Possibilities for Insertion Devices at the APS

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Magnetic Devices Group
Advanced Photon Source

Type of Insertion Devices

- Wavelength Shifter (Superconducting Wiggler)

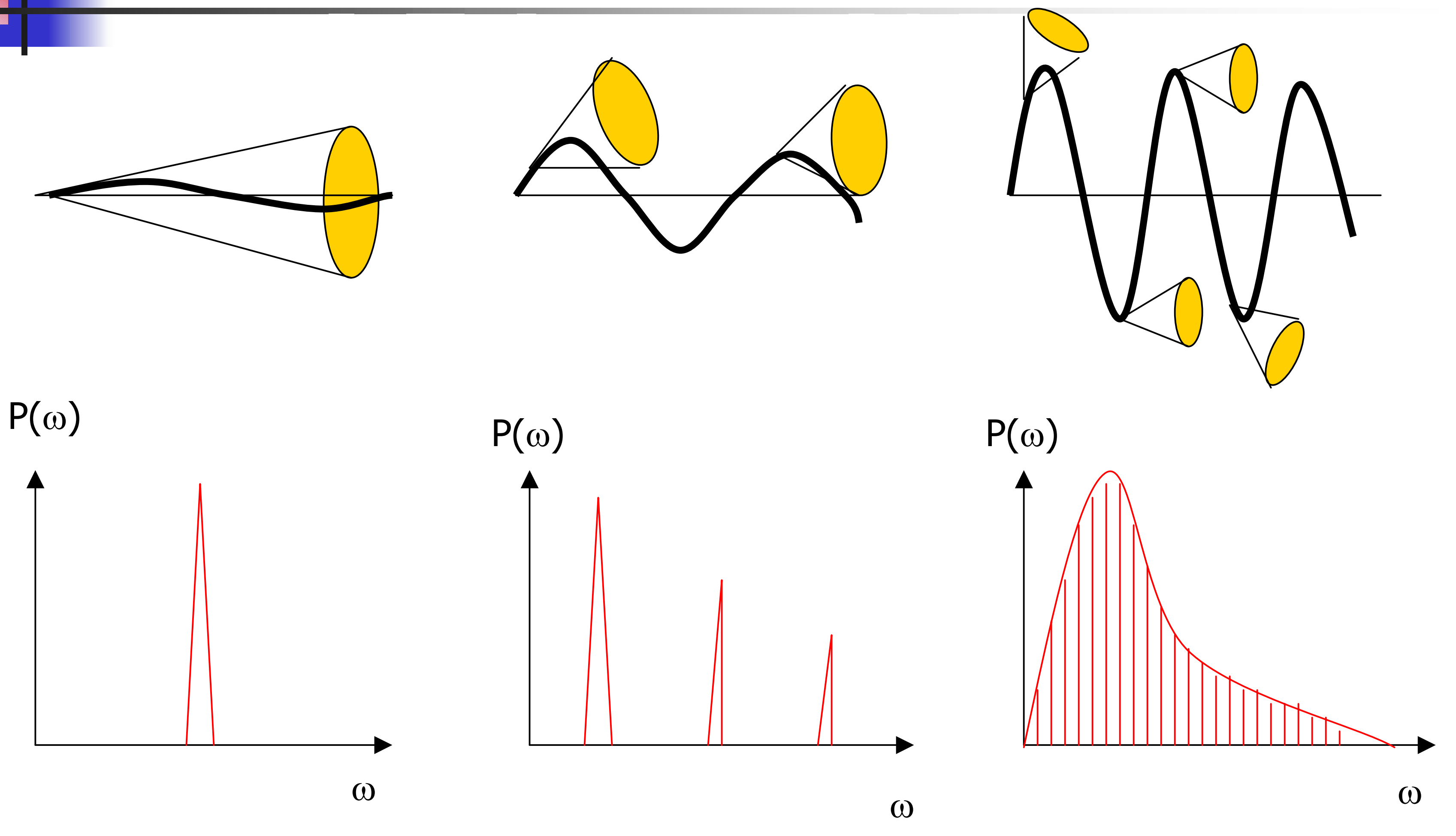
- Multipole Wiggler

  Planar or Elliptical Device
- Undulator

  Planar Device (Periodic or Quasi-periodic)
  Elliptical (Variable Polarization) Device
  Figure-8
- Magnet Technology

  Electromagnetic (Super or Normal), Permanent Magnet
  In-vacuum device

Principle of Radiation



Important Equations

Critical Energy of Wiggler Radiation

$$\mathcal{E}_c[\text{keV}] = 0.667\,E[\text{GeV}]^2\,B_0[\text{T}]$$

Undulator Radiation

$$K = 0.934 B_0[\text{T}]\lambda_u[\text{cm}]$$

$$\mathcal{E}_1[\text{keV}] = 0.95\frac{E[\text{GeV}]^2}{\left(1+\frac{K_x{}^2}{2}+\frac{K_y{}^2}{2}\right)\lambda_u[\text{cm}]}$$

Total Power

$$P_T[\text{kW}] = 0.633\,E[\text{GeV}]^2\,B_0[\text{T}]^2\,L[\text{m}]I[\text{A}]$$

On-axis power density of elliptical device

On axis power density of elliptical undulator is written as:

$$\boldsymbol{P_{den}(0,0)=8.448\times10^{-2}NE^4(K_x^{\,2}+K_y^{\,2})F/\lambda_u}\quad \textbf{[W]},$$

N is a number of periods, E is an electron energy in [GeV], λ_u is an undulator period length in [m].

$$F=\int_{-\pi}^{\pi}\left\{\frac{L_y^{\,2}\sin^2\alpha+L_x^{\,2}\cos^2\alpha}{D^3}-\frac{\left(L_xK_x-L_yK_y\right)^2\sin^2 2\alpha}{D^5}\right\}d\alpha$$

$$D=1+K_x^{\,2}\sin^2\alpha+K_y^{\,2}\cos^2\alpha$$

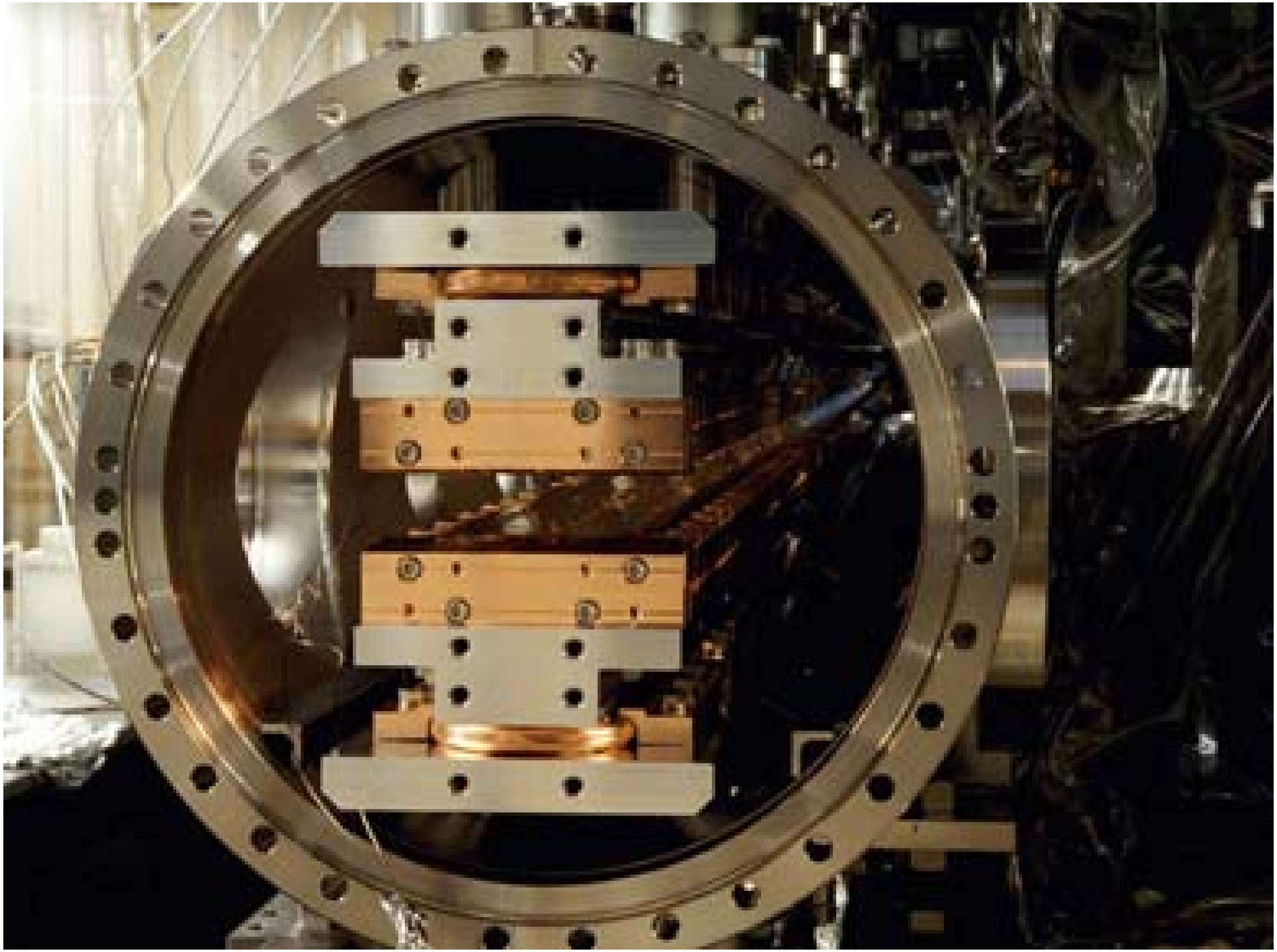
$$L_y=\frac{K_y}{\sqrt{K_x^{\,2}+K_y^{\,2}}}\qquad\qquad L_x=\frac{K_x}{\sqrt{K_x^{\,2}+K_y^{\,2}}}$$

K_x=93.4B_x[T]λ_u[m], K_y=93.4B_y[T]λ_u[m]

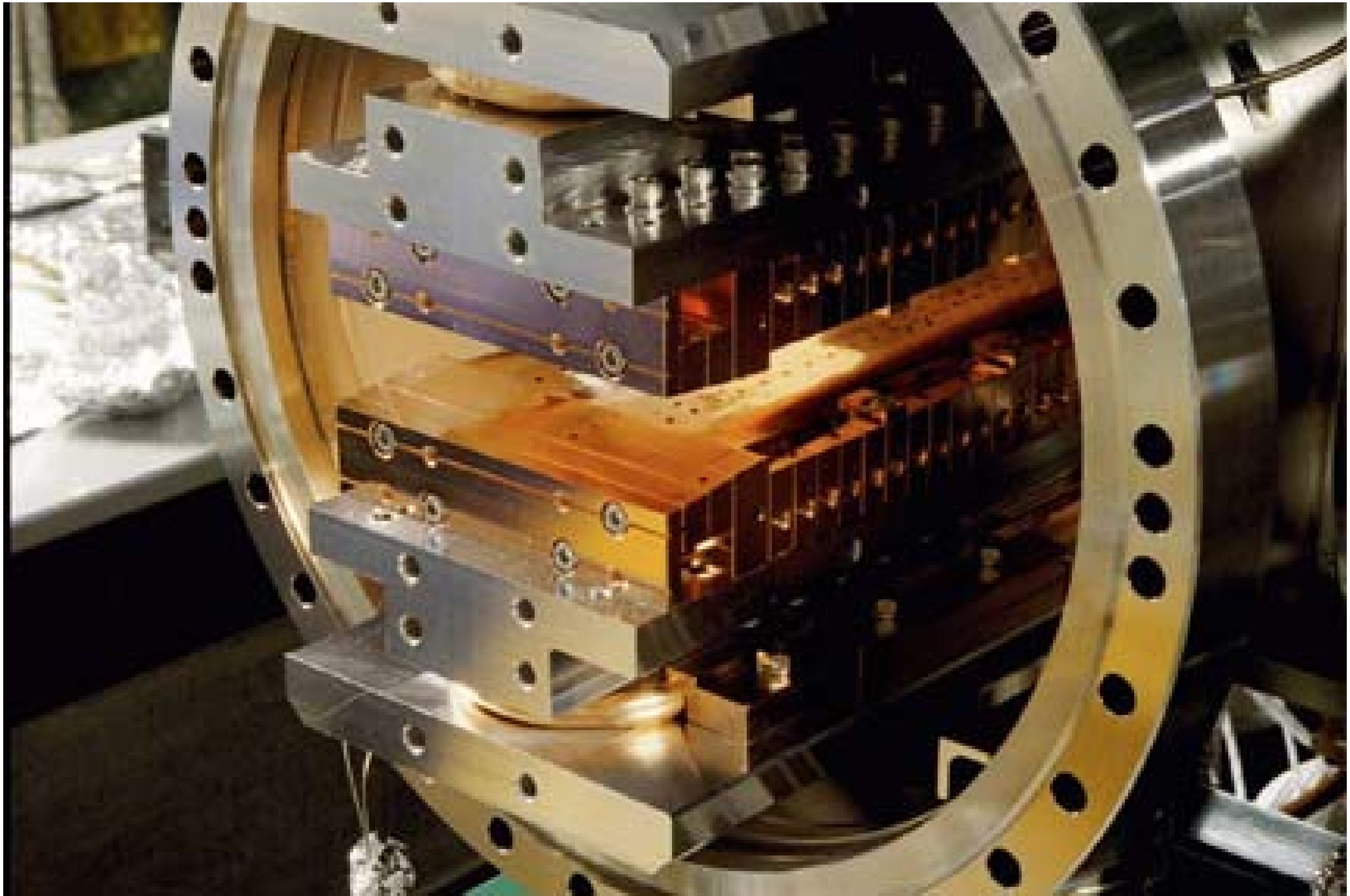
Special devices installed in various facilities

- APPLE-II (Variable polarization device)
  SSRL, SPring-8, ALS, SRRC, ELETTRA,
  ESRF, BESSY, PLS, CLS
- Quasi-Periodic Undulator
  ELETTRA, ESRF, BESSY, SLS
- Figure-8 Undulator
  SPring-8, ELETTRA
- In-Vacuum Undulator
  NSLS, SPring-8, ESRF, SLS
- Electromagnetic Helical Undulator (Wiggler)
  APS, ELETTRA

Spring-8 in-vacuum undulator



50 μm nickel foils with 10 μm copper coating are put on the magnet surfaces.



