

# RHIC Performance and Repair Plans

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C-AD MAC-20  
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# Outline

## RHIC Performance

- RHIC Run 2023 timeline and achievements

- RHIC accelerator availability

- Operational challenges

## APEX (Accelerator Physics Experiments) during Run 2023

## RHIC Repair Plans for Run 2024

- Event on 1 August 2023

- Causal analysis and external “RHIC Recovery” review

- Repair status

## Summary

# RHIC Performance

# RHIC Run-23 timeline and achievements

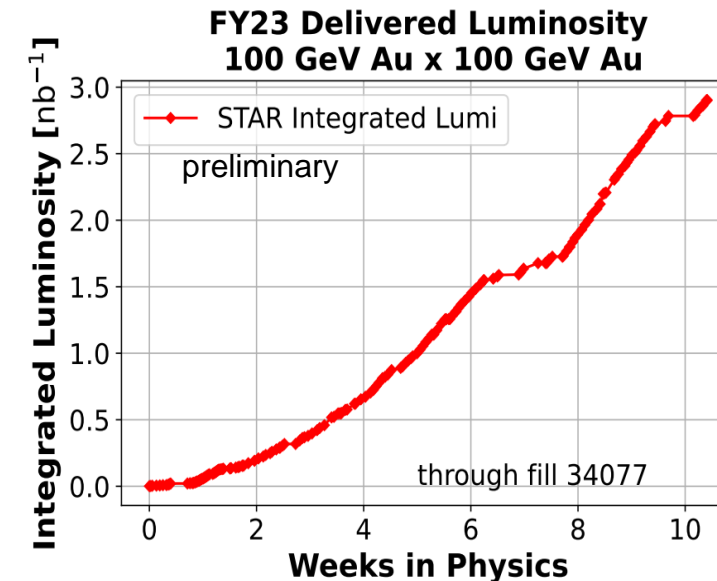
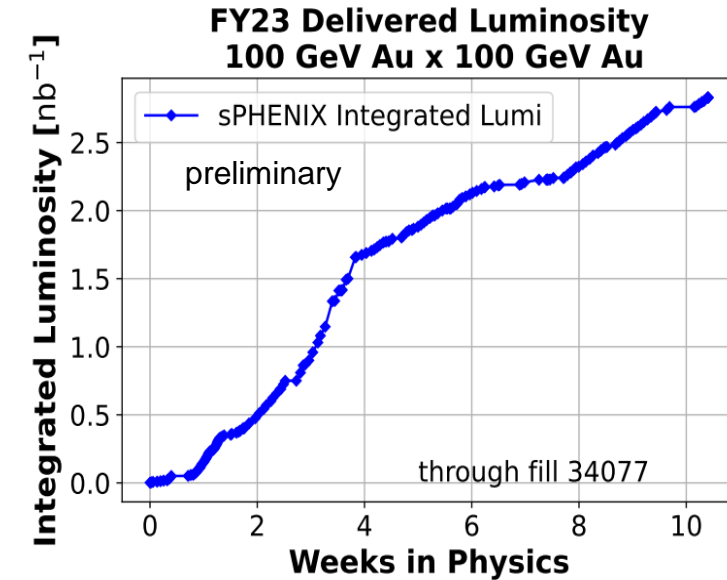
Run Coordinator:  
Travis Shrey

## Timeline for sPHENIX commissioning with Au+Au (100 GeV/beam)

- sPHENIX MIE PD-4 project approval 12 Dec 2022
- sPHENIX integration and readiness reviews xx Xxx 2023
- RHIC 4K cooldown 5 May 2023
- First beam injection 8 May 2023 (Blue), 10 May 2023 (Yellow)
- sPHENIX commissioning with beam 18 May 2023
- STAR physics “declared” 20 May 2023
- APEX and maintenance alternating weeks starting 24 May 2023
- Blue Ring 1004B valve box failure 1 August 2023
- End of RHIC Run 2023 4 August 2023

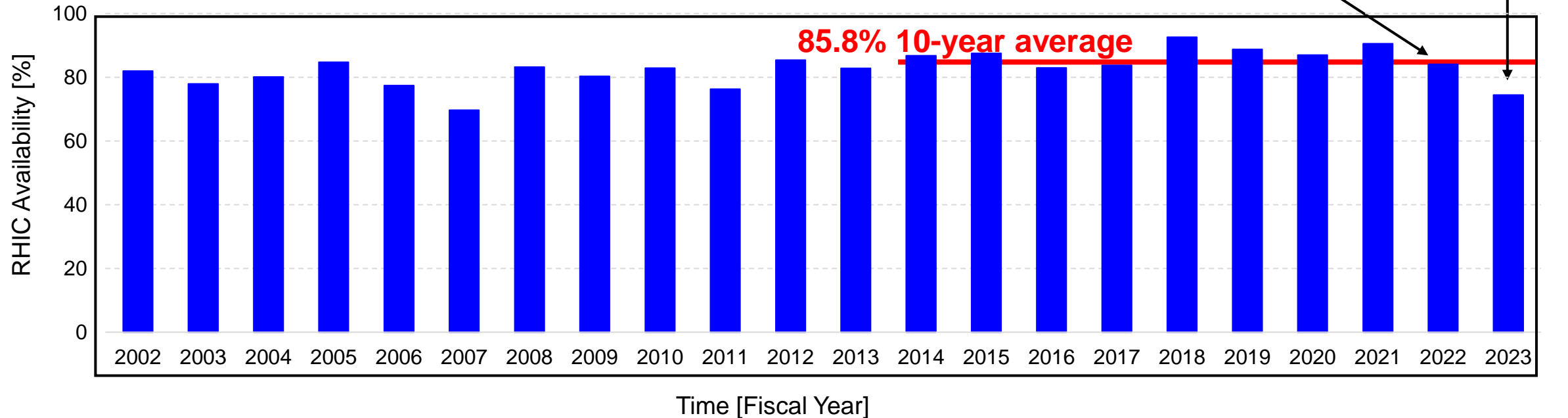
## Achievements

- Provided wide variety of RHIC beam conditions (number of bunches, bunch intensities, up to 2 mrad crossing angles), met sPHENIX commissioning requirements per sPHENIX schedule.
- Provided collisions also for STAR with 1 mrad crossing angle and luminosity-leveling; ~30% of minimum-bias goal (Run23+25) collected.



