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Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
FAIR Future Artificial Intelligence Research

Streaming Readout Workshop

SRO-XII

December 2-4, 2024
University of Tokyo, Japan

Real-Time data reduction with Artificial Intelligence for SRO.

Fabio Rossi (presenter), **Marco Battaglieri**
Istituto Nazionale di Fisica Nucleare
Genova (Italy)

Edoardo Ragusa, **Paolo Gastaldo**
SEALab Università di Genova (DITEN)
Genova (Italy)

Gagik Gavalian
Jefferson Lab
Newport News (Virginia)

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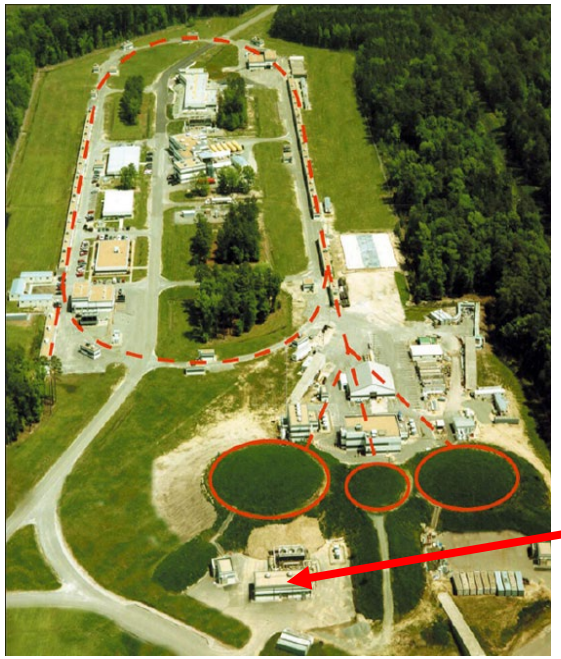
High Energy Physics Experiment: Beam Dump eXperiment (BDX)

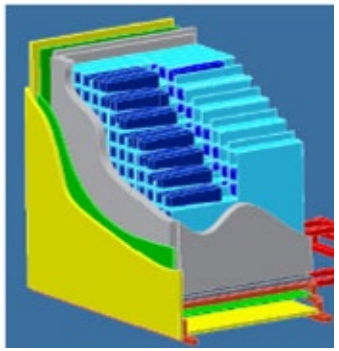
Jefferson Lab

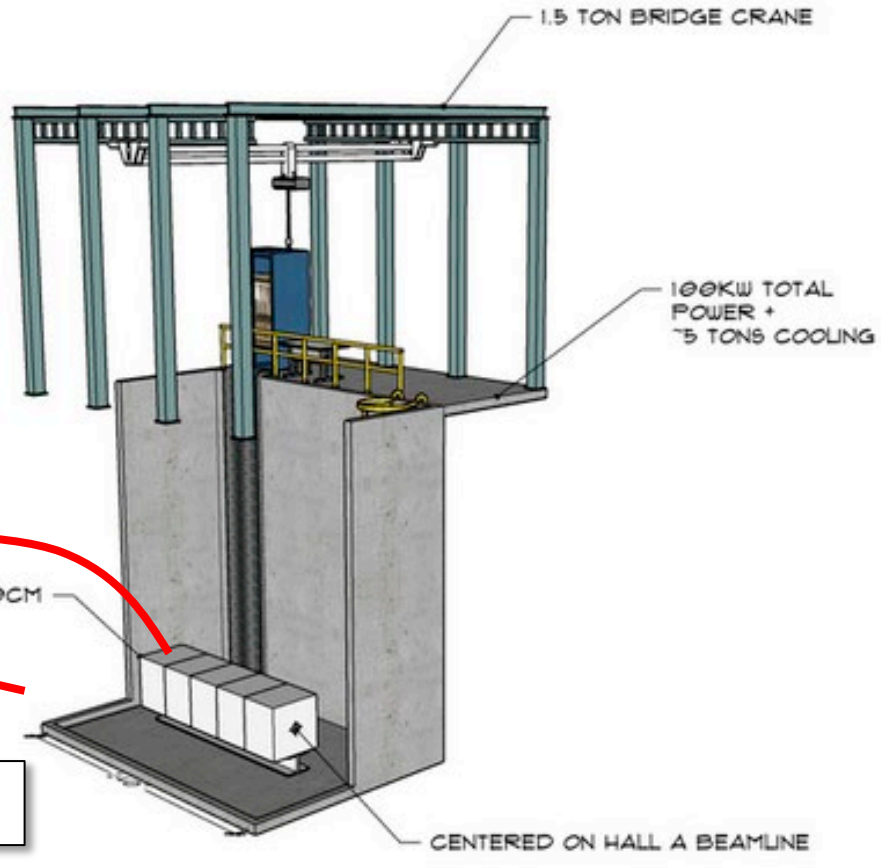


≈1000
Calorimeter channels
(30MB/s)

≈ 300
Veto channels
(500MB/s)

Single module





Very rare occurrence of Dark Matter events

Retrieved from: Battaglieri, M., et al. "Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab." arXiv preprint arXiv:1607.01390 (2016).

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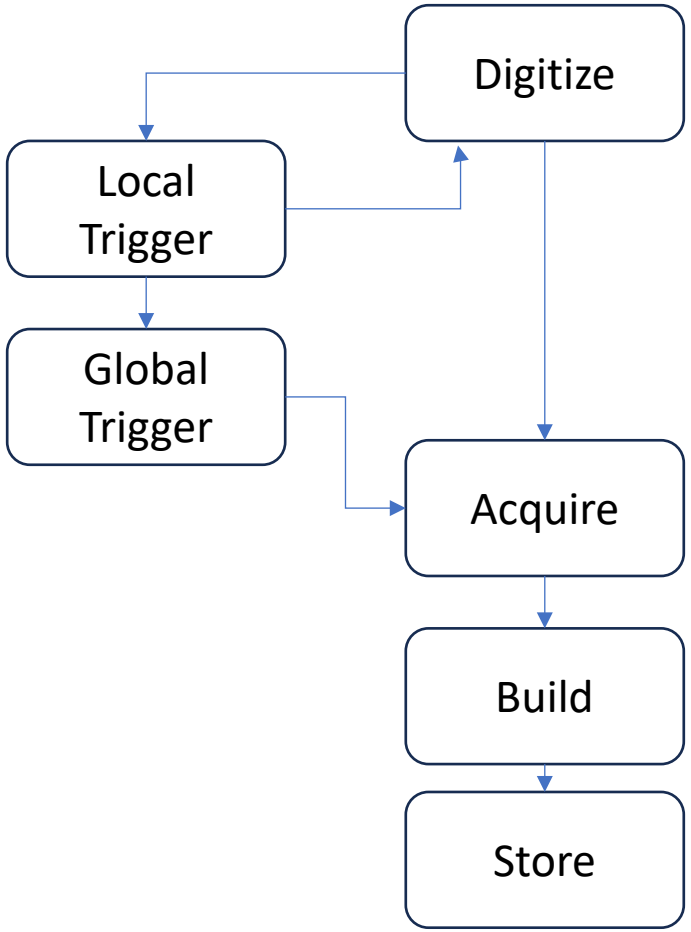
Traditional triggered DAQ VS Streaming Readout



Cons:
Only few information form the trigger.
Trigger logic difficult to implement and debug.
Not easy to adapt to different condition.

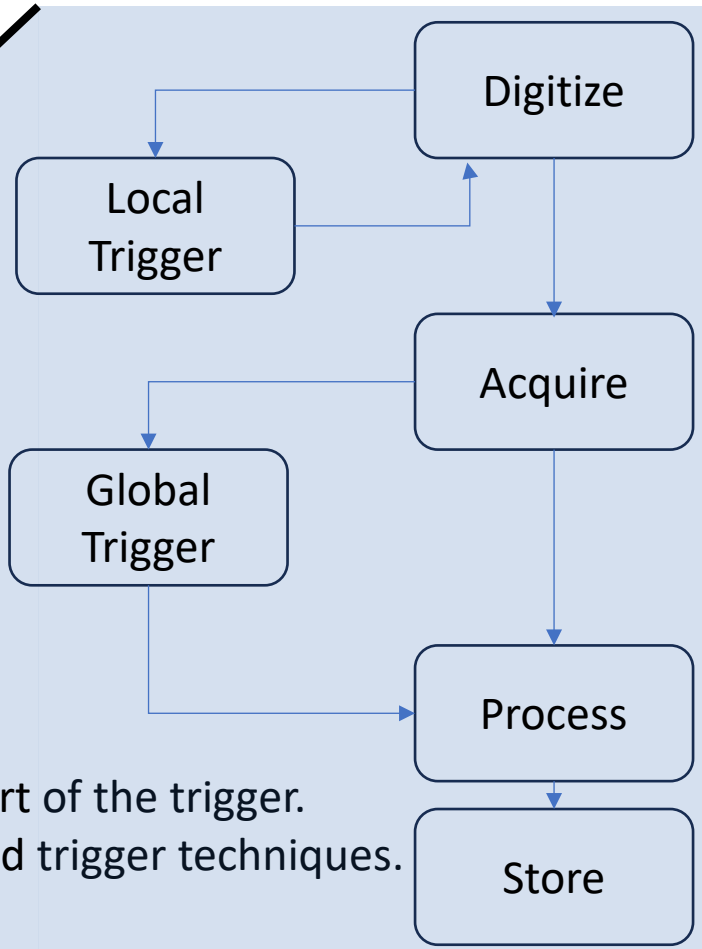
Pros:
It works reliably.

Triggered

Streaming

Cons:
<u>High data rate.</u>
New design.

Pros:
All channels can be part of the trigger.
High level sophisticated trigger techniques.
Software trigger.



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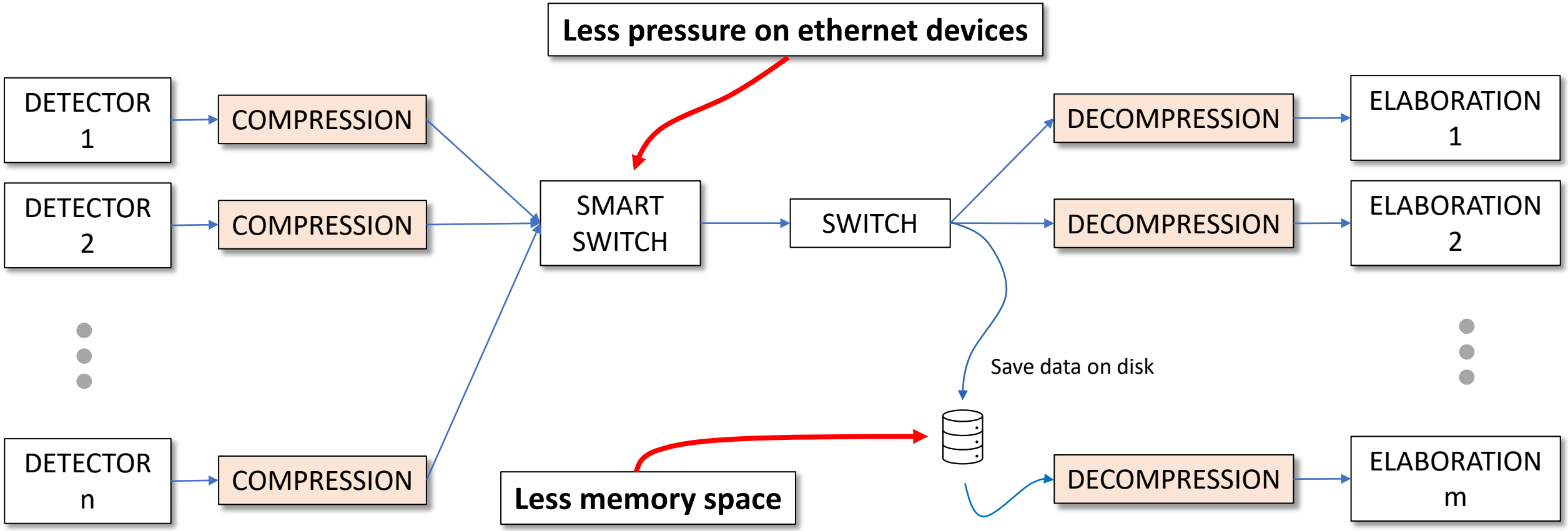
Block scheme of data flow



