DUNE DAQ readout R&D at ProtoDUNE Single-Phase

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CERN

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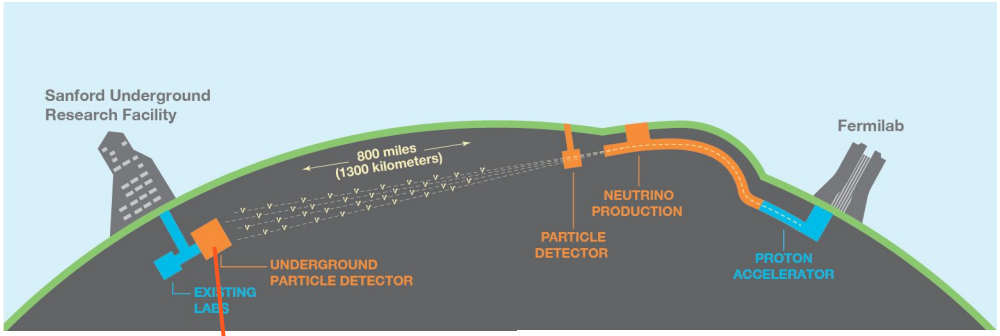
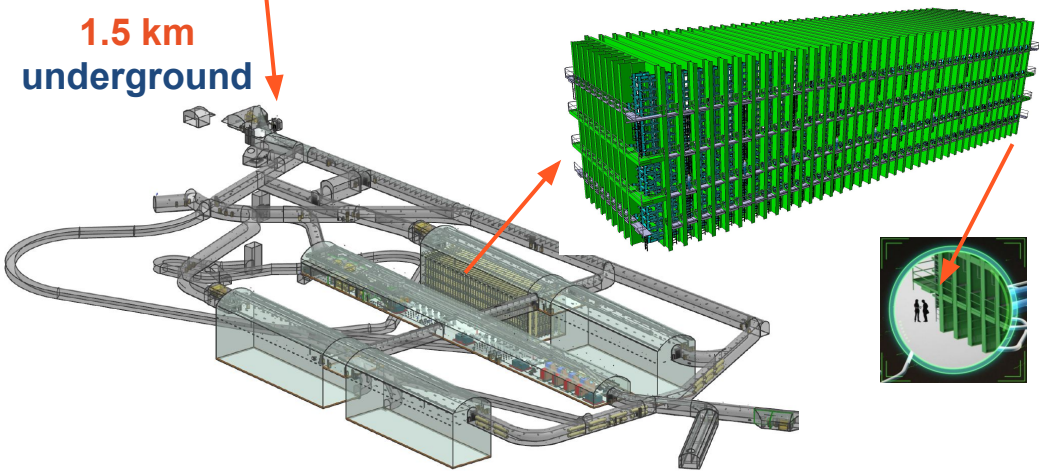
Outline of the talk

- DUNE and its single-phase prototype
  - DAQ differences
- Integration objectives and results
  - FELIX readout
  - Self-triggering
- Summary and outlook

DUNE - Deep Underground Neutrino Experiment



1.5 km underground

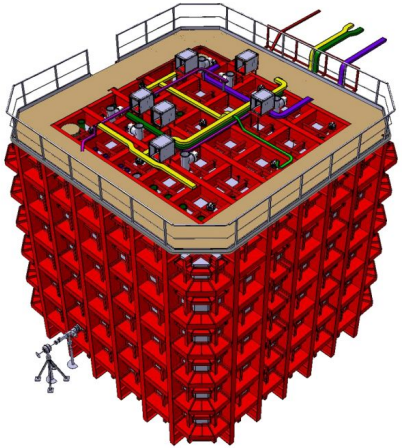


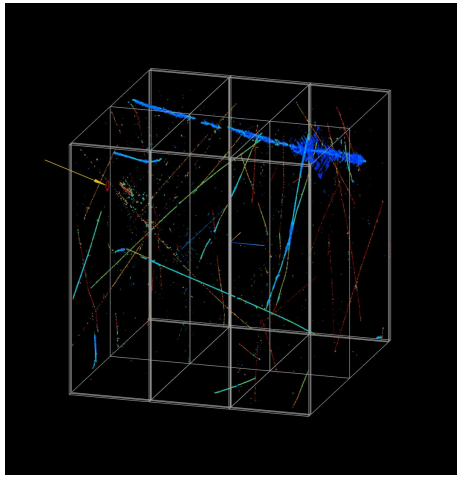
- Future experiment due to take data in 2025
- Varied physics program
  - Neutrino beam from Fermilab
  - Explosion of supernovas
  - Atmospheric & solar neutrinos
  - Proton decay
- Underground: shielded environment

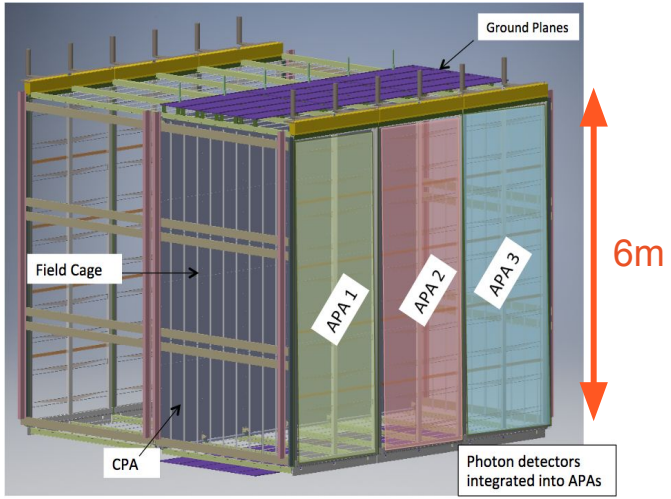
- DUNE "Far Detector"
  - 4 super-module in 4 caverns excavated in a former gold mine
  - Liquid Argon Time Projection Chamber detectors (LAr-TPC)
  - Cryostat internal dimensions: 14m x 14m x 62m = 17.000 ton LAr
  - Liquid argon @ 87K (-186 °C)

