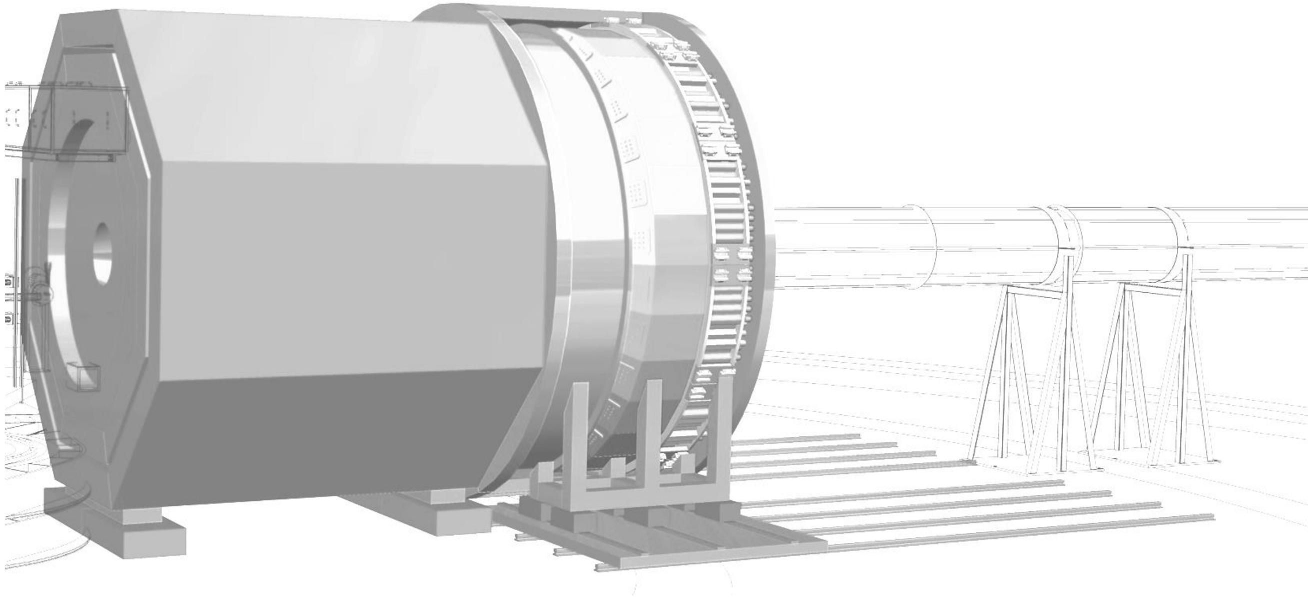


SoLID Streaming Read Out Consideration

Streaming Readout Workshop

May 15th, 2020

Alexandre Camsonne

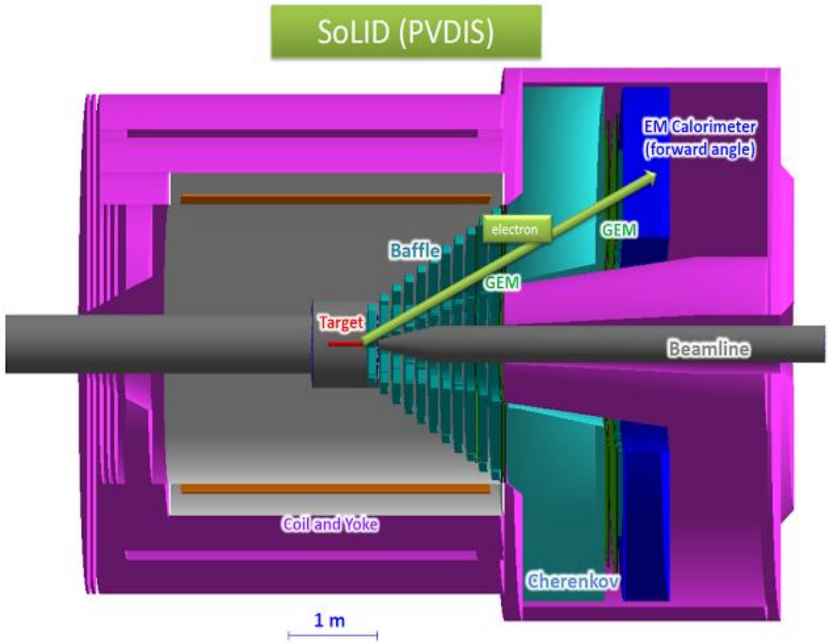
Hall A

Jefferson Laboratory

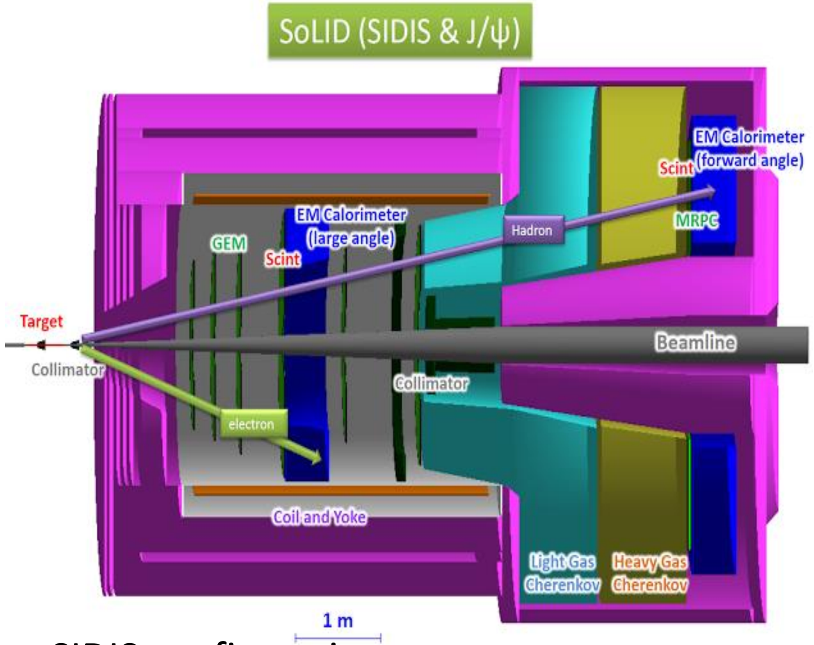
Outline

- SoLID experiments overview
- Requirements
- GEM detectors
- GEM readout(s)
- Electromagnetic Calorimeter trigger and readout
- Cerenkov readout
- PVDIS DAQ layout
- SIDIS DAQ layout
- Trigger and data rates
- Streaming option for PVDIS consideration

SoLID experiments overview



- PVDIS configuration
  - Inclusive DIS electrons
  - Trigger Calorimeter + Cerenkov
  - 30 individual sectors
  - 12 KHz/sector = less 500 KHz total



- SIDIS configuration
- Trigger :
  - Electron trigger : Calorimeter+Light Gas Cerenkov
  - Pion trigger
    - Scintillator + calorimeter
  - Main trigger : coincidence eπ
- 100 KHz of coincidence eπ
- J/ψ 30KHz triple coincidence ee^-e^+

Data Acquisition Requirement and Design

Experiments	PVDIS	SIDIS-^{3}He	SIDIS-Proton	J/ψ
Reaction channel	$p(\vec{e}, e')X$	$(e, e'\pi^{\pm})$	$(e, e'\pi^{\pm})$	$e + p \rightarrow e' + J/\Psi(e^-, e^+) + p$
Approved number of days	169	125	120	60
Target	LH_2/LD_2	^{3}He	NH_3	LH_2
Unpolarized luminosity ($cm^{-2}s^{-1}$)	$0.5\times10^{39}/1.3\times10^{39}$	$\sim 10^{37}$	$\sim 10^{36}$	$\sim 10^{37}$
Momentum coverage (GeV/c)	2.3-5.0	1.0-7.0	1.0-7.0	0.6-7.0
Momentum resolution	$\sim$2%	$\sim$2%	$\sim$3%	$\sim$2%
Polar angular coverage (degrees)	22-35	8-24	8-24	8-24
Polar angular resolution	1 mr	2 mr	3 mr	2 mr
Azimuthal angular resolution	-	6 mr	6 mr	6 mr
Trigger type	Single e^-	Coincidence $e^- + \pi^{\pm}$	Coincidence $e^- + \pi^{\pm}$	Triple coincidence $e^-e^-e^+$
Expected DAQ rates	$<$20 kHz $\times$ 30	$<$100 kHz	$<$100 kHz	$<$30 kHz
Backgrounds	Negative pions, photons	(e,$\pi^-\pi^{\pm}$) (e,e'K$^{\pm}$)	(e,$\pi^-\pi^{\pm}$) (e,e'K$^{\pm}$)	BH process Random coincidence
Major requirements	Radiation hardness 0.4% Polarimetry π^- contamination Q^2 calibration	Radiation hardness Detector resolution Kaon contamination DAQ	Shielding of *sheet-of-flame* Target spin flip Kaon contamination	Radiation hardness Detector resolution

GEM Requirements and Design: PVDIS

- High rate operation up to localized hit rates of approximately 1 MHz/cm^2.
- Instrument 5 locations with GEMs:
  - 30 GEM modules a location: each module with a 12-degree angular width.

