ROOT Compression with ZSTD

GSoC project “Novel Applications of Zstandard (ZSTD) compression algorithm to ROOT”

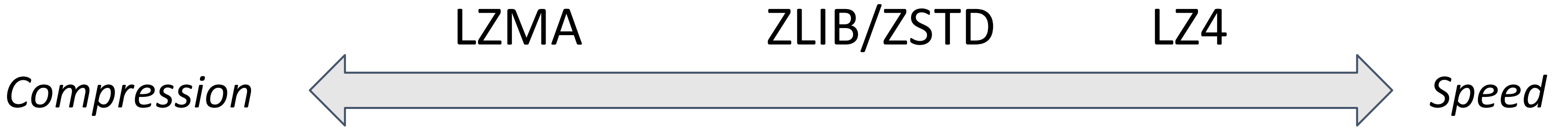
Alfonso Luis Castaño Marín, Universidad de Murcia, Spain

Mentors: Brian Bockelman, Oksana Shadura

ROOT

Due to the huge amount of data processed at CERN, compression is fundamental.

Depending on the case we will care more about compression or speed.



LZMA ZLIB/ZSTD LZ4

Compression *Speed*

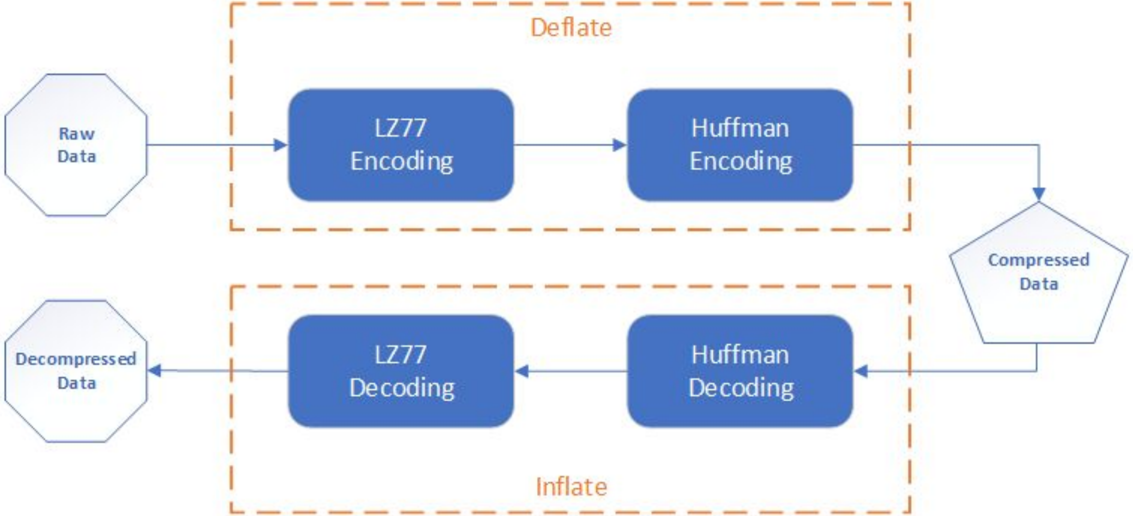
ZSTD

Promising alternative for cases where a balance between compression and speed is required. https://github.com/facebook/zstd

What ZSTD promises:

- Better than ZLIB in all metrics: compression speed, decompression speed, and compression ratio.
- Decompression speed should be constant regardless of compression level.
- High dynamic range in tradeoff between compression speed and ratio.
- Does not achieve compression ratio of LZMA, neither speed of LZ4.

