Accelerated Monte Carlo Particle Generators for the LHC

(MC@GPU)

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O U T L I N E

- MC generators in high-energy heavy-ion physics
- The biggest data challenge: LHC & WLCG with GPUs?
- GPU based PRNG for MC generators
- Performance tests by GPU based MC
- What can we learn from pp MC simulations?
- Outlook

MC generators in high-energy collisions

Why do we need Monte Carlo generators?

There are problems with no analytical expression, no closed form, or no deterministic description, like:

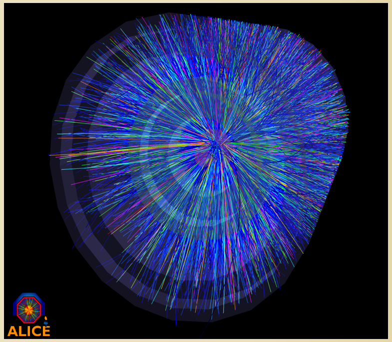
- stohastic processes (independent events)
- numerical (multi-D) integration
- optimalization

Solution & errors

Random sampling of numerical results

Error estimation by standard devitaion

Fast random numbers → Computing & IT

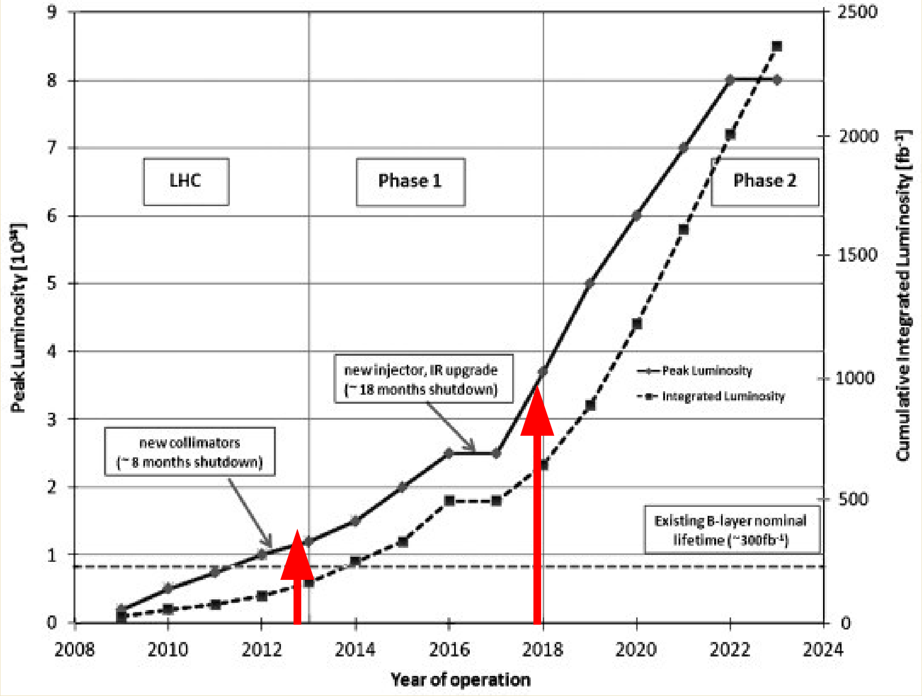


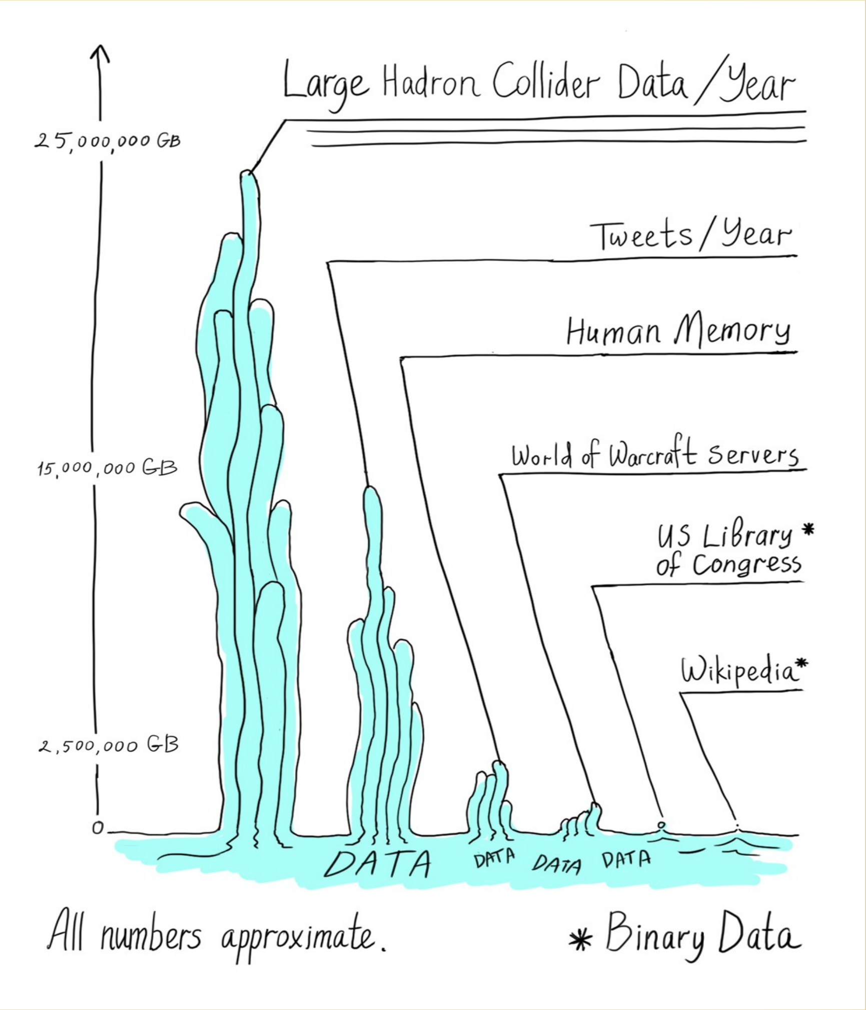
The biggest data challenge: LHC

WLCG – Worldwide LHC Computing GRID:

15-20 Petabytes data per year

...and more after LHC upgrades

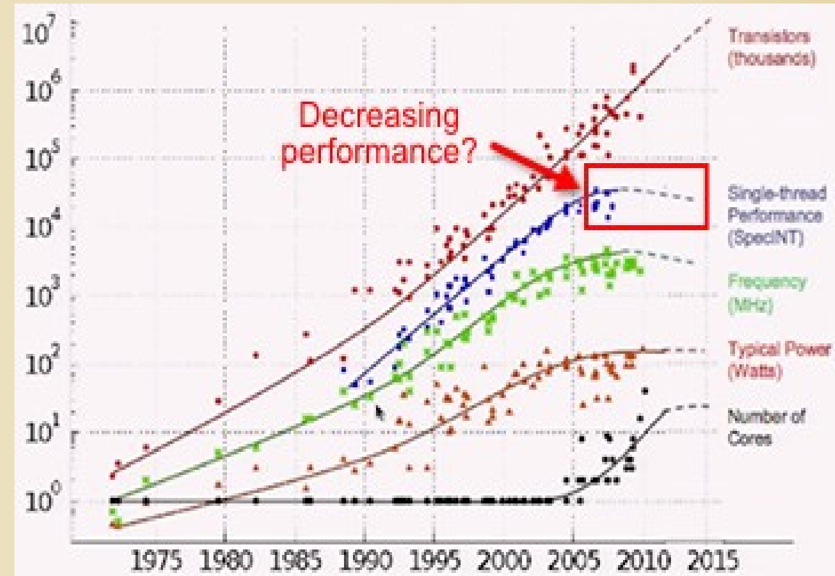




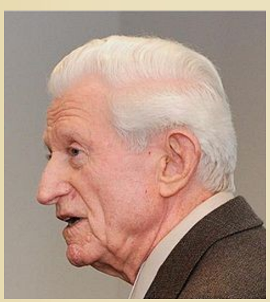
Fast computing=parallel computing

- Moore's law:

Every 2nd year the number of transistors (integrated circuits) are doubled in computing hardwares.

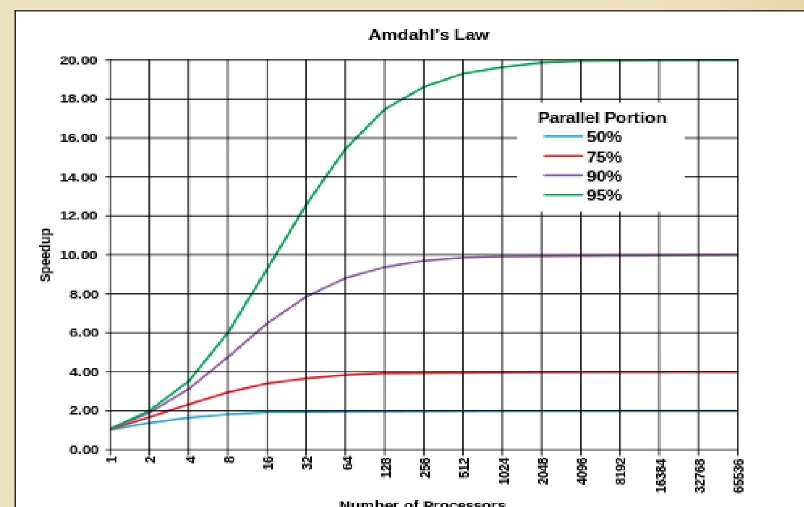


- Amdalh's law:



The theoretical speedup is given by the portion of parallelizable program, p, & number of processors, N, is:

