Introduction to Rate and Computing Session

Jin Huang
Brookhaven National Lab

BROOKHAVEN NATIONAL LABORATORY

EIC: unique collider
→ unique real-time system challenges

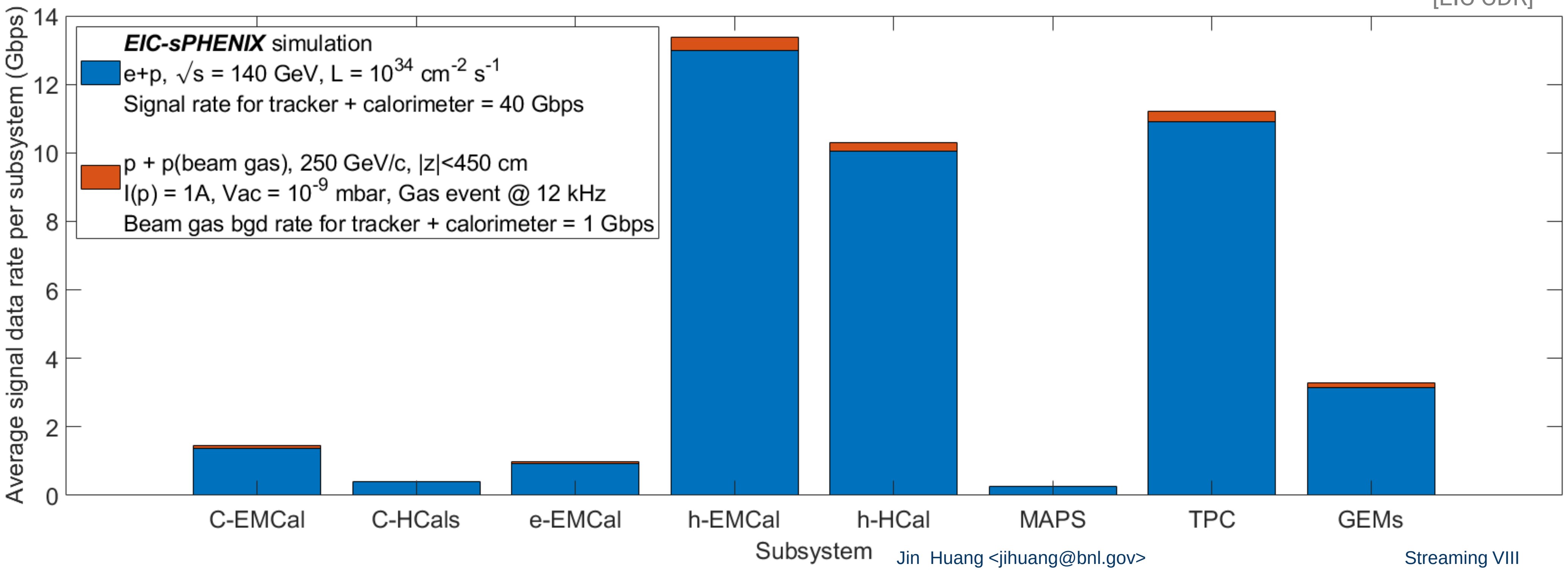
	EIC	RHIC	LHC → HL-LHC
Collision species	$\vec{e}+\vec{p}, \vec{e}+A$	$\vec{p}+\vec{p}/A, A+A$	$p+p/A, A+A$
Top x-N C.M. energy	140 GeV	510 GeV	13 TeV
Bunch spacing	10 ns	100 ns	25 ns
Peak x-N luminosity	10^{34} cm^{-2} s^{-1}	10^{32} cm^{-2} s^{-1}	10^{34} → 10^{35} cm^{-2} s^{-1}
x-N cross section	**50 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 triggering bias

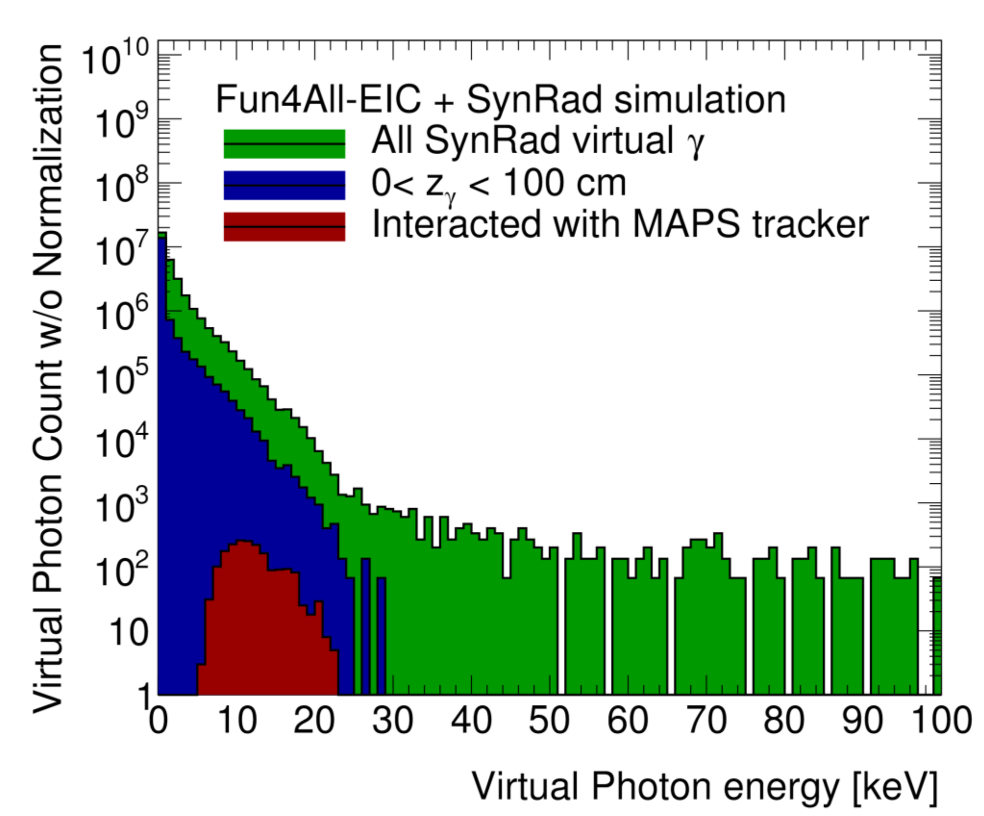
Signal data rate -> DAQ strategy

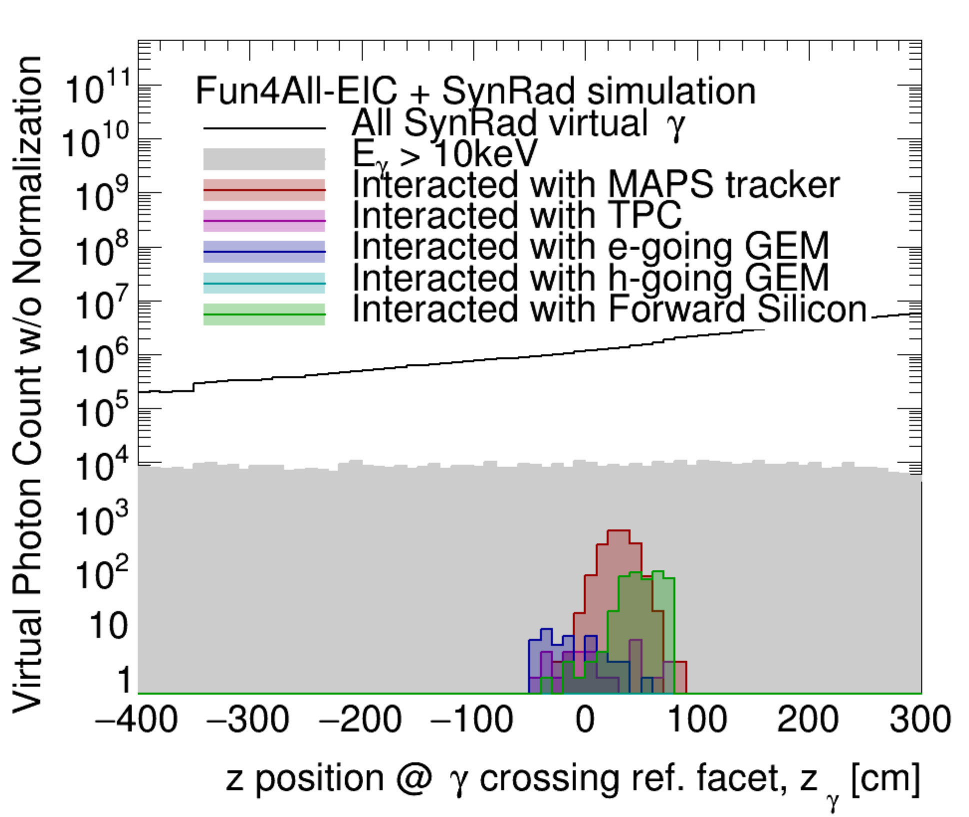
- What we want to record at the end: total collision signal ~ 100 Gbps @ 10^{34} cm^{-2} s^{-1}
- Therefore, we could choose to stream out all EIC collisions data
- Orders of magnitude different from LHC, where it is necessary to filter out uninteresting p+p collisions (CMS/ATLAS/LHCb) or highly compress collision data (ALICE)

[EIC CDR]



But, that is not the whole story:
e.g. synchrotron background is still uncertain!





