Ultra-fast low-noise preamplifier for Low Gain Avalanche Detectors

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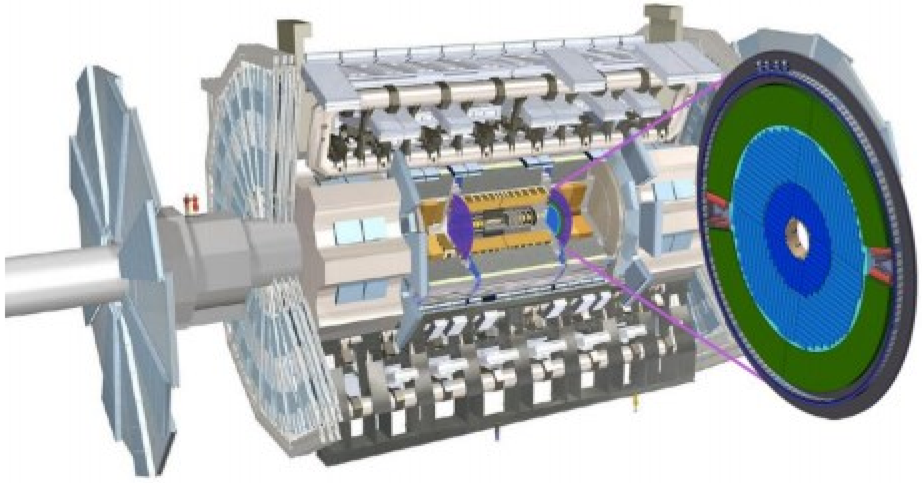
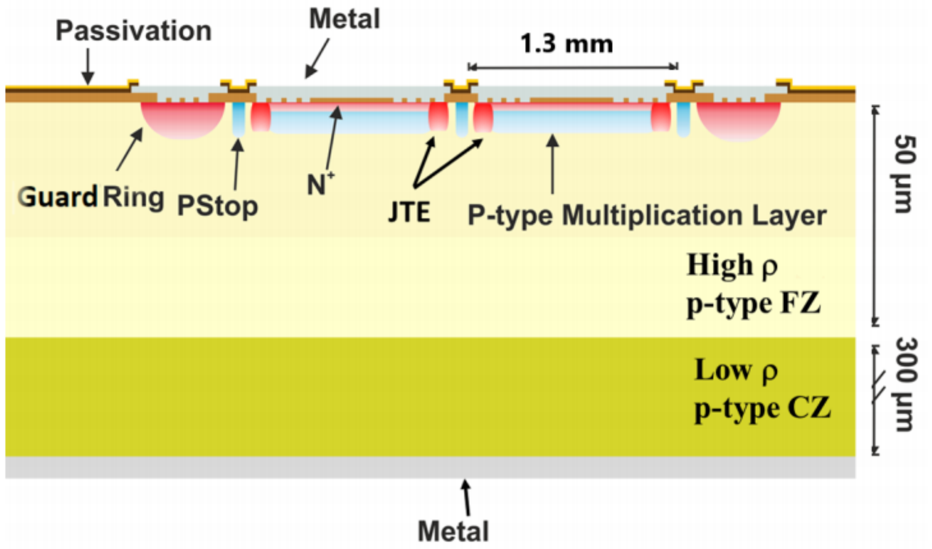
Contents

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.

