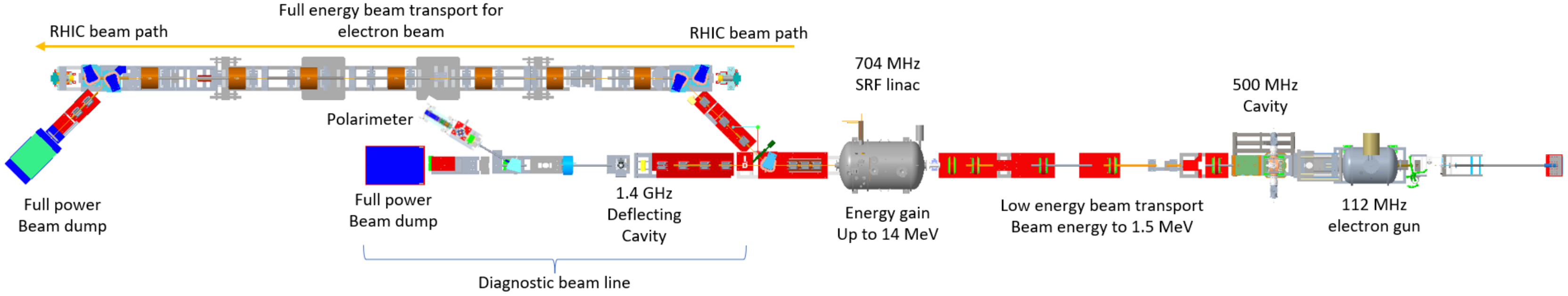
CeC status and plans for Run-25

Yichao Jing for the CeC X team

CAD MAC21 12.16-12.18 2024

Outline

- Where we are with CeC X experiment
  - Beam noise (control)
  - Imprint of ions
  - Matching with recombination
  - Gain of amplifier
- Status of funded DOE proposal using CeC accelerator
  - High current SRF gun
  - Polarized source with SRF gun
- Plans for Run 25



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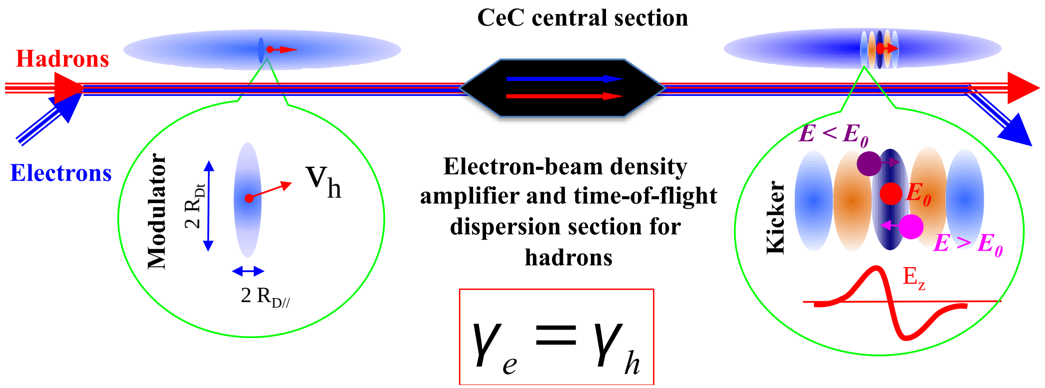
Coherent electron Cooling

All CeC systems are based on the identical principles:

- Hadrons create density modulation (imprint) in the co-propagating electron beam
- Density modulation is amplified using broad-band (microbunching) instability
- Time-of-flight dependence on the hadron's energy results in energy correction and in the longitudinal cooling. Transverse cooling is enforced by coupling to the longitudinal degree of freedom.



UM HE 91-28
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COHERENT ELECTRON COOLING
1. Physics of the method in general

Ya. S. Derbenev
Randall Laboratory of Physics, University of Michigan
Ann Arbor, Michigan 48109-1120 USA

ABSTRACT

A microwave instability of an electron beam can be used for a multiple increase in the collective response for the perturbation caused by a heavy particle, i.e. for enhancement of a friction effect in electron cooling method. The low-scale instabilities of a few kind can be

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Coherent Electron Cooling

Vladimir N. Litvinenko[1,*] and Yaroslav S. Derbenev[2]
[1]Brookhaven National Laboratory, Upton, Long Island, New York, USA
[2]Thomas Jefferson National Accelerator Facility, Newport News, Virginia, USA

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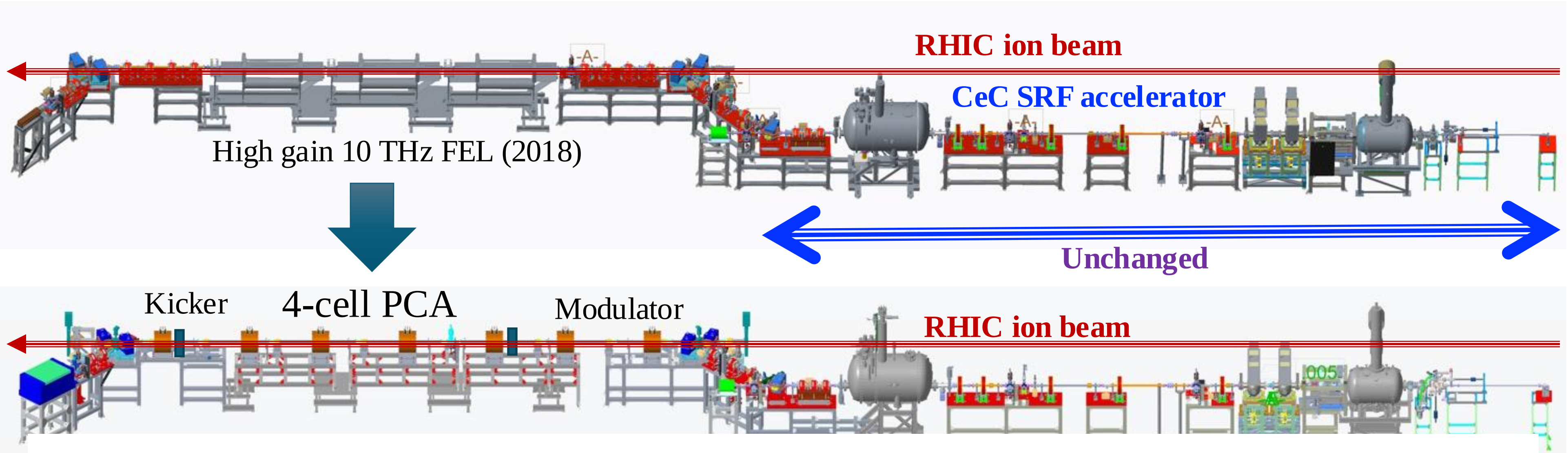
Microbunched Electron Cooling for High-Energy Hadron Beams

D. Ratner*
SLAC, Menlo Park, California 94025, USA

(Received 11 April 2013; published 20 August 2013)

Overview of the CeC X at RHIC

- 2014-2017: built cryogenic system, SRF accelerator and FEL for CeC experiment
- 2018: started experiment with the FEL-based CeC. It was not completed: **28 mm** aperture of the helical wigglers was insufficient for RHIC with 3.85 GeV/u Au ion beams. We discovered microbunching Plasma Cascade Instability and developed design of Plasma Cascade Amplifier (PCA) for CeC
- In 2019-2024
  - 2019: PCA-based CeC with with 75 mm aperture was built and commissioned.
  - 2022: During Run 20, we demonstrated high gain Plasma Cascade Amplifier (PCA) and observed presence of ion imprint in the electron beam
  - 2021: We observed regular e-cooling in Run 21, but CeC cooling was washed out by large timing jitter of the seed laser and resulting 0.35% RMS e-beam energy jitter
  - 2023: New laser profile at injector was tested to provide better final temporal distribution uniformity
  - 2023-2024: Establish new key beam parameters and work on improving beam quality



The CeC Plasma Cascade Amplifier has a bandwidth of 15 THz >2,000x of the RHIC stochastic cooler

Initial Key Performance Parameters @ CeC X status

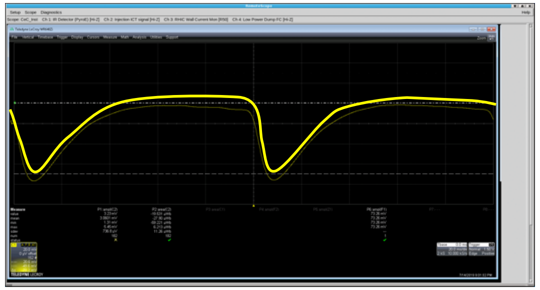
- ✓ Unique SRF accelerator generating high brightness electron beam, compressing it to 75 A at 1.25 MeV kinetic energy and accelerating it to 14.6 MeV
- ✓ Precise control of noise in electron beam: can suppress it to the level close to Poisson shot noise - for cooling - or increase thousands-fold to heat ion beam
- ✓ Demonstrated high gain in both FEL and Plasma-Cascade Amplifiers
- ✓ Observed presence of ion imprint in electron beam radiation
- ✓ Observed recombination of 14.56 MeV elections with 26.5 GeV/ u Au ions
- ✓ Regular electron cooling of hardon beam at record energy of 26.5 GeV/ u

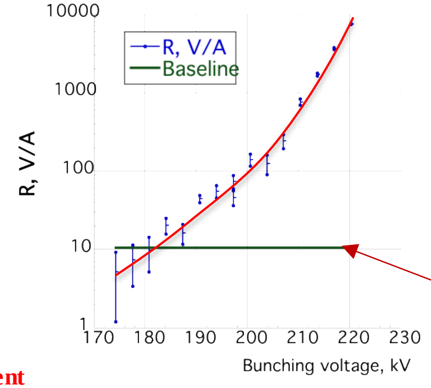
Electron beam KPP

Parameter	Initially Planned	Demonstrated	
Lorentz factor	28.5	up to 29	✓
Repetition frequency, kHz	78.2	78.2	✓
Electron beam full energy, MeV	14.56	up to 14.8	✓
Total charge per bunch, nC	1.5	nominal 1.5, up to 20	✓
Average beam current, μA	117	120	✓
Ratio of the noise power in the electron beam to the Poison noise limit	<100	<10 (lattice of Run20)*	✓
RMS momentum spread $\sigma_p = \sigma_p/p$, rms	$\leq 1.5\times10^{-3}$	$<5\times10^{-4}$, slice 2×10^{-4}	✓
Normalized rms slice emittance, μm rad	≤ 5	2.5	✓

