Streaming DAQ Rate Requirement

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Thanks to the inputs from many colleagues!

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	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**

- EIC luminosity is high, but collision cross section is small ($\propto \alpha_{EM}^2$) → low collision rate
- But events are precious and have diverse topology → hard to trigger on all process
- Background and systematic control is crucial → avoiding a trigger bias

EIC x-sec : further quantification [Courtesy E. Aschenauer]

- Inelastic e+p scattering x-sec:
  - For a luminosity of 10^{34} $cm^{-2}s^{-1}$ 50ub corresponds to **500 kHz**
- Elastic e+p cross-section:
  - For EIC central barrel, elastic cross section is **small** comparing to the inclusive QCD processes
- Beam gas interaction:
  - Beam proton – beam gas fix target inelastic interactions. The pp elastic cross section is smaller (~7 mb)
  - For a vacuum of 10^{-9} mbar in the detector volume (10m) this gives a rate of **14 kHz**

Beam [GeV]	HERA	5 x 50	10 x 100	18 x 275
$Q^2>10^{-9}$ GeV	65.6	**29.9**	**41.4**	**54.3 ub**
$Q^2>1$ GeV	1.29	0.45	0.65	0.94 ub

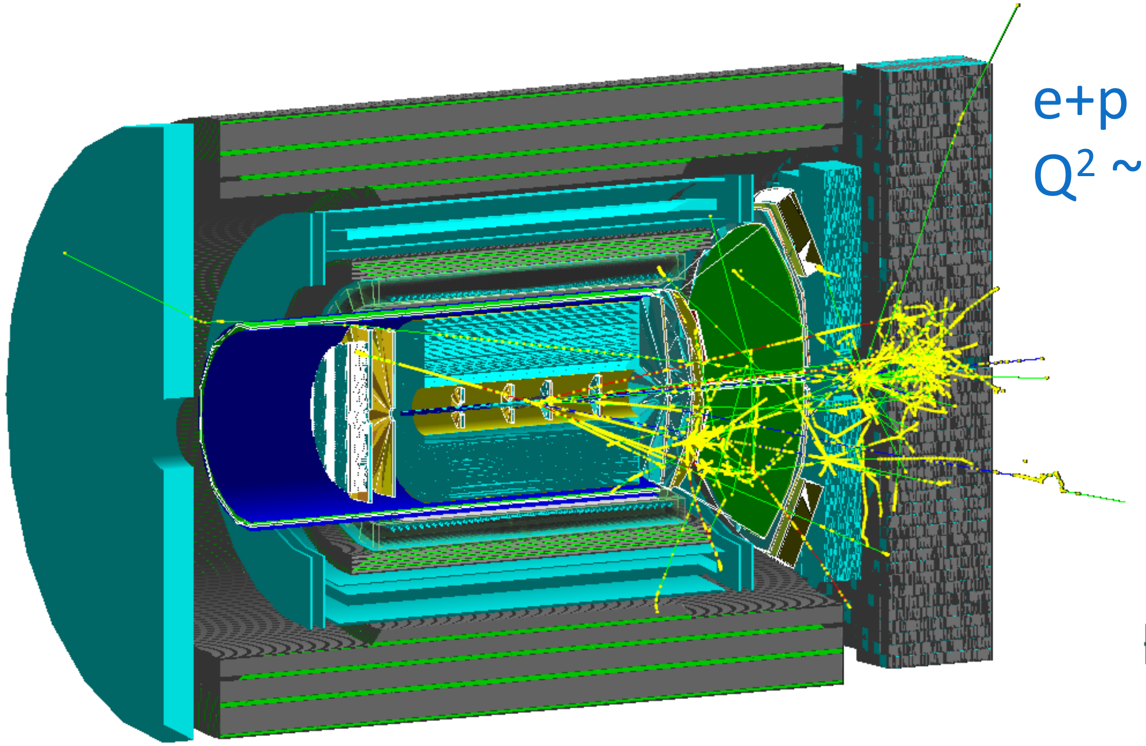
Beam [GeV]	HERA	5 x 50	10 x 100	18 x 275
σ [y_{Exp} >-4]	5 pb	**5 ub**	**0.7 ub**	**0.06 ub**
σ [y_{Exp} >-6]	11 ub	420 ub	100 ub	29 ub

E_p:	50 GeV	100 GeV	275 GeV	920 GeV
	38.4 mb	**38.4 mb**	**39.4 mb**	41.8 mb

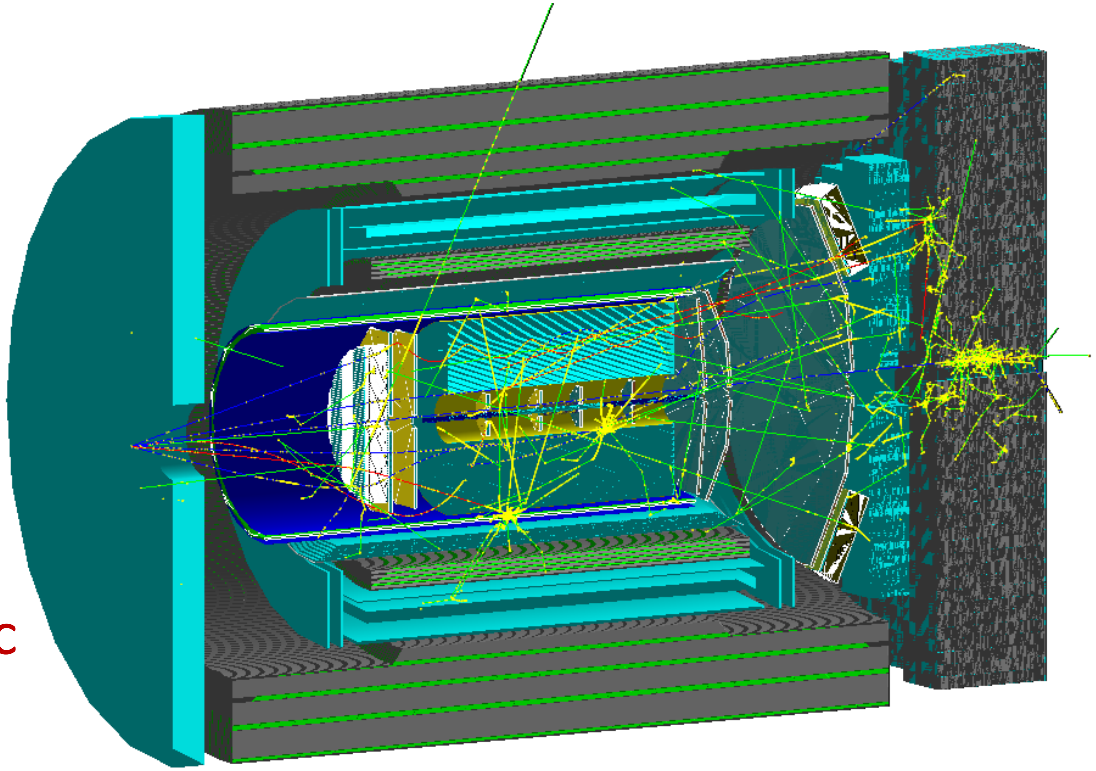
EIC DAQ in Geant4 simulation

Refs: sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/

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



Data Rate

e+p, Pythia6 Q2>0

p+p(gas) Pythia8

MAPS silicon tracker

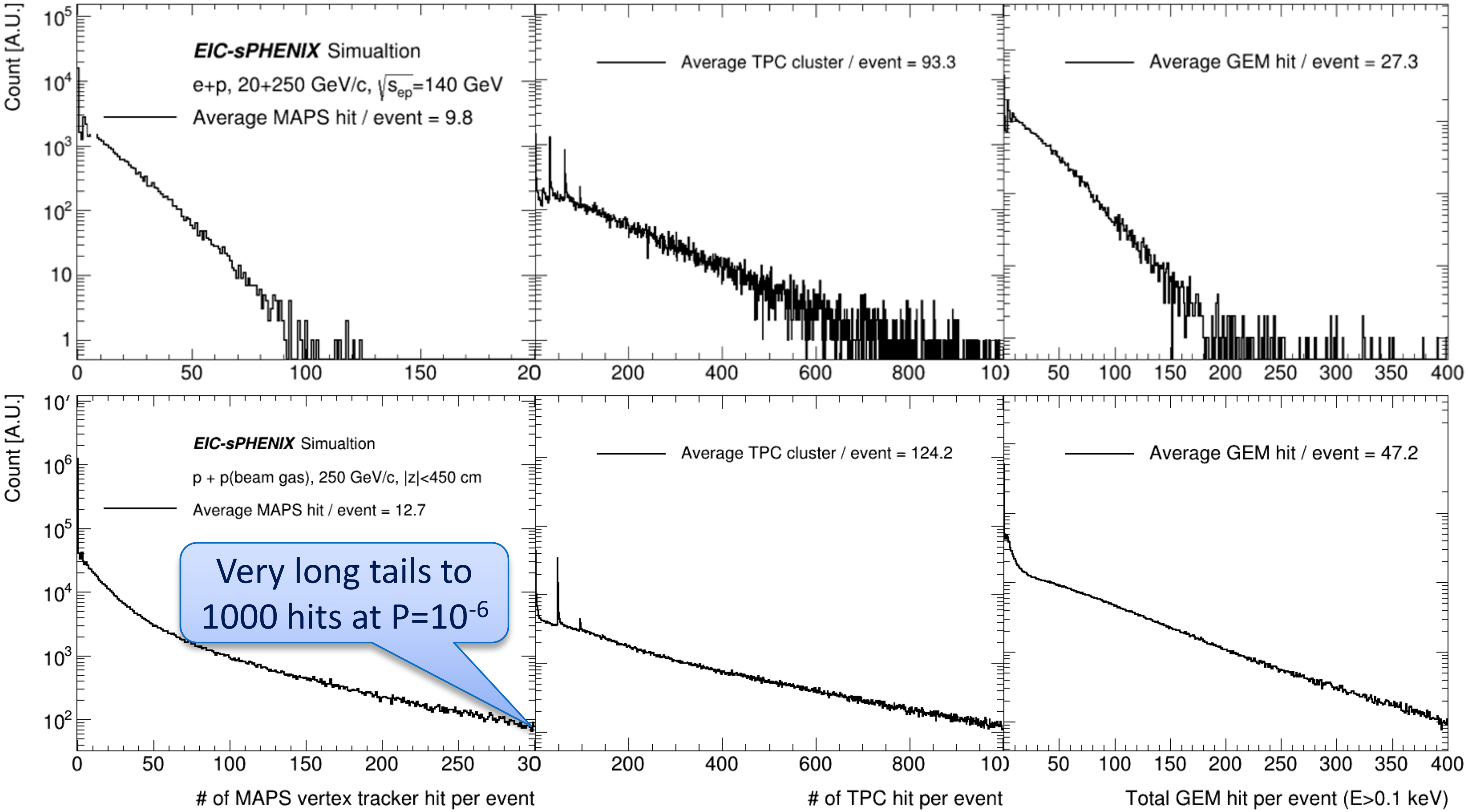
Raw data: 16-24 bit / MAPS hit (3-layer ALPIDE model)

