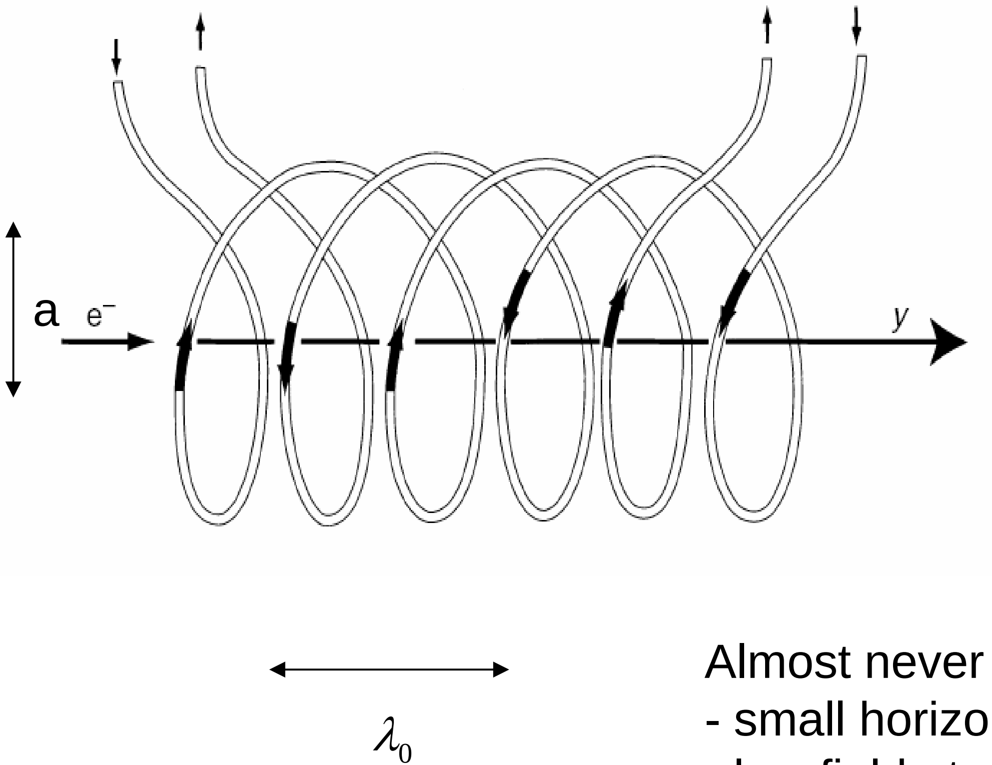
IV
Variable polarisation and other exotic Insertion Devices

Pascal ELLEAUME

European Synchrotron Radiation Facility, Grenoble

Helical Undulator using Bifilar Helix



A bifilar Superconducting
Helical Undulator
was used In 1972
for the first FEL
at HEPL, Stanford
known since1950s
Fixed Helicity

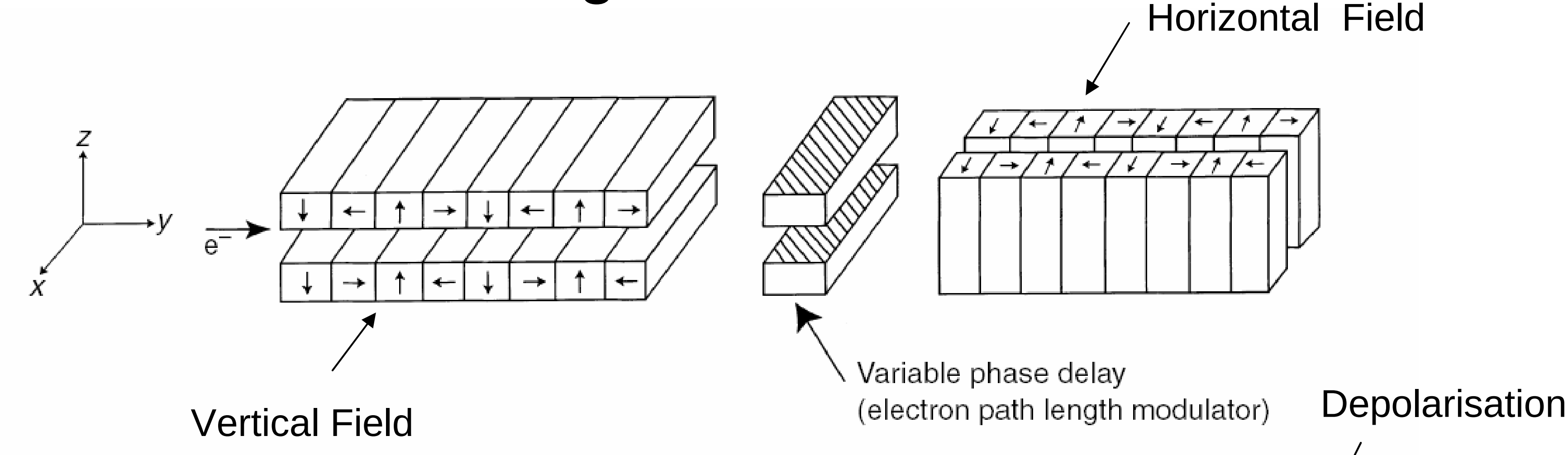
$$B_{\perp} = \frac{4\pi}{10\lambda_0}\left[(\frac{2\pi a}{\lambda_0})K_0(\frac{2\pi a}{\lambda_0}) + K_1(\frac{2\pi a}{\lambda_0}) \right]$$

Almost never used in synchrotron Sources :
- small horizontal aperture
- low field at room temperature
- no variation of polarisation

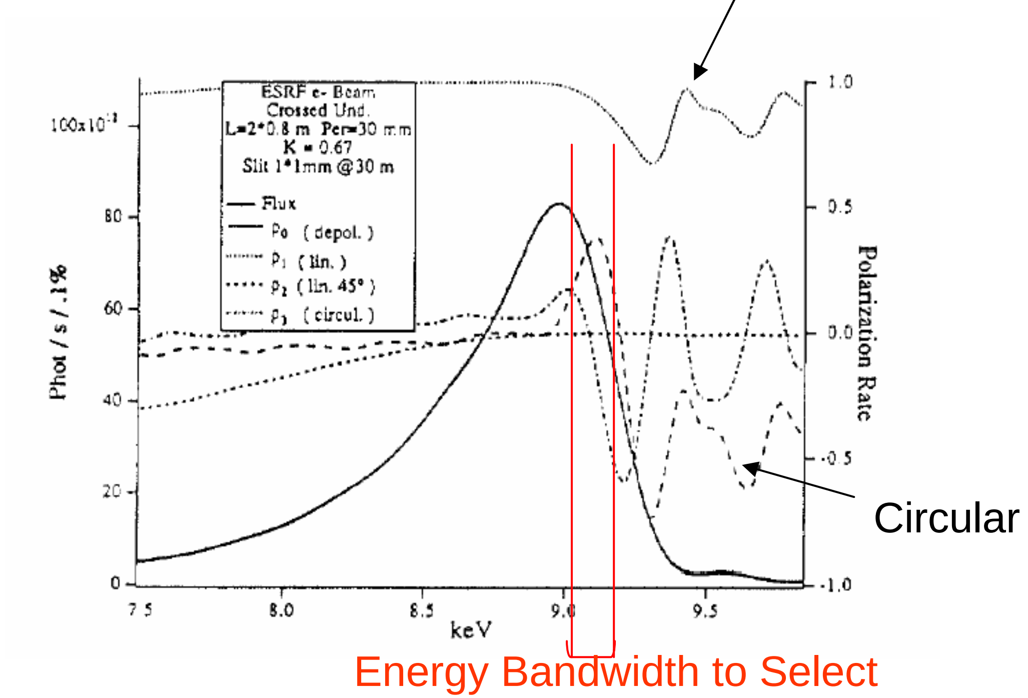
See L.R. Elias, J.M.J. Madey, Rev. Sci. Instrum. 50(11), Nov. 1979

- Beamline scientist are asking for variable polarization insertion devices which can produce :
  - Circular polarisation (left or right)
  - Linear polarisation (horiz, vertical, inclined)
  - Slow or fast switching of polarisation
  - High brilliance (=> preferably undulators)

