Study on the application of SiPM to γ ray and charged particle measurement using scintillation crystals

Sunghan Bae[1*], Sunghoon Ahn[1], Soomi Cha[1], Kevin Insik Hahn[1], Jongwon Hwang[1], Dahee Kim[1], Yung Hee Kim[1], Chaeyeon Park[1,2] and Xesus Pereira López[1]

[1]Center for Exotic Nuclear Studies, Institute for Basic Science (IBS), Daejeon 34126, Republic of Korea
[2]Department of Physics, Ewha Womans University, Seoul 03760, Republic of Korea

Characteristics of SiPM

- **Silicon Photo Multiplier**
  - High density pixel array (~ 10^2 pixel/mm²)
  - Single-photon avalanche photodiode (Geiger mode)
  - Fast rise time (~ ns)
  - Compact size (< 1 cm² per SiPM)
  - Highly resistant to magnetic field

Advantages over PMT

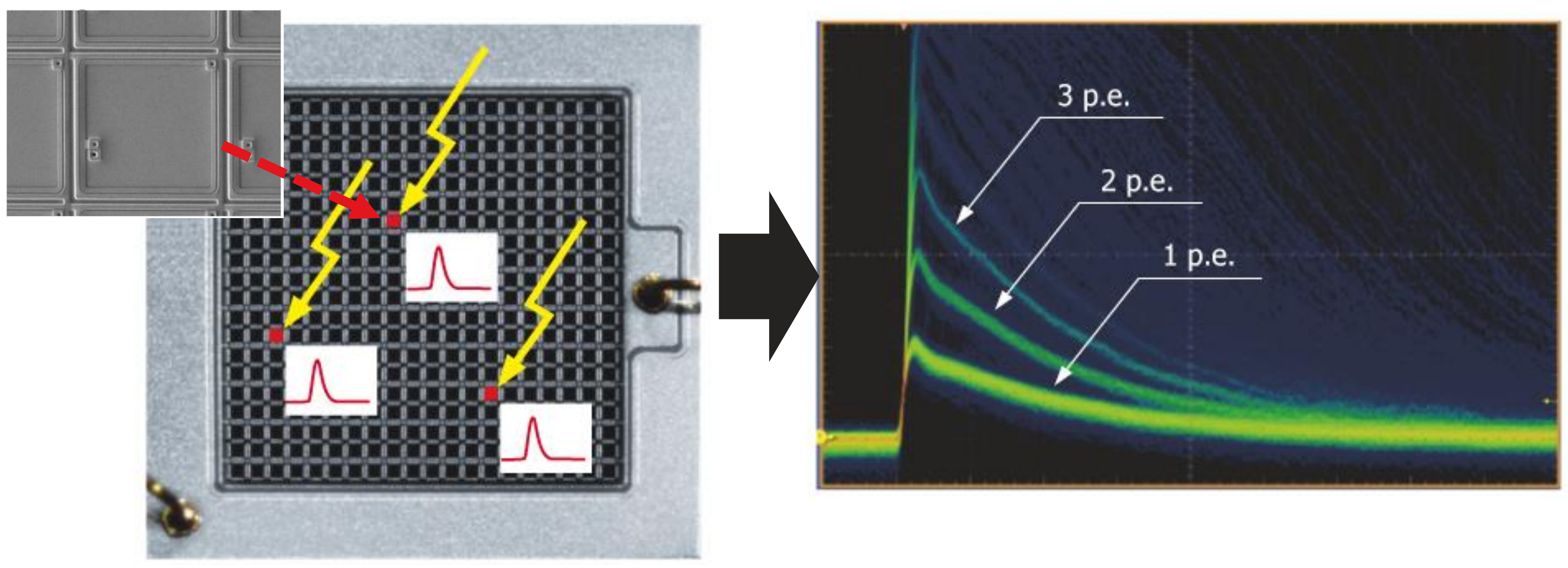

Figure 1. A schematic drawing for the structure and output signals of SiPM, taken from Ref. [1], [2].