ProtoDUNE Single-Phase

- Demonstrate design, construction, and operation of the single-phase technology DUNE TPCs
- External cryostat dimensions: 10m x 10m x 10m 750 ton of LAr
- Charged particle beam from SPS







- Ionisation tracks are collected by the wires of the Anode Plane Assemblies (APAs)
- 6 APAs in ProtoDUNE-SP (4% of the 150 APAs of a DUNE supermodule)
- Scintillation light collected by Photon Detectors installed on APA frame
- **Successful beam run in Q4 2018**

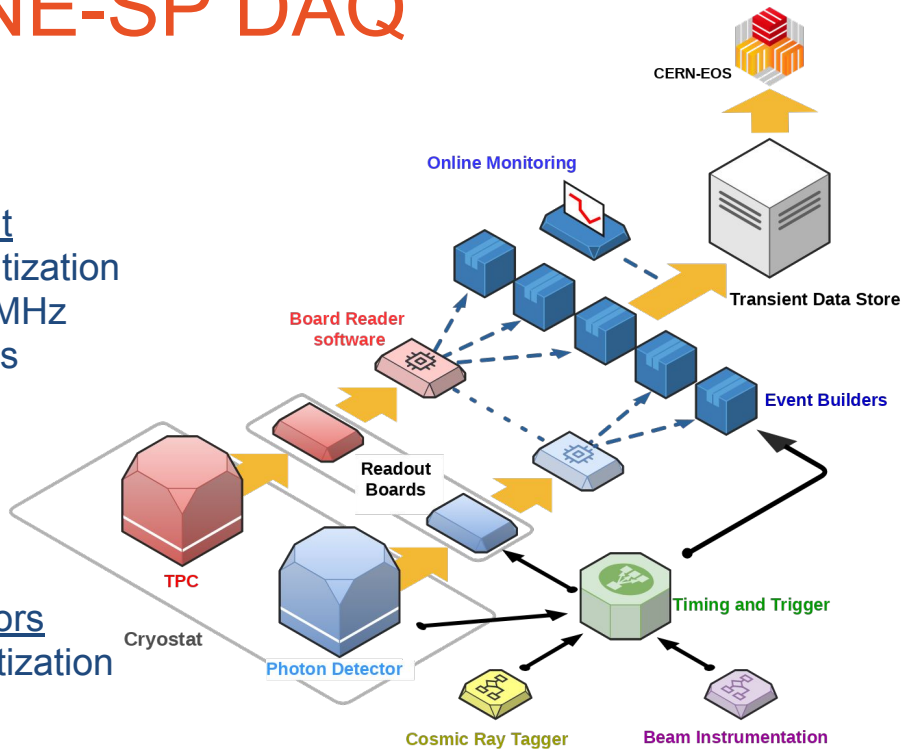
ProtoDUNE-SP DAQ

TPC readout

- Continuous digitization 464 Bytes @ 2MHz
- 15.360 channels
- 55 GByte/s
- Large buffers O(GBs)

