RHIC Performance in Run-25

Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

(succeeds A. Seryi)

Michiko Minty
Accelerator Operations and Research Division head, C-AD

C-AD MAC-22
17 – 19 December 2025

Outline

RHIC Run-25

- RHIC Schedule – past 3 years with sPHENIX
- RHIC Run-25 - Timeline and Performance

RHIC Run-25 - Accelerator availability

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Responses to MAC-21 Recommendations

Summary

RHIC Run-25

RHIC Schedule – past 3 years with sPHENIX
RHIC Run-25 - Timeline and Performance

RHIC schedule – past 3 years with sPHENIX

2023

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

sPHENIX installation completed

Run-23 (Au+Au, $\sqrt{s_{NN}}$=200 GeV)
5/1/23 - 8/4/23 (early end)

RHIC repairs, preparation and sPHENIX upgrades for Run-24

CAD prep completed

CAD support for sPHENIX

2024

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

sPHENIX upgrades completed

Run-24 (p↑+p↑, $\sqrt{s_{NN}}$ ~200 GeV) 4/15/24 - 10/1/24

Preparation for Run-25

CAD repairs and prep completed

Run-24 (Au+Au, $\sqrt{s_{NN}}$=200 GeV)
10/1/24 - 10/21/24

2025

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Run-25 (Au+Au, $\sqrt{s_{NN}}$=200 GeV)
3/24/25 – 12/8/25

Run-25 (p↑+p↑, $\sqrt{s_{NN}}$ ~200 GeV)
12/8/25 – late Jan 2026
Beam operation ending at latest on 28 Jan 2026

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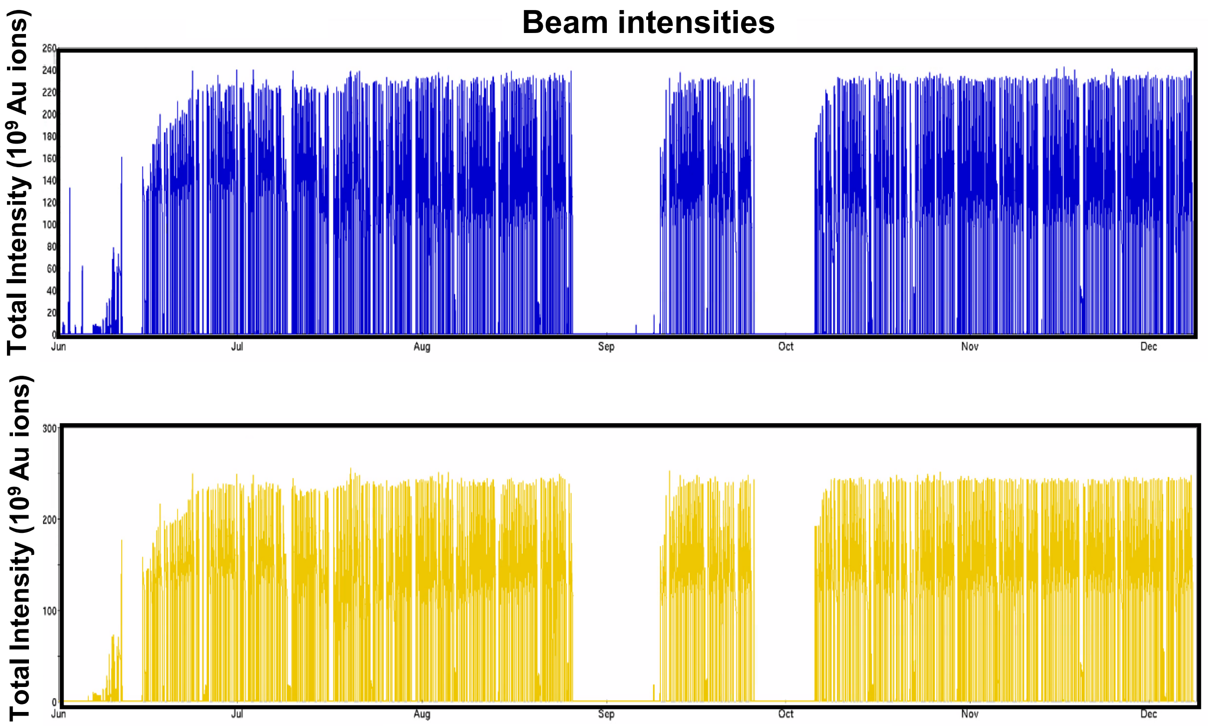
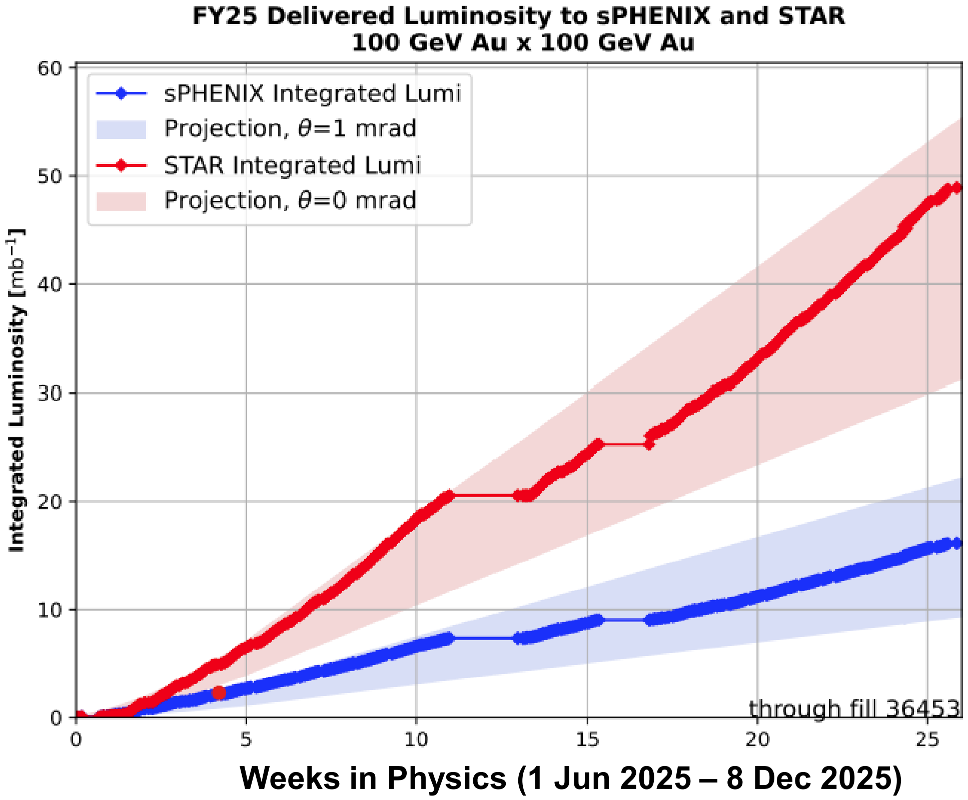
RHIC Run-25 timeline and performance

