Beam Slice by table-top Laser

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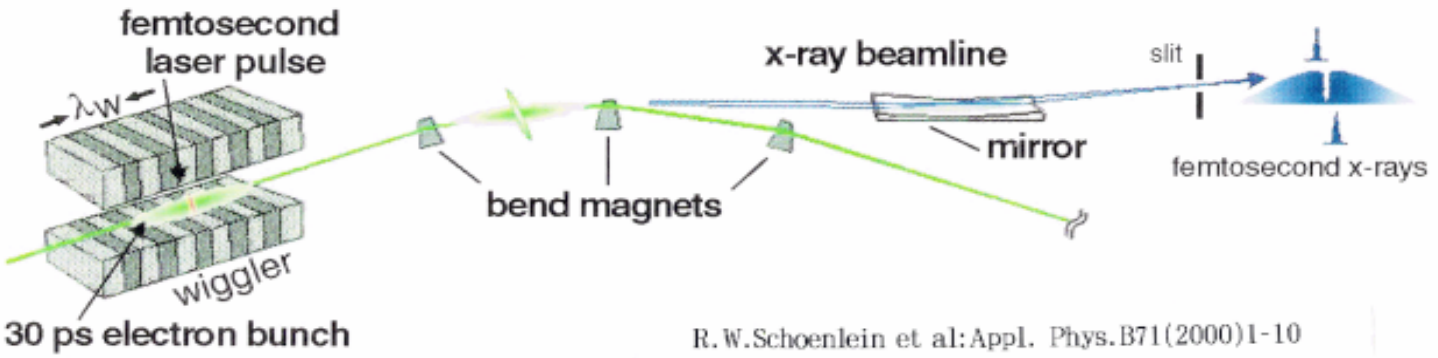
History

- Beam slice method by laser was proposed by Berkeley group in 1996. (A.A.Zholents, M.S.Zolotorev, Phys. Rev. Lett. 76 (1996) 912)
- This method was demonstrated at the 1.5 GeV Advanced Light Source in 1999.(A.Zholnents:PAC(1999)2370)
- The beamline of the femtosecond x-ray pulses has been operating since 2001.
- At the BESSY Ⅱ (1.7GeV), SLS (2.4GeV), SOLEIL(2.75GeV), the beam slice study is in progress.

Layout of beam slice system



- Electrons are accelerated (decelerated) by femtosecond laser in the wiggler under FEL interaction.
- These energy kicked electrons are separated in bending magnets.
- This slice beam will produce synchrotron radiation with femtosecond duration.

PF-AR ring in KEK

- Beam is injected at 3 GeV and accelerated up to 6.5 GeV.
- We will consider the feasibility of 3 GeV beam slice.
- In the ring, 5.5 meter space is available to install an wiggler.

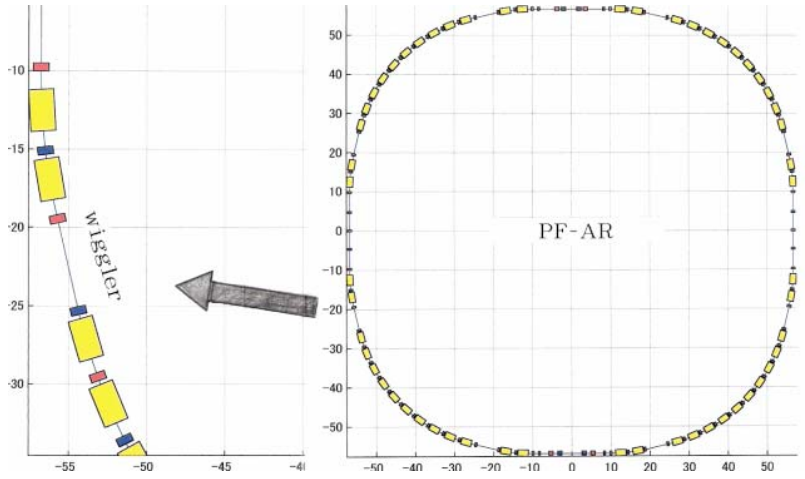
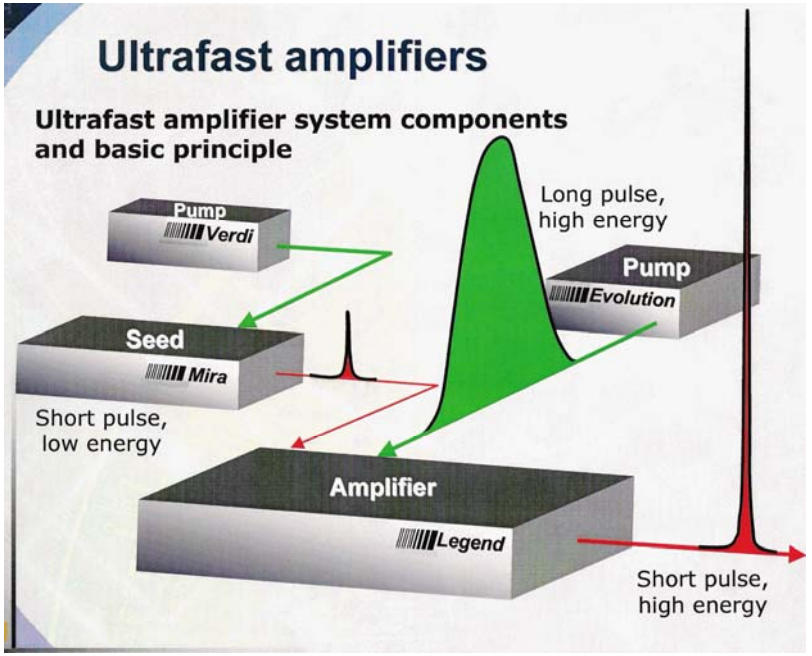


