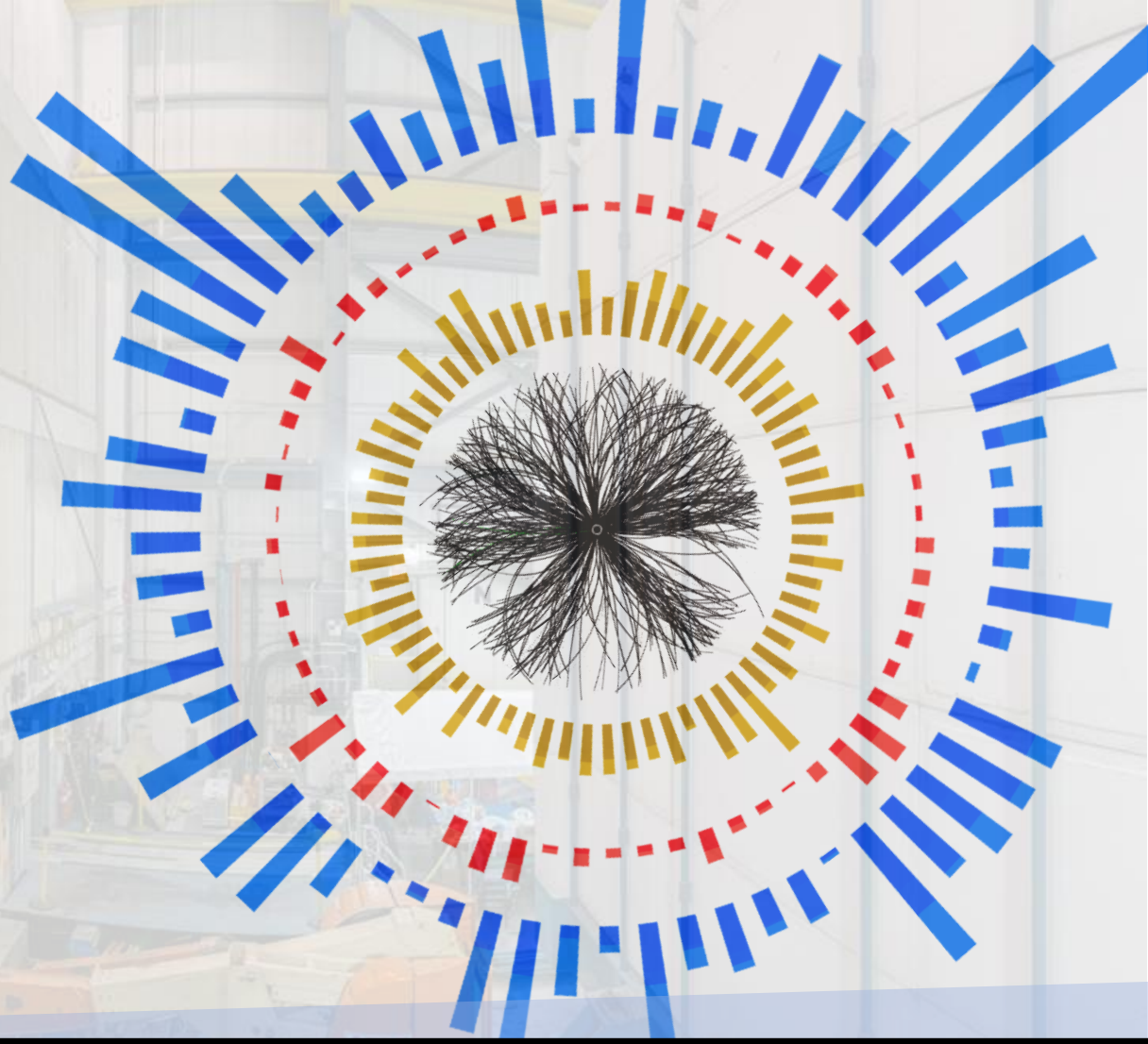


sPHENIX Performance and Challenges

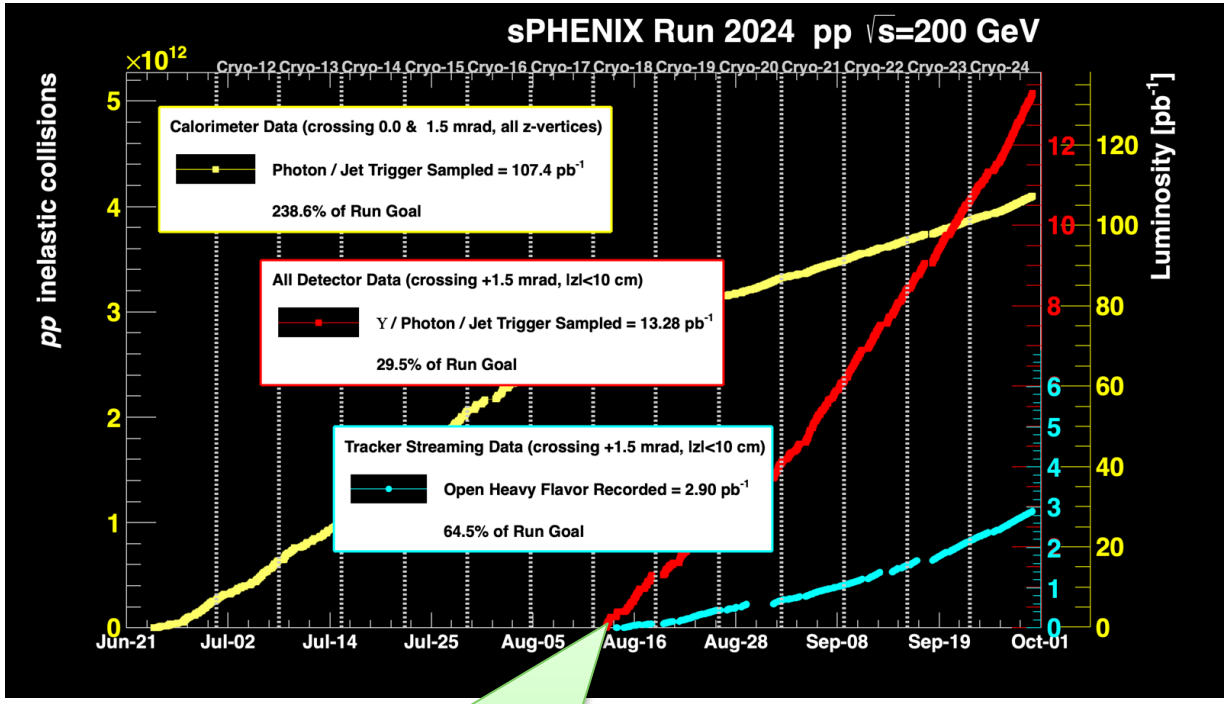
Jin Huang (BNL)
for sPHENIX collaboration

Oct 16, 2025

Data recorded: 2025-06-10 05:50:10 EST
Run / Event: 66641 / 146
Collisions: Au + Au @ $\sqrt{s_{NN}}$ = 200 GeV

sPHENIX status

- A decade of prototyping, reviewing, construction, and preparation
  - Installed on schedule despite pandemic, supply chain issues (including chips, Ne), and lack of IR access during RHIC Run22
  - Thanks to constant support of each past PAC
- Commissioning 2023-2024
  - Run23 cut short with RHIC magnet incident
- First full detector data in Run24
  - 7-week of p+p physics run time
    - 13 pb^{-1} or 30% goal of full detector p+p lumi
    - Tracking streaming HF program reached 2.9 pb^{-1} or 65% of run goal,
      thanks to improved streaming capability
      (10%-str. planned, 30%-str. reached)
  - Short Au+Au run for MVTX commissioning



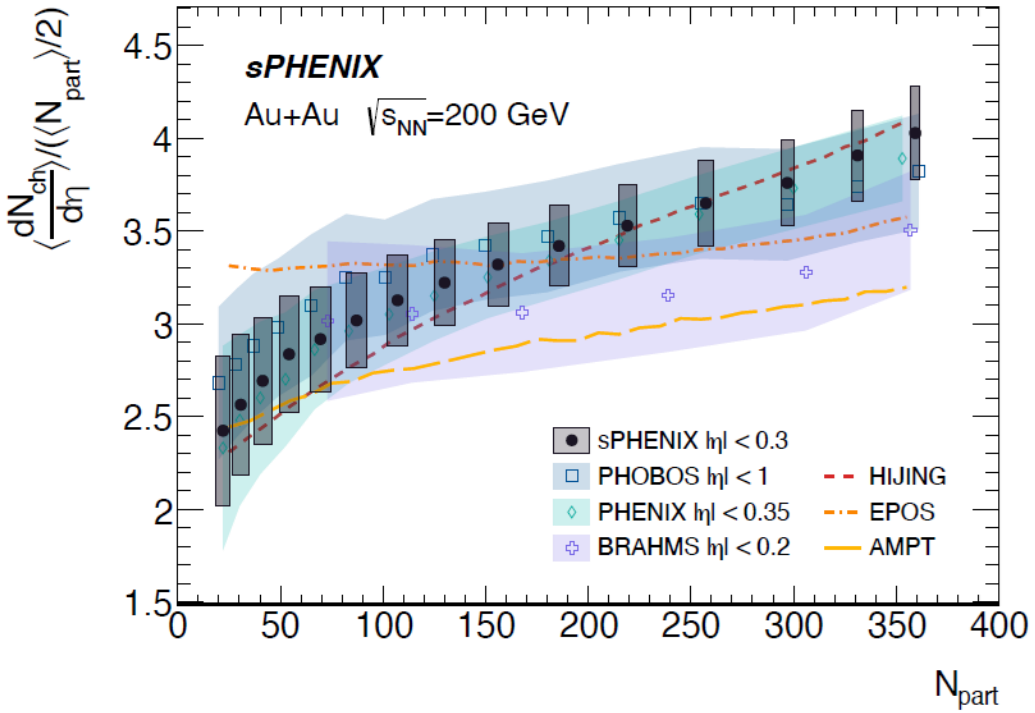
Aug 2024: Completed p+p commissioning

Many sPHENIX results from Run24:
https://www.sphenix.bnl.gov/PublicResults

First papers, now final journal publication

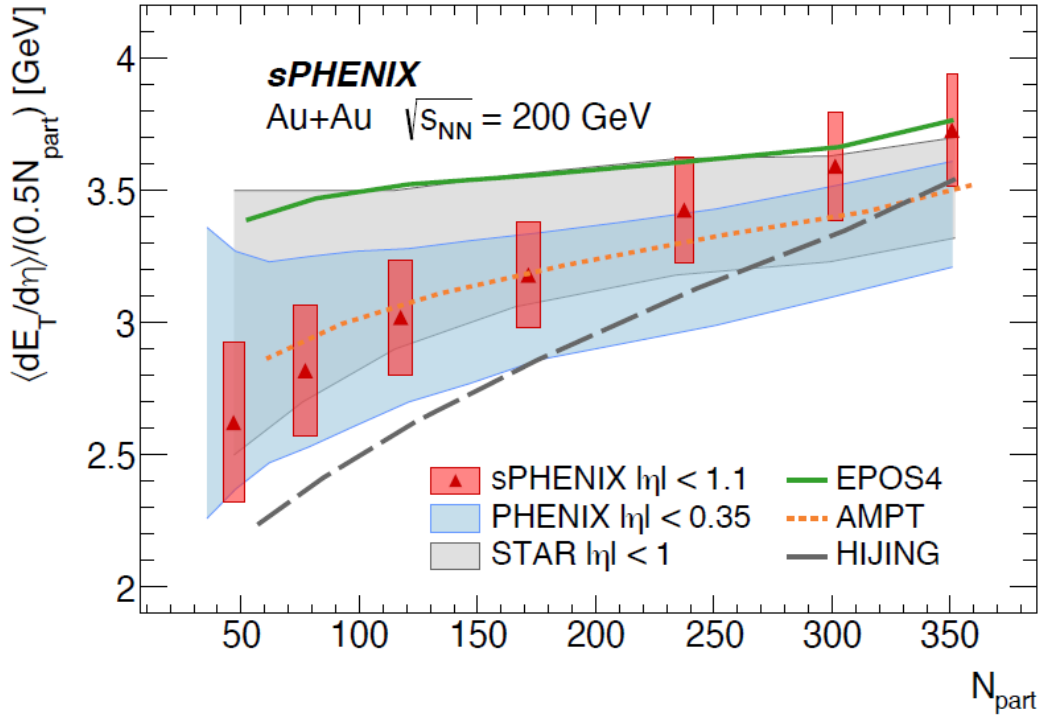
Charged Hadron Multiplicity

arXiv:2504.02240 -> **JHEP 08 (2025) 075**



Transverse Energy Density

arXiv:2504.02242 -> **PRC 112 (2025) 024908**

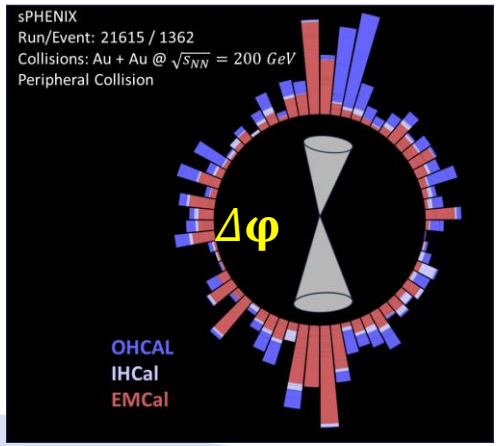


Within 6 months of Run 24 completion, submitted standard candle Au+Au measurements
→ Consistent with past publications; physics readiness from online to offline

