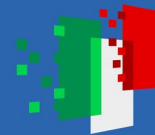




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Future
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AI for real time data processing

Digital Twins for Nuclear and Particle physics

NP-Twins 2025

October 6-8, 2025

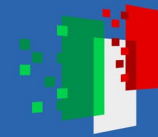
Università di Messina

Fabio Rossi

Istituto Nazionale di Fisica Nucleare
Genova (Italy)

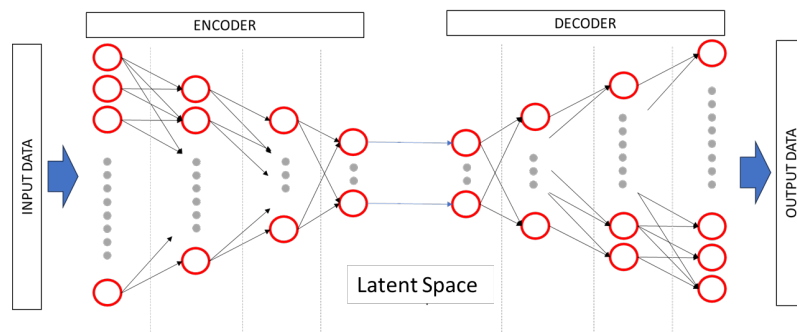


**Digital Twins for Nuclear and Particle Physics
NP-Twins 2025**

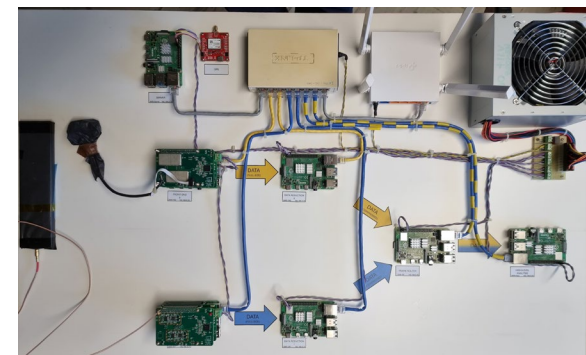


Outline

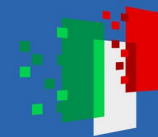
- Data Reduction
 - Autoencoder
 - Implementation
 - Results for CLAS12 data
 - Lossless compression
- Educational version of SRO
 - Description
 - Capability and Limitations
 - Data visualization
 - Research application



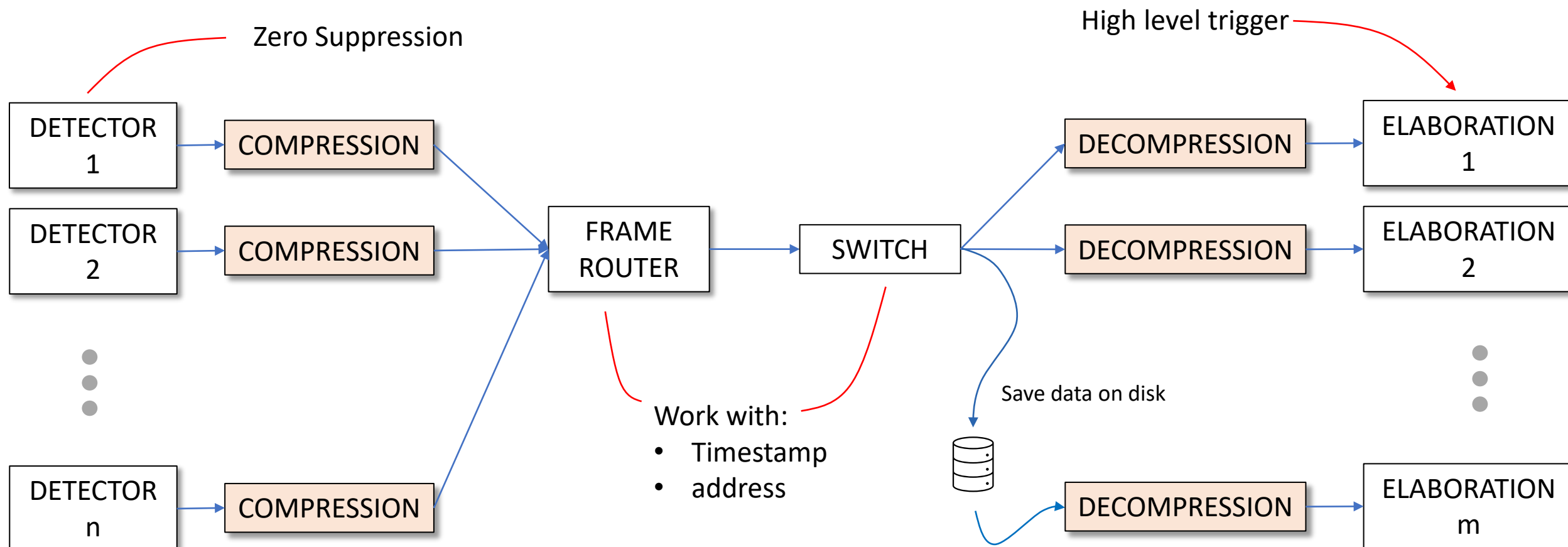
Fabio Rossi, Marco Battaglieri, Edoardo Ragusa, Paolo Gastaldo, Gagik Gavalian



Fabio Rossi, Marco Battaglieri, Stefano Grazzi



Streaming Readout block scheme





Data reduction algorithm: Autoencoder

Machine Learning Algorithm

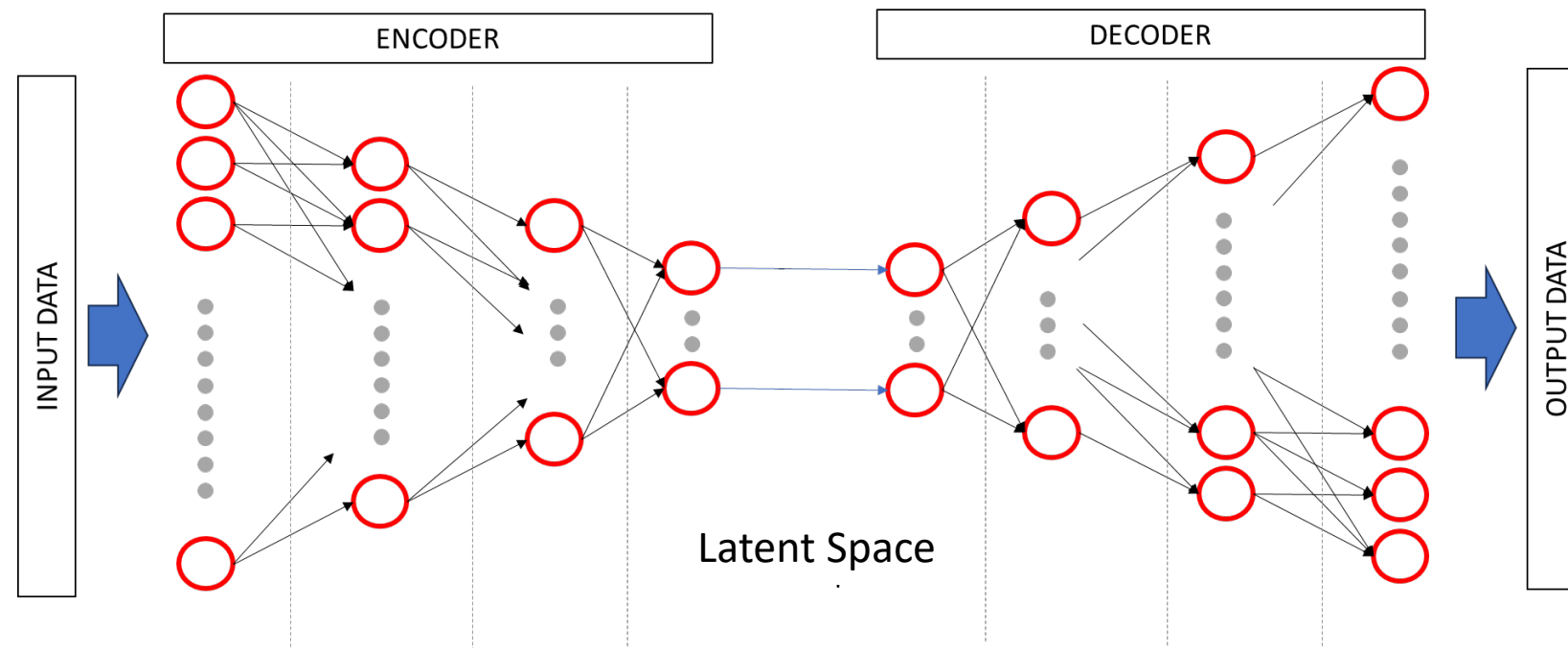
Dimensionality reduction

Unsupervised learning

Artificial Neural Network

Composed of two function:

- encoding
- decoding



FULLY CONNECTED AUTOENCODER WITH DENSE LAYER

Lossy compression algorithm

Rossi F., Battaglieri M., Ragusa E., Gastaldo P., Gavalian G.

