The performance of RHIC BES-II in 2020 and outlook

Chuyu Liu

AGS/RHIC Users' Meeting

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BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

- Overview of Run-20
- Operation performance of Au+Au collisions at 5.75 GeV and 4.6 GeV
- FXT, CeC and others
- Operations during pandemic
- Beam development of Au+Au collisions at 3.85 GeV and the outlook for Run-21

RHIC Run-20 overview

RHIC Run-20

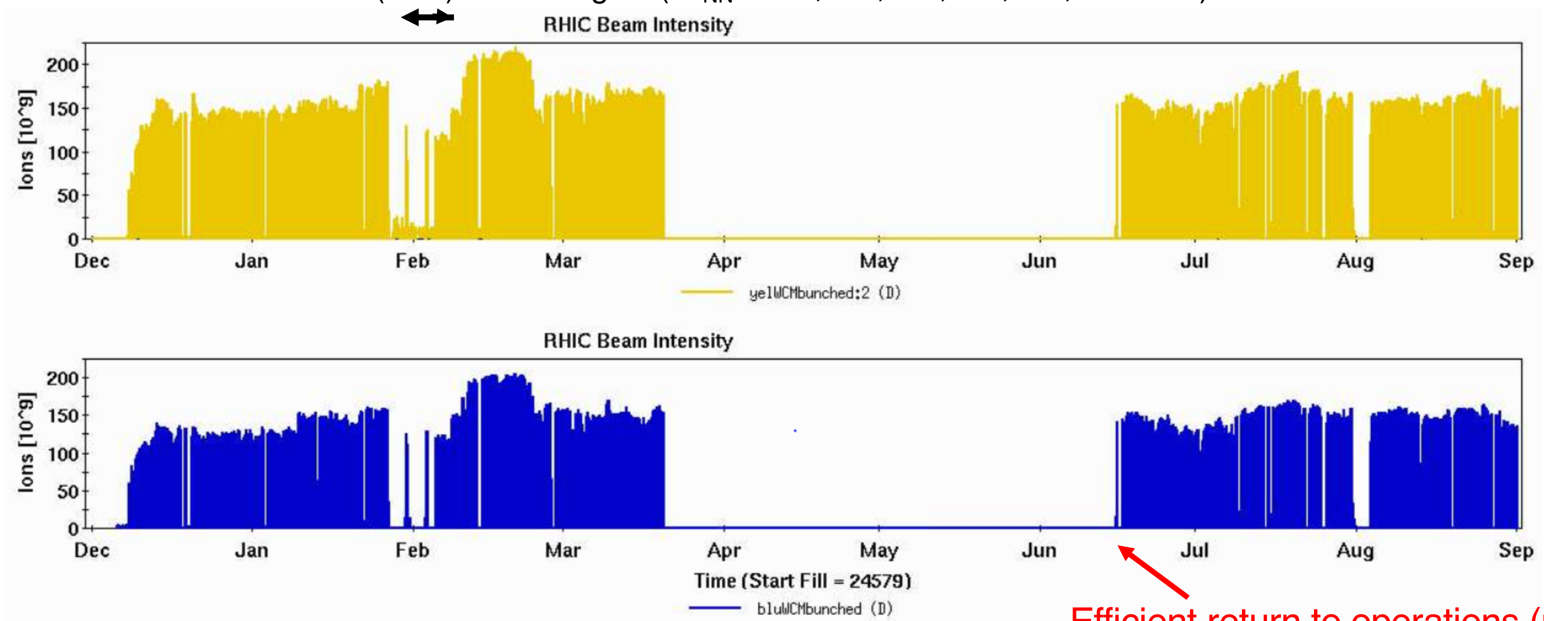
10 different modes, all with Au

Run coordinator: Chuyu Liu

Au+Au at $\sqrt{s_{NN}}$ = 11.5 GeV

Au+Au at $\sqrt{s_{NN}}$ = 9.2 GeV

Au+Au (FXT) at 6 energies ($\sqrt{s_{NN}}$ = 3.5, 3.9, 4.5, 5.2, 6.2, 7.8 GeV)



Efficient return to operations (min-safe conditions) after shutdown due to COVID

+ interspersed operations for CeC PoP at 26.5 GeV/nucleon particle energy
+ LEReC cooling commissioning with Au+Au at $\sqrt{s_{NN}}$ = 7.2 GeV - since September 2nd , 2020

Beam Energy Scan II scoreboard

Beam Energy (GeV/nucleon)	$\sqrt{s_{NN}}$ (GeV)	μ_B (MeV)	Run Time	Number Events Requested (Recorded)	Date Collected
13.5	27	156	24 days	(560 M)	Run-18
9.8	19.6	206	36 days	400 M (582 M)	Run-19
7.3	14.6	262	60 days	300 M (324 M)	Run-19
5.75	11.5	316	54 days	230 M (235 M)	Run-20
4.59	9.2	373	102 days	160 M (162 M)[1]	Run-20+20b
31.2	7.7 (FXT)	420	0.5+1.1 days	100 M (50 M+112 M)	Run-19+20
19.5	6.2 (FXT)	487	1.4 days	100 M (118 M)	Run-20
13.5	5.2 (FXT)	541	1.0 day	100 M (103 M)	Run-20
9.8	4.5 (FXT)	589	0.9 days	100 M (108 M)	Run-20
7.3	3.9 (FXT)	633	1.1 days	100 M (117 M)	Run-20
5.75	3.5 (FXT)	666	0.9 days	100 M (116 M)	Run-20
4.59	3.2 (FXT)	699	2.0 days	100 M (200 M)	Run-19
3.85	3.0 (FXT)	721	4.6 days	100 M (259 M)	Run-18
3.85	7.7	420	11-20 weeks	100 M	Run-21[2]

all Run-20 goals achieved or exceeded!

