The Monte Carlo Event Generator DPMJET-III*

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Abstract. A new version of the Monte Carlo event generator DPMJET is presented. It is a code system based on the Dual Parton Model and unifies all features of the DTUNUC-2, DPMJET-II and PHOJET1.12 event generators. DPMJET-III allows the simulation of hadron-hadron, hadron-nucleus, nucleus-nucleus, photon-hadron, photon-photon and photon-nucleus interactions from a few GeV up to the highest cosmic ray energies.

1 Introduction

Hadronic collisions at high energies involve the production of particles with low transverse momenta, the so-called *soft* multiparticle production. The theoretical tools available at present are not sufficient to understand this feature from QCD and phenomenological models are typically applied instead. The Dual Parton Model (DPM) [1] is such a model and its fundamental ideas are presently the basis of many of the Monte Carlo (MC) implementations of soft interactions in codes used for Radiation Physics simulations.

Many of these implementations are however limited in their application by, for example, the collision energy range which they are able to describe or by the collision partners (hadrons, nuclei, photons) which the model can be used for. With respect to modern *multi-purpose* codes for particle interaction and transport these limitations at high energy are clearly often a disadvantage.

In this paper we present the DPMJET-III code system, a MC event generator based on the DPM which is unique in its wide range of application. DPMJET-III is capable of simulating hadron-hadron, hadron-nucleus, nucleus-nucleus, photon-hadron, photon-photon and photon-nucleus interactions from a few GeV up to the highest cosmic ray energies.

In the present paper we give an overview over the different components and models of DPMJET-III and present a few examples for comparisons of model results with experimental data.

2 The Concept of the Program

DPMJET-III is the result of merging all features of the event generators DPMJET-II [2,3] and DTUNUC-2 [4,5] into one single code system. The latter two codes

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are similar in their underlying concepts, however they differ in the Monte Carlo realization of these concepts, in particular, of the DPM.

Whereas individual nucleon-nucleon collisions in DPMJET-II are simulated based on the DTUJET model [6], DTUNUC-2 is using PHOJET1.12 [7,8]. Since PHOJET describes not only hadron-hadron interactions but also hadronic interactions involving photons, DTUNUC-2 allows also the simulation of photoproduction off nuclei. Therefore, the strength of DTUNUC-2 is in the description of photoproduction and nuclear collisions up to TeV-energies. On the other hand, DPMJET-II is widely used to simulate cosmic-ray interactions up to the highest observed energies [3].

However, many program modules in DPMJET-II and DTUNUC-2 are also identical. Examples are the Glauber-Gribov formalism for the calculation of nuclear cross sections [9], the formation-zone intranuclear cascade [10], the treatment of excited nuclei [11,12] and the HADRIN-model for the description of interactions below 5 GeV [13].

The core of DPMJET-III consists of DTUNUC-2 and PHOJET1.12. In addition all those features of DPMJET-II were added which were not part of DTUNUC-2 so far. This includes, for example, quasi-elastic neutrino interactions [14] and certain baryon-stopping diagrams [15].

3 Models Implemented in DPMJET-III

3.1 The Realization of the Dual Parton Model

The DPM combines predictions of the large N_c, N_f expansion of QCD [16] and assumptions of duality [17] with Gribov's reggeon field theory [18]. PHOJET, being used for the simulation of elementary hadron-hadron, photon-hadron and photon-photon interactions with energies greater than 5 GeV, implements the DPM as a two-component model using Reggeon theory for soft and perturbative QCD for hard interactions. In addition to the model features as described in detail in [19], the version 1.12 incorporates a model for high-mass diffraction dissociation including multiple jet production and recursive insertions of enhanced pomeron graphs (triple-, loop- and double-pomeron graphs). In the following only the new features are briefly discussed.

High-mass diffraction dissociation is simulated as pomeron-hadron or pomeron-pomeron scattering, including multiple soft and hard interactions [20]. To account for the nature of the pomeron being a quasi-particle, the CKMT pomeron structure function [21] with a hard gluonic component is used. These considerations refer to pomeron exchange reactions with small pomeron-momentum transfer, $|t^2|$. For large $|t^2|$ the rapidity gap production (e.g. jet-gap-jet events) is implemented on the basis the color evaporation model [22].

