GAMMA-RAYS GENERATION WITH 3D 4-MIRROR CAVITY FOR ILC POLARIZED POSITRON SOURCE*

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Abstract

We are developing a ILC polarized positron source based on the laser-Compton scattering. We have already performed a photon generation experiment at the KEK-ATF using a Fabry-Perot type 2-mirror laser pulse stacking cavity [1]. The laser pulses are accumulated and their power was enhanced in the Fabry-Perot cavity. In order further improve performance of the laser power enhancement, a new three dimensional 4-mirror cavity is designed. In this article, we report status of the photon generation experiment.

INTRODUCTION

We are developing ILC polarized positron source based on the laser-Compton scattering. The generation of polarized positron by laser-Compton scattering was already verified [2], [3]. In this scheme, tens of MeV photons can be generated by collisions of laser photons with about 1 GeV electron beam. To increase the intensity of generated photons by laser-Compton scattering, increasing intensity of laser pulses and focusing at collision point by accumulation them in an optical cavity.

We already achieved laser intensity enhancement of 760 and laser waist size is 30μm (1σ) by the 2-mirror Fabry-Perot cavity. To increase the intensity of generated photons more, it is necessary to use high reflectivity mirrors and to make laser waist size smaller. However, it is difficult to achieve the improvement of enhancement and focusing performance at the same time with a 2-mirror Fabry-Perot cavity. Thus, to achieve the two requirement, now we developed three dimensional 4-mirror cavity.

4-MIRROR CAVITY

In order to increase the number of generated photons by laser-Compton scattering, it is necessary to increase the enhancement factor of the optical cavity by using the high reflectivity mirrors and make the laser waist size small. However, it is difficult to make laser waist size smaller than present waist size (30μm) with the 2-mirror Fabry-Perot cavity since it is sensitive to misalignment by its nature.

To reduce the laser waist size with 2-mirror cavity, cavity has to be concentric type ($\rho \sim L/2$), where ρ is the curvature radius of mirror and L is the length of Fabry-Perot cavity. This type is very sensitive to transverse mirror misalignment. In other words, it is unstable as a resonator. On the other hand, in 4-mirror cavity, it is possible to reduce the laser waist size with confocal type ($\rho \sim L$). The 4-mirror cavity consists of two plane mirrors and two concave mirrors, and the confocal type is insensitive to transverse misalignment. So the 4-mirror cavity can be stable with a small laser spot size.

However, in the 4-mirror cavity, effective focal length (f_t, f_s) are different in tangential plane and sagittal plane, and the difference causes astigmatism at the focal point. f_t and f_s are expressed as

$$f_t = \frac{\rho}{2}\cos\theta \tag{1}$$

$$f_s = \frac{\rho}{2\cos\theta} \tag{2}$$

where θ is reflection half angle of concave mirror. Because of this astigmatism, laser profile inside the 4-mirror cavity will be ellipse in principle.

To avoid the astigmatism, the cavity has to be three dimensional configuration. Our 3D 4-mirror cavity is shown in Fig. 1. 3D 4-mirror optical cavity generally have a circular polarization dependent property due to the rotation of the image in the three dimensional optical path. And a new method utilizing this property to obtain a differential signal can be lock an optical cavity at a resonance peak [4].

Circular Polarization Property

In a 3D 4-mirror cavity, only circular polarized light can be stored due to the rotation of the image in the three dimensional optical path. We lock a 4-mirror optical cavity at resonance peak using this property.

A linear polarization light was injected to the 4-mirror cavity. Then we measured the output of the differential amplifier while scanning the cavity length. The setup and signal observed is shown in Fig. 2, Fig. 3. The top line is the signal of the photo-diode that measured the transmission.

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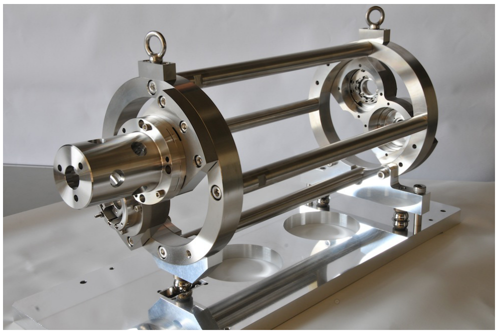

Figure 1: 3D 4-mirror cavity.

