BNL: sPHENIX SRO DAQ

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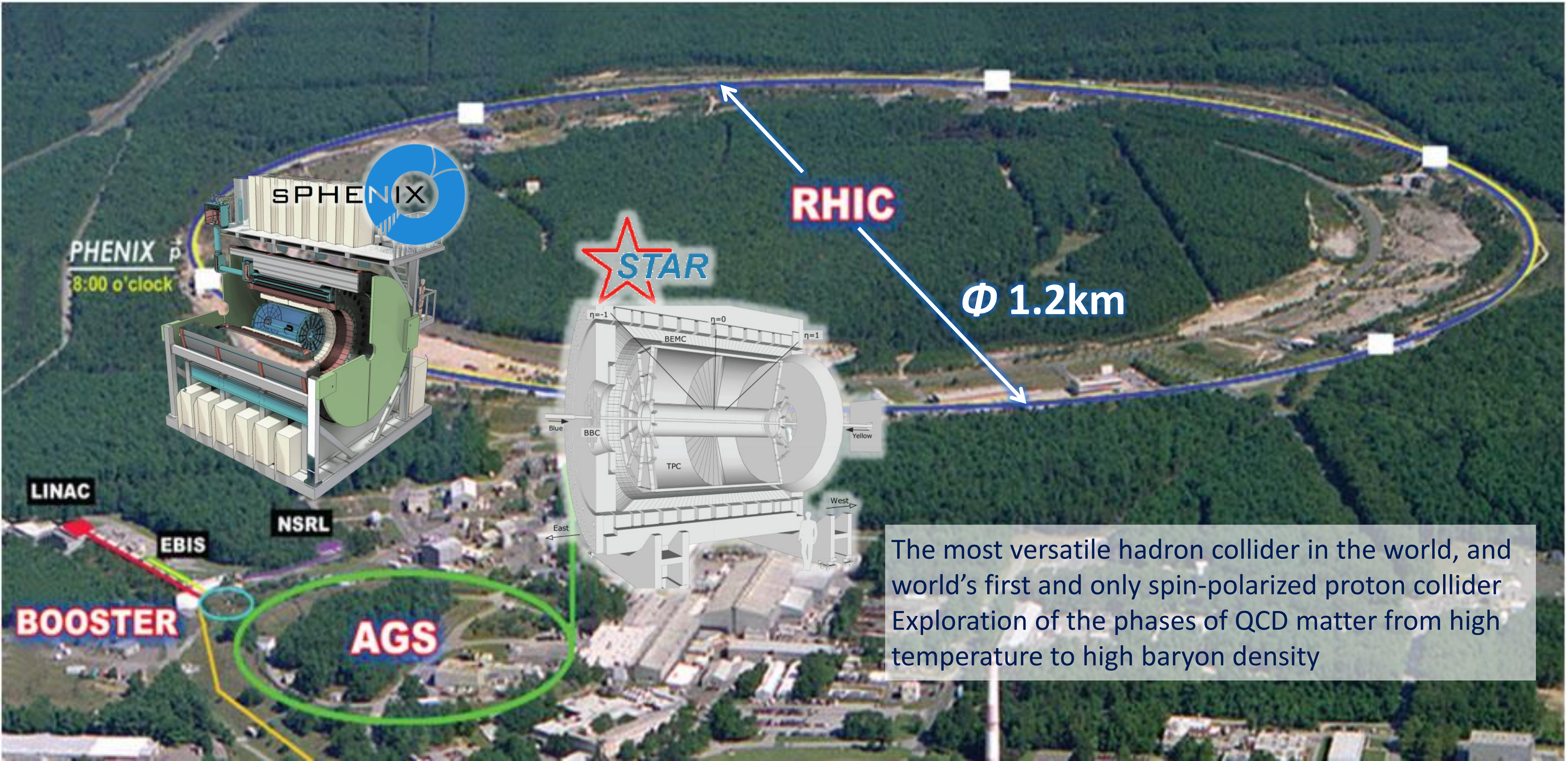
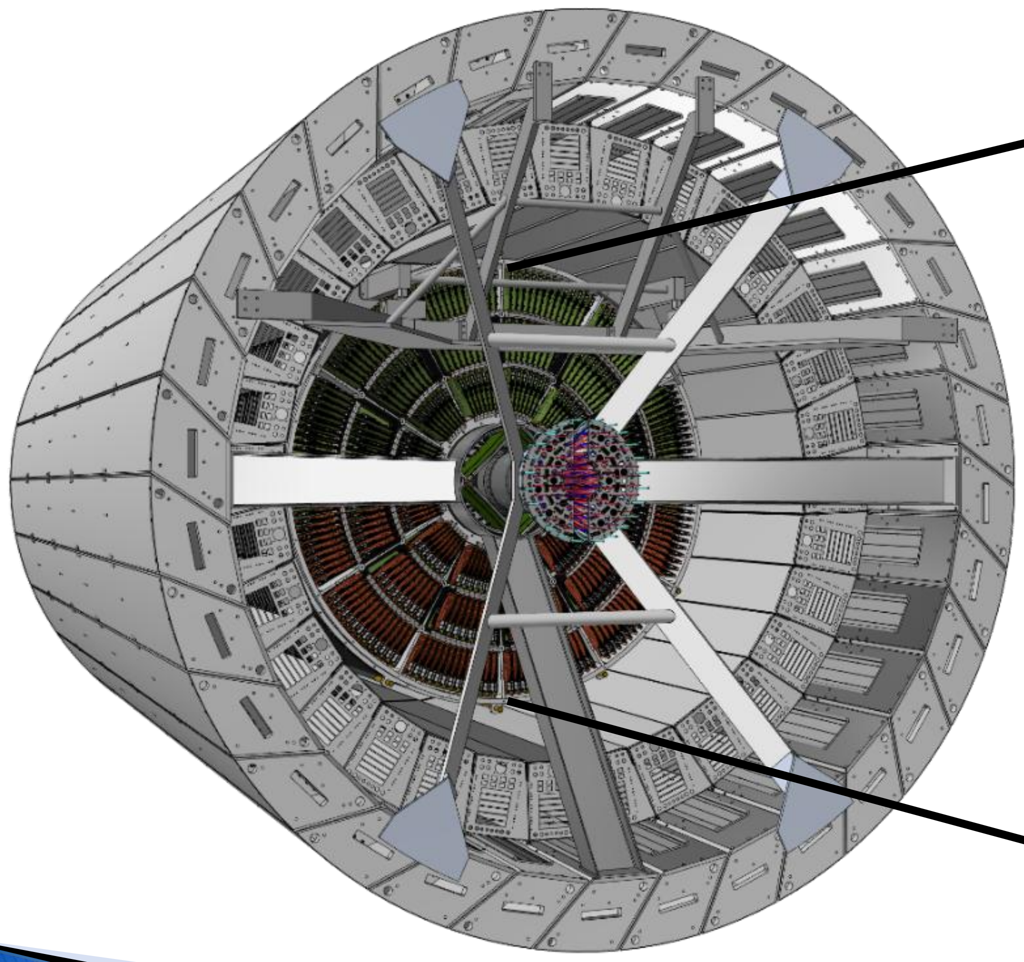
Relativistic Heavy Ion Collider (RHIC) in 2023+



