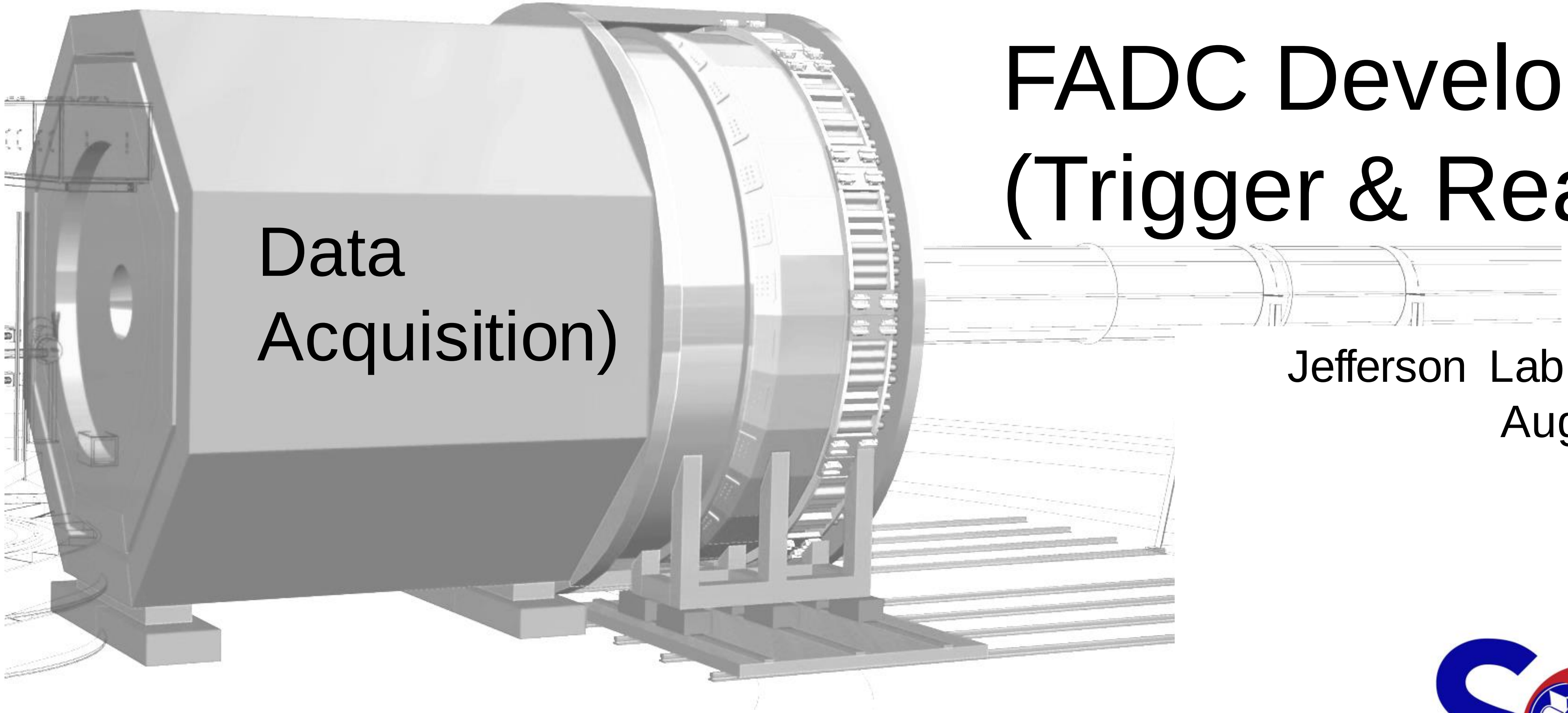

FADC Developments (Trigger & Readout)

Jefferson Lab SoLID Pre-R&D Review
August 7th, 2020

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Jlab FEDAQ

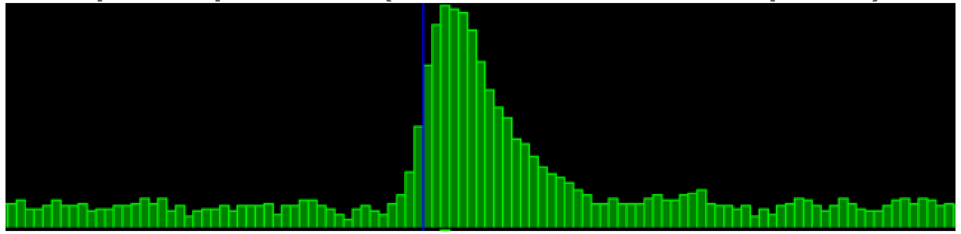
Overview

- FADC250 Module
- VTP Module
- VXS Crate
- ECAL FADC Trigger
- PVIDS DAQ
- SIDIS DAQ
- FADC Readout with VTP