Run coordinator: T. Shrey

• 4K cooldown start, start	24 Mar 2025, then 28 May 2025
• Beam injection	31 May 2025 (Blue), 5 June 2025 (Yellow)
• **Au+Au at $\sqrt{s_{NN}}$=200 GeV**	**8 June 2025 – 8 Dec 2025**
• APEX and maintenance	alternating weeks starting 25 June 2025
• **p↑+p↑ at $\sqrt{s_{NN}}$=200 GeV**	**since 8 Dec 2025 (underway)**





Minimal downtime during summer operations, three major interventions with rapid and efficient return to optimal performance.

Performance Summary, RHIC Run-25

Au+Au, $\sqrt{s_{NN}}$ ~200 GeV (8 June 2025 – 8 Dec 2025)

- Priority (NPP PAC) for sPHENIX, provided collisions also for STAR.
- sPHENIX background issue identified in Run-24 eliminated (found and removed a legacy “mask”)

sPHENIX Physics Target in Run-25: 7 nb^{-1} (50B events)		
Collision Species	Cryoweeks	Projected luminosity, $\lvert z\rvert < 10$ cm
Au+Au 200 GeV	20	2.4 – 4.2 nb^{-1} recorded
Au+Au 200 GeV	28	3.6 – 6.4 nb^{-1} recorded

sPHENIX beam use request (Nov 2024)

✅ 6.6 nb^{-1} recorded

$\sqrt{s_{NN}}$ (GeV)	Species	Number Events/ Sampled Luminosity	Year
200	Au+Au	8B+**5B** / 1.2 nb^{-1}+**20.8** $\mathbf{nb^{-1}}$	2023+2024+**2025 (20 cryo-weeks)**
200	Au+Au	8B+**9B** / 1.2 nb^{-1}+**28.6** $\mathbf{nb^{-1}}$	2023+2024+**2025 (28 cryo-weeks)**

STAR beam use request (Nov 2024)

✅ 24.3 nb^{-1} recorded

p↑+p↑, $\sqrt{s_{NN}}$ ~200 GeV (8 Dec 2025 – late Jan 2026)

sPHENIX beam use request (Nov 2024)

If Au+Au luminosity target is met, ordered priority list for additional running:			
Collision Species	Physics weeks	Projected luminosity, $\lvert z\rvert < 10$ cm	
1. *p+p* 200 GeV	8	13 pb^{-1} sampled + 3.9 pb^{-1} streaming	in progress
2. *p*+Au 200 GeV	5	80 nb^{-1} sampled + 24 nb^{-1} streaming	not funded
3. O+O 200 GeV	2	13 nb^{-1} sampled + 3.9 nb^{-1} streaming	not funded

- expect to achieve additional requested physics goals (p+p for sPHENIX)
- may run additional experiments (FXT and CeC) if p↑+p↑ goal is achieved (contingent on DOE approval)

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RHIC Run-25 Availability

RHIC Run-25 intervention #1

courtesy T. Shrey
RHIC Run-25 run coordinator

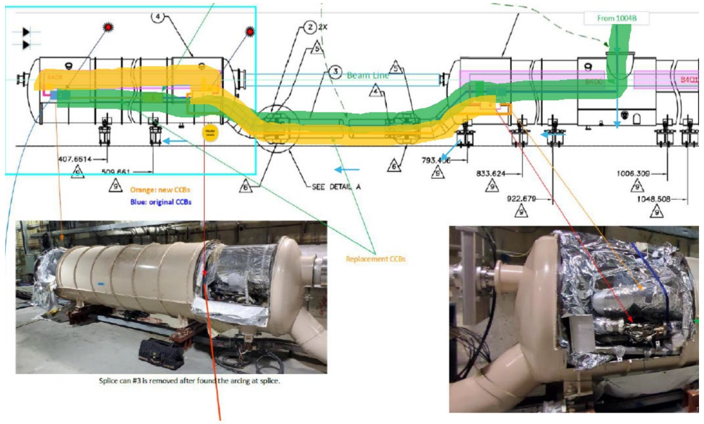
2 Month delay to start the run

Blue ring main dipole would not pass the high-potential test once the ring was cold. Limited number of places where the fault could be narrowed down, required a full cryogenic warm up.

After exhaustive work from large parts of the department the short was identified after opening multiple areas in sector 4. It was found to be a sharp point on a repaired splice from the DX failure in Run23. Cryostat opening to the start of the cooldown took over 1 month.

Simultaneous with this were power supply failures for both extraction bumps in the AGS. Pulsed power group and power supply technicians effectively built all new supplies and wrapped up one day before RHIC was ready for beam.

Beam Operations began 5/31/25



RHIC Run-25 intervention #2

courtesy T. Shrey
RHIC Run-25 run coordinator

Power line failure

A failed arm on one of the 69 kV power poles that feed the north campus was identified. The single pole carried both the main feed and the alternate feed; PSEG would not carry out the repair without both lines shut off.

A power interruption of more than a few hours would result in massive helium inventory loss from the cryogenic plant if the rings remained cold. Cryogenic experts worked around the clock to warm up in a controlled way that utilized all of our storage capacity.

The repair was ultimately completed very quickly (90 minutes) and minimal helium inventory was lost. Cooldown commenced immediately and beam operation was restored; total time lost was 14 days.