And it shows the points that the cavity's resonance of right and left-handed polarized light. The bottom line is output of the differential amplifier. The signal crossed zero at the point of resonance. The circular polarization peak can be switched with this differential signal. It means the polarization of the generated photons by laser-Compton can be switched quickly.

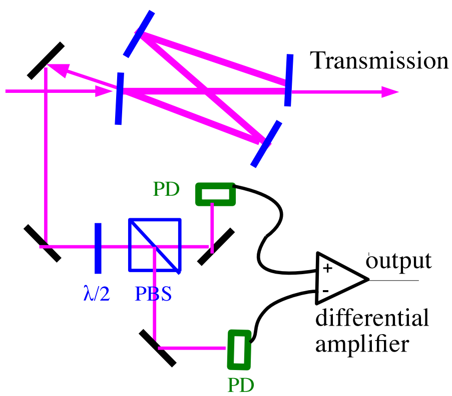

Figure 2: Setup to obtain the differential signal.

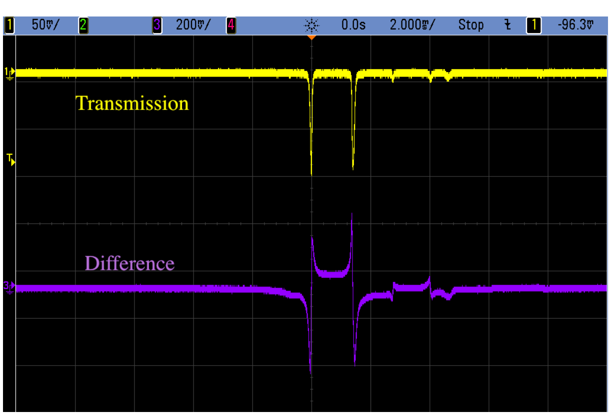

Figure 3: Signal of transmission and difference.

Focusing Property

Focusing property of three dimensional 4-mirror cavity is depend on a geometry of mirrors. Schematic of our 3D 4-mirror cavity is shown in Fig. 4. The configuration of this 4-mirror cavity is slightly twisted. Because, to control the effect of the rotation of the image in the three dimensional optical path.

The calculation of laser spot size at collision point is shown in Fig. 5. In this calculation curvature radius of mirror, ρ is 420mm. The laser profile in a 3D 4-mirror cavity is generally ellipse on a small spot size. According to calculation, our 3D 4-mirror cavity can be achieved $\sim 15\mu m(1\sigma)$ with almost circle laser profile.

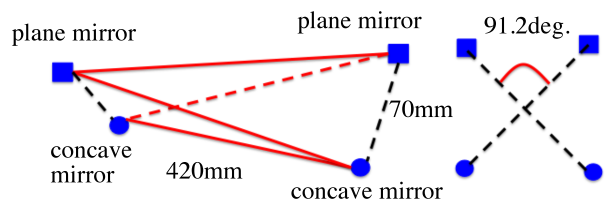

Figure 4: Schematic of the three dimensional 4-mirror cavity.

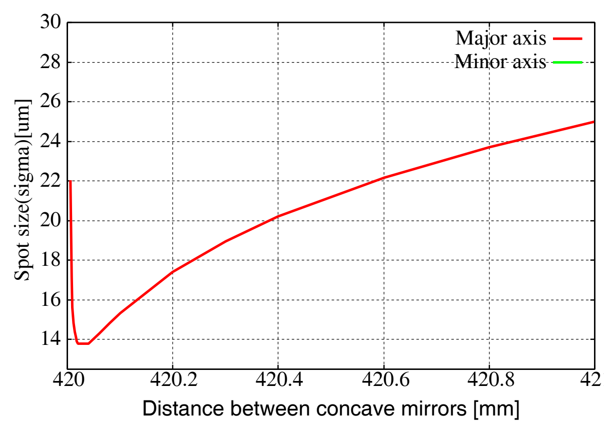

Figure 5: Spot size at collision point.

