Follow up discussion on timing protocol

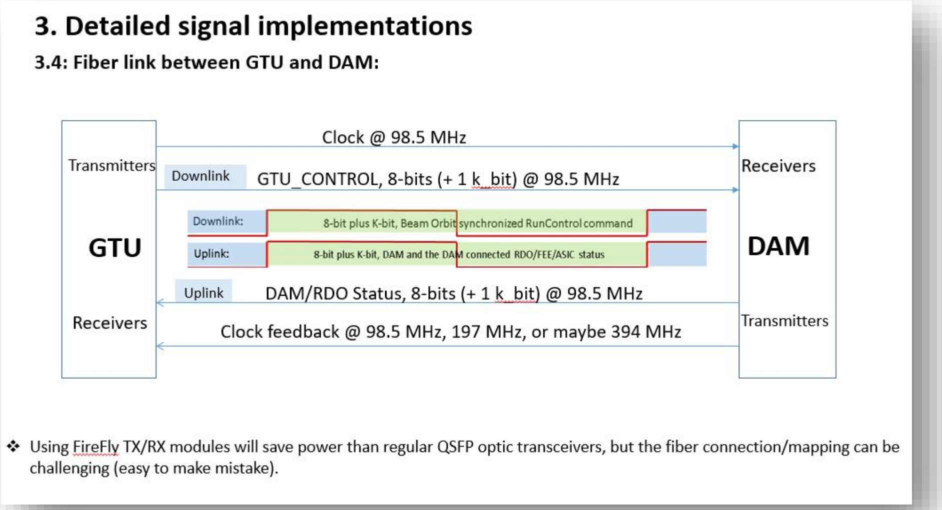
Jin Huang (BNL)

In follow up to William's talk on Apr-11 [link]
Thanks to discussion with William Gu
With aim towards writing the timing protocol specification document

BCO embedding in GTU->DAM->RDO links?

- Separated clock/frame counters at GTU/DAM/RDO levels can be error prone
  - Example used in PHENIX and part of sPHENIX. Prone to misalignment
- Alterative is to broadcast beam clock counter (BCO) from GTU on every clock cycle using MGT links
  - Example used in sPHENIX GTU->DAM links
  - GTU keep a master 64bit BCO. Persistent at power off; Never rollover, start from 0 from first GTU power on
  - 7.88Gb/s GTU->DAM link (8Byte * 8b10b * 9.5MHz)
    - Lower 48bit of master BCO (rollover in one month>>1 run)
    - 8 bit of GTU fast command bit
      [Reset, RevTick, TimeFrameStart, TimeFrameEnd, 4 user bits]
    - User bits are subsystem specific, usually doing specific task synced with beam orbit, such as calibration pulser during abort gap
    - Comma character: easy realign links during operation
  - In data time frame is identified by the start BCO counter
- BCO Used in online/offline processing to sync and ID timeframes and events

William's slides Apr-11 [link]



sPHENIX clock data embedding in GTU->DAM link 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

MGT based GTU->DAM links?

- Use 10Gbps capable GTU->DAM optical links
- DAM belong to the same subsystem receive identical GTU data from a single MGT→Fanout→Firefly
  - Reduce the MGT use in GTU to ~30
  - Example implementation in sPHENIX
  - DAM specific config received via slow control interface via PCIe from EBDCs
- Feedback from DAM->GTU are low speed that use IO pins
  - Busy feedback, clock feedback for TOF-like

