RHIC BES-II performance in 2019 and outlook

Chuyu Liu

2019 RHIC & AGS

Annual Users' Meeting

The Golden Age of Heavy Ion Collisions

06/06/2019

BROOKHAVEN NATIONAL LABORATORY

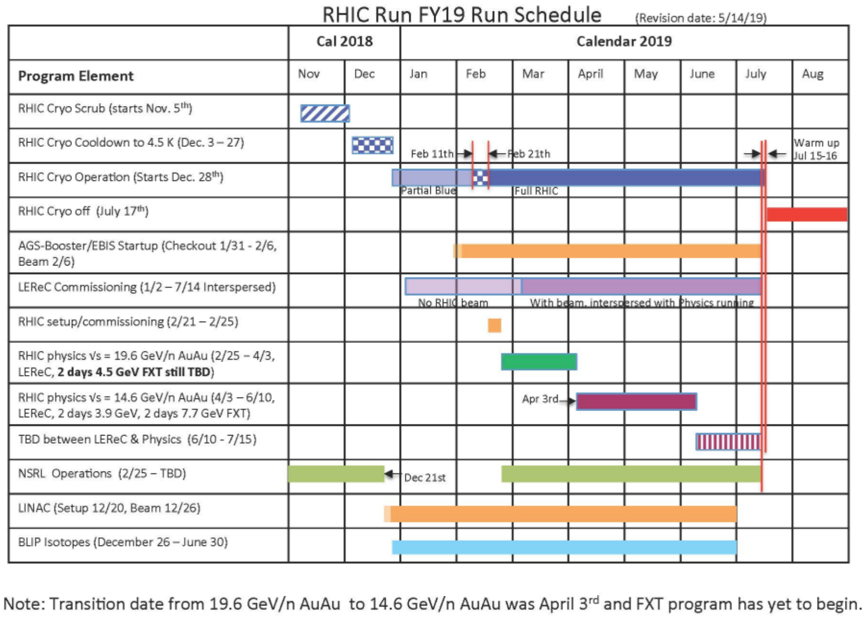
U.S. DEPARTMENT OF ENERGY

Outline

- Overview of RHIC Run-19
- Challenges for Beam Energy Scan II (BES-II)
- Run-19 performance in colliding mode
- Run-19 fixed target experiments
- Projections for Run-20
- Summary

Overview of Run-19

- LEReC electron beam commissioning before RHIC started on Feb. 11th.
- Interleave of physics program and LEReC commissioning.
- Physics at 9.8 GeV/nucleon went smoothly. STAR was flexible on LEReC dedicated time allocation.
- Physics at 7.3 GeV/nucleon went smoothly as well with physics running during weekends.
- Fixed target experiments at 7.3 GeV/nucleon beam energy was greatly improved with large beta star.
- Physics at 3.85 GeV/nucleon and more are planned for the rest of the Run-19.



RHIC Run FY19 Run Schedule (Revision date: 5/14/19)

	Cal 2018		Calendar 2019							
Program Element	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug
RHIC Cryo Scrub (starts Nov. 5th)										
RHIC Cryo Cooldown to 4.5 K (Dec. 3 – 27)										
RHIC Cryo Operation (Starts Dec. 28th)										
RHIC Cryo off (July 17th)										
AGS-Booster/EBIS Startup (Checkout 1/31 - 2/6, Beam 2/6)										
LEReC Commissioning (1/2 – 7/14 Interspersed)										
RHIC setup/commissioning (2/21 – 2/25)										
RHIC physics √s = 19.6 GeV/n AuAu (2/25 – 4/3, LEReC, **2 days 4.5 GeV FXT still TBD**)										
RHIC physics √s = 14.6 GeV/n AuAu (4/3 – 6/10, LEReC, 2 days 3.9 GeV, 2 days 7.7 GeV FXT)										
TBD between LEReC & Physics (6/10 - 7/15)										
NSRL Operations (2/25 – TBD)										
LINAC (Setup 12/20, Beam 12/26)										
BLIP Isotopes (December 26 – June 30)										

Note: Transition date from 19.6 GeV/n AuAu to 14.6 GeV/n AuAu was April 3rd and FXT program has yet to begin.

Challenge #1: Intra-beam scattering

- At BES-I/II beam energies, which are below the transition energy (~24 GeV/nucleon for Au beam), both longitudinal and transverse beam emittance grow rapidly due to intra-beam scattering (IBS).

