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

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C-AD MAC-21
16 – 18 December 2024

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Outline

40 minutes
26 slides minus 7 transitions → 19 slides

RHIC Performance in Run-24

- Timeline and achievements
- Accelerator availability

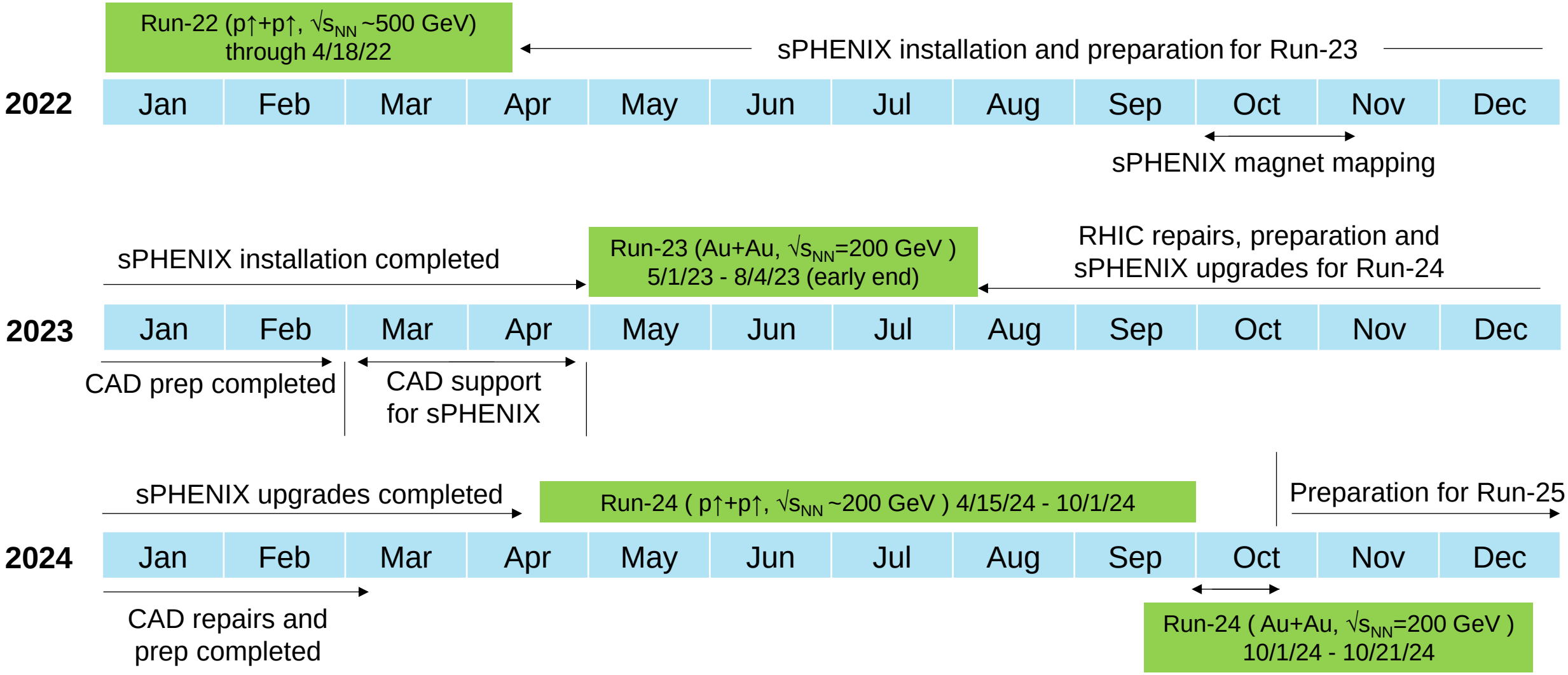
Planning for Run-25

- 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

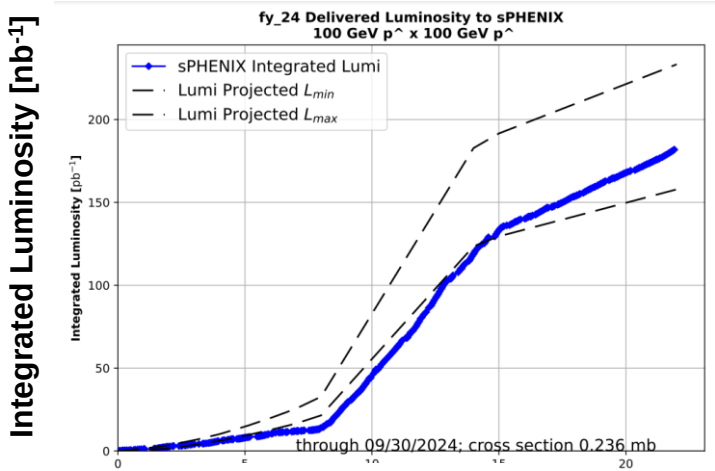
Performance Summary, (p↑+p↑, $\sqrt{s_{NN}}$ ~200 GeV)

- All repairs reported at last MAC (feedthrough, DX magnet replacement, USI upgrade, refined cryo controls, and re-installation) 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.

