Finale of RHIC Beam Energy Scan II Operation

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Virtual RHIC Retreat 2021

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Outline

- Overview of Run-21
- Run-21 programs
- Summary

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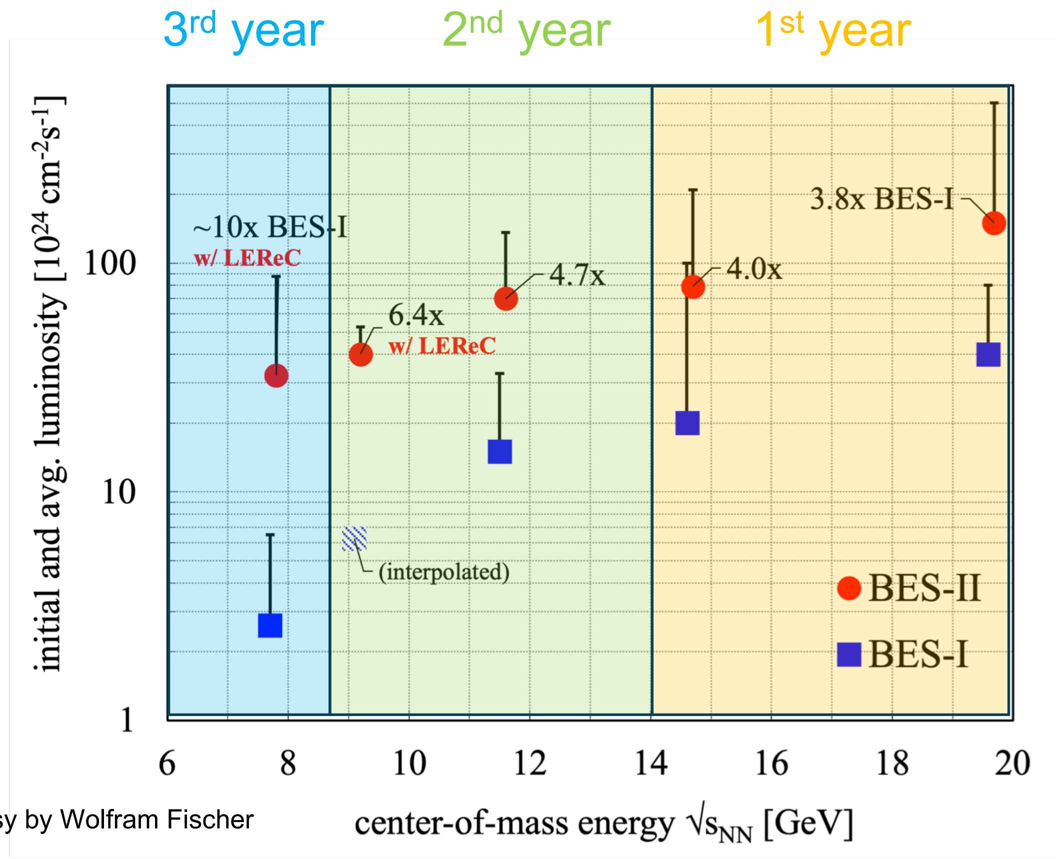
Trilogy of BES-II



Courtesy by Wolfram Fischer

The third year of BES-II operation is the most challenging, exciting and rewarding one of the three.

Run-21 programs and schedule

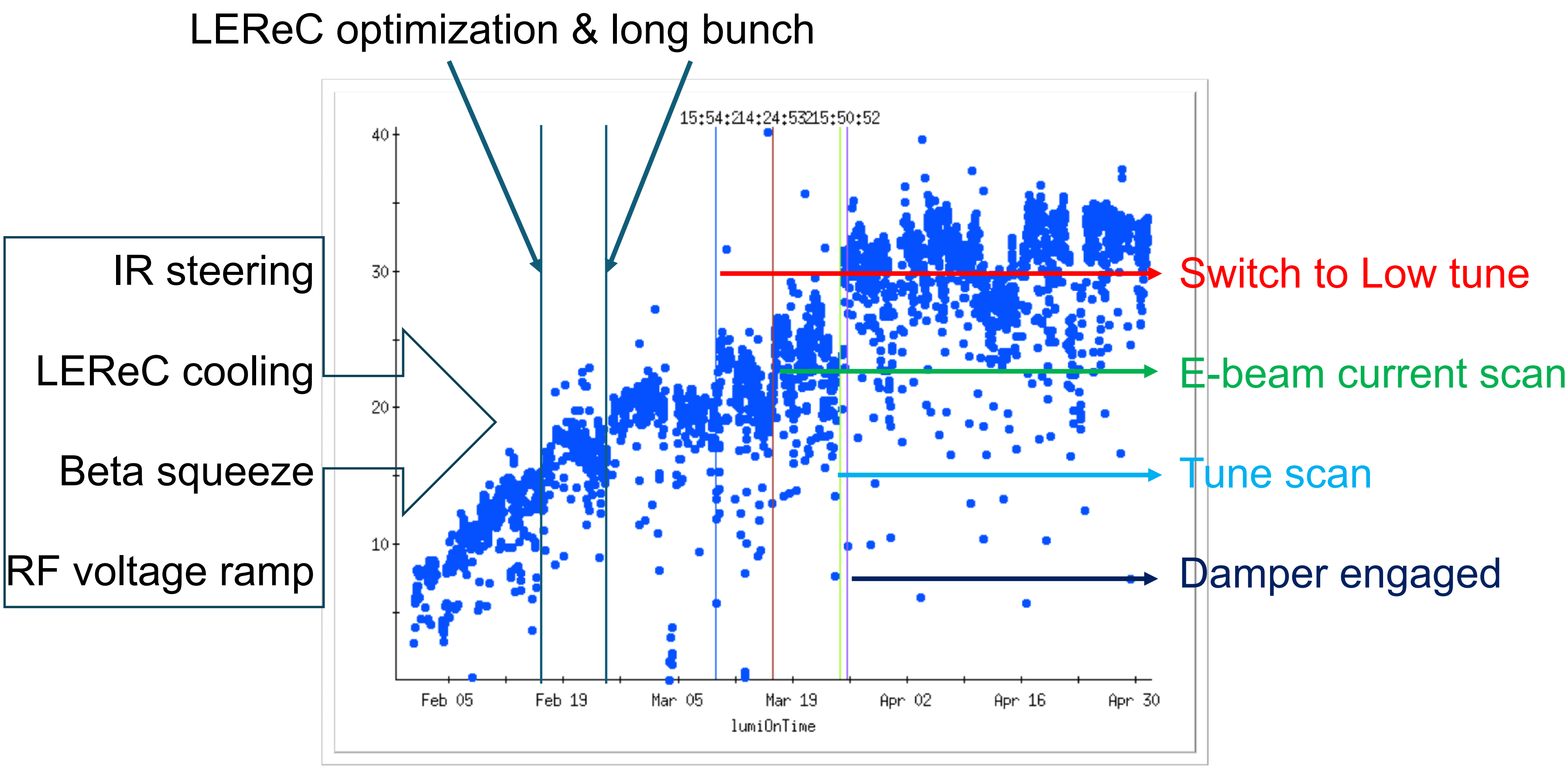
Single-Beam Energy (GeV/nucleon)	$\sqrt{s_{\mathrm{NN}}}$ (GeV)	Run Time	Species	Events (MinBias)	Priority
3.85	7.7	11-20 weeks	Au+Au	100 M	1
3.85	3 (FXT)	3 days	Au+Au	300 M	2
44.5	9.2 (FXT)	0.5 days	Au+Au	50 M	2
70	11.5 (FXT)	0.5 days	Au+Au	50 M	2
100	13.7 (FXT)	0.5 days	Au+Au	50 M	2
100	200	1 week	O+O	400 M 200 M (central)	3
8.35	17.1	2.5 weeks	Au+Au	250 M	3
3.85	3 (FXT)	3 weeks	Au+Au	2 B	3