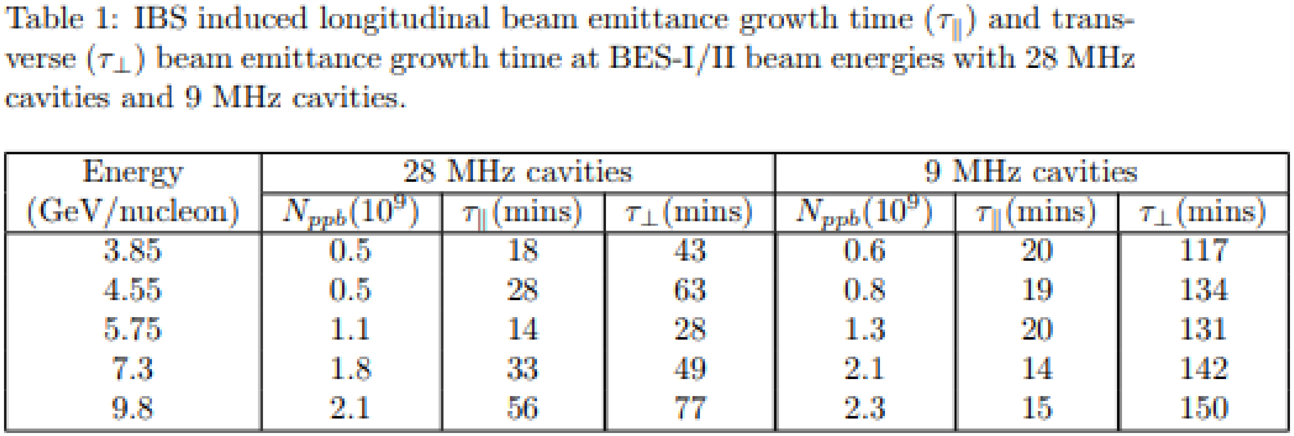


Table 1: IBS induced longitudinal beam emittance growth time ($\tau_{\|}$) and transverse ($\tau_{\perp}$) beam emittance growth time at BES-I/II beam energies with 28 MHz cavities and 9 MHz cavities.

Energy	28 MHz cavities			9 MHz cavities		
(GeV/nucleon)	$N_{ppb}(10^9)$	$\tau_{\|}$(mins)	$\tau_{\perp}$(mins)	$N_{ppb}(10^9)$	$\tau_{\|}$(mins)	$\tau_{\perp}$(mins)
3.85	0.5	18	43	0.6	20	117
4.55	0.5	28	63	0.8	19	134
5.75	1.1	14	28	1.3	20	131
7.3	1.8	33	49	2.1	14	142
9.8	2.1	56	77	2.3	15	150

LEReC cooling

- The Low Energy RHIC electron Cooling (LEReC), using a linear electron accelerator, is designed to combat the IBS effect by cooling RHIC ion beams, and therefore to improve luminosities at the three lowest beam energies.

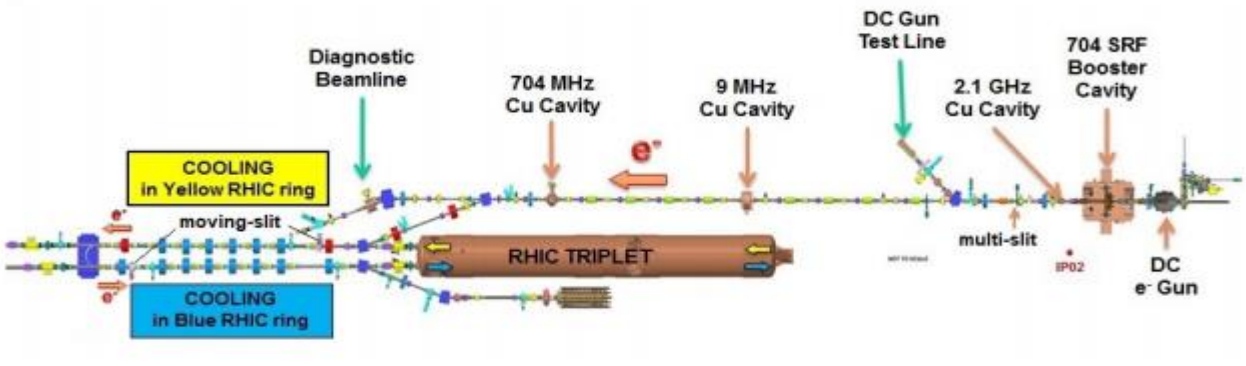


Figure 1: Schematics of Low Energy RHIC electron Cooling accelerator. Low energy electron beam is transported through a beamline with solenoids, merged into a cooling section in the Yellow RHIC ring first, turned around and merged into a cooling section in the Blue RHIC ring.

Challenges #2: Space charge

- At the BES-I/II beam energies, the ions in the beam experience a strong direct space charge force. The space charge force introduces incoherent and coherent tune shifts.
- The space charge effects are significantly reduced by using the new 9 MHz cavities due to reduced peak beam intensity.
- The 9 MHz cavities provide a larger bucket area than the 28 MHz cavities.

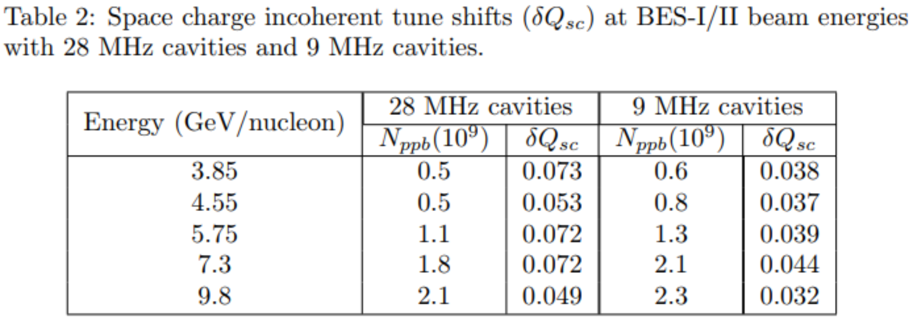


Table 2: Space charge incoherent tune shifts (δQ_{sc}) at BES-I/II beam energies with 28 MHz cavities and 9 MHz cavities.

