Upgrades for the CMS simulation

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for the CMS collaboration
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CMS simulation faces significant challenges for both today and tomorrow

Higher LHC luminosity means:
• Need for more accurate simulations
• Need for more events (ideally more events/CHF)
• More demanding pileup simulation requirements

Major detector upgrades in 2017, during LS-2 and for HL-LHC mean:
• New detector concepts to develop, benchmark and validate
• The need to make reliable simulations for HL-LHC luminosities

Increases in LHC luminosity and CMS detector upgrades push our simulation capabilities
Detector upgrades push continued simulation development in CMS

2017 upgrades

HL-LHC upgrades

Muon ID

Tracking

Calorimetry
CMS Monte Carlo Simulation approach

Physics Generators

Particle 4-vectors

Geometry/Material Description

Geant 4

Simulated Hits from Pileup Interactions

Simulated Hits

Electronics Simulation

= “Digitization”

Simulated Raw Data
I focus this presentation on progress in CMS simulation and digitization

• Upgrades to Geant4 configuration for upcoming major simulation production

• Integration of software for new detectors which will be installed in 2017 and proposed for HL-LHC upgraded CMS detector

• Deployment of premixing scheme for pileup interaction simulation performed at the digitization level
Recap from CHEP 2015:
Simulation improvements for Run 2

• Geometry updates: Improvements to Run 1 detector model and integration of Run 2 detector changes
• Migration from Geant4 9.4p03 to 10.0p02
• Introduced Russian roulette method for sampling low energy particles
• New forward hadron calorimeter parameterized simulation (shower library instead of GFlash)
• Improved simulation library packaging
• Improved mixing module for high pile-up simulation
• Developed simulation for multi-threaded CMSSW framework

Together these improvements gained a factor of 2 in simulation time/event for 2015/2016 MC
What have we changed since then?

• New Geant4 10.2 built in multithreaded mode.
• Minor changes applied by CMS:
  1. FTF model parameters defined as in 10.1p03
  2. Fix to G4SubtractedSolid
  3. Fix to G4CutTubs
     • Our first use of this shape to model support structure of new pixel detector
• Production platform slc6_amd64_gcc530
What have we changed since then?

• Default physics list: FTFP_BERT_EMM
  – FTFP_BERT: Standard hadronic physics list
    • Bertini-style cascade for hadrons < 5 GeV
    • FTF (Fritiof) model for high energies (> 4 GeV)
  – EMM means:
    • Default EM physics in HCAL (“Option 0“) in order to get an unbiased response of the sampling calorimeter
    • EM “Option 1“ physics in other all detectors (increased multiple scattering step length limit)
  – This physics list choice and our choice to revert changes in FTFP made in recent 10.2 patches was based on comparisons of single particle response using test-beam (2006) and run-2 data (See details in S.Banerjee talk)
Memory for CMS run with Geant4

10.2p02

- A node with 12 Intel cores was used to study memory utilisation
- 13 TeV hard scattering event were simulated
  - Results after 1000 events are shown
  - CMS private patches to 10.0 include backports of fixes of memory leak and memory optimisation
  - Results for 10.1 and 10.2 are practically the same
  - No dependency on Physics List
- No problems to run CMS SIM production in the MT mode

<table>
<thead>
<tr>
<th>Release</th>
<th>1st thread (GB)</th>
<th>Delta per thread (GB)</th>
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<tbody>
<tr>
<td>10.0p02+CMS patches</td>
<td>1.33</td>
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<tr>
<td>10.2p02</td>
<td>0.76</td>
<td>0.19</td>
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</table>

CHEP2016
Where our simulation CPU goes

- Geometry/Field
- EM physics
- Had. Physics
- CMS detectors/actions
- Other
CMS CPU performance for 2017

- Overall, no substantial changes in our technical performance since 2015
  - Modest improvements in CPU performance in Geant4 10.2p2 and in CMS sensitive detector code offset by other changes
- No noticeable performance loss (or gain) with threading (up to 8 threads)

