Simulation load & requirements

typical MC campaign in ATLAS 2011
- $O(10^9)$ events $<<$ recorded data
- future precision measurements will need more

fast MC is needed to cope with present/future needs
- higher statistics raises additional questions: I/O, disk space, reconstruction time
- see talk of R. Brun on simulation R&D this afternoon
Simulation hierarchy

- high
  - full
  - library
  - alternative/fast
- low
  - parametric

CPU CONSUMPTION

HIERARCHY

ACCURACY
Simulation hierarchy

- High Hierarchy:
  - Full
  - Library
  - Alternative/Fast

- Low Hierarchy:
  - Parametric

- CPU Consumption
- Accuracy
- Event reconstruction (efficiency/fakes)
- Physics object creation

Date: Friday, October 7, 2011
Simulation in ATLAS ❖ 20+ years of simulation

- full: Geant4 / Fluka, Flugg / Geant3
- library: Frozen Showers
- alternative/fast: AFII (Atlfast2) / AFIIIF (Atlfast2F)
- parametric: Atlfast(1)
Full Simulation ❖ Geant4

- **geometry model:** Geant4 (translated from ATLAS GeoModel), very detailed, $O(10^6)$ nodes
- **physics engine:** Geant4
- **tuning possibilities:** via geometry/material physics list, step length, process cuts

Talks at this WS

Friday, October 7, 11
Geant4 • tuning the simulation

adapting ID material (+ 10/20 %)
investigate effects on ID tracking
- to keep geometry structure
done by changing material
density of certain elements

ATLAS Preliminary
Simulation

20% X₀ sample
10% X₀ sample
nominal

Minimum Bias Events (N=900 GeV)

MC (10%) / MC (nominal)
MC (20%) / MC (nominal)

<table>
<thead>
<tr>
<th>η</th>
<th>K_{S}^{0} fitted mean ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.99</td>
<td>Data / MC (nominal)</td>
</tr>
<tr>
<td>1.00</td>
<td>Beam Pipe</td>
</tr>
<tr>
<td>1.01</td>
<td>Pixel Layer-0</td>
</tr>
<tr>
<td>1.02</td>
<td>Pixel Layer-1</td>
</tr>
<tr>
<td>1.03</td>
<td>Pixel Layer-2</td>
</tr>
<tr>
<td>1.04</td>
<td>SCT Layers</td>
</tr>
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Minimum Bias Events (N=900 GeV)

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<td>1.05</td>
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</table>
Geant4 ♦ tuning the simulation

changing the geometry description
see talk of Olivier Arnaez

electron shower shape dependence on geometry model, changing blended material into individual layers

changing the physics list

ATLAS calorimeter response to anti-neutrons (0.1 < p_T < 50 GeV)
The library approach ❖ Frozen Showers

**geometry model:** Geant4 (translated from GeoModel)

**physics engine:** Geant4 (library, pre-simulated showers)

**tuning possibilities:** limited to shower shapes in library
Fast simulation ❖ AFII & AFIIF

AFII
- parametric cell response of the ATLAS calorimeter: FastCaloSim
- Inner Detector & Muon System: Geant4

AFIIF
- parametric cell response of the ATLAS calorimeter: FastCaloSim
- Inner Detector & Muon System: fast Monte Carlo track simulation (FATRAS)
Fast simulation ❖ Ways to speed up simulation

- approximate geometry
- optimise transport and navigation
- approximate models
- parameterisations
- take shortcuts
- use new technologies
Fast simulation ❖ Ways to speed up simulation

- approximate geometry
- optimise transport and navigation
- approximate models
- parameterisations
- take shortcuts
- use new technologies

... danger of re-invent the wheel
Fast simulation ❖ simplified geometry model

ATLAS TrackingGeometry
- *Inner Detector & Calorimeter*: simplification to layers and cylindrical volumes keeping the exact description of sensitive elements

navigation through the geometry is only done using the layers and volume boundaries, modules are found by intersection with layer

material is mapped onto layers using Geant4 description and geantinos
Fast simulation ◀ simplified geometry model

