Streaming readout requirements : rates and more

Alexandre Camsonne

Streaming Readout Workshop X

May 17th 2022

Outline

- Detector 1 Working Group
- Yellow report : physics rate
- Streaming readout and DAQ requirements
- ECCE detector
- ATHENA detector
- Toward detector 1
  - Sensors for detector 1
- Backgrounds
  - Beam related
    - Synchrotron
    - Beam Gas
  - Sensor noise
    - SiPMT
- To do list
- Conclusion

See David Lawrence talk at Tuesday at 11:45 AM for data processing

See Martin Purschke talk at Tuesday at 3:30 PM for ECCE DAQ

See Jeff Landgraf talk at Tuesday at 4:15 PM for ATHENA DAQ

Detector 1 interim DAQ Working Group

- Merging from ECCE and ATHENA DAQ Working Group
- Conveners : Jeff Langraf (BNL), Jo Schambach (ORNL), Chris Cuevas (JLab), Alexandre Camsonne (JLab)
- Meeting Tuesday and Thursdays
- Follow developments of other detector groups design with updates to ECCE based design : setting up to have conveners attend meeting and detector WG contact with DAQ
- Some detectors very similar for both proposal : DIRC, Far Forward. Far Backward, DAQ
- Some detectors have a bit different design and technologies : Calorimeters, Cerenkov PID, TOF PID : updated design soon, though many sensors are common

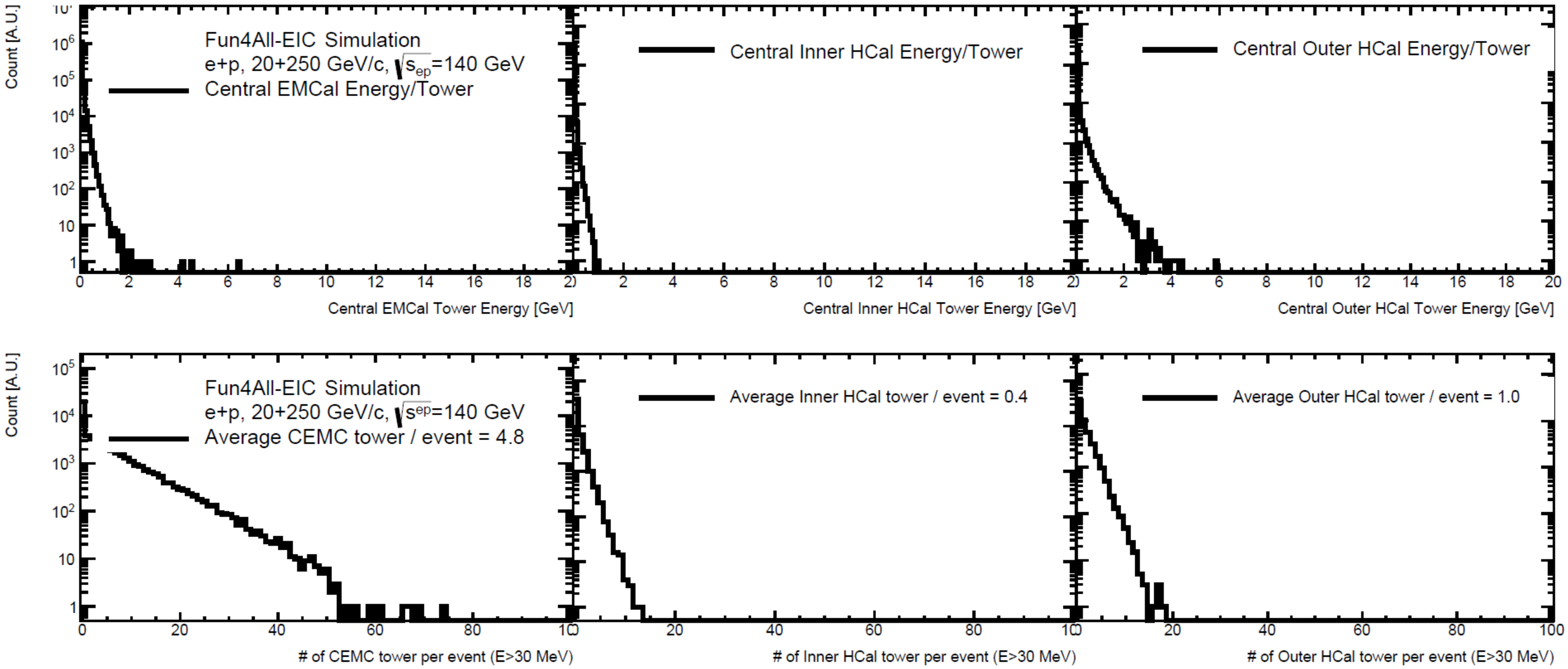
Physics rate from Yellow Report/CDR

- Total crossection

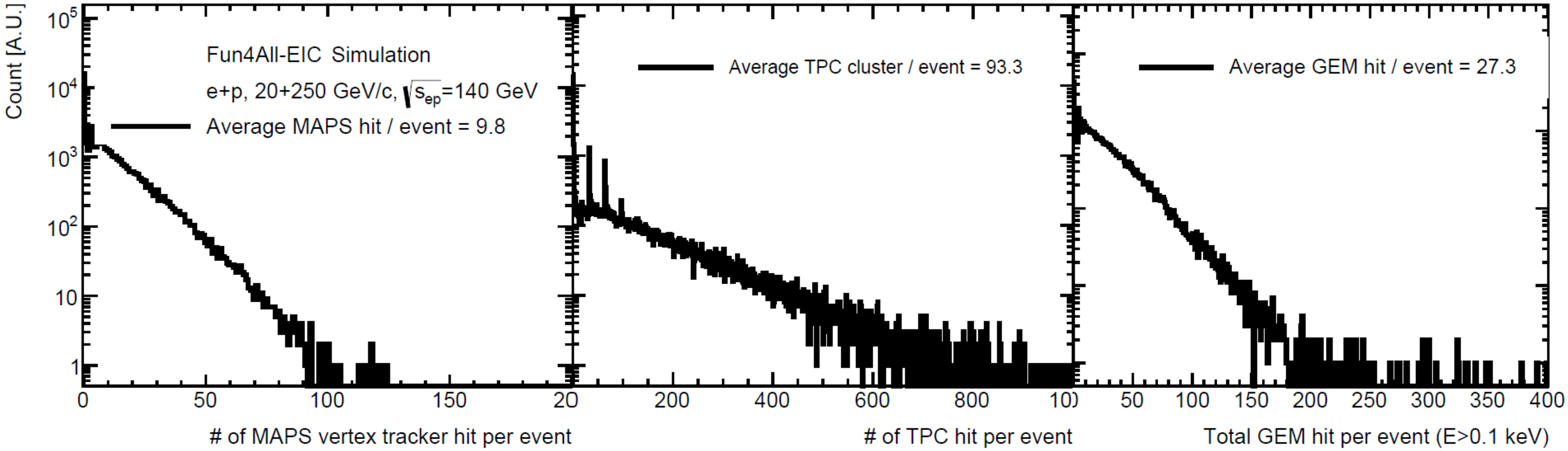
σ_{tot}(μb)		E_e [GeV] 5	10	18
E_p [GeV]	41	25.9	30.1	35.0
	100	32.1	37.1	41.6
	275	39.4	44.6	49.3

Species	p	electron	p	electron	p	electron	p	electron	p	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
n_b	290		1160		1160		1160		1160	
L [10^{33} cm^{-2}s^{-1}]	1.65		10.05		4.35		3.16		0.44	
γ_p	293.1		293.1		106.6		106.6		43.7	
γ_e	35225.1		19569.5		19569.5		9784.8		9784.8	
$E_{\gamma,\min}$ [GeV]	0.18		0.1		0.1		0.05		0.05	
σ_{BH} [mb]	236.8		229.6		217.1		208.5		197.5	
$\mathscr{L}_b$ [mb^{-1}]	0.073		0.111		0.048		0.035		0.005	
λ_{phot}	17.2		25.4		10.4		7.3		1.0	

Multiplicities from YR



Multiplicities in trackers from YR



Streaming DAQ requirement

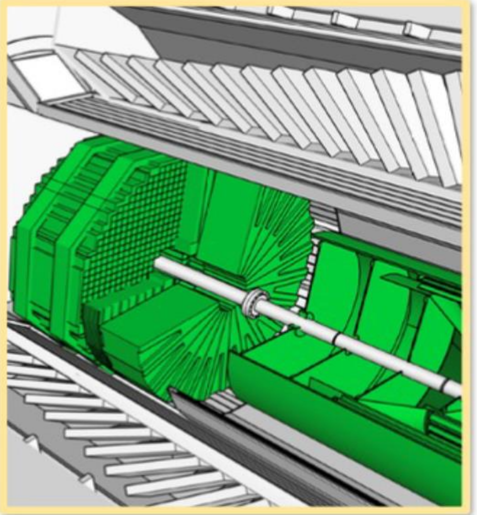
Collider:

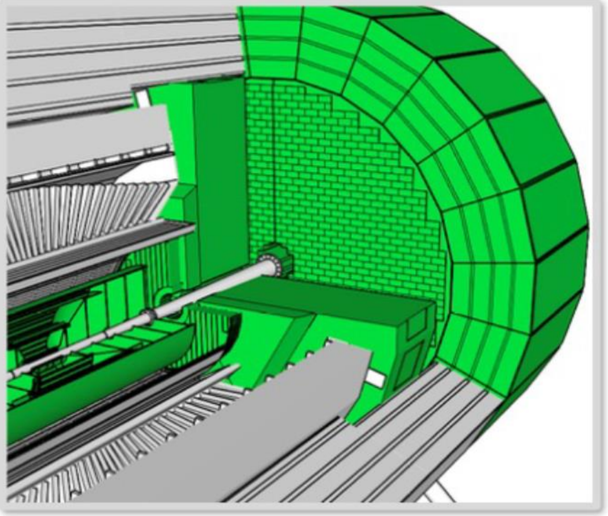
- ➢ EIC will deliver beam in up to 1160 bunches (~100MHz)
- ➢ Expected physics rate ~500KHz