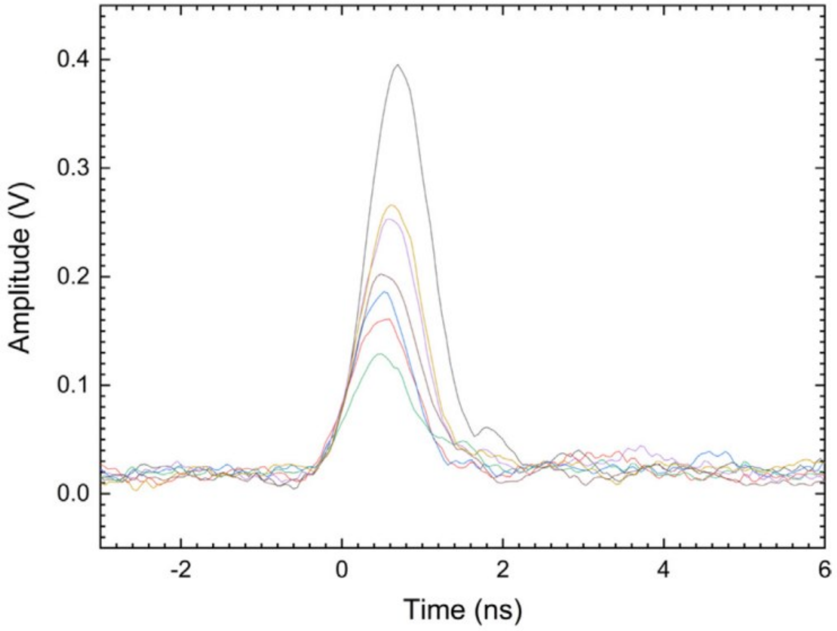




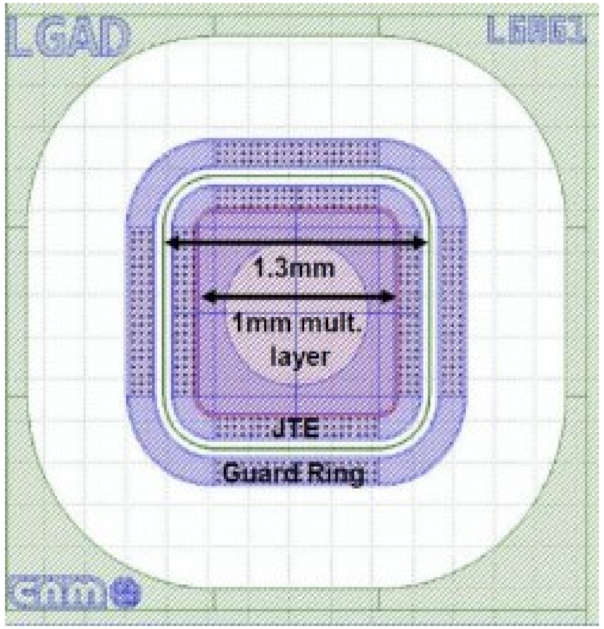
Cross section of a 2 × 2 LGADs array.

Introduction

- To study the dynamic characteristics of LGAD, we need to obtain and process the response signal of the LGADs under external excitation
- The LGAD preamplifier needs to have low noise, low jitter, high gain, and enough bandwidth. Besides, a wide dynamic range of the amplifier is also demanded.



Waveforms of the output from LGAD after amplification



Sketches of the single pad LGAD sensors

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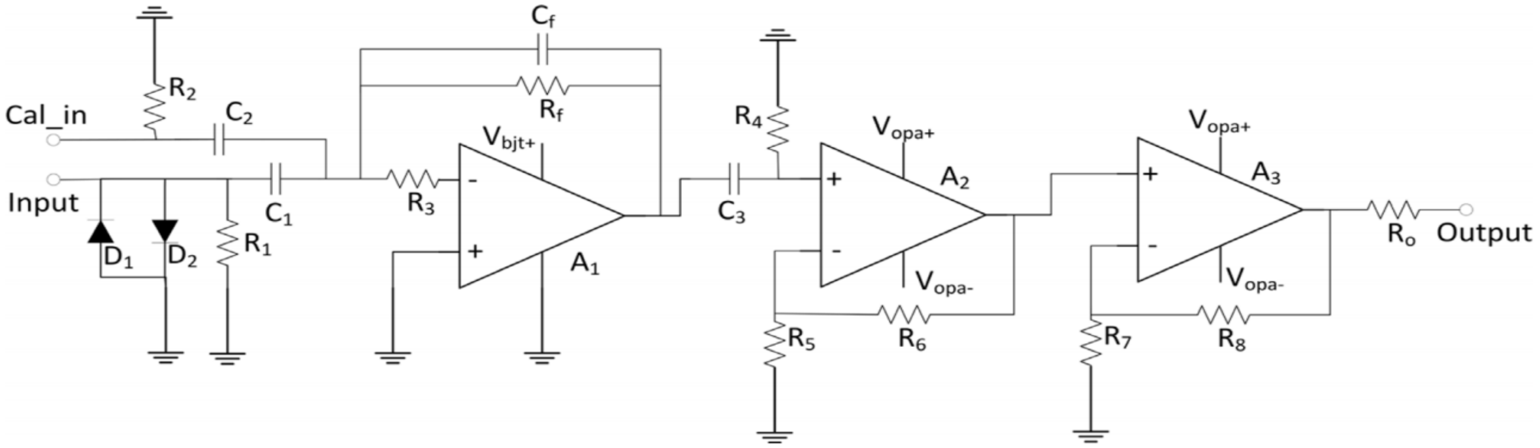
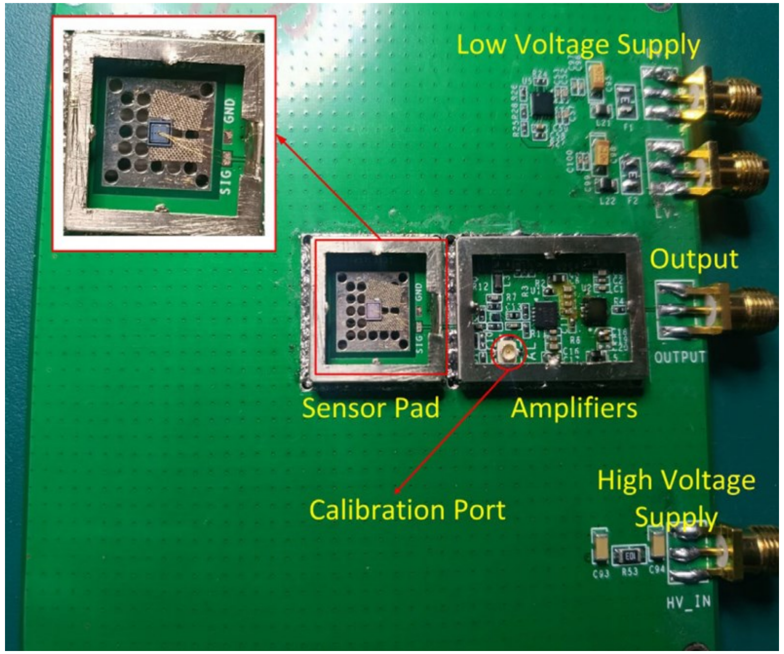
Electronic design



