

Digital switch boards for IV and CV measurements of large-array LGADs

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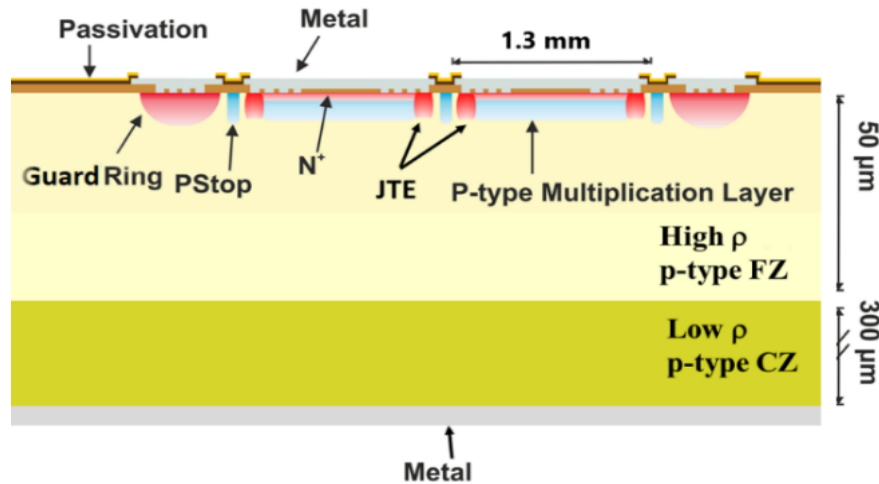
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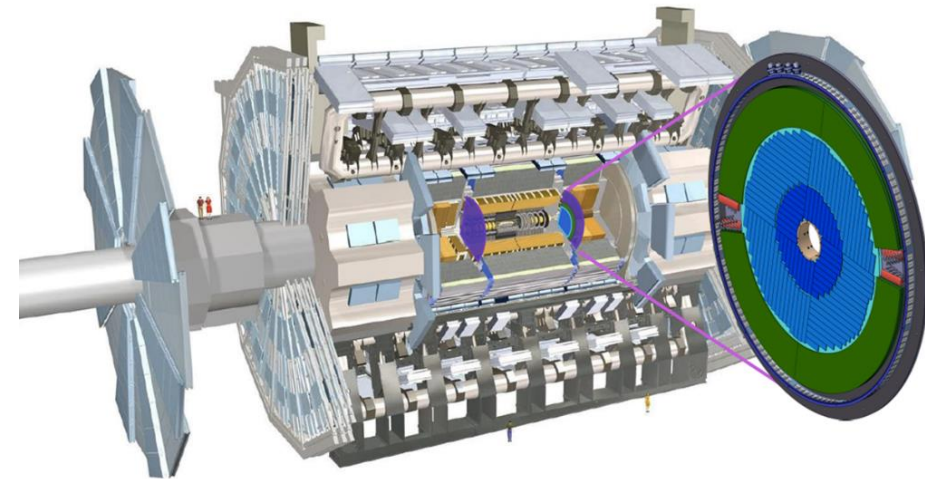
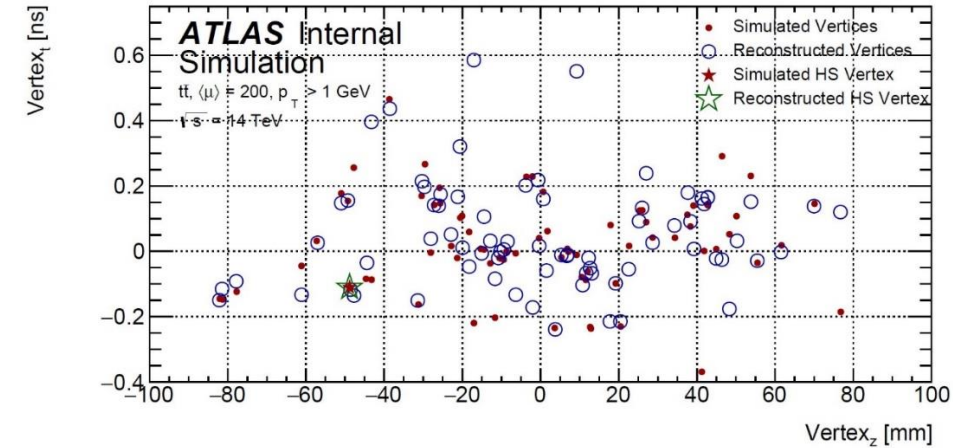
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Introduction

- ▶ A High-Granularity Timing Detector (HGTD), with up to 30 ps time resolution per track, is proposed for the ATLAS Phase II upgrade, to address the new challenge of greatly increased pile-up interactions.
- ▶ The technology chosen for the HGTD sensors is Low Gain Avalanche Detector (LGAD) — a novel semiconductor detector.

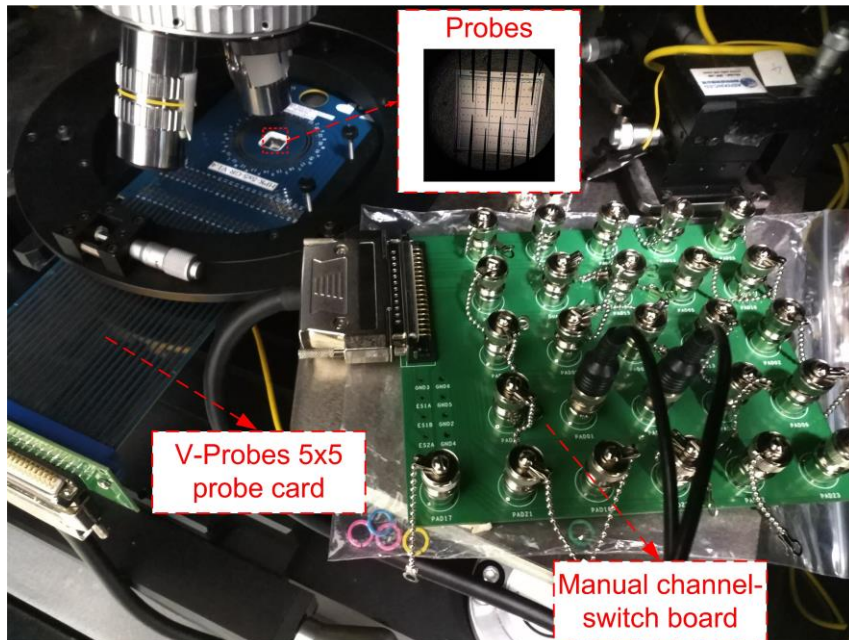


Cross section of a 2×2 LGADs array.



Introduction

- The current-voltage (IV) and capacitance-voltage (CV) measurements are important methods to study the electrical characteristics of semiconductor devices, including LGADs .
- For large-array LGADs, the channel under test should be connected to the LCR meter or pico-ammeter alternately for the measurements, while other channels are usually grounded.