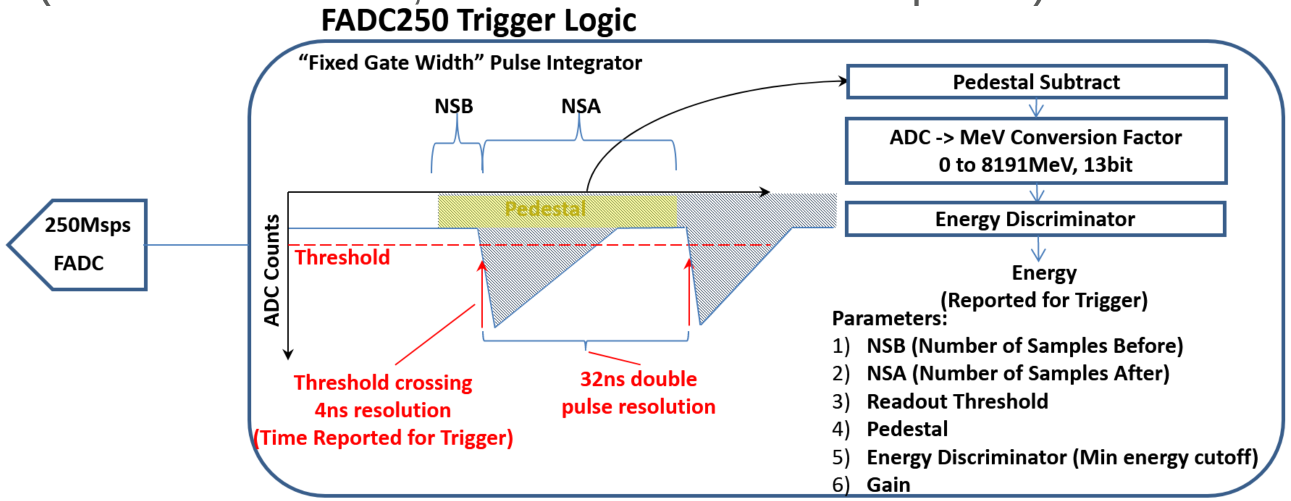
FADC250

- 16 channels, 250Msps Flash ADC
- VME based module, supports 2eSST200 (200MByte/sec)
- Triggerable up to ~200kHz (depends on readout configuration/occupancy)
- VME data can provide raw pulse samples, or extracted charge/time (as well as scalers, pedestal data, and others)

Example raw pulse data (each bin is 4ns, 12bit amplitude):



- Trigger output (for each channel, to VTP over VXS backplane):



- FADC250 has been used for >10 years at Jlab in many small to large experiments

VXS Based Trigger

VTP (VXS Trigger Processor)

- Used in the crate when a trigger needs to be formed from the FADC250 (and/or other Jlab modules) - up to 16 FADC250 modules send trigger data to the VTP

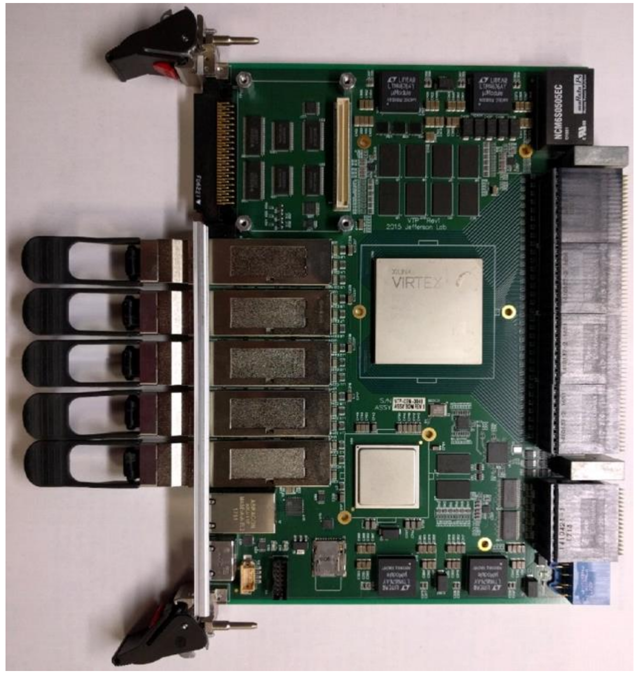
- Each FADC250 in the VXS crate is connected to the VTP with 4 full duplex serial links that can operate up to 6.25Gbps each

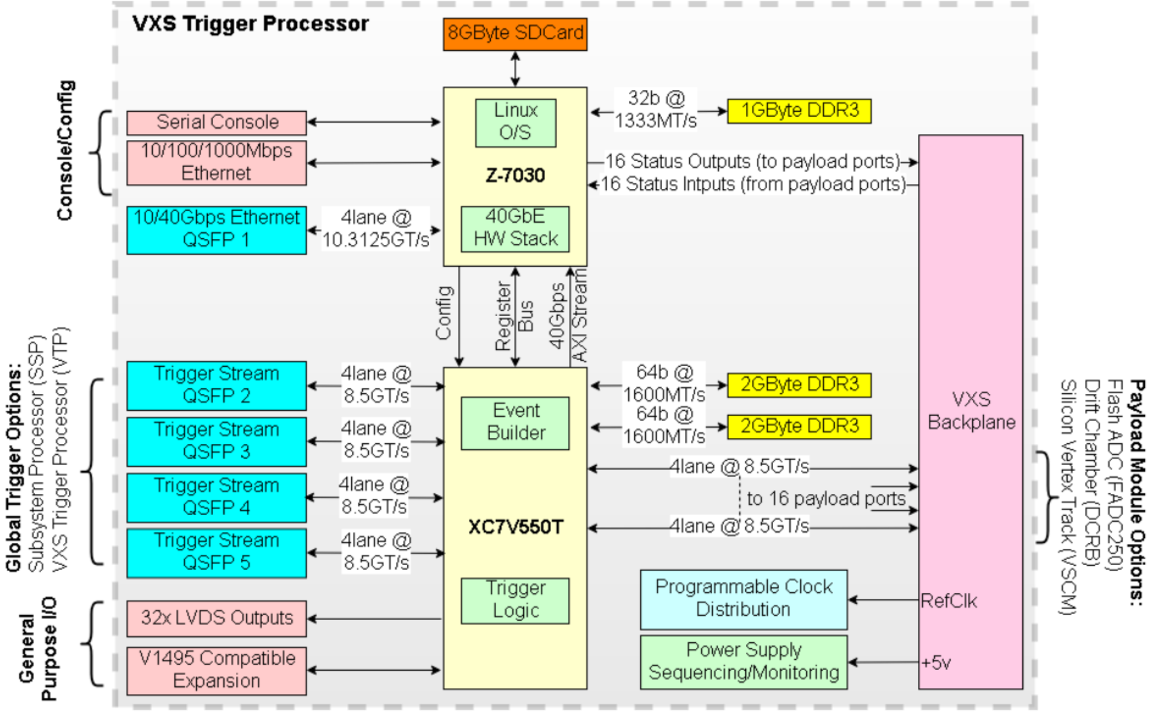
- The trigger requires 10Gbps of bandwidth from each FADC -> VTP, so normally runs 4 serial links at 2.5Gbps

