A conversation at YR DAQ/electronics kick off meeting

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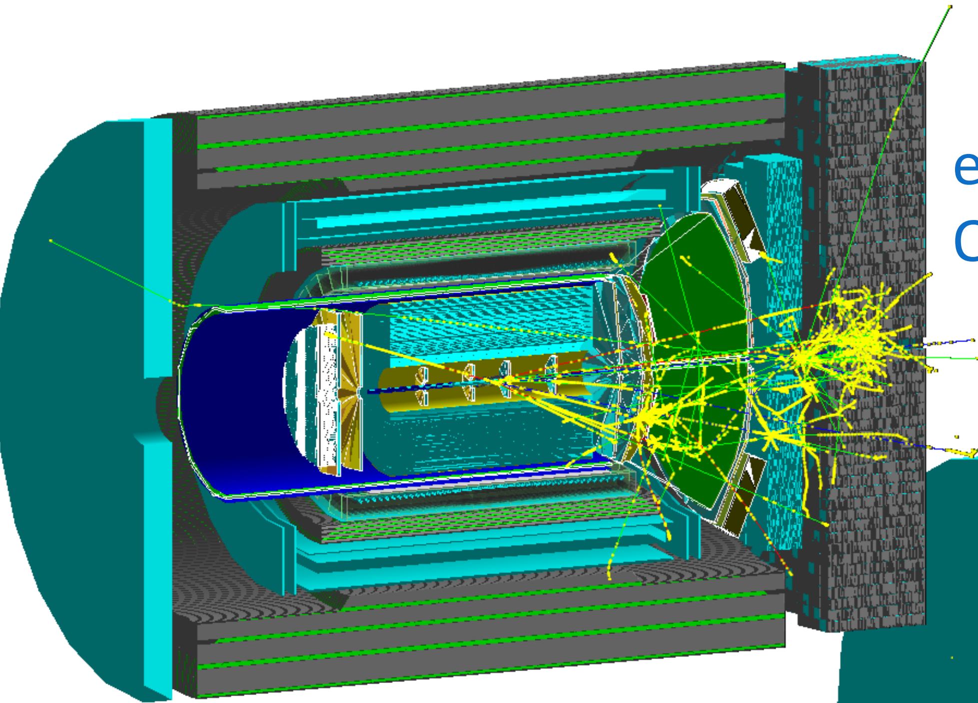
EIC: unique collider
→ unique real-time system challenges

	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

- EIC luminosity is high, but collision cross section is small ($\propto \alpha_{EM}^2$) → low collision rate
- Lower collision rate and small event size → signal data rate is low
- But events are precious and have diverse topology. Background and systematic control is crucial