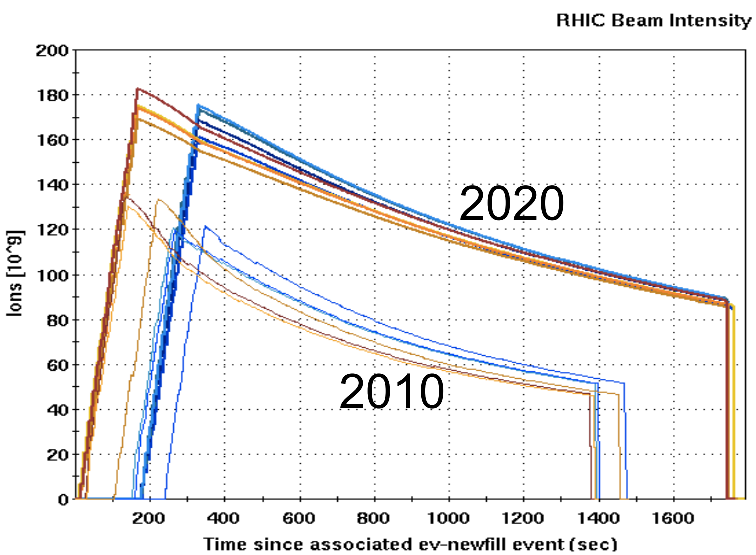
Courtesy STAR collaboration

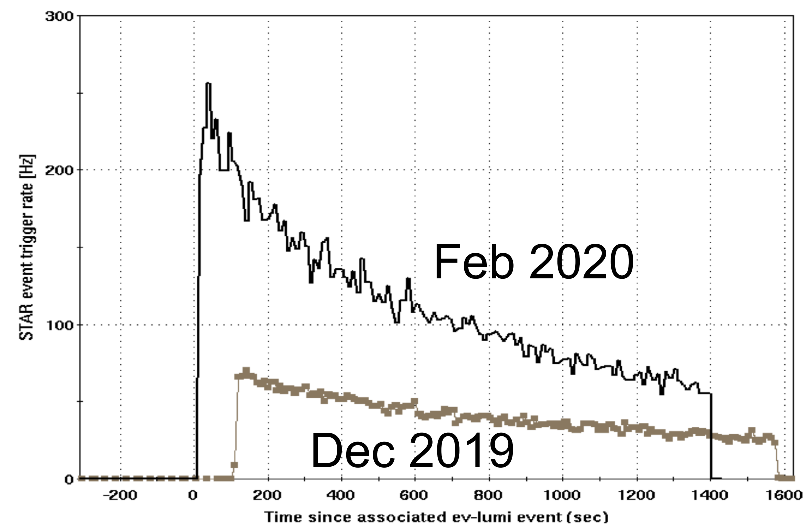
The challenges in 2020 operation

- Space charge, intra-beam scattering and beam-beam effects at low energies limits the lifetime of the beams in collision.
- Operation of bunched electron beam cooling for the first time in the world for physics at 4.6 GeV Au+Au collision.
- Compatibility of physics programs, LEReC and CeC. Quick and reproducible mode switch is a must.
- The COVID-19 paused the RHIC operation for 3 months, and changed the way how we operate RHIC.
- RHIC and injector operation during the summer with high temperature and humidity.

Au+Au collision at 5.75 GeV in Run-20

Operation performance of collision at 5.75 GeV





The average luminosity achieved in 2020 was 5 times of that in 2010!

The STAR trigger rate was improved by ~2 over the course of the operation in Run-20

https://www.agsrhichome.bnl.gov/RHIC/Runs/

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Contributions to the improvements of luminosity at 5.75 GeV

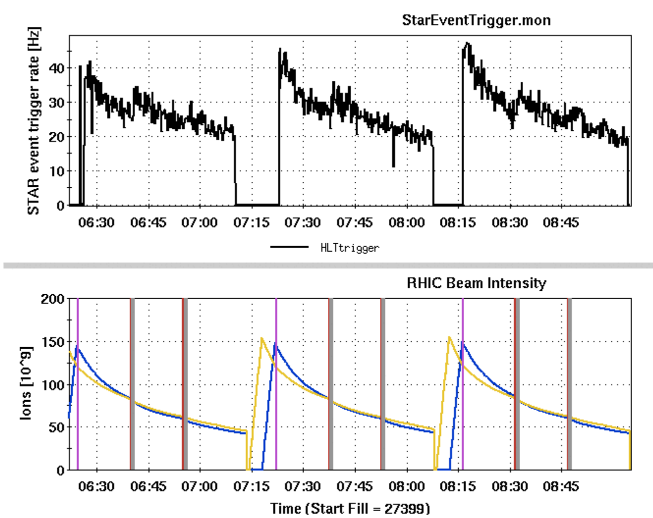
- Bunch intensity improvement
  - High reliability, high quality Tandem beam
  - Double RF systems for large long. Acceptance and better bunched beam lifetime
  - Raised intensity limit in AGS from 8 to 9.8E9 per cycle
- Exploration of working points for beam with large space charge tune shift
  - Design SC tune shift was 0.06, at the end of the program it was pushed to 0.11!!
  - Raised tunes from 0.09 to 0.12 and implemented different tunes for injection and store (lower tunes).