- VTP receives integrated & calibrated pulse integrals & timestamps from up to 256 FADC250 channels in 1 crate

- Can exchange information with other VTPs using 1 or more of the full-duplex QSFP optical interfaces

VTP:

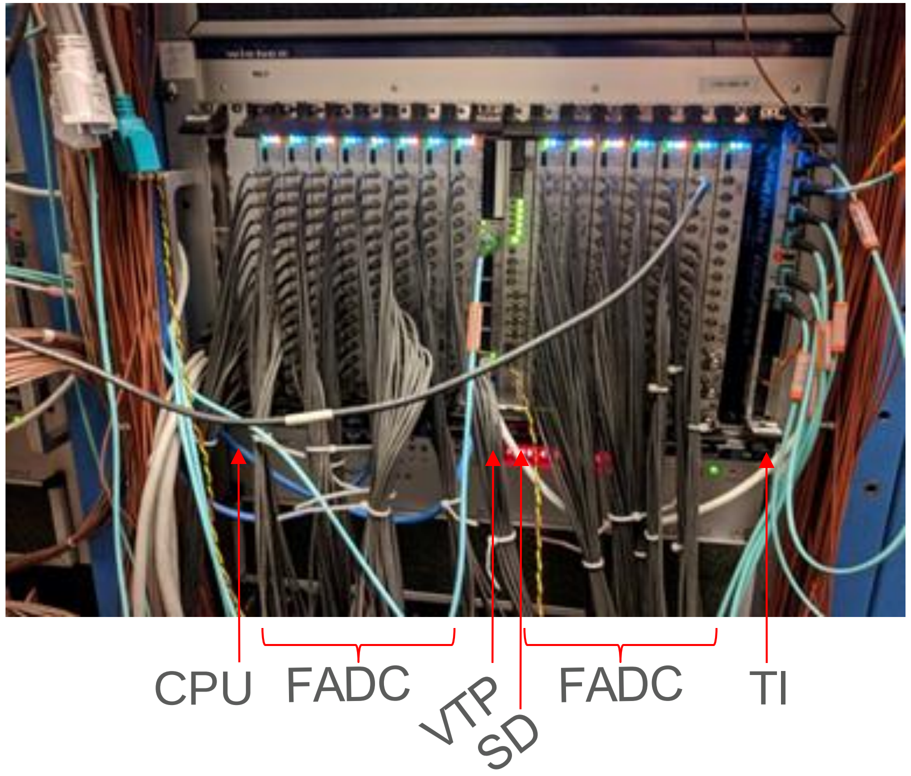




VXS Crate

- 21 slot VME crate, with VITA 41 VXS extension
- VXS allows us to distribute high quality point-to-point signals
  - Used for clock, trigger, etc. distribution on backplane
  - Also used for high speed serial communication – to be discussed later
- VME CPU in first slot manages the crate, reads out module data on trigger (or block of triggers), formats and ships data over ethernet
- VME readout mode used: 200MB/s, in practice we can get ~180MB/s, but often we are limited by the Ethernet
- CPU ethernet is typically 1Gbps, which limits data rate from crate to ~100MB/s. Adding a 10Gbps Ethernet card to CPU the ~180MB/s VME bandwidth is possible.

VXS Crate of FADC250 (256 channels)

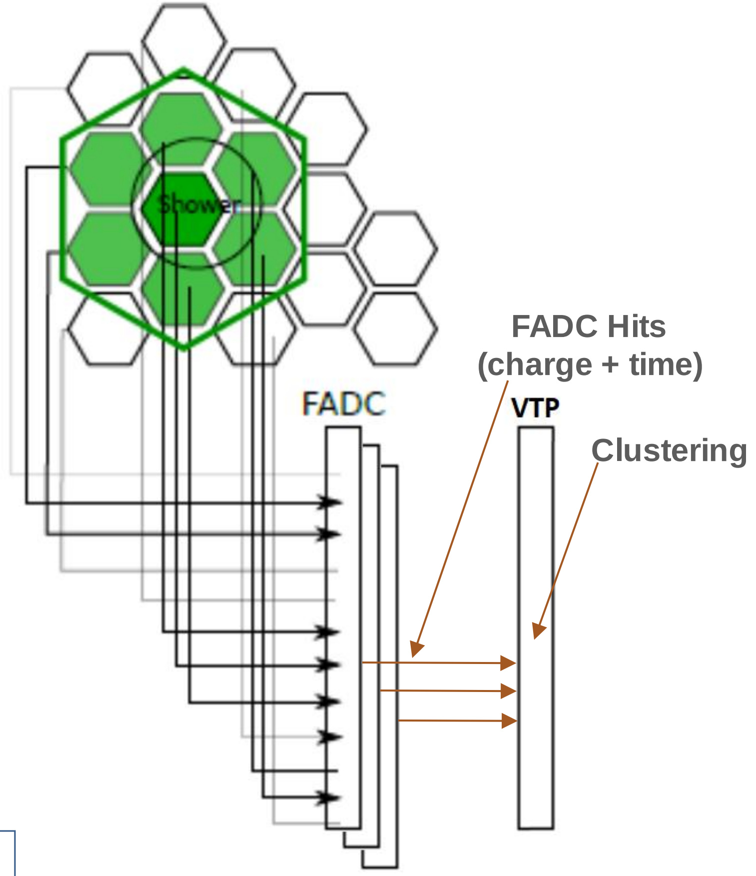


- CPU: Intel/Linux
- FADC: Flash ADC 250MHz 16channels
- VTP: VXS Trigger Processor
- SD: Signal Distribution
- TI: Trigger Interface

