Low Energy RHIC electron Cooling (LEReC):

Performance in Run-20, upgrades for Run-21

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on behalf of LEReC team

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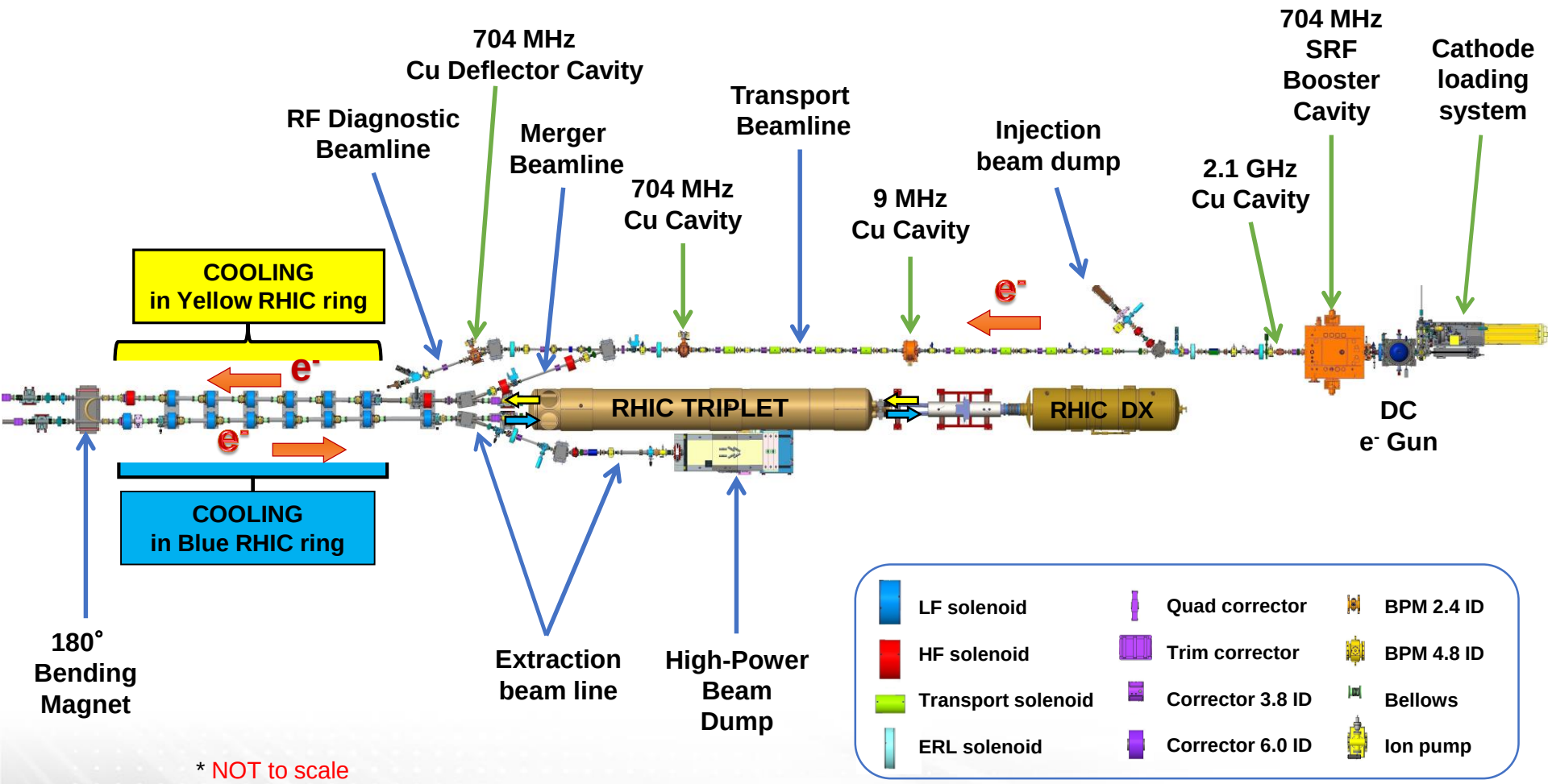
BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

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

LEReC summary for 2020

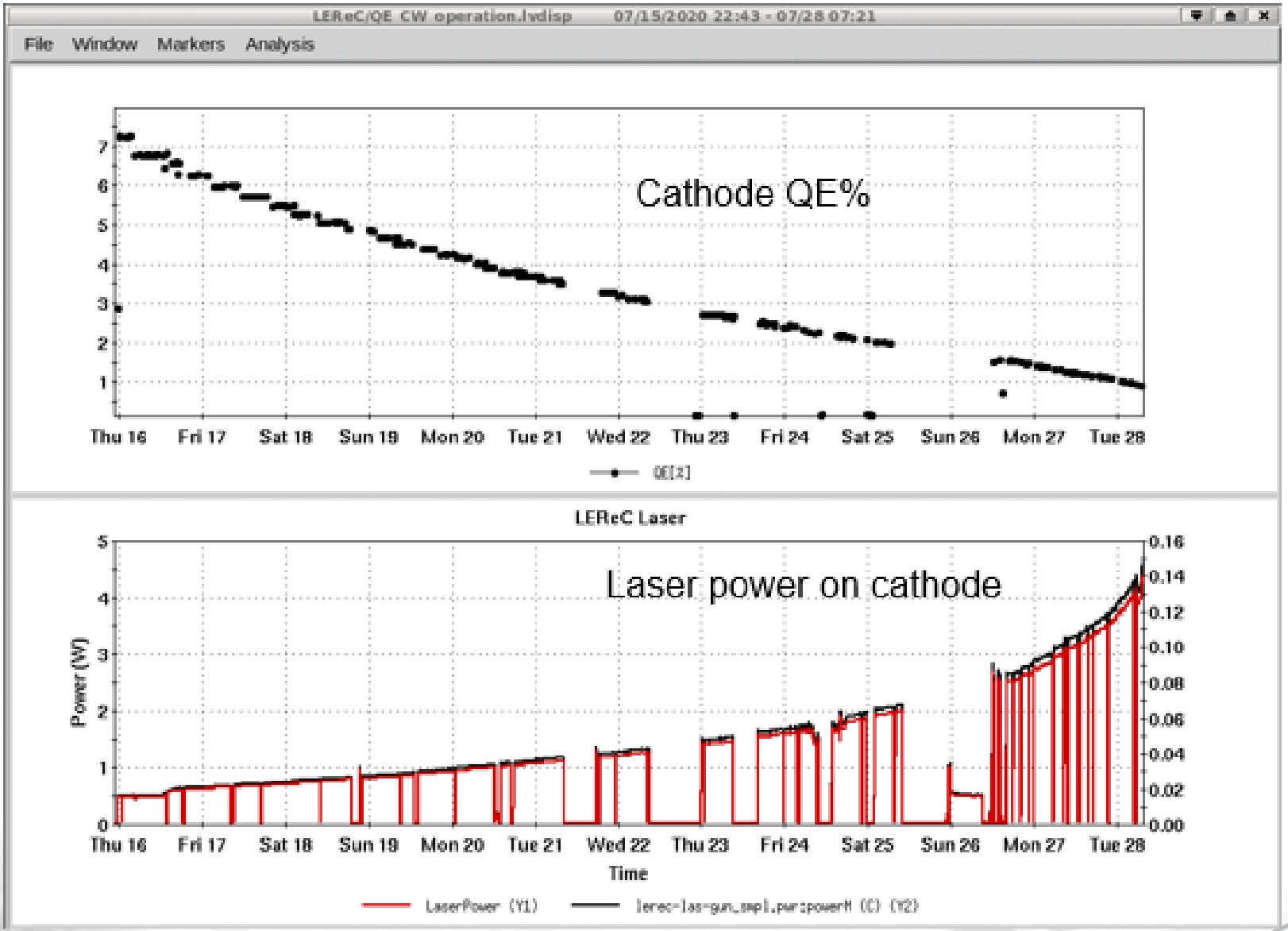
- Cooling was commissioned and optimized using 2MeV electron beam for Physics operation with Au ions at 4.6GeV/nucleon
- Electron-ion beam alignment in cooling sections was improved by implementing the channel switching scheme for BPMs electronics which resulted in improved transverse cooling
- Cooling was made fully operational, including implementation of laser position feedbacks, intensity feedback, energy feedback, automatic cooling section orbit corrections and feedback
- Controls of LEReC accelerator was transferred to the MCR operations, with support by LEReC experts when needed.
- Stable 24/7 running for Physics at 4.6GeV of high-current electron accelerator over many weeks
- Cooling was commissioned using 1.6MeV electron beam for Physics operation at 3.85GeV in 2021.