- **Example Inner Detector:**
  
  $O(100)$ layers and detector boundaries

- **Muon System:**
  
  simplification of chambers & exact transcript into TrackingGeometry classes
Geant4 / TrackingGeometry material comparison

Geant4 material

TrackingGeometry representation

example for TrackingGeometry layer
Fast simulation ❖ optimised transport model

ATLAS TrackingGeometry is a fully connective geometry with interlinked nodes
- built from one common surface class to be used with extrapolation engine
- result of propagation to current node guides to next node
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![Diagram of ATLAS TrackingGeometry](image-url)
Fast simulation ❖ optimised transport model

ATLAS TrackingGeometry is a fully connective geometry with interlinked nodes
- built from one common surface class to be used with extrapolation engine
- result of propagation to current node guides to next node
Fast simulation ❖ AFII (FastCaloSim)

**geometry model:** ATLAS calorimeter reconstruction geometry

**physics engine:** ATLAS extrapolation engine (transport) shower shape parameterisation

**tuning possibilities:** shape modification, energy response scaling
Fast simulation ❖ AFII

HIERARCHY

CPU CONSUMPTION

G4

ATLFAST2

low

high

ACCURACY

$1 \times 0.1$

?
Fast simulation ❖ AFII

- **AFII setup:**

  **Step 1:**
  *Inner Detector with Geant4*
  *Calorimeter, Muon System with Geant4 for μ, all other particles are killed at Calo entry*

  **Step 2:**
  *Calorimeter cell response from parameterisation applied to particles from ID*

- **Shower parameterisation:**
  parameterisation of shower shape variables, allows tuning to data distributions

---

**Figure 4:** Comparison of the total energy response $E_{\text{TOT}}$ in the EM calorimeter for Atlfast-II and the full Geant 4 simulation for photons with a true energy of 20 GeV in the pseudorapidity range $1.00 < \eta < 1.05$. These tests have been performed for a range of energies and pseudo-rapidities. Figure 5 summarizes the results for the mean and RMS for photons generated with an energy of 20 GeV. A point is considered "good" if the mean energy and RMS resolutions agree to within $3\sigma$ or if the K-S test probability is greater than 0.01. In general, FastCaloSim reproduces the full simulation well, except for the calorimeter transition region near $|\eta| = 1.5$. At the lowest probed energy of 1 GeV discrepancies are also visible at $|\eta| > 3.5$. For the highest energies ($\geq 50$ GeV) the RMS responses differ by more than $3\sigma$ for some points in the range $|\eta| < 0.7$.

**Figure 6:** An example is given in Figure 6, which compares FastCaloSim and Geant 4 simulation using the shower parameterisation for Geant4/AFII. The electron shower shapes from $Z \rightarrow ee$ events for electrons with $E_T = 40 \text{ GeV}$ are shown. The data points are plotted with error bars, representing the total statistical and systematic uncertainties. The MC predictions (G4.9.2 and G4.9.4, new geo.) and the fast simulation (AFII), all normalised to the number of data entries, are shown as a blue histogram, filled yellow histogram, and a dashed red histogram, respectively.
Fast simulation ◆ AFII comparison to Geant4

extensive validation in the context of SUSY analyses for summer 2011

AFII was found to be accurate enough within systematic of jet energy scale (5%)

part of the SUSY signal grid simulation of ~ 60 mio events done with AFII
Fast simulation ❖ AFII comparison to Geant4

ATLFAST2 validation in context of top physics analyses

- number of jets, jet properties well reproduced
- reproduce $m_W$ and $m_{top}$ within statistical uncertainties