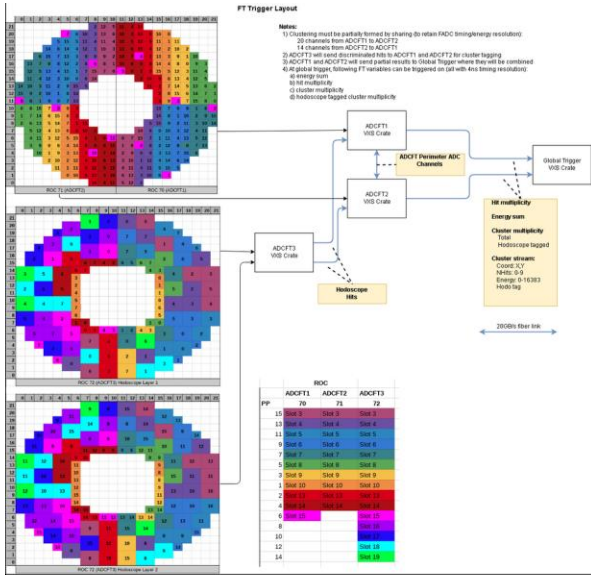
ECAL FADC Trigger

- ECAL cluster: sum of 7 crystals (all combinations)
- All FADCs reports hits (charge + time) to VTP where (1+6) clustering is performed
- This development still needs to be done, but it is very similar to CLAS12 FT and HPS ECAL triggers which have more channels in the crate – resources for SoLID case on VTP is no issue:
  - ➢ VTP+FADC250 already in used for these setups
  - ➢ Optical sharing of perimeter channel performed for CLAS12 FT
  - ➢ Geometry matching (with hodoscope for FT/HPS)

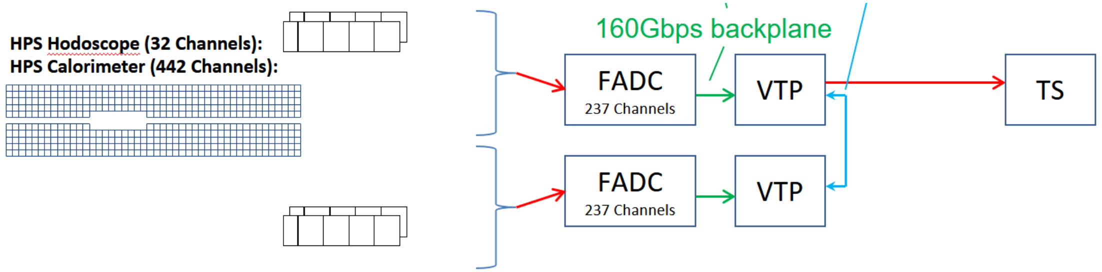
SoLID ECAL trigger clustering:



CLAS12 FT:

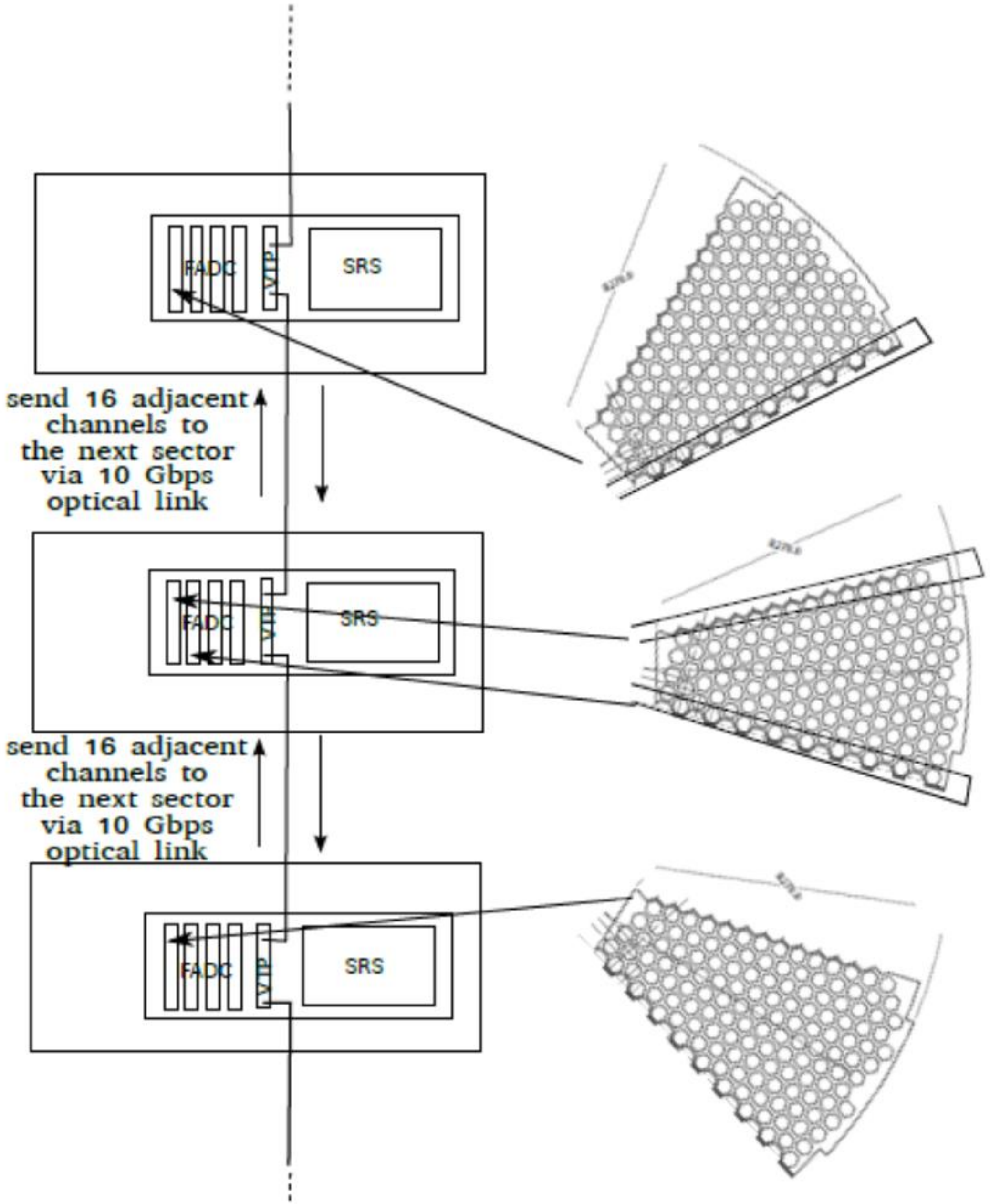


HPS:



PVDIS DAQ

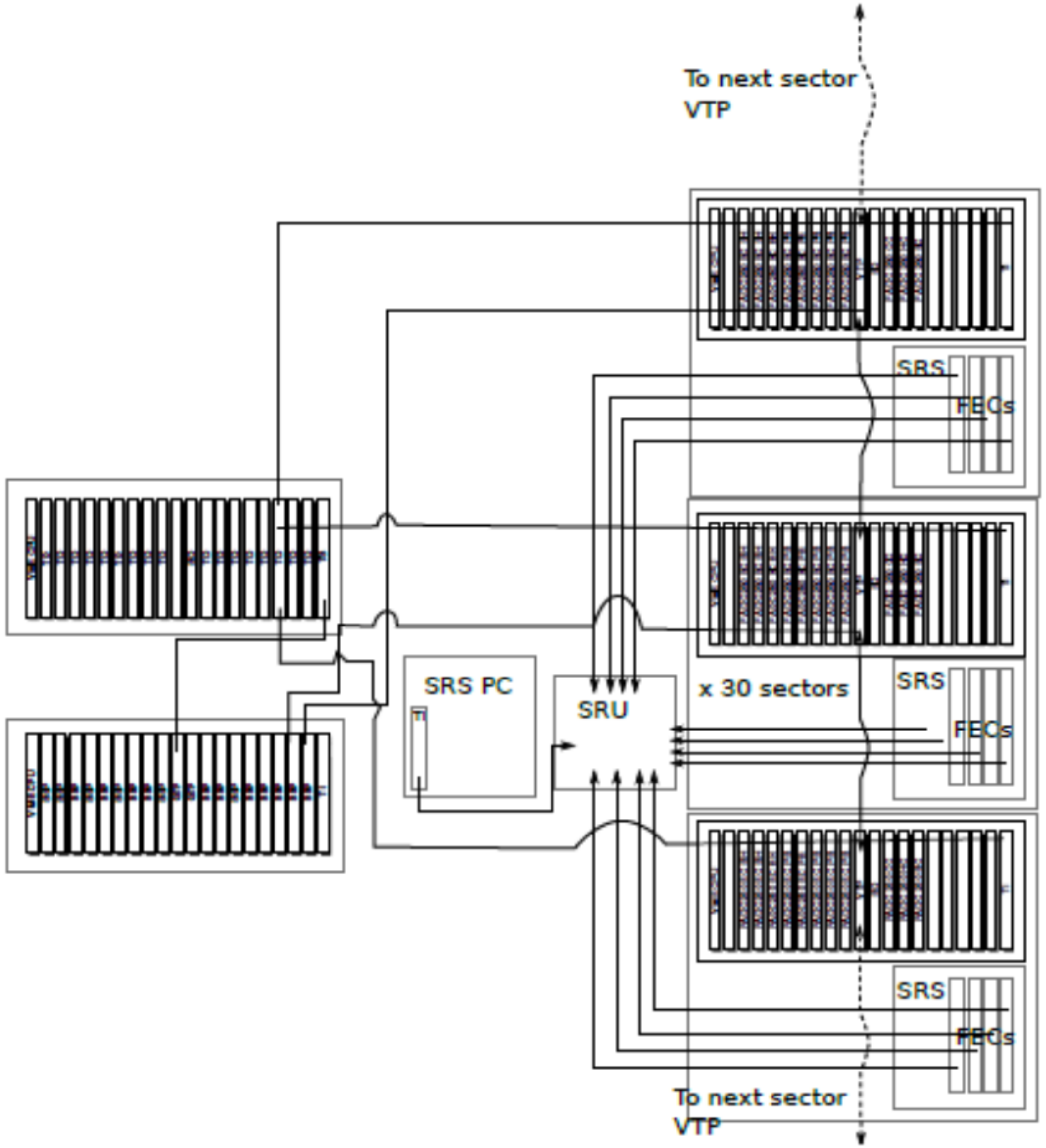
- 30 sectors / VXS crates => 30 mostly independent DAQ systems, but must share bordering channels
- Trigger: coincidence ECAL cluster and Cerenkov
- Sector trigger rate: 20kHz, data rate: 94MB/s
- Total trigger rate: 600kHz, data rate: 2.9GB/s