RF-finger for In-vacuum undulator

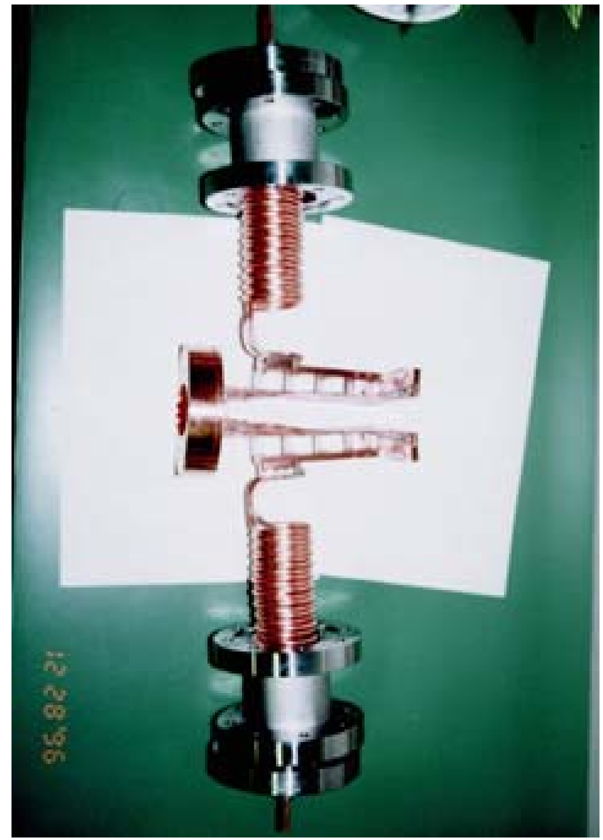
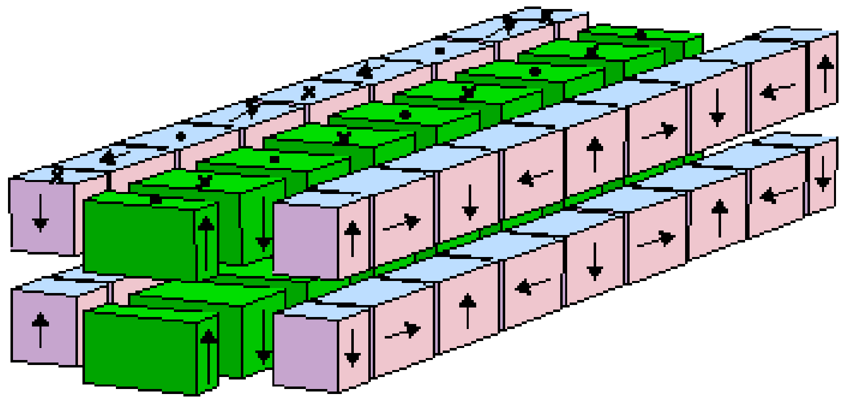
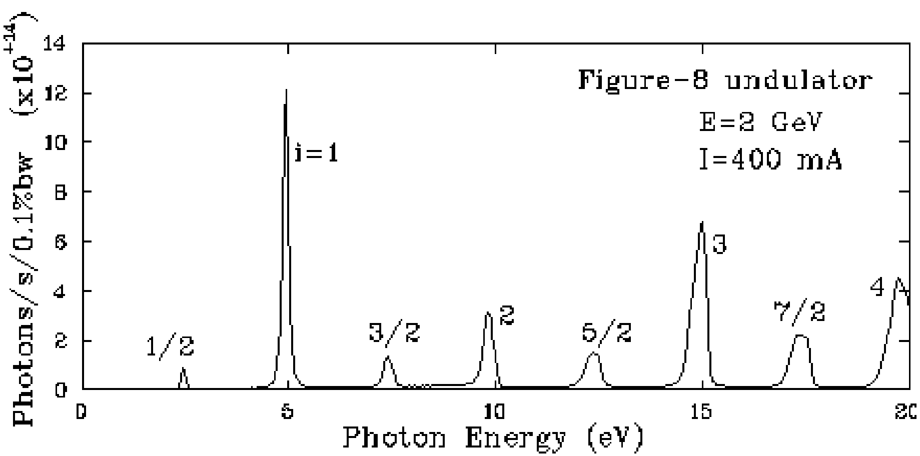
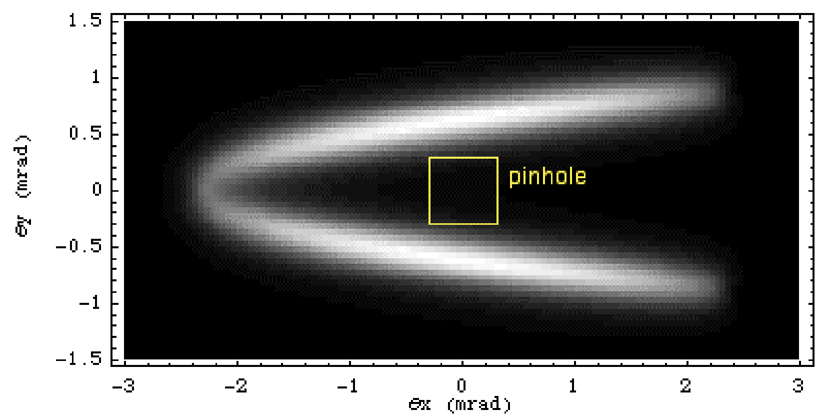


Figure-8 Undulator



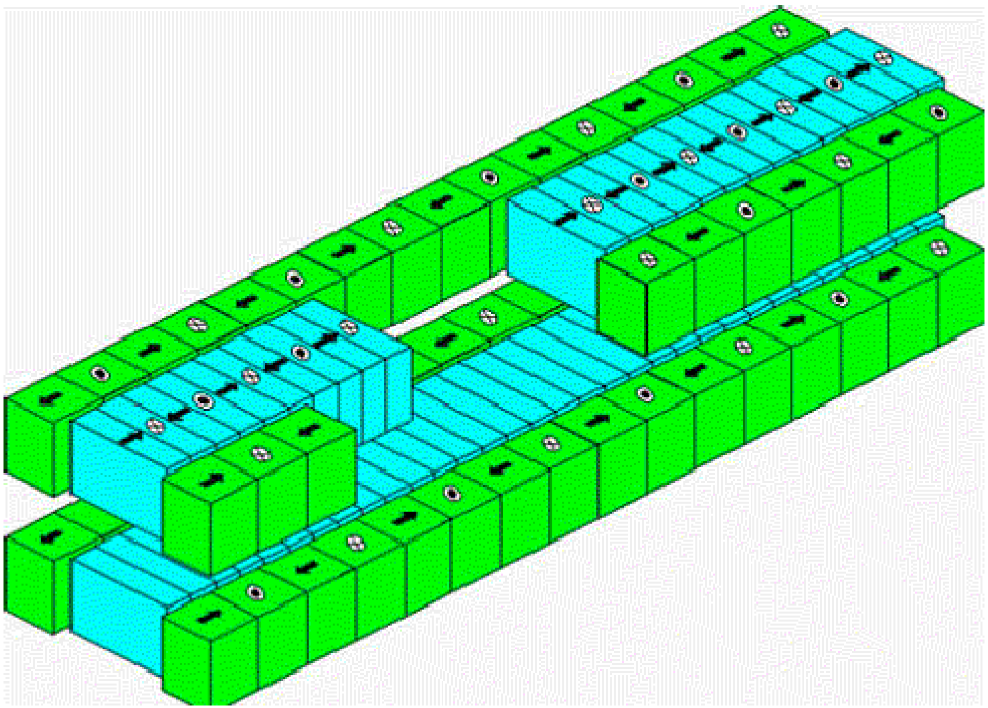


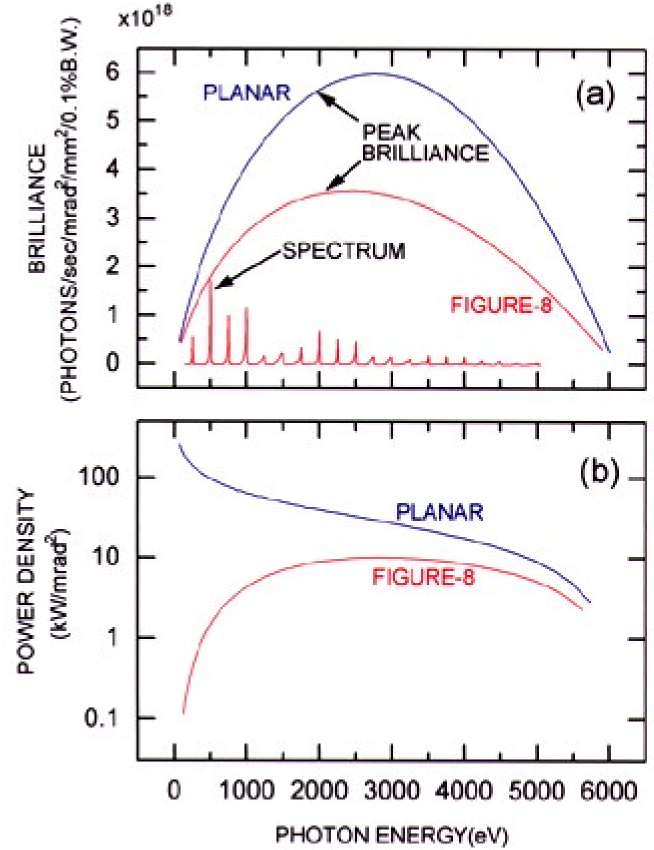


Spring-8 BL27SU Light Source

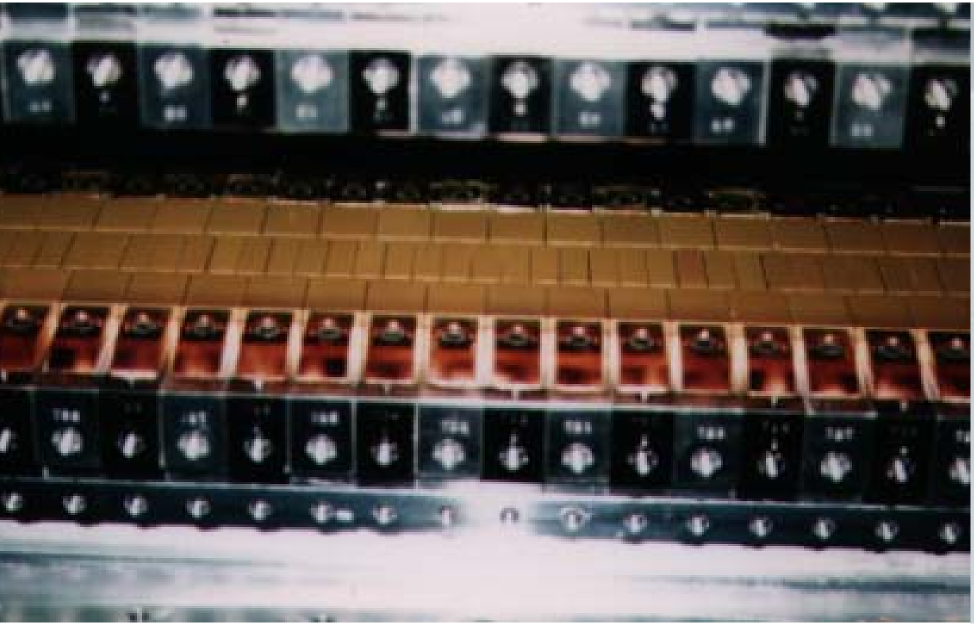
Type	Figure-8 undulator
Undulator period	100 mm
Number of periods	44
Tunable energy range	0.17 ~ 5.8 keV
Peak Brilliance	1.1×10^{19} phs/s/mrad^2/mm^2/0.1% b.w. (at 1st harmonic 500 eV)
Total power	2.7 kW (at 1st harmonic = 500 eV)
Power density	1.7 kW/mrad2 (at 1st harmonic = 500 eV)

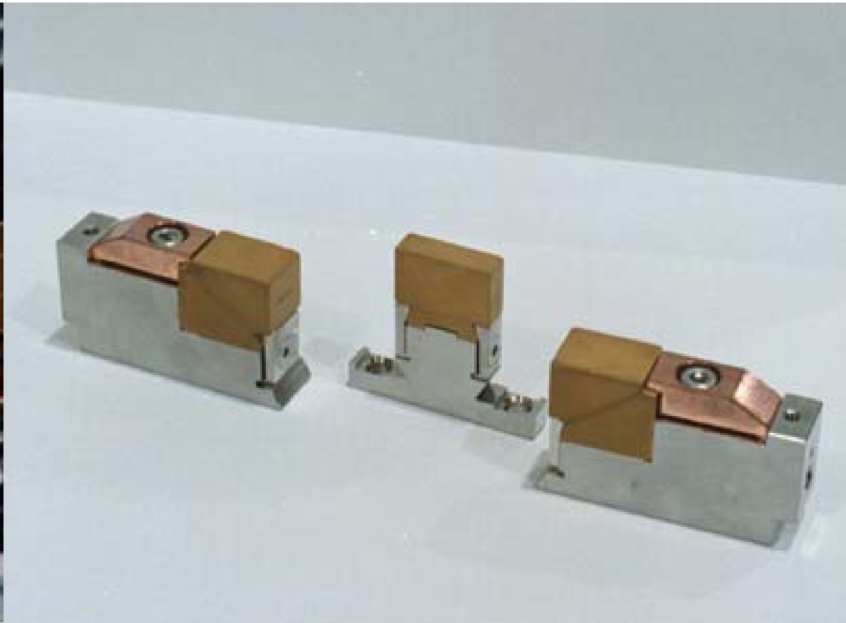
Period Length = 10 cm, Length = 4.4 m, Kx = Ky = 3.34



