Geant4 Performance Monitoring

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Outline of Talk

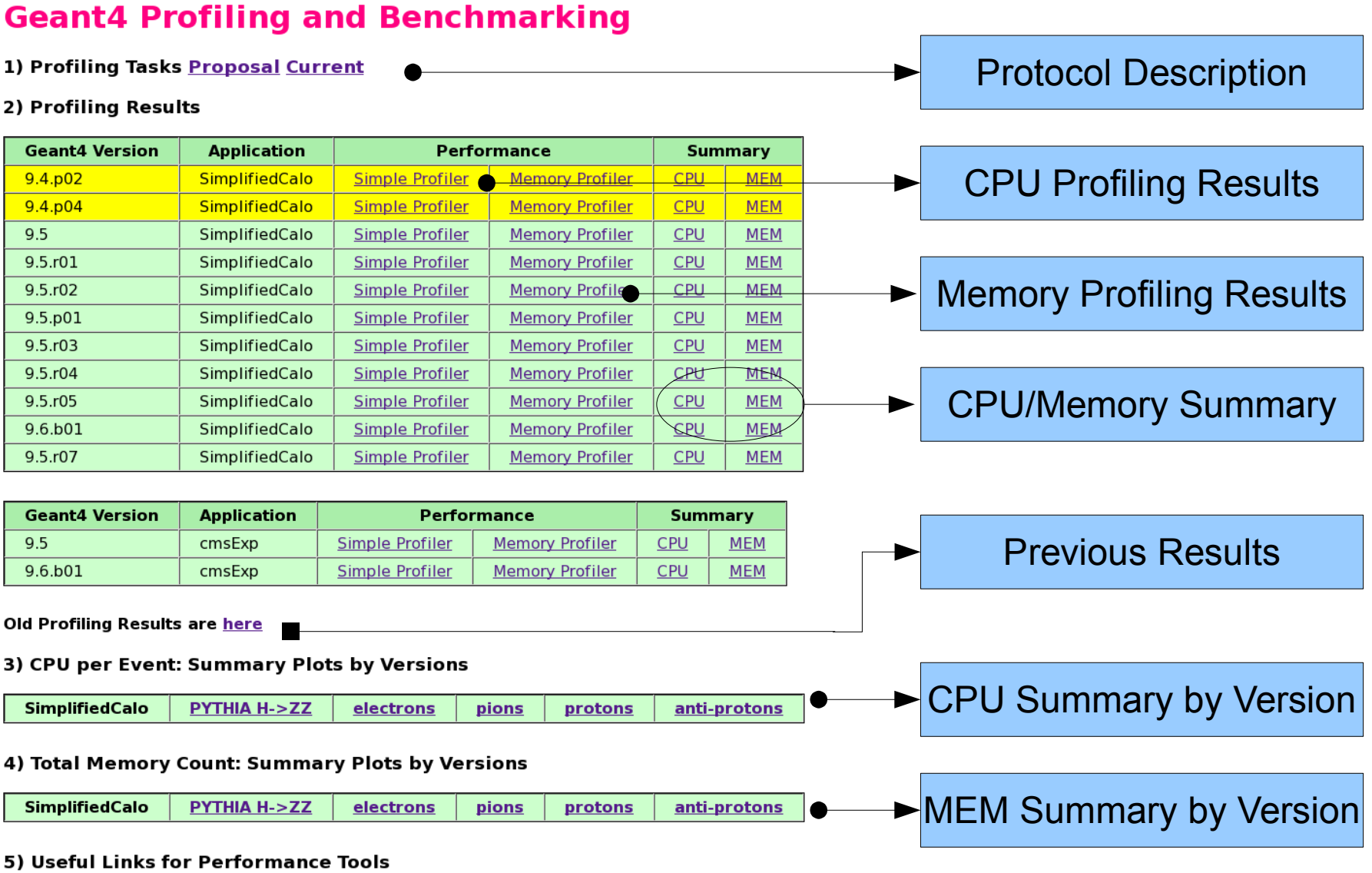
- Geant4 Computing Performance Task Force
- Protocol/Procedure, Tools and Applications
- Results
  - CPU time
  - CPU and memory profiling
- Conclusions

G4CP Task Force

- Geant4 Computing Performance (G4CP) Task Force is a part of the Geant4 testing and quality assurance working group led by G. Folger and D. Elvira
- The charge is to
  - monitor Geant4 software through its development cycle for expected or unexpected changes in computing performance
  - identify problems and opportunities for code improvement and optimization
  - report results and findings to the appropriate Geant4 working group leaders and the Steering Board

