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SCHOOL ON SYNCHROTRON RADIATION

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Synchrotron Radiation Source with Synchrotron Radiation Program

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School on Synchrotron Radiation

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Radiation from Bending Magnets

Radiation is emitted along the curved path of the beam. The photon characteristics depend on beam energy and magnetic fields.

Critical photon energy of synchrotron radiation from bending magnet,

$$\varepsilon_c(\text{keV}) = 0.665 E^2(\text{GeV}^2) B(\text{T}),$$

where E is the beam energy and B is the magnetic field.

The photon energy is determined by the field of the bending magnet, which is a fixed parameter for a storage ring. The photon energy generated, is therefore fixed

Radiation Hardening:

In a low energy storage ring, the bending magnet radiation does not provide enough intensity at hard x-rays. Replacing a bending magnet by a superconducting magnet with the same deflection angle will provide more of hard x-ray. This superconducting magnet of a stronger field will be shorter in length.

Example:

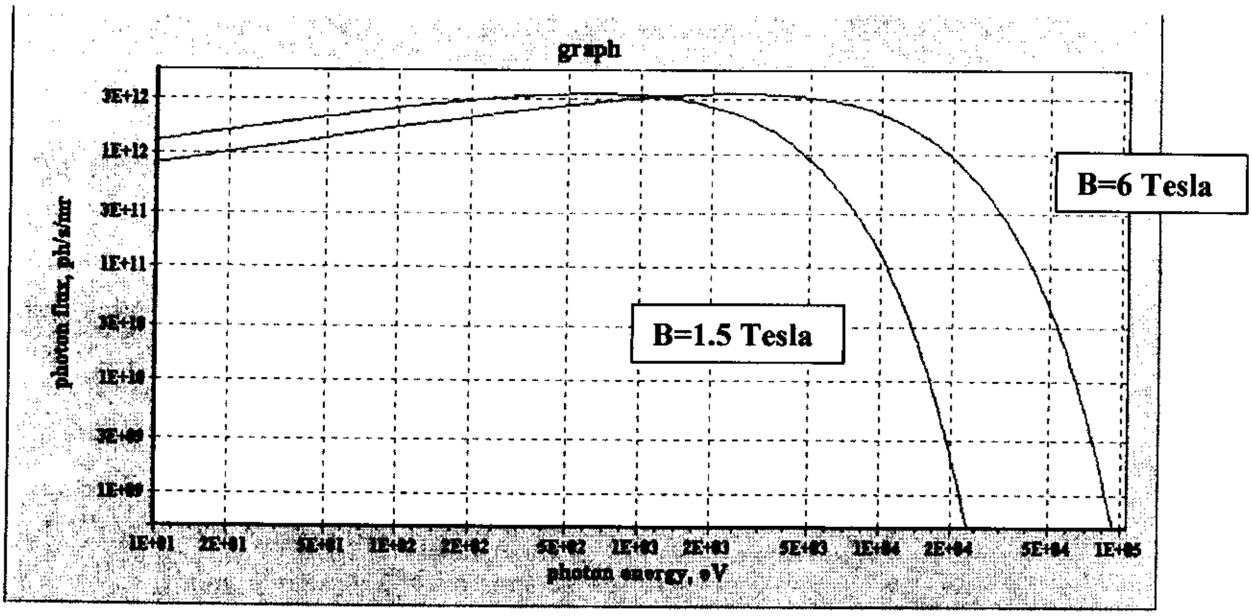
The bending magnet radiation of 1.5 GeV beam from a 1.5 Tesla bending magnet has the critical photon energy of

$$\varepsilon_c = 0.665 E^2(\text{GeV}^2) B(\text{T}) = 2.24 \text{ keV}.$$

With a 6 Tesla superconducting magnet, the critical photon energy becomes 8.98 keV.

To obtain the same deflection angle, the length of the magnet can be obtained from

$$l(m) = \frac{\varphi E(\mathrm{GeV})}{0.3B(\mathrm{T})}$$, where φ is the deflection angle in rad.



The graph shows the photon spectrum from a 1.5 Tesla bending magnet and a 6 Tesla superconducting magnet. Employing a superconducting magnet can extend the photon spectrum to higher energy.

Wave Length shifter

For the same purpose of radiation hardening, a wave length shifter is installed in a magnet free section of the ring. A wave length shifter consists of three dipole magnets with a high field central magnet two lower field magnets, opposite direction on either side. The magnetic field of the side poles is designed to compensate the deflection by the central pole resulting in the total deflection angle of zero. The central pole serves as a radiation source and determines the photon energy. Its field strength can be adjusted freely and can be very strong with a superconducting magnet to generate higher photon energy.

Wiggler Magnet Radiation

Wiggler magnet is an insertion device, which consists of a series of dipole magnets with alternating field direction. The total deflecting angle is zero. Many poles of the magnet increase the photon flux. If the magnet is constructed to provide strong fields, it will serve as a wavelength shifter at the same time.

The magnetic field strength depends on:

- the period length
- the design and magnet materials used
- the gap height which is variable over a limited range

Define the strength parameter K, $K = 0.934 B(\text{Tesla}) \lambda_p(\text{cm})$.

