Status of CMS Simulation

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Status of CMS full simulation

- CMS used Geant4 10.0p02 for 2015-2016 Run-2 simulation
  - >16 billion events are produced
  - Sequential Geant4 in production
  - QGSP_FTFP_BERT_EML Physics List
- Geant4 10.2p02 is used for 2017 Run-2 simulation production
  - >10 billion events are produced
  - Minor fixes from Geant4 10.2p03 are added
    - FTFP configuration from Geant4 10.1 is used
  - FTFP_BERT_EMM PhysicsList
  - Multithreaded Geant4
  - Recently two extra fixes were backported

CMS migrated to Geant4 10.4 for 2018 production

- Geant4 10.4 is adopted as a production version for 2018 MC production for Run-2
  - Relevant known fixes are added on top of 10.4 as CMS private patches
  - The MT mode, production platforms (gcc7.3):
    - slc6-amd64-gcc700
    - slc7-amd64-gcc700
- New features implemented in CMS full simulation for 2018 production
  - MixMax random number generator for both hits and for digi;
  - VecGeom external geometry library
  - New Geant4 stepper for computing of trajectories in magnetic field G4DormandPrince475
  - Smart tracking in magnetic field option allowing faster computations for low-energy changed particles
  - Overall simulation speedup is ~30%

CMS plans for LS2

- Target Geant4 version for Run-3
  - From today we plan to use the version of December 2019
- CMS has interest to all variants of performance improvements in Geant4
  - Improvements to EM and Had physics models and physics lists
  - Improved geometry and tracking using R&D work on Geant4 and GeantV
    - More fast transportation(s)
    - More fast navigator
  - FastSim may benefit from interfaces to ML tools
    - At least, on level of running examples
- Test-beam activities toward new forward calorimeters will be increased in order to have final design
  - Close cooperation to understand test-beam results will be required
- CMS full simulation may be performed at HPC
  - Optimizations of Geant4 for this use-case is required
- Status of migration of CMS to DD4Hep:
  - Create a working VolumeBasedMagneticField object from a DD4Hep description
  - Choose one CMS sub detector and show we can build the reconstruction geometry from a DD4Hep description
  - See if we can migrate to DD4hep by sub-detector

CMS Requirement

- CMS software group is working on Legacy CMSSW release for Run-2
  - Will be used for analysis of Run-2 for ~10 years
- We expect that all known fixes for technical problems will be included in patch3 but physics performance will not be changed
  - According to CMS plans we need Geant4 10.4patch3 in January 2019
    - If this is not possible we will continue with private patches

Problem of killed tracks

Was identified first by Sunanda Banerjee with Geant4 10.5beta

The problem was slightly reduced for 10.5 version

Was confirmed it with CMS simulation for Geant4 10.4

We expect it was there since Run-1

Warnings

- There are 2 types of messages which appear
  - More often one gets this message

```
*** G4Exception : GeomNav1002
      issued by : G4PropagatorInField::ComputeStep
 Unfinished integration of track (likely looping particle)
   of momentum (-13.3262,2.72214,132.395) ( magnitude = 133.092 )
 after 1000 field substeps  totaling 2930.79686268 mm  out of requested
   step 1000000 mm  a fraction of 0.2931 %
 in volume BeamVacuum11 with material Vacuum ( density = 1e-16 g / cm^3 )
 *** This is just a warning message. ***
-------- WWWW -------- G4Exception-END --------- WWWW -------
```

- Some of the thresholds during transportation (for reporting such messages) were relaxed by large factors

- The old thresholds are restored. This reduces the # of warnings by a factor of 4. But still there are a large number of warnings. Number of occurrences of these warnings are summarized

- The same configuration has been tried with two standard CMSSW versions using Geant4 version 10.4 + VecGeom version 00.05.00 within the releases 10_2_5_patch1 or 10_3_0_pre4. They show no warning messages.

Warnings of Type 1

- 3000 events were generated for single muon, pion, electron and minimum bias events and 1500 events for t-tbar events.