ePIC DAQ counting

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
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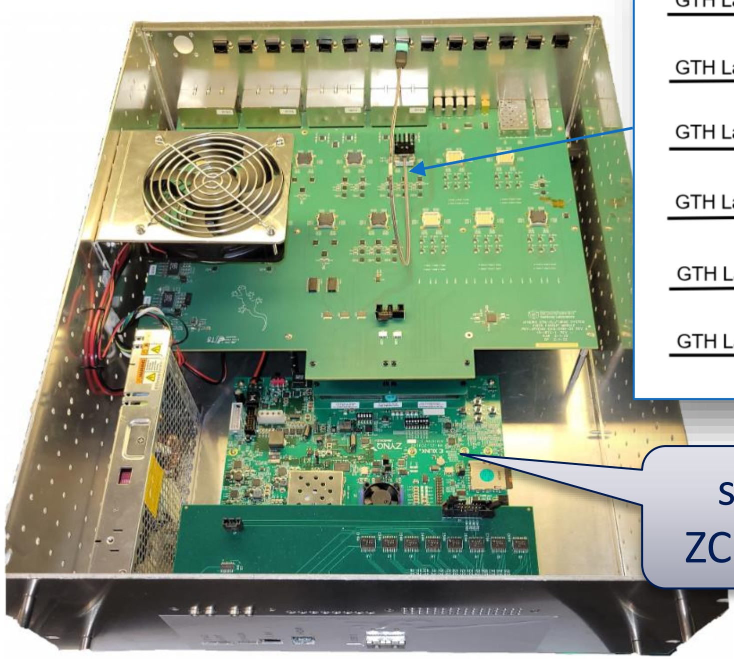
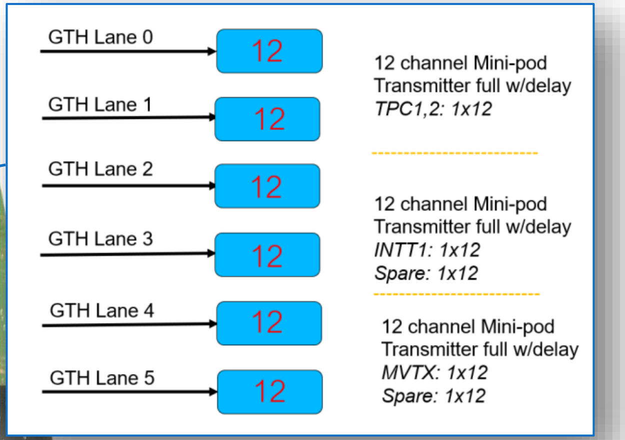
TOTAL	36.9B	10.4M	596k	202k	140k	2980	6826	100	2,000	96

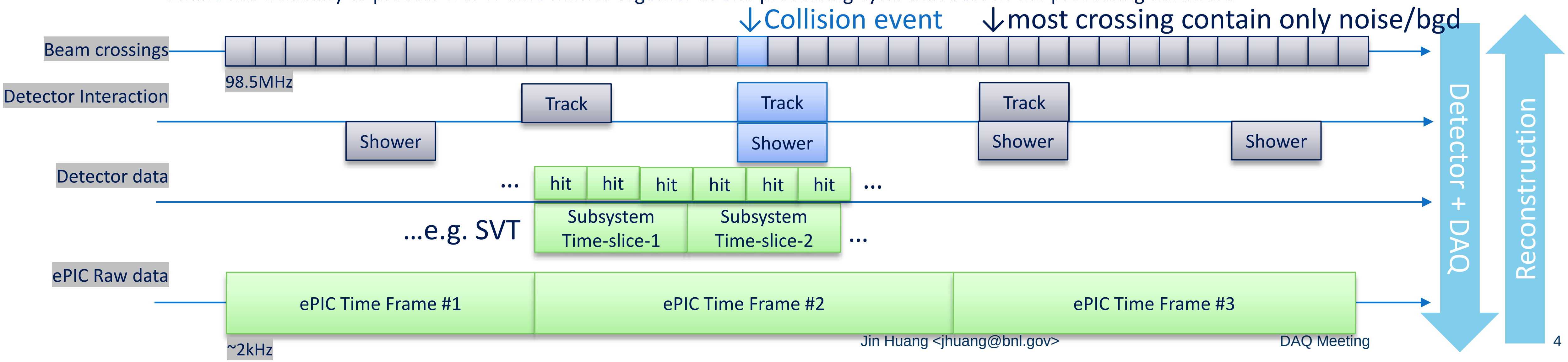




sPHENIX GTM (GTU)
ZCU102+Optical Fanout

Unlink DAQ Time-Frames from Beam Revolution?

