C-AD Run 18 Report

2018 RHIC & AGS Annual Users' Meeting

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BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Overview

Run 18 was in many ways a unique and challenging heavy ion run for the Collider. This year involved four different configurations of the Physics program:

- ***100 GeV $^{96}Zr^{40+}$ x 100 GeV $^{96}Zr^{40+}$***
- ***100 GeV $^{96}Ru^{44+}$ x 100 GeV $^{96}Ru^{44+}$***
- ***13.5 GeV $^{197}Au^{79+}$ x 13.5 GeV $^{197}Au^{79+}$***
- ***3.85 GeV $^{197}Au^{79+}$ Fixed Target Operation*** *(Yellow ring only)*

Additionally, we continued support of the coherent electron cooling proof of principle (CeC PoP) project with its own configuration:

- ***26.5 GeV $^{197}Au^{79+}$*** *(Yellow ring only)*

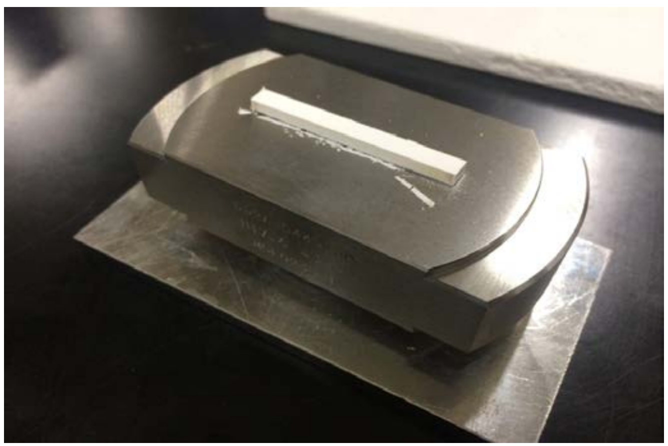
Commissioning of the low energy RHIC electron cooling system (LEReC) also took place (see following talk).

Zirconium and Ruthenium

- The isobar run required our ion sources produce beams from two rare isotopes:
  - ^{96}**Zr** – 2.8% natural abundance
  - ^{96}**Ru** – 5.5% natural abundance
- Neither source material (ZrO_2 at EBIS, Ru metal at Tandem) produces sufficient beam intensity as required by the RHIC, unless enriched.
- Complications:
  - Enriched ^{96}Ru was not available in any sufficient quantity.
  - Enriched ^{96}Zr is commercially available, but ZrO_2 powder does not make a good target for EBIS laser ion source.

Zirconium and Ruthenium: more precious than Gold

With assistance from experts at RIKEN, Japan, six enriched ^{96}Zr targets were made, employing their expertise in the sintering process.



Part of sintering process at RIKEN to form solid ZrO_2 targets for EBIS

Sidenote: $^{96}Zr^{16+}$ and $^{90}Zr^{15+}$ have the same rigidity in Booster. We could save on enriched material by tuning up EBIS and Booster with a source of natural Zr.

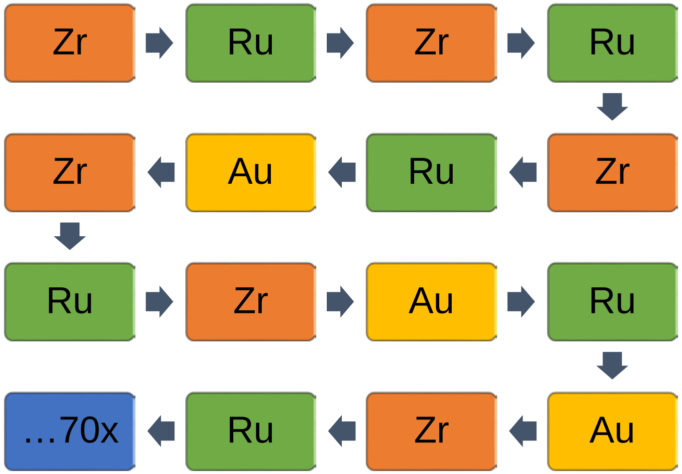
With the facility just coming online, the DOE Isotope Program provided 500mg of ^{96}Ru, with a dedicated production run at the Enriched Stable Isotope Pilot Plant (ESIPP) at Oak Ridge.

At 25% abundance (mixed at Tandem with ^{27}Al), this source produced more than sufficient intensity for the needs of this run.

Electromagnetic separation of ^{96}Ru. Image courtesy of ESIPP at ORNL.