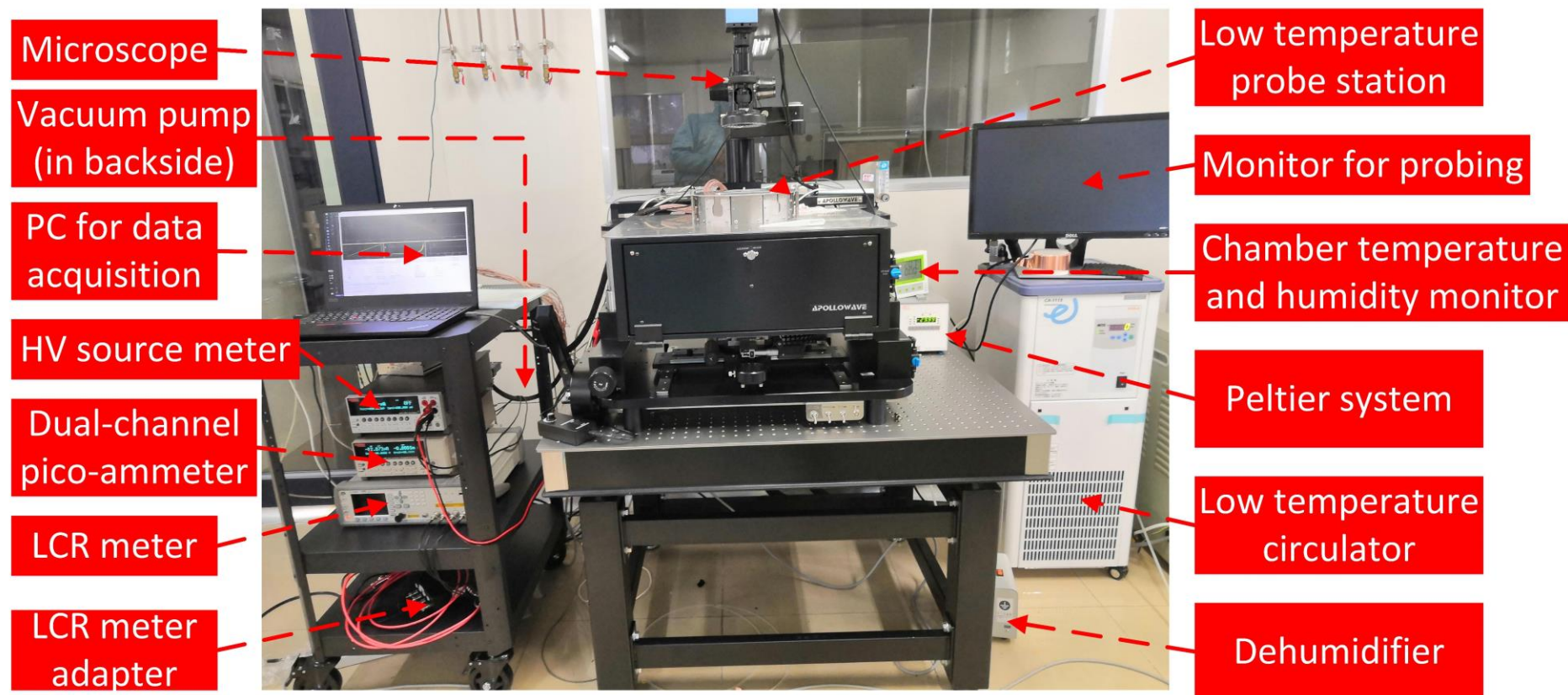


Our manual channel-switch board for 5×5 LGADs array
Drawbacks: troublesome to use; cannot be used on 15×15 LGADs array

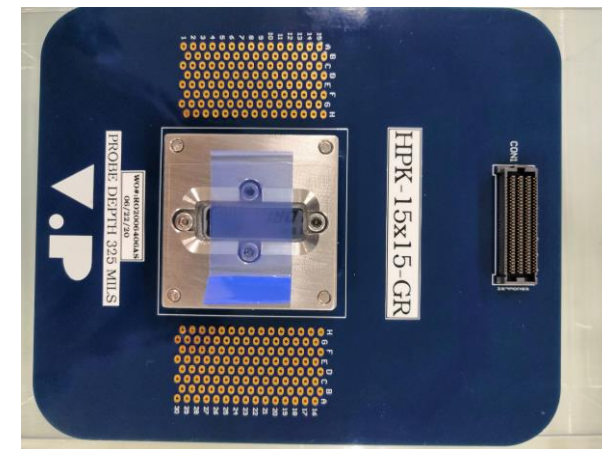


Fully automatic probe station
Drawbacks: expensive; cannot ground other channels at the same time

Setups for the IV and CV measurements



Test platform for IV and CV measurements of LGADs.