Excellent return to full operations post recovery (ref slide 5)

RHIC Run-25 intervention #3

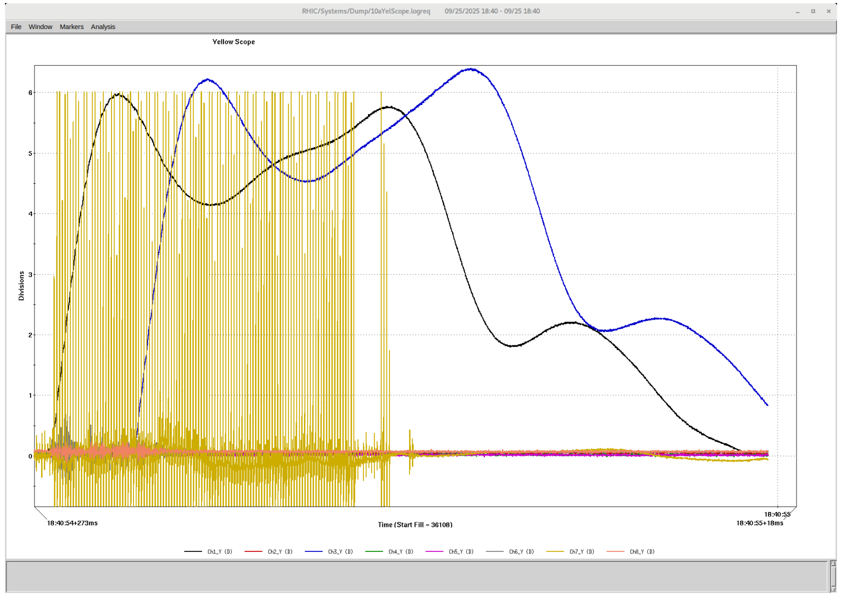
courtesy T. Shrey
RHIC Run-25 run coordinator

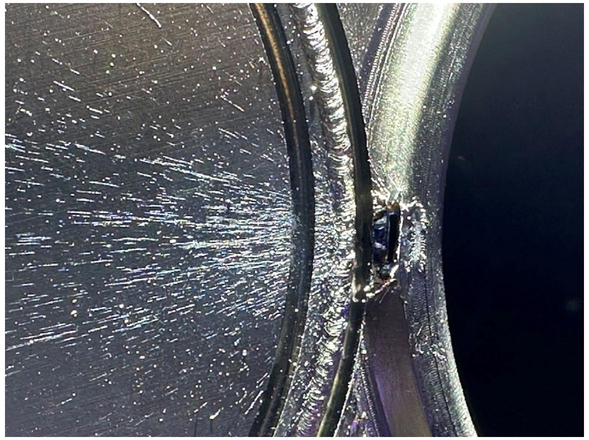
Abort kicker failure

Two modules of the abort kicker fired early in a still-unexplained failure mode of the system (module 1 thyratron appears to have been conducting continuously for 12 seconds). The almost-perfect overlay in delays pushed 2/3 of the bunch train into the small section of flange between the circulating beampipe and the dump window.

Vacuum group and riggers disassembled the dump pipes and a weld repair was made spectacularly fast. Vacuum bakeout and pump down took approximately 1 week, with a total downtime of 11 days.

In response to the failure MCR will be monitoring injection and store performance of the abort kicker modules going forward for every fill. There is an indication that the failure was preceded by strange timing shifts in the module in question for several stores before the incident.

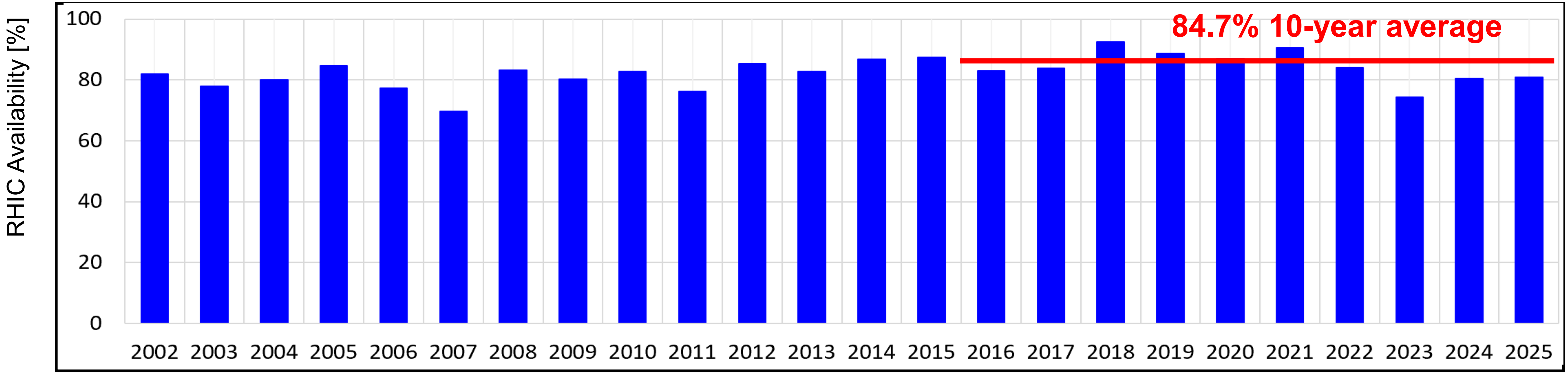




Excellent return to full operations post recovery (ref slide 5)

RHIC Availability

C. Naylor



Availability = beam time / scheduled beam time
Availability targets: 82.5% (< FY20) , 85% (FY21-FY22), 82.5% (FY23), 80.0% (FY24-FY25)