ZLIB: LZ77 + Huffman Encoding



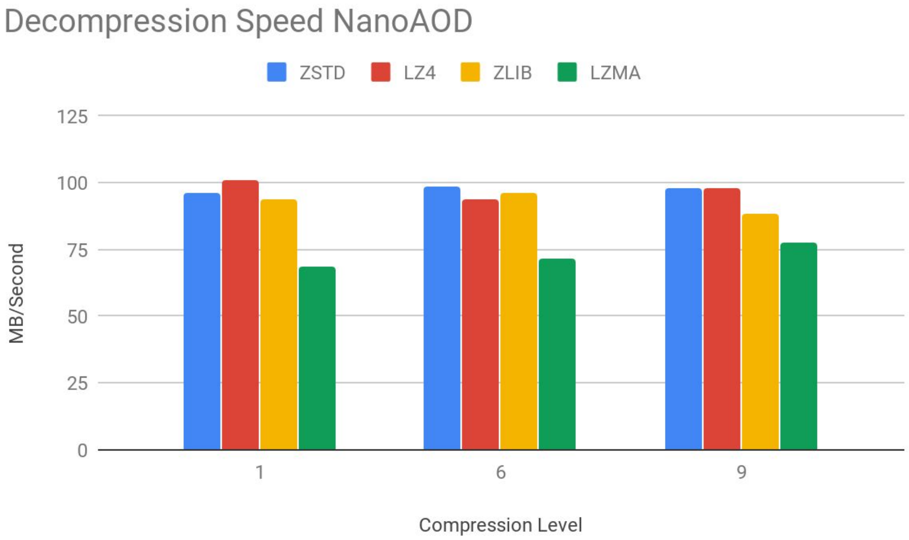
ZSTD

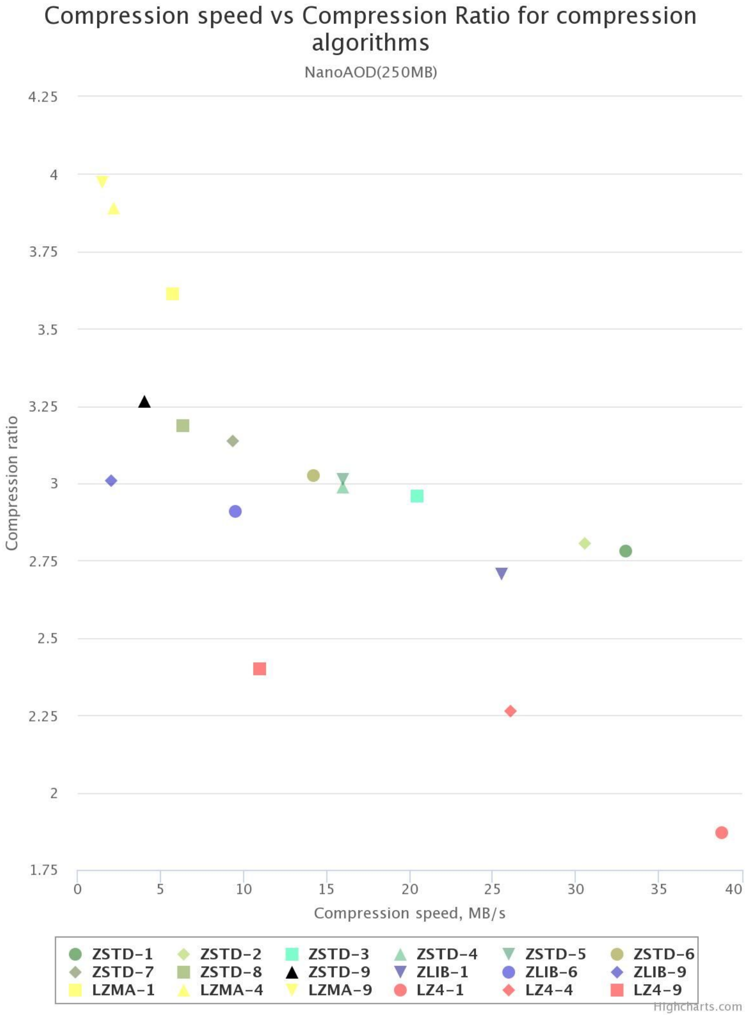
ZSTD follows the idea of ZLIB but introduces new techniques and improvements:

- Finite State Entropy (Arithmetic encoding)
- Dictionary Training
- Bigger Window Size
- Branchless design style
- Parallel decoding in single core
- And many more