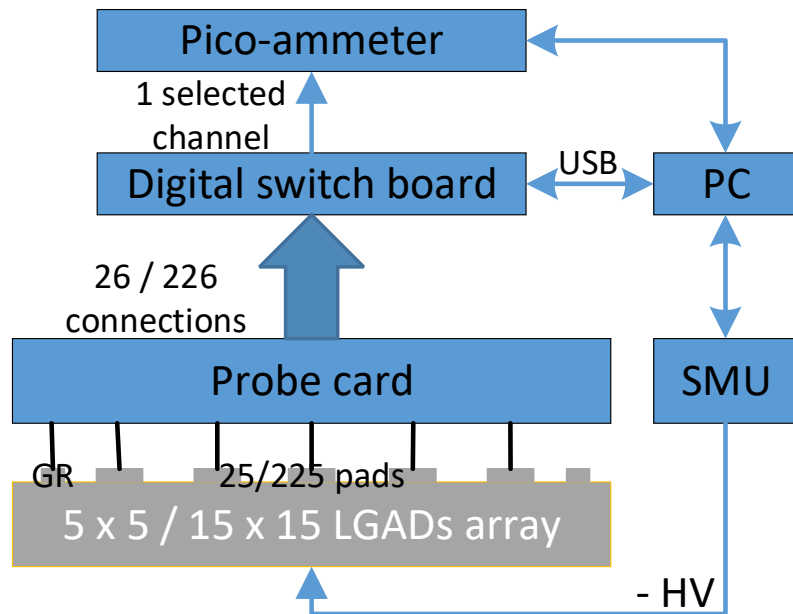
Probe card



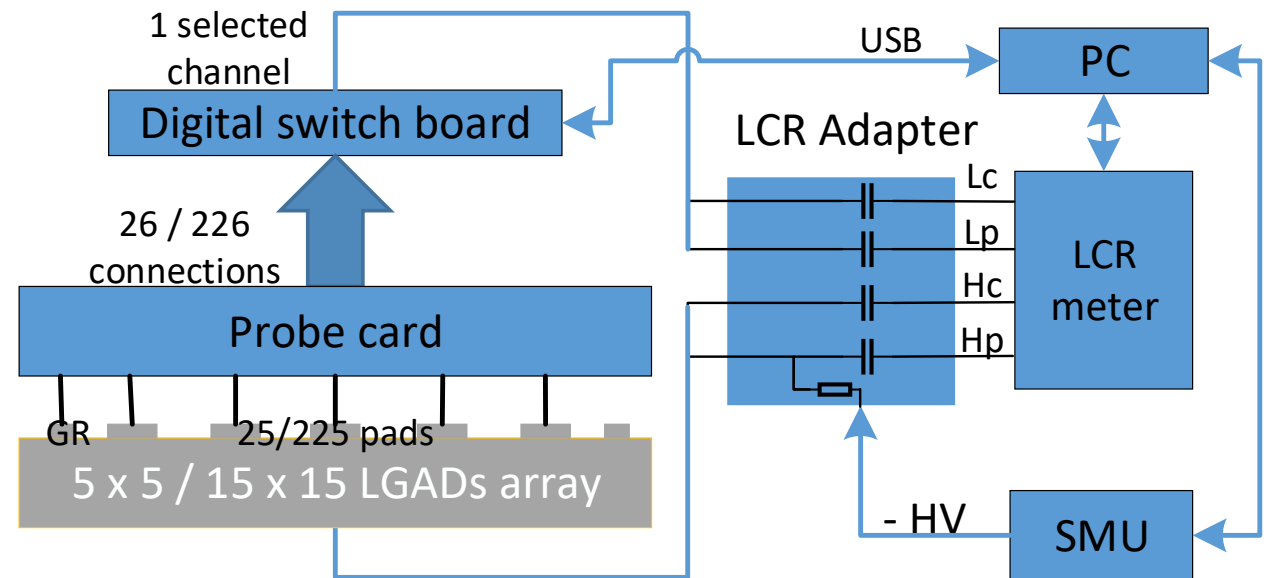
LCR meter adapter

Setups for the IV and CV measurements

All pads and GR on the sensor of large-array LGADs are connected by a dedicated probe card, and the channel under test is selected by our digital switch board while other channels are grounded directly.



Setups for IV measurement of 5×5 and 15×15 LGADs arrays

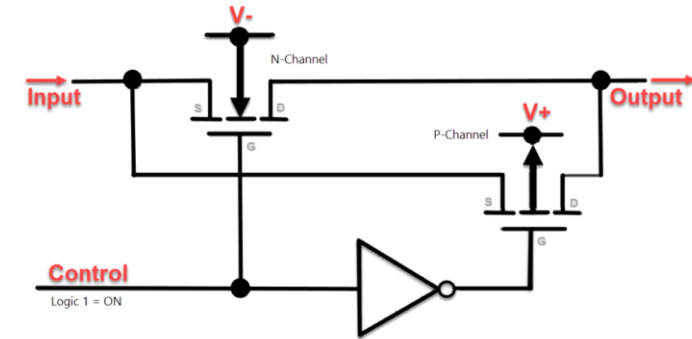


Setups for CV measurement of 5×5 and 15×15 LGADs arrays

Digital switch boards

- ▶ For $1.3 \times 1.3 \text{ mm}^2$ LGAD pads with active thicknesses of $50 \text{ }\mu\text{m}$:
 - ▶ leakage current : as low as 10 pA
 - ▶ capacitances after full depletion: about 3 pF
- ▶ Requirements for the digital switch boards :
 - ▶ 1:26 or 1:226 channel selection
 - ▶ Channel switch can be controlled by PC
 - ▶ leakage current and the noise caused by electronic: less than 10 pA
 - ▶ bandwidth: cover the range of $[100 \text{ Hz}, 100 \text{ kHz}]$ for the CV measurements

The pivotal components to achieve the function are **analog switches**.



The internal construction of a typical analog switch

Advantages:

- no mechanical vibration while switching;
- low ON-resistance;
- low leakage-current;
- low power consumption;
- suitable bandwidth