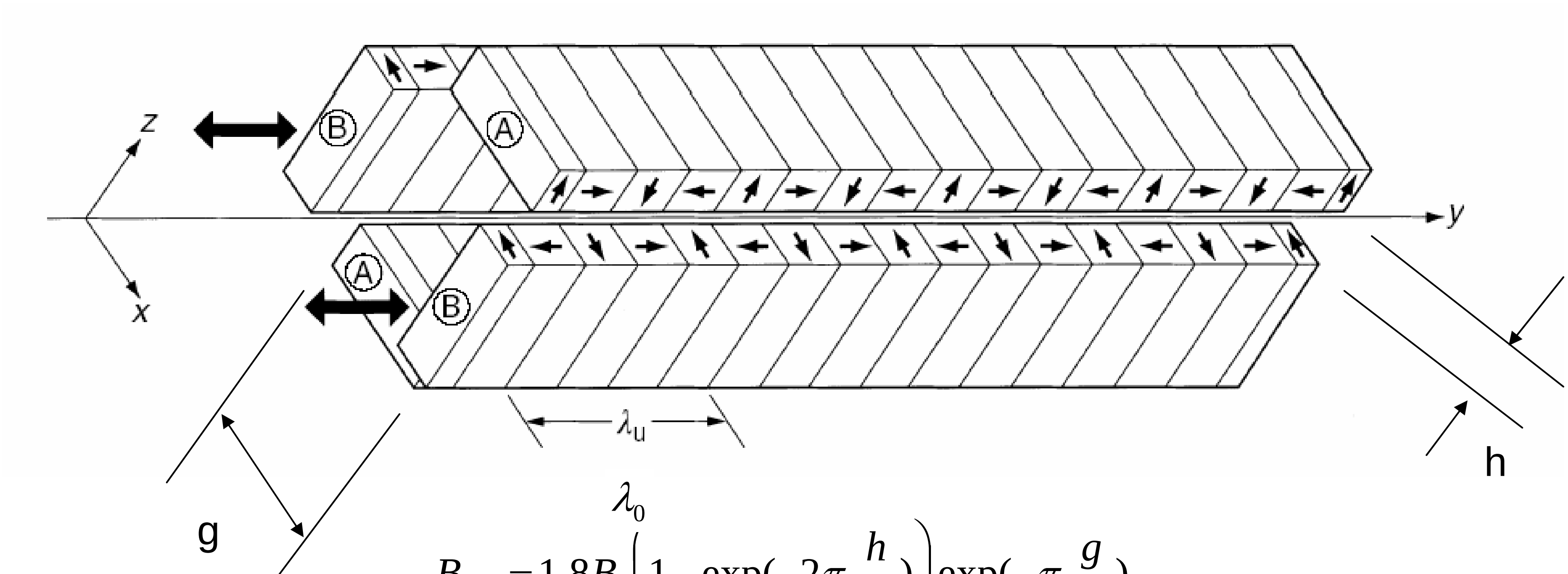
Crossed Undulator (K.J. Kim)
Fast Switching of Polarisation



- polarisation varies over a narrow wavelength range.
- strong depolarisation by emittance and energy spread.
- can only be used at very low energy.



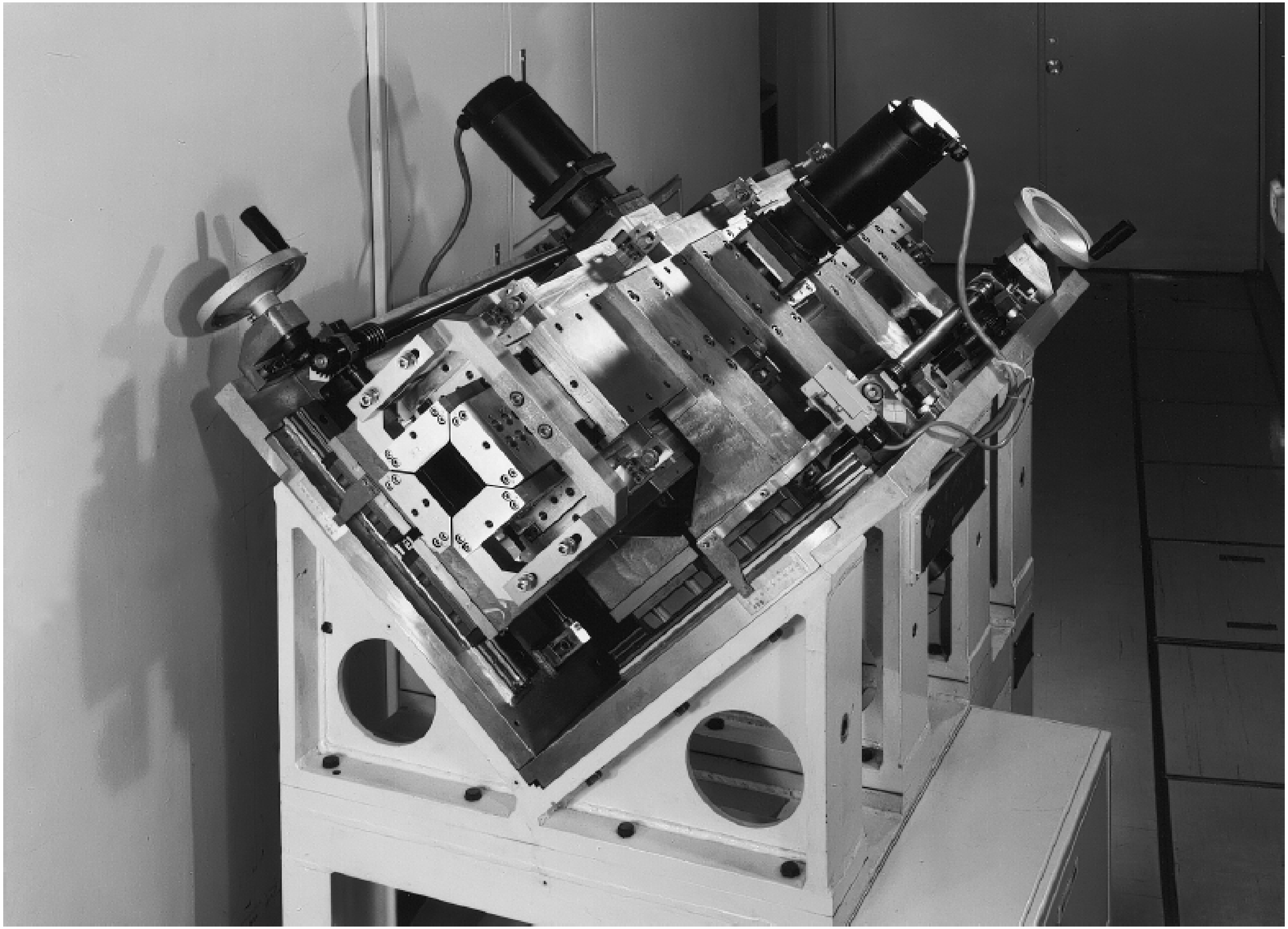
Two Orthogonal Permanent Magnet Planar Undulators



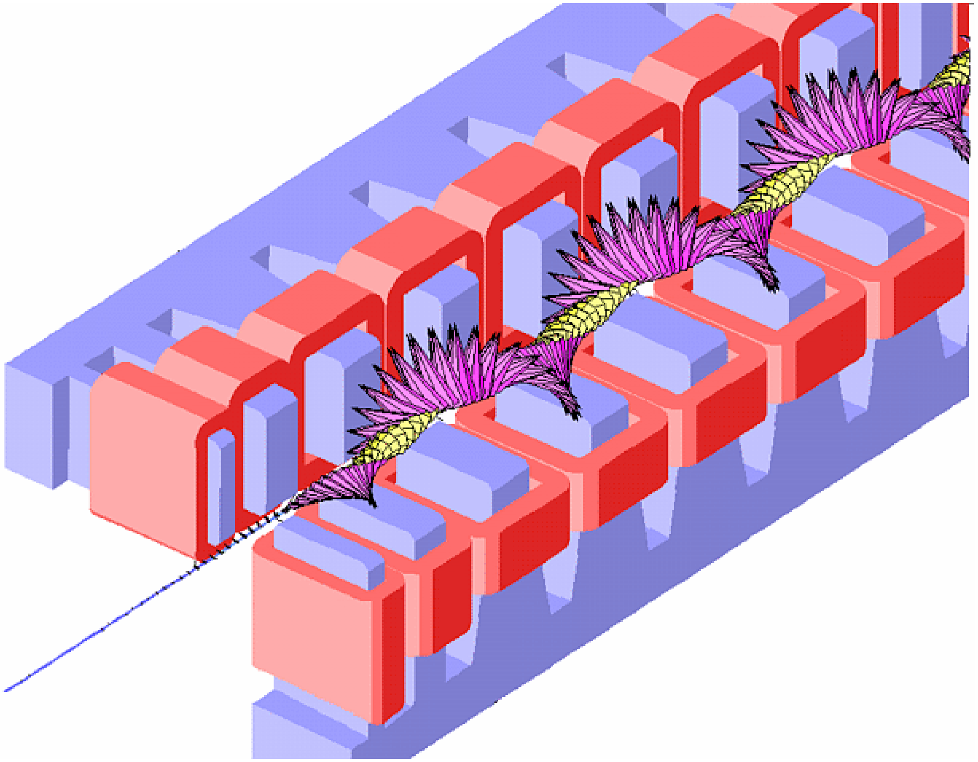
$$B_{x,y} = 1.8 B_r \left(1 - \exp(-2\pi \frac{h}{\lambda_0}) \right) \exp(-\pi \frac{g}{\lambda_0})$$

