Memristive tabular variational autoencoder

for compression of analog data in high energy physics

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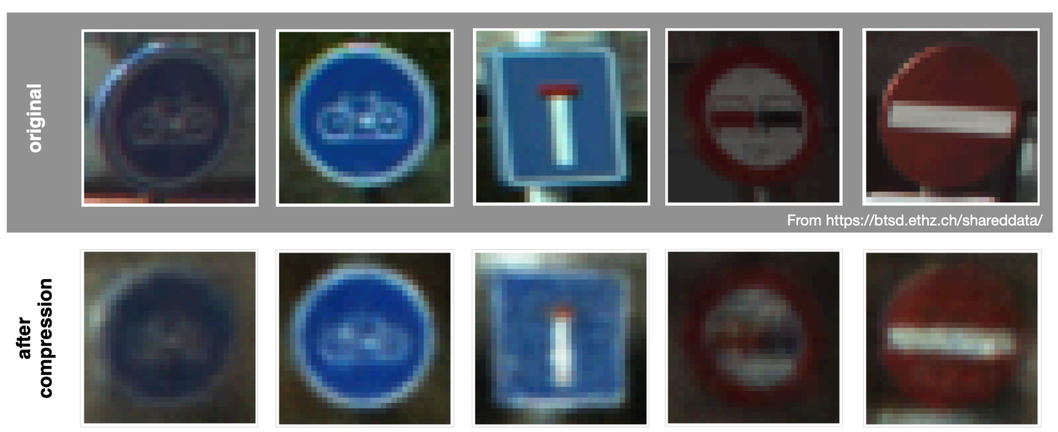
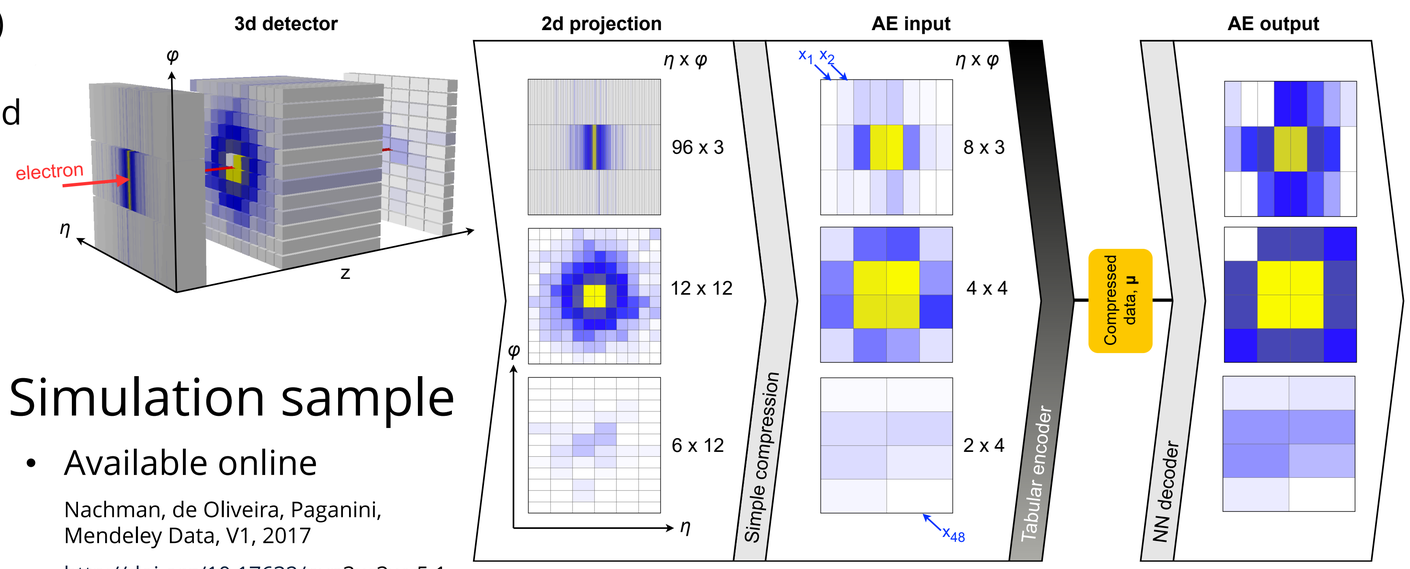
Useful info

