17TH ADVANCED BEAM DYNAMICS WORKSHOP ON
FUTURE LIGHT SOURCES

A Variable-Period Undulator Design Study for SPEAR

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A Variable-period Undulator Design Study for SPEAR*

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Talk Outline

- Background fundamentals
- Variable-period undulator design (principles)
- Variable-period undulator design concept for SPEAR III
- R&D issues
- Summary

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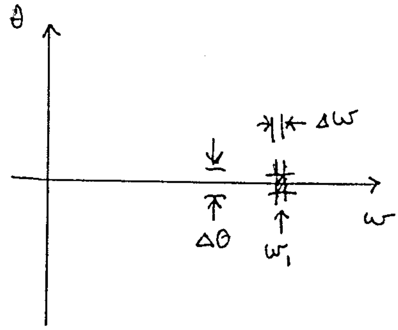
- general questions of insertion device/machine optimality and the role of MPU technology

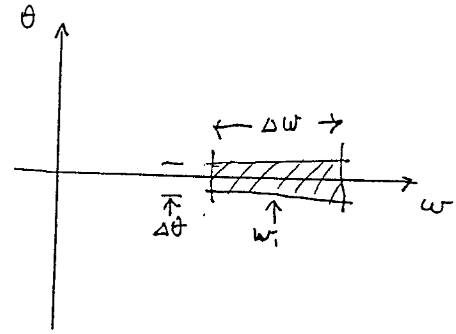
1) spectral/angular & flux requirements (Dumond plots)



(typical narrowband ω-θ experimental acceptance)

↓

undulator source

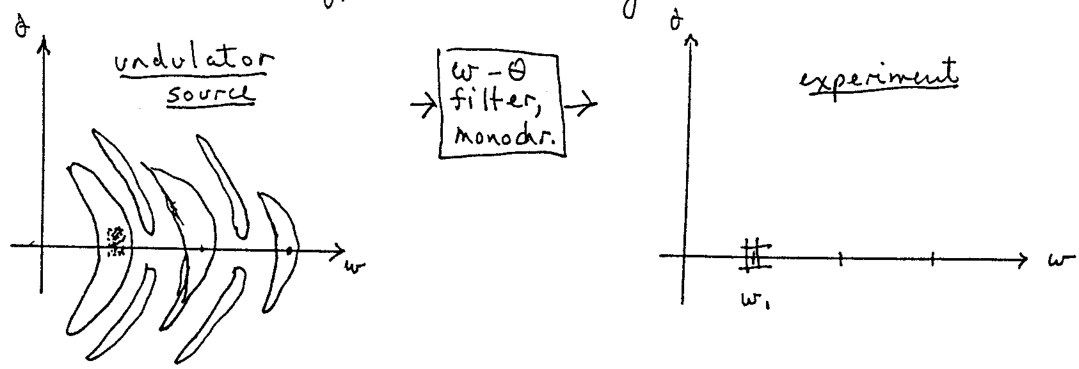


(typical wideband ω-θ experimental acceptance)

↓

wiggler source

Typical Matching Process



In practice, all source flux outside the dotted area is thrown away. Thus, a "optimal" undulator should generate as little flux as possible outside of the experiment's ω-θ acceptance. Note this implies that an "optimal" device should have:

1) low K
2) low-K tunability (implies period variation)
3) high flux in exp't's. ω-θ area.
4) narrow spectrum (if experiment demands it)
5) a machine with a low emittance

BACKGROUND FUNDAMENTALS: short-period insertion devices:

$$\boxed{P = \frac{2}{3}\frac{e^2}{c}\gamma^6\left[(\boldsymbol{\beta})^2 - (\boldsymbol{\beta}\times\boldsymbol{\beta})^2\right] \quad (CGS)}$$

for sinusoidal trajectory, $\boldsymbol{\beta} = \boldsymbol{\beta}_{par} + \boldsymbol{\beta}_{perp}$

$$\boldsymbol{\beta}_{perp}\times\boldsymbol{\beta} \equiv 0\,; \quad \boldsymbol{\beta}_{par}\times\boldsymbol{\beta} \equiv \beta_{par}\beta_{perp} \qquad \Rightarrow \qquad P \cong \frac{2}{3}\frac{e^2}{c}\gamma^4\left(\boldsymbol{\beta}_{perp}\right)^2$$

In terms of undulator parameters,

$$x \cong \frac{K\lambda_u}{2\pi\gamma}\sin\left(\frac{2\pi\beta^* ct}{\lambda_u}\right)$$

$$\beta_{perp} \equiv \frac{K\beta^*}{\gamma}\cos\left(\frac{2\pi\beta^* ct}{\lambda_u}\right)$$

$$\beta_{perp} \equiv -\frac{2\pi K\beta^{*2} c}{\gamma\lambda_u}\sin\left(\frac{2\pi\beta^* ct}{\lambda_u}\right)$$