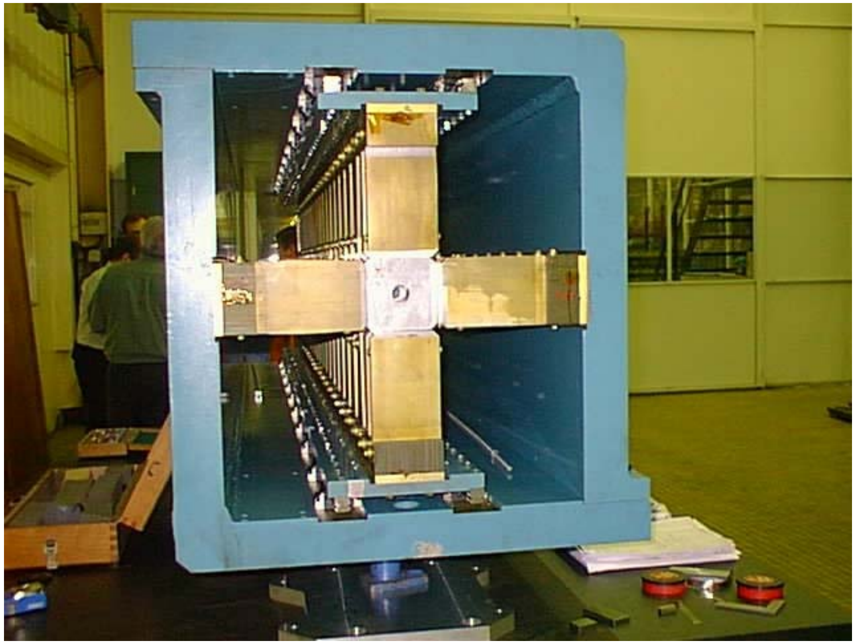
Variable Polarization Undulator (circular, elliptical, linear)
Inefficient in terms of gap and period, suitable for low energy

Onuki, H., *Nucl. Instrum. Meth*. **A 246**, 94 (1986).



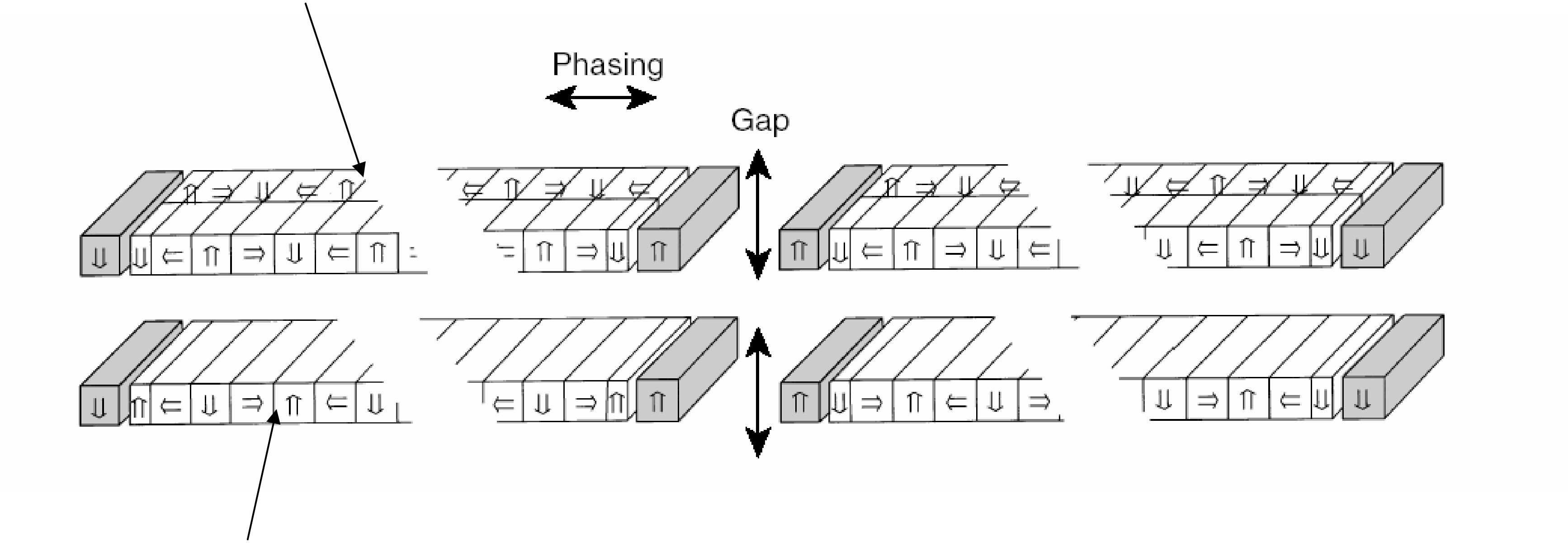
Electro-magnet Helical undulator (Ophelie at LURE)





ESRF Helios Type Undulator

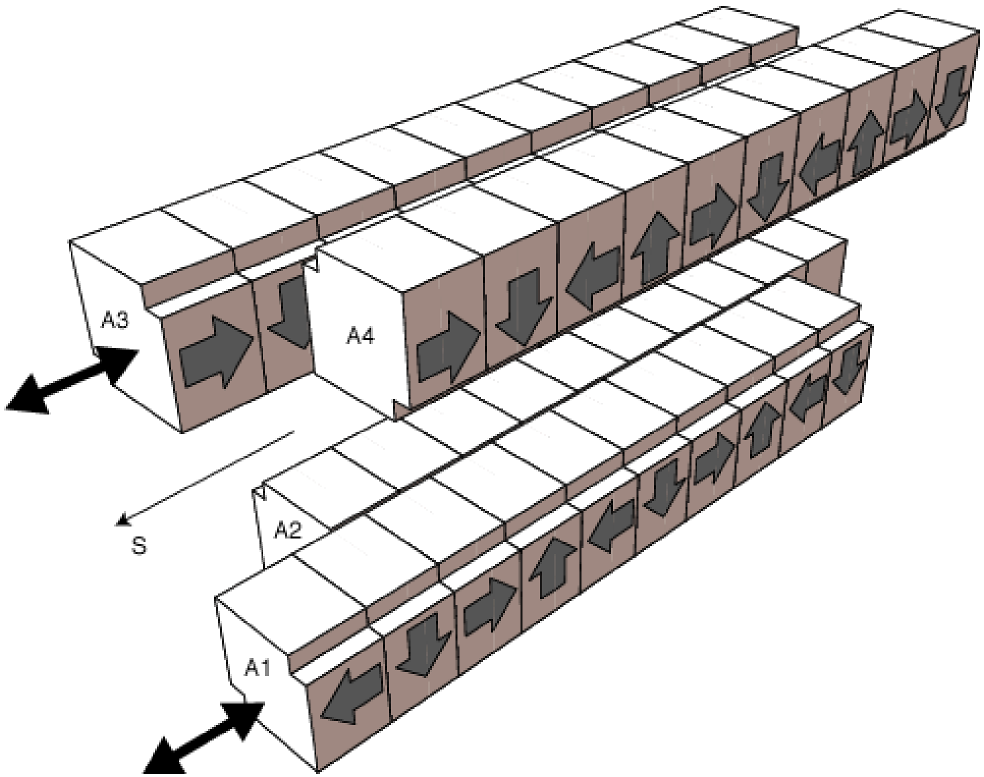
Horizontal Field

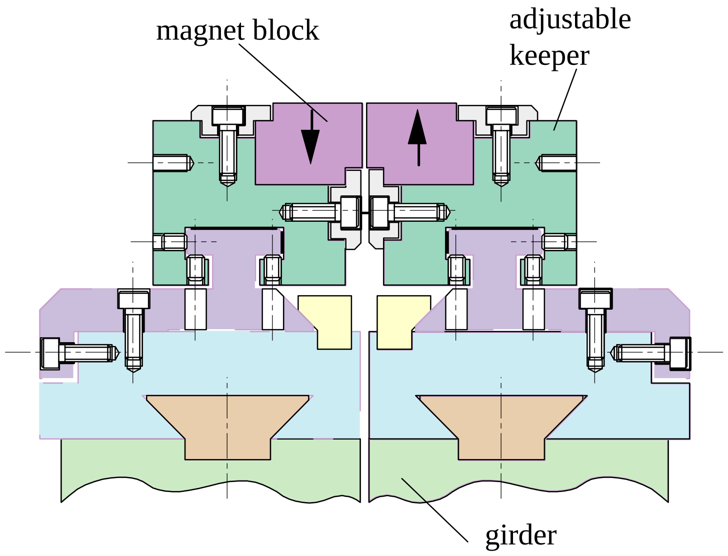


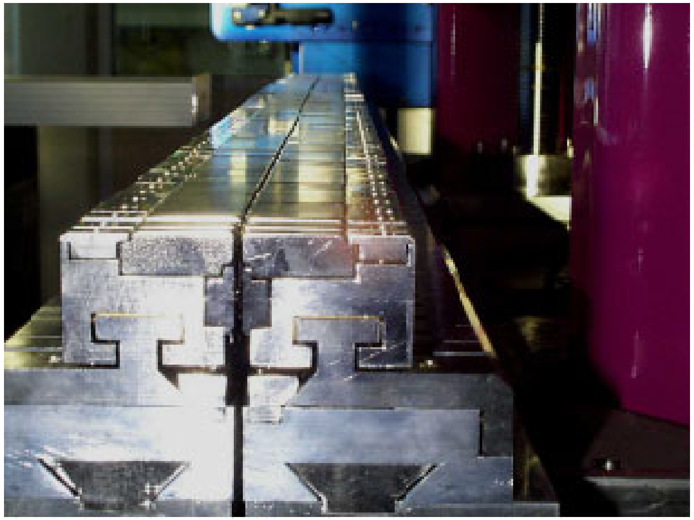
Vertical Field

- Simple to build & low magnetic forces
- Lower field than the Apple II
- Generates closed orbit distortion ~ $1/E^2$