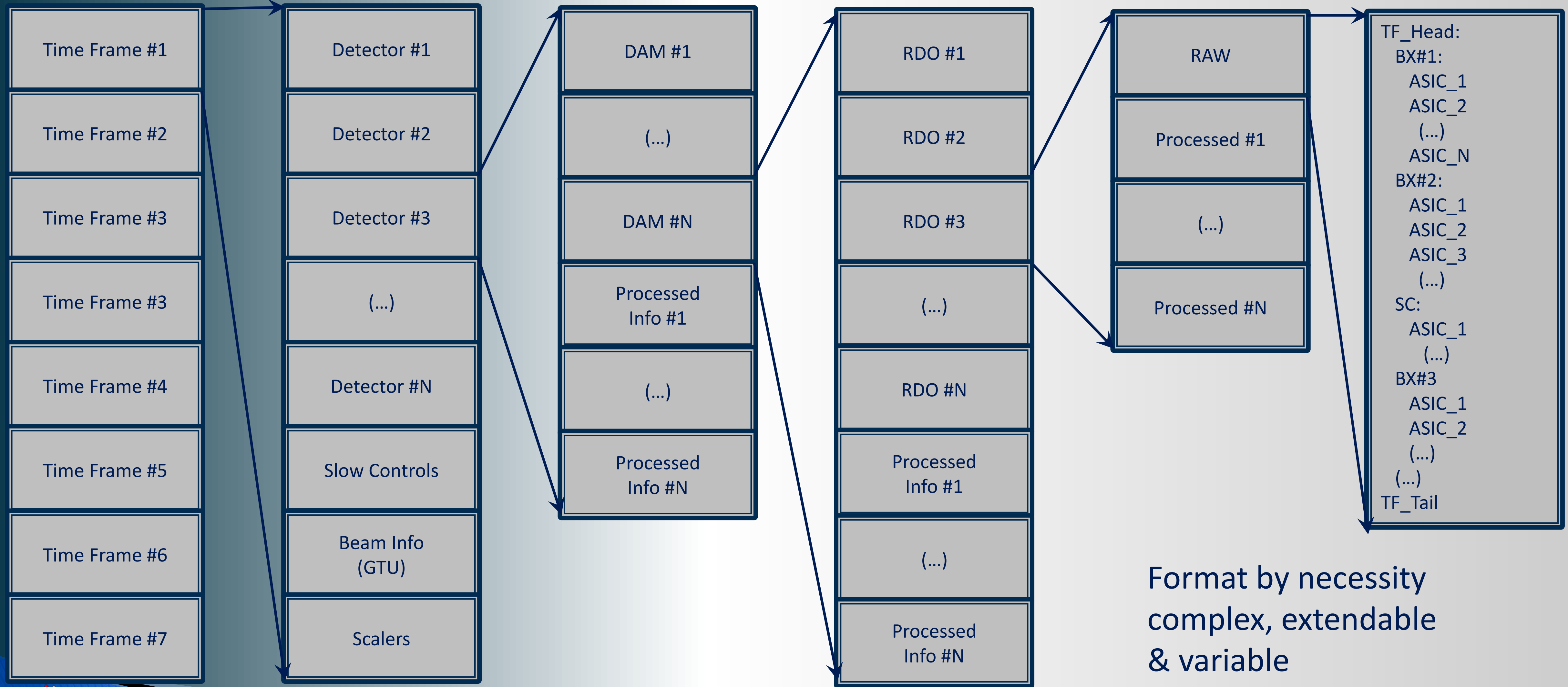
- Proposed ePIC Time Frame specification
  - <=2^16 crossing: 16-bit integer sufficient to locate hit's BX in Time Frame; <=665us/300 events/10MB
  - Exact length defined by GTU sync signal: most flexible
- There is advantages to detach time-frame from beam revolution
  - DAQ/electronics should be able to handle conditions where beam revolution/abort gap do not apply : e.g. cosmic data, test beam
  - EIC intend to control relative luminosity to 10e-4 level; alignment of time-frame to beam revolution risk align subtle pattern recognition efficiency bias with the spin states
- From upstream of DAQ:
  - Hits are sorted and time-index within time frame. Depending on subsystem, can happen at ASIC, RDO, or DAM levels.
  - Can be organized in sub-timeframe slices depending on subsystem need (example is SVT uses a few us strobe window)
- For downstream of DAQ:
  - Time Frames will be order in data files
  - Neighboring time frames should be used to recover hits at the edge of the time frames
  - Offline has flexibility to process 1 or N time frames together at one processing cycle that best fit the processing hardware



Extra Information

DAQ File Organization (Example…)

From Mar-21 meeting, Jeff's talk on Time Frame Organization and Data Volumes [link]



Format by necessity complex, extendable & variable

Readers

From Mar-21 meeting, Jeff's talk on Time Frame Organization and Data Volumes [link]

Two distinct sets of readers needed

- Data Bank Navigation

  rdr = getBank("NameOfBank")   or
  rdr = getBank(TimeFrame, "lfhcal/dam_3/rdo_6/raw")

- Detector Bank specific readers (presumably implemented as plugins)

  hit = rdr->nextHit()
  hit.bx
  hit.highResTOA
  hit.channel
  hit.adc

- Could, of course have multiple readers instantiated at a time for simultaneous decoding
- One likely needs to fill intermediate data structure for processing, so time frame for DAQ and time frame for tracking need not be tied together!