Extrapolating the two-channel eikonal-unitarization of a hadron-hadron amplitude as used in PHOJET to very high energies raises the question of the treatment of enhanced graphs which become more and more important at high energy and lead to large multiplicity fluctuations. A full amplitude calculation including enhanced graphs is very involved and not suited for a Monte Carlo implementation. Therefore, based on the results of [23], we use the simpler approach of

interpreting each soft pomeron as the sum of a series of a bare soft pomeron and enhanced graphs (Froissaron). In practice, this results in the simulation of possibly recursive subdivisions of a single Froissaron cut into various other configurations such as, for example, two cut pomerons or a single cut pomeron and a diffractive scattering. However, the current implementation should only be considered as a first step toward a consistent treatment of enhanced graphs at very high energy because of its limitation to soft interactions.

3.2 Hadronic Interactions Involving Photons

The photon is assumed to be a superposition of a *bare* photon interacting in direct processes and a *hadronic* photon interacting in resolved processes.

The description of interactions of the hadronic photon with nuclei is based on the Generalized Vector Dominance Model (GVDM) [24]. Photons are assumed to fluctuate into quark-antiquark states V of a certain mass M and the interaction is described as scattering of the hadronic fluctuation on the nucleus. Correspondingly, the scattering amplitude a_{VA} reads [4]

$$a_{VA}(s,Q^2,M^2,\boldsymbol{B}) = \int \prod_{j=1}^{A} d^3r_j \; \psi_A^\star \; a_{VA}(s,Q^2,M^2,\boldsymbol{B}_1,\ldots,\boldsymbol{B}_A) \; \psi_A \tag{1}$$

$$a_{VA}(s,Q^2,M^2,\boldsymbol{B}_1,\ldots,\boldsymbol{B}_A) = \frac{i}{2}\left(1-\prod_{\nu=1}^{A}\left[1+2ia_{VN}(s,Q^2,M^2,\boldsymbol{B}_\nu)\right]\right) \tag{2}$$

where a_{VA} is expressed in terms of interactions on individual nucleons N according to the Gribov-Glauber picture (see below). The model is limited to low photon-virtualities Q^2 satisfying the relation $Q^2 \ll 2m_N\nu$ (ν and m_N being the photon energy and nucleon mass). For individual $q\bar{q}$-nucleon interactions it is sufficient to consider only two generic $q\bar{q}$-states, the first one grouping ρ^0, ω and ϕ and $\pi^+\pi^-$-states up to the ϕ-mass together and the second one including all $q\bar{q}$-states with higher masses [7].

Direct photon interactions are treated as either gluon-Compton scattering or photon-gluon fusion processes on a single nucleon. The consideration of so-called anomalous interactions allows a steady transition between direct and resolved interactions [4].

Finally, an interface to LEPTO6.5 [25] allows to simulate deep-inelastic scattering off nuclei.

3.3 The Gribov-Glauber Multiple Scattering Formalism

The Monte Carlo realization of the Gribov-Glauber multiple scattering formalism follows the algorithms of [9] and allows the calculation of total, elastic, quasi-elastic and production cross sections for any high-energy nuclear collision. Parameters entering the hadron-nucleon scattering amplitude (total cross section and slope) are calculated within PHOJET.

For photon-projectiles ideas of the GVDM have been incorporated in order to correctly treat the mass of the hadronic fluctuation and its coherence length

as well as pointlike photon interactions [4]. Realistic nuclear densities and radii are used for light nuclei and Woods-Saxon densities otherwise.

During the simulation of an inelastic collision the above formalism samples the number of "wounded" nucleons, the impact parameter of the collision and the interaction configurations of the wounded nucleons. Individual hadron(photon,nucleon)-nucleon interactions are then described by PHOJET including multiple hard and soft pomeron exchanges, initial and final state radiation as well as diffraction.

As a new feature, DPMJET-III allows the simulation of enhanced graph cuts in non-diffractive inelastic hadron-nucleus and nucleus-nucleus interactions. For example, in an event with two wounded nucleons, the first nucleon might take part in a non-diffractive interaction whereas the second one scatters diffracively producing only very few secondaries. Such graphs are prediced by the Gribov-Glauber theory of nuclear scattering but are usually neglected.

Finally, all color neutral strings are hadronized according to the Lund model as implemented in PYTHIA [26,27].

3.4 The Intranuclear Cascade and Break-up of Excited Nuclei

The treatment of intranuclear cascades in spectator prefragments and their subsequent fragmentation is largely identical to the one described in Refs. [11,12].

Particles created in string fragmentation processes are followed on straight trajectories in space and time. A certain formation time is required before newly created particles can re-interact in the spectator nuclei. These re-interactions are of low energy and are described by HADRIN[13] based on parameterized exclusive interaction channels. In nucleus-nucleus collisions the intranuclear cascade is calculated in both the projectile and target spectators.