# RHIC accelerator availability

courtesy C. Naylor



Availability = beam time / scheduled beam time

(denominator excludes scheduled maintenance)

Availability goals: 82.5% < FY20,  
85% FY21-FY22  
82.5% FY23

RHIC Run 2023: 72.7%

Average over last 10 years: 85.8%

# Primary challenge for RHIC Run 2023: operation during summer months

From DOE 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	<ul style="list-style-type: none"><li>• ensure existing systems are operable at full capacity</li><li>• verify existing AC spares inventory (9 portable units, 6 portable high-volume fans)</li></ul>
	AC ductwork modifications	
	New procurements	<ul style="list-style-type: none"><li>• spare AC systems for RHIC alcoves (5)</li><li>• portable AC units for RHIC service buildings (6) for power supply quench detection racks</li></ul>

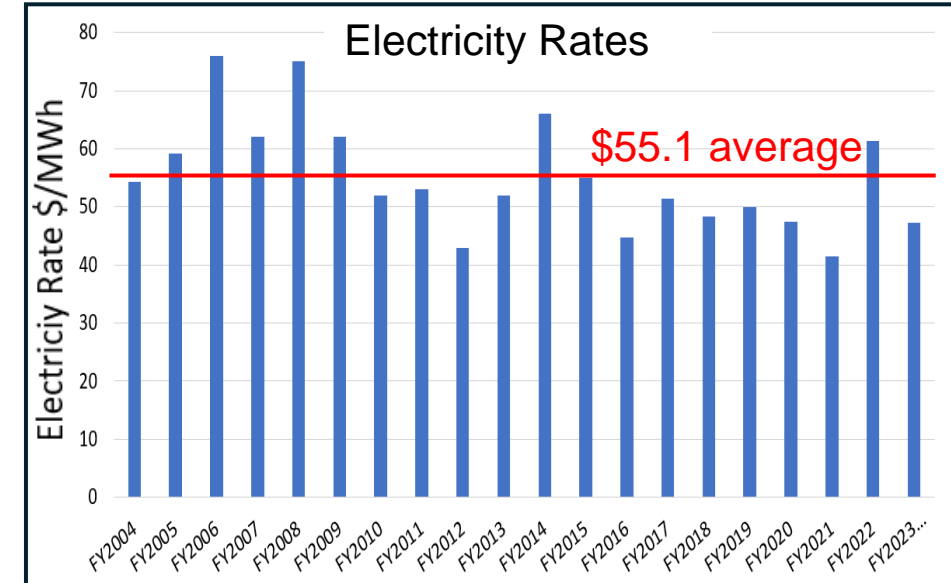
Not achieved, RHIC  
main magnet power  
supply building



# Supply chain and inflation: Helium and Electrical Costs

Electrical costs no fixed price contract, price volatility

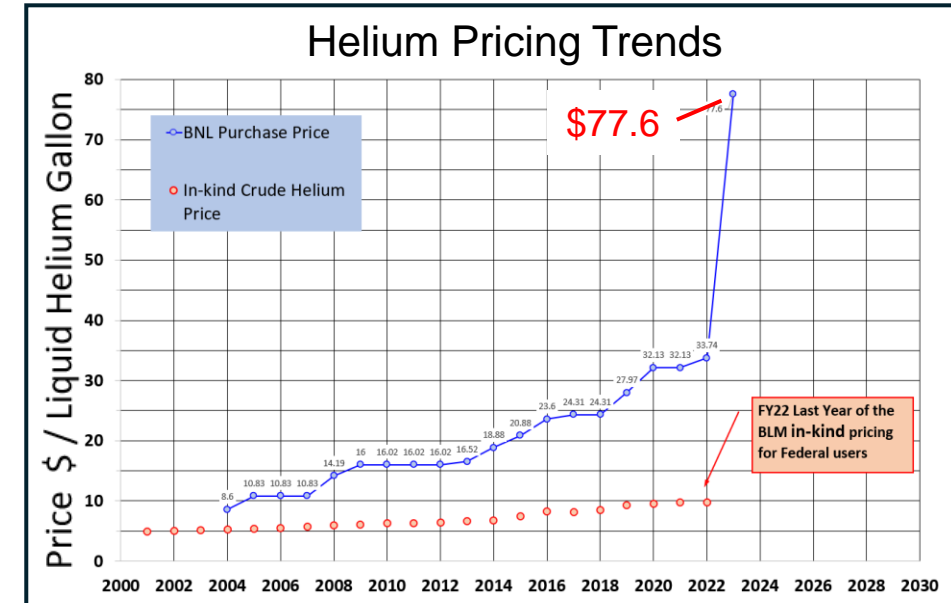
FY21: \$41.4/MWh  
 FY22: \$61.4/MWh  
 FY23: \$47.3/MWh actual  
 (had planned for \$70.0/MWh)  
 FY24: planning for \$82.4/MWh



Cost of LHe

FY23: no more “in-kind” pricing from Bureau of Land Management (BLM) Reserves due to 2013 Act eliminating Federal Helium Reserves