Energy (GeV/nucleon)	28 MHz cavities		9 MHz cavities	
	$N_{ppb}(10^9)$	δQ_{sc}	$N_{ppb}(10^9)$	δQ_{sc}
3.85	0.5	0.073	0.6	0.038
4.55	0.5	0.053	0.8	0.037
5.75	1.1	0.072	1.3	0.039
7.3	1.8	0.072	2.1	0.044
9.8	2.1	0.049	2.3	0.032

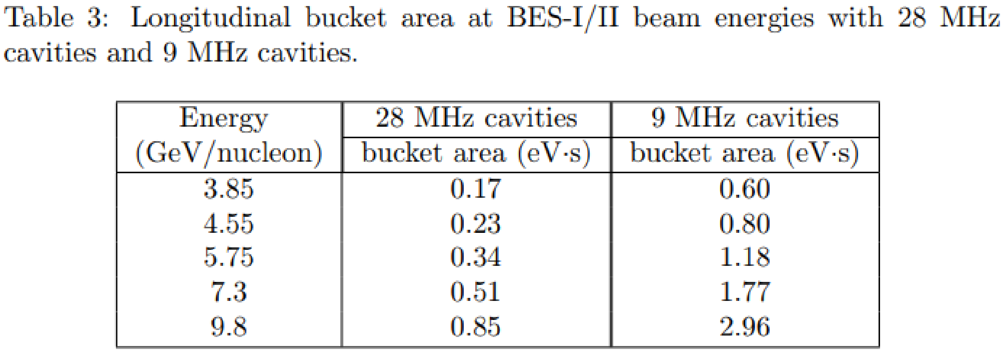


Table 3: Longitudinal bucket area at BES-I/II beam energies with 28 MHz cavities and 9 MHz cavities.

Energy (GeV/nucleon)	28 MHz cavities bucket area (eV·s)	9 MHz cavities bucket area (eV·s)
3.85	0.17	0.60
4.55	0.23	0.80
5.75	0.34	1.18
7.3	0.51	1.77
9.8	0.85	2.96

Challenges #3: beam-beam

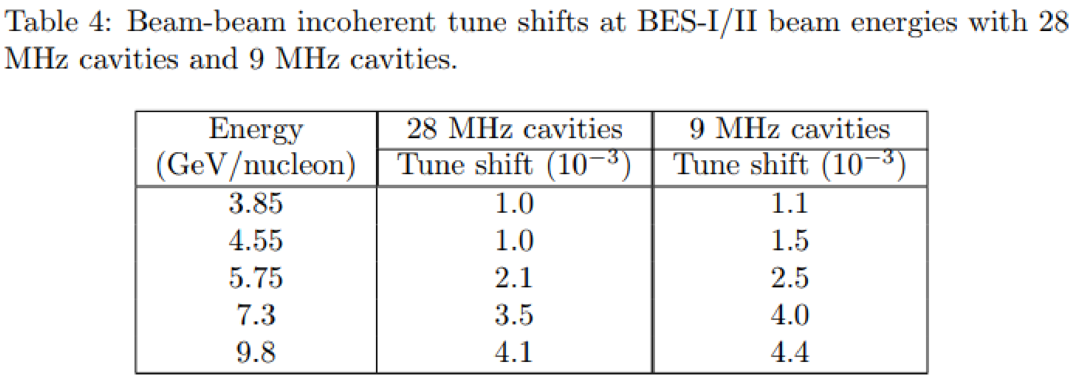
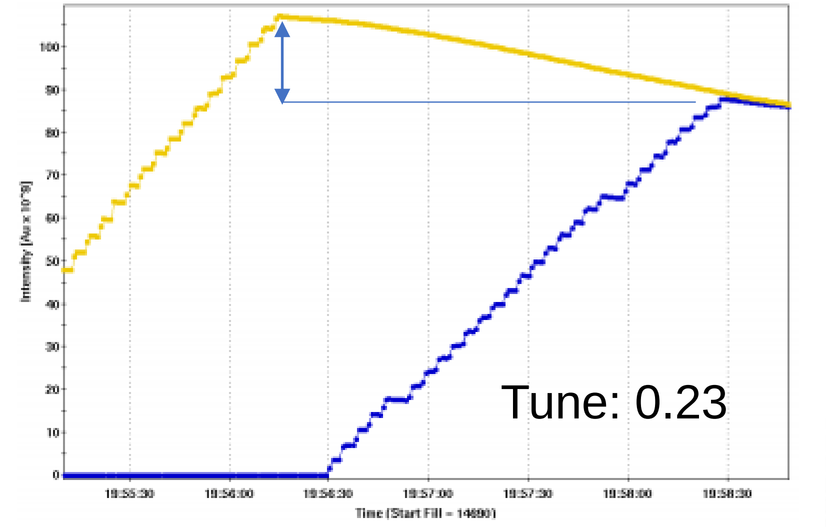


Table 4: Beam-beam incoherent tune shifts at BES-I/II beam energies with 28 MHz cavities and 9 MHz cavities.