Use: $\beta^* \cong 1\,; \quad \lambda = \frac{\lambda_u}{2\gamma^2}\left(1+\left(K^2/2\right)\right)$

$$\boxed{P = \frac{2e^2}{3c}\left(\frac{2\pi K c^2}{\gamma}\right)^2 = \frac{2e^2}{3c}\frac{\left(2\pi K c^2\right)^2}{\lambda}\frac{\left(1+\left(K^2/2\right)\right)}{2\lambda_u}}$$

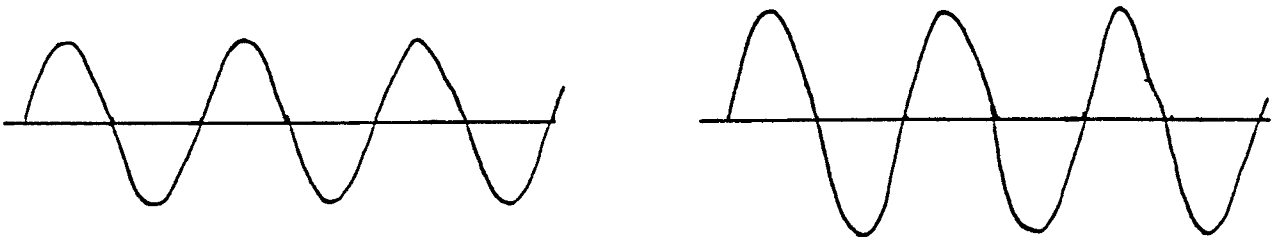
Effect on Brightness (assume fixed K, fixed λ, fixed undulator length):

- **reduce** $\lambda_u \rightarrow \lambda'_u$ **=> reduce energy by** $\sqrt{\frac{\lambda'_u}{\lambda_u}}$
- **in-band flux** $\propto N_u$ **=> Brightness** $\propto \frac{1}{\lambda_u^2}$

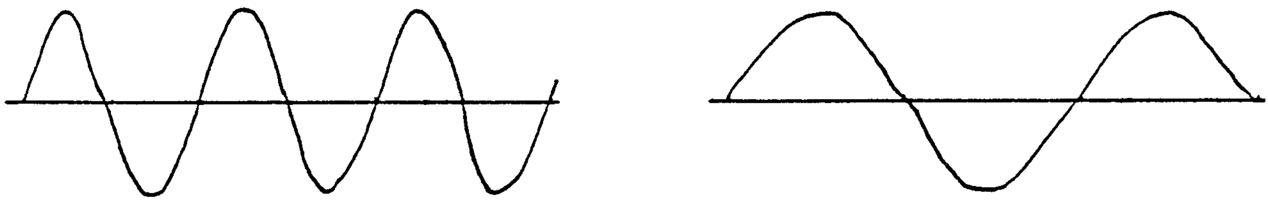
(but must also consider effect of energy reduction on the emittance)