Mode switching

- To eliminate systematics, the request was made to alternate daily between species.
- There are over a million parameters in our control system
  - It can be difficult to keep track of all that is necessary to change between different RHIC setups
  - It’s a time-consuming process to accomplish manually.
- Expanding use of software previously developed to make quick changes to injector setups, we were able to create sequences to switch the RHIC between Zr, Ru, and Au modes, and identify the relevant parameters to save and reload when changing species.
- With little additional cost in setup and store-to-store time, this was one key to producing high integrated luminosity for Run 18.



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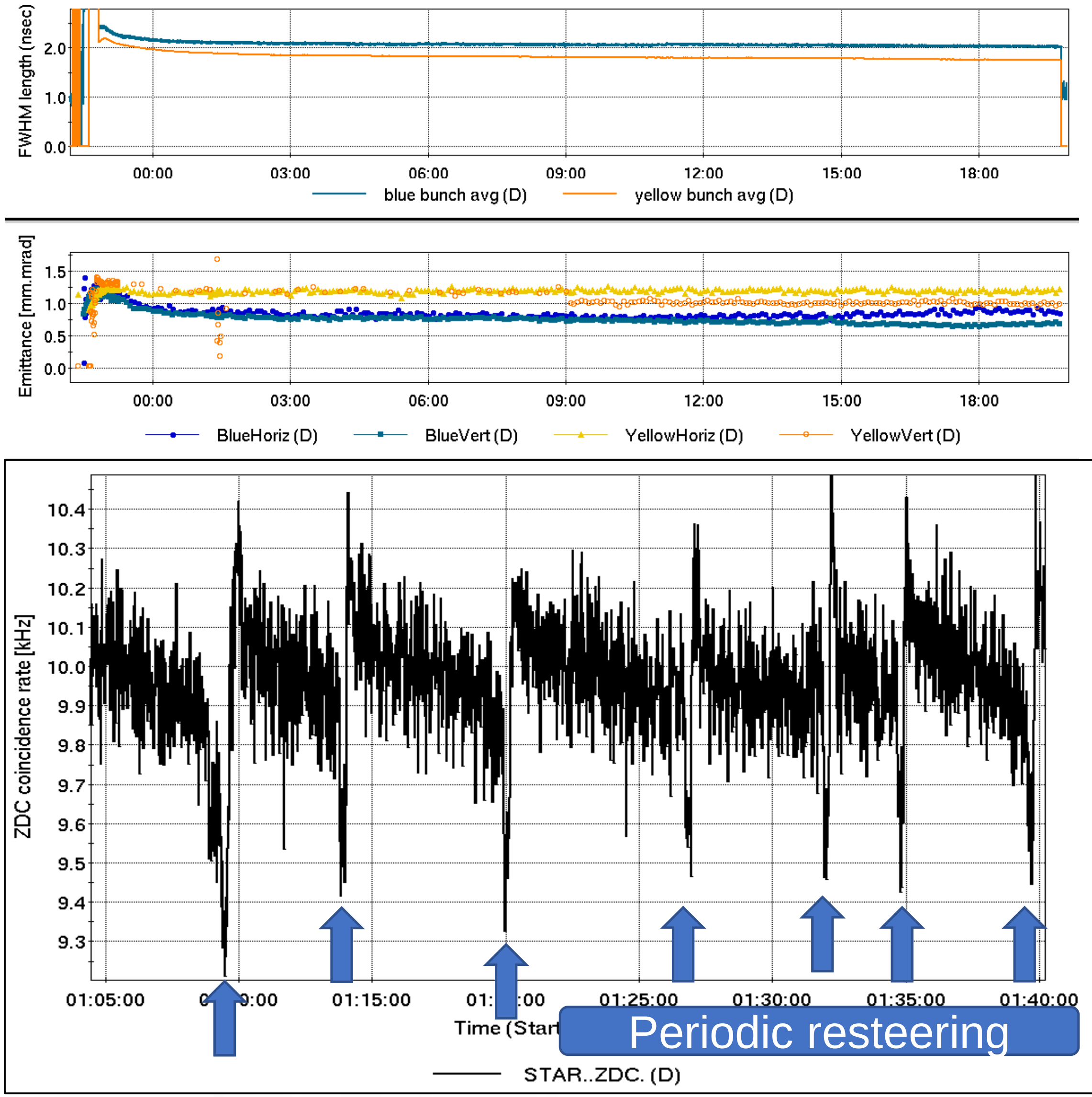
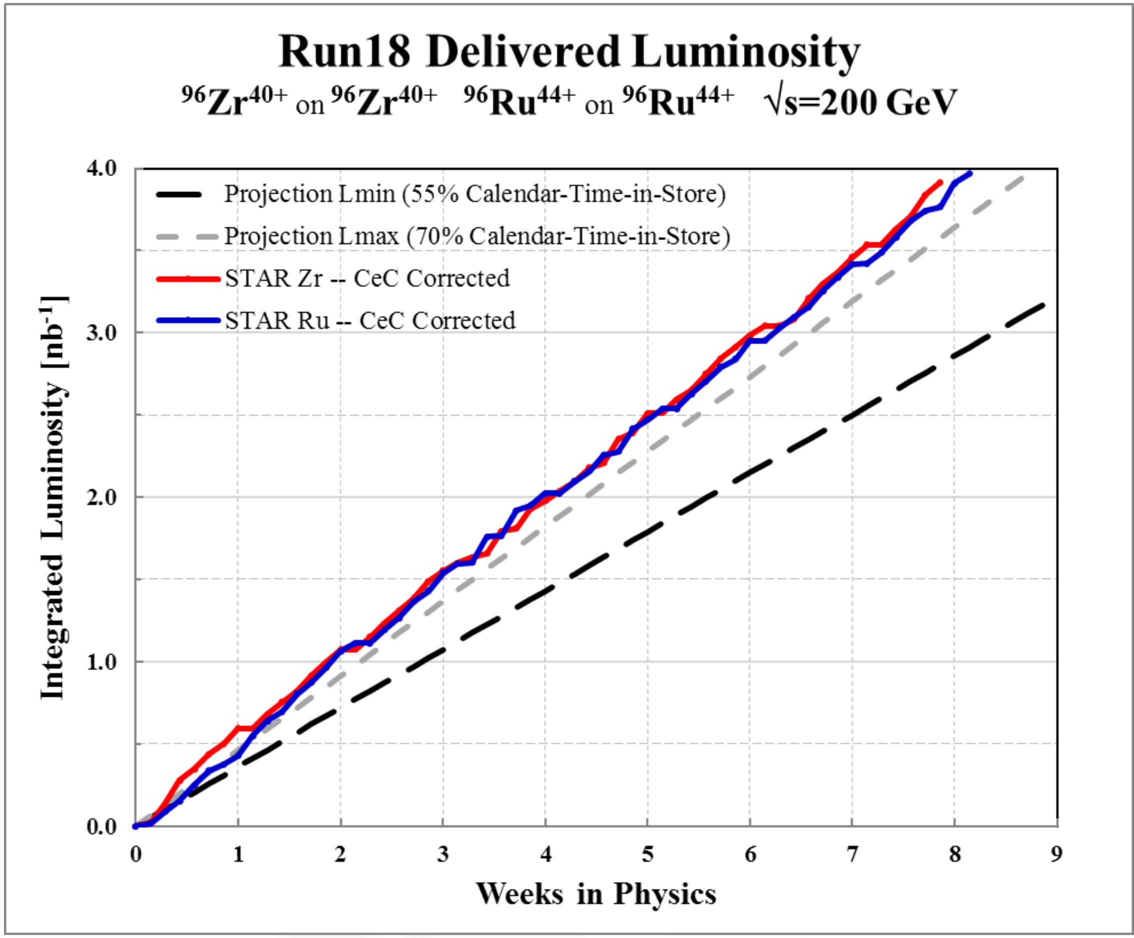
Level luminosity