Test Assembly

- **SiPM**
  - S13360-6050PE MPPC from HAMAMATSU
  - 6×6 mm², 14400 pixels/MPPC, 50 µm pixel-pitch
  - $\lambda_{response}$: 320 ~ 900 nm (λ_{peak}: 450 nm), $V_{operation}$: 56 V (±5)
- **Scintillators**
  - GAGG:Ce crystal ($Gd_3Al_2Ga_3O_{12}$:Ce) 40×40×5, 40×40×3 mm³, λ_{peak}: 520 nm, τ_{decay}: 0.2 µs, ~50k photons/MeV
- DAQ with **CAEN V1730SD digitizer**

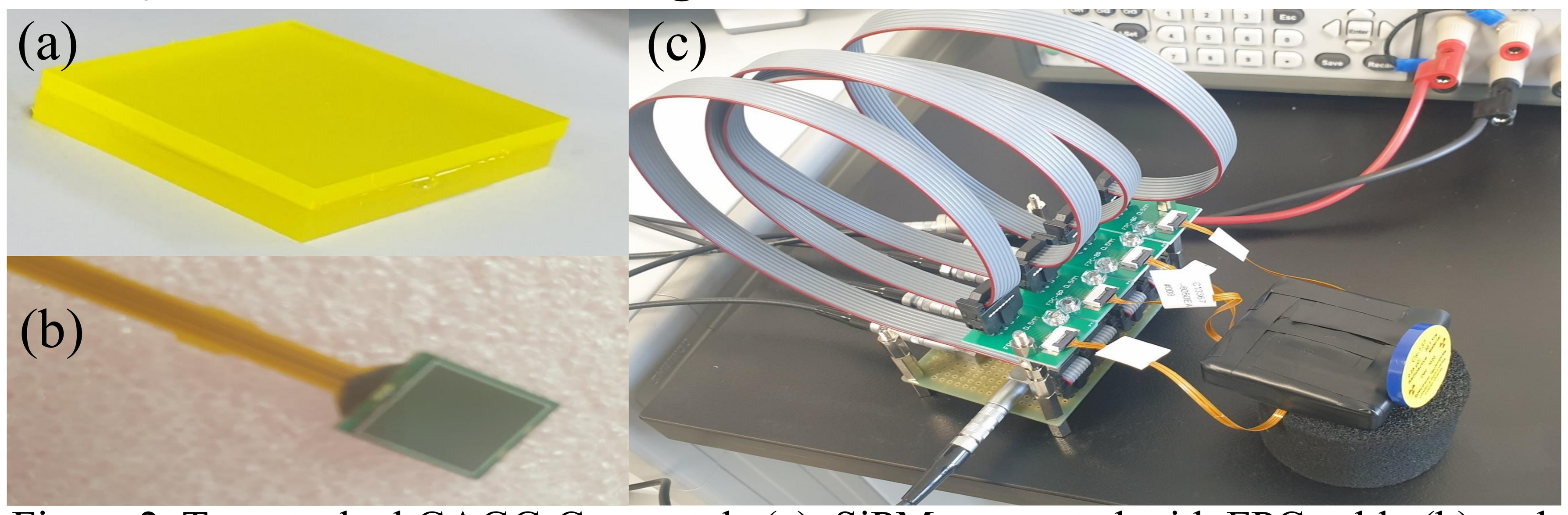

Figure 2. Two stacked GAGG:Ce crystals (a), SiPM connected with FPC cable (b) and quadruple-SiPM GAGG:Ce assembly (c)

Miscellaneous Characteristics

- **Position dependence**
  - Possible application for a coarse position estimation of the source.

