SYNCHROTRON RADIATION @ SUPERB

Synchrotron Light Beamlines

XV SuperB General Meeting at California Institute of Technology

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OUTLINE

- Benchmark results for Super-B as lightsource.
- Source parameters as function of beam energy.
- Beam line layout.

COMMENTS TO BENCHMARK STUDY

- Compare bend magnet and undulator synchrotron radiation from SuperB HER and LER to other dedicated sources: NSLS II, PEP X, ESRF, ...

- The calculation is done analytically using the formalism described in the standard literature (X-RAY DATA BOOKLET, Wiedemann, ...)

- Source point data for SuperB for bend calculation extrapolated and same as NSLS-II for undulator calculation.

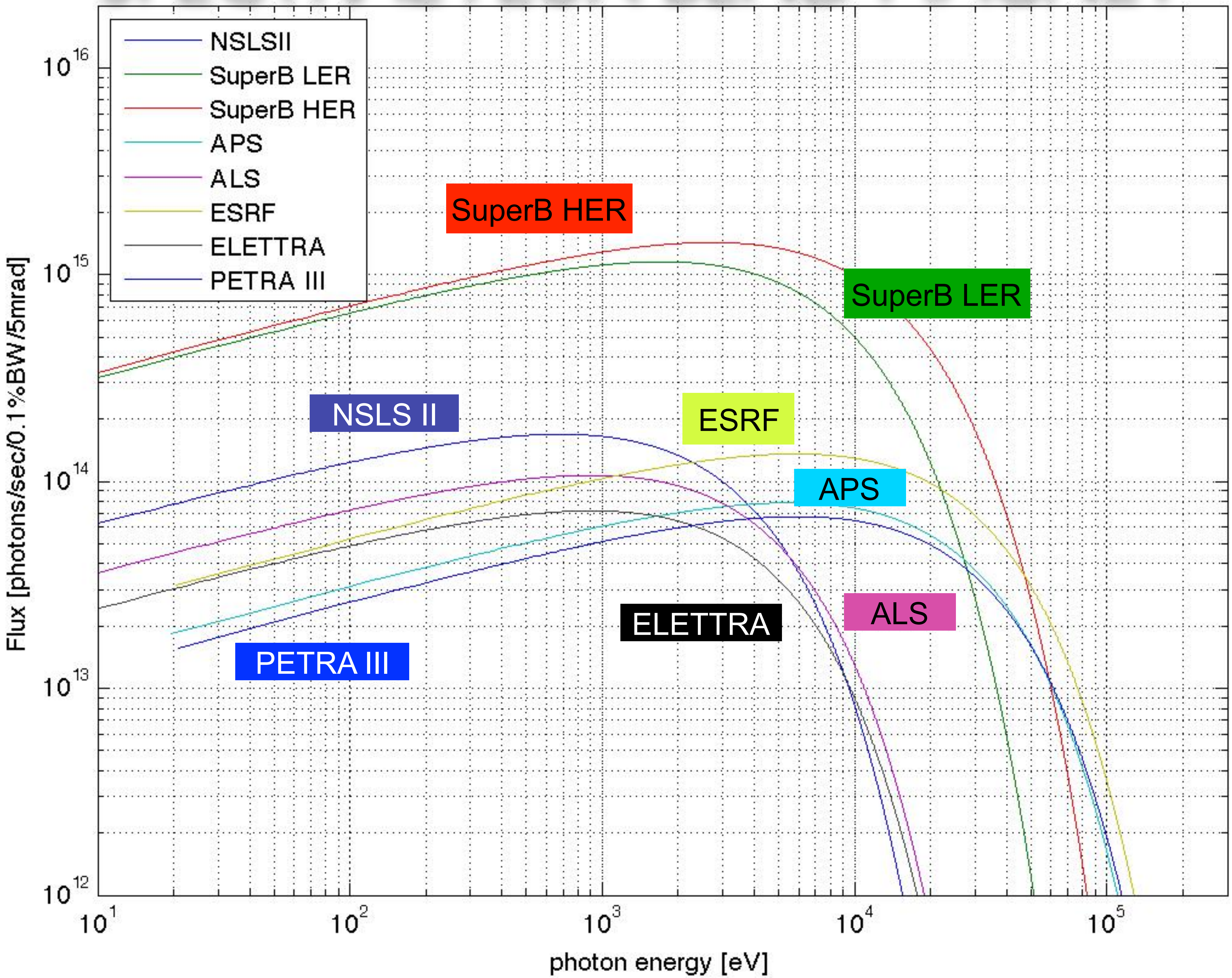
- Used 8 pm as minimal vertical emittance to take diffraction limit into account.

PARAMETER TABLE BEND MAGNET

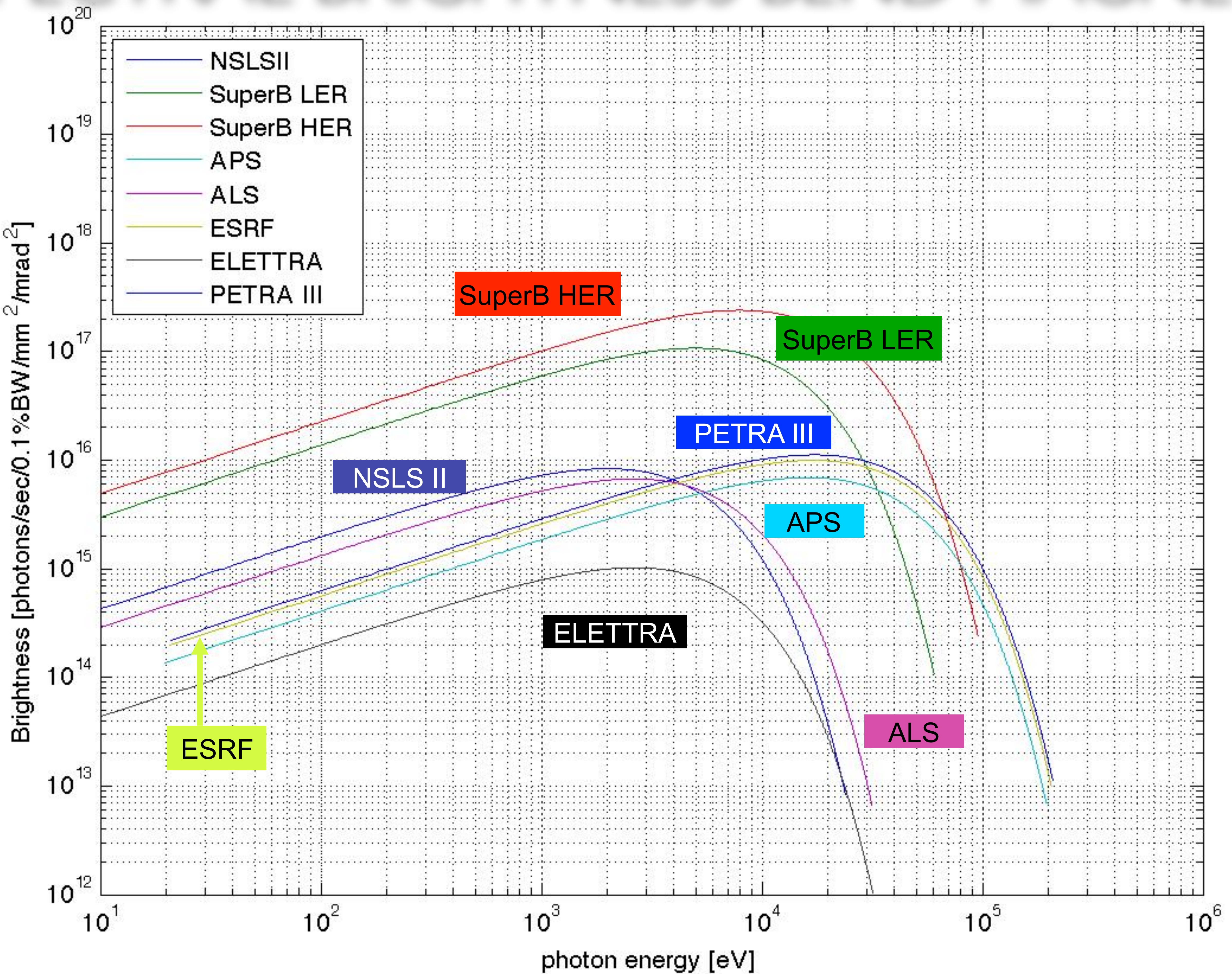
Parameters *	SuperB HER	SuperB LER	NSLS II	APS	ESRF	ELETTRA	ALS
E [GeV]	6.7	4.18	3	7.0	6.03	2.0	1.9
I [mA]	1892	2447	500	100	200	320	500
ρ [m]	69.64	26.8	24.975	38.961	23.623	5.55	4.81
εx [m rad]	2.0 E-9	2.46 E-9	0.55 E-9	2.514 E-9	4.0 E-9	7.0 E-9	6.3 E-9
εy [m rad]	5.0 E-12	6.15 E-12	8.0 E-12	22.6 E-12	25.0 E-12	70.0 E-12	50 E-12
γy [m^-1]	0.334	0.537	0.05	0.101	0.10	0.5	0.740
σx [mm]	82.1 E-3	92.1 E-3	125.0 E-3	81.7 E-3	77.0 E-3	139.0 E-3	101.8 E-3
σy [mm]	8.66 E-3	9.11 E-3	13.4 E-3	27.0 E-3	29.5 E-3	28.0 E-3	8.2 E-3

