Round Beam Workshop

Soleil, 29 14-15 June 2017

PHOTON BEAM FROM AN UNDULATOR IN THE CASE OF AN EMITANCE ADAPTER

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- Ideal undulator photon beam: Single electron emission
- Photon beam with electron beam
- Case of emittance adapter
- Possible undulator schemes with emittance adapter

SINGLE ELECTRON EMISSION

Undulator with length L, photon wavelength λ_n (harmonic # n)

r.m.s. photon beam divergence: $\Sigma_0' \approx \sqrt{\dfrac{\lambda_n}{2L}}$

r.m.s. source size: $\Sigma_0 \approx \dfrac{\sqrt{2\lambda_n L}}{2\pi}$

Estimates from numerical simulations
(second order moment from 2D profiles)

Photon beam phase space area: $\varepsilon_i = \Sigma_0 \Sigma_0' \approx \dfrac{\lambda_n}{2\pi}$

Intrinsic beta function of undulator: $\beta_i = \dfrac{\Sigma_0}{\Sigma_0'} \approx \dfrac{L}{\pi}$

UNDULATOR BEAM WITH REAL ELECTRON BEAM

Resulting photon beam phase space: convolution of single electron emission with electron beam distribution

$$S_{x,z} = \Sigma_{x,z}\Sigma'_{x,z} = \sqrt{\left(\varepsilon_{x,z}\beta_{x,z} + \frac{\lambda_n L}{2\pi^2}\right)\left(\frac{\varepsilon_{x,z}}{\beta_{x,z}} + \frac{\lambda_n}{2L}\right)}$$

$$m_{x,z} = \frac{\beta_{x,z}}{\beta_i}$$

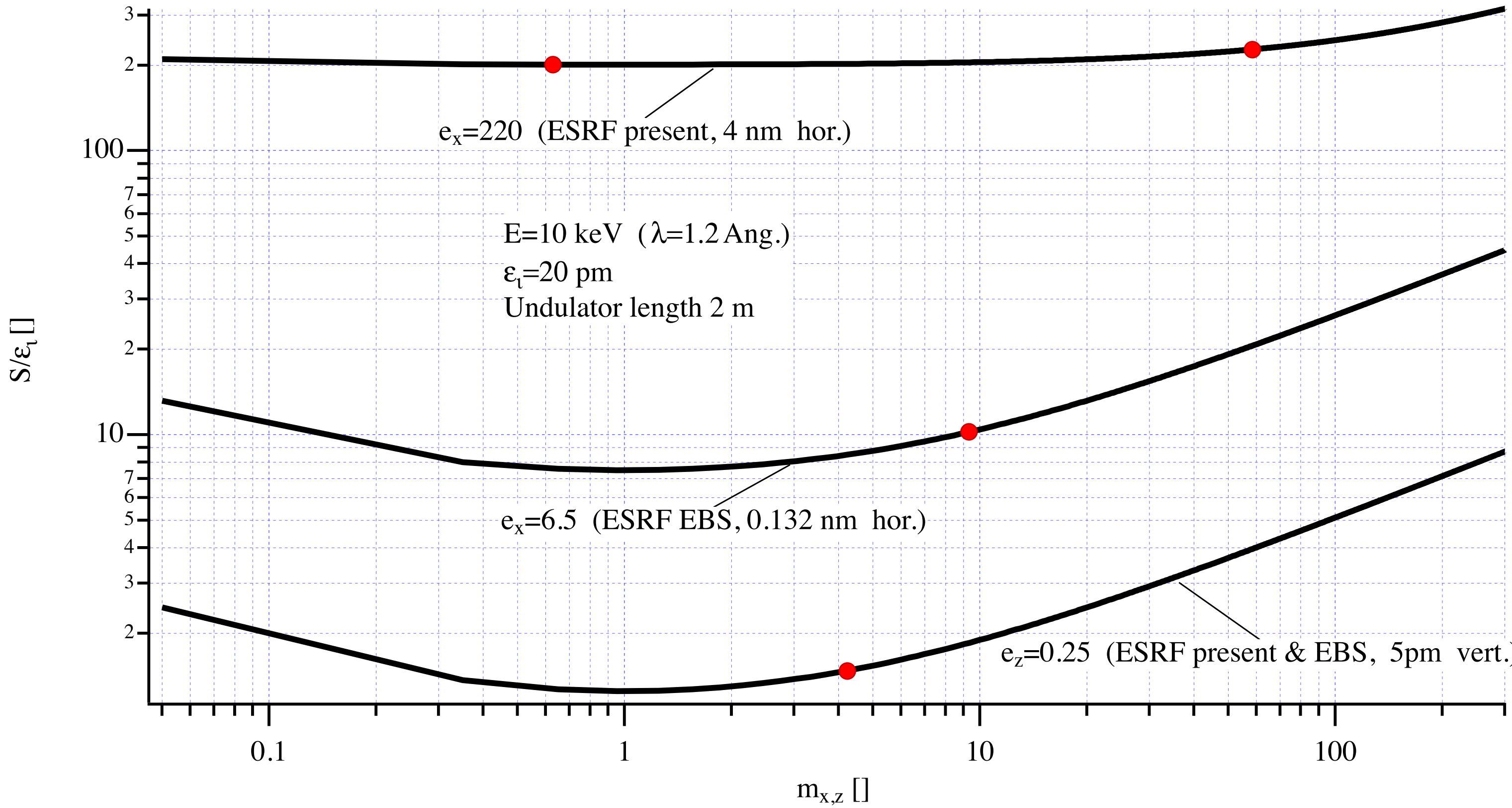
$$S_{x,z} = \frac{\lambda_n}{2\pi}\sqrt{\left(e_{x,z}m_{x,z} + 1\right)\left(\frac{e_{x,z}}{m_{x,z}} + 1\right)}$$

