Geant4 10.0beta: First Results for MT
(Performance, Physics Validation, Reproducibility)

Alberto Ribon (CERN PH/SFT)
Soon Yung Jun (Fermilab)

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Part I

Performance of Geant4-MT

Soon Yung Jun
(Fermilab)

Performance Benchmarking

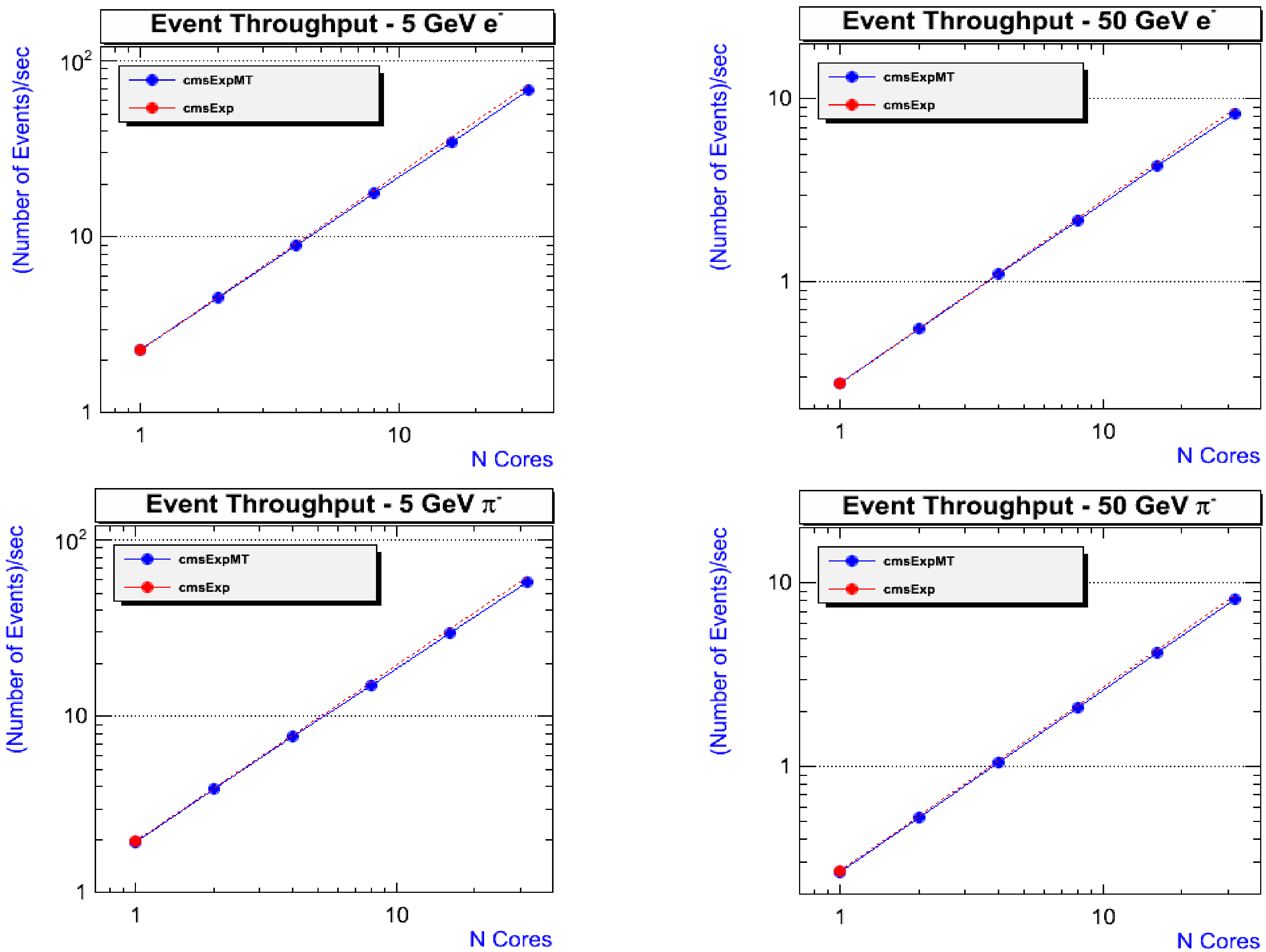
- Applications linked with Geant4-MT (beta or r07)
  - SimplifiedCalo
  - CmsExpMT: CMS detector geometry and a simplified (volume based) magnetic field map
- Hardware platforms
  - AMD Opteron(tm) 6128 (4x8 cores, 2.0 GHz, 66GB)
  - Intel Xeon L5520 (2x8 cores, 2.27 GHz) and Xeon Phi P5110 (60 cores, 1.1053 GHz, 8GB)
- Performance metrics
  - event throughput (scalability)
  - memory reduction

