Coherent electron Cooling (CeC) experiment at RHIC

Vladimir N Litvinenko for CeC group

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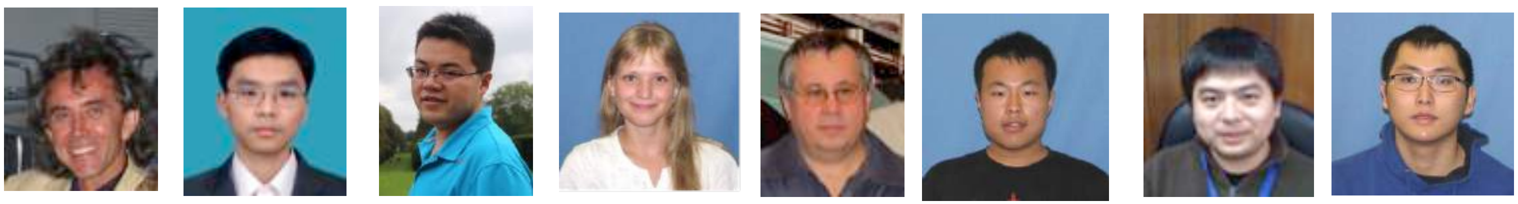

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Center for Accelerator Science and Education

CAD MAC, December 1, 2020

Why we doing this?

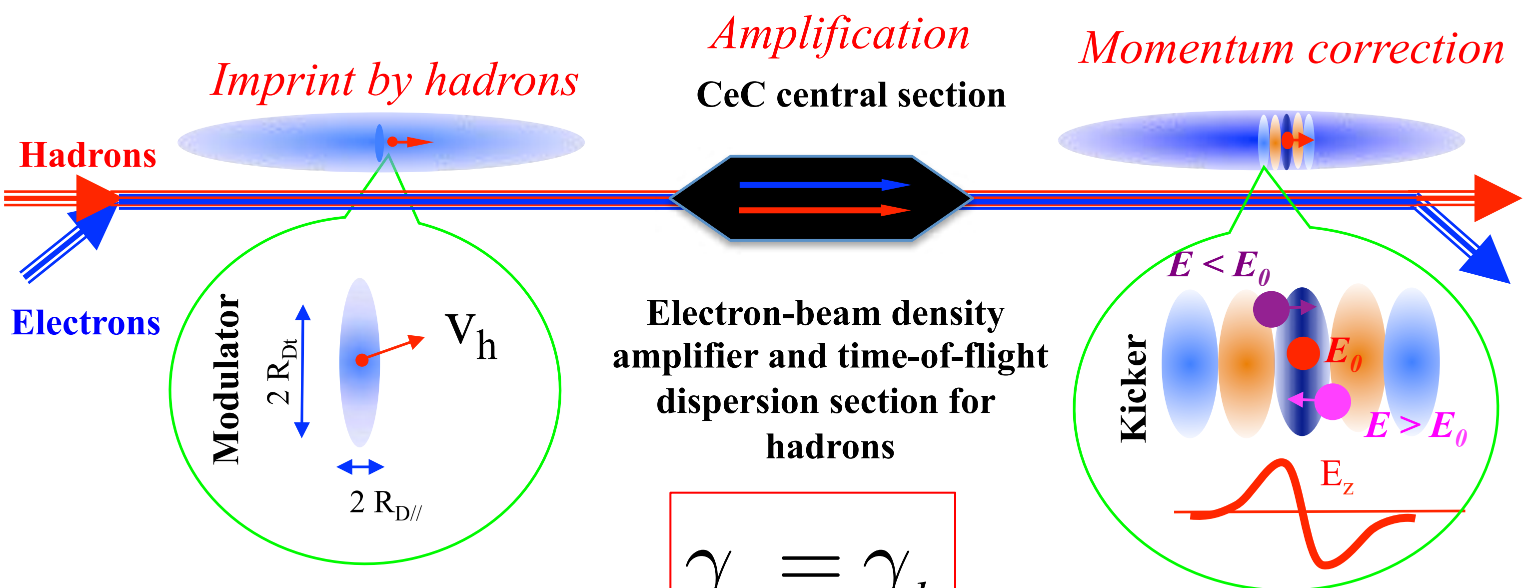
- 2018 NAS Assessment of U.S.-Based Electron-Ion Collider Science: *The accelerator challenges are two fold: a high degree of polarization for both beams, and high luminosity.*

- April 2018 eRHIC pCDR review committee report:

"*The major risk factors are strong hadron cooling of the hadron beams to achieve high luminosity, and the preservation of electron polarization in the electron storage ring*. The Strong Hadron cooling [**Coherent Electron Cooling (CeC)**] is needed to reach $10^{34}/(cm^2 s)$ luminosity. ***Although the CeC has been demonstrated in simulations, the approved "proof of principle experiment" should have a highest priority for RHIC***."

What is Coherent electron Cooling

- Short answer – stochastic cooling of hadron beams with bandwidth at optical wave frequencies: 1 – 1000 THz
- Longer answer on next pages

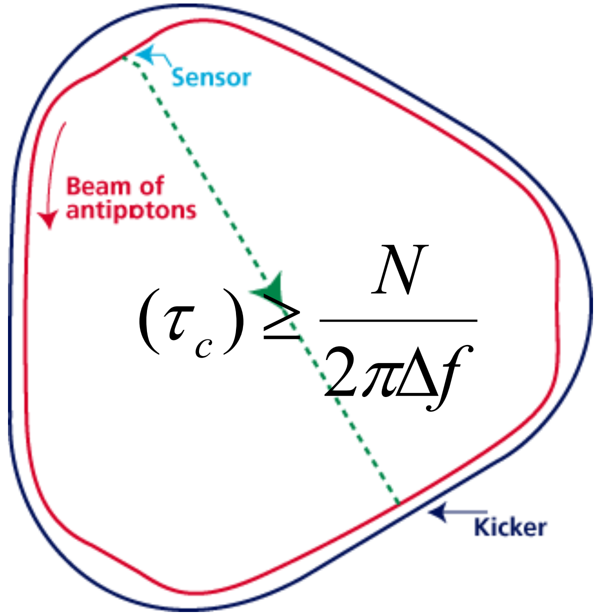


$$\gamma_e = \gamma_h$$

Critical conditions for the stochastic cooler

S. van der Meer
1984 Nobel physics prize

RF stochastic cooling is reaching its limits at ~ 10 GHz bandwidth



$$(\tau_c) \geq \frac{N}{2\pi\Delta f}$$

$$\langle x \rangle = \frac{1}{N_s}\sum_i x_i = \frac{1}{N_s} x_k + \frac{1}{N_s}\sum_{i \neq k} x_i$$

$$\tau_c = -\left(f_{rev} \frac{1}{\varepsilon}\frac{d\varepsilon}{dn} \right)^{-1} = \frac{N_s}{f_{rev}} \propto \frac{I_{peak}}{Z} \cdot \frac{1}{\Delta f}$$

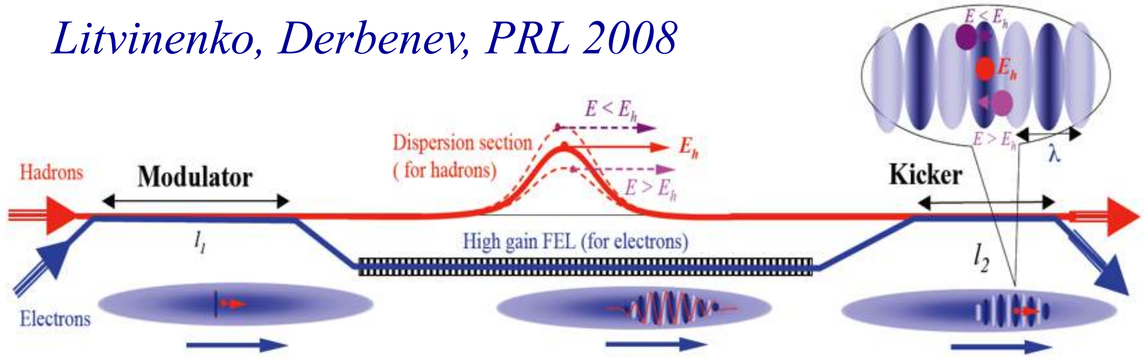
$$N_s = \frac{\dot{N}}{\Delta f} = \frac{I_{peak}}{Ze} \cdot \frac{1}{\Delta f}$$

- ✓ **Linearity:** Amplifier must be linear (no saturation) and low noise
- ✓ **Overlapping:** Amplified signal induced by individual particle in the modulator (pick-up, sensor) must overlap with the particle in the kicker
- ✓ **Bandwidth:** Cooling decrement per turn can not exceed $1/N_s$, where N_s is number of the particles fitting inside the response time of the system: $\tau \sim 1/\Delta f$
- ✓ **Noise:** noise in the system should not significantly exceed system signal introduced by shot noise in the hadron beam

S. van der Meer, Rev. Mod.Phys. 57, (1985) p.689
S. van der Meer, 1972, Stochastic cooling of betatron oscillations is ISR, CERN/ISR-PO/72-31

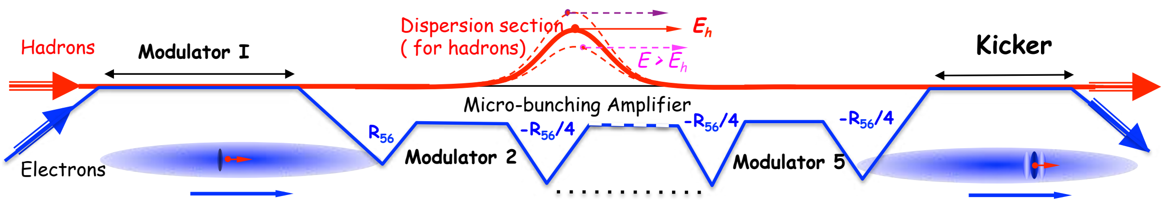
CeC schemes

Litvinenko, Derbenev, PRL 2008



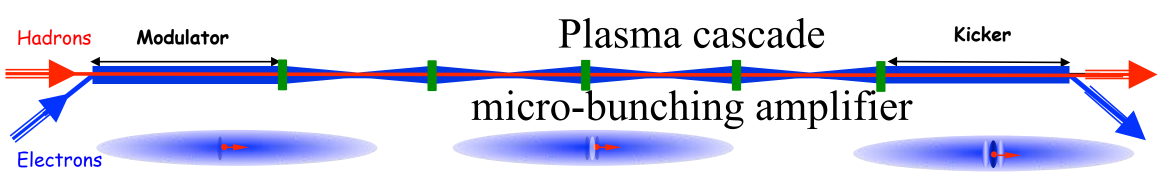
High gain FEL amplifier

Ratner, PRL 2013



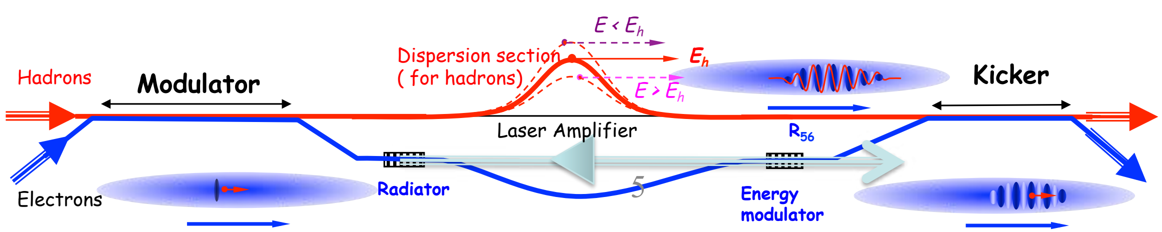
Multi- Chicane Microbunching amplifier

Litvinenko, Wang, Kayran, Jing, Ma, 2017



Plasma-Cascade Microbunching amplifier

Litvinenko, Cool 13

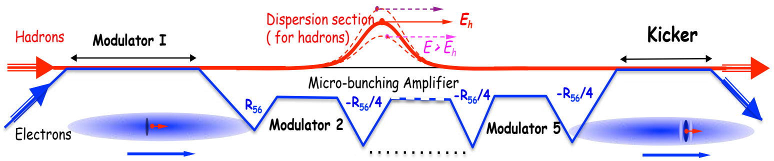


Hybrid laser-beam amplifier

What can be tested experimentally?

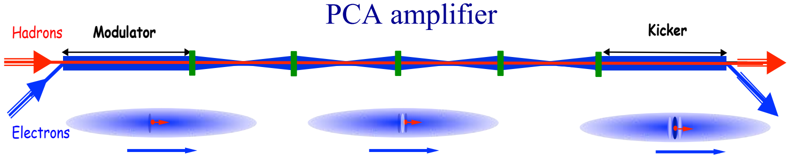
RHIC Run 18

High gain FEL amplifier with low-a_w wigglers



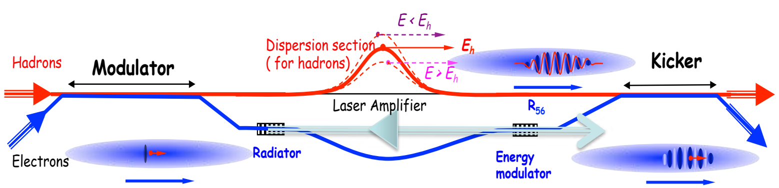
Cooling test would require significant modification of the RHIC lattice & superconducting magnets with cost exceeding $20M.

