# An EIC DAQ Strategy

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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 | 107 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
- Lower collision rate and small event size → signal data rate is low
- But events are precious and have diverse topology. Background and systematic control is crucial

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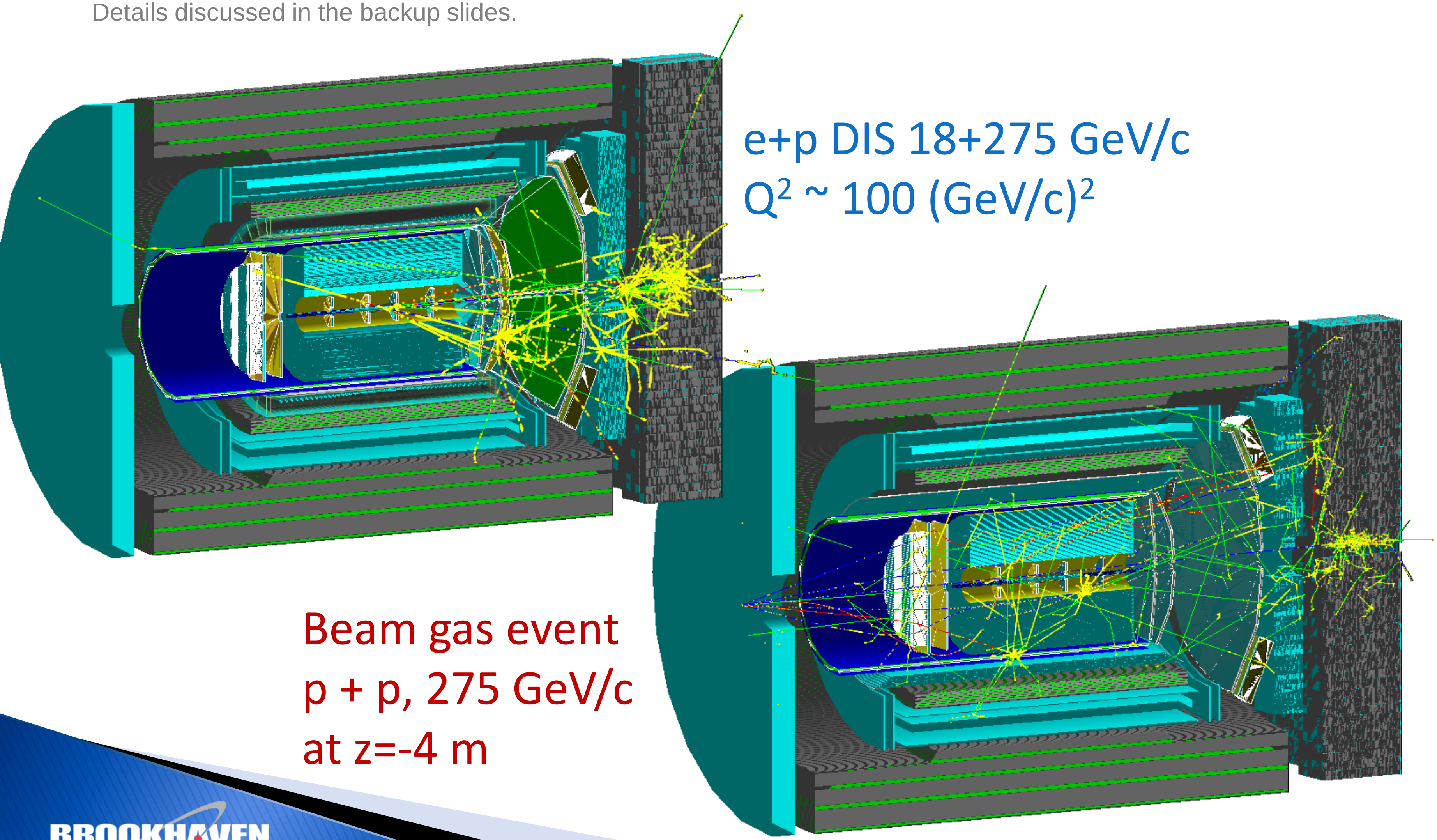
# EIC DAQ in Geant4 simulation

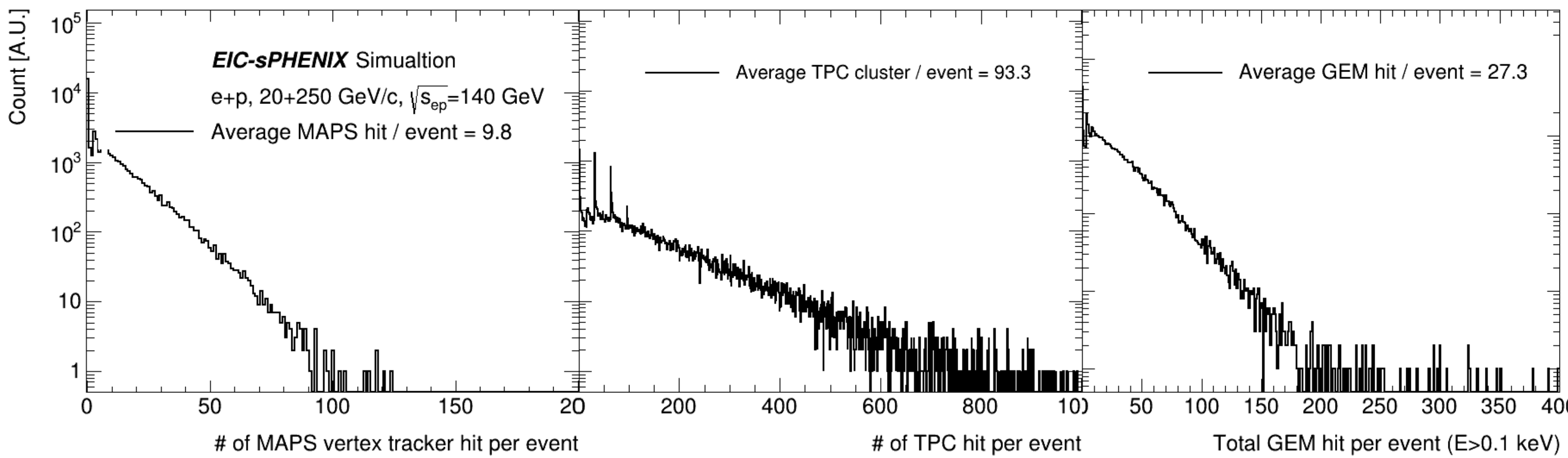
Note sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/ , Simulation: https://eic-detector.github.io/
Details discussed in the backup slides.



# GEANT4-based detector simulation for DAQ simulation: tracker

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

Extract mean value/collision that produces average signal data rate and tails that produce the buffer depth and latency requirements




Raw data: 16 bit / MAPS hit

3x10 signal hit / collision → 0.2 Gbps @$10^{34}$ $cm^{-2}s^{-1}$

- MAPS is vulnerable to beam background see later slides
- ALPIDE MAPS noise are moderate, see later slides too

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

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

See backup slides for full set of detectors

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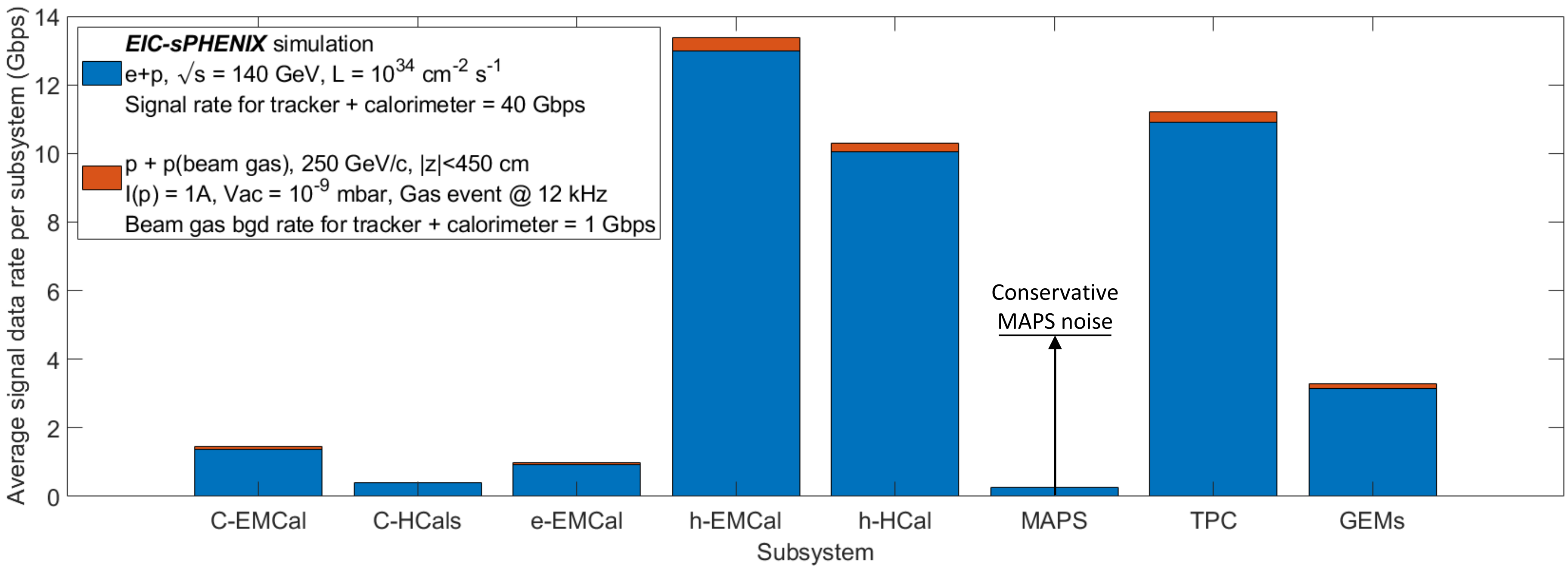
# Sum everything so far

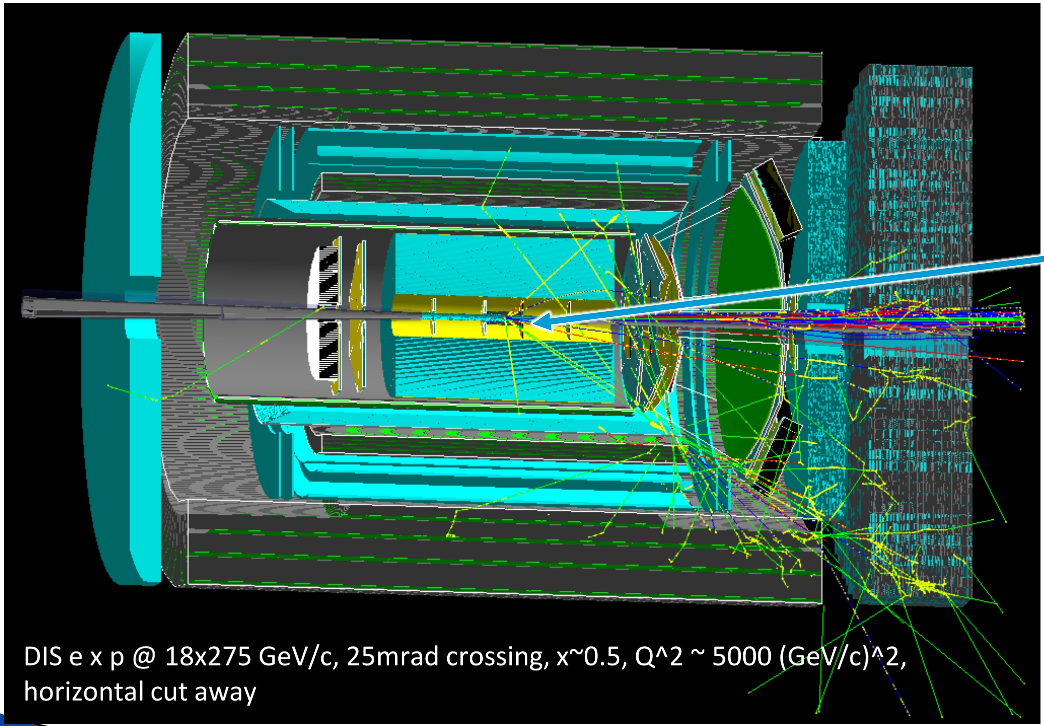
sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/ , Simulation: https://github.com/sPHENIX-Collaboration/singularity

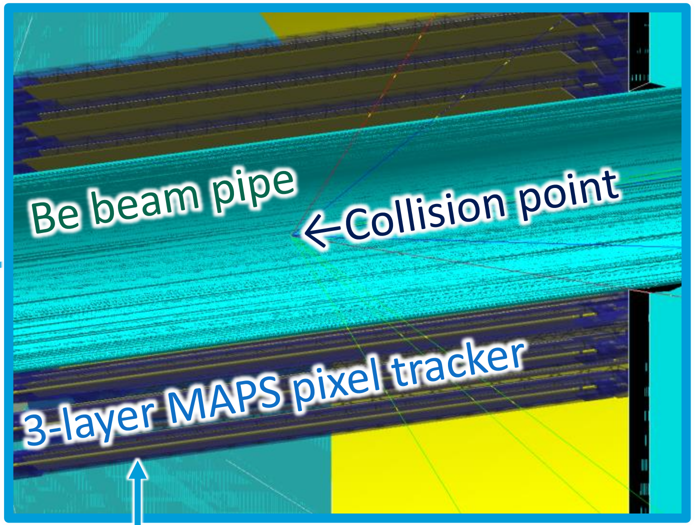
- What we want to record: total collision signal ~ 100 Gbps @ $10^{34}$ $cm^{-2}$ $s^{-1}$ less than sPHENIX peak disk rate
- Consider it an evolving estimation with EIC detector design and their intrinsic noise
- For YR studies over the coming ½ year
  - Need to include realistic PID simulation and far forward instrumentation
  - Need to include as much as other source of background and noises (e.g. synchrotron)



# Synchrotron background: vac chambers

- Mar-2020 EIC 25mrad beam pipe and vac chamber (details)
- Incorporated in simulation: Link to note w/ details



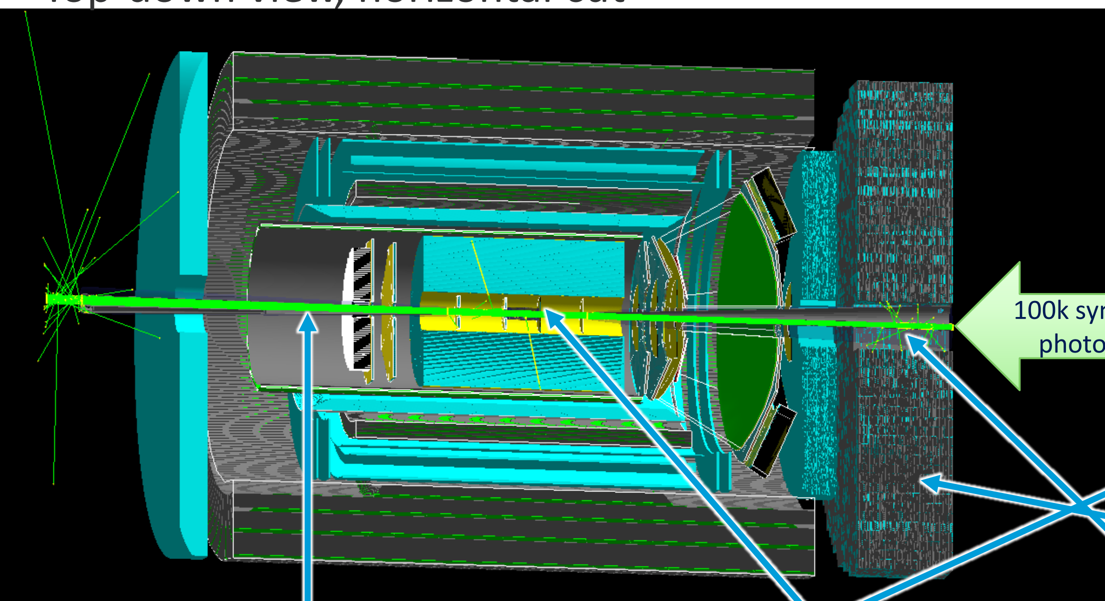




sPHENIX/ALICE ALPIDE ASIC model:
Geant4 transport (1.8 keV photon threshold for Be pipe)
-> energy loss trail in active silicon
-> produce ionization trail -> ionization diffusion
-> map to readout pixels -> electronics threshold
-> Pixel hit -> ALPIDE data format
-> Data rate

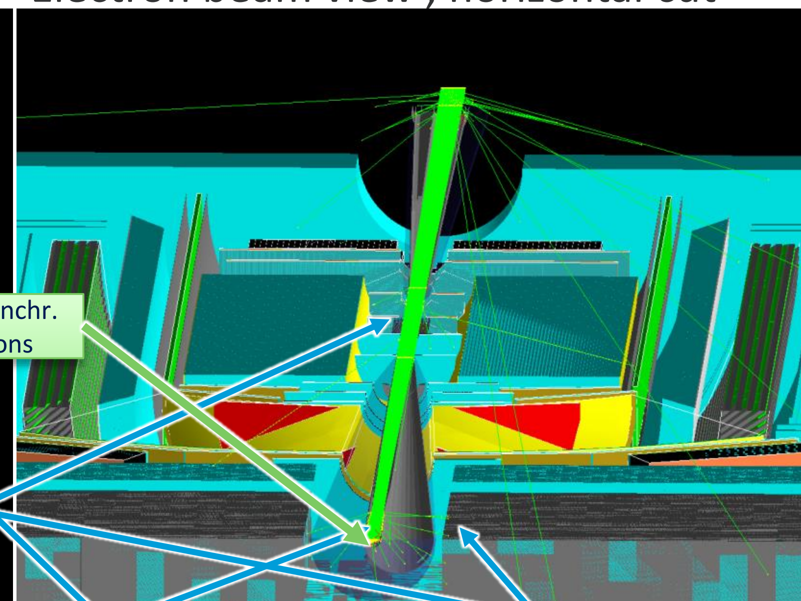
# Synchrotron background: on-going

- SynRad synchrotron photon source within the vacuum by EIC accelerator experts: Charles Hetzel (BNL) and Marcy Stutzman (JLab)
- On-going work: run more statistics and demonstrate control of normalization

Top-down view, horizontal cut




Electron beam view , horizontal cut



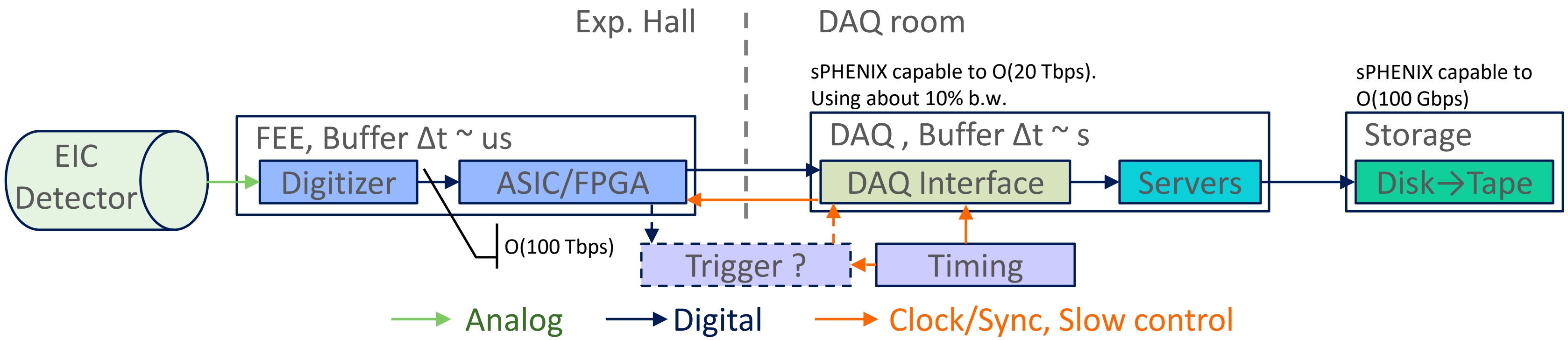
After photon absorber, most photon pass through detector region without interaction

Some photon fly out and hit detector near and far. Need stat. to quantify

Photon absorber in vac chamber, z=3.3-4.5m

Hits in inner bore of forward hadronic calorimeter

# A strategy for an EIC real-time system



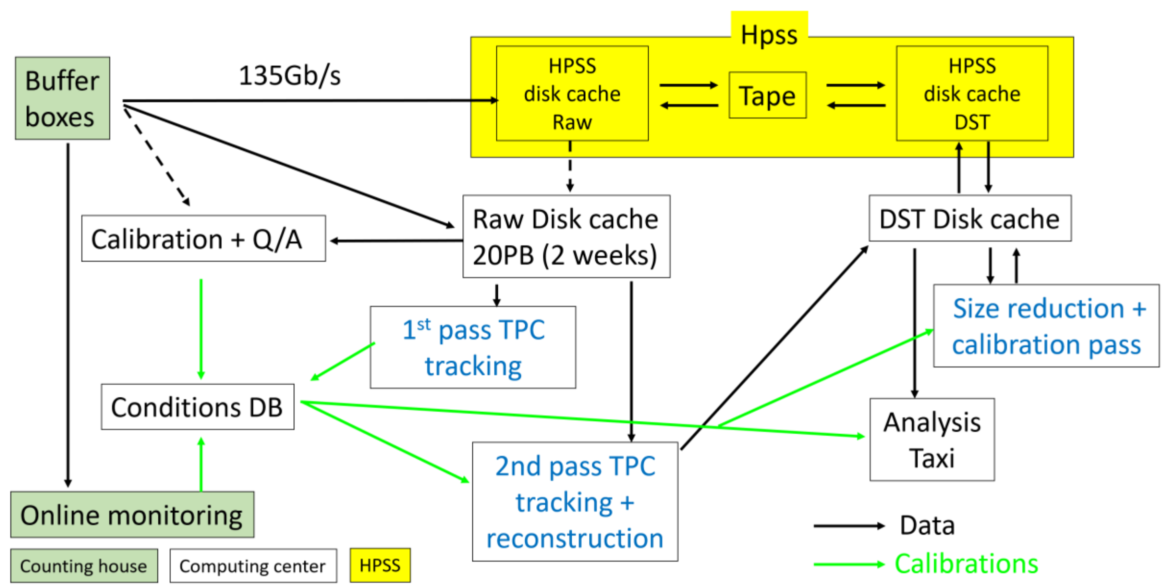

- For the signal data rate from EIC (100 Gbps), we can aim for filtering-out and streaming all collision in raw data without a hardware-based global triggering
  - Diversity of EIC event topology → streaming DAQ enables expected and unexpected physics
  - Streaming minimizing systematics by avoiding hardware trigger decision, keeping background and history
  - At 500kHz event rate, multi-µs-integration detectors would require streaming, e.g. TPC, MAPS
- Requirement
  - All front-end to continuously digitize data or self-triggering
    e.g. PHENIX FVTX, STAR eTOF, all sPHENIX trackers, any many prototypes in eRD23 consortium
  - Reliably synchronize all front-ends and identify faults
  - Recording all collision data (100 Gbps if raw)
  - If needed, filtering out background with low signal loss ($10^{-4}$?)
  - Requiring reliable data flow → control systematics:
    Low data loss rate < $10^{-4}$(?) and/or loss in a deterministic manor

# Possible computing concept

Discussion see also talk: Graham Heyes

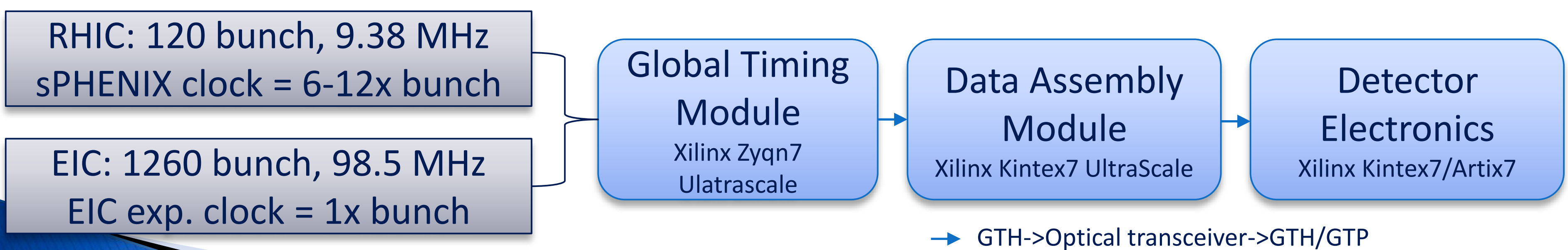
- With raw data on-disk, it would be possible use offline computing for prompt reconstruction:
  - Event software triggering in offline software
  - No-risk in data-loss, cost-effective infrastructure, redo w/ better calibration
- Calibration: limitation for both reconstruction and analysis
  - Particular difficult in initial years of EIC
  - May take multiple reconstruction iteration for calibration alone (e.g. for TPC)
    e.g. sPHENIX buffer data for two weeks at computing center for calibration and prompt reconstruction

sPHENIX computing plan
Link [sPH-COMP-2019-001]



# Timing and synchronization

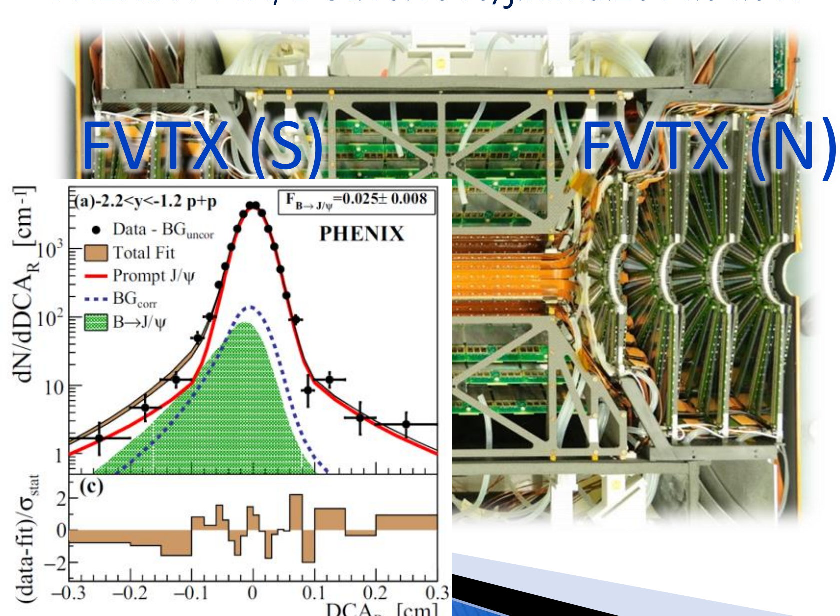
- Precision timing is relative (e.g. ToF, TPC, coincidence), with exception that we need to know which bunch is colliding
- Therefore, collider experiment DAQ and FEE usually sync to beam bunch RF/collision clock
  - Then we need to be able to handle variation in beam clock. EIC clock variation seems simpler than RHIC (no ramp, weaker energy dependence), but design still on going
- Current EIC RF design: modifying or rebuilding RHIC 28 MHz RF cavities as 24.5 MHz resonators → 1260 bunch, 98.5 MHz bunch clock
  - In discussion with RHIC RF group on testing sPHENIX timing distribution chain at RF clock source
  - On-going discussion on higher frequency bunch too (100-500MHz)
- Timing system also collect/distribute busy, to ensure loss is uncorrelated with event type



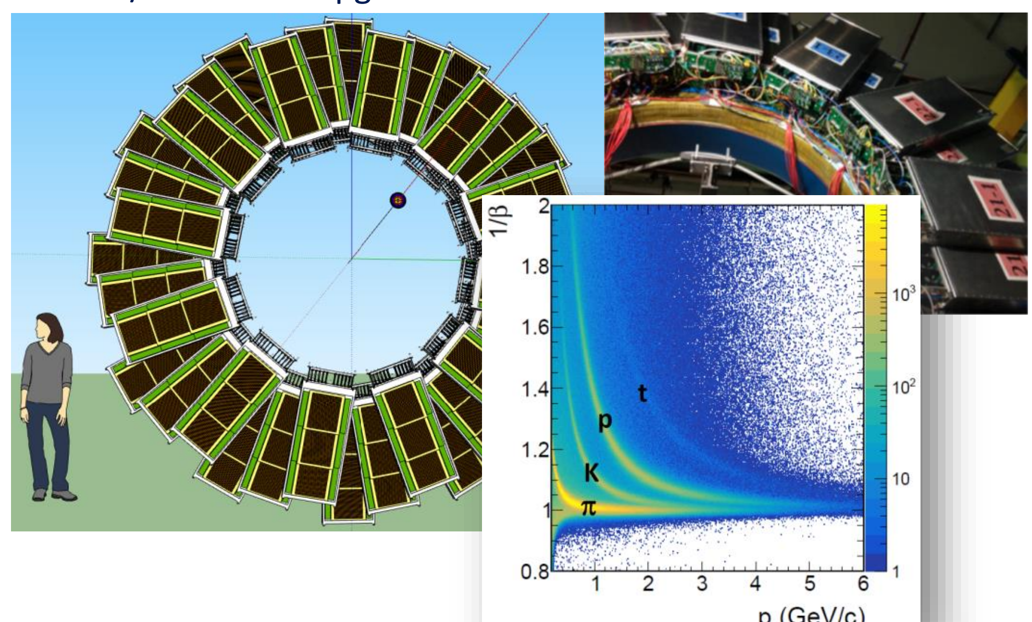
# Large streaming system in EIC community