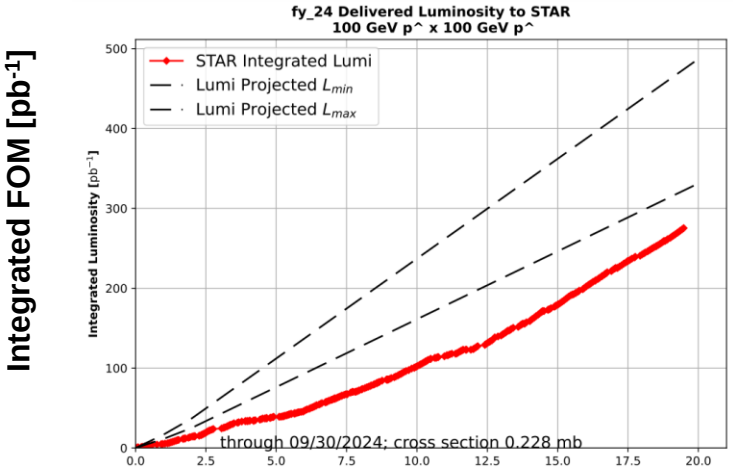
Performance Summary, (Au+Au, $\sqrt{s_{NN}}$ ~200 GeV)

- Priority (NPP PAC) to ensure sPHENIX readiness 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

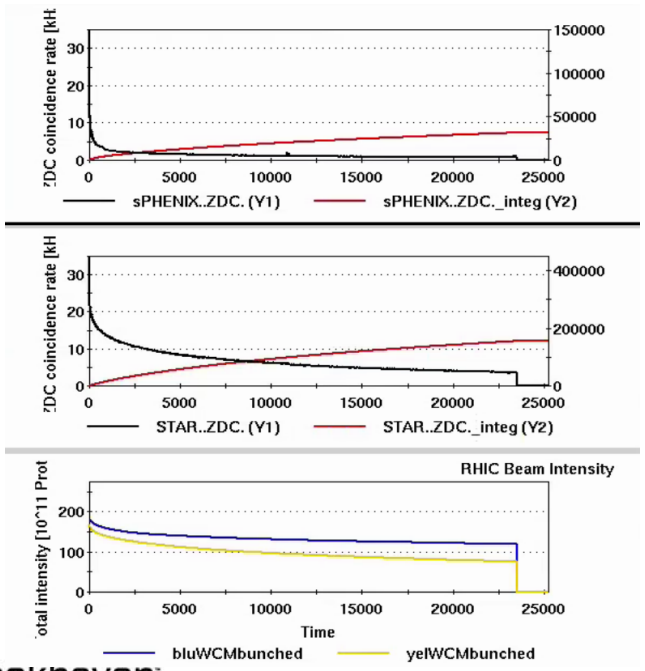
2024 | Apr | May | Jun | Jul | Aug

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

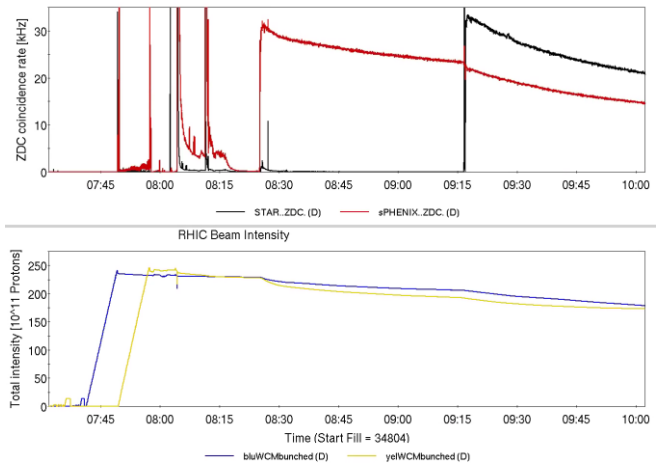
sPHENIX and STAR:
head-on collisions
(25 Jun – 13 Aug)