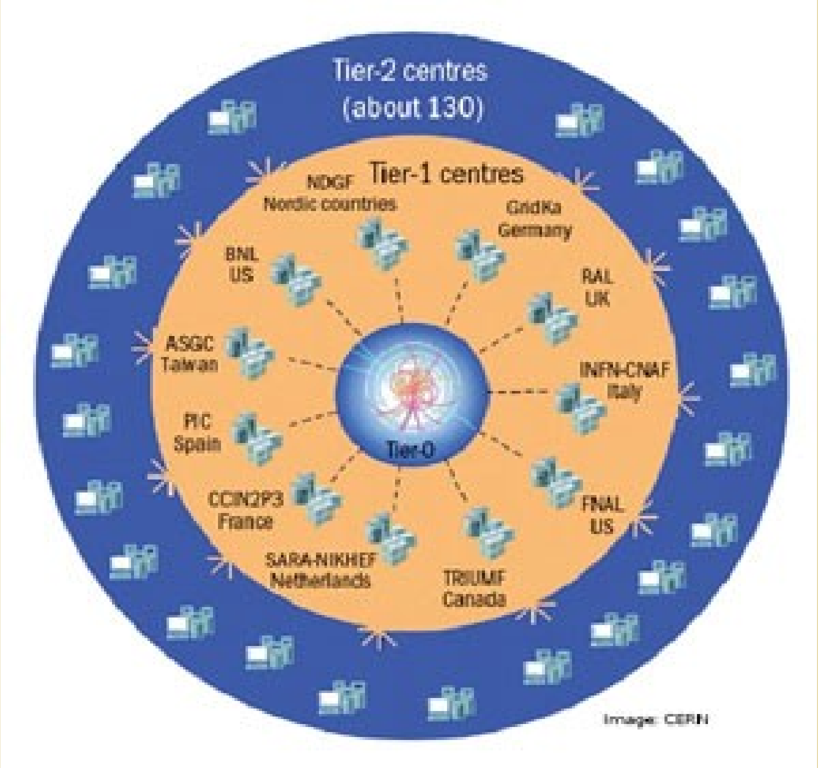
$$S(N) = \frac{1}{(1-P) + \frac{P}{N}}.$$

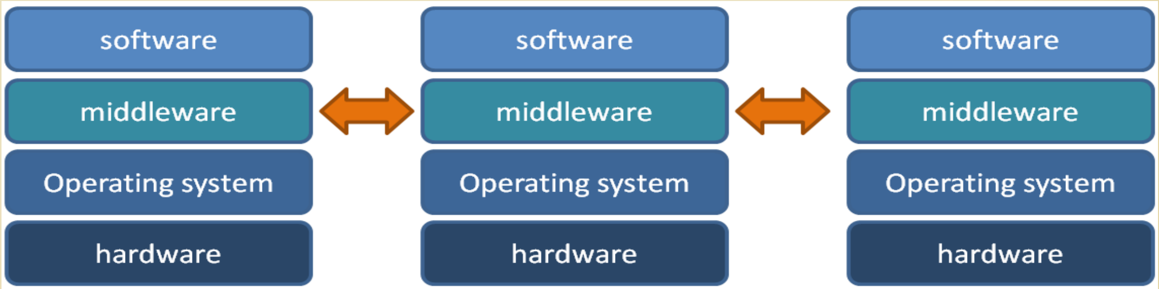


How to improve the WLCG resources

WLCG:

- Critical points are the number and performance of the WNs
- There are multicore machines with single thread.
- If there are free multicores or GPU resources, improvement can be made at the sofrware and middleware level (cheap).
- Certainly, there is a budget issue as well.





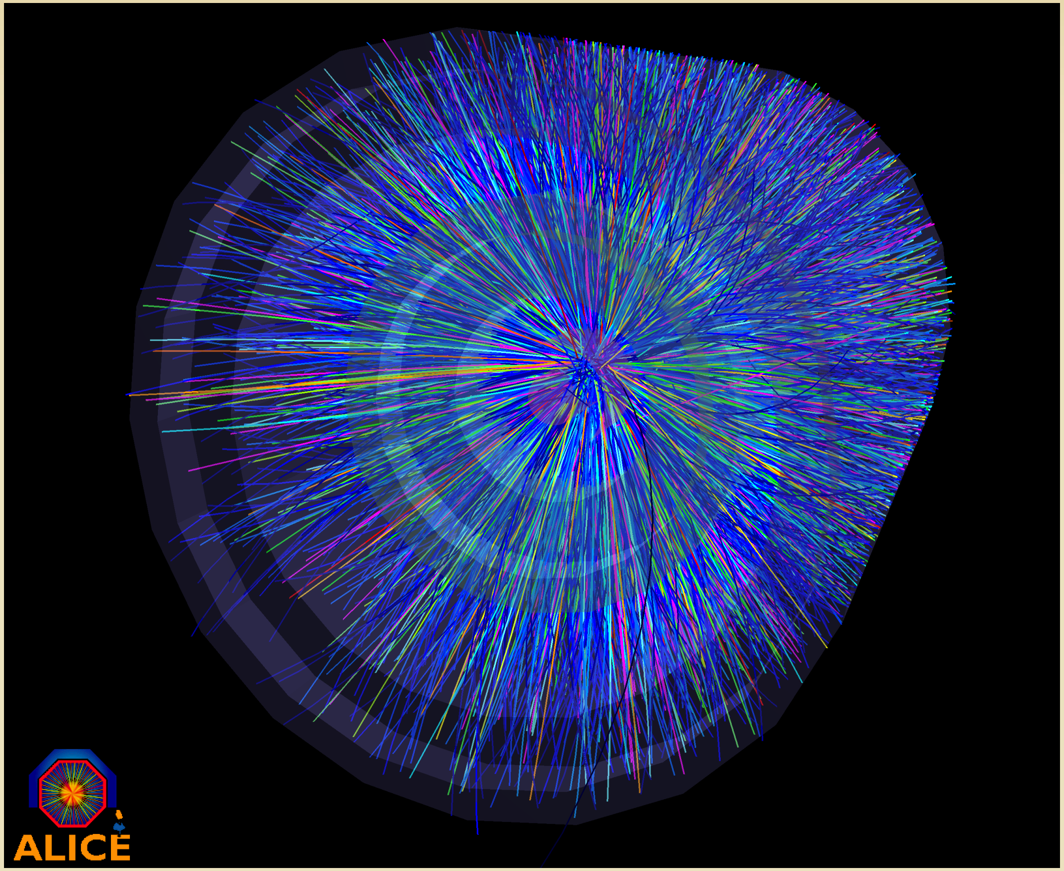
When is the moment to use GPUs?

No direct answer!

- Pilot study to define parameters to be optimized
- Need for large scale and large-large scale computing
- Have time (5-10 times more code development)
- Manpower high-level (close to hardware) programming
- $$$$$$

What has been done so far to help us? – without CUDA, etc...

- Several libs & toolkits (BLAS, FFTW, CUBLAS, CUFFT)
- Wrappers (C, FORTRAN → CUDA)
- OpenCL standards (Ati, NVidia)
- Mathematica, MatLab (with GPU support)



GPU based PRNG
for
MC event generators

GPU based PRNG for MC event generators

- Software frameworks

CERN

- OS: SLC 2.6.32-279.1.1.el6.x86_64
- Graphics: fglrx 9.002 (Catalyst 12.10)
- GCC: 4.4.6 20120305 (Red Hat 4.4.6-4)
- OpenCL: 1.2 AMD APP SDK 2.8

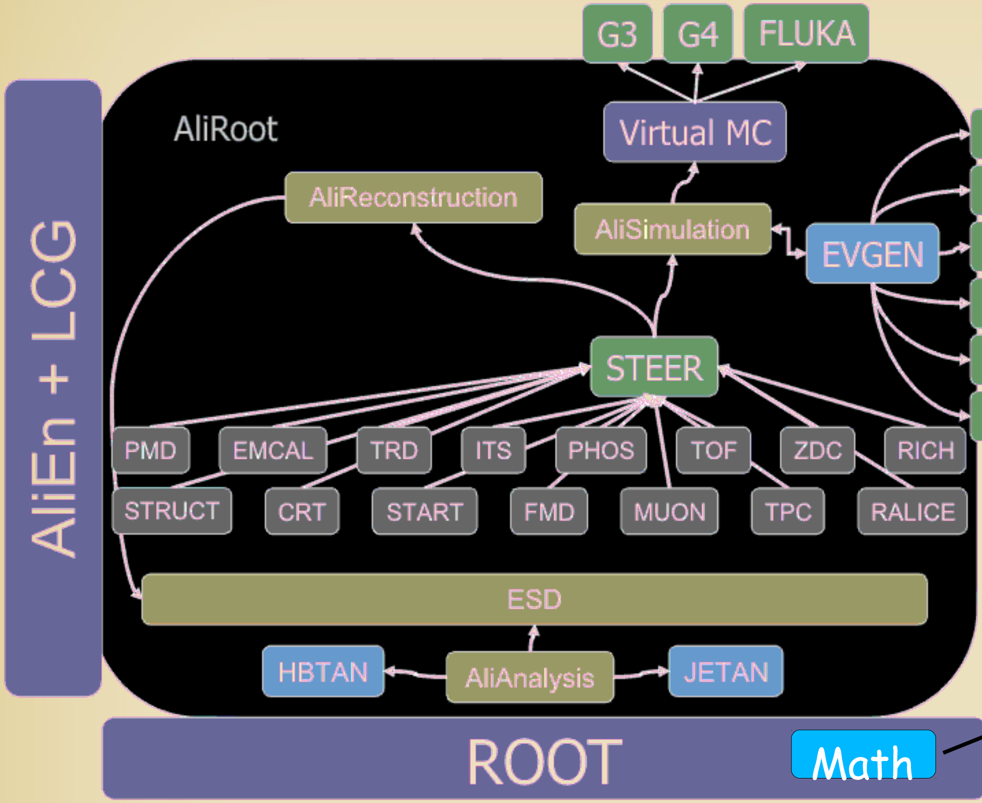
ALICE

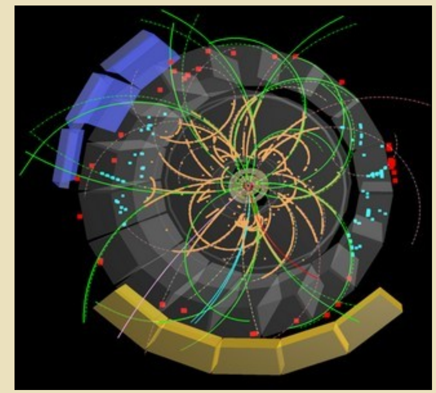
- Aliroot: v5-03-73-AN
- Root: v5-34-02
- Geant3: v1-14