Table-top Laser

- We use commercial laser.
- Wavelength :1 μ m

  Pulse length :100 fs
  Pulse power :7mJ
  Repetition rate :1kHz
- Amplifier is cooled by liquid nitrogen.



Wiggler design is determined by FEL resonance condition.

$$FEL \;-\; resonance$$

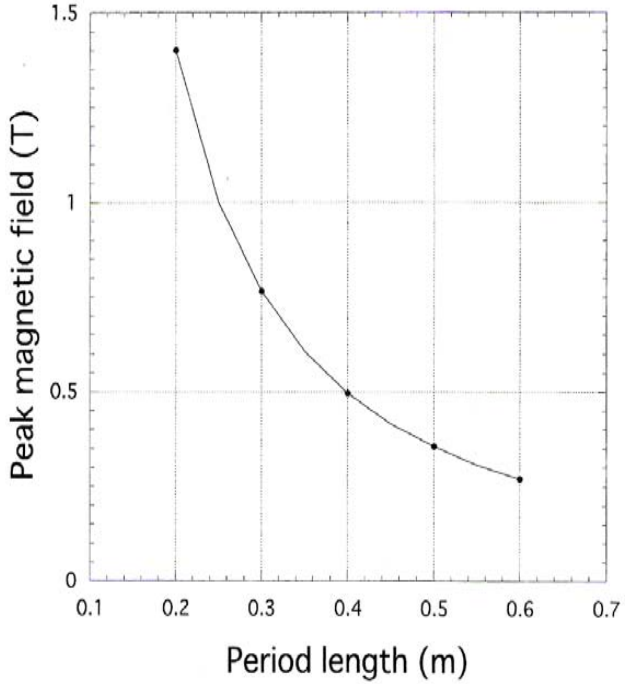
$$\lambda = \frac{\lambda_W}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

where

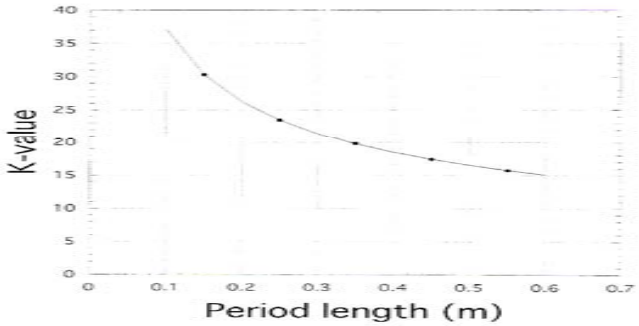
$$wiggler \quad : K = 93.37\, B_W \lambda_W$$

$$beam \quad : \gamma = \frac{3GeV}{0.511\ MeV} + 1$$

$$laser \quad : \lambda = 1\mu m$$



Undetermined parameter is period length.



- High K-value and long period wigglers are shown in TESLA damping 5GeV ring design reports.
- (1)permanent magnet
  period length 40cm,
  number of period 12,
  peak field 1.67 T,
  K-value 62.4,
  gap 25mm.
- (2)electromagetic wiggler :
  period length 55cm,
  number of period 8,
  peak field 1.8T,
  K-value 67.2,
  gap 25mm.