Detector:

- ➢ Streaming Design
  - Physics requires min-bias data
  - High collision rates
  - low detector occupancy
- ➢ O(100 Gbps) output rates

From the Proposal





Backward Endcap

Tracking:
- ITS3 MAPS Si discs (x4)
- AC-LGAD

PID:
- mRICH
- AC-LGAD TOF
- $PbWO_4$ EM Calorimeter (EEMC)

Barrel

Tracking:
- ITS3 MAPS Si (vertex x3; sagitta x2)
- μRWell outer layer (x2)
- AC-LGAD (before hpDIRC)
- μRWell (after hpDIRC)

h-PID:
- AC-LGAD TOF
- hpDIRC

Electron ID:
- SciGlass EM Cal (BEMC)

Hadron calorimetry:
- Outer Fe/Sc Calorimeter (oHCAL)
- Instrumented frame (iHCAL)

Forward Endcap

Tracking:
- ITS3 MAPS Si discs (x5)
- AC-LGAD

PID:
- dRICH
- AC-LGAD TOF

Calorimetry:
- Pb/ScFi shashlik (FEMC)
- Longitudinally separated hadronic calorimeter (LHFCAL)

See Martin Purschke talk at Tuesday at 3:30 PM

Rough Subsytem Count ECCE

- ~ 20 different detector components combined in the 3 parts (backward/forward/central barrel)
- Just a quick overview for reference here (backward/forward), read all about it in the proposal

Topic	Challenge	ECCE solution	Comment
Far-Backward – Low-Q^2 Tagger	Measure low-Q^2 photo-production with as minimal a Q^2-gap as possible.	Spectrometer with AC-LGAD tracking and $PbWO_4$ calorimetry	
Far-Backward – Luminosity Detector	e-ion collision luminosity to better than 1% and relative Luminosity for spin asymmetries to 10^{-4}	Zero Degree Calorimeter with x-ray absorber and e^+/e^- pair spectrometer with AC-LGAD tracking and $PbWO_4$ calorimetry	two complementary detection systems
Far-Forward – B0 Spectrometer	$\eta > 4$ charged particle tracking and γ measurement	Four Si trackers with 10 cm $PbWO_4$ calorimeter	
Far-Forward – Off-momentum Detectors	forward particles (Δ, Λ, Σ, etc) decay product measurement	AC-LGAD detectors	Sensors on one side detect p, on other side p^- from Λ decay; sensors outside beam pipe
Far-Forward – Roman Pots	Detect low-p_T forward-going particles	AC-LGAD detectors	fast timing (~35 ps) removes vertex smearing effects from crab rotation; 10σ from beam
Far-Forward – Zero-degree Calorimeter	Measure forward-going neutrons γ and heavy-ion fission product	FOCAL-type calorimeter with high-precision EM and Hadron Calorimetry	Upgrade option: AC-LGAD layer to capture very high rapidity charged tracks

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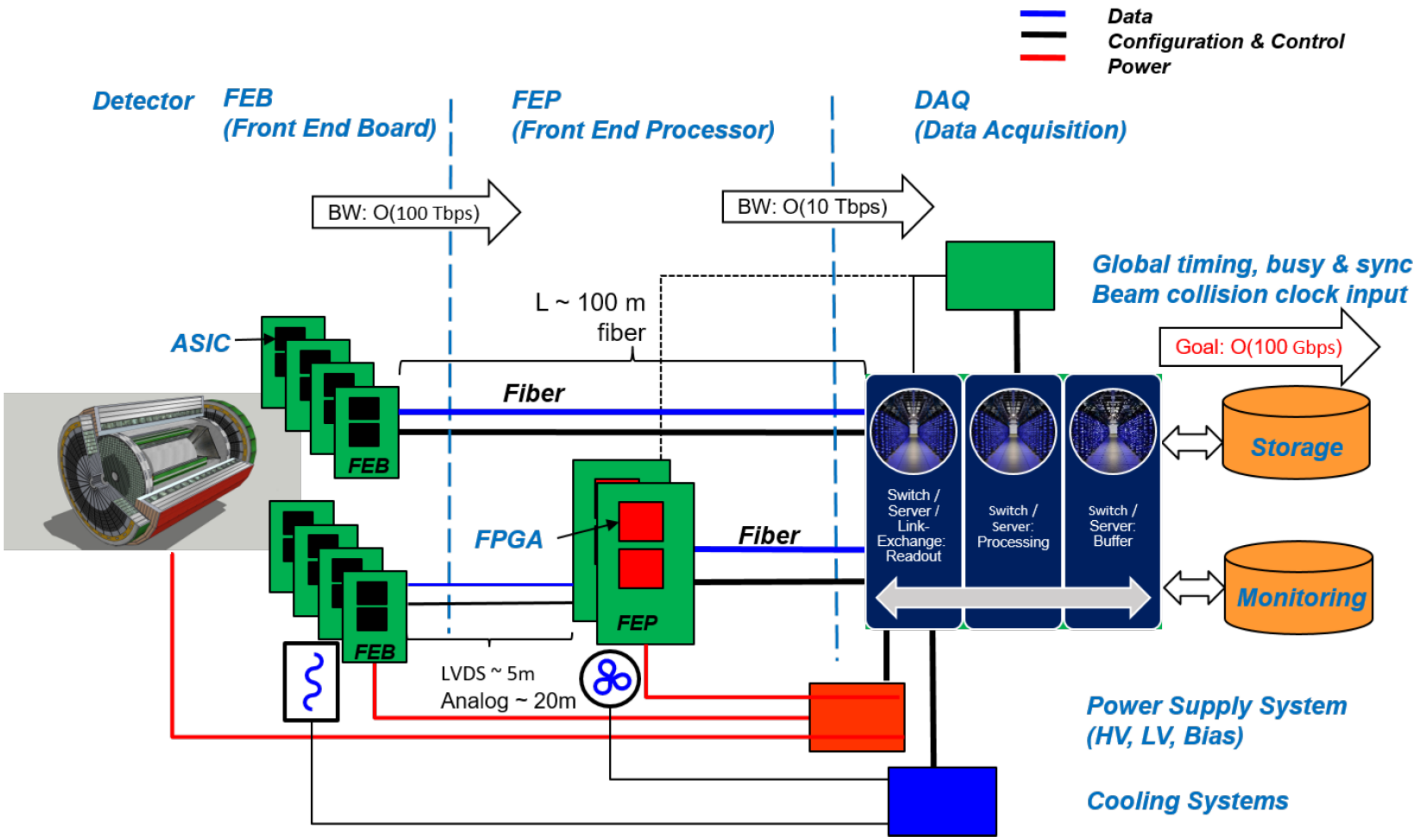
Raw Data Requirements *(estimated)*

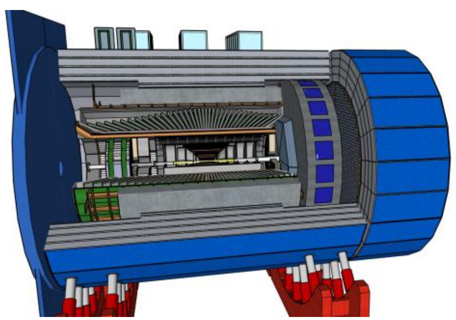
ECCE Runs	year-1	year-2	year-3
Luminosity	$10^{33}\text{cm}^{-2}\text{s}^{-1}$	$2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$	$10^{34}\text{cm}^{-2}\text{s}^{-1}$
Weeks of Running	10	20	30
Operational efficiency	40%	50%	60%
Disk (temporary)	1.2PB	3.0PB	18.1PB
Disk (permanent)	0.4PB	2.4PB	20.6PB
Data Rate to Storage	6.7Gbps	16.7Gbps	100Gbps
Raw Data Storage (no duplicates)	4PB	20PB	181PB
Recon process time/core	5.4s/ev	5.4s/ev	5.4s/ev
Streaming-unpacked event size	33kB	33kB	33kB
Number of events produced	121 billion	605 billion	5,443 billion
Recon Storage	0.4PB	2PB	18PB
CPU-core hours (recon+calib)	191Mcore-hrs	953Mcore-hrs	8,573Mcore-hrs
2020-cores needed to process in 30 weeks	38k	189k	1,701k