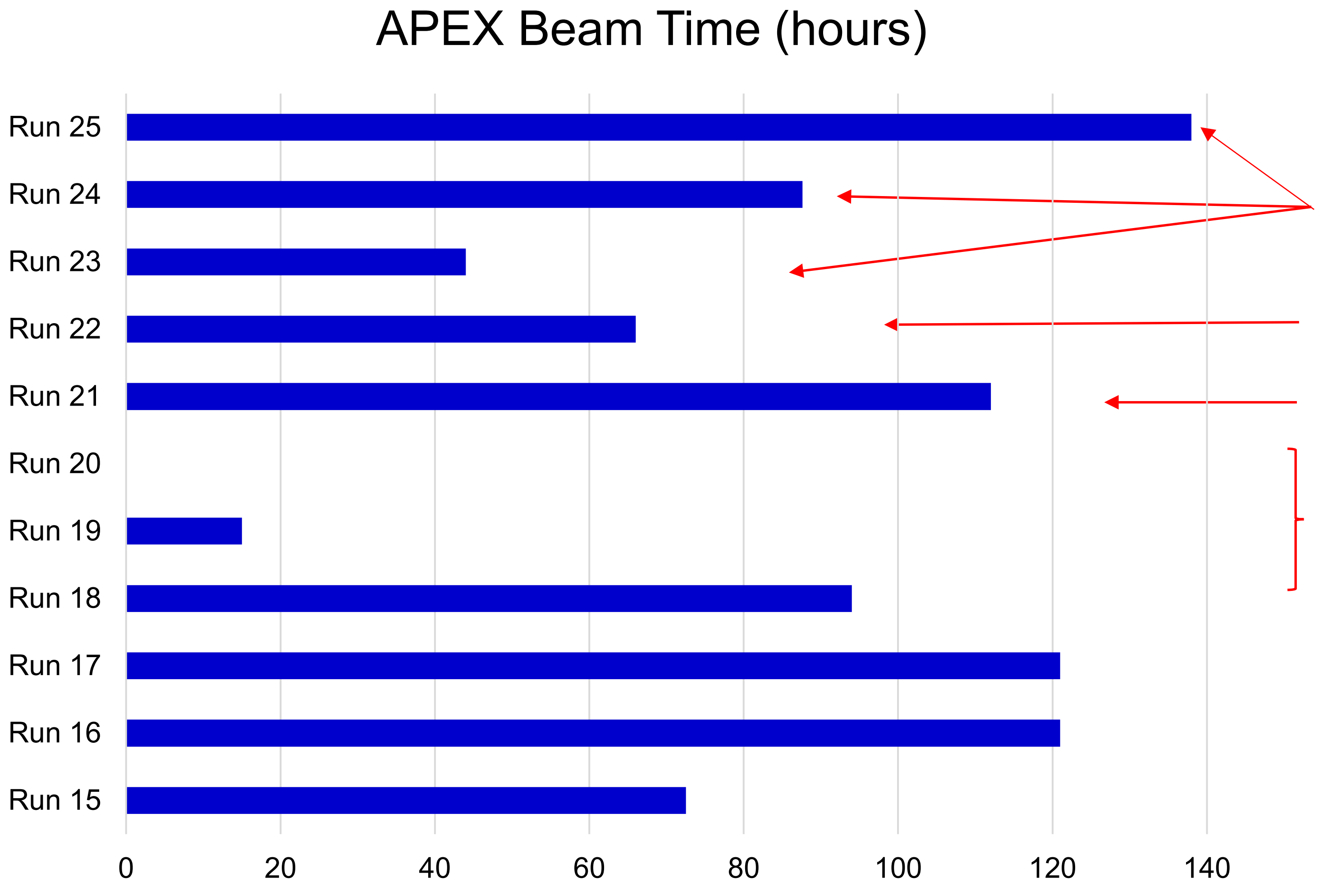
RHIC Run FY25: **81.0% (12/9/25)**
Average over last 10 years: **84.7%**

RHIC Runs-23, 24, and 25: operated during summer months (hence lower targets)
Accelerator availability goal for RHIC Run-25 met (so far)
Availability target for the EIC: 85.0% (with no plans for operation during the summer)

RHIC Run-25 Accelerator Physics Experiments (APEX)

Accelerator Physics Experiments (APEX) - Overview

APEX coordinators:
H. Huang (C-AD) and
Y. Luo (EIC)



experiments to inform EIC design and/or operation

experiments to inform EIC design and beam cooling studies

focus: beam cooling studies

(minimal APEX during BES-II and pandemic)

APEX workshop held January 2025 https://indico.bnl.gov/event/26073/. Featured:

- comprehensive review of EIC-related requests for final year of RHIC operations (next slide)
- detailed plans for experiments

APEX proposals* and status in final year of RHIC operations

Index	Proposal title	Spokesperson	ime asked (h	ime used (h	Grade	Species	Energy	Status
24-03	Accelerating flat gold ion beams from 31GeV to 100GeV	Y. Luo	48	29	0A	Au	31, 100GeV	Done
25-01	Maximize beam-beam parameter with flat beam collision in RHIC	Y. Luo	12	25	0A	Au	100GeV	
25-04	RF transient beam loading studies	F. Severino	4	4	0A	Au	injection	Done
23-02	IP8 optics tunning with crossing angle and short vertex	X. Gu	12	3.5	1A	Au	100GeV	Done
25-09	Measure Longitudinal Impedance in RHIC	M. Blaskiewicz	6	4	1A	Au	injection	Done
25-12	Octupole Limit in RHIC	M. Blaskiewicz	6	6	1A	Au	injection	Done
25-08	Using Sextupole to Reduce Vertical Emit. Growth in Flat Beam Collision	D. Xu	12	20	1A	Au	store	Done
25-10	Benchmark IBS Rate with Coupling for Flat Beam	Y. Luo	12	5.5	1A	Au	store	
23-10	Transition Jump with Reduced Number of Jump Quadrupoles	H. Lovelace	16	20	1B	Au	ramp	Done
25-02	Coherent electron Cooling Experiment	V. Litvinenko	168	13	1B	Au	19.57 GeV	
Total			**296**	**130**				

* (only highest priority experiments shown here)

All highest priority (grade 0A and 1A) experiments completed.

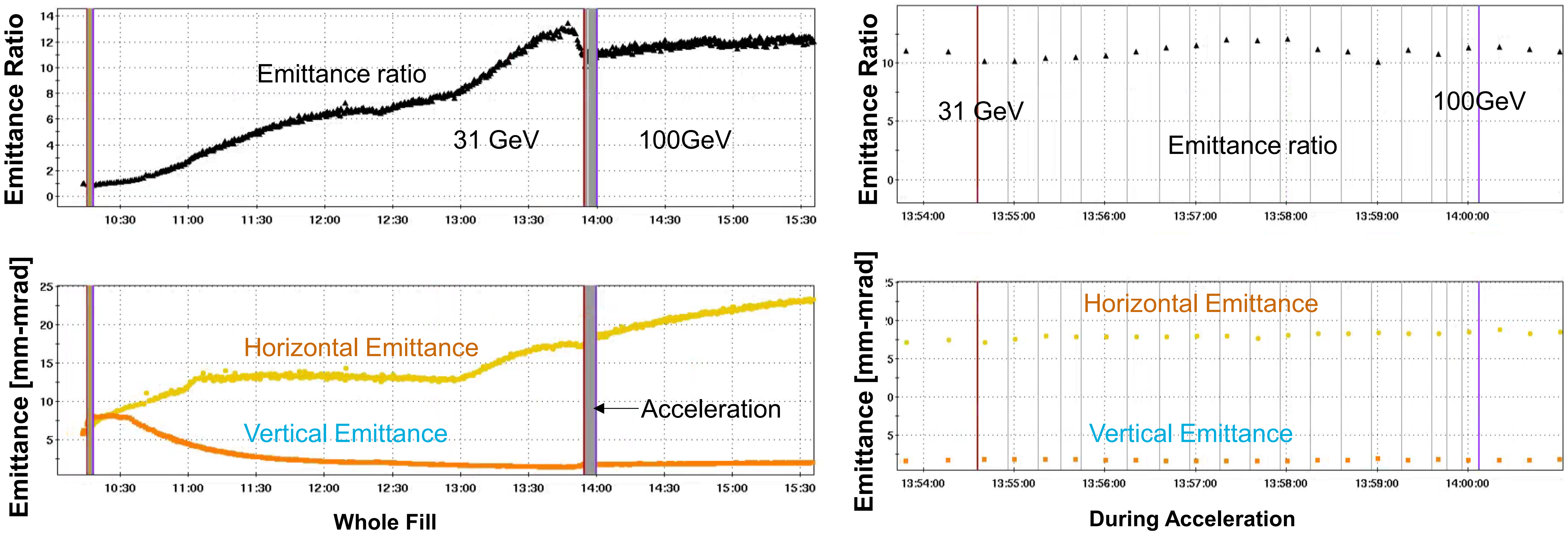
Key focus areas:
1. Flat beam studies ✅ → next slides
2. Transition crossing (with fewer transition-crossing quadrupoles) ✅ → next slides
3. Impedance measurements ✅
4. Coherent electron Cooling – in progress

