Effect of energy jitter on CeC cooling

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Joint CeC meeting, July 23, 2021

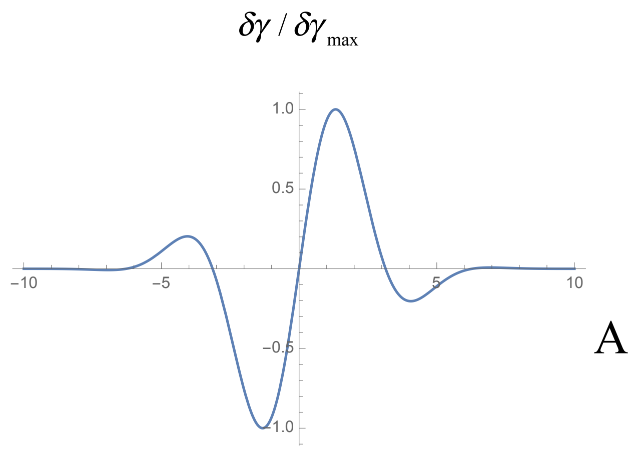
Continue with a simple 1D model

- Real 3D model is replaced by a trivial longitudinal kick with shape described by dimensionless parameter *r* repressing the relative bandwidth of the amplifier

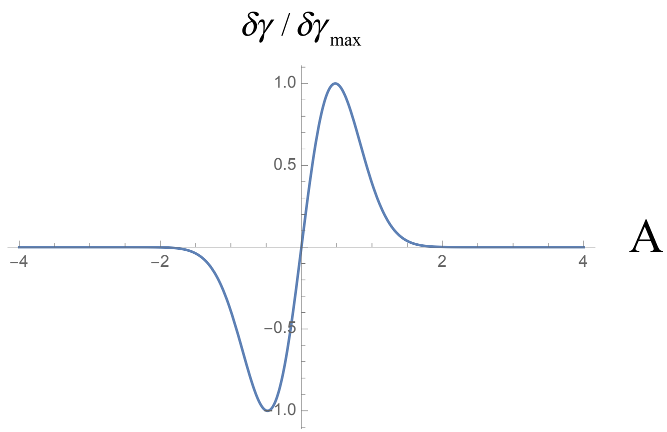
$$\delta\gamma = \Delta\gamma \cdot \sin\omega(t-\Delta t)\cdot e^{-\frac{(t-\Delta t)^2}{2\tau^2}} \equiv \Delta\gamma \cdot \sin kz \cdot e^{-\frac{\kappa^2 z^2}{2}}; z = R_{56}(\delta_e - \delta_h); \delta_{h,e} = \frac{\gamma_{h,e}-\gamma_o}{\gamma_o};$$

$$\frac{d\delta_h}{dn} = \frac{\delta\gamma_h}{\gamma_o} = \frac{\Delta\gamma}{\gamma_o}\cdot \sin kz \cdot e^{-\frac{\kappa^2 z^2}{2}} = \xi \cdot \sin kz \cdot e^{-\frac{z^2}{2\varsigma^2}}; r = \frac{1}{\omega\tau} = \frac{1}{k\varsigma} = \frac{\kappa}{k}$$

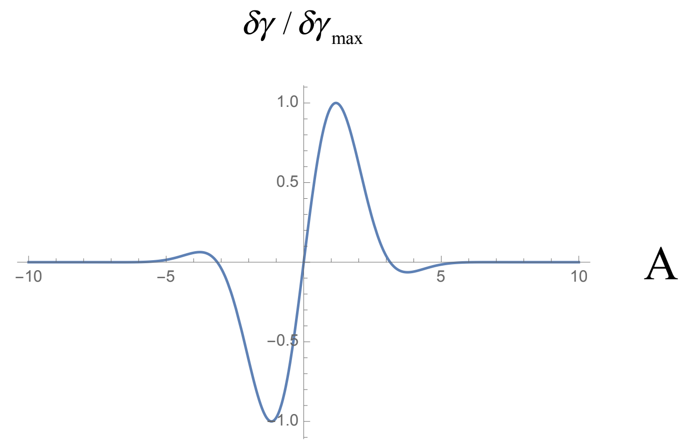
$$g(A,B) = \bar{g}(A,r) = \sin A \cdot e^{-\frac{B^2}{2}} = \sin A \cdot e^{-r^2\frac{A^2}{2}};$$



