Simulation studies of FEL Green function and its saturation

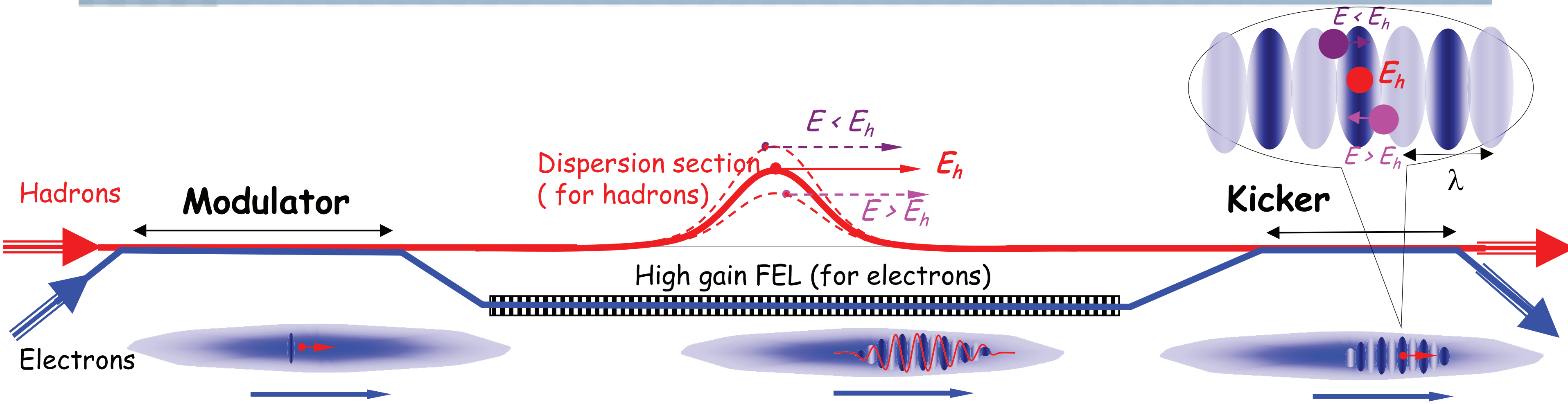
Y.Jing, V.N. Litvinenko, G. Wang and Y. Hao

Brookhaven National Laboratory

Outline

- Coherent e- Cooling and its requirements
- FEL Green function and saturation criteria
- GENESIS simulation of signal saturation under various radiation wavelengths
- Summary

CeC@RHIC and the FEL gain



FEL amplifies the initial energy variation proton beam imprints on the electron beam and the amplified signal is used as a FB to correct proton beam downstream.

Key issue for the FB is the amplification in the undulator – gain of the FEL

Saturation of FEL

- The gain of FEL is limited by saturation. For our interests, we want to operate the FEL within linear regime (so we have predictable phase information). Thus e-beam density perturbation needs to be less than initial beam density

$$\frac{\delta n}{n} < 1$$

- We can write beam density using Green function (for 1D case) in linear regime as

$$n(\tau) = n_o + \delta(z - z_o) + G_\tau(z - z_o), \; G_\tau(z) = \mathrm{Re}\, G_o(z) e^{ik_o z}$$

- And we reach saturation with maximum bunching gain

$$g_{\max} \sim \sqrt{\frac{I_p \cdot \lambda_o}{ec \cdot M_c}} \sim 144 \cdot \sqrt{\frac{I_p[A] \cdot \lambda_o[\mu m]}{M_c}} \qquad M_c = \frac{\int_{-\infty}^{\infty} \left| g(z) \right|^2 dz}{g_{\max}^2 \lambda_o}$$