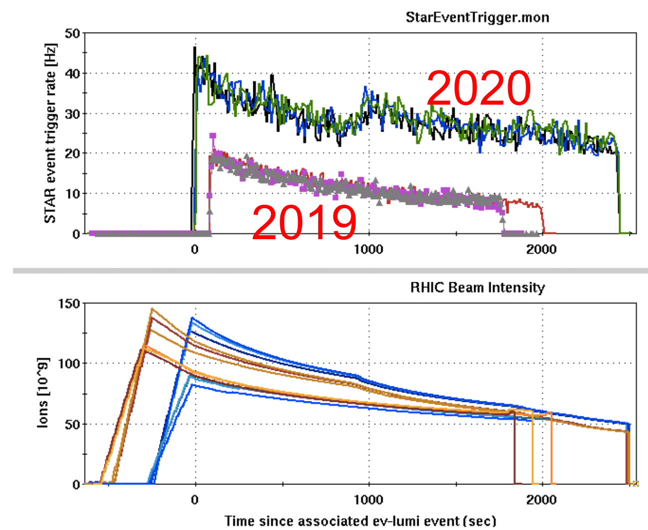
Contributions to the improvements of luminosity (continued)

- Suppression and control of the background.
- Multiple efforts to shorten the turn-around time between stores
  - shortening the super cycle length
  - balance between bunch merging and fill time
  - Shortening gap cleaning
  - Broadcasting lumi-on as soon as possible
- Constant machine tuning by the machine specialists and shift crew

Au+Au collision at 4.6 GeV in Run-20

Operation performance of collision at 4.6 GeV





The average luminosity achieved in 2020 was 4.2 times of that interpolated from BES-I

The STAR trigger rate was improved by >2 compared to that in 2019

LEReC achievements - UPP demonstration

UPP: "Luminosity increase of a factor of four compared to the one delivered in Beam Energy Scan Phase-I physics program (with new 9 MHz RHIC RF system which is presently under construction)."

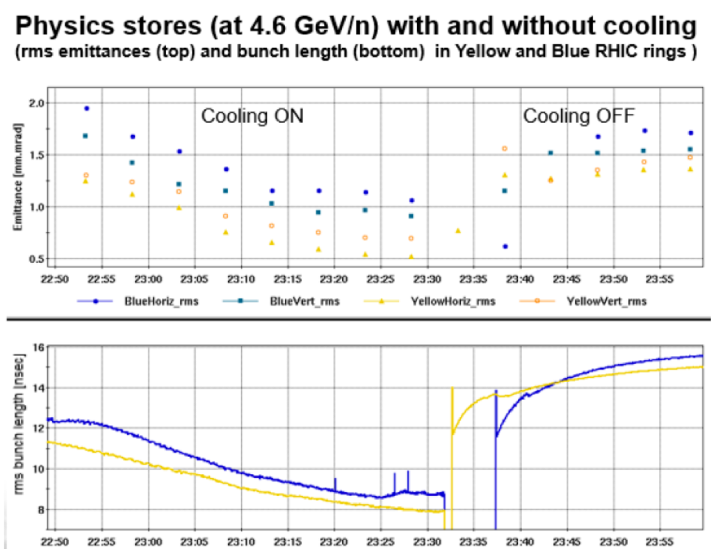


Fig. 1. Physics stores with and without cooling. With cooling, both longitudinal and transverse beam size growth due the IBS was counteracted. In addition, good transverse cooling was achieved allowing a dynamic beta-squeeze during the physics store.

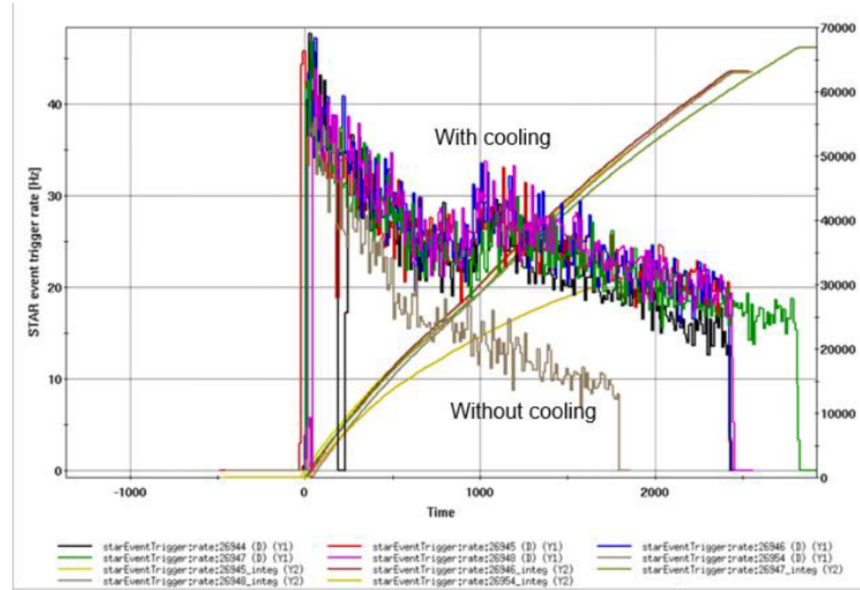


Fig. 2. Production physics stores with and without cooling.