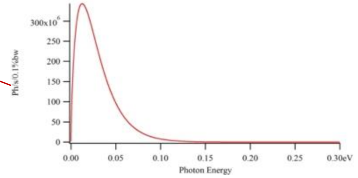
Run 18-19: control of the noise in electron beam

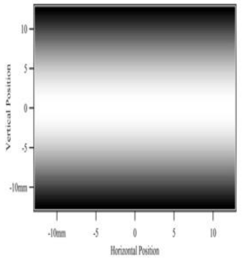
Run 18 lattice and beam: 0.6 nC per bunch
Large signal of 2,500 V/A ~ 250-fold above base line. Can be seen both on scope and measured easily



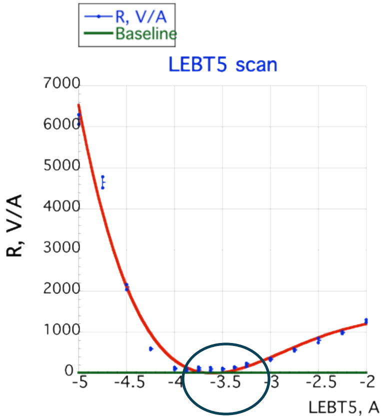


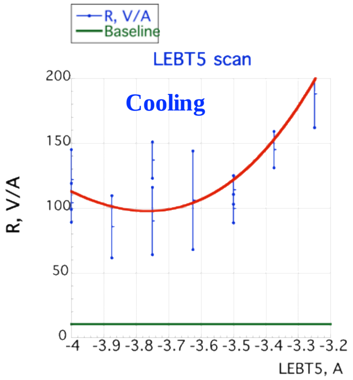
Poisson statistical shot noise was established with the radiation power simulated by Igor Pro (SRW)

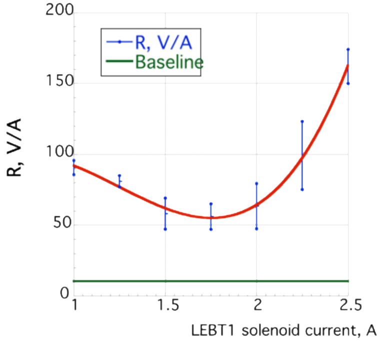




1.5 nC, 75 A peak current

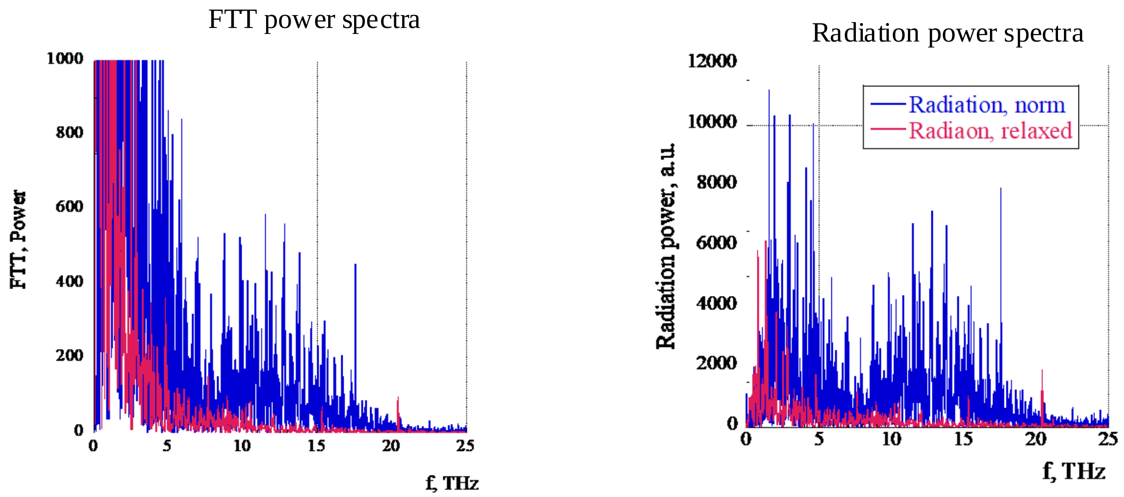






We demonstrated that with 75 A peak current we can reduce beam noise to acceptable level. It could be as low as 6-10 times above the baseline

Simulation results of the PCI in CeC accelerator using Impact T for standard (Run 18) lattice (blue) and new relaxed lattice (red)



FTT and Radiation spectrum of the compressed 0.7 nC electron bunch profile at the exit of the SRF linac simulated by Impact-T. Blue color lines is for standard CeC lattice used during RHIC Run 18. Red color lines are for a new designed lattice of the CeC accelerator. Horizontal axis is the frequency measured in THz. The simulation was performed for 1.25 MV SRF gun voltage, standard bunching cavity voltages for 20-fold compression The relaxed LEBT lattice has following currents in six LEBT solenoids: 7.83 A, -2 A, 2 A, -2 A, 2 A, -2 A.

- Simulations show suppression of the PCI at frequencies ~ 10 THz down to the noise floor (defined by the code). The low frequency structures represent that of the compressed electron bunch. Red color spikes near 15 and 20 THz are computing artifacts related to the mesh and time step.
- In Run 20, measurements show that the e-beam noise in the 1.5 nC beam is from 2 to 5 times higher than the baseline (Poisson statistical shot noise).

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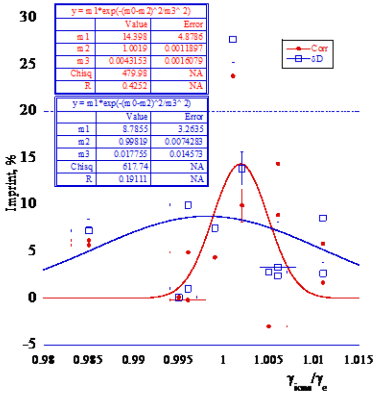
The Ion Imprint studies: Run 2020

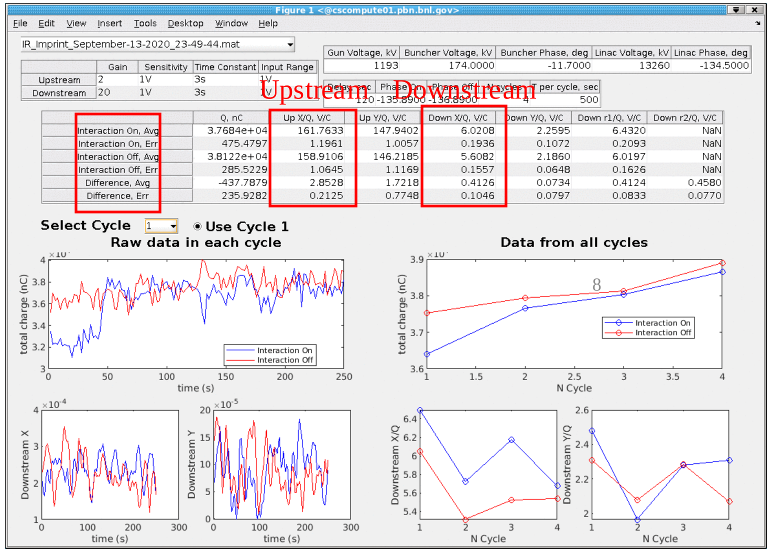


We observed clear presence of the ion imprint in the electron beam resulting in increase of the e-beam radiation at 35 μm with average imprint of

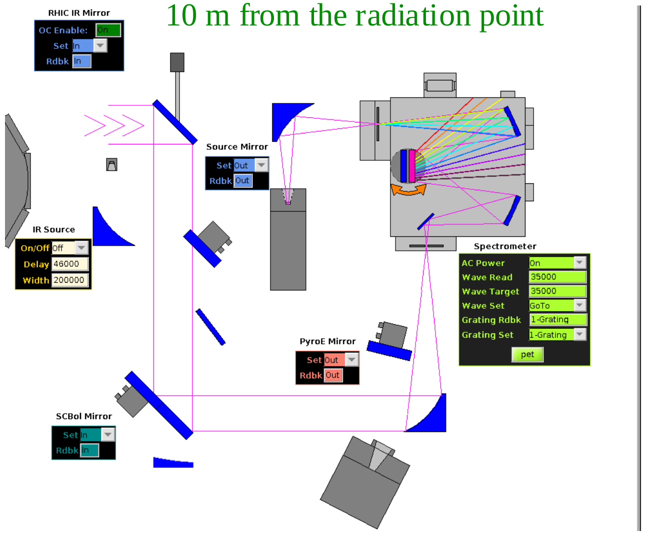
$$\langle \text{imptint} \rangle = 4.7\% \pm 0.4\%(\text{systematic}) \pm 0.3(\text{random})\%$$

We applied PCA to boost radiation at 35 μm at the level detectable by current IR detectors after the spectrometer

Typical "good" measurement:
4 cycles with 500 measurements each

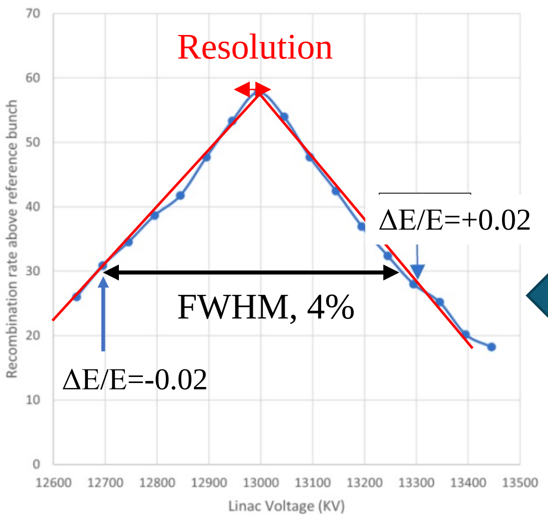


Downstream IR diagnostics
10 m from the radiation point



Recombination of electrons with Au ions: Run 21

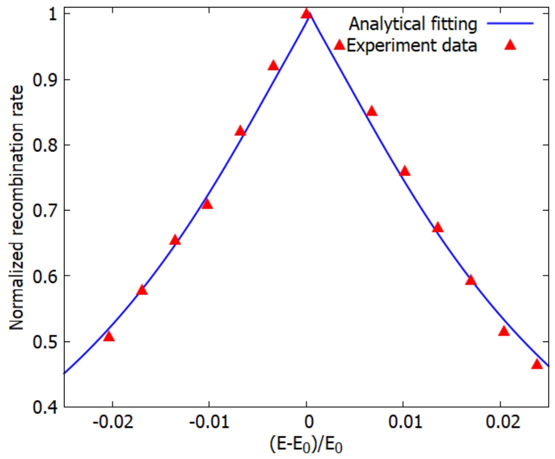
Experiment



Triangular shape of the measured dependence allows to define matching of the relativistic factors with accuracy ~ 0.2%, which is significantly smaller than 4% FWHM.