G4CP Monitoring for 2012

- http://oink.fnal.gov/perfanalysis/g4p/index.html



Performance Tools and Applications

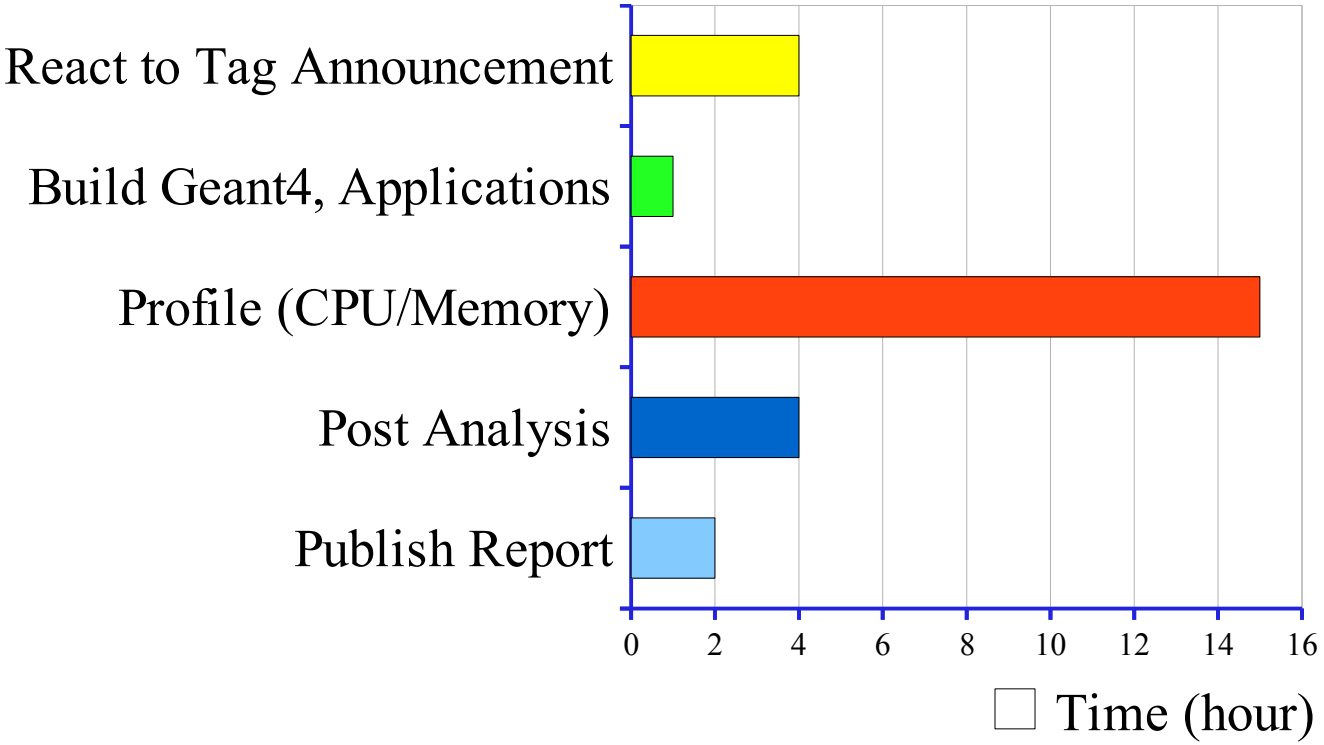
- Profiling tools
  - FAST/SimpleProfiler for CPU profiling https://cdcvs.fnal.gov/redmine/projects/fast
  - IgProf for memory profiling http://igprof.sourceforge.net/index.html
  - also see talks by K. Genser and M. Kelsey at 2011 Meeting
- Geant4 applications
  - SimplifiedCalo: common base for all releases adapted from A. Dotti and modified for PYTHIA inputs and performance measurements (timing, igprof)
  - cmsExp: another standalone application with the CMS geometry (gdml) and a magnetic field map extracted from CMSSW used for major releases
  - Other Geant4 applications can be added

Platform for Benchmarking and Profiling

- Migrated from a mixed hardware environment to a homogenous AMD cluster using pbs
- Cluster layout
  - Linux SL6/5 machines (cluck.fnal.gov+grunt[1-5].fnal.gov)
  - Server: AMD Opteron™ 6136 (2.4 GHz, 65 GB, 1x32 cores)
  - Worker: AMD Opteron™ 6128 (2.0 GHz, 66 GB, 5x32 cores)
  - post analysis with R and root
  - Web server (oink.fnal.gov)

Procedure and Typical Times

- The goal is to have a summary within 2-days after a reference, candidate, public, patch release is made available