- Important to exercise any streaming DAQ concepts in collider settings of comparable rates
- Individual streaming detector front-end successful operated at RHIC
  - PHENIX FVTX (2012-2016): later slides
  - STAR eTOF (2018 - on-going): see talk Friday Pierre-Alain Loizeau
- Future: BDX, CLAS12 @ Jlab (see talk Sergey Boyarinov, Lorenzo Campana), full tracking system setting at sPHENIX (later slides)

PHENIX FVTX, DOI:10.1016/j.nima.2014.04.017

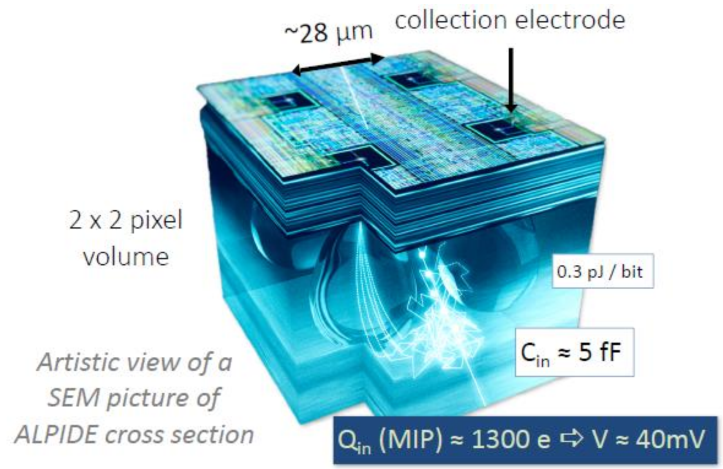


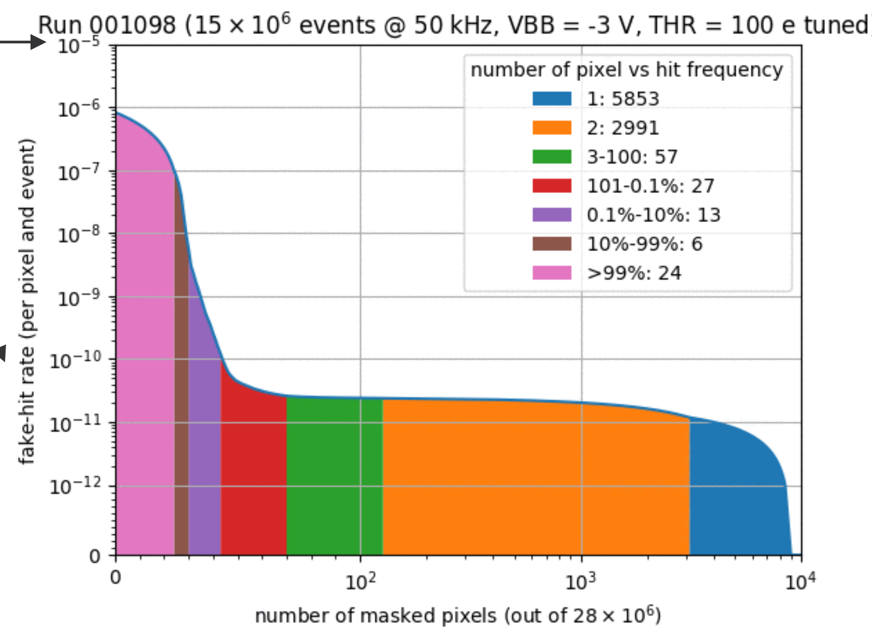

STAR/CBM eTOF Upgrade arXiv:1609.05102



# Detector 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 → 5 Gbps
  - $10^{-10}$ noise rate x 100kHz → negligible
- EIC DMAPS (need demo)
  - D. Neyret Mar 11: 10ns, noise < $10^{-9}$
  - $10^{-9}$ noise rate x 100MHz → ~1 Gbps
- Other detectors
  - Need to establish noise rate in large prototype
  - Online noise filtering w/ feature extraction
- Encouraging detector technology choice w/ low noise

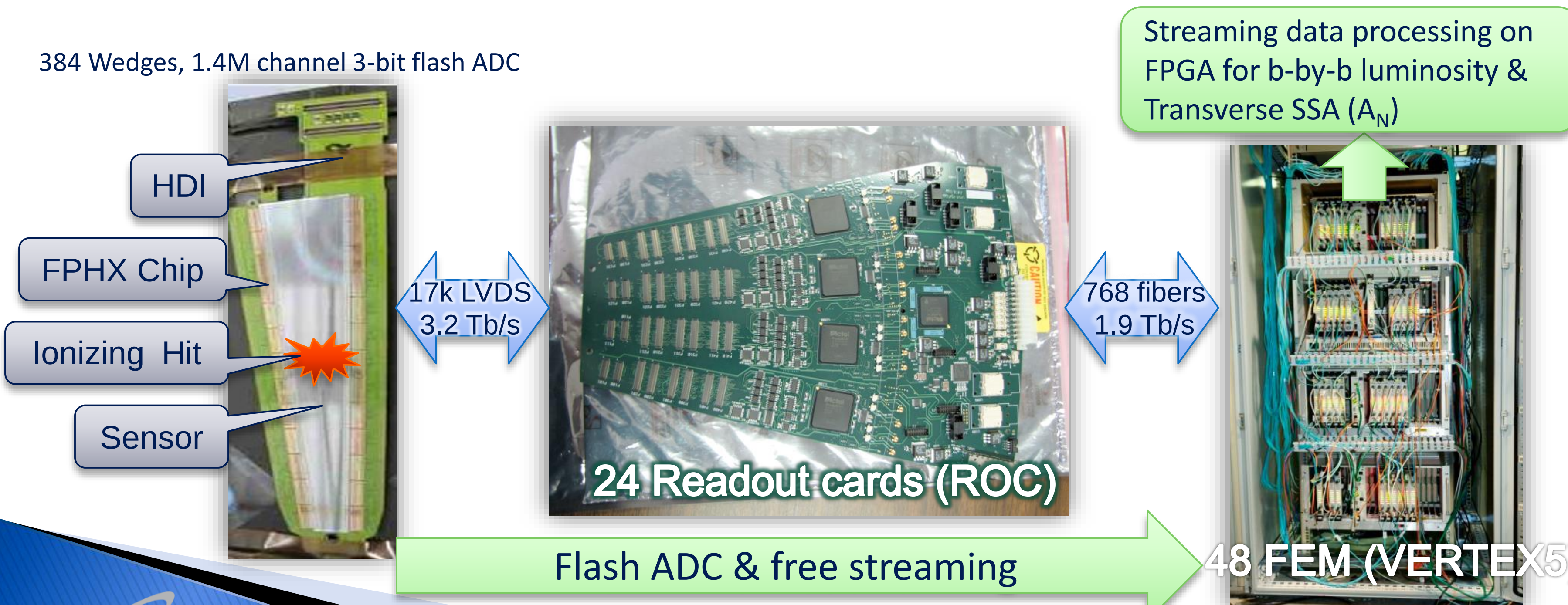


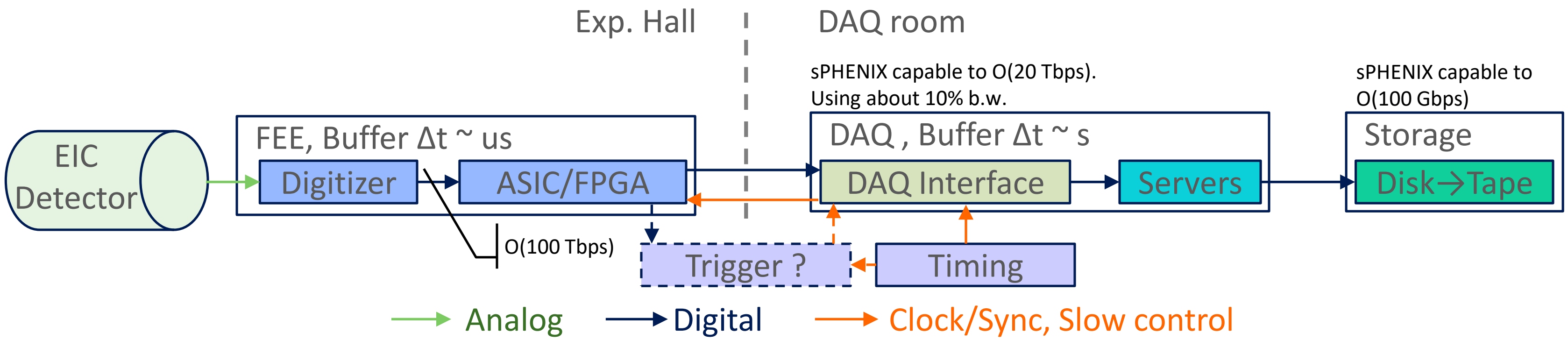

ALICE ITS commissioning run, from Felix Reidt, QM2019

# Noise control: a detector case study

- PHENIX FVTX (2012-2016) : DOI:10.1016/j.nima.2014.04.017
  1.4M channels, 3-bit flash ADC, zero-suppression on chip, Tbps streaming readout, FPGA-based simple analysis access full statistics, late-stage trigger throttled data stream for global event building
- Low noise (Z.S.>5σ noise) w/ digitization ASIC on detector, hits dominated by collision data
- Regular noise channel masking (suppress $10^{-4}$ problematic channels)
- Dedicated serial links/buffers in readout
- Buffer on server memory prior sending to shared network (TPC/IP network)
  Report low latency busy signal for back presure



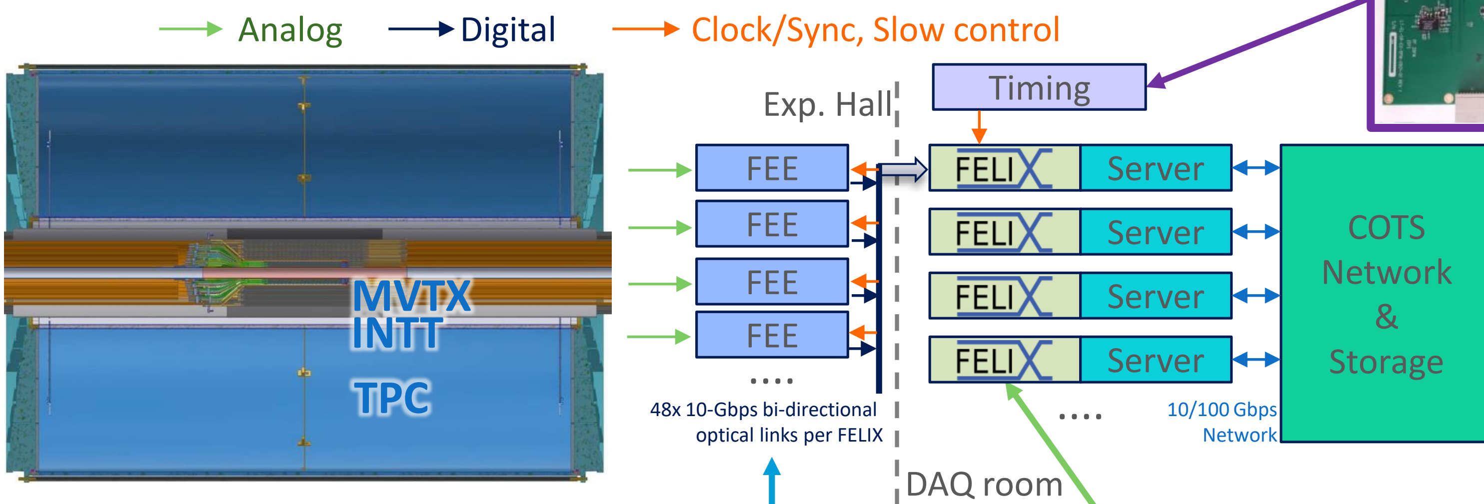
# Noise control: hybrid DAQ strategy

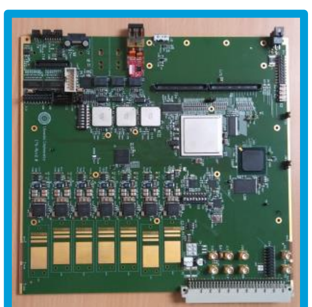



- At the start of EIC operation
  - Background could be significantly higher
  - Same time: lossy software data reduction is not yet established
- Possible solution at initial operation:
  Hybrid streaming readout with a calorimeter trigger
  - Many high profile EIC physics event leave distinct calorimeter signature for triggering (e.g. DIS/DVCS)
  - Use calo trigger to throttle streaming data to ensure lossless record full triggered event
  - Fill rest DAQ bandwidth with streaming data outside triggered time-window
  - Sliding scale adjust two data streams.
    Reference: LHCb Turbo stream, sPHENIX tracker DAQ (later this talk)
- Later running: Trigger/sync signal from the trigger components could be used for data validation and calibration
  - E.g. periodically send slow calibration/laser trigger pulses and collect non-zero suppressed data from for gain/pedestal calibration

# Streaming readout for sPHENIX trackers

- Hybrid with triggered calorimeters
- Supported by RCDAQ authored by Martin Purschke

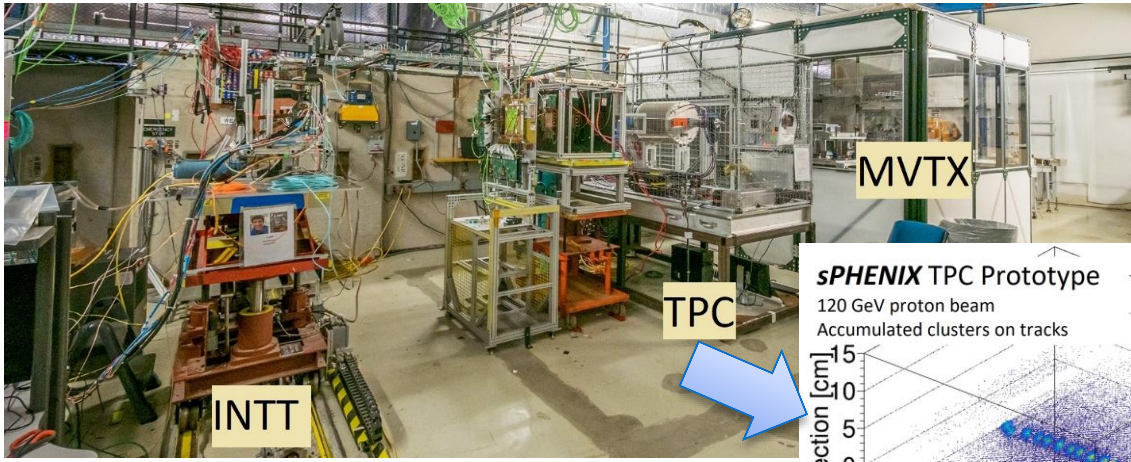
MVTX RU, 200M ch
ASIC: ALPIDE

INTT ROC, 400k ch
FPHX

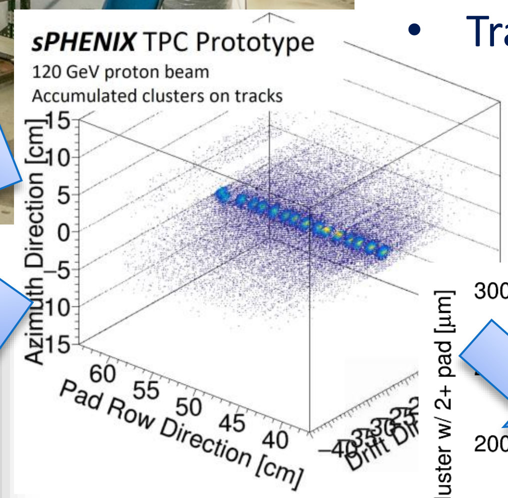
TPC FEE, 160k ch
SAMPA

BNL-712 / FELIX v2 x48
Streaming ASIC → DAQ @ 48x 10Gbps

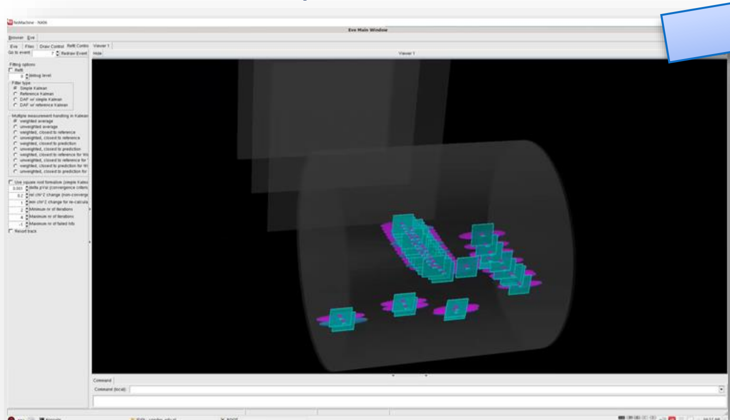
# Test beam in June 2019



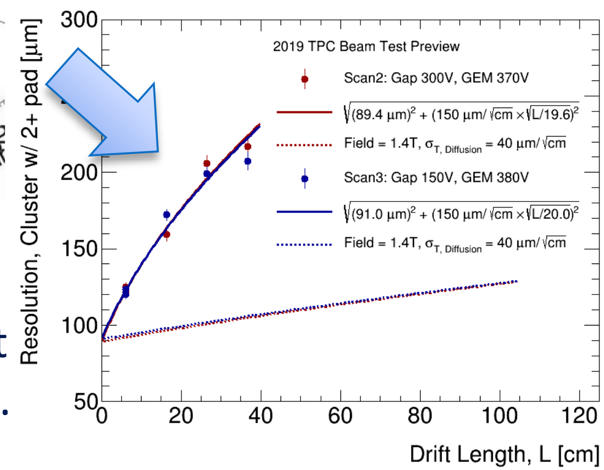

- 2k chan SAMPAv4
  (10b SAR 20MHz ADC + DSP)
- Clustering
- Track finding




Simulated response in Geant4



- Kalman-filter fit
- Resolution proj.



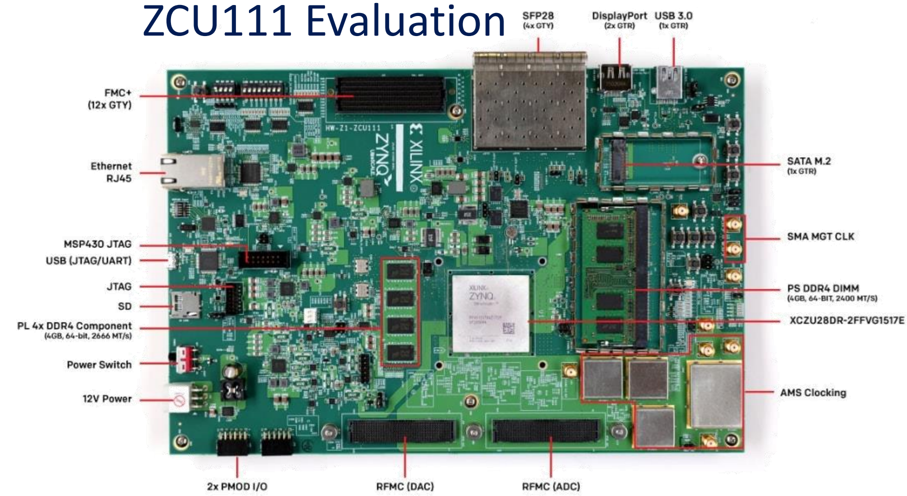

```
$ dlist  rcdaq-00002343-0000.evt -i
```
← SAMPA testbeam raw data via RCDAQ, courtesy M. Purschke

```
 -- Event     1 Run:  2343 length: 5242872 type:  2 (Streaming Data)  1550500750
Packet  3001 5242864 -1 (sPHENIX Packet)  99 (IDTPCFEEV2)$
```

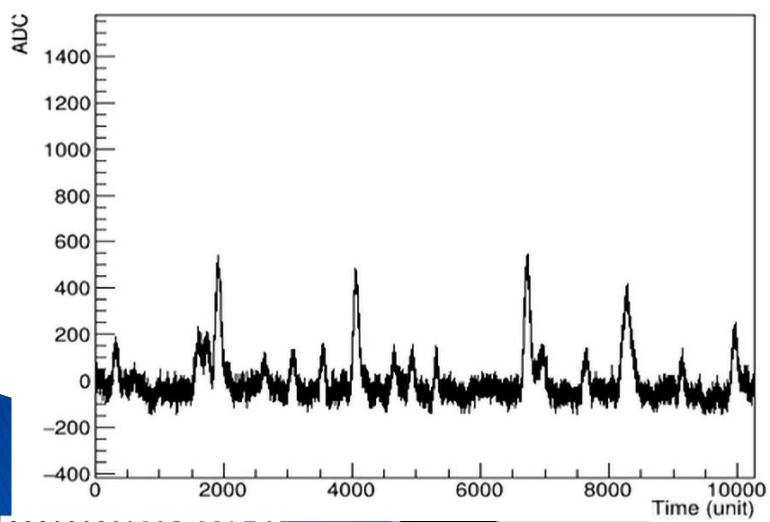
# New development: RFSoC

- RFSoC commercially available recently
- Xilinx Zynq RFSoC chip:
  8-16 chan ADC, 2-4Gsps,
  Ultrascale+ FPGA, ARM cores,
  multiple 25Gbps transceivers

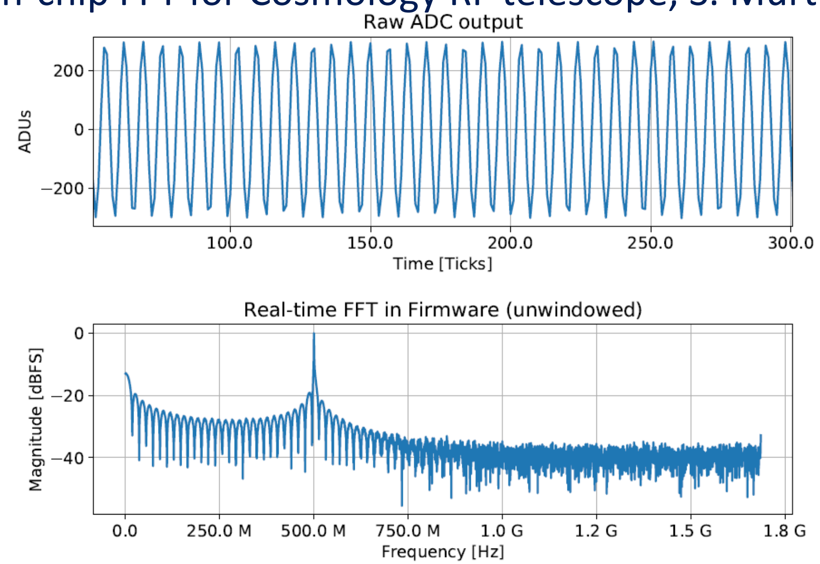
ZCU111 Evaluation




SiPM+EMCal preamp: single photon counting




On-chip FFT for Cosmology RF telescope, S. Murthy(BNL)



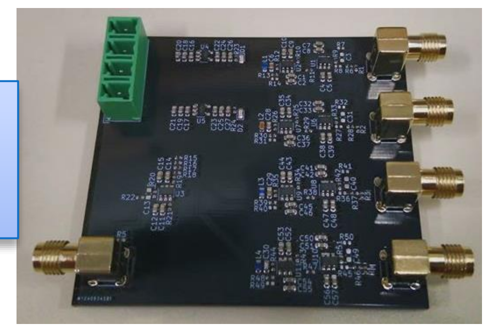
# New development: RFSoC for EIC

- Commercial board today: ~$1k/ADC channel, but fast evolving (Gen-3 out this year)
- Single chip ADC signal processing, noise suppression, feature building
- High density readout via analog multiplexer: Mishra et.al. NIMA 2018
  Transport and digitize multiple analog channels per ADC channel via frequency modulation

8-16 channel ZCU RFSoC (Avnet)

¼-1/8 reduction of data cables off calorimeter

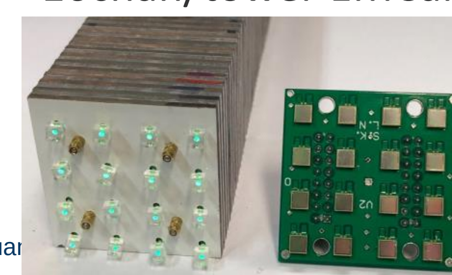
4→1 analog multiplexer prototype, S. Murthy(BNL)



On-detector

sPHENIX barrel EMCal, Signal cable

eRD1 UTFSM/BNL
16chan/tower EMCal

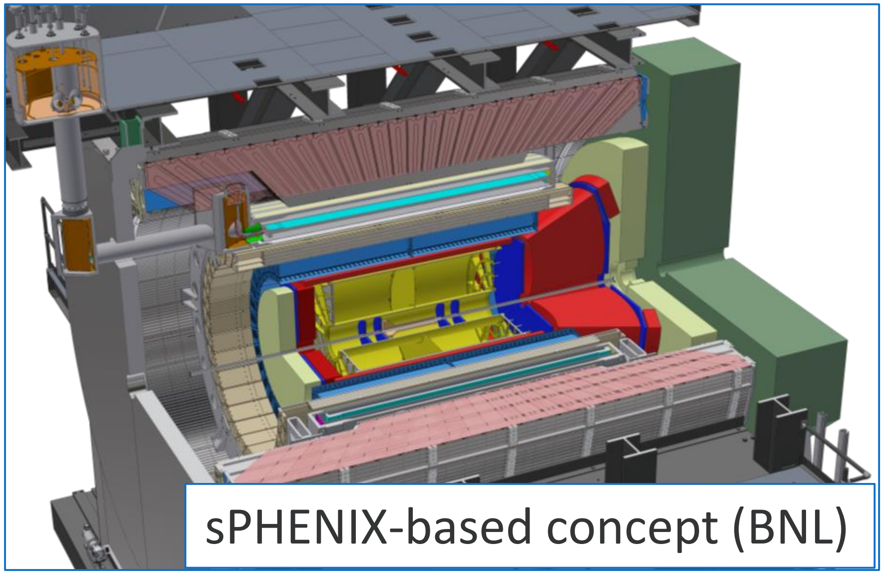


# Summary

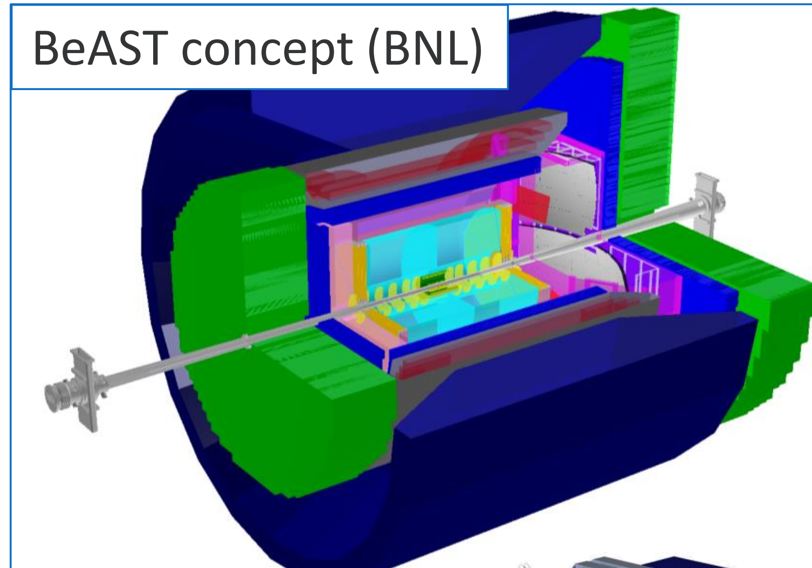
- DAQ driven by uniqueness of EIC, very different from fix target or LHC
- DAQ signal rate simulation for an EIC detector concept and streaming readout ASIC and FPGA systems
- Proposing a streaming DAQ requirement
  - All front-end to continuously digitize data or self-triggering
  - Reliably synchronize all front-ends and identify faults
  - Recording all collision data (100 Gbps if raw)
  - If needed, filtering out background with low signal loss ($10^{-4}$?)
  - Requiring reliable data flow → control systematics
- One DAQ strategy
  - Raw time-framed zero-suppressed data to disk, permanent storage in tape
  - Software event triggering and building @ offline: allow time for calibration, high stat. background timeframes for systematic estimation, and physics trigger not envisioned in running stage.
  - Key factor for analysis latency is calibration, e.g. TPC may require one iteration of reconstruction just for calibration purpose.