This finding will reduce the range where we need to search for the CeC signature by 5-to-10 fold.

Experiment vs Calculations



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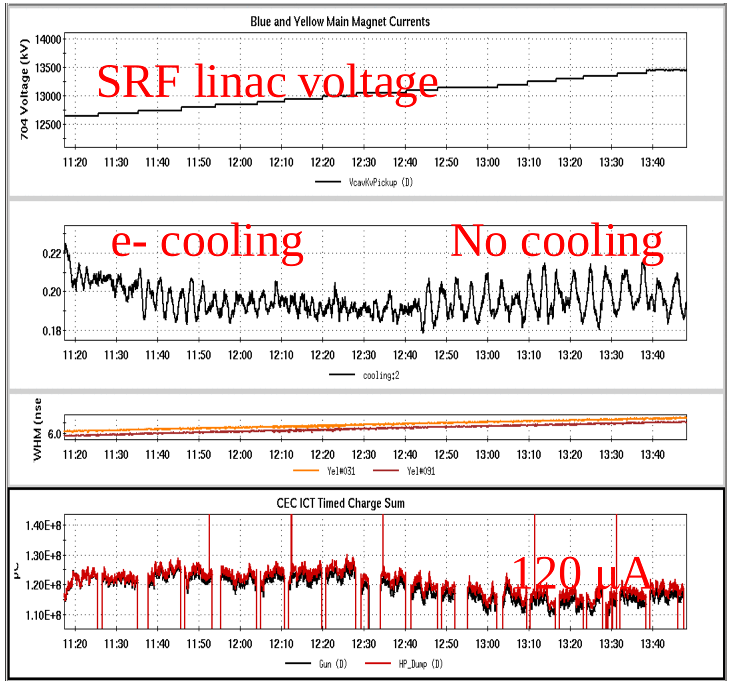
$$\alpha_r = \frac{\int_{-\infty}^{\infty} d^3v_i d^3v_e f_e(v_e) f_I(v_i) \left|\vec{v}_e - \vec{v}_i\right| \sigma\left(\left|\vec{v}_e - \vec{v}_i\right|\right)}{\int_{-\infty}^{\infty} d^3v_i d^3v_e f_e(v_e) f_I(v_i)}$$

$$f_e(v_e) = \frac{1}{(2\pi)^{3/2}\beta_{e,\perp}^2 \beta_{e,z}} \exp\left(-\frac{v_{e,x}^2 + v_{e,y}^2}{2\beta_{e,\perp}^2}\right) \exp\left(-\frac{(v_{e,z} - v_{z0})^2}{2\beta_{e,z}^2}\right)$$

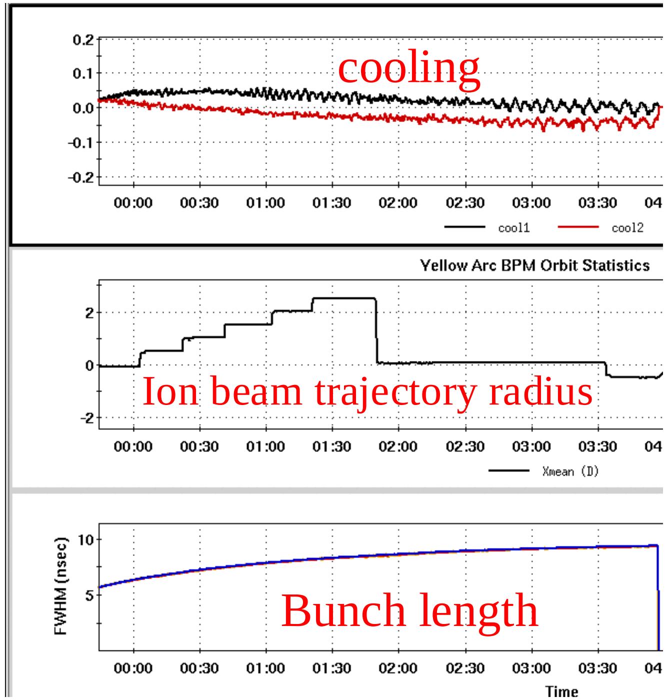
$$f_I(v_i) = \frac{1}{(2\pi)^{3/2}\beta_{i,\perp}^2 \beta_{i,z}} \exp\left(-\frac{v_{i,x}^2 + v_{i,y}^2}{2\beta_{i,\perp}^2}\right) \exp\left(-\frac{v_{i,z}^2}{2\beta_{i,z}^2}\right)$$

This results include convolution of the exact formula recombination cross-section (in the commoving frame) with distributions of two beams

Search for CeC signature and observation of regular bunched electron cooling of 26.5 GeV/u Au ion beam



Changing e-beam energy requires multiple adjustments

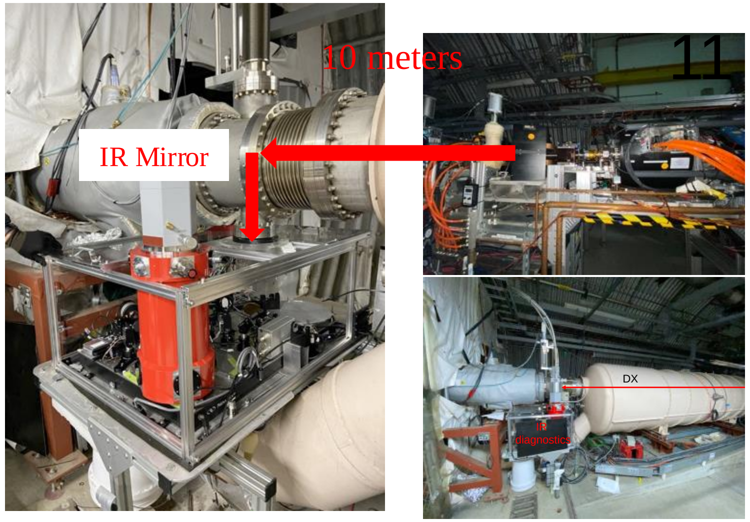


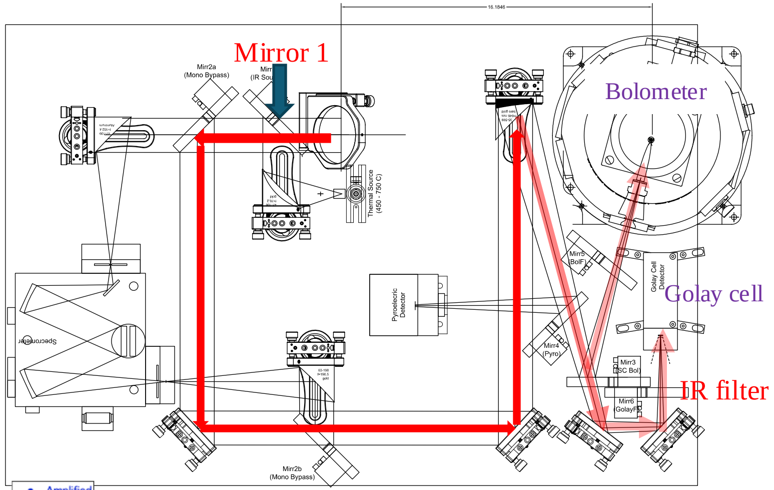
Adjusting ion beam energy – 1 mm x_{mean} corresponds to 0.1% change in the ion beam energy.

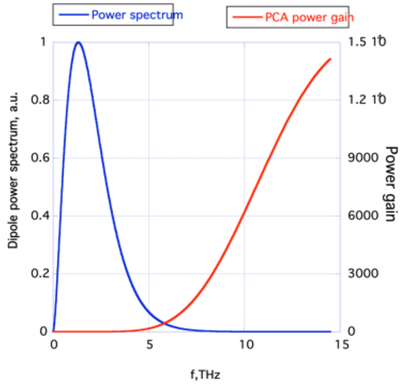
- There was no attempt of improving regular non-magnetized electron cooling – we used the lattice optimized for PCA CeC - and the best electron cooling rate was ~ 100 hours. It is consistent with cooling rate estimation made by Dmitry Kayran.
- We had an ongoing APEX proposal which explores the full potentials of this high energy electron cooling using CeC accelerator.

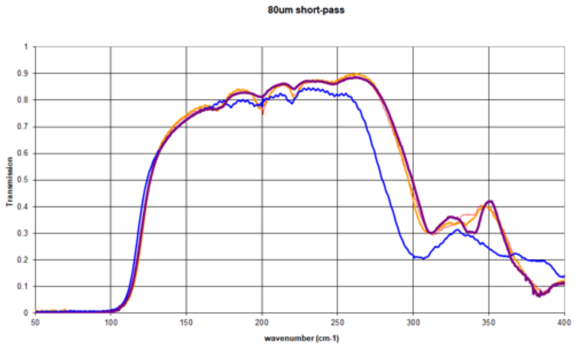
PCA gain measurements in Run 22

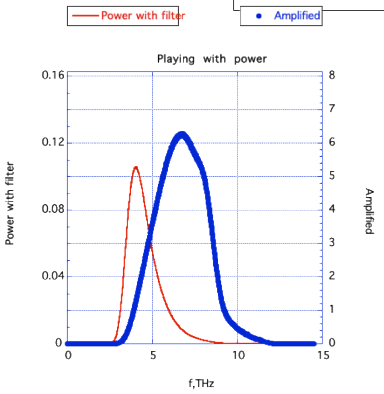
- We used IR radiation from the bending magnet at the exit of the CeC section. Critical frequency of synchrotron radiation from the bending magnet is 1.3 THz
- PCA gain peaks at 15 THz and there is no gain below 4 THz
- IR radiation is intercepted by 2" mirror 10 meters downstream
- For there measurements, the radiation was delivered to two most sensitive IR detectors: broad-band Golay cell or cryo-cooled Bolometer.
- IR filter with passband of 3.5-10 THz was used in front of the Golay cell to improve sensitivity at high frequencies
- Signal from Golay cell was detected by lock-in amplifier synched with the electron bunch pattern (typically 5 Hz, five 100 msec bunch trains per second). We used 3rd order modulation-demodulation (MDM) technique to remove background unrelated to IR radiation, by periodically blocking IR using Mirror 1.
- Signal from Bolometer was delivered in unsynchronous mode (140 kilo-samples per second) with respect to electron beam pattern. Analog signal was not available. We developed MatLab application for asynchronous detection of this digital pattern.
- PCA gain was evaluated by comparing radiated power in the PCA lattice (strong solenoids) with relaxed lattice (weak solenoids) using the same setting of the CeC accelerator and the electron beam