FY21: \$32.1/LHe gallon  
 FY22: ~\$33.7/LHe gallon  
 FY23: \$77.6/LHe gallon  
 (had planned for \$50/LHe gallon)  
 FY24: planning for \$77.6/LHe gallon



# Supply chain and inflation

## Other impacts of supply chain on RHIC Operations:

- highest impact: air conditioning in RHIC main magnet power supply building
  - unit #1 (25-ton) – OK
  - unit #2 (25-ton) – OK
  - unit #3 (2 25-ton stages) – 1 stage down, other stage awaiting parts (6 months so far)
  - unit #4 (2 25-ton stages) – late arrival of parts, unsuccessful attempts at repair implemented multiple (3 10-ton) movable AC units during run
- air conditioning units on rooftop for sPHENIX delayed by 5 months (installed during run)
- air conditioning for LEReC and CeC-X laser trailer resulted in 1 missed APEX opportunity
- delayed delivery (6-8 months) of new AGS skew quadrupole power supply (no AGS beam tests for P+P in Run 2023)
- delayed delivery (~ 6 months) of integrated circuits and isolation amplifiers) for machine protection enhancement
- delayed delivery (~ 6 months) of CEC-X cooling section power supplies (although in time for Run 2023)
- other groups report no effect on RHIC operations owing to healthy spares inventories and/or work-arounds
- good news: most groups (except laser group) report delivery times trending towards those pre-COVID

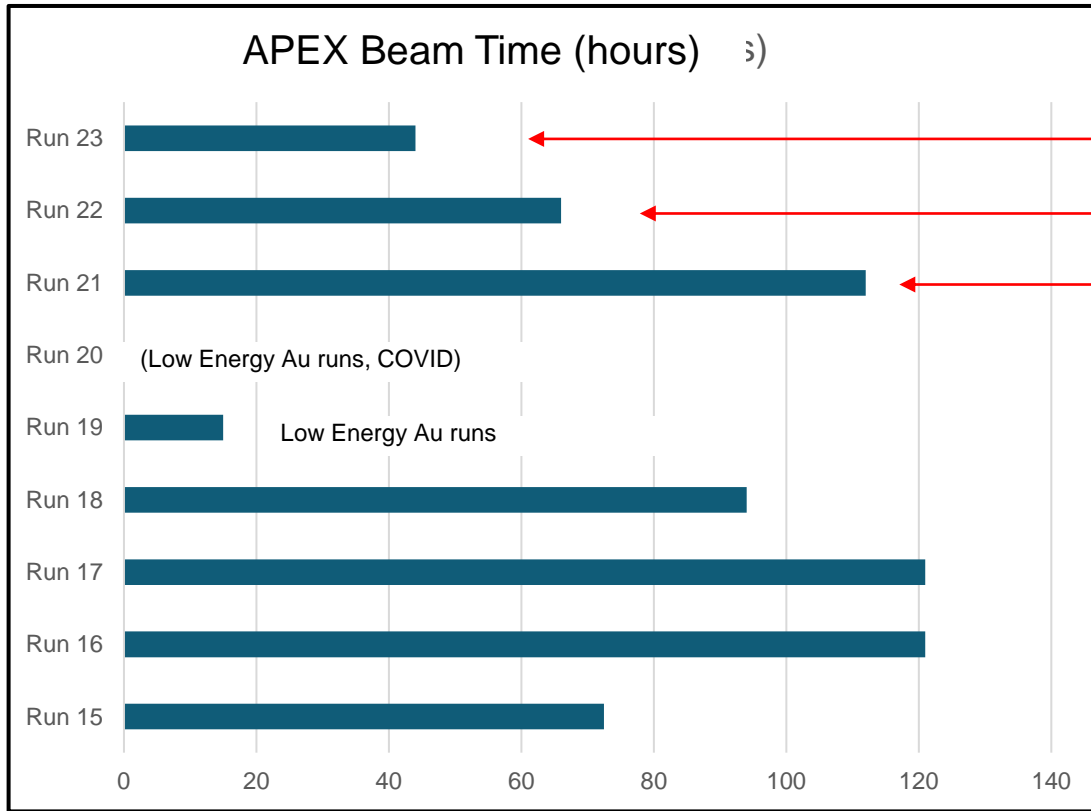
## Impacts of inflation on RHIC operations

- EBIS: (30-50)% for parts (diode pack, drift tube and smaller supplies, due to increased material costs)
- LINAC RF: DC blocking capacitor (350% increase since 2018)  
5 kW amplifiers (160% increase since 2020)
- good news: most groups report costs reducing to pre-COVID levels



# APEX (Accelerator Physics Experiments) during Run 2023

# Recent APEX Overview



focus: experiments to inform EIC design

focus: experiments to inform EIC design, beam cooling studies

focus: beam cooling studies

## APEX experiments during Run 2023

Experiments	Spokesperson	Actual Beam Time allocated (hours)
IPM voltage test	Medani	2
Test of ERL BPM	Igor	2
Luminosity optimization with ML	Xiaofeng	2+2=4
Precise decoupling test for EIC large emittance ratio	Yun	5+8+3 =16
RHIC Snake Aperture Optimization	Vincent	10
LeREC related experiments	Alexei, Sergei	10
Total		44 hours