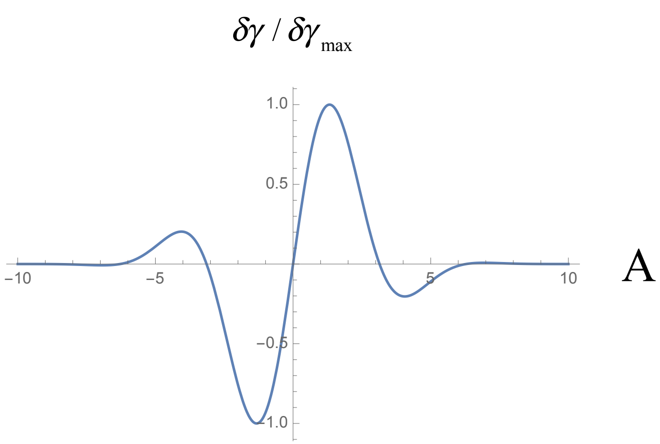
Reminder of parameter r - it is relative bandwidth



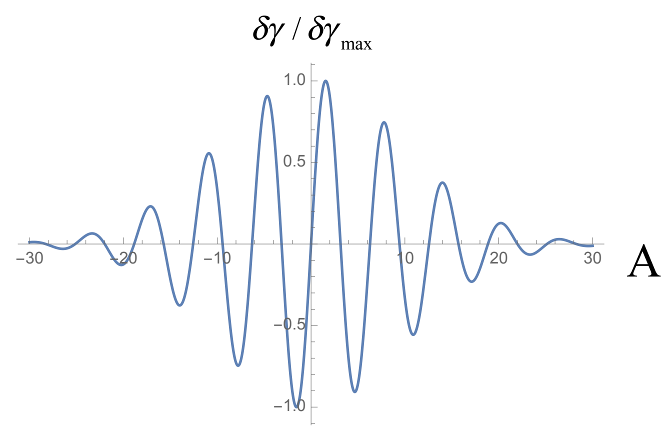
r=2



r=0.6

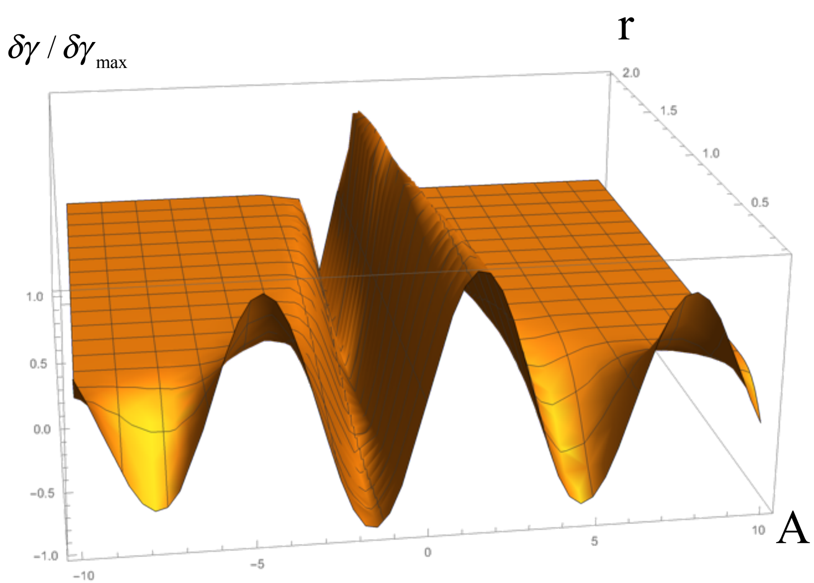


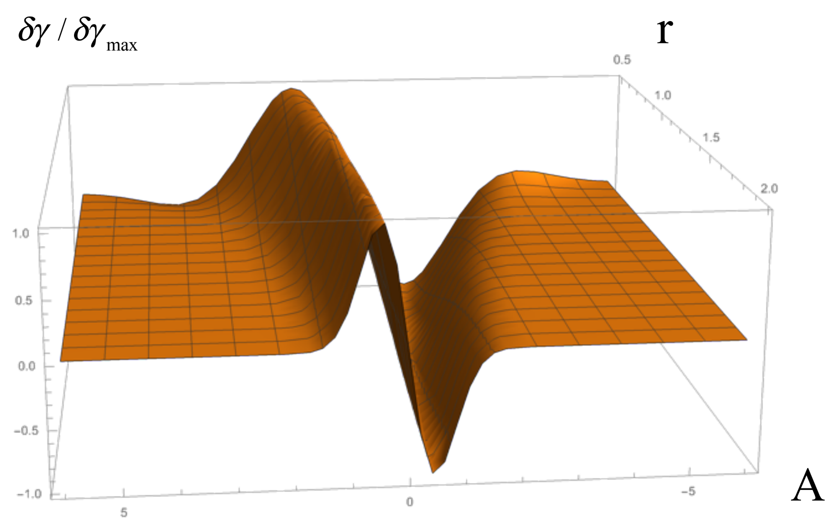
r=0.435



r=0.1

Kick shapes


δγ / δγmax
r
2.0
1.5
1.0
0.5
1.0
0.5
0.0
−0.5
−1.0
−10
−5
0
5
10
A


δγ / δγmax
r
0.5
1.0
1.5
2.0
1.0
0.5
0.0
−0.5
−1.0
5
0
−5
A

Energy jitter

- Assume that energy of election beam is random and has Gaussian distribution

$$f(\delta_e)=\frac{1}{\sqrt{2\pi\sigma}}e^{-\frac{\delta_e^2}{2\sigma^2}};\ z=R_{56}(\delta_e-\delta_h); x=kz=kR_{56}(\delta_e-\delta_h);$$

$$dx=kR_{56}d\delta_e;\ \delta_e=\frac{x}{kR_{56}}+\delta_h$$

$$\langle\delta\gamma\rangle=\frac{\Delta\gamma}{\sqrt{2\pi\sigma}}\int_{-\infty}^{\infty}e^{-\frac{\delta_e^2}{2\sigma^2}}\sin kz\cdot e^{-\frac{\kappa^2z^2}{2}}d\delta_e=\frac{\Delta\gamma}{\sqrt{2\pi\sigma}kR_{56}}\int_{-\infty}^{\infty}e^{-\frac{\left(\frac{x}{kR_{56}\sigma}+\frac{\delta_h}{\sigma}\right)^2}{2}}\sin x\cdot e^{-\frac{r^2x^2}{2}}dx;$$