First sPHENIX jet quenching result

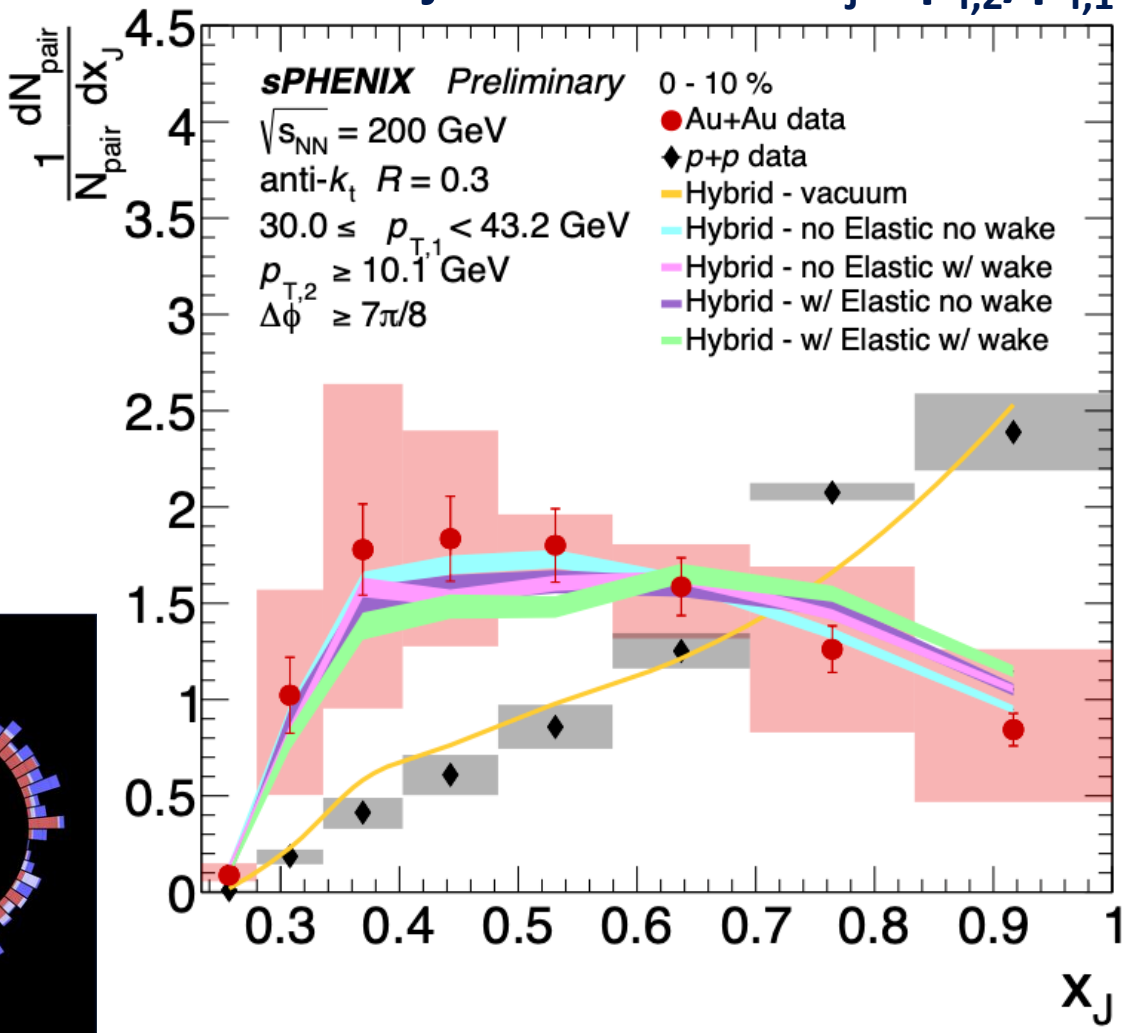
- First sPHENIX jet quenching result shown at Initial Stages conference [link]
  - Based on small Au+Au data set collected in Run 2024
- Significant di-jet imbalance observed compared to p+p x_J measurement
  - Described well by model predictions

Many more preliminary sPHENIX results,
Being finalized for publication:
https://www.sphenix.bnl.gov/PublicResults



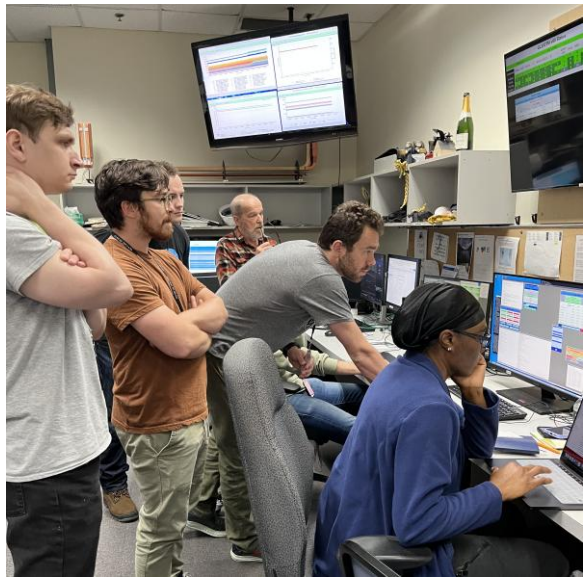
SPH-CONF-JET-2025-04

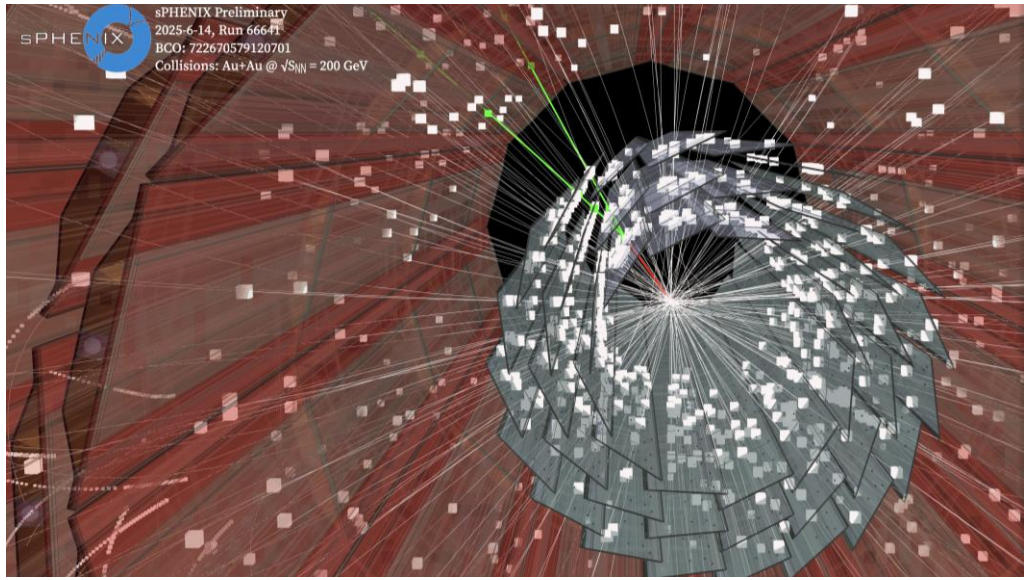
Di-jet Imbalance: $x_J = p_{T,2}/p_{T,1}$

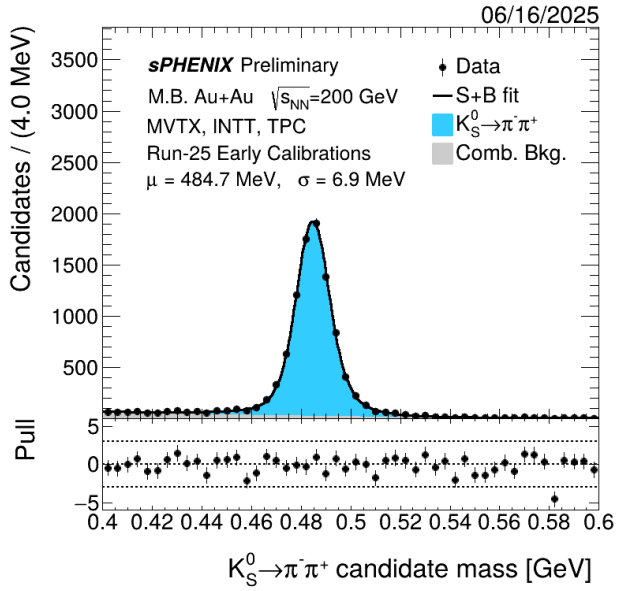


sPHENIX status (continued)

- Intra-run upgrade
  - Major TPC HV upgrade, data buffer server upgrade
  - CAD-sPHENIX taskforce on MVTX background mitigation
- Run25 shift started Feb 18, 2025
  - Flow of flammable gas for HV system and TPC line laser commissioning
  - Non-stop shift through the RHIC blue ring short repair March-June
- First collision June 9; continue through summer months and two major RHIC down periods