It would be nice to have internal communications about upcoming releases

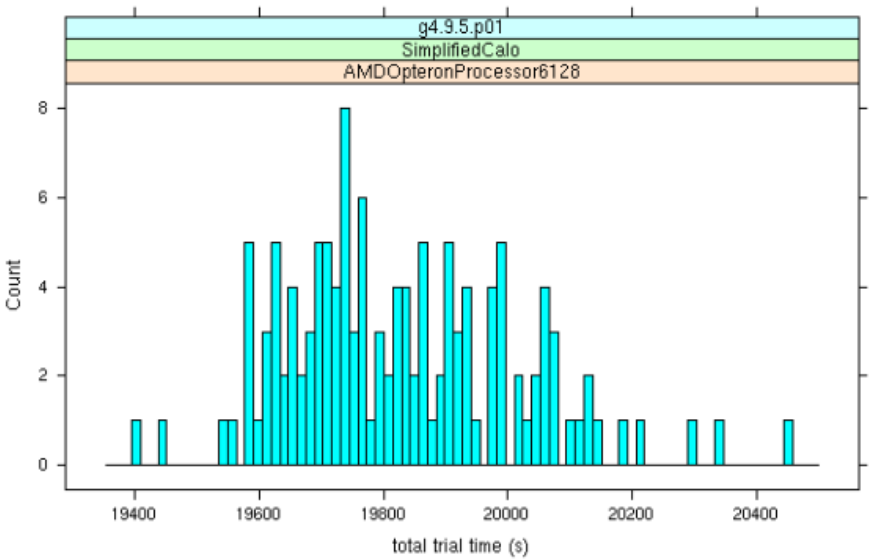
Profiled Samples and Physics Lists

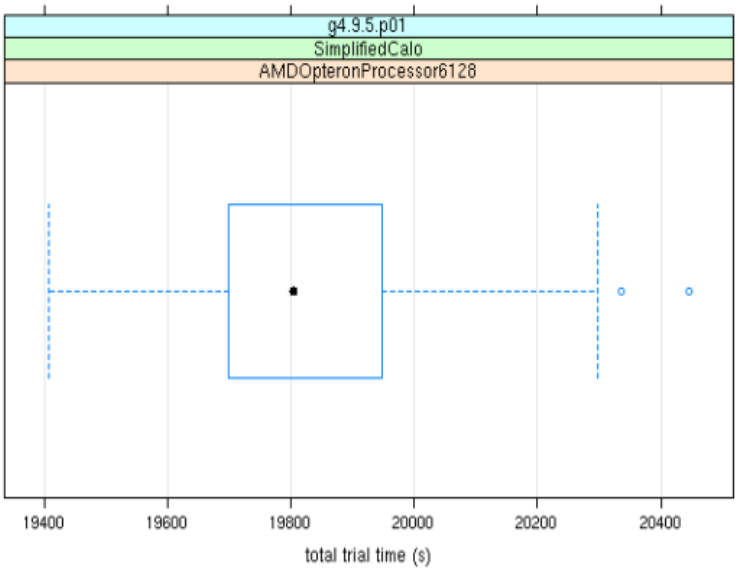
- 37 event samples: 36 single particle events and 1 PYTHIA 14 TeV pp-> Higgs to ZZ (all decays)
  - physics lists and projectiles were selected to cover relevant physics processes
  - FTFP_BERT (default), QGSP_BERT, QGSP_BIC, LHEP
  - magnetic field: 0, 4Tesla
  - beam energies: 1, 5, 10, 50 GeV for single particles

Sample	Physics List	B-Field	Energy
Higgs->ZZ	FTFP_BERT	ON (4.0T)	14 TeV PYTHIA
Electrons	FTFP_BERT	ON (4.0T)	1 GeV 5 GeV 10 GeV 50 GeV
		OFF (0 T)	1 GeV 5 GeV 10 GeV 50 GeV
Pions-	FTFP_BERT	ON (4.0T)	1 GeV 5 GeV 10 GeV 50 GeV
		OFF (0 T)	1 GeV 5 GeV 10 GeV 50 GeV
	QGSP_BERT	ON (4.0T)	1 GeV 5 GeV 10 GeV 50 GeV
	QGSP_BIC	ON (4.0T)	1 GeV 5 GeV 10 GeV 50 GeV
	LHEP	ON (4.0T)	1 GeV 5 GeV 10 GeV 50 GeV
Protons	FTFP_BERT	ON (4.0T)	1 GeV 5 GeV 10 GeV 50 GeV
Anti-Protons	FTFP_BERT	ON (4.0T)	1 GeV 5 GeV 10 GeV 50 GeV

Total CPU Time Measurements

- Measure the mean and uncertainty of the total CPU
  - 50 Higgs events run on 128 nodes
  - 2000 single particles events run on 32 nodes
  - uncertainty shown in the box plot is the middle 50% of the distribution whereas summary plots show the standard deviation of the distribution (1σ)





CPU Time Summary Table

CPU Time in seconds/event

Geant4.9.5 SimplifiedCalo 02

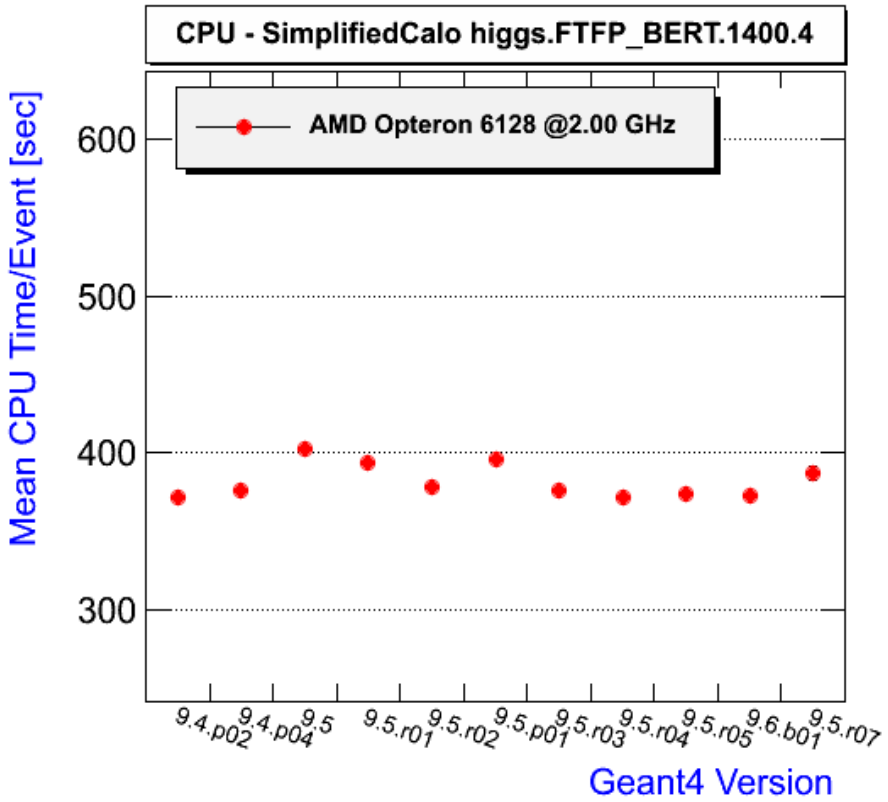
Sample	Physics List	B-Field	Energy	Mean CPU/event
Higgs->ZZ	FTFP_BERT	4.0T	14 TeV	402.3700

