# COMPTON X-RAY GENERATION AT THE KAERI SC RF LINAC *

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*Abstract*

The KAERI SC RF linac with one 352 MHz cryomodule is routinely operating at 10 MeV. The maximum accelerating gradient achieved so far is about 7.7 MV/m and is expected to increase up to 9 MV/m, if thermal loss and/or vibration instability is sufficiently suppressed. As a next step, we plan to generate Compton X-rays using external lasers at the straight section, just after the SC linac. This beamline will be relocated to downstream next to undulator beamline for a FEL, when the recirculating beamline is built. In this paper, the KAERI SC RF Linac system is described and 1 keV Compton X-ray generation and the possibility of increase of the flux at the given system are discussed.

## INTRODUCTION

Since 1992, KAERI has developed electron accelerator systems for free electron lasers, from a mm-wave to an FIR wavelength. The first is an electrostatic accelerator used for the generation of the mm-wave FEL, which was dismantled after its demonstration. The second one is a magnetron-driven microtron, dedicated to a compact FIR FEL with a wavelength range of 100 - 300 μm [1]. The FIR FEL is now routinely operating with an average power of 10 Watt for a macropulse of 3-4 μsec, a spectral width of 0.5 %, and a high stability of less than 1% jitter. Beam diagnostic system for the users of THz applications is under development. The third is a superconducting (SC) Radio-frequency (RF) linear accelerator (Linac) [2,3], being developed for a multi-purpose system: high power FIR FELs, a compact quasi-monochromatic X-ray source via Compton scattering, a 10 MeV electron beam irradiator. The 10 MeV electron beam irradiator is currently commissioning for R&D on electron beam irradiation applications, capable of operating up to 100 kW. At the downstream of the SC linac, a straight beamline will be installed to demonstrate the generation of 1 keV Compton X-rays using an external laser in 2006 and will be moved next to undulator when the recirculating beamline be installed. (See Figure 1)

## THE KAERI RF LINAC SYSTEM

The KAERI SC RF linac system is comprised of the 2 MeV injector, the main linac, and beam transport lines. The injector is consisted of a DC electron gun, a buncher, and two RF accelerating cavities. The electron gun generates electron bunches of 300 kV and 1 nC per pulse. It can generate the average current up to 50 mA by increasing the repetition rate up to 22 MHz. The buncher can compress each electron bunch with the pulse duration less than 1 nsec. Two NC (Normal Conducting) RF cavities are operated at 176 MHz and accelerate electron beams to 2 MeV. However, the maximum average current is limited by the power of RF generator, as 10 mA at the energy of 2 MeV.

Main accelerator consists of one SC RF cryomodules, of which is comprised of two 352 MHz 4-cell SC cavities, transferred from CERN. The typical gradient of cryomodule is 6–8 MV/m. The electron beam parameters are listed in Table 1.

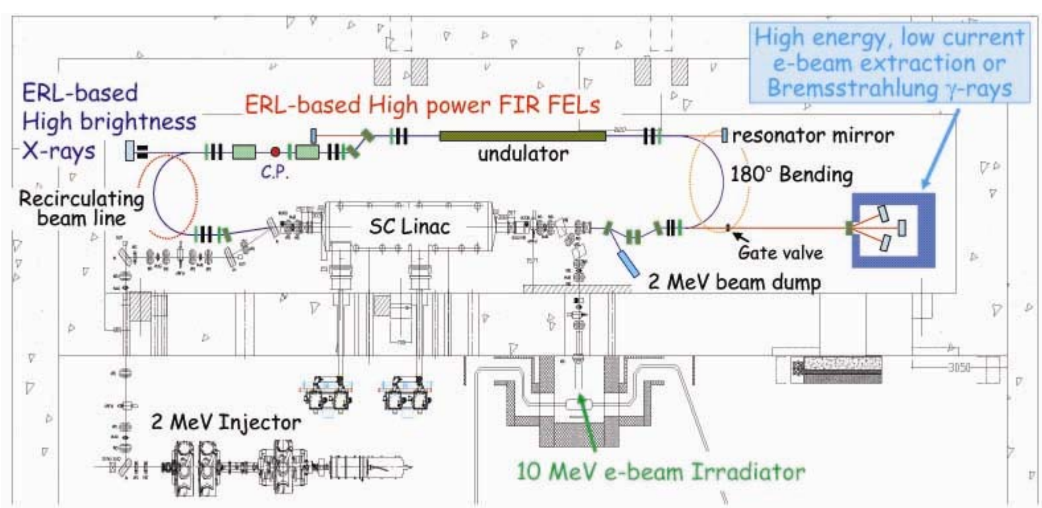


Figure 1: Layout of Multi-purpose Quantum beam generation system.

