Simulation strategies for the LHC ATLAS experiment

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The ATLAS detector

General purpose detector designed to cover all the expected physics channels at LHC using p-p collisions with energies up to 14 TeV and Pb-Pb collisions at 5.5 TeV/nucleon.

ATLAS operation

- ▶ Experiment performing according to design specifications.
- ▶ Excellent operational efficiency.
- ▶ Extremely good understanding of the apparatus and detector simulation for this stage of operation.

ATLAS Detector Status

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.3%
SCT Silicon Strips	6.3 M	99.2%
TRT Transition Radiation Tracker	350 k	97.1%
LAr EM Calorimeter	170 k	98.1%
Tile calorimeter	9800	96.9%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.9%
LVL1 Muon RPC trigger	370 k	99.5%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.0%
TGC Endcap Muon Chambers	320 k	98.6%

Events

Highest-mass QCD dijet at ATLAS: $3.1 \text{ TeV}/c^2$ for two leading jets (red and green)!

Events

$Z \rightarrow \mu^+ \mu^-$ in 7 TeV LHC collisions at ATLAS

ATLAS simulation framework

- ▶ Simulation of physics events / detector via common ATLAS software framework (Athena)
- ▶ Detector simulation based on Geant4
- ▶ Multiple layouts supported: ATLAS + test beam setups, etc.

ATLAS GeoModel: shared geometry translation to G4/reco

Framework used for large scale ($\sim 500\text{M}$ event) production on LHC Computing Grid: $\sim 8\text{M}$ event/day. Failure rate $< 10^{-6}$.

Some alternative layouts for ATLAS simulation

Cosmics commissioning

Combined test-beam

ATLAS simulation details

- ▶ Event generation interfaces for ~ 40 generator codes: maintained, validated, and tuned
- ▶ Truth-level HepMC events smeared with beam-spot parameters and tracked through detector description by Geant4 application
⇒ HITS
- ▶ Detector description parameters and conditions data from tagged database entries. Including variation tags for test stands, ATLAS commissioning, extra material, misalignments, etc.
- ▶ Special cases: cosmics, forward detectors, beam halo and cavern background (require extra particle transport); R -hadrons, stopped gluinos, Q-balls, monopoles...
- ▶ Pile-up, halo and non-beam backgrounds included at digitization stage: merging of HITS files – now with bunch structure.

ATLAS core simulation framework

- ▶ Full sim currently using **G4 9.2.patch02.atlas04** – ~ 12 patches incorporated for issues reported by / affecting ATLAS. Next major update: straight to G4 9.4.
- ▶ Several access layers: G4 classes augmented with Athena features via FADS – Framework for ATLAS Detector Simulation – and configured / steered by an Athena algorithm / Python scripting layer.
- ▶ Particle scoring done in Athena det-specific classes. Enables optimisation for task, e.g. LAr calorimeter groups G4 HITS before persistency to save memory.
- ▶ Currently re-writing aspects of these layers: initial requirement was for interactive usage at a prompt. In practice never used this way – developers → users in ATLAS, and most usage now via fixed steering “transform” scripts.

Fast simulation

G4 sim very CPU/memory intensive: some analyses require higher stats than possible $\Rightarrow$ fast sim

- ▶ **ATLFAST-I**: direct HepMC $\rightarrow$ reco smearing by parameterised detector/reco resolution
- ▶ **ATLFAST-II**: parameterised particle showers (**FastCaloSim**) and simplified tracking (**FATRAS**)
- ▶ **Fast G4**: use “frozen” pre-simulated shower libraries for 10 MeV–1 GeV
- ▶ Can also simulate e.g. only inner detector for track-only analyses

Fast simulation CPU performance

Relative timings of $t\bar{t}$ ATLAS detector sim events:

Simulation comparison to data

Excellent understanding of detector:

Pixel detector:

Silicon central tracker (SCT):

Simulation comparison to data

Excellent understanding of detector:

Close-up of secondaries in 1st pixel layer (data, sim):

Simulation tuning to data

Geometry fixes from design to correct sim photon conversion radius:

Also two fixes for anomalous G4 events with **energy non-conservation**:

- ▶ Jets at 55 and 67 GeV found in J0 ($p_{\perp} \in [7 - 14]$ GeV) slice! No truth match: energy not conserved in G4 $\gamma + \text{Pb} \rightarrow \pi^+ \pi^- + X$
- ▶ In $\pi^+ + \text{He} \rightarrow \text{pp} + X$, protons with 47 TeV each!
Pretty clearly a bug!
- ▶ G4 produced patches: in production and in new G4 releases.

Performance monitoring and optimisation

- ▶ Performance monitoring with a variety of physics and particle-gun events
- ▶ Done for all new releases, G4 builds, etc.; robustified statistics
- ▶ Sim CPU used to be production bottleneck, now reco disk space

CPU focus: field stepper system

- ▶ RK4 adaptive steppers used for particle propagation. Calls to B field map $\Rightarrow \sim 20\%$ of sim CPU
- ▶ 11 calls in **ClassicalRK4** stepper $\Rightarrow$ 4 using **AtlasRK4** stepper with analytic error calc
- ▶ **AtlasRK4** also has field-caching in a fixed radius: further field-call reduction
- ▶ Further reduction to only 2 calls possible with G4 NystromRK4 stepper

- ▶ Also “stepper dispatcher”: choose stepper based on region, track PID, energy, proposed length

Summary

- ▶ Simulation framework very successful: excellent detector description, improving performance: simulating 1M events per day in ATLAS MC production.
- ▶ Work is never done! Optimisation, new G4 versions, new physics list validation, fast simulation, structural re-working.
- ▶ Current development effort: forward detectors, cavern bg, stepper dispatcher, pile-up bunch structure and data-MC overlays. ATLAS upgrade.
- ▶ Described in full detail in ATLAS sim paper: [arXiv:1005.4568](https://arxiv.org/abs/1005.4568)