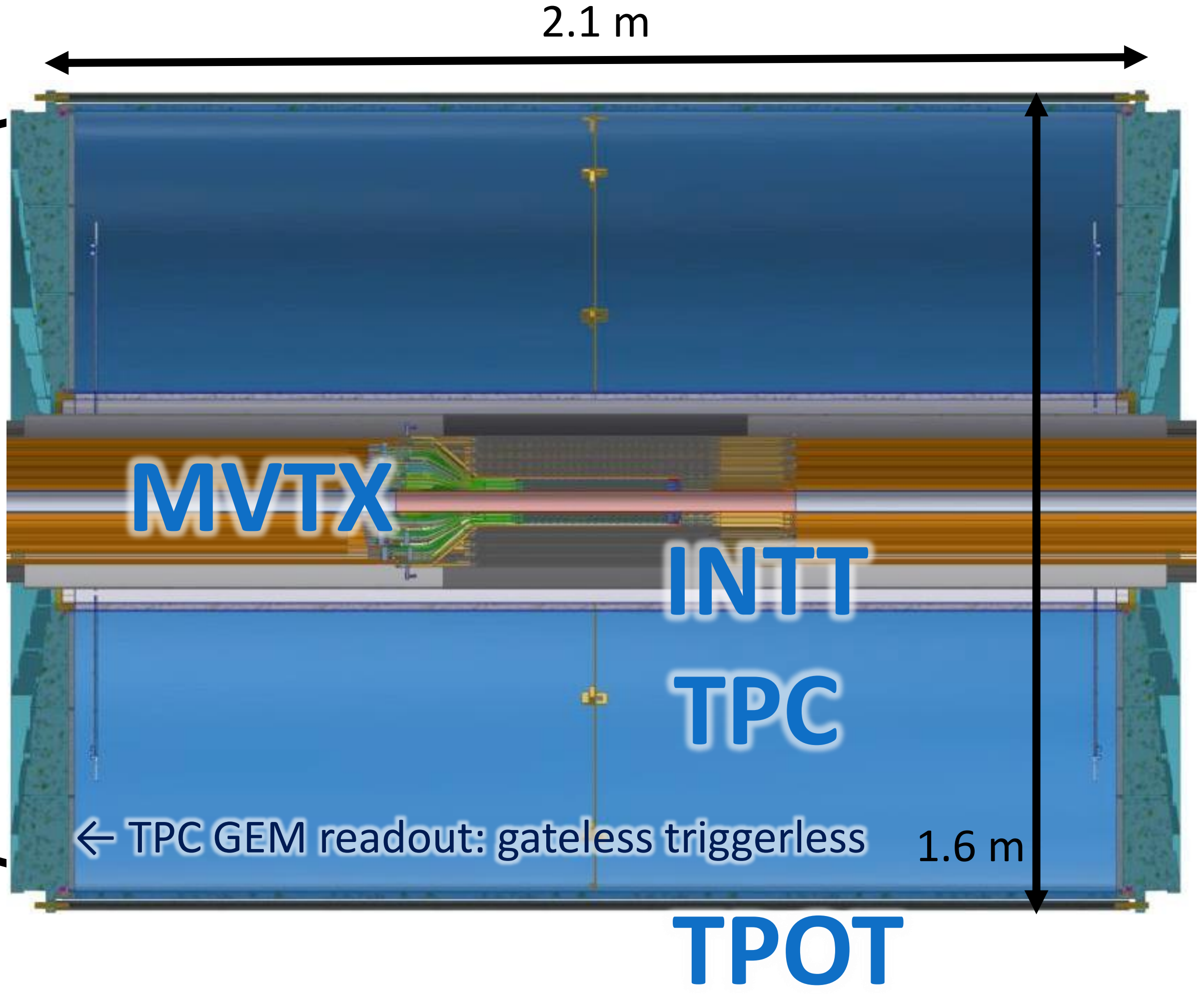
The most versatile hadron collider in the world, and world's first and only spin-polarized proton collider
Exploration of the phases of QCD matter from high temperature to high baryon density