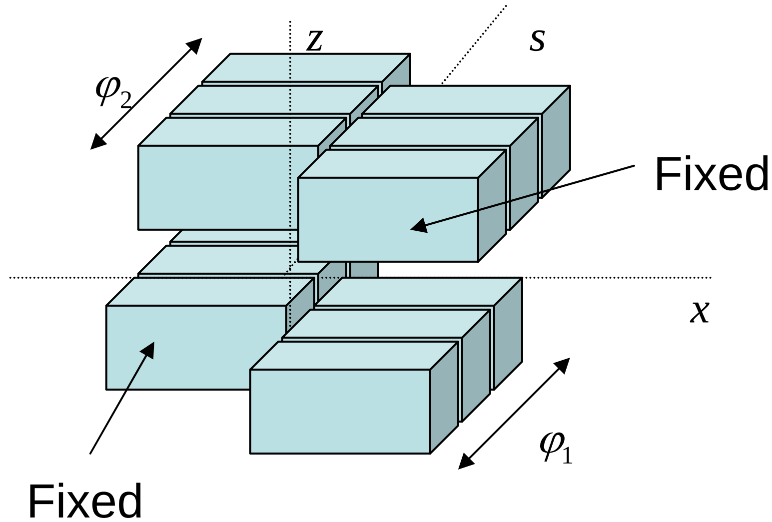
Apple II (Sasaki) Linear/helical Undulator







Very popular :
- High magnetic field (at given period and gap)
- Generates any polarization (linear,elliptical,..)
- The field error correction is now mastered even though delicate



$$[B_z(0,0,s), B_x(0,0,s)] =$$
$$\left[B_{z0}\cos(2\pi\frac{s}{\lambda_0}+\varphi_2), B_{x0}\cos(2\pi\frac{s}{\lambda_0}+\varphi_2)\right]+$$
$$\left[B_{z0}\cos(2\pi\frac{s}{\lambda_0}), -B_{x0}\cos(2\pi\frac{s}{\lambda_0})\right]+$$
$$\left[B_{z0}\cos(2\pi\frac{s}{\lambda_0}), -B_{x0}\cos(2\pi\frac{s}{\lambda_0})\right]+$$
$$\left[B_{z0}\cos(2\pi\frac{s}{\lambda_0}+\varphi_1), B_{x0}\cos(2\pi\frac{s}{\lambda_0}+\varphi_1)\right]$$

with B_{z0}, B_{x0} *function of the magnetic gap*

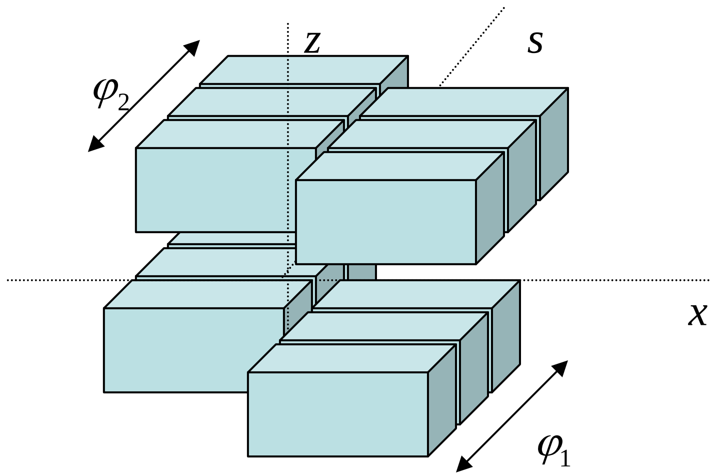
Symmetric Motion : $\varphi_2 = \varphi_1 = \varphi$

$$[B_z(s), B_x(s)] = \left[4B_{z0}\cos(\frac{\varphi}{2})\cos(2\pi\frac{s}{\lambda_0}+\frac{\varphi}{2}), -4B_{x0}\sin(\frac{\varphi}{2})\sin(2\pi\frac{s}{\lambda_0}+\frac{\varphi}{2})\right]$$

$\varphi = 0 \Rightarrow [B_z(s), B_x(s)] = \left[4B_{z0}\cos(2\pi\frac{s}{\lambda_0}), 0\right]$: *Vertical*

$\varphi = \pi \Rightarrow [B_z(s), B_x(s)] = \left[0, -4B_{x0}\sin(2\pi\frac{s}{\lambda_0})\right]$: *Horizontal*

$\varphi = \arctan(\frac{B_{z0}}{B_{x0}}) \Rightarrow [B_z(s), B_x(s)] = 4B\left[\cos(2\pi\frac{s}{\lambda_0}+\frac{\varphi}{2}), -\sin(2\pi\frac{s}{\lambda_0}+\frac{\varphi}{2})\right]$: *Helical*



Antisymmetric Motion : $\varphi_2 = -\varphi_1 = \varphi$

$$[B_z(s), B_x(s)] = \left[4B_{z0}\cos^2(\frac{\varphi}{2}), -4B_{x0}\sin^2(\frac{\varphi}{2})\right]\cos(2\pi\frac{s}{\lambda_0}) \quad : \quad \textit{Linear}$$

$$\varphi = 0 \quad \Rightarrow \quad [B_z(s), B_x(s)] = \left[4B_{z0}, 0\right]\cos(2\pi\frac{s}{\lambda_0}) : \quad \textit{Vertical}$$

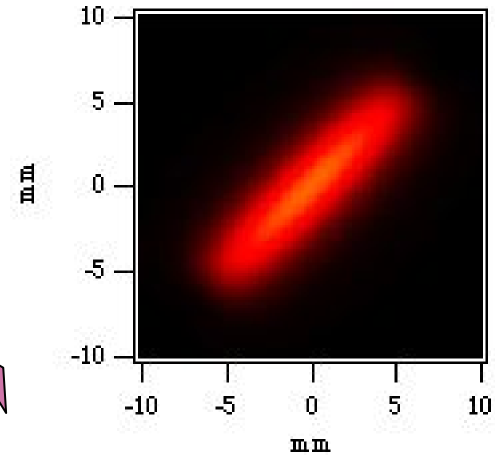
$$\varphi = \pi \quad \Rightarrow \quad [B_z(s), B_x(s)] = \left[0, -4B_{x0}\right]\cos(2\pi\frac{s}{\lambda_0}) : \quad \textit{Horizontal}$$

Radiation Pattern from Apple II

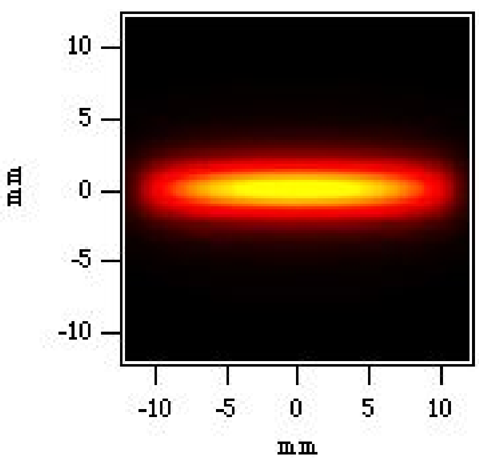
Apple II on the ESRF
Period : 88 mm
Gap : 16 mm,
Power density @ 30m

Vary φ, *with* $\varphi = \varphi_1 = -\varphi_2$

Linear incline Field & Polar.

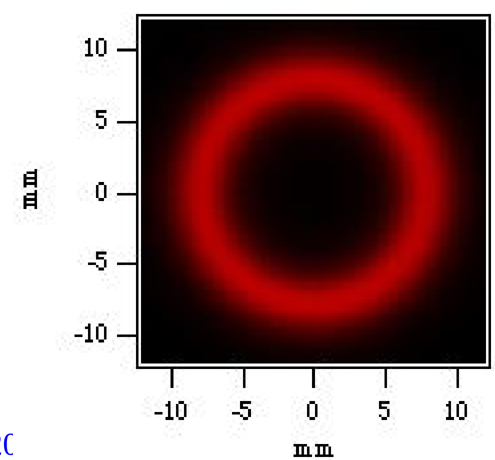


Vertical Field
Horizontal Traj. & Polar.