Performance Measurement

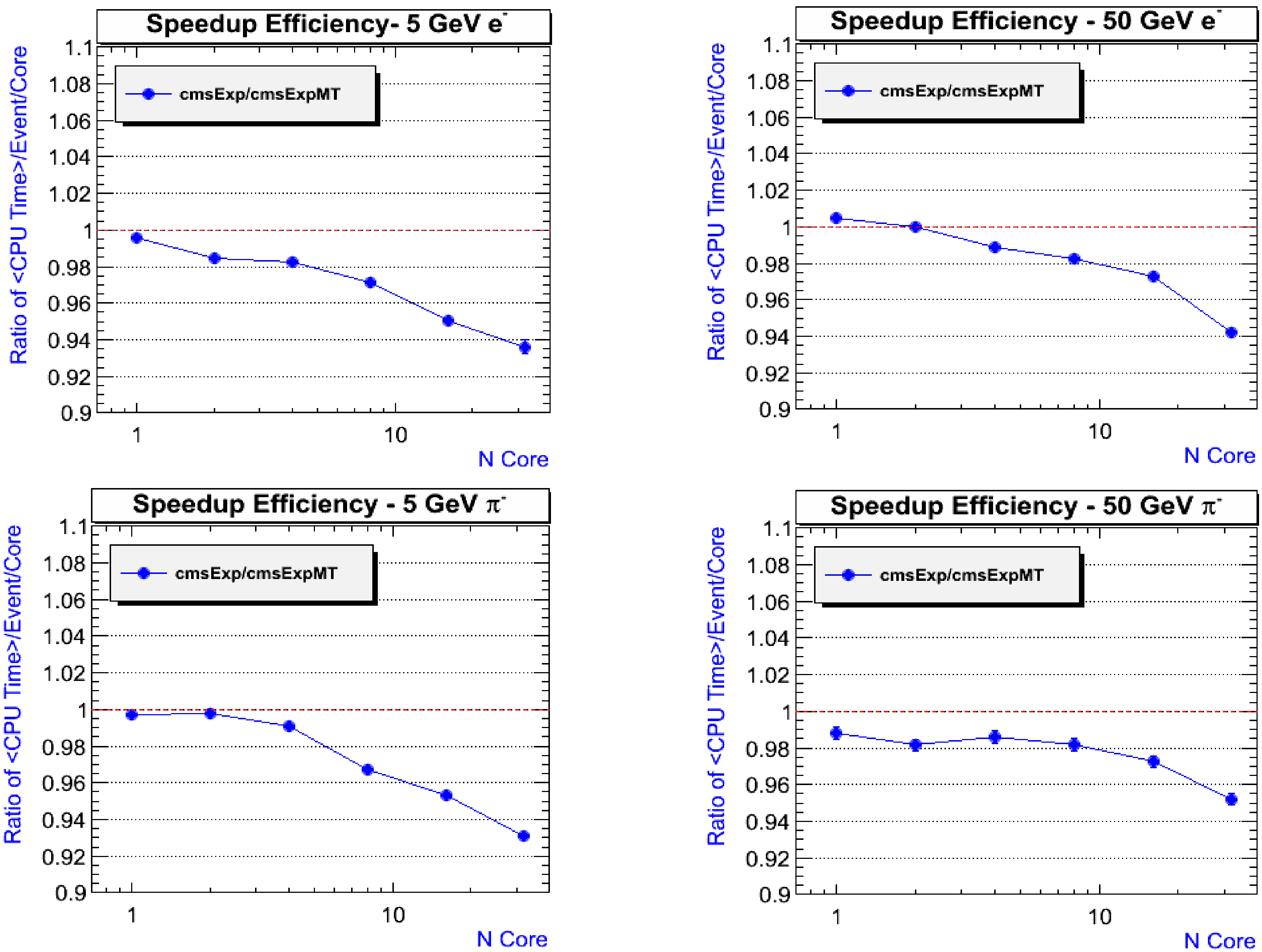
- Weak scaling: a fixed number of events per thread
- Event throughput
  - the number of events processed per unit second
  - a good measure of scalability
  - speedup efficiency (sequential CPU/[MT CPU/nt])

    as the number of threads (nt)
- Memory reduction
  - shared memory: geometry, tables of EM physics
  - Rn = (n-1)x(Shared memory) + (initial overhead for TLS)
  - memory reduction ([MT Mem/nt]/Sequential Mem)
    as the number of threads (nt)

Event Throughput – cmsExpMT (ref-07)