Comparing measurements with expectations

- Golay cell + IR filter measurements resulted in the average increase of IR power by factor 65 with PCA lattice
  - With 50% of electron bunch satisfying PCA condition (peak gain of 100 at 15 THz), expected increase of the measured IR power is 60
- Cryo-cooled bolometer measurements resulted in 100±20 average and 300±50 peak increase of IR power caused by PCA lattice
  - The bolometer manual specifies the sensitivity range from 6 THz to 60 THz, but absence of calibrated spectral response does not allow accurate comparison
  - Very crude estimation (using a step-function response in 6 to 60 THz) shows that with 50% of electron bunch satisfying PCA, expected increase of the measured IR power is 535
- Both results are in reasonable agreement with our expectations

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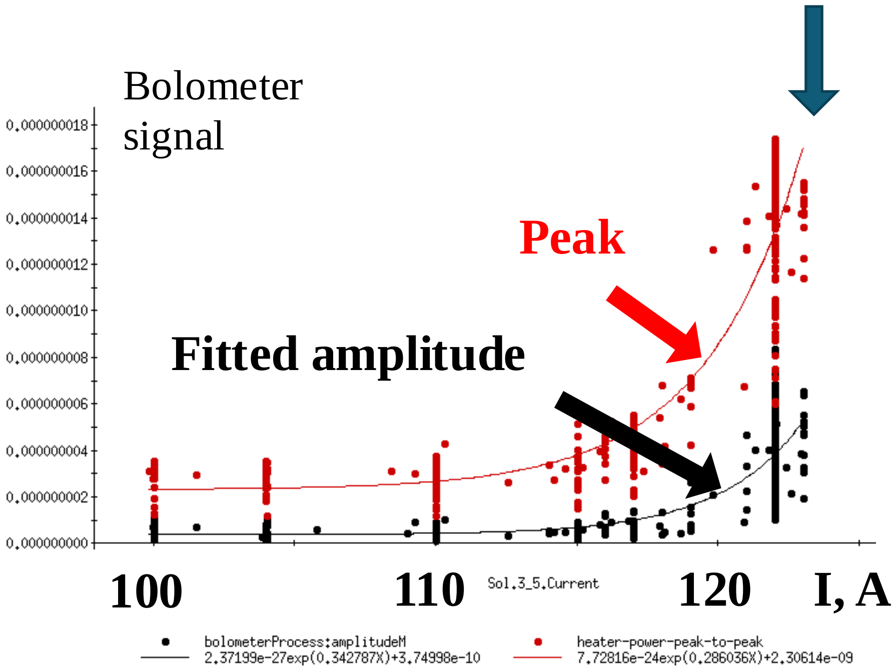
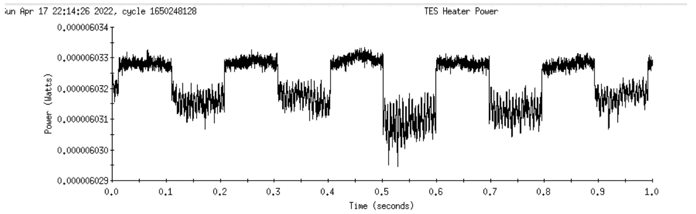


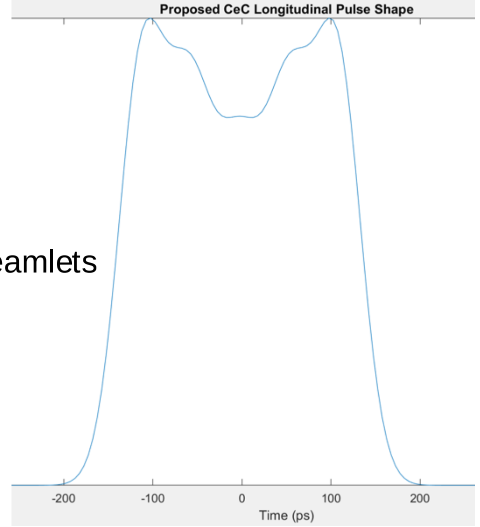
Exponential growth of the IR signal at the bolometer as function of current in PCA solenoids: e-fold increase each 3 A (2.4%)



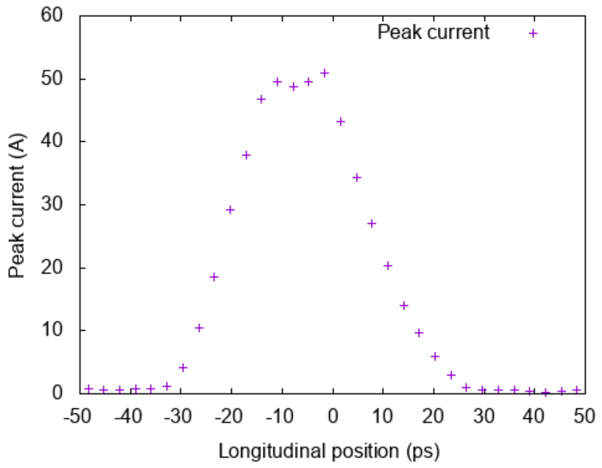
Laser pulse shaping in Run 23

- 3D cooling simulation requires the electron beam to have uniform current distribution (<10% peak-to-peak variation) as well as good quality over 15 ps duration or more
- Beam dynamics simulation shows the temporal uniformity can be achieved using modified initial laser pulse shape with peaks on the sides and deep in the middle.
- The simulated beam emittance is slightly higher than requirement (achieved 1.7 um, slice; required 1.5 um, slice), further improvement in simulation is underway.

5 Gaussian beamlets



Initial current dist.



Final current dist.

Performance of individual beamlet

- We measured individual beamlets (transverse emittances, arrival time, longitudinal energy spread etc.) and they seem to perform reasonably consistent.
- Measured beam properties agree reasonably well with simulation predictions.
- When combining 5 beamlets, the relative strength of laser power is not as desired, #1,3,5 have significantly weaker power than #2,4 (6%, 45%, 1%, 45%, 3%).
- The alignments of 5 beamlets need to be improved (smearing minimized) so that the emittance does not blow up (measured 10 um norm., slice when they combined).
- Work will continue to demonstrate temporally uniform compressed electron beam.

Parameter	Sim.	Exp.
Charge per bunch, nC	0.3	0.3
Bunch length, RMS, ps	30.8	31.7-32.4
Bunch length, FW, ps	119	120-123
Final peak current, A	3.0	3.2-3.4
Normalized emittance (slice), RMS, µm	1.0	0.9-1.0
Beamlets separation, ps	55	54-56

1	gun frequency	1.13E+08				
2	ps per deg	2.46E+01				
3	#	1	2	3	4	5
4	beamlets gun phase (deg)	-8	-5.8	-3.5	-1.3	1
5						
6	arrival time (ps)	-196.66	-142.58	-86.04	-31.96	24.58
7						
8	separation (ps)	-54.08	-56.54	-54.08	-56.54	

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Laser system upgrade after Run 23

1. Detailed investigations after the end of the run revealed that low power in three beamlets were not related to the reflectivity of the mirror but to the error in setting splitters and combiners in the laser trailer. The problem was fixed as soon as it was found.

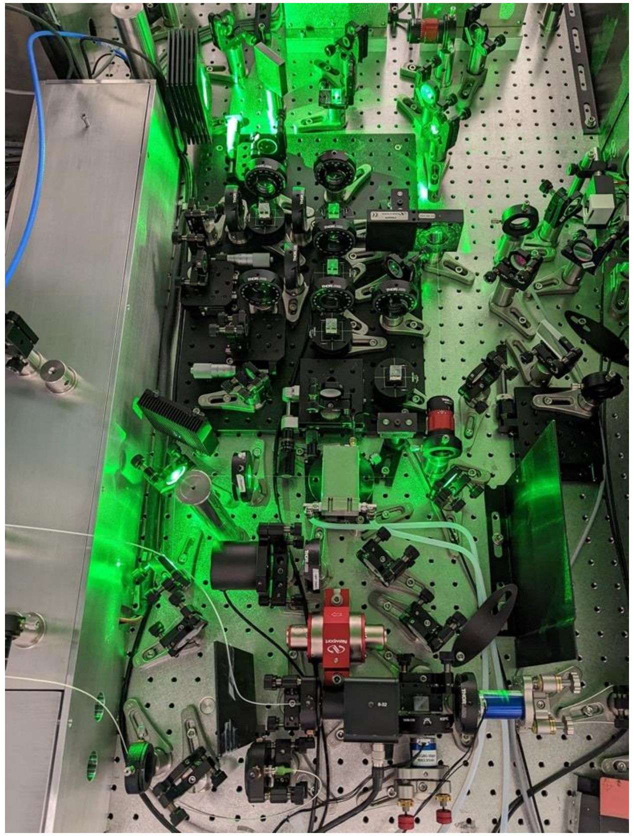
2. Power glitch in August damaged the key Pockels cell in the regenerative amplifier system – the system was fixed and is fully operational

3. Further investigations by Patrick Inacker showed that input pulse energy from the seed laser (mode locked oscillator) is ~ 2 pJ and required very high (75 dB to 80 dB) amplification. He procured fiber amplifier to increase the seed pulse energy to 250 pJ.

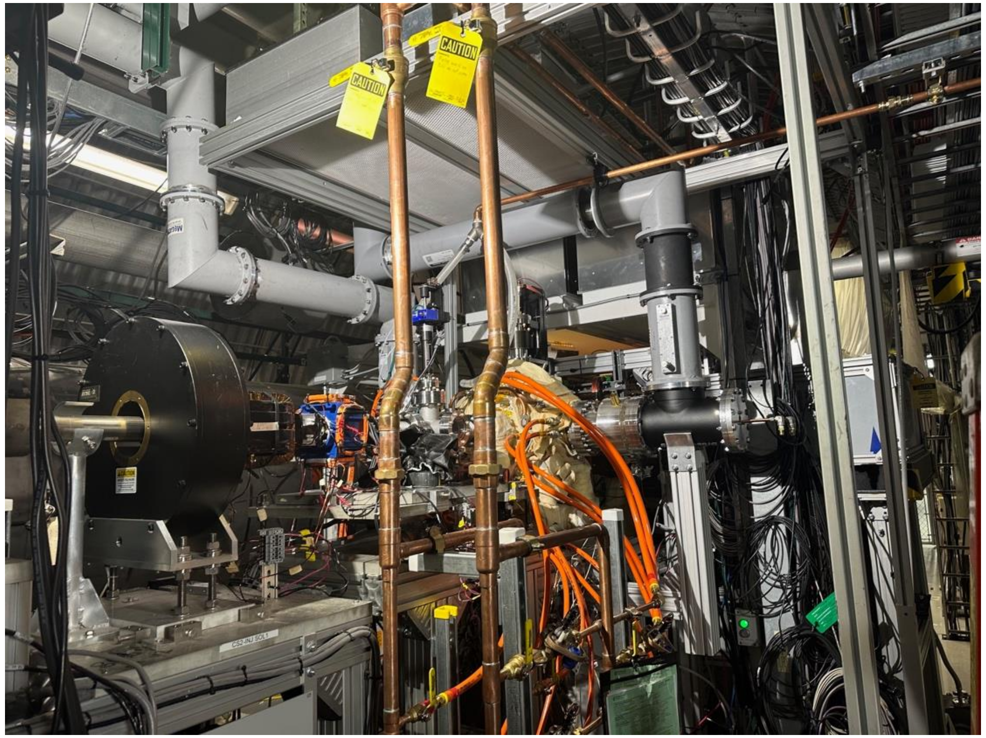
4. This will allow to set regenerative amplifier to a nominal gain between 50 dB and 60 dB and improve pulses-to-pulse stability below 1% RMS jitter.

