

# Performance Measurement Tools (for parallel application)

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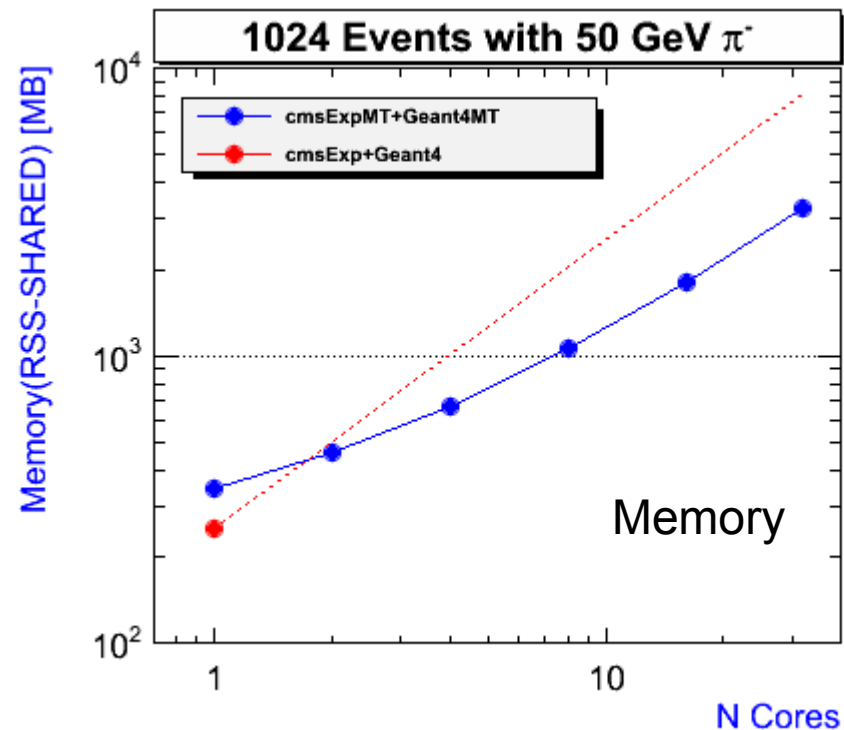
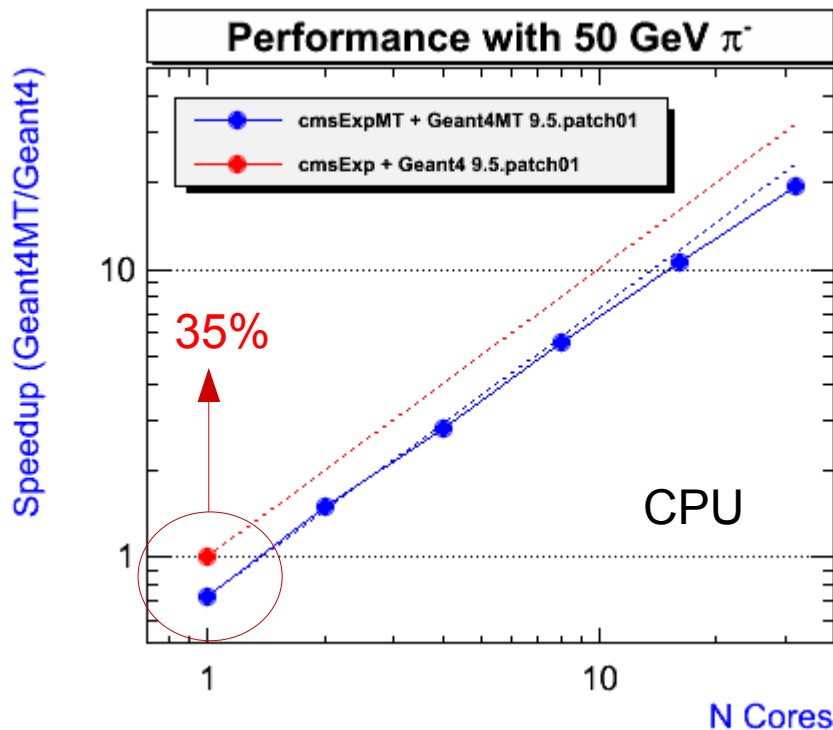
# Introduction