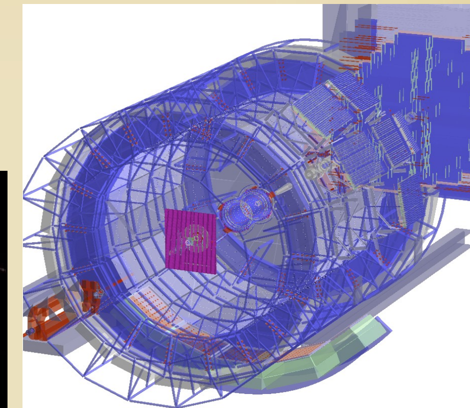
PRNG tester

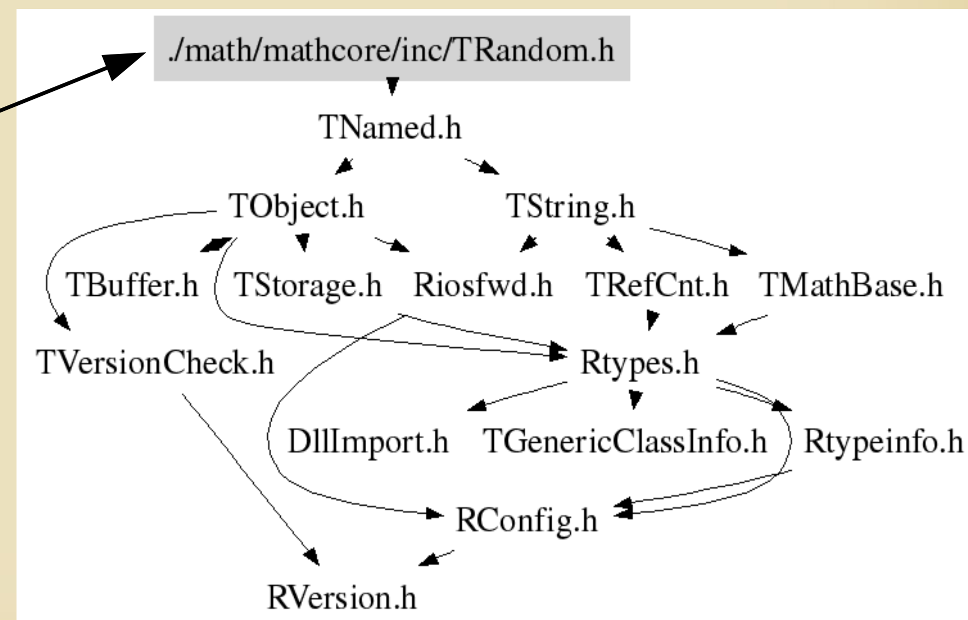
- Dieharder: 3.31.1

GPU based PRNG for MC event generators

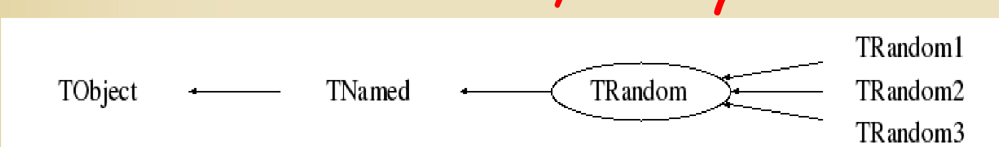








AliRoot framework for ALICE data simualtion, reconstruction, analysis



GPU based PRNG for MC event generators

- The tested PRNG codes

  Trandom1 (RANLUX)

  TRandom2 (Tausworthe)

  TRandom3

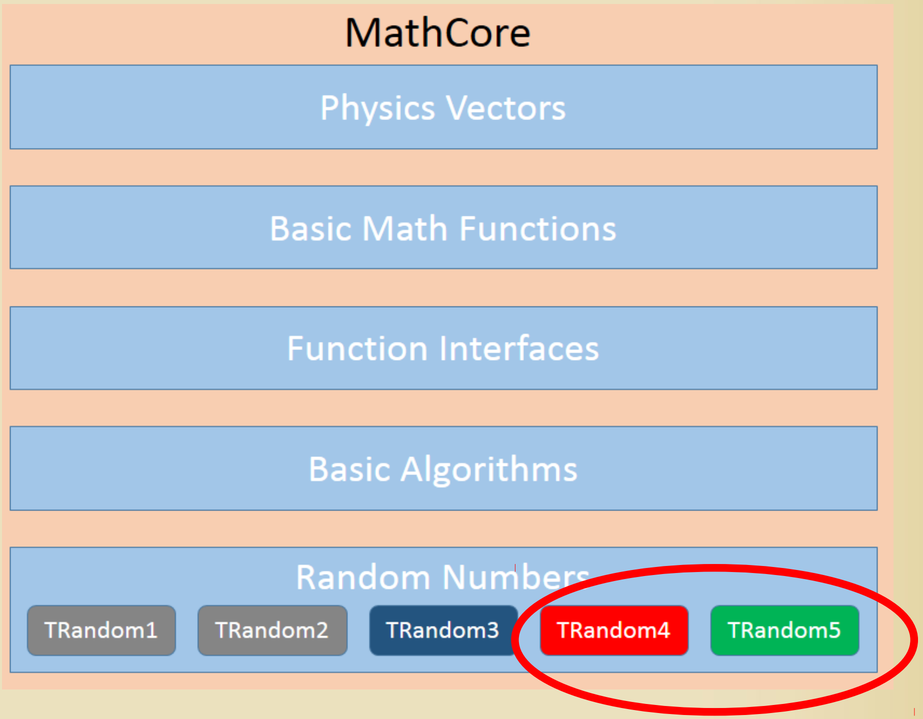
  - Original CPU based Mersenne Twister) algorithm

  TRandom4

  - CPU/GPU based SFMT (SIMD-oriented Fast Mersenne Twister) algorithm

  TRandom5

  - CPU/GPU based MWC64X algorithm



GPU based PRNG for MC event generators

- From the *user* side
  - Installation:

    Driver + OpenCL (SDK)

    Pre-complied modules
  - Usage:

    TRandomX, can be take as a regular PRNG.

    CPU/GPU run can be choosen via parameters:

    GPU: parameter > 200

    CPU: parameter < 200

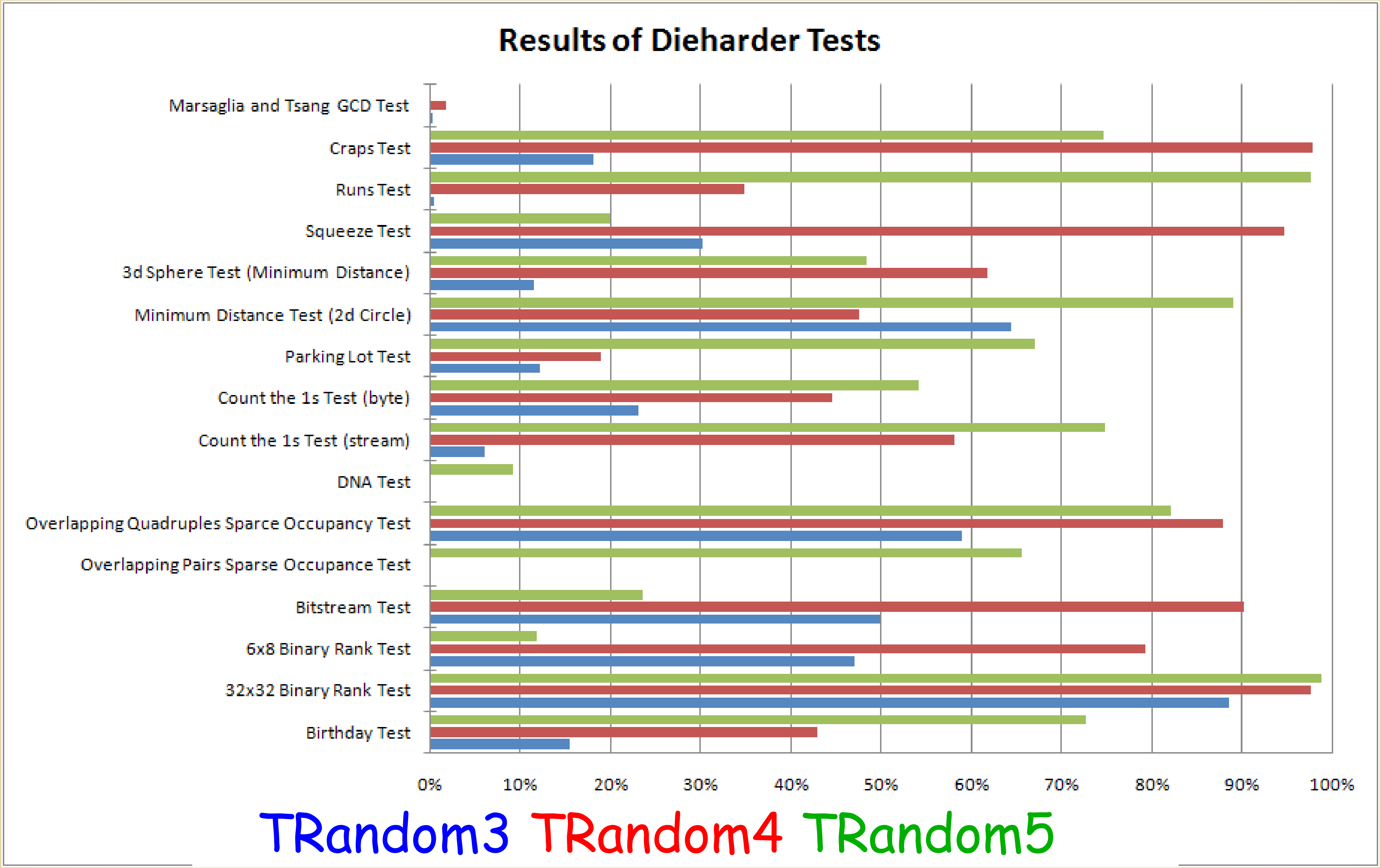
```
AliGenerator*  CreateGenerator();

//void fastGen(Int_t nev = 50000, char* filename = "galice.root")
void fastGen(Int_t nev = 20000, char* filename = "galice.root")
{
//  Runloader
    TStopwatch timer;
  timer.Start();
  gSystem->SetIncludePath("-I$ROOTSYS/include -I$ALICE_ROOT/include -I$ALICE_ROO
T");
  gSystem->Load("liblhapdf.so");      // Parton density functions
  gSystem->Load("libEGPythia6.so");   // TGenerator interface
  gSystem->Load("libpythia6.so");     // Pythia
  gSystem->Load("libAliPythia6.so");  // ALICE specific implementations


    AliRunLoader* rl = AliRunLoader::Open("galice.root","FASTRUN","recreate");

    rl->SetCompressionLevel(2);
    rl->SetNumberOfEventsPerFile(nev);
    rl->LoadKinematics("RECREATE");
    rl->MakeTree("E");
    gAlice->SetRunLoader(rl);

//  Create stack
    rl->MakeStack();
    AliStack* stack      = rl->Stack();

//  Header
    AliHeader* header = rl->GetHeader();

//  Setting TRandom4 as defult generator
    TRandom5 r5(201);
    gRandom=&r5;

//  Create and Initialize Generator
    AliGenerator *gener = CreateGenerator();
    gener->Init();
    gener->SetStack(stack);
```

