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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

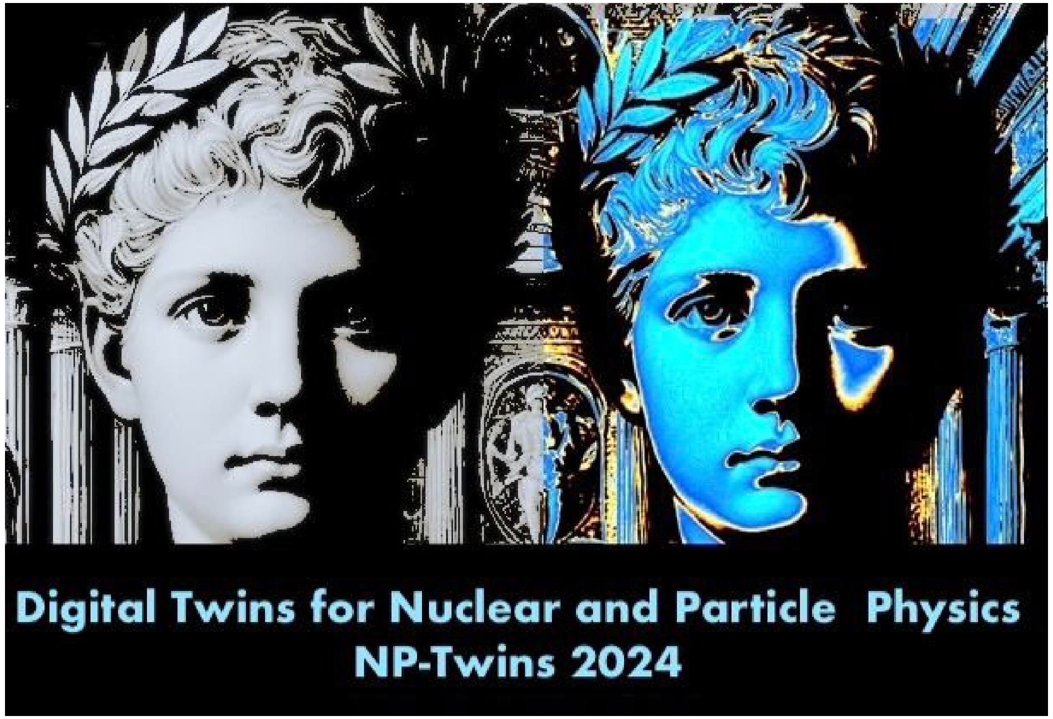
FAIR
Future Artificial Intelligence Research

AI for real time data-reduction

Digital Twins for Nuclear and Particle physics

NPTwins 2024

December 16-18, 2024
Museo Diocesano di Genova



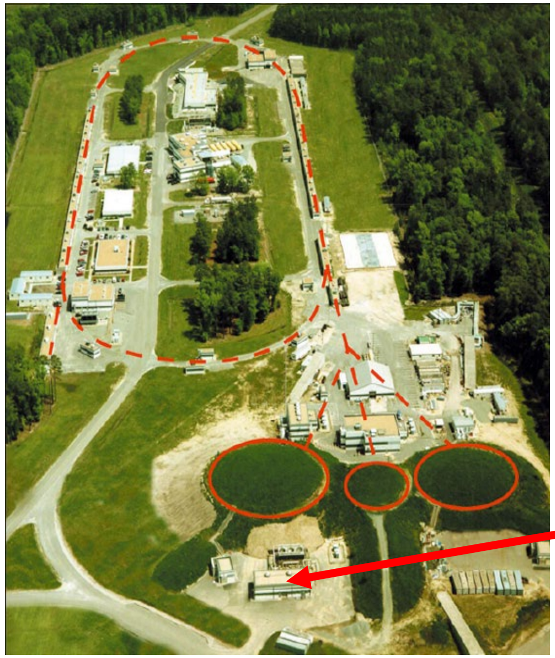
Fabio Rossi (presenter), **Marco Battaglieri**
Istituto Nazionale di Fisica Nucleare
Genova (Italy)

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

Gagik Gavalian
Jefferson Lab
Newport News (Virginia)

High Energy Physics Experiment: Beam Dump eXperiment (BDX)

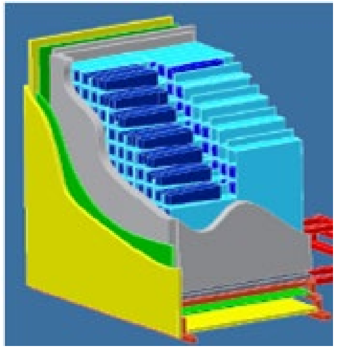
Jefferson Lab

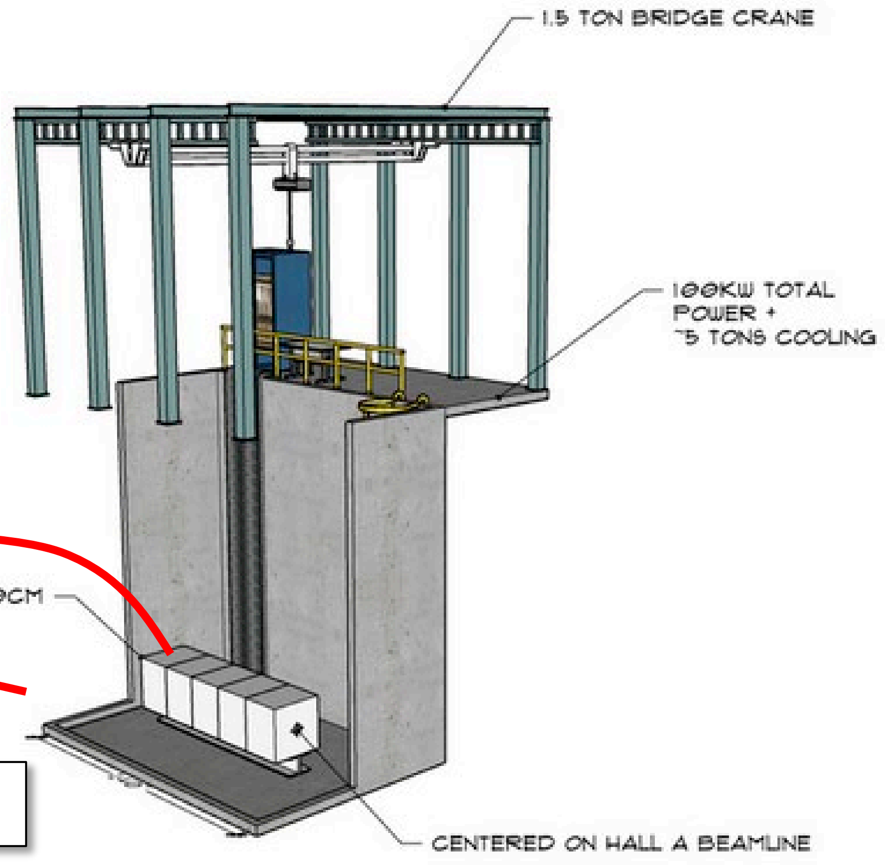


≈1000
Calorimeter channels
(30MB/s)

≈ 300
Veto channels
(500MB/s)

Single module

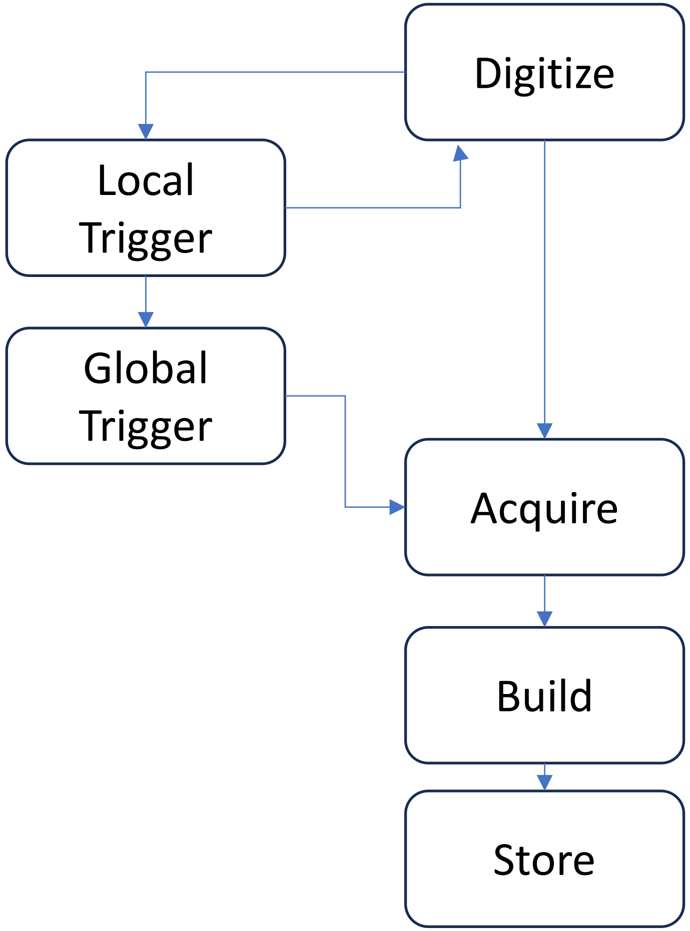



1.5 TON BRIDGE CRANE
100KW TOTAL POWER + ~5 TONS COOLING
5 MODULES AT 80CM x 100CM x 100CM
CENTERED ON HALL A BEAMLINE

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).

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.

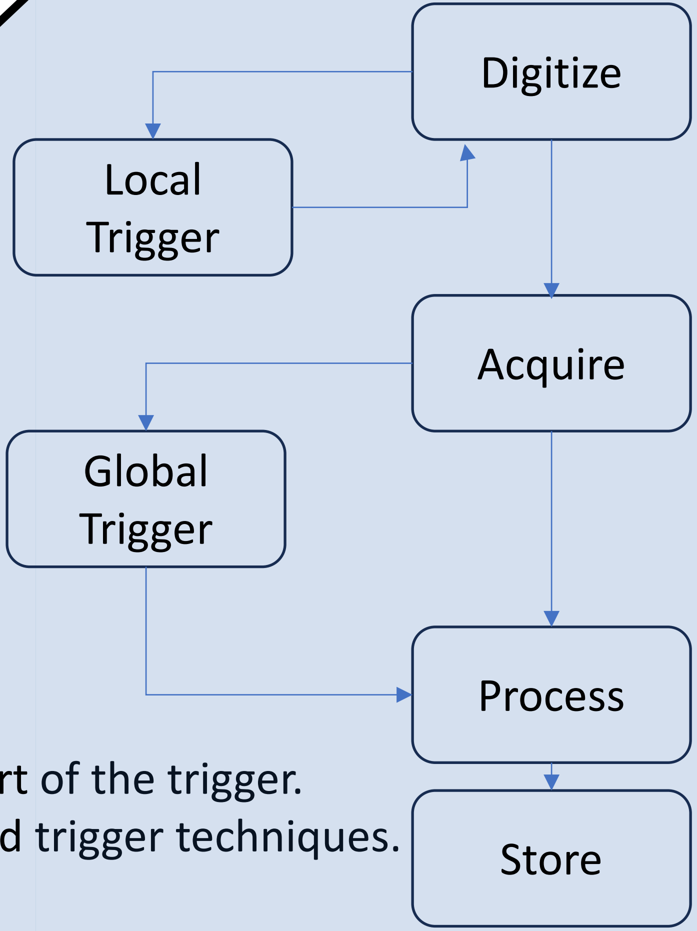
Pros:
It works reliably.

