Exploring Compression Techniques for ROOT IO

Zhe Zhang, Brian Bockelman
University of Nebraska-Lincoln
zhan0915@huskers.unl.edu, bbockelman@cse.unl.edu

Nebraska
UNIVERSITY OF
Lincoln

Agenda

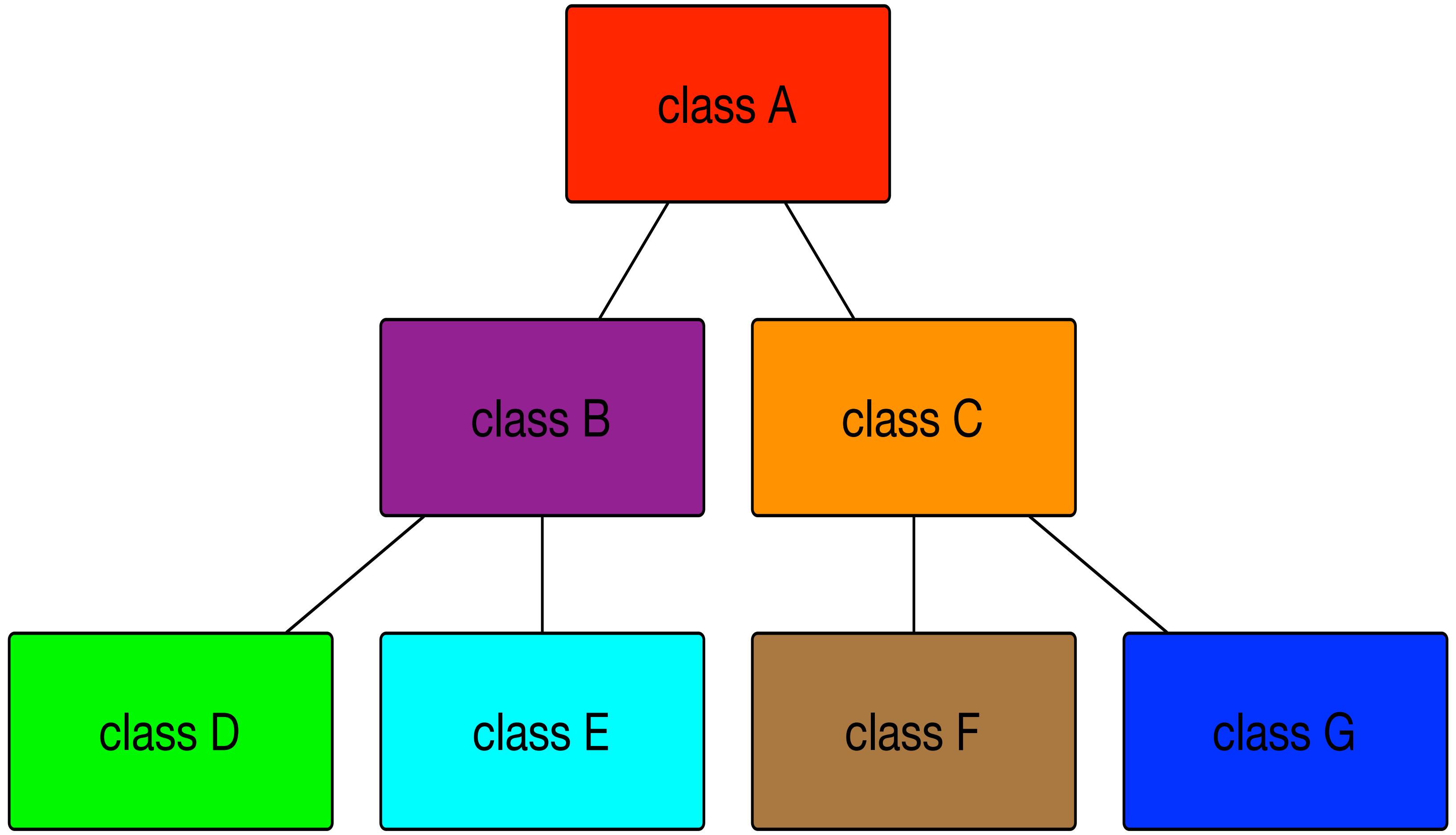
- Introduction
- Motivation
- Approaches
- Results
- Conclusions

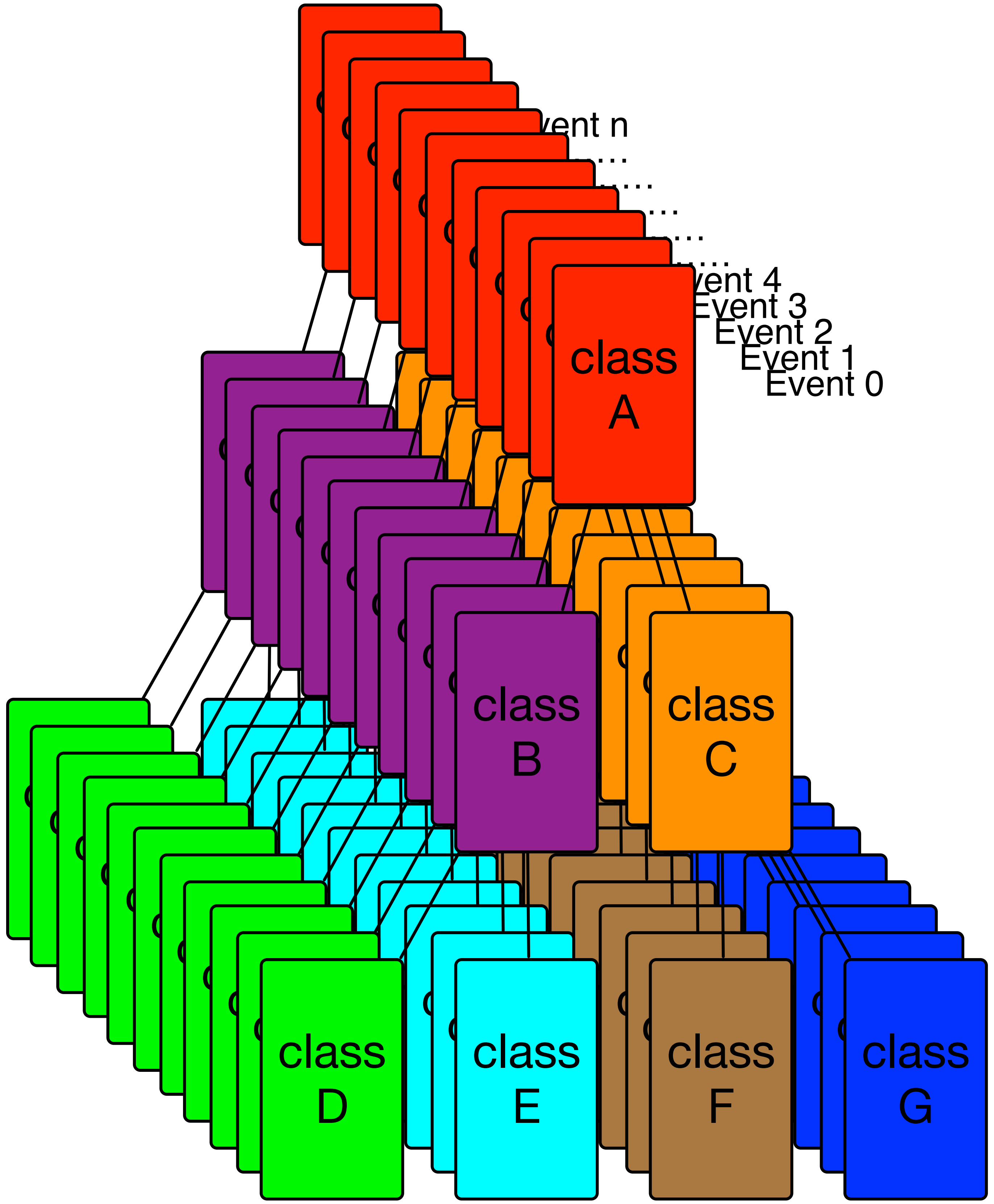
Introduction

- ROOT is a software tool to store large amount of objects and help researchers to analyze and visualize the data.
  - ROOT uses tree to store objects.
  - Trees allow user to sequentially and randomly access entries.
  - Trees allow user to access sub-branches.

Event Structure:

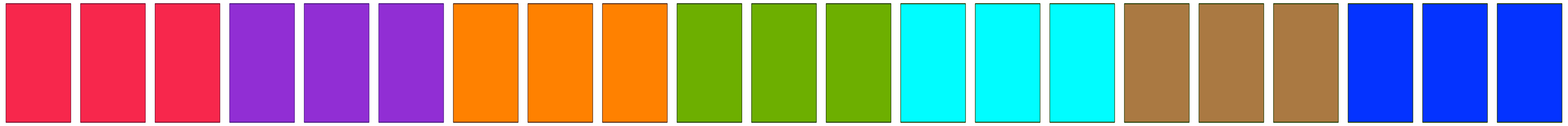
```
class A {
    class B {
        class D;
        class E;
    };
    class C {
        class F;
        class G;
    };
};
```





Trees are serialized by branches:

- Easy comparison across branches.
- Redundant data are close together.



Motivation

- ROOT works well for the common case (reading sequentially through a fixed set of branches) – can we beat its performance for various other use cases?
  - Alternative compression algorithms
  - Performance of random reads
  - Comparison to naïve approach

Alternative Compressions:

- Zlib vs LZMA vs LZ4 (right table)
- Tradeoffs between compression ratio and decompression speed

