

# Streaming Experience with sPHENIX TPC



Charles Hughes  
on behalf of the sPHENIX TPC Group

Streaming Readout Workshop SRO-XII - December 2024

University of Tokyo



# Outline

- sPHENIX and sPHENIX TPC Intro
- TPC Front & Back End Electronics Readout
- sPHENIX Streaming
- sPHENIX Run '24
  - Noise Reduction
  - 100 % streaming
  - Hybrid trigger + streaming (physics program)

(see also talks by [Yihui Ren](#), [Martin Purschke](#), and [Cameron Dean](#))

# sPHENIX Overview

## Tracking Detectors

- **MVTX**
- **INTT**
- **TPC**
- **TPOT**

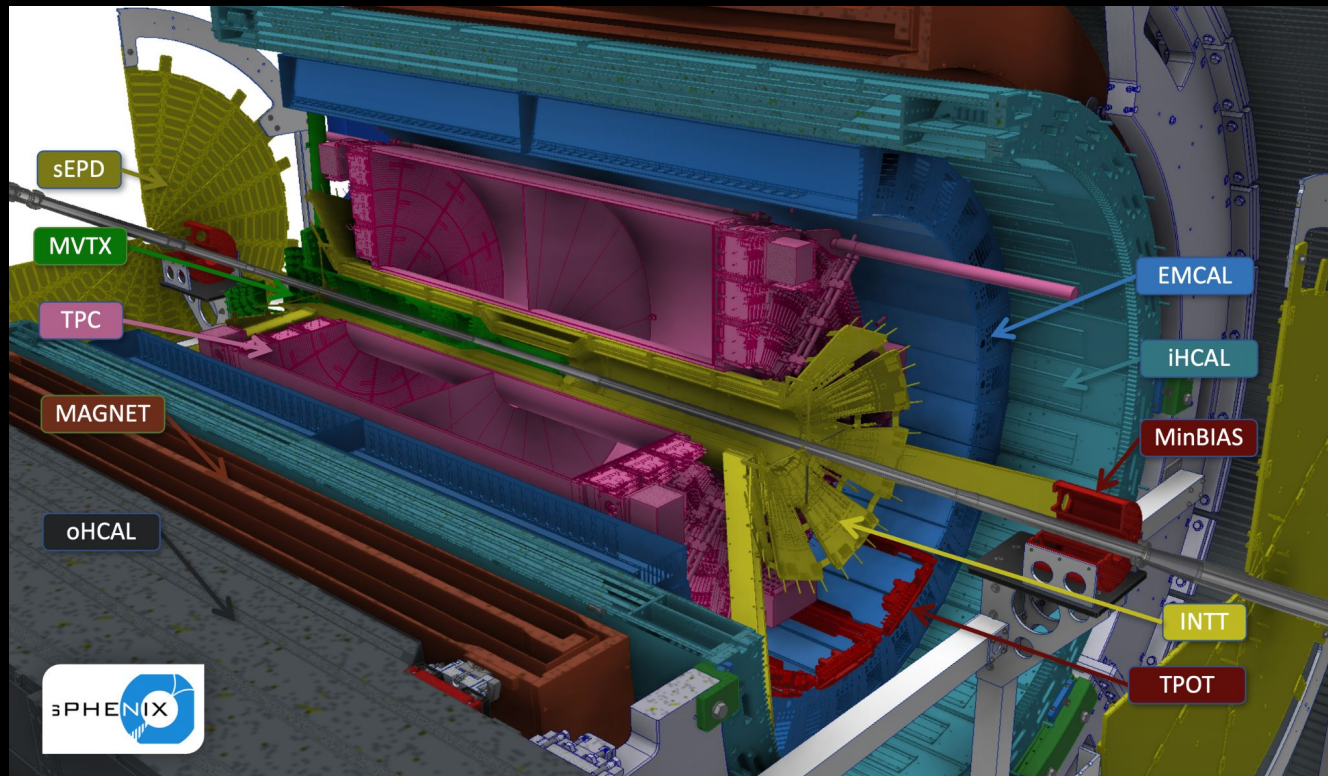
## Calorimetry

- **EMCAL**
- **HCAL (inner/outer)**

## Magnet

## Forward Detectors

- **sEPD**
- **MBD (minBIAS)**





# sPHENIX Overview

## Tracking Detectors

- MVTX
- INTT
- **TPC**
- TPOT