SIDIS DAQ

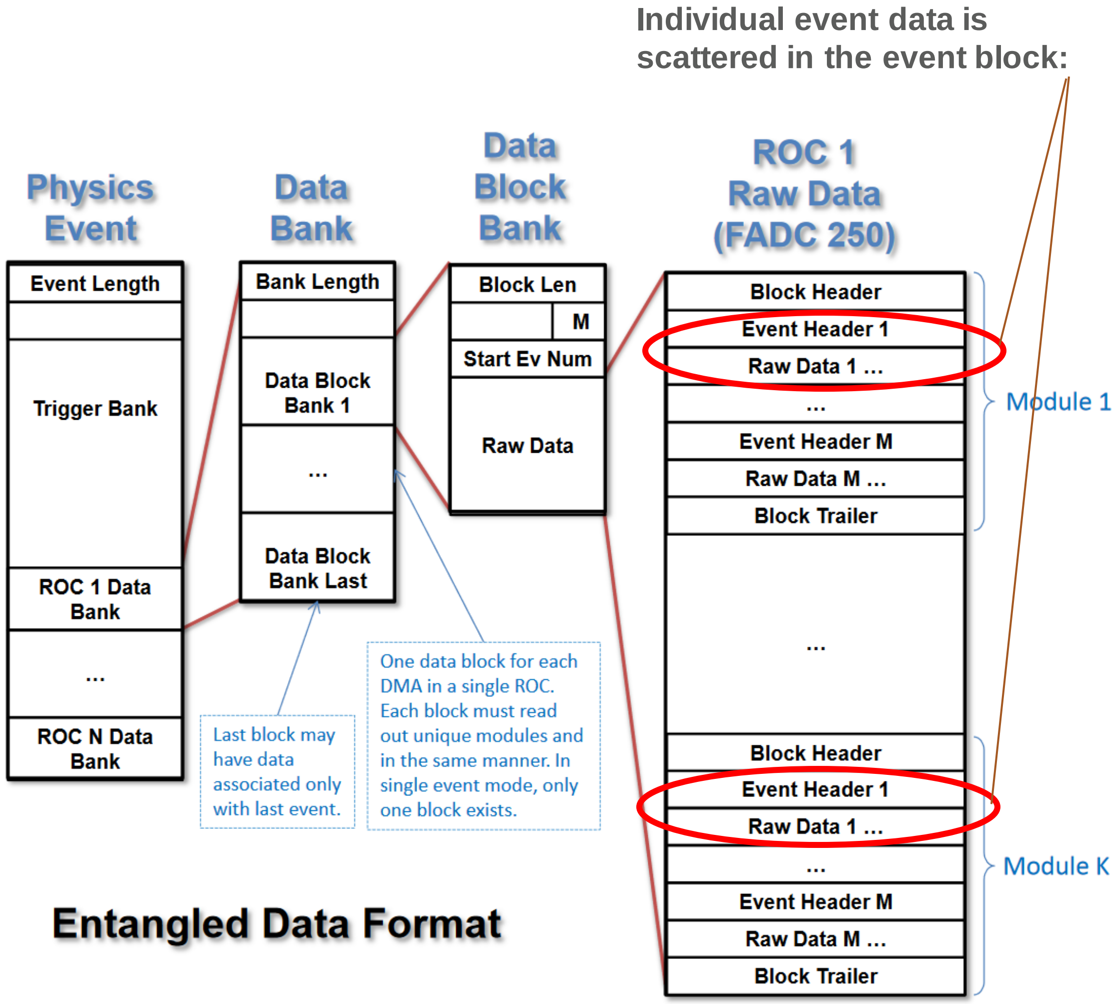
- 1 DAQ system
- Trigger: coincidence ECAL cluster and Cerenkov
- All sectors combined to form a global trigger
- Capable of 100kHz & data rate: 2.9GB/s

(data rate assume 1 sample take per GEM channel)



Event blocking

- To reduce CPU & VME readout overhead, events are readout in "blocks" of events
  - ➢ Typically events are readout in blocks of 20 or 40 events
  - ➢ Trigger rates >100kHz can be achieved with low dead-time in this way – otherwise ~10kHz is the non-event blocking limit
- This complicates the data structure because now single events are "entangled" (i.e. spread across the data record), making offline data processing a bit of an annoyance



