Upgrades for the CMS simulation

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for the CMS collaboration

CHEP 2016

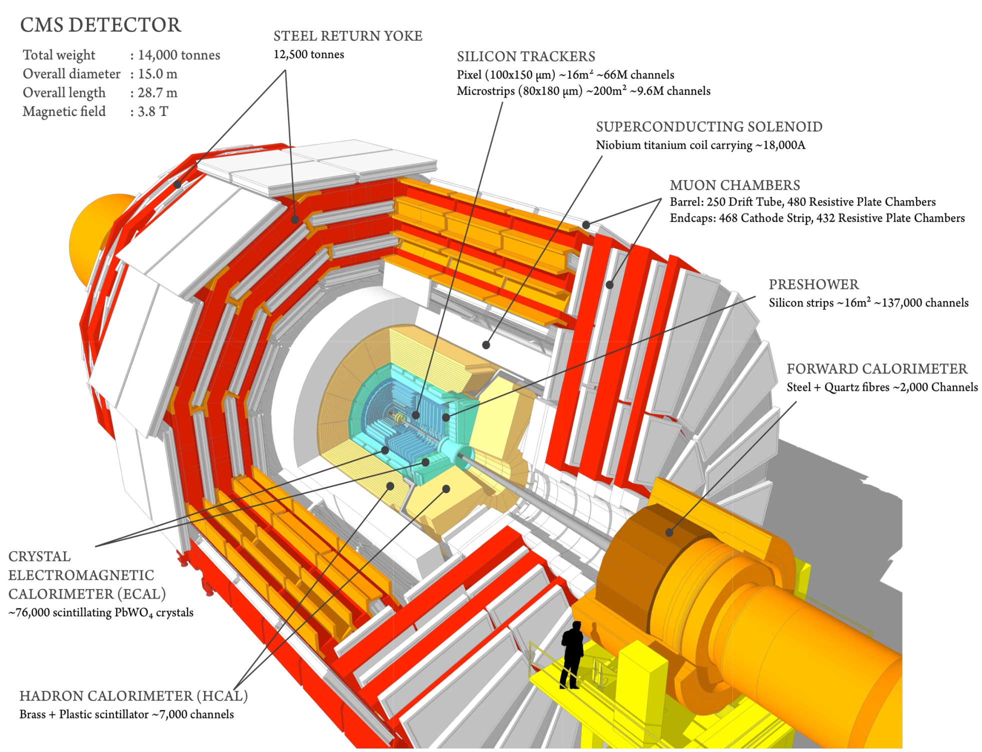
CMS simulation faces significant challenges for both today and tomorrow

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

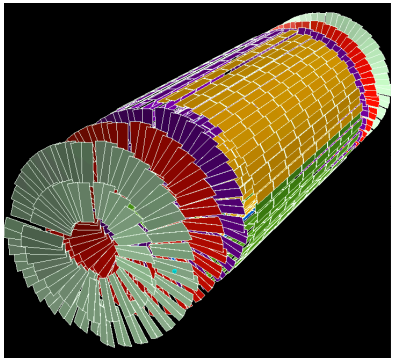


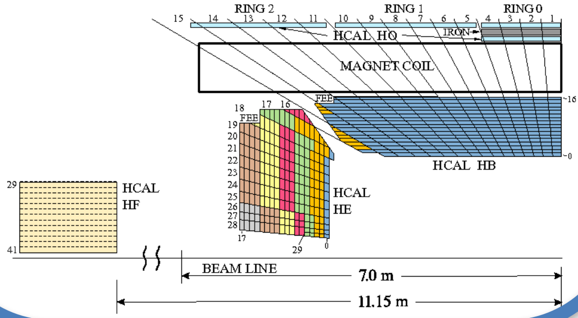
Increases in LHC luminosity and CMS detector upgrades push our simulation capabilities