$$e_{x,z} = \frac{\varepsilon_{x,z}}{\left(\frac{\lambda_n}{2\pi}\right)}$$

Assumptions/approximations:

- Undulator at the waist of electron beam in ID straight
- Impact of energy spread not taken into account
- Photon energy ~ on axis resonance (no detuning)

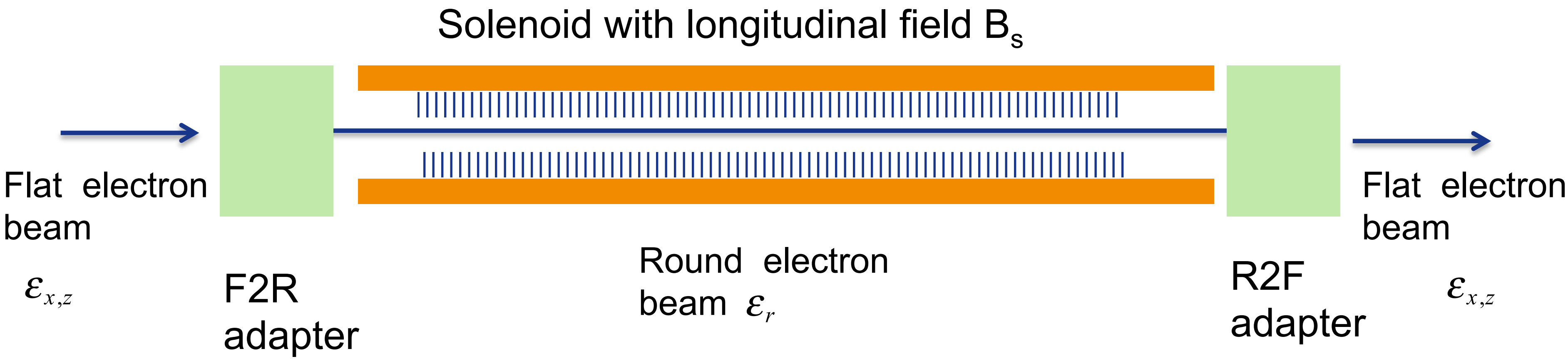
BETA MATCHING UNDULATOR-ELECTRON BEAM



$$S_{x,z} / \varepsilon_i = \sqrt{\left(e_{x,z} m_{x,z} + 1\right)\left(\frac{e_{x,z}}{m_{x,z}} + 1\right)}$$

for constant emittance S is minimum for m=1 (i.e $\beta = \beta_i \approx \frac{L}{\pi}$)

