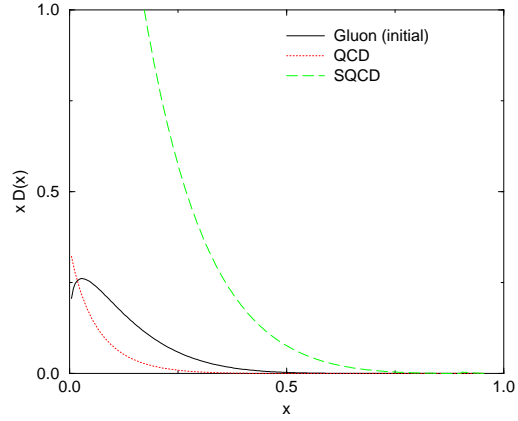


Fig. 1. The gluon fragmentation function  $x D_g^{p,\bar{p}}(x, Q^2)$  at the lowest scale (input)  $Q_0 = 10$  GeV, and its evolved QCD (regular) and SQCD/QCD evolutions with  $Q_f = 10^3$  GeV. The SUSY fragmentation scale is chosen to be 200 GeV.

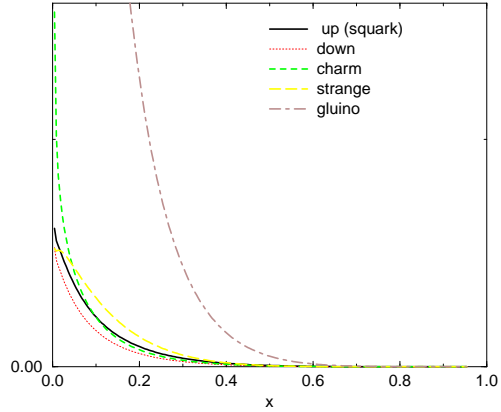


Fig. 2. The fragmentation functions of squarks and gluino at the lowest scale (input)  $Q_0 = 10$  GeV, with  $Q_f = 10^3$  GeV and SUSY scale 200 GeV.

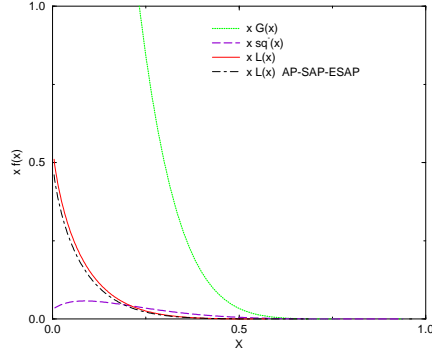


Fig. 3.  $xf(x)$  in the AP-ESAP evolution with a very large final scale  $Q_f = 10^3$  GeV and with a squark mass  $m_{\tilde{q}} = 100$  GeV. Shown are the non-singlet squark, the gluon and the gluino distributions for the AP-ESAP evolution. The gluino distribution for the AP-SAP-ESAP evolution is also shown (with  $m_{2\lambda} = 40$  GeV).

**Acknowledgments:** A.F. Thanks the CERN theory division for hospitality. The work of C.C. is supported in part by INFN (iniziativa specifica BARI-21) and by MURST. The work of A.F. is supported by PPARC.

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