Detector upgrades push continued simulation development in CMS

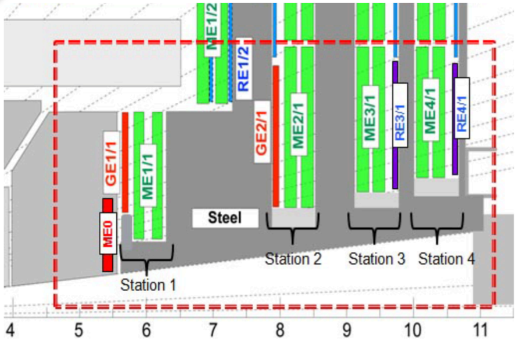
2017 upgrades

HL-LHC upgrades

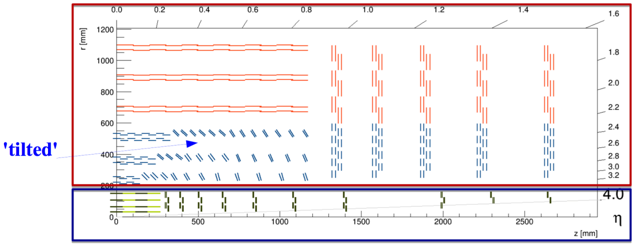




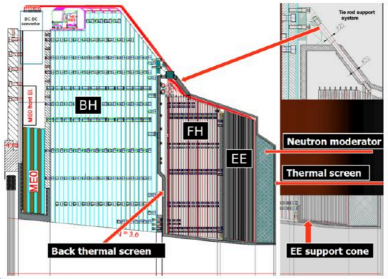
Muon ID