TPC

Raw data: 3x5 10 bit / TPC hit + headers (60 bits)

Forward/backward GEM

Raw data: 3x5 10 bit / GEM hit + headers (60 bits)

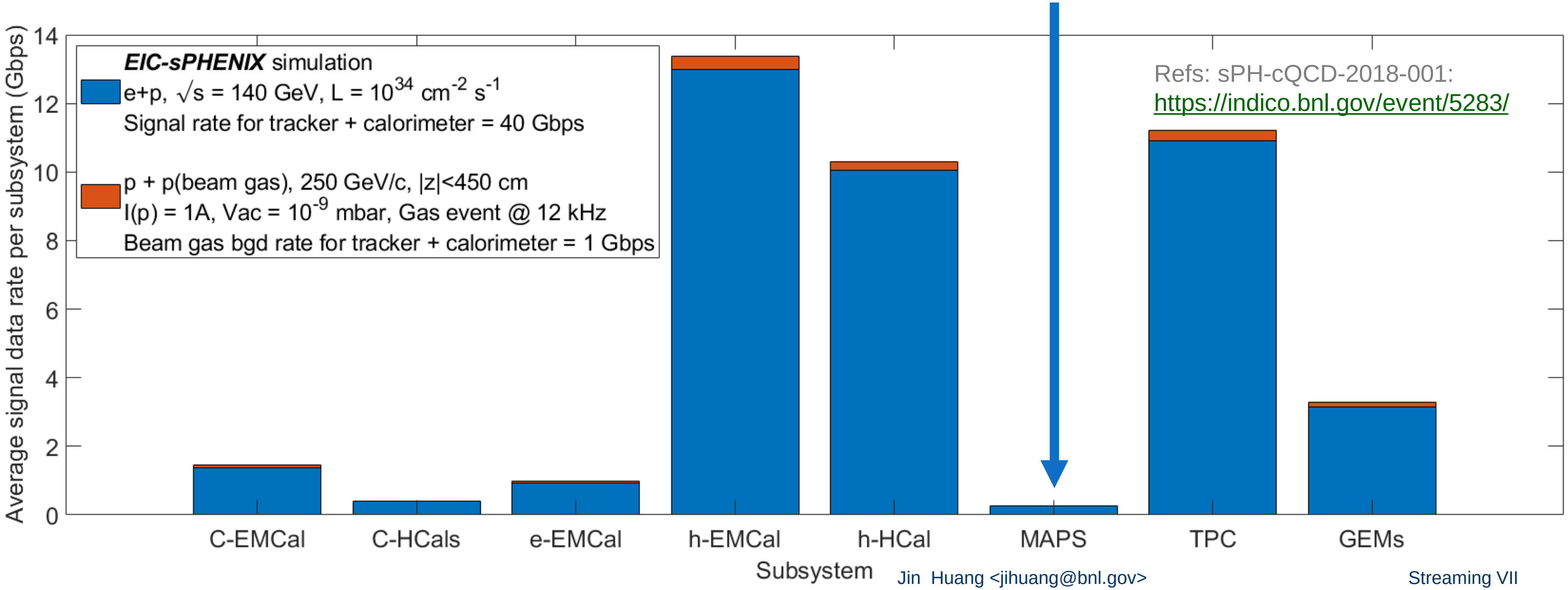


Very long tails to 1000 hits at $P=10^{-6}$

Refs: sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/

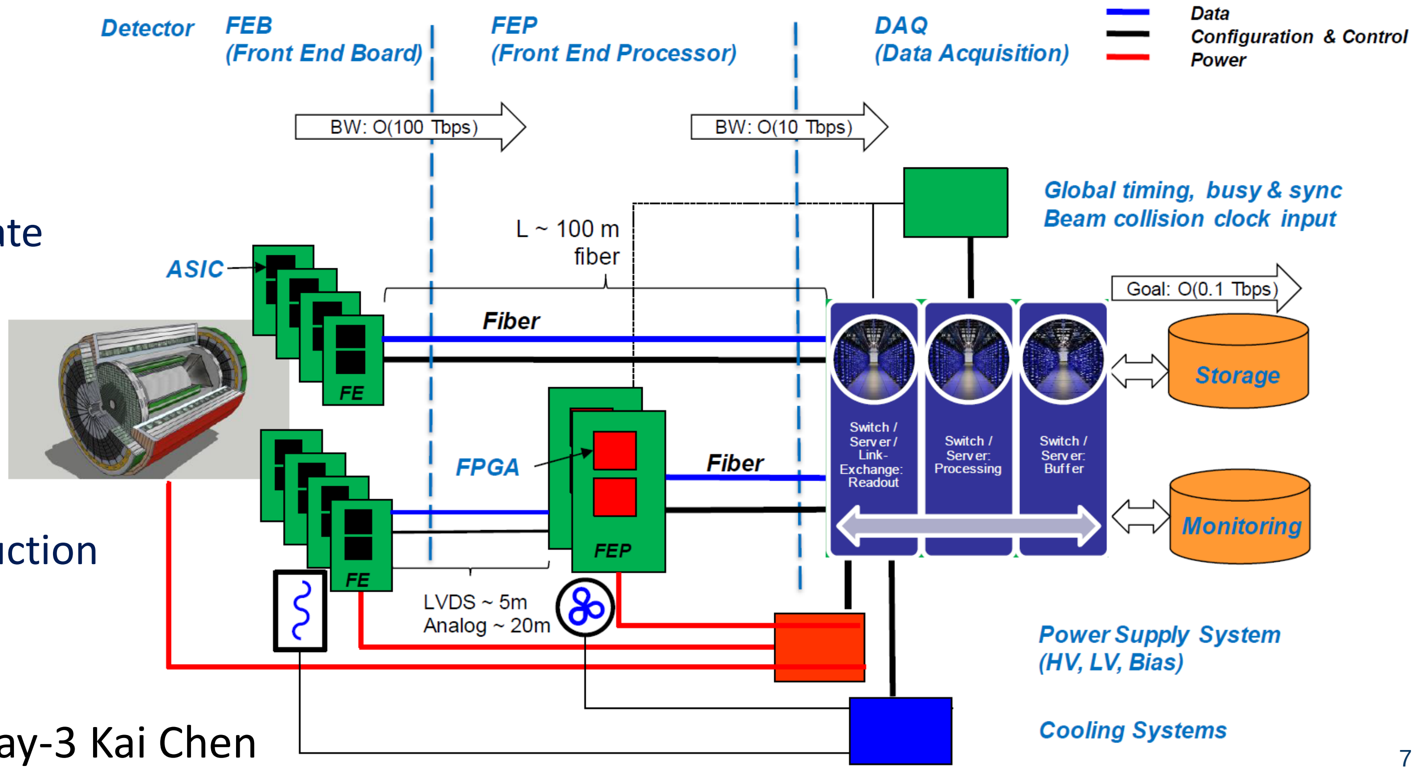
Signal data rate -> DAQ strategy

- 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)
- Collision induced signal data from barrel silicon tracker is very moderate, but important considerations on additional rates from detector noise, synchrotron radiation and photon production rates (later slides)



Strategy for an EIC real-time system

- For the signal data rate from EIC (100 Gbps, link), we can aim for filtering-out from background and streaming all collision 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
  - Aiming at 500kHz event rate, multi-μs-integration detectors would require streaming, e.g. TPC, MAPS
- **EIC streaming DAQ**
  - → Triggerless readout front-end (buffer length : μs)
  - → DAQ interface to commodity computing (e.g. FELIX/CRU). Background filter if excessive background rate
  - → Disk/tape storage of streaming time-framed zero-suppressed raw data (buffer length : s)
  - → Online monitoring and calibration (latency : minutes)
  - → Final Collision event tagging in offline production (latency : days+)



