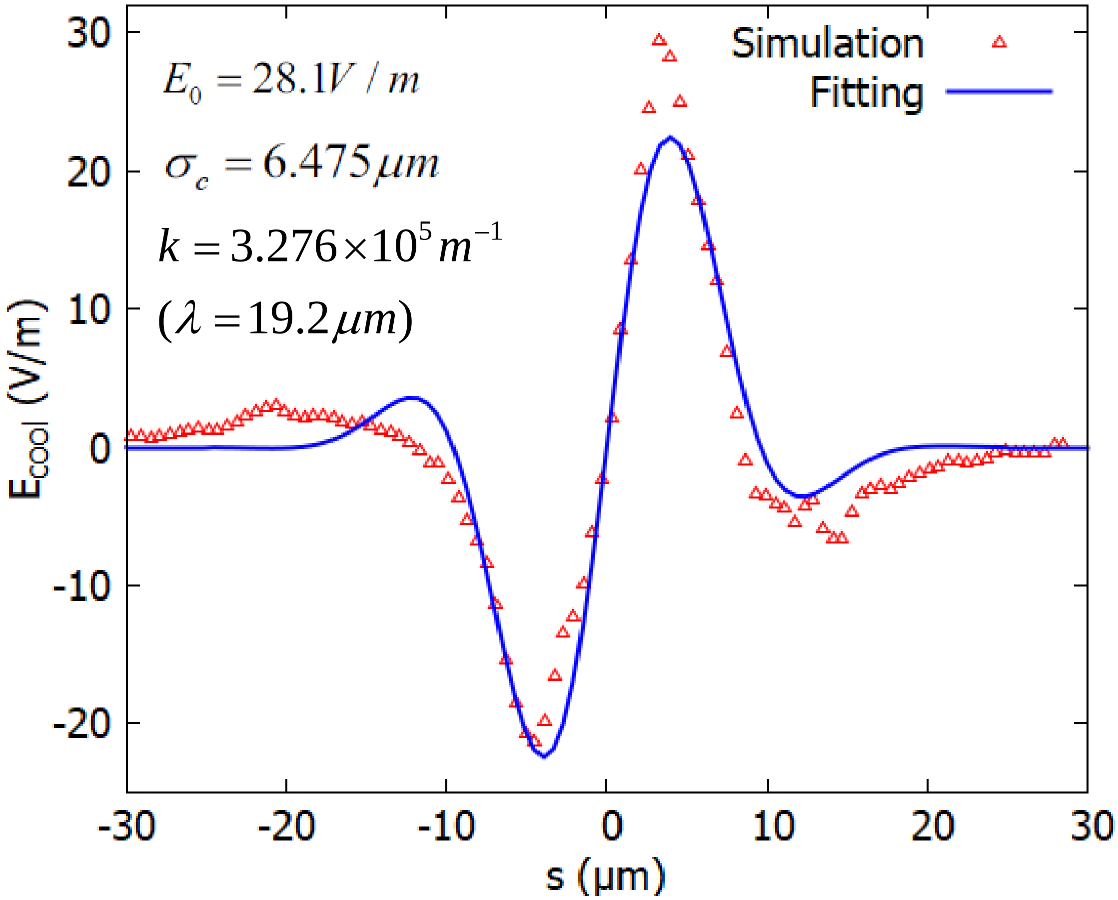
Tolerance on the Bunch-by-Bunch Energy Jitter for the CeC Experiment

G. Wang

Analytical analysis

Courtesy to V. Litvinenko



Simulation results are from Jun's simulation with SPACE

$$E_{fit}(z) = E_0 \exp\left(-\frac{z^2}{2\sigma_c^2}\right)\sin(kz)$$

$$f(\delta_e) = \frac{1}{\sqrt{2\pi}\delta_{jit}} \exp\left(-\frac{\delta_e^2}{2\delta_{jit}^2}\right)$$

$$\langle\delta\gamma\rangle = Zel_k \int_{-\infty}^{\infty} f(\delta_e) E_{fit}(\Delta z)\, d\delta_e \qquad \Delta z = R_{56}(\delta_e - \delta_h) \qquad \sigma_{jit} \equiv R_{56}\delta_{jit}$$

$$\langle\delta\gamma\rangle = -Zel_k E_A \exp\left(-\frac{z_h^2}{2\tilde{\sigma}_c^2}\right)\sin(\tilde{k}z_h)\cdot R_{jit} \qquad \eta = \sqrt{1+(\sigma_{jit}/\sigma_c)^2}$$

$$R_{jit} \equiv \eta^{-1}\exp\left(-\frac{k^2\sigma_{jit}^2}{2\eta^2}\right)$$

Overall reduction factor for the local cooling rate due to energy jitter.