- *Preprint* arXiv: 2602.15990
- *Keywords* memristor, analog content addressable memory (ACAM) in-memory computing (IMC), knowledge distillation
- *Example* Belgian street sign images compressed using our method



Setup at future collider experiment, a study

- 1 - 100 GeV e^+ on a generic 3-layer calorimeter



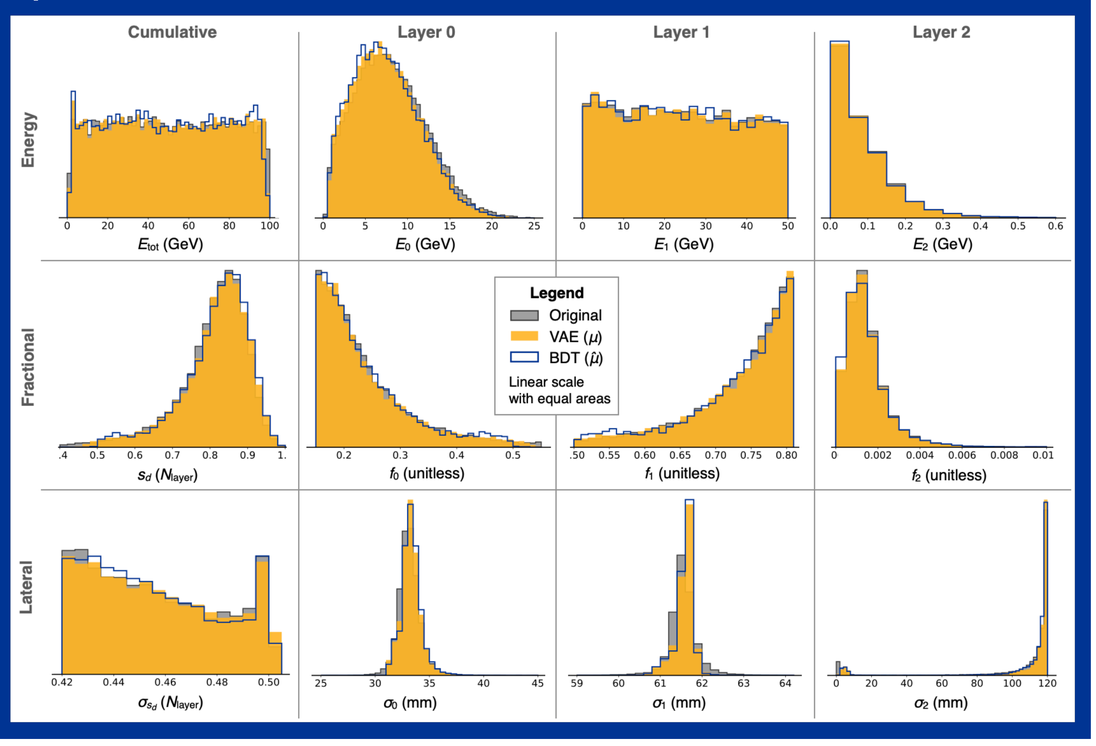
