Fully Parameterised Fast Monte Carlo Simulation in LHCb

2016 IEEE Nuclear Science Symposium

Benedetto G. Siddi
03/11/2016
The role of Monte Carlo simulation in high energy physics experiment is to mimic the behaviour of a detector to understand experimental conditions and performance.

Monte Carlo data is processed as real data in Reconstruction and Physics Analysis, but it contains the information about the generated events.

Comparing real and simulated events, we can understand detector effects and obtain pdf's for signal and background components.
The LHCb Detector

- **Single arm spectrometer** at LHC in the pseudorapidity range $2<\eta<5$;
- Optimized to study hadron decays containing $b$ and $c$ quarks:
  - CP violation, rare decays, heavy flavor production;
- **Excellent vertex resolution** and separation of B vertices;
- Good momentum and mass resolution;
- Excellent PID capabilities (good separation $K-\pi$ and muon identification);

- Run 1: collected $1.1 \text{ fb}^{-1} @ \sqrt{s} = 7 \text{ TeV}$ in 2011 and $2.1 \text{ fb}^{-1} @ \sqrt{s} = 8 \text{ TeV}$ in 2012
- Run 2: collected about $2.0 \text{ fb}^{-1} @ \sqrt{s} = 13 \text{ TeV}$
- Full Detector Simulation and Full Event Reconstruction are very detailed but slow;
- Fast Detector Simulation and Fast Event Reconstruction are faster but less detailed. It is possible:
  - To simplify the slowest part of simulation (e.g. calorimeter response) and reconstruction (e.g. track reconstruction)
  - Fully parameterise the response of the detector and the reconstruction using specific libraries like Delphes, described later in this talk
The current simulation framework in LHCb exploit the modularity of the Gaudi\textsuperscript{1} Architecture

\textsuperscript{1}http://inspirehep.net/record/568472
Delphes is a modular framework for fast simulation. It is written in C++ and is available as a library. Originally written for LHC central colliders:

- The parametric simulation includes:
  - tracking system, embedded into a constant magnetic field,
  - calorimeters with electromagnetic and hadronic sections,
  - muon system,
  - very forward detectors arranged along the beam-line

- It performs:
  - propagation of stable particles,
  - “interaction” with the detector (parametric approach to efficiency and resolution convolution),
  - reconstruction of physics objects
Fully Parameterised Fast Monte Carlo Simulation in LHCb

B. Siddi
INFN Ferrara

2016 IEEE Nuclear Science Symposium
Delphes in LHCb

• What is the minimal output necessary to do analysis in LHCb?

• We want to be able to do a simple analysis with Delphes output using as much as possible existing LHCb analysis tools

• Proto Particles (i.e. holder of objects)
  • Pointers to tracks
  • Pointers to Calo objects
  • Pointer to Rich objects

No lower level reconstructed objects!
Delphes flow

- Delphes version 3.3.0 + modifications for LHCb, has been integrated in LHCb simulation framework Gauss.
  - It takes in input particles generated from the generator part of Gauss,
  - It writes as output objects in the format necessary for LHCb analysis framework.
- The final Goal is to have a fully usable Delphes within Gauss for physics analysis.

Delphes workflow

- Propagator inside constant magnetic field
- Efficiency smearing module
- Momentum smearing for different particles types
- Merge all smeared tracks in a single particles container

- HepMC Reader

- ChargedHadronEfficiency
  - chargedHadrons
  - electrons
  - muons

- ElectronEfficiency
  - electrons

- MuonEfficiency
  - muons

- ChargedHadronMomentumSmearing
  - chargedHadrons
  - electrons
  - muons

- ElectronEnergySmearing
  - electrons

- MuonMomentumSmearing
  - muons

- TrackMerger
  - stableParticles
Delphes flow

- Delphes version 3.3.0 + modifications for LHCb, has been integrated in LHCb simulation framework Gauss.
  - It takes in input particles generated from the generator part of Gauss,
  - It writes as output objects in the format necessary for LHCb analysis framework.
  - The final Goal is to have a fully usable Delphes within Gauss for physics analysis.

Delphes workflow

- Track Merger
- Smearing of the impact parameter
- MisID smearing by giving a misidentification probability
- Calorimeter response smearing
- Calorimeter response merger
Modification of Delphes

- The original Delphes Particle Propagator module has been written for a solenoidal magnetic field in a cylindric acceptance.
- Now it has been rewritten:
  - LHCb acceptance;
  - Simple transport in a dipole field;
  - 3 different acceptance regions for charged particles.

- In acceptance before the magnet and not after (1)
- In acceptance after the magnet and not before (2)
- In acceptance both before and after the magnet (3)

Original Delphes output shows a cylindrical symmetry not suitable for LHCb.
Modification of Delphes

- The original Delphes Particle Propagator module has been written for a solenoidal magnetic field in a cylindric acceptance.
- Now it has been rewritten:
  - LHCb acceptance;
  - Simple transport in a dipole field;
  - 3 different acceptance regions for charged particles.

- In acceptance before the magnet and not after (1)
- In acceptance after the magnet and not before (2)
- In acceptance both before and after the magnet (3)

Delphes output after new Particle Propagator module, 
\( z = \) the end of the tracking system
Resolution and efficiencies

- Track resolution and efficiency parameterisation is obtained from LHCb full simulation.

**Efficiencies**
- Reconstructed in tracker acceptance
  - Binning variables: X, Y, angle $\phi$

**Resolutions**
- MC Rec - MC Truth RMS
  - Binning variables: Tx, Ty, Momentum P

B. Siddi
INFN Ferrara

Fully Parameterised Fast Monte Carlo Simulation in LHCb

2016 IEEE Nuclear Science Symposium
Validation of Delphes in LHCb

- The new Delphes module has been tested with a sample of min bias events reconstructed within Delphes and compared with the LHCb full simulation.

![Distribution of slope $T_y$, blue Delphes, red full Simulation](image1)

![Distribution of $x$ variable, blue Delphes, red full Simulation](image2)
Conclusions

- Fast simulation is a crucial in LHC experiments to cope with the large amount of Monte Carlo statistics needed for upgrades.

- Delphes has been integrated within the LHCb simulation framework Gauss.

- Delphes has been extended for LHCb with:
  - A simple propagator for propagating particles inside the LHCb acceptance and magnetic field;
  - Particle efficiencies and resolution smearing according to the LHCb full simulation.

- The first results for the comparison between full and fully parameterised simulations have been shown here; the next step is to reduce as much as possible the differences and make this implementation usable for physics analysis.