Possibility of the very short period undulator as an incident photon source for Compton gamma-ray
コンプトンガンマ線用入射フォトンソースとしての極短周期アンジュレータの可能性

Haruo Ohkuma
大熊春夫

JASRI/SPring-8
高輝度光科学研究センター　光源基盤部門　特別研究嘱託

RCNP, Osaka University
大阪大学　核物理研究センター　特任教授

Aichi-SR
あいちシンクロトロン光センター　光源アドバイザー

KEK
高エネルギー加速器研究機構　物質構造科学研究所　客員教授

LASTI, Hyogo University
兵庫県立大学　高度産業科学技術研究所　客員教授

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Outline

1. Synchrotron Radiation Facility and Undulator Radiation

2. Photon Energy from Undulator Radiation

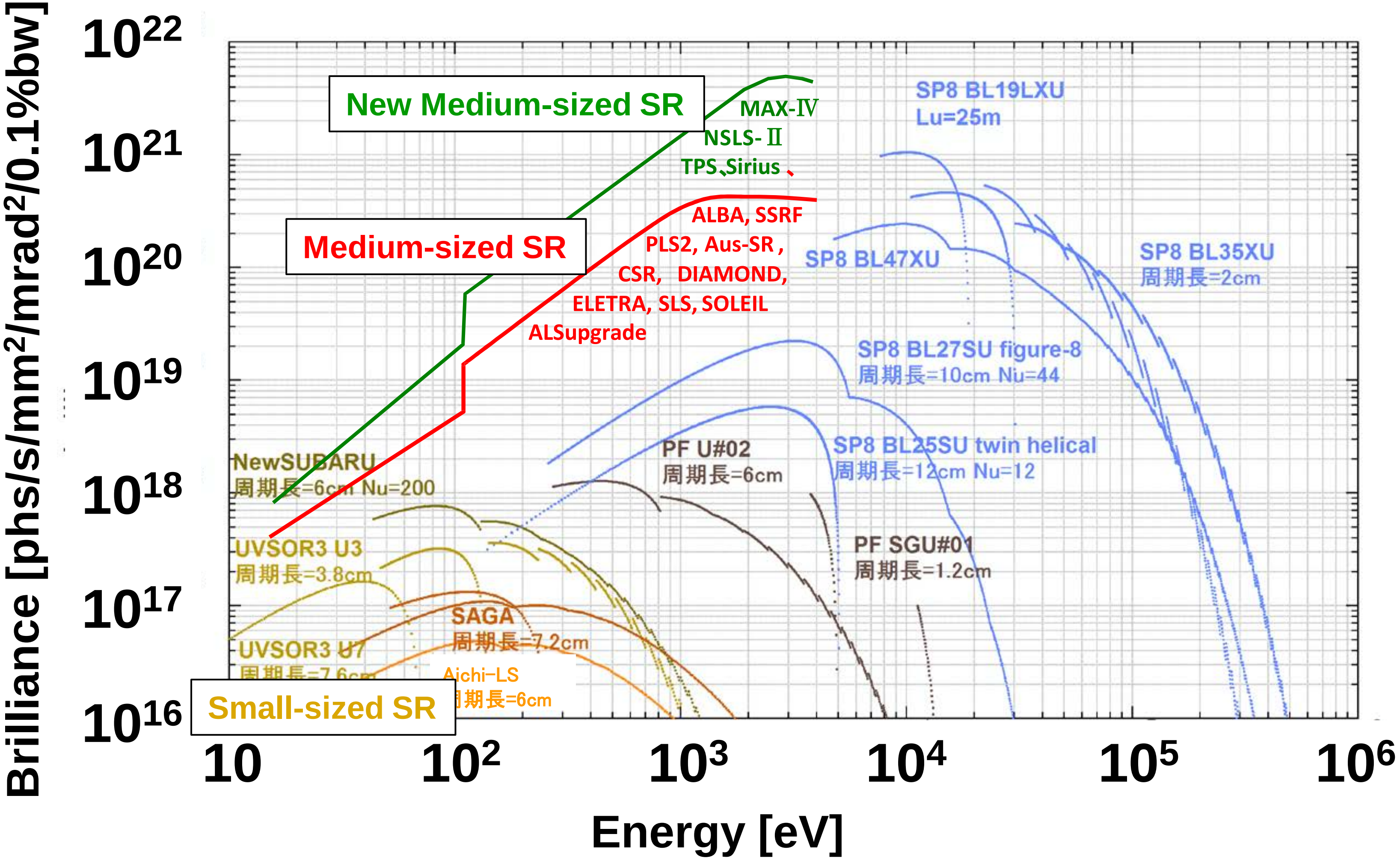
3. What is Very Short Period Undulator?

4. Design of Small Synchrotron Radiation Source for Very Short Period Undulator

5. Generation Test of Synchrotron Radiation from Very Short Period Undulator at Aichi-SR

6. Installation of Very Short Period Undulator for High Energy Gamma-ray Source

Photon Energy and Brilliance of Undulator Radiation at Various Synchrtoron Radiation Facility



Photon Energy from Undulator Radiation

Energy of Electron Beam: $E_e[GeV]$
Period Length: $\lambda_u[cm]$
Photon Energy of Undulator Radiation: $\hbar\omega[keV]$

$$\hbar\omega[keV] = 0.950 \frac{E_e^2[GeV]}{\left(1 + \frac{K^2}{2}\right)\lambda_u[cm]}$$

K-value : $K = 0.934\lambda_u[cm]B_0[T]$
Magnetic Field of Undulator : $B_0[T]$

Very Shrot Period Undulator ⟹ λ_u: 2mm ∼ 8mm

Feature of (Very) Short Period Undulator

- High Photon Energy Radiation at Low Energy SR
  $\lambda_u = 4\ mm$ ($B_0 = 0.2165\ [T]$ at $gap = 2\ mm$, $E_e = 1.0\ GeV$ ⟹ $\hbar\omega = 2.4\ keV$
- Small Installation Space
- Large Number of Period ⟹ High Brilliance
- Low Cost (?)

Defect

- Need Small Vertical Betatron function
- Narrow Tuning Range of Photon Energy

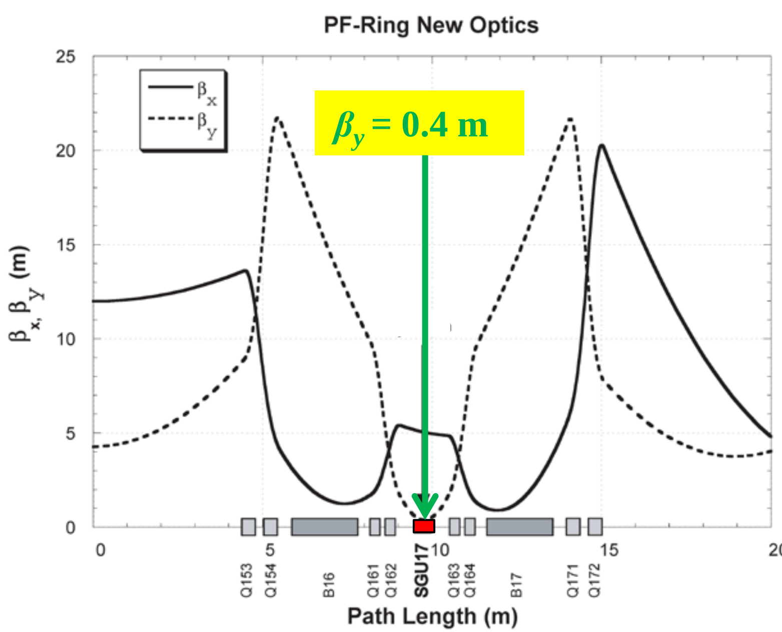
Short Gap (Period) Undulator of KEK-PF (2005)