Discussion 1: event keying

- One way to view information provided by streaming DAQ is clock triggered events at *each* beam bunch crossing; offline reconstruction/analysis apply event selections to select the interesting set of events for physics measurements
- Option 1 for event key is the beam crossing counter
  - GTU counting 98.5MHz beam crossing clock with a 64bit counter
  - DAQ/electronics will broadcast EIC beam crossing counter to indexing all detector hits
- Option 2 for event key could be a tuple (run, time-frame, crossing counter in time-frame)
- Either is sufficient. Could use both too

Event key

- Generalizes the concept of event number and possibly run number to streaming scenarios
- Event number: For each level in the event hierarchy, have:
  - Absolute number: Starts at 0, increments by 1 monotonically
  - Relative number: Starts at 0 for each parent, increments by 1 monotonically
  - User key: Could be anything
- Run number:
  - Key for reloading resources such as calibrations
  - Helps to be a number, not an interval

Reference to last meeting, Nathan's talk [link]

Discussion 2: what is an (DAQ) run for ePIC?

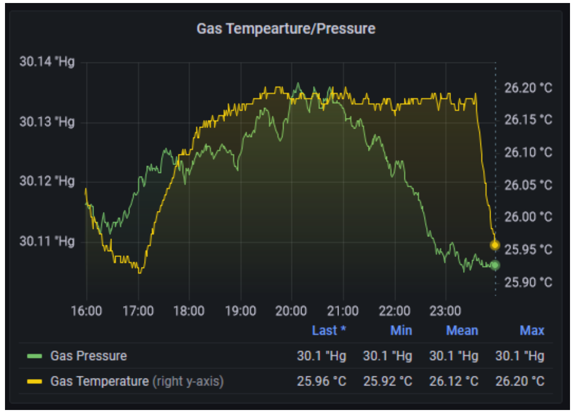
This is a discussion. Scenarios for a “DAQ run” could be:

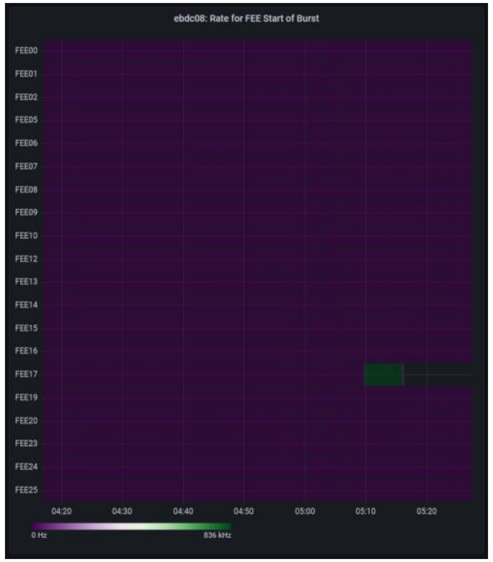
- Electron bunch replacement at O(1)Hz
  - Restarted automatically driven by accelerator bunch replacement control
  - Effectively a *luminosity block*, O(1000) ePIC time frames, require lumi/polarization measurement, scalar reading synchronized to the edge of the lumi window
- Data taking period between human-driven configuration changes (~1hr)
  - Commonly used by many experiment, neatly mapped in configuration DB storage
- Entire hadron ring fill (few hours)
- Not using a DAQ run concept, just luminosity blocks/time frames