APEX - Flat Beam Acceleration for the EIC

Y. Luo et al

Motivation – EIC wants “flat beams” (emittance ratio 10:1) to collide with (flat) electron beams

Experiment - generated flat Au beams at injection energy and acceleration to high energy



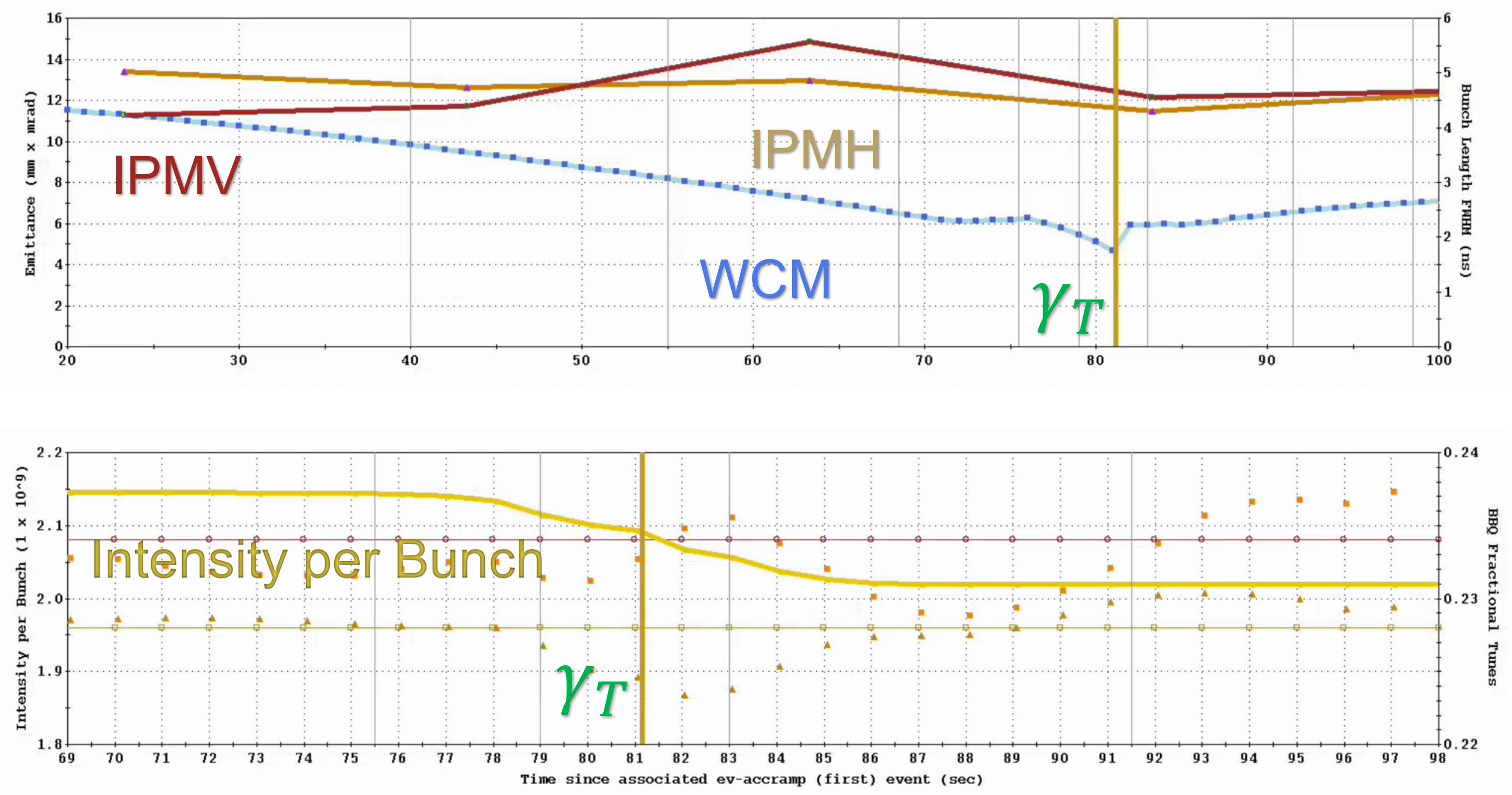
✅ Results - gold ion beam with a maximum transverse beam emittance ratio 13:1 was generated at 31 GeV/nucleon with stochastic cooling. Transverse emittance ratio 11:1 was well maintained during acceleration from 31 GeV/nucleon to 100 GeV/nucleon.