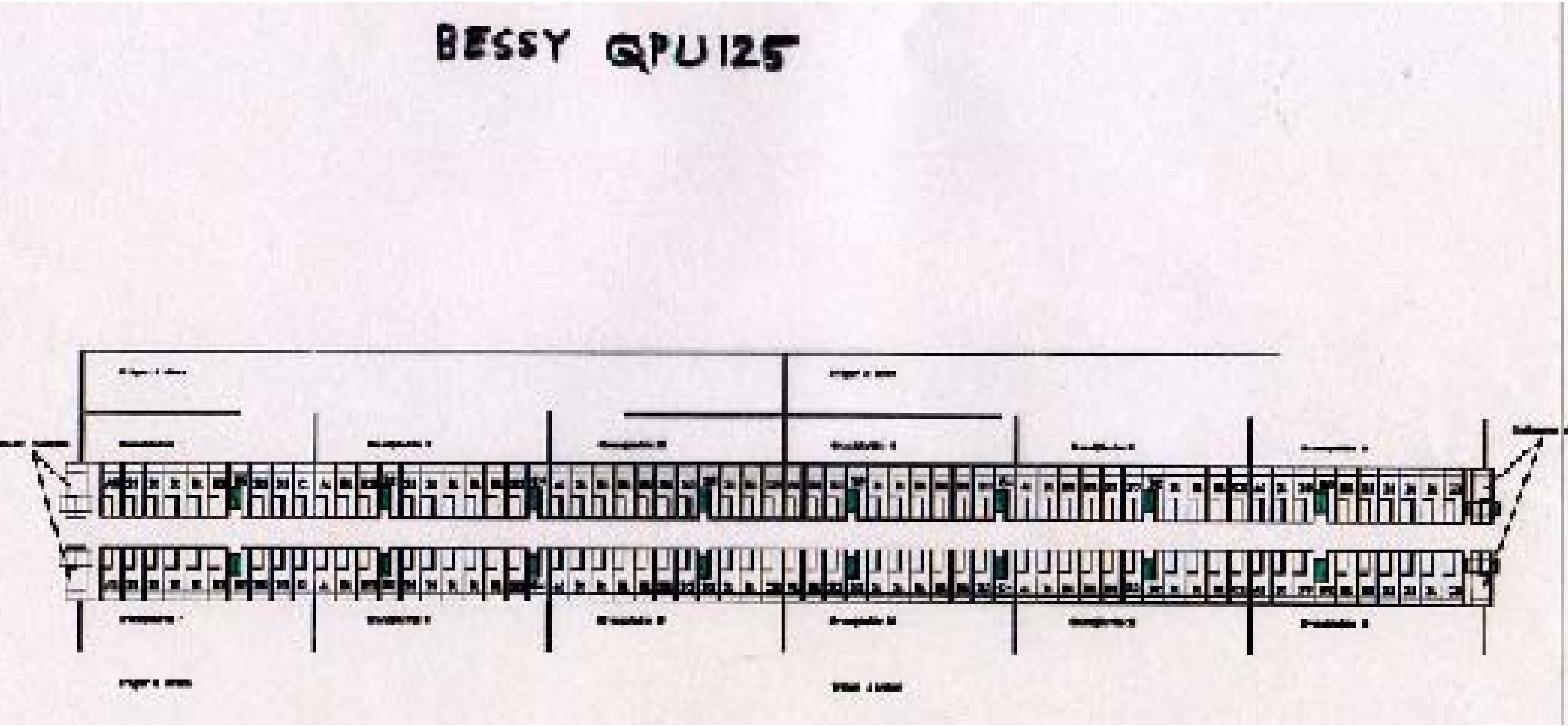


Structure of Figure-8 Undulator

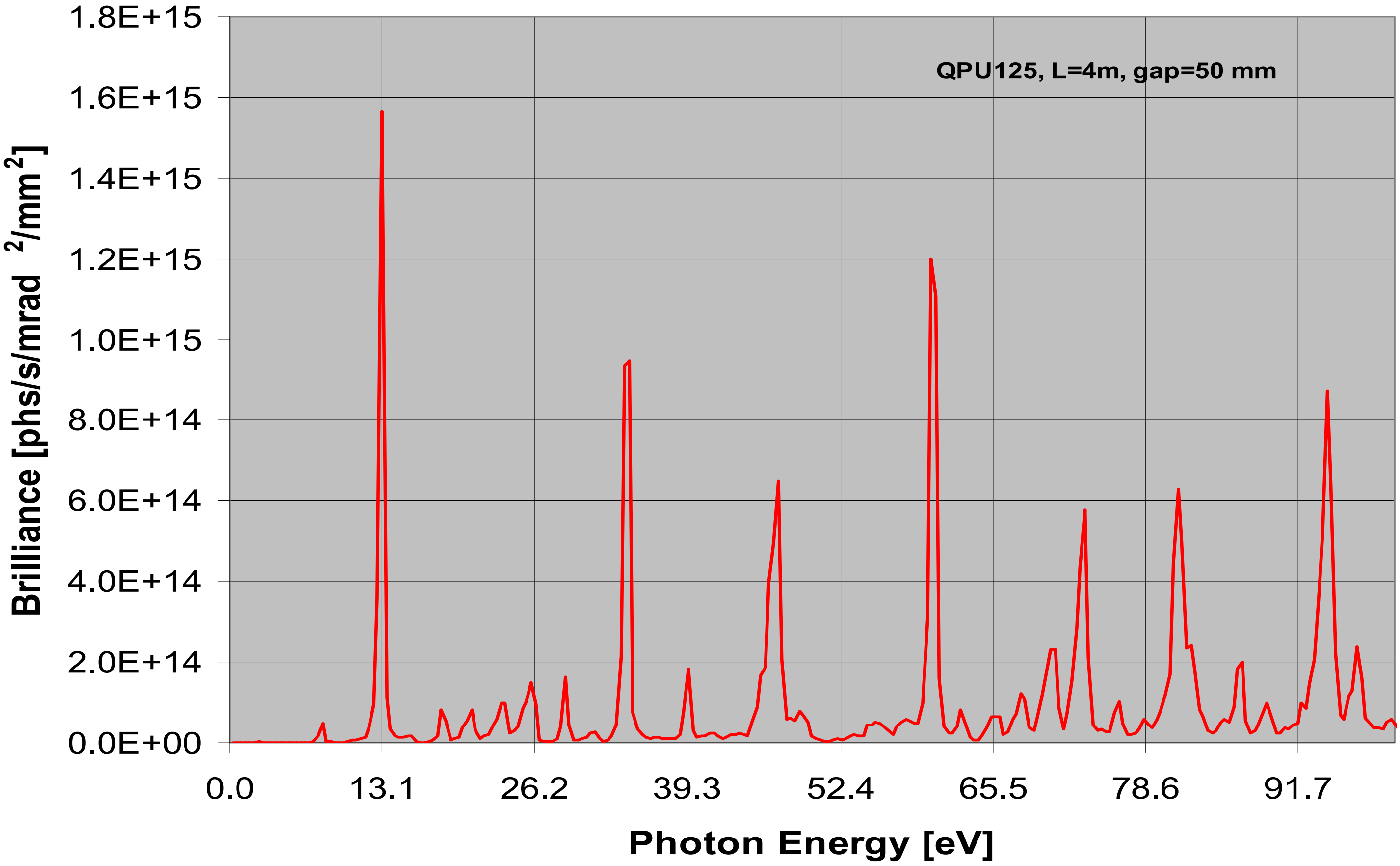


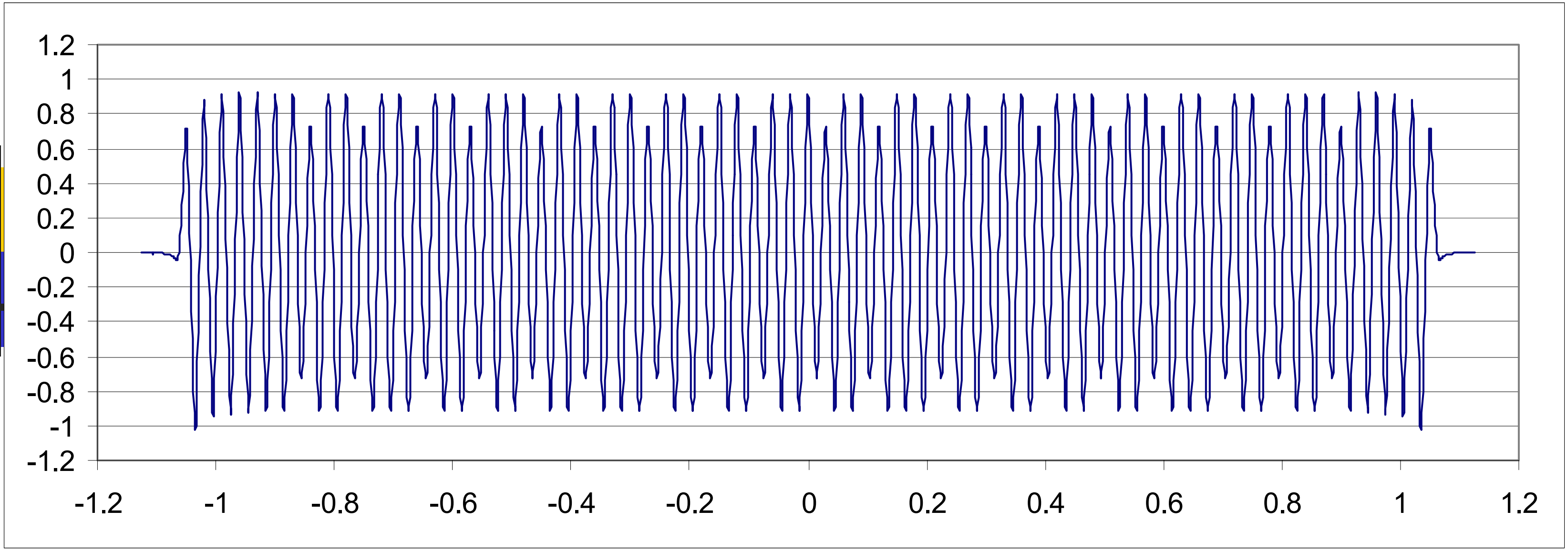


Quasi-Periodic Undulator at BESSY

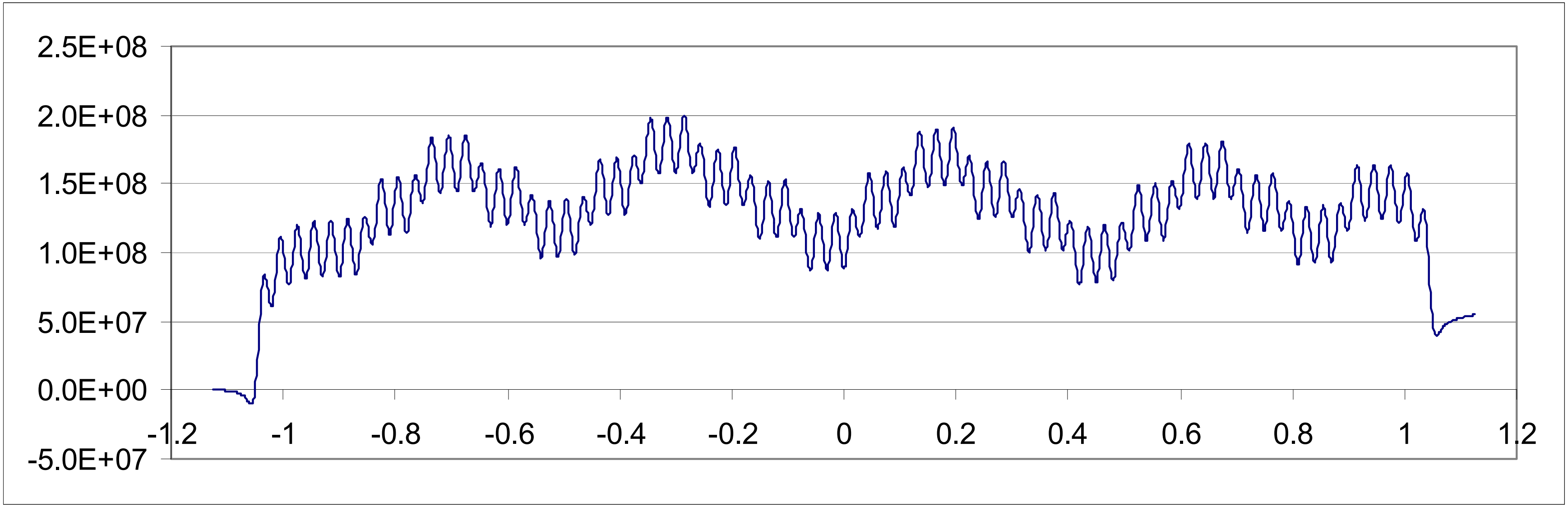


CAMD QPU125, L=4m, Gap=50 mm