PCA amplifier



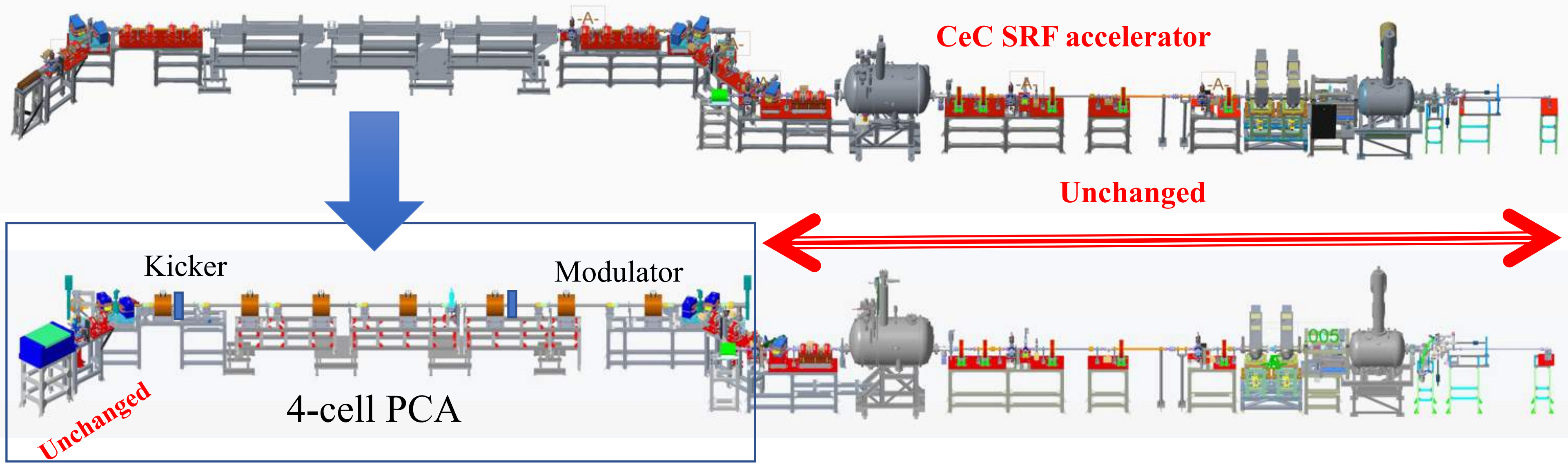
RHIC Runs 20-22

Plasma-Cascade Amplifier

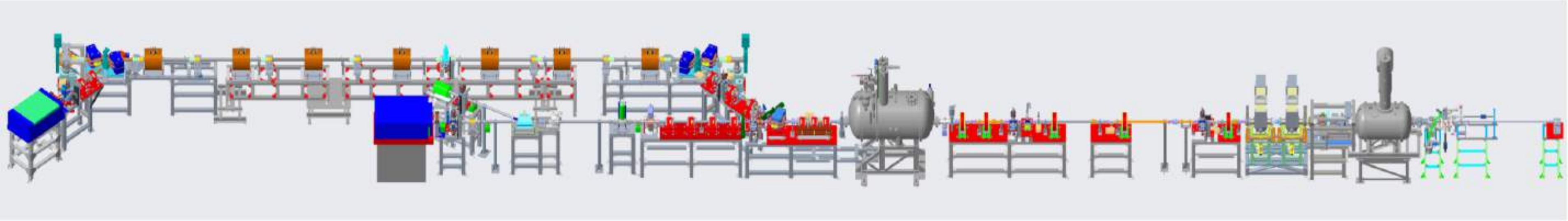


Cooling test would require significant modification of the RHIC lattice & superconducting magnets with cost exceeding $20M

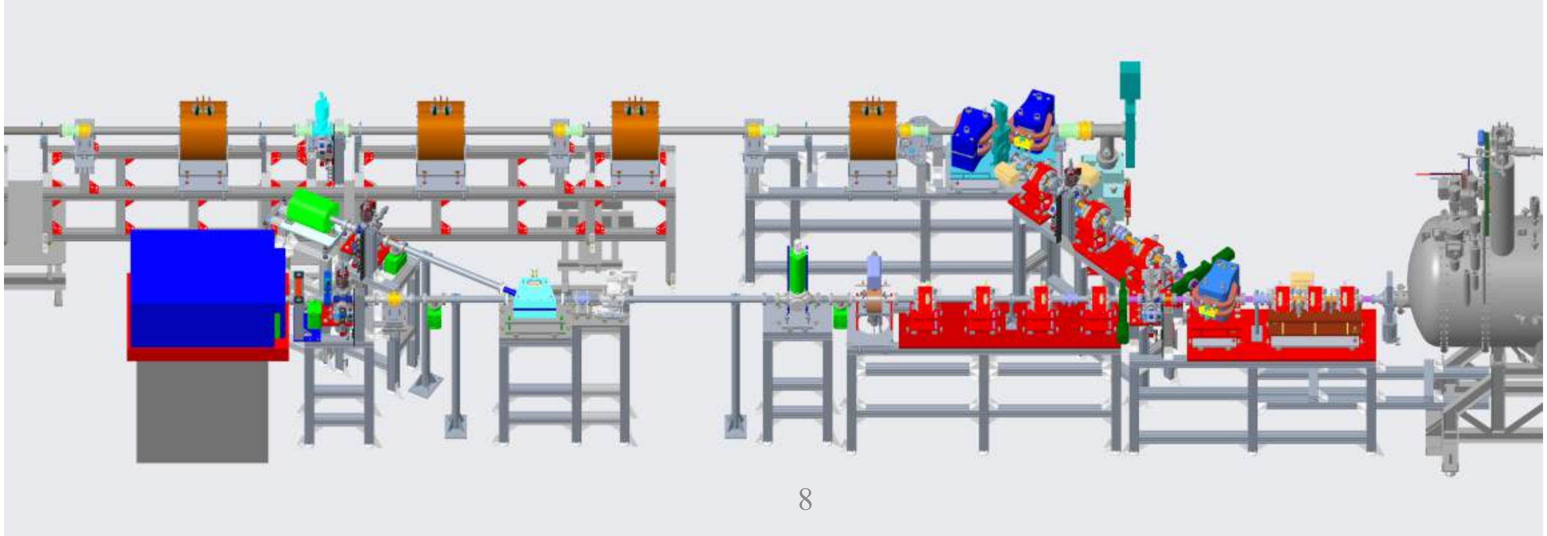
New CeC PCA Beamline: Run 2020



CeC project: FY20-FY23



- Main additions for Run 2021 is the time-resolved diagnostics beam-line (TRDBL)
  - Will allow to evaluate local beam quality of electron beam with time resolution of 1 psec
  - Critical for achieving KPP for Run 2021



Run 2020 Accomplishments

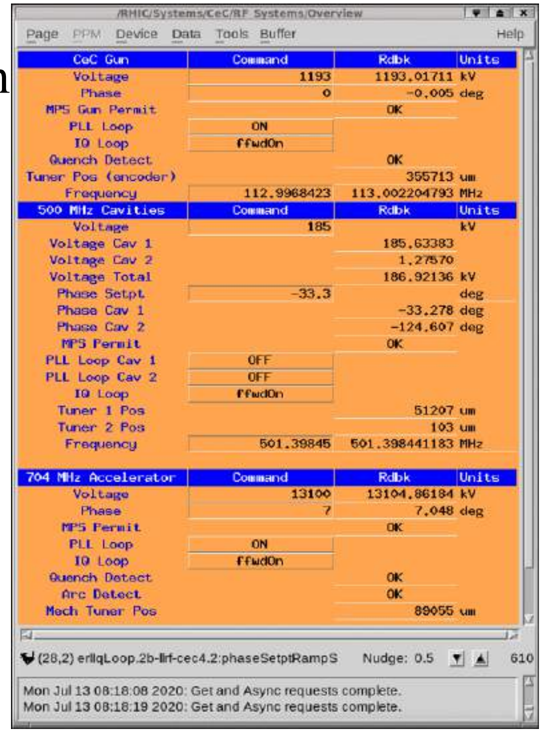
- We demonstrated Key Performance Parameters (KPP) for this run.
- Completed analysis of the key experimental data collected during the Run 20.
- Confirmed strong amplification in Plasma Cascade Amplifier (PCA) and presence of ion imprint in the electron beam.
- Early completion of all main milestones for this run:
  - **Milestone CEC11030: Necessary Beam Parameters (KPP) established for Run 20**
  - **Milestone CEC11040 "Investigation of plasma cascade amplification"**
  - **Milestone CEC11050 "Investigation of the ion imprint in the electron beam"**
- We continue simulation of the beam-dynamics and CeC performance
- The time-resolved diagnostics beam-line is under installation at IP2

Table 2-1: Electron beam KPP

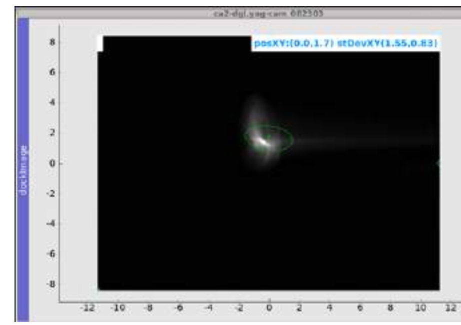
Parameter		
Lorentz factor	28.5	✓
Repetition frequency, kHz	78.2	✓
Electron beam full energy, MeV	14.56	✓
Total charge per bunch, nC	1.5	✓
Average beam current, µA	117	✓
Ratio of the noise power in the electron beam to the Poison noise limit	<100	✓
RMS momentum spread $\sigma_p = \sigma_p/p$, rms	$\leq 1.5\times10^{-3}$	✓
Normalized rms slice emittance, µm rad	≤ 5	✓

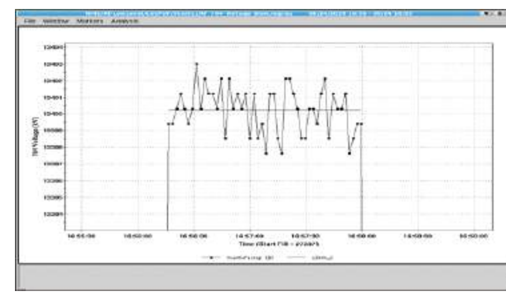
Accelerator system and Beam energy

- According to the simulation using magnetic measurements results: the dipole current should be 93.9 A for γ=28.5, pc=14.5545 MeV
- An approximate ration between *pc* and dipole current is: 0.155 MeV/A, e.g.
- pc[MeV]=0.15500*I[A].



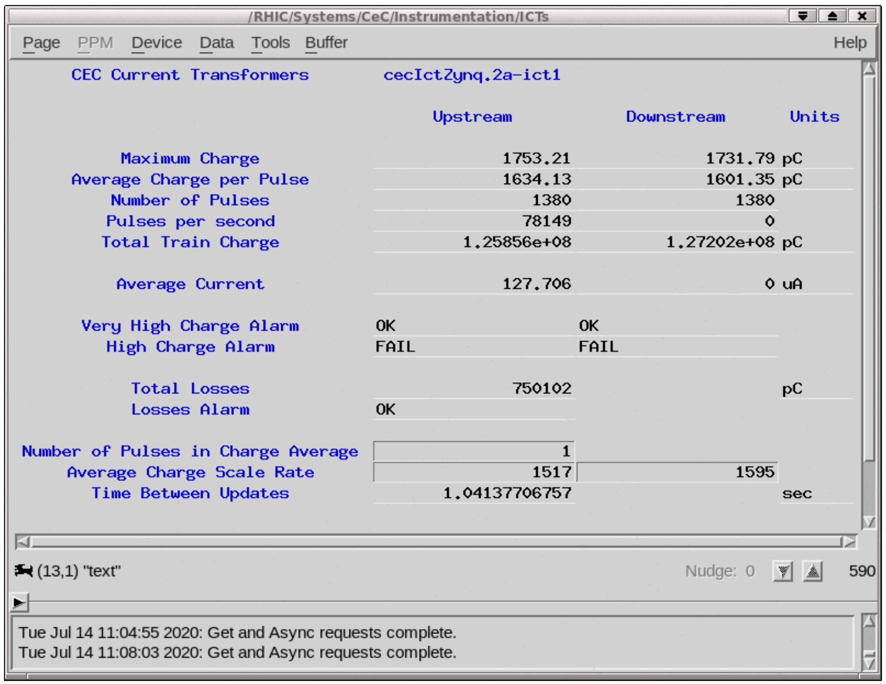
Description	Max Curr [A]	Curr Stpt[A]	Curr Rdbk [A]
Triple Quad 1	6.4	0	0.00004
Triplet Quad 2	6.4	0	0.00003
Triplet Quad 3	6.4	0	-0.00007
First Dipole PS	112	96.2	96.20018
Dog Leg Quad 1	6.4	0	-0.00011

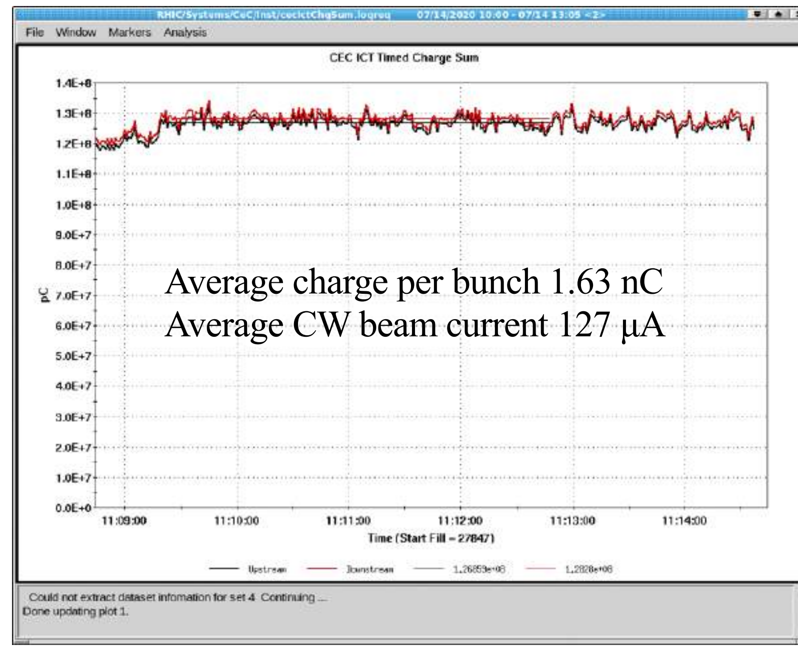




- **Maximum energy with this setting is 14.92 [MeV], γ=29.2, 2.5% above γ=28.5**
- **Linac has additional 2.2% head room to operate at 13.4 MV**

Charge per bunch and CW beam current





Standard settings for 1.5 nC bunch operation

/RHIC/Systems/CeC/RF Systems/Overview

Page PPM Device Data Tools Buffer Help

CeC Gun	Command	Rdbk	Units
Voltage	1193	1193.01711	kV
Phase	0	0.005	deg
MPS Gun Permit		OK	
PLL Loop	ON		
IQ Loop	ffwdOn		
Quench Detect		OK	
Tuner Pos (encoder)		354987	um
Frequency	112.9968423	113.002204793	MHz
500 MHz Cavities	**Command**	**Rdbk**	**Units**
Voltage	185		kV
Voltage Cav 1		185.67528	
Voltage Cav 2		1.26747	
Voltage Total		186.91833	kV
Phase Setpt	-37		deg
Phase Cav 1		-36.996	deg
Phase Cav 2		-127.656	deg
MPS Permit		OK	
PLL Loop Cav 1	OFF		
PLL Loop Cav 2	OFF		
IQ Loop	ffwdOn		
Tuner 1 Pos		51165	um
Tuner 2 Pos		89	um
Frequency	501.39845	501.398441183	MHz
704 MHz Accelerator	**Command**	**Rdbk**	**Units**
Voltage	13100	13101.28055	kV
Phase	-6	-5.993	deg
MPS Permit		OK	
PLL Loop	ON		
IQ Loop	ffwdOn		
Quench Detect		OK	
Arc Detect		OK	
Mech Tuner Pos		89046	um
Tuner Piezo			V
Frequency	703.95841	703.958410	MHz

(28,2) erlIqLoop.2b-llrf-cec4.2:phaseSetptRampS Nudge: 1 363

high limit
Sat Jul 4 20:40:36 2020: Value sent for (11,2)