sPHENIX experiment
Completed first/commissioning run in 2023!
N
ABLE

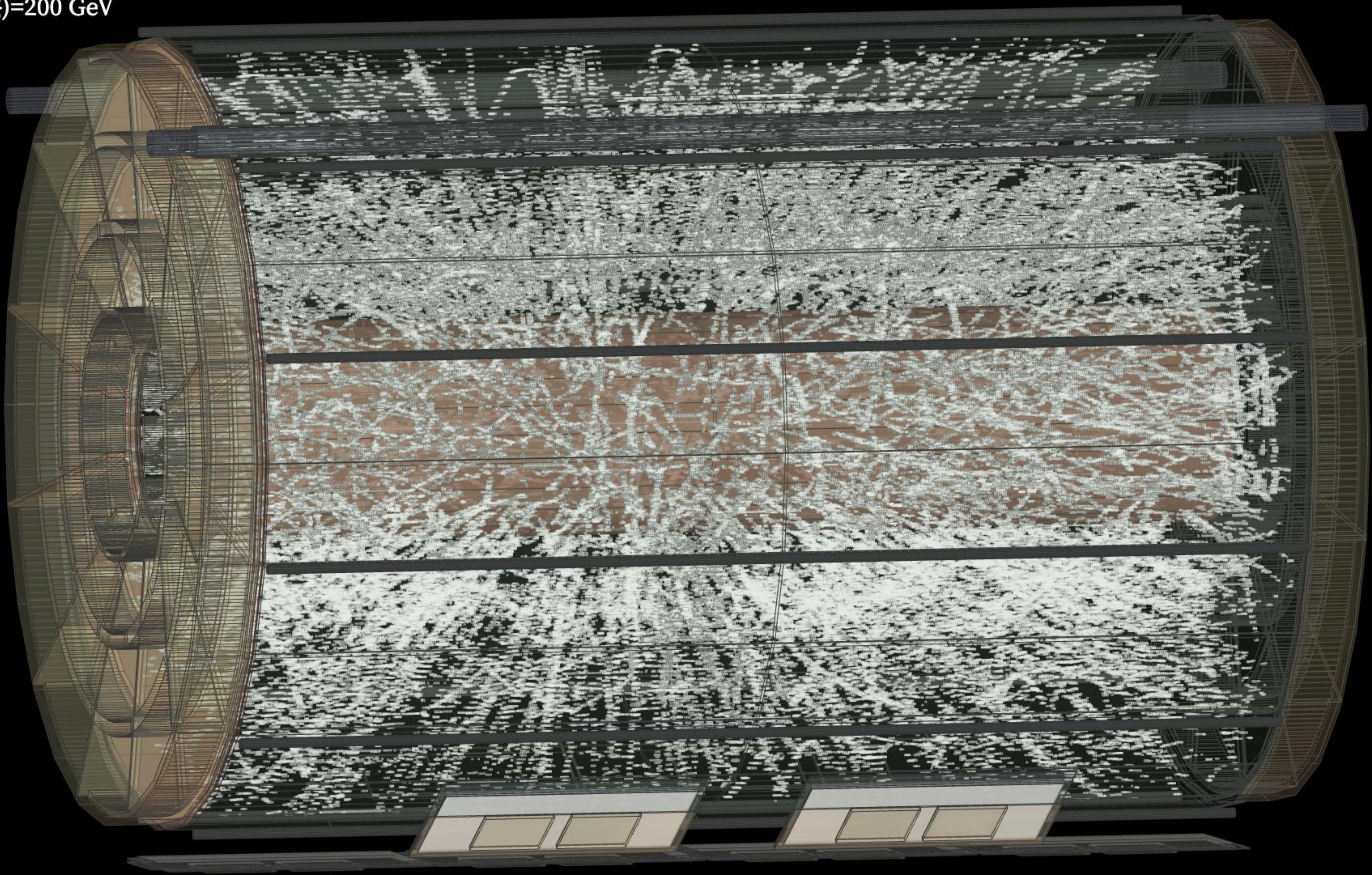
sPHENIX Tracking Detectors: all supports streaming mode