World's first electron cooling in a collider (cooling of ion beams in collisions and luminosity optimization with cooling) became operational.

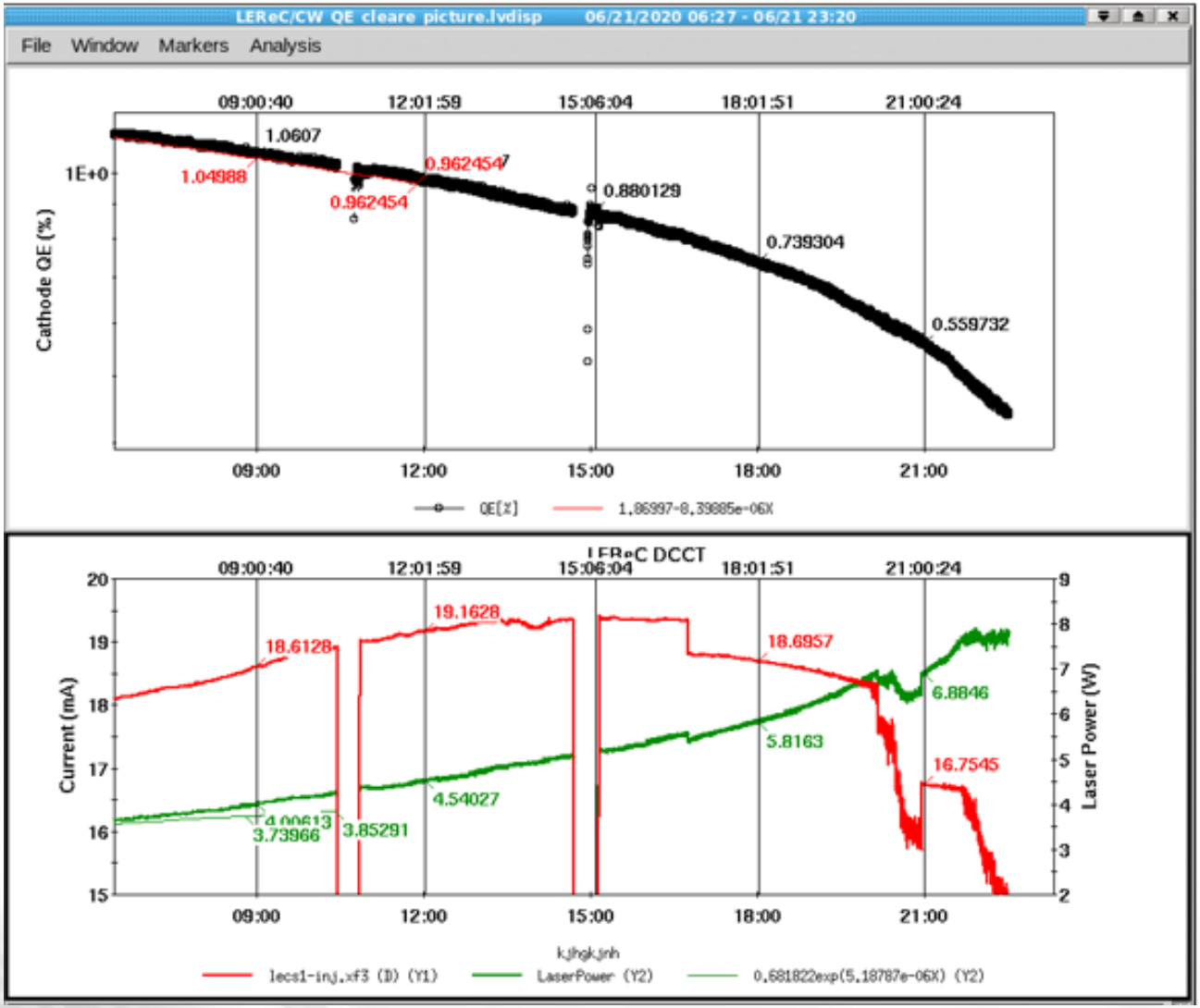
LEReC operational experience

- Overall, stable and reliable operation of all accelerator systems with high-current (15-20mA) electron beam
- Very robust cathodes with high QE (typical initial QE around 8%). Some vacuum issues with one of the FW vacuum suites which resulted in cathodes decay.
- Most MPS trips during high-current operations were caused by beam losses, BPMs and RF cavities. Typical recovery time was very fast (it takes few minutes to clear MPS and ramp up e-beam current). Longest uninterrupted high-current running without a single MPS trip: 58 hours.
- Occasional RF trips due to Power Amplifiers or due to laser beam becoming less stable. SRF cavity required conditioning by the end of the run.
- Very few Gun trips. Most trips happened when anode ion clearing power supply was down resulting in ion back bombardment.