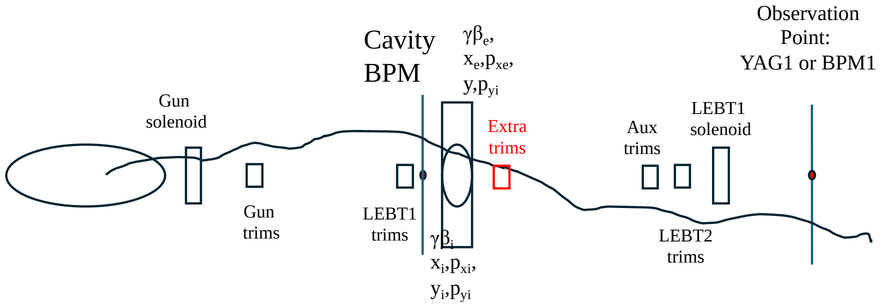
5. When laser system tuning is completed, we will return to tests at the laser gun table of the pulse energy in individual beamlets.

6. We started discussions of new IR laser and delivery systems (likely a fiber) for generating polarized electrons from GaAs photocathode.



New 500 MHz bunching cavity installed and operational in Run 24

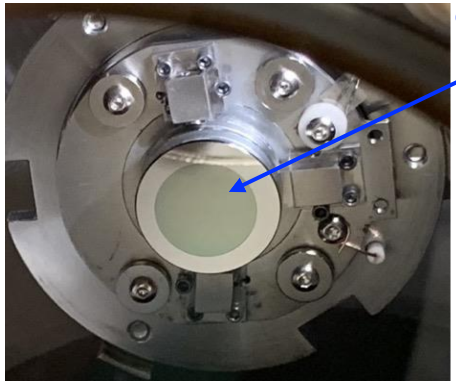




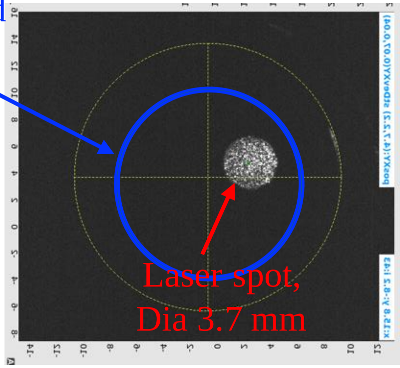
- Old bunching cavity loaned by UK's Daresbury laboratory with strong transverse fields resulting in **12.5 mrad/MV** vertical and **4 mrad/mV** horizontal time-dependent transverse kicks to the electron beam. Initial measurements with the new cavity showed that both transverse kicks are significantly smaller: ~ **2 mrad/MV** vertically and **0.5 mrad/MV** horizontally: 6- to 8-fold reduction compared with the old system.
- We pursued program to improve it further by adding two extra trims around the bunching cavity which allowed us to control trajectory of the electron beam though the cavity: both in position and in the angle.
- Various aspects of time dependent beam trajectory in transverse 4D phase space was investigated that can be result from: the cavity displacements and tilts, the beam displacement and angles, asymmetry of the cavity fields and, finally, chromatic effects and transverse dispersion coming from stray fields.

Efforts to eliminate transverse kicks in Run 24

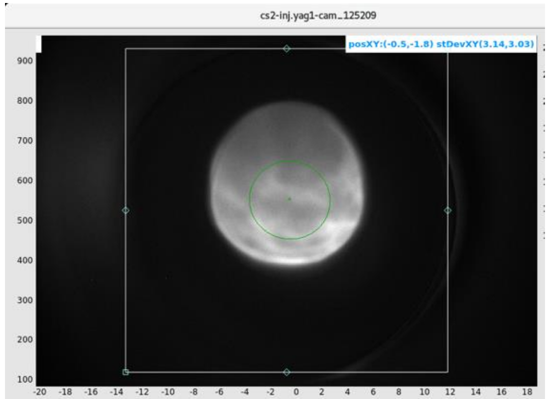
Using larger (14 mm in diameter as comparing to 10 mm in earlier Runs) photocathode allowed us to adjust laser spot position by 3.35 mm horizontally and 1.45 mm vertically, which puts electron beam on axis of the gun solenoid (uncorrected large offsets: 14 mrad in x, 7 mrad in y versus the SRF gun axis).



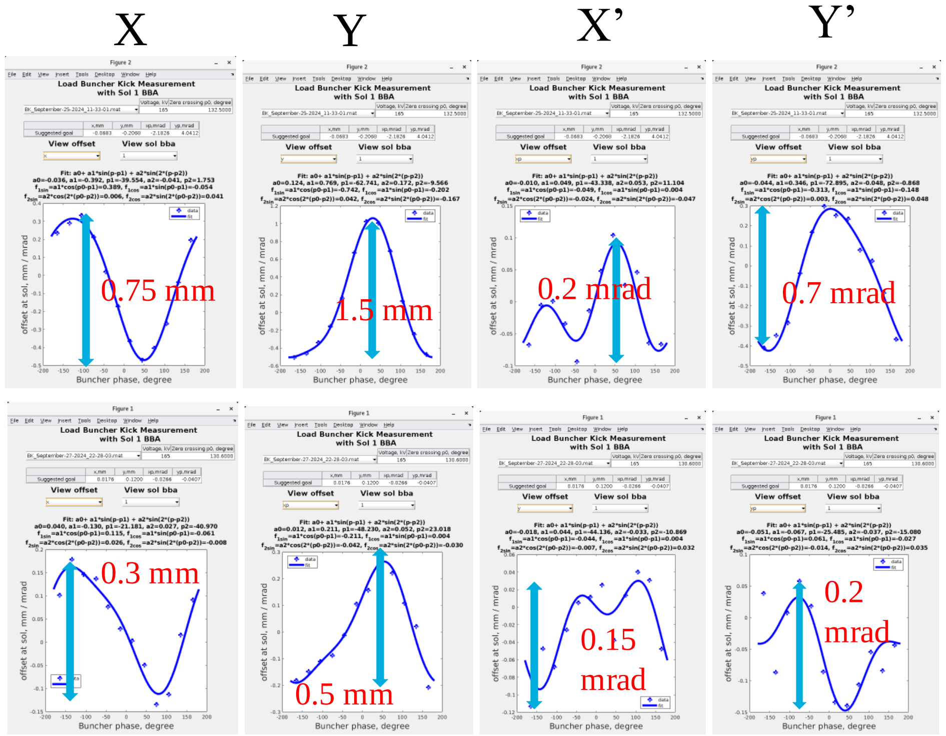
Photocathode in the preparation chamber



Laser spot shifted from the 3.35 mm horizontally and 1.45 mm vertically



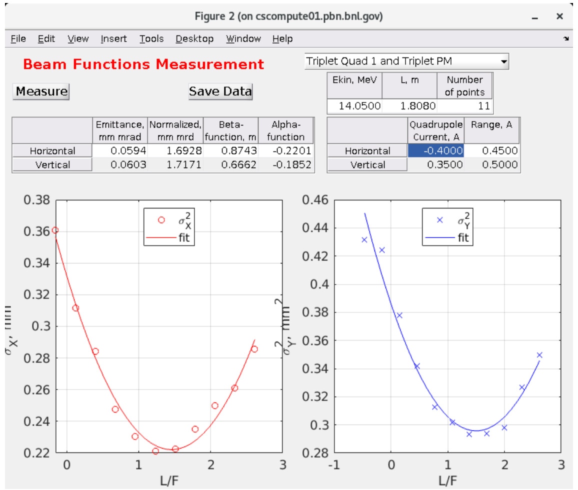
E-beam profile at first CeC profile monitor (more round)

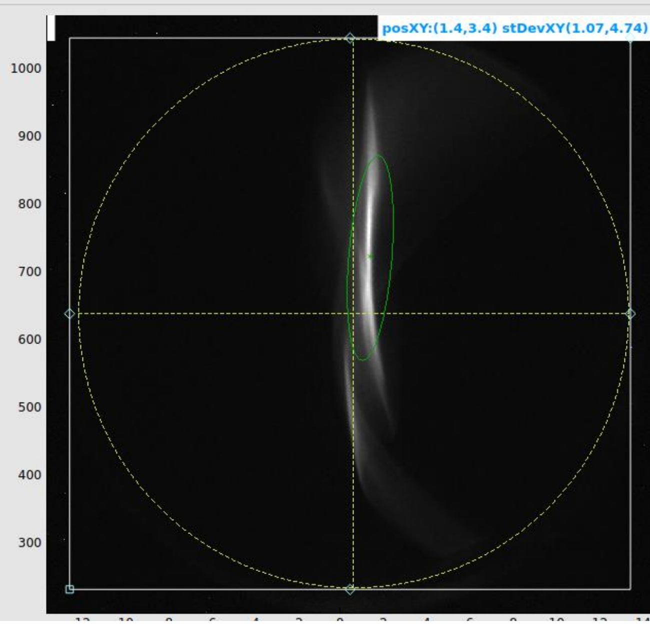


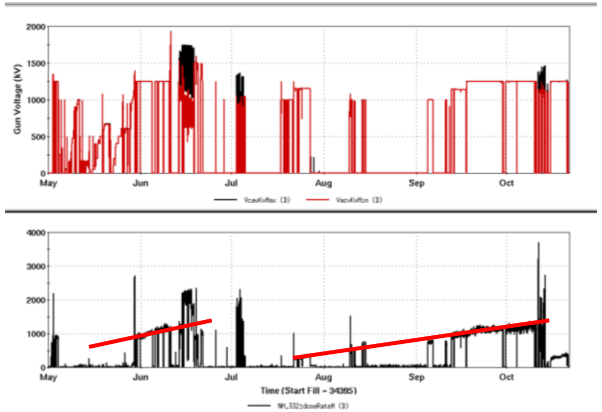
Using measured response matrix, we reduced kicks to very small values by moving the e-beam trajectory though the center of the new buncher cavity.