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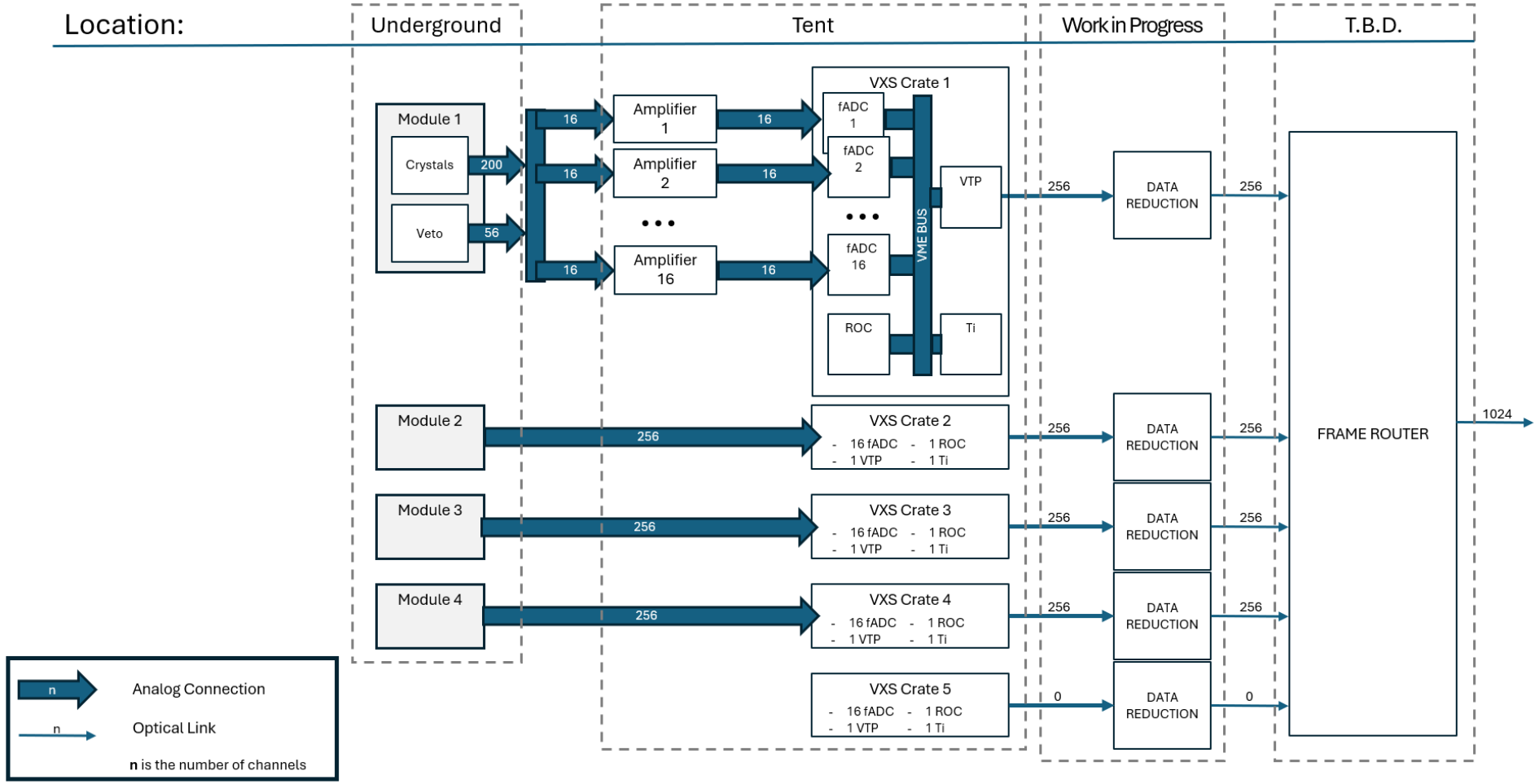
Detailed BDX data flow scheme



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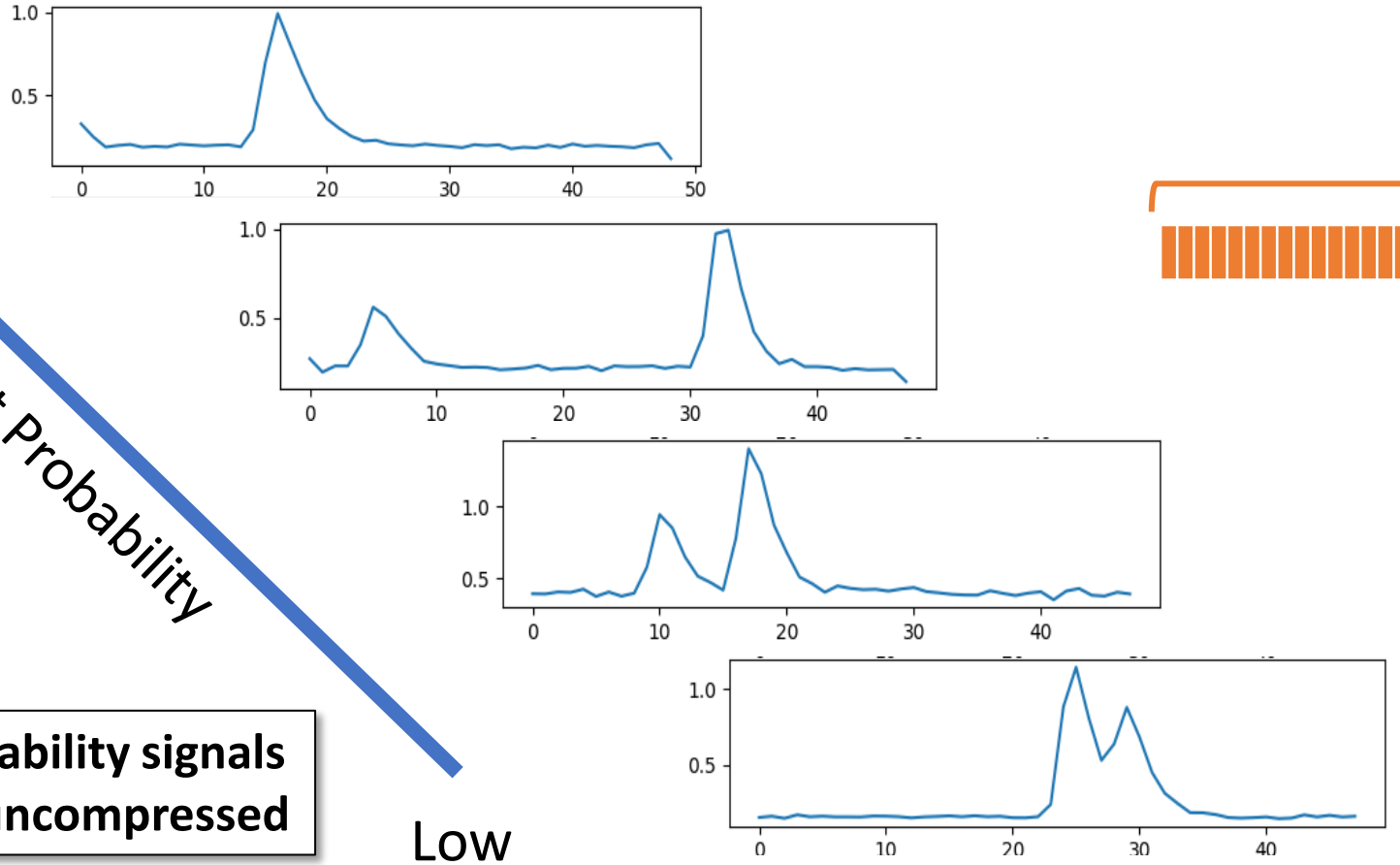
Data from physical Experiment