Typical cathode performance



Cathode QE drop under high laser power (June 21)

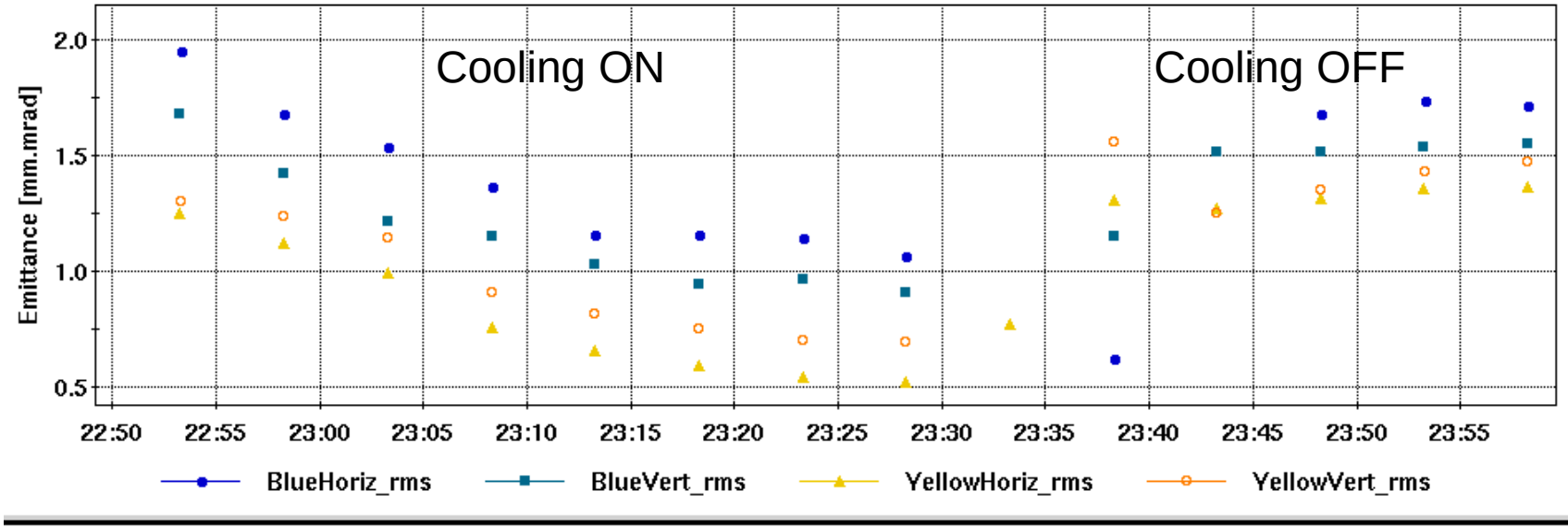


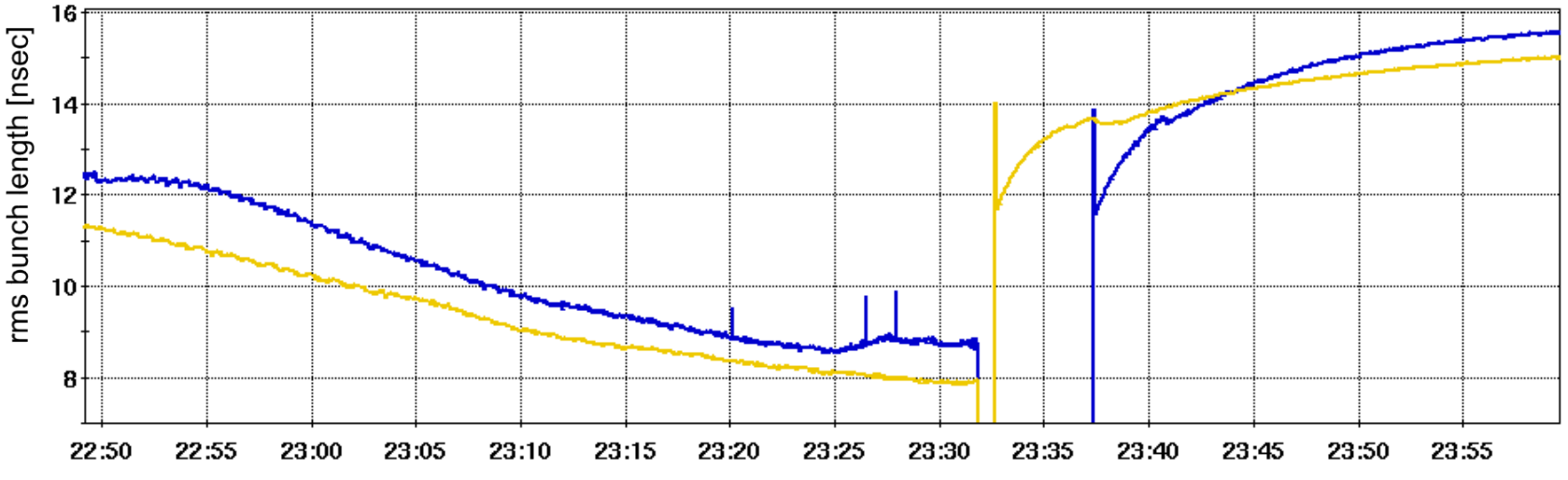
Strong QE drop, once laser power on the cathode went above 5W.

Interesting R&D for future high-current operations and design for EIC.