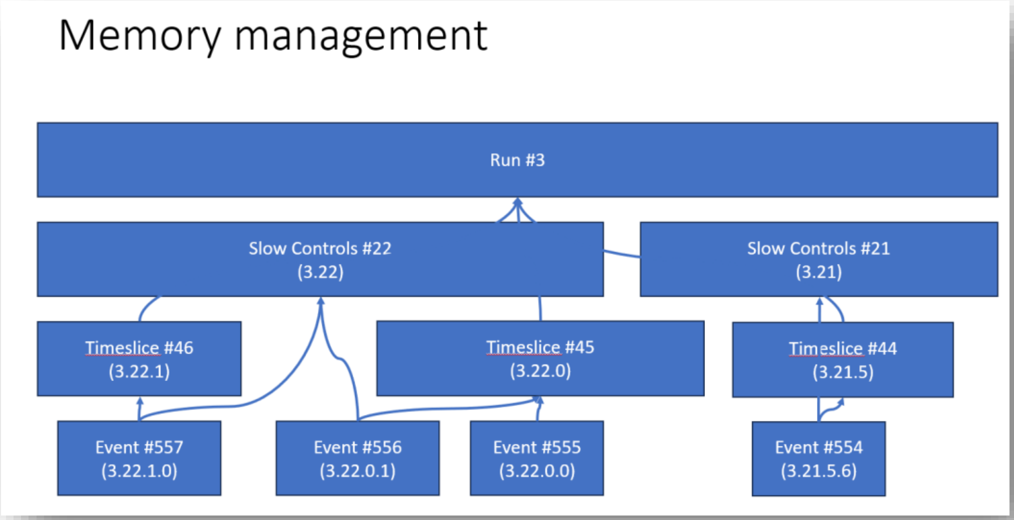
In any case, run start/end will be marked with beam crossing counter at GTU

Discussion 3: slow control (SC) data

- It is good practice to embed slow control data in raw data, but embedded data are hard to use
  - Some periodic reading require interpolation between readings (e.g. temperature); some requires future slow control reading (masking unstable FEEs in deadmap)
- Slow control data will be recorded to online DBs
  - Slow control recording persists regardless data taking
  - A mirror of online DB will be available for offline use
- *Suggest* detach slow control data access from reconstruction pass
  - Instead, use online database sources to produce calibration files (gain map, deadmap, etc.) as input to reconstruction, with validity marked with beam counter ranges
  - Use (automated) calibration job to process slow control data to form calibration input to reconstruction jobs, fits well in the multi-pass calibration computing plan
- Calibration access require scalable calibration database in offline world