THREE WAYS OF TUNING AN UNDULATOR DEFINES THREE UNDULATOR CLASSES

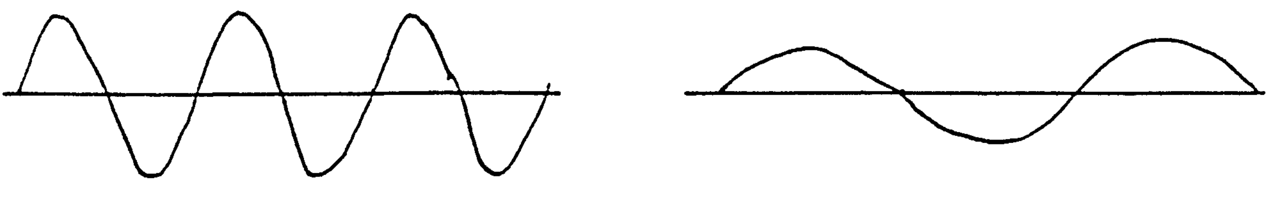
1) Constant-period, Variable-field



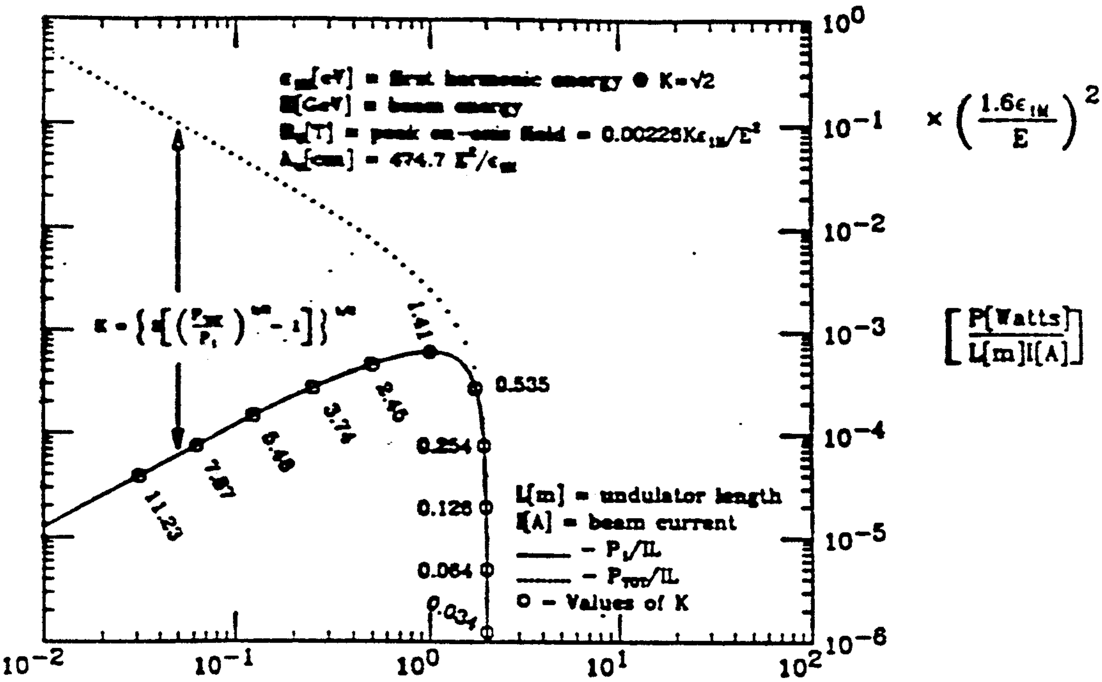
2) Constant-field, Variable-period



3) Constant-K



UNIVERSAL PERFORMANCE CURVES FOR CONSTANT-PERIOD, VARIABLE-FIELD TRANSVERSE MAGNETOSTATIC UNDULATORS