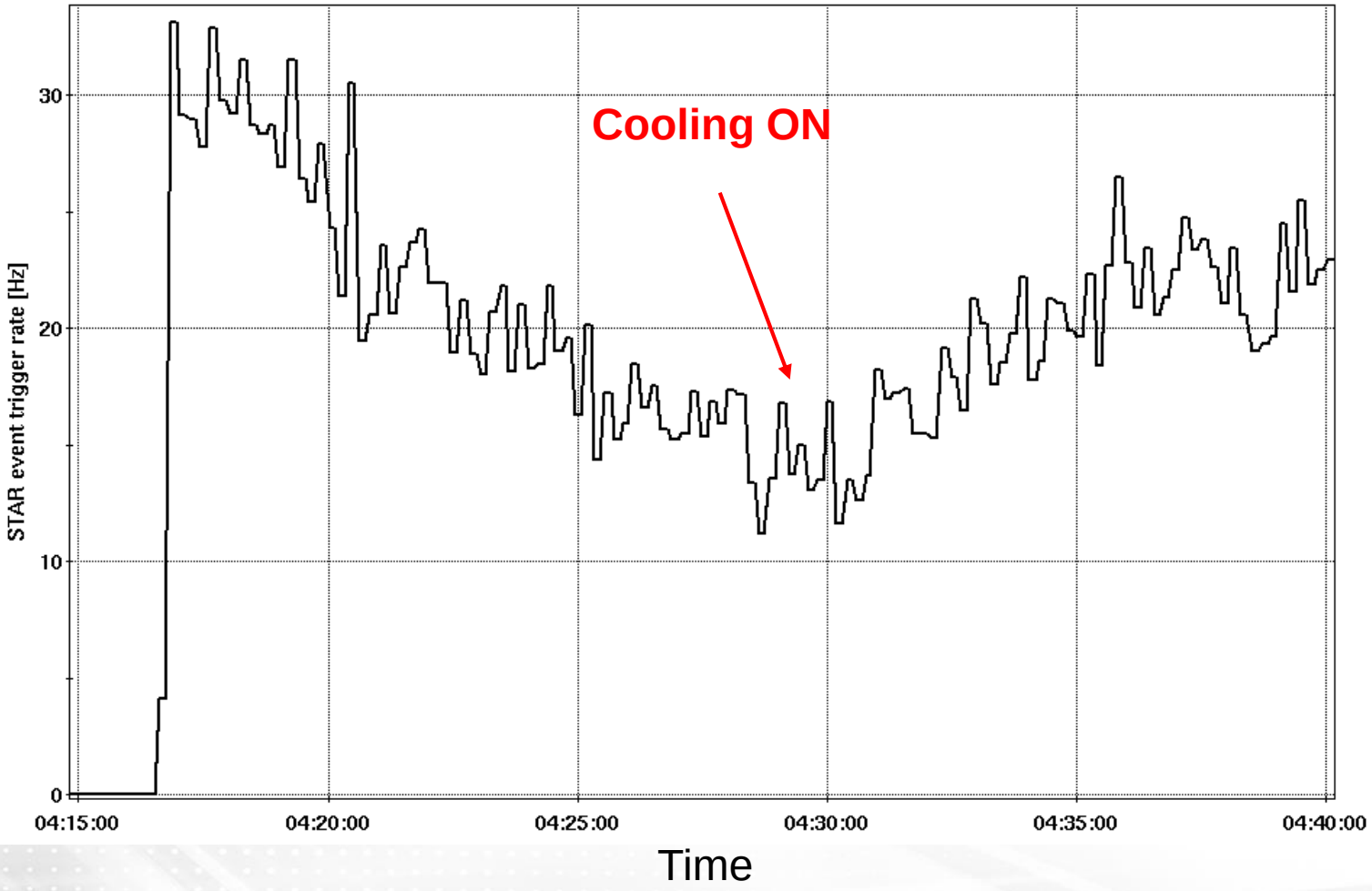
Physics stores (at 4.6 GeV/n) with and without cooling

(rms emittances (top) and bunch length (bottom) of ions in Yellow and Blue RHIC rings)

