Task 3: Timing orchestra of DAQ and data organization

Few slides to kick start the discussion, please interrupt to discuss at any moment

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- **Including inputs from last a few meetings**
- **Towards forming the ePIC specification document**

ePIC

Experiment Clock

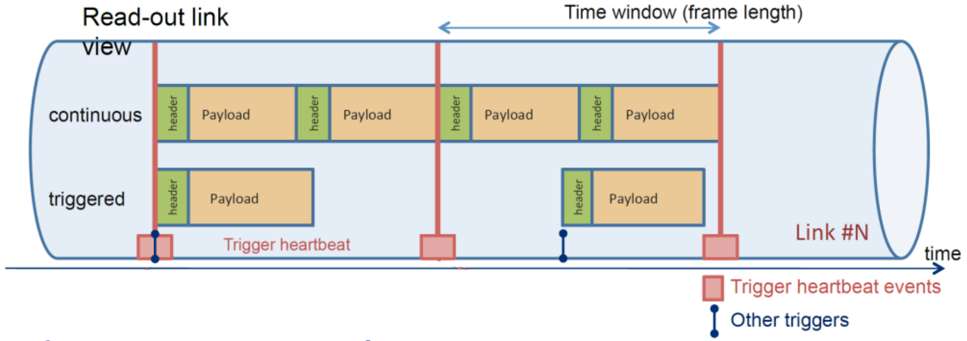
- Clock will be distributed from GTU to FEB to synchronize digitizers and tag time of the hits
- For collider experiment, it is common to synchronize FEB clock to a harmonics of the beam collision clock
  - Absolute time of hit is not useful
  - But relative time to bunch crossing is critical for T0, spin, and luminosity tagging
  - EIC Clock frequency: 98.5MHz (no ramp variation), 1260 RF bunches, 12.8us/revolution
- SVT is a special case: fixed to LHC clock by lpGBT [40.078 MHz], slow [few -10us integrated], and synced to fast detectors offline [sPHENIX implementation]
- ePIC design specification discussion
  - We have multiple ASICs of various digitization frequency
    - E.g. ~40MHz (EICROC), ~50MHz (SALSA), ~200MHz (AstroPix)
  - Shall we distribute clock at 9.85MHz (1/10 harmonic of EIC crossing clock, 126*revolution frequency)?
    - Then FEB/DAM of each subsystem can generate their own synchronized clock at multiples of 9.85MHz
    - Existing example is sPHENIX 9.4MHz clock x 6*16bit per clock @ 1.1Gbps; W Gu tested to 7.9Gbps
  - Clock counter and sync signal broadcasted from GTU->DAM->FEE

Example: sPHENIX clock data embedding at 6x 9.4MHz beam clock, 12Byte/beam clock [sPHENIX TDR]

clock count		0	1	2	3	4	5
bits 0-7	mode bits/BCO	mode bits	BCO bits 0-7	BCO bits 8-15	BCO bits 16-23	BCO bits 24-31	BCO bits 32-39
bit 8	beam clock	1	0	0	0	0	0
bit 9	LVL1 accept	X	0	0	0	0	0
bit 10	endat0	X	X	X	X	X	X
bit 11	endat1	X	X	X	X	X	X
bit 12	modebit en.	1	0	0	0	0	0
bits 13-15		3 user bits	0	1	2	3	4

Time-binning

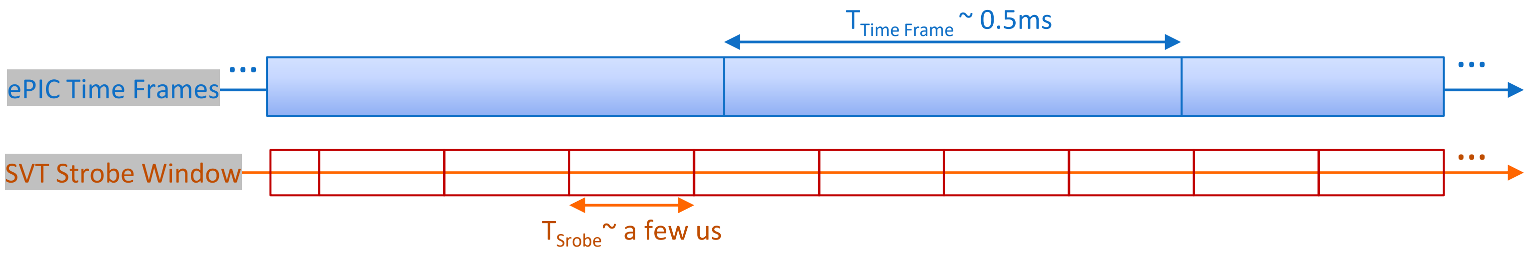
Example:
ALICE heartbeat frame
O(20)ms [ALICE-TDR-019]