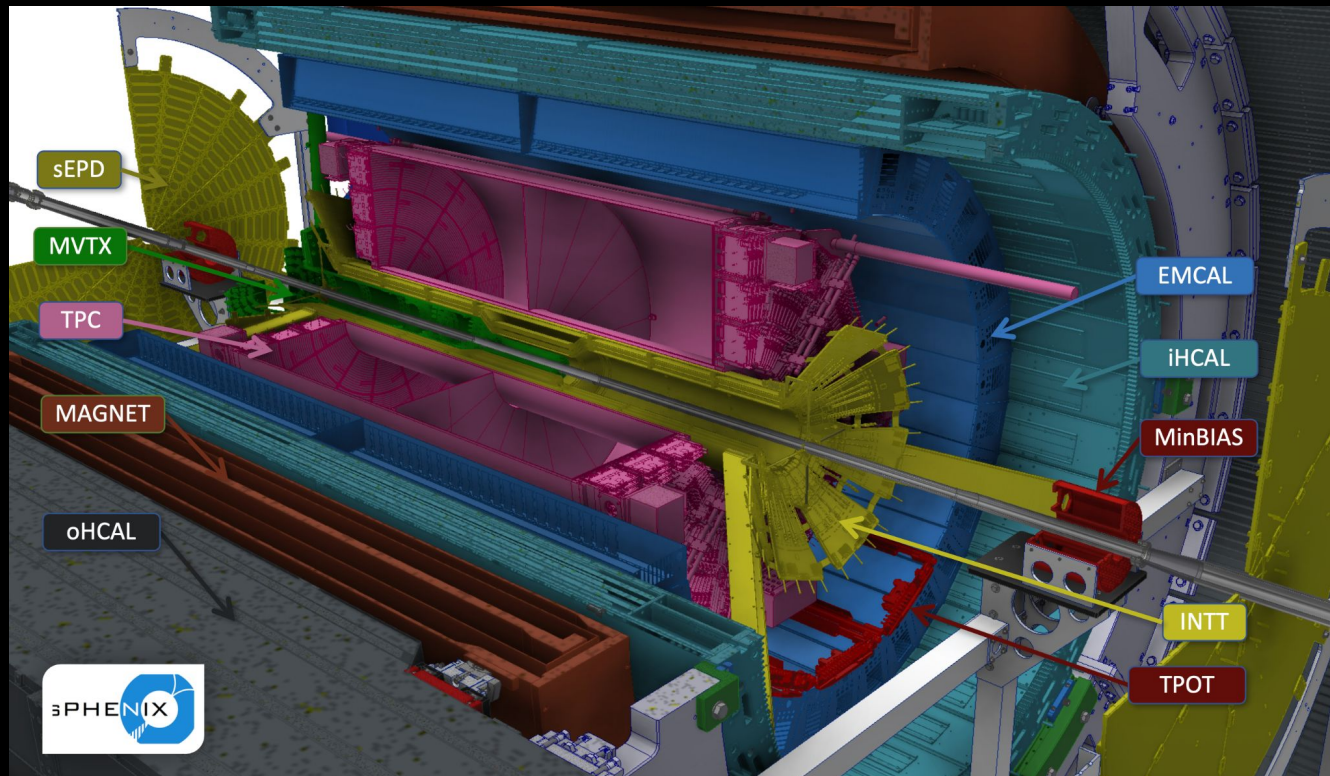
## Calorimetry

- EMCAL
- HCAL (inner/outer)

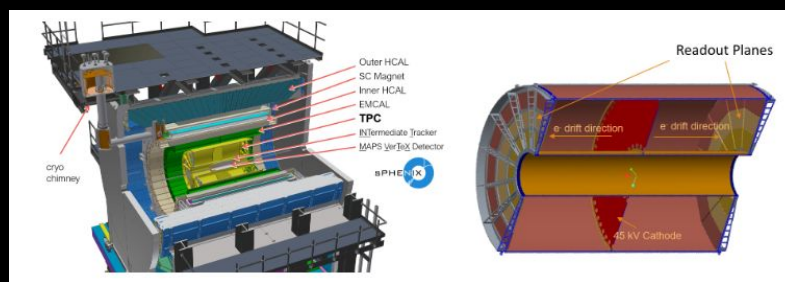
## Magnet

## Forward Detectors

- sEPD
- MBD (minBIAS)



# sPHENIX TPC



- Gaseous Drift Detector
  - Ar/CF<sub>4</sub>/ISO 75:20:5 % drift gas
    - O(13 μs) drift time
  - GEM (Gaseous Electron Multiplier) amplification
    - 4 Kapton + Copper GEMs / module
  - Un-gated like ALICE TPC
    - Allows for streaming readout
  - Zig-zag segmented copper sensor pads
    - Improves position resolution

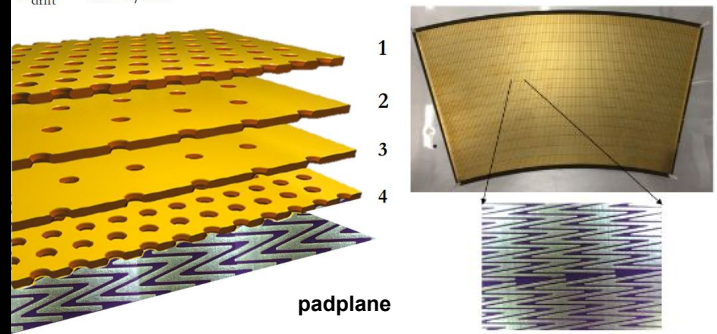
$E_{\text{drift}} = 400 \text{ V/cm}$

Standard pitch  
not rotated

Large pitch  
rotated

Large pitch  
not rotated

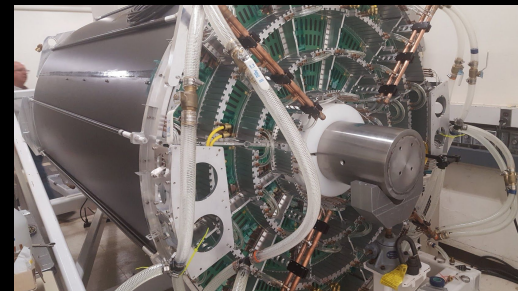
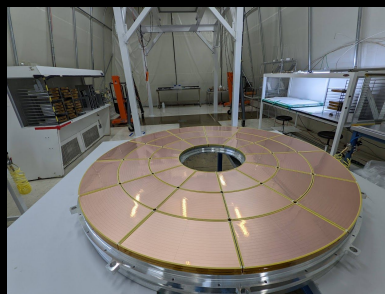
Standard pitch  
rotated