V.N. Litvinenko, C-A/AP/480, tech-note, BNL, March 2013 and G.Wang's talk

GENESIS simulation setup

GENSIS

Signal (δ like)+ shot noise — Shot noise

=

response

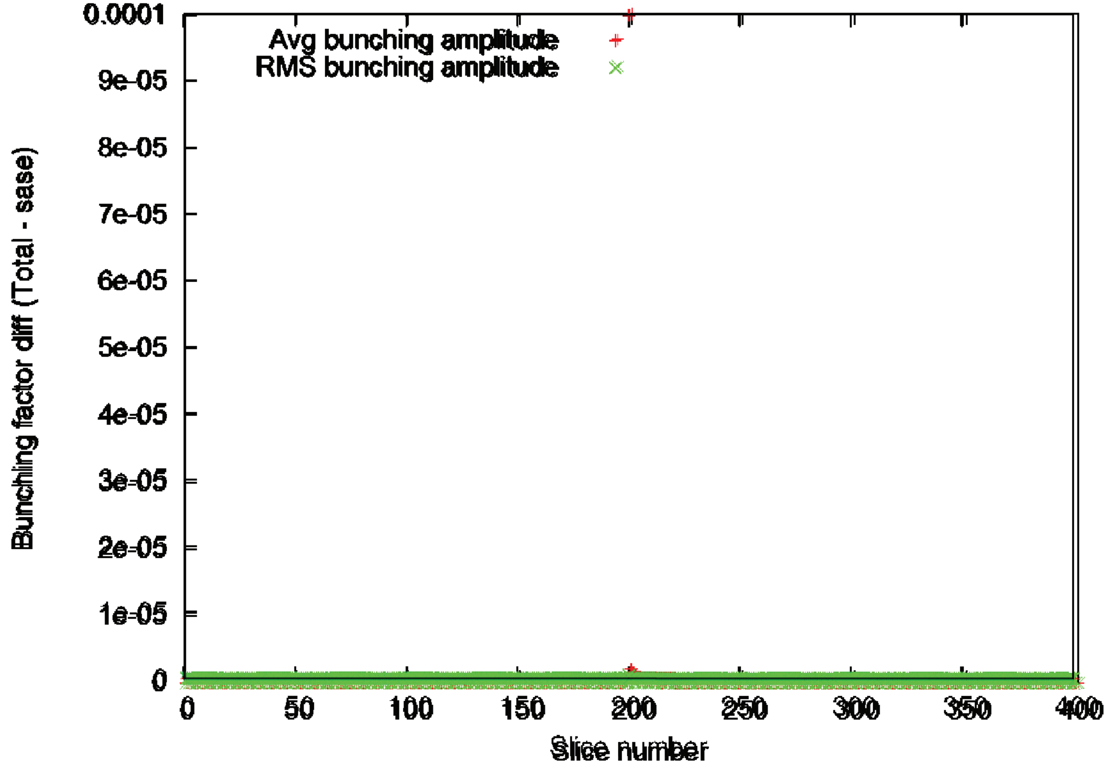
Initial bunching assumed for signal and bunching phase extracted with modified GENESIS source code.

32 random seeds are used for statistics

e- beam parameter

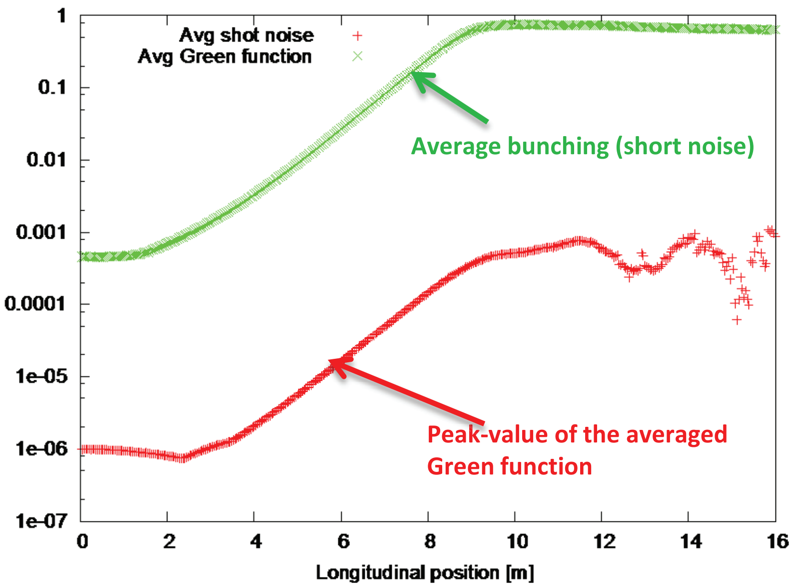
	Infrared(Proof of principle)	Visible near UV(eRHIC)	Vaccum UV(LHC)
Beam energy (MeV)	21.8	136	3812.3
Beam current (peak, A)	100	10	30
Normalized emittance (μm)	5	1	1
Beam energy spread (dp/p)	1×10^{-3}	1.5×10^{-5}	2.5×10^{-5}
Undulator period (cm)	4	3	10
Undulator strength Aw (Kw/√2)	0.4	1	10
Radiation wavelength	12.7 um	423.5 nm	90.7 nm
Mc	35.8	102	70.6