Results: CMS

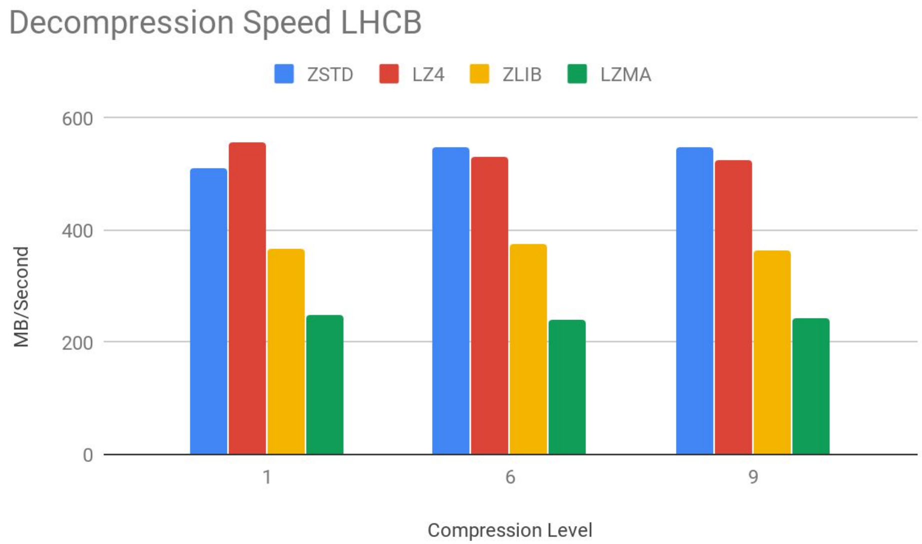
File from 2017, probably different schema than current NanoAOD, currently testing in newer file (3GB).