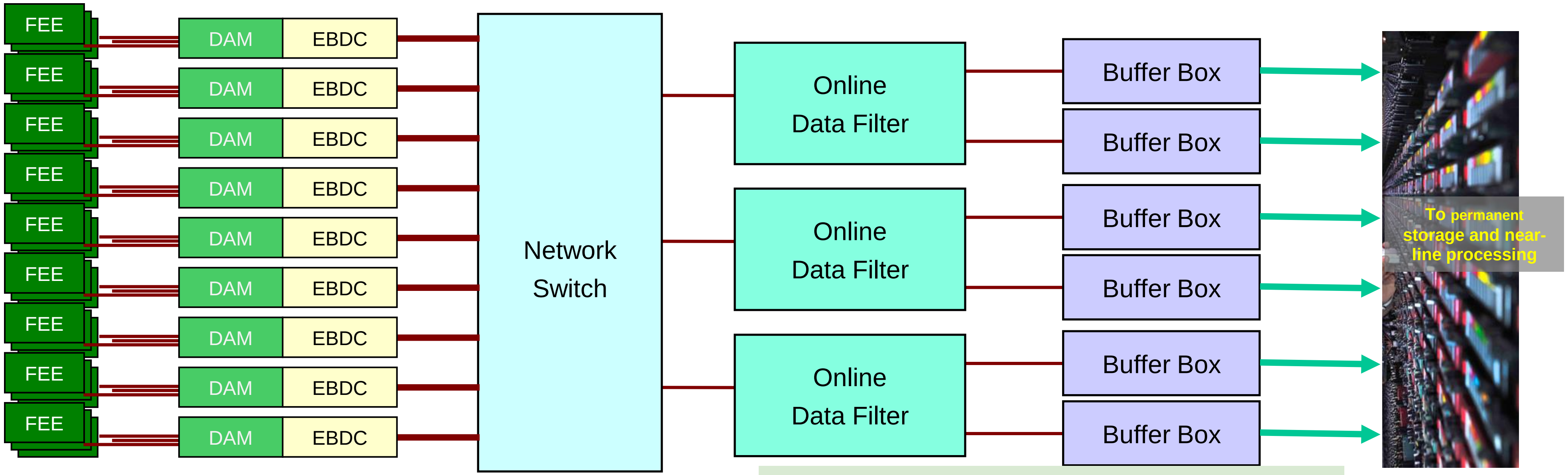
Yellow report streaming DAQ design



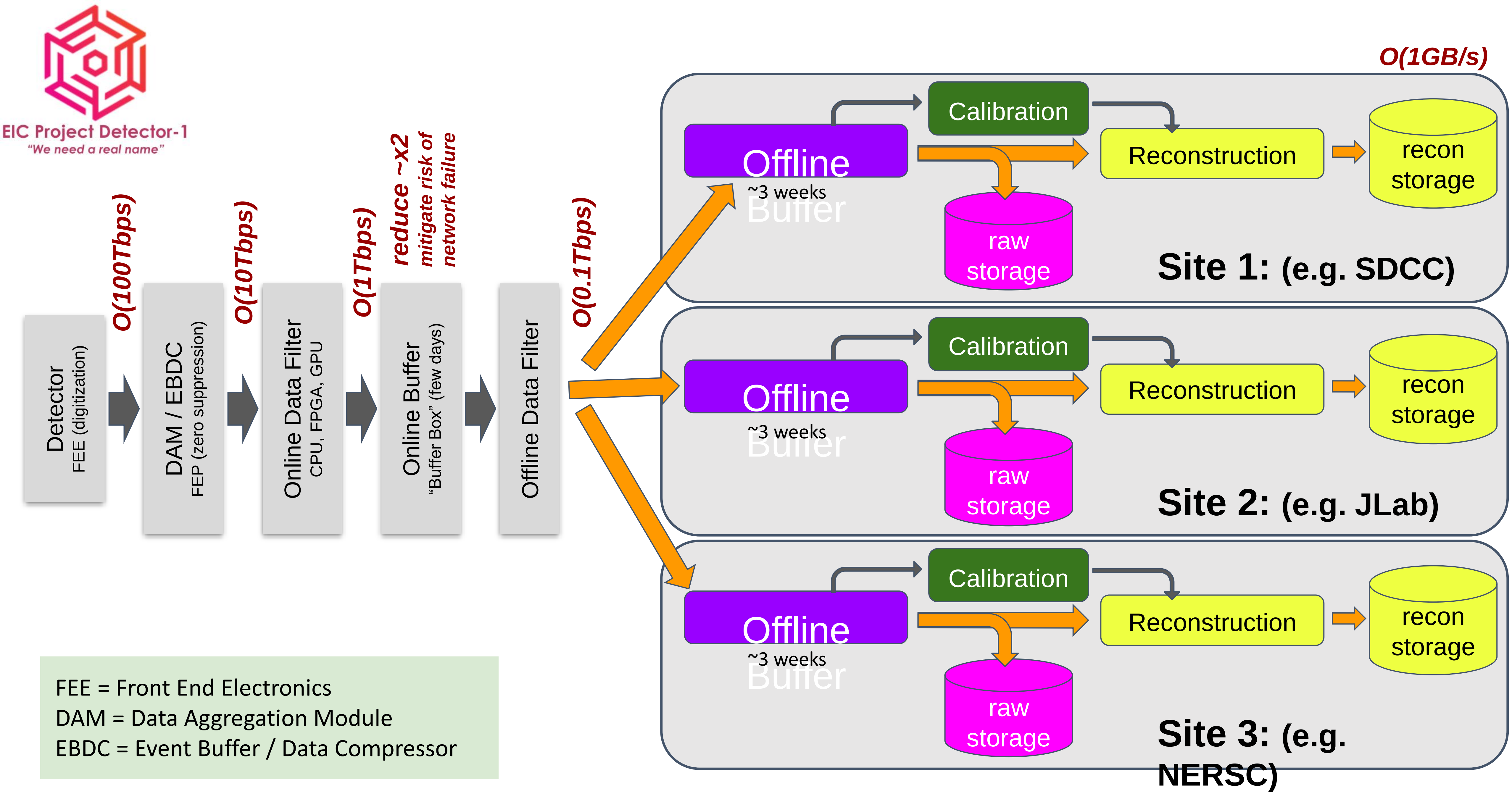
DAQ: Overview

- **Community solidly behind Streaming Data Acquisition System (SRO)**
  - Widely recommended by experts: EIC Computing Consortium, EIC Yellow Report
  - No need to wait for all signals from single crossing to read out data
  - Removes nearly all deadtime
  - Less restrictions for filter criteria and potentially less bias





FEE = Front End Electronics
DAM = Data Aggregation Module
EBDC = Event Buffer / Data Compressor



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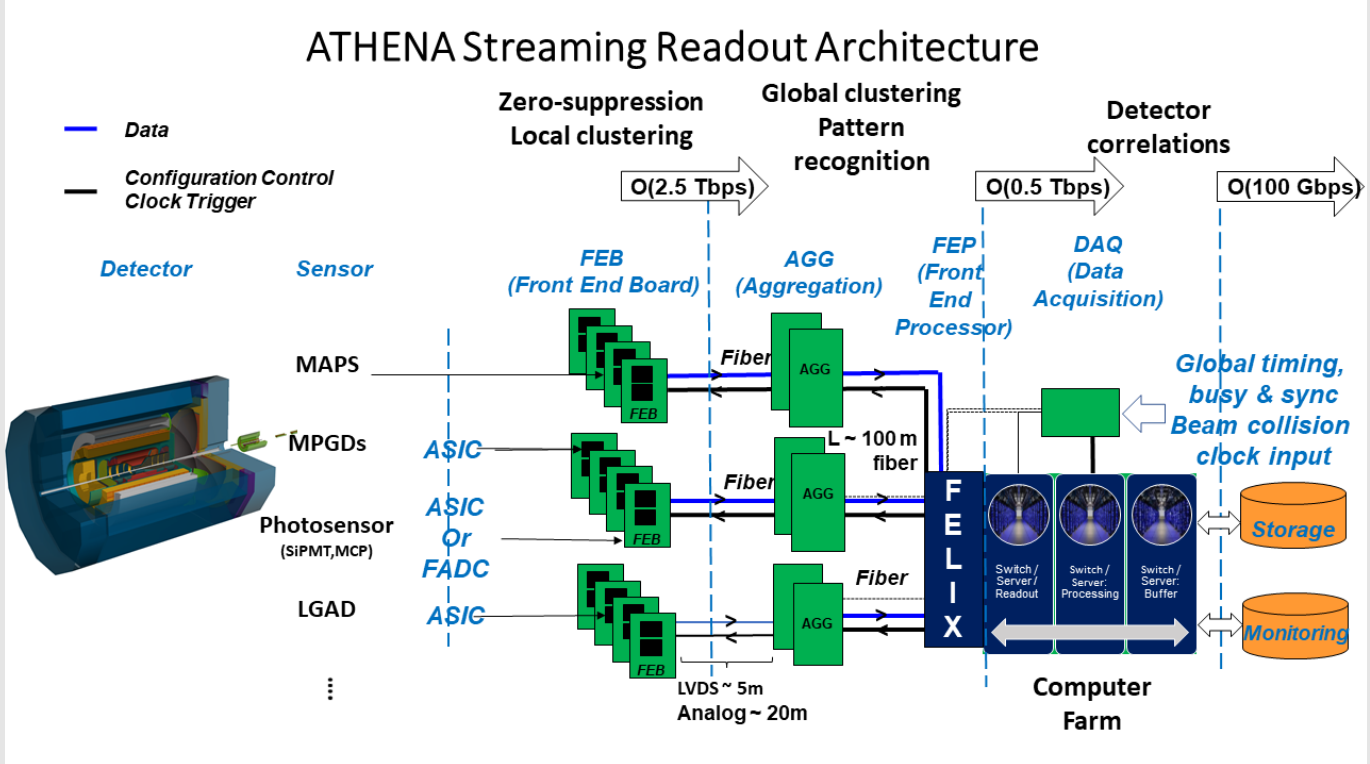
Proposed Athena DAQ