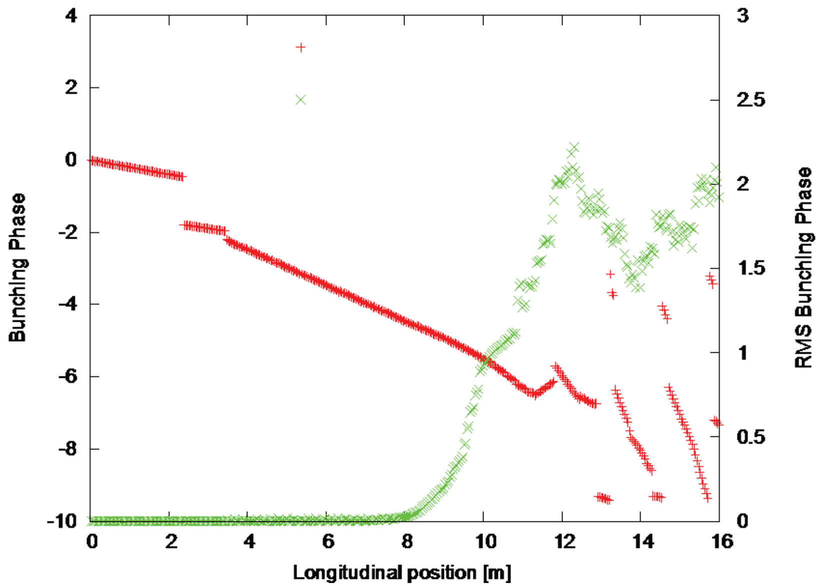
Bunch profile evolution



Head of the bunch starts to pick up information during propagation. When it's near the saturation, the entire bunch gets noisy as is shown with the rms over different random seeds.

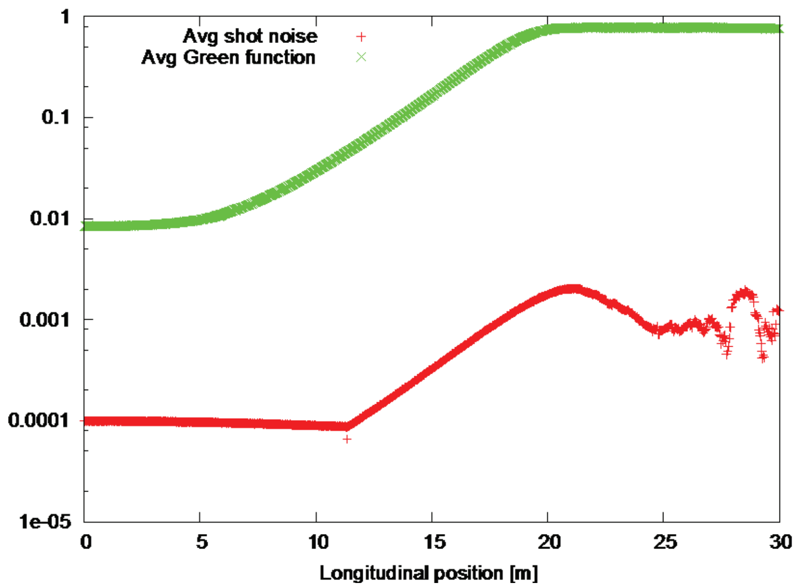
Bunching amplitude and phase (infrared)