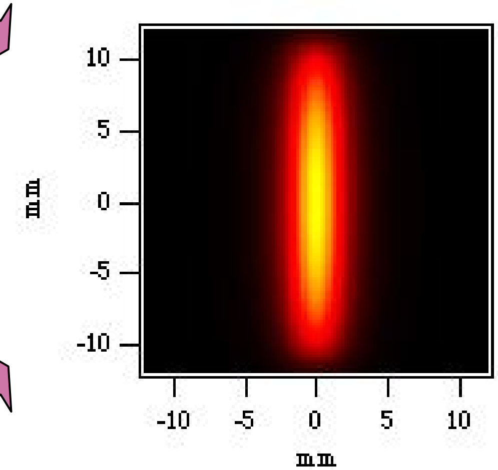


Vary φ, *with* $\varphi = \varphi_1 = \varphi_2$

Helical Field
Helical Traj. & Circul Polar.



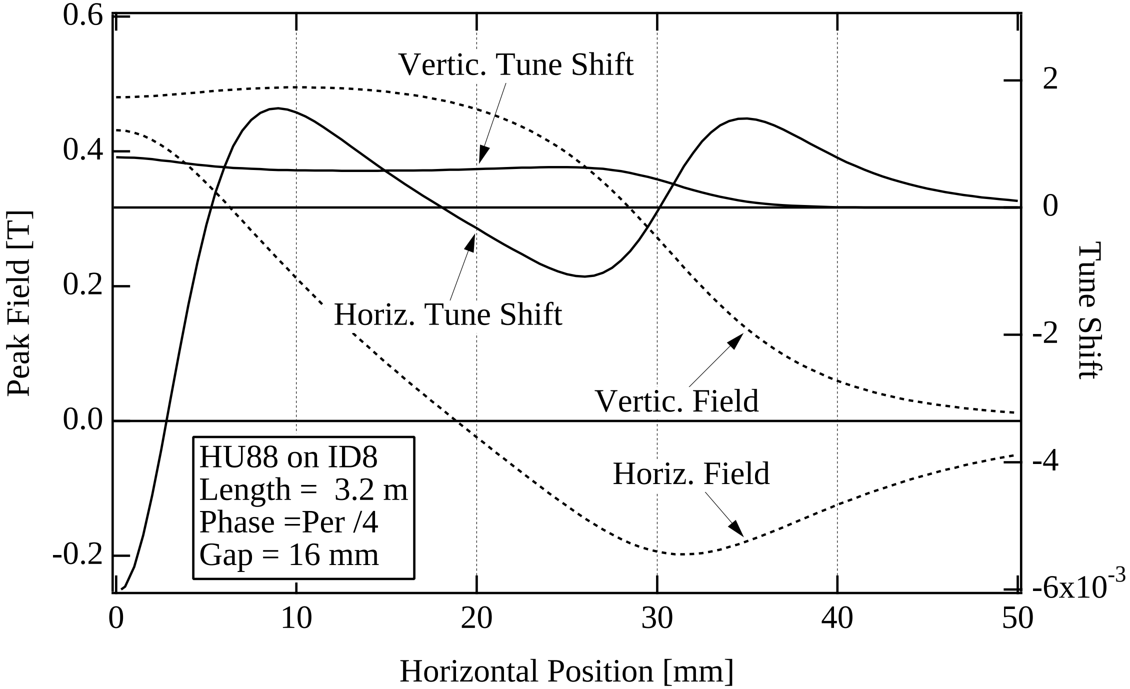
Horizontal Field
Vertical Traj. & Polar.



Vertical

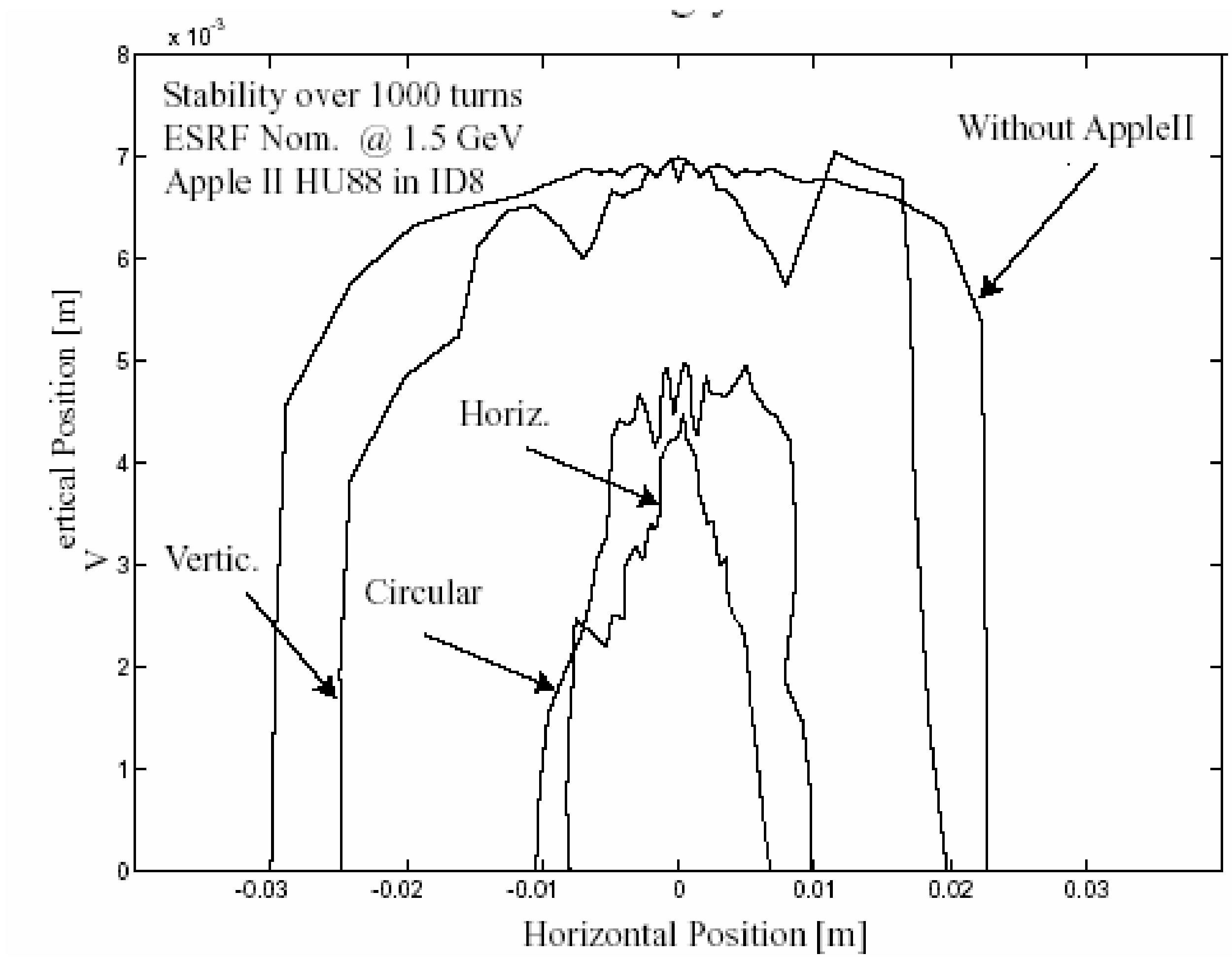
2nd Order Tune Shift of an Apple II at the ESRF