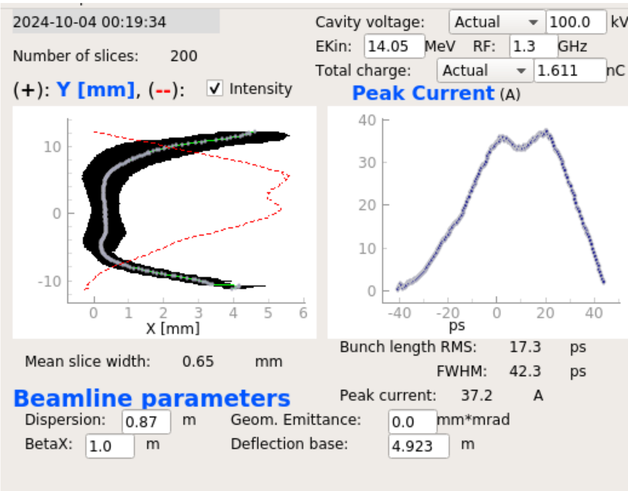
Beam quality in Run 24

- In October we demonstrated electron beam parameters, which were very close to those needed for successful CeC operation:
  - Bunches with semi-flat peak-current: ~30 psec with 63% of charge
  - Flat energy profile for the core of the beam
  - Relative slice energy spread ~ 2 10^{-4}
  - Projected normalized emittance was less than 2 mm mrad, and in number of measurements as low as 1.5 mm mrad
- Unfortunately, the parameters were achieved with different machine set ups and we did not complete tuning of the time-resolved slice emittance measurements, which will continue to be our goal for machine development.
- We are concerned about the observed growth of radiation and level of dark current during SRF gun operation. Gun conditioning needs to follow to clean up.
- We consider is likely a result of Cs evaporation from the CsK_2Sn photocathodes. Hence, we plan to switch to NaKSb photocathodes for the Run 25, with Na having significantly higher evaporation temperature









Short summary of Run 24

1. We completed challenging Run 24 in afternoon of October 21, 2024:
   a. Nearly 6 months delay with new 500 MHz cavity and faulty FPC pushed installation into RHIC run and commission to July 19 – three months after the start of the Run.
   b. On July 27 failure of the end-effector overheated the photocathode and contaminated the gun into nonoperational status. Warming up and He conditioning restored operation of the SRF gun cavity but restoring the cathode transport system took till September 11
   c. Increase of radiation and dark current triggering IP2 alarm stopped our operation on October 10. Quick He conditioning allowing to operate with new cathode on October 15
   d. We operated CeC accelerator for 20% of this run time. RHIC stray fields and frequent up and down ramps further inhibited efficiency of CeC operation.
2. We managed to accomplish only a portion of our goals for this Run:
   a. Importantly, new 500 MHz cavity with significantly weaker transverse kicks if fully operational
   b. As we reported previously, we minimized its transverse kick by adjusting the e-beam trajectory. Amplitudes of the kicks were reduced from ~2.5 mrad to ~ 0.05 mrad in vertical, and from 0.75 mrad to ~ 0.2 mrad horizontally, when comparing old and new cavity.
   c. We investigating possible reasons for residual horizontal kick to identify remedy to reduce it further
3. During operations from September 11 till October 10, we demonstrated electron beam quality close to our specification.
   a. Unfortunately, we continued suffering from power jitter in our laser system, which never reached required 1% RMS level
   b. At best we operated with power jitter ~1.7% RMS, which typically increased to 2-3% RMS level during length of an 8 hour shift. Laser power jitter remains main obstacle for stable CeC system operations.

High current (1-3 mA) with SRF gun

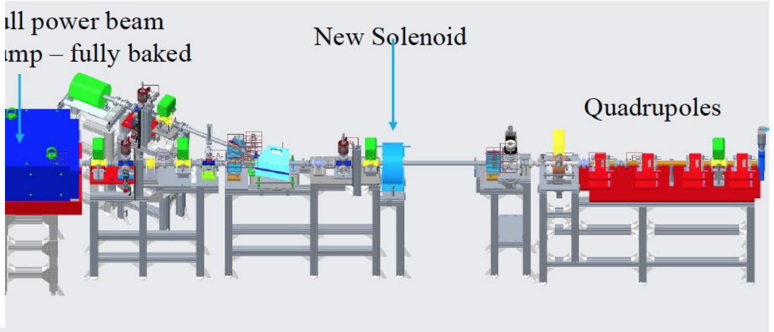
Beam dynamics studies

Desired beam parameters to deliver 1-3 mA

- Charge/bunch: 1.5-3.5 nC
- Operational repetition rate:
  - If using linac & buncher: 0.837 MHz
  - No linac & buncher: 2.974 MHz
- Higher current (3-10 mA) can be achieved by scaling up charge/bunch or repetition rate.

Operation without linac			
P [kW]	I_{beam} [mA]	V_{gun} [MV]	Q_{bunch} [nC]
2.5	1	1.35	0.34
f [MHz]	2	1.25	0.67
2.974	3	0.833	1.01
	4	0.625	1.34
	5	0.5	1.68

Operation with linac @ 3-6 MV			
P [kW]	I_{beam} [mA]	V_{gun} [MV]	Q_{bunch} [nC]
2.5	1	1.35	1.19
f [MHz]	2	1.25	2.39
0.837	3	0.833	3.58
	4	0.625	4.78
	5	0.5	5.97

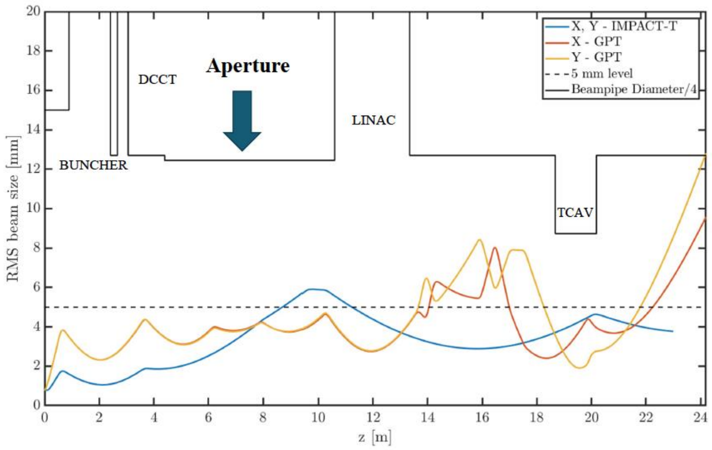


New solenoid provides additional focusing for low energy beam between quadrupoles and the full power beam dump

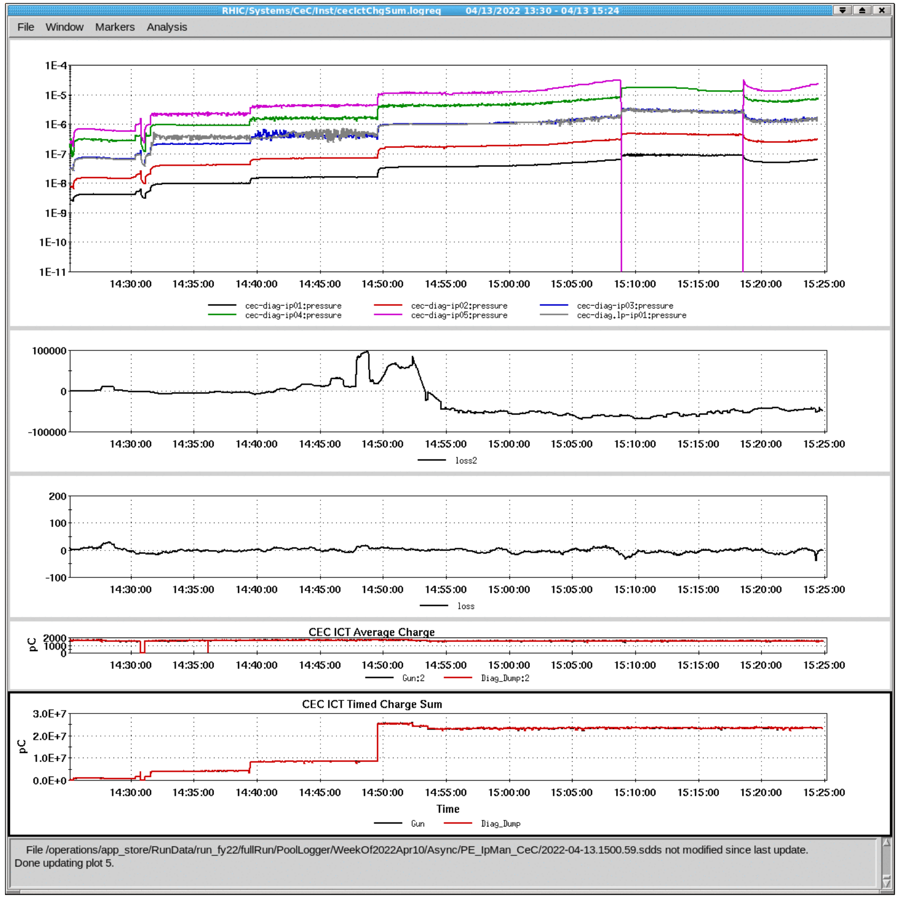
We tested propagation of 1.5 nC 1.25 MeV bunches to the beam dump with very low losses

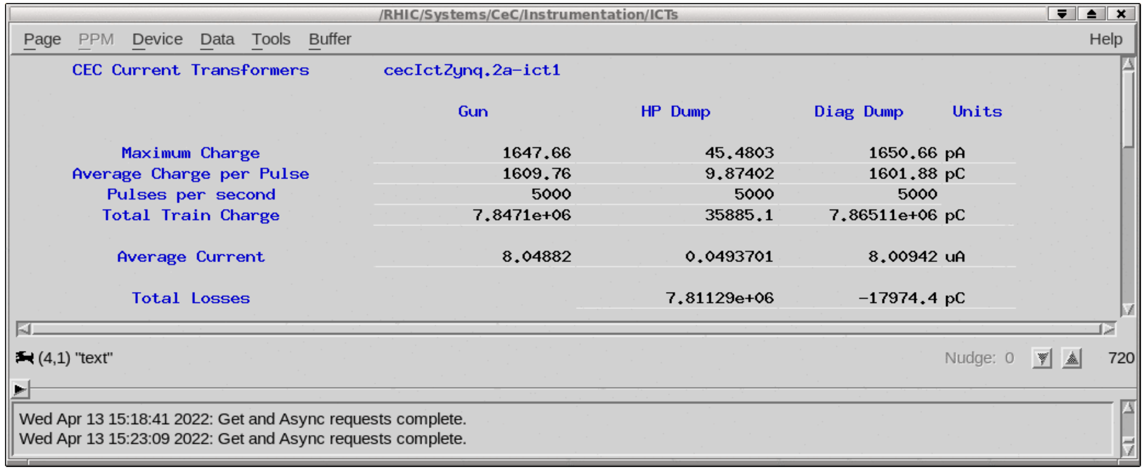
Parameter	Value
Bunch charge [nC]	1.5
Beam current @ 0.837 MHz [mA]	1.25
Laser pulse length [ps]	750
Gun voltage [kV]	833

Linac & buncher are OFF



Achieved in experiments (Run 22 and 23)





- In Run 22, we were able to propagate high current beam (~28 uA) to the dump without significant losses. However, the dump generates enormous amount of outgassing, which overwhelms the near-by ion pump with pressure rising to mid-E-5 range. The pump then overheats and shuts down.
- After fixing the outgassing issue during the shutdown, we were able to propagate >5 nC bunches (~ 0.13 mA) to the beam dump. Higher current would need change of laser rep rate which would interfere with normal CeC operation (need dedicated mode).
- We still target at operating with 1-3 mA beam current if time allows (cooling experiments take the priority).