Excitation energies of prefragments are calculated by summing up the recoil momenta transfered to the respective prefragment by the hadrons leaving the nuclear potential (a constant average potential is assumed). The prefragments are assumed to be in an equilibrium state and excitation energy is dissipated by the evaporation of nucleons and light nuclei and by the emission of photons.

4 Comparison to Experimental Data

Since DPMJET-III is the result of merging DPMJET-II and DTUNUC-2 its predictions have to be in agreement to experimental data where there was agreement for the two latter codes before. However, this has to be proven again. Here, only a few examples are given which should represent the large amount of comparisons of DPMJET-III results with experimental data which exist.

Fig. 1a shows the transverse momentum distribution of negative hadrons from p-W collisions together with data [28]. The rapidity distributions of negative hadrons in central S-S and S-Ag collisions are compared to data [29] in Fig. 1b. Two examples for interactions involving photons are given in Fig. 2. Hadronic interactions of muons are described by the radiation off the muon of a quasi-real photon and the subsequent interaction of the photon. Fig. 2a shows average

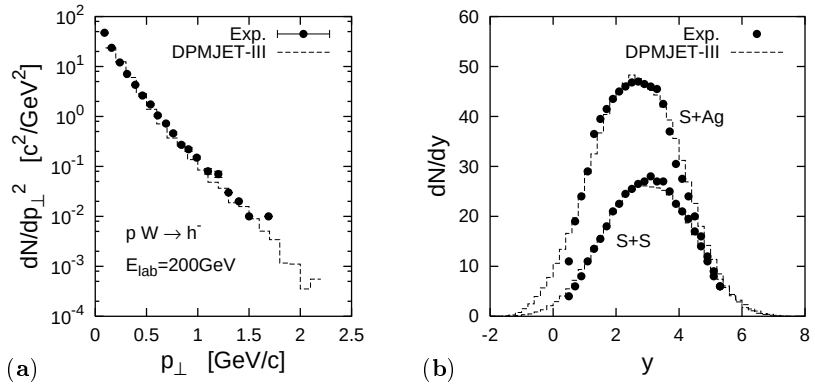

Fig. 1. Negatively charged hadron production in nuclear collisions at 200 GeV/nucleon

multiplicities of charged hadrons from μ-Xe interactions at 490 GeV compared to data [30]. In Fig. 2b the calculated inclusive transverse momentum cross section of charged particles produced in two-photon collisions at LEP is compared to the combined data set of the ALEPH, L3, and OPAL Collaborations for low-Q^2 deep inelastic scattering [31].

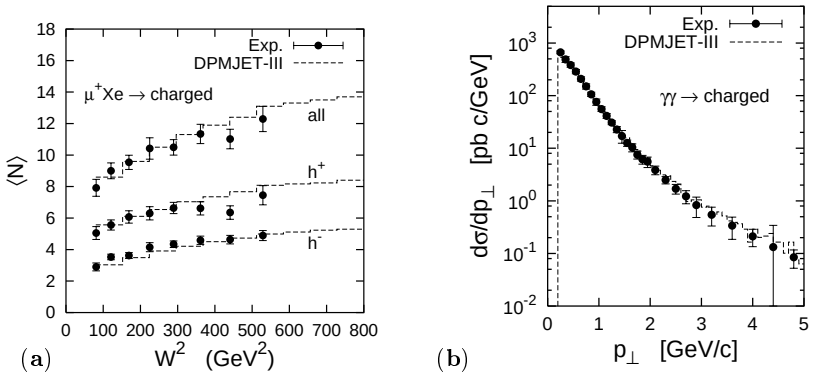

Fig. 2. Comparison of DPMJET-III results to data on interactions involving photons.

5 Conclusions

A new version of the DPMJET event generator is presented. DPMJET-III is based on DPMJET-II, DTUNUC-2 and PHOJET1.12 and unifies all features of these three event generators in one single code system. It has been thoroughly tested and, in due time, will largely superseed the older DPMJET and DTUNUC versions.

It is presently not advisable to use the code for very low-energy nucleus-nucleus collisions (below $\approx 10-20$ GeV). This requires further testing and tuning of parameters. Furthermore deficiencies exist in the description of some effects observed in heavy ion collisions at AGS- and SPS-energies (e.g. strangeness enhancement, transverse energy flow).

The code is available on request from the authors (Stefan.Roesler@cern.ch, Johannes.Ranft@cern.ch) and further information can be found on the World Wide Web (`http://home.cern.ch/sroesler/dpmjet3.html`).

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