<table>
<thead>
<tr>
<th>Geant4 version and configuration</th>
<th>Number of threads</th>
<th>CPU for ttbar (events/thread relative rate)</th>
<th>CPU for QCD (events/thread relative rate)</th>
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<tbody>
<tr>
<td>10.2p02 seq.</td>
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<td>1</td>
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<tr>
<td>10.2p02 MT</td>
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<tr>
<td>10.2p02 MT</td>
<td>8</td>
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<td>0.89</td>
</tr>
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</table>
Simulating Extreme Luminosities

- Model pileup by including G4hits from MinBias events generated separately from the hard-scatter event
  - Hits are loaded one interaction at a time, processed and accumulated for the final digitized output
- The pileup interaction simulation is the sum of many interactions

Tens or hundreds of interactions per bunch crossing
This method of pileup simulation is very I/O intensive: 1000s of minbias to read per hardscatter event

• Newly deployed solution: “Pre-Mixing” which proceeds in 2 steps
  1. Upfront I/O intensive step: Create library of events containing only pileup contributions

```plaintext
Simulated hits from one interaction

“Accumulate” hits/Energy

THEN

Electronics Simulation

Simulated Raw Data
```

repeat until all minbias interactions are processed
Then hard-scatter and pileup events are combined as “RAW” data format events

- The hard-scatter sample is created and processed through the digitization step with no pileup, convert to our raw data format.

- Then the two streams are merged.

- Only 1 pileup event is needed for each “hard scatter” MC event.
  - Much easier to process through computing infrastructure once the premixing sample is created.

Diagram:

- Physics Generators
- Geant 4
- Electronics Simulation
- Simulated Raw Data

- Simulated “Digis”
- Digi-Mixer (channels + noise)
- Simulated Raw Data

- Unpacking (RawToDigi)
- Simulated Raw Data

Flowchart: Physics Generators → Geant 4 → Electronics Simulation → Simulated Raw Data

Simulated Raw Data → Unpacking (RawToDigi) → Digi-Mixer (channels + noise) → Simulated Raw Data
Premixing lessons learned

• After a long development and validation process, **premixing deployed in CMS MC production** since this summer

• Issues and benefits we found
  – Extended “raw” format extended to ensure **sufficient precision** for close-by interactions
  – **Event reuse**: We now potentially re-use entire pileup events instead just individual minimum bias events in Monte Carlo production
  – **Flexibility** considerations: Generating multiple pileup configurations is now more time consuming
  – **Major CPU savings**: At current pileup, our digitization+reconstruction processing runs ~2x faster (with a one time cost of the up front production of the premixed library)
Premixing lessons learned

• The premixing library is big (~0.1*N(PU) MB/event)
  – Must save sufficient information from the pileup events to allow an accurate digitization
  – This is still a huge savings over the I/O seen in our old approach (~40x). We can run production using remote reads of premixing library

Premixing has brought a substantial operational improvement to our operations!
Conclusion: Looking forward

- CMS simulation continues to improve physics accuracy and to make better use of CPU resources
  - Latest Geant4 developments going into production after extended physics studies
  - Pileup simulation has been reimplemented in more technically efficient (CPU and I/O) manner while maintaining physics performance

- Supporting near-term (and major) detector changes as well as Phase-II CMS upgrades pose new challenges.
Extra information
CMS multithreaded simulation

- CMS has developed and deployed a multi-threaded framework based on TBB. Our simulation workflow is an important user
  - At the same time, we need to work within the Geant-4 mutliithreading model (POSIX threads)

- Master vs worker threads
  - Master must not do any work
  - Worker threads simulate events in their own event loops (Spawned by CMSSW Framework via TBB)

- Constrains and requirements we worked through:
  - Initialization of SIM module should be done once
  - Access to geometry and field should be const
  - Both Sequential and MT simulation should be functional within a CMSSW release
Dynamic of CPU and RSS for 13 TeV CMS simulation run in MT mode for Geant4 10.2p02

- Maximum CPU efficiency is achieved after simulation ~500 events
  - The turnon shape is expected due to
    1. CMS and Geant4 initialisation before 1st event
    2. Lazy initialization of hadron physics in Geant4