Cec PoP in Run-17 and plans for Run-18

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Results of Run 17 and plans for Run 18

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It take the village… the CeC team – never can get all your pictures but really appreciates all your efforts

Content

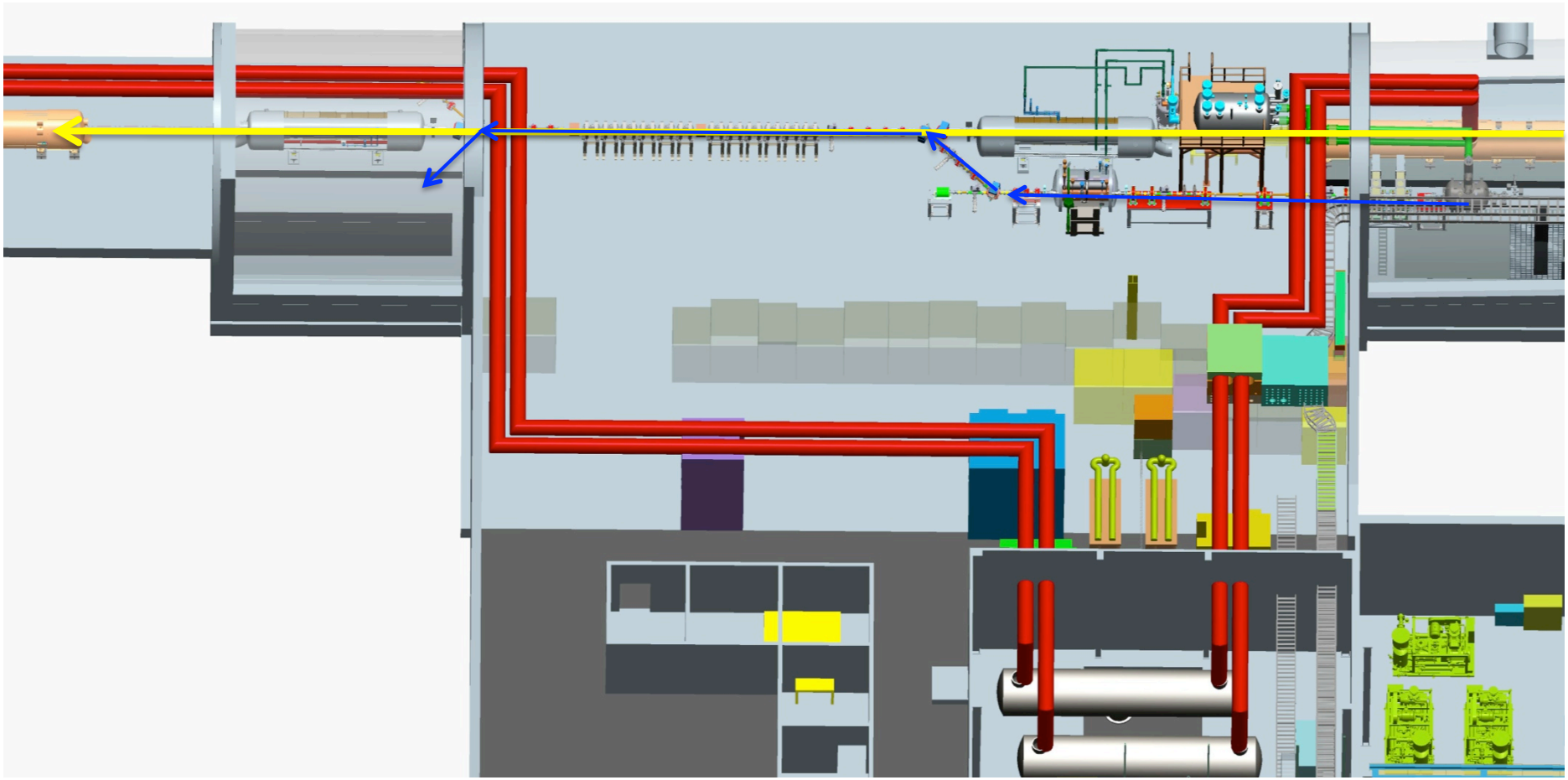
- Why we doing it?
- Run 17
  - Main achievements
  - What worked and what did not?
- Plan for Run 18
  - Shutdown jobs
  - Plan for demonstrating CeC
- Q&A

It is all about future
CeC effect on eRHIC design

- **Short term:**
- If CeC is successful and is fully operational, eRHIC LR could reach $2x10^{33}$ luminosity with 5 mA polarized electron current.
- It removes main uncertainties in LR design of 50 mA of polarized e-beam
  - 5 mA, 0.5 nC/bunch
  - 100x lower HOM power
  - 10x lower TBBU threshold
  - 3x shorter hadron bunches
  - 3x higher frequency of crab cavities -> 1/3 of the voltage
  - Up to 3x smaller β*
  - 10x lower SR losses
  - 10x lower SR back-ground
  - and many positive effects for EIC detector

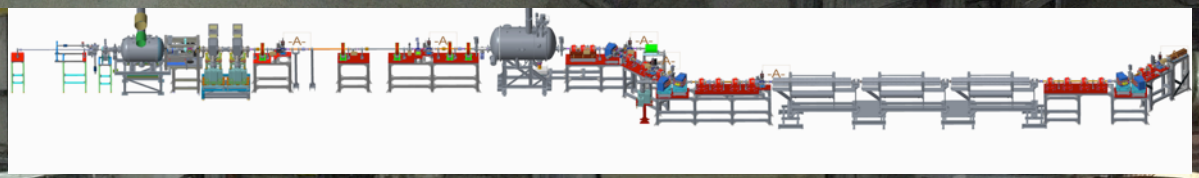
- **Final goal: eRHIC/EIC with $2x10^{34}$ luminosity**

Test: Coherent electron Cooling (CeC) Demonstration Experiment



Panoramic views (before LEReC installation)

From inside RHIC ring



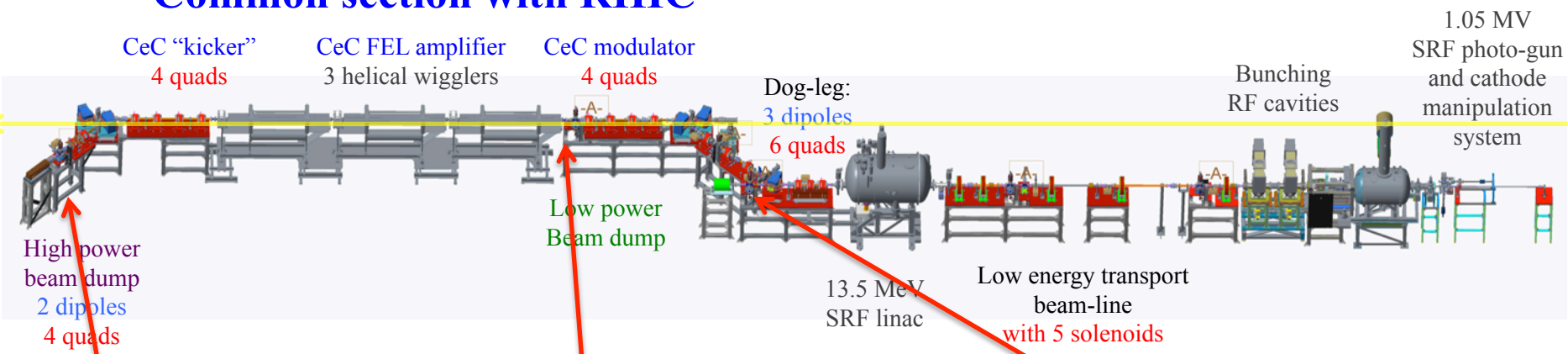
From outside RHIC ring

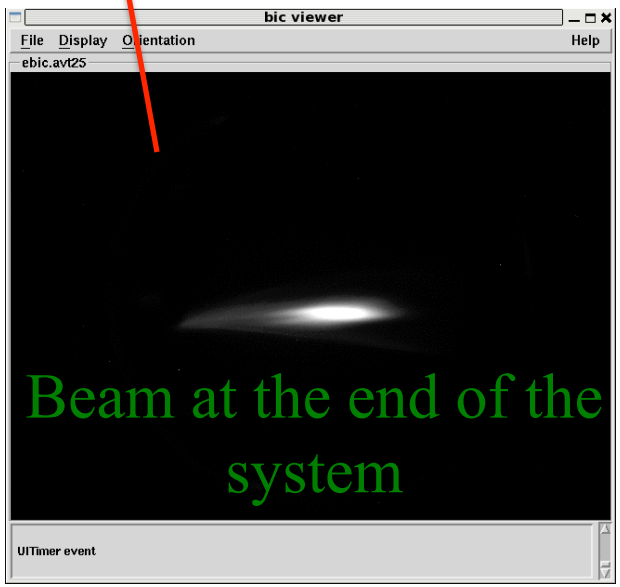
Main achievements

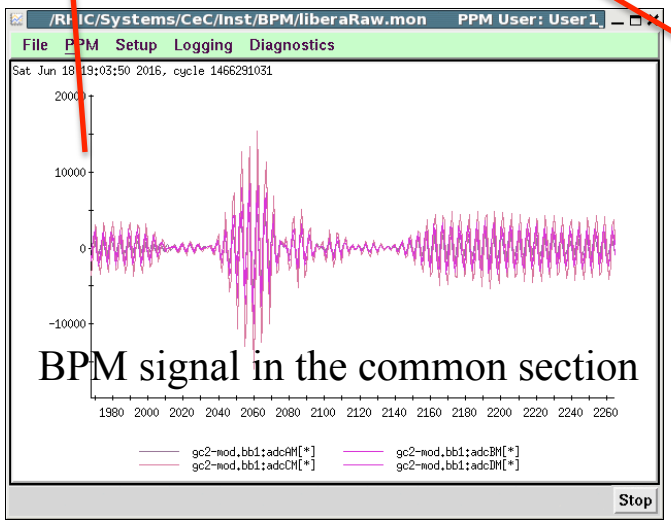
- CeC SRF accelerator is fully commissioned. Electron beam at full power was propagated through the entire system to the high power beam dump with low losses
- Beam diagnostics is fully commissioned and beam dynamics is well understood
- Electron bunches are compressed and desirable level of peak current is demonstrated
- Synchronization of electron and ion beams was established and interaction between the beams was detected
- The system is ready for demonstration of coherent electron cooling during RHIC Run 18