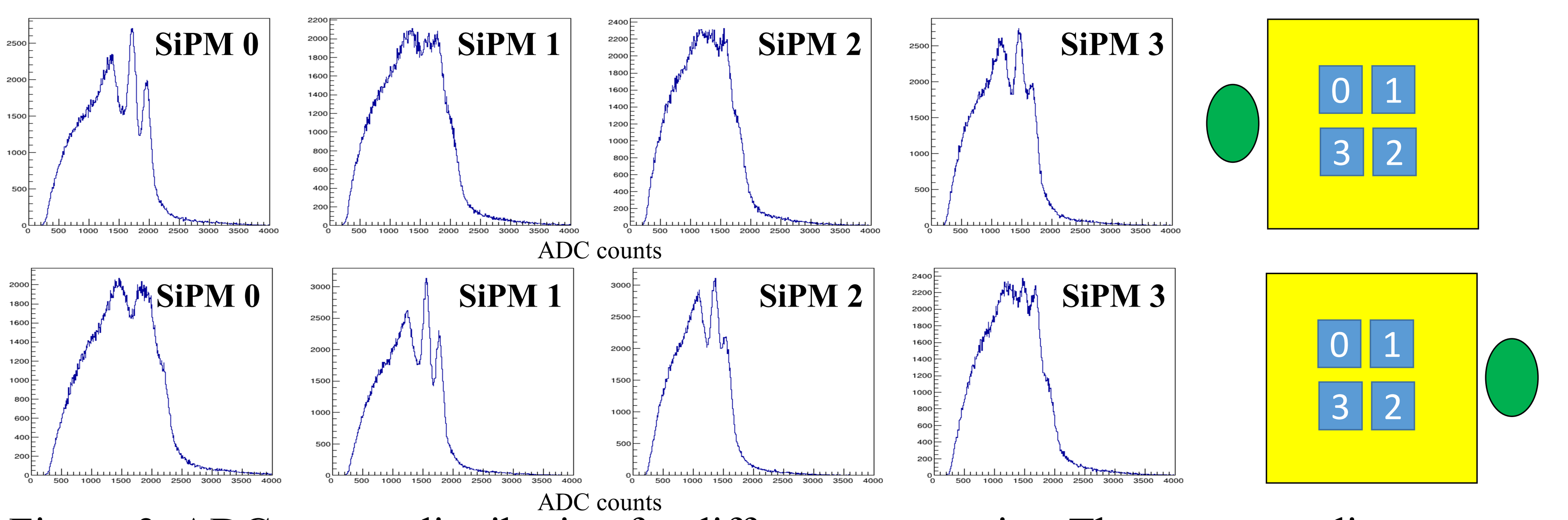

Figure 3. ADC counts distribution for different geometries. The corresponding geometry of ^{60}Co source (green), GAGG:Ce (yellow) and SiPM (blue) are drawn on the right-side.

- **Geometric mean for comfortable multi-SiPM signal processing**
  - Using $A_{total} = (A_0 \times A_1 \times A_2 \dots A_n)^{1/n}$ instead of $A_{total} = (A_0 + A_1 + A_2 \dots A_N)/N$
  - Comparable energy resolutions to the arithmetic mean with gain matching
  - Advantage: applicable before the gain matching for each SiPM

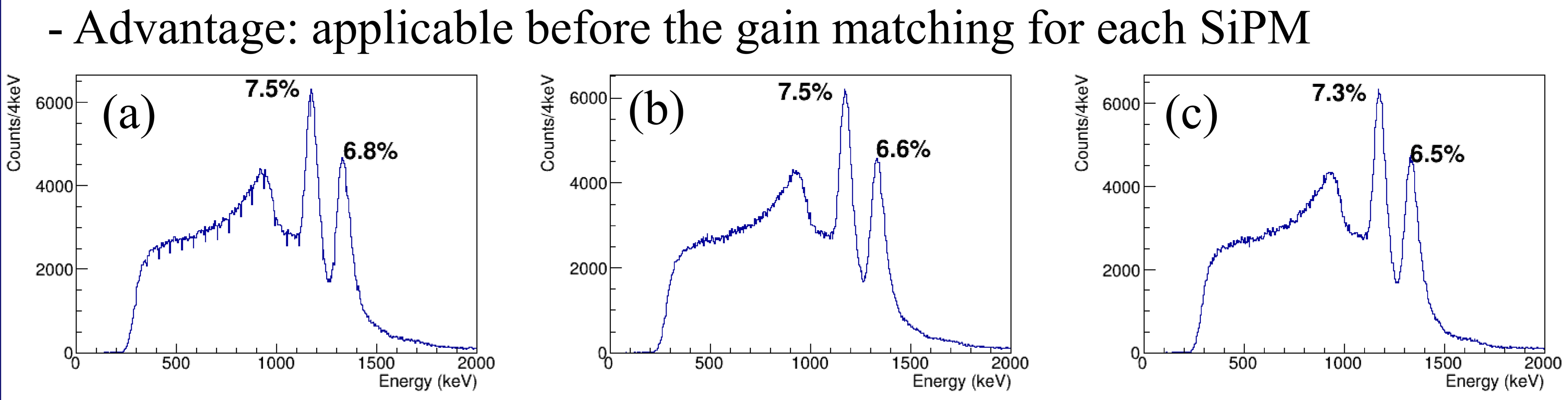

Figure 4. The energy resolutions with ^{60}Co source. The arithmetic mean of raw ADC is (a) and gain-matched ADC with ^{137}Cs data is (b) and the geometric mean of raw ADC is (c).