- The initial request from STAR was to maintain level ZDC rates at 10 kHz, ±5 kHz over the course of a store.
- Other parameters (intensity, emittance, etc.) needed to be as repeatable as possible from store to store as well between Zr and Ru.
- We were able to maintain 10 kHz, ***±0.5 kHz*** for over 20 hours.
  - Initial beam intensity allowed for mis-steering beams, automatically adjusting to maintain collision rates
  - Stochastic cooling applied to maintain beam emittance during store.



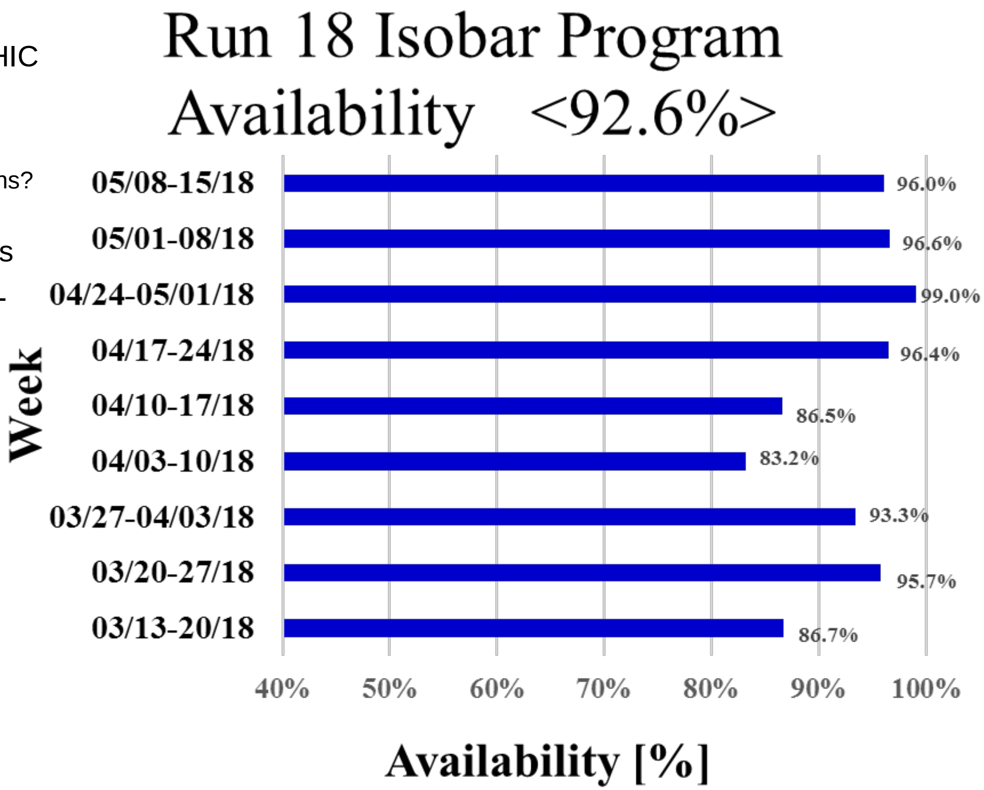
Results: 200 GeV Ru & Zr

- Setup three (Ru, Zr, Au) beams, started physics in 6 days
  - A new record for beam setup (for one beam -- we set up 3)
  - First time RHIC had 3 different species within same 24 hours
  - Includes 2 snowstorms (unscheduled)
- Regular switching incurred minimal delays (~5 min/store)
- Exceeded projected luminosity, which helped STAR accumulate a larger data set than originally planned



Why so good?

- Availability was high.
    - Rigidity at store energy slightly lower = less stress on RHIC magnet systems
    - Only 1 abort system kicker prefire
        - Lower voltage at this store energy? Thyratron grid modifications? Less beam losses?
    - Low failure rate from most all injector/collider subsystems
    - Reduced secondary beams from ion collisions, lower off-momentum losses, etc.
- Stores were long
    - Fewer setup periods to cycle the Collider
- Stochastic cooling
    - Constant emittance over stores
- Luminosity levelling
    - Constant rates over 20 hours gave better integrated luminosity
- Intensity requirements were low
    - Stochastic cooling more effective
    - Intensity margin allowed for luminosity leveling
    - Less strain on source, injectors
    - One collision point, less beam-beam interactions