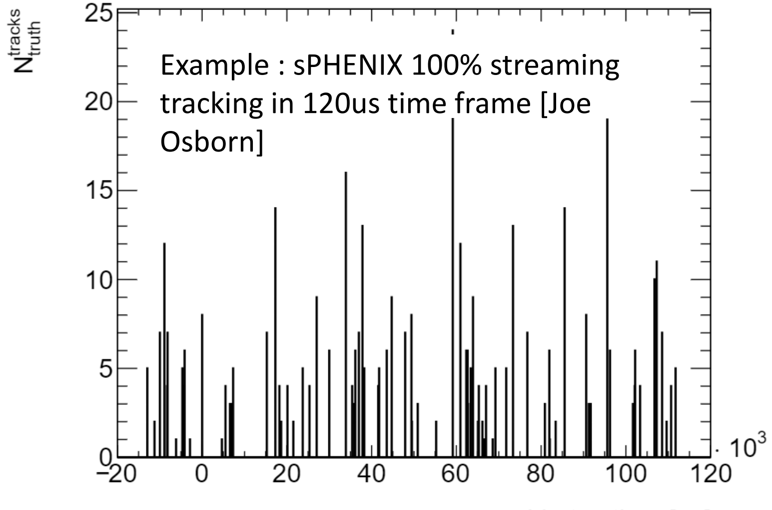


- Many streaming readout experiment bin detector data in time bins to manage and sync data
  - Heart-beat frame (ALICE), Time slice (CBM), Trigger Frame (sPHENIX hybrid DAQ)
- Choices of bin width inputs:
  - Multiples of EIC revolution 12us [W. Gu@last meeting: https://indico.bnl.gov/event/21613/]
  - Fixed to 2^16 crossing ~ 665us/300 events/10MB [J.Huang @ SRO X]
  - Variable and defined by GTU time-frame-edge signal [T. Ljubicic]
- ePIC design specification discussion
  - Pick a name? e.g. Time frame?
  - Pick a max length? E.g. <=2^16 crossings? Lead to well controlled buffer size and in-time-frame time-stamp bit length (16 bit would be sufficient)
  - Have GTU send out time-frame-edge signal which defines the frame length? Retain most flexibility

Data organization and offline interface discussion

- Time frames of ~0.5ms would contain 300 events/10MB, building blocks of offline data batches
- Timeframes should be built on-line?
  - Built prior to storage; stored in time sequence of frames; within a frame, time-order of hit is not required
  - Allow for sync check frame-by-frame, localize data for offline, allows for data reduction using multiple ePIC subsystems
  - Online computing resource needed
- Sync of SVT to rest of ePIC
  - E.g. we can assign SVT strobe window to timeframe based on its start time
- Offline processing cycle can take few time-frames at a time,
  recover edge hits, and process 0.5-few ms of continuous data at a time.