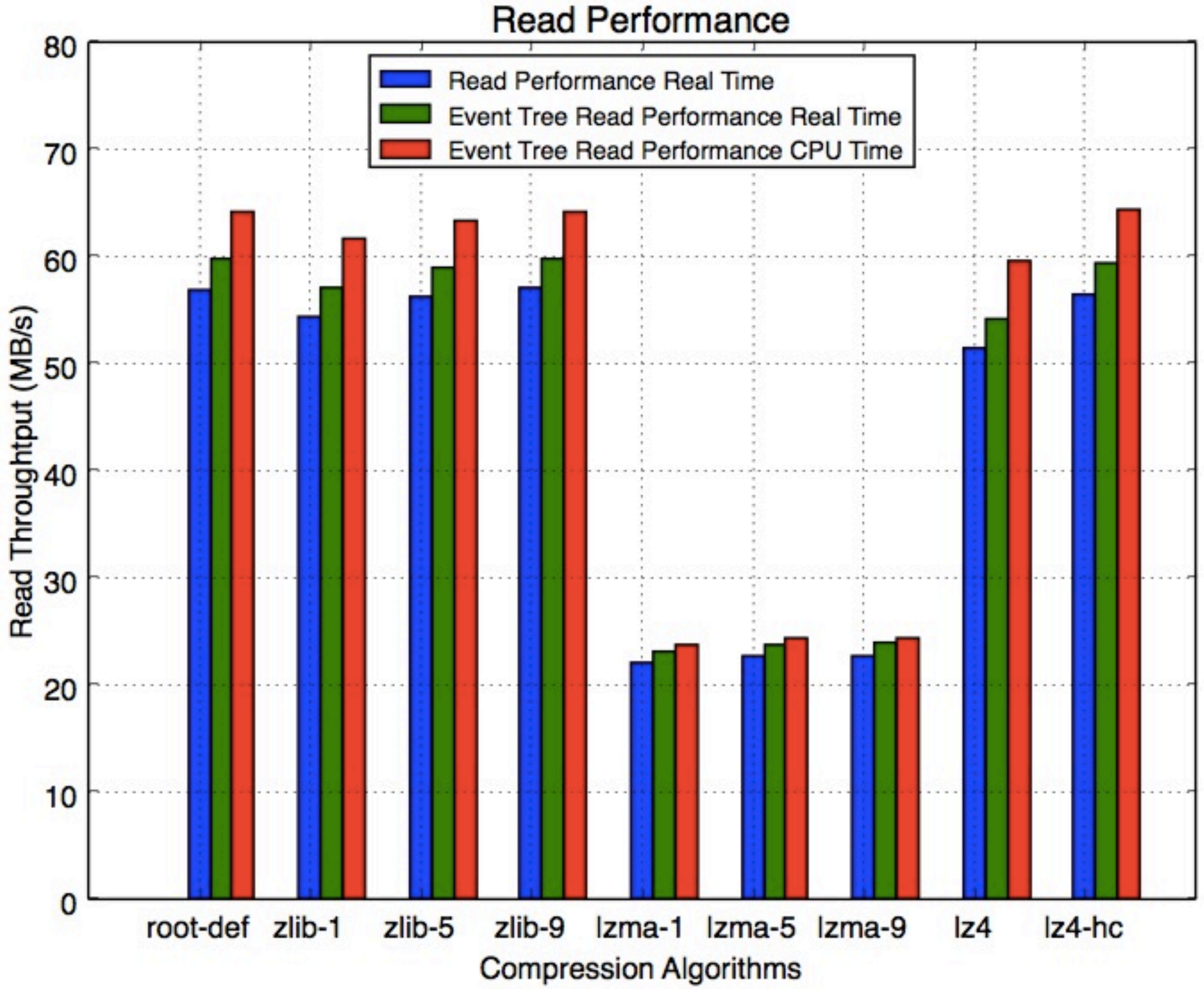
	Zlib	LZMA	LZ4
Fast compression speed			✗
Medium compression speed	✗		
Slow compression speed		✗	
Fast decompression speed			✗
Medium decompression speed	✗		
Slow decompression speed		✗	
High compression ratio		✗	
Medium compression ratio	✗		
Low compression ratio			✗

Test Setup:

- CMS file contains 9 trees.
- The tree of **Events** has 213 branches and 6500 entries.
- Raw data file is 6.4 GB.

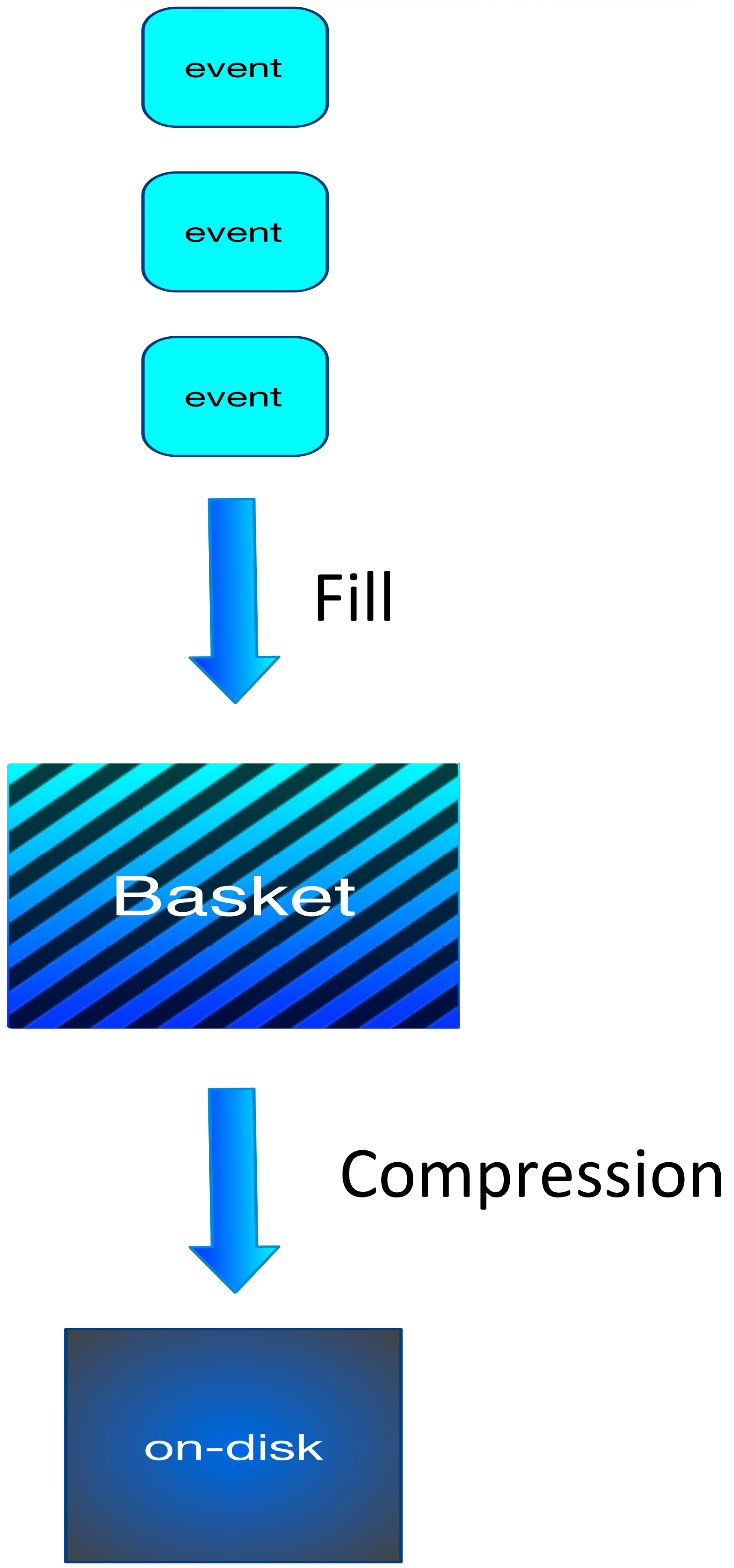
Read performance:

- LZ4-HC performs slightly better than Zlib-6 but not significant.



ROOT pipeline:

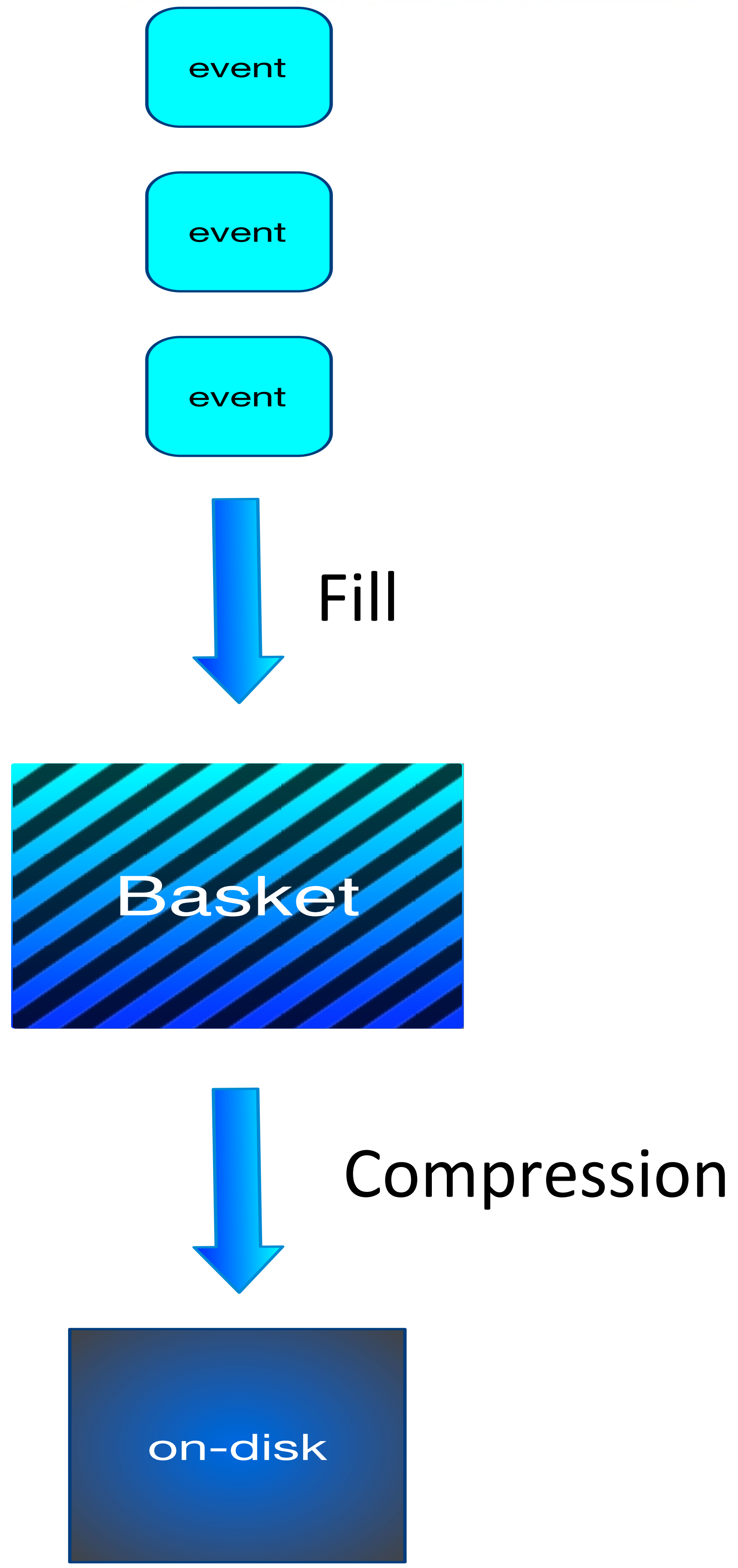
- Each branch has a basket.
- Each basket is filled with events.
- Each basket is compressed and flush to disk once it is full.



ROOT pipeline:

- Each branch has a basket.
- Each basket is filled with events.
- Each basket is compressed and flush to disk once it is full.

What if we only want to read a single event with several bytes out from a basket of 32 KB ?