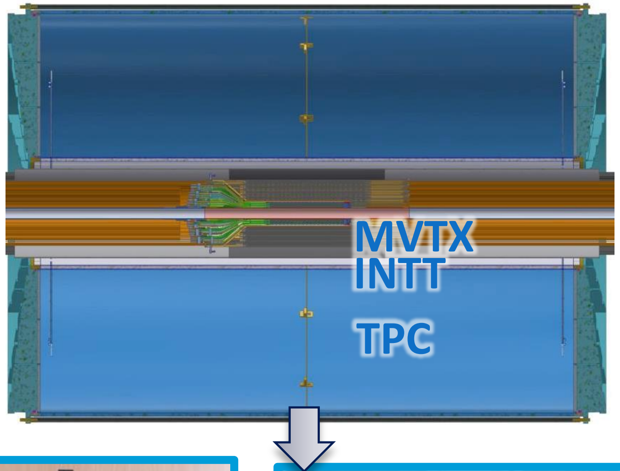
Ref: EIC-CDR, See also Day-3 Kai Chen

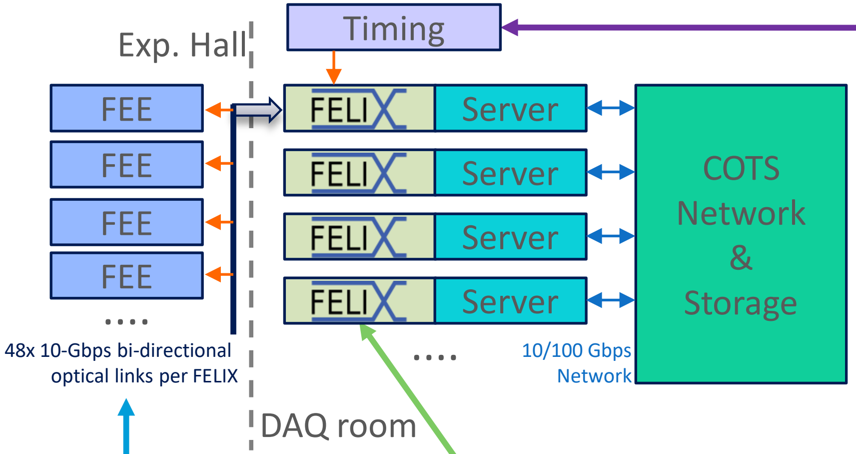
Large-scale streaming readout towards EIC

- CRU/FELIX-based large-scale streaming DAQ application in ALICE, LHCb, sPHENIX and CBM [See also Day-3]
- Other streaming data model as in CLAS-12, Hall-D, Compass++ [See also Day-3]

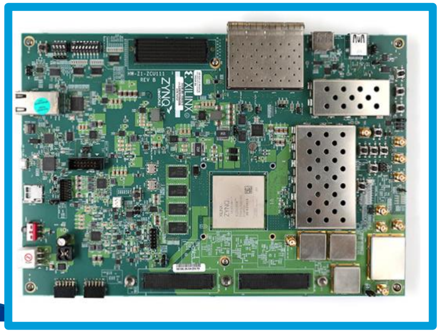
sPHENIX streaming DAQ for tracker

Precision timing digitizer
DRS4GlO (SBIR/LDRD)

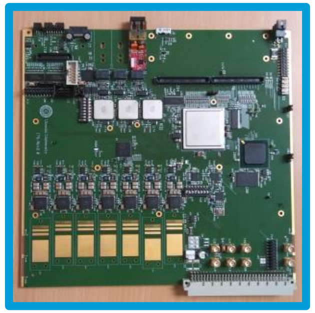




Global Timing Module
(NSLS II/sPHENIX)
To test with RHIC RF low glitter clock source



High density multiplexer+ ADC
RFSoC Digitizer (LDRD)



MVTX RU, 200M ch

INTT ROC, 400k ch

ALPIDE (ALICE/sPHENIX), FPHX (PHENIX)

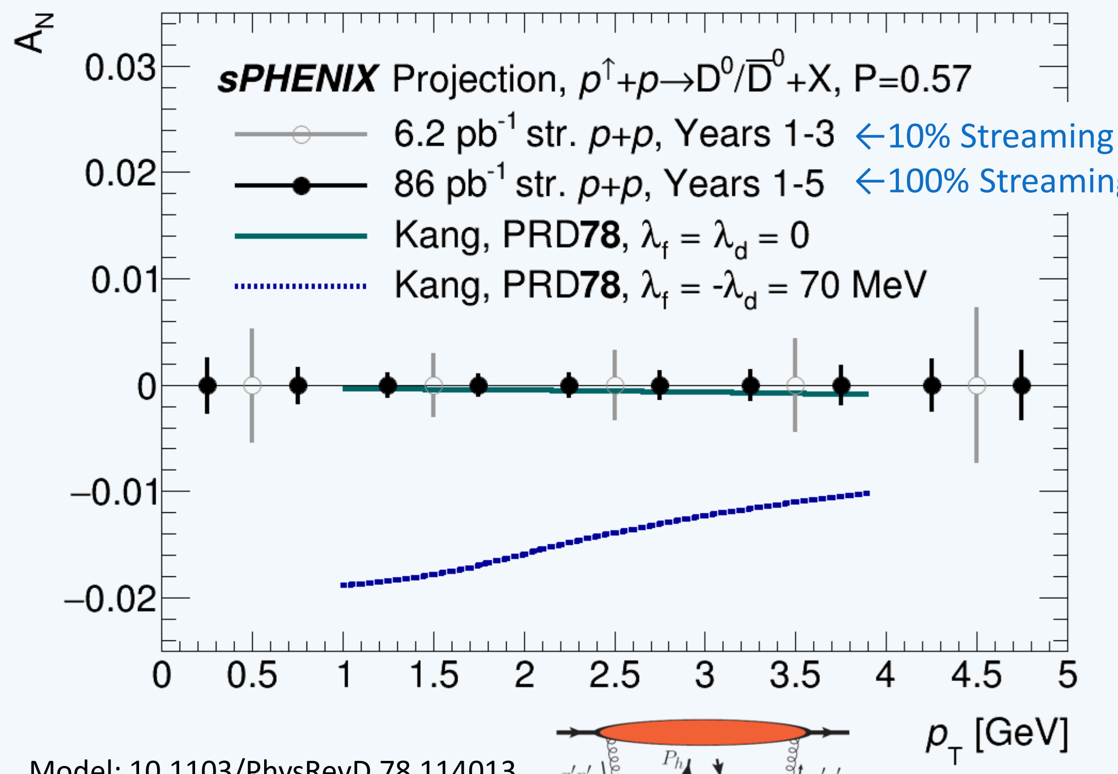
TPC FEE, 160k ch
SAMPAv5 (ALICE/sPHENIX)

BNL-712 / FELIX v2 x48 (ATLAS/sPHENIX)

Streaming-DAQ enabled scientific connection: Gluon dynamics via heavy flavor A_N

Universality test on gluon Sievers

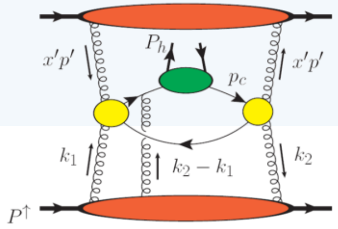
sPHENIX D^0 trans. spin asymmetry, $A_N \rightarrow$ Gluon Sievers via tri-g cor.



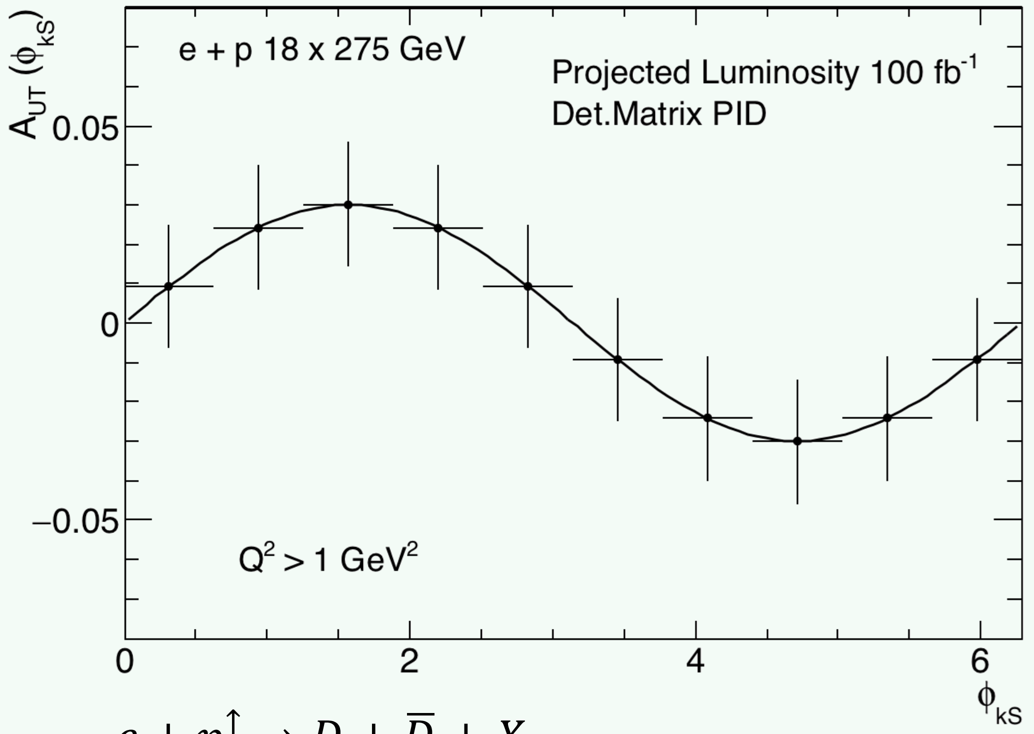
←10% Streaming DAQ

←100% Streaming DAQ

Model: 10.1103/PhysRevD.78.114013



EIC SIDIS D^0 transverse spin asymmetry → Gluon Sievers



$e + p^{\uparrow} \rightarrow D + \overline{D} + X$

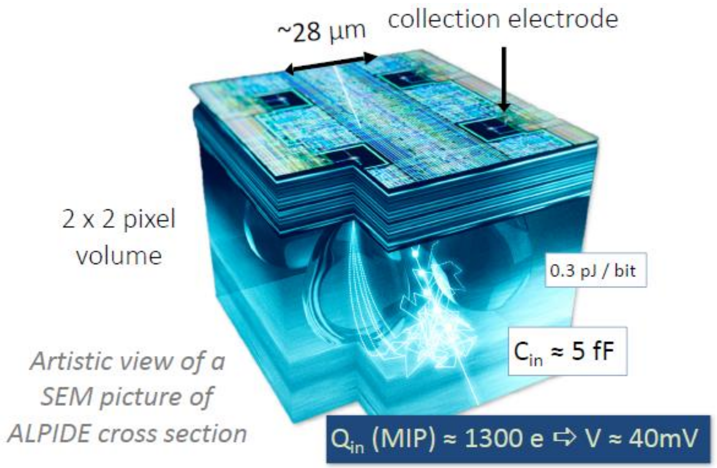
[CNFS HF@EIC workshop, Nov 4-6, 2020]