For a wiggler magnet, $K \gg 1$.

Undulator Radiation

In a series of dipole magnets with weak magnetic field ($K \leq 1$), the particles oscillate periodically like sinusoidal oscillation and generate quasi-monochromatic radiation.

The photon energy (forward radiation),

$$\varepsilon_i(eV) = 9.4963 \frac{iE^2}{\lambda_p(1 + \frac{1}{2}K^2)} ,$$

where E : beam energy

K: strength parameter

λ_p: period length

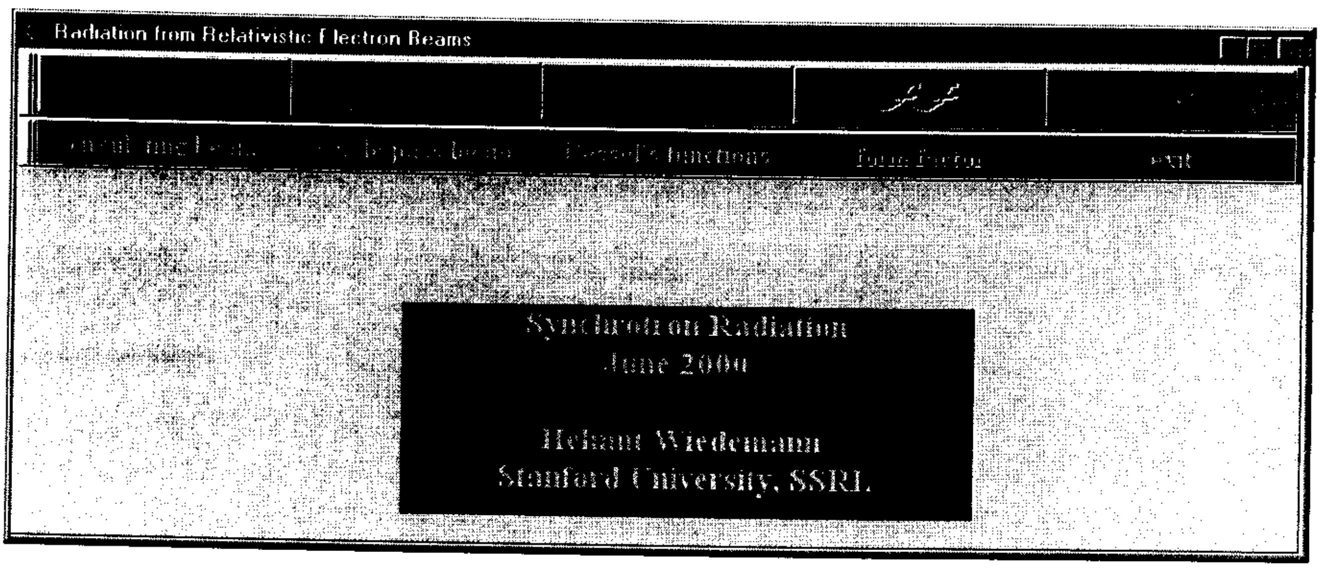
i : harmonic number

The photon energy is tunable as the undulator strength is adjusted (by changing the gap height).

Synchrotron Radiation and Insertion device Radiation Characterization using the Synchrotron Radiation program

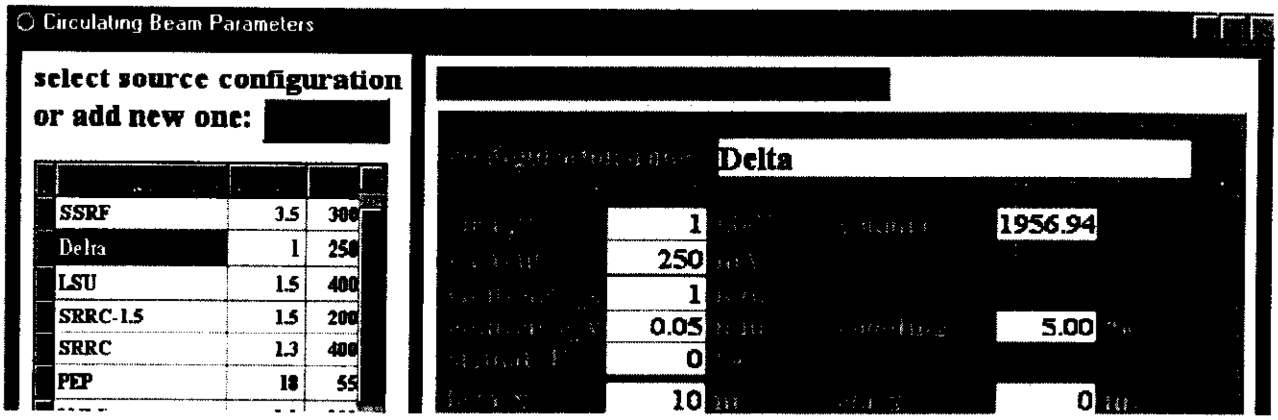
The Synchrotron Radiation Program will be used to characterize the synchrotron radiation. You should use the program to calculate the radiation properties of the storage ring that you have designed, add some insertion devices and study the radiation properties obtained. The program can also be used to study the radiation properties for any storage ring of your interest (parameters for most of existing storage rings are available in the program). The following note will show you how to get start with the program.