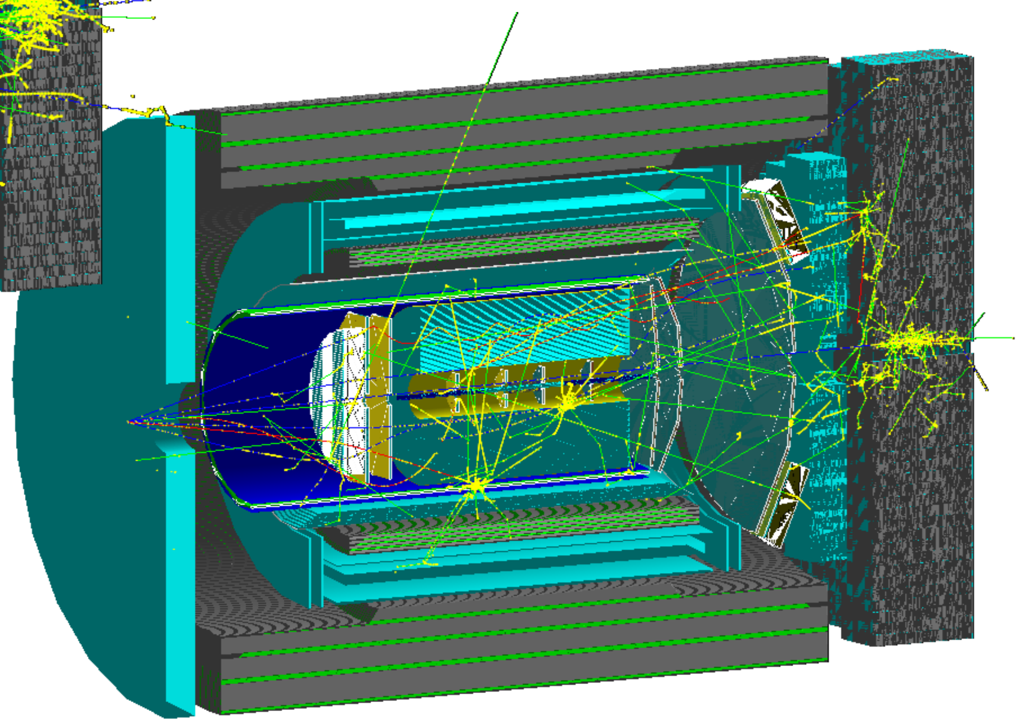
EIC DAQ in Geant4 simulation

Note sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/ , Simulation: https://eic-detector.github.io/