“Artificial intelligence data reduction algorithm for streaming readout in high energy physics experiment”

The 2024 World Congress in Computer Science, Computer Engineering, and Applied Computing https://doi.org/10.1007/978-3-031-85856-7_5



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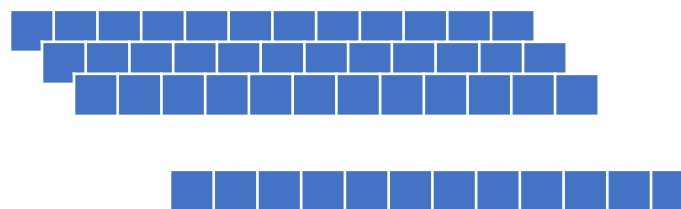
Implementation: High performance server

High performance
DELL C6400 server

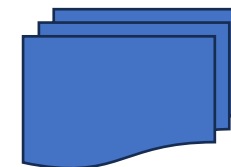


4 x AMD EPYC 7413
24 Core Processor

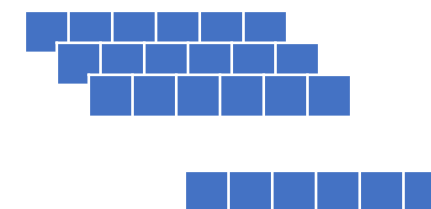
Input Batch



Parallel Execution
(OpenMP)



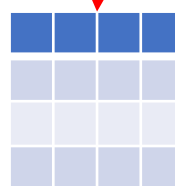
Compressed Batch



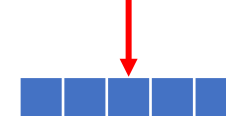
Original Signal

Single process

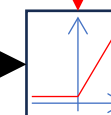
Weights



Bias

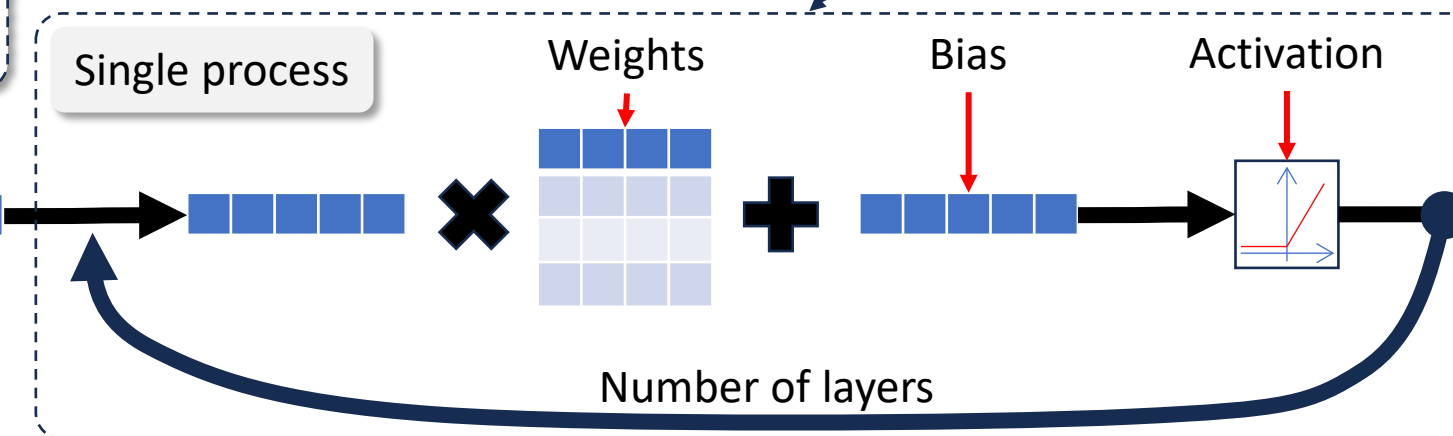


Activation



Compressed Signal

Number of layers



Rossi F., Battaglieri M., Gavalian G., Ragusa E., Gastaldo P.
"Real Time implementation of Artificial Intelligence compression algorithm for High-Speed Streaming Readout signals"
Conference on Computing in High Energy and Nuclear Physics CHEP 2024