- **Necessity of performance analysis**
  - benchmarking/monitoring
  - efficient use of resources
  - optimization and tuning
- **Emerging parallelism**
  - parallel applications
  - heterogeneous systems
- **Performance tools are essential**
  - complexity of applications
  - diversity of architectures



# Problem Statement

- Search tools and libraries for parallel applications
  - profiling multithreaded applications of Geant4
  - performance evaluation for GPGPU codes
- A user application: cmsExpMT (cms geom + b-field map)



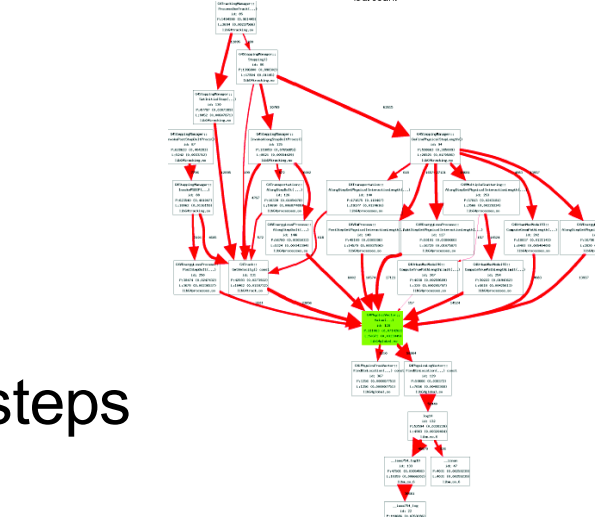
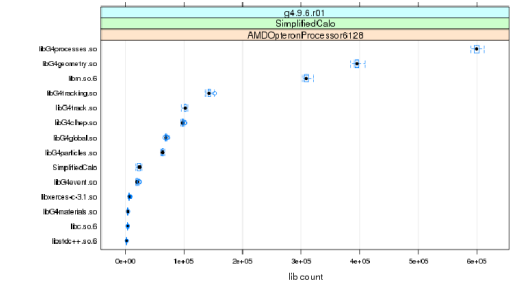
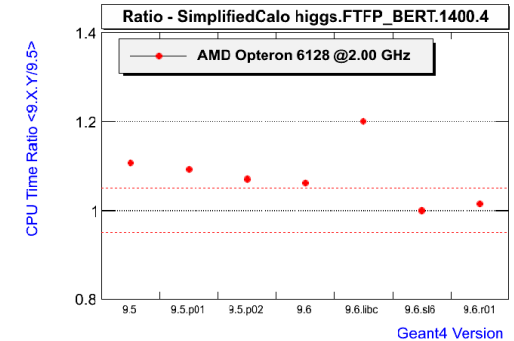
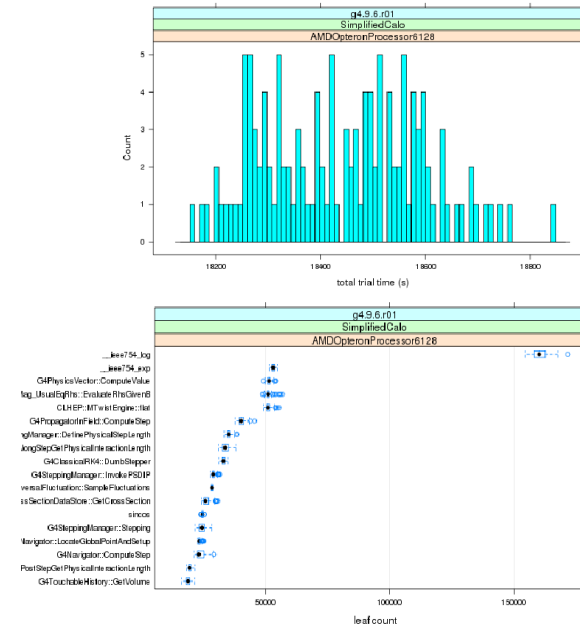
# Review of Geant4 Performance Profiling

- Tools

- FAST (CPU)
- IgProf (memory)

- Metrics

- time (version, physics)
- leaf counts (funs, libs)
- call path analysis
- heap (live, max, total)
- statm (vsize/rss)
- number of tracks and steps