Energy Resolution

- Radiation sources: ^{137}Cs (E_γ = 662 keV), ^{60}Co (E_γ = 1.17, 1.33 MeV)
- **E resolution was better with higher bias and merged quadruple SiPM**

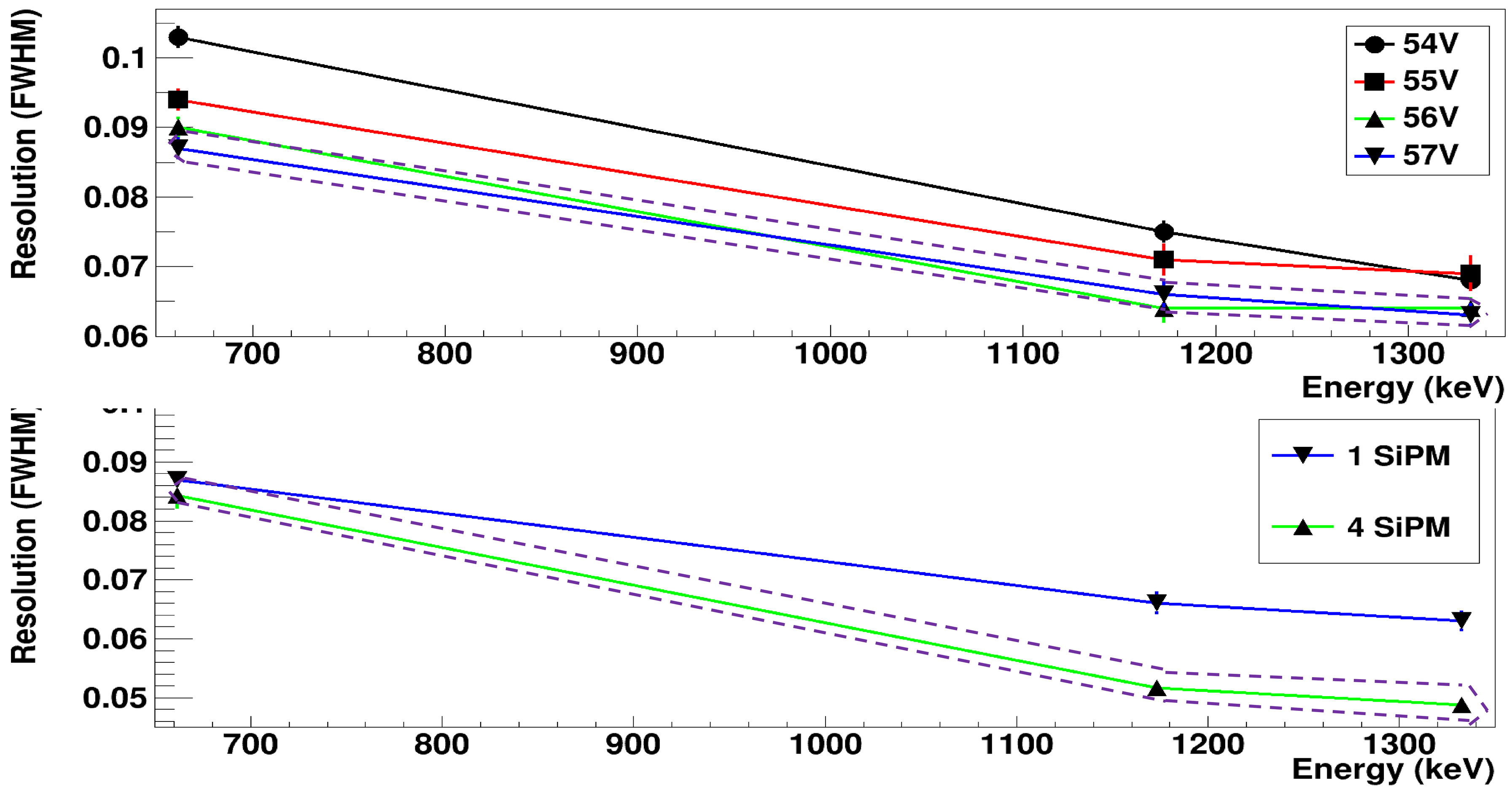

Figure 5. The effects of bias voltage on energy resolution for single SiPM assembly (upper) and resolution comparison with quadruple SiPM assembly (lower). Quadruple SiPM with 57 V bias showed best energy resolution (inside dashed line).