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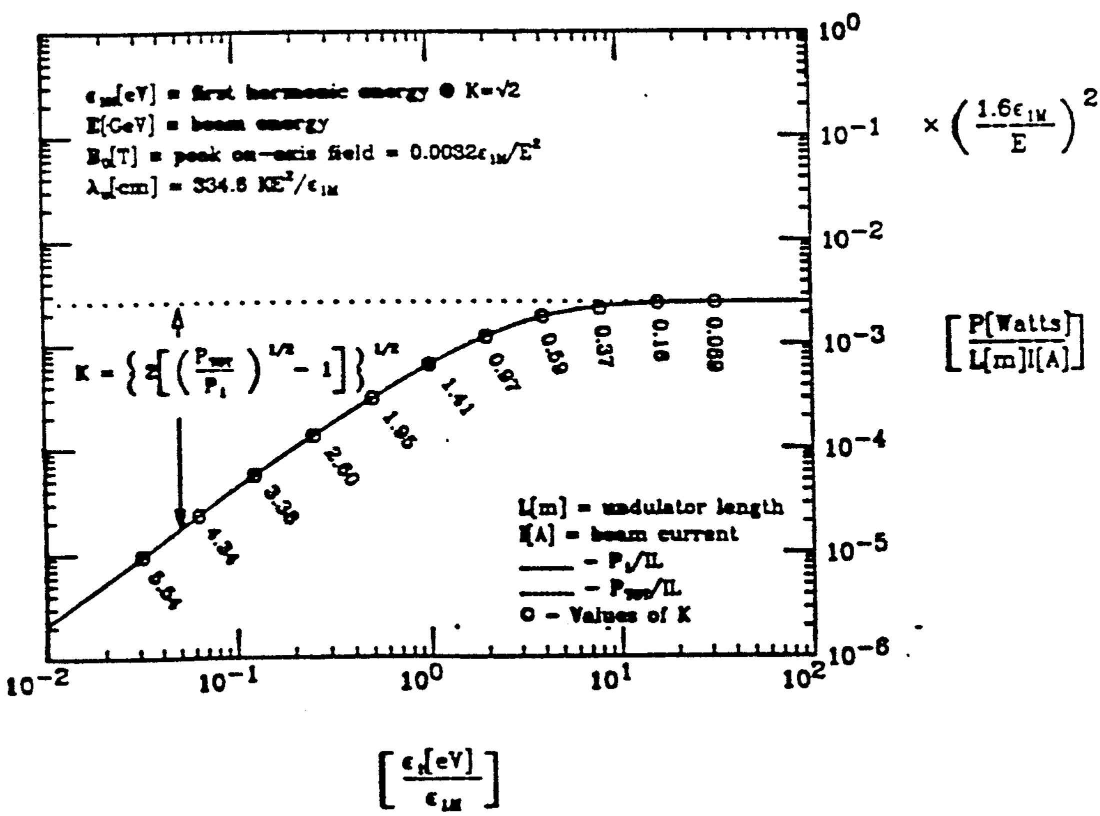
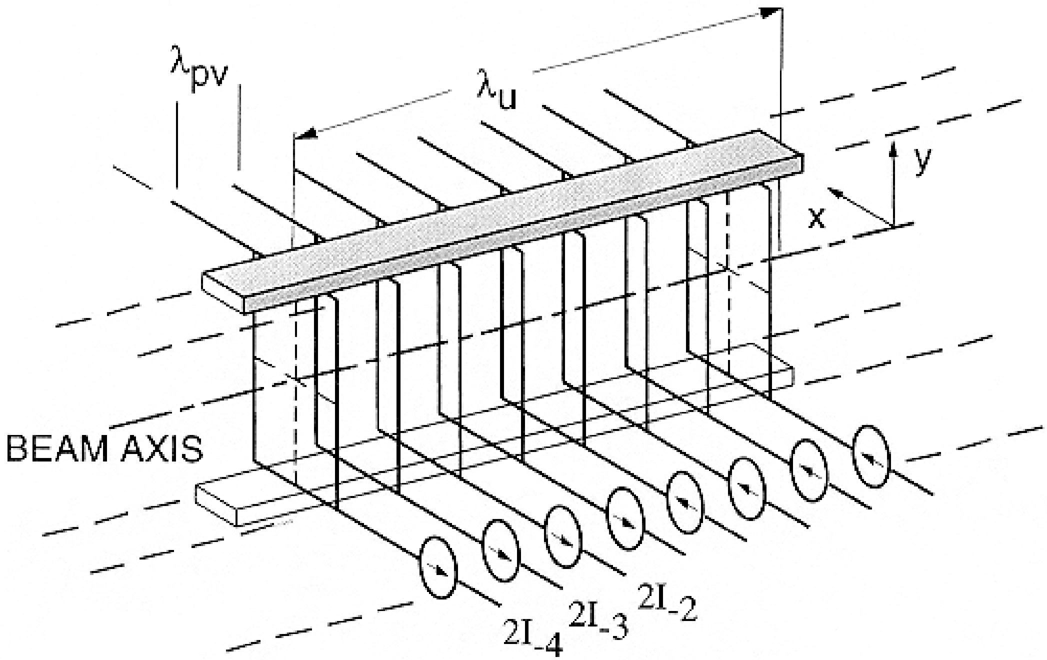


• VARIABLE-PERIOD DESIGN PRINCIPLES



- sample function

$$I_j = I_0 \cos\left(2\pi z\left(\frac{1}{\lambda_u}\right)+\phi\right)\Bigg|_{z=j\lambda_{pv}}$$