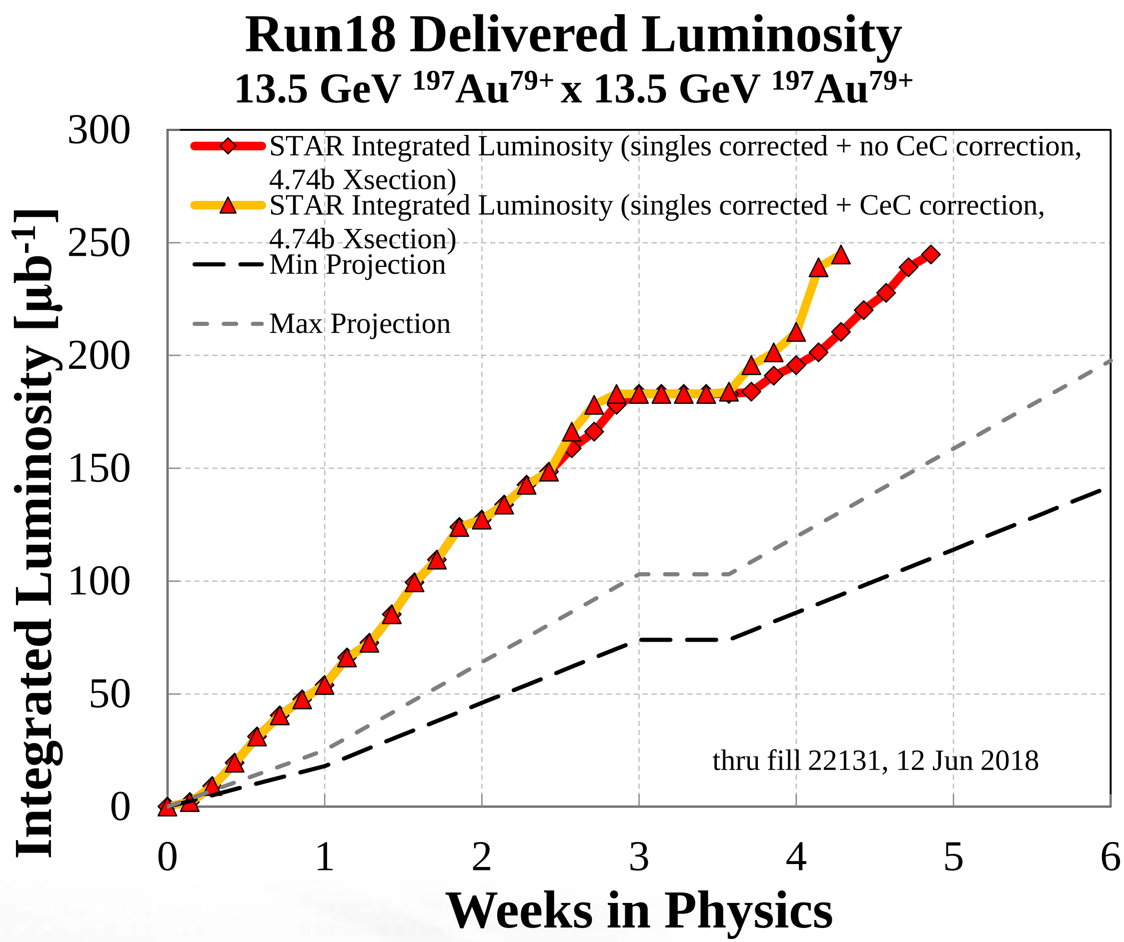
Courtesy P. Ingrassia

"Medium" energy gold

- In contrast to the isobar program, Au at 13.5 GeV ($\sqrt{s_{NN}} = 27$ GeV) makes use of a previous setup, but required more constant attention
  - Store length down to 1.5 hours
  - No stochastic cooling at this energy
  - No data rate limits from experiment: maximum intensity required
- Explored tune working points near the integer
  - Loss rates at store improved
  - Orbit control issues due to resolution of power supply interface
  - Ramp losses were concentrated in undesirable locations
- Machine time shared with CeC project
  - Concurrently, STAR made use of its fixed target at 26.5 GeV

Results: 27 GeV Au

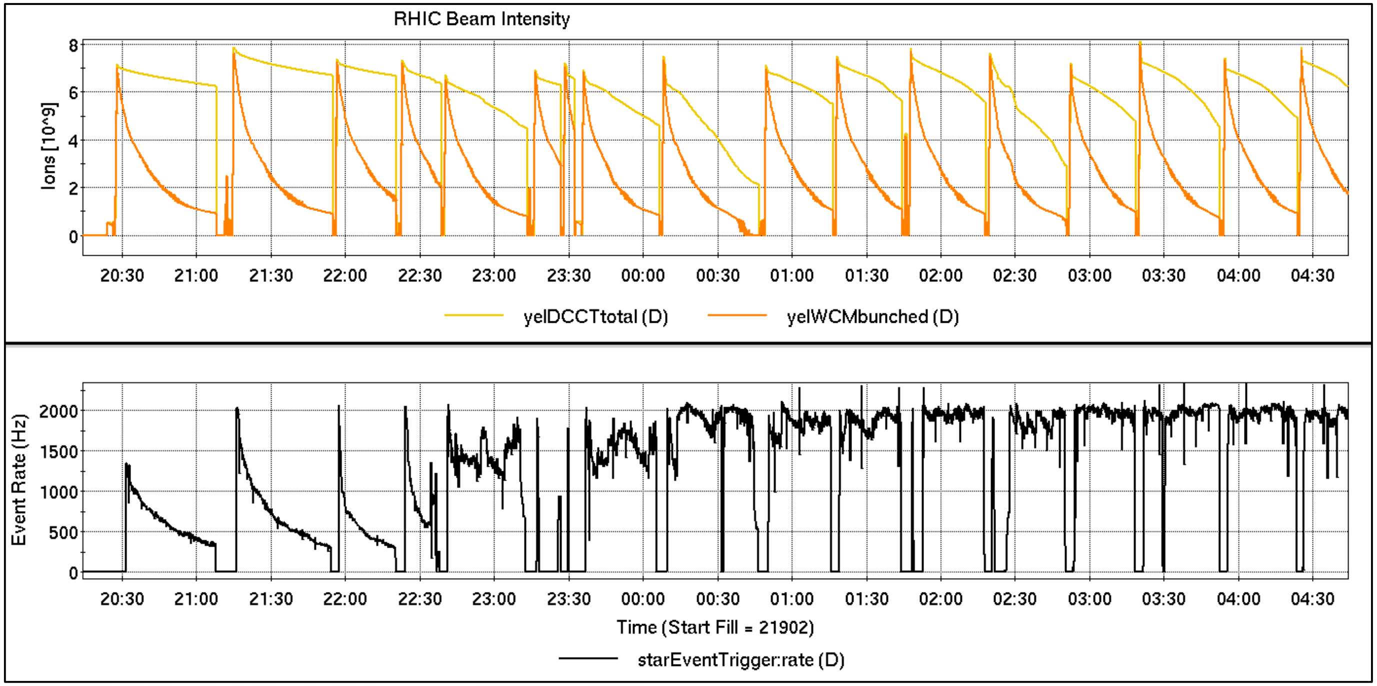
- From setup to physics: 25 hours
- Exceeded projected luminosity goals
- In beginning of run, intensity limited by background rates at STAR
- Later in run, intensity limited by source performance (still, 30-40% above previous run)