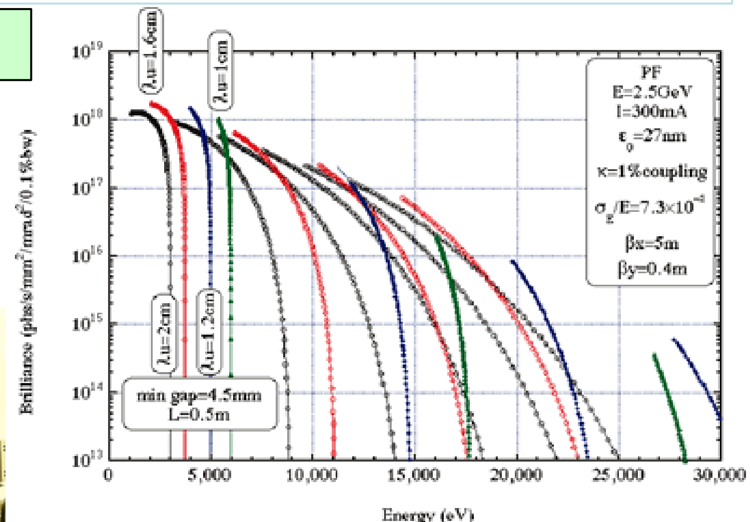
- Lattice modification between two bending magnets
- 1.4 m short straight section can be obtained
- Installation short period and short gap undulator
- First short gap undulator, SGU#17 (2005) at Photon Factory

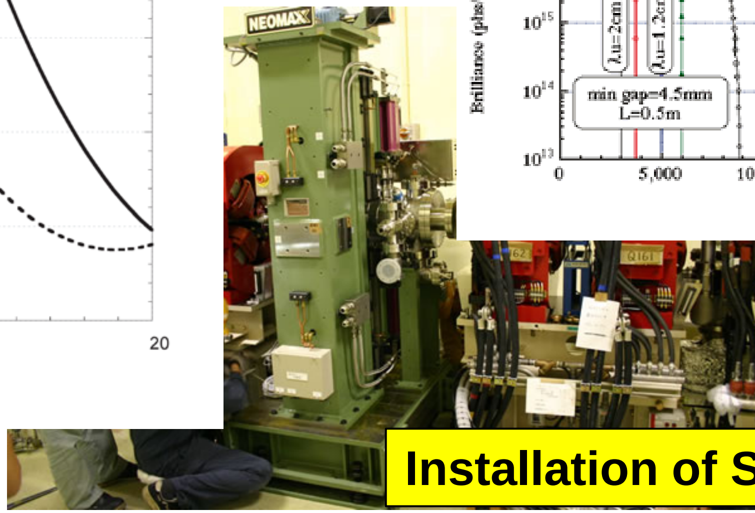
  Period length: λ_u = 16mm, Number of period: N = 29 (Total length: 460 mm), Minimum gap: 4.5mm

  ⇨ 2keV〜15keV photon Energy can be covered (Use to 7th Harmonic)

S. Yamamoto, et al., AIP Conf. Proc. 879, 384(2007).







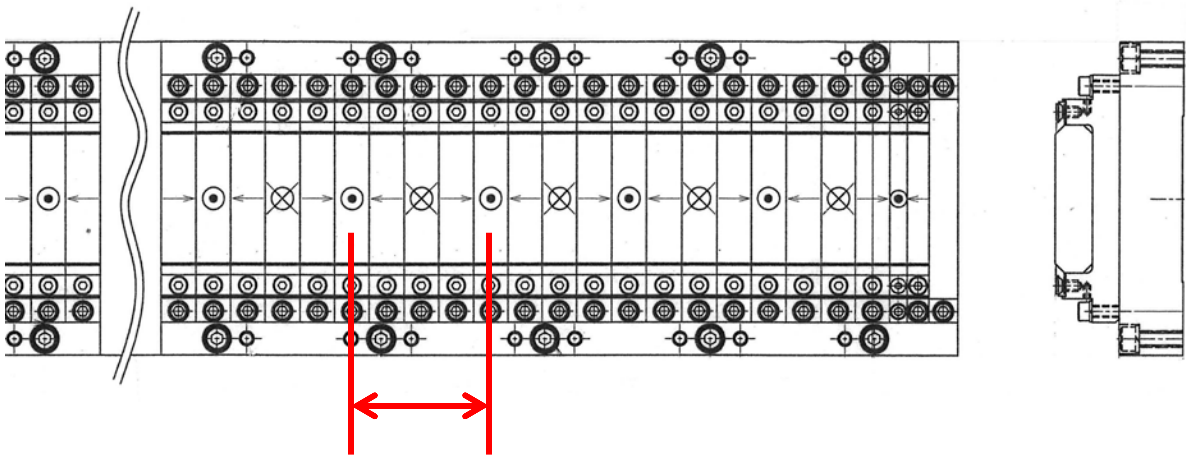
Installation of SGU#17

Undulator of Conventional Type using Permanent Magnet Blocks

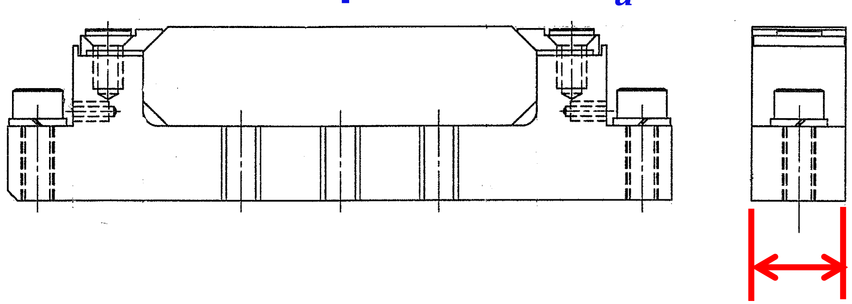
One Period is consist of Four Mag. Pieces（Halbach Type）