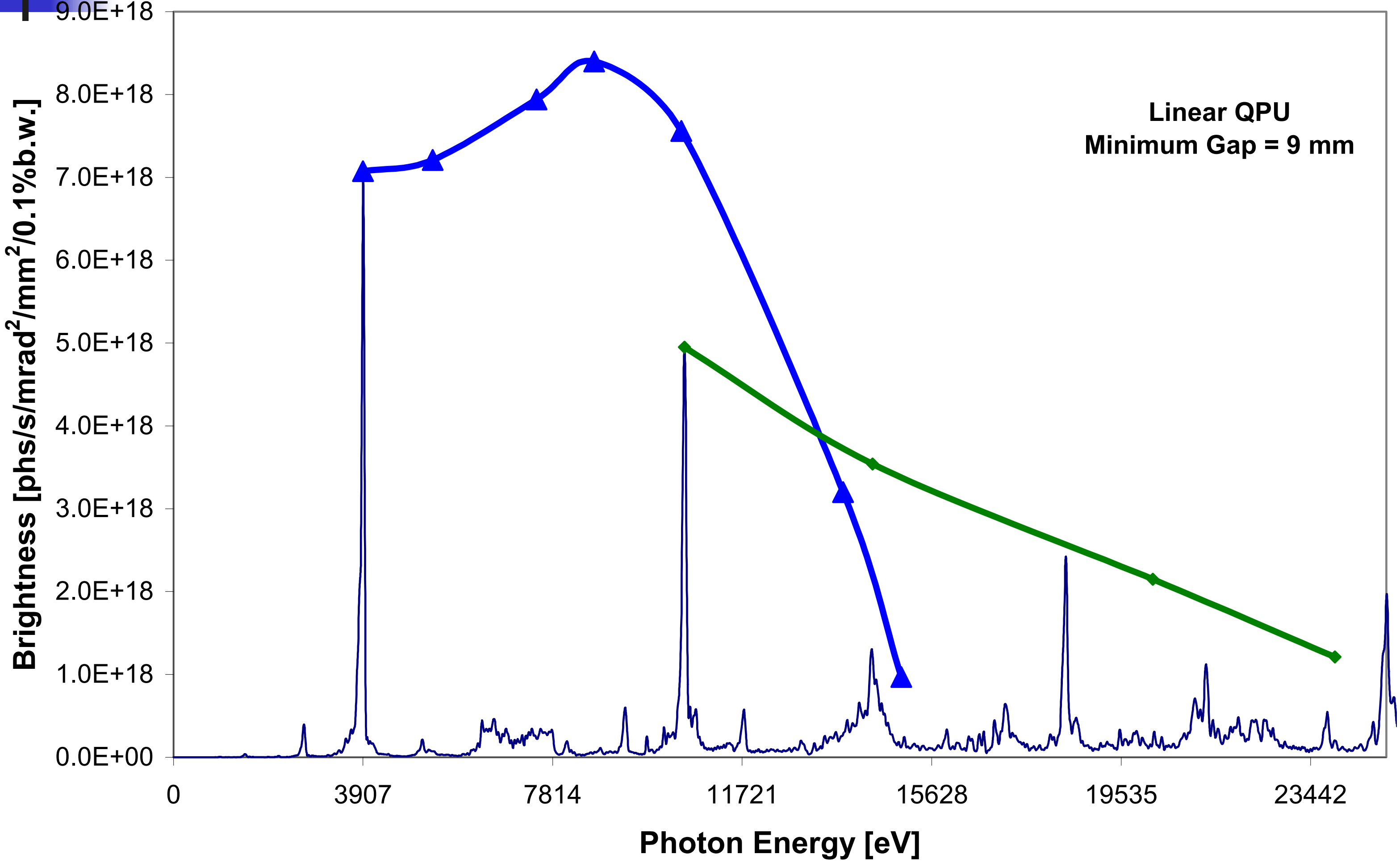


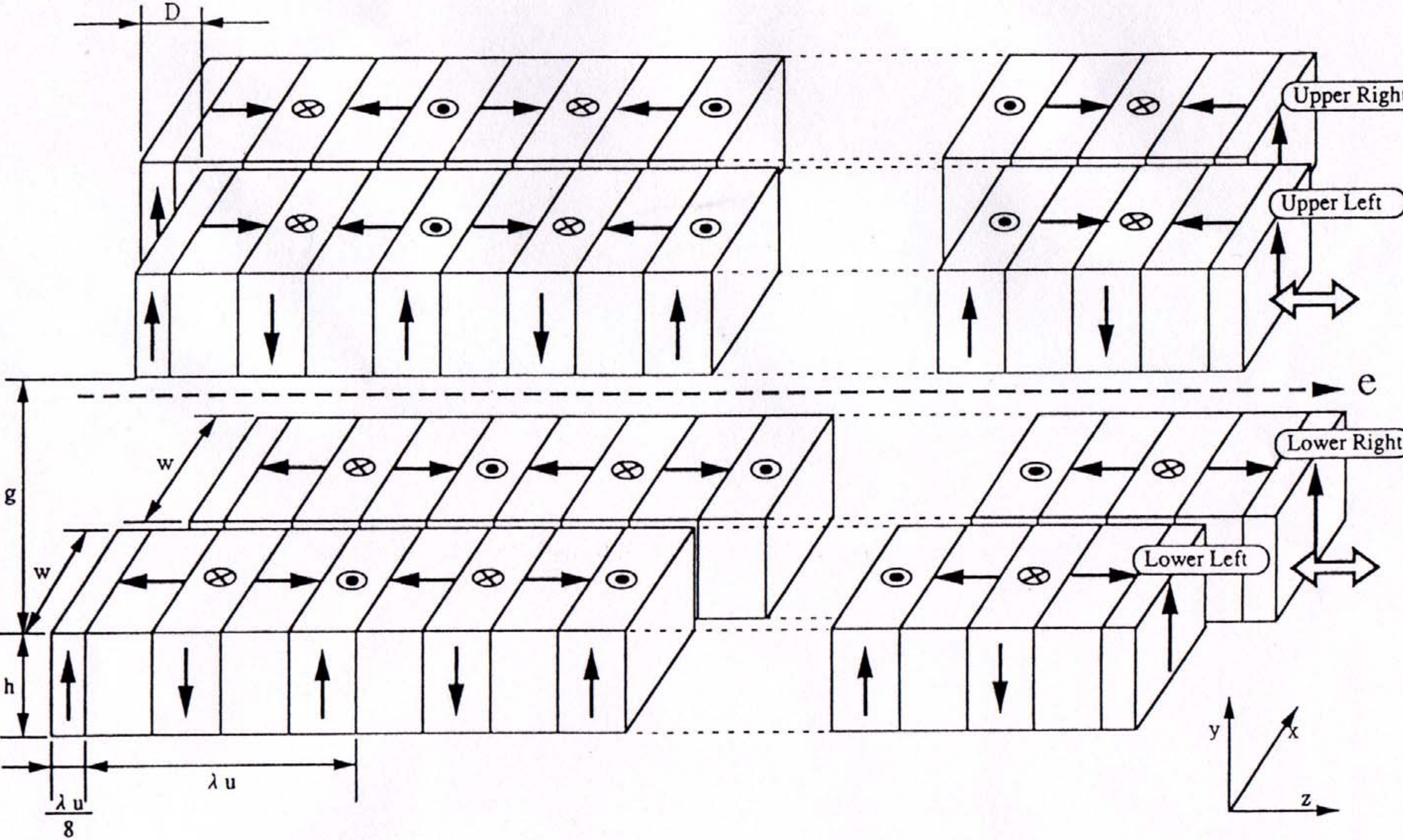
Magnetic field distribution of 30mm-period QPU: Gap = 9 mm



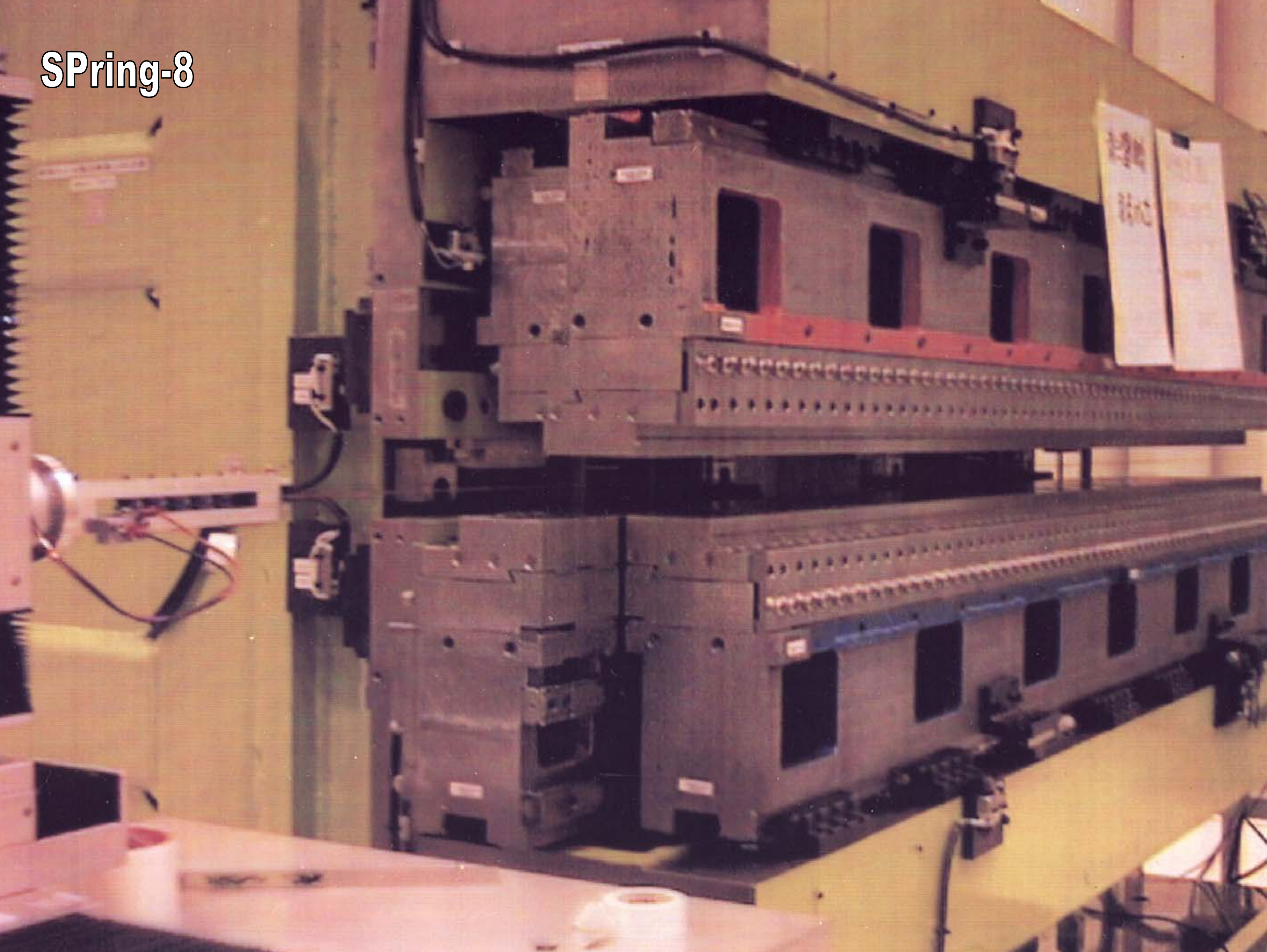
Electron trajectory in 30 mm-period QPU: arbitrary unit for vertical scale.