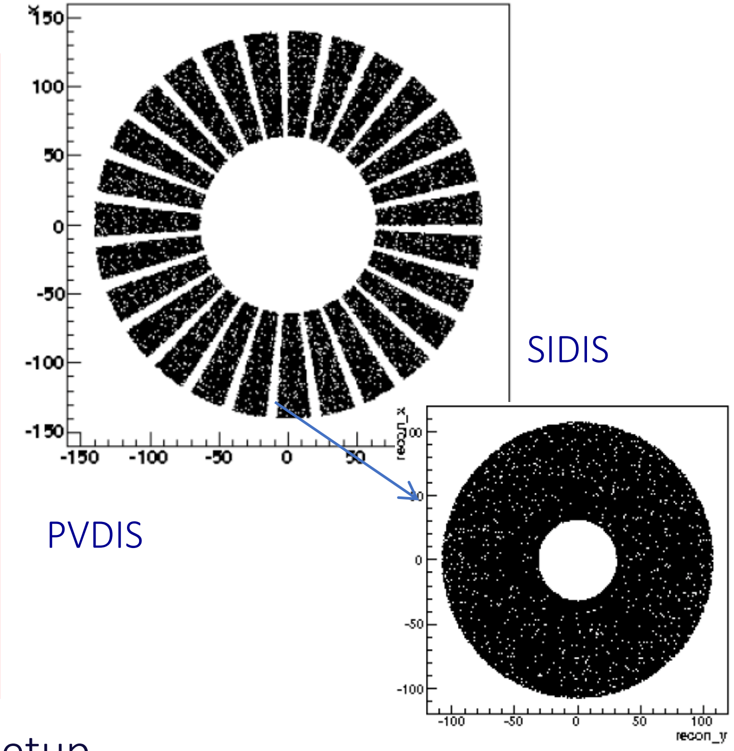
Location	Z (cm)	R_{min} (cm)	R_{max} (cm)	Surface (m^2)	# chan
1	157.5	51	118	3.6	24 k
2	185.5	62	136	4.6	30 k
3	190	65	140	4.8	36 k
4	306	111	221	11.5	35 k
5	315	115	228	12.2	38 k
Total				$\approx$ 36.6	$\approx$ 164 k

- The high occupancy at layer #1: may require splitting each readout strip into two channels: this will add another 12 k channels
- So, total number of channels needed could be : ~ 176 k
- With ~ 15% spares (to account for losses during production etc.) need to plan for 200 k readout channels
- Lot of data at high occupancy; but we can have multiple parallel DAQs

GEM Requirements and Design: SIDIS

- ❑ Compared to PVDIS, rates a bit lower: 0.15 MHz/cm^2.
- ❑ But need to read the whole layer based on a single trigger: no sectors here: no possibility to have many parallel DAQs.
  - ➢ bandwidth could be an issue: but ways to handle it.
- ❑ Instrument 6 locations with GEMs:

Plane	Z (cm)	R_I (cm)	R_O (cm)	Active area (m^2)	# of channels
1	-175	36	87	2.0	24 k
2	-150	21	98	2.9	30 k
3	-119	25	112	3.7	33 k
4	-68	32	135	5.4	28 k
5	5	42	100	2.6	20 k
6	92	55	123	3.8	26 k
total:				~20.4	~ 161 k



- ➢ More than enough electronic channels from PVDIS setup.
- ➢ The two configurations will work well with no need for new GEM or electronics fabrication.

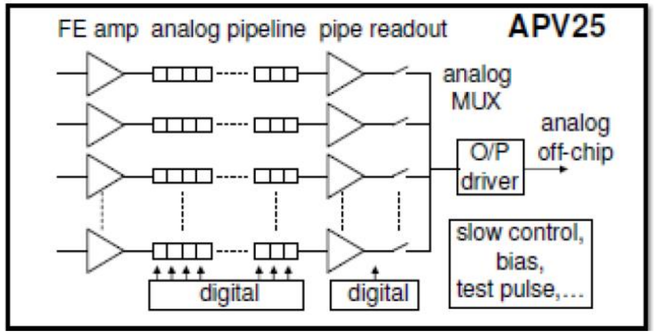
GEM readout

- DAQ based on 12 GeV pipelined electronics (Flash ADC) designed for use in Halls B & D. (Supports up to 200 kHz trigger rate and meets PVDIS and reach deadtime systematic of less than 0.1%)
- Added GEM readout similar to SBS but with trigger rates up to 100 KHz
  - APV25 based readout 100 K channels

    3.6 us readout time per sample

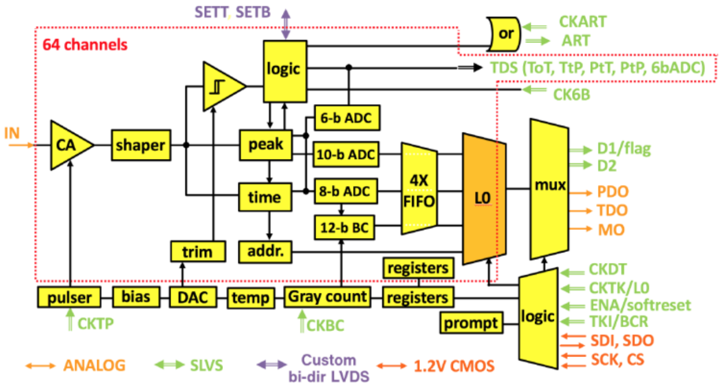
    Set limit to 200 KHz in one sample mode and 60 KHz with 3 samples

    (note that HPS currently running at 50 KHz with 6 samples)



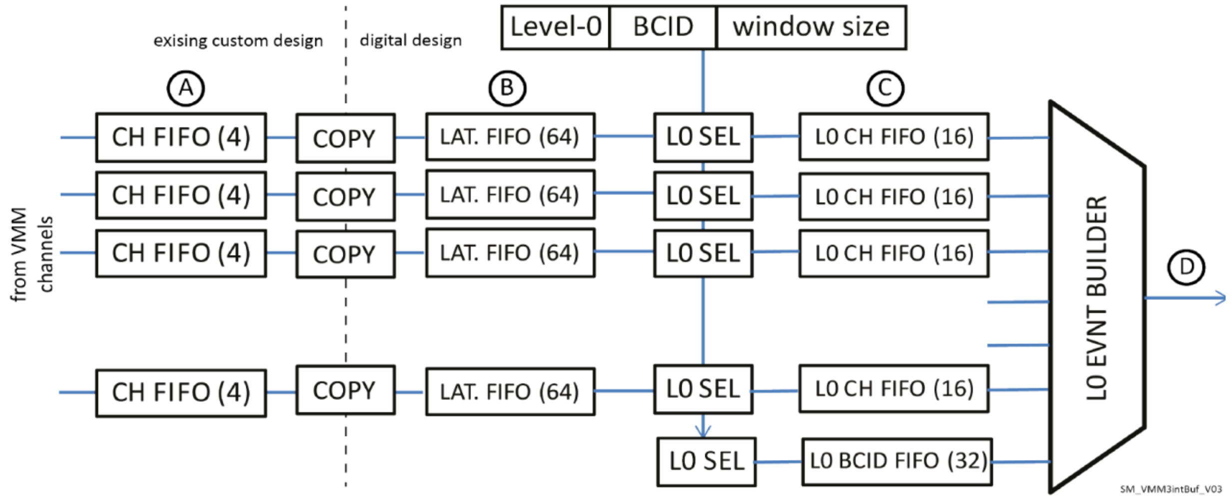
  - VMM3 chip for remaining channels

    VMM3 block diagram



- ASIC for ATLAS New Small Wheel
- Radiation hard
- 64 channels
- 6 bit and 10 bit ADC, 8 bits TDC, 12 bits Beam Crossing time stamp
- Deadtimeless up to 4 MHz of rate per channel thanks to multilevel FIFO
- Latency up to 16 μs
- Self triggering path
- Data link up to 320 Mbit/s

VMM3



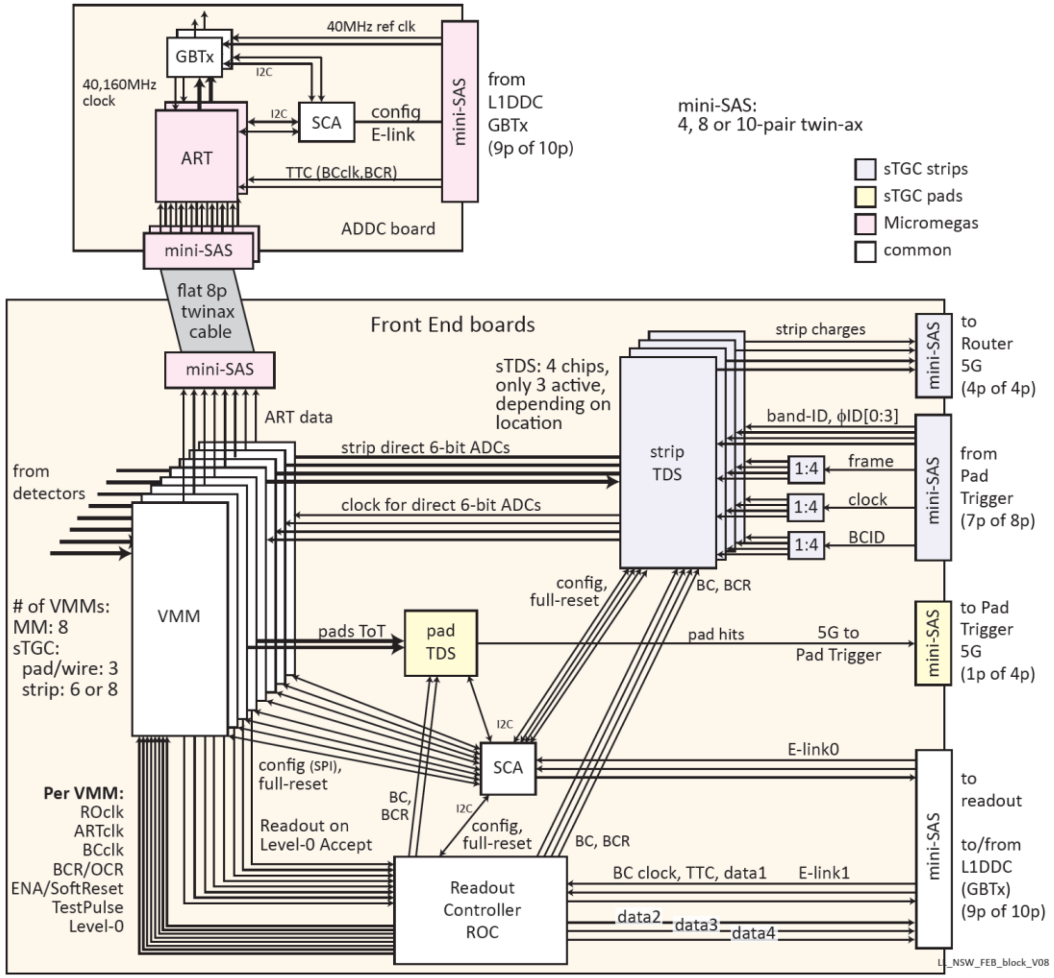
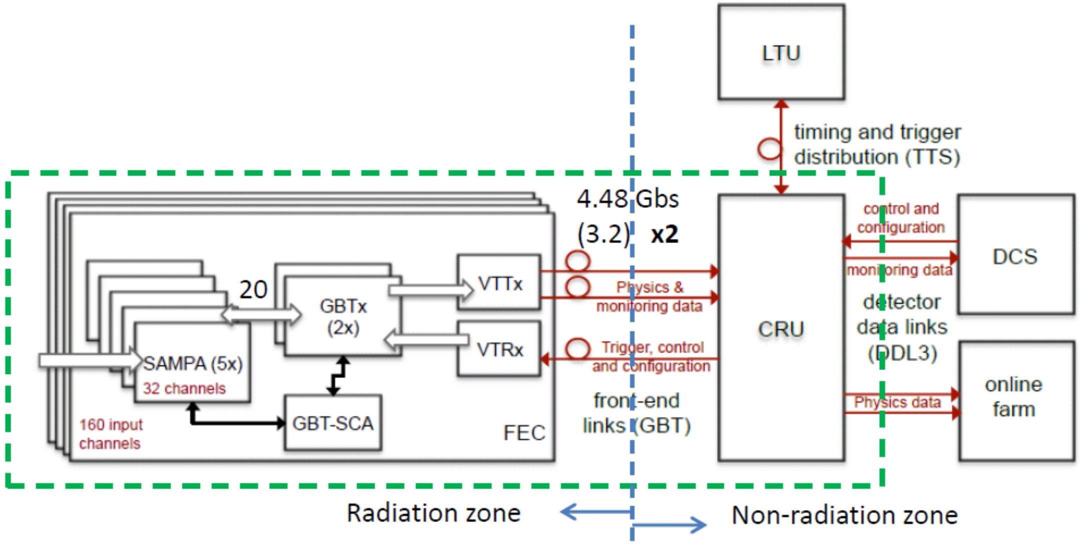
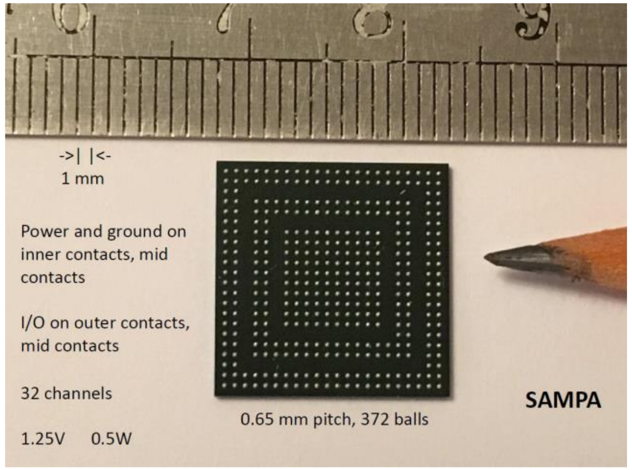