padplane

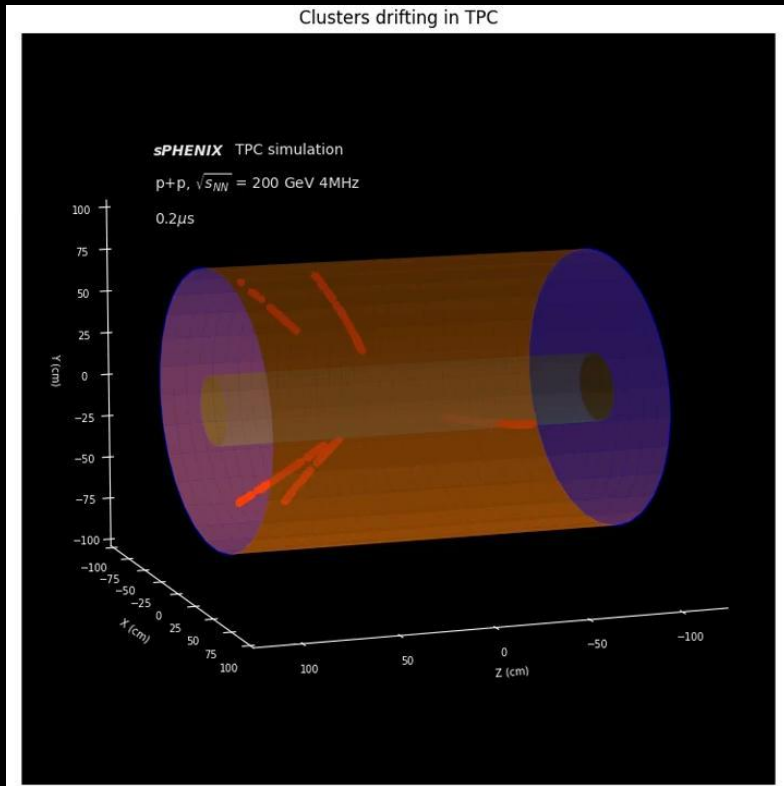
- 72 GEM modules/2 sides
  - 36 modules / full  $\phi$
  - 3 modules / full r
  - $20 < r < 78 \text{ cm}$ ,  $|\eta| < 1.1$ , full  $\phi$

- Measures Momentum
  - Momentum resolution:
    - $\Delta p/p \sim 0.02 * p$  (for  $p \sim 5 \text{ GeV}/c$ )
  - O(150 μm) spatial resolution

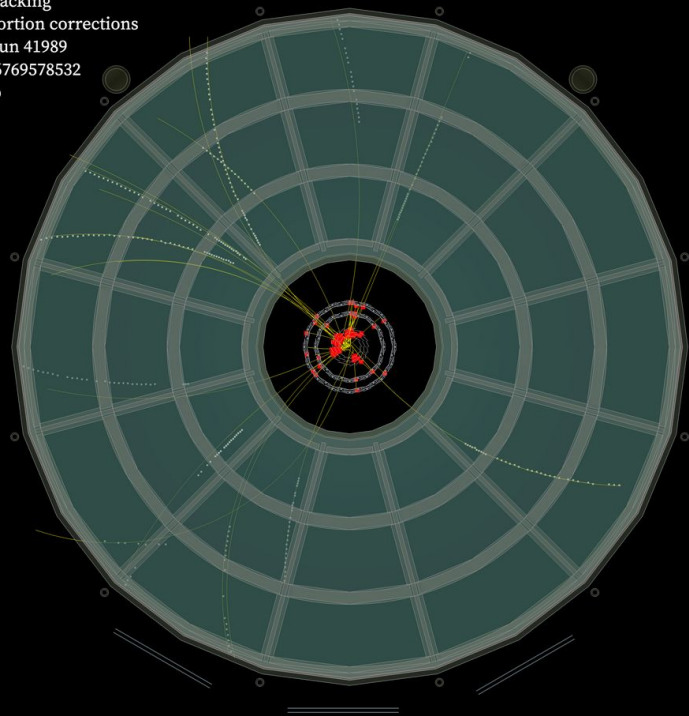


# sPHENIX TPC Event Display

Clusters drifting in TPC



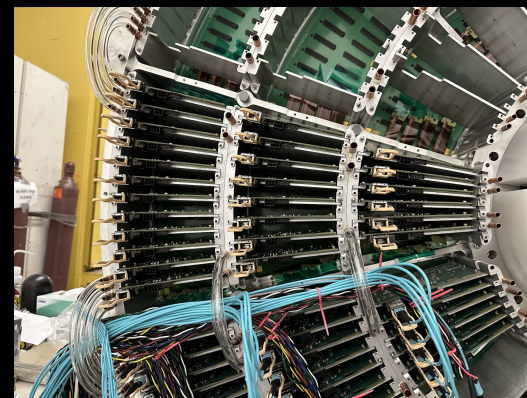
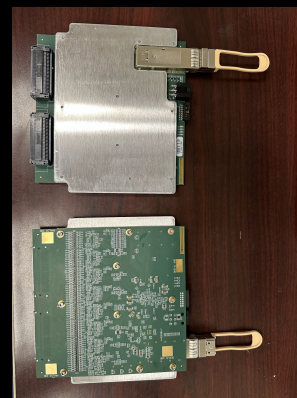
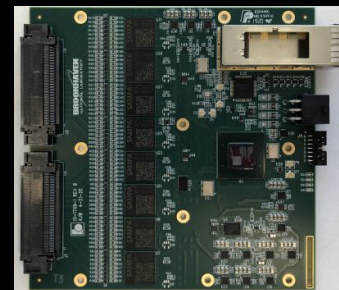
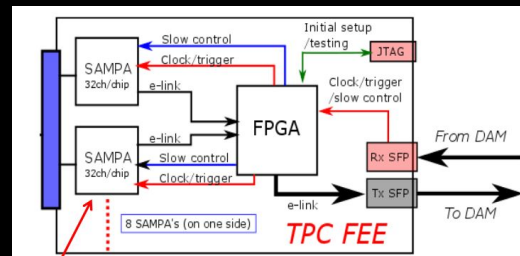
sPHENIX Tracking  
No TPC distortion corrections  
2024-6-12, Run 41989  
BCO: 401966769578532  
200 GeV p+p





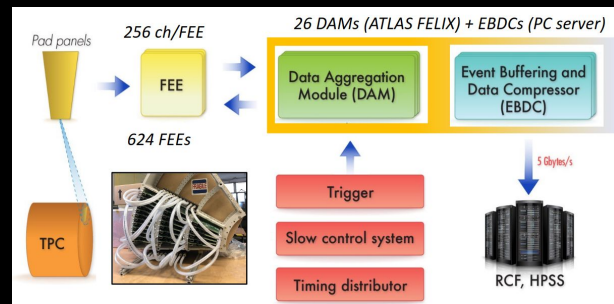
# sPHENIX TPC Front End Electronics

- Front End Electronics (FEE) Card
  - 8x **Sampa v5 ASIC**
  - 80 ns shaping time
  - 20 MHz sampling frequency
  - Operated in ZS mode
    - 3E12 ADC samples/s prior to ZS
  - 1x Xilinx Artix-7 FPGA
  - 256 pads
- Aluminum Plate for liquid cooling
- 26x FEE per sector, 24 sector total
  - ~ 160K channel