λ_u = 10mm ⇨ Width of one Mag. Piece = 2.5mm

Difficult below λ_u = 10mm

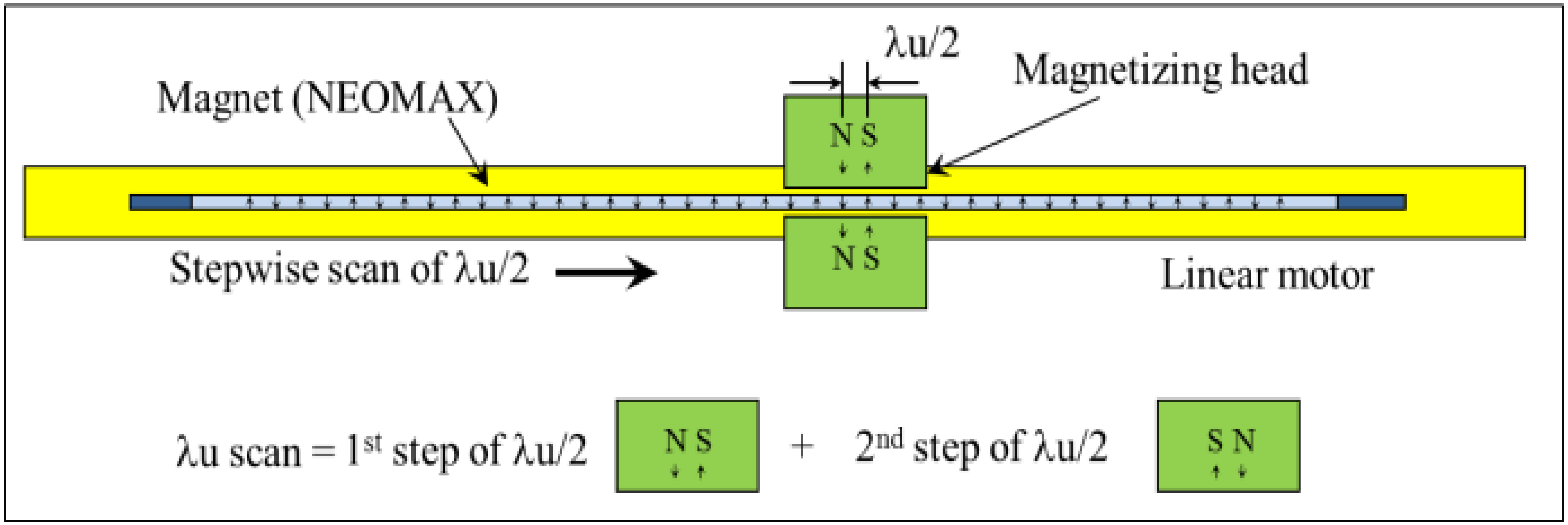


One period ： λ_u

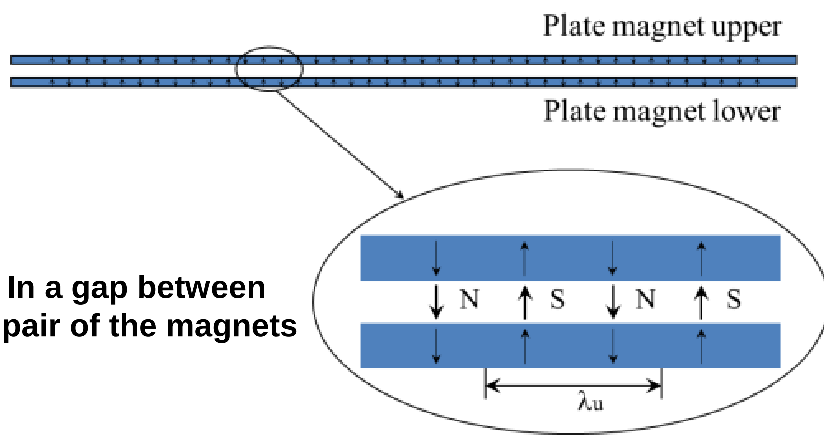


Width of Mag. piece ＝ $\lambda_u/4$

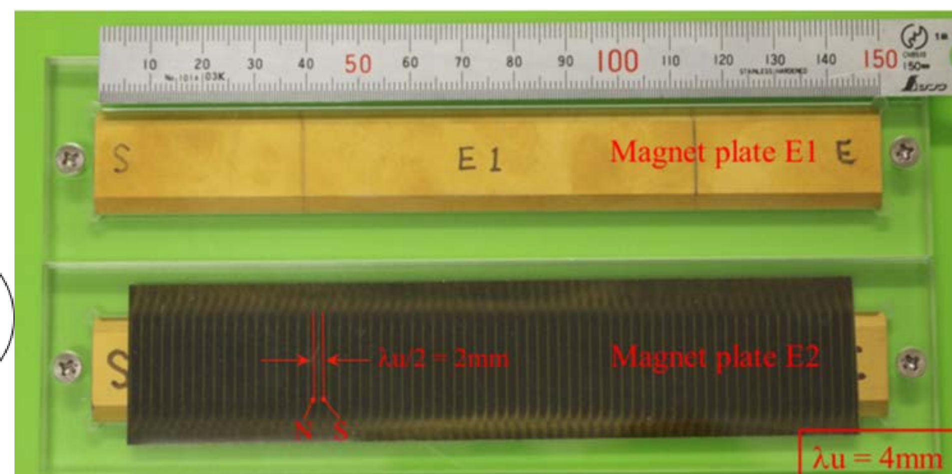
Very Short Period Undulator（by S. Yamamoto (KEK)）



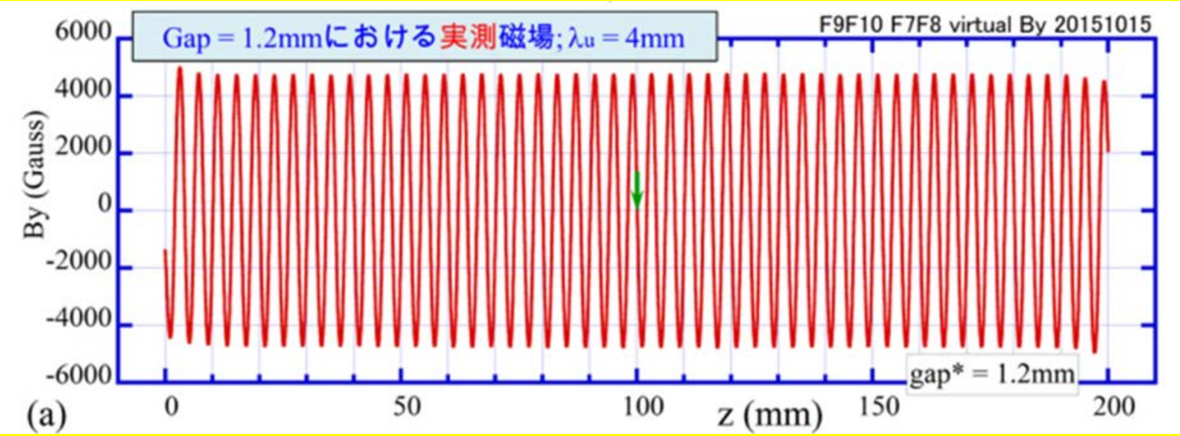
The magnetic plate of Ne-Fe-B compound material is inserted by magnetizing heads. By heads are moved by stepwise scan, the magnetic plate are periodically magnetized.