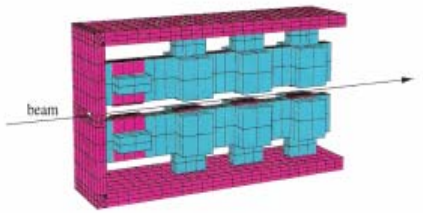


Figure 5.6.3: *Partial view of the permanent magnet wiggler. The permanent magnet material is drawn in blue and the iron poles and yoke in magenta. The side yoke plates which enclose the whole structure are not shown.*

permanent

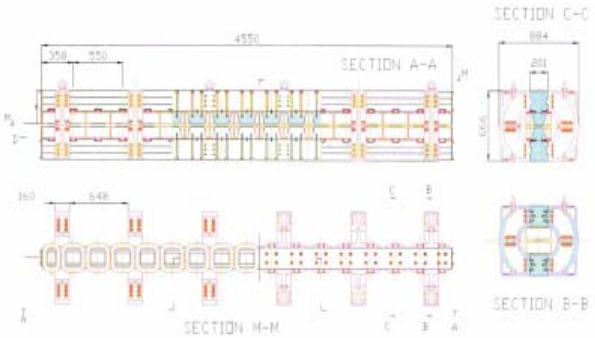


Figure 5.6.4: *Electromagnetic wiggler.*

elecromagnetic

We adopt the following parameters for simulations:
period length 40cm, number of period 12,
peak field 0.5T, K-value 18.5.

FEL Basic Equations

- Dr. Y.Miyahara (Spring 8) has improved usual FEL equations in order to design beam slice system. (N.I.M. A506(2003)316)
- We use the initial region of a single pass FEL. → Beam energy modulation occurs, but laser field does not change because the average change of beam energy over one wavelength is zero.

$$\dot{\eta} = -\frac{\alpha E_{s0}(\Delta z) K[JJ]}{2\gamma^2} \cdot \frac{\exp\left[-x^2/w^2(z)\right]}{w(z)/w_0} \sin(\phi + \phi_1)$$

$$\dot{\phi} = 2k_W c\eta$$

where

$$\eta = \frac{\gamma - \gamma_r}{\gamma_r},\ [JJ] = J_0(\xi) - J_1(\xi),\ \xi = \frac{K^2/4}{1 + K^2/2}$$

$$\Delta z = \Delta z_0 - \left(c - \langle \dot{z} \rangle\right)t,\quad w(z) = w_0\left(1 + z^2/L_R^2\right)^{1/2}$$

$$\phi_1 = -\theta(z) + \left(\frac{r}{w_0}\right)^2 \left(\frac{z}{L_R}\right)\left[1 + \left(\frac{z}{L_R}\right)^2\right]$$

Parameters for FEL Simulation

- Beam (gaussian)
  Beam length 100ps
  Transverse size 1mm
  Energy spread 0.005

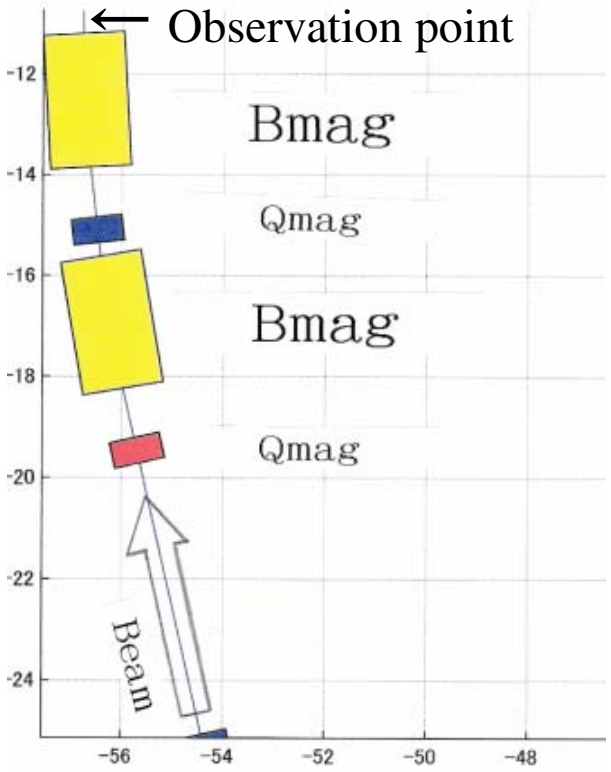
- Approximation in FEL
  X'=0 : no divergence
  Y=0,Y'=0 : sheet beam