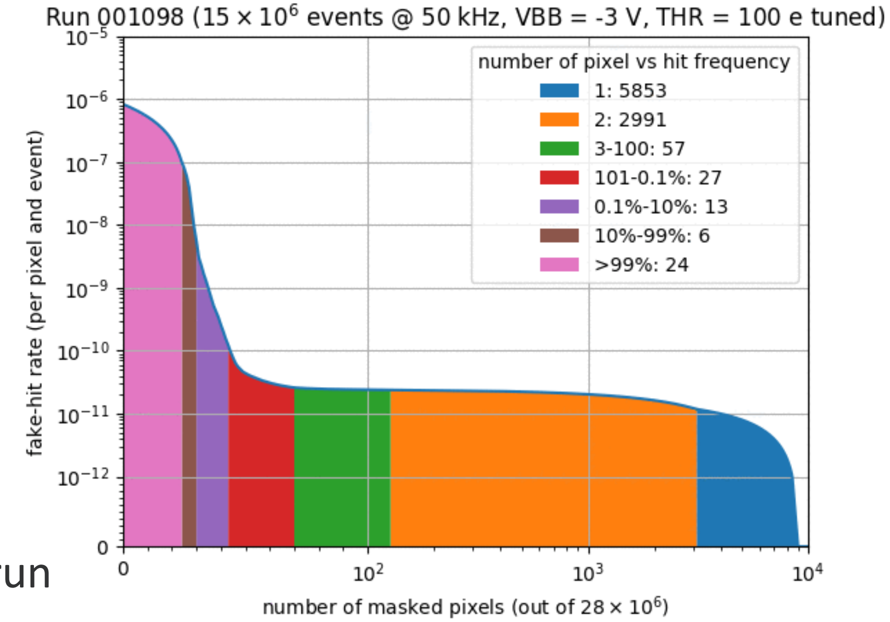
Considerations for detector designs [See also day2]

- EIC is a high precision low interaction rate collider
  → low noise detector and low background experiment
- No L1 trigger would be sent to front-end. ASIC requires to operation in zero-suppressed data-pusher mode or continuous time-framed modes
- Synced with collider collision clock (98.5 MHz @ top energy)
- Special considerations of data rate in readout [Rest of the talk]
  - Dark noise
  - Synchrotron background
  - Noise filtering

Considerations for intrinsic noise

- Largest-channel-count detector:
  Silicon pixel vertex tracker
  - Most recent MAPS (ALPIDE) in large applications:
    - ALICE ITS: 12.5B channels
    - sPHENIX-EIC vertex tracker: 200M chan
  - sPHENIX-EIC MAPS tracker
    - 10^{-5} noise rate x 100kHz frame→ 5 Gbps, handleable
    - 10^{-10} noise rate x 100kHz frame→ negligible
  - EIC DMAPS
    - YR group quoting L. Gonella: expect noise of 10^{-9}
    - 10^{-9} noise rate x 100MHz frame → ~1 Gbps, handleable
- Inputs highly desired for all subsystems [Day-2]





Ref: ALICE ITS commissioning run
Felix Reidt, QM2019

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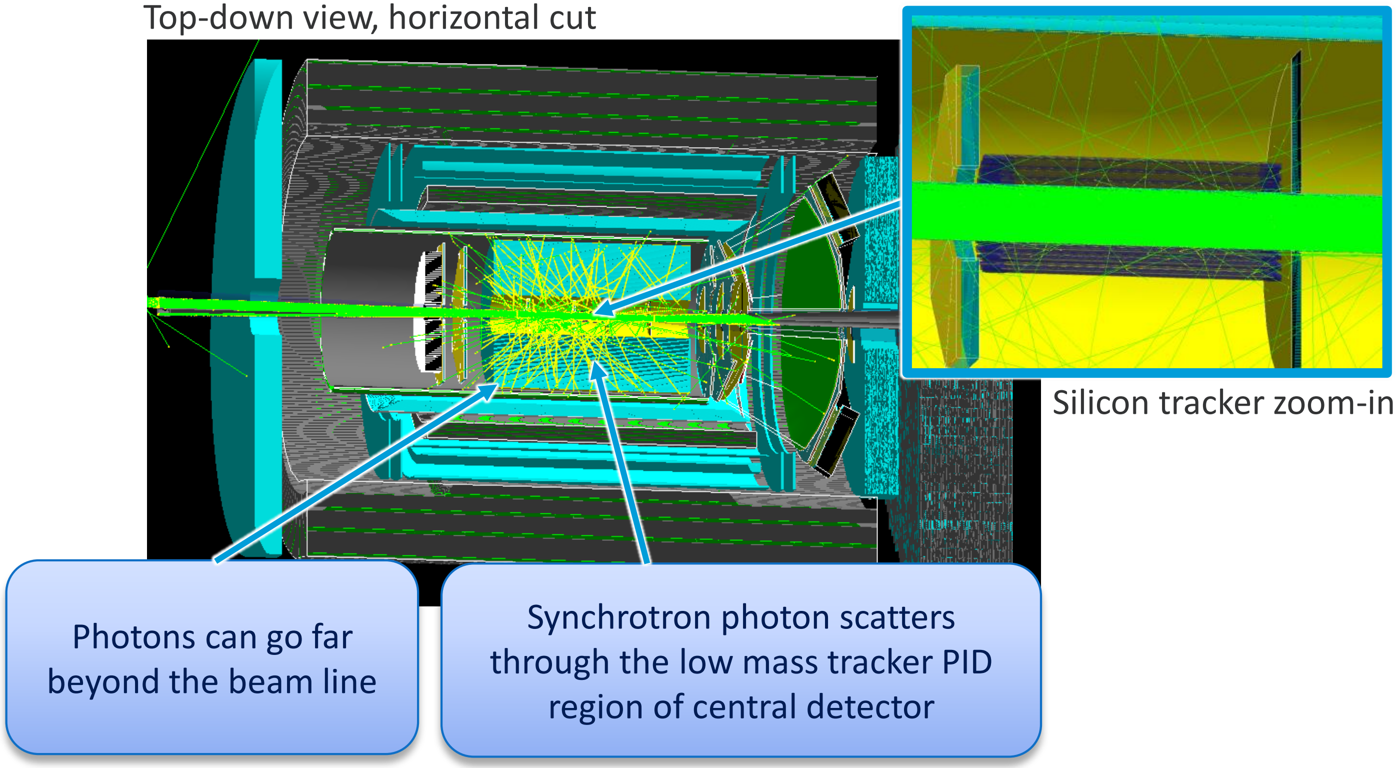
Synchrotron background

- Synchrotron background is major challenge for high energy collider with electron beams
- Many detectors at EIC could be venerable to Synchrotron background
  - E.g. challenging for readout design, background filtering tracking, and fake large DCA for HF
- Strong emphasize on co-design of collider, IR and experiment that is low in Synchrotron background from the start:
  - eRD21
  - bi-weekly IR background meeting joining accelerator and detector physicists

- 100k SynRad synchrotron photon by Marcy Stutzman (Jlab)
- Reproduce this Geant4 simulation from GitHub: macros / SynRad->HepMC reader

