Preliminary Study for the OFFELO

Y. Hao & V. N. Litvinenko
Collider-Accelerator Department
Brookhaven National Laboratory

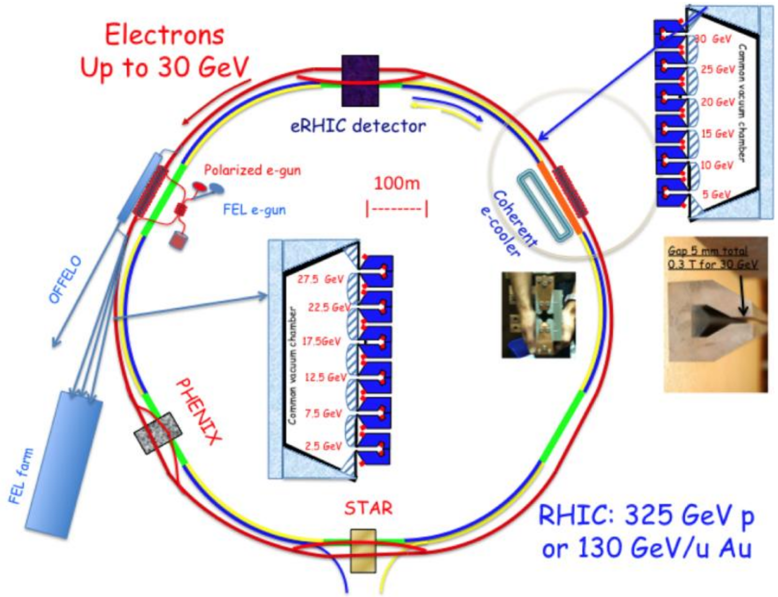
Outline

- OFFELO – Optics Free FEL Oscillator
- What is OFFELO
- Simple model to explore the feature
  - Power Saturation
- Simulation (Time Independent/Dependent)
- To-dos

eRHIC based FEL

Electron: 5 Gev to 20 GeV
upgradable to 30 GeV
2-linac multi-pass ERL that support many possible energy for FEL

Rep rate can be achieved as high as 78KHz, parallel with RHIC operation
=> High Average Power



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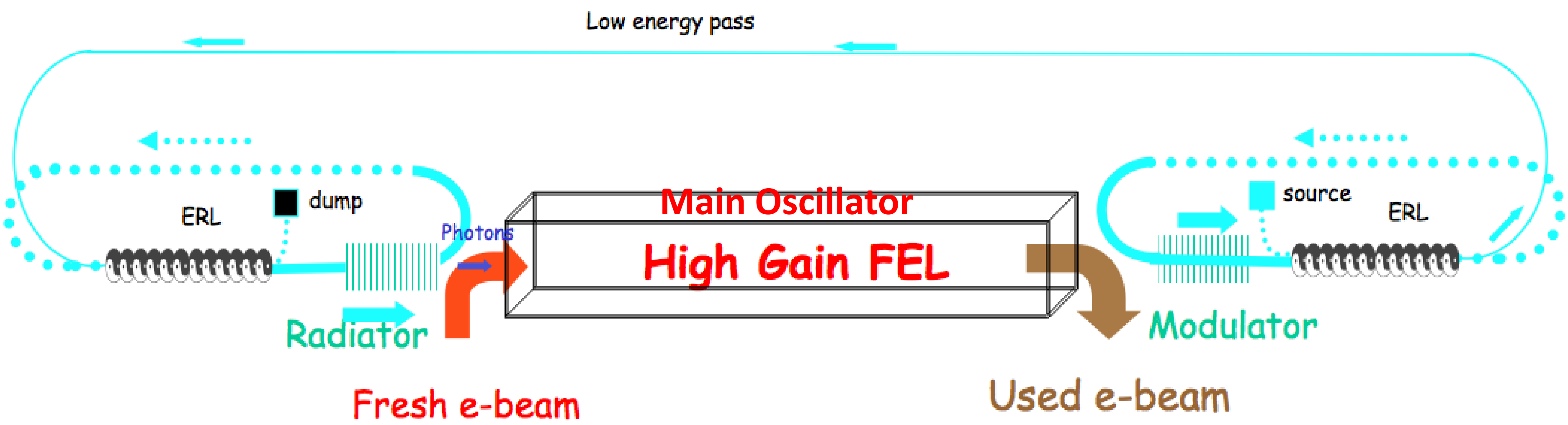
Top Energy of the ERL (collision energy)	Available Energy for FEL
5 GeV	2.55, 2.96, 3.37, 3.78, 4.18, 4.59, 5.00
10 GeV	3.47, 4.28, 5.10, 5.92, 6.73, 7.55, 8.37, 9.18, 10.00
15 GeV	2.75, 3.98, 5.20, 6.43, 7.65, 8.88, 10.10, 11.33, 12.55, 13.78, 15.00
20 GeV	3.67, 5.30, 6.93, 8.57, 10.20, 11.83, 13.47, 15.10