Detector	Number of Channels	Detector Readout Technologies
DIRC	100k	MCP-PMT
DRICH	300k	SiPM *
ERICH	225k	SiPM *
EcalBarrelScFi	4000	SiPM using FPGA based readout boards derived from the STAR DET-ADC board
EcalEndcapN	3080	SiPM
EcalEndcapP	26600	SiPM
EcalImgBarrel	619M	MAPS*
HcalEndcapN	10000	SiPM
HcalEndcapP	2375	SiPM
HcalBarrel	26600	SiPM
Inner Vertex Tracker	60B	MAPS*
MPGDTrackerBarrel	66k	Micromegas
uRWELLTrackerEndcap	50k	uRWELL
GEMTrackerEndcap	28k	GEM
B0Silicon [[2]] [3]	400M	MAPS*
B0preshower	260k	AC-LGAD readout with ALTIROC ASIC
RP	550k	AC-LGAD readout with ALTIROC ASIC
OffM	320k	AC-LGAD readout with ALTIROC ASIC
ffiZDCSi	213k	Silicon strip detectors - DC-LGADs
ffiSDCSciFi	576	PMTs
ZDCSiPb	500k	If silicon used, less if silicon fibers used.
ZDCScint	36-72	PMTs; depends on whether two sections are read-out indepdenently.
TOF	332k	AC-LGAD
Luminosity monitoring and Low Q tagging	4000	6 PMT based calorimeters *

See Jeff Landgraf talk at Tuesday at 3:30 PM

Some Obvious Points

Detector	Channels
RICH	625k
Calorimeters	72k
Imaging Calorimeter (MAPS)	619M
Tracking MAPS	60B
Tracking MPGDs	144k
Far Forward (MAPS)	400M
Far Forward	1100k
Far Backward	4k
TOF	332k
Total MAPS	61B
Total Channels	2.3M

- Assume O(100Gbps) Bandwidth to tape
  - Hit Size ~ 64 bits (24 bits time, 24 bits position, 12 bits, 4 status)
  - 1 Hit / bunch crossing = 6.4Gbps (~5% of bandwidth assumed)
  - At 500Khz, average event size ~25KB (~3.1K hits / event)
- 2.3M channels + 60k MAPS sensors
  - In flux, but currently ~4.5k Fiber reading into ~120 FELIX boards
- Assume O(3.5Tbps) Bandwidth to DAQ computers
  - 2.3M channels + 60k MAPS sensors
    - ~4.5k Fiber reading into ~120 FELIX boards
    - ~ < 1Gbps / fiber (fiber capacity ~6 Gbps)
    - ~ < 25Gbps / FELIX (FELIX bandwidth ~100 Gbps)
- We will need to pay a lot of attention to noisy channels, flaky fibers, and any other potential noise sources

Side by side ATHENA/ECCE

Detector	Readout Technology	Channel Count
Silicon Tracking	Si MAPS	37B
GEM/MMG Layer	GEM	217K
Cylindrical MPGD *	GEM	60M
HP-DIRC	MAP/MT	100-330k
ECAL	SiPM	1.7K
HCAL	SiPM	24K
ECAL imaging	Si MAPS	480M
dRICH	PMT/SiPM	350K
mRICH	PMT/SiPM	330K
B0	Si MAPS	32M + 320K
Off-Momentum	AC-LGAD (eRD24)	750K
Roman Pots	AC-LGAD (eRD24)	500K
ZDC	LGAD + ASIC eRD27	225+366
TOF	AC-LGAD	15M

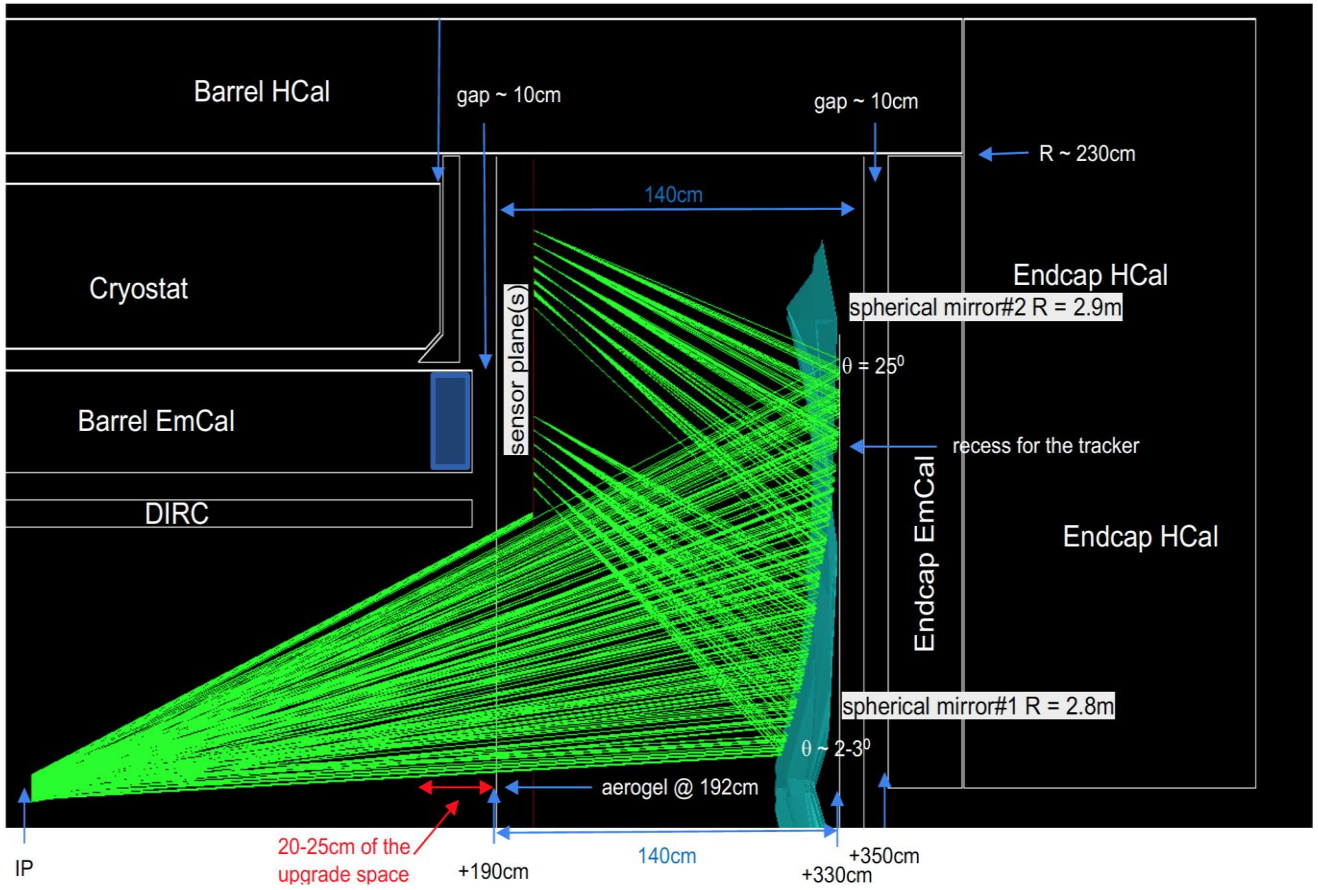
PID WBS Name	Detector	Channels
Barrel PID	hpDIRC	69,632
	TOF	8,600,000
Electron Endcap	mRICH	65,536
	TOF	920,000
Hadron Endcap	dRICH	5,376
	TOF	1,840,000
Far-Forward Detectors	Roman Pots	524,288
	B0 Detector	2.6M
	Off-Momentum Detectors	1.8M
Far-Backward Detectors	Low-Q^2 Tagger	4.6M
	Luminosity Monitor	268,441

Sensor technologies

Detector	Readout Technology candidates
Silicon Tracking	Si MAPS ITS3 like
GEM/MMG Layer	MGPD
Cylindrical MPGD *	MPGD
HP-DIRC	MAP/MT, MCPPMT
ECAL	SiPM
HCAL	SiPM
dRICH	PMT/SiPM
mRICH	PMT/SiPM
B0	Si MAPS ITS3 like (ITS2)
Off-Momentum	AC-LGAD (eRD24)
Roman Pots	AC-LGAD (eRD24)
ZDC	LGAD + ASIC eRD27
TOF	AC-LGAD

Significant SiPM Dark Currents expected in dRICH and pfRICH detectors

- Sensors are inside the 3T magnetic field,
  - SiPM sensors are envisioned.
  - Thresholds must be sensitive to single photons
- Dark Currents at this threshold ~3Khz / channel increasing to ~300Khz / channel after several years after which annealing will be performed
  - Mitigate by ~3 by applying timing window with respect to bunch crossing
  - Read up to 3.3Tbps into the DAQ computers but filter using
    - Software trigger
    - Potentially ML/AI if turns out practical
  - Software trigger reduces dark current volume to ~<15.5Gbps
  - As a potential mitigation the timing system & FELIX could be adopted to supply hardware trigger.