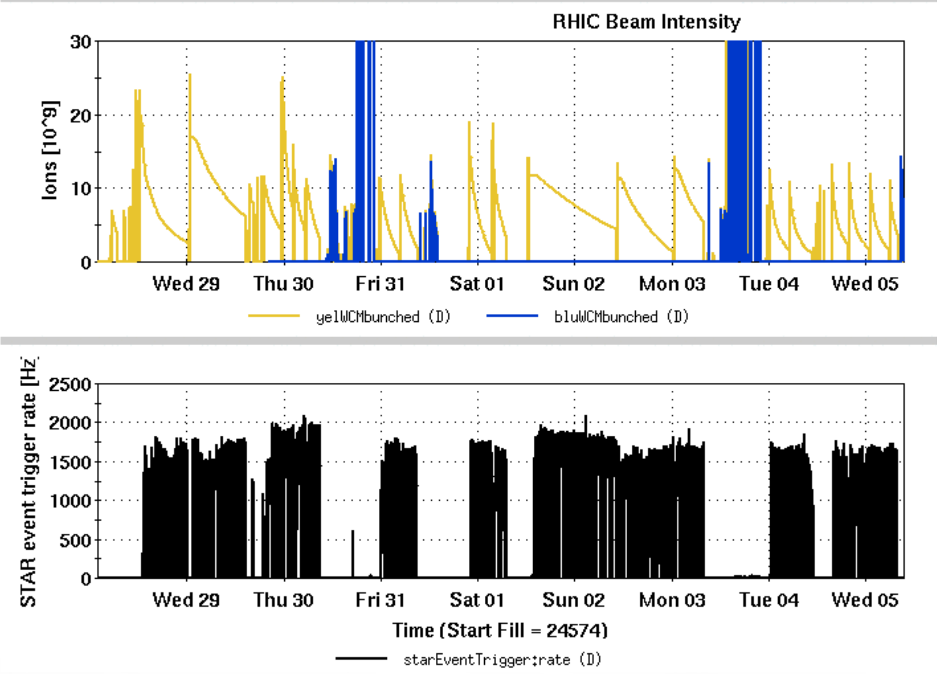
The average store luminosity at 4.6 GeV/n reached 26x10^{24} cm^{-2}s^{-1}, **4.2 times larger** than the interpolated luminosity from BES-I.

Courtesy LEReC team

FXT, CeC and others

FXT experiments in 2020

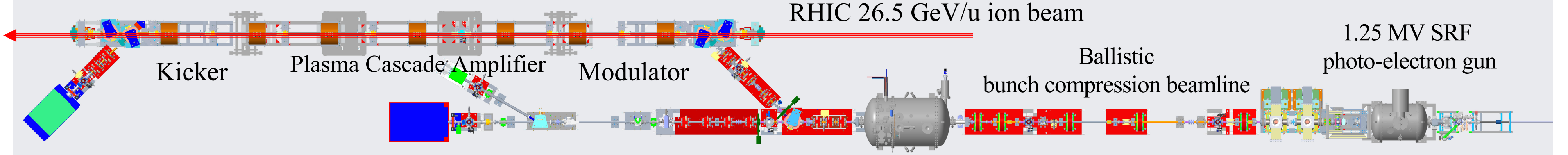
For FXT, one prefers a large beam size near IP6, which can be achieved by increasing beam emittance and/or beta star.



The STAR trigger rate was kept near constant just below 2 k with background under control.

Coherent electron Cooling experiment at RHIC in Run-20

Courtesy V.N. Litvinenko



- Current CeC system has seven high field solenoids, five of which serve as a 4-cell Plasma-Cascade μ-bunching amplifier with 15 THz bandwidth and amplitude gain exceeding 100.
- Experimental program with this system started this winter, i.e. during RHIC run 20, and was restarted in June after interruption by COVID-19 related RHIC shut-down
- All necessary electron beam parameters – the beam energy and peak current, the beam emittances and energy spread, the low noise in the beam (critical and most not-trivial requirement) - had been demonstrated. The full CW beam was propagated with low losses through the newly built PCA CeC
- The CeC run was completed in mid-September and preliminary analysis showed that all goals for this run had been achieved:
  1. Demonstrating KPP for the e-beam
  2. Plasma Cascade amplification
  3. Ion imprint
- The project plans are to demonstrate longitudinal CeC in 2021 and 3D (both longitudinal and transverse) CeC in 2022.