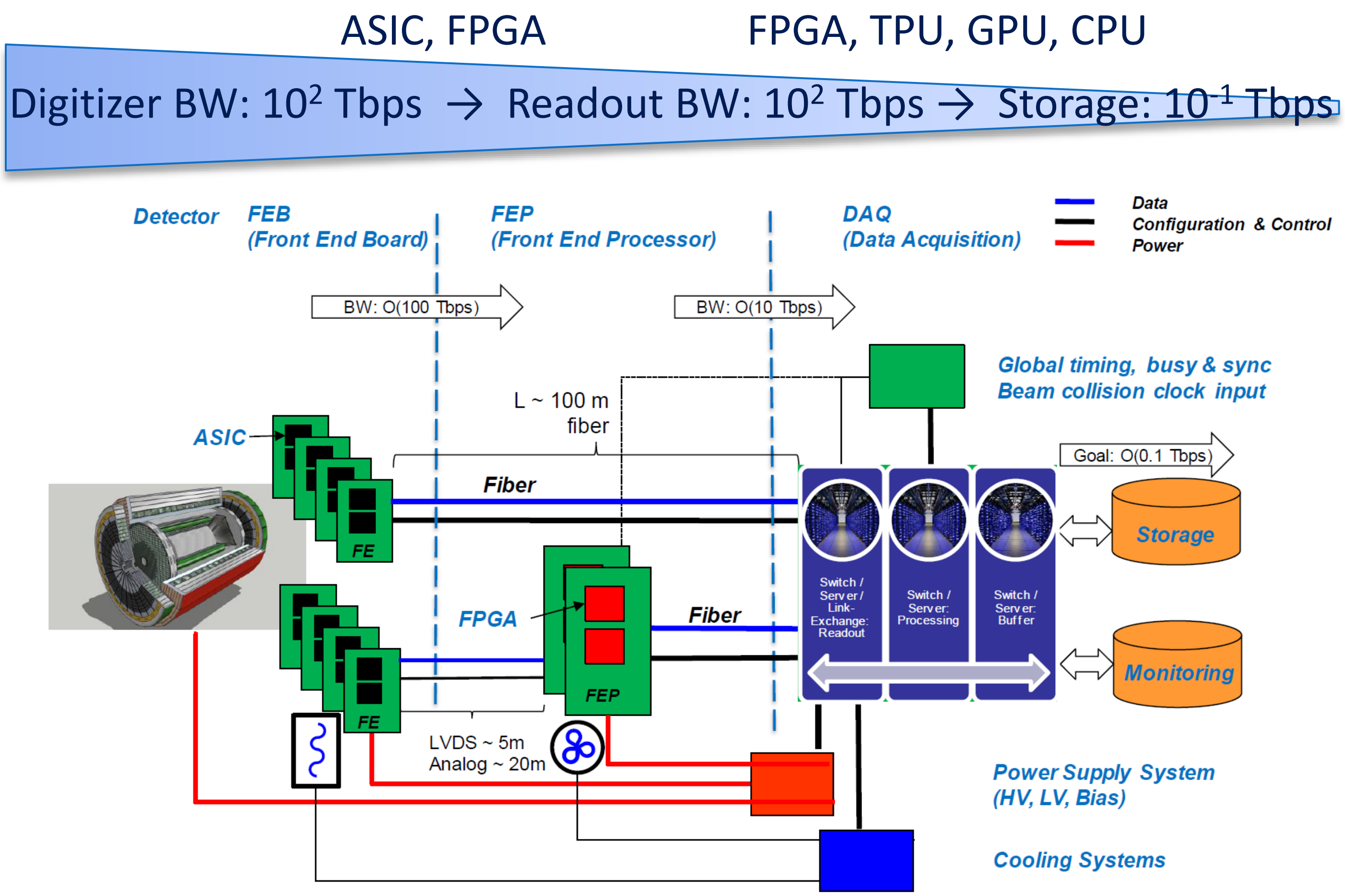
Energy dependence of MAPS vertex tracker to synchrotron

Beam-pipe exit-location

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

Real-time computing for streaming data pipeline

- Despite low signal rate, the raw data rate can be filled with noises and background
  - Need low background & low noise detector & electronics design
- An essential job of EIC real-time computing: reliable streaming data reduction to fit permanent storage
  - Broad topic, e.g. triggering is a form of data reduction too
- And more traditional roles for online/offline server farm:
  - Online monitoring/fault det.
  - Calibration
  - Production → Initial analysis pass

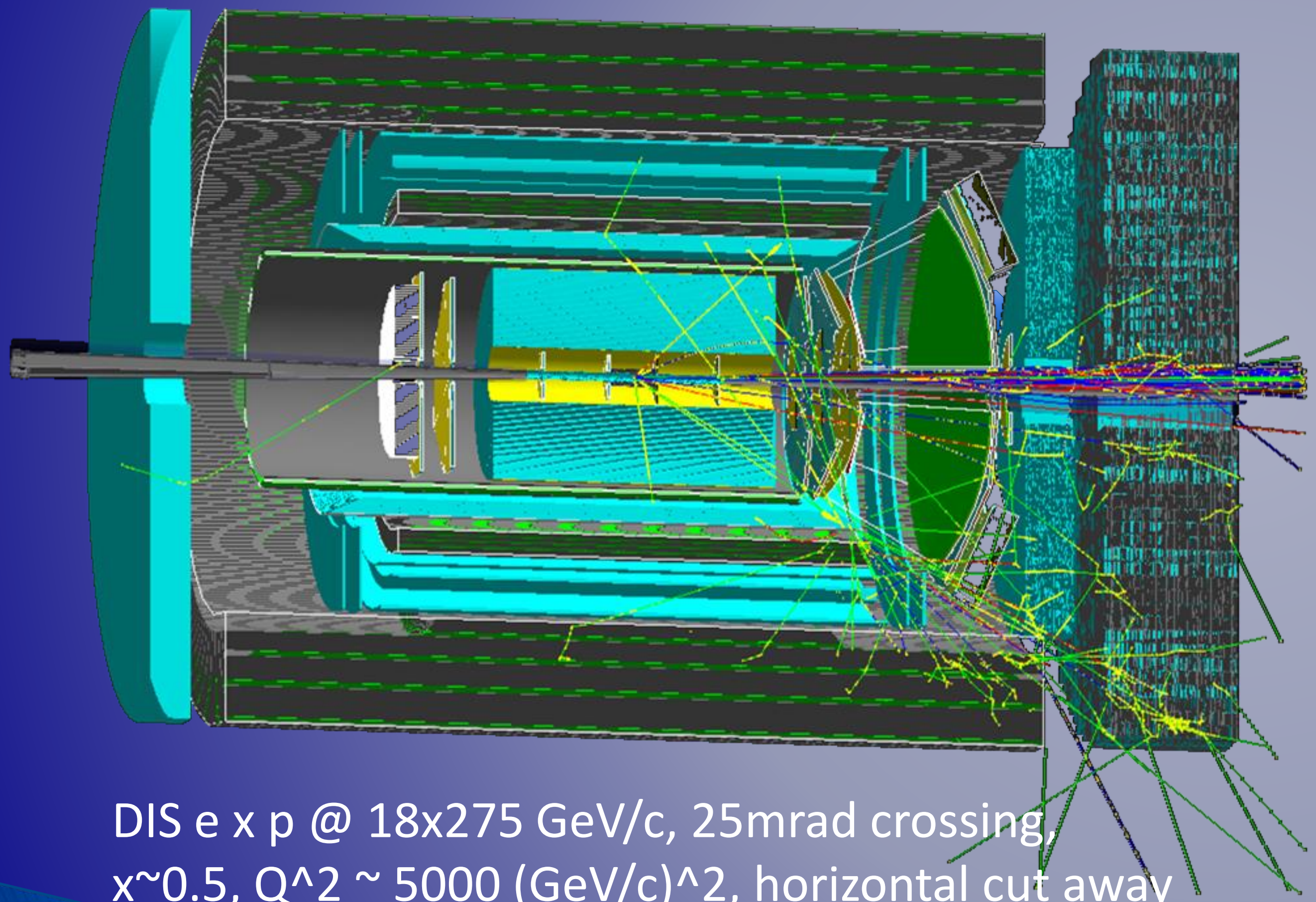


[EIC CDR]

Components of streaming data reduction and processing

- Low background & low noise detector & electronics design [Last three sessions]
- Region of interest & zero suppression, see ASIC talks [Hardware session]
- Feature extraction:
  - see talks of C. Crawford (Real-time least-squares pulse fitting for digital spectroscopy), S. Miryala (ML on ASIC for streaming ADCs)
- Local and global triggering:
  - see talk S. Furletov (ML on FPGA for Event Selection)
- Noise filtering and compression :
  - see talk of Y. Huang (ML data compression and noise filtering for real-time computing)
- Higher level object reconstruction: e.g. ALICE O^2 ,
  - see also talk J. Osborn (Streaming readout and data management at ORNL)

