



FANSY: simulation of coplanar particle generation in hadron interactions

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Abstract: The phenomenon of coplanarity of most energetic structures of gamma-ray-hadron families found in mountain and stratospheric X-ray - emulsion chamber experiments cannot be explained without a coplanar particle generation with large transverse momenta in hadron interactions at superhigh energies. A phenomenological model, which makes it possible to simulate such interactions, is presented. Different versions of this model are considered and compared with models applied by the CORSIKA package.

Introduction

EAS and X-ray-emulsion chamber experiments have formed an opinion that soft and semihard hadron interactions are well-described with quark-gluon string models (QGSM). On the other hand, there is such a robust and transparent phenomenon as the tendency to a coplanarity of most energetic cores of gamma-ray-hadron ($\gamma - h$) families (groups of high-energy ($E \gtrsim 4$ TeV) particles in EAS cores) which has been first found by the *Pamir* Collaboration (see Refs. [5-8] in [1]) and confirmed later in mountain (see Ref. [9] in [1]) and stratospheric (see Refs. [10-12] in [1]) experiments and is not described by QGSMs.

As is shown in [1] the coplanarity phenomenon at superhigh energies is

- 1) not a result of cascade fluctuations;
- 2) not explained in the QCD framework;
- 3) characterized by a cross section comparable with the proton's total inelastic one;
- 4) related to most energetic particles;
- 5) characterized with a specific correlation between longitudinal (p_L) and transverse (p_t^{copl}) momenta of particles in the coplanarity plane: the lower is p_L , the higher is p_t^{copl} .

So, while accounting for the theoretical attempts, this problem seems to be resolved by using the following two ways:

(a) a concept [2] of the angular momentum conservation in the creation of a relativistic fast-rotating quark-gluon string (QGS) stretched between colliding hadrons (Fig. 4d in [1]). The coplanarity of secondaries appears in [2] as a simple kinematic effect with a cross section being comparable with the usual inelastic one;

(b) a model of semihard double diffraction inelastic dissociation (SHDID) [3], which assumes the coplanarity to be a result of a QGS tension in the diffraction cluster between a semihardly scattered constituent quark and other spectator quarks of the projectile hadron and its following rupture [3] (Fig. 4b in [1]). This concept is quantitatively developed better, however it will be applied in our next works.

The concept [2] is only an idea. If so, one could develop only a phenomenological approach which would allow us to outline the goal of future theoretical efforts. After all, only the comparison with experimental data could give an answer on a verity of models. Let us stress that this work does not pretend to a theoretical description of processes taking place at energies under consideration and proposes a phenomenological tool to study these processes.

This work considers several versions of pp interactions of the model named FANSY (FAN-like Secondary particle Yield). All these versions differ in transverse characteristics only. As a result, all the longitudinal characteristics of these models are identical in terms of x_F or p_Z and differ in terms

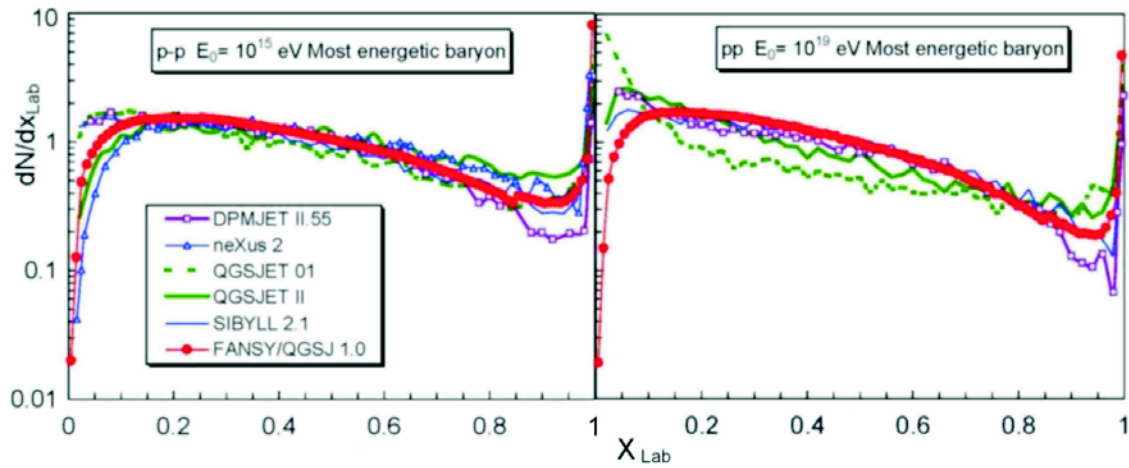


Figure 1: Model dN/dx_{Lab} distributions for the most energetic baryon at $E_0 = 10^{15}$ and 10^{19} eV.

of pseudorapidity. The below-considered FANSY versions are labelled '1.0' as they are initial and will be improved in accordance with new experimental and theoretic achievements.