GPU based PRNG for MC event generators

- Behind the scene
  - TRandom4 & TRandom5
  - No single random number generation only in 500k blocks
  - RAM buffer is for random numbers.
  - Only speeddown is the 'stack depth check'.
  - Copy work from buffer is by the CPU.
  - Due to OpenCL platform this works on both CPU/GPU

- Constructor
  - It contains all tasks
    - Platform check
    - Context creation
    - Device info
    - Kernel compilation
    - Command queue
    - Buffer allocation
    - Sending random seeds to devices
    - Tread ID settings

The PRNG quality test



The PRNG quality test

- Summary of the DieHard quality tests of PRNGs

  TRandom3 – Original CPU based Mersenne Twister

  TRandom4 – CPU/GPU based SFMT (SIMD-oriented Fast MT)

  TRandom5 – CPU/GPU based MWC64X algorithm

PRNG modules	Platform	Total Kuiper KS p
TRandom3	CPU	29.27 %
TRandom4	CPU/GPU	53.59 %
TRandom5	CPU/GPU	55.56 %

Performance

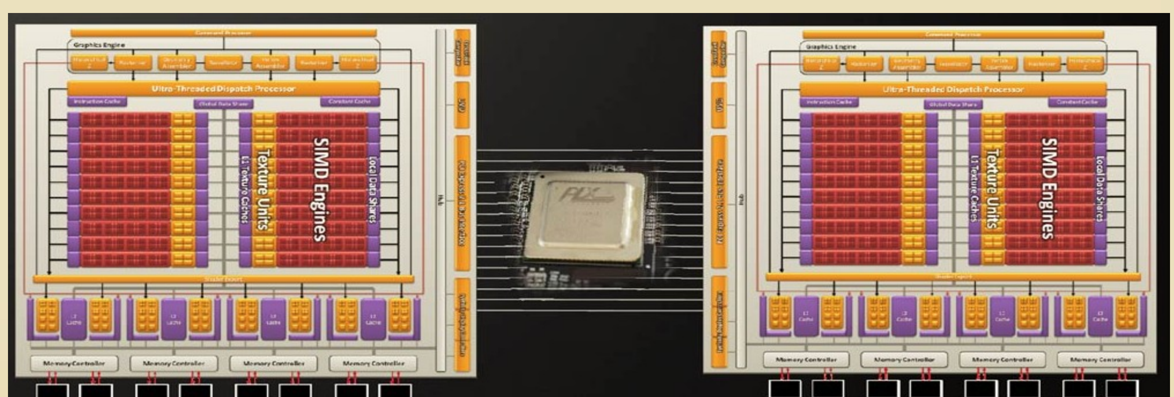
Performance tests by GPU based MC

- Hardware framework

gpu001 at GPU Laboratory of the Wigner RCP

- MB: ASUS P6T6 PCIExpress 2.0x16
- CPU: Core i7 920 (2.76 Ghz, 8 KB cache)
- Memory: 12GB DDR3 (1333 MHz)
- HDD: 1 TB
- GPU: 3 pcs. ATi Radeon HD5970

  (2 GPUs, 735 MHz, 1+1 GB GDDR, 4.64 TFlop)



Performance tests by GPU based MC

- Hardware framework

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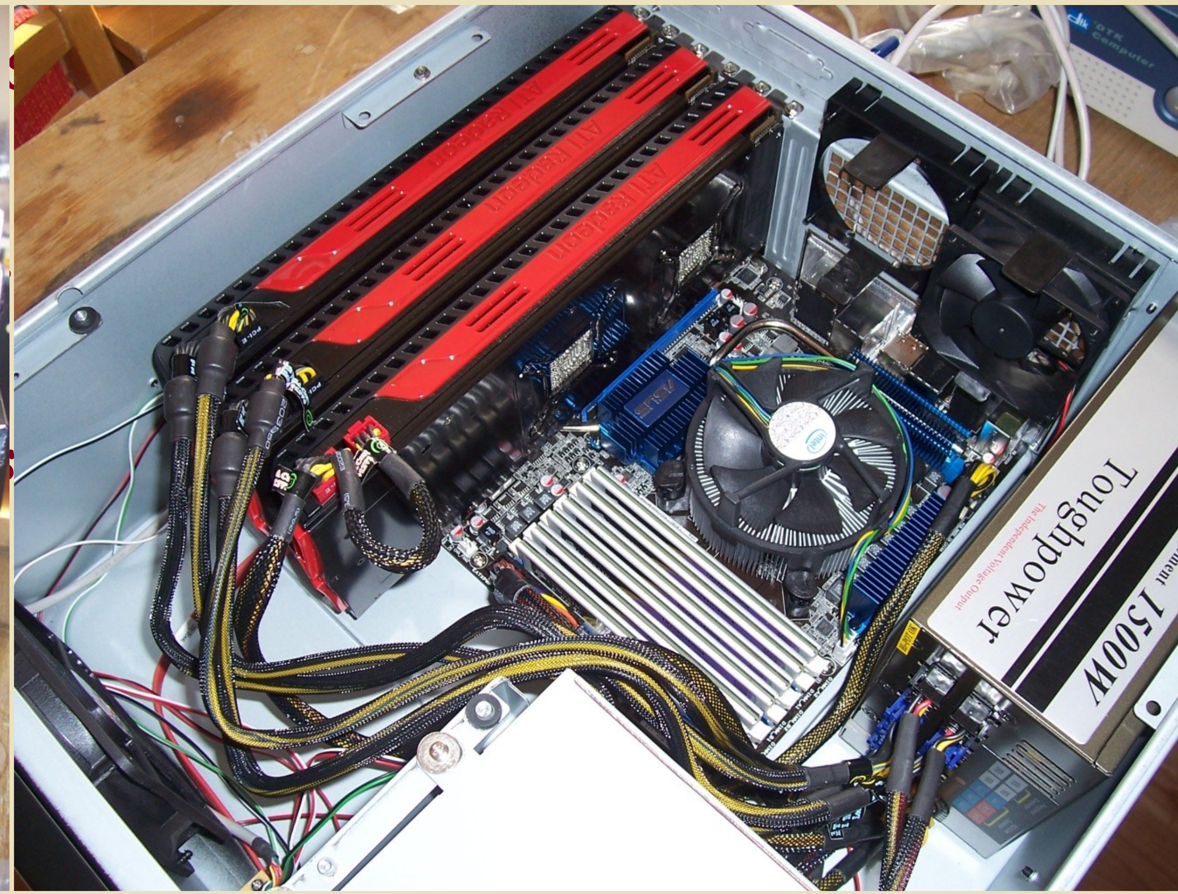


The main question is: How about SPEED?

- Levels of speedtest

  Kernel speed

  - Real geneation time of a PRNG in CPU or in GPU.