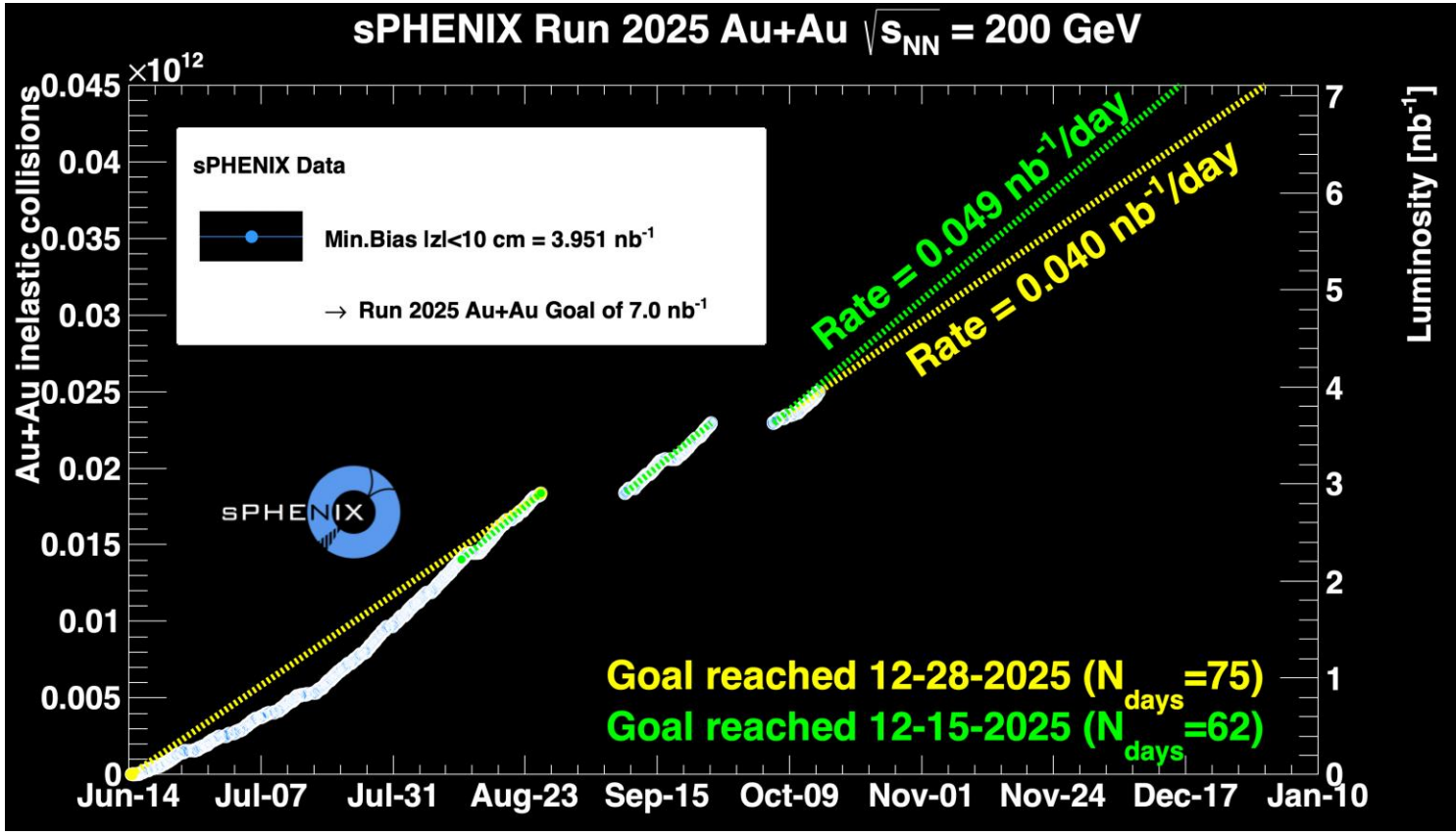


Run 25 sPHENIX Shifters (to date): 162 unique shifters for 350 shifts!

Tracking progress toward Au+Au luminosity goal

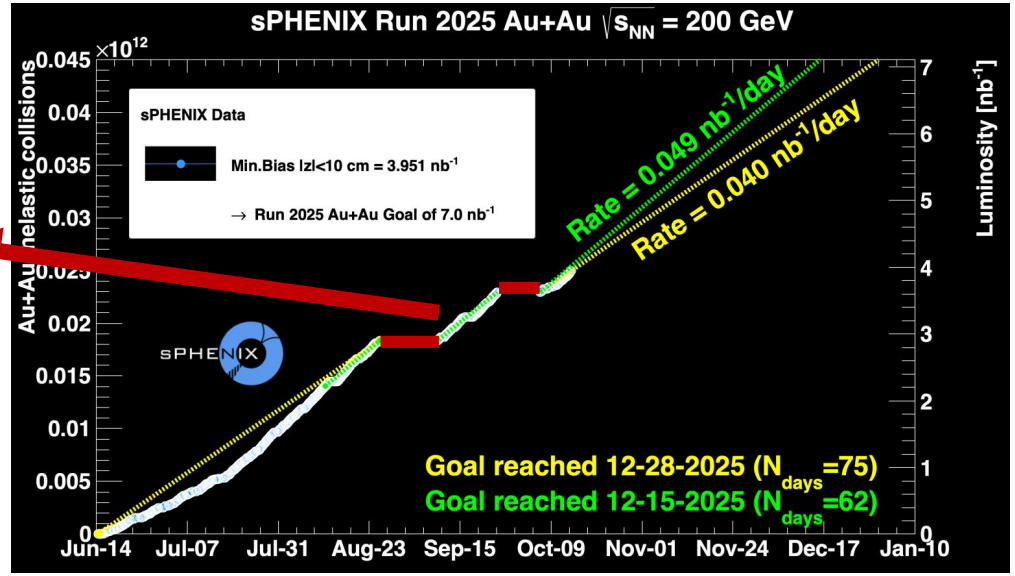
- Au+Au goal: 7 nb^{-1}
  - In |z-vertex| < 10 cm
  - i.e. sPHENIX full acceptance
- Current projection:

  Completing Au+Au lumi target in mid to late December 2025
  - Assuming no more major disruption to facility operation
  - Based on data collection averages prior to recent RHIC down time



Challenges: facility up time

- Two major facility-wide down time [see talk T. Shrey]
  - Aug 26 – Sept 9 : damaged pole supporting power lines to RHIC discovered
  - Sept 25 – Oct 6 : prefire of abort kicker -> RHIC vac. breach
- The Collaboration rose to the challenge keeping detector safe, limited damage; then use of down time for calibration runs
- After facility recovery: sPHENIX quickly recover and ramp up back for efficient physics production



Emergency meeting in response to changing powerline work schedule

Safe detector shutdown

Ensuring safe gas flow to detector during power down

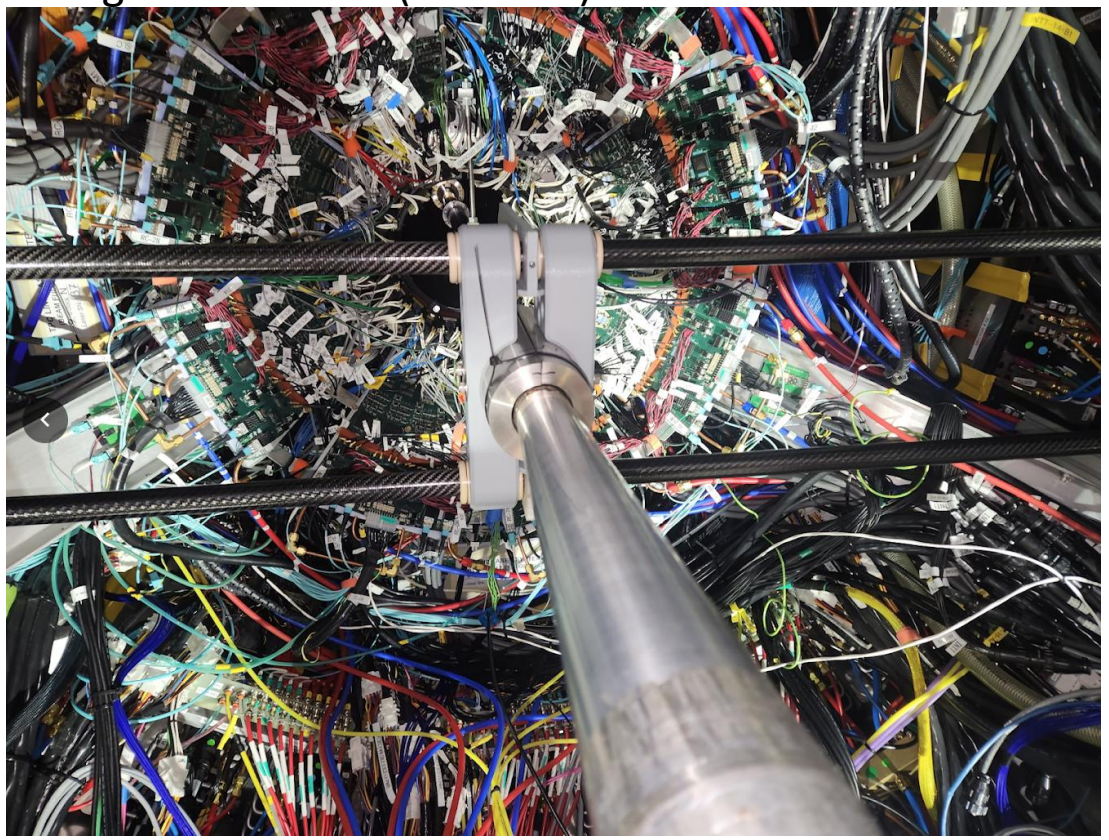
Last leaving sPHENIX at 5AM shortly before power outage

Challenges: MVTX background mitigation

- Ion background on MVTX sensor leading to extreme density hits and on-chip readout chain reset (auto-recovery or AR)
- Work closely with CAD developing mitigation options and start of Run 25 plan

Mitigation options	Test Time (h)	Test condition	Readiness on March 24	In use? As of now
Baseline	2	Dedicated time	Y	Yes
Donut Counters	0	Detection	Y	Yes
Gap Cleaning	1	Passive	Y	Yes
Stochastic Cooling	8	Passive	Y	Yes
RF Voltage	0.5	Passive	Y	Yes
Single octuple	4	Dedicated time	Y	No
NLC correction	8	Dedicated time	Y	No
Last sextant sextuples	4-8	Dedicated time	N	No
Collar abosrbers	1 day	Dedicated time	Y	Mounted, Not inserted
W-fct optimization	8	Dedicated time	N	No
DispIP4 w/mask	8+	Dedicated time	N	No

Background scatter (movable) and donut counters

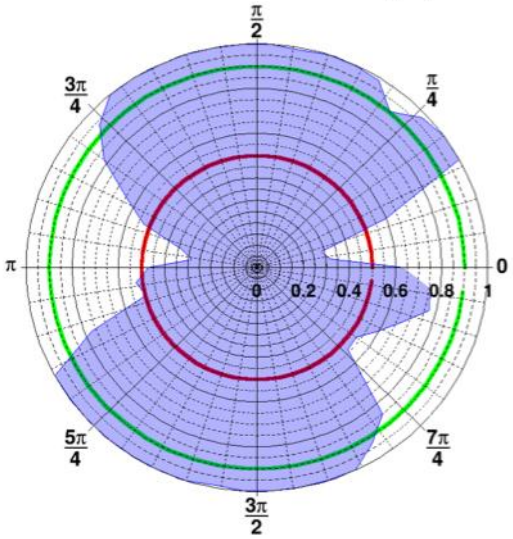


Challenges: MVTX background mitigation (continues)

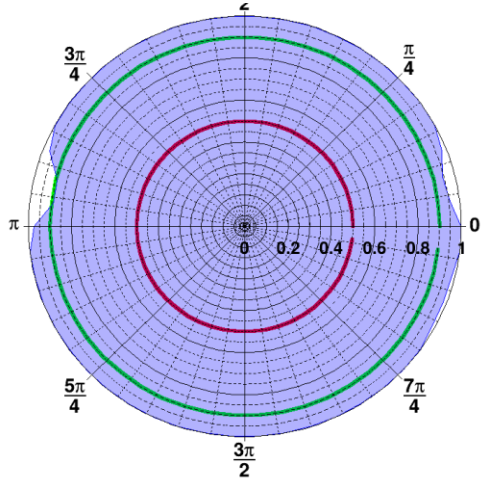
- Run25 commissioning:
  - Intra-run RHIC improvement for background [June mini-PAC]
  - Streaming mode Auto-recovery (AR) rate is inoperable without time-consuming intervention (and may still not work)
  - Trigger mode reduced AR rate by 20x
- Run25 Au+Au work point:
  Trigger mode, ≥90% acceptance for two-(out of three)-hit tracklets
  - With limited run time, decision to prioritize physics reaching sufficient AR mitigation

MVTX two-hit tracklet azimuthal acceptance

Streaming Mode:
Run 67527, June 15, 2025
ZDC coincidence: 8.0 kHz
AR rate > 40Hz (saturated)



Triggered Mode:
Run 67510, June 15, 2025
ZDC coincidence: 20.0 kHz
GL1 rate: 11.8 kHz
AR rate< 10Hz



Challenges: MVTX background mitigation (continues)

What if running p+Au?