	10.5.cand01 (Native)	10.5.cand01 (VecGeom)	10.5.cand02 (VecGeom)
Muon	510	530	530
Muon (barrel)	227	286	286
Muon (endcap)	675	593	593
Pion	2194	2144	2144
Pion (barrel)	942	1053	1053
Pion (endcap)	2518	2519	2519
Electron	2523	2503	2503
Electron (barrel)	689	684	684
Electron (endcap)	4377	4547	4547
Minimum Bias	245 k	242 k	242 k
t-tbar	381 k	381 k	381 k

- The frequency does not depend on geometry type used within Geant4: Native/VecGeom
- Frequency is comparable to the last reference release

Second Type of Warning

- An example of the second type of warning:

```
*** G4Exception : Transport-001-ExcessSteps
      issued by : G4Transportation::AlongStepDoIt
Transportation is killing track that is looping or stuck.
  Track is e+ and has 132.582 MeV energy  ( pre-Step = 132.582 )
  momentum = (-2.47961,-18.8804,131.723) mag= 133.092
  position = (36.934,22.1826,3481) is in volume 'BeamVacuum11',
  its material is 'Vacuum' with density = 9.99998e-17 g/cm^3
Total number of Steps by this track: 13
Length of this step = 2930.8 mm
Number of propagation trials = 1 ( vs maximum = 10 for 'important' particles )
  ( Number of *calls* of Transport/AlongStepDoIt = 1971467 )
```

- Even high momentum used to be killed in some earlier reference versions
  - We no longer find evidence of such killed tracks in runs with similar statistics

Warnings of Type 2

- These warnings are less frequent than those of Type 1
- Please note that the native geant4 geometry versions using the same reference tag give warnings at similar rate

	10.5.cand01 (Native)	10.5.cand01 (VecGeom)	10.5.cand02 (VecGeom)
50 GeV Muon	0	0	0
Muon (barrel)	0	0	0
Muon (endcap)	0	1	1
50 GeV Pion	1	0	0
Pion (barrel)	0	0	0
Pion (endcap)	2	4	4
50 GeV Electron	1	1	1
Electron (barrel)	0	0	0
Electron (endcap)	1	2	2
Minimum Bias	1321	1319	1319
t-tbar	1778	1697	1697