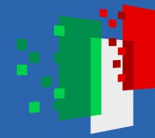
Compression of 1 signal in 1 μ s



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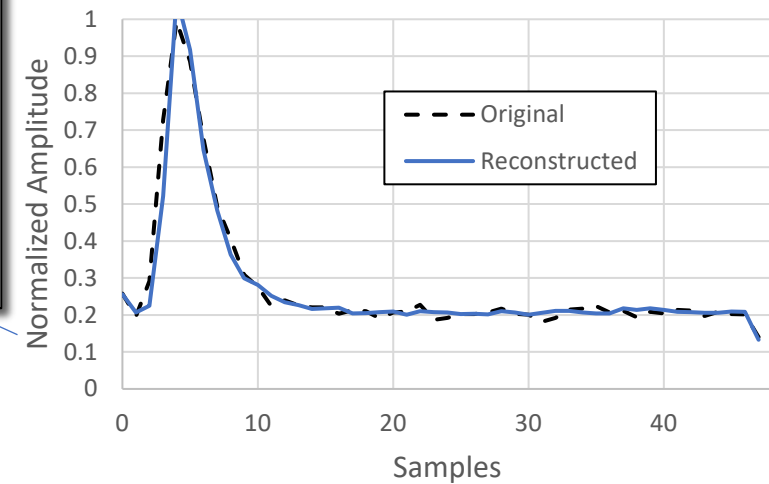
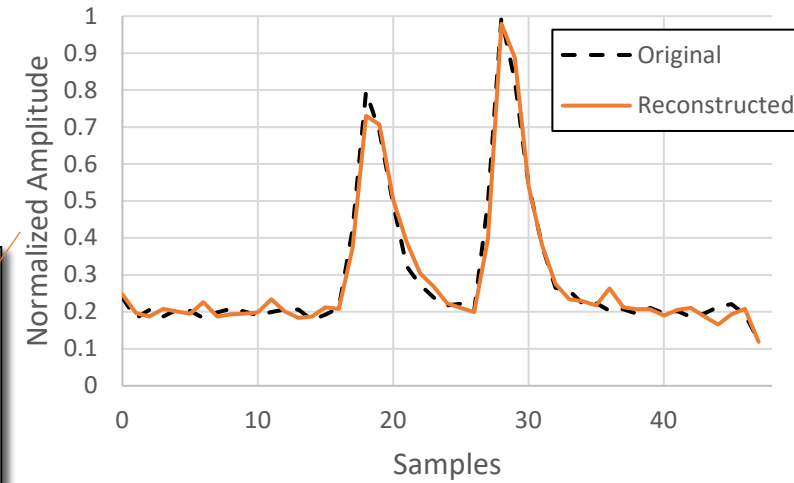
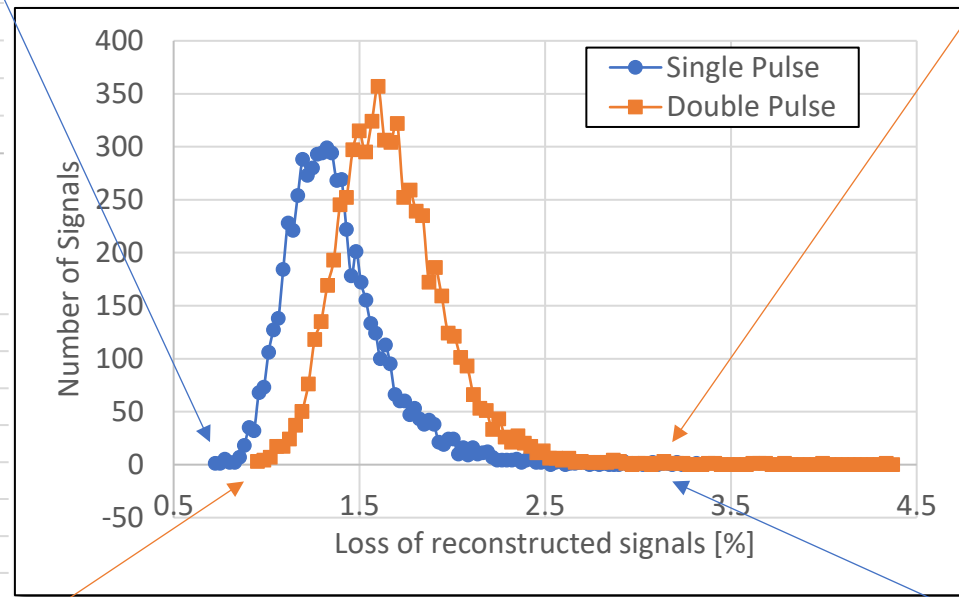
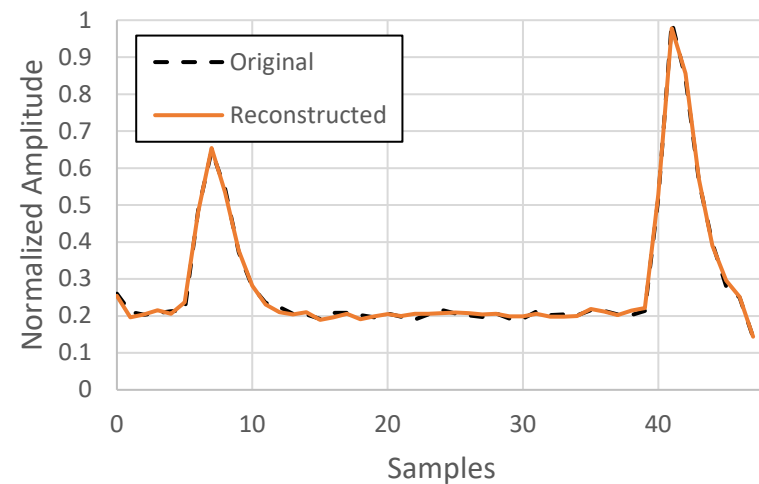
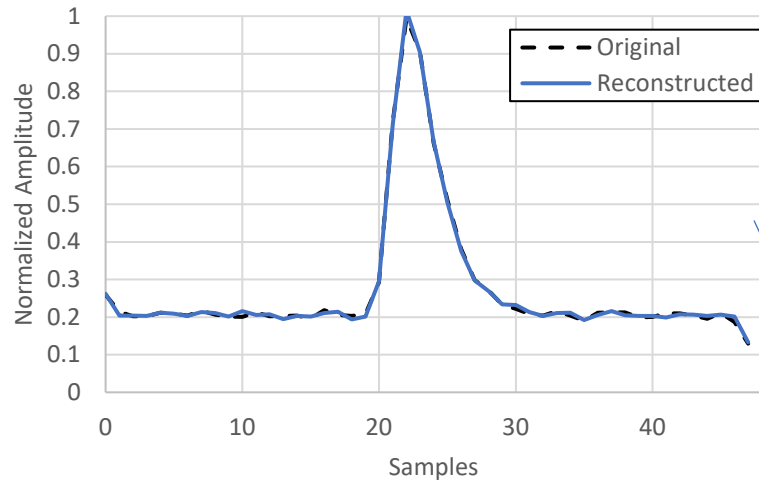


