On possibilities to generate γ rays in 5 to 6 GeV region in SPring-8

1. Motivation

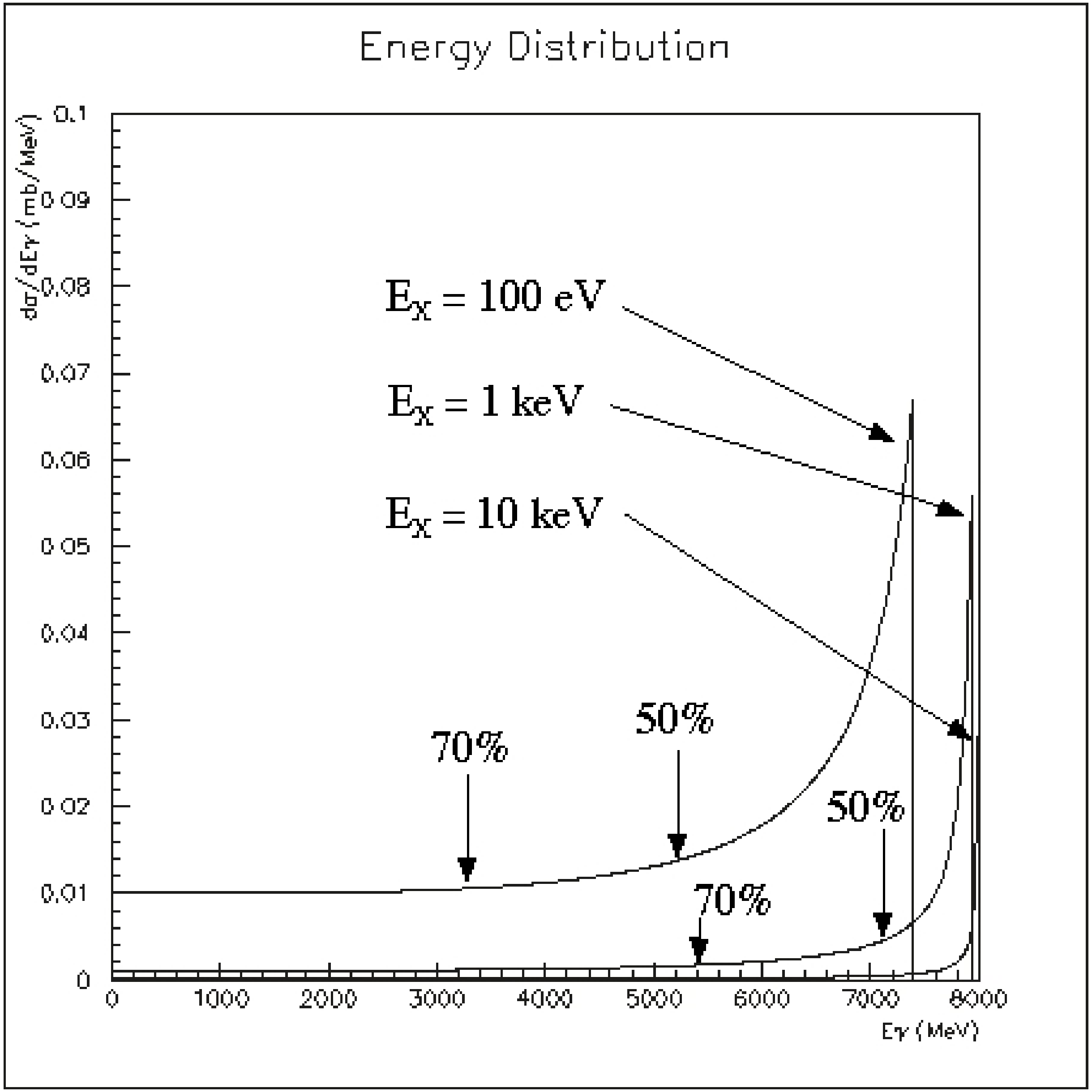
2. An idea to generate high energy γ ray

