EIC data rates and noise estimates for a streaming readout system

Jin Huang (BNL)



Thanks to the inputs from many of our colleagues! Partly based on our past reports in SRO workshops and eRD23

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	$10^{34} \rightarrow 10^{35} \mathrm{cm}^{-2} \mathrm{s}^{-1}$
x-N cross section	50 µb	40 mb	80 mb
Top collision rate	500 kHz	10 MHz	1-6 GHz
dN _{ch} /dη in p+p/e+p	0.1-Few	~3	~6
Charged particle rate	4M N _{ch} /s	60M <i>N</i> _{ch} /s	30G+ <i>N</i> _{ch} /s

• EIC luminosity is high, but collision cross section is small ($\propto \alpha_{EM}^2$) \rightarrow 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

Early EIC Detector Concepts



EIC DAQ in Geant4 simulation

Note sPH-cQCD-2018-001: https://indico.bnl.gov/event/5283/ , Simulation: https://eic-detector.github.io/



e+p DIS 18+275 GeV/c Q² ~ 100 (GeV/c)²

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

BROOKHAVEN NATIONAL LABORATOR

Jin Huang <jhuang@bnl.gov>

Tonko's estimation: Signal rate = 16*8 Gbps ~ 100 Gbps @ 10³³ 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 =) <mark>16 GB/s</mark>

e+p collision 18+275 GeV/c DIS @ Q² ~ 100 (GeV/c)²



Jin Huang <jhuang@bnl.

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.2	0x250.1Meven	ts.Rac	lCor=0.root		
CKIN(3)	changed	from	0.00000	to	0.0000
CKIN(4)	changed	from	-1.00000	to	-1.0000

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

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

+ headers (60 bits)

3x10 signal hit / collision \rightarrow 0.2 Gbps @10³⁴ cm⁻²s⁻¹

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

See backup slides for full set of detectors

Jin Huang <jhuang@bnl.gov>

EIC collision signal data rate summary

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

- Tracker + calorimeter ~ 40 Gbps
 - + PID detector + 2x for noise ~ 100 Gbps
 - Similar rate to an earlier estimation T. Ljubicic for BeAST (2015)
- > Unlike LHC or RHIC, signal-collision data rate of 100 Gbps seems quite manageable:
 - Smaller than sPHENIX TPC peak disk rate of 200 Gbps
- Far-forward spectrometers/instruments not yet included



Beam-gas interactions

- p + p (beam gas) cross section ~ 40 mb @ 250 GeV
- Beam gas interaction rate = 2.65e10(H₂/cm²/10m) * 2(proton/H₂) * 40e-27(40mb→cm²) * 1(A) / 1.6e-19(C/proton) = 13kHz / 10m beam line < 10% EIC collision rate</p>

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

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

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 x 10 ¹⁰ molecules/cm ²
Luminosity (Ring-Ring)	10.05 x 10 ³³ cm ⁻² s ⁻¹
Bunch intensity (R-R) (e/p)	15.1 / 6.0 x 10 ¹⁰
Beam Current (R-R) (<mark>e</mark> /p)	2.5 / 1 A
Bunch spacing (Ring-Ring)	8.7 ns \rightarrow 1320 bunches
ElectronxProton beam energy	10 GeV x 275 GeV

Beam gas multiplicity

- > 250 GeV/c proton beam on H₂ 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



10

Jin Huang <jhuang@bnl.gov>

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.



GEANT4-based detector simulation: beam gas event on tracker

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



NAL LABORATORY

Jin Huang <jhuang@bnl.gov>

1st EIC YR Workshop

12

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



13

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 \rightarrow 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



Run 001098 (15 × 10⁶ events @ 50 kHz, VBB = -3 V, THR = 100 e tuned) number of pixel vs hit frequency 5853 10^{-6} 2:2991 ake-hit rate (per pixel and event) 3-100: 57 10^{-7} %-10%: 13 10^{-8} >99%: 24 10^{-9} 10^{-10} 10-11 10^{-12} 10² 10³ 10^{4} number of masked pixels (out of 28 × 10⁶)

ALICE ITS commissioning run, from Felix Reidt, QM2019

Jin Huang <jhuang@bnl.gov>

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 @ 10³⁴ cm⁻² s⁻¹ less than sPHENIX peak disk rate
- For YR studies over the coming ½ year
 - Need to include realistic PID simulation and far forward instrucmentation
 - Need to include as much as other source of background and noises (e.g. synchrotron)



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 \rightarrow 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 \rightarrow control systematics:
- Low data loss rate $< 10^{-4}$ (?) and/or loss in a deterministic manor

16

Streaming/trigger hybrid 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



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)
 - STAR eTOF (2018 on-going)
 - Both have standalone streaming DAQ and synchronized with the global experiment trigger with timestamps
- Future: <u>BDX, CLAS12 @ Jlab</u>, full tracking system setting at sPHENIX