Simplified schematic of the LGAD preamplifier



Picture of the single-channel LGAD preamplifier.

- Transimpedance Amplifiers(TIA) can take full advantage of the fast signal slew rate, and we choose SiGe:C RF transistor-BFR840L3RHESD, whose transition frequency is 75 GHz
- A2 serves as an intermediate amplifier stage, requiring low noise and high gain,the device choosen for it is LMH6629
- As the output driver, A3 is characterized by wide dynamic range and strong load capacity.The device choosen for it is THS4303

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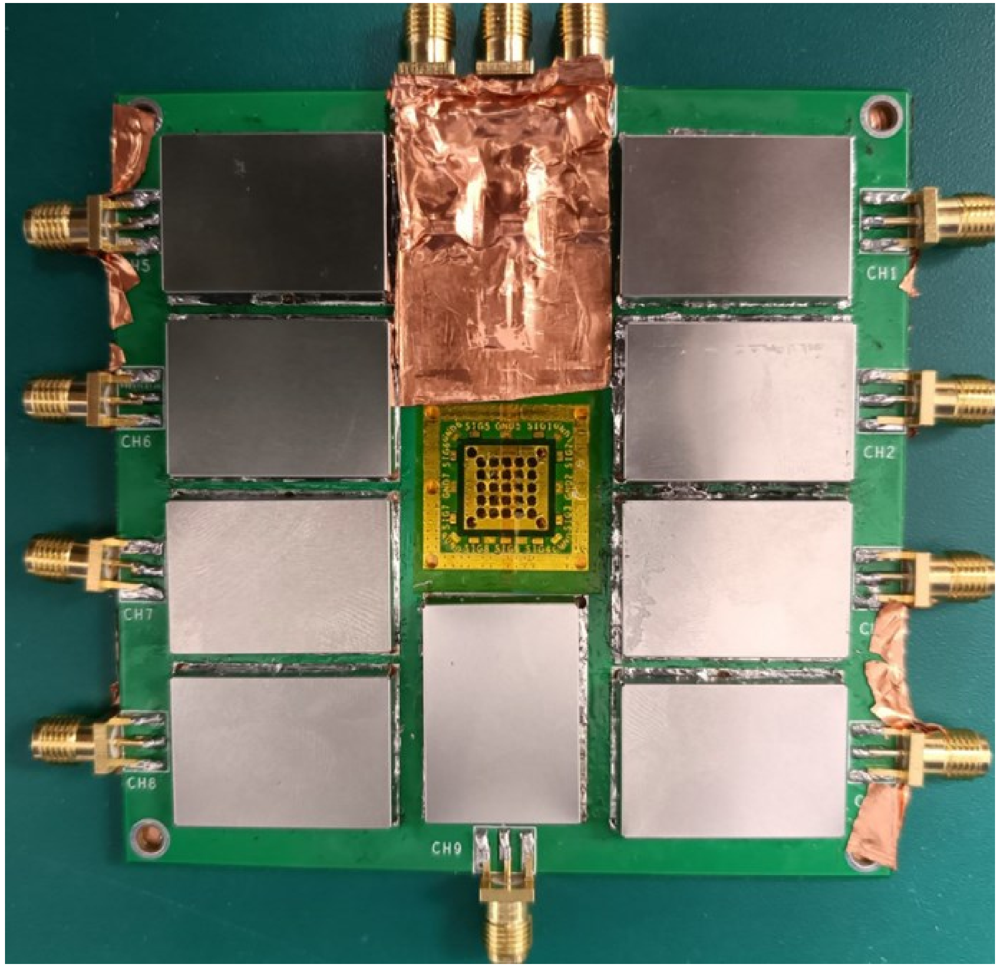
Electronic design