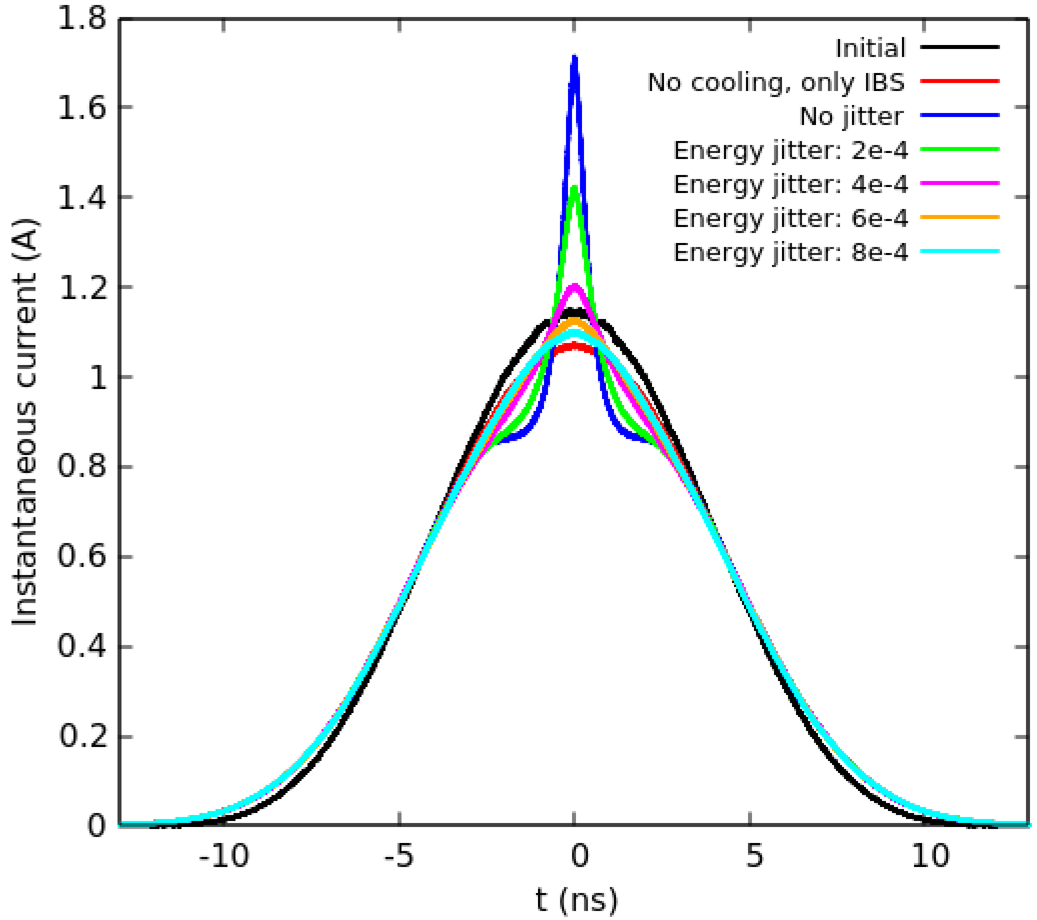
$$\tilde{\sigma}_c \equiv \sigma_c \eta$$

