Coherent electron Cooling Proof-of-Principle Experiment – Q&A

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Slide prepared by Gang Wang

Homework question

- Question: Based on the recent realistic simulations of CeC cooling, can you present a summary of updated requirements for the experiment, and also highlight any new effects and requirements that need to be taken into account.

Required parameters for the electron beam in CeC X			
I_{peak} (t_0)	50 Amp	$\delta E_{amp,cool}(r=0)/E$	>1.5e-9
Peak-to-Peak Variation of I(t) for $\|t-t_0\|$<7.5 ps	10 %	$\delta E_{amp,cool}(r=\sigma_{x,y})/E$	>0.75e-9
Norm. emittance (RMS)	1.5 µm.rad	Relative energy jitter (RMS)	<2e-4
Energy spread (RMS)	<2e-4	Slice to slice variation of α, β and ε within 15 ps around bunch center (peak-to-peak)	<10 %
$\sigma_{x,y}$ at modulator/kicker	> $\sigma_{ion,x}$, $\sigma_{ion,y}$		

- These requirements are according to the current simulations and understandings. The following effects should be taken into account in the future:
  - Dependance of cooling force on the transverse offset of the ion in the modulator section;
  - Dependance of the cooling force on the transverse angles of the ion.

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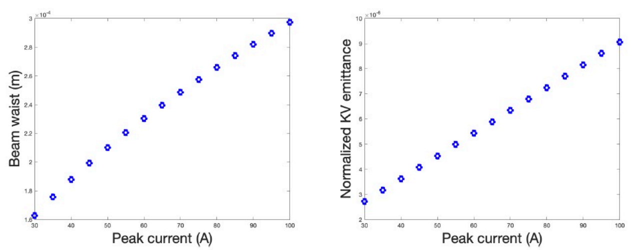
- Requirement for beam were part of the dedicated studies in 2020 and were discussed at CeC X retreat. These requirements and parameters did not change, but they have to be applied to significant (50% or more) of the 1.5 nC in electron bunch
- Stability is paramount for demonstration of CeC

Defining requirements for e-beam and CeC system: summaries from CeC X retreat

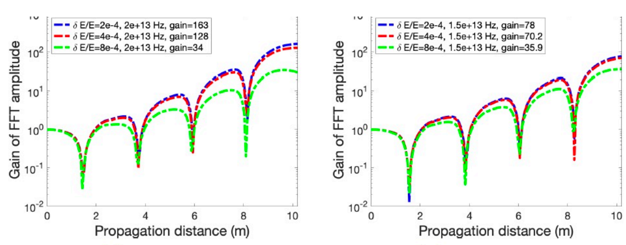
Jun Ma & team

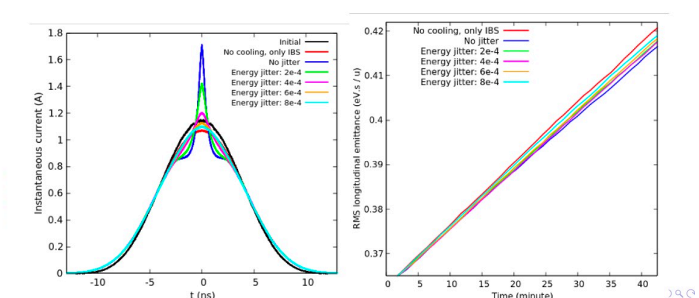
Electron Beam Requirements for CeC Experiment

Sensitivity studies: energy spread & peak current, beam emittance and asymmetry, matching, orbit distortions, energy jitter