Counter: MEM\_LIVE, Sorted by self cost

Rank	Total %	Self %	Calls	Symbol name	Callers
20	23.40	8.027592	9,840	@@@libstdc++.so.6	
82	18.24	6.275500	148,152	@@@libc.so.6	
54	12.72	4.362152	25,130	@@@vector.so.6	
51	11.78	4.038328	9,708	@@@libc.so.6	
95	7.79	1.563440	5	@@@libc.so.6	
73	4.20	1.440554	313	@@@libc.so.6	
84	3.40	1.164194	36,717	@@@libc.so.6	
115	1.92	657.376	7	@@@libc.so.6	
123	1.57	337.312	1	@@@libc.so.6	
70	1.01	346.664	1,173	@@@libc.so.6	
100	0.84	373.136	612	@@@libc.so.6	
102	0.84	372.000	75	@@@libc.so.6	
108	0.88	361.000	6,271	@@@libc.so.6	
128	0.79	273.364	2,134	@@@libc.so.6	

Name	Particle	Mean	Sigma	Low	1/4Quad	Median	3/4Quad	High
1	Nstep e-	1.9214e+07	6.1294e+05	1.7891e+07	1.8846e+07	1.9196e+07	1.9663e+07	2.0736e+07
2	Nstep e+	2.6696e+06	1.3309e+05	2.4400e+06	2.5659e+06	2.6553e+06	2.7668e+06	3.0220e+06
3	Nstep gamma	1.6601e+07	5.0588e+05	1.5485e+07	1.6303e+07	1.6598e+07	1.6969e+07	1.7838e+07
4	Nstep N	7.0410e+06	7.5337e+05	5.0027e+06	6.5169e+06	7.2466e+06	7.5037e+06	8.0701e+06
5	Nstep other	3.9529e+05	4.3766e+04	2.7979e+05	3.5370e+05	4.0674e+05	4.2379e+05	4.5151e+05
6	Nstep p	3.2549e+05	3.5179e+04	2.3170e+05	3.0530e+05	3.3502e+05	3.4787e+05	3.7748e+05
7	Nstep pi-	4.2773e+04	4.6553e+03	3.1341e+04	3.9691e+04	4.4302e+04	4.6106e+04	5.0434e+04
8	Nstep pi+	4.2990e+04	4.7467e+03	2.9472e+04	3.9956e+04	4.4154e+04	4.6512e+04	4.9173e+04
9	Ntrack e-	1.4359e+07	4.3076e+05	1.3392e+07	1.4117e+07	1.4360e+07	1.4676e+07	1.5402e+07
10	Ntrack e+	3.6313e+05	1.3851e+04	3.3542e+05	3.5306e+05	3.6146e+05	3.7300e+05	3.9866e+05
11	Ntrack gamma	4.4820e+06	1.1061e+05	4.1621e+06	4.3837e+06	4.4722e+06	4.5919e+06	4.8104e+06
12	Ntrack N	2.1833e+05	2.3542e+04	1.5538e+05	2.0211e+05	2.2634e+05	2.3322e+05	2.5154e+05
13	Ntrack other	2.1537e+05	2.2964e+04	1.5382e+05	1.9906e+05	2.2243e+05	2.2942e+05	2.4733e+05
14	Ntrack p	8.5583e+04	9.1407e+03	6.0811e+04	7.9987e+04	8.8626e+04	9.1228e+04	9.8422e+04
15	Ntrack pi-	3.0006e+03	3.3441e+02	2.1540e+03	2.7600e+03	3.1005e+03	3.2040e+03	3.4680e+03
16	Ntrack pi+	3.1720e+03	3.3850e+02	2.2400e+03	2.9900e+03	3.2775e+03	3.4060e+03	3.6460e+03

# Metrics for Parallel Applications

- **Multithreaded applications**
  - speedup, scalability
  - memory (cache miss, TLB miss, coherence)
  - communication
  - I/O
- **GPU applications**
  - memory throughput
  - arithmetic intensity
  - occupancy vs. latency
  - ILP vs. TLP
  - locality (spatial/temporal)
- **Platform dependence**
  - NUMA
  - distributed memory models