3. Synchrotron radiation from undulators

4. Almost NOGO theorem

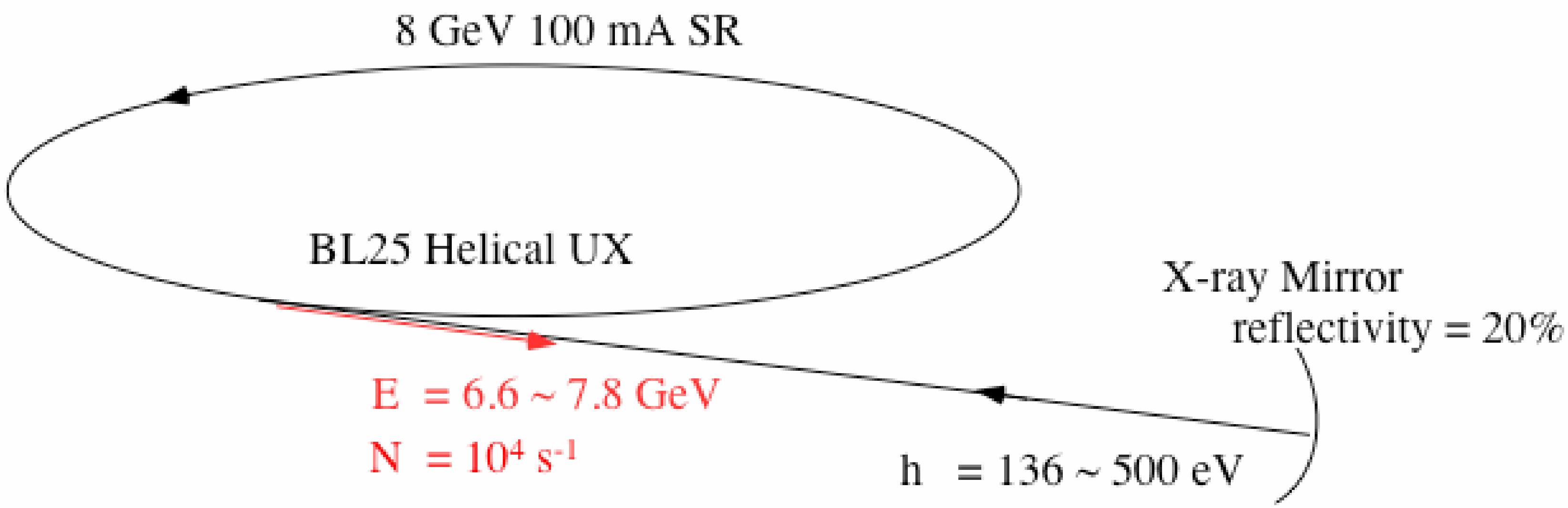
5. Discussion

High energy CBS provides quasi-monochromatic γ-ray

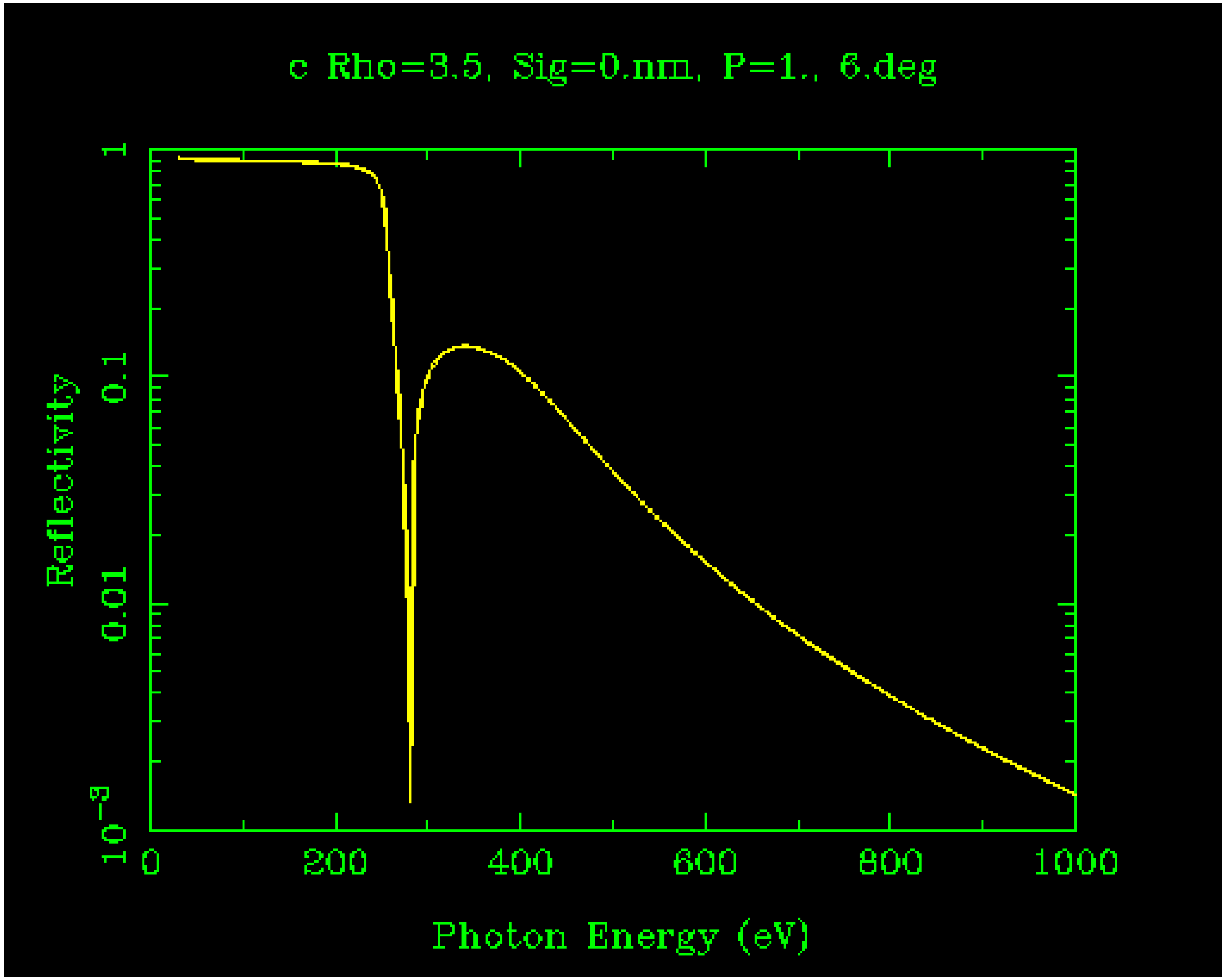


Production of HLEP (1)