Applications Plans

- **CsI-SiPM calorimeter for active target TPC**
  - Reaction vertex and type identification
  - **CsI-SiPM for calorimeter** of γ, p and α
  - Micromegas and DSSD for charged particle tracking and PID
  - γ rays coincident with charged particles
  - TexAT_v2, AToM-X

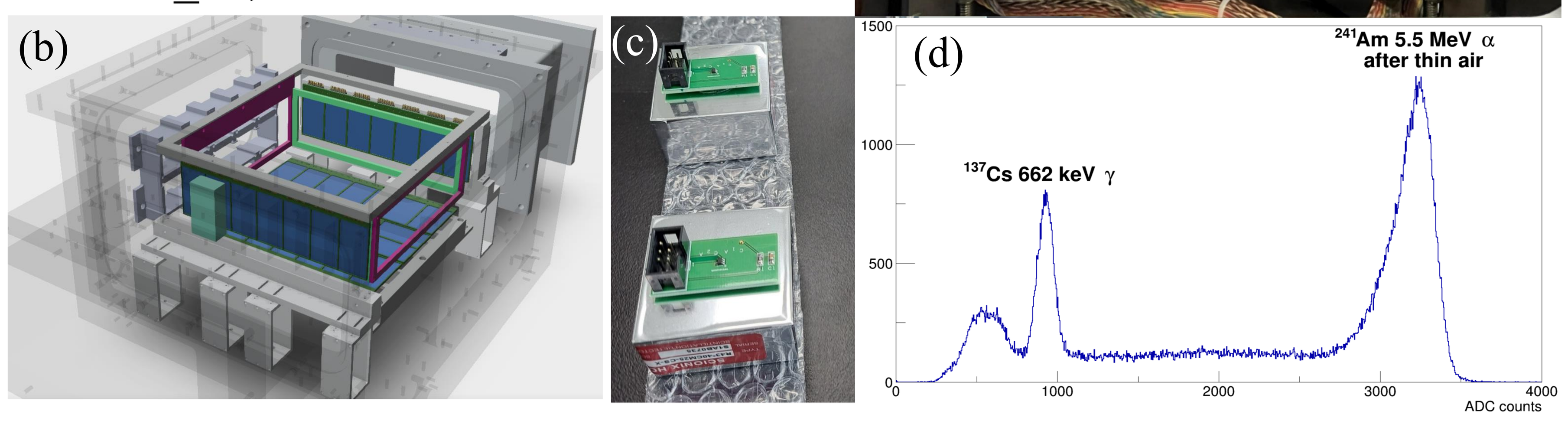

Figure 6. (a) Schematic drawing for TexAT and (b) the picture for TexAT assembly. CsI-SiPM were placed behind the Si detectors. The CsI-SiPM assemblies are as in (c). Test result for ^{137}Cs and ^{241}Am source is in (d). The FWHM for ^{137}Cs γ peak was 11%. The broad α peak is due to partly removed reflective mylar foil for α particle transmission.

- **Segmented plastic scintillator + SiPM array (under developing)**
  - High time resolution achievable (< 100 ps) [3]
  - Segmentation for position determination and multiplicity identification

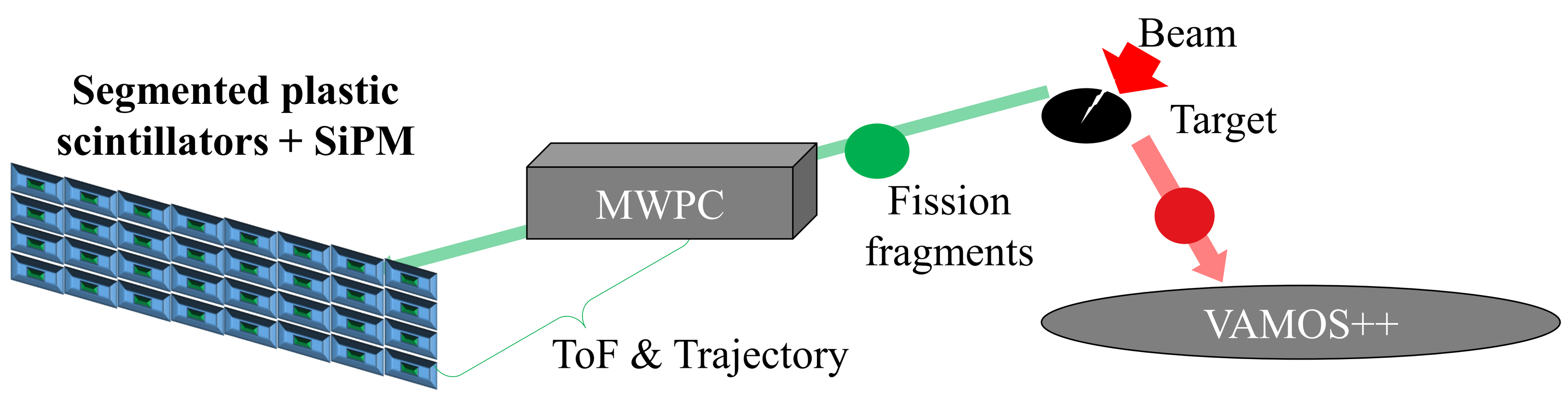

Figure 7. A schematic drawing for possible segmented ToF detector for GANIL VAMOS++ spectrometer