8 cryoweeks of *p*+Au (5 physics weeks)

- RHIC switchover/setup time
- sPHENIX MVTX commissioning
- physics data-taking

Besides the 13 day switch over and ramp up time, sPHENIX would require one more week of sPHENIX commission time to establish a working point for MVTX then rest of experiment:

- MVTX work point
  - Re-establish reasonable auto-recovery rate for trigger mode (AR rate may change w/ different beam angle in p+A)
  - Attempt to mitigate background for streaming mode operation (or no HF program). No guarantee of success in streaming capability in p+A
- Followed by other subsystem commissioning in the MVTX beam tune
  - TPC HV re-commission under the new background load
  - Jet and photonic trigger re-commission

See also physics capability implication in BUP talk D. Perepelitsa

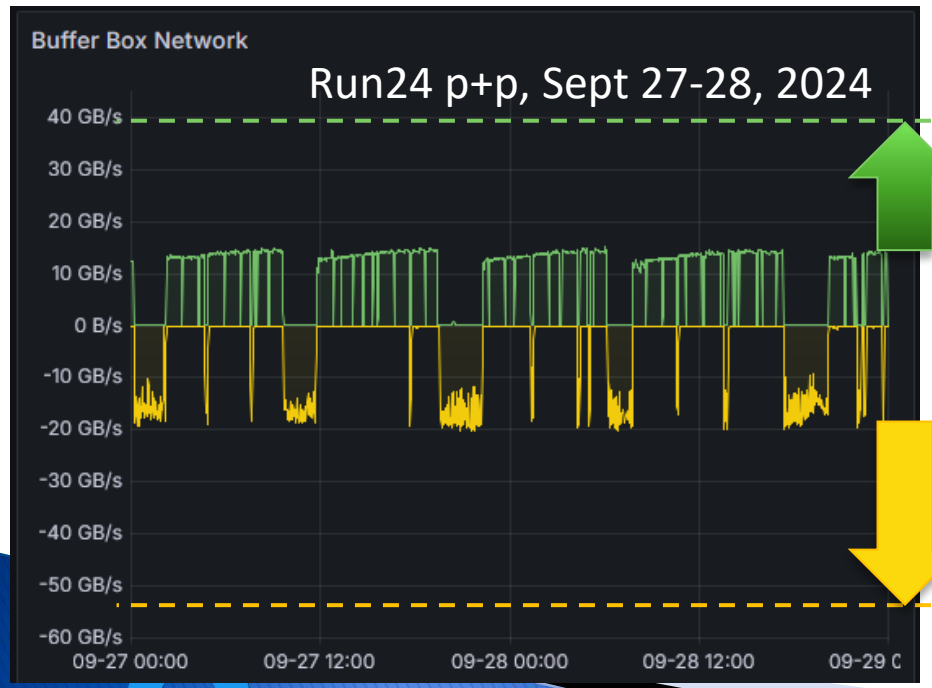
Report from C-AD, 12 Oct 2025 [link], switch over and ramp up:

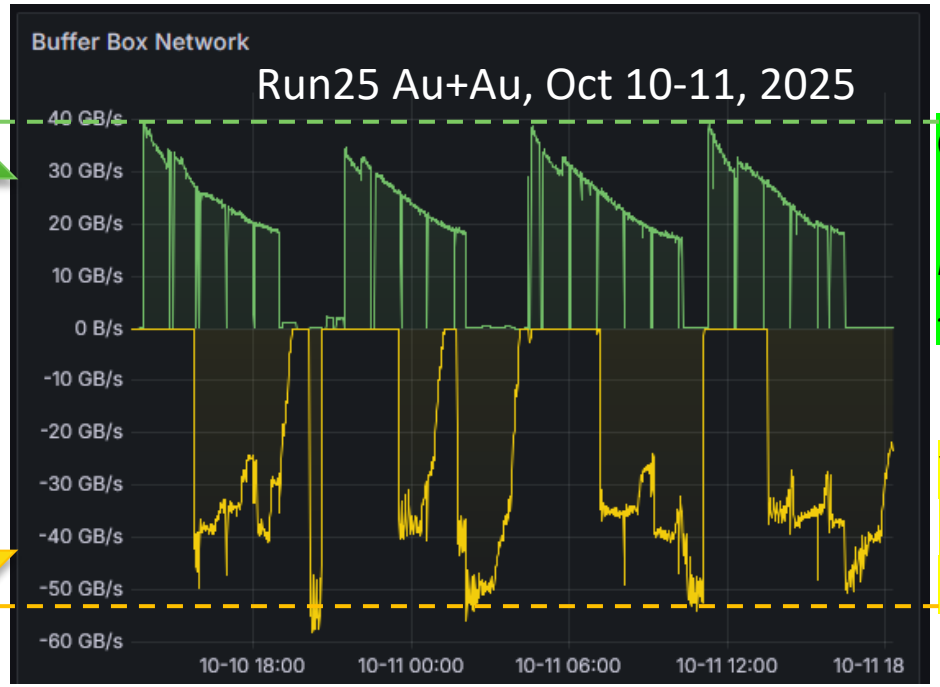
- **polarized p – Au: 3 days** for repositioning DX magnets for asymmetric energy beam operations, in parallel 16 hours for preparation of Siberian snakes power supplies (with 1 team preparing 1snake) and also in parallel 12 hours for yellow ring polarimeter fiber installation (to be followed by 3-4 days of vacuum conditioning during RHIC setup)
- **polarized p – Au: 10 days** (including ½ day for p-C polarimeter target conditioning). Note: p-Au last run in 2015 so for short run expect ~2/3 of run-15 luminosity performance.

Mitigation options	Time (h)	Test condition	Status 10/14
Single octuple	4	Dedicated time	No
NLC correction	8	Dedicated time	No
Last sextant sextuples	4-8	Dedicated time	No
Collar abosrbers	1 day	Dedicated time	Mounted Not inserted
W-fct optimization	8	Dedicated time	No
DispIP4 w/mask	8+	Dedicated time	No

Performance improvements: data pipeline

- Improved sPHENIX data rate with data buffer server upgrade and tuning
- Peak Run24 ~14GB/s
  → determining factor for streaming fraction in p+p and open-HF statistics.
- Peak Run25 > 35GB/s
  → would significantly improve streaming fraction for p+p by more than x2, expect >60%-str.





Green: sPHENIX logging rate
-Factor of 2.5 improvement from Run 24
-determines pp streaming fraction

Yellow: Data migration to SDCC
-Also significantly improved in Run 25

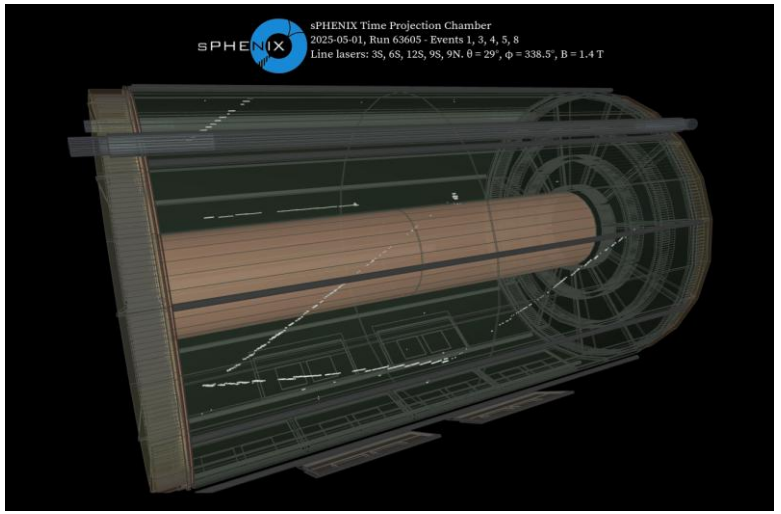
Performance improvements: TPC

HV System Upgrade

- New CAEN HV system installed, commissioned, and in daily use
  - Gain balancing done
  - Improve resilience to beam-induced GEM damages

Line Laser Commissioning

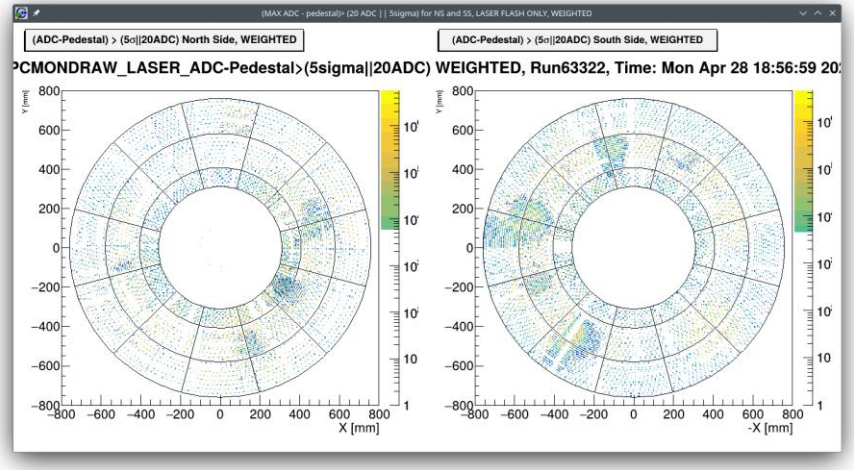
- Fully deployed



- Laser scan the TPC volume for static distortion correction
  - Run during “down” times

Diffuse Laser Commissioning

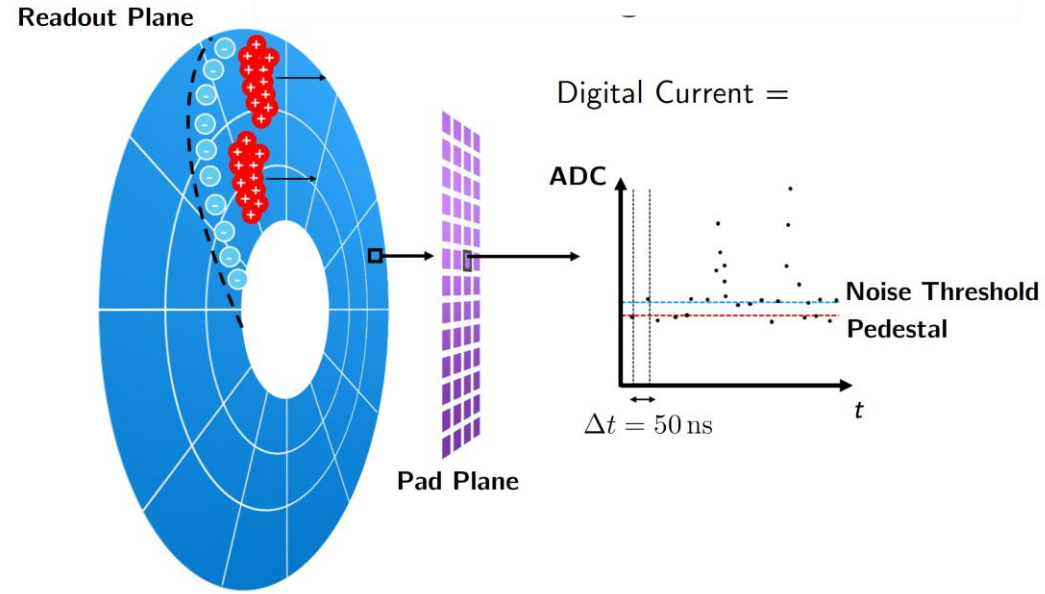
- All diffuse lasers successfully illuminate TPC central membranes

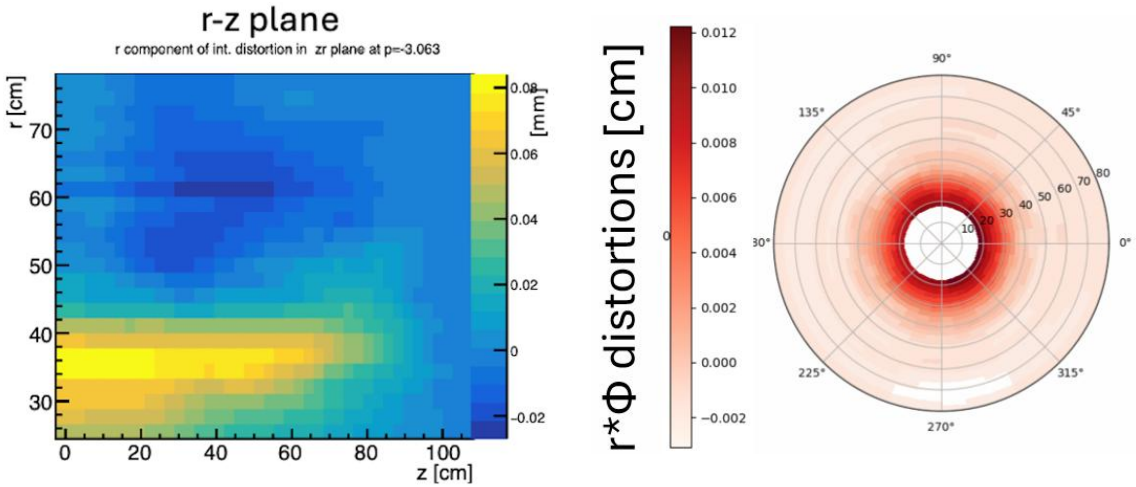


- Good calibration hit coverage across the readout plane

Performance improvements: TPC (continue)