- The Synchrotron Radiation program main window:

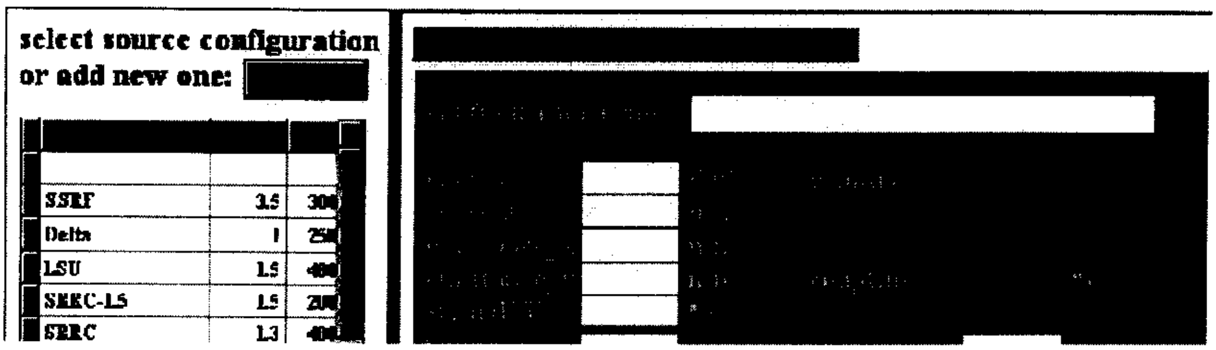


- For a study of synchrotron radiation from a storage ring, select the calculation for a **circular beam**.

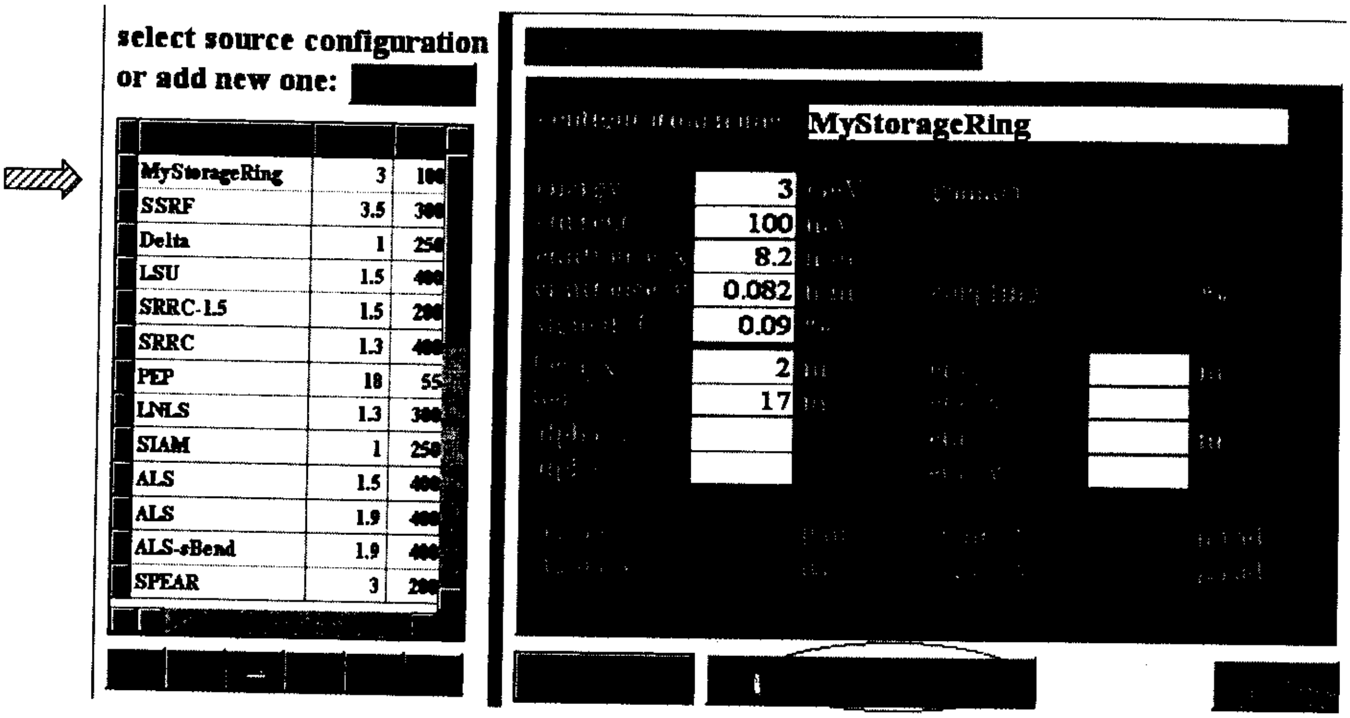
- The Circulating Beam Parameters window will be opened. There are several storage rings listed in the table on the left. The parameters of the selected ring will be shown on the right.