100 1 week d+Au 123.9/109.0 (min-bias, central)

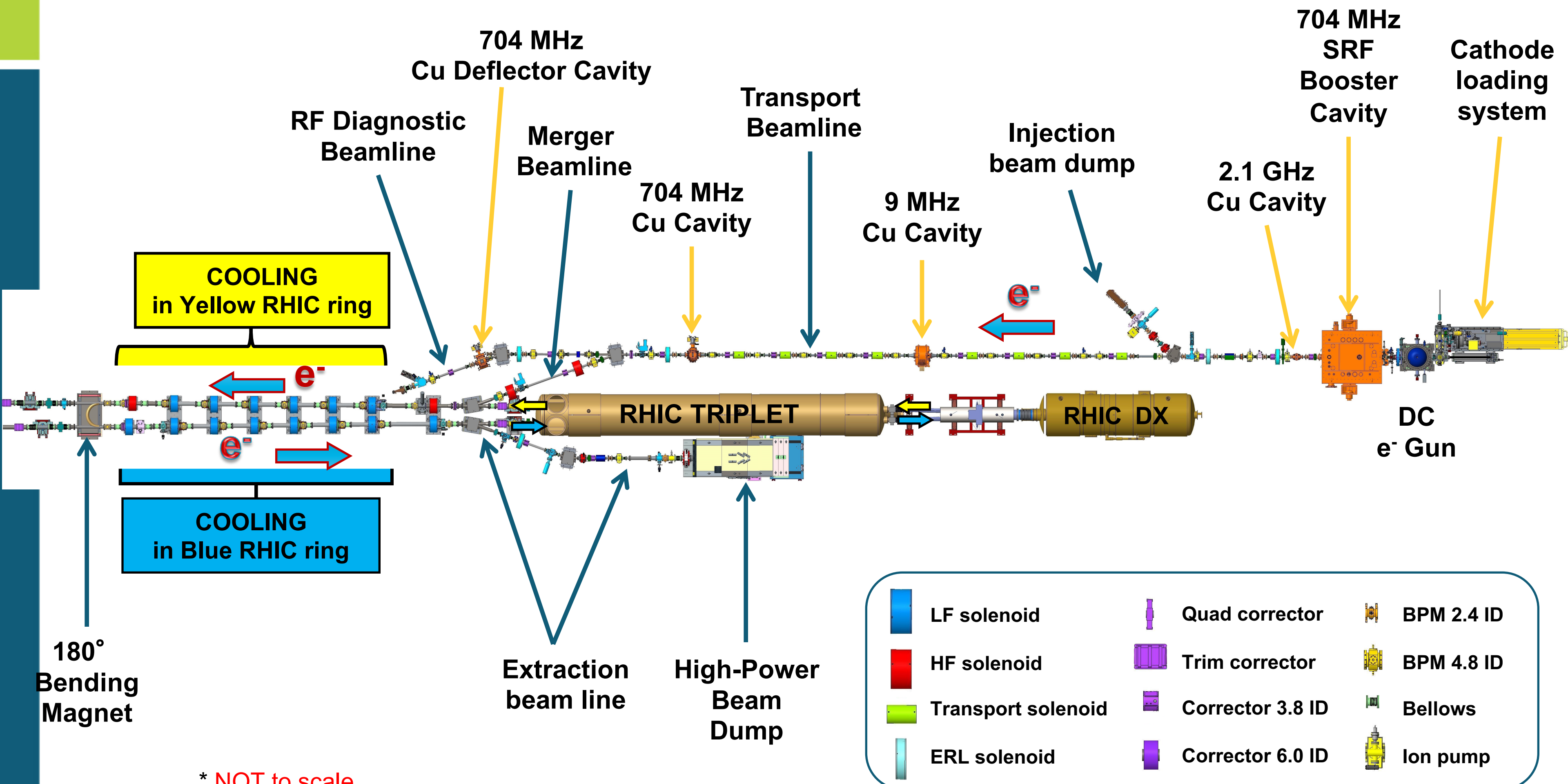
Operation of Au+Au at 7.7 GeV

The lowest energy in collision mode

Non-stop performance improvement of Au+Au collision at 7.7 GeV



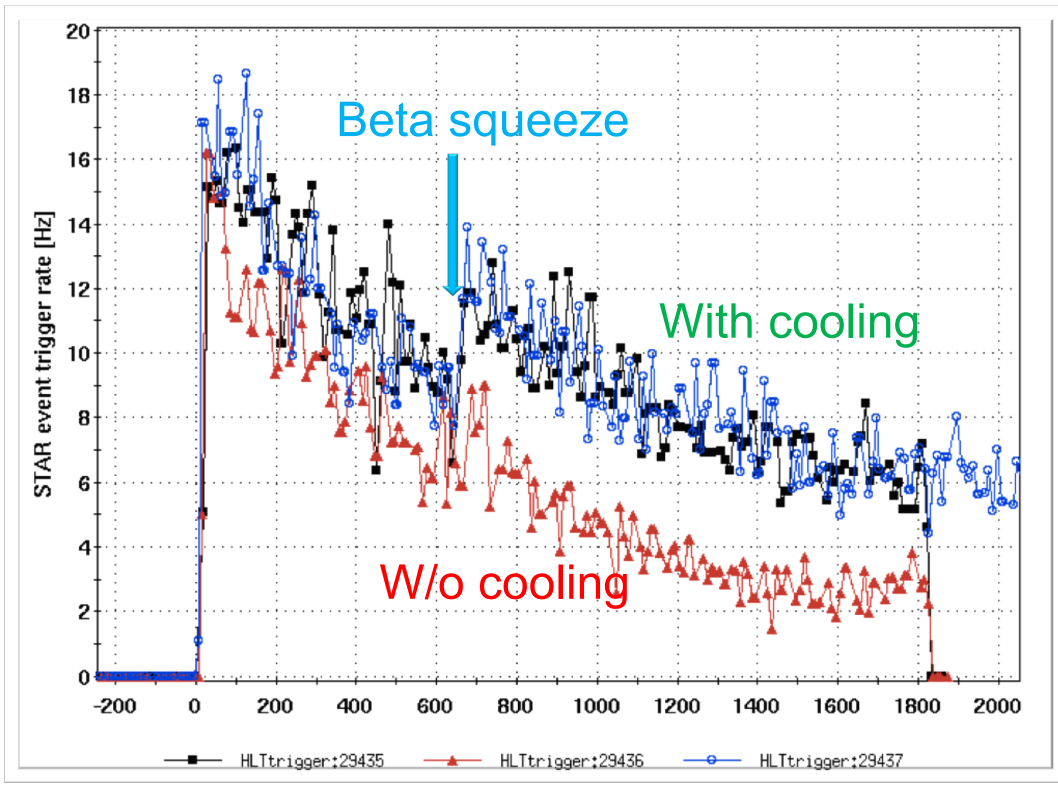
LEReC – world's first electron cooler based on rf-accelerated electron bunches employing high-current electron accelerator (as such, a prototype of high-energy cooler)

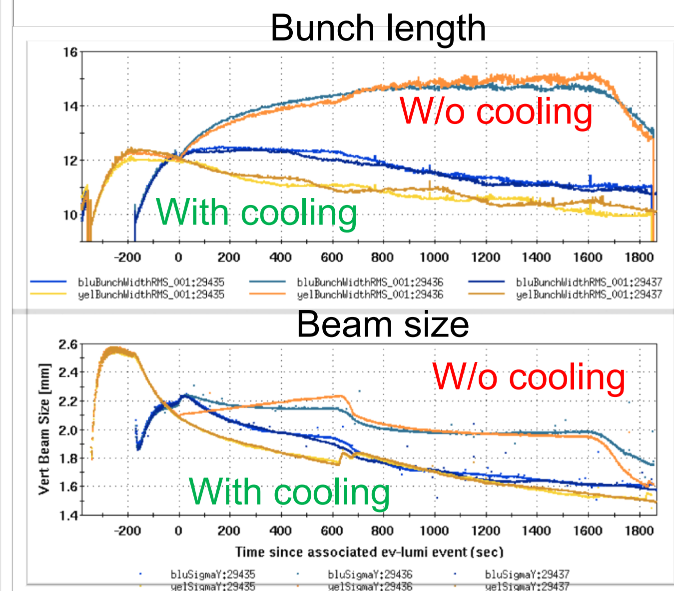


