Upgrading the ATLAS Fast Calorimeter Simulation

Zdenek Hubacek
(Czech Technical University in Prague)
On behalf of the ATLAS Collaboration

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Outline

• Simulation of the ATLAS Detector
• Integrated Simulation Framework
• Fast Calorimeter Simulation
ATLAS Monte Carlo Production Chain

Event Generation
EVGEN

Detector Simulation
HITS

Digitization
RDO

Reconstruction
ESD/AOD

Rootification
D3PD/HIST

μ times
Detector Simulation Alternatives

Always a tradeoff between accuracy and speed

- Geant4 / Fluka, Flugg / Geant3
- Frozen Showers
- AFII (Atlfast2) / AFIIIF (Atlfast2F)
- Atlfast(1)

• What is the best choice?
• Can we optimize?
Why Fast Simulation

- Limited CPU resources, Limited disk space
- Grid CPU dominated by MC production
  - Precise detector simulation is CPU intensive
  - Production takes large fraction of disk space
  - Sensitivity limitation for physics analyses which need large MC statistics
- ~50% RunI MC was fast simulation
- Higher luminosity/pileup in RunII requires larger MC production
• For most physics analyses, high precision is only needed for some particles/regions within each event

• ISF brings the possibility to mix different simulators
  – (Geant4/Fast tracking sim./Fast calorimeter sim.)
    • In different subdetectors
    • In the same subdetector – Geant4 for interesting objects, fast simulation for the rest of the event
  – CPU reduction factor: 10-100 depending on selected simulators
ISF Design

- ISF fully integrated in the ATLAS software framework (Gaudi Athena)
- SimKernel – responsible for sending particles to different simulators
- ParticleBroker – keeps particle lists and determines which simulator should be used for each particle
Standard ATLAS Simulator: Geant4

- Close collaboration with Geant4 team
- Stable, validated and precise simulation
- Currently using G4 v9.6
- Full description of the ATLAS detector
- High CPU consumption
  - Large number of G4 volumes
  - Mostly in (EM) calorimeters and for low energetic particles

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FATRAS

- Fast ATLAS Tracking Simulation (inner detector and muon spectrometer)
- Simplified detector geometry and simplified interaction processes
Frozen Showers

- Many high energetic particles in the forward direction
- Replace low energetic particles in the shower with pre-simulated EM showers (1 GeV electron and similar)
- Used by default in the full simulation in forward calorimeters
FastCaloSim - Calorimeter Simulation

- Parameterization of calorimeter response based on Geant4 full simulation
- Tuned to data
- Used as an alternative to the full simulation, requires dedicated calibration
FastCaloSim

- Energy and shape parametrization for single particles (e, γ, π) (E-η grid)
- Priority order
  - Correct simulation of the total energy
  - Correct simulation of the longitudinal shower depth
  - Correct simulation of energy fractions in each calorimeter layer
  - Correct simulation of correlation of energy fractions in each calorimeter layer
  - Correct description of the lateral energy distributions (shower shapes)
Current FastCaloSim Performance and Limitations

- Lateral shower shapes could be tuned to data to improve agreement
- Hadronic objects not well described due to average shower shape simulation
- Prototype of random fluctuation model tested
New Parameterization

• Re-simulate single particles (e, γ, π) on a fine energy and η grid (approx 15x100 points)
  – Using full Geant4 simulation, current ATLAS geometry
  – Save detailed spatial information (x,y,z,t,E) of the developed shower

• Re-derive the energy parameterization (longitudinal) and shower shape (lateral)
  – Reduce the amount of information to a compact form
  – Use TMVA Regression to approximate histograms
Energy Parametrization Method

1\textsuperscript{st} PCA:

- **G4 Inputs:**
  - Energy fractions $f$
  - Total energy $\rightarrow N$ inputs
- Cumulative distributions
- Inverse error function
- Gaussians
- PCA
- PCA output data
  - N components

To be stored:
- Only the bin number for each input event

2\textsuperscript{nd} PCA:

- **G4 Inputs:**
  - Energy fractions $f$
  - Total energy $\rightarrow N$ inputs
- Cumulative distributions
- Inverse error function
- Gaussians
- PCA
- PCA output data
  - N components

Bin 1

Regression Training
- TMVA method MLP
- Store weights in root files

Binning:
- ~10 bins in the leading components of the 1\textsuperscript{st} PCA

To be stored:
- PCA Matrices
- Mean and RMS of PCA output data
- MLP weights
Energy Parametrization Method

1st PCA:

- **G4 Inputs:**
  - Energy fraction
  - Total energy
  → N inputs

2nd PCA:

- **Bin 1**
- **Bin 10**

**ATLAS** Simulation Preliminary

- **PCA**
  - PCA output data
  - N components

Regression Training:

- TMVA method MLP
- Store weights in root files

PCA Matrices
- Mean and RMS of PCA output data
- MLP weights

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Toy Simulation

From random numbers and stored weights and PCA matrix

ATLAS Simulation Preliminary

Gaussian random numbers

Inverse PCA

Inverse PCA output (Gaussians)

Error function

Inverse PCA output (Uniform)

Inverse Regression

Simulated Inputs

ATLAS Simulation Preliminary

Events / 0.08

KS: 0.98, $\chi^2$: 0.67

Parametrisation

FullSim Input

Pions 200 GeV

$2.9 < |\eta| < 3.1$

ATLAS Simulation Preliminary

Events / 0.09

KS: 0.76, $\chi^2$: 0.37

Parametrisation

FullSim Input

Photons 50 GeV

$0.2 < |\eta| < 0.25$
(Lateral) Shower Shape

- Get average shower shape per layer and per PCA bin
- Optimal binning derived iteratively
Shower Shape

- The binned energy fractions are fit with a Neural Network
- Store TMVA weights instead of histograms
Towards a Prototype

- Work on going on a prototype to implement the particle simulation

Closure Test

Input Hits → CaloGeo+ Eff maps → Cell Energy distribution

Energy Paramet → Shape Inputs → Random # using shapes

Check for agreement on cell level

ATLAS Simulation Preliminary Dominant Electromagnetic Layer (EM2)
Summary

• (Fast) calorimeter simulation essential for ATLAS physics program
• ATLAS implemented Integrated Simulation Framework for greater simulation flexibility
• FastCaloSim – fast parameterized calorimeter update in development