Triggered

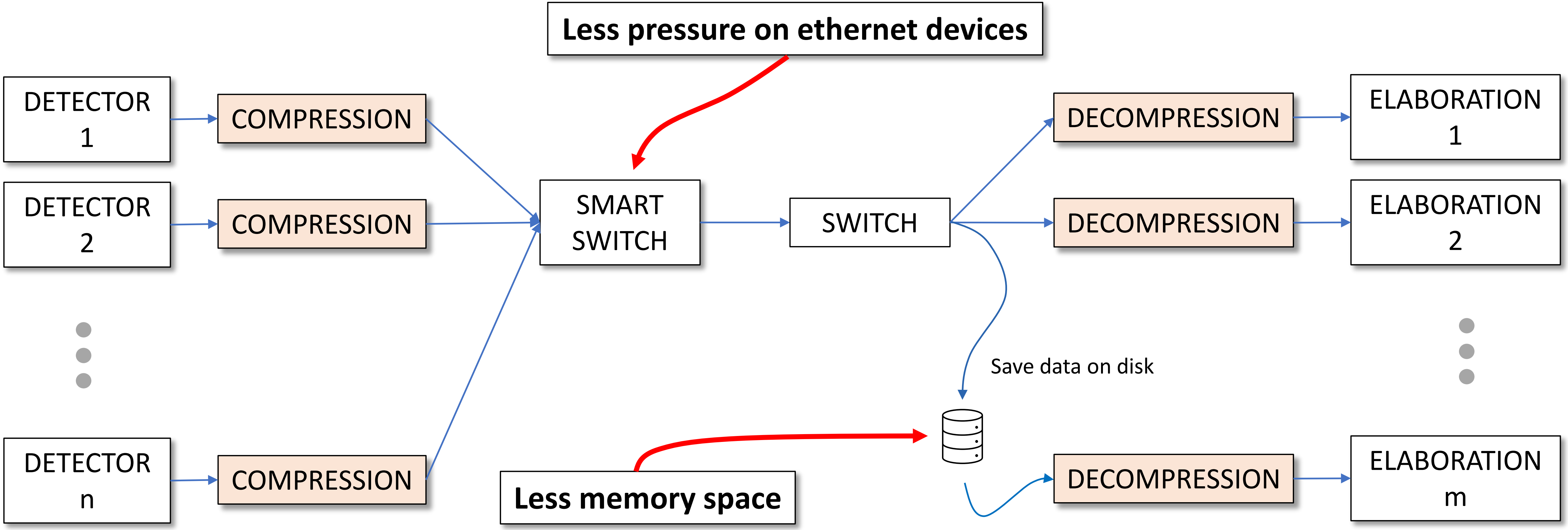
Streaming

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

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



Block scheme of data flow



Less pressure on ethernet devices

DETECTOR 1

DETECTOR 2

DETECTOR n

COMPRESSION

COMPRESSION

COMPRESSION

SMART SWITCH

SWITCH

Save data on disk

Less memory space

DECOMPRESSION

DECOMPRESSION

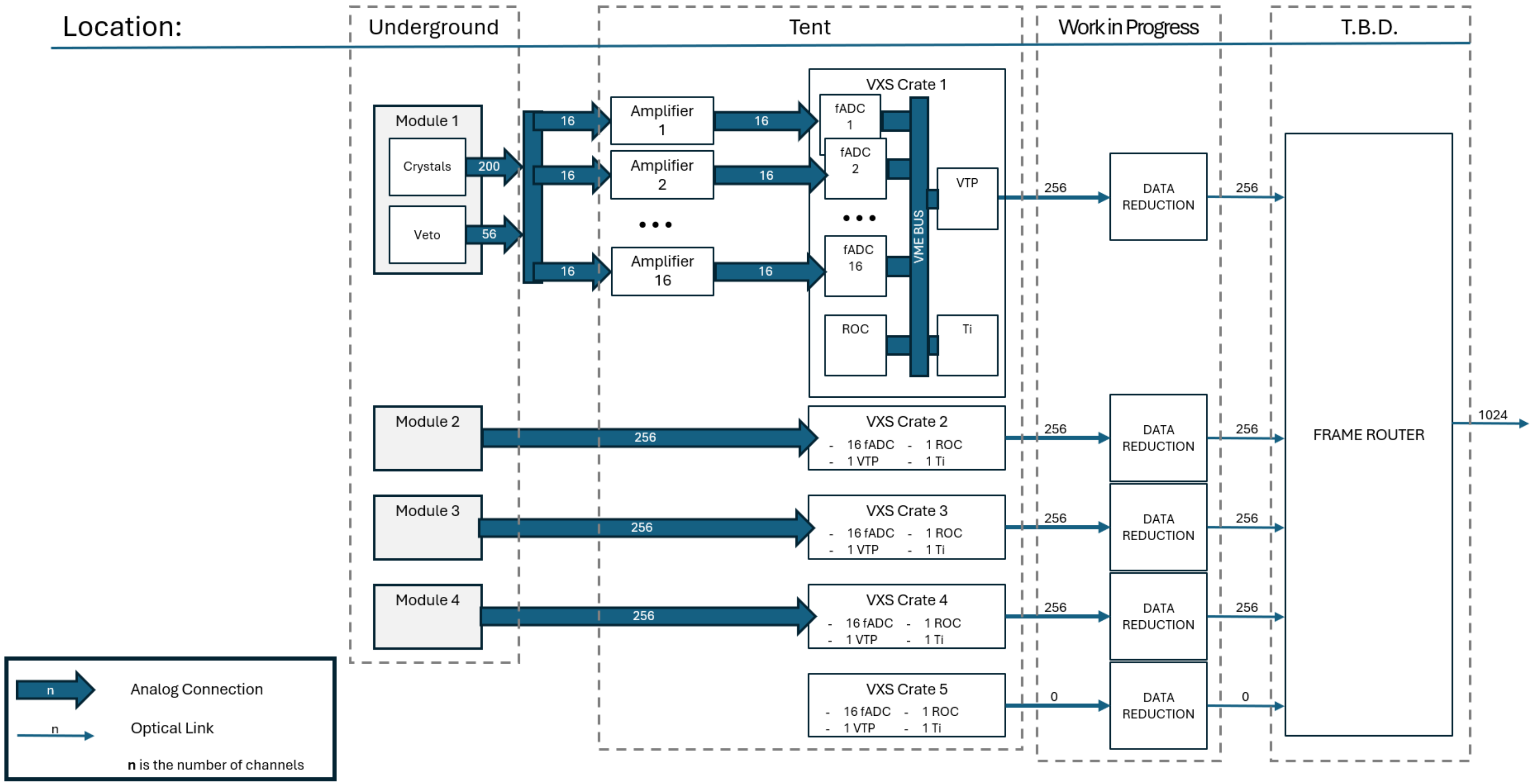
DECOMPRESSION

ELABORATION 1

ELABORATION 2

ELABORATION m

Detailed BDX data flow scheme



Data reduction algorithm: Autoencoder

Machine Learning Algorithm

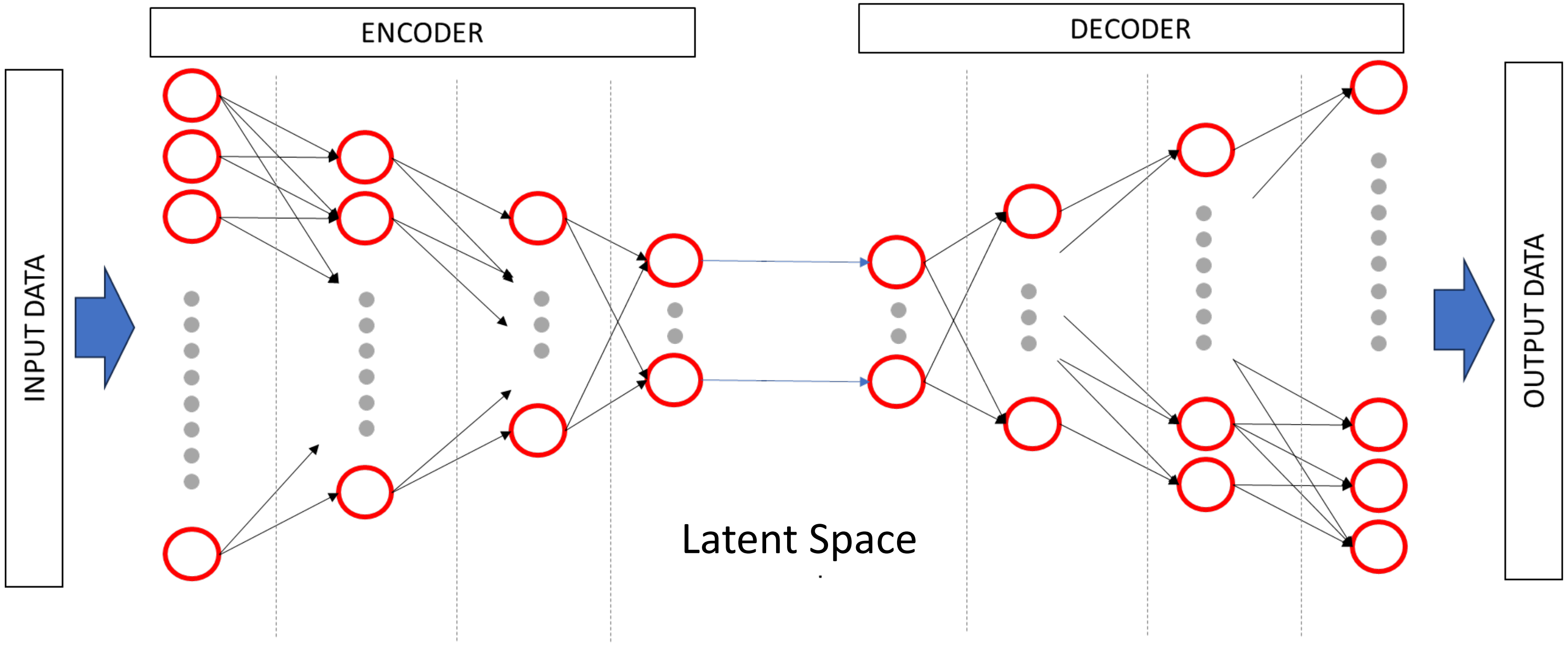
Dimensionality reduction

Unsupervised learning

Artificial Neural Network

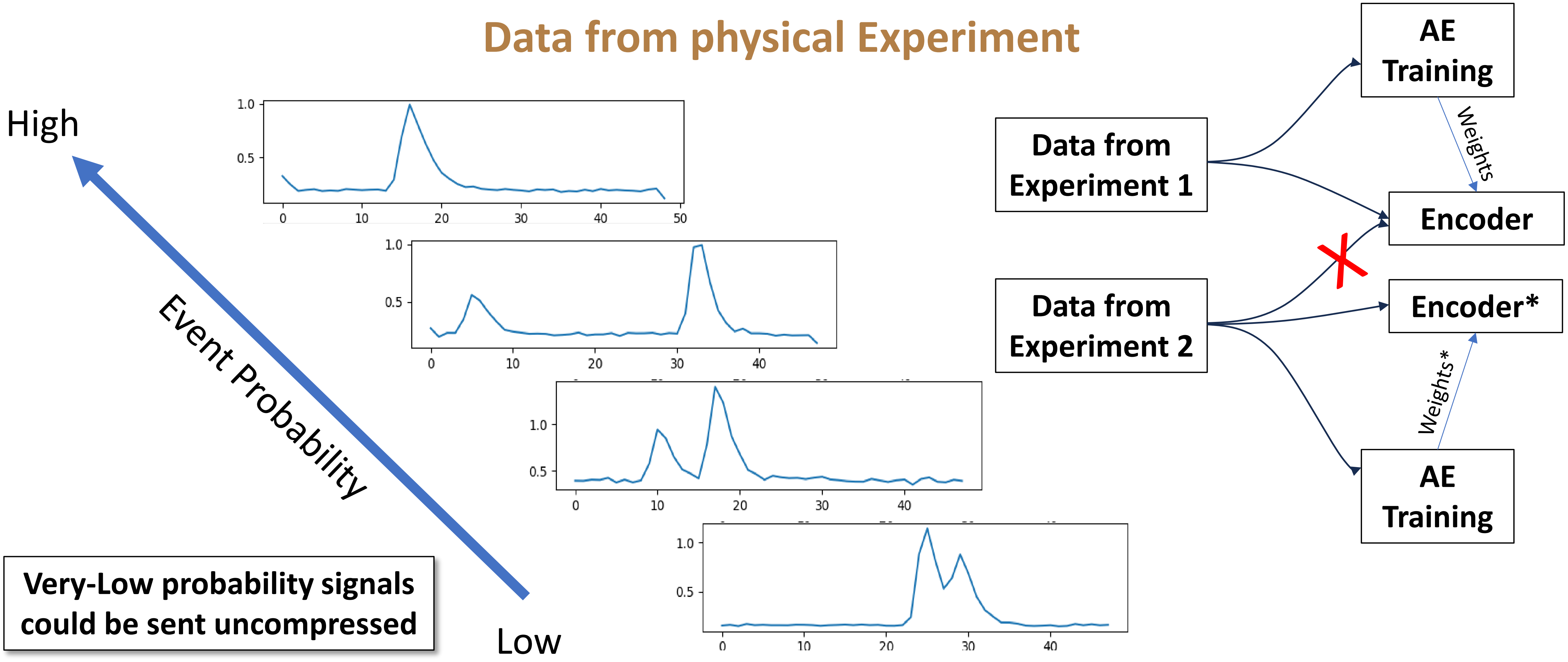
Composed of two function:
- encoding
- decoding