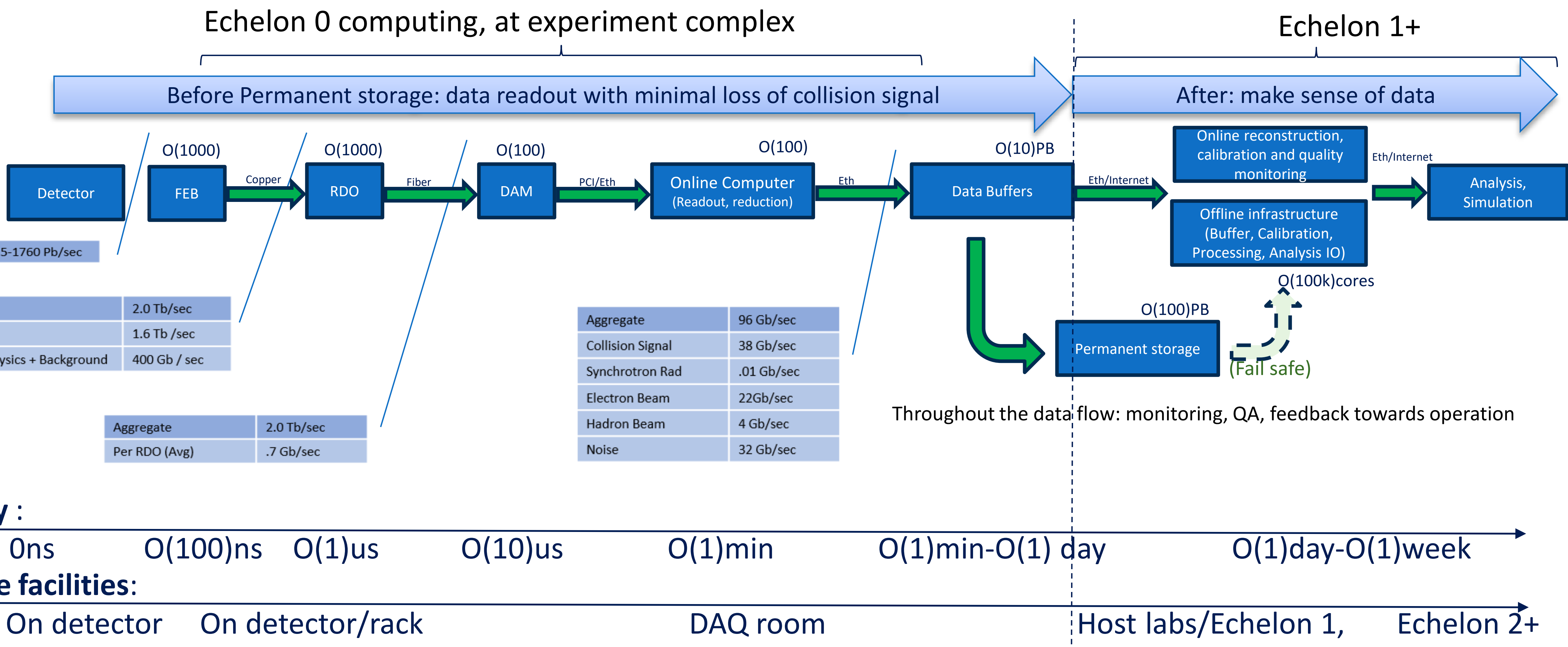




Extra Information

- Feel free to share your views
  Live note on indico [link]

ePIC streaming computing: online to offline



100% Occupancy	27.5-1760 Pb/sec

Aggregate	2.0 Tb/sec
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Reference:

- ePIC 2023 Computing plan and review [link]
- ePIC DAQ wiki: https://wiki.bnl.gov/EPIC/index.php?title=DAQ
- ECCE computing plan, *Nucl.Instrum.Meth.A* 1047 (2023) 167859

Echelon 0 computing at streaming readout DAQ

- Readout routing, time frame building [see Discussion 1]
- Primary function: data reduction
  - Traditional DAQ: triggering was the main method of data reduction, assisted by high level triggering/reconstruction, compression
  - Streaming DAQ need to reduce data computationally: zero-suppression, feature building, lossless/lossy compression
- Challenge: any information loss is permanent; observe full DAQ rate with less than O(1min) of latency
  - Reliable data reduction methods; Sized to peak data rate + contingency; More expensive (than offline) to develop and maintain
  - → Application, only if needed; three subsystem need identified below
- Other critical roles:
  - Slow control; Monitoring (in coordination with monitoring via prompt reconstruction); Meta data collection, database service