(a) a_o (b) ε_n

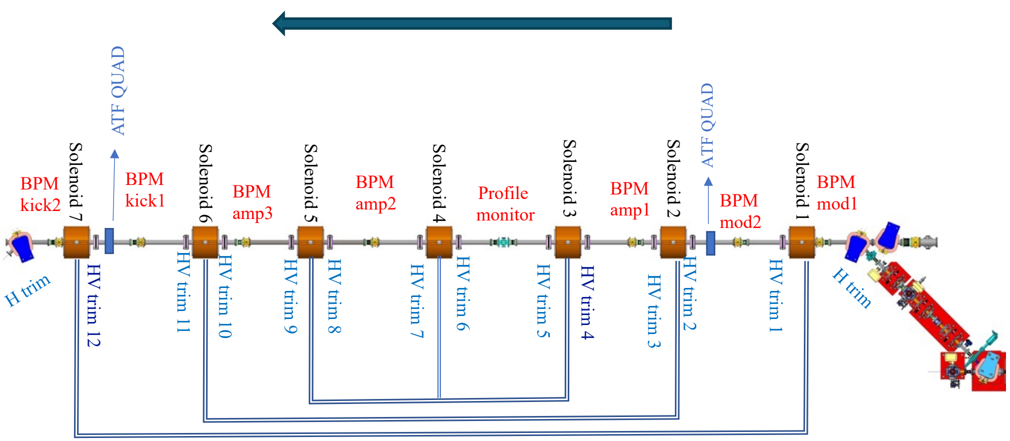


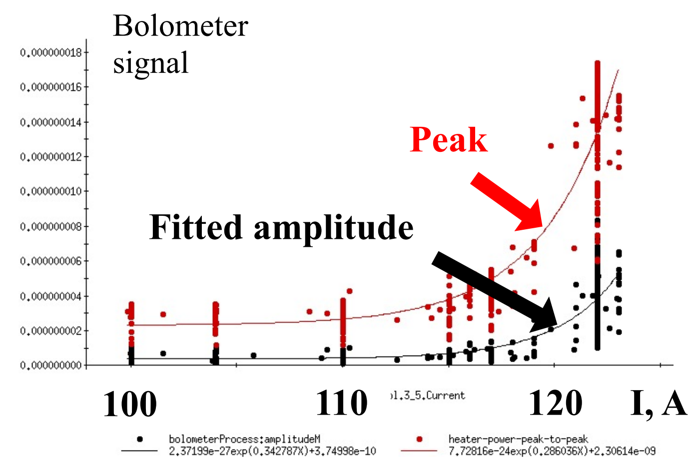


- Yichao Jing & team
- *Requirements for CeC systems*
- Sensitivity studies: laser intensity and timing jitter, SRF gun, Bunching cavities and SRF linac voltage and phase jitter and drifts, power supplies jitter and drifts

Items	requirements	Beam parameter effect
Laser jitter (ps, rms)	5	2e-4 energy jitter
Laser intensity (rms)	1%, transverse uniformity needs improvement	Peak current variation
Trim PS (A, rms)	5e-5	10 um orbit jitter in common section
Gun phase (deg, rms)	< 0.1	<0.2 kV/ps energy chirp for core
Gun voltage (kV, rms)	< 0.5 kV	For less than < 1 ps separation between peak current and energy slices
buncher phase (deg, rms)	0.2	Energy jitter < 2e-4, chirp jitter < 0.2 kV/ps
buncher voltage (kV, rms)	1.4	Chirp jitter < 0.2 kV/ps

- CeC X is a demonstration experiment and factor 2 reduction in cooling – as soon as it is understood – is acceptable. We will need to wait for longer time - 80 minutes instead of 40 minutes used in Gang's simulation – to see similar effect
- We know how to distinguish CeC from standard e-cooling – the problems so far is to observe CeC – for example, we can reduce ion beam emittance and improve cooling by scraping ion beam using collimators, better matching of electron beam (it is not currently does in simulations) and also by increasing PCA gain





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

Q2: List the observed beam stability issues that hampered progress with the CeC experiments, and list possible mitigations

- ❑ Electron bunch time structure changes: pulse to pulse and long term drifts
- ❑ There are significant change variations resulting in changes of peak current, pulse structure and beam envelope: pulse to pulse and long term drifts
- ❑ Possible mitigations
  - ❑ Improving laser amplitude and timing stability
  - ❑ Reducing sensitivity to charge and laser pules structure varyations
  - ❑ Use new stable laser system

  P.S. According to RF group, our SRF accelerator is very stable

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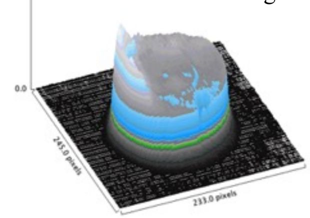
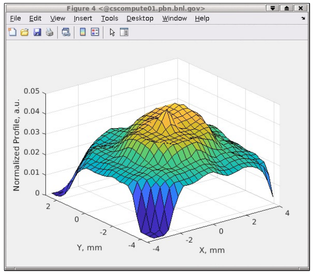
Possible sources of problem with beam quality