Simulation sample

- Available online

Nachman, de Oliveira, Paganini, Mendeley Data, V1, 2017

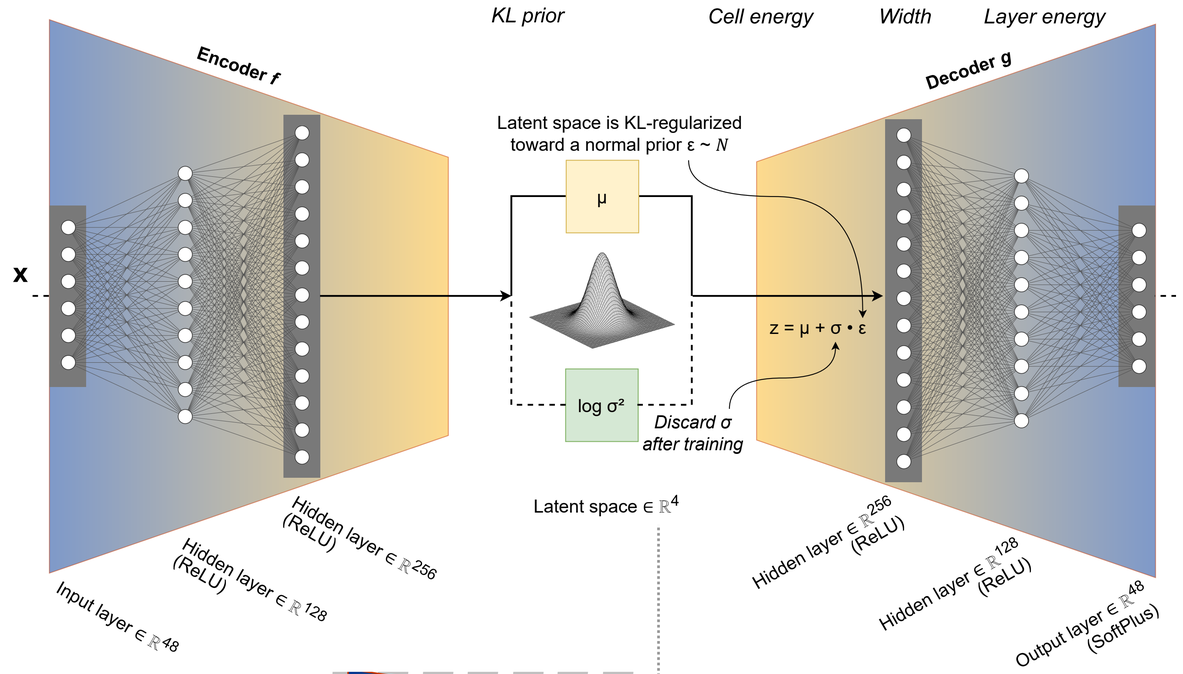
http://doi.org/10.17632/pvn3xc3wy5.1

Input variables are analog values, not digitized



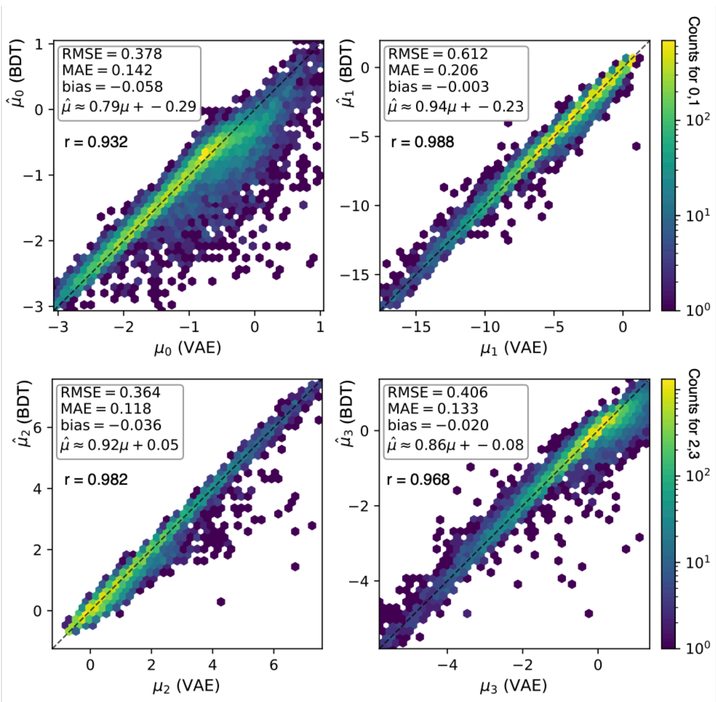
Variational Autoencoder with a normal constraint in latent space

