Signatures of (Un)particles from a Hidden Sector in multiparticle dynamics at Tevatron/LHC

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Abstract. The study of multiparticle dynamics in hadron-hadron collisions at Tevatron and LHC could provide useful information on new physics in addition to the expected signatures on the transverse plane. We suggest that an analysis of inclusive correlations between emitted particles in $pp$ inelastic collisions, and factorial moments of multiplicity distributions, may be helpful in uncovering (un)particles from Hidden Sectors, using underlying events tagged by hard products like high-$p_T$ leptons and photons, and applying stringent selection criteria like event shape variables, etc.

Keywords: New physics, multiparticle dynamics, unparticle, hidden valley, fractality

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INTRODUCTION

Multiparticle hadroproduction has been extremely useful along decades to understand the strong interaction dynamics [1]. In Ref.[2] we explored the possibility of applying well-known techniques based on inclusive correlations and moments of multiplicity distributions to the quest for a Hidden Sector (HS) at Tevatron/LHC experiments. In all fairness, multiparticle production is still not fully understood, while our proposal is based on possible departures of “anomalous” from “standard” events. Nonetheless, one might expect that, once stringent selection criteria are applied to events, distinctive features associated to a HS would become useful in the search strategy and subsequent interpretation of new phenomena in multiparticle dynamics.

Hidden sectors

In this work we focus on Unparticle physics [3] in particular, though the main ideas can be generally applied to Hidden Valley models [4]. In these models, the Standard Model (SM) is accompanied by a HS of new particles not been yet observed due to typically an energetic barrier or a weak coupling to SM particles. We will assume further that particles coming from a HS can decay back to SM particles [4], thereby modifying the conventional pattern of the parton cascade in multiparticle production.

So far most signatures of new physics (like jets, missing energy, high-$p_T$ leptons or photons, displaced vertices) have been considered on the transverse plane with respect to the beam direction. In a complementary way, we advocate that a new stage of matter might also show up in soft physics of underlying events tagged by hard products, e.g. through particle (pseudo)-rapidity correlations (either integrated or not).
FIGURE 1. Pictorial representation of a 3-step scenario where unparticles (for our particular HS choice) are produced at a hard parton interaction in \( pp \) collisions, subsequently decaying into final-state SM particles through cluster formation. The number of unparticles sources at the onset of the cascade may fluctuate, and a large (and “continuously variable”) mass of the unparticle stuff would induce additional long-range correlations among the final-state SM particles.

INCLUSIVE (LONGITUDINAL) RAPIDITY CORRELATIONS

Experimental results in multibody production along decades have steadily supported the tendency of produced particles to merge into correlated groups [1]. This experimental evidence has traditionally led to the view of a two-step process for high-energy hadron collisions. The resulting multiplicity distribution is thus given by the convolution for particle emission sources (strings, clusters/clans, fireballs...) with the decay/fragmenting distribution of sources. However, observable consequences could derive from a new stage of matter (stemming from a HS) generated at the onset of the parton shower (see Fig.1) leading to a 3-step scenario in hadronic collisions at very high energy.

The inclusive 2-particle (rapidity) correlation function is defined as

\[
C_2(y_1,y_2) = \frac{1}{\sigma_{in}} \frac{d^2\sigma}{dy_1 dy_2} - \frac{1}{\sigma_{in}} \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2}
\]

(1)

where \( \sigma_{in} \) denotes the inelastic \( pp \) cross section and subscripts 1 and 2 refer to the two considered particles event by event. \( C_2(y_1,y_2) \) is usually split in two terms:

\[
C_2(y_1,y_2) = C^{SR}_2(y_1,y_2) + C^{LR}_2(y_1,y_2)
\]

(2)

where the short-range (SR) part is generally assumed to be more sensitive to dynamical correlations, while \( C^{LR}_2(y_1,y_2) \) stands for long-range (LR) correlations usually due to the mixing of different topologies. In this work we focus on the central rapidity region.