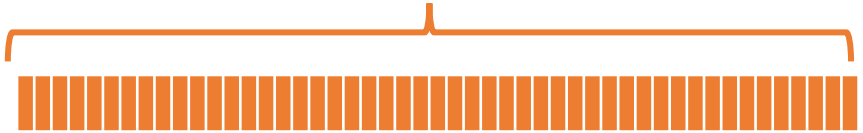
High



Event Probability

Low

48 samples



Very-Low probability signals could be sent uncompressed

Data reduction algorithm: Autoencoder

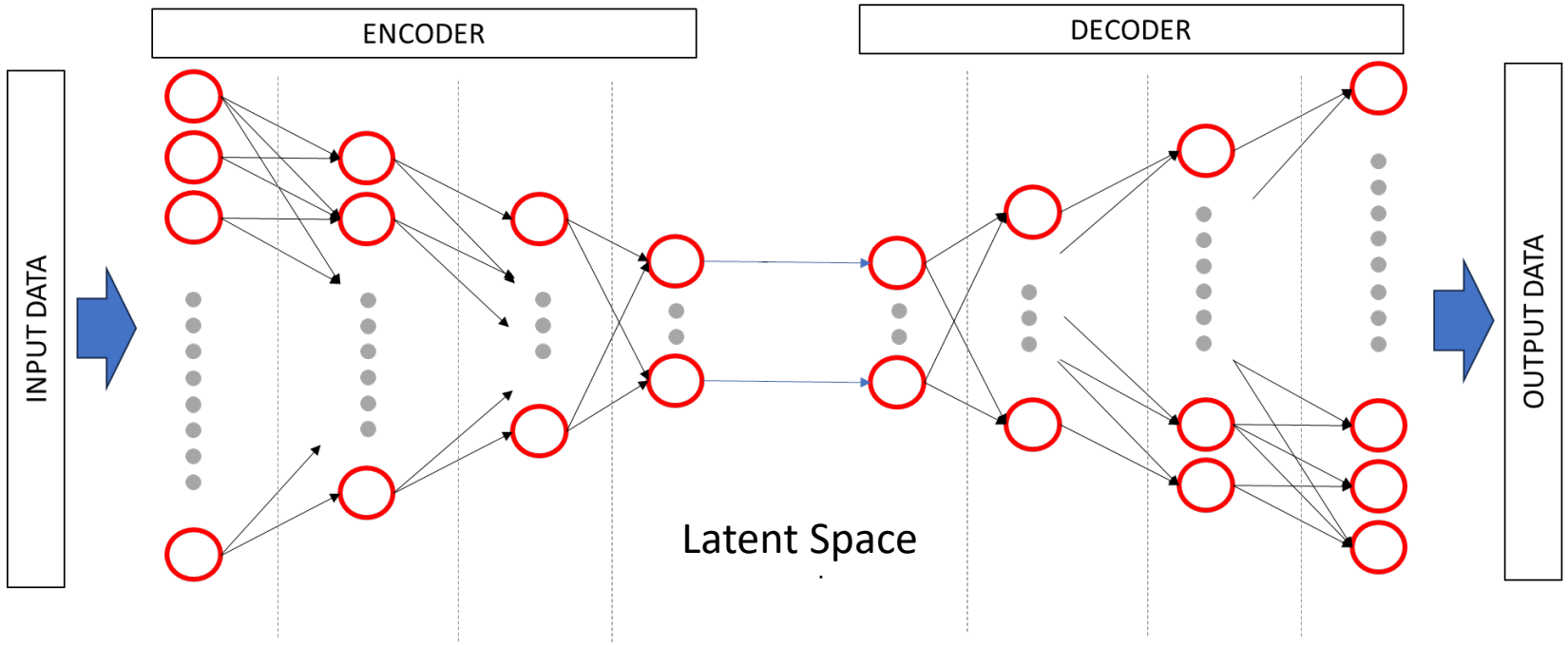
Machine Learning Algorithm

Dimensionality reduction

Unsupervised learning

Artificial Neural Network

Composed of two function:
- encoding
- decoding



FULLY CONNECTED AUTOENCODER WITH DENSE LAYER

Lossy compression algorithm

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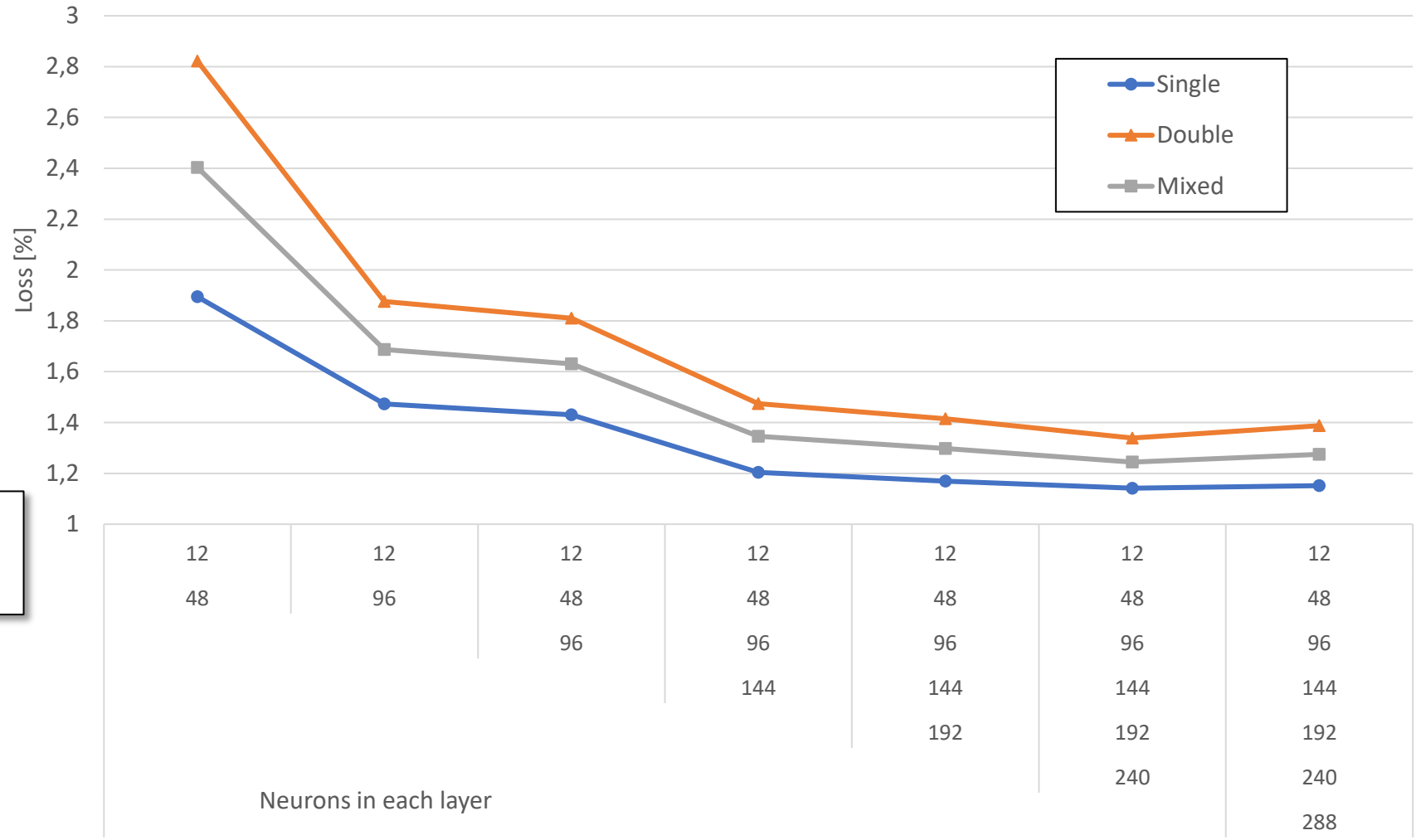
Autoencoder Training: Different configuration

Test increasing:

- Layer number
- Neurons in each layer

Few improvement adding more and more parameters



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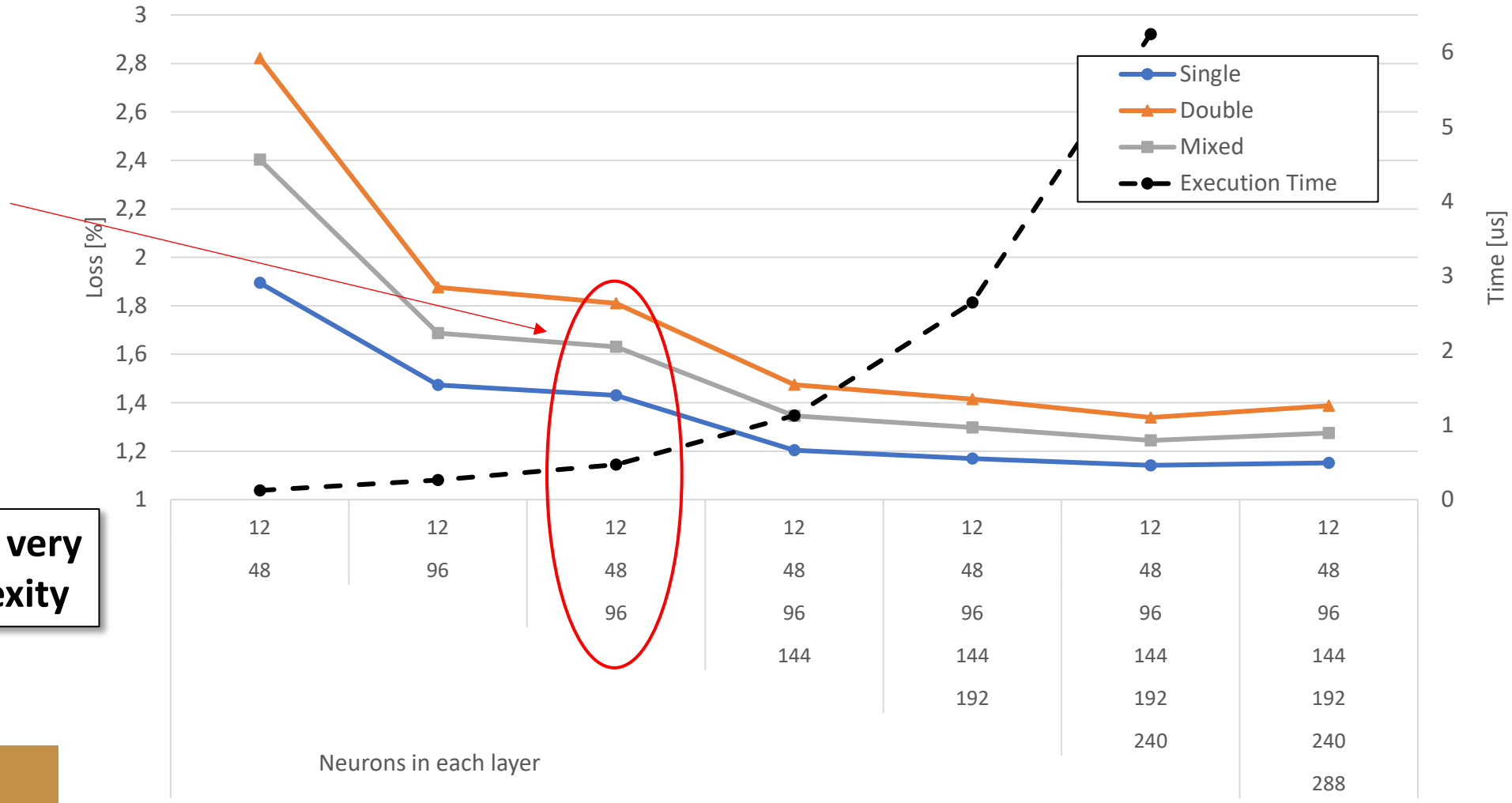
Autoencoder Training: Different configuration

Chosen configuration

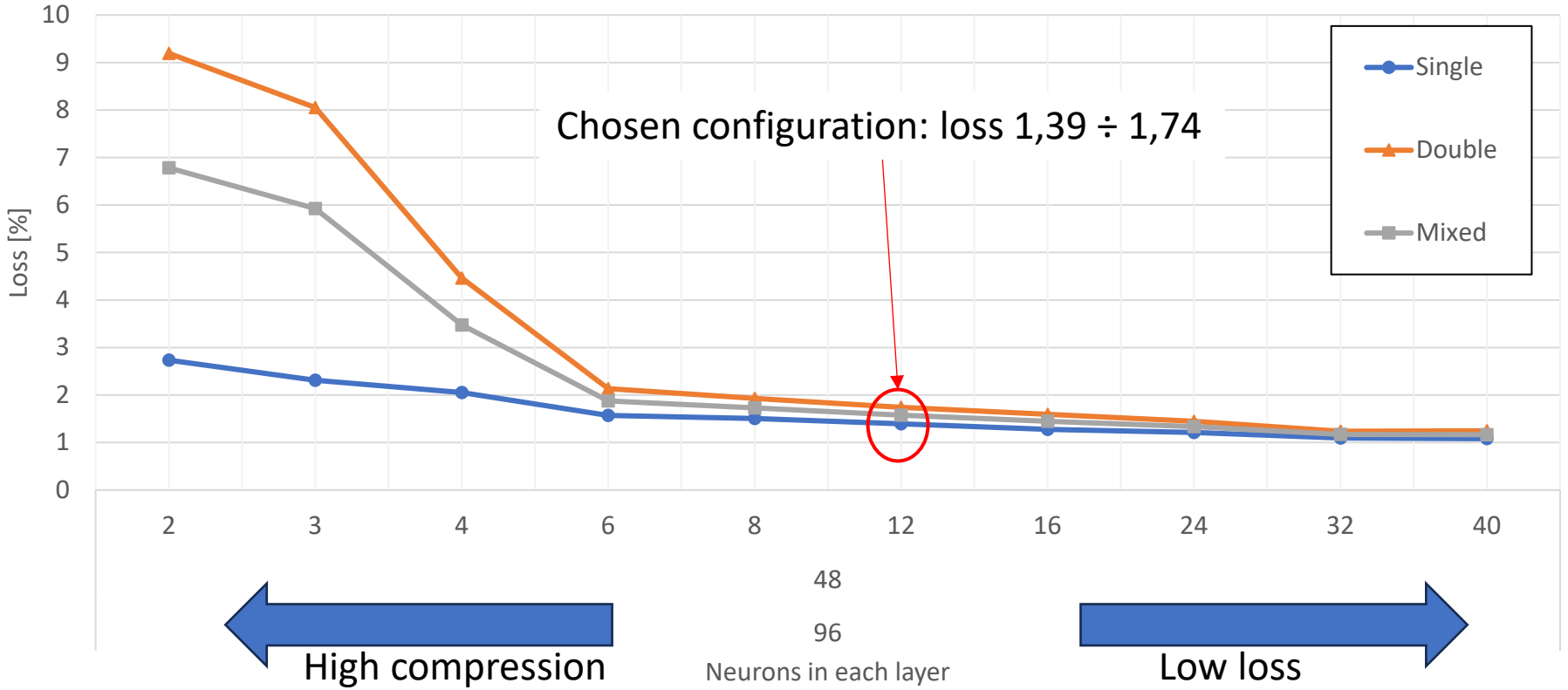
Layers: 3

Neurons:
96
48
12



Execution time increase very fast with model complexity

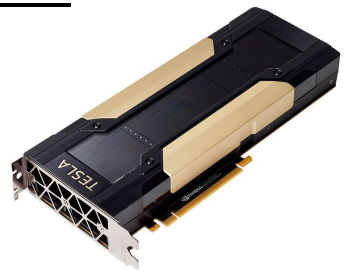
Autoencoder Training: Different latent space