Detector Group	Channels					RDO	Fiber	DAM	Data Volume (RDO) (Gb/s)	Data Volume (To Tape) (Gb/s)
	MAPS	AC-LGAD	SiPM/PMT	MPGD	HRPPD					
Tracking (MAPS)	36B					400	800	17	26	26
Tracking (MPGD)				202k		118	236	5	1	1
Calorimeters	500M		104k			451	1132	19	502	28
Far Forward	300M	2.6M	170k			178	492	8	15	8
Far Backward	82M		2k			50	100	4	150	1
PID (TOF)		7.8M				500	1500	17	31	1
PID Cherenkov			320k		140k	1283	2566	30	1275	32
TOTAL	36.9B	10.4M	596k	202k	140k	2980	6826	100	2,000	96

3 subsystem data reduction need beyond FEB/RDO zero-suppression

- Calorimeter cluster building (CPU/GPU?)
- FB high-rate tracker: Tracklet building (CPU/GPU?)
- dRICH: Collision throttling (2 tier DAM FPGA)

EPIC Detector Scale and Technology Summary:

Detector System	Channels	RDO	Gb/s (RDO)	Gb/s (Tape)	DAM Boards	Readout Technology	Notes
Si Tracking: 3 vertex layers, 2 sagitta layers, 5 backward disks, 5 forward disks	7 m^2 36B pixels 5,200 MAPS sensors	400	26	26	17	MAPS: Several flavors: curved its-3 sensors for vertex Its-2 staves / w improvements	Fiber count limited by Artix Transceivers
MPGD tracking: Electron Endcap Hadron Endcap Inner Barrel Outer Barrel	16k 16k 30k 140k	8 8 30 72	1	.2	5	uRWELL / SALSA uRWELL / SALSA MicroMegas / SALSA uRWELL / SALSA	64 Channels/Salsa, up to 8 Salsa / FEB&RDO 256 ch/FEB for MM 512 ch/FEB for uRWELL
Forward Calorimeters: LFHCAL HCAL insert* ECAL W/SciFi Barrel Calorimeters: HCAL ECAL SciFi/PB ECAL ASTROPIX Backward Calorimeters: NHCAL ECAL (PWO)	63,280 8k 16,000 7680 5,760 500M pixels 3,256 2852	74 9 64 9 32 230 18 12	502	28	19	SiPM / HG2CROC SiPM / HG2CROC SiPM / Discrete SiPM / HG2CROC SiPM / HG2CROC Astropix SiPM / HG2CROC SiPM / Discrete	Assume HGCROC 56 ch * 16 ASIC/RDO = 896 ch/RDO 32 ch/FEB, 16 FEB/RDO estimate, 8 FEB/RDO conserve. HCAL 1536x5 *HCAL insert not in baseline Assume similar structure to its-2 but with sensors with 250k pixels for RDO calculation. 24 ch/feb, 8 RDO estimate, 23 RDO conservative
Far Forward: B0: 3 MAPS layers 1 or 2 AC-LGAD layer 2 Roman Pots 2 Off Momentum ZDC: Crystal Calorimeter 32 Silicon pad layer 4 silicon pixel layers 2 boxes scintillator	300M pixel 1M 1M (4 x 135k layers x 2 dets) 640k (4 x 80k layers x 2 dets) 400 11,520 160k 72	10 30 64 42 10 10 10 2	15	8	8	MAPS AC-LGAG / EICROC AC-LGAD / EICROC AC-LGAD / EICROC APD HGCROC as per ALICE FoCal-E	3x20cmx20cm 600^cm layers (1 or 2 layers) 13 x 26cm layers 9.6 x 22.4cm layers There are alternatives for AC-LGAD using MAPS and low channel count DC-LGAD timing layers
Far Backward: Low Q Tagger 1 Low Q Tagger 2 Low Q Tagger 1+2 Cal 2 x Lumi PS Calorimeter Lumi PS tracker	1.3M pixels 480k pixels 700 1425/75 80M pixels	12 12 1 1 24	150	1	4	Timepix4 Timepix4 (SiPM/HG2CROC) / (PMT/FLASH) Timepix4	
PID-TOF: Barrel Endcap	2.2M 5.6 M	288 212	31	1	17	AC-LGAD / EICROC (strip) AC-LGAD / EICROC (pixel)	bTOF 128 ch/ASIC, 64 ASIC/RDO eTOF 1024 pixel/ASIC, 24-48 ASIC/RDO (41 ave)
PID-Cherenkov: dRICH pfRICH DIRC	317,952 69,632 69,632	1242 17 24	1240 24 11	13.5 12.5 6	28 1 1	SiPM / ALCOR HRPPD / EICROC (strip or pixel) HRPPD / EICROC (strip or pixel)	Worse case after radiation. Includes 30% timing window. Requires further data volume reduction software trigger