$$\langle\delta\gamma\rangle==\frac{\Delta\gamma}{\sigma kR_{56}}I; I=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty}e^{-\frac{\left(\frac{x}{kR_{56}\sigma}+\frac{\delta_h}{\sigma}\right)^2}{2}}\sin x\cdot e^{-\frac{r^2x^2}{2}}dx$$

- Integration results in similar functional dependence but with reduced amplitude and broader curve

$$\langle\delta\gamma\rangle=\langle\Delta\gamma\rangle e^{-\frac{1}{2}(\kappa' R_{56}\delta_h)^2}\sin k' R_{56}\delta_h;$$

$$\langle\Delta\gamma\rangle=\frac{\Delta\gamma}{\sqrt{1+(\sigma\kappa R_{56})^2}}e^{-\frac{1}{2}\frac{(kR_{56}\sigma)^2}{1+(\sigma\kappa R_{56})^2}};\kappa'=\frac{\kappa}{\sqrt{1+(\sigma\kappa R_{56})^2}};k'=\frac{k}{1+(\sigma\kappa R_{56})^2}.$$

Dimensionless Z parameter

$$X = kR_{56}\delta_h; Y = \kappa R_{56}\delta_h = rX; \ Z = \sigma k R_{56}$$

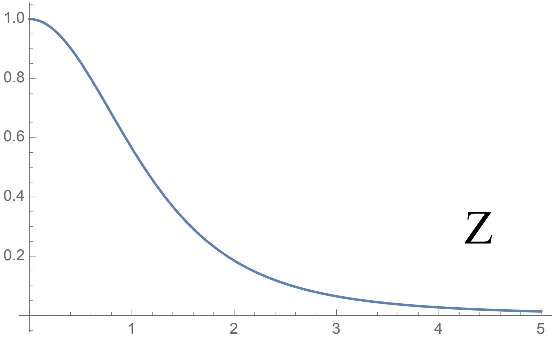
$$\langle \Delta\gamma \rangle = \frac{\Delta\gamma}{\sqrt{1+r^2Z^2}} e^{-\frac{1}{2}\frac{Z^2}{1+r^2Z^2}}; \kappa' = \frac{\kappa}{\sqrt{1+r^2Z^2}}; k' = \frac{k}{1+r^2Z^2}.$$