Compression ratio is a parameter and could be chosed as loss tradeoff

Autoencoder: Training time

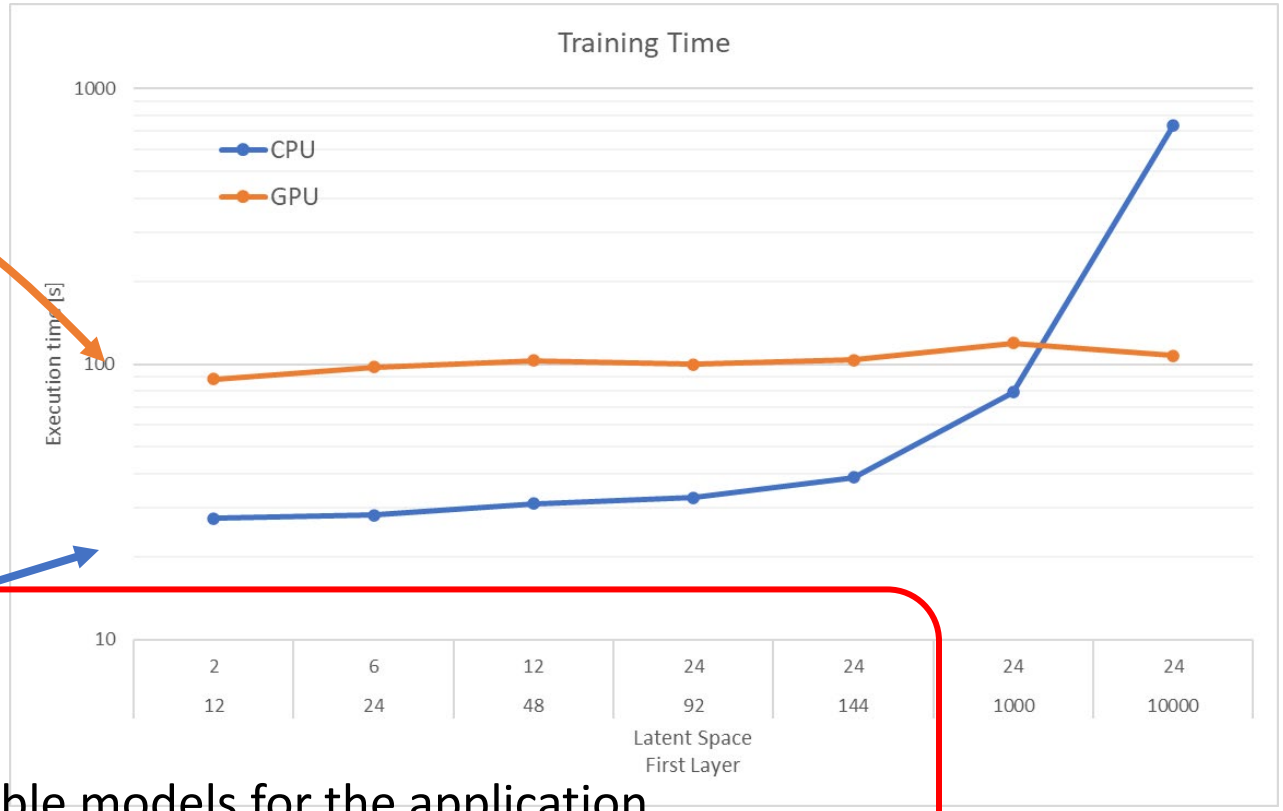
GPU



CPU

AMD Ryzen 5 5600U

6 core, 12 Logic processor



Suitable models for the application

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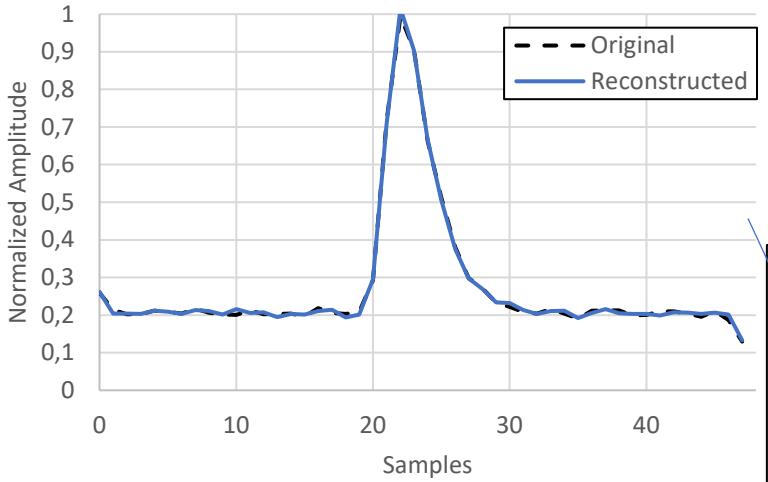
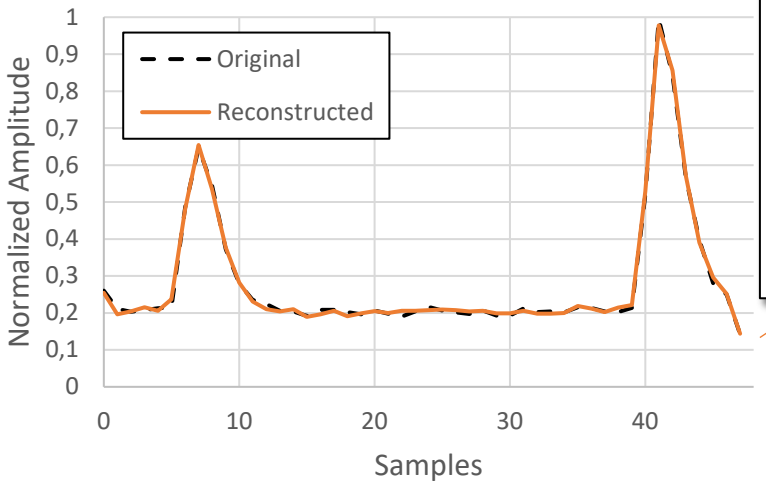
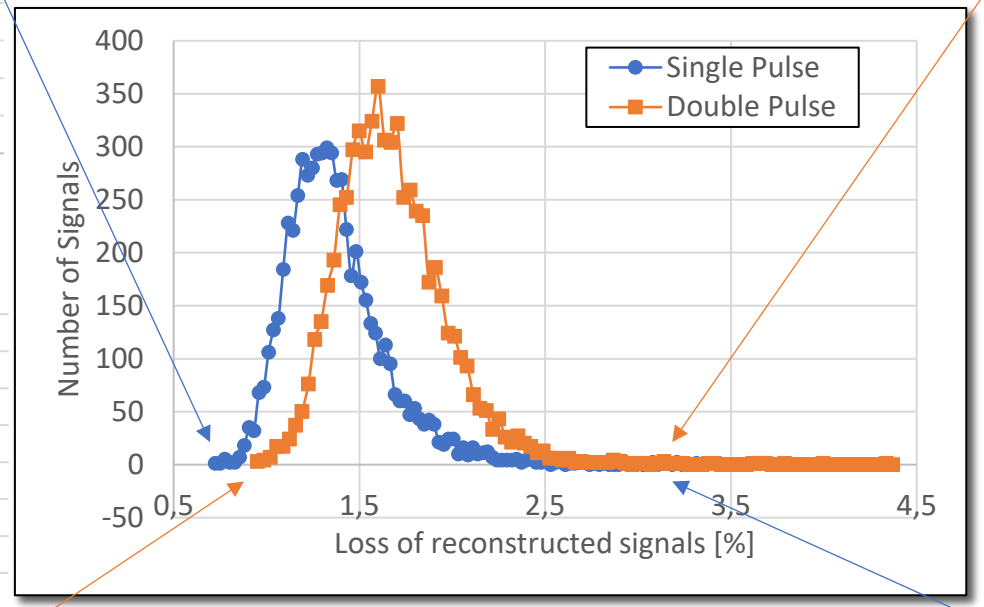
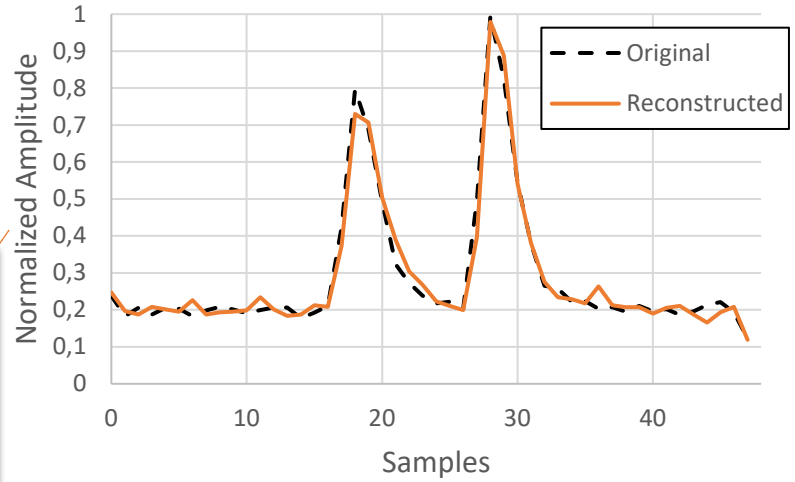
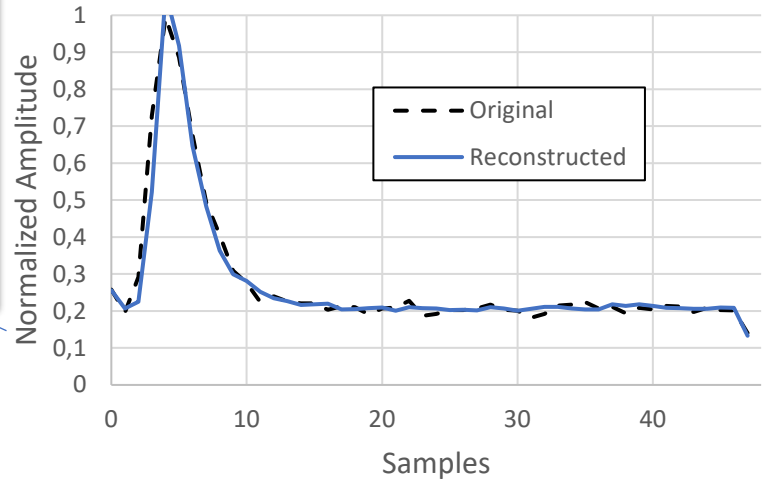
Signals Compression