<table>
<thead>
<tr>
<th>e channel</th>
<th>$N_{jets} \geq 4$</th>
<th>$N_b \geq 1$</th>
<th>$N_{jets} \geq 4$</th>
<th>$N_b \geq 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full sim.</td>
<td>4735 ± 13</td>
<td>3202 ± 10</td>
<td>7012 ± 14</td>
<td>4780 ± 11</td>
</tr>
<tr>
<td>ATLFAST</td>
<td>4617 ± 45</td>
<td>3104 ± 38</td>
<td>7033 ± 53</td>
<td>4793 ± 42</td>
</tr>
<tr>
<td>Fast / Full</td>
<td>0.975 ± 0.010</td>
<td>0.969 ± 0.013</td>
<td>1.003 ± 0.008</td>
<td>1.003 ± 0.009</td>
</tr>
</tbody>
</table>

AFII jets being scaled by 1.0.1
Fast simulation in ID/MS ✨ FATRAS

**geometry model:** ATLAS TrackingGeometry

**physics engine:** ATLAS extrapolation (transport)
material effect integration parameterised
Geant4 for particle decay (and more ?)

**tuning possibilities:**
- material scaling
- interaction probabilities
- smearing factors

\[ \pi \approx 3 \]
Fast simulation ✶ AFIIF

CPU CONSUMPTION

HIERARCHY

ACCURACY

- high
- G4
- ATLFAST2F

low

[Diagram showing the hierarchy and accuracy with G4 and ATLFAST2F at the high level, CPU consumption at 1, and accuracy at ?]
Fast simulation in ID/MS  ❖  FATRAS

Parameterisation of material interactions

(a) multiple scattering
(b) ionisation energy loss

(c) bremsstrahlung photon radiation
(d) bremsstrahlung photon conversion
Fast simulation in ID/MS  ❖  FATRAS

(e) nuclear interactions (parametric model implemented)

<table>
<thead>
<tr>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10^1</td>
<td>10^2</td>
<td>10^3</td>
<td>10^4</td>
<td>10^5</td>
</tr>
</tbody>
</table>

Outgoing particle energies from hadronic interaction:

- Geant4
- FATRAS

Angular distribution of outgoing particles:

- Geant4
- FATRAS

Phase space restrictions:

- Δφ
- Δη

Entries/bin

n particles, energy distributions, parameterised from Geant4

pion

X

Friday, October 7, 11
Fast simulation in ID/MS ▶ FATRAS

FATRAS in comparison to data
- ID reconstruction, tracks with $p_T > 500$ MeV
- using exact same sensitive detector elements:
  conditions data being fully integrated

Figure 6: Comparison of the track impact parameters $d_0$ and $z_0$ w.r.t. the primary vertex in 900 GeV collision data (black points) and MC simulated with FATRAS (shaded histogram).

Alternative geometries. It has already been successfully used for studying different concepts of a potential replacement of the ATLAS inner detector.

References
[r] The ATLAS Collaboration et al.
[s] Km Edmonds, Sm Fleischmann, Tm Lenzi, Cm Magassi, Jm Mechnichi, and Am Salzburger.

Figure 4: Schematic display of the pixel cluster creation in FATRAS.

In FATRAS, pixel clusters are created by calculating the relative path length of a track to a pixel volume and counting all pixels as hits where this quantity passes a tunable threshold. Comparison of the mean cluster size in the ATLAS pixel detector in 900 GeV collision data (black points) and MC simulated with FATRAS (shaded histogram).

Figure 5: Comparison of the geometric distribution of pixel detector hits in FATRAS (a) and the mean size of pixel clusters versus the associated track at different ` for (b).

The distribution is shaped by the existence of inactive pixel modules that are taken into account by FATRAS. The tails of the distributions are modeled with FATRAS in comparison to data.