Horizontal Tune shift vary with phase => must be compensated on low energy rings

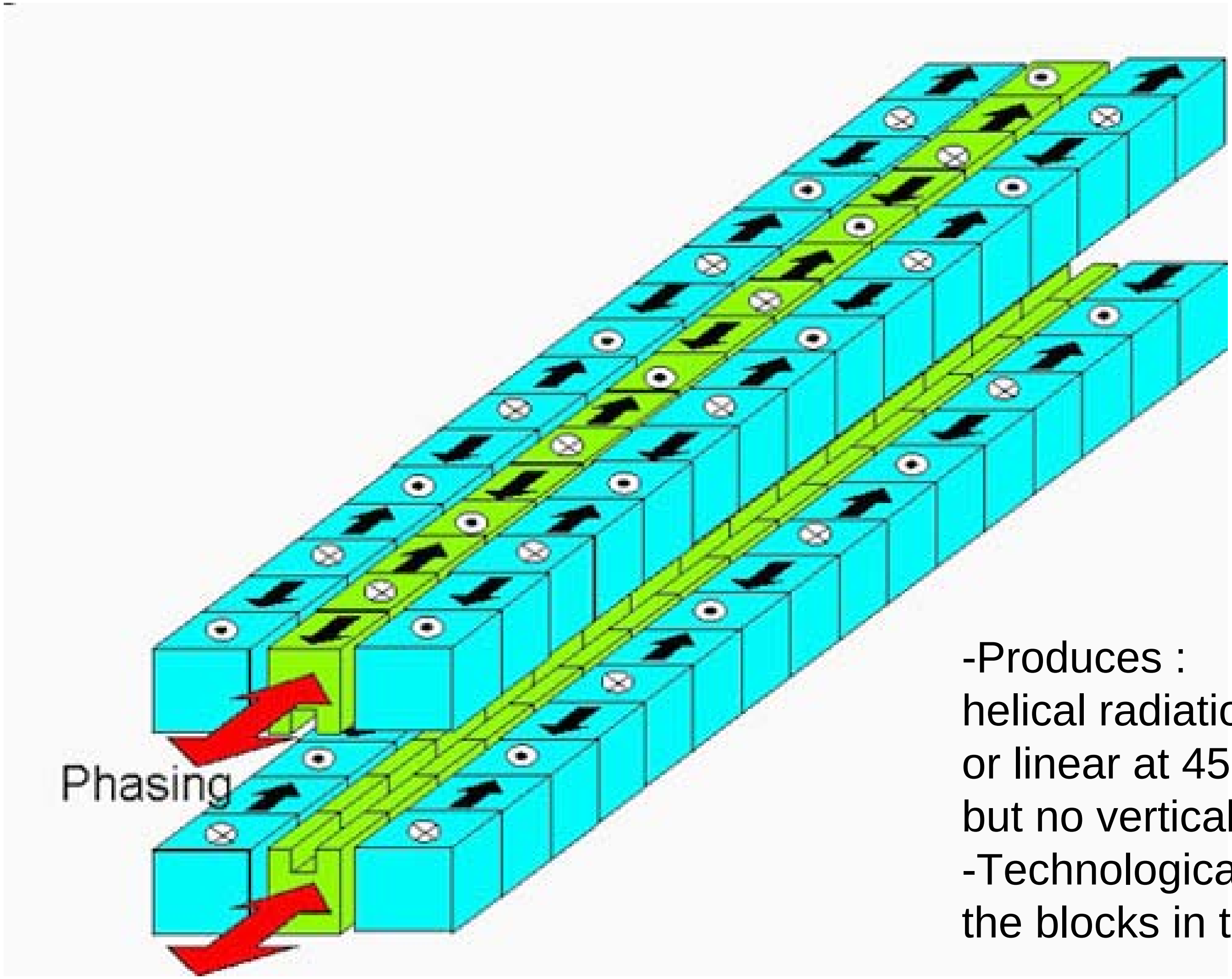


Period = 88 mm
Gap = 16 mm
Length = 3.2 m
Energy = 6GeV
Betax,z = 35, 2.5 m

Apple II may reduce the dynamic aperture

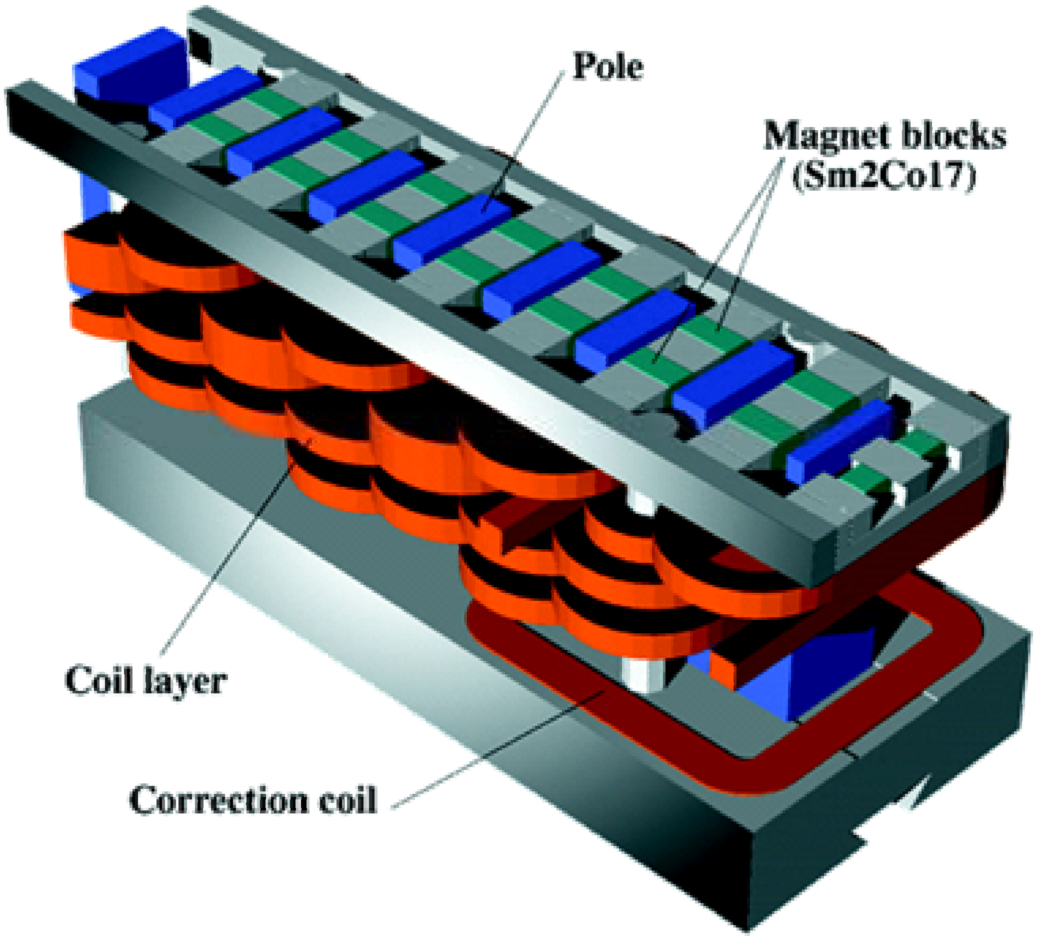


Spring8 type Linear/Helical Undulator



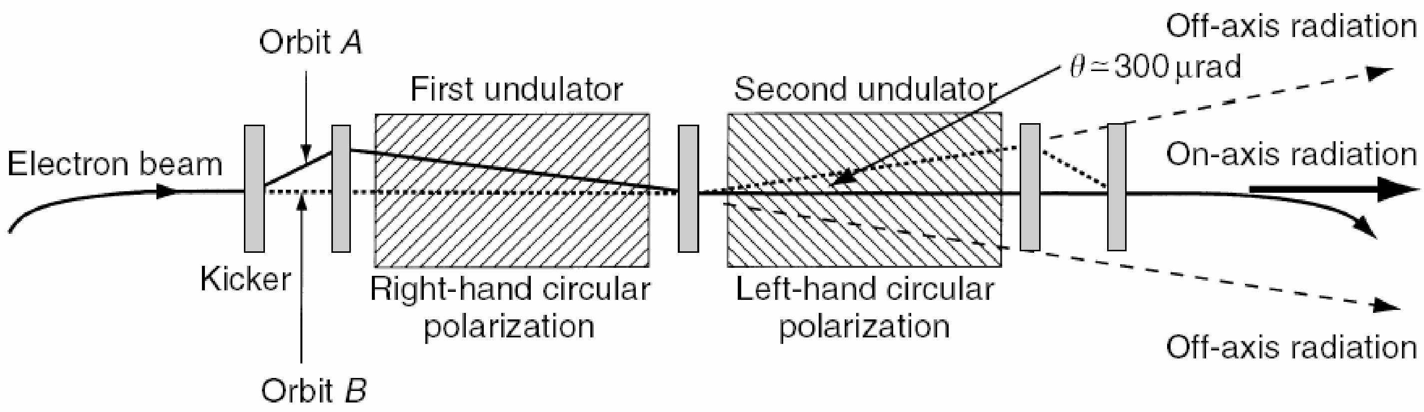
-Produces :
helical radiation
or linear at 45 degrees
but no vertical or horizontal
-Technological difficulties to hold
the blocks in the middle raw