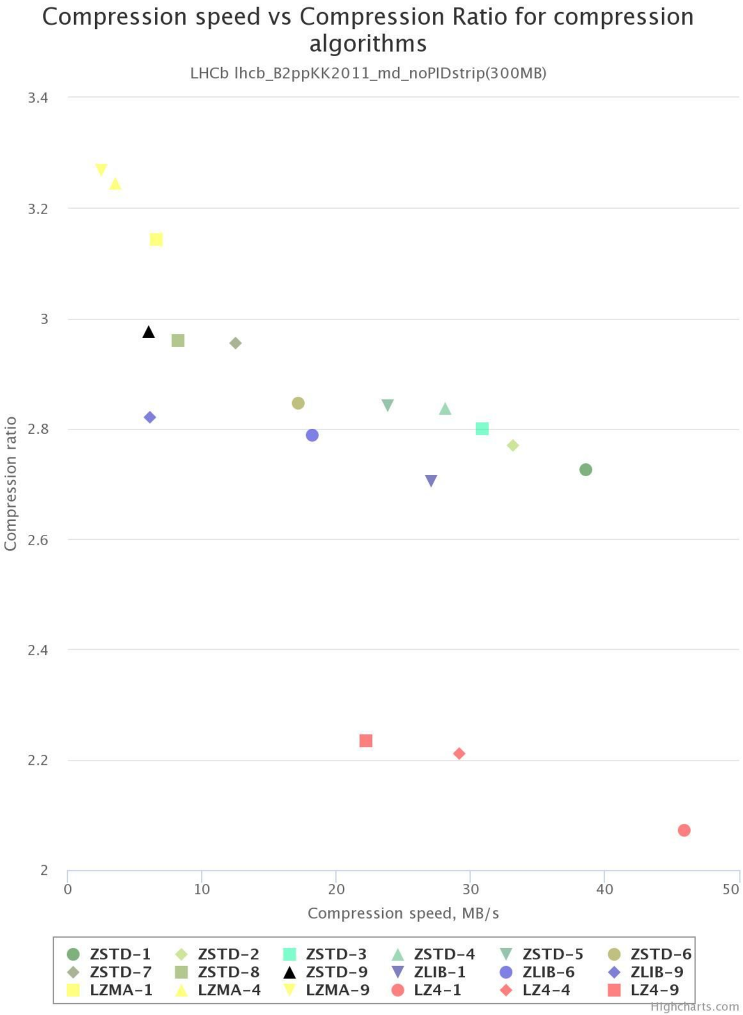




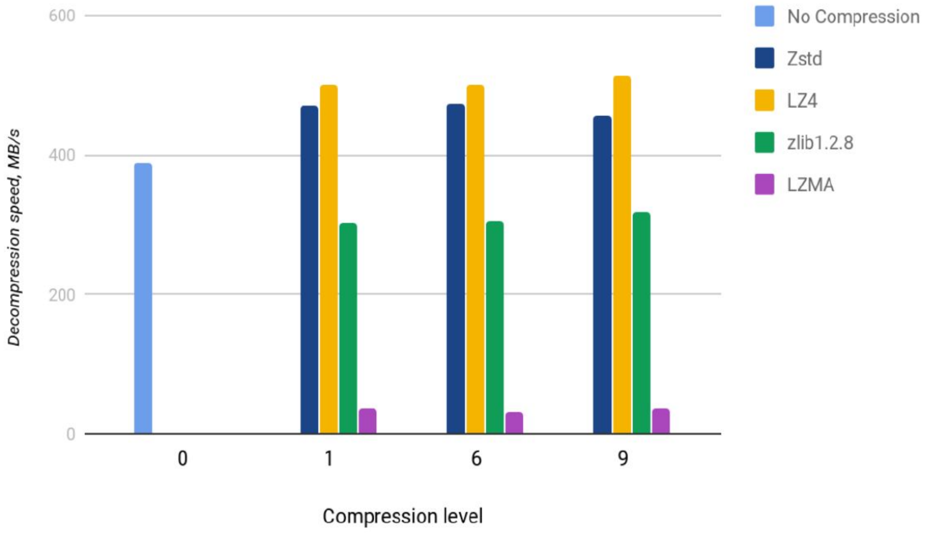
Results: LHCB

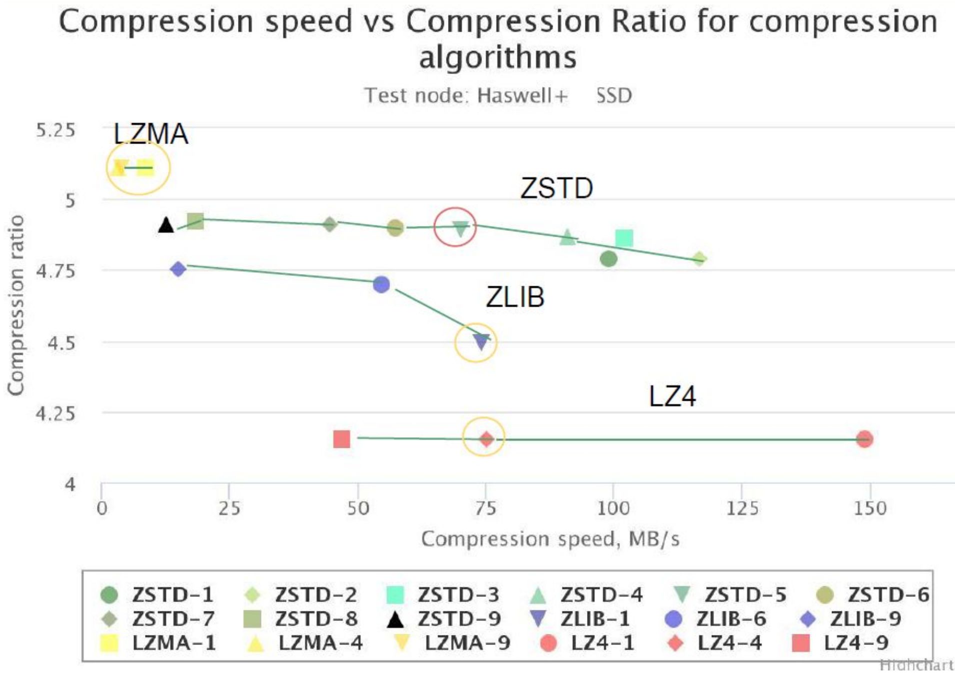
Uncommon branch distribution, several trees with few baskets.