# Extra information

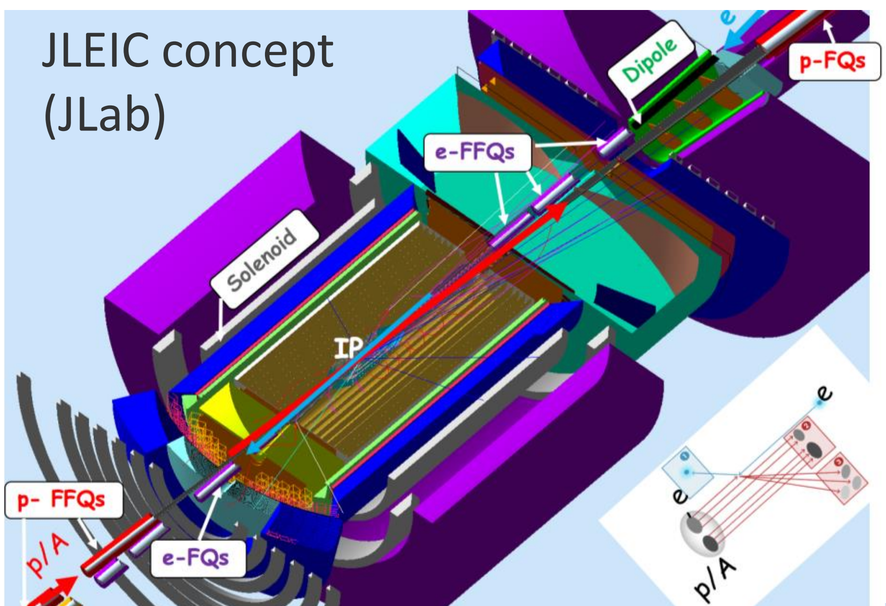
# Early EIC Detector Concepts



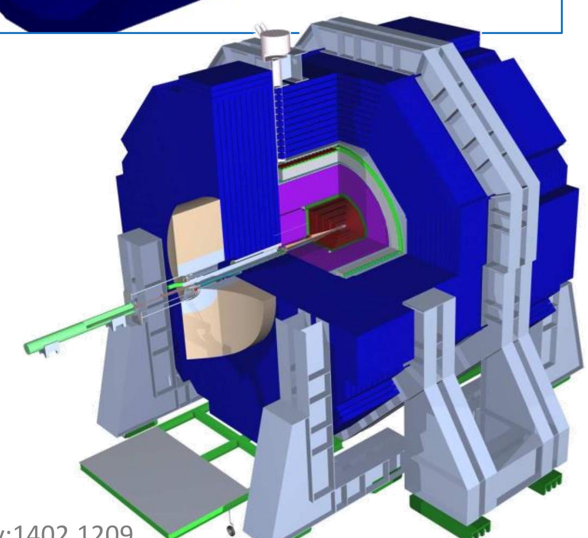
sPHENIX-based concept (BNL)



BeAST concept (BNL)




JLEIC concept (JLab)



TOPsiDE concept (ANL)

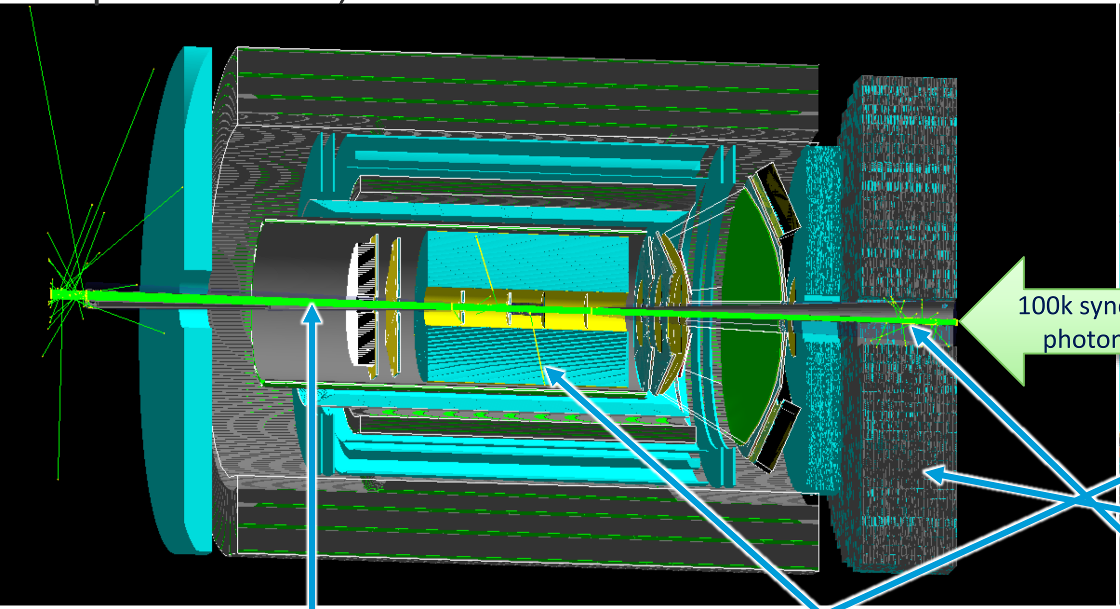
References reports :

- ePHENIX LOI: arXiv:1402.1209
- eRHIC design report, preCDR: arXiv:1409.1633
- MEIC (JLEIC) design summary: arXiv:1504.07961
- On-going development and updates

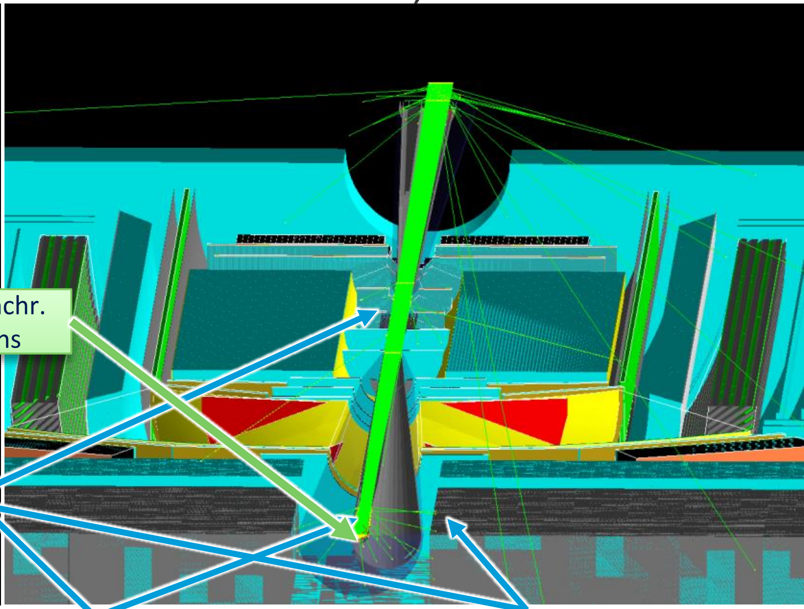
# Synchrotron radiation photon in detector simulation 1

- 100k SynRad synchrotron photon by Charles Hetzel
- Reproduce this from GitHub: macros / SynRad->HepMC reader

Top-down view, horizontal cut



Electron beam view , horizontal cut




After photon absorber, most photon pass through detector region without interaction

Some photon fly out and hit detector near and far. Need stat. to quantify

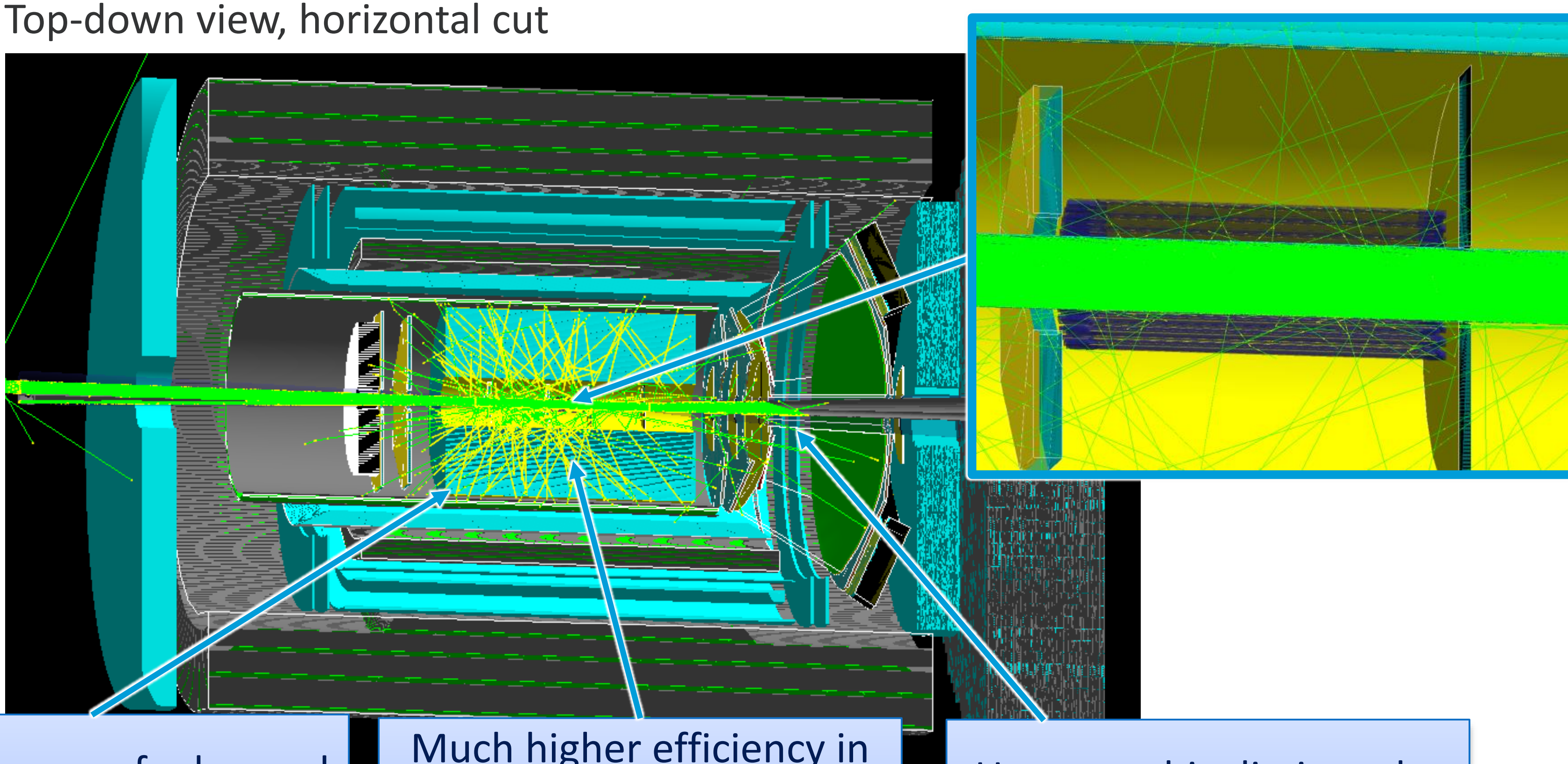
Photon absorber in vac chamber, z=3.3-4.5m

Hits in inner bore of forward hadronic calorimeter

# Synchrotron radiation photon in detector simulation 2

- 100k SynRad synchrotron photon by Marcy Stutzman, @ 1/36 cylindrical facet just inside the pipe, z= -2 - +2m
- Reproduce this from GitHub: macros / SynRad->HepMC reader

Top-down view, horizontal cut



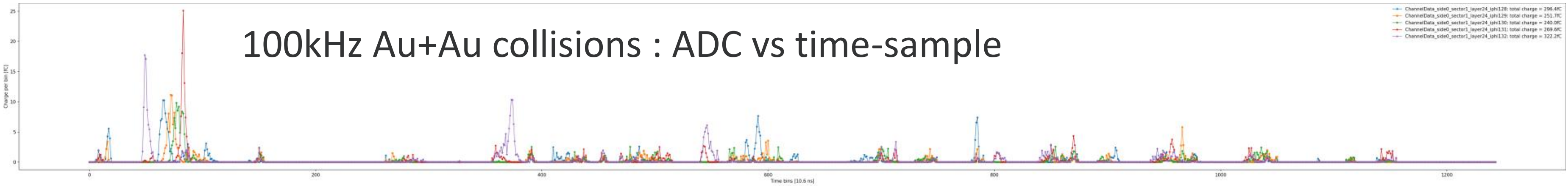
Photons can go far beyond the beam line

Much higher efficiency in filtering out photons that can generate detector hits

Upstream hits limit to the length of the facet

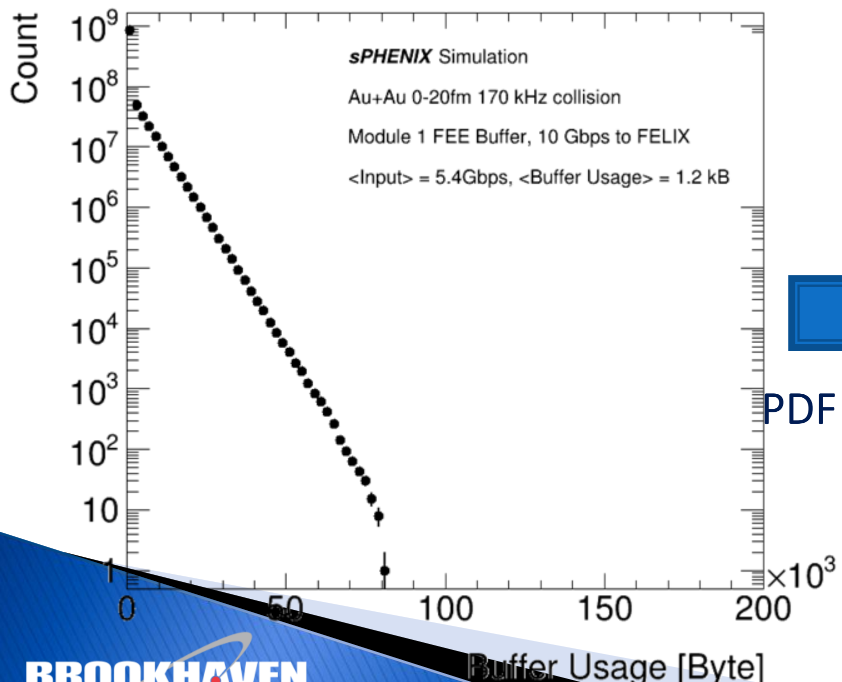
# Streaming readout sim. for TPC


- Based on Fun4All sim+reco framework: https://eic-detector.github.io/
- Steps: Pileup collision simulation → Geant4 ionization e-loss → generate initial ionization → parameterized drift → GEM amplification sim → readout zigzag strip mapping → SAMPA shaping + noise baseline → SAMPA DSP zero suppression emulation → raw data wave packet
- TPC Streaming readout open dataset (270GB HDF5): https://www.phenix.bnl.gov/phenix/WWW/publish/jinhuang/sPHENIX/TPCMachineLearningData/

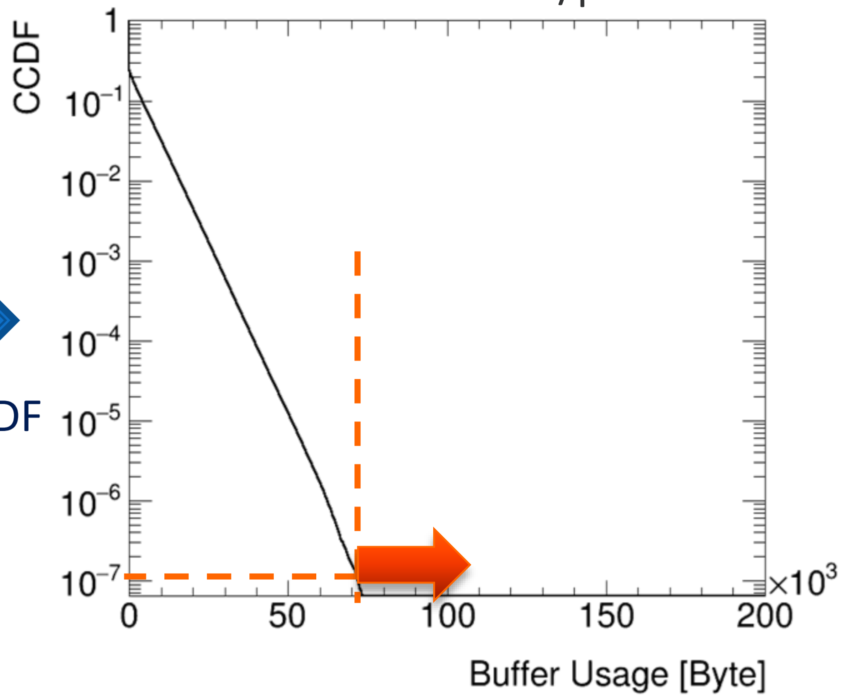
# Streaming readout buffer


- Raw data rate after zero suppression fluctuate due to event fluctuation, event size fluctuation and ionization density fluctuations
- Pumping simulated raw data wave packet through dedicated FEE→FELIX link using a continuous-time leaky-basket simulation
- For given streaming buffer size, we can give probability of FEE SRO FIFO buffer overflow
- Many more instance on FELIX, SAMPA (TPC) and ALPIDE (MAPS vertex) streaming buffer simulation in backup

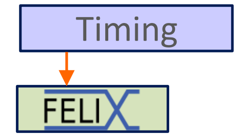



PDF -> CCDF

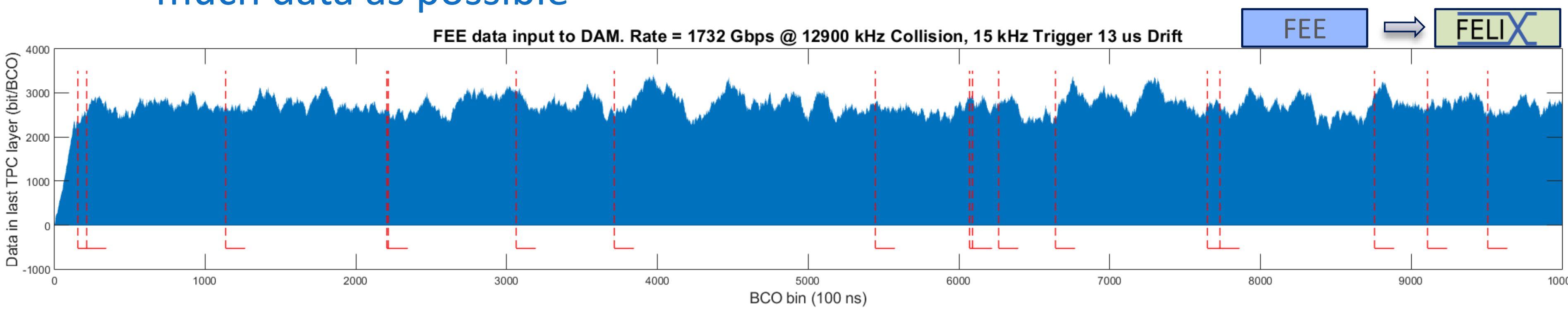
FEE SRO FIFO buffer overflow/μs vs buffer size

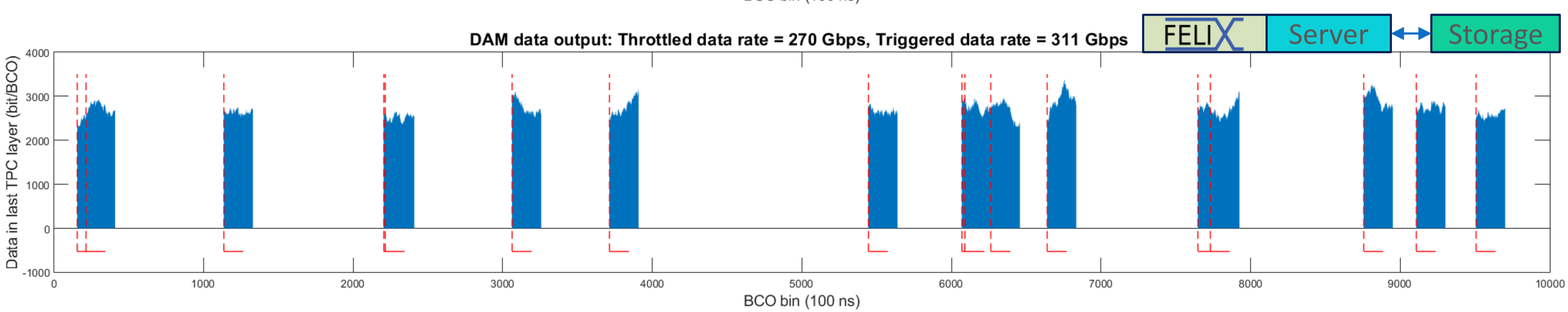


# Streaming/trigger hybrid DAQ for sPHENIX TPC




- The RHIC full collision data rate + lossless compression >> storage rate
- sPHENIX streaming tracker can record use calorimeter trigger as a data throttle for loss-less data reduction for triggered events + streaming as much data as possible



# Collision data rate

# Tonko's estimation:

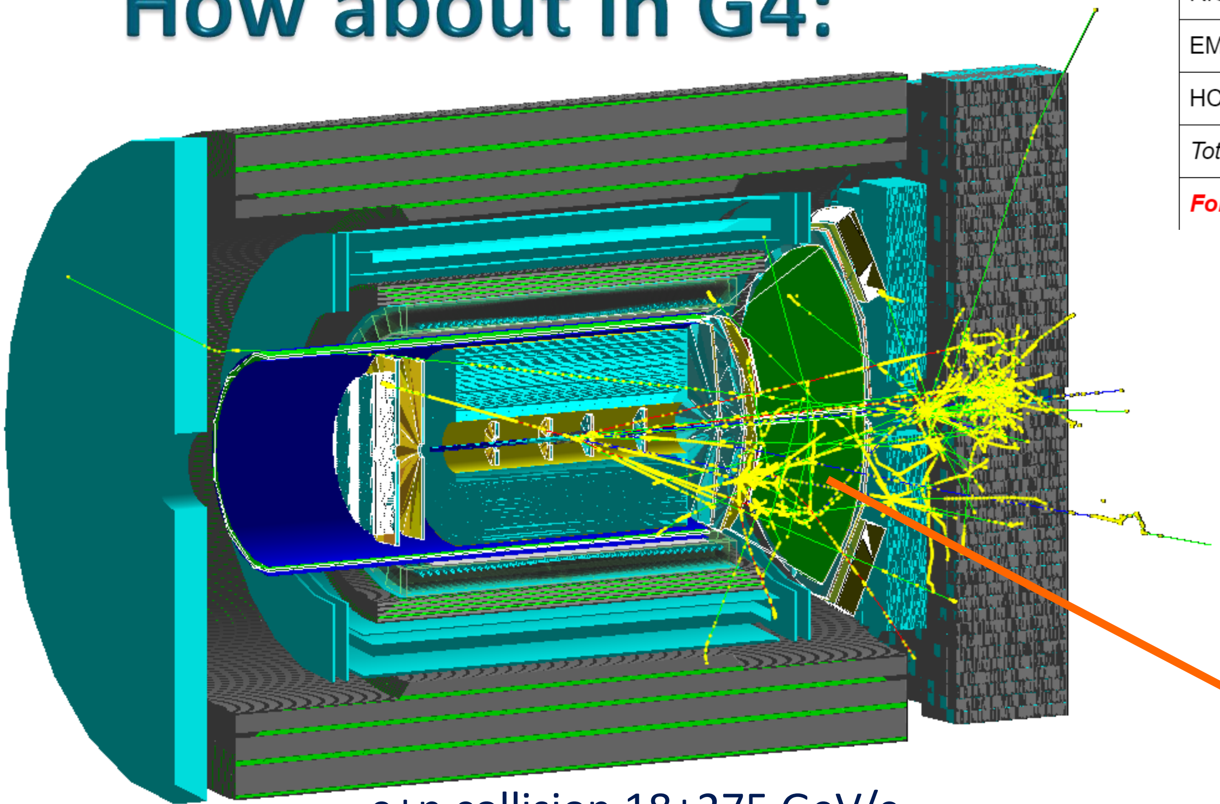
## Signal rate = 16*8 Gbps ~ 100 Gbps @ $10^{33}$ $cm^{-2}$ $s^{-1}$, 200kHz collision

# How about in G4:

Tonko's estimation (2015)

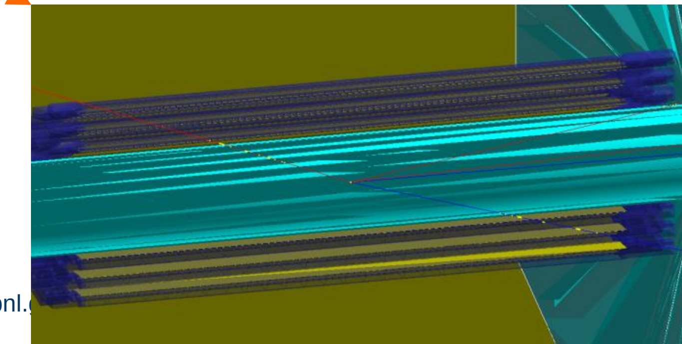
The eRHIC Detector ("BeAST") Readout Scheme

| Detector | Bytes per track |
|---|---|
| TPC | 100 x (80+4+4) ~ 9000 |
| Silicon | 7 x (4+4+4) ~ 90 |
| RICH | 20 x (4+4+4) ~ 250 |
| EMCal | 1 x (4+4+4) ~ 20 |
| HCal | 1 x (4+4+4) ~ 20 |
| *Total per track* | *9.4 kB* |
| ***For 1.7M tracks/s*** | ***(1.7M x 9.4 kB =) 16 GB/s*** |



e+p collision 18+275 GeV/c

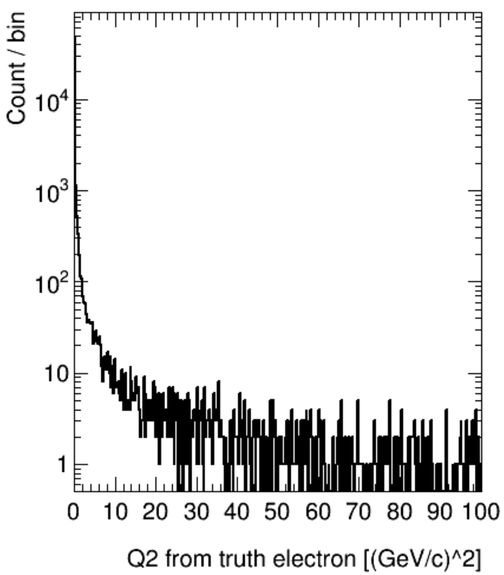
DIS @ $Q^2$ ~ 100 $(GeV/c)^2$

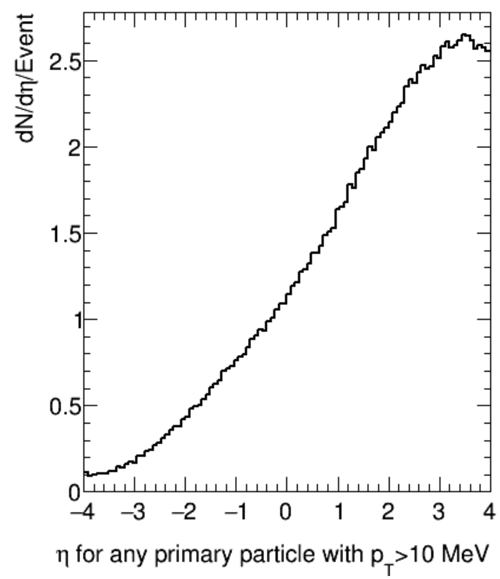


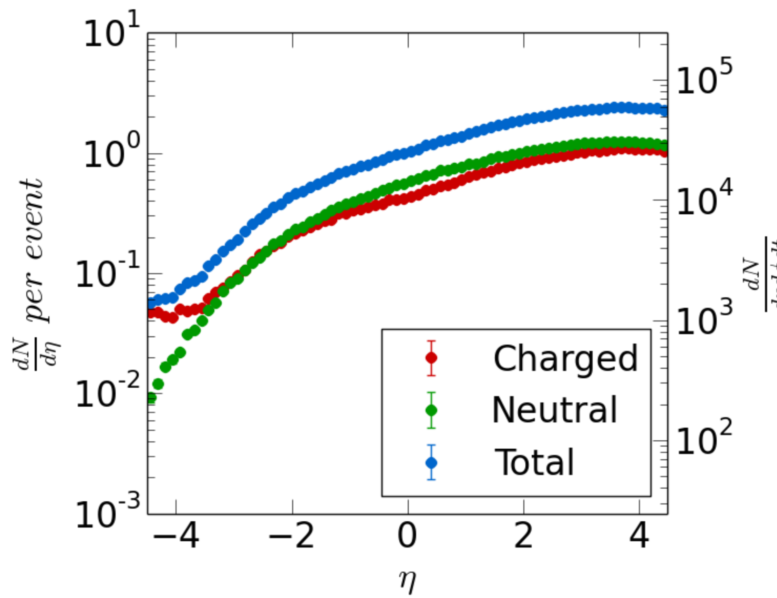
# Full detector “Minimal bias” EIC events in sPHENIX framework: quick first look