Four experimental periods:  
24 May, 14 June, 28 June, 26 July

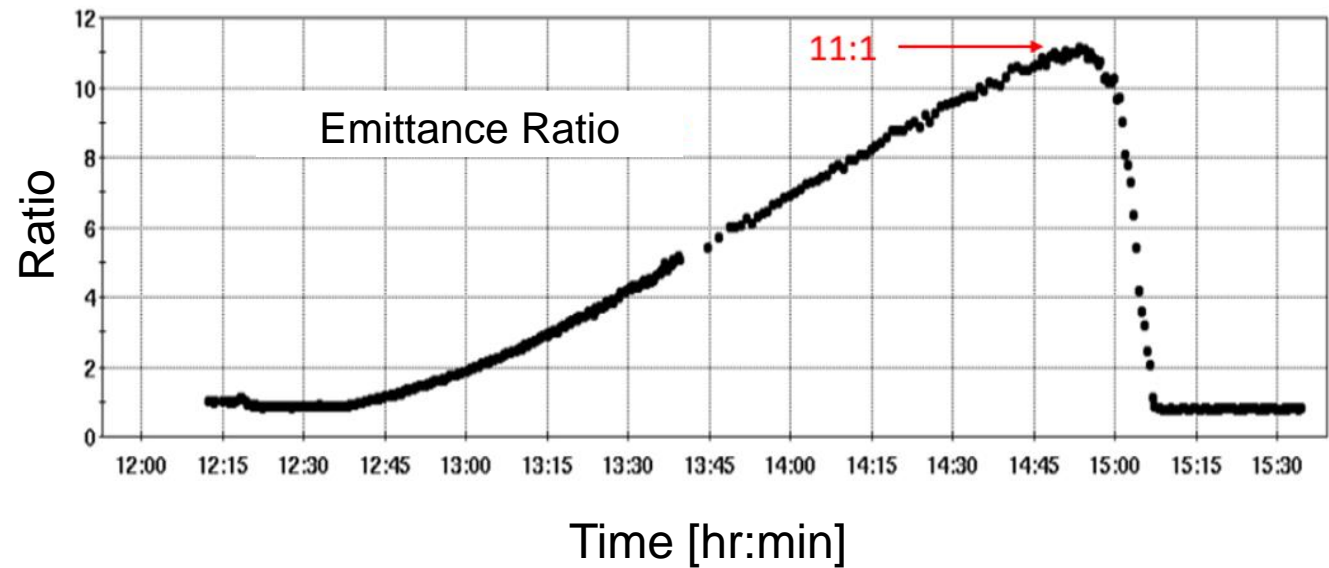
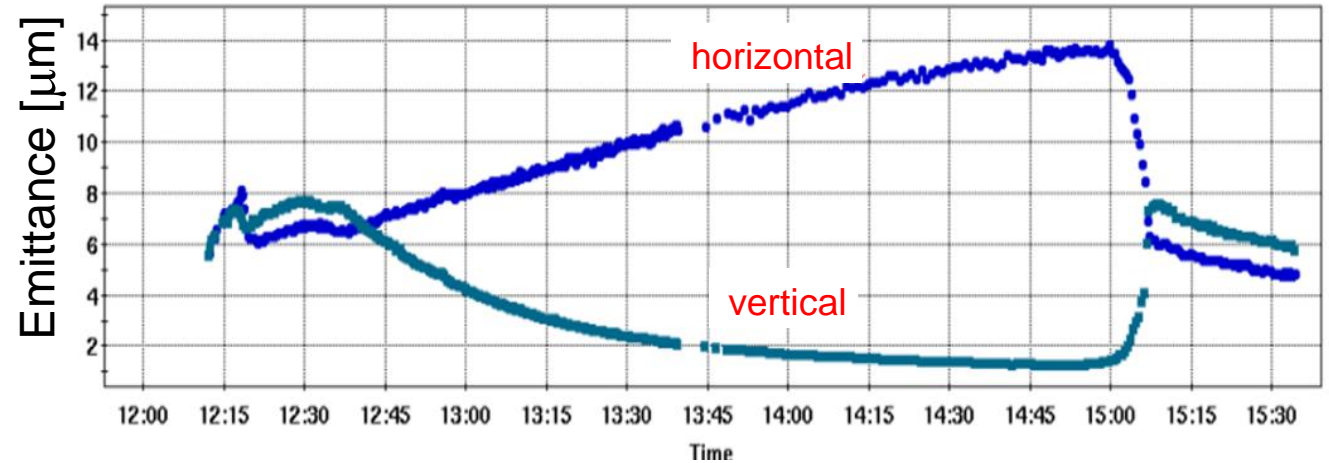
# APEX - Precision Decoupling for Large Emittance Ratio

EIC luminosity is enhanced by large beam size ratio at the interaction point.

While flat electron beams are naturally produced by synchrotron radiation, the use of the flat hadron beam in storage rings is unusual.

Very good correction and control of betatron coupling is required to produce large hadron emittance ratio.

The experiment in RHIC intended to demonstrate feasibility of creating the flat hadron beam and the adequacy of present decoupling system for this task.

