

The ATLAS Fast Monte Carlo Production Chain Project

This content has been downloaded from IOPscience. Please scroll down to see the full text.

2015 J. Phys.: Conf. Ser. 664 072024

(<http://iopscience.iop.org/1742-6596/664/7/072024>)

View [the table of contents for this issue](#), or go to the [journal homepage](#) for more

Download details:

IP Address: 137.138.124.206

This content was downloaded on 24/02/2016 at 13:45

Please note that [terms and conditions apply](#).

The ATLAS Fast Monte Carlo Production Chain Project

Roland Jansky, on behalf of the ATLAS Collaboration

University of Innsbruck, Innsbruck, Austria

E-mail: roland.jansky@cern.ch

Abstract. During the last years ATLAS has successfully deployed a new integrated simulation framework (ISF) which allows a flexible mixture of full and fast detector simulation techniques within the processing of one event. The thereby achieved possible speed-up in detector simulation of up to a factor 100 makes subsequent digitization and reconstruction the dominant contributions to the Monte Carlo (MC) production CPU cost. The slowest components of both digitization and reconstruction are inside the Inner Detector due to the complex signal modeling needed in the emulation of the detector readout and in reconstruction due to the combinatorial nature of the problem to solve, respectively. Alternative fast approaches have been developed for these components: for the silicon based detectors a simpler geometrical clustering approach has been deployed replacing the charge drift emulation in the standard digitization modules, which achieves a very high accuracy in describing the standard output. For the Inner Detector track reconstruction, a Monte Carlo generator information based trajectory building has been deployed with the aim of bypassing the CPU intensive pattern recognition. Together with the ISF all components have been integrated into a new fast MC production chain, aiming to produce fast MC simulated data with sufficient agreement with fully simulated and reconstructed data at a processing time of seconds per event, compared to several minutes for full simulation.

1. Introduction

During the successful run 1 of the Large Hadron Collider (LHC) ATLAS [1] Grid CPU usage was dominated by Monte Carlo (MC) production (see fig. 1). These resources were needed because of the required very precise, but also highly CPU demanding full simulation which was mainly used. Besides the CPU usage also ATLAS consumption of available disk-space on the GRID was dominated by storing MC event samples (fig. 2). This put a limit on the available MC statistics and therefore directly limited the sensitivity of certain physics analyses. With the increased luminosity as well as the higher pileup expected for run 2 this situation will even worsen. Both of these changes will make the production of larger MC samples as well as the reconstruction of the events a far bigger challenge. The need for faster methods to produce MC events with reasonable agreement to full simulation is therefore evident. ATLAS plans to achieve this by introducing the so called fast MC production chain.

As already stated the very accurate detector simulation, but also the detailed digitization procedure and the track reconstruction are the main consumers of ATLAS computing resources. The idea to achieve a faster MC production is to sacrifice a certain level of this accuracy for speed. This can be done by simulating in detail only what is needed and using fast simulation approaches otherwise. Digitization can be parametrized in order to skip the very detailed emulation of



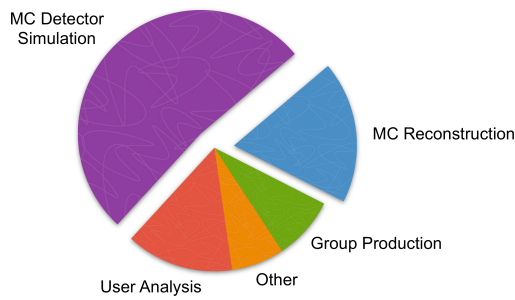


Figure 1. Relative CPU grid usage averaged over all ATLAS grid sites in 2012.

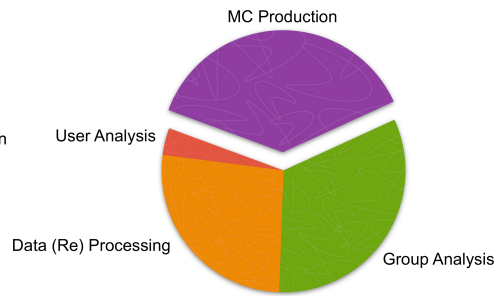


Figure 2. Relative grid disk utilization averaged over all ATLAS grid sites for the year 2012.

detector readout effects done in the full simulation chain. Likewise the track reconstruction can be speed-up by not running the CPU demanding pattern recognition but instead utilizing the information from simulation to directly reconstruct tracks. This trade off between accuracy and speed is demonstrated in fig. 3. To further optimize this in respect of resource consumption, it is reasonable to combine all these alternatives into one chain, going from event generation to a ROOT [2] readable file suitable for analysis usage, without intermediate output. This minimizes file I/O overhead and disk-space.