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Signals Compression

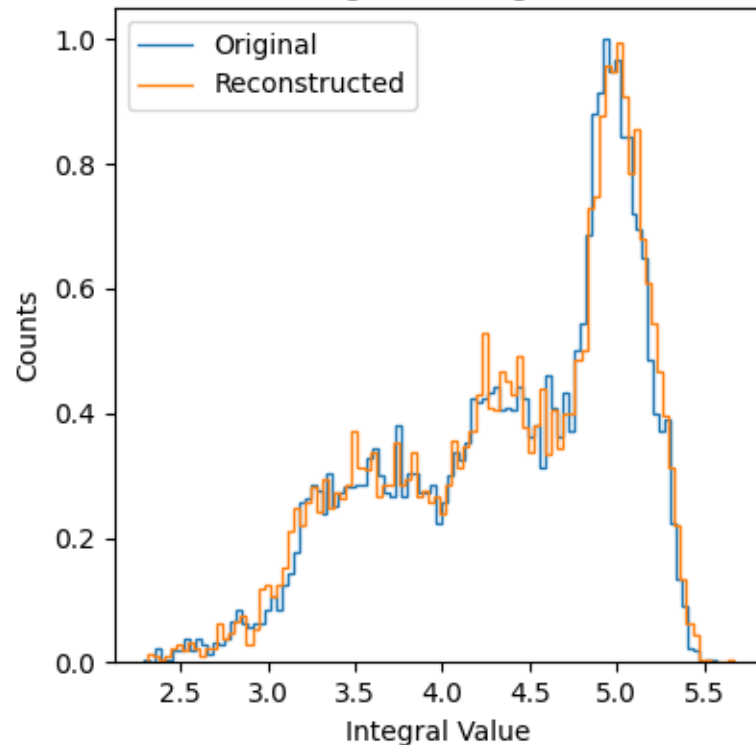


Data from CLAS12

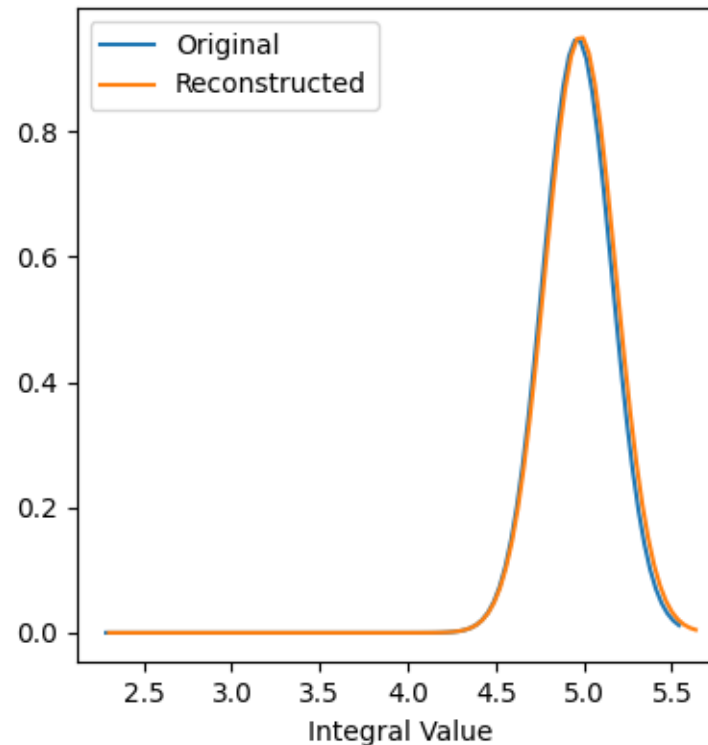


Signals Compression: Integral and spectrum of CLAS12 Data

Integrals histogram



Best Fit



	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

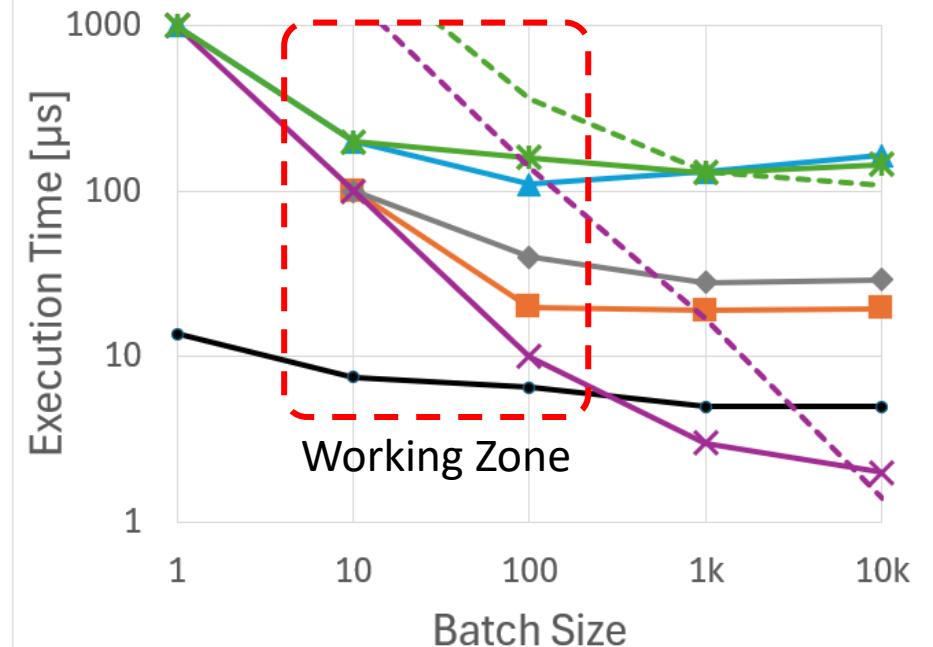
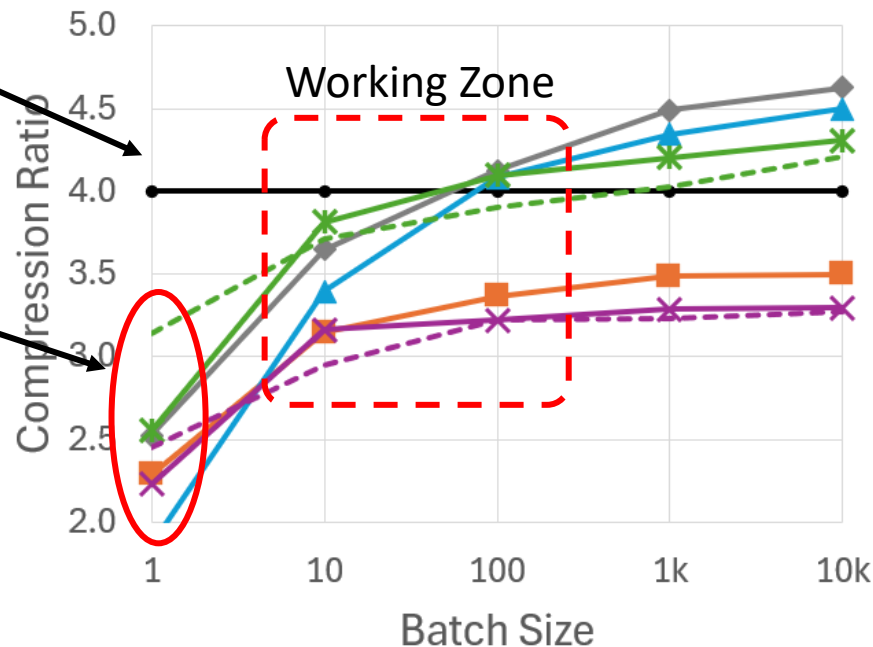


Comparison with standard lossless compression

Autoencoder compression
ratio is a Parameter

Standard compression ratio
depends on signals number

Better compression ratio



Autoencoder

Gzip

bzip2

XZ

Zstd(L1)

Zstd(L19)

Zstd(L1, Dictionary)

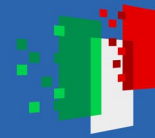
Zstd(L19, Dictionary)



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Educational Version of SRO

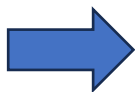
Main Goals:

- SNRI Class in November
- Students Stages
- Outreach activities in general

But could also be useful for research

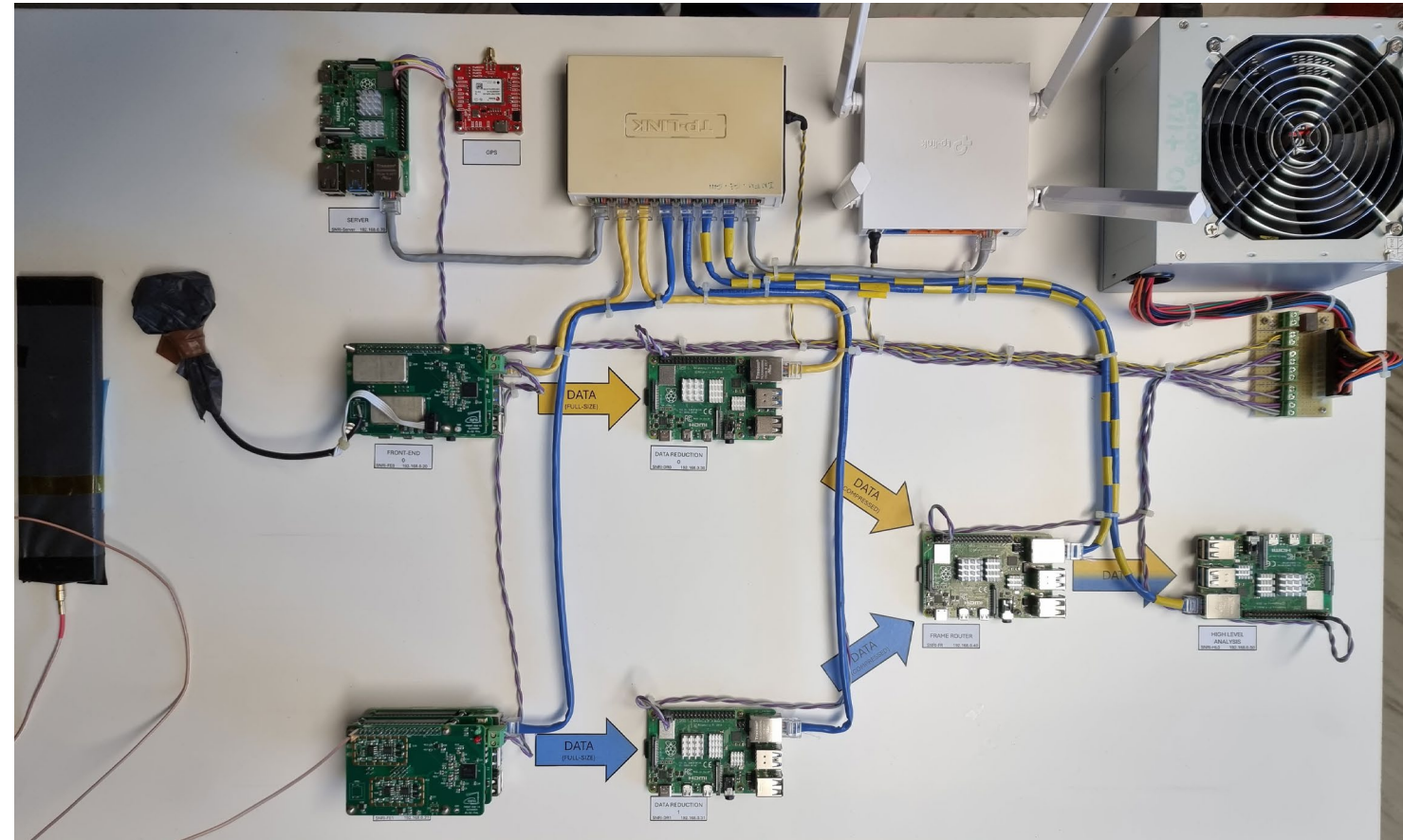
- Understand overall behavior of SRO
- Easy testbench for ideas/algorithm
- Study bottleneck