Photon Detectors

- Continuous digitization @ 150 MHz
- 240 channels
- Self triggering



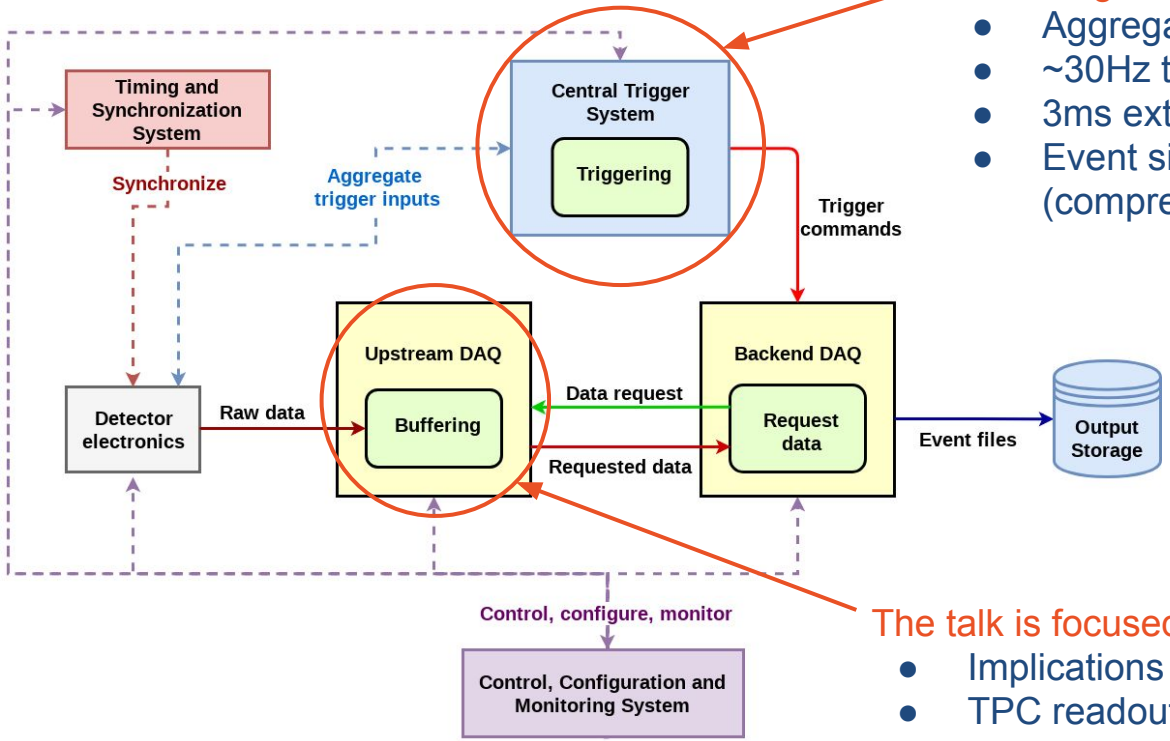
DAQ farm

- On-detector electronics connected to DAQ via ~700 optical fibers
- ~20 high performance servers for dataflow, monitoring and control
- 700TB on-site storage
- Maximum 20 Gb/s data rate towards EOS

Timing and trigger

- Phase-aligned master clock to all components
- Aggregate trigger inputs from CRT/PD/BI
- External trigger due to high rate of cosmic flux

ProtoDUNE-SP DAQ



External global trigger:

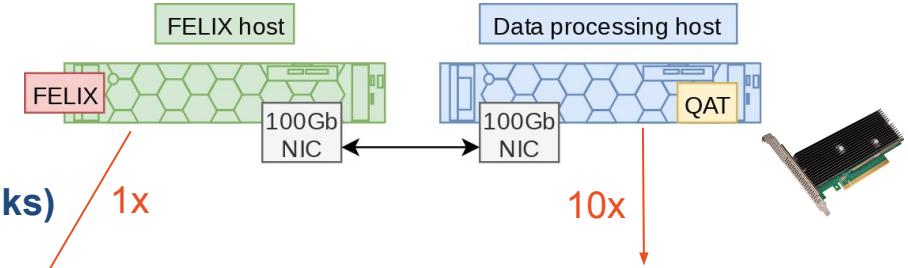
- Aggregated inputs
- ~30Hz trigger rate
- 3ms extraction windows
- Event size: ~60MB (compressed)

The talk is focused on this!

- Implications due to trigger
- TPC readout with FELIX

William Panduro Vazquez - **FELIX: commissioning the new detector interface for the ATLAS trigger and readout system**

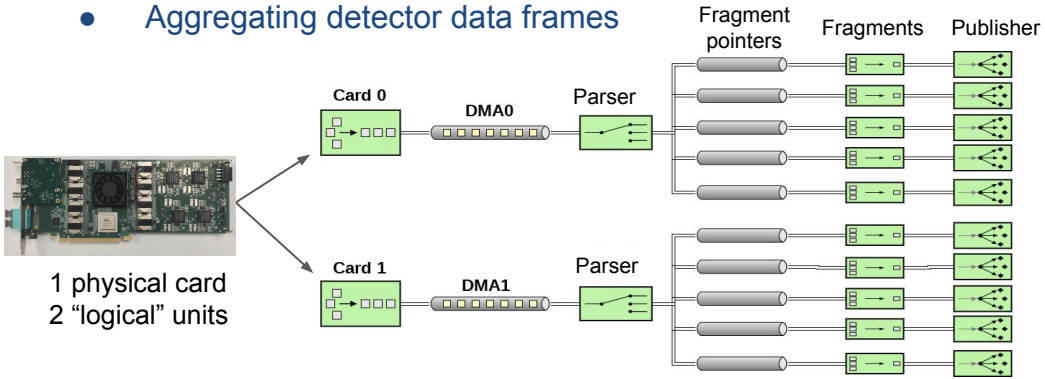
FELIX in ProtoDUNE



1 FELIX card handles a single APA (10x ~1GB/s links)

Modest modifications on FPGA gateware
for lower memory I/O rate:

- Increasing DMA payload size
- Aggregating detector data frames

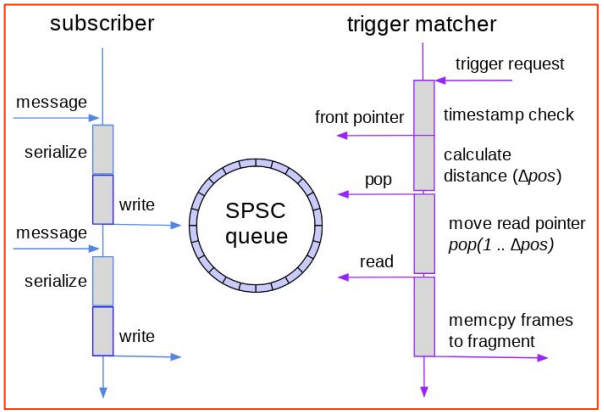


Data routing software is customized:

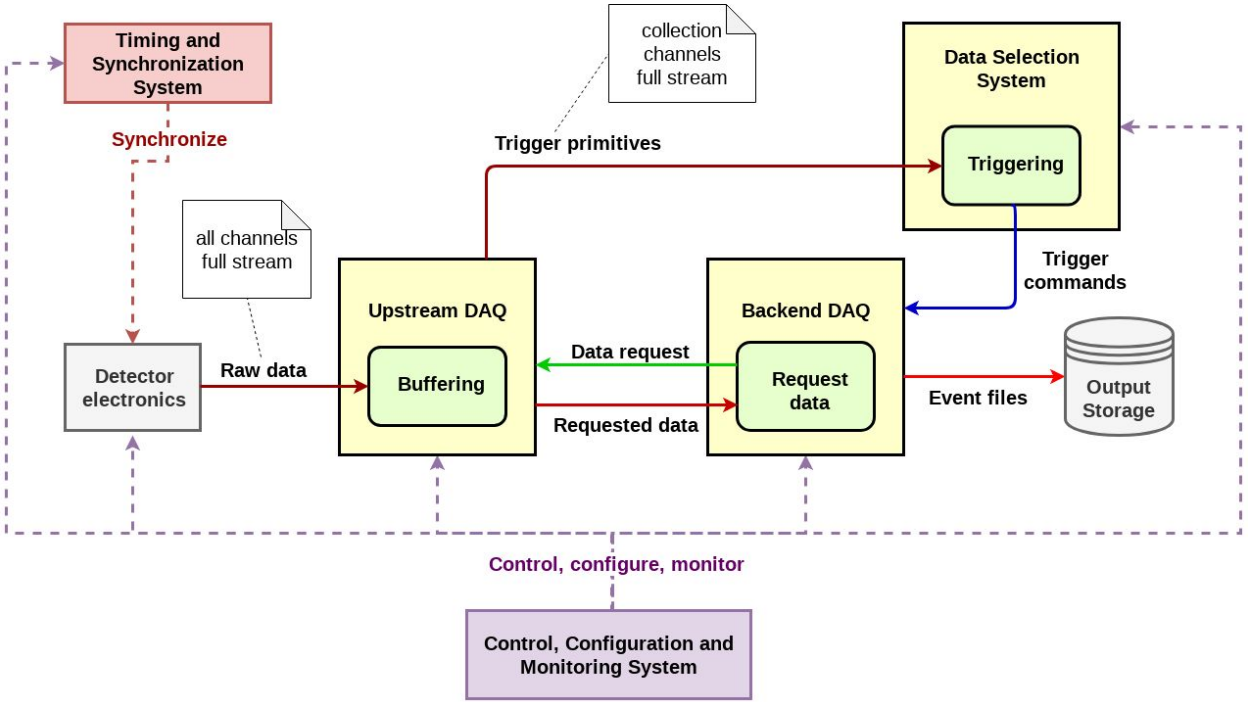
- Scatter-gather: collects pointers for detector data fragments
- Single copy pipeline: serialization to user buffer
- Data published on Infiniband over Ethernet

BoardReader process

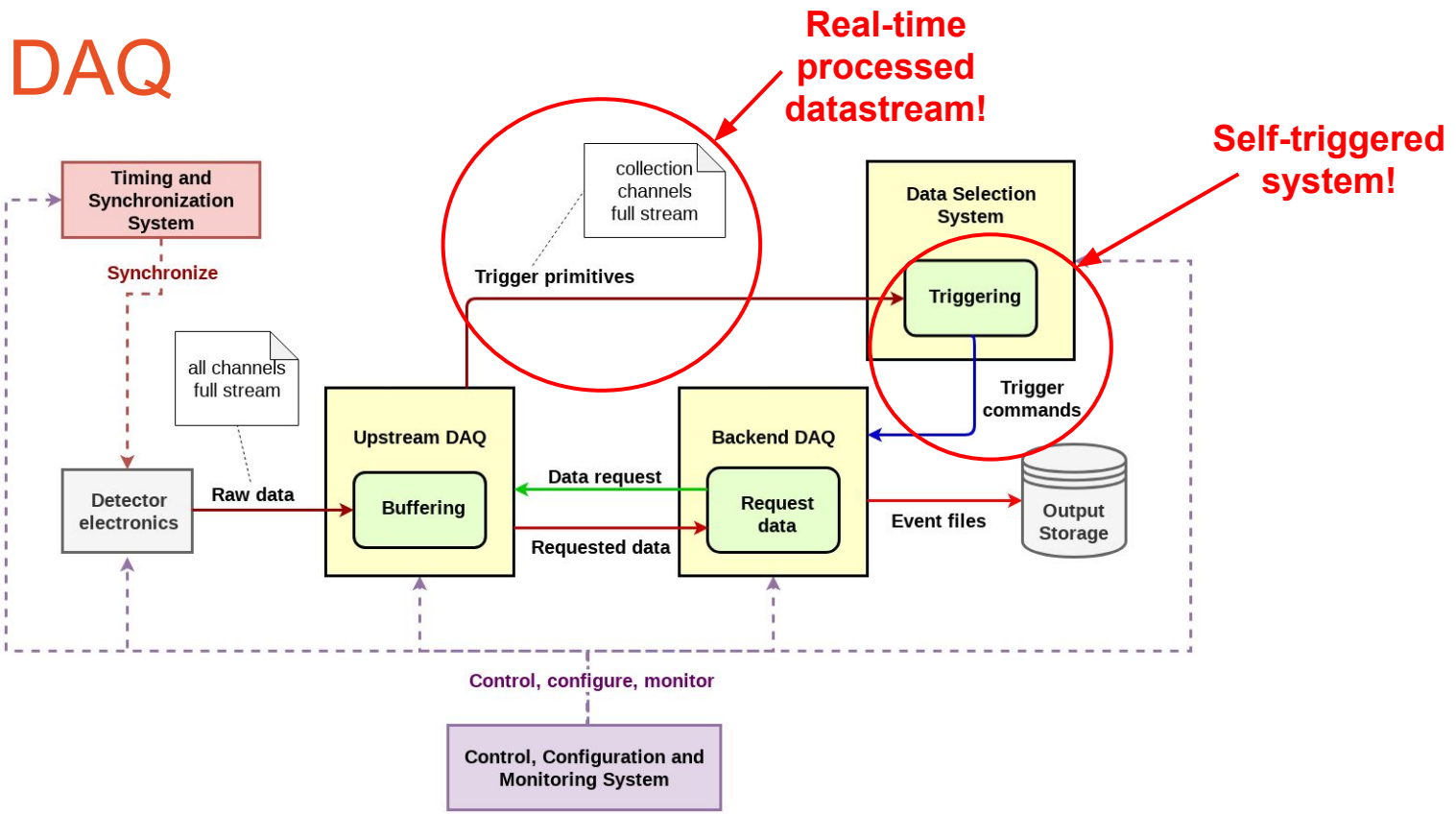
- Subscribes to single link & buffers data
- Extracts data fragments for triggers
- Reorders data (AVX2 & 512)
- Hardware accelerated compression
  - Intel® QuickAssist (QAT)