# sPHENIX TPC Backend

- 24 x Data Aggregation Module
  - ATLAS FELIX cards [[doi:10.1109/TIM.2019.2947972](https://doi.org/10.1109/TIM.2019.2947972)]
  - Distribute Clock + Trigger, readout
  - 47x 10 Gbps bidirectional optical link
  - Kintex Ultrascale FPGA
- 24 x Event Buffer Data Compressor (4U Servers)
  - Hosting FELIX card via PCIe Gen3x16
  - Lossless data compression, transmit via 25GbE
- Online buffer disk
  - 6PB
  - >10GB/s logging for TPC



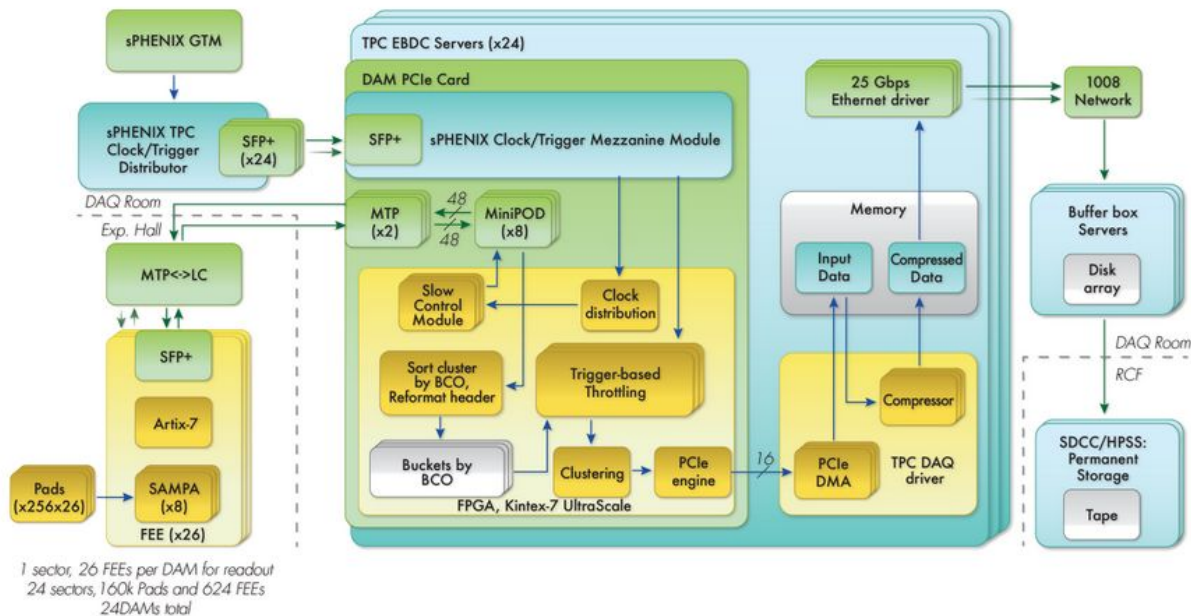


# sPHENIX TPC Backend Continued

256ch FEE based on ALICE  
to be SAMPaV5 w/ 80ns shaper

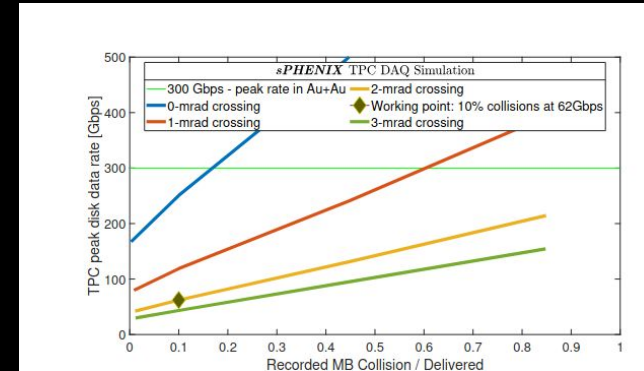


sPHENIX DAM based on ATLAS FELIX



# sPHENIX TPC - Streaming

- sPHENIX planned to run hybrid trigger + streaming mode during Run 24
  - Streaming desired for capturing low momentum HF decays (see talk by [Cameron Dean](#))
  - Hybrid scheme uses extended readout - beyond 14 us drift time - additional xings captured
- [BUP 2022](#) projection is 10 % true streaming rate (true streaming rate ~ 20 kHz)
- Run 24 achieved 30 % true streaming rate
  - Possible because of careful preparation and data pipeline monitoring
- Additionally, TPC ran 100 % streaming standalone during Run 24
  - Run with raised noise threshold + lowered GEM Voltage (low gain)

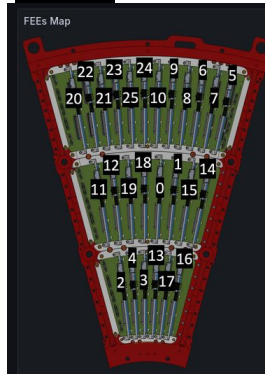
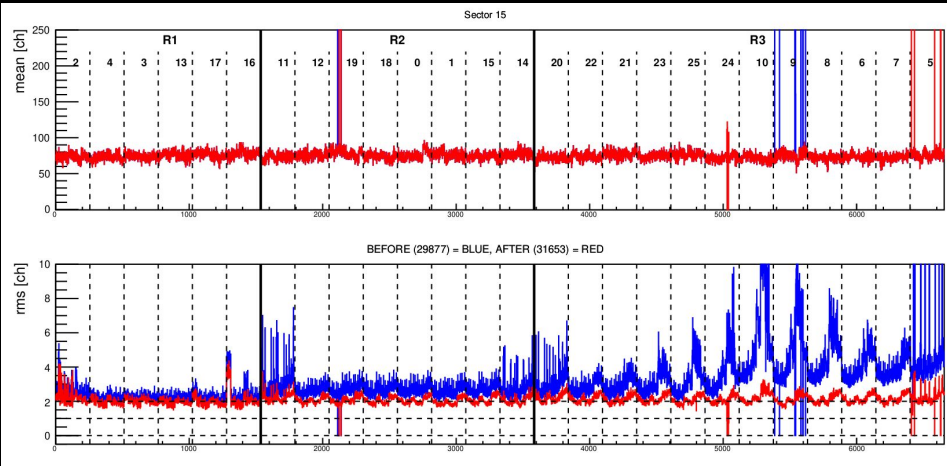