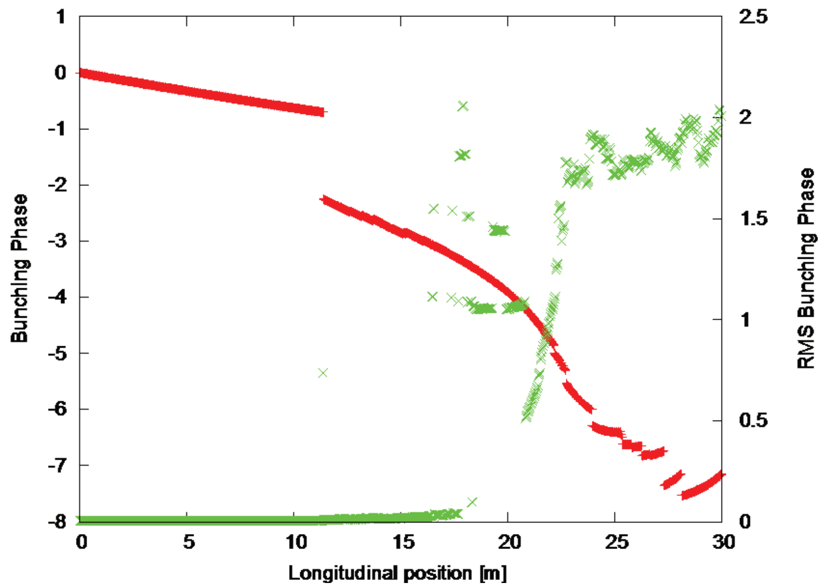




Signal grows exply until ~ 9 m with gain at 409 and it continues to grow and saturates with gain of 777 @ 11.5 m. This is to be compared with theoretical estimation at 858.

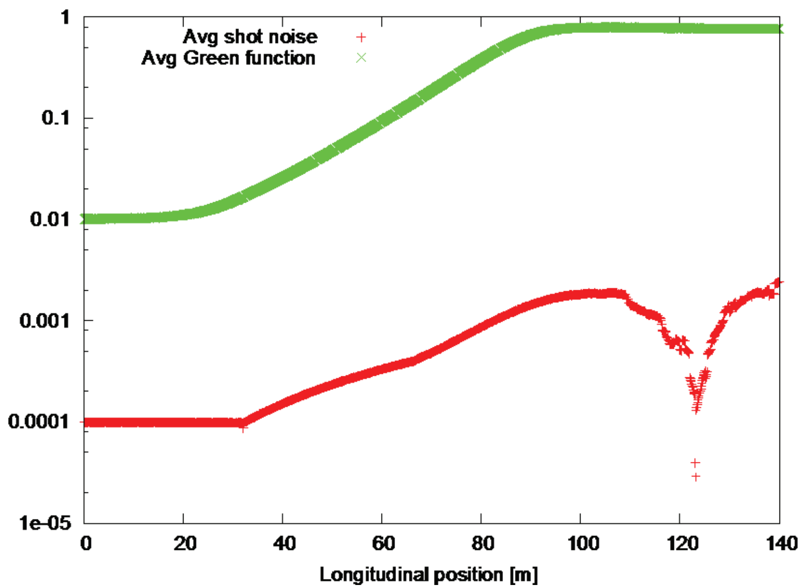
Bunching amplitude and phase (visible)

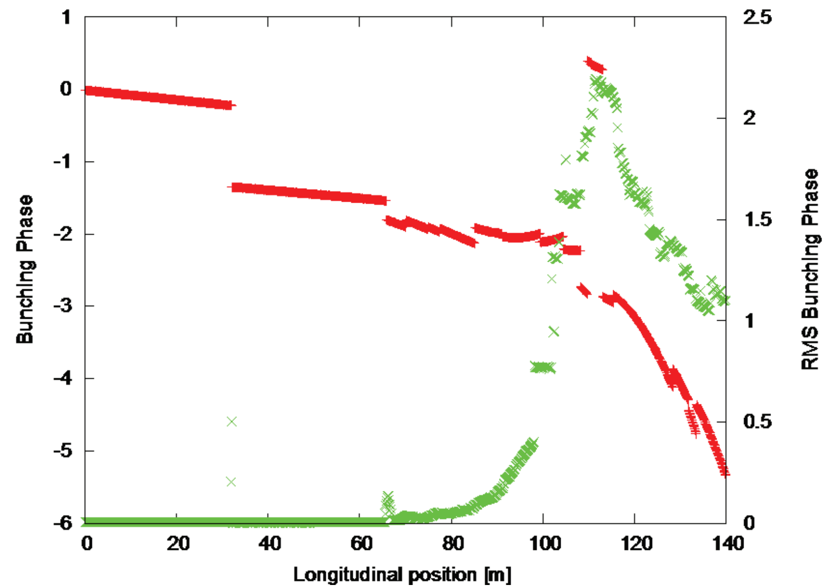




Bunching factor for the entire bunch saturates at ~20 m (|b|~1) with noise. Signal starts to grow linearly after delay and saturates at roughly the same location as the entire bunching factor. Max gain of bunching factor at 20 m is 27 and the theoretical estimation gives 29.4.

Bunching amplitude and phase (VUV)





Maximum gain at 100 m is 18.7 and the theoretical estimation gives 28.3.

Summary

- We studied the FEL Green function and derived a criteria of its saturation.
- We used GENESIS to simulate evolution of the FEL Green function in the presence of shot noise.
- The simulation results agree well with the theoretical predictions.