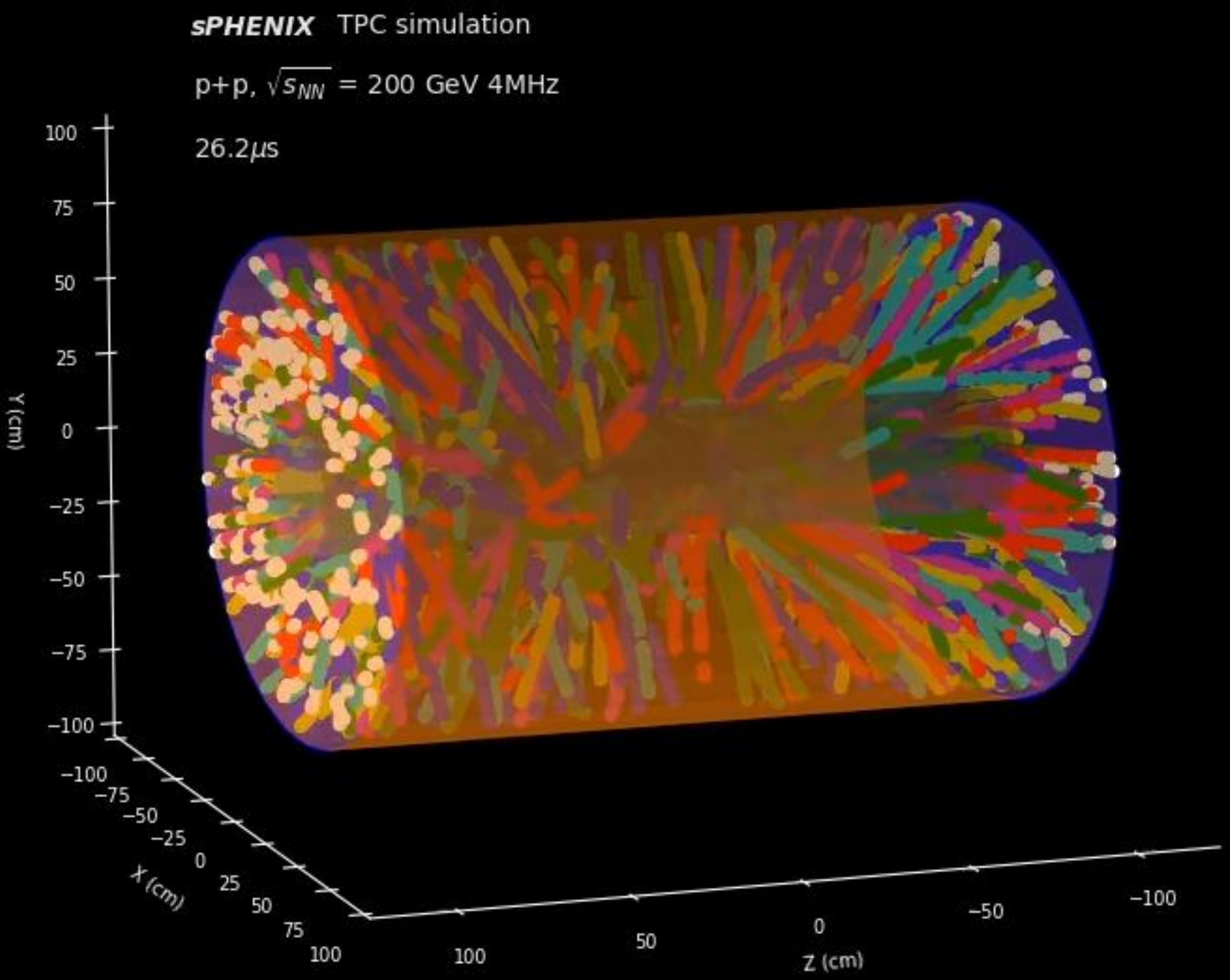


Detectors inside the magnet



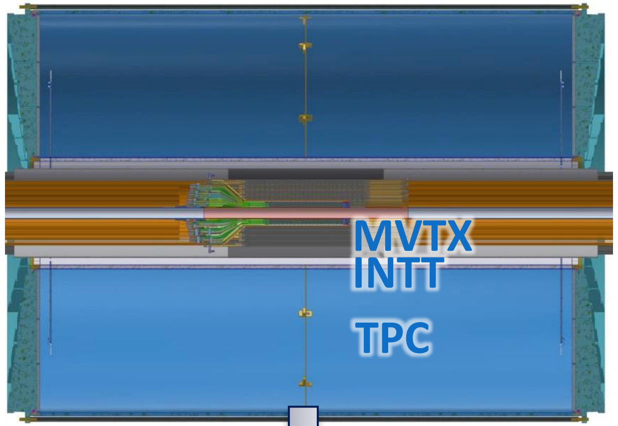
sPHENIX Time Projection Chamber
100 Hz ZDC, MBD Prescale: 2, HV: 4.45 kV GEM, 45 kV CM, X-ing Angle: 2 mrad
2023-06-23, Run 10931 - EBDC03 reference frame 43
Au+Au sqrt(s_{NN})=200 GeV

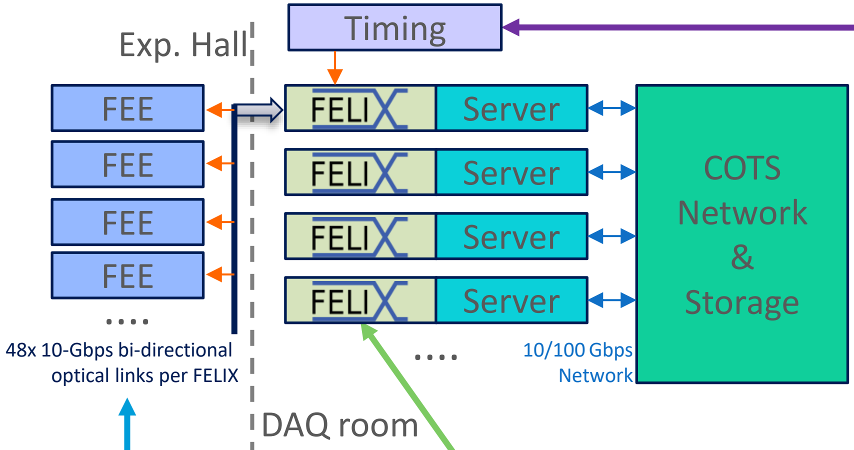



sPHENIX TPC simulation
p+p, $\sqrt{s_{NN}}$ = 200 GeV 4MHz
26.2μs
Y (cm)
100
75
50
25
0
−25
−50
−75
−100
X (cm)
−100
−75
−50
−25
0
25
50
75
100
Z (cm)
100
50
0
−50
−100

