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# 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

There is such a robust and transparent phenomenon as the tendency to some 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 is not described by modern quark-gluon string models (QGSM). This effect has been first found by the *Pamir* Collaboration with X-ray–emulsion chambers (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.

The coplanarity phenomenon is [1]
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 inelastic one at $E_0 \gtrsim 10^{16}$ eV;
4) related to most energetic particles;
5) characterized with a specific correlation between longitudinal ($p_L$) and transverse ($p_t^{\rm copl}$) momenta of particles in the coplanarity plane: the lower is $p_L$, the higher is $p_t^{\rm copl}$.

There are two theoretical ways which seems to be capable to resolve this problem :
(a) an idea [2] on the angular momentum conservation of relativistic fast-rotating quark-gluon strings (QGS) stretched between colliding hadrons (in this case a cross section of coplanar particle generation is 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 constituent quark scattered semihardly and other spectator quarks of the projectile hadron and its following rupture. The concept is quantitatively developed and will be applied in our next works.

As the concept [2] is only an idea, we can only develop a phenomenological approach. 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 1.0 (FAN-like Secondary particle Yield). These versions differ in transverse characteristics only, i.e., all the longitudinal characteristics of these models are identical in terms of $x_F$ or $p_Z$ and differ in terms of $\eta$.

## 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 $dN/dx_{\rm F}$ distribution (where $x_{\rm F} = p_Z/p_0$) for the most energetic baryon generated in pp interactions at $E_0 = 10^{15}$ eV and $10^{19}$ eV in

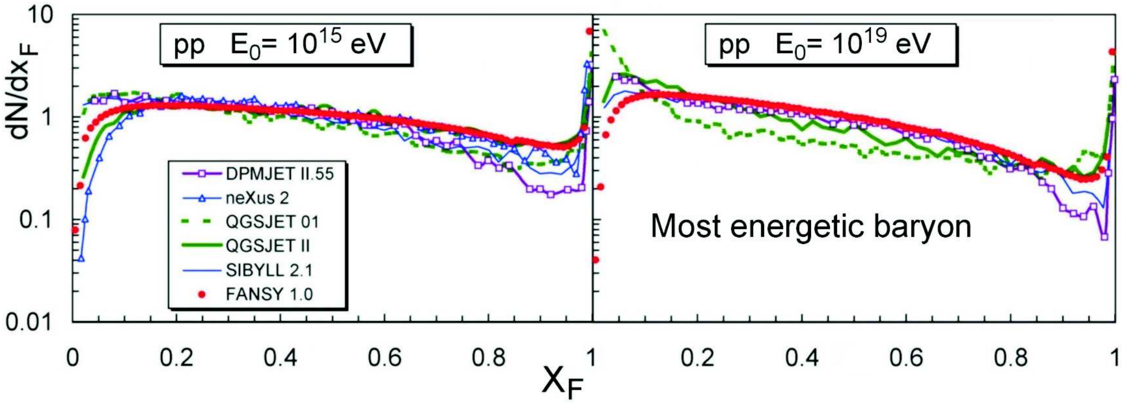


Figure 1: Model $dN/dx_{\rm F}$ distributions for the most energetic baryon at $E_0 = 10^{15}$ and $10^{19}$ eV.

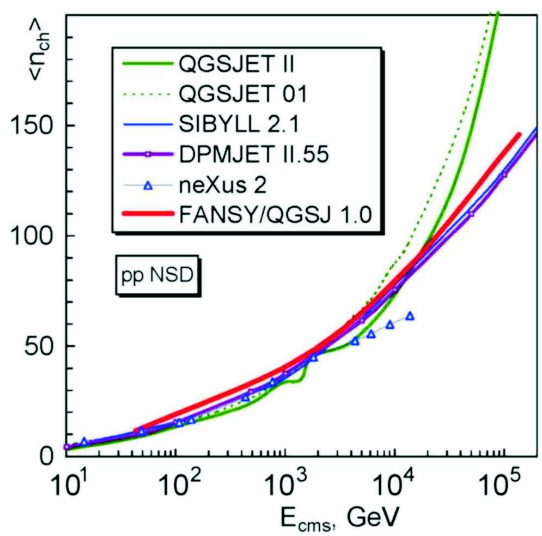


Figure 2: Model energy dependencies of charged-particle multiplicities, $n_{ch}(E_0)$.

different models. Fig. 2 displays energy dependencies of charged-particle multiplicities, $n_{ch}(E_0)$.