Raspberry



- In scale system
- Reduced performance

Reduced performance but not in functionality

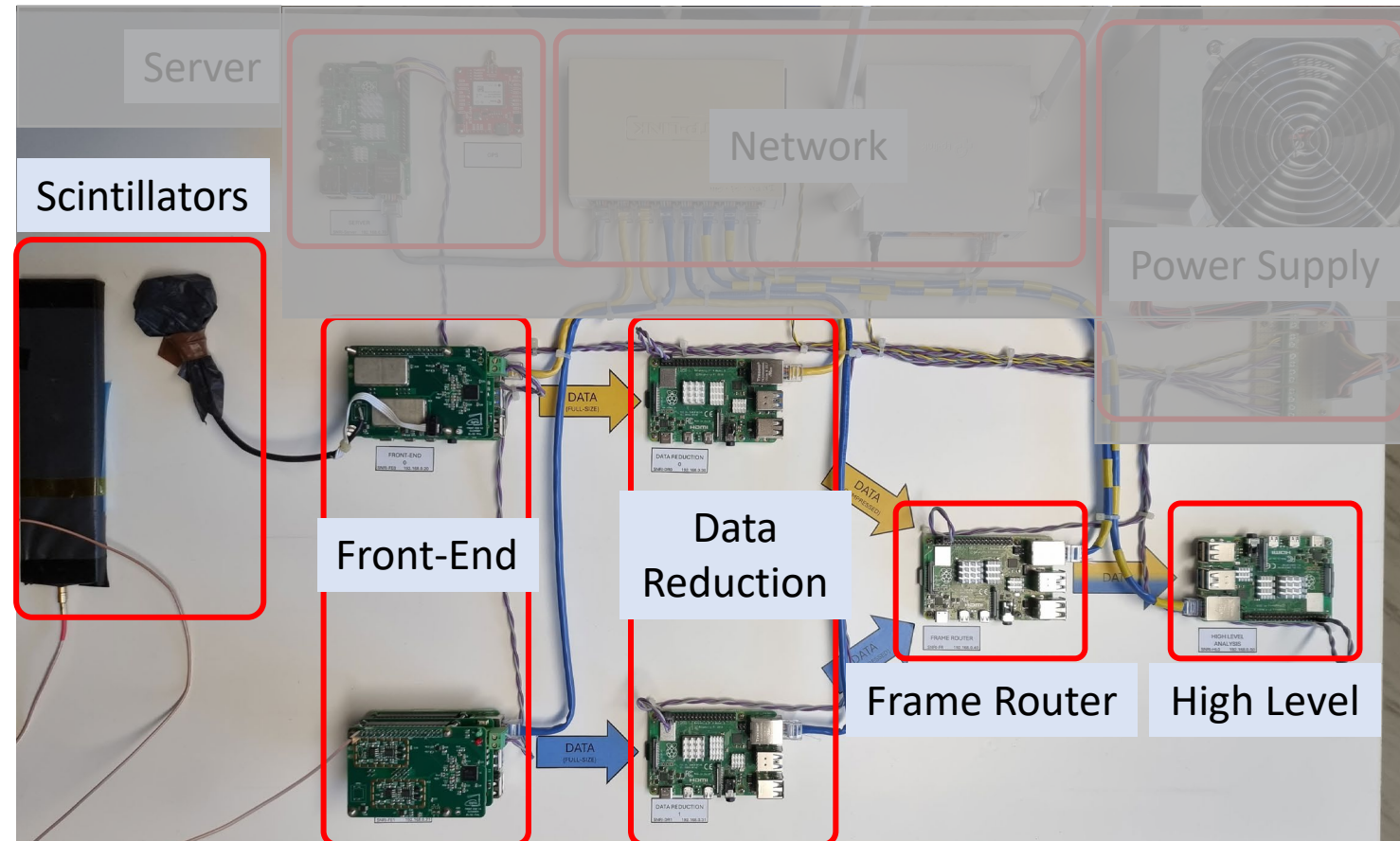




Educational Version of SRO: Data path

- Scintillators
 - Different type: BGO, CsI(Tl)
- Front-End
 - 10MS/s 12 bit 2 channels
 - Bias 24 to 81 Vdc
 - Voltage, current or charge preamplifier
- Data Reduction
 - Autoencoder
- Frame Router
 - Standard implementation
- High Level
 - High level trigger: check for coincidence

