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Fermilab

$n \to \bar{n}$ Search at DUNE

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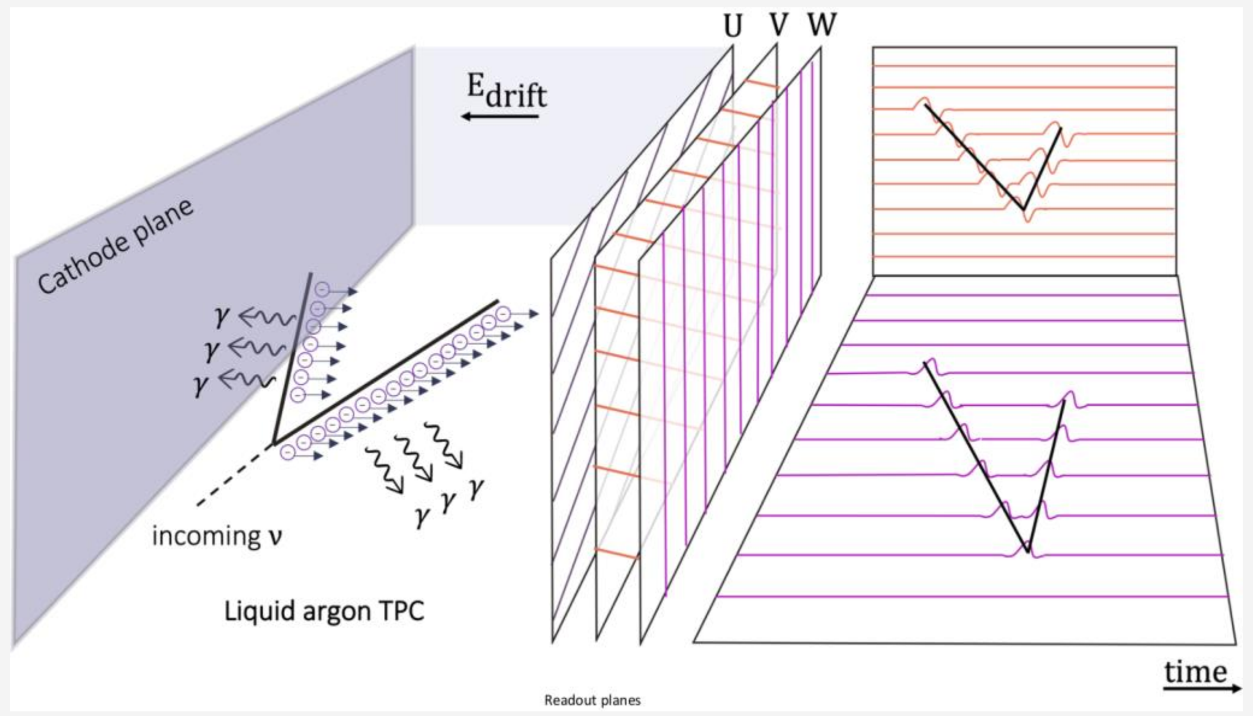
DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Abstract

Neutron-antineutron ($n \to \bar{n}$) transitions[1] are a baryon number violating process with ΔB=2. The Deep Underground Neutrino Experiment (DUNE) is sensitive to this process through its high-resolution liquid argon time projection chamber.

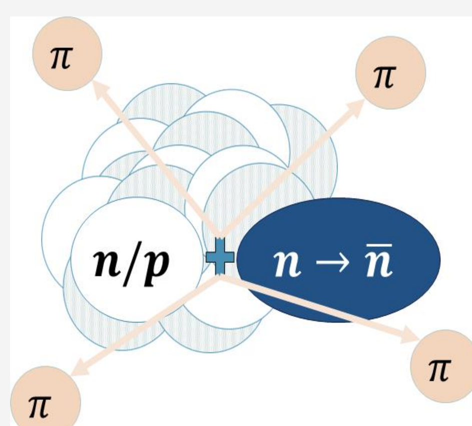
This work presents a new transformer-based machine learning approach for $n \to \bar{n}$ search.