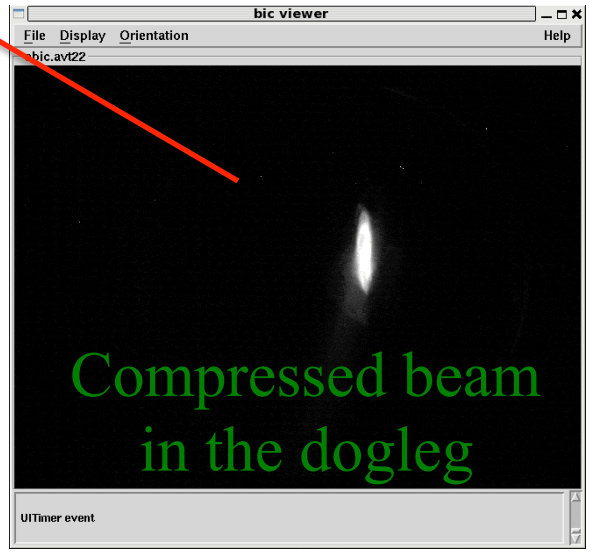
The CeC system commissioning

Common section with RHIC









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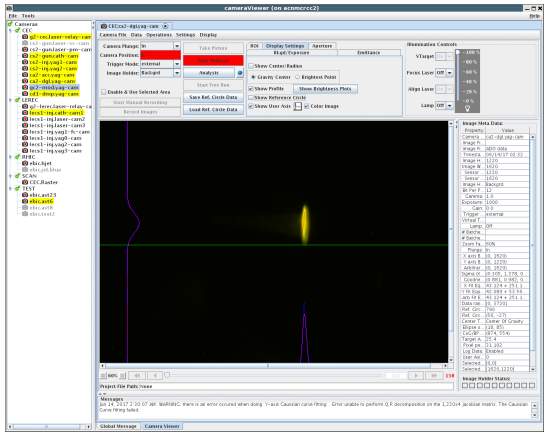
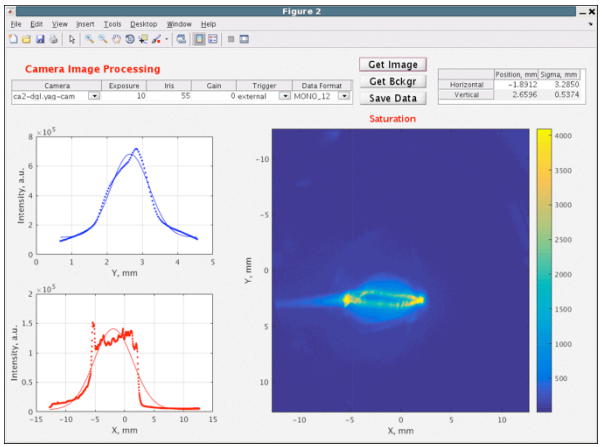
Main advances

- We were able to generate electron beam with quality sufficient for the CeC experiment and FEL amplification
  - 0.5 nC, 50 A bunches were generated, accelerated and propagated through the system
  - What is needed is to improve stability of all subsystems, task for this shutdown
- We identified a number of problems (insufficient number of trim coils, need to compensate stray fields of DX and D0 magnets, error with helicity of 3rd wiggler, need for temperature controlled RF cables….) and are pursuing implementation of this plan

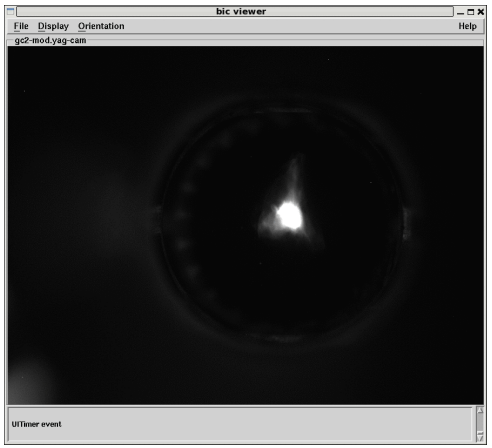
Sub 0.1% energy spread



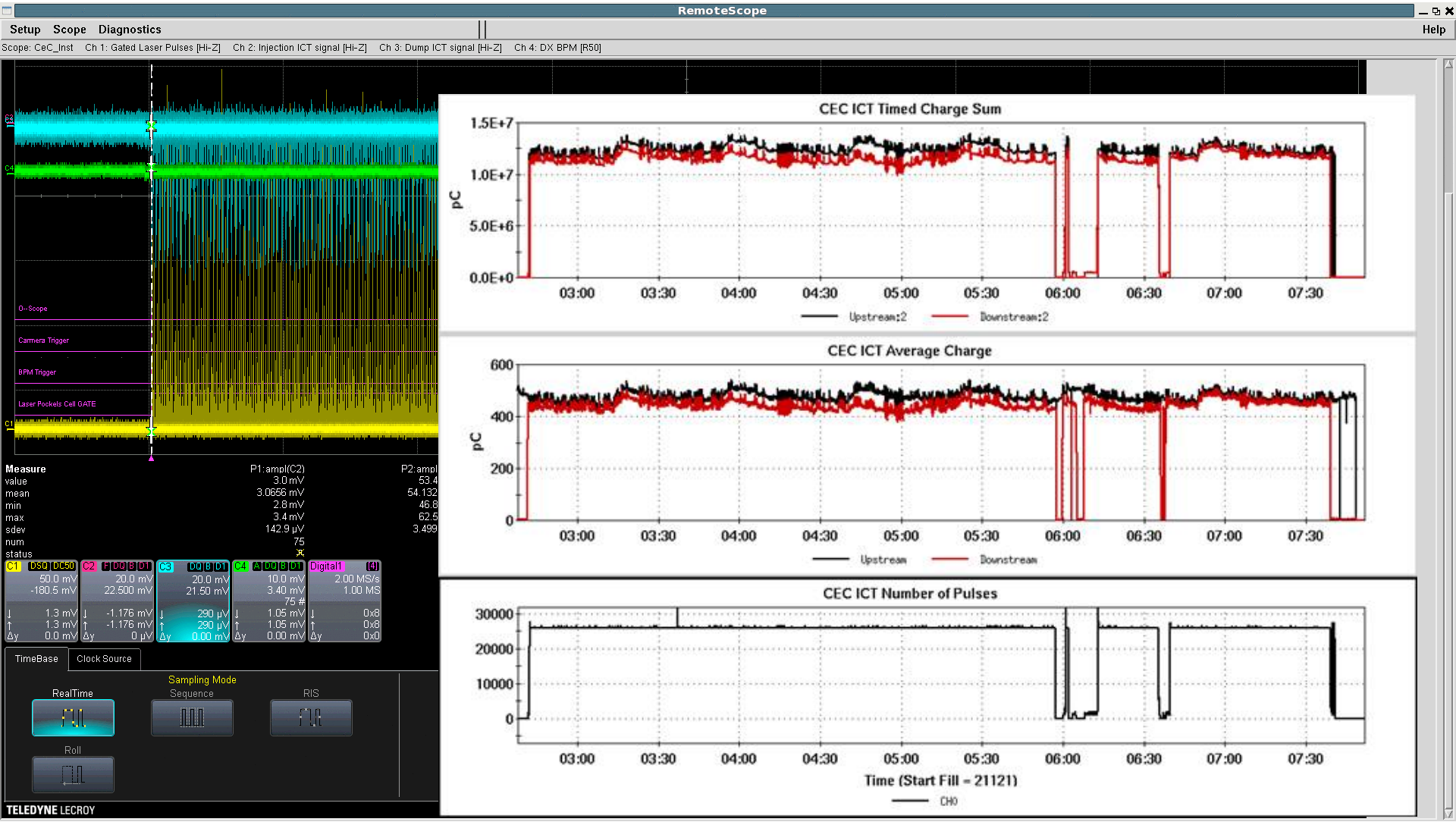
40 A peak current in the bunch



Low emittance beam in FEL



Operating in CW mode



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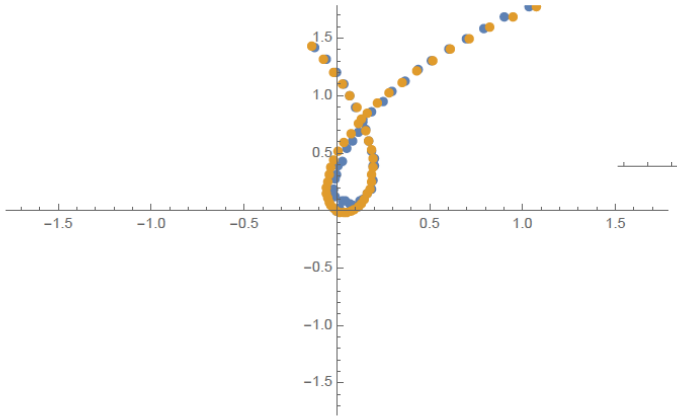
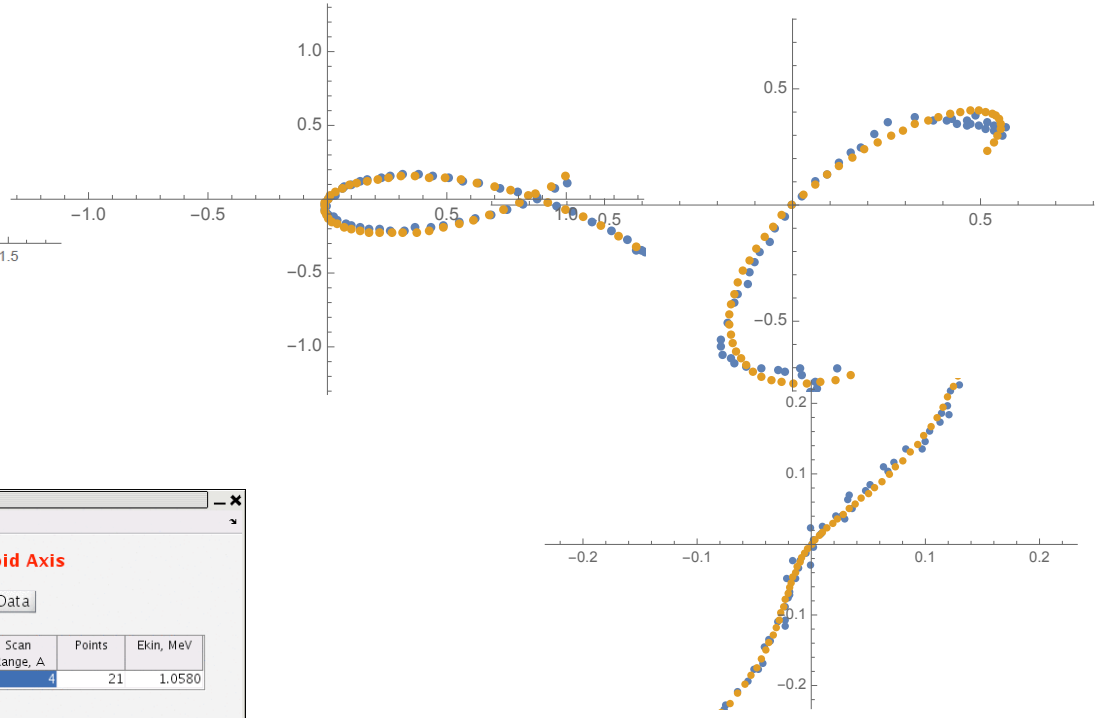
Accelerator Physics highlights