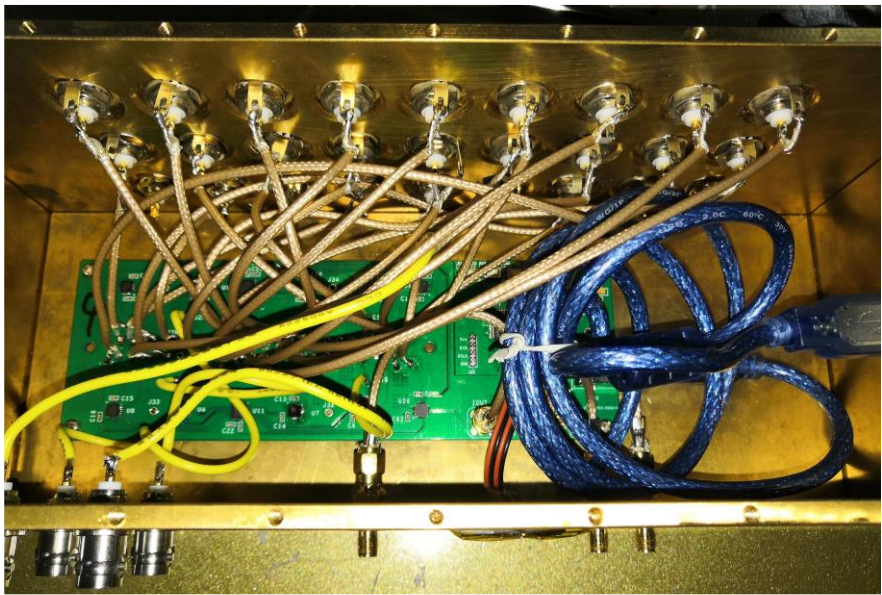
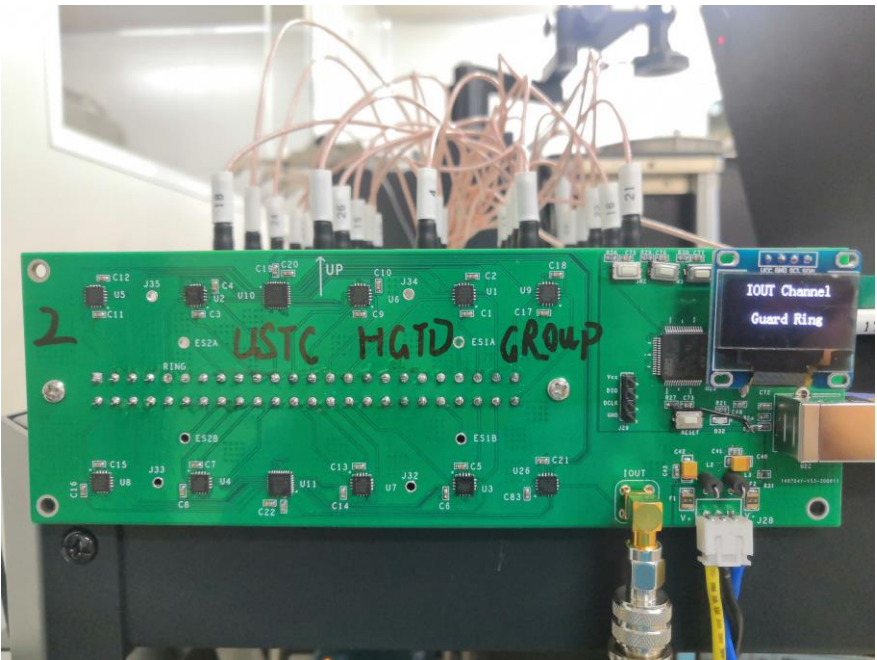
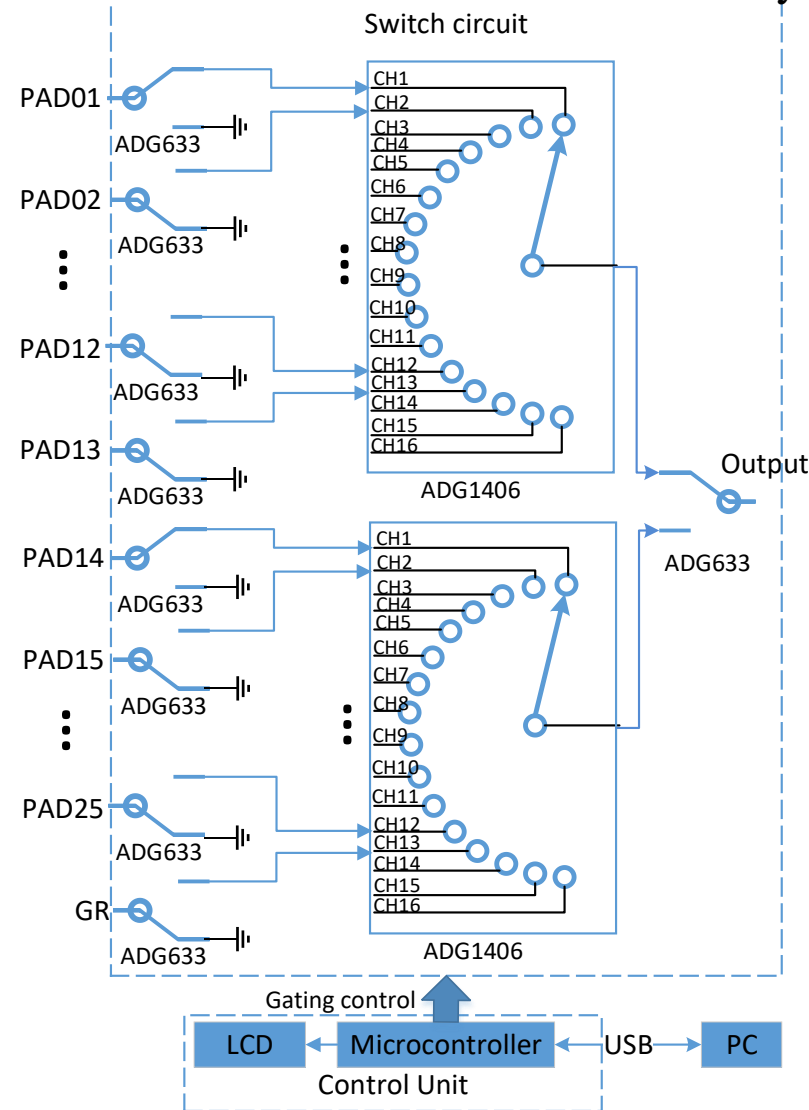
- Satisfy our demands!

Reduce noise:

- Reasonable circuit design and layout;
- Suitable components;
- Appropriate shielding