Figure 2: Overall connection diagram of the VMM.

SAMPA

- SAMPA
- 80 or 160 ns shaping time





FEC – Front End Card (160 ch / FEC)
CRU – Common Readout Unit (12 FECs / CRU = 1920 ch / CRU
DCS – Detector Control System
LTU – Local Trigger Unit

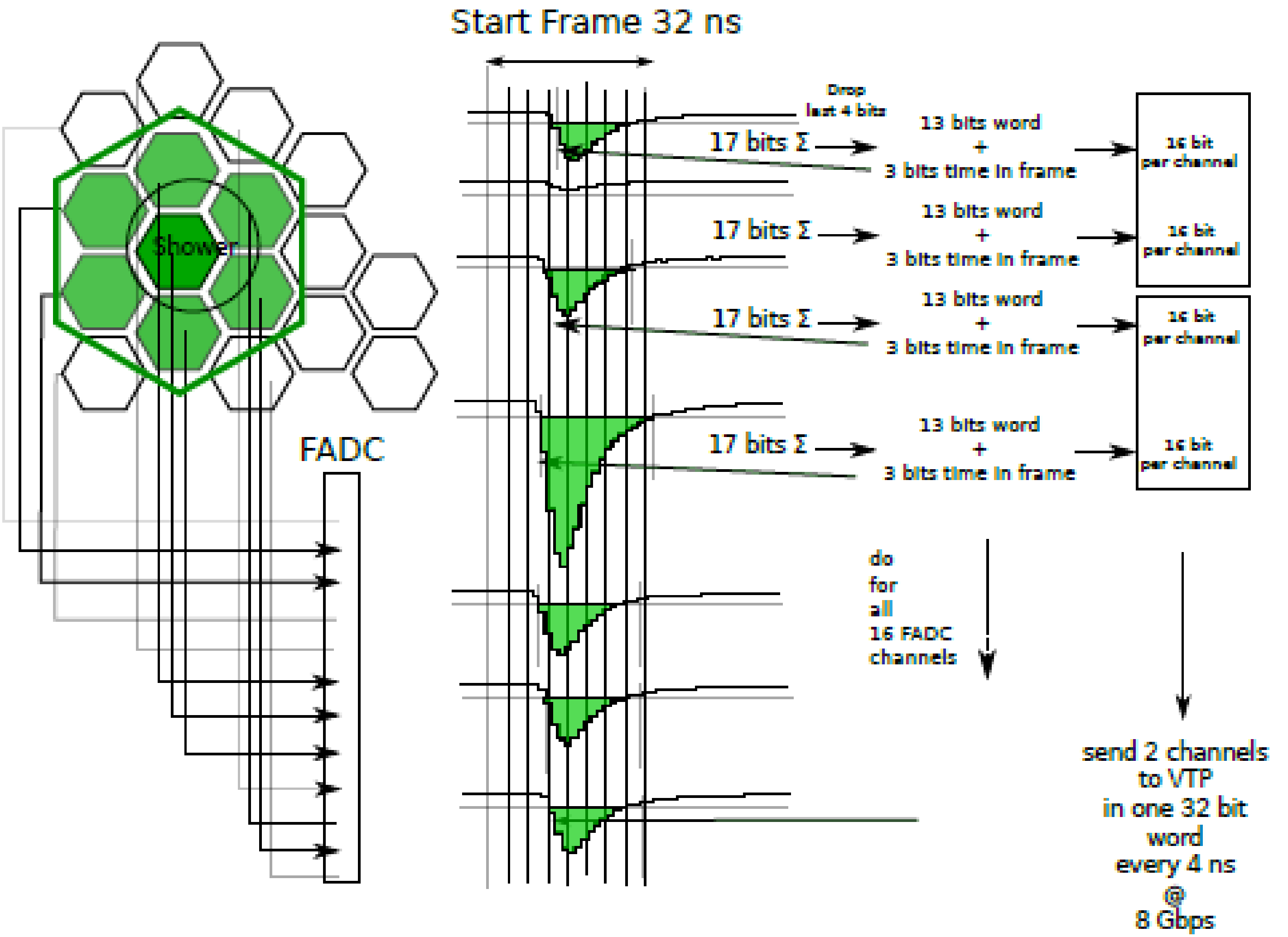
SAMPA tracking efficiency with full background

Efficiency comparison

	APV25	SAMPA 80ns	SAMPA 160ns
FA efficiency 0%	98.7%	97.8%	74.5%
FA efficiency 100%	97.3%	96.7% (95.3%)	74.6% (83.9%)
LA efficiency 0%	98.5%	97.9%	76.7%
LA efficiency 100%	93.4%	95.4%	70.2% (72.3%)

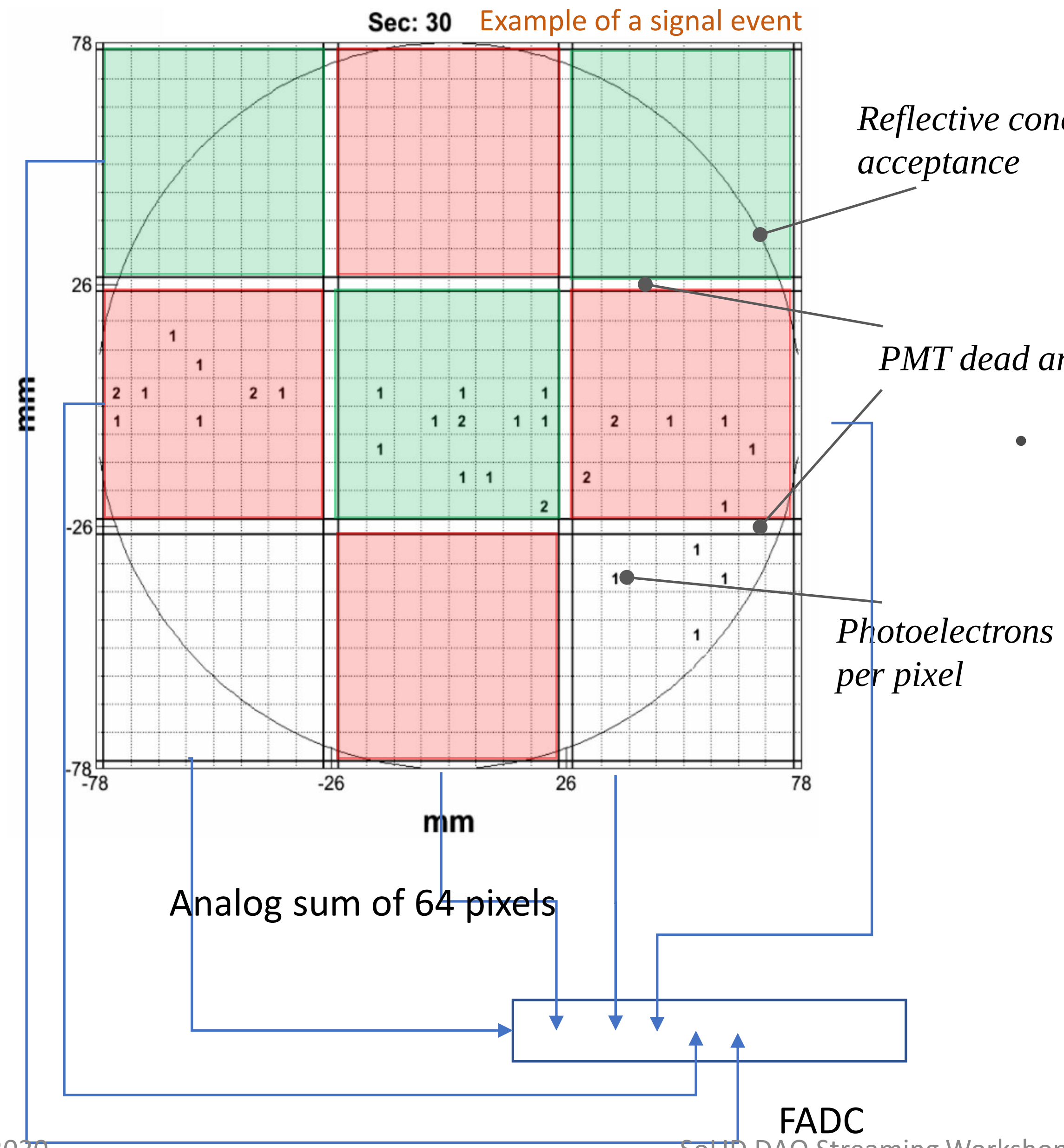
SAMPA: 80ns shaping time comparable with APV25
160ns significantly lower

