EIC Yellow report content
Readout and DAQ

4st EIC yellow report workshop

Outline of the DAQ/electronics section

1. Introduction
2. Glossary
3. Overview on DAQ Structure
4. Constraints and Environment
5. Readout Electronics: Present State of the Art
6. Possible Readout Chip Evolution and Future Technological Constraints
7. Existing streaming readout DAQ Systems for particle physics experiments
8. A Progressive Approach toward the EIC DAQ System
9. Experimental Validation of the Approach

Constraints on readout electronics (subsection 4)

Summary of constraints depending of the detectors to be read

- characteristics of the signals → requirements in term of front-end electronics performance: peaking time, gain, noise level, dynamics,...
- information to be extracted from the signals: amplitude, time, at which resolution ?
- number of channels
- expected signal rates
- environment: radiation level, temperature
- any other important information

Part of the inputs from detectors still missing in order to complete this subsection (signal characteristics for PID and partly calorimetry; rates and environment for ~all detectors)

Detector	Sub-system	Type	Sub-type	Channels
Tracking				
	Silicon Vertex Tracker	Si	Pixel	200M
	TPC	GEM	Pads	160K
	GEM	GEM	Strips	217K
	uRWELL	GEM	Strips/Pads	
	Cylindrical Micromegas	GEM	Strips	
	Drift Chambers	DWC	Wires	
	sTGC	GEM	Pad, Strip, Wire	
	Straw Tubes	Straw	Wires	
Calorimetry				
	e-EMCal	Cal	PMT/SiPM	5k
	C-EMCal	Cal	PMT/SiPM	24k
	h-EMCal	Cal	PMT/SiPM	26k
	h-Hcal	Cal	PMT/SiPM	3k
	c-Hcals	Cal	PMT/SiPM	2.8k

Detector	Sub-system	Type	Sub-type	Channels
PID				
	mRICH @ e-endcap	RICH	PMT/SiPM	
	dRICH @ h-endcap	RICH	PMT/SiPM	300k
	GEM RICH	GEM	Strips	220k
	hpDIRC @barrel	DIRC	PMT/SiPM	100k
	psTOF @barrel	TOF	PMT/SiPM	
	LGAD TOF	TOF	PMT/SiPM	
	LAPPD/MCP-PMT TOF	TOF	PMT/SiPM	
Far Forward Detectors				
	ZDC		PMT/SiPM	
	Low Q2 tagger		PMT/SiPM	
	Luminositymonitors		PMT/SiPM	
	Roman Pots	Si Strips	Si	
	Proton Spectrometer		PMT/SiPM	
	Lepton Polarimeter		PMT/SiPM	
	Hadron Polarimeter		PMT/SiPM	

F. Barbosa, J. Huang, K. Chen

Readout Variant	Channels (actual)	Channels w/+10% Spares	Type
V1	200M	220M	Si
V2	220k+	242k+	Straw/GEM - fADC
V3	377k+	415k+	GEM
V4	461k+	507k+	PMT/SiPM

State of the art and evolution of readout electronics
(subsections 5-6)

- Generic introduction to frontend electronics: amplification, shaping
- Introduction to digitization and local data treatment (zero-suppression, common mode reduction, baseline subtraction)
- Review of chips commonly used in particle physics detectors, in particular for MPGD readout, with comparison table
- Discussion on what is presently missing and on possible evolutions, subsection to be completed in agreement with the constraints from the detectors