* Source of data different web pages, CDRs and presentations

SPECTRAL FLUX BEND MAGNET



SPECTRAL BRIGHTNESS BEND MAGNET



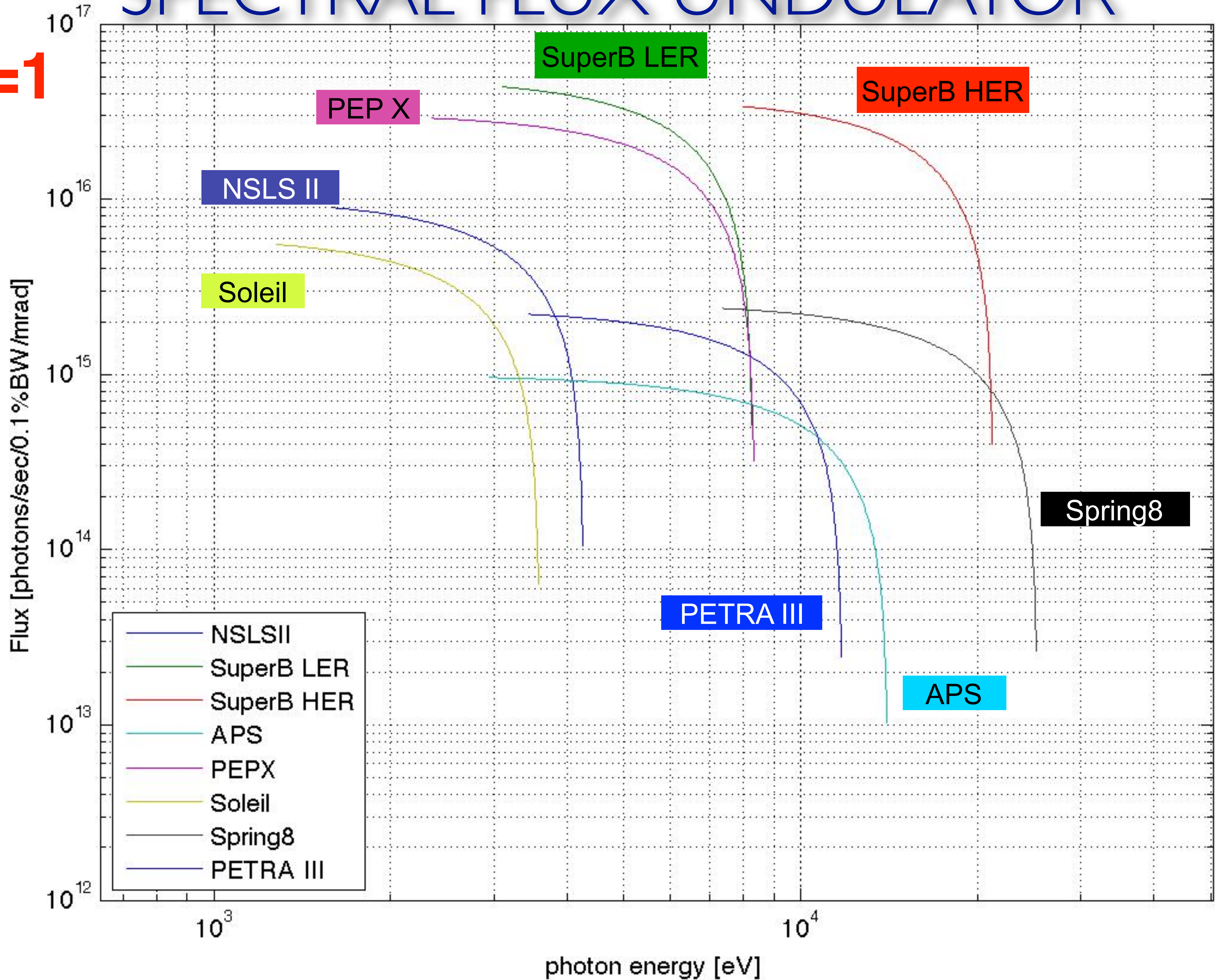
PARAMETER TABLE UNDULATOR

Parameters *	SuperB HER	SuperB LER	NSLS II	APS	PEPX	Soleil	Spring8	Petra III
	IVU20	IVU20	IVU20	U33	IVU23	U20	U24	U29
E [GeV]	6.7	4.18	3	7.0	4.5	2.75	8.0	6.0
I [mA]	1892	2447	500	100	1500	500	100	100
σx [mm]	60.0 E-3	66.5 E-3	33.3 E-3	278 E-3	22.2 E-3	3.88 E-1	286 E-3	140 E-3
σy [mm]	2.4 E-3	2.6 E-3	2.9 E-3	8.9 E-3	7.0 E-3	8.08 E-3	6.0 E-3	5.6 E-3
$\sigma x'$ [mrad]	33.3 E-3	37.0 E-3	16.5 E-3	11.8 E-3	7.4 E-3	14.5 E-3	11.0 E-3	7.9 E-3
$\sigma y'$ [mrad]	2.1 E-3	2.7 E-3	2.7 E-3	3.3 E-3	1.2 E-3	4.6 E-3	1.0 E-3	4.1 E-6
N [1]	148	148	148	72	150	90	186	172
λu [mm]	20	20	20	33	23	20	24	29
Kmax [1]	1.83	1.83	1.83	2.75	2.26	1.0	2.21	2.2
Kmin [1]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

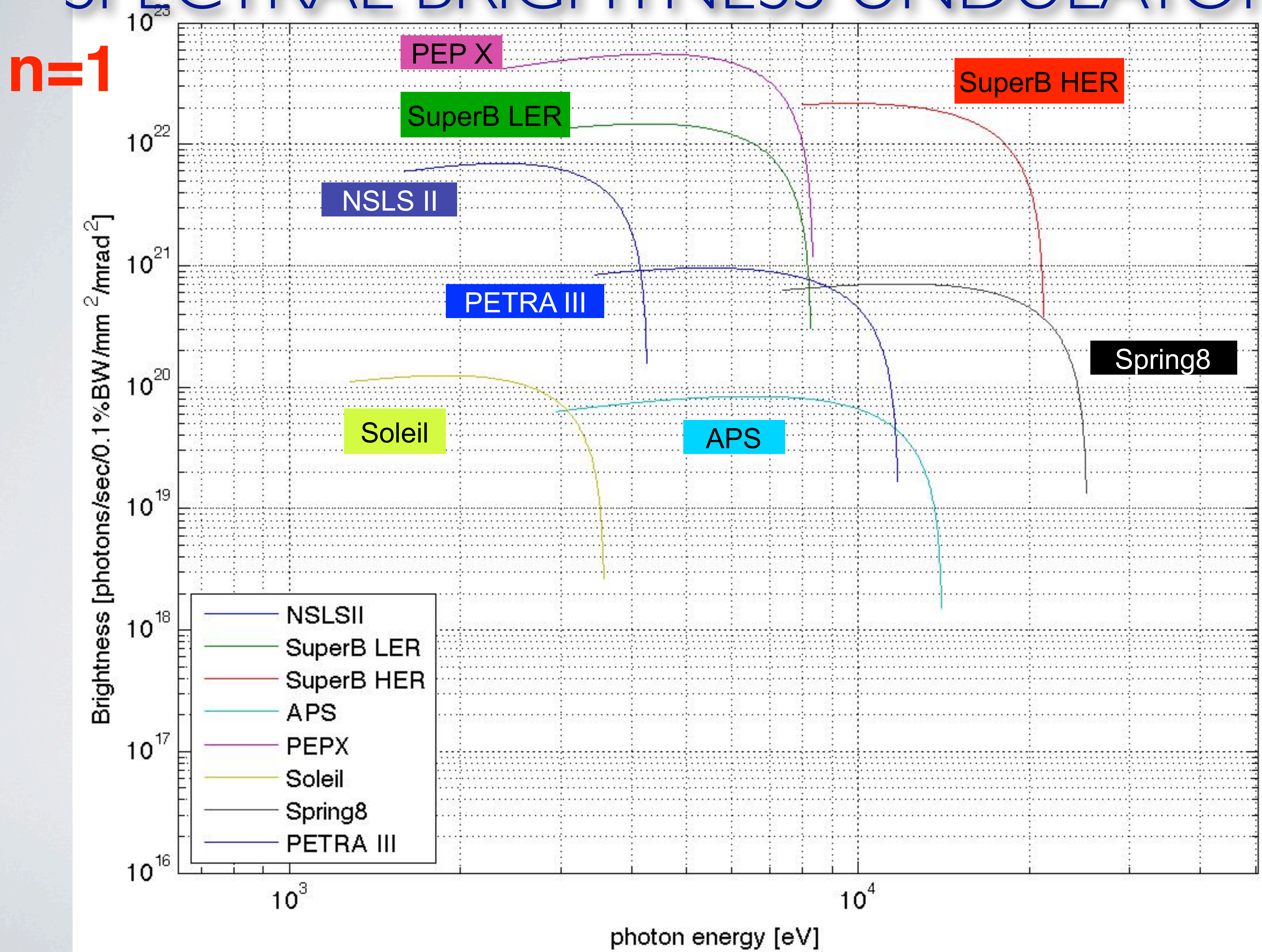
* Source of data different web pages, CDRs and presentations

SPECTRAL FLUX UNDULATOR

n=1



SPECTRAL BRIGHTNESS UNDULATOR



COMMENTS TO SOURCE PARAMETER STUDY

- I changed all "free" parameters to have a better comparison with PEPX: Undulator, beta-functions,...

- Changed the HER energy to 4.5 GeV as PEPX and 3.35 GeV (1/2 of original) to show the brightness development with these changes.

- Coupling factors of 1e-3 have been achieved in standard operation in lightsources. Looked at the brightness when using this in HER instead of 2.5e-3.

- Used 8 pm as minimal vertical emittance to take "standard" diffraction limit into account.

ENERGY DEPENDENCE OF THE EMITTANCE

$$\varepsilon_x = C_q \gamma^2 \frac{\left\langle \frac{H(s)}{\rho^3} \right\rangle}{J_x \left\langle \frac{1}{\rho^2} \right\rangle}$$

$$H(s) = \gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2$$

$$J_x = 1 - \vartheta$$

$$C_q = \frac{55}{32\sqrt{3}} \frac{\hbar c}{mc^2} = 3.84 \cdot 10^{-13}\, m$$

$$\vartheta = \frac{\oint \frac{\eta}{\rho^3}\left(1 + 2k\rho^2\right) ds}{\oint \frac{1}{\rho^2} ds}$$