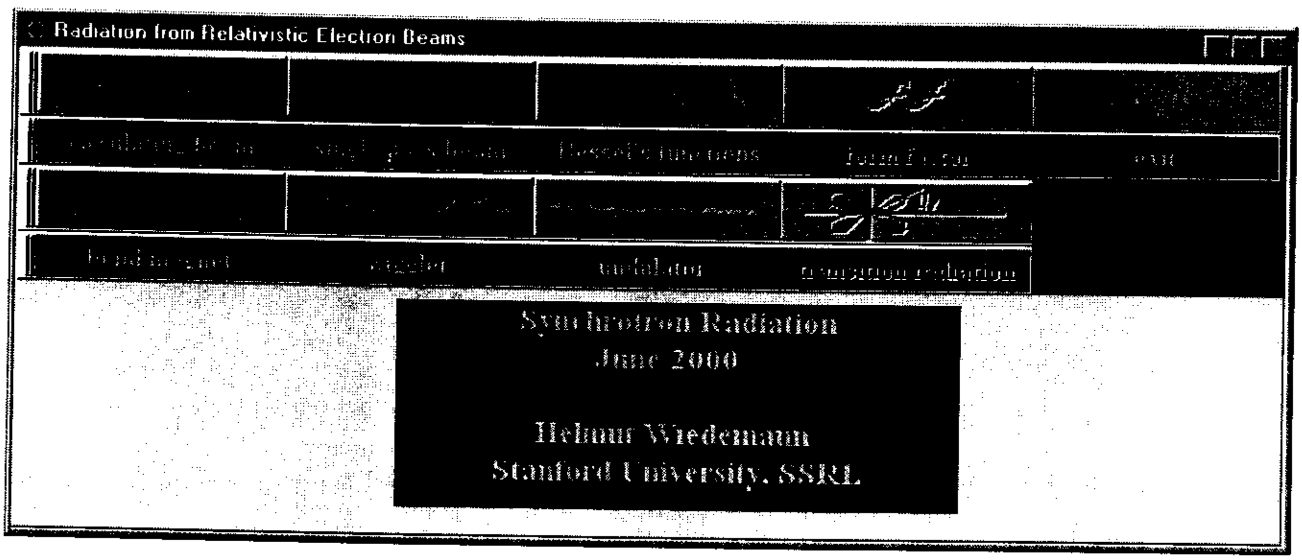
- To add a new storage ring on the list, click **Yes** at *add new one (storage ring).* A new blank entry will appear at the top of the list together with a new beam configuration sheet.



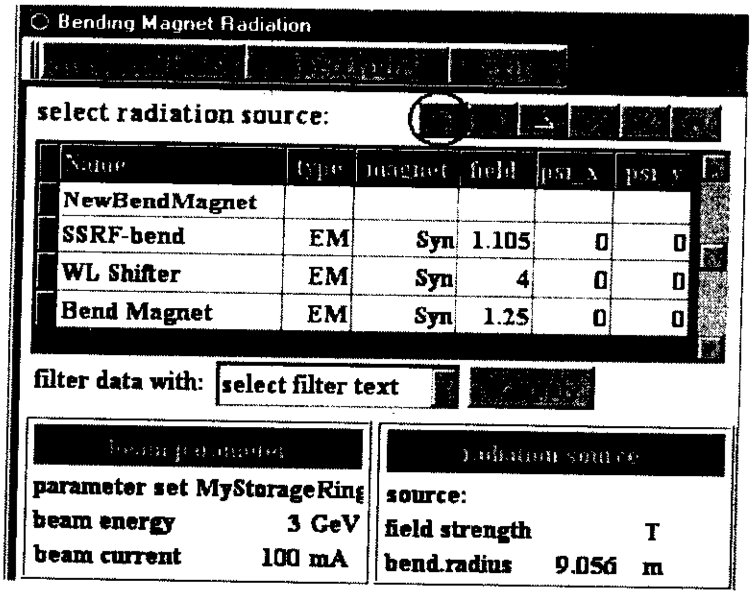
- Create a new ring configuration using the information from your storage ring design.
- Select **Accept and Close** option.