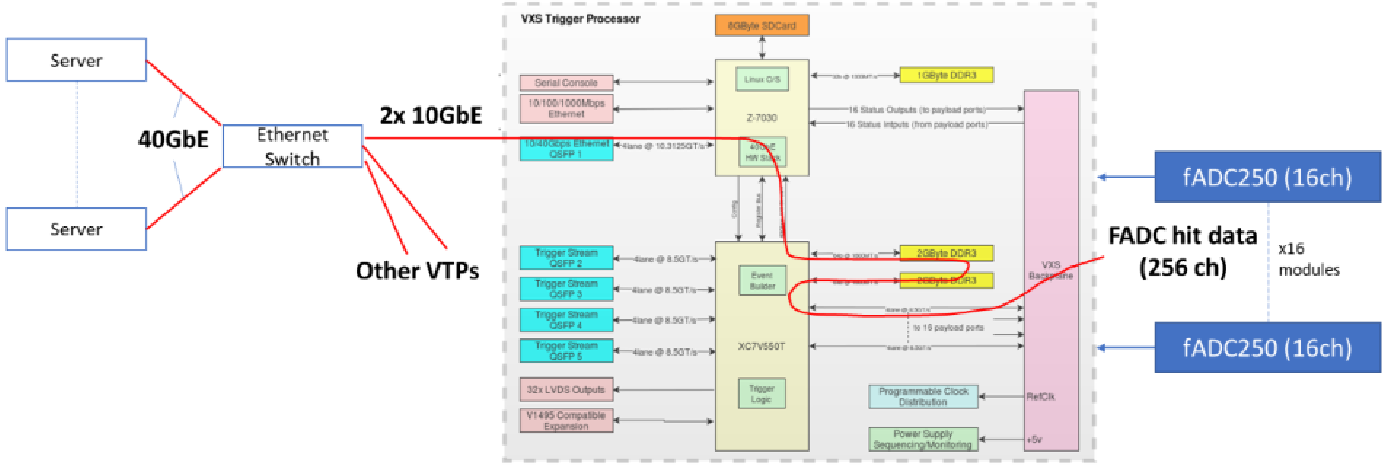
Entangled Data Format

Streaming DAQ

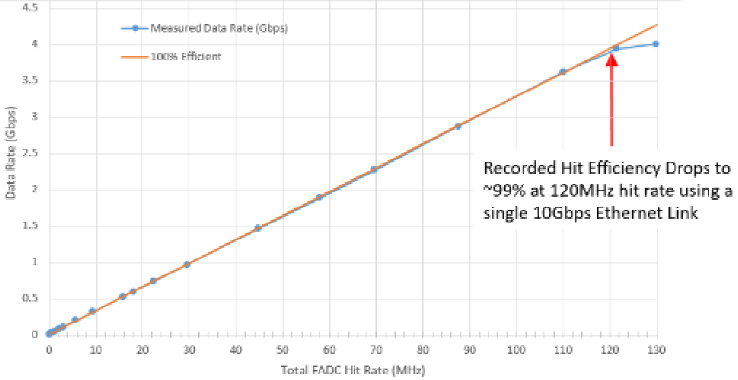
VTP + FADC250 has recently been used in a Streaming DAQ project where VTP collects hits from all FADC250 in crate and streams it over multiple 10Gbps Ethernet links using TCP. Several firmware components are re-usable which is a significant help.

Front-end setup 2 VXS crates, each with VTP w/ 2x 10GbE optical links, 11 FADC250 modules, 336 PbWO crystals w/APD

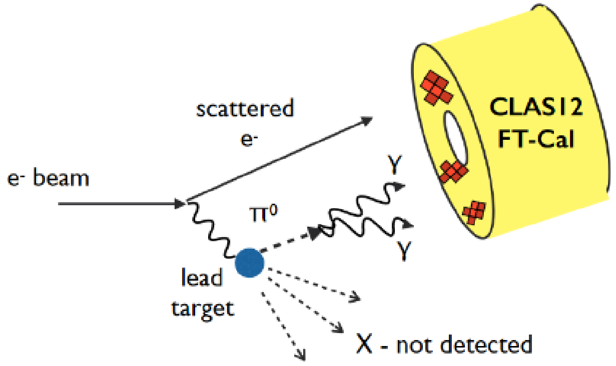
Backend setup servers connected to front-end ethernet switch by 40GbE. Combination of CODA, TRIDAS (by INFN), JANA2, ROOT for configuration, event selection, event reconstruction, and online monitoring

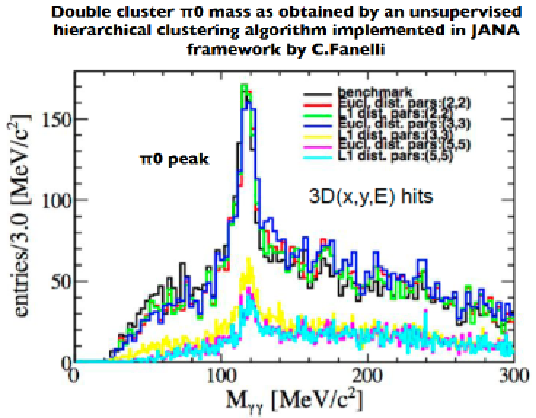


Rate capability Close to 1MHz rate per FADC channel before suffering efficiency loss (nearly 2x better after recent bandwidth improvements)