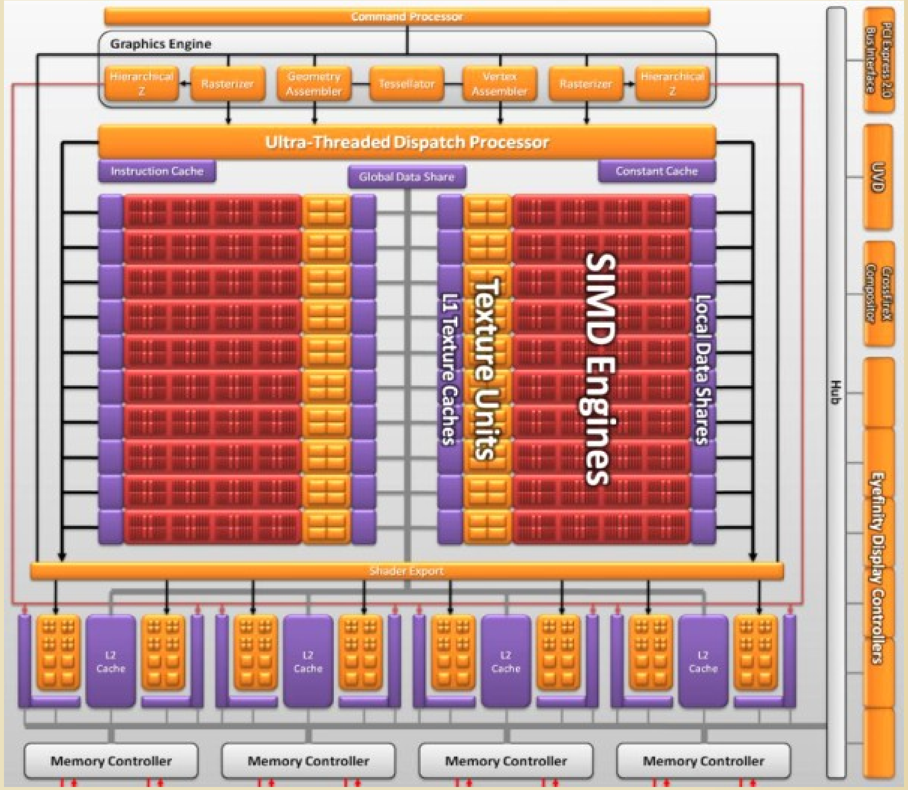
  Total speed

  - Generation time of the PRNGs within the proper program framework

  Real speed

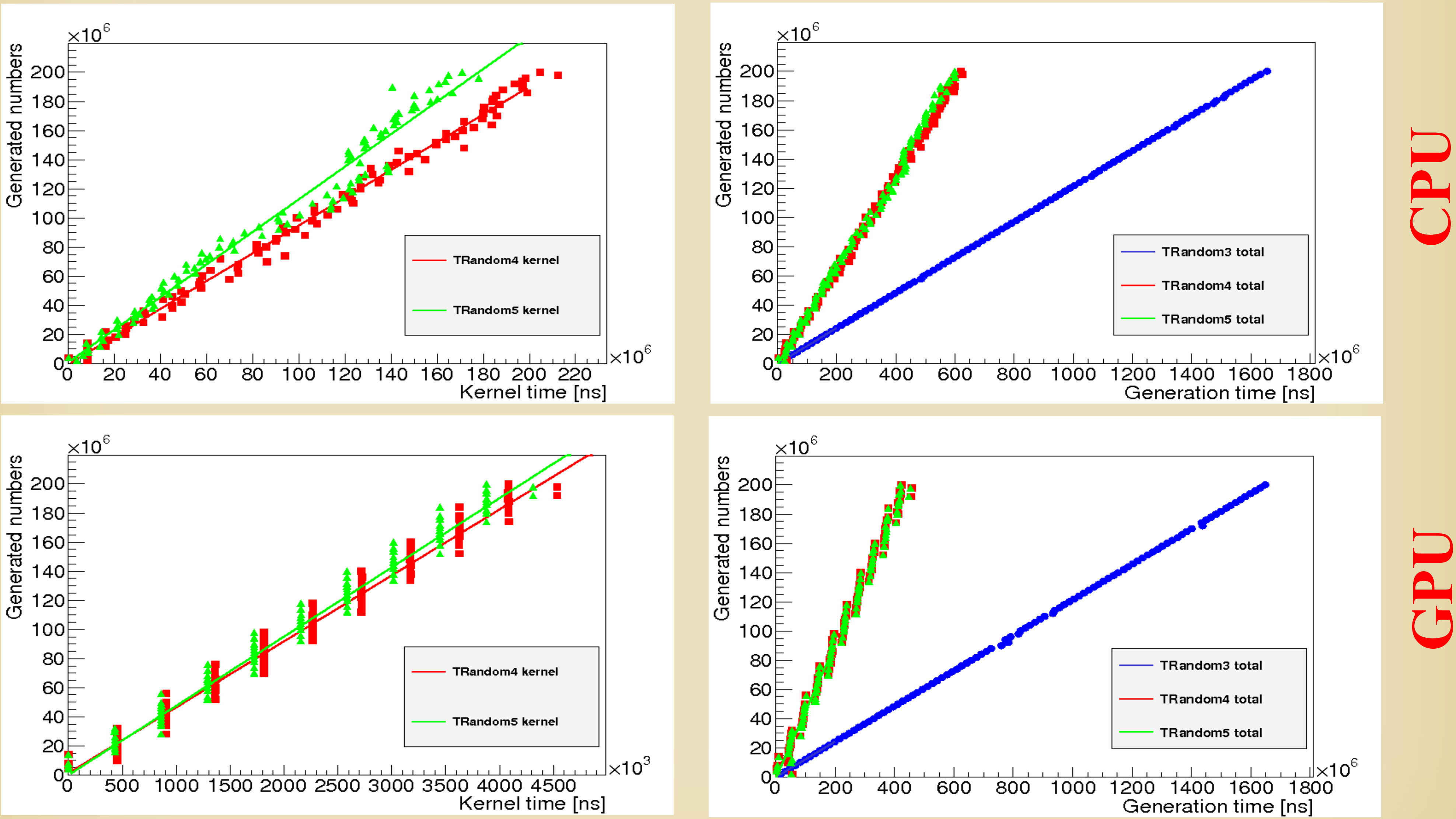
  - The above two, but with real (V)RAM usage.

  Here we used a 200 million event sample!