Results: 2000Events





Current status of ZSTD: Ready to merge

PR 3947: Integrate ZSTD in ROOT github.com/root-project/root/pull/3947/

PR 352 : Integrate ZSTD in Roottest github.com/root-project/roottest/pull/352

ZSTD: Advanced Compression

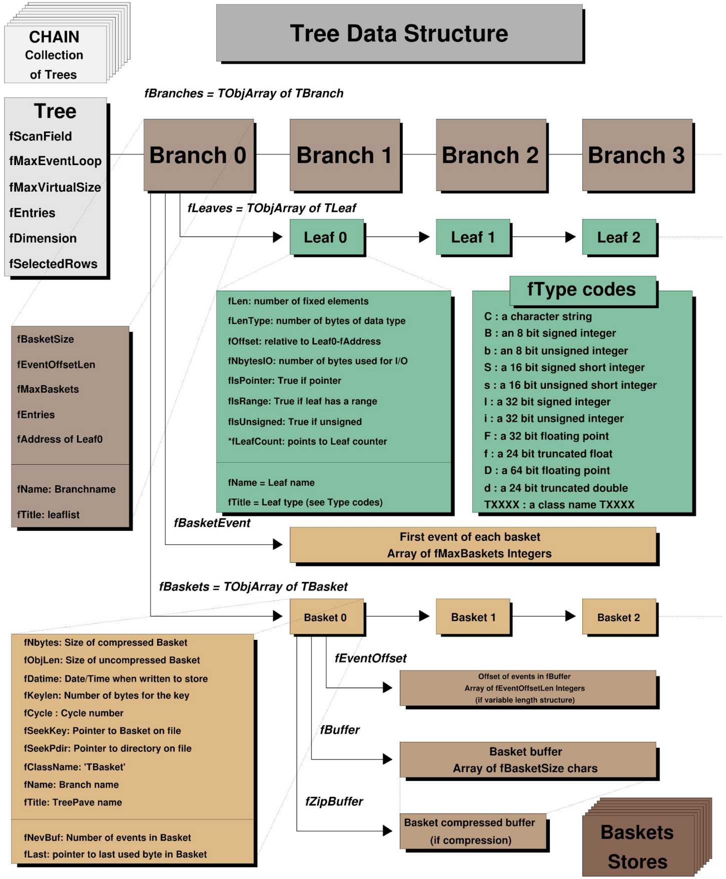
- The advanced API of ZSTD allows to develop novel optimized solutions that have never been tried before: Compression Engine and Dictionaries Reusing.

- A Compression Engine is a class that will process all compressions requests. This centralization provides multiple benefits like reusing resources, one-time initializations and find synergies between compressed chunks.

- The dictionaries that are generated for a given data can be reused for similar data, reducing significantly the overhead of the dictionary size.

A little of background

- ROOT files have mostly Trees and Tuples.
- Inside them we have branches.
- A branch usually stores values of the same variable.
- A branch is divided in memory buffers called baskets.
- Each basket is compressed separately!



CHAIN
Collection
of Trees

Tree Data Structure

Tree
fScanField
fMaxEventLoop
fMaxVirtualSize
fEntries
fDimension
fSelectedRows

fBranches = TObjArray of TBranch

Branch 0
Branch 1
Branch 2
Branch 3

fLeaves = TObjArray of TLeaf

Leaf 0
Leaf 1
Leaf 2

fBasketSize
fEventOffsetLen
fMaxBaskets
fEntries
fAddress of Leaf0

fName: Branchname
fTitle: leaflist

fLen: number of fixed elements
fLenType: number of bytes of data type
fOffset: relative to Leaf0-fAddress
fNbytesIO: number of bytes used for I/O
fIsPointer: True if pointer
fIsRange: True if leaf has a range
fIsUnsigned: True if unsigned
*fLeafCount: points to Leaf counter

fName = Leaf name
fTitle = Leaf type (see Type codes)

fType codes
C : a character string
B : an 8 bit signed integer
b : an 8 bit unsigned integer
S : a 16 bit signed short integer
s : a 16 bit unsigned short integer
I : a 32 bit signed integer
i : a 32 bit unsigned integer
F : a 32 bit floating point
f : a 24 bit truncated float
D : a 64 bit floating point
d : a 24 bit truncated double
TXXXX : a class name TXXXX

fBasketEvent

First event of each basket
Array of fMaxBaskets Integers

fBaskets = TObjArray of TBasket

Basket 0
Basket 1
Basket 2

fNbytes: Size of compressed Basket
fObjLen: Size of uncompressed Basket
fDatime: Date/Time when written to store
fKeylen: Number of bytes for the key
fCycle : Cycle number
fSeekKey: Pointer to Basket on file
fSeekPdir: Pointer to directory on file
fClassName: 'TBasket'
fName: Branch name
fTitle: TreePave name

fNevBuf: Number of events in Basket
fLast: pointer to last used byte in Basket

fEventOffset

Offset of events in fBuffer
Array of fEventOffsetLen Integers
(if variable length structure)