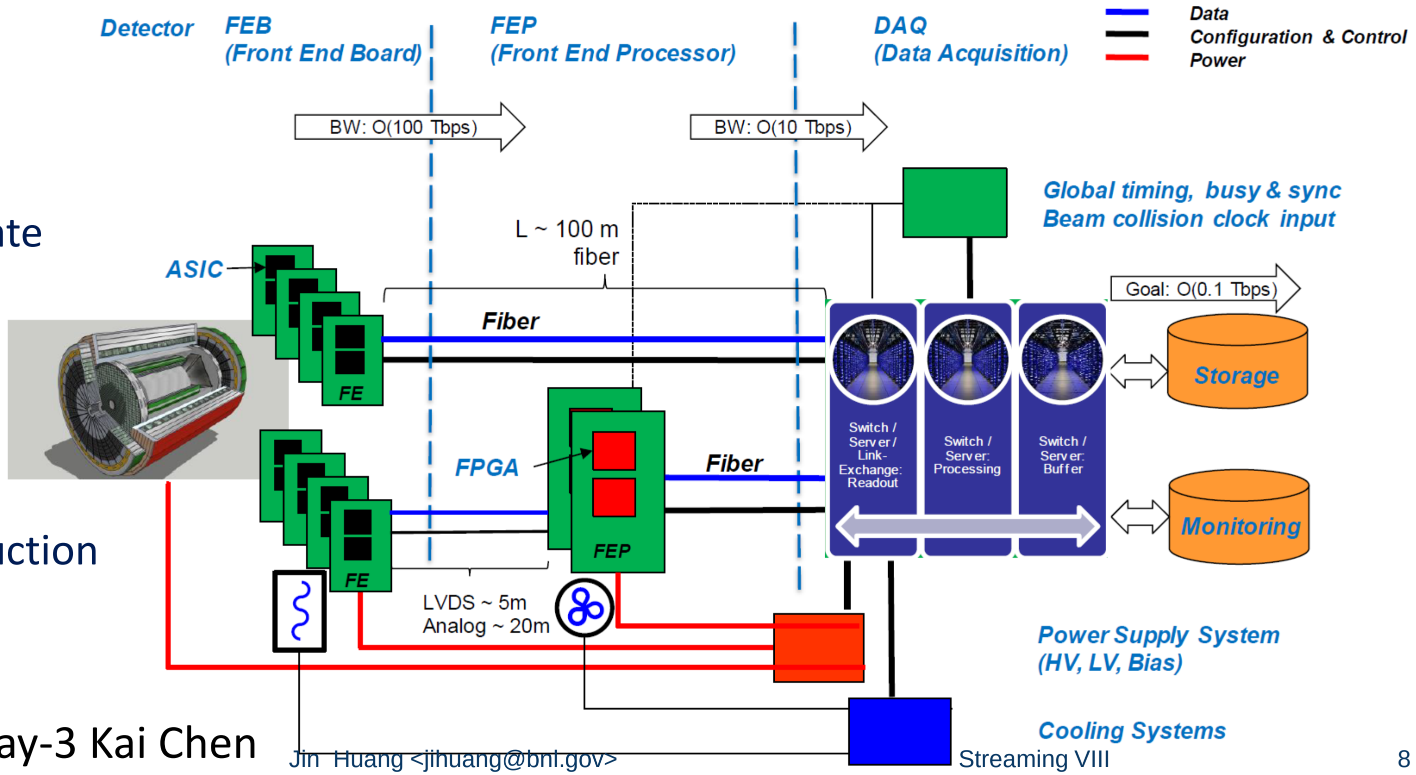
Extra information



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

Strategy for an EIC real-time system

- For the signal data rate from EIC (100 Gbps, see also 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+)

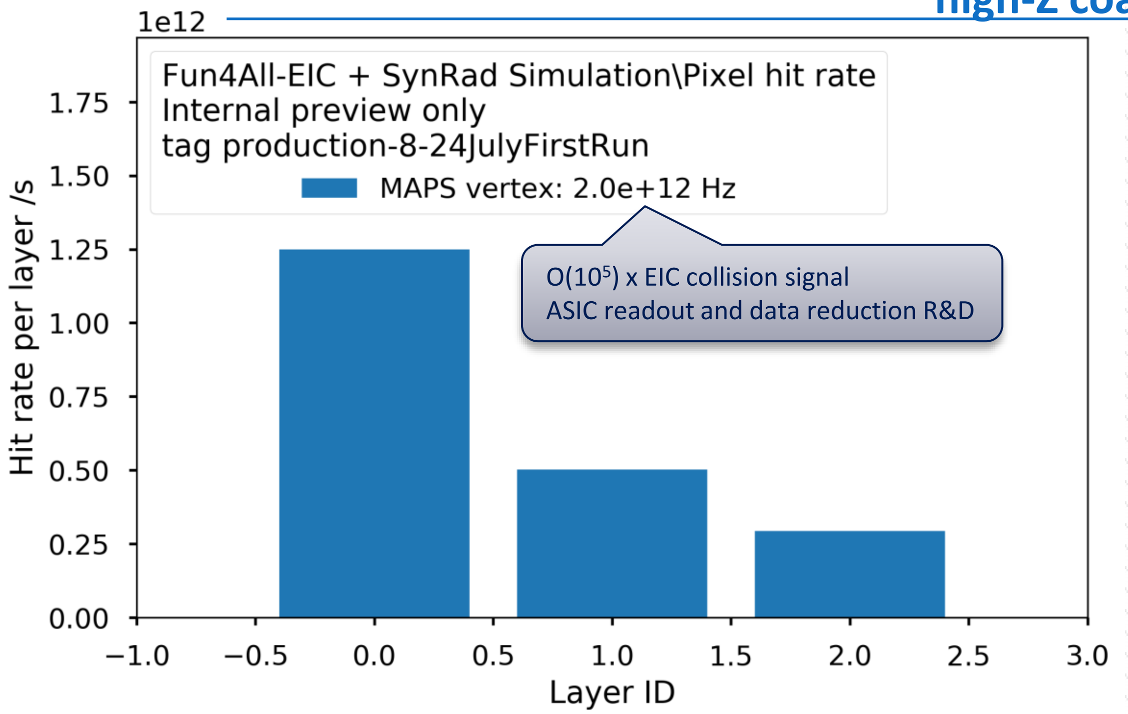


Ref: EIC-CDR, See also Day-3 Kai Chen

Synchrotron background: detector response

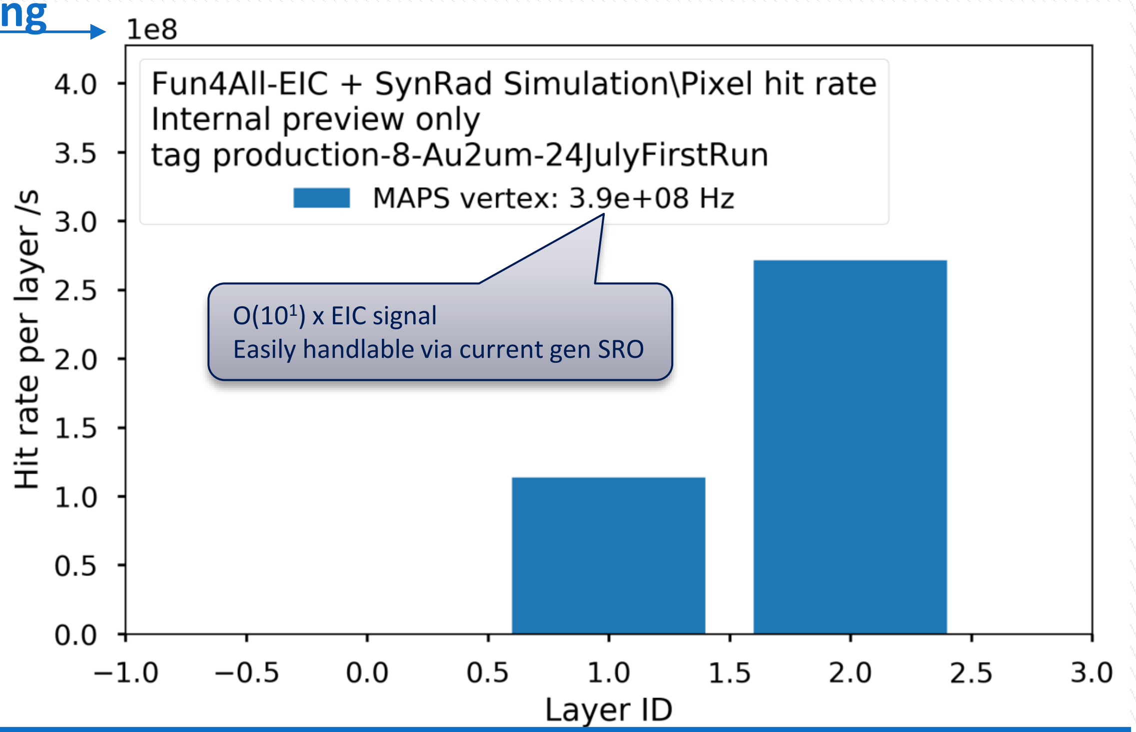
- In the most recent lattice + beam chamber geometry, there is a known issue with main dipole fan reflect over far upstream beam chamber to Be-beam pipe section.
- Beam chamber tuning on-going, expect to reduce by orders of magnitude [DO NOT QUOTE THIS RATE]
- The reflected dipole fan induce high hit 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