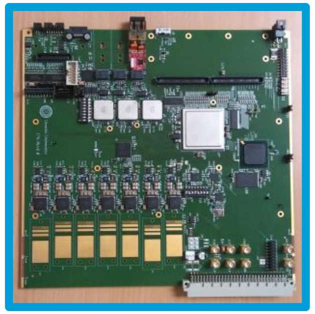
Streaming readout electronics
Driven by common DAQ software: RCDAQ

sPHENIX streaming DAQ for tracker





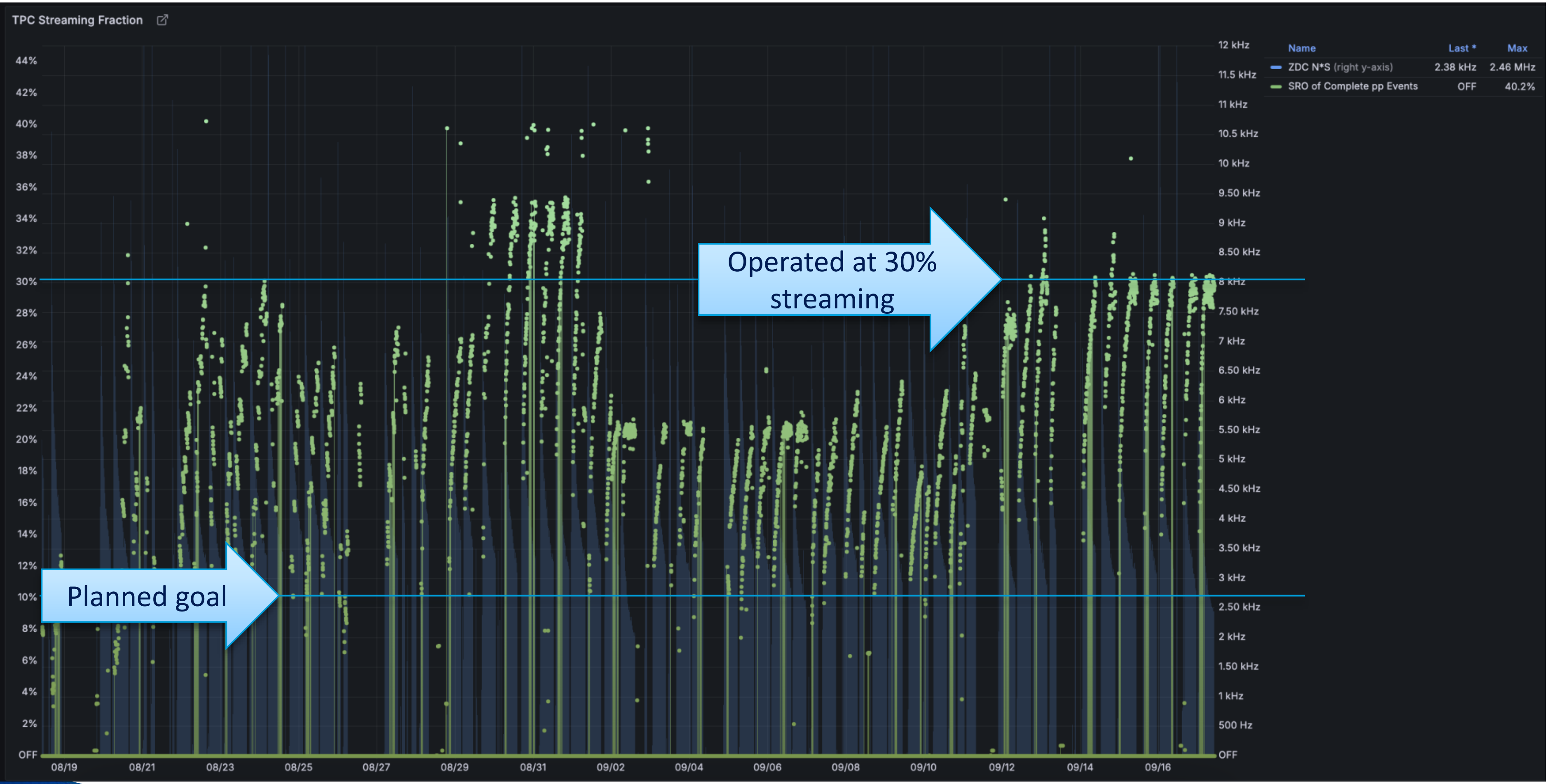
Global Timing
Module
(NSLS II/sPHENIX)
Receiving from RHIC RF
low glitter clock source



MVTX RU, 200M ch INTT ROC, 400k ch TPC FEE, 160k ch BNL-712 / FELIX v2 x38 (ATLAS/sPHENIX)

ALPIDE (ALICE/sPHENIX), FPHX (PHENIX) SAMPAv5 (ALICE/sPHENIX) FELIX Ref: 10.1109/tim.2019.2947972

First physics run in 2024!



