A NIFTY Simulation of the LArPix Readout Architecture

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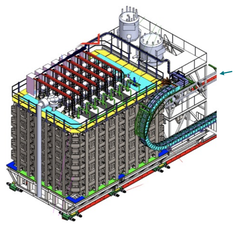
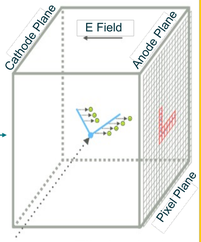
Office of Science

LArPix

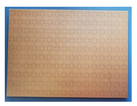


The DUNE ND-LAr sub-detector is composed of 35 LAr-TPC modules



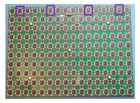
Each module has 40 anode tiles, each of which have 10,240 pixels.

Tile front-side



Each tile has 160 interconnected readout ASICs (LArPix), 4 of which connect to the DAQ

Tile back-side



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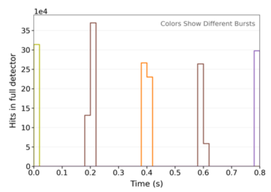
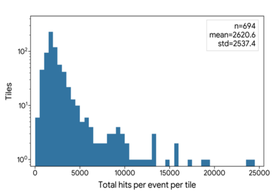
Data

NIFTY

LArPix Readout

- 10 MHz readout (100 ns clock)
- Data packets for each hit are 66 bits long → 6.6 us to move
- 5 Hz neutrino beam spill (200 ms to readout data)
- 200 ms / 6.6 us = **30,300 data-moving rounds available** to readout between spills without pileup
- Large occupancy showers can generate **O(1E4) hits in a Tile**





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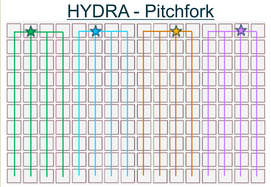
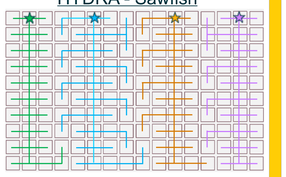
HYDRA Router

Previous LArPix design used static routing networks that tell each chip in a tile which single neighbor to send its data to.

HYDRA - Pitchfork



HYDRA - Sawfish



Pros

- Simple (no knowledge of neighbors)
- Minimal data movement
- Can reprogram to avoid static failures

Cons

- No back-pressure → overfills buffers - data quickly piles up at 4 I/O chips
- Cannot detect dynamic failures

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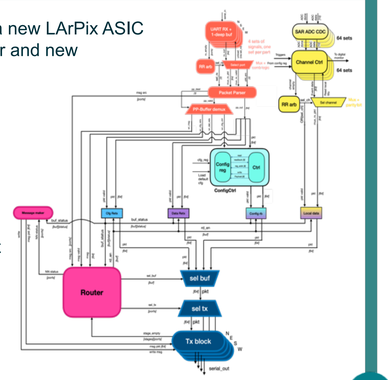
NIFTY Router

NIFTY aims to design a new LArPix ASIC with an intelligent router and new functionality:

- Dual buffers
- Ability to send data to all neighbors instead of just one
- NIFTY Messages that pass buffer status and heartbeat info to neighboring chips
- Optimizing the router logic is the purpose of this work



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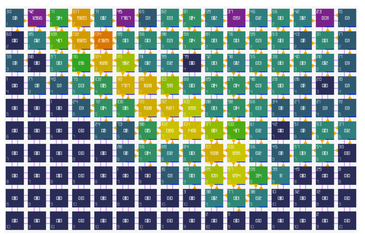
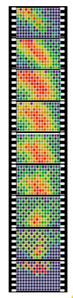
NIFTY Simulation

The NIFTY simulation takes hit distributions from LAr-TPC Monte Carlo simulations as the input and then generates realistic data loads and monitors each data packet hop-by-hop (6.6 us) as it passes between chips towards the readout aggregators.



Color scale shows buffer occupancy.



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NIFTY Router: A First Draft

Implemented a simple router in the NIFTY Sim as a starting point for router logic investigation:

- Score and rank neighboring chips, where the score =
  - w_dist x (dist. to DAQ)+ w_occ x (sum of buffer occ.)
- Prioritize sending data to neighbors with the lowest score.
- When sending data, pull from the fullest buffer
- When not sending data, send a NIFTY message
- Don't send data to your neighbor if their buffer is fuller than yours.
  - Prevents chips with more data than ports always sending data in all directions, regardless of the scores.

This simple router provides a basis for these studies, yet is known to be flawed and cause oscillations in data when neighboring chips have similar buffer occupancies.