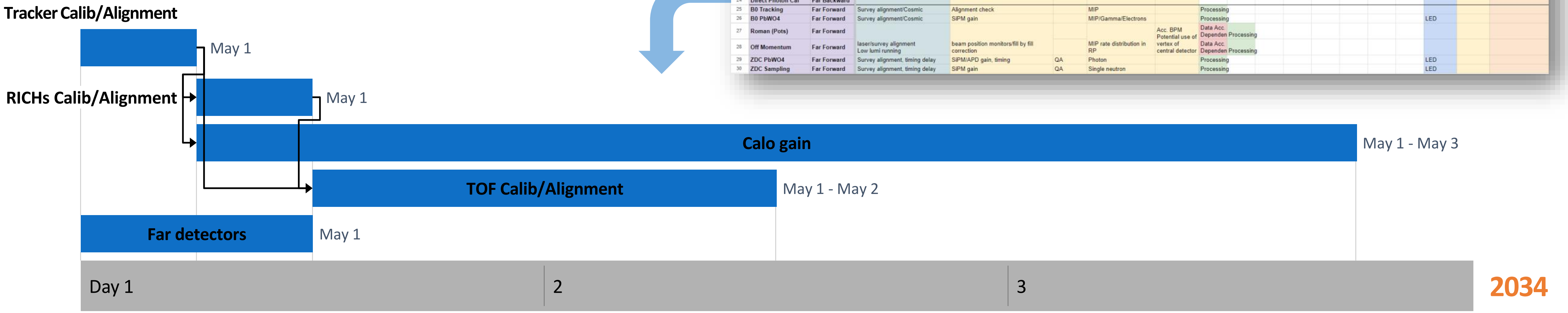




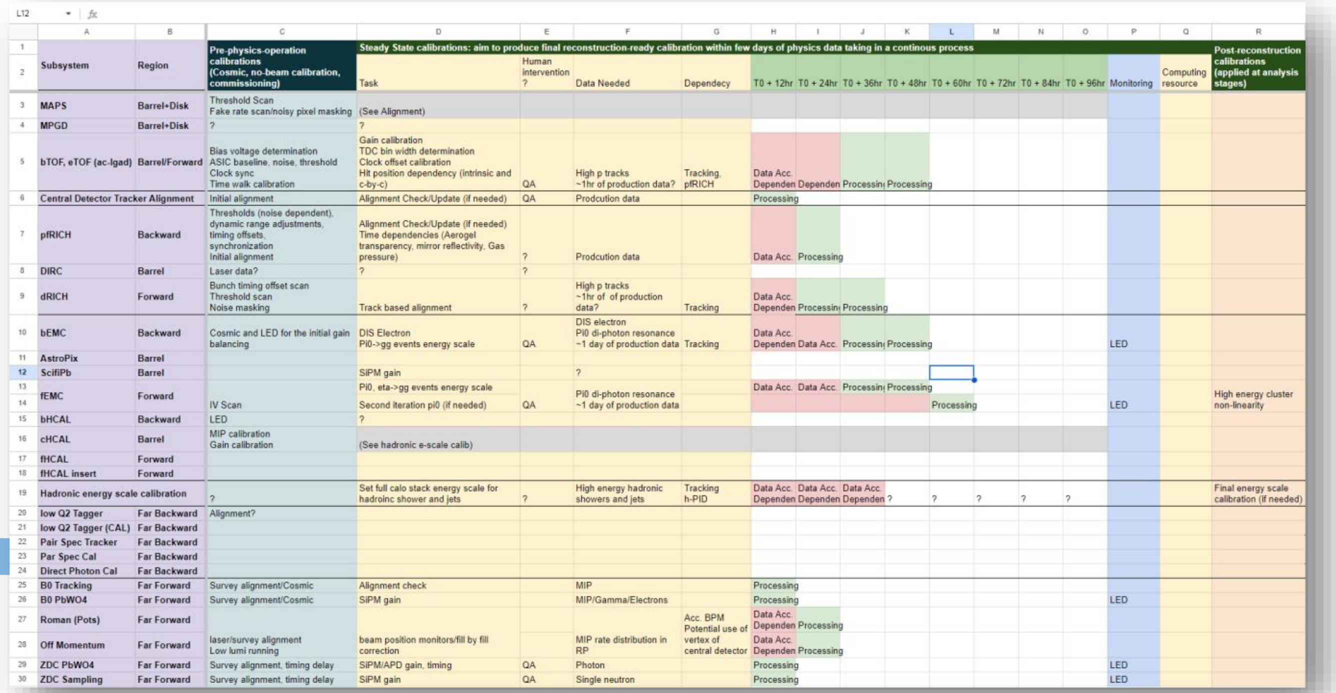
Reference to last meeting, Nathan's talk [link]

Discussion 4: Calibration workflow

- Calibration workflow seems fits into the prompt reconstruction computing model. Inputs welcomed.
- High level summary plot:

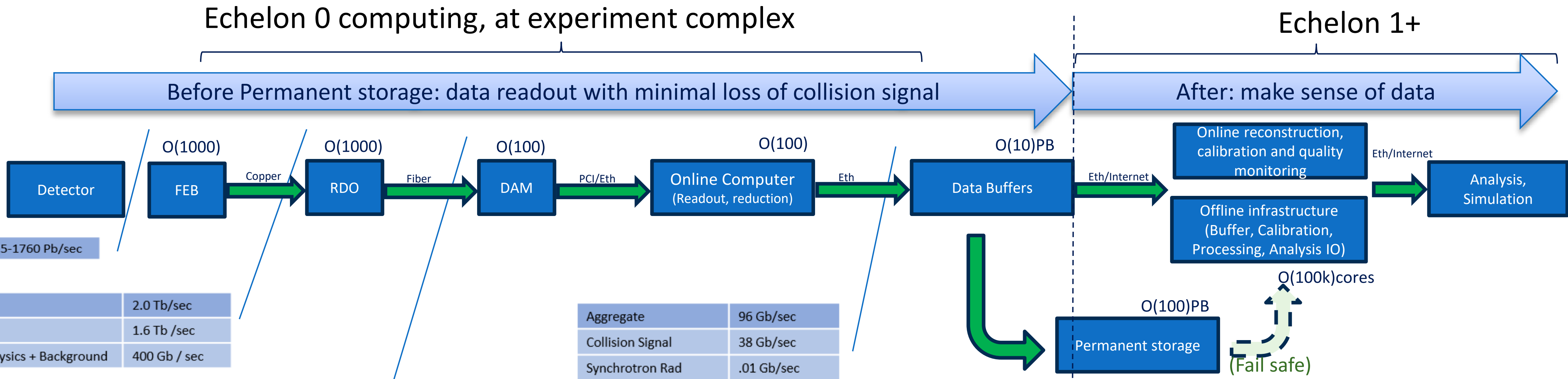


Working document for calibration workflow



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1			Pre-physics-operation calibrations (Cosmic, no-beam calibration, commissioning)	Steady State calibrations: aim to produce final reconstruction-ready calibration within few days of physics data taking in a continous process														Post-reconstruction calibrations (applied at analysis stages)
2	Subsystem	Region		Task	Human intervention ?	Data Needed	Dependecy	T0 + 12hr	T0 + 24hr	T0 + 36hr	T0 + 48hr	T0 + 60hr	T0 + 72hr	T0 + 84hr	T0 + 96hr	Monitoring	Computing resource	
3	MAPS	Barrel+Disk	Threshold Scan Fake rate scan/noisy pixel masking	(See Alignment)														
4	MPGD	Barrel+Disk	?	?														
5	bTOF, eTOF (ac-lgad)	Barrel/Forward	Bias voltage determination ASIC baseline, noise, threshold Clock sync Time walk calibration	Gain calibration TDC bin width determination Clock offset calibration Hit position dependency (intrinsic and c-by-c)	QA	High p tracks ~1hr of production data?	Tracking, pfRICH	Data Acc. Dependen	Dependen	Processin	Processing							
6	Central Detector Tracker Alignment		Initial alignment	Alignment Check/Update (if needed)	QA	Prodcution data		Processing										
7	pfRICH	Backward	Thresholds (noise dependent), dynamic range adjustments, timing offsets, synchronization Initial alignment	Alignment Check/Update (if needed) Time dependencies (Aerogel transparency, mirror reflectivity, Gas pressure)	?	Prodcution data		Data Acc.	Processing									
8	DIRC	Barrel	Laser data?	?	?													
9	dRICH	Forward	Bunch timing offset scan Threshold scan Noise masking	Track based alignment	?	High p tracks ~1hr of of production data?	Tracking	Data Acc. Dependen	Processin	Processing								
10	bEMC	Backward	Cosmic and LED for the initial gain balancing	DIS Electron Pi0->gg events energy scale	QA	DIS electron Pi0 di-photon resonance ~1 day of production data	Tracking	Data Acc. Dependen	Data Acc.	Processin	Processing					LED		
11	AstroPix	Barrel																
12	ScifiPb	Barrel		SiPM gain		?												
13	fEMC	Forward		Pi0, eta->gg events energy scale		Pi0 di-photon resonance ~1 day of production data		Data Acc.	Data Acc.	Processin	Processing							
14			IV Scan	Second iteration pi0 (if needed)	QA							Processing				LED		High energy cluster non-linearity
15	bHCAL	Backward	LED	?														
16	cHCAL	Barrel	MIP calibration Gain calibration	(See hadronic e-scale calib)														
17	fHCAL	Forward																
18	fHCAL insert	Forward																
19	Hadronic energy scale calibration		?	Set full calo stack energy scale for hadroinc shower and jets	?	High energy hadronic showers and jets	Tracking h-PID	Data Acc. Dependen	Data Acc. Dependen	Data Acc. Dependen	?	?	?	?	?			Final energy scale calibration (if needed)
20	low Q2 Tagger	Far Backward	Alignment?															
21	low Q2 Tagger (CAL)	Far Backward																
22	Pair Spec Tracker	Far Backward																
23	Par Spec Cal	Far Backward																
24	Direct Photon Cal	Far Backward																
25	B0 Tracking	Far Forward	Survey alignment/Cosmic	Alignment check		MIP		Processing										
26	B0 PbWO4	Far Forward	Survey alignment/Cosmic	SiPM gain		MIP/Gamma/Electrons		Processing								LED		
27	Roman (Pots)	Far Forward					Acc. BPM Potential use of vertex of central detector	Data Acc. Dependen	Processing									
28	Off Momentum	Far Forward	laser/survey alignment Low lumi running	beam position monitors/fill by fill correction		MIP rate distribution in RP		Data Acc. Dependen	Processing									
29	ZDC PbWO4	Far Forward	Survey alignment, timing delay	SiPM/APD gain, timing	QA	Photon		Processing								LED		
30	ZDC Sampling	Far Forward	Survey alignment, timing delay	SiPM gain	QA	Single neutron		Processing								LED		

ePIC streaming computing: online to offline



100% Occupancy	27.5-1760 Pb/sec

Aggregate	2.0 Tb/sec
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Aggregate	96 Gb/sec
Collision Signal	38 Gb/sec
Synchrotron Rad	.01 Gb/sec
Electron Beam	22Gb/sec
Hadron Beam	4 Gb/sec
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Throughout the data flow: monitoring, QA, feedback towards operation

Latency :