RHIC Program Advisory Committee 2020 Report

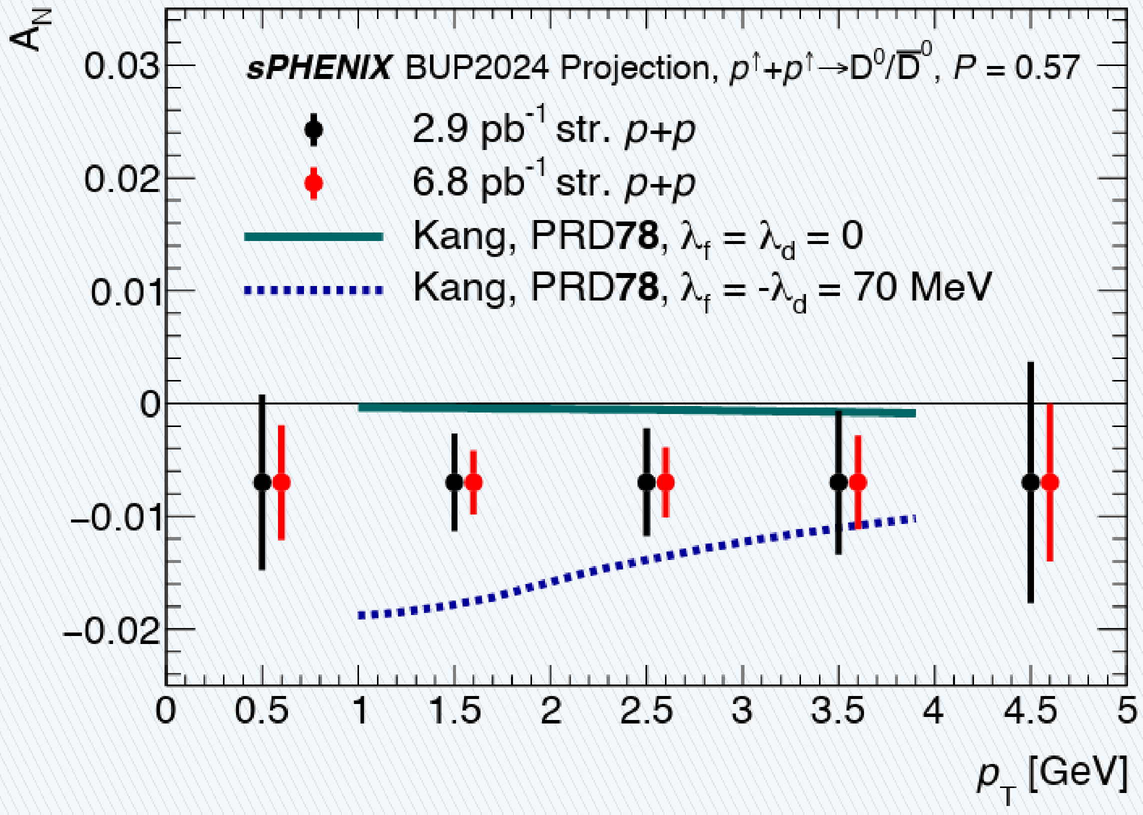
The PAC commends sPHENIX for developing the continuous streaming readout option that will increase their data collection in Run-24 by orders of magnitude. This is particularly important and allows unique access to novel open heavy flavor measurements.

RHIC Program Advisory Committee 2024 Report

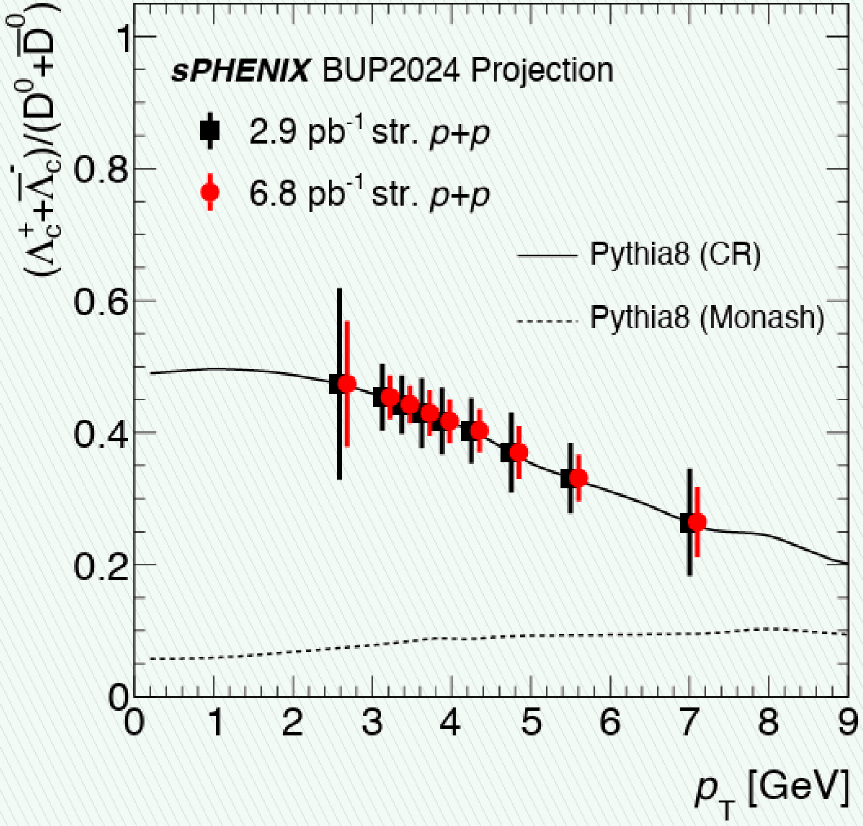
sPHENIX… The streaming readout rate for the tracking detectors (MVTX, INTT and TPC) exceeded the original goal of 10% by a factor of three on average during the run enabling acquisition of a significant amount of data for open heavy flavor physics.