SPEED without writing (V)RAM

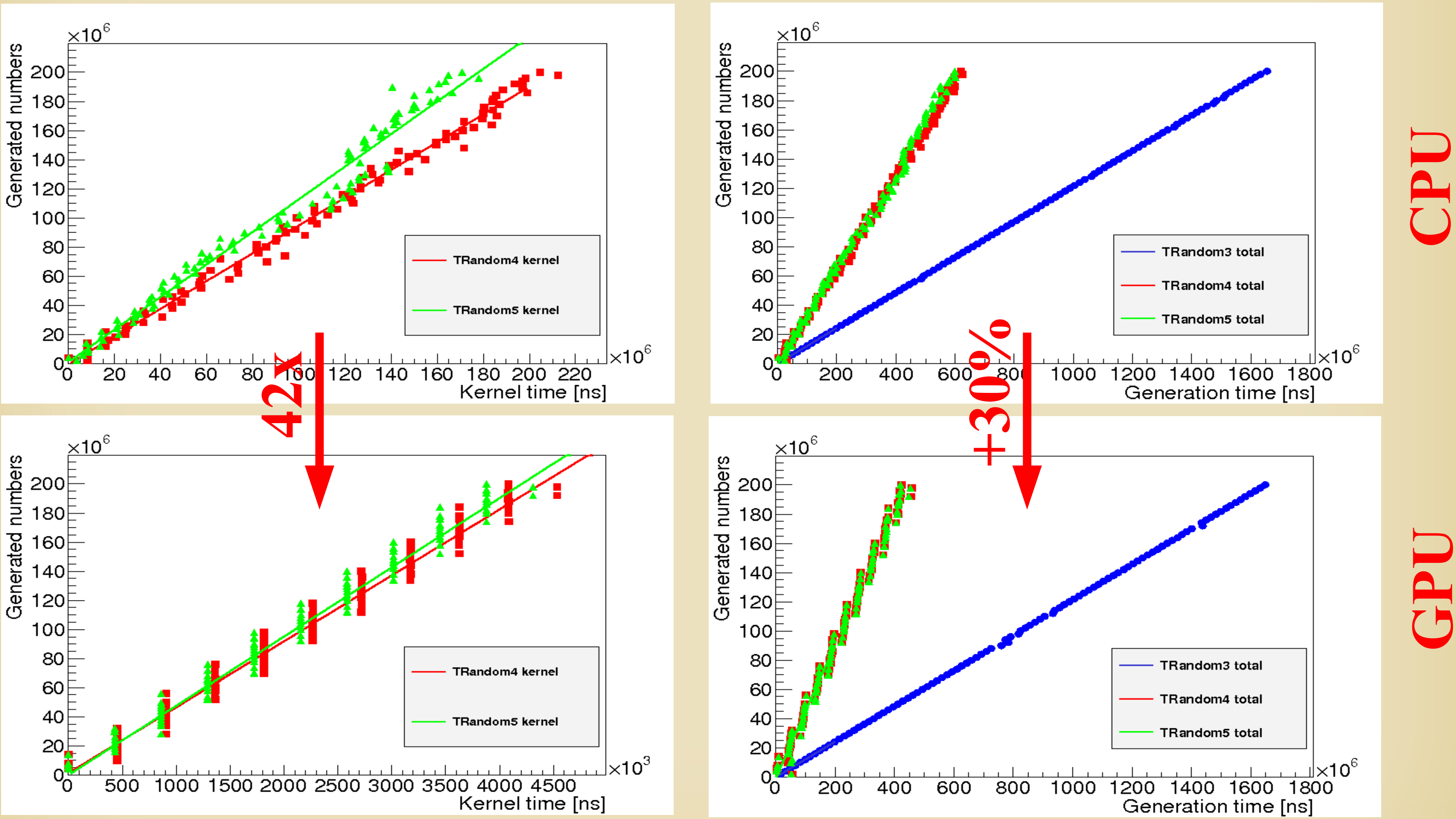
Kernel time | Full calculation



SPEED without writing (V)RAM

Kernel time

Full calculation

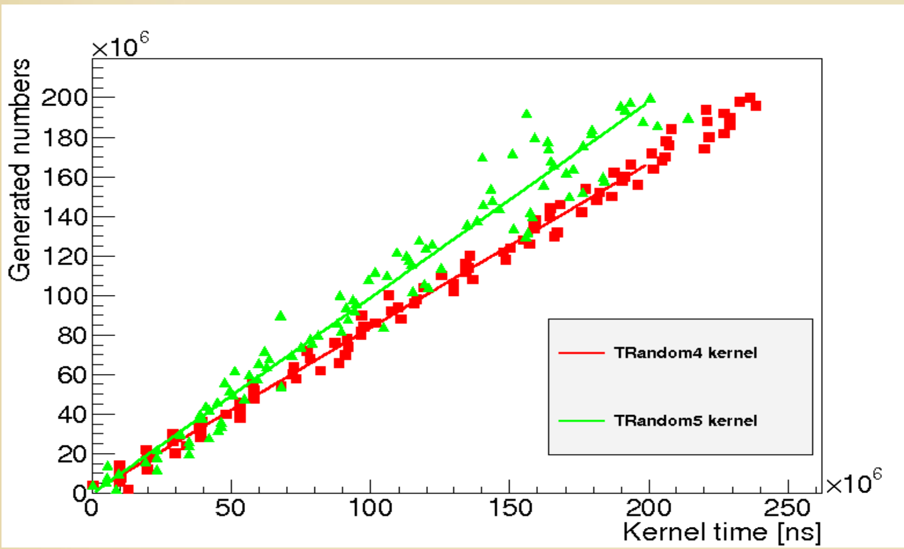


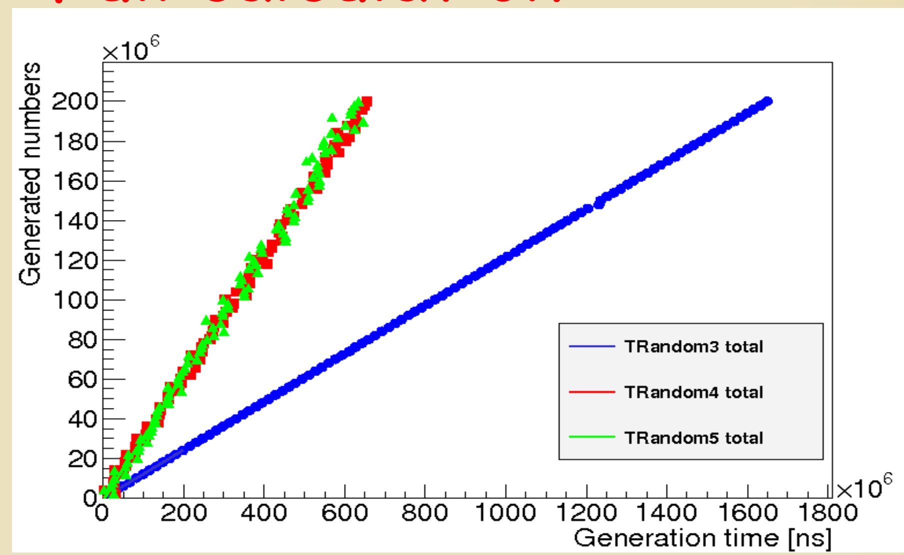
SPEED with writing (V)RAM

Kernel time

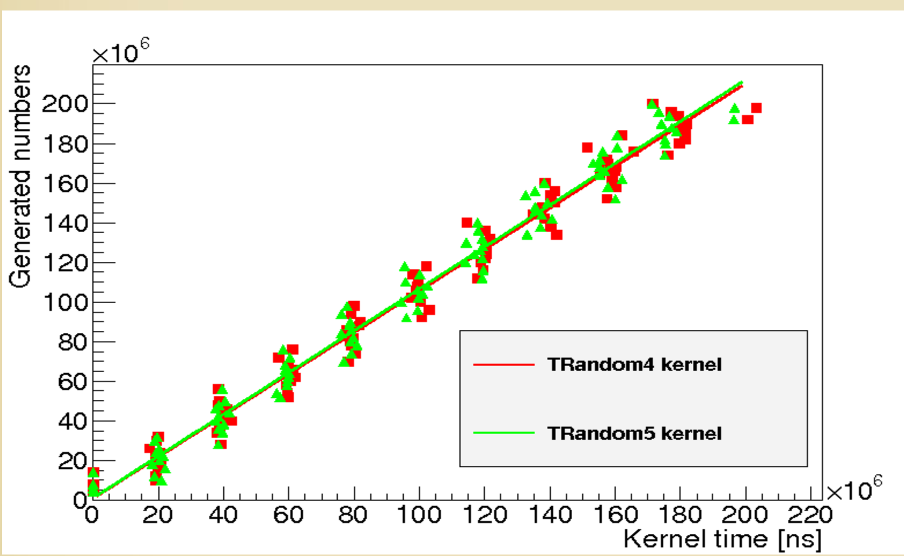
Full calculation

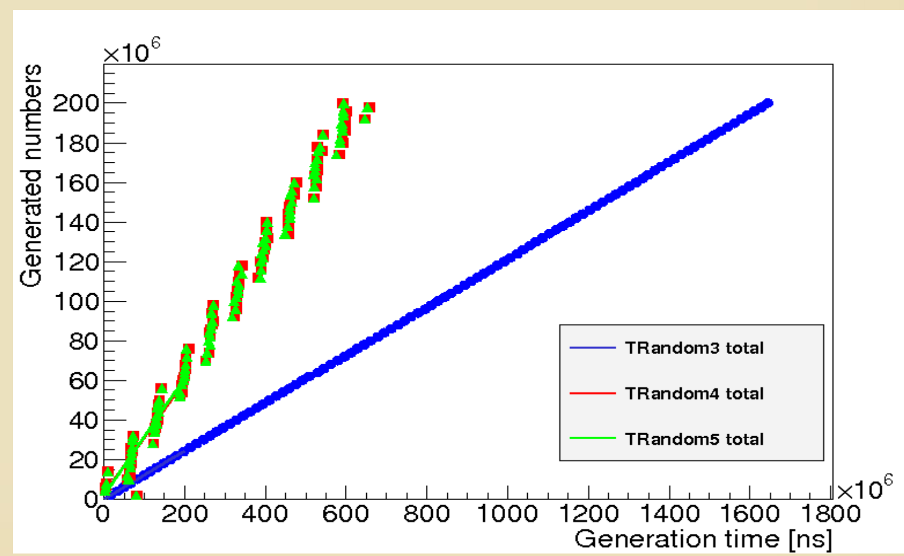
CPU





GPU



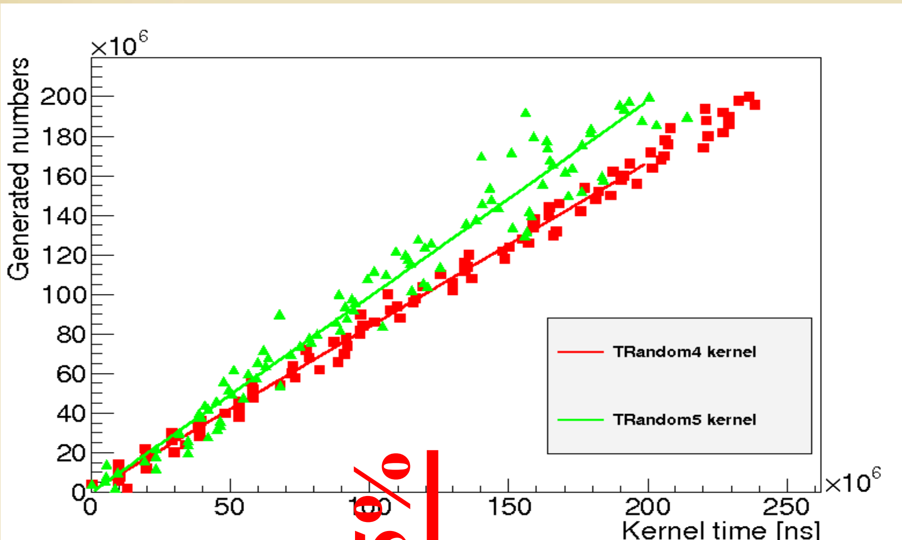


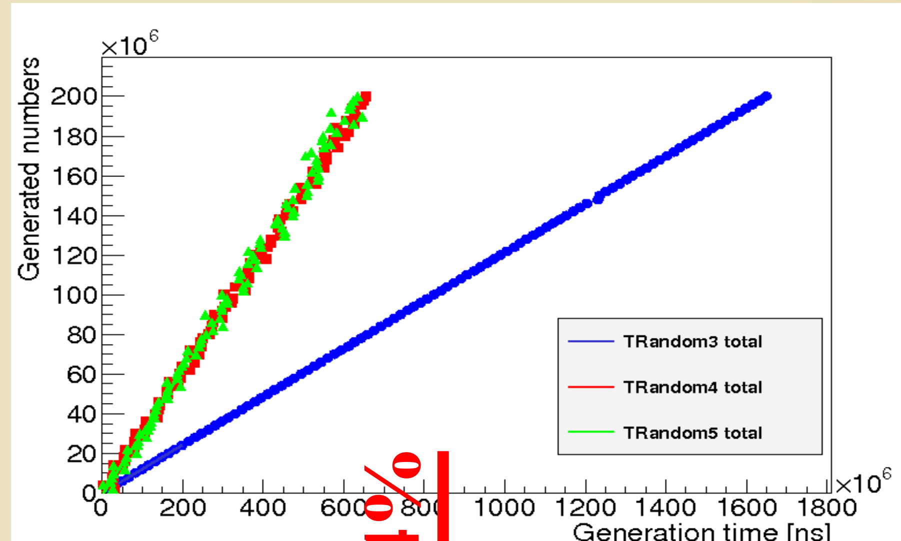
SPEED with writing (V)RAM

Kernel time

Full calculation

CPU

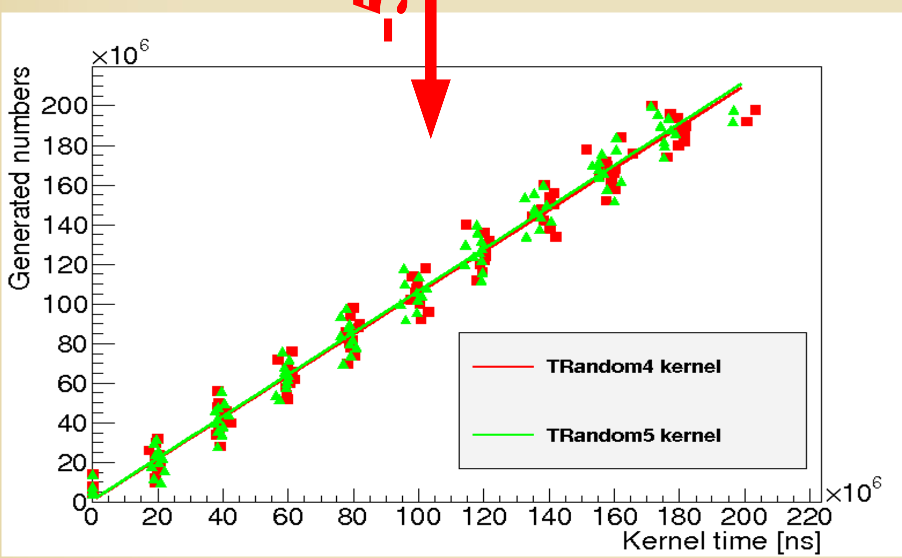


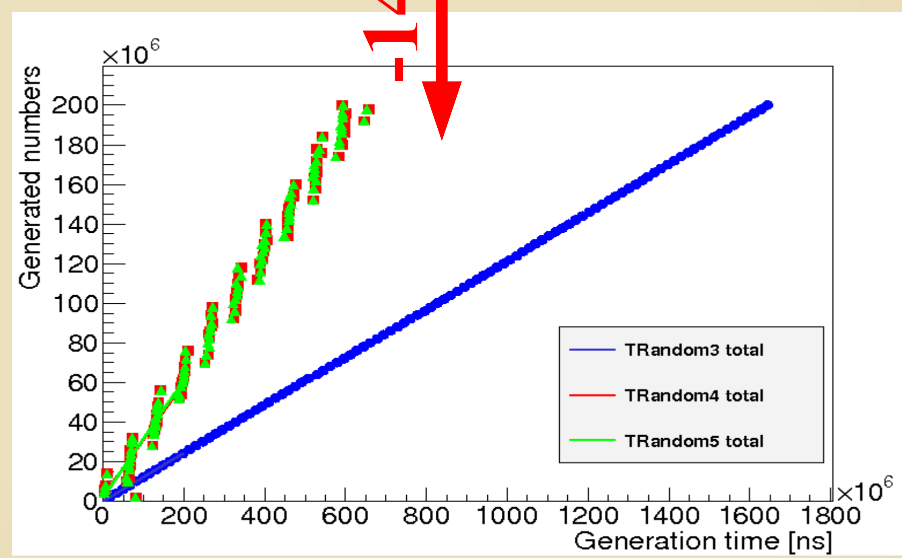


-5%

-14%

GPU





So, how about SPEED test?

- For this setup (Core i7 vs. ATi Radeon HD5970)

TRandom3 < TRandom4 < Trandom5

PRNG modules and run types	$v_{CPU\ kernel}$ [#/μs]	$v_{GPU\ kernel}$ [#/μs]	$v_{CPU\ total}$ [#/μs]	$v_{GPU\ total}$ [#/μs]
TRandom3 RW	121.71 ± 0.22%	—	121.71 ± 0.22%	—
TRandom4 RW	953.44 ± 0.96%	1047.22 ± 1.59%	321.38 ± 2.94%	284.846 ± 7.89%
TRandom5 RW	1 118.87 ± 1.72%	1055.64 ± 1.58%	338.06 ± 2.50%	295.71 ± 6.76%
TRandom3 NW	121.69 ± 0.15%	—	121.69 ± 0.15%	—
TRandom4 NW	953.44 ± 0.96%	45 325.54 ± 2.23%	321.379 ± 2.94%	451.910 ± 3.51%
TRandom5 NW	1 118.87 ± 1.72%	47 583, 52 ± 3.16%	338.059 ± 2.50%	456.508 ± 3.62%

+10x

+3x

+10x

+3x

So, how about SPEED test?