By Jeff Landgraf, presented on Aug 22 WG meeting [link], Updated Sept 19

Summary of Channel Counts

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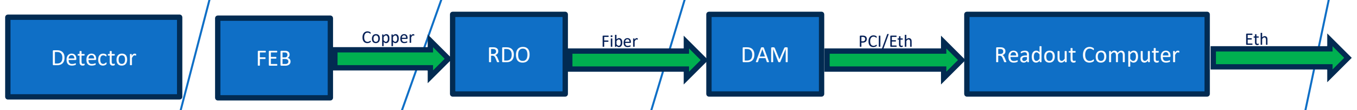
Summary of Data Flow



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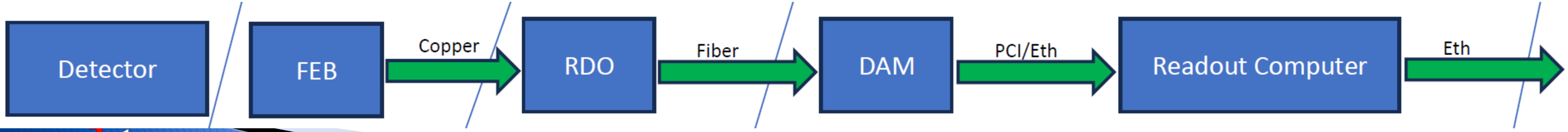
Streaming DAQ – Computing : consideration 1

For kickstart the discussion, please interrupt to discuss at any moment

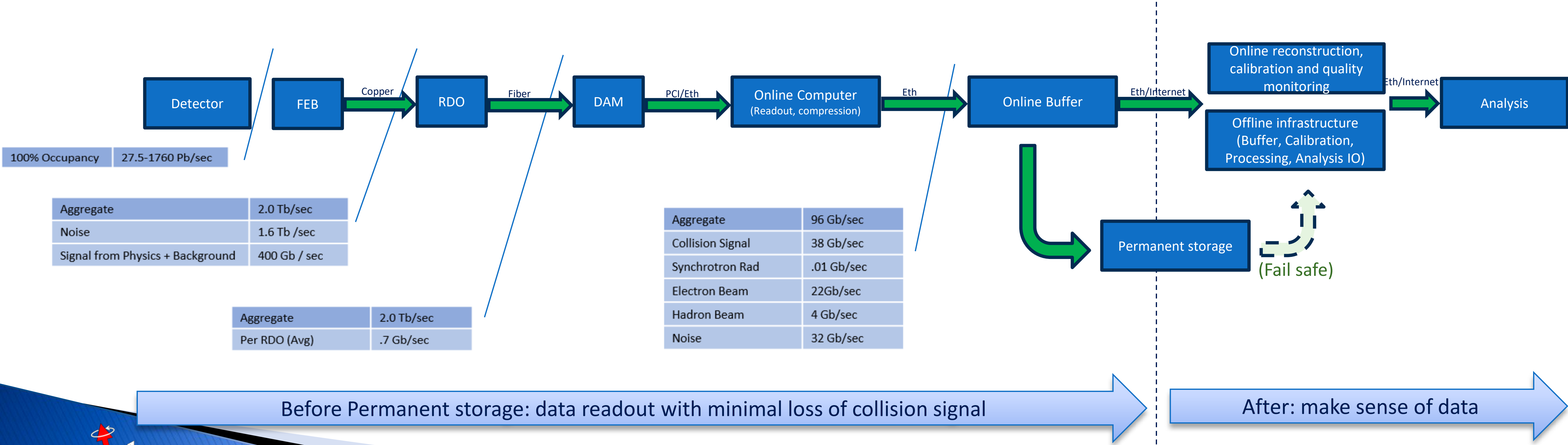
- Streaming DAQ naturally leads to no clear separation of streaming DAQ and computing
  - Streaming DAQ relies on data reduction computationally (i.e. no real-time triggering) → Any data reduction in streaming DAQ is a computing job
  - Which could be done at ASIC, FPGA, online-computers
  - Example could be zero-suppression (simple or sophisticated), feature extraction (e.g. amplitude in calo and tracklet in FB tracker)
  - Require minimal loss of collision signal; any data reduction require stringent bias control/study
- Citing ePIC software principles https://eic.github.io/activities/principles.html :
  We will have an unprecedented compute-detector integration:
  - We will have a common software stack for online and offline software, including the processing of streamed data and its time-ordered structure.
  - We aim for autonomous alignment and calibration.
  - We aim for a rapid, near-real-time turnaround of the raw data to online and offline productions.