All nodes are fully customizable with C code

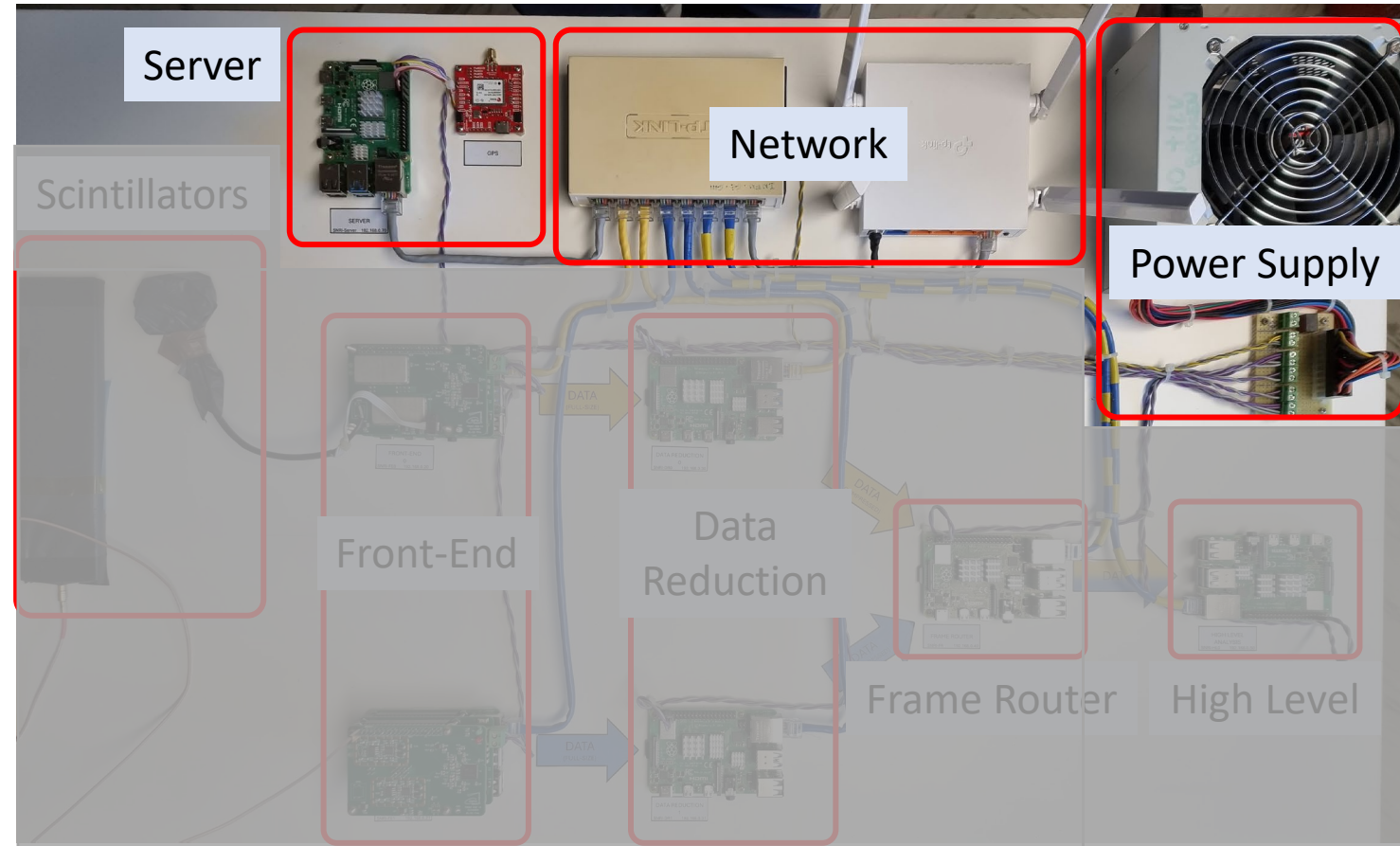


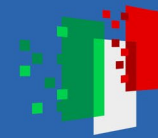


Educational Version of SRO: Aux

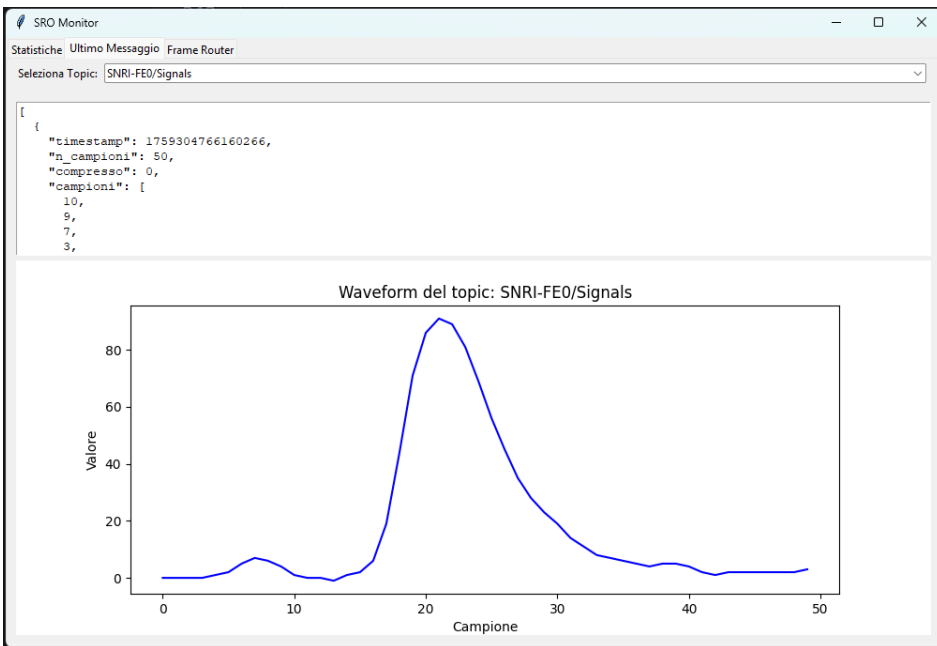
- Server
 - Timing NTP
 - Global time with GPS
 - Broker MQTT
- Network
 - Star connection
 - Possible to access each part easily
 - Wi-Fi or Ethernet
- Power Supply
 - 5V, 12V, 9V

