RHIC Performance in Run-24 and Planning for Run-25

(succeeds A. Seryi)

Michiko Minty
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Accelerator Division Head, C-AD

C-AD MAC-21
16 – 18 December 2024

Outline

RHIC Performance in Run-24

- Timeline and achievements
- Accelerator availability

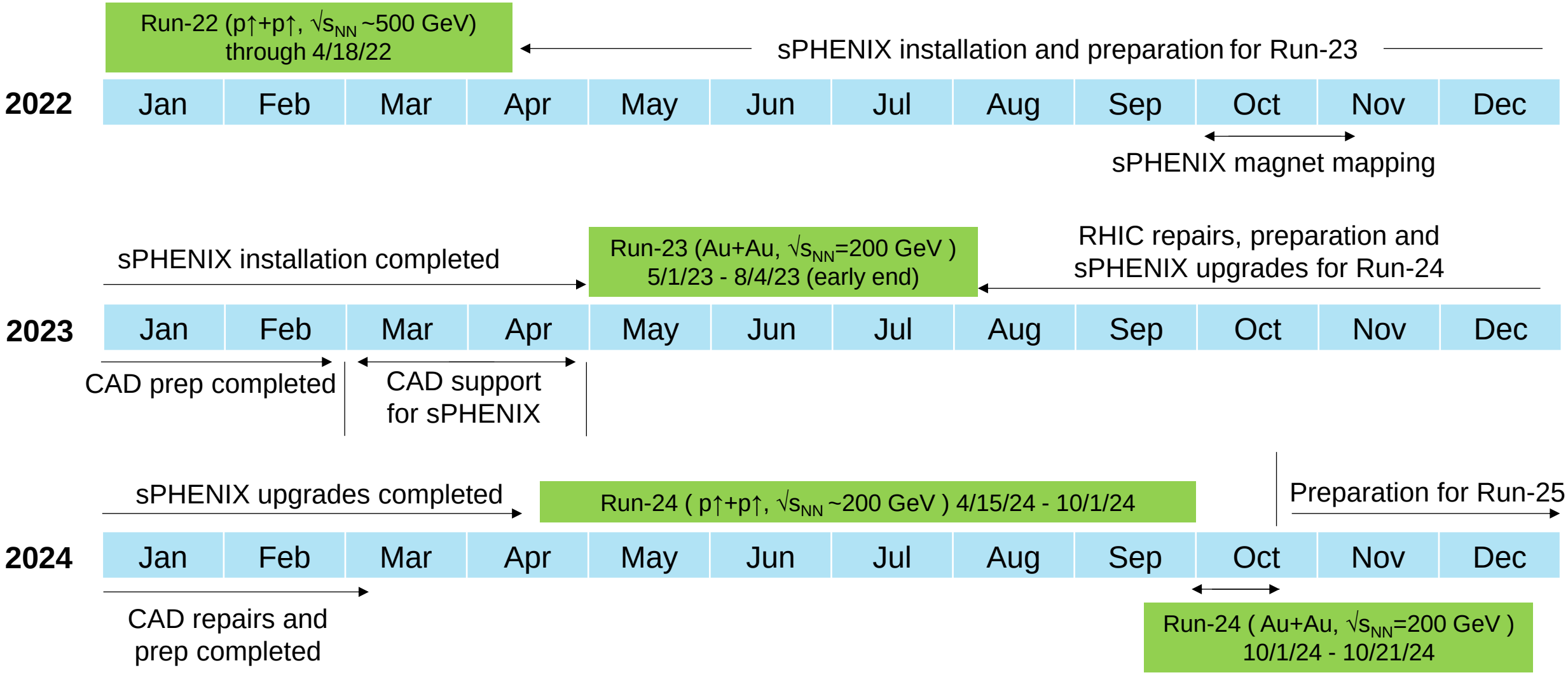
Planning for Run-25

- Preparations for Run-25
- Other beam time requests

Summary

RHIC Run-24 Timeline and Achievements

Recent RHIC schedule



RHIC Run-24: funding received for 19 cryo-weeks (+ 6 week carryover from Run-23)
started (6 weeks) later than planned
received approval for an additional 2 cryo-weeks → 27 cryo-weeks total

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RHIC Run-24

Run coordinator: K. Hock

Timeline

- **4K cooldown start, start of p↑+p↑ at $\sqrt{s_{NN}}$ ~200 GeV** **15 Apr – 1 Oct 2024**
- Beam injection 19 Apr 2024 (Blue), 23 Apr 2024 (Yellow)
- sPHENIX commissioning with beam 27 Apr 2024
- STAR physics "declared" 30 Apr 2024
- APEX and maintenance alternating weeks starting 8 May 2024
- USI (approval to operate with isobutane at sPHENIX) 27 Jul 2024
- **Start of Au+Au, $\sqrt{s_{NN}}$=200 GeV** **1 – 21 Oct 2024**
- Physics "declared" 8 Oct 2024

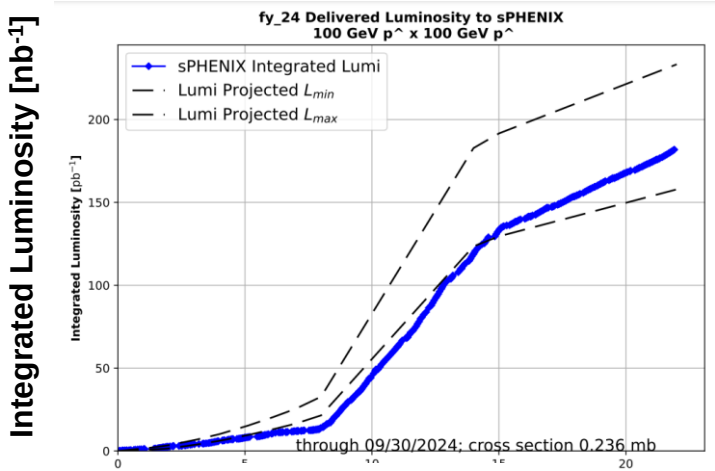
Performance Summary, (p↑+p↑, $\sqrt{s_{NN}}$ ~200 GeV)

- All repairs reported at last MAC (feedthrough, DX magnet replacement, USI upgrade) + refined cryo controls successfully completed.
- Priority (NPP PAC) for sPHENIX, provided collisions also for STAR.
- Run evolved differently than envisioned (next slide), responded to circumstances.
- Minimal accelerator downtime due to lack of air conditioning (last year's challenge), but several (lab-external) power interruptions impacted accelerator availability.
- Run goals met for both sPHENIX and STAR.

