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Please do not adjust your projector.

DAQ Group

Hall and group leaders meeting

February 25th 2020

So, I started to write this talk and went back to my folder of old talks to use
The last one as a template…

DAQ Group

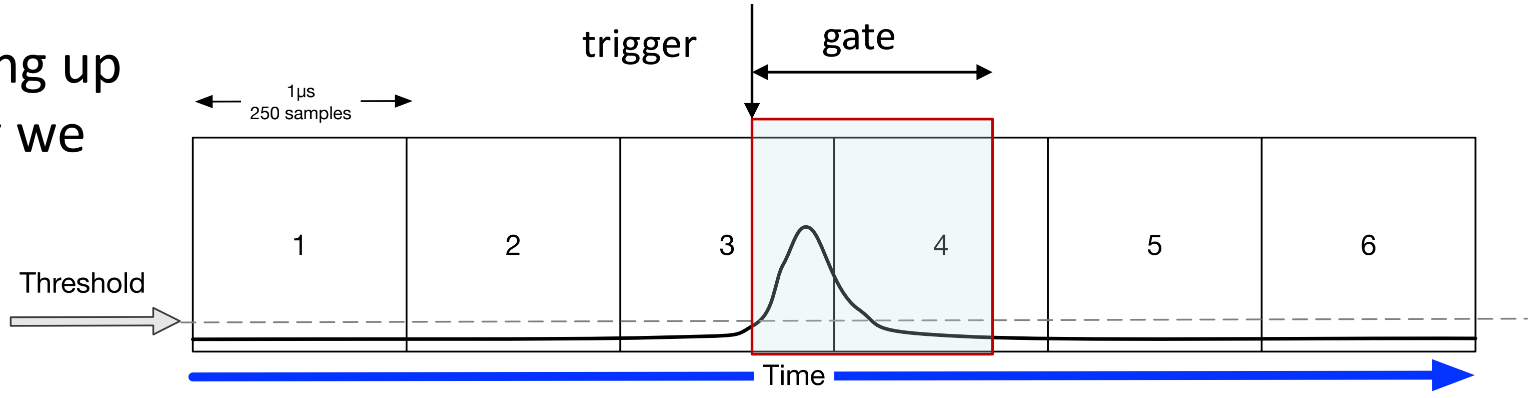
Hall and group leaders meeting

November 12th 2019

…little wonder that it didn't seem long ago. The good thing is that it makes this presentation a bit shorter.

Streaming readout

As part of the lab agenda I am writing up what streaming readout is and why we would use it. Quick refresher :



The diagram shows a single 4 ns/sample ADC channel. To read it out we could:

1. Save every ADC sample, 250 per µs, maybe 1 Gbyte/s per channel.
    - Generates deterministic fixed rate of fixed length blocks with fixed timing.
    - Wasteful because there are large periods of time when there is no signal.

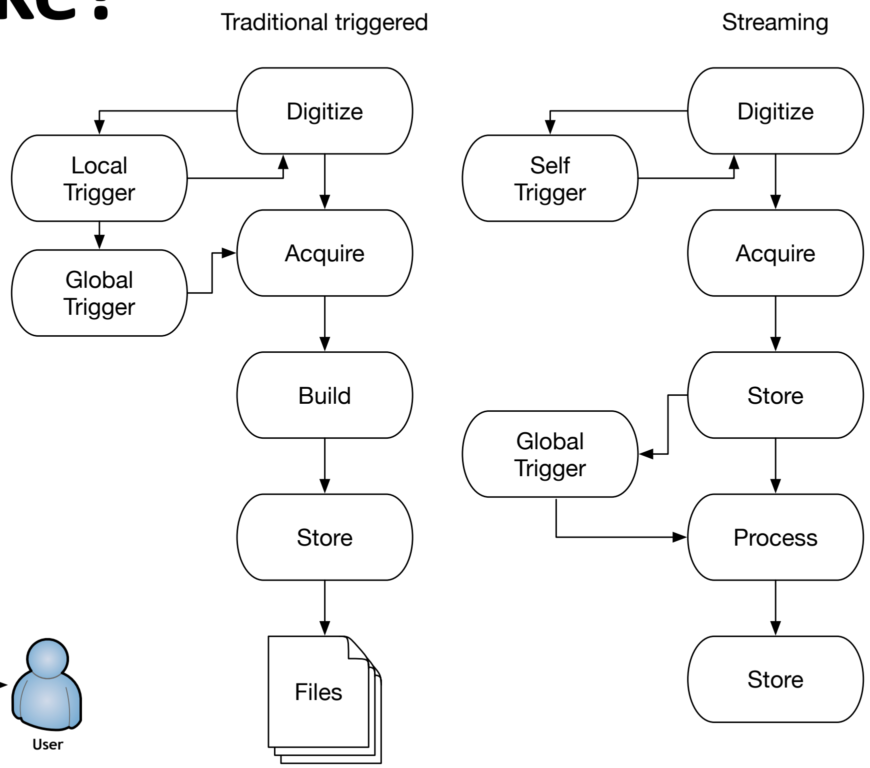
2. Use a trigger to tell the ADC when to start sampling and a gate to determine how many samples
    - This is effectively what we do now. Variable length blocks with random timing.
    - Needs electronics to generate the trigger, potential to introduce bias into the data, other issues.

3. Effectively save every ADC sample but encode the data in a space saving format.
    - For example, In this 1 µs period there were only N words of data above threshold and here they are.
    - There is a continuous stream of variable length data blocks. (There is always a block even if it is empty).
    - **This is streaming readout.**

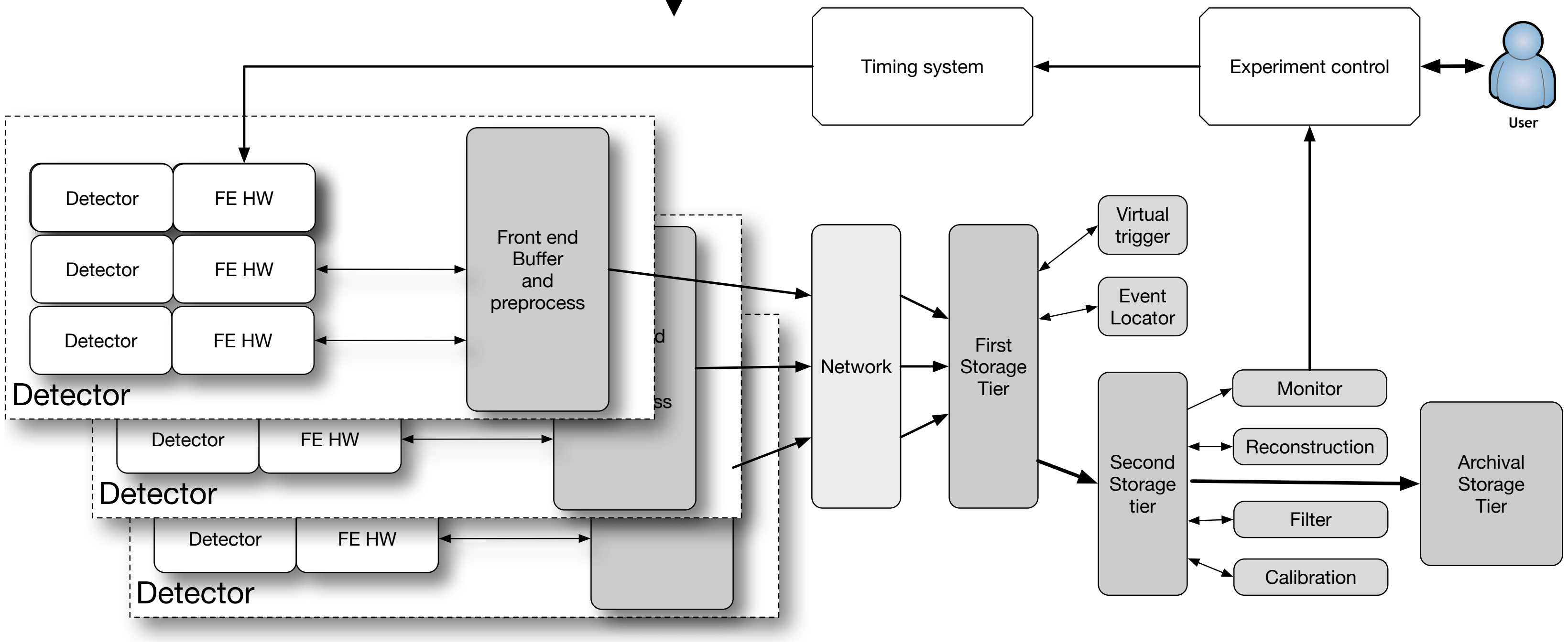
- **Aim to have paper completed later this week and distribute to hall leaders and other interested folks.**

What does a streaming system look like?