FULLY CONNECTED AUTOENCODER WITH DENSE LAYER



Lossy compression algorithm

Data from physical Experiment

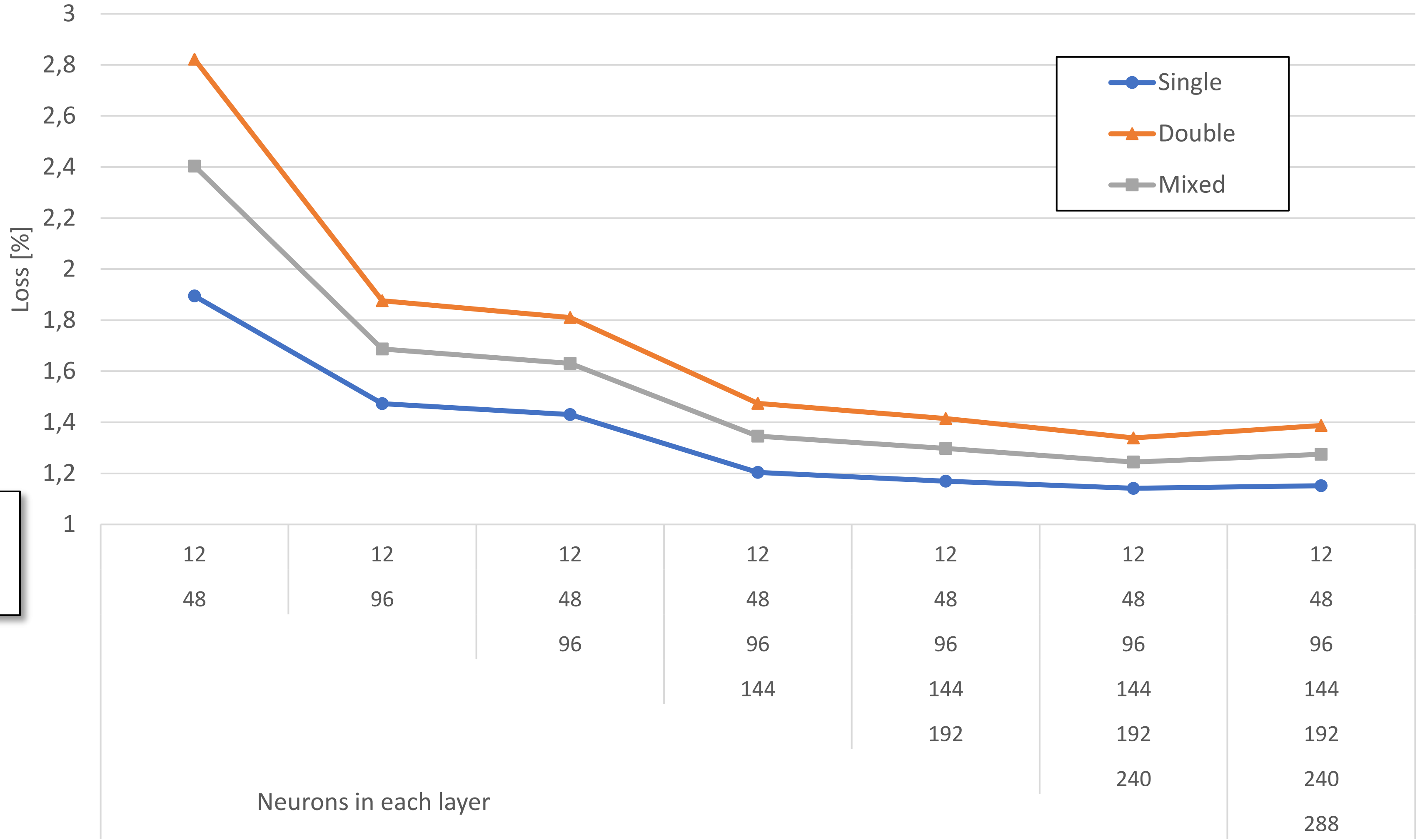


Very-Low probability signals could be sent uncompressed

Autoencoder Training: Different configuration

Test increasing:

- Layer number
- Neurons in each layer



Few improvement adding more and more parameters

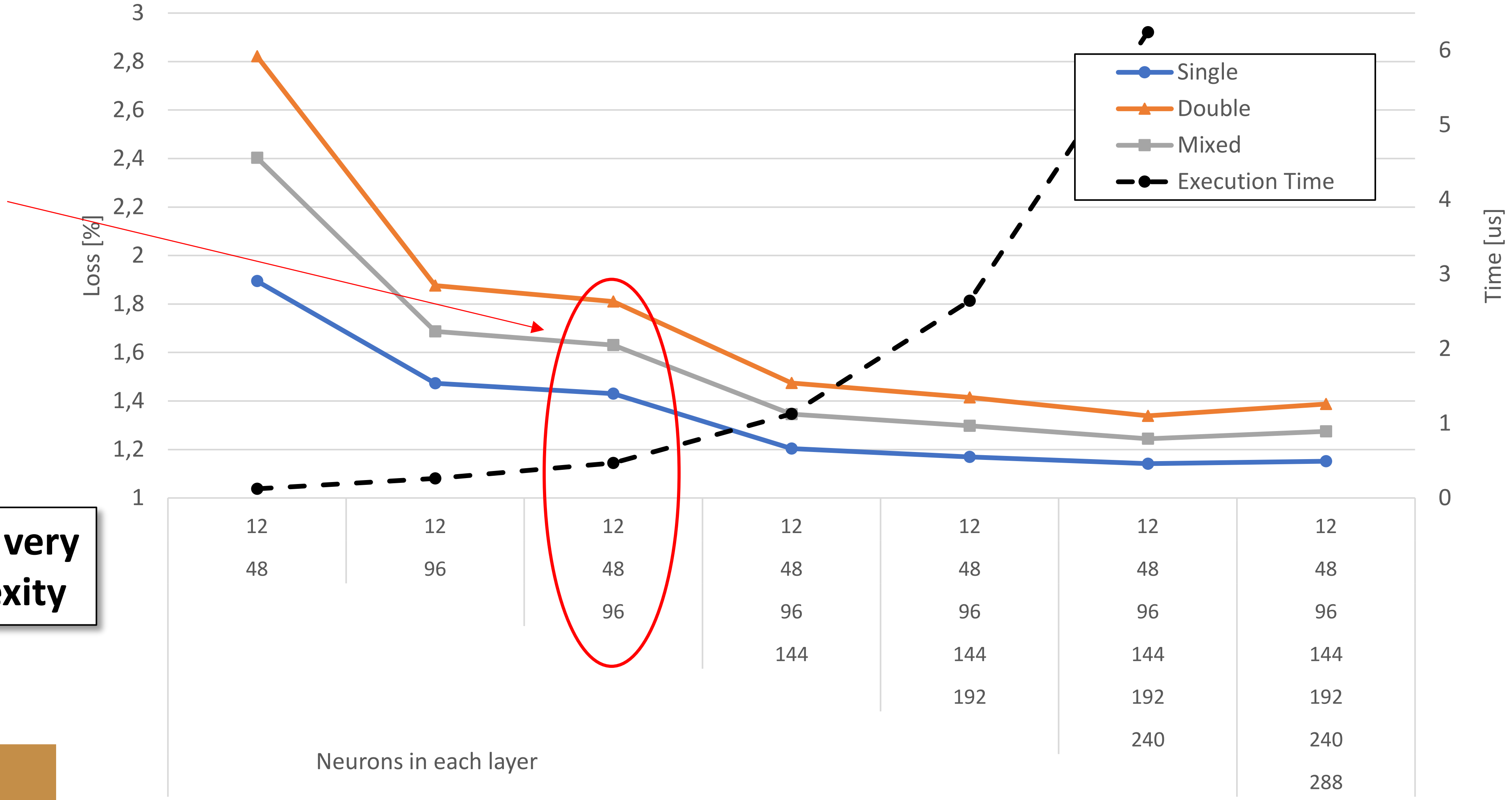
Autoencoder Training: Different configuration

Chosen configuration

Layers: 3

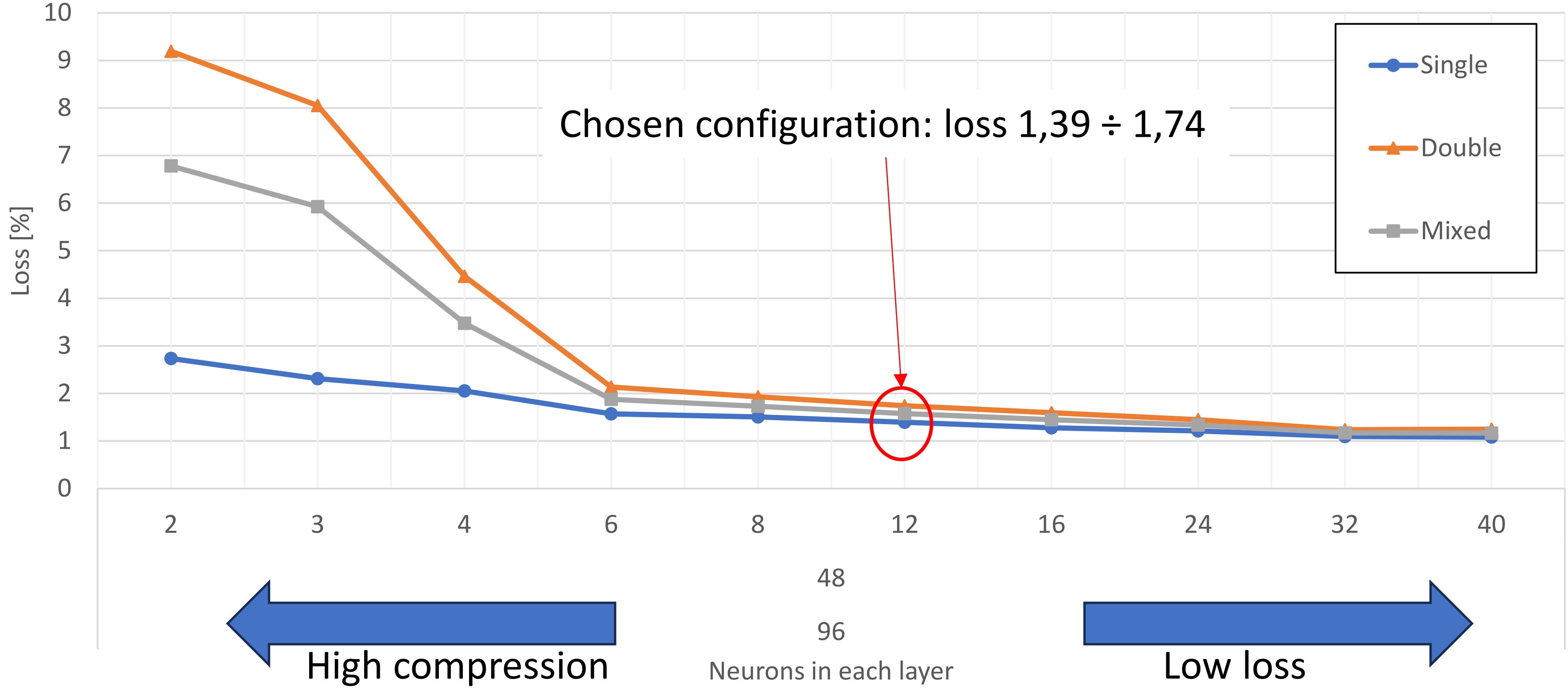
Neurons:

96
48
12



Execution time increase very fast with model complexity

Autoencoder Training: Different latent space



Chosen configuration: loss 1,39 ÷ 1,74

High compression

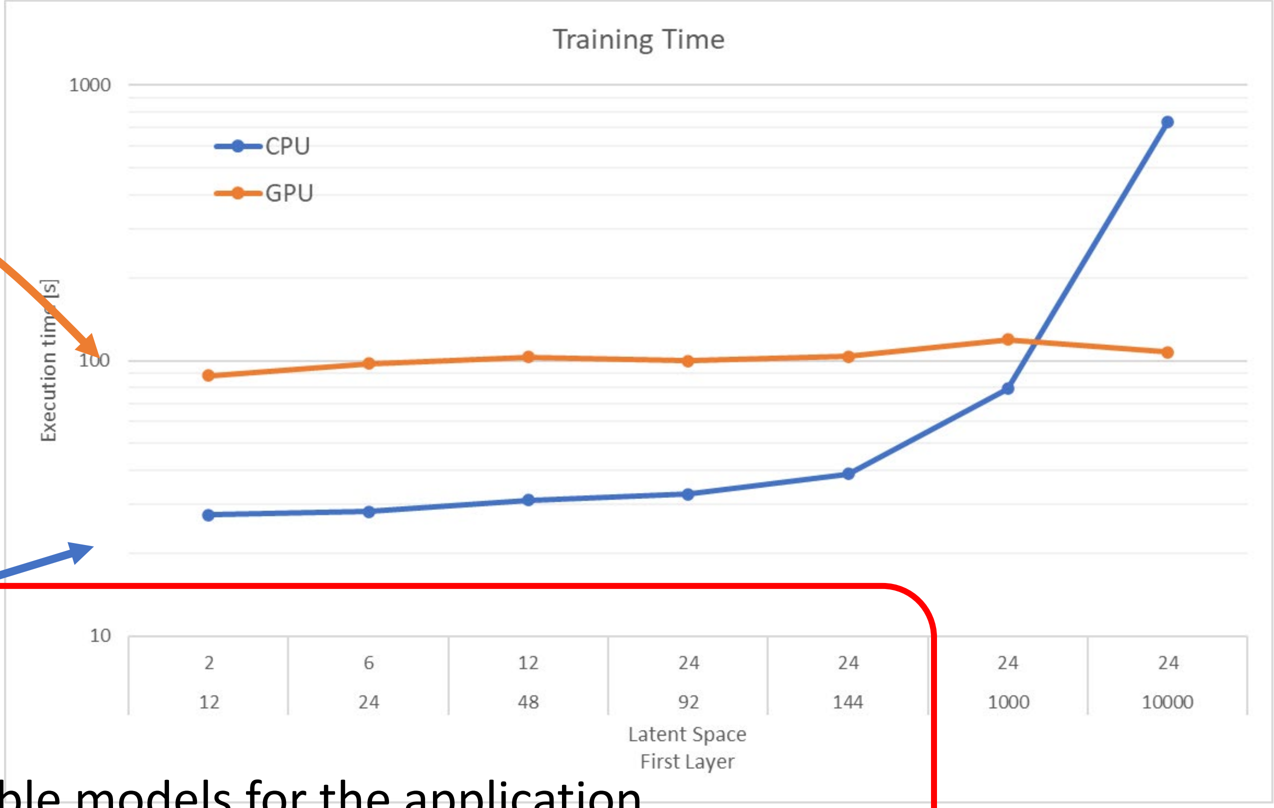
Low loss

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

Autoencoder: Training time

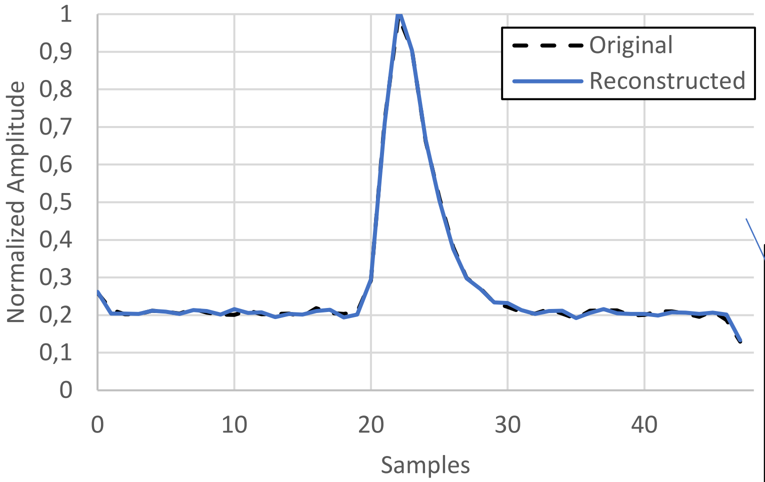
GPU

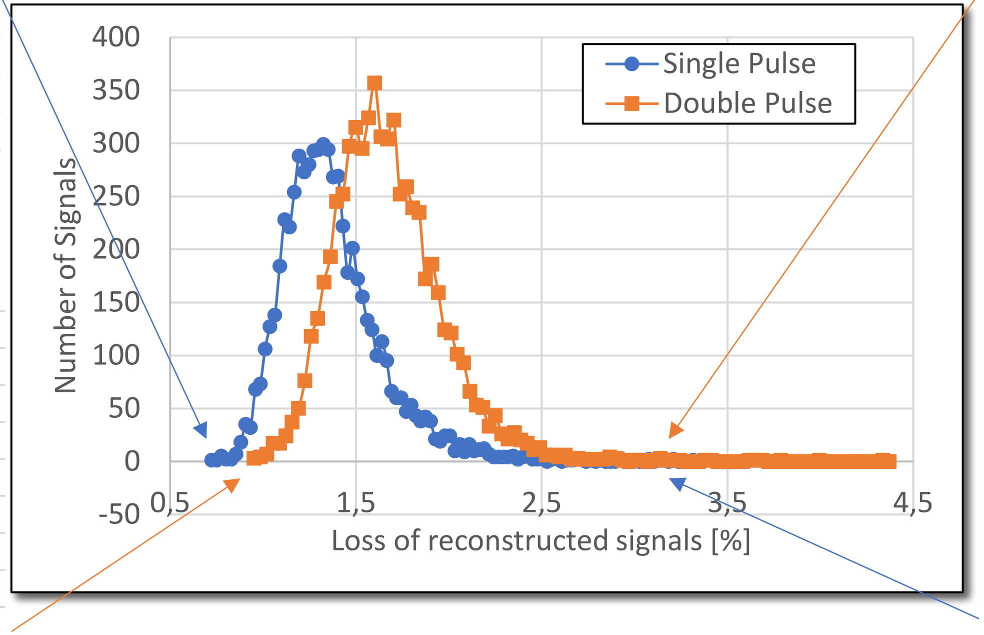
CPU
AMD Ryzen 5 5600U
6 core, 12 Logic processor