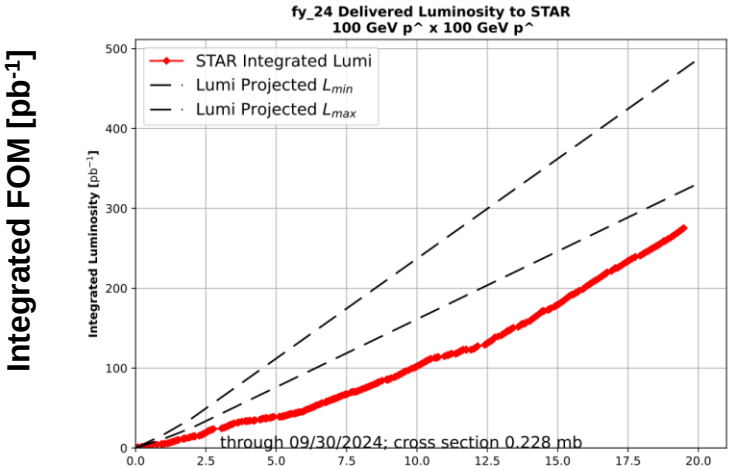
Performance Summary, (Au+Au, $\sqrt{s_{NN}}$ ~200 GeV)

- Priority (NPP PAC) to prepare for RHIC Run-25.
- Run goals not met for sPHENIX and C-AD, STAR (planned) run goals met.

sPHENIX - FY24 Delivered Luminosity
100 GeV p↑ x 100 GeV p↑



STAR - FY24 Delivered Figure of Merit (LP^2)
100 GeV p↑ x 100 GeV p↑



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RHIC Run-24, p↑+p↑ at $\sqrt{s_{NN}}$ ~200 GeV

Run coordinator: K. Hock

RHIC 4K cooldown, 15 Apr

STAR physics "declared", 30 Apr

two-week STAR "low-luminosity" run
(using luminosity levelling)

Authorization to operate with
isobutane at sPHENIX, 27 Jul

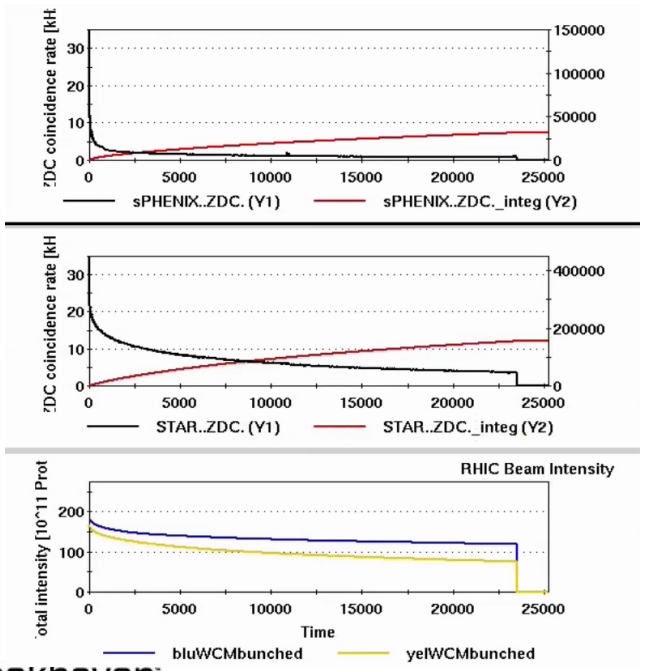
2024 | Apr | May | Jun | Jul | Aug

sPHENIX: -2 mrad crossing angle
STAR: 0 mrad (head-on)
(through 25 Jun)

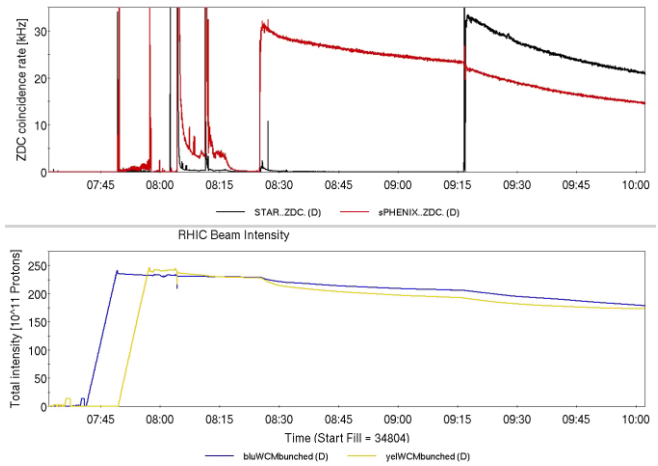
sPHENIX and STAR:
head-on collisions
(25 Jun – 13 Aug)

sPHENIX: +1.5 mrad crossing angle
STAR: 0 mrad (head-on)
(since 13 Aug)

6/25/24

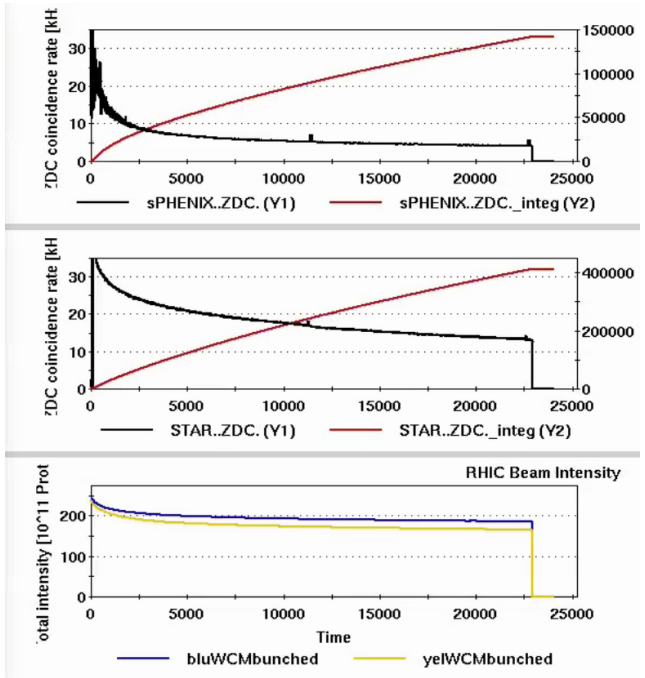


7/15/24



With head-on collisions at both sPHENIX and STAR, beam-beam limit required delayed start of collisions at one of the two experiments (STAR)

8/17/24



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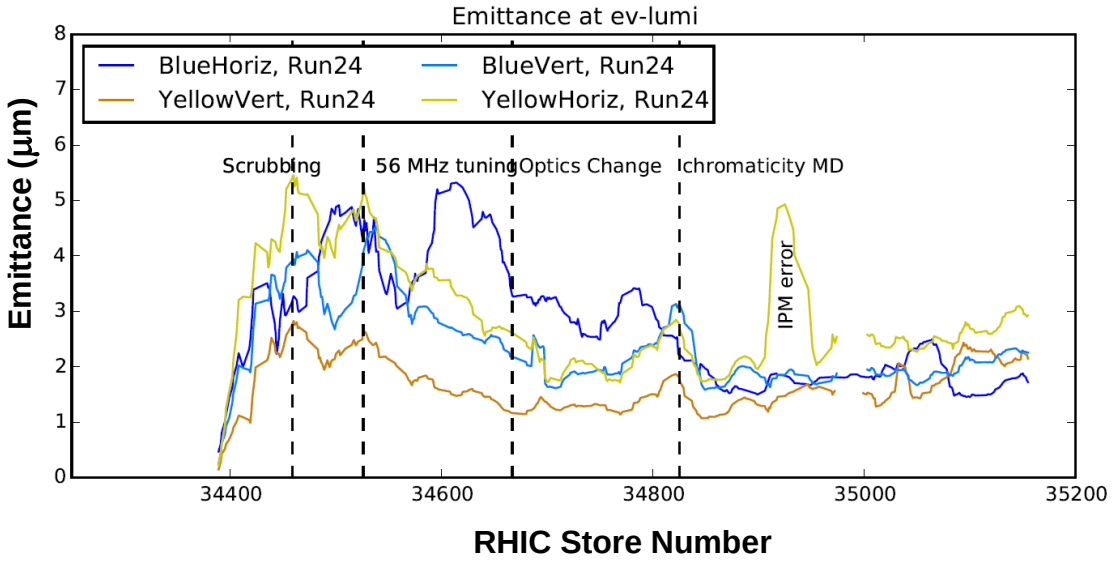
M. Minty C-AD MAC-21 (16-18 Dec 2024)