- In a streaming system we effectively move the trigger from before the data is acquired to after.



- In a practical system:
  - A timing system synchronizes streams at source.
  - Front-end outputs data in streaming format on a net.
  - DAQ consists of tiers processing separated by tiers of temporary storage

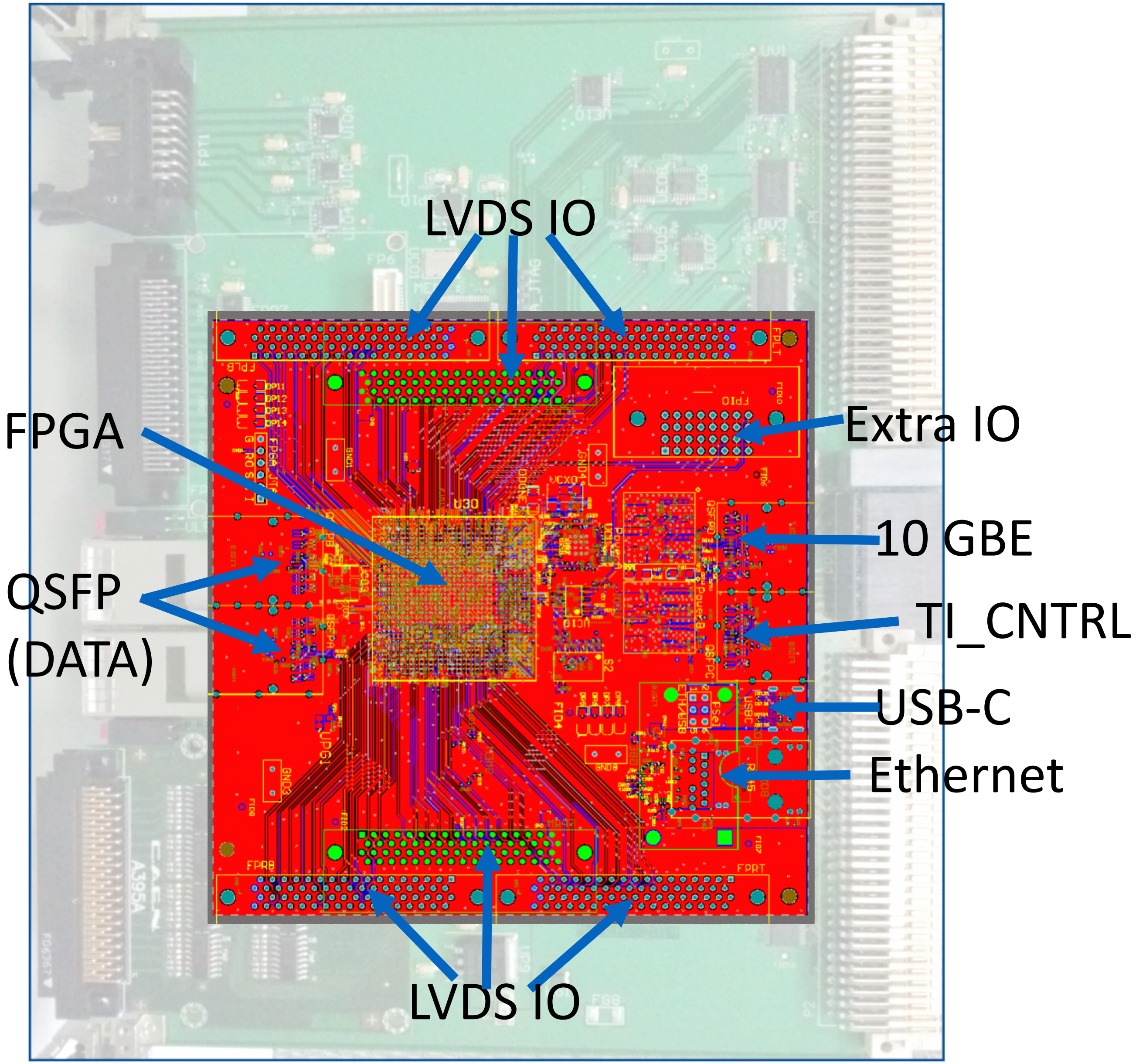


What are we doing?

- Work on the parts of a practical streaming system in parallel.
  - Hardware
  - Firmware
  - Data transport – streaming format and protocol
  - Frameworks for virtual trigger, calibration, reconstruction etc.
- Aim to support upcoming experiments like TDIS, SoLID etc.
- Aim to see how we can retrofit this readout mode for existing detectors -> CLAS12
- Use any opportunities we have to gain practical experience.

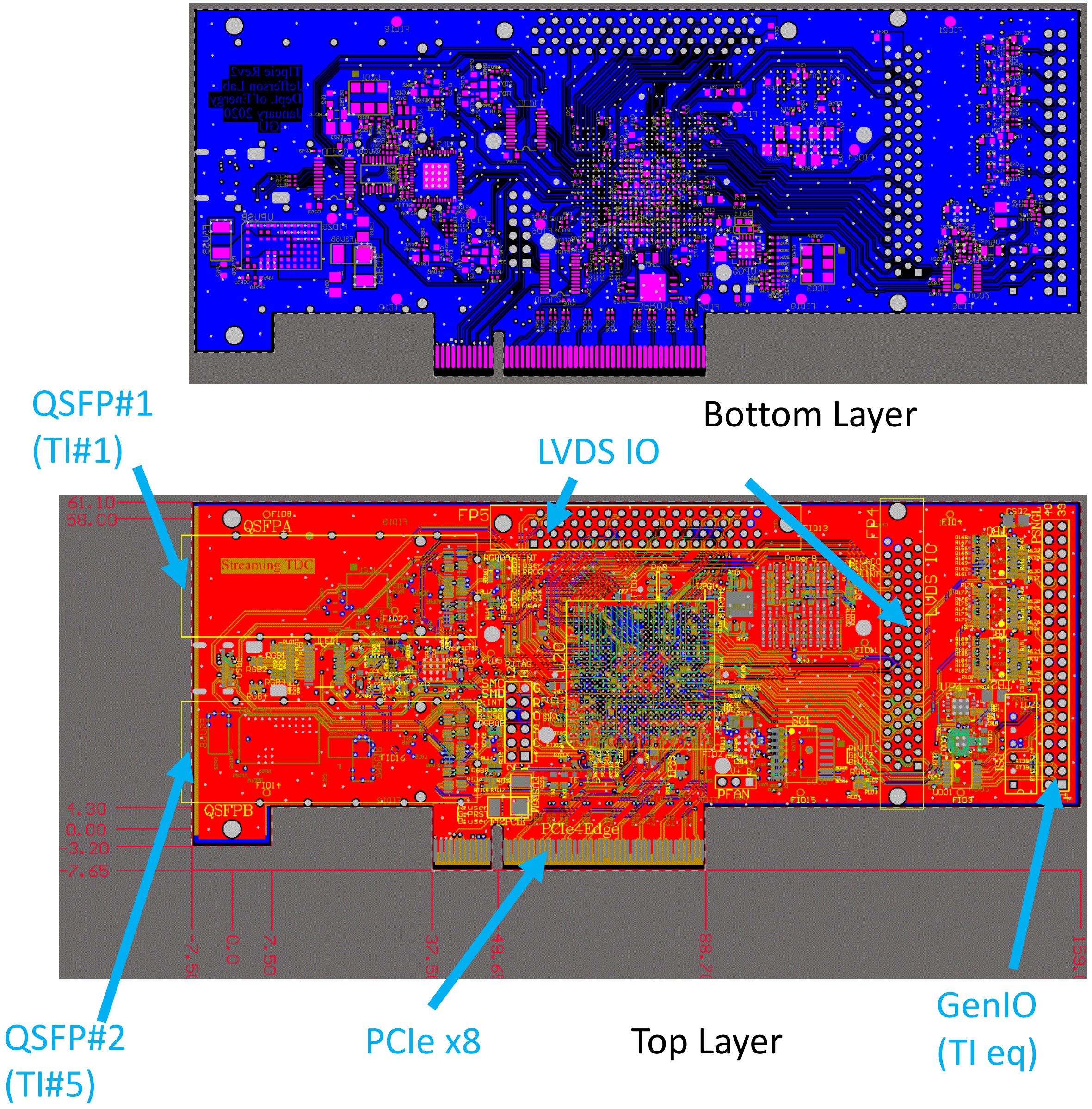
Hardware/firmware - STDCartix: Condensed VETROC