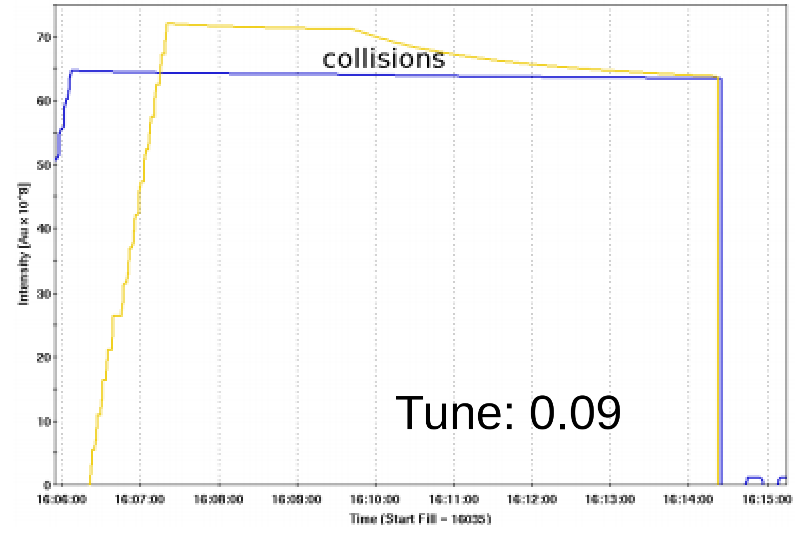
Energy (GeV/nucleon)	28 MHz cavities Tune shift (10^{-3})	9 MHz cavities Tune shift (10^{-3})
3.85	1.0	1.1
4.55	1.0	1.5
5.75	2.1	2.5
7.3	3.5	4.0
9.8	4.1	4.4

Significant beam loss



Tune: 0.23

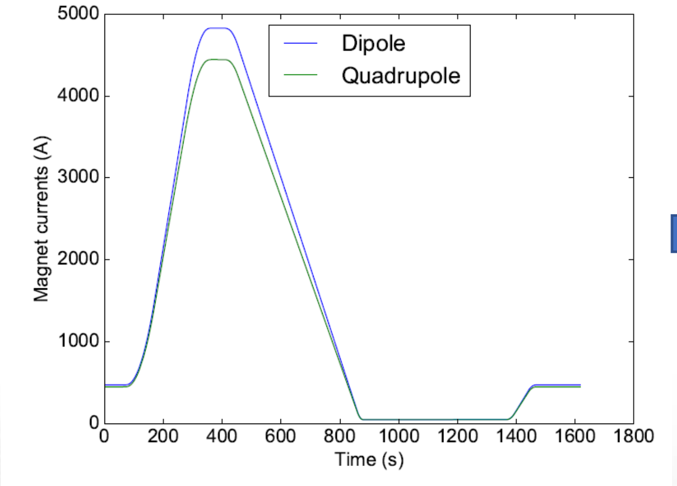
Much improved lifetime with collision



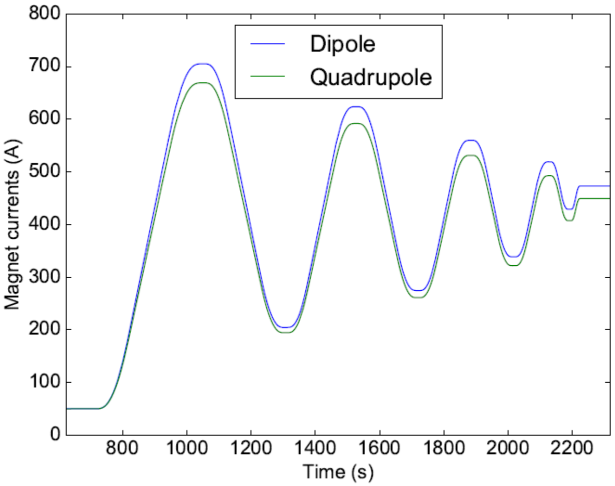
Tune: 0.09

Challenge #4: persistent current in superconducting magnet

- Persistent currents in superconducting magnets introduce significant field errors.
- The decay of magnetic field errors causes the drifts of beam oribts, tunes and chromaticities.

