Pileup and Event Overlay in ATLAS simulation

Bill Lockman

Introduction
Pileup
Event overlay
Event overlay validation
Summary
Backgrounds in ATLAS

Backgrounds to hard scatter process

- minimum-bias background (<23>/bunch @ L=10^{34}\text{cm}^{-2}\text{sec}^{-1})
- beam-gas, beam-halo
- cavern backgrounds (neutron-photon “gas”)
- cosmics
- detector noise

Signal integration

Subsystems sensitive to hits from particles in earlier or later BC WRT trigger – some subsystems have very long integration times
Pileup

– On separate streams
  • simulate minimum bias background
  • simulate beam halo and beam-gas
  • simulate cavern background
    – since not well known, include 5 cavern events/BC (safety factor SF=5)
  • simulate the physics event of interest

– mix the above streams at the G4 hit level
  • include backgrounds from -36 to +32 BC (determined by the slowest system, the muon monitored drift tubes (MDT))

– Digitize the mix with noise simulation enabled
– CPU and memory intensive at high luminosity
In muon spectrometer, cavern backgrounds the main problem at L=2x10^{33}

with pileup, 25 ns bunch spacing, L=2x10^{33}
Safety factor (SF) = 5 Cavern events/BC
Integrate -36 to +32 BC

with pileup, 25 ns bunch spacing, L=2x10^{33}
Safety factor (SF) = 5 Cavern events/BC
Integrate -36 to +32 BC
Pileup developments

Pileup at $L=10^{34}$ cm$^{-2}$sec$^{-1}$:

- Barely fits (memory-wise) into a typical grid machine (2GB real memory)

Upgrade ($>10^{34}$ cm$^{-2}$sec$^{-1}$)

- Big effort to optimize CPU and memory usage during pileup digitization and reconstruction

Cavern background (see previous talk). Being redone using

- G4 (vs G3) with scoring volumes
- New version of Pythia
- Improved neutron transport models

From K. Assamagan Freiburg workshop July 3, 2009
Pileup Digitization Challenges

- **CPU:**
- **Memory:**

- CPU and Memory usage increase linearly with luminosity at luminosities we can simulate.
- Extrapolate that L=$10^{35}$ pileup will require $\sim 30$GB of virtual memory.
- Such machines exist, but this cannot be expected for the grid

from J. Chapman
Event Overlay

Modeling of machine backgrounds using real data

• From zero-bias triggered real data, obtain:
  – Minimum bias
  – beam halo and beam-gas
  – cavern backgrounds, cosmic ray
  – detector noise

• Add (overlay) the G4 simulation of the hard scatter process with the real zero bias data
  – Monte Carlo events simulated without noise
  – Conditions from the real data with some simulation folders added
  – Mix is sub-detector specific (see backup)
    • For details see: https://twiki.cern.ch/twiki/bin/viewauthAtlasProtected/PileupOverlay

Can also perform MC + MC event overlay
Single tau MC+MC overlay

A single high-pT MC tau event overlayed onto a min-bias MC event
- Higher track multiplicity; energy depositions in EM and HAD calorimeters

from Trevor Vickey, Copenhagen ATLAS tau workshop, April 16-17, 2009
Single tau MC+MC Overlay

Single high-pT MC tau event overlayed onto min-bias MC event

from Trevor Vickey, Copenhagen ATLAS tau workshop, April 16-17, 2009
tau-ID in the presence of soft physics background from minbias

Embed single tau into minimum bias event using MC + MC overlay (zero pileup scenario)

Test of MC + MC event overlay.

from Trevor Vickey, Copenhagen ATLAS tau workshop, April 16-17, 2009
OverlayValidation

- OverlayValidation compares MC on cosmics (or MC on MC) raw data (RDO) occupancy with summed occupancies from input (MC) signal and cosmic ray (or MC) “background”