Digital switch boards

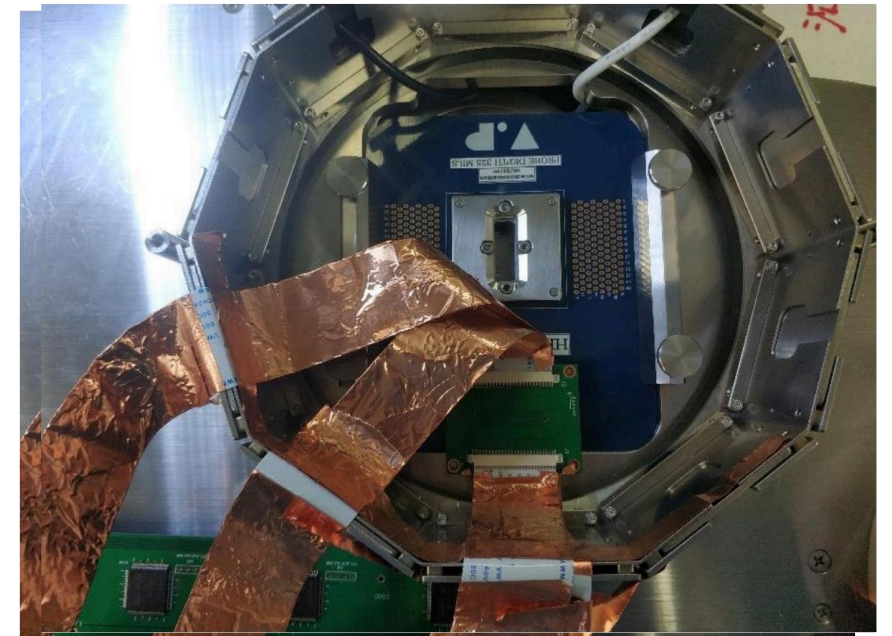
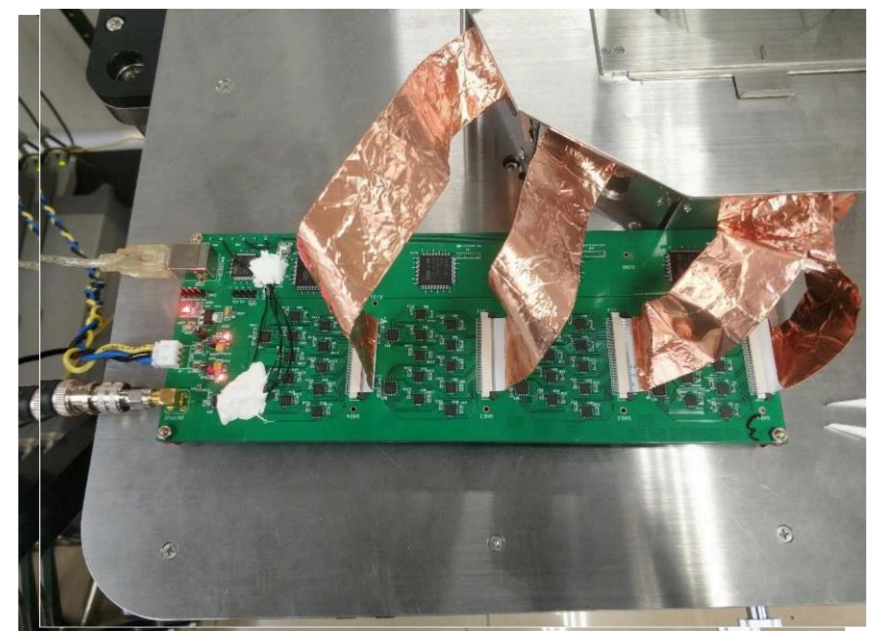
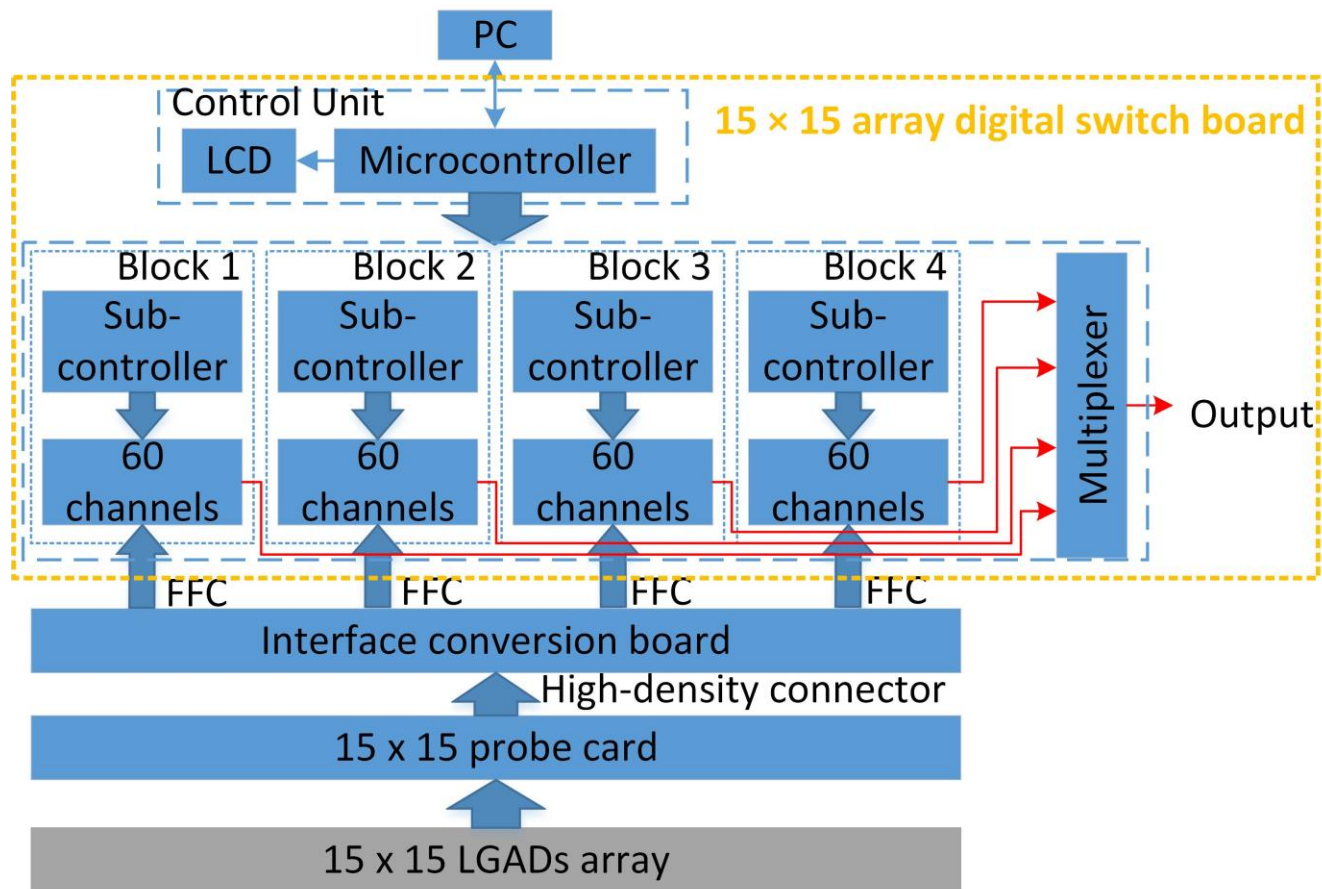
digital switch board for the IV and CV measurements of 5×5 LGAD arrays



a copper shielding box can reduce noise

Digital switch boards

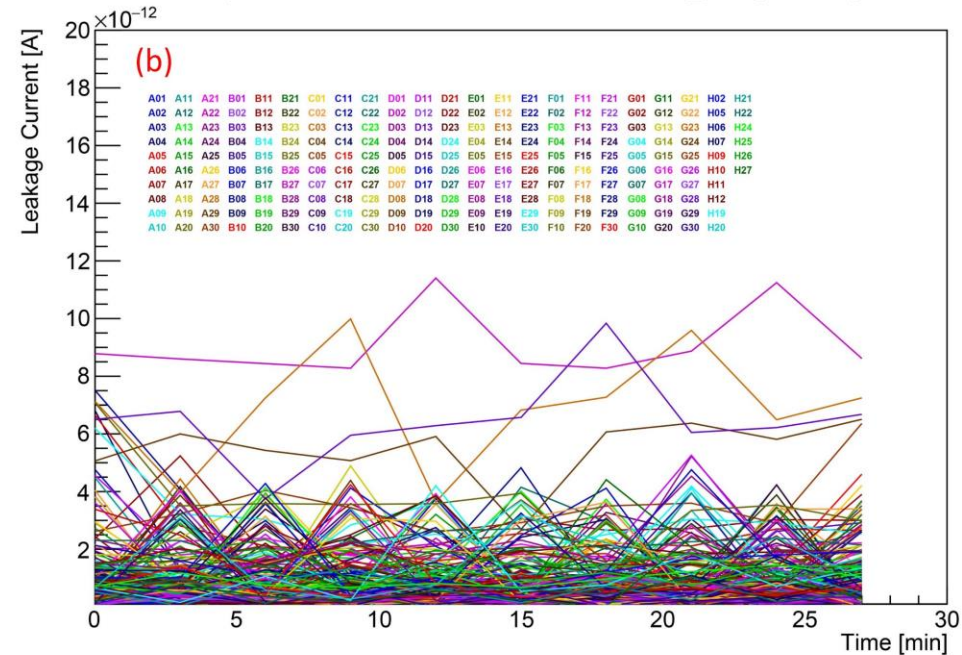
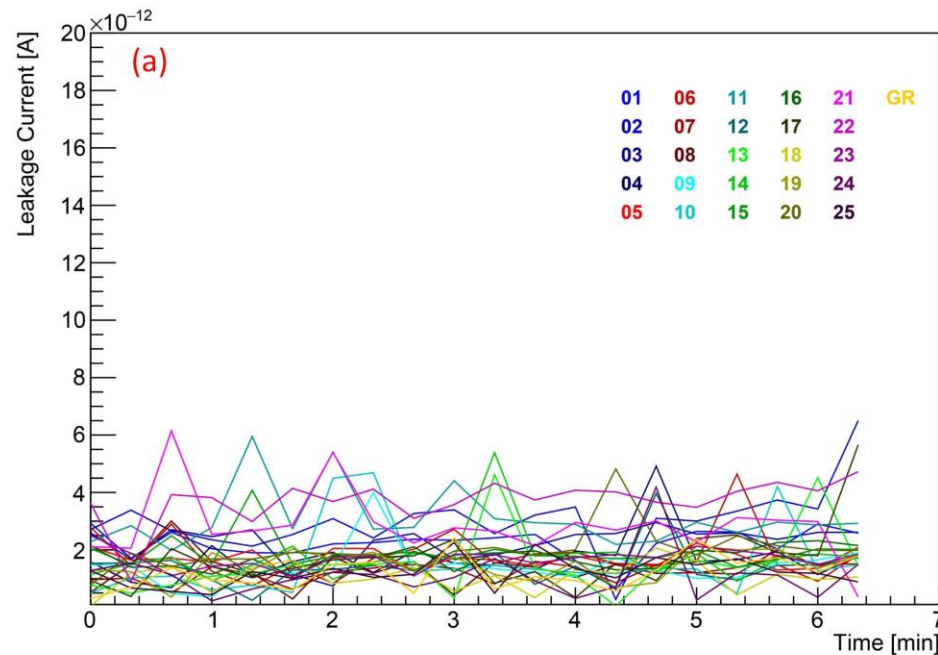
digital switch board for the IV and CV measurements of 15×15 LGAD arrays