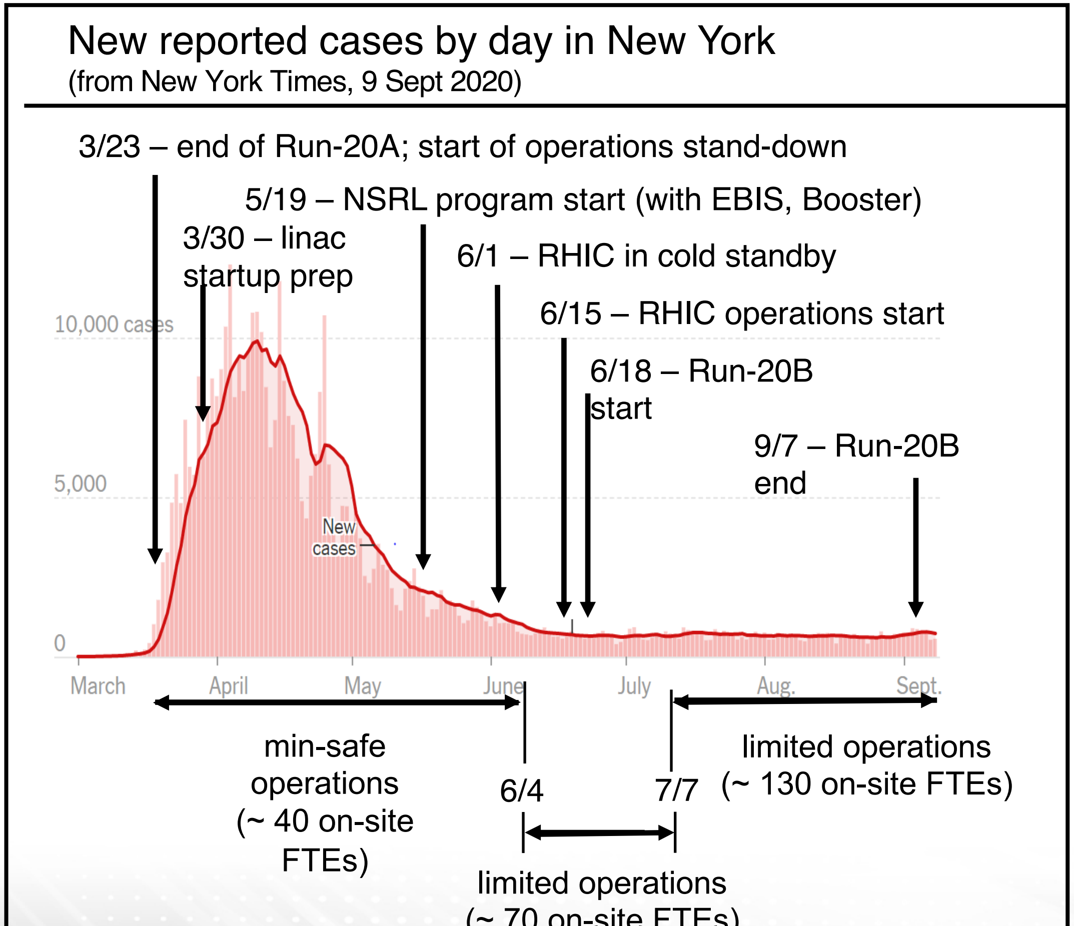
Compatibility of multiple (10) programs

- The programs require different system settings so design efforts are necessary to accommodate each and every programs.
  - Fixed target and CeC commissioning can happen anytime during the run with a success of ramping up from 7.3 GeV
  - Use 28 MHz cavities as the main RF system at 5.75 GeV
  - Quick switch between physics at 5.75 GeV and LEReC commissioning at 4.6 GeV (9 MHz cavity frequency with h=121 at 5.75 GeV and h=122 at 4.6 GeV are close)

- Mode switching and reproducible hysteresis ramps are required for quick switching between programs.
  - Re-optimization of the wiggle ramp

Operations during pandemic

RHIC operation during COVID pandemic



Courtesy Michiko Minty

Major challenges

- Critical system maintenance during stand-down
- Startup of accelerators during min-safe
- Personnel management (including adapting to change)
- Work Planning, Enhanced Work Planning
- Coordination of new ways of doing work (to minimize time and/or staff required for a particular task, sequential scheduling of work, etc.)
- Tracking of staff and maintaining compliance
- Remote checkout, turn-on, and operation
- Procurement and management of personal protective equipment
- Maintain communication channels and develop new tools for effective communication