## 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 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 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 $p_t^{\rm copl}$ and lower (in CMS) $p_L$ values. Starting with a moment, the $p_t^{\rm copl}$ 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 trans-

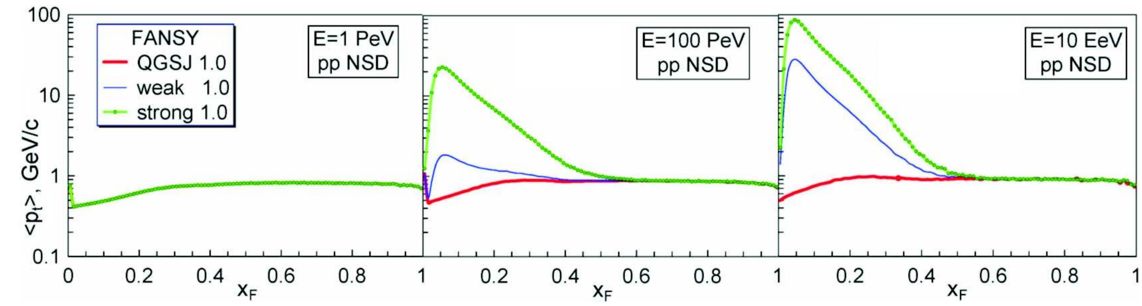


Figure 3: Correlations between $x_F$ and $\langle p_t^{\rm copl}(x_F)\rangle$ for charged particles in pp interactions in FANSY/QGSJ/weak/strong versions at $E_0 = 10^{15},\ 10^{17}$ and $10^{19}$ eV.

verse momenta of particles is unknown, we consider below FANSY/weak FANSY/strong model versions which differ first of all in $p_t^{\rm copl}$ value.

Figs. 3 – 5 display dependencies of average transverse momentum of charged particles on $x_F$, $\langle p_t^{\rm copl}(x_F)\rangle$ (Fig. 3), and pseudorapidity, $\langle p_t(\eta)\rangle$ (Fig. 4); pseudorapidity distribution, $dn_{ch}/d\eta$ (Fig. 5), in CMS in QGSJ/weak/strong FANSY versions at different energies.

Fig. 6 displays energy dependencies of fraction of aligned events in FANSY/QGSJ/weak/strong versions (all types of particles are taken into account). To analyze events' alignment degree, the parameter $\lambda_N$ [4] is applied for coordinates of intersection of trajectories of particles with a target plane situated normally to the beam axis. Events are referred to as aligned ones, if the requirement $\lambda_N \geq 0.8$ ($N$ =4, 5, 6) is satisfied for their $N$ most energetic particles.

## Verification of models

Preliminary simulations indicate that LHC experiments designed to study the most forward kinematic region (LHCf and ZDC e.g.) seem to be incapable of detection of coplanar particle generation corresponding to the above-considered models due to their rather inadequate cross-section sizes ($\sim 10$ cm). For instance, searches for coplanar particle generation of FANSY/weak type require a $\sim 100$-cm cross-section detector.

## 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.

LHC experiments designed to study the most forward kinematic region seem to be unable to verify these models.