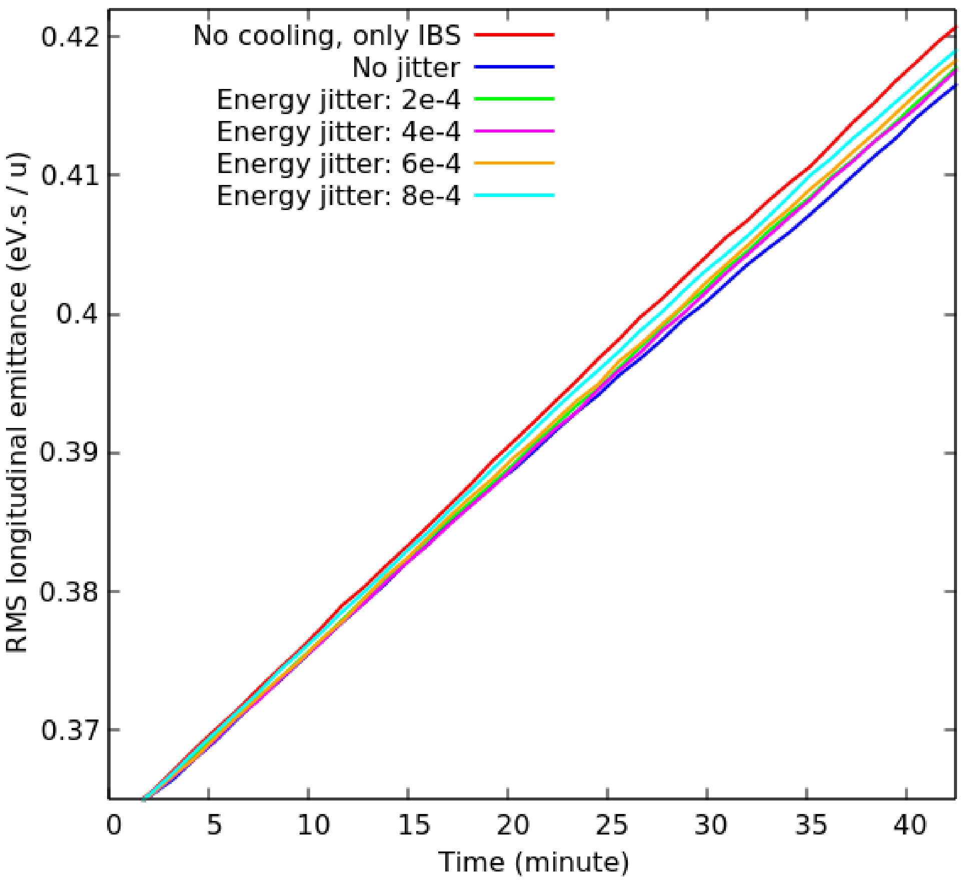
$$\tilde{k} \equiv k\eta^{-2} \Rightarrow \tilde{\lambda} \equiv \lambda\eta^2$$

Both effective wavelength and coherent length are broadened due to energy jitter.

Tolerance of Energy Jitter for **RUN 21 Parameters**

Settings from RUN 21 is used: RMS energy spread 0.12% and bunch length of 3.5ns, RF voltage of 0.4 MV, Bunch intensity of 8.4e8





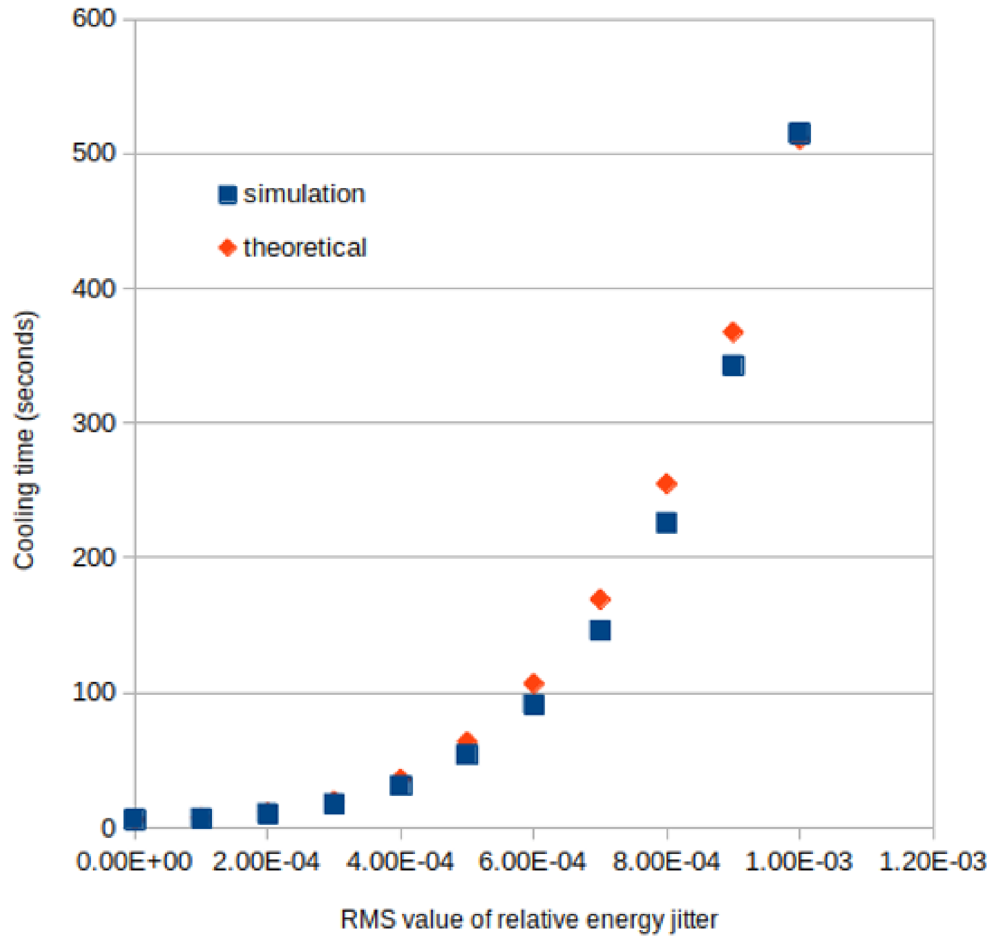
Benchmarking Simulation with Analytical Results