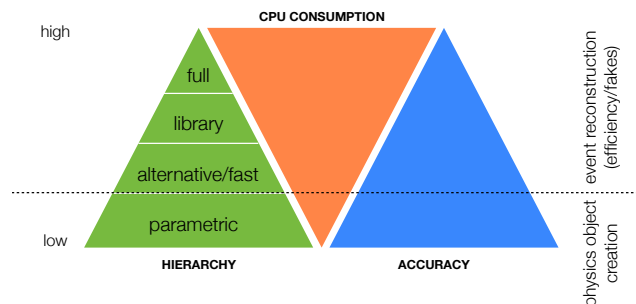


Figure 3. Accuracy pyramid sketching the dependency of CPU consumption and accuracy on the respective used MC approach.

2. Full MC Production Chain

The bulk production of MC events for ATLAS is usually performed on the GRID and is described elsewhere [3]. Here a short overview of the main components of this production chain are presented. This standard chain structure applies to the default full simulation based on Geant4 [4], but is also valid for alternative approaches [5].

2.1. Event Generation

The first step in the MC production chain is the generation of the physics event by creating sets of particle four-momenta. In ATLAS this step is typically carried out by event generators, such as PYTHIA [6] and HERWIG [7]. MC event generators are usually externally provided

software packages that are interfaced to the ATLAS software. Decays of non-stable particles that do not reach the detector material are carried out by the event generator, stable or longer lived particles that are to decay in the detector volume are forwarded to the detector simulation.

2.2. Detector Simulation

The next step is the simulation of the interaction of the particles with the sensitive and non-sensitive detector material. In sensitive detector elements, interacting particles create so called hits, which are collected for further processing in the digitization step.

2.3. Digitization

Hits created in the detector simulation need to be further processed to mimic the output of the detector readout. This process is different for every sub-detector and includes many subtle effects including signal collection, pulse shaping, readout emulation and many more. Common to almost all sub-detectors is however that the digitization deals with the noise modeling, channel masking and – most prominently in ATLAS – with the event pileup.

2.4. Reconstruction

Event reconstruction consists of the local pattern recognition (i.e. the clustering and resolving of readout channels on the readout detector elements), reconstruction of tracks, segments, vertices, cells and clusters in the different sub-detectors, and finally the creation of high level objects, such as particles of different identification, jets including their flavor tag, or missing energy estimation.

3. Fast Detector Simulation

Full MC simulation is based on Geant4 – the most commonly used detector simulation, which is fully validated for run 2 – and provides a very detailed description of every possible particle interaction within the detector (which in simulation consists of up to 30 million volumes). This comes at the cost of being highly CPU intensive (up to 15 minutes/event), where most of this time is spend in the electromagnetic calorimeter. Some faster approaches used within ATLAS are described below. The Frozen Showers method [8] replaces low-energetic particles in particle showers with pre-simulated Geant4 electromagnetic showers based on particle characteristics, like its energy. This is already the default approach for the forward electromagnetic calorimeters, even in full simulation.

| ISF simulation setup | Speedup | Accuracy |
|---|---------|---|
| Full Geant4 | 1 | best possible |
| Geant4 with FastCaloSim | ~25 | approximated calorimeter |
| Fatras with FastCaloSim | ~750 | all subdetectors approximated |
| Fatras with FastCaloSim simulate only particles in cones around photons | ~3000 | all subdetectors approximated event simulated only partially |

gg → H → γγ no pileup

Figure 4. Comparison of different simulation options possible with the ISF and their possible relative speed-up for $gg \rightarrow H \rightarrow \gamma\gamma$ events without pileup contributions.

The main feature of the so called ATLFASTII production setup is FastCaloSim [9]. Once again this is utilizing a parametrization of the calorimeters response based on pre-computed tables derived from full simulation. With the help of data, this can be tuned to be accurate enough to represent the physical interactions correctly. Figure 5 nicely shows the level of agreement which can be achieved. Muons are exempted from this and are still handled by Geant4. During the last MC production campaign, ATLAS simulated 3.9 billion events using the full simulation approach (combining Geant4 and frozen showers) and 3 billion events with ATLFASTII instead. The speed-up between the two is about a factor of 10.

FATRAS [10] is the analog for the fast simulation of a particle’s interaction with the ATLAS tracking system. It utilizes the geometry used by track reconstruction [11]. Instead of volumes the detector is described by thin layers and the interactions therein are modeled by fast algorithms. This can give an estimated boost in speed of a factor of two compared to full Geant4 simulation.

With the newly deployed integrated simulation framework (ISF) it is possible to mix these different simulation techniques within the same event, where the choice of simulator could depend on the detector region or the particle type. This enables the production chain to simulate in detail only the parts of the event which are relevant to the respective analysis and use the faster alternatives for the rest. The possible speed-ups through this method are described in fig. 4 for an example physics use case. A possible partition of the different simulator flavors depending on different factors is shown in fig. 6.