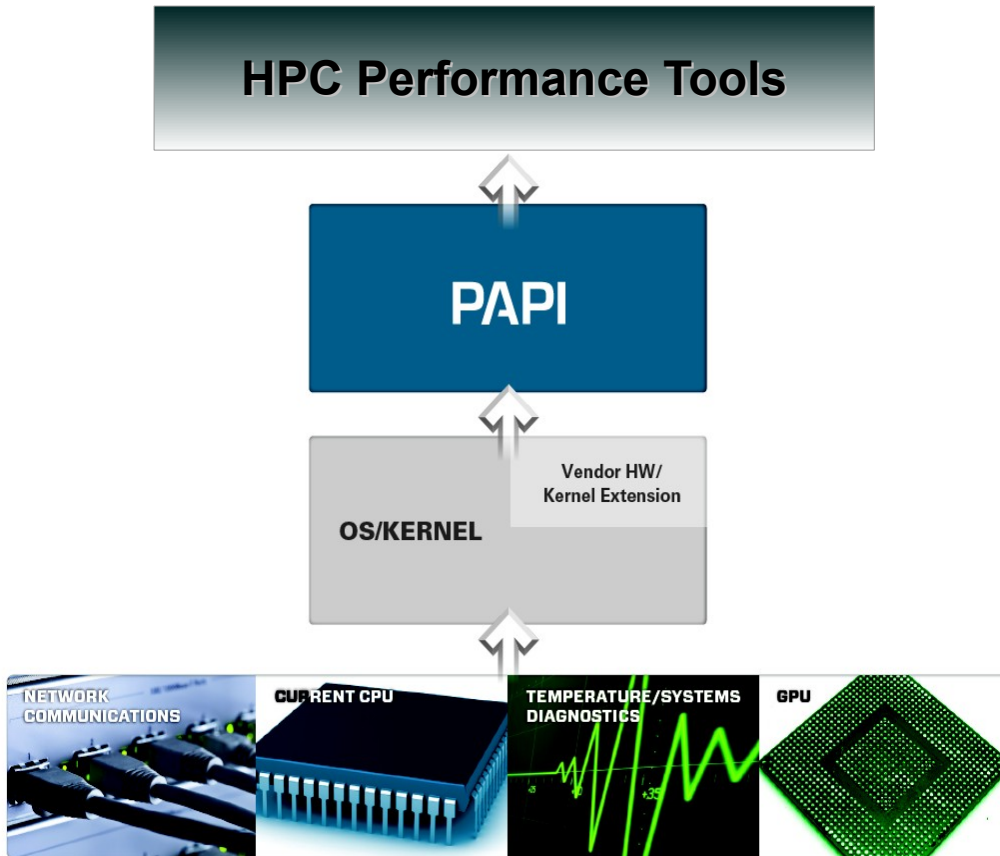
# Performance Tool Requirement

- Support parallelism and multi-threaded applications
- Open source (support Linux)
- Transparent instrumentation (applicable on binaries)
- Light time overhead and precision of measurement
- Advanced analysis (tracing, callgraph)
- Easy to use, but extensible
- Documentation and support

# Performance Tools: A Short List

- **Community infrastructures:**
  - PAPI and MuMMI (UTK)
  - Paradyn (DynInst, MRNet) (UW, UMD)
- **Integrated tool kits:**
  - HPCToolkit (Rice)
  - Open|SpeedShop (Krell)
  - TAU (Oregon)
  - nvvp (NVIDIA)
- **Tracing tools:**
  - Jumpshot (ANL)
  - Scalasca (Jülich)

# PAPI (Performance API)



- A standard API to access hardware performance counters
- Relation between software performance and processor events
- Event metrics : platform specific metrics, cache hit/miss, Flops, power consumption (MuMMI)



# Open|Speedshop

- Comprehensive performance analysis for sequential, multithreaded, and MPI applications
- The base functionality includes
  - sampling experiments
  - support callstack analysis
  - hardware performance counters
  - multi-threaded, MPI profiling and tracing
  - floating point exception analysis
- GUI and CLI (command line instruction)
- Almost ready to support GPU (95%) and MIC (if funded)

# Default View and Stats Panel

OpenSpeedShop

File Tools Help

User Time [1]

Process Control

Run Cont Pause Update Update the display with the current information. Terminate

Status: Process Loaded: Click on the "Run" button to begin the experiment.