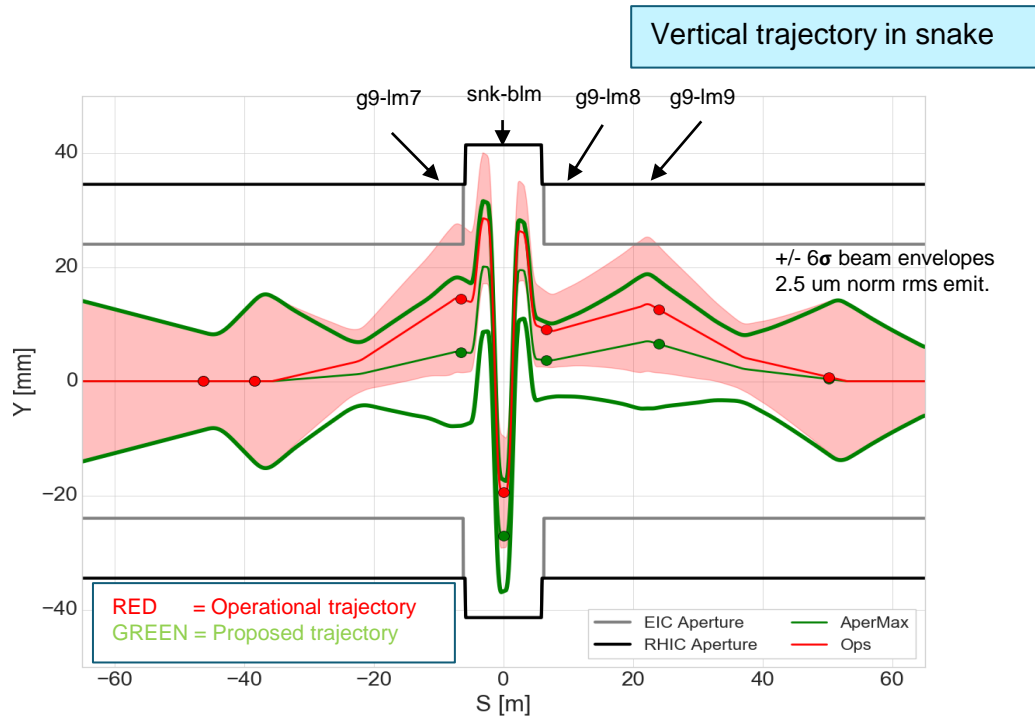


Result: goal of > 10:1 emittance ratio demonstrated.

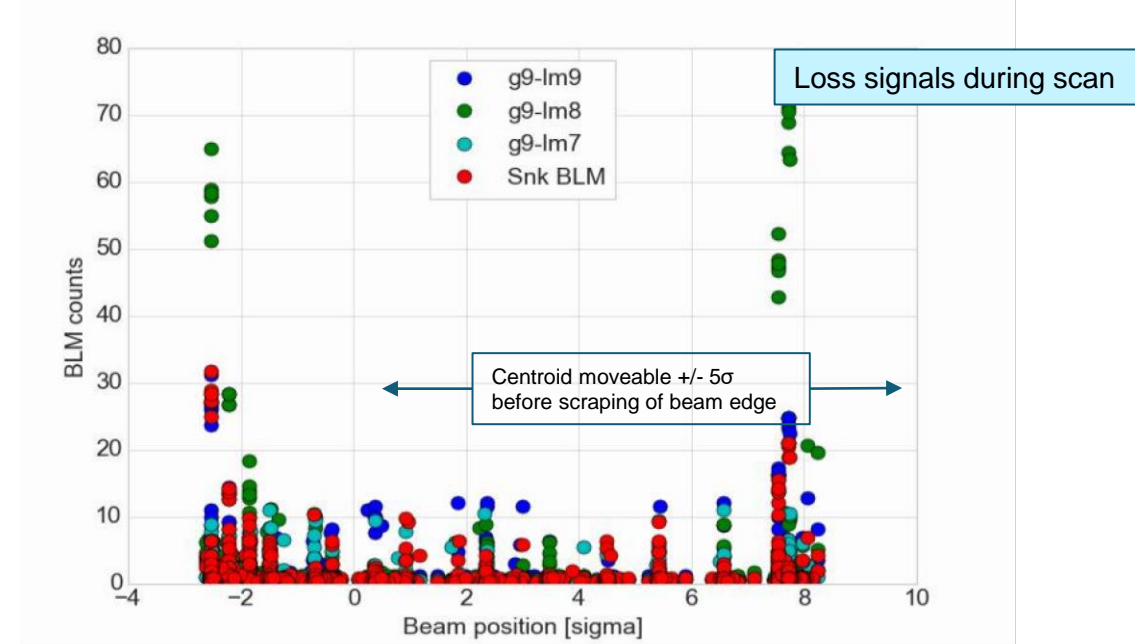
# APEX - RHIC Snake Aperture Optimization

Proposed EIC beam screen design restricts aperture in the arcs. New aperture would impinge on present RHIC beam envelope near snake locations (red envelopes). New trajectory established (green envelope) and scanned.

Model: predicts  $\sim 9\sigma$ , with limiting aperture in snake body.



Experiment shows +/- 5 $\sigma$  of centroid motion before beam edge at +/- 5-6 $\sigma$  contacts aperture. Shows  $\sim 10\sigma$  clearance between beam centroid on central trajectory and aperture with loss signal consistent with primary scraping in snake body.



Result: Trajectory exists with sufficient aperture to inject beam in EIC without modifying the screen design near the snake. Assumes local EIC optics approximate RHIC optics.

# APEX - Advanced Beam Cooling

While both LEReC and CeC established electron beam operations, no beam cooling experiments took place in Run 2023.

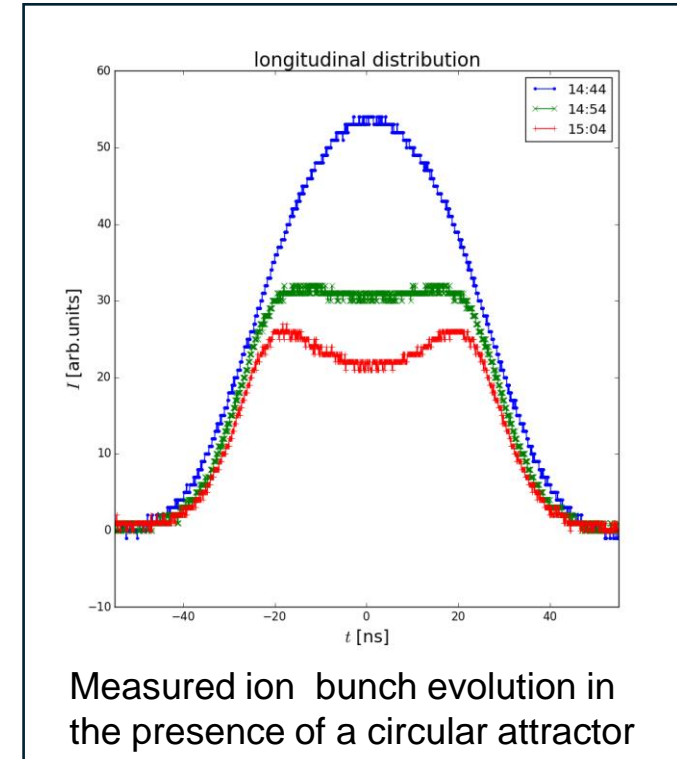
## LEReC – advances in accelerator science