For an ion bunch with small energy spread,
i.e. $z_h << 2\pi / \lambda$ and $z_h << \sigma_c$, we can linearize the previous expression to

$$\langle \delta\gamma \rangle = -Zel_k E_A k z_h \cdot \eta^{-3} \exp\left(-\frac{k^2 \sigma_{jit}{}^2}{2\eta^2} \right)$$

The increases of the cooling time due to the energy jitter can be expressed as

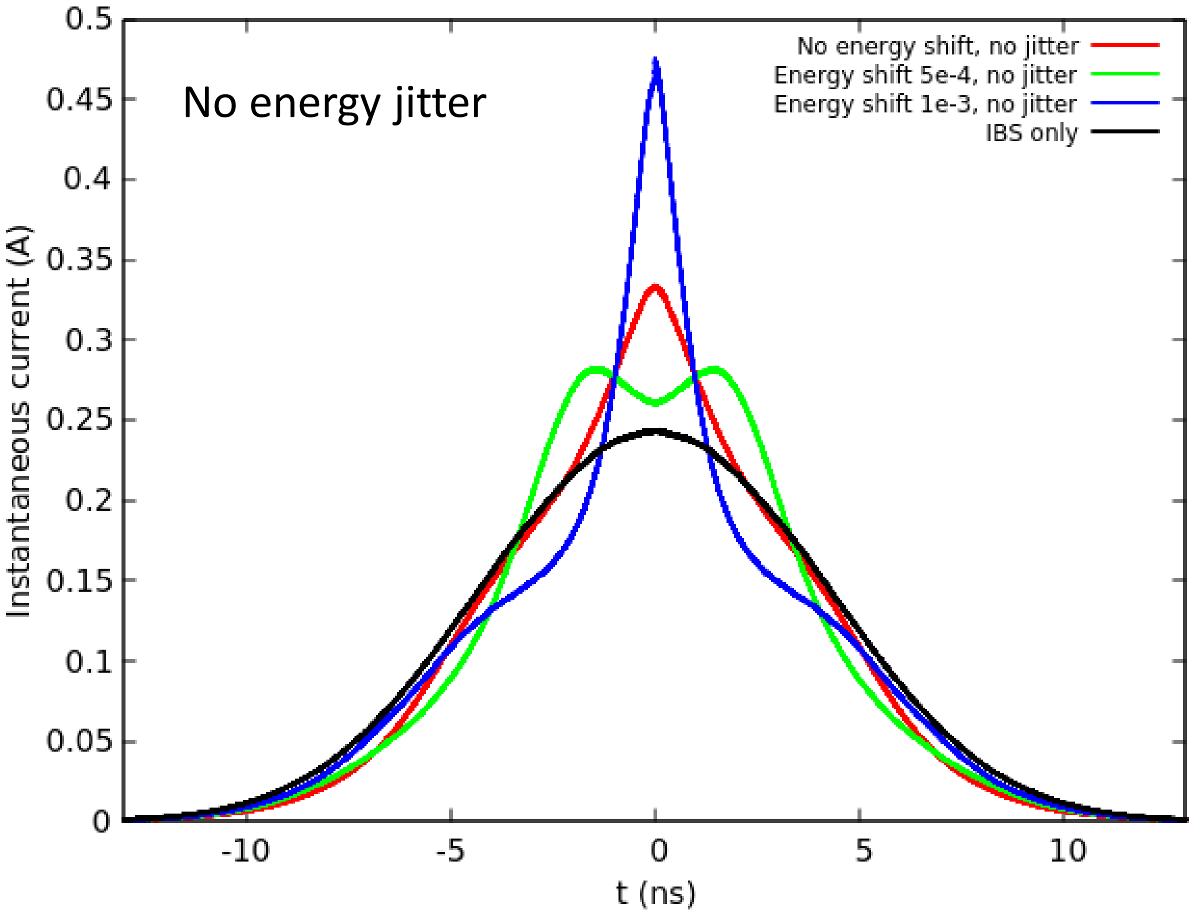
$$\tau_{cool}\left(\delta_{jit}\right) = \tau_{cool}\left(0\right)\left(1 + R_{56}{}^2 \delta_{jit}{}^2 / \sigma_c{}^2\right)^{3/2} \exp\left(\frac{1}{2} \frac{k^2 R_{56}^2 \delta_{jit}{}^2}{1 + R_{56}{}^2 \delta_{jit}{}^2 / \sigma_c{}^2} \right)$$