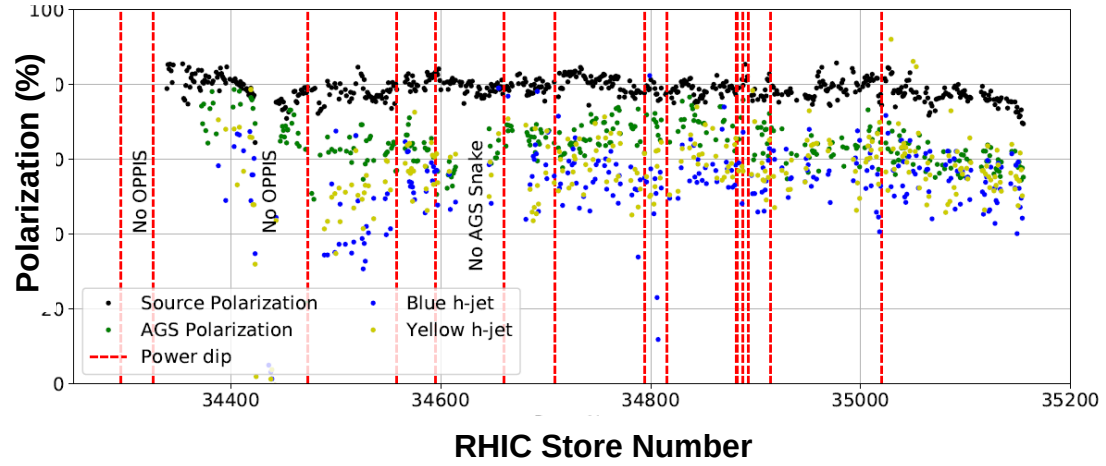
Emittances and Polarization

Run coordinator: K. Hock

- Fully damping the 56 MHz (FPC1 and FPC2) resulted in a factor of 3 reduction in emittances
- Optics corrections provided a further reduction of emittance and improved beam stability
- Further tuning of the chromaticity mitigated beam instabilities and further improved emittances
- Smaller emittances translate directly to higher polarization

Ring	$<P_{run15}>$	$<P_{run24}>$ (preliminary)
Blue	53.0	54.7
Yellow	57.4	57.8





Emittances and polarization restored to Run-15 levels.

RHIC Run-24, Au+Au at $\sqrt{s_{NN}}$ ~200 GeV

Run coordinator: K. Hock

On Oct 8, 2024 high sPHENIX MVTX Detector “auto-recovery events” were reported (not unlike that observed at the LHC). The remainder of the run primarily focused on studies to minimize occurrence. Note: stray particles difficult to detect (MVTX auto-recovery rate upsets not correlated with signals in any RHIC beam loss monitors).

Working hypothesis: off-momentum Au ions lost on aperture and fragments reach sPHENIX MVTX some of which lead to auto-recovery rate upsets.

sPHENIX MVTX Experimental Background Task Force established with accelerator and detector physicists. Simulations are underway or planned to simulate several approaches:

- particle tracking under various scenarios
- particle tracking with relocated mask serving as momentum collimator
- addition of absorber material close to MVTX (FLUKA simulations)

Note: realignment of sPHENIX beam pipe not under consideration at this time.

See next two presentations by K. Hock (on RHIC Run-24 experience) and A. Drees (with Task Force update)

RHIC Run-24 Availability

Reliability - operation during summer months

Experiment readiness led to accelerator operations during the summer (Run-23 and Run-24).

Concerns and mitigation plans detailed in 2022 RHIC Science & Technology Review:

Concerns	Heat	Many support buildings not equipped to operate with sustained high temperatures Many unique AC systems
	Humidity	Reduced cooling tower efficiency, increased load on AC equipment Condensation issues
	Power	More frequent power dips and/or outages (storm related), possible brown-outs
	Air Conditioning	Aging equipment, some obsolete controls and parts
Mitigation	Maintenance • ensure existing systems are operable at full capacity • verify existing AC spares inventory (9 portable units, 6 portable high-volume fans)	
	AC ductwork modifications	
	New procurements • spare AC systems for RHIC alcoves (5) • portable AC units for RHIC service buildings (6) for power supply quench detection racks	

RHIC Run-23: accelerator availability impacted by air conditioning (AC) availability in building containing RHIC main magnet power supplies.

RHIC Run-24: strengthened mitigation efforts (next slide), AC tech support, availability tracking efforts

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RHIC Run-24 operations not held off by AC

RHIC Run-25: margin for error will be smaller – working to improve on mean time to repair.

Recent and Future RHIC Run Air Conditioning System Repairs and Upgrades

D. Chan

Completed Repairs during RHIC Run

- 1000P - condenser Fan Replacement
- 1002A - Thermostat Failure
- 1006 - STAR Control Room – System Replaced
- 1008IR - Condenser Fan and Blade Replacement
- 1009A - Refrigerant Leak
- 1002D, 1002F, 1005E, 1007W, 1010A, 1010B - Bard Unit Failures
- sPHENIX – Chiller Coil Replacement, Electrical grounding of IR Split Unit and sPHENIX – Gas Mixing House AC Unit
- 1012 – 50 ton package unit failure, split AC unit
- 1004A – split AC unit
- 1006 – 200 ton chiller
- 1004B – control room and high bay AC units
- 1006 – rooftop chiller

Completed Replacements

- E18, A18, B18, 1002 Bard Units
- 1006 Control Room

Upcoming RHIC Maintenance Replacements

- 1007W, 1005E – Bard Units
- 1004A – 75 Ton Package Unit
- 1004B – 50 Ton Package Unit
- L18 – 12.5 Ton Package Unit
- ~ 15 alcove split AC units

RHIC Run 25/26 Preparation

- Check existing spare parts inventory to replenish those used in Run-24
- Procure contract to ensure availability of larger capacity AC systems with portable generators (May – Oct 2025)

1004A Rental AC Unit

1004A Portable AC Unit

1008 AH Portable AC Unit

1004B Replacement AC

1012A Rental AC Unit

1004B 2nd Unit

911 Rental Chiller

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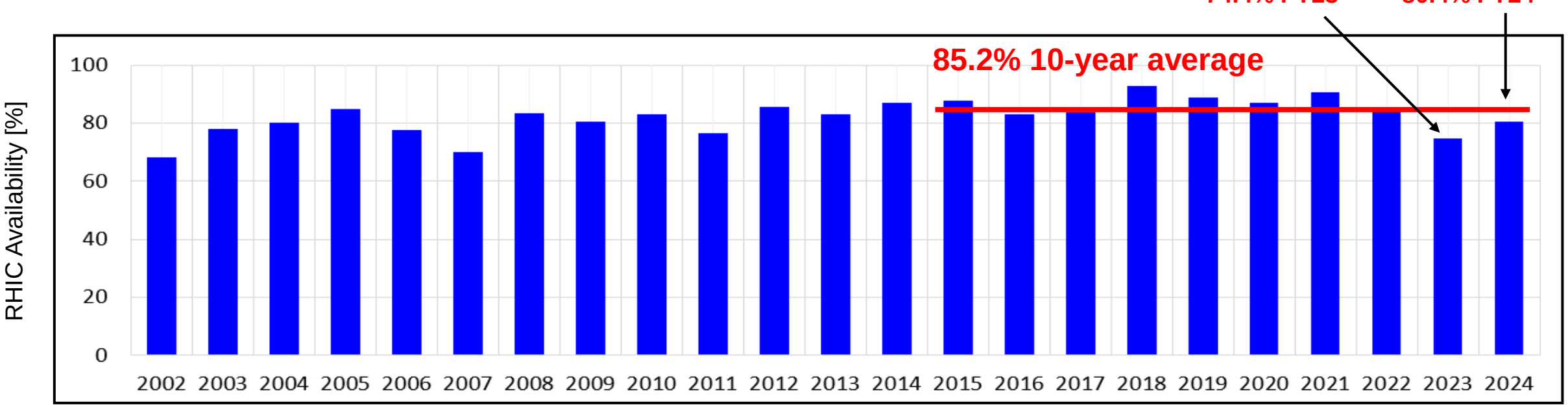
C. Naylor

RHIC Availability



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

RHIC Run FY24: **80.4%**
Average over last 10 years: **85.2%**

Availability primarily impacted by environmental factors (heat, humidity, storm-related issues) in Run 2023 and by summer storm-related issues in Run 2024.