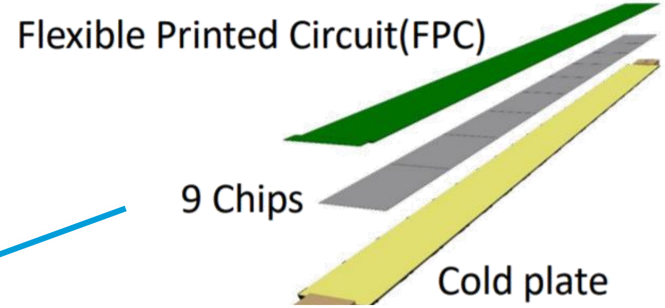
Top-down view, horizontal cut



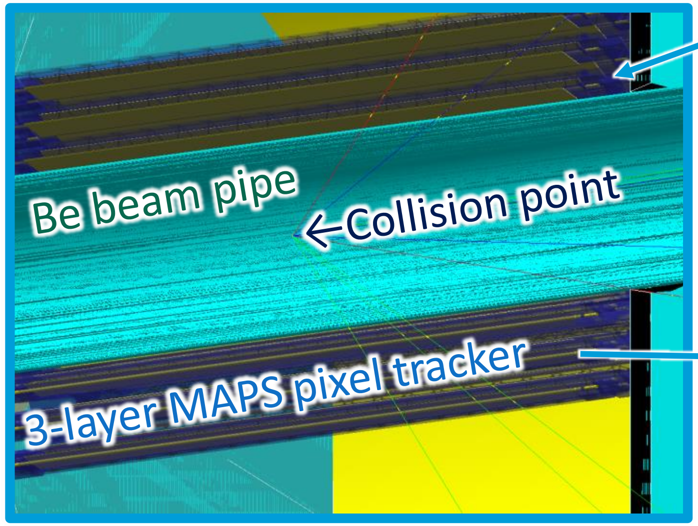
Silicon tracker zoom-in

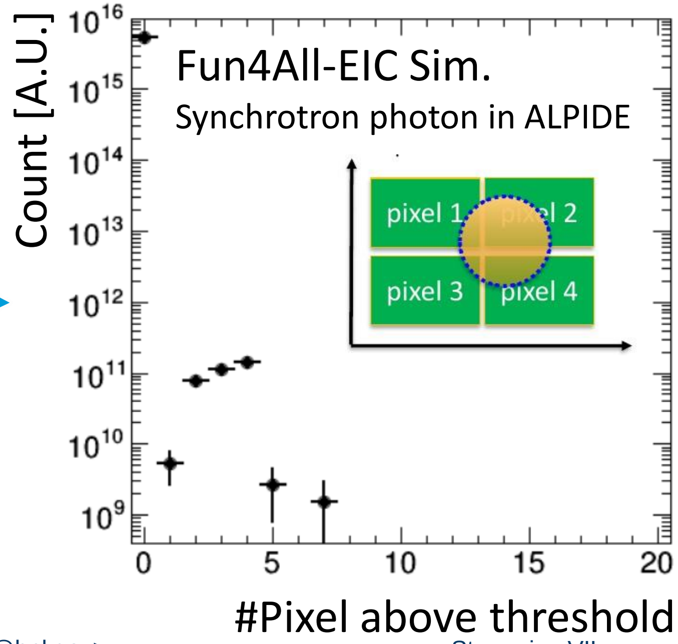
Synchrotron background: detector response

- Synchrotron photon interaction are digitized to detector data rate with sPHENIX ALPIDE model
- Calibrated with 2019 sPHENIX test-beam



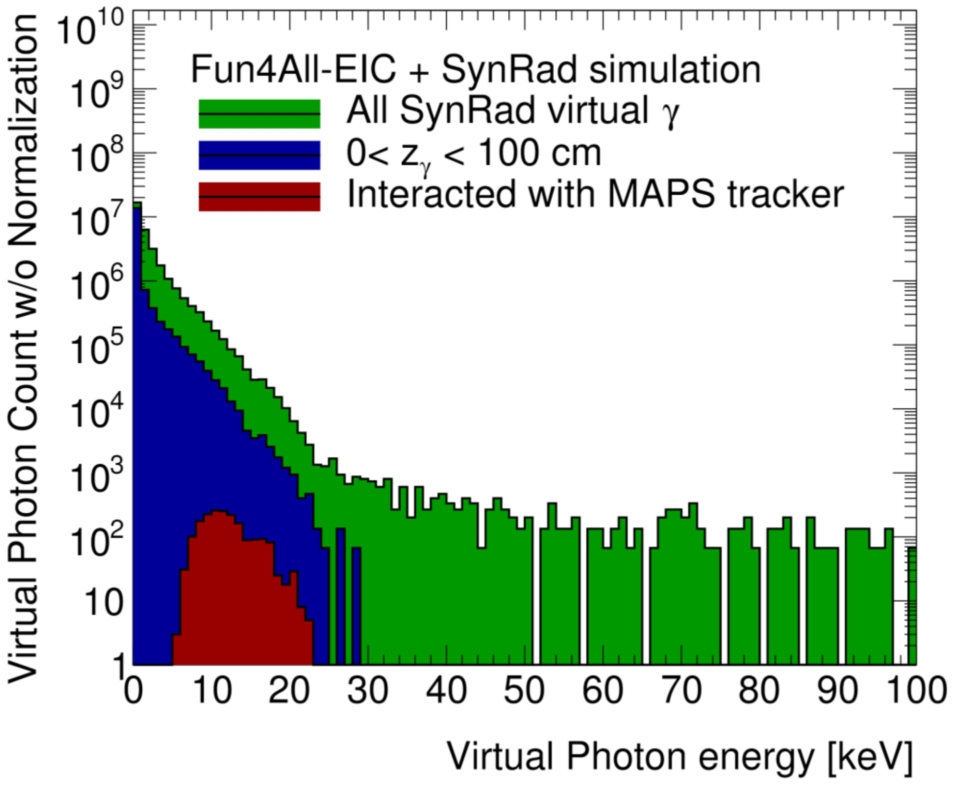
<u>sPHENIX/ALICE ALPIDE ASIC model:</u>
Geant4 transport
(1.8 keV photon threshold for Be pipe)
-> Ionization energy loss in active silicon
-> produce ionization trail
-> ionization diffusion
-> map to readout pixels
-> electronics threshold (~1keV)
-> Pixel hit -> ALPIDE data format
-> Data rate

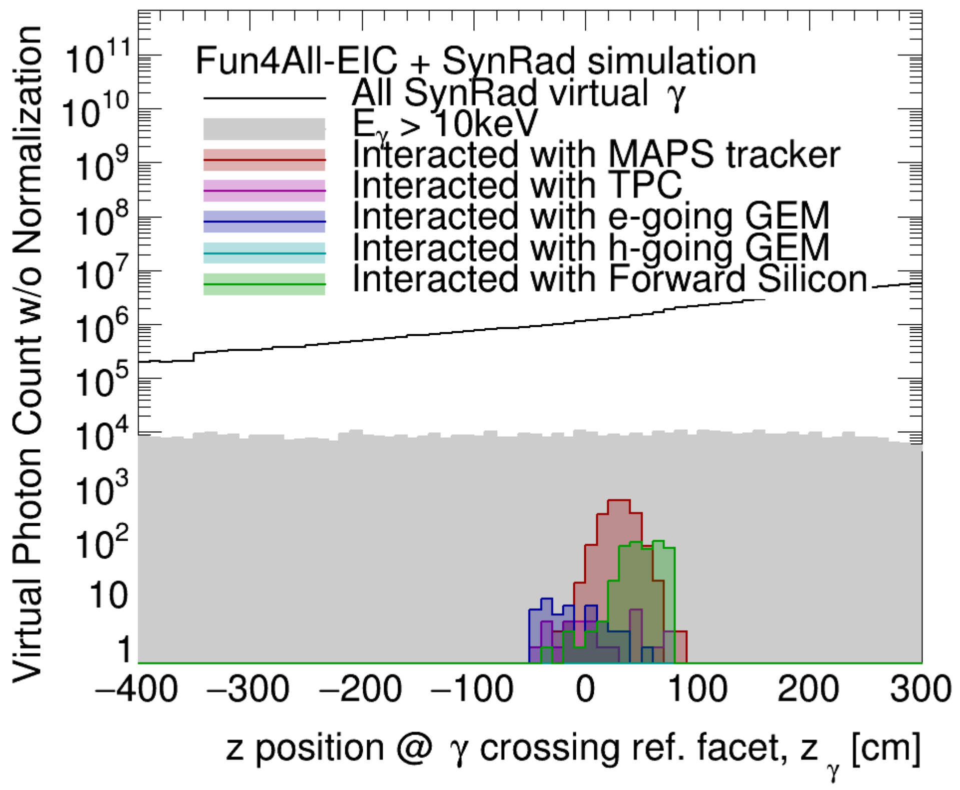




Synchrotron background: detector response

- Iterating with accelerator design to avoid 10keV photon that exits -50 to +100cm from beam pipe





Energy dependence of MAPS vertex tracker to synchrotron

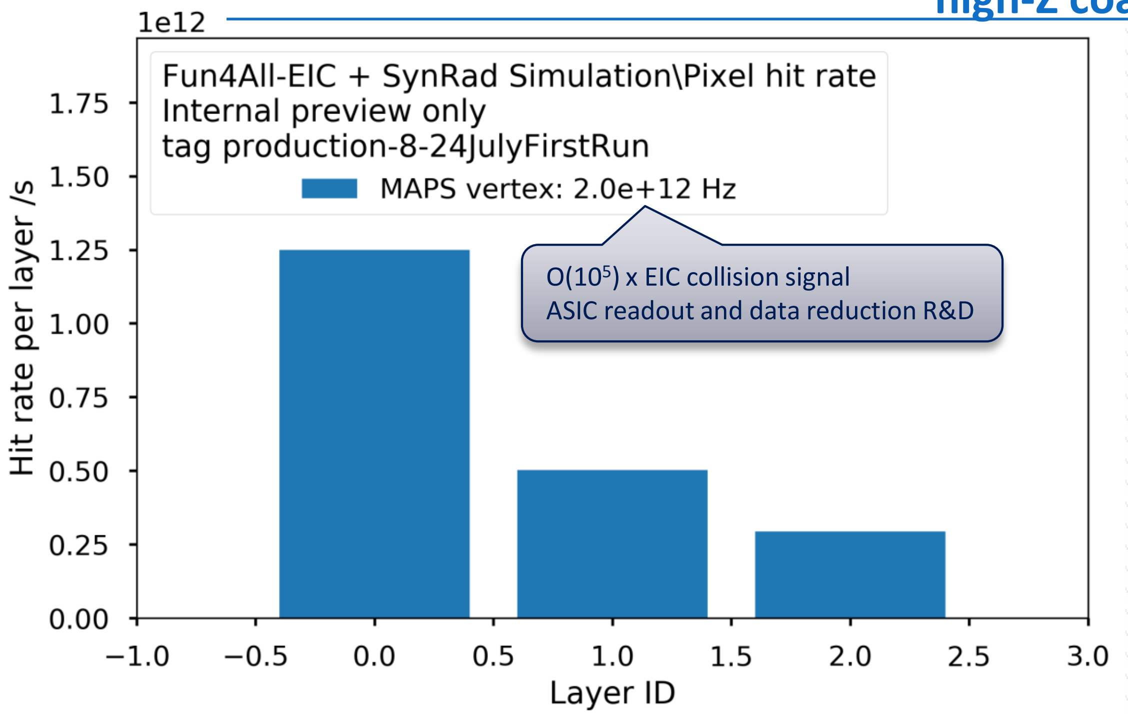
Beam-pipe exit-location

Note: all photons simulated for detector interaction, without cuts on z or energy. July-2020 lattice/chamber