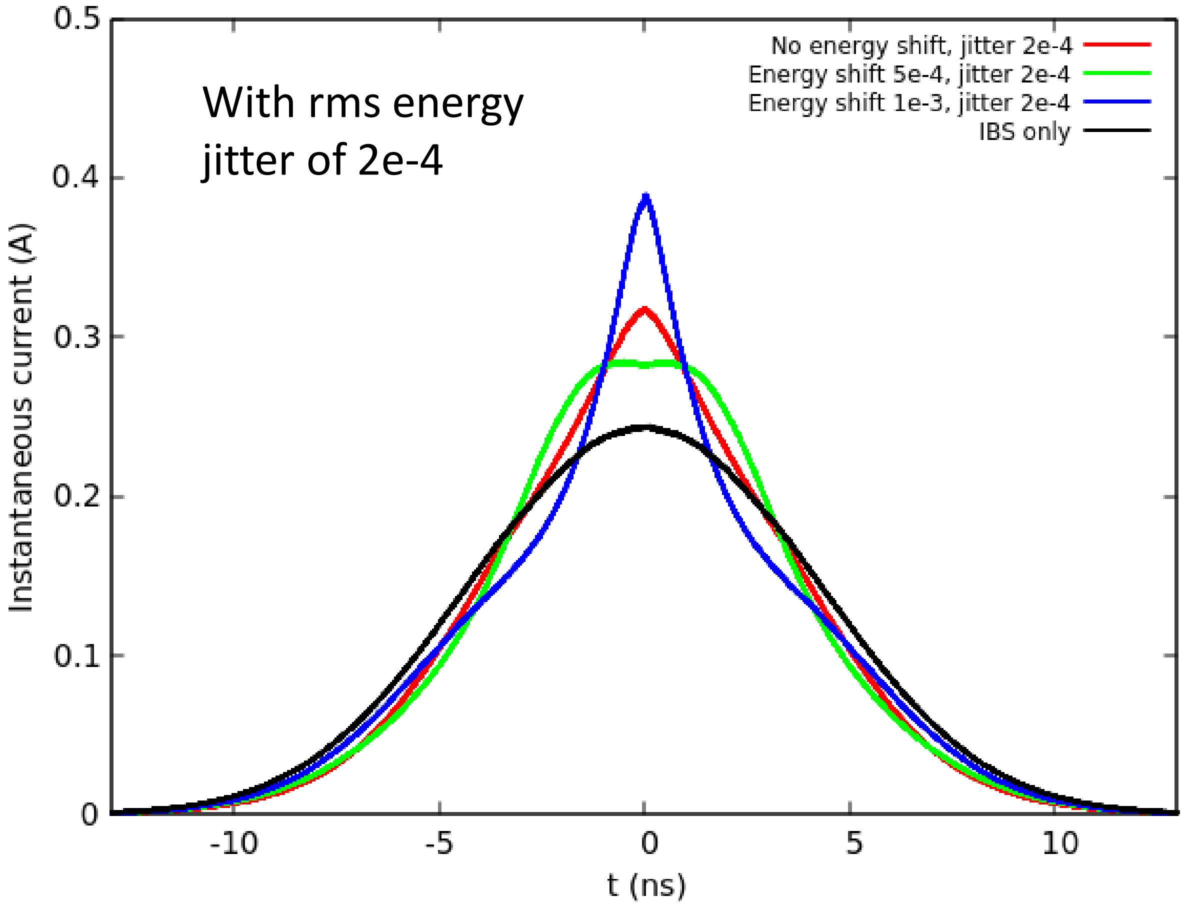


Preferred Parameters for **Run 23**

Electron beam parameters		Ion beam parameters	
Energy, γ	28.5	Energy, γ	28.5
Peak current, A	50	Bunch intensity	2e8
Bunch charge, nC	1.5	Bunch length (RMS), ns	3.5
RMS relative energy spread	2e-4 (slice) <5e-4 (projected)	Relative energy spread (RMS)	6E-4
Normalized emittance, RMS, mm.mrad	3	RF voltage (28MHz), KV	100
Beam width at modulator/kicker, RMS, mm	0.485	Normalized transverse emittance, RMS, mm.mrad	2.5
Minimal beam width at amplifier, RMS, mm	0.1	β^* at cooling section, m	5
RMS bunch length, ps	12	Average β function at cooling section, m	10
Cooling section length for CeC, m	3	Longitudinal emittance, eV.s / u	0.18
Cooling section length for e cooling, m	6		