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Kernel calculation is faster (NW)

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+10x

+10x

+3x

+3x

+45x

+30%

So, how about SPEED test?

- For this setup (Core i7 vs. ATi Radeon HD5970)

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Kernel calculation is faster (NW), but real speed (RW) is slower

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+10x
+3x
-5%
-14%
+10x
+3x
+45x
+30%

Note$_1$: New GPU cards are 2-5 times faster

So, how about SPEED test?

- For this setup (Core i7 vs. ATi Radeon HD5970)

  TRandom3 < TRandom4 < Trandom5

  Kernel calculation is faster (NW), but real speed is slower

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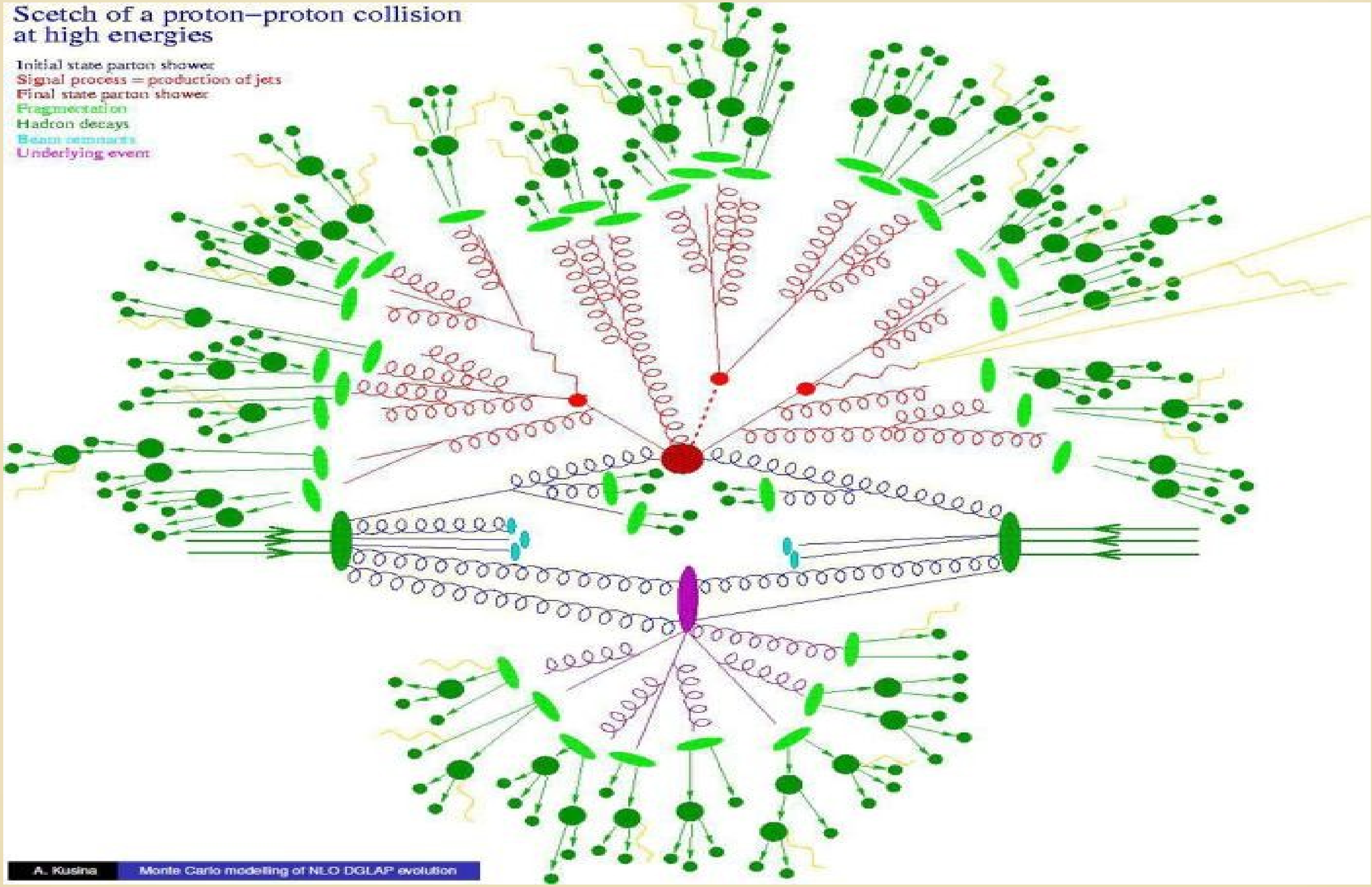
+2x faster

Note$_2$: Parallel computing (OpenCL) improves speed!

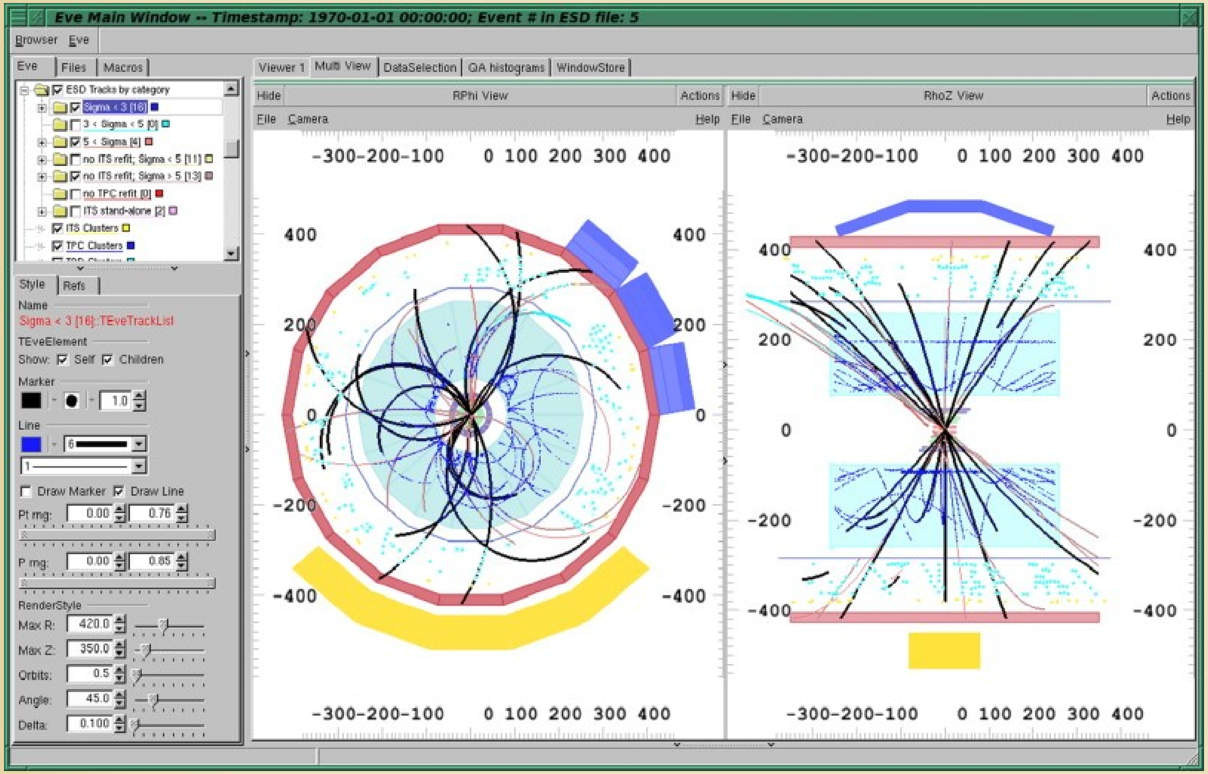
Some Physics: proton-proton collisions

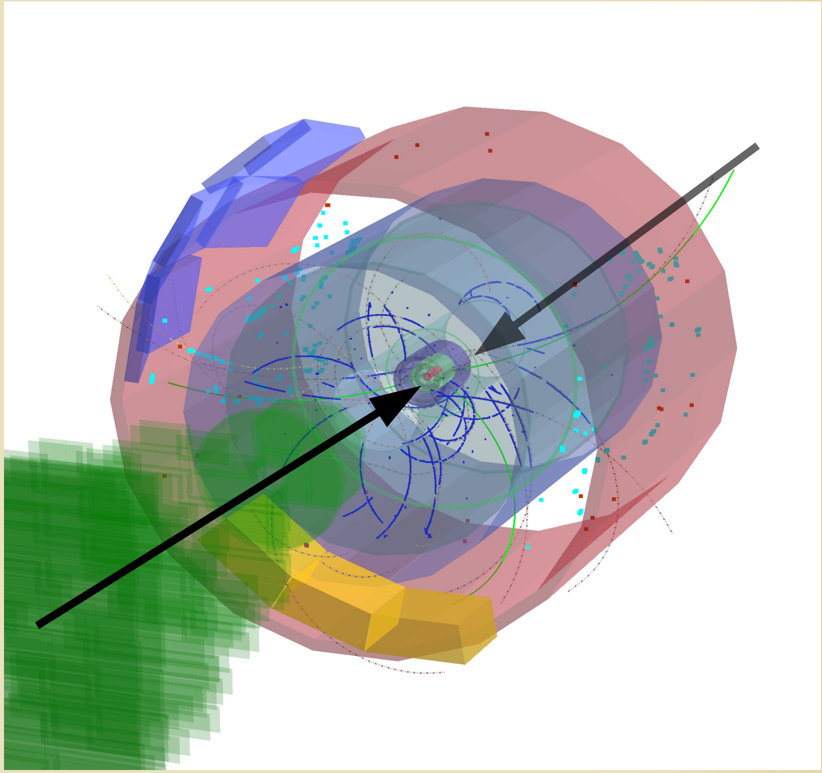
- Theoretical model of a pp collisions



Some Physics: proton-proton collisions

- A reconstructed pp event in the ALICE experiment



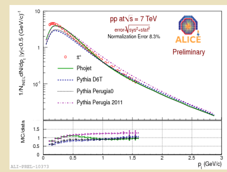


Some Physics: pp collisions at GPU

- 400k TRandom5 PRNG

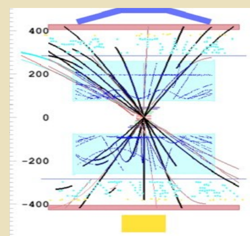
Transverse momentum spectrum

dN/dp_T (Tsallis distr.)