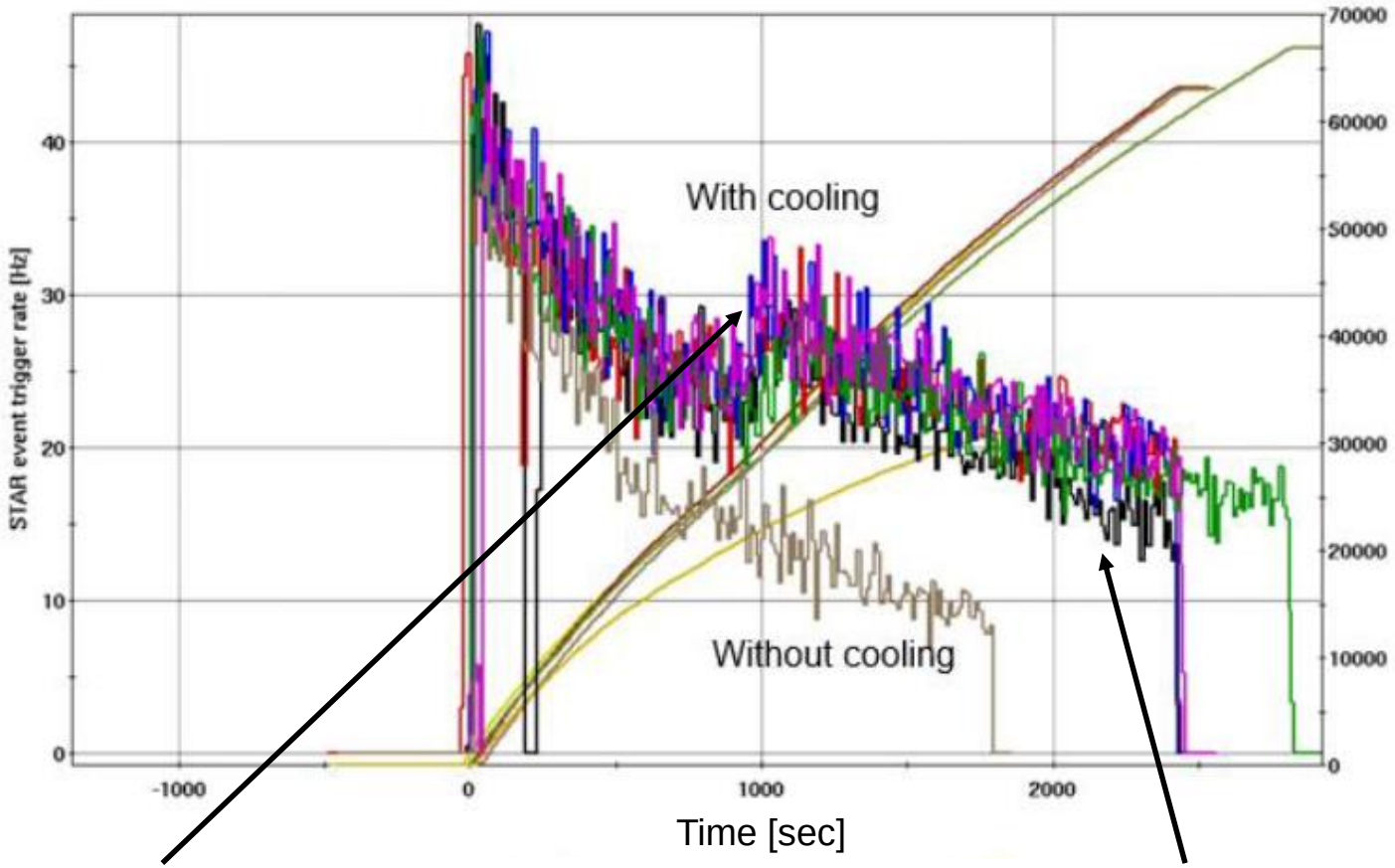




Physics store with electron beam (cooling) restored later in the store



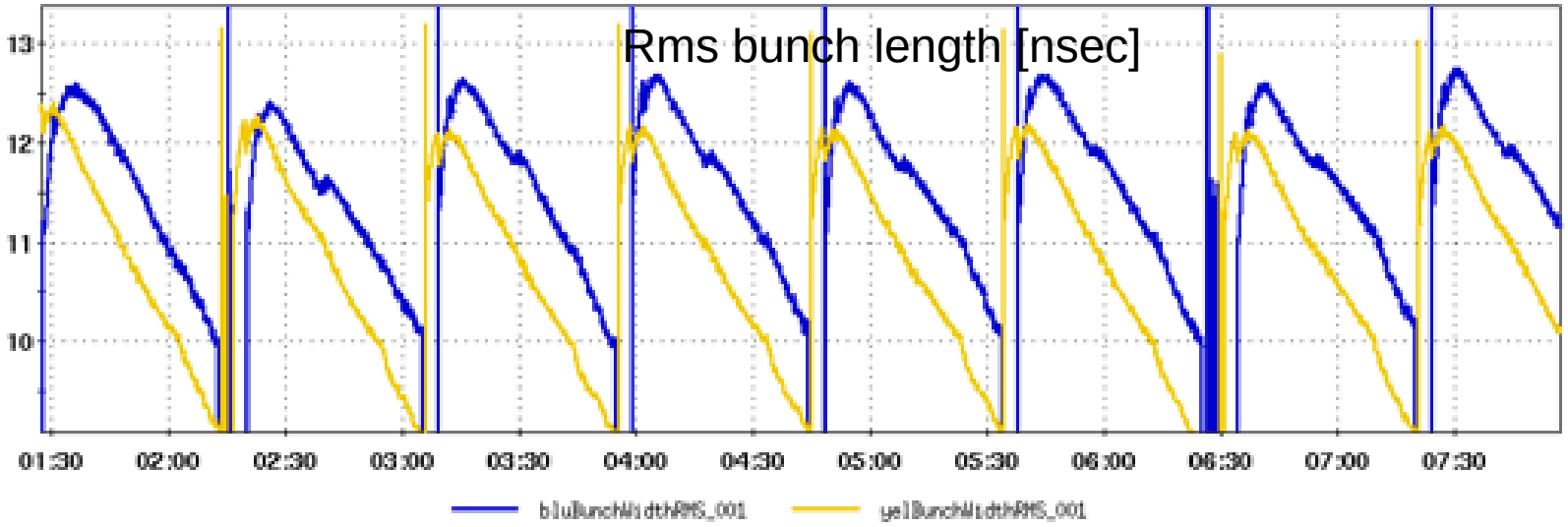
Several physics stores at 4.6 GeV/nucleon with cooling (2 MeV electrons) (vertical axis: events rate [Hz] within +/-0.7m (left); store integrals (right))

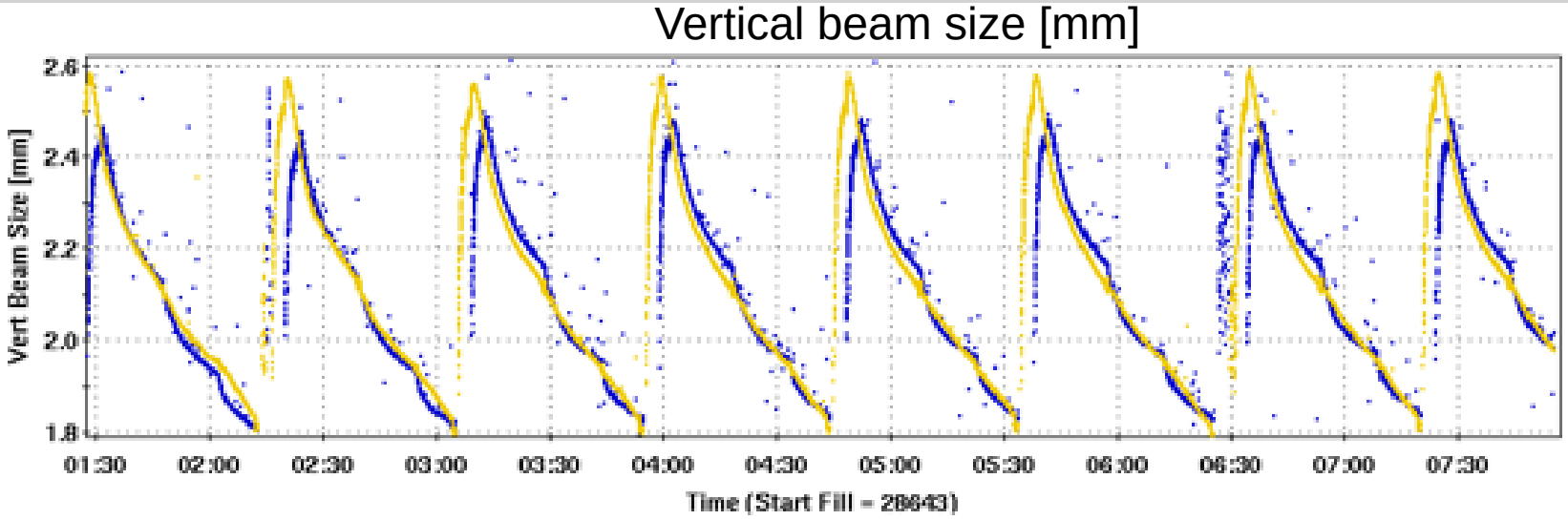


Dynamic squeeze of beta-function at collision point, while transverse beam sizes of ion beams are being cooled