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

STAR/CBM eTOF Upgrade arXiv:1609.05102



Streaming readout for sPHENIX trackers



BHUUKHAVEN NATIONAL LABORATORY

Jin Huang <jhuang@bnl.gov>

19

RC DAQ in EIC-themed campaigns Courtesy to Martin Purschke (BNL)

nob/io	Control
mlp	vm2
Runnin	g for 9s
Run:	13
Events:	41
Volume:	0.179
File: rcdaq-000	01377-0000.evt
Clo	se
Er	nd
COC X RCDAQ Status	
RCDAQ Status	
mlpvm2	
Running for 8 s	
Run: 1375	
Events: 374	
Volume: 0.160316 N	ИВ
File: rcdaq-00001375-000	0.evt
CONTROL	
RCDAQ Control	
mlpvm2	

RCDAO Control



) R Y



Dual-sided PWO readout (2017











Jin Huang <jhuang@bnl.gov>

Recent test beam in June 2019



\$ 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)\$

Streaming readout sim. for TPC



- Based on Fun4All sim+reco framework: <u>https://eic-detector.github.io/</u>
- 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): <u>https://www.phenix.bnl.gov/phenix/WWW/publish/jinhuang/sPHENIX/TPCMachineLearningData/</u>



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



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





24

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 \rightarrow control systematics
- Work towards YR
 - Completing the background data rate study
 - Completing hit and noise rate for more detector types, in particular far forward instrumentation and PID
 - If you would like to have a set of EIC full detector SRO dataset, Fun4All simulation provides basis to do so

Extra information





Jin Huang <jhuang@bnl.gov> 1st E

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



Tonko's estimation: Signal rate = 16*8 Gbps ~ 100 Gbps @ 10³³ 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 =) <mark>16 GB/s</mark>

e+p collision 18+275 GeV/c DIS @ Q² ~ 100 (GeV/c)²



Jin Huang <jhuang@bnl.

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.2	0x250.1Meven	ts.Rad	dCor=0.root		
CKIN(3)	changed	from	0.00000	to	0.0000
CKIN(4)	changed	from	-1.00000	to	-1.00000

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

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

- 3x10 signal hit / collision \rightarrow 0.2 Gbps @10³⁴ cm⁻²s⁻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 / 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/

31

GEANT4-based detector simulation for DAQ simulation: forward calorimeters

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



32

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



Beam gas estimation for eRHIC detectors



Assuming flat 10e-9 mbar vac in experimental region



Jin Huang <jhuang@bnl.gov> 1st EIC YF

Beam-gas interactions

- p + p (beam gas) cross section ~ 40 mb @ 250 GeV
- Beam gas interaction rate = 2.65e10(H₂/cm²/10m) * 2(proton/H₂) * 40e-27(40mb→cm²) * 1(A) / 1.6e-19(C/proton) = 13kHz / 10m beam line < 10% EIC collision rate</p>

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

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

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 x 10 ¹⁰ molecules/cm ²
Luminosity (Ring-Ring)	10.05 x 10 ³³ cm ⁻² s ⁻¹
Bunch intensity (R-R) (e/p)	15.1 / 6.0 x 10 ¹⁰
Beam Current (R-R) (<mark>e</mark> /p)	2.5 / 1 A
Bunch spacing (Ring-Ring)	8.7 ns \rightarrow 1320 bunches
ElectronxProton beam energy	10 GeV x 275 GeV

Beam gas multiplicity

- > 250 GeV/c proton beam on H₂ 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



36

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)



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)



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)



Jin Huang <jhuang@bnl.gov>

41

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

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



Jin Huang <jhuang@bnl.gov>

43

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

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)



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.



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.



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





Jin Huang <jhuang@bnl.gov> 1st E

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), onchip 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 \rightarrow 10⁻⁶ (proposal assumed 10⁻⁴)



ALICE ALPIDE Data

- 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
 - <u>Summarized here https://indico.bnl.gov/event/5454/</u>, 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





60

MVTX digitization and per-track multiplicity

- At MVTX LBNL workfest, Tony retuned MVTX clusterizer to ALICE data
 - <u>Summarized here https://indico.bnl.gov/event/5454/</u>, 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



NATIONAL LABORATORY

61

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

 $dN_{Ch}/d\eta$

Count



Chip multiplicity [Pixel]

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 <



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

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



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 0



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.
- \rightarrow longer tail



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

- Triggered mode looks safe
- #pixel readout in average 15kHz trigger spacing = 1s/15kHz/25ns-perhit = 2700 hits
- Further quantify probability of buffer overflow need some continuoustime 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 10us to readout its data



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:
 - <u>https://www.phenix.bnl.gov/WWW/sPHENIX/doxygen/html/da/dbf/classHFMLTriggerOccupancy.html</u>
 - <u>https://github.com/sPHENIX-Collaboration/analysis/blob/master/HF-Jet/HFMLTrigger/macros/OccupancySim.C</u>



71