Stats Panel [1] ManageProcessesPanel [1]

Showing Functions Report:

View/Display Choice

Functions Statements Linked Objects

Executables: /home/syjun/g4p/test/openss/cmsExpMT/bin/cmsExpMT Host: cluck.fnal.gov Pids: 1 Threads: 33

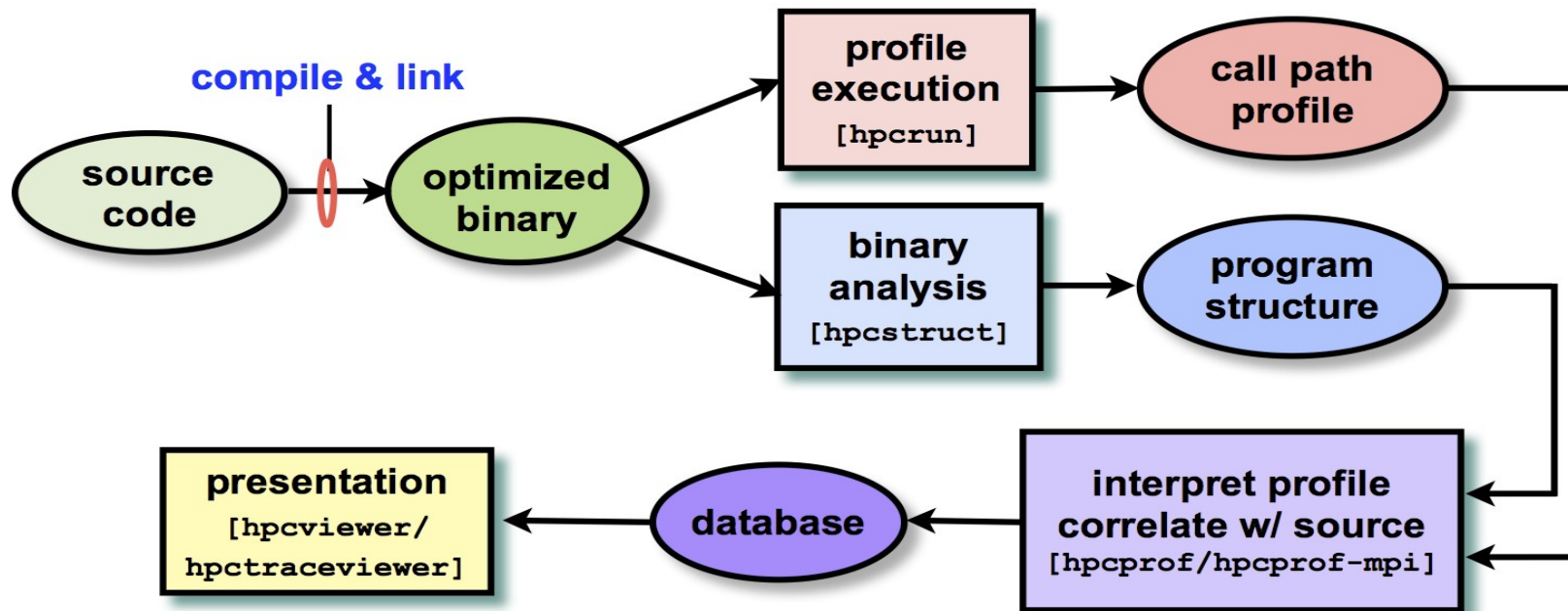
% of Total Exclusive CPU Time	Exclusive CPU time	Inclusive CPU time	% of Total Exclusive CPU Time	Function (defining location)
11.216171	105.742855	105.742855	11.216171	__tls_get_addr (/lib64/ld-2.12.so)
10.128193	95.485712	95.485712	10.128193	__ieee754_log (/lib64/libm-2.12.so)
6.012668	56.685713	56.685713	6.012668	__ieee754_exp (/lib64/libm-2.12.so)
4.748917	44.771428	62.885713	4.748917	G4HadronCrossSections::CalcScatteringCrossSection
3.279086	30.914285	156.999997	3.279086	G4CrossSectionDataStore::GetCrossSection (/home/s
	20.400000	64.571427	2.163833	G4ElasticHadrNucleusHE::HadrNucDifferCrSec (/hor
	16.028571	47.514285	1.700155	G4Navigator::LocateGlobalPointAndSetup (/home/sy
	15.400000	15.400000	1.633482	cmsExpMagneticField::GetFieldValue (/home/syjun/g
	12.571428	62.085713	1.333455	G4hPairProductionModel::ComputeDMicroscopicCro
	11.885714	14.371428	1.260721	G4ProductionCutsTable::ScanAndSetCouple (/home/
other				