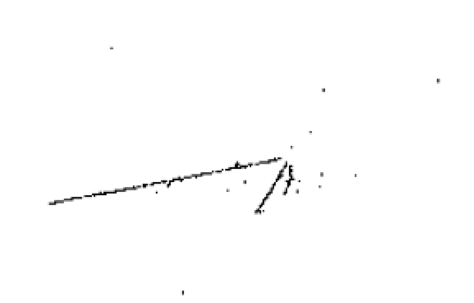
Neutron-antineutron Transition

- A neutron in Ar nucleus oscillates to an antineutron.
- The antineutron annihilates, producing multiple pions.

We want to preserve more $n \to \bar{n}$ events while maintaining the same background level.



Hadronic activity with prominent muon track



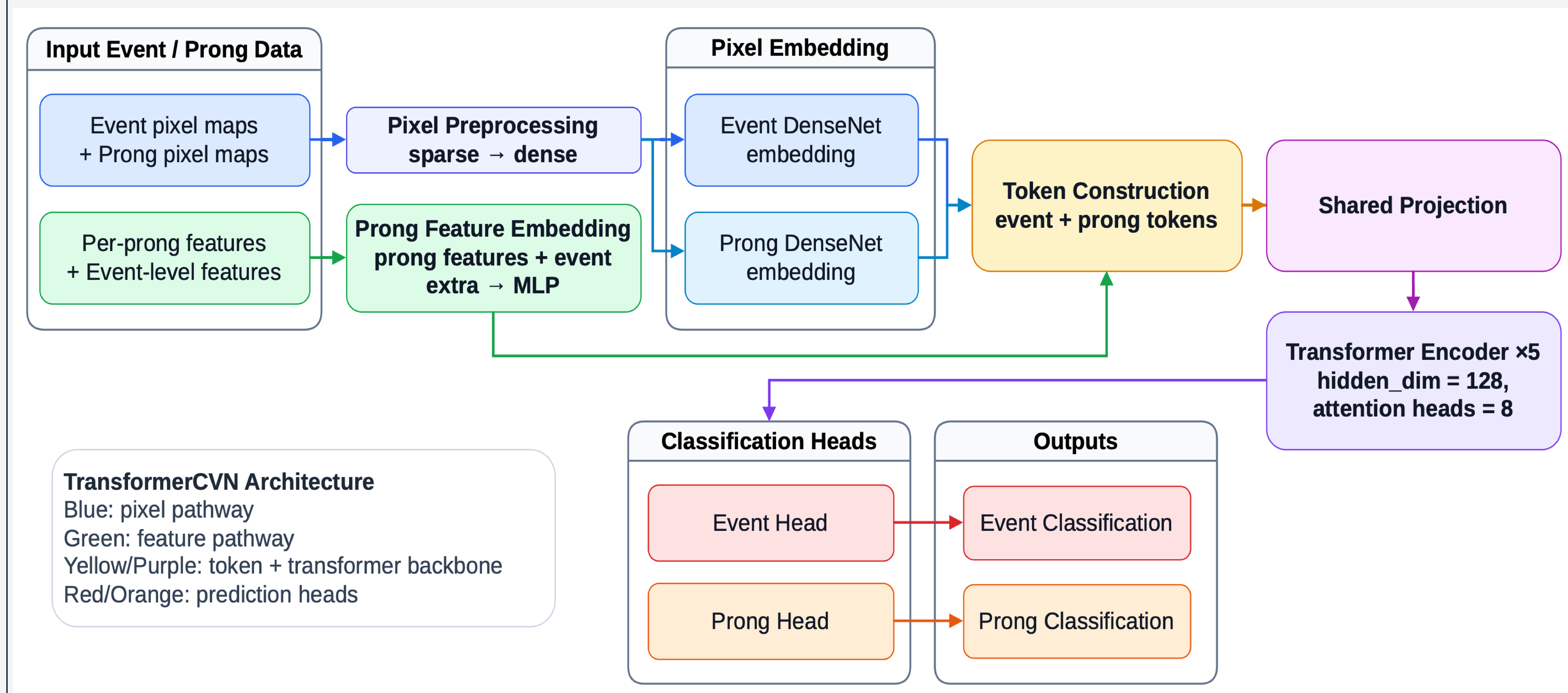
A simulated atmospheric neutrino (background)