/RHIC/Systems/CeC/Magnet PS

Page PPM Device Data Tools Buffer Help

Low Energy Beamline	Description	Max Curr [A]	Curr Stpt[A]	Curr Rdbk [A]	Volt
cs2-gun.sol-ps	SRF gun solenoid	13.4	8.23	8.22877	
cs2-inj.sol1-ps	LEBT solenoid 1	8.4	-2.77	-2.77107	
cs2-inj.sol2-ps	LEBT solenoid 2	8.4	3.02	3.01952	
cs2-inj.sol3-ps	LEBT solenoid 3	8.4	-2.94	-2.94105	
cs2-inj.sol4-ps	LEBT solenoid 4	8.4	3.19	3.18940	
cs2-inj.sol5-ps	LEBT solenoid 5	8.4	-3.95	-3.95049	-
cs2-gun.tv1-ps	Gun Vertical Corr 1	1	0	0.00003	
cs2-gun.th1-ps	Gun Horizontal Corr 1	1	0	0.00000	
cs2-gun.tv2-ps	Gun Vertical Corr 2	5	-1.21346	-1.21336	
cs2-gun.th2-ps	Gun Horizontal Corr 2	5	-0.0534179	-0.05306	
cs2-inj.tv1-ps	LEBT Vertical Corr 1	5	0.289347	0.28938	
cs2-inj.th1-ps	LEBT Horizontal Corr 1	5	0.199696	0.19974	
cs2-inj.tv2-ps	LEBT Vertical Corr 2	0.5	-0.0437255	-0.04370	
cs2-inj.th2-ps	LEBT Horizontal Corr 2	2	0.147285	0.14678	
cs2-inj.tv3-ps	LEBT Vertical Corr 3	2	0.356849	0.35671	
cs2-inj.th3-ps	LEBT Horizontal Corr 3	2	-0.536859	-0.53678	
cs2-inj.tv4-ps	LEBT Vertical Corr 4	2	-0.104297	-0.10396	
cs2-inj.th4-ps	LEBT Horizontal Corr 4	2	-0.0279625	-0.02776	
cs2-inj.tv5-ps	LEBT Vertical Corr 5	2	-0.355008	-0.35613	
cs2-inj.th5-ps	LEBT Horizontal Corr 5	2	-0.0771666	-0.07809	
cs2-inj.tv6-ps	LEBT Vertical Corr 6	2	0.263399	0.26320	
cs2-inj.th6-ps	LEBT Horizontal Corr 6	2	-0.116311	-0.11617	
cs2-inj.tv7-ps	LEBT Vertical Corr 7	2	-0.145216	-0.14491	
cs2-inj.th7-ps	LEBT Horizontal Corr 7	2	-0.0548503	-0.05461	
cs2-inj.tv8-ps	LEBT Vertical Corr 8	2	-0.102304	-0.10316	
cs2-inj.th8-ps	LEBT Horizontal Corr 8	2	-0.466461	-0.46763	
cs2-inj.tv9-ps	LEBT Vertical Corr 9	5	-0.0504025	-0.05025	
cs2-inj.th9-ps	LEBT Horizontal Corr 9	5	-0.136048	-0.13560	
cs2-inj.tv10-ps	LEBT Vertical Corr 10	5	-0.0155594	-0.01529	
cs2-inj.th10-ps	LEBT Horizontal Corr 10	5	-1.13363	-1.13352	

(1,4) "text" Nudge: 0.01 80

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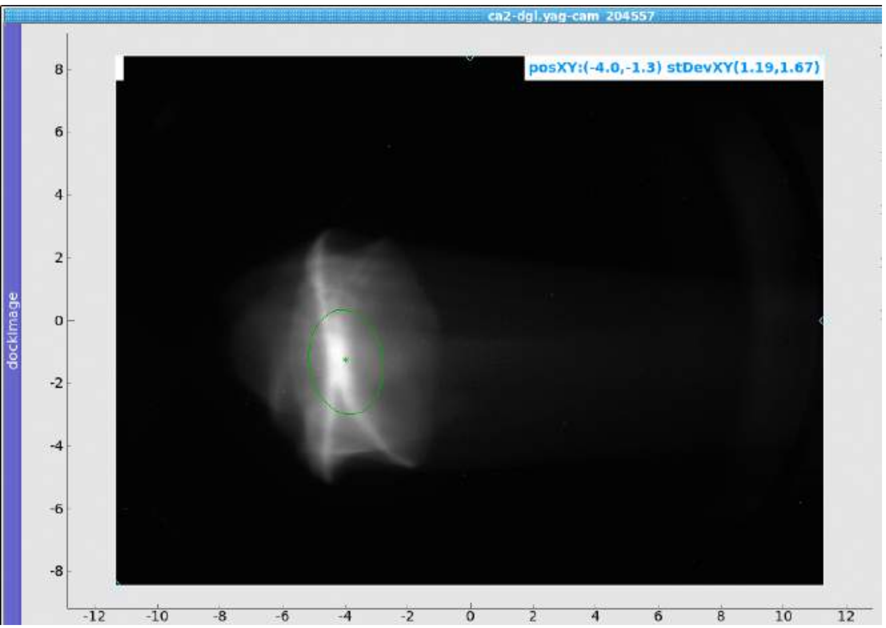
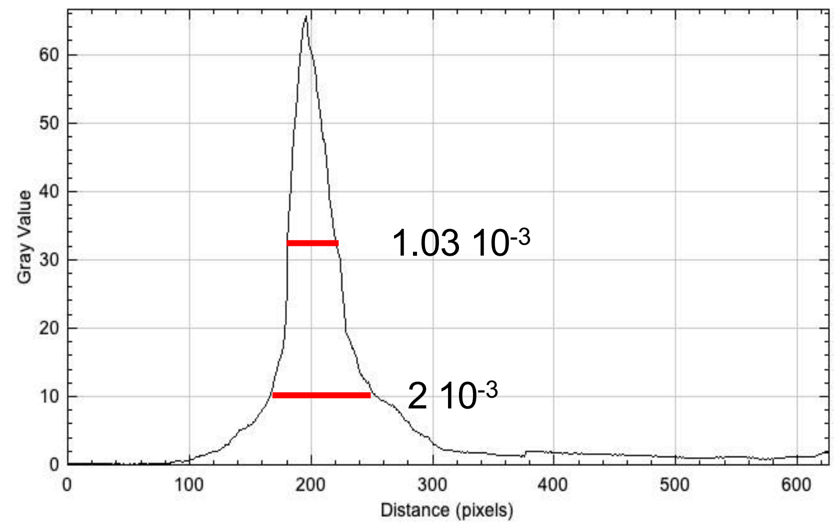
Full beam energy spread

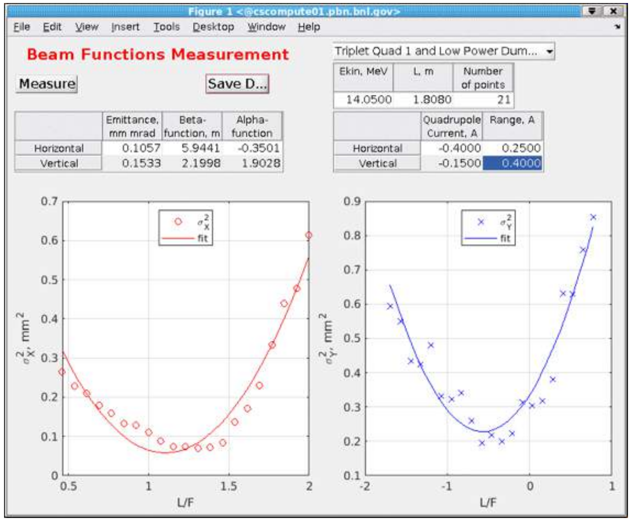
YAG screen in the dogleg: no quadrupoles, D_h=1.3 m

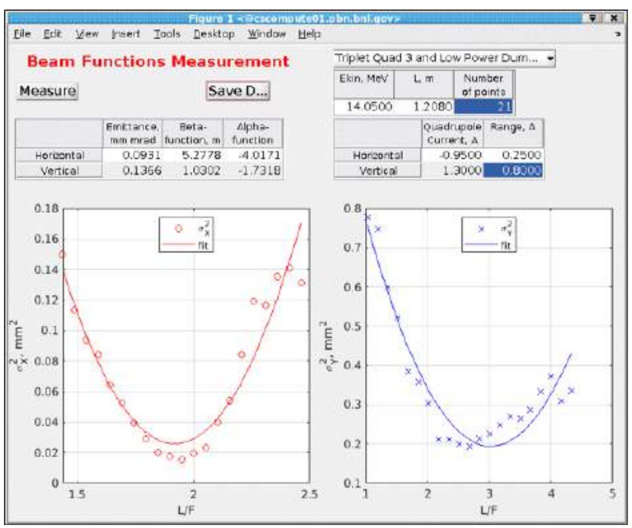




Scaling: 31 pixels per 1 mm, FWHM energy spread is 1.03 10^{-3}; RMS energy spread is 4.4 10^{-4}

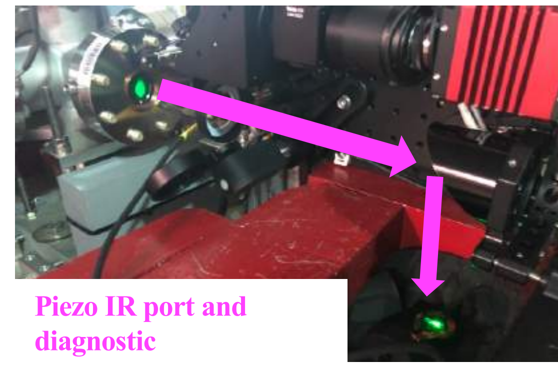
Projected emittances





- **Projected emittances** are, by definition, larger than **slice emittances.**
- Plot shows measured geometrical projected emittance, which are γβ~28.5 times smaller than normalized values
- Measured values of horizontal normalized emittance are 2.8±0.2 mm rad and for the vertical normalized are 4.3±0.6 mm rad.
- **Slice emittances definitely satisfy the KPP.**

The e-beam noise level

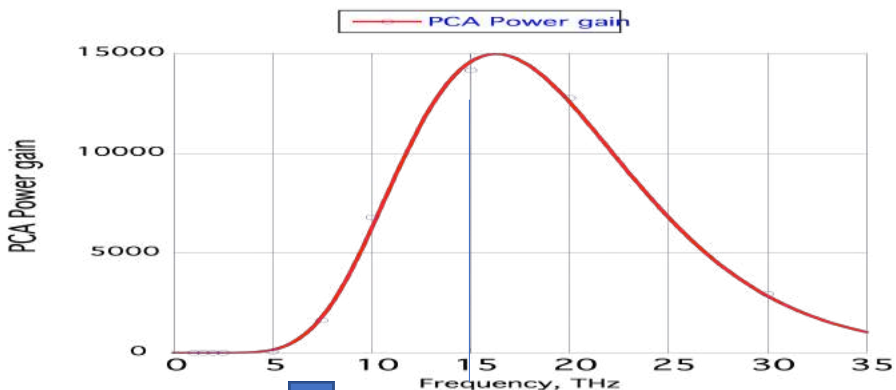


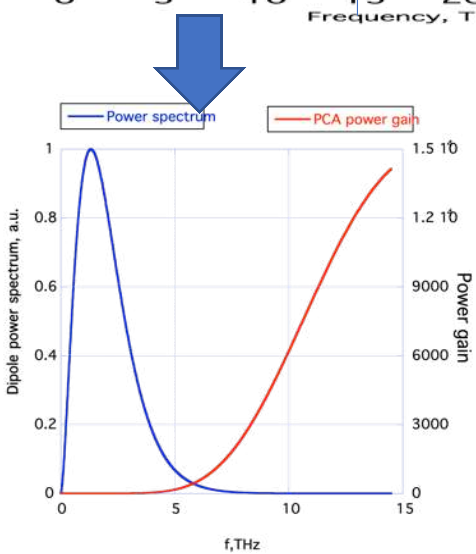
- Beam noise in the electron beam was evaluated using technique established during Run 19
  - The THz beam noise power was measured using power of IR radiation from the first dipole magnet. The IR power was measured by the Gentec broad-band IR detector connected to a lock-in amplifier synchronized with pulsing electron beam.
  - IR radiation from the bending magnet was periodically blocked, e.g. we used modulation-demodulation technique to eliminate effect of X-rays from dumped beam on the IR detector (very important!)
- The baseline power level (e.g. power from the Poisson shot noise) was measured using long low charge (~300 pC) beam propagating in relaxed low-beam transport lattice. Such measurements were in good agreement with simulation.
- In all measurements the measured IR power was normalizes to measured average beam current
- The power of electron beam with 1.5 nC per bunch and the nominal compression (see slide 5) were compared with the baseline level

- **Summary of results (see back-up slides for details)**
- **Measured ratio of the noise power in the electron beam to the Poison noise limit is more than 2 and less then 12**
- **Beam noise satisfy KPP**

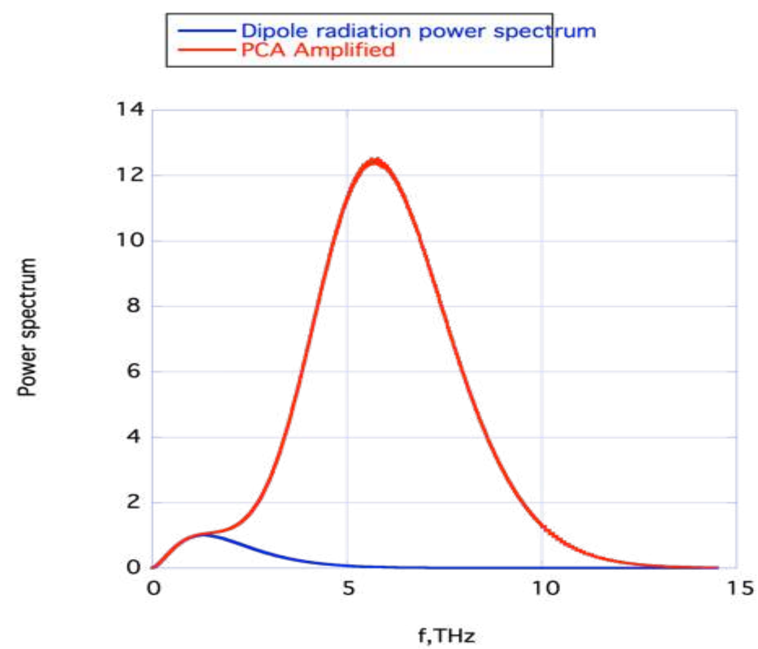
The PCA studies

- Initially we observed 5-fold increase in the power of the broad-band radiation from the dipole magnet when a high-gain micro-bunching PCA lattice was used
- In late July – early August the PCA power-boost was increased to **200-fold**
- Weak overlap of PCA gain curve and the radiation spectrum from the dipole is the reason the measured PCA boost of the dipole radiation is in hundreds, not in thousands. Simulated PCA power gain peaks at 16.5 THz at 15,000 (with peak amplitude gain of 122.5)
- Detailed analysis shows that maximum PCA amplitude gain was ~ 380, e.g. exceeded the design value (122.5 at 16.5 THz) by more than 3-fold.