Multiplicity check for all particles
Minimal bias Pythia6 e+p 20 GeV + 250 GeV
53 µb cross section

BNL EIC taskforce studies
https://wiki.bnl.gov/eic/index.php/Detector_Design_Requirements



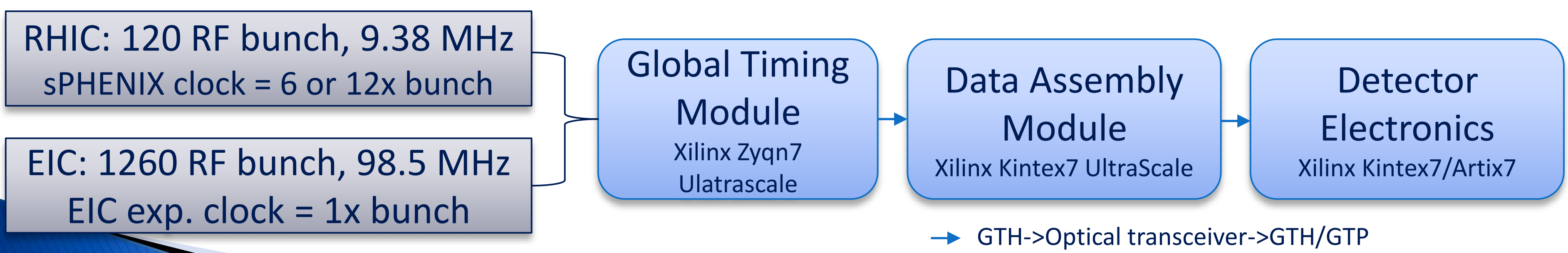




Based on BNL EIC task-force eRHIC-pythia6 55ub sample

```
pythia.ep.20x250.1Mevents.RadCor=0.root
CKIN(3)       changed from       0.00000 to        0.00000
CKIN(4)       changed from      -1.00000 to       -1.00000
```

# Timing and synchronization

- Precision timing is relative (e.g. ToF, TPC, coincidence), with exception that we need to know which bunch is colliding
- Therefore, collider experiment DAQ and FEE usually sync to beam bunch RF/collision clock
  - Then we need to be able to handle variation in beam clock. EIC clock variation seems simpler than RHIC (no ramp, weaker energy dependence), but design still on going
- EIC RF : modifying or rebuilding RHIC 28 MHz RF cavities as 24.5 MHz resonators
  - In discussion with RHIC RF group on testing sPHENIX timing distribution chain at RF clock source
- Timing system also collect/distribute busy, to ensure loss is uncorrelated with event type



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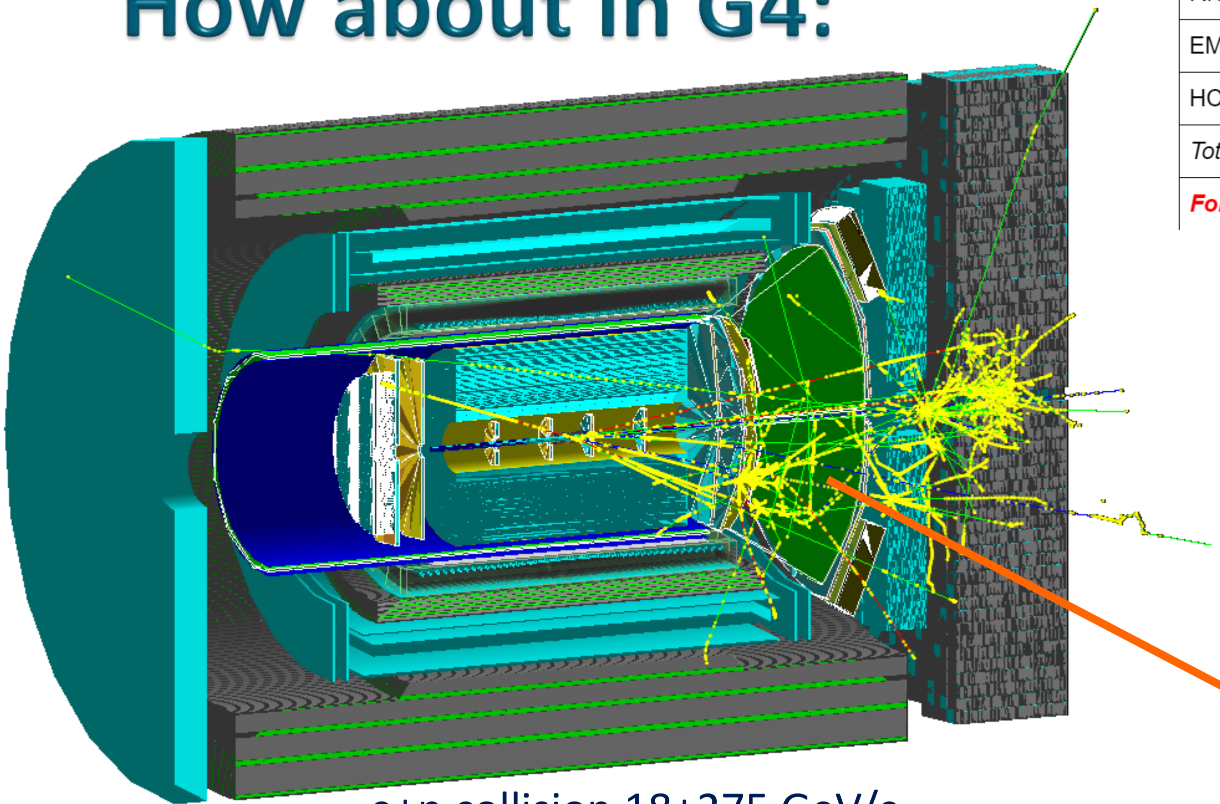

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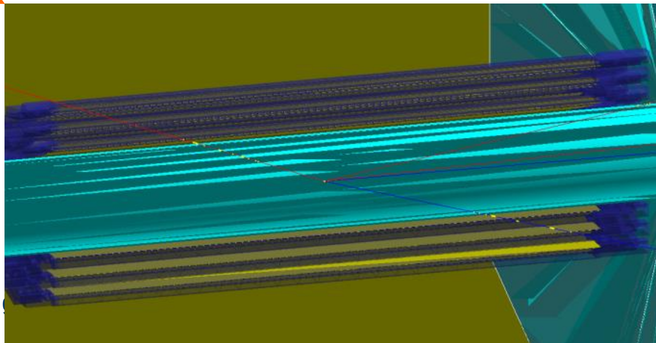

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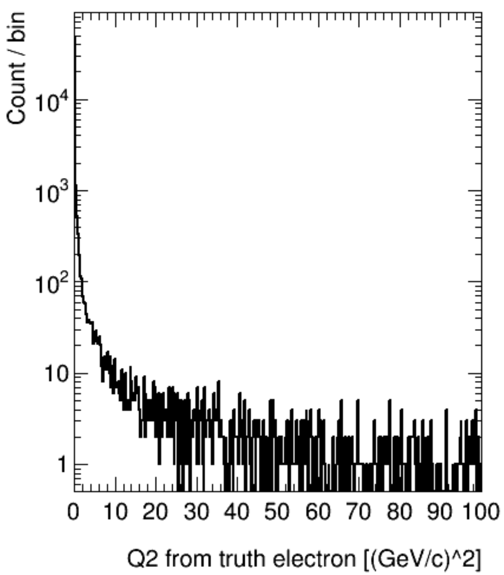