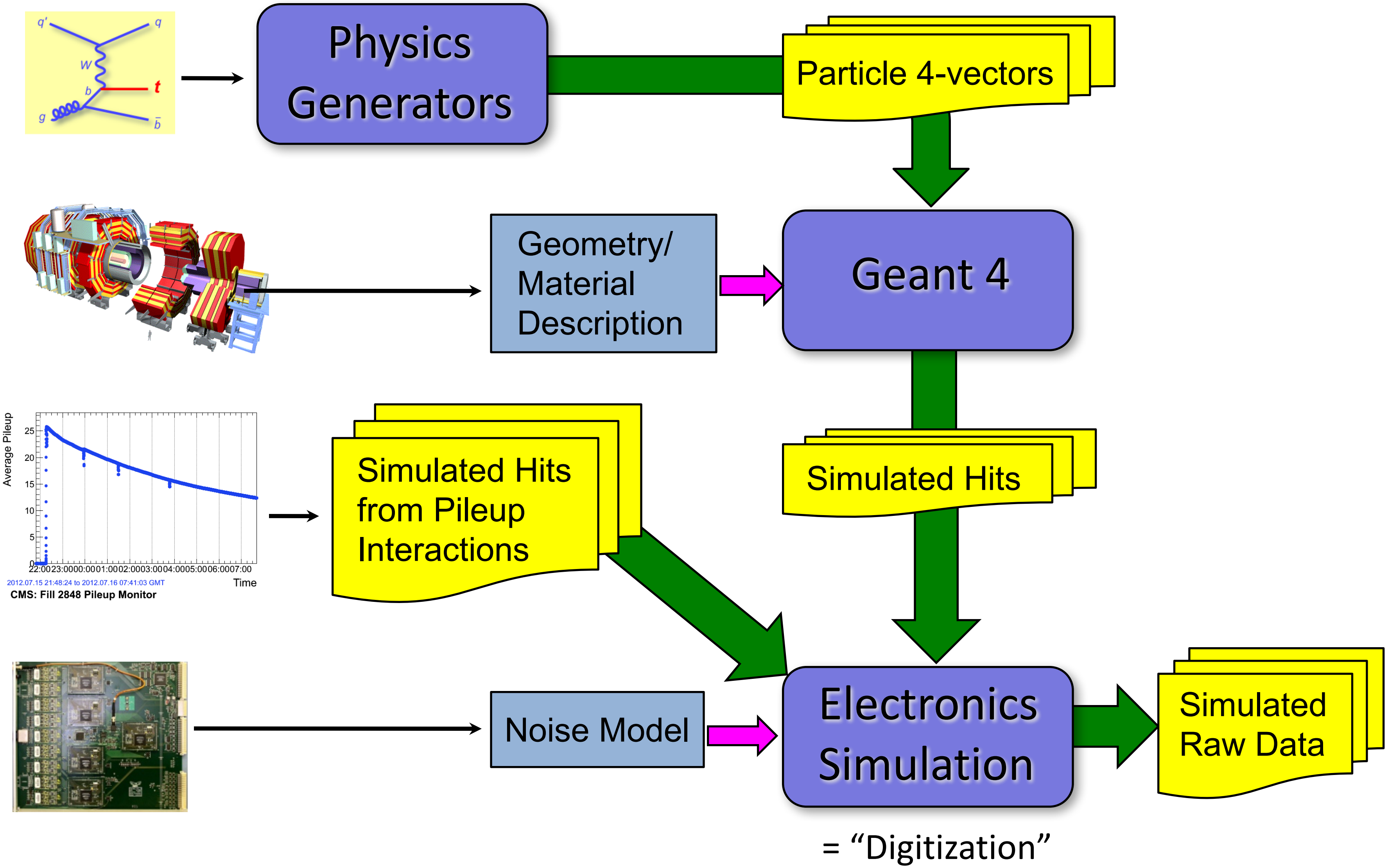
Tracking



Calorimetry



CMS Monte Carlo Simulation approach



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

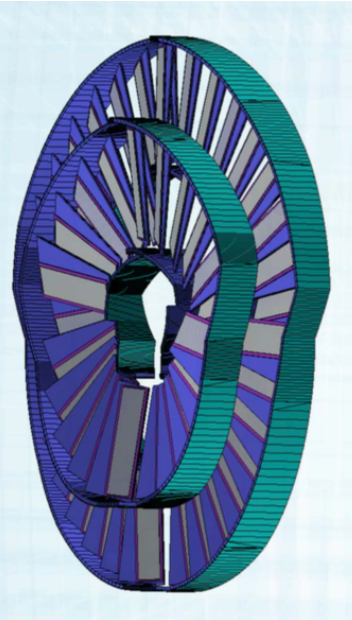
Recap from CHEP 2015: Simulation improvements for Run 2