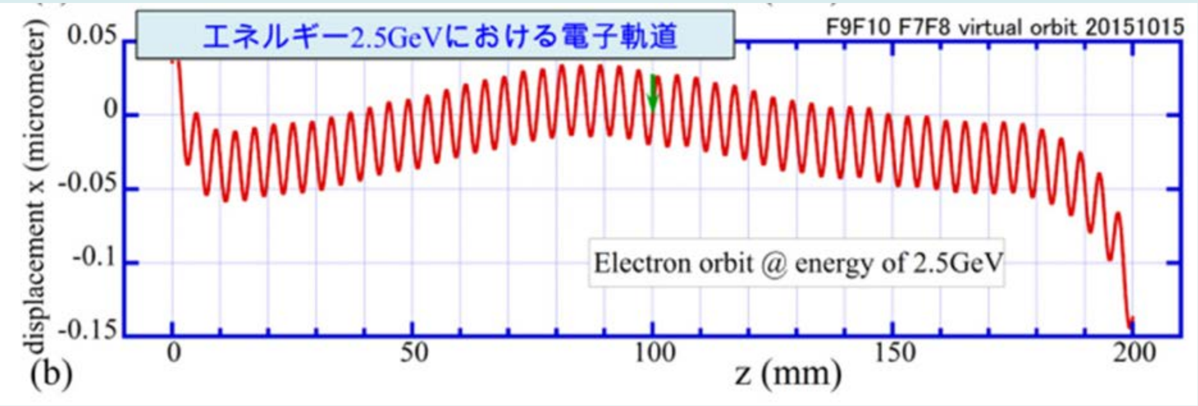
In a gap between a pair of the magnets



Measurement of Periodic Magnetic Field



Period Length : λ_u **= 4 mm, B = 5000 Gauss**



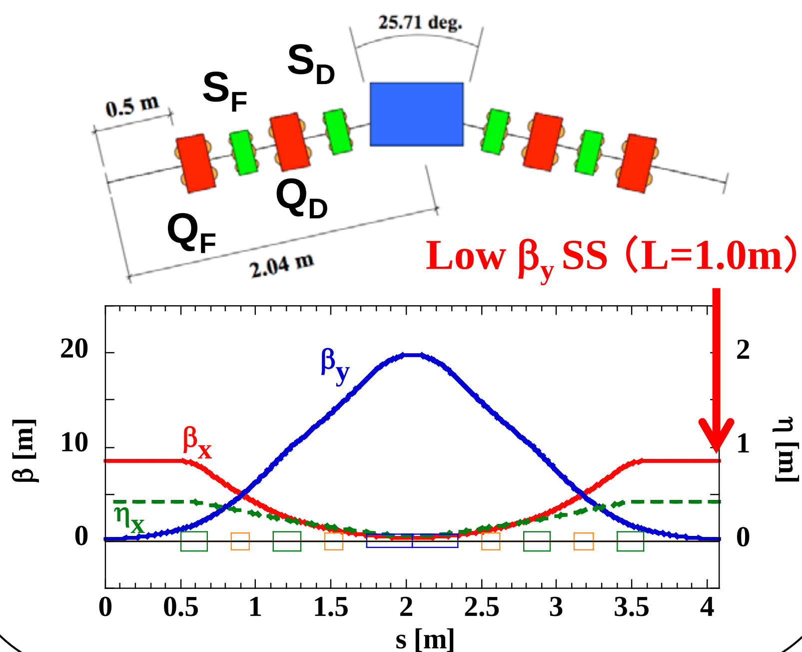
Calculated Electron Beam Orbit
from Measured Undulator Magnetic Field

S. Yamamoto, Proc. of PASJ2017, pp.216-220 (2017)

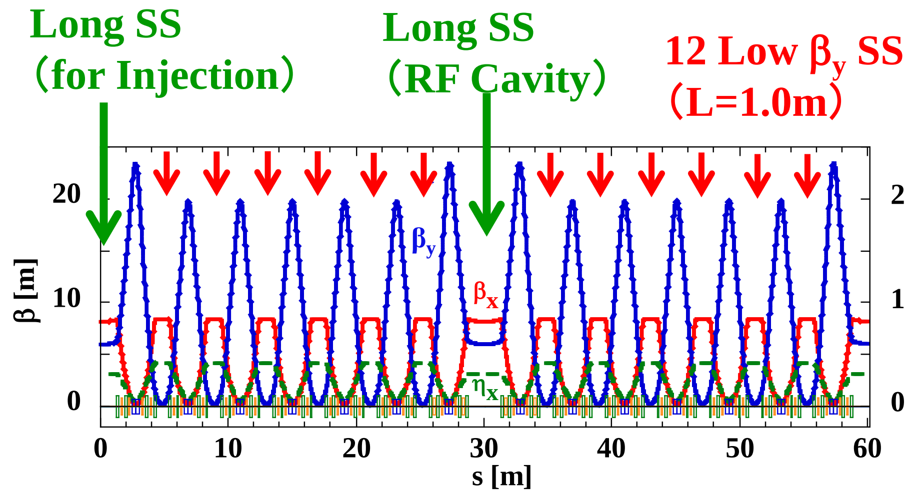
Design of Low Energy Small Ring for Very Short Period Undulator