Random Access Compression:

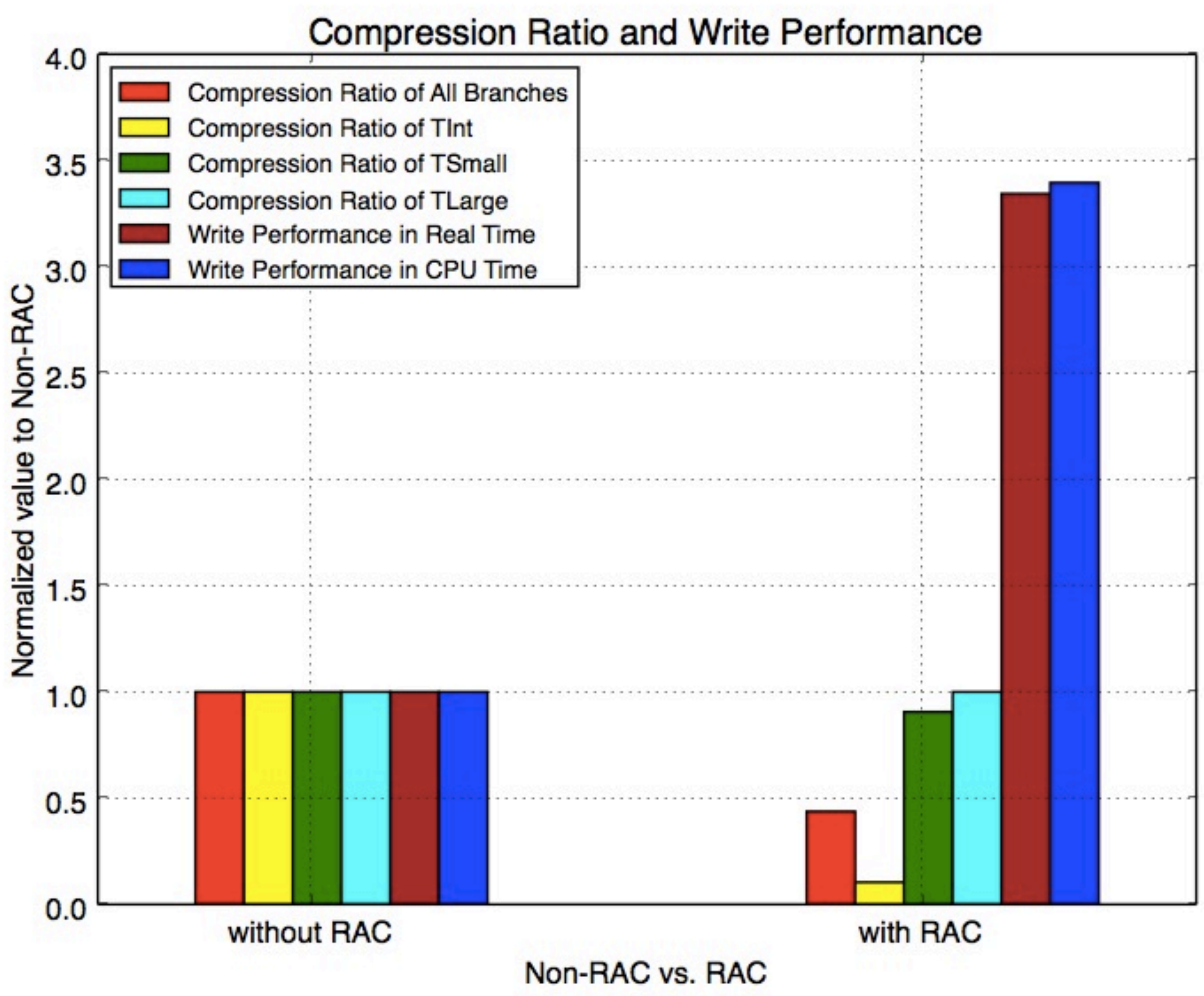
Add array of offsets for compressed entries in TKey. ROOT searches the offset before decompress the basket; can decompress individual events.

Handcrafted objects:

- Tlarge (4MB):
  - *is an array which contains 1,000,000 elements of which each is 4 bytes, and each random float number is repeated 60 times.*
- Tsmall (4KB):
  - *is an array which contains 1,000 elements of which each is 4 bytes, and each random float number is repeated 6 times.*
- Tint (39B):
  - *is an Int array which contains 6 integer with the same value.*

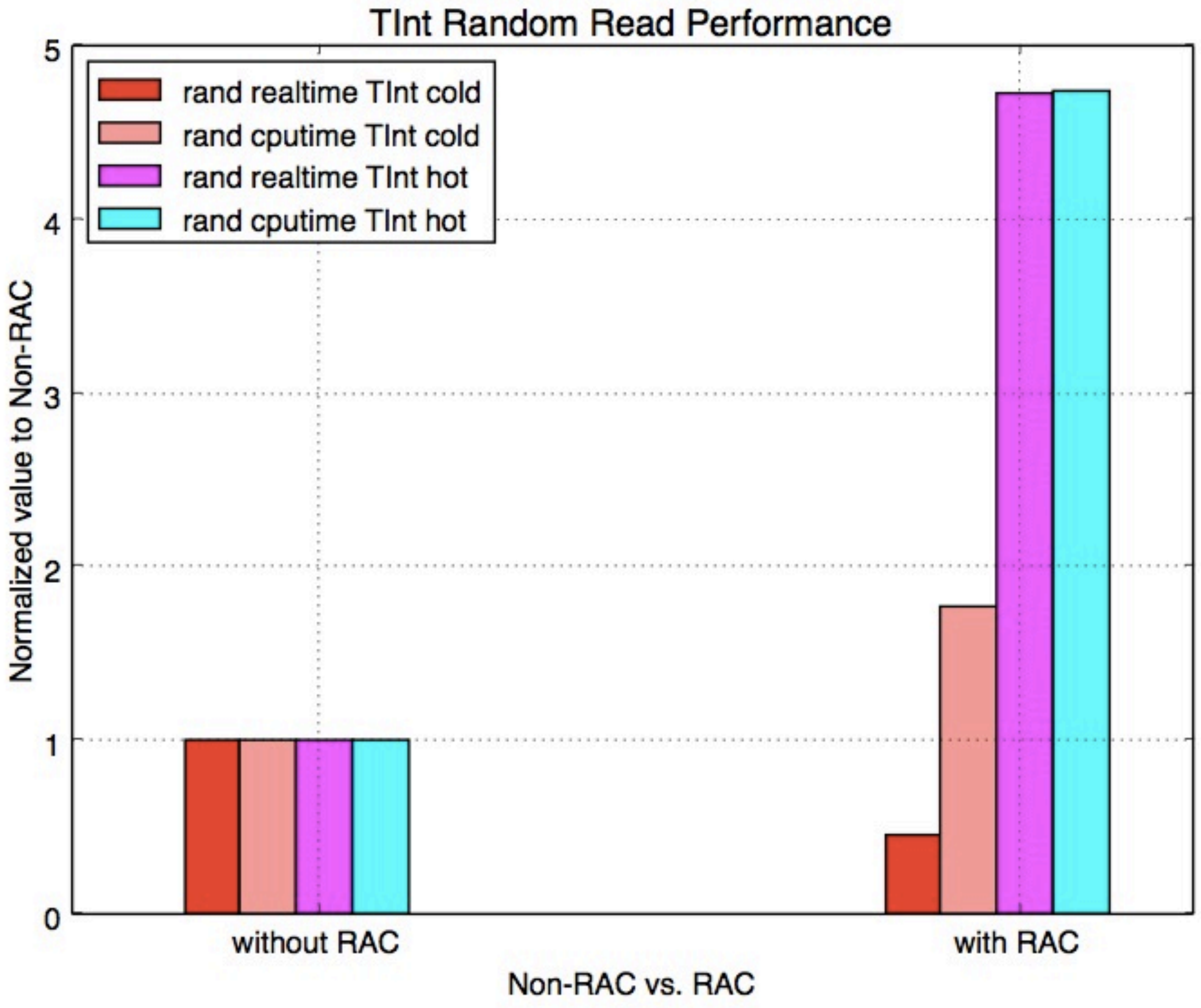
RAC Compression Ratio:

- Tiny events decrease compression ratio.
- Once the size of single event goes beyond basket size, RAC is basically the same thing with non-RAC.



RAC Read performance:

- For small events, RAC requires more IOs to read data, but it still needs less CPU time to decompress data.
- Once data are in cache, RAC becomes much faster.

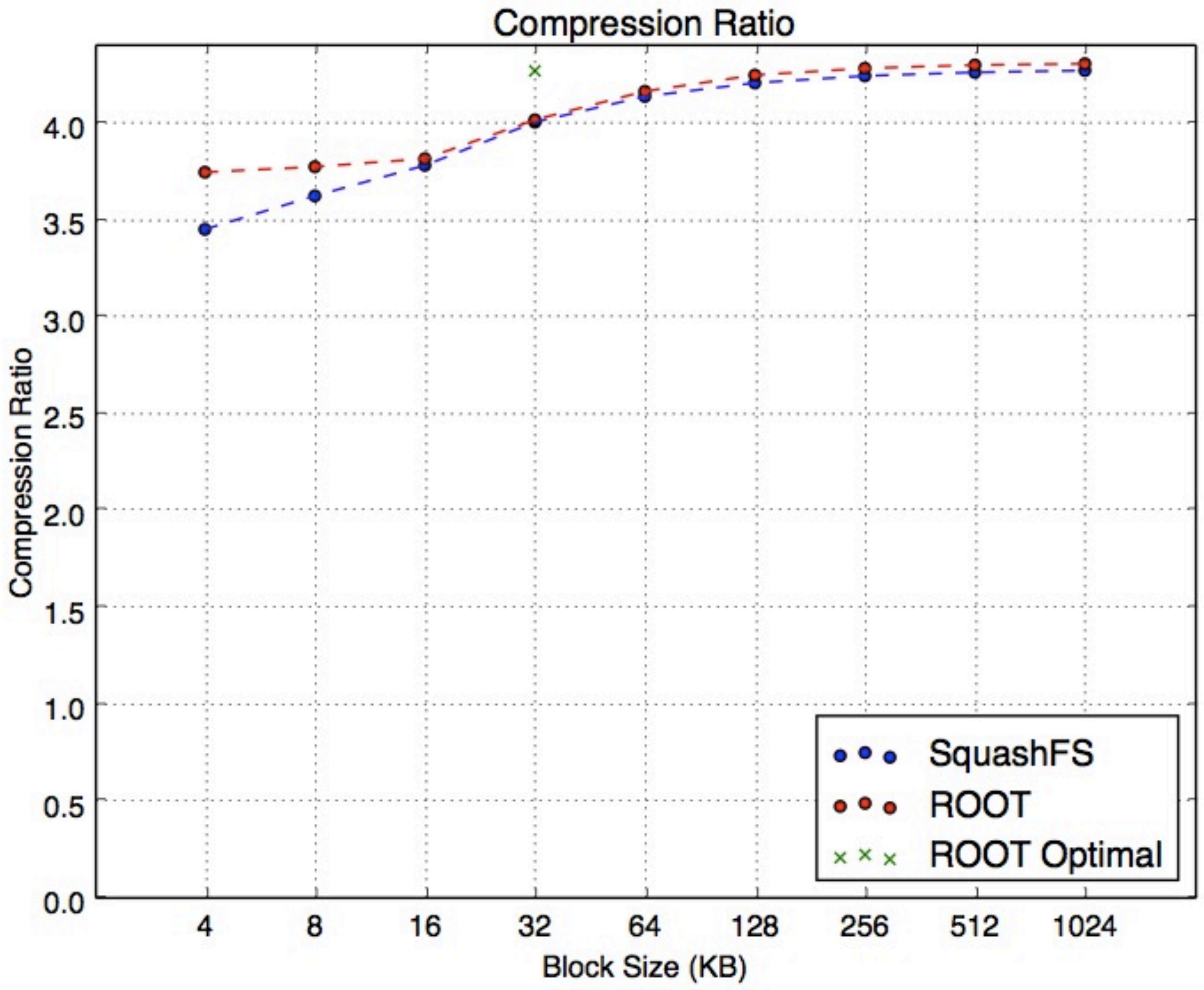


External Compression:

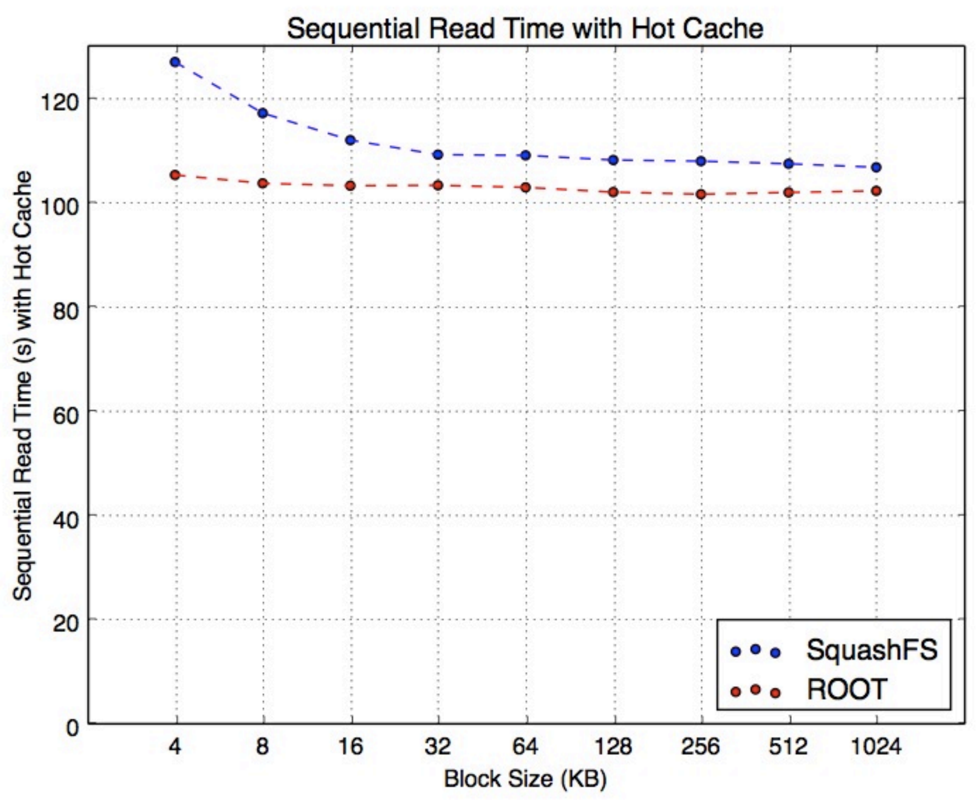
Dividing uncompressed ROOT file into equal size of blocks on disk and independently compress each block. Done with no knowledge of actual file contents, using SquashFS.

Compression Ratio:

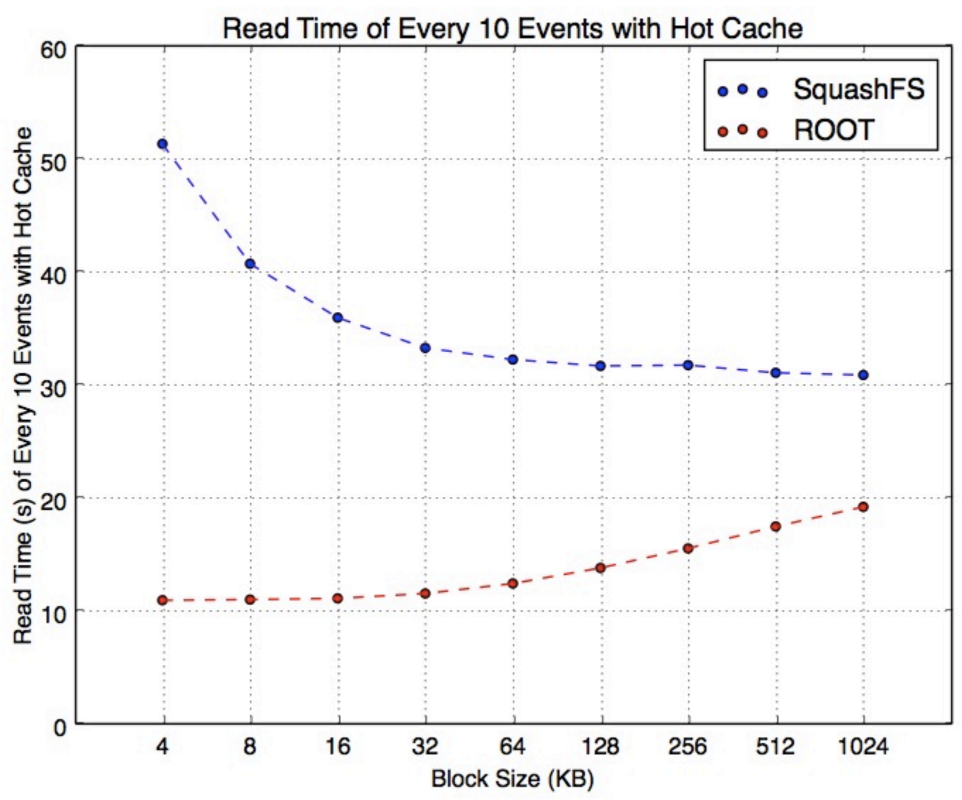
- ROOT gives better compression ratio than SquashFS.



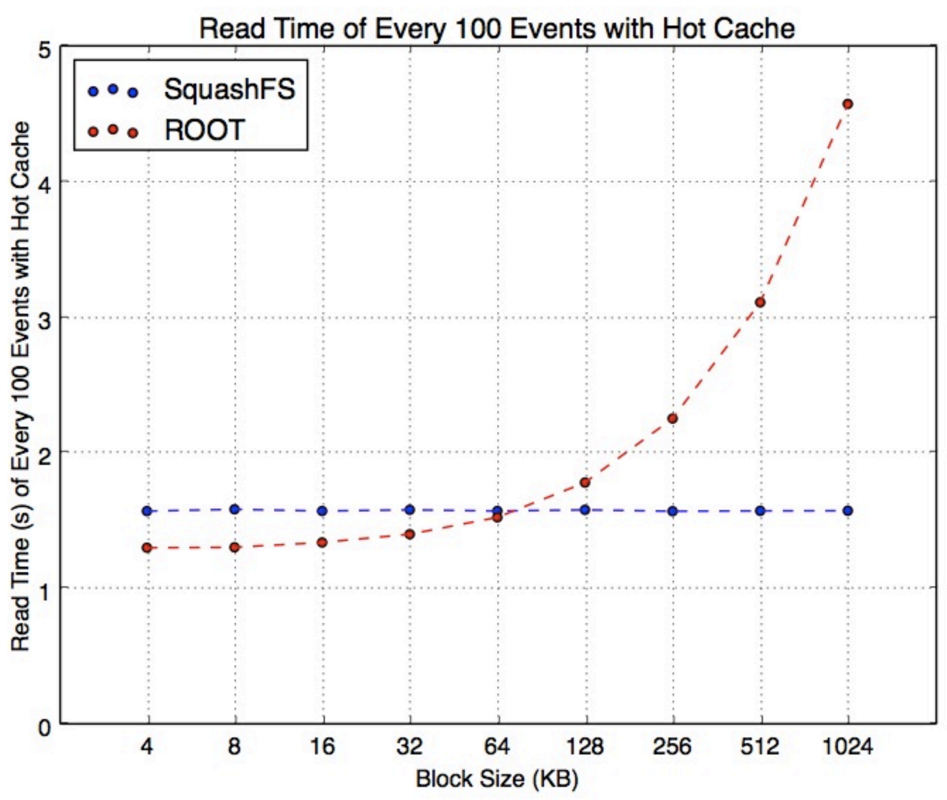
ROOT Optimal: indicates the default setting in current ROOT where each basket size is dynamically configured by input data



Sequentially reads all events



Read every 10th events



Read every 100th events

Read Performance with Hot Cache:

- ROOT understands the data layout better.
- User-space decompression degrades read speed.

Conclusions:

- LZ4 does not have significant improvement over Zlib.
- RAC can dramatically accelerate random read speed for small objects although it needs more storage.
- ROOT decompresses basket in user space where random reads in memory might slow down.
- ROOT has a lot of good features: fast sequential access, sub-branches accesses, good knowledge of event structure, etc. but there is still some room to improve.