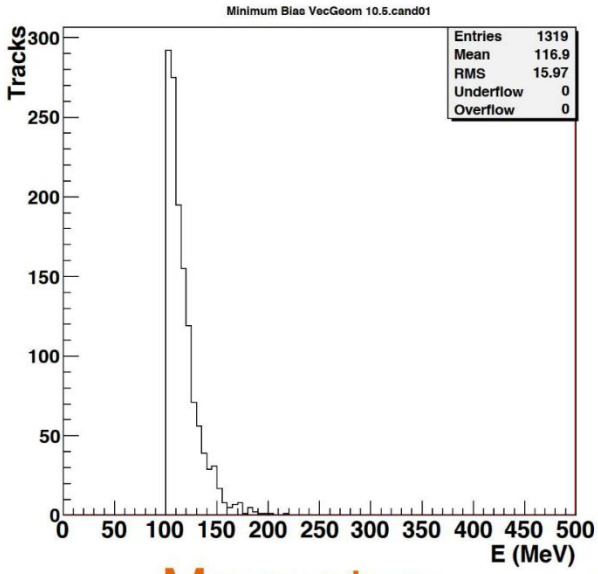
Warnings of Type 2

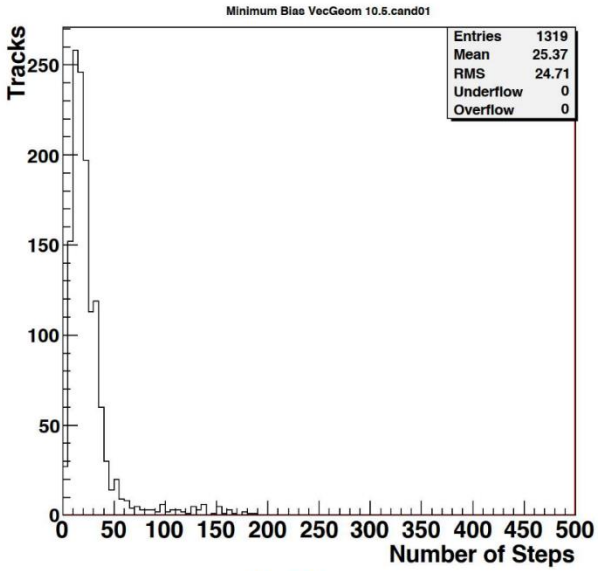
- The second type of warning is associated with killing of the tracks. It is important to look into the properties of the tracks which are killed.
- Frequency of killing tracks is similar in the 10.5.cand01 and 10.5.cand02 versions
- Following characteristics are observed
  - The medium was always air or vacuum.
  - The tracks which are killed are electron or positrons of momentum around 100 MeV or slightly higher
  - Tracks of no other types are killed (unlike earlier reference releases)

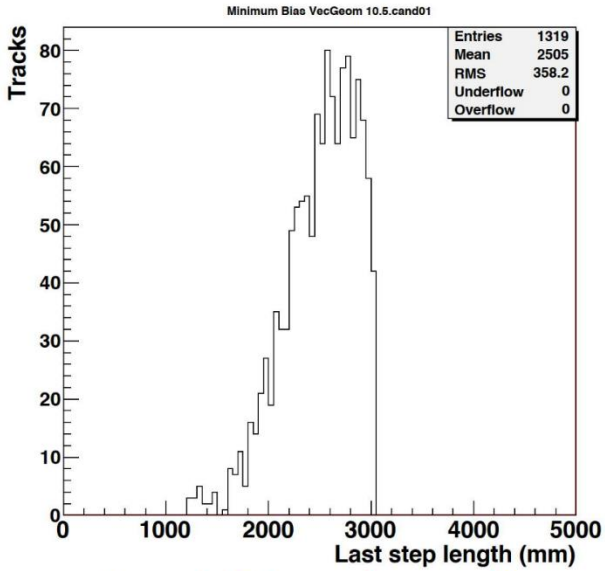
	Native (Minbias)	VecGeom (Minbias)	Native (t-tbar)	VecGeom (t-tbar)
e^+	633	878	619	813
e^-	688	900	700	884
μ^+	0	0	0	0
μ^-	0	0	0	0
π^+	0	0	0	0
π^-	0	0	0	0
proton	0	0	0	0