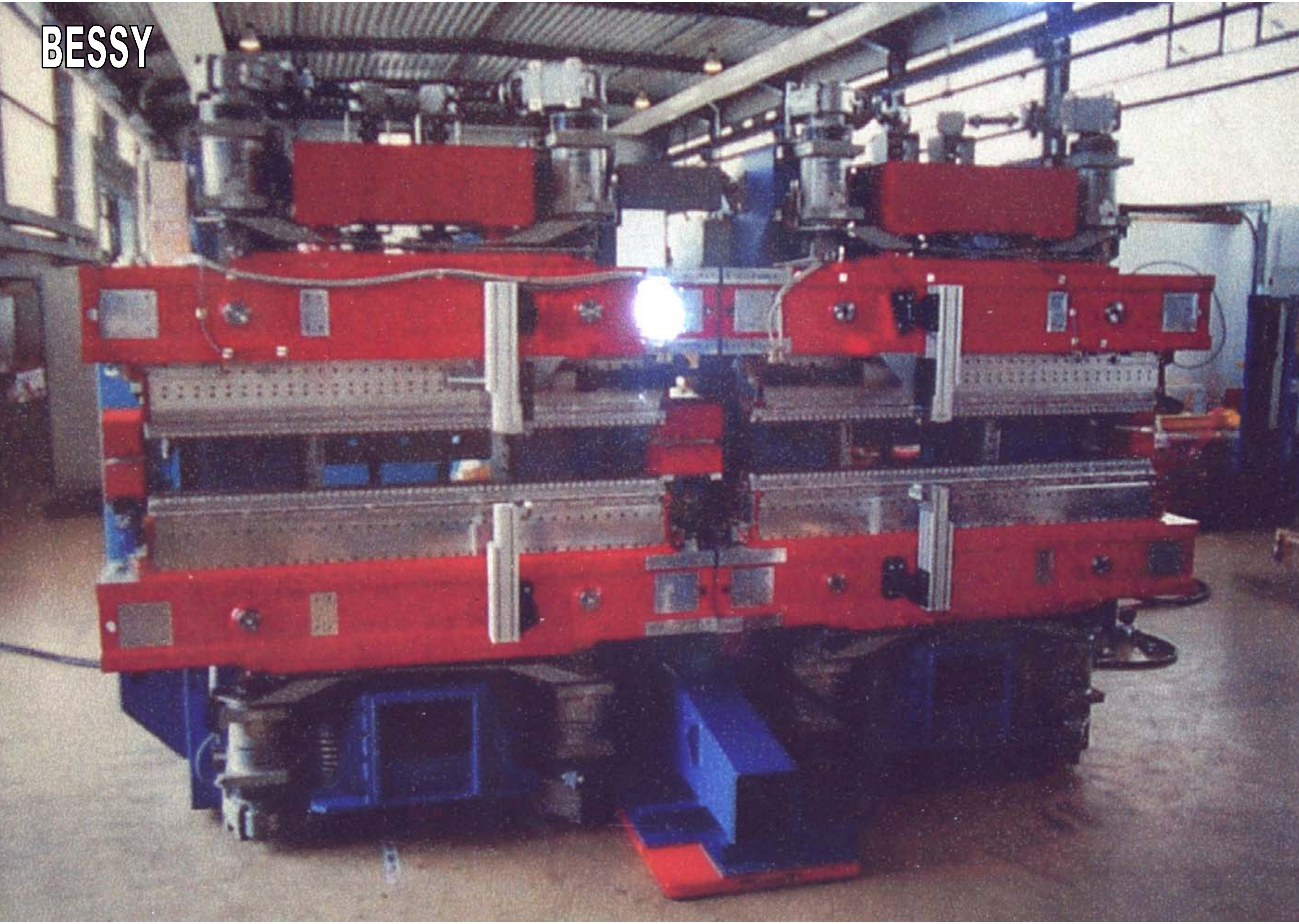
Brilliance of 30-mm-period QPU in APS



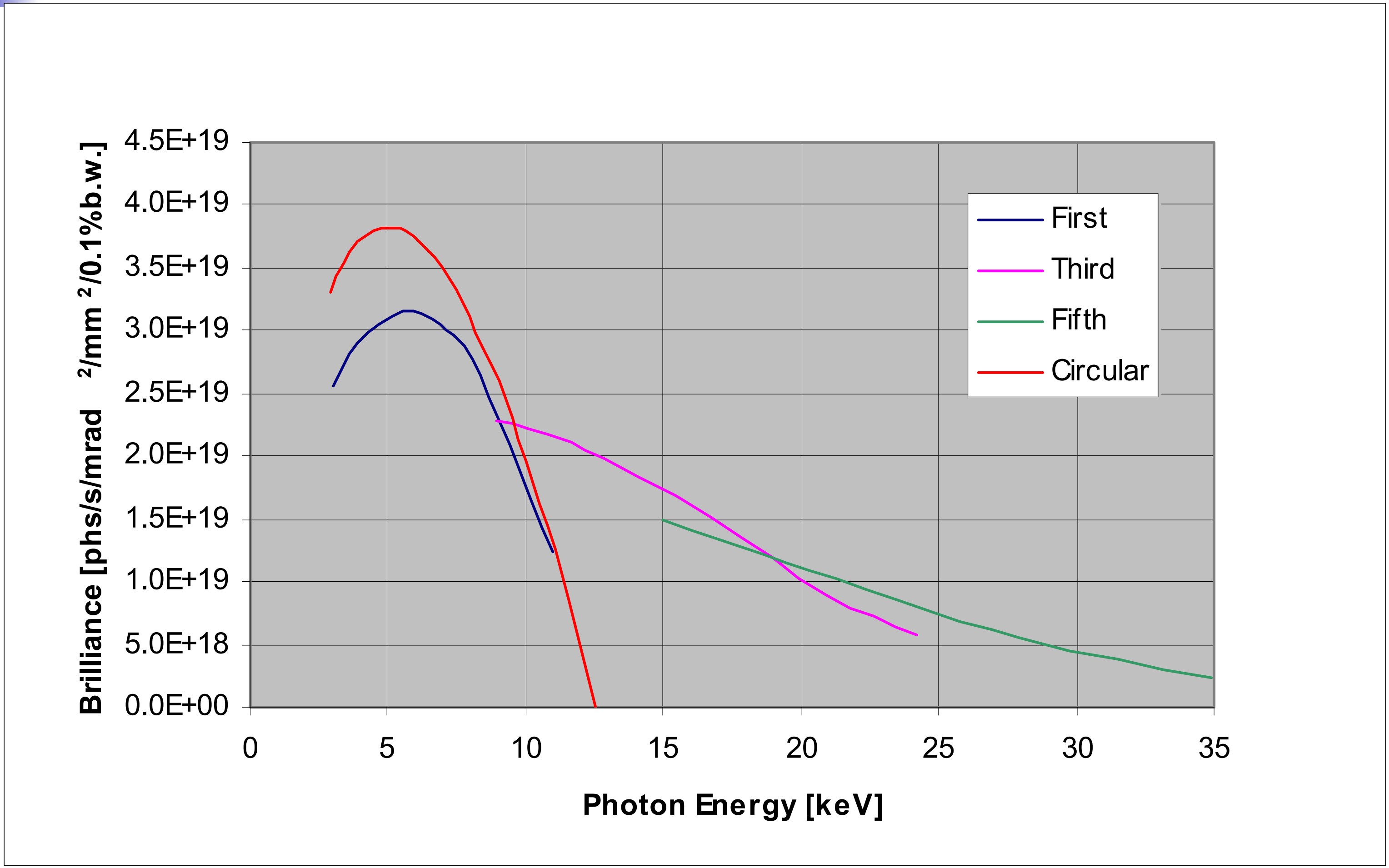


Schematic view of the magnetic structure for generating variably polarized undulator radiation. $D=\lambda_u/4$.

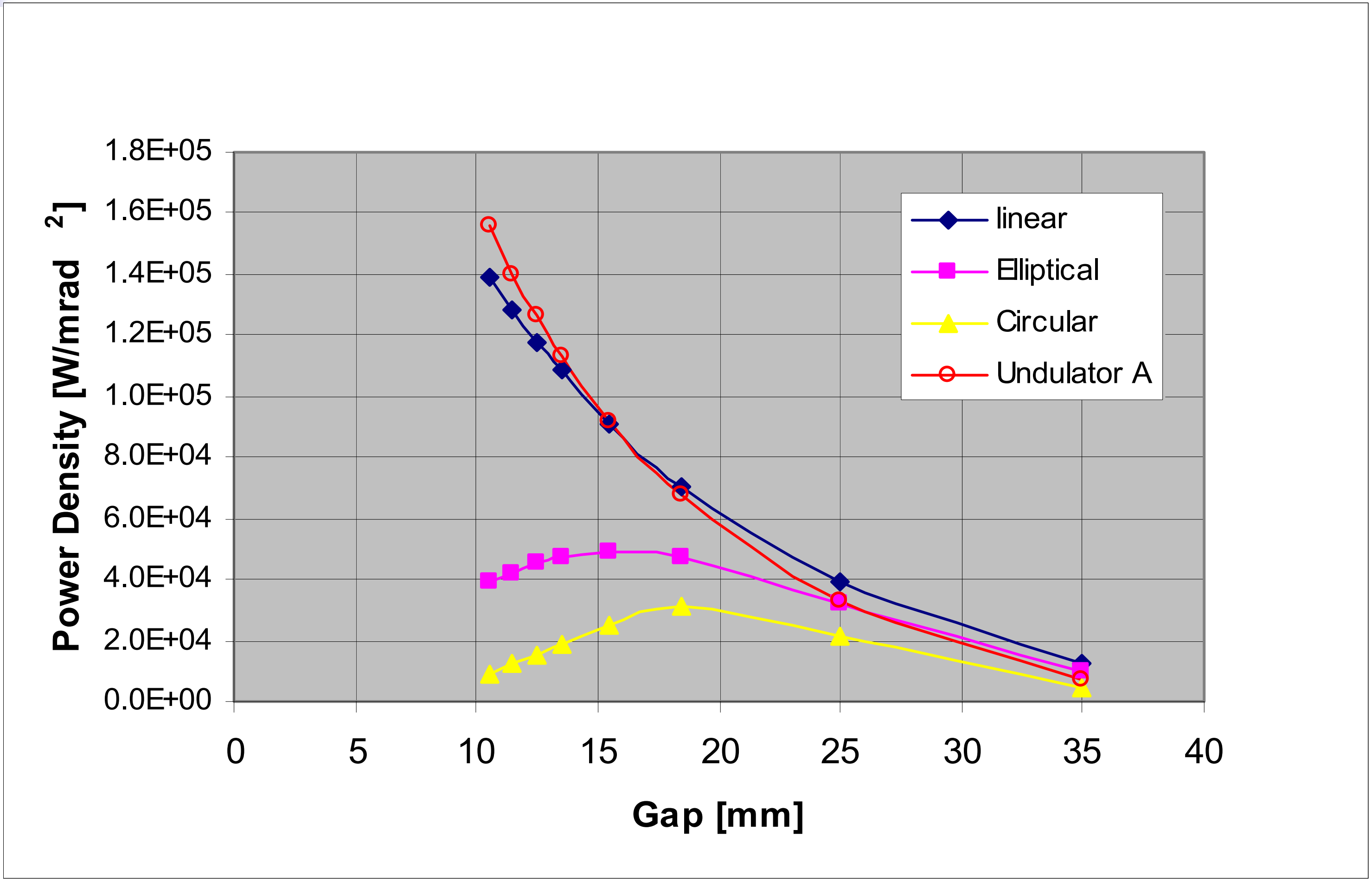

SPring-8


BESSY

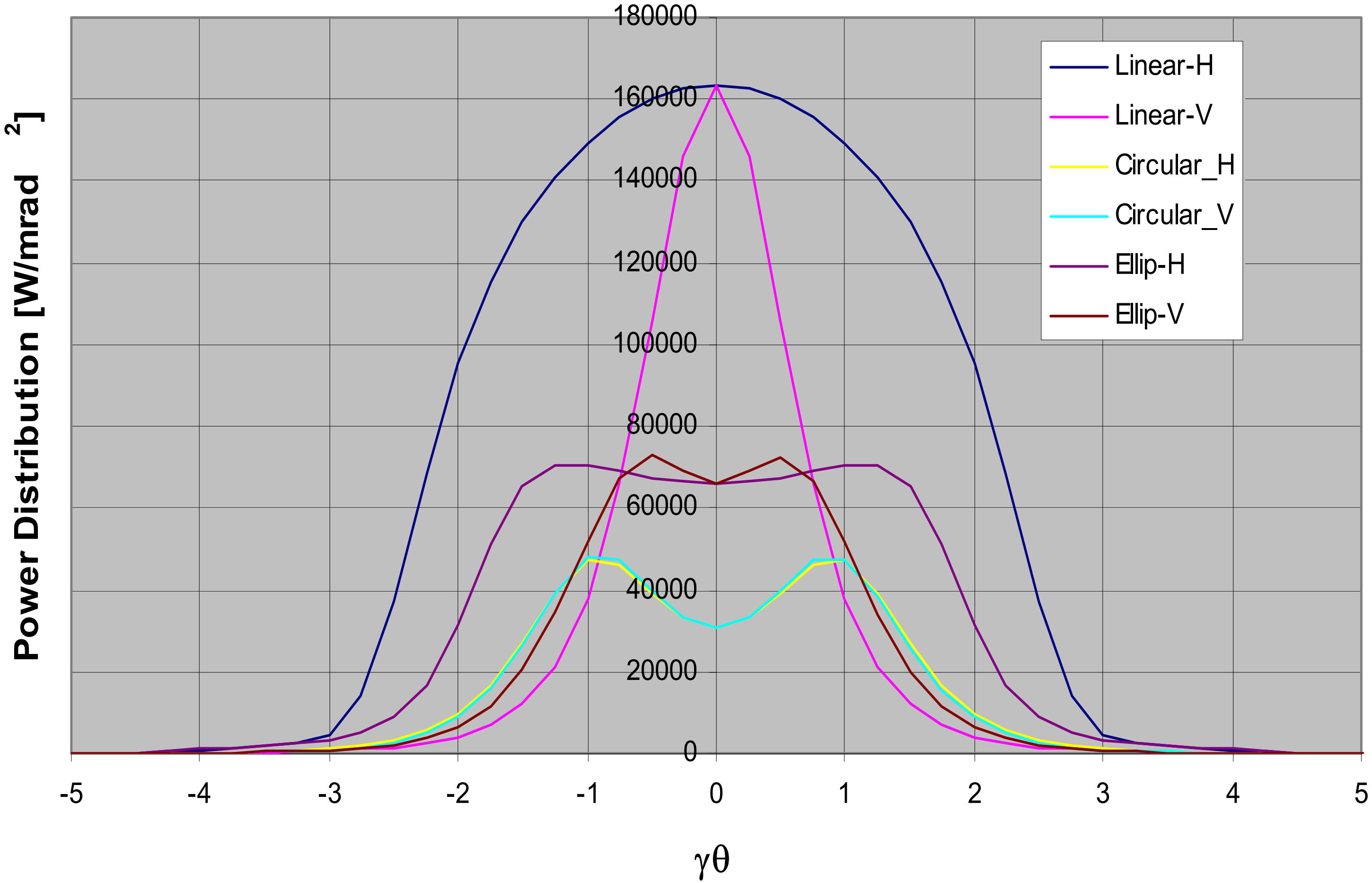
Tuning ranges of EPU37 in elliptical mode and circular mode
Electron: 7 GeV, 100 mA, 3.5 nmrad



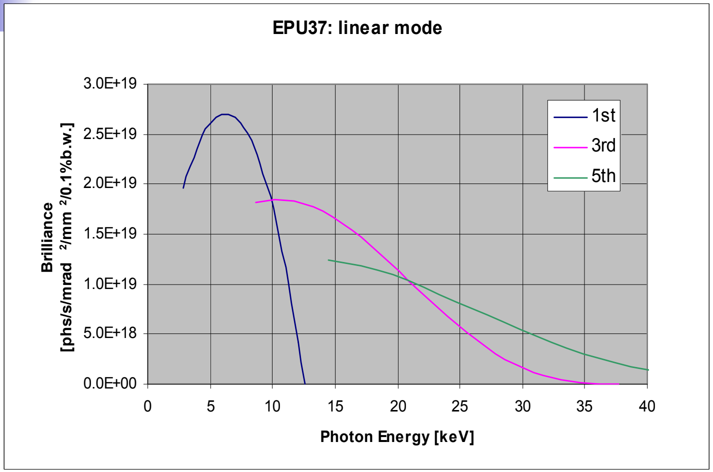
EPU37 + Undulator A On-axis Power Density
Electron : 7 GeV, 100 mA

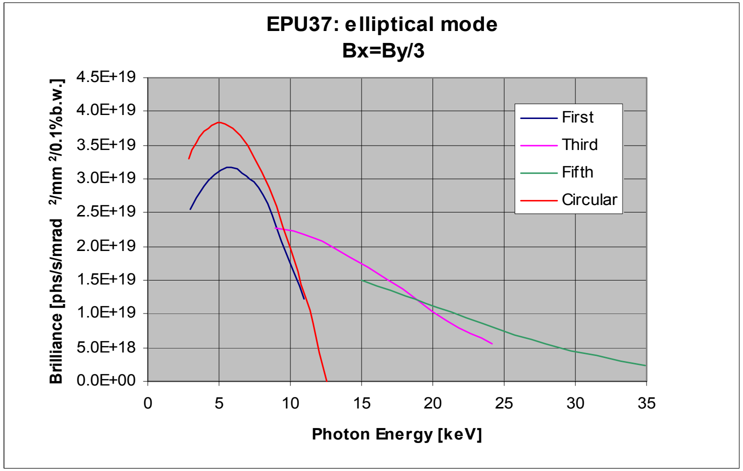


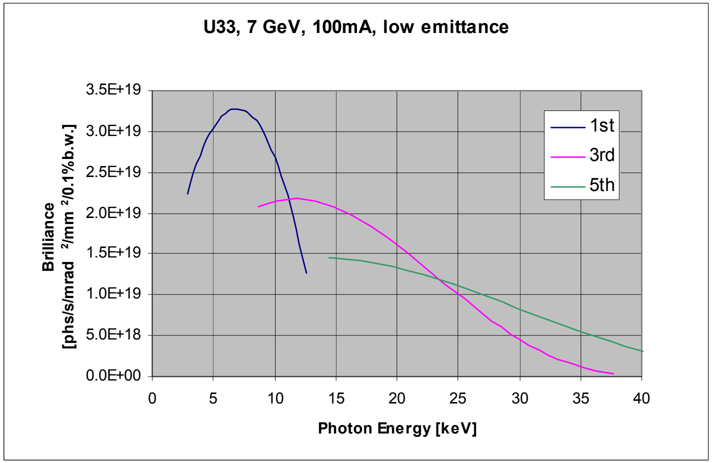
Angular Power Density Distribution of APPLE Device: L=2.15 m, l=30 mm, gap=9 mm Electron: 7 GeV, 100 mA