- Analyzed data from APEX 2022 and published (details in backup slides):  
Experimental demonstration of circular attractor at relativistic energy using LEReC

*S. Seletskiy, A. Fedotov, D. Kayran, “Experimental studies of circular attractors in the first rf-based electron cooler”, PRAB 26, 024401 (2023).*

Demonstrated influence of circular attractor on CeC

*S. Seletskiy, A. Fedotov, D. Kayran, “Circular attractors as heating mechanism in coherent electron cooling” PRAB 25, 054403 (2022).*

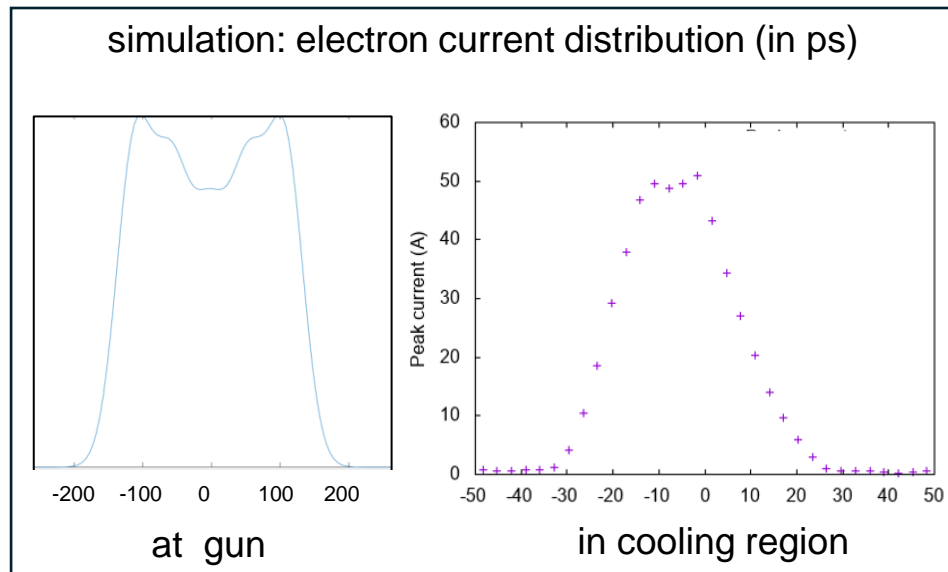


- Electron beams re-established in 2023 reproducing design beam parameters.
- APEX for LEReC this year (10 hours) was devoted to establishing 3.85 GeV beam (with 100 GeV initial conditions).

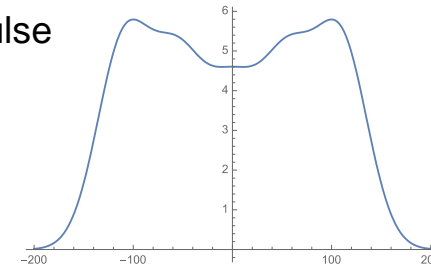
# APEX - Advanced Beam Cooling

## CeC – advances in accelerator technology

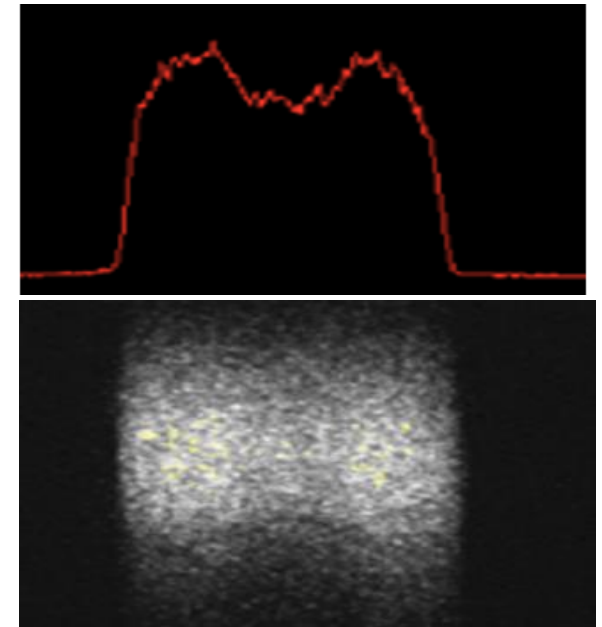
- Updated cooling simulation require the electron beam in cooling section to have uniform current distribution (<10% peak-to-peak variation) as well as good quality over 15 ps duration
- Beam dynamics simulations show that the uniform distribution can be achieved using a new (non-Gaussian) distribution of the laser pulse profile.
- The laser system was upgraded to produce five overlapping Gaussian laser pulses (using five interferometers). Efforts underway to ensure same laser profile at laser gun table.



proposed  
laser pulse  
shape



streak camera measurement  
(laser trailer)