According to our study [2], the \( C^{LR}_2(y_1,y_2) \) piece in Eq.(2) should become enhanced in a 3-step scenario wrt a standard 2-step cascade as a consequence of larger fluctuations of the number (and mass) of the primary sources of partons. In addition, the correlation length in the \( C^{SR}_2(y_1,y_2) \) term should become larger because of the (presumably) higher mass of the intermediate hidden (un)particle stuff. Therefore longer and stronger correlations between particles can be expected from both SR and LR terms in Eq.(2) whenever a HS appears in the cascade. Nevertheless, other conventional sources of possible LR effects in multiparticle production [5] should be properly taken into account.
Intermittency, multifractality and entropy

Fluctuations in small phase space regions (intermittency) have been commonly described by the scaled moments $F_q(\delta y)$ of a multiplicity distribution $P_n$ (corresponding to the normalized phase-space integral over the $q$-particle density function) as the rapidity interval under study $\Delta Y$ is split into $M$ bins of equal size $\delta y = \Delta Y / M$ [8].

On the other hand, the fractality nature of multiparticle hadroproduction is deeply connected with intermittent behaviour exhibiting a power-law dependence of the multiplicity moments with the cell size [8]. If self-similar dynamical fluctuations exist, $F_q(\delta y)$ should obey a power-law increase ($M$-scaling) at small $\delta y$, i.e.

$$F_q(\delta y) \sim \delta y^{-\phi_q} \sim M^{\phi_q} \rightarrow \ln F_q = a_q - \phi_q \ln \delta y \equiv A_q + \phi_q \ln M$$

where the “intermittency exponents” $\phi_q (\phi_q > 0)$ are related to the anomalous fractal dimensions $d_q$ [6, 7] as

$$d_q = \frac{\phi_q}{q-1}$$

Moreover, the power scaling between $F_q$ and $F_2$ ($F$-scaling),

$$F_q(M) \sim [F_2(M)]^{\beta_q} \rightarrow \ln F_q(M) = \beta_q \ln F_2(M)$$

represents another interesting relation, where the $\beta_q$ coefficient can be expressed as

$$\beta_q = \frac{\phi_q}{\phi_2} = \frac{d_q}{d_2}(q-1)$$

Monofractality ($d_q = d_2, \forall q$) implies that $\beta_q = q - 1$, which can be tested from (5).

Brax and Peschanski [9] proposed a better approximation than Eq.(6) using a Lévy stable law description of multiparticle production:

$$\beta_q = \frac{\phi_q}{\phi_2} = \frac{q^\mu - q}{2\mu - 2}$$

where $\mu$ is the Lévy index (also known as the degree of multifractality) which permits an estimation of the cascading rate; $\mu$ should be in principle restricted to the interval $0 < \mu \leq 2$ (region of stability) with $\mu = 0$ characterizing monofractal behaviour.
Instead of the law expressed in Eq.(7), $\beta_q$ has been parametrized in the Ginzburg-Landau model of phase transitions as

$$\beta_q = (q - 1)^\nu$$

(8)

where $\nu = 1$ now implies monofractality. The motivation for all these approaches in heavy-ion collisions comes from the need of a signal for Quark-Gluon Plasma formation through, e.g., a (second-order) phase-transition, since the correlation length would then diverge, and the system behave as a simple fractal \[10\].

We are certainly not considering here such kind of phase-transition, but extra LR correlations from a HS leading to a similar effect on both $\mu$ and $\nu$ estimators. Indeed our results shown in Fig.2 are consistent with the interpretation that multiparticle production including a HS approaches monofractality; the intermittency exponents, all $d_q$ values and $\mu$ and $\nu$ estimators turn out to be smaller in a 3-step scenario than in a 2-step cascade.

Let us finally note that the (Shannon) entropy, defined for a multiplicity distribution $P_n$ as $S = \sum P_n \ln P_n$ \[11\], might become another indicator of a HS in multiparticle production. For example, it is relevant to verify to what extent entropy is additive \[12\] by checking whether $S(R) = S(R_1) + S(R_2)$ using particles belonging to regions $R_1$ and $R_2$ well separated in rapidity space (e.g. forward and backward hemispheres).

**SUMMARY**

Intermittency and (multi)fractality can be sensitive to a HS altering the pattern of the parton cascade in high-energy inelastic $pp$ collisions. From our study in \[2\] we conclude that longer and stronger correlations between emitted particles, and larger scaled moments in multiplicity distributions, should be expected than in a conventional QCD cascade, while the pattern of the multiparticle system approaches monofractality - or merely becomes less fractal. The challenge remains however in tagging those anomalous underlying events (where such new phenomena would show up through soft physics) by appropriate selection cuts, to be compared with a control sample of standard events. More work requiring prior tuning and Monte Carlo generation of events at LHC energies is required before drawing any conclusion about the feasibility of our proposal.

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