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Physics of Simulation Machines: The Event Generators

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Abstract **-- The tool used to make predictions for collision experiments taking into account all aspects of QCD are Monte Carlo (MC) event generators. The most important feature of this generator is the ability to generate results at hadron level by the simulation of full events as they are observed by a detector in reality. They are widely used by the experimentalists for data analysis as well as by theorists to make predictions. As event generators are main tools in high energy physics, so it is important to know the physics behind these event generators. The aim of this review paper is to explain the physics behind event generators, which are mostly common between almost all the event generators. In this paper we present an overview of physics aspects of general purpose event generators so that event generators are considered as real physics tools rather than black boxes.**

Keywords **- Monte Carlo Event generator; Large Hadron Collider; Tevatron; Parton Density Functions.**

I. INTRODUCTION

General purpose event generators play an essential role not only in data analysis but also in QCD modeling and planning future experiments. The most important feature of these generator is the ability to generate results at hadron level by the simulation of full events as they are observed by a detector in reality. The purpose of this review is to illustrate the main components of general purpose Monte Carlo event generators (GPMCEG).

II. MAIN PHYSICS ASPECTS OF MC EVENT GENERATOR

The processes involved in an event are complex, including many physical aspects which can be either strong interaction or electroweak. Therefore, a description of a typical high energy physics process should simulate several sub-processes. It is divided into the following sections:

III. HARD SCATTERING

Hadrons are composite objects made up of partons (quarks and gluons). Initially one parton from each hadron undergo a hard collision. Short lived resonances such as the top, $W^{\pm}$, Z^0 are produced in the hard processes which subsequently decay into their decays products [1].

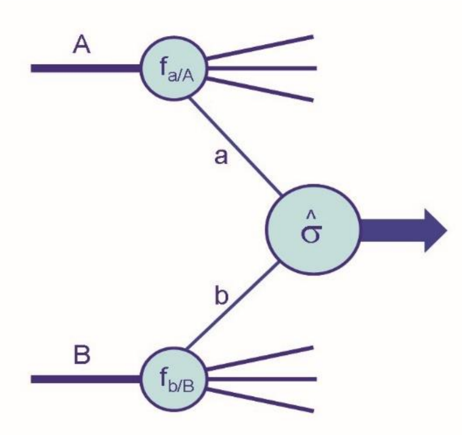

Fig. 1 Diagrammatic structure of a generic hard scattering process [2]

So it is essential to first consider the partonic structure of the colliding hadrons. The QCD factorization theorem can be used to calculate a wide variety of hard scattering cross sections in hadron-hadron collisions. It rests on the concept that parton model ideas (originally developed in the context of deep inelastic scattering) could be extended to hadron-hadron collisions. The QCD factorization theorem states that the hadronic cross section σ $(AB \rightarrow \mu^+\mu^- + X)$ is a convolution of the partonic cross section $\hat{\sigma}$ for $q\bar{q} \rightarrow \mu^+\mu^-$ with the parton distribution functions $f_{q/A}(x)$ extracted from deep inelastic scattering processes, corresponding to the structure depicted in Fig. 1. Hard scattering is calculable by perturbative quantum field theory, the starting point for which is Matrix Elements (MEs).

IV. PARTON SHOWER

Emissions associated with the two incoming colliding partons are called Initial State Radiation (ISR). Such emissions can be modeled by so calledspace like parton showers i.e. partons have $m^2 = E^2P^2 < 0$. Emissions associated with outgoing partons are instead called Final State Radiation (FSR), and can be approximated by time like parton showers i.e. partons have $m^2 = E^2P^2 \geq 0$. Fig. 2 shows schematically a hard hadron collision. Two hadrons (*A* and *B*) are coming in and one incoming parton in each hadron undergoes a hard scattering, resulting in outgoing partons. The hard scattering of the incoming partons at a scale *Q*, can be calculated using perturbative QCD.