Availability goal met in FY24.

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Preparations for Run-25/26

Beam User Requests (presented to NPP PAC, 7-8 Nov 2024)

sPHENIX

J.Haggerty "sPHENIX Summary and Run 25 Plan"

sPHENIX Physics Target in Run-25: **7 nb^{-1} (50B events)**		
Collision Species	Cryoweeks	Projected luminosity, $\|z\| < 10$ 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
If Au+Au luminosity target is met, ordered priority list for additional running:		
Collision Species	Physics weeks	Projected luminosity, $\|z\| < 10$ cm
1. p+p 200 GeV	8	13 pb^{-1} sampled + 3.9 pb^{-1} streaming
2. p+Au 200 GeV	5	80 nb^{-1} sampled + 24 nb^{-1} streaming
3. O+O 200 GeV	2	13 nb^{-1} sampled + 3.9 nb^{-1} streaming

STAR

J.H. Lee "STAR Summary and Run 25 Plan"

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

Planning guidance for BURs: 20 or 28 week cryoweeks.
Plan to start RHIC Run-25/26 with Au+Au with 100 GeV beams.
NPP PAC will reconvene a few weeks after RHIC Run-25/26 start to further prioritize recommendations.

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Run 25/26 with 20/28 weeks Au+Au at 100 GeV/n

W. Fischer et al

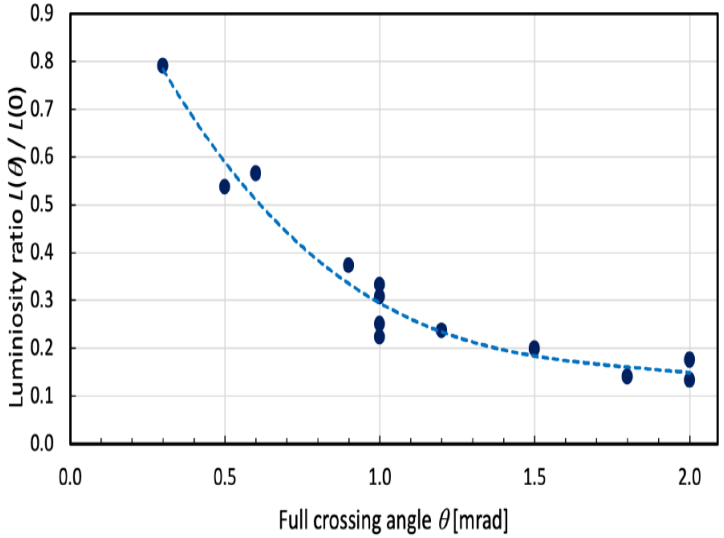
Note: 2 cryo-weeks were already spent to extend Run-24

RHIC Run start	0.5 weeks	Final cooldown to 4K
Set-up mode	2.0 weeks	RHIC re-commissioning and MVTX background studies
Ramp-up mode	0.5 weeks	8 hours/day for experiments
Data taking for physics	14.5 / 22.5 weeks	24/7 operation for sPHENIX and STAR
Controlled turn-off	0.5 weeks	End of run after 18 / 26 weeks

Demonstrated and projected luminosities for 100 GeV/n Au+Au runs

Parameter	Unit	FY2007	2010	2011	2014	2016	2023	2025E
No of bunches k_b	…	103	111	111	111	111	111	111
Ions/bunch, initial N_b	10^9	1.1	1.1	1.3	1.6	2.0	1.65	1.75
Envelope function at IP β^*	m	0.85	0.75	0.75	0.70	0.70	0.70	0.70
Beam-beam parameter ξ/IP	10^{-3}	-1.7	-1.5	-2.1	-2.5	-3.9	-3.2	-3.4
Initial luminosity L_{init}	**10^{26} cm^{-2}s^{-1}**	**30**	**40**	**50**	**80**	**155**	**101**	**115**
Average/initial luminosity	%	40	50	60	62	56	56	60
Average store luminosity L_{avg}	**10^{26} cm^{-2}s^{-1}**	**12**	**20**	**30**	**50**	**87**	**44**	**68**
Time in store	%	48	53	59	68	65	44	50
Max. luminosity/week ($\theta = 0$)	μb^{-1}	380	650	1000	2200	3000	1300	2300
Min. luminosity/week ($\theta = 0$)	μb^{-1}							1300

Measured lumi ratio with crossing angle



Planning basis: 4K cooldown starting 24 Mar 2025.

Major Shutdown Activities Prior to Run – 25/26

P. Sampson

Ion Sources

- EBIS work for RHIC Run-25 with high-intensity Au
- LION source installation

LINAC

- First full LINAC maintenance since 2019
- Refurbish Bldg. 930 backup chiller; air handlers (continuing)
- ARR* preparations

AGS Booster

- Vacuum valve replacement and bake
- Gauge instrumentation replacements
- 911 chiller replacement (supplies Booster RF cavities)
- LLRF upgrades (continuing)
- ARR* preparations

AGS

- ARR* preparations
  - Lighting and legacy cable removals
  - Cable tray / trench remediation (continuing)

RHIC

- No major accelerator upgrades planned
- Address sPHENIX “auto-recovery” events
- Address higher He leak rate identified in Run-24
- 56 MHz cavity (commissioning in Run-24)
- “Early removals” for EIC

Sitewide

- Possible tower 7 Motor Control Center and Switchgear upgrade
- Main Feeder MPO upgrades to continue
- High tension wire pole replacement
- Alternate feed upgrade
- Temple Place upgrades

**ARR = Accelerator Readiness Review (DOE process to verify safe commissioning and operation of accelerators)*

Focus on EBIS preparation, sPHENIX “auto-recovery” events, ARRs, and early removals for the EIC.