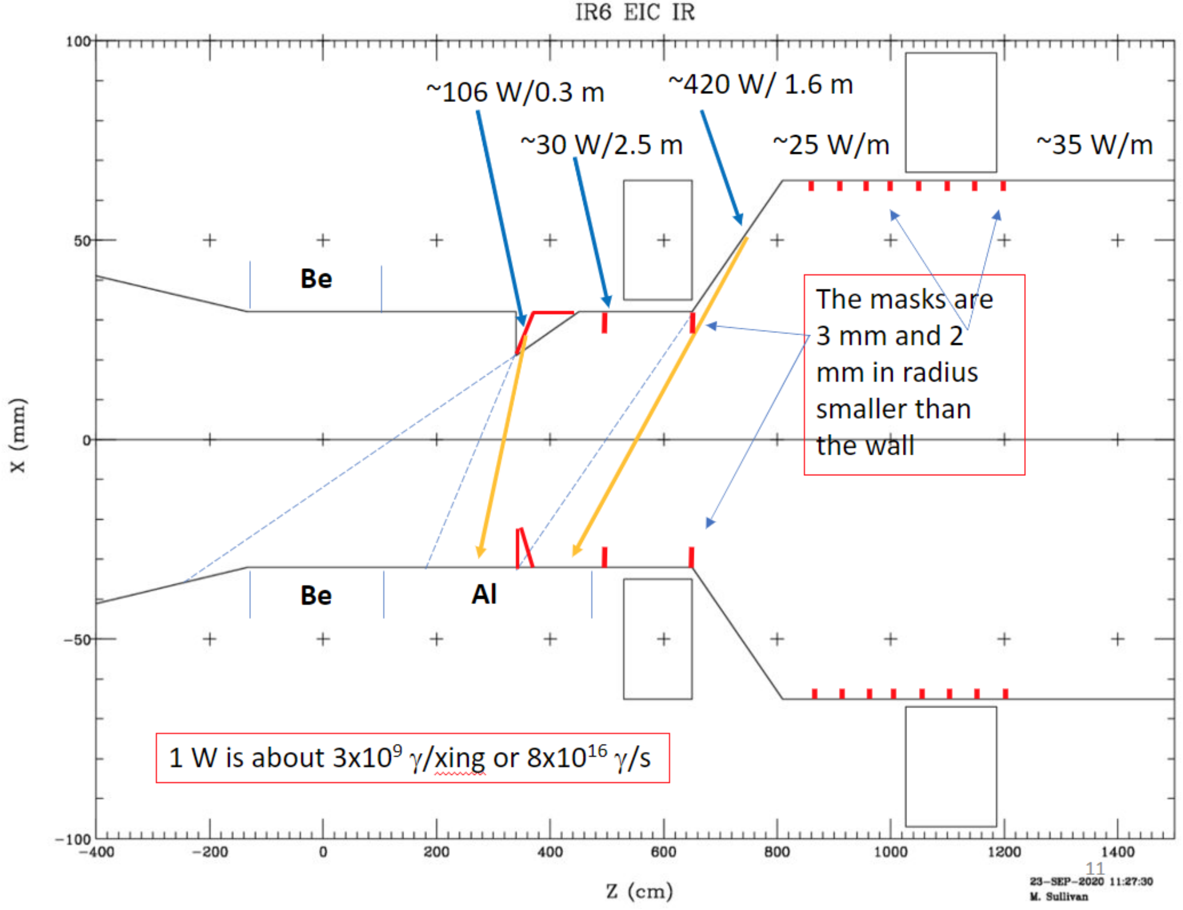
Synchrotron background is likely remaining concerning and undetermined

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

Remedy strategies:

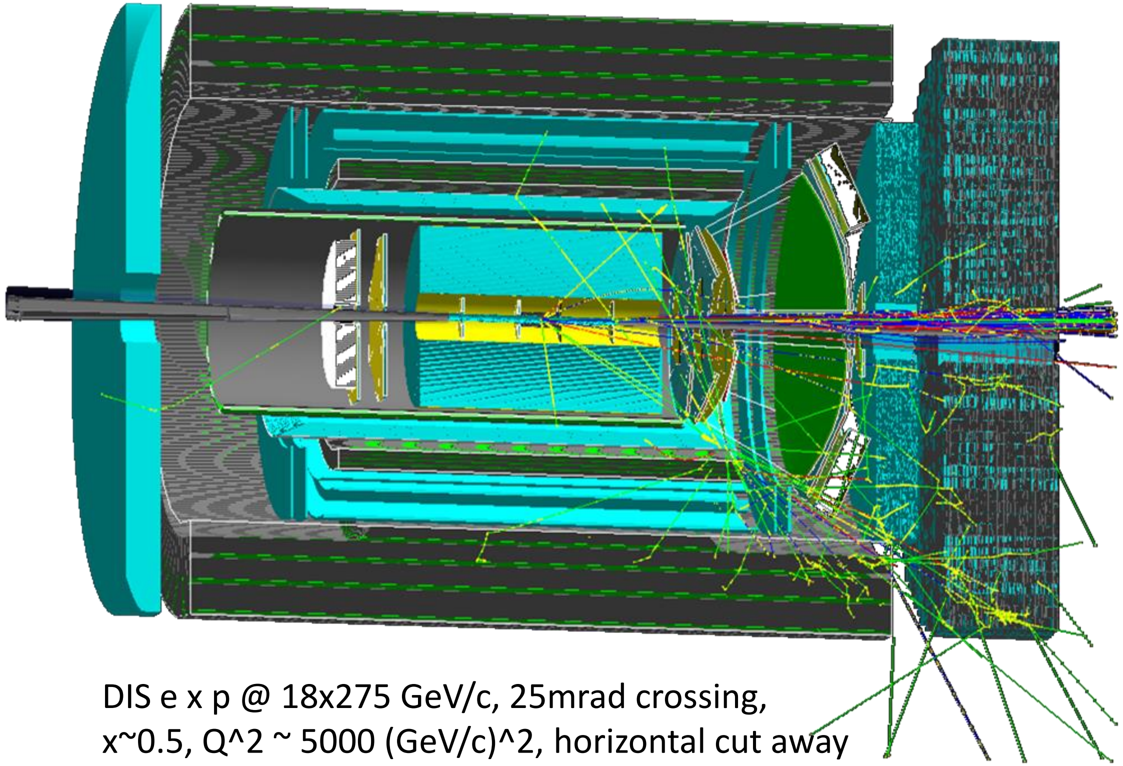
- Trigger-SRO hybrid:
  - e.g. use calorimeter-based fixed latency trigger, and use it to throttle SRO data
- Digital real-time background filtering:
  - e.g. building features (tracks, clusters, wavelet fits):
  - On FPGA [BNL CSI/SBIR] or on ML-ASIC [BNL LDRD 21-023]
- Validate any data reduction with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

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



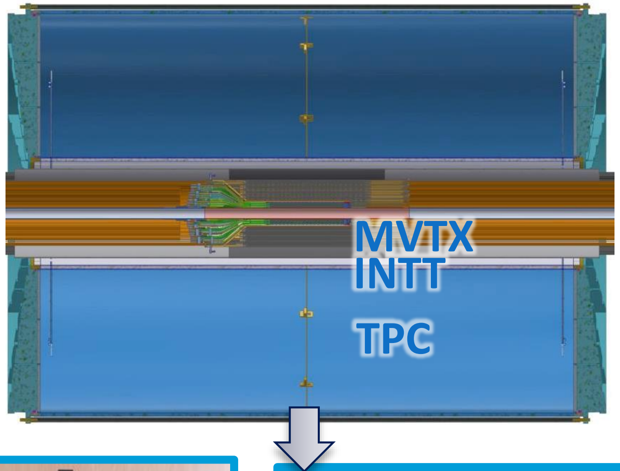
DIS e x p @ 18x275 GeV/c, 25mrad crossing, x~0.5, Q^2 ~ 5000 (GeV/c)^2, horizontal cut away

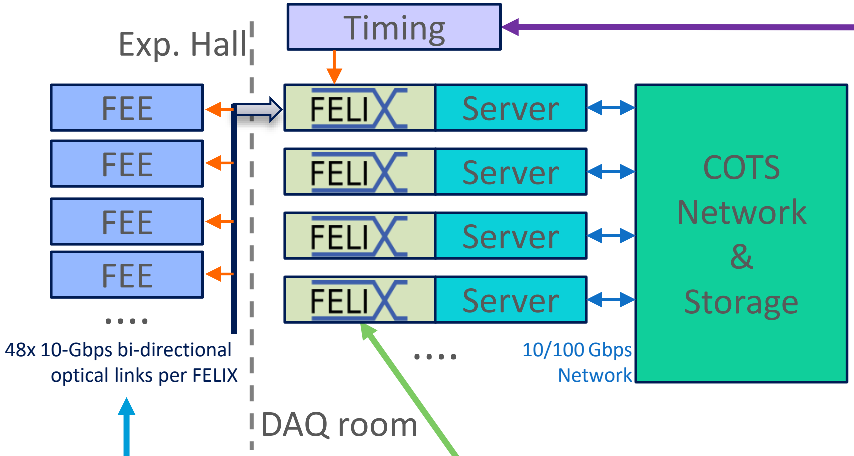
Large-scale streaming readout towards EIC

- CRU/FELIX-based large-scale streaming DAQ application in ALICE, LHCb, sPHENIX and CBM [See also Day 2-3]
- Other streaming data model as in CLAS-12, Hall-D, Compass++ [See also Day 2-3]

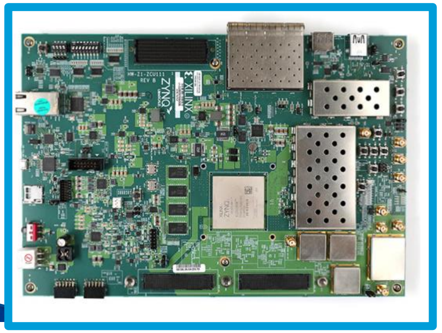
sPHENIX streaming DAQ for tracker [See also Martin's talk on Day-2]

Precision timing digitizer
DRS4GIO (SBIR/LDRD)

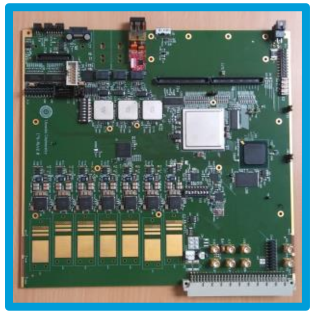




Global Timing Module (NSLS II/sPHENIX)
To test with RHIC RF low glitter clock source