e+p DIS 18+275 GeV/c

Q^2 ~ 100 $(GeV/c)^2$



Beam gas event

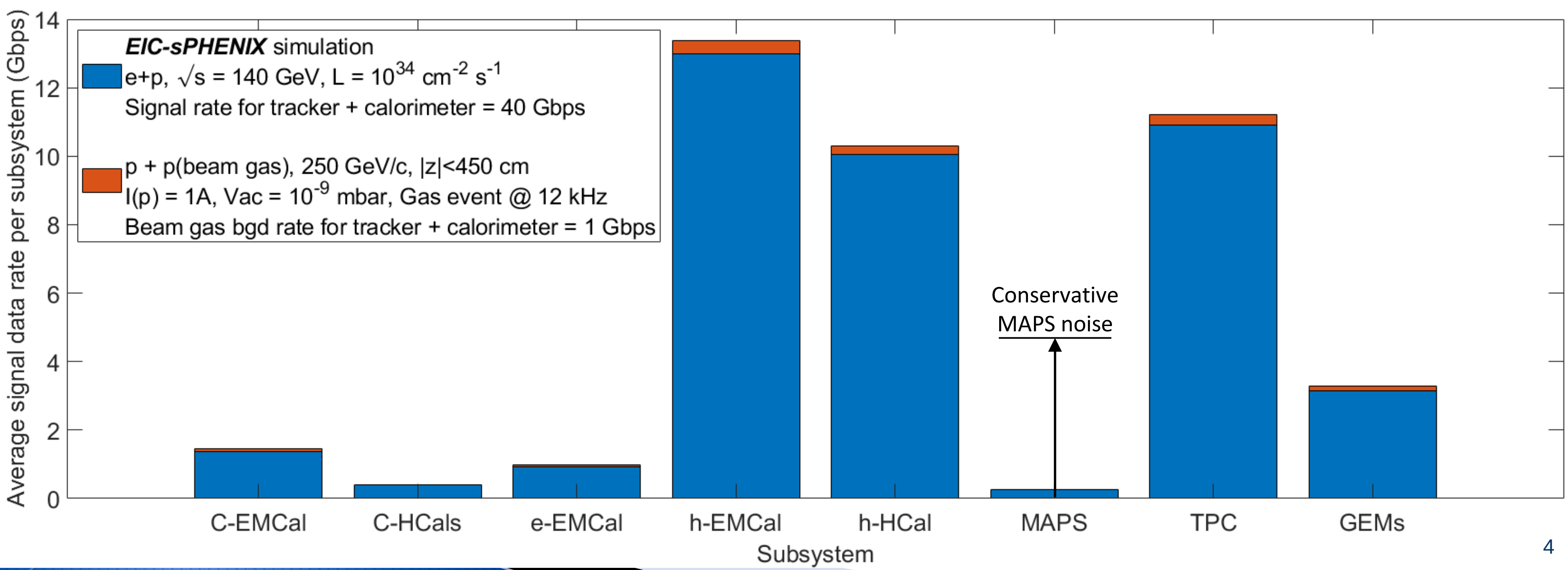
p + p, 275 GeV/c

at z=-4 m

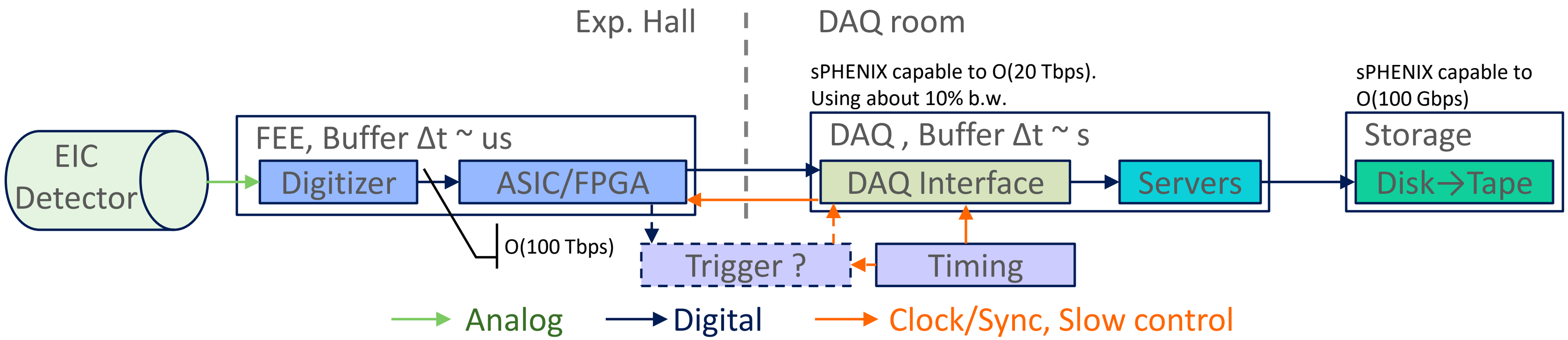
Signal data rate -> DAQ strategy

Note sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/ , Simulation: https://eic-detector.github.io/

- What we want to record: total collision signal ~ 100 Gbps @ 10^{34} cm^{-2} s^{-1}
  - Assumption: sPHENIX data format, 100% noise
  - Less than sPHENIX peak disk rate. 10^{-4} comparing to LHC collision
- Therefore, we could choose to stream out all EIC collisions data
- In addition, DAQ may need to filter out excessive beam background and electronics noise, if they become dominant.
  - Very different from LHC, where it is necessary to filter out uninteresting p+p collisions (CMS/ATLAS/LHCb) or highly compress collision data (ALICE)
  - Such filtering does not require real-time event reconstruction