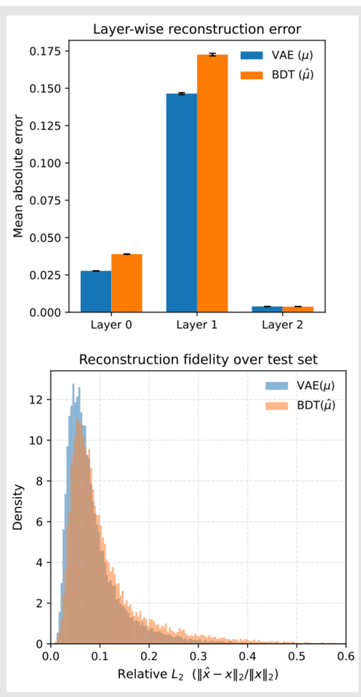
- Physics-informed loss function $\mathcal{L}(\mathbf{x}, \hat{\mathbf{x}}) = \beta \cdot D_{\mathrm{KL}}\left(q \,\|\, \mathcal{N}\right) + \sum_{\ell} \left(\lambda_\ell \cdot \mathcal{L}_\delta(x_\ell) + \alpha_\ell \cdot \mathcal{L}_\sigma(\sigma_\ell) + \gamma_\ell \cdot \mathcal{L}_E(E_\ell) \right)$



Physics results vs. full VAE model

- High correlation between pre- vs. post-distillation
- Reconstruction error similar to full VAE model