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

6/25/24

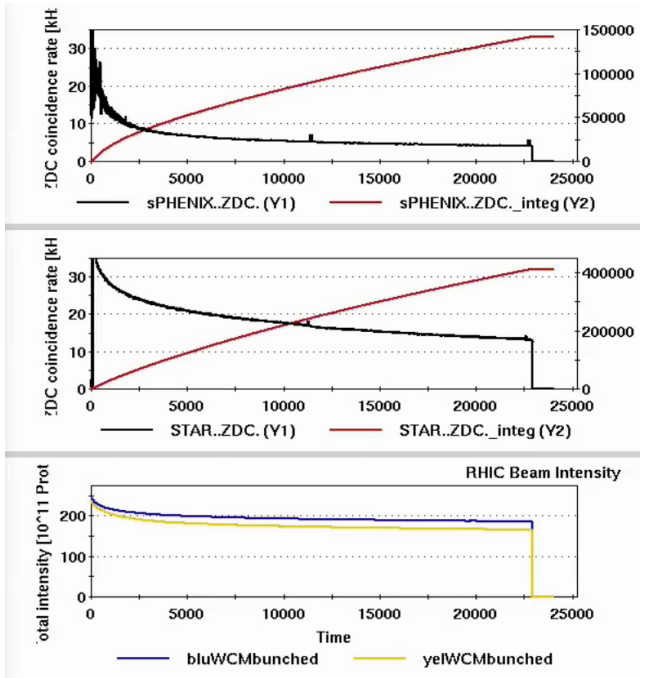


7/15/24



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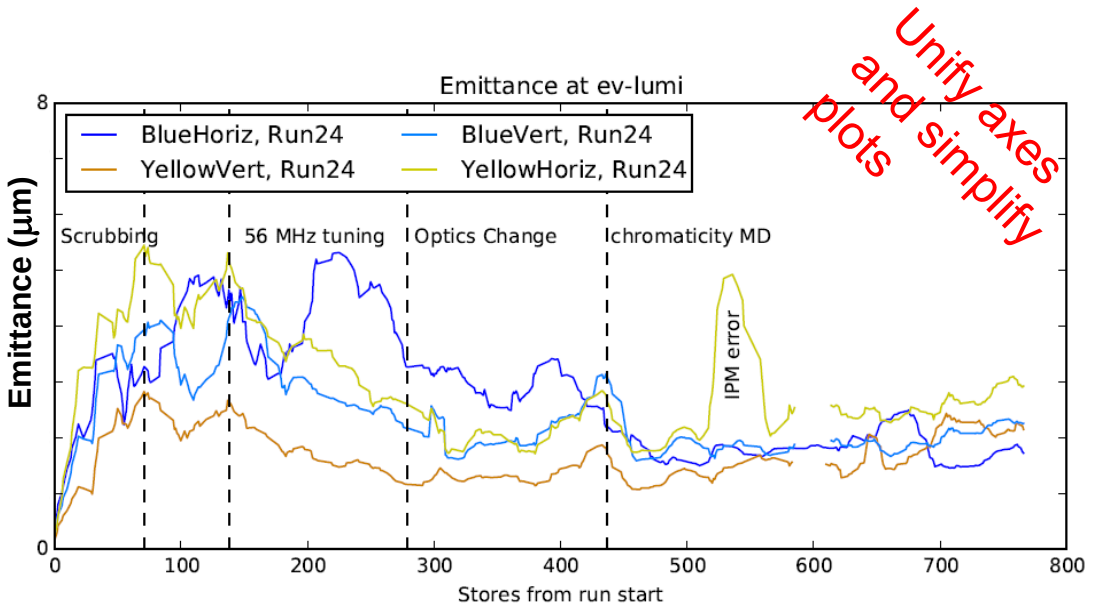
M. Minty C-AD MAC-21 (16-18 Dec 2024)

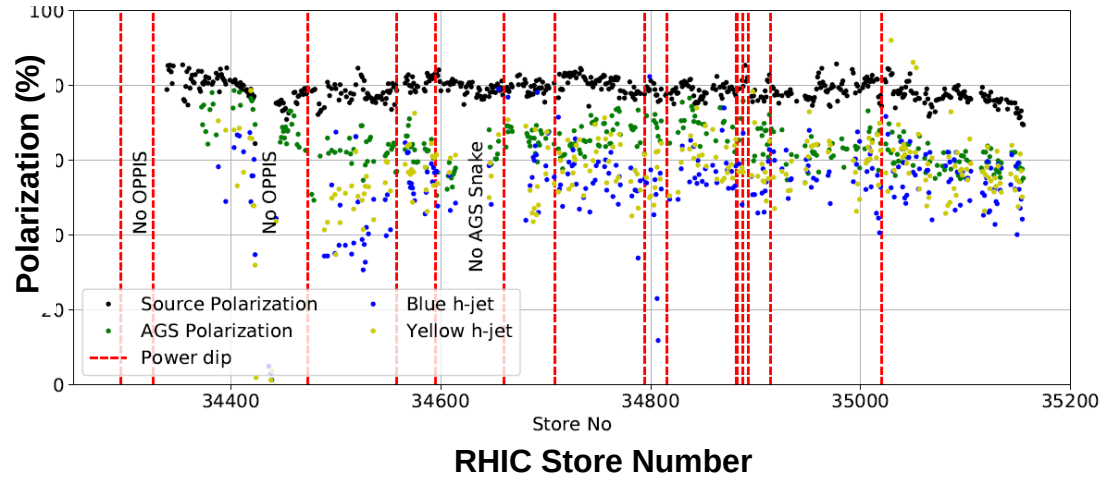
Emittances and Polarization

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.

Working hypothesis: off-momentum Au ions lost on aperture and fragments reach sPHENIX MVTX

Note: stray particles difficult to detect (MVTX auto-recovery rate upsets not correlated with signals in any RHIC beam loss monitors)

C-AD Task Force established (led by A. Drees) 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)

Update

Realignment of sPHENIX beam pipe not under consideration at this time.

Further details to be provided in next two presentations.

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 (for AC) will be smaller – need to improve on mean time to repair.