EMITTANCE ADAPTER



A.W. Chao, P.Raimondi, SLAC-PUB-1408
R. Brinkmann, Proc. EPAC 2002, Paris, France

Flat beam with

- horizontal emittance ε_x
- vertical emittance $\varepsilon_z = r\varepsilon x \quad r << 1$

(i.e typical electron beam in 3rd generation light source)

ROUND ELECTRON BEAM IN EMITTANCE ADAPTER

$\beta_L = 2p_0 / eB_s$ Larmor betatron function in solenoid

Apparent emittance $\varepsilon_r \approx \varepsilon_x \sqrt{r}$

Rms size $\sigma_r \approx \sqrt{\varepsilon_x \ \beta_L / 2}$

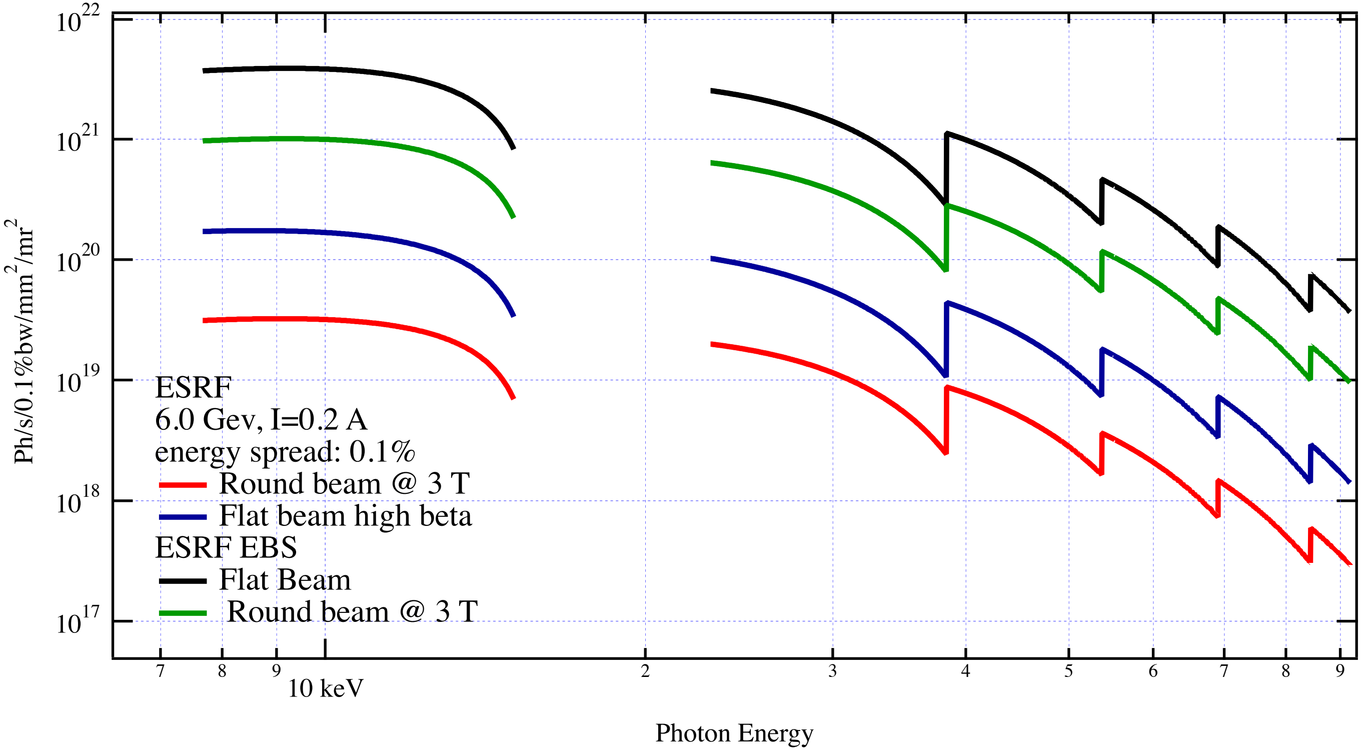
Rms divergence $\sigma'_r \approx \sqrt{2 \ \varepsilon_z / \beta_L}$