Nelyubin-Fujiwara-Nakano-Wojtsekhowski NIM **A425** (1999) 65



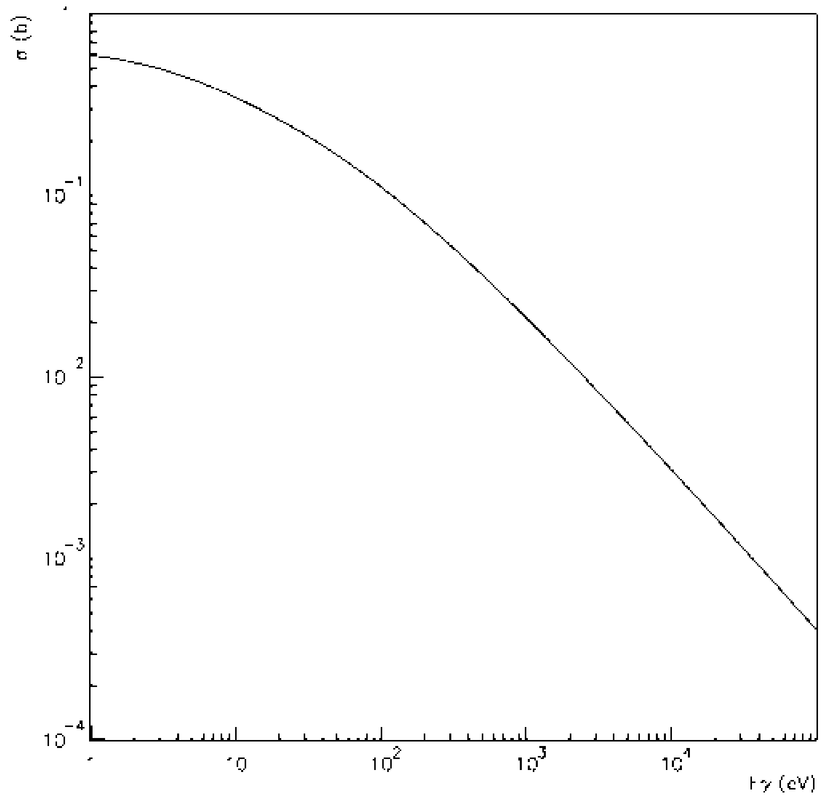
Reflectivity of Diamond



Gamma Yield

$$\dot{N}_\gamma = 2\frac{I}{e}\frac{\sigma l}{c s_x}\dot{N}_{ph} = 4.5\times10^{-14}\frac{l[\mathrm{m}]}{s_x[\mathrm{mm}^2]}\dot{N}_{ph}$$

Total Cross Section



Photon Flux from Planer Undulator

$$\frac{d\dot{N}_{ph}^{Plan}}{d\omega d\Omega} = \alpha\gamma^2 N^2 \frac{I}{e}\frac{1}{\omega}\sum_{k=1}^{\infty} F_k^{Plan}(K, \gamma\theta, \phi; \omega/\omega_1)$$

$$\alpha\frac{I}{e} = 4.55\times10^{16}\,(\mathrm{s}^{-1})\; I[A]$$

Angular Spectral Function

$$F_k^{Plan}(K, \gamma\theta, \phi; \omega/\omega_1) = G_k(K, \gamma\theta, \phi) H_k(\omega/\omega_1)$$

$$K = \gamma\theta_0 = \frac{eB_0\lambda_0}{2\pi\beta mc} = 0.934 \times B_0[T]\lambda_0[cm]$$

$$\omega_1 = \omega_1(\gamma\theta) = \frac{2\beta\gamma^2\omega_0}{1 + K^2/2 + \gamma^2\theta^2}$$

Choice of Undulator

$$100\ eV = \omega_1(0) = \frac{4\pi\beta\hbar c\gamma^2/\lambda_0}{1+K^2/2}$$

$$K = 0.934 \times B_0[T]\lambda_0[cm]$$

$$P_{tot} \sim N\gamma^2 K^2/\lambda_0$$

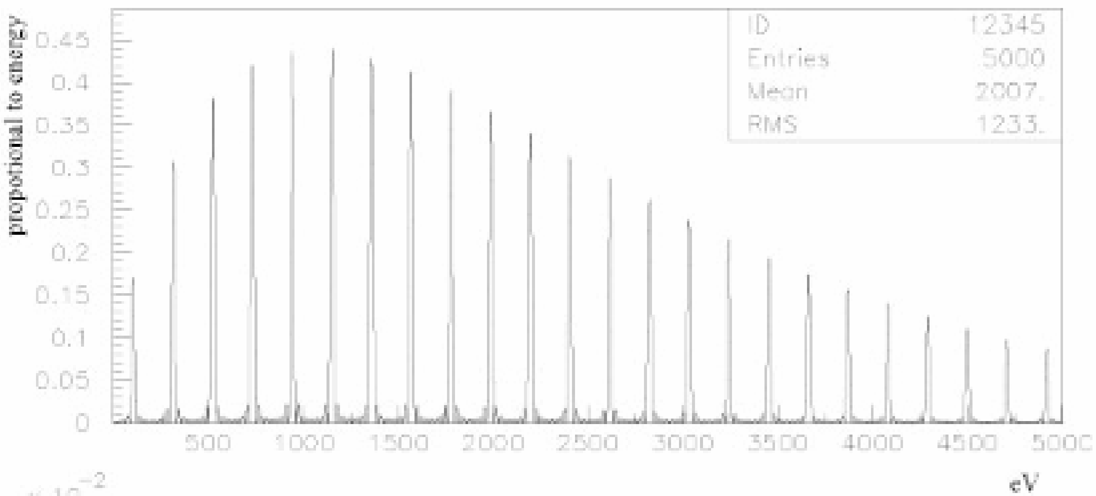
Portion of the fundamental= $\dfrac{K^2}{(1+K^2/2)^2}$