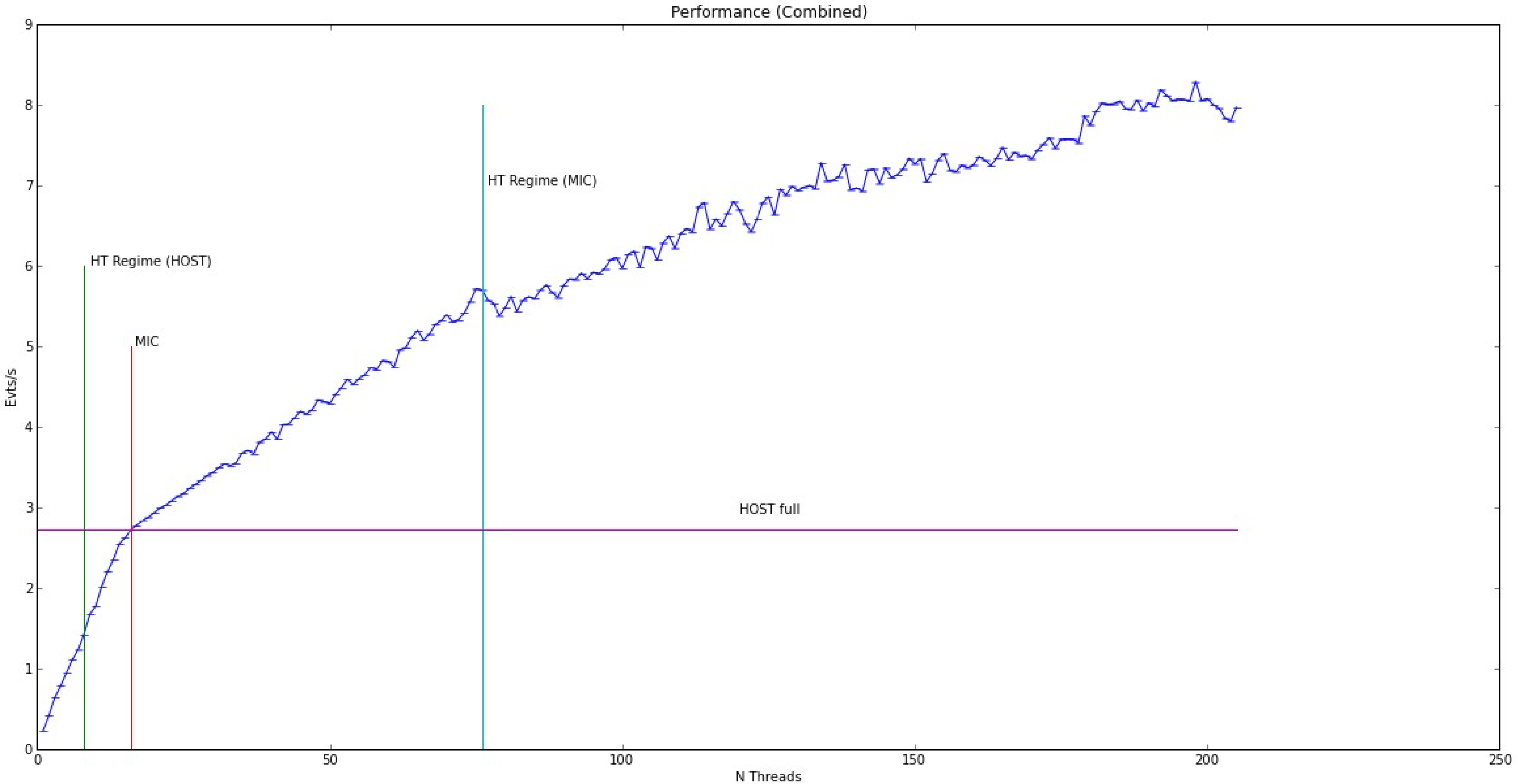


Speedup Efficiency – cmsExpMT (ref-07)

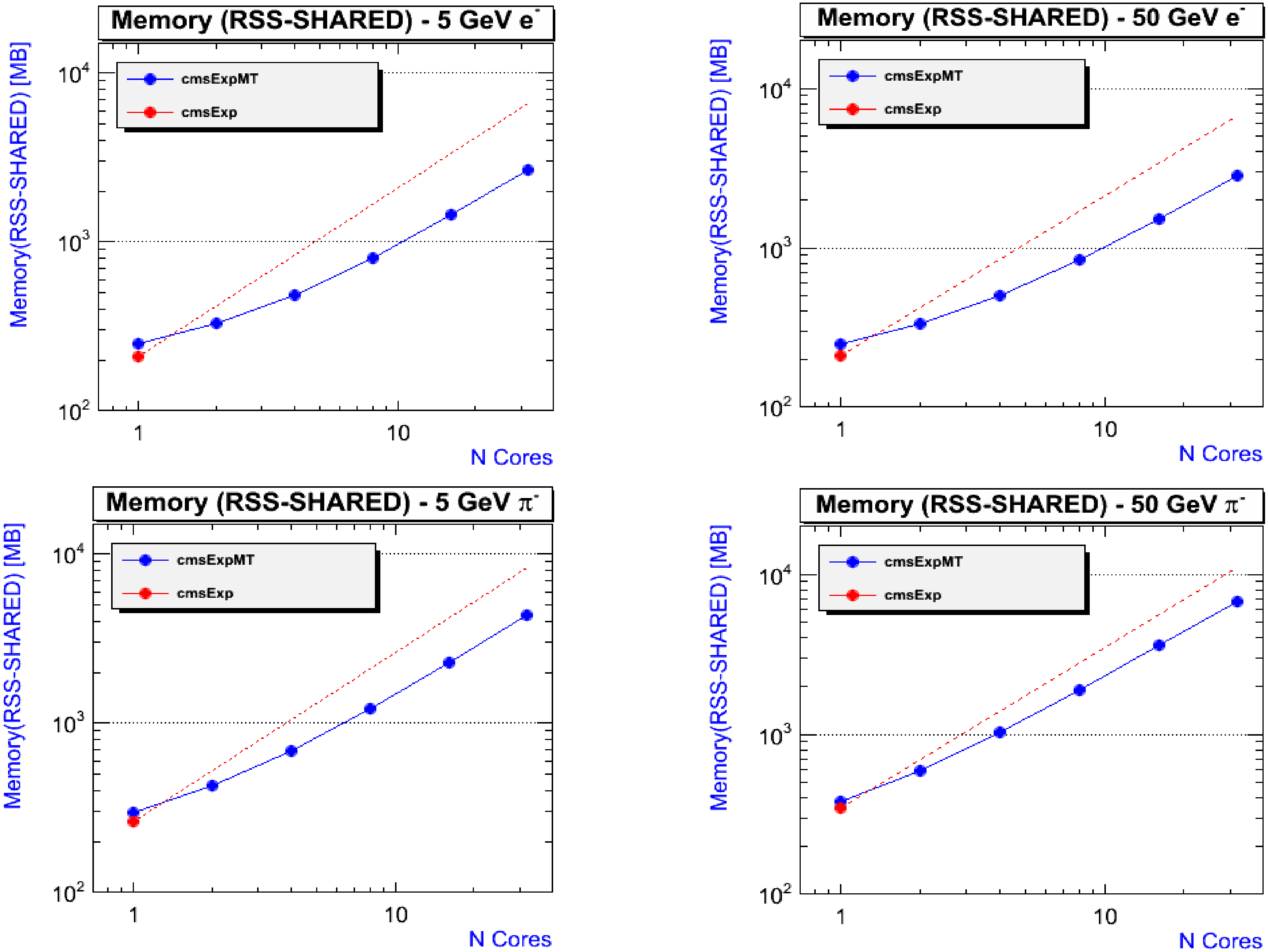


Event throughput in Intel+MIC
(Andrea Dotti)