Effective beta function $\beta_r = \frac{\sigma_r}{\sigma'_r} = \frac{\beta_L}{2}\sqrt{\frac{\varepsilon_x}{\varepsilon_z}} = \frac{\beta_L}{2\sqrt{r}}$

		ESRF	SOLEIL	ESRF-EBS
Flat beam	E [Gev]	6	2.75	6
	$\varepsilon_{x,z}[pm]$	4000/5	4000/5	132/5
	$\beta_{x,z}[m]$	37.2/3	5/8	6.8/2.7
	$\sigma_{x,z}[\mu m]$	385/3.8	148/6.3	30/3.7
	$\sigma'_{x,z}[\mu rad]$	10.3/1.3	27/0.8	4.4/1.4
Round beam	B_s[T]	3	3	3
	$\beta_L[m]$	13.2	6.05	13.2
	$\varepsilon_r[pm]$	140	140	11.5
	$\beta r[m]$	187	86	76
	$\sigma_r[\mu m]$	162	110	29.5
	$\sigma'_r[\mu rad]$	0.87	1.3	0.39

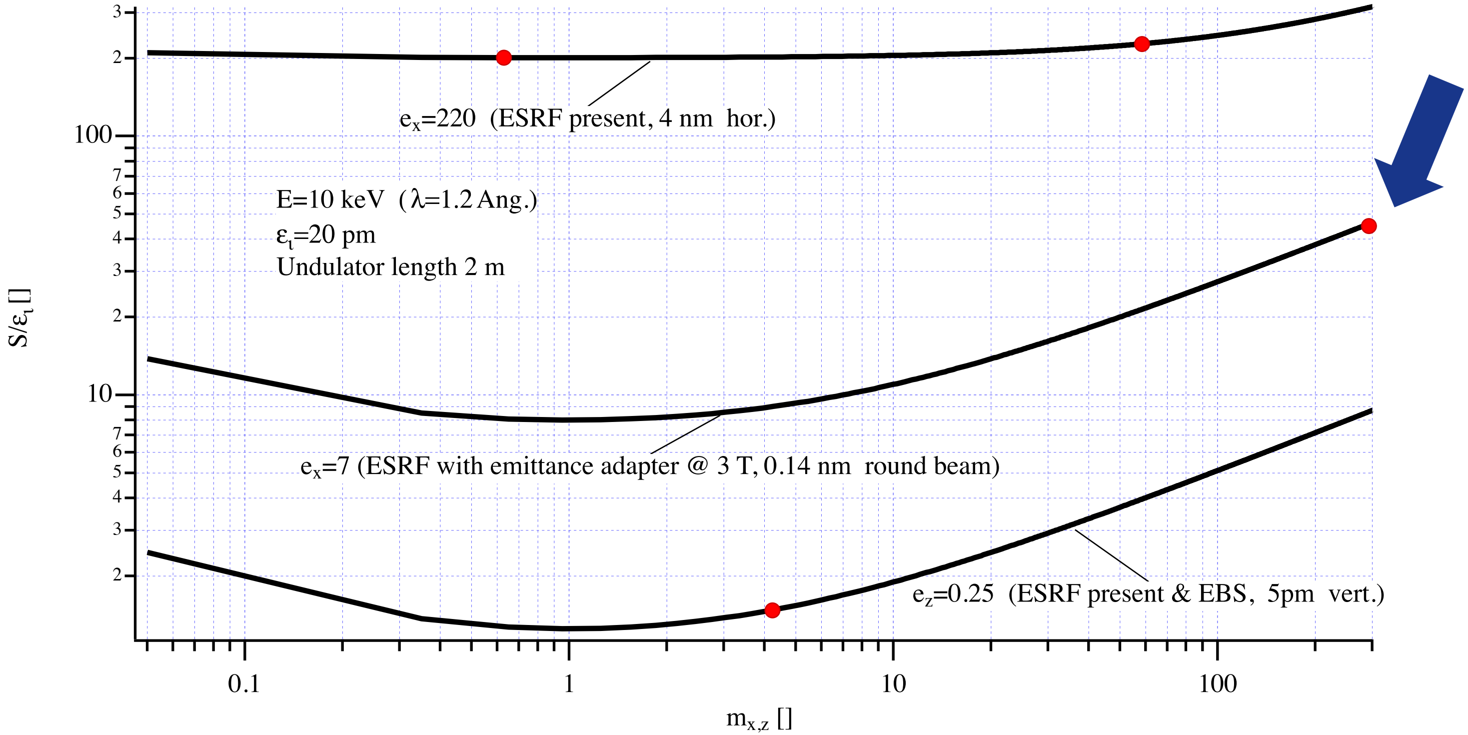
Solenoid field 3 T