2024 RHIC Run Air Conditioning Systems

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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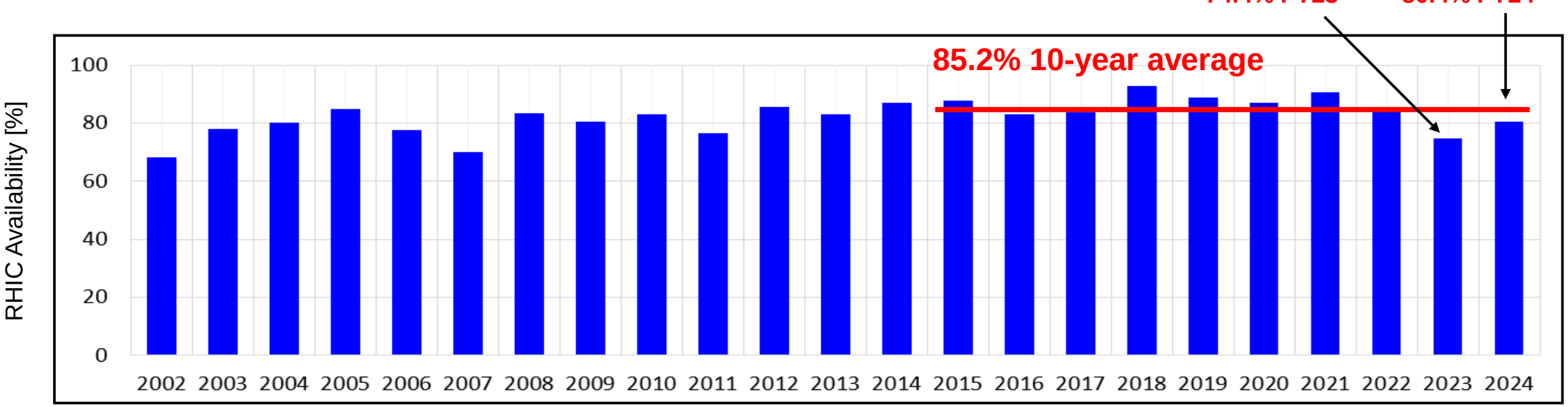
C. Naylor

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 evaluate further priority recommendations.

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

W. Fischer et al

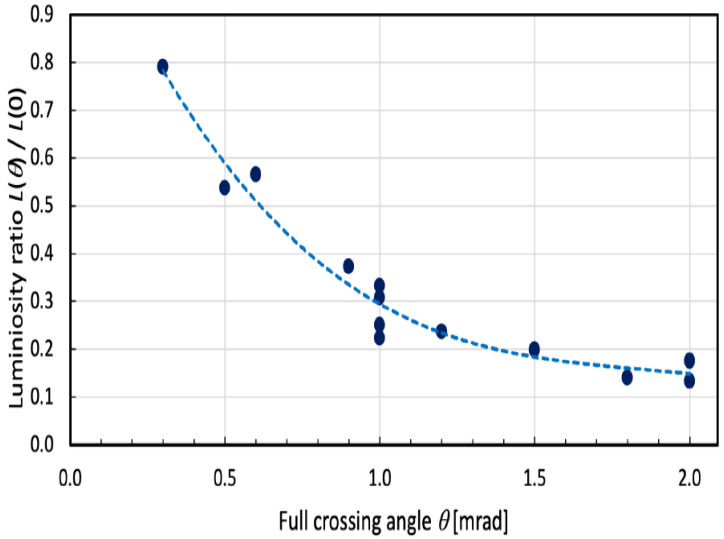
Note: 2 cryo-weeks were already spent to extend Run-24

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

Table 1: Demonstrated and projected luminosities for 100 GeV/nucleon 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: 22 week shutdown with 4K cooldown starting 24 Mar 2025

Note: NPP PAC recommended considering a shorter shutdown, further coordination with experiments needed.

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Major Shutdown Activities Prior to Run – 25/26

P. Sampson

Ion Sources

- EBIS work for RHIC Run-25 with high-intensity Au (see later slides)
- LION source installation

LINAC

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

AGS Booster

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

AGS

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

RHIC

- No major accelerator upgrades planned
- Address higher He leak rate identified in Run-24
- 56 MHz cavity (commissioning in Run-24)
- “Early removals” for EIC as schedule and staffing allow (less than planned, focus on E-Lenses)

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

Focus on EBIS preparation, IRRs and ARRs, and early removals for the EIC.