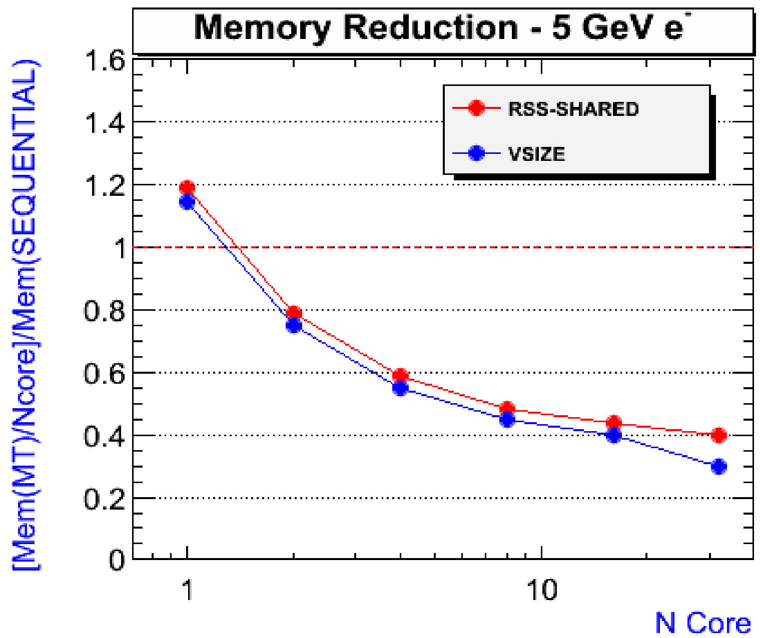
- Multi-threaded SimplifiedCalo shows a nearly linear scalability up to the maximum number of threads available (16+194 with hyperthreading limited by the MIC memeory)

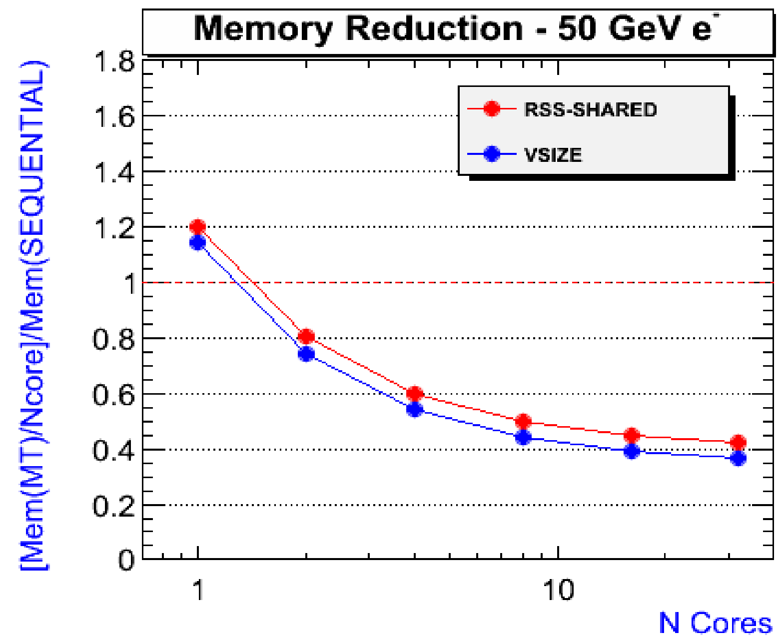


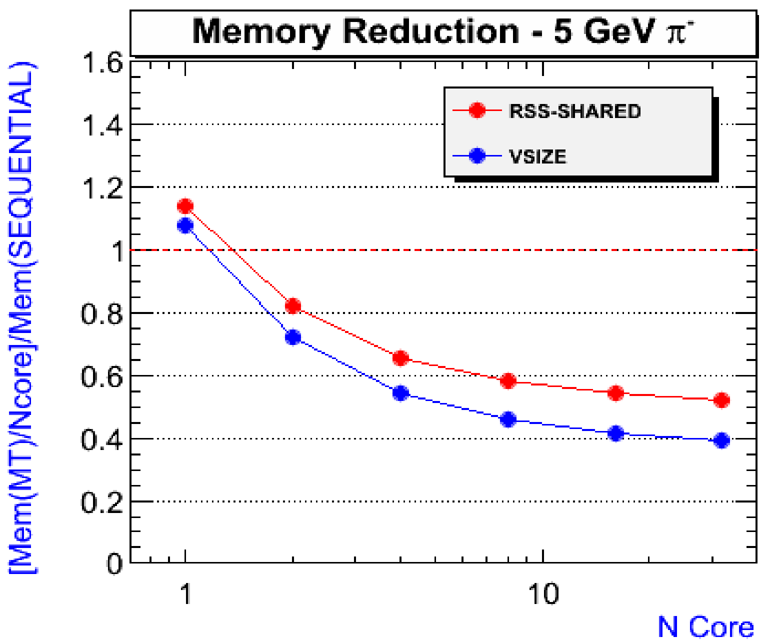
Memory – cmsExpMT (ref-07)