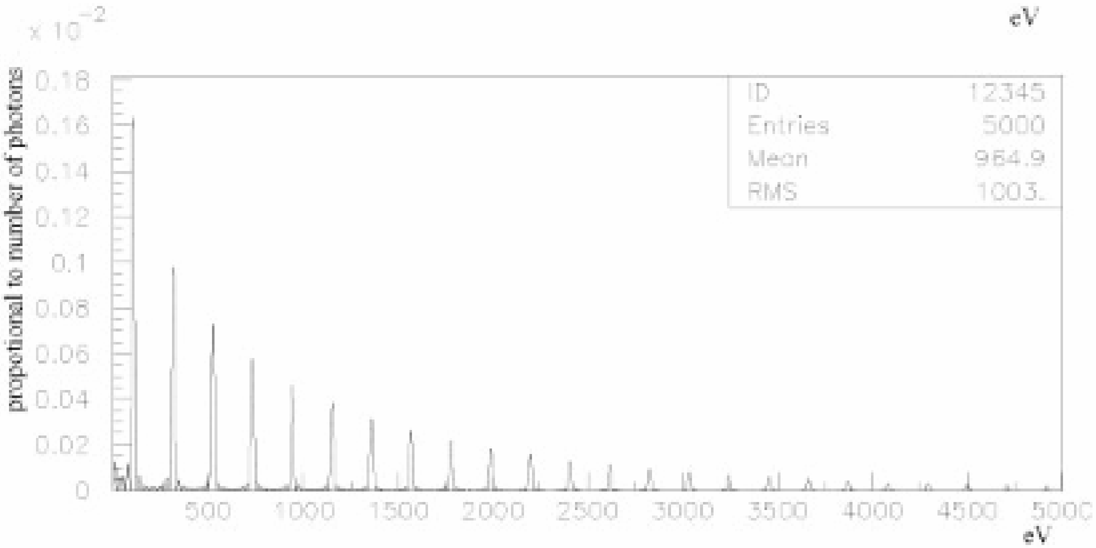
$$\lambda_0 < 1\,m$$

$$\Rightarrow \quad \boxed{K = 3 \quad \lambda_0 = 1.1\,m}$$

$B_0 = 300$ kG

Harmonics Composition





Angular Function

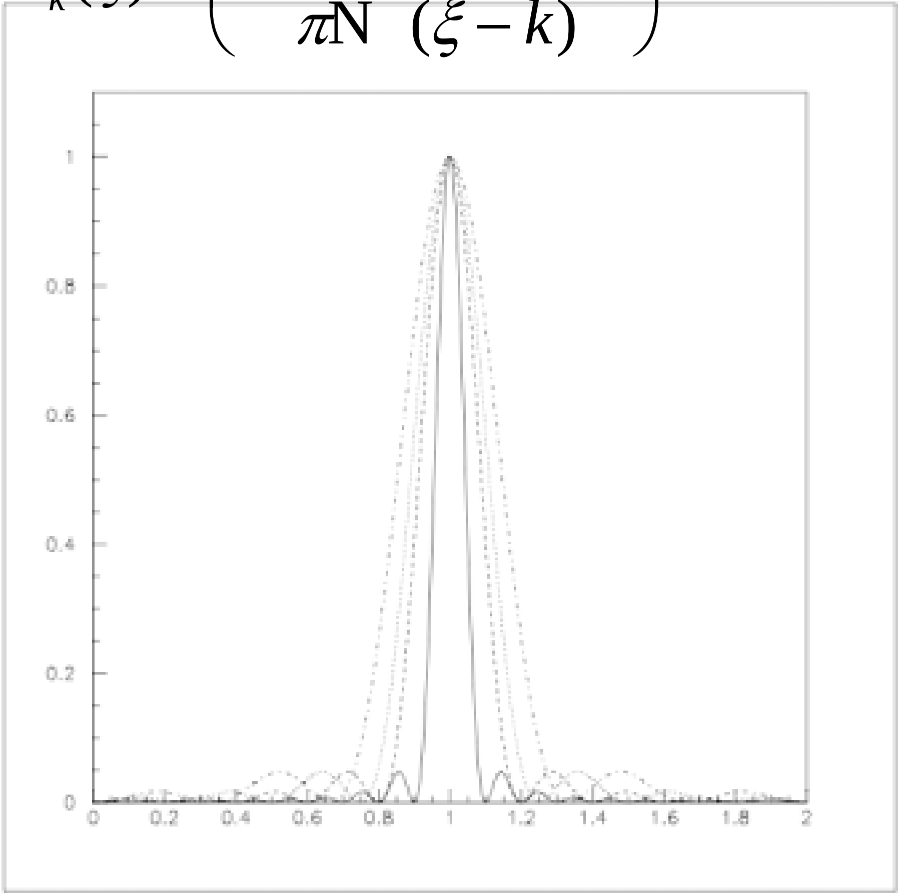
$$G_k(K,\gamma\theta,\phi)=\frac{4k^2}{(1+\frac{1}{2}K^2+\gamma^2\theta^2)^2}\left\{\left|S_1\gamma\theta\cos\phi - \left(S_1+\tfrac{2}{k}S_2\right)\frac{1+\frac{1}{2}K^2+\gamma^2\theta^2}{2\gamma\theta\cos\phi}\right|^2+[\gamma\theta S_1\sin\phi]^2\right\}$$

$$S_\nu=\sum_{n=-\infty}^{\infty}n^\nu J_n(k\varsigma)J_{2n+k}(k\eta)$$

$$\varsigma=\frac{K^2/4}{1+\frac{1}{2}K^2+\gamma^2\theta^2}\quad,\qquad \eta=\frac{2K\gamma\theta\cos\phi}{1+\frac{1}{2}K^2+\gamma^2\theta^2}$$