Synchronization, global timing and networking

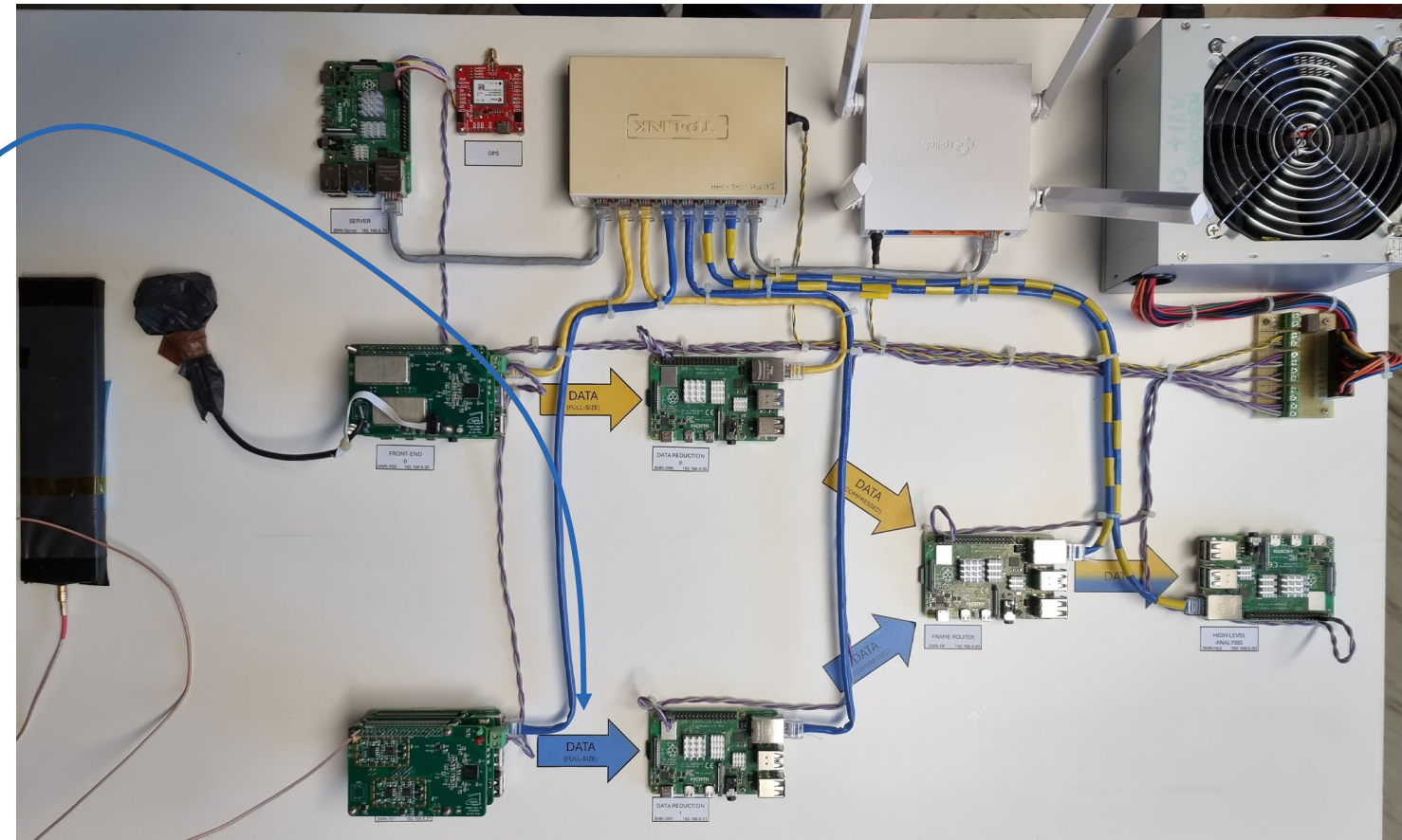




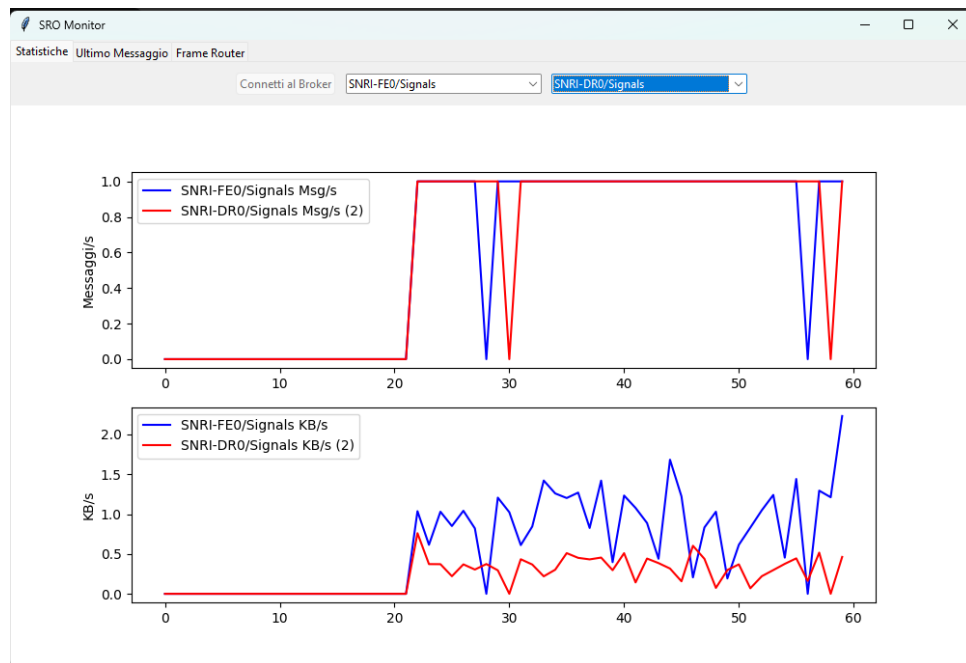
Educational Version of SRO: Front-End



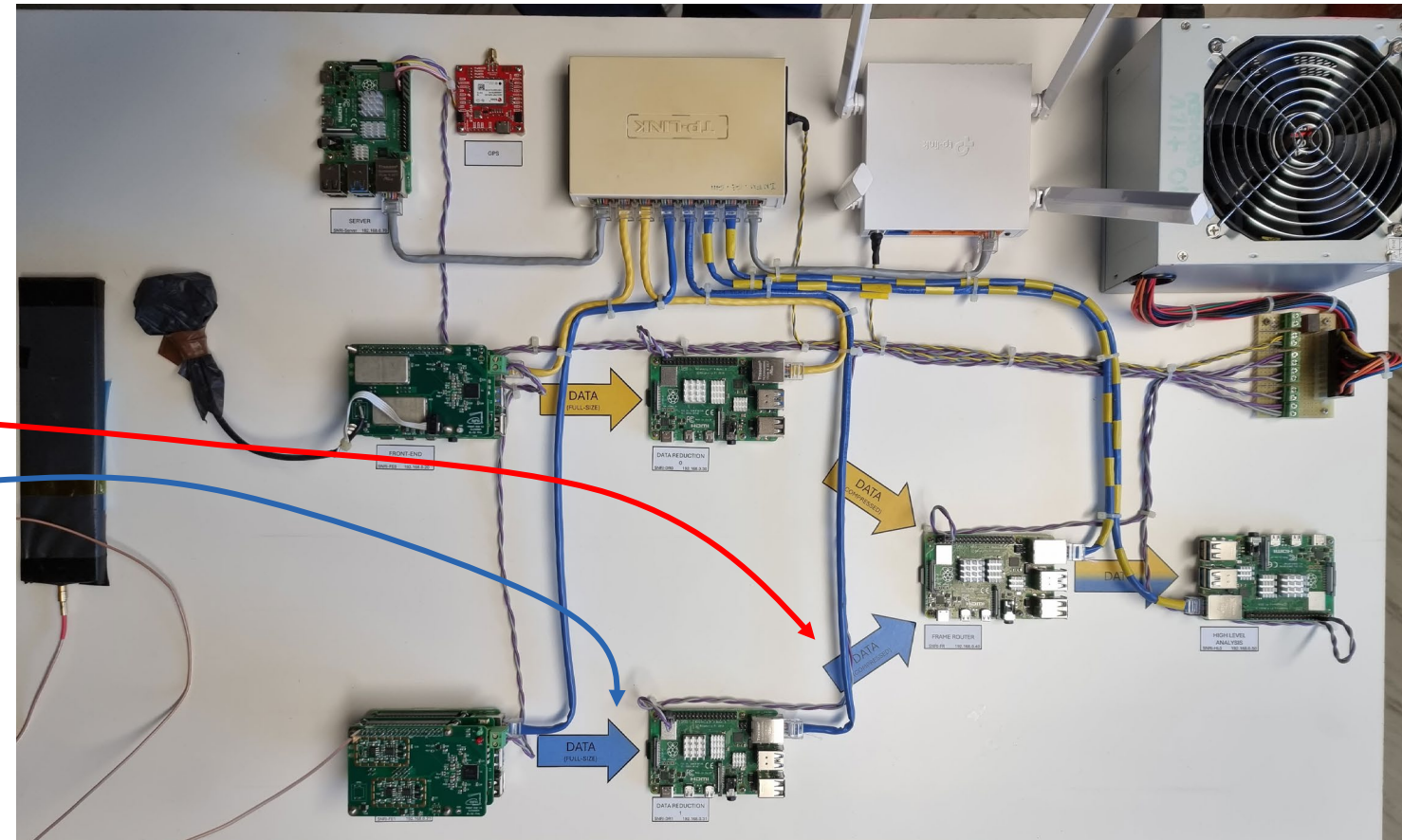
View single acquired signals



Educational Version of SRO: Data Reduction



Verify data reduction performance real-time

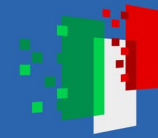




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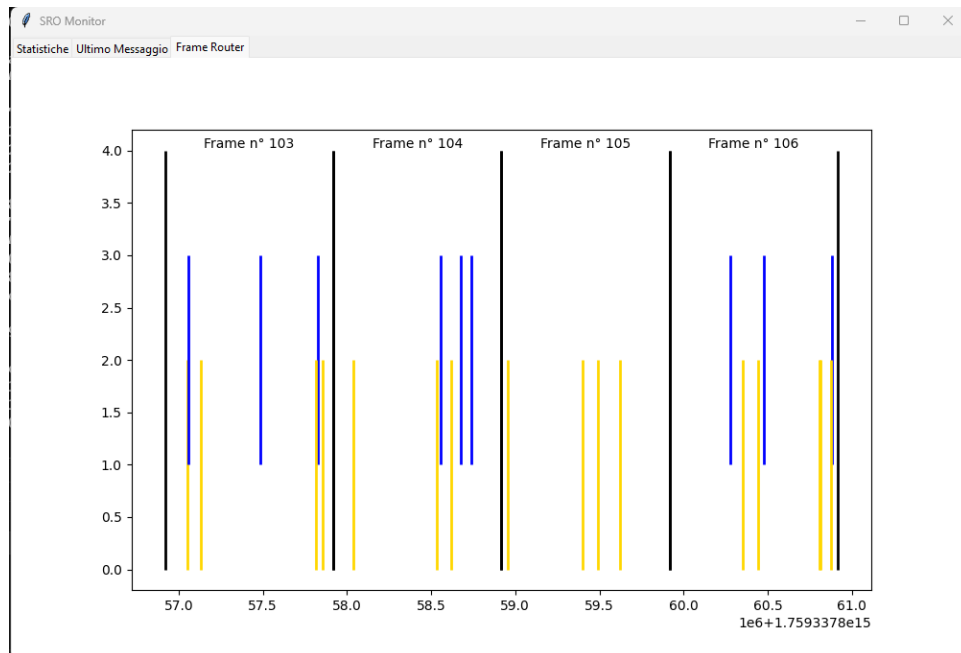


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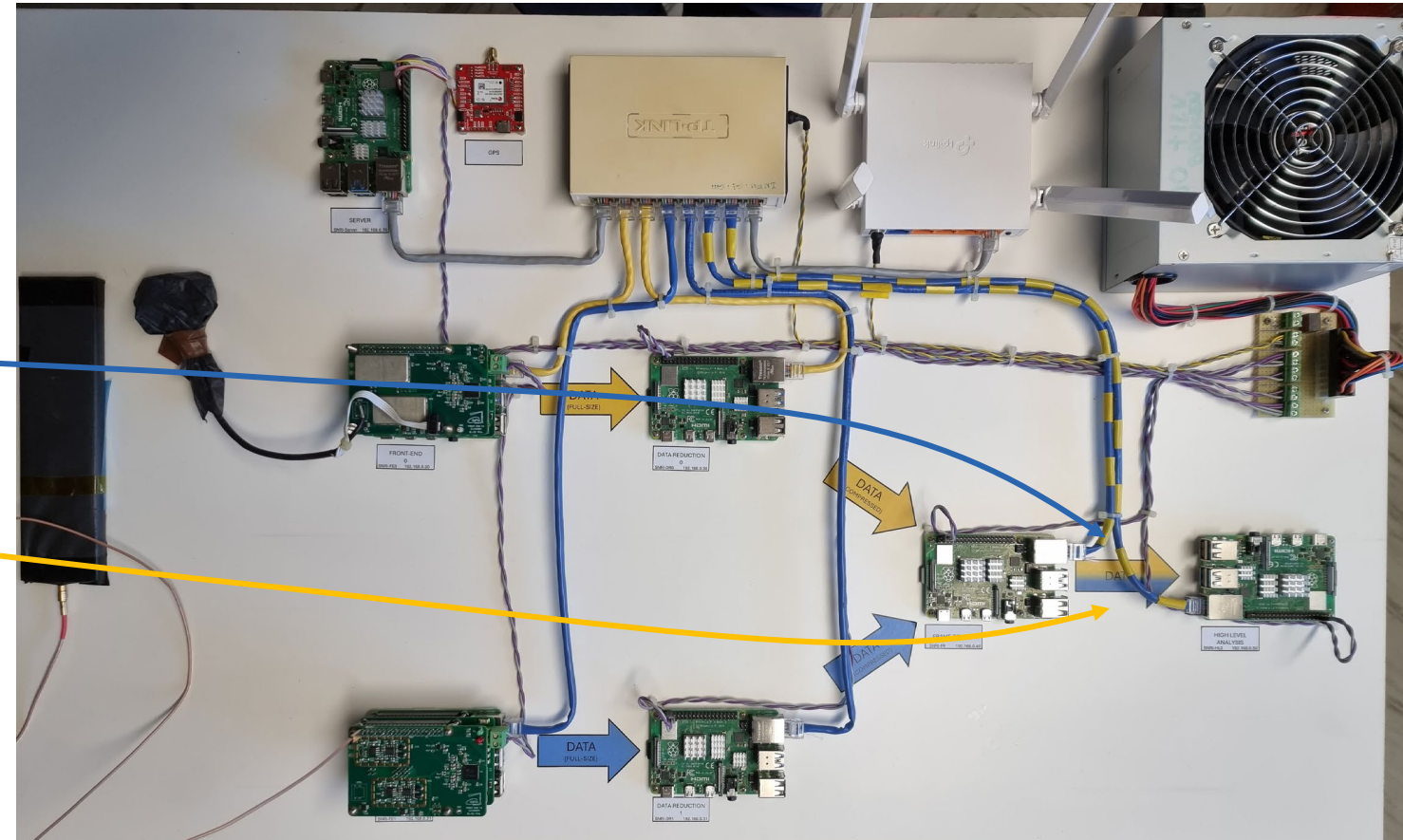