- Package dedicated to this in ATLAS: OverlayValidation

- Focus is on inner detector and muon RDO validation
  – Also implementing reconstruction level (ESD) validation of track parameters

- For “sparse” events overlay is nearly perfect except for some problems in muon Monitored Drift Tubes (MDT)
Current OverlayValidation Involvement

• William Lockman (SCIPP):
  • OverlayValidation package infrastructure
  • SCT, TRT raw data objects (RDO) validation code

• Michael Kelsey (SLAC):
  • OverlayValidation Muon systems RDO validation algorithms
Overlay Validation

• Input signal: Monte Carlo G4 hits collection
  • 1000 single muon events, $E_t=100$ GeV, $|\eta| < 3.0$
  • Geometry: ATLAS-GEO-03-00-00
  • MC conditions: OFLCOND-SIM-00-00-06

• Input background:
  • 1000 zero bias trigger cosmic ray events
  • Geometry: ATLAS-GEO-03-00-00
  • Data conditions: COMCOND-ES1C-000-00

• Overlay:
  • conditions: COMCOND-ES1C-000-00

• Release: 14.2.25.11
• Package tag: OverlayValidation-00-00-50

Same geometry
RDO Occupancy Histogram Comparisons

Cosmic ray background:

Simulated signal:
- G4hits
- digitization: noise off

Overlay:
- MC G4hits
- ByteStream
- overlay

Output:

Output: png files
Plot layout

- **Overlay (O) distribution:**
  - red fill black outline histogram

- **Background (B) distribution:**
  - grey fill histogram

- **Signal (S) distribution:**
  - green fill histogram stacked on background
    - red visible when \( O > S + B \)

- **Legend information:**
  - Kolmogorov (KS) comparison between overlay and input sum
  - # of bins where \( O > S + B \) or \( O < S + B \)
Sample Pixel

RDO Occupancy comparisons:

MC on Cosmic ray
Pixel Barrel Layer Occupancies

Algorithm by M. Kocian (SLAC)

η

φ

η

φ
SampleSemiConductor Tracker (SCT)

RDO Occupancy comparisons:

MC on Cosmic ray
SCT Barrel Occupancies – 14.2.25.11

Algorithm by W. Lockman (UCSC)

η

φ

η

φ

η

φ

η

φ

η

φ

η

φ
Sample Muon Monitored Drift Tube

RDO Occupancy comparisons:

MC on Cosmic ray and MC on MC
Algorithm by M. Kelsey (SLAC)

MC + cosmics: 1K events

MC + MC: 100 Events
MDT EC-Neg RDO Occupancies – 14.2.25.11

Algorithm by M. Kelsey (SLAC)

MC + cosmics: 1K events

MC + MC: 100 Events

η
Muon MDT RDO Occupancy comparisons

MC + cosmics:
- In many MDT layers, there is no mismatch between the overlay- and signal + background RDO occupancy distributions

MC + MC:
- The overlay- and signal + background RDO occupancy distributions match perfectly
MDT Muon Overlay Validation: Barrel

MC + cosmics: 1K events
## Overlay Validation Status

### RDO validation – 14.2.25.11:

<table>
<thead>
<tr>
<th>Pixels</th>
<th>OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCT</td>
<td>OK</td>
</tr>
<tr>
<td>TRT</td>
<td>OK</td>
</tr>
<tr>
<td>MDT</td>
<td>some mismatches</td>
</tr>
<tr>
<td>RPC</td>
<td>Work ongoing</td>
</tr>
<tr>
<td>CSC</td>
<td>Work ongoing</td>
</tr>
<tr>
<td>TGC</td>
<td>Work ongoing</td>
</tr>
<tr>
<td>L1</td>
<td>Not implemented yet</td>
</tr>
</tbody>
</table>

### OverlayValidation – 15.3.X:

- Conversion to produce validation histograms with standard production scripts (“transforms”) in progress
- Testing use of job transforms in the context of overlay validation underway
- Ongoing automated nightly standalone tests of overlay transforms (RTT)

The problems seen in the muon subsystem is still under investigation. May be due to differences in how we digitize the signal without backgrounds versus how the digitization of the overlaid sample is performed (muon system cable maps not consistent between simulation and real data?)