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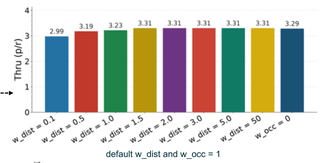
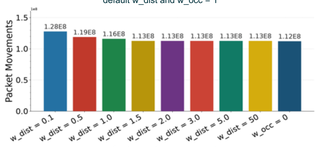
NIFTY Router: Optimal Score Weights

Scanning over score weights shows a nearly negligible impact. This is due to the score having no impact on the behavior of chips that have more data than ports.

- Throughput (the average number of data packets delivered to the DAQ per round) slightly increases.



- Total chip activity slightly decreases



- No significant impact on maximum required buffer size.

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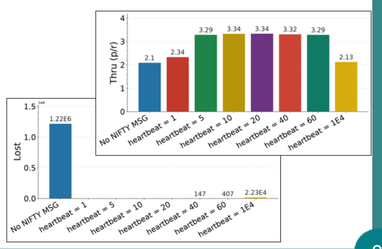
NIFTY Router: When to Force a NIFTY Msg

If a chip is constantly sending data, then it's neighbor will never get a NIFTY msg. Need to force a NIFTY msg instead of data for one round in order to update neighbor. How often this occurs is set by the heartbeat period. If no NIFTY msg is received within that period, then the chip marks it's neighbor as bad and won't send data to it until it receives a NIFTY msg.

Simulating different heartbeat periods when 5% of chips are disabled shows that **too small of a period, and data throughput is decreased**, but **too large of a period, and data is lost to failed chips.**



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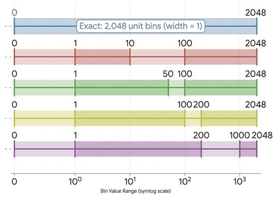
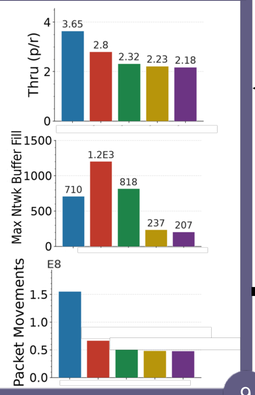
NIFTY Router: Coarse Buffer Info

Quantized the buffer fill information into 4 bins (2 bits):





Cons: decreases throughput

Pros: decreases maximum required buffer size and chip activity.

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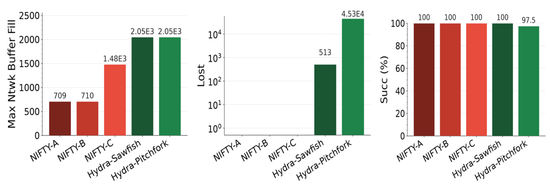
NIFTY vs HYDRA

Compare the HYDRA routers with variations of the NIFTY router:

- **NIFTY-A**: w_occ = 1, w_dist = 0.01, heartbeat_period = 20
- **NIFTY-B**: w_occ = 1, w_dist = 2, heartbeat_period = 20
- **NIFTY-C** = NIFTY-B but allows data to be sent to neighbors with higher buffer occupancy



Even without dead chips, HYDRA routers lose data due to congestion and maxing out the network buffers (size = 2048).

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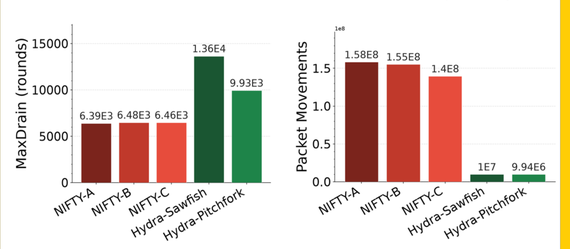
NIFTY vs HYDRA (cont…)

The NIFTY router has better throughput and drains the data from the network faster, but also come with more chip activity.



* Not a straight forward comparison of logic since NIFTY uses multiple ports

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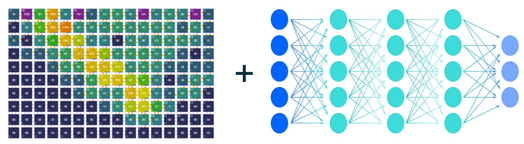
Next Steps

We will pair this NIFTY sim with machine learning to optimize a router that is aware of all stats for all chips in the network. The machine learning weights will then depict which stats are most important. For example, would buffer status from next-to-nearest-neighbors help? What about even further? Once we know the most important information for the router, we can then study further the effects of discretizing and binning that info in order to to use less bits and stuff more variables into the NIFTY messages.



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https://nifty.lbl.gov/www/