Physics made only possible by streaming DAQ

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



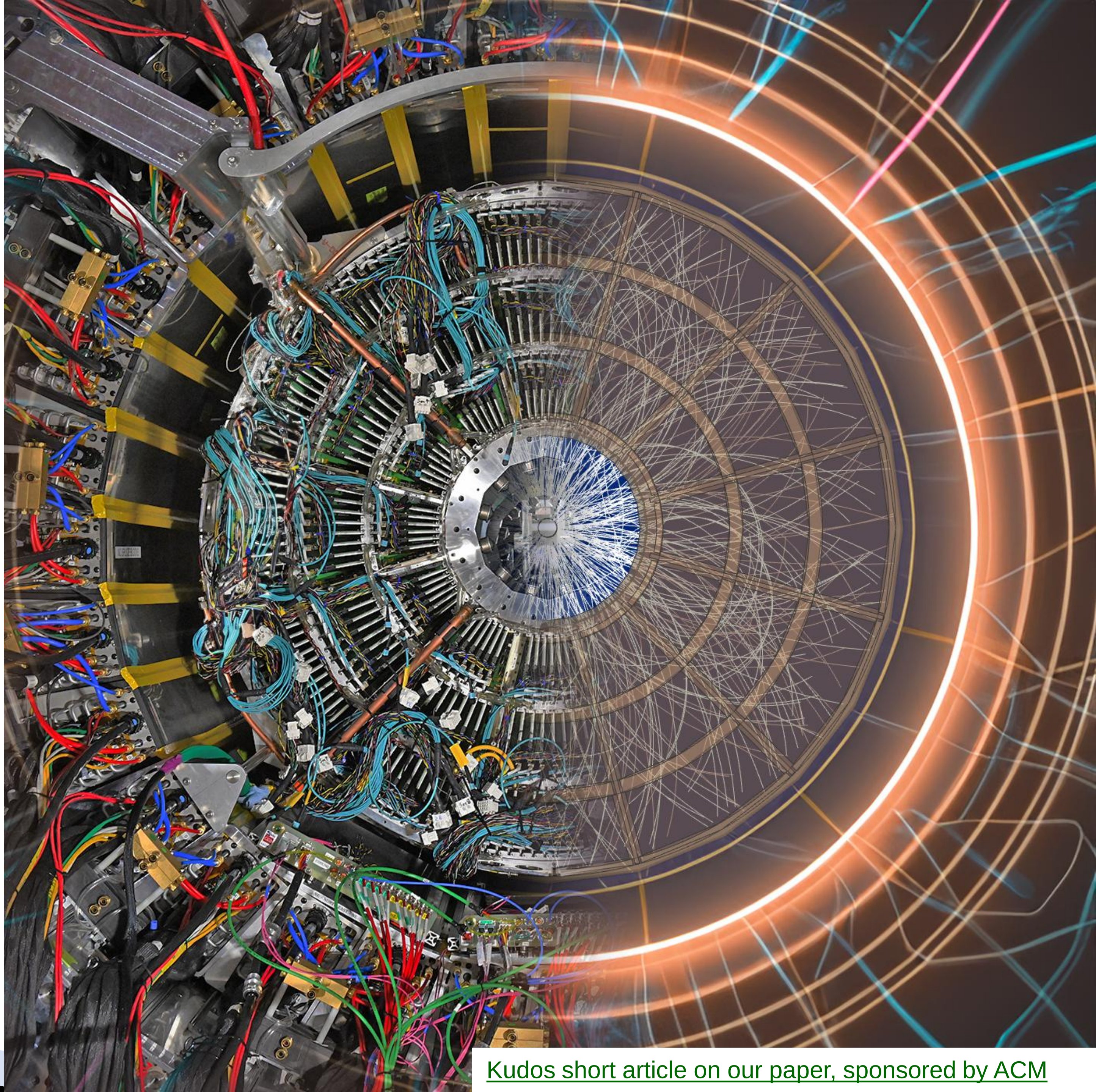
First Charm baryon to meson ratio at RHIC
→ charm hadronization



[sPHENIX Beam Use Proposal 2024]
Model: 10.1103/PhysRevD.78.114013

AI in sPHENIX streaming

- sPHENIX simulation data used for exploring AI-driven data reduction
- NP-data optimized anto-encoder data reduction:
  - arXiv:2411.11942 **[physics.ins-det]**
  - arXiv:2412.01754 **[cs.AI]**
  - DOI: 10.1145/3624062.3625127
  - DOI: 10.1109/ICMLA52953.2021.00179
  - https://github.com/BNL-DAQ-LDRD/NeuralCompression_v3
  - https://github.com/BNL-DAQ-LDRD/NeuralCompression_v2
- Tagging/triggering on FPGA
  - arXiv:2501.04845 **[physics.ins-det]**
  - arXiv:2312.15104 **[physics.ins-det]**



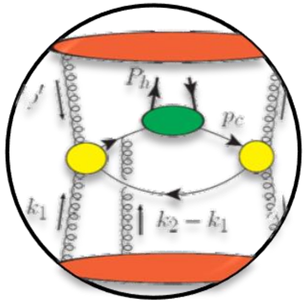
Kudos short article on our paper, sponsored by ACM

Summary

- sPHENIX just completed the first successful run with streaming tracker
  - Tripled the target streaming fraction (to 30% delivered pp collision recorded)
  - The streaming capability enables a wide spectrum of low p_T HF physics program by increasing their statistics by orders of magnitudes, commended by the PAC for years
- Few thoughts for future streaming experiments
  - Application of Streaming DAQ carries cost and risks, adoption (or not) should be justified by physics program
  - A noisy piece of streaming detector likely become a dead piece of detector in streaming data
  - A streaming data pipeline can become full sooner or later (high instantaneous rate from Poisson distribution of collision, background, and noise), therefore it by design needs to handle congestion gracefully.
  - Many ideas work at small scales, but our streaming system need to be designed at the scale for the entire experiment and robust against multiple failure mode
- If you would like to prototype streaming system: come to join sPHENIX ☺
  - Real streaming data, 4D tracking, high fidelity streaming simulation, 40x(FELIX+EBDC), MAPS+SAMPA (current generation of the ePIC SVT/MPGD chip family)