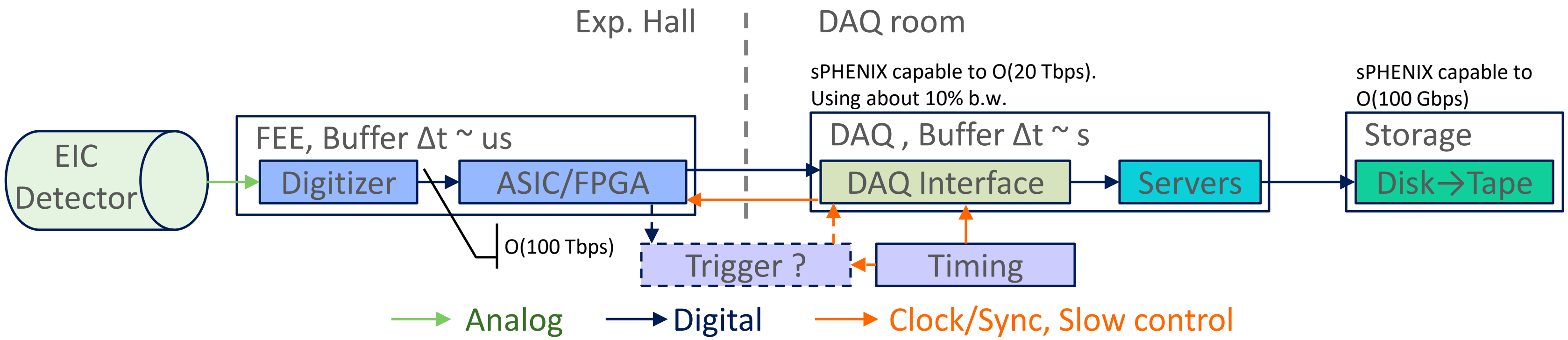


A strategy for an EIC real-time system



- For the signal data rate from EIC (100 Gbps), we can aim for filtering-out and streaming all collision in raw data without a hardware-based global triggering
  - Diversity of EIC event topology → streaming DAQ enables expected and unexpected physics
  - Streaming minimizing systematics by avoiding hardware trigger decision, keeping background and history
  - At 500kHz event rate, multi-μs-integration detectors would require streaming, e.g. TPC, MAPS
- Requirement
  - All front-end to continuously digitize data or self-triggering
    e.g. PHENIX FVTX, STAR eTOF, all sPHENIX trackers, any many prototypes in eRD23 consortium
  - Reliably synchronize all front-ends and identify faults
  - Recording all collision data (100 Gbps if raw)
  - If needed, filtering out background with low signal loss (10^{-4}?)
  - Requiring reliable data flow → control systematics:
    Low data loss rate < 10^{-4}(?) and/or loss in a deterministic manor

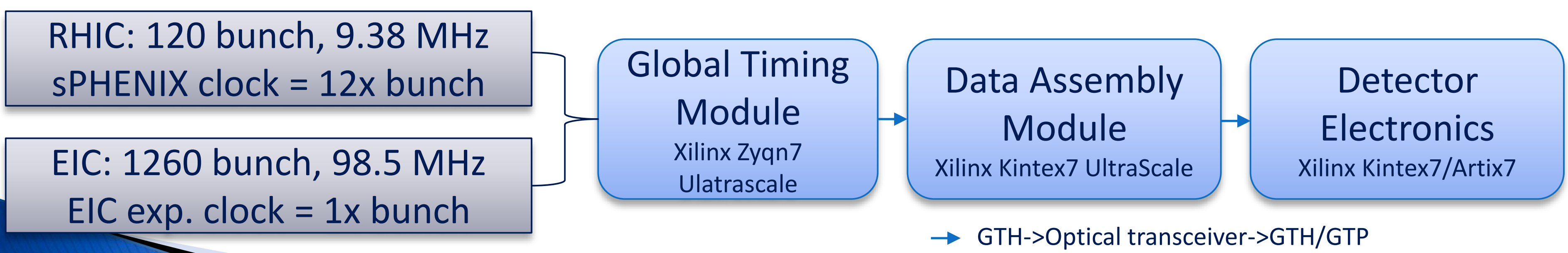
Streaming/trigger hybrid strategy



- At the start of EIC operation
  - Background could be significantly higher
  - Same time: lossy software data reduction is not yet established
- Possible solution at initial operation:
  Hybrid streaming readout with a calorimeter trigger
  - Many high profile EIC physics event leave distinct calorimeter signature for triggering (e.g. DIS/DVCS)
  - Use calo trigger to throttle streaming data to ensure lossless record full triggered event
  - Fill rest DAQ bandwidth with streaming data outside triggered time-window
  - Sliding scale adjust two data streams.
    Reference: LHCb Turbo stream, sPHENIX tracker DAQ (later this talk)
- Later running: Trigger/sync signal from the trigger components could be used for data validation and calibration
  - E.g. periodically send slow calibration/laser trigger pulses and collect non-zero suppressed data from for gain/pedestal calibration

