Simulations of Beyond Standard Model Physics in Herwig++

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Outline

- Basics of event generation,
- Outline of method for inclusion of BSM physics in Herwig++,
- Results.

Event Generation

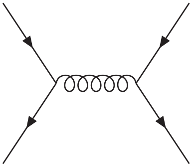
An event generator aims to give a realistic description of the final-state particles that interact with a detector.

Herwig++ is a new C++ general-purpose event generator built upon the experience of its predecessor HERWIG but with many improvements to the physics simulation.

General-purpose means that it is capable of handling all stages of the event generation process.

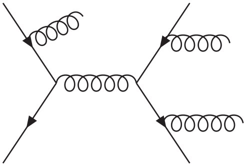
Monte Carlo Event

Hard Interaction



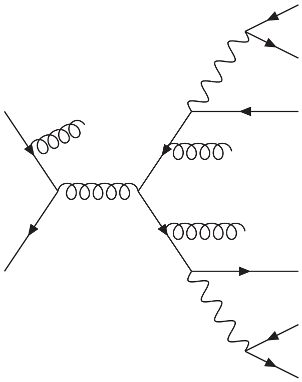
Monte Carlo Event

Hard Interaction • Parton Showers



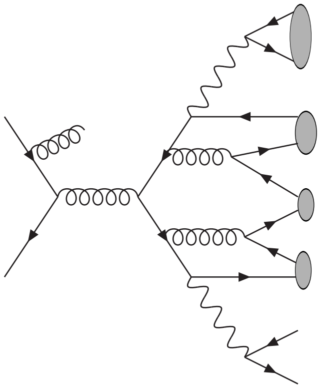
Monte Carlo Event

Hard Interaction • Parton Showers • Perturbative Decays



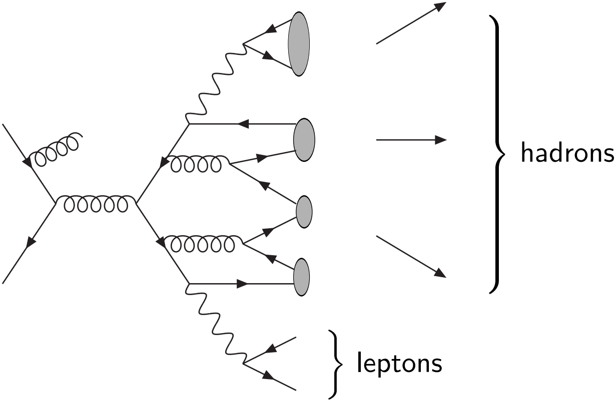
Monte Carlo Event

Hard Interaction • Parton Showers • Perturbative Decays • Hadronization



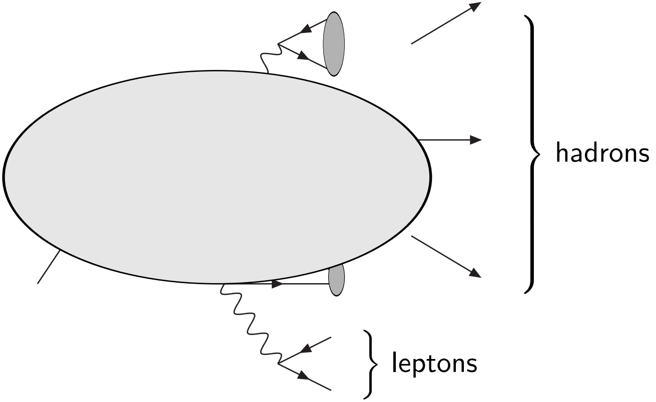
Monte Carlo Event

Hard Interaction • Parton Showers • Perturbative Decays • Hadronization • Decays



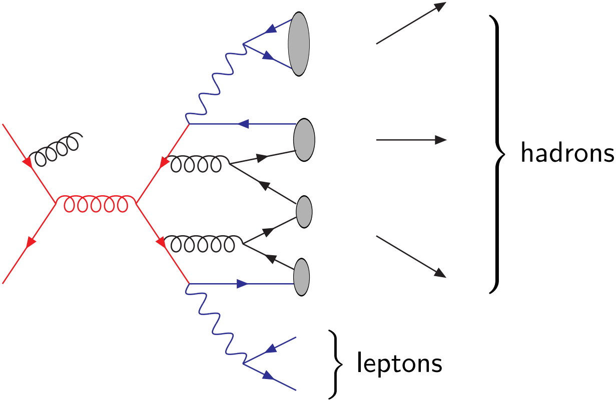
Monte Carlo Event

Hard Interaction • Parton Showers • Perturbative Decays • Hadronization • Decays • Underlying Event



BSM Steps

Hard Interaction • Parton Showers • Perturbative Decays • Hadronization • Decays



Issues and Motivation

In older generators new model processes were encoded by hand.