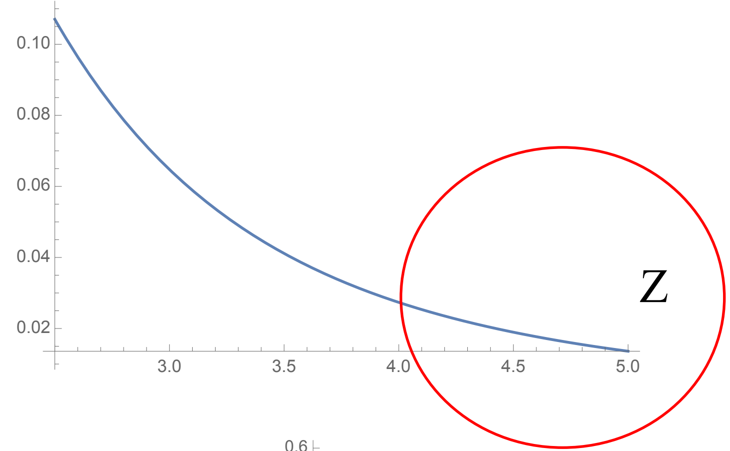
$$\langle \delta\gamma \rangle = \langle \Delta\gamma \rangle e^{-\frac{1}{2}\frac{(rX)^2}{1+r^2Z^2}} \sin\frac{X}{1+r^2Z^2};$$