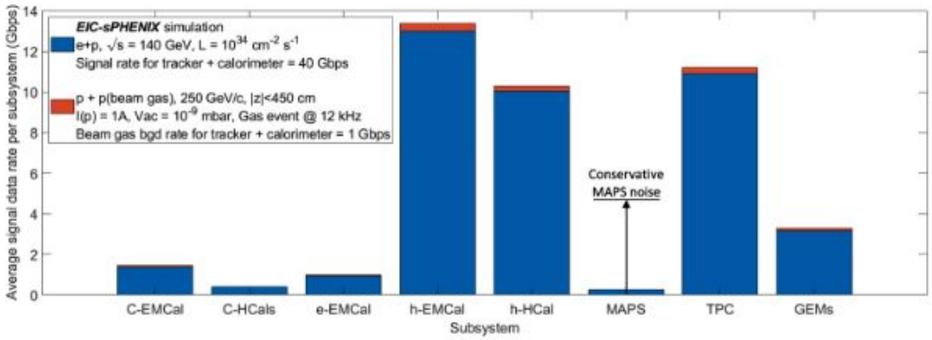
	SAMPA	VMM	TIGER	DREAM	AGET	AFTER
Architecture	Front-end + ADC + DSP	Front-end + S&H + discri + 3xADC	Front-end + S&H + discri + TDC + ADC	Front-end + analog memory		
	Analog characteristics					
Number of channels	32	64	64	64	64	72
Input dynamic range	66/500 fC	0.1-2.0pC	2.0-50 fC	50-600 fC	120 fC - 10 pC	120-600 fC
Peaking time range	160-300 ns	25, 50, 100 and 200 ns	60 ns (TDC), 170 ns (ADC)	50 ns - 1 μs	50 ns - 900 ns	100 ns - 2 μs
Full signal occupancy	550 ns					
Polarity	+/-	+/-		+/-	+/-	+/-
Detector capacitance range	18.5 pF/40-80 pF	200pF	up to 100pF	200 pF		¡30pF
Noise level	600/900 e^-	300 e^- at 9 mV/fC	up to 2000 e^-	610 e^- + 9 e^-/pF	580 e^- + 9 e^-/pF	370 e^- + 14.6 e^-/pF
Sensitivity/Gain	4/20-30 mV/fC		12.4 mV/fC (TDC), 11.9 mV/fC (ADC)			120 fC/mV
Remarks			CR-RC shapers			
	Digital characteristics					
Sampling frequencies	10-20 MHz	200 MHz	1-40 MHz	1-50 MHz	1-100 MHz	1-100 MHz
ADC resolution	10-bit	10-bit	10-bit (Wilkinson)	No ADC	No ADC	No ADC
TDC time resolution		8-bit + 12 global	5 ns			
Remarks	10 MS/s			Internal trigger	Internal trigger	
Data treatment functions	On-board DSP	none	none			
Data bandwidth	11x320 Mbit/s	1 Gbit/s (ideal 9.7 Gbit/s)	1.28 Gbit/s (triggerless)			
Streaming readout capacity	3.4G bit/s		Readout on internal trigger, programmable threshold			
	Other information					
Die size	9.6x9.0 mm^2	15.3x8.3 mm^2	5×5 mm^2			7.8 x 7.4 mm2
Package size	TFBGA 15x15 mm^2	400BGA				28 x 28 mm
Power consumption	20 mW/ch	10 mW/ch	12 mW/ch @ 3.3V	10 mW/ch	10 mW/ch	10 mW/ch
Technology	130 nm CMOS	130 nm MOSFET	110 nm CMOS			350 nm AMS CMOS
Remarks						

Constraints on DAQ (subsection 4)

Main constraint for the DAQ: events-rate and data-rate (physics samples + backgrounds/noise)

- Current estimate from EIC-sPHENIX detector model, at 10^{34} cm^{-2} s^{-1} - thanks to Jin and collaborators!
- Total collision data rate: 100 Gb/s, including a first-order estimate for MAPS noise and p+p(beam gas) interactions
- This number seems to be not critical - in principle, we can write all collision data to the disk without any online processing/filtering.
  - LHCB: 40 Tb/s

	EIC	RHIC	LHC → HL-LHC
Collision species	$\vec{e}+\vec{p}, \vec{e}+A$	$\vec{p}+\vec{p}/A, A+A$	$p+p/A, A+A$
Top x-N C.M. energy	140 GeV	510 GeV	13 TeV
Bunch spacing	10 ns	107 ns	25 ns
Peak x-N luminosity	10^{34} cm^{-2} s^{-1}	10^{32} cm^{-2} s^{-1}	10^{34} → 10^{35} cm^{-2} s^{-1}
x-N cross section	50 μb	40 mb	80 mb
Top collision rate	500 kHz	10 MHz	1-6 GHz
$dN_{ch}/d\eta$ in p+p/e+p	0.1-Few	~3	~6
Charged particle rate	4M N_{ch}/s	60M N_{ch}/s	30G+ N_{ch}/s



Possible DAQ structure (subsection 3)

This section summarizes the arguments that, inside the Readout and DAQ working group, were discussed supporting the adoption of a streaming DAQ system for the future EIC detector

- Comparing with “traditional”, hardware-based (at least for first level) triggered systems:
  - Easy implementation of online algorithms by physicist, using modern programming languages
  - Can simulate (and not emulate) the effect of the online selections with MC for validation / efficiency determination
- Looking forward: (thanks to Markus and software WG for inspiring discussions)
  - A seamless data processing from DAQ to analysis is possible: opportunity to optimize resources and speed-up
  - Utilize emerging software technologies, e.g. AI/ML, at all levels of data processing

Clear statement in the YR document:

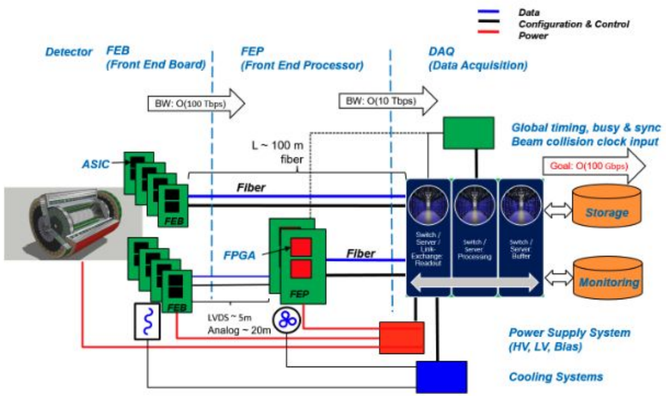
For these reasons, we propose to design and develop a full streaming-readout DAQ system for the EIC detector, integrating all the sub-detector components.

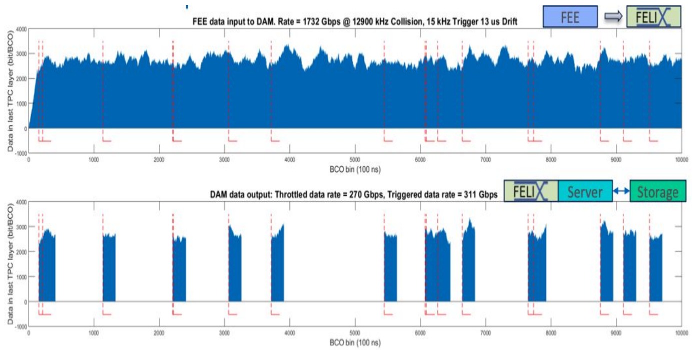
DAQ state of the art (subsection 7)

Short summary of existing streaming DAQ systems, to provide the reader with the message that such a system is already a reality in particle physics at accelerators.

- LHCb
- sPHENIX
- Ongoing developments at BNL: RCDAQ
- Ongoing developments at JLab: ERSA
- References to Amber/COMPASS++ and ALICE systems

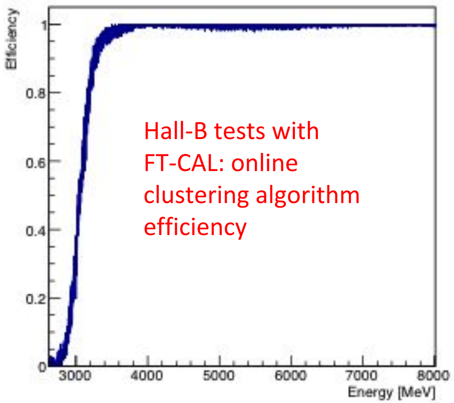
Progressive approach on DAQ and validation
(subsection 8)





- Streaming readout has many advantages compared to purely triggered DAQ: modularity, online data treatments, easily adaptable to detection setup changes, etc…
  - However, unexpected large noise level could exceed the system capacity, which must be prepared for such an event.
- Streaming readout system must avoid as much as possible raw data deletion after event selection and reconstruction, in order to limit data loss in case of flaw in the reconstruction software.
- Present technologies already good enough to build streaming readout systems
- **Proposed solution:** design a modular system evolving with the experiment.
  - Hybrid streaming readout during the first (low-luminosity) part of the run to fully understand the detector: if possible, filterless streaming. If unforeseen high-rate from detectors: *cross-detector zero suppression,* where only interesting portions of the data stream are further processed. This can be achieved both with a parallel hardware system (sPHENIX-like), or with a software system. Calorimeter is an excellent candidate to provide the signature.
  - Online filtering and online reconstruction gradually introduced when the detector is under control.

Validation
(subsection 9)



sPHENIX-TPC prototype

- Despite the conceptual simplicity of a triggerless DAQ, a realistic implementation with the specific detector readout is necessary to validate this solution and demonstrate the expected performances
- A dedicated test and validation program, with complementary experimental efforts, has already started in view of the EIC detector design and construction.
  - This section gives a brief overview of the ongoing activities

@JLAB:

- Tests with a streaming readout system prototype in Hall-B/Hall-D.
  - Hall-B tests with the FT-CAL calorimeter: online clustering algorithms implemented and tested. Inclusive π^0 production used as a benchmark for the system efficiency
  - Hall-D tests with PbWO4 calorimeters prototypes

@BNL:

- Test of the sPHENIX-TPC prototype in streaming readout mode at the FermiLab Test Beam Facility (FTBF) in 2019
  - FELIX readout board operated in “streaming mode”
  - Validation of the “mixed” approach currently adopted for sPHENIX (tracking detectors in streaming mode, calorimeters in trigger mode)

Conclusion

Writing task started in October

Already 23 pages written

Contribution of many peoples in and outside of the WG

Still some parts to complete or improve, some inputs missing to do so

Thanks a lot to all contributors !