UNDULATOR BRILLIANCE



Undulator: staggered undulator
Period 22 mm, L=2 m, K=1.42

BETA MATCHING!



Beta matching requires too high solenoid field for round beam: $B_s = \frac{\pi p_0}{eL\sqrt{r}}$ (easily > 100 T)
or (very) long undulator

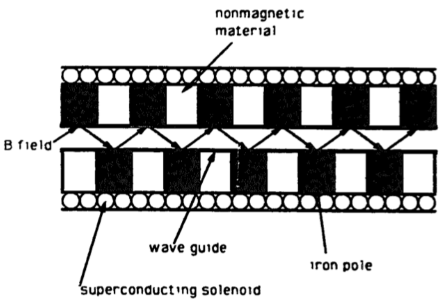
UNDULATOR SCHEME

- Longitudinal solenoid field (can be few Tesla)

  - Reverse field in magnet blocks if permanent magnet !
  - Max field in conductors if conventional SCU
  - Magnetic forces

- Use solenoid field as source for undulator field

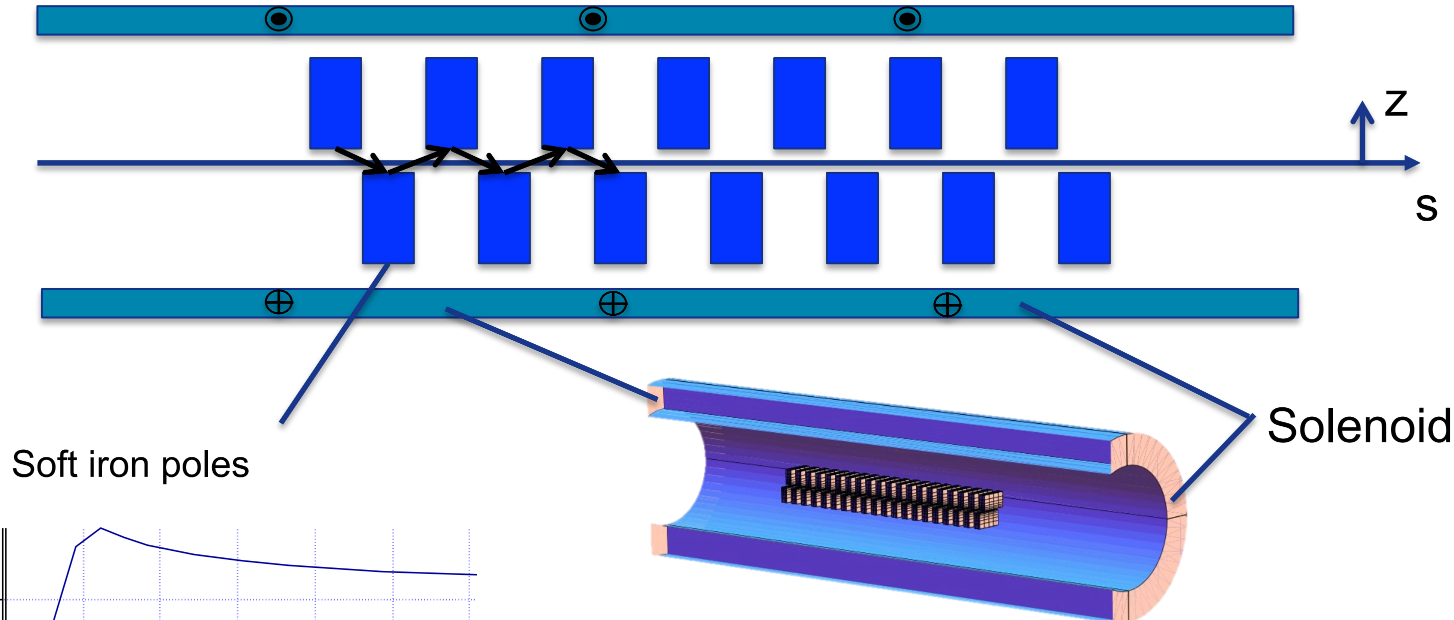
  - Concept of staggered undulator (1990-1992)