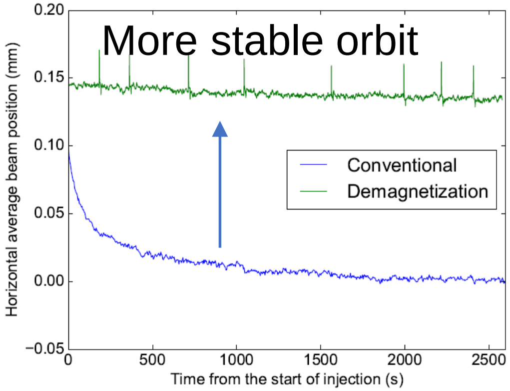


Regular cycle



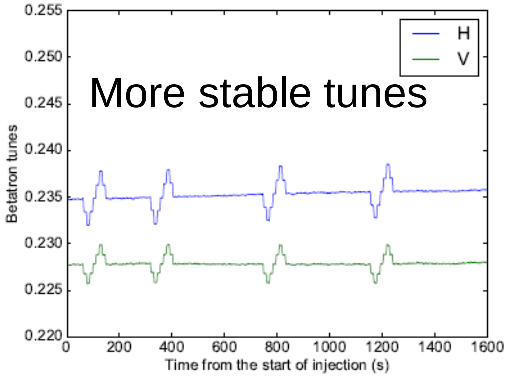
Demagnetization cycle

Reduction of persistent current by demagnetization cycle

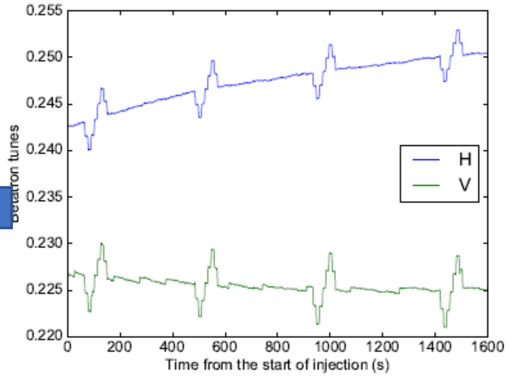


More stable orbit

FIG. 6: Comparison of the horizontal average beam position drifts, due to persistent currents decay in superconducting dipoles, with the conventional cycle (the blue curve) and the demagnetization cycle (the green curve).



More stable tunes



More stable chromaticity

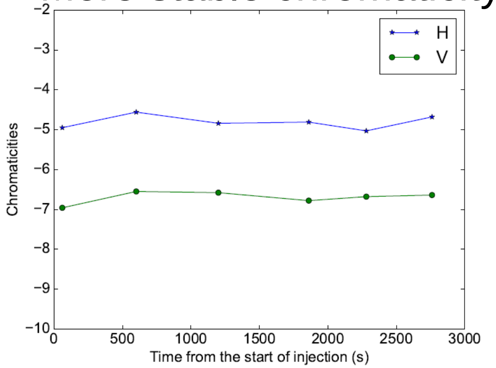
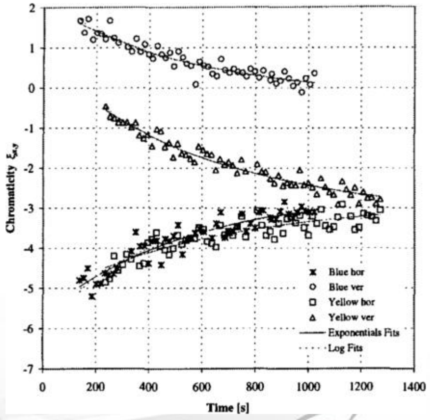
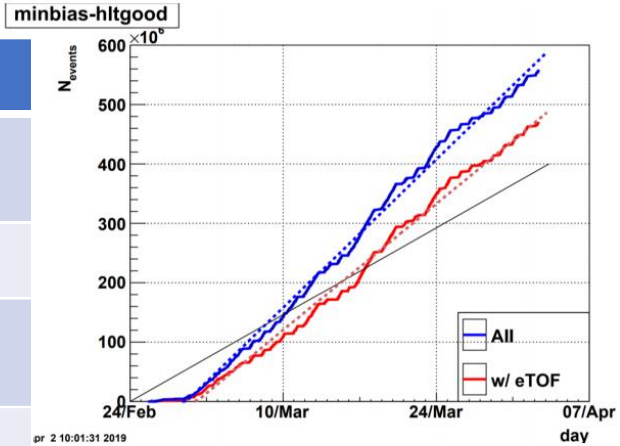


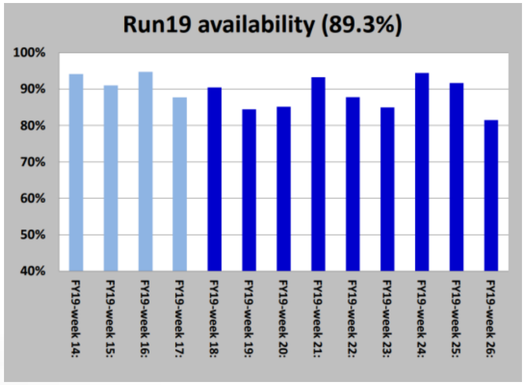
FIG. 8: The measured beam chromaticities after the demagnetization cycle.



