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A fast profile monitor with scintillating fiber hodoscopes for high-intensity photon beams

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ABSTRACT

A fast beam-profile monitor has been developed for high-energy photon beamlines at the Research Center for Electron Photon Science, Tohoku University. The position of the photon converted into an electron–positron pair in a 0.5 mm-thick aluminum plate is measured with two hodoscopes made of scintillating fibers with cross-sections of $3 \times 3\ \text{mm}^2$. Events in which charged particles are produced upstream are rejected with a charge veto plastic scintillator placed in front of the plate, and pair-production events are identified with a trigger plastic scintillator placed behind the plate. The position is determined by a developed logic module with a field-programmable gate array. The dead time for processing an event is 35 ns, and a high data acquisition efficiency ($\sim 100\%$) can be achieved with this monitor for high-intensity photon beams corresponding to 20 MHz tagging signals.

1. Introduction

A tagged photon beam with an energy of around 1000 MeV is a powerful tool for revealing the structure of hadrons [1] and to investigate their medium modification in a nucleus [2], both of which are hot topics in the field of nuclear physics. For this purpose, two GeV-tagged photon beamlines were constructed at the Research Center for Electron Photon Science (ELPH), Tohoku University. A magnetic spectrometer, NKS2 [3], which detects charged particles, is placed on the first beamline [4], and an electromagnetic calorimeter, FOREST [5], which mainly detects photons, is placed on the second beamline [6]. In both beamlines, bremsstrahlung photons are generated by inserting a thin carbon wire with a diameter of 11 μm into circulating electrons in the electron synchrotron [7], which has been renamed the Booster STorage (BST) ring (previously known as the STretcher Booster (STB) ring) due to the removal of its slow-extraction function after the earthquake in 2011. The energy of each photon is tagged by measuring the momentum of its corresponding post-bremsstrahlung electron [4,6]. A profile monitor giving a two dimensional intensity map of the photon beam is an important device for optimizing the photon beam direction and studying the properties of the circulating electron beam with the wire inserted [8].

Two types of the measurement of the photon beam profile have been made at ELPH. One is an analog-type measurement using a film or a charge-coupled device (CCD) video camera. A photon beam spot is taken with a Polaroid or Instax film which is placed behind a lead plate with a thickness of 5 mm. The plate is used as a radiator to produce secondary particles namely electron–positron pairs and associated X-rays. To reduce the measurement time, a higher sensitivity of the film is desired (a few seconds for ISO3000). At present, the highest sensitivity of an available instant

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film is ISO800. The beam spot is also taken with a video camera in a way similar to that described in Ref. [9]. When a photon irradiates a 3 mm-thick tungsten plate, the secondary particles resulting from the interaction in the plate make light on a fluorescent screen, a phosphor panel DRZ-High (Mitsubishi Chemical Corporation). The light is delivered to the camera through a reflective mirror and an image intensifier (Hamamatsu Photonics C4273). The dynamic range of the measured intensity is limited by the film or camera performance. The position-resolution is limited by the shower development through a thick converter for a short time measurement. The most serious problem is that the linearity of the intensity map measured with a film or a CCD camera is not guaranteed due to reciprocity law failure characteristics or saturation effects. Therefore, an alternative profile monitor with scintillating fiber hodoscopes has been developed. The detector and its readout system are described in Sections 2 and 3, respectively. The typical measured profiles are presented in Section 4.

2. Detector for the photon profile measurement

A method to measure the intensity map of the photon beam is discussed in this section. The detector setup is described in Section 2.1. The uniformity of the output signal from the trigger plastic scintillator and the effect of the secondary particle spread to the measured profile are described in Sections 2.2 and 2.3, respectively.

2.1. Detector setup

The detector system for the profile measurement consists of a plastic scintillator (PS) for charge veto, an aluminum plate converter with a thickness of 0.5 mm, a trigger PS, and two layers of scintillating fiber (SciFi) hodoscopes. Fig. 1 shows a schematic view of the current detector system for the photon beam profile measurement. Several versions have been tested for the trigger PS components. In the original version [6], two trigger PSs were used and the thickness of three PSs measured 5 mm each. To reduce the counting rate of the detector system, a single trigger PS is used and the thicknesses of charge and trigger PSs have been reduced to 1 mm, giving the singles rate of the trigger PS less than a few MHz for stable operation at the normal intensity of the photon beam. Each hodoscope consists of 16 SciFis with cross-sections of 3×3 mm^2, and the first and second layers determine the y and x positions, respectively. The trigger condition of the data acquisition is described as