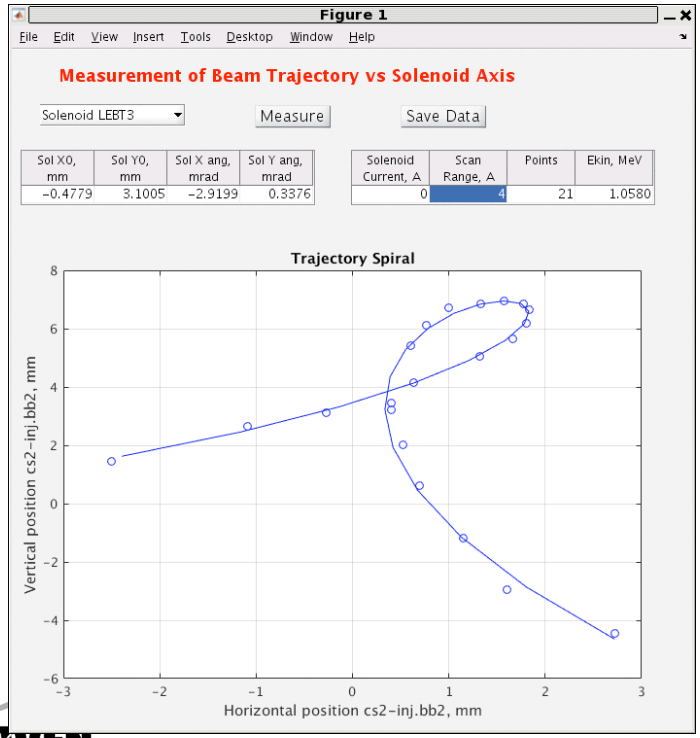
- 113 MHz SRF gun with room-temperature CsK_2Sb cathodes demonstrated excellent performance
  - CsK_2Sb cathodes survived for months of operation (and exhibit QE improvement during operation)
  - Beam with charge up to 4 nC per bunch were demonstrated
  - Projected normalized emittance of 0.32 mm mrad was demonstrated for 0.5 nC bunches
  - Multipacting is well understood and a process of avoiding it is developed, tested and implemented
- World's first 2K cryostat with superfluid heat exchanger (used for 5-cell 704 MHz linac) demonstrated excellent performance and good microphonics isolation ($\Delta f \sim 10$ Hz pk-to-pk)
- Beam-based alignment using solenoids was demonstrated with full restoration of the beam trajectory
- A self-consistent simulations of Debye shielding in finite electron beam propagating in the modulator with quadrupoles

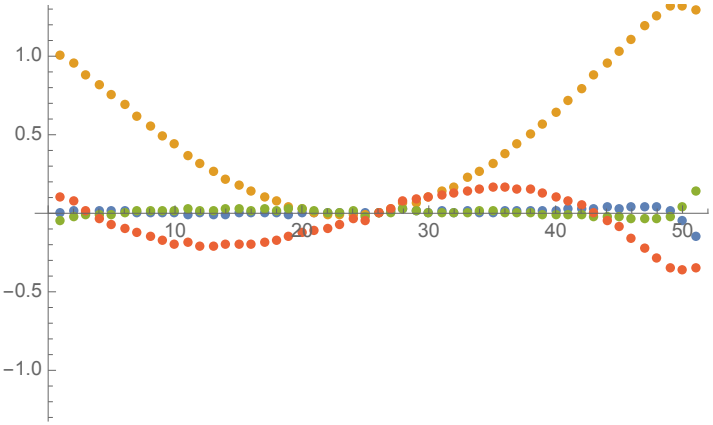
Solenoid BBA: gives *x,x',y,y'*





Blue measurements, yellow – solution





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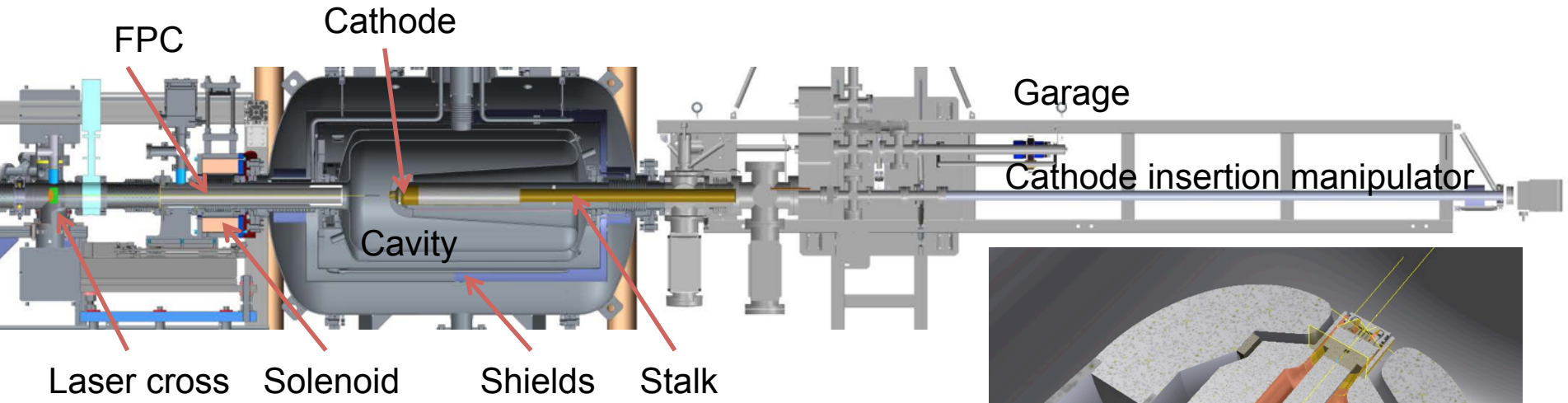
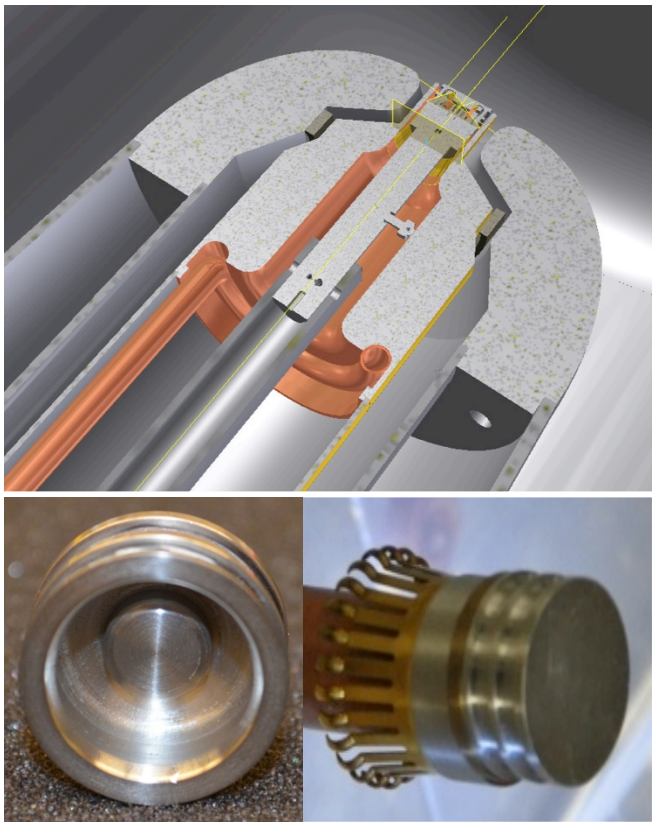
CeC SRF Gun with CsK_2Sb photocathode



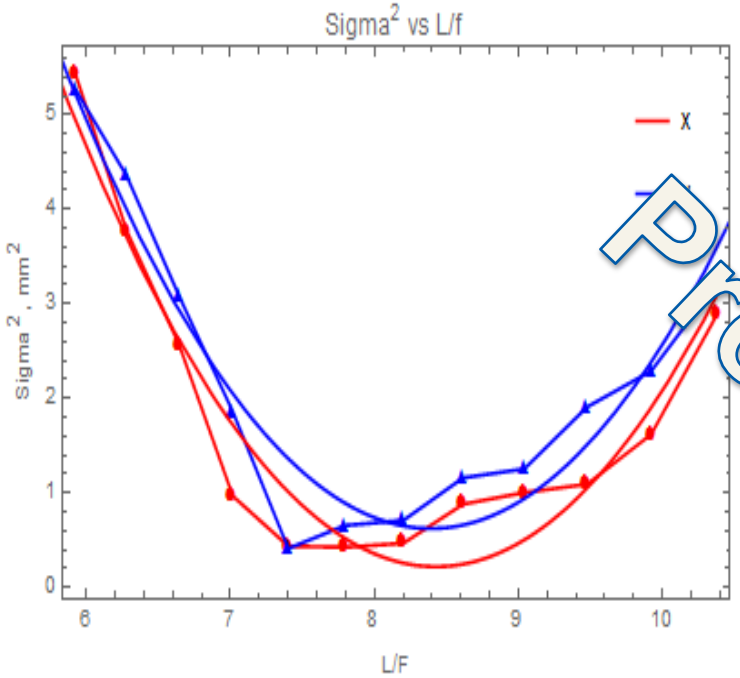
Because of low energy if the e-beam, the SRF gun was operating at harmonic of 3rd sub-harmonic of RHIC revolution frequency for 26.5 GeV/u , e.g. 26 kHz

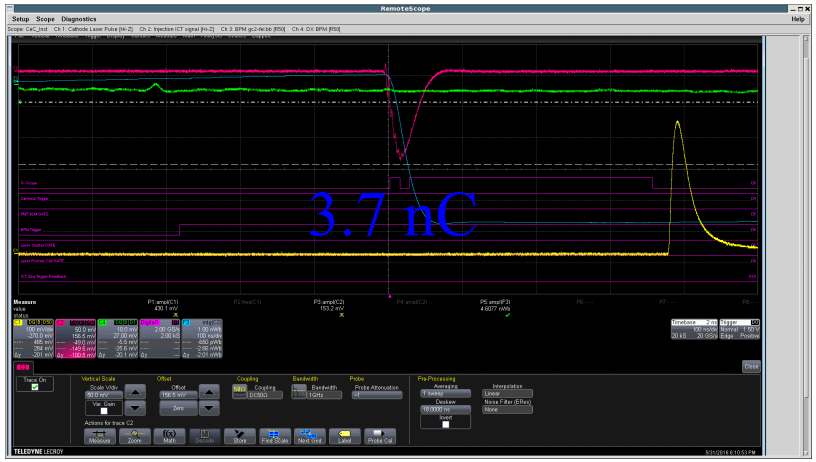
Will be retuned in few weeks to operate on harmonic of RHIC revolution frequency for 26.5 GeV/u , e.g. 78 kHz