DUNE DAQ


Timing and Synchronization System
Synchronize
collection channels full stream
Trigger primitives
Data Selection System
Triggering
Trigger commands
all channels full stream
Upstream DAQ
Buffering
Backend DAQ
Request data
Data request
Requested data
Detector electronics
Raw data
Event files
Output Storage
Control, configure, monitor
Control, Configuration and Monitoring System

DUNE DAQ


Real-time processed datastream!
Self-triggered system!
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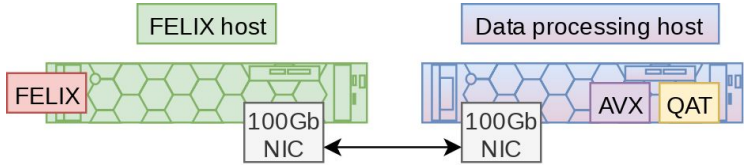
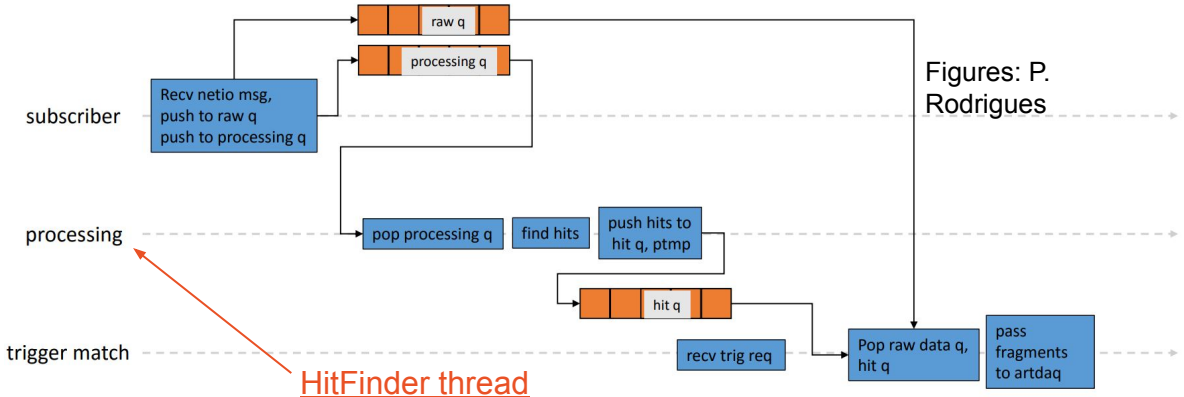
“Hit” finding



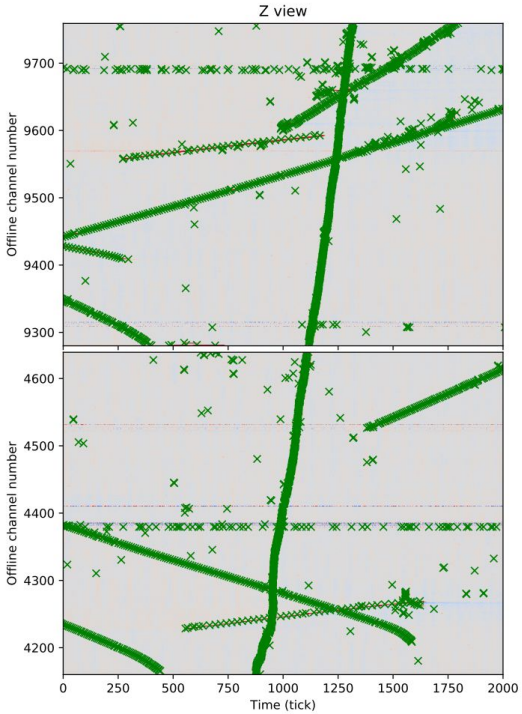
Real-time processing and selection of interesting data regions for trigger decision