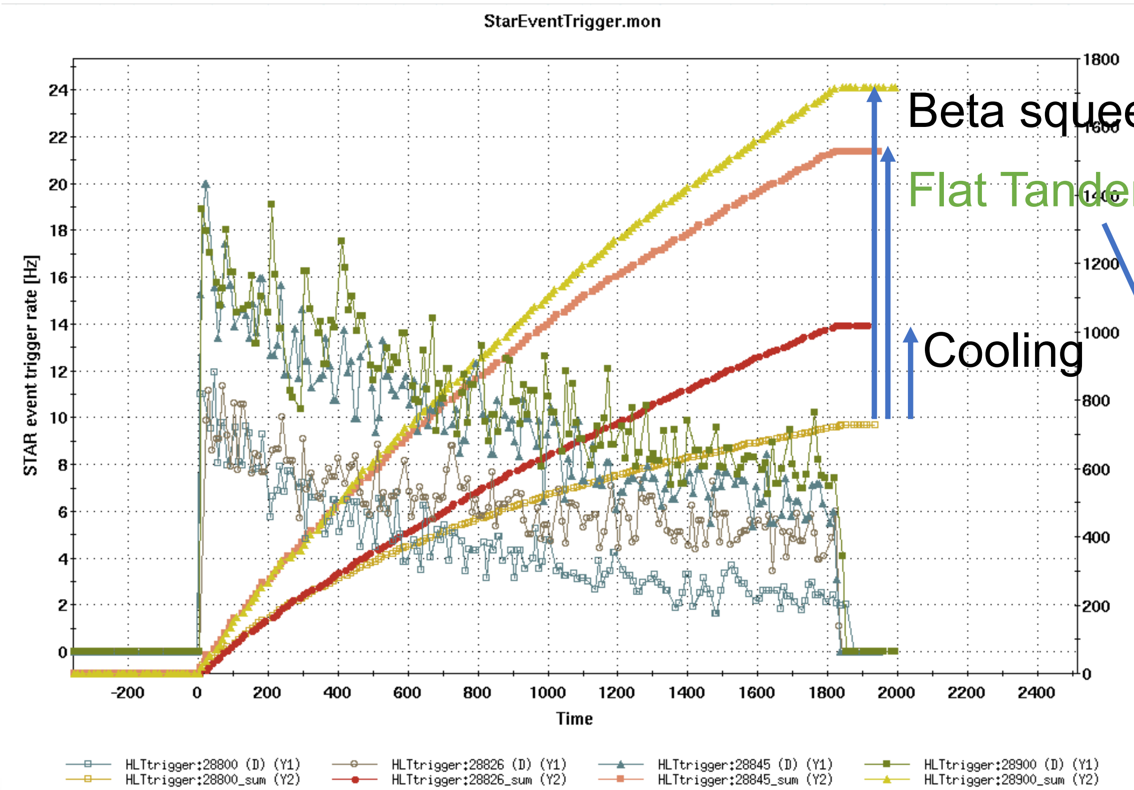
Despite challenges, RHIC operations, LEReC and STAR resumed Run-20B at Run-20A peak performance levels within 3 days of beam operation.

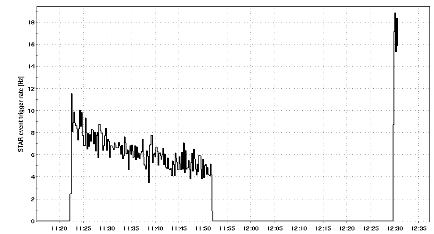
Challenges of operation during the summer time

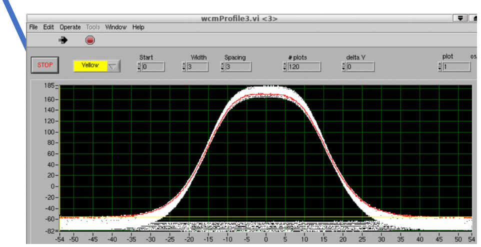
- Power dips! storms! It was a big effort to recover from the downtime which may take up to 24 hours. Close communication between group leaders with shift crew was very helpful.
- Systems have to be turned off temporarily due to high temperature and humidity. For example, the BPMs, the RF stations. It puts limits on development time in the injectors and operation of RHIC.

Test at 3.85 GeV and outlook of Run-21

Improvement of collision rates at 3.85 GeV







longitudinal ion bunch profile
with higher harmonic cavities

The improvement made during beam development at 3.85 GeV made the physics goal in Run-21 reachable in reasonable time frame (15 to 20 wks).

Summary of tuning at 3.85 GeV

- 9 MHz cavities at 180 kV. 28 MHz cavities with opposite phase for defocusing and focusing, at 110 kV and 50 kV.
- Cavity voltage scan (ramping down defocusing and ramping up focusing) did not make a significant difference.
- Transverse cooling efficiency was the best with voltage at constant.
- Beta squeeze bring down beta star from 4.5 to 3.5/3 m.

Outlook of Run-21

- Au+Au 3.85 x 3.85 GeV (w/cooling)
  - New 1.4 GHz cavity to be installed to lengthen electron bunch to alleviate the heating effect
  - Transverse bunch-by-bunch damper to be engaged to stabilize ion beam with small energy spread
- Up to 4 FXT energies, Au beam on gold FXT
- O+O at $\sqrt{s_{NN}}$ = 200 GeV or Au+Au 8.55 x 8.55 GeV (w/o cooling)

Summary

- Beam Energy Scan Phase-II RHIC operation in 2020 was successful despite expected and unexpected challenges.
  - The goal of physics program at 5.75 GeV was exceeded with intensity increase and tuning of working point.
  - The goal of physics program at 4.6 GeV was exceeded with excellent LEReC cooling and 9 MHz RHIC RF system.
  - The goals for all FXT experiments were achieved.
  - CeC and other beam developments made progress.

- The final year of Beam Energy Scan Phase-II RHIC operation in 2021 seems promising based on the results from test run.