* NOT to scale

New 1.4 GHz RF cavity allows LEReC operation with longer electron bunches which helps to reduce "heating" effect on ions from the electrons.

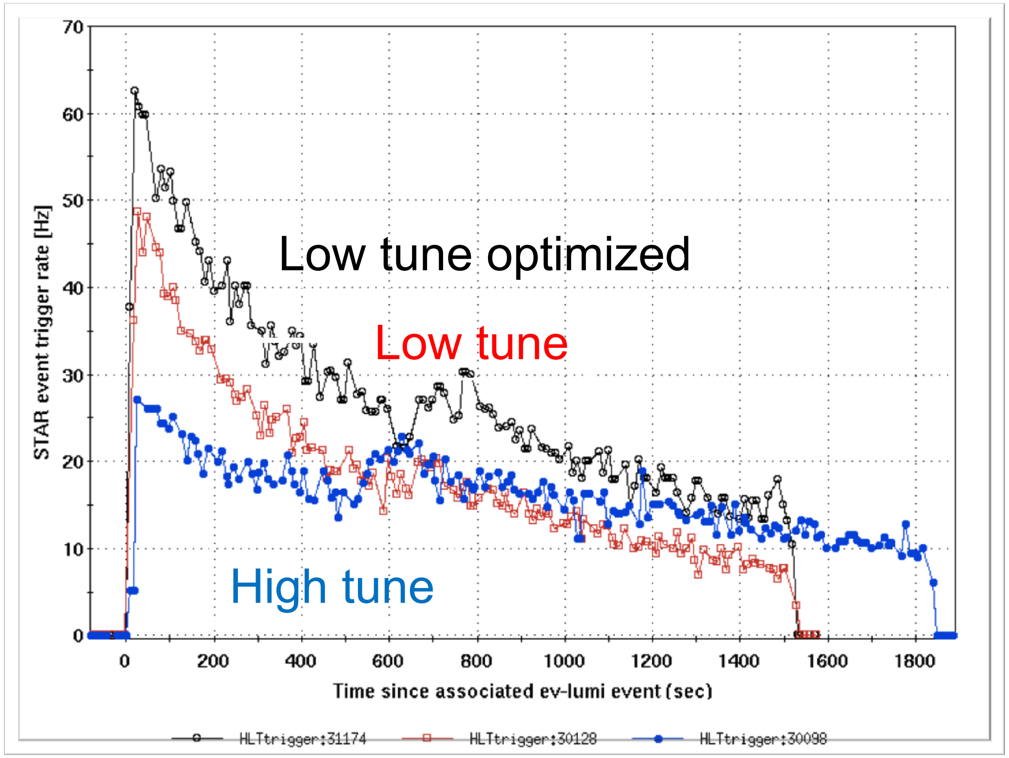
Cooling vs no-cooling





Cooling reduces/maintains the longitudinal and transverse size of the beam therefore reduces the luminosity decay rate. In addition, it enables beam size reduction by squeezing the beta (envelope) function at IP.