Extended EBIS

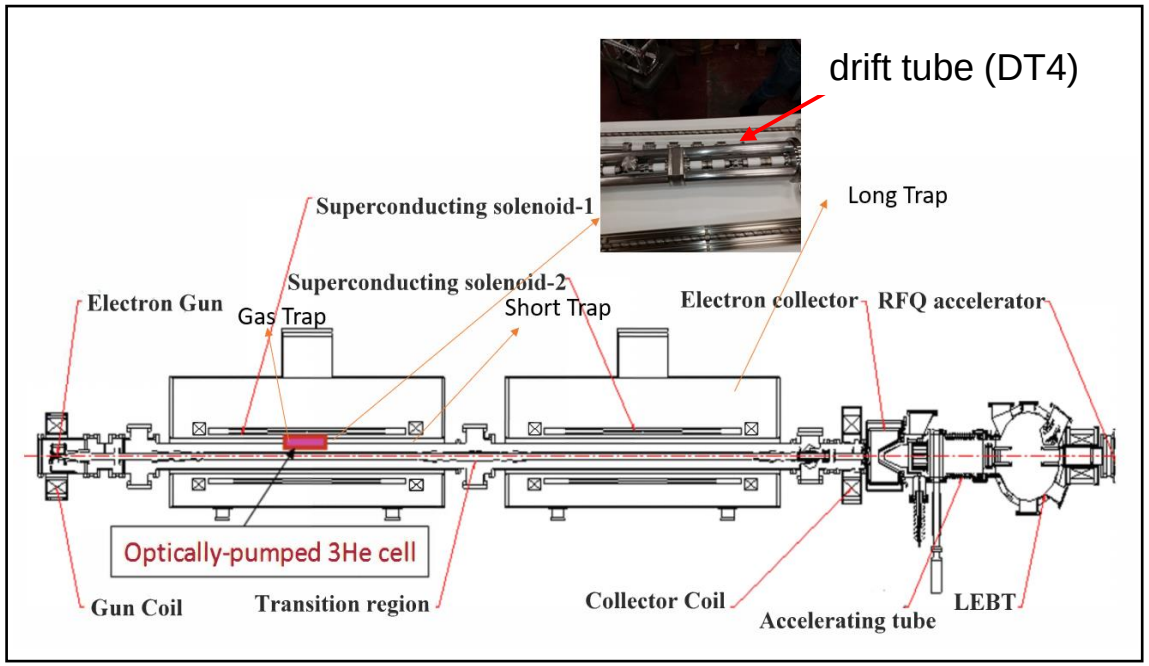
E. Beebe et al

Goals - improvements over EBIS

- ~ 40% more ion intensity
- 2 mA polarized $^{3}He^{++}$
- better performance with noble gases (gas cell)
- provision of ions from H to U

Status

- operating for NSRL (since Apr 2023)
- demonstrated all ion species (Jun 2023)
- past issues for high rep-rate operation:
  - voltage breakdown
  - low cathode lifetime (new manufacturer)
- cathode replaced (Nov 2024)
- drift tube replacement underway

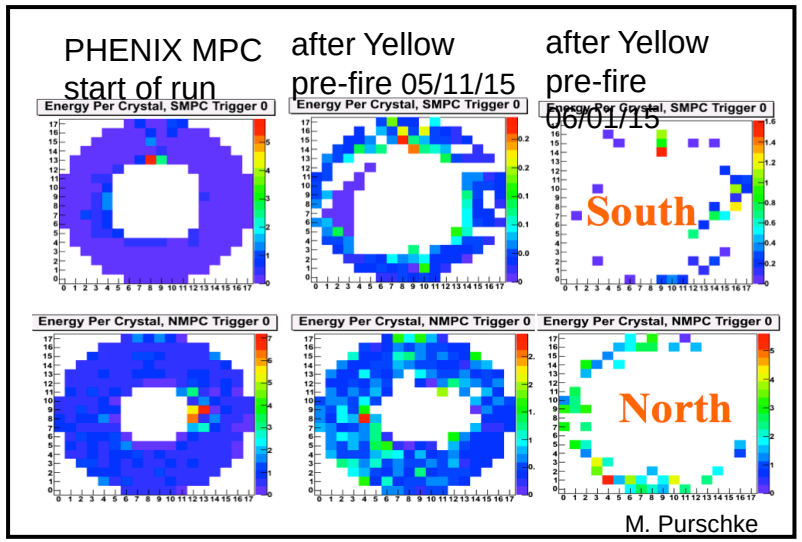


See presentation by E. Beebe

RHIC Machine Protection System (MPS) - update

A. Drees et al

- **Motivation**: protect sPHENIX and RHIC SC magnets
- **Issue**: RHIC abort system thyratrons occasionally fire spontaneously and asynchronously cause ~10 bunches to miss the beam dump
- **Solution**: added series mechanical relays (Run20) and compensated for added time delay of 6ms (~460 turns) via additional inputs to the existing RHIC MPS



Permit Input	Details	Status
BLM	Thresholds tightened	✓
BPM-MPS	36+8 per ring Orbit changes	✓ Run20
CPS-BPS	All 18 alcoves equipped Powering failures	✓ Run21
sPHENIX	New magnets	✓ Run23
NQ-BPS	143 power supplies Focusing failures	✓ Run-24

No abort kicker pre-fire mishaps since installation of series relays.
All known failure modes addressed with new inputs.

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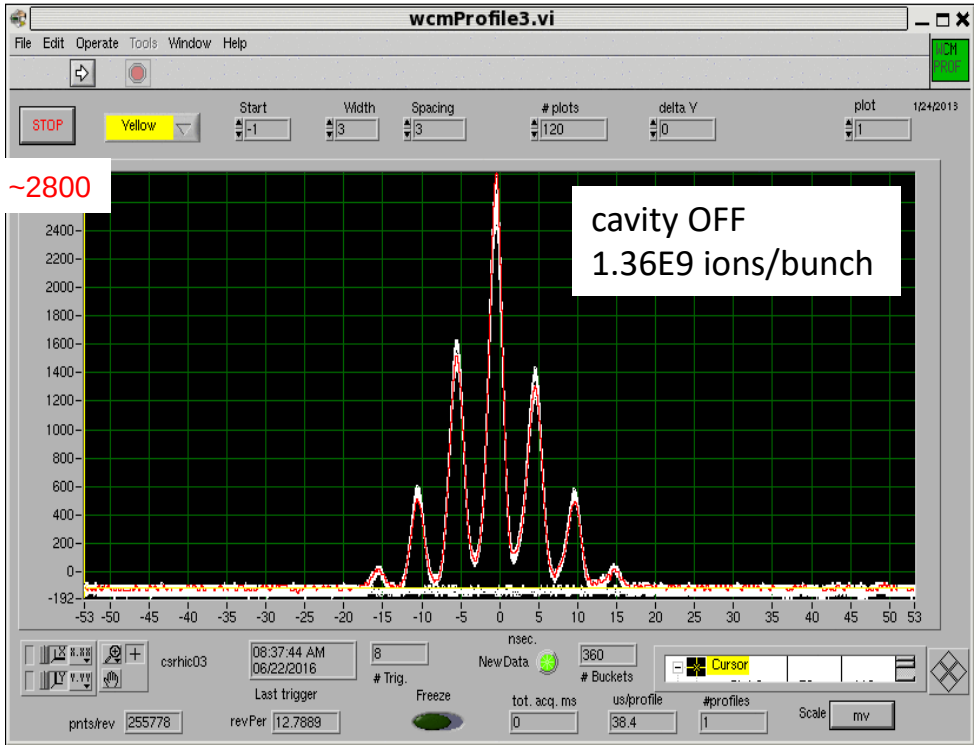
56 MHz cavity – effect on bunch distribution