$$\lambda_u = M\,\lambda_{pv}$$

$$-\left(\left(N-1\right)/2\right) \le j \le \left(\left(N-1\right)/2\right)$$

- re-synthesize

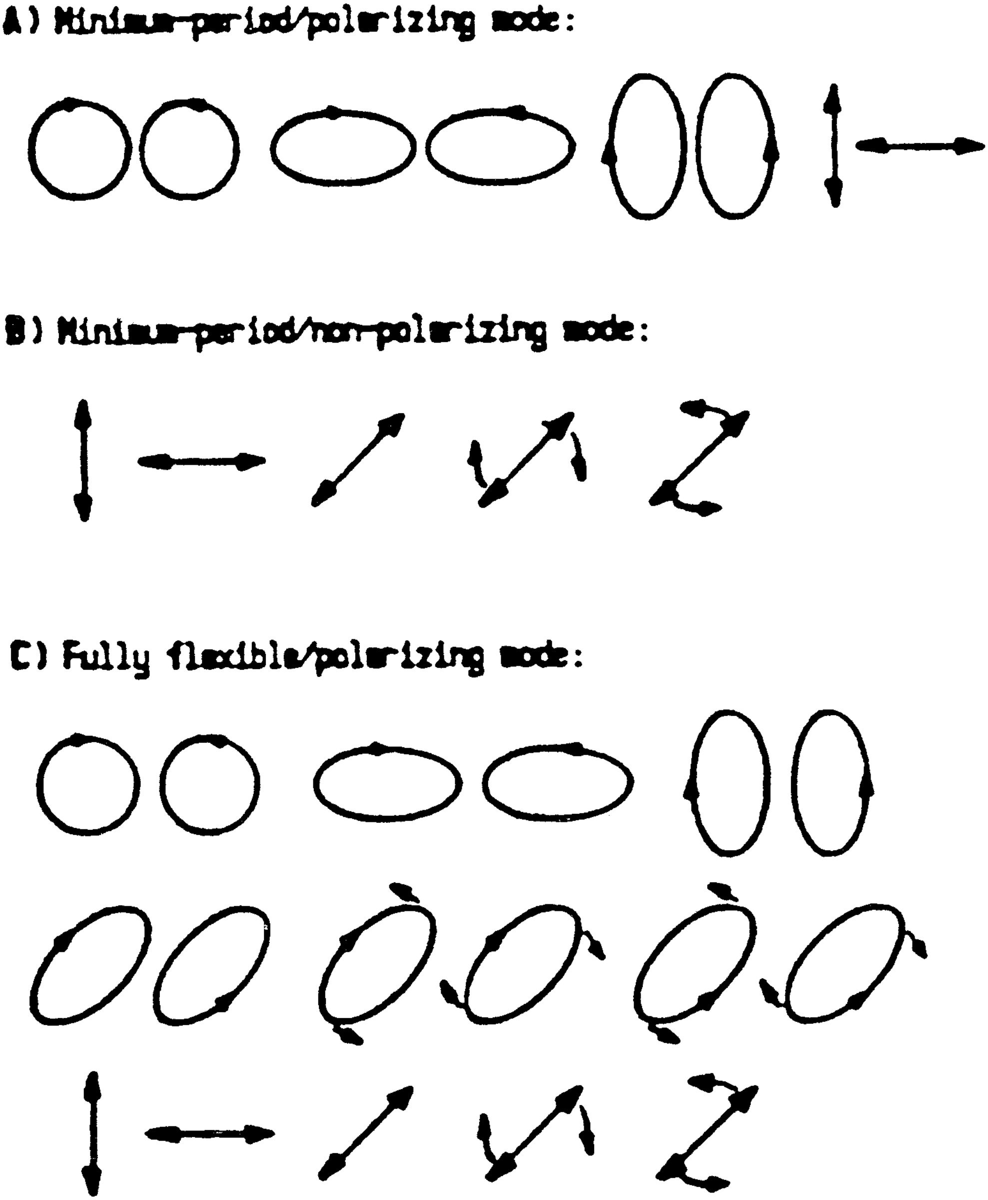
$$
B_x(0,0,z) = -\frac{\mu_0 I_0 e^{-(\pi g_x/\lambda_u)}}{\lambda_{pv}} \left\{ \begin{array}{l} \sin\left(2\pi z\left(\frac{1}{\lambda_u}\right)-\phi\right) + e^{-\left(\pi g_x\left(1-\left(\frac{2}{N}\right)\right)/\lambda_{pv}\right)} \sin\left(2\pi z\left(\frac{1}{\lambda_{pv}}-\frac{1}{\lambda_u}\right)+\phi\right) \\ + e^{-(\pi g_x/\lambda_{pv})} \sin\left(2\pi z\left(\frac{1}{\lambda_{pv}}+\frac{1}{\lambda_u}\right)-\phi\right) + e^{-\left(\pi g_x\left(2-\left(\frac{2}{N}\right)\right)/\lambda_{pv}\right)} \sin\left(2\pi z\left(\frac{2}{\lambda_{pv}}-\frac{1}{\lambda_u}\right)+\phi\right) \\ + e^{-(2\pi g_x/\lambda_{pv})} \sin\left(2\pi z\left(\frac{2}{\lambda_{pv}}+\frac{1}{\lambda_u}\right)-\phi\right) + e^{-\left(\pi g_x\left(3-\left(\frac{2}{N}\right)\right)/\lambda_{pv}\right)} \sin\left(2\pi z\left(\frac{1}{\lambda_{pv}}-\frac{1}{\lambda_u}\right)+\phi\right) \\ \qquad + \ldots\ldots \end{array} \right\}
$$

$$
\left[\lambda_{pv} < g_H ;\ M \ \text{small}\right] \rightarrow B_x(0,0,z) \cong -\frac{2\mu_0 I_0 e^{-(\pi g_H/\lambda_u)}}{\lambda_{pv}} \left\{ \sin\left(2\pi z\left(\frac{1}{\lambda_u}\right)-\phi\right) \right\}
$$