Streaming DAQ – Computing : consideration 2

For kickstart the discussion, please interrupt to discuss at any moment

- Sooner or later, a copy of data is stored and saved for permanent storage
- This stage of first permanent storage could be viewed as a DAQ – computing boundary



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Streaming DAQ – Computing : consideration 2

For kickstart the discussion, please interrupt to discuss at any moment

- Paid by project
- Has a hard archival limit (O(100Gbps)) from both throughput and tape cost
- Main goal on “online-computing” is data reduction to fit output pipeline
- Stringent quality and bias control for any lossydata reduction
- As minimal reduction as affordable to
  - (1) reduce unrecoverable systematic uncertainty
  - (2) reduce complexity, cost, failure modes.
  - Any processing beyond minimal need a physics motivation to justify project cost/schedule reviews (and possible descope reviews)
- High availability: any down time cost $O(0.1)M/day → usually on host lab

Before permanent archival: DAQ

- Driven by collaboration, operation fund
- We would like to complete within a small latency (<O(1)week)
  - Usually driven by calibration and debugs
- Main goal on “offline-computing” is to bring out physics objects for analysis
- Quality control for reconstruction
- Can afford to redo reconstruction if new algorithm or with new physics insights (at cost of time, effort and computing)
- Can wait for short interruptions and can be distributed

After permanent archival: Computing

(last session today)

Towards the computing review Oct 19-20: the charge

1. At this stage, approximately ten years prior to data collection, is there a comprehensive and cost-effective long-term plan for the software and computing of the experiment?
2. Are the plans for integrating international partners' contributions adequate at this stage of the project?
3. Are the plans for software and computing integrated with the HEP/NP community developments, especially given data taking in ten years?
4. Are the resources for software and computing sufficient to deliver the detector conceptional and technical design reports?
5. Are the ECSJI plans to integrate into the software and computing plans of the experiment sufficient?

Quick recap in Streaming Computing WG

- SRO WG meetings was kickstarted in July 2023, started with overview discussions (July 11 & 18)
- Aug meetings
  - Data rate
  - Open-minded discussion on streaming computing model
  - Concluded a list of follow up discussions
- Sept 14 meeting on Item-1 DAQ-Computing interface
- Coming:
  - Consensus forming for streaming computing model
  - Preparation towards ePIC computing review in Oct 2023

Discussions:

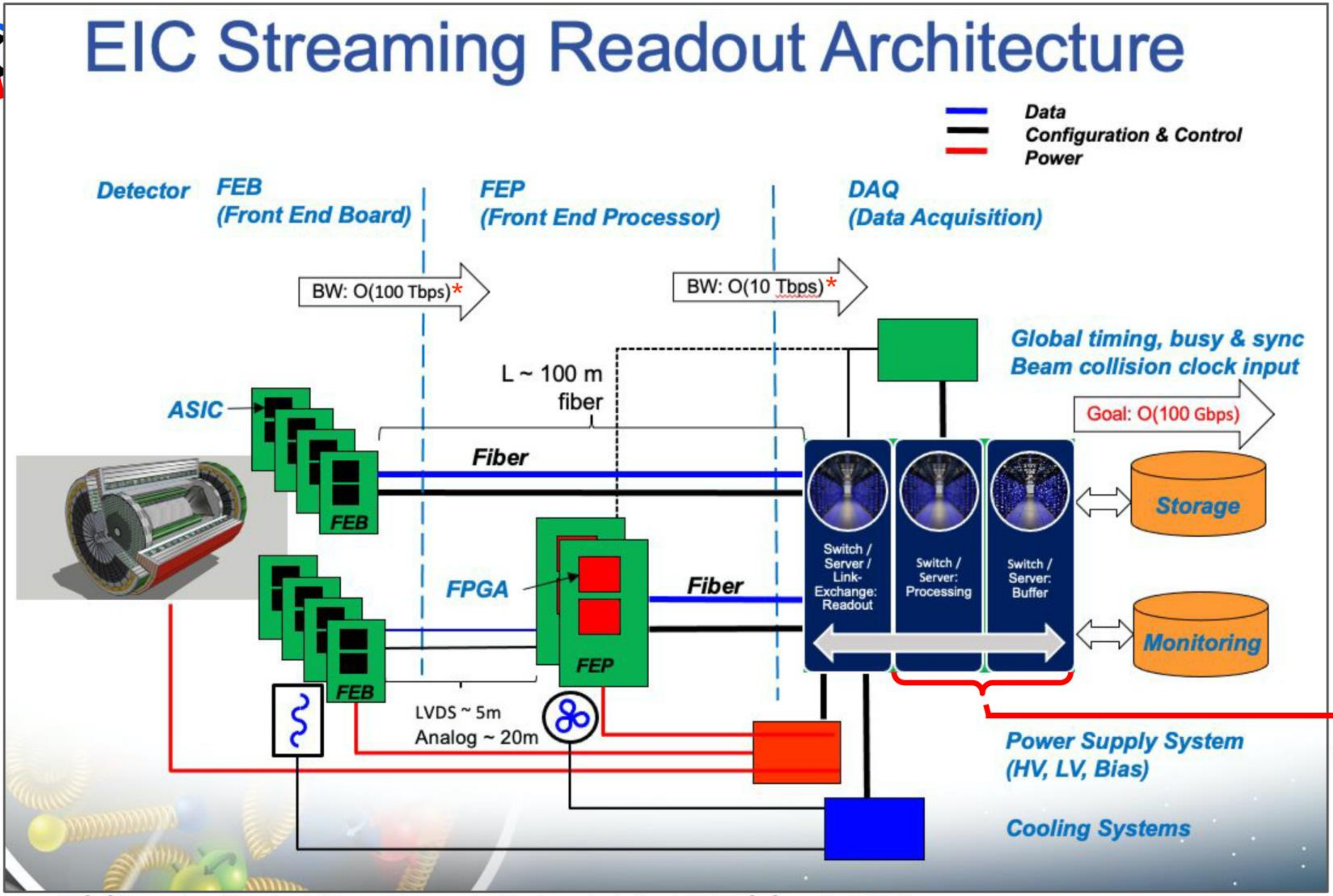
1. We need to define the interface between the streaming DAQ and the streaming computing.
2. What are the requirements for autonomous calibration of the ePIC detectors? What is the latency for doing this?
3. What is the algorithmic workflow for a holistic reconstruction of physics events?
4. Specific requirements for Echelon 1. Failback modes.
5. What is the raw data that we will keep?
6. What use cases for physics analyses to discuss in detail?
7. **Less critical**: We need to define the data model and requirements for the data format. Feedback system.
8. **Less critical**: How many passes will be needed?

Why streaming DAQ/computing?

	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	100 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**

- Events are precious and have diverse topology → hard to trigger on all process
- Signal data rate is moderate → possible to streaming recording all collision signal, event selection in offline reconstruction using all detector information after calibration
- Background and systematic control is crucial → avoiding a trigger bias; reliable data reduction

Streaming DAQ has been selected for EIC since YR and preCDR time



factor of 100 in data reduction

*ATHENA estimates assumed much more suppression at early stages, but still 100Gbps output. (See J. Landgraf talk at SRO X)

EIC Streaming Readout (From Fernando Barbosa's talk at AI4EIC Sep. 9, 2021)