Silicon avalanche-photodiode linear array detector with multichannel scaling system for pulsed synchrotron X-ray experiments

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1. Introduction

We developed a silicon avalanche-photodiode (Si-APD) linear array detector to be used for pulsed synchrotron X-ray experiments. The Si-APD linear array (S5343-9158, Hamamatsu Photonics) consists of 64 pixels (pixel size: 100 × 200 μm^2) with a pixel pitch of 150 μm and a depletion depth of 10 μm (**Fig. 1**). An ultra-fast frontend circuit allowed each pixel a high output rate >10^7 cps for the synchrotron X-ray beam. Counting pulses over continuous 1024 time bins for every one-nanosecond, the no dead-time sampling was realized in each pixel by high-performance integrated circuits. The multichannel scaling method (**Fig. 2**) enabled us to record a time spectrum at each pixel with a time resolution of 1.4 ns (FWHM) while measuring count distribution along the linear array. This method was successfully applied to nuclear forward scattering on ^{57}Fe.

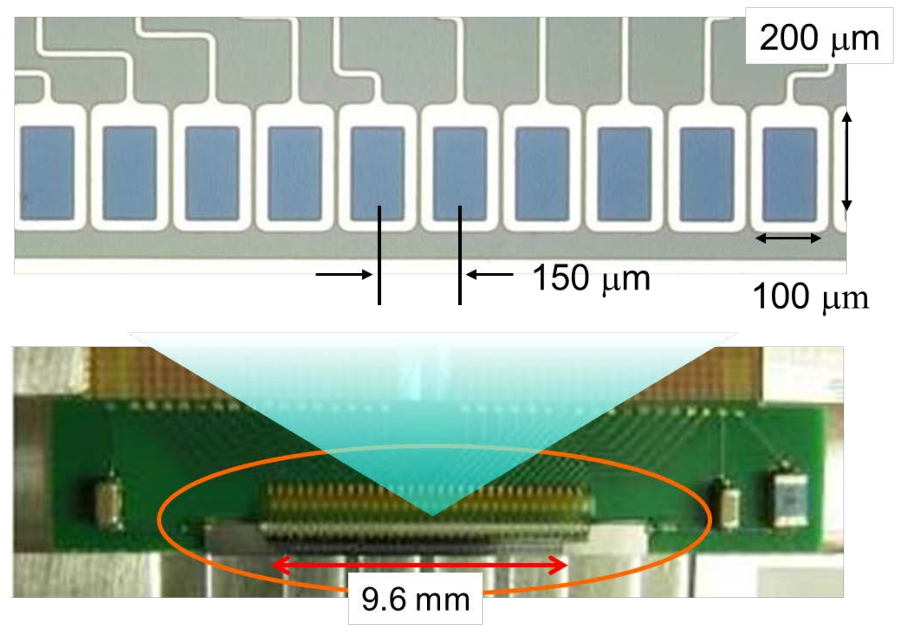

Fig. 1 **64 pixel Si-APD linear array (Hamamatsu Photonics S5343-9158)**

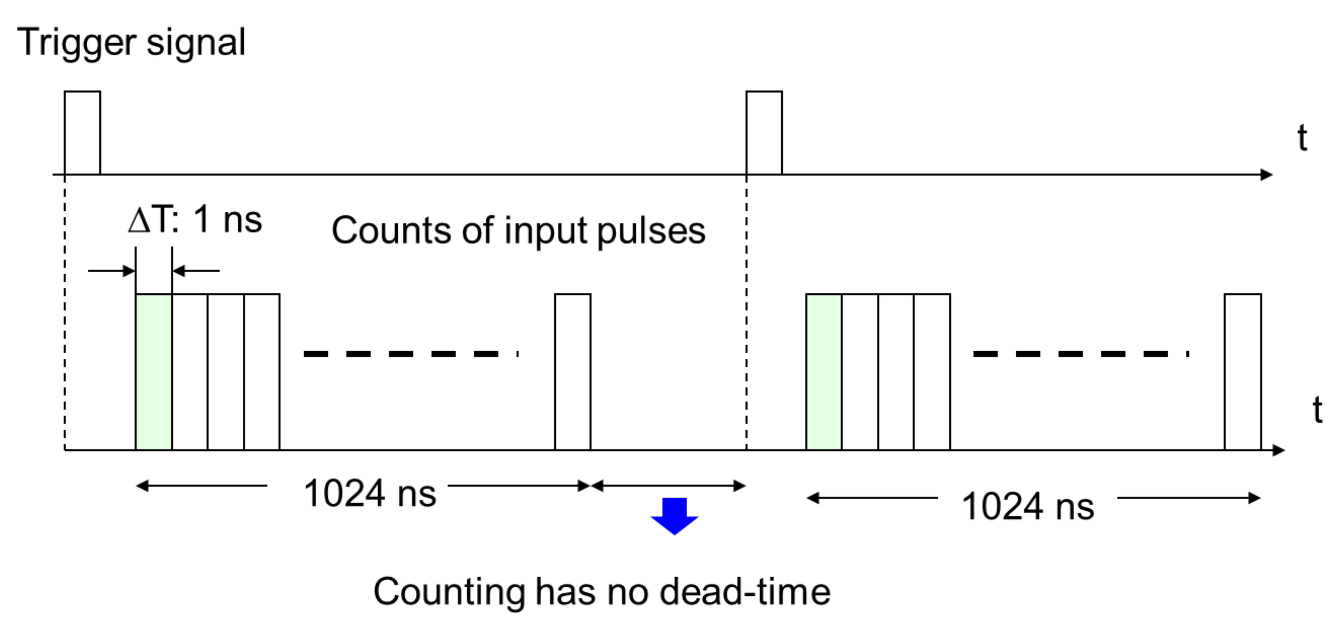

Fig. 2
Principle of Multichannel scaling

2. A 64 pixel detector system