Properties of Killed Tracks

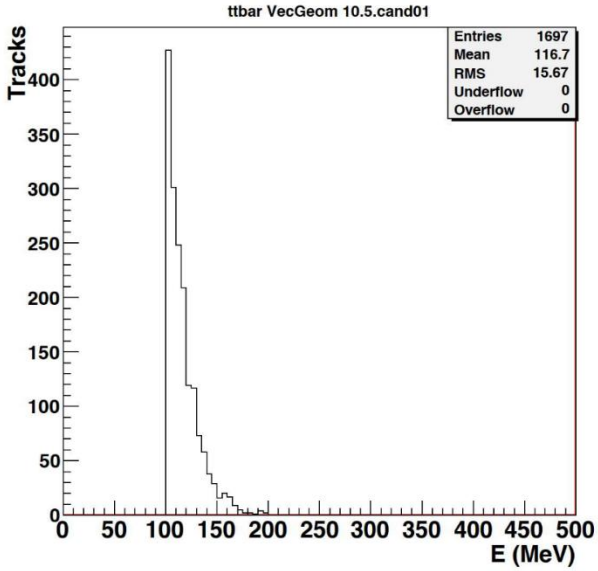
Minimum Bias

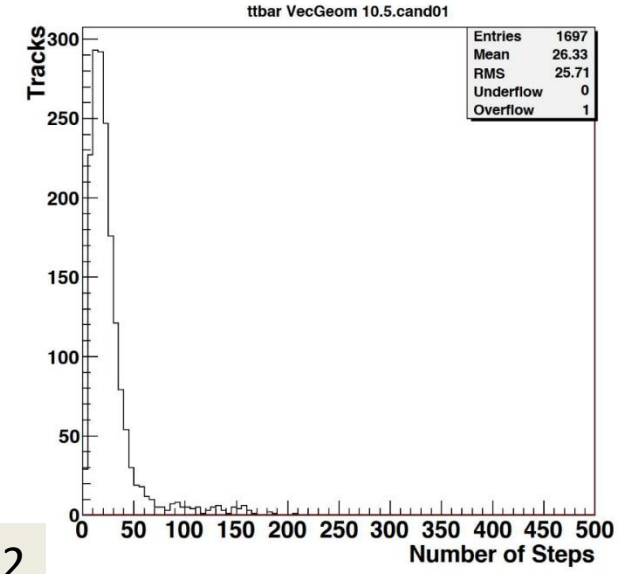


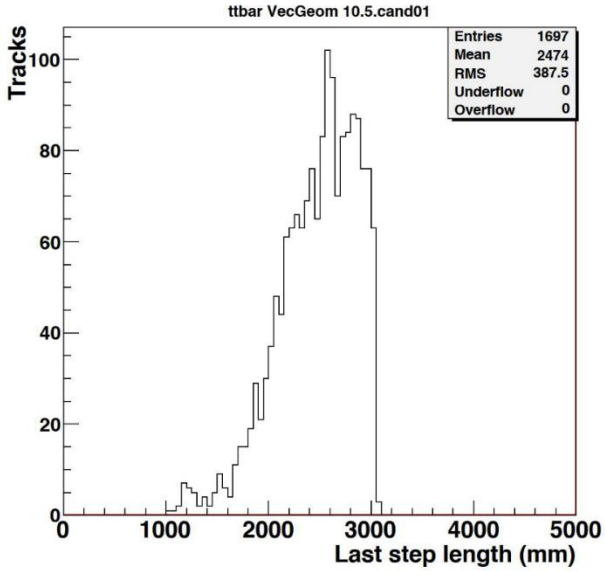




Momentum t-tbar # Steps Last Step Length







Killed track issue

- When a new step is computed by Geant4, each process limit the step according to its cross section and random number
  - In normal materials step limit due to interactions is of order mm-cm
  - In Air or Vacuum physics step limitation is very large
  - Propagation in field has “maximum step” parameter, which is equal to 1 km
  - Integration of trajectory in field is numerical and may not converge for a long step if limits on accuracy are too tight
    - A track is killed by Geant4 transportation and does not produce hits
    - The effect practically does not depend on generator or field stepper
    - For CMS is seen in the beam pipe, in the muon system, and in the cavern
  - This problem was there for ~10 years and tracks were killed silently
    - Mainly e+- below 100 MeV are killed but few muons are killed as well outside the main detector
- CMS would consider this issue as a critical one
  - We cannot claim that it is affecting analysis
  - It is not optimal, if some tracks are killed and do not produce hits, even if it is a minor effect
  - It is not good to have a lot of warning
  - it is not good to kill tracks silently

Discussion on killed track issue

- In a typical collider detector there are different arias
  - practically uniform magnetic field in central part of a detector
  - significantly non-uniform magnetic field at edges, because magnetic flux should be returned
- If a global parameters are defined for transportation in magnetic field, then these parameters are optimized for accurate simulation in the uniform field
  - How such set of parameters are working at edges?
  - Is it only responsibility of a user group to define a correct set of parameters or Geant4 can take care on a part of problem?
- User interface to field is complicate
  - User access several classes to define parameters and a stepper
  - Should it be more user friendly?
- Likely the parameter set and stepper should be frequently changed in run time
  - Can this use case be supported by Geant4 team?
  - CPU performance, multi-threaded mode, and reproducibility are requirements