Data Volume Estimates

- Three different approaches, depending on goal
  - Maximum data volume which would change the character of the DAQ
    - dRICH and pfRICH resource limits are defined by worst-case SiPM dark currents
    - Far Backward resource limits are defined by expected data volume, but are low (just 1 FELIX board)
    - All other detectors are currently limited by connections, and have at least an order of magnitude excess rate capability which implies useful flexibility (e.g. disable feature extraction for tests, etc.)
    - Excursions beyond an order of magnitude would change DAQ, but might be addressable by software trigger (or even hybrid trigger system) but must be addressed as changes.
  - Detector Expert Estimates
    - These are the estimates presented in the Athena proposal
    - Physics estimates not uniform (yellow report, CDR, extrapolation from simulations for physics)
    - Estimates include engineer knowledge about likely detector issues.
  - Full simulations of proton beam gas, electron beam gas, synchrotron radiation and collisions.
    - These came together at the very end of the proposal process
    - Include detector response thresholds / instrumentation, but not fully simulated sensor response. Assume translation between hits→data volume

Detector Expert Estimates of data volumes

Detector	Channels	DAQ Input(Gbps)	DAQ Output(Gbps)
B0 Si	400M	<1	<1
B0 ac-lgad	500k	<1	<1
RP+Offm+ZDC	700k	<1	<1
FB Cal	4k	80	1
eCal	34k	5	5
hCal	39k	5.5	5.5
imCal	619M	4	4
Si Tracking	60B	5	5
Micromegas Tracking	66k	2.6	.6
GEM Tracking	28k	2.4	.5
uRWELL Tracking	50k	2.4	.5
dRICH	300k	1830	14
pfRICH	225k	1380	12
DIRC	100k	11	11
TOF	332k	3	.8
Totals		3400	61

Far forward detectors have low acceptance

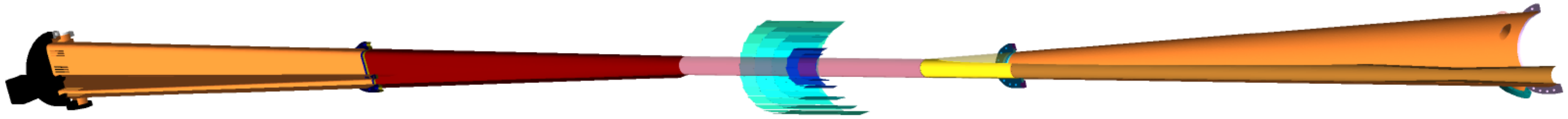
Far backward do low Q tagging and Luminosity measurements but have high signal rate due to bremsstrahlung. The data is used primarily for histogramming, but also have subset that will be readout in concert with central detector collisions

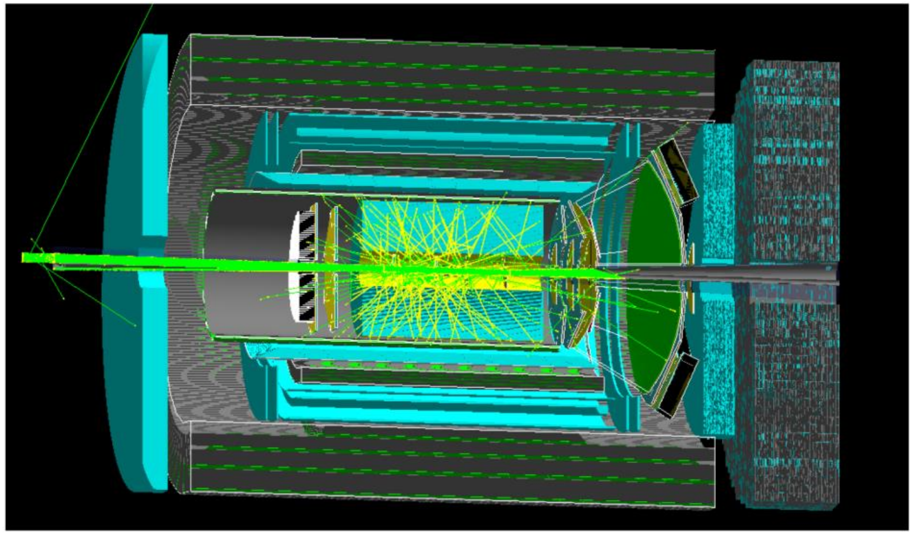
Calorimeters with SiPM readout have higher thresholds and time-clustering in FEE

MAPS have enormous numbers of very quiet pixels. Also, they read out over 100-200ns time (<< 2us)