ECAL FADC trigger



- ECAL trigger main electron trigger for all experiments
- HPS scheme : data from each channel of FADC is integrated and send to the processing trigger module through the VXS backplane
- Cluster of 1 + 6 surrounding blocks to reduce trigger rates coming from background hits
- Will be used for SBS, NPS before SoLID

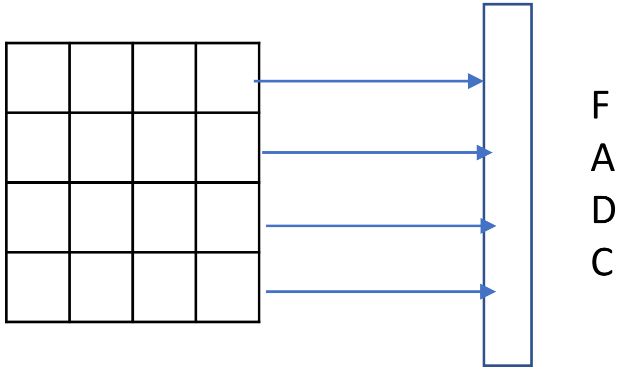
LGC Requirement and Design: Trigger Level Response



- The rate per MaPMT can be in the hundreds of kHz to > 1 MHz.
- Trigger level logic is necessary to minimize rate to DAQ.
- A coincidence trigger between MaPMTs in a single sector plus a threshold for the number of photoelectrons detected per sector is required. Typically this is expressed as:
  - (# of PMTs in coincidence) x (number of PE's per PMT)
  - A coincidence of 2 sectors with 2pe threshold trigger is expected to keep a 95% efficiency and rates within DAQ requirements.

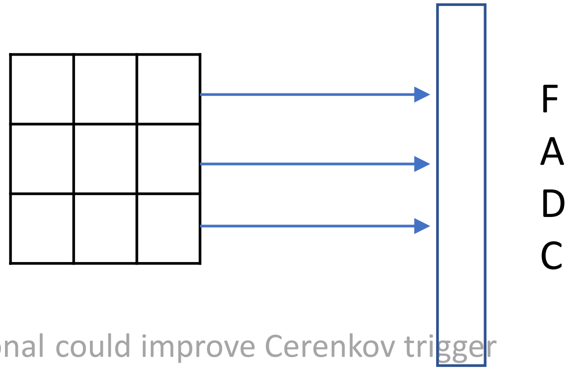
Cerenkov PMT readout

- Light gas Cerenkov
  - 64 channels MAPMT



- MAROC3 close to what we need
  - 64 channels
  - Variable gain
  - Discriminated fast logic signal
  - Missing : analog sum of 8, need sum of 64
  - Radiation hardness is pretty good, need to be tested, possibility of new version to handle Single Event Upset
  - MAROC default option
  - MAROC test board available

  - Will check design with electronics group for FADC analog output

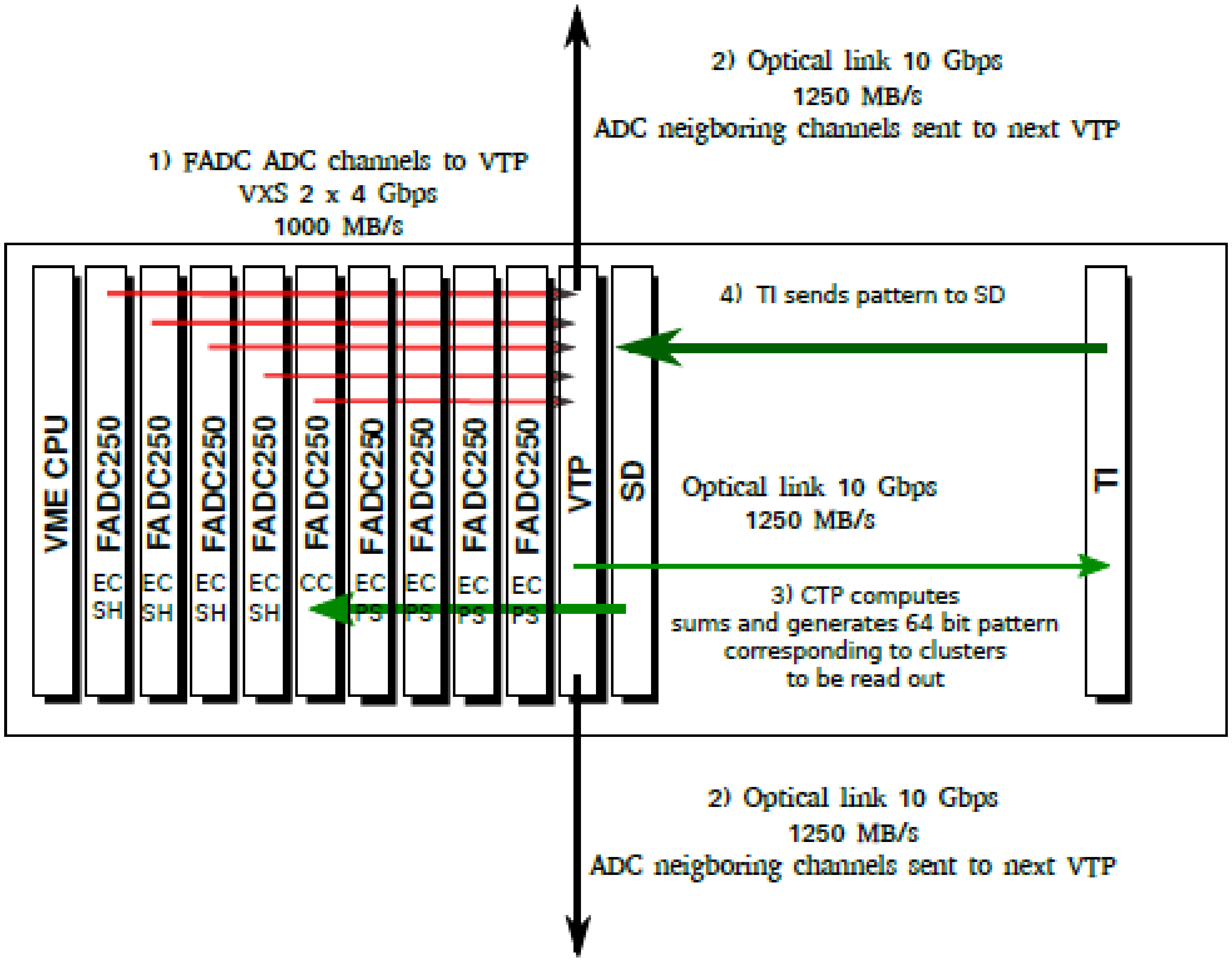


- Possible readout schemes
  - FADC only (default)
  - FADC + VETROC
  - VETROC only : needs to be evaluated

  - Preferred : Add TDC readout for each Cerenkov channel 232 VETROC additional could improve Cerenkov trigger

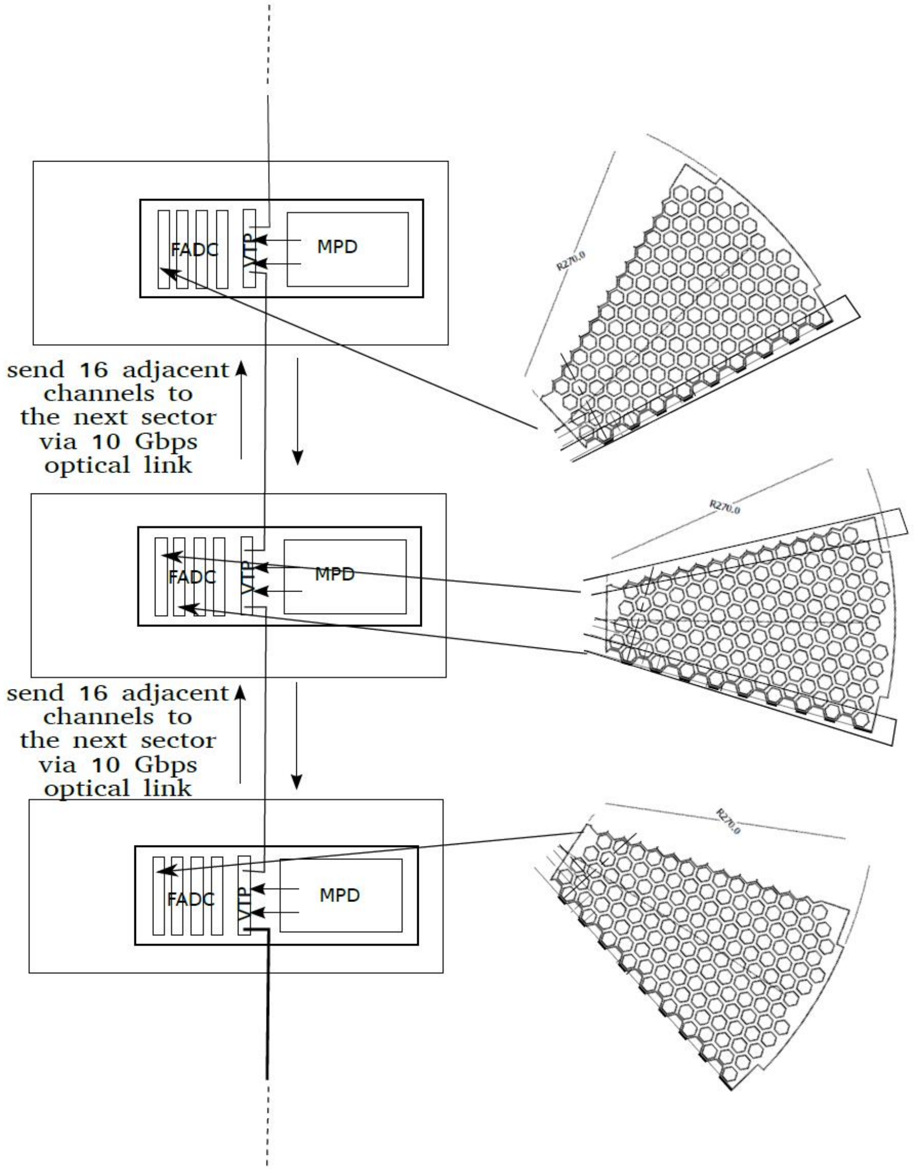
  - Need simulation to evaluate options
  - Need to follow with electronics group to start testing