Simulation with both CeC and e cooling working together

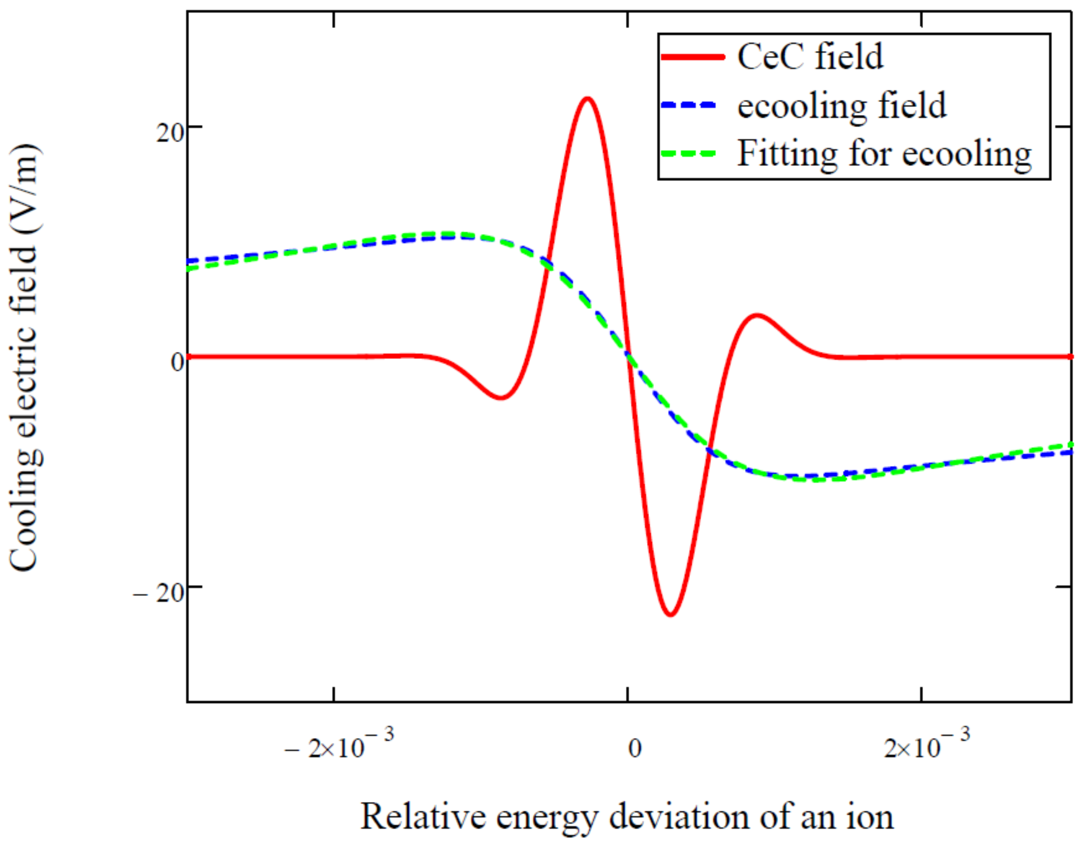


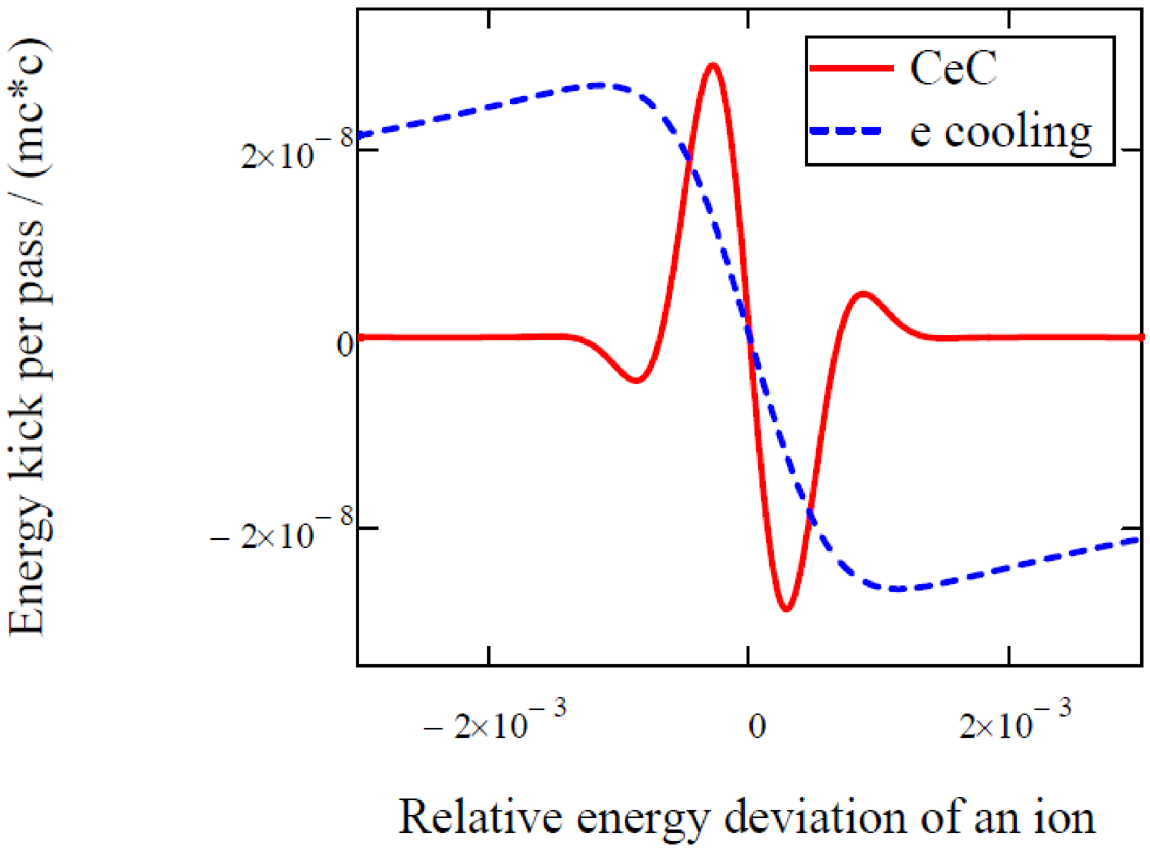


Summary

- According to the simulations for ion beam parameters in RUN 21, the tolerance for the bunch-by-bunch energy jitter in the electron beam is ~2e-4.
- The tolerance needs to be updated for the ion beam parameters preferred for RUN 23 and later. However, jitter level at 2e-4 seems to be sufficient from preliminary simulations.

Comparison of cooling field between CeC and e cooling





Artificially turning on and off CeC and e cooling to see effects

RHIC 28MHz RF voltage: 0.1 MV
RHIC bunch intensity: 2e8
Relative energy difference between electron bunch and ion bunch (to compensate delay due to solenoid in electron beam line): 1e-3