Fixed Target

Within the medium energy Au run, the RHIC was reconfigured to run beam at low energy, 3.85 GeV in the Yellow ring. The circulating beam was moved down vertically to interact with a fixed gold target in the STAR detector.

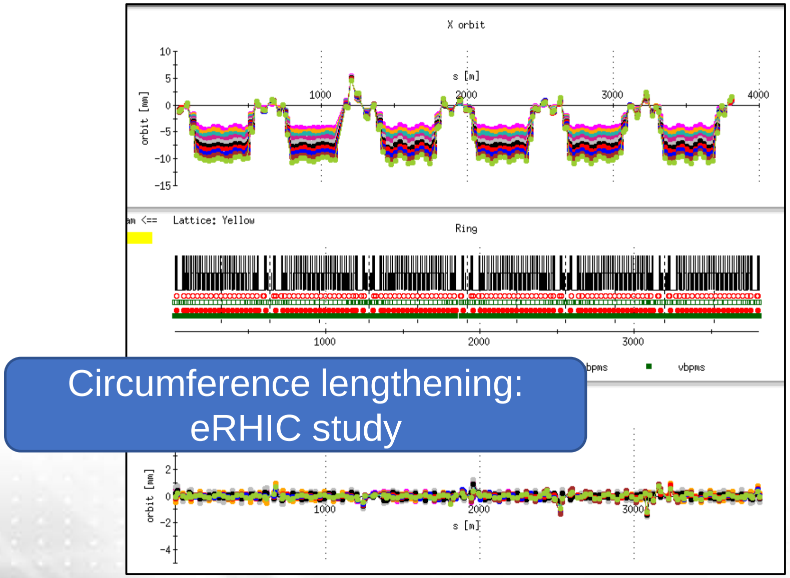
Operators were able to deliver sustained data rates by exciting beam with baseband tune meter (BBQ) kicker.

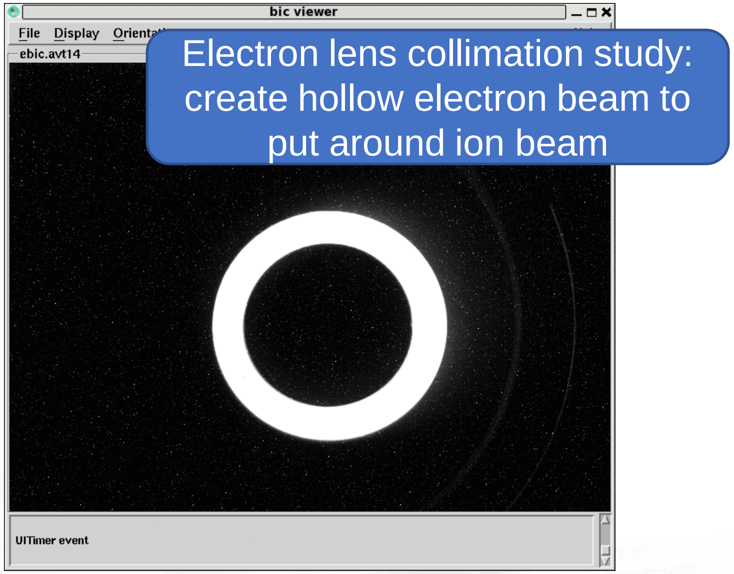


As a result, STAR gained more than 3 times their original event goal.