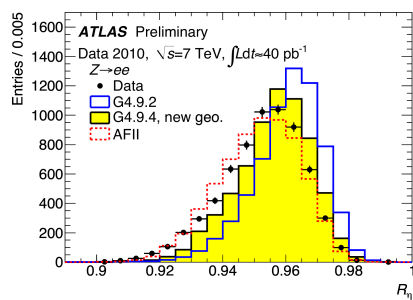


Figure 5. Ratio R_η of deposited energies in a 3x7 cells cluster with respect to a 7x7 cells cluster in the bulk electromagnetic calorimeter layer 2. The MC samples have been normalized to match the number of entries in data [12].

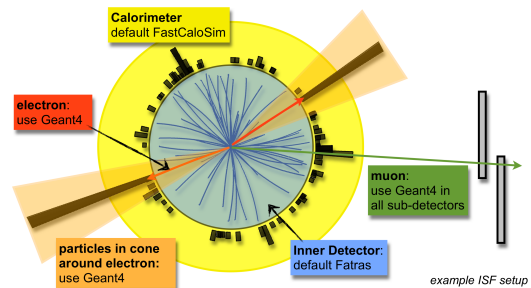


Figure 6. A sketch of a potential simulation setup using the ISF. The picture shows the flexibility of the framework, allowing for different simulators within the same event.

4. Fast Digitization

The previously shown possible speed-ups in simulation make the following component of the MC production chain the new bottleneck for achieving a truly fast MC production. About 50% of the CPU consumption in digitization comes from emulating the Inner Detector (ID). Hence two faster alternatives for the two different sensor technologies used within the ID were developed.

For the Silicon detector the charge deposition is estimated for each readout channel by projecting the simulated track length on the readout surface, see fig. 7. This is corrected for the Lorentz angle drift due to the ATLAS magnetic field. The charge deposits are furthermore smeared to account for multiple scattering of the drifting charge carriers.

In the Transition Radiation Tracker (TRT), the response is emulated from simulated hits by evaluating the radius of closest approach (see fig. 8). The uncertainty of the measurement is also taken into account by creating a smeared hit position. In addition the transition radiation response is parametrized to still allow particle identification.

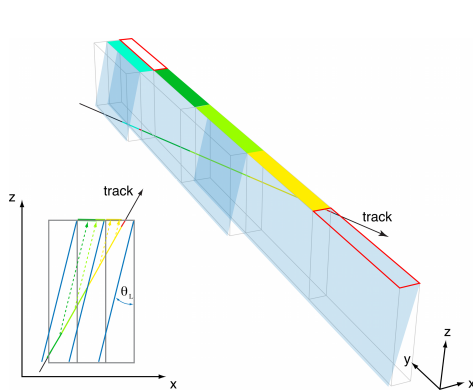


Figure 7. Sketch of the approach used for the fast digitization of silicon detectors: the particle path length is projected onto the sensitive surface, corrected for Lorentz angle drifts, and then smeared.

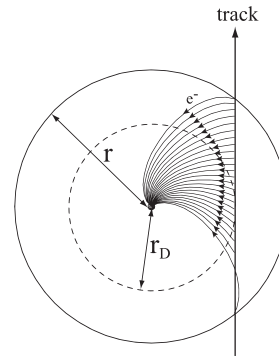


Figure 8. Sketch of the approach used for the fast digitization of the TRT: the radius of closest approach is calculated considering the uncertainty on the measurement from simulation, giving an estimate for the drift radius r_D used for reconstruction.

5. Fast Track Reconstruction

Track reconstruction finds particles trajectories from digitized hits. Due to the combinatorial problem, which rapidly grows in complexity with high pileup, this uses significant CPU resources even in the full MC chain. The main consumer is again the ID reconstruction. This motivates the switch to a MC generator information (so called “truth”) based track reconstruction [13], which emulates the effects of the default algorithms. The truth seeded approach is realized by skipping the time consuming pattern recognition, track seeding and ambiguity treatment completely and instead using the MC truth information directly to assign the correct hits to each track and then fit the particles trajectories. In order to preserve the effects of the skipped algorithms for the signal event, only tracks from pileup interactions are reconstructed with this fast approach, therefore still keeping the CPU consumption under control. The tracks in the fast approach are manipulated by changing the hit content and efficiency, as well as by applying similar selection criteria as in normal reconstruction, in order to mimic the effect of skipped algorithms. As one can see in fig. 9, this reproduces the expected distributions quite well, while achieving a significant speed-up, especially at high pileup (see fig. 10).