Spectral Function

$$H_k(\xi) = \left(\frac{\sin[N \; \pi(\xi - k)]}{\pi N \; (\xi - k)} \right)^2$$



Result

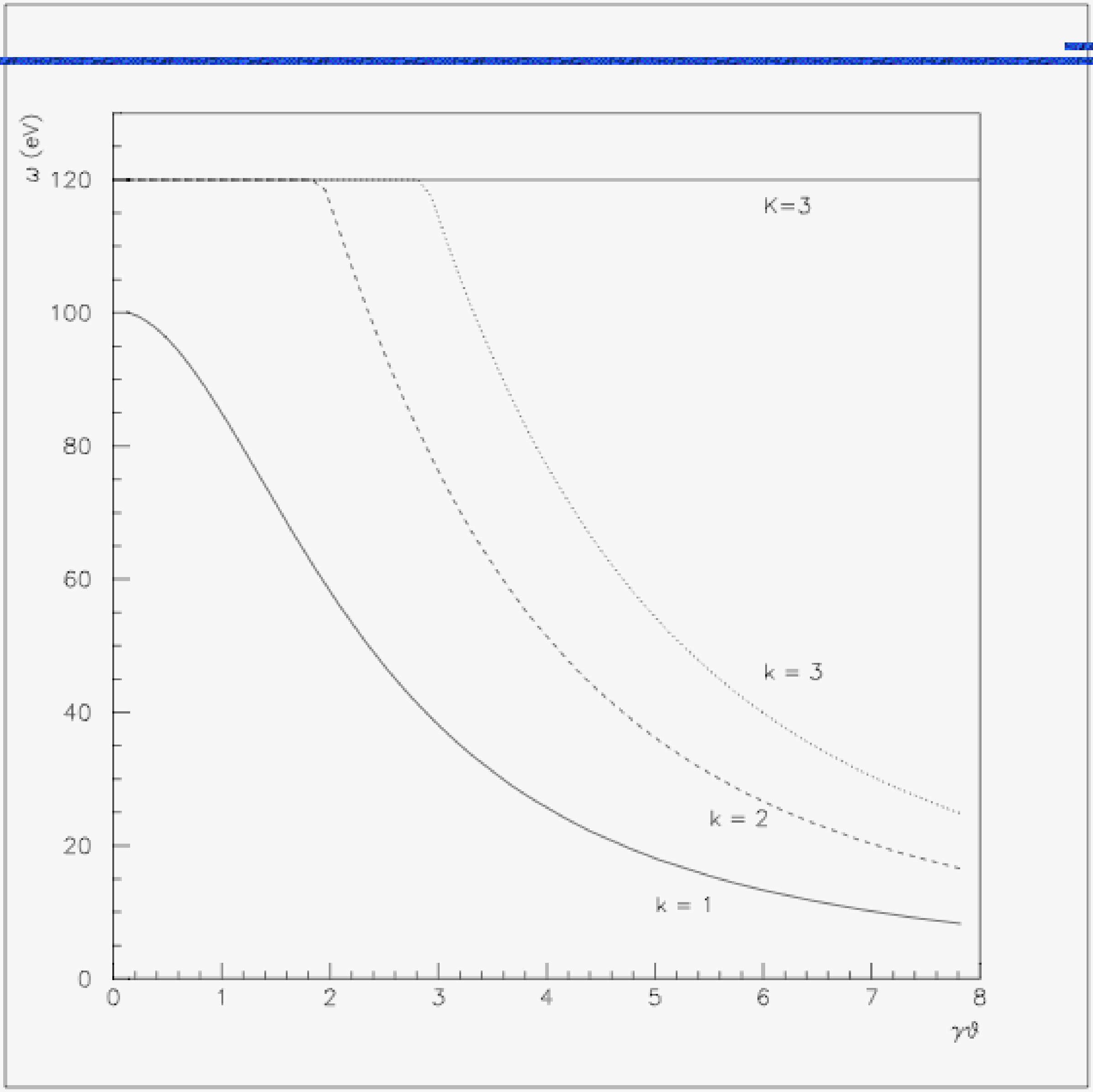
$$\dot{N}(\overline{\omega},\overline{\theta}) = \alpha N \frac{I}{e} \sum_{k=1}^{\infty} \frac{1}{k} \int_0^{\gamma\overline{\theta}} dg\, g\, \theta(g > g_k(\overline{\omega}))$$

$$\times \int_0^{2\pi} d\phi\, G_k(K, g, \phi)$$

$$= \alpha N \frac{I}{e} \times factor$$

$$g_k(\omega) = \sqrt{1 + K^2/2}\sqrt{\frac{k\omega_1(0)}{\omega} - 1}$$

factor $= 3.3$ for $\overline{\theta} = 0.5$ mrad



ω (eV)
120
100
80
60
40
20
0
K=3
k = 3
k = 2
k = 1
0
1
2
3
4
5
6
7
8
γϑ

Photon Flux from Bending Magnet (1)

$$\frac{d\dot{N}_{ph}^{Bend}}{d\omega d\Omega} = \frac{3\alpha}{4\pi^2}\gamma^2 \frac{I}{e}\frac{1}{\omega} F^{Bend}(\gamma\psi; \omega/\omega_c)$$

$$\omega_c = \frac{3c\gamma^3}{2\rho} \quad , \qquad \rho = \frac{\gamma\beta m_e c^2}{eB}$$