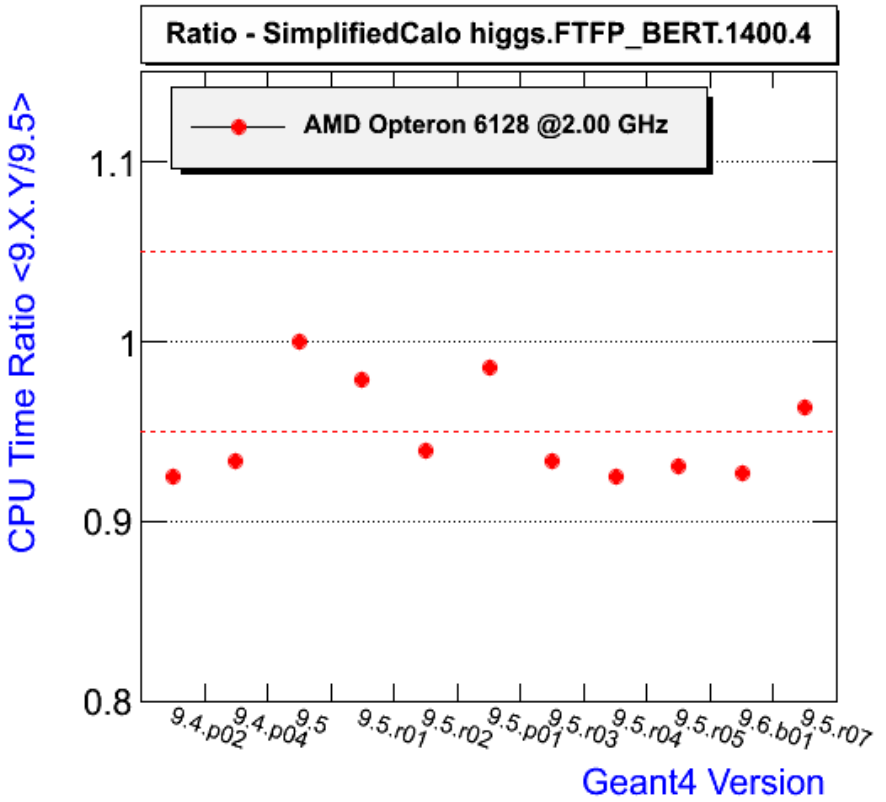
Sample	Physics List	B-Field	Beam Energy			
			1 GeV	5 GeV	10 GeV	50 GeV
Electron	FTFP_BERT	0.0T	0.0203	0.1025	0.2048	1.0179
		4.0T	0.0254	0.1283	0.2565	1.2839
Pion-	FTFP_BERT	0.0T	0.0382	0.1594	0.3016	1.3881
		4.0T	0.0420	0.1844	0.3353	1.5724
	QGSP_BERT	4.0T	0.0420	0.1807	0.3056	1.5054
	QGSP_BIC	4.0T	0.0360	0.1477	0.2540	1.3242
	LHEP	4.0T	0.0098	0.0567	0.1246	0.7364
Proton	FTFP_BERT	4.0T	0.0280	0.1695	0.3437	1.5867
Anti-Anti_Proton	FTFP_BERT	4.0T	0.0935	0.2254	0.3836	1.6693

Processor: AMD Opteron(tm) Processor 6128 (CPU: 2000 MHz, Cache: 512 KB)
Total Memory: 66007532 kB

CPU Time Summary by G4 Version

- Mean CPU/Event by versions: e.g. Higgs to ZZ





- Comparison with a reference release (version 9.5)