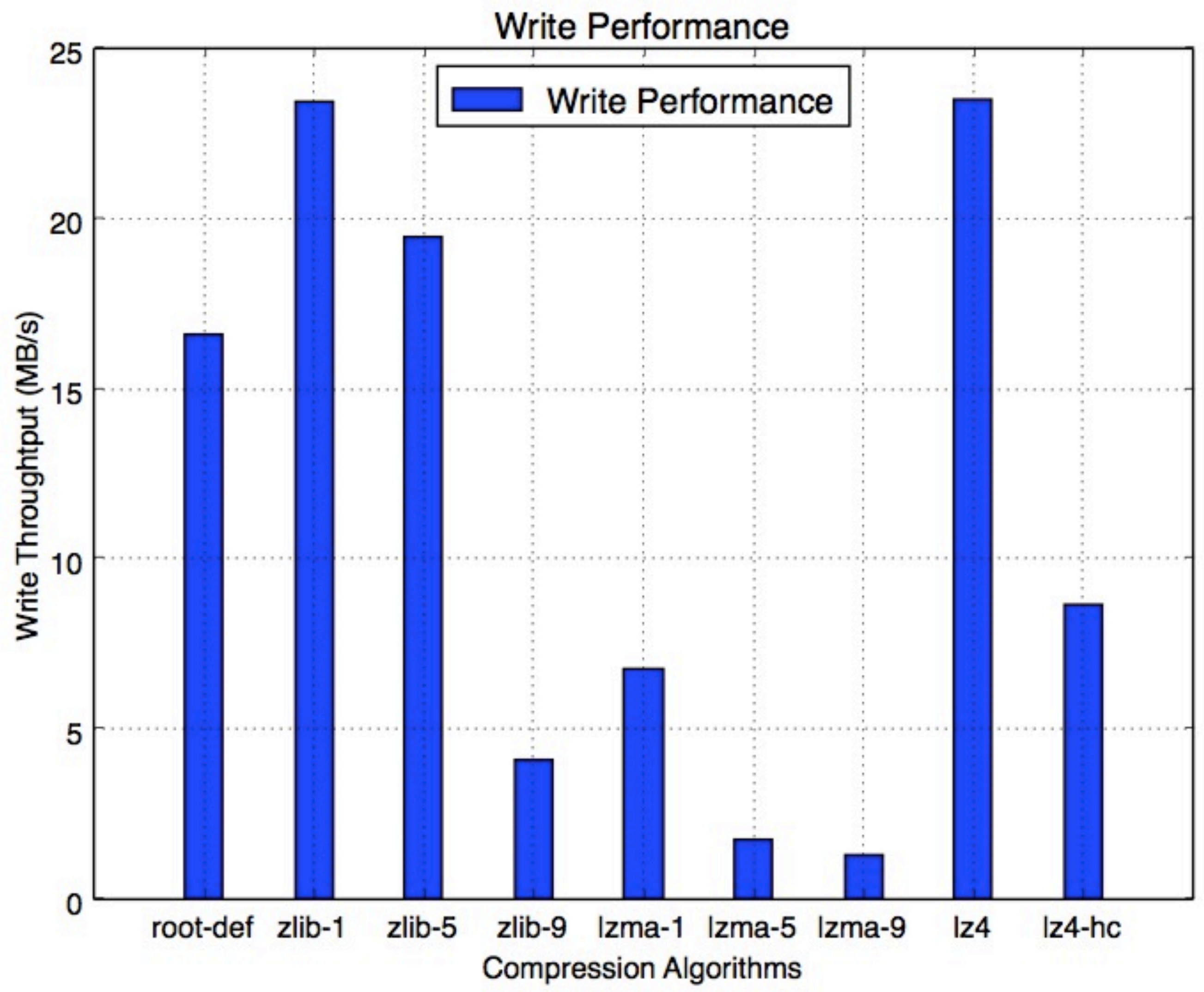
Questions?

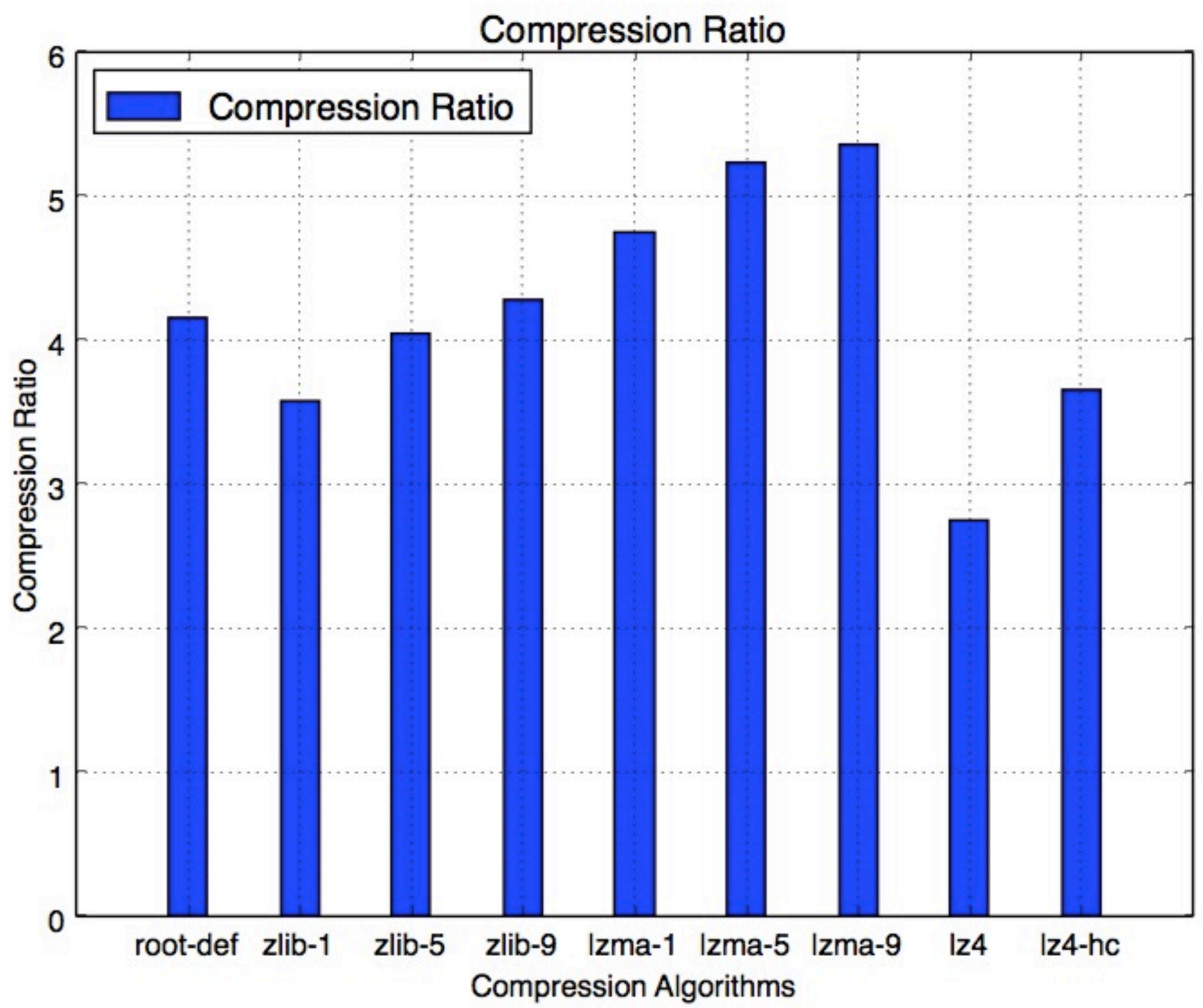
References:

- Alternative compression algorithms
  - https://github.com/root-mirror/root/pull/81
- Additional compression algorithms from gitbub@pseyfert
  - https://github.com/root-mirror/root/pull/177
- RAC (not backward compatible):
  - https://github.com/root-mirror/root/pull/152

Write Performance:

- LZ4 Compression is faster than Zlib and LZMA in general and has similar performance with Zlib-1
- LZMA is slowest





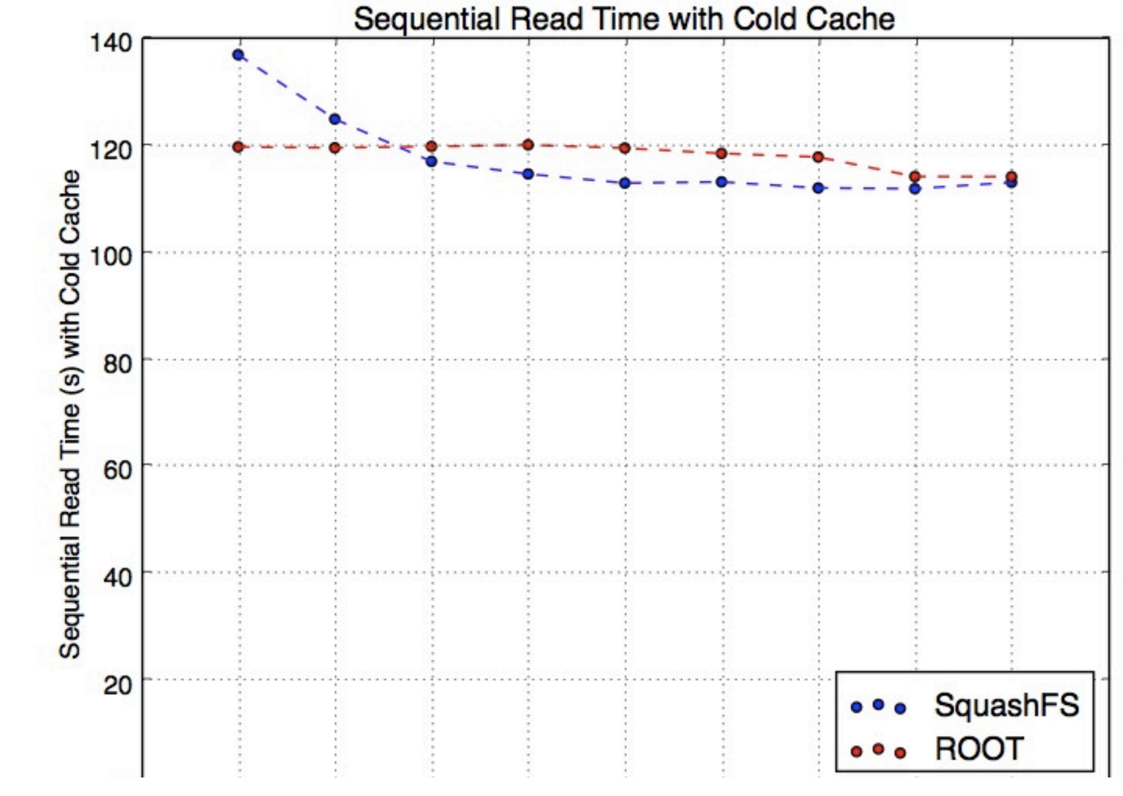
Compression Ratio:

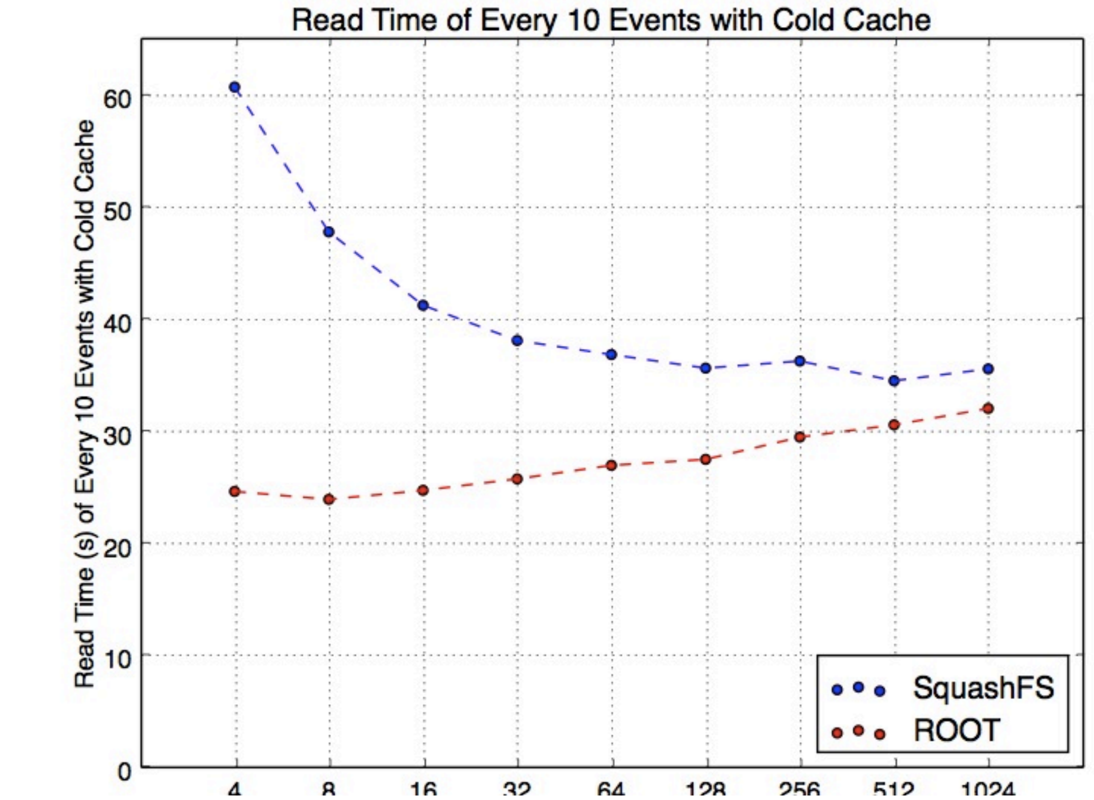
- LZMA has the best compression ratio.
- LZ4 is worst
- LZ4-HC sits between Zlib-1 and Zlib-6 (Default by ROOT)