Latice Structure of Unit Cell

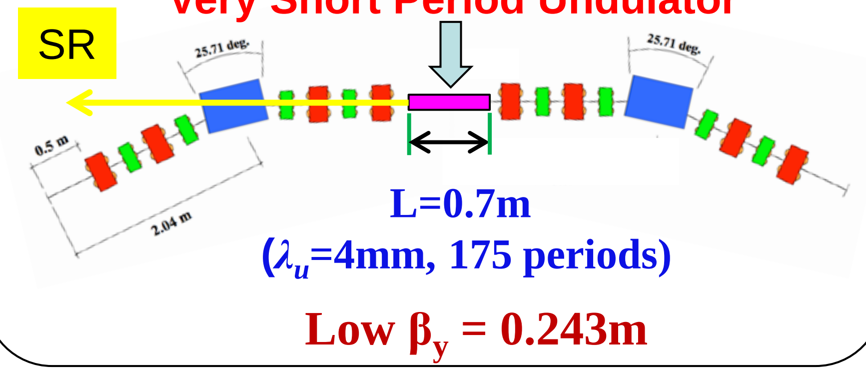
Combined BM



Lattice Structure of Whole Ring



Very Short Period Undulator

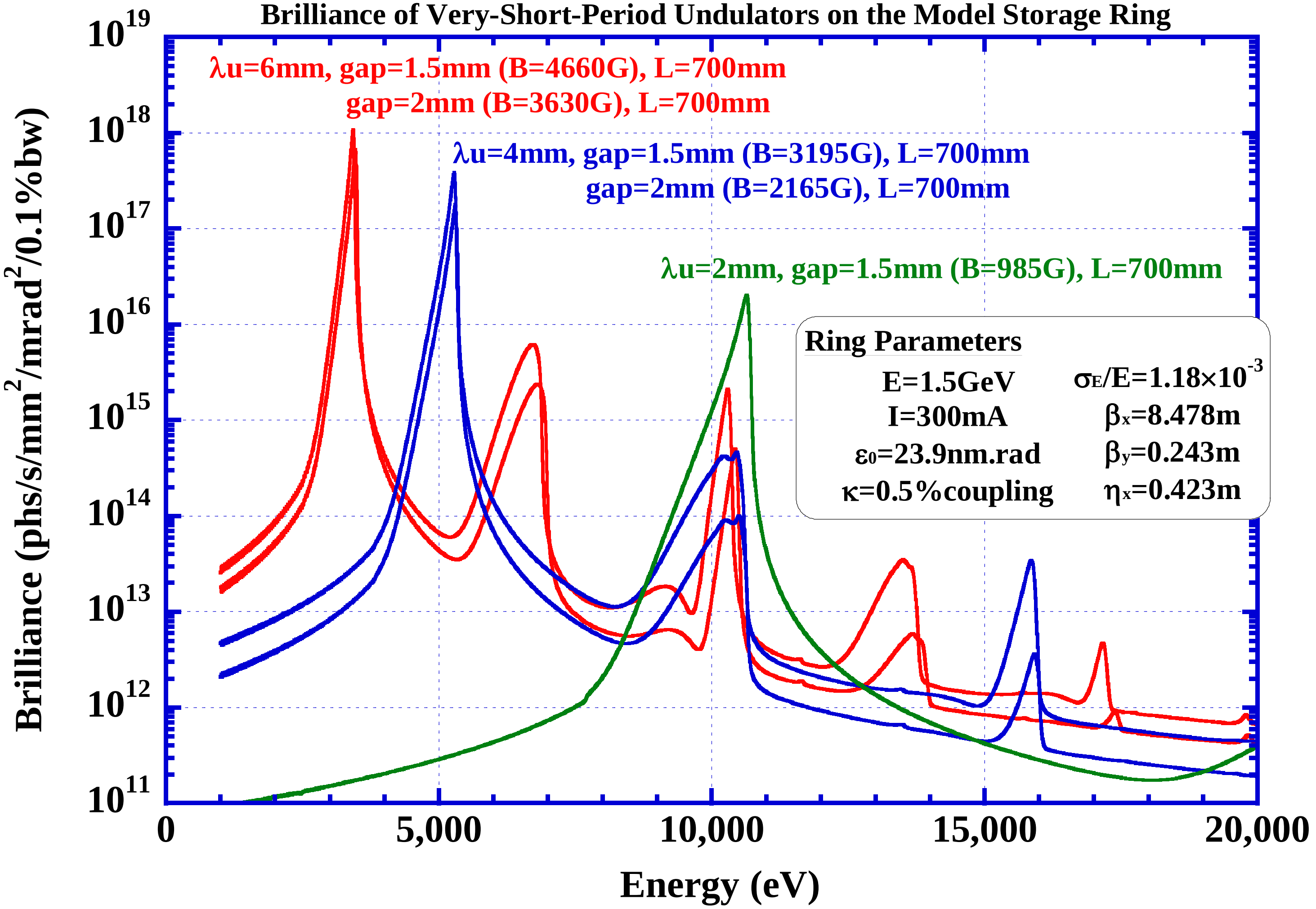


Parameters

Beam Energy	1.5 GeV
Circumference	60.12 m
Natural Emittance	23.9 nm.rad
Effective Emittance	35.7 nm.rad
Low β_y Straight Section	L = 1.0 m
	β_x = 8.478 m
	β_y^{center} = 0.243 m
	η_x = 0.423 m

H. Ohkuma, S. Yamamoto, Proc. of PASJ2017, pp.221-225 (2017)

Undulator Spectrum of Very Short Period Undulator



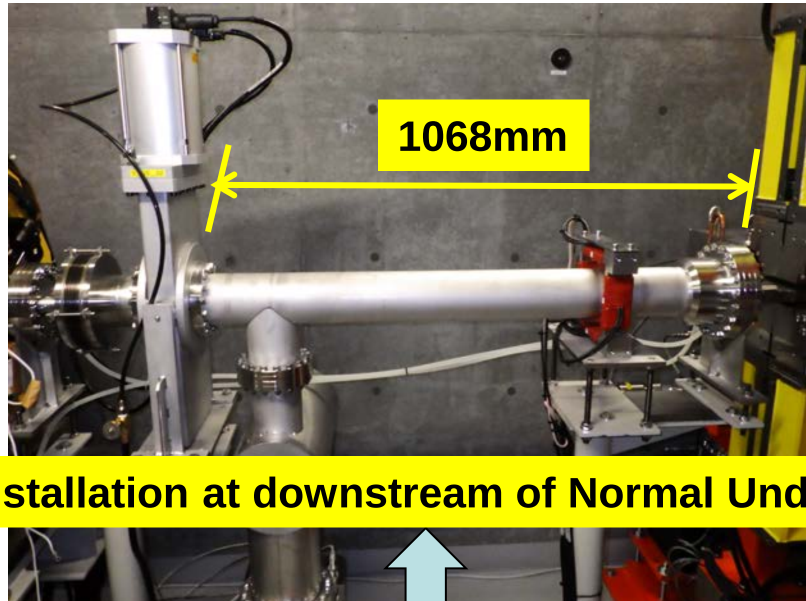
Period length=6mm : gap=1.5mm(B=4660G), gap=2mm(B=3630G)

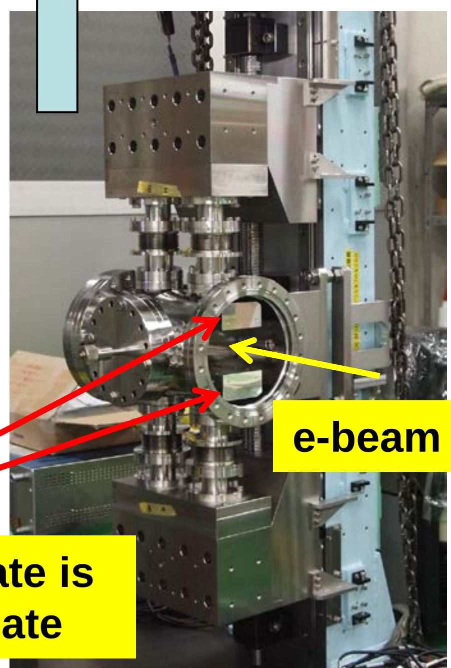
Period length=4mm : gap=1.5mm(B=3195G), gap=2mm(B=2165G)