BUT.... → DEPENDENCE OF DIFFRACTION LIMIT ON ENERGY

$$\lambda = \frac{\lambda_u}{2\gamma^2 n}\left(1 + \frac{K^2}{2}\right), \quad n = 1,3,5,\ldots$$

$$\sigma_r = \frac{1}{4\pi}\sqrt{\lambda N \lambda_u}$$

$$\sigma'_r = \sqrt{\frac{\lambda}{N\lambda_u}}$$

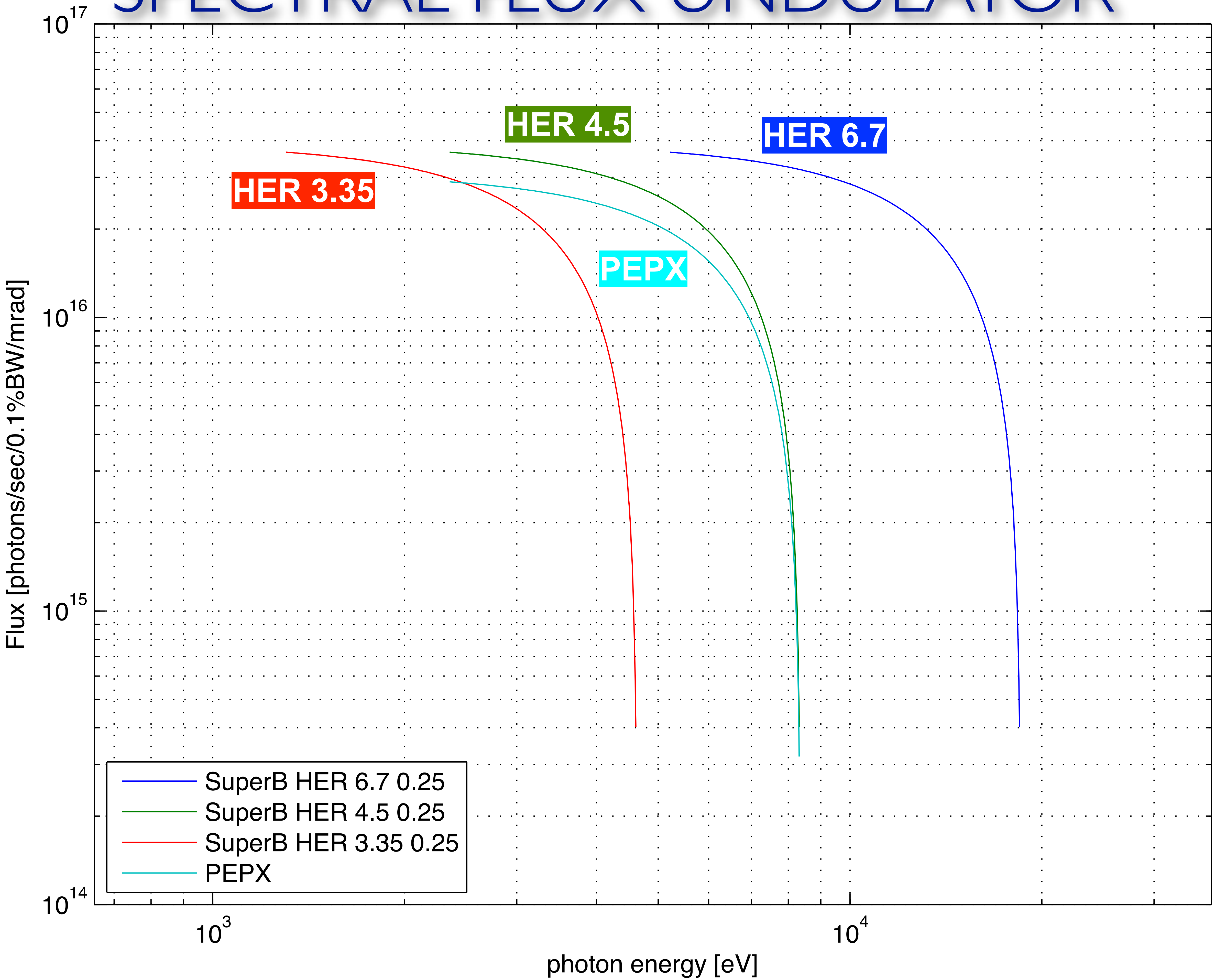
SPECTRAL BRIGHTNESS DEPENDENCE ON BEAM ENERGY

$$\Sigma_u(E) = \left[\varepsilon\left(E^2\right)_u \beta_u + \eta_u^2 \delta^2 + \left(\frac{1}{4\pi} \sqrt{\lambda\left(\frac{1}{E^2}\right) N \lambda_U} \right)^2 \right]^{\frac{1}{2}}$$

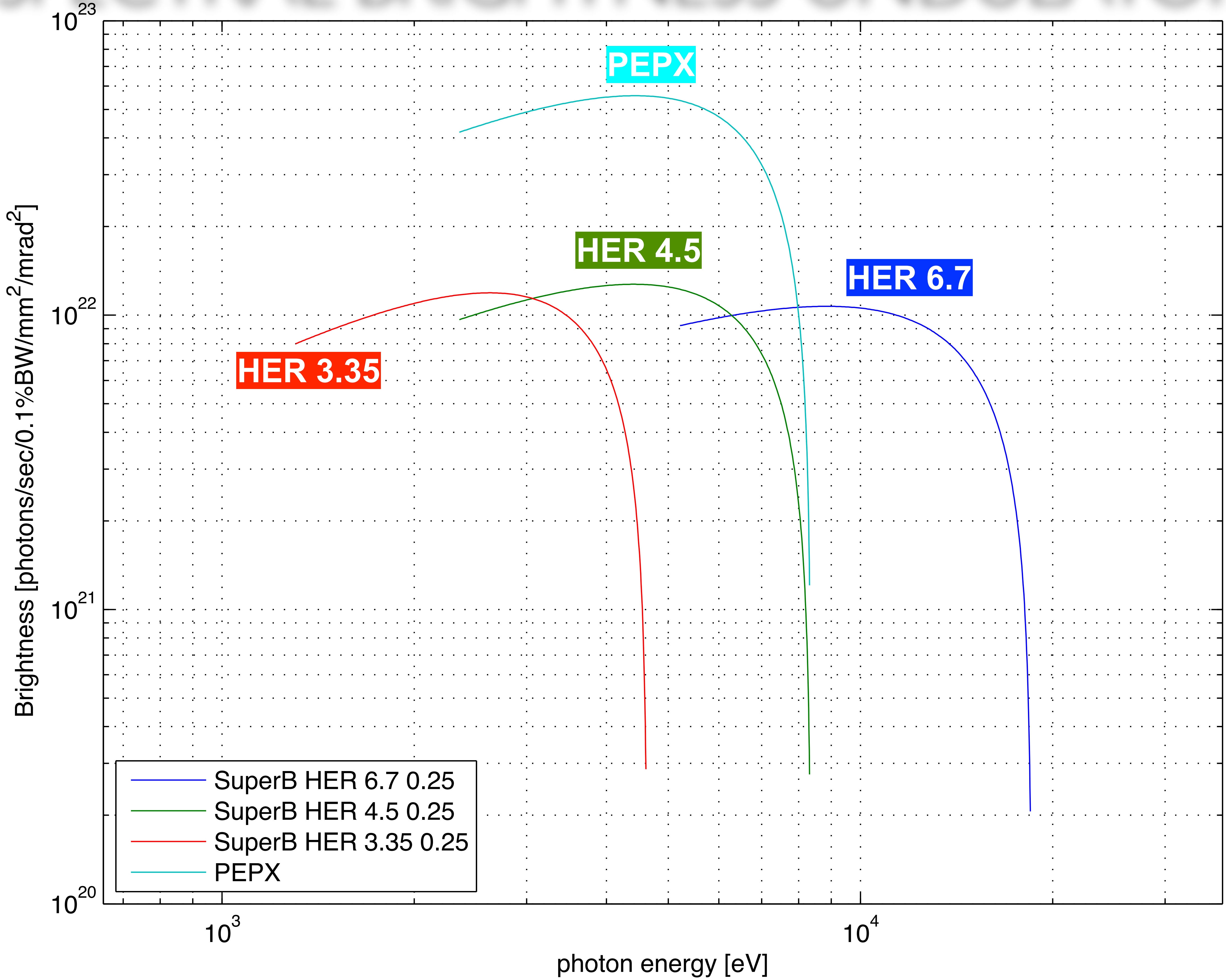
$$\Sigma'_u(E) = \left[\varepsilon\left(E^2\right)_u \gamma_u + \eta_u'^2 \delta^2 + \lambda\left(\frac{1}{E^2}\right) N \lambda_U \right]^{\frac{1}{2}}$$