PVDIS crate layout



- FADC VXS readout
- Plan to transfer full Waveform

DAQ overview PVDIS



- 1800 channels of shower
- 1800 channels of preshower
- 270 channels for Light Gas Cerenkov
- 30 individual sectors
  - 61 shower per sector
  - 61 preshower sector
  - 9 Cerenkov
  - 4700 GEM channels

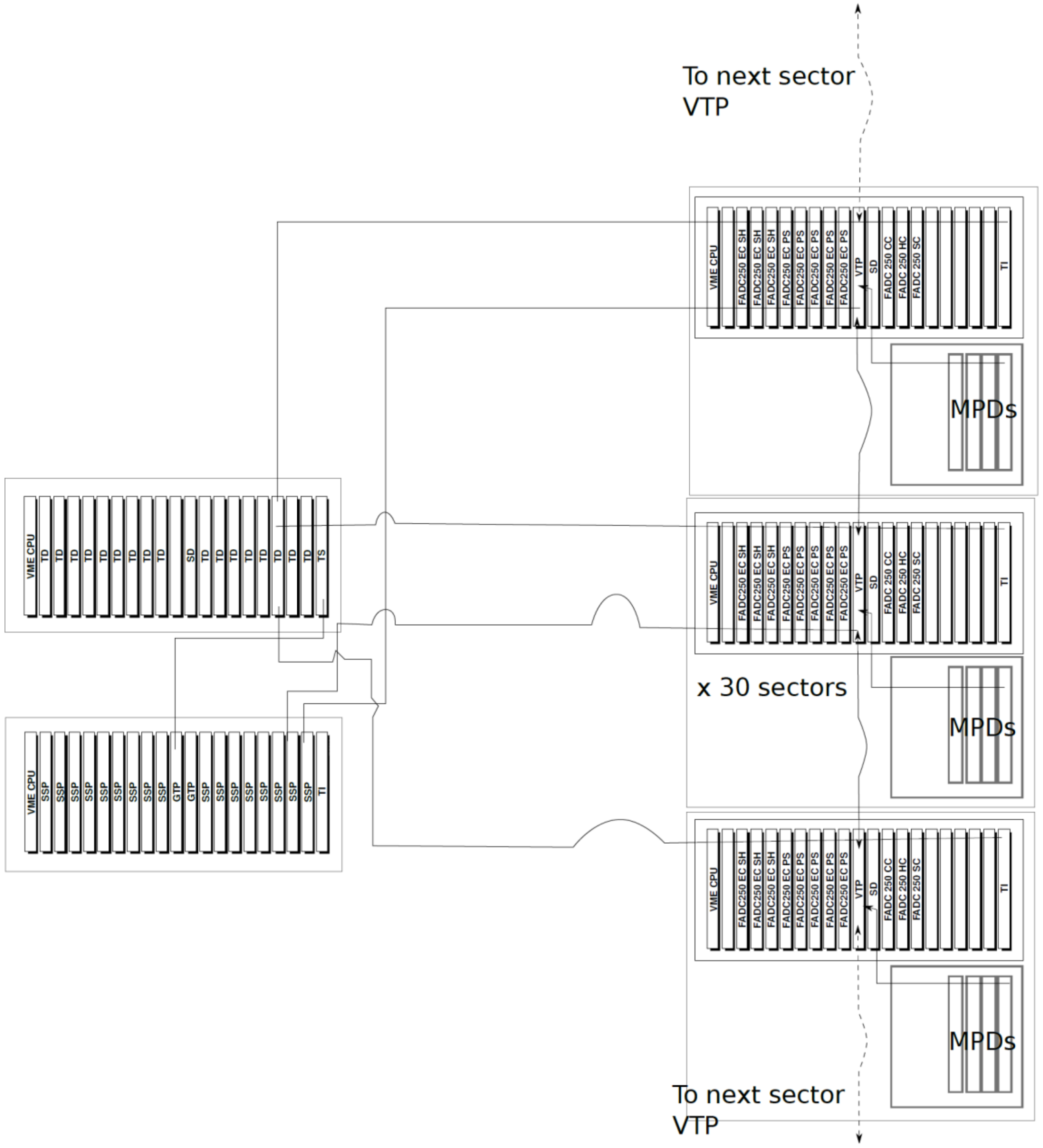
- Trigger : coincidence Ecal and Cerenkov

- Transfer data from adjacent blocks of neighboring sector for clustering

- Scaling of SBS HCAL trigger from 288 channels (2 crates) to 1800 channels in 15 crates (2 sectors per crate)

- GEM readout using INFN MPD module with optical link to VTP

DAQ overview SIDIS



- Similar to Hall D
- Reconfiguration of PVDIS crates to gather data of each trigger to a main VTP to produce the electron pion coincidence
- 100 KHz trigger rate capability

Trigger rates PVDIS

	PVDIS
Singles ECAL	230 KHz
Singles rates Cerenkov	803 KHz
Accidental 30 ns	4.1 KHz
DIS electron	7.7 KHz
Total rate	**12.1 KHz**

SIDIS Trigger Rates

Rate (kHz) Ecal+LGC(2,2)+SPD(>0.425MeV)	7 modules **3 GeV** trigger threshold for LAEC +Up window+ down widow
FA e$^-$	60+1.1+1.8
FA hadron no e$^-$	29+3.6+5.3
LA e$^-$	4.1+3.6+2.6
LA hadron no e$^-$	7.7+6.5+3.8
hadron trigger	8013+2591+3887
SIDIS coin	31.2
Hadron coin	14.7+2.52+2.61=19.83
Total rate	**<85 kHz** (30ns time window)

Event size data rates PVDIS

		Max data rate	Occupancy	Fired strips	Event size	Data rate MBs	After noise cut	strips firing	event size bytes		MB/s
1	1156		21.17	244.73	3038.03	60.76	9.97	115.25	1430.76	1430.76	28.62
2	1374		10.35	142.21	1765.39	35.31	5.11	70.21	871.61	871.61	17.43
3	1374		8.81	121.05	1502.71	30.05	4.42	60.73	753.92	753.92	15.08
4	2287		3.07	70.21	871.60	17.43	1.64	37.51	465.61	465.61	9.31
5	2350		2.79	65.57	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

About 0.094x30 = 2.9 GB/s for PVDIS at 20 KHz

SIDIS event size

Occupancies with one sample readout for 100 KHz rate

GEM	Occupancy	Number of strips firing	XY strips	Strips per chambers	Max rate MB/s	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

Tape

Cost							2018	2020	2023
		Days	Data rate	Seconds	Total data TB	Double	DLO8 in $	LTO 9	LTO10
E12-11-108	Pol proton	120	3900	10368000	40435	80870	473850	242611	126360
E12-12-006	J/Psi	60	4000	5184000	20736	41472	243000	124416	64800
E12-10-006	Transv. Pol. 3He	90	6000	7776000	46656	93312	546750	279936	145800
E12-11-007	Long. Pol. 3 He	35	6000	3024000	18144	36288	212625	108864	56700
E12-10-007	PVDIS	169	6000	14601600	87610	175219	1026675	525658	273780
	Total	474		40953600	213581	427162	2502900	1281485	667440
Actual days	Actual years		Time in s						
948	2.60	474	40953600						

Tapes							2018	2020	2023
		Days	Data rate	Seconds	Total data TB	Double	DLO8 in $	LTO 9	LTO10
E12-11-108	Pol proton	120	3900	10368000	40435	80870	6318	3235	1685
E12-12-006	J/Psi	60	4000	5184000	20736	41472	3240	1659	864
E12-10-006	Transv. Pol. 3He	90	6000	7776000	46656	93312	7290	3732	1944
E12-11-007	Long. Pol. 3 He	35	6000	3024000	18144	36288	2835	1452	756
E12-10-007	PVDIS	169	6000	14601600	87610	175219	13689	7009	3650
	Total	474		40953600	213581	427162	33372	17086	8899
Actual days	Actual years		Time in s						
948	2.60	474	40953600						