7. Summary
Since the development of FATRAS was started, it has proven to be a useful tool, not only for debugging the track reconstruction algorithms and the simplified reconstruction geometry of the ATLAS detector, but also as a fast simulation engine. Comparisons with real collision data show that the description of the physics processes and the material distribution are modeled in a realistic way. The speed increase with respect to a detailed detector simulation which also uses a much more complex description of the detector is significant. This implies that FATRAS is a perfect tool for investigating questions that are related to tracking and also for simulating FATRAS in comparison to data - ID reconstruction, tracks with $p_T > 500$ MeV - using exact same sensitive detector elements: conditions data being fully integrated.
Fast simulation in ID/MS ❖ AFII/AFIIIF

- ATLAS standalone Muon System and combined (ID/MS) muon reconstruction

![Graphs showing standalone and combined muon reconstruction resolution vs. muon p_T](image-url)
Fast simulation ✶ ATLFAST

Fully parametric simulation
- *smearing approach to create physics objects (no reconstruction)*
- *has been used in the TDR phase of ATLAS*
Fast simulation ❖ ATLFAST

Long experience in ATLAS using parametric simulation

- extremely fast
- no efficiencies/fakes
- no pile-up effects
- however, often requested by theorists/externals, generic applications on the market (e.g. Delphes)

Is parametric smearing something we (as a community) want to provide?

ATLAS prefers to publish unfolded fiducial measurements to a parameteric public simulation.
Recap

- Full
- Library
- Alternative/Fast
- Parametric

- Geant4 / Fluka (Flugg) / Geant3
- Frozen showers
- AII / AFIIF
- Atlfast(1)
Recap

- Geant4
- Frozen showers
- AFIIF / AFIIF
- Atlfast\(^{(1)}\)

Geant4 is used for public results and is part of the current MC11 campaign in the forward calorimeter.
Recap

All simulation setups run in Athena

- **run in G4 setup:**
  - G4 run/event handling
  - G4 particle stack

- **run in G4/FATRAS setup:**
  - requires 2/1 simulation job

- runs in ATLFAST setup
The Integrated Simulation Framework

ISF
The Integrated Simulation Framework
**The nutshell ISF vision**

**DefaultFlavorCalo:**
use fast MC

**FlavorFilterID:**
use full MC in cone around electron

**DefaultFlavorID:**
use fast MC

**FlavorFilter:**
process $\mu$ with full MC

**FlavorFilterID:**
use full within jet containing $b$-hadron
The nutshell ISF design

Particle Stack -> Simulation Kernel

GeoFilter

ISimService

FlavorFilter

ID
Calo
MS
“else”

ISimService

fast MC
full MC
fast MC
full MC
fast MC
full MC
misc.
The nutshell ISF design

encapsulation of particle stack from flavors
- one central stack
- one simulation kernel

- division of ATLAS simulation into sub-geometries
The nutshell ISF design

flavor filtering for each sub detector
- allows refinement of simulation to optimise speed/accuracy balance

- flexibility to integrate new simulation flavors
- prepare for parallel particle processing
The nutshell ISF design & prototype

encapsulation of common services defined by interfaces
- event handling, stack handling, truth filling, hit recording, barcode creation

aim to feed central hit collection from ISF flavors
- to allow for common pile-up digitization

FastCaloSim & FATRAS have been imported to the prototype
- first simulation tests running
- we want to gather experience
  how to mix simulation flavors

Geant4 interfacing on the way
- Geant4 can/will still keep
  an internal particle stack
- learn how to feed a future
  parallel simulation flavor
ISF benefits  ● mix and play

A common hit service in the ISF
- AFII creates already “SimHit” objects similar to Geant4 hits

plan to update FATRAS in Inner Detector
- implemented parameterized material effects → ISF: use Geant4
- did not deploy ATLAS digitization model → ISF: create hits like Geant4
new parameterisation of hadronic leakage into the Muon System

4.3.2 Punch-Through Particle Types

The two most fundamental properties that need to be understood, regarding calorimeter punch-through events are:

1. the rate of occurrence of such events
2. the particle types penetrating the ATLAS muon spectrometer most frequently

Different types of particles will have different effects on the sensitive detector elements in the ATLAS muon spectrometer. For example, high energetic, charged particles will

Figure 4.3: Initial particle and the punch-through particles of a typical calorimeter punch-through event. Beside the position, also the particle momentum, the energy and the Monte Carlo particle number can be retrieved for the initial- and punch-through particles, respectively.
ATLAS fast simulation ➤ today & tomorrow