- **Streaming capable VETROC**
- Specifications:
  - 192 (6*32) - LVDS IO channels
  - 2 - QSFP connectors (up to 8*6 Gbps)
  - 1 - USB-C (power)
  - 1 - 1000BASE-T GBE (power)
  - 10 GBE (4*2.5 Gbps)
  - TI interface
  - Xilinx Artix-7 xc7a200 FPGA
- Status:
  - The PCB layout is done. Need a real-world application (streaming) to produce some:
    - FPGA-based TDC (35ps or better).
    - Standalone IO board.
    - Anything you can program the FPGA to do.



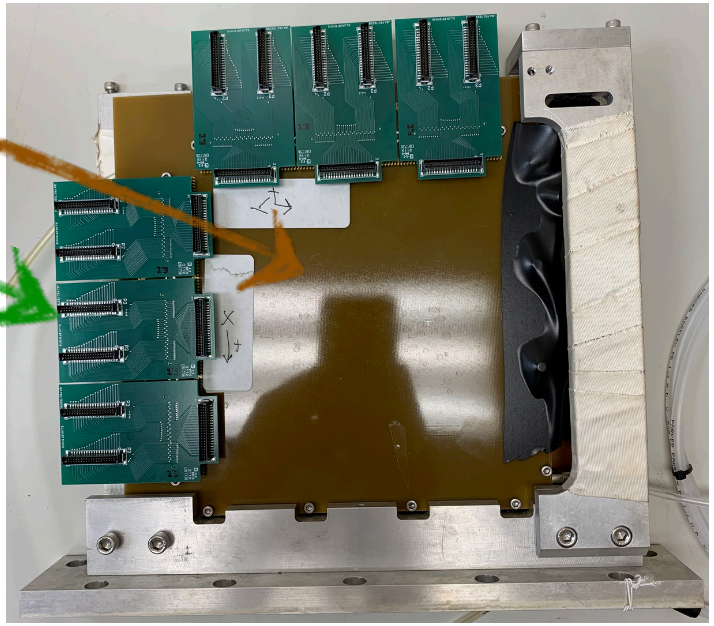
Hardware/firmware - 2nd generation of PCIexpress TI.

- Requested by Sergey in hall-B.
- Improvements:
  - Two optic interfaces, it can interface with the TS/TD and a TI_master (similar to HallB/D setup).
  - PCIex8 Gen 3, should be compatible with all the current computer/CPU PCIexpress slots.
  - VME TI copper_cable_IO (34-pin) to keep the full VME TI_master functions, plus some extras.
- Other uses:
  - **Streaming readout adaptor**: sources 8*16 Gbps (two QSFP connectors), destination: CPU (via the PCIe, up to 8*16 Gbps).
  - Standalone configuration: USB-C power and control (no VME, nor PCIexpress).
  - 64-channel high resolution (<20ps) FPGA based TDC, or simply a 64-channel LVDS IO board.
- Status:
  - Two prototypes are due in next month.
  - FPGA firmware development underway.



Streaming readout for GEMs – Ed and ~~Eric.~~

- INDRA-ASTRA Facility (CC F110)
- Variety of hardware that is "streaming capable"
  - User programmable network switch with 100 Gb/s data link
  - Fast multi-core server machines with 100 Gb/s data links
  - Fast PC's with several PCIe slots for testing high speed data links, FPGAs, GPU's, etc.
- Triple-GEM detector provides 768 channels of analog data
- Custom transition card fabricated to facilitate ALICE FEC inputs
- Prototype to evaluate readout via 800 channels of SAMPA readout (5 FEC's, 25 SAMPA chips) in streaming mode.