Command Panel

openss>>

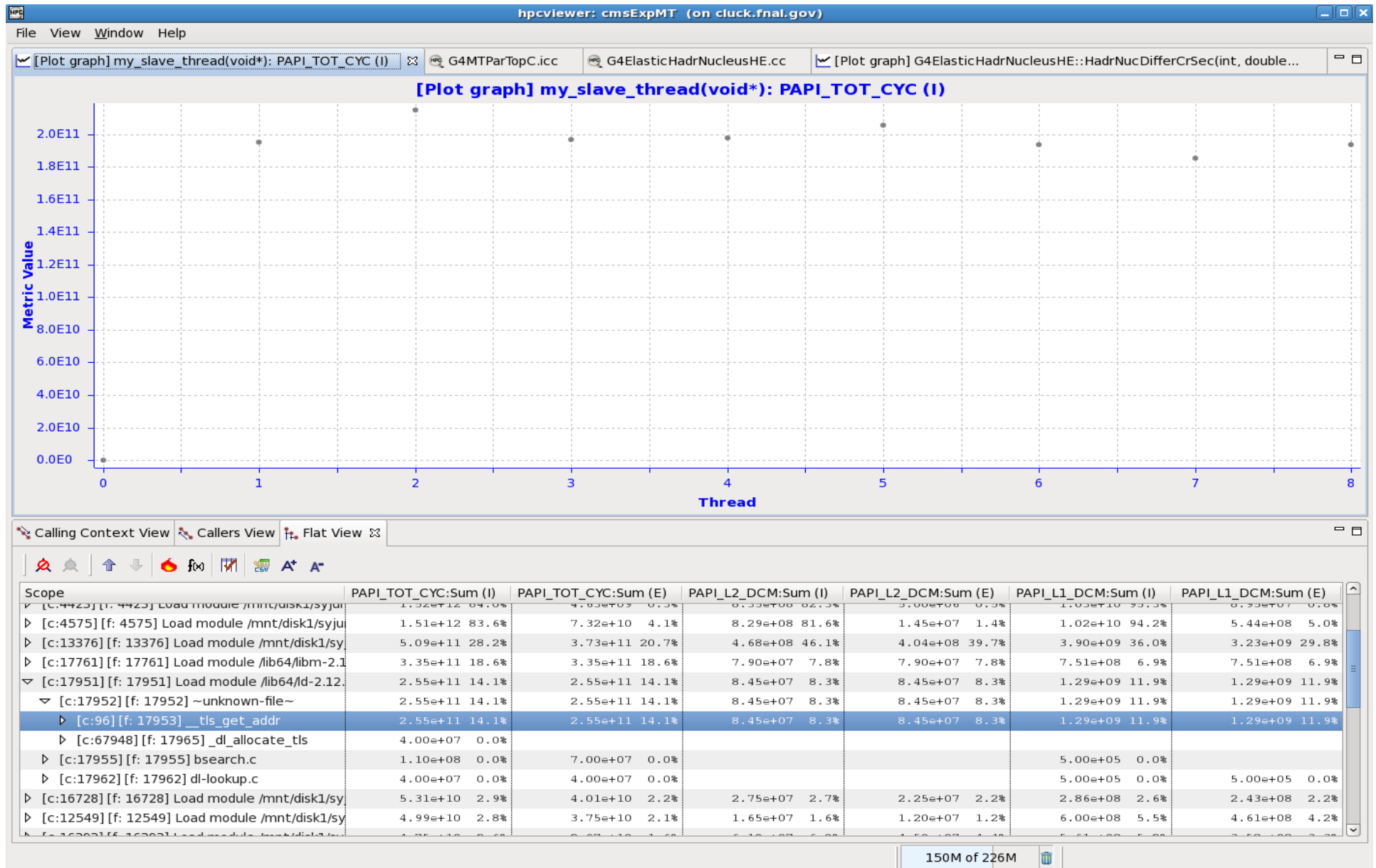
# HPCToolkit

- Overview of HPCToolkit tool's work flow (from manual)



- Code centric view, GUI and text-base flat profile
- Supporting performance analysis of heterogeneous architecture (hybrid CPU/GPU)