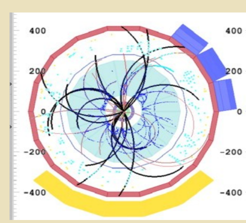
Rapidity distribution

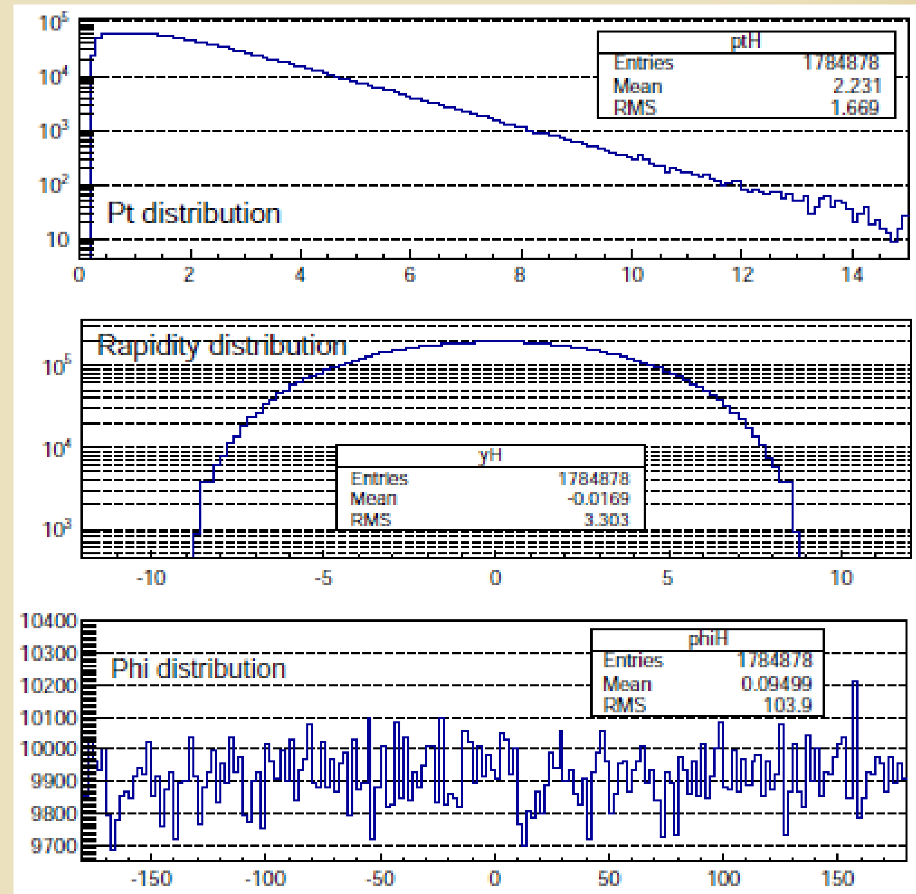
dN/dy (Gaussian distr.)



Angular distribution

$dN/d\varphi$ (Isotropy)



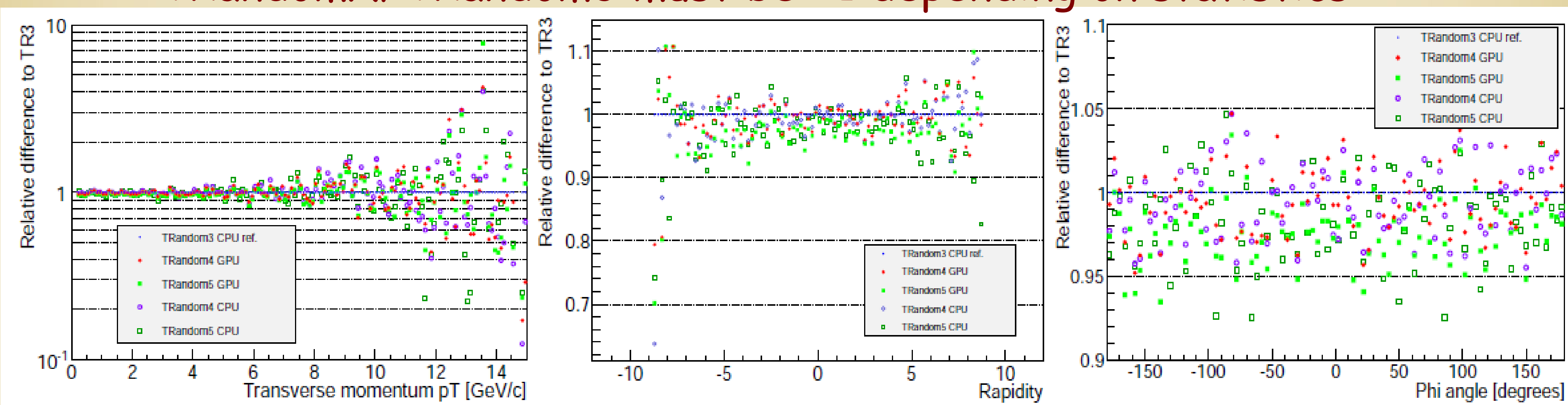


Some Physics: pp collisions at GPU

- To check the validity of the 'physics':

  Compare calulated distributions to the original Trandom3 CPU

  TRandomX/TRandom3 must be ~1 depending on statistics



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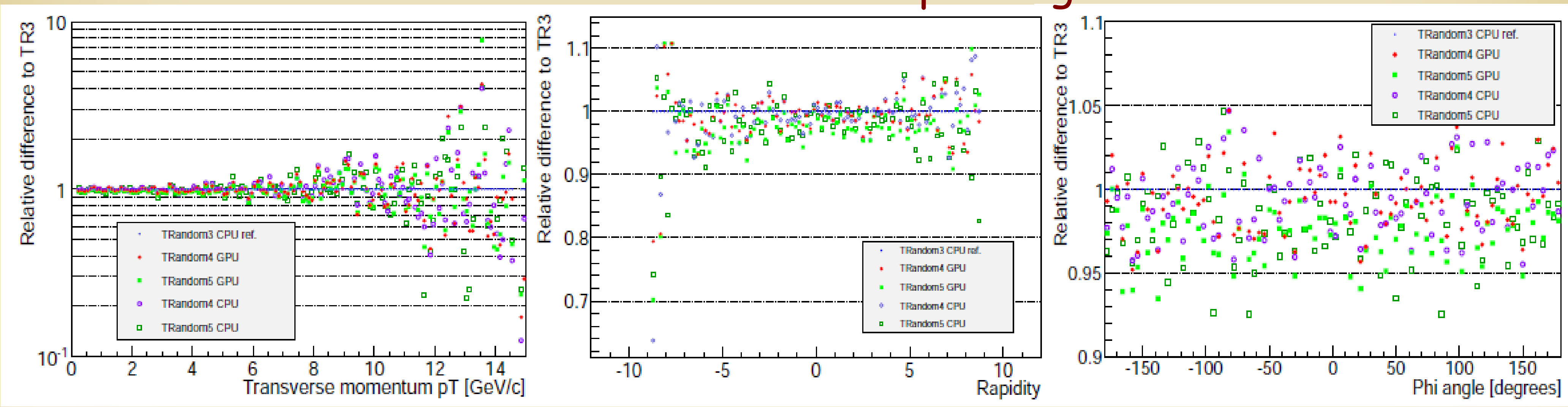

10% agreement	5% agreement	5% agreement
up to p_T<6 GeV/c	in |y|<5	in the whole φ

SUMMARY

- Aim
  - Faster MC event generation for HIC
- Resuts for pp MC @ GPUs
  - Diehard test of open source PRNGs: (SFMT, MWC64X) on GPUs
  - Implementation of new GPU based modules (TRandom4, TRandom5) to Root/AliRoot framework
  - Tests: simulation of high-energy pp collisions
- Take away message
  - GPUs can be used for Monte Carlo generators in HIC
  - One needs more programming (CUDA/OpenCL/...)
  - Need to optimize (price/speed) since other technologies available (e.g. Intel Xeon Phi)

O U T L O O K

- The presented results are on
  - AliRoot, especially AliPYTHIA for proton-proton
  - CPU/GPU SIMD-oriented Fast MT & MWC64X
  - Standalone machine (with ATi Radeon HD5970)
- How to improve?
  - Ongoing: HIJING calculations (need for more PRNGs), so might be more efficient, faster
  - Trivial: Buy new fast cards and re-test – we are on it and we hope the funding agency on it as well.
  - The framework is almost ready to test in the GRID using JDL (required HW: GPUs, SW: OpenCL/CUDA/...)
  - More faster PRNGs on CPUs/GPUs (Tiny MT, MTGP), but note, faster PRNG less randomness quality.
  - Further modules can be moved to GPU

BACKUP

The PRNG quality test

Some DieHard tests by George Marsaglia

Birthday spacings: Choose random points on a large interval. The spacings between the points should be asymptotically exponentially distributed. The name is based on the birthday paradox.

Overlapping permutations: Analyze sequences of five consecutive random numbers. The 120 possible orderings should occur with statistically equal probability.

Ranks of matrices: Select some number of bits from some number of random numbers to form a matrix over {0,1}, then determine the rank of the matrix. Count the ranks.

Monkey tests: Treat sequences of some number of bits as "words". Count the overlapping words in a stream. The number of "words" that don't appear should follow a known distribution. The name is based on the infinite monkey theorem.

Count the 1s: Count the 1 bits in each of either successive or chosen bytes. Convert the counts to "letters", and count the occurrences of five-letter "words".

Parking lot test: Randomly place unit circles in a 100 x 100 square. If the circle overlaps an existing one, try again. After 12,000 tries, the number of successfully "parked" circles should follow a certain normal distribution.

Minimum distance test: Randomly place 8,000 points in a 10,000 x 10,000 square, then find the minimum distance between the pairs. The square of this distance should be exponentially distributed with a certain mean.

Random spheres test: Randomly choose 4,000 points in a cube of edge 1,000. Center a sphere on each point, whose radius is the minimum distance to another point. The smallest sphere's volume should be exponentially distributed with a certain mean.

The squeeze test: Multiply 231 by random floats on [0,1) until you reach 1. Repeat this 100,000 times. The number of floats needed to reach 1 should follow a certain distribution.

Overlapping sums test: Generate a long sequence of random floats on [0,1). Add sequences of 100 consecutive floats. The sums should be normally distributed with characteristic mean and sigma.

Runs test: Generate a long sequence of random floats on [0,1). Count ascending and descending runs. The counts should follow a certain distribution.

The craps test: Play 200,000 games of craps, counting the wins and the number of throws per game. Each count should follow a certain