dRICH/pfRICH subject to SiPM dark currents

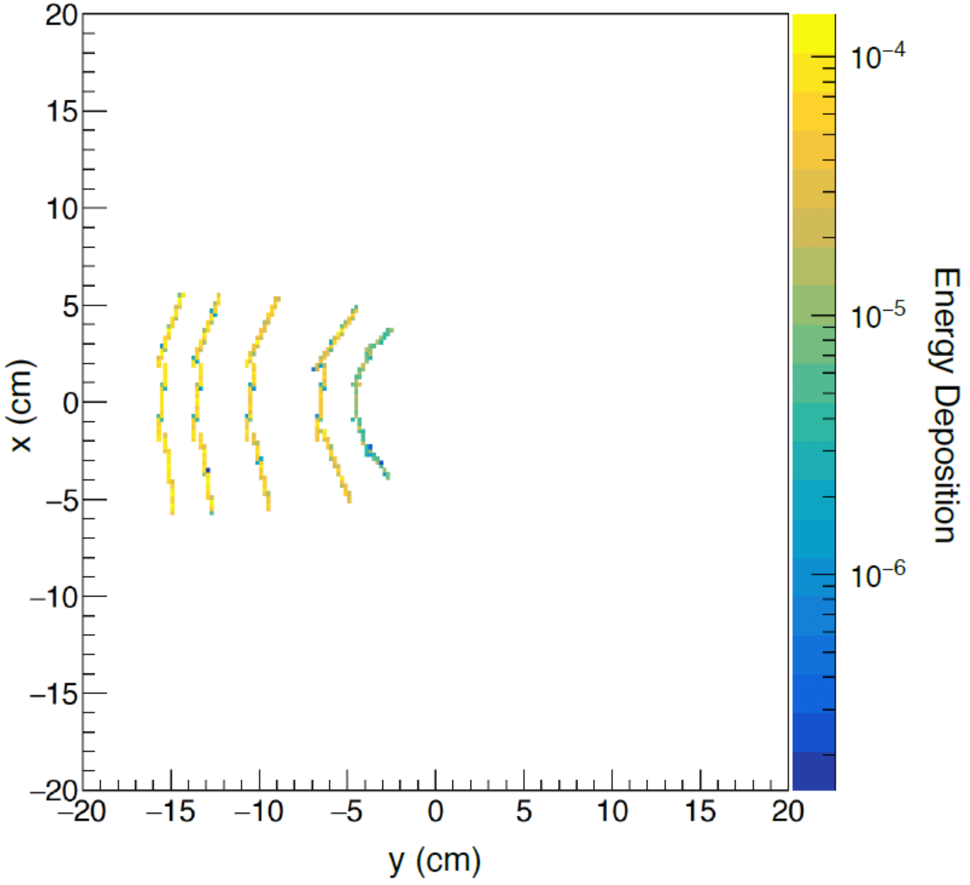
Synchrotron radiation studies from YR

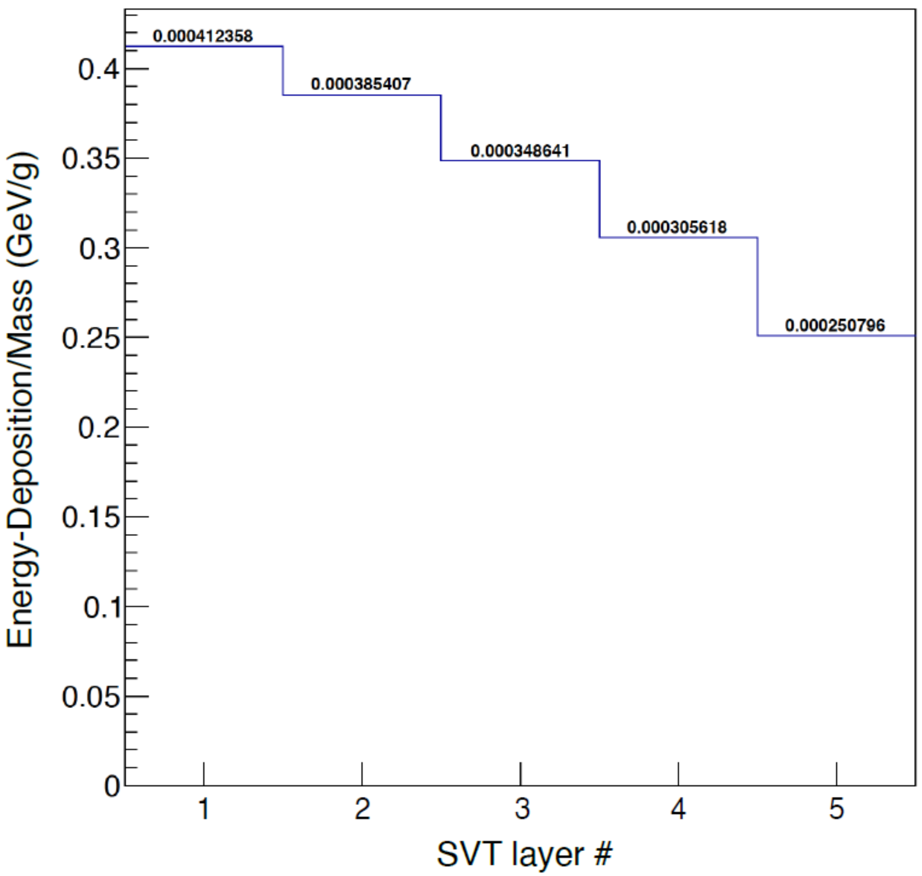




YR Geant4 simulation using synchrotron radiation input files from Synrad

Synchrotron radiation in trackers

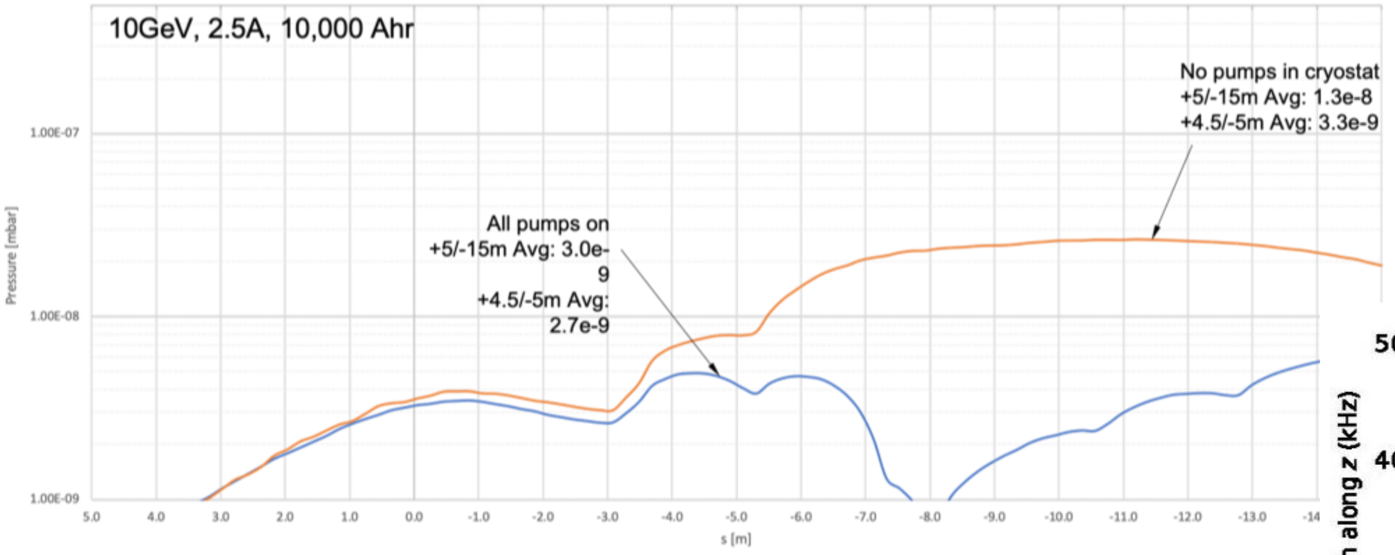




Energy deposit in 5 layers silicon vertex tracker

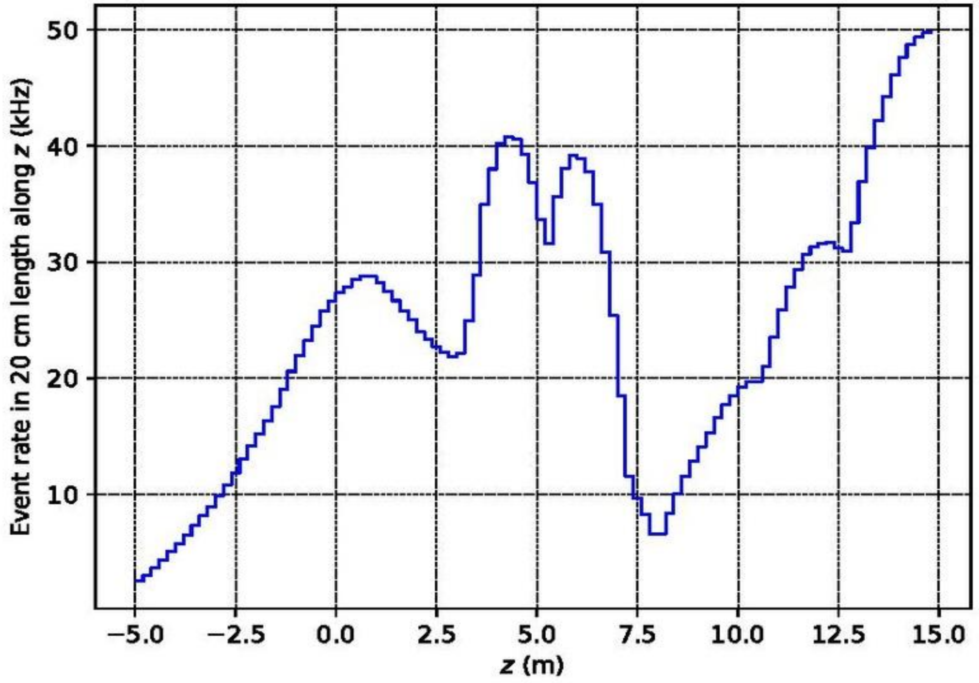
Beam Gas & Synchrotron Radiation Simulations

(Elke Aschenauer, Adam Jaroslav, Zhengqiao Zhang, Deepak Samual, Reynier Cruz Torres)



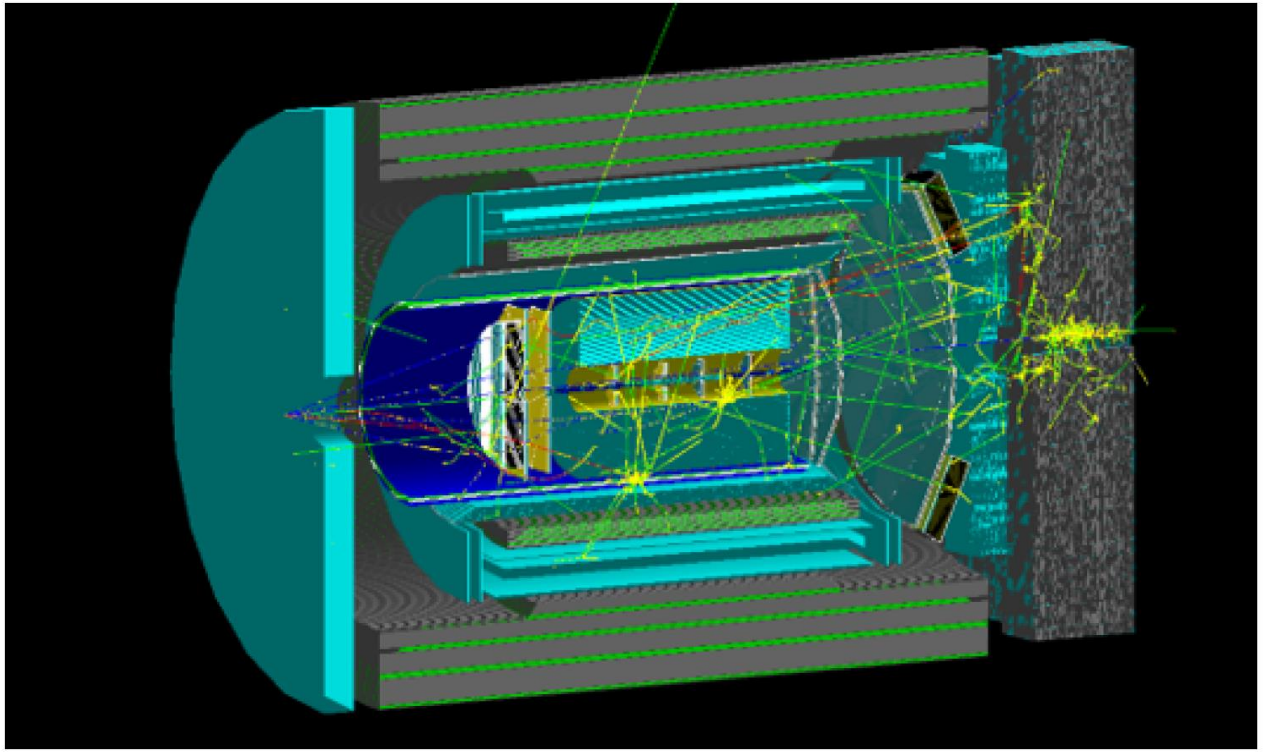
Vacuum

“For all simulations, physics, detector performance and backgrounds, it is very important to simulate all the different beam effects, like crossing angle, divergence…”