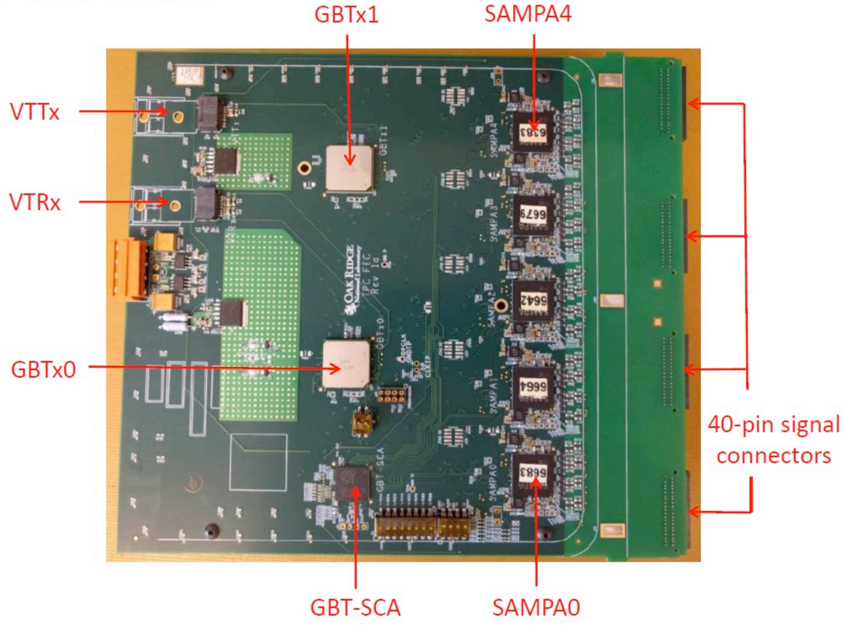


SAMPA readout test system

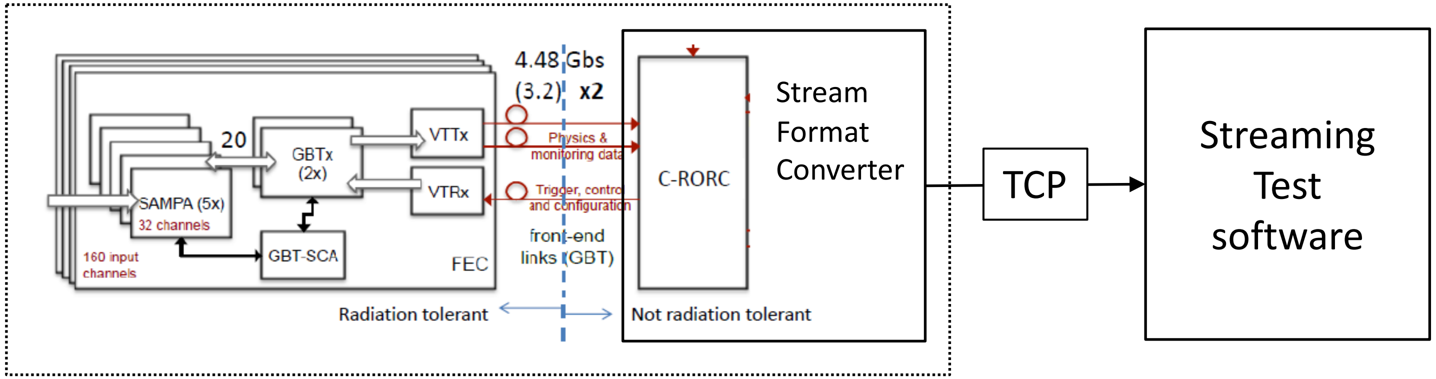
- SAMPA serial data streams on a FEC are concentrated into two 4.48 Gb/s serial data streams by a pair Gigabit Transceiver ASICs (GBTx).
- The system architecture is shown in the schematic below.
- Streams are transmitted from the FECs over fibers to a PCIe based Common Readout Unit (C-RORC).
  - The FPGA engine on the readout unit filters and compresses data for transmission to a server via 100 Gb ethernet.
  - In addition to the uplink paths used for data and monitoring, the GBTx provides a fixed latency downlink path for trigger, control, and configuration of FEC components.
  - Components on the FECs are radiation tolerant.

- Going back a few slides, the first level of tiered storage in this case is hidden inside the Streaming Test Software.

FEC – JLab version



Streaming Readout Prototype System

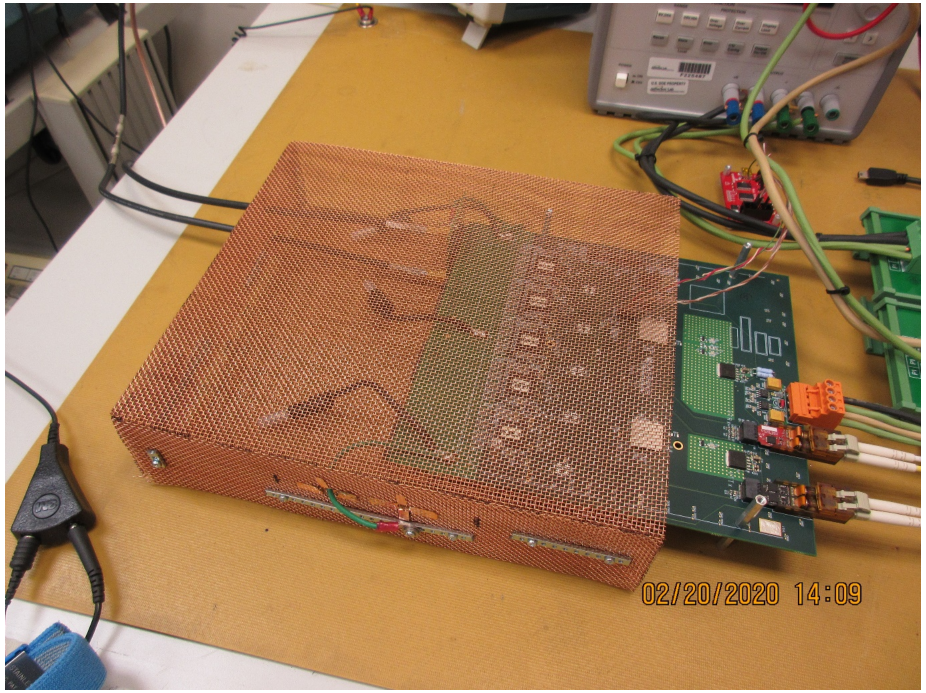


FEC – Front End Card (160 ch / FEC)   (5 FEC = 800 ch)
C-RORC – Common Read Out Receiver Card (PCIe)
GBTx – Giga Bit Transceivers
GBT-SCA – GBTx Slow Controls Adapter
VTTx, VTRx – Fiber optic transceivers

Test Setup for SAMPA evaluation

Front-end assembly consisting of FEC and test pulse card are shielded from external noise with a small Faraday cage. Input pulses are applied through the pair of coaxial cables on the left.

SAMPA Test Stand Roadmap



GEM Readout 2   (ACTIVE)

- Pedestal database for all FEC channels
- SAMPA threshold values for all channels based on pedestal database
- Study GEM pulse data (e.g. pulse shape, time resolution of correlated hits)
- Stream continuous GEM data over the network

TDIS

- Direct triggering of SAMPA chips (non-continuous mode)
- Readout prototype mTPC
- Construct new FECs with new SAMPA chip (80 ns shaping time)

Firmware upgrades   (ACTIVE)

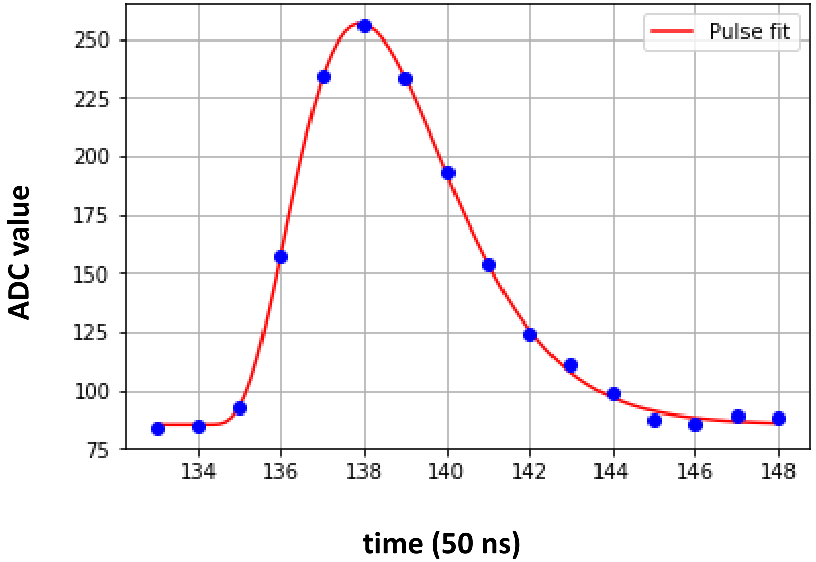
- Modify current readout card firmware to stream only hit data to PC memory
- Pulse feature extraction in FPGA

Integrate FELIX read out hardware/software

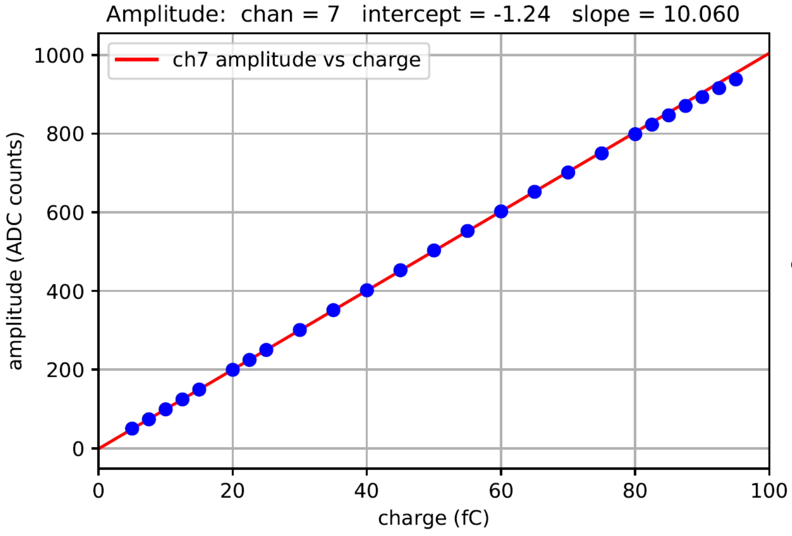
- Use FELIX software to configure FEC (GBTx, GBT-SCA, SAMPA)
- Modify FELIX firmware for GBT wide bus mode (no forward error correction)
- Powerful FPGA allows for more complex pulse feature extraction