$$F^{Bend} = \left(1+\gamma^2\psi^2\right)^2 \left[K_{2/3}(\xi) + \frac{\gamma^2\psi^2}{1+\gamma^2\psi^2} K_{1/3}(\xi)\right]\left(\frac{\omega}{\omega_c}\right)^2$$

$$\xi = \frac{1}{2}\frac{\omega}{\omega_c}\left(1+\gamma^2\psi^2\right)^{3/2}$$

Photon Flux from Bending Magnet(2)

$$8\,\text{GeV},\quad 1\,\text{T} \quad \Rightarrow \quad \omega_\text{c} = 42.6\,\text{keV}/\hbar$$

$$100\,\text{eV} \quad \Rightarrow \quad \omega_c / \omega = 426$$

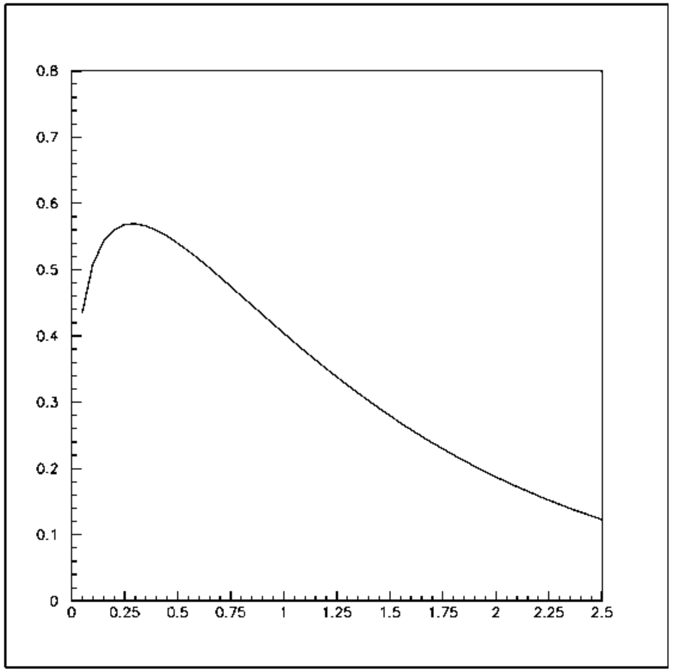
Vertical angular spread

$$\Delta\psi \approx \frac{1}{\gamma}\left(\frac{\omega_c}{\omega}\right)^{1/3} = 0.5\,\text{mrad}$$

Photon Flux from Bending Magnet (3)

$$\int_0^{\gamma\pi} d(\gamma\psi) F^{Bend}(\gamma\psi;\omega/\omega_c) = \frac{16\pi^2}{27} S(\frac{\omega}{\omega_c})$$

$$S(\xi) = \frac{9\sqrt{3}}{8\pi}\xi\int_\xi^\infty d\xi' K_{5/3}(\xi')$$



$$\approx 1.34\xi^{1/3}$$

for $\xi << 1$

Photon Flux from Bending Magnet(4)

$$\frac{d\dot{N}_{ph}^{Bend}}{d\omega d\Theta} = \frac{4\alpha}{9}\frac{I}{e}\gamma\frac{1}{\omega}S(\omega/\omega_c)$$

$$\omega << \omega_c \quad \Rightarrow$$

$$\int_0^{\omega} d\omega' \int_{\Delta\Theta} d\Theta \frac{d\dot{N}_{ph}^{Bend}}{d\omega' d\Theta} \approx \frac{16\alpha}{9}\frac{I}{e}\gamma\left(\frac{\omega}{\omega_c}\right)^{1/3}\Delta\Theta$$

$$= 1.1\times 10^{16} \times I[\mathrm{A}] \times \left(\gamma\Delta\Theta\right) \ \ (\mathrm{ph/s})$$