$$B_u = \frac{F_u}{(2\pi)^2 \Sigma_x \Sigma_y \Sigma'_x \Sigma'_y}$$

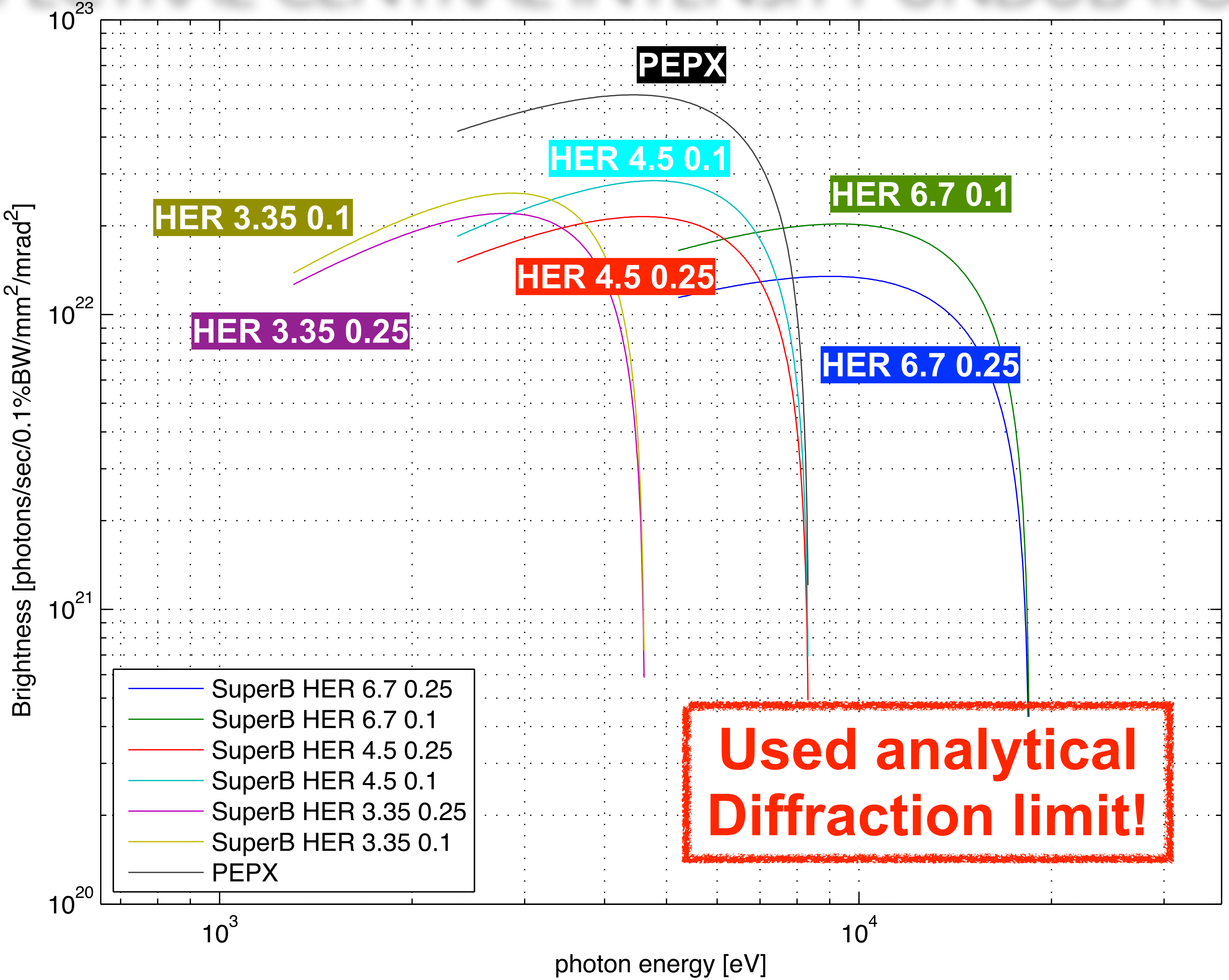
SPECTRAL FLUX UNDULATOR



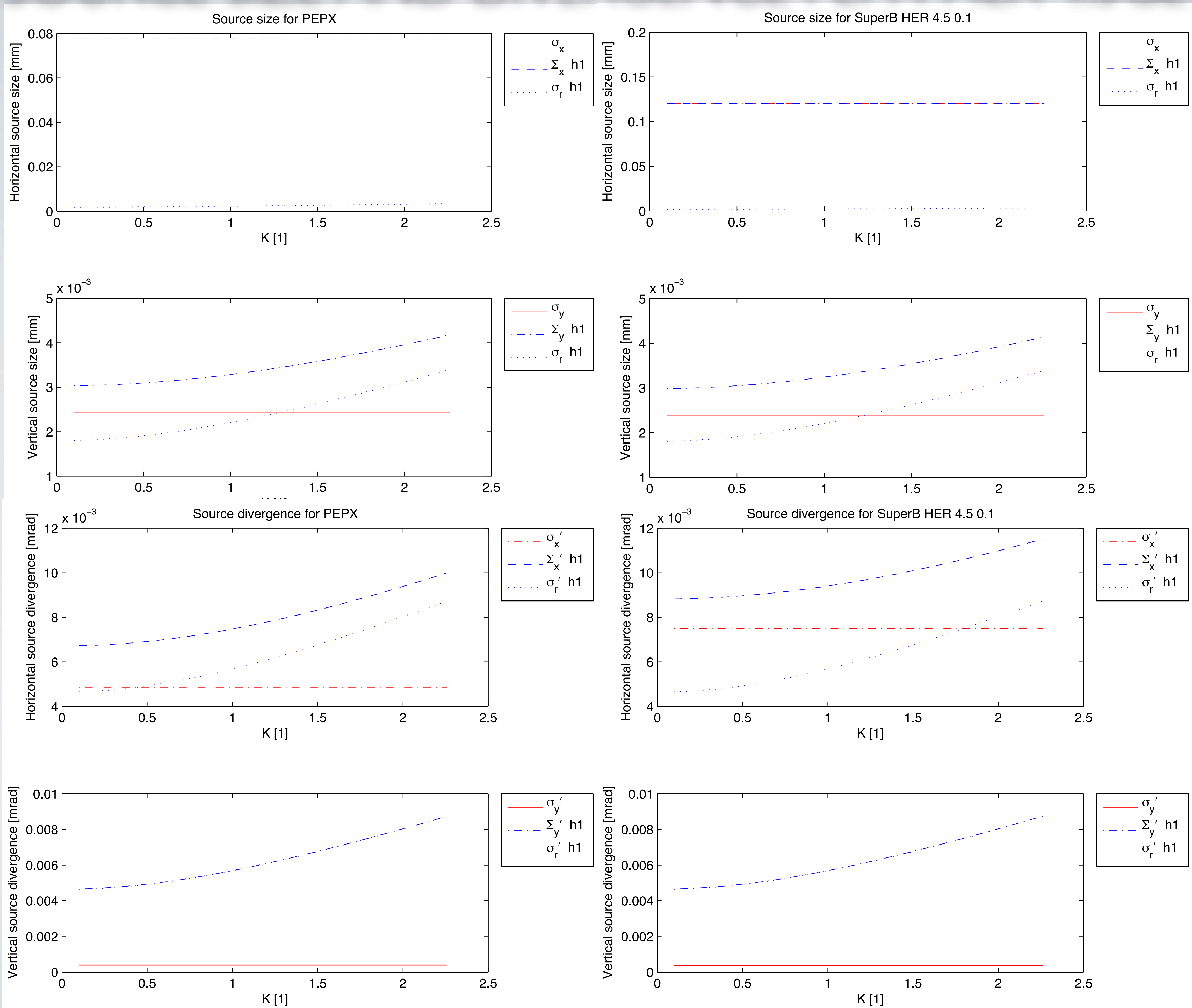
SPECTRAL BRIGHTNESS UNDULATOR



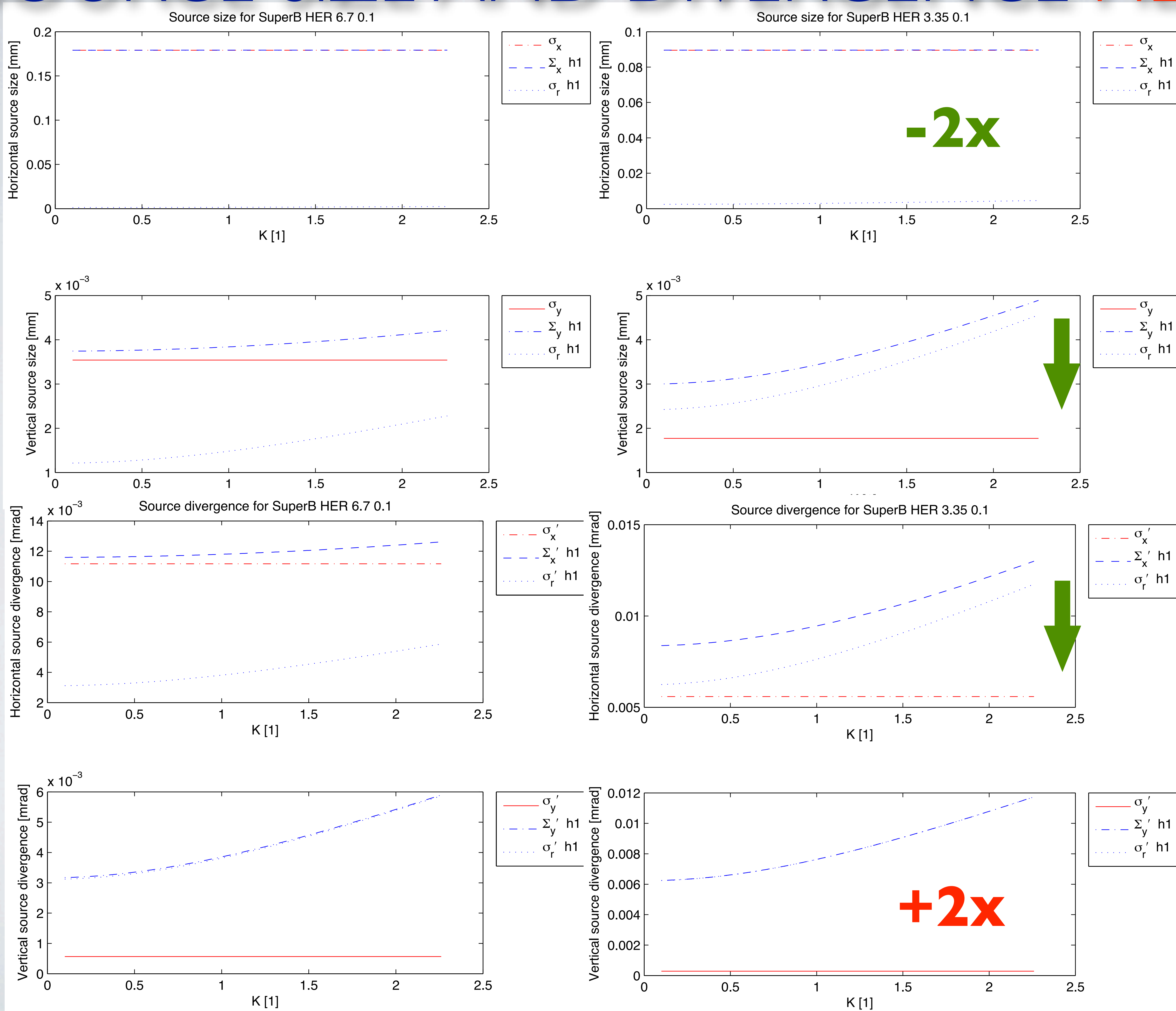
SPECTRAL CENTRAL INTENSITY UNDULATOR



SOURCE SIZE AND DIVERGENCE PEPX HER 4.5GEV



SOURCE SIZE AND DIVERGENCE HER



FINDINGS FOR EMITTANCE REDUCTION

- The beam size reduction of 16, by reducing the beam energy to 1/2 is original value, is being partially reversed by the increase of the diffraction limit.

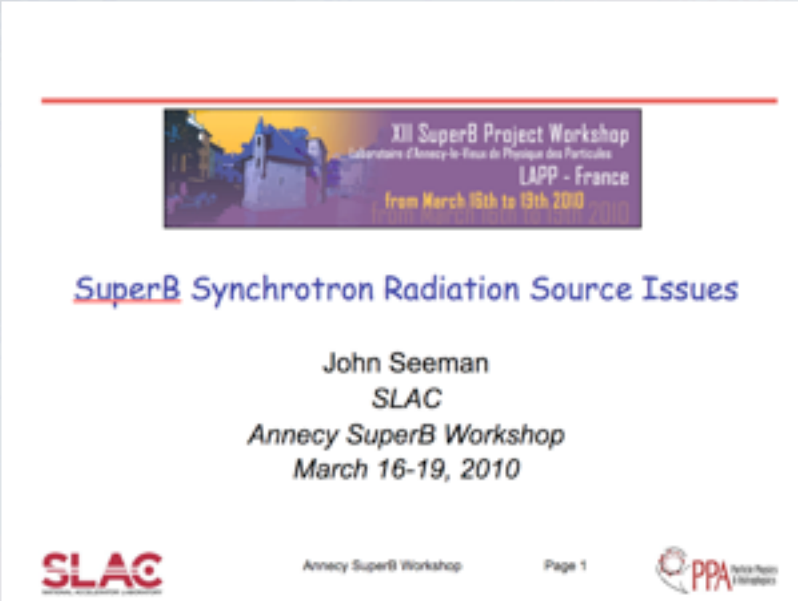
- The main gain established by PEPX is through the very small horizontal emittance.

