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Imaging high energy photons with PILATUS II at the tagged photon beam at MAX-lab

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ABSTRACT

In photonuclear experiments precise location of the photon beam relative to the experimental sample is critical. Previously used techniques such as using photographic film to identify the position, intensity and centroid of the beam is time-consuming and a faster method is required. PILATUS is a single-photon-counting pixel detector developed at the Paul Scherrer Institute (PSI), Switzerland. It is a silicon-based, two-dimensional detector with a large dynamic range and zero readout noise. Designed as an X-ray detector, its optimal quantum efficiency is between 3 and 30 keV. This paper reports measurements carried out at the MAX-lab tagged photon facility in Lund, Sweden. The beam endpoint energy of approximately 200 MeV is far above the designed optimal energy detection range of PILATUS, and provides a critical test of the use of PILATUS under high energy conditions.

The detector was placed in the photon beam and images were taken both downstream of other experiments, and in close range of a 19 mm collimator. The successful measurements demonstrate the versatility and robustness of the detector and provide an effective way of quickly and accurately monitoring beam position and profile in real time.

1. Introduction

In photonuclear experiments knowledge of beam size, intensity profile and position are important in determining the reliability of experimental results. For example if the target is not fully illuminated or if the beam's spatial intensity profile is not centred, the experimental data can be seriously compromised. Changes in beam characteristics must be known in order to make precise measurements. A beam profile monitor improves the accuracy and efficiency in data-taking during photon tagging experiments with low cross-sections.

One method of obtaining details of the photon beam such as its location or its intensity centroid is by recording an image on photographic film. However, the analysis of these pictures can be imprecise and not necessarily systemised. The process is also time consuming and disruptive to prolonged beam stability. An alternative method should be found.

Alternative systems of photon beam monitoring include blade-type monitors that analyse the photoelectric response from metal blades placed at the edges of a beam or in the beam fringes [1], and CCD-camera-based monitor systems [2]. A single-photon-counting detector system would provide an immediate visual image of the beam spot free from readout noise, provided it could operate under a high energy photon flux. This paper reports on measurements of the photon tagging beam at MAX laboratory in Lund, Sweden, using a single-photon-counting detector, the PILATUS 100K module.

2. Experimental setup

2.1. The PILATUS detector

The PILATUS detector is a single-photon-counting X-ray detector developed at the Paul Scherrer Institute for use at the Swiss Light Source. It is produced by DECTRIS in three sizes, the PILATUS 100K, the PILATUS 2M and the PILATUS 6M. For this experiment a PILATUS 100K module was used.

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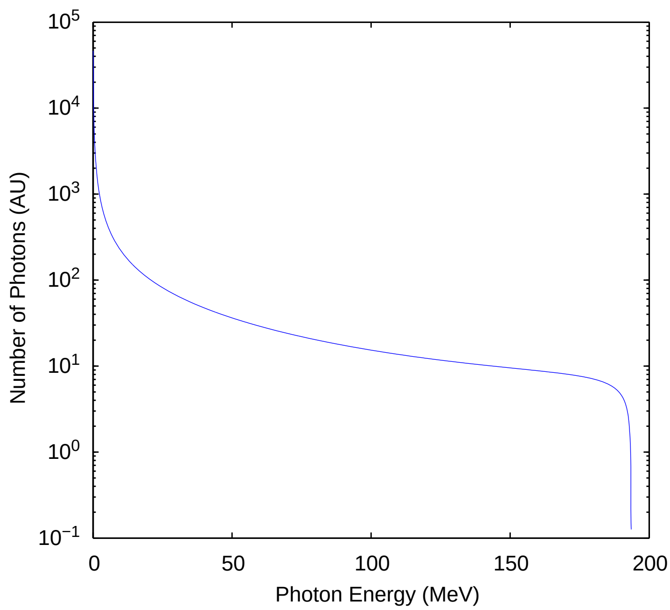

Fig. 1. Theoretical bremsstrahlung count spectrum from 194 MeV electrons incident on a 300 μm aluminium target. While only photons from 167.5 to 179.5 MeV are tagged by the magnetic spectrometer, the beam consists predominantly of photons lower than the tagged energy. This has implications for PILATUS which has optimal quantum efficiency at 3–30 keV.