- TPC digital current used for calibrate fluctuation of TPC space charge
  - ASIC+FPGA calculate charge accumulation on each TPC pads, processing 3 trillion ADC samples per second, recorded every 1ms
  - Last major technical capability commissioned (required Au+Au beam)
- As part of commissioning, TPC regularly took physics data in 100% streaming of Au+Au collisions through month of August
  - Thanks to 2.5x improved data logging
  - Experience and tool chain exercised for p+p streaming operation (if given opportunity)

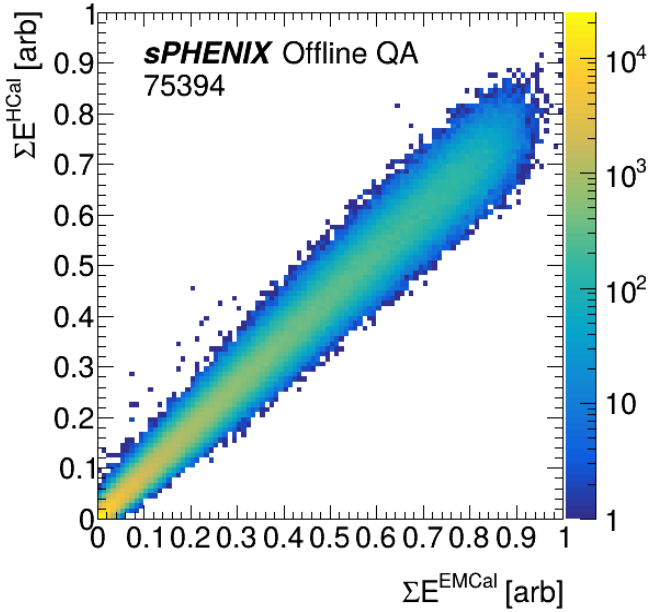




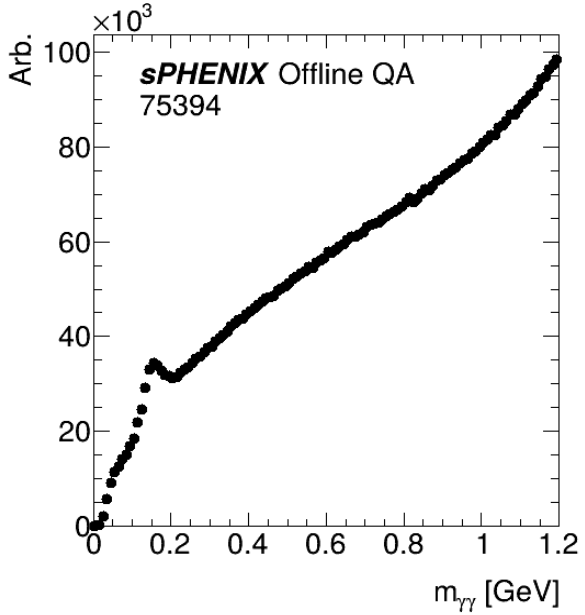
Offline data quality assurance (Offline QA)

- Deep data quality check taking advantage of prompt data production in offline
  -> Now formal shift in Au+Au operation
- Made possible by the substantial computing resources and excellent operation of SCDF
  - sPHENIX uses one of the largest HTCondor computing cluster in the world; 163PB data in tape storage
- Since Oct-1, power distribution issue at SCDF reduced available CPU resource to 70%, limiting fast reco-QA and analysis; mitigation in progress at SCDF & F&O.
  It is essential to maintain sPHENIX computing resource for reliable QA for Run25 operation and productive analysis

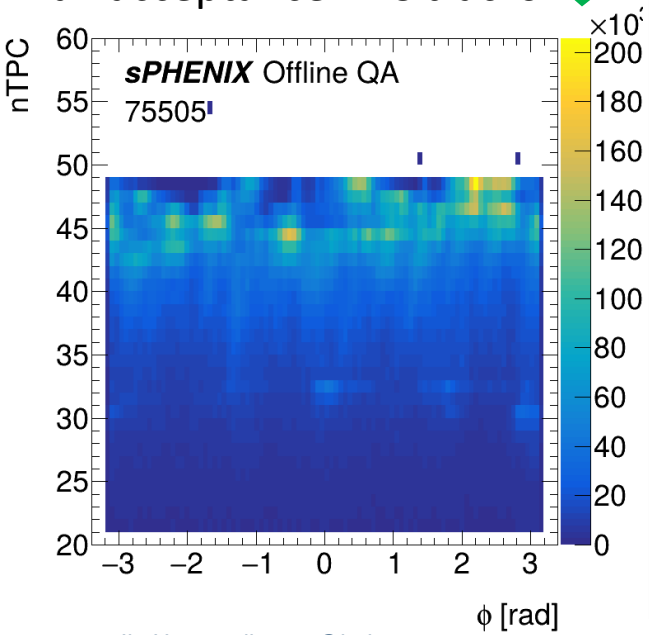
EMCal & HCal correlated ✓



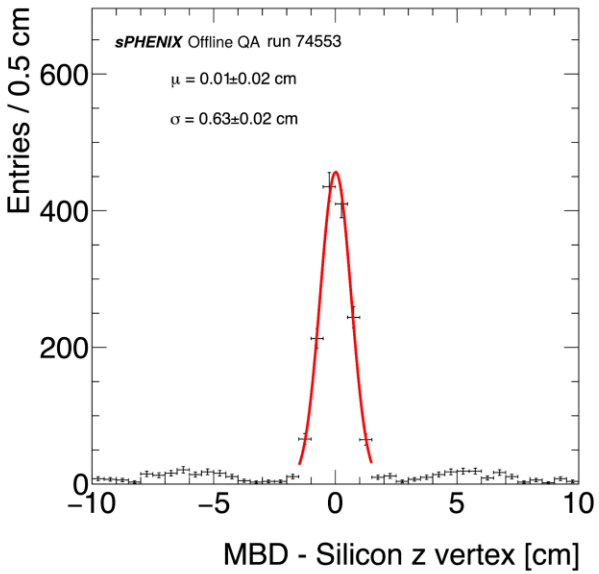
π^0 observed (pre-calib) ✓



Full acceptance TPC tracks ✓



Silicon-MBD correlated ✓



Performance, Challenges, and Perseverance

- sPHENIX collaboration demonstrated efficient use of beam time
  - Importance of high facility up time, both at accelerator and experimental infrastructure
- In Run25, sPHENIX reached full capability
  - 2.5x improvement over data logging throughput! → 60-100% streaming if running p+p
  - Feature completion with commissioning of TPC digital current, laser system → qualitatively improved calibration and systematics control
- Ion beam background remain challenge on the MVTX
  - Work point established for Au+Au physics using trigger mode
  - No assurance of Open HF in p+A via streaming mode with heavy ion beam
- Projected reaching Au+Au luminosity goals in middle to end of December
  - Assuming no major disruption in the facility up time

sPHENIX Managed through three major RHIC repairs, summer running, on track in completing Au+Au in ~10 weeks

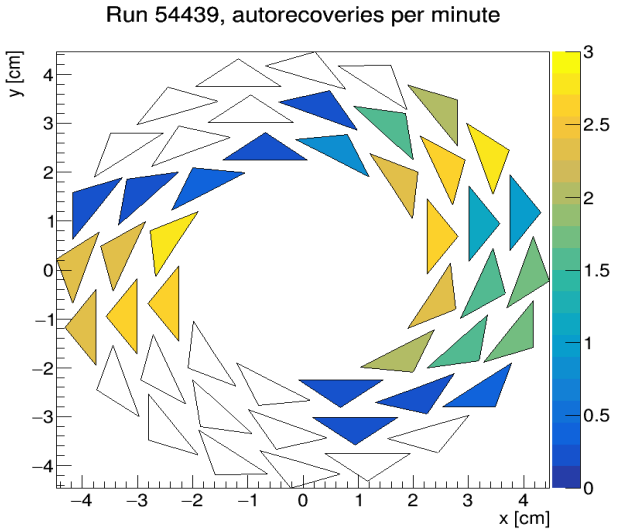
sPHENIX is only limited by beam time

Extra information

Observed significant background improvement for Run25!

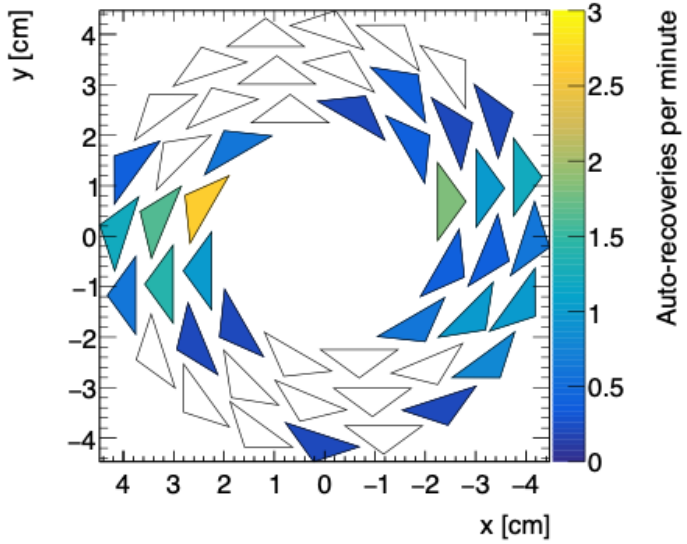
[see also talk by Kiel Hock]

Run 24



Outside Inside

Run 25



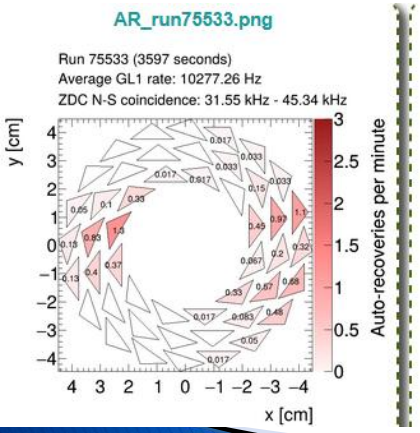
Notes:

- The diagnostic streaming mode used in this study to enhance Auto-recovery upset rate for clear measurement of background.
  - Production run aim to use trigger mode (~1/15 reduction)
- Both test performed at 56x56 bunch collisions

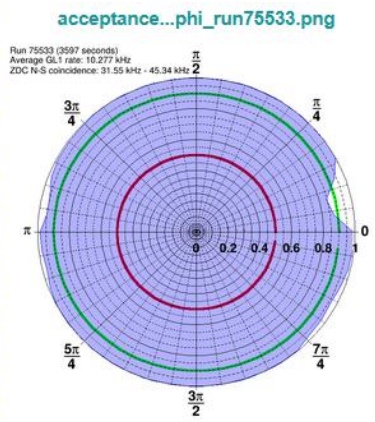
Thanks to many regular meetings between sPHENIX and C-AD to work on addressing the MVTX beam background issue!