- The reduction of the vertical emittance through smaller coupling is most effective at higher energies but the effect on the brightness is smaller than by energy reduction with analytical diffraction limit. With standard 8 pm no gain at all!

- By reducing β_x and β_y there is some room for increase but not substantial.

- Different undulator parameter also effect the diffraction limit.

LAYOUT

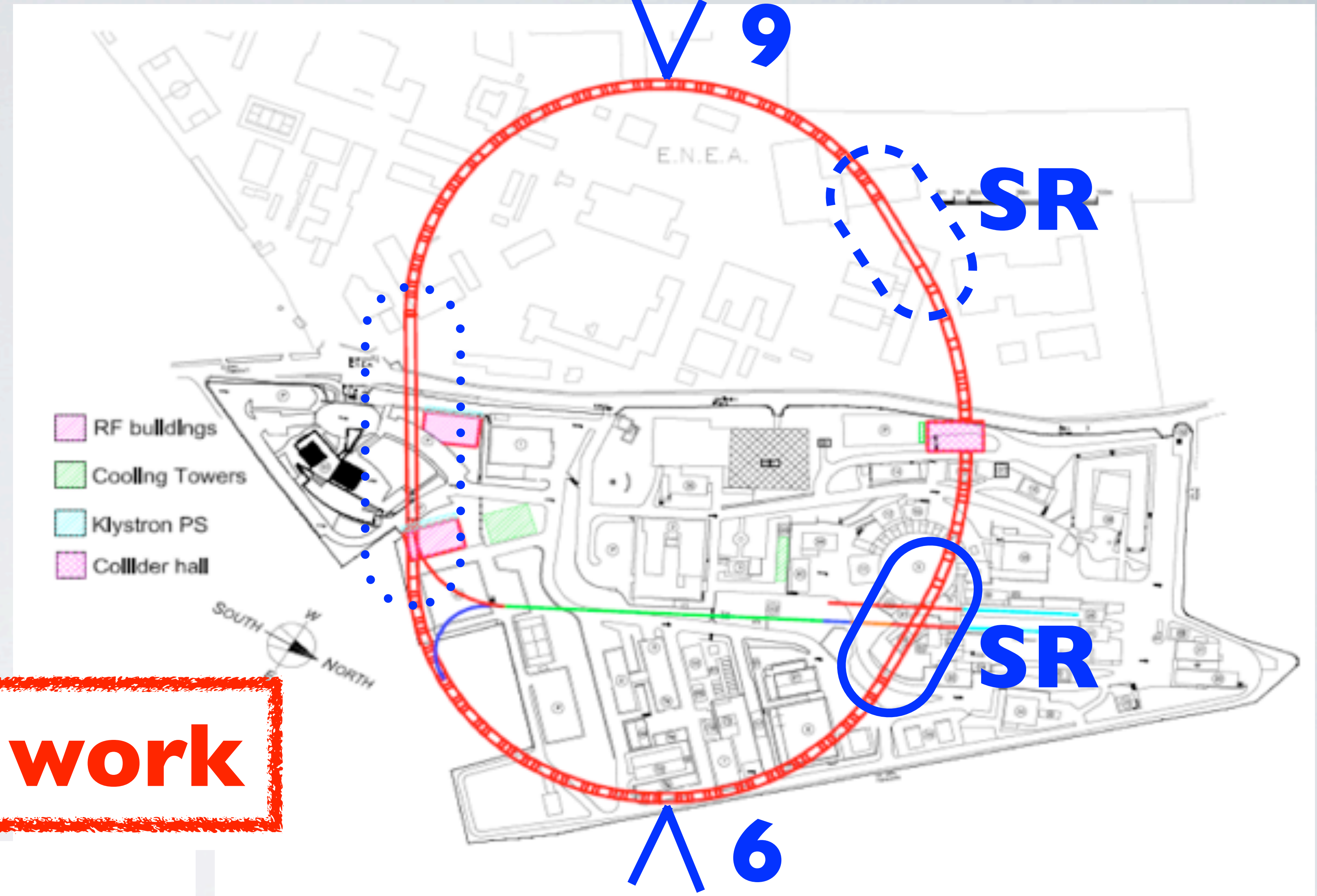

XII SuperB Project Workshop
LAPP - France
from March 16th to 19th 2010

SuperB Synchrotron Radiation Source Issues

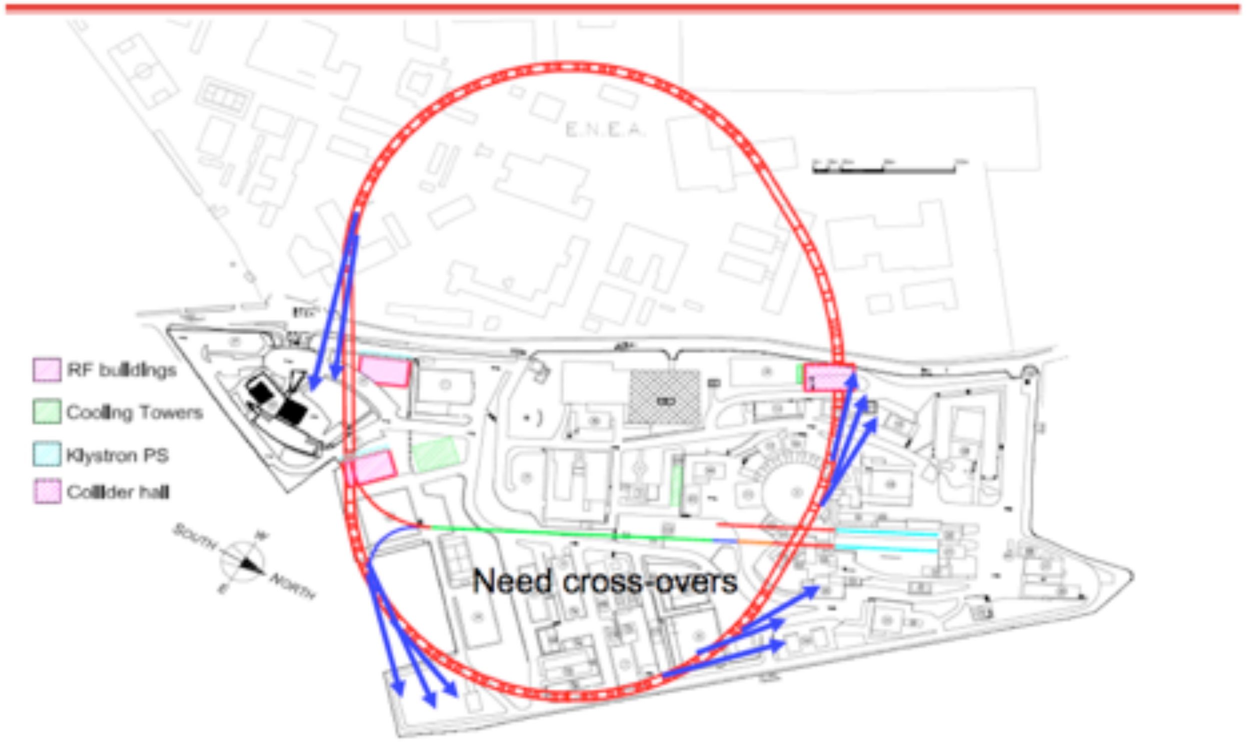
John Seeman
SLAC
Annecy SuperB Workshop
March 16-19, 2010

SLAC Annecy SuperB Workshop Page 1 PPA

Needs much more work



Frascati Site: Potential LER SR Beam Lines



SLAC Annecy SuperB Workshop Page 27 PPA

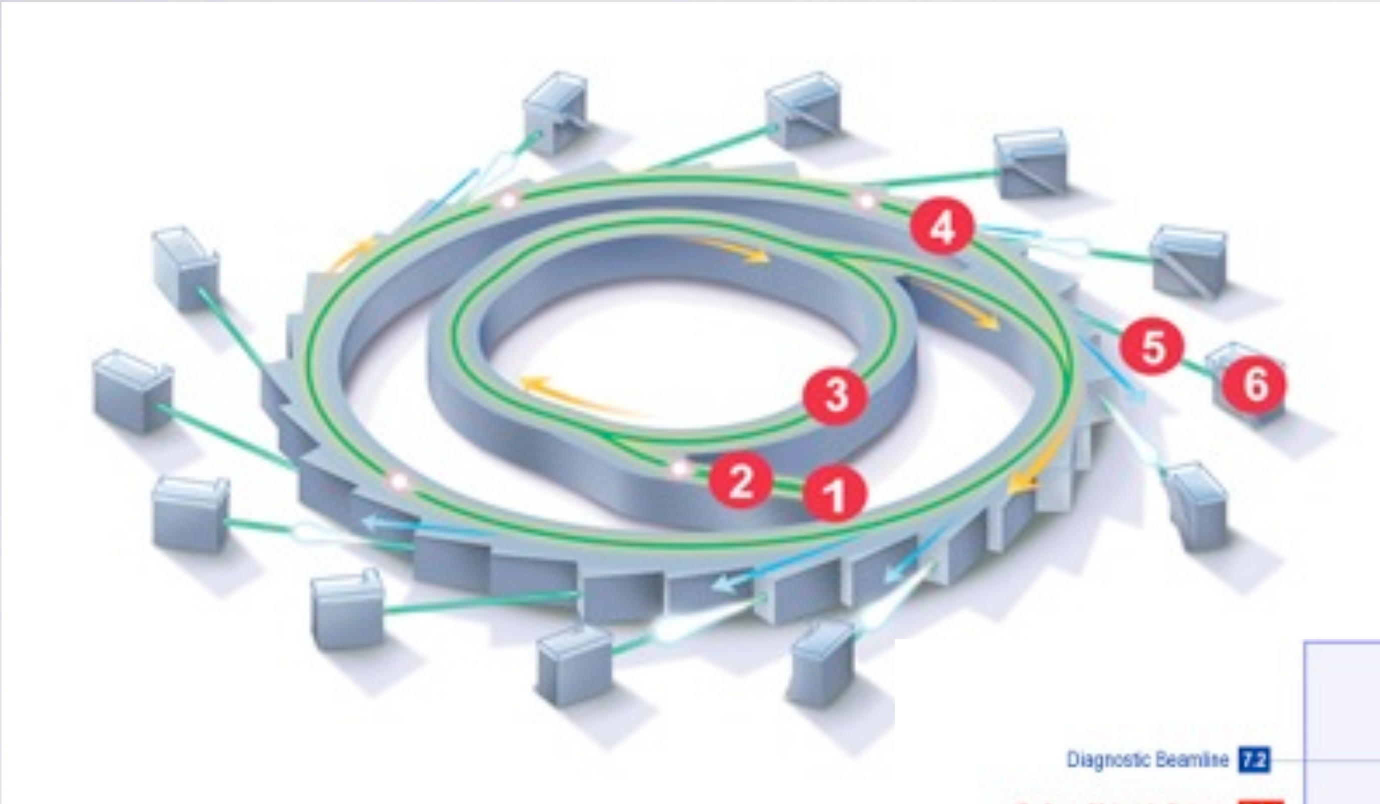
Frascati Site: Potential HER SR Beam Lines