High density multiplexer+ ADC
RFSoC Digitizer (LDRD)



MVTX RU, 200M ch

INTT ROC, 400k ch

ALPIDE (ALICE/sPHENIX), FPHX (PHENIX)

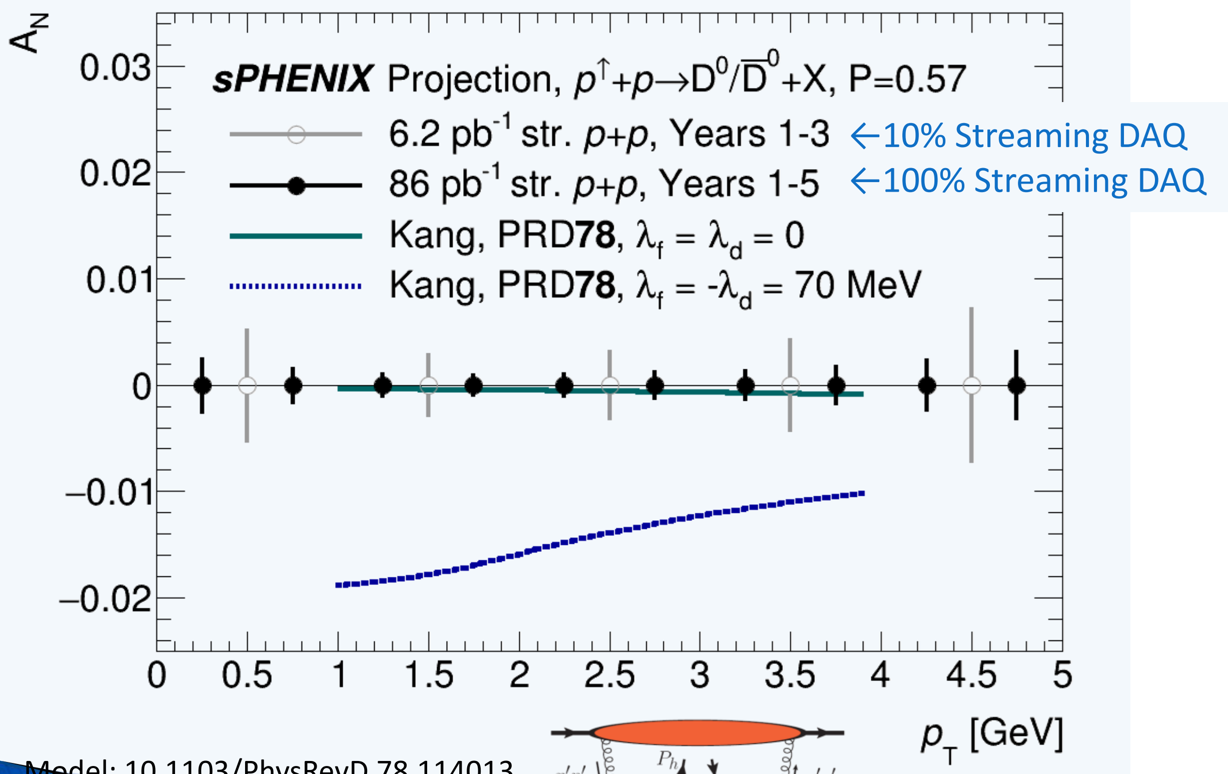
TPC FEE, 160k ch
SAMPAv5 (ALICE/sPHENIX)

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

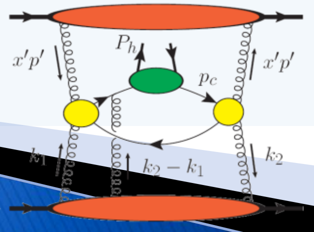
Streaming-DAQ enabled scientific connection: Gluon dynamics via heavy flavor A_N

Universality test on gluon Sievers

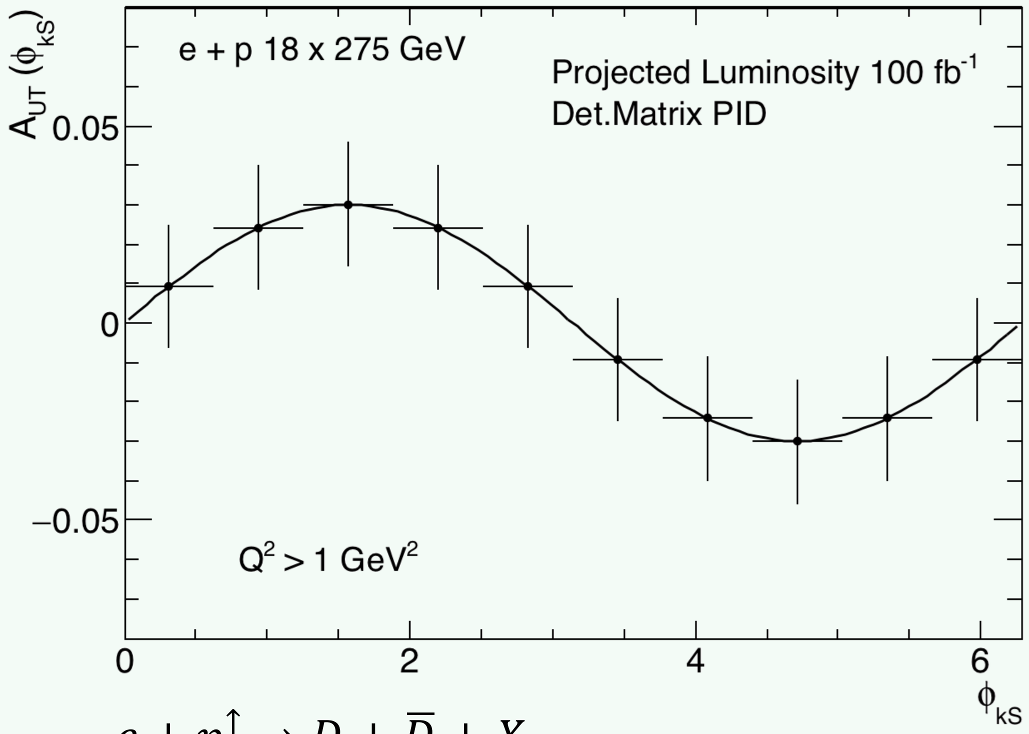
sPHENIX D^0 trans. spin asymmetry, A_N → Gluon Sievers via tri-g cor.



Model: 10.1103/PhysRevD.78.114013



EIC SIDIS D^0 transverse spin asymmetry → Gluon Sievers



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

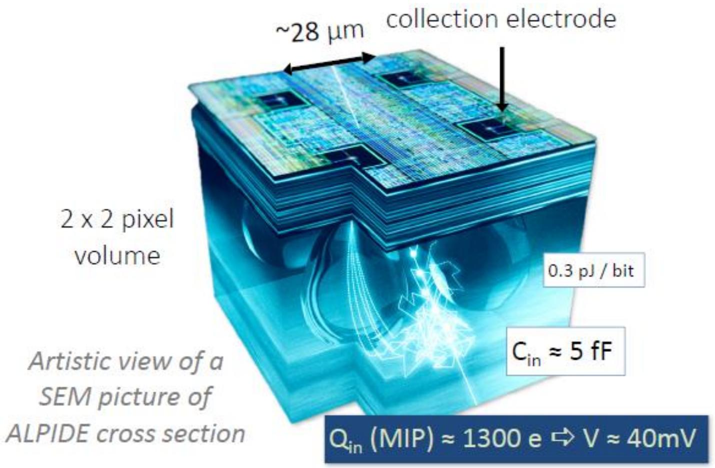
[CNFS HF@EIC workshop, Nov 4-6, 2020]

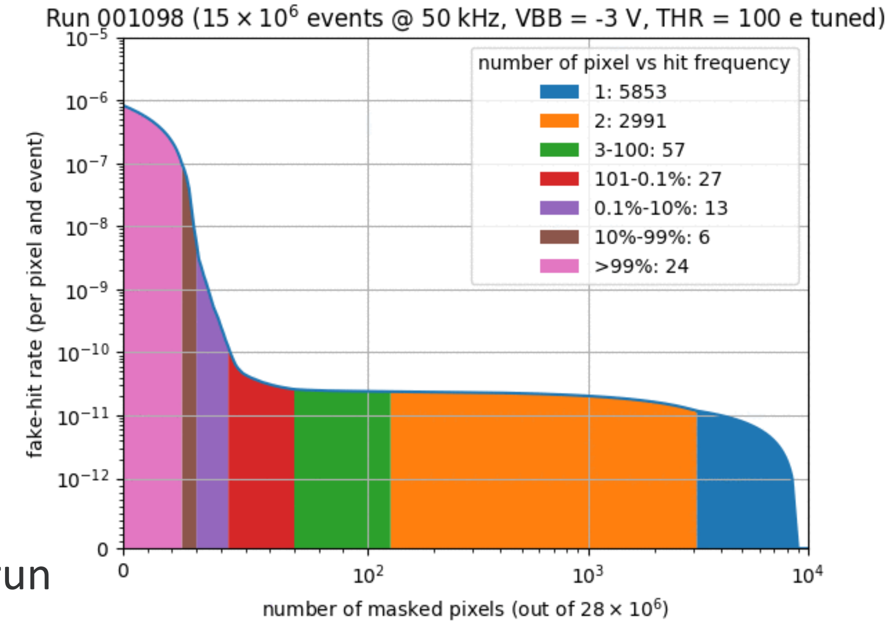
Considerations for detector designs [See also day2]

- 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]