Goal: X-Ray FEL. Scheme?

- Single pass SASE
  - Similar peak power as LCLS
  - Take advantage of the high rep. rate, high average power
- Oscillator – temporal coherence
  - @ K.J Kim (PRL) concept of XFELO
  - Make it OPTICS FREE, Possible?
  - Ideas starts from N.A.Vinokurov, 1995
  - @V. Litvinenko 2002 FEL conference
  - No worry of the choice of the mirror and absorption of optical system.

Optics Free FEL Oscillator, HOW?

Several possible implements



Feed-back scheme: Two electron beam are included.

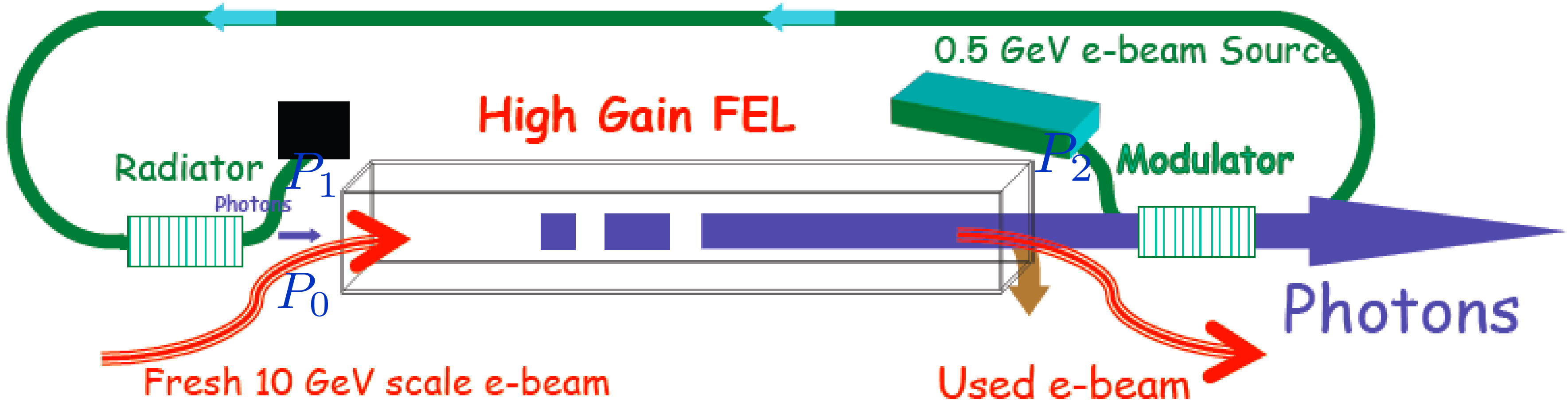
✓High energy: Radiate in the Main Oscillator

✓Low energy: Carry the feedback information

Two scheme of satuation

- Saturation of the system in the Main oscillator
- Saturation of the feed-back loop

Simple Model



The iteration map:

$$P_{n+1} = G_o\left(P_{n+1}\right) \cdot \left[P_{SR} + C_{fb}\left(P_n\right) \cdot P_n\right]$$

Simplification by assuming the oscillator is a linear amplifier:

$$P_{2,n} = G\left(P_{1,n} + P_0\right)$$

$$\frac{\delta\gamma}{\gamma} = \frac{a_w\,[JJ]\,L_m}{\gamma^2\sigma_L}\sqrt{\frac{P_{2,n}}{P_A}} \qquad b_n = J_1\left(\delta\gamma\frac{d\theta}{d\gamma}\right)\exp\left[-\sigma_r\left(\frac{d\theta}{d\gamma}\right)^2/2\right]$$

$$P_{1,(n+1)} = \frac{Z_0}{32\pi}\left(\frac{I_{fb}K\,[JJ]\,L_r}{\gamma\sigma_e}b_n\right)^2$$