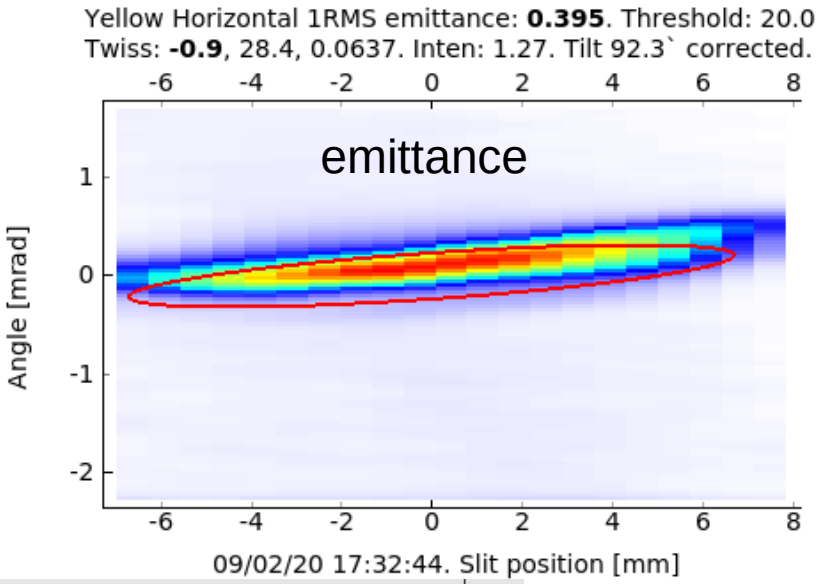
Longer stores with cooling

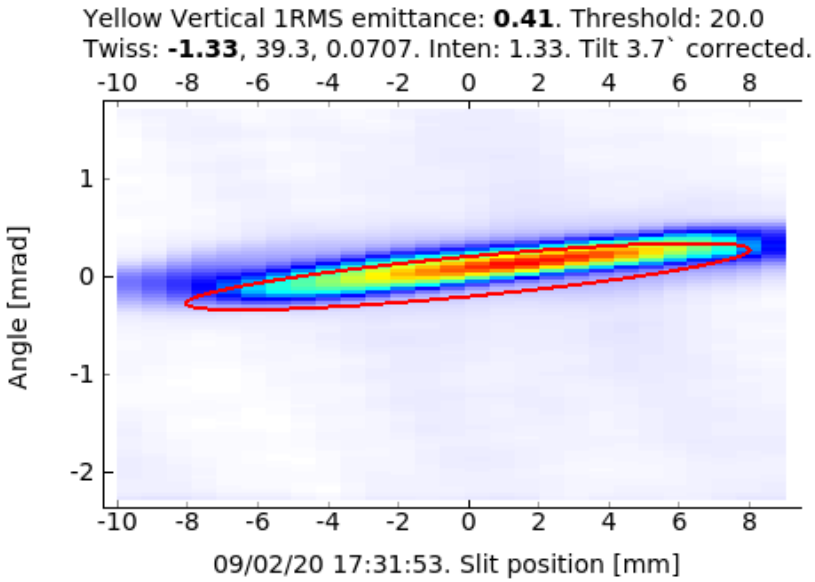
Typical cooling performance (August 26, 2020), 2 MeV electrons, Au ions at 4.6GeV/n



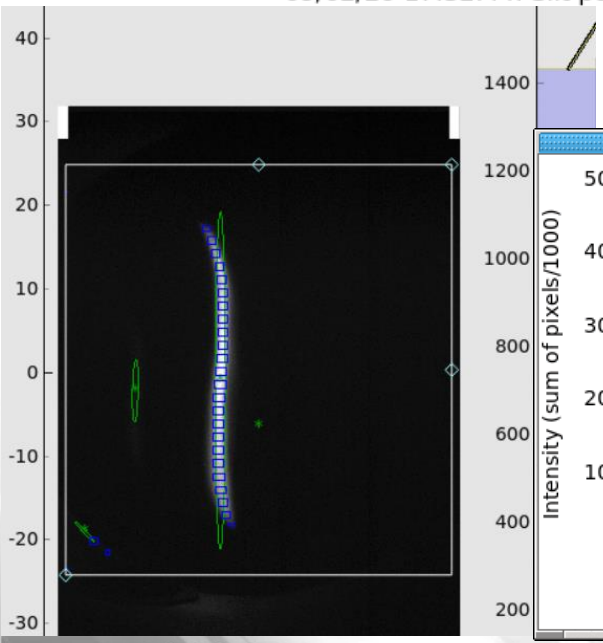


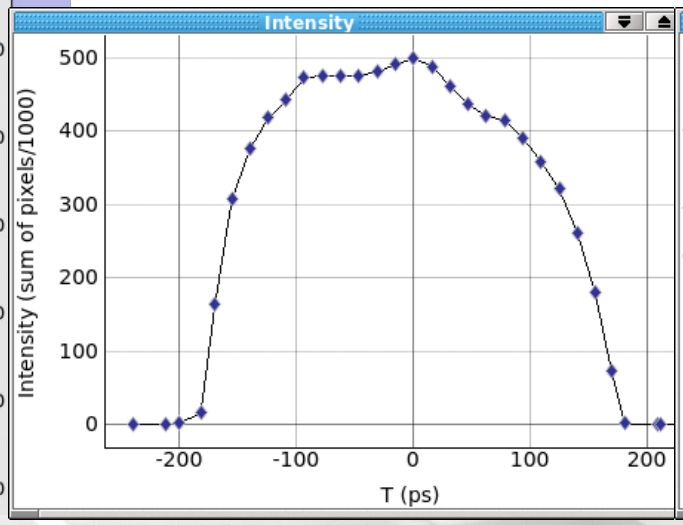
LEReC – electron beam quality at 1.6MeV, for cooling of Au ions at 3.85GeV/n