Performance at 9.8 GeV/nucleon

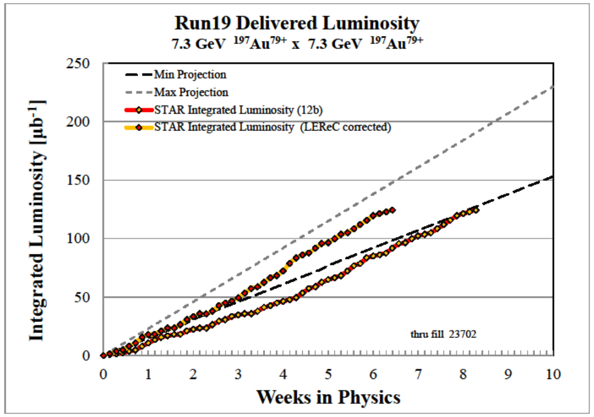
Parameters	Unit	Value	Note
Bunch intensity	ppb	1.8E9	Bunched, at collision, limited by beam-gas
Beta star	m	2	Started with 3
Working point		(0.09, 0.085)	
f_RF	MHz	28	
Setup time	days	7	Include other energies
Time between stores	minutes	20	
Store length	minutes	60	
Peak luminosity	10^{24}cm^{-2}s^{-1}	500	
Average luminosity	10^{24}cm^{-2}s^{-1}	130	

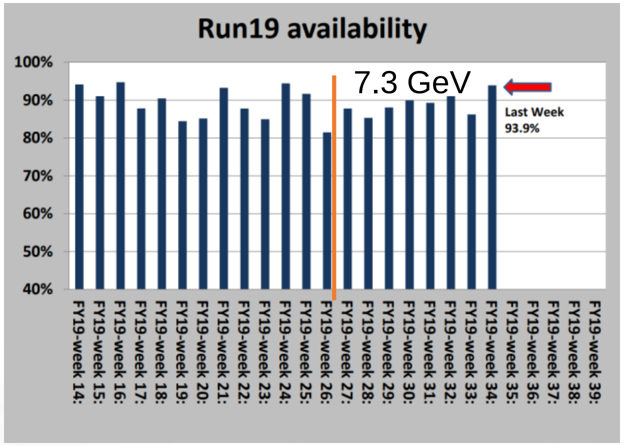




Performance at 7.3 GeV/nucleon

Parameters	Unit	Value	Note
Bunch intensity	ppb	1.8E9	Bunched, at collision, limited by bucket area
Beta star	m	B: 2.5, Y: 3	Comprise bwt lumi verus background
Working point		(0.09, 0.085)	Low loss with collision
Setup time	days	2	AGS RHIC synchro
f_RF	MHz	28	
Time between stores	minutes	20	
Store length	minutes	45	
Peak luminosity	$10^{24}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	240	
Average luminosity	$10^{24}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	60	