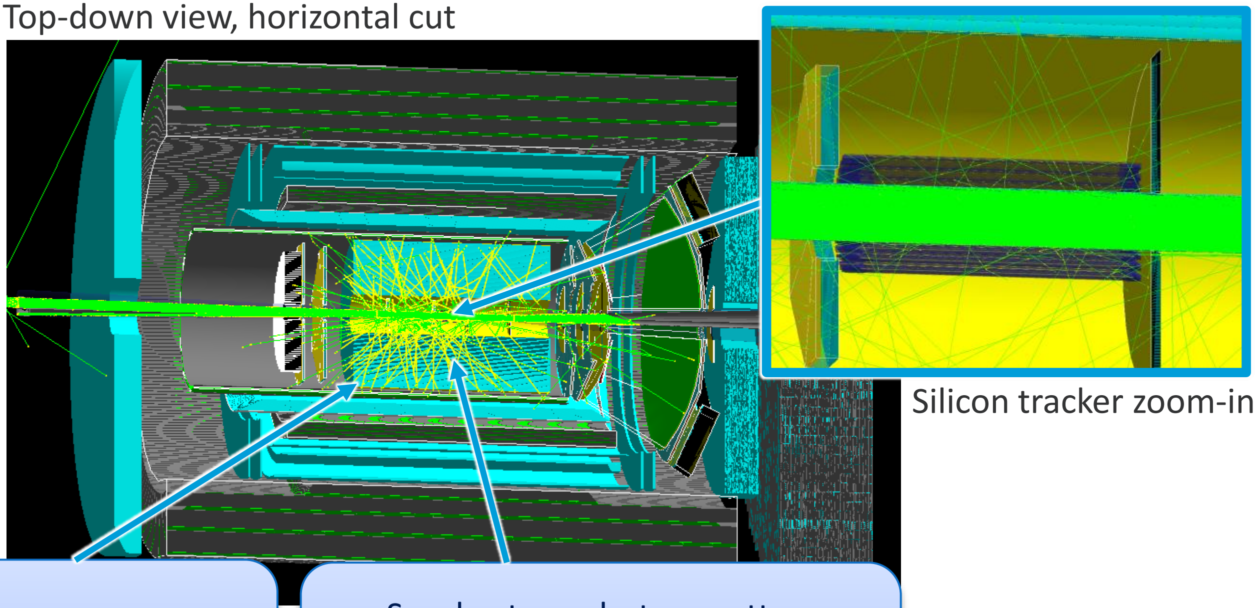
Ref: ALICE ITS commissioning run
Felix Reidt, QM2019

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



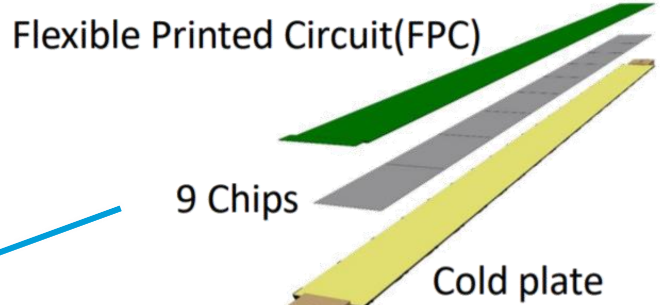
Silicon tracker zoom-in

Photons can go far beyond the beam line

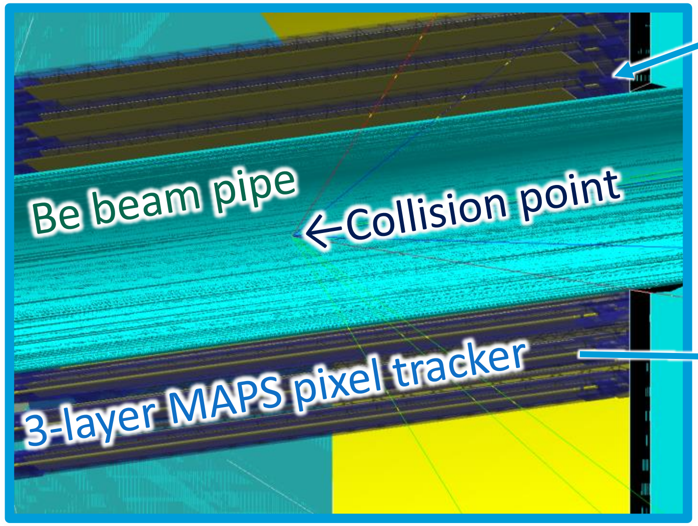
Synchrotron photon scatters through the low mass tracker PID region of central detector

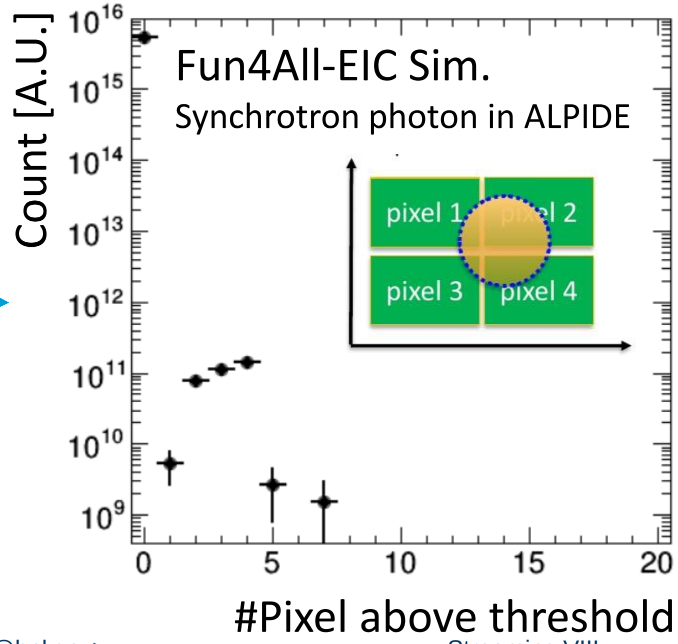
Synchrotron background: detector response

- 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





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**

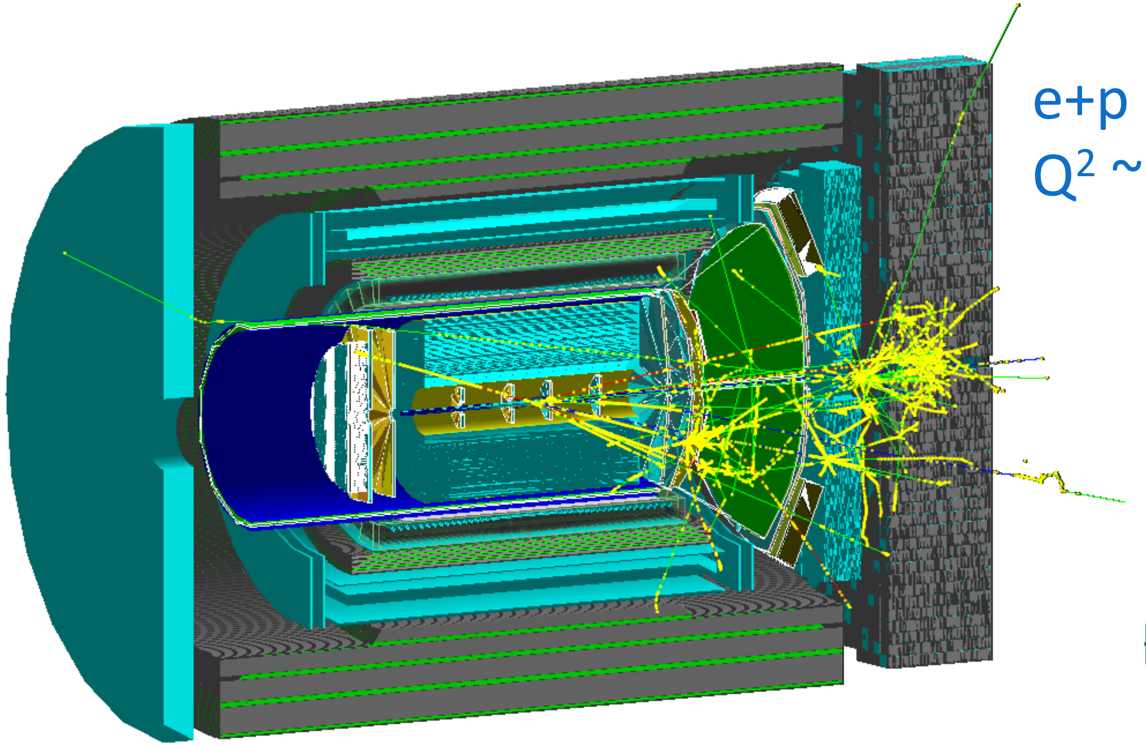
Beam [GeV]	HERA	5 x 50	10 x 100	18 x 275
Q^2>10^{-9} GeV	65.6	**29.9**	**41.4**	**54.3 ub**
Q^2>1 GeV	1.29	0.45	0.65	0.94 ub