## Acknowledgements

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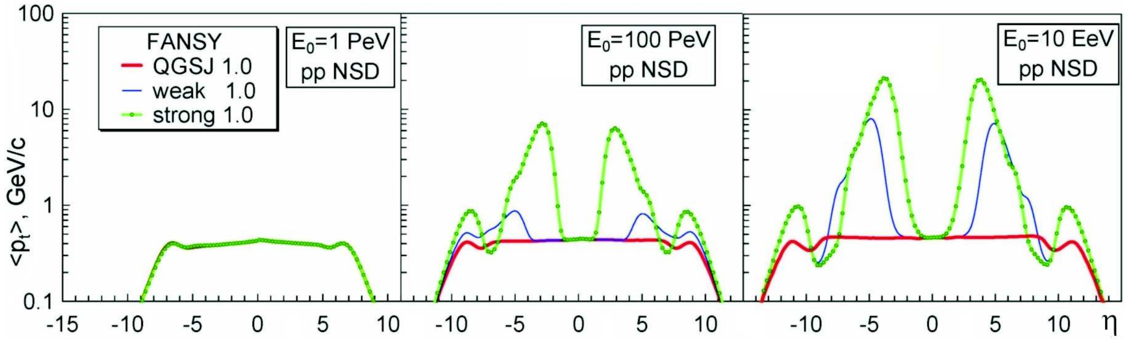


Figure 4: Pseudorapidity dependence of average transverse momentum, $\langle p_t^{\rm copl}(\eta)\rangle$, for charged particles in FANSY/QGSJ/weak/strong versions at $E_0 = 10^{15},\ 10^{17}$ and $10^{19}$ eV.

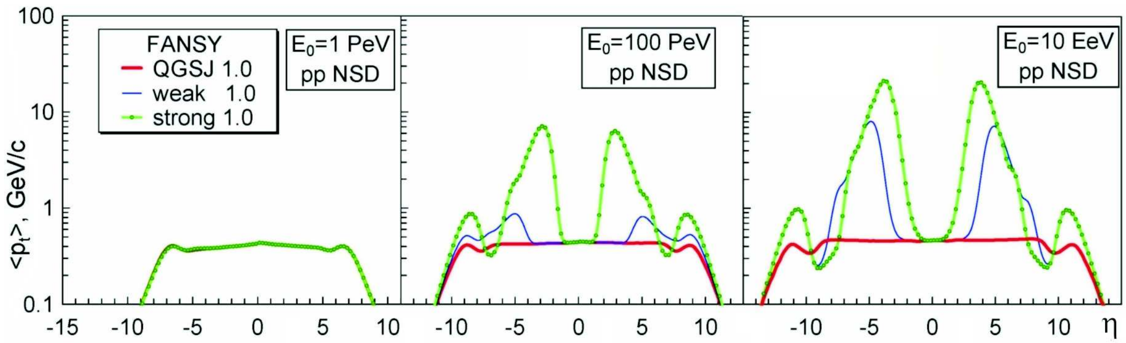


Figure 5: Pseudorapidity distribution, $dn_{ch}/d\eta$, for charged particles in FANSY/QGSJ/weak/strong versions at $E_0 = 10^{15},\ 10^{17}$ and $10^{19}$ eV.

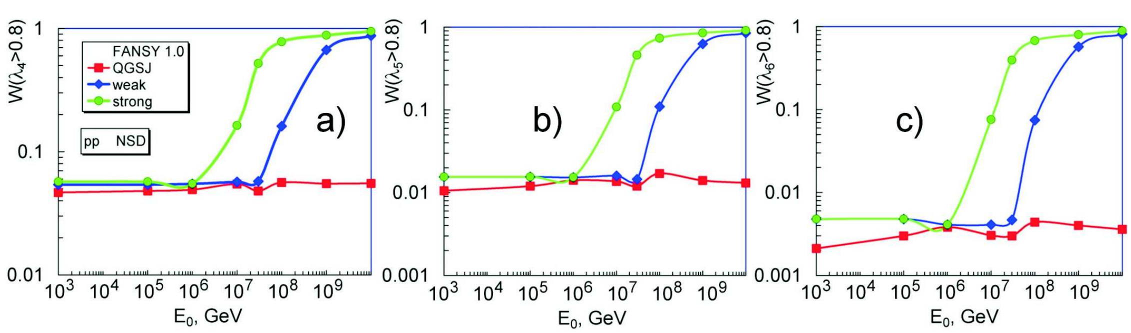


Figure 6: Energy dependence of fraction of aligned events in FANSY/QGSJ/weak/strong versions (all types of most energetic particles are taken into account): (a) $w(\lambda_4)$ for 4 particles; (b) $w(\lambda_5)$ for 5 particles; (c) $w(\lambda_6)$ for 6 particles. Lines are drawn by eye.