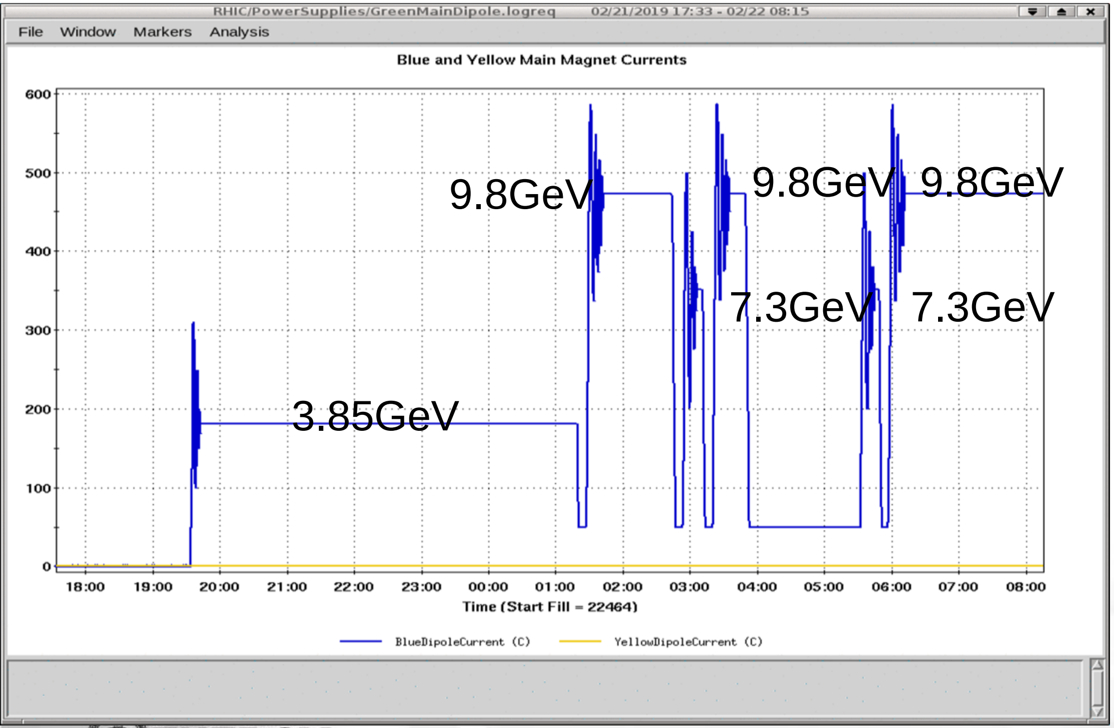


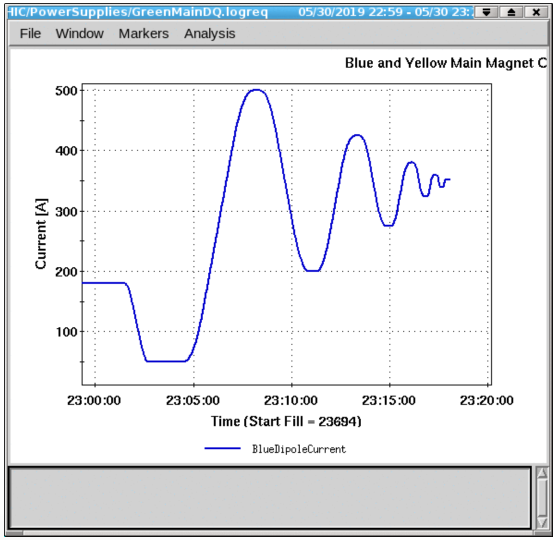
What’s new compared to Run-11

- For physics at 9.8 and 7.3 GeV/nucleon:
  - Wiggle (demagnetization) ramp for RHIC superconducting magnets to reduce persistent current effects.
  - New betatron working point at 0.09/0.08.
  - Beta squeeze at IP6 for higher luminosity.
  - Upgrade of corrector control from 12 to 16 bit.
  - ATR re-alignment, additional BPM at WD4.
- For LEReC cooling commissioning:
  - New 9 MHz cavities for 3.85 GeV/nucleon, much improved lifetime.
  - Improved lifetime due to wiggle (demagnetization) ramp.
  - Flat orbit in LEReC cooling section with g1-tvx separation bump.

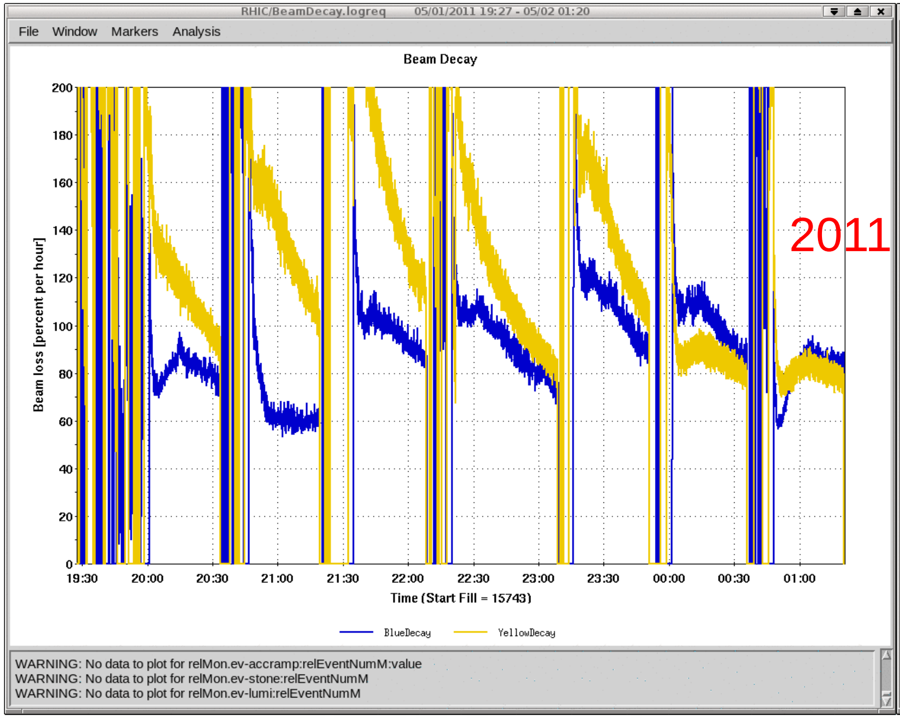
Mode-switching and wiggles

- Benefits: quickly switch between energies, zero wait time for persistent currents to settle down; Orbit, tune and chromaticity stability much improved; automatically restore correct settings for systems.





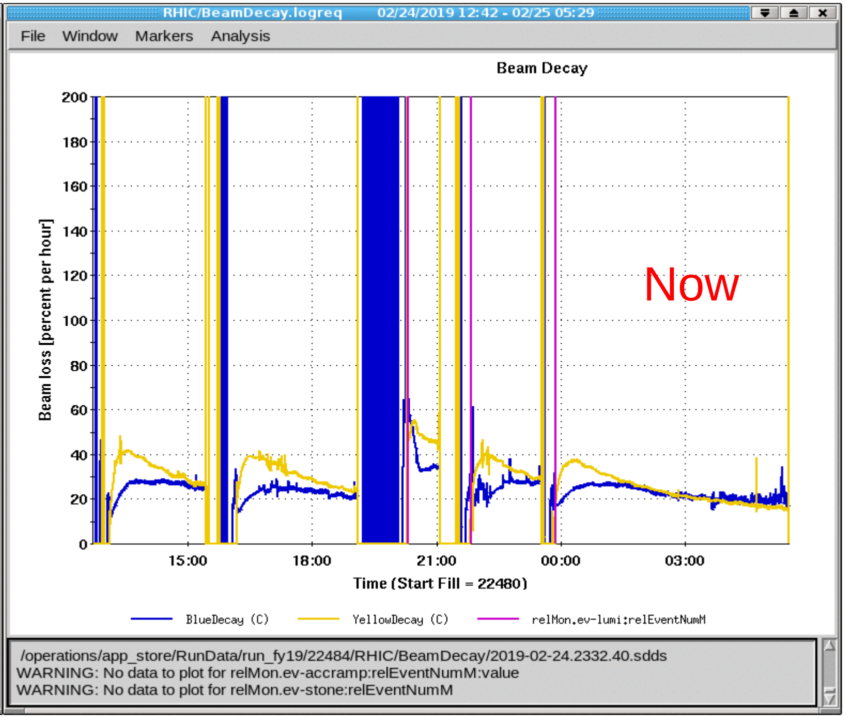
Less beam loss with the new working point at 9.8 GeV