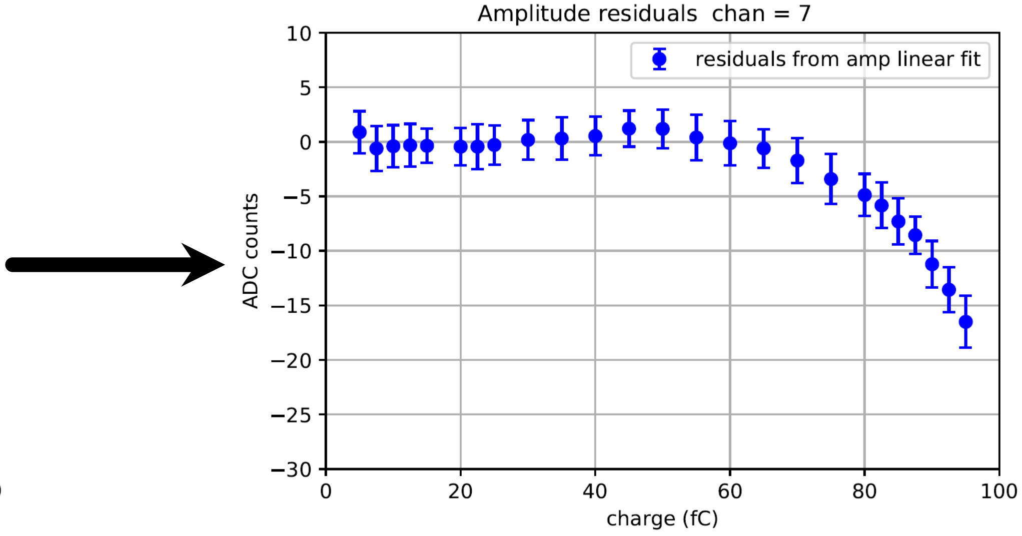
Example SAMPA output

- Right - Cosmic ray pulse on a single strip of the GEM detector. SAMPA gain = 20 mV/fC. Signal represents about 22 fC of charge collected. ADC is 10 bits precision sampling at 20 MHz.



- Below – Linearity test using pulser.



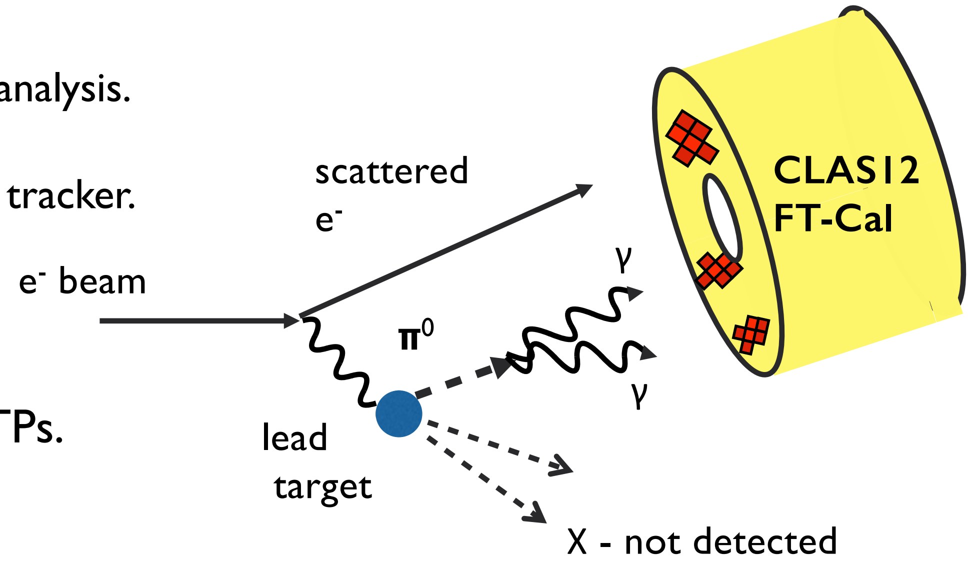


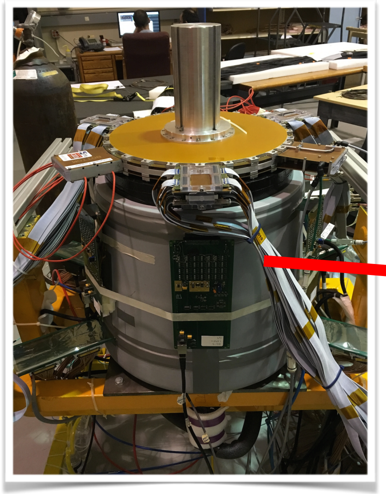
Opportunistic testing - Streaming RO - CLAS12-Forward Tagger

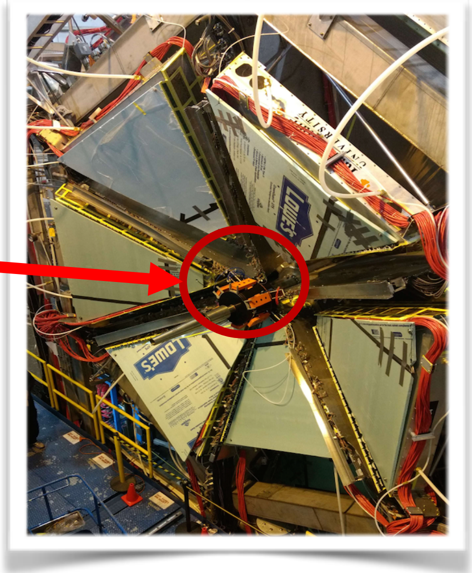
- **Main goal is a Streaming Readout DAQ full chain test:**
  - Front End hard/firmware + Run Control + Streaming software + online analysis.
  - Aim for n-beam test (10.4 GeV on lead target) in Jan/Feb 2020.
  - Detector, Hall-B CLAS12 Forward Tagger is calorimeter, hodoscope, and tracker.
- First attempt:
  - CLAS12 Forward Tracker Calorimeter only.
  - Calorimeter is 332 PbWO crystals (APD).
  - Readout is two crates of fADC250 boards (10+12) read by 2 VTPs.
- Secondary goals:
  - While collecting data look for 3 clusters in FT-CAL.
  - Identify the reaction :

$$e\,Pb \rightarrow (X)\, e'\, \pi^0 \rightarrow (X)\, e'\, \gamma\, \gamma$$

  - Reconstruct M_{π^0} in real time.