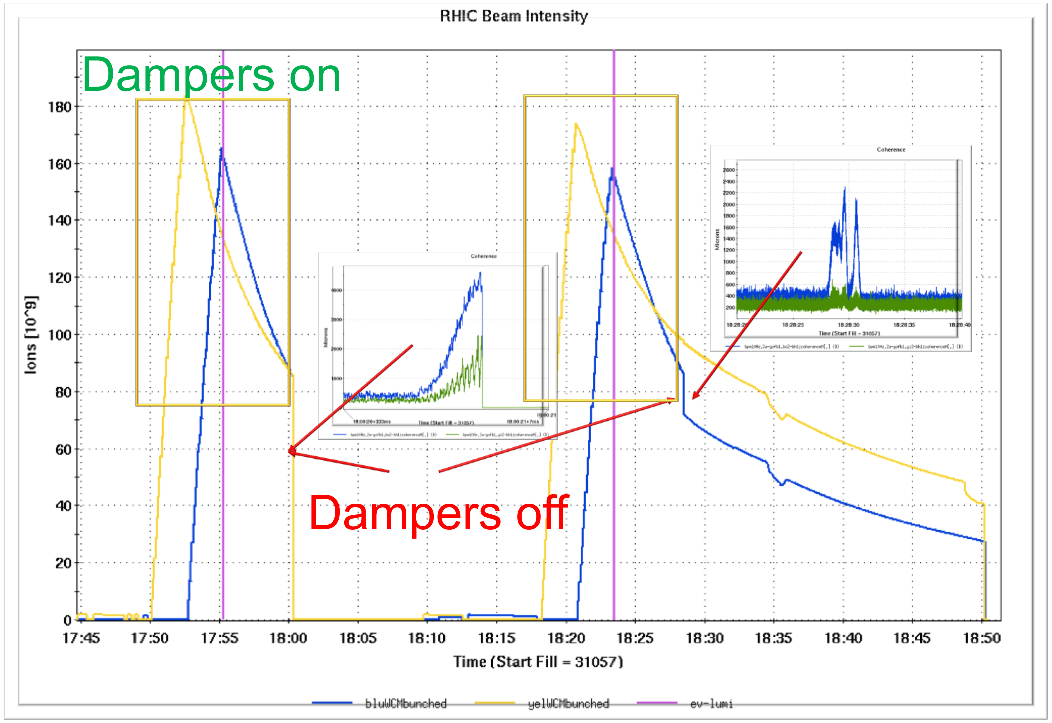
High tune vs low tune



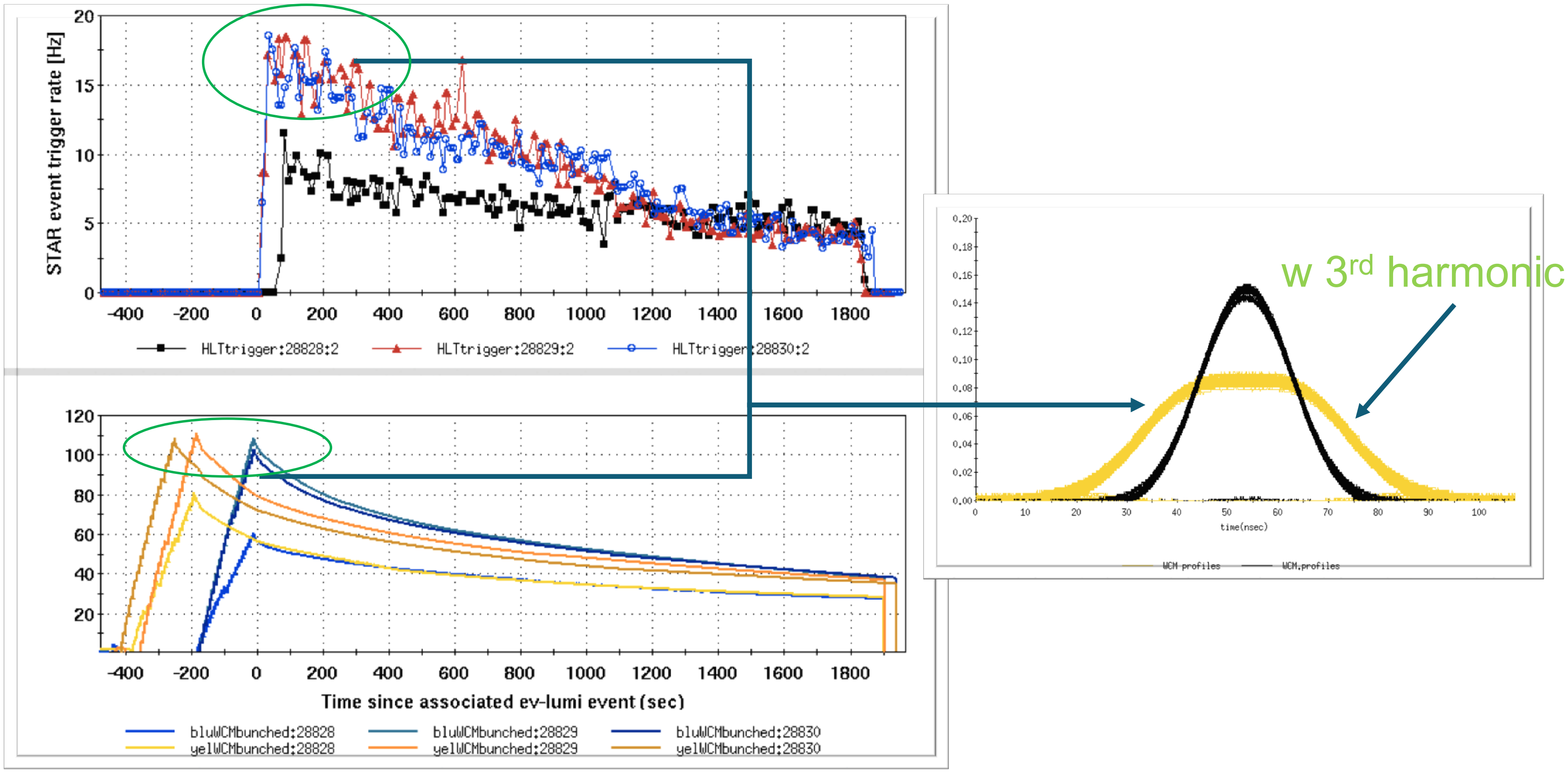
At low tune (0.12), beam lifetime is better than that at high tune (0.23) so RHIC can take more beam from the Tandem source.
Even the cooling is less efficient at low tune, higher integrated lumi was achieved.