EXPERIMENT WITH THE 3D 4-MIRROR CAVITY

We performed gamma-rays generation experiment by laser-Compton scattering at the KEK-ATF. The crossing angle of the laser pulses and the electron beam is 14°, which determined the maximum energy of the Compton gamma at 28MeV. The energy of the gamma-rays was discriminated by the slit placed between the laser-electron interaction point and the gamma-ray detector. As a result, the energy of gamma-rays detected in the detector is 19-28MeV with the average of 24.5MeV. The parameters of the electron beam in the ATF DR are in Table 1.

We installed the 4-mirror cavity in the north straight section of ATF damping ring in the summer of 2011. The

Table 1: Parameters of ATF DR

Description	Value
Electron energy	1.28 GeV
Beam intensity	1×10^{10} e / bunch
Bunch spacing	5.6 ns
Beam size (σ_x / σ_y)	100 / 10 μm
DR revolution	2.16 MHz

optics and the 4-mirror cavity are placed on the movable table. We scanned the position of the optical cavity relative to the electron beam to find the optimum position. Then, the timing of laser pulses relative to electron bunches was adjusted by changing relative phase between the ATF master oscillator and laser pulses. The parameters of our laser system are in Table 2.

Table 2: Parameters of Laser System

Description	Value
Laser wavelength	1064 nm
Laser frequency	357 MHz
Laser power	10 W (28 nJ/ pulse)
Finesse of 4-mirror cavity	5000
Average power stored in cavity	700 W
Crossing angle	14 deg.

RESULT

The laser position dependence of the number of gamma-rays and energy distribution at the optimum position is shown in Fig. 6, Fig. 7.

In the vertical position scanning plot, $\sigma = 17\mu$m. It is convolution of electron beam and laser spot size. At this time, electron beam size was $10 \pm 1\mu$m and expected laser size is 15μm. So the width of vertical scan plot is reasonable.

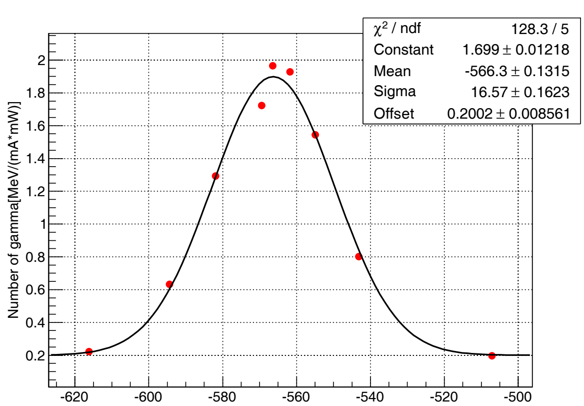

Figure 6: Vertical laser position scan.

And we detected 780MeV gamma-rays per crossing with 5 bunches operation. The average energy of 1γ is 24.5MeV, it is ~32 photons per crossing. Since the revolution of the electron bunches in the ATF DR is 2.16MHz, it can be estimated that $\sim 7 \times 10^7$ photons are generated per second.

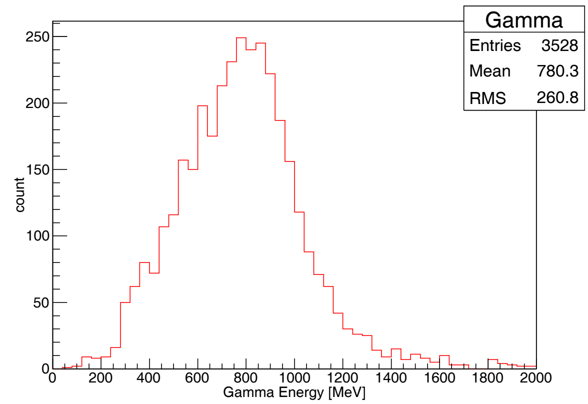

Figure 7: Energy distribution of gamma-rays with 5 bunches operation.

SUMMARY

In order to increase the number of generated photons by laser-Compton scattering, we installed 3D 4-mirror optical cavity in the ATF DR and performed gamma-rays generation experiment using that cavity. Then we detected ~32 photons per crossing with 5 bunches operation.

Laser spot size at collision point seems to be achieved design value. On the other hand, stored laser power in the 4-mirror cavity has to be improve. For example, we need more coupling efficiency (currently, it is ~0.5).

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