Extended EBIS

E. Beebe

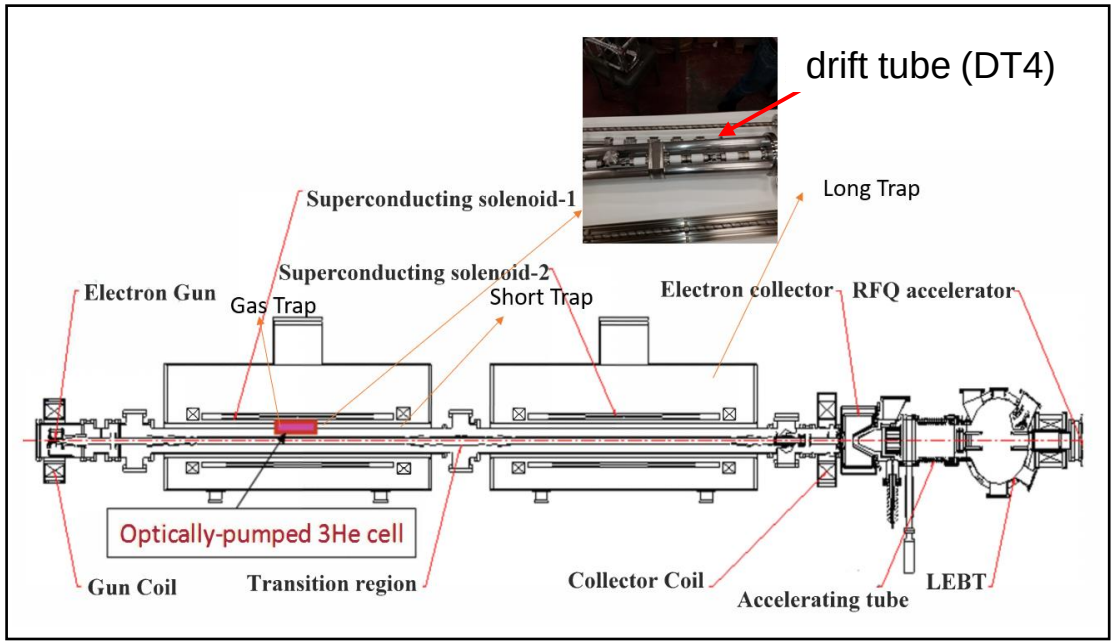
Goals: improvements over EBIS

- ~ 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)
- outstanding issues for high rep-rate operation:
  - low cathode lifetime (new manufacturer)
  - voltage breakdown in (smaller diameter) drift tubes (DT4 and DT6)

Parameter	Required for run25	Achieved
Electron current	> 8 A	6.7 A
# Au ion single Pulse @ Xf108	1.2 E9	1. E9
# Au ions 12 Pulse mod @ Xf 108	1.2 E9	8.E8 (stable for 10-20 min only)



Cathode replaced (Nov 2024), increase DT4 and DT6 diameter (if needed)
Plan B: provision of Au beams from Tandem (as in RHIC Run-23).

update

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56 MHz cavity – effect on bunch distribution

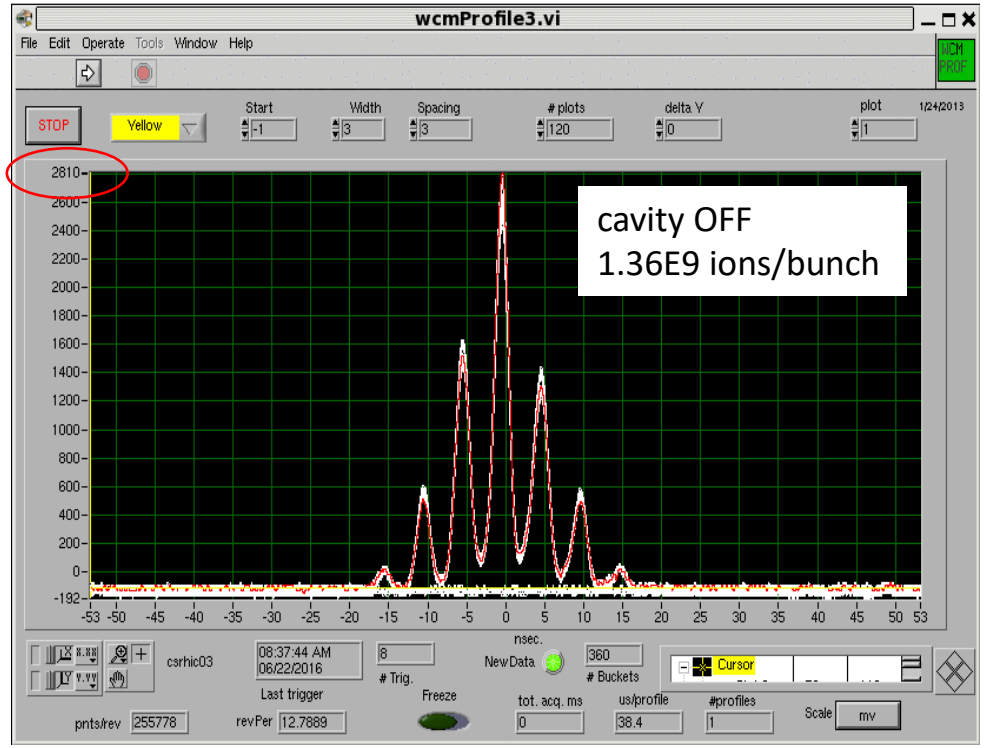
M. Blaskiewicz, K. Smith, K. Mernick, S. Polizzo, F. Severino, Q. Wu, A. Zaltsman

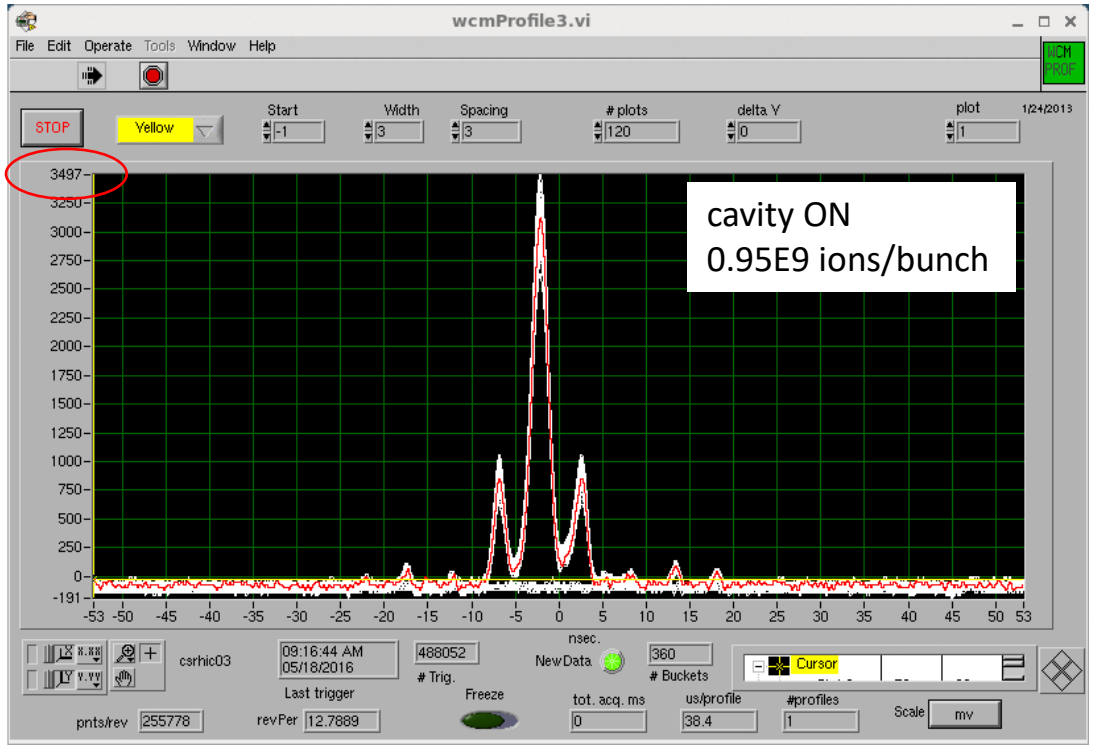
Increases luminosity in the detector's vertex