SLAC Annecy SuperB Workshop Page 26 PPA

COMMENTS TO BEAM LINE LAYOUT STUDY

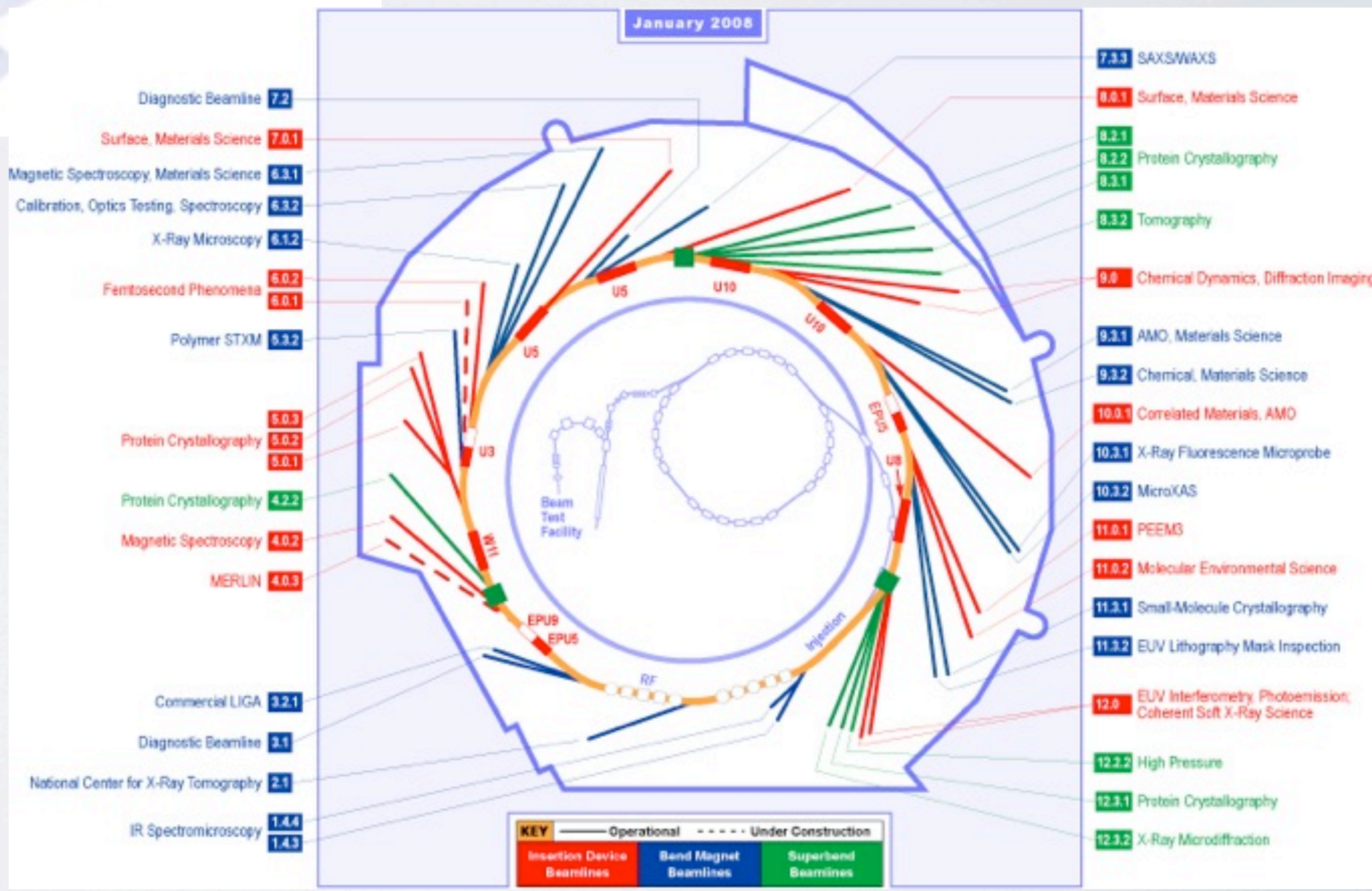
- Distances quoted are from the source point.
- The geometry shown is to scale!
- Basis for these calculations is the MAD deck survey file.
- Plots shown should be used to discuss synchrotron light beam line layout. (how many, where, how long, what type,...)
- Any further layout work need more specifics for the beam lines.

SYNCHROTRON BEAM LINE LAYOUT



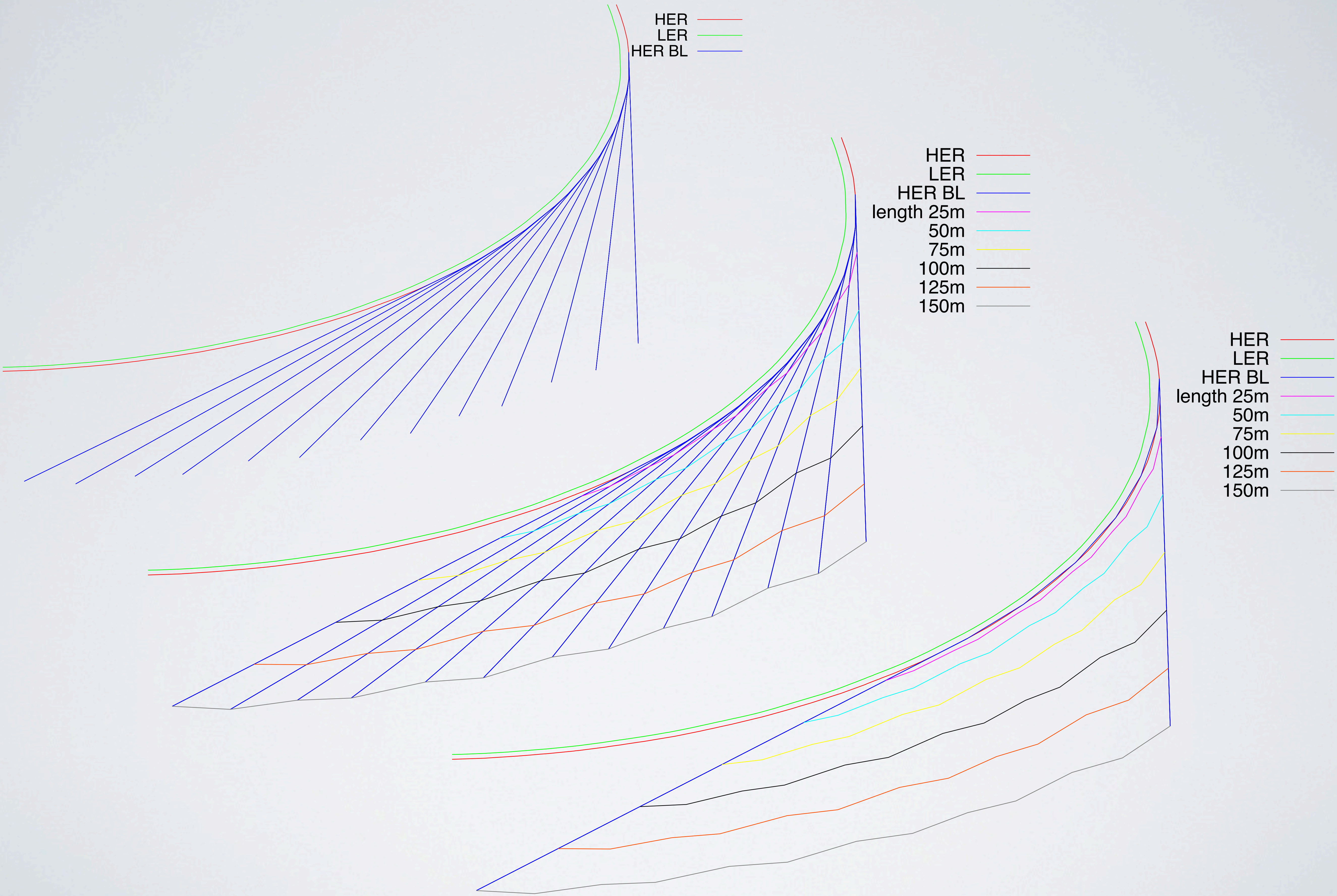
Typical Lightsource layout

ALS "beam line clock"