Trigger and data rates

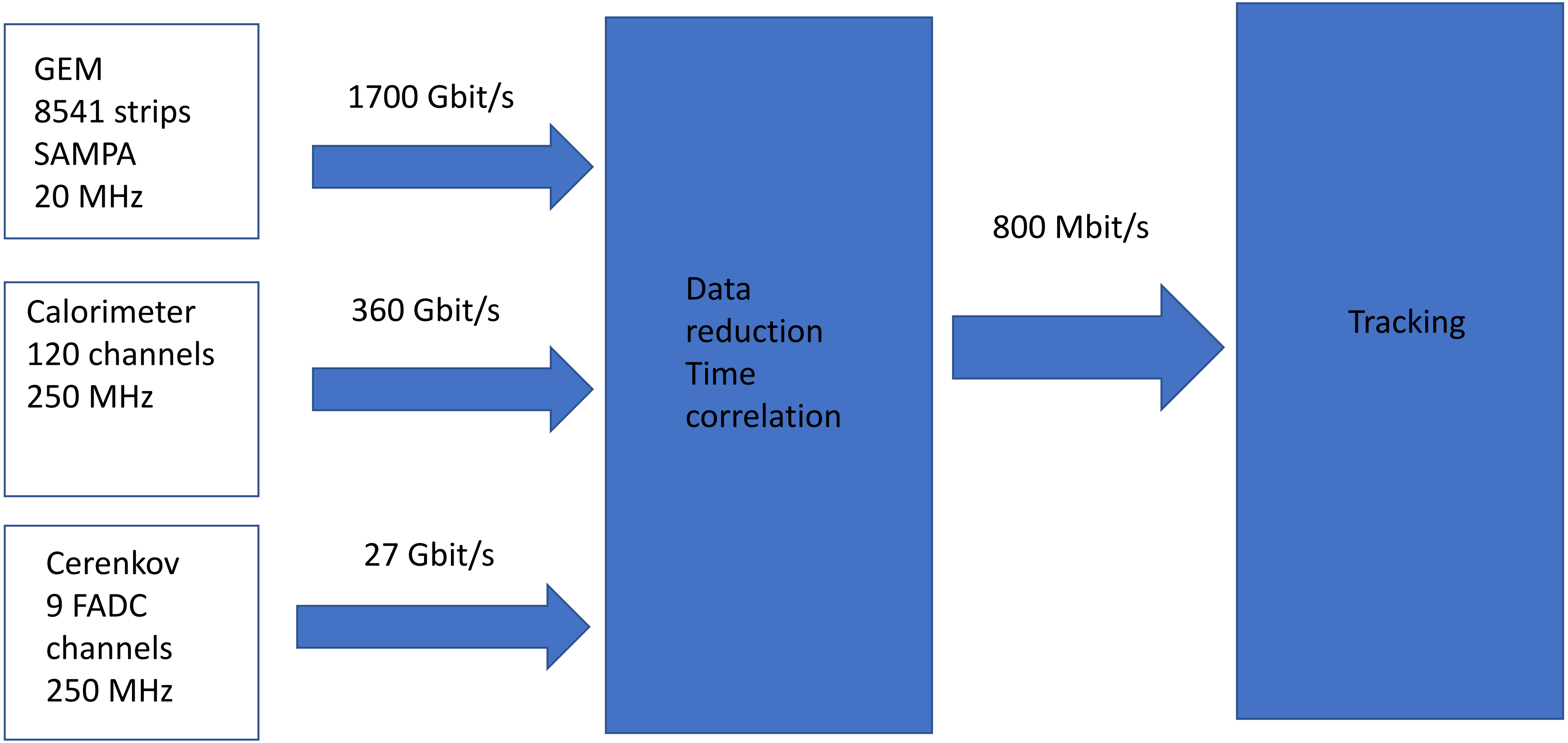
	PVDIS	SIDIS	J/ψ
Trigger rate maximum	20 KHz	100 KHz	30 KHz
Data rate	3.3GB/s	3.36GB/s	3.90GB/s
Running time	169 days	125 days	60 days
Total raw data	48.2 PB	36.2 PB	40.4 PB

Expected SIDIS rate is 85 kHz
Table numbers are without compression. If compressing may reduce data rates and size by 2.5

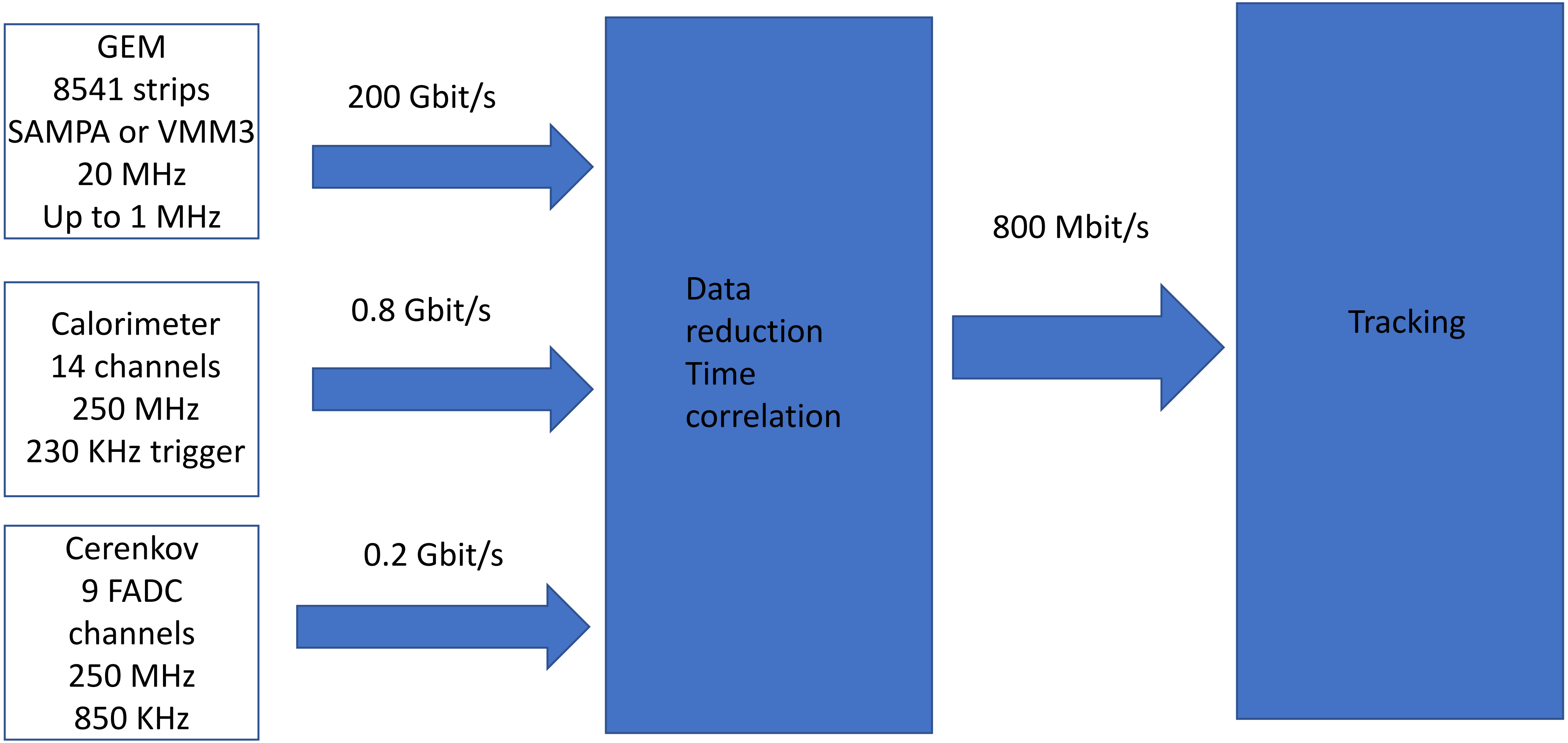
SoLID Streaming Readout

- L3 farm not included in project, seems tape silo can handle rate, triggered DAQ default solution
- Data dominated by GEM data
- Switch to VMM3 makes the system full streaming capable
- PVDIS is a good candidate for streaming since sectors are independents
- If computing resources available, would like to process more the data (tracking) to reduce the data size

PVDIS streaming per sector



PVDIS semi-streaming per sector
(activate suppression on board)



Conclusion

- SoLID high luminosity experiment 10^39 cm-2.s-1
- PVDIS could run SRO straightforwardly, more difficult for SIDIS
- Need to evaluate required computing resources
- Baseline triggered
- SRO limitation in high background, high occupancy conditions
- VMM3 gives streaming and L3 options for GEMs
- SAMPA would be a good option if radiation hardness is sufficient but costly

Backup

SILO capabilities

- Mix of LTO 5 to LTO 8 : 24 drives total
  - Current 5 GB/s
    - 8 drives LTO5
    - 8 drives LTO6
    - 4 LTO7 (300 MB/s)
    - 4 LTO8 (360 MB/s)
  - each LTO8 drive is 360 MB/s about 10 K$ each
  - Max : 24 * 360 = 8.64 GB/s
  - to handle 1 GB/s : 4 drives about 40 K$
  - increase to 4 GB/s (1GB + dup + read) about 120 K$
  - can upgrade all to LTO8 more : 200 K$ -> 8.64 GB/s
  - need to write and read at same time
  - LTO8 available in 2017

Silo capabilities

	2008	2010	2012	2015	2018	2020	2023
LTO	4	5	6	7	8	9	10
capacity	0.8	1.5	2.5	6.25	12.8	25	48
capacity compressed	1.6	3	6.25	15	32	62.5	120
price	35	20	26	135			
data rate	120	140	200	300	472	708	1100
data rate c	240	280	400	750	1180	1770	2750
				126			
Total size silo		16.86	28.1	70.25	143.872	281	539.52
		33.72	70.25	168.6	359.68	702.5	1348.8
Max size		28740	47900	119750	245248	479000	919680
		57480	119750	287400	613120	1197500	2299200
Max rate		1680	2400	3600	5664	8496	13200
		3360	4800	9000	14160	21240	33000

SAMPA occupancies SIDIS (160 ns shaping)

Chamber	1 sample %	6 samples %	6 samples Noise cut %	9 samples %	9 samples Noise cut %
1	4.0	10	4.33	8.5	6.1
2	13.7	26.4	11	30.3	13.2
3	5.79	14.2	6.14	17.9	8.38
4	3.76	9.2	3.93	11.8	5.56
5	3.36	8.67	3.80	11.3	5.43
6	2.50	6.5	2.85	8.53	4.10

SAMPA data rates SIDIS (160 ns shaping)

- Occupancies higher than with APV25
- Data rates assuming processing and recording one amplitude for 100 KHz
  - 1 samples : 4.4 GB/s
  - 6 samples : 4.2 GB/s
  - 9 samples : 5.7 GB/s
- Need to evaluate if tracking can be improved offline if record more samples in data file
- Data reduction on the fly desired with additional processing than noise cut