The simplified iteration map:

$$\frac{P_{2,n+1}}{GP_0} = 1 + \xi J_1^2\left(\eta\sqrt{\frac{P_{2,n}}{GP_0}}\right)$$

$$\xi = \left(\frac{I_eK\,[JJ]\,L_r}{\gamma\sigma_e}\right)^2\exp\left[-\sigma_r\left(\frac{d\theta}{d\gamma}\right)^2\right]\frac{Z_0}{32\pi P_0} \qquad \eta = \frac{a_w\,[JJ]\,L_m}{\gamma\sigma_L}\sqrt{\frac{GP_0}{P_A}}\frac{d\theta}{d\gamma}$$

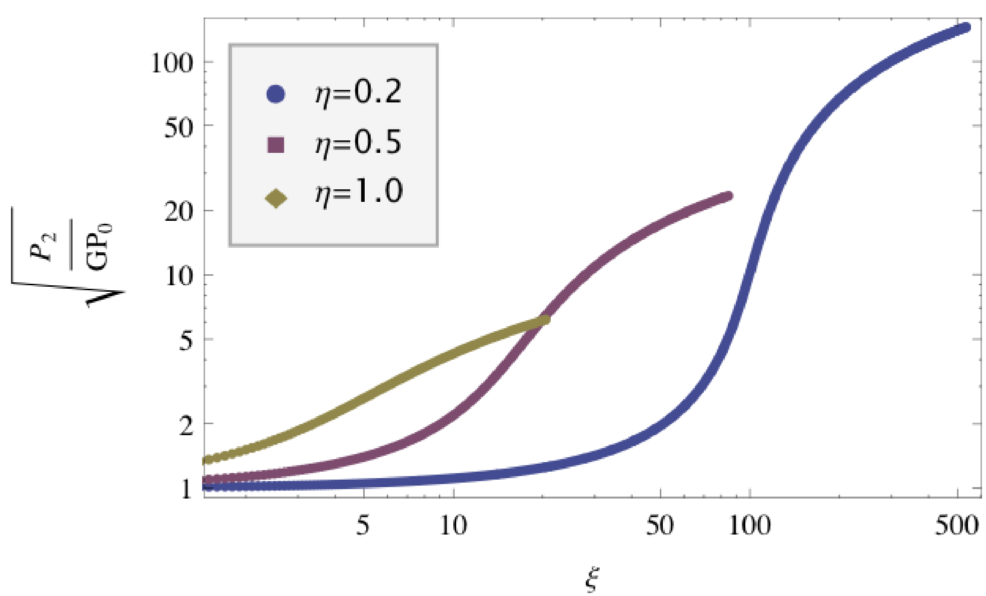
Fix Points

The fix points: $$\frac{P_{2,\infty}}{GP_0} = 1 + \xi J_1^2 \left(\eta \sqrt{\frac{P_{2,\infty}}{GP_0}} \right)$$

The real root always exists with any positive parameters.

Criterion of stability of fix points:

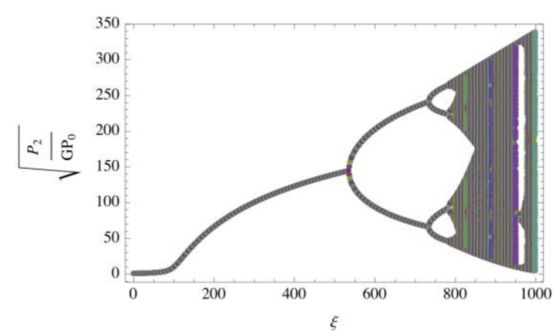
$$-1 < \left[1 + \xi J_1^2 (\eta x)\right]' \Big|_{x=\sqrt{P_{2,\infty}/GP_0}} < 1$$