Total Memory Usage Summary Table

Total Memory in Counts/1,000,000

Geant4.9.5 SimplifiedCalo 02

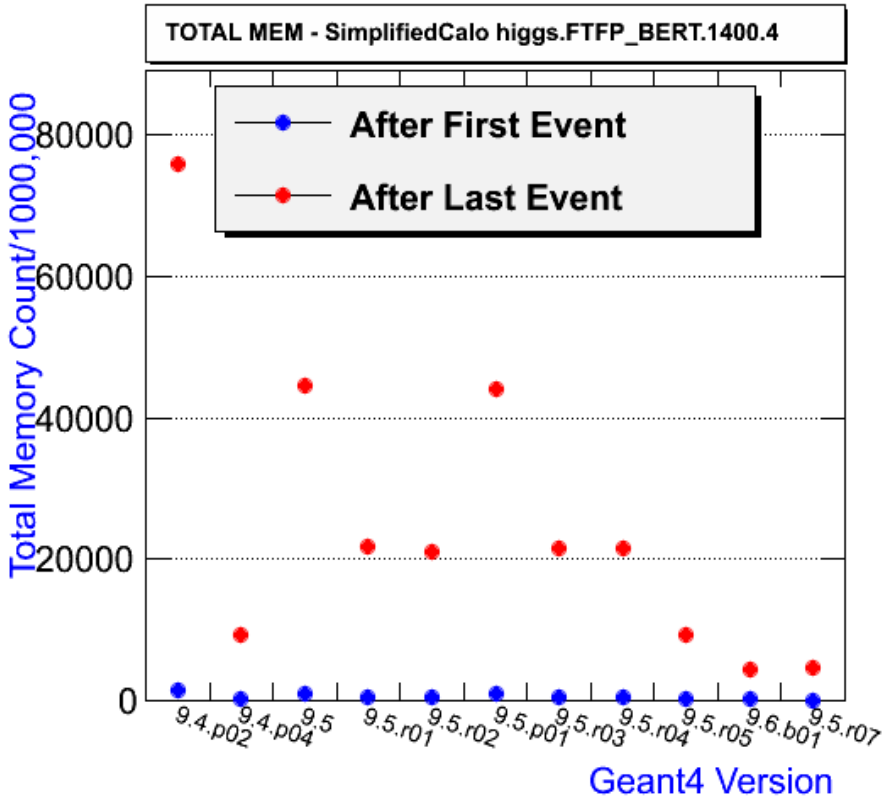
Sample	Physics List	B-Field	Energy	After First Event	After Last Event
Higgs->ZZ	FTFP_BERT	4.0T	14 TeV	968.585	44605.2

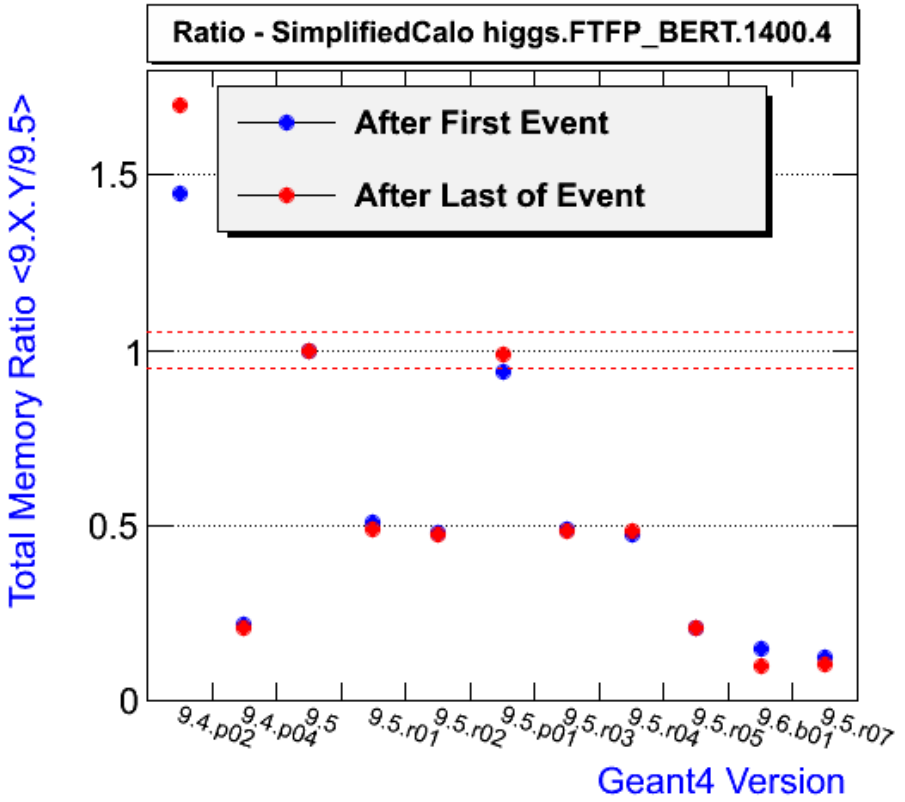
Sample	Physics List	B-Field	Beam Energy/Process							
			1 GeV		5 GeV		10 GeV		50 GeV	
			First Event	Last Event	First Event	Last Event	First Event	Last Event	First Event	Last Event
Electron	FTFP_BERT	0.0T	45.0322	107.315	45.5164	313.746	45.6204	631.363	48.0828	2894.89
		4.0T	45.0255	98.8889	45.4184	340.353	45.4368	617.775	48.3236	2857.01
Pion-	FTFP_BERT	0.0T	45.5672	140.473	46.045	500.056	46.6979	834.934	48.9052	3505.08
		4.0T	45.1807	151.908	46.0593	480.806	46.3829	833.626	49.2488	3527.73
	QGSP_BERT	4.0T	23.5204	122.912	23.6356	379.442	24.3621	758.966	26.6613	3464.94
	QGSP_BIC	4.0T	135.429	1152.54	138.888	3456.85	115.609	5190.61	164.202	20259.2
	LHEP	4.0T	21.2686	39.143	21.2906	127.155	21.8497	291.454	22.5939	1887.82
Proton	FTFP_BERT	4.0T	45.4494	66.7184	45.5805	376.801	46.8221	706.116	49.6192	3502.52
Anti-Anti_Proton	FTFP_BERT	4.0T	45.6494	626.9	46.034	783.319	46.7595	1137.35	48.8555	3853.91

Processor: AMD Opteron(tm) Processor 6128 (CPU: 2000 MHz, Cache: 512 KB)
Total Memory: 66007532 kB