# HPCToolkit: hpcviewer

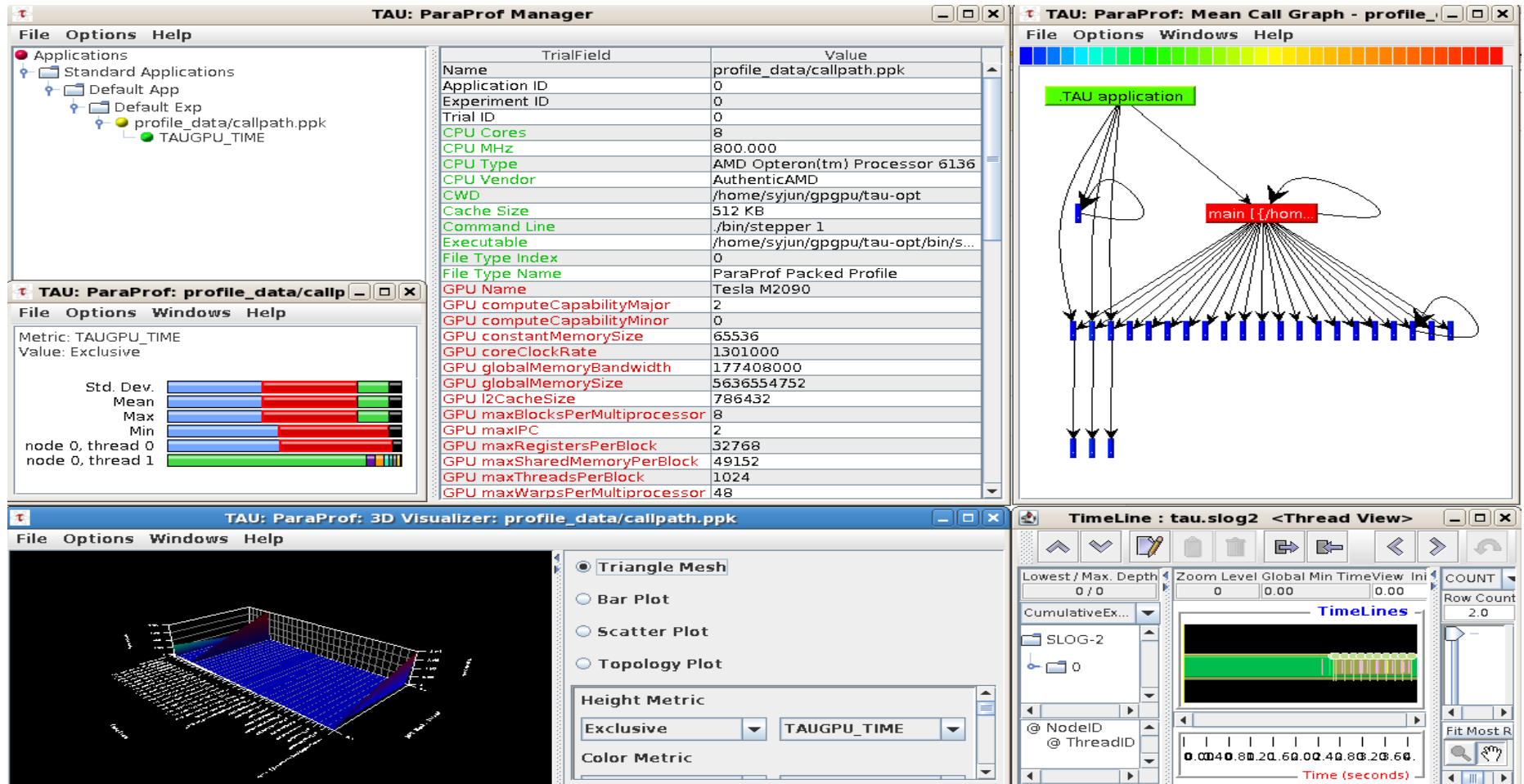


# TAU (Tuning Application Utilities)

- Dynamic, compiler based, source based Instrumentation
- Analysis tools
  - ParaProf
  - PerfExplorer
  - Tracer (Jumpshot, vampir)
- Various built-in graphical presentations
- Capable to measure performance of GPU with cuda/openCL
- Disadvantage: compiler/source-based instrumentation