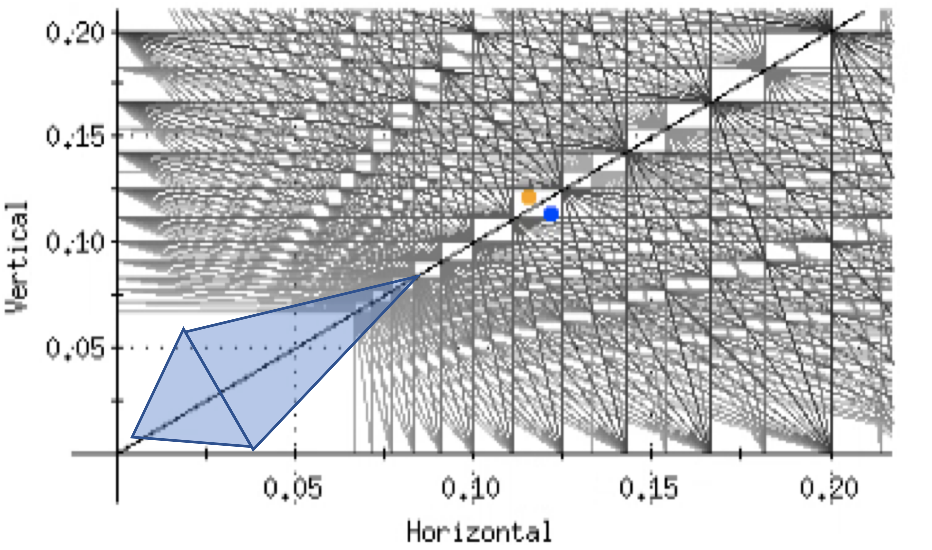
Thank you for your attention!

AGS intensity limit

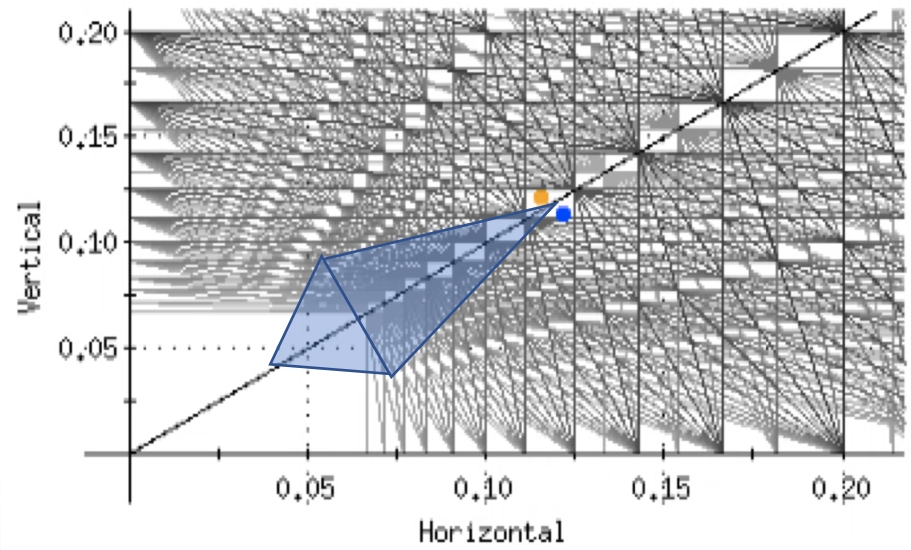
- AGS intensity limit (total intensity per cycle) was raised from 8E9 to 9.6E9 on Wednesday Jan. 15.
- Reasonable transmission efficiency at the BtA foil was maintained by rotating the foil.
- Flashes on the plunging stripping foil have been observed, no damage was found after the run.

Working point for collisions at 5.75 GeV

- The higher tunes (0.12) were proven to alleviate emittance blow-up earlier in the run at 5.75 GeV with space charge tune shift ~0.1.
- We moved up the tunes again after the tunes drifted down and injected bunch intensity was raised with improved AGS intensity.