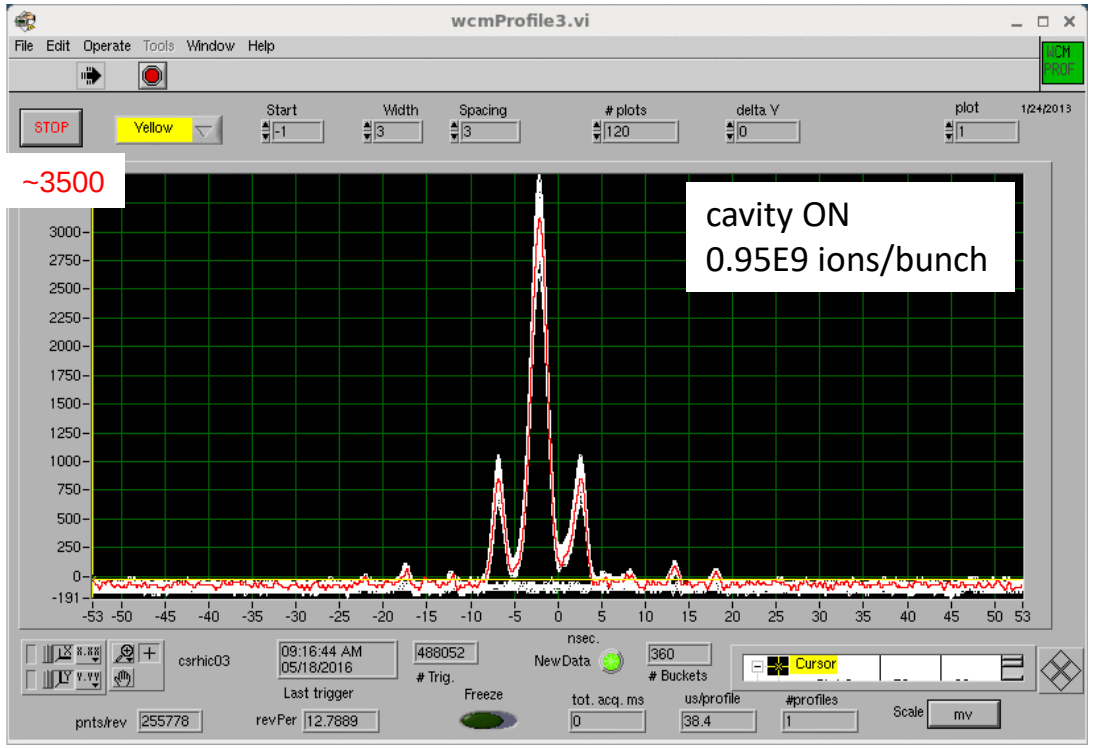
M. Blaskiewicz, K. Smith, K. Mernick, S. Polizzo, F. Severino, Q. Wu, A. Zaltsman

Increases luminosity in the detector's vertex

- increases peak current in primary bunch and reduces current in satellite bunches
- also enables smaller β^* at the interaction point due to reduced hourglass effect

Run16 (d+Au): longitudinal distribution (wall current monitor)



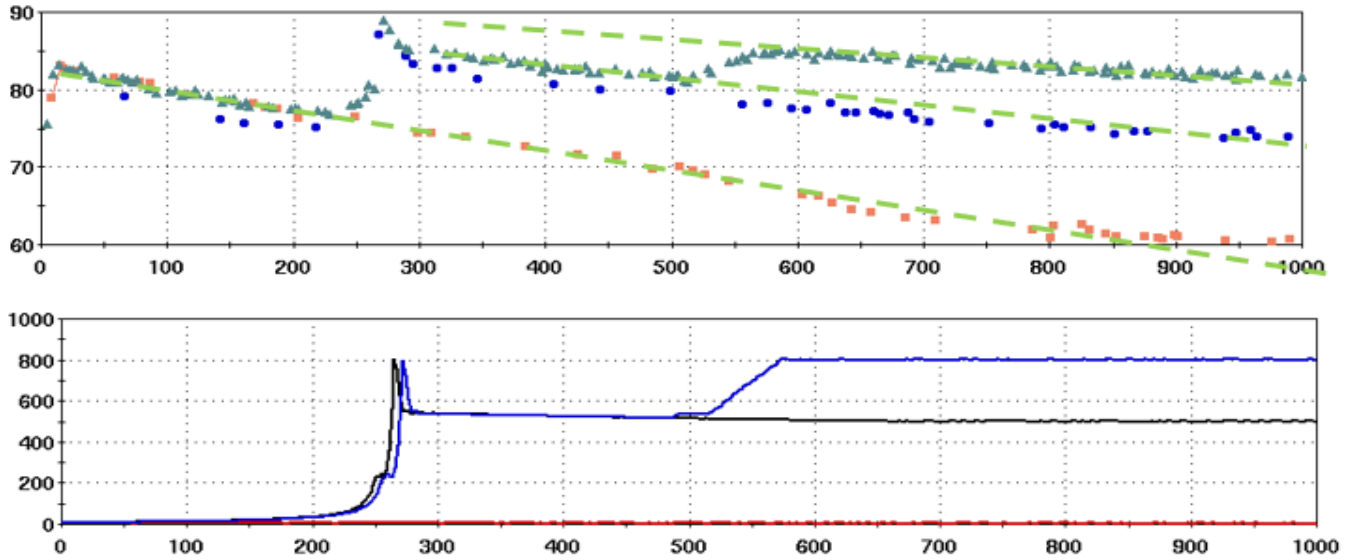


Peak current with 56 MHz SC cavity substantially higher even with lower bunch intensity

56 MHz cavity – effect on luminosity

Run16: >15% increase in luminosity in PHENIX (+/- 10 cm) vertex with the 56 MHz cavity

Qiong Wu et al



PHENIX 10cm / ZDC

56 MHz Cavity Voltage (kV)

Time (seconds after lumi-event)

< Run24 - 56 MHz cavity HOM coupler modified

Run24 - cavity reinstalled and commissioned up to 1.3E9 Au ions/bunch (limited by charge from pre-injectors), ~1.8E9 desired for Run25

- spectrum of HOMs found to be different and possibly insurmountable

Run25 - HOM spectrum to be reevaluated, cavity detuning allows for transparency

Note: luminosity projections (slide 15) do not include potential benefits from the 56 MHz cavity

Other Beam Time Requests

Beam Time Requests (beyond Au+Au)