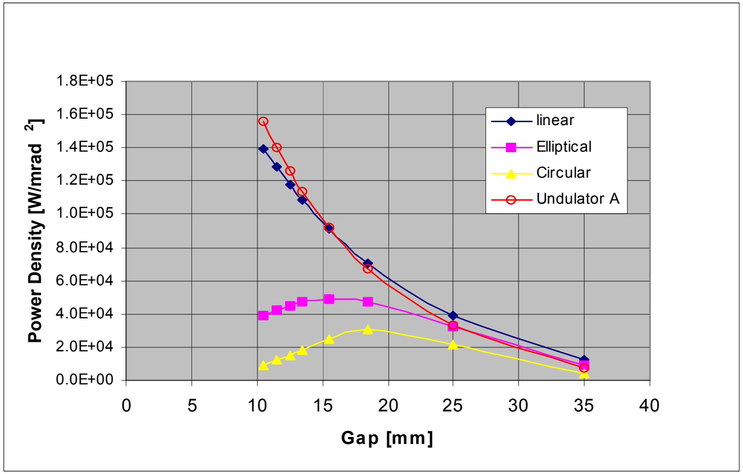


Spectral Range and Power Density Consideration



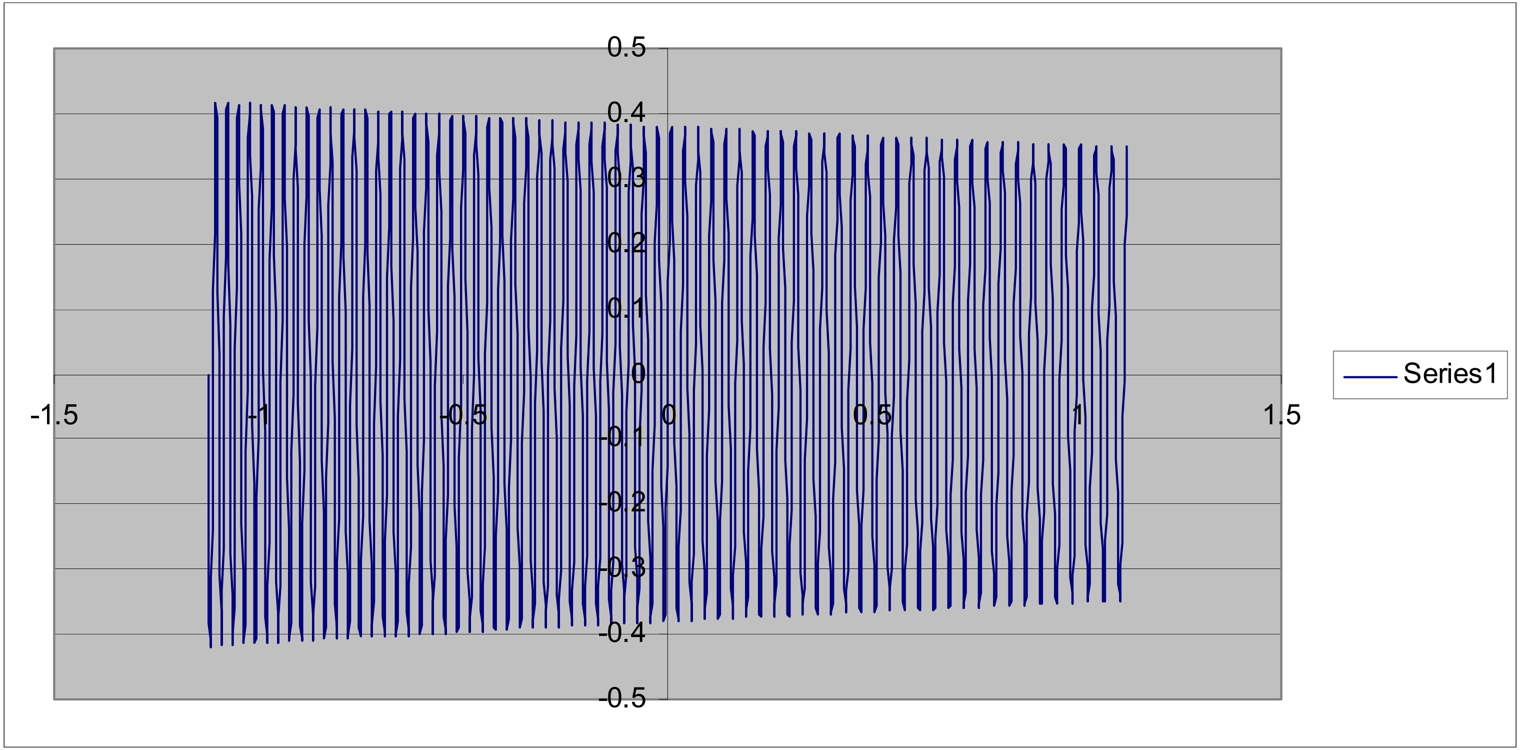


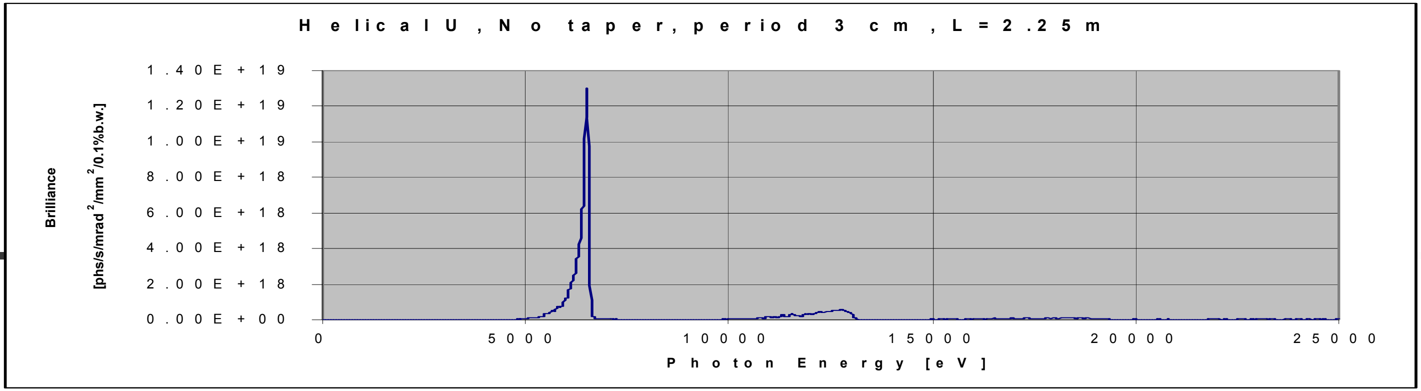


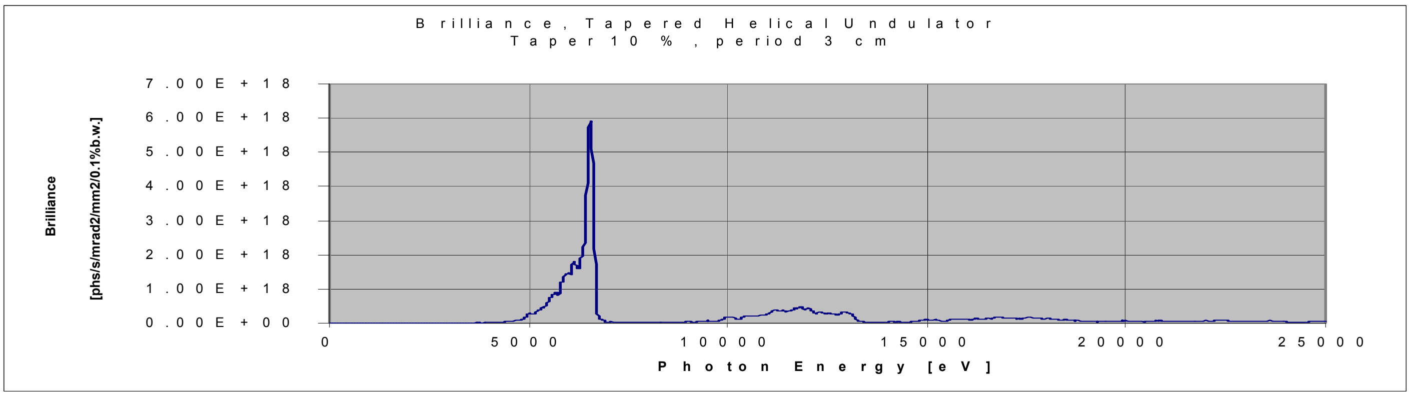


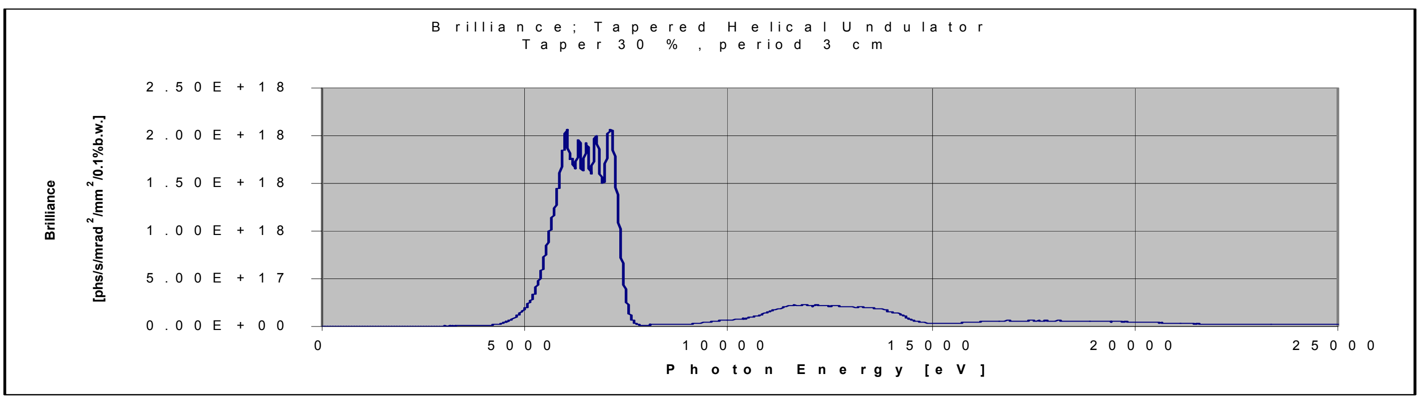
Tapered Period Helical Undulator

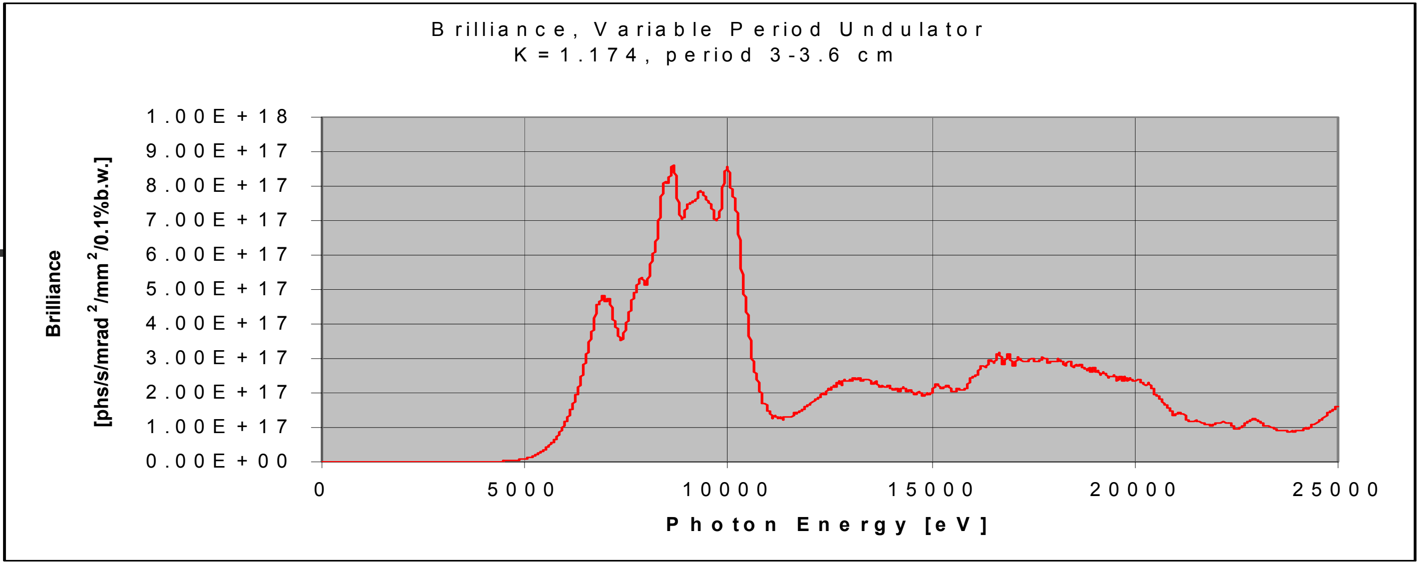
Horizontal Field, Period = 3.0 - 3.6 cm, K=1.174