We fabricated an X-ray detector using a 64-pixel Si-APD linear-array device and an ultrafast pulse processing circuit. **Figure 3** shows a photograph of the inside of the detector case. An ultrafast frontend application-specific integrated circuit (ASIC) was designed in the 0.8 μm BiCMOS technology to process a nanosecond-width pulse from each pixel of the Si-APD.

3. Performance of the Si-APD linear-array detector system

The properties of the detector system were investigated at beamline BL-14A of Photon Factory, KEK, using a synchrotron X-ray beam. An 8-keV X-ray beam profile was recorded by scanning the detector position at every 0.1mm along the vertical direction. Count rates >2.2 × 10^7 s^{-1} per pixel were observed at the peak around pixel No. 42, as shown in **Fig. 6.** The time resolution of the system was measured by using the single-bunch peak profile, and was determined to be 1.4±0.1 ns (FWHM) (**Fig. 7**).

A count distribution for all the 64 pixels was measured with the 14.4 keV beam of 6 μm (FWHM) in diameter, normal to the detector window, while scanning the detector in the horizontal direction by a step of 0.01 mm per one second. **Figure 8(a)** shows peaks of pixel No. 30-40 and the FWHM was 0.13±0.01 mm at No. 32. The detection efficiency ε was 1.3±0.2% for the Si 7.2 μm depletion layer. When the detector was rotated 12° to the incident beam, the peak width reduced to 0.03±0.01 mm by using a step of 0.002 mm and ε = *4.2*±0.2% was obtained (**Fig. 8(b)**).