# sPHENIX TPC Noise Reduction

- Reducing noise important for streaming/hybrid operations
  - Limiting case: noisy FEE/sectors are effectively dead (MIP indistinguishable from noise)

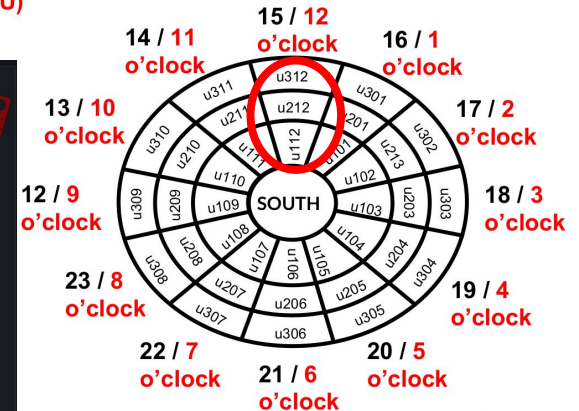
Run 29877 (02/15/24) - BEFORE

Run 31653 (03/04/24) - AFTER



Sector Number (BNL)

O'Clock (SBU)

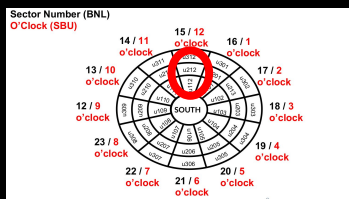
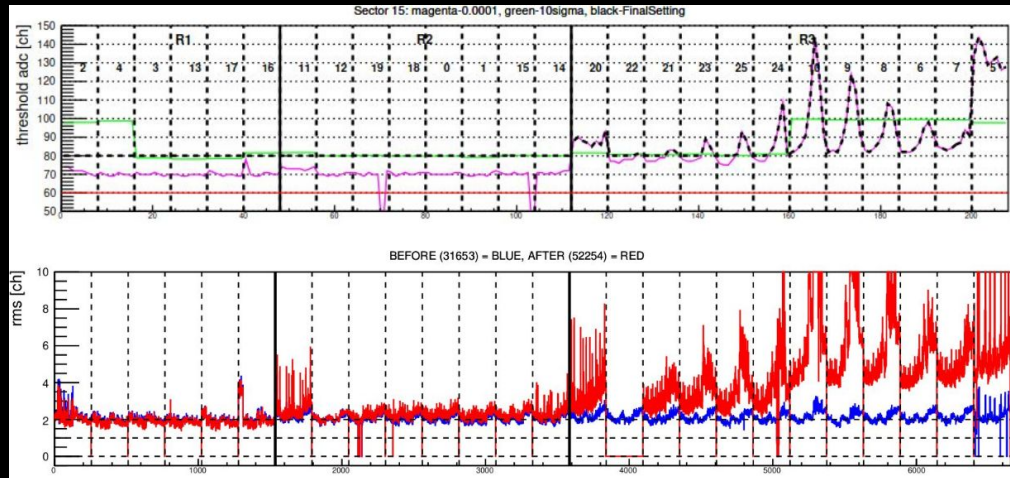
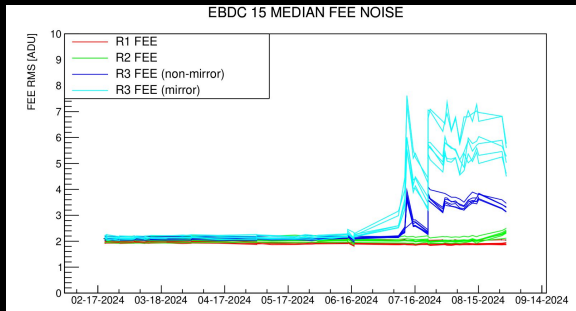




# sPHENIX TPC Noise Threshold Tuning

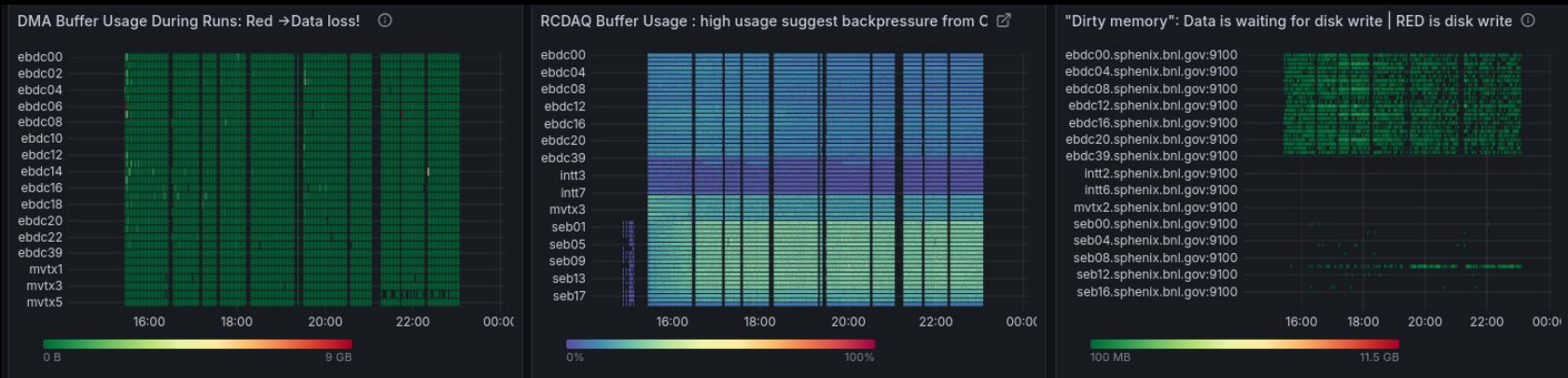
- Though noise was reduced before start of run, it crept back in over time as run progressed - in particular non-Gaussian noise
- ZS threshold tuned to account for this