- 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



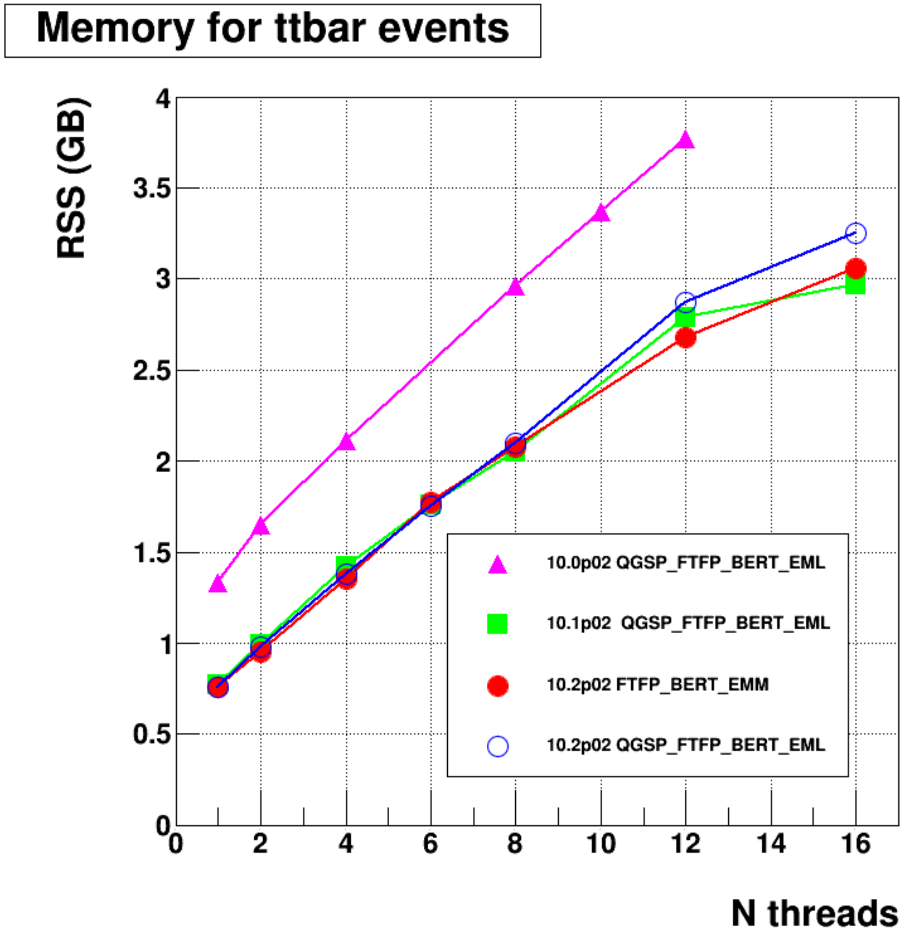
- Production platform slc6_amd64_gcc530

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)