The flexible flat cable (FFC) can fit our probe station well.

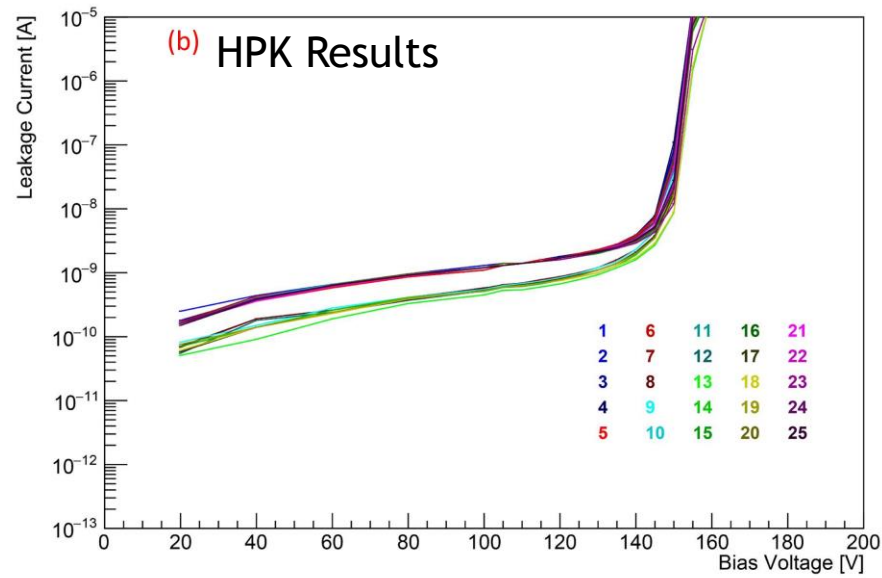
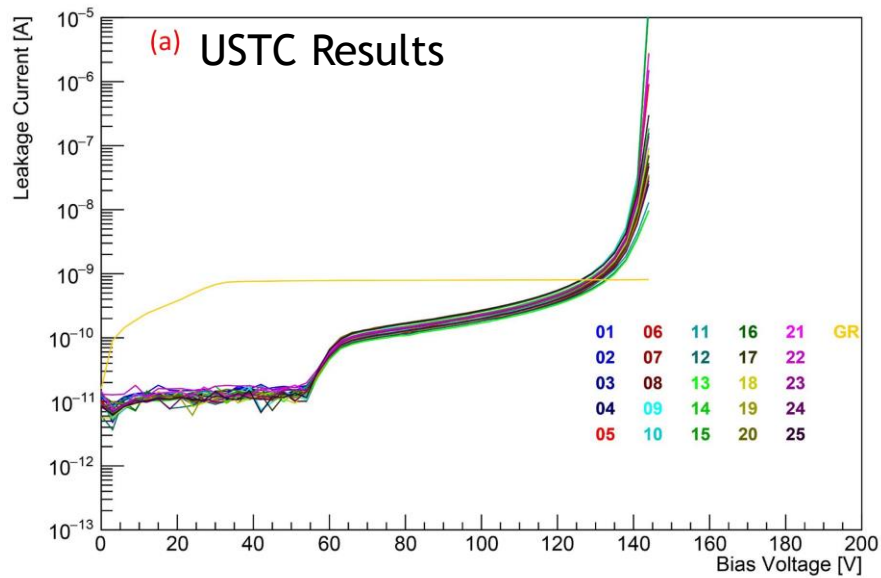
Test results – Noise

- ▶ **Test Methods:** connect the digital switch board and the probe card, but left the needles on the probe cards floated
- ▶ **Results:** the current noise caused by electronic and the background is basically in the order of pA, meeting the design requirements



The open-circuit currents of all channels on the 5×5 (a) and 15×15 (b) array digital switch boards