Photon Flux from Helical Undulator

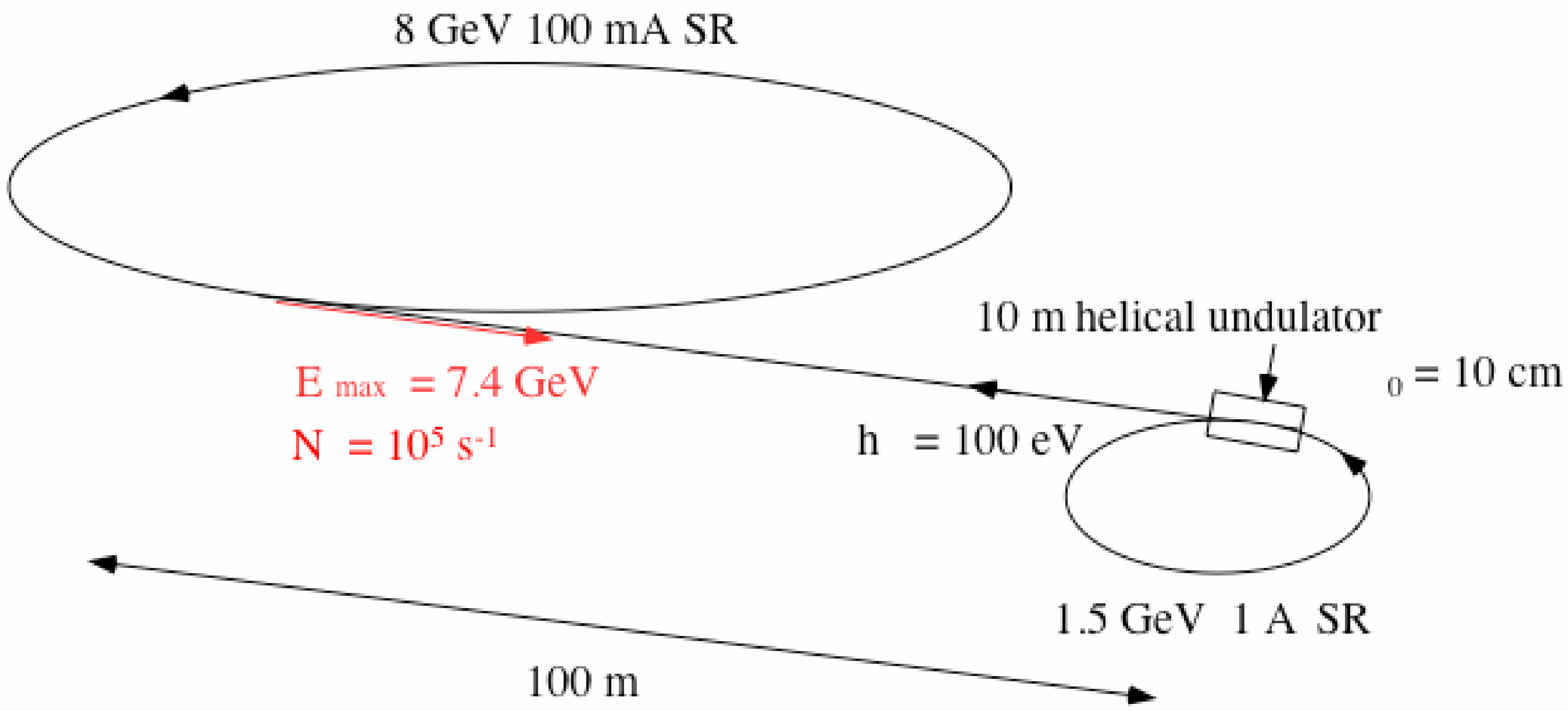
$$\frac{d\dot{N}_{ph}^{Hel}}{d\omega d\Omega} = \alpha\gamma^2 N^{2} \frac{I}{e}\frac{1}{\omega} F^{Hel}(K, \gamma\theta; \omega/\omega_{1h})$$

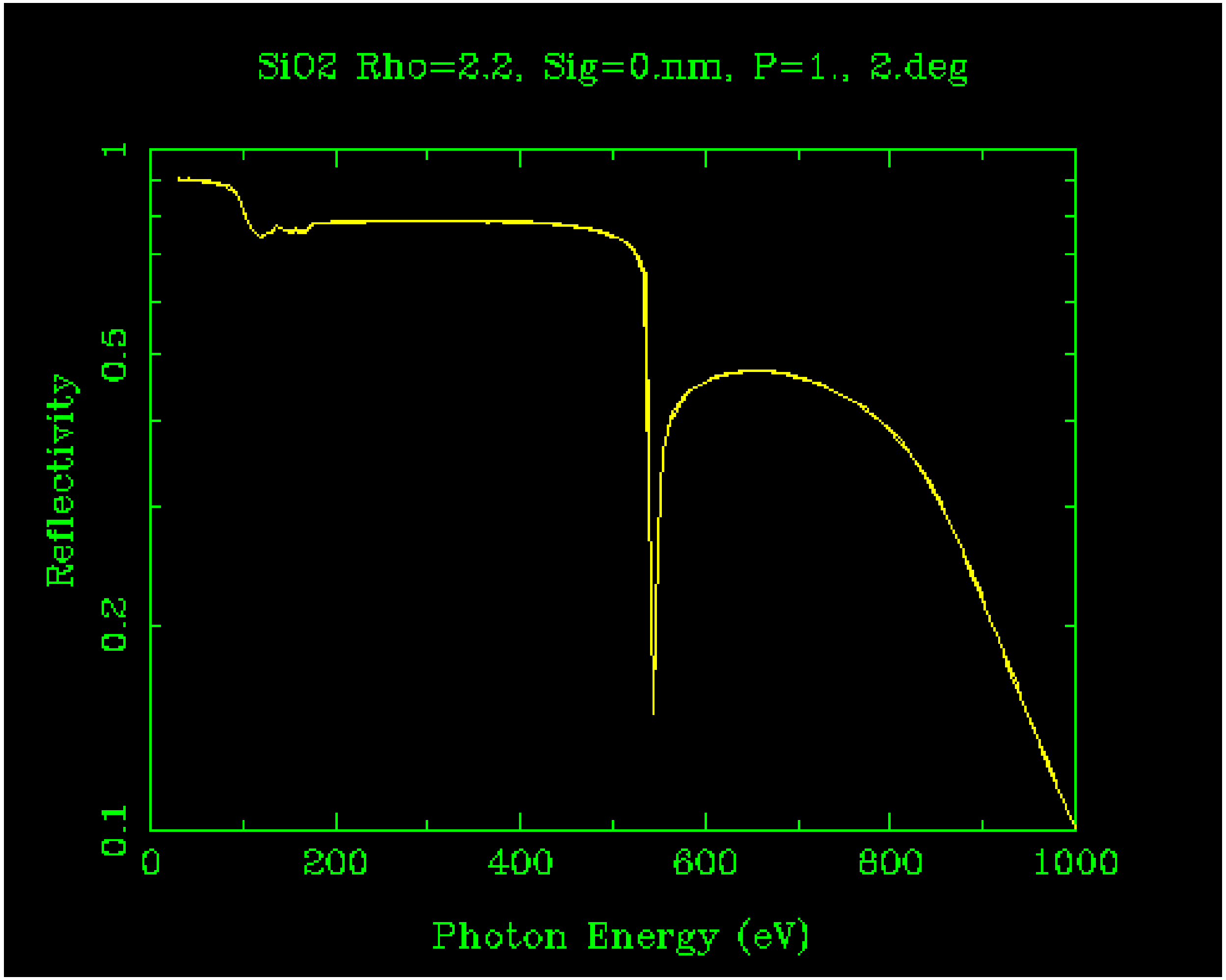
$$\omega_{1h} = \omega_{1h}(\gamma\theta) = \frac{2\beta\gamma^2\omega_0}{1+K^2+\gamma^2\theta^2}$$