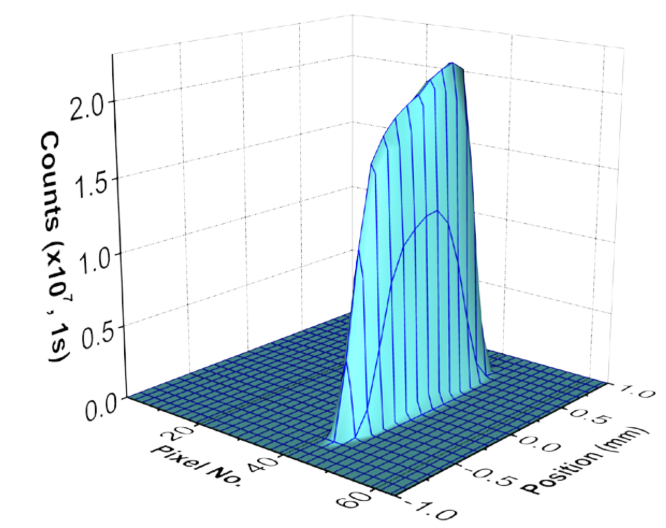

Fig. 6 **8-keV beam profile recorded by the detector**

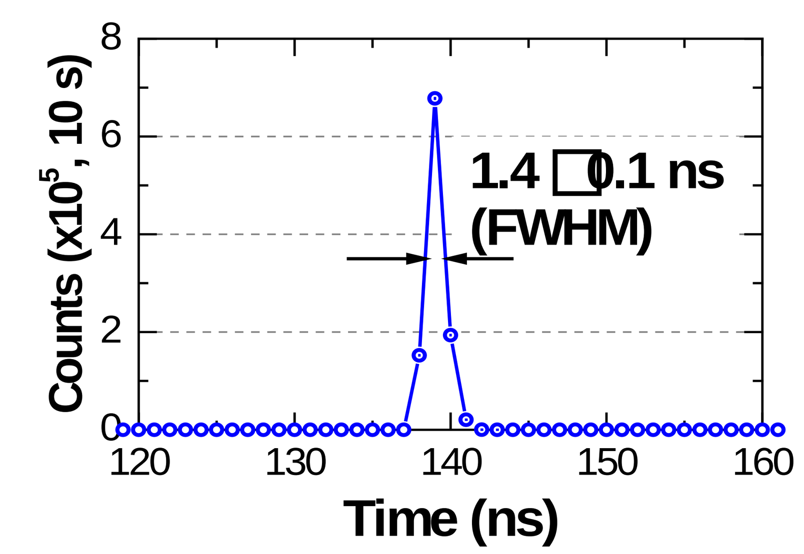

Fig. 7 **Time spectrum measured at 8 keV**

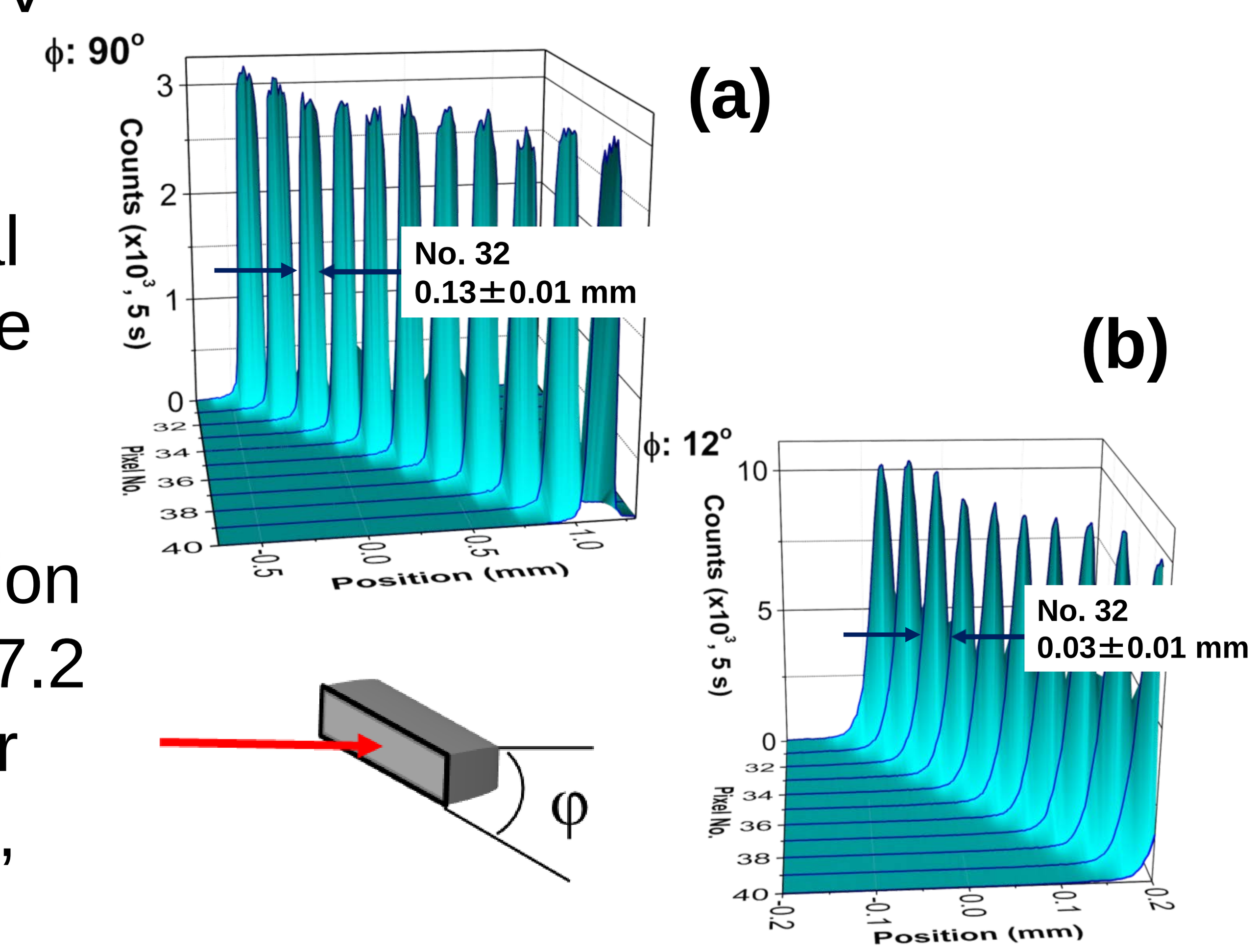

Fig. 8 **Count distribution at 14.4 keV: (a) φ = 90° and (b) φ = 12°.**

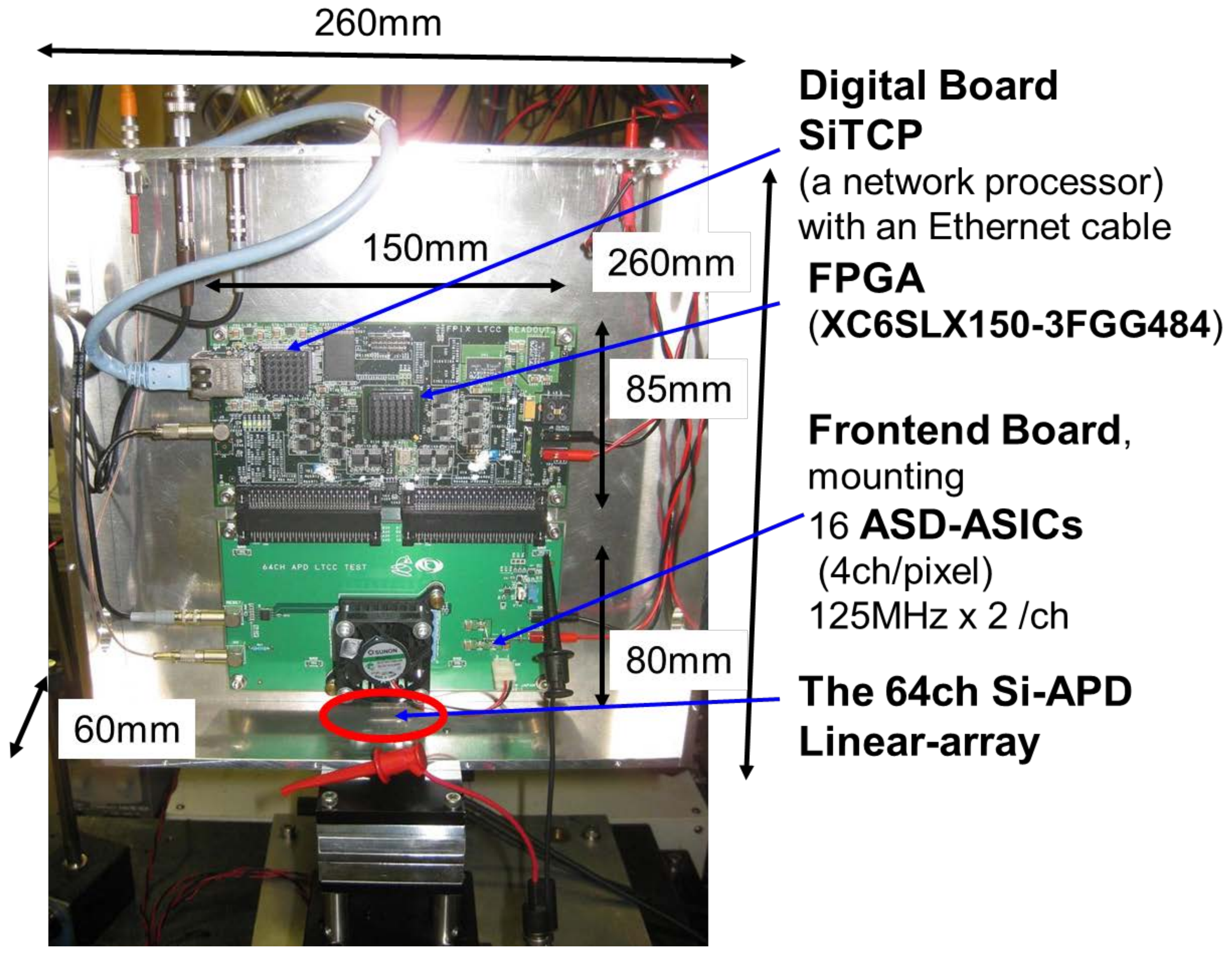

Fig. 3 Photograph of the frontend and digital boards. The ASD-ASICs and a FPGA chip are mounted on the boards.

The architecture block diagram of the ASIC is indicated in **Fig. 4**. On the digital board, one chip of field-programmable gate arrays (FPGA, Xilinx Spartan-6) was used to detect a pulse timing and to count the pulses with each channel having a 36-bit count depth in the memory. The spec of multichannel scaling is summarized in **Table 1**.