Synchrotron background: detector response

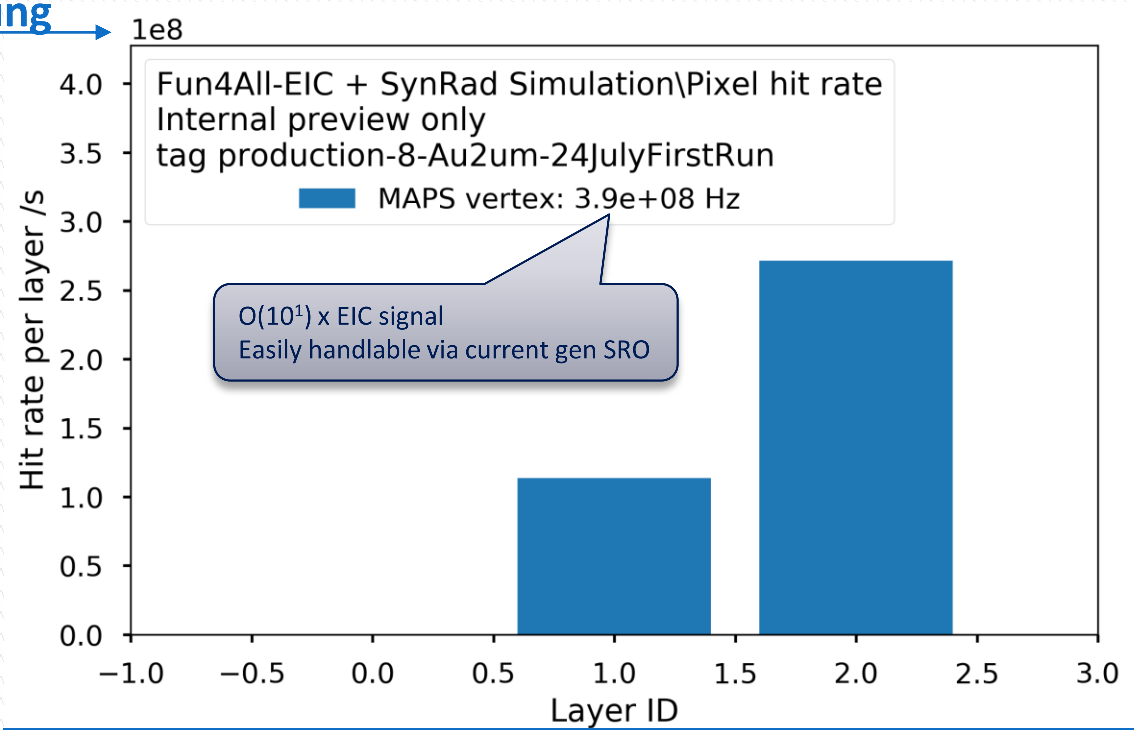
- In the most recent lattice + beam chamber geometry, there is a known issue with main dipole fan reflect over far upstream beam chamber to Be-beam pipe section.
- Beam chamber tuning on-going, expect to reduce by orders of magnitude [DO NOT QUOTE THIS RATE]
- The reflected dipole fan induce high hit rate in barrel detectors prior to photon shield tuning, but high-Z coating on chamber, e.g. 2-μm Au coating (0.06 X_0) on Be pipe significantly reduces the synchrotron rate

high-Z coating



Default 760μm-Be beam pipe

Dominated by dipole fan reflection. Expected to reduce with tuning



High-Z-coated beam pipe (+2μm Au)

Dominated by dipole fan reflection. Expected to reduce with tuning

Background outlook for SRO@EIC

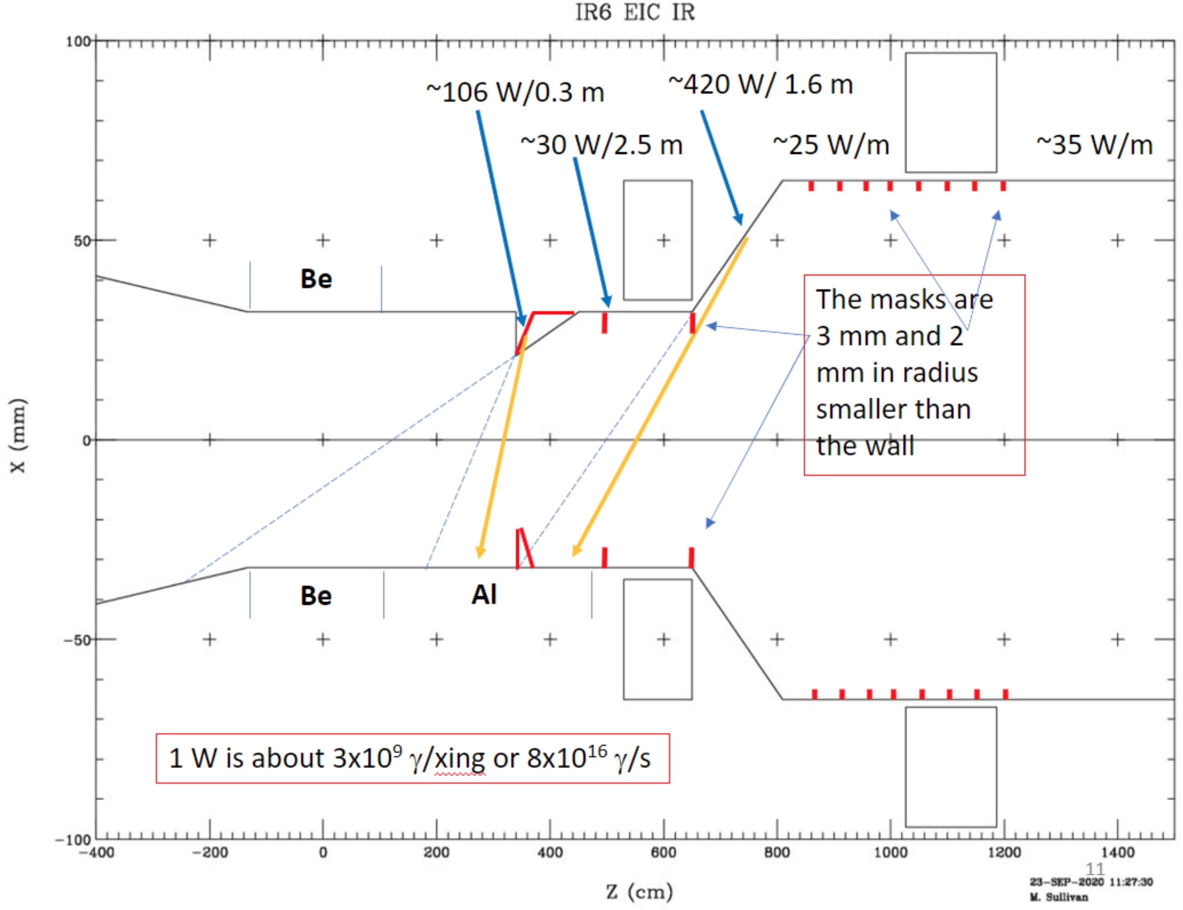
Synchrotron background is likely remaining concerning and undetermined

- As both machine and experimental region design evolves
- Prepare for the case of a large background, in particular at initial ops.

Remedy strategies:

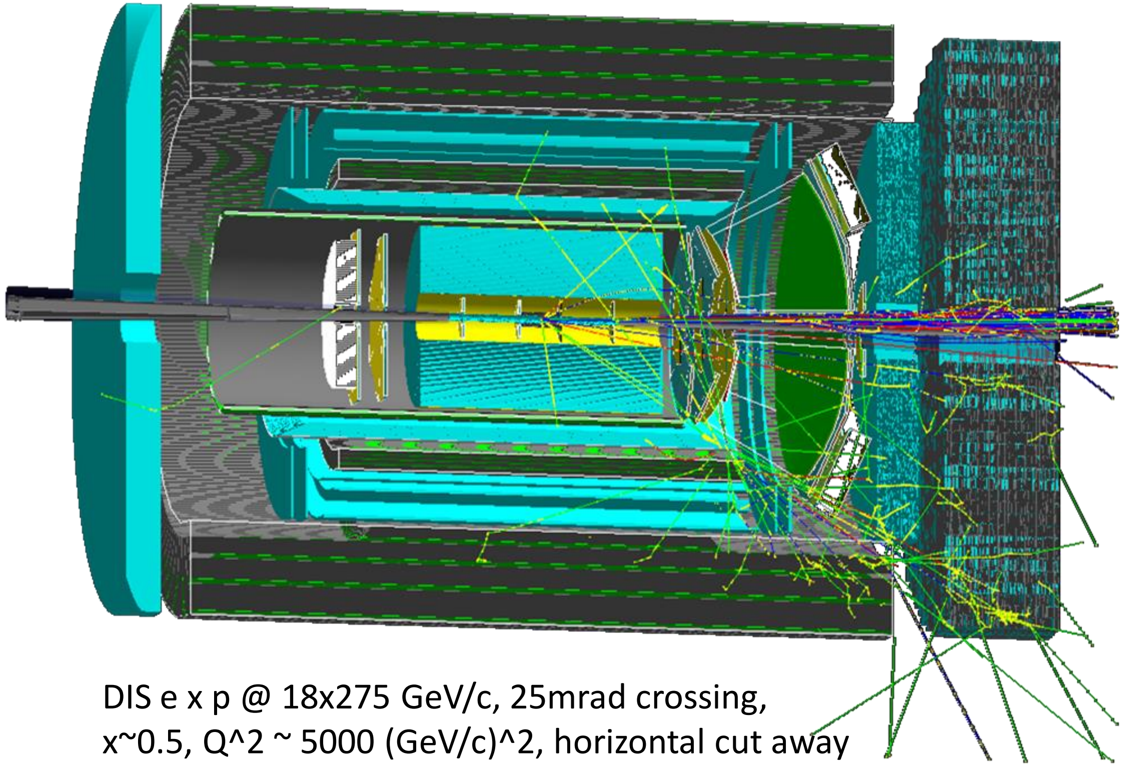
- Trigger-SRO hybrid:
  - e.g. use calorimeter-based fixed latency trigger, and use it to throttle SRO data
- Digital real-time background filtering:
  - e.g. building features (tracks, clusters, wavelet fits):
  - On FPGA [BNL CSI/SBIR] or on ML-ASIC [BNL LDRD 21-023]

SR Background shielding optimization [M. Sullivan, Oct 2020 EIC SR meeting]



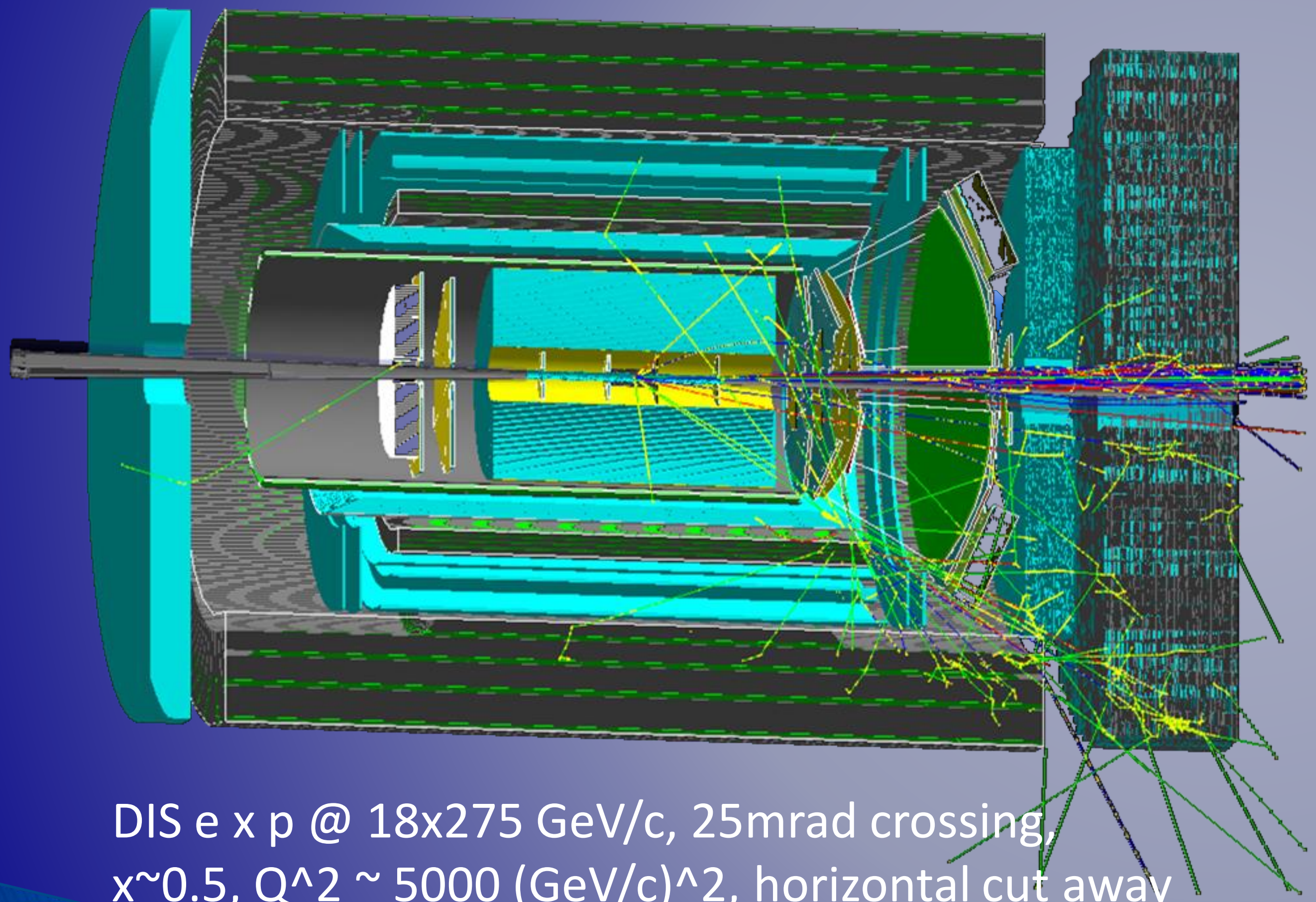
Summary

- Unique requirement of EIC driven the use of streaming DAQ.
- Precision low-cross section experiment desires low noise detector and low background
- Special challenges to SRO@EIC:
  - High channel count → superb noise control
  - Ongoing tuning to reduce synchrotron background by co-designing experiment and accelerator

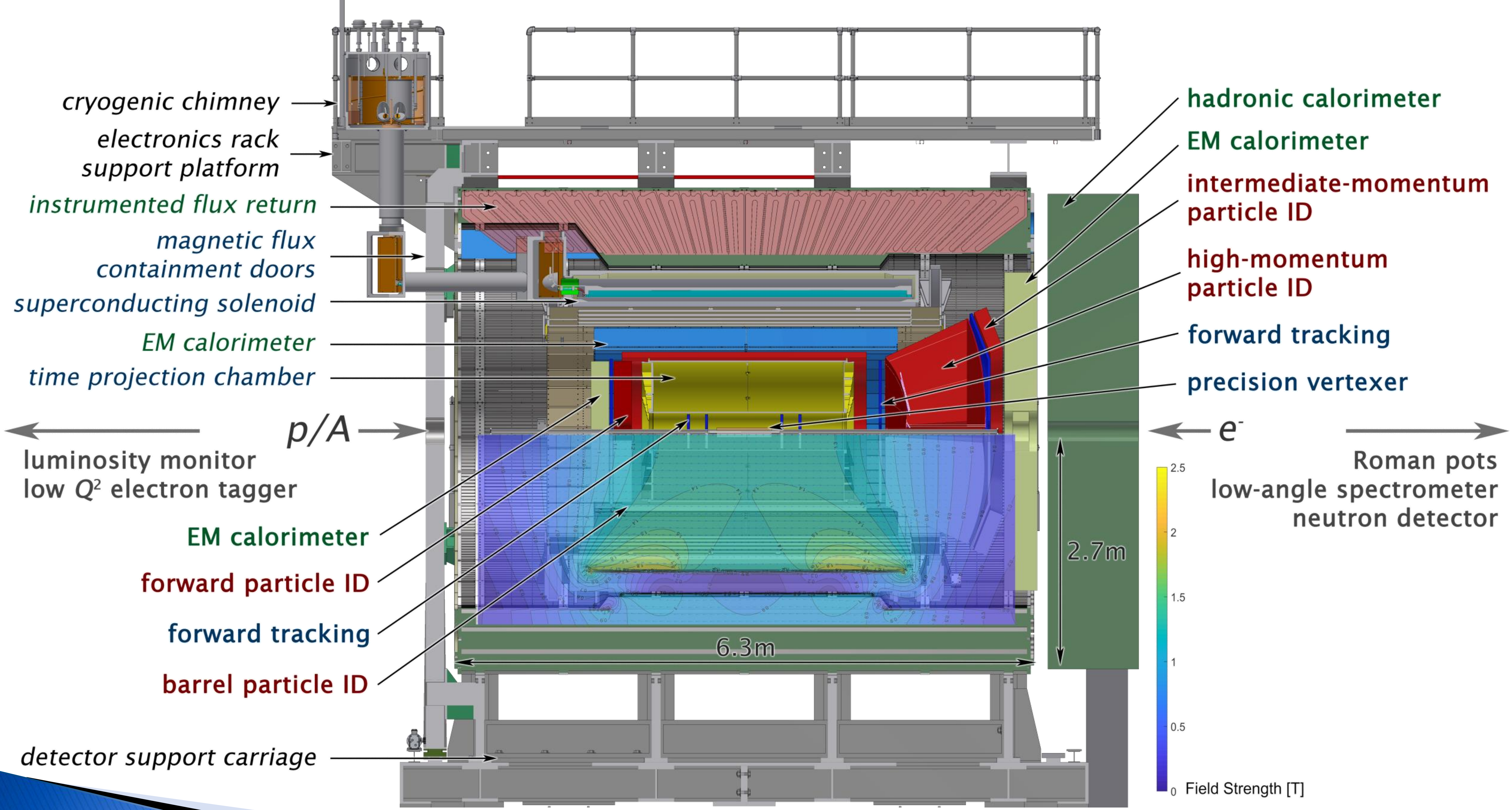


DIS e x p @ 18x275 GeV/c, 25mrad crossing, x~0.5, Q^2 ~ 5000 (GeV/c)^2, horizontal cut away