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

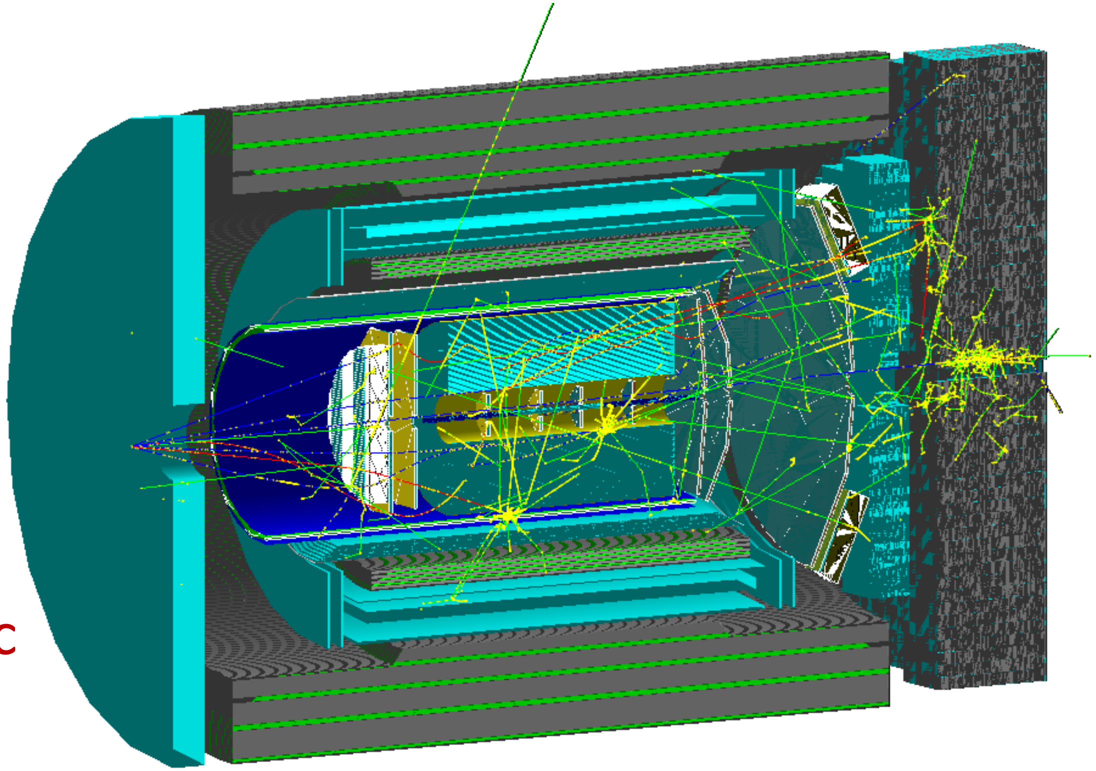
E_p:	50 GeV	100 GeV	275 GeV	920 GeV
	38.4 mb	**38.4 mb**	**39.4 mb**	41.8 mb

EIC DAQ in Geant4 simulation

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



e+p DIS 18+275 GeV/c
$Q^2 \sim 100\ (\mathrm{GeV}/c)^2$



Beam gas event
p + p, 275 GeV/c
at z=-4 m

Data Rate

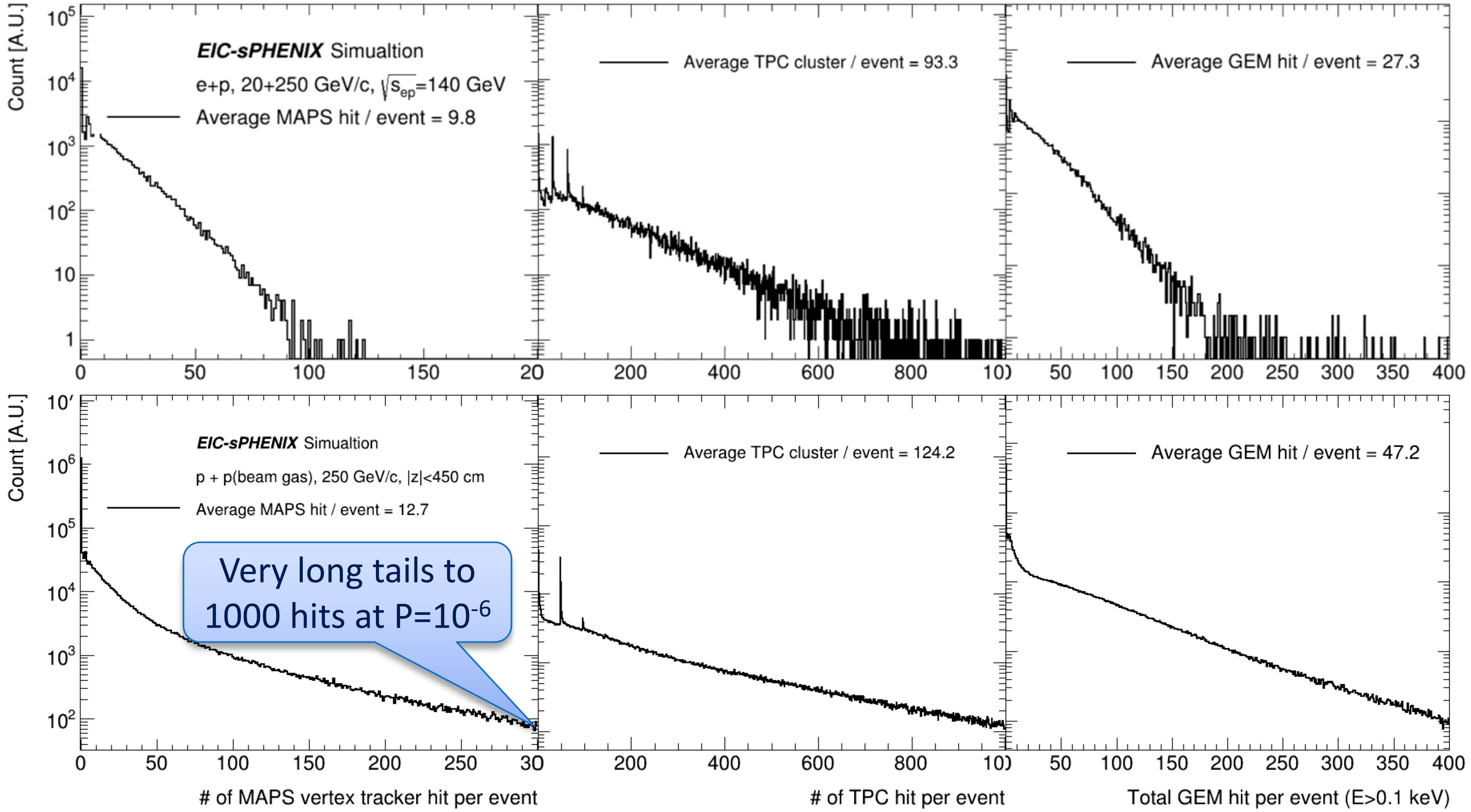
MAPS silicon tracker
Raw data: 16-24 bit / MAPS hit
(3-layer ALPIDE model)

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

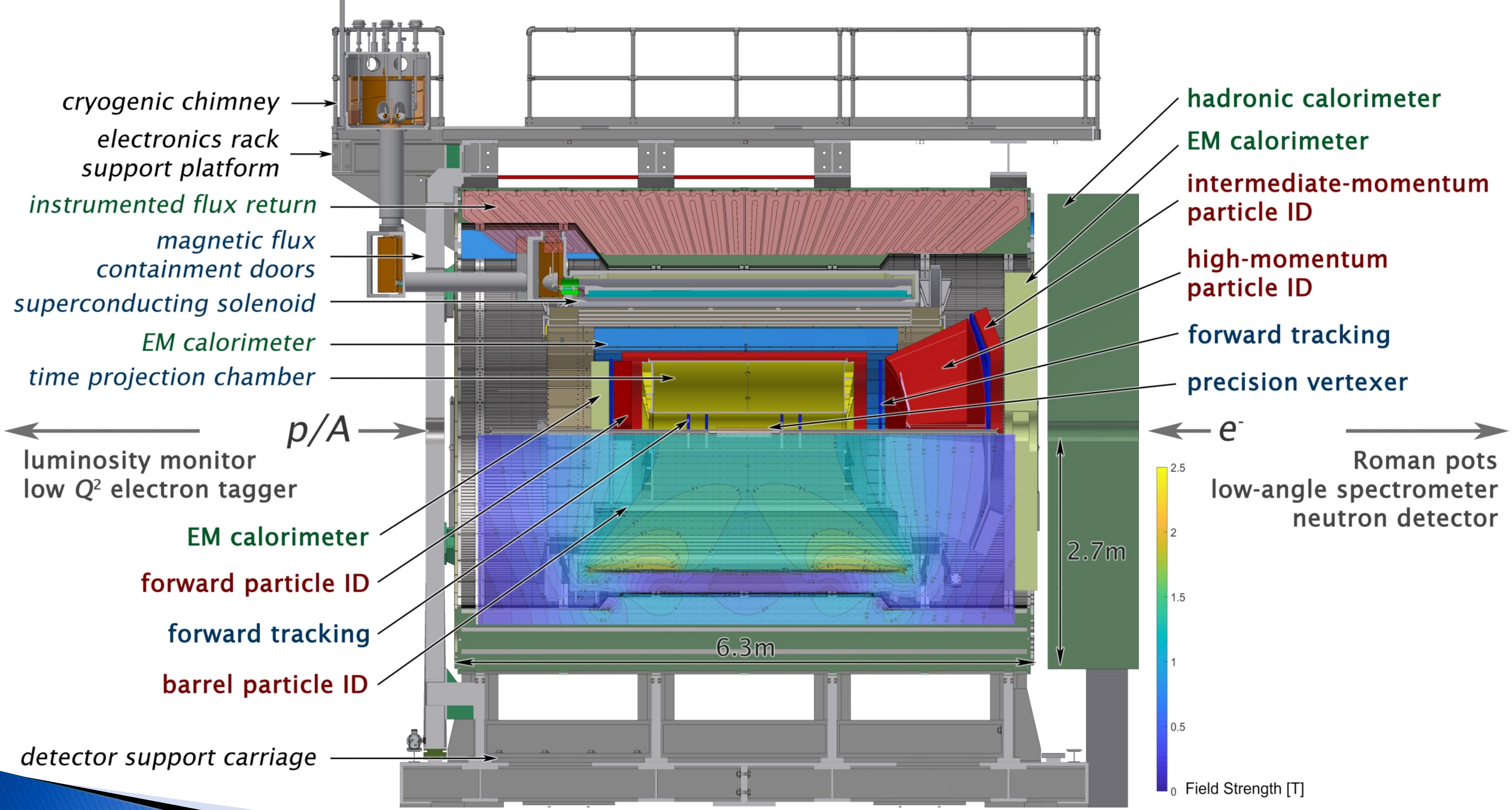
Forward/backward GEM
Raw data: 3x5 10 bit / GEM hit
+ headers (60 bits)