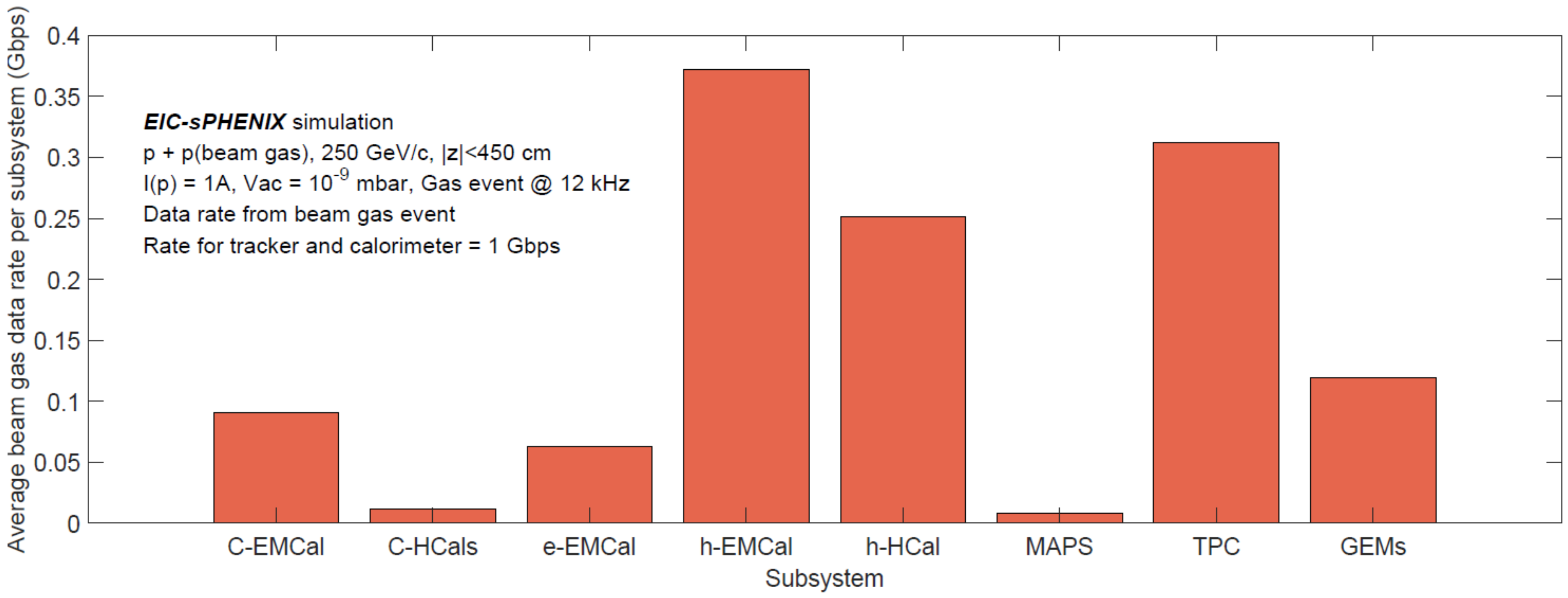


Electron Beam Gas Production

Beam Gas from YR



Beam gas data rates from YR

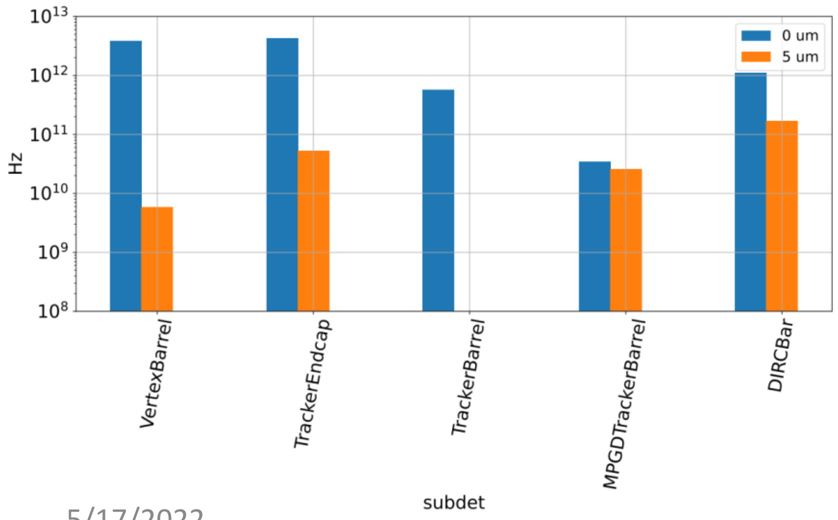


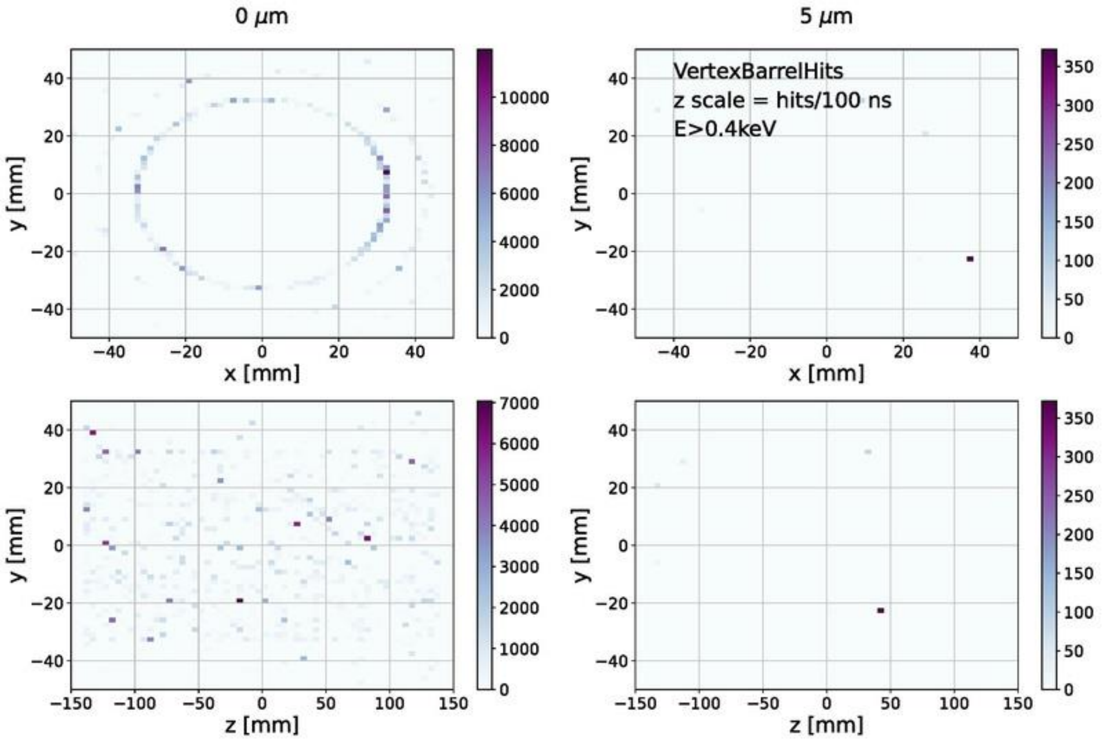
Beam Gas & Synchrotron Radiation Simulations

(Elke Aschenauer, Adam Jaroslav, Zhengqiao Zhang, Deepak Samual, Reynier Cruz Torres)

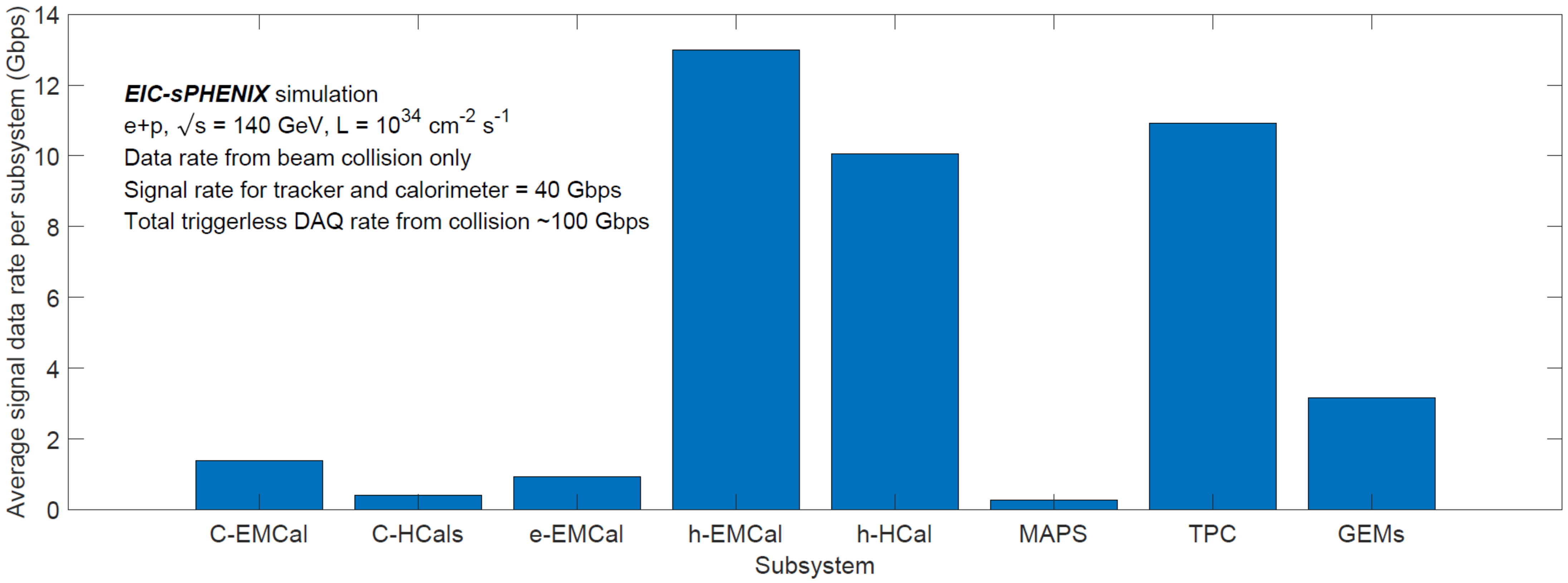
Synchrotron Radiation

- Studied effect of 5 um gold coating on beam pipe.
- Did not translate these to data volumes because misleadingly high
    - Weighted Montecarlo statistics too low.
    - Thresholds set at assumed minimum detector sensibility, not by desired zero-suppression threshold (used .2KeV for MPGD, .4KeV for MAPS)