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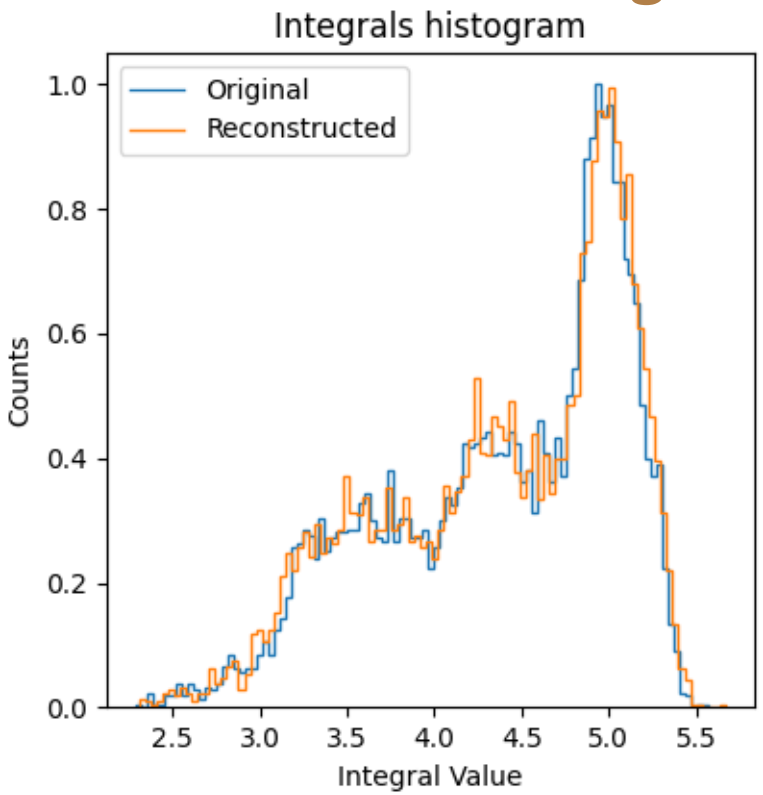
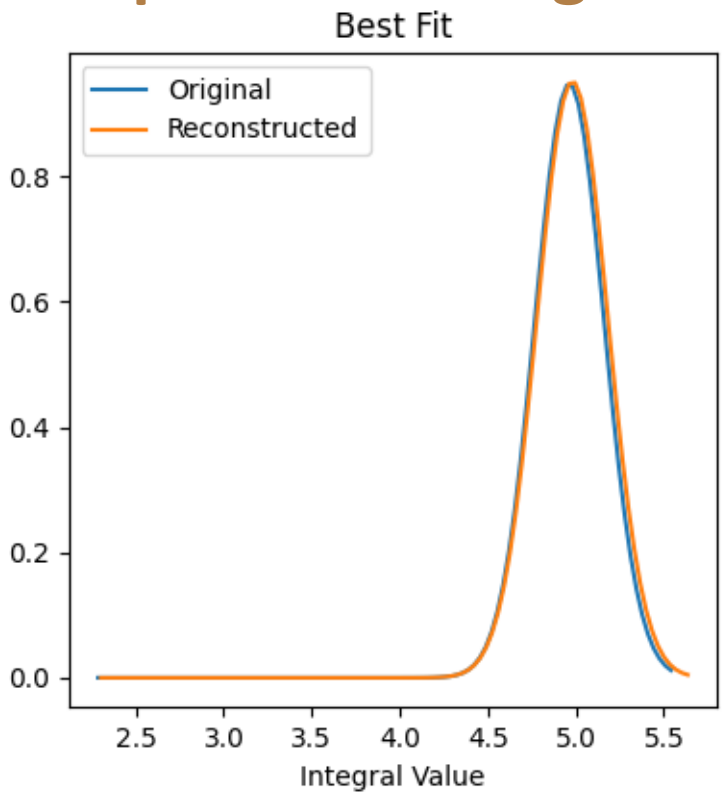
Signals Compression: Integral and spectrum





	A	μ	σ
Original	199,124	4,963	0,1952
Recon.	199,992	4,981	0,2006
Diff. [%]	0,44	0,35	2,77

Good performance also on the derived quantities for physical analysis

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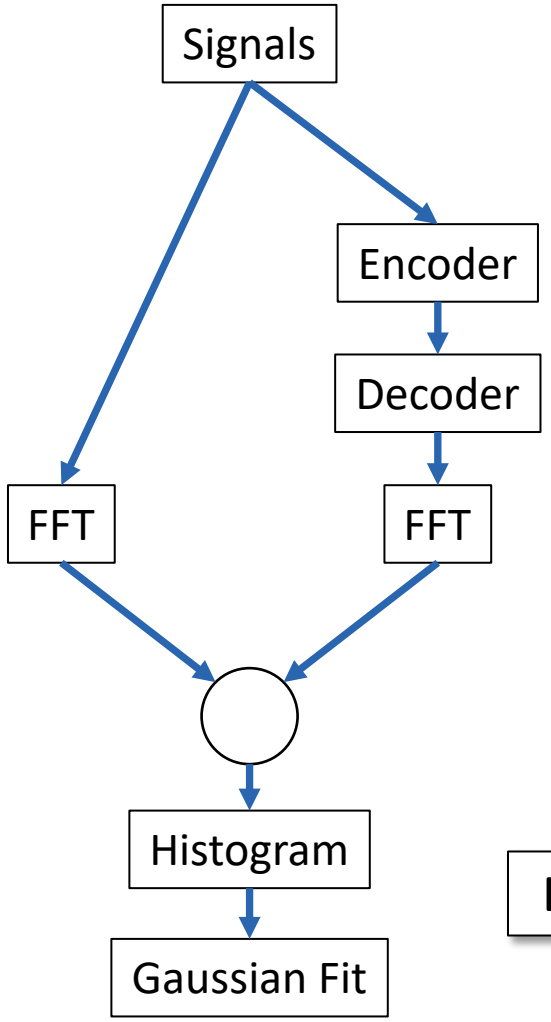
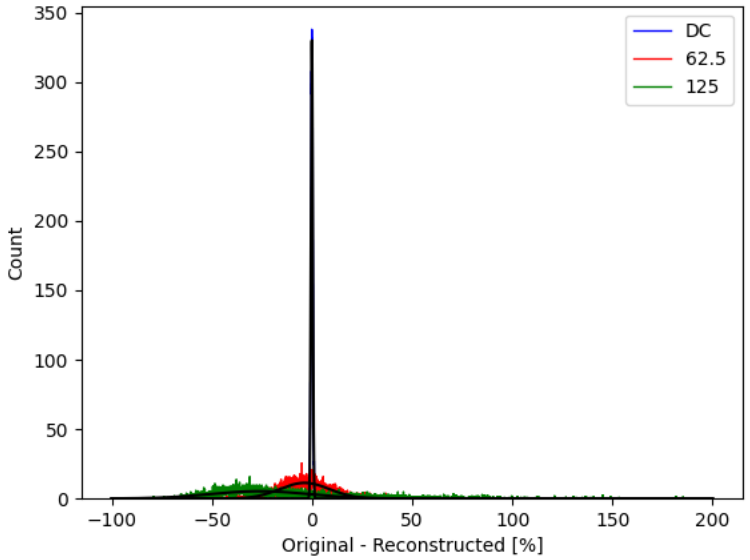
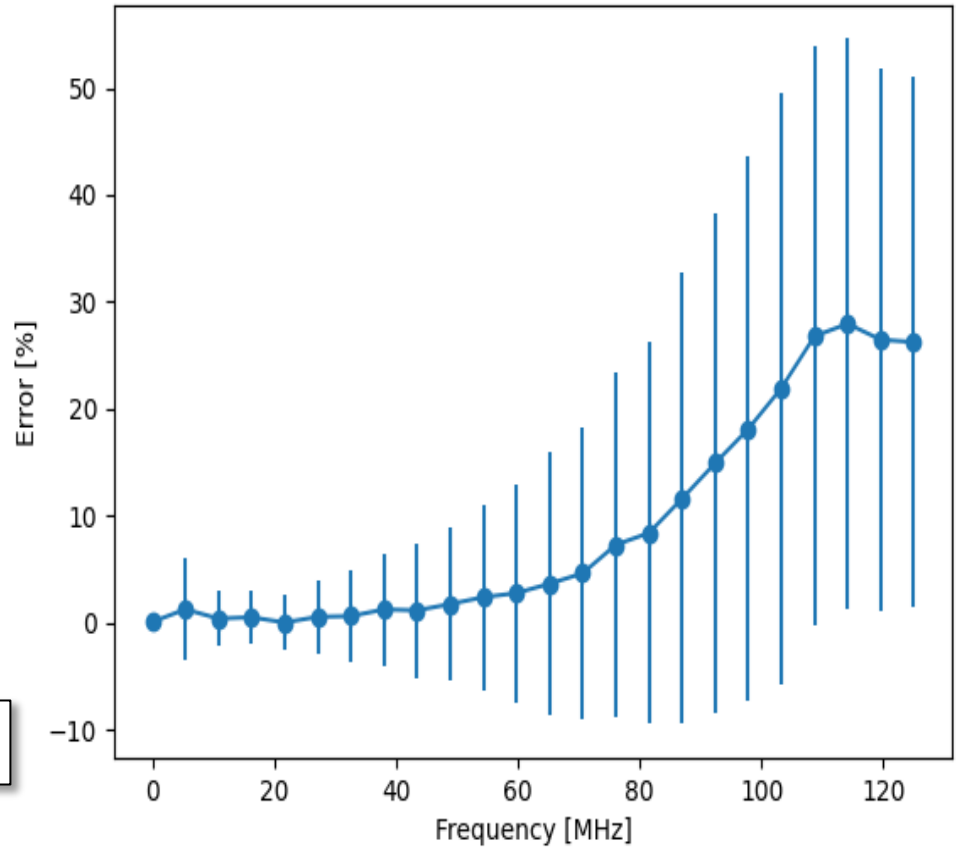
Signals Compression: FFT analysis







Better reconstruction of low frequency

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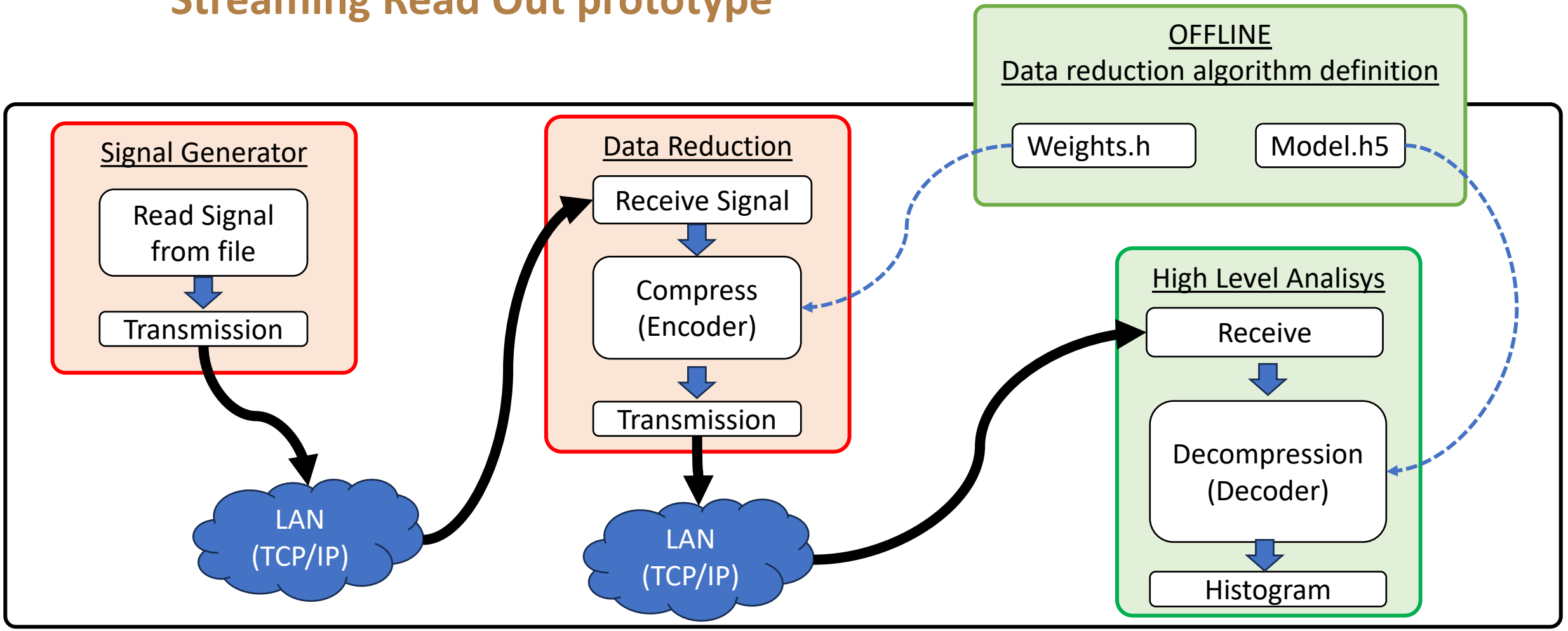
Streaming Read Out prototype