July 16, 2009
Tasks for Overlay

OverlayValidation tasks in 15.X.Y:

- Finish modifying infrastructure to use production transforms to create validation hists
- Understand mismatches seen in MDT RDO validation
- Implement remaining subsystem RDO validation algorithms (remaining muon, L1)
- Implement and test tracking validation
- Test Event Display Validation
- Implement detailed run time testing (RTT) based on validation histogram comparisons
ATLAS Pileup/Overlay Group Personnel

ATLAS Pileup group contributors:

Kétévi Assamagan (BNL)\(^1\), Georges Azuelos, Piyali Banerjee\(^2\) (Montreal), Paolo Calafiura, Andrei Gaponenko (LBNL), John Chapman\(^3\) (Cambridge), Michael Kelsey, Peter Kim, Martin Kocian, William Lockman (UCSC), David Miller (Stanford), Ximo Poveda Torres, Trevor Vickey, Yingchun Zhu (Wisconsin), Peter Sherwood (UC London), Sasha Solodkov (IHEP), Guillaume Unal (CERN)

Indirect contributors:

Andrea Dell’acqua (CERN), Borut Kersevan (Jozef Stefan Inst.), Sandro Di Mattia (Mich. St.), Stefania Spagnolo (U. Salento), Zachary Marshall (Columbia)

My apologies to those whose names I may have omitted

New members are welcome and needed!

Notable individuals:

\(^1\)Past contact: Kétévi Assamagan
\(^2\)Overlay contact: Piyali Banerjee
\(^3\)Pileup contact: John Chapman

Simulation group coordinators: Charlie Young, Adele Rimoldi

July 16, 2009

SLUO/LHC workshop  Simulation Session  Bill Lockman
Summary

• **Pileup:**
  - Big effort to optimize pileup for high luminosity \((10^{34})\) and for the upgrade
  - Pileup digitization and reconstruction @ \(L=10^{34}\) now running on the GRID for the first time (thanks to core computing and pileup teams)
    - access to high luminosity simulation will be available to anyone in ATLAS

• **Event Overlay:**
  - Will be used in production simulation to model the machine backgrounds to physics processes of interest (MC+DATA)
  - Also for performance studies (MC+MC)
  - all subsystem overlays implemented
  - Nightly run time tests with MC + cosmic ray and MC+MC
  - MC + cosmics and MC + MC mixed samples are being produced

• **Event Overlay Validation:**
  - Inner detector and calorimeter validation done.
  - Need to complete remaining muon and L1 validation (MC + cosmics)
EXTRA
Pileup simulation Details

- Every collision is normally simulated only for few a 100 ns of the propagation time
- Neutrons may fly in the ATLAS cavern for a few seconds until they are thermalized, thus producing some kind of a permanent neutron-photon gas which creates a constant rate of Compton electrons and spallation protons - this is cavern background
- The cavern background is problem for the muon spectrometer
- The cavern background is simulated separately and mixed in the pileup during the digitization
- Since we do not know the absolute cavern rate, we use a Safety Factor (SF) on the cavern events:
  - E.g., SF=5 -> take 5 cavern events instead 1, x5.
- Beam Halo: LHC’s contribution to background, resulting from proton losses, including gas impurities in the beam pipe, collimator effects. The simulation provided by the Machine Division. The ATLAS digitization to overlay beam halo events onto ATLAS simulated events is done through a beam halo pileup mechanism.
- Beam Gas: various gas species in the beam pipe. This is simulated with HIJING (A+A, p+A generator) in Athena with the appropriate timing offsets and added to standard samples through the same pileup event merging mechanism.