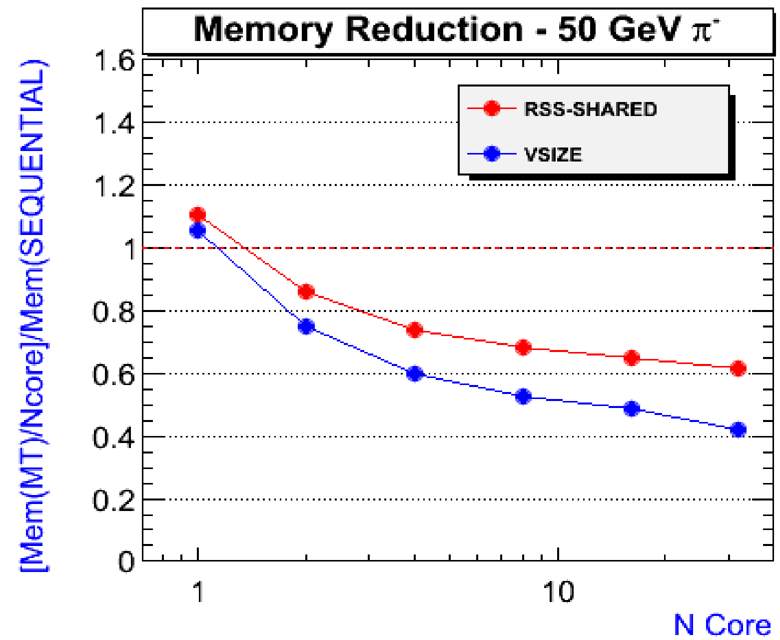


Memory Reduction – cmsExpMT (ref-07)









Preliminary Profiling Results

- No major issue in preliminary profiling

Open|SpeedShop (osspcsamp)

Geant4.9.6.r07 cmsExpMT

Sample	Energy	Sequential	Multi Thread
Electrons	5 GeV	S1	T1 T2 T4 T8 T16 T32
	50 GeV	S1	T1 T2 T4 T8 T16 T32
Pions	5 GeV	S1	T1 T2 T4 T8 T16 T32
	50 GeV	S1	T1 T2 T4 T8 T16 T32

Exclusive CPU time in seconds.	% of CPU Time	Function (defining location)
163.110000	4.156505	__ieee754_log (libm-2.12.so)
140.450000	3.579064	cmsExpMagneticField::GetVolumeBase
115.210000	2.935878	G4Navigator::LocateGlobalPointAndS
100.390000	2.558222	G4CrossSectionDataStore::GetCrossS
85.850000	2.187701	__ieee754_atan2 (libm-2.12.so)
80.550000	2.052642	G4PhysicsVector::Value (libG4globa
78.480000	1.999893	__ieee754_exp (libm-2.12.so)
71.800000	1.829668	G4PhotoNuclearCrossSection::GetIso
68.650000	1.749397	G4SteppingManager::DefinePhysicalS
59.510000	1.516484	CLHEP::RanecuEngine::flat (libG4cl
58.190000	1.482846	G4Transportation::AlongStepGetPhys
54.980000	1.401046	G4HadronCrossSections::CalcScatter
54.580000	1.390853	G4Navigator::ComputeStep (libG4geo
50.420000	1.284845	G4SteppingManager::Stepping (libG4
48.690000	1.240759	G4CrossSectionDataStore::GetIsoCro
48.510000	1.236172	G4VoxelNavigation::ComputeStep (li
47.810000	1.218334	G4BGGNucleonInelasticXS::CoulombFa
46.130000	1.175523	G4PhysicsLogVector::FindBinLocatio
44.570000	1.135770	G4NavigationLevel::~G4NavigationLe
43.410000	1.106210	G4CrossSectionDataStore::GetCrossS
39.380000	1.003514	G4Mag_UsualEqRhs::EvaluateRhsGiven
39.380000	1.003514	G4SteppingManager::InvokePSDIP (li
39.310000	1.001730	G4ClassicalRK4::DumbStepper (libG4
38.760000	0.987715	G4EnhancedVecAllocator<G4Navigatio

Exclusive CPU time in seconds.	% of CPU Time	Function (defining location)
167.360000	4.208250	__ieee754_log (libm-2.12.so)
139.140000	3.498661	cmsExpMagneticField::GetVolum
108.970000	2.740039	G4Navigator::LocateGlobalPoin
95.920000	2.411899	G4CrossSectionDataStore::GetC
86.690000	2.179811	G4PhysicsVector::Value (libG4
82.830000	2.082752	__ieee754_exp (libm-2.12.so)
80.040000	2.012598	__ieee754_atan2 (libm-2.12.so
67.350000	1.693509	G4SteppingManager::DefinePhys
65.110000	1.637184	G4PhotoNuclearCrossSection::G
60.280000	1.515734	CLHEP::RanecuEngine::flat (li
57.070000	1.435019	G4HadronCrossSections::CalcSc
56.200000	1.413143	G4CrossSectionDataStore::GetI
54.600000	1.372911	G4Navigator::ComputeStep (lib
53.950000	1.356567	G4VoxelNavigation::ComputeSte
48.770000	1.226317	G4SteppingManager::Stepping (
46.890000	1.179044	G4PhysicsLogVector::FindBinLo
46.440000	1.167729	G4Transportation::AlongStepGe
46.070000	1.158425	G4CrossSectionDataStore::GetC
45.170000	1.135795	G4BGGNucleonInelasticXS::Coul
42.980000	1.080728	G4SteppingManager::InvokePSDI
40.440000	1.016860	G4NavigationLevel::~G4Navigat
39.710000	0.998504	G4Mag_UsualEqRhs::EvaluateRhs
39.300000	0.988194	G4EnhancedVecAllocator<G4Navi
38.800000	0.975622	G4PropagatorInField::ComputeS