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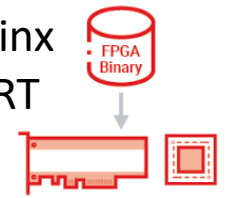
Implementation of Data Reduction Node

4 x NVIDIA Tesla V100 GPU

INFN CNAF

Xilinx XRT



XILINX VITIS AI

ALVEO V70 FPGA

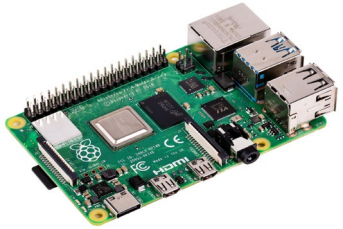
Data Reduction

Receive Signal

Compress (Encoder)

Transmission

Raspberry Pi 4 Rev. B



Low cost hardware

LAN (TCP/IP)

High performance DELL C6400 server (4 x AMD EPYC 7413 24-Core Processor)

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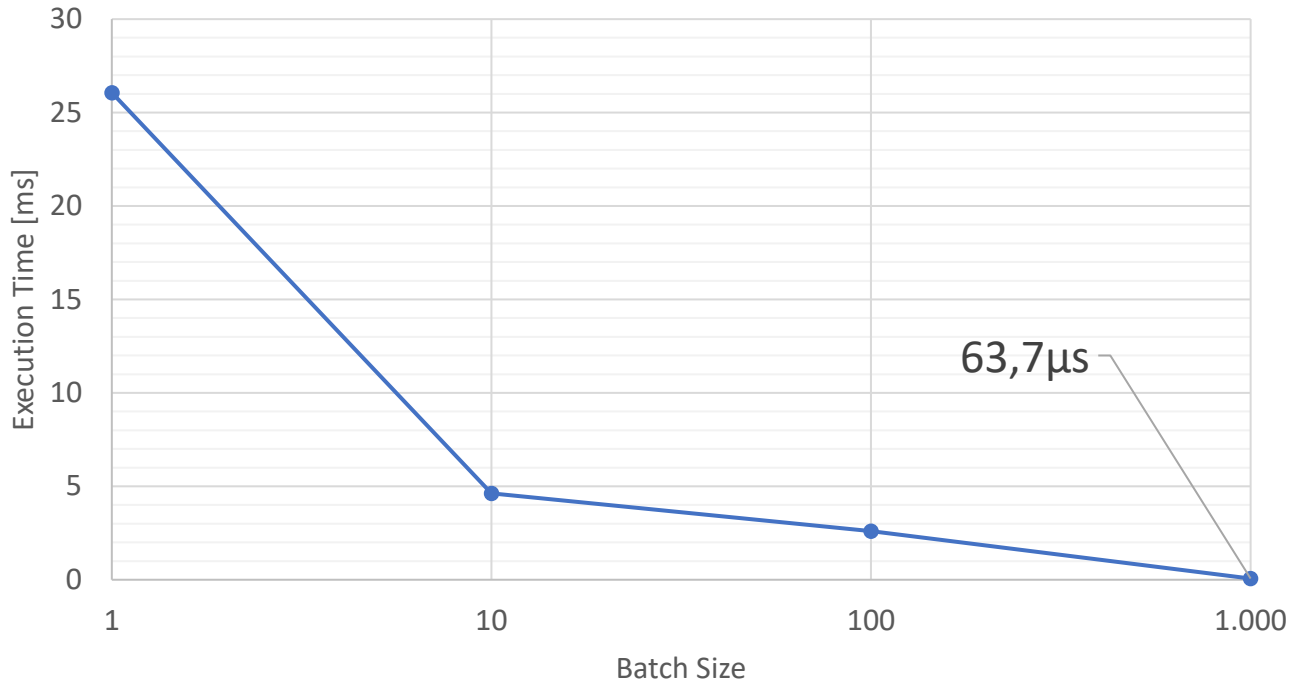
Implementation: GPU

4 x NVIDIA Tesla V100 GPU

INFN CNAF



Execution time not enough for the application!

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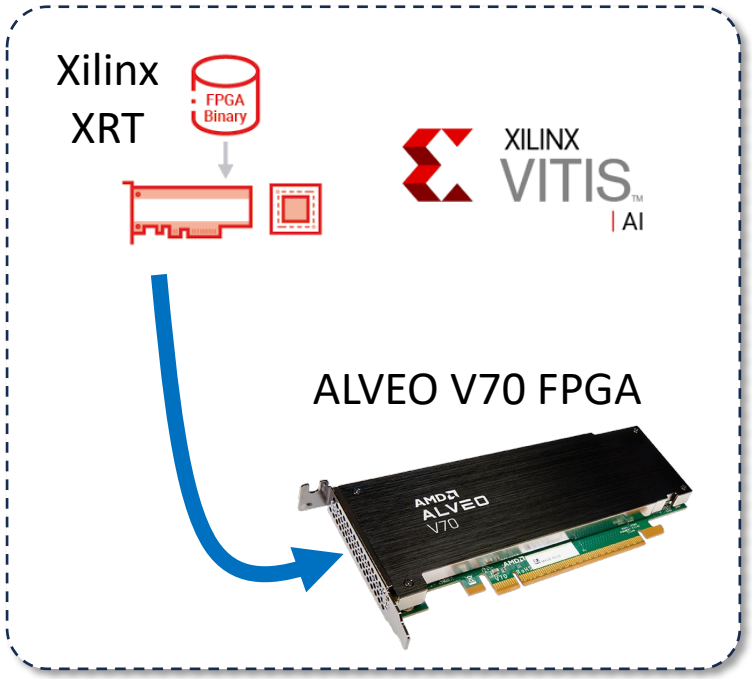
Implementation: FPGA



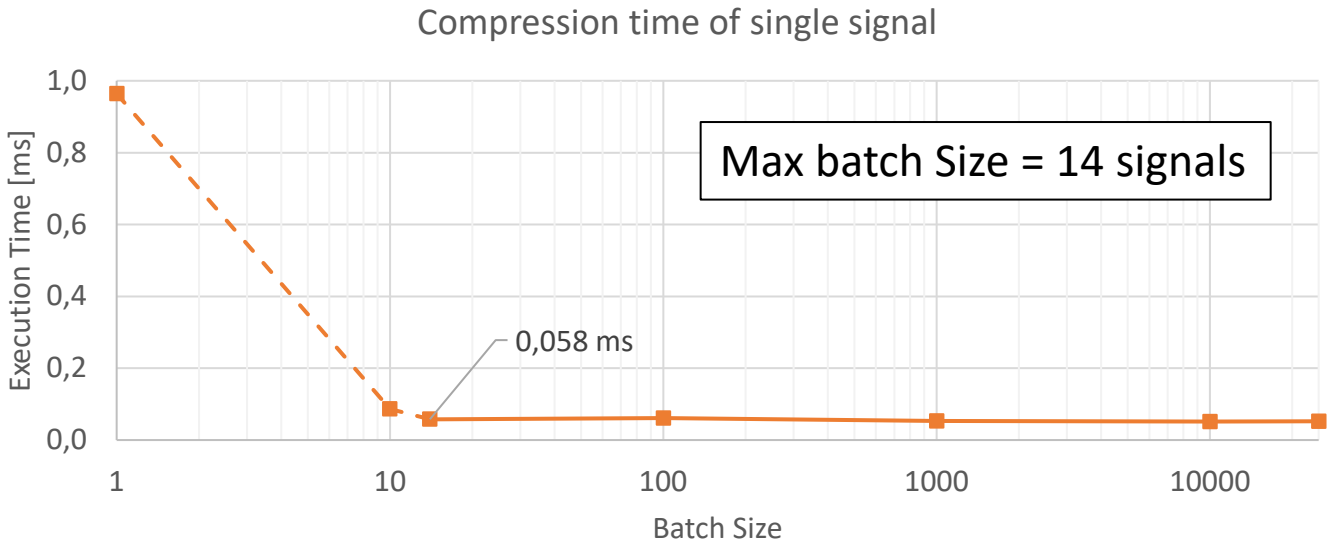
DEFINITION
- Definition
- Training
- Test
- Validation

PREPARATION
- Pruning
- Quantization

XILINX VITIS AI

INITIALIZATION
- Compilation
- Deployment

ONLINE
- Inference



Execution time still not enough for the application!

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Implementation: High performance server

High performance
DELL C6400 server

4 x AMD EPYC 7413
24 Core Processor

Input Batch

Parallel Execution
(openmp)