- 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

Update pending outcome of meeting on 12/5/24

Demonstrated improvement in longitudinal focusing during run in 2016 (d-Au) Yellow ring (Au) wall current monitor





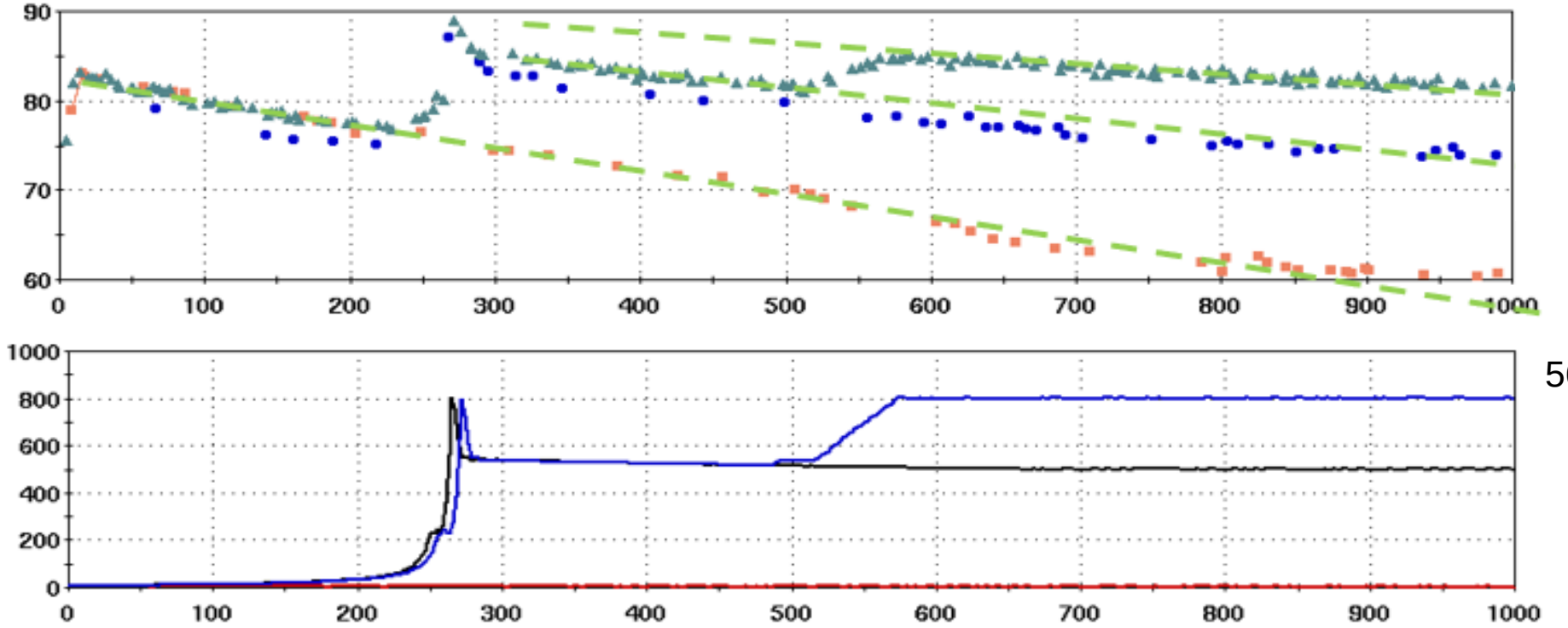
Peak current with 56 MHz SC cavity substantially higher even with lower bunch intensity

56 MHz cavity – effect on luminosity

Qiong Wu et al

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

Run-16 with 56 MHz SC RF cavity OFF and ON
Blue: 1.95 E9 deuterons / bunch, Yellow: 2.09E9 Au ions/bunch



PHENIX 10cm / ZDC

56 MHz Cavity Voltage (kV)

Time (seconds after lumi-event)