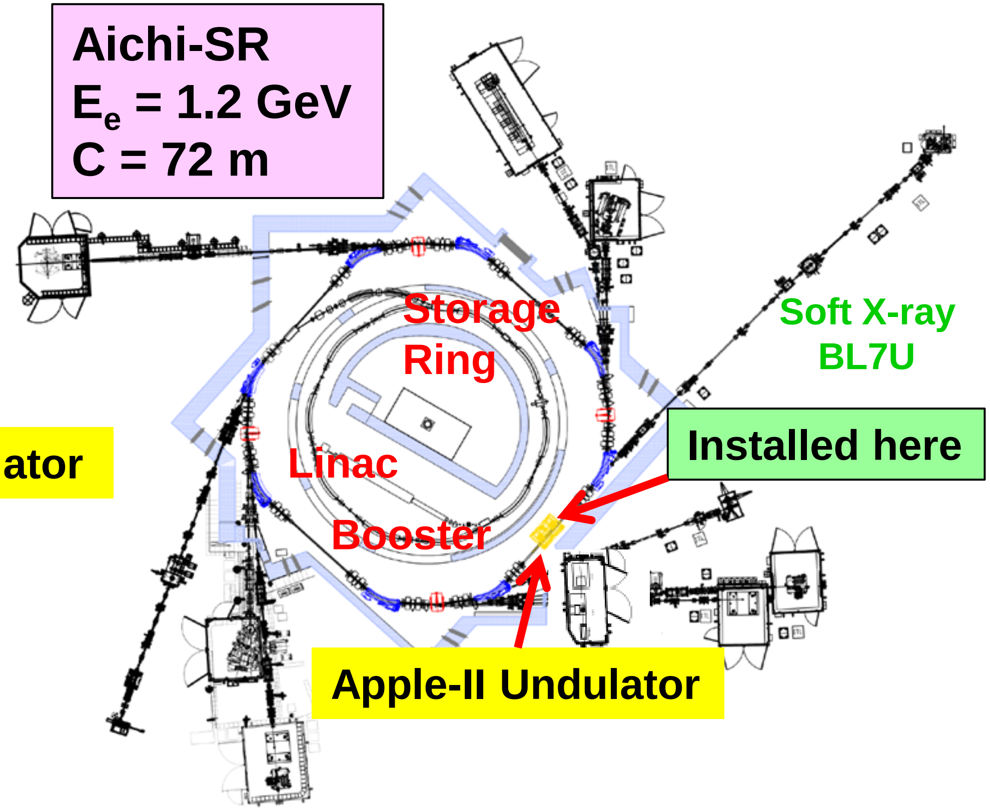
Period length=2mm : gap=1.5mm(B=985G)

H. Ohkuma, S. Yamamoto, Proc. of PASJ2017, pp.221-225 (2017)

Test Plan of Very Short Period Undulator at Aichi-SR







Very short period undulator put in the chamber of 280mm length will be installed at the downstream of the straight section (1668mm of available space) for Apple-II undulator.

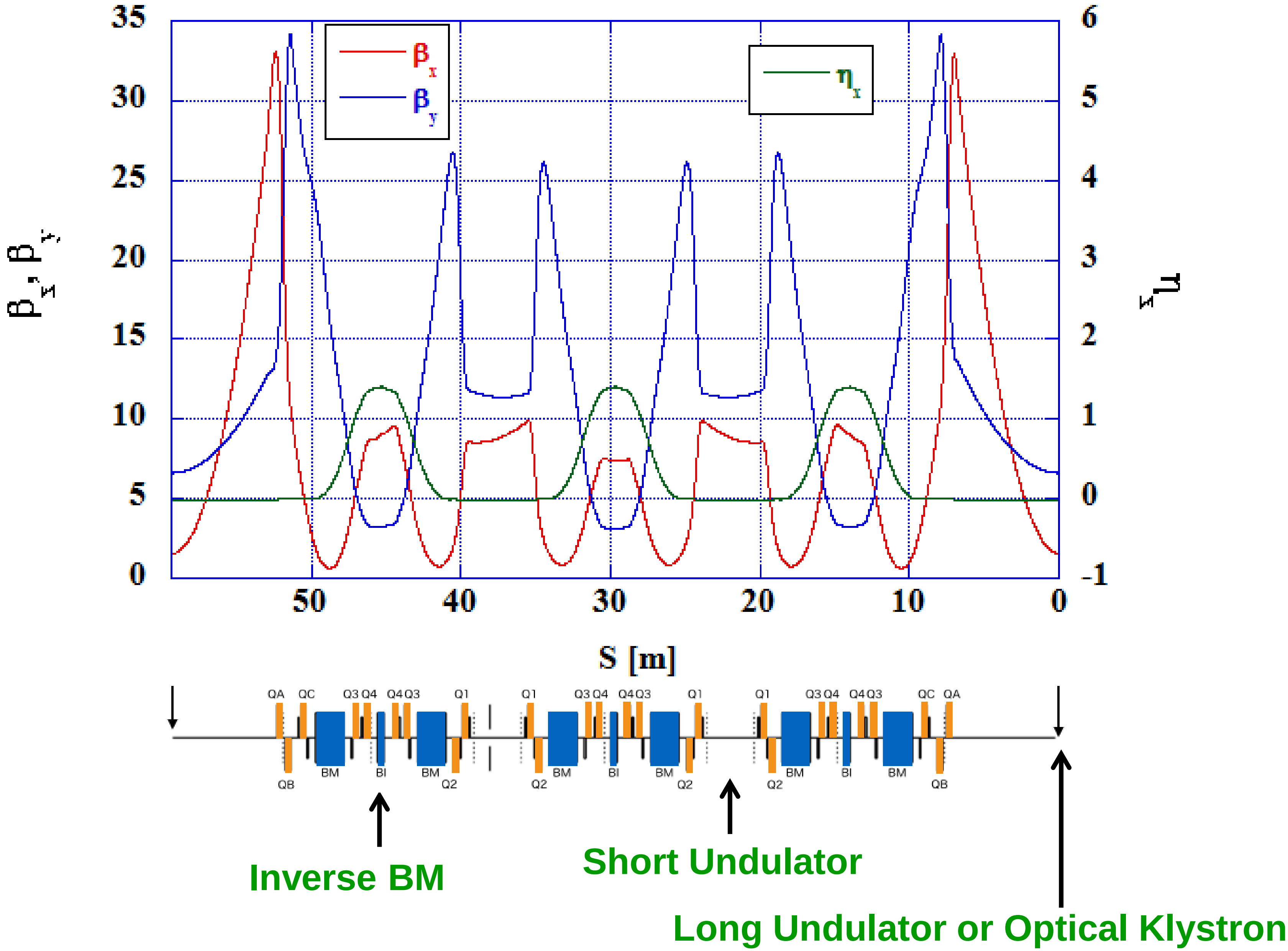
Very short period undulator can be installed in a small space of the ring