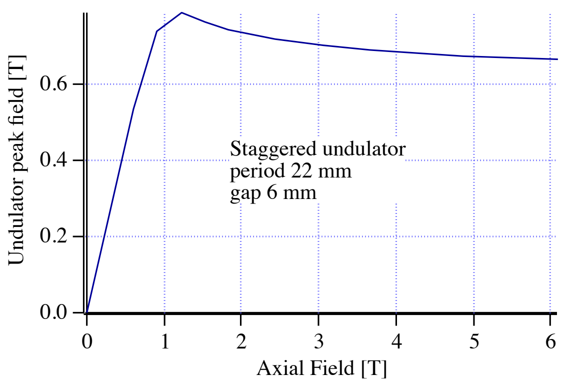


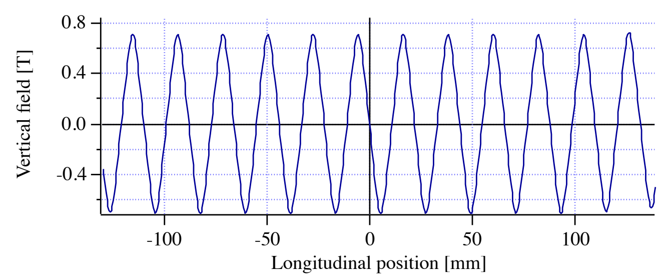
- Use some small fraction of longitudinal field for building undulator field

- A. H. Ho, et al., Nucl. Instrum. Methods A296, 631 (1990)

STAGGERED UNDULATOR







Transverse field along beam axis

DIFFERENT STAGGERED UNDULATOR VARIANTS

- S. Sasaki (2005)
- Add PM blocks with magnetization anti-parallel to the solenoid field
- ~ 25 % field increace