Memory Usage Summary by G4 Version

- Total memory count by version: e.g. for Higgs to ZZ



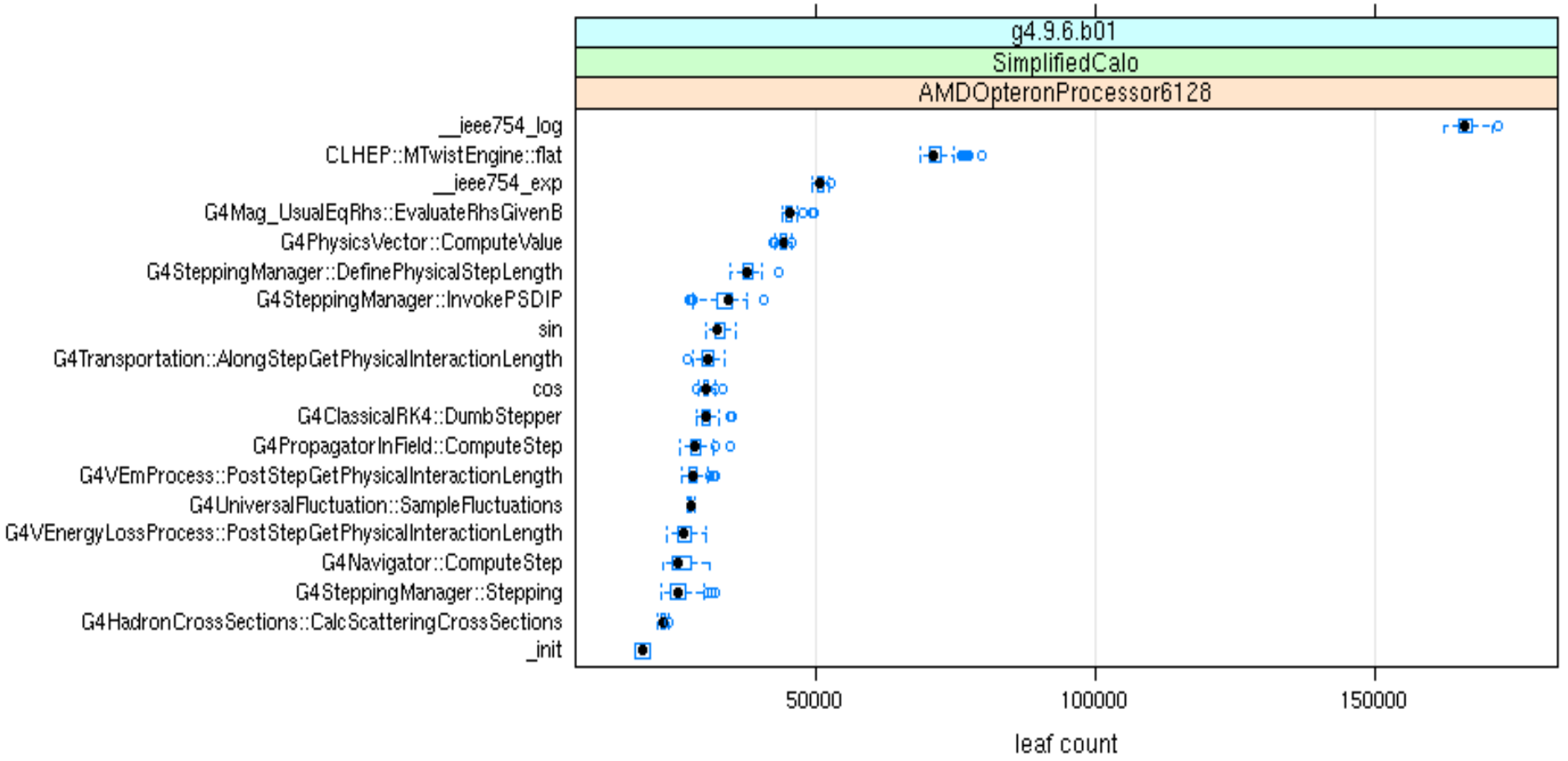


Profiling Results

- CPU (tables, plots) using FAST
  - function leaf count
  - function path count
  - function library count
- Memory (navigable tables) using IgProf
  - live memory count
  - maximum memory count
  - total memory count
  - memory count differences between events

Function Leaf Count

- Number of times a function was observed at the top of the stack: e.g. SimplifiedCalo with g4.9.6.b01