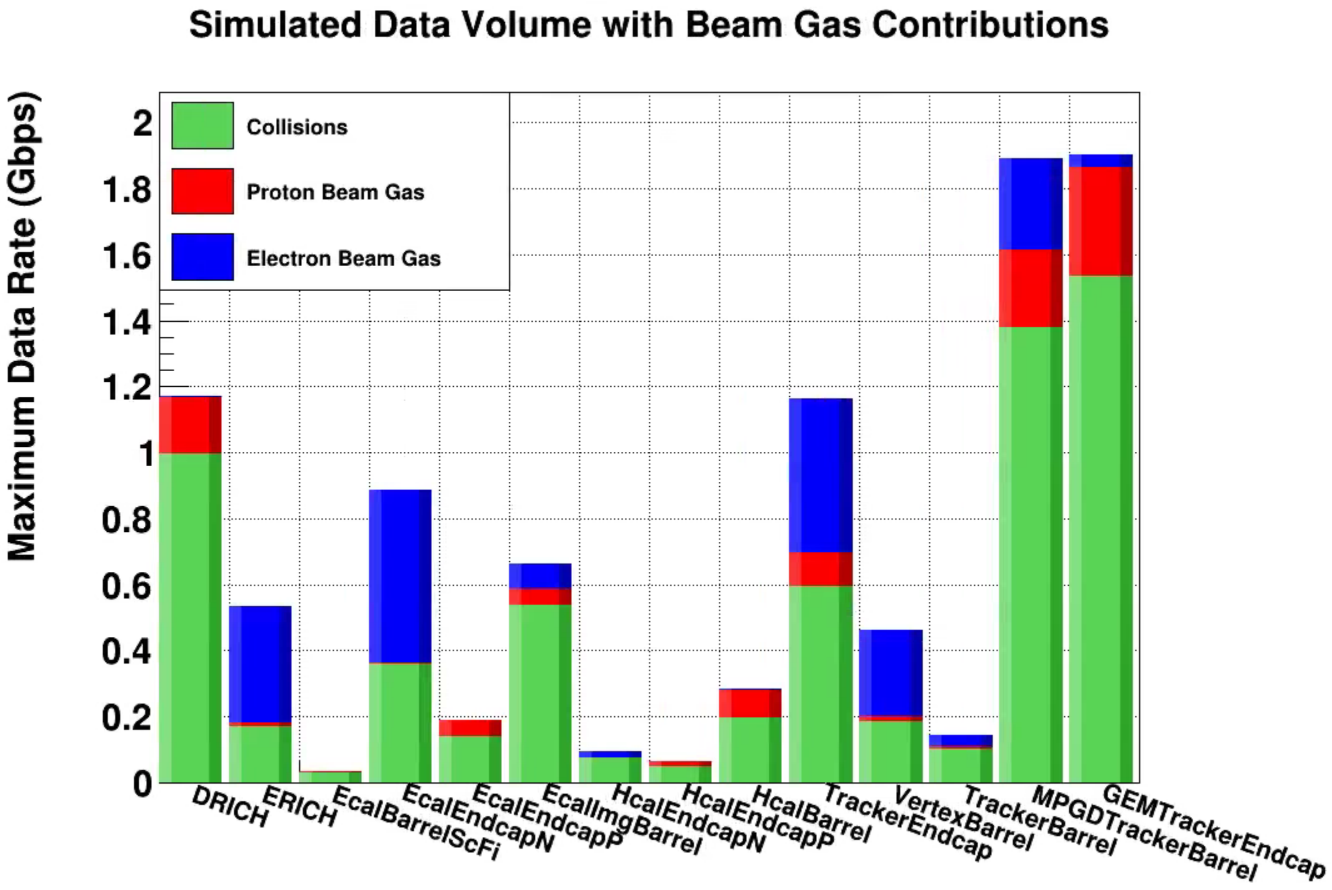




Data rates from YR



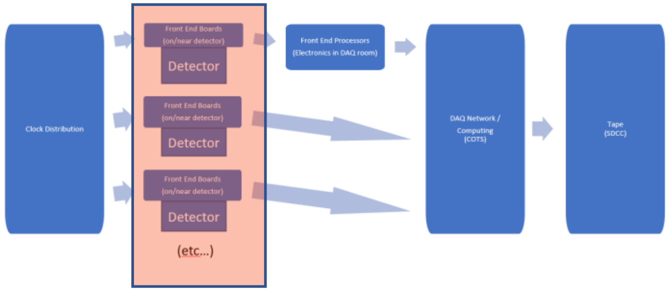
Simulated Data Rates for ATHENA



Group as per detector expert table and compare

Detector	Channels	DAQ Input(Gbps)	DAQ Output(Gbps)	DAQ Output (Sim Collision + Beam Gas)
B0 Si	400M	<1	<1	-
B0 ac-lgad	500k	<1	<1	-
RP+Offm+ZDC	700k	<1	<1	-
FB Cal	4k	80	1	[1]
eCal	34k	5	5	1.2
hCal	39k	5.5	5.5	.45
imCal	619M	4	4	.7
Si Tracking	60B	5	5	1.8
Micromegas Tracking	66k	2.6	.6	1.9
GEM Tracking	28k	2.4	.5	1.9
uRWELL Tracking	50k	2.4	.5	-
dRICH	300k	1830	14	1.2
pfRICH	225k	1380	12	.55
DIRC	100k	11	11	[1.2]
TOF	332k	3	.8	[3.5]
Totals		3400	61	13.4

Front End Boards (FEB)



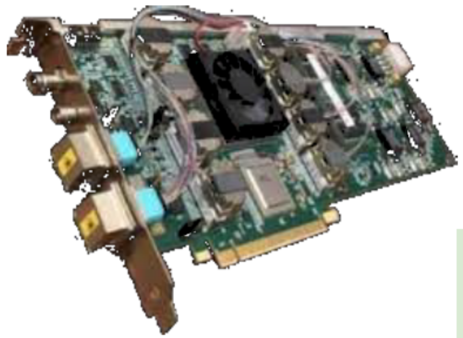
- The collider performance:
  - ~500KHz of collisions
  - ~60-100Gbps zero suppressed data
  - ~15 KB/event
  - ~100 bytes/bunch crossing
- We have an enormous number of channels but the Silicon MAPS readouts test the relevance of the concept of channel.
- Challenging data compression scheme
  - Noise reduction
  - Zero suppression
  - Background elimination

Detector	Readout Technology	Channel Count
Silicon Tracking	Si MAPS	37B
GEM/MMG Layer	GEM	217K
Cylindrical MPGD *	GEM	60M
HP-DIRC	MAP/MT	100-330k
ECAL	SiPM	1.7K
HCAL	SiPM	24K
ECAL imaging	Si MAPS	480M
dRICH	PMT/SiPM	350K
mRICH	PMT/SiPM	330K
B0	Si MAPS	32M + 320K
Off-Momentum	AC-LGAD (eRD24)	750K
Roman Pots	AC-LGAD (eRD24)	500K
ZDC	LGAD + ASIC eRD27	225+366
TOF	AC-LGAD	15M

DAM Boards

Detector system	DAM boards	Channel/Fiber Count
Barrel		
Si Tracker	4	100 fibers
uRWell	12	278,000 channels, 576 fibers
AC-LGAD TOF	30	1400 fibers
hpDIRC	5	200 fibers
BECAL	2	9,088 channels , 72 fibers
iHCAL + oHCAL	1	3,264 channels, 26 fibers
Forward		
AC-LGAD TOF	6	300 fibers
dRICH	5	220 fibers
FEMC	8	47,850 channels, 375 fibers
LFHCAL	10	58,590 channels, 460 fibers
Backwards		
mRICH	7	288 fibers
AC-LGAD TOF	3	150 fibers
EEMC	1	2878 channels, 24 fibers
Far-Forward		
B0 Detector, Roman Pots, Off-Momentum Detectors, ZDC	26	7.4M
Far-Backward		
Luminosity Monitor & Low-Q^2 Tagger	18	4.9M
Sum	**138**	

- Transition data to COTS Computing
- Built-in FPGA provides processing/Data aggregation



ATLAS FELIX board is an example of a DAM board

COTS = Commercial Off The Shelf
DAM = Data Aggregation Module

Time of flight requirements

- DIRC requires 100 ps but could benefit from 50 ps
- TOF AC-LGAD based could reach timing resolution down to 25 ps

- Dedicated timing for ensuring at least 10 ps resolution from clock distribution

- Achieved at CERN

DAQ: Timing System

- Each beam crossing identified with unique 64-bit value
- Communicated to DAM boards which distribute to FEE
  - Data transferred at multiple of accelerator clock (e.g. x6)
    - 16bits per transfer *(16x6 = 96bits/crossing)*
  - Additional data embedded across transfers
    - “mode” bits can indicate different actions to FEE
  - Crossing number used to stamp all data from front end
    - Specifics of timing will be detector dependent
  - System modeled after working sPHENIX system

FEE = Front End Electronics
DAM = Data Aggregation Module

sPHENIX Prototype Timing Board

sPHENIX ZCU102 Timing module

Integration of the DAQ with detector

- Choice of technologies and readout method can affect the detector performance some compromise might need to be found
  - Examples
    - More fibers is better in terms of bandwidth but space limitation for services can constrain fiber counts
    - FADCs are ideal for streaming DAQ but use more power so can optimize number of bits, sampling rate to reduce power consumption

To do

- When detector configuration finalized
- Simulation with overlay of physics signal, physics background, beam backgrounds (synchrotron, beam gas, halo), sensor noise, electronics noise
- Run through zero suppression algorithm : thresholds, time or amplitude clustering , AI/ML algorithm
- Get expected data rates
- Do detector reconstruction : check accuracy and efficiencies

Conclusion

- Detector rates and occupancies of EIC detector makes it an ideal case for streaming readout
- Detector 1 was chosen with ECCE detector as starting point, some optimization of ECCE detector working with ATHENA collaborators
- Detector can be design with streaming in mind
- Singles rates need to be evaluated carefully, background eliminated as early as possible
- Noisy detectors such as SiPMT could pose a bit of challenge because of amount of data but after processing expect similar results as triggered
- EIC can take full advantage of streaming readout and AIML for quick turn around of cablibration and physics
- DAQ well integrated in analysis software (see next talk)