56 MHz cavity recommissioned during Run-24 up to 1.5E9 Au ions/bunch (next year aim for 1.8E9)

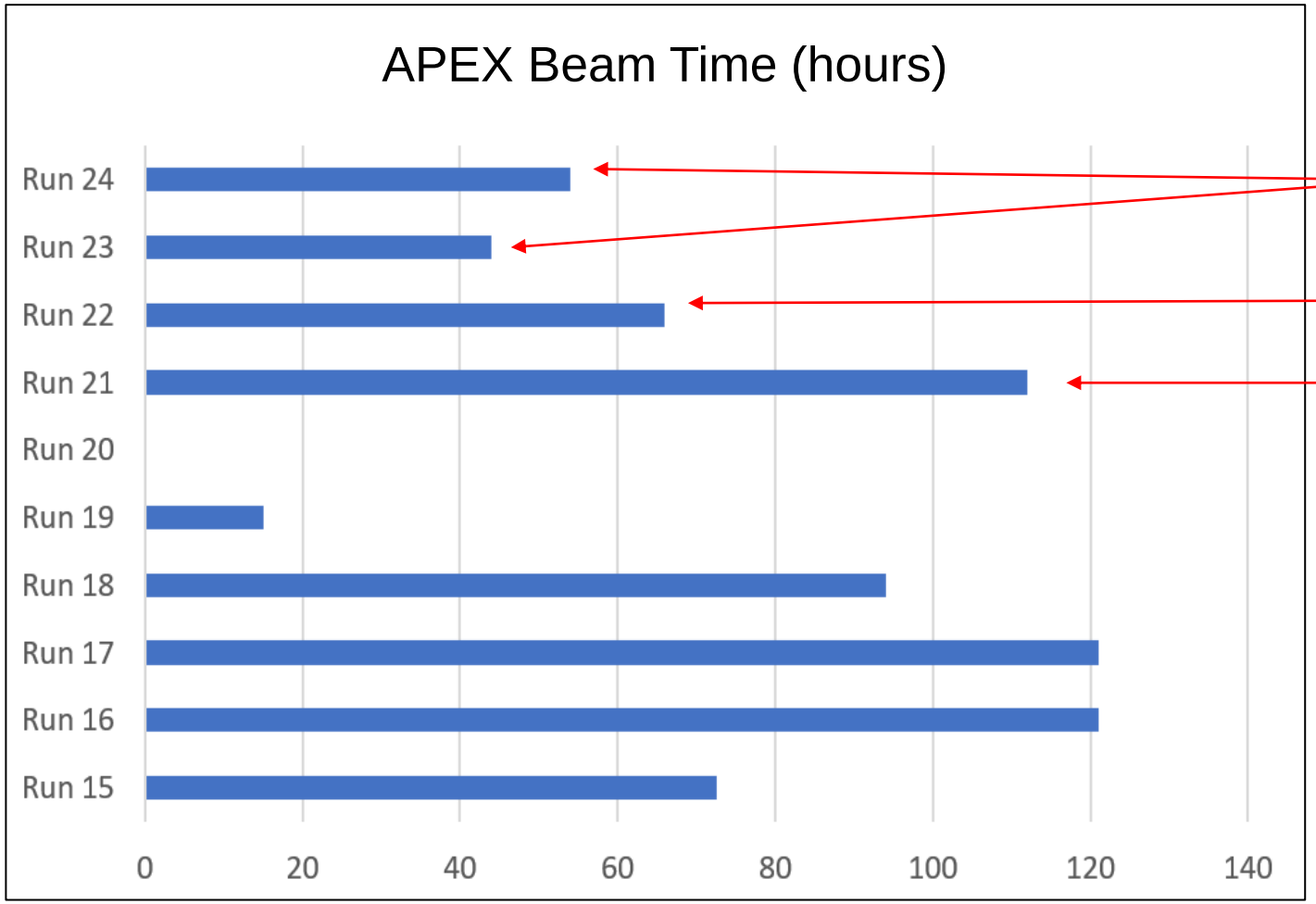
Other Beam Time Requests

Beam Time Requests (not including BURs)

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 ASE expires 12/31/2024 (any update on plans to extend or redo?)

Accelerator Physics Experiments (APEX) - Overview



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)

Replace with beam time requests known to date

Assumptions Run-25/26 (standard practice reminder)

- no APEX before physics program started (assume 2 weeks for this in Run 25/26)
- one APEX session = 15 hours APEX +1 hour back-to-physics
- APEX takes place every other week
- all experiments reviewed and prioritized by APEX acceptance committee

The request for APEX beamtime exceeds planned allocations.
Run-25/26 APEX workshop planned XX/XX/XX.

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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