The PILATUS 100K module has a sensitive area of 85.3 mm × 34.1 mm consisting of an array of 16 detector chips in an 8 × 2 array. This provides an array of 487 × 195 (94 965) pixels, each of size 172 μm × 172 μm. Connected to each pixel is a readout system consisting of a preamplifier, a pulse shaper, a comparator and a 20-bit counter, providing a 1 MHz per pixel per second count rate capability, with a ~2 ms chip-parallel readout time. The intrinsic dead time of the detector is ~10 ns the time for which the signal must remain below the threshold level in order to resolve two separate counts. The readout chips are indium bump-bonded to a 300 μm Hamamatsu silicon sensor consisting of p+ implants embedded in a high resistivity (~8 kΩ cm) n bulk. The system is reverse biased to 120 V. Physically, the entire module is 275 × 146 × 85 mm in size [3,4].

The data acquisition system for the module uses a PCI card and is controlled from a PC using TVX, PILATUS' user interface. For the experimental work carried out at MAX-lab, the PC remained in the experimental hall and was controlled through a remote VNC interface. Designed to be radiation tolerant using UMC[1] 250 nm technology, the detector incurred no detectable damage in the experiments under high energy beam flux.

2.2. MAX-lab tagged photon beam

The electron source for the bremsstrahlung photon beam used in MAX-lab's nuclear hall is the MAX I storage ring operating in pulse-stretching mode. An initial 200 MeV electron pulse from a LINAC is injected into MAX I with a frequency of 10 Hz and stretched over time to maximise the duty cycle of the extracted electron beam. The electron beam is extracted from MAX I to the nuclear hall where it strikes a bremsstrahlung radiator chosen to suit the scheduled photonuclear experiments. The bremsstrahlung photons then are collimated to provide the photon beam while the electrons are magnetically swept into the electron dump [5]. The theoretical bremsstrahlung spectrum for our experiment is plotted in Fig. 1 [6].

[1] UMC: United Microelectronics Corporation, Taiwan.

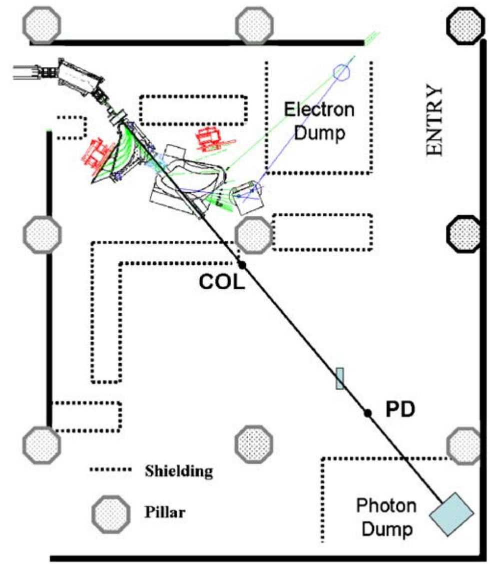

Fig. 2. Nuclear experimental hall: positions PD and COL denote the acquisition sites: photon dump and collimator.

Table 1
Experimental set up configurations.

Configuration	PILATUS position	PILATUS cover	Lead	Other
A	PD	Off	~1 cm	–[a]
B	COL	Off	None	–
C	PD	On/off	5 mm/none	–[b]
D	PD	Off	None	–

PD and COL refer to position denoted in Fig. 2. The PILATUS cover is a 2.5 mm thickness of aluminium affixed on the detector, covering the sensitive area. Measurements included insertion of lead sheets at various distances from the detector face, described in detail in main text.
[a] Pb covering left half of the sensitive area.
[b] Series of four set up configurations with and without two converters—the PILATUS cover and 5 mm of lead.

2.3. Measurements

The PILATUS detector was set up in the nuclear experimental hall and images were taken at two detector positions as marked in Fig. 2: near the photon dump (PD), downstream of two target experiments; and 40 cm from the 19 mm beam collimator (COL). The bremsstrahlung radiator on the opposite side of the collimator was a 300 μm thickness of aluminium. Measurements involved the insertion of converters at various distances in front of the detector including different thicknesses of lead and the PILATUS protective cover, a 2.5 mm thickness of aluminium affixed to the front of the detector to cover the sensitive area. Table 1 summarises the experimental configurations for the measurements.

3. Experimental tests and results

3.1. Beam spot measurements

In order to image the beam spot, the detector was placed in Configuration A: at the PD position with 1 cm of lead inserted in