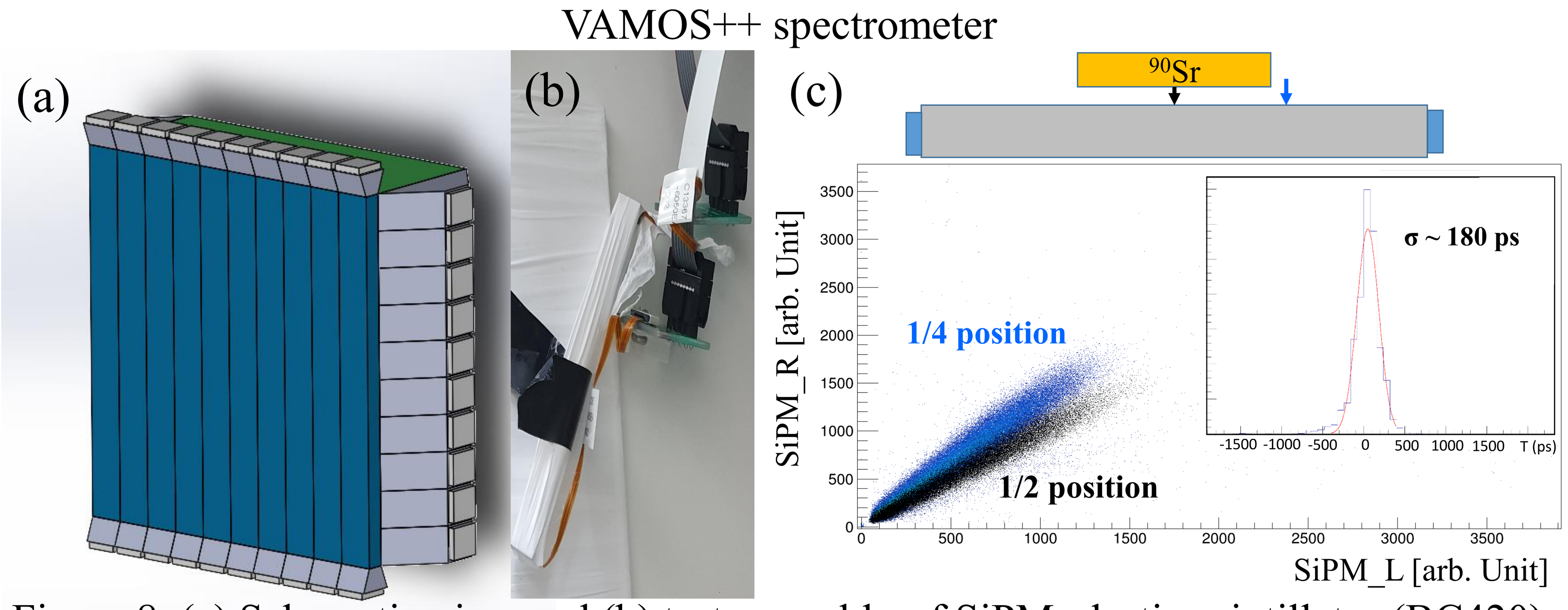

Figure 8. (a) Schematic view and (b) test assembly of SiPM-plastic scintillator (BC420) array for β decay detection in an approved ANL experiment. (c) A simple drawing for the bench test and its results that show position dependency of signals and time resolution.

Acknowledgement The authors acknowledge the supports from the Institute for Basic Science (IBS) of the Republic of Korea under Grant No. IBS-R031-D1 and IBS-R031-Y2

References
[1] A. Ghassemi et al. “MPPC Technical note”, Hamamatsu Photonics K.K.
[2] Hamamatsu Photonics K. K., https://www.hamamatsu.com/jp/en/product/optical-sensors/mppc/what_is_mppc/index.html.
[3] M. L. Cortés et al. *Nucl. Instr. Meth. A*, 899, 2018, p. 101-105.

* shbae2703@ibs.re.kr