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DECAY: A Monte Carlo Library for the Decay of a Particle with ROOT Compatibility

Radosław A. Kycia[1,2,*], Piotr Lebiedowicz[3] and Antoni Szczurek[3,4]

[1] *Masaryk University, Department of Mathematics and Statistics, Kotlářská 267/2, 611 37 Brno, The Czech Republic.*
[2] *Cracow University of Technology, Faculty of Materials Science and Physics, Warszawska 24, PL-31155 Kraków, Poland.*
[3] *Institute of Nuclear Physics Polish Academy of Sciences, Radzikowskiego 152, PL-31342 Kraków, Poland.*
[4] *College of Natural Sciences, Institute of Physics, University of Rzeszów, ul. Pigonia 1, PL-35310 Rzeszów, Poland.*

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Abstract. Recently, there is a need for a general-purpose event generator for decays of an elementary particle or a hadron to a state of higher multiplicity ($N \geq 2$) that is simple to use and universal. We present the structure of such a library for preparation of generators that generate kinematics of decay processes and can be used to integrate any matrix element squared over phase space of this decay. Some test examples are presented, and results are compared with results known from the literature. As one of examples we consider the Standard Model Higgs boson decay into four leptons. The generators discussed here are compatible with the ROOT interface.

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1 Introduction

In modern high energy physics or hadronic physics, the prime role is played by complex multiprocess Monte Carlo generators. One example of such a versatile tool is PYTHIA [1,2].

However, apart from beam colliding experiments, there are various experiments (e.g., [3–7]) that measure decaying unstable particle products. In many cases, there are specific

*Corresponding author. *Email addresses:* kycia.radoslaw@gmail.com (R. A. Kycia), Piotr.Lebiedowicz@ifj.edu.pl (P. Lebiedowicz), Antoni.Szczurek@ifj.edu.pl (A. Szczurek)

generators for such processes, with specific matrix elements and kinematics tuned for the particular decay.

However, in some theoretical investigation, there is a need for a simple yet versatile generator for prototyping new theories or to understand mechanism of decays of mesons or baryons. Good examples are exotic decays of conventional mesons, decays of glueballs or tetraquarks. One typical choice is the GENBOD code [8] which uses the Raubold and Lynch algorithm. It is delivered in ROOT package [9–11] as `TGenPhaseSpace` class. There are some inconveniences in the use of this generator. The events are weighted, and it requires some additional work to integrate some expression over a phase space and generate events. Moreover, some additional tools must be added to provide adaptive Monte Carlo integration/simulation. In the current version there is also an artificial restriction to 18 particles in the final state.

Some inconveniences were present during our theoretical investigations of the phenomenology of decaying processes [12–14], where the $1\to 4$ decay process was simulated from the $1\to 2$ process with a corresponding spectral functions. This motivated us to construct a new, more powerful Monte Carlo generators for decays that have no constraints for the multiplicity of particles in the final states. They should be compatible with ROOT software and, due to adaptivity, can handle with integrands that have 'small' support in the Lorentz Invariant Phase Space (LIPS). These tools are based on some elements from our previous exclusive MC generator GenEx [15, 16]. The essential requirement in designing these tools is that the interface should be fully compatible with ROOT generator `TGenPhaseSpace` and use effectively other ROOT components. The generators are implemented in C++ 2011, however it uses rather standard C++ grammar, so it should be also compatible with newer standards.

One of the application of these tools will be to use them in central exclusive diffractive production of $\pi^+\pi^-\pi^+\pi^-$ [12, 17] and $K^+K^-K^+K^-$ [13] in proton-proton collisions that proceeds via resonances. These processes are under recent experimental studies at RHIC and LHC [5–7].

Another application is their use in search of hypothetical resonances of new physics and study their properties, e.g., in the four-lepton channel [18, 19]. The $H \to ZZ \to 4\ell$ channel, as compared to other final states, has the advantage of being experimentally clean and, for this reason, is considered the "golden" channel to explore the possible existence of a heavy Higgs resonance. As an example, we consider the decay $H\to ZZ\to 4\ell$ of spin 0 Higgs boson with mass $M_H = 125.1$ GeV.

The paper is organized as follows: In the next section, implementation details and usage of the library will be presented. The package also contains three generators for decays with two, three, and four particles in the final states. The physical process of these kinds for testing purposes are described in the second part of the paper. These are the application of 4-Fermi theory to μ decay and the Standard Model Higgs boson decay into four leptons. We also discuss the usage of the software for generation of the phase space for a variable mass decay.