SAMPA tracking efficiency with full background

Efficiency comparison

	APV25	SAMPA 80ns	SAMPA 160ns
FA efficiency 0%	98.7%	97.8%	74.5%
FA efficiency 100%	97.3%	96.7% (95.3%)	74.6% (83.9%)
LA efficiency 0%	98.5%	97.9%	76.7%
LA efficiency 100%	93.4%	95.4%	70.2% (72.3%)

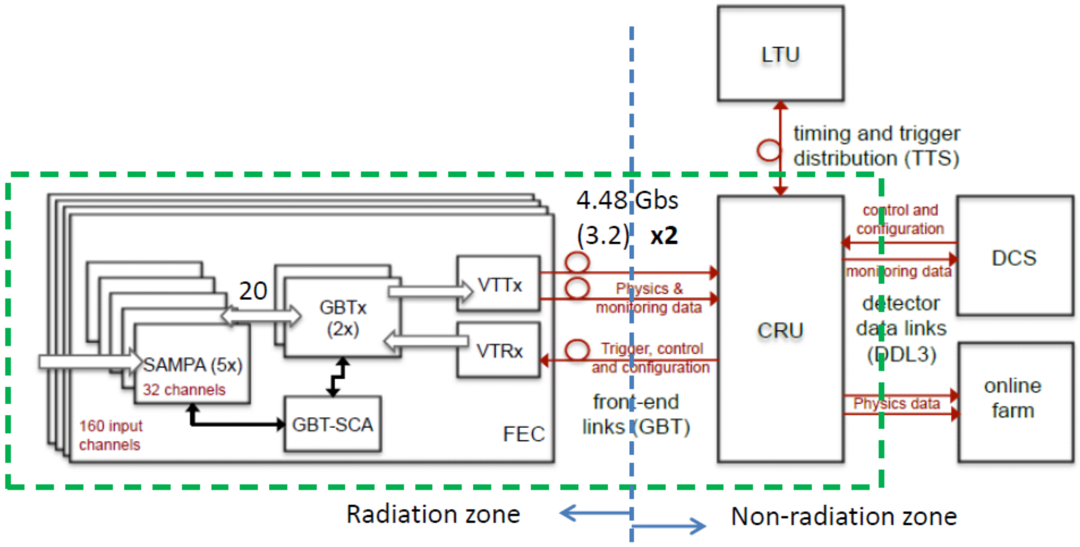
SAMPA: 80ns shaping time comparable with APV25
160ns significantly lower

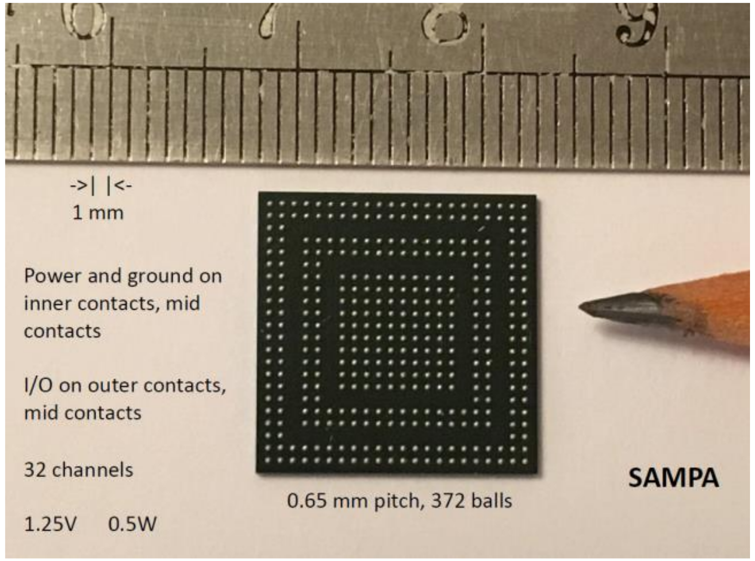
GEM APV readout with SSP

- Implementation of noise rejection on SSP for SBS
- Need to evaluate rejection factor for SoLID background
- Check ultimate performance for trigger rates

Test stand at JLAB : SAMPA

- SA

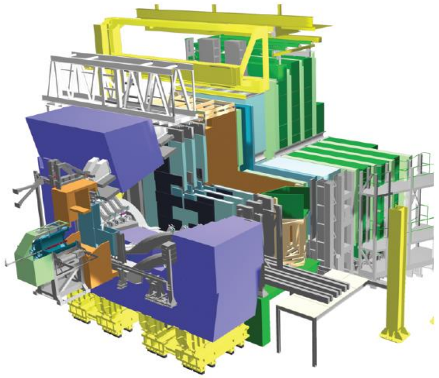




FEC – Front End Card (160 ch / FEC)
CRU – Common Readout Unit (12 FECs / CRU = 1920 ch / CRU
DCS – Detector Control System
LTU – Local Trigger Unit

JINST 8 (2013) P04022

Real-Time Processing



Simple feature-building, e.g. in FPGAs, required to reduce the data rate.*

1 TB/s
post zero suppression

50 GB/s

1 MHz

Heavy use of machine learning:
V.Gligorov, MW, JINST 8 (2012) P02013.

Real-time reconstruction for all charged particles with p_T > 0.5GeV.

8 GB/s

Data buffered on 10 PB of disk.

Real-time calibration & alignment.

Full real-time reconstruction for all particles available to select events.

0.7 GB/s (mix of full + partial events)

*LHCb will move to a triggerless-readout system for LHC Run 3 (2021-2023), and process 5 TB/s in real time on the CPU farm.

GEM – Readout Electronics

- 128 analog ch / APV25 ASIC
- 3.4 μs trigger latency (analog pipeline)
- Capable of sampling signal at 40 MHz
- Multiplexed analog output (100 kHz readout rate)

	Channels	APV25	MPDs
Front Tracker	28000	216	16
Rear Tracker	12000	100	7

MPD (INFN)

05/Aug/2019

MPD Main Block

Arriga GX FPGA
128 MB DDR2-RAM
Firmware V4.0 (74% resources):
FIR Filter (16 param)
Zero Suppression
Common mode and pedestal subtraction
Remote config,
≈2 ns trigger time resolution

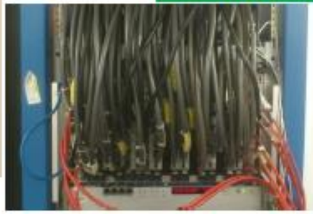
MPD-SSP Interface — SSP-Protocol — Aurora Protocol

MPD-VME Interface — VME-Protocols — 2eSST / 2eVME / VME32 ... / VXS

Optical Fiber

VME (64x)