With simulated PCA amplitude gain of 120 the predicted increase in the radiated power is 21.8 X

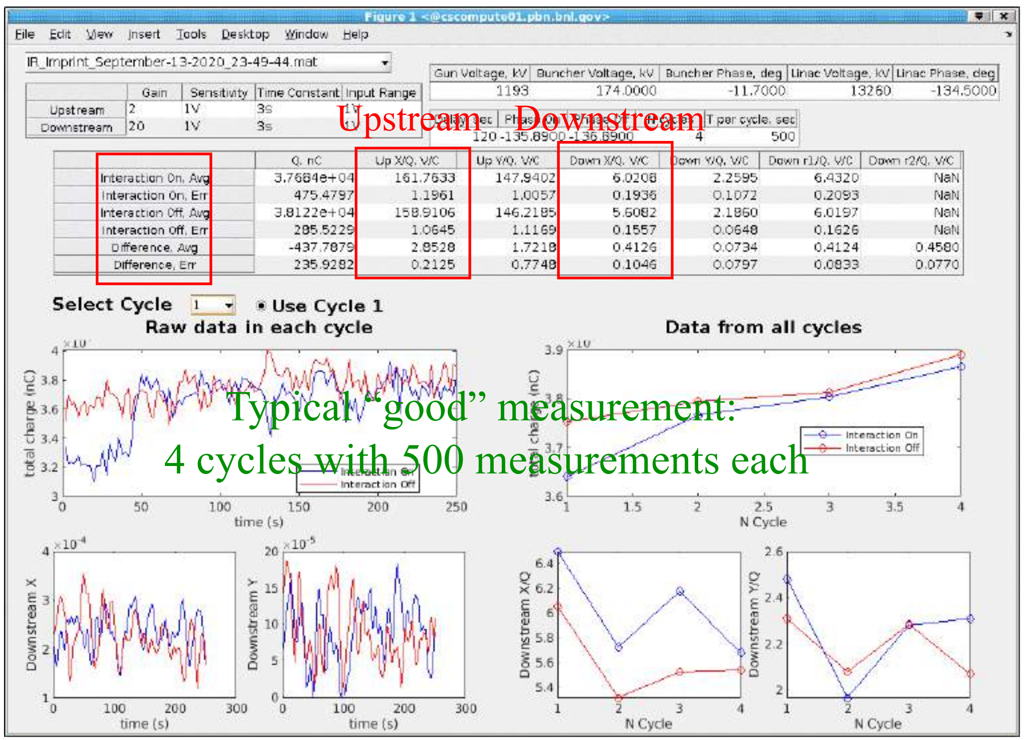


The Ion Imprint studies

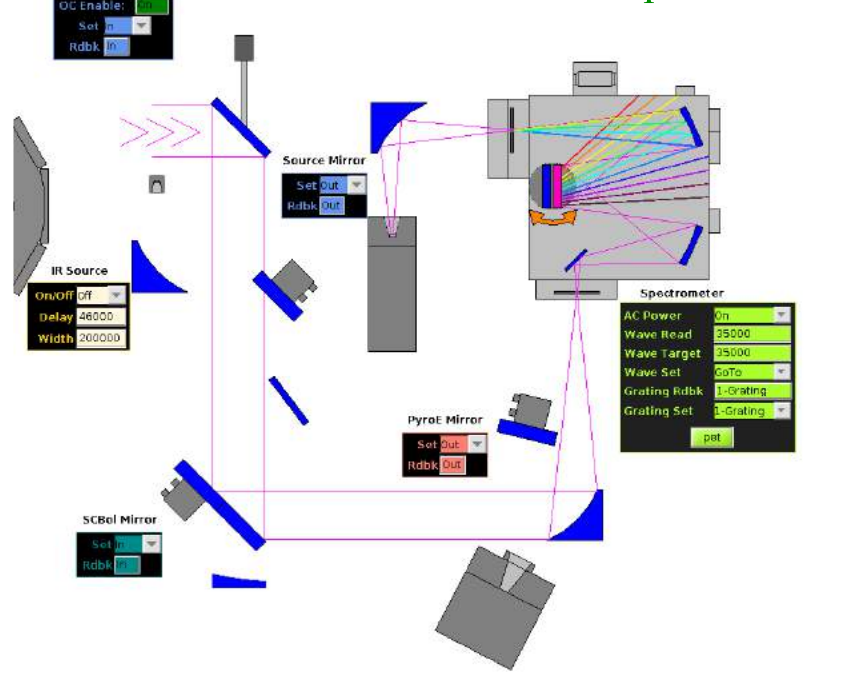
- We observed clear presence of the ion imprint in the electron beam resulting in increase of the e-beam radiation at 35 μm with average imprint of

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

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



Downstream IR diagnostics
10 m from the radiation point



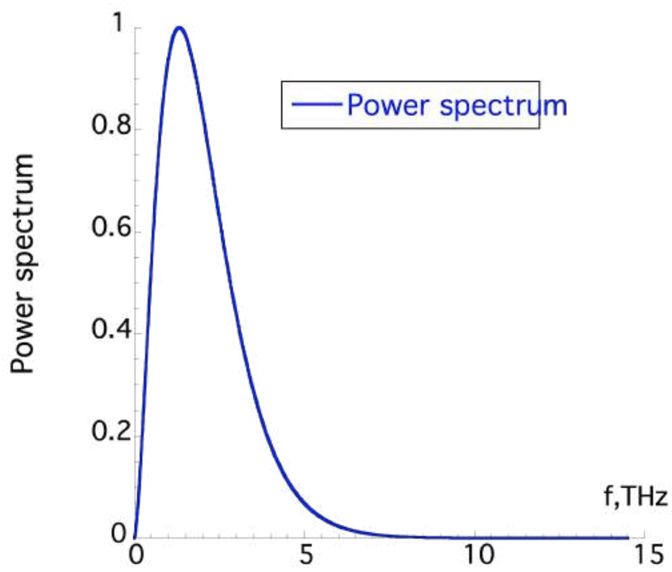
Off-line Data analysis

- Imprint of the ion beam: compared power of the IR radiation from electron beam overlapping with (ON) or separated from (OFF) the ion bunch
- This was done in two measurement modes:
  - (A) Measuring the broad-band radiation from electron beam with low peak current and relaxed lattice (no PCA)
  - (B) Measuring power at 35 μm and using high-gain PCA lattice
- We analyses 28 completed and saved scans with total of 105 "ON-OFF" cycles (in average there was 3.75 cycles per scan).
  - Each scan was characterized by 76 parameters
  - In addition, each cycle was characterized by 124 parameters to define quality of the cycle and detect possible errors (mirrors in wrong position, failure of a major system, failure of data login, etc..)
- A dedicated application analyzed saved data and calculated significant portion data for each individual cycle
- *Two scans were eliminated: one because of the operator errors (mirror was off) and the other because of erratic behavior of the CeC accelerator (tracked to instability in the laser feed-back system)*

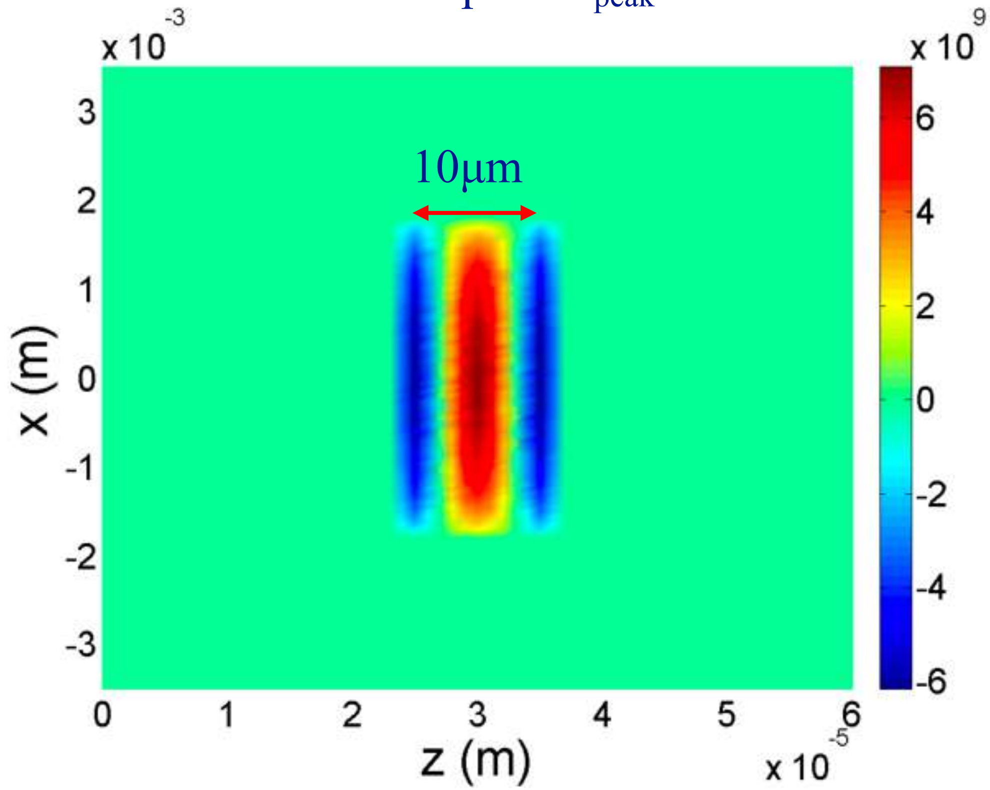
Off-line Data analysis – cont..

- Measurements using broad-band radiation resulted in null results: e.g. imprint of -0.04%±0.8%
- We attribute it to the absence harmonic of ion imprint at low frequencies ~ 1 THz where dipole radiation peaks.

Dipole power spectrum
Peak at 1.3 THz



Simulated ion imprint: f_{peak}=30 THz

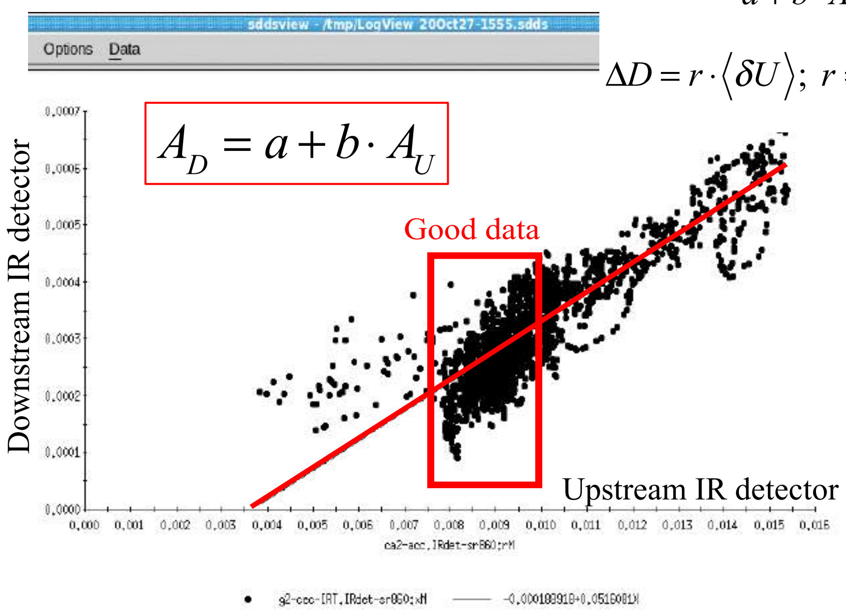


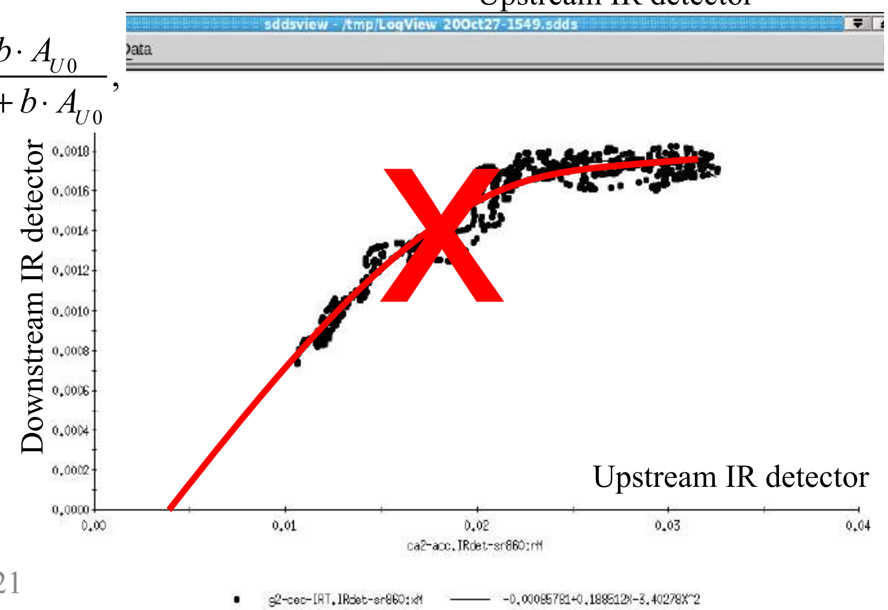
Off-line Data analysis – cont..

- Measurements using PCA-amplifier imprint and spectrometer filtering signal at 35 μm (8.6 THz) resulted in non-zero imprint in both in the raw data (8.4%) and in corrected data (4.7%)
- We used data accumulated in the upstream IR detector (before e-beam interaction with ion beam) as indicator of systematic changes in the electron beam
- We eliminated all cycles where variations of the IR power exceeded ±25%
- Correlations between the downstream and upstream detectors were subtracted

$$d\ln A_D \cong \frac{b\cdot A_{U0}}{a+b\cdot A_{U0}}\, d\ln A_U;$$

$$\Delta D = r\cdot\langle \delta U\rangle;\ r = \frac{b\cdot A_{U0}}{a+b\cdot A_{U0}},$$





Summary of the imprint measurement results

#	Date	Time	N cycles	Good cycles	$\gamma_{ions}/\gamma_{elec}$ Estimation	δD	δU	σ, δD
19	12-Sep	8:22	2	1	1.006	3.33%	-5.14%	4.84%
20	12-Sep	8:57	2	1	1.006	2.43%	-10.48%	3.03%
21	12-Sep	16:55	4	2	1.005	2.80%	5.98%	1.34%
22	12-Sep	18:16	4	2	1.011	8.60%	2.60%	1.29%
23	12-Sep	20:21	4	2	1.011	2.67%	0.96%	1.18%
25	13-Sep	3:20	4	3	1.002	13.90%	3.60%	1.78%
26	13-Sep	5:13	4	1	0.999	7.50%	2.97%	1.23%
27	13-Sep	5:13	2	1	0.996	1.02%	1.18%	3.68%
28	13-Sep	8:05	4	2	0.995	0.09%	-0.04%	1.85%
29	13-Sep	19:34	4	1	1.001	27.70%	4.37%	2.45%
30	13-Sep	23:49	4	4	0.985	7.29%	1.53%	1.19%
31	14-Sep	1:03	4	4	0.985	7.23%	0.94%	1.28%
32	14-Sep	8:24	4	4	0.996	9.97%	4.80%	1.54%
						<δD>	<δU>	<σ>
		Weighted avarage				7.50%	1.85%	0.32%

Weighted average

$$\langle A\rangle_W = \frac{\sum_i^{N_S} n_i \langle A_S\rangle_i}{\sum_i^{M} n_i} \equiv \frac{\sum_i^{N_C}\langle A_C\rangle_i}{N_C}$$