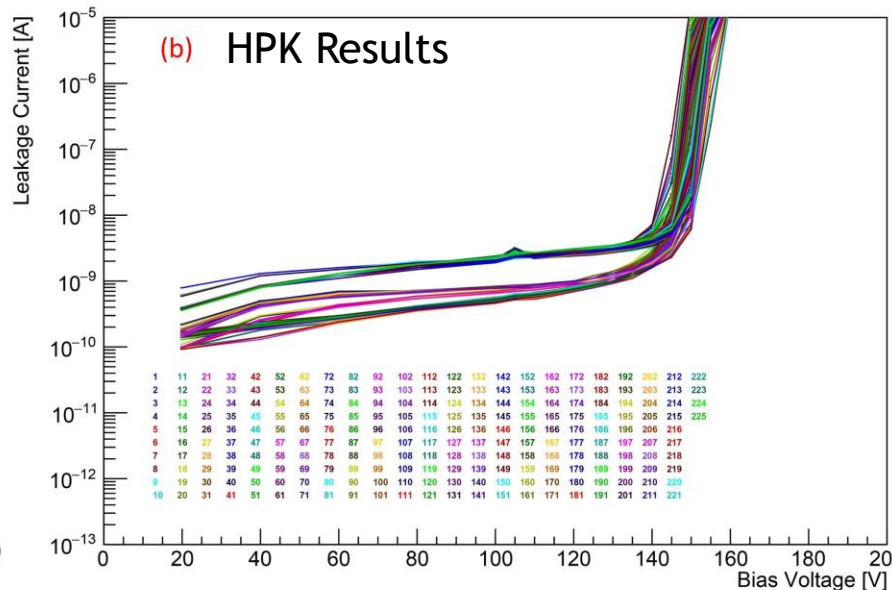
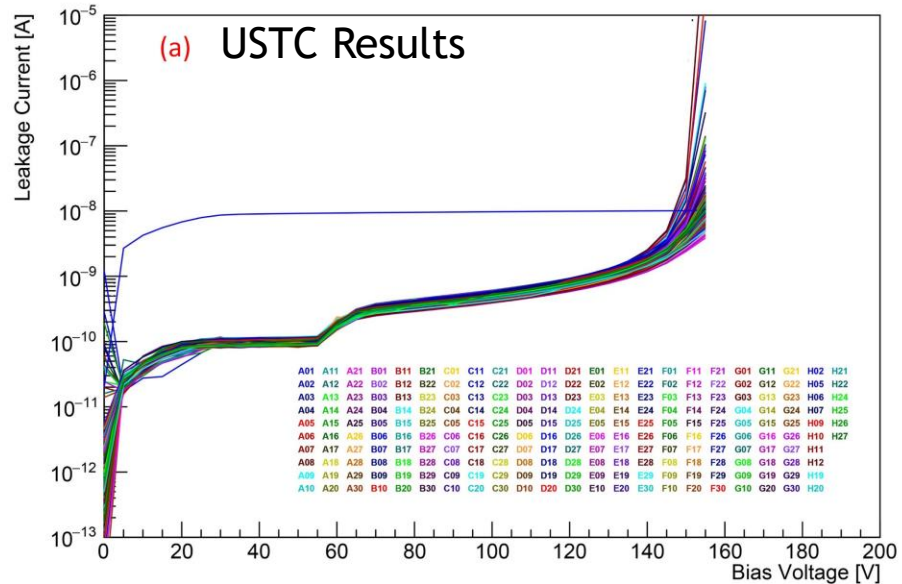
Test results – IV measurement performance



IV curves of HPK Batch-2 W1-P1 5×5 LGADs array

(a) measured by us with the 5×5 array digital switch board

(b) measured by HPK with the automatic probe station



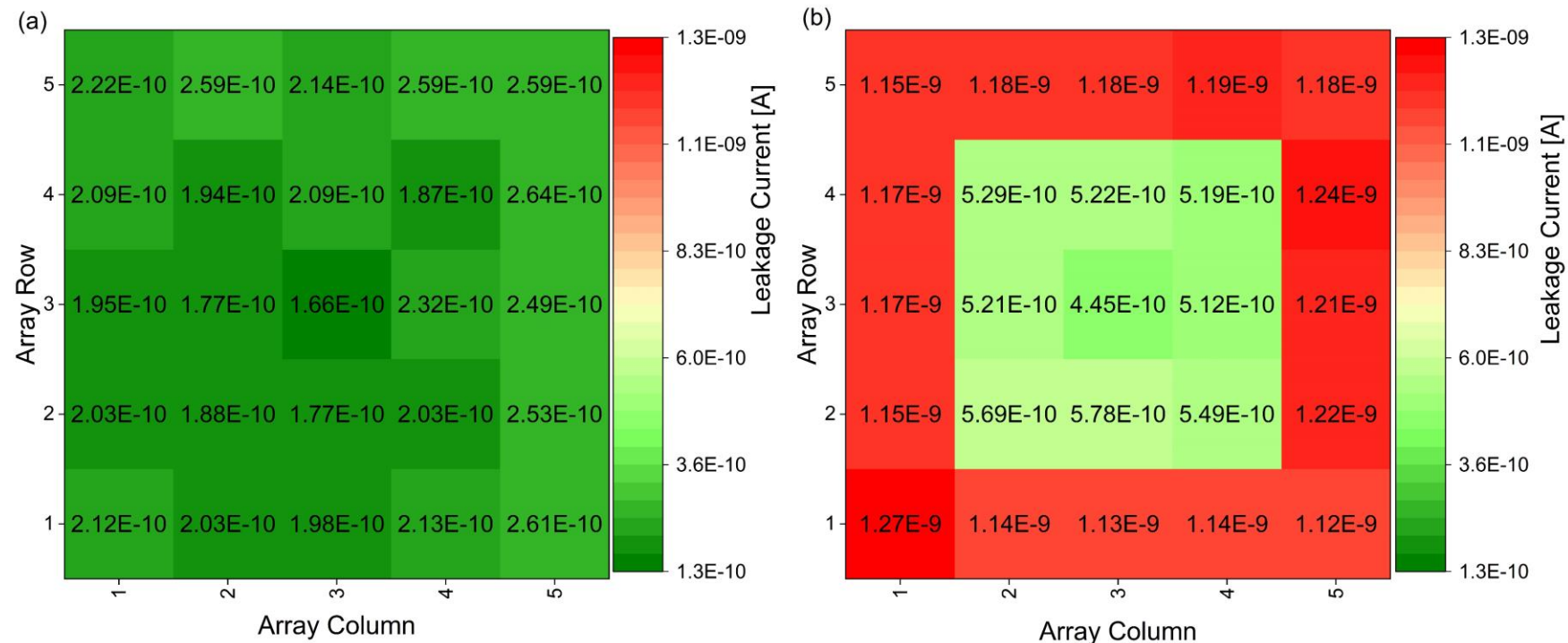
IV curves of HPK Batch-2 W1-P7 15×15 LGADs array

(a) 226 IV curves measured by us with the 15×15 array digital switch board

(b) 225 IV curves measured by HPK with the automatic probe station.