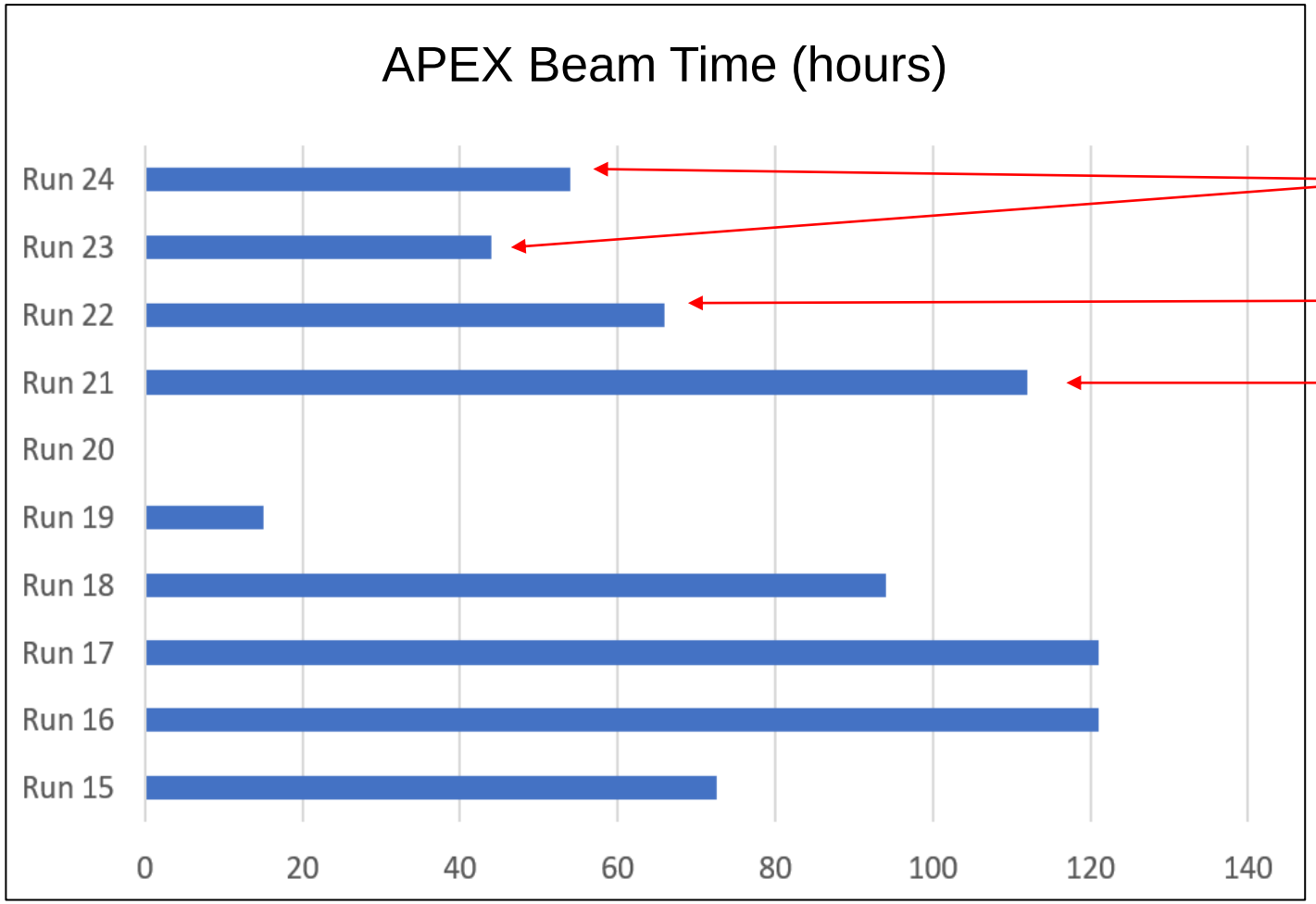
Proposed Activity	Duration	Relevance / Comment
APEX for EIC	up to 2 weeks	needed to inform EIC design
p+Au	5 weeks minimum	high priority per past PACs, cancelled in 2024 due to funding constraints
FXT at STAR	3 weeks	3 energies, 3 species, 3 targets (reference STAR BUR)
CeC	2-3 weeks	advancements in accelerator science

Note: RHIC Accelerator Safety Envelope (ASE), documenting verifiable bounding conditions, physical and administrative requirements, and credited controls to ensure safe operation and addressing accelerator-specific hazards, expires 31 Dec 2025

Accelerator Physics Experiments (APEX) - Overview

RHIC Retreat, Nov 2024 - M. Minty

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



experiments to inform EIC design

experiments to inform EIC design and beam cooling studies

focus: beam cooling studies

(minimal APEX during BES-II and pandemic)

APEX workshop held March 2024 https://indico.bnl.gov/event/22322/. Featured:

- comprehensive list of EIC-related APEX requests for 2024/2025 (next slide)
- detailed plans for experiments

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APEX 2024/2025 Objectives

Topic	#Studies	requested Hours	Relevance for EIC
Collective Effects	2	14	confirm vacuum design
Flat Beam	3	84	Feasibility flat beam
Instrumentation	3	14	Confirm concepts & designs
Dynamic Aperture	2	6	Confirm simulations
Transition Crossing	3	24	Ensure concept
Hadron Polarization	4	46	Confirm simulation and design
Beam* Cooling	9	133	Confirm cooling feasibility, simulation and design
Beam Optics	2	18	Backup simulations
Radial Shift	1	32	Confirm feasibility of large beam radial offset in HSR

*coherent electron cooling, electron cooling, and stochastic cooling

Total of 29 studies, 371 hours @ 46.4 shifts, 15.5 days, 2.2 cryo weeks

APEX 2024/2025

Y. Luo, H. Huang

Run-24 APEX requests 123 hours (p), 56 hours (Au)
Run-24 APEX experiments performed 87 hours (p), 0 hours (Au)

Run-25 APEX requests (to date) 294 hours

Index	Experiment Title	Spokesperson (s)	Beam Time Request (hours)	Grade	Beam Species	Energy (GeV)
22-05	studies of electron-ion heating effect	S. Seletskiy	12	1B	Au	3.85
22-06	studies of ion beam lifetime in the presence of electron beam	S. Seletskiy	16	1B	Au	3.85
22-07	dispersive cooling	A. Fedotov	18	1B	Au	3.85
22-12	ramp to 255 GeV with polarized protons with working point near 1/3	G. Robert-Demolaize, Y. Luo	16	1B	p	255
23-01	test of BPM for energy-recovery linac	I. Pinayev	5	1B	Au	injection
23-02	IP8 optics tunning with crossing angle and short vertex	X. Gu	12	1A	Au	100
23-03	electron cooling of 26.5 GeV Au beam	V. Litvinenko	16	1A	Au	26.5
23-04	CeC plasma cascade amplifier experiment	V. Litvinenko	48	1A	Au	26.5
23-05	radial shift in RHIC using dipole field offset	G. Robert-Demolaize	32	1A	Au	100
23-08	loss response to cooling	M. Blaskiewicz	1	1A	Au	100
23-10	transition jump with reduced number of jump quadrupoles	H. Lovelace III, S. Peggs	8	1B	Au	ramp
24-02	global coupling measurement and correction based on turn-by-turn orbit	C. Liu, Y. Luo	6	1B	p/Au	injection & store
24-03	accelerating flat gold ion beams from 31GeV to 100GeV	Y. Luo	48	0A	Au	31, 100
24-08	beam-based Alignment for RHIC rings	M. Sangroula, C. Liu	6	1B	p	injection
24-11	study on IBS growth in presence of crab dispersion for flat beam	D. Xu	12	1B	Au	store
24-12	investigate beam-beam impact on hadron beam flatness	D. Xu	24	1B	Au	store
24-13	transition crossing with HSR screens	S. Verdu-Andres	8	1A	Au	ramp
24-15	recombination rate of the proton beam in the CeC cooling section	G.Wang	6	1A	p	26.7

The request for APEX beamtime exceeds planned allocations.
Run-25/26 APEX workshop planned in January 2025.

Summary

Summary

RHIC performance in RHIC Run-24: p↑+p↑ (24 weeks) and Au+Au (3 weeks) both at $\sqrt{s_{NN}}$ ~200 GeV

- Total of 27 cryo-weeks: 19 weeks + 6 week carryover from RHIC Run-23 + additional 2 weeks to be charged to RHIC Run-25.
- Prior to RHIC Run-24, all repairs (valve box and splice failures, DX magnet replacement) and re-installation of Siberian snake magnet were completed successfully.
- Accelerator operations for both p↑+p↑ and Au+Au evolved differently than expected; provided a wide variety of RHIC beam conditions for sPHENIX commissioning and for physics at STAR
- Achieved p↑+p↑ run goals for sPHENIX and STAR
- Achieved Au+Au run goal for STAR but not for sPHENIX due to emergent issue with MVTX auto-recovery events.
- Accelerator availability: fiscal year (p↑+p↑ run) met 80% target, operation during summer months (environmental controls) very successful yet impacted by storm-related power interruptions; 10-year average is 85.2%.