Function Count Table

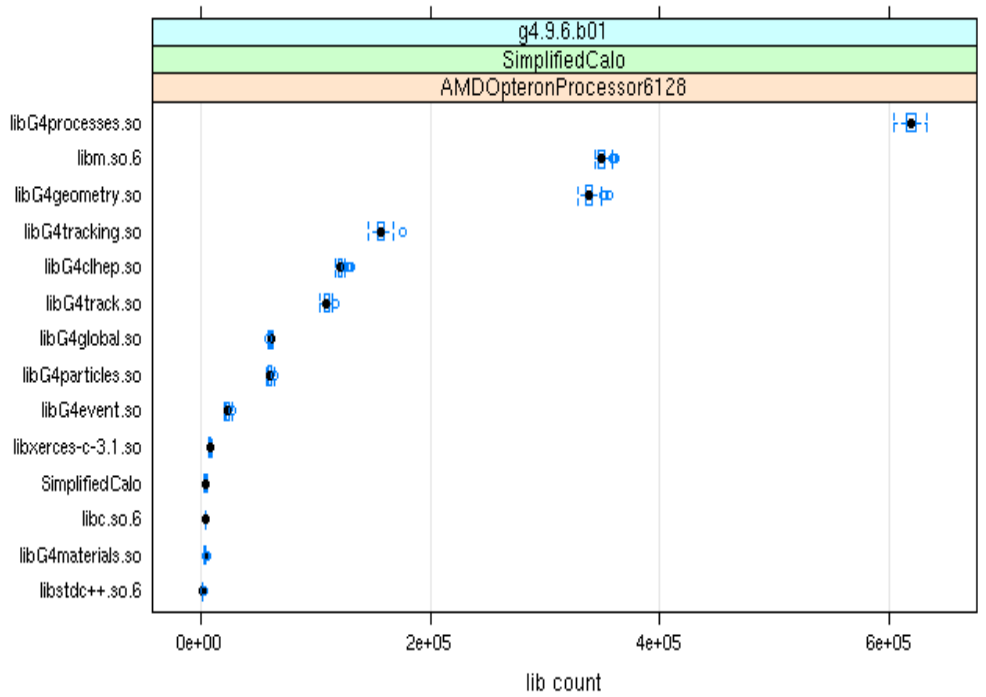
- Top 20 functions with SimplifiedCalo+g4.9.6.b01

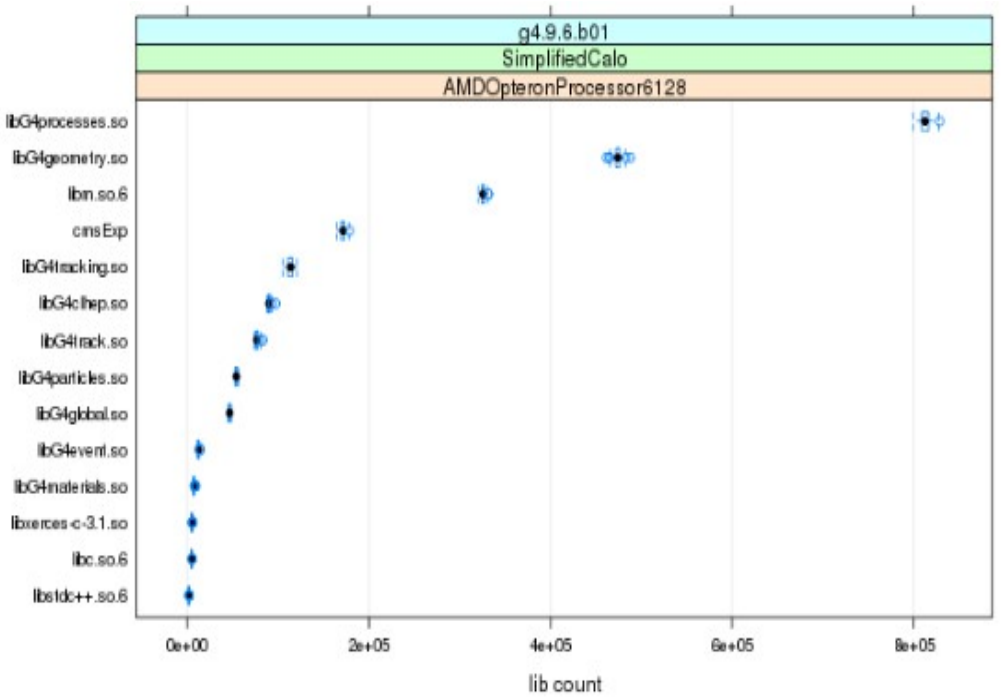
Name	short	mname	max.leaf.median	leaf.lw	leaf.lh
16	__ieee754_log	AMDOpteronProcessor6128	166064.0	162502	164970.0
1	CLHEP::MTwistEngine::flat	AMDOpteronProcessor6128	~71151.0	~68560	~70361.0
15	__ieee754_exp	AMDOpteronProcessor6128	~50767.0	~49278	~50392.0
4	G4Mag_UsualEqRhs::EvaluateRhsGivenB	AMDOpteronProcessor6128	~45278.0	~44173	~44867.5
6	G4PhysicsVector::ComputeValue	AMDOpteronProcessor6128	~44322.0	~42353	~43869.0
8	G4SteppingManager::DefinePhysicalStepLength	AMDOpteronProcessor6128	~37729.5	~34712	~36976.5
9	G4SteppingManager::InvokePSDIP	AMDOpteronProcessor6128	~34351.5	~27298	~32242.5
19	sin	AMDOpteronProcessor6128	~32492.0	~30244	~31885.0
11	G4Transportation::AlongStepGetPhysicalInteractionLength	AMDOpteronProcessor6128	~30754.0	~27001	~29858.0
18	cos	AMDOpteronProcessor6128	~30446.0	~28537	~29995.0
2	G4ClassicalRK4::DumbStepper	AMDOpteronProcessor6128	~30240.0	~28559	~29665.5
7	G4PropagatorInField::ComputeStep	AMDOpteronProcessor6128	~28413.0	~25750	~27781.0
13	G4VEmProcess::PostStepGetPhysicalInteractionLength	AMDOpteronProcessor6128	~27929.0	~26164	~27202.0
12	G4UniversalFluctuation::SampleFluctuations	AMDOpteronProcessor6128	~27657.5	~26954	~27430.0
14	G4VEnergyLossProcess::PostStepGetPhysicalInteractionLength	AMDOpteronProcessor6128	~26494.0	~23389	~25484.0
5	G4Navigator::ComputeStep	AMDOpteronProcessor6128	~25508.0	~22685	~24407.0
10	G4SteppingManager::Stepping	AMDOpteronProcessor6128	~25505.5	~22253	~23994.5
3	G4HadronCrossSections::CalcScatteringCrossSections	AMDOpteronProcessor6128	~22696.0	~21854	~22483.5