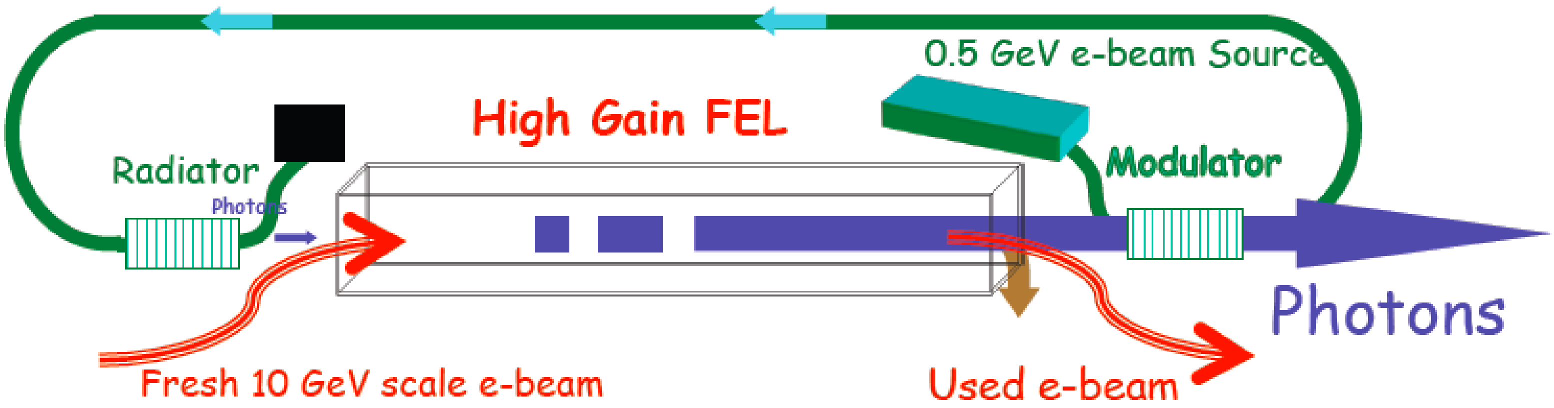
Therefore, to avoid saturation in bunching:

Make it looks linear

- Higher feed-back current
- Shorter modulator



Genesis Simulation



The process is simulated by Genesis. Undulators are connected by extracting and importing the beam distribution and radiation info.

Time Independent simulation for the saturation power.

Preliminary time dependent simulations for the study of frequency spectrum of the output radiation.

Parameters for High Energy Electron Beam

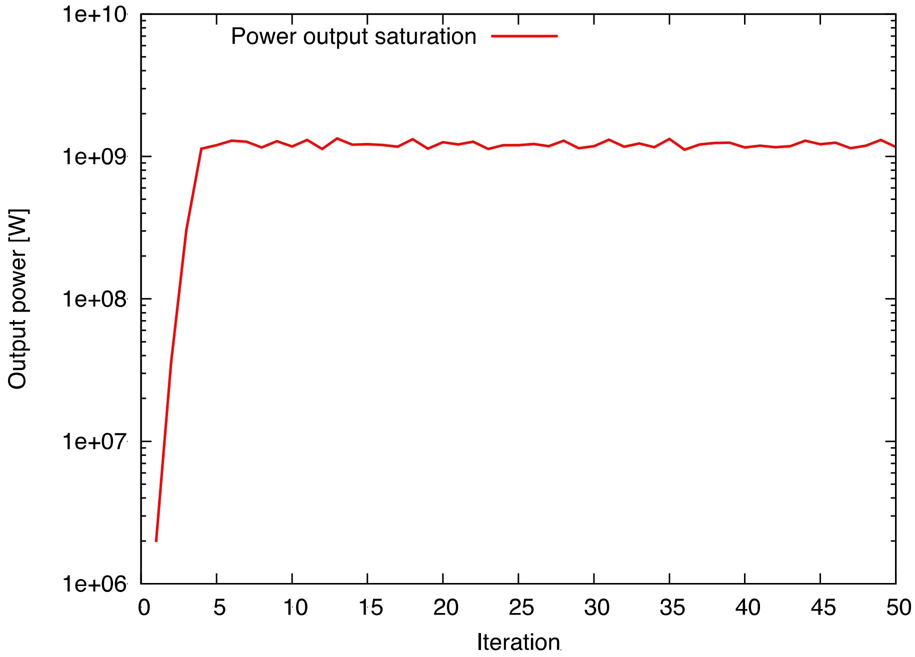
Parameters of high energy beam	Values
Electron energy (GeV)	13.6
Energy deviation dE/E	1e-4
Peak current (A)	3000
Normalized emittance (mm-mrad)	1.5
Undulator period [m]	0.03
Undulator length [m]	60
Undulator parameter K	2.616
Radiation wavelength [nm]	0.166
Average beta function [m]	18