Test results – IV measurement performance

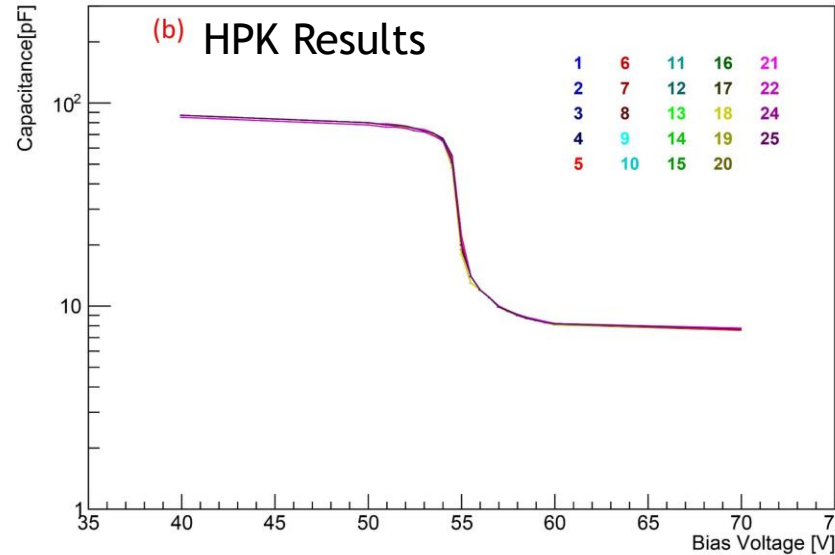
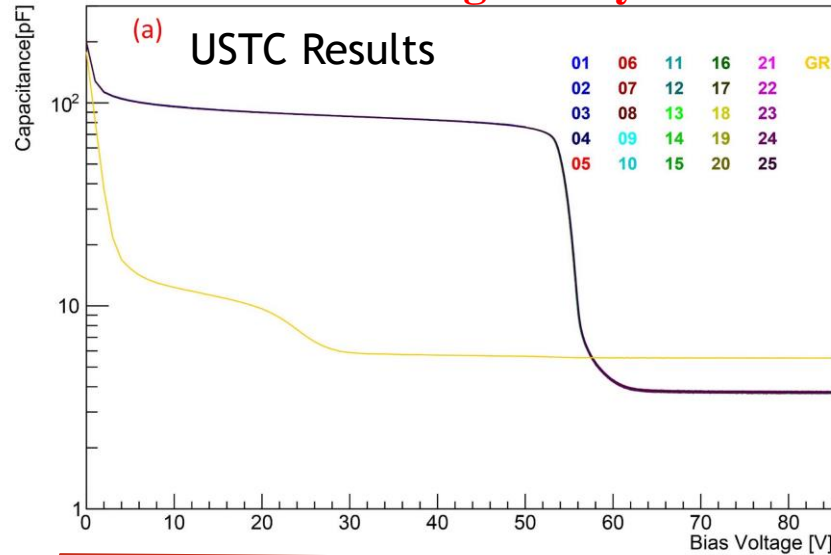
- The IV curves of the large-array sensor measured by our system have a similar leakage current and VBD to those measured by HPK (using automatic probe station), but show a better uniformity.



Distribution of leakage currents on the 5×5 LGADs array with 100 V bias voltage (a typical bias voltage when the sensor is fully depleted but not broken down), (a) measured by us with the 5×5 array digital switch board, (b) measured by HPK with the automatic probe station. 12

Test results – CV measurement performance

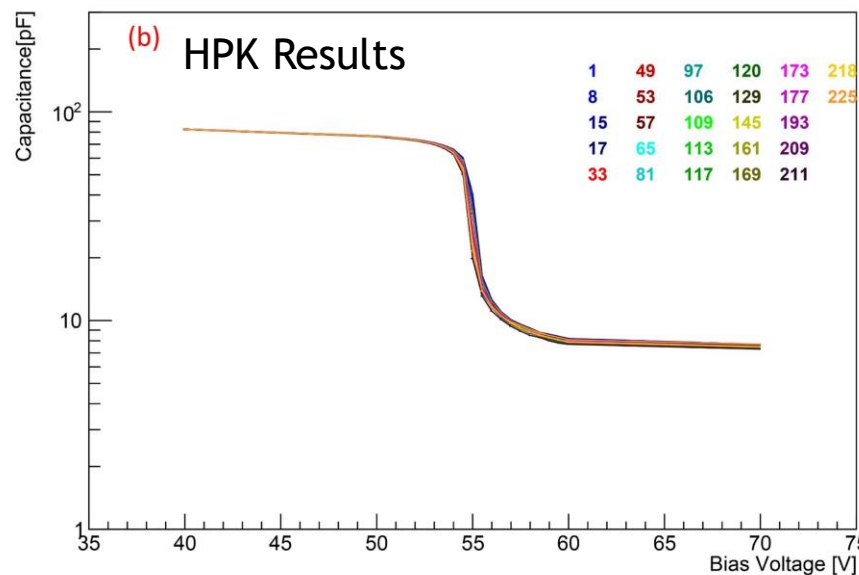
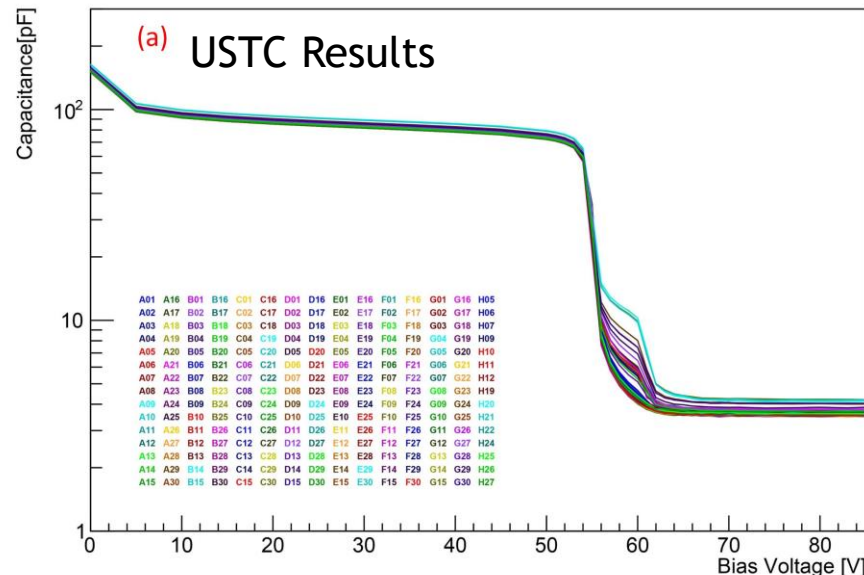
Both digital switch boards and the automatic probe station can complete the CV measurements of large-array LGADs well!



CV curves of HPK Batch-2 W1-P1 5×5 LGADs array

(a) measured by us with the 5×5 array digital switch board

(b) measured by HPK with the automatic probe station.



CV curves of HPK Batch-2 W1-P7 15×15 LGADs array

(a) 225 CV curves measured by us with the 15×15 array digital switch board

(b) 27 CV curves of sampling channels measured by HPK with the automatic probe station

Summary

- ▶ The digital switch boards can greatly **improve the efficiency** during the IV and CV measurements **at a lower cost**.
- ▶ The overall **leakage currents and noise** on the two digital switch boards are **lower than 10 pA**.
- ▶ Compared with the HPK results measured by automatic probe station, the IV curves measured by our platform have **better uniformity and accuracy**.
- ▶ The digital switch boards can complete the **CV measurements** of large-array LGADs well.
- ▶ Our digital switch boards have been sent to CERN and IHEP for promoting LGAD research.

The background of the slide features abstract, overlapping green geometric shapes, primarily triangles and polygons, in various shades of green, creating a modern and dynamic visual effect.

Thanks for your attention!

More application information of our digital switch boards
will be shared in Xiangxuan's talk (next one)!