ATLAS has extremely profited from Geant4 simulation
- close collaboration with Geant4 community is extremely profitable

ATLAS has a long-standing experience with fast simulation
- starting from ATLFAST in TDR times
- first AFII used in public results for summer conferences 2011
- bulk production of AFII samples in new MC11 campaign

Currently fast/full simulation require different setups

Huge effort started to develop an integrated simulation framework
- steer all simulation flavors from one single framework
- vision: mix fast and full MC techniques in one single event
- feedback this experience into simulation R&D for the future (long-term)
Backup section
Timing Tables

<table>
<thead>
<tr>
<th>Sample</th>
<th>Full G4 Sim</th>
<th>Fast G4 Sim</th>
<th>Atlfast-II</th>
<th>Atlfast-IIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Bias</td>
<td>551.</td>
<td>246.</td>
<td>31.2</td>
<td>2.13</td>
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<tr>
<td>$t\bar{t}$</td>
<td>1990</td>
<td>757.</td>
<td>101.</td>
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<tr>
<td>Jets</td>
<td>2640</td>
<td>832.</td>
<td>93.6</td>
<td>7.68</td>
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<tr>
<td>Photon and jets</td>
<td>2850</td>
<td>639.</td>
<td>71.4</td>
<td>5.67</td>
</tr>
<tr>
<td>$W^\pm \rightarrow e^\pm \nu_e$</td>
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<td>447.</td>
<td>57.0</td>
<td>4.09</td>
</tr>
<tr>
<td>$W^\pm \rightarrow \mu^\pm \nu_\mu$</td>
<td>1030</td>
<td>438.</td>
<td>55.1</td>
<td>4.13</td>
</tr>
</tbody>
</table>

Table 1: Simulation times per event, in kSI2K seconds, for the full Geant 4 simulation, fast Geant 4 simulation, Atlfast-II, Atlfast-IIF [4]. Atlfast-II uses the full simulation for the inner detector and muon system and FastCaloSim in the calorimetry. Atlfast-IIF uses FastCaloSim for the calorimetry and FATRAS for the inner detector and muon system. All times are averaged over 250 events.

**TABLE I:** Average time required for production of simulated hits for single muon samples in ATLAS MuonSpectrometer.

<table>
<thead>
<tr>
<th>Simulated hit creation (MS only)</th>
<th>Geant4 [s/event]</th>
<th>FATRAS [s/event]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T=10\text{GeV}$</td>
<td>$0.13\pm0.01$</td>
<td>$0.015\pm0.002$</td>
</tr>
<tr>
<td>$p_T=100\text{GeV}$</td>
<td>$0.17\pm0.02$</td>
<td>$0.015\pm0.002$</td>
</tr>
</tbody>
</table>
ATLAS/FATRAS extrapolation engine

IN
Extrapolator
OUT

INavigator
Navigator

IPropagator

StraightLinePropagator
HelixPropagator
RungeKuttaPropagator
STEP_Propagator

IMagneticFieldTool
MagneticFieldTool
MagneticFieldTool_xk

IMaterialEffectsUpdator
MaterialEffectsUpdator
McMaterialEffectsUpdator

IMultipleScatteringUpdator
MultipleScatteringUpdator

IEnergyLossUpdator
EnergyLossUpdator
McEnergyLossUpdator
McConversionCreator
ATLAS/FATRAS extrapolation engine

IN

Extrapolator

OUT

IInterpolator

Navigator

INavigator

IPropagator

StraightLinePropagator

HelixPropagator

RungeKuttaPropagator

STEP_Propagator

IMagneticFieldTool

MagneticFieldTool

MagneticFieldTool_xk

IMaterialEffectsUpdator

MaterialEffectsUpdator

McMaterialEffectsUpdator

IMMagneScatteringUpdator

MultipleScatteringUpdator

G4MaterialEffectsUpdator

IEnergyLossUpdator

EnergyLossUpdator

McEnergyLossUpdator

McConversionCreator