- Laser (gaussian)
  Laser length 100fs
  Transverse size 1mm

- Simulation particles
  30000

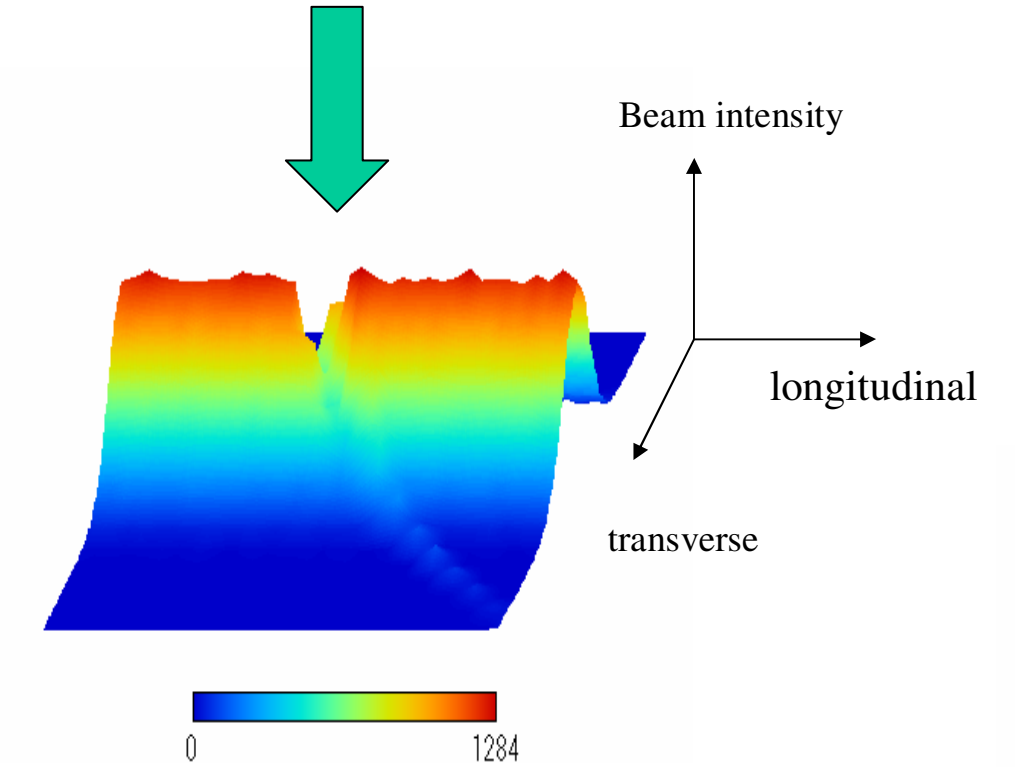
Beam Separation

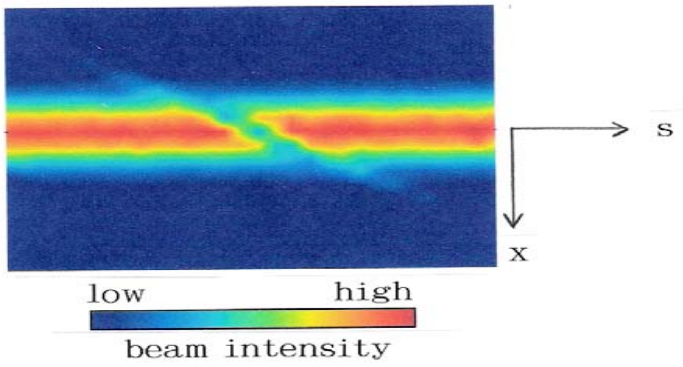
- After the energy modulation, the beam passes 2 bend magnets and 2 quadrupoles magnets.
- Output beam profile after the second bend magnet are calculated by transfer matrix method.

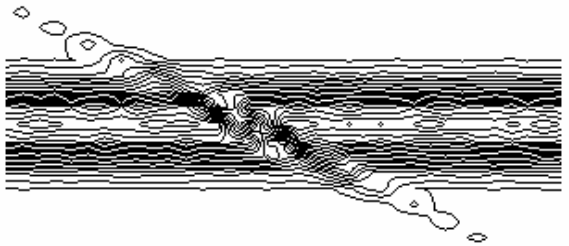


Beam Structure at the observation point

Dip by Laser







Contour map per 5% step shows two side beams .
Those will produce ~100fs SR.

Conclusions

- This is a preliminary simulation with several assumptions.
- The beam slice seems to be possible at PF-AR 3 GeV operation.
- The detail estimation is not yet done.
- The study to optimize parameters will be performed.