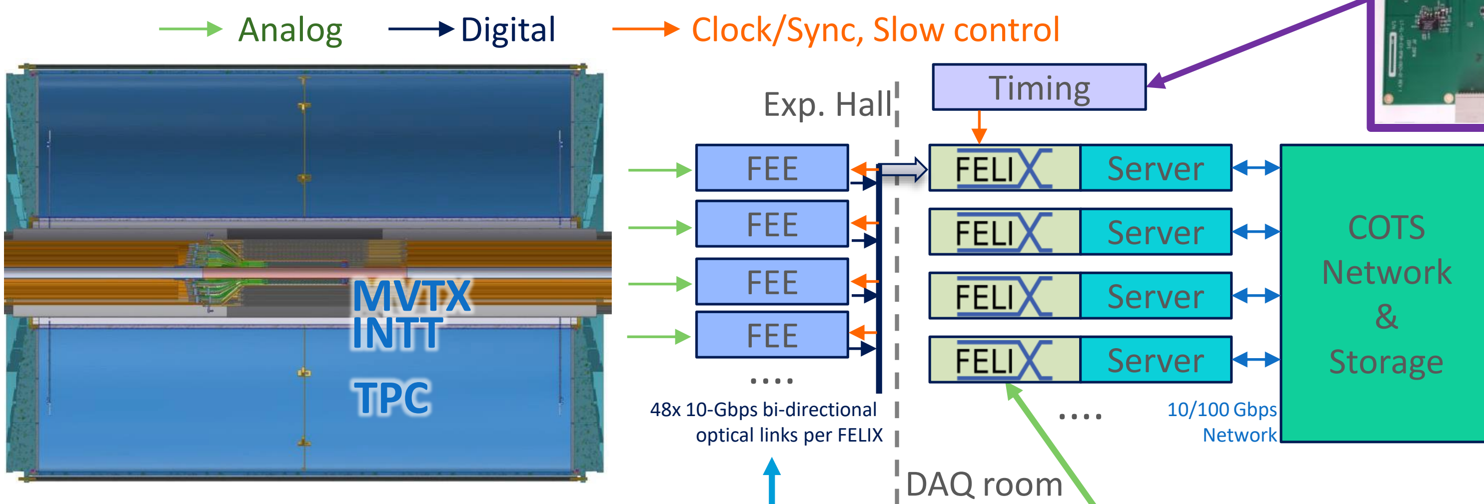
Timing and synchronization

- Precision timing is relative (e.g. ToF, TPC, coincidence), with exception that we need to know which bunch is colliding
- Therefore, collider experiment DAQ and FEE usually sync to beam bunch RF/collision clock
  - Then we need to be able to handle variation in beam clock. EIC clock variation seems simpler than RHIC (no ramp, weaker energy dependence), but design still on going
- EIC RF : modifying or rebuilding RHIC 28 MHz RF cavities as 24.5 MHz resonators
  - In discussion with RHIC RF group on testing sPHENIX timing distribution chain at RF clock source
- Timing system also collect/distribute busy, to ensure loss is uncorrelated with event type



Streaming readout for sPHENIX trackers

- Hybrid with triggered calorimeters
- See also talk by Martin



MVTX RU, 200M ch
ASIC: ALPIDE

INTT ROC, 400k ch
FPHX

TPC FEE, 160k ch
SAMPA

BNL-712 / FELIX v2 x48
Streaming ASIC → DAQ

Summary

- DAQ driven by uniqueness of EIC, very different from fix target or LHC
- Beam-clock-based experiment clock is commonly used, driven by physics such as proton spin sign and luminosity counting
- DAQ simulation for an EIC detector concept
- Proposing a streaming DAQ requirement
  - All front-end to continuously digitize data or self-triggering
  - Reliably synchronize all front-ends and identify faults
  - Recording all collision data (100 Gbps if raw)
  - If needed, filtering out background with low signal loss (10^{-4}?)
  - Requiring reliable data flow → control systematics
- Streaming hardware @ BNL
  - Streaming readout detectors: PHENIX strip tracker (2012-2016), STAR endcap time-of-flight (2018+), sPHENIX tracking system (2023+, ALPIDE, FPHX, SAMPA v5), Generic digitizer test-ground with 4Gsps single-chip ADC+FPGA+ARM (XCZU28DR)
  - FELIX-type DAQ interface (LDRD)
  - Prototyping timing system (sPHENIX R&D)