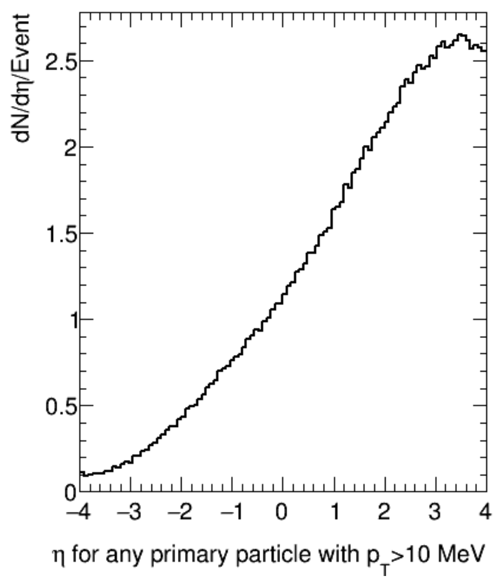


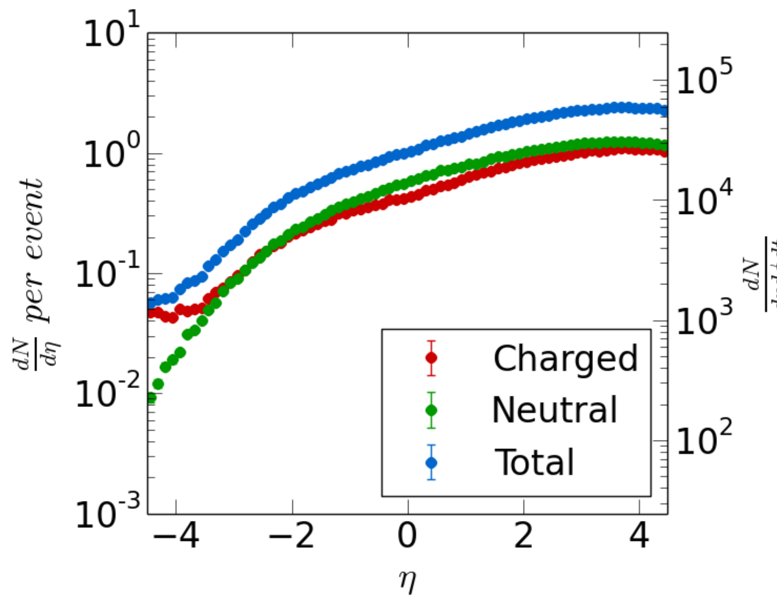


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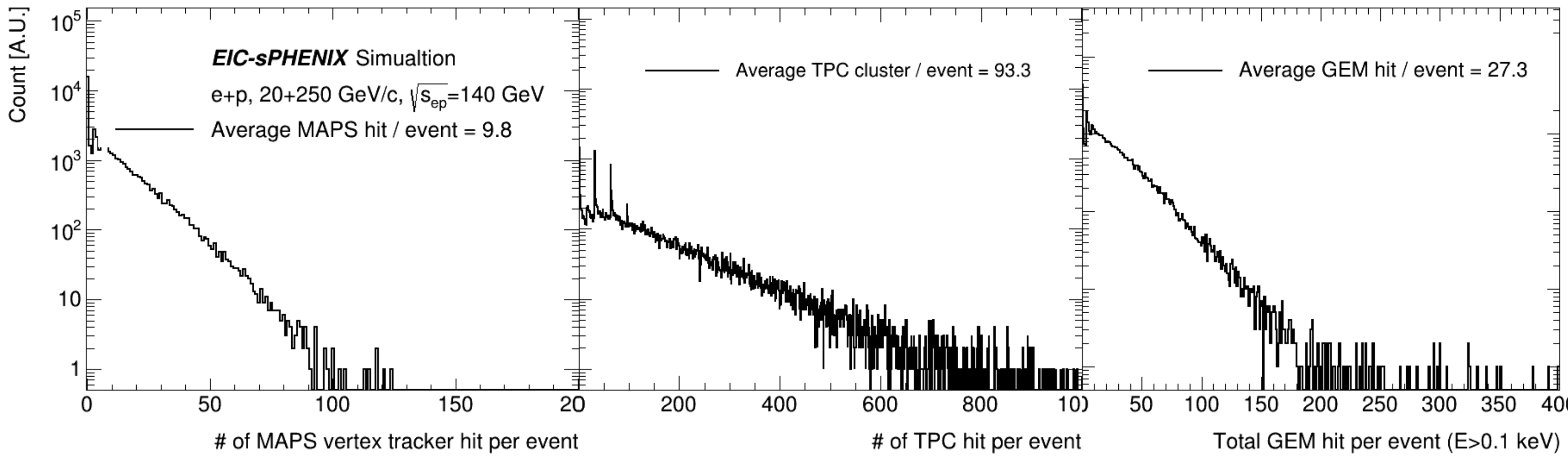
```

# GEANT4-based detector simulation for DAQ simulation: tracker

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

Extract mean value/collision that produces average signal data rate and tails that produce the buffer depth and latency requirements




Raw data: 16 bit / MAPS hit

3x10 signal hit / collision → 0.2 Gbps @$10^{34}$ $cm^{-2}s^{-1}$

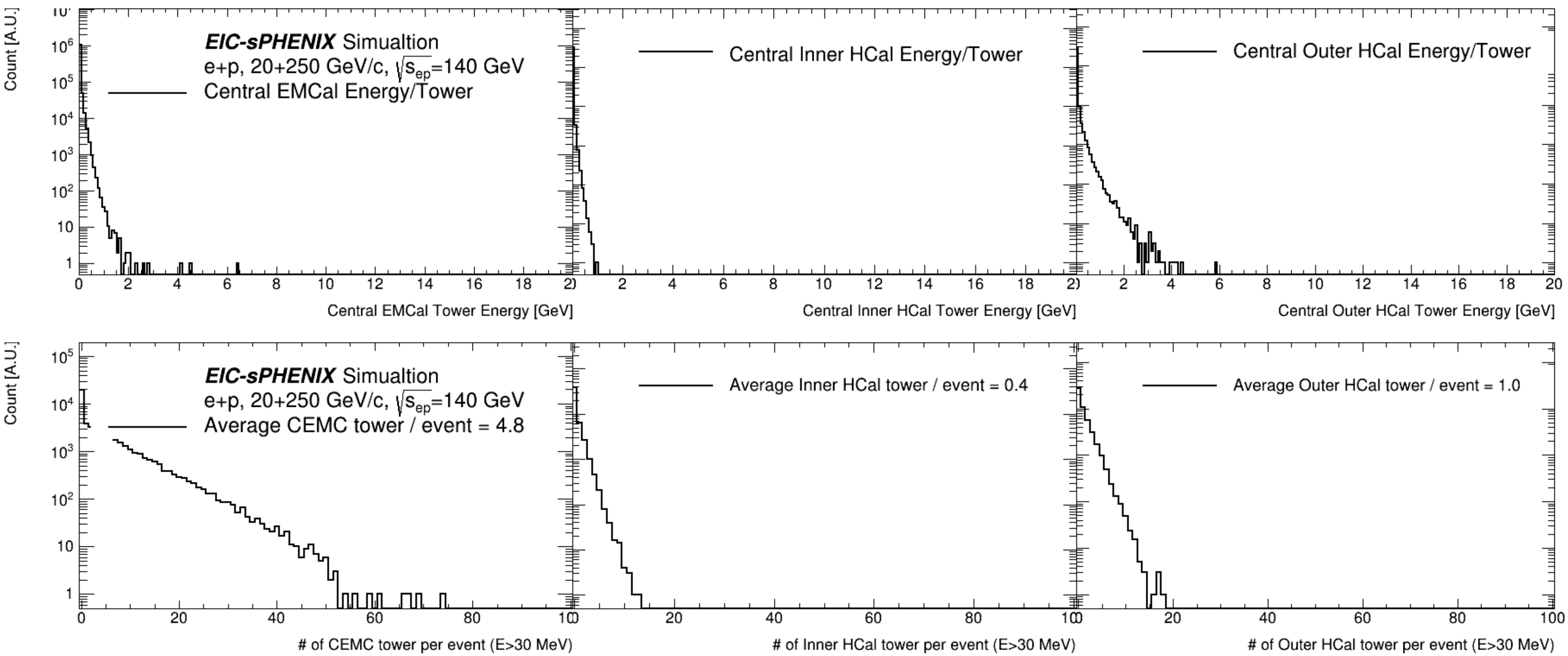
- MAPS is vulnerable to beam background see later slides
- ALPIDE MAPS noise are low, expect $10^{-6}$ /pixel/strobe, 200M pixel, 3us strobe → ~1Gbps

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

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

# GEANT4-based detector simulation for DAQ simulation: central calorimeters

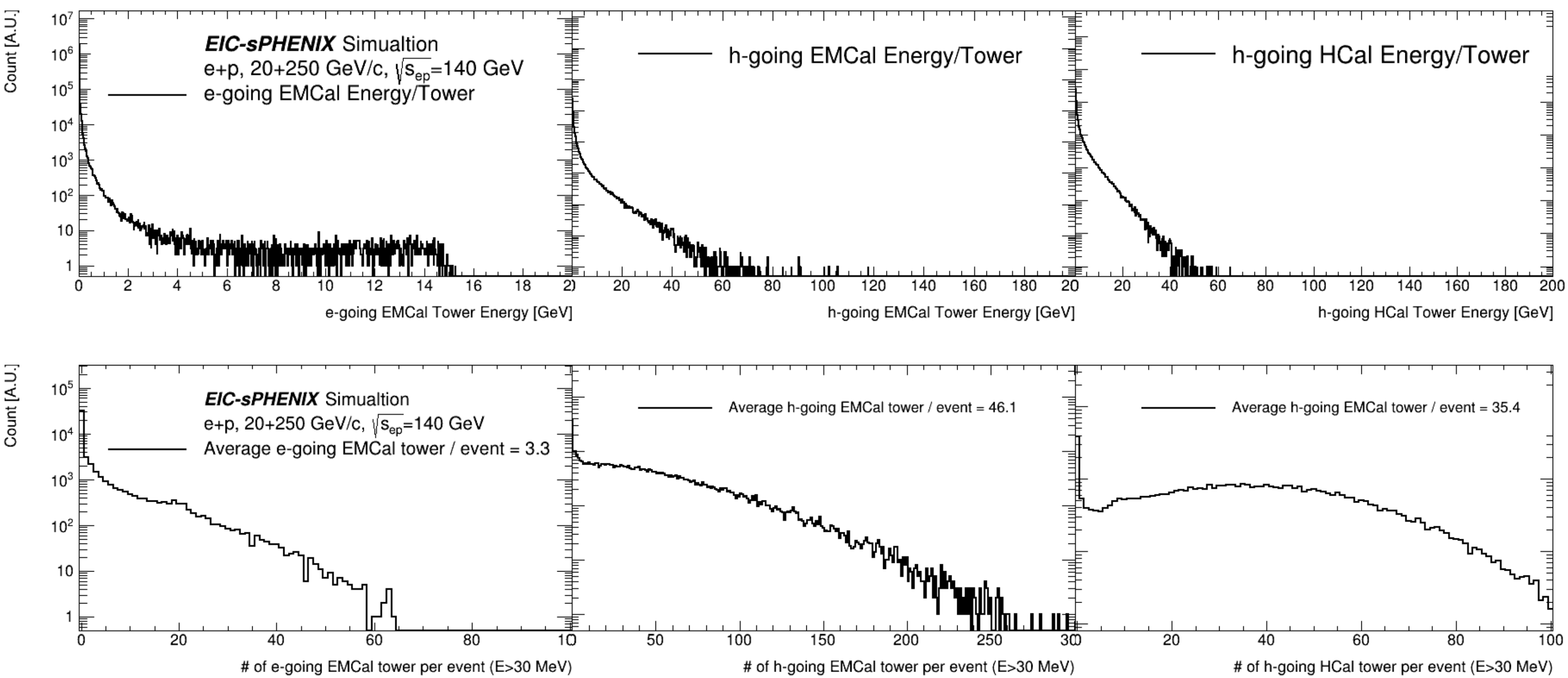
Raw data: 31x 14 bit / active tower +padding + headers ~ 512 bits / active tower




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

# GEANT4-based detector simulation for DAQ simulation: forward calorimeters

Raw data: 31x 14 bit / active tower +padding + headers ~ 512 bits / active tower

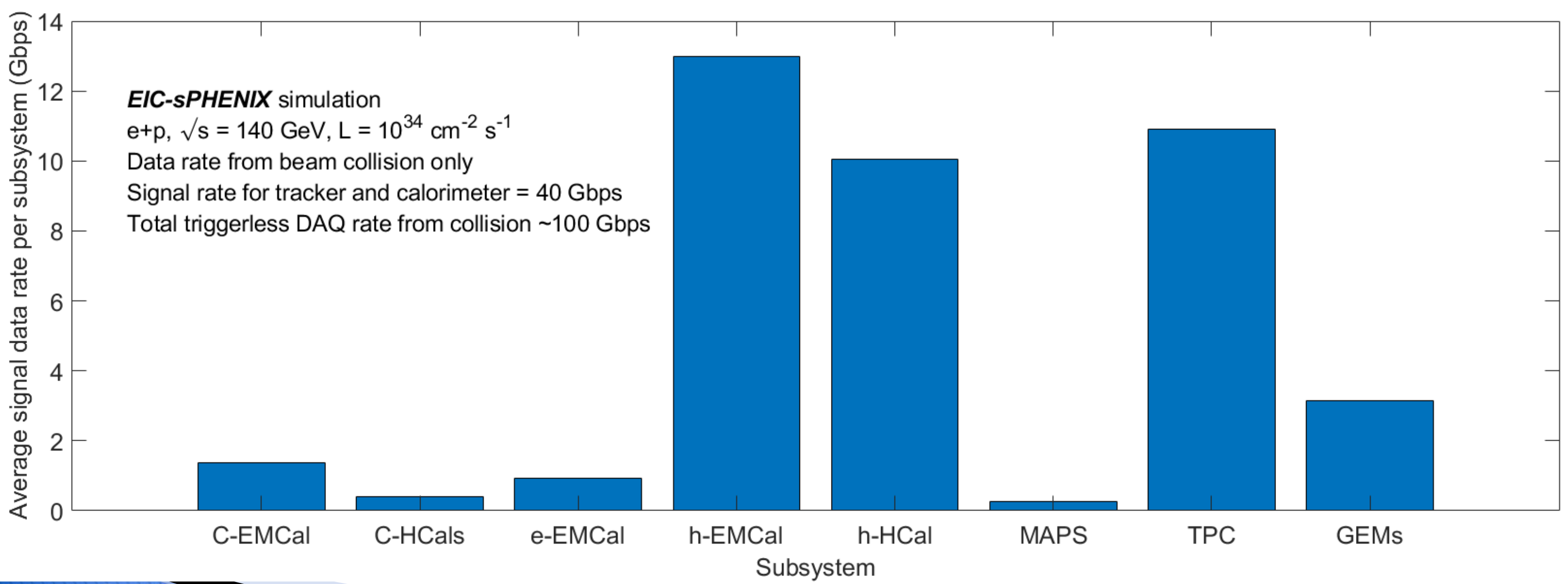



sPH-cQCD-2018-001, https://indico.bnl.gov/event/5283/

# EIC preliminary data rate summary

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

- Tracker + calorimeter ~ 40 Gbps
- + PID detector + 2x for noise ~ 100 Gbps
- Signal-collision data rate of 100 Gbps seems quite manageable,
  - < sPHENIX TPC peak disk rate of 200 Gbps (See Martin's talk)
- Machine background and noise would be critical in finalizing the total data rate
  - From on-going EIC/sPHENIX R&D prototyping will show noise level from state-of-art MAPS and SAMPA ASICs, e.g. ALPIDE MAPS noise rate ~ 1 Gbps
  - Enough FPGA/CPU resource with prevision for noise filtering in EIC online system



# Notes for readers explaining the intrinsic MAPS noise:

- Usually in the detector hit format, hits from a small segment of detector is packaged together in packets of a chunk of time and a subset of the detector, then put onto the data stream. Then, In the MAPS tracker's raw data from the chip, there are 16 bit/hit "short" hit format and a "long" 24bit/hit format.
- When we reformat the data in the FELIX: we could choose to reformat the hits into packets addressing hits in each of the stave (~5M pixel per stave). At this stage, we can use 24-bit hit address. Note, all hits have the same time stamp and are in the same stave, which are common information striped and concentrated to the next level. Then hits from a stave are put together, which is added with a packet header and trailer. The header address the time stamp in 40bit and stave address (1 in 50 staves) and trailer would have a 32 bit check sums. But the header space cost distributed to the 5M * 1e-5 noise hits are minimal (1.5 bit / hit). Then calculating the data volume again from the noise are
- In summary, 10^-5 MAPS noise level, 200 M channel, and 100kHz strobe rate, and 25.5bit data/hit = 5 Gbps

# Beam gas estimation for eRHIC detectors

- Assuming flat 10e-9 mbar vac in experimental region

# Beam-gas interactions

- p + p (beam gas) cross section ~ 40 mb @ 250 GeV
- **Beam gas interaction rate** = 2.65e10($H_2$/cm$^2$/10m) * 2(proton/$H_2$) * 40e-27(40mb→cm$^2$) * 1(A) / 1.6e-19(C/proton) = **13kHz / 10m beam line < 10% EIC collision rate**
- The following estimation assumes
  - HERA inspired flat 10e-9 mbar vac in experimental region of |z|<450 cm
  - 2M M.B. Pythia-8 beam gas events simulated in Geant4 full detector

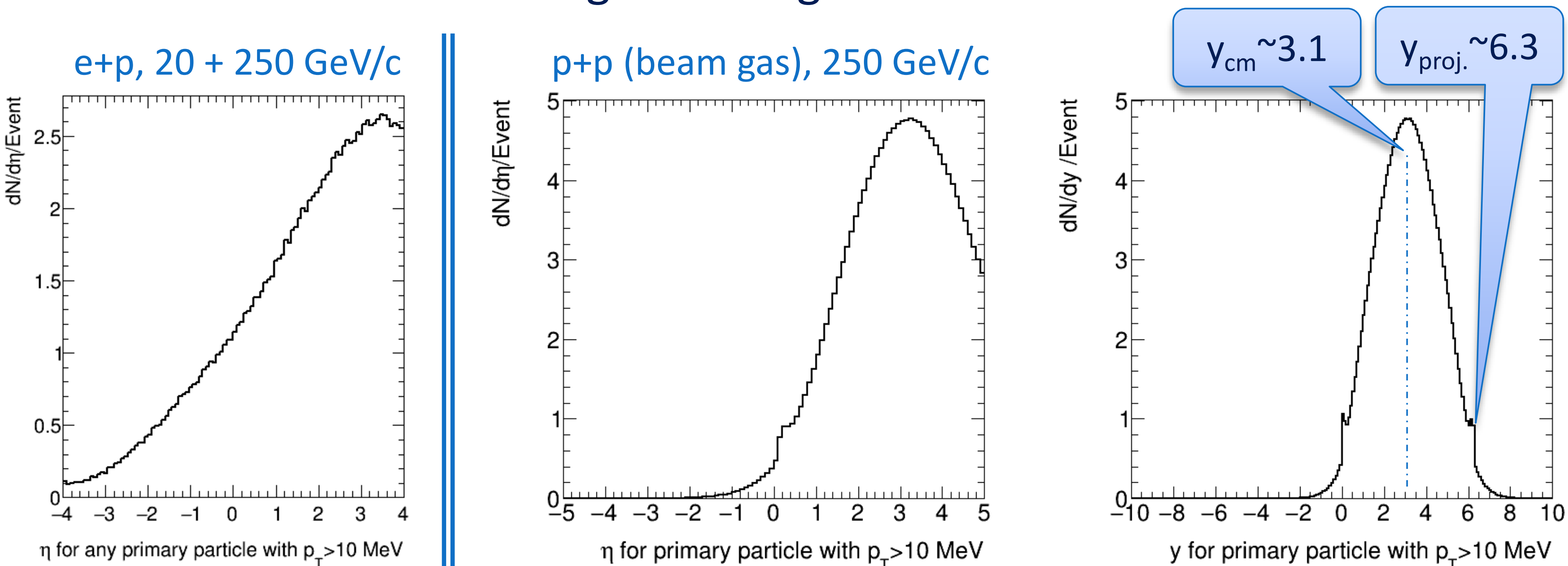
| | |
|---|---|
| Vacuum pressure | $10^{-9}$ mbar |
| Beampipe temperature | Room temperature |
| Average atomic weight of gas | Hydrogen ($H^2$) |
| Molecular density (for 10 m pipe) | $2.65 \times 10^{10}$ molecules/cm$^2$ |
| Luminosity (Ring-Ring) | $10.05 \times 10^{33}$ cm$^{-2}$s$^{-1}$ |
| Bunch intensity (R-R) (e/p) | 15.1 / 6.0 x $10^{10}$ |
| Beam Current (R-R) (e/p) | 2.5 / 1 A |
| Bunch spacing (Ring-Ring) | 8.7 ns → 1320 bunches |
| ElectronxProton beam energy | 10 GeV x 275 GeV |

Courtesy: E.C. Aschenauer
eRHIC pre-CDR review

BROOKHAVEN NATIONAL LABORATORY