Looking Forward: MD and APEX

- In addition to running the Physics program, C-AD uses the collider to conduct accelerator physics experiments (APEX) and machine development (MD)
  - Machine Development is focused to improve the machine conditions in the present or near future.
  - Accelerator Physics Experiments are intended to increase our understanding of the collider and its beam dynamics, and test concepts to be used in future accelerator design.



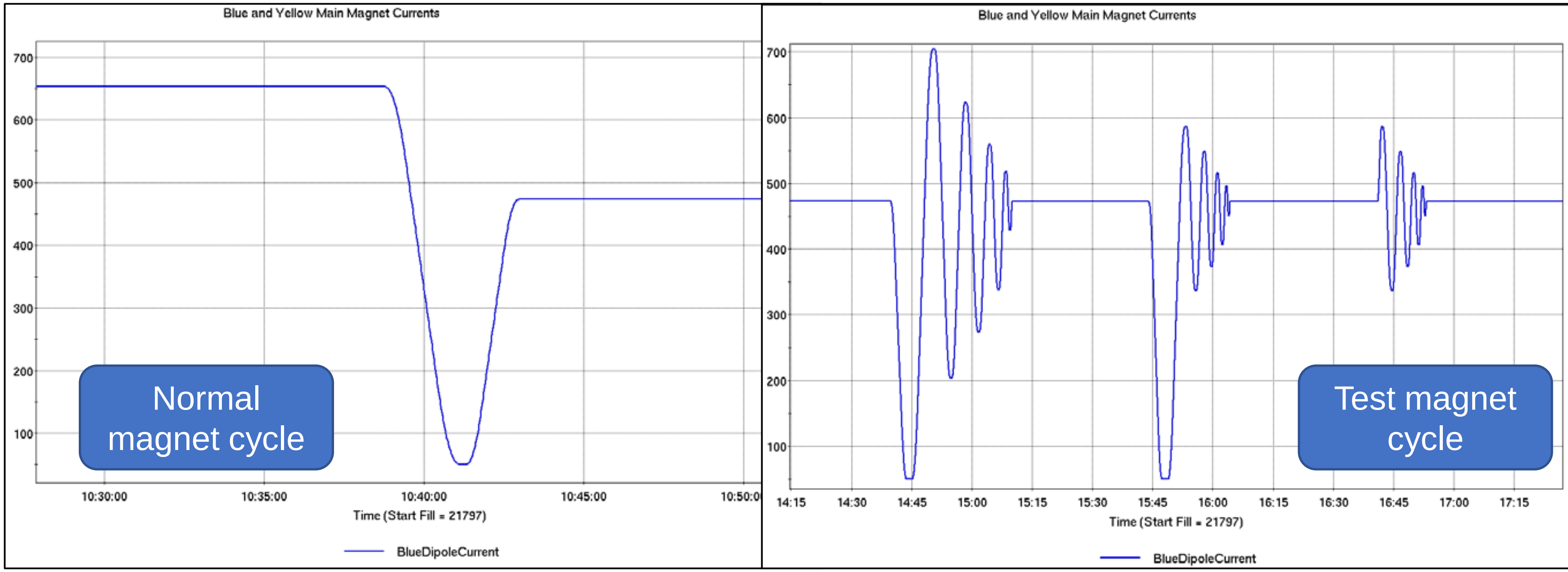


Looking forward: BES-II tests

While at low energy during the fixed target portion of Run-18, Machine Development with beam took place to better prepare for upcoming runs at low energy. Other test took place at normal injection energy.

- As a direct impact, the beam conditions were improved for the remainder of the fixed target run following the MD session (tune, coupling adjustments).
- Experience gained with orbit corrections at low energy and near-integer tunes confirm the need to upgrade power supply interface controls, from 12- to 16-bit resolution.
- New magnet cycles were tested in an attempt to improve reproducibility and reduce harmonic components caused by persistent currents in the dipoles.

Looking forward: BES-II tests



Hysteresis cycles: extra "wiggles" intended to reduce amplitude of persistent current drift, and minimize sextupole component in main dipole magnets

Looking forward: BES-II tests

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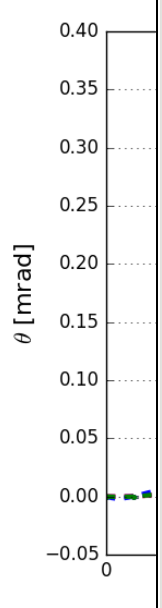