fBuffer

Basket buffer
Array of fBasketSize chars

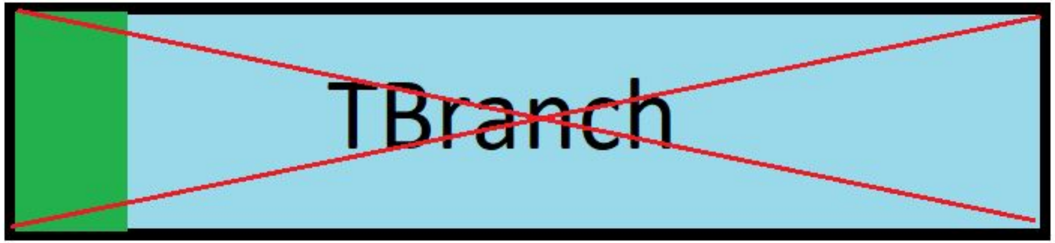
fZipBuffer

Basket compressed buffer
(if compression)

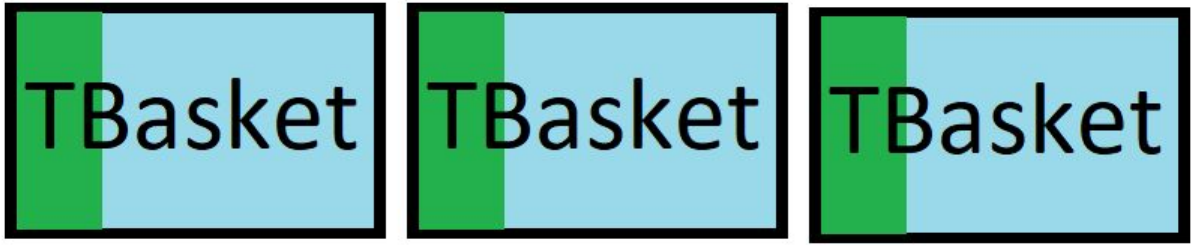
Baskets
Stores

Branch compression

Instead of this:



We have this:



Synergic compression

Since baskets within a branch hold similar data, using a common dictionary could be very efficient.

The creation of the dictionary can follow two different approaches: Dictionary Training or Dictionary Reutilization

Dictionary Reutilization seems to offer the highest potential and flexibility for ROOT.

Trade-offs of Dictionary Reutilization

- **Reduce overhead of storing the Dictionary:** The amount of dictionaries that should be stored will drop from N (baskets) to 1. The improvement in the file size reduction will be determined by this.

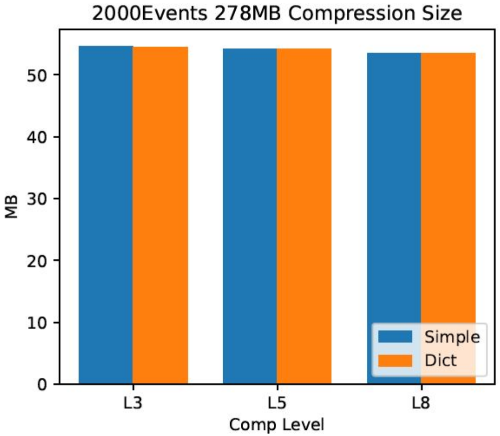
- **Improve compression speed:** Dictionary will be generated only once, it could speed up the process.

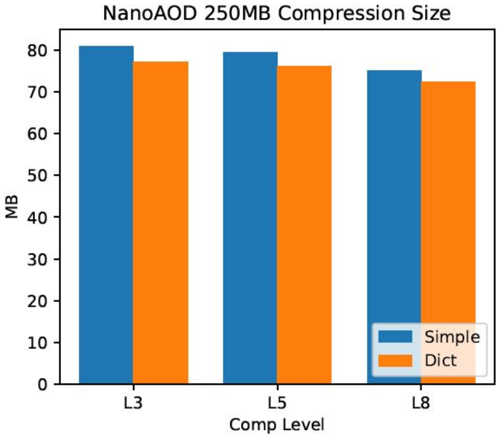
- **Worse compression ratio if first basket is not representative:** We don’t have any more customized dictionaries per basket.