Parameters for Feed-back Electron Beam

Parameters of low energy beam	Values
Electron energy (GeV)	1
Energy deviation dE/E	1e-5
Peak current (A)	15
Normalized emittance (mm-mrad)	0.015
Undulator period [mm]	0.636*
Number of undulator period (Modulator/Radiator)	120/800
Undulator parameter K	0.1
Radiation wavelength [nm]	0.166
R56 of the transport arc	0

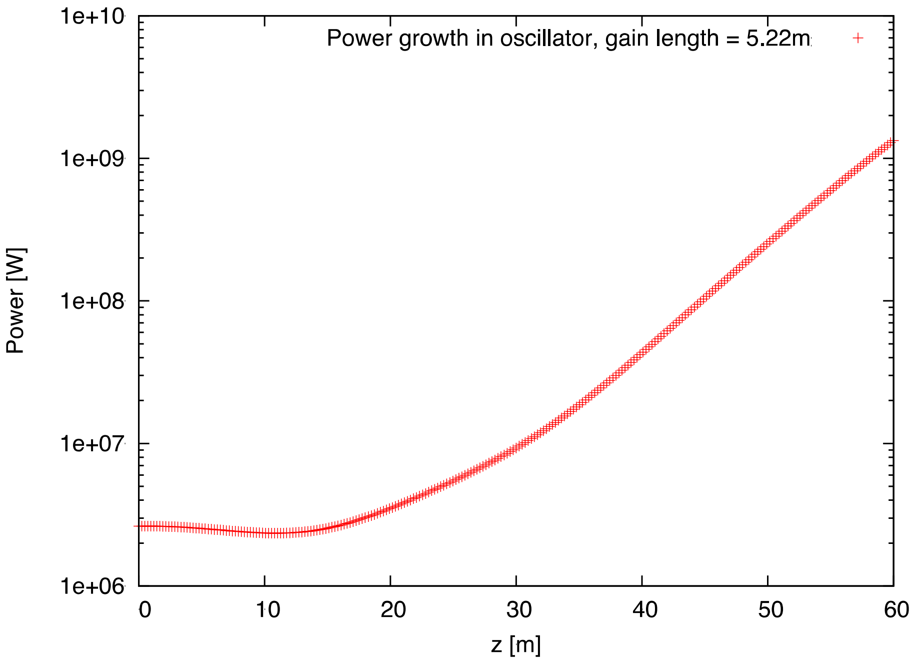
Impossible to achieve now for an magnet undulator. In further study this will be replaced by a harmonic radiation with longer period.