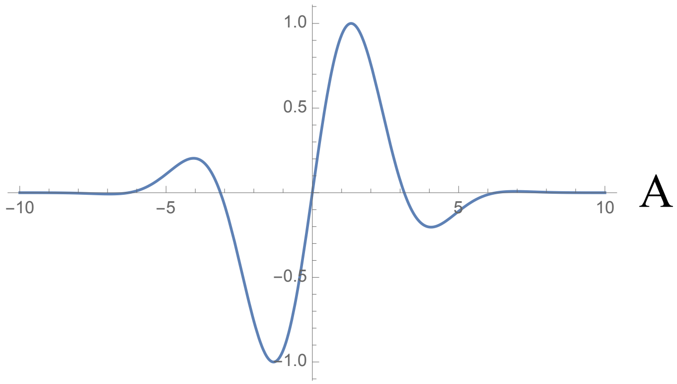
Example

r=0.435

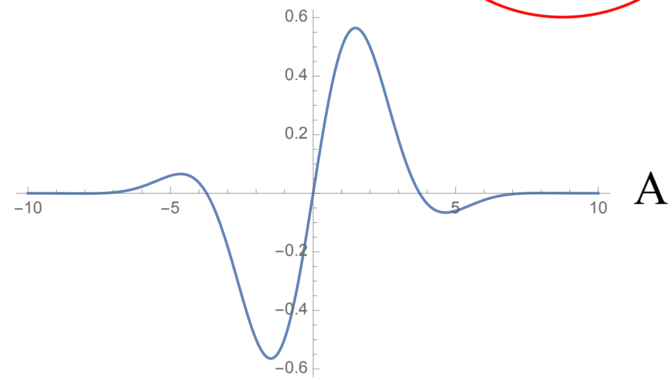
$Z = \sigma k R_{56}$



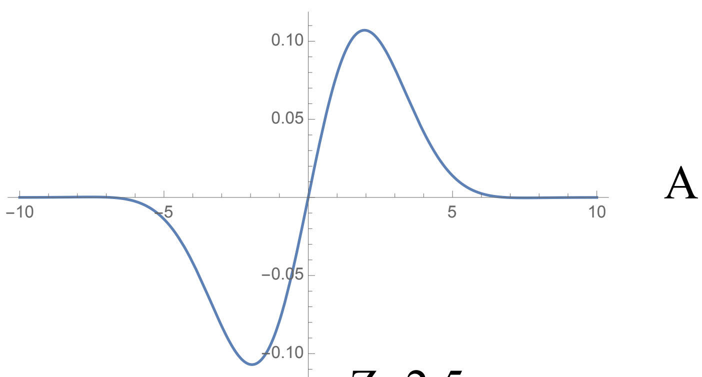




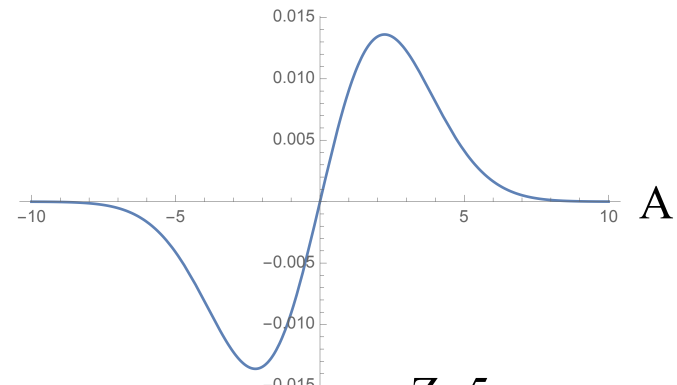
Z=0



Z=1



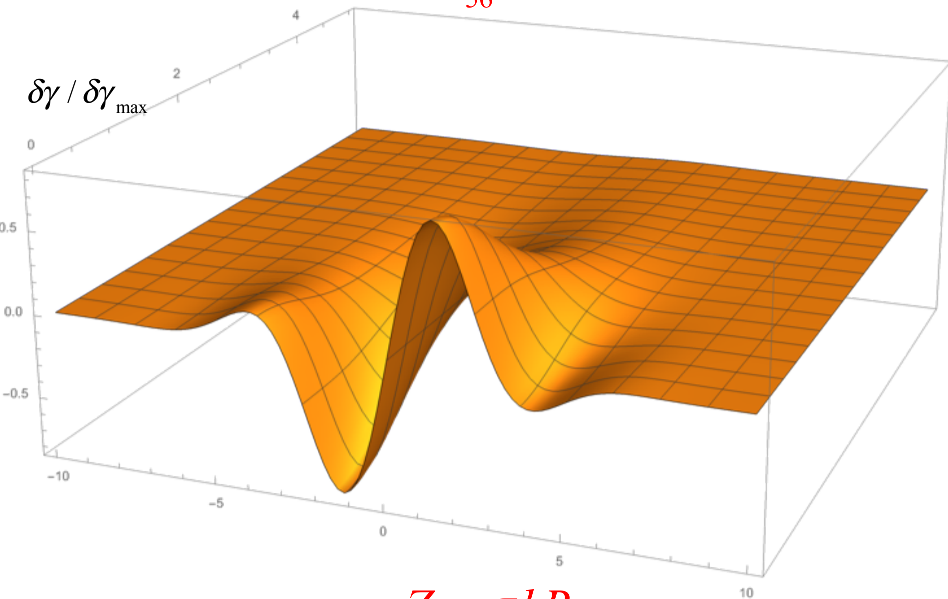
Z=2.5



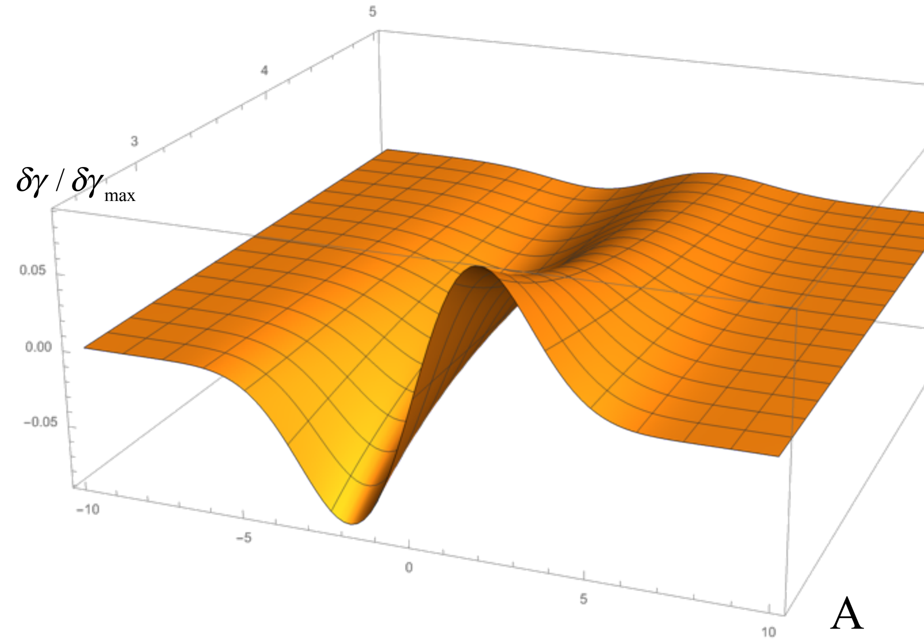
Z=5

3D pics

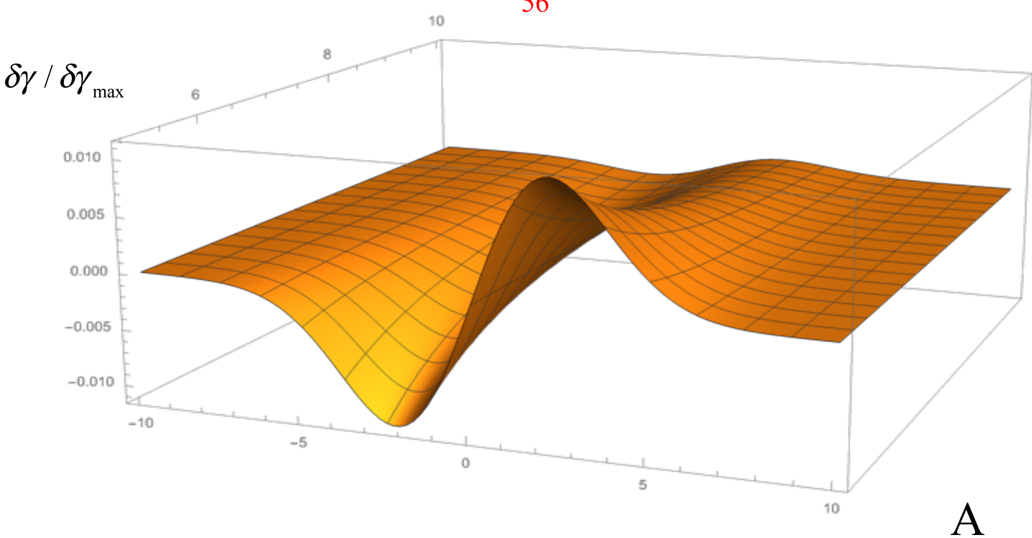
$Z = \sigma k R_{56}$



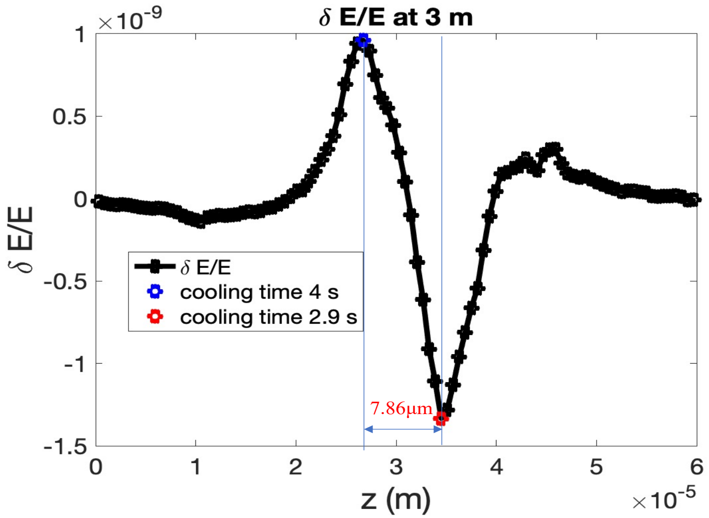
$Z = \sigma k R_{56}$



$Z = \sigma k R_{56}$



Some numbers