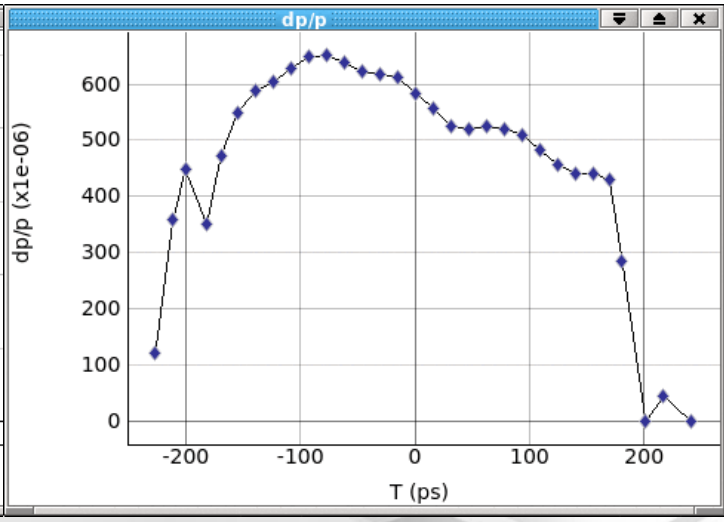




Energy spread

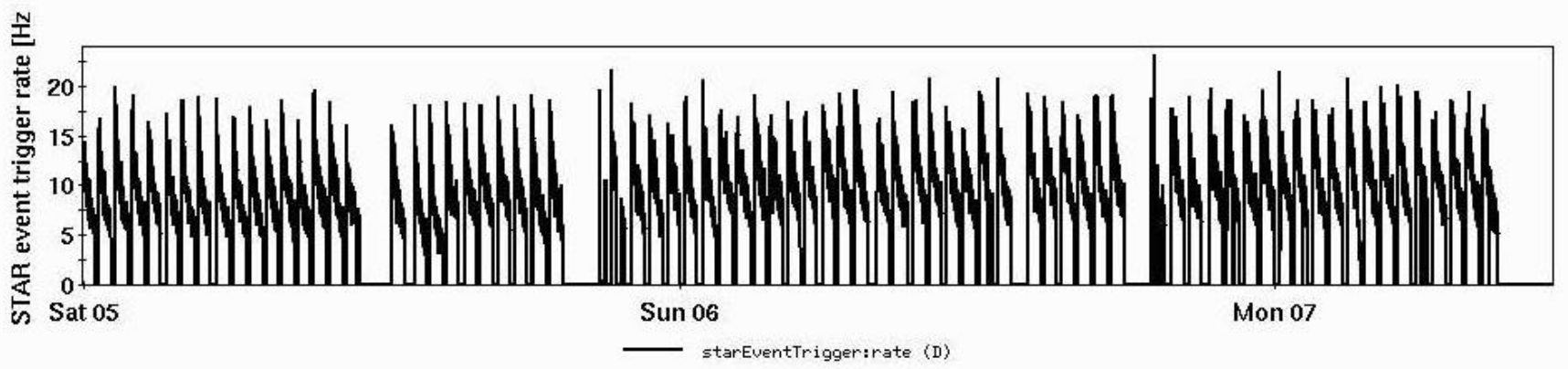




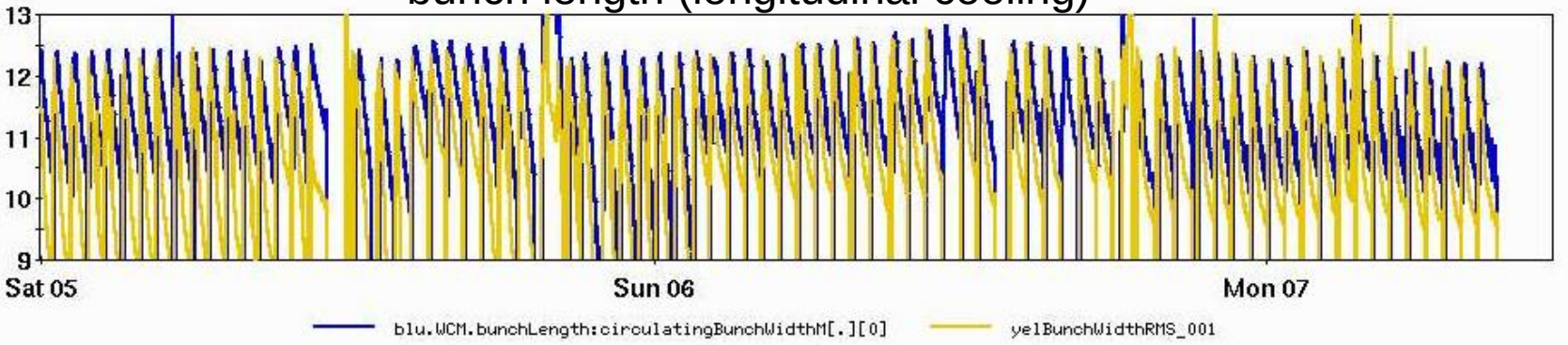


Baseline physics run with cooling (September 5-7)

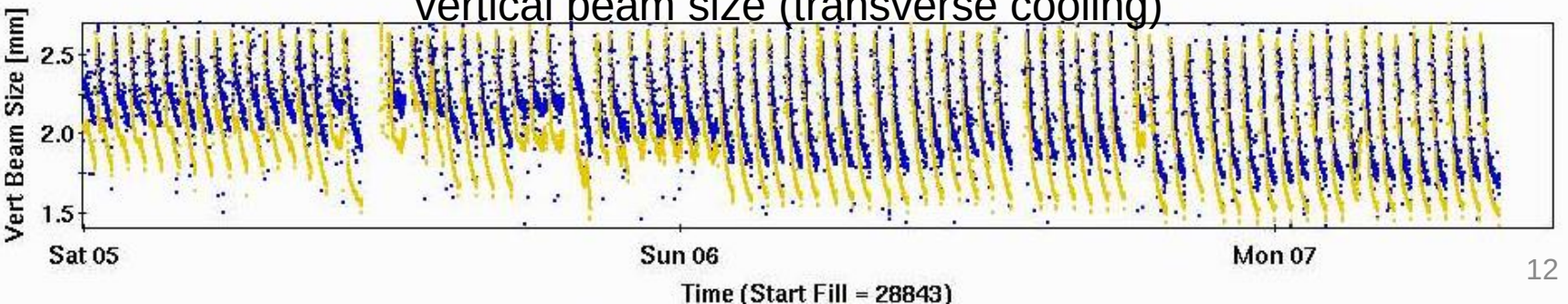
Stable and efficient operation of LEReC and RHIC at $\sqrt{s_{NN}}$ = 7.7 GeV



bunch length (longitudinal cooling)



vertical beam size (transverse cooling)



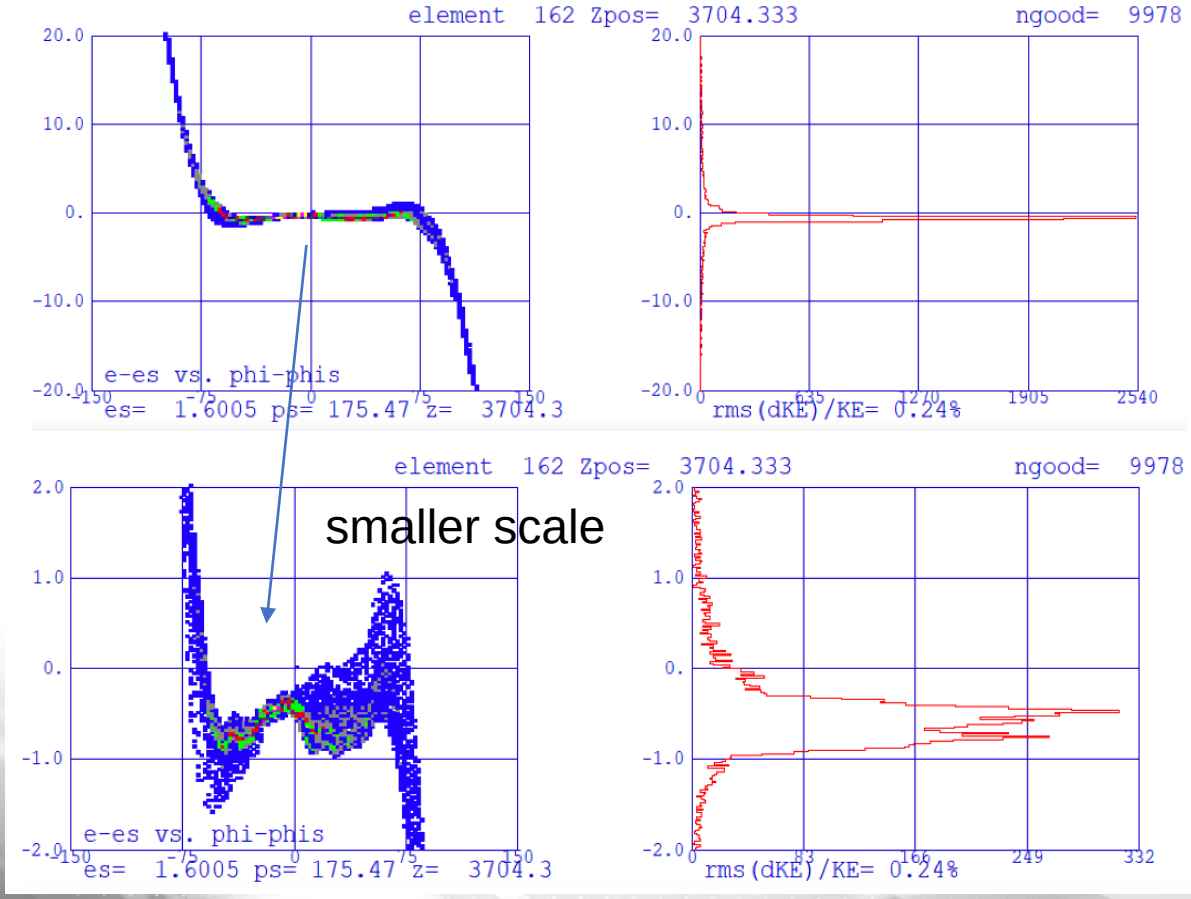
LEReC plans for shutdown and Run-21

- Gun HVPS tests: testing of 3 new inverters and new controls chassis was performed with high-current CW e-beam; voltage ripple with new controls chassis is the same as with present one in operations – done
- Gun re-conditioning – done
- Install fast vacuum valve for additional protection of the SRF booster cavity - done
- Develop and optimize electron beam optics with longer bunches using 1.4GHz cavity – simulations optimization done
- Install new 1.4 GHz RF cavity and all related systems to allow LEReC operation with longer electron bunches which should help to reduce “heating” effect on ions from the electrons – in progress