- Multi-channel preamplifier board
  - A 9-channel preamplifier board
  - Good uniformity across channels
  - Based on a 6-layer PCB to reduce noise and crosstalk caused by increased channels
  - Each channel has separate shielding shells mounted on the both sides of the PCB

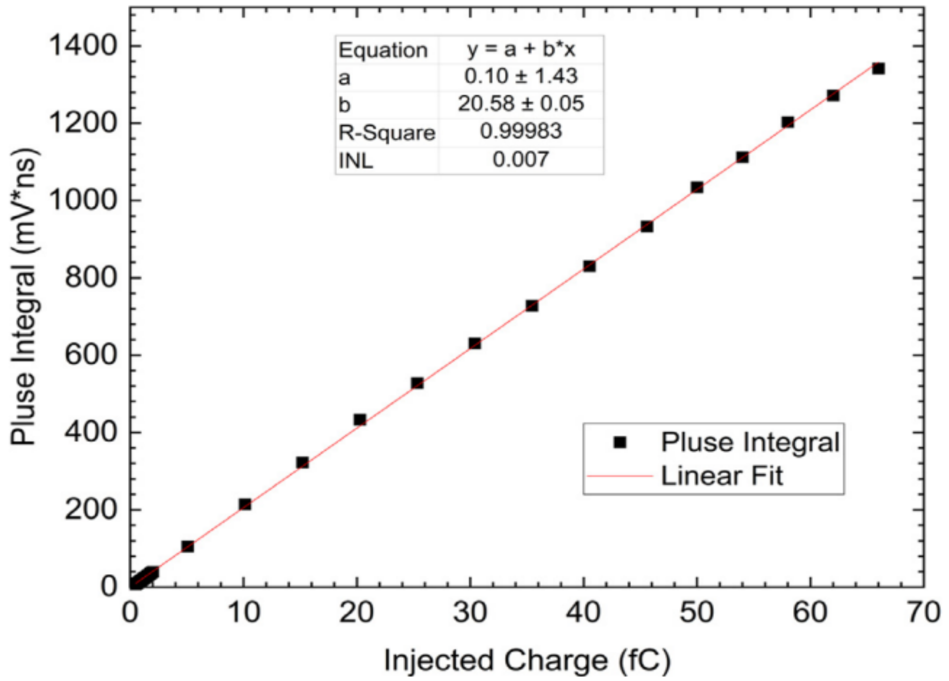


Picture of the 9-channel LGAD preamplifier board.

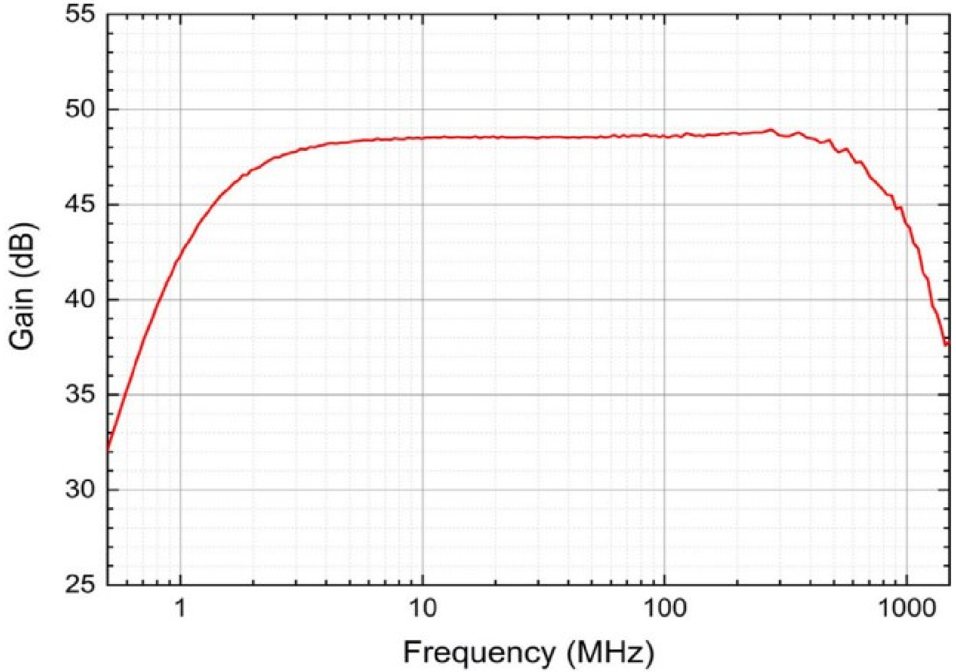
Nuclear Inst. and Methods in Physics Research, A 1040 (2022) 167222

Test results

- Electronic performance tests
  - The charge gain is 20.58 mV ns/fC