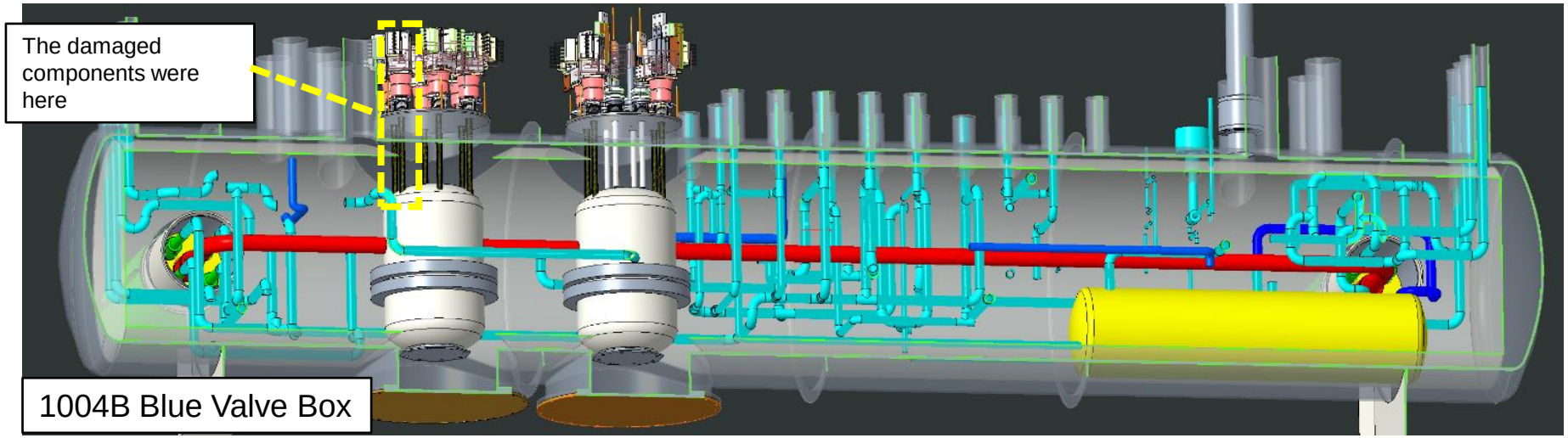
- Emergent issue with sPHENIX MVTX Detector “auto-recovery events” a major concern, accelerator-based potential mitigation efforts under evaluation (next two presentations).
- Shutdown activities include EBIS preparation (Tandem as back-up), 56 MHz cavity?, ARRs, early removals for EIC and preventative maintenance.
- The NPP PAC plans to reconvene a few weeks after RHIC Run-25 start to provide further recommendations.
- Have multiple other beamtime requests prior to end of RHIC-era, possible operation in CY26 contingent on ASE extension/revision.

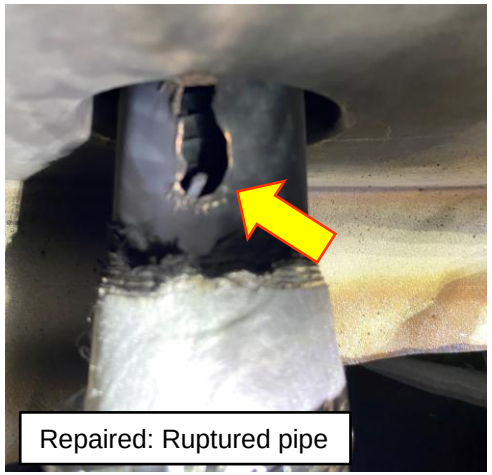
Supplementary Slides

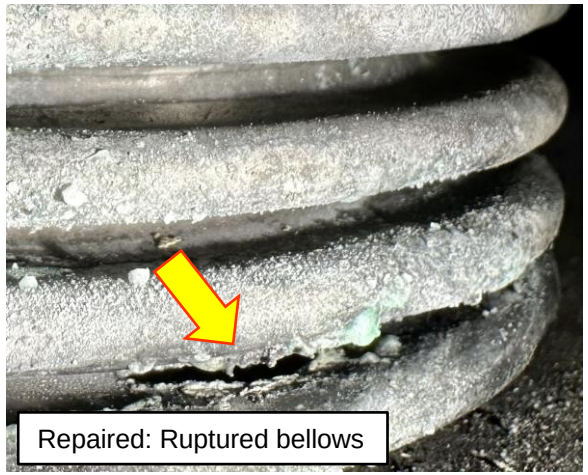
RHIC Run-24 repair work

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/



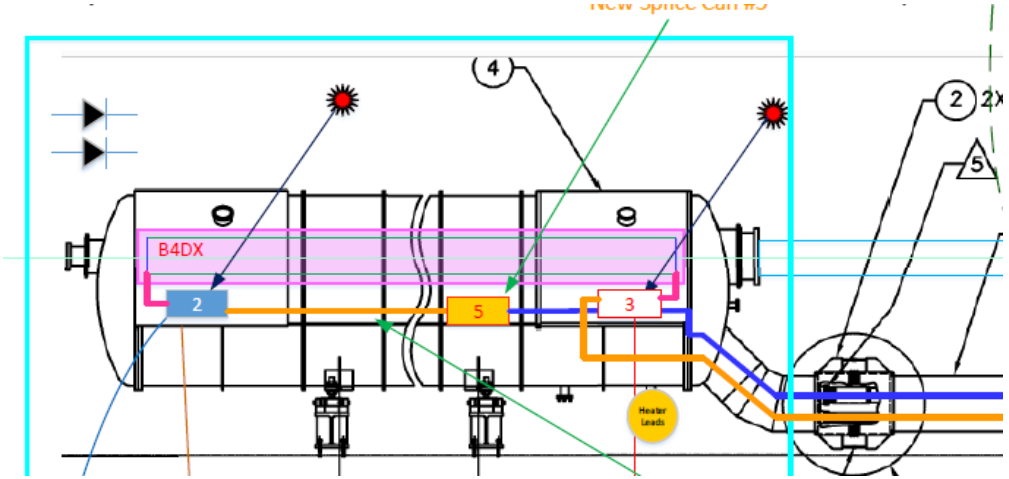




External review committee concurred with diagnoses and plans for repairs.

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.