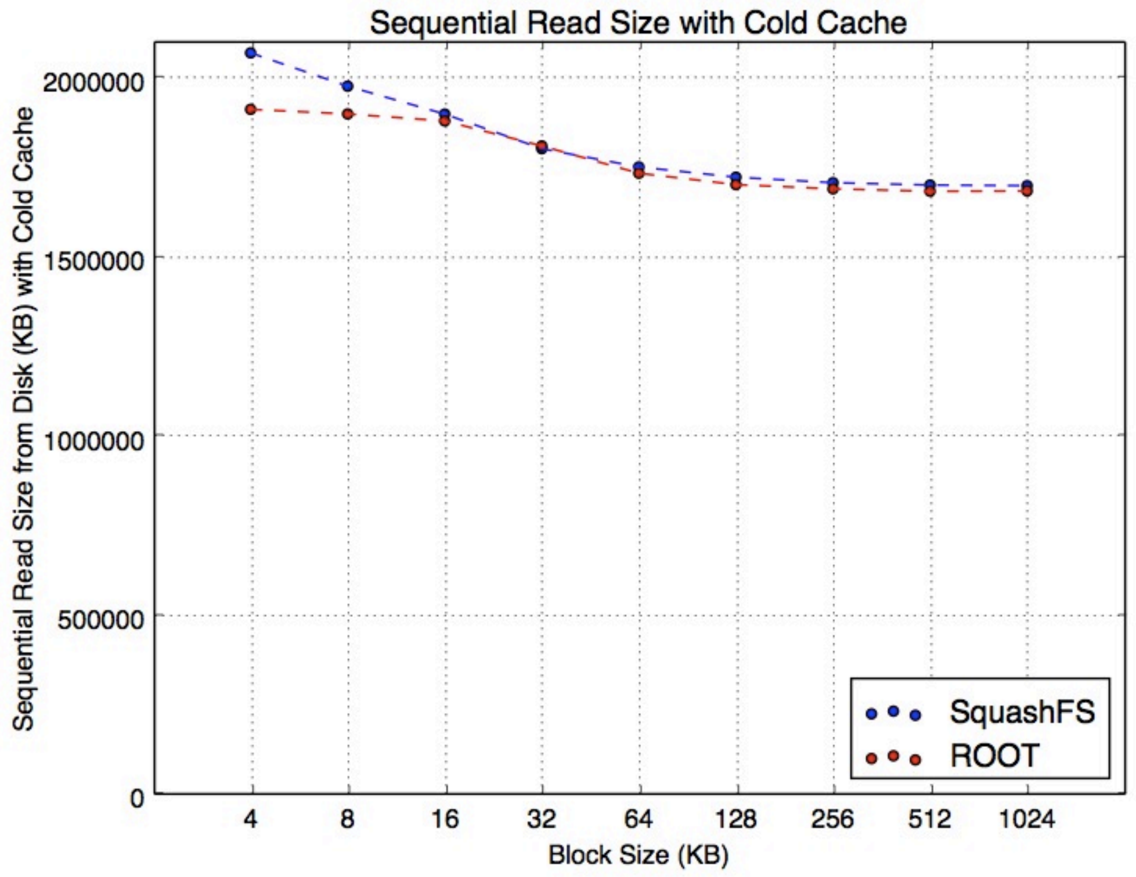
Nebraska
UNIVERSITY OF
Lincoln

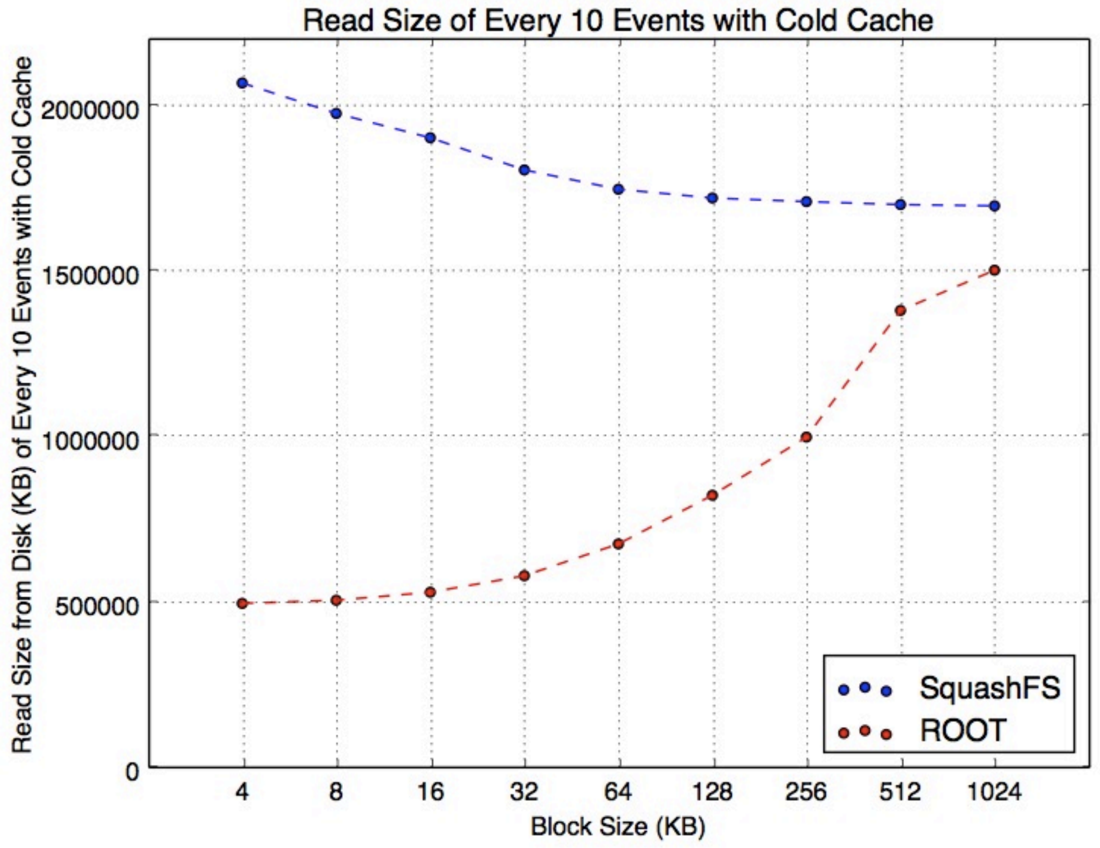
Appendix

Cold Cache:
Read all events sequentially
&
Read every 10^{th} events









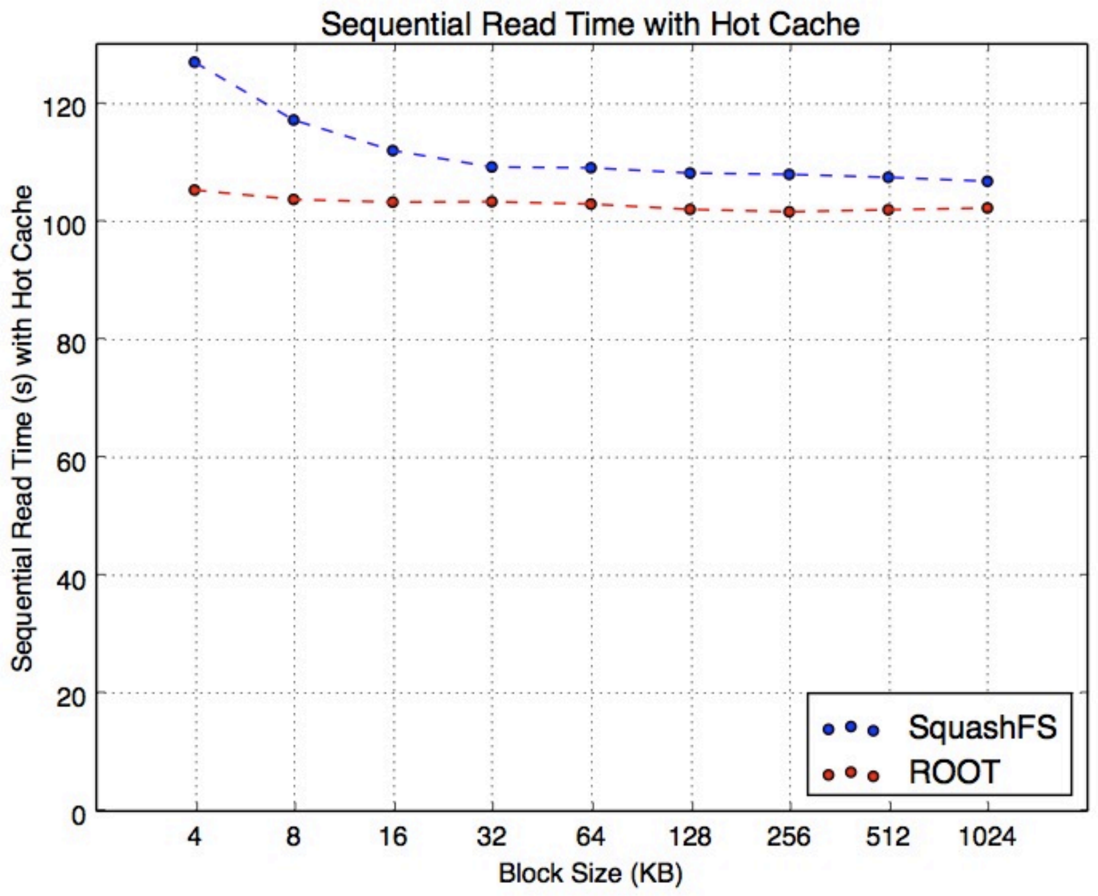
Appendix

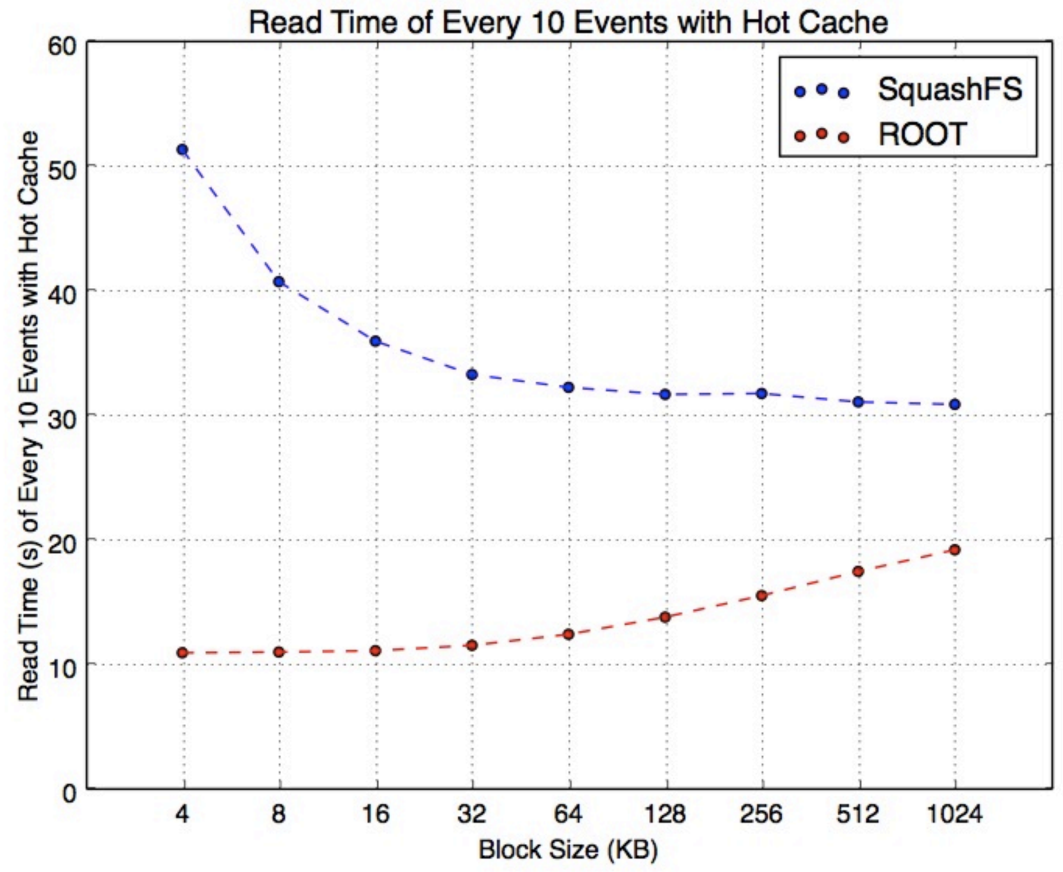
Hot Cache:

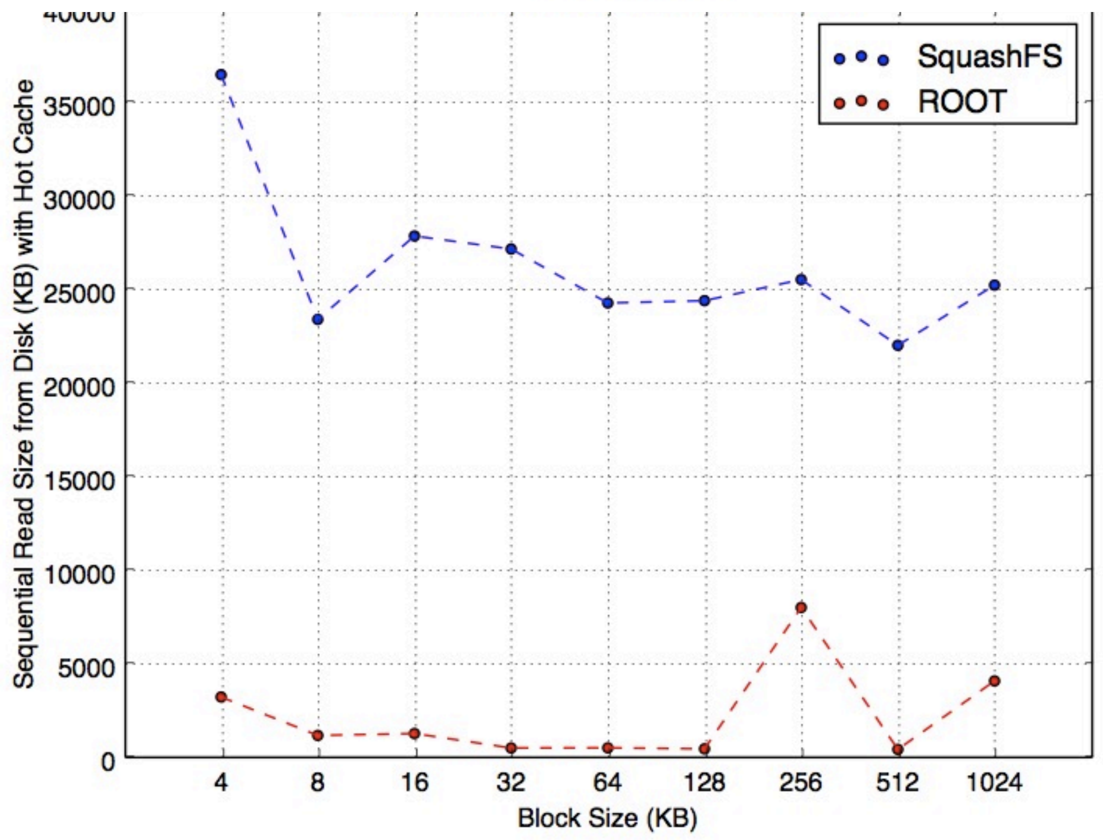
Read all events sequentially

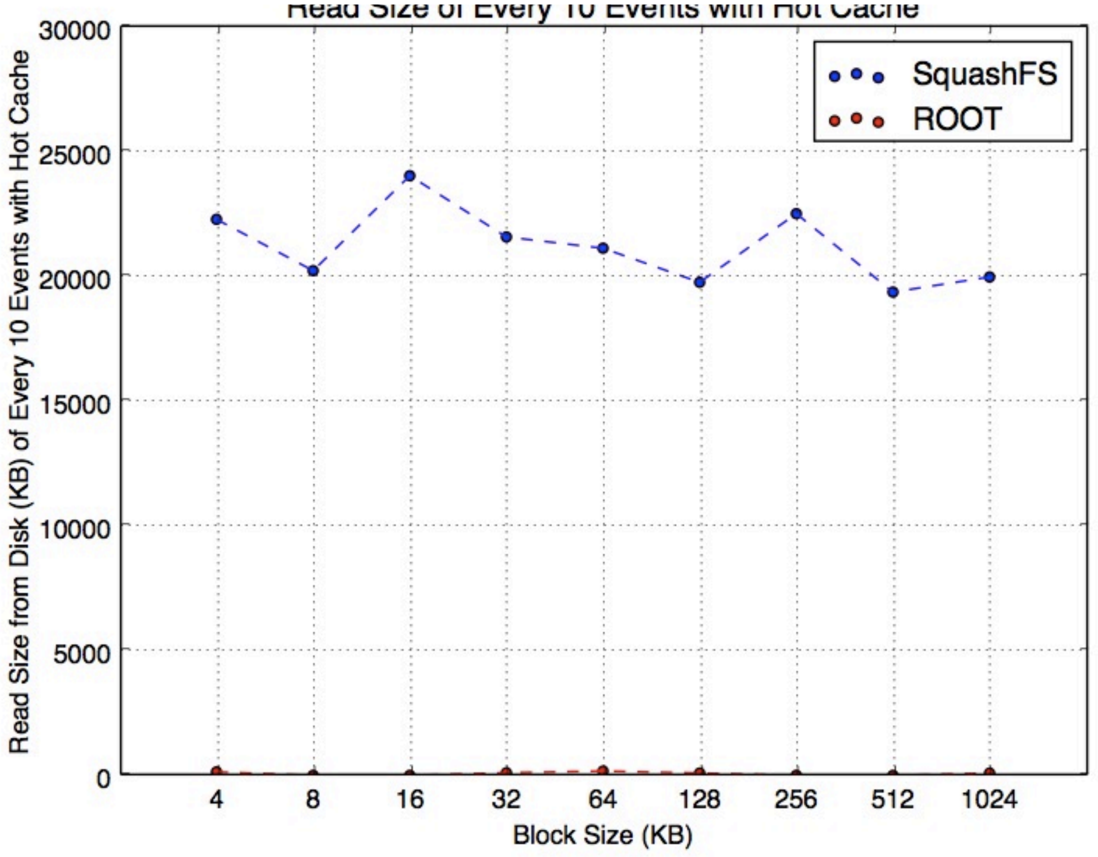
&

Read every 10th events



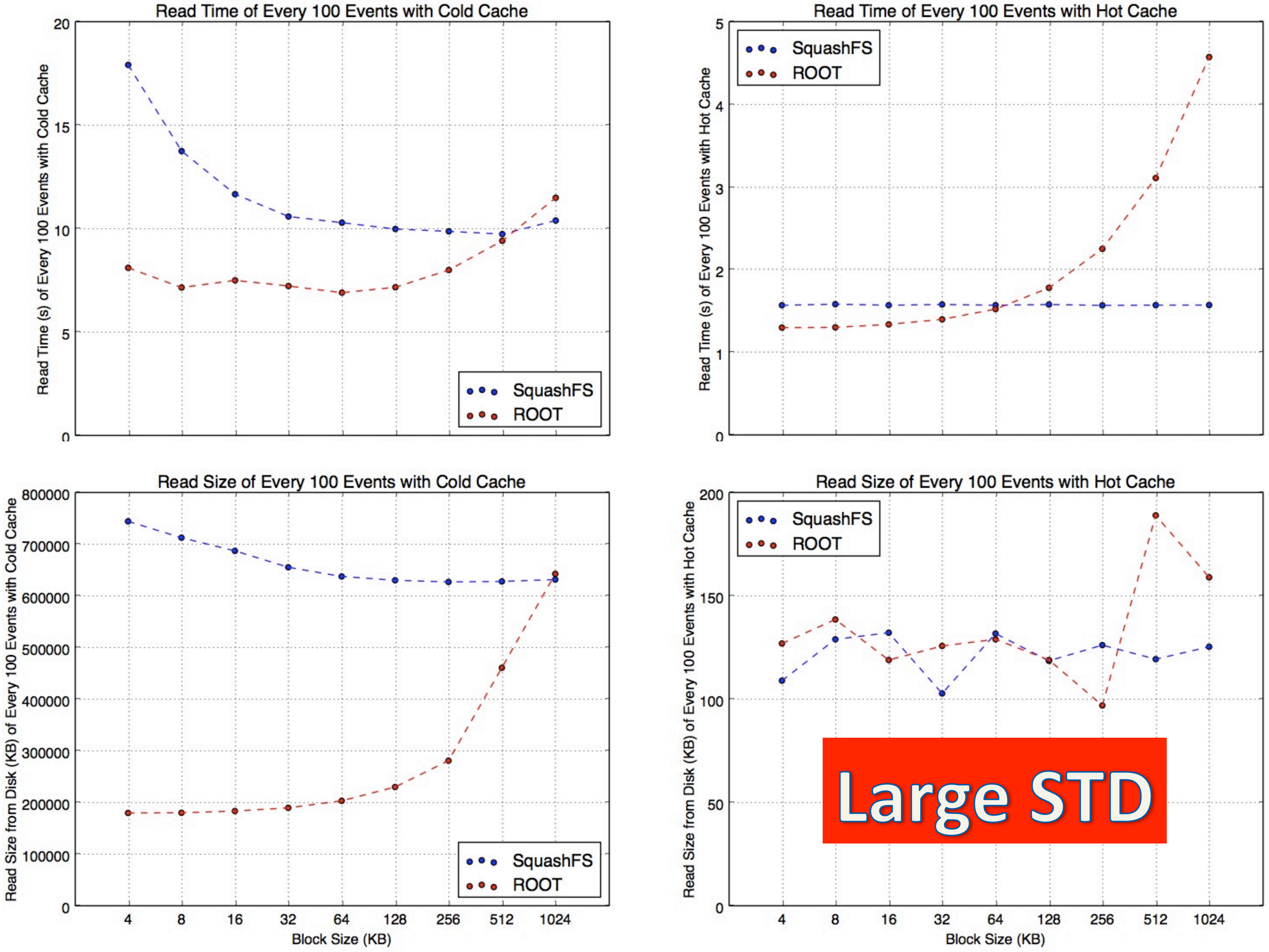






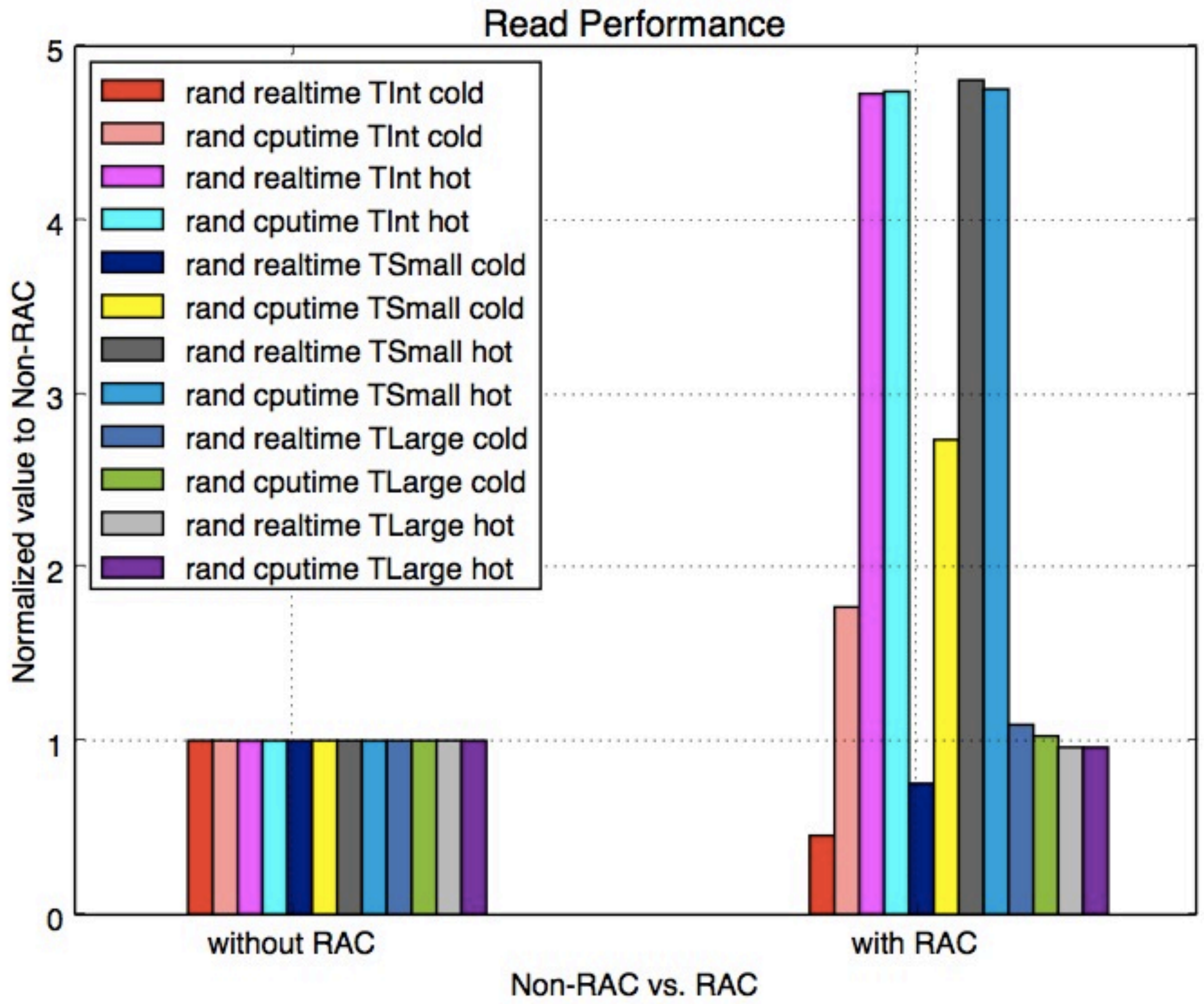
Appendix

Read every 100th events with cold/hot caches



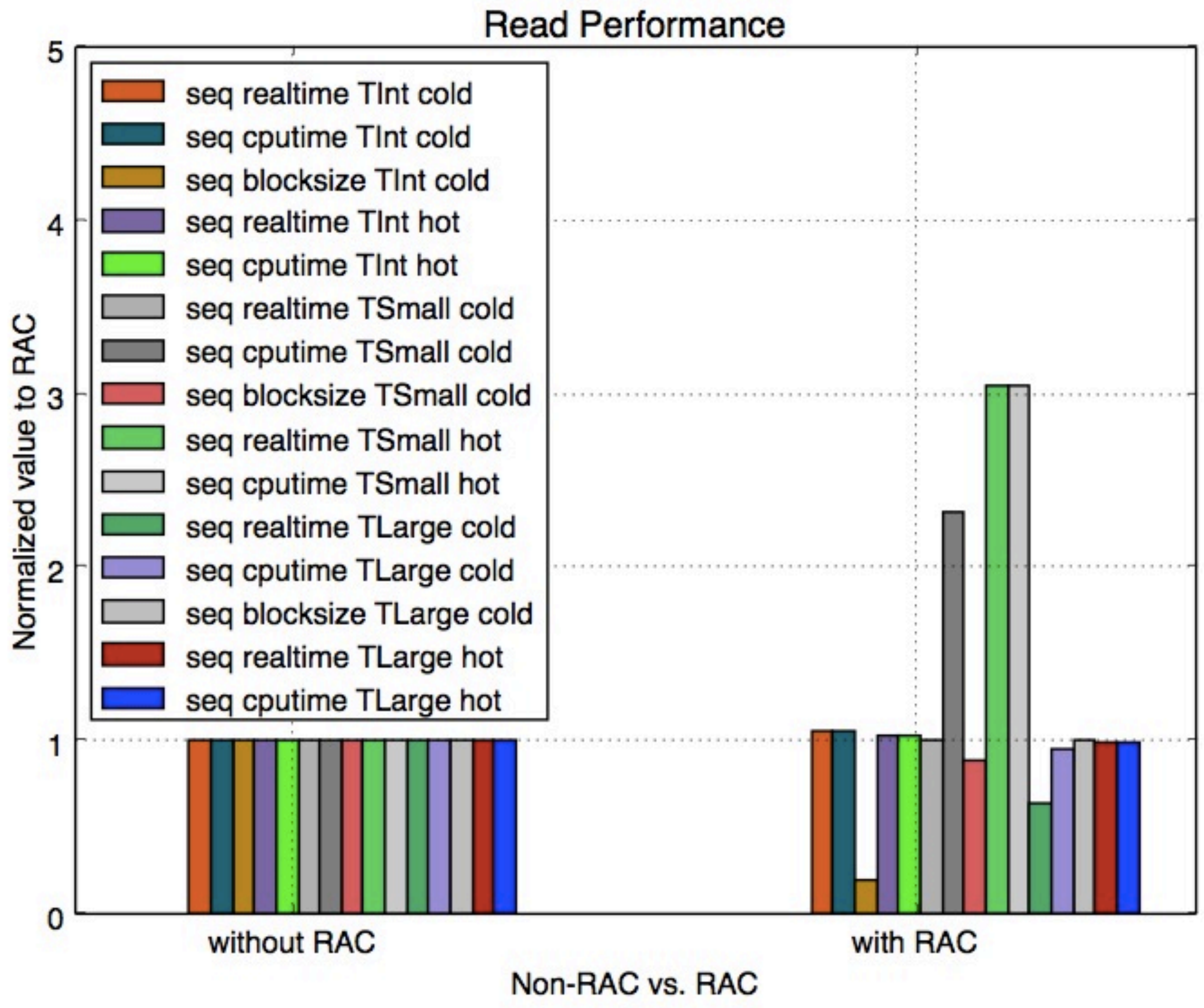
Appendix

RAC Random Read performance



Appendix

RAC Sequential Read performance



Appendix

Comprehensive RAC Read performance