e+p, Pythia6 Q2>0

p+p(gas) Pythia8

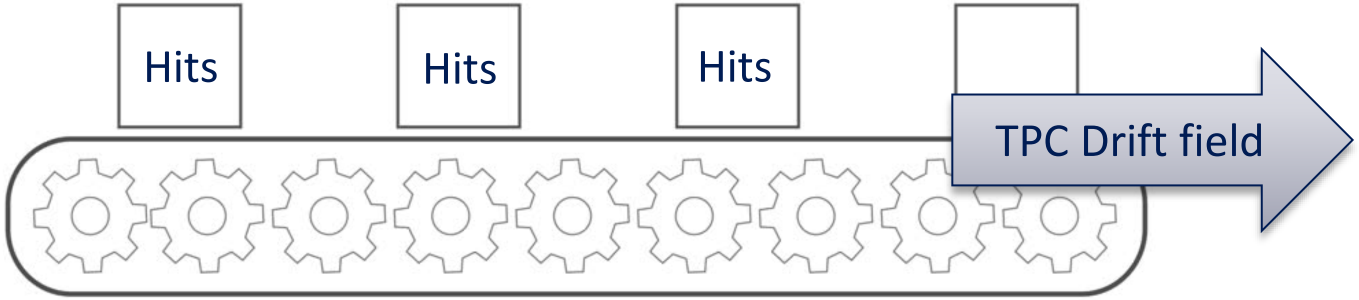


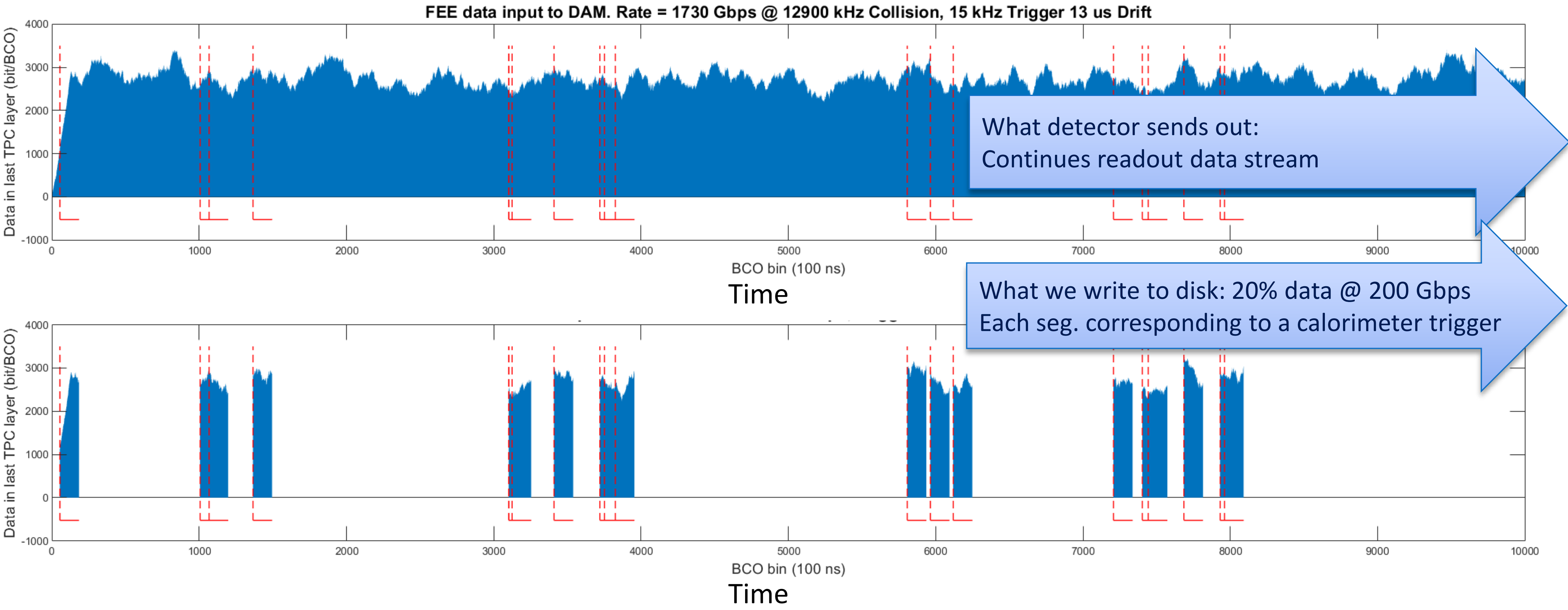
Refs: sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/



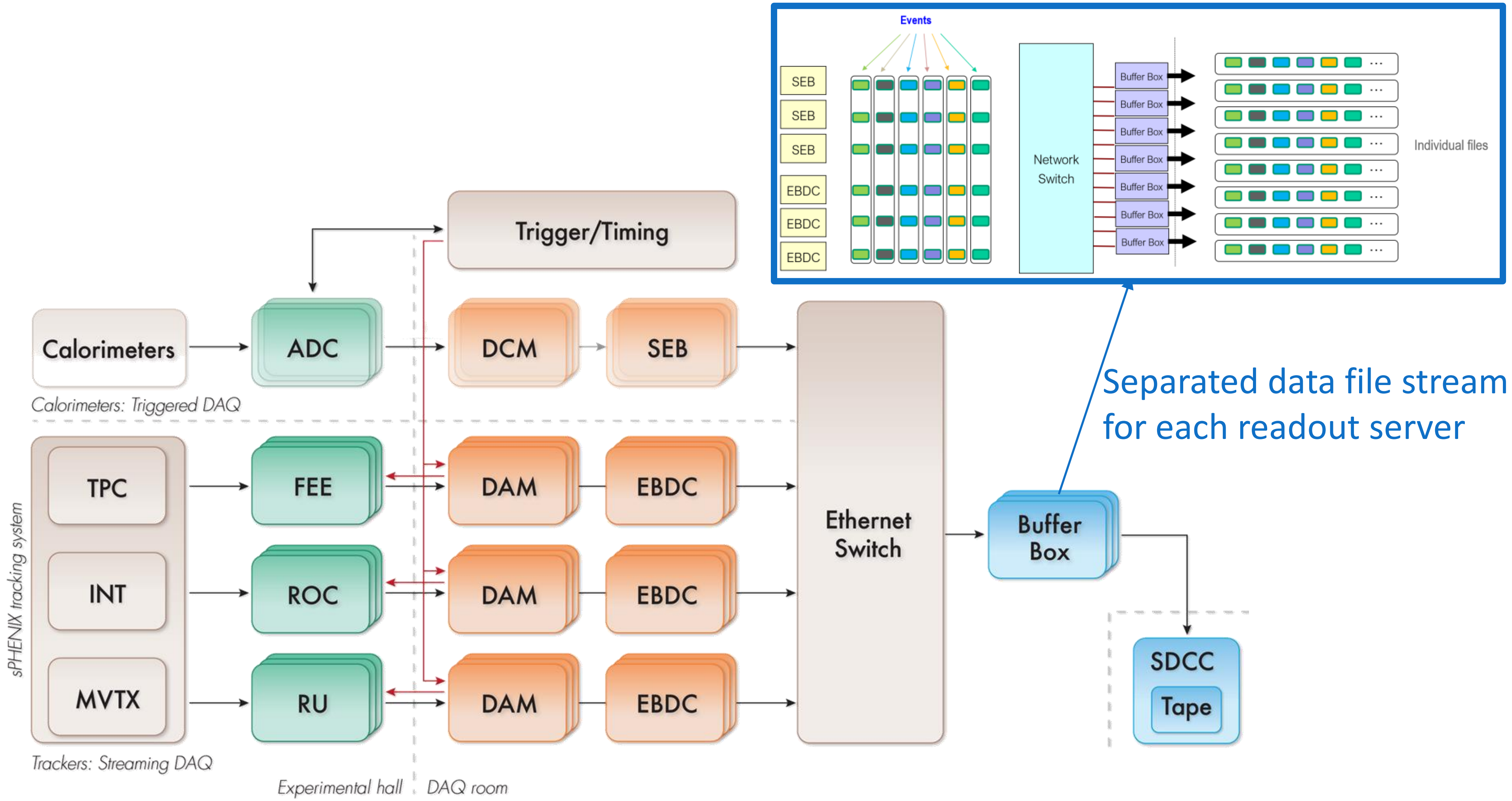
cryogenic chimney
electronics rack support platform
instrumented flux return
magnetic flux containment doors
superconducting solenoid
EM calorimeter
time projection chamber
p/A
luminosity monitor
low Q^2 electron tagger
EM calorimeter
forward particle ID
forward tracking
barrel particle ID
detector support 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



See Collaboration meeting DAQ talk by M. Purschke