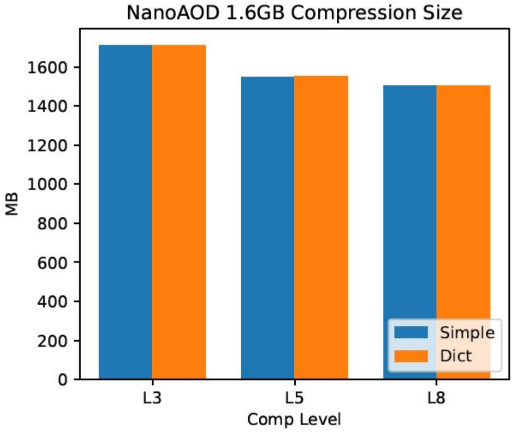
Results

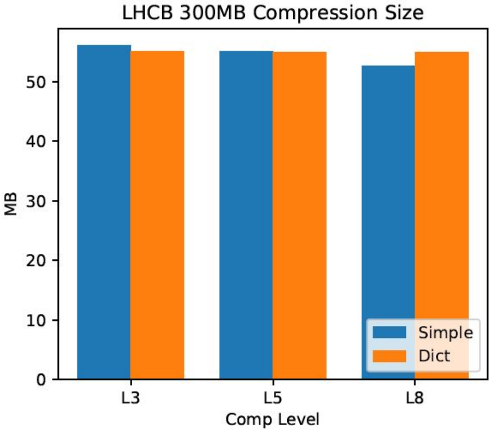
- Same or slightly better compression ratios thanks to reduction of dictionary overhead.

- Highly dependent on the structure of the Tree.


2000Events 278MB Compression Size


NanoAOD 250MB Compression Size

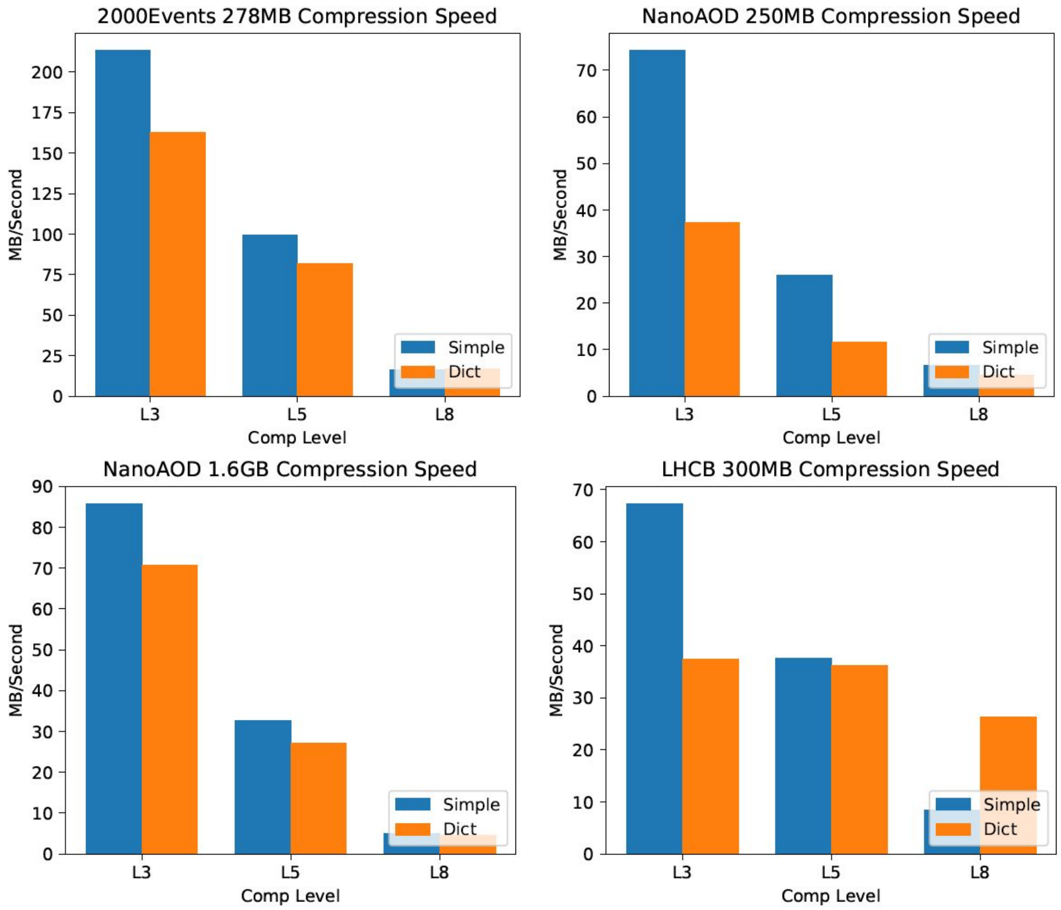

NanoAOD 1.6GB Compression Size


LHCB 300MB Compression Size

Results

- Regression in compression speed in some scenarios.