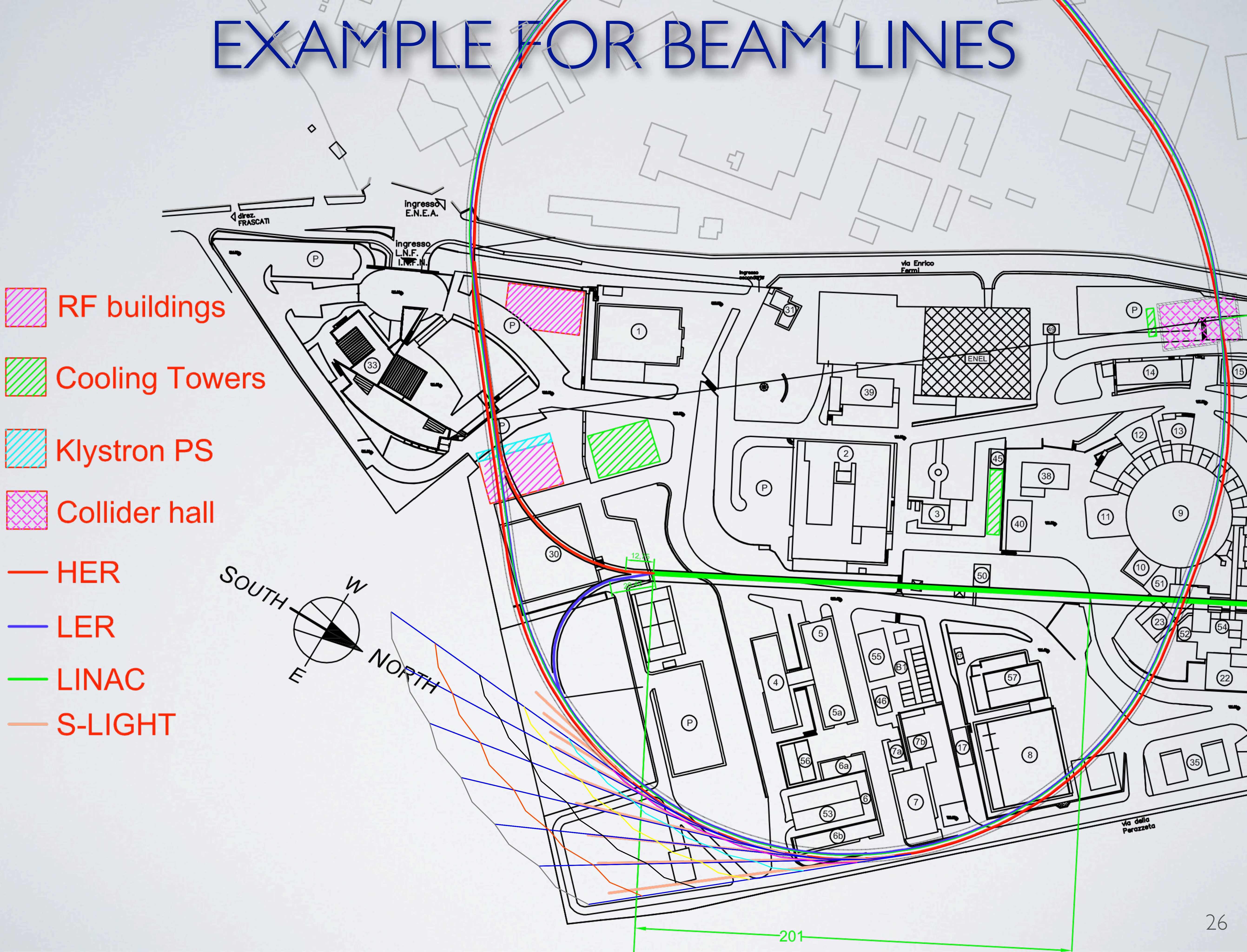
SUPER-B BEND MAGNET BEAM LINES

DEPICTION METHODS OF BEAM LINES



POSSIBLE BEAM LINES

EXAMPLE FOR BEAM LINES



CONCLUSION

- Synchrotron radiation generated with both HER and LER compete very well with state of the are dedicated lighsources in opration, construction and design.

- The lattices are already well optimized with respect to source point parameters. Only small gains still possible.

- Layout work has advanced to a point for specific choices of beam lines and site related considerations.

BACKUP SLIDES

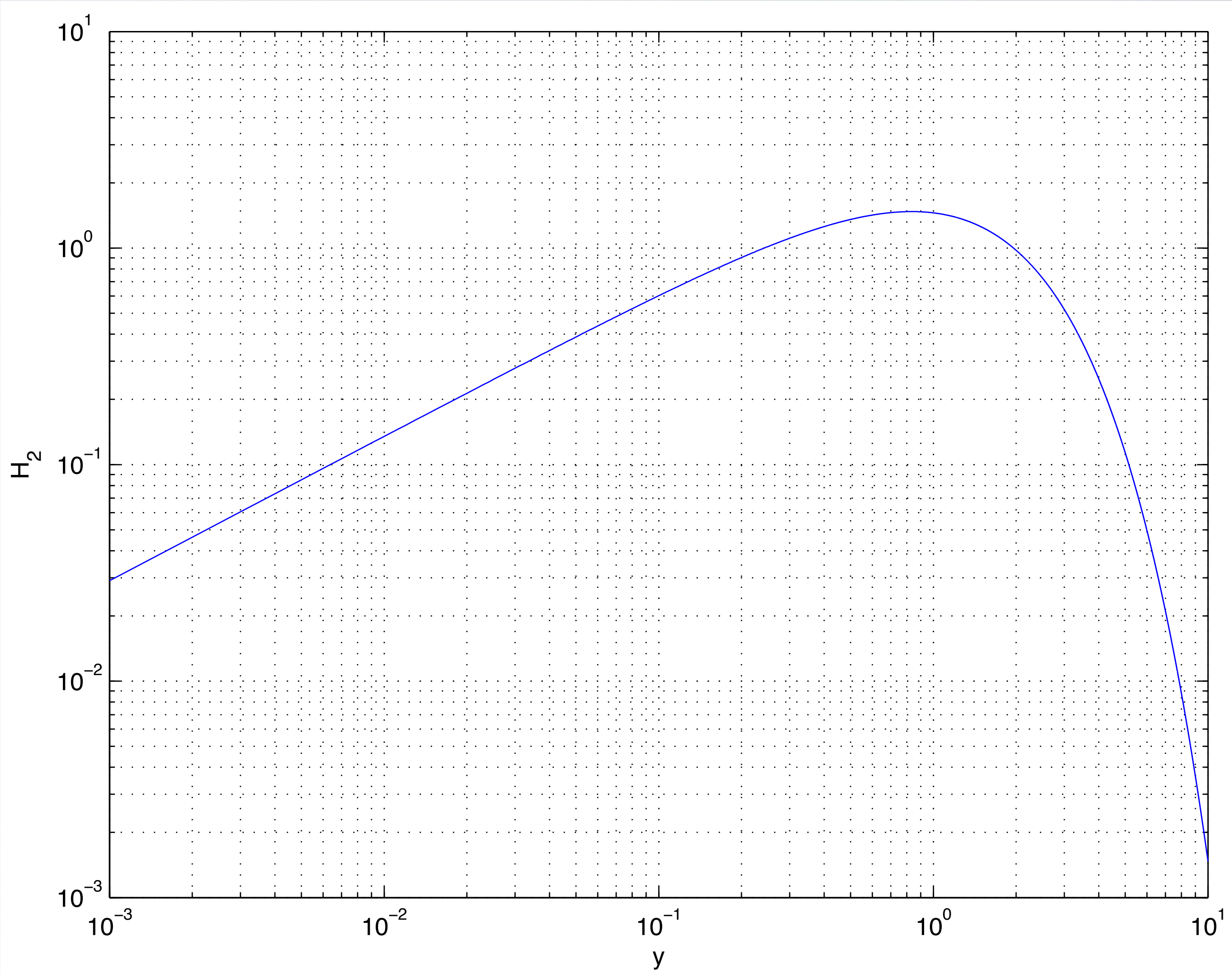
- Formalism used for calculation
- Sources for information
- Basic relation used for calculating synchrotron radiation (Schwinger)

SOME SOURCES

- Hulbert and Weber: "Flux and brightness calculations for various synchrotron radiation sources."
- Wiedemann: "Synchrotron Radiation"
- Kwang-Je Kim: "Characteristics of Synchrotron Radiation"
- NSLS II web page: NSLS-II Source Properties and Floor Layout.
- Seemann: "SuperB Synchrotron Radiation Source Issues."
- Cai: "Choice of Parameters for PEP-X."
- Various Web pages: ALS, ELETTRA, APS, ESRF.

SPECTRAL CENTRAL INTENSITY BEND MAGNET CALCULATION

$$\left.\frac{d^2F}{d\theta\cdot d\psi}\right|_{\psi=0} = \frac{3\alpha}{4\pi^2}\gamma^2\frac{\Delta\omega}{\omega_C}\frac{I}{e}H_2(y)$$



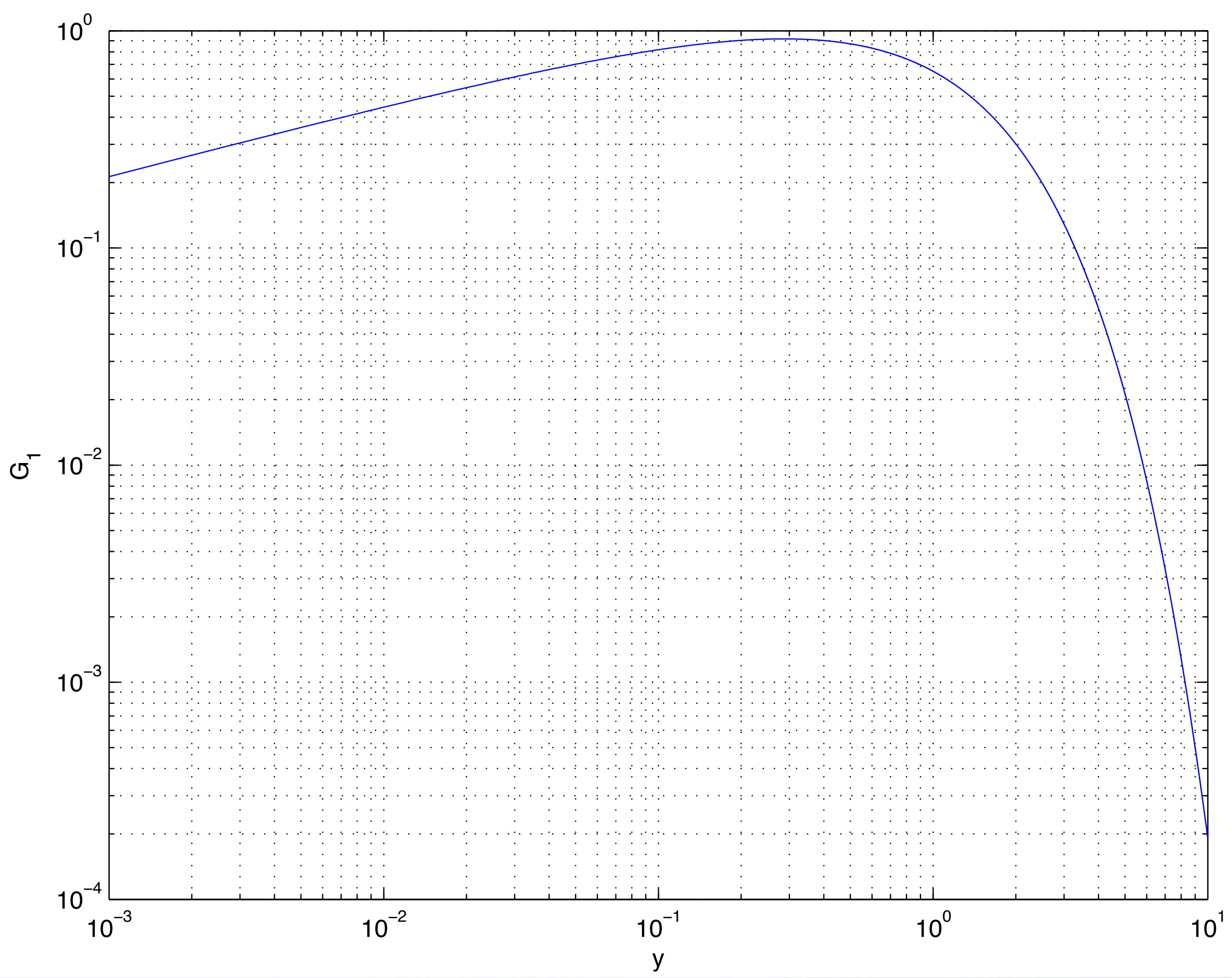
$$H_2(y) = y^2 K_{2/3}^2\left(\frac{y}{2}\right)$$

$$\left.\frac{d^2F}{d\theta\cdot d\psi}\right|_{\psi=0} = 1.327\times 10^{13}\,E^2[GeV]\;I[A]\;H_2(y)$$