Correlations

$$d\ln A_D \cong \frac{b\cdot A_{U0}}{a+b\cdot A_{U0}} d\ln A_U;$$

$$\Delta D = r\cdot\langle\delta U\rangle;\; r = \frac{b\cdot A_{U0}}{a+b\cdot A_{U0}},$$

$$r = 1.5\pm 0.2$$

Downstream

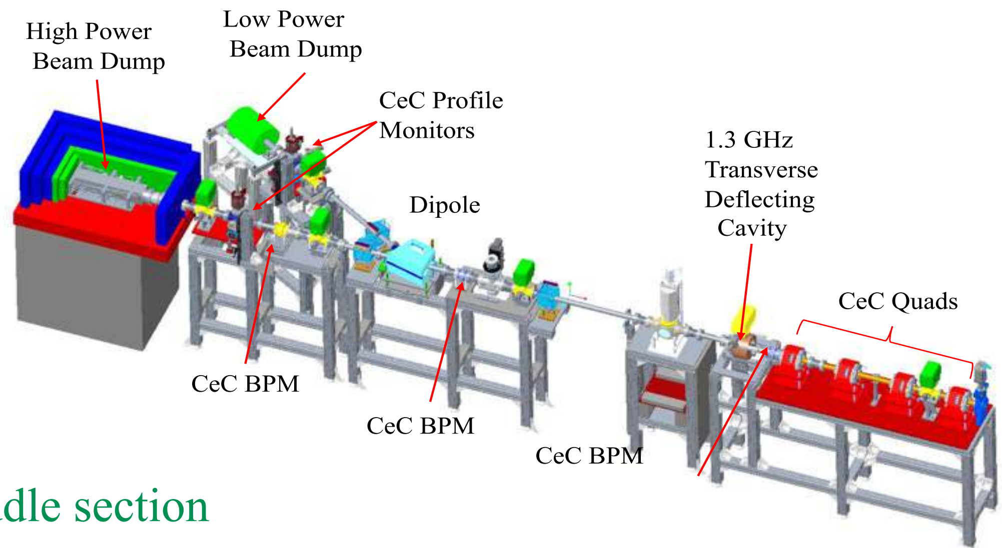
$$\delta D = \frac{\langle X_{D\,ON}\rangle}{\langle X_{D\,OFF}\rangle}\cdot\frac{\langle Q_{OFF}\rangle}{\langle Q_{ON}\rangle} - 1 \qquad \delta U = \frac{R_{U\,ON}}{R_{U\,OFF}}\cdot\frac{\langle Q_{OFF}\rangle}{\langle Q_{ON}\rangle} - 1;\; R_U = \sqrt{\langle X_U\rangle^2 + \langle Y_U\rangle^2}$$

$$\delta = \frac{\langle A_{ON}\rangle}{\langle A_{OFF}\rangle}\cdot\frac{\langle Q_{OFF}\rangle}{\langle Q_{ON}\rangle} - 1;\; \sigma_\delta = \sqrt{\frac{\sigma^2_{AON}}{\langle A_{ON}\rangle^2} + \frac{\sigma^2_{AOFF}}{\langle A_{OFF}\rangle^2} + \frac{\sigma^2_{QON}}{\langle Q_{ON}\rangle^2} + \frac{\sigma^2_{QOFF}}{\langle A_{OFF}\rangle^2}}$$

$$\delta D_C = \delta D - r\cdot\delta U = 4.7\%$$

Time-resolved diagnostic beamline

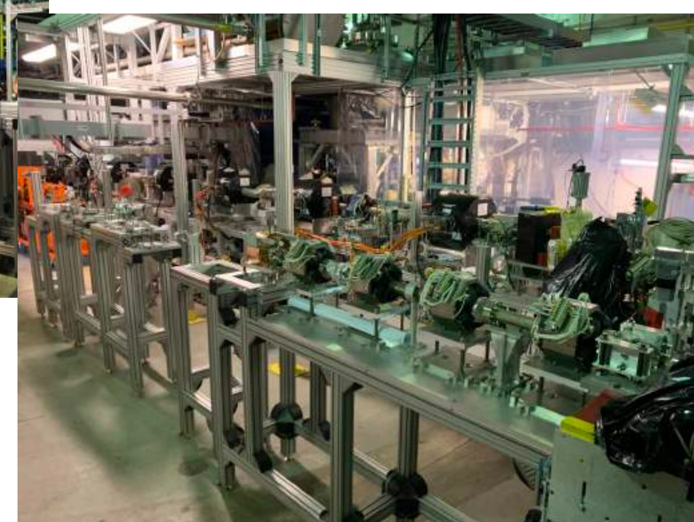
Progressing well:
we are on schedule to have it ready
for commissioning in February 2021



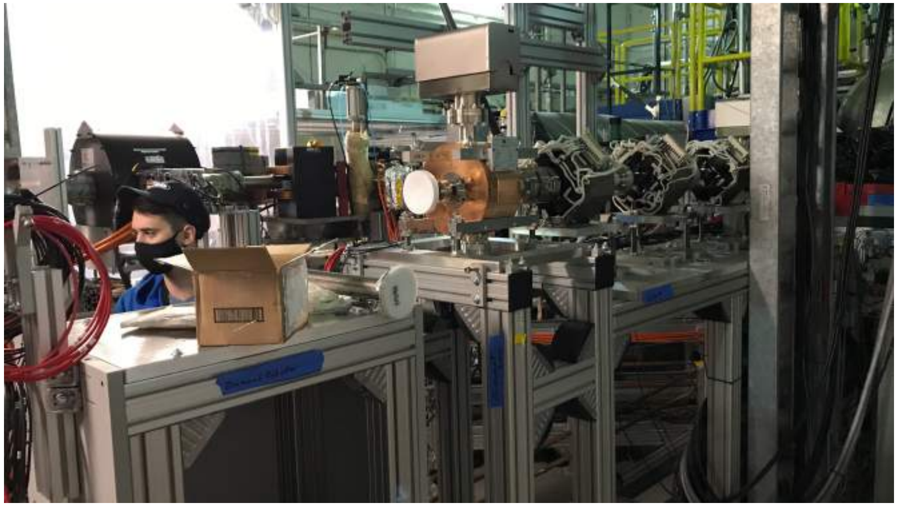
End section

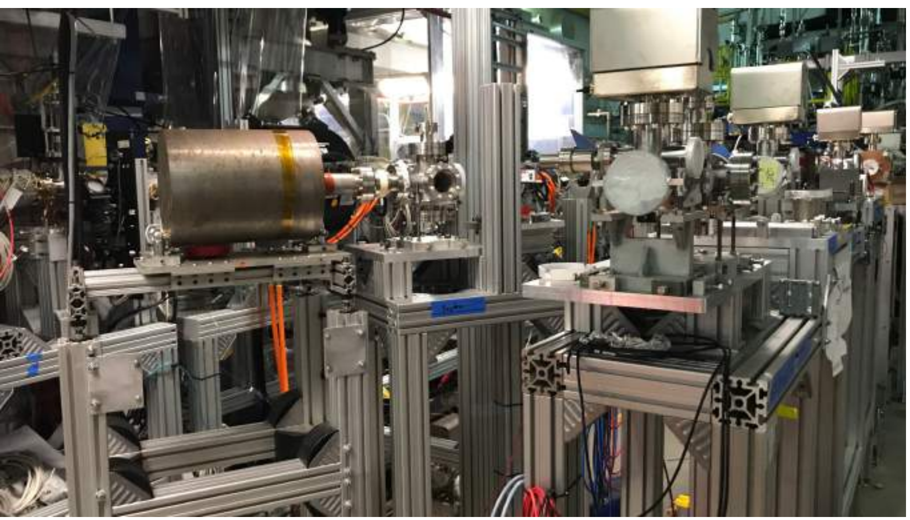
Middle section

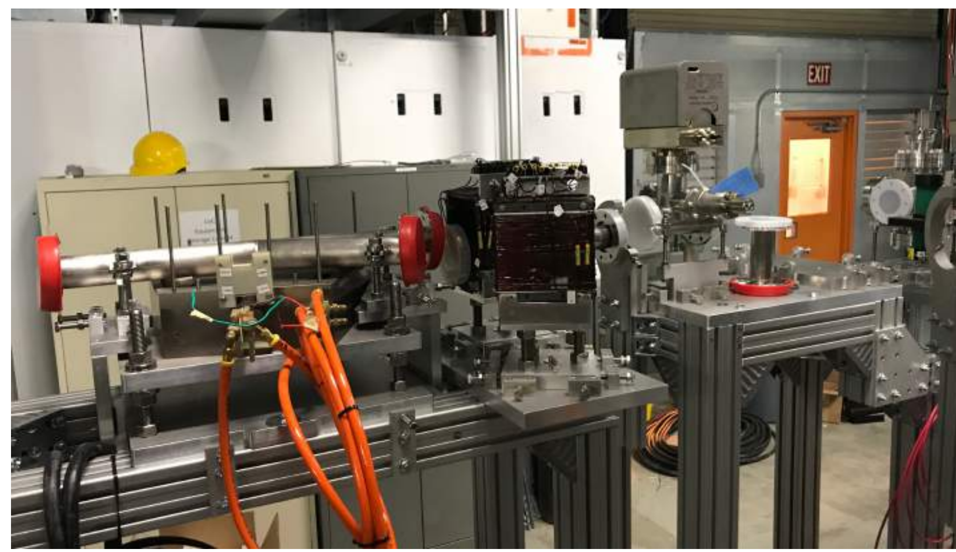
Quads and
transverse RF cavity



TRDBL: November 23, 2020







Plan for experimental demonstration of PCA-based CeC

- RHIC Run 20 – requested 8 days of dedicated RHIC time
  - Commissioned the PCA-based microbunching CeC system
  - Generated low-noise CW electron beam with required parameters
  - Demonstrated plasma-cascade amplification in the CeC section
  - Observed ion imprint in the electron beam
- Fall 2020 – in the process of time-resolved diagnostic beamline installation

- RHIC Run 21 - requested 14 days of dedicated time
  - Commission time-resolved diagnostic beamline
  - Measure and optimize electron beam parameters
  - Establish interaction of electron and ion beams
  - Demonstrate longitudinal cooling of ion bunch in PCA-based CeC
  - Evaluate longitudinal cooling

- RHIC Run 22 –we plan to ask for 14 days of dedicated time
  - Reestablish operation of CeC system
  - Demonstrate 3D – longitudinal and transverse - cooling of ion bunch in PCA-based CeC
  - Evaluate PCA-based microbunching CeC

Conclusions

- We learned how to control noise in the electron beam how generate electron beam with necessary quality for the CeC experiment
- In spite of challenges imposed by COVID-19 pandemic (including delay with cry-cooled IR detector), we achieved all goals for RHIC Run 20 by demonstrating strong amplification in PCA and presence of PCA-amplified ion imprint in the electron beam. Strong and continuous support by C-AD staff was critical for this success
- Goals for the upcoming RHIC run are well defined:
  - Commission new time-resolved diagnostic beam-line
  - Verify and tune parameters of the CeC electron beam
  - Align axes of PCA solenoids with the IP2 axis
  - Commission new cry-cooled IR detector
  - Match relativistic factors of electron and ion beams using signature of the ion imprint and signal from the recombination monitor
  - Attempt to demonstrate longitudinal cooling of 26.5 GeV/u ion beam
- Successful experimental demonstration of PCA-based CeC will serve as a perfect starting point for design of realistic cooler for future Electron-Ion Collider

The CeC project involved the following:

… never can get all of your photos…

Back-ups

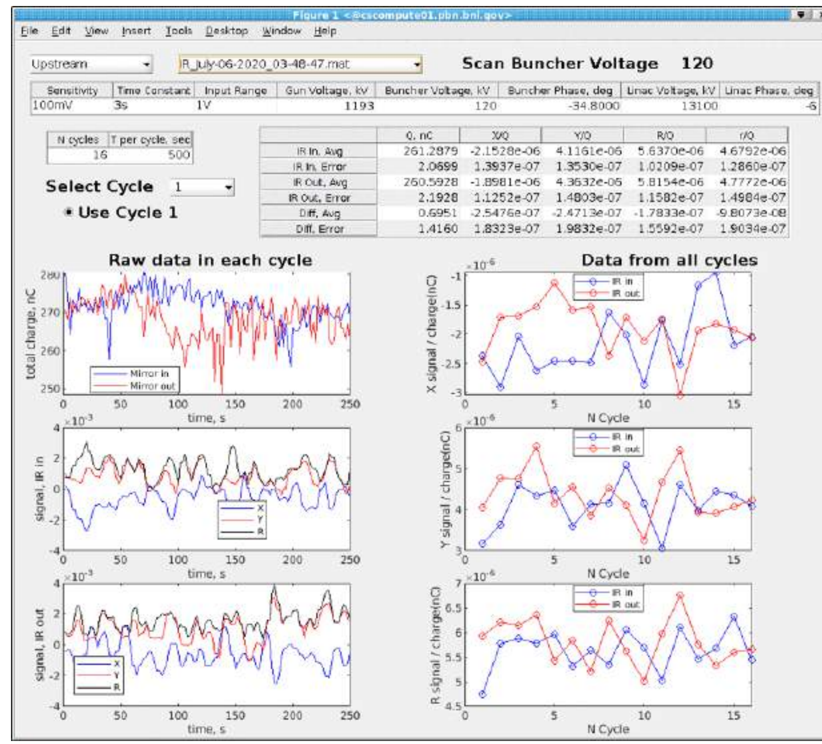
Responses to MAC-16 Recommendations

- Implement the plan to add a transverse deflecting cavity at the end of the straight beam line along with the TROG system at high priority
- Consider developing faster codes (like "Elegant" or BMAD) that have a simplified space charge treatment and can run faster to allow a quick exploration of important effects in CeC.
- Work out a conceptual scheme of EIC strong cooling based on PCA. Optimize and formulate a set of electron beam parameters (such as beam current, bunch length, energy spread, etc.) for such a cooling system. Compare with the cooler based on MBEC.

- A dedicated time-resolved diagnostics beam-line (TRDBL) with 1.3 GHz transverse deflecting cavity has been designed, procured/constructed and is in an advanced stage of installation in RHIC IP2
- We were unable to identify code capable of properly simulating important CeC processes (the imprint, the PCA amplifier and the kicker) faster than currently used codes (SPACE and Impact-T). 1D and simplified models of space-charge effects are too crude to proper simulations of CeC
- We developed conceptual design of the CeC based on micro-bunching Plasma- Cascade Instability for the EIC. In contrast with CeC conceptual scheme using chicane-based micro-bunching amplifier (Ratner, 2013), our design does not require expensive separation system for electron and hadron beams while providing estimated 3D cooling time is under 5 minutes.

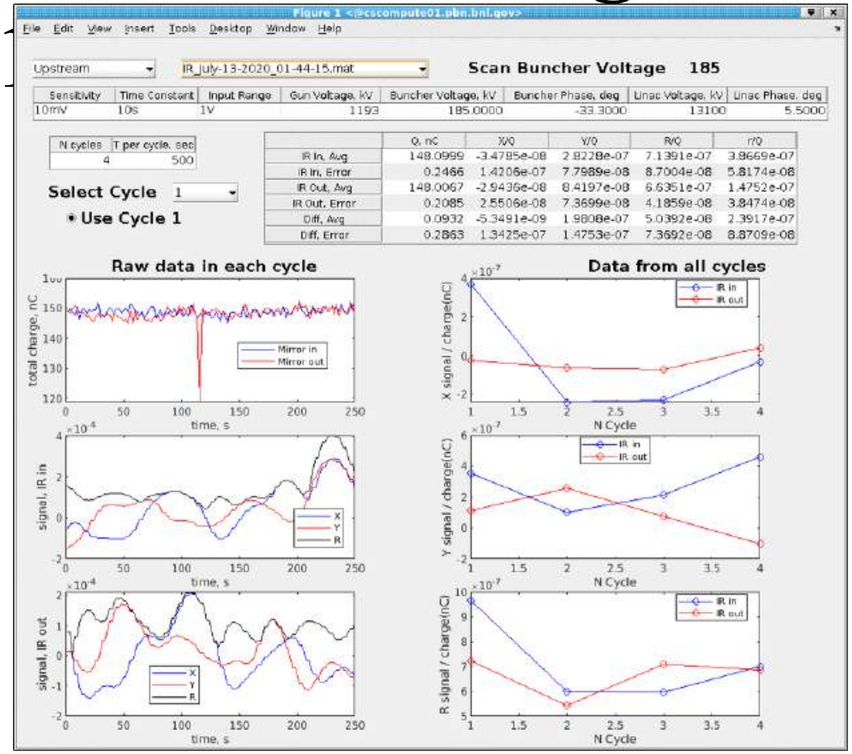
Additional Information 1: baseline (shot noise) measurements

- We used beam with 300 pC per bunch and relaxed bunching (120 kV bunching voltage) and relaxed focusing to simulate nearly ideal shot noise source
- Two overnight scans using lock-in amplifiers and DMD technique (opening and blocking the e-beam radiation) gave
  - <X>=-37 ± 22, <Y>=51 ± 22, R=63 ± 32
  - <X>=-32 ± 18, <Y>=75 ± 20, R=82 ± 27
- Two nights together give
  - <X>=-35 ± 14
  - <Y>=61 ± 16
  - R=70 ± 21.
- This defines both the signs of X and Y, and the value of the R range from 50 to 90.



Additional Information 2: sample 1.5 nC bunch with standard setting (slide 1

- The e-beam and accelerator setting are identical to that used for the beam emittances and energy spread measurements
- Typical scan of the radiation from e-beam with 1.5 nC charge per bunch
  - <X>=-5 ± 47, <Y>=198 ± 50, R= 198 ± 55
- This measurement shows 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).