From K. Assamagan, Freiburg workshop July 3, 2009
**ATLAS detector integration times in pileup simulation**

<table>
<thead>
<tr>
<th></th>
<th>Time / ns</th>
<th>Crossing at 25 ns</th>
<th>Bunch Crossing at 25 ns</th>
<th>Bunch Crossing at 25 ns</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Limit</td>
<td>-</td>
<td>-</td>
<td>69</td>
<td>-40</td>
<td>+32 Specified in terms of bunch crossings, rather than a time window.</td>
</tr>
<tr>
<td>MDT MDTSimHitCollection#MDT_Hits</td>
<td>-1000</td>
<td>700</td>
<td>69</td>
<td>-40</td>
<td>+26 Fixed - Unlimited before Digitization-00-17-11</td>
</tr>
<tr>
<td>LAr LArHitContainer#LArHitEMB LArHitContainer#LArHitEMEC LArHitContainer#LArHitNHC LArHitContainer#LArHitTCAL</td>
<td>-501</td>
<td>126</td>
<td>38</td>
<td>-32</td>
<td>+5 Fixed</td>
</tr>
<tr>
<td>Tile TileHitVector#TileHitVec TileHitVector#MDTSimHits</td>
<td>-200</td>
<td>130</td>
<td>15</td>
<td>-8</td>
<td>+6 Fixed - Range altered Digitization-00-17-10 onwards</td>
</tr>
<tr>
<td>RPC RPCSimHitCollection#RPC_Hits</td>
<td>-100</td>
<td>100</td>
<td>9</td>
<td>-4</td>
<td>+4 Fixed - Unlimited before Digitization-00-17-11</td>
</tr>
<tr>
<td>TGC TGCISimHitCollection#TGC_Hits</td>
<td>-75</td>
<td>75</td>
<td>7</td>
<td>-3</td>
<td>+3 Window size variable. Depends on bunch spacing. Unlimited before Digitization-00-17-11</td>
</tr>
<tr>
<td>CSC CSCSimHitCollection#CSC_Hits</td>
<td>-75</td>
<td>75</td>
<td>7</td>
<td>-3</td>
<td>+3 Fixed - Unlimited before Digitization-00-17-11</td>
</tr>
<tr>
<td>TRT TRTUncompressedHitCollection#TRTUncompressedHits</td>
<td>-50</td>
<td>75</td>
<td>6</td>
<td>-2</td>
<td>+3 Fixed</td>
</tr>
<tr>
<td>Truth Gen Event NoEventCollection#TruthEvent</td>
<td>-50.5</td>
<td>50.5</td>
<td>5</td>
<td>-2</td>
<td>+2 Fixed - Not everything is kept see MC Truth Taskforce recommendations</td>
</tr>
<tr>
<td>BCM SiHitCollection#BCM_Hits</td>
<td>-50</td>
<td>+25</td>
<td>4</td>
<td>-2</td>
<td>+1 Fixed</td>
</tr>
<tr>
<td>SCT SiHitCollection#SCT_Hits</td>
<td>-50</td>
<td>+25</td>
<td>4</td>
<td>-2</td>
<td>+1 Fixed</td>
</tr>
<tr>
<td>Pixels SiHitCollection#PixelHits</td>
<td>-25</td>
<td>+25</td>
<td>3</td>
<td>-1</td>
<td>+1 Wider for lower luminosities</td>
</tr>
<tr>
<td>Calo Calibration CaloCalibrationHitContainer#HCALCalibrationHitActive CaloCalibrationHitContainer#HCALCalibrationHitDeadMaterial CaloCalibrationHitContainer#HCALCalibrationHitInActive CaloCalibrationHitContainer#TileCalibrationCellHitCnt CaloCalibrationHitContainer#TileCalibrationEMHitCnt</td>
<td>-25</td>
<td>+25</td>
<td>3</td>
<td>-1</td>
<td>+1 Fixed</td>
</tr>
<tr>
<td>LUCID LUCID_SimHitCollection#LucidSimHitVector</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0 LUCID is only sensitive to current BC</td>
</tr>
<tr>
<td>Truth Track Records TrackRecordCollection_p2_MoonEntryLayer</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0 Uncertain how much is kept python cxx</td>
</tr>
<tr>
<td>BLM SiHitCollection_p2_BLMHits</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0 Not used in digitization currently.</td>
</tr>
<tr>
<td>Truth Track Records TrackRecordCollection_p2_MoonExitLayer TrackRecordCollection_p2_CaloEntryLayer</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0 Not used - NB written to RDO file in non-pileup jobs</td>
</tr>
</tbody>
</table>
# Pileup minbias events/bunch crossing