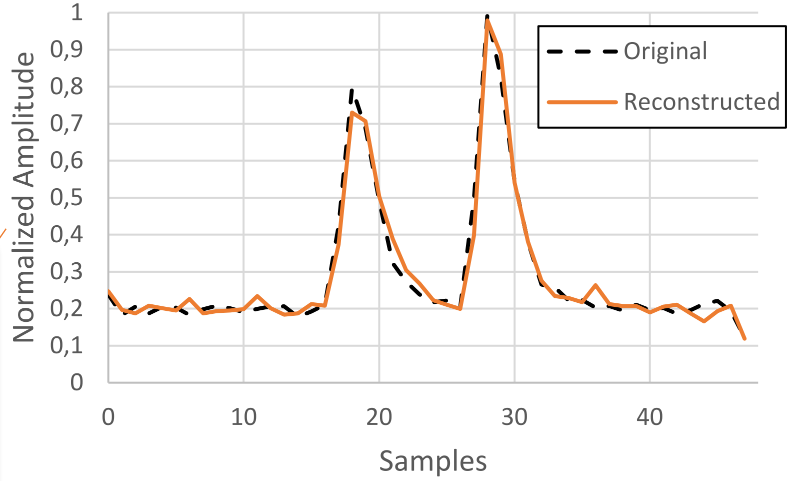


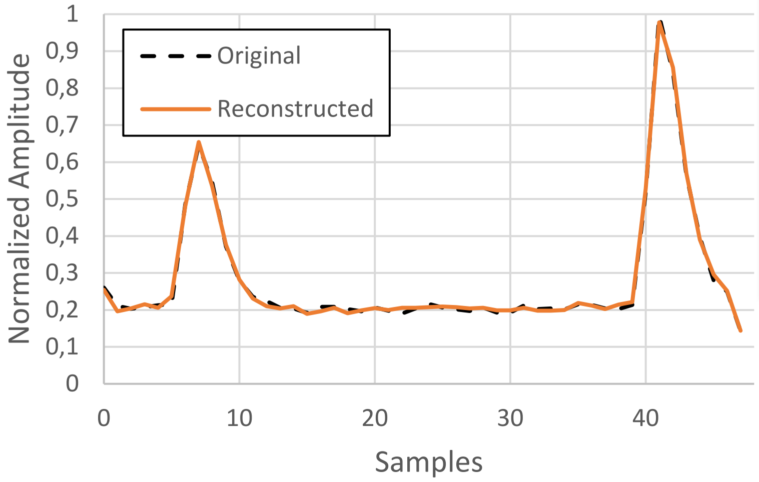
Suitable models for the application

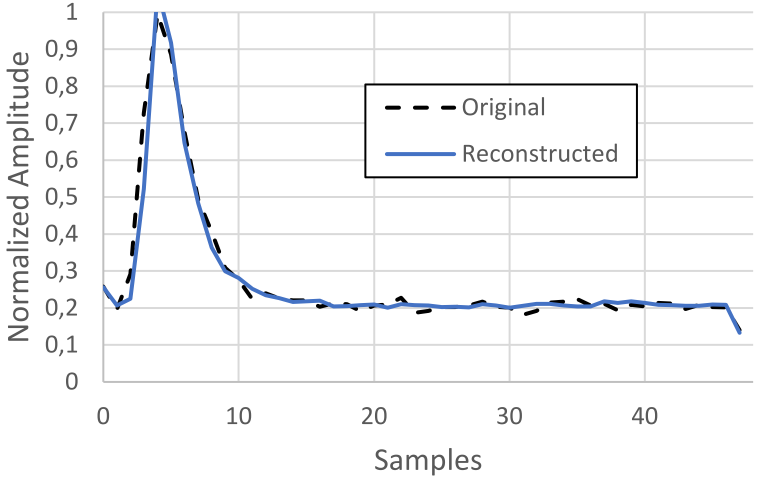
Signals Compression



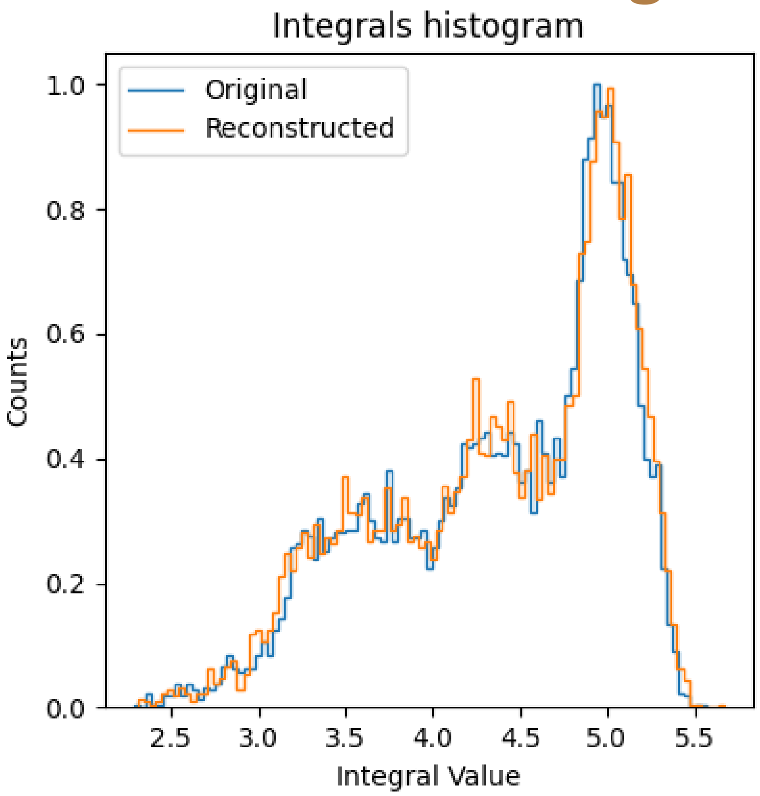


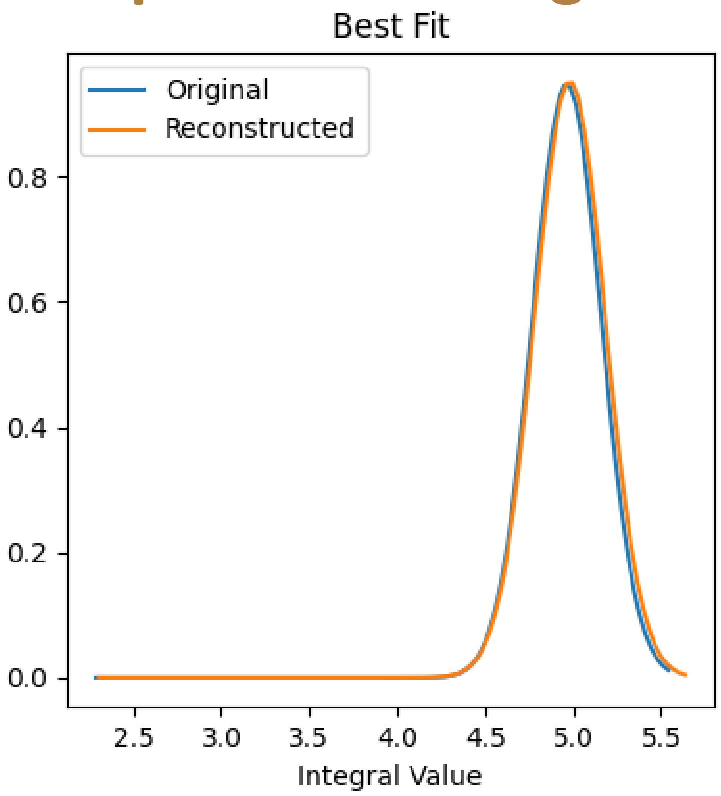






Signals Compression: Integral and spectrum





	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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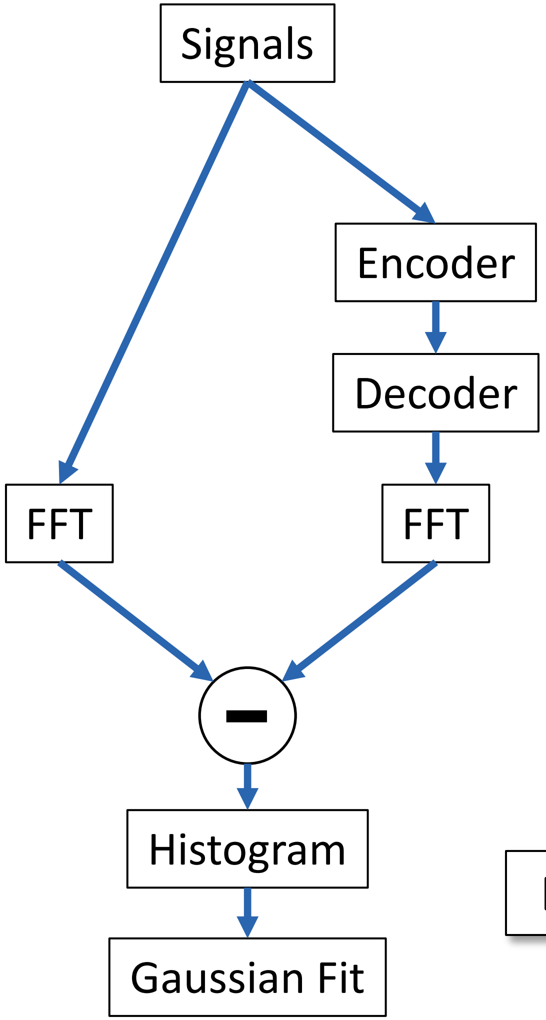
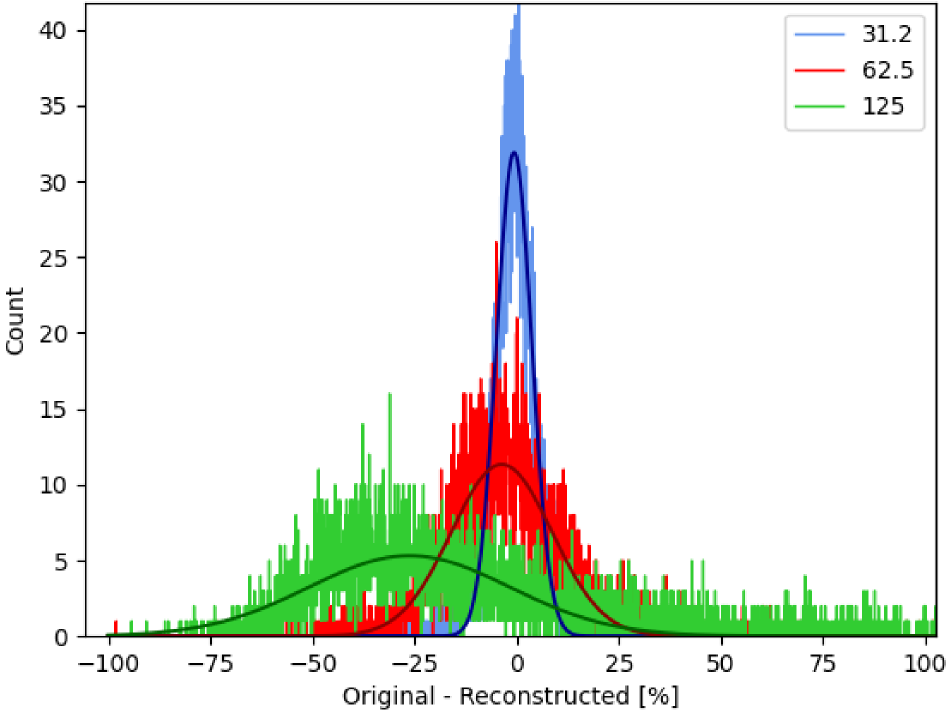
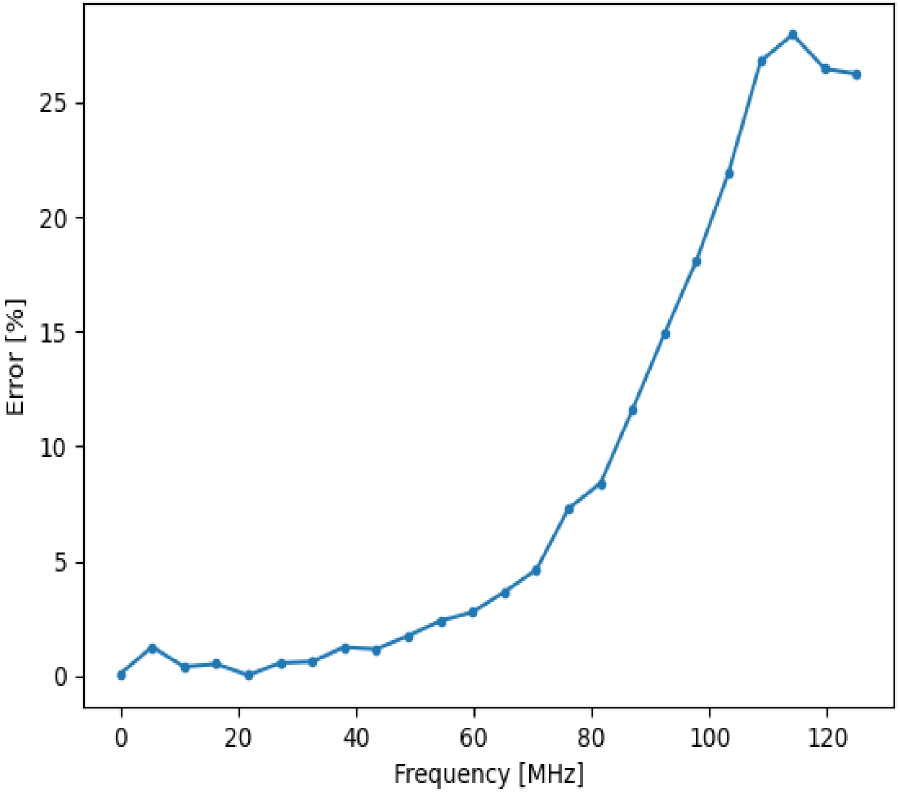
Signals Compression: FFT analysis





Better reconstruction of low frequency



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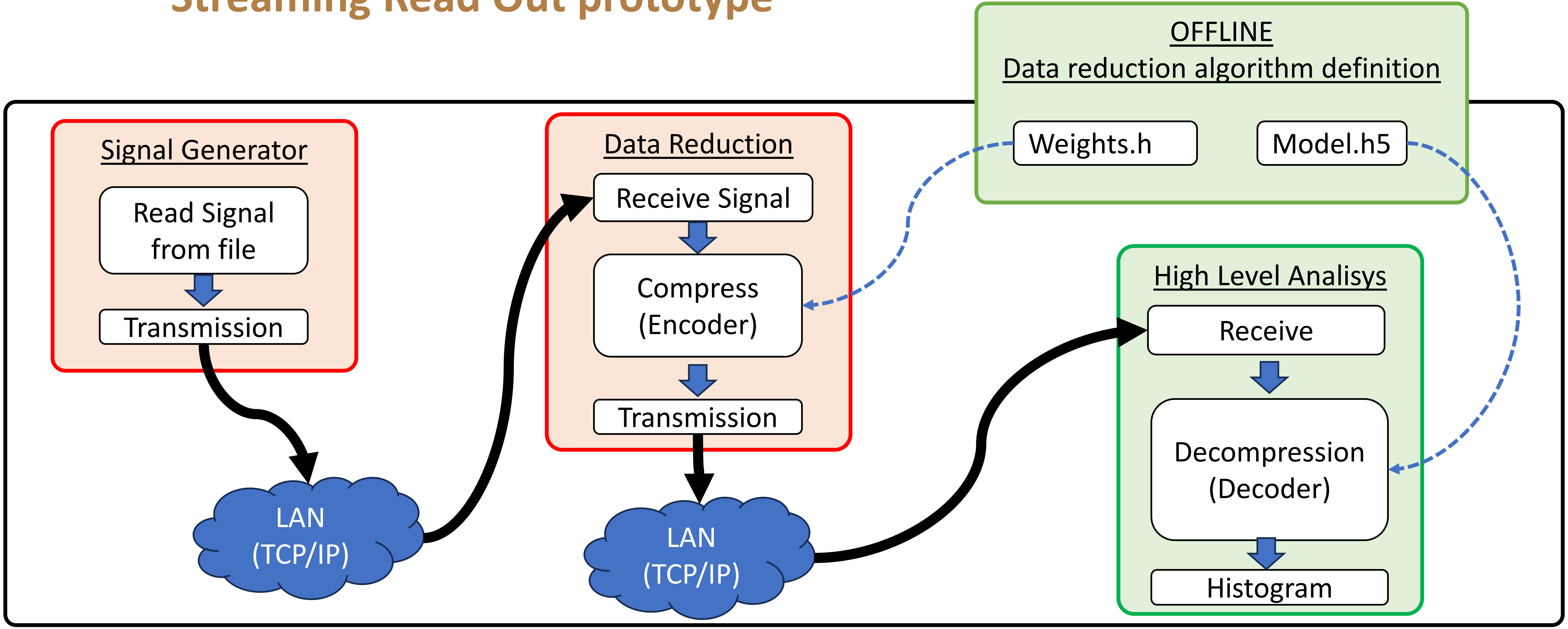
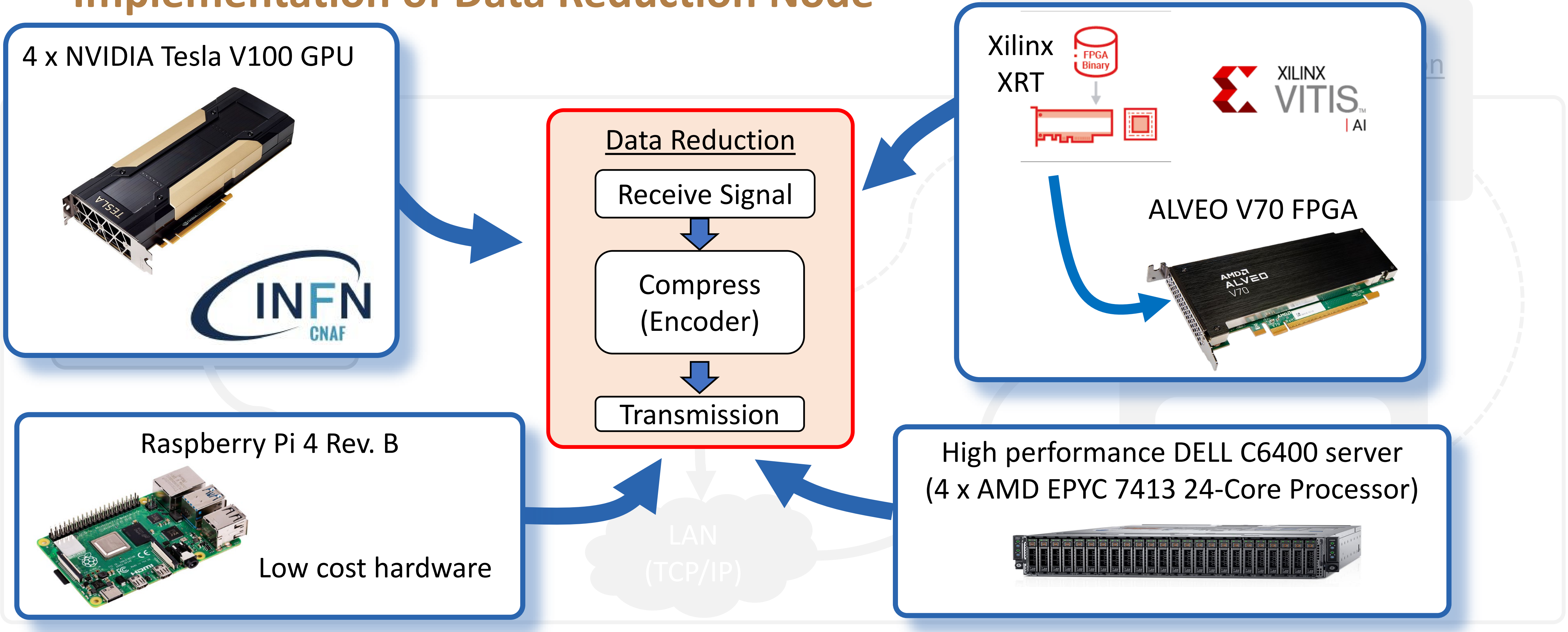
Streaming Read Out prototype