RHIC/BeamDecay.logreq 05/01/2011 19:27 - 05/02 01:20

2011

WARNING: No data to plot for relMon.ev-accramp:relEventNumM:value
WARNING: No data to plot for relMon.ev-stone:relEventNumM
WARNING: No data to plot for relMon.ev-lumi:relEventNumM



RHIC/BeamDecay.logreq 02/24/2019 12:42 - 02/25 05:29

Now

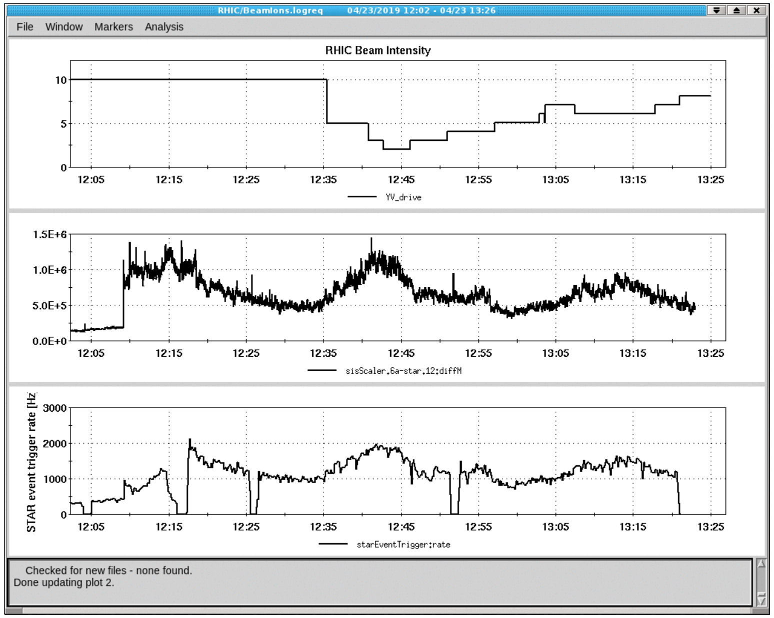
/operations/app_store/RunData/run_fy19/22484/RHIC/BeamDecay/2019-02-24.2332.40.sdds
WARNING: No data to plot for relMon.ev-accramp:relEventNumM:value
WARNING: No data to plot for relMon.ev-stone:relEventNumM

Operational challenges for physics at 9.8 and 7.3GeV

- Beam-gas interaction induced background, beam scrubbing was not quite effective at 9.8 GeV.
- Limited bucket acceptance at 7.3 GeV: tight tolerance on injection matching, more de-bunched beam.
- Background control: injection kicker kicking de-bunched beam; beam scraping in the triplets with squeezed beta star.
- Run gap cleaning at the end of stores to avoid generating background and hurting bunched beam.

Fixed target test run at 7.3 GeV/nucleon

- Beta star at IP6 was designed 10 m, lattice with even larger beta function was available.
- Required orbit shift was ~9 mm. Event rate was very sensitive to orbit in this neighborhood.
- Background was well under controlled.
- BBQ kicker, engaged to improve event rate, was very effective.



Checked for new files - none found.
Done updating plot 2.

Projections for Run-20

- Plan to have LEReC cooling operational for 3.85 and 4.55 GeV/nucleon, but not for 5.75 GeV/nucleon because electron beam energy is limited by RF system.
- The improvement of luminosity at 5.75 GeV is expected from more bunch intensity, better lifetime, more stable machine condition.
- Smooth running for all fixed target energies are expected.
- O+O collision at 100 GeV requires 2e28 cm^-2s^-1 average luminosity (RHIC can provide lumi 8 times of that).

Summary

- RHIC physics running and LEReC commissioning coexisted near perfectly during 2019.
- RHIC performance at 9.8 and 7.3 GeV were substantially improved with new developments compared to previous running.
- LEReC team achieved their tremendous goals during cooling commissioning in 2019, and demonstrated for the first time cooling of ion bunches with RF accelerated electron bunches.
- Fixed target experiments running conditions were improved with larger beta star. Future FXTs will benefit as well.
- We are planning for a challenging RHIC running with operational LEReC next year.