Compressed Batch

Single process

Weights

Bias

Activation

Original Signal

Compressed Signal

Number of layers

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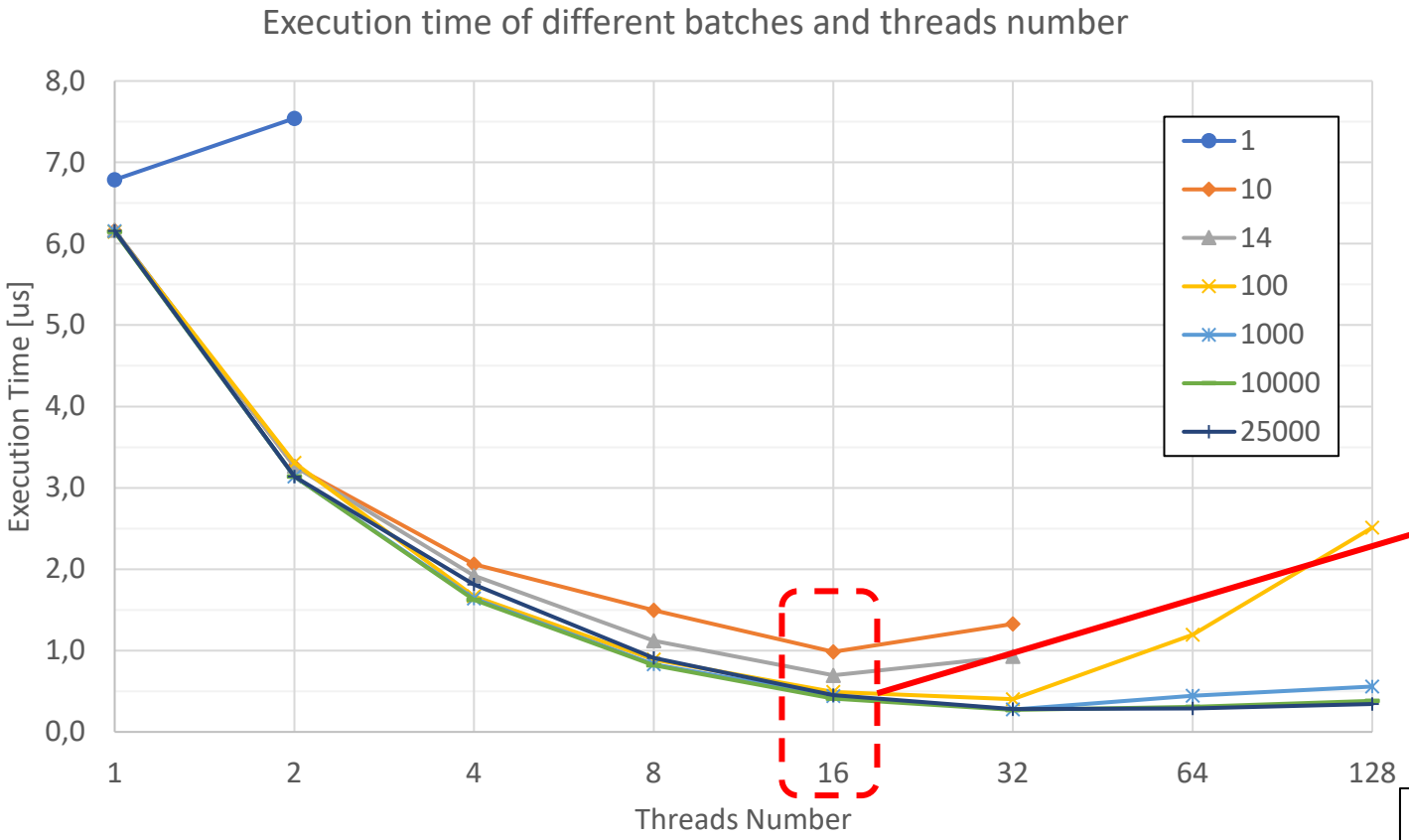
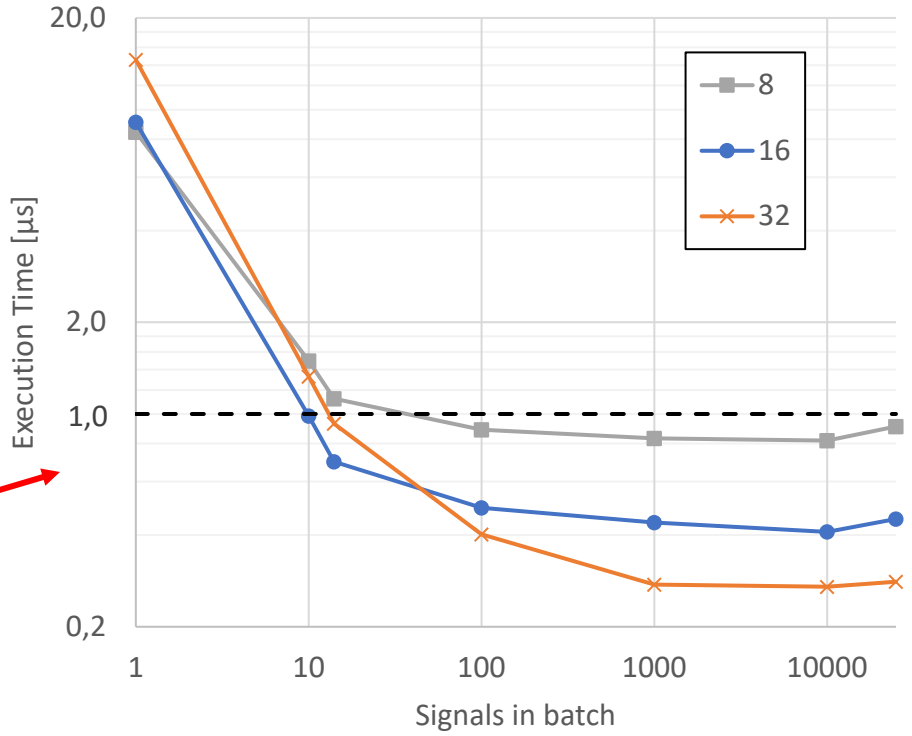
Implementation: High performance server





Chosen 16 Threads
Reasonable execution time for the application

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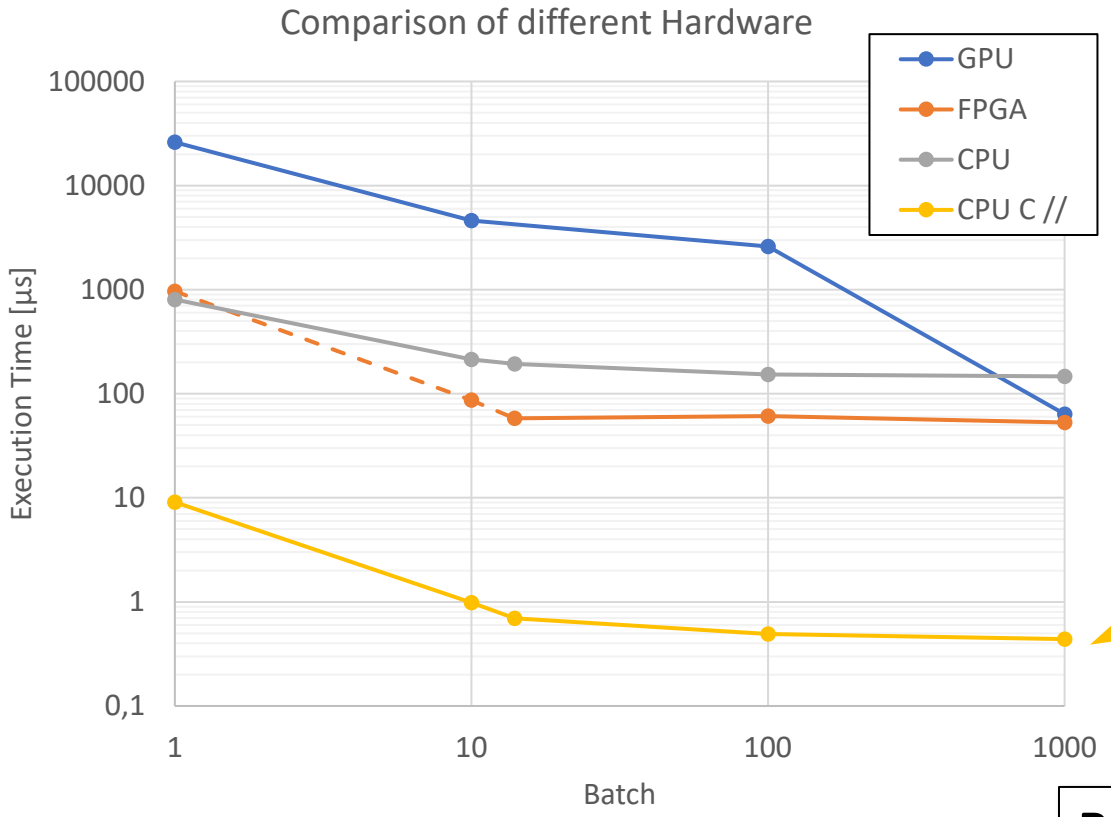
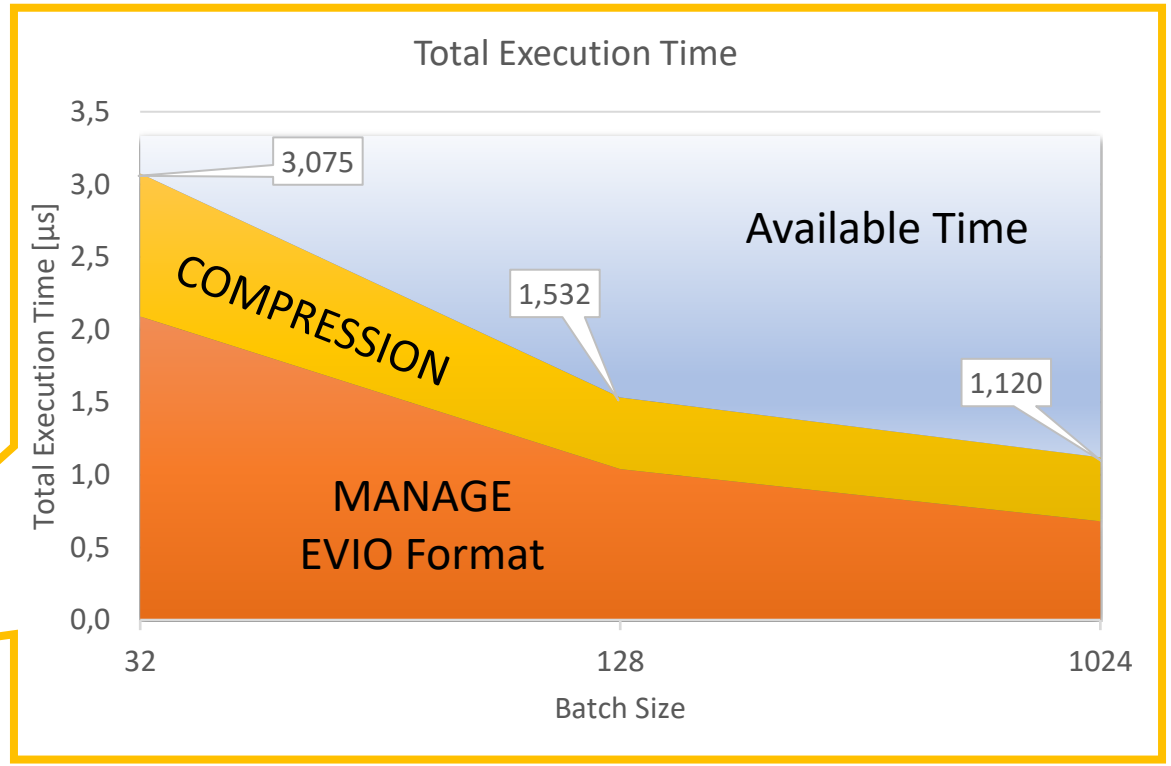
Conclusion