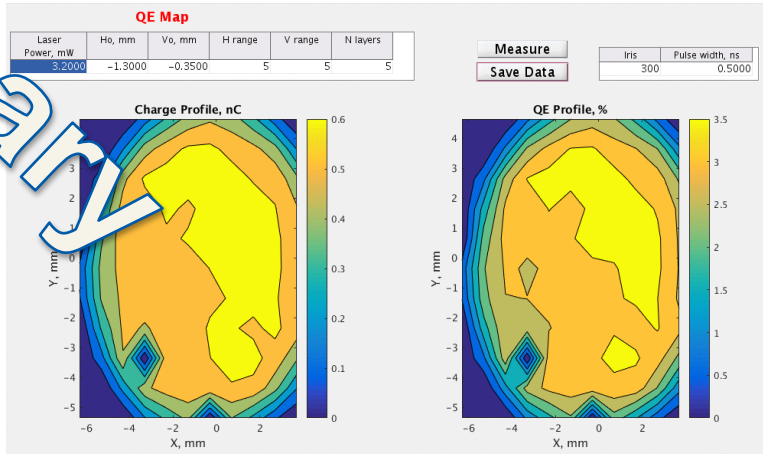


Photocathode end assembly

Record performing 113 MHz SRF photo-electron gun:
now cathodes keep high QE for months







Preliminary

Best result so far:
Gun Solenoid and YAG1 profile monitor
0.32 mm mrad normalized emittance at
0.5 nC/bunch

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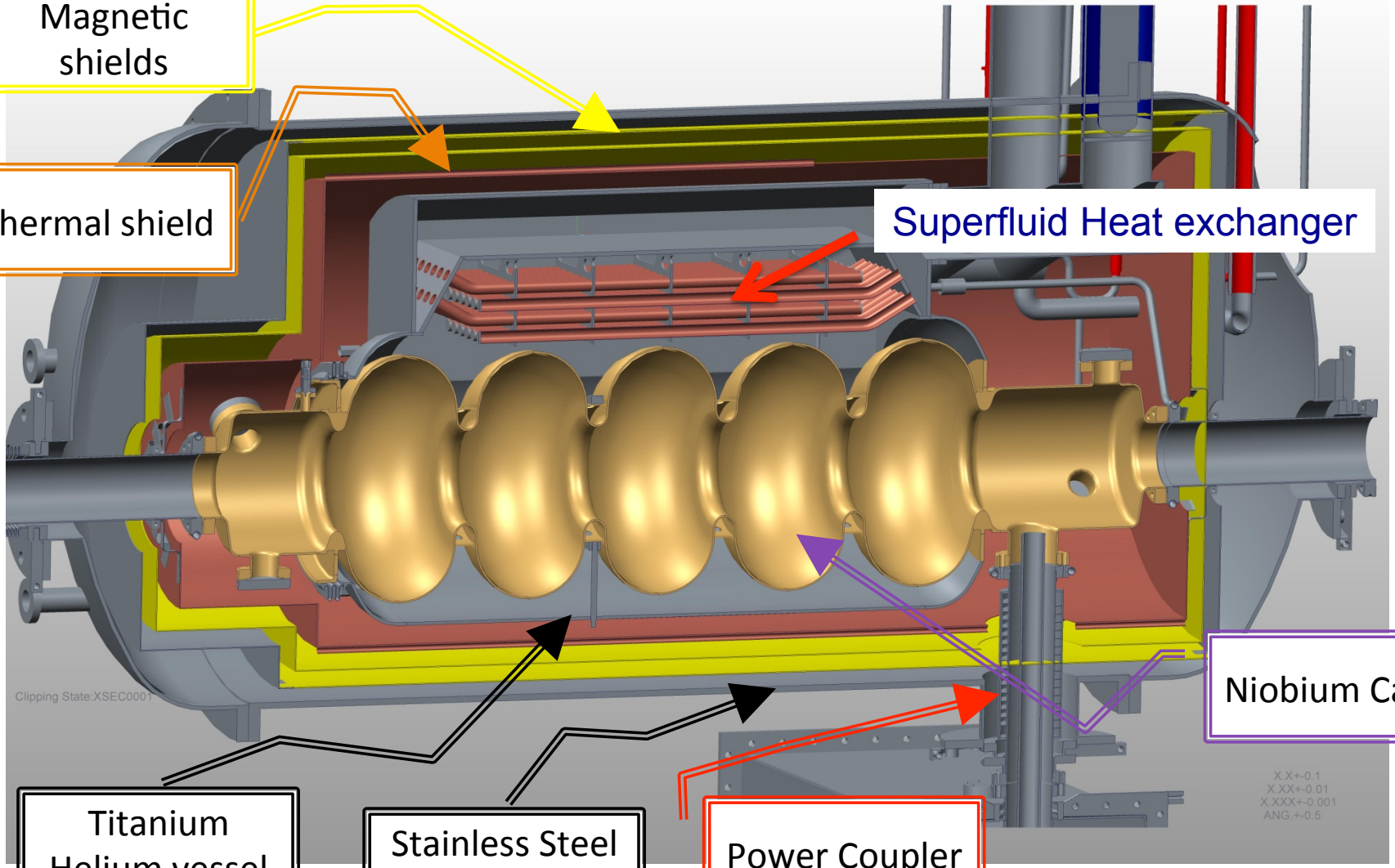
704 MHz 5-cell linac cryostat with superfluid heat exchanger: microphonics < 10 Hz p-to-p



What worked and what did not? Main points

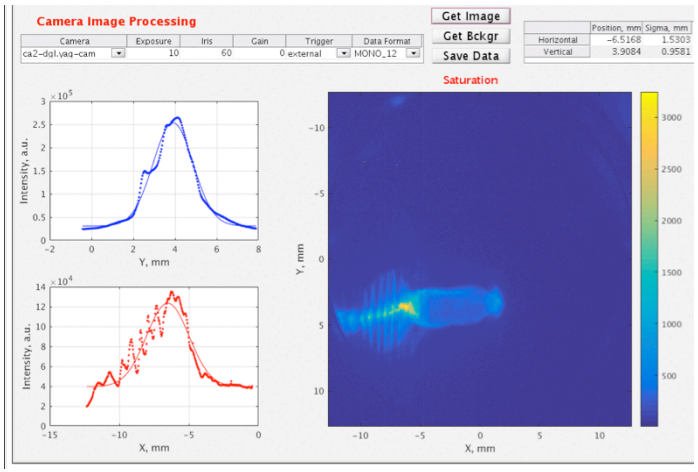
- SRF gun working very well
- SRF5-cell linac was cleaned and re-commissioned
- All three RF system in CeC accelerator are operation and phase locked with RHIC
- e-Beam was propagated through the CeC system with low loss
- Electron and ion beams were synchronized and we detected their interaction

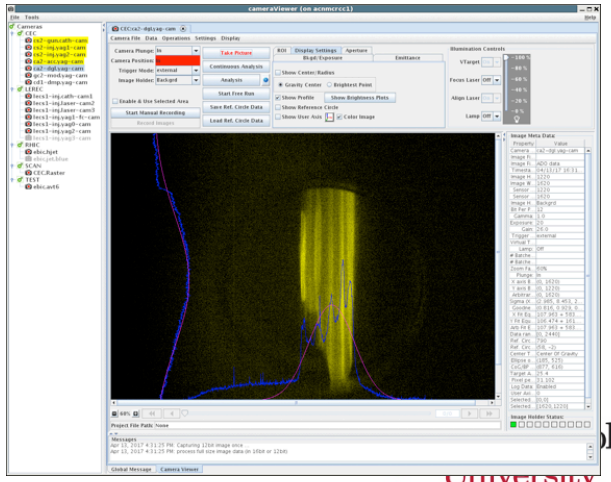
- SRF linac did not reached design accelerating of 20 MV, but only 13.5 MV
- e-beam energy limit to below 15 MeV moved the FEL from 13 to 30 μm rendering IR diagnostics completely unusable – hence making FEL commissioning into a "blind-folded" contest
- Pulse-to-pulse stability of the system (both laser and RF) did not allow us to use energy spread at the beam-dump as a measure of FEL lasing
- Laser system was unreliable

Additional challenges

- Time, phase and amplitude stability of the subsystem is not to the specification. Making reproducible set-ups was prevented by uncontrollable variation in the subsystems
  - Plan to install temperature controls of the loop-back and a monitoring scope for LLRF and laser systems
- Laser system had very large fluctuations of power and time structure, making reliable bunch compression very difficult and some time impossible
  - Replacing the laser
- "Perfect liars" – systems which measuring their own performance and "always correct" – example, power supply which suddenly doubled the current, while reporting exactly what it was asked for…
  - Trying to figure out how to solve this without major rebuilding
- Huge RFI noise in IR2, impeding high precision beam parameters measuring and controls
  - SOLUTION IS UNKNOWN
- ….. list is rather long