0ns O(100)ns O(1)us O(10)us O(1)min O(1)min-O(1) day O(1)day-O(1)week

Possible facilities:

On detector On detector/rack DAQ room Host labs/Echelon 1, Echelon 2+

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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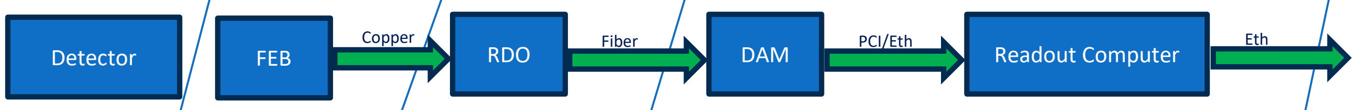
Summary of Data Flow



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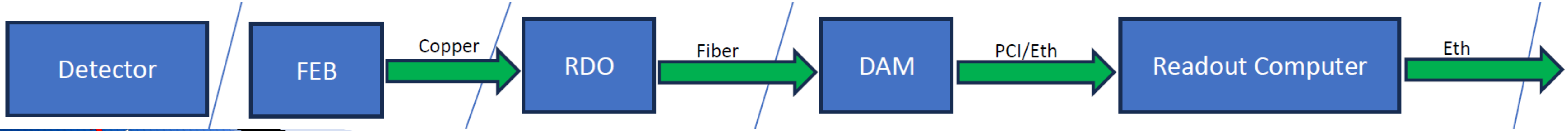
Streaming DAQ – Computing : consideration 1

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

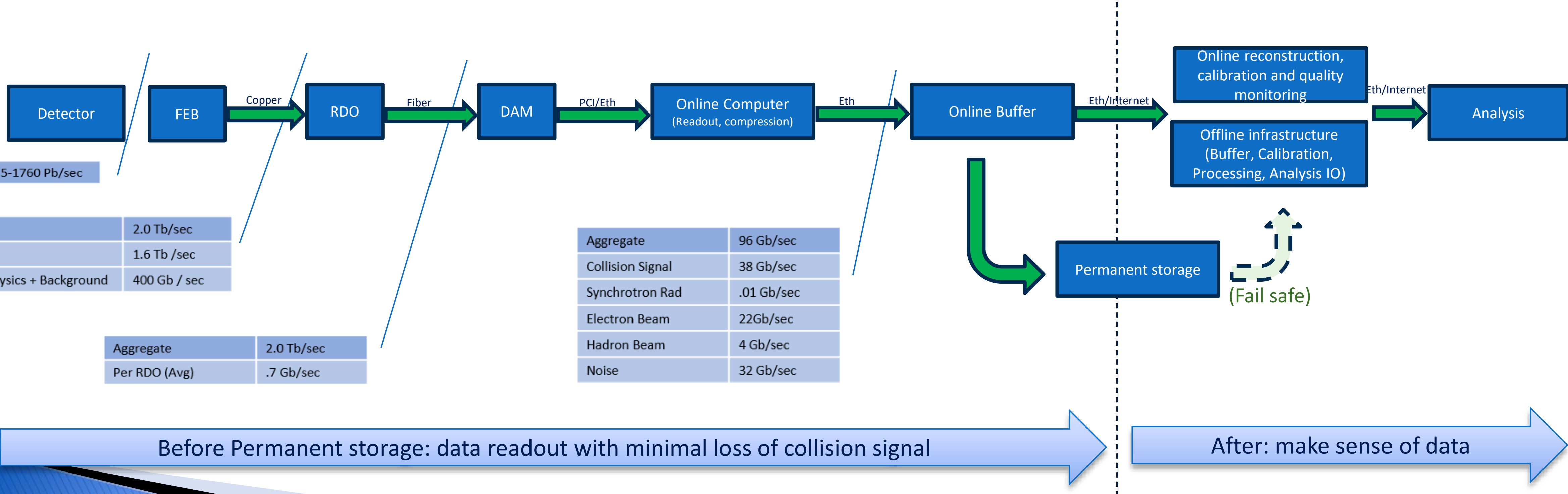
- Streaming DAQ naturally leads to no clear separation of streaming DAQ and computing
  - Streaming DAQ relies on data reduction computationally (i.e. no real-time triggering) → Any data reduction in streaming DAQ is a computing job
  - Which could be done at ASIC, FPGA, online-computers
  - Example 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

Before permanent archival: DAQ

- 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

After permanent archival: Computing

- 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

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}/dη 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