Rate can be managed for EVIO packet with at least 32 signals

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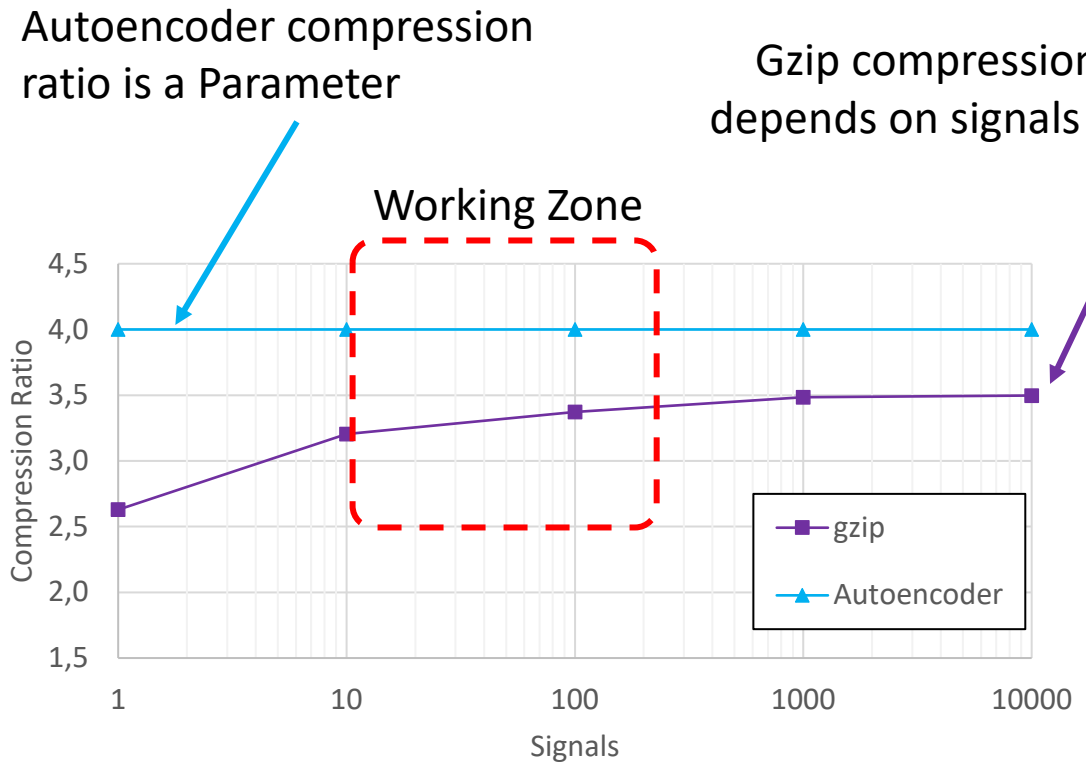
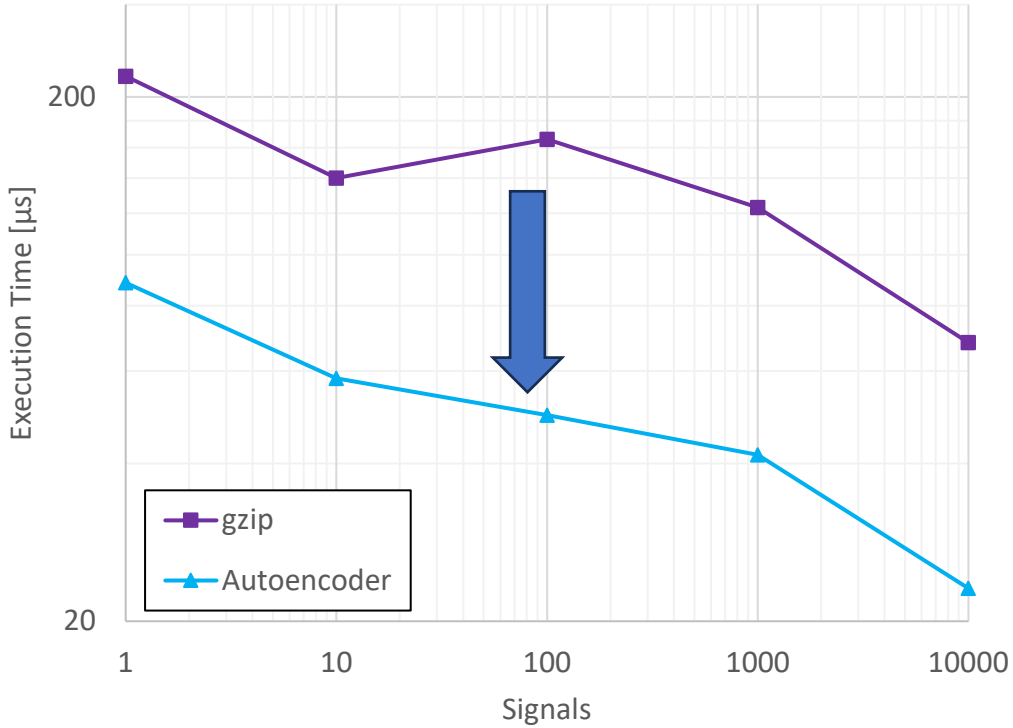
Comparison with standard lossless compression

Autoencoder compression ratio is a Parameter

Gzip compression ratio depends on signals number



gzip



Better compression ratio

Better also on execution time

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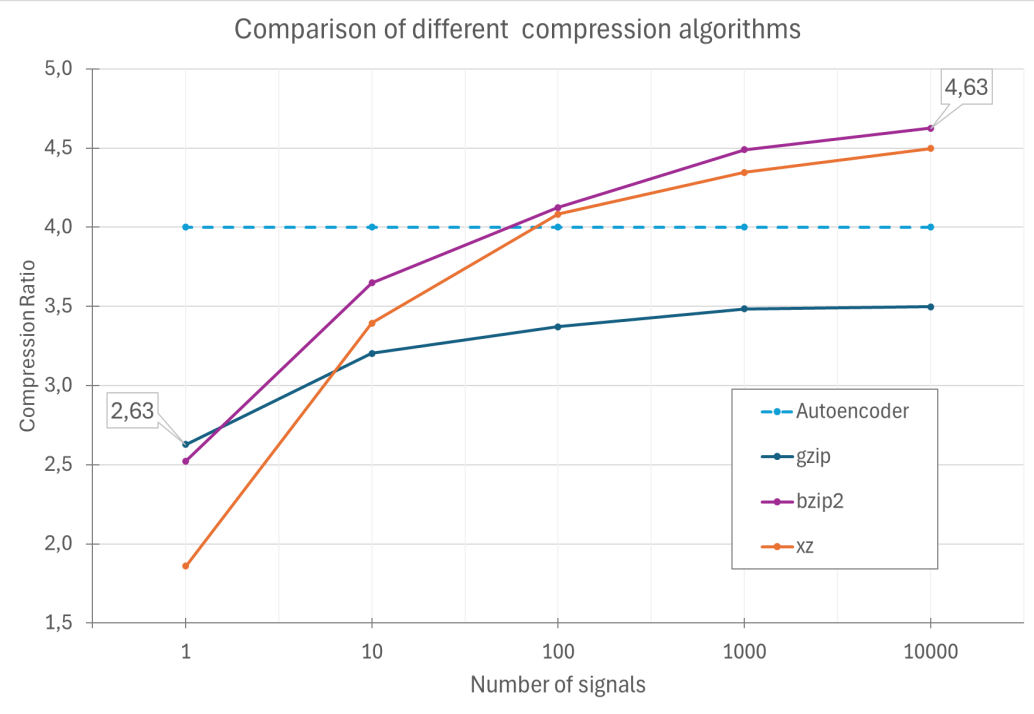
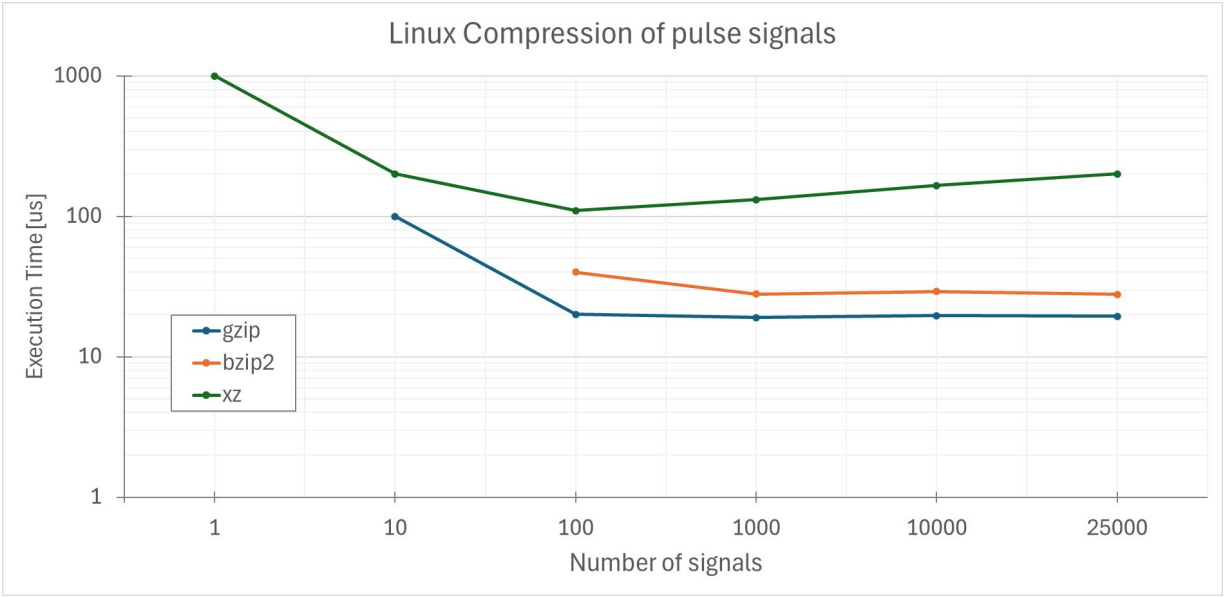
Comparison with standard lossless compression





High compression ratio with Bzip2 and X

bzip2

XZ

Very poor execution times:

bzip2	**50% slower**
XZ	**10 times slower**

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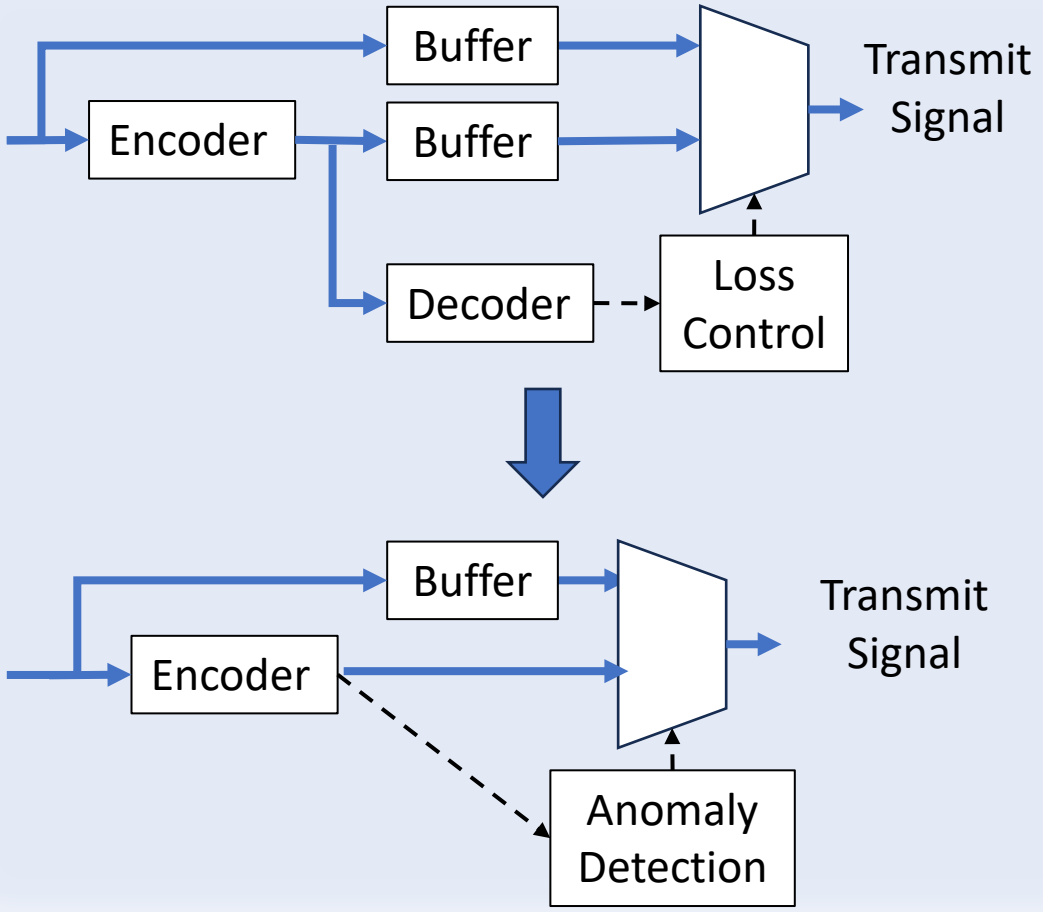
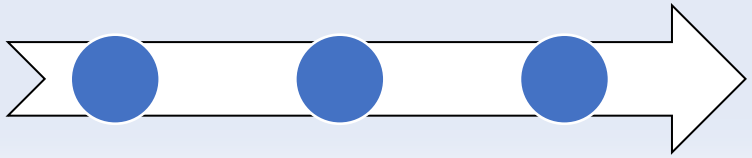
Further Studies



Reduce execution time removing the decoder

Statistical analysis of signals in each EVIO packets



Estimate performance on real acquisition

Low level FPGA implementation

Dedicated connectivity (2xQSFP28 @ 100GbE)

...or very Low level

Reduce execution time and maybe save money

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Thank you for your attention

FUTURE AI RESEARCH

https://fondazione-fair.it

Jefferson Lab

https://www.jlab.org

INFN GENOVA

https://www.ge.infn.it

SEAlab

https://sealab.unige.it

ACKNOWLEDGMENT

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