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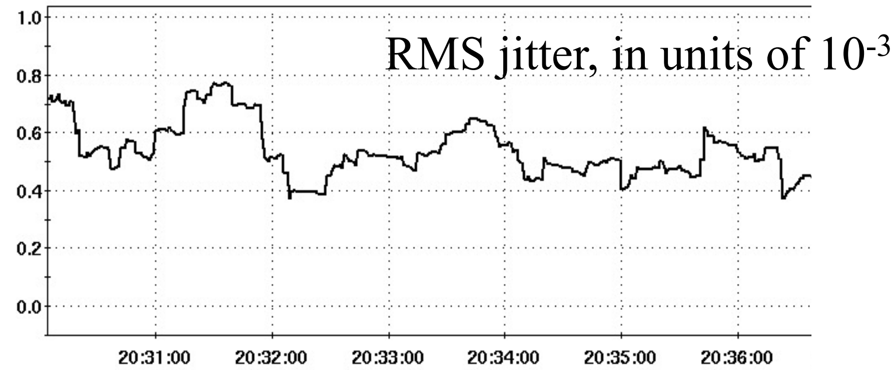
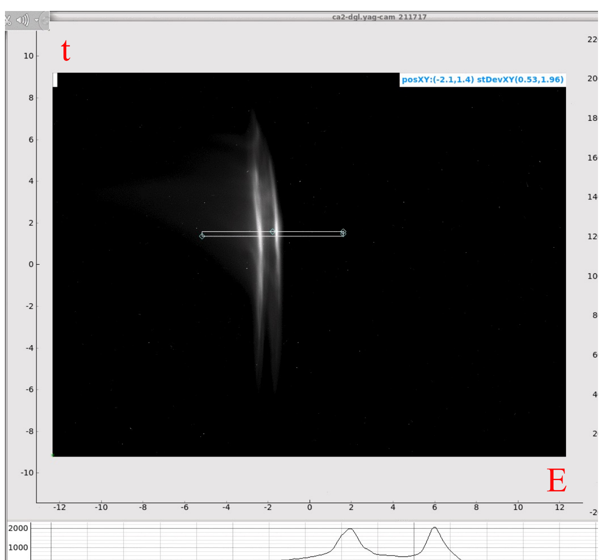
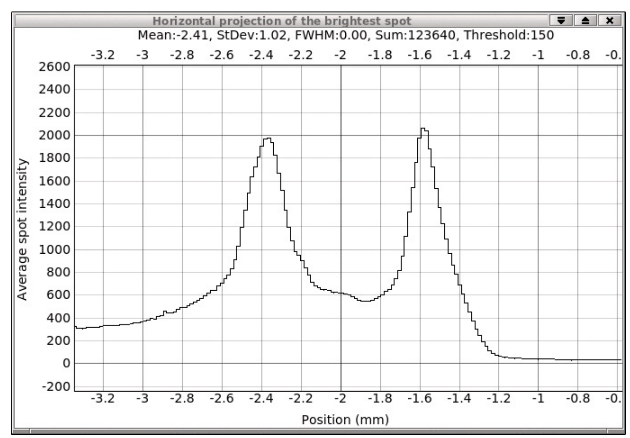
- σ is RMS values of relative energy jitter
- For r=0.435 and Z=0 maximum is located at X=1.32512, hence k=3.372 10^5,m^{-1} and Z=1 for σ=2 10^{-4} .
- It means for σ=0.1% we would have Z=5
- The kick is not only weaker by also 70% broader:
  - Maximum[A, r=0.435, Z=0] -> 1 at A=**1.325**
  - Maximum[A, r=0.435, Z=5] -> 0.0136 at A= **2.239**
- It means that with σ=0.1% cooling for the central particles (with energy spread up to 0.06%) is 0.8% of that for σ=0.
- It may explain very slow cooling or the fact that we did not detect it yet

Supporting data



- We scanned the laser phase to see how it affects the beam position on dogleg YAG: 0.36% energy change per 100 psec jump.
- On June 10, 2021 peak to peak jumps in energy were 0.35%. It can be result of 100 psec timing jitter in the laser pulses timing
- We indeed observed pulse-to-pulse energy jumps at this level