Figures: P. Rodrigues

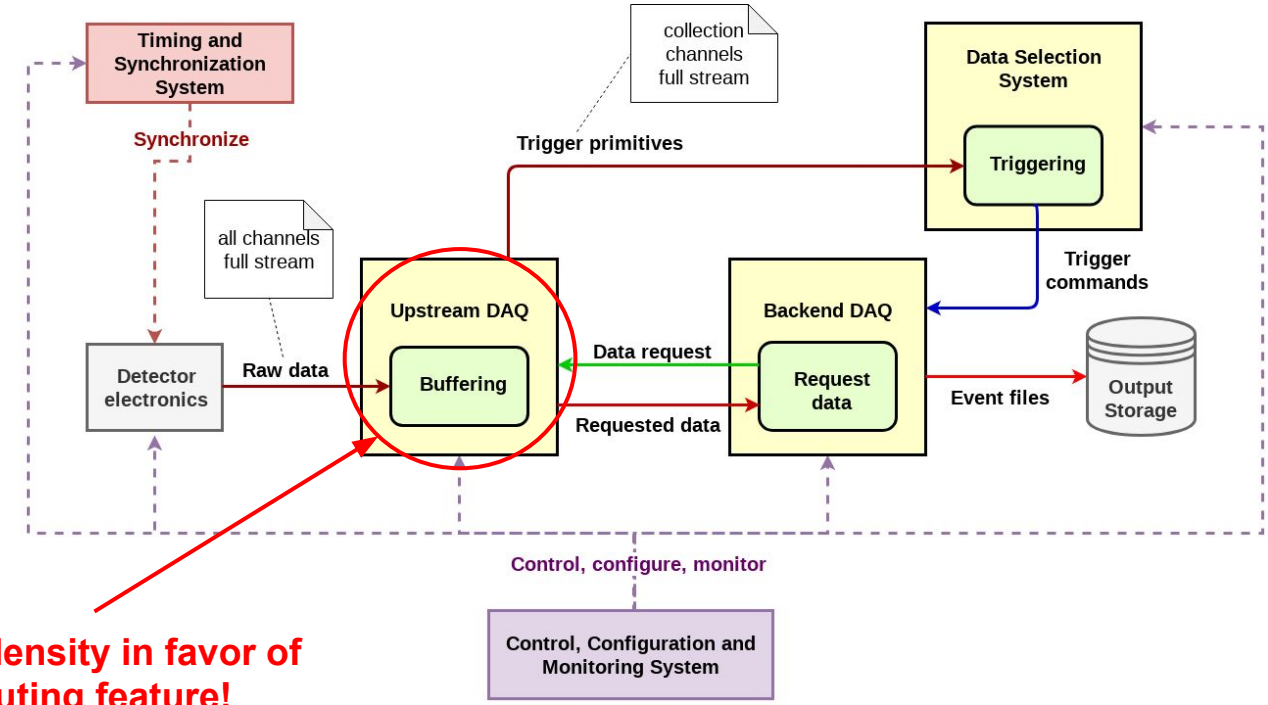
HitFinder thread

- Extract collection channel
- Do pedestal, filter, hit-finding (FIR filter)
- Implementation with specific AVX2 registers and instructions



Operational in ProtoDUNE: With full self-triggering chain!

DUNE DAQ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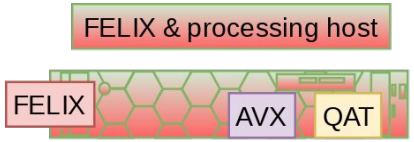
High density in favor of routing feature!

OnHost BoardReader



Merged FELIX data routing software,
with data selection (trigger-matching) algorithm

- Eliminated 100Gb P2P connection
- Reduced space and cost requirement

Covered:

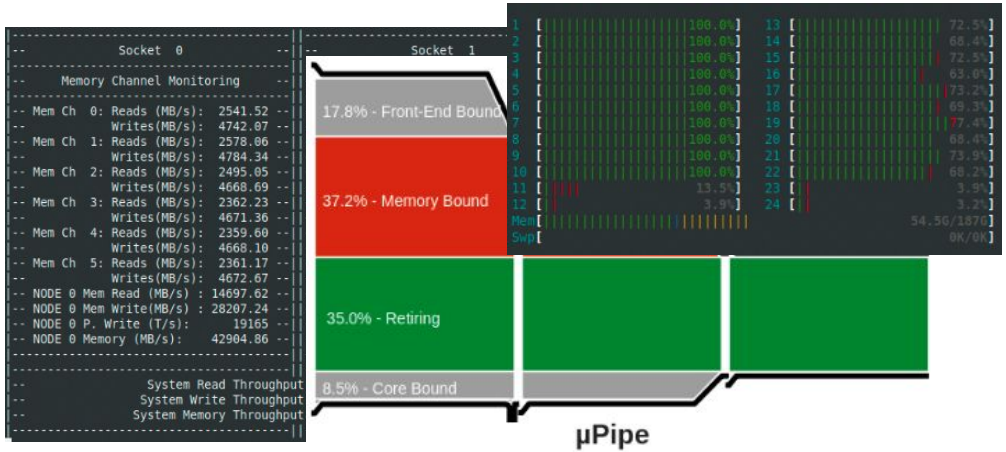
- Extensive server evaluation
  - PCIe riser configurations,
  - BIOS settings
- Optimized for memory throughput
  - Performance profiling
- Heavy NUMA balancing between processing threads and allocated memory
- Interrupt moderation of 10Gb NIC

2 x OnHost process

1 x DMA parser
5 x link parser
5 x hit finder
5 x trigger matcher

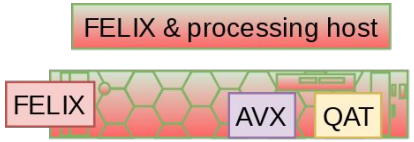
→ High memory I/O

→ High CPU util.