H. Lovelace et al

APEX - Acceleration through transition energy with fewer transition jump quadrupoles for the EIC

Motivation – EIC lattice would benefit from fewer transition jump quadrupoles (space constraints)

Experiment – accelerate beams with reduced number of transition jump quadrupoles



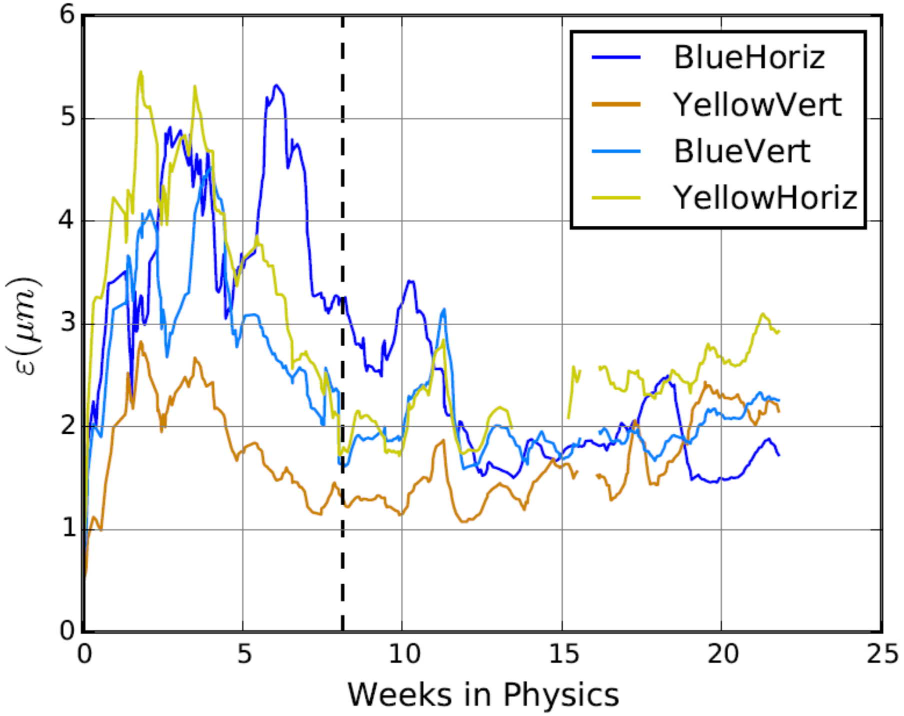
✅ Results – with reduced number of transition jump quadrupoles (40 compared to 48 in RHIC), minimal beam loss (~6%) with no dilution of emittances with ~2 x10^9 particles per bunch, ~110 bunches

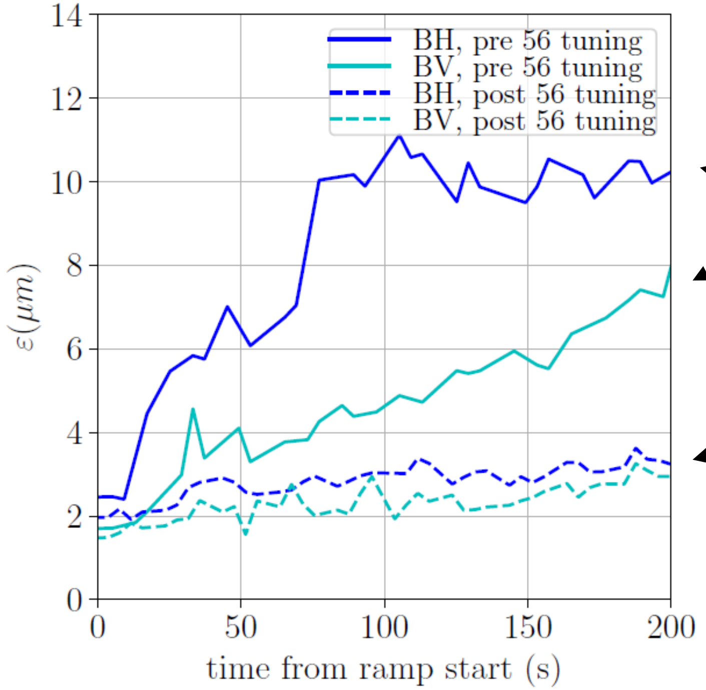
Response to MAC-21 Recommendations

RHIC performance in Run-24

courtesy K. Hock
RHIC Run-24 run coordinator

R1: The nature of the instabilities encountered (*during scrubbing run with ~~Au~~ protons*) should be described in more detail.





Emittances during acceleration

un-damped

damped

- Although no instability was directly observed with our instrumentation, it drove large emittance growth on ramp, with a dependence on intensity.
- The cause for emittance growth was caused by insufficient damping of the 56 MHz SRF cavity (comparison on right).
- No dedicated time was spent on ‘un-damping’ the 56 MHz cavity for additional measurements.
- Additional updates to optics and chromaticity further reduced emittances to nominal values of 2-2.5 μm.

RHIC planning for Run-25

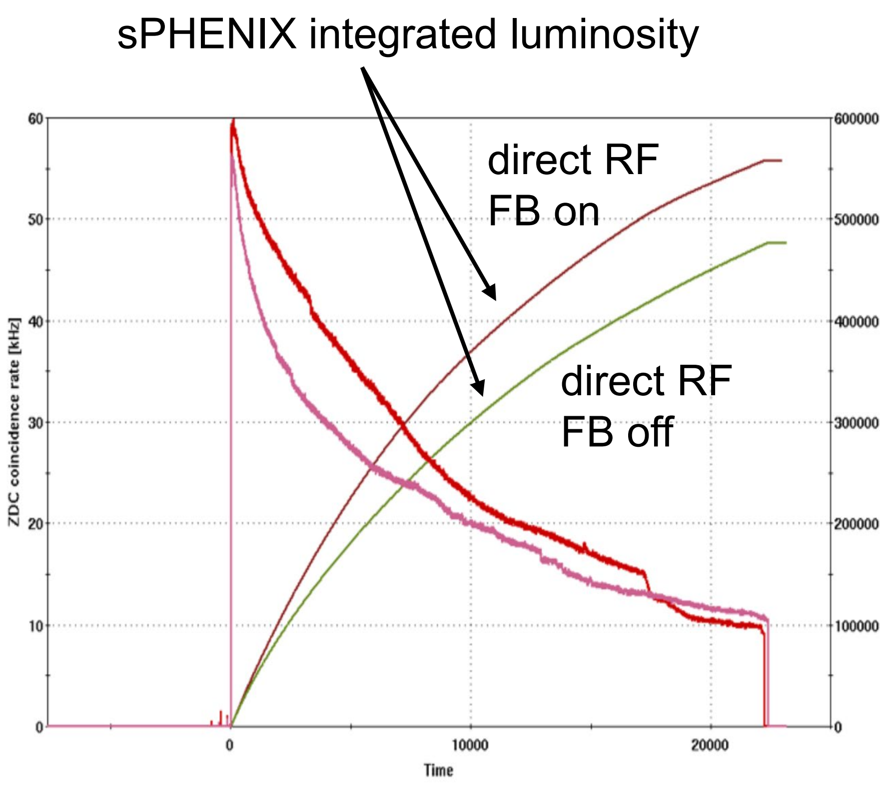
courtesy K. Mernick, F. Severino et al

R2: Define a strategy for the 56 MHz cavity before the start of the run, that achieves an optimal trade-off between invested time and expected performance gain.