- Requires further investigation, there should be potential to improve speed over baseline.



2000Events 278MB Compression Speed

NanoAOD 250MB Compression Speed

NanoAOD 1.6GB Compression Speed

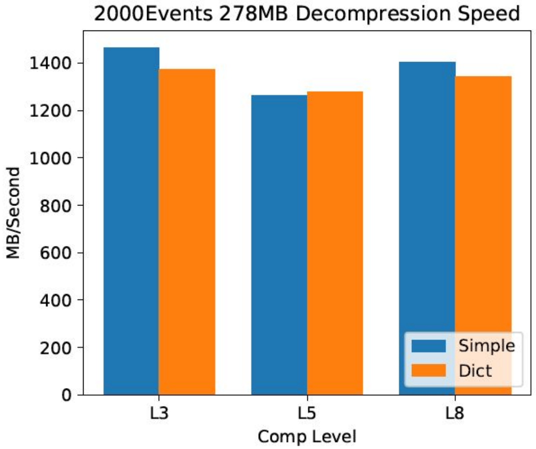
LHCB 300MB Compression Speed

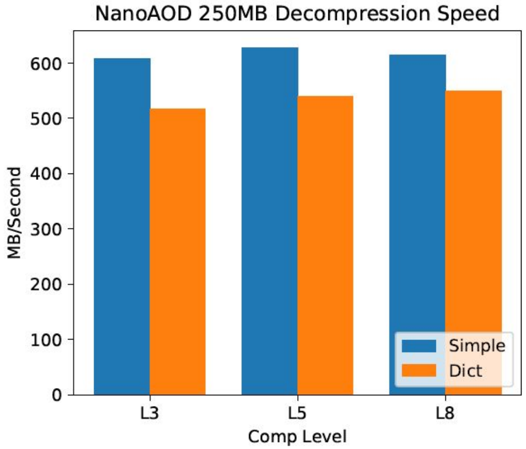
Results

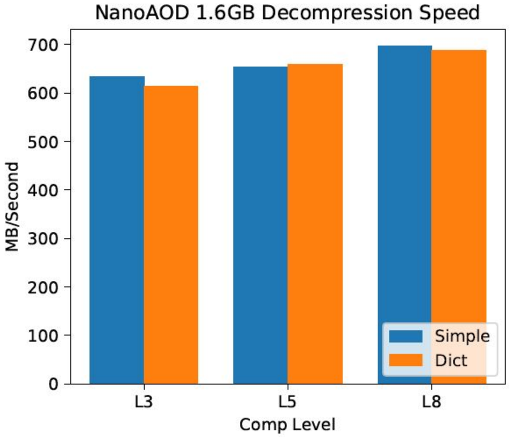
- More uniform results than in compression.

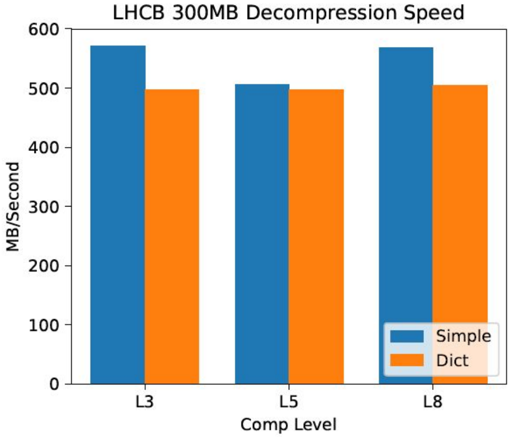
- Decompression speed is mostly determined by file size in ZSTD.

- Hence, limited room for improvement over the baseline without reducing the file size.









Conclusions

ZSTD: Fundamental Compression

- Outperforms in all metrics ROOT’s default compression algorithm.
- Fully tested, integrated in ROOT and ready to merge.
- Still novel algorithm, new improvements will keep appearing.
- Unlocks the use of advanced compression dictionaries across ROOT projects.

ZSTD: Advanced Compression

- Infinite new possibilities to find synergies across data structures.
- Already obtaining compression improvements in certain scenarios.
- Deep investigation in process to understand in detail the structure of the data generated by main CERN experiments.