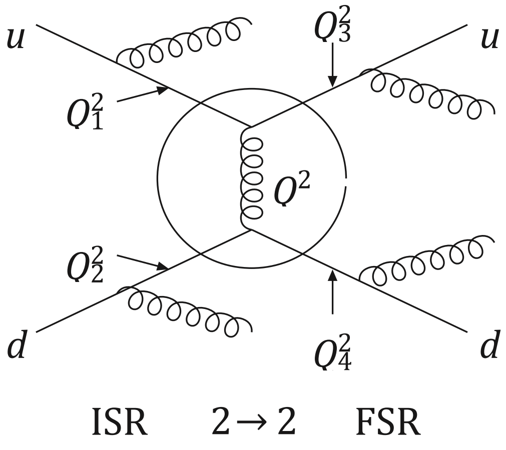

Fig. 2 The factorization of a 2→n process

But all incoming and outgoing partons undergo branchings as well, giving rise to the parton showers (and to scale dependent PDFs). A lower order perturbative calculation fails to describe the shower behavior, where perturbative QCD calculations become too complicated at higher orders to be used. But an approximate perturbative treatment of QCD to all orders is adequate at describing the branching physics.

V. MULTIPLE PARTON INTERACTIONS

As beam particles consists of multiple partons, so there is maximum probability for several interactions in the same event. These additional interactions arises because one parton from one beam is scattering against various different partons from the other beam in a hadron-hadron collision.

Charged particle density, p⊥> 100MeV, √s = 7TeV

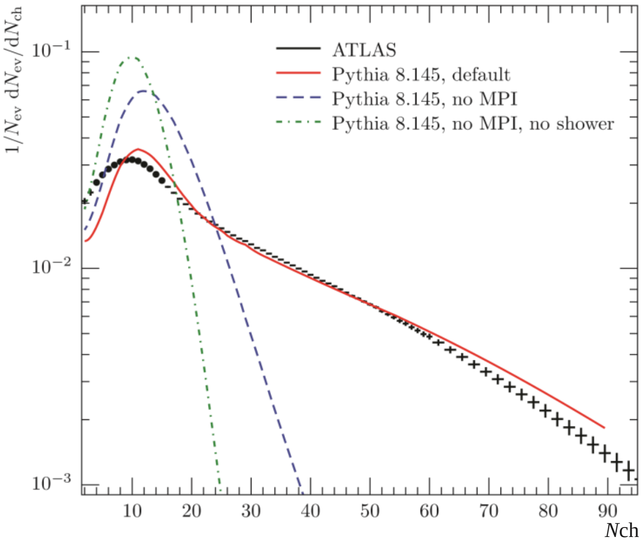

Fig. 3 Description of the charged particle multiplicity measured by the ATLAS experiment with/without MPI and parton showers [3], for particles with pt>100 MeV, | η |<2.5[4]

Fig. 3 shows the comparison of the ATLAS minimum bias charged track multiplicity to a Monte Carlo model with and without MPI. It is clearly seen that the multiplicity distribution cannot be predicted without MPI. This behavior is independent of whether parton showers are included or not. Description of multiplicity distribution is a strongest argument that MPI must be included in realistic models of soft physics. Many calculationsof the total hadron hadron cross section [4-5] also support the presence of MPI.

Sjöstrand and van Zijl [6] proposed first detailed Monte Carlo model for perturbative MPI , still a similar physical picture is used in most modern implementations. Useful additional references can be found in [7-9].

VI. HADRONISATION

It is well known that QCD perturbation theory is accurately described at short distance scale whereas this theory breaks at large distances because partons interact strongly in this regime. Hadronization is basically non perturbative process for which different models have been proposed. PYTHIA uses the Lund model [10] to describe the hadronization process. The Lund model calculates the transition from a multi-parton system to final state hadrons with a string fragmentation model. Details can be found in [1,11, 12]. It describes the behavior of quarks inside hadrons. The string gets potential energy by the movement of the quarks. This potential energy increases as q-q pair move apart, and at some point string breaks by the production of new quark antiquark pair. In other words, inside the string field quark antiquark fluctuations absorb energy from the string to become real particles. According to Lund model, the string breaks proceed with the outermost hadrons, containing the endpoint quarks, towards the center of the string until only on mass shell hadrons remain.

VII. CONCLUSION

Event generators are software libraries that provide the full simulations of the high energy collision. They randomly generate events as those produced in particle accelerators or in early universe. The main physics aspects of the general purpose Monte Carlo event generators are reviewed.

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