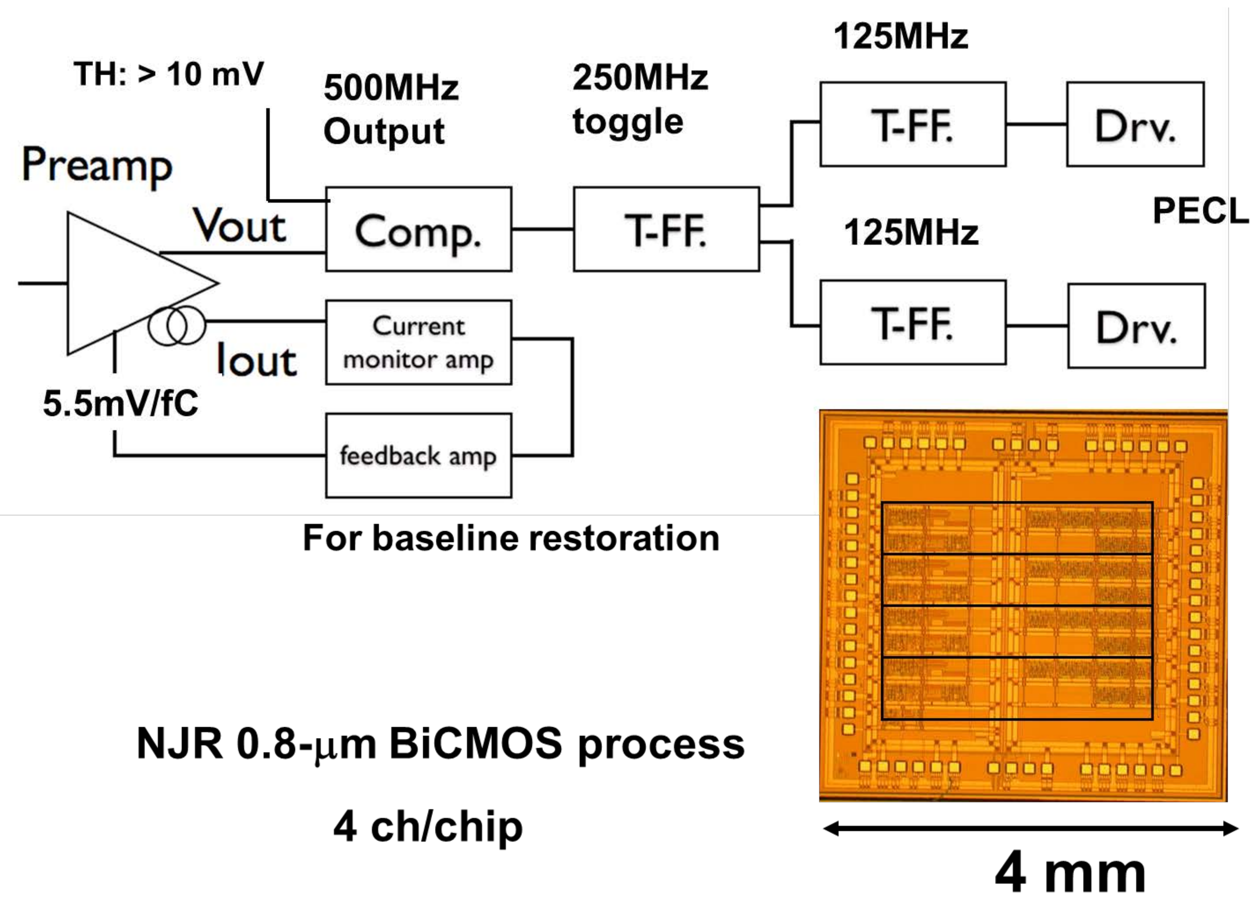

Fig. 4 The architecture block diagram of the ASIC

Spec of Multichannel scaling	
Number of time bins	1024 (count density: 36 bits per channel)
Time bin (ΔT):	1 ns to 167 ms
measuring time	2 μs to 4295 s

Table 1 Spec of the multichannel scaling system

The detector was mounted on motorized stages for the horizontal and vertical directions, which were controlled by an intelligent driver through a LabVIEW program installed on a PC. The driver, DAQ-WS and PC were connected via a local Gigabit Ethernet network (**Fig. 5**).