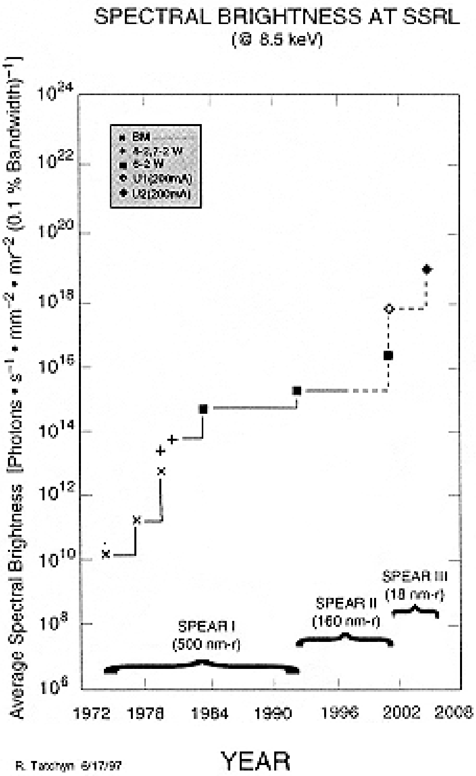
$$
\boxed{B_0 = -\frac{2\mu_0 I_0 e^{-(\pi g_H/\lambda_u)}}{\lambda_{pv}}}
$$

- **<u>note</u>: fully flexible spectral/polarization capabilities can be implemented by rotating two fully flexible Variable-Period (VP) insertion devices relative to each other by a non-zero angle about the z axis**

- **<u>also</u>: strong focusing can be implemented by "biasing" in a FODO quadrupole field**



8. Polarization capabilities of a fully flexible field synthesizer.

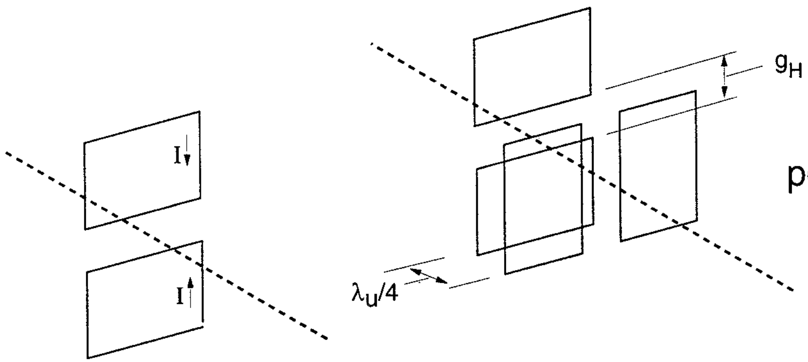


SPEAR INSERTION DEVICES

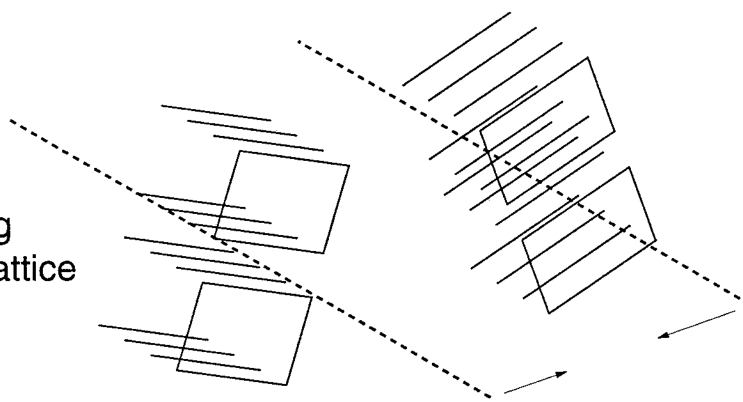
ID	YEAR	Field [T]	Length [m]	Period [m]	gap [mm]	K	Poles	Peri-ods
BM	1974	0.52						
BM	2001	1.19						
4-2 W	1979	1.8	1.2	0.4		74	6	3
4-2 W	1981	1.8	1.8	0.45		74	8	4
6-2 W	1983	1.05	1.9	0.07		6.8	54	27
10-2 W	1987	1.49	1.93	.129		17.8	30	15
9-3 W	1997	2.1	2.04	0.26		50	16	8
11-2 W	2001	1.9	2.275	0.175		31	26	13
U1	2001	0.5	4	0.03	10	1.4		133
U2*	2005	0.5	4	0.01	3.5	0.47		400