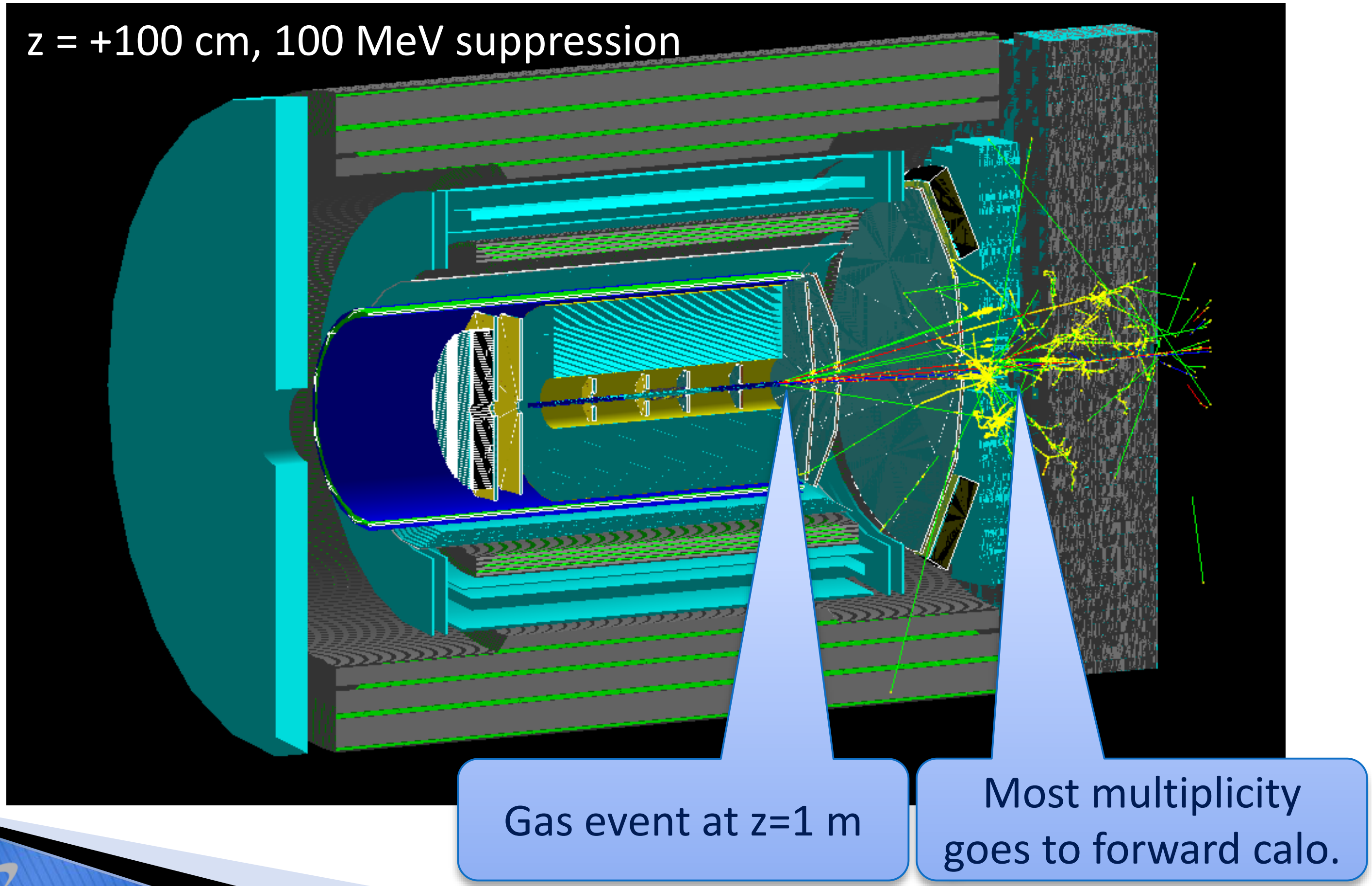
# Beam gas multiplicity

- 250 GeV/c proton beam on $H_2$ gas target
- C.M. rapidity~3.1, sqrt[s] ~ 22 GeV, cross section~40 mb
- Lab per-pseudorapidity multiplicity is higher than e+p, but ***not*** orders of magnitude higher



# Beam gas event in a detector

- 250 GeV proton beam on proton beam gas, sqrt[s] ~ 22 GeV
- For this illustration, use pythia-8 very-hard interaction event (q^hat > 5 GeV/c)



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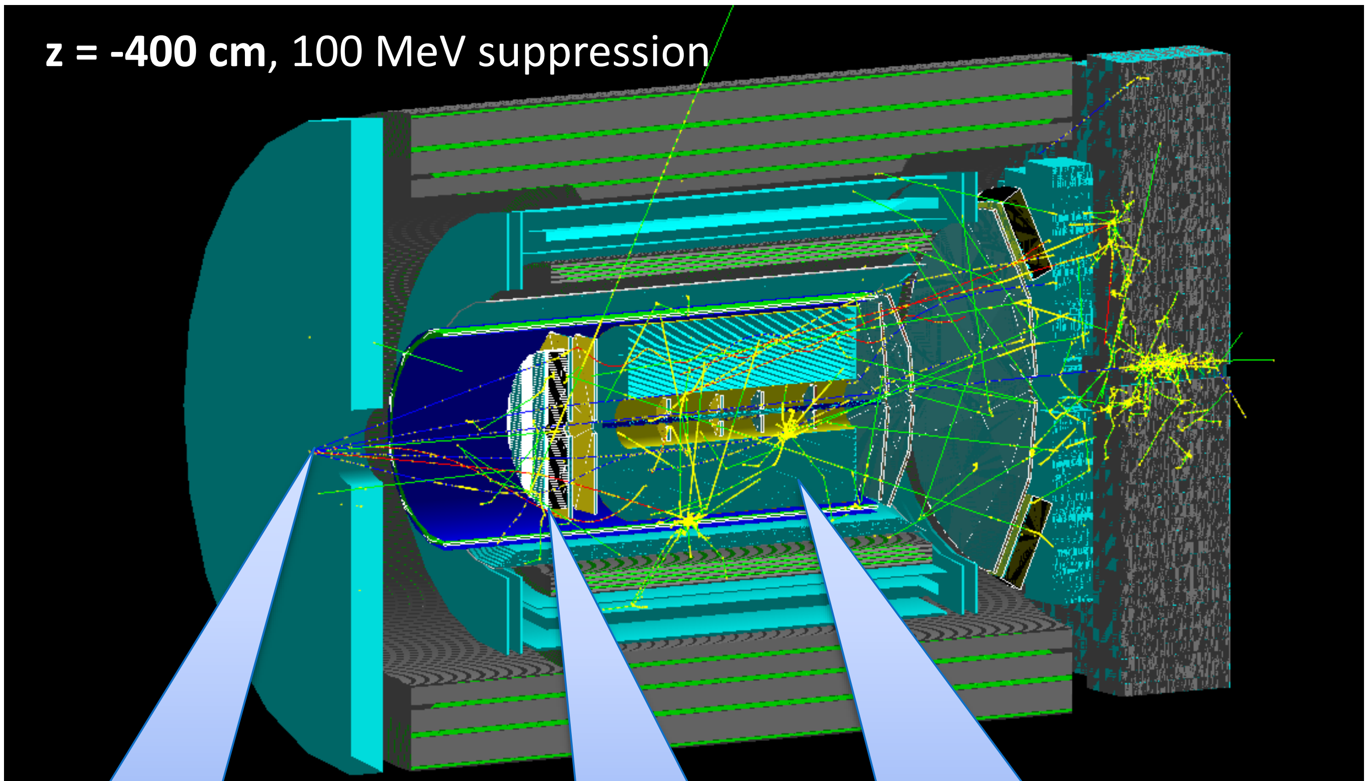
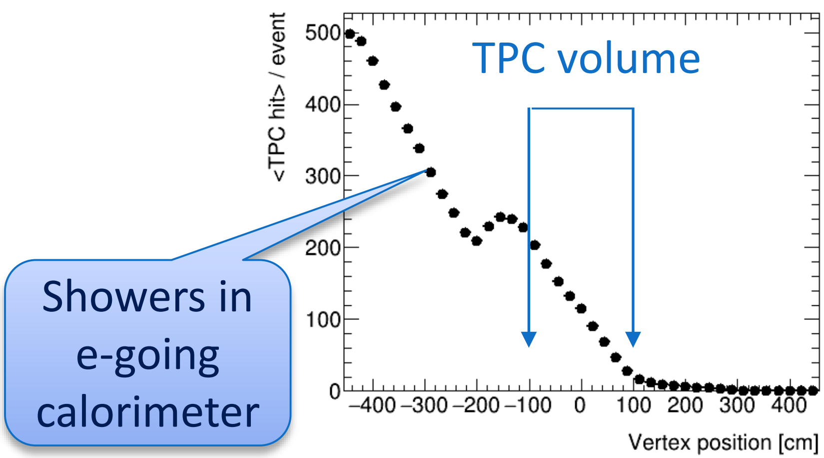
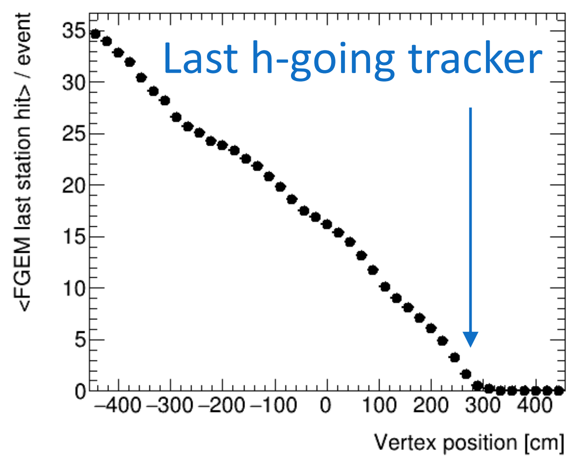
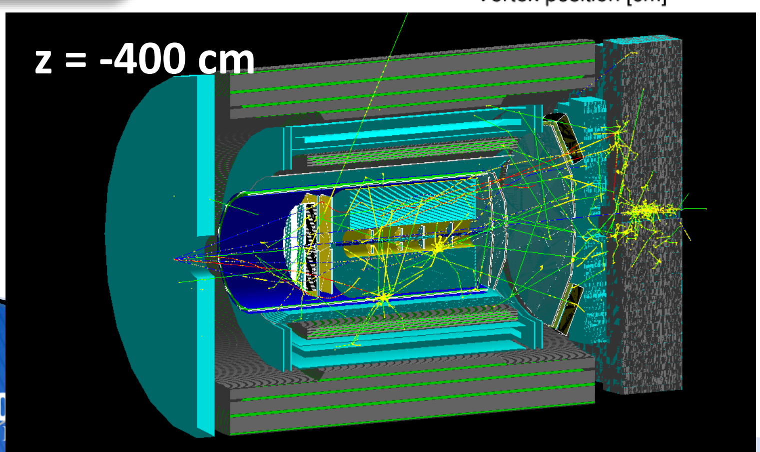


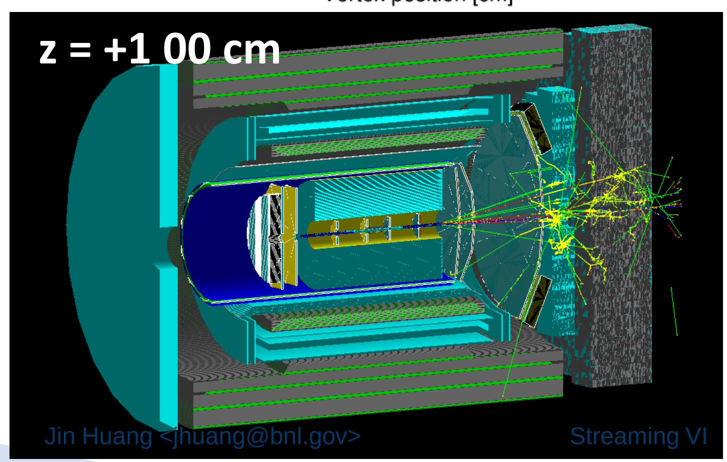
# Beam gas vertex sensitivity - tracker

- Average active hit for each beam gas vertex bin
- 250 GeV proton beam on proton beam gas, Pythia-8 M.B.



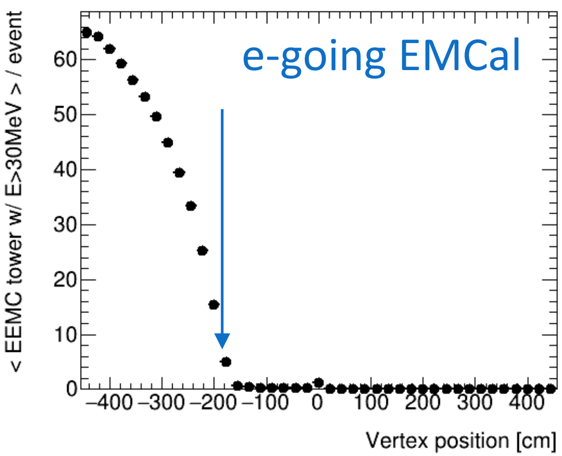



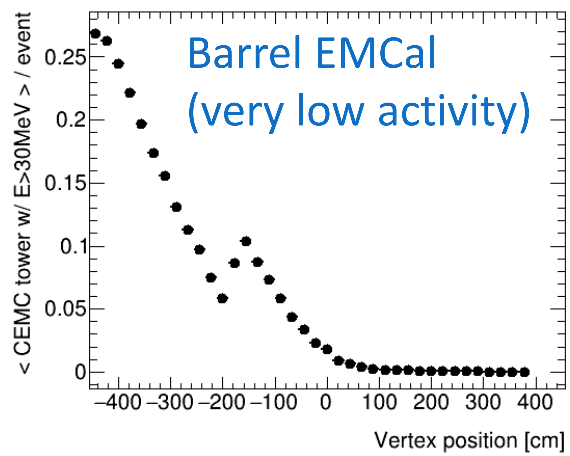



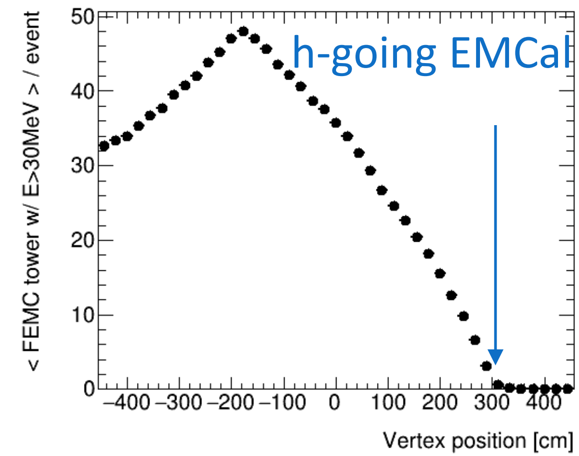



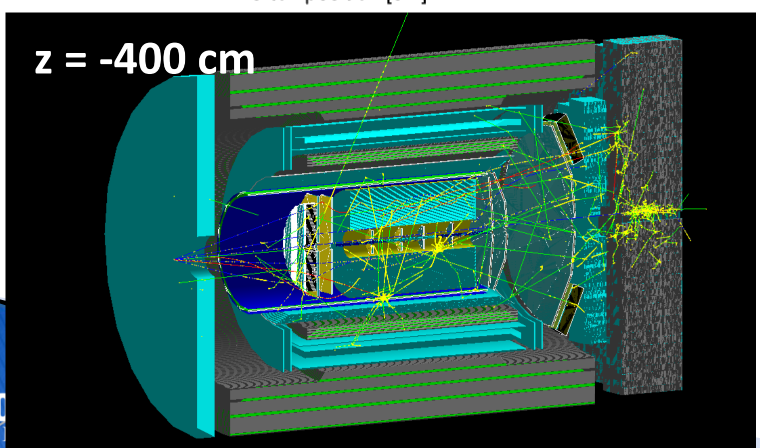
# Beam gas vertex sensitivity – calo.

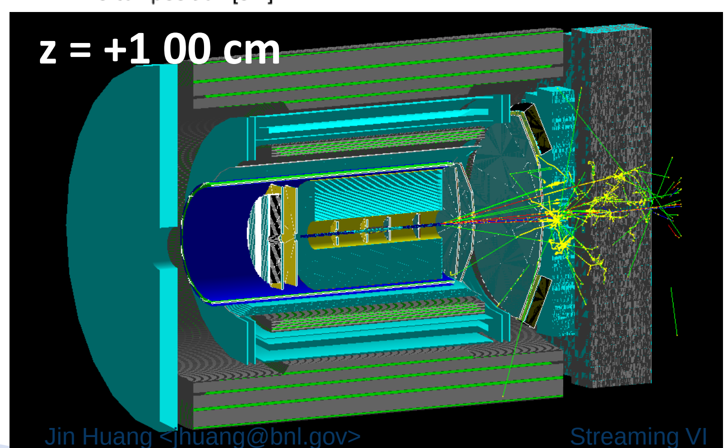
- Average active hit for each beam gas vertex bin
- 250 GeV proton beam on proton beam gas, Pythia-8 M.B.



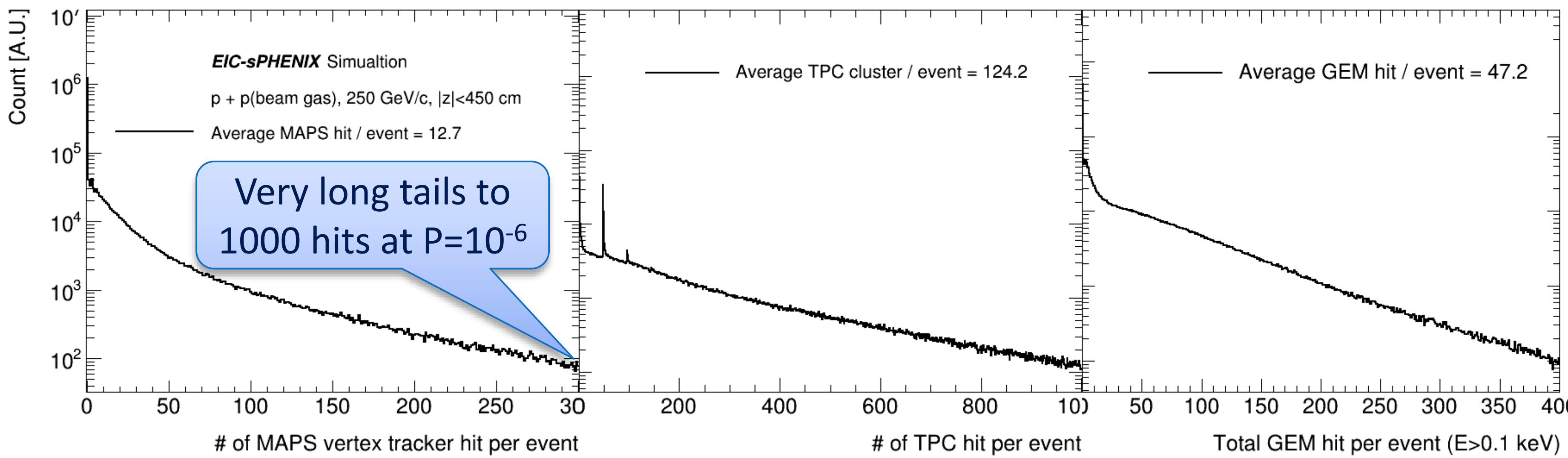



# GEANT4-based detector simulation: beam gas event on tracker

Extract mean value/collision (signal data rate) and tails (relates to buffer depth requirement)



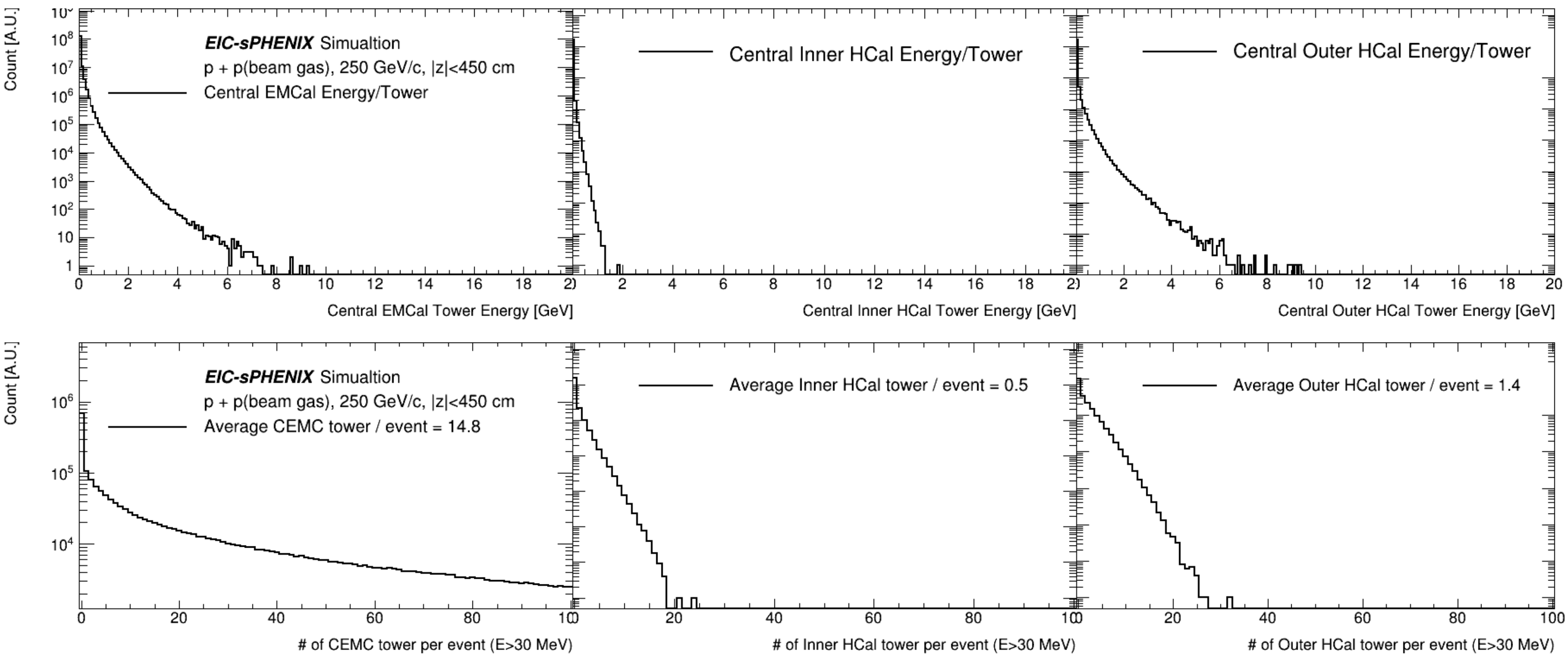

Raw data:
3 pixel x 16 bit / MAPS hit

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

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

# GEANT4-based detector simulation: beam gas event on central calorimeters

Raw data: 31x 14 bit / active tower +padding + headers ~ 512 bits / active tower



# GEANT4-based detector simulation: beam gas event on forward calorimeters

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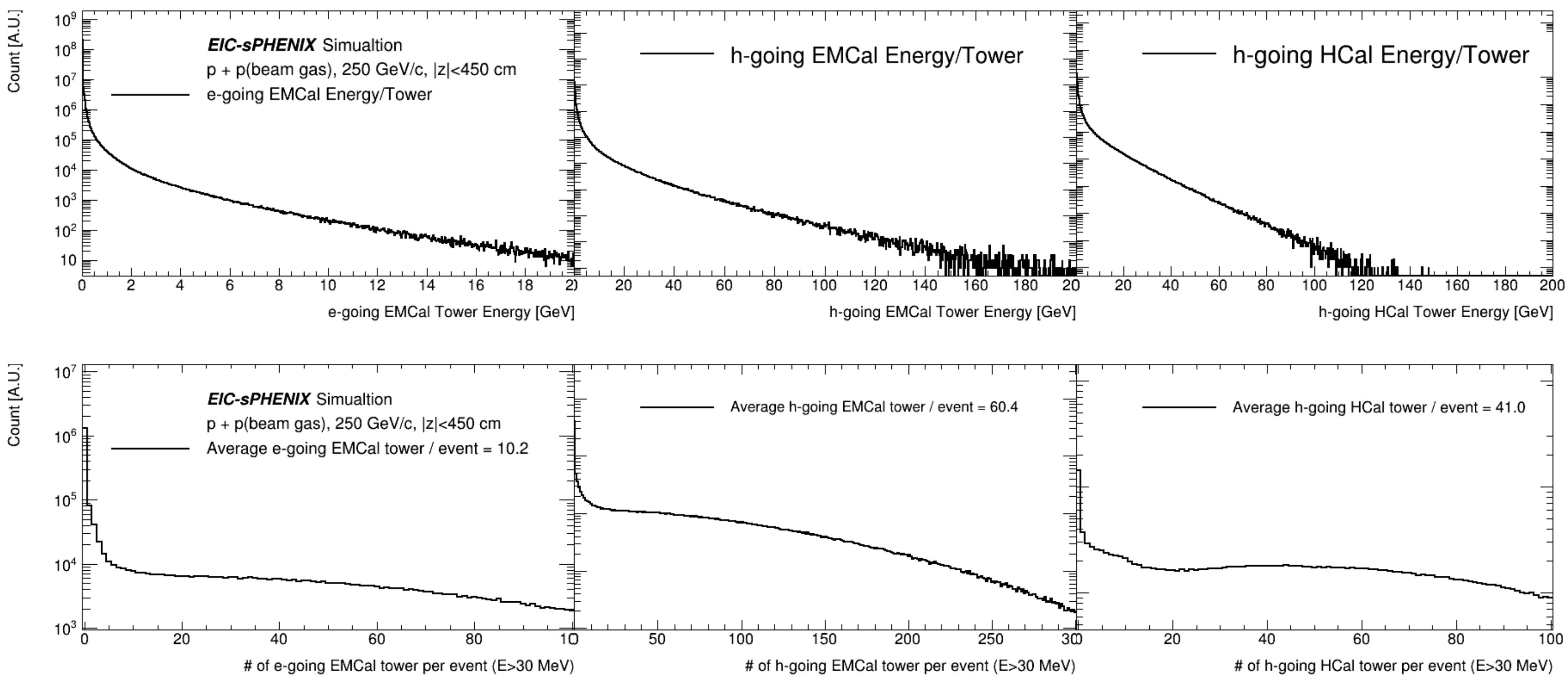
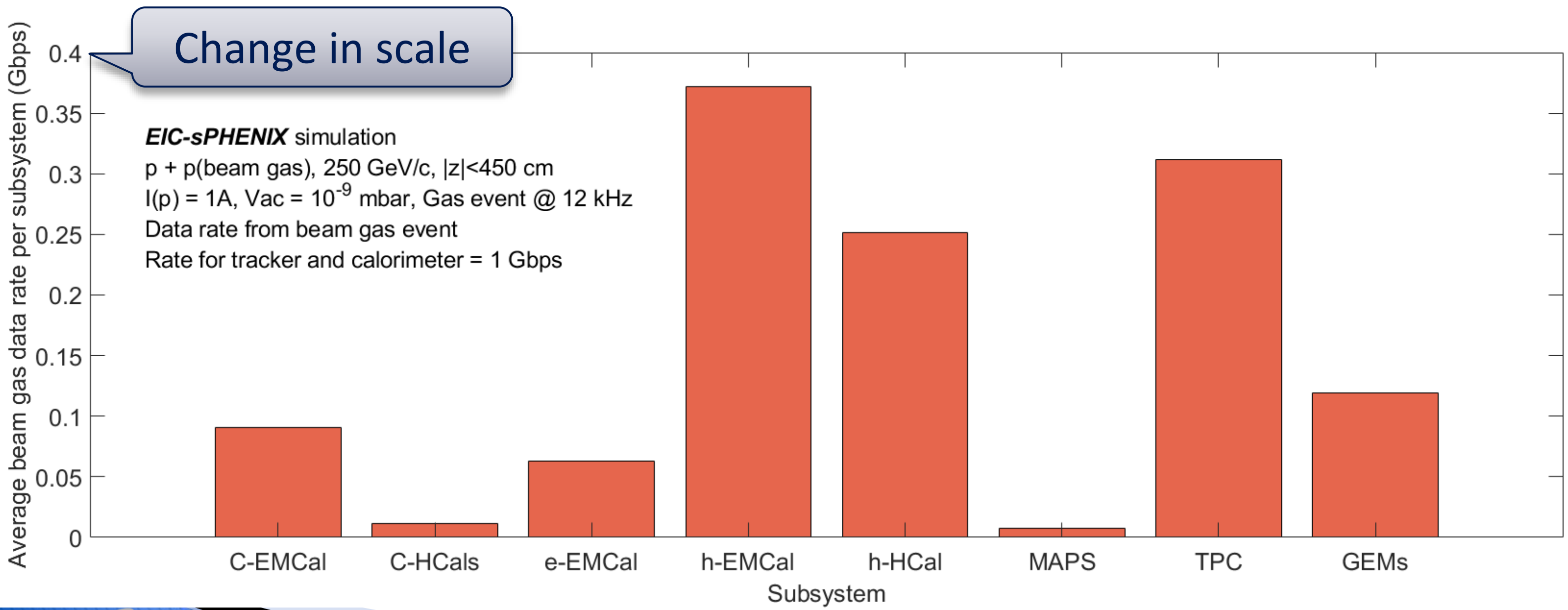


# Rate summary for beam gas

- Very similar rate distribution among subsystems when compared with EIC collisions
- With an assumed vacuum profile
  - Based on HERA experience, assuming $10^{-9}$ mbar flat within experiment region (|z|<450 cm)
  - Overall ~ 1 Gbps @ 12kHz beam gas << EIC collision signal data rate

  Thanks to the discussions with E. Aschenauer, A. Kiselev, and C. Hyde
- Further investigation needed:
  - In the experimental region : Dynamic vac profile
  - Beyond experiment region: beam gas profile, possible passive shielding and active veto



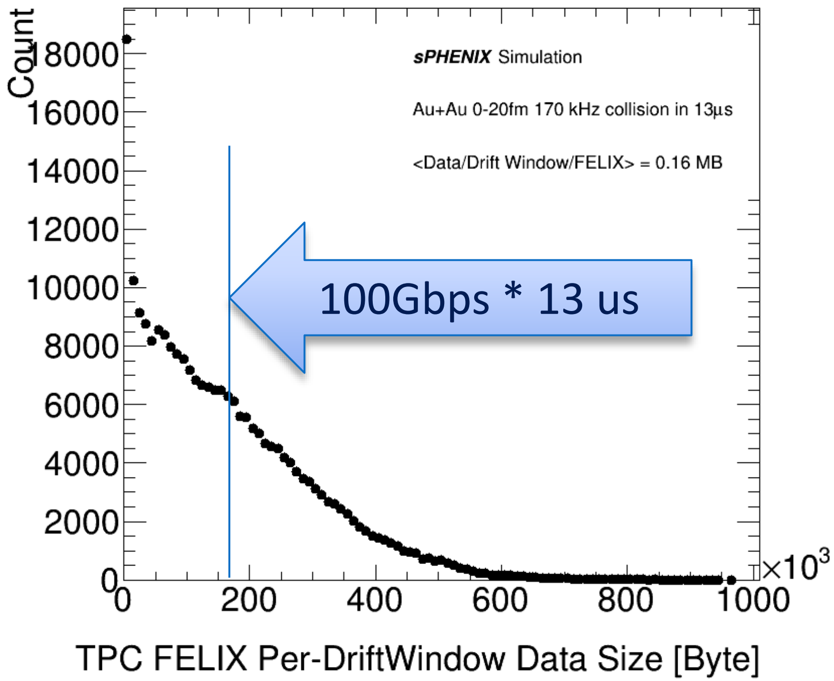
# Streaming DAQ buffer usage simulation: FELIX/SAMPA

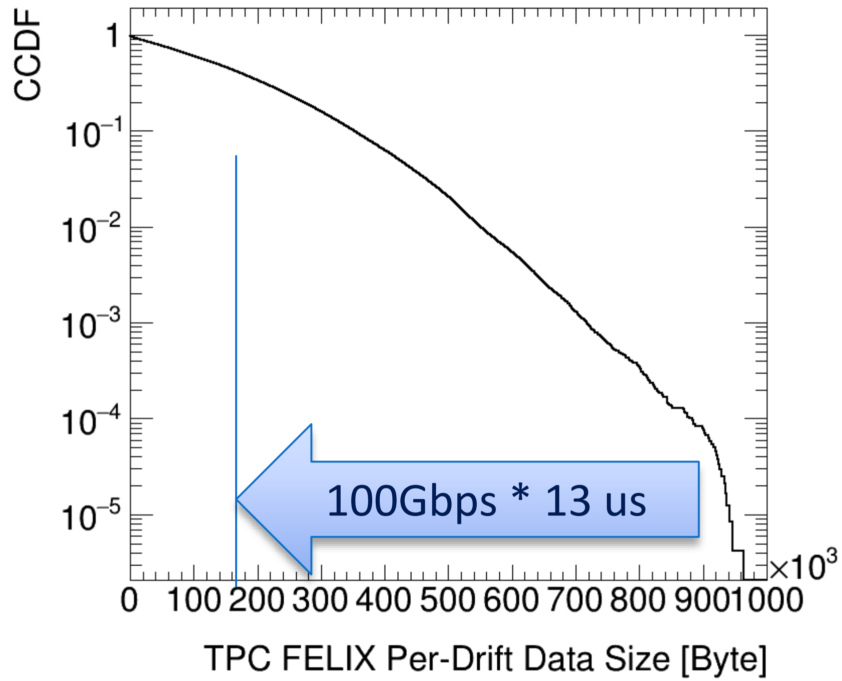
# New studies: How about buffer usage?

- In the Feb DAQ workfest, there was lots of discussion on how TPC DAQ fits into sPHENIX global trigger and busy control
- Following that, John K. demonstrated that via using Block RAM, we could allocate 77Mb in The DAM/FELIX FPGA
  - Up to demonstrate in actual usage as FIFO under all constraints
- This study quantify buffer usage on FEE and FELIX with Geant4-simulated data stream and a "leaky-basket" buffer simulation
  - Assuming "tight-packed" data, 2x 8bit header + tightly packed 10bit ADC data

# Geant4 simulation of Per-FELIX data

- Estimating per-FELIX data at random time-window of 13us
- Per FELIX data has mean of 0.16MB (100Gbps) and a very long tail



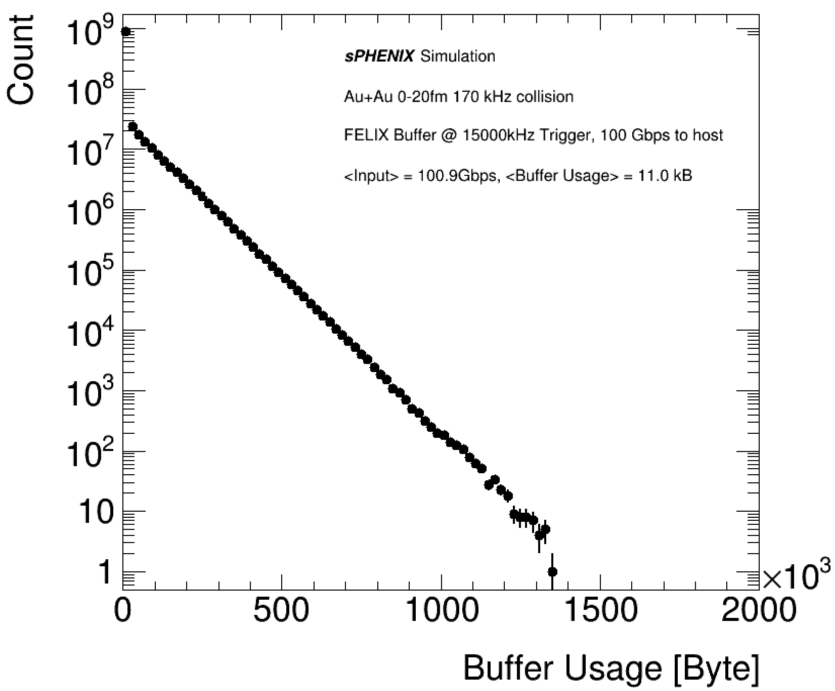



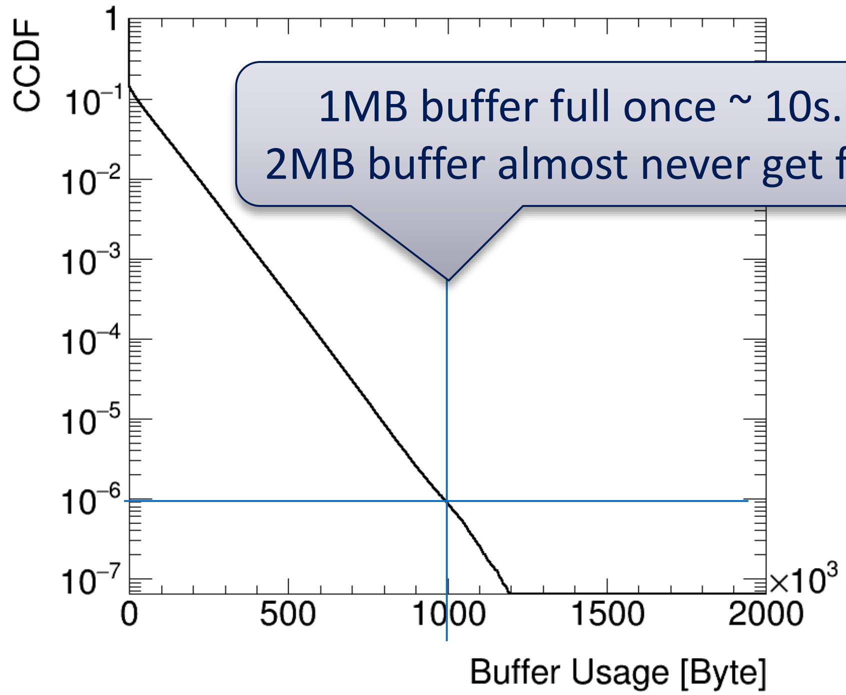
# FELIX buffer usage

- At ~100Gbps input and demonstrated FELIX output at a similar rate, transmitting all hits to the EBDC memory for trigger reduction is impractical.
- However, if we throttle data on FELIX, we could dramatically reduce load on PCIe transmission
- Required buffer depth ~ **70 Mb/9 MB**
  - Guaranteed buffer for trigger delay = 16bit * 256 chan/FEE * 26 FEE * 20/us * **6.4us** = 14 Mb / **1.7 MB**
  - FIFO for DMA transmission, next slides ~ **2MB**
  - Guaranteed buffer for taking the current trigger before generating a real-time busy signal = 16bit * 256 chan/FEE * 26 FEE * 20/us * **13us** = 27 Mb/**3.5 MB**

# FELIX buffer usage in simulation

- Using a leaky basket simulation to estimate buffer usage and probability of buffer full
- At 100 Gbps DMA transfer (demonstrated throughput by ATLAS)