Isotropic hadronic activity

A simulated $n \to \bar{n}$ transition (signal)

Model

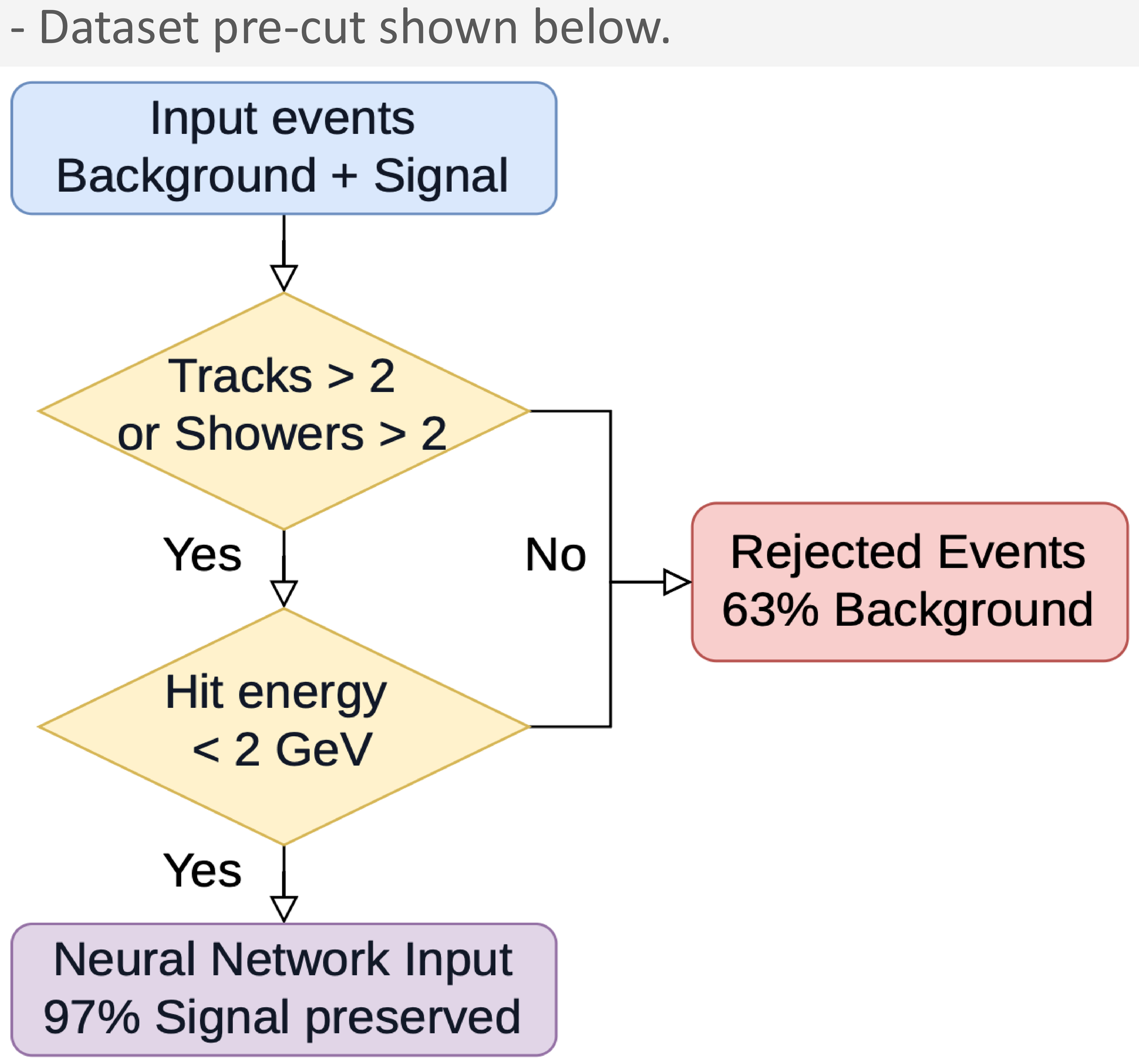
We use a custom-designed Transformer-based neural network, specifically optimized for the complex sparse topologies of LArTPC events. The backbone of our model is inherited from DUNE TransformerCVN[2]. The pipeline is shown below.