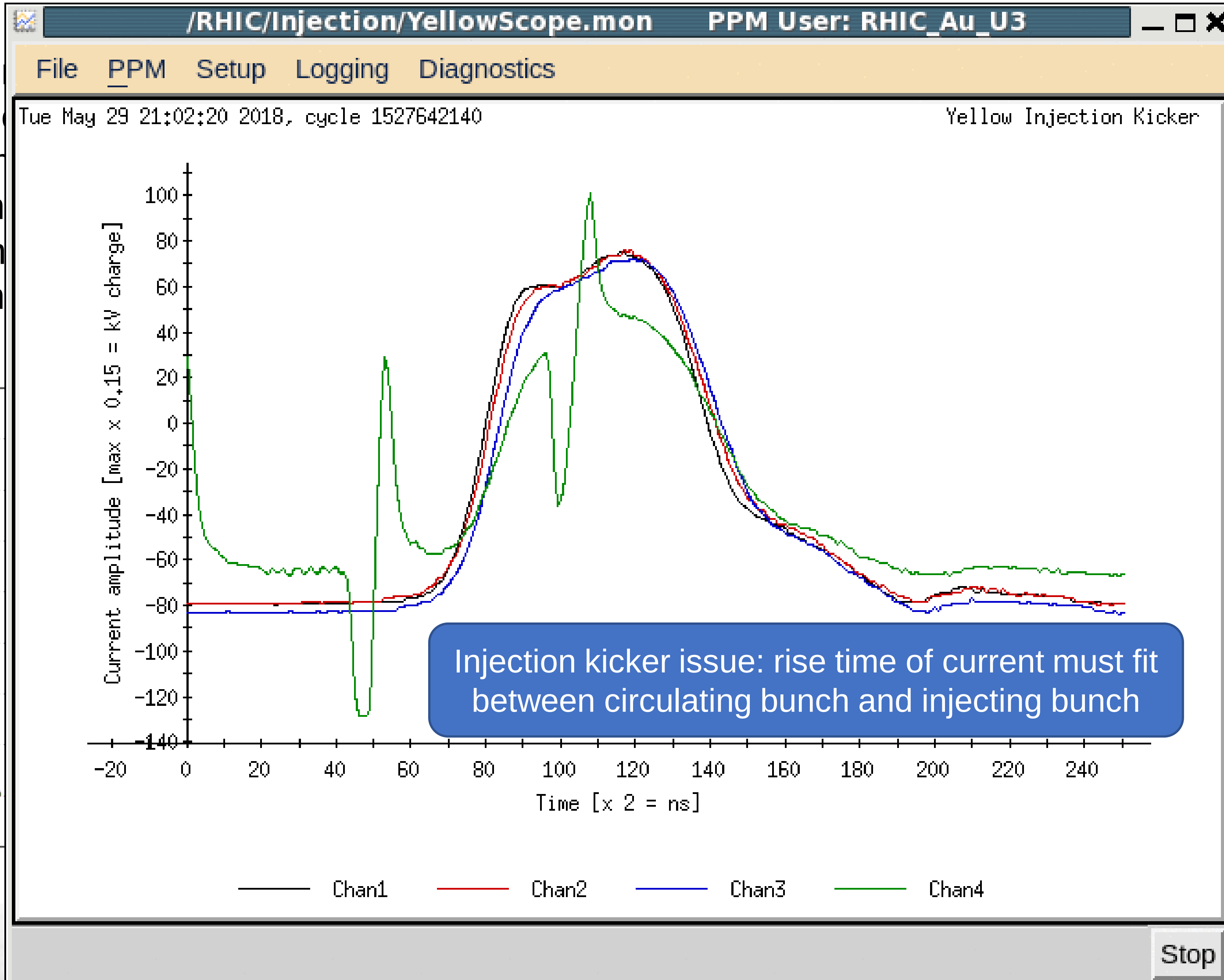

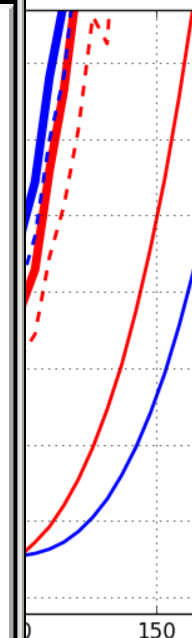

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Summary

- Run 18 was a challenging run that required the Collider be more versatile than previous runs. The RHIC again showed that it is adaptable, as that challenge was met or exceeded on nearly all counts.
- Time was spent to better prepare for upcoming runs, BES-II and beyond.
- The C-AD complex ran with high availability. More than five different setups were used in the collider, with dozens of switches between setups. Those that produced data for the Physics program did so exceedingly well.
- The hard work of the Operations Group and entire C-AD staff made the task of Run Coordinator much more simple. My thanks to all for the effort behind Run 18.