period 15 mm, gap 6 mm

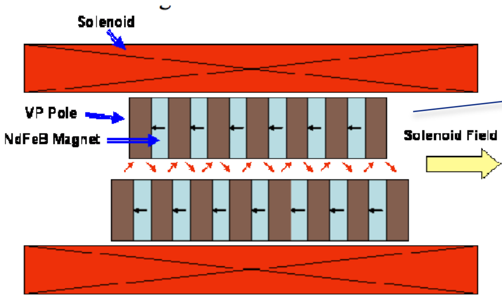
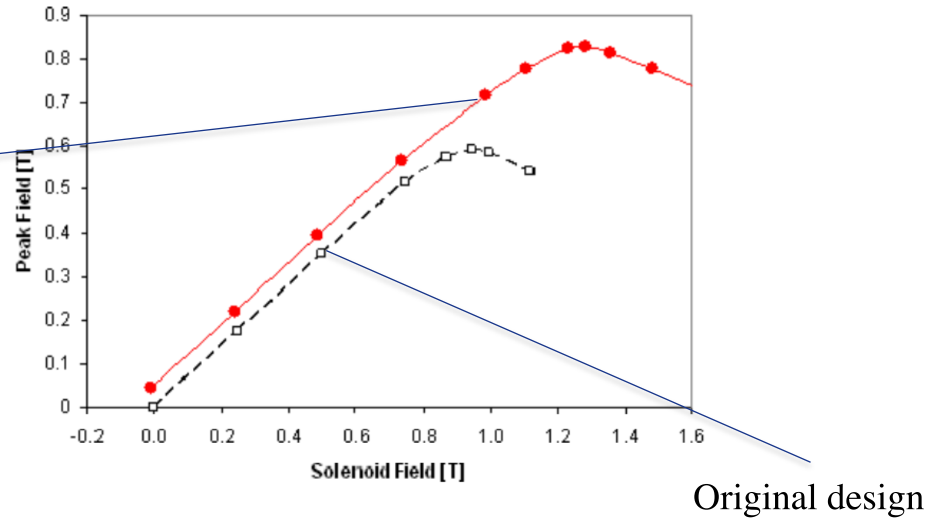
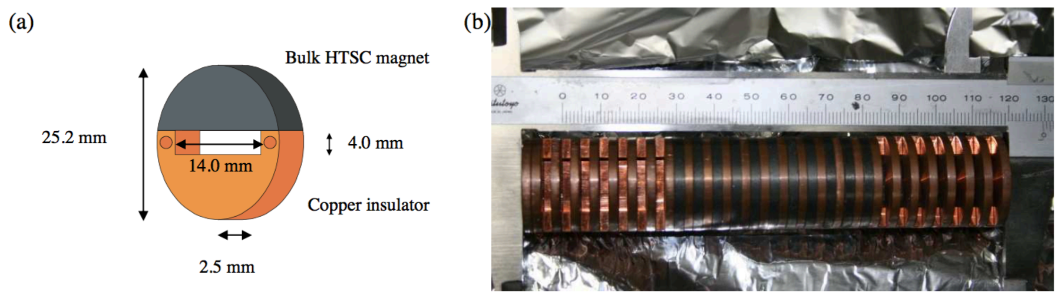


Figure 1: Schematic of a hybrid staggered undulator.



BULK HTS STAGGERED UNDULATOR

Replace iron poles with bulk HTS material



Toshiteru Kii, Ryota Kinjo, Mahmoud A. Bakr, Taro Sonobe, Keisuke Higashimura et al. : Synchr. Rad. Instr. (2010)

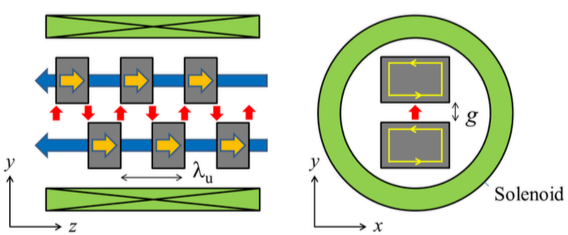
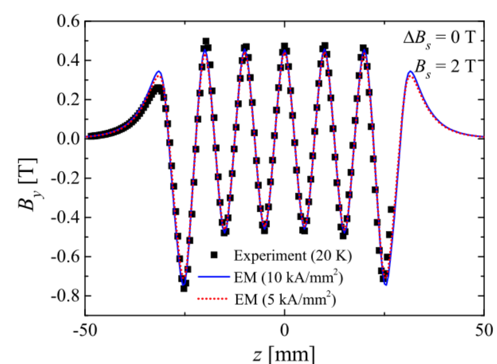


FIG. 1. Schematic view of BHSAU.

Ryota Kinjo et al. Phys. Rev. Spe. Top. A. B. (2014)



Period 10 mm
Gap 4 mm
T=20 K

SUMMARY

Brilliance of photon beam from undulator in emittance adapter

- Limited due to large beta of round electron beam
- Better beta matching requires a priori very high solenoid field or very long undulator

Undulator technology

- staggered undulator concept seems interesting with emittance adapter
  - undulator field generated by solenoid field
- Other type of undulators (conventional PMU, SCUs) probably need more studies