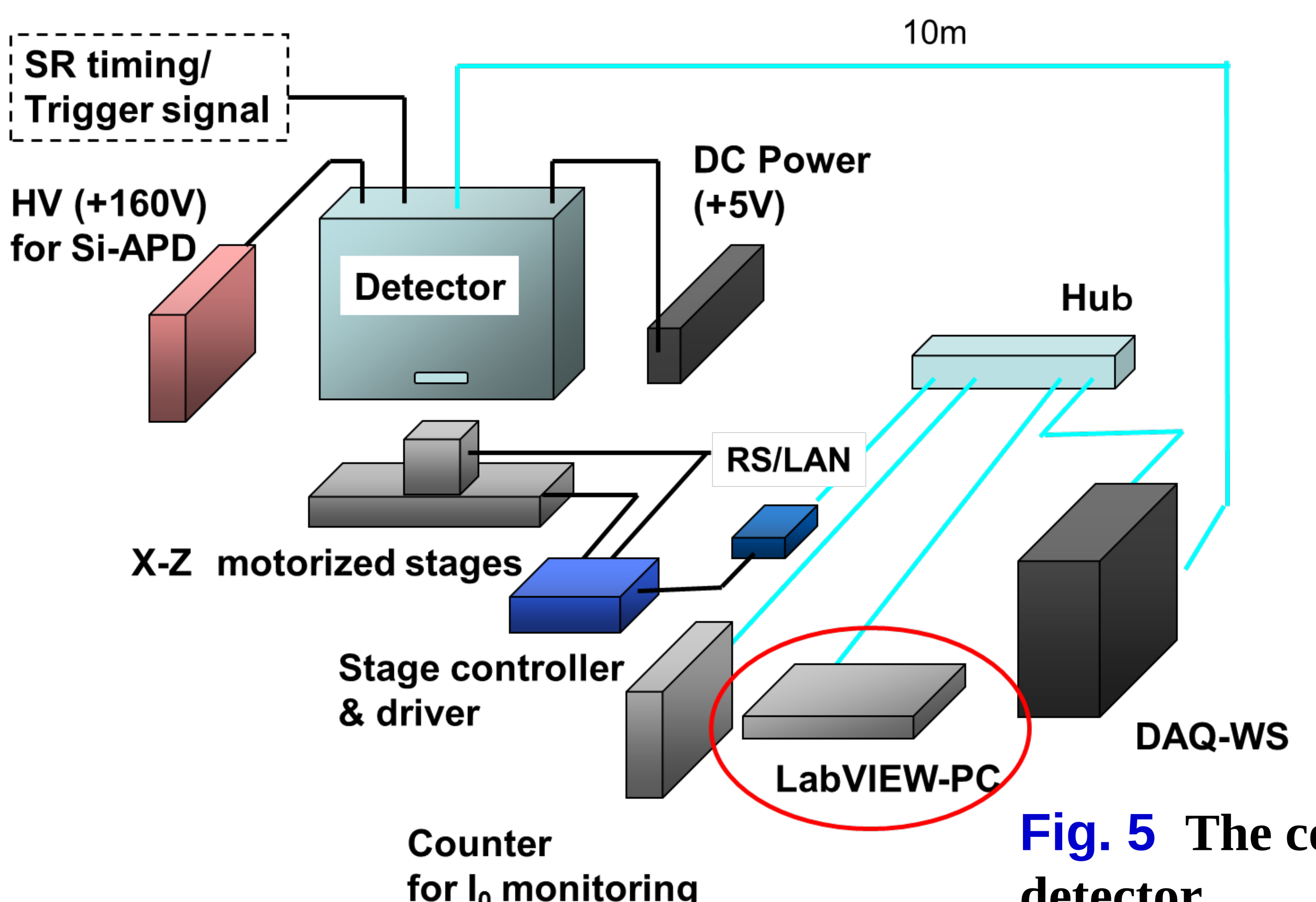

Fig. 5 The control system of the detector

4. Application to Nuclear Resonant Scattering experiments

We applied the detector system to the nuclear resonant scattering experiment on ^{57}Fe (the 1st excited level: 14.413 keV, half-life: 98 ns) using synchrotron radiation. The experimental setup at beamline BL09XU of SPring-8, is shown in **Fig. 9**. The detector system counted the resonant γ-ray photons emitted from hyperfine splitting levels which were generated depending on surrounding electronic states.

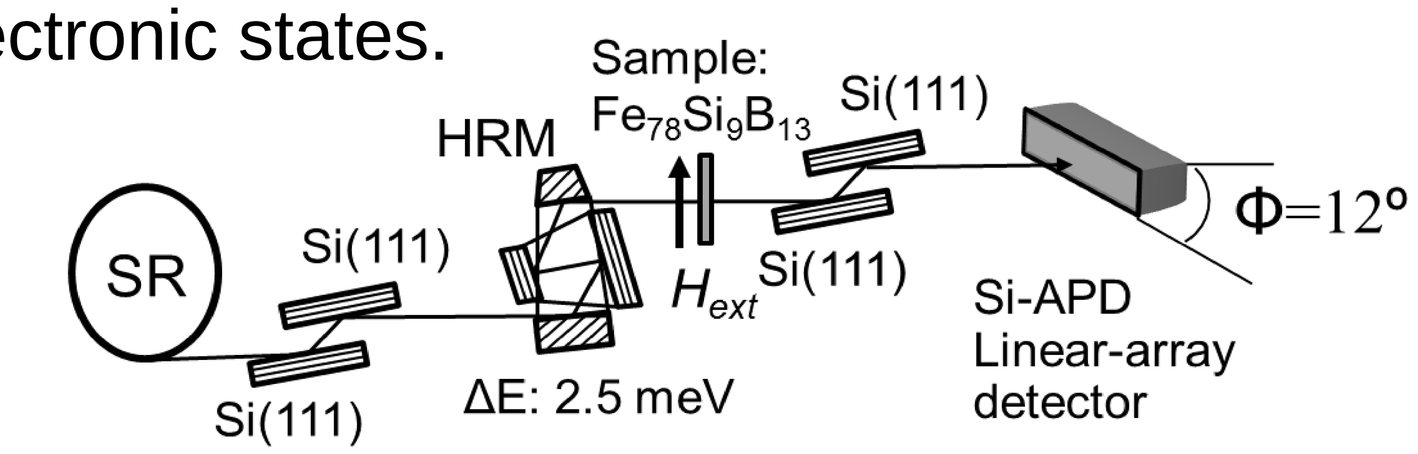

Fig. 9 Experimental setup for Nuclear Forward Scattering at BL09XU, SPring-8

While increasing temperature at a sample of $Fe_{78}Si_9B_{13}$ amorphous alloy, time spectra were measured at room temperature, 299 K and at 830 K with the linear-array system, as shown in **Fig. 10**. The observed peaks of *t*>10 ns at 299 K almost disappeared at 830 K. It is known as the result on this amorphous alloy that magnetic properties change by crystallization of α-Fe(Si), Fe_2B in the glass structure at temperatures >803 K. The detector system could successfully obtain magnetic information on the sample at each temperature in each relatively short period of 600 s.