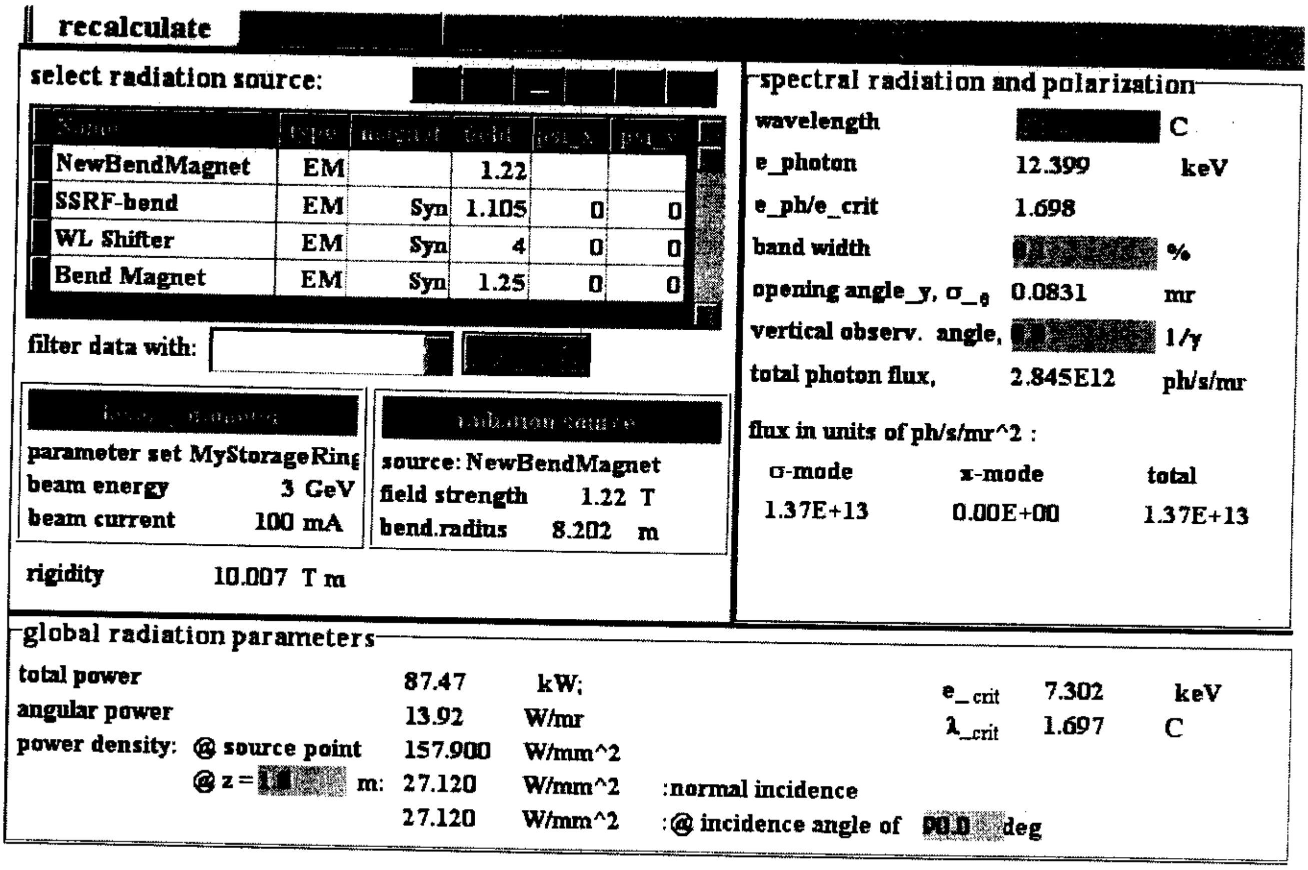
- The main window will be reopened with options of the radiation sources (bending magnet, wiggler, undulator, or transition radiation).



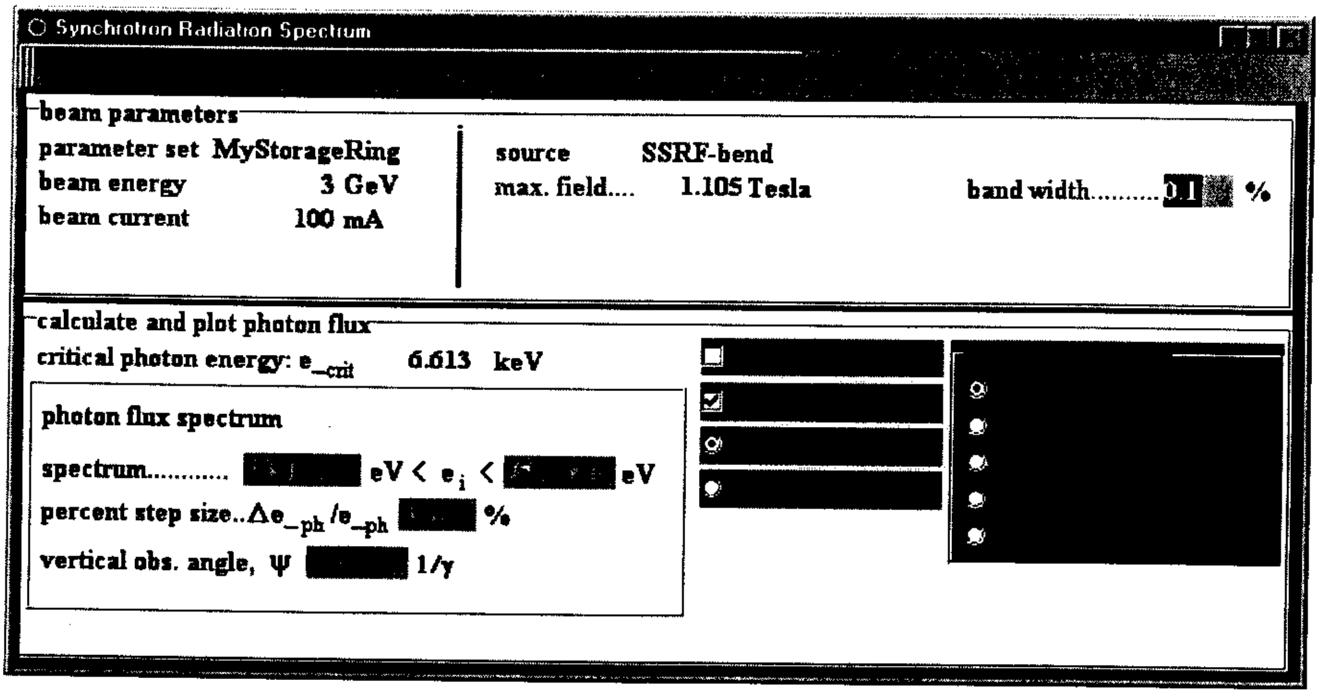
- Synchrotron Radiation from bending magnets: Add a new bending magnet by clicking at the **plus** sign and put in the magnet parameter from the storage ring (type of magnet: EM for Electro Magnet or PM for Permanent Magnet and the field in Tesla).