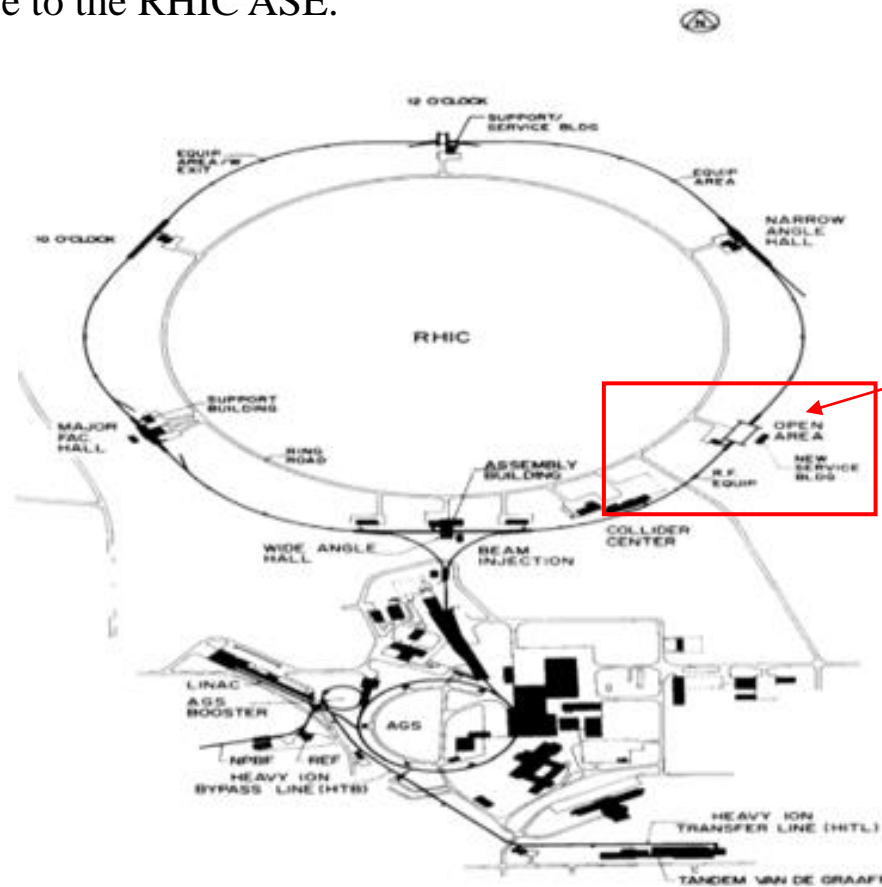


- Manufacturing process has started for new 500 MHz bunching cavity.
- New transfer system for photocathodes successfully tested.

# RHIC repair plans for Run 2024

# Event on 1 Aug 2023

- On 1 Aug 2023 the Blue Ring Quench Interlock (QLI) System commanded the RHIC energy extraction system to dissipate the stored energy in the Blue Ring. Due to uncertainties in the sequence of events and estimated time for recovery, RHIC Run 2023 was terminated six weeks early (on 4 Aug 2023).
- The DOE Office of Science has approved carryover of these six weeks into RHIC Run 2024.
- The unexpected release of Helium in Building 1004B through the valve box access port necessitates a USI (Unreviewed Safety Incident) requiring a change to the RHIC ASE.



Helium venting at Bldg. 1004B

1004B Valve Box





# Event on 1 Aug 2023, continued

- Other damage subsequently revealed

# Causal analysis and external “RHIC Recovery Review”

- An external review (chair: Marc Ross, SLAC) to assess causal analysis and schedule for repairs was held on 28 Nov 2023. The review committee concurs with planned repairs and schedule.

# Repair status

# Add slide on operation through summer months

# Summary

# Summary

## RHIC Performance

- RHIC Run 2023 priority was commissioning of the new sPHENIX detector
- The sPHENIX commissioning plan was successfully completed per schedule however terminated early due to the 1 August 2023 event
- RHIC accelerator availability was impacted by operation during summer months

## APEX (Accelerator Physics Experiments) during Run 2023

- No beam cooling experiments performed (due to early conclusion of Run 2023)
- Many experiments completed to inform design decisions for the EIC

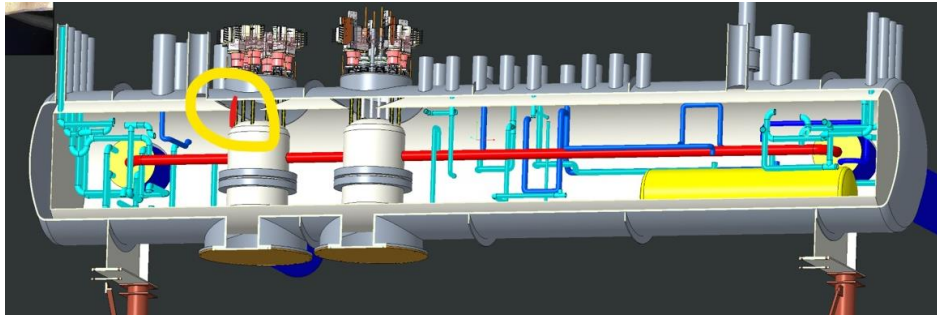
## RHIC Repair Plans for Run 2024

- Causal analysis largely confirmed by external “RHIC Recovery” review committee
- Repairs progressing well
- RHIC Run 2024 contingent on authorization by the Brookhaven Site Office

# Event on 1 Aug 2023

- At 12:31 on 1 Aug 2023 a spurious trip of the Quench Interlock System commanded the RHIC power supplies to turn off and for the energy extraction system to begin dissipating the stored energy in the Blue Ring. At 12:39 the Cryo control room informed the MCR that the Blue Valve Box in 1004 B was venting Helium to the exterior of the building.
- Decision to end RHIC Run-23 made on 4 Aug 2023. RHIC Valve Box/Short status (30 Aug 2023) at RHIC Retreat.
- Following numerous safety reviews (hazards: electrical, confined-space, oxygen deficiency) and work planning, the valve box was opened on 1 Sep 2023; Helium breach found on warm cable interface at top (of the inside) of the valve box

1004B Valve Box



Helium venting at Bldg. 1004B



1004B Valve Box



- Valve box lead pots (LP) accessed on 7 Sep 2023 (VB #1) and 8 Sep 2023 (VB#2). Damage to 12-conductor cold-to-warm, gas-cooled current lead found in LP #1, no trouble found in LP #2.