"The threshold comparison with 10sigma setting is shown in the plot. **Magenta** shows the thresholds at which the noise picking probability is  $1.0e-4$ . **Green** shows the 10sigma threshold. The **black ones** are thresholds to be applied in the FEE. Each threshold is as: if Magenta is below 80ADU, it will be ADU, if Magenta is above 80ADU, it will be Magenta values."

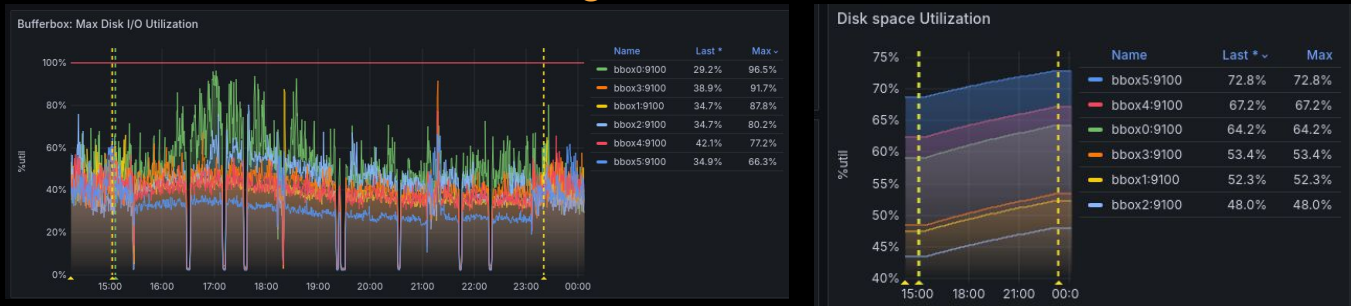


# sPHENIX TPC Data Pipeline Monitoring

- DAM DMA buffer -> RCDAQ Buffer -> Disk on EBDC



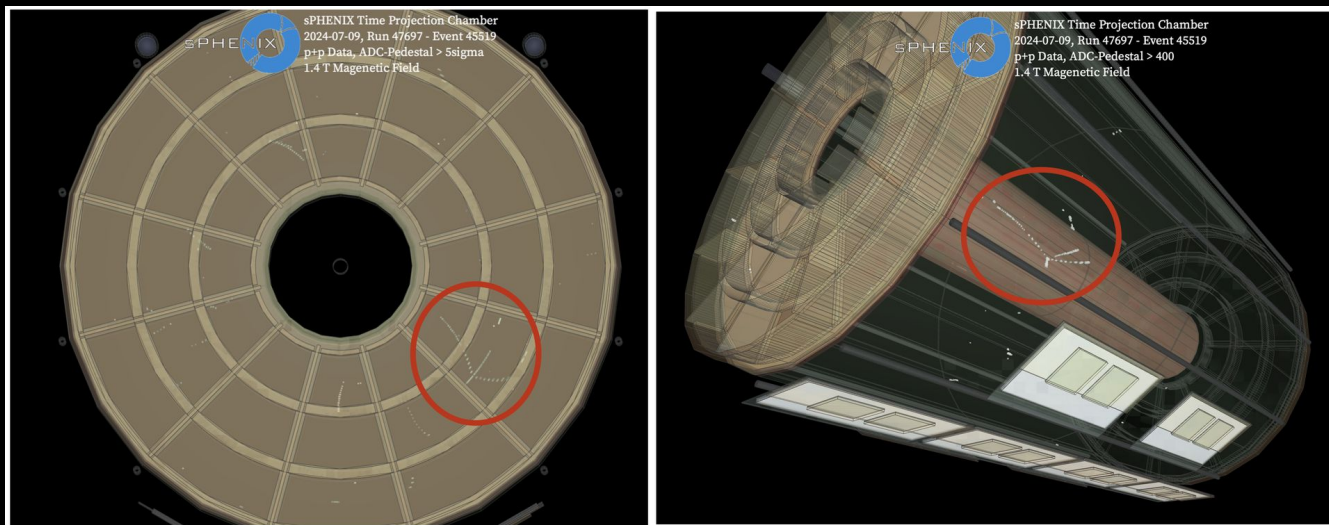
- Additional Monitoring EBDC -> Buffer Box



# sPHENIX TPC Run 24 - 100 % Streaming Standalone Runs

- 100 % streaming
  - 20 kHz clock trigger, 200 ADU ZS threshold ( $\sim 70\sigma$ ), 50 us readout
- Lowered GEM operating point
  - $\sim 86$  % operating voltage