MVTX AR rate and acceptance, Recent fill Oct 14

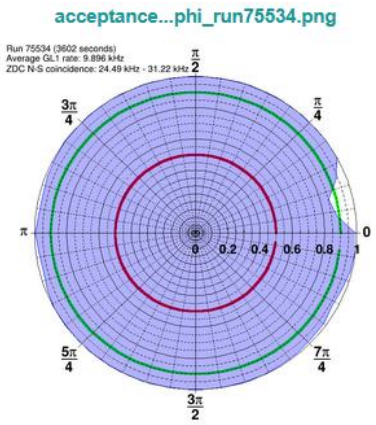
AR_run75533.png



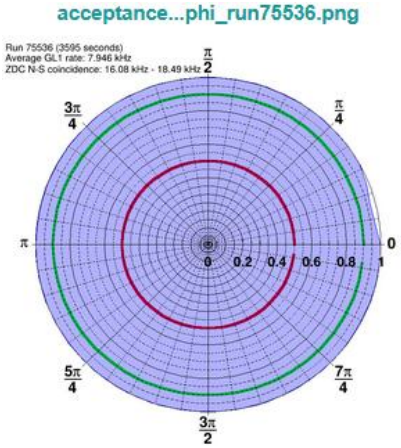
acceptance...phi_run75533.png



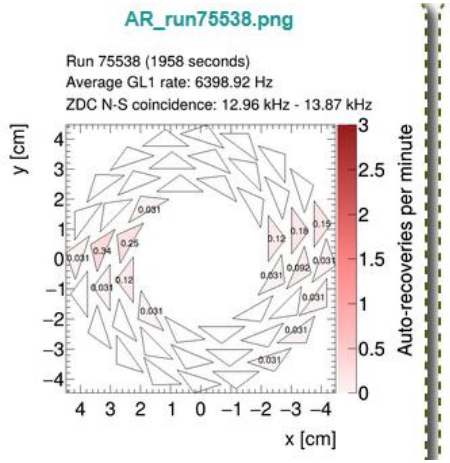
acceptance...phi_run75534.png



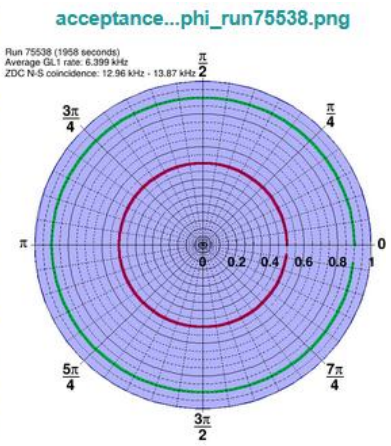
acceptance...phi_run75536.png



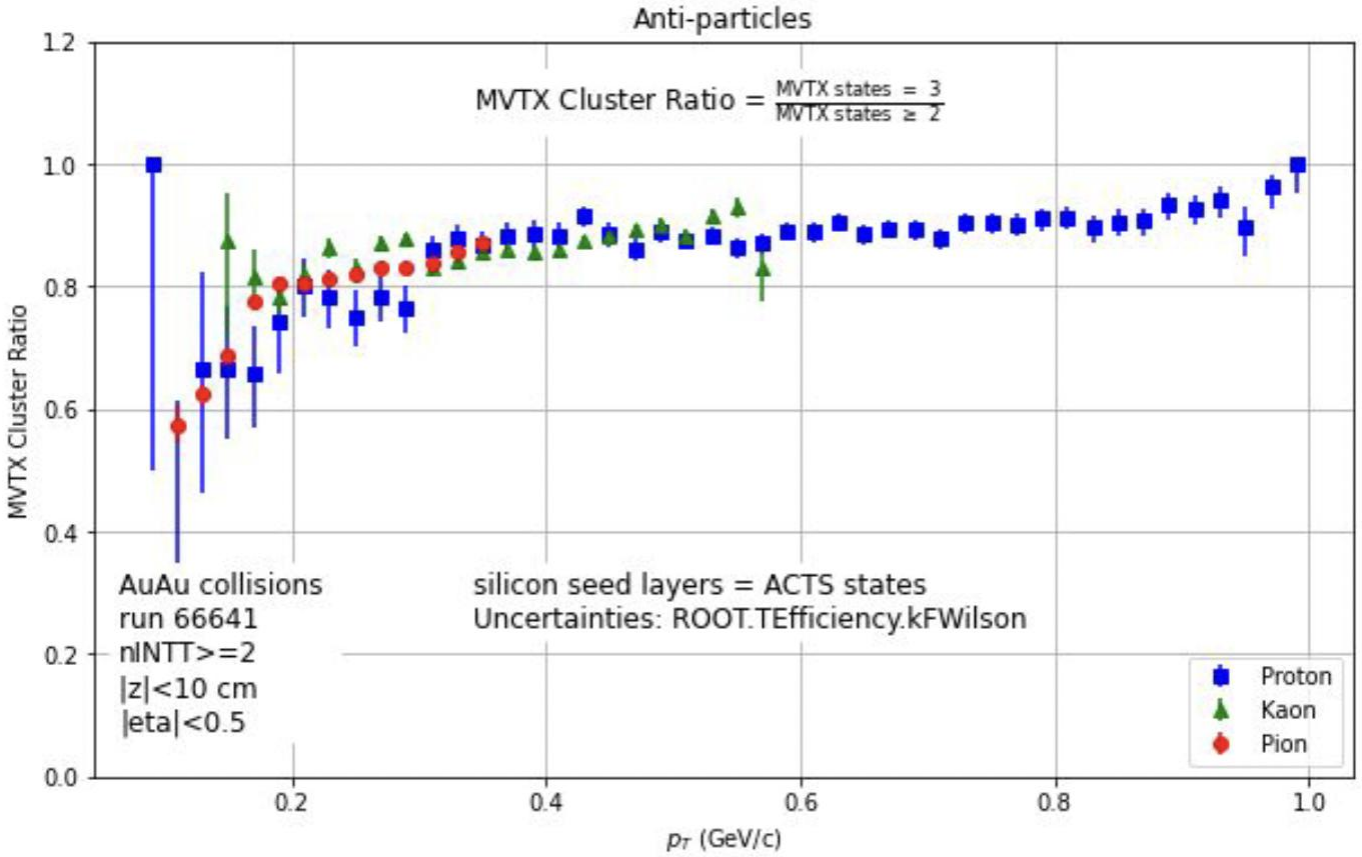
AR_run75538.png



acceptance...phi_run75538.png



MVTX efficiencies in triggered mode



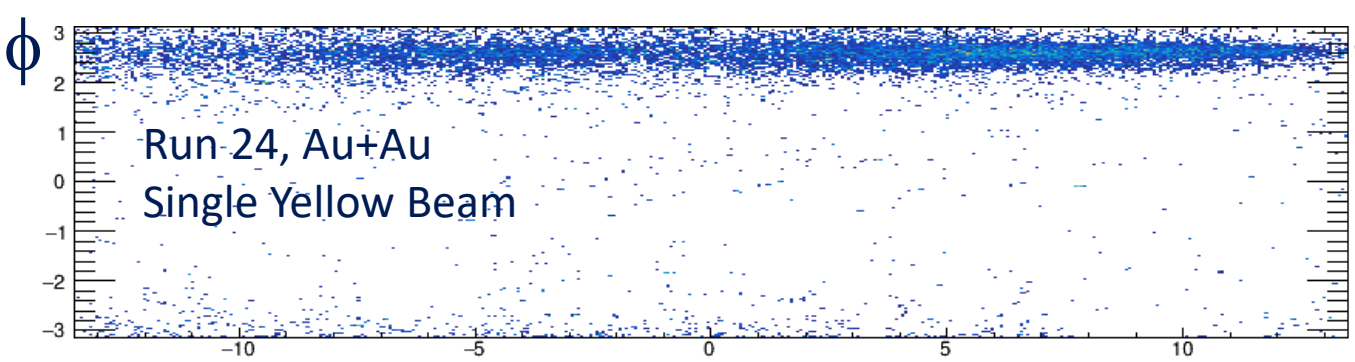
1. Took Au+Au run w/ MVTX in extended mode
2. Reconstructed full tracks with all 4 trackers
3. Use dE/dx from TPC to isolate tracks by PID
4. Compare track yields for tracks with 3 clusters (i.e. one on each layer) to tracks with at least 2 clusters (i.e. enough hits were dropped to lose a layer)

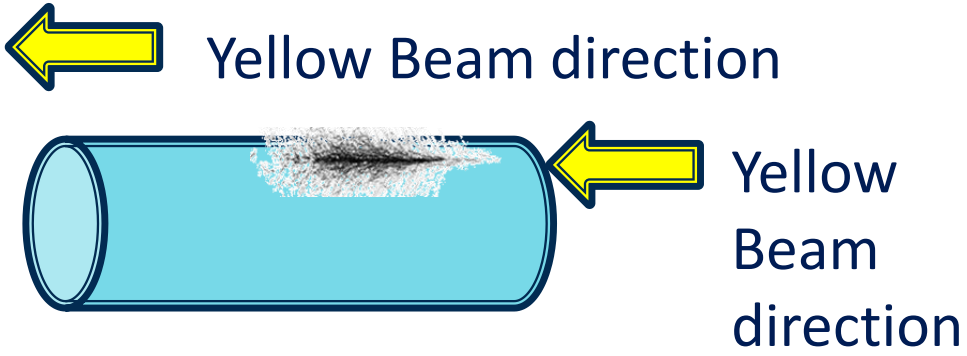
Also to note:

- Most probable cluster shape is a 2x2 square, accounting for roughly 17% of all clusters
- 1x1 cluster accounts for about 6%
- Both shapes are roughly flat with trigger latency

MVTX: Ion Beam Background Issues

[see also talk by Kiel Hock]



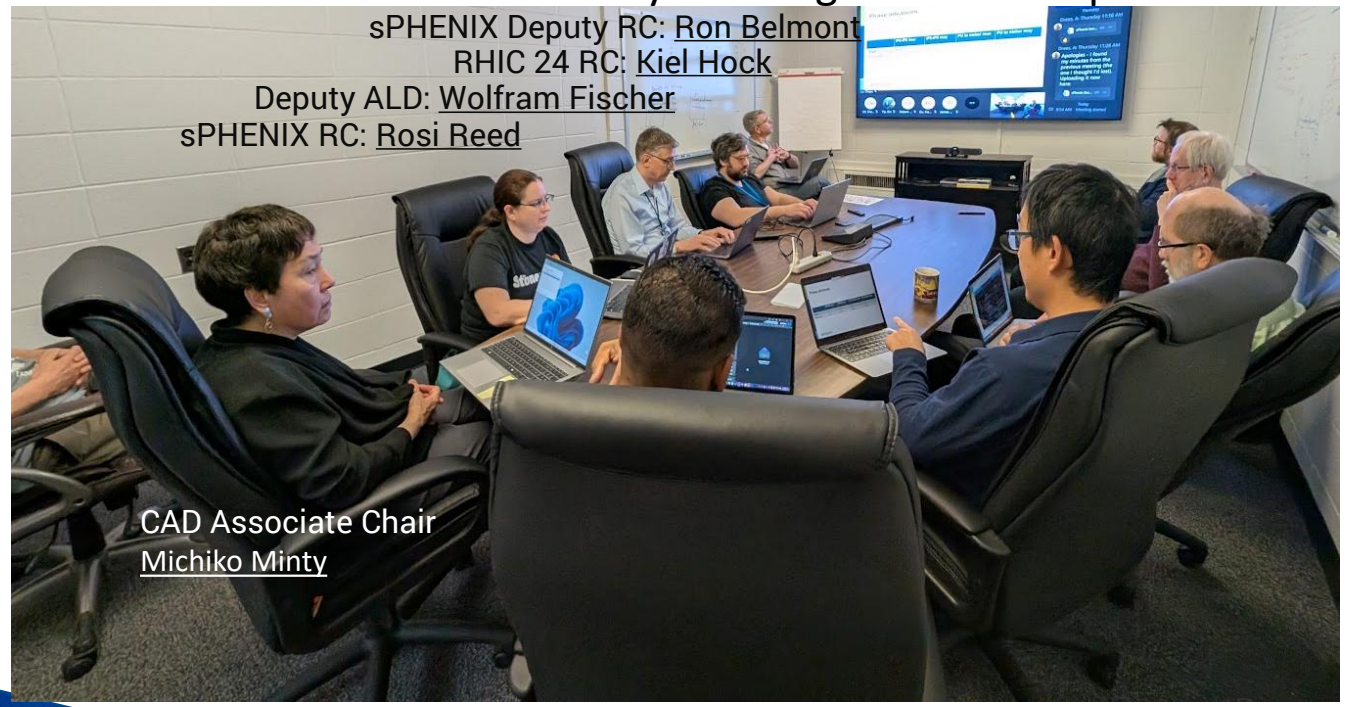


- Background event with large amount hit in MVTX sensor, upset readout logic, require ~20s recovery
- Hundreds of tests during Run 24 Au+Au running with the help of CAD
  - No ideal configuration removes the background
- Move from streaming to triggered mode
  - Triggered mode is much less suspectable to upset events (1/15 reduction)
  - Verification we can run in this mode (next slides)
- Regular joint sPHENIX-CAD background meetings after Run 24 conclusion