Lead pot in valve



Damaged current lead



Helium leak



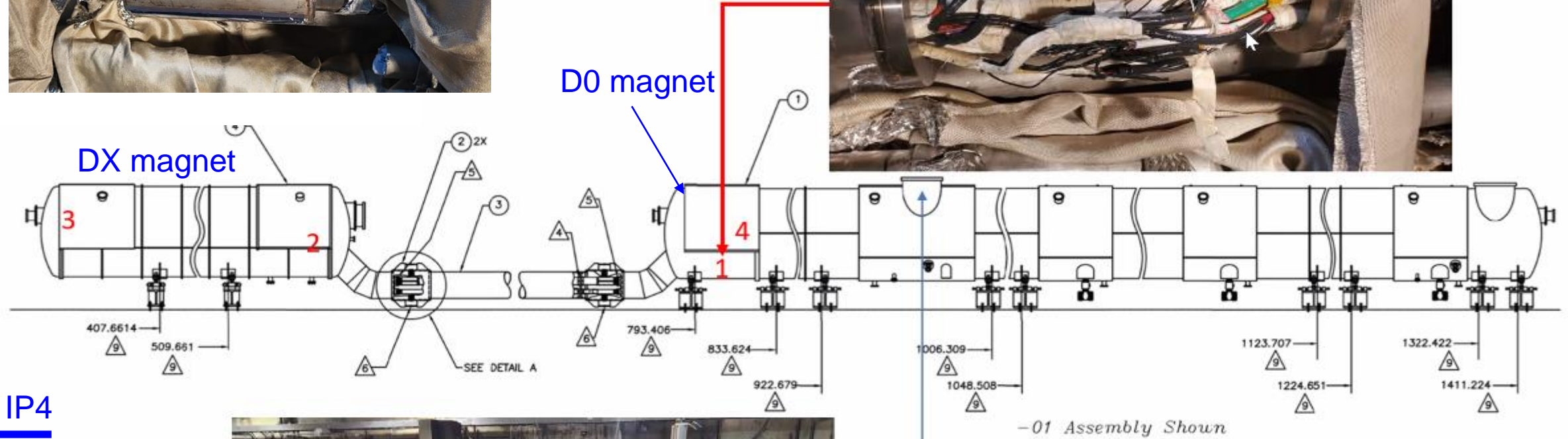
- Throughout this time, extensive electrical tests of the superconducting cable distribution system were made to localize the short(s) of the Blue Ring dipole and quadrupole magnet strings ultimately isolating the presence of a short and unusual voltage tap readings in the tunnel at the IR4 D0 and DX magnet interface in the RHIC tunnel.

“splice cans”, which provide electrical continuity of super-conducting cables (locations of suspected shorts) were accessed starting 18 Sep 22023

Splice can (#1) before opening



Splice can #1 after opening (no trouble found)



to IP4



DX magnet



Inside the RHIC tunnel

Location of electrical connections to 1004B valve box

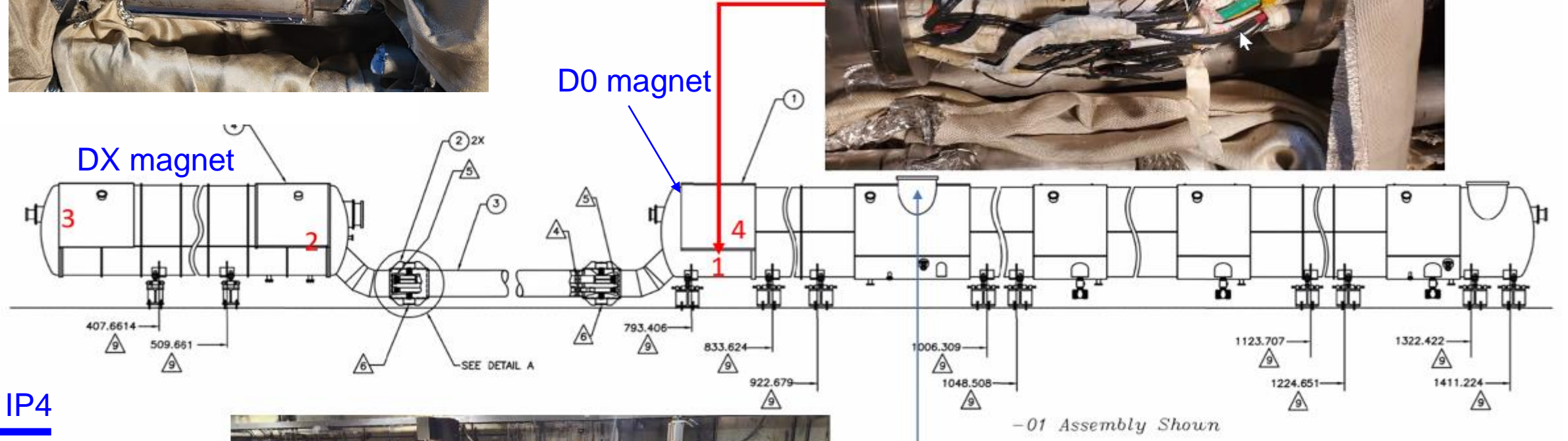


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DX magnet



Inside the RHIC tunnel