* for conceptual study only

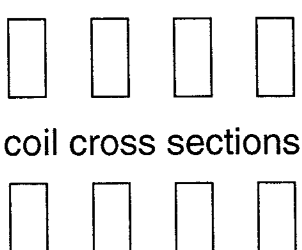
SC Wire-Pair Undulator Structures



90 deg
polarizing lattice

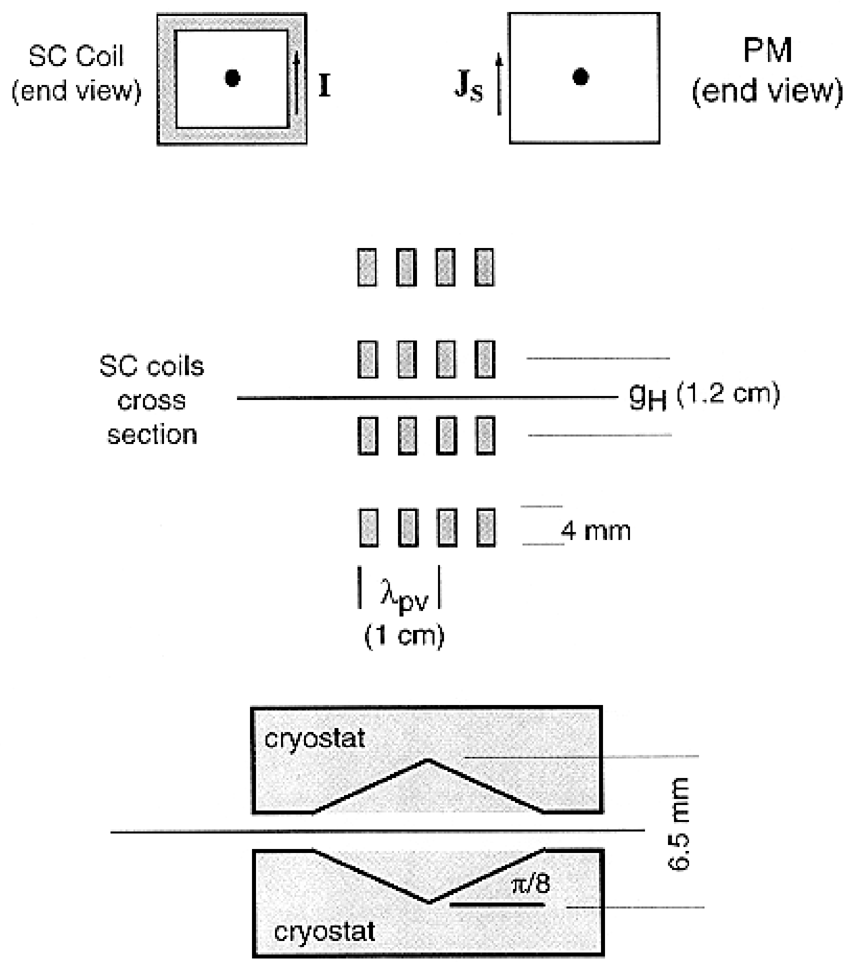


135 deg
polarizing lattice



coil cross sections

SC Variable Period Undulator Feature



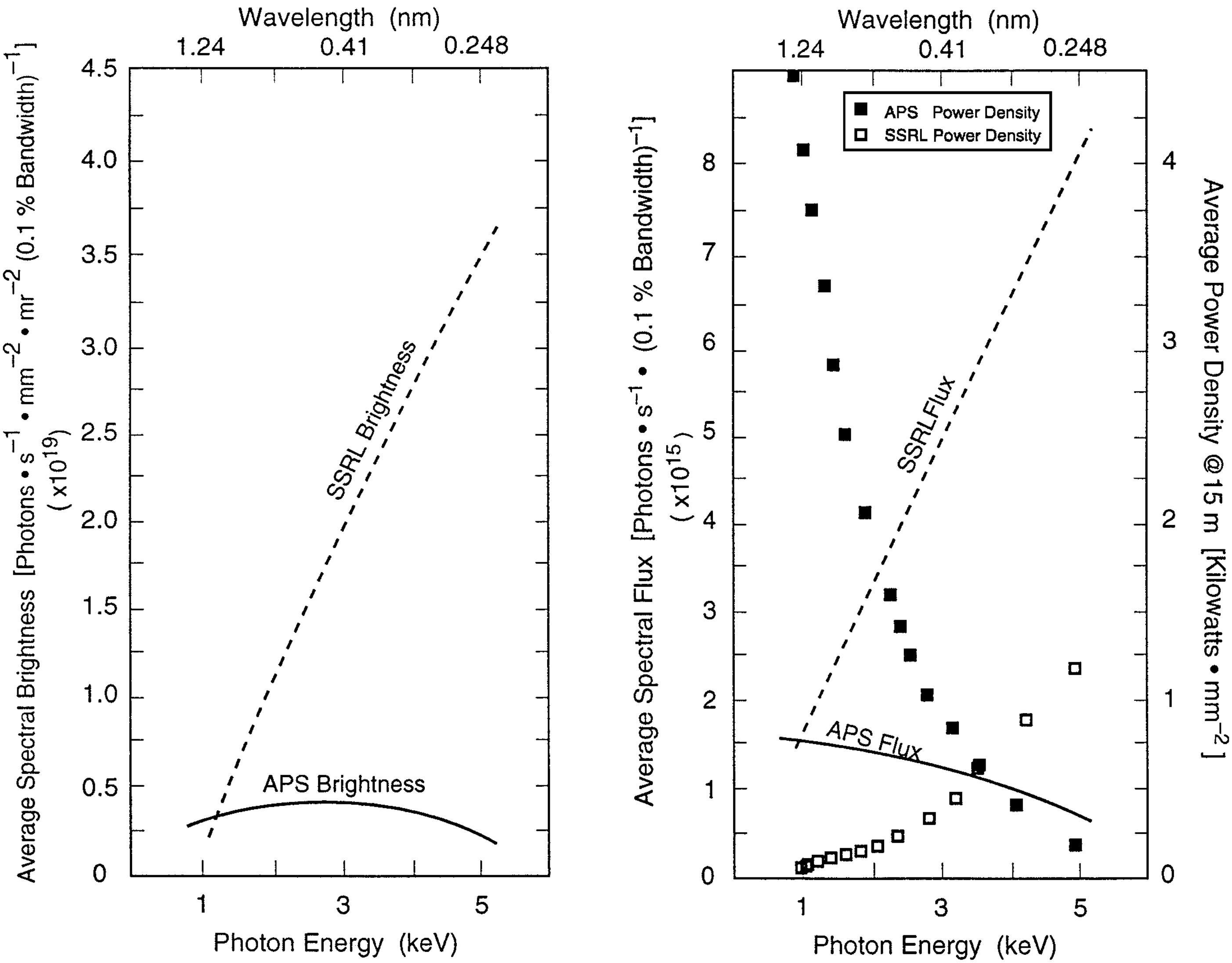
SUPERCONDUCTING MATERIAL PARAMETERS*

Material	Operating Temperature	Total Field [T]	Peak J [A/mm^2]	Average J [A/mm^2]
NbTi	4.35° K	5	3300	1600
Nb-free Sn	4.35° K	12	2300	1000

*Shlomo Caspi, private communication

Performance of a K=1 Undulator on SPEAR III vs. a Conventional Undulator Optimized for 3 keV on the APS

(APS Undulator: L=4.5 m; λ_U=8 cm; K(3 keV)=1.414; E=7 GeV; I=200 mA)
(SSRL Undulator: L=4.5 m; λ_U(3 keV)=1.38 cm; E=3 GeV; I=200 mA)



R. Tatchyn 6/17/97

TECHNOLOGICAL DIRECTIONS FOR INSERTION DEVICE R&D

- **small-gap, in-vacuum devices**

problem: small-gap devices are limited in length to local values of the beta function, which must be small ($\sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y}}$)

solution (r&d): superimposed (distributed) strong focusing

problem: beam lifetime, impact on lattice optics

solution (r&d): improved vacuum, lattice optimization

problem: field strength (to keep K frm getting too small)

solution (r&d): alternative technologies (e.g., radiation-field)

- **variable-period devices (field synthesizers)**

problems: field strength

solutions (r&d): superconducting techniques, "hysteresis-free" permeable materials, mechanically tunable PM structures

problems: complexity, cost

solutions control technology advancements

A variable-period undulator design study for SPEAR*

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ABSTRACT

Despite their many theoretical advantages [1-5], variable-period (VP) undulators remain underrepresented at 3rd and earlier-generation light sources. Of the limited number of devices that have been designed or built [6-8], most have not incorporated the capability for fully flexible VP operation. In this talk the basic principles of variable-period operation are briefly reviewed, in particular in conjunction with short-period insertion device technology [9]. An overview of developments that may still be required to make VP technology more prevalent on future generation light sources will be presented for workshop discussion. For illustrative purposes, the performance of a long VP superconducting undulator for SPEAR, based on a recent design study, will be reviewed.

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