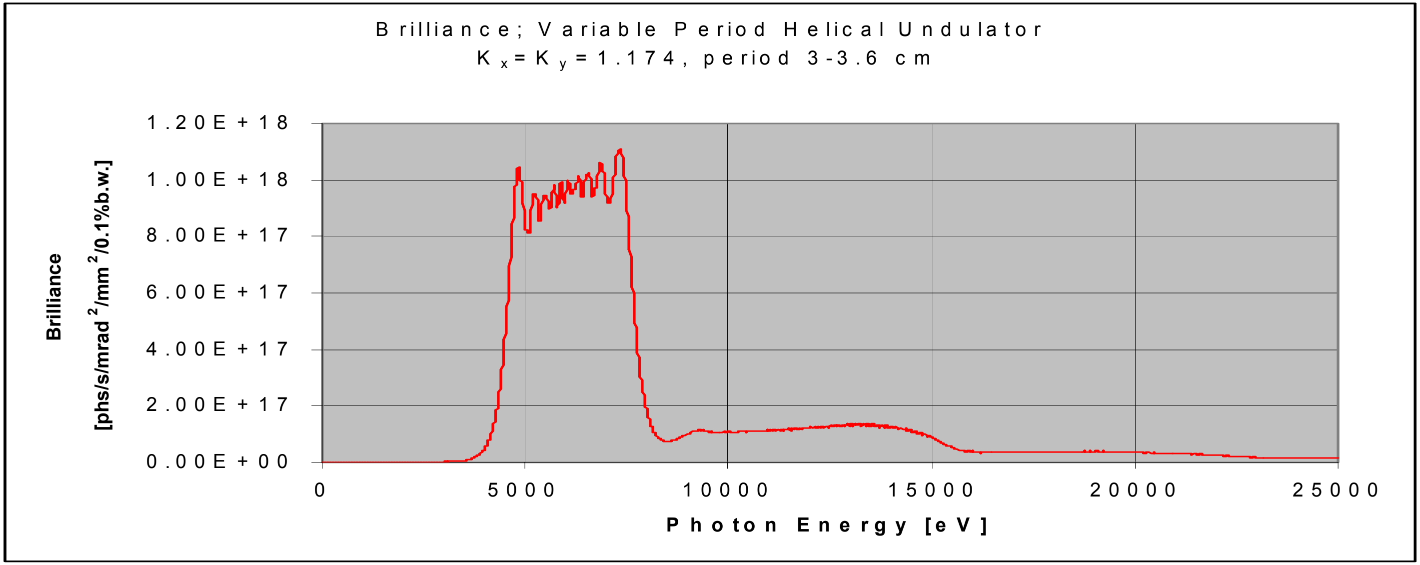


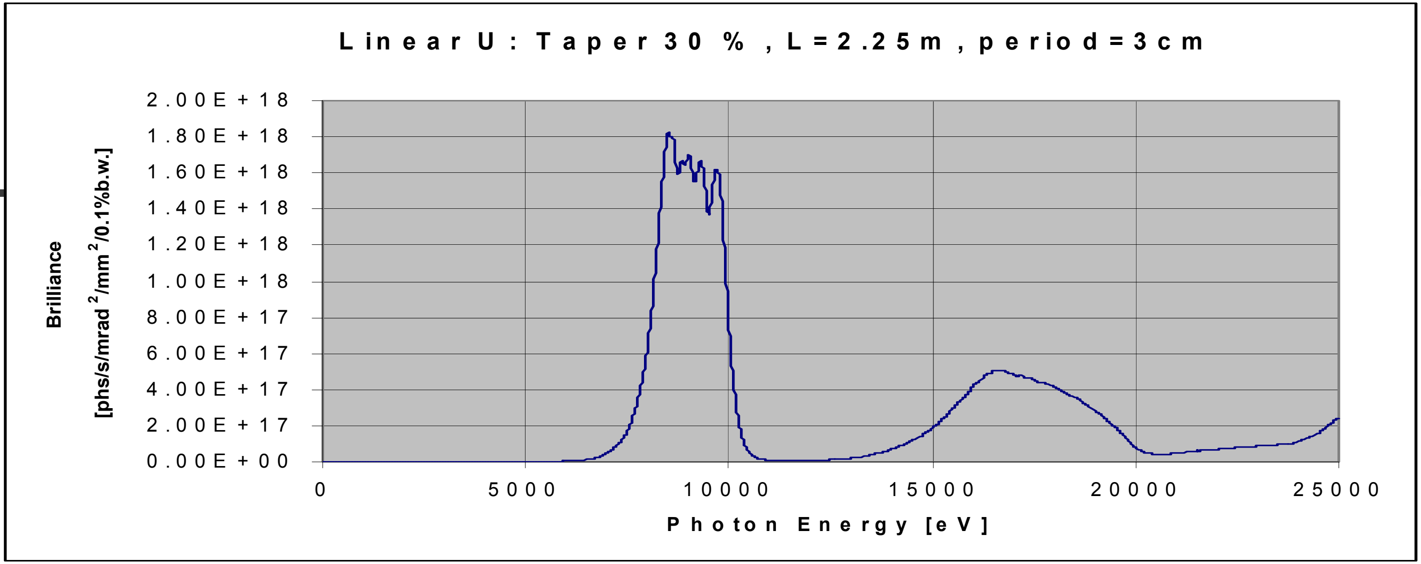

Helical U, No taper, period 3 cm, L = 2.25 m
Brilliance
[phs/s/mrad^2/mm^2/0.1%b.w.]
1.40E+19
1.20E+19
1.00E+19
8.00E+18
6.00E+18
4.00E+18
2.00E+18
0.00E+00
0
5000
10000
15000
20000
25000
Photon Energy [eV]


Brilliance, Tapered Helical Undulator
Taper 10 %, period 3 cm
Brilliance
[phs/s/mrad2/mm2/0.1%b.w.]
7.00E+18
6.00E+18
5.00E+18
4.00E+18
3.00E+18
2.00E+18
1.00E+18
0.00E+00
0
5000
10000
15000
20000
25000
Photon Energy [eV]

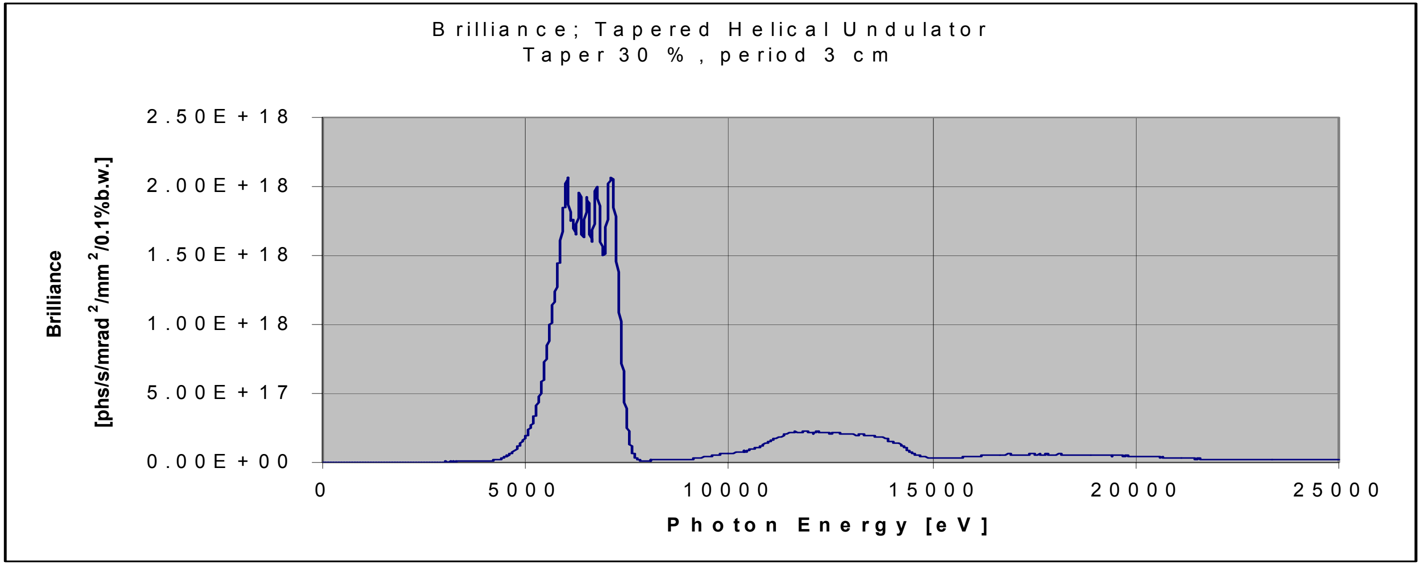

Brilliance; Tapered Helical Undulator
Taper 30 %, period 3 cm
Brilliance
[phs/s/mrad^2/mm^2/0.1%b.w.]
2.50E+18
2.00E+18
1.50E+18
1.00E+18
5.00E+17
0.00E+00
0
5000
10000
15000
20000
25000
Photon Energy [eV]


Brilliance, Variable Period Undulator
K = 1.174, period 3-3.6 cm
Brilliance
[phs/s/mrad ^{2}/mm ^{2}/0.1%b.w.]
1.00E+18
9.00E+17
8.00E+17
7.00E+17
6.00E+17
5.00E+17
4.00E+17
3.00E+17
2.00E+17
1.00E+17
0.00E+00
0
5000
10000
15000
20000
25000
Photon Energy [eV]


Brilliance; Variable Period Helical Undulator
$K_x = K_y = 1.174$, period 3-3.6 cm
Brilliance
[phs/s/mrad ^{2}/mm ^{2}/0.1%b.w.]
1.20E+18
1.00E+18
8.00E+17
6.00E+17
4.00E+17
2.00E+17
0.00E+00
0
5000
10000
15000
20000
25000
Photon Energy [eV]



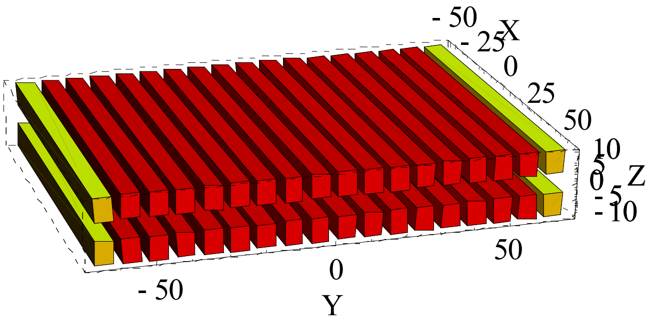
Linear U: Taper 30 % , L=2.25m , period=3cm
Brilliance
[phs/s/mrad 2/mm 2/0.1%b.w.]
2.00E+18
1.80E+18
1.60E+18
1.40E+18
1.20E+18
1.00E+18
8.00E+17
6.00E+17
4.00E+17
2.00E+17
0.00E+00
0
5000
10000
15000
20000
25000
Photon Energy [eV]

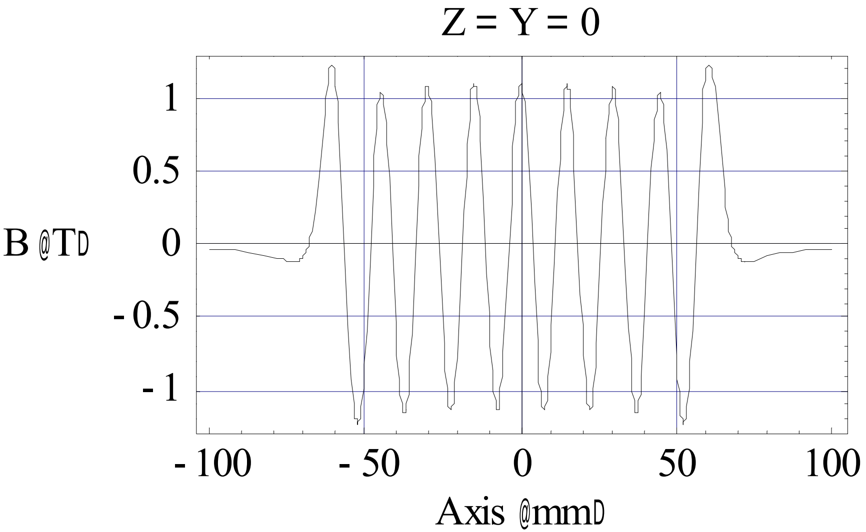


Brilliance; Tapered Helical Undulator
Taper 30 % , period 3 cm
Brilliance
[phs/s/mrad 2/mm 2/0.1%b.w.]
2.50E+18
2.00E+18
1.50E+18
1.00E+18
5.00E+17
0.00E+00
0
5000
10000
15000
20000
25000
Photon Energy [eV]