Exclusive CPU time in seconds.	% of CPU Time	Function (defining location)
4445.200000	3.455208	cmsExpMagneticField::GetVolumeBaseBfield (cmsExpMT)
4220.720000	3.280722	G4Navigator::LocateGlobalPointAndSetup (libG4geometr
4173.260000	3.243832	__ieee754_log (libm-2.12.so)
3324.950000	2.584449	G4CrossSectionDataStore::GetCrossSection (libG4proce
2978.090000	2.314839	G4PhysicsVector::Value (libG4global.so)
2641.130000	2.052923	__ieee754_atan2 (libm-2.12.so)
2351.700000	1.827952	__ieee754_exp (libm-2.12.so)
2308.410000	1.794303	G4SteppingManager::DefinePhysicalStepLength (libG4tr
2036.690000	1.583098	G4PhotoNuclearCrossSection::GetIsoCrossSection (libG
2001.680000	1.555885	CLHEP::RanecuEngine::flat (libG4clhep.so)
1787.340000	1.389281	G4VoxelNavigation::ComputeStep (libG4geometry.so)
1734.460000	1.348178	G4CrossSectionDataStore::GetIsoCrossSection (libG4pr
1706.780000	1.326663	G4HadronCrossSections::CalcScatteringCrossSections (
1639.070000	1.274032	G4Transportation::AlongStepGetPhysicalInteractionLen
1622.740000	1.261339	G4Navigator::ComputeStep (libG4geometry.so)
1550.650000	1.205304	G4CrossSectionDataStore::GetCrossSection (libG4proce
1436.450000	1.116538	G4BGGNucleonInelasticXS::CoulombFactor (libG4process
1435.940000	1.116141	G4SteppingManager::Stepping (libG4tracking.so)
1432.300000	1.113312	G4SteppingManager::InvokePSDIP (libG4tracking.so)
1423.790000	1.106697	G4PhysicsLogVector::FindBinLocation (libG4global.so)
1317.140000	1.023799	G4Mag_UsualEqRhs::EvaluateRhsGivenB (libG4geometry.s
1257.190000	0.977201	G4EnhancedVecAllocator<G4NavigationLevel>::allocate
1240.180000	0.963979	G4NavigationLevel::~G4NavigationLevel (libG4geometry
1200.970000	0.933502	G4PropagatorInField::ComputeStep (libG4geometry.so)

Summary on Performance

- Performance of multi-threaded applications of Geant4 shows good scalability (near-linear) and memory reduction
  - incorporate Geant4 MT benchmarking/profiling into the regular performance monitoring task
  - improve analysis/summary/presentation
  - extend performance measurements with Intel® MIC
- Other relevant talks in the parallel session 3A
  - Performances of Geant4MT on MIC architecture (A. Dotti)
  - Profiling Tools and Results (S.Y. Jun)
  - Many other MT related talks

Part II

Physics Validation and Reproducibility of Geant4MT

Alberto Ribon
CERN PH/SFT

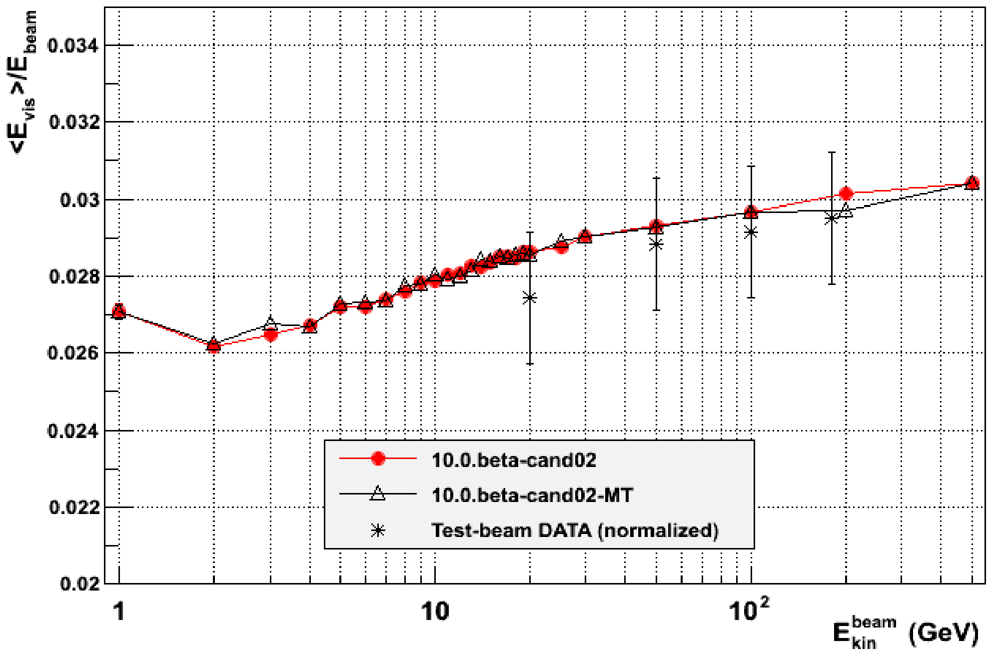
Validation : G4 MT *vs.* sequential (1/3)