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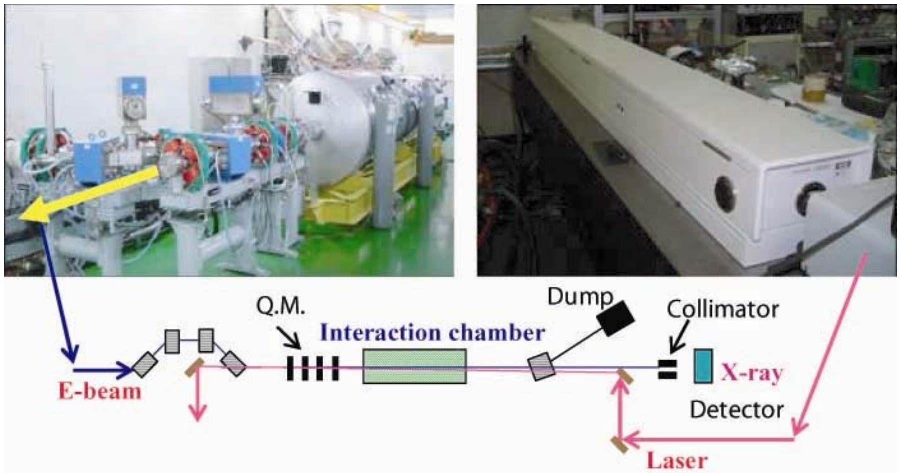


Figure 2: Layout for 1keV Compton X-ray generation.

Table 1. Parameter of electrons in the SC RF Linac

| Parameter | Value |
|---|---|
| Energy | 10 – 20 MeV |
| Ave. current | Up to 10 mA |
| Emittance | < 50 $\pi$mm·mrad |
| Radio Frequency | 352 MHz |
| Repetition rate | Up to 22 MHz |

## 1 keV COMPTON X-RAY GENERATION AT KAERI

### *1 keV Compton X-rays*

Quasi-monochromatic X-rays can be generated via Compton scattering. With a high quality electron beam in the SC RF linac, the high brightness of X-rays can be achieved. There are several schemes to generate Compton X-rays. For the first demonstration, we will use external lasers for scattering with electron beam from the linac. As shown in Figure 2, Compton scattering beamline will be installed in the straight line of downstream. We expect to generate X-rays at the energy range of 1–2.6 keV using 10 MeV electrons.

Figure 3 illustrates the expected parameters of X-rays depending on the normalized emittance and the beta function at the collision point. Here, the energy and current of electron beam is 10 MeV and 5 mA, respectively. The average power of the Nd:YLF laser is 20 W at 88 MHz repetition rate. As we expected, with lower emittance, the flux and energy resolution of X-rays are higher. But, as the beta function is decreased, the energy resolution of X-rays is deteriorated while the flux is increased. For X-rays with a few % of energy spread and $10^7$ photons/sec of flux, the beta function should be around 10 cm. It is easy to manipulate the Rayleigh range of the input laser to match the electron beam size, but it is difficult to deliver the laser beam inside the vacuum chamber without intercepting scattered X-rays, especially with electron beam at the low energy.

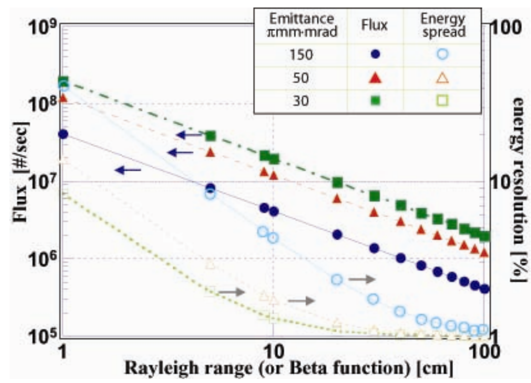


Figure 3: The expected Compton X-rays depending on the emittance and the beta function of electron beam.

According to simulation using the code OPTI, additional four quadrupoles, which are the same type in the beamline, are enough to get the beta function of 10 cm at the collision point. In this case the collision point is located at the distance of 4 m from the gate in front of the cryomodule.

### *Non-linear Compton X-rays*

We investigate the feature of Compton scattering of an intense fs Ti:Sapphire laser light with a micro-bunched electron beam, with a scale of less than 300 nm. It will be produce high harmonics due to non-linear Compton scattering and at a certain condition high harmonics will be coherently added up to produce an atto-second X-ray pulse. The micro-bunching of electron beam can be obtained through the energy modulation in an undulator and the density modulation in a half-period strong magnet. By selecting the proper seed laser, the micro-bunching with required scale can be produced.

To observe the nonlinear Compton scattering, the spectra of Compton scattered X-rays are numerically calculated [4,5,6] using an electron with an initial energy of 10 MeV and an 20 fsec, 800 nm Ti:Sapphire laser light with two different intensity, $10^{17}$ W/cm$^2$ and $10^{20}$ W/cm$^2$.