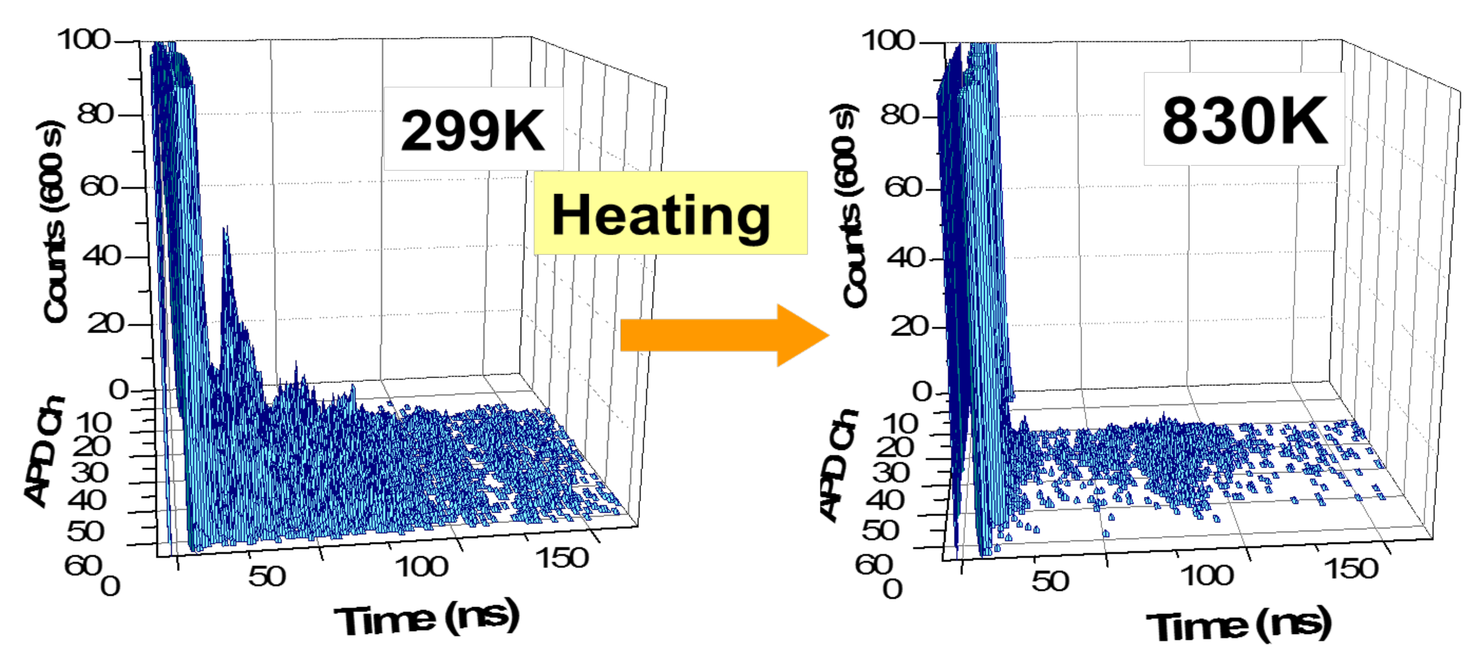

Fig. 10 Time spectra of NFS on $Fe_{78}Si_9B_{13}$ amorphous alloy, observed in real time while increasing temperature from 299 K to 830 K

5. Summary

We have successfully developed a Si-APD linear array detector and multichannel scaling system with 1 ns sampling for pulsed synchrotron X-ray experiments. The system demonstrated a time resolution of 1.4 ± 0.1 ns (FWHM). The nuclear forward scattering (NFS) measurements were executed for ^{57}Fe with the detector system. Time spectra were obtained for the NFS at each pixel directly related to a position on the sample. In the future, we will improve the time resolution of the multichannel scaling to 0.7 ns (FWHM) with 0.5 ns sampling in the near future.