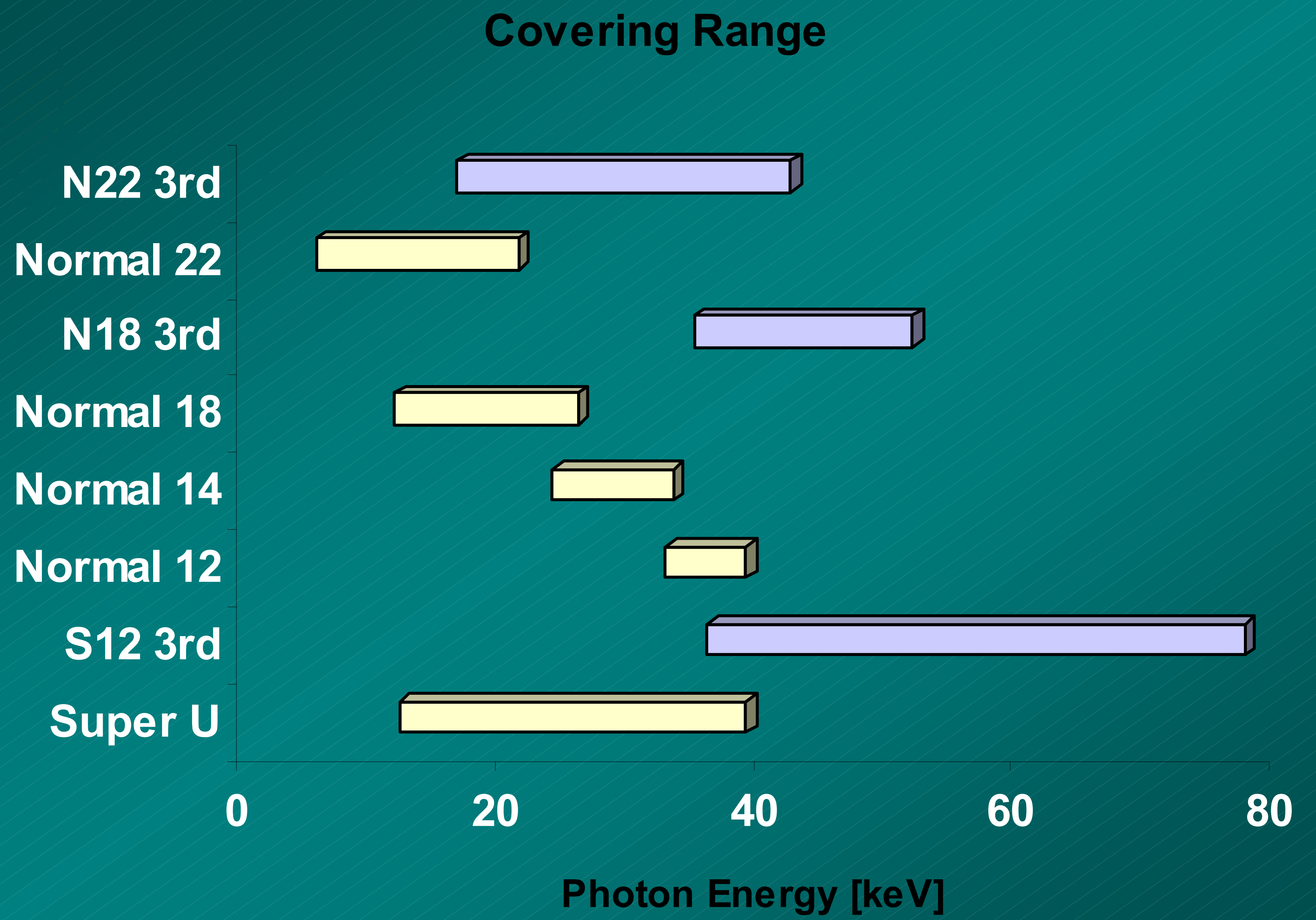
Superconducting Undulator

Period=15 mm, Gap=6 mm, j=1200 A/mm^2



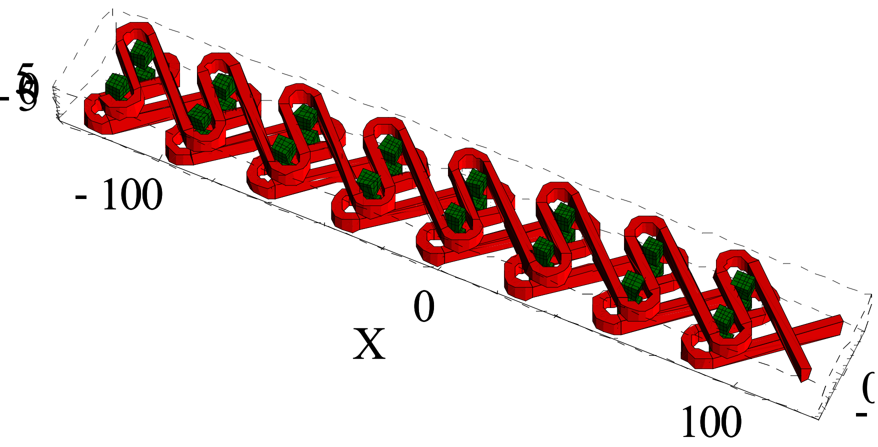


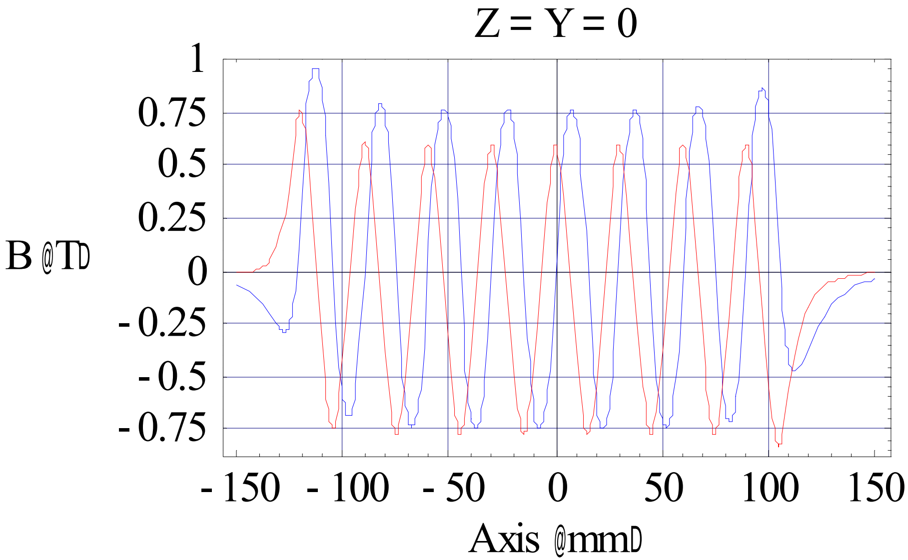
Comparison Between Permanent Magnet Device and Superconducting Device



Snake Coil Helical Undulator

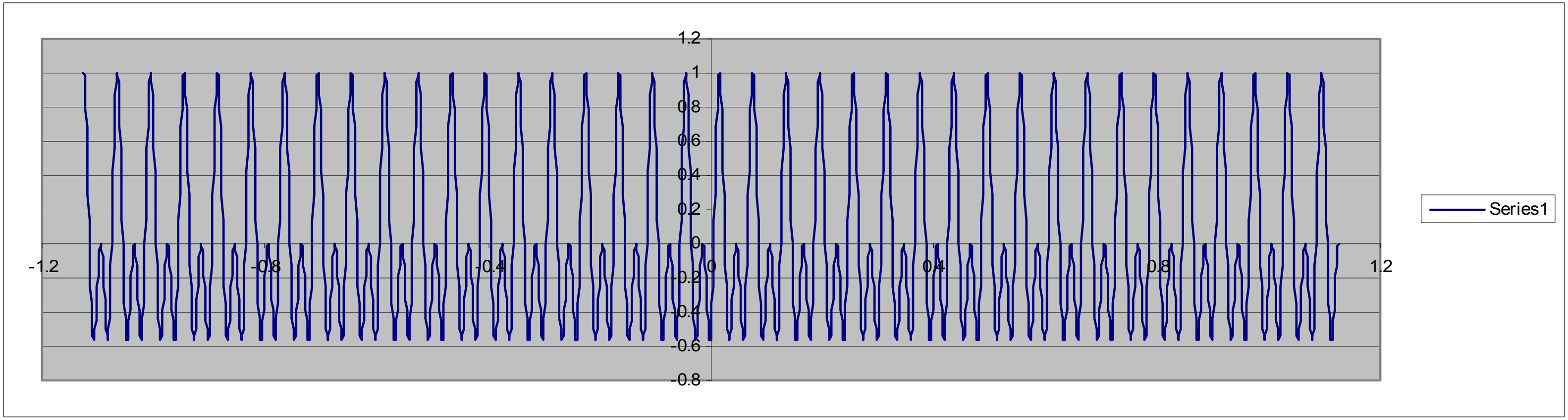
Period:30mm, Gap:6mm, j=1kA/mm^2



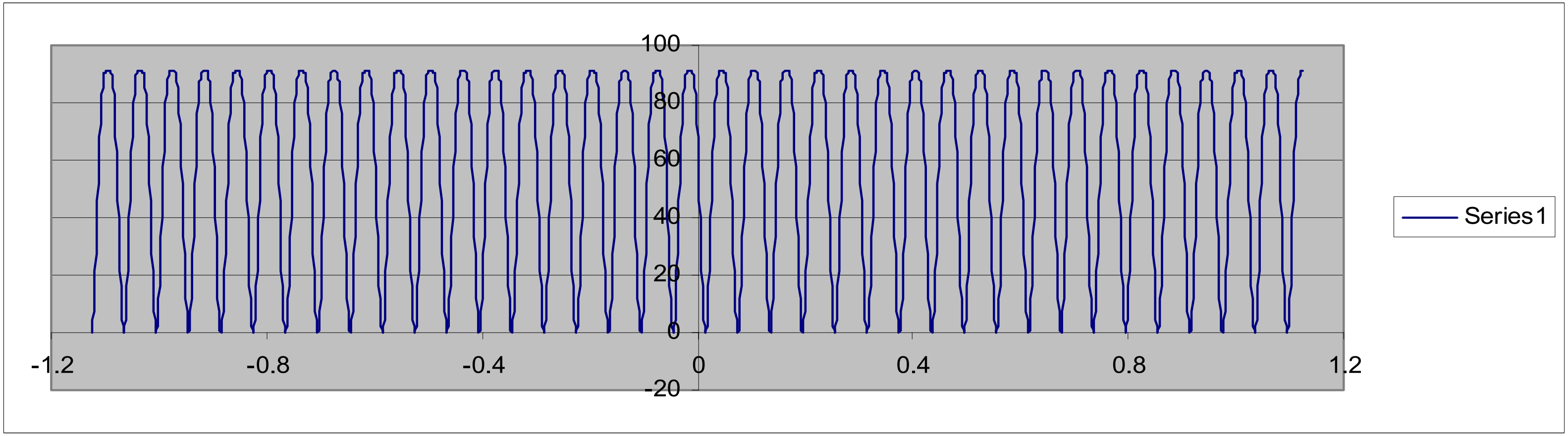


Asymmetric Undulator: 60 mm period

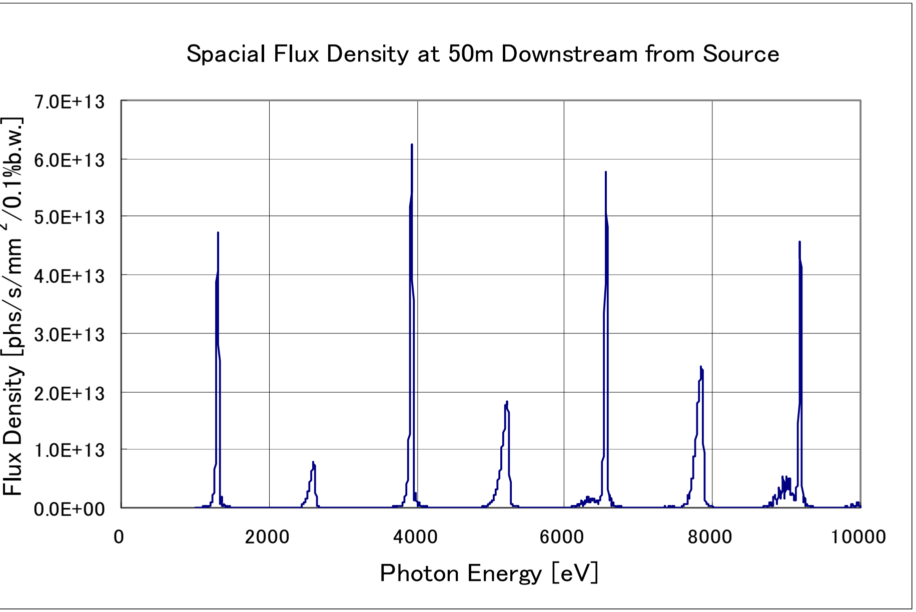
Magnetic Field



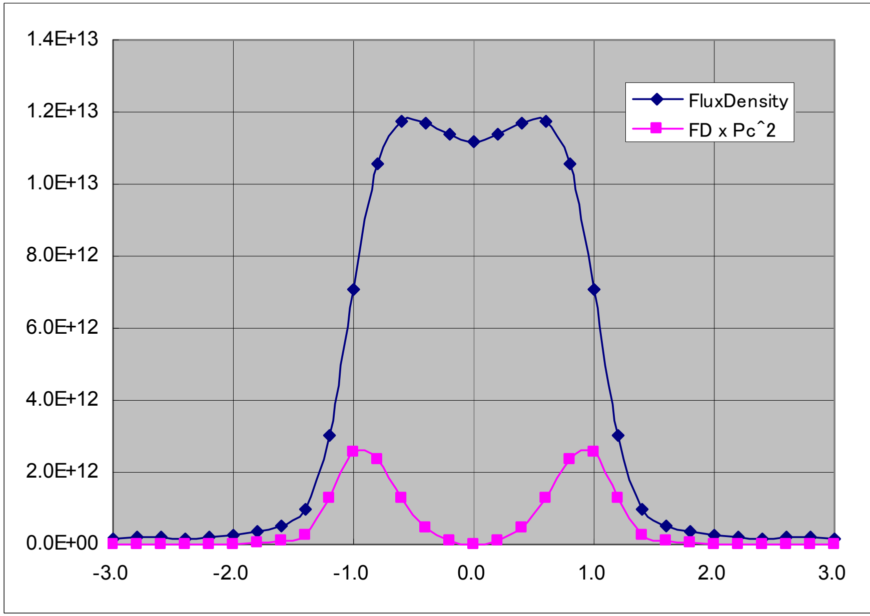
Electron Trajectory



Asymmetric Undulator: 60 mm period length



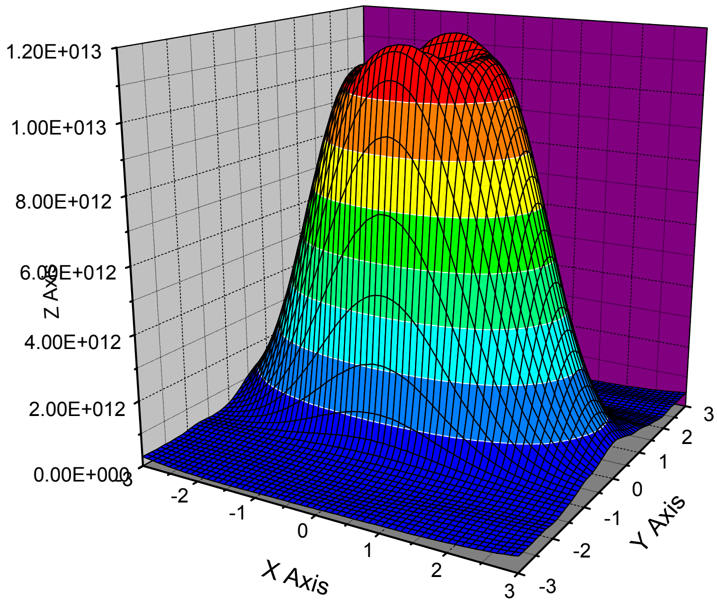
Spectral flux density

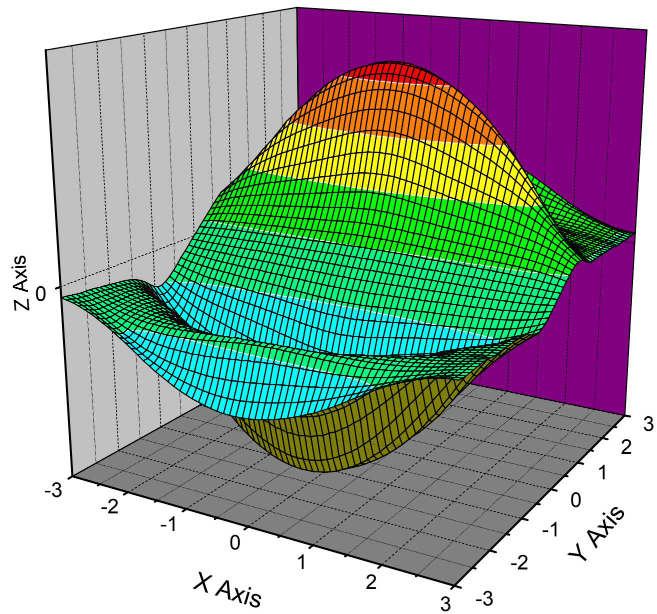


Flux density distribution of 2^{nd} harmonic (2600 eV)

Flux Density and Circular Polarization Distributions of Asymmetric Undulator

Second harmonic: Photon Energy = 2600 eV





APS: Low emittance mode, 3.5 nmrad, coupling 1%

Software for Calculating Undulator Radiation

- URGENT (ELETTRA, FORTRAN, VAX, UNIX)
  Source code available, periodic undulator only
- XOP (APS/ESRF, IDL, UNIX, PC)
  Run on IDL, periodic undulator only
- UR (APS, FORTRAN, UNIX)
  Source code available, arbitrary field
- SRW (ESRF, Igor, Mac, PC)
  Run on IgorPro, can be downloaded from WWW, cover all possible device, user friendly
- SPECTRA (SPring-8, C, PC, UNIX)
  User friendly, no angular distribution, near field, can be downloaded from WWW

Insertion Device Designing Strategy

- Listen users' requirements

  photon energy range, flux, brilliance, polarization, etc.
- List machine parameters

  ring energy, current, emittance, beta functions, etc.
- Listen machine's requirements

  minimum gap, length of straight section, J1, J2, etc.
- Conceptual design
- Estimate performance
- Listen users' demands
- Engineering design