Calorimeter observables should remain **statistically** the same for **sequential** and **MT**

- *Grid validation*
  - SimplifiedCalo : sequential (i.e. use G4RunManager)
  - Beam particle: pi- ; beam energies: 1 - 500 GeV
  - 5 calorimeter types (Fe-Sci, Cu-LAr, W-LAr, Pb-LAr, PbWO4)
  - Various physics lists
  - Link against G4 or G4**MT**
- *Local validation*
  - 20 GeV pi- Cu-LAr , k0L Fe-Sci, p W-LAr , n Pb-LAr, k- PbWO4
  - (sequential) SimplifiedCalo linked against G4 vs.
    MT SimplifiedCalo (i.e. use G4MTRunManager) linked against G4**MT**
  - 5'000 events for sequential or 1-thread MT;
    20'000 events for 4-threads

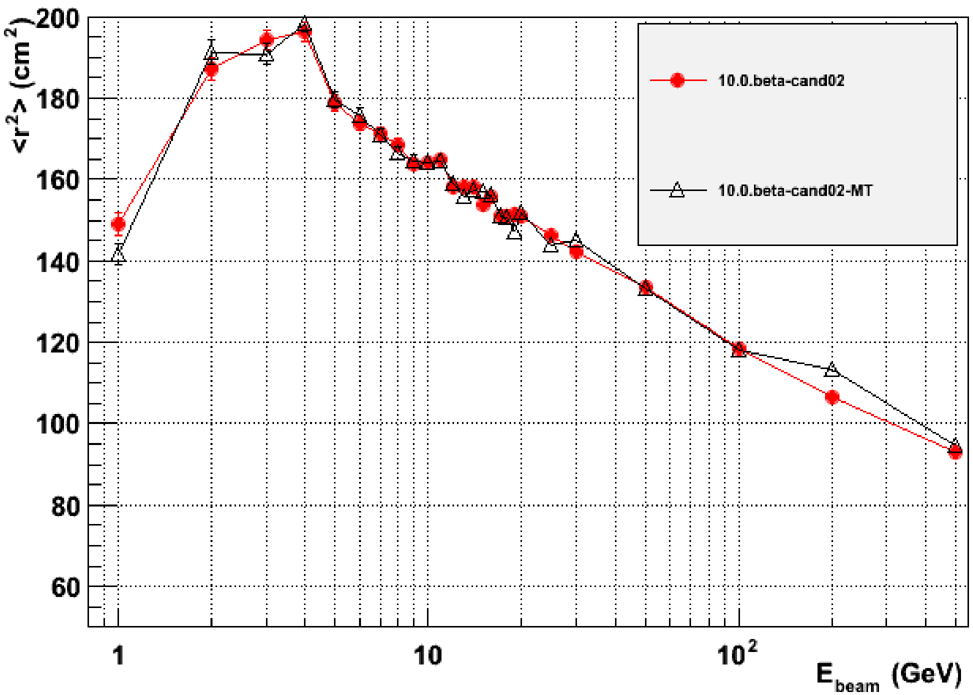
Validation : G4 MT *vs.* sequential (2/3)

Response



FTFP_BERT
pi- Fe-Sci
(ATLAS TileCal)