GaAs cathode deposition and QE evolution

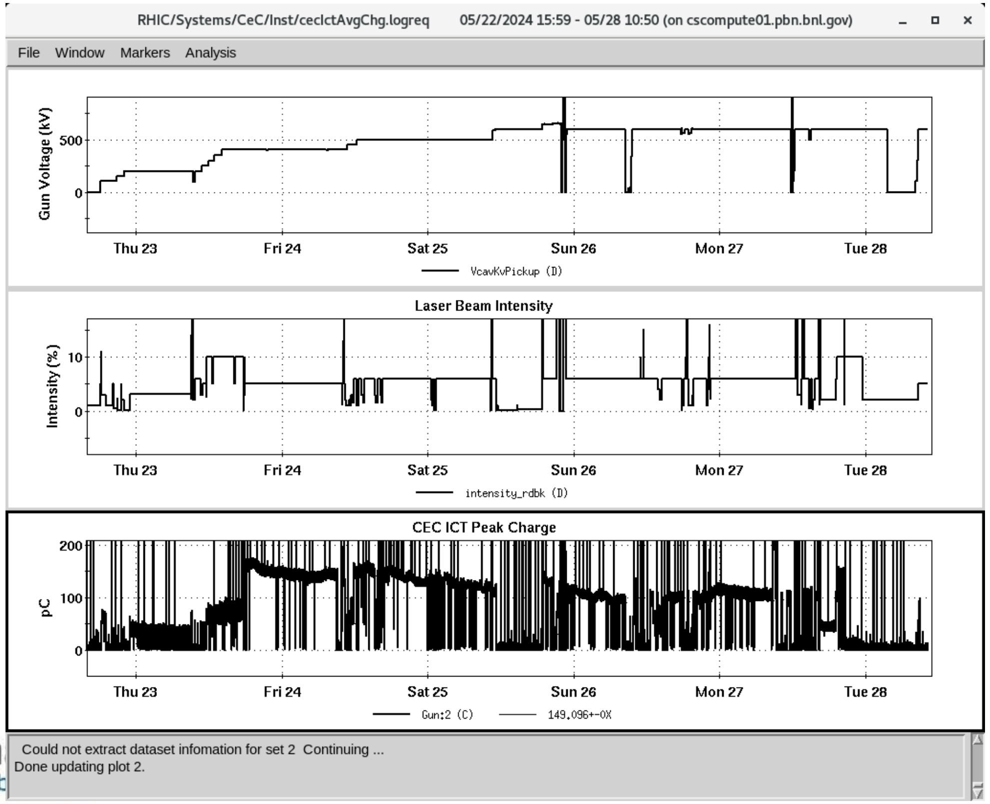
The CeC photocathodes are produced in BNL's Instrumentation Department. A deposition system is built in capable of producing both CsK_2Sb and GaAs photocathodes, a SHUV vacuum transport suit ("garage") with vacuum better than 10^{-11} torr. It also modified two Mo cathode packs: a square GaAs crystal is inserted into the cut in the puck's surface, attached by a thin layer of In and topped with a polished metal cup firmly screwed to the Mo puck.

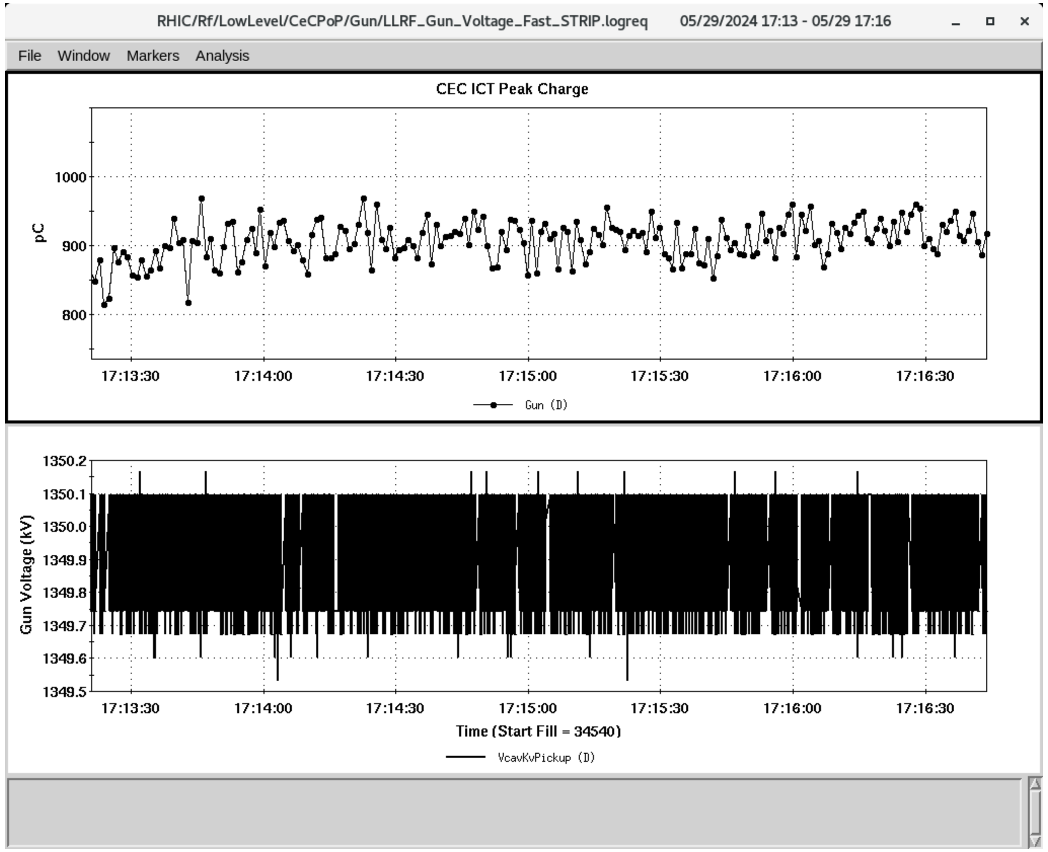
The modified CeC Mo cathode puck with a square GaAs crystal inserted under a meatal cup with a 5 mm hole in diameter.

1. Two GaAs photocathodes produced with initial QE of 4.8% in green light.
2. After the cathode was moved into the garage, the QE dropped to 1%. After that, both GaAs cathodes were kept on the load-lock, where vacuum was in mid-E-12 torr range waiting for the SRF gun to be cooled.
3. After several days the cathode was inserted into the gun, with QE estimated to be below 0.5%.
4. During the cathode insertion process, we observed vacuum evolution in various locations at back of the SRF gun. We have reasons to believe that QE of GaAs cathode suffered 5 to 10 fold degradation during this transfer. This is one of the problem we plan to address in the future.
5. Measured QE with beam generated ~ 0.04%
6. No measurable loss of QE when operating in the gun

High voltage operation and peak performance of the GaAs cathode

- Since we found that GaAs cathode in this configuration could operate at high voltages ~ 1 MV, we switched to our regular mode of SRF gun operation that we used with CsK_2Sb photocathodes.
- Using this regular mode of operation, we tested that GaAs cathode could operate at voltages as high as 1.375 MV. Maximum charge per bunch observed with this photocathode was ~ 0.9 nC.



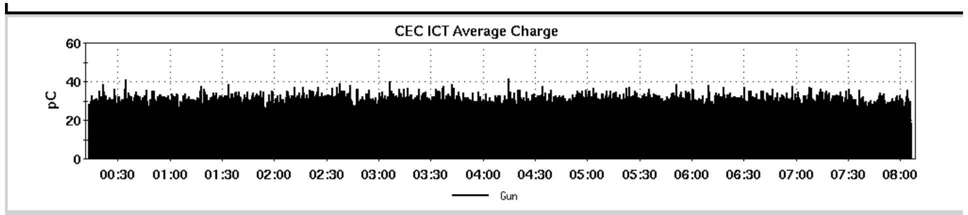


Short Summary of the GaAs cathodes tests

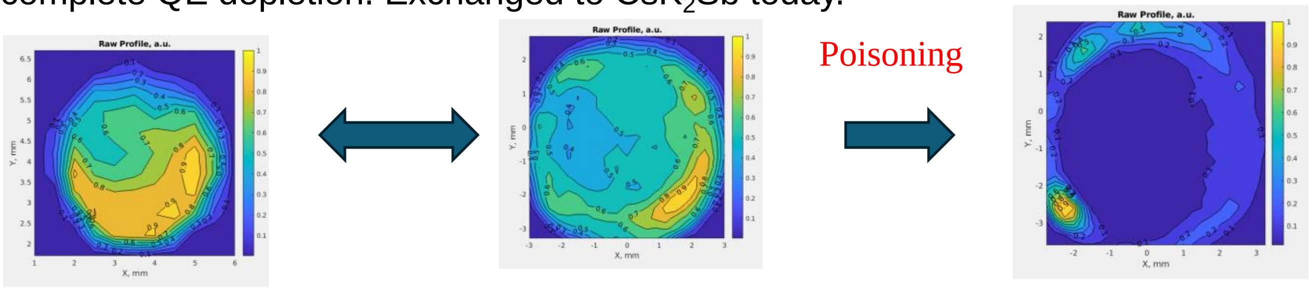
1. We demonstrated that GaAs cathode can successfully operate in the CeC SRF gun at voltages above 1 MeV (maximum tested was 1.375 MV) for extended periods of time with out significant QE degradation. They also can generate change per bunch exceeding 1 nC.