Downstream at the Long Undulator
in NewSUBARU

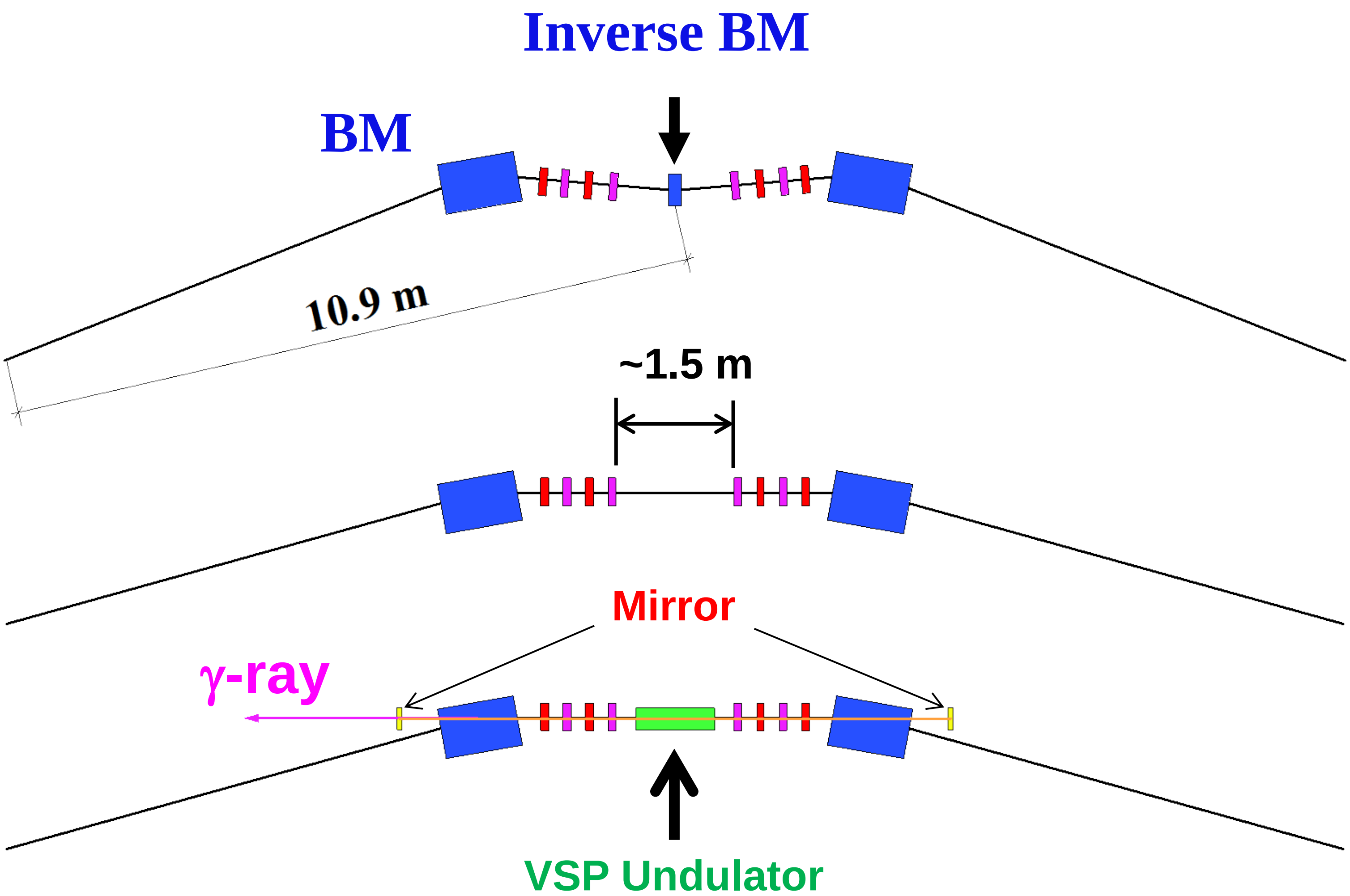
Downstream at the Optical Klystron
in NewSUBARU