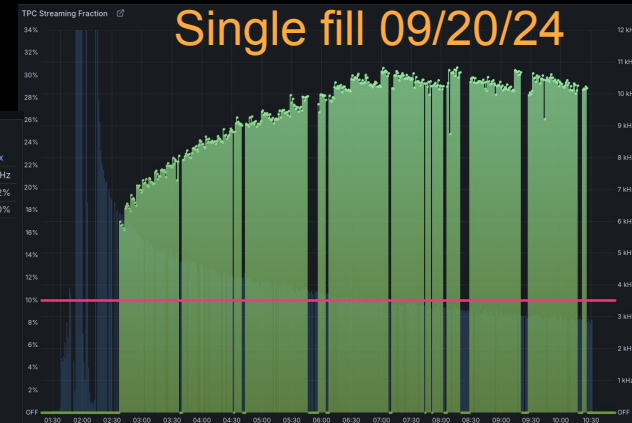
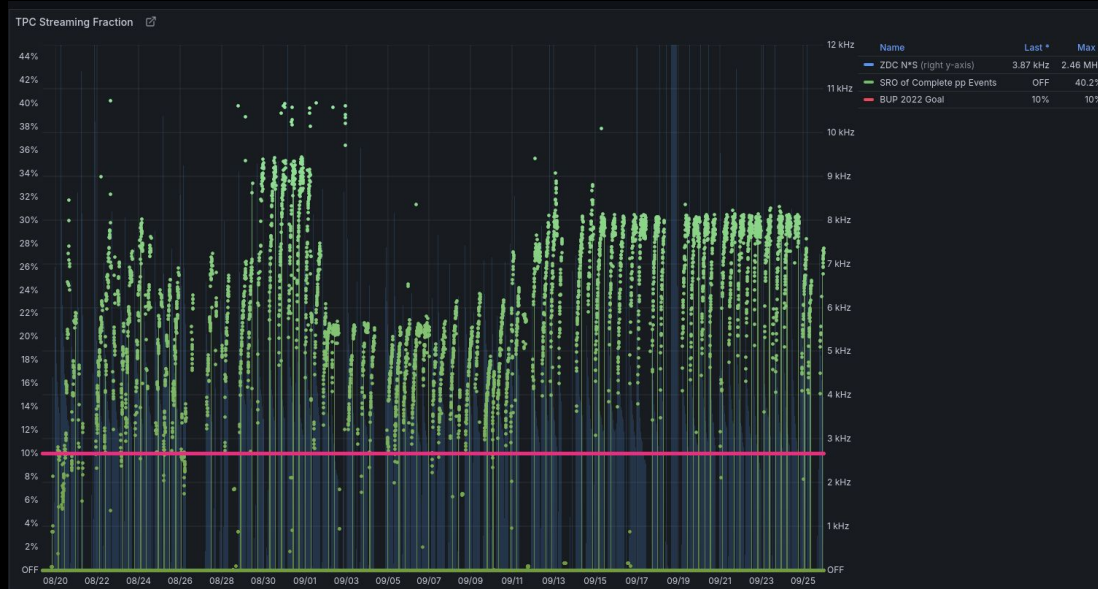
Shows heavy ionizing events, likely nuclear fragmentation (spallation) in TPC gas





# sPHENIX TPC Run 24 - Hybrid Trigger + Streaming Physics Runs

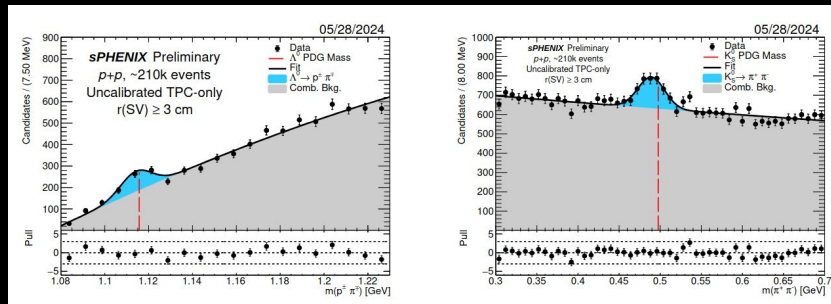
- During Run '24 TPC was run hybrid triggered + streaming mode
  - Achieved up to 30 % true streaming fraction
  - Expectation from [2022 BUP](#) was 10 %



Streaming fraction increases as collision rate decreases within a fill -> works around disk bandwidth limitations

# Outlook & Summary

- sPHENIX TPC has a versatile and robust readout system
  - Leverages latest versions of well-tested hardware (SAMPA v5 & FELIX card)
- TPC readout was run in hybrid trigger + streaming mode in Run '24 for p+p physics
  - 30 % streaming exceeding BUP 2022 goal
- TPC also run in 100 % streaming standalone
  - Useful for heavily ionizing events in TPC
- Run '25: long AuAu run in triggered mode
  - Lower collision rate - all physics triggerable
  - Challenge is the higher data volume/collision



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 - EBDO03 reference frame 43  
Au+Au sqrt(s<sub>NN</sub>)=200 GeV