- Hallo – result of the QE and laser beam non-uniformity. Large deviations of the electron bunch density on the cathode results in transverse filamentation of the electron beam
- 5% RMS, 30% peak-to-peak pulse to pulse laser power jitter causes dramatic variations in beam dynamics of our space-charge dominated beam, which are sufficient to explain observed variation in PCA gain
- 30% ramp in the temporal profile of the laser pulses caused significant modification in the beam dynamics (when compared with beer-can from previous laser) and could be cause of additional losses in the CeC system

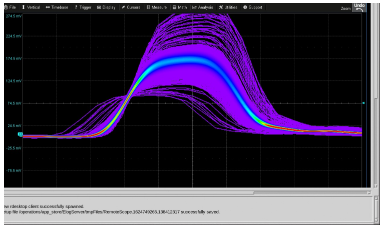
Measured transverse density of electron beam emerging from electron gun



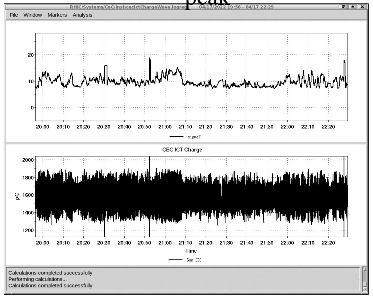
Measured QE profile at the end for Run 23



Sample of the green laser pulses in the laser trailer. The jitter roughly doubles at the SRF gun laser table



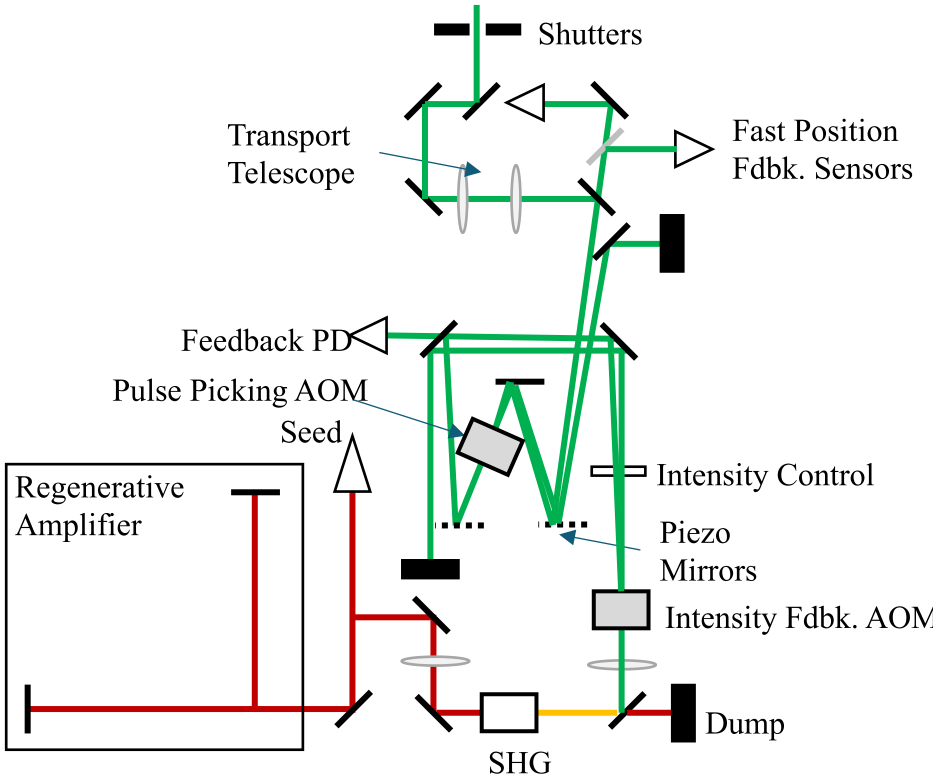
During last days of the run, jitter in the change per bunch caused by laser power jitter was 10% RMS and 40% peak-to-peak