Implementation of Data Reduction Node



4 x NVIDIA Tesla V100 GPU

Data Reduction

Receive Signal

Compress (Encoder)

Transmission

Xilinx XRT

ALVEO V70 FPGA

Raspberry Pi 4 Rev. B

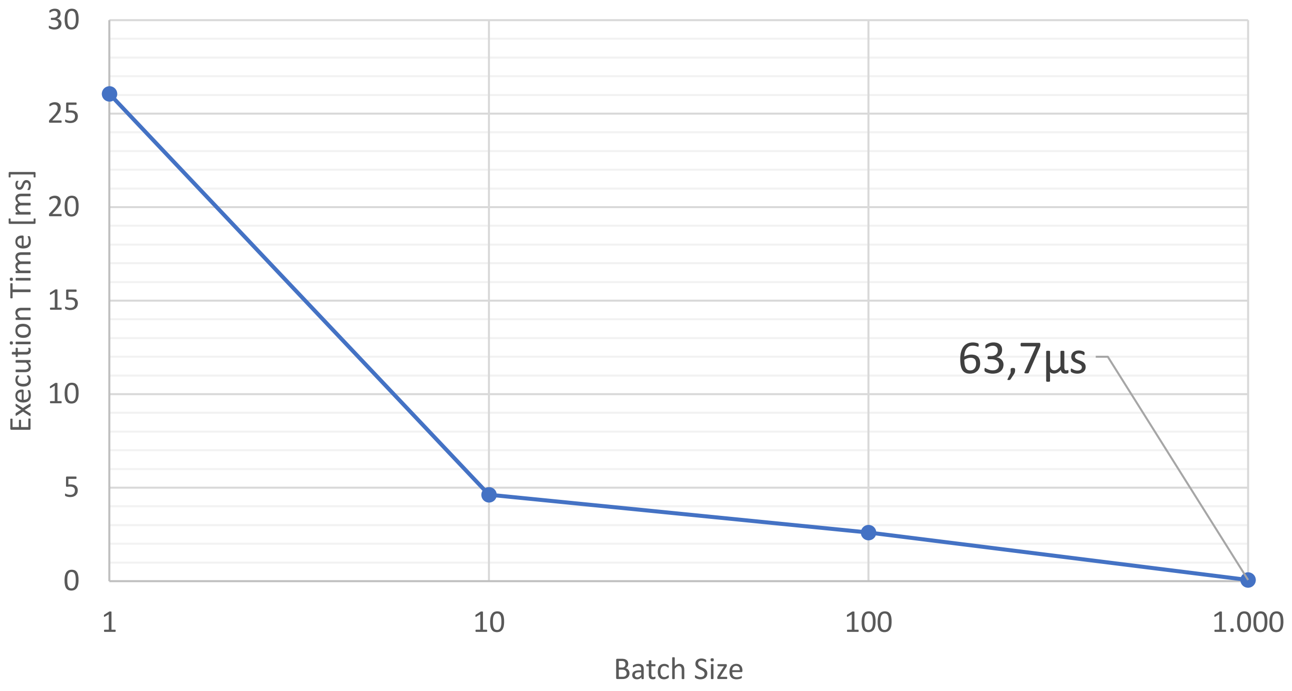
Low cost hardware

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

Implementation: GPU

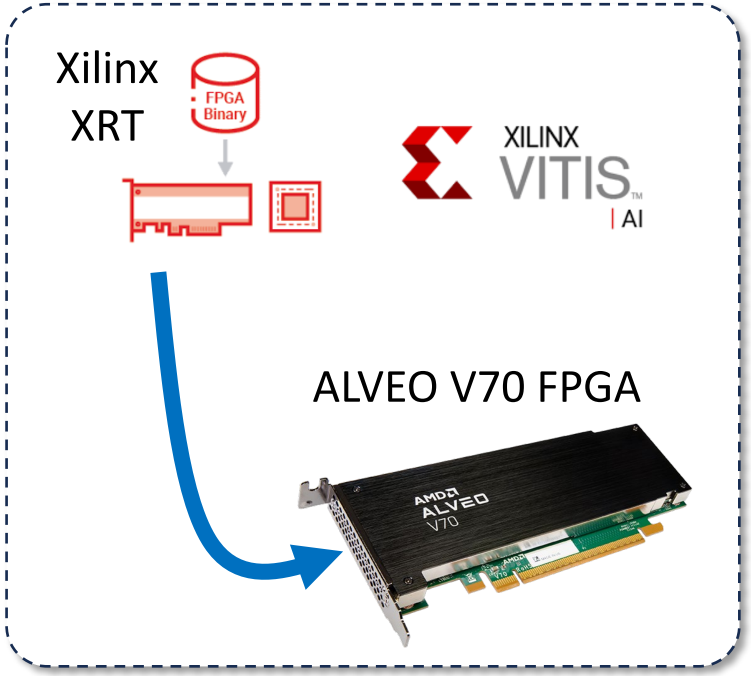
4 x NVIDIA Tesla V100 GPU

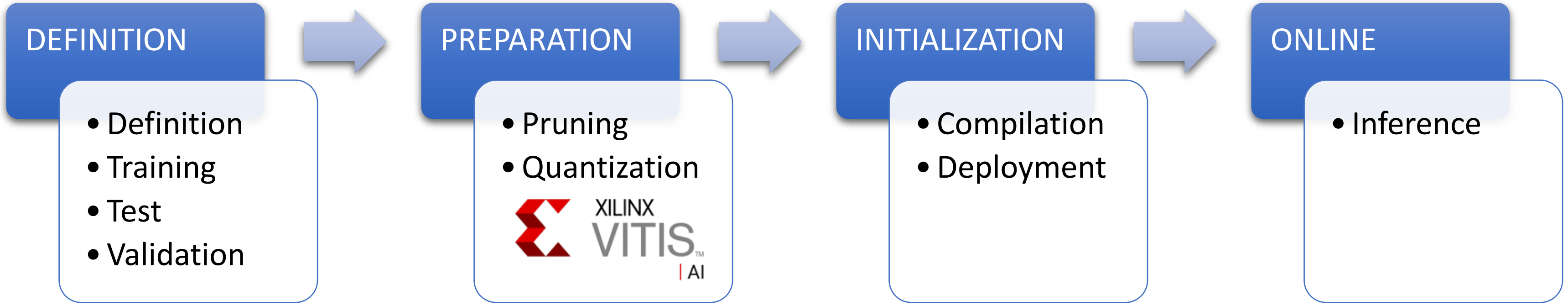
INFN CNAF



Execution time not enough for the application!

Implementation: FPGA





DEFINITION

- Definition
- Training
- Test
- Validation

PREPARATION

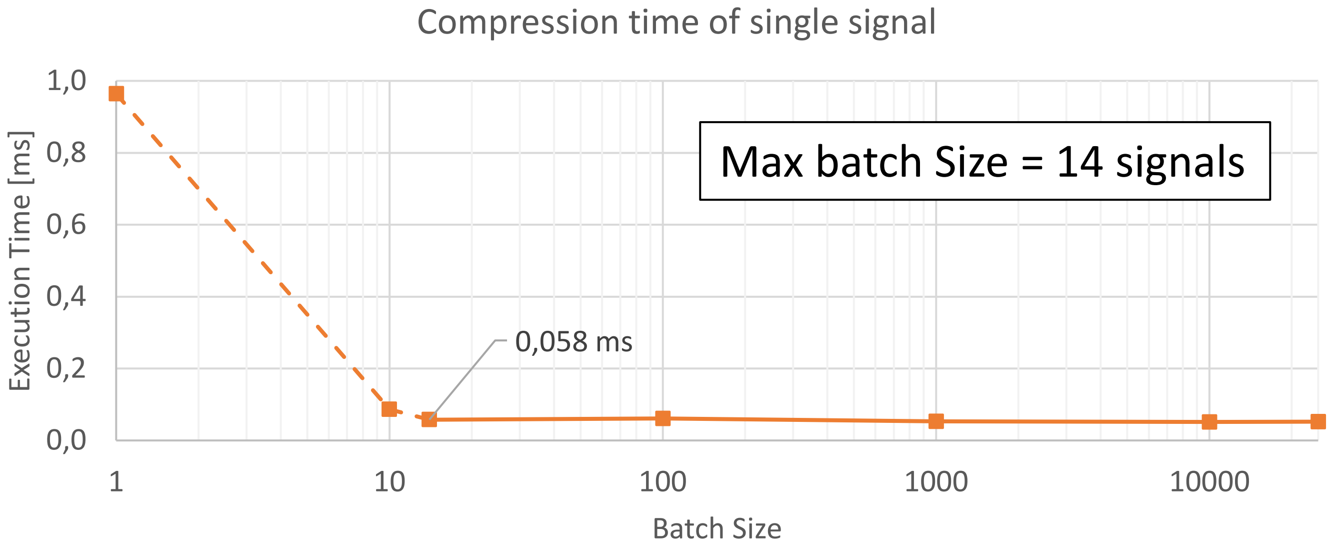
- Pruning
- Quantization

INITIALIZATION

- Compilation
- Deployment

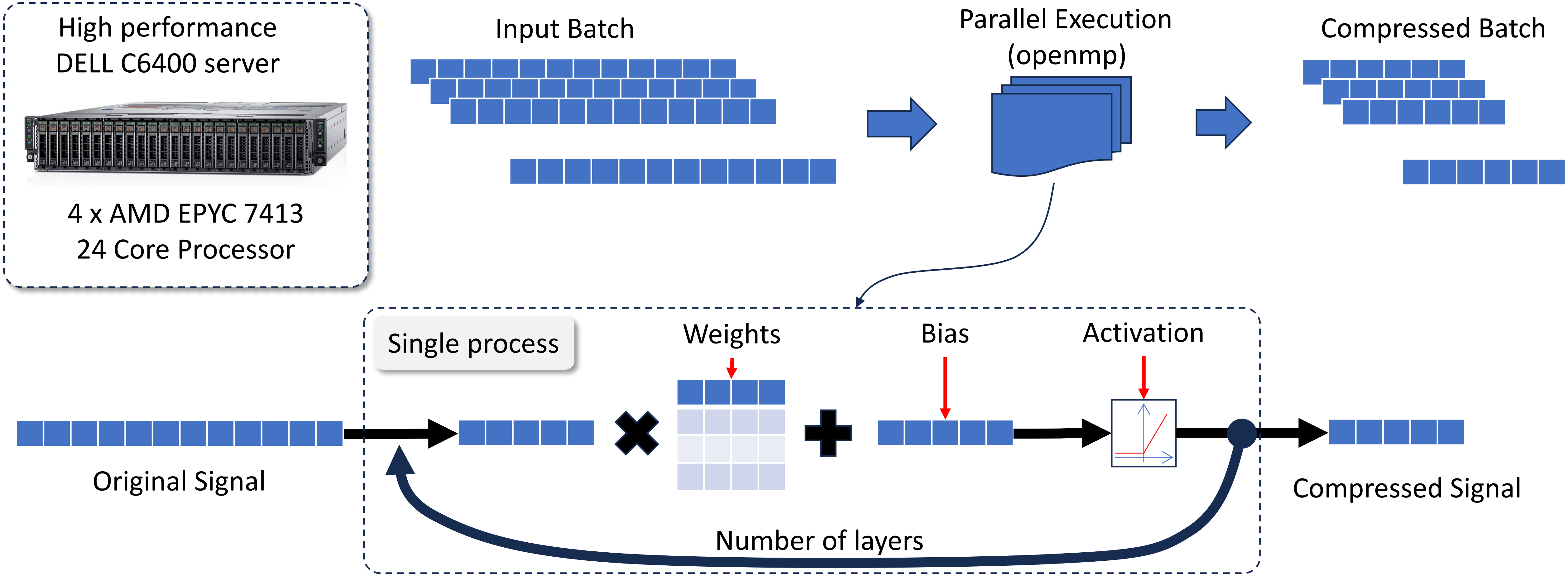
ONLINE

- Inference



Execution time still not enough for the application!