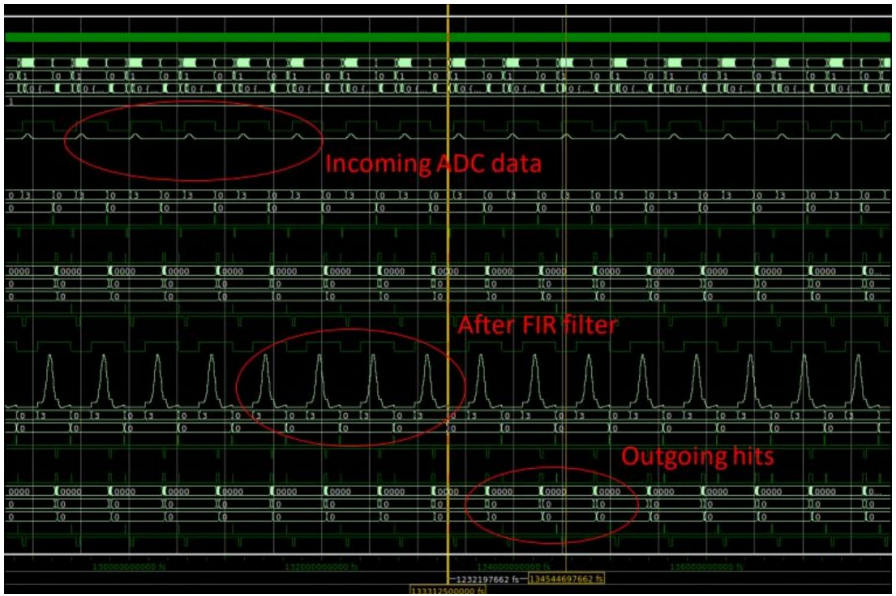
Operational in ProtoDUNE: Provides expected performance characteristics! (Ex. compression)

HitFinding in FELIX FPGA



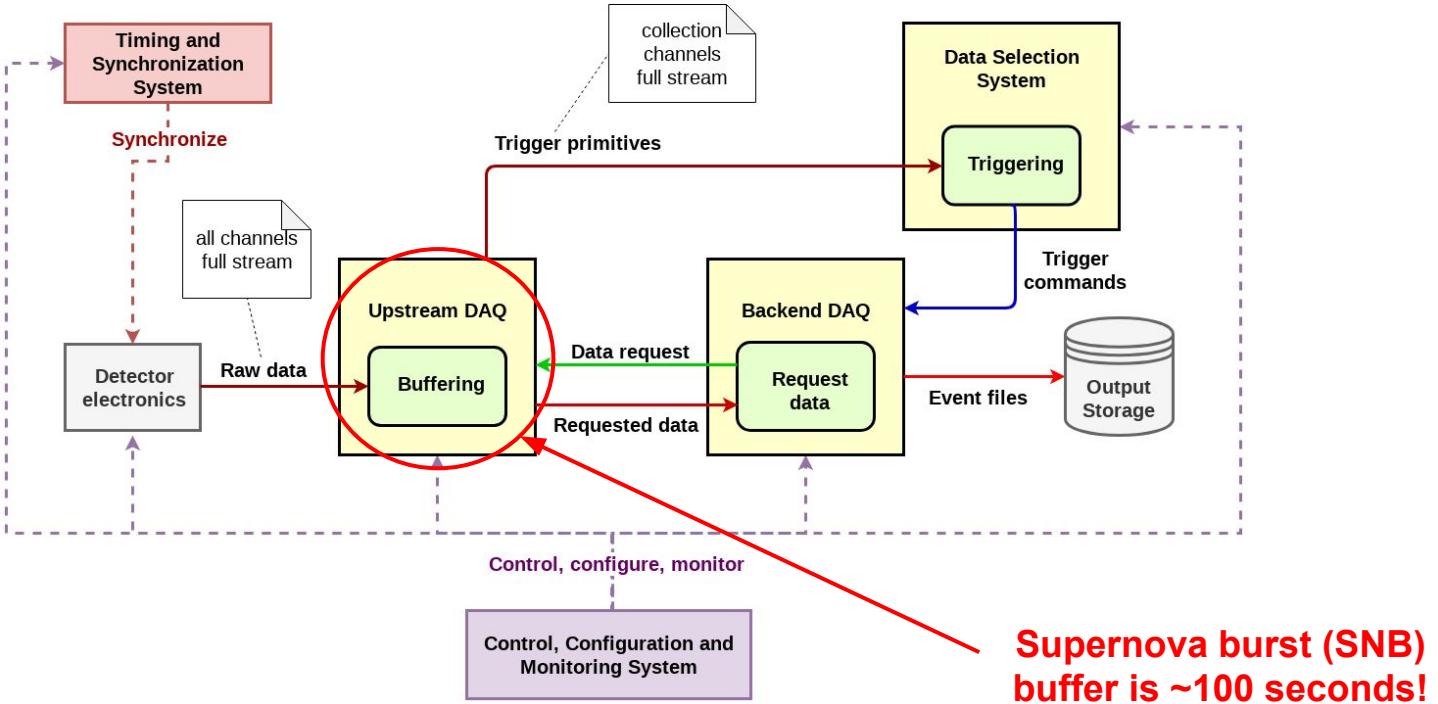
FPGA gateware R&D for HitFinding

- Bitwise and byte operations are CPU heavy
- FPGA HitFinder implementation is ready
- Integration with FELIX is ongoing
- Outgoing hits have dedicated virtual links



Ongoing work, in collaboration with DUNE DAQ and FELIX developers.

DUNE DAQ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Supernova burst (SNB) buffer is ~100 seconds!

Supernova Burst trigger

A supernova could produce thousands of neutrino events within several seconds!