Knowledge Distillation

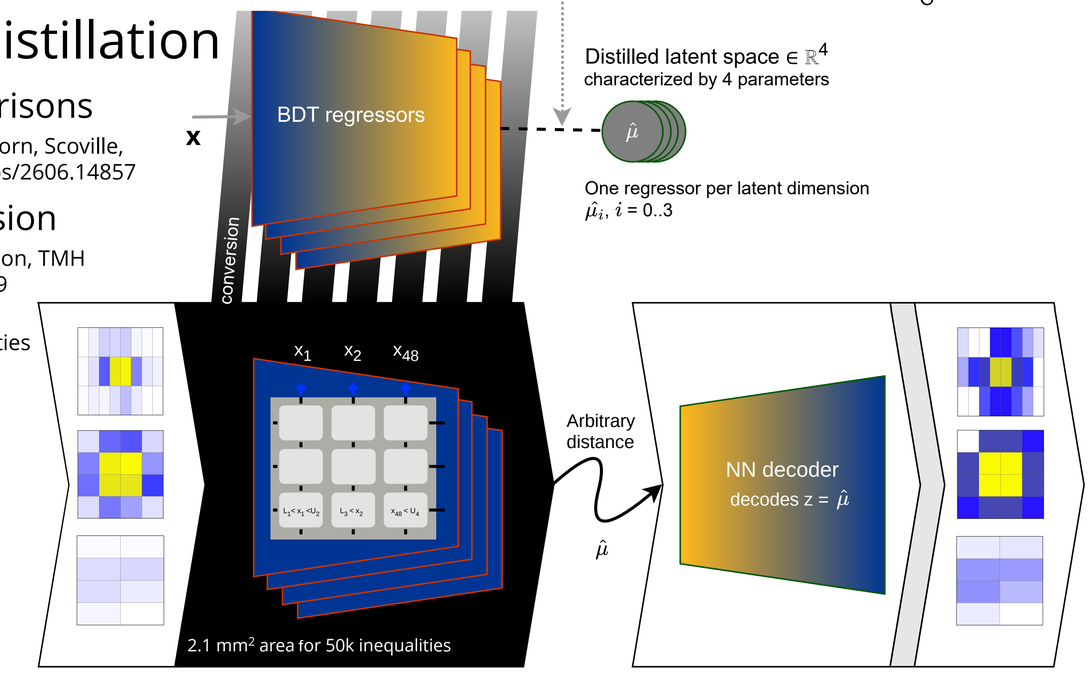
- Study of comparisons

Cohen, Gupta, Hoogendoorn, Scoville, TMH, Rankin, arxiv.org/abs/2606.14857

- Use BDT regression

Serhiayenka, Roche, Carlson, TMH NIM-A 1072 (2025) 170209

Parallelize root-to-node
Convert to list of inequalities
Called "tabular" version