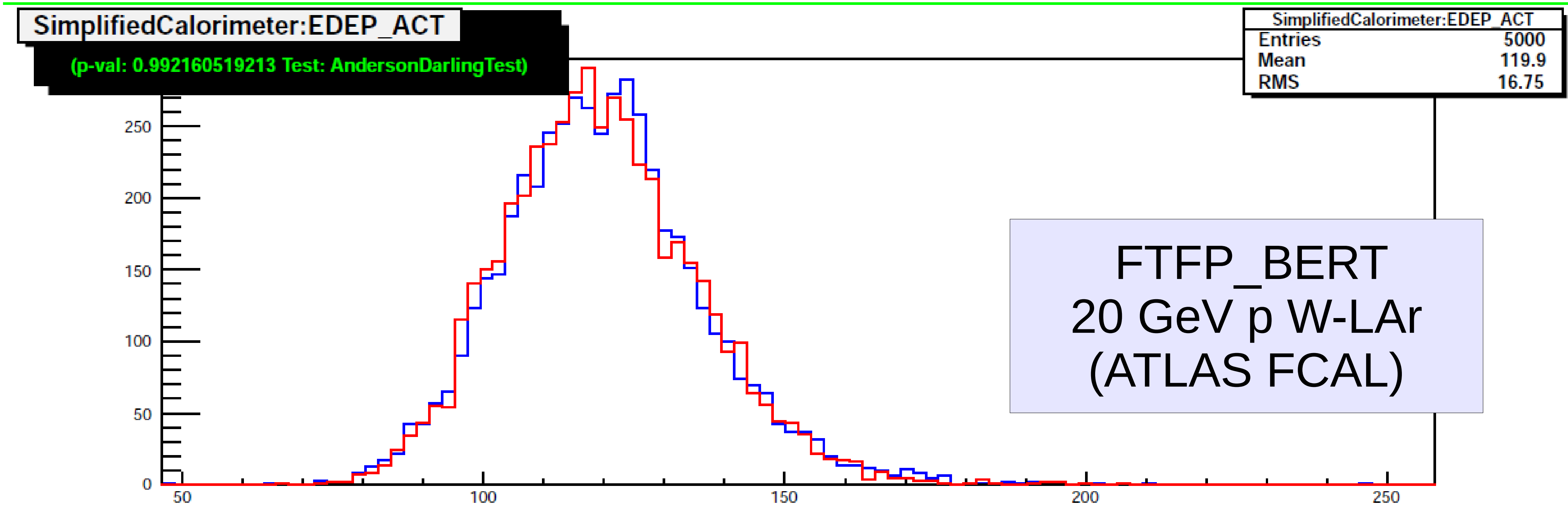
Lateral shower shape



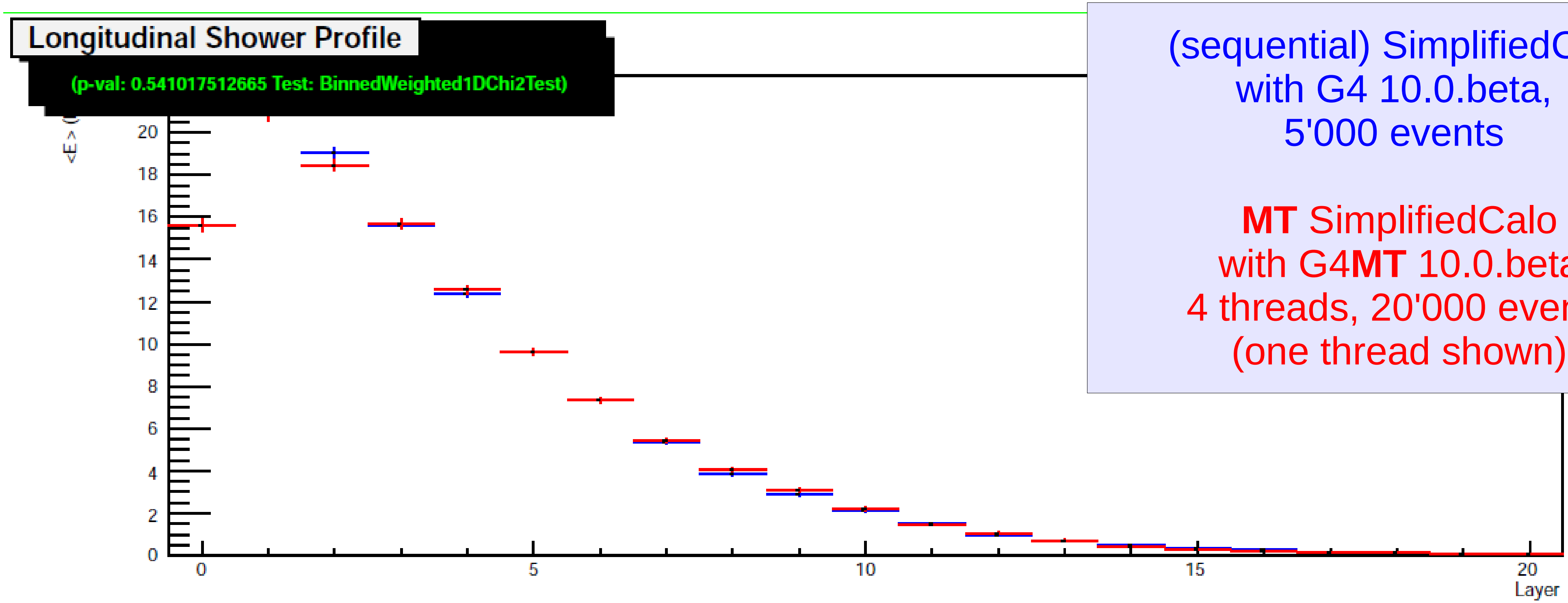
(sequential) SimplifiedCalo with G4 10.0.beta

(sequential) SimplifiedCalo with G4**MT** 10.0.beta

Validation : G4 MT vs. sequential (3/3)



FTFP_BERT
20 GeV p W-LAr
(ATLAS FCAL)



(sequential) SimplifiedCalo
with G4 10.0.beta,
5'000 events

MT SimplifiedCalo
with G4**MT** 10.0.beta
4 threads, 20'000 events
(one thread shown)

Reproducibility : G4 MT *vs.* sequential (1/2)

G4 **sequential** and **MT** should behave **identically** if the starting random generator status is the same

- **Prerequisite: event-level reproducibility of sequential G4**
  - An event remain unchanged regardless if we run other events before, whenever the starting random generator status is the same
  - First achieved in G4 9.6, and maintained since then
- New test for G4MT vs sequential
  - **MT** SimplifiedCalo linked against G4**MT**
  - Save the random generator status at each event (thread):

    /random/setSavingFlag 1
    /random/saveEachEventFlag 1
  - For each event, compare with a single-event run of the sequential SimplifiedCalo linked against sequential G4, initialized with the same random generator status, e.g.

    /random/resetEngineFrom *G4Worker3_run0evt760.rndm*

Reproducibility : G4 MT *vs.* sequential (2/2)

- Results
  - FTFP_BERT physics list
  - 5000 tests in total : 1000 events for 5 combinations
    20 GeV pi- Cu-LAr , k0L Fe-Sci, p W-LAr , n Pb-LAr, k- PbWO4
  - **~9%** reproducibility violations in G4 **10.0.beta**
    - Found a problem (cached value) in G4MuPairProductionModel
  - **~0.1%** reproducibility violations in G4 **9.6.ref07**
    - Found thread-collision problem (cache shared among threads) in Bertini
  - **~7%** reproducibility violations in G4 **9.6.ref08**
    - Found problems in G4MuPairProductionModel
  - **0%** reproducibility violations in
    G4 **9.6.ref08 + emmuons-V09-06-19**

=> **Full reproducibility (sequential & MT) achieved!**