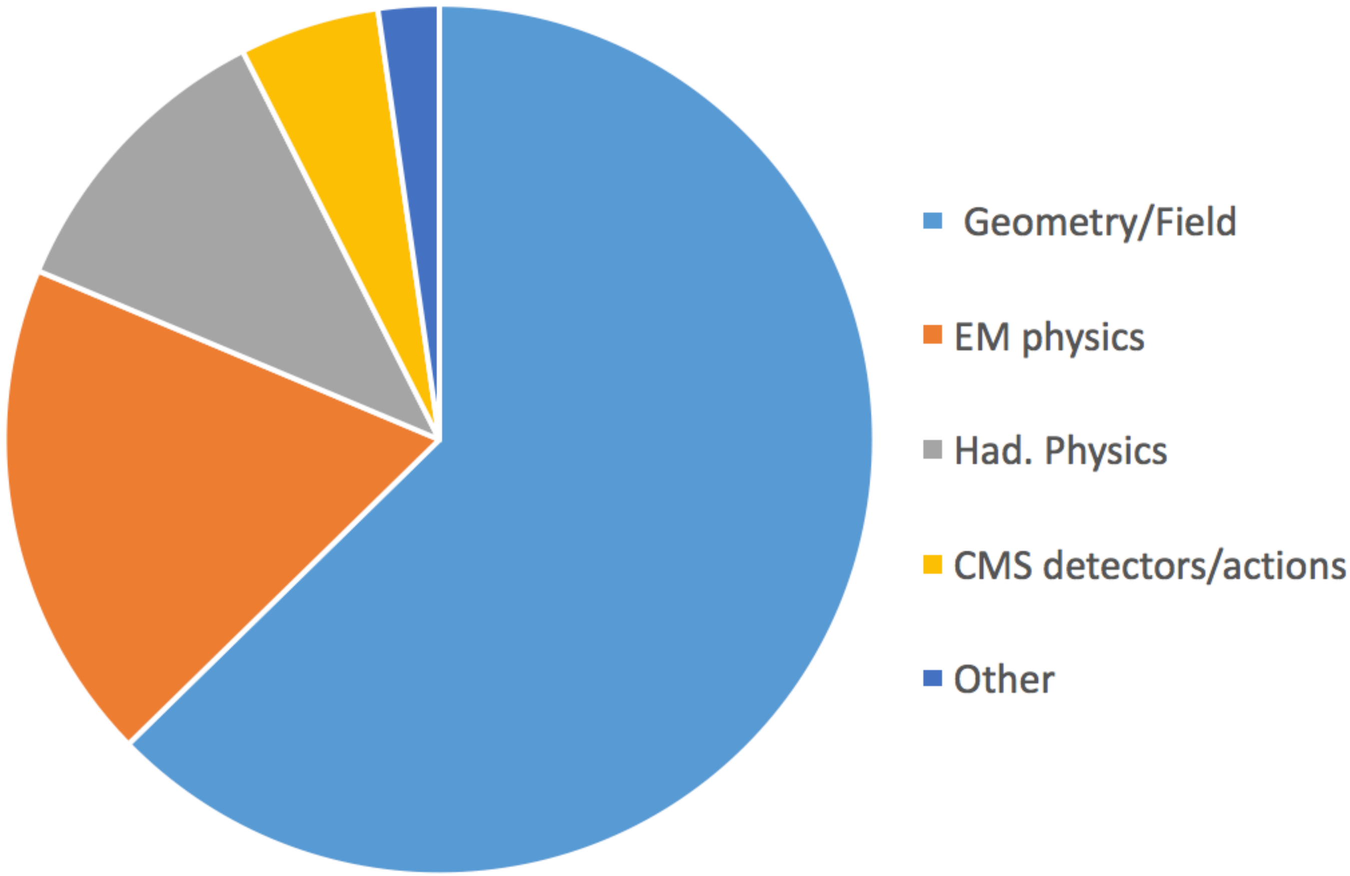
Memory for CMS run with Geant4 10.2p02

- 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



Release	1st thread (GB)	Delta per thread (GB)
10.0p02+CMS patches	1.33	0.23
10.2p02	0.76	0.19

Where our simulation CPU goes



CMS CPU performance for 2017

Geant4 version and configuration	Number of threads	CPU for ttbar (events/thread relative rate)	CPU for QCD (events/thread relative rate)
10.2p02 seq.	1	1	1
10.2p02 MT	1	1.07	0.94
10.2p02 MT	4	1.1	0.89
10.2p02 MT	8	1.13	0.89