Additional Information 3: Parameter of the IR detector

Certificate #:	**506449-171103**	**Customer Name:**	
Model Number:	**THz5I-BL-BNC**	**Instrument ID:**	
Head Serial Number:	**506449**	**Date of Calibration:**	**November 3, 2017**
		Calibration Due Date:	*****
Cal. Procedure:	**100-1025**		

Calibration Data

Calibration								
Meaurement Parameter	Sensitivity		Into Load	Power	Rep.Rate	Ambient Temp.	Relative Humidity	Beam Ø
@ 633 nm	V/W	%	Ω	uw	Hz	°C	%	mm
Rv (P to P)	2.12E+05	± 2.1	NA	8.2	5	21	33	1
Rv (RMS)	6.91E+04	± 2.1	NA	8.2	5	21	33	1
					Hz	°C	%	mm
Vn (RMS) @ 1 Hz BW	1.30E-04	± NA	NA	NA	5	21	33	NA
	$W/Hz^{1/2}$				Hz	°C	%	mm
NEP (P to P)	6.10E-10	NA	NA	NA	5	21	33	NA
NEP (RMS)	1.90E-09	± NA	NA	NA	5	21	33	NA

Data analysis: sample from Jun Ma

	Nick-name for the scan/cycle	Jun_16		Jun_30	Jun_31		Jun_32
	Parameter						
Notation	eLog link (s)	http://www.cadops2.bnl.gov/elogs/entryList.jsp?DATABY=day&ELOG=CeC_2020&DATE=09/11/2020&DIR=none#1290942		http://www.cadops2.bnl.gov/elogs/entryList.jsp?DATABY=day&ELOG=CeC_2020&DATE=09/13/2020&DIR=none#1292941	http://www.cadops2.bnl.gov/elogs/entryList.jsp?DATABY=day&ELOG=CeC_2020&DATE=09/13/2020&DIR=none#1292958		http://www.cadops2.bnl.gov/elogs/entryList.jsp?DATABY=day&ELOG=CeC_2020&DATE=09/14/2020&DIR=none#1293246
	Scan parameter - unique for all cycles						
	Date	11-Sep		13-Sep	13-Sep		14-Sep
	Start Time	5:22		22:39	23:53		7:24
	Finish Time	6:23		23:49	1:03	14-Sep	8:24
	STAR colissions - ON, OFF	OFF		ON	ON		OFF
	Number of requested cycles	4		4	4		4
	Number of completed cycles	4		4	4		4
	Time per cycle, sec	500		500	500		400
	Delay time, sec	60		120	120		120
	Amplifier's parameters						
	Upstream gain	2		2	2		2
	Downstream gain	20		20	20		20
	Upstream time constant, sec	3		3	3		3
	Downstream time constant, sec	3		3	3		3
	Upstream sensitivity and range, V	1		1	1		1
	Downstream sensitivity and range, V	1		1	1		1
	Other relevant information						
	IR diagnostics status						
	Upstream Mirror position (IR, V or unknown)	IR		IR	IR		IR
	Downstream IR Mirror position (in/out, unknown)	in		in	in		in
	Downstream detector: Pyro or Golay	Golay		Golay	Golay		Golay
	If with spectrometer: mirror or grating	mirror		Grating	Grating		Grating
	If with spectrometer: position, nm	18		35000	35000		35000
	Scan results, averaged over all cycles	**Uncorrected**	**Corrected (if needed)**				
	Used cycles	4		4	4		4
	Up X/Q, Interaction on, V/C	68.55538529		161.7260758	161.6638956		180.4078296
	Up X/Q, Interaction on, err, V/C, *when available*	0.640378722		0.252986695	0.223021488		0.376608491
Xu_r	Up X/Q, Interaction off, V/C	69.72244387		158.9072862	160.4459474		171.5954485
	Up X/Q, Interaction off, err, V/C, *when available*	0.652115893		0.236978511	0.188870759		0.417415492
dXu	Up X/Q, difference, V/C	-1.167058581		2.818789654	1.217948204		8.812381101
exu	Up X/Q, difference err, V/C, *when available*	0.913969389		0.346642586	0.292251172		0.562200719
	Up Y/Q, Interaction on, V/C	64.59838824		147.9389021	149.0315272		164.9768134
	Up Y/Q, Interaction on, err, V/C, *when available*	0.72892951		0.264376204	0.18178862		0.376415154
Yu_r	Up Y/Q, Interaction off, V/C	65.41636859		146.2241879	147.3449944		157.9430976
	Up Y/Q, Interaction off, err, V/C, *when available*	0.638716157		0.222015865	0.168389024		0.334807387
dYu	Up Y/Q, difference, V/C	-0.817980345		1.714714266	1.686532771		7.033715804
eyu	Up Y/Q, difference err, V/C, *when available*	0.969173132		0.345232996	0.2477942		0.503770141
	Down X/Q, Interaction on, V/C	21.13271673		6.015009102	5.525007736		6.106660995
	Down X/Q, Interaction on, err, V/C, *when available*	0.25396782		0.044459423	0.049721757		0.055639488
Xd_r	Down X/Q, Interaction off, V/C	19.64302223		5.606477692	5.373343003		5.552165138
	Down X/Q, Interaction off, err, V/C, *when available*	0.296266234		0.049693612	0.046573284		0.063531456
dXd	Down X/Q, difference, V/C	1.489694493		0.40853141	0.151664734		0.554495857
ed	Down X/Q, difference err, V/C, *when available*	0.390222161		0.066679047	0.068127263		0.084451161
	Down Y/Q, Interaction on, V/C, only when useful	4.263709501		2.257999459	2.363136667		1.71898537
	Down Y/Q, Interaction on, err, V/C	0.273834282		0.050897203	0.047206823		0.058277151
	Down Y/Q, Interaction off, V/C	4.581278891		2.185091916	2.227219818		1.643961791
	Down Y/Q, Interaction off, err, V/C	0.24994497		0.054236968	0.053344474		0.055907397
	dYd: Down Y/Q, difference, V/C	-0.31756939		0.072907542	0.135916849		0.075023579
	Down Y/Q, difference err, V/C, when available	0.370752886		0.074378585	0.071232837		0.080758054
	Slew rate in Up X, Interaction on, % per hr	20.5801		16.9103	10.023		23.1434
	Slew rate in Up X, Interaction off, % per hr	19.2403		9.5025	-9.6135		6.5119
	Slew rate in Up Y, Interaction on, % per hr	-4.1538		20.4643	-0.9474		21.4556
	Slew rate in Up Y, Interaction off, % per hr	-26.7343		14.4932	-2.0512		8.1059
	Slew rate in Down X, Interaction on, % per hr	-101.826		-11.3299	-1.9002		-19.58
	Slew rate in Down X, Interaction off, % per hr	106.1668		-14.8017	-1.0027		-39.3151
	Slew rate in Down Y, Interaction on, % per hr	40.7143		22.2607	5.5961		-29.4952
	Slew rate in Down Y, Interaction off, % per hr	105.9851		-25.3354	23.6378		-103.4968
	Slew rate in Up R/Q, Interaction on, % per hr	6.3592		-1.1727	8.3092		9.2802
	Slew rate in Up R/Q, Interaction off, % per hr	-3.2482		0.4493	-4.0577		-5.9126
	Slew rate in Down R/Q, Interaction on, % per hr	-98.8389		-26.8828	2.5853		-33.4025
	Slew rate in Down R/Q, Interaction off, % per hr	105.1928		-27.5322	4.7059		-57.644
Rur	Sqrt(Xu_r^2+Yu_r^2)	95.60606915		215.9468423	217.8381266		233.2188243
dRu	Up change in R/Q : Sqrt(dXu^2+dYu^2)	1.425172823		3.299366625	2.080334255		11.27524805
eu	Sqrt(exu^2+eyu^2)	1.332154872		0.489230931	0.383161472		0.754886749
du	Up: change, du=dRu/Rur, %	1.490671916		1.527860556	0.954990886		4.83462177
erru	Up: error eu/Rur, %	1.393378981		0.226551556	0.17589275		0.32368174
	Uncorrected "imprint"						
di	Raw imprint, di=dXd/Xd_r, %	7.583835499		7.286774906	2.82253959		9.987020255
errd	Raw imprint error errd=e_d/Xd_r%	1.986568849		1.18932155	1.267874814		1.521049154
	Corrected "imprint"						
dic	dic=(di-du)/(1-du), %	6.185367113		5.848267726	1.885555588		5.414152269
	error=sqrt(erru^+errd^2), %	2.42651206		1.210706965	1.280017502		1.555107841

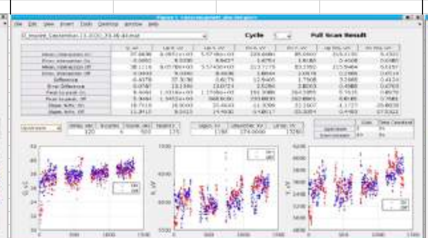
Data analysis: sample from Jun Ma cont..