At the LHC we do not know what type of BSM physics will be discovered.

Implement a mechanism by which new physics models can be incorporated into Herwig++ with a minimal amount of work

Do not compromise on the simulation of the physics, *i.e.* automatically include things like spin correlations throughout the simulation.

Requirements

- A set of Feynman rules for the new model;
- A list of all the new states in the model;
- Information on the calculation of the new particle spectrum.

M. Gigg and P. Richardson, Eur. Phys. J. C51 (2007) 989 [arXiv:hep-ph/0703199].

Using available C++ facilities, we split the information up into spin-dependent parts and model dependent parts.

Feynman Rules

These tell us how the new states in our model interact with each other.

For example, consider the FFV vertex:

$$\mathrm{ic}\bar{\psi}\gamma^{\mu}\left(a_L P_L + a_R P_R\right)\psi\,\epsilon_{\mu}$$

Model specific information is contained in the constants c ,a_L, a_R.

In addition to having functions to calculate quantities related to that vertex type, each stores a list of particles that can interact there.

Hard Process

We need to calculate $|\mathcal{M}|^2$ for a given process.

Herwig++ contains a library of classes designed to calculate the matrix element for a $2 \rightarrow 2$ process with each class being based upon particular set of external spins.

While calculating the full matrix element we store the amplitude level information, which is used to keep the spin correlations throughout the event generation - P. Richardson, JHEP 0111 (2001) 029, [arXiv:hep-ph/0110108].

While showering and hadronization are separate stages, they require an colour structure for the hard process to be set up.

Model Spectrum & Perturbative Decays

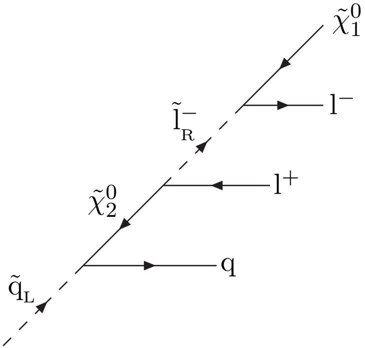
Again we have a library of classes capable of calculating the matrix element for a particular spin configuration of a $1 \rightarrow 2$ decays (we are currently working on the $1 \rightarrow 3$ decays)

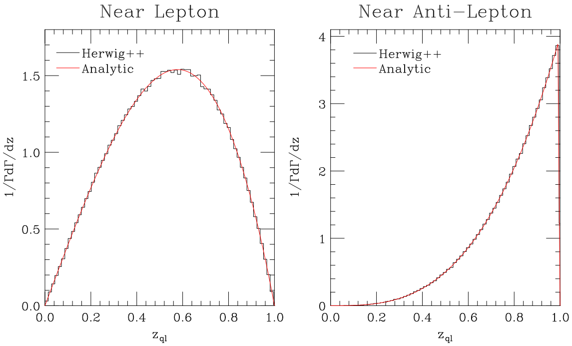
For a supersymmetric model there are spectrum generators that can also give a decay table in SUSY Les Houches (SLHA) format (Currently any three body decays that are read in will be decayed via phase-space).

Other models do not have such generators therefore the information on how to calculate the spectrum must also be given. The possible decays are then determined automatically.