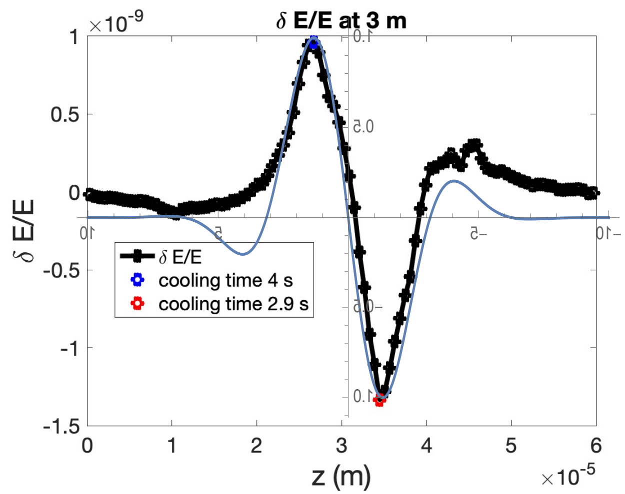


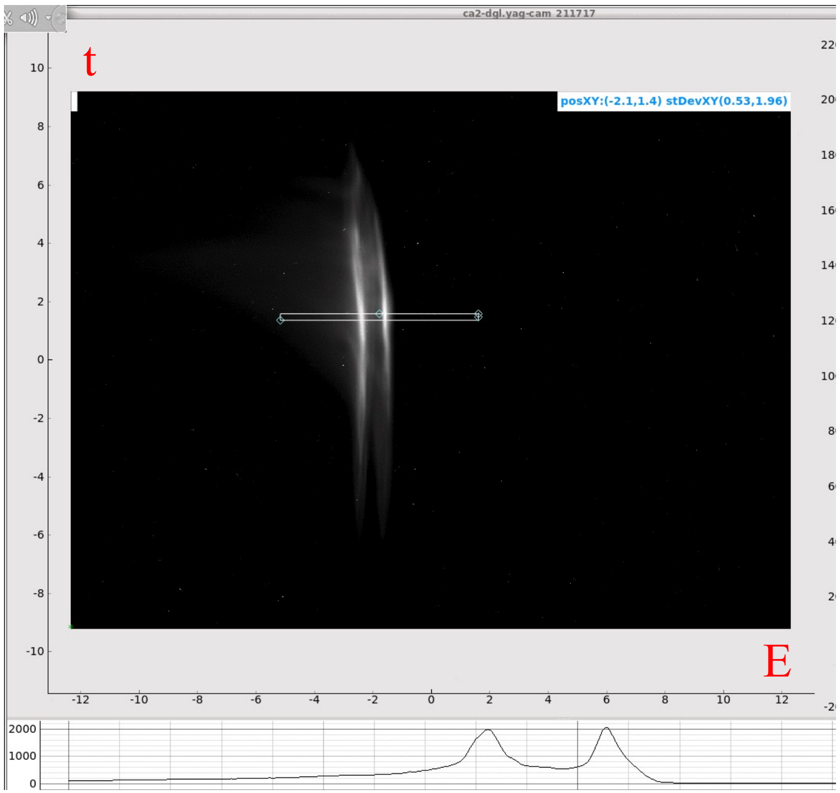
0.8 mm separation, which is 0.3% energy difference between consecutive bunches

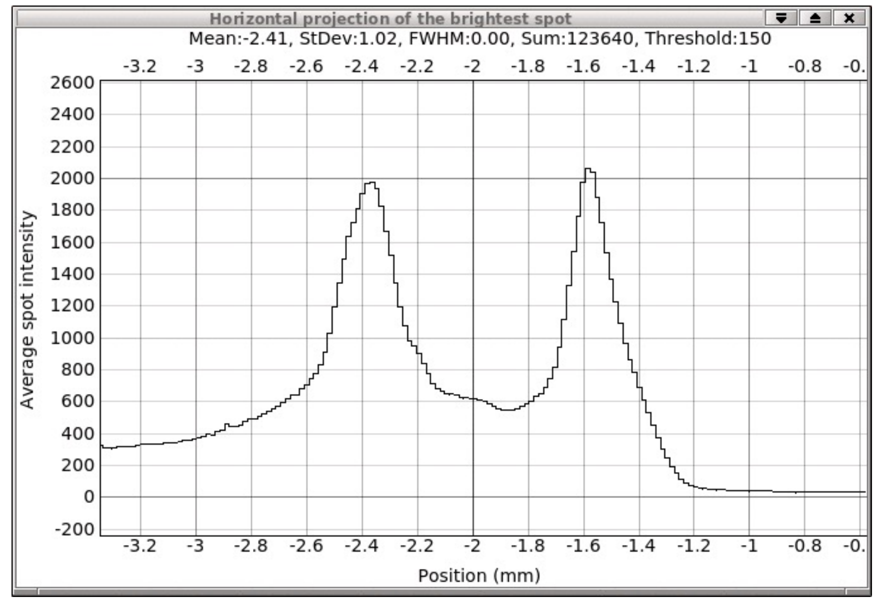
Summary

- Pulse to pulse e-beam energy jitter – currently attributed to timing and power jitter of the drive laser – is at 0.35%-0.4% level. Estimated RMS value if in 0.05% - 0.1% range. There is no remedy to this problem except replacing the seed laser and also trimming down laser power jitter
- In addition there are slow drifts at 0.1% level, which in principle can be removed by slow feedback – still need top be verified that it is
- All these number significantly larger than the slice energy spread of the electron beam core (<0.02% RMS) as well as requirements for the energy stability of the electron beam for CeC to operate - $\sigma \leq 0.02\%$
- It is most likely explanation why we did not observed either cooling or anti-cooling associated with CeC process during the energy scan
- We need to fix this problem before start of the next run

Back ups


δ E/E at 3 m
×10^-9
1
0.5
0
-0.5
-1
-1.5
δ E/E
0 1 2 3 4 5 6
z (m)
×10^-5
δ E/E
cooling time 4 s
cooling time 2.9 s





0.8 mm separation, which is 0.3% energy difference between consecutive bunches