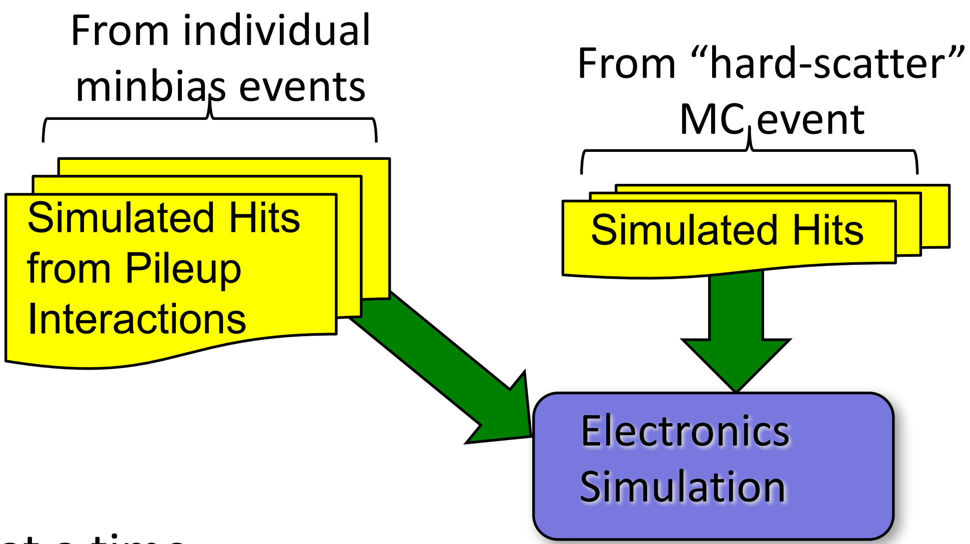
CMS 2015/6

CMS 2017

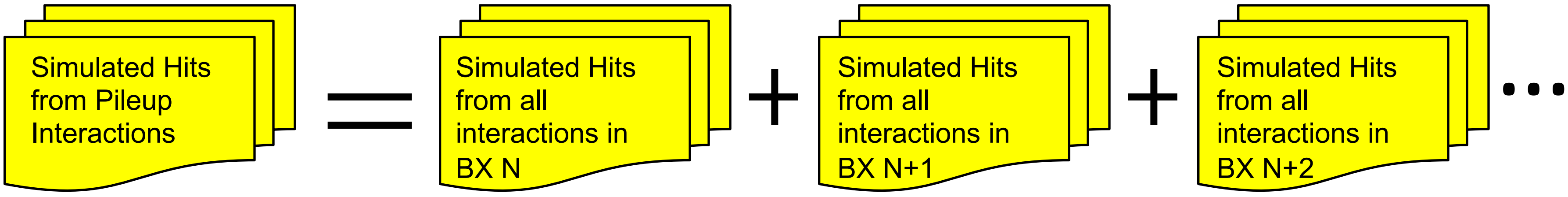
- Overall, no substantial changes in our technical performance since 2015
  - Modest improvements in CPU performance in Geant4 10.2p2 and in CMS sensitive detector code offset by other changes
- No noticible performance loss (or gain) with threading (up to 8 threads)

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



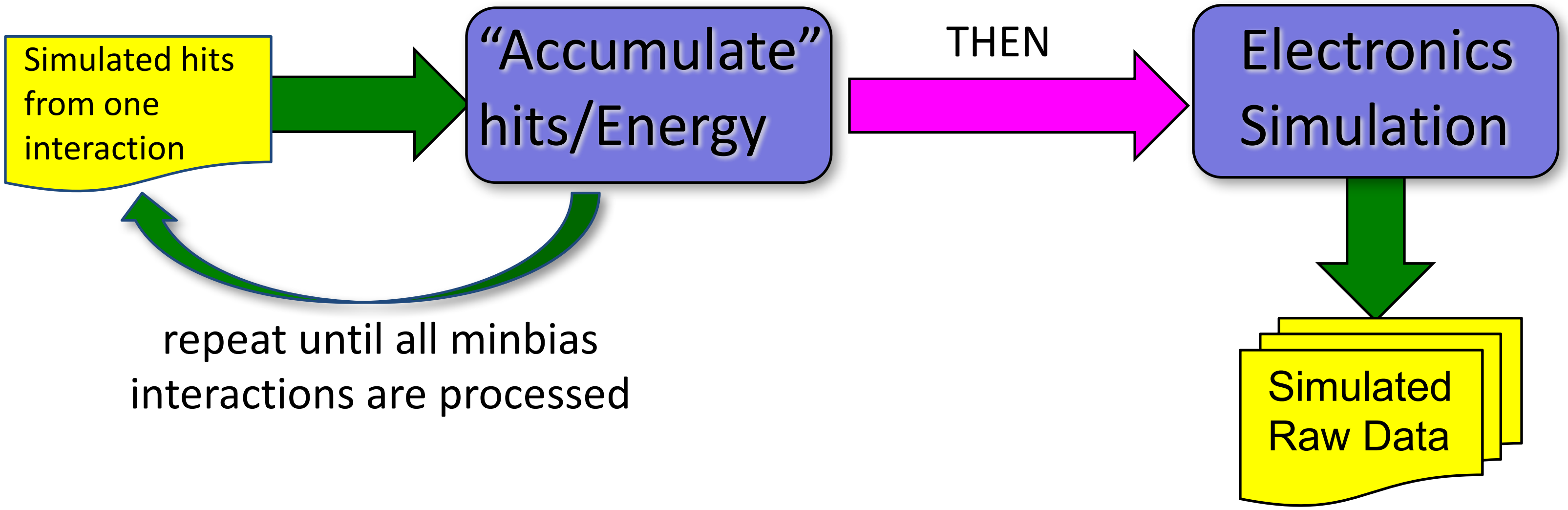
- The pileup interaction simulation is the sum of many interactions