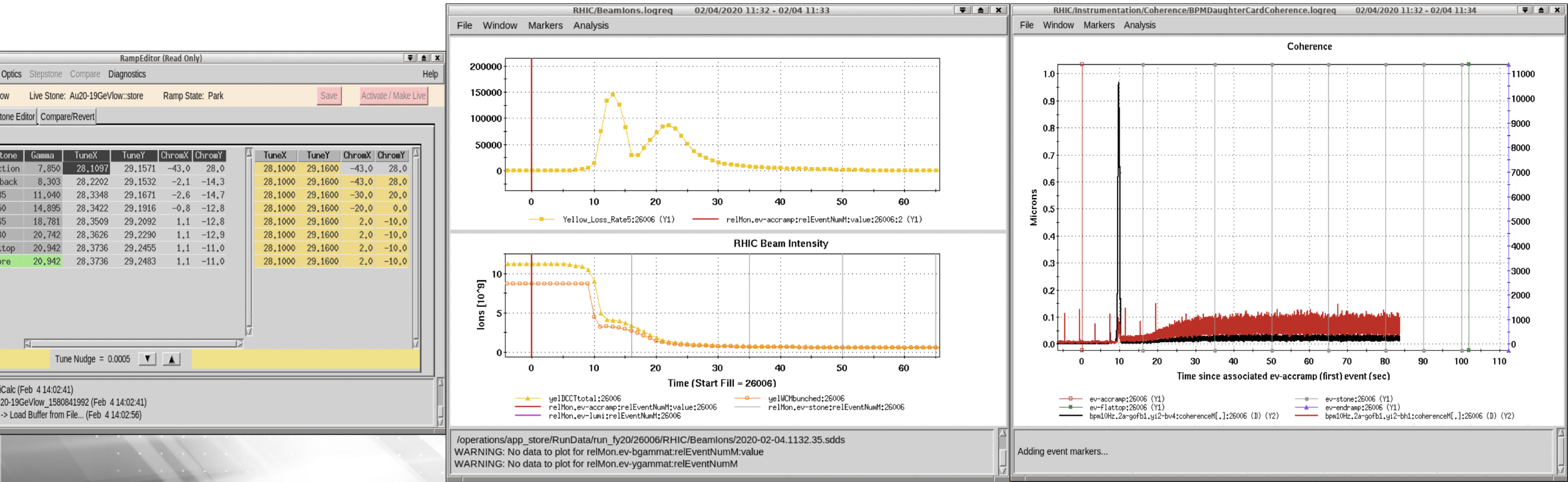
Old tunes



Current tunes

“wiggle&ramp”

- The first ramp during the "wiggle&ramp" beam study. During this ramp, the design lattice doesn't change except for the sextupole compensation (chromaticity settings in rampEditor, see picture above). We lost most of the beam at 10 s due to coherence in vertical plane (vertical chrom rises and cross zero during the swing of beam chromaticity).
- With the residual beam, measurements of tunes and chroms were made in the end at store. All measured parameters are in the right range (-5 chroms).
- The second ramp during the "wiggle&ramp" beam study. During this ramp, the sextupole compensation was implemented from accramp to second stone at 16 s to compensate the chrom swing observed during the first ramp. We lost the beam at 5 s due to coherence in horizontal plane (the compensation started too early at 0 second which move the H chrom up towards zero).



Operation configuration at 4.6 GeV

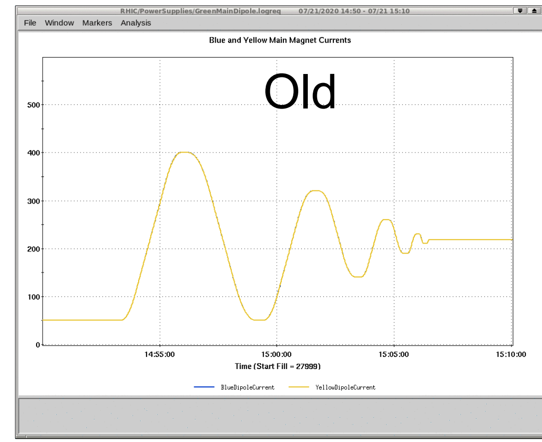
- LEReC cooling was operational with high uptime.
- Bunch merge scheme 4→1 in AGS. Beam intensity in RHIC with EBIS was 150E9 ions per ring.
- Store length was 30 minutes without cooling, 40 minutes with cooling.
- Beta squeeze reduced the beta star from 4.5 m to 3.5 m, then to 3m.

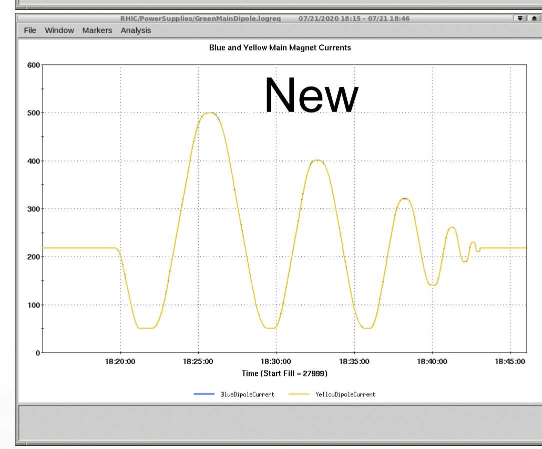
Running at high temperature

- The BPM electronics are extremely hot in the following areas: 7C, 7W, 8B, 10A. AC tech made progress to bring temp down in 1004A and 7W.
- BPMs in 8B were turned off for a few hours. Physics stores kept running without compromised performance.
- STAR background kept drifting more with large temp variations.
- We would not be able to ramp with BPMs in 8B turned off. CeC commissioning with ion should avoid hot days.

Modification to wiggle ramp

- At low operating current, both iron and persistent current contribute substantially to the magnetic field (50-50 at injection energy).
- The decay of persistent current has been almost eliminated with wiggle ramp. So both contributions are static.
- The modified wiggle introduces a radius shift less than 0.1 mm for both cases, after CeC ramps and magnet dropping to zero.
- The experimental tests last year were helpful. Discussion with Peter and Al was helpful.





Items need further investigation

- We attempted to operate with tunes below integer however beam instability was a big issue.
- We tested wiggle and ramp scheme for better field stability at injection, however, compensation of snap-back needs optimization.
- Operation at 4.6 GeV was strongly affected by the "mismatch" issue, which was not yet definitely attributed to neither chromaticity adjustment nor stripping foil deformation. Stripping foil measurement is ongoing.
- Lifetime was better (both 4.6 and 3.85 GeV) with beam in collision at lower tunes (~0.12) compared to high tunes (0.23). However, adding electron cooling made lifetime worse at lower tunes.