Data & Pre-processing

We use Local Fermi Gas, Effective Spectral Function, and Bodek-Ritchie for nuclear modeling, and hA and hN for final state modeling, in the GENIE generator.

- 2 million events in total.
- 6 different $n \to \bar{n}$ model, 1 atmosphere neutrino (background) model.
- 2 cm pixel size and 7 m map size for computation efficiency.
- Dataset pre-cut shown below.

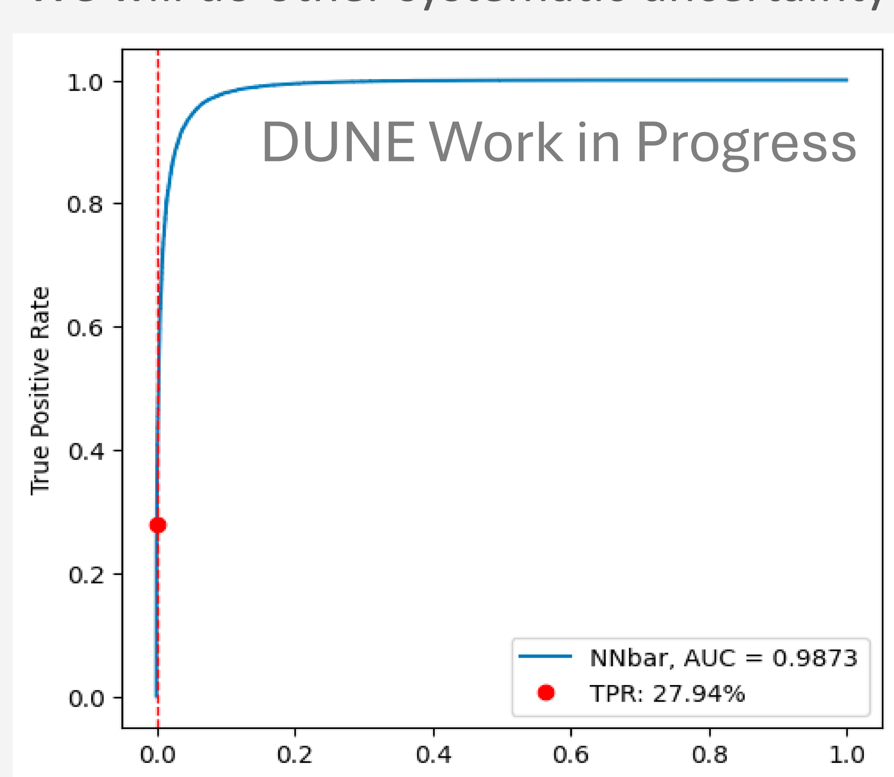


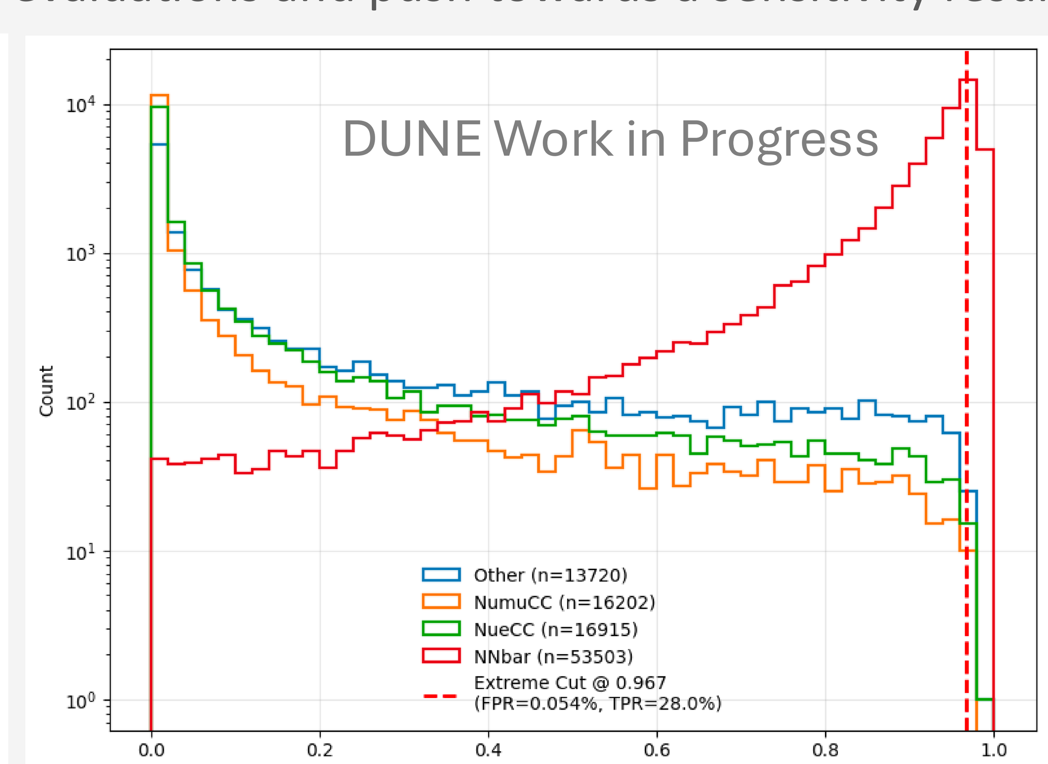
Performance

By deploying our Transformer-based architecture and optimized kinematic precuts, we drastically boosted the $n \to \bar{n}$ true positive rate to 27.94%—achieving a 3× performance improvement over the DUNE TDR[3] baseline (8% signal efficiency).

- ROC curve is shown with chosen background efficiency.
- Event counts vs threshold is shown. At the red dotted line, signal efficiency is 27.98% ± 0.19%.
- We further evaluated its performance across six distinct datasets embodying various Final State Interaction (FSI) scenarios. Results shown in the table.

We will do other systematic uncertainty evaluations and push towards a sensitivity result.