FANSY/QGSJ: a traditional version

The FANSY/QGSJ version is based on QGSM concept and takes into account the jet generation beginning from the semihard range. The majority of its parameters is placed between those of QGSJET II and SIBYLL 2.1 models.

Fig. 1 displays dN/dx_{Lab} distribution (where $x_{Lab} = p_z/p_0$) for the most energetic baryon generated in pp interactions at $E_0 = 10^{15}$ eV and 10^{19} eV in different models. Fig. 2 displays energy dependencies of charged-particle multiplicities, $n_{ch}(E_0)$. Fig. 3 displays $dn_{ch}/d\eta$ distributions for charged particles generated at $E_0 = 10^{19}$ eV.

FANSY/weak and FANSY/strong

A mechanism of physical realization of the concept [2] is unknown. Sticking to a semiclassical framework, the following center-of-mass (CMS) naive picture could be imagined. Let the QGS angular momentum be initially distributed proportionally to the distance from the string center. The tension is about uniformly distributed over the string. Near

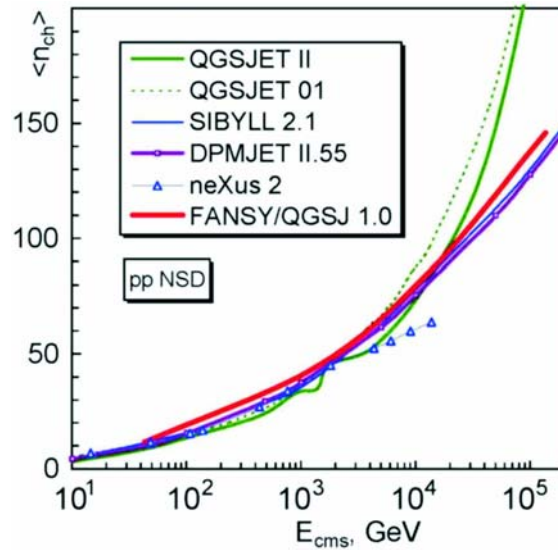


Figure 2: Model energy dependencies of charged-particle multiplicities, $n_{ch}(E_0)$.

the string center, velocities of different QGS parts are also distributed proportionally to the distance from the string center. However, velocities of QGS parts adjoining the interaction hadrons depend no longer on distance to the center and equal to the light velocity. In what follows, the parts adjoining the interaction hadrons tend to go aside from the hadrons due to the angular motion and angular momentum conservation. The tension in these

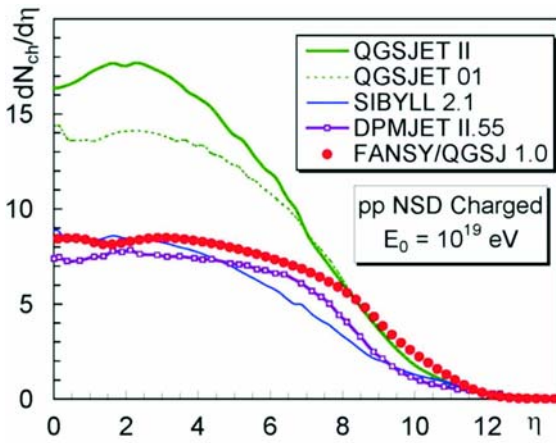


Figure 3: Model $dn_{ch}/d\eta$ distributions for charged particles at $E_0 = 10^{19}$ eV.

ranges becomes higher than the average string tension. So, these parts are the first to rupture.

Due to the centrifugal force, the subsequent rupture process goes from the string ends to its center. As it takes a certain time, each next disruption takes place after an additional string turn that leads to generation of particles with higher p_t^{copl} and lower (in CMS) p_L values. Starting with a moment, the p_t^{copl} growth stops and begins to decrease as the angular momentum begins to decrease, on the one hand, due to the approach to the QGS center. On the second hand, the QGS' angular motion decreases as a whole due to the continued motion of the projectiles away.

This picture is to be symmetrical in CMS in the case of interaction of similar hadrons. In the case of hadron-nucleus interaction, the symmetry is broken, both in kinematic sense and with respect to parameters of the generated temporary string whose features, most likely, differ in ranges adjacent to the projectile and target nucleus.

As a detailed space-time mechanism of transformation of the QGS angular momentum into transverse momenta of particles is unknown, we consider below FANSY/weak FANSY/strong model versions which differ only in p_t^{copl} value. So, the only our goal is to propose phenomenological models which could be compared with experimental data.

The below-considered model versions (FANSY/weak FANSY/strong) differ in value of transverse momentum.

Figs. 4, 5, 6 display dependencies of average transverse momentum of charged particles on x_F , $\langle p_t^{\text{copl}}(x_F) \rangle$ (Fig. 4), and pseudorapidity, $\langle p_t(\eta) \rangle$ (Fig. 5); pseudorapidity distribution, $dn_{ch}/d\eta$ (Fig. 6), in CMS in QGSJ/weak/strong FANSY versions at different energies.