2. We clearly observed significant degradation of QE during cathode transfer and this portion of the experiment needs significant improvements. Creation of more uniform QE is needed for generating better quality beam.

3. Normal operation of the CeC SRF gun results in excellent vacuum inside the cavity and the location of the cathode. Maintaining these condition is important part for future successful operations with GaAs cathodes.



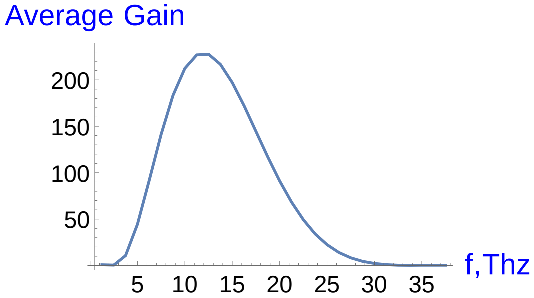
4. It apparent that exposure of GaAs cathodes to burst of aggressive gases frozen at the cold surfaces of the gun would case not only instantaneous reduction of the QE but its continuous and relatively fast degradation till complete QE depletion. Exchanged to CsK_2Sb today.

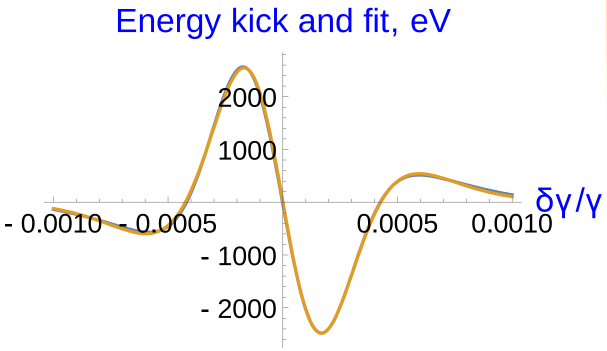


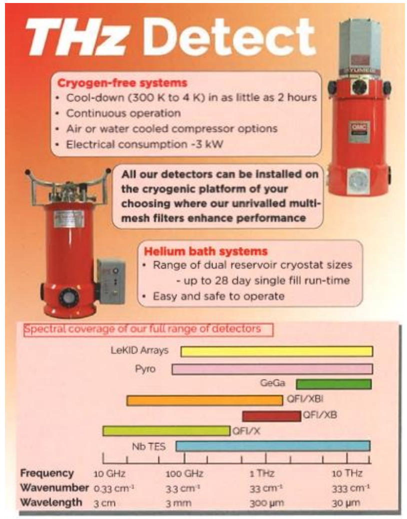
Plans for Run 25

1. First, we plan to fix few remaining minor problems as well as check alignment of the CeC system during RHIC shutdown.
   a. We identified 25 tasks that we would like to complete during the shutdown
   b. In parallel, we will run all necessary simulations to optimize setting for Run 25, including, but not limited, understanding of residual horizontal kick from the bunching cavity
2. We decided to explore more relaxed mode of CeC operation with 10 MeV electron beam:
   a. CeC cooling would require twice lower peak current
   b. RHIC will operate at 18.2 GeV/u, below the transition energy, which will provide for better quality Au beam, which is easier to cool
   c. Our main concern was about IR diagnostics, which should detect lower frequency of radiation, but these concerns turned out to be unnecessary.
3. We plan to demonstrate this experimentally at the beginning of next run
4. This new operational point would provide us with relaxed requirements for the electron beam, which would significantly increase our chances to demonstrate CeC during next run
5. We will need dedicated time for such demonstration. The case for such operation was presented to NPP PAC.

#	Task	Responsible Group/Person
1	Laser: 1% RMS power jitter	Patrcik I.
2	Laser: Pulse measurements at gun table	Patrcik I.
3	Laser: Position?	Patrcik I.
4	Laser: Measure time jitter of the laser pulses	Patrcik I.
5	NaKSb photocathodes for next run	John S./Luca C.
6	Investigate CsK_2Sb cathodes removed from gun	John S./Luca C.
7	Fix illumination and focus of all profile monitors	Lenny D.
8	Fix cables for 2 profile monitors that are none responsive	Lenny D./ Bill E.
9	Add "external" synch for Gun2 camera	Lenny D.
10	Take out, examine and possibly replace laser cross	Cliff B.
11	500MHz FPC replacement ?	Cliff B./Binping X./Vacuum Group
12	Re-align the bunching cavity?	Cliff B. and Survey Group
13	Survey: Locate LEBT solenoids	Cliff B. and Survey Group
14	Survey SRF linac: location?	Cliff B. and Survey Group
15	Survey: Locate transport magnets	Cliff B. and Survey Group
16	Build an air-coil sextupole magnet and install it upper LEBT section	Cliff B.
17	LEBT gun_tv1 aux trim polarity is wrong	Anthony D./Igor P.
18	LEBT th1_aux trim strength should be increased	Anthony D./Igor P.
19	Common section sol 1 and sol 5 polarities should be corrected	Anthony D./Igor P.
20	LLRF system to operate SRF gun at h+1=1447 harmonic of RHIC operating with 18.196 GeV/u Au ion beam. Change of bunching cavity and SRF linac harmonics as well.	Geetha N./Freddy S./ Patrick I.
21	Check operation of all IR diagnostics	Lenny D.
22	Compton polarimeter	Cliff B./Tony C./Instrumentation Group
23	Prepare GaAs cathodes	John S./Luca C.
24	Adjust alignment laser on the common section profile monitor	Patrcik I.
25	Shield exist hole from High Power beamdump	Cliff

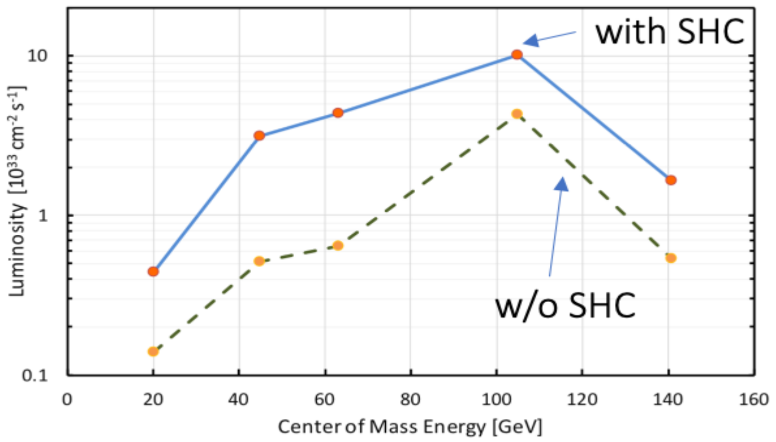






Brookhaven National Laboratory

Proposal for dedicated time for CeC demonstration after completion of RHIC physics Run 25



NAS Assessment of U.S.-Based EIC Science: *The accelerator challenges are two fold: a high degree of polarization for both beams, and high luminosity.*

- ✓ Demonstration of CeC would provide confidence that EIC cooler could do the job
- ✓ CeC system is fully operational
  - ✓ Necessary beam parameters were demonstrated
  - ✓ High gain Plasma-Cascade Amplification was experimentally demonstrated
  - ✓ Ion imprint in electron beam was experimentally observed
- ✓ Remaining challenge – demonstrate stability

- ✓ Coherent electron Cooling remains the leading candidate for EIC to achieve design average luminosity of 10^{34} $cm^{-2}sec^{-1}$
- ✓ We propose to have a dedicated 3-weeks RHIC run to ensure experimental demonstration of Coherent electron Cooling technique

- ✓ Two-step program towards successful demonstration of CeC
  - ✓ During RHIC physics run we will bring all CeC systems to full readiness
  - ✓ 3 weeks of RHIC operation with Au ion in Yellow at CeC operational energy to complete following tasks:

1. Develop RHIC ramp to the CeC operations energy – 2 days
2. Adjust CeC systems to new stray fields and restore the e-beam quality – 2 days
3. Propagate e-beam in the CeC section, and align ion and electron beams – 3 days
4. Match relativistic factors of ion and electron beams – 1 day
5. Restore High-Gain Plasma-Cascade amplification with CW e-beam – 3 days
6. Fine system tuning and demonstration of Coherent electron Cooling – 10 days

Important: Previous experience proved that any switching from regular RHIC physics operation to dedicated CeC shift or APEX session resulted in significant loss of time. This is the main reason why we suggest to separate CeC dedicated RHIC operation from RHIC physics run. Still, it is possible to move one week of dedicate (for example as part of APEX) during the physics run and reduce post-physics CeC tun to two weeks.

Proposed modes of operation

- To maximize chances for success, we will develop two modes of operation during RHIC physics run, below and above RHIC transition energy.
- Lower energy of operation would provide for better quality of ion beam and easier choice of electron beam parameters, but this will new mode to develop
- **Best mode will be selected for the demonstration**

Parameter	Mode 1	Mode 2
γ, relativistic factors of the beams	19.57	28.5
Au ion beam energy, GeV/u	18.2	26.5
Electron beam energy, MeV	10	14.56
Peak current, A (core, 50% of the beam)	$\geq$ 22	$\geq$ 45
Normalized emittance (core, > 50% of the beam), μm rad	$\leq$ 1.5	$\leq$ 1.5
RMS relative energy spread (core, > 50% of the beam), 10^{-4}	$\leq$ 2	$\leq$2
Energy flat top (core, > 50% of the beam), $\lvert 10^4\ \delta\gamma/\gamma \rvert$	< 1.5	<1.5

- **We will apply for APEX time, used for developing ramps and creating initial set up for CeC but cooling demonstration is unlikely in this scenario without dedicated time.**
- **We are still aiming on demonstration of longitudinal CeC before RHIC stops operations**

Summary

- We developed techniques to measure/suppress the instability induced beam noise (Run 18-20).
- We observed the imprint of ion beam and the recombination of electrons and ions (Run 20, 21).
- We made a new step of verifying high PCA gain at frequencies of 6 THz and above – thanks to new pieces of IR diagnostics, i.e. bolometer (Run 22).
- We are in the process of generating beam with qualities satisfying requirements by recent cooling simulation (Run 23-24).
- CeC accelerator still suffers from lack of reliability: both in terms for beam parameter jitter and poor repeatably of operation set-ups. We have developed several significant improvements to generate stable electron beam required to demonstrate CeC. New techniques have been proposed and will be verified at the beginning of Run 25.
- We are still targeting to demonstrate longitudinal Coherent electron Cooling (Run 25).