Minimal Supersymmetic Standard Model

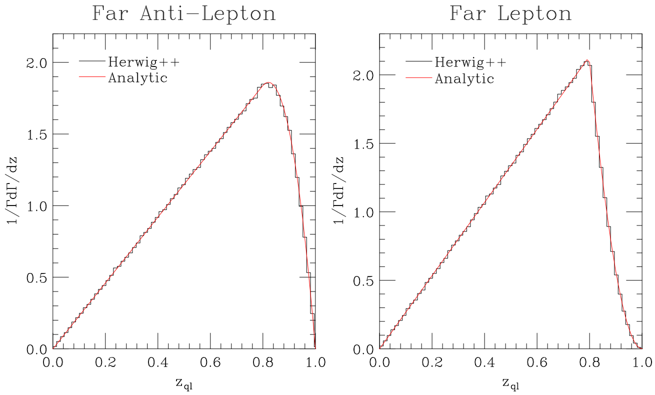
For parameter point SPS 1a





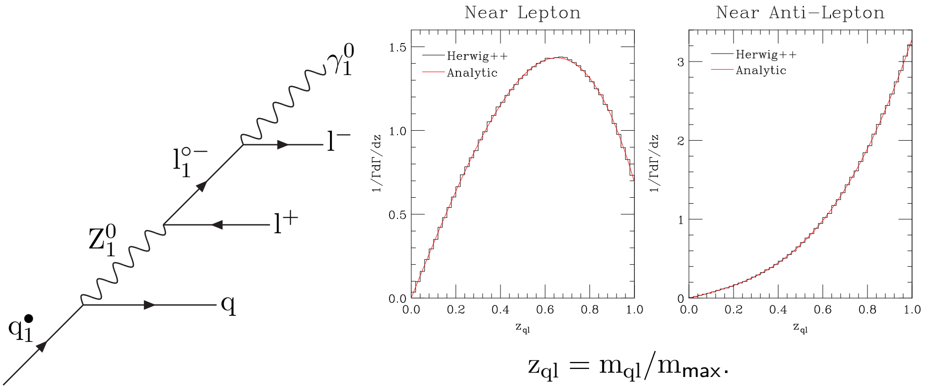
$$z_{ql} = m_{ql}/m_{max}.$$

Minimal Supersymmetric Standard Model



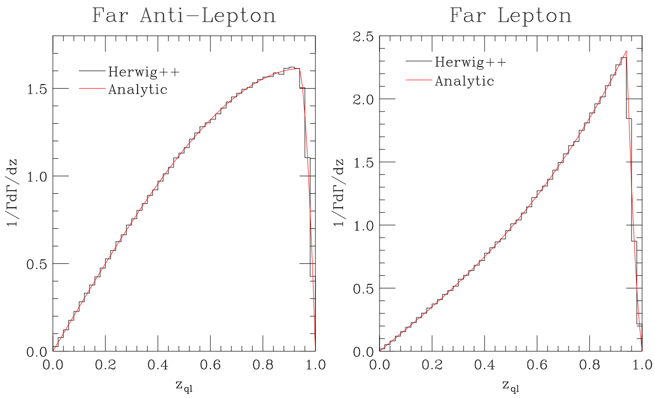
Minimal Universal Extra Dimensions

Plots for $\mathrm{R}^{-1} = 500\,\mathrm{GeV}$ and $\Lambda\mathrm{R} = 20$ in MUED.



$$z_{ql} = m_{ql}/m_{max}.$$

Minimal Universal Extra Dimensions

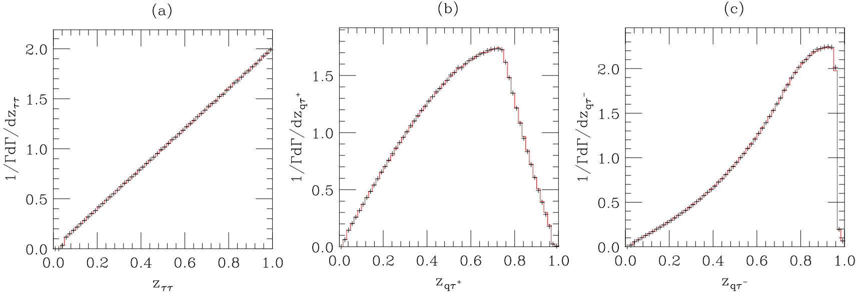


Analytic expressions taken from JHEP 0510 (2005) 069 [arXiv:hep-ph/0507170], J. M. Smillie and B. R. Webber

Invariant Mass Distributions

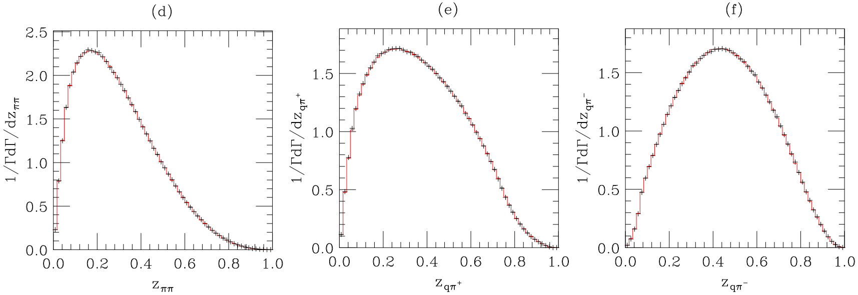
Another interesting set of distributions occur from a similar chain $\tilde{q}_L \to q\,\chi_2^0 \to \tau_{near}^{\pm}\,\tilde{\tau}_1^{\mp} \to \tau_{far}^{\mp}\,\chi_1^0$ where the the τs decay to a $\pi\,\nu_\tau$

τ distributions:



Invariant Mass Distributions

π distributions:



Plots for SPS1a where the red line is HERWIG+TAUOLA and the black crosses are Herwig++.

Summary

- Incorporating new BSM physics models in to Herwig++ is now a simpler task,
- High multiplicity final states are achieved by generic $2 \longrightarrow 2$ production processes followed by perturbative decays with full spin correlations,
- The models available in subsequent releases will be Randall-Sundrum Model, MSSM, MUED, NMSSM, Little Higgs with and without T-Parity,
- The code and the manual can be downloaded from `http://projects.hepforge.org/herwig`.