Conclusion

A computer code of a phenomenological FANSY model is developed to study the coplanarity phenomenon. The code includes the FANSY/QGSJ version based on QGS/QCD/minijets concepts as well as FANSY/weak and FANSY/strong versions using different energy dependencies of the coplanar particle generation.

Acknowledgements

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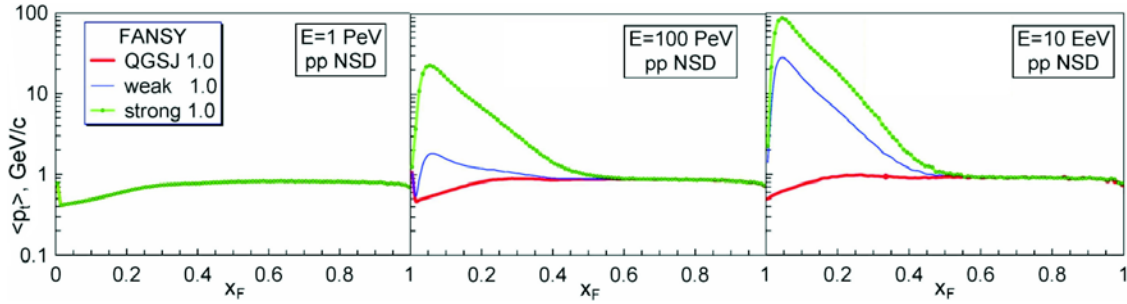


Figure 4: Correlations between x_F and $\langle p_t^{\text{copl}}(x_F) \rangle$ for charged particles in pp interactions in FANSY/QGSJ/weak/strong versions at $E_0 = 10^{15}$, 10^{17} and 10^{19} eV.

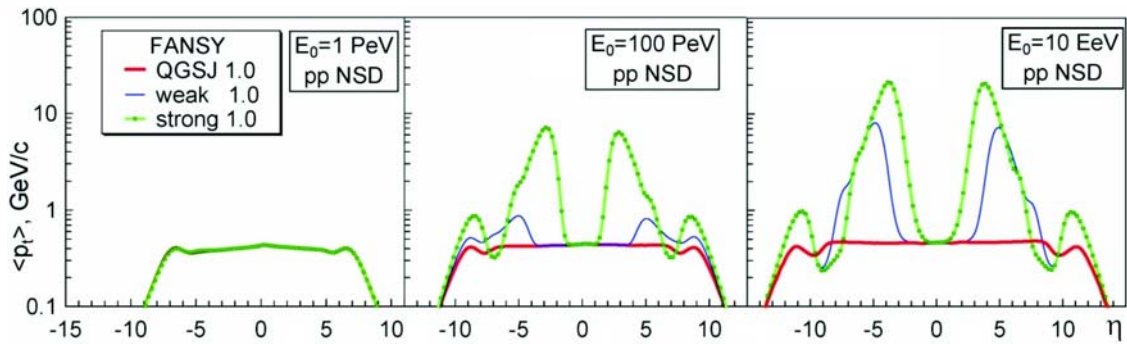


Figure 5: Pseudorapidity dependence of average transverse momentum, $\langle p_t^{\text{copl}}(\eta) \rangle$, for charged particles in FANSY/QGSJ/weak/strong versions at $E_0 = 10^{15}$, 10^{17} and 10^{19} eV.

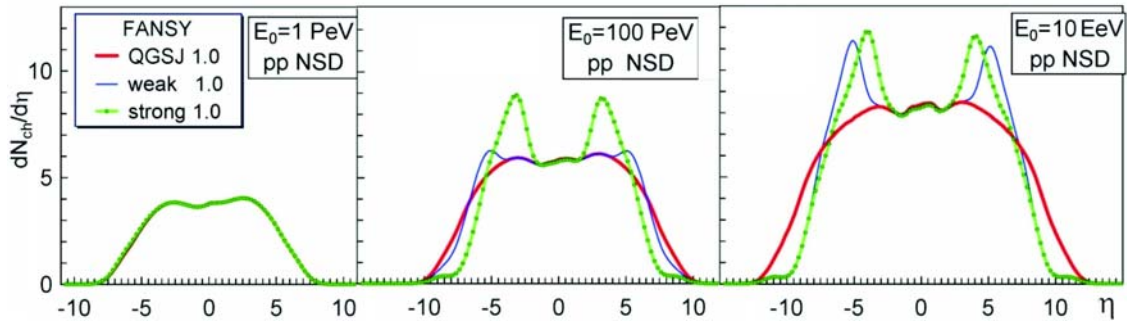


Figure 6: Pseudorapidity distribution, $dn_{ch}/d\eta$, for charged particles in FANSY/QGSJ/weak/strong versions at $E_0 = 10^{15}$, 10^{17} and 10^{19} eV.