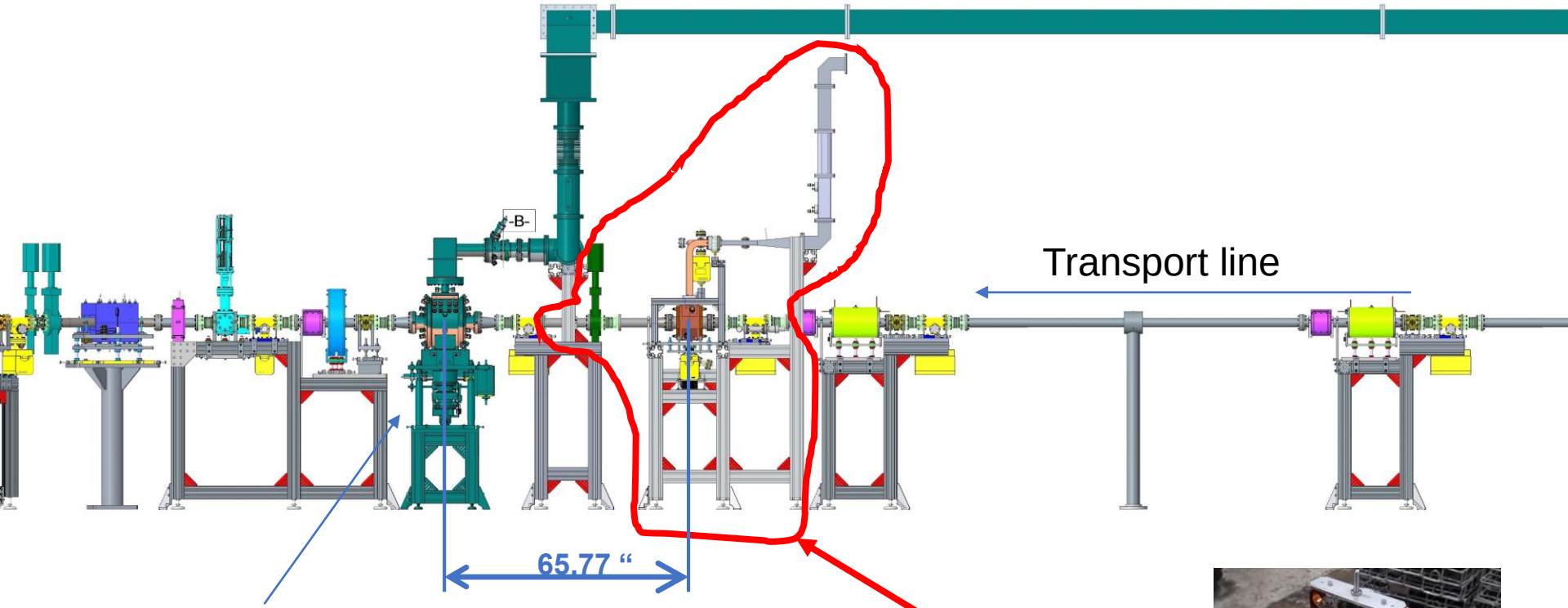
Expected longitudinal performance with 1.4GHz cavity

- Increase in electron bunch length by a factor 1.5 preserving the same sliced energy spread
- Longer bunch length should result in reduced “heating” effect from electrons on ions

Longitudinal phase space of electron beam at the end of transport line.

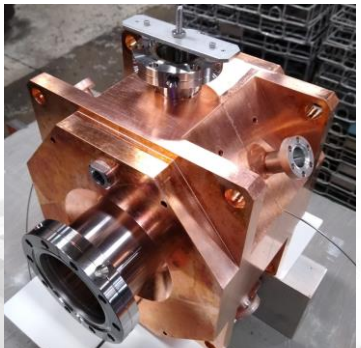


Location of new 1.4GHz RF cavity at the end of Transport line (installed next to 704 MHz warm RF cavity)



704 MHz warm RF cavity (present location)

1.4 GHz warm RF cavity (NEW)



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Things to Do

- Address laser issues related to intensity controls
- Better laser observations and controls (9MHz laser signal) to aid operators
- Address issue related to MPS trips on BPMs
- Upgrade of MPS BLM systems (install glass fibers, upgrade to HV power supplies/software, fix problem with yellow pmt1 cable)
- Transfer cooling section orbit feedback into the standard controls application
- Transport orbit correction script/application
- Additional controls/alarms indicating that application/feedback is not working or reached some limits (like in energy feedback application)
- Test Gun HVPS controls with new (updated) controls chassis
- Test new Gun HVPS multiplier
- Check Gun performance before inserting active cathode
- Integrated fast vacuum valve and 1.4GHz RF cavity into MPS
- Commission 1.4GHz RF systems
- Commission electron accelerator with new 1.4GHz RF cavity
- Commission and optimize cooling with longer electron bunches

LEReC plans for 2021

Oct-Dec., 2020:	Installation and commissioning of 1.4GHz RF cavity and related systems
January 2021:	Once SRF booster is at 2K, SRF tests and conditioning
January 2021:	Commissioning of electron accelerator with new 1.4GHz RF cavity
February 2021:	Cooling commissioning and optimization with 1.4GHz RF cavity
February 2021:	Physics run with cooling at 3.85GeV.
February – June 2021:	Cooling studies and R&D for high-energy cooling (as APEX)

Summary

- World's first electron cooling in a collider was successfully commissioned and became fully operational during 2020 RHIC Physics run with Au ions at 4.6GeV.
- Stable and reliable accelerator and cooling performance during many weeks of Physics running
- Cooling was commissioned for Physics operation at 3.85GeV.
- New 1.4GHz RF cavity and supporting systems are being installed.
- LEReC is the only electron cooler which uses non-magnetized electron bunches produced with rf-acceleration (high-energy cooling approach). As such, it offers unique opportunity to study various effects relevant to high-energy cooling, including effects on ion beam lifetime. We plan to do such experimental studies in 2021 and possibly beyond.

Successful LEReC operation became possible due to hard work of many people from C-AD!
Thank you!