Tens or hundreds of interactions per bunch crossing

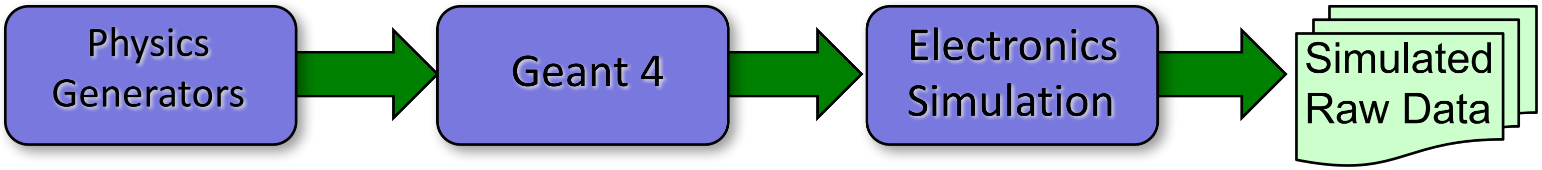
This method of pileup simulation is very I/O intensive: 1000s of minbias to read per hardscatter event

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

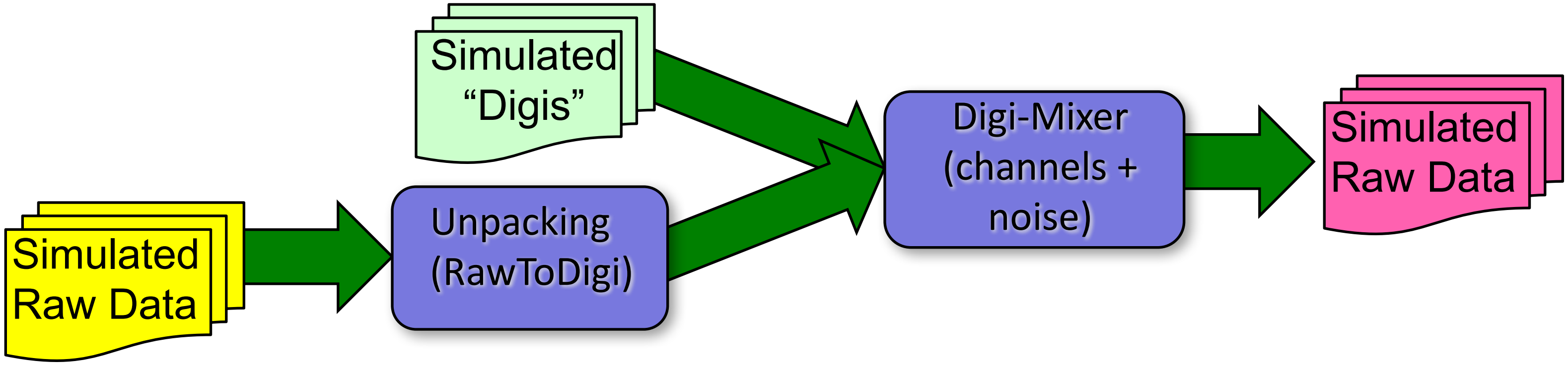


Then hard-scatter and pileup events are combined as “RAW” data format events

- 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

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 closeby 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 techically efficient (CPU and I/O) manner while maintaining physics performance