Library Count

- Top three libs of SimplifiedCalo and cmsExp with 9.6.b01

SimplifiedCalo	cmsExp
libG4Processes.so	libG4processes
libm.so.6	libGeometry
libGeometry.so	libm.so.6





Memory Profiler/IgProf

- Memory snapshots at specific stages

Memory profiling reports

- MEM_LIVE: memory that has not been freed - snapshot of the heap, i.e. a heap profile.
- MEM_MAX: the largest single allocation by any function
- MEM_TOTAL: the total amount of memory allocated by any function - a snapshot of poor memory locality

- N: memory snapshot at the end of N-th event
- Diff(N-M): memory difference between N-th and M-th event - direct memory leakage
- End of Run: memory snapshot at the End of Run

Geant4.9.6.b01 SimplifiedCalo B=4.0T

Sample	Physics List	Energy	MEM_LIVE	MEM_MAX	MEM_TOTAL
Higgs->ZZ	FTFP_BERT	14 TeV	1 Diff(51-1) 51 End of Run	1 Diff(51-1) 51 End of Run	1 Diff(51-1) 51 End of Run
Electrons	FTFP_BERT	5 GeV	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run
		50 GeV	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run
Pions-	FTFP_BERT	5 GeV	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run
		50 GeV	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run
	QGSP_BERT	5 GeV	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run
		50 GeV	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run	1 Diff(1001-1) 1001 End of Run

IgProf Navigation

(Sort by self cost)

Rank	Total %	Cumulative	Calls	Symbol name
1	100.00	4,420,321,677	75,797,685	<spontaneous>
4	100.00	4,420,319,411	75,797,679	main
3	100.00	4,420,319,411	75,797,679	__libc_start_main
2	100.00	4.420.319.411	75.797.679	start

Rank	% total	Counts		Calls		Paths		Symbol name
		to / from this	Total	to / from this	Total	Including child / parent	Total	
	92.39	4,083,732,829	4,099,765,629	69,192,650	70,001,309	1	1	G4SteppingManager::InvokePSDIP(unsigned long)
[21]	**92.39**	**0**	**4,083,732,829**	**0**	**69,192,650**	**1**	**1**	**G4HadronicProcess::PostStepDoIt(G4Track const&, G4Step const&)**
	72.19	3,191,174,011	3,437,009,485	53,500,448	57,595,782	1	3	G4CascadeInterface::ApplyYourself(G4HadProjectile const&, G4Nu
	18.97	838,692,220	840,287,730	15,242,229	15,264,831	1	2	G4TheoFSGenerator::ApplyYourself(G4HadProjectile const&, G4Nuc
	1.20	53,197,302	53,197,302	442,978	442,978	1	1	G4BinaryLightIonReaction::ApplyYourself(G4HadProjectile const&
	0.01	655,408	655,408	6,942	6,942	1	1	G4ElectroVDNuclearModel::ApplyYourself(G4HadProjectile const&,
	0.00	13,416	13,416	26	26	1	1	G4HadronicProcess::FillResult(G4HadFinalState*, G4Track const&
	0.00	400	464	25	29	1	2	G4CrossSectionDataStore::SampleZandA(G4DynamicParticle const*,
	0.00	72	72	2	2	1	1	G4LCapture::ApplyYourself(G4HadProjectile const&, G4Nucleus&)

15	99.00	4,376,167,418	75,106,945	G4RunManager::DoEventLoop(int, char const*, int)
16	98.81	4,367,852,679	74,965,066	G4EventManager::DoProcessing(G4Event*)
17	98.75	4,365,145,345	74,916,535	G4TrackingManager::ProcessOneTrack(G4Track*)
18	98.75	4,365,142,249	74,916,529	G4SteppingManager::Stepping()
20	92.75	4,099,765,629	70,001,309	G4SteppingManager::InvokePSDIP(unsigned long)
19	92.75	4,099,765,629	70,001,309	G4SteppingManager::InvokePostStepDoItProcs()
21	92.39	4,083,732,829	69,192,650	G4HadronicProcess::PostStepDoIt(G4Track const&, G4Step const&)
22	77.75	3,437,009,485	57,595,782	G4CascadeInterface::ApplyYourself(G4HadProjectile const&, G4Nucleus&)
23	77.75	3,436,902,313	57,595,489	G4InuclCollider::collide(G4InuclParticle*, G4InuclParticle*, G4CollisionOutput&)

Conclusions

- A protocol for benchmarking and profiling was established and executed for all Geant4 reference and public releases throughout the year 2012
- Provided tables and plots give a general overview of Geant4 performance
- Profiling tools (FAST and IgProf) can be used standalone by individual developers for (unit) tests
- It is time to review the protocol, tools, and analysis for improvement

Input from developers is encouraged and welcome!