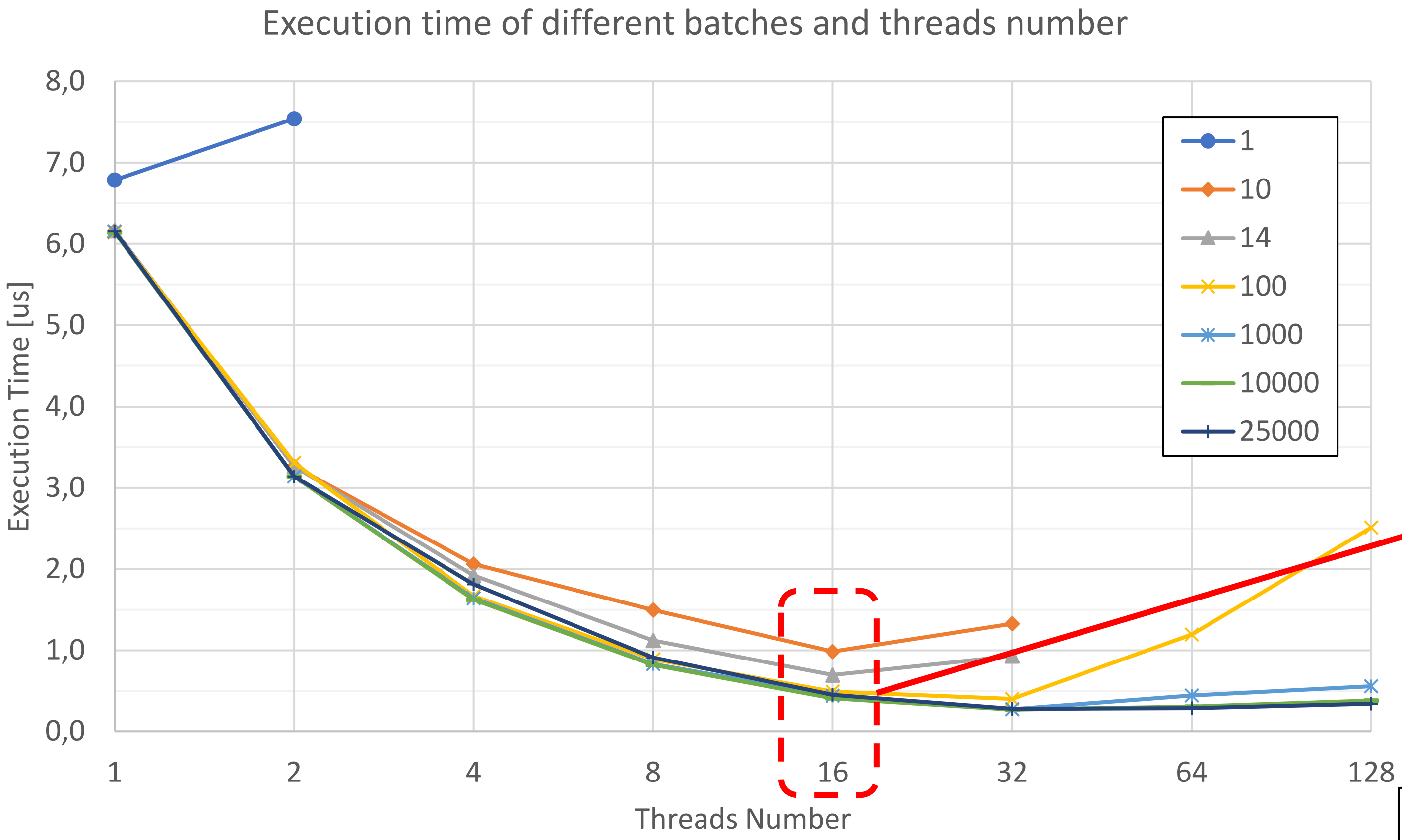
Implementation: High performance server

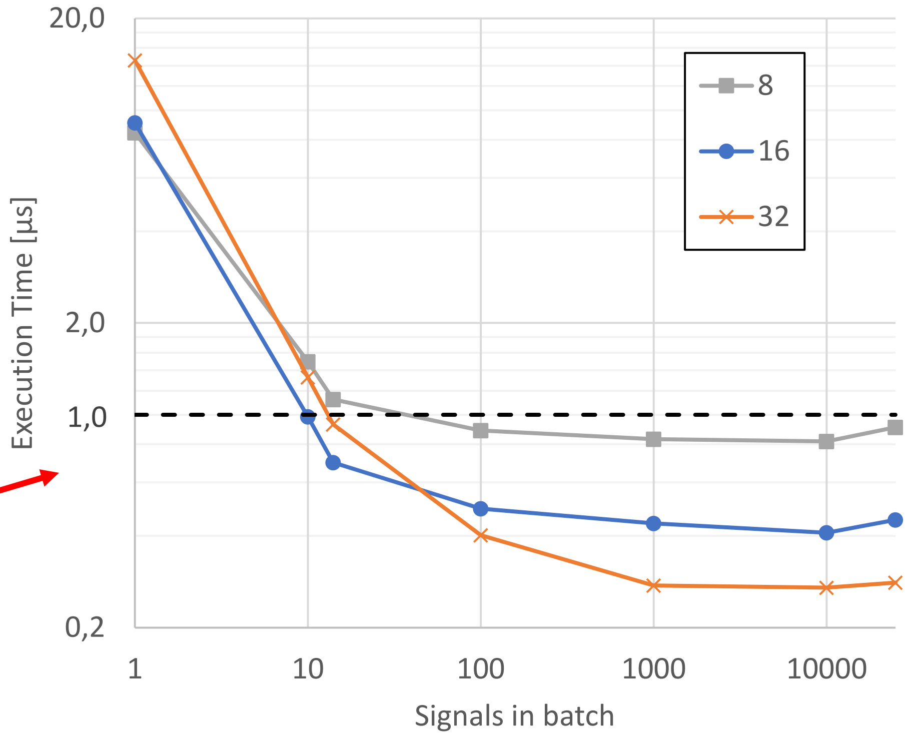


High performance DELL C6400 server

4 x AMD EPYC 7413 24 Core Processor

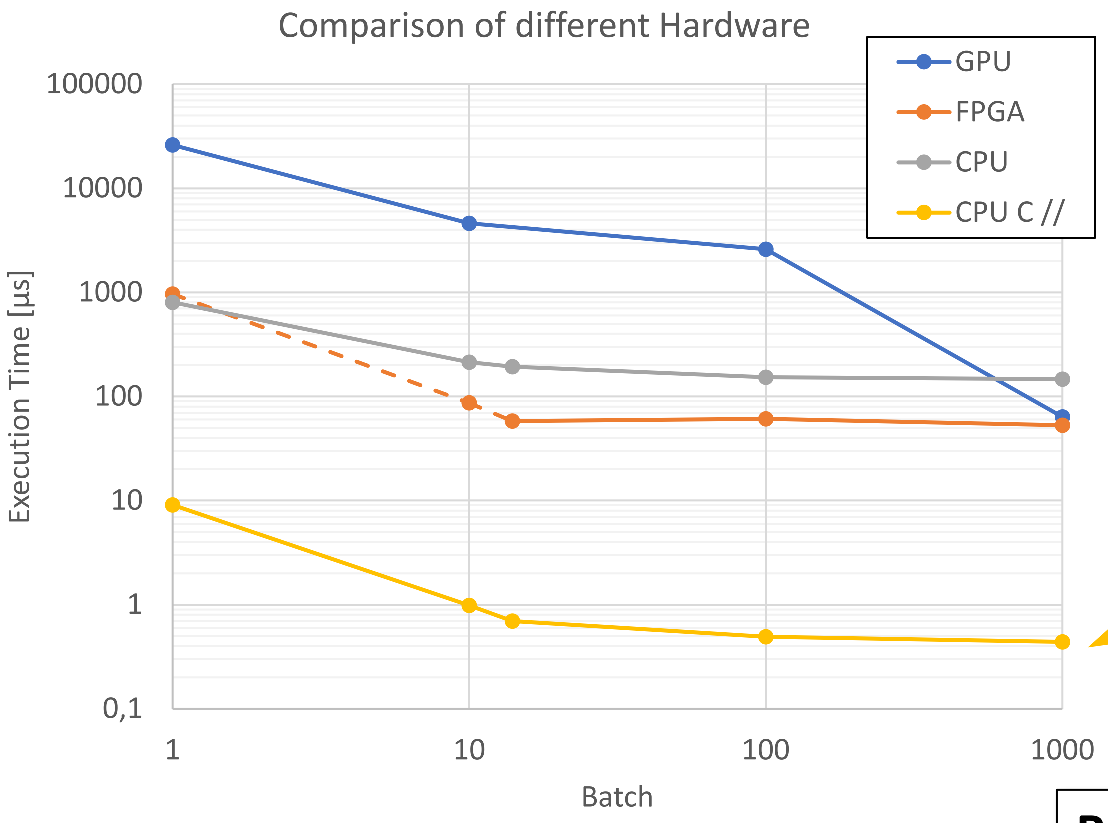
Implementation: High performance server

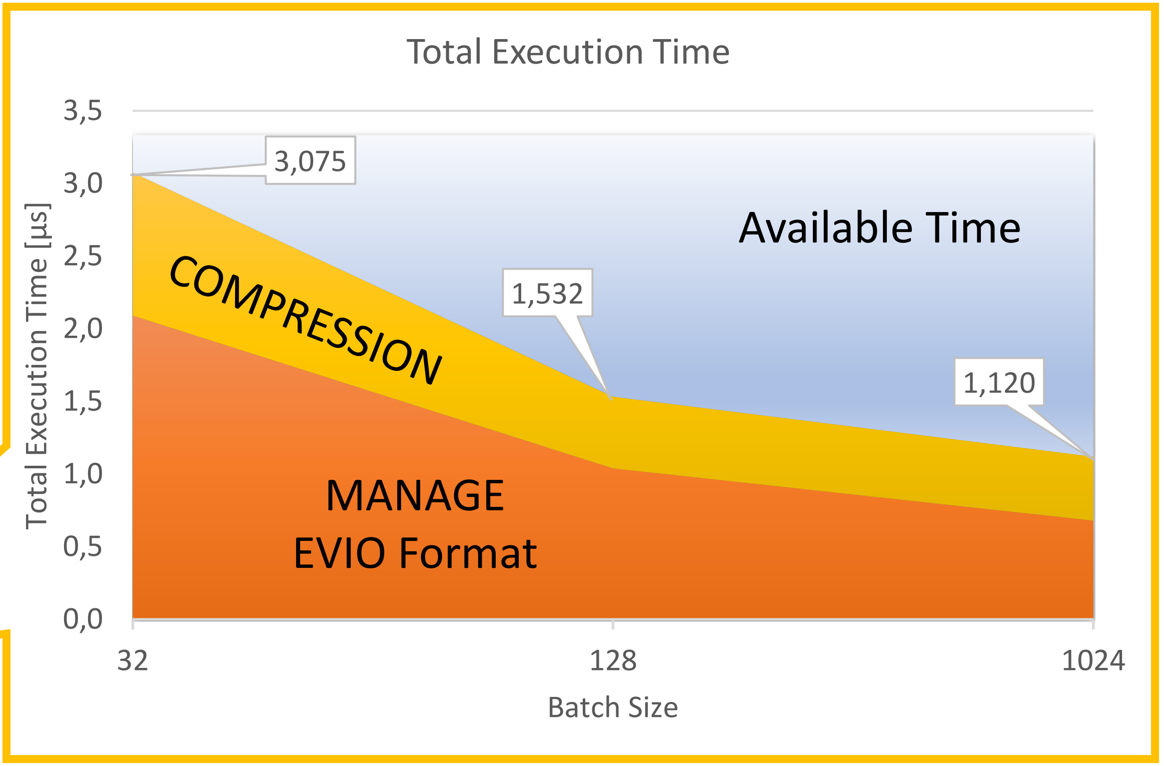




Chosen 16 Threads
Reasonable execution time for the application

Conclusion





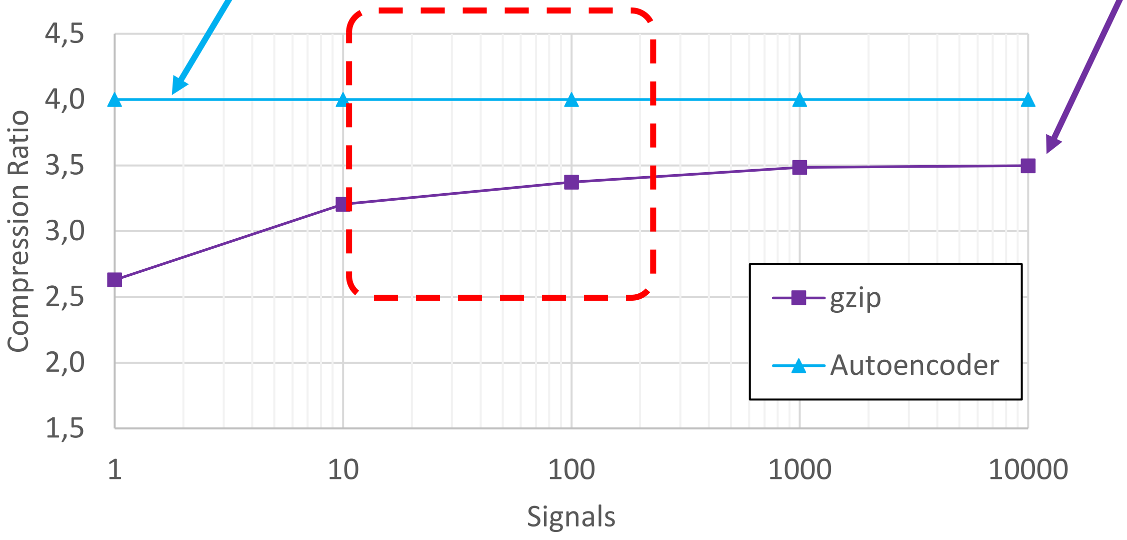
Rate can be managed for EVIO packet with at least 32 signals