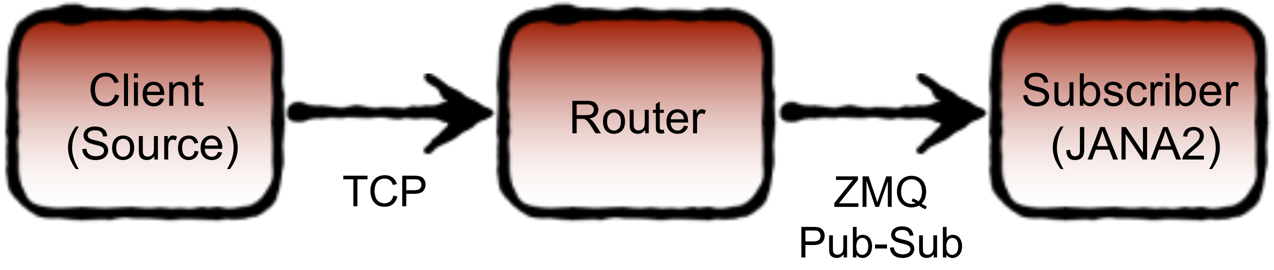






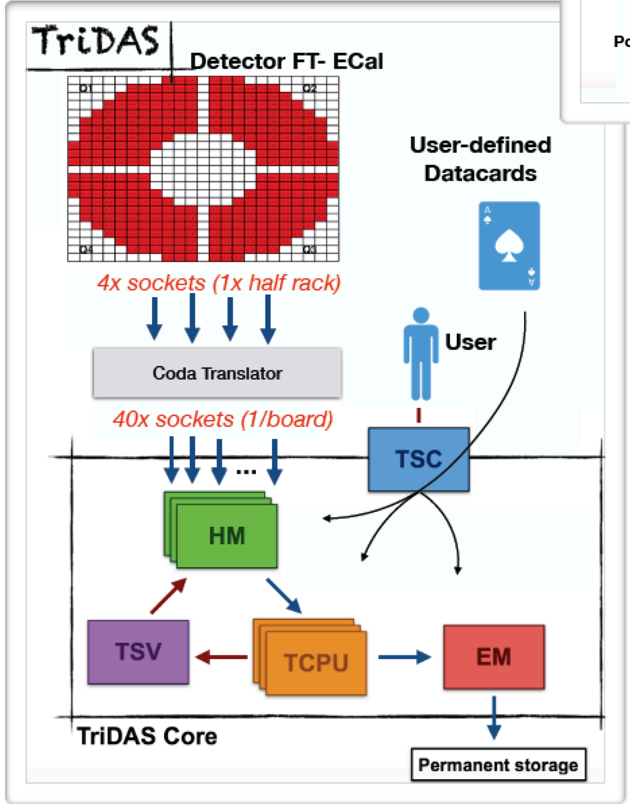
Strategy for a quick test

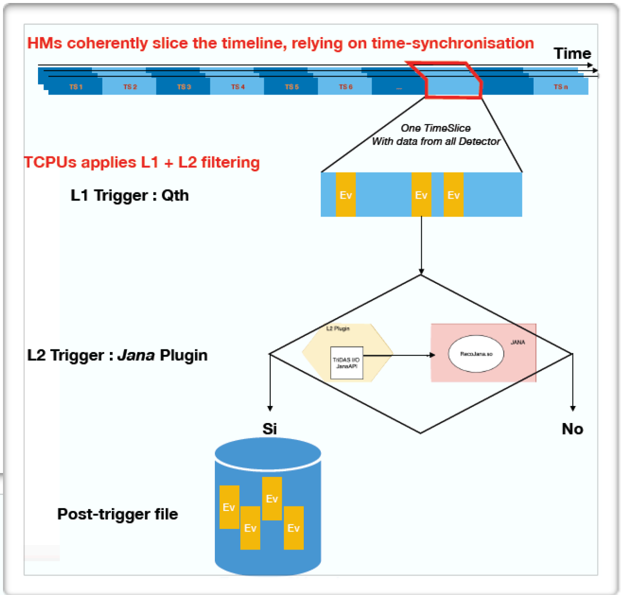
- We have basic software used in the GEM/SAMPA tests.
  - Already used to test of VTP readout of fADCs:
    - VTP sends data in streaming format using TCP to Router.
    - Router receives data and publishes data to subscribers (analyzers).
      - Open source ZeroMQ library used as the publish-subscribe data transport between router and subscriber.
  - JANA2 plugin developed to receive data.
- Note :
  - The Router was meant for rapid prototyping not for streaming readout of a detector in beam conditions. What can we do here for a rapid prototype?



TriDAS - T.Chiarusi, C.Pellegrino

- TriDAS is an existing streaming DAQ developed for theKM3NeT neutrino detector.
  - It is not ideal for use in a large-scale NP experiment but “good enough” for this test.
- TriDAS installed on Hall-B cluster.
- Readout fADCs using VTP – Ben
- VTP outputs in same streaming format used by previous JLab tests.
- Translate this format to one used by TriDAS
- Set up TriDAS to do a virtual triggers.
  - First goal TriDAS writes to disk.
- Develop a JANA plugin with goals to:
  - Implement a L2 in JANA
  - Try online reconstruction.
  - Store reconstructed data from JANA.

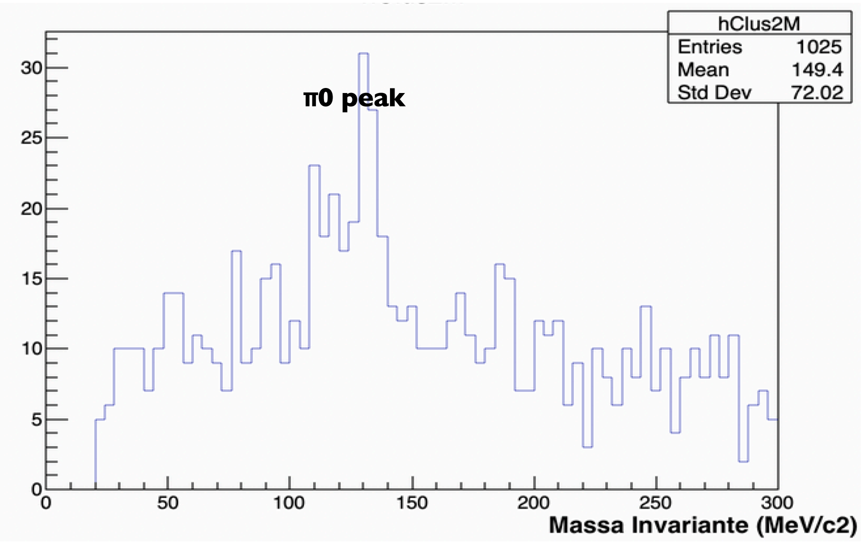




Can TriDAS do the job?

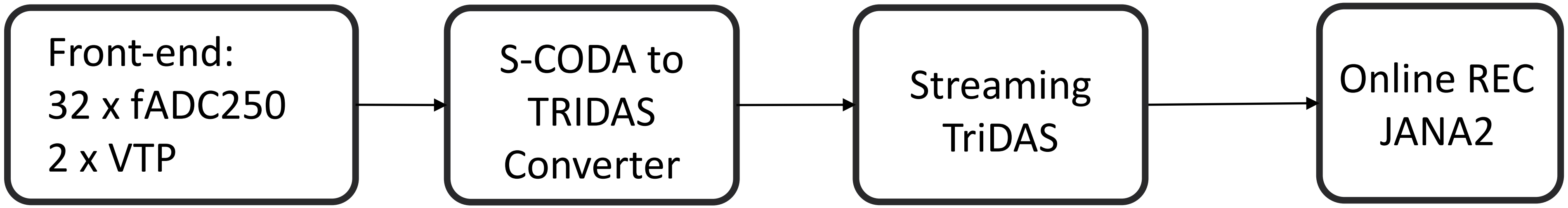
- Try feeding RG-A data, taken with CODA based triggered DAQ, into TriDAS and see what is needed to find the π^0 mass peak.

- Looks like TriDAS can do that and can likely manage the rates from this small detector.