SPECTRAL FLUX BEND MAGNET CALCULATION

$$\frac{dF_{bm}(y)}{d\theta} = \frac{\sqrt{3}}{2\pi}\alpha\gamma\frac{\Delta\omega}{\omega}\frac{I}{e}G_1(y)$$

$$G_1(y) = y\int_y^\infty K_{5/3}(y')\,dy'$$



$$\frac{dF_{bm}(y)}{d\theta} = 2.457\times 10^{13}\,E[GeV]\;I[A]\;G_1(y)$$

SPECTRAL BRIGHTNESS BEND MAGNET CALCULATION

$$B_{bm} = \frac{\left.\dfrac{d^2F(y)}{d\theta \cdot d\psi}\right|_{\psi=0}}{2\pi\, \Sigma_x(y)\, \Sigma_y(y)}$$

$$\Sigma_x(y) = \left[\varepsilon_x \beta_x + \eta_x^2 \delta_E^2 + \sigma_r^2(y)\right]^{\frac{1}{2}}$$

$$\sigma_r(y) = \frac{\lambda}{4\pi\sigma_\psi(y)}$$

$$\Sigma_y(y) = \left[\varepsilon_y \beta_y + \sigma_r^2(y) + \frac{\varepsilon_y^2 + \varepsilon_y \gamma_y \sigma_r^2(y)}{\sigma_\psi^2(y)}\right]^{\frac{1}{2}}$$

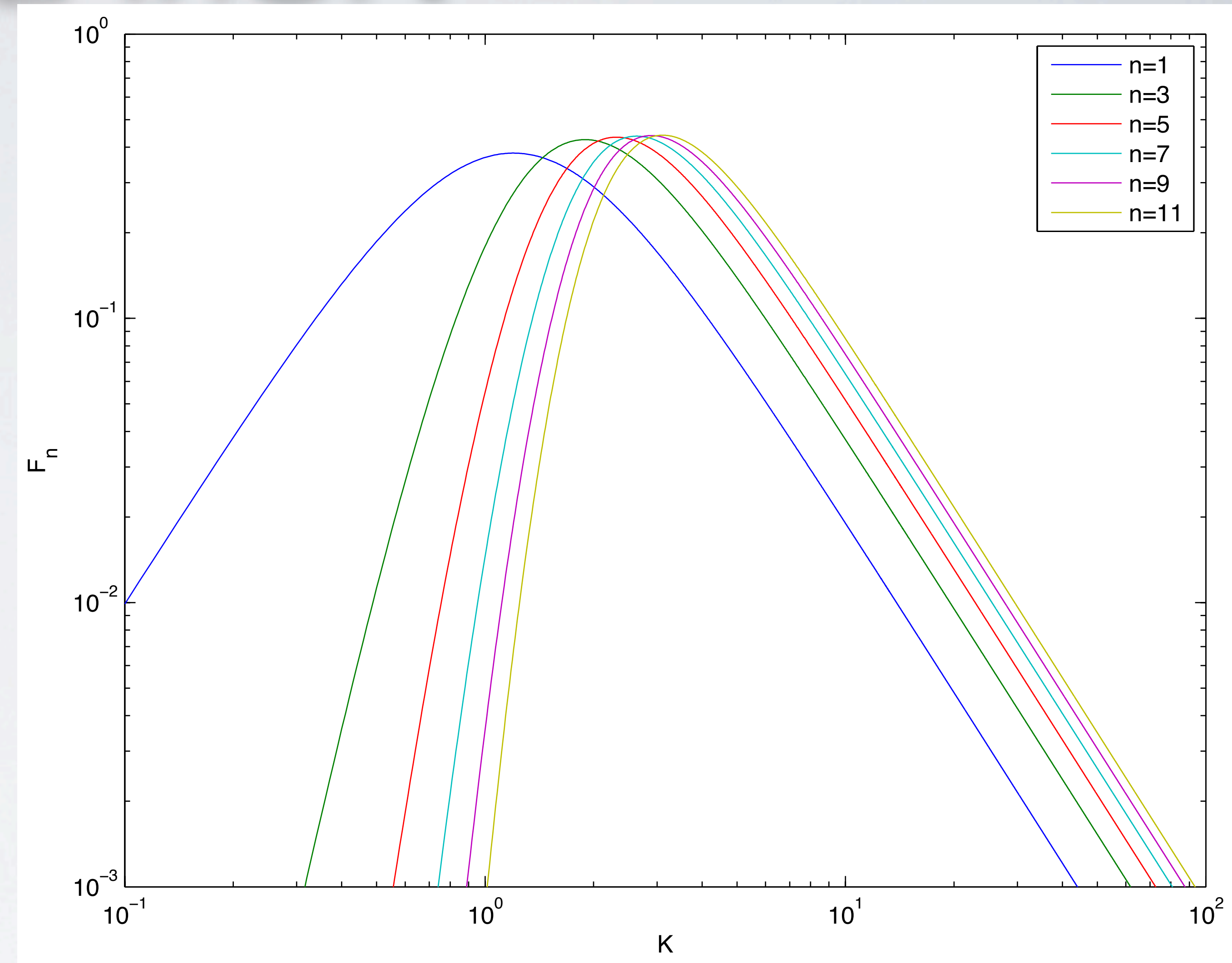
$$\sigma_\psi^2(y) = \frac{1}{\sqrt{2\pi}} \frac{\dfrac{dF_{bm}(y)}{d\theta}}{\left.\dfrac{d^2F_{bm}(y)}{d\theta\, d\psi}\right|_{\psi=0}}$$

SPECTRAL FLUX UNDULATOR CALCULATION

$$F_u(K,\omega) = \pi\alpha N \frac{\Delta\omega}{\omega}\frac{I}{e} Q_n(K) \;, \quad n = 1,3,5,\ldots$$

$$Q_n(K) = \left(1+\frac{K^2}{2}\right)\frac{F_n(K)}{n} \;, \quad n = 1,3,5,\ldots$$

$$F_n(K) = \frac{K^2 n^2}{(1+K^2/2)^2}\left[J_{\frac{n-1}{2}}\left(\frac{nK^2}{4\left(1+\frac{K^2}{2}\right)}\right) - J_{\frac{n+1}{2}}\left(\frac{nK^2}{4\left(1+\frac{K^2}{2}\right)}\right)\right]^2$$



$$F_u(K,\omega) = 1.431\times10^{14} N Q_n(K)\; I[A] \;, \quad n = 1,3,5,\ldots$$

$$\lambda = \frac{\lambda_u}{2\gamma^2 n}\left(1+\frac{K^2}{2}\right) \;, \quad n = 1,3,5,\ldots$$

n	harmonic number
N	number of periods
λ_u	period length
K	strength parameter
λ	undulator radiation wave length

$$K = \frac{eB_0\lambda_u}{2\pi mc} = 0.934\lambda_u[cm]\; B_0$$

$$\varepsilon = \frac{ch}{\lambda}$$

SPECTRAL CENTRAL INTENSITY UNDULATOR CALCULATION

$$\left.\frac{d^2F_u}{d\theta\cdot\, d\psi}\right|_{\psi=\theta=0} = \frac{F_u}{2\pi\ \Sigma'_x\Sigma'_y}$$

$$\Sigma'_x = \sqrt{\sigma'^2_x + \sigma'^2_r}$$

$$\Sigma'_y = \sqrt{\sigma'^2_y + \sigma'^2_r}$$

$$\sigma'_r = \sqrt{\frac{\lambda}{N\lambda_u}}$$

SPECTRAL BRIGHTNESS UNDULATOR CALCULATION

$$B_u = \frac{F_u}{(2\pi)^2 \Sigma_x \Sigma_y \Sigma'_x \Sigma'_y}$$

$$\Sigma_x = \sqrt{\sigma_x^2 + \sigma_r^2}$$

$$\Sigma_y = \sqrt{\sigma_y^2 + \sigma_r^2}$$

$$\sigma_r = \frac{1}{2\pi}\sqrt{\lambda N \lambda_u}$$

ANGULAR DISTRIBUTION OF RADIATION EMITTED BY ELECTRONS MOVING THROUGH A BEND MAGNET WITH A CIRCULAR TRAJECTORY IN THE HORIZONTAL PLANE

$$\frac{d^2F_{bm}(\omega)}{d\theta\cdot d\psi} = \frac{3\alpha}{4\pi^2}\gamma^2\frac{\Delta\omega}{\omega}\frac{I}{e}y^2\left(1+X^2\right)^2 \times \left[K^2_{2/3}(\xi) + \frac{X^2}{1+X^2}K^2_{1/3}(\xi)\right]$$

F_{bm}	photon flux (number of photons per second)
θ	observation angle in the horizontal plane
ψ	observation angle in the vertical plane
α	fine stricture constant
γ	electron energy
ω	angular frequency of photons
ω_C	critical angular frequency of photon distribution
ε	photon energy
ε_C	critical photon energy
I	beam beam current
e	electron charge
c	speed of light
B	magnetic field strength
E	electron beam energy
ρ	radius of instantaneous curvature of the electron bean trajectory

$$\rho = \frac{E}{ecB}$$

$$\rho[m] = 3.33\ \frac{E[GeV]}{B[T]}$$

$$\omega_C = \frac{3\gamma^2 c}{2\rho}$$

$$\varepsilon_C = \hbar\omega_C$$

$$\varepsilon_C[keV] = 0.665\ E^2[GeV]\ B[T]$$

$$\xi = \frac{y\left(1+X^2\right)^{3/2}}{2} \qquad X = \gamma\psi$$