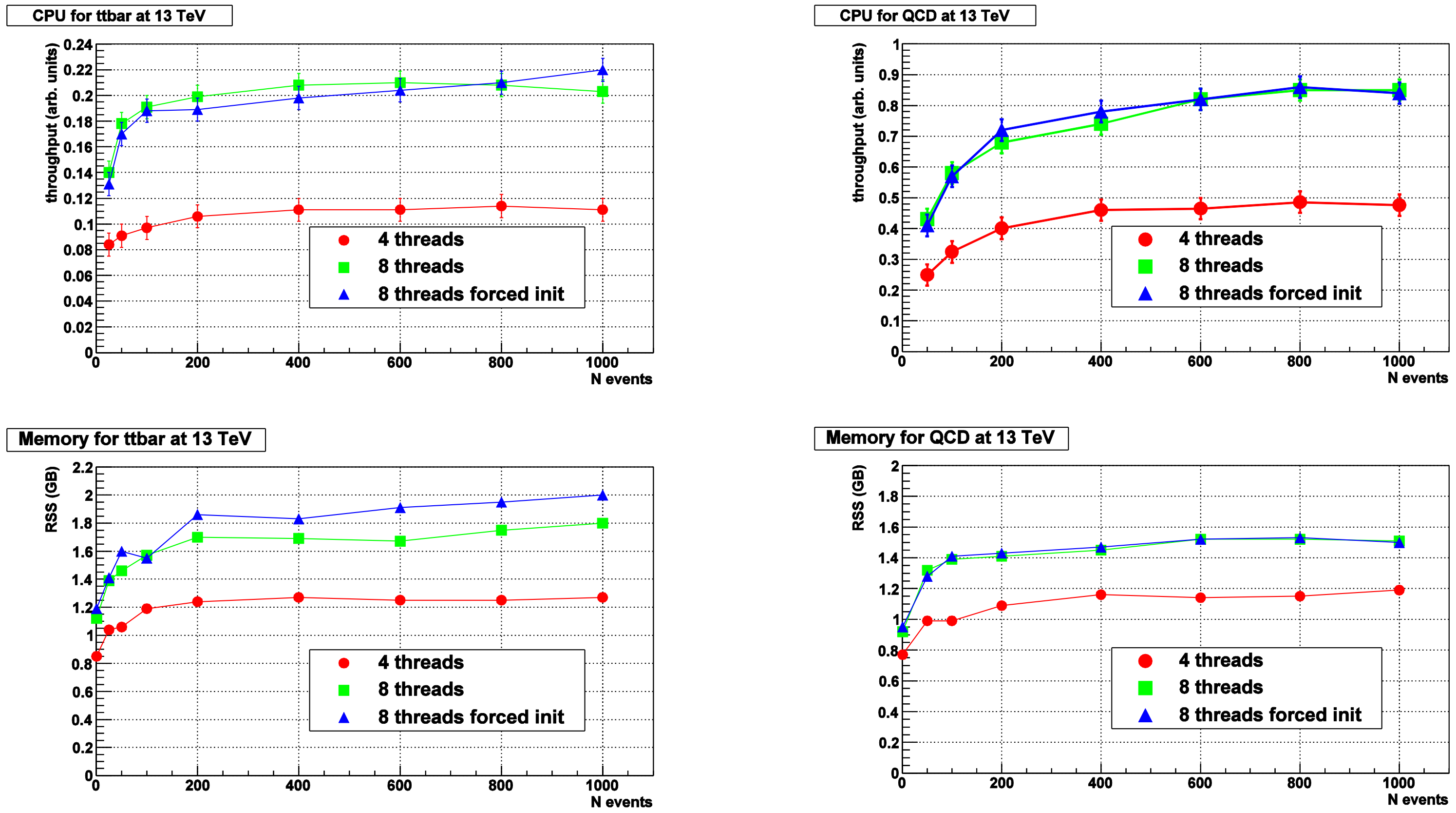
- Supporting near-term (and major) detector changes as well as Phase-II CMS upgrades pose new challenges.

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 mutlithreading 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



- Maxmum 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