- For 2025, we developed direct RF feedback to reduce the impedance of 166 MHz and 377 MHz HOM modes and developed ‘multi-harmonic’ processing in the LLRF for better diagnostics. This system was installed and tested before the run and on early maintenance days. Beam commissioning was mostly done in 2 shifts (July 7 & 10).

- Running in this mode provided about a 15% increase in luminosity in the sPHENIX 10 cm vertex.

- Later in July, a hardware failure of one of the FPCs occurred. The exact failure mode is still not fully determined but is suspected to be the semi-rigid coax connection through the insulating vacuum. After evaluating this failure and unknowns around it, we determined that it was not worth the risk of invested time and potential further failures to run the cavity anymore.



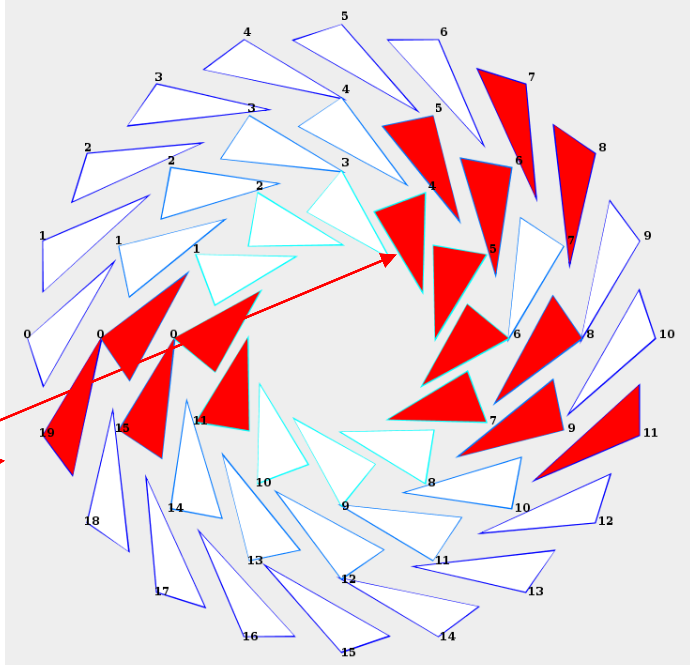
RHIC Run-24: experimental backgrounds

R3: Calculate the overall aperture bottleneck for a betatron halo particle (at a setting of horizontal collimator, e.g. 8 sigma-beta-x) that at the same time has an energy offset at the momentum aperture (e.g. 4.5 sigma-E). Use the known local aperture, the horizontal beta function and the horizontal dispersion to see if such a particle can get lost at the second taper in front of sPHENIX or at another "high impact" location that can shine into the detector. Only if this is true, a global momentum collimation can safely protect the experiment. Otherwise, local origins of off-momentum ions might be responsible, to be counteracted by local protection measures.

RHIC Run-24 experience (during last two weeks of the three-week test run with Au+Au:

- Au particles were transiting the length of the MVTX detector, depositing a large amount of charge and causing the detector to go into an auto-recovery process (ARP).
- The ARP required approximately 20 s, during that time data could not collected.