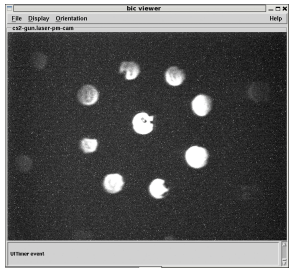
5 micro-bunches inside
300 psec bunch



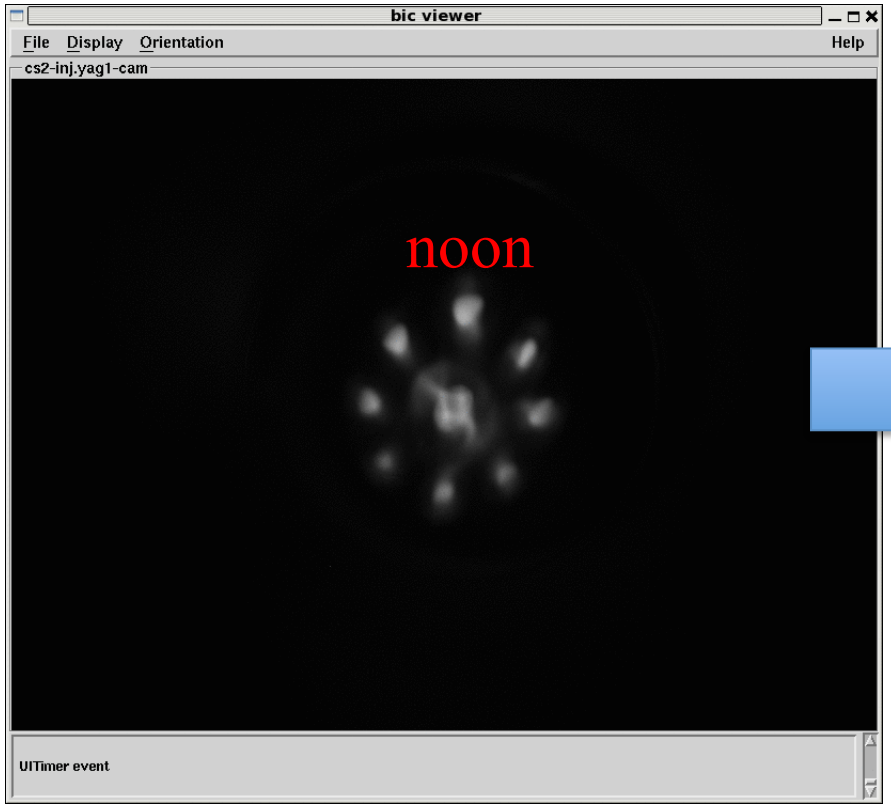


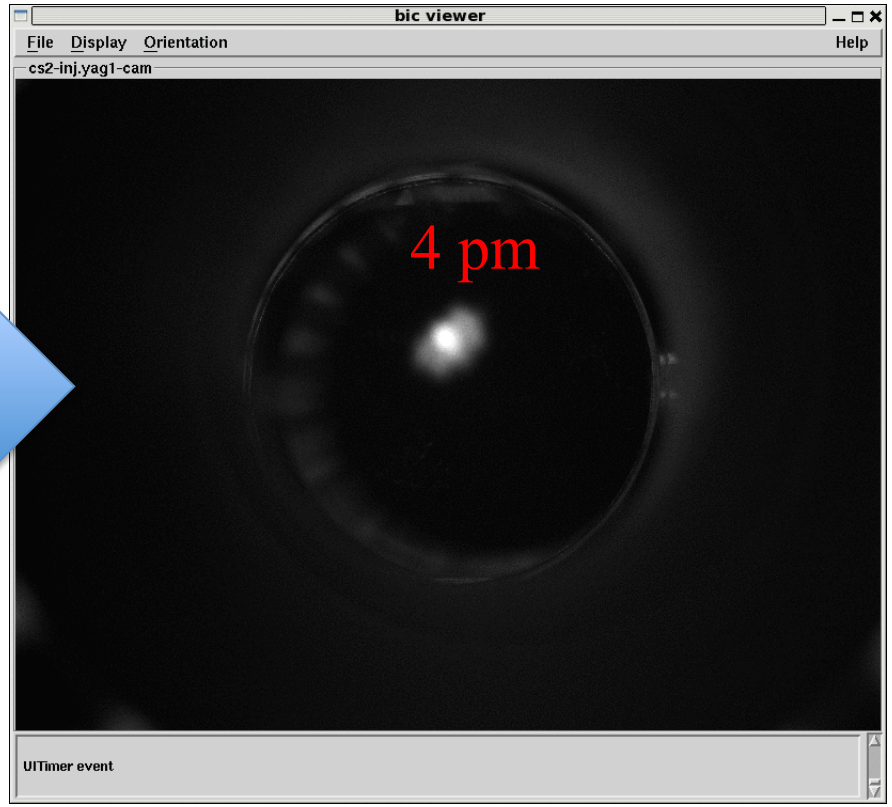
Mystery of June 27

Laser spots



- Simple system: SRF gun, 1 solenoid, YAG screen
- With 2 systems reporting perfect performance images taken at the same solenoid setting of 8.05 A and the same gun voltage 1.05 MV

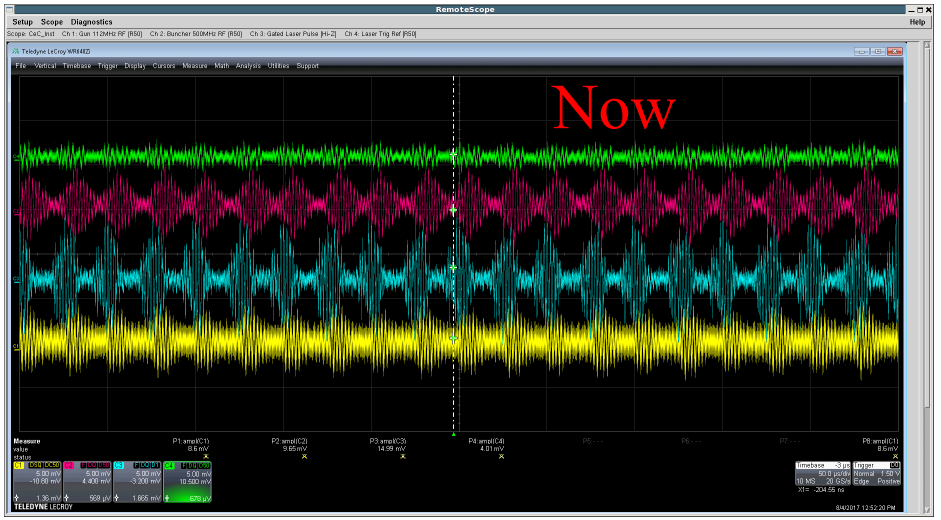


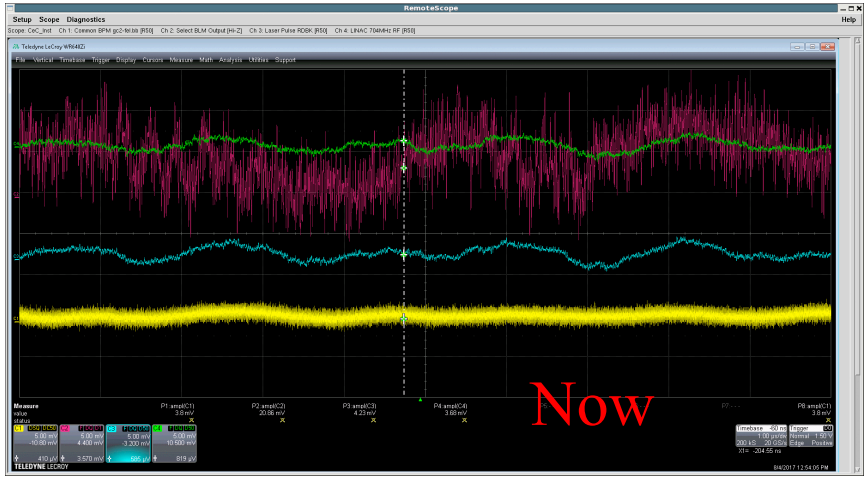


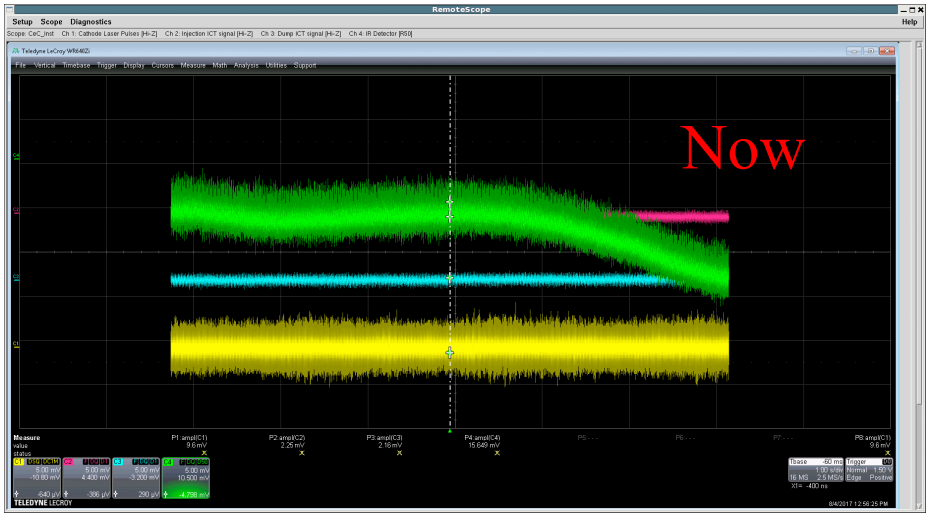
No explanation found yet…

RFI – noise in each and every cable

- RFI at IP2 generates broad-band noise in each and every CeC cable, making measuring of weak signals impossible, and measuring large signals inaccurate.