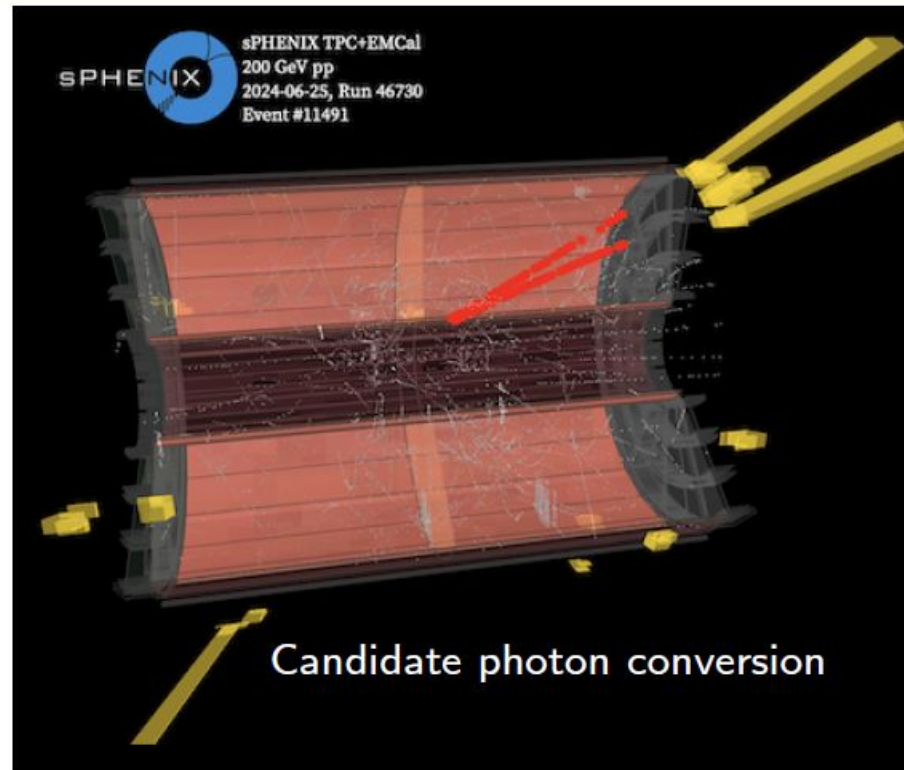
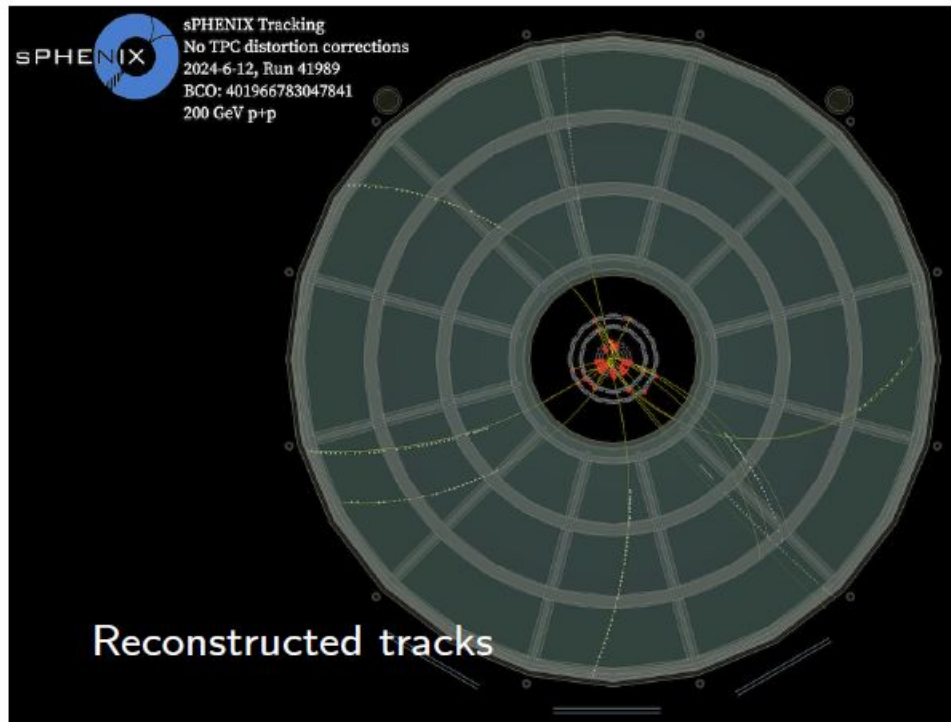
# Outlook & Summary continued

- Important to prepare a quiet (noise free) system to the extent possible for streaming
- Important to monitor the data streaming off the detector



# Backup

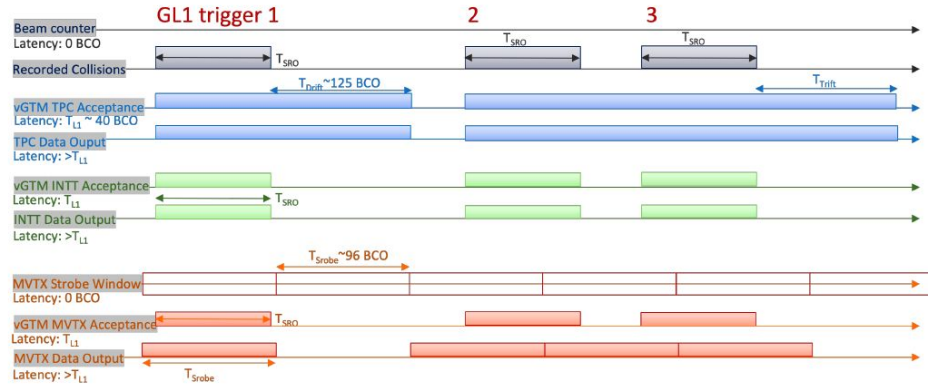
# sPHENIX 2024 in Review



- 24 weeks proton-proton + 3 weeks Au+Au data at  $\sqrt{s} = 200$  GeV

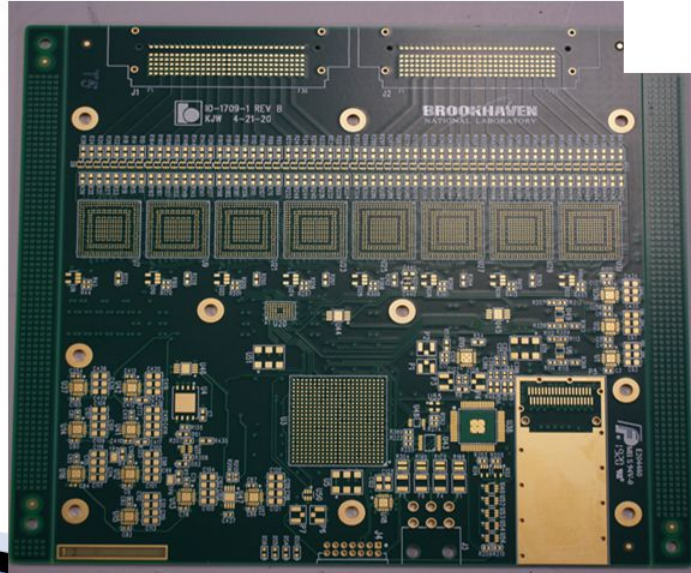
# Streaming operation

## Hybrid Streaming and 4D Reconstruction



- Collected hybrid streamed data - silicon 100% streamed and TPC streamed  $50\mu s$  of additional unbiased  $p+p$  collisions
- Assemble tracks in space and shift TPC track in time based on INTT measurements' time bucket





**A: Steady-State Thermal**  
 Temperature  
 Type: Temperature  
 Unit: °C  
 Time: 1  
 4/7/2020 4:45 PM