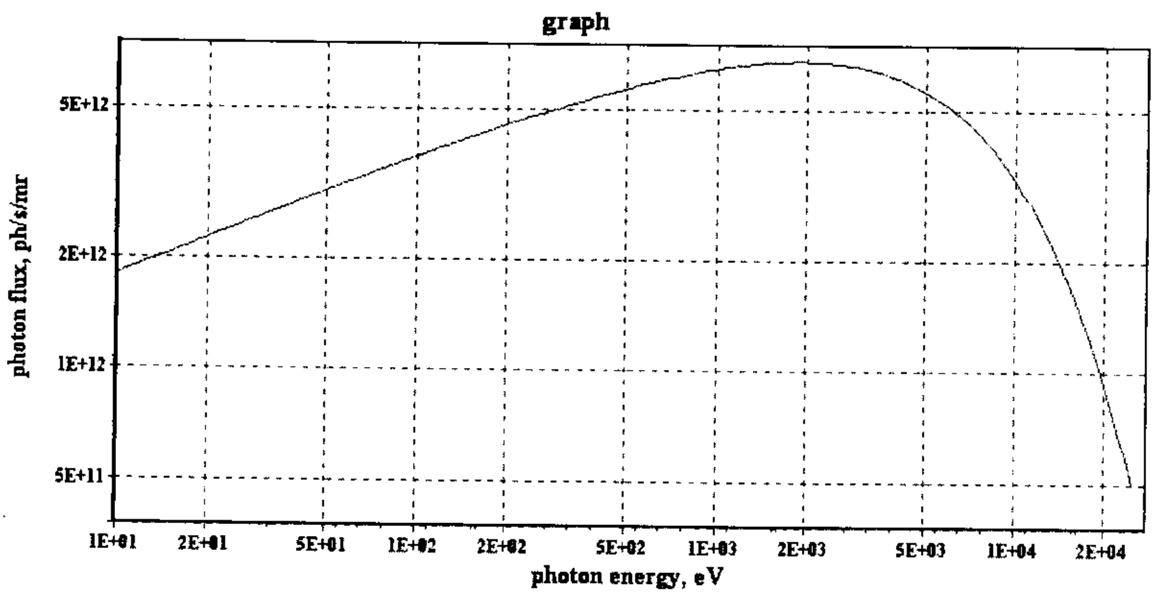
- Click **apply** to update the parameters and click **recalculate** for radiation properties. The results will be posted in the window.