Time Independent Simulation

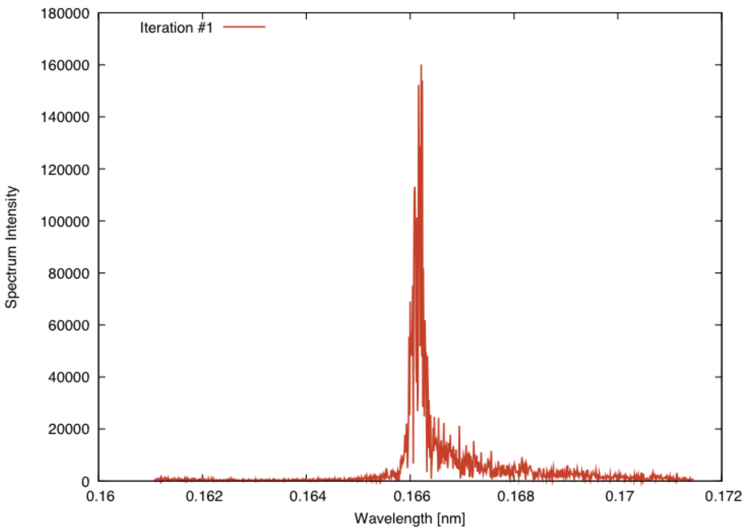


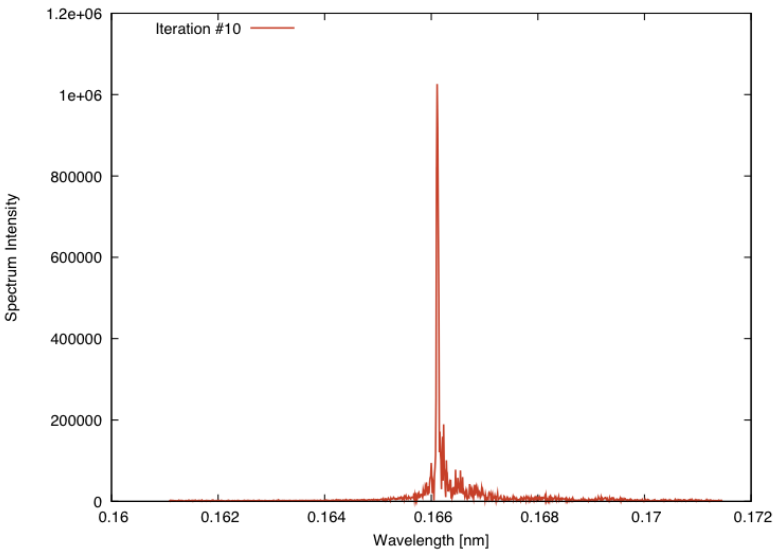
The curve shows the system saturates at 1.3GW because of the nonlinear bunching.

Power in main oscillator in #40 iterations.
3-D Gain length 5.22m

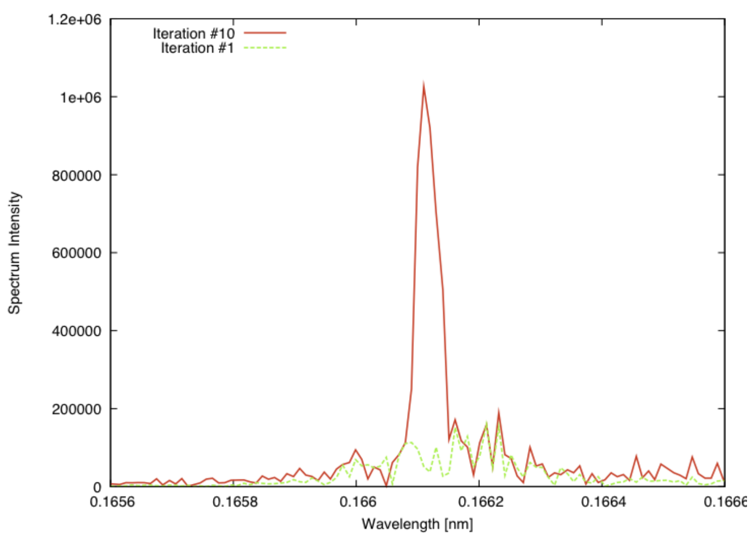


Preliminary Time Dependent Results





After the first iteration
FWHM 2e-3



After the 10th iteration
FWHM 3e-4

To-Do lists

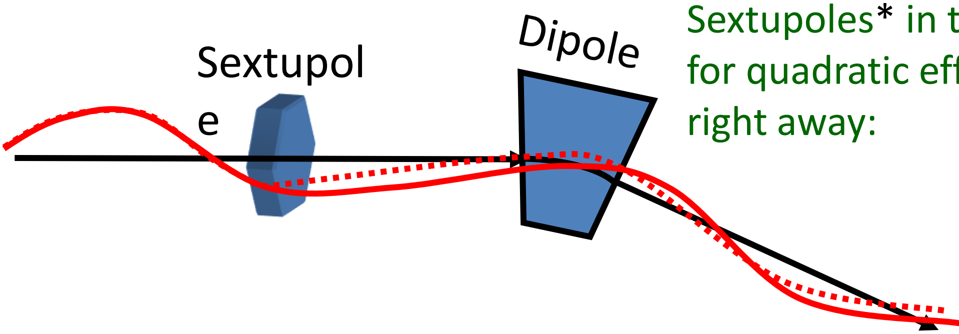
- Through time dependent simulation
- Use high order harmonics with reasonable undulator period
- The synchrotron radiation effect on the feedback information
- The time of flight control
  - Precise R_{56} and higher orders
  - Transverse dependence, vanish at least to 2^{nd} order