Fast Switching electromagnet/permanent magnet helical undulator



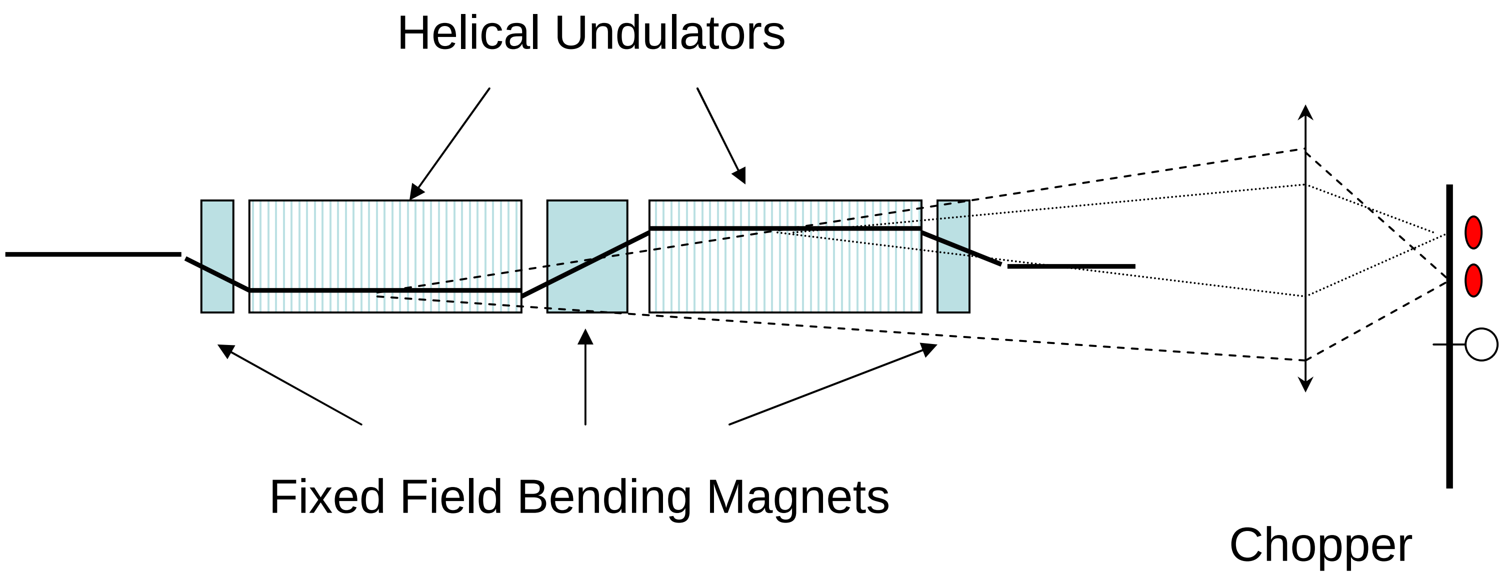
Field : 0.2 T
Period : 80 mm
Gap : 16 mm
Current : 250 A
Designed for 10 Hz flipping

Fast Switching by Electron Beam Deviations



Induces perturbations to all other beamlines if not tuned precisely !

Fast Switching using Chopper



- No perturbation to the electron beam
- Requires very high quality optics
- Adequate only for low/medium energy ring (length of the bending magnets)

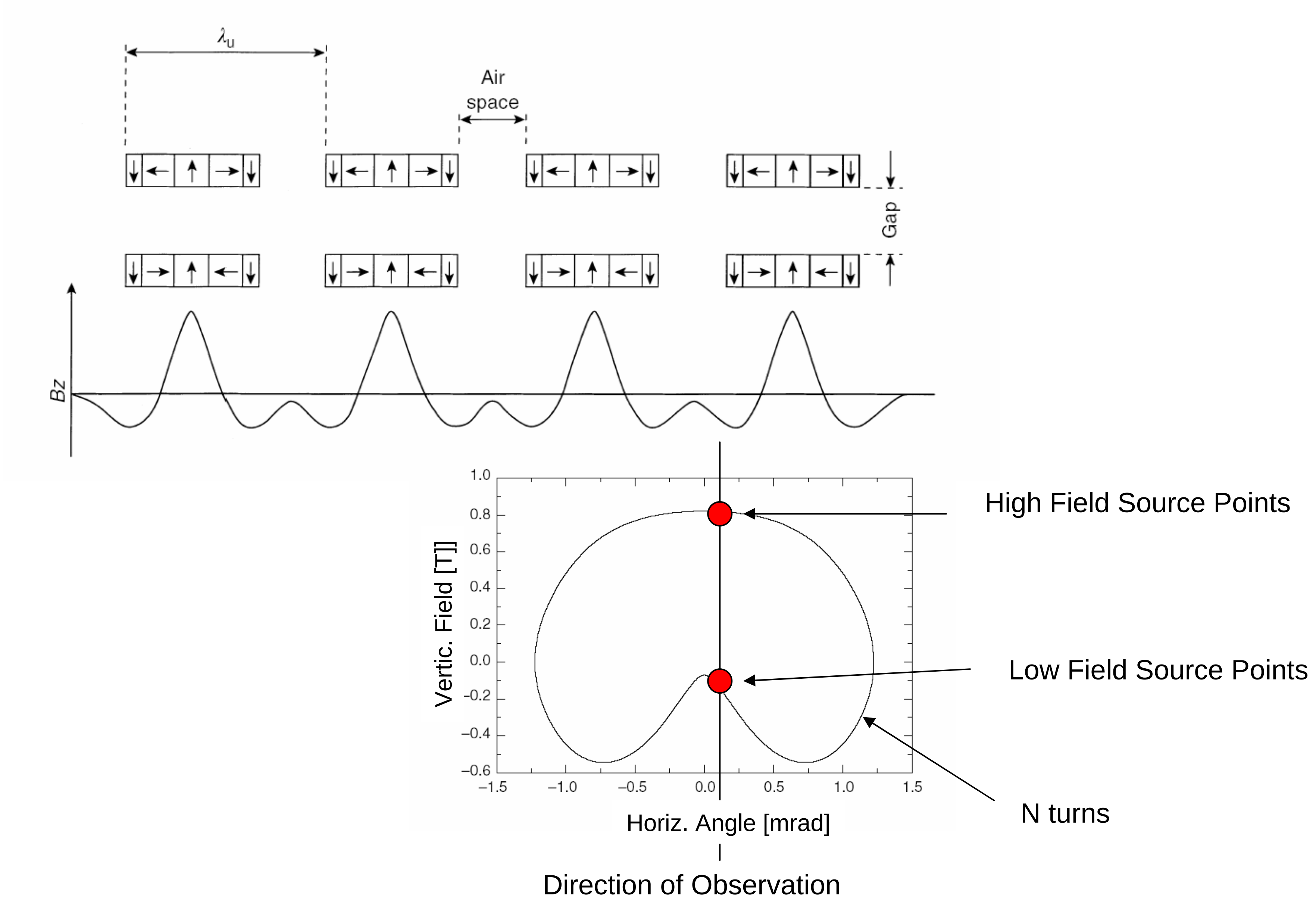
Wiggler Sources of Circular Polarisation

- The radiation from wigglers is less brilliant than helical undulators but the only way to produce circularly polarized radiation at high energy.

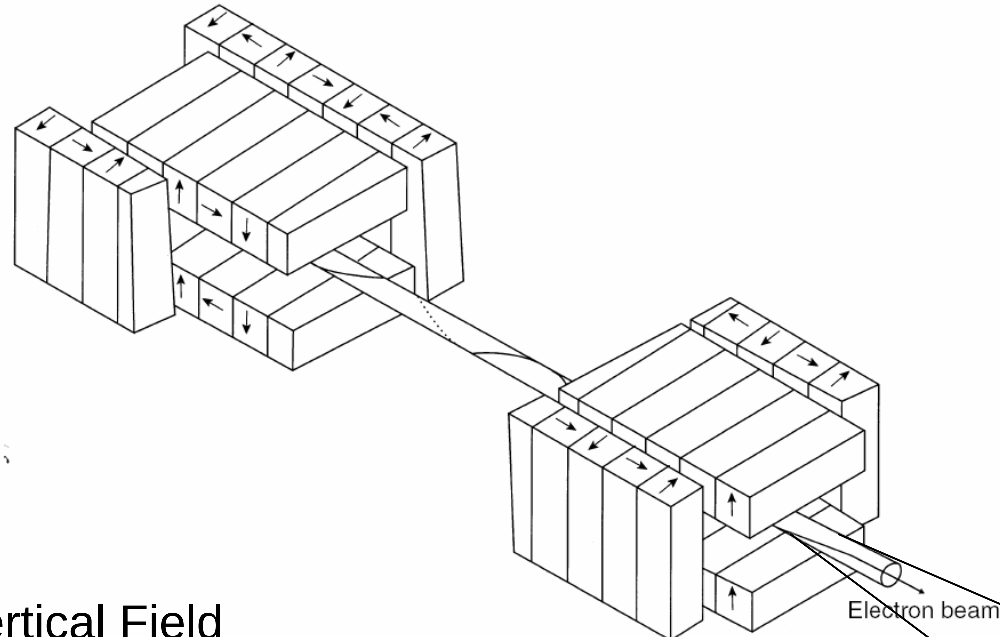
- Based on the bending magnet radiation right (left) circularly polarized when observed below and above the orbit plane.