π⁰ reconstructed signal from streaming readout rest



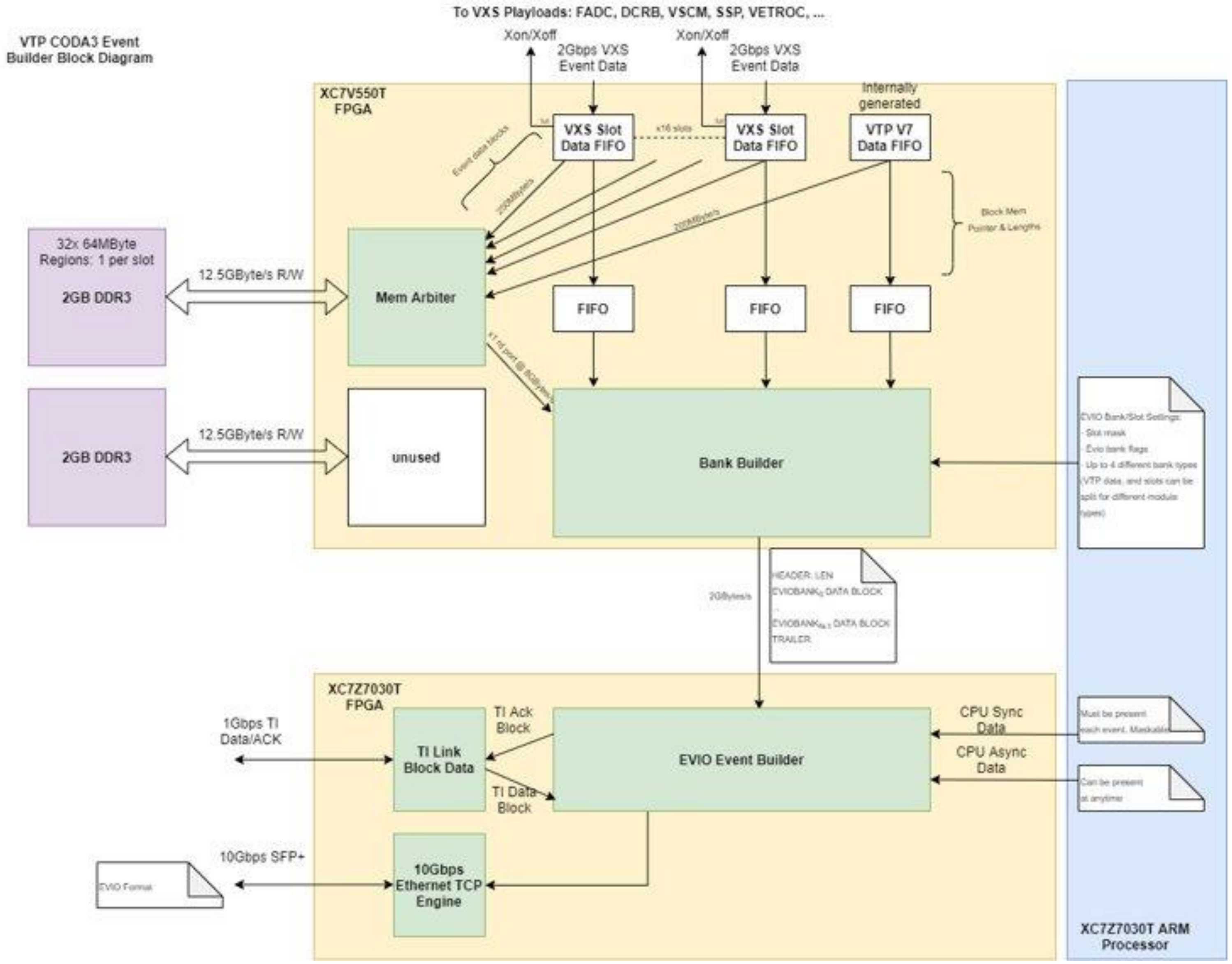


VXS Readout with VTP

- Increasing the FADC250 -> VTP serial link will allow sending both trigger and readout data over the same link:
  - ➢ Normally we run 4 lanes at 2.5Gbps provide 10Gbps for the trigger
  - ➢ Changed to 4 lanes at 3.125Gbps to be enough for trigger + **200MB/s of event readout bandwidth from each FADC250** to the VTP – this is significantly more than the VME 200MB/s limit which is for the whole backplane
  - ➢ Protocol for FADC250<->VTP has been updated to handle combined trigger+event data streams
- VTP has 4 free 10Gbps compatible Ethernet optical links available for transmitting event data onto the network. Currently only a single 10Gbps link is planned to be used. **Nearly the full link 10Gbps link speed can be utilized for event data transport.**
- All event building, Ethernet, and TCP/IP is done in the FPGA and there is no significant overhead associate with individual events – this means **no event block is needed to support high trigger rates**.

VTP CODA3 Block Diagram

- Firmware will be fully compliant with CODA3 event builder: downstream components won't know the difference.
- VTP has large memory buffers to hold event data from individual modules (64MB per module)
- The CPU on the VTP will run a readout list – it can optionally participate event-by-event, but the main difference between this readout list and the traditional VME CPU readout list is that all VME module data will be handled in firmware.
- This is a generic implementation that can support other Jlab modules besides the FADC250 (e.g. DCRB, VSCM, SSP, VETROC) - other experiments besides SoLID can benefit from this development.



Status & Conclusion

- Tasks & status:

1. FADC250 <-> VTP protocol for shared trigger+event data defined, and firmware has been completed

2. VTP FPGA CODA based readout controller framework defined, firmware in progress, expected completed this fall – this is the main work/focus.

3. ECAL VTP clustering firmware: has been evaluated and considered of similar complexity as existing calorimeter trigger implemetations already done on VTP. Firmware has not started, but expected completed this fall.

4. Debugging & performance testing still needed, will begin as soon as (2) and (3) are ready.

Backup

PVDIS sector trigger rates:

	Old	Hall D
Singles ECAL	290 KHz	230 KHz
Singles rates Cerenkov	1.9 MHz	803 KHz
Accidental 30 ns	16.5 KHz	4.1 KHz
DIS electron	10 KHz max	7.7 KHz
Total rate	**27 KHz**	**12.1 KHz**

SIDIS sector data rates:

Occupancies with one sample readout by Weizhi , rates for 100 KHz

GEM	Occupancy	Number of strips	XY strips	Strips per chambers	MB/s
1	2.21	453	906	27180	245
2	8.78	510	1020	30600	1184
3	3.63	583	1166	34980	559.5
4	2.31	702	1404	42120	428.7
5	1.78	520	1040	31200	244.71
6	1.3	640	1280	38400	220
Total	20.01	3408	6816	204480	2901

GEM dominating 2.9 GB/s same requirement as PVDIS

PVDIS sector data rates:

				Event size		Data rate MBs	After noise cut	strips firing	event size bytes		MB/s
1	1156	21.17	244.73	3038.03	3038.03	60.76	9.97	115.25	1430.76	1430.76	28.62
2	1374	10.35	142.21	1765.39	1765.39	35.31	5.11	70.21	871.61	871.61	17.43
3	1374	8.81	121.05	1502.71	1502.71	30.05	4.42	60.73	753.92	753.92	15.08
4	2287	3.07	70.21	871.60	871.60	17.43	1.64	37.51	465.61	465.61	9.31
5	2350	2.79	65.57	813.93	813.93	16.28	1.50	35.25	437.60	437.60	8.75
					Total	159.83				Total	79.19
FADC											
	20000						10				
	Event size FADC	Nb channel	Header			Trailer	Sample				
	Calorimeter	14	4			4	12	280			
	Preshower	9	4			4	12	180	400		
	Cerenkov	9	4			4	12	180			
									11600000		
								740	11600000	11.6	
									Total rate	94	MB/s