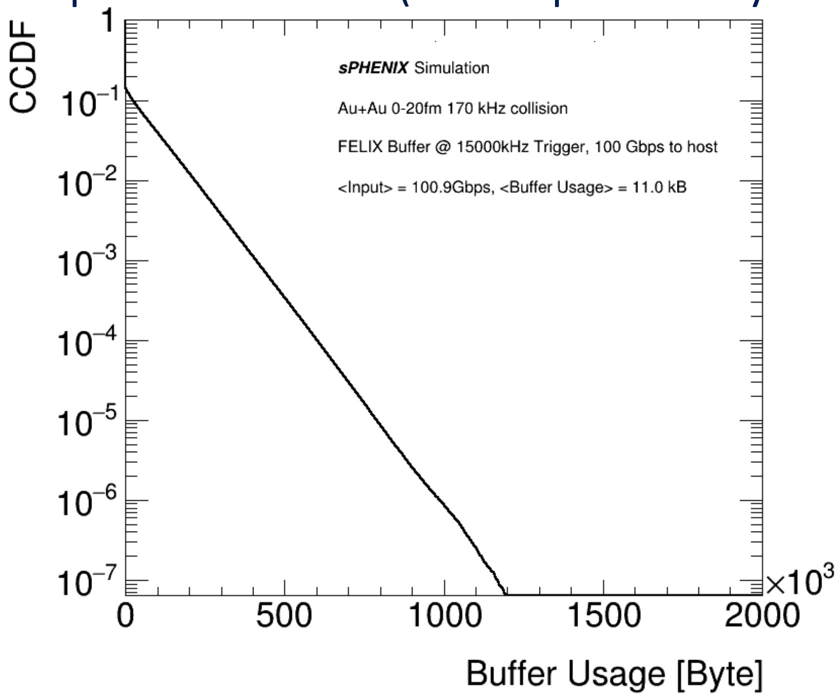




1MB buffer full once ~ 10s.
2MB buffer almost never get full

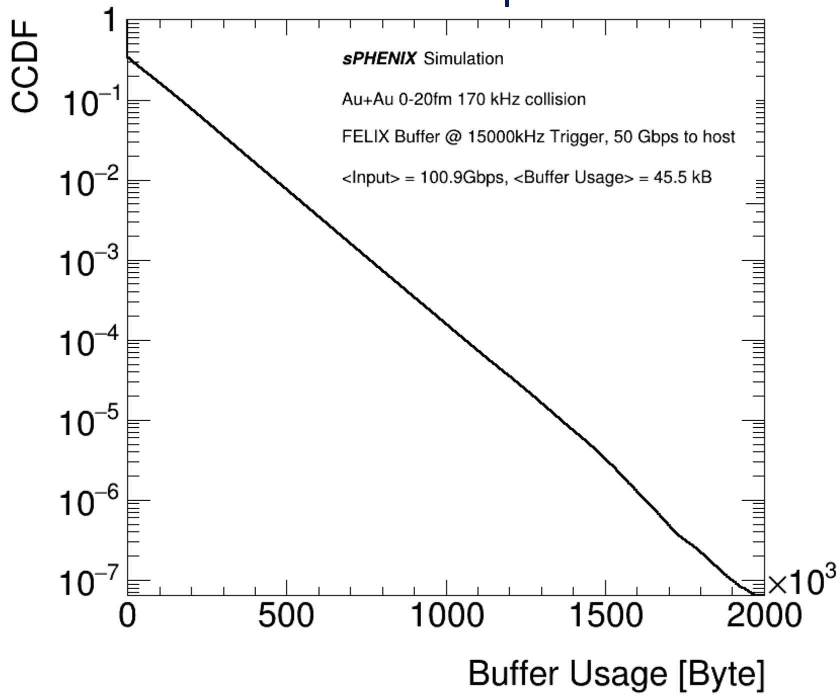
# FELIX buffer usage in simulation

- How about slower than expected DMA transfer? Say half speed, 50 Gbps
- 1 MB buffer would lead to $10^{-4}$ busy in any time frame. 2 MB would be quite comfortable.

100 Gbps DMA transfer (shown possible by ATLAS)

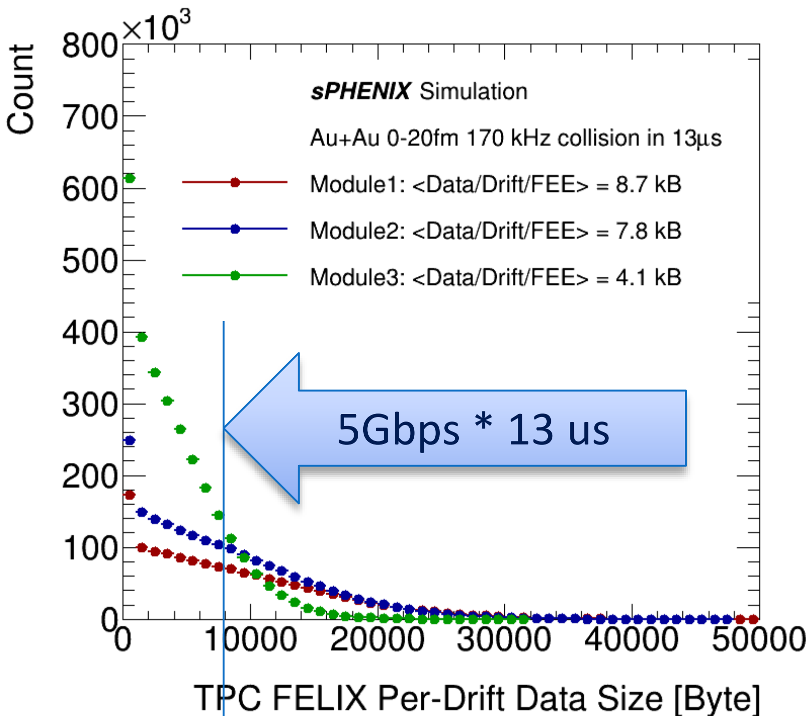


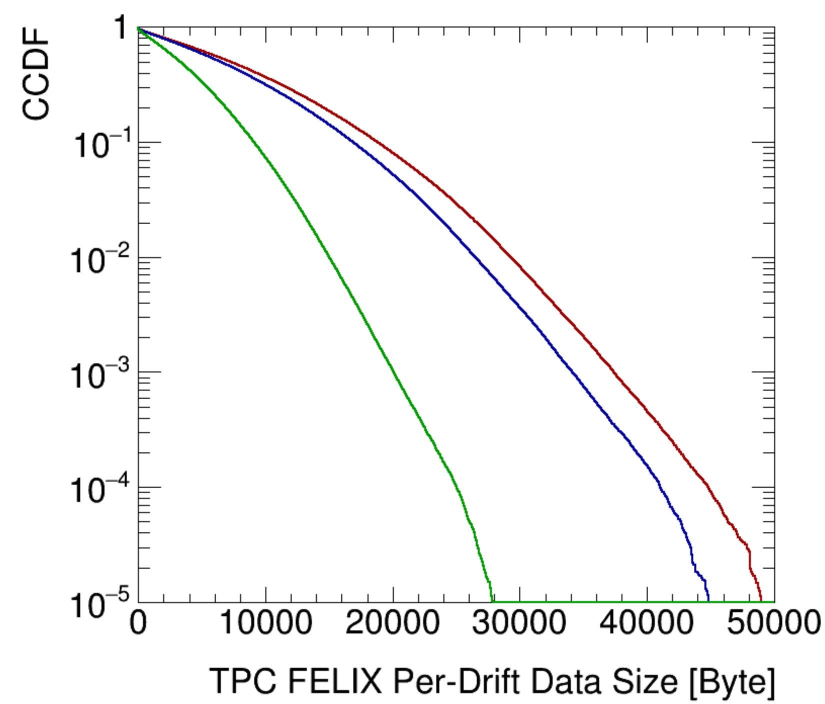

Much slower 50 Gbps DMA transfer



# How about FEE? - Data & fluctuations

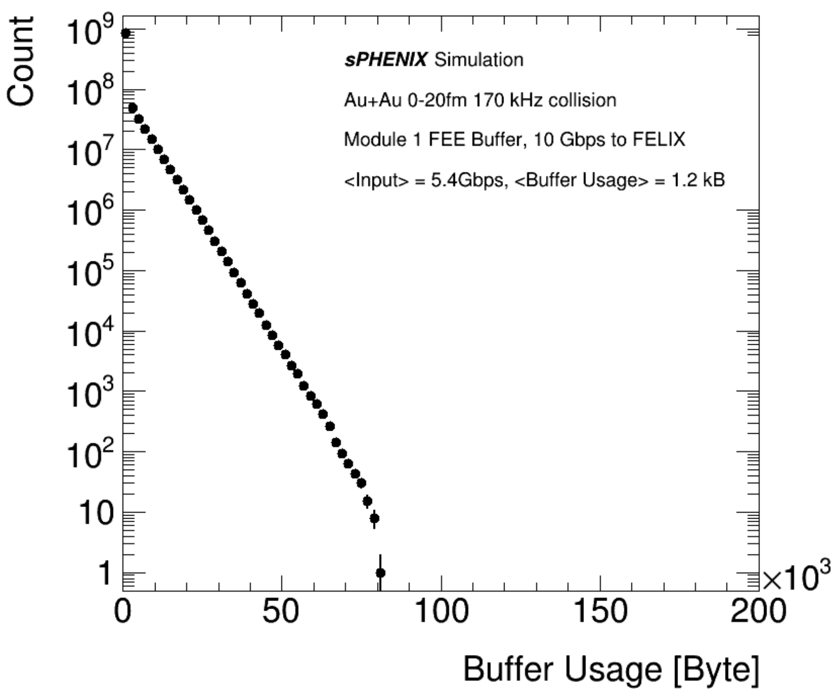
- FEE observe similar large fluctuation in occupancy too.
- Depending on FEE's location, average data rate is ~5Gbps @ module 1&2, 2.5 Gbps @ module 3.

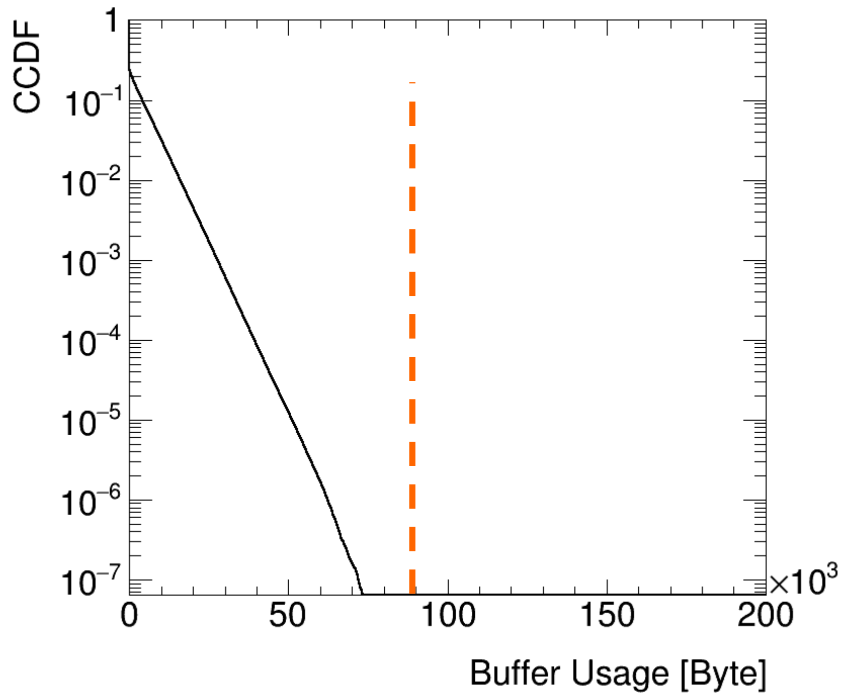


# Buffer usage - Module 1 FEE

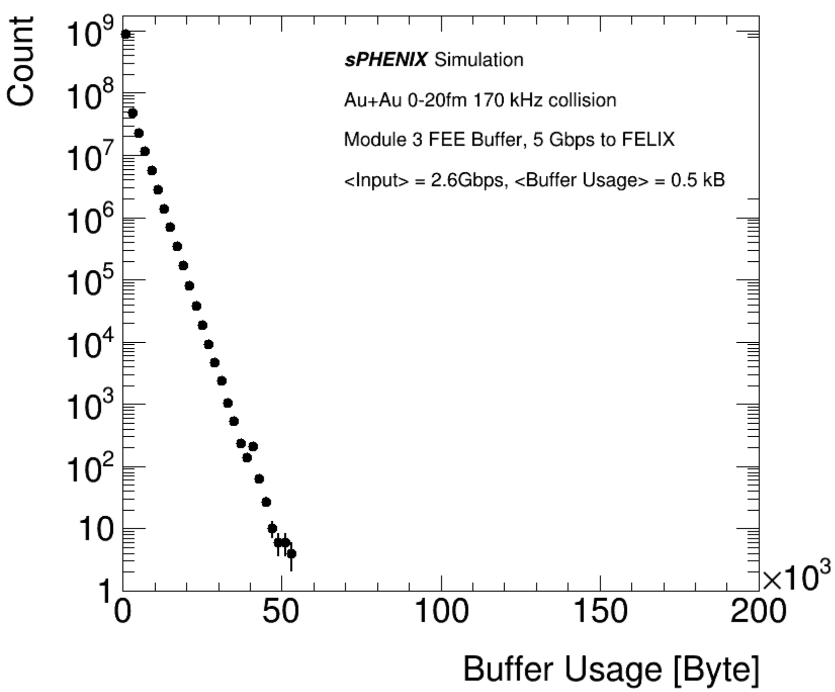
- Assuming double 6.5Gbps links to FELIX, with total 10Gbps payload rate after encoding and max 95% usage

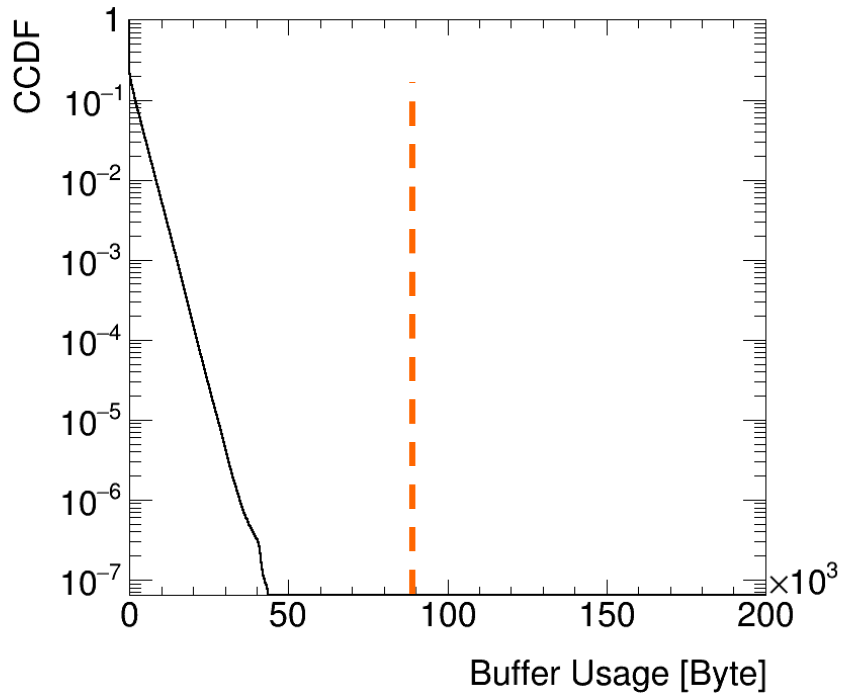


# Buffer usage - Module 3 FEE

- Assuming single 6.5Gbps link to FELIX, with total ~5Gbps payload rate after encoding and max 95% usage

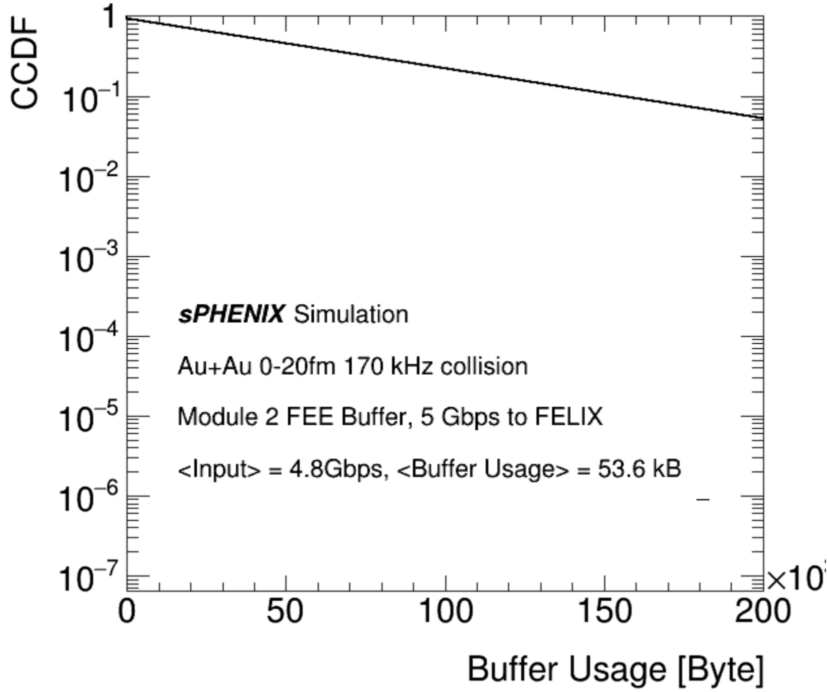


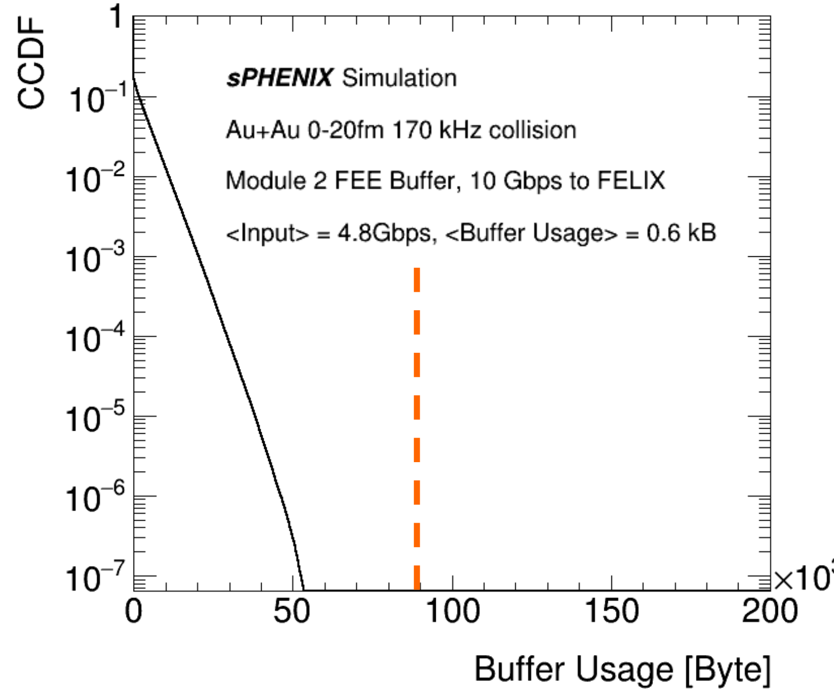
# Buffer usage - Module 2 FEE

- Previous we assume single data link on module-2 FEEs. However, at this rate we would require double 6.5Gbps links.

Single uplinks per module-2 FEE



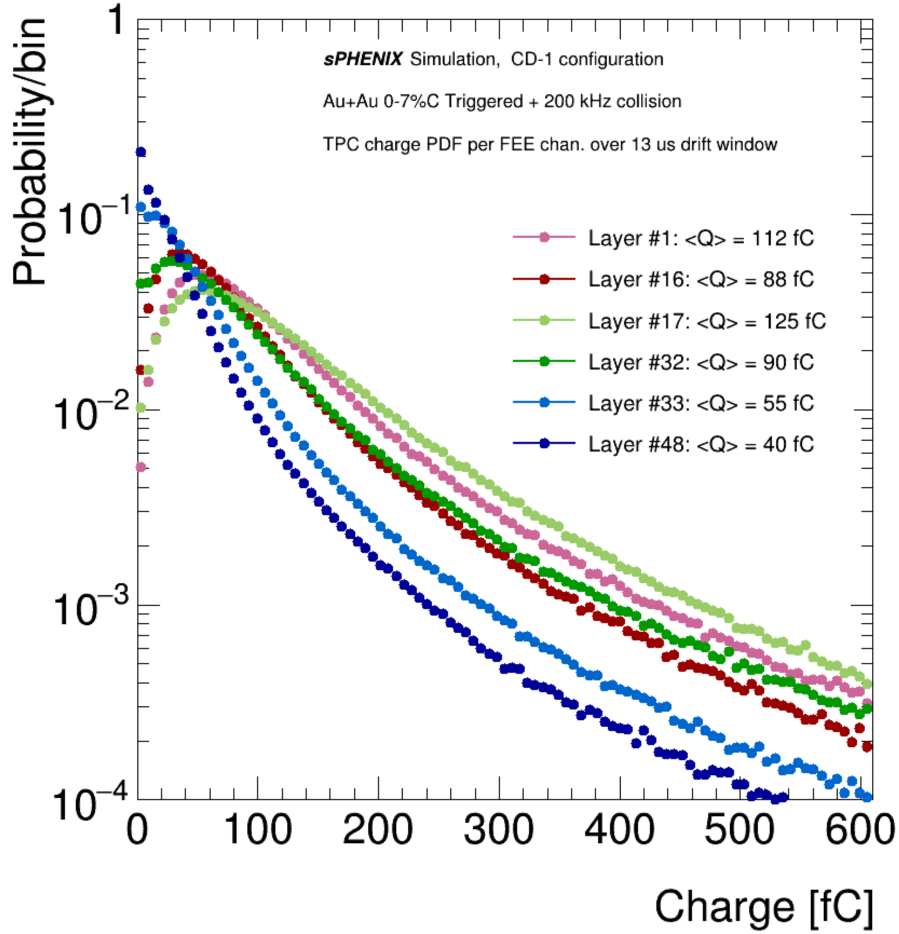

Double uplinks per module-2 FEE

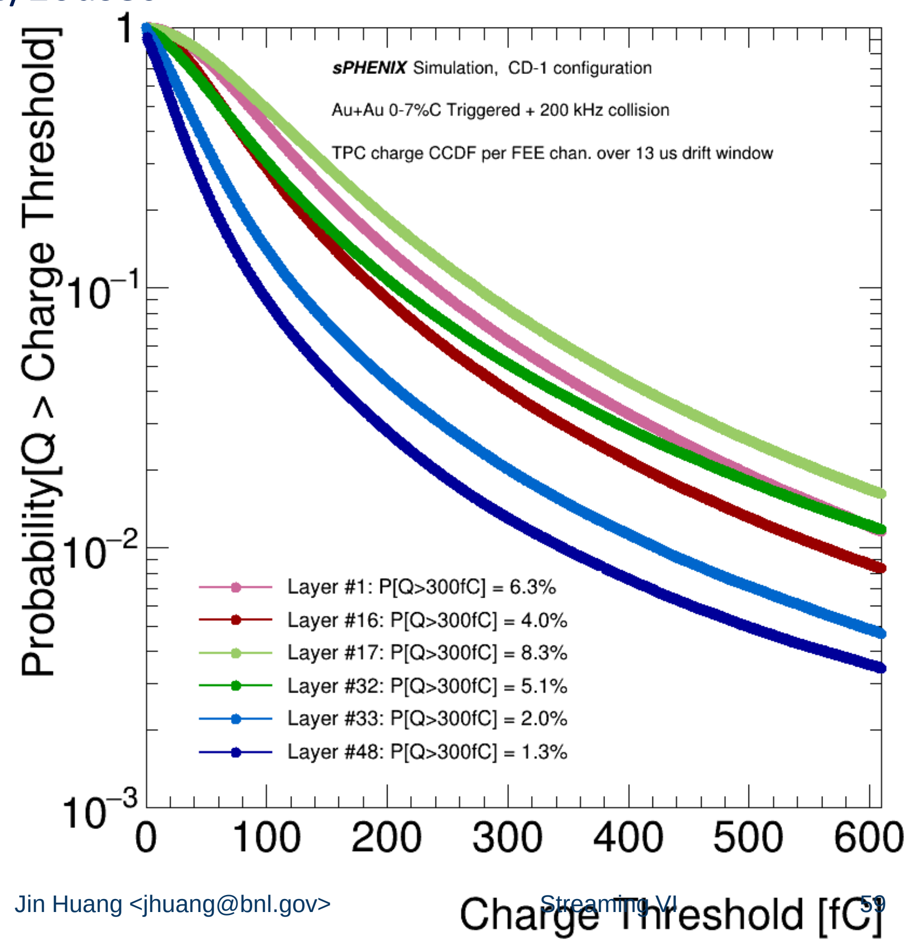


# BTW, we also have simulated charge injection to SAMPA

- Max charge layer: **Module-2's 1st layer (#17)**
  - Average <Q>~125 fC
  - P[Q > 300 fC/13 us] ~ 8%, P[Q>600fC/13 us] < 2%
- SAMPA chip is expect to operate 600-700 fC/20usec

TPC Layer shown:
[1-16]: R1, [17-32]: R2, [33-48]:R3

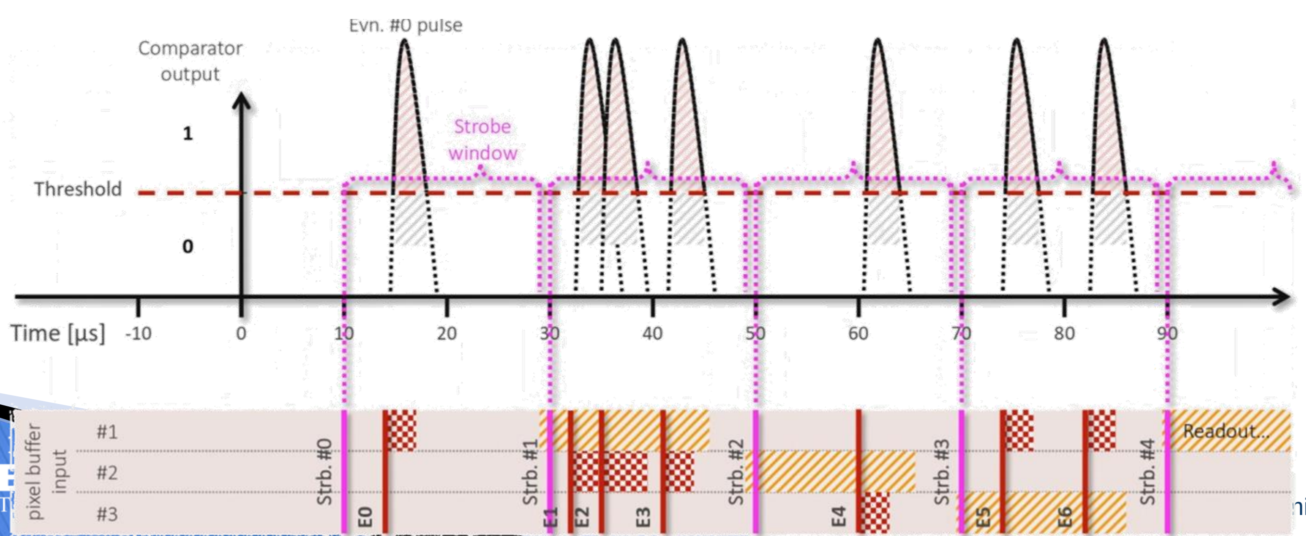


# Streaming DAQ buffer usage simulation: ALPIDE

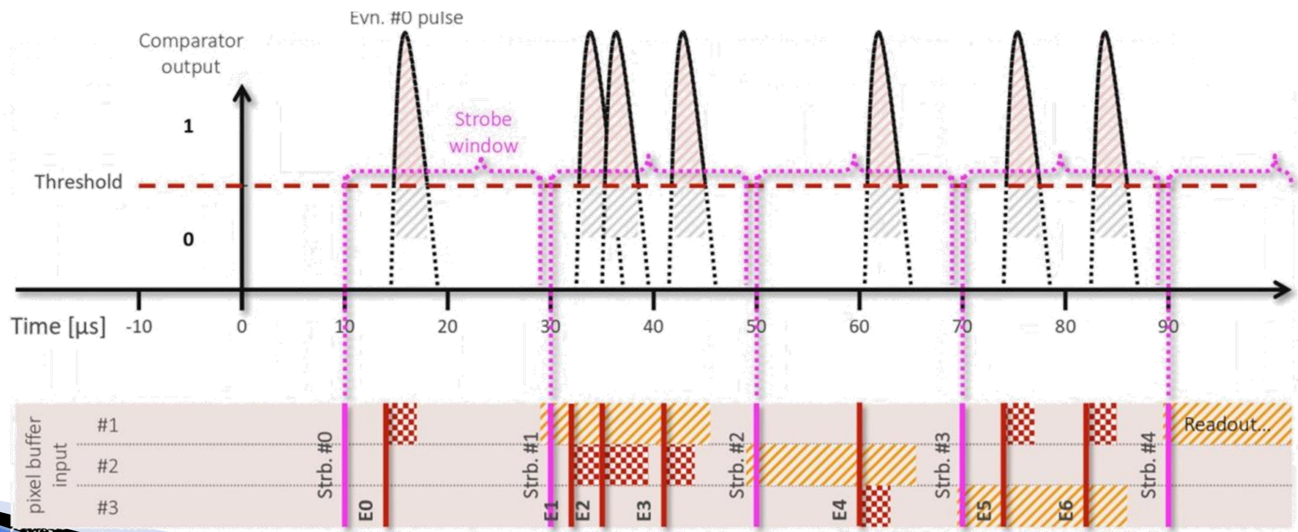
# Introduction 1

- Simulating whether we could run MVTX/ALPIDE chip in continuous mode instead of triggered mode, in order to decouple analog shape time tuning from global sPHENIX trigger latency choices
- This is a quantitate question related to ALPIDE hit multiplicity distribution (this study), on-chip buffer depth and how fast ALPIDE can pump out data.
  - ALPIDE has three-hit depth buffers for each pixel (one take data, one for readout, and one for safety factor)
  - Sho quote ALICE chip simulation of 25ns/hit, ~50% link utilization
- From sPHENIX DAQ workfest: the triggered chip-mode with continuous trigger is preferred.
  - Allow using the 3rd hit buffer in ALPIDE chip, will be useful in AuAu operation
  - In case of busy, always complete the current strobe and loss the next strobe. This generate a deterministic busy states, and induce a loss of efficiency acceptance **without centrality bias**.



# Introduction 2

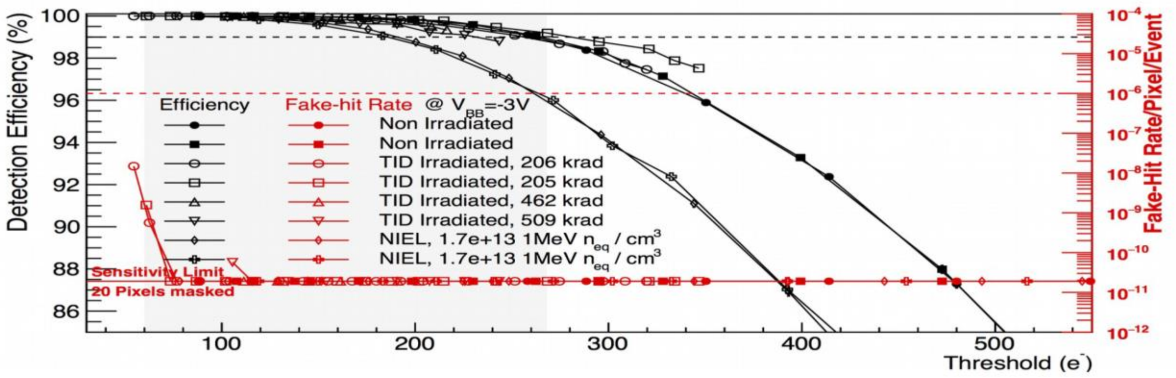
- Thanks to the many input from the last meeting
- New information incorporated in this talk:
  - From LBNL MVTX workshop: Tony Frawley retuned the MVTX digitizer with ALICE data. Now occupancy reduced by ~50%
  - Also in LBNL MVTX workshop: Xin Dong estimated the UPC electron occupancy
  - Count duplicated hits in continuous triggered modes (Thanks to Joachim Schambach)
  - Baseline noise → $10^{-6}$ (proposal assumed $10^{-4}$)

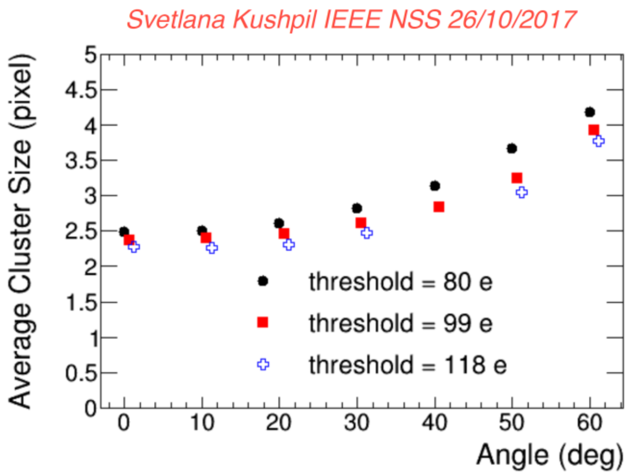


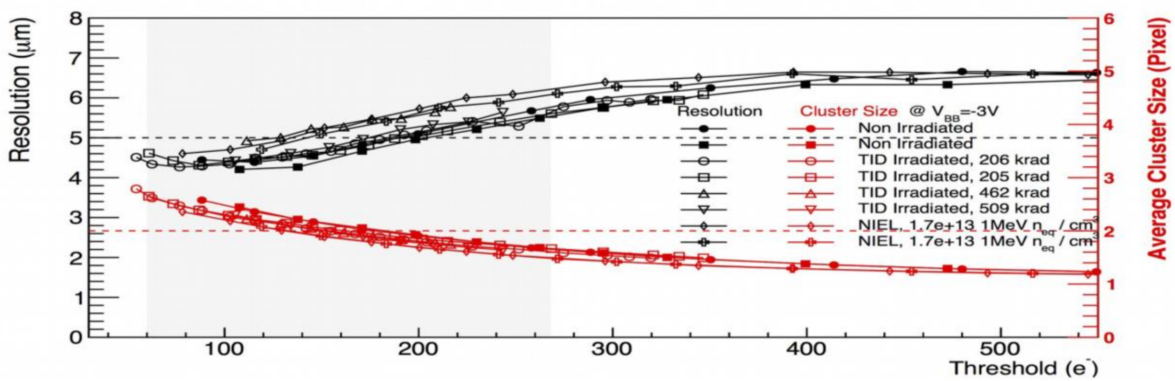
# ALICE ALPIDE Data

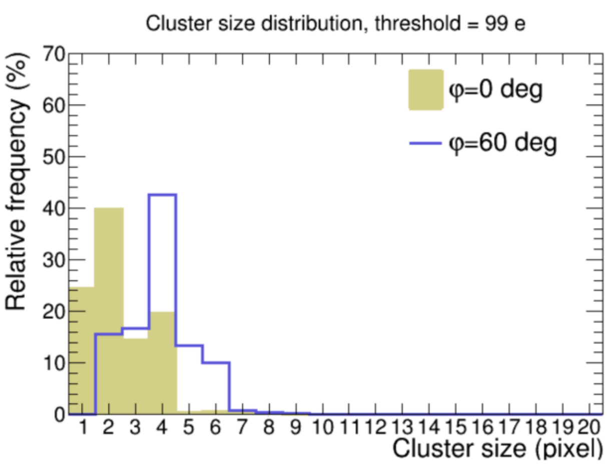
Svetlana Kushpil IEEE NSS 26/10/2017

- ALICE has detailed study regarding cluster multiplicity
- Thanks for discussion with Sho & Gerd during sPHENIX DAQ workfest



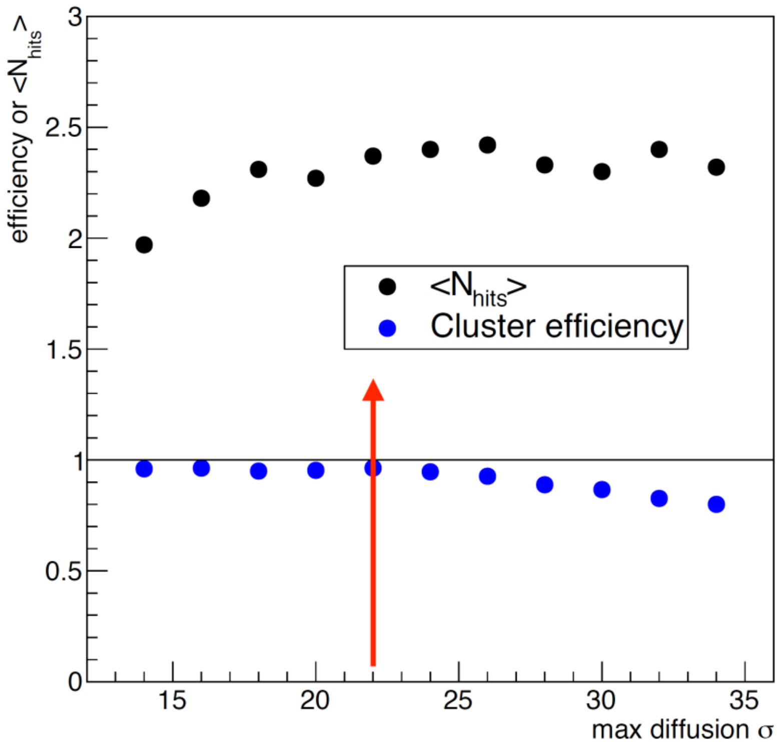



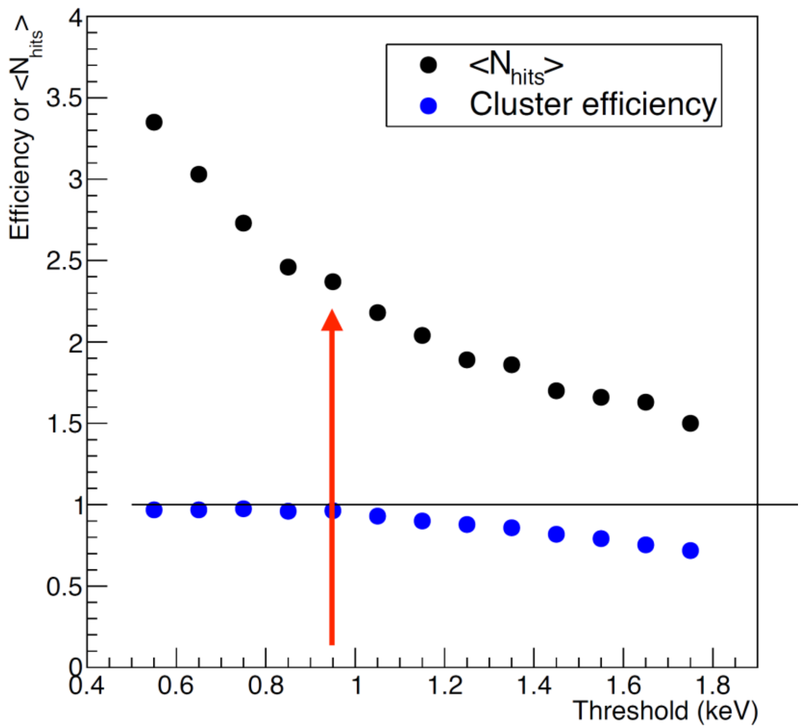



# MVTX digitization and per-track multiplicity

- At MVTX LBNL workfest, Tony retuned MVTX clusterizer to ALICE data
  - Summarized here https://indico.bnl.gov/event/5454/ , Pull request 598
- Result average per-track cluster size ~2.3, which is reduced from ~6 before the tuning
  - Significant reducing the multiplicity in the end



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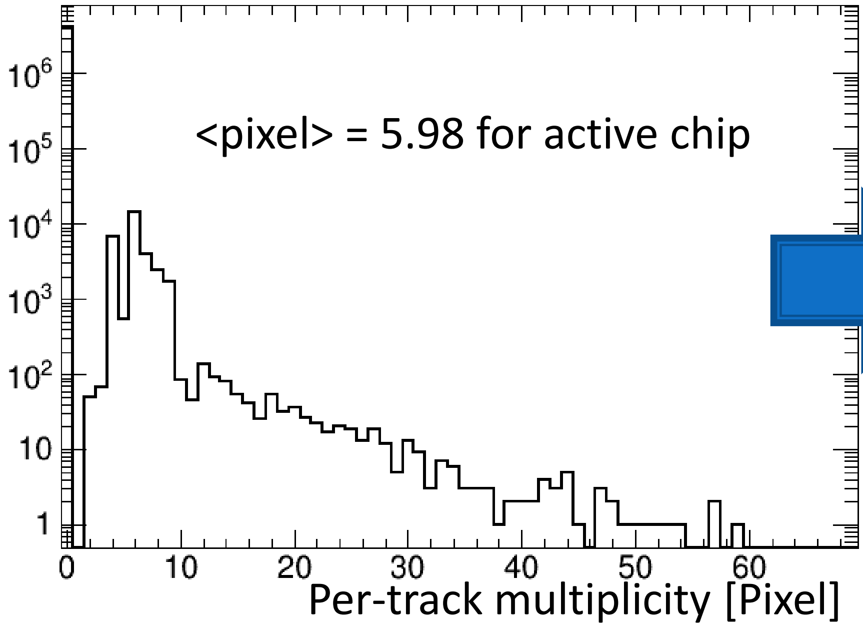
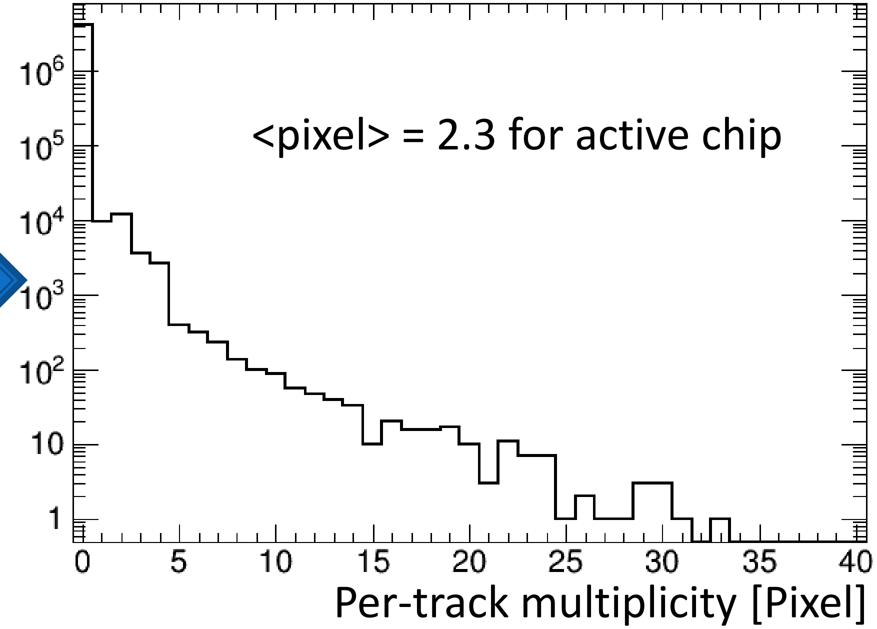
**Prior** to the Tony's Mar-2019 tuning, PR598



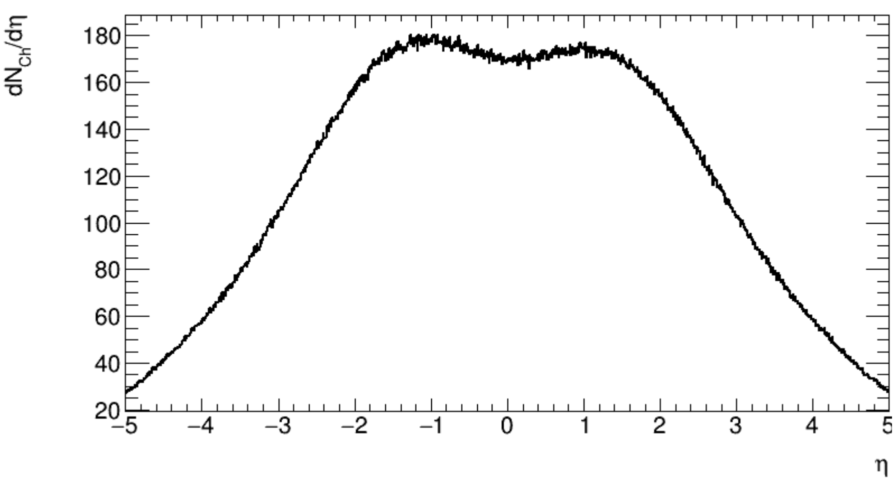