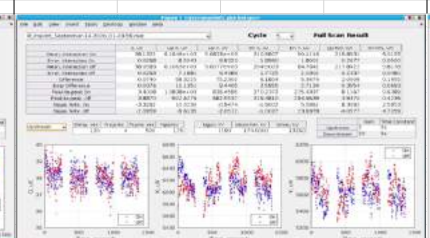
Comments, if needed																
Cycle Results	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 1**	**Cycle 2**	**Cycle 3**	**Cycle 4**
Date	11-Sep	11-Sep	11-Sep	11-Sep	13-Sep	13-Sep	13-Sep	13-Sep	13-Sep	14-Sep	14-Sep	14-Sep	14-Sep	14-Sep	14-Sep	14-Sep
Start Time (approximate if not available)	5:21	5:37	5:52	6:08	22:39	22:57	23:14	23:32	23:53	0:11	0:29	0:46	7:24	7:39	7:54	8:09
Finish Time (approximate if not available)	5:37	5:52	6:08	6:23	22:57	23:14	23:32	23:49	0:11	0:29	0:46	1:03	7:39	7:54	8:09	8:24
Was the cycle interrupted? Yes/No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Was the cycle completed? Yes/No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	yes
Other relevant information: *were measurments affected by transitions?*	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Failure of main system? Yes/No *Gun, buncher, linac, laser, MPS...*	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Up X/Q, Interaction on, V/C	65.97733525	67.55640131	73.48710944	67.2244668	164.5569272	159.2012852	160.4684427	162.8246959	157.2294894	160.9422865	165.2490663	163.2869631	176.9671937	182.7885813	179.9837744	181.8225697
Up X/Q, Interaction off, V/C	67.81603546	69.57519811	72.13531069	69.34745098	161.4200294	156.4037624	158.1961365	159.6217334	162.6523206	159.2491889	161.5842232	158.289939	174.5411893	168.0243632	172.7968039	171.0615409
Up X/Q, difference, V/C	-1.838700214	-2.0187968	1.351798751	-2.122984181	3.136897827	2.797522789	2.272306244	3.202962545	-5.422831206	1.693097635	3.664843107	4.997024106	2.426004329	14.76421811	7.18697047	10.76102882
Up Y/Q, Interaction on, V/C	60.99755013	70.29787585	67.77937785	59.39454785	149.1206137	146.4425592	146.0438994	150.1538255	148.1395946	148.240205	151.4333807	148.3278347	162.8929852	165.7952118	164.5072283	166.6854372
Up Y/Q, Interaction off, V/C	66.93671444	66.08957391	66.0916065	62.54840041	147.649272	143.0314594	146.317982	147.8767497	146.4422994	147.5509319	148.8178502	146.5800356	160.2037968	155.2041007	158.1944919	158.185561
Up Y/Q, difference, V/C	-5.939164311	4.208301936	1.68777135	-3.153852564	1.47134169	3.411099744	-0.274082561	2.277075791	1.697295237	0.689273018	2.61553045	1.747799122	2.689188422	10.59111112	6.312736383	8.499876292
Down X/Q, Interaction on, V/C	24.09558612	22.68445495	18.76335731	19.00419501	6.495682064	5.727292521	6.176993826	5.68330845	5.36869734	5.580369558	5.873475882	5.280062726	6.255328412	6.495013239	5.935673922	5.753306304
Down X/Q, Interaction off, V/C	16.15020857	18.93299589	21.71280494	21.75815617	6.048581356	5.314931702	5.527043263	5.54215647	5.350986862	5.154554649	5.58585432	5.403081305	6.026137193	5.61751233	5.323765152	5.253386233
Down X/Q, difference, V/C	7.945377556	3.751459055	-2.949447633	-2.753961168	0.447100707	0.412360819	0.649950563	0.141151981	0.017710478	0.425814909	0.287621562	-0.123018579	0.229191219	0.877500909	0.61190877	0.499920071
Down Y/Q, Interaction on, V/C, only when useful	4.044494628	4.960732049	3.46793147	4.579508275	2.48073758	1.966272354	2.283084949	2.307832031	2.484784871	1.990538084	2.606233233	2.368125893	1.719978231	1.821297059	1.980367034	1.36884459
Down Y/Q, Interaction off, V/C	3.86788089	4.569057794	5.01437206	4.870753354	2.310441581	2.077998951	2.28536689	2.07033106	2.089556769	2.281953475	2.351728488	2.186777819	2.160835375	1.360897223	1.554912861	1.51135724
Down Y/Q, difference, V/C	0.176613738	0.391674255	-1.54644059	-0.291245079	0.170295999	-0.111726597	-0.002281942	0.237500971	0.395228102	-0.291415391	0.254504745	0.181348074	-0.440857144	0.460399835	0.425454173	-0.142512649
Up X/Q variations, Interaction on, rms, %	21.58030121	19.91030934	17.028264	23.38867483	3.604833333	2.621166667	3.123442623	1.857142857	2.151147541	3.539836066	2.917619048	1.971129032	2.569206349	2.256212121	3.8503125	4.129411765
Up X/Q variations, Interaction off, rms, %	20.03369806	23.7293526	18.22391993	20.85797055	2.925409836	2.228813559	3.43	2.938387097	2.960645161	1.950983607	2.013934426	2.325833333	6.711129032	3.958833333	3.836612903	3.080634921
Up X/Q variations, Interaction on, p-to-p, %	107.1942197	112.5310308	84.2499526	117.7566958	14.78312406	10.68722063	13.71942815	9.914920226	11.48781357	15.06900944	11.39841161	9.260250306	15.10656994	12.600353	17.31507531	16.00300858
Up X/Q variations, Interaction off, p-to-p, %	92.99616795	107.580473	81.06788653	99.34553296	14.24090691	11.29049304	19.40966752	11.20807964	12.24136034	10.74330985	9.830997027	11.08641449	26.86094598	15.11529154	16.08437706	11.96861826
Up Y/Q variations, Interaction on, rms, %	26.74340334	21.66953327	24.04958176	25.26373476	4.231481481	2.805272727	2.441428571	2.775172414	2.331052632	3.118035714	2.386206897	2.330535714	2.407068966	1.799333333	5.833220339	3.98
Up Y/Q variations, Interaction off, rms, %	24.83032372	18.94871205	20.91204403	21.29704996	3.196909091	2.791851852	2.570714286	2.095	3.065892857	2.049642857	2.21625	2.655714286	4.278947368	4.019107143	4.901754386	1.945344828
Up Y/Q variations, Interaction on, p-to-p, %	133.7224179	95.78885236	113.8584467	127.945987	17.81870946	14.54396294	11.31559304	13.55504299	10.02580882	12.65394966	11.69047727	10.69614125	11.47937533	8.448746897	34.11016228	16.07507923
Up Y/Q variations, Interaction off, p-to-p, %	107.5998475	82.74956574	102.1026259	93.33135344	13.6526123	12.0424473	13.32656113	10.7301996	12.19586356	9.655378699	11.08505986	10.4744457	16.8388532	19.02357507	19.56411022	8.983737601
Down X/Q variations, Interaction on, rms, %	22.30105084	22.49364022	26.43107989	28.21331619	15.40713168	16.13983031	12.26237603	19.91167767	15.90768487	23.19305877	17.87748522	21.32779464	15.49121085	13.89371815	24.47921576	16.48287113
Down X/Q variations, Interaction off, rms, %	42.59739153	32.55441928	25.40811185	28.20400936	21.44449339	20.40164625	18.50159001	16.47691951	18.26552567	15.83762295	15.33216783	25.49331388	23.78608525	22.72235458	19.32160935	23.27501423
Down X/Q variations, Interaction on, p-to-p, %	96.15101923	105.9406306	139.3168559	150.4550553	68.45120563	64.60320632	65.76154438	85.29771433	86.06960726	127.7764985	96.39340269	86.64252906	71.58685416	71.81251191	99.40931281	79.45804937
Down X/Q variations, Interaction off, p-to-p, %	180.6883266	135.9822239	131.8507709	127.525021	103.0341063	87.6250494	78.77680854	78.33411118	84.93348629	68.80654317	62.97319696	111.5389665	100.8992304	95.30089089	87.7835483	90.39948237
Down Y/Q variations, Interaction on, rms, %	116.3277046	128.719014	183.8967619	146.5403771	46.93692197	47.65364411	47.35175225	55.57785452	46.10524557	49.01378579	34.8325832	44.99251289	75.28923072	57.55516531	57.04901822	80.99631719
Down Y/Q variations, Interaction off, rms, %	130.7374715	107.9090744	131.4352723	113.5600881	49.68861005	54.01024756	67.51684478	45.91291821	56.13033297	51.06027814	54.16451345	52.27373758	53.53740964	81.23693594	64.33140366	71.37475441
Down Y/Q variations, Interaction on, p-to-p, %	425.3537093	691.4109325	811.9939988	633.9877031	204.1005386	269.8385433	239.9516533	296.3094389	201.2689425	243.8353659	143.9823925	193.2962493	398.8508731	235.0261357	246.9289534	322.2310593
Down Y/Q variations, Interaction off, p-to-p, %	573.5459622	486.0813478	547.2288657	607.0831285	203.9972044	260.4989613	301.7479519	217.9442089	289.3568237	242.0345414	253.0176637	252.3939509	246.9599166	367.8419857	320.919454	312.0798147
Slew rate in Up X, Interaction on, % per hr	398.4052	28.5107	-113.8294	-83.0284	88.2511	-45.5912	118.6928	-7.2019	-29.8019	120.2482	-58.6358	-31.6478	69.9843	59.7973	176.3312	215.1261
Slew rate in Up X, Interaction off, % per hr	42.0437	-90.429	2.3981	664.5817	43.4953	21.1017	-32.4842	98.2233	-123.3903	-24.0204	-34.3396	-43.4107	-278.7847	-9.8651	-88.0707	18.7913
Slew rate in Up Y, Interaction on, % per hr	497.4156	126.9202	-67.6321	29.5701	111.2809	-40.1494	71.3666	-43.4293	-64.3472	115.6982	-60.5124	-11.8964	-64.9751	-2.6734	209.3104	180.751
Slew rate in Up Y, Interaction off, % per hr	-482.64	-46.2416	-155.1434	147.9735	85.1438	70.3626	-60.7317	75.2065	-111.9537	-44.5727	-2.9496	-49.3193	-171.714	-61.0218	-134.599	19.3824
Slew rate in Down X, Interaction on, % per hr	-400.7302	169.6698	-192.279	134.4435	81.4102	-14.731	13.0405	137.2577	-113.2144	-27.238	111.064	121.9408	184.4595	95.8408	520.4575	43.6411
Slew rate in Down X, Interaction off, % per hr	-400.5153	26.5956	-171.0347	-104.9427	-453.4878	-2.8751	137.9811	-140.795	-433.0645	-132.0659	-157.8969	-590.2417	28.8794	-161.907	215.0753	-97.6204
Slew rate in Down Y, Interaction on, % per hr	1071.7	-343.3054	3484	-99.8414	341.5613	369.223	350.2437	530.747	-881.1884	282.3686	183.0025	284.3965	1688.1	-636.8026	5470.4551	1409.6
Slew rate in Down Y, Interaction off, % per hr	1771.6	1579.4	-393.337	-604.6952	-841.144	964.5699	-1524.8	-304.7557	782.4765	-456.8486	5.3192	1080.4	-749.7119	1373.7	314.1137	-362.5556
Slew rate in Up R/Q, Interaction on, % per hr	450.2556	77.643	-102.7029	-6.6786	-66.8516	-98.036	74.1297	-33.9289	-45.0569	90.4815	-36.0488	2.464	-39.1041	0.0582	154.887	240.4851
Slew rate in Up R/Q, Interaction off, % per hr	-192.2453	-59.5661	-39.4943	411.6842	-21.3717	51.3506	-44.692	58.3292	-85.9262	-9.4331	7.1688	-61.8101	-256.0229	-13.1561	-248.0946	36.5833
Slew rate in Down R/Q, Interaction on, % per hr	-354.1595	144.2287	-80.9524	148.5726	-50.963	-29.1863	30.4475	181.4644	-247.7623	-19.9694	146.3418	174.3291	242.9653	10.8894	478.999	157.8808
Slew rate in Down R/Q, Interaction off, % per hr	-258.0587	121.9572	-152.2873	-149.9448	-586.6874	133.2149	-103.9905	-190.138	-239.8884	-161.2078	-106.22	-370.777	-86.0198	-56.5615	84.0513	-100.2852
Conclusion: good, may be, bad, need repaires	good	good	good	good	good	good	good	good	good	good	good	good	good	good	good	good
Train rep-rate (1, 5, 10) , Hz	5				5				5				5			
Number of bunches per train	5000				5000				5000				5000			
Charge per e-bunch, nC	0.287348	0.286669	0.286283	0.286429	1.45316	1.50903	1.52276	1.54423	1.53591	1.51833	1.52075	1.52235	1.40787	1.43657	1.43258	1.48189
Charge variation, p-to-p %	20.94568259	25.13002801	22.38204853	21.85358326	32.75207135	19.18185854	20.63	10.85265796	13.52878749	11.97763332	10.71642282	10.66837455	23.90135453	11.35691265	18.97695068	14.08404133
Upstream average current, μA	7.2816	7.25715	7.29213	7.31596	36.3988	37.8087	38.0034	38.6186	38.3792	37.971	38.0415	38.0733	35.1343	35.8593	35.8302	37.0786
Upstream average current variation, p-to-p %	13.7245935	11.57382719	11.61347919	13.90972613	29.45481719	18.08075919	9.880431751	10.07752741	10.94759661	10.73582471	9.65209048	7.507360801	21.1007477	11.876417	16.40962093	11.176258
Downstream average current, μA	7.24461	7.22314	7.25947	7.28461	36.4836	37.8946	38.0025	38.6701	38.4519	37.9642	37.8795	38.0228	35.1947	35.9124	35.8553	37.0527
Downstream average current variation, p-to-p %	13.45400235	11.64272048	11.76917874	13.98921837	29.24355053	17.93395365	9.7785672	10.05971022	10.75889618	10.64134105	11.13948178	9.191590309	20.77585546	11.48572638	16.11254124	11.087721
Start, Number of ions per bunch,10^9	1.19413	1.18715	1.17857	1.17401	1.36508	1.3452	1.34524	1.32478	1.29899	1.27402	1.24965	1.24042	1.31963	1.30761	1.31375	1.31652
Start, RMS ion bunch length	3.64485	3.72673	3.77877	3.86285	3.10026	3.27169	3.50864	3.58664	3.66421	3.72984	3.78922	3.8578	2.3691	2.77324	3.07099	3.28035
Finish, Number of ions per bunch,10^9	1.18715	1.17857	1.17401	1.17274	1.3452	1.34524	1.32478	1.30391	1.27402	1.24965	1.24042	1.21919	1.30761	1.31375	1.31652	1.29861
Finish, RMS ion bunch length	3.72673	3.77877	3.86285	3.9274	3.27169	3.50864	3.58664	3.66489	3.72984	3.78922	3.8578	3.89085	2.77324	3.07099	3.28035	3.36923
DDS phase, Interaction on	-135.89				-135.89				-135.89				-135.89			
DDS phase, Interaction off	-136.89				-136.89				-136.89				-136.89			
Gun voltage, MV	1.193				1.193				1.193				1.193			
Gun phase, degrees (if available)	0.3				0.3				0.3				0.3			
Gun crest phase, degrees (if available)	0.2989				0.3371				0.3371				0.3371			
Buncher 1 voltage, kV	150				174				174				174			
Buncher phase, degrees	-14.7				-11.7				-11.7				-11.7			
Bunchers zero crossing phase, degrees (if available)	-2.3773				2.1955				2.1955				2.1955			
Linac voltage, MV	13.04				13.26				13.26				13.1			
Linac phase, degrees	-130.5				-134.5				-134.5				-133.5			
Linac mini-spread phase, degrees (if available)	-130.5				-133.5				-133.5				-133.5			

Data analysis: sample from Jun Ma cont..

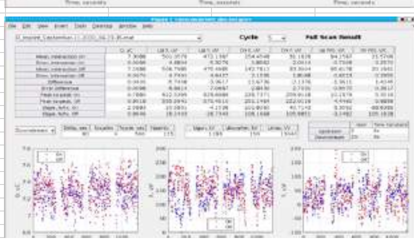
Energy estimation from the RF, MeV	14.65568262				14.86632962				14.86632962				14.70752103			
1st Dipole current, A	93.58	93.58	93.58	93.58	96	96	96	96	95.8	95.8	95.8	95.8	94.675	94.675	94.675	94.675
Dipole trim (triplet to dogleg) current, A	0.1				0.2				0.2				0.2			
Triplet BPM: average x position, mm	0.214703	0.223616	0.189298	0.117332	1.08913	1.02979	0.928166	0.929076	0.94114	0.910268	0.934903	0.959063	0.926383	0.940024	0.95403	0.914905
Peak-to-peak variation: triplet BPM x mm	0.31	0.319	0.337	0.347	0.243	0.359	0.199	0.23	0.273	0.334	0.23	0.427	0.333	0.212	0.21	0.291
Dogleg average BPM x position, mm	-2.90863	-2.96062	-2.91603	-2.82736	-3.71738	-3.9038	-3.78347	-3.74523	-3.86814	-3.95728	-3.92399	-3.91368	-3.99646	-3.97484	-4.09474	-4.0006
Peak-to-peak variation: Dogleg BPM x mm	0.307	0.331	0.319	0.314	0.696	0.334	0.292	0.272	0.311	0.374	0.351	0.401	0.427	0.301	0.151	0.294
Energy estimation from the dogleg pc, MeV	14.64843061	14.65099562	14.6487957	14.64442104	15.06817508	15.07761024	15.07152005	15.06958464	15.04439747	15.04889966	15.04721828	15.04669756	14.87413282	14.87305368	14.87903834	14.87433946
Energy estimation from the dogleg E, MeV	14.65734084	14.65990428	14.65770571	14.6533337	15.07683725	15.08626698	15.08018029	15.07824599	15.05307332	15.05757291	15.0558925	15.05537208	14.88290792	14.88182942	14.88781055	14.88311444
Estimation of the beam energy variation																
(need to define formula)																
Main Dipole current, A	93.58				96				95.8				94.55			
Dipole trim (dogleg to modulator) current, A	1.02278				1.03				1.07				1.07			
Solenoid 1-7 currents, A	51.1				75				75				75			
Solenoid 2-6 currents, A	51.3				110				110				110			
Solenoid 3-45- currents, A	49.8				120.9				121.4				121.4			
e-Beam positions in the modulator X &Y																
Modulator BPM1, X, mm:	-0.0157225	-0.0260192	-0.0501173	-0.0953133	0.0601315	0.0229142	-0.0578769	-0.0659852	-0.0287885	-0.0137899	-0.0189753	0.00965495	-0.0390189	-0.019864	0.00644469	-0.0275258
variation of postion duing interaction, mm	0.269	0.304	0.31	0.313	1.564	2.413	0.422	0.236	0.27	0.196	0.365	0.257	0.273	0.228	0.109	0.375
Modulator BPM1, Y, mm	0.438245	0.443061	0.442898	0.436071	0.376104	0.287473	0.197072	0.0934088	0.198418	0.150498	0.115798	0.166844	0.135469	0.094591	0.109743	0.18132
variation of postion duing interaction, mm	0.092	0.048	0.04	0.133	1.329	0.807	0.659	0.458	0.345	0.357	0.437	0.435	0.295	0.313	0.303	0.349
Modulator BPM2, X, mm	-0.0214097	-0.0335473	-0.0692909	-0.128061	0.0128347	-0.107229	-0.192539	-0.207516	-0.158894	-0.132395	-0.149534	-0.128832	-0.058125	-0.0444192	-0.0126293	-0.0386469
variation of postion duing interaction, mm	0.355	0.425	0.346	0.401	1.877	2.48	0.46	0.254	0.231	0.408	0.466	0.264	0.275	0.197	0.308	0.414
Modulator BPM2, Y, mm	-0.619797	-0.624527	-0.629547	-0.656286	-0.206104	-0.311478	0.0871664	0.0837242	0.109313	0.137774	0.122673	0.130324	-0.199925	-0.185158	-0.160949	-0.193354
variation of postion duing interaction, mm	0.232	0.248	0.206	0.243	1.609	2.07	0.44	0.211	0.179	0.334	0.382	0.269	0.229	0.047	0.141	0.218
Amplifier BPM1, X, mm:	0.0828149	0.0700877	0.0424043	-0.0124956	-0.808623	-0.77516	-0.258203	-0.242271	-0.263887	-0.253553	-0.248888	-0.266401	0.0698595	0.0724022	0.0656894	0.0607948
variation of position during interaction, mm	0.39	0.449	0.225	0.411	0.263	0.774	0.102	0.07	0.092	0.086	0.089	0.083	0.116	0.091	0.104	0.095
Amplifier BPM1, Y, mm	0.336422	0.33208	0.347665	0.350957	0.812057	0.848572	0.791735	0.845725	0.79374	0.825625	0.840099	0.817592	0.114213	0.137736	0.133702	0.0919099
variation of position during interaction, mm	0.253	0.235	0.203	0.296	0.591	0.541	0.389	0.257	0.207	0.215	0.253	0.24	0.157	0.224	0.256	0.301
Amplifier BPM2, X, mm	0.0780352	0.0954623	0.125616	0.185554												
Amplifier BPM2, Y, mm	-0.282705	-0.285668	-0.288837	-0.282806												
Amplifier BPM3, X, mm	0.239678	0.25561	0.282807	0.346214												
Amplifier BPM3, Y, mm	-0.217371	-0.22203	-0.249481	-0.277022												
Kicker BPM1, X, mm:	-0.426988	-0.4223	-0.41111	-0.386485												
Kicker BPM1, Y, mm	0.0263169	0.0296101	0.0199103	0.017813												
Kicker BPM2, X, mm	0.253246	0.247797	0.234918	0.213841												
Kicker BPM2, Y, mm	0.0966459	0.104267	0.106943	0.112481												
Comments: add info about drifts of positions																
Ion beam positions, X & Y: yo1-b1 and yi2-b1 BPMs s= 2530 & 2580 m																
yo1-b1 , X, mm	-4.33025	-4.32953	-4.32865	-4.32991	-4.32477	-4.32953	-4.32424	-4.32595	-4.30865	-4.33003	-4.32584	-4.32735	-4.4737	-4.49405	-4.49906	-4.51042
yo1-b1 , Y, mm	-3.9017	-3.89054	-3.92985	-3.9385	-3.93157	-3.92275	-3.91328	-3.91954	-3.92995	-3.92697	-3.92787	-3.93452	-3.90239	-3.8764	-3.85409	-3.83272
yi2-b1 , X, mm	2.73947	2.73768	2.73143	2.72724	2.72752	2.73865	2.72511	2.73054	2.72318	2.73437	2.73193	2.73262	2.80502	2.81752	2.82158	2.83623
yi2-b1 , Y, mm	-0.330897	-0.34294	-0.308456	-0.301331	-0.296687	-0.307047	-0.307728	-0.307135	-0.301809	-0.298908	-0.297108	-0.299118	-0.320476	-0.343651	-0.364692	-0.387751
Horizontal offset in arcs, <x>, mm	0.2				0.2				0.2				0.2			
RHIC dipole current, A	1285.38				1285.38				1285.38				1285.38			
RHIC RF frequency, MHz	2.81E+07				2.81E+07				2.81E+07				2.81E+07			
Ion Energy estimation																
(need to define formula)																
Ion beam positions on CeC BPMs: if available																
mod_bb1-y , X, mm	-0.189346	-0.199031	-0.209648	-0.217604	-0.200436	-0.205703	-0.20847	-0.221515	-0.234079	-0.236456	-0.240854	-0.258113	-0.235027	-0.235624	-0.233151	-0.236337
mod_bb1-y , Y, mm	0.223901	0.221707	0.230841	0.231122	0.174772	0.172428	0.172608	0.172875	0.174691	0.177593	0.176881	0.177541	0.181608	0.175465	0.171094	0.165516
amp.bb2-y , X, mm	0.18714	0.184829	0.182701	0.178634	-0.0326929	-0.022284	-0.0172808	-0.0067655	0.00268333	0.0162463	0.0262269	0.0240781	-0.0465875	-0.0485219	-0.0418444	-0.0349797
amp.bb2-y , Y mm	-0.134712	-0.132238	-0.138034	-0.14393	0.0450693	0.0423125	0.0365522	0.0277219	0.0211972	0.00661857	0.00240741	-0.00349012	0.0359461	0.0362823	0.0314791	0.0243247
kck_bb2-y , X, mm	0.0357128	0.0360494	0.0345338	0.0281053	-0.011809	-0.010167	-0.0190506	-0.0202847	-0.0202889	-0.0246075	-0.0205177	-0.0259018	-0.0730185	-0.0783974	-0.0809046	-0.0860576
kck_bb2-y , Y, mm	0.161165	0.165691	0.15529	0.152204	0.111833	0.118309	0.125214	0.124622	0.127507	0.125859	0.129946	0.131144	0.138007	0.143931	0.149301	0.154198