Model	Precut efficiency	CVN efficiency	Total efficiency
hA-LFG	$97.13\% \pm 0.05\%$	$28.94\% \pm 0.49\%$	$28.11\% \pm 0.48\%$
hA-ESF	$97.26\% \pm 0.05\%$	$29.39\% \pm 0.44\%$	$28.59\% \pm 0.43\%$
hA-BR	$97.40\% \pm 0.05\%$	$27.08\% \pm 0.44\%$	$26.38\% \pm 0.43\%$
hN-LFG	$97.75\% \pm 0.05\%$	$27.21\% \pm 0.47\%$	$26.60\% \pm 0.45\%$
hN-ESF	$97.09\% \pm 0.06\%$	$27.87\% \pm 0.53\%$	$27.06\% \pm 0.52\%$
hN-BR	$97.16\% \pm 0.06\%$	$26.96\% \pm 0.48\%$	$26.19\% \pm 0.47\%$

Acknowledgement

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References

[1] Abe, K., et al. “Neutron-antineutron oscillation search using a 0.37 megaton-years exposure of Super-Kamiokande.” Physical Review D 103.1 (2021): 012008.
[2] Shmakov, Alexander, et al. "Interpretable Joint Event-Particle Reconstruction for Neutrino Physics at NOvA with Sparse CNNs and Transformers." arXiv preprint arXiv:2303.06201 (2023).
[3] Abi, Babak, et al. "Deep underground neutrino experiment (dune), far detector technical design report, volume ii: Dune physics." arXiv preprint arXiv:2002.03005 (2020).