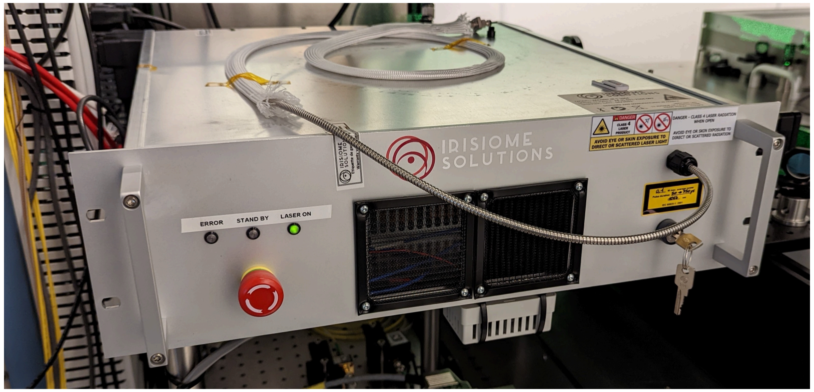
Laser system layout for run22

- New seed laser with 5 psec RMS time jitter is installed and is operational
- Bandwidth for operation at variable repetition rates (78kHz-5MHz)
- Exchange of IR Pockels Cell Pulse Picker with AOM to enable 0-100% duty cycle operation for high repetition rate operation (1-5MHz)
- Maintaining CW beam throughout the entire system to enable high bandwidth position and intensity feedbacks and limit thermal effects from repetition rate changes
- Addition of second AOM for fast intensity feedback
    - Still need to work out efficient noise detection method to reach 2kHz feed-back.

As risk reduction strategy, we used contingency funding and purchased new back-up seed mode-locked laser system capable of 0.2 psec jitter



New seed laser arrived November 10, 2021
Installed & operating



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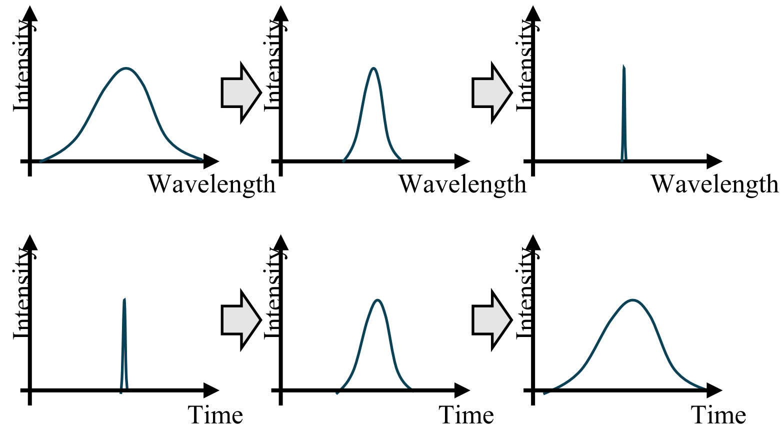
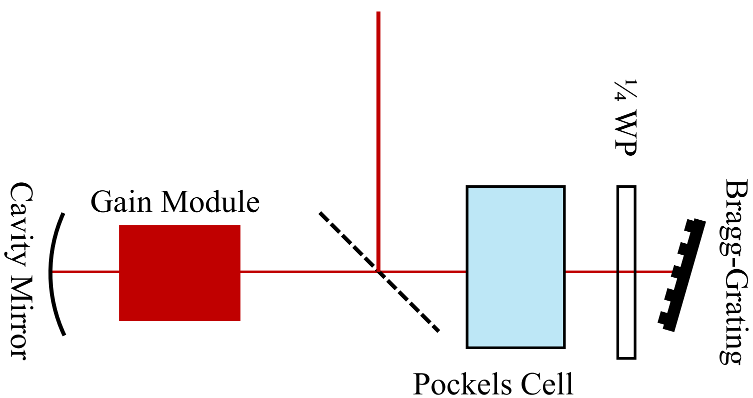
Risk reduction: Mode-locked seed laser

- Mode-locked Oscillator - Jitter: ~200fs rms
- 2-4ps pulse duration, 5-10nm Bandwidth
- Chirped gaussian output

Bragg Grating inside of Regenerative amplifier narrows spectral bandwidth and increases pulse duration with each roundtrip:
Target duration: 350ps FWHM => 1.25GHz Bandwidth

Spectral filtering to reduce bandwidth of seed pulse





Regenerative Amplifier
2 Grating bounces per roundtrip

Our likely choice for Run 23

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