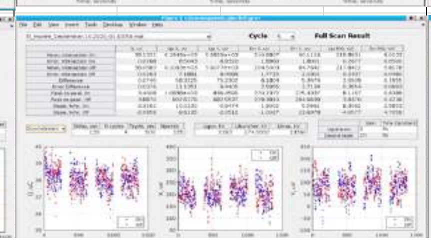
Upstream plot

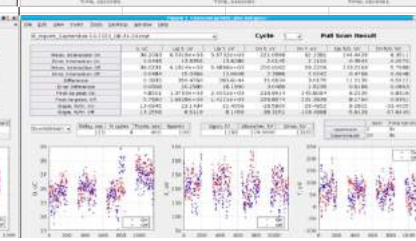




Downstream plot

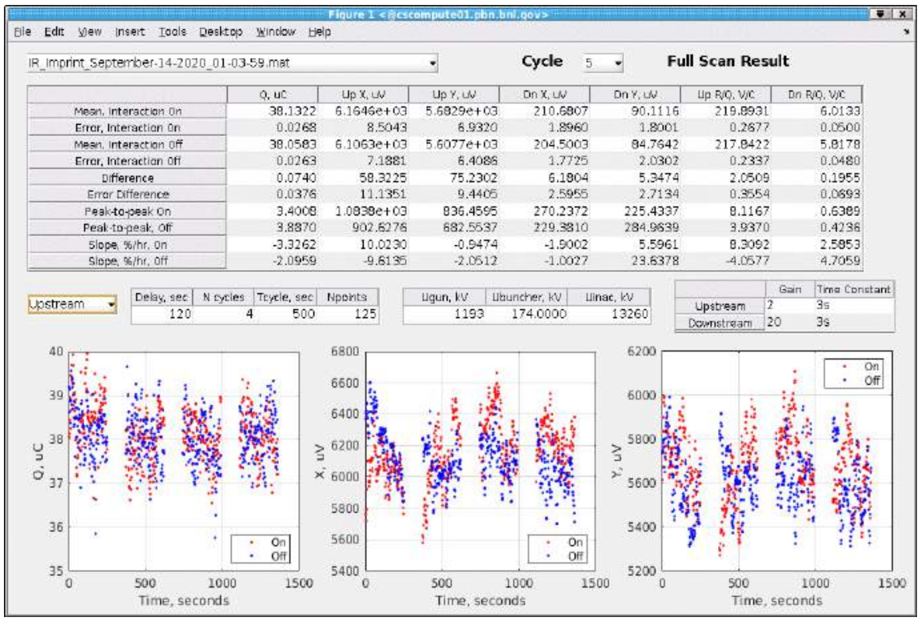


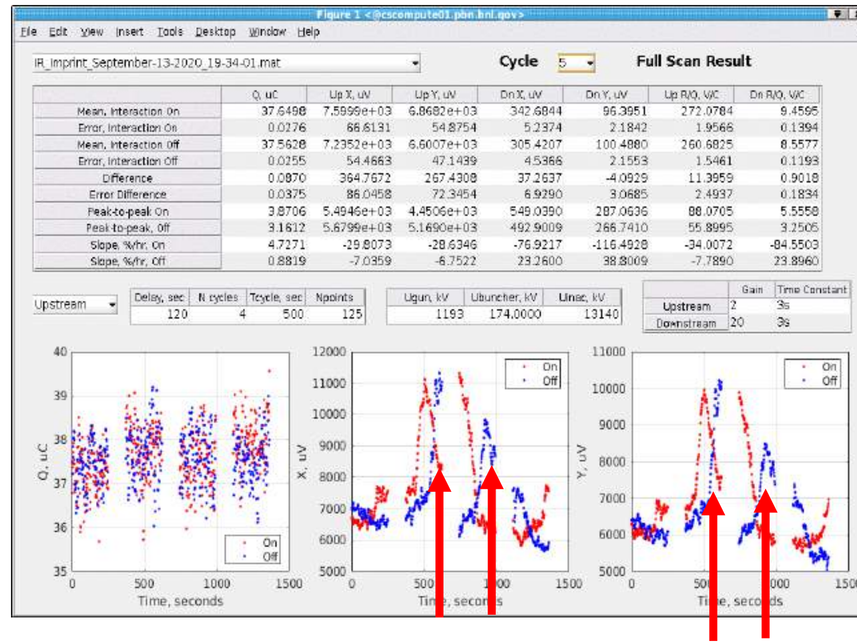




Samples of good and bad cycles

Upstream – 4 cycles each





Good Good Bad Bad

Typical cycle for downstream IR detector

Figure 1 <@cscompute01.pbn.bnl.gov>

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temp_IR_Imprint_Cycle4of4_September-13-2020_05-13-47.mat

Cycle 1

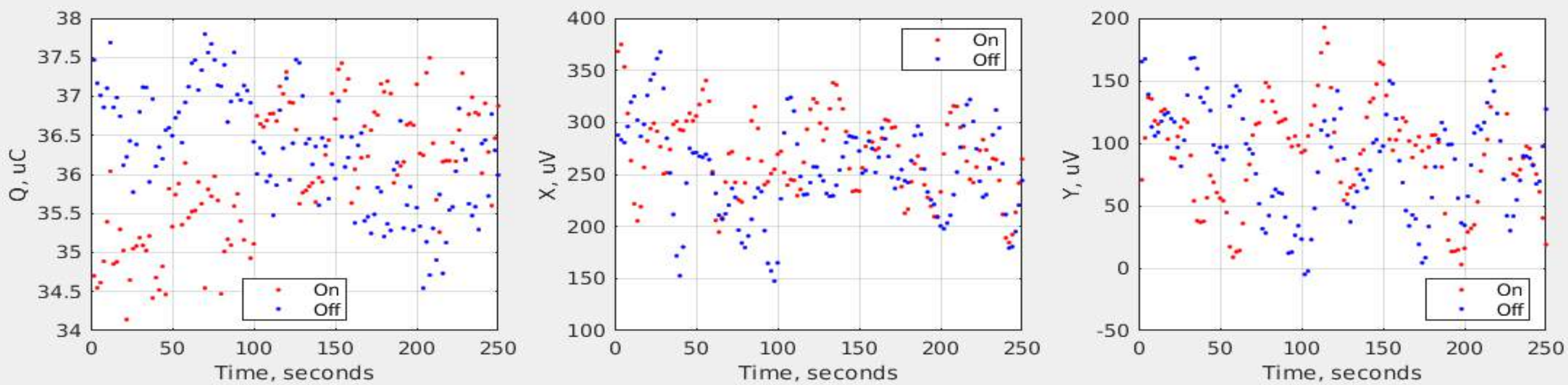
	Q, uC	Up X, uV	Up Y, uV	Dn X, uV	Dn Y, uV	Up R/Q, V/C	Dn R/Q, V/C
Mean, Interaction On	35.9775	6.3365e+03	5.7172e+03	269.1368	92.4547	237.2173	7.9098
Error, Interaction On	0.0747	13.1425	14.3728	3.4693	3.7497	0.6225	0.0987
Mean, Interaction Off	36.3278	6.1964e+03	5.6282e+03	252.7819	87.1889	230.4272	7.3606
Error, Interaction Off	0.0661	25.9136	19.7249	4.0437	3.7168	0.7667	0.1112
Difference	-0.3503	140.1078	88.9766	16.3549	5.2658	6.7901	0.5491
Error Difference	0.0997	29.0558	24.4059	5.3280	5.2796	0.9876	0.1487
Peak-to-peak On	3.3510	697.9811	706.8007	190.2863	189.7534	NaN	NaN
Peak-to-peak, Off	3.2532	1.5911e+03	1.1516e+03	220.1416	173.3431	NaN	NaN
Slope, %/hr, On	78.5547	-31.4624	18.3594	-207.0242	-155.6600	-87.6593	-280.1573
Slope, %/hr, Off	-63.3703	-160.3256	-145.3007	-131.4187	-653.1625	-90.1632	-123.5200

Downstream

Delay, sec	N cycles	Tcycle, sec	Npoints
60	4	500	125

Ugun, kV	Ubuncher, kV	Uinac, kV
1193	174	13180

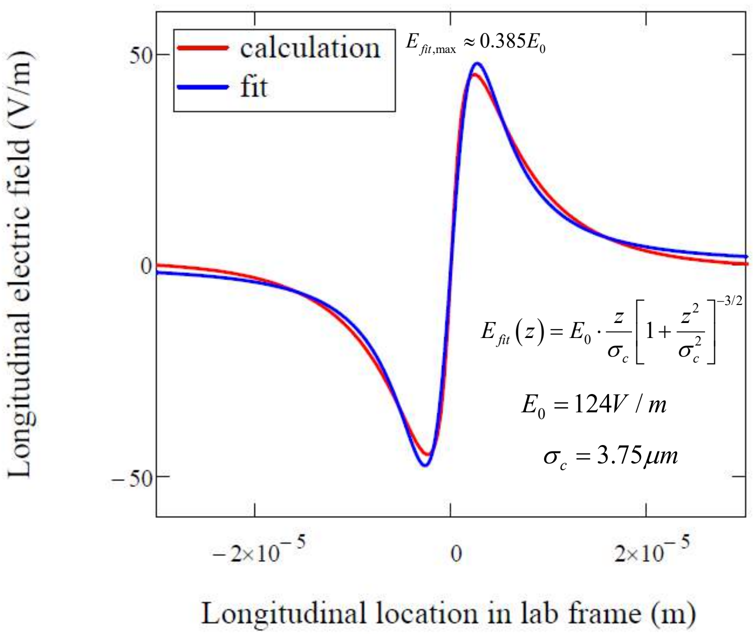
	Gain	Time Constant
Upstream	2	3s
Downstream	20	3s



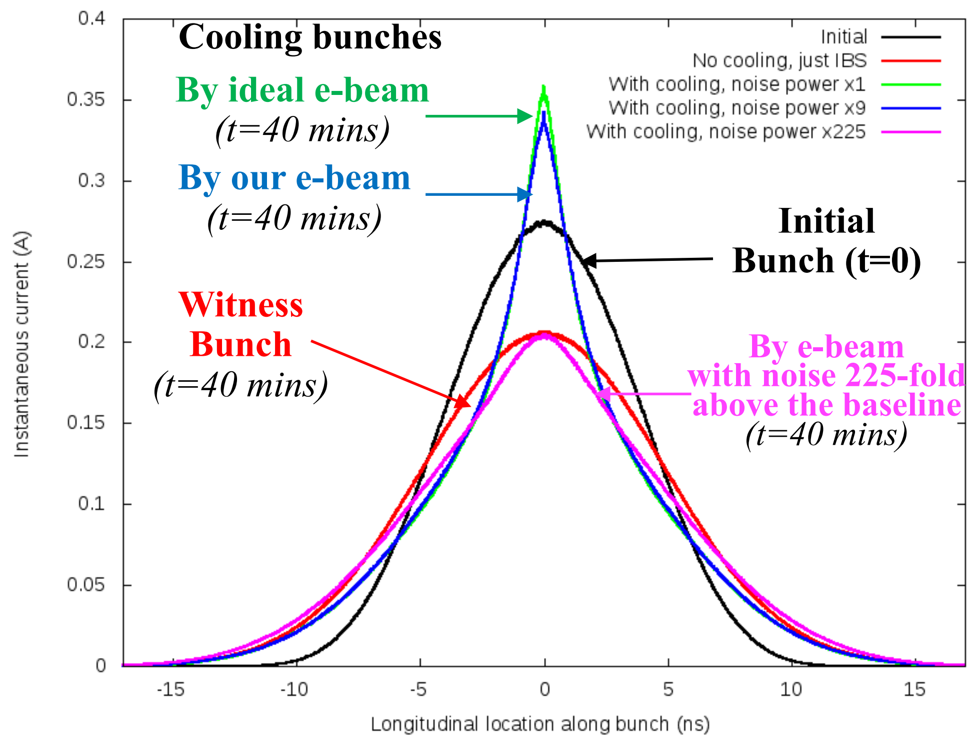
Simulated performance: full 3D treatment

CeC theory is important for scaling and for benchmarking of codes – full 3D simulations is the must for any reliable predictions, which have to be tested experimentally

Predicted evolution of the 26.5 GeV/u ion bunch profile in RHIC



Simulated and fitted (used in simulations of the ion beam cooling) energy kick in the PCA-based CeC experiment system



Black – initial profile, red – witness (non-interacting) bunch after 40 minutes. Profiles of interacting bunches after 40-minutes in PCA-based CeC for various levels of white noise amplitude in the electron beam: green– nominal statistical shot noise (baseline), dark blue – 9 fold above the baseline, and green – 225 fold above the baseline

Cooling will occur if electron beam noise is below 225-times the base-line (shot noise)
We demonstrated beams with noise as low as 6-times the baseline