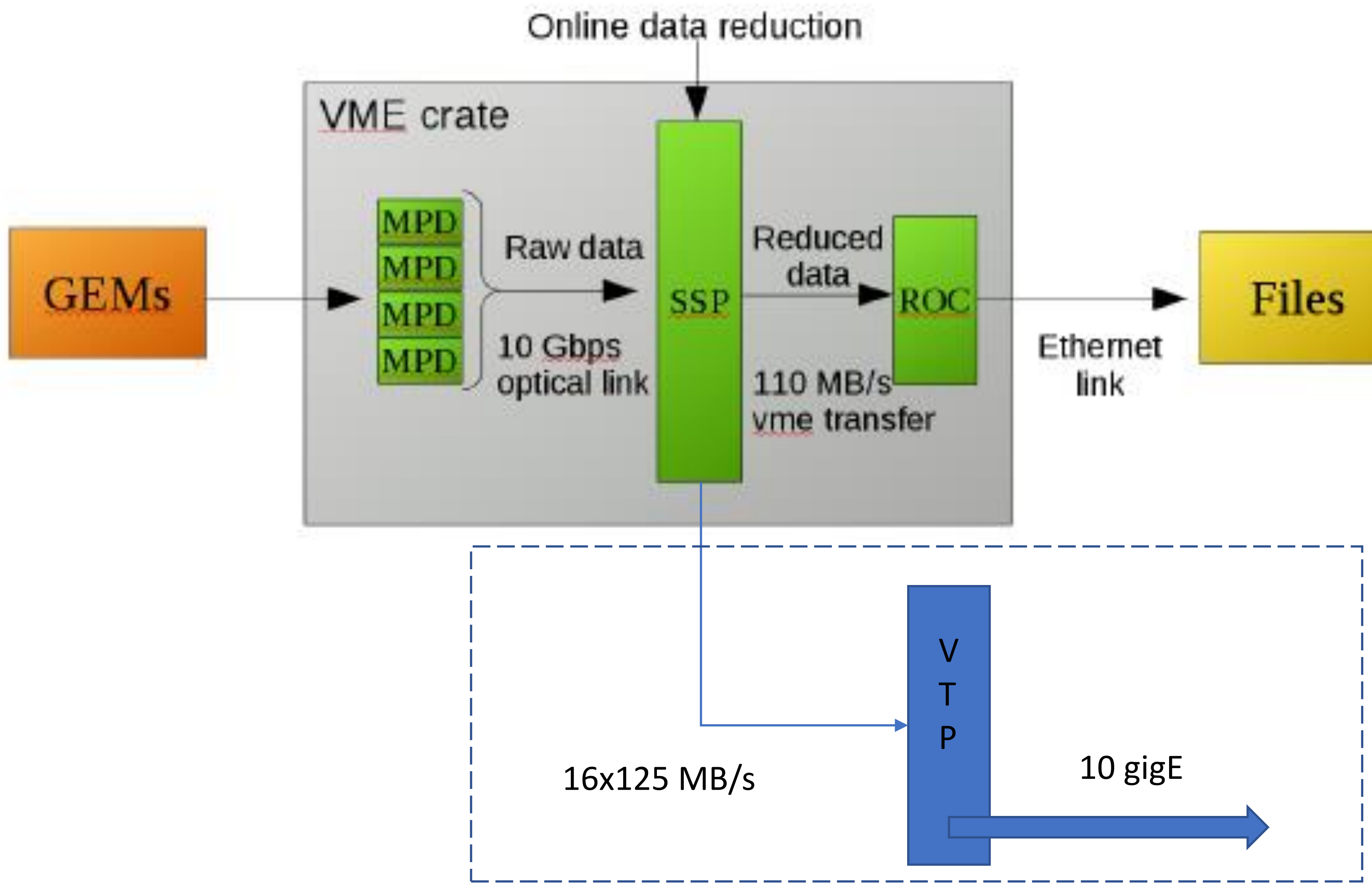
All major firmware issues fixed so far



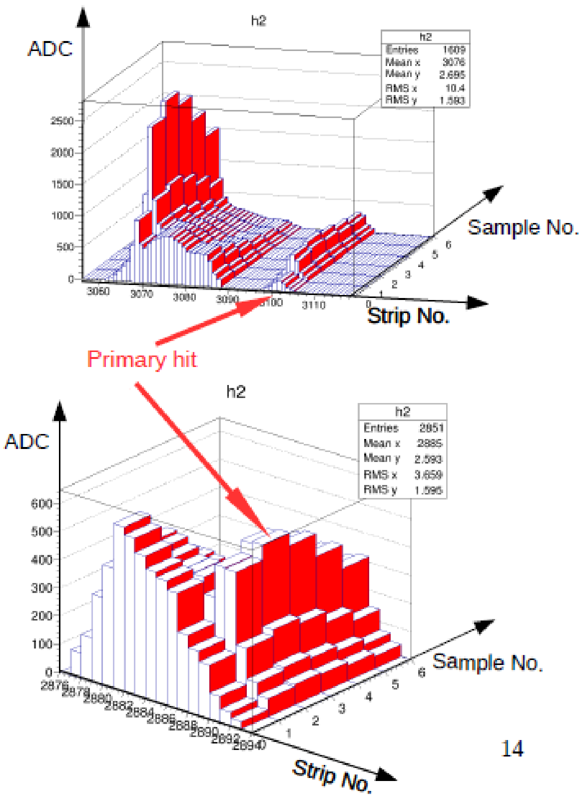
Electronics is up and running (or going to run) on:

- **Front-GEM cosmic test in VME mode**
- **SSP mode in Rear GEM cosmic test**
- **PREX UVa GEM**

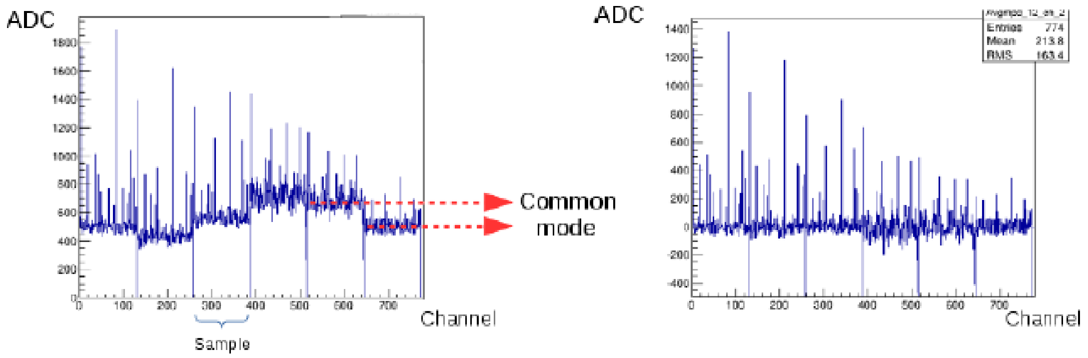
SSP data reduction



SSP data reduction



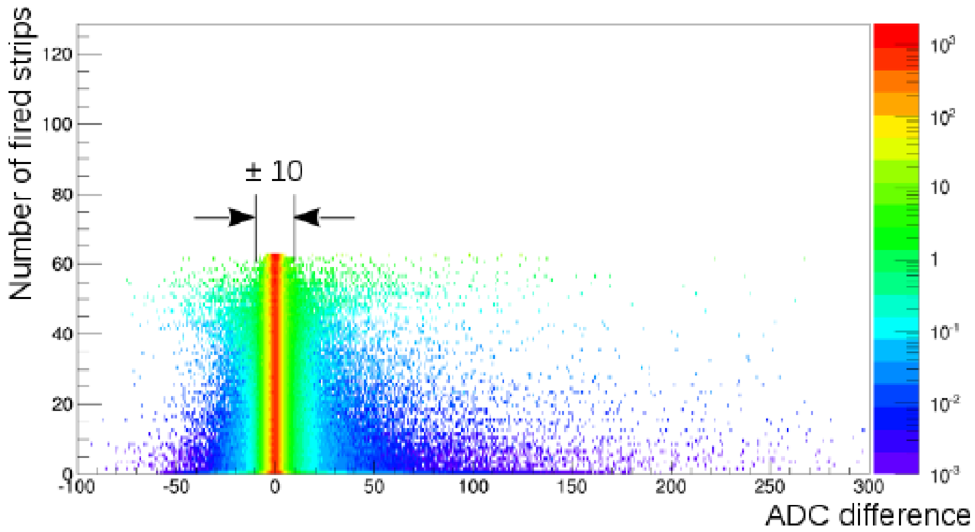
14



- Common noise subtraction
- Zero suppression
- Transfer 6 samples

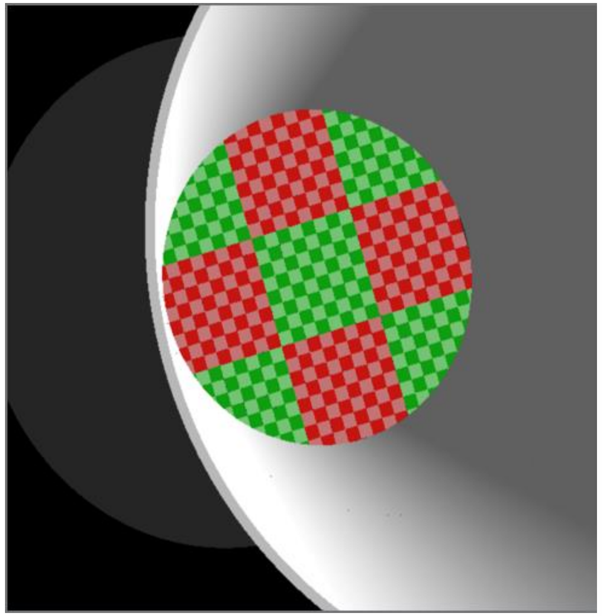
SSP implementation

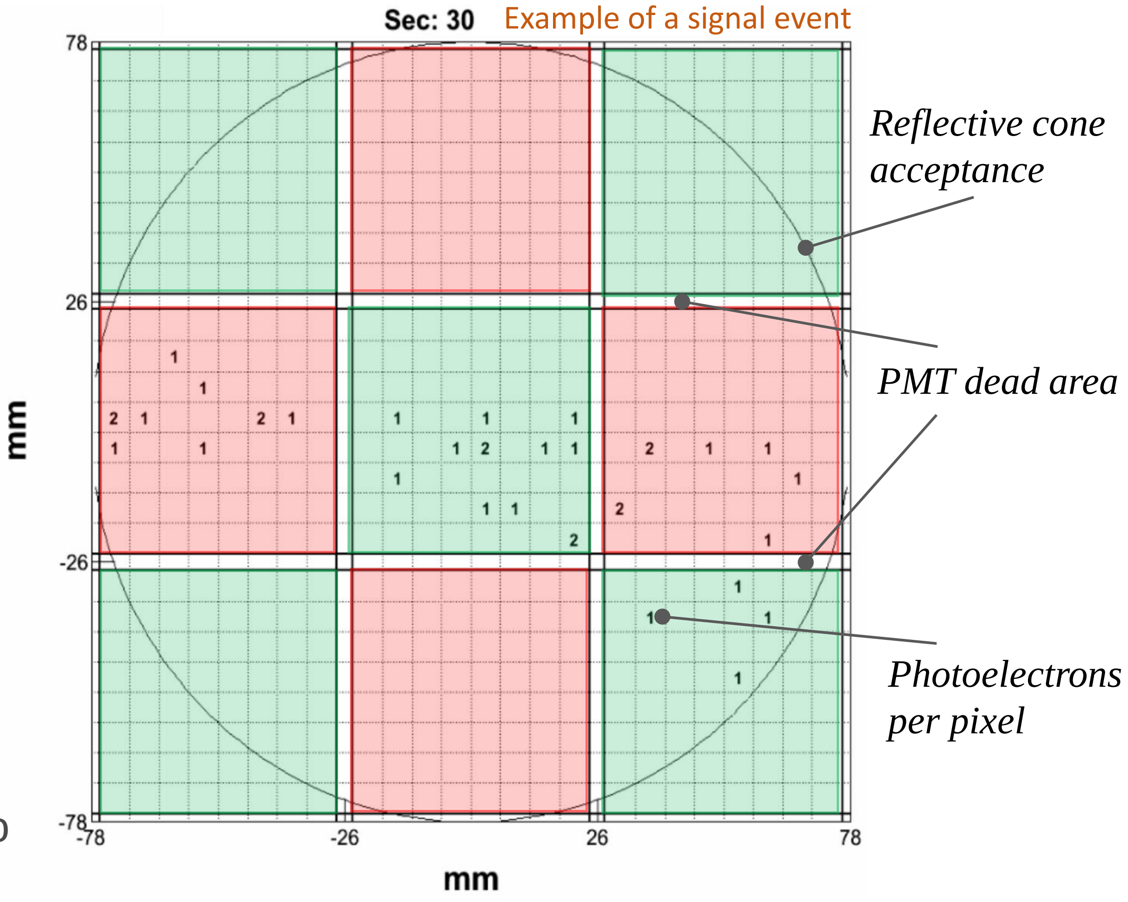
- First implementation up to 4 MPDs



- Offline vsonline treatment
- Very good efficiency of online treatment

LGC Requirement and Design: Trigger Level Response





- The rate per MaPMT can be in the hundreds of kHz to > 1 MHz.

- Trigger level logic is necessary to minimize rate to DAQ.

- A coincidence trigger between MaPMTs in a single sector plus a threshold for the number of photoelectrons detected per sector is required. Typically this is expressed as:
  - (# of PMTs in coincidence) x (number of PE's per PMT)
  - A 2x2 trigger is expected to keep a 95% efficiency and rates within DAQ requirements.