# TAU for CUDA/openCL?

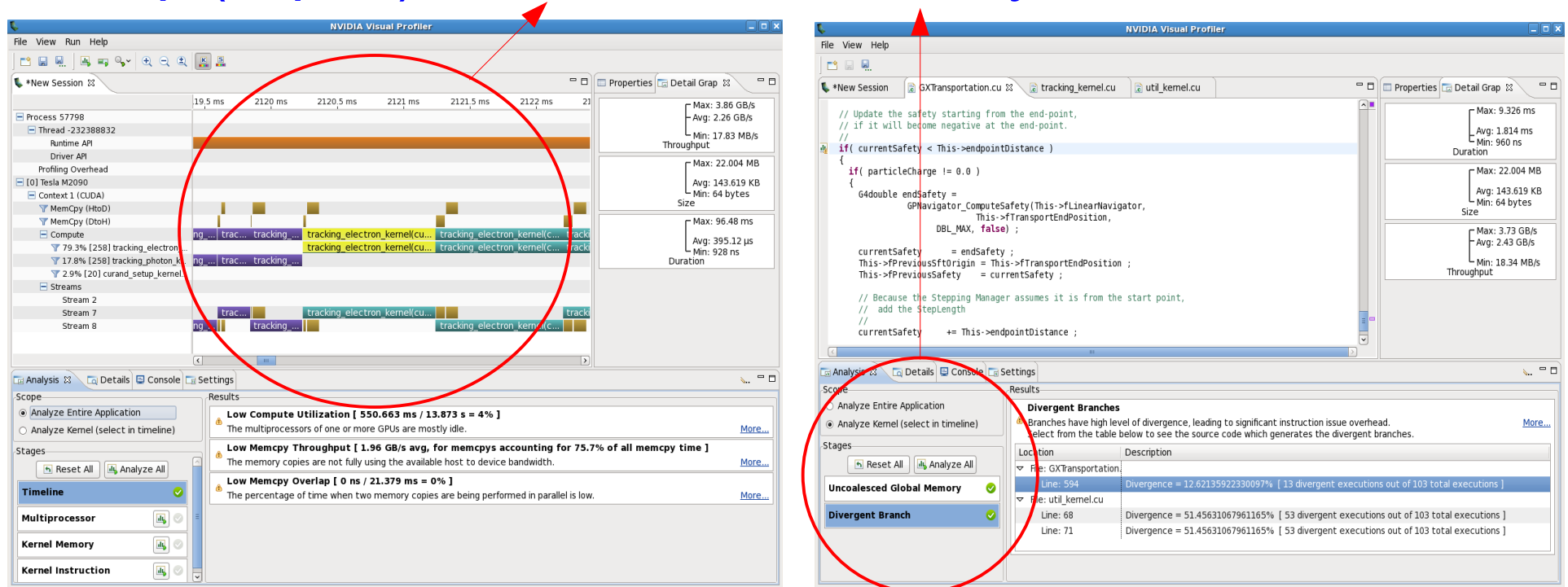
- Test tau with cupti on a Runga-Kutta stepping algorithm



Provides general profiling information (H2D, kernel, D2H), but no details for 'inside' device codes

# NVIDIA GPU Tools

- CUPTI, NVML, occupancy calculator
- nvvp (nvprof) : timeline, kernel analysis with source



- No good way to measure exclusive time for each device function

# Other Tools: Another Short List

- **Community Infrastructure and libraries**
  - CBTF (Component Based Tool Framework) (Krell)
  - GPTL (General Purpose Timing Library) (ORNL)
  - gperftools (Google Performance Tools)
- **Integrated Tools**
  - Intel: VTune Amplifier, Cluster/Parallel Studio (License)
  - AMD: CodeAnalyst, APP Profiler/Kernel Analyzer (openCL)
  - IBM: HPMToolkit
- **Tracing Tools**
  - KOJAK (OPARI, EPILOG, EARL, EXPERT/CUBE)
  - Vampir (License)



# Summary

- Profiling serial and parallel codes is a critical step in assessing the efficiency of software development
- Various tools and libraries are available for performance profiling and analysis
- Performance analysis is domain specific  
(domain knowledge, architecture, programming models)
- Collaborating with ASCR institutes
  - Bob Lucas, Pedro Diniz (ISI)
  - Rob Fowler, Paul Ruth (RENCI)
  - Boyana Norris (ANL)