Figure 4 shows the angular spectrum of the Compton backscattered radiation With the laser intensity of $10^{17}$

W/cm$^2$ (Figure 4(a)), the spectrum shows Doppler shifted monochromatic radiation, caused by linear Compton scattering. When the laser intensity enters a relativistic regime, $10^{20}$ W/cm$^2$ (Figure 4(b)), polychromatic spectrum is generated with maximum photon energy increased by factor of 10.

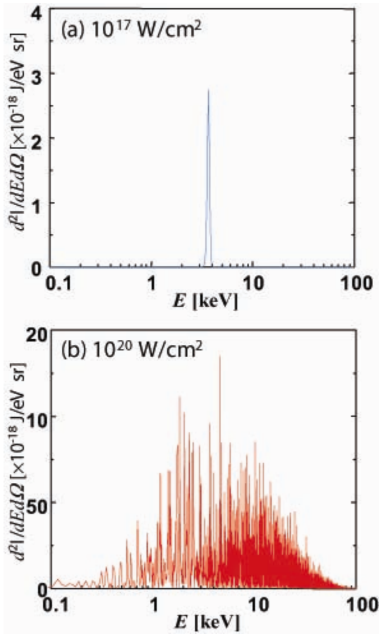


Figure 4: Compton scattered radiation at ϕ=0. (a) linear scattering and (b) non-linear Compton.

The angular distributions of Compton backscattered X-rays for different laser intensities, $10^{17}$ W/cm$^2$ and $10^{19}$ W/cm$^2$, and $10^{20}$ W/cm$^2$, are illustrated in Figure 5. As we expected, the intense laser light strongly deflects the electron orbit, resulting in widely spread distribution.

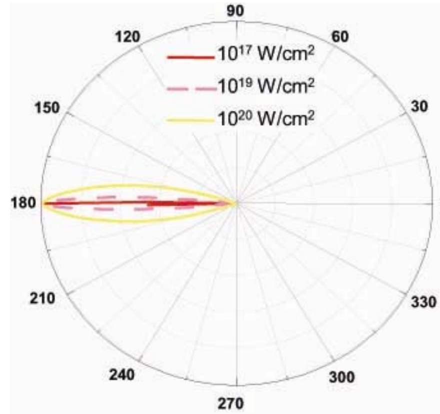


Figure 5: The angular distribution of Compton backscattered X-rays for different laser intensities.

In order to investigate the condition for generating the nonlinear Compton scattering, the angular spectra at different intensities are plotted in Figure 6. A 1.5 MeV electron is used for numerical simulation. High harmonics appear from the laser intensity of $5\times10^{17}$ W/cm$^2$ and are generated more and more at higher intensity. Since the electromagnetic field of intense laser wiggles an electron, the wavelength of fundamental radiation is red-shifted as the intensity is increased, similar to undulation radiations.

Furthermore, we observe that at least two kinds of sources of harmonic generation are involved in this spectrum at Compton scattering of an electron with the intense laser light. For an electron with higher energy, harmonic peaks are close up together (See Figure 4 (b)) so that it is hard to analyze. It also shows the intensity of the fundamental is changed as the intensity of laser is increased. The intensity of lasers can be optimized to produce either high brightness fundamental Compton X-rays or intense higher harmonics. We need more detailed investigation.

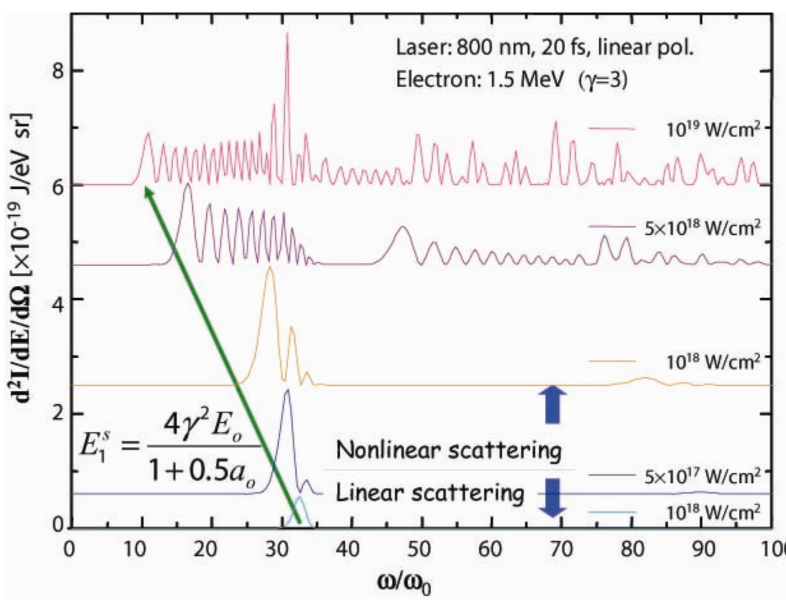


Figure 6: The angular spectra of Compton backscattered X-rats at ϕ=0 for different laser intensities

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