6. The Fast Monte Carlo Production Chain

When one combines all these individual components into one combined chain, which mostly depends on the faster solutions, the current handling of I/O is suboptimal. In the full chain an individual output file is written after each stage, while in the next stage it is read in again (as input). The solution is as obvious as it is simple: in the fast MC production chain there exists only one initial input file (from event generation) and consequently only one single output file

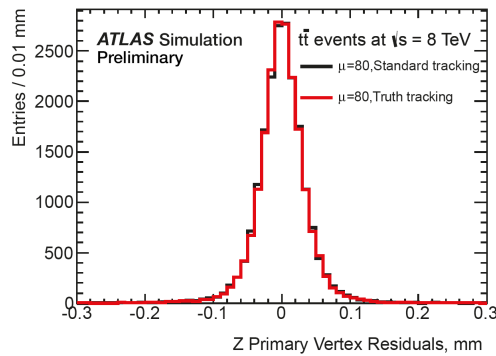


Figure 9. Comparison of the longitudinal primary vertex resolution using tracks reconstructed with the standard tracking and the truth based approach at $\mu = 80$, where μ denotes the average number of collisions per bunch crossing.

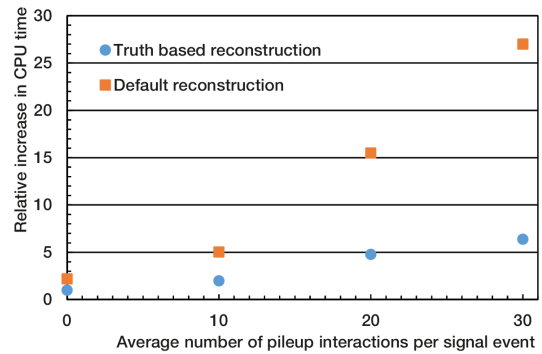


Figure 10. Comparison of the dependency of the CPU time on the average number of pileup interactions in the event between the default reconstruction and the truth based approach.

is produced. Most commonly this would be a ROOT readable file ready for analysis. With this fast approach the target is to have a processing time of the order of seconds per event. Thus in addition to the central MC production on the GRID also individual clients are able to produce high enough statistics for their purposes with their local hardware.

References

- [1] The ATLAS Collaboration 2008 The ATLAS Experiment at the Large Hadron Collider *JINST* 3 S08003 (DOI: 10.1088/1748-0221/3/08/S08003).
- [2] Antcheva I *et al* 2011 ROOT: A C++ Framework for Petabyte Data Storage, Statistical Analysis and Visualization *Comput.Phys.Commun.* 182 1384-85 (DOI: 10.1016/j.cpc.2011.02.008).
- [3] Golubkov D *et al* 2012 ATLAS Grid Data Processing: system evolution and scalability *J. Phys.: Conf. Ser.* 396 032049 (DOI: 10.1088/1742-6596/396/3/032049).
- [4] GEANT4 Collaboration Agostinelli S *et al* 2003 GEANT4: A simulation toolkit *Nucl. Instrum. Meth.* A506 250–303 (DOI: 10.1016/S0168-9002(03)01368-89).
- [5] ATLAS Collaboration 2010 The ATLAS Simulation Infrastructure *Eur. Phys. J.* C70 823-874 (DOI: 10.1140/epjc/s10052-010-1429-9).
- [6] Sjostrand T *et al* 2008 A brief introduction to PYTHIA 8.1. *Comput.Phys.Commun.* 178 852-867 (DOI: 10.1016/j.cpc.2008.01.036).
- [7] Bahr M *et al* 2008 Herwig++ physics and manual *Eur.Phys.J.* C58 639-707 (DOI: 10.1140/epjc/s10052-008-0798-9).
- [8] Barberio E *et al* 2009 Fast simulation of electromagnetic showers in the ATLAS calorimeter: Frozen showers *J. Phys.: Conf. Ser.* 160 012082 (DOI: 10.1088/1742-6596/160/1/012082).
- [9] Yamanaka T on behalf of the ATLAS Collaboration 2011 The ATLAS calorimeter simulation FastCaloSim *J. Phys.: Conf. Ser.* 331 032053 (DOI: 10.1088/1742-6596/331/3/032053).
- [10] Mechnich J on behalf of the ATLAS Collaboration 2011 FATRAS - the ATLAS Fast Track Simulation project *J. Phys.: Conf. Ser.* 331 032046 (DOI: 10.1088/1742-6596/331/3/032046).
- [11] Salzburger A *et al* 2007 The ATLAS Tracking Geometry Description ATL-SOFT-PUB-2007-004.
- [12] <https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/EGAMMA/PublicPlots/20111005/ATL-COM-PHYS-2011-1299/index.html>
- [13] Jansky R 2013 Truth Seeded Reconstruction for Fast Simulation in the ATLAS Experiment CERN-THESIS-2013-194.