Suppressing beam instability by bunch-by-bunch damper

- Bunch-by-bunch feedback system was engaged operational in 2021 to enable 10-15% more intensity.
- Feedback has been on from start of injection to the start of physics data taking.



Alleviating space charge effect



The reduction of peak current by engaging 3rd harmonic cavities improves greatly the beam lifetime.

Major changes between BES-I and BES-II

- 4 bunches per AGS cycle with 2.3E9 Au ions per bunch at AGS extraction with Tandem ion source.
- Implementation of third harmonic cavity to flatten bunch profile for reduced space charge, therefore high intensity in RHIC.
- Stable LEReC cooling operation, improved cooling performance with long electron bunches made possible by 1.4 GHz cavity. Beta squeeze in the middle of stores.
- Switching to lower tune for better ion beam lifetime therefore higher intensity, and scanning of e beam current.
- Implementation of bunch-by-bunch damper ensured higher intensity operation.
- Orbit corrector controller upgrade and improved measurement and control of beam properties.
- Reduce lattice nonlinearity due to persistent current and stabilize the magnetic field with wiggle ramp (demagnetization cycle).
- Employment of three 9 MHz cavities per ring.
- injection kicker reconfiguration for short rise time and longer flattop.

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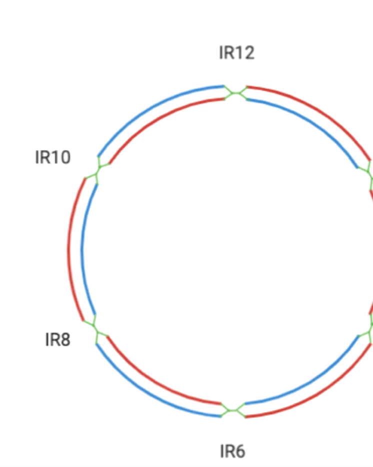
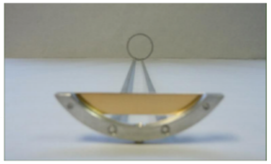
Operation of FXT, O+O, Au+Au at 17.3 GeV, d+Au at 200 GeV

Fixed target operation

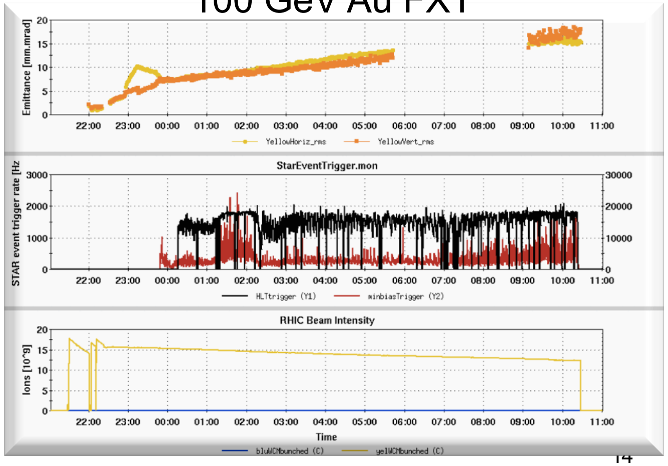
- Fixed target at beam energy 3.85, 44.5, 70 and 100 GeV.
- 12 bunches with moderate intensity (1.5E9 ions per bunch) equally distributed in the yellow ring.
- Vertical orbit bump to bring beam close to the target and maintain the rate.
- 100 GeV FXT was performed with big challenges on machine side.
    - An orbit bump of ~17 mm was set up with maximum available strength on IR correctors.
    - All available methods were used to blow up emittance: Injection mismatch, ARTUS kicker, IBS & coupling, BBQ kicker.

FXT setup



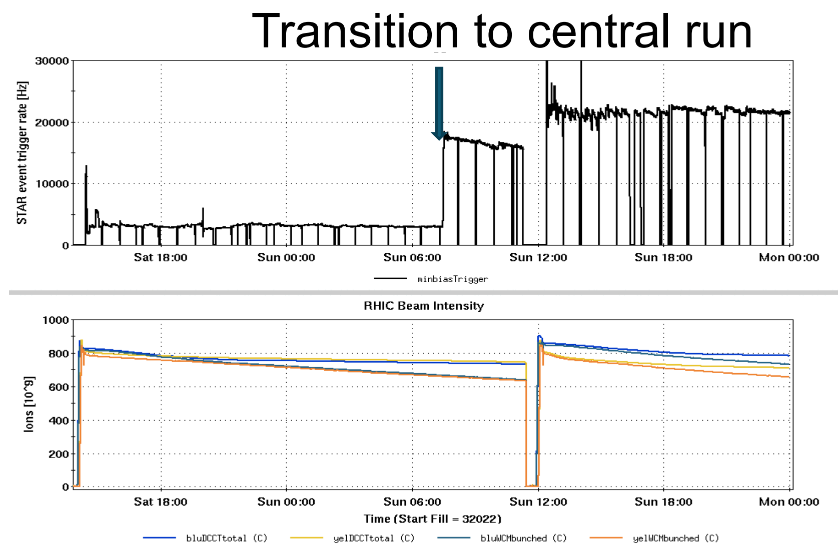


100 GeV Au FXT



O+O at CoM 200 GeV

- Oxygen is a new species for RHIC. The setup took 3 calendar days with FXT running overnight.
- Store length was over 20 hours and 15 hours for the min-bias and central run.
- Calibration run for a day with STAR solenoid polarity reversed.
- To reduce vertex longitudinal rms to 10 cm, beam was rebucketed and crossing angle of 1.65 mrad was put in.



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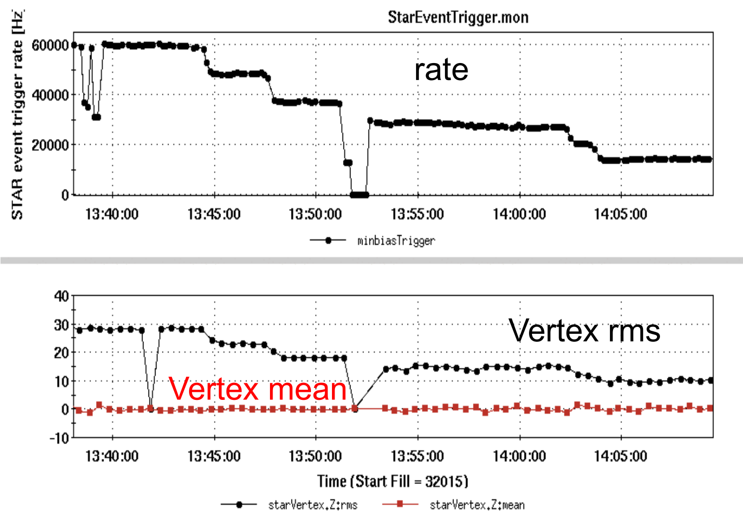
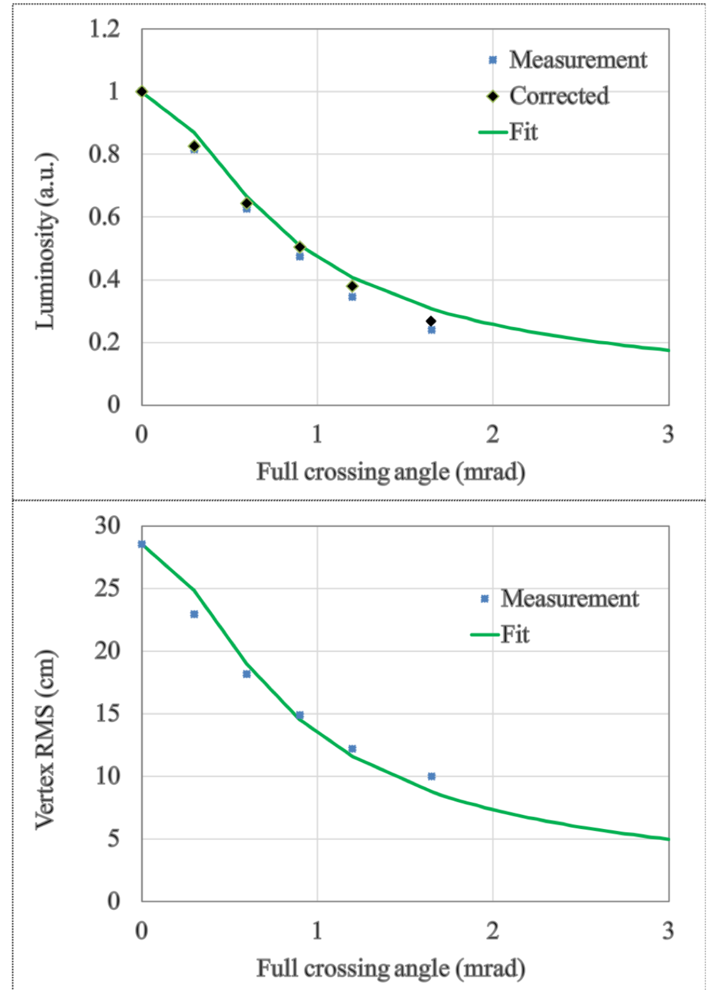
Crossing angle effects

Implementation of horizontal crossing angle

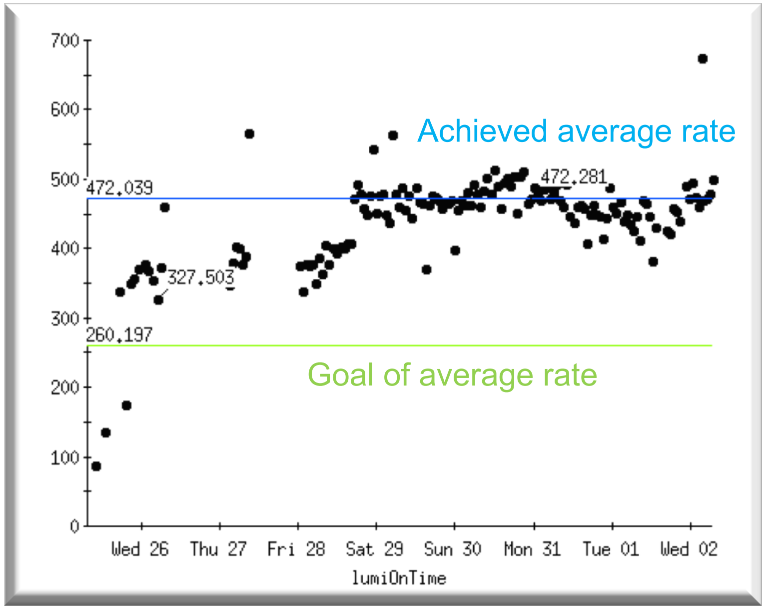




The crossing angle was less effective than predicted to reduce the vertex rms due to non-gaussian bunch profile.
The fittings on the right plots were performed with bunch length as a variable.

Au+Au at CoM 17.3 GeV

- New energy for collision mode.
- Experience of low energy operation gained in the past two years gave us guidance on the optimal configuration of RHIC for this energy.
- Careful evaluation of the exact energy due to its proximity to AGS transition energy.
- Beam setup in AGS needed more care but went smoothly.



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d+Au collision at CoM 200 GeV

- Initially a 1 mrad crossing angle was implemented to reduce the longitudinal vertex size, unfortunately beam transverse size blow-up was observed ended with high background.
- With zero crossing angle and vertical offset for luminosity leveling, the collision vertex showed three peaks, which was explained by the difference of lumi reduction at the center bucket and the satellite bucket of the Au beam.
- The side peaks were suppressed by reducing beam intensity and vertical beam offset at IR.
- The side peaks were removed when STAR implemented a timing cut based on neutron detection in the Au beam direction.

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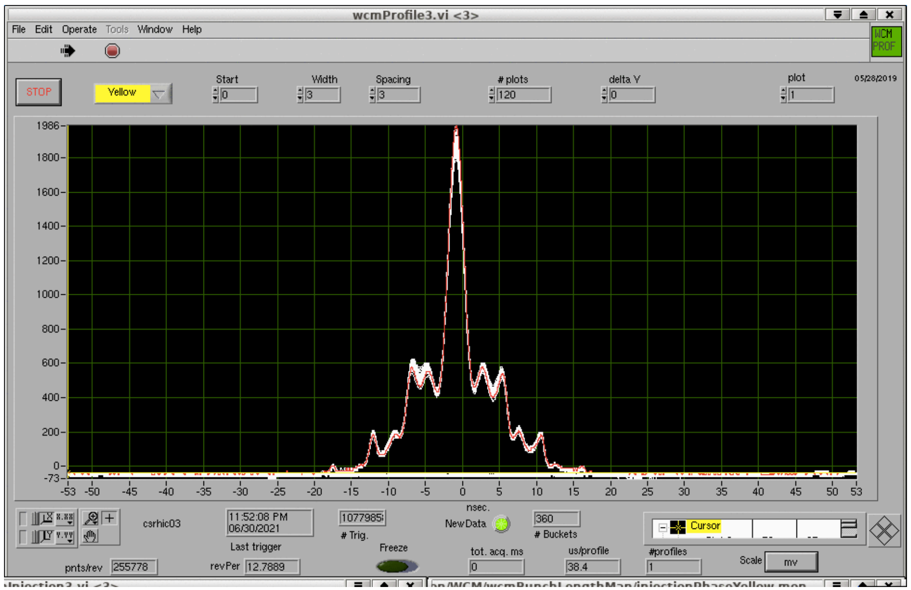
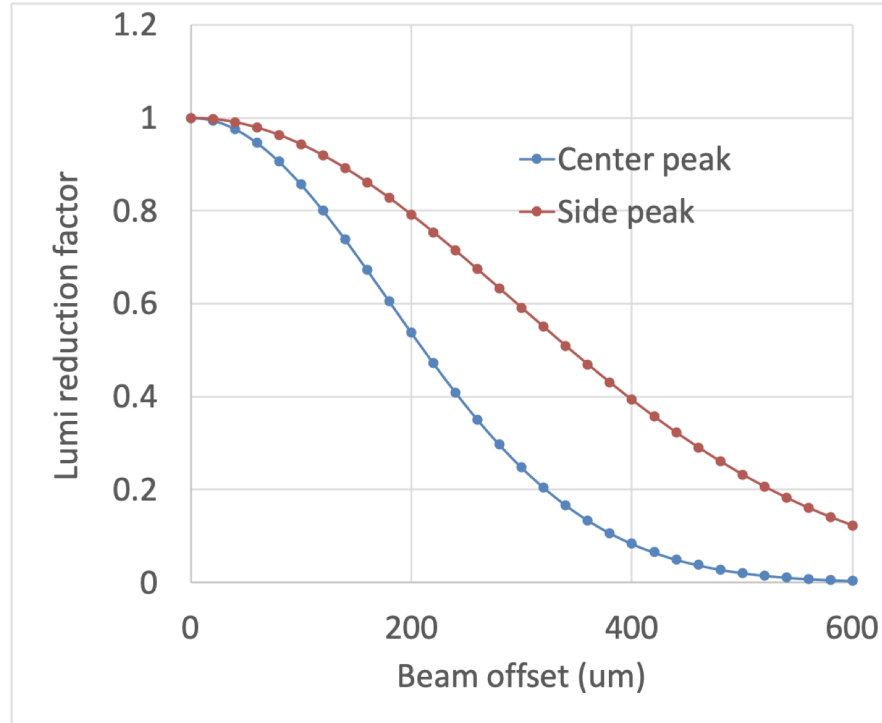
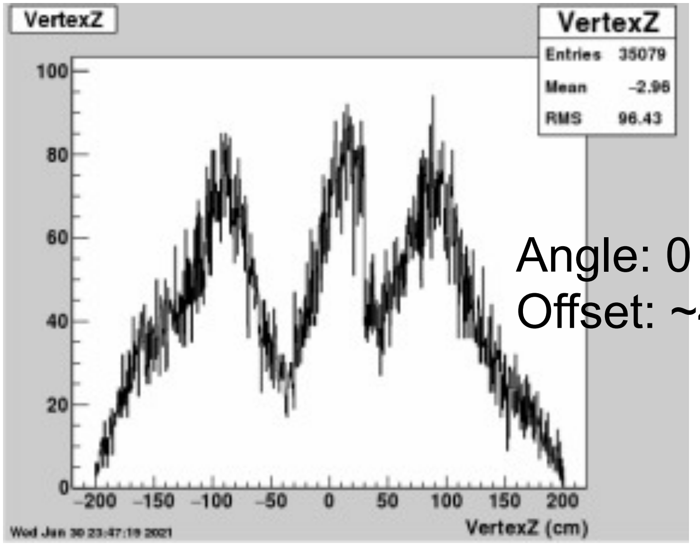
Explanation of multiple peaks



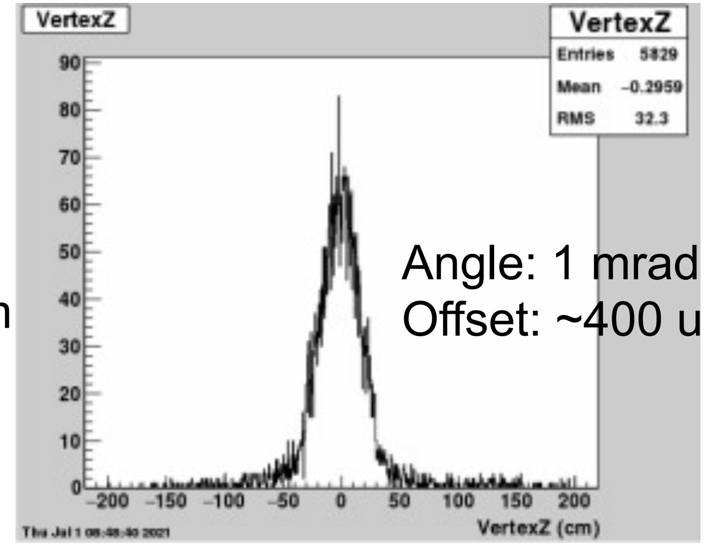


With 400 um vertical offset between d and Au beams, the rates from center peak is reduced by a factor of 4 more than the side peaks. The intensity of the center peak of Au beam was a factor of 3-4 higher than the side peaks. So we observed three peaks in the vertex.

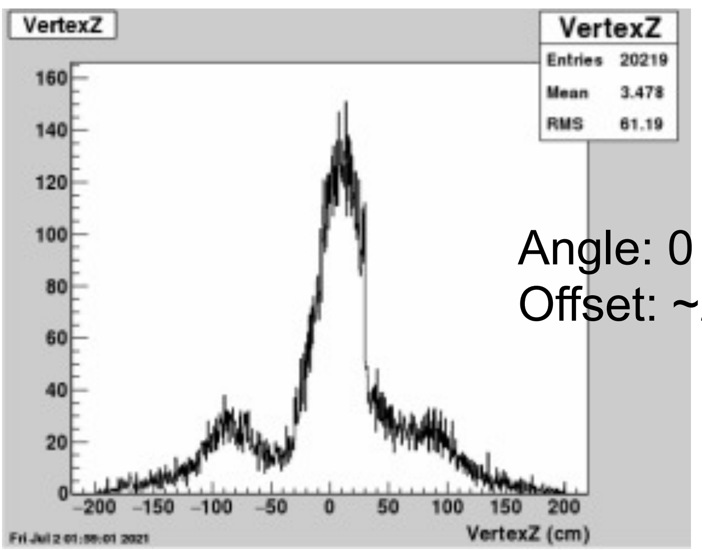
Vertex distributions



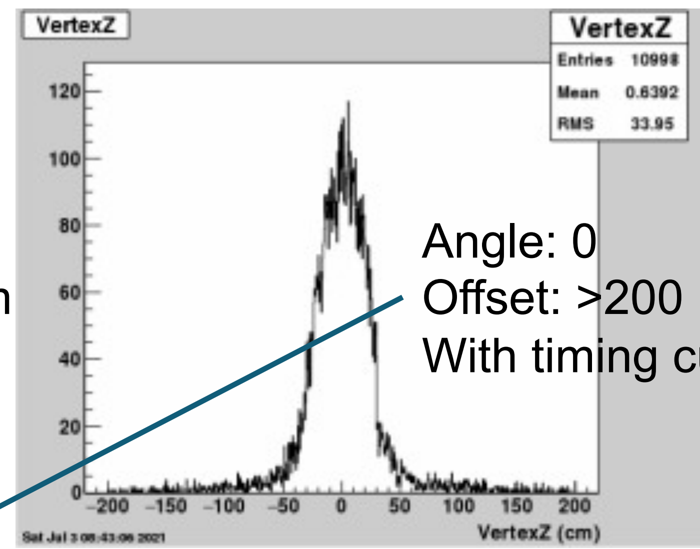
Angle: 0
Offset: ~400 um



Angle: 1 mrad
Offset: ~400 um



Angle: 0
Offset: ~200 um

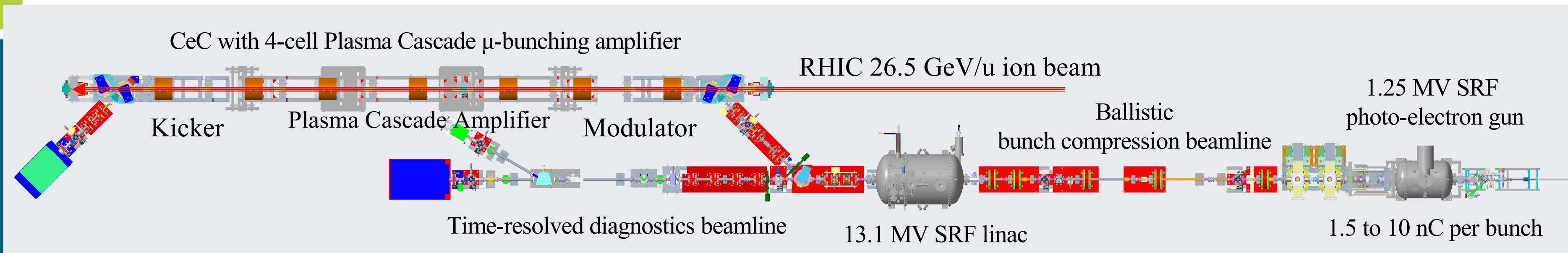


Angle: 0
Offset: >200 um
With timing cut

>200 um bc bunch number increased from 28 to 56

Coherent electron Cooling experiment at RHIC in Run-21

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.
- 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 achieved the following last year:
    1. Demonstrating KPP for the e-beam
    2. Plasma Cascade amplification
    3. Ion imprint
- The team worked on solenoid alignment, ion and electron beam alignment this year.
- Parasitic fixed target data acquisition during CeC studies.
- The project plans are to demonstrate longitudinal CeC in 2021 and 3D (both longitudinal and transverse) CeC in 2022.

Accelerator Physics Experiments (APEX)

- Cooling studies:
  - Electron-ion heating
  - Bayesian optimization
  - Coherent excitation
  - Dispersive cooling
  - Painting cooling
  - Recombination study
  - Electron-ion focusing

>120 hours

- Electron-ion collider studies:
  - Radial shift test
  - Fine decoupling

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Things contributed to the successful completion of BES-II

- On technical level, all planned improvement worked as expected. Furthermore, we did not hesitate on any adventurous acts of which some delivered surprising results.
  - Planned improvements: use Tandem to provide high quality beam, LEReC upgrade with new 1.4 GHz cavity, bunch-by-bunch damper
  - Unplanned improvements: reduce peak intensity with 3rd harmonic cavities, explore alternative tunes and associated e-beam current scan.
- On administrative level, the right people are working on the right things.
  - Challenges were handled with efficiency: Demanding beam setup work, demanding 12-hour shift, complicated schedule, CeC, maintenance and APEX coordination

Things need more investigation

1. Development of uneven intensity pattern across the ion bunch train towards the end of store.
2. With STAR solenoid polarity flipped, the rate was unreasonably low even though reasonable beam conditions were established and skew quads settings were proven to be OK.
3. Discrepancy of reported beam size/emittance between H-jet, IPMs and STAR detector, for example emittance blow-up observed by STAR were not reported by H-jet and IPMs.
4. Beam emittance blow-up during d+Au collisions by beam-beam with horizontal crossing angle and vertical beam offset.
5. Line voltage oscillations from PSEG observed by CAD and NSLS-II.

Summary

- The final year of BES-II was most challenging. Both LEReC, RHIC and its injectors' performance were greatly improved.
- A few good decisions were made for the Au+Au at 7.7 GeV to make use of the full potential of the source, injector and RHIC.
- Switching between multiple physics programs was again demanding.
- Physics programs, CeC experiment, APEX studies and other tests coexisted in harmony.

Section Break

Subtitle

Print-friendly Section Break

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