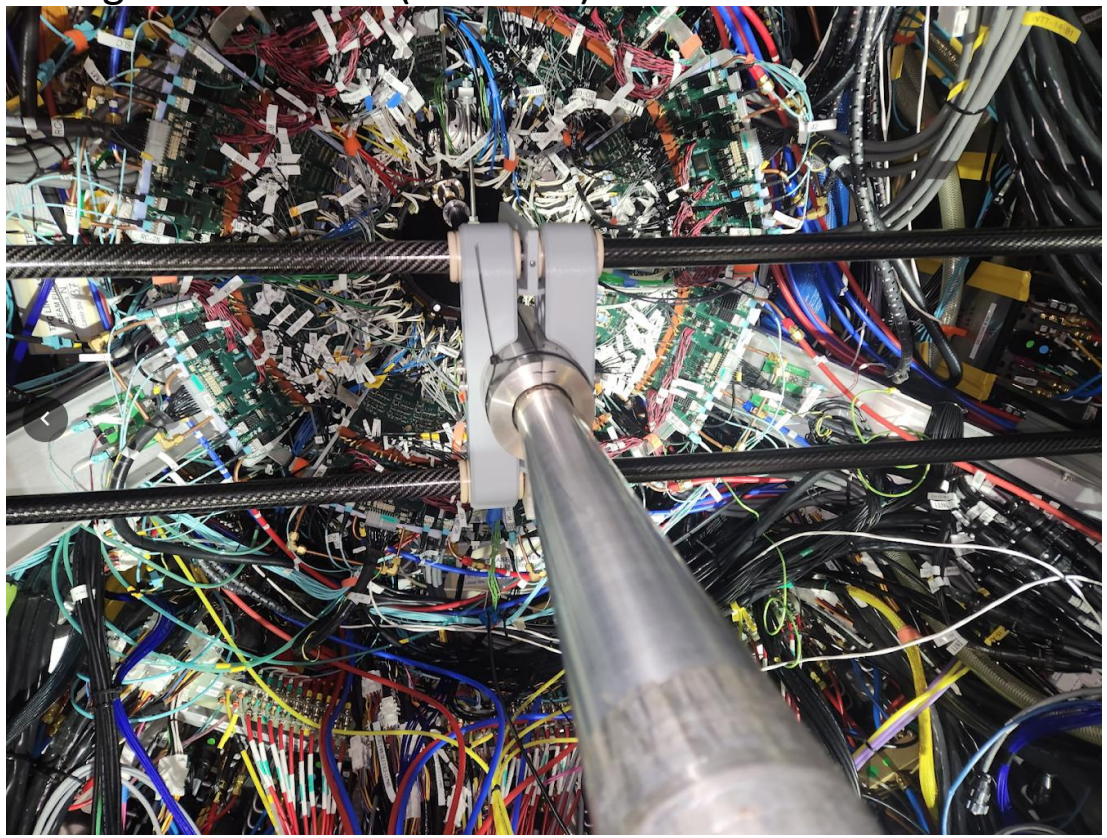
MVTX background mitigation

- Working closely with CAD developing multiple mitigation options and start of Run 25 plan [see also talk by Kiel Hock]

Bi-weekly meeting with CAD in past months



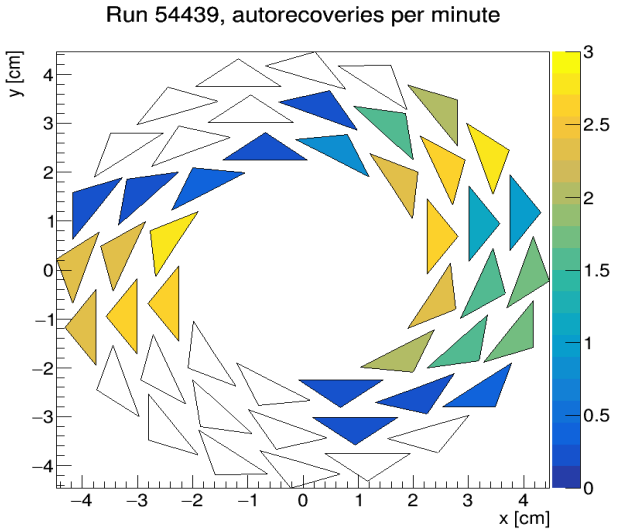
Background scatter (movable) and donut counters



Observed significant background improvement for Run25!

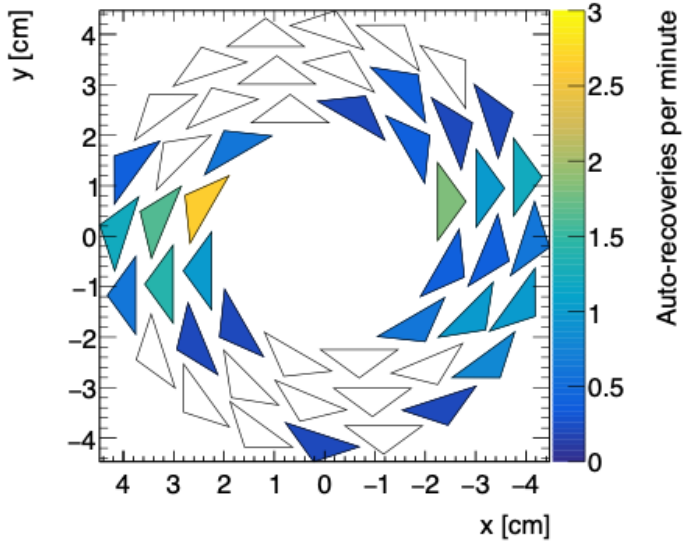
[see also talk by Kiel Hock]

Run 24



Outside Inside

Run 25



Notes:

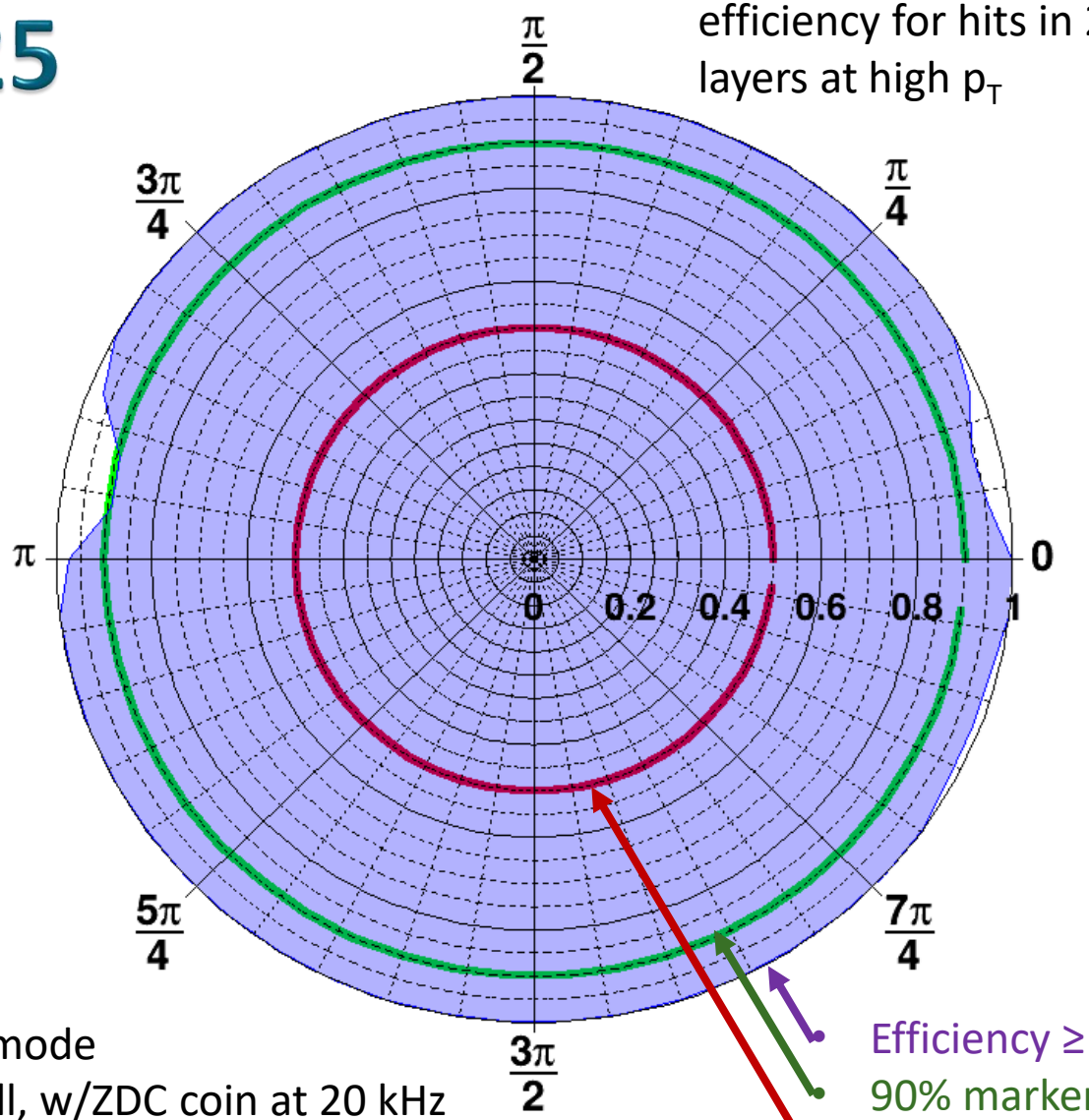
- The diagnostic streaming mode used in this study to enhance Auto-recovery upset rate for clear measurement of background.
  - Production run aim to use trigger mode (~1/15 reduction)
- Both test performed at 56x56 bunch collisions

Thanks to many regular meetings between sPHENIX and C-AD to work on addressing the MVTX beam background issue!

MVTX operation for Run 25

- MVTX demonstrated capability to operate in Au+Au at physics quality beam and rate
- We are cautiously optimistic to run MVTX at full RHIC luminosity and trigger rate
- Further improvement under discussion, but need to balance with physics uptime