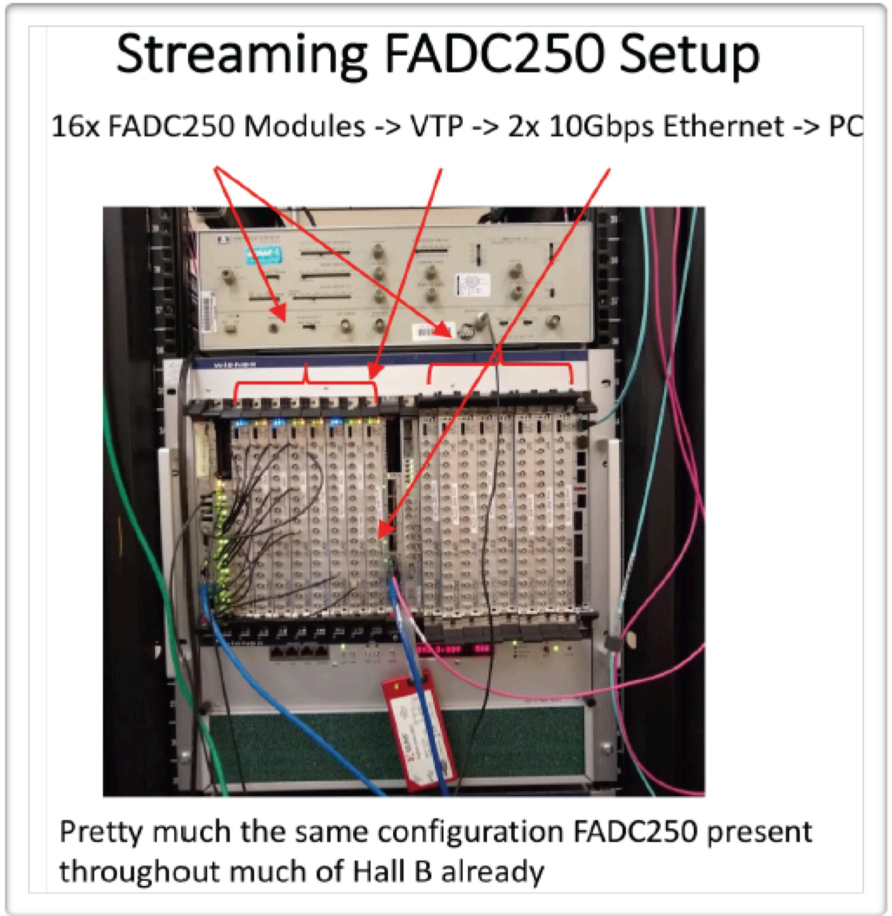


Double-clusters (π^0) mass obtained from FT-Cal RG-A data fed to TRIDAS

Front-end setup - D.Abbott, F.Ameli, C.Cuevas, P. Musico, B.Raydo

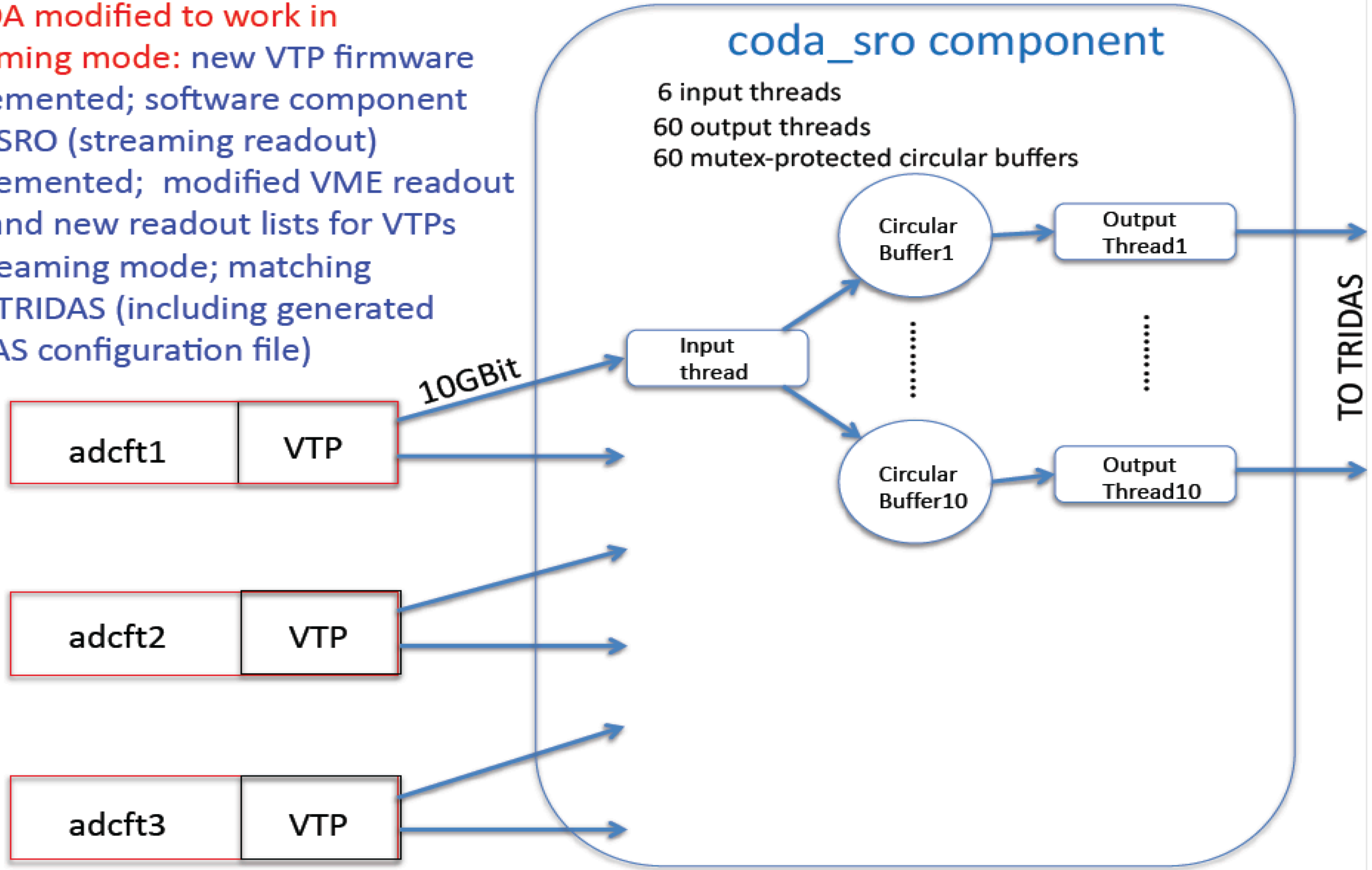


- Front-end peak data rates ~150MBytes total (from both VTPs)
  - Less than current VTP limit: ~2 GByte/sec.
  - Less than theoretical max: 10 GBytes/sec
- Issues:
  - VTP 10GbE ethernet links showed stability problems.
  - TCP/IP library on VTP was found to be responsible.
  - Ben is working on fixing it.
  - Note: some other groups use UDP because of lack of a good and cheap TCP implementation on FPGAs.