<table>
<thead>
<tr>
<th>Luminosity (cm$^{-2}$-sec$^{-1}$)</th>
<th>bunch spacing (ns)</th>
<th># minbias events/bunch</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{31}$</td>
<td>450</td>
<td>4.1</td>
</tr>
<tr>
<td>$2 \times 10^{32}$</td>
<td>75</td>
<td>3.5</td>
</tr>
<tr>
<td>$10^{33}$</td>
<td>75</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>2.3</td>
</tr>
<tr>
<td>$10^{34}$</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>$10^{35}$</td>
<td>25</td>
<td>230</td>
</tr>
<tr>
<td>super LHC</td>
<td></td>
<td>~400</td>
</tr>
</tbody>
</table>
Zero bias random trigger data

• From the filled bunches, select events at random. Zero bias trigger is not the minimum bias trigger
• The LVL1 trigger word to inform the detector RODs of such events
• HLT pass-through
• Send these events to a dedicated zero-bias stream
• Use bunch-by-bunch luminosity information in the analysis to obtain a correctly weighted sample of events. Or use a zero bias trigger that follows (is normalized to) a physics trigger – luminosity scaling is then automatic
• Rate: 1-2Hz
Event overlay with real data

- The mix of simulation and real data is sub-detector specific:

<table>
<thead>
<tr>
<th>Sub-detector</th>
<th>Mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel</td>
<td>Signal RDO + data RDO</td>
</tr>
<tr>
<td>Silicon Microstrip Tracker (SCT)</td>
<td></td>
</tr>
<tr>
<td>Transition Radiation Tracker (TRT)</td>
<td></td>
</tr>
<tr>
<td>Liquid Argon Calorimeter</td>
<td>Signal G4 hits + data RDO</td>
</tr>
<tr>
<td>Tile Calorimeter</td>
<td>Signal G4 hits + Calo digits</td>
</tr>
<tr>
<td>Muon Cathode Strip Chambers (CSC)</td>
<td>Signal RDO + data RDO</td>
</tr>
<tr>
<td>Muon Monitored Drift Tubes (MDT)</td>
<td></td>
</tr>
<tr>
<td>Muon Resistive Plate Chambers (RPC)</td>
<td></td>
</tr>
<tr>
<td>Muon Thin Gap Chambers (TGC)</td>
<td>Signal digit + data digit</td>
</tr>
</tbody>
</table>
Early data

- We will have pileup at the beginning:
  - For example $10^{32}$ cm$^{-2}$s$^{-1}$, 450 ns bunch spacing $\rightarrow$ 4 minimum bias interaction/bunch
  - Assume $5 \times 10^{31}$ cm$^{-2}$s$^{-1}$ with 150 bunches $\rightarrow$ 1.8 interactions/bunch
  - One should consider early data analysis with pileup effects!

- LHC operation for early data scenario:
  - CME: 8 to 10 TeV
  - Luminosity = $0.5 - 2 \times 10^{32}$ cm$^{-2}$ s$^{-1}$
  - Bunch spacing: 450 ns ($\rightarrow$ 50 ns ?)
  - Integrated luminosity up to 200/pb

From K. Assamagan, Freiburg workshop July 3, 2009