Approximate track efficiency for hits in 2 layers at high p_T

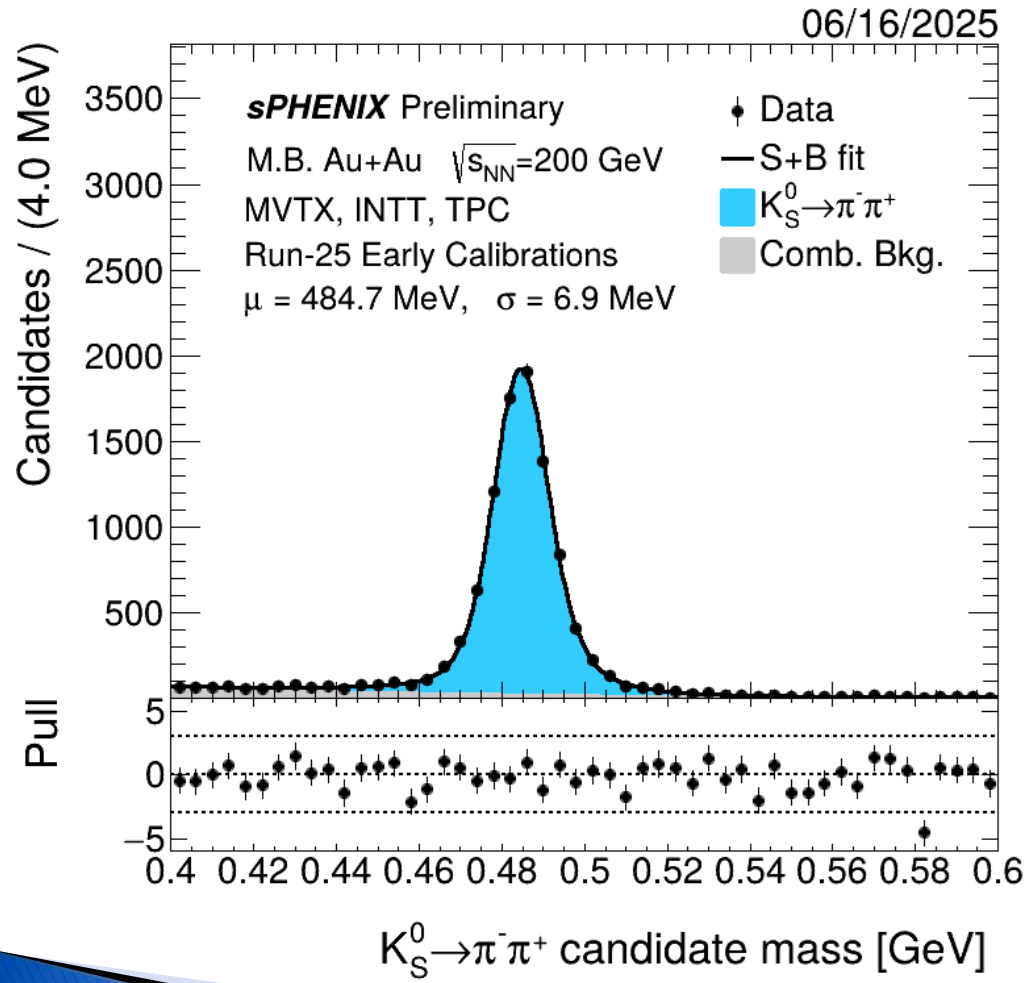


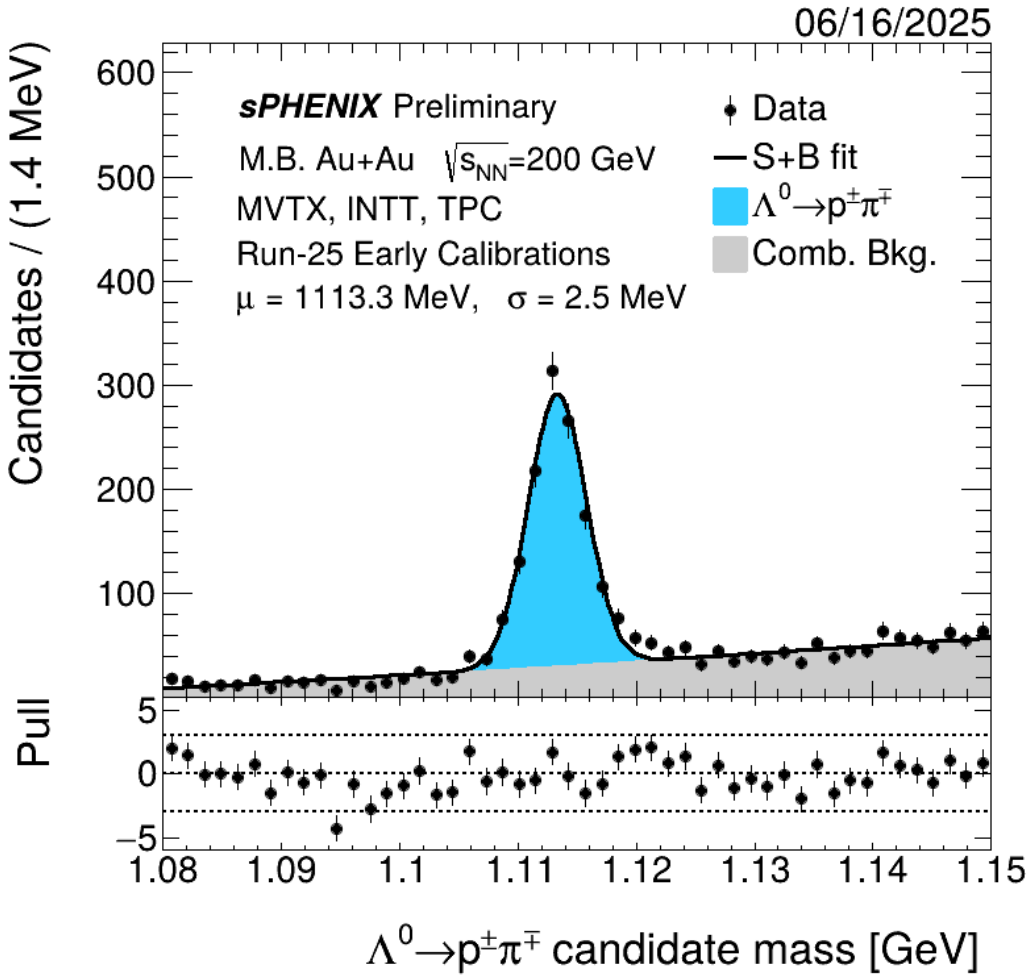
- Triggered mode
- 111x111 fill, w/ZDC coin at 20 kHz
- Triggered at 12 kHz

MVTX background mitigation options

Topic	Order	Person(s)	Readiness on March 24	Time (h)	Invasiveness	Notes	Status 10/14
Baseline	1	All	Y	2	dedicated	Ready after ramp+store development	Yes
Donut Counters	1	Sean	Y	0		Ready in parallel with baseline	Yes
Gap Cleaning	2	CAD	Y	1	passive	Ready following baseline and Artus setup	Yes
Stochastic Cooling	2	Kevin M	Y	8	passive	Ready following baseline +1 week setup for SC	Yes
RF Voltage	3	Brendan+Steve	Y	0.5	passive	Ready following baseline	Yes
Single octuple	3	Henry	Y	4	dedicated	Ready following baseline	No
NLC correction	3	Steve+GRD	Y	8	dedicated	Script ready to generate corrrection following baseline	No
Last sextant sextuples	3	Vincent	N	4-8	dedicated	Simulations ongoing	No
Collar abosrbers	4	John H	Y	1 day	dedicated	Ready after baseline when needed	No - installed
W-fct optimization	5	Chuyu+GRD+Xiaofeng	N	8	dedicated	Lattice optimization and DA simulations ongoing	No
DispIP4 w/mask	6	Chuyu+GRD	N	8+	dedicated	Development ongoing	No

First Run 25 Au+Au resonance reconstruction





Timeline Part 1

- Feb 14 – Readiness Review
- Feb 18 – Start of shifts
- Feb 19 – Start of Isobutane
- Mar 24 – Poletip doors close for start of run
- Mar 26 – Power supply bus in the blue ring fails hipot test
- April 1 – Initial date for first collisions
- April 4 – Ring Warm up for repair started
- April 25 – Short in the PS bus found
- May 9 -12 – Dry Run
- May 20 – Start of 4-person shifts
- June 10 – RHIC Physics declared the first time’
- June 14 – Start of 111x111 and sPHENIX Physics Counting

Timeline Part 2

- June 24 – Heat stand down
- June 30 – Power Dips stopped RHIC operations
- July 7 – 56 MHz Commissioning
- July 7 – Faulty ODH signal disrupts data taking
- July 10 – 56 MHz Commissioning
- July 14 – Power Dip
- July 17 – Vernier Scan
- Jully 22 – Crossing Angle Scan
- July 25 – Weather stand down
- July 31 – Power Dips + Weather stand down

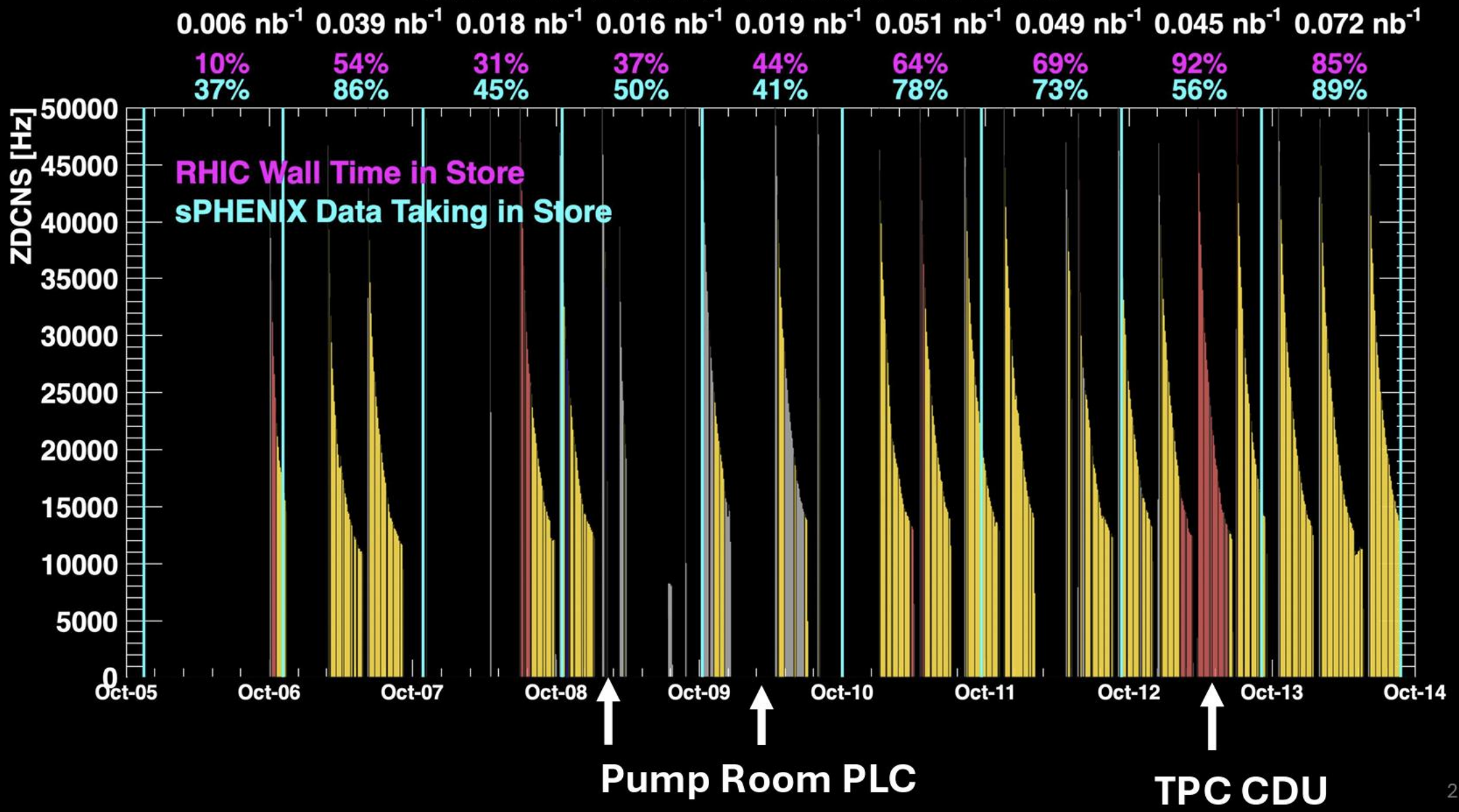
Timeline Part 3

- Aug 14 – TPC PLC Issue
- Aug 25 – Squirrel induced power dip
- Aug 26 – Issue with the 69 kV power line cross arm, Booster could not be run
- Aug 29 – SDCC Power outage
- Aug 30 – Repair of 69 kV power line
- Sept 2 – sPHENIX turns back on
- Sept 10 – Restart of collisions
- Sept 17/18 – TPC CDU issues preventing TPC runs
- Sept 25 – Prefire of abort kicker damages RHIC

Timeline Part 4

- Sept 28 – Leak repaired
- Oct 6 – Restart of collisions
- Oct 8 – Pump room PLC issue
- Oct 12 – TPC CDU issue

sPHENIX Wall Time



Minister of Science and ICT of Republic of Korea touring sPHENIX, Sept 23 2025

Discussed using cutting-edge AI in sPHENIX and future collaboration opportunities

Cutting-edge AI at sPHENIX

- Foundation model:
  - arXiv:2508.14087
  - ssrn.5389206
- Real-time data reduction:
  - arXiv: 2111.05423
  - arXiv: 2310.15026
  - arXiv: 2411.11942
- Generative AI
  - PRC 110 (2024) 034912
  - arXiv:2303.16280
- AI trigger in FPGA
  - arXiv:2501.04845
  - arXiv:2312.15104

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Dr. Yeonju Go
Goldhaber Fellow, BNL; sPHENIX Jet Topical Group Convener