2. Emittance effects

Quadratic term

$$\delta S_2 \propto \int_o^L \frac{x'^2 + y'^2}{2} ds$$

$$x = a_x\sqrt{\beta_x(s)}\cos\left(\psi_x(s) + \varphi_x\right) + \eta(s)\frac{\delta E}{E_o};\; y = a_y\sqrt{\beta_y(s)}\cos\left(\psi_y(s) + \varphi_y\right).$$



Sextupoles* in the arcs are required to compensate for quadratic effect sextupole kick + symplectic conditions give us right away:

$$\Delta x'_{sext} = K_2 l \cdot \left(x^2 - y^2\right) \;\Rightarrow\; \delta S = -\eta(s)\cdot \Delta x'_{sext} = -\eta(s) K_2 l \cdot \left(x^2 - y^2\right)$$

$$\frac{1}{2}\int_o^L \left(x'^2 + y'^2\right) ds - \sum_n \eta(s_n)\left(K_2 l\right)_n \cdot \left(x^2(s_n) - y^2(s_n)\right) ds \Rightarrow 0$$

Sextupoles located in dispersion area give a kick ~ x^2-y^2 which affect the length of trajectory. Two sextupoles placed 90^o apart the phase of vertical betatron oscillations are sufficient to compensate for quadratic term with arbitrary phase of the oscillation

Four sextupoles located in the arcs where dispersion are sufficient to satisfy the cancellation of the quadratic term in the non-isochronism caused by the emittances. Fortunately, the second order achromat compensates the chromaticity and the quadratic term simultaneously. *In short it is the consequence of Hamiltonian term*:

$$h \propto -g(s)\cdot \delta \cdot \left(\frac{x^2 - y^2}{2}\right) \Rightarrow C_x \cdot \delta \cdot \frac{a_x^2}{2} + C_y \cdot \delta \cdot \frac{a_y^2}{2}$$

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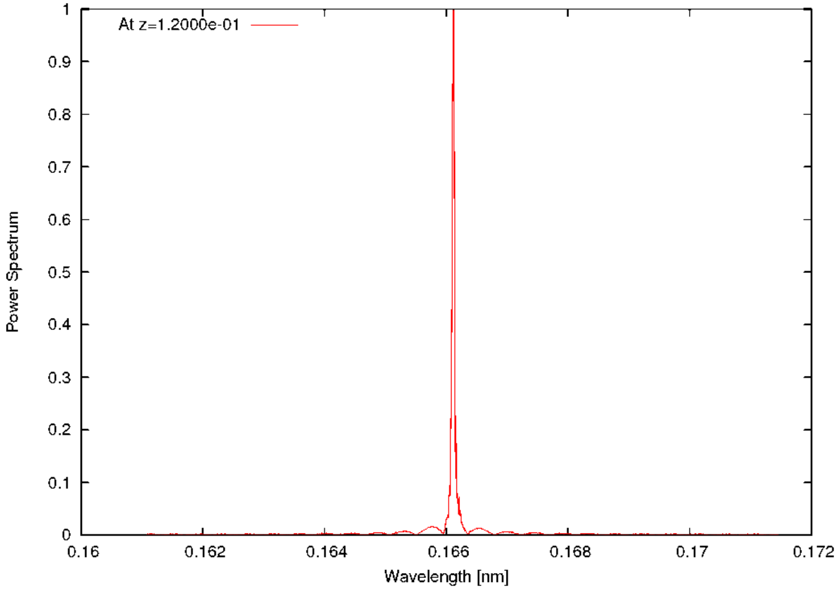
•This scheme is similar to that proposed by Zolotarev and Zholents. (PRE 71, 1993, p. 4146) for optical cooling beam-line and tested using COSY INFINITY. It is also implemented for the ring FEL: A.N. Matveenko et al. / Proceedings 2004 FEL Conference, 629-632

Brief Summary

- ✓ OFFELO – a candidate to deliver full coherence radiation without mirror. Suitable for the scenarios which is lack of mirrors or need full control of the parameter.
- ✓ Avoid high nonlinear regime in the feed-back loop. – Reach higher saturation power.
- ✓ The spectrum gets improved iteration by iteration – from the preliminary results, as expected.
- ✓ Need to demonstrate the feed-back signal can be transported safely from the modulator to the radiator.



Thanks for your attention!