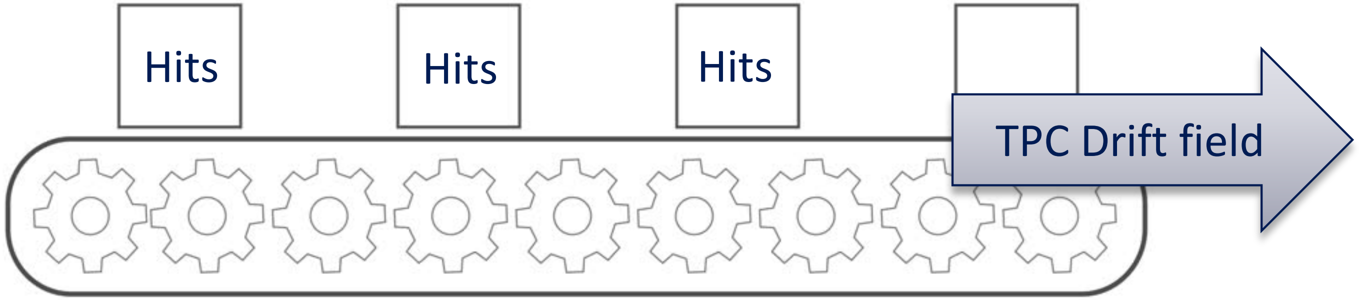
Extra information

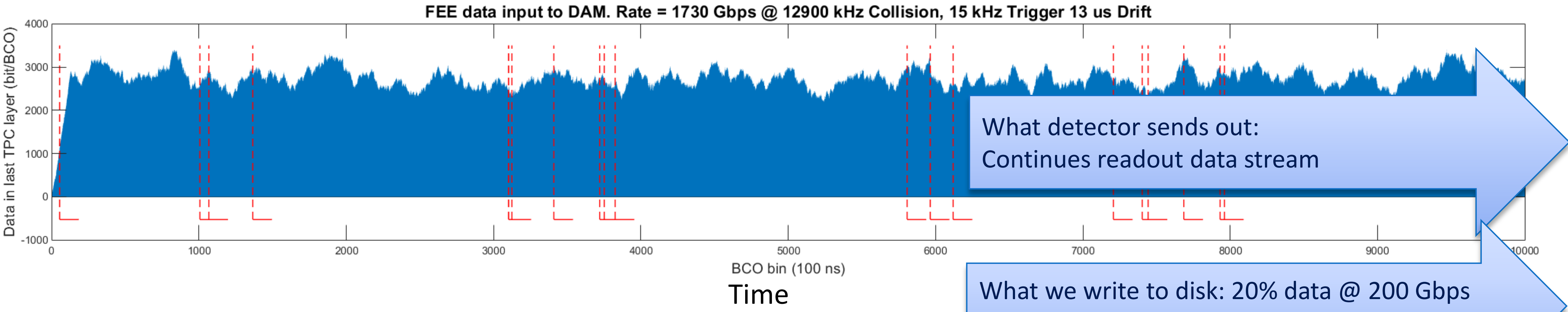


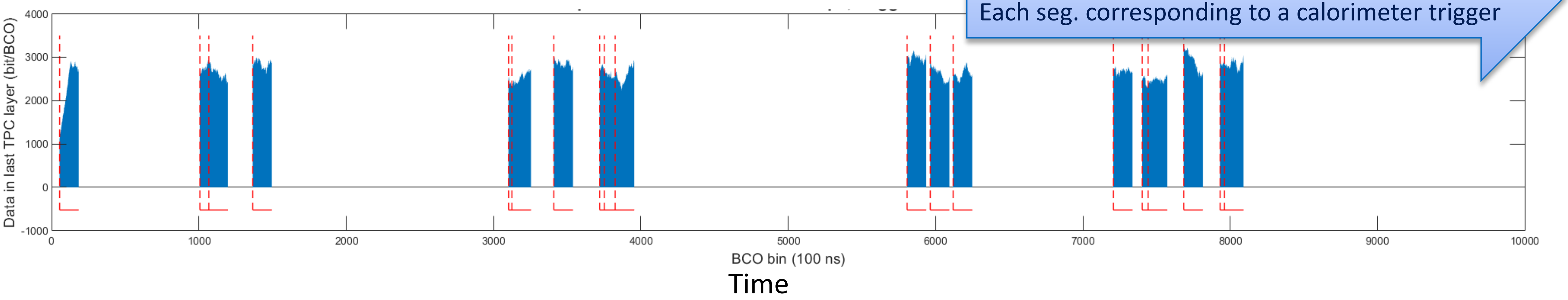
DIS e x p @ 18x275 GeV/c, 25mrad crossing,
x~0.5, Q^2 ~ 5000 (GeV/c)^2, horizontal cut away


cryogenic chimney
electronics rack support platform
instrumented flux return
magnetic flux containment doors
superconducting solenoid
EM calorimeter
time projection chamber
p/A
luminosity monitor
low Q^2 electron tagger
EM calorimeter
forward particle ID
forward tracking
barrel particle ID
detector support carriage
hadronic calorimeter
EM calorimeter
intermediate-momentum particle ID
high-momentum particle ID
forward tracking
precision vertexer
e^-
Roman pots
low-angle spectrometer
neutron detector
2.7m
6.3m
2.5
2
1.5
1
0.5
0
Field Strength [T]

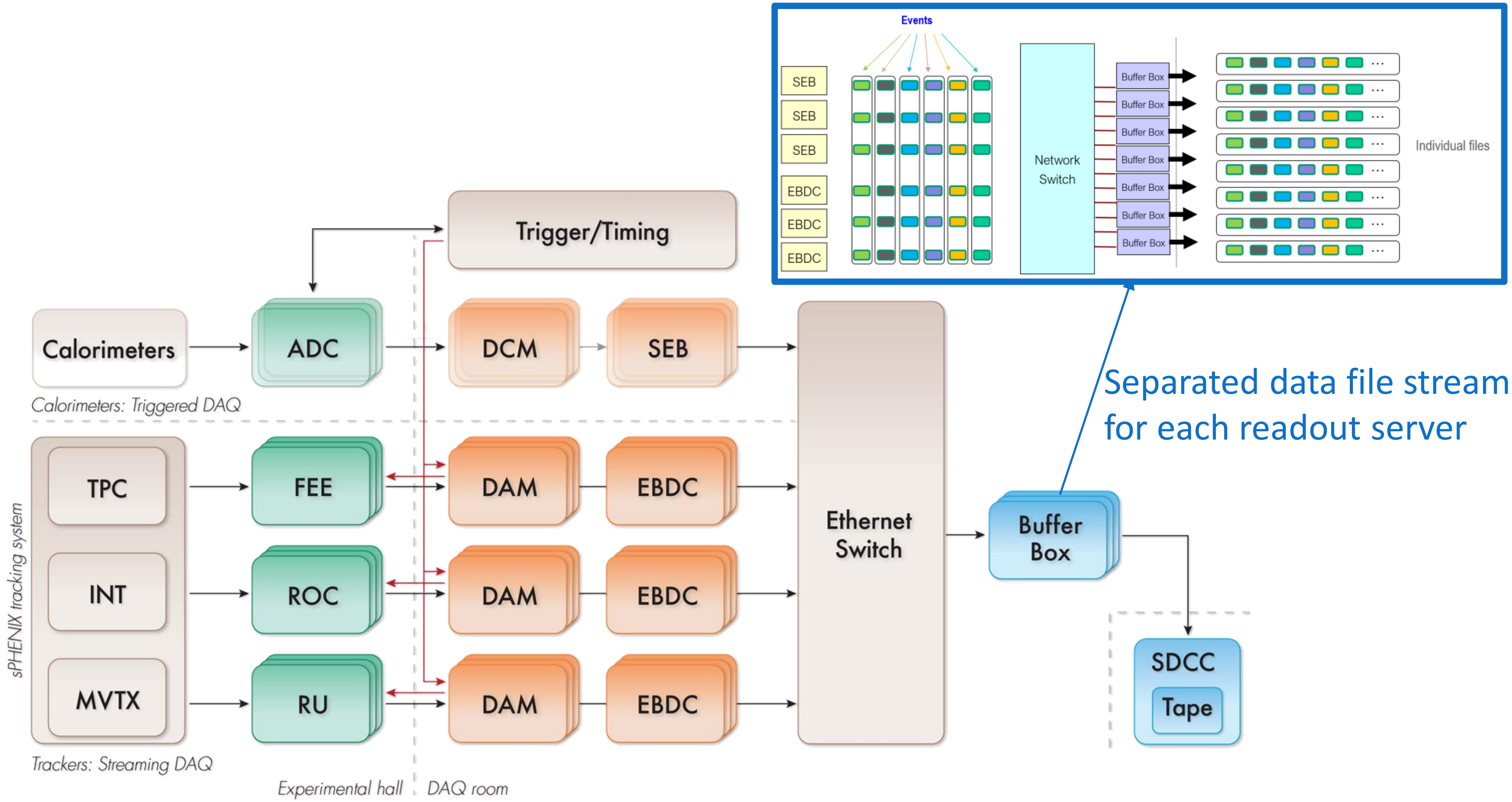
TPC data stream in sPHENIX triggered DAQ







Readout hardware in current plan



Separated data file stream for each readout server

See Collaboration meeting DAQ talk by M. Purschke