$$F^{Hel} = \kappa^2 \sum_{k=1}^{\infty}\left[J'^2_k(\xi) + \left(\frac{\gamma\theta}{K} - \frac{k}{\xi}\right)^2 J_k^2 \right] \times \left[\frac{\sin[N\pi(\omega/\omega_{1h} - k)]}{N\pi(\omega/\omega_{1h} - k)} \right]^2$$

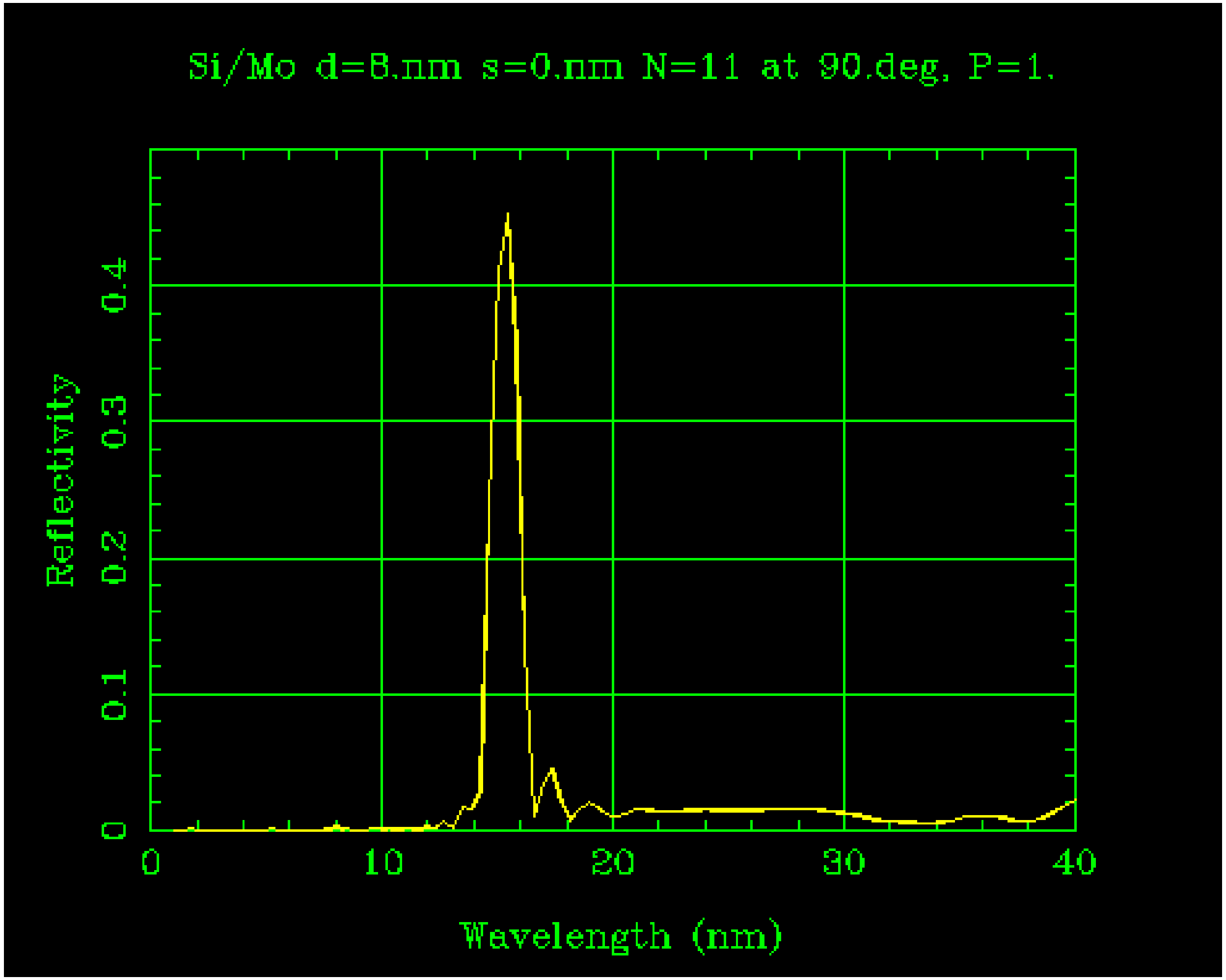
$$\kappa = \frac{\omega}{\omega_{1h}} \frac{2K}{1+K^2+\gamma^2\theta^2} \quad , \qquad \xi = \kappa\gamma\theta$$

Production of HLEP (2)





SiO2 Rho=2.2, Sig=0.nm, P=1., 2.deg
Reflectivity
1
0.5
0.2
0.1
0
200
400
600
800
1000
Photon Energy (eV)


Si/Mo d=8.nm s=0.nm N=11 at 90.deg, P=1.
Reflectivity
0
0.1
0.2
0.3
0.4
0
10
20
30
40
Wavelength (nm)