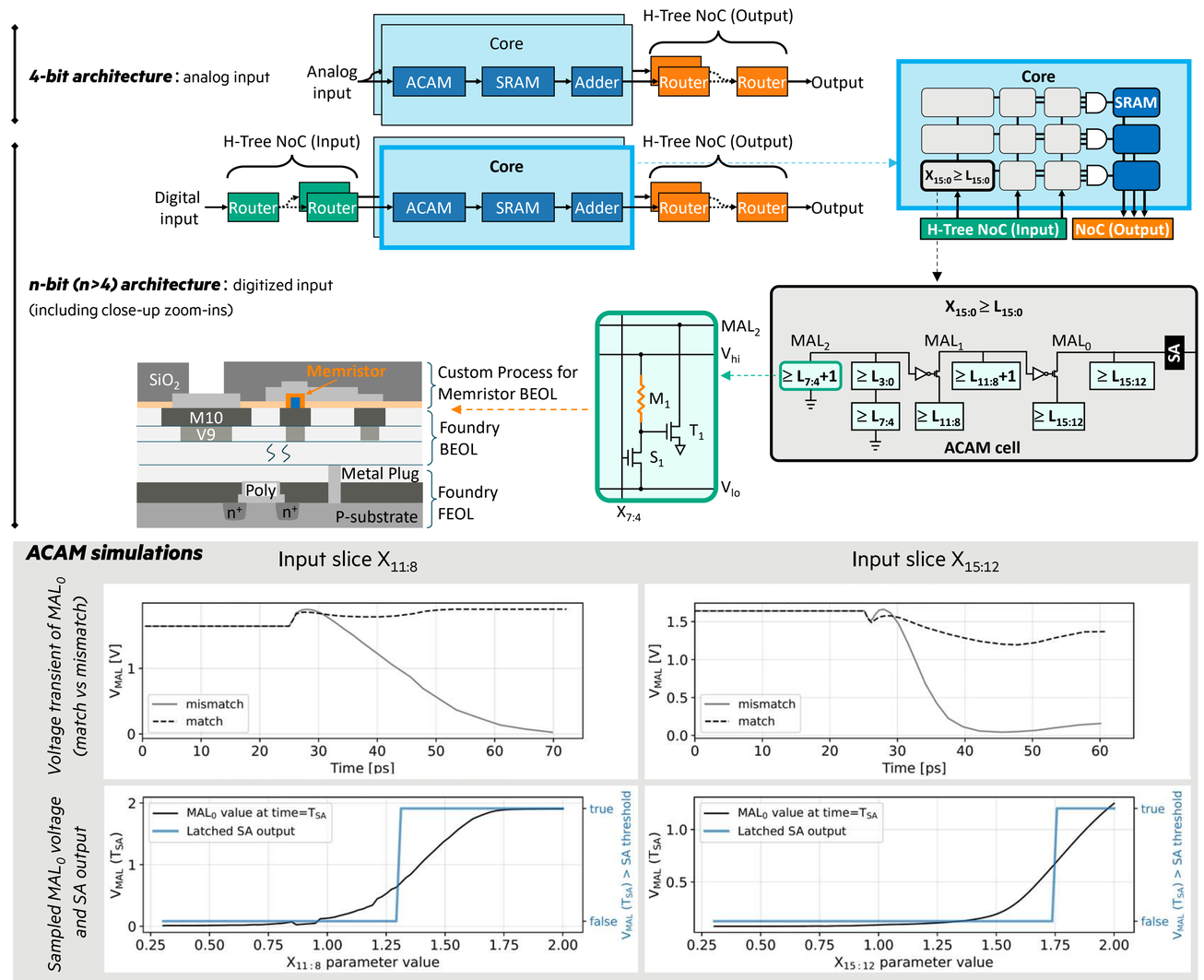
Device by HPE

- Memristor

Theory: Chua (1971)
Found: HP Labs (2008)

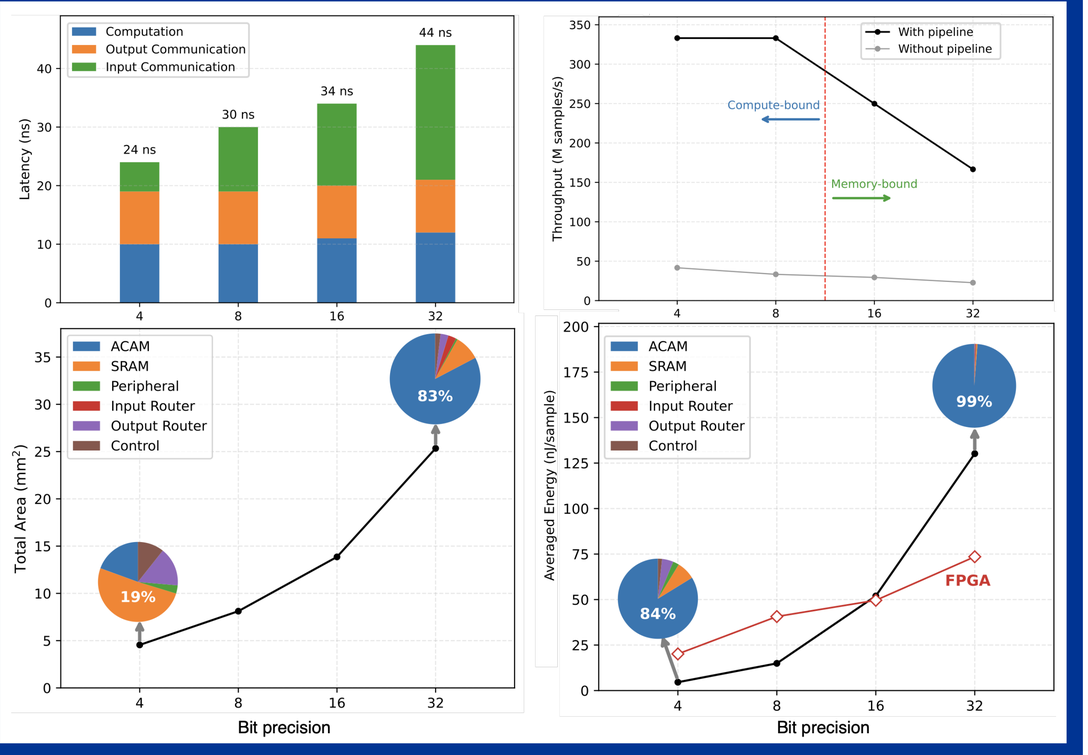
- Custom layer

Trees implemented previously at HPE
Pedretti et al., Nature Commun. 12, no. 1 (2021) 5806



Device results for 12x compression of 4-bit inputs

- 350 MHz throughput, 10 ns latency, 4.1 nJ per compression
- Compare vs. FPGA implementation: 43 ns, 20 nJ



ACAM simulations