Inverse Bending Mag. Section of NewSUBARU

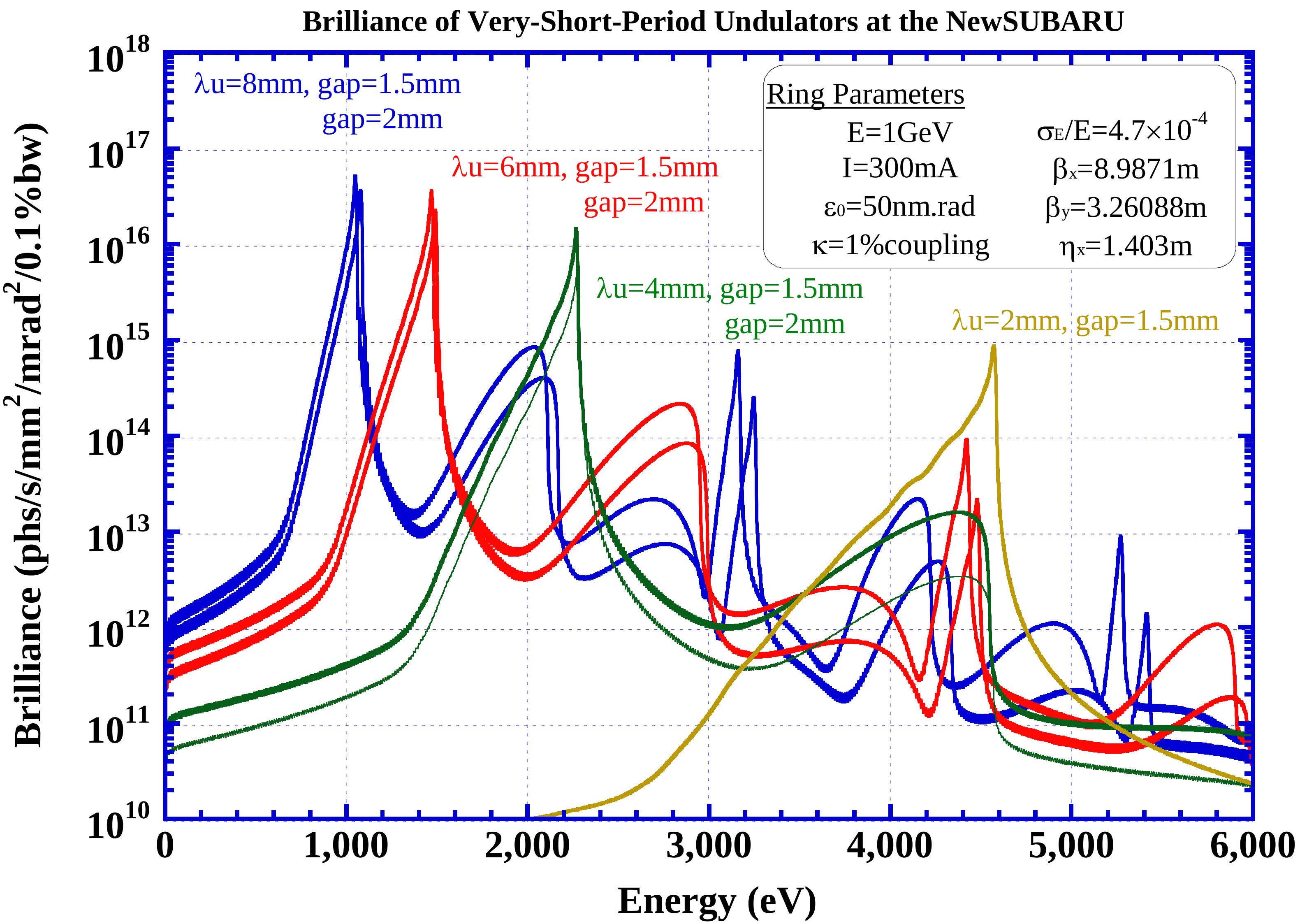
Optical Function of NewSUBARU



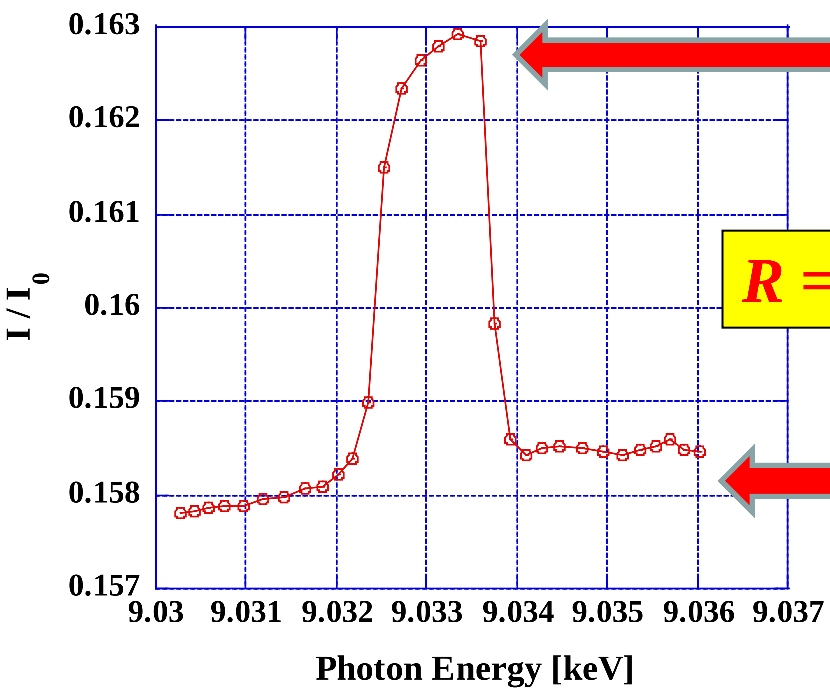
Remove the Inverse BM and Bending Radius of BM is changed.
Approximately 1.5 m Short Straight Section can be available.



Spectrum of Very Short Period Undulator at NewSUBARU



Diamond (333) Bragg Reflection at normal-incidence

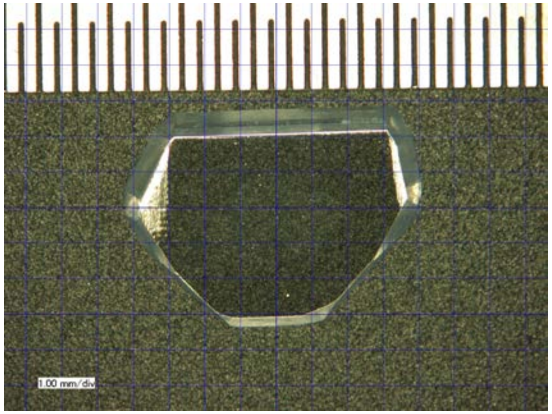


$\left({}^{I}/_{I_0}\right)_{R\neq0} = 0.163$

$R = 0.63$

$\left({}^{I}/_{I_0}\right)_{R=0} = 0.1583$

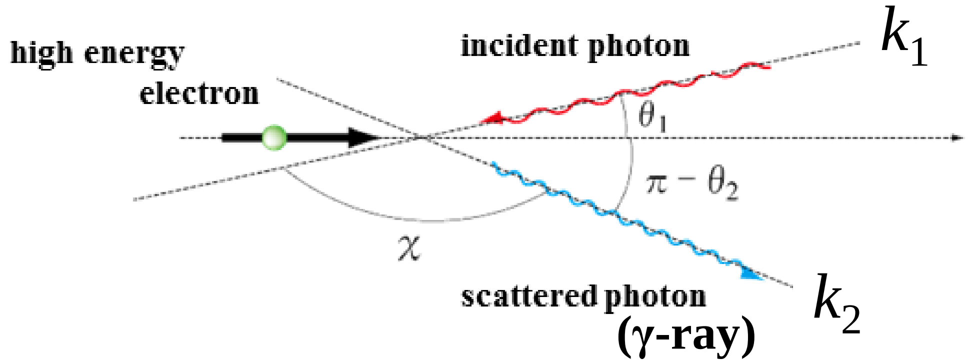
9.033 keV



Diamond Crystal

Backward Compton Scattering

Schematic diagram of BCS



$$k_2 = k_1 \frac{1 + \beta \cos\theta_1}{1 + \beta\cos\theta_2 + \frac{k_1}{E_e}(1 - \cos\chi)} \qquad (1)$$

In case of head-on collision, maximum energy of scattered photon :

$$k_{2\max} = \frac{k_1(1+\beta)}{1 + \beta + \frac{2k_1}{E_e}} \approx \frac{4k_1E_e^2}{(m_ec^2)^2 + 4k_1E_e} \qquad (2)$$

When k_1 is 2.4 keV, E_e = 1 GeV ⇒ $k_{2\max}$ ~ 1 GeV

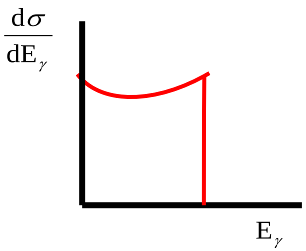
(photon energy of γ-ray is almost equal to electron energy).

Spectrum shape

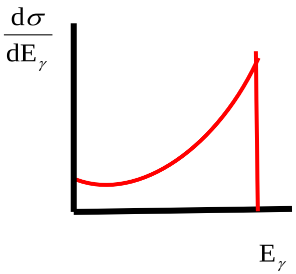
$$\frac{1}{\sigma_0}\frac{d\sigma}{d(k_2/E_e)} = \frac{3}{16\lambda}\left[\frac{\lambda^2(1-x)^2}{1+\lambda(1-x)} + 2(1+x^2) + O[x^n]\right] \qquad (3)$$

σ_0 : Thomson scattering cross-section,
$\lambda = 2\gamma k_1/m_e c^2$, $x = \cos\theta_0$ (θ_0 : photon scattering angle)

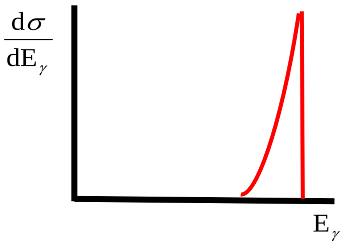
For low k_1 , the second term of Eq. (3) is dominant. γ-ray spectrum is the parabolic shape with wide photon energy range.



For high k_1, the first term of Eq. (3) is dominant and γ-ray spectrum dumps in the low energy region.



For very large k_1, higher-order term x^n (n > 2) of Eq. (3) becomes important. γ-ray spectrum uprises steeply near the maximum BCS gamma-ray of k_{2max}.



Summary

(1) We presented the possibility of very short period undulator as an incident photon source for Compton gamma-ray.

(2) Very short period undulator can be installed in small space of electron storage ring.

(3) We plan to test the photon generation from very short period undulator at Aichi-SR.

(4) There is little interference with use of synchrotron radiation for Compton gamma-ray generation using a very short period undulator.

(5) The cost of the very short period undulator is less expensive than that of the undulator of conventional type.

(6) Circular polarized SR can be generated using the undulator with slanting periodic magnetic fields. ⇨ Circular polarized gamma-ray.

Acknowledgment

- Very short period undulator is proposed and developed by Prof. S. Yamamoto of KEK.

  S. Yamamoto; "Undulator Development Towards Very Short Period Lengths"; Synchrotron Radiation News, Vol.28, No.3 (2015) p.19.

- The development of very short period undulator and the design of storage ring for the installation of very short period undulators are supported by JSPS KAKENHI (Grant-in-Aid for Scientific Research) Grant Number 26246044.