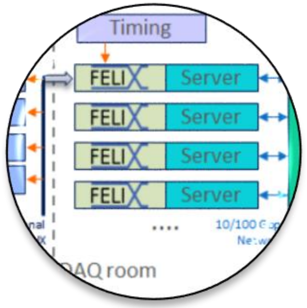
Extra information

Streaming DAQ and real-time AI:
A new and paradigm shift for experiments in next NP LRP



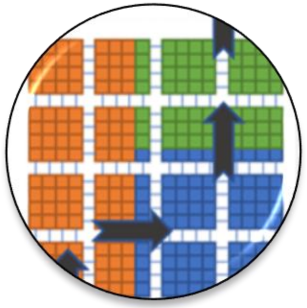
NP Physics

- Diverse topology
- Stringent sys. Ctrl
- Max data preservation



Streaming DAQ

- New physic capability accessible only via streaming DAQ
- Example: adopted for sPHENIX and EIC
- Require data reduction computationally



Opportunities for AI enhancement

- Specialized AI algorithm for reliable and high-performance data reduction
- Novel hardware emerging for high-throughput AI computing

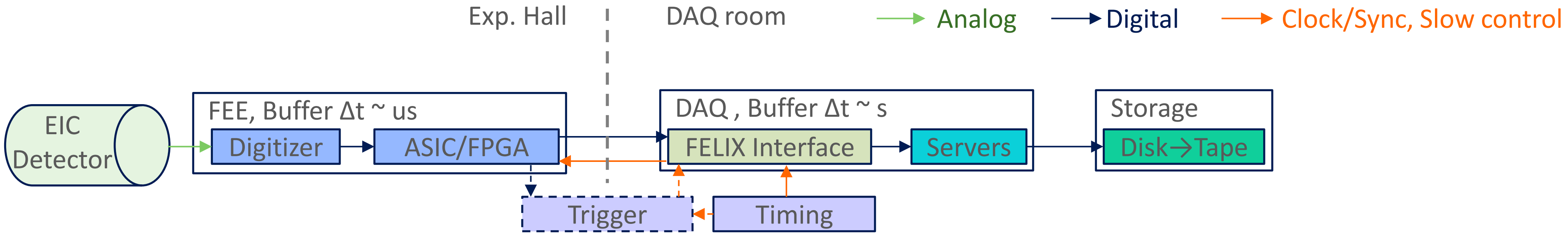
Physics need → Streaming DAQ → Opportunity for real-time AI → Enhanced physics program

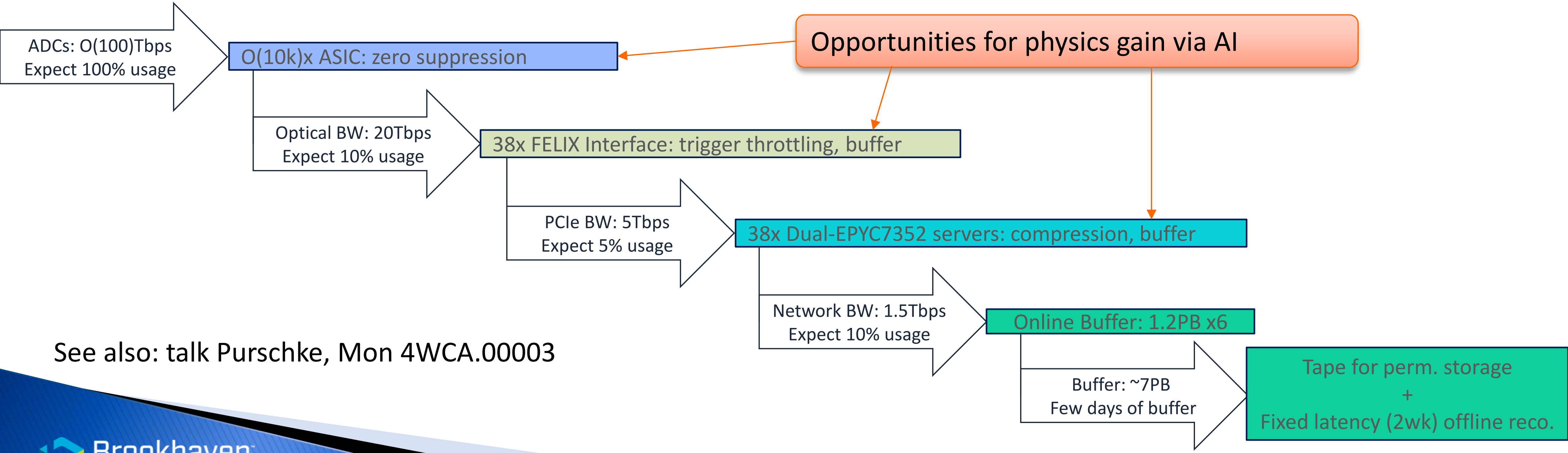
Nuclear collider experiments: unique real-time system challenges leads to streaming DAQ

	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}/dη 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**

- Signal data rate is moderate → possible to streaming recording all collision signal
- But events are precious and have diverse topology → hard to trigger on all process
- Background and systematic control is crucial → avoiding a trigger bias; reliable data reduction

sPHENIX Streaming data flow





See also: talk Purschke, Mon 4WCA.00003

AI in streaming readout DAQ

- Main challenge: data reduction
  - Traditional DAQ: triggering was the main method of data reduction, assisted by high level triggering/reconstruction, compression
  - Streaming DAQ need to reduce data computationally: zero-suppression, feature building, lossy compression
- Opportunities for Real-time AI
  - Emphasize on reliable data reduction, applicable at each stages of streaming DAQ: Front-end electronics, Readout Back-end , Online computing
  - Data quality monitoring, fast calibration/reconstruction/ feedback
    - Has many AI application too
    - Not focus of this talk, nonetheless important for NP experiments