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Educational Version of SRO: Frame Router



Frame Router functionality





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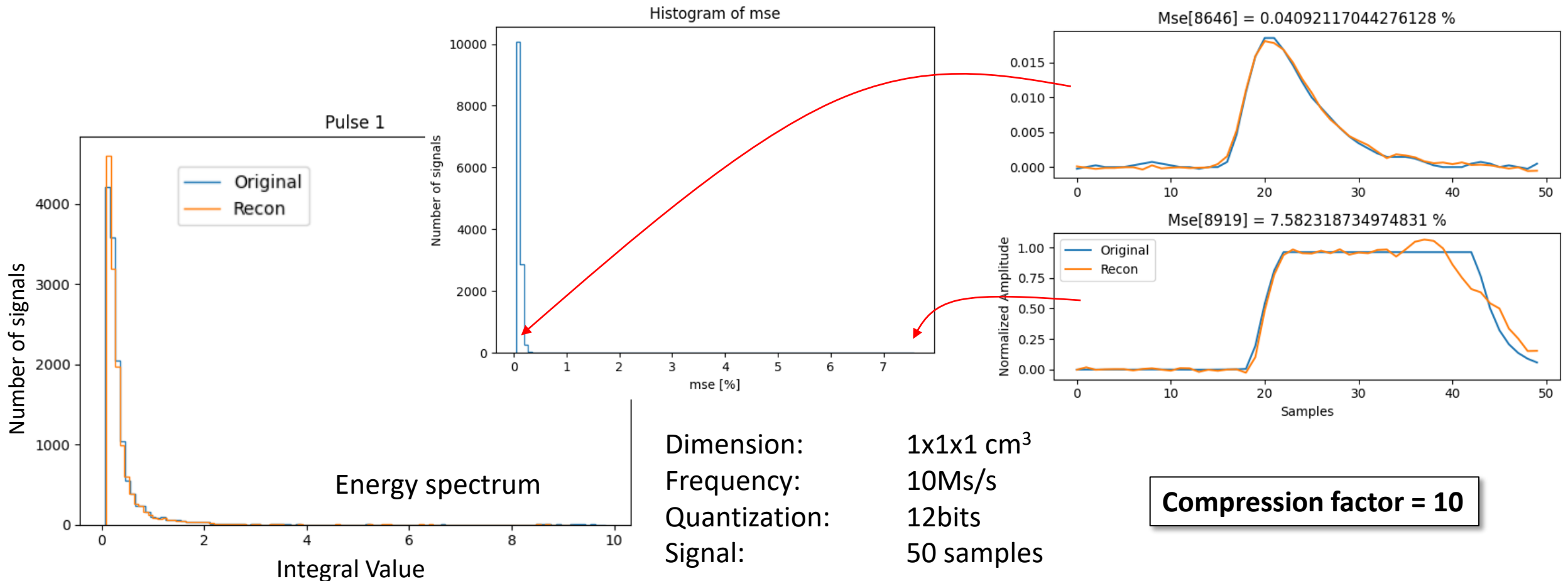


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Preliminary study on data compression: BGO





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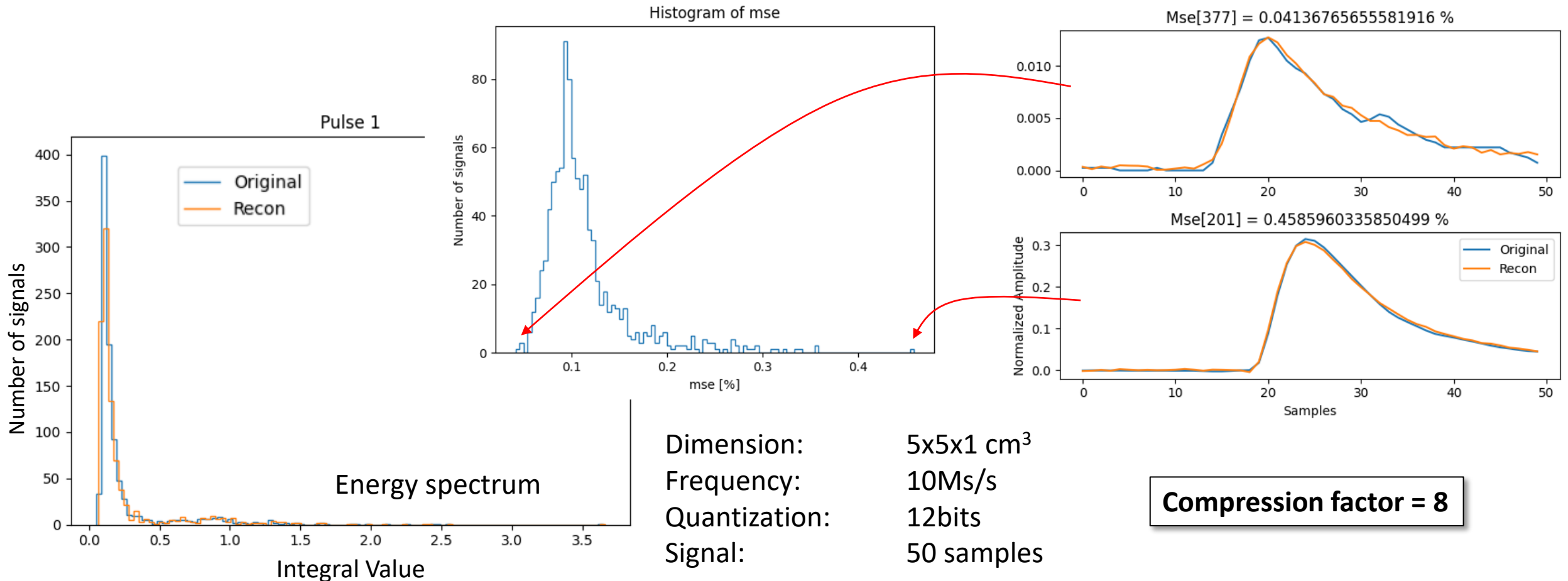


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Preliminary study on data compression: Csl(TI)





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Thank you for your attention



FUTURE AI RESEARCH

<https://fondazione-fair.it>



<https://www.jlab.org>



<https://www.ge.infn.it>



<https://sealab.unige.it>

ACKNOWLEDGMENT

Authors have received support from: **FAIR - Future Artificial Intelligence Research, funded by the European Union Next-Generation EU (Italy)Research) – spoke 6.**