$$\overline{[\text{charge PS}]} \otimes [\text{trigger PS}]. \tag{1}$$

The charge PS signal rejects the events in which charged particles are produced upstream. The discriminator thresholds for producing logic signals of the charge and trigger PSs are set to $0.5V_{\text{mip}}$ and $1.5V_{\text{mip}}$, respectively, where V_{mip} is the average pulse height of the minimum ionizing particles. A fraction ($\sim 0.43\%$) of the incident photon beam is converted by the aluminum plate into electron–positron pairs, which pass through the trigger PS and the hodoscopes. The reconstruction of the photon incident positions is based on the hit SciFis in the hodoscopes oriented along x and y axes. Since the width of the delivered photon beam is expected to be ~ 8 mm, the resolution of the position determination with this detector setup is sufficient. In the following analysis, we require only one hit SciFi per layer.

The charge and trigger PSs are connected to a photomultiplier tube (PMT) Hamamatsu H7195MOD. In addition to the supplied voltage for each PMT, power supply boosters are used in place of the voltage divider resisters at the last three stages to allow stable operation for high-intensity beams. The 16 SciFis in each layer are connected to a 4×4 multi-anode metal-packaged PMT Hamamatsu H6568-10MOD. The detector itself can be used without a gain drop for the tagged photon intensity of 10^7 Hz [6], giving single rates of 1.5 and 2.5 MHz for the charge and trigger PSs, respectively, and a trigger rate of 0.63 MHz.

2.2. Uniformity of the charge and trigger PS outputs

To obtain the beam profile in real time, a simple analytical scheme is desired. Thus, the uniform energy response of the charge and trigger PSs with respect to the incident position is important for minimizing the systematic uncertainty of the measured profile. In previous research, the trigger PS with a size of 55×55 mm^2 was connected to two H7195 PMTs arranged in an L-formation [10]. The signal `Gv` of the charge PS with a size of 70×70 mm^2 was generated with PMT connected at the right side. The signals `Gt1` and `Gt2` of the trigger PS came from the two PMTs connected at the right and upper sides, respectively. Fig. 2 shows the prototype setup for the trigger and charge PSs, and the definition of the coordinates. The $+x$ is defined as the right side in the downstream view. The position uniformity of the energy response of the charge and trigger PSs was investigated using minimum ionizing particles through the detector.

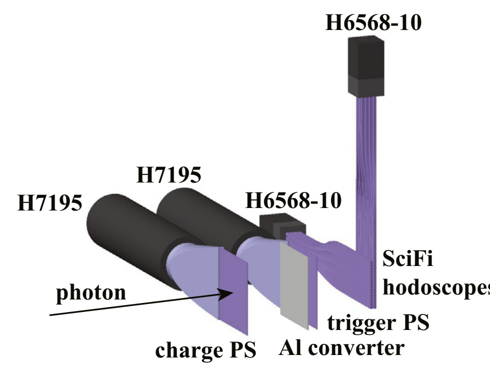

Fig. 1. Schematic view of the current detector system for the photon beam profile measurement. It consists of two plastic scintillators (PSs) with thicknesses of 1 mm. A 0.5 mm-thick aluminum plate is used as an e^+e^- converter. Two scintillating fiber (SciFi) hodoscopes are placed downstream of the PSs. Each hodoscope has 16 SciFis with cross-sections of 3×3 mm^2, and two layers of SciFi hodoscopes cover the active area of 48×48 mm^2.

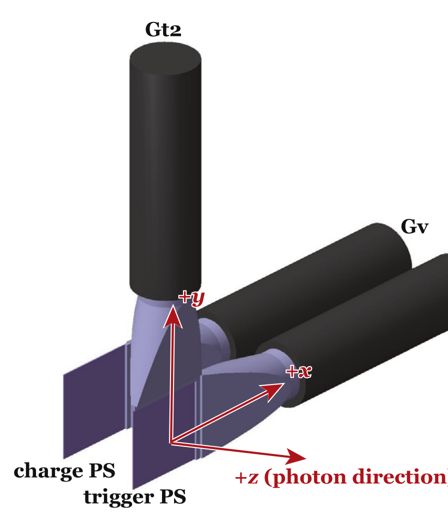

Fig. 2. Prototype setup for the trigger and charge PSs, and definitions of the coordinates. The charge PS is connected to a PMT at the right (`Gv`), and the trigger PS is connected to two PMTs at the right (`Gt1`) and at the top (`Gt2`). The $+x$ axis is defined as the right side in the downstream view.