But recording the data is tricky:

- Long time for trigger decision
- Physics event is distributed over time
- Most critical data: avoid any potential losses

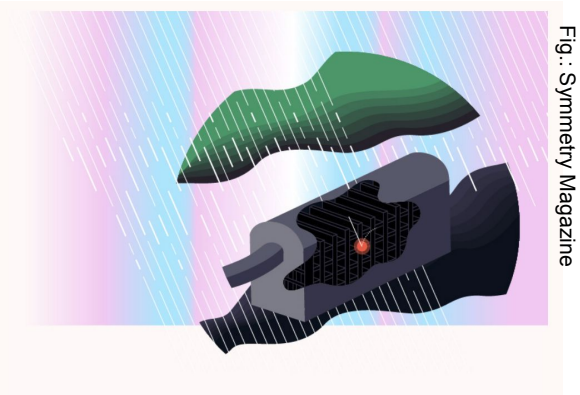


Fig.: Symmetry Magazine

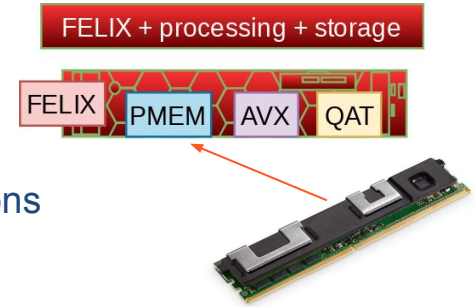
Requirements:

- 10s transient buffer (15TB for one detector module)
- On trigger: 100s continuously persisted data stream (150TB)

Possible solutions:

- Dedicated ultra-fast distributed NAS?
  - How to dimension a network + storage to cope with this I/O rate?
- Bring storage close to readout?
  - NVMe SSDs?
- ???

SNB buffer prototype



Evaluation of RDIMM + NVDIMM (Non-Volatile Memory Module) solutions

Hardware:

- C628 chipset + Cascade Lake Xeon® Platinum L SKU processor
- 192GB RAM + 6TB Intel® Optane™ DC NVDIMMs

Software:

- Persistent Memory Development Kit (PMDK - libpmem)
- pmem in AppDirect (persistent) mode,
  mounted as dax filesystem in interleaved configuration
- For each APA link:
  - Fixed 100GB pmem pool
  - On SNB trigger:
    - Persist 10s buffer
    - Persist incoming 1GB/s data for 100s!

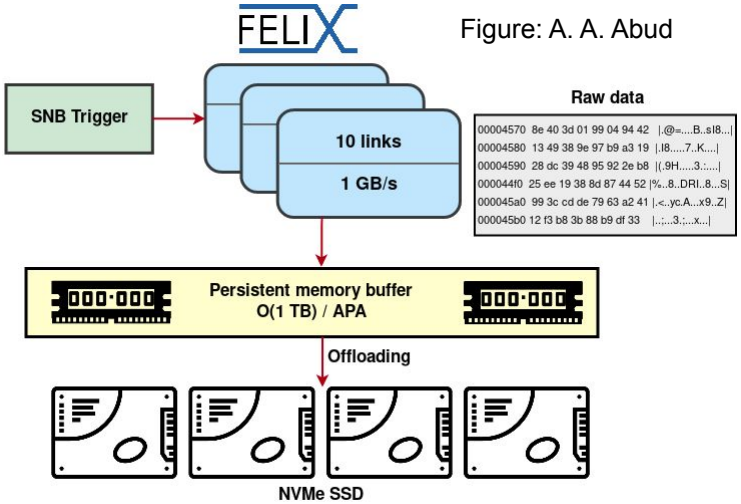
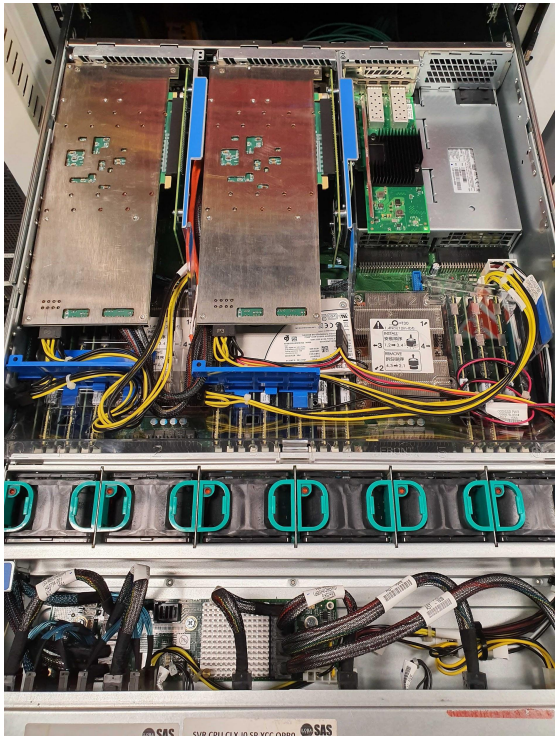


Figure: A. A. Abud

Preliminary, SNB trigger functional prototype in ProtoDUNE! (Half APA)

Outlook

- Continue hit-finding optimization
- Integrate fake SNB trigger to ProtoDUNE-SP
  - In order to validate the storage and data transmission flow
- Aim for 2 FELIX cards in the same server
  - Testing FELIX driver with NUMA support
- Continue incorporating emerging technologies for data processing, storage, and compression



Conclusions

- We applied the FELIX system to a new experiment
- Substantial progress on DUNE DAQ prototypes and their integration to PDSP
- DUNE DAQ benefits from advancing data center and server technologies
- There are a lot of further possibilities to explore

Also, thanks to ATLAS FELIX developers for their support