Example of sPHENIX MVTX Si strips in ARP

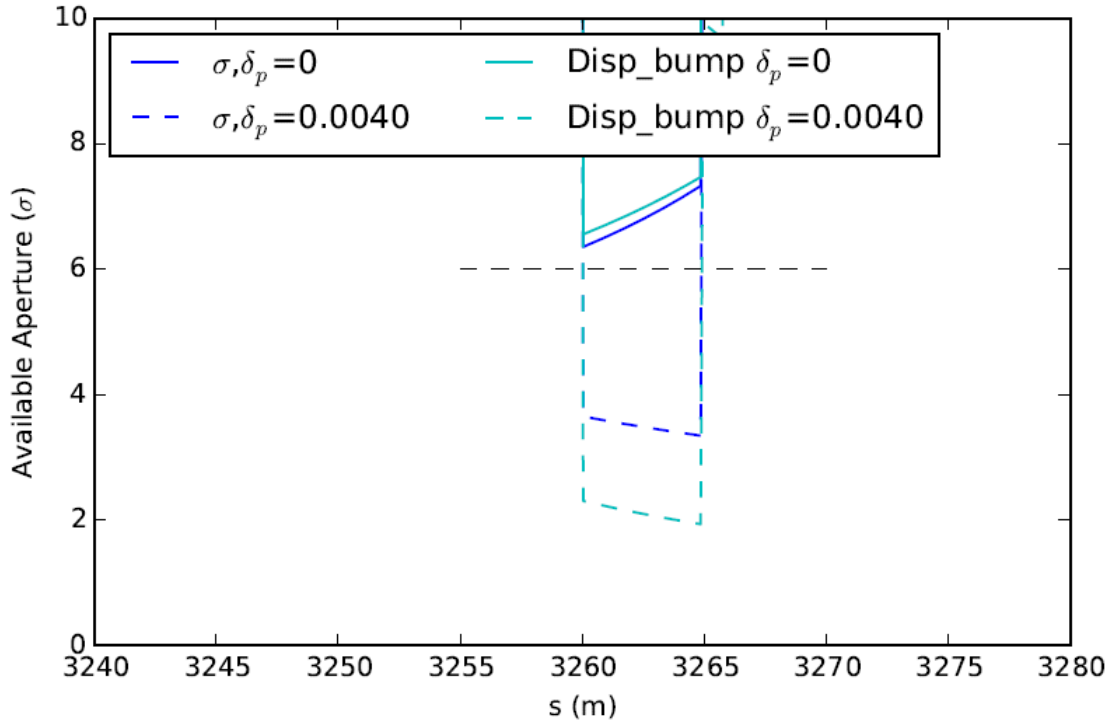


RHIC Run-24: experimental backgrounds

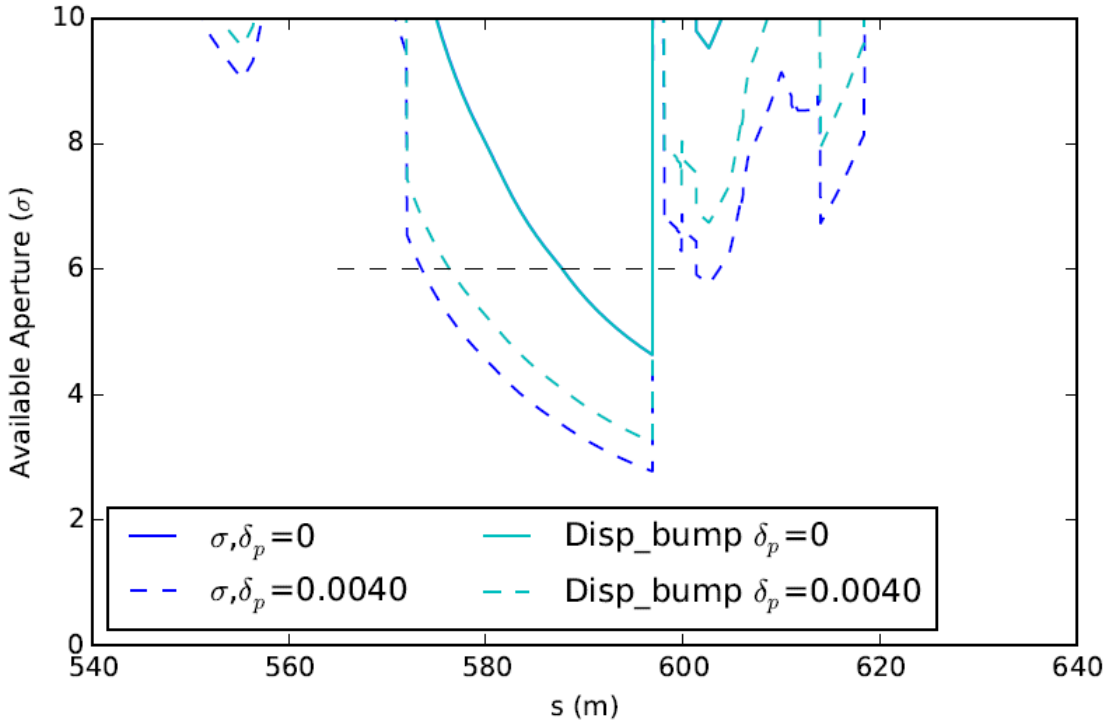
courtesy K. Hock
RHIC Run-24 run coordinator

Calculations of aperture and momentum aperture

Mask location (fully inserted)



Collimator location (inserted to 6 sigma)



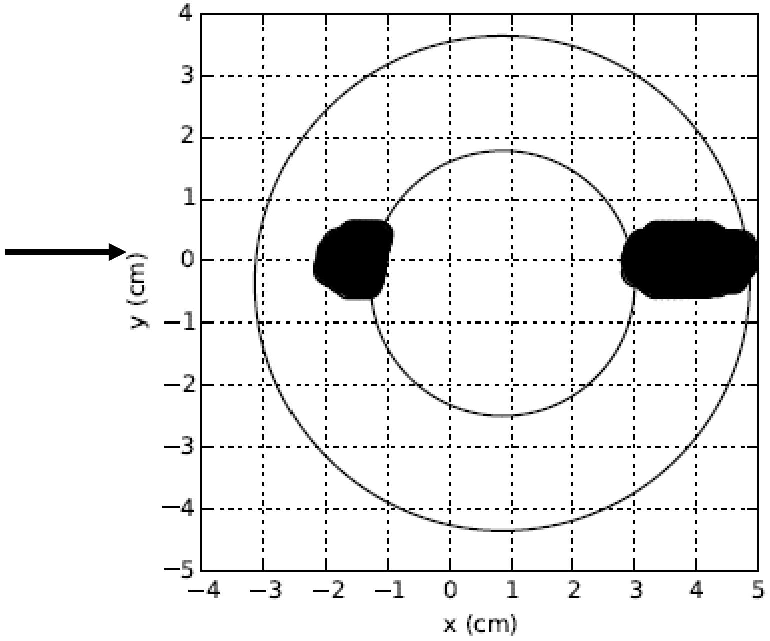
- Only in the case of high momentum offset and with increased dispersion at the location of an additional warm-section ‘mask’, was the mask more efficient than existing collimation at removing high momentum particles.
- A new mask was installed and additional power supplies were integrated in support of the dispersion bump.

RHIC Run-24: experimental backgrounds

K. Hock
RHIC Run-24 run coordinator

Through tracking, it was determined that the source of the background was upstream of the triplets.

- At that location, a legacy “mask” was rediscovered. The jaws of the mask had been mechanically fixed in an open state, but limited the aperture to ±2.48 cm from the nominal ±3.4 cm.
- Forward tracking from this location showed particles with very low momentum error would strike the MVTX.
- This mask was removed shortly before the start of RHIC Run-25.
- The background problem of RHIC Run-24 was eliminated.



Local origin of backgrounds identified and resolved.

R4: Check the dependence of background on bunch intensity and horizontal collimator settings.
R5: The addition of local shielding in sPHENIX seems like a good idea and should be done before Run-25 if at all possible.

These two recommendations were not pursued as a result of these extensive analyses.

Summary

Summary

RHIC performance in RHIC Run-25 with Au+Au at $\sqrt{s_{NN}}$ ~200 GeV

- Total of 31 cryo-weeks including 2 weeks from RHIC Run-24.
- Emergent issue from Run-24 with sPHENIX backgrounds (MVTX auto-recovery events) resolved by removal of upstream legacy hardware.
- Incurred three interventions during run (main dipole short in Blue Ring, 69 kV power line breakage, abort kicker failure), excellent recovery to full operations each time.
- Achieved (NPP PAC definition) Au+Au run goals for sPHENIX and STAR.
- Accelerator availability: operation during summer months (environmental controls) very successful - achieved 80% target (81.0%) with 10-year average of 84.9% (just shy of 85.0% required for the EIC).
- Accelerator Physics Experiments (APEX): all highest priority experiment to inform design and/or operation of the EIC were successfully executed.

Underway (since 8 Dec 2025): p↑+p↑ at $\sqrt{s_{NN}}$ ~200 GeV for sPHENIX.

Other experiments (FXT for STAR and Coherent Electron Cooling) TBD, contingent on reaching p↑+p↑ luminosity goal and DOE approval.

RHIC operations will conclude at latest on 28 Jan 2026 making way for the Electron-Ion Collider.