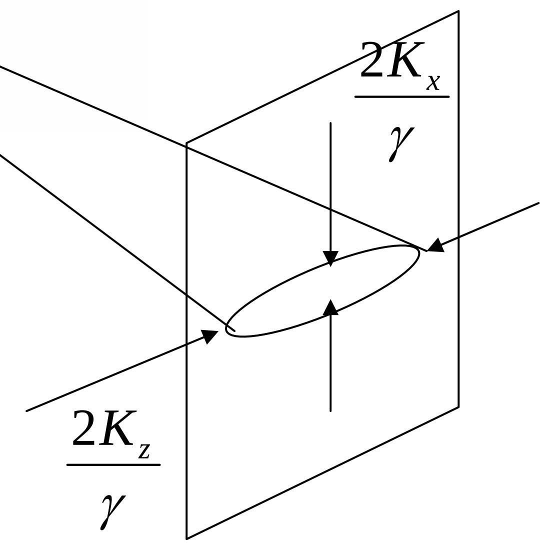
- Two types of devices are used
  - Asymmetric wigglers
  - Ellipsoidal wigglers

Asymmetric Wiggler



Ellipsoidal Wiggler





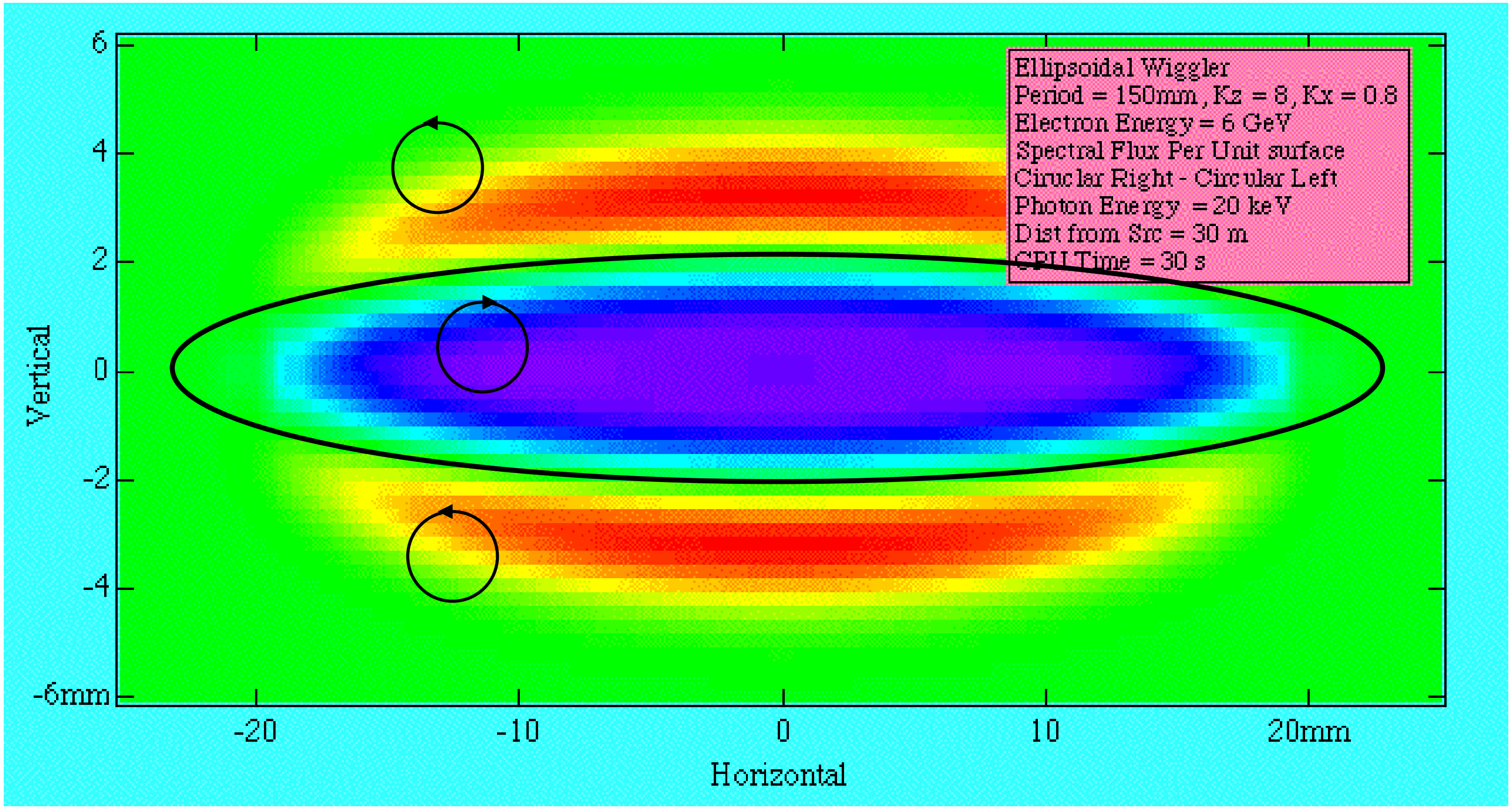
High Vertical Field
Low Horizontal Field
Same period but
Phase shifted by 90 deg

$$K_x \sim 1$$

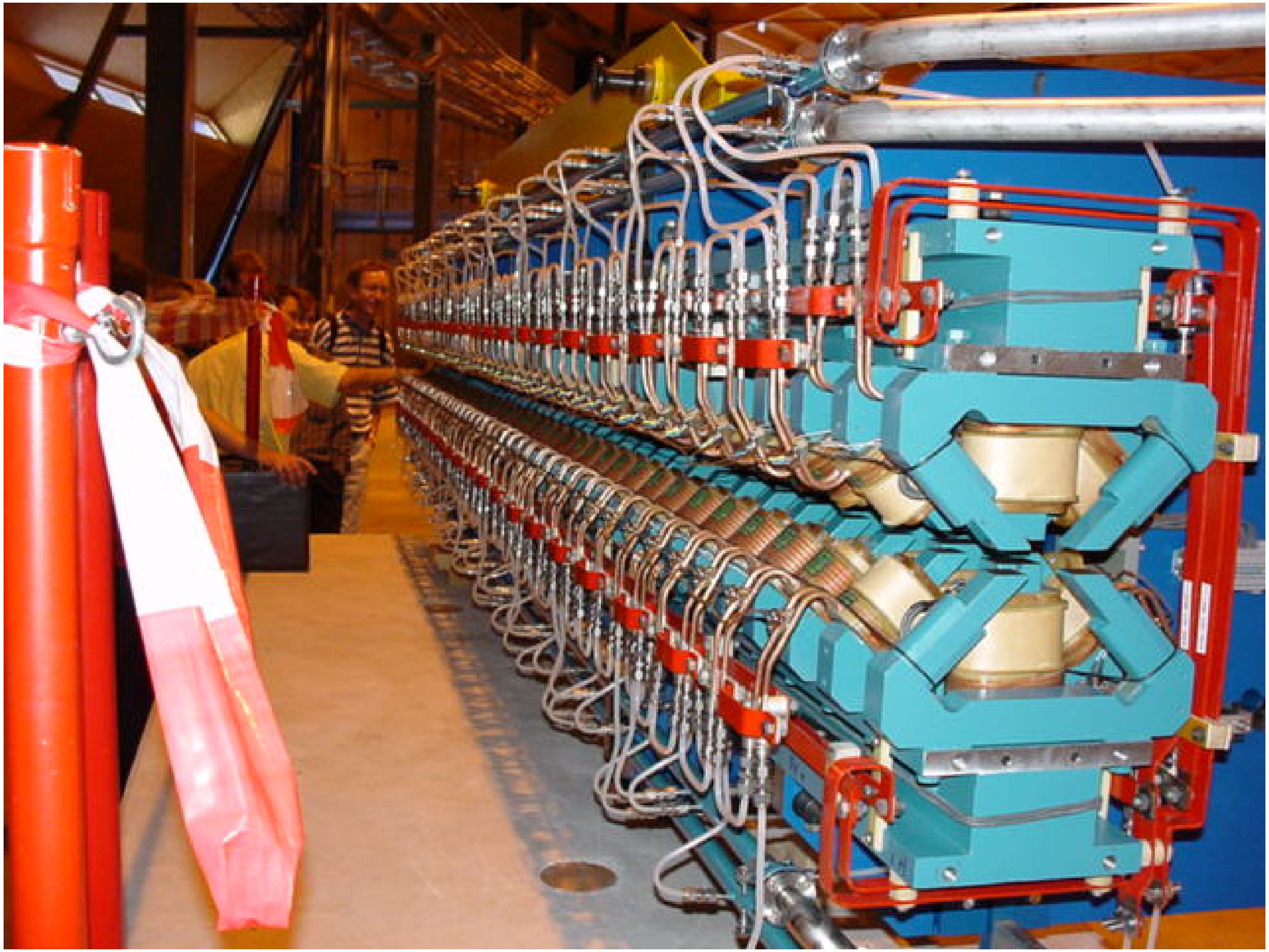
$$K_z \sim 5-20$$

Radiation from Ellipsoidal Wiggler

Period = 150 mm
Kz = 8
Kx = 0.8



ELETTRA / SLS Helical Undulator/Wiggler



Ellipsoidal Wiggler vs Asymmetric Wiggler

- An ellipsoidal wiggler has two source points per period (one for asymmetric wiggler).
- Ellipsoidal is used on-axis => no multiple source points.
- Radiation from ellipsoidal wigglers is used on a maximum of flux => less sensitivity to closed orbit distortion.
- An asymmetric wiggler is simpler mechanically but much more delicate magnetically => can generate large field integrals