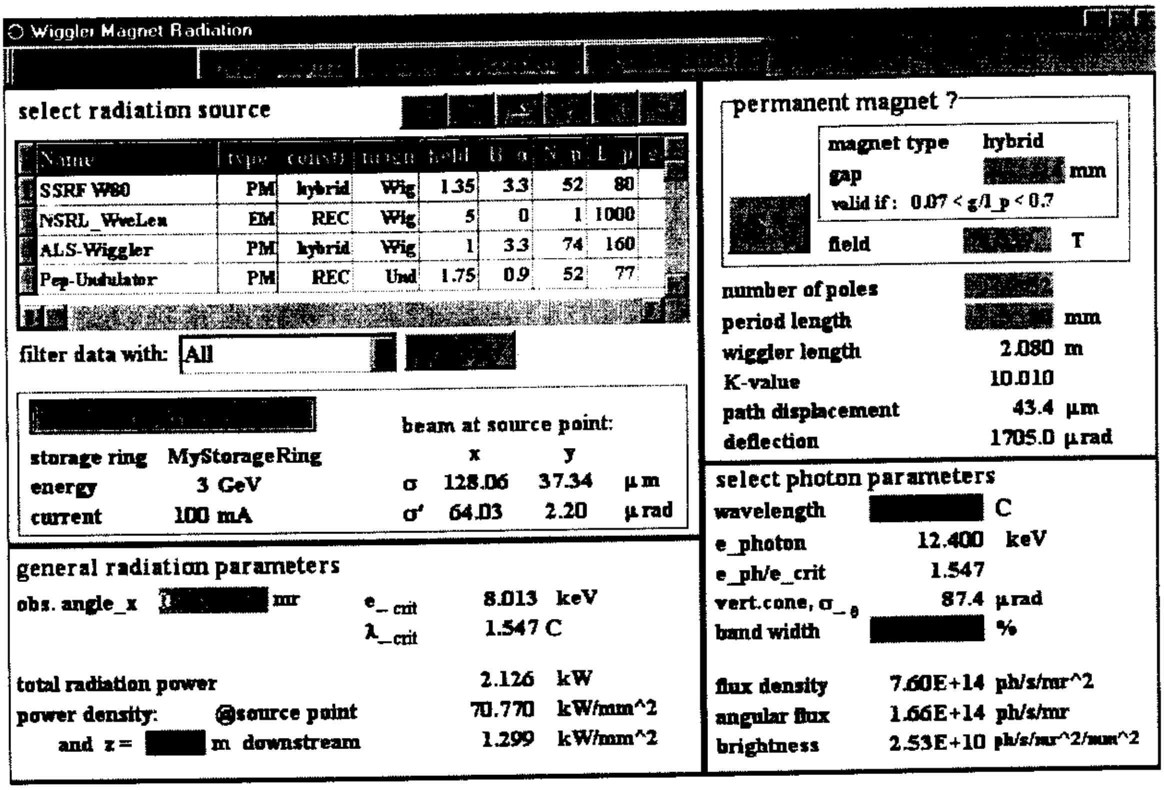
- Select **spectrum** to illustrate the spectral photon flux in a graph format.
- The spectrum window is then activated. Select the spectrum of the interest and its parameter to be plotted.

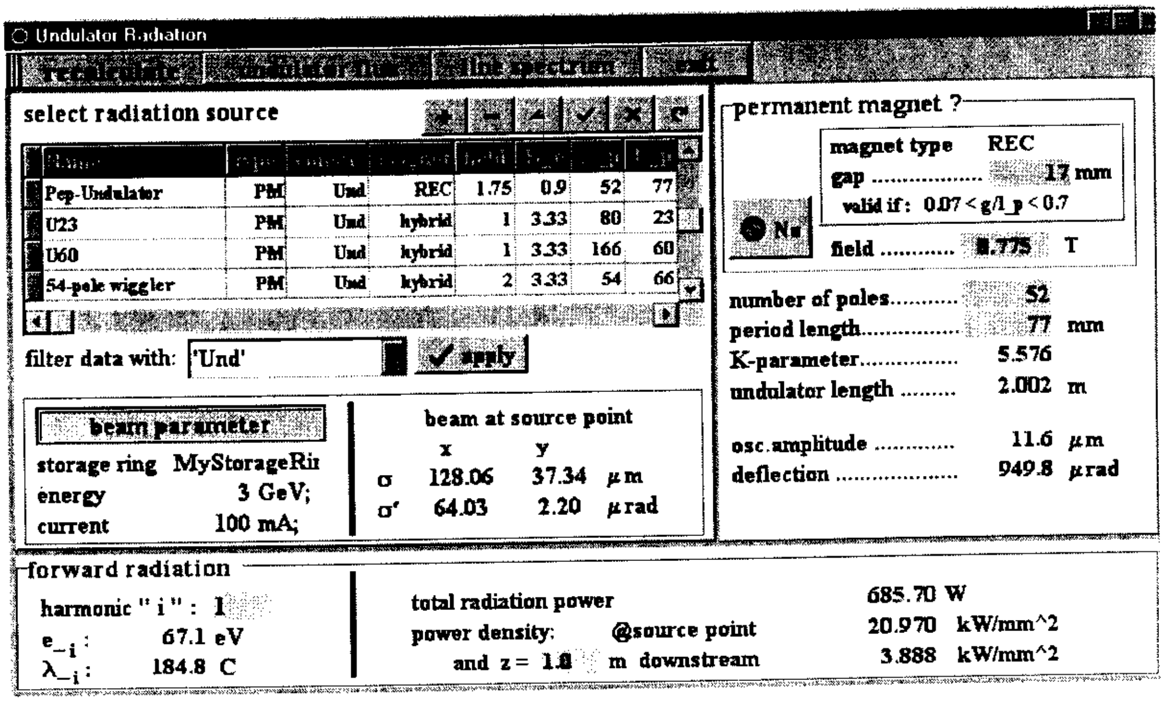


- For example, a graph of photon flux:

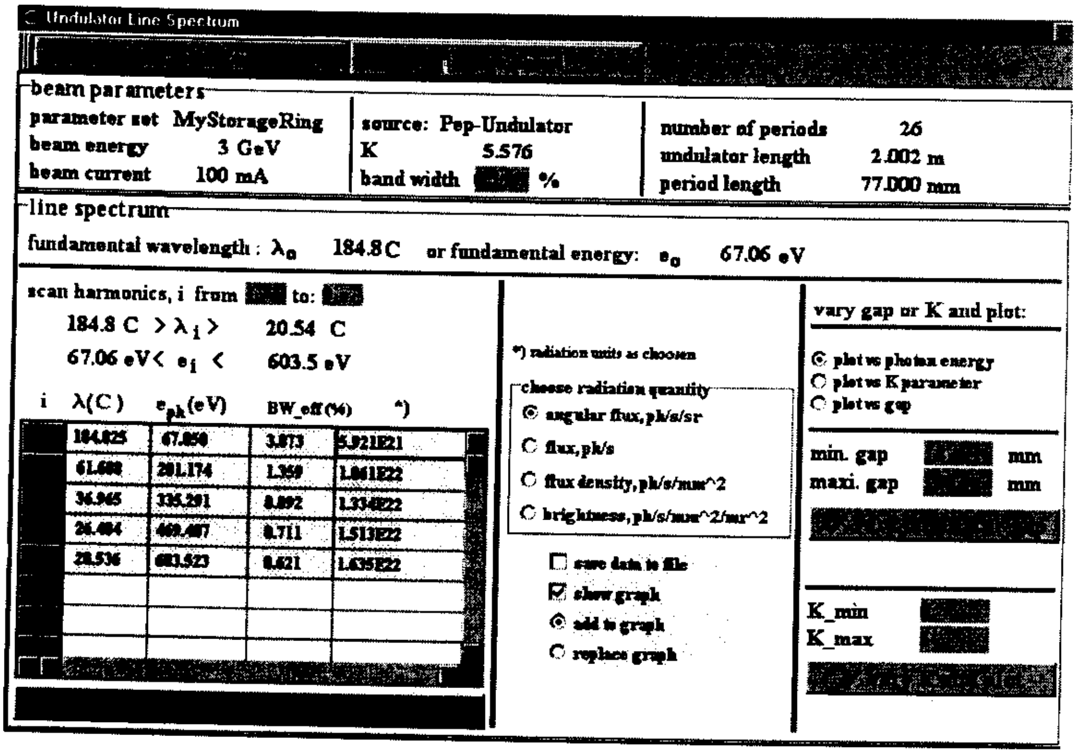


- The calculations for Synchrotron Radiation from Wiggler magnet and Undulator Radiation work in a similar way.

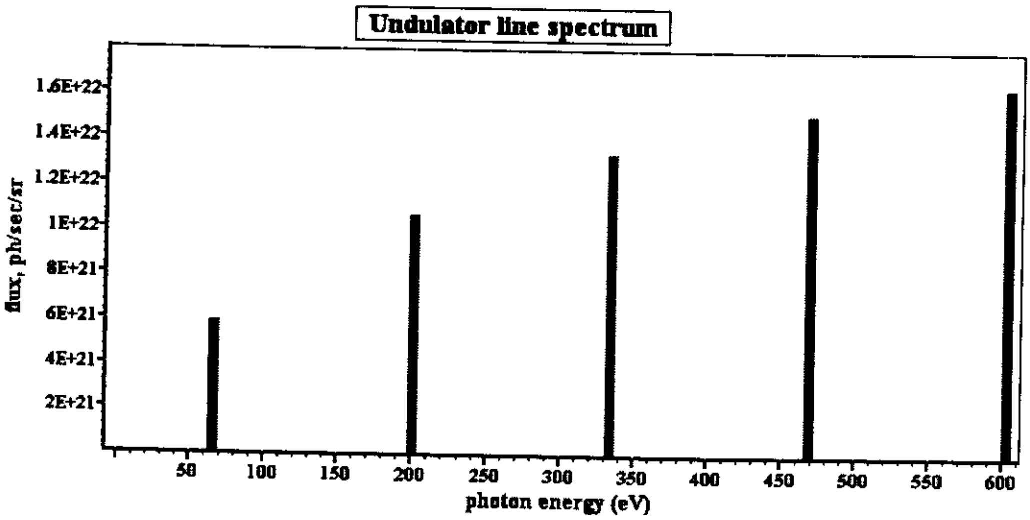




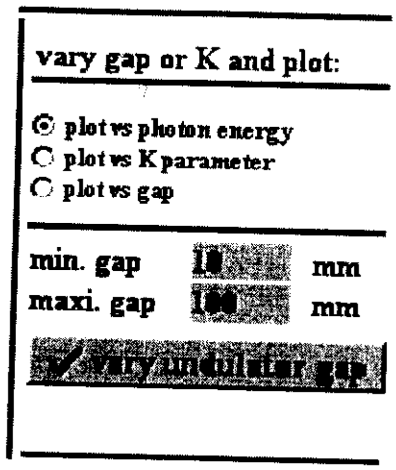
- Features in the calculations for Undulator Radiation include **line spectrum** in which the calculation of the photon spectrum for higher harmonic can be done, as well as the undulator line spectrum plot.



- Undulator line spectrum up to the 9th harmonic:



- The calculations with variations of undulator gaps or K parameters are also available.



- For example, varying the Pep-undulator gap from 10 mm to 100 mm, the photon flux up to the 9[th] harmonic will be as shown in the graph.