**After** the Tony's Mar-2019 tuning, PR598

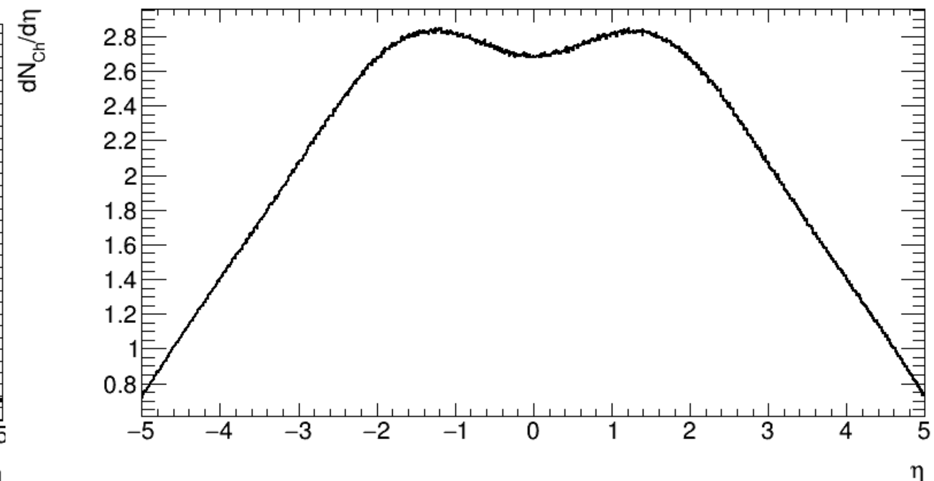


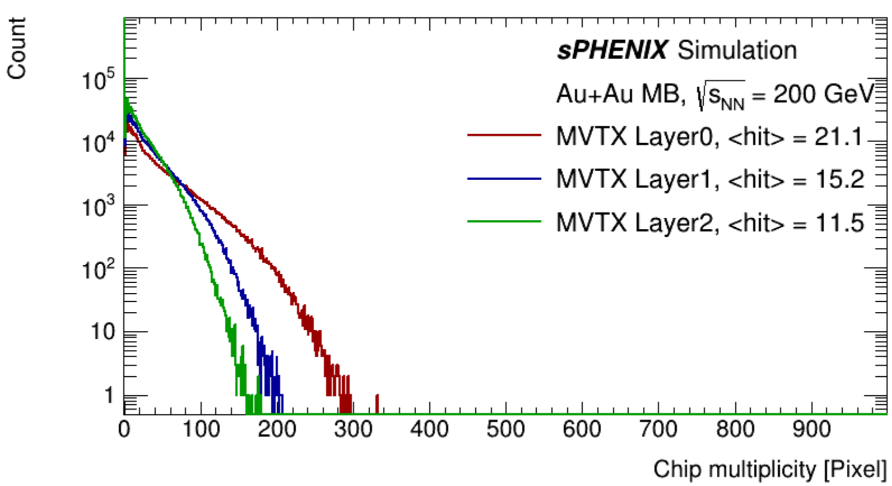
# Per-MB-collision multiplicity, 30-cm sigma Gauss Vertex, 200 GeV AuAu & pp

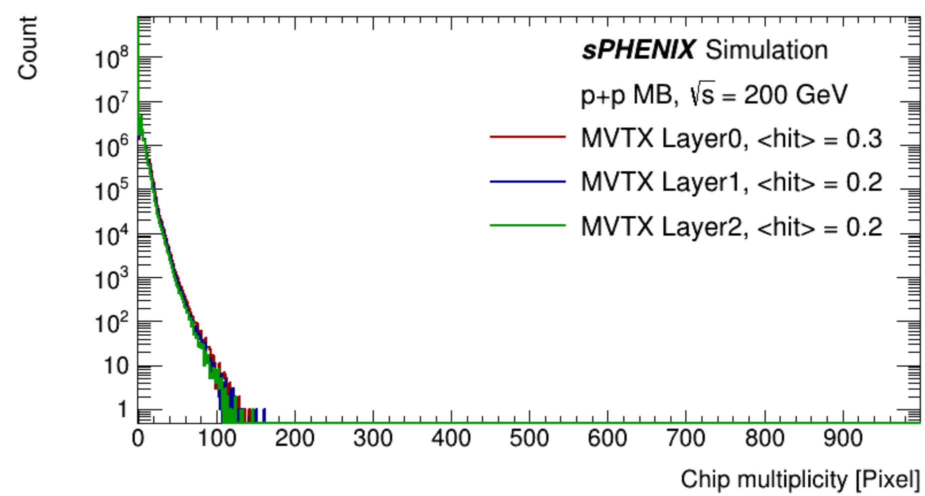
sHIJING M.B. Au+Au

Pythia-8 M.B. p+p (Sanghoon's tunes)



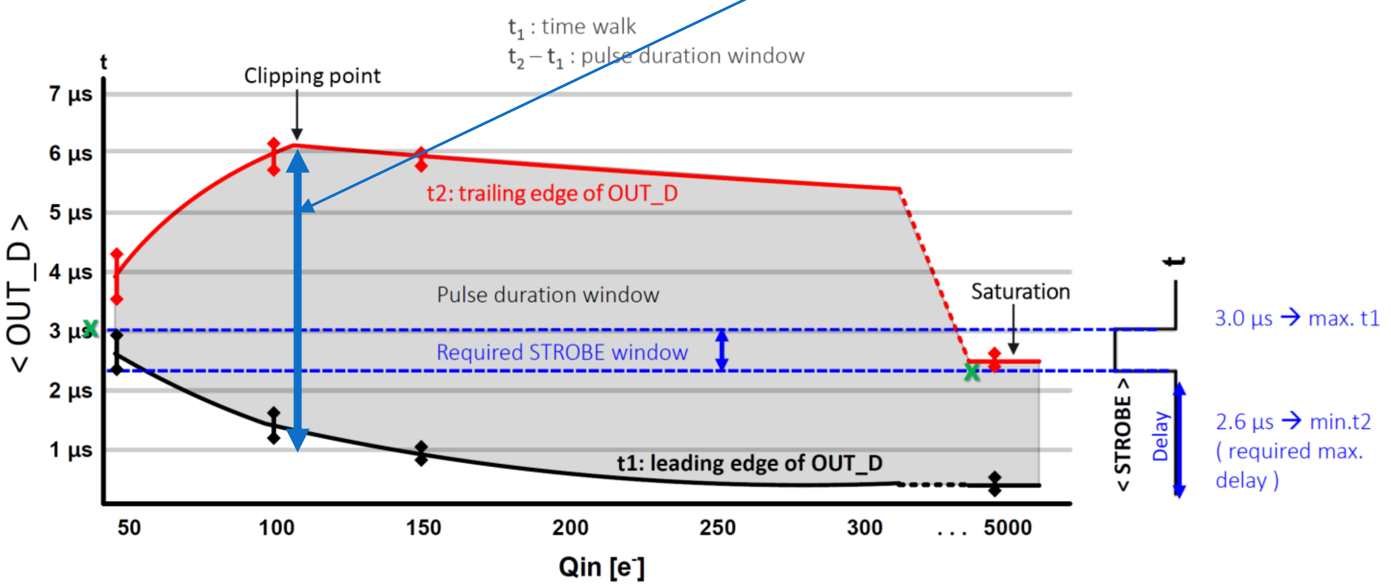
# Per-strobe ALPIDE multiplicity

Four factor contributes in a MC simulation:

- Per-collision multiplicity, PDF as in last page
- Number of pile up collision, Poisson distributed
- The triggered collision, |z|<10 cm (trigger mode only)
- Number of noise, Poisson distributed

+ Comments received from the last MVTX meeting:

- Duplicated hits between strobes are not included yet (Thanks to Jo)
  - (Conservatively) assuming 5us of additional data absorbed into each strobe.
- UPC electron background not included (Thanks to Xin)
- Aiming for $10^{-6}$ noise in final detector (Many)



# UPC electron multiplicity – Xin Dong

https://conferences.lbl.gov/event/201/

## sPHENIX MVTX vs. STAR HFT

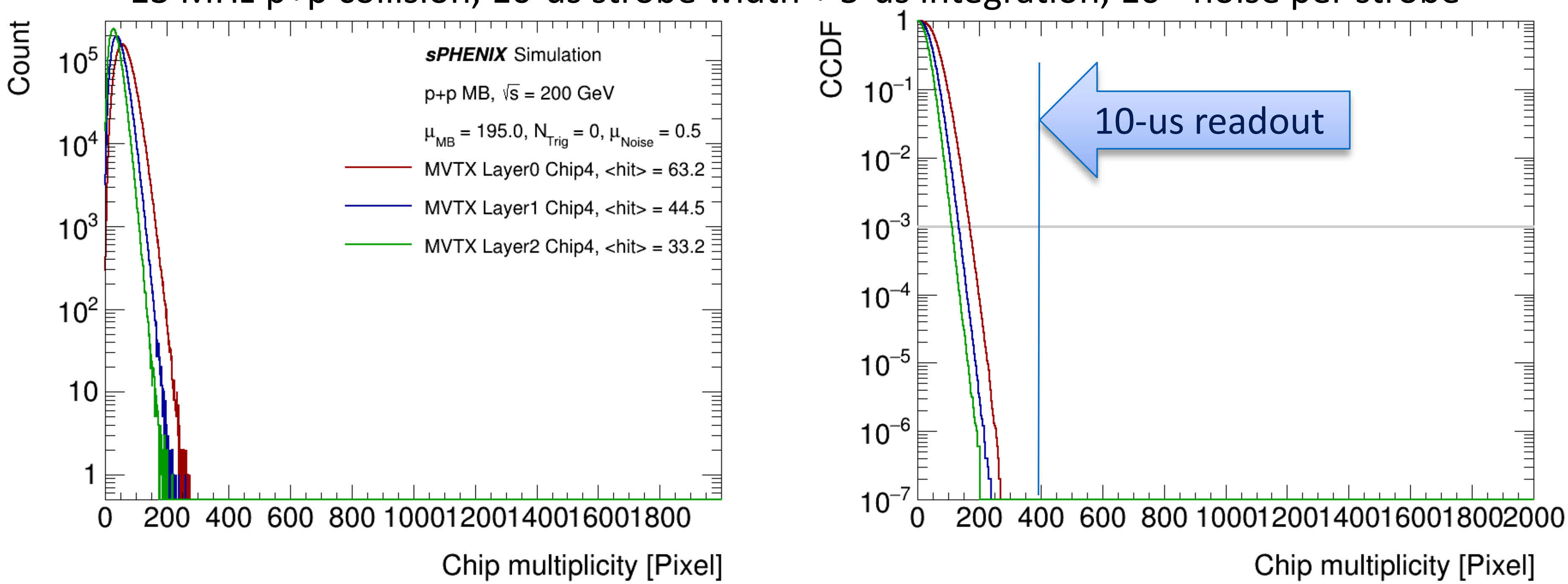
| | STAR HFT | sPHENIX MVTX |
|---|---|---|
| B filed (T) | 0.5 | 1.5 |
| Integration Time | ~ 200 us | <10 us |
| Luminosity | 50kHz | 200kHz |
| First layer radius (cm) | 2.8 | 2.2 |
| MB pileup hits ($cm^{-2}$) | 13 | 13./5 ~ 2.6 |
| UPC electrons ($cm^{-2}$) | 33 | 33./5 /~5 ~ 1-2 |

Assuming 2 hits/sensor/strobe

# p+p multiplicity, per-strobe, chip-4

- p+p data is completely dominated by pile-ups
- Central limit theorem: High number of pile up → low non-Gauss high tails
- Continuous-mode is quite safe @ 10-us strobe window

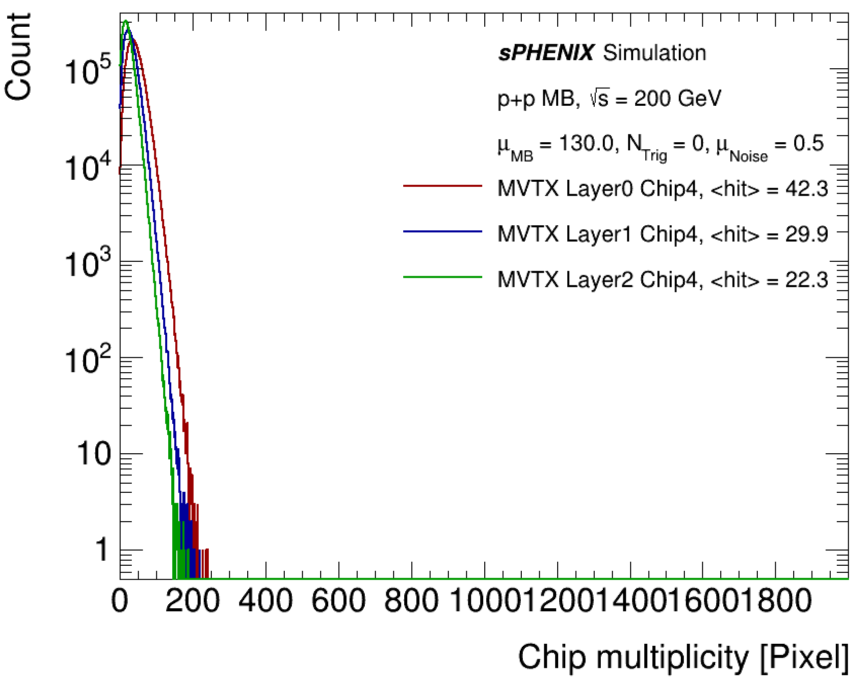
13 MHz p+p collision, 10-us strobe width + 5-us integration, $10^{-6}$ noise per strobe

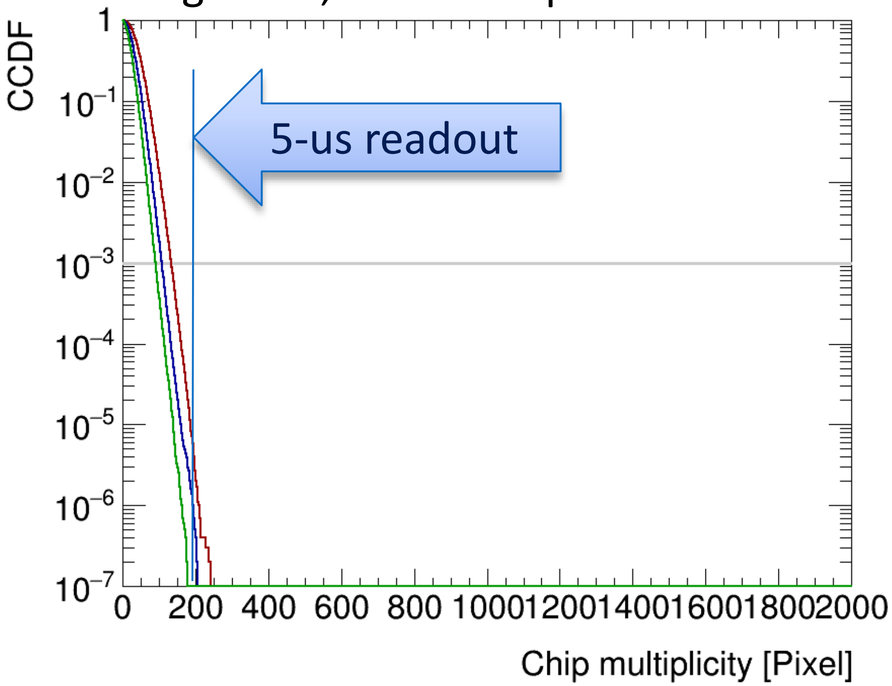


# p+p multiplicity, per-strobe, chip-4

- Continuous-mode is plausible at 5-us strobe window too
  - Probability [readout-time per-strobe > 5us] < $10^{-5}$

13 MHz p+p collision, **5-us strobe width** + 5-us integration, $10^{-6}$ noise per strobe

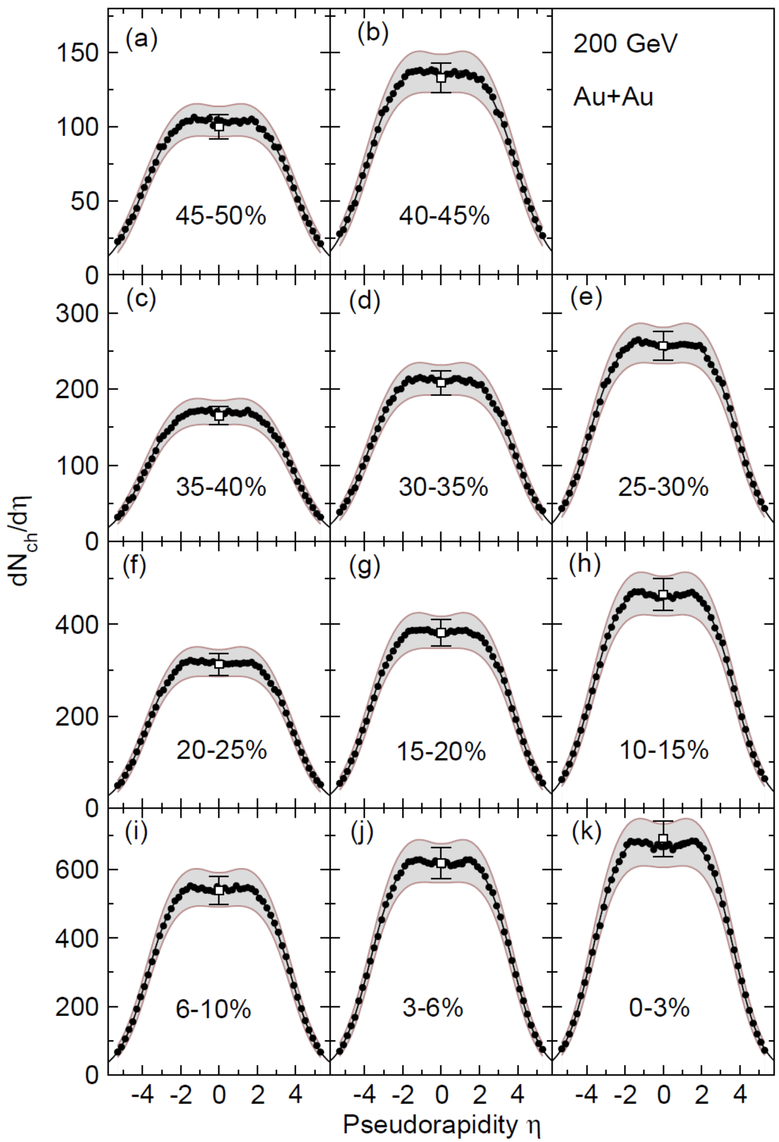


# Au+Au collision

- Tail in the Au+Au collision is significantly different:
- Au+Au collision has large fluctuation
- Mean pile up is low integer
  - 2 pile up for 10us integration at 200kHz collision
  - Can easily fluctuate to several times larger at 0.1% Prob.
- → longer tail

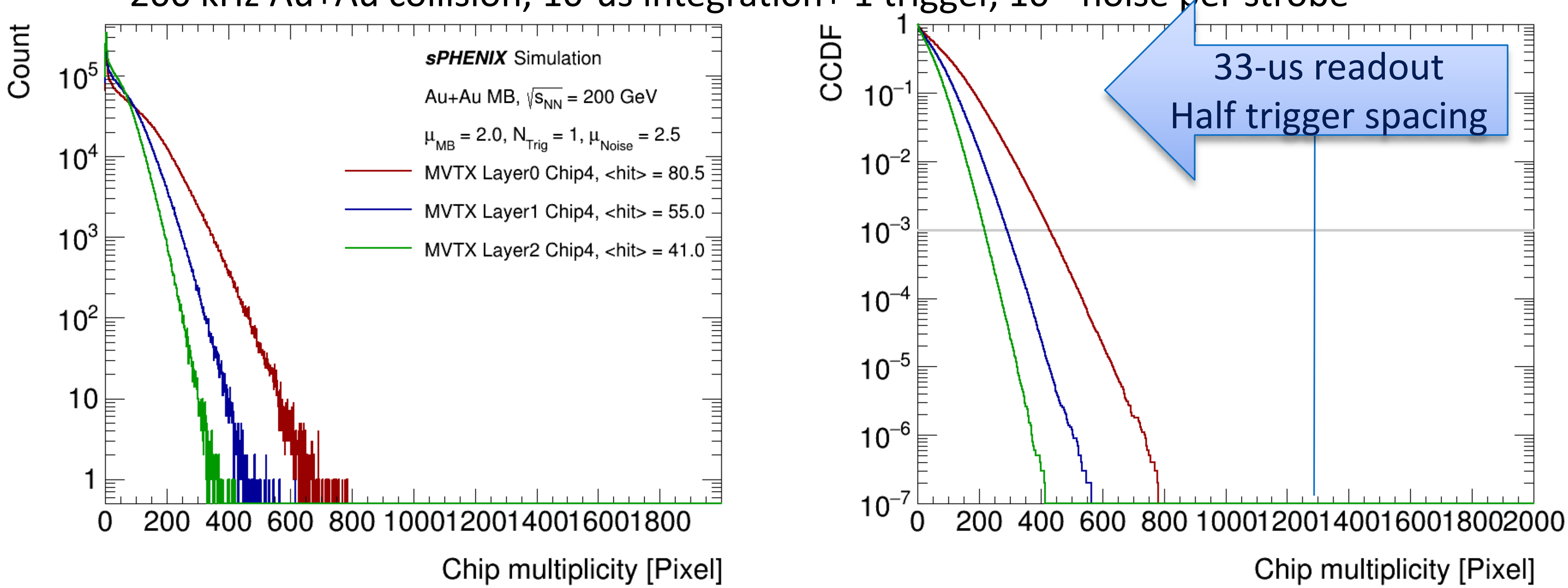
PHOBOS 10.1103/PhysRevC.83.024913



# Au+Au multiplicity, per-strobe, chip-4

- Triggered mode looks safe
- #pixel readout in average 15kHz trigger spacing = 1s/15kHz/25ns-per-hit = 2700 hits
- Further quantify probability of buffer overflow need some continuous-time simulation

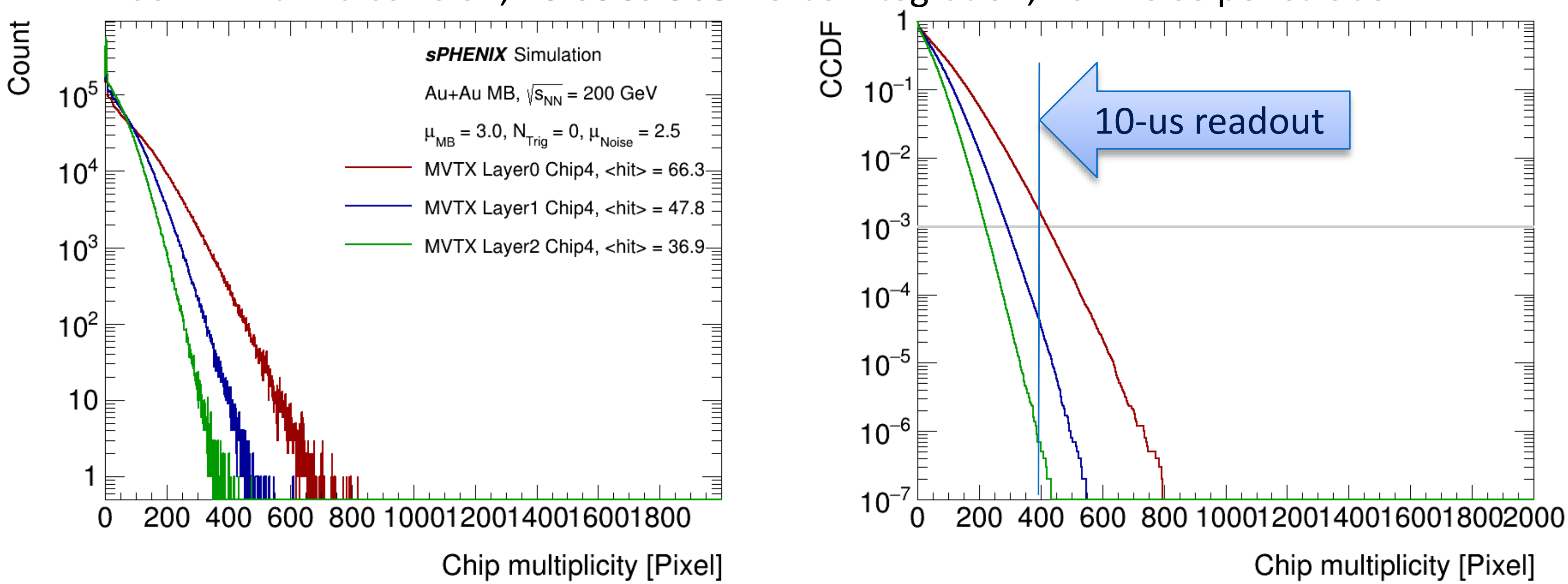
200 kHz Au+Au collision, 10-us integration+ 1 trigger, $10^{-6}$ noise per strobe



# Au+Au multiplicity, per-strobe, chip-4

- Continuous mode is much more trickier
- <0.1% inner layer chip-4 would require more than 10-us to readout its data

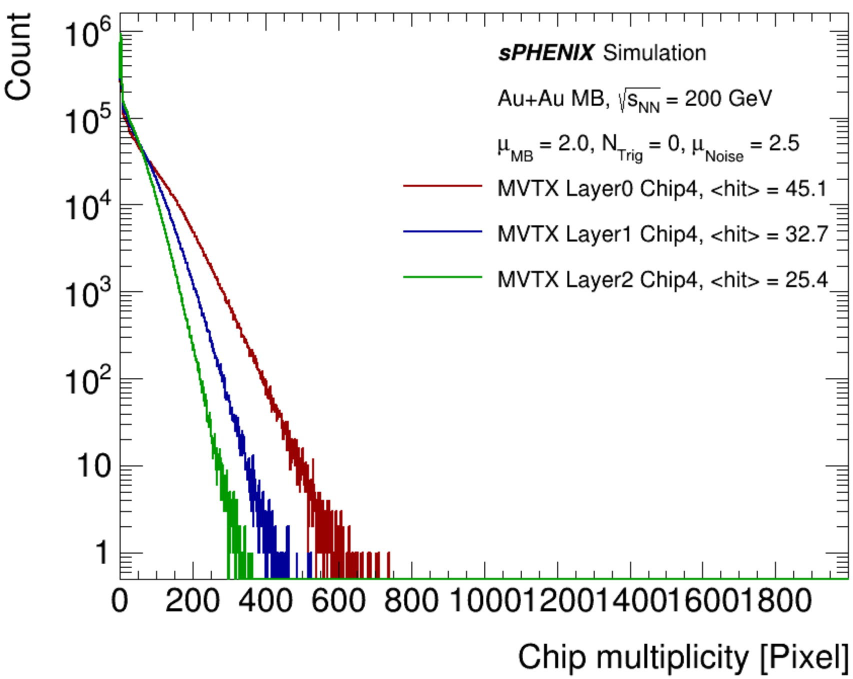
200 kHz Au+Au collision, **10-us strobe** + 5-us integration, $10^{-6}$ noise per strobe

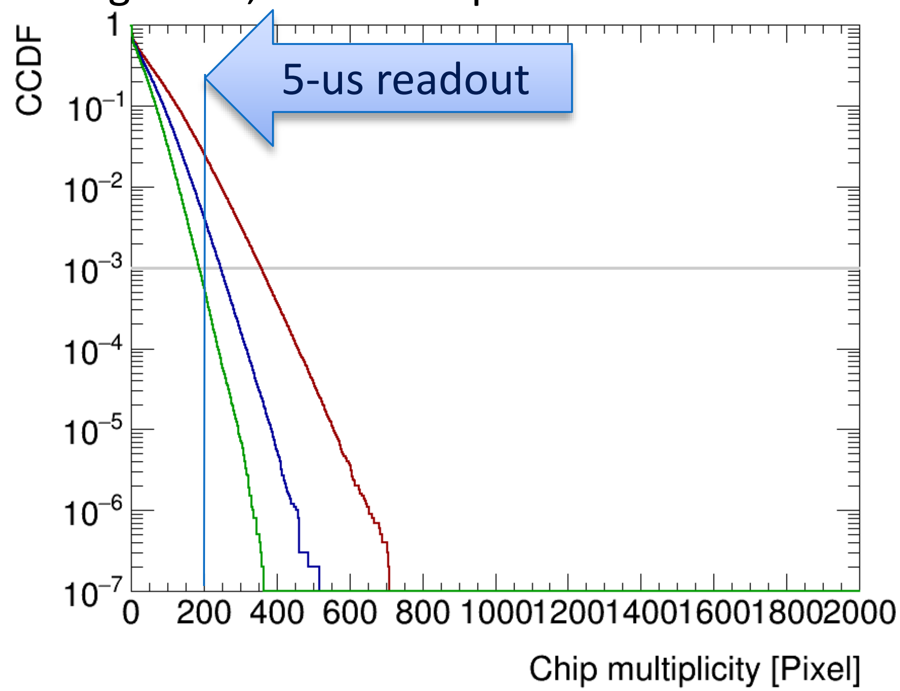


# Au+Au multiplicity, per-strobe, chip-4

- Reducing integration window to 5-us is trickier, due to high fraction of noise and higher fluctuation in pile up
- Percent-level chance that 3rd buffer is needed to avoid the loss

200 kHz Au+Au collision, **5-us strobe** width+ 5-us integration, $10^{-6}$ noise per strobe



# Summary

- Full scale simulation of per-strobe multiplicity in order to shed light on ALPIDE transmission dead-time and possibility of operating in the continuously triggered chip-mode
  - Repeated after many follow up, in particular tuned digitizer to reflect chip tests.
- p+p data has low tails, plausible for continuously triggered chip-mode
- Au+Au data has much higher fluctuation. In continuously triggered chip-mode with 5us strobe, percent chance that strobe readout time > strobe period
  - The 3rd buffer is used
  - Need continuous-time leaky basket simulation to get data loss rate.
- Code location:
  - https://www.phenix.bnl.gov/WWW/sPHENIX/doxygen/html/da/dbf/classHFMLTriggerOccupancy.html
  - https://github.com/sPHENIX-Collaboration/analysis/blob/master/HF-Jet/HFMLTrigger/macros/OccupancySim.C