CODA run control - S.Boyarinov, B.Raydo

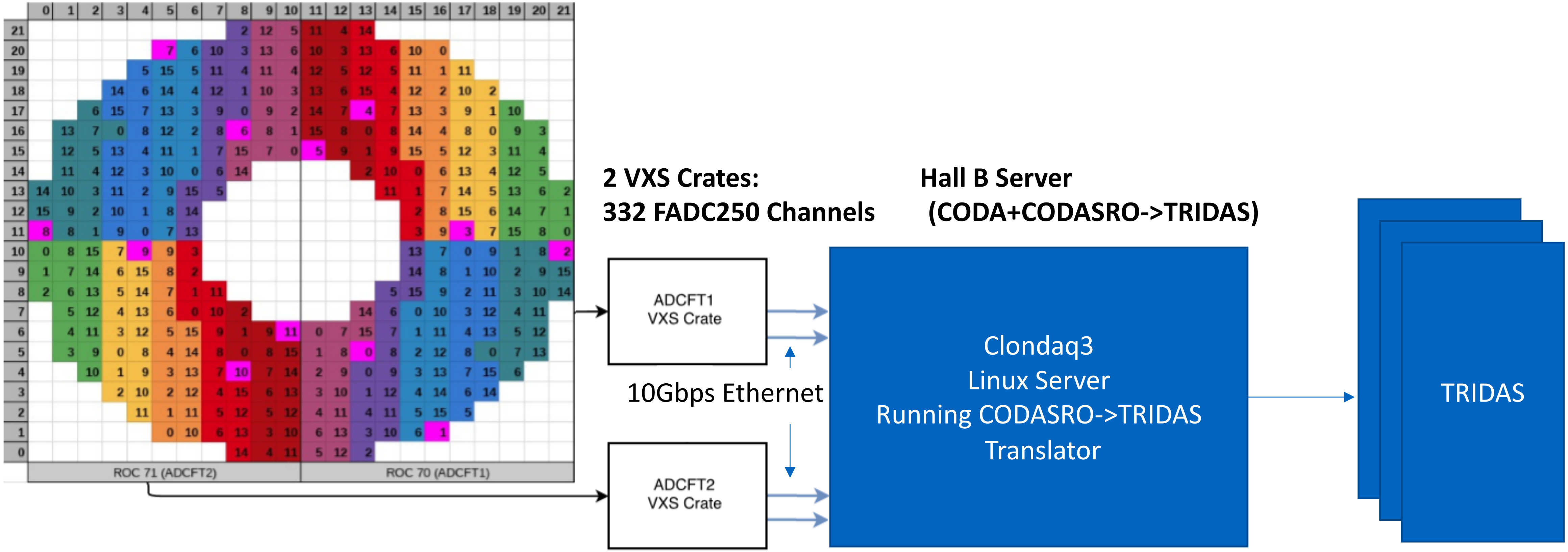
CODA modified to work in streaming mode: new VTP firmware implemented; software component type SRO (streaming readout) implemented; modified VME readout lists and new readout lists for VTPs in streaming mode; matching with TRIDAS (including generated TRIDAS configuration file)



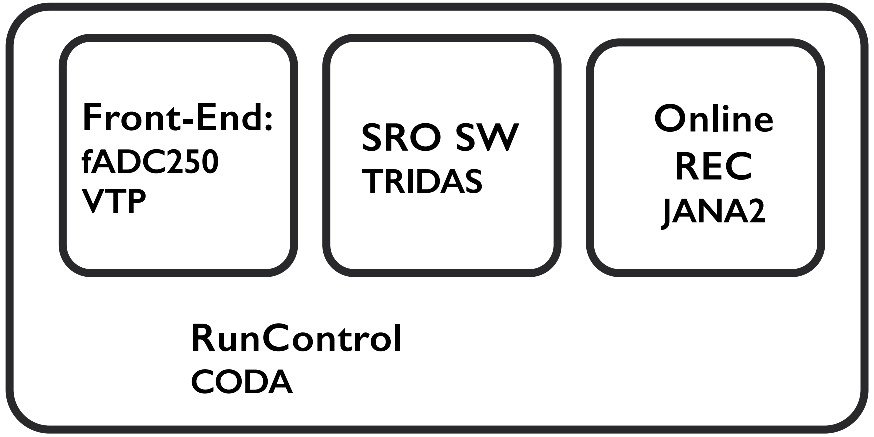
Hall B FT Calorimeter Streaming Test w/VTP – From Ben

- Used existing VXS crates with VTP and FADC250 modules
- VTP firmware update and 4x 10GbE connections was all that was needed to convert existing DAQ in the hall
- Plenty of issues to debug, but data was collected during a few short runs with beam and full calorimeter reporting
- Total data rate from VTPs was <300MB/s – well within the link capacity
- VTP had consistent stability problem with the 10GbE TCP/IP stack. Expected to be addressed well before the streaming DAQ test in Hall D.

332 PbWO4 Forward Tagger Calorimeter

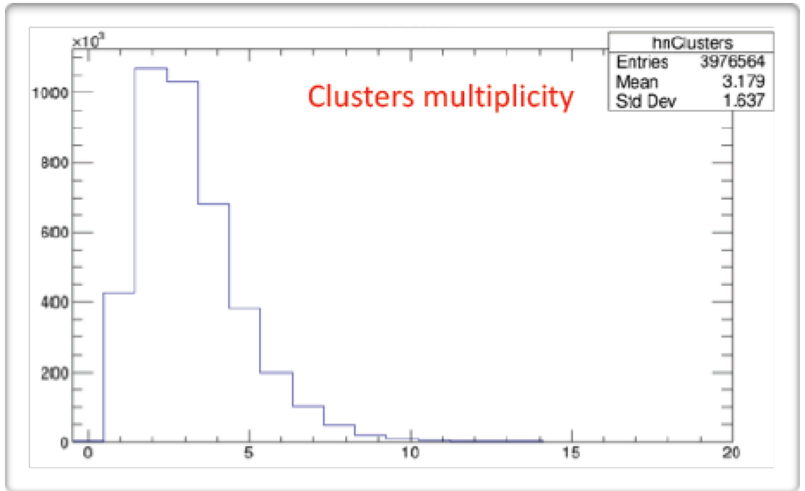


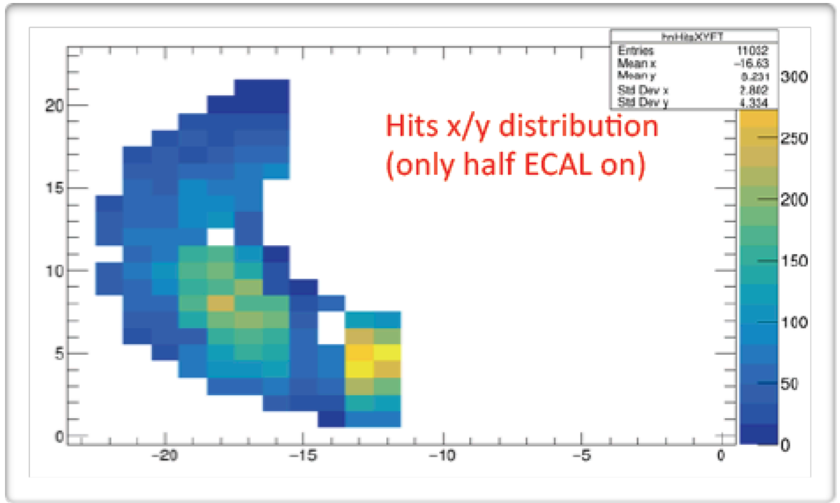
Streaming RO - CLAS12-FT online reconstruction



JANA2 + REC

N.Brei, D.Lawrence,
M.Bondi', A.Celentano, C.Fanelli, S.Vallarino





- FE setup:
  - FT-Cal only
  - TET (on fADC250)=15/50,
  - L1 threshold: 2000 (MeV)
  - L1 time window: 400 ns
- Tridas+JANA2+monitoring
- JANA2:
  - single-thread
  - L2 plugins: scaler (write all L1 to disk) + JANA2 (tag L1 events)
  - Online clustering enabled
  - Different runs taken with >=1 cluster, >=2 clusters, >=3 clusters

Streaming summary

- Between mid-December and mid-February we went from next to nothing to a full in-beam demonstration of readout in streaming mode – holidays ate nearly two weeks of that. Impressive cooperation between JLab and INFN!! Thanks Marco!!

- What worked:
  - Data was taken in streaming mode and stored to disk.
  - L1 and L2 triggering in software after acquisition worked.
  - Integration with existing CODA for Run Control and configuration worked.
  - JANA2 was able to reconstruct events and perform analysis.

- What wasn't so good:
  - Firmware TCP library is buggy and introduced instabilities.
  - Aggressive schedule and limited beam time meant that online JANA2 reconstruction was not used.

- What's next?
  - Hall-B was reconfigured for BONUS – no opportunities for more beam time for a while.
  - Hall-B have detectors that use the fADC and VTP – will try for tests there
  - Continue work on all of these projects and keep a consistent picture.