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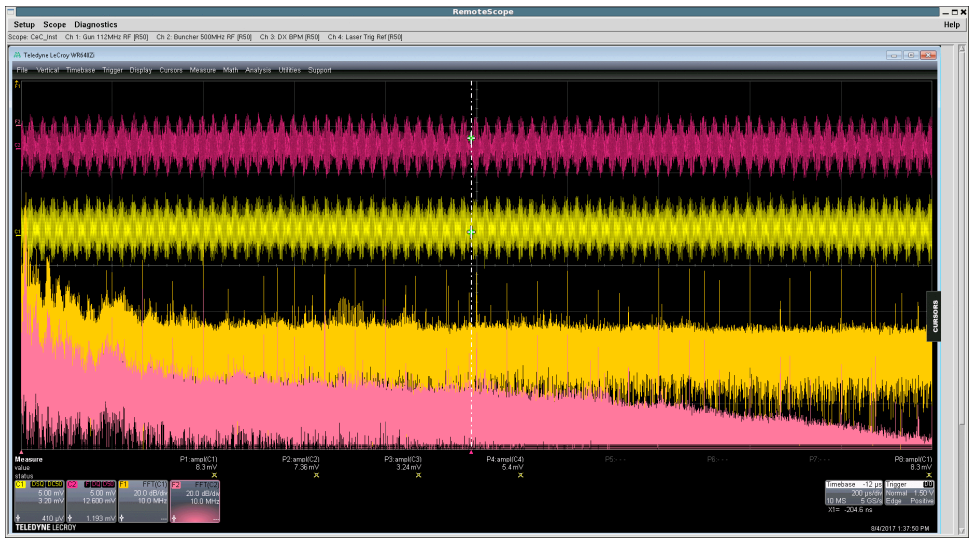
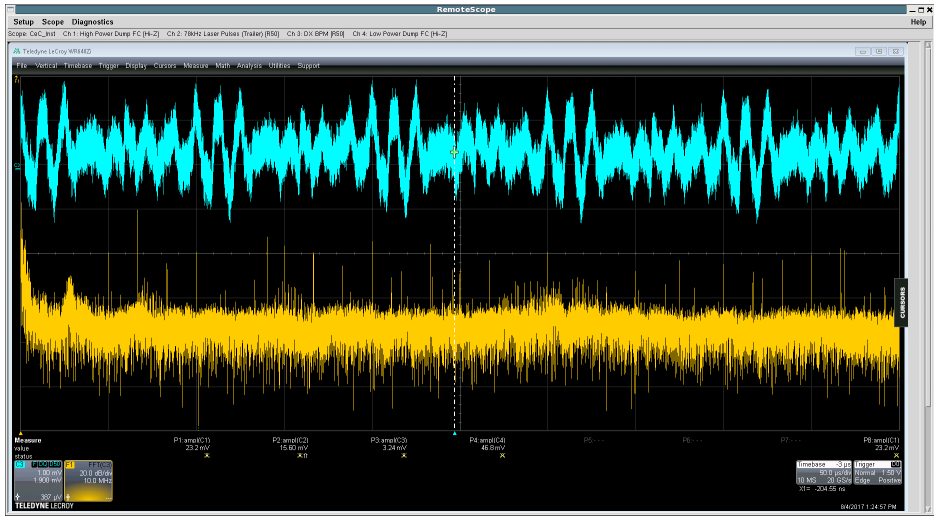
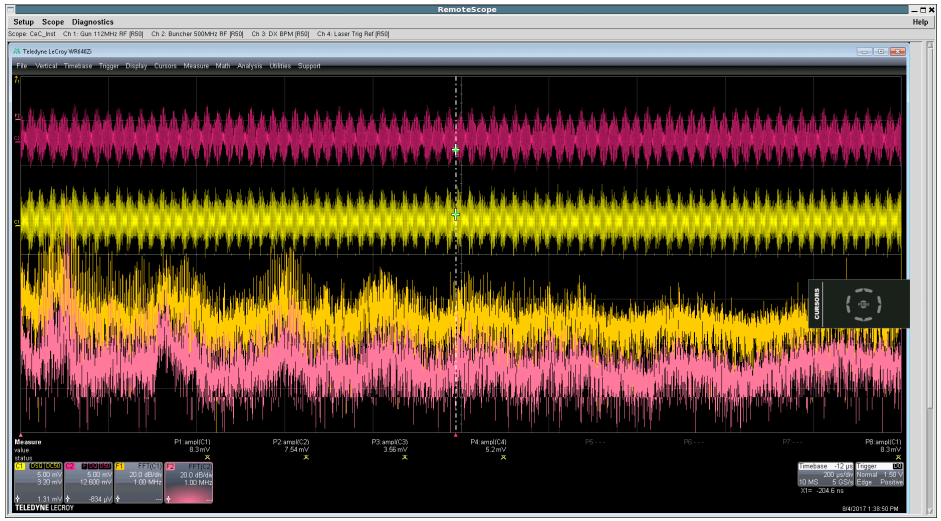
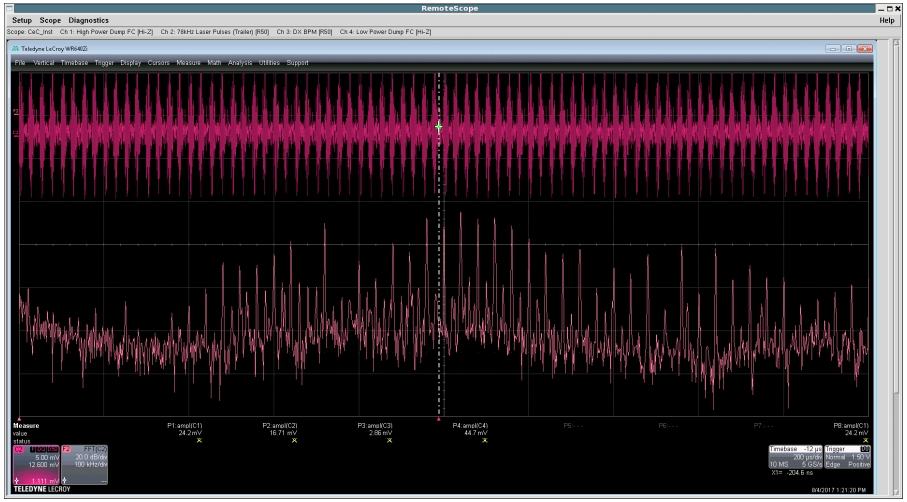
Now RHIC off, LEReC off: a lot of frequencies plus broad-band noise

More at CeC elog, August 4, 2017: http://elog.pbn.bnl.gov:8080/elogs/entryList.jsp?DATABY=day&ELOG=CeC_2017&DATE=08/04/2017&PAGE=1&DIR=forward&AUTO=yes









Identifying and eliminating sources of noise will be critical to any high precision measurements

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Beam parameters

Parameter	Design	Status	Comment
Species in RHIC	Au^{+79}, 40 GeV/u	Au^{+79} 26.5 GeV/u	To match e-beam
Particles/bucket	10^8 - 10^9	10^8 - 10^9	✔
Electron energy	21.95 MeV	**15 MeV**	**SRF linac quench**
Charge per e-bunch	0.5-5 nC	0.1- 4 nC	✔
Peak current	100 A	50 A	Sufficient for this energy
Pulse duration, psec	10-50	12	✔
Beam emittance, norm	<5 mm mrad	3 - 4 mm mrad	✔
FEL wavelength	13 μm	**30 μm**	**New IR diagnostics**
Rep-rate	78.17 kHz	26 kHz**	Temporary**
e-beam current	Up to 400 μA	40 μA	Temporary**
Electron beam power	< 10 kW	600 W	Temporary**

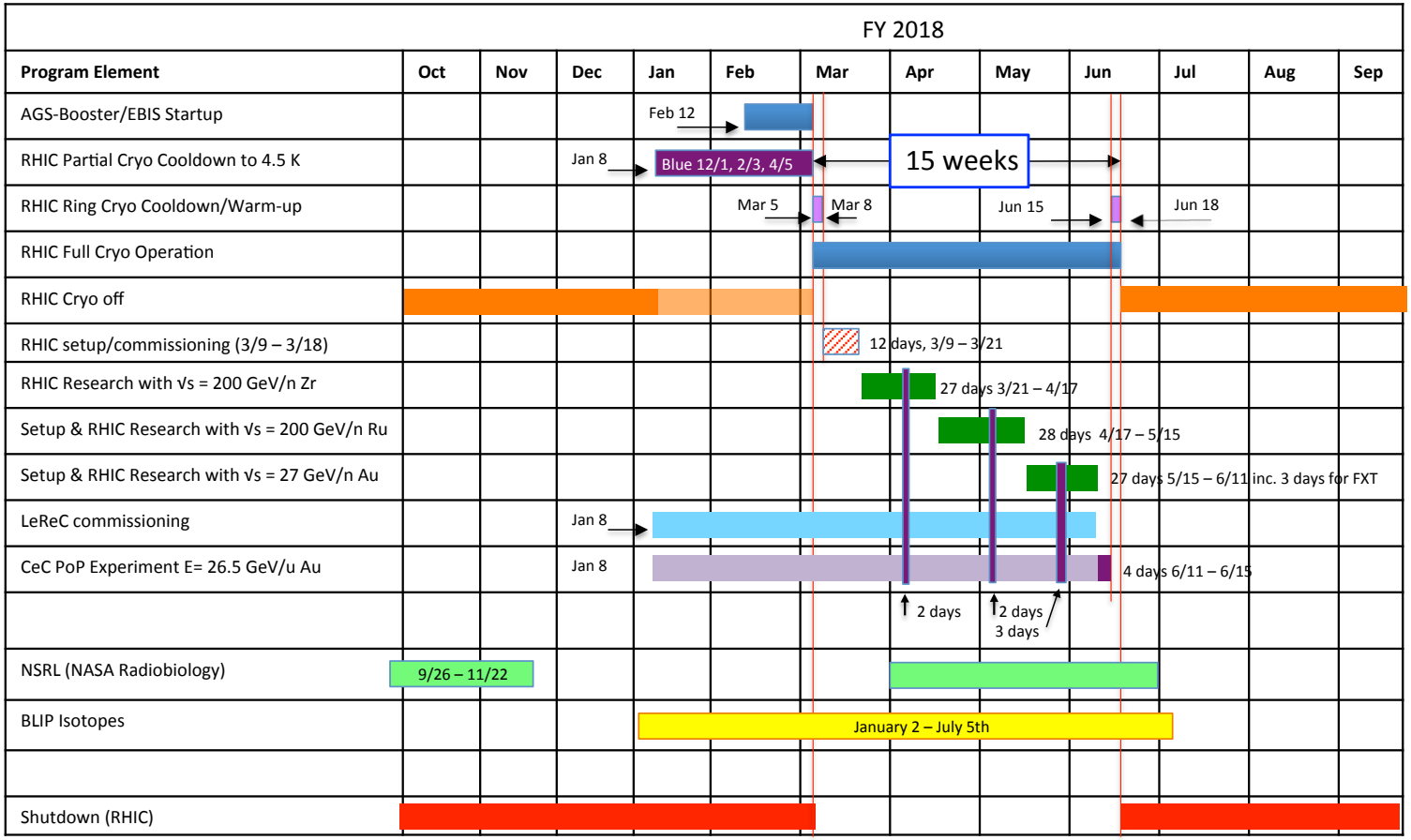
***Will be changed to 78 kHz after retuning the gun frequency*

Beam parameters are sufficient for the CeC demonstration experiment

Next step: demonstrating CeC

C-A Operations FY18

Last revision: July 21, 2017



Zr run = 27 days (24.5 “physics” + 2 CeC + .5 float)
Ru run = 28 days (1.5 setup + 24.5 “physics” + 2 CeC)
Au run = 27 days (1 setup + 20 “physics” + 3 FXT + 3 CeC)
“physics” = physics + APEX + maintenance

Dates for first three CeC periods are approximate (early April, early and late May)
CeC parasitic commissioning =
CeC Dedicated running = (Total of 11 days)