Planning for Run-25: Au+Au at $\sqrt{s_{NN}}$ ~200 GeV with other operating modes TBD and dependent on budget

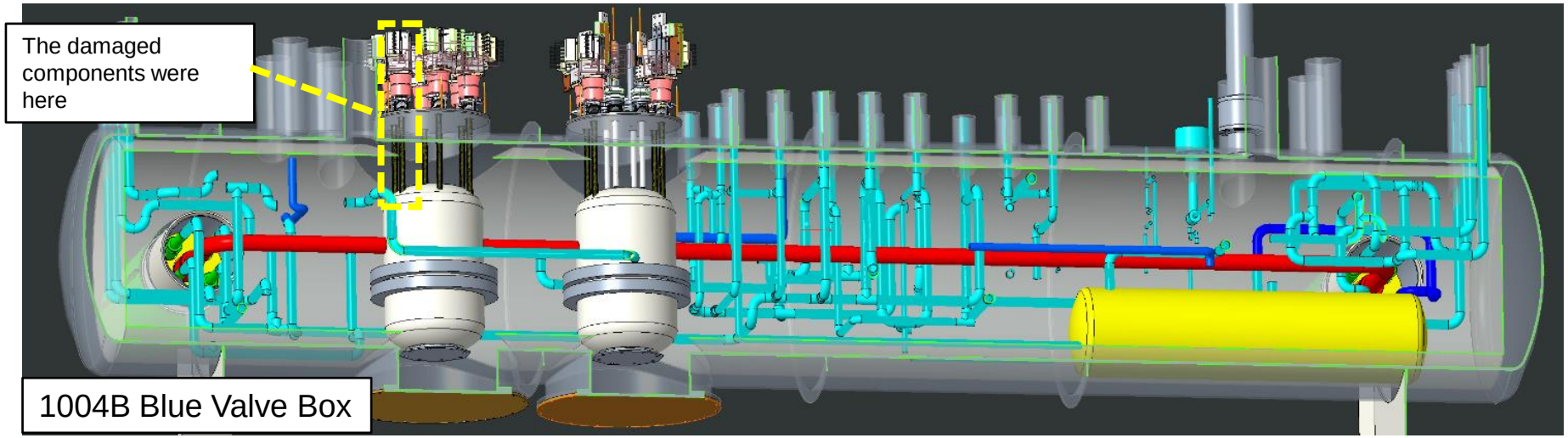
- Emergent issue with sPHENIX MVTX detector “auto-recovery events” a major concern, accelerator-based potential mitigation efforts under evaluation (next two presentations).
- Shutdown activities include EBIS preparation (Tandem as back-up), sPHENIX background mitigation, ARRs, early removals for EIC and preventative maintenance.
- Have multiple other beamtime requests prior to end of RHIC-era, possible operation in CY26 contingent on ASE extension/revision.
- The NPP PAC plans to reconvene a few weeks after RHIC Run-25 start to provide further recommendations.

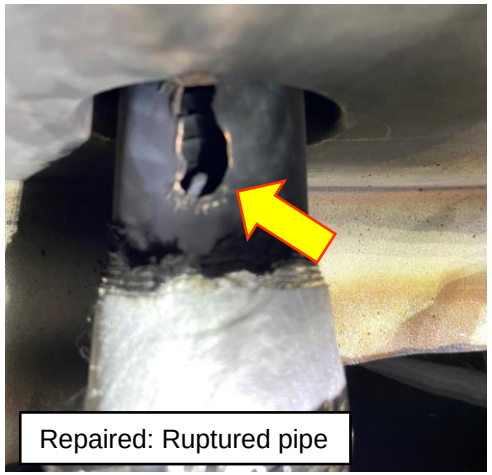
Supplementary Slides

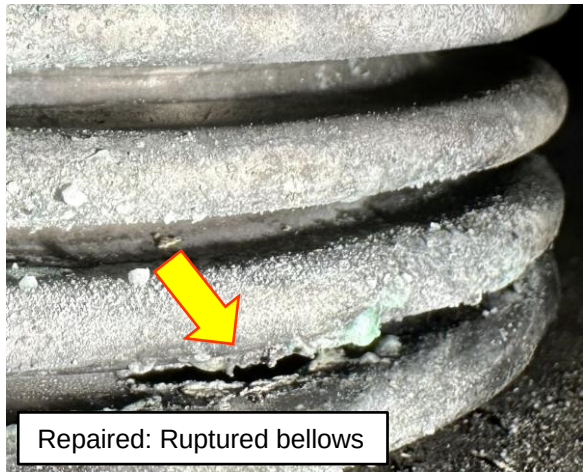
RHIC Run-24 repair work

R. Feder, C. Mi, J. Escallier et al

Failure of a magnet power supply 150A current lead in 1004B blue valve box (Aug 2023)
External review of causal analysis and engineering solutions (Nov 2023) https://indico.bnl.gov/event/20923/



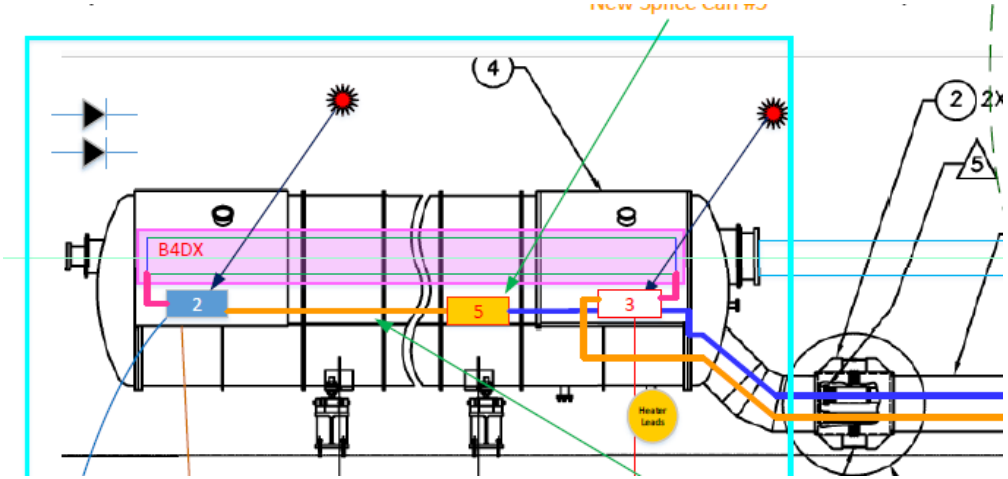




External review committee concurred with diagnoses and plans for repairs.

Downstream damage found at 4:00 cable splice joints and in the DX magnet, and later at the B3Q8 diode
8-month recovery effort involving more than 40 people across many disciplines and departments.

C. Mi, R. Feder, et al



Repaired: sector 4 DX magnet

Repaired: SC splice joint at can #2

Repaired: SC splice joint at can #3

All repairs completed, RHIC ASE and USI (additional ODH controls) updated, all systems operating as expected.

RHIC Blue Snake Magnet

C. Atanasio, M. Hartsough, M. Milidantri et al

- Two Snake magnets damaged during Run-22 (13 Dec 2021, 12 Dec 2021).
- With strong support of SC Magnet Division, repair completed Jul 2023.
- Installed for RHIC Run-24.

Installed prior to Run-24, magnet fully functional and working as expected.