Comparison with standard lossless compression

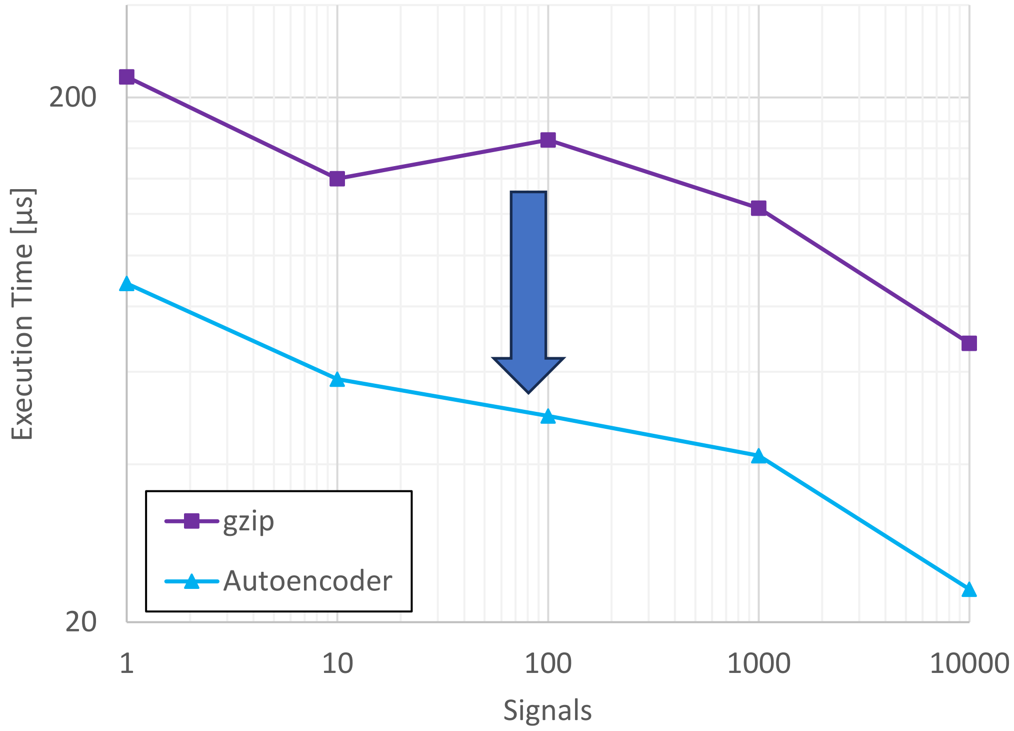
Autoencoder compression ratio is a Parameter

Gzip compression ratio depends on signals number

Working Zone



Better compression ratio



Better also on execution time

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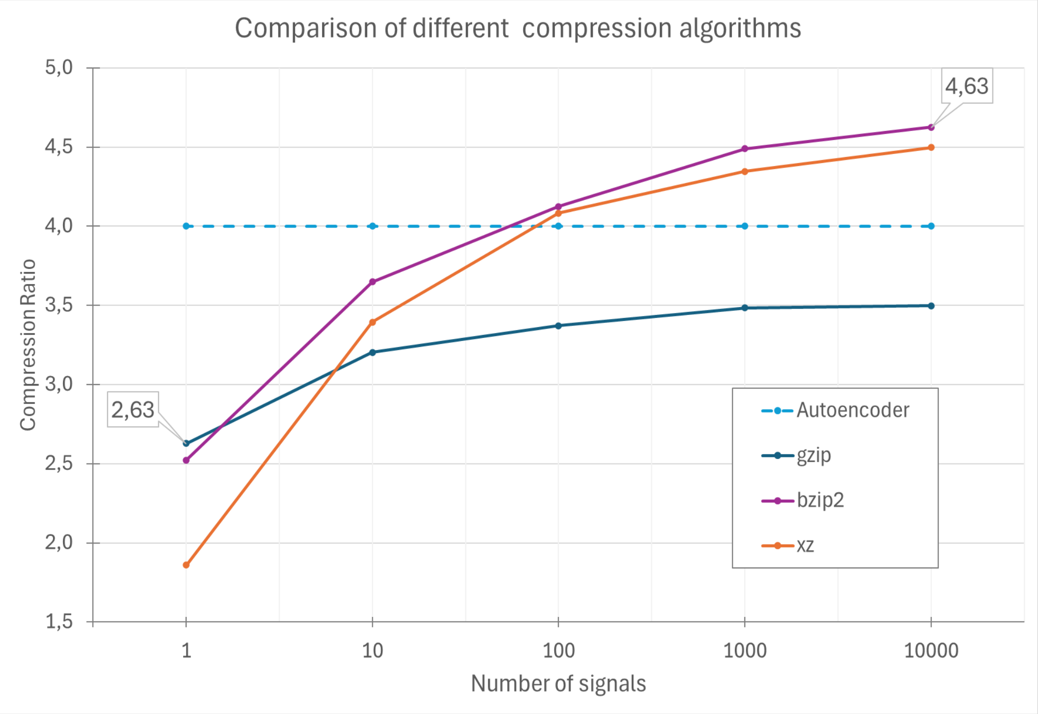
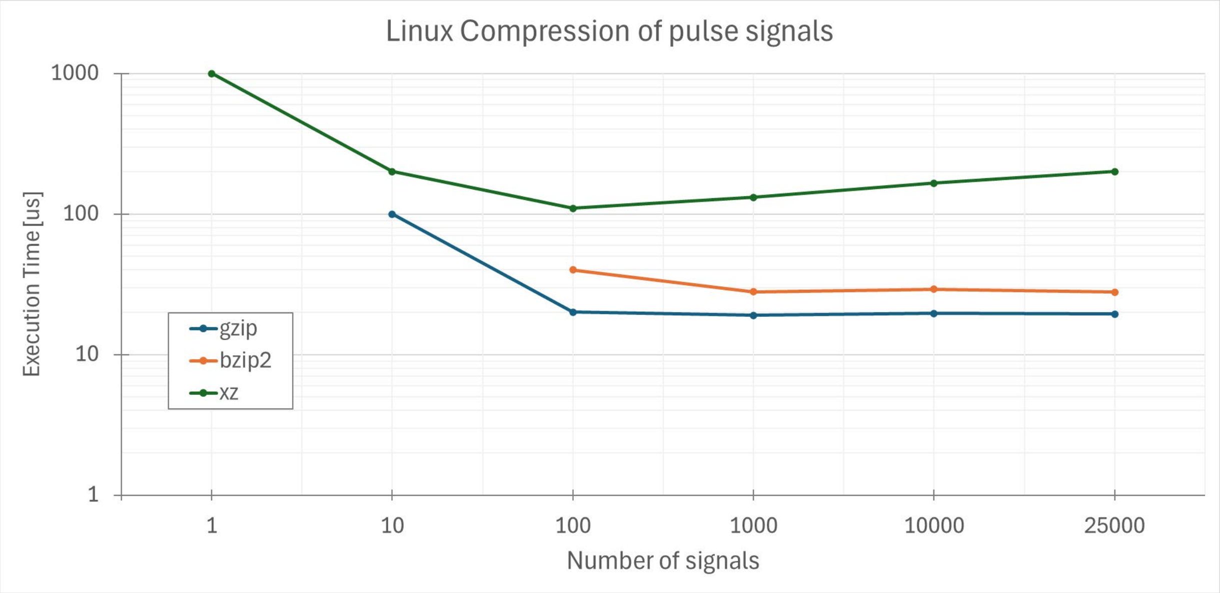
Comparison with standard lossless compression



High compression ratio with Bzip2 and X



bzip2

XZ

Very poor execution times:

bzip2	50% slower
XZ	10 times slower

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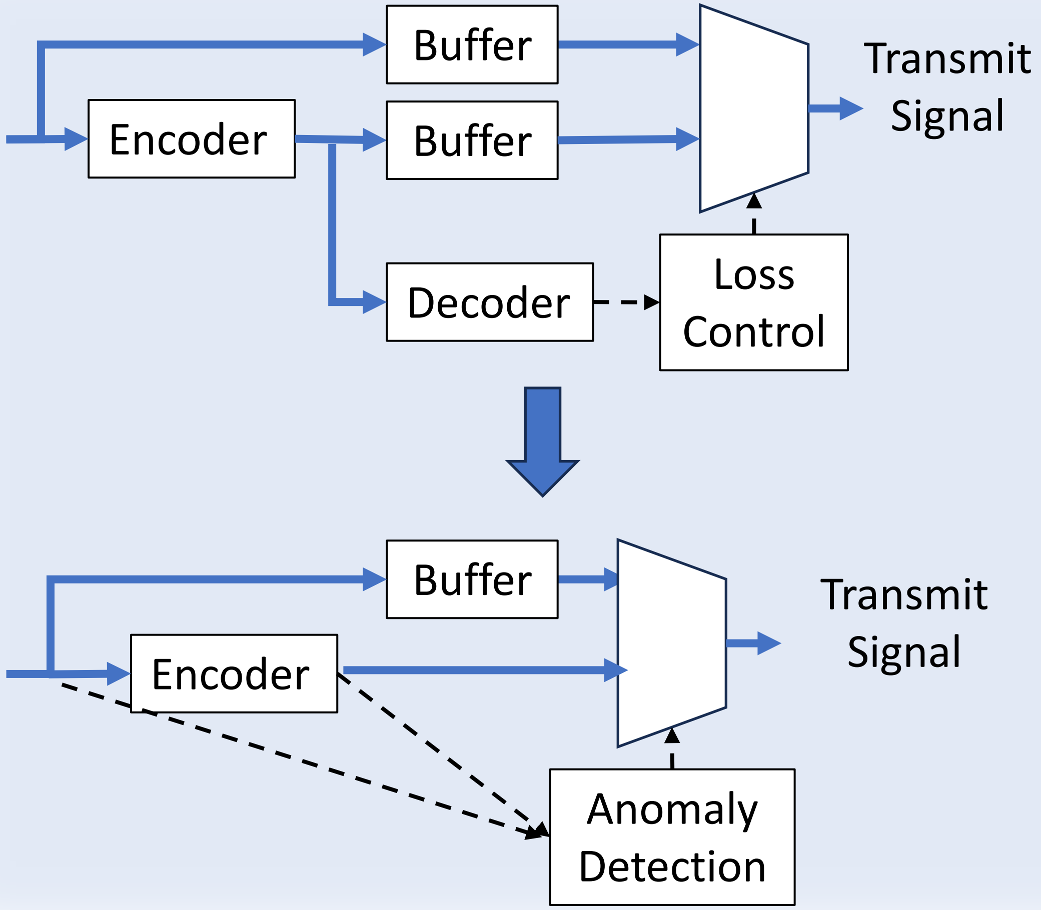
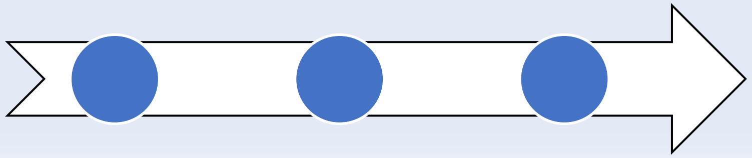
Further Studies



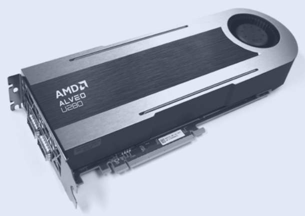
Reduce execution time removing the decoder

Statistical analysis of signals in each EVIO packets



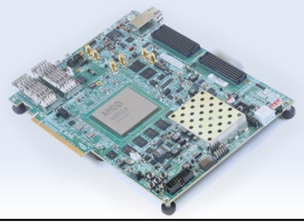
Estimate performance on real acquisition

Low level FPGA implementation



Dedicated connectivity (2xQSFP28 @ 100GbE)

…or very Low level



Reduce execution time and maybe save money

Thank you for your attention

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ACKNOWLEDGMENT

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