Preliminary plan for CeC experiment during Run 18

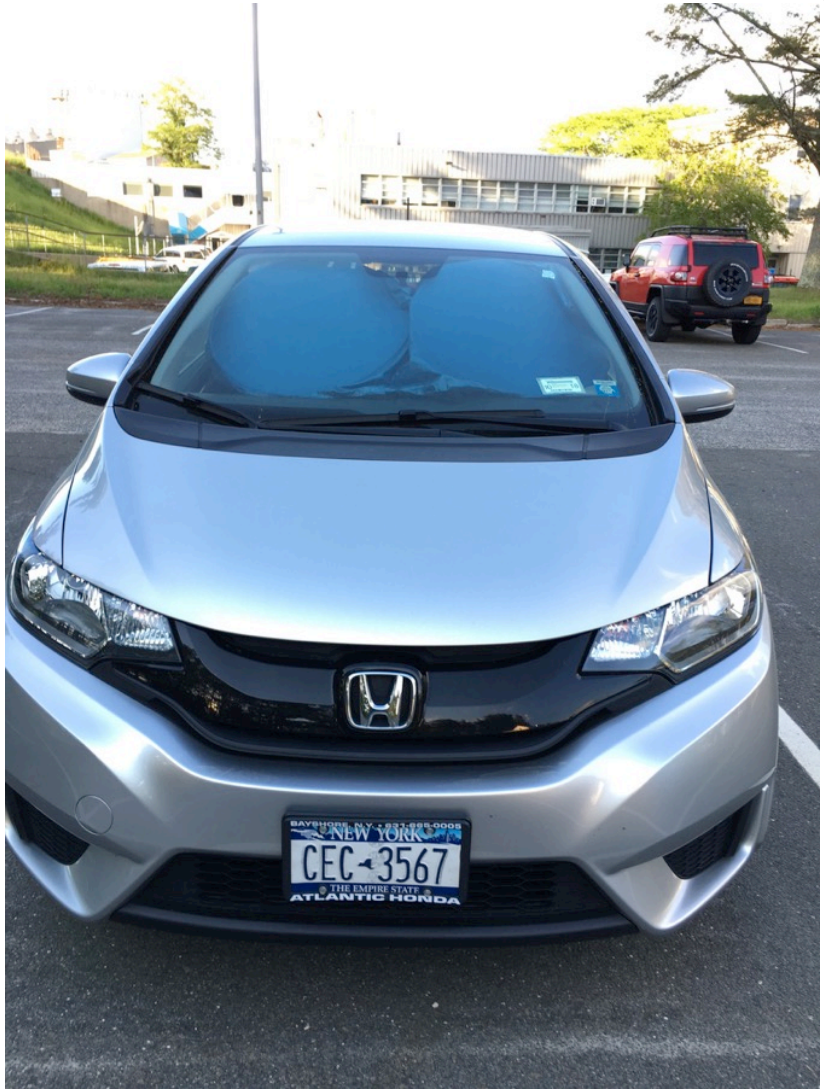
Has to be coordinated with LEReC commissioning

Activity	Aggressive schedule	Conceivable Schedule
Re-establish CeC accelerator operation	1/8– 2/3	1/8– 2/15
Establish required e-beam parameters CeC FEL commissioning	2/4 – 3/5	2/16 – 3/15
Establishing CeC system operations at various RHIC settings, compensating stray magnetic fields	3/5 – 3/21	3/16 – 3/30
Co-propagate, align and synchronize electron and ion beams, match relativistic factors of two beams	3/22 - 4/7 2 days dedicated	3/31 – 4/15 2 days dedicated
Develop control of the FEL amplification, observe amplification of density modulation induced by ions	4/8 – 5/5 2 days dedicated	4/16 – 5/10 2 days dedicated
Refine tools for observation of ion beam cooling, observe cooling/anti-cooling via CeC	5/6 – 5/25 3 days dedicated	5/11-5/30 3 days dedicated
Develop various CeC accelerator settings (charge, peak current, FEL gain) and characterize CeC cooling	5/26 -6/15 4 days dedicated	5/31 -6/15 4 days dedicated

Conclusions

- During Run 17 the CeC was given an excellent opportunity and plenty of time to make as much progress as it was technically and physically possible
- The CeC accelerator is fully commissioned
  - But low energy gain of the SRF linac prevented us from demonstrating the FEL amplification and the CeC cooling – *it is my main disappointment*
- We defined and are implementing all necessary step for demonstration CeC experiment during RHIC Run 18
- The fact that LEReC program requires earlier delivery of LiHe to IP2, will give CeC extra time to re-commission the accelerator
- Coordination with LEReC installation and operation will be critical for CeC successful demonstration
- During RHIC Run 18 we plan to involve RHIC operators in CeC operations, for example in testing its accelerator settings

CeC remains popularity at C-AD

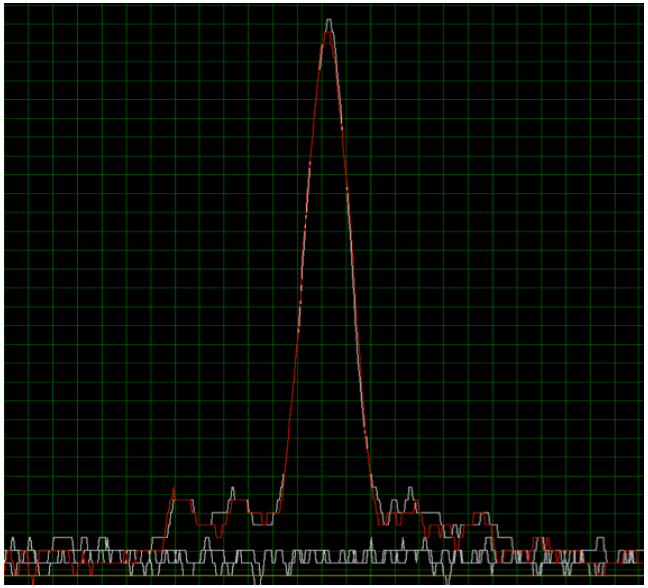


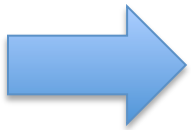
Back-up

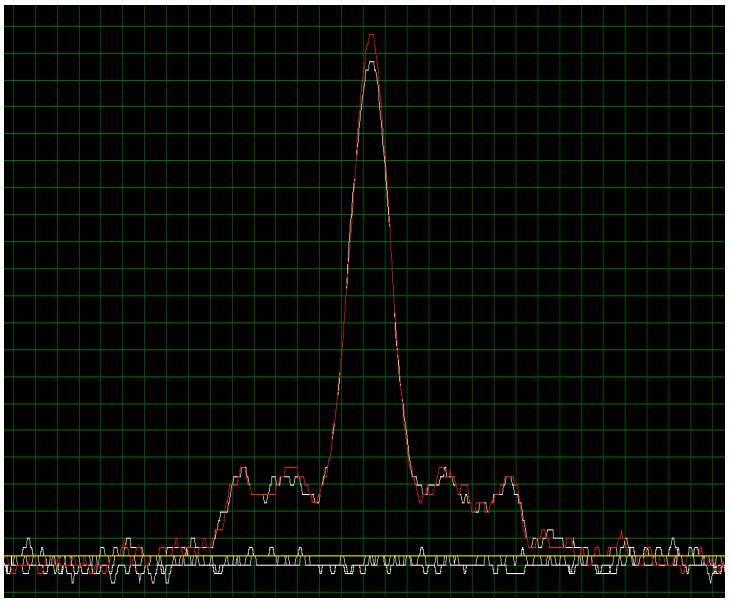
Main disappointment

- We were unable to see signal from CeC FEL
  - SRF linac failed to reach design accelerating voltage of 20 MV, making our IR FEL diagnostics useless and us “blind-folded”
  - We were unable to see radiation at 3rd harmonic of FEL radiation (which was weak to start from) because of strong RFI
  - Laser/RF system stability was insufficient to measure energy spread increase by FEL interaction

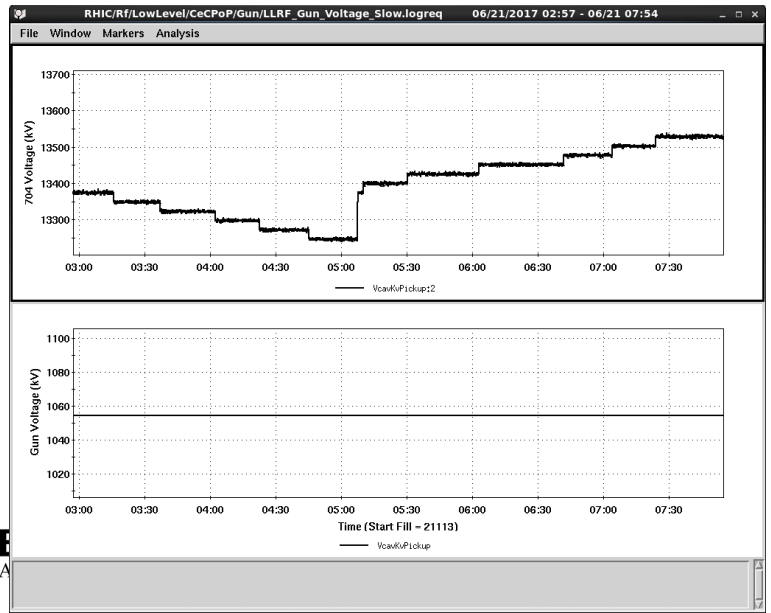
Interaction with ion bunches: June 19

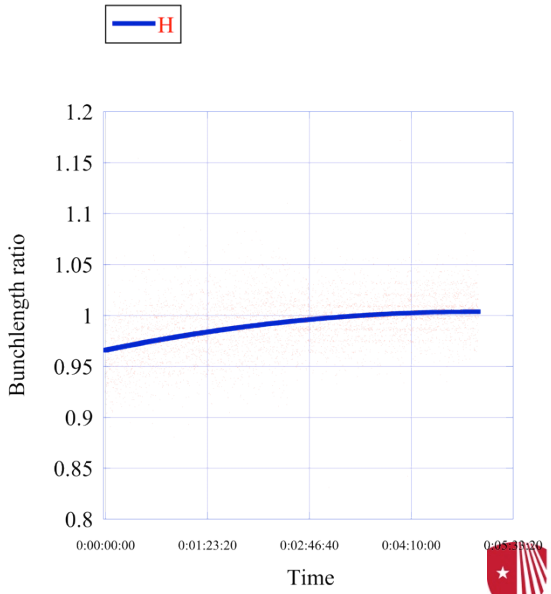






Preliminary





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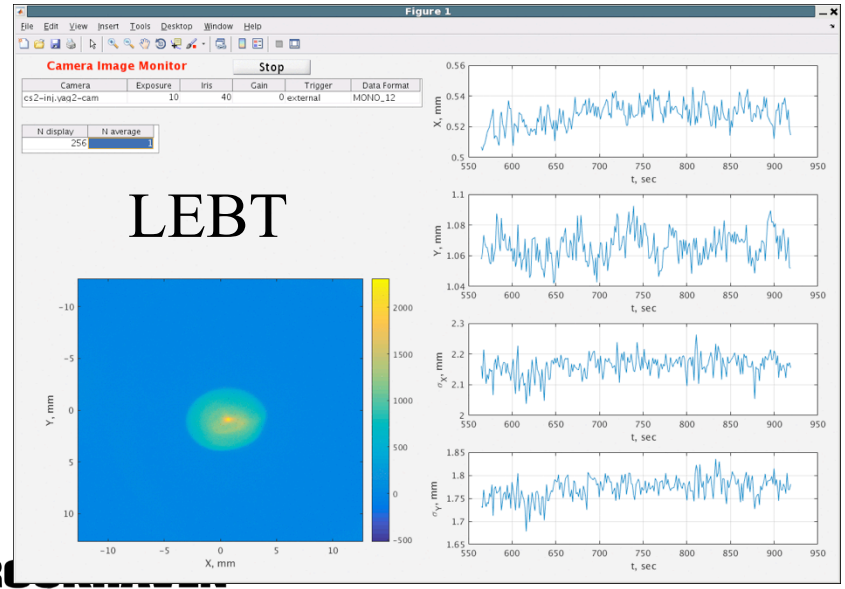
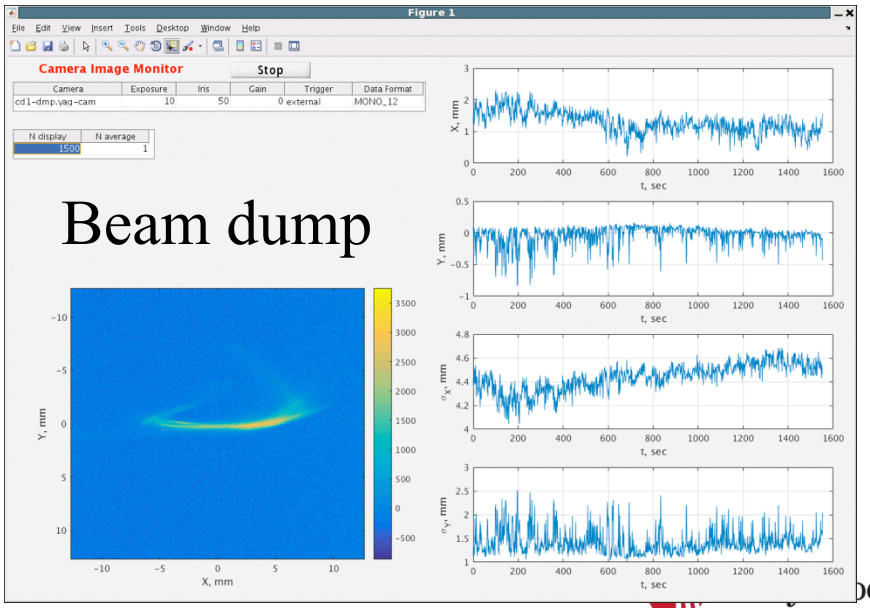
Stability of the beam

- Remaining hope for a "blind-folded" team (never tried by any FEL team) was to observe fluctuations of the energy spread at the exhaust of the FEL, e.g. in front of the power dump
- It would require a stable – bunch to bunch- electron beam, e.g. a repeatable operation of laser (pulse energy, time of arrival and position), RF phases and amplitudes of 3 RF systems (the gun, the bunching cavities and linac) and magnets
- Igor Pinayev created a script which allowing tracking the energy spread in the front of the dump and we attempted to observe the energy spread dependence on the phases between three undulators, but also no luck. Pulse to pulse variations were too large to detect influence of the FEL lasing/phasing

YAG2: 50 μm center of gravity and 5% r.m.s. size variations



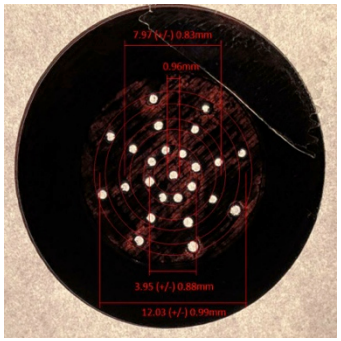
YAG at the beam exhaust: shot to shot variation are too large to detect FEL action



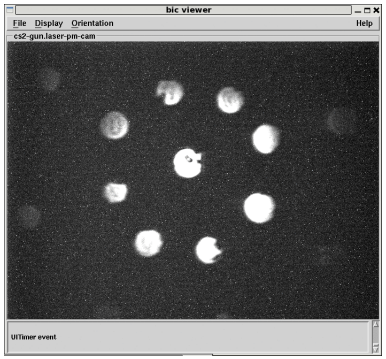
Mystery of June 27

- Generated laser pattern to pin the SRF gun optics
- Made system as simple as focusing: source (SRF gun), gun solenoid and e-beam profile monitor (YAG screen)
- Fixed gun voltage. Focused e-beam on the YAG screen by adjusting gun solenoid

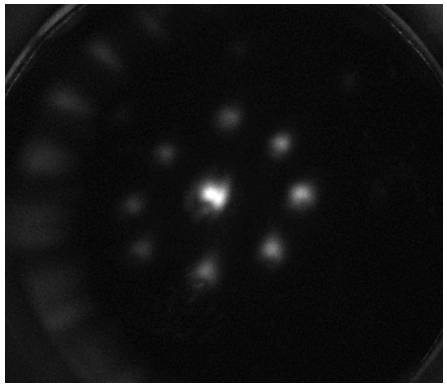
Target



Laser spots

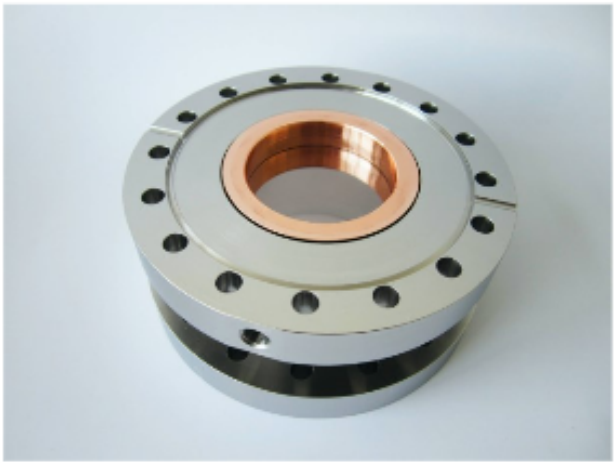


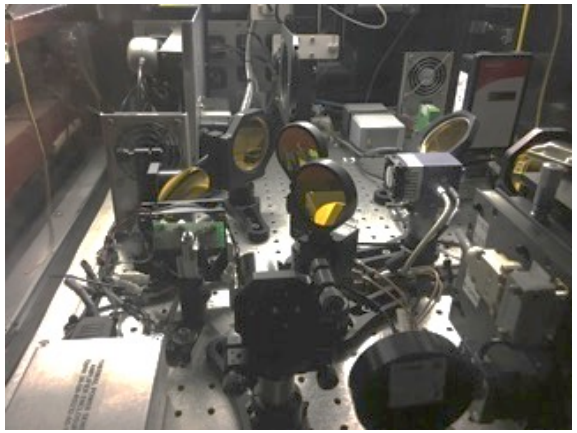
e-beam image

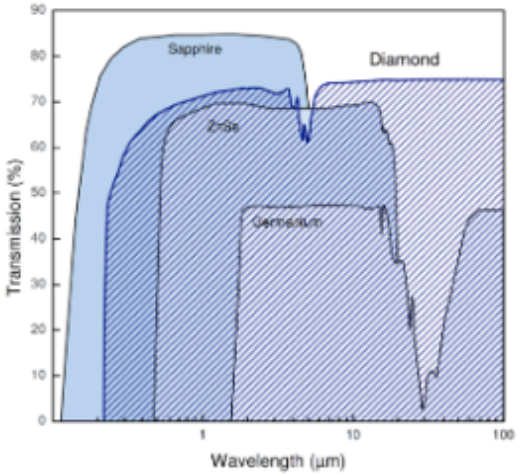


IR diagnostics for 30 μm: critical

1. Procure and install new IR SVD diamond window
2. Upgrade the IR diagnostics detector system to be sensitive at 30 μm







This diagnostics is critical for all steps beyond accelerator commissioning:

1. Optimizing phasing of FEL wigglers
2. Aligning the e-beam on the FEL axis
3. Establishing FEL lasing/amplification
4. Establishing interaction with ions and fining the matched energies
5. Observing CeC action (cooling/heating)

CeC Shutdown 2017 To Do List

1. RE-Polish cathode pucks (if needed)
2. Add bellow/port-aligner for the cathode launcher alignment
3. Re-tune gun to the required frequency, place cathode stalk in correct position
4. Adjust gun solenoid transversely
5. Align laser cross mirrors (need to move temporarily the laser table off the way)
6. Finalize the laser delivery line
7. Measure laser pulse temporal profile using streak-camera (with ATF folks)
8. Replace laser (regenerative amplifier) and commission the laser prior operation start
9. Replace lens for gun cathode camera with longer focal length, fix other cameras (small changes)
10. Install BPM (352 MHz) between two 500 MHz cavities, procure 352 MHz BPM electronics
11. Replace broken BPM feed through on the first LEBT BPM, check cables for the rest of BPMs for kinks/bad contacts
12. Install and test compensation coils around DX and D0 magnets
13. Rework and add new air-core corrector, install double μ-metal shielding where is appropriate
14. Procure and install power supplies for new trims
15. Put extension and move lower vacuum pumps in low energy beam transport
16. Modify the end of the LEBT by putting BPM2 at the end of the beamline, move Solenoid 5 upstream
17. Fix the helicity of the third helical wiggler (replacing the pin-holding plates)
18. Alignment survey of common section elements
19. Modify or replace phase shifters (at least one)
20. Re-configure trims in the kicker section
21. Replace failed ICT in front of the high power dump, find the reason of the fault
22. Procure and install new IR SVD diamond window
23. Upgrade the IR diagnostics detector system to be sensitive at 30 μm
24. Improve phase, timing and amplitude stability of RF and laser systems,
25. Stabilize temperatures of RF cables and LLRF rack
26. Finish controls (pet-pages, MATLAB applications)
27. CLEAN THE AREA – DONE

PLAN FOR RHIC RUN 18

- ✓ Start operation of all room temperature systems prior to RHIC start
  - ✓ *RHIC 18 run is short and we can not afford months of delay with some of critical systems as it happened during Run 17*
- ✓ Start operation of CeC system as soon as our SRF cavities are cold
- ✓ Establish stable phase, amplitude and timing (RF and laser) to deliver stable reliable electron beam, synch electron beam with ion beam with 26.5 GeV/u
- ✓ Commission new IR diagnostics and establish FEL operation
- ✓ Align electron and ion beams transversely
- ✓ Synchronize the ion and electron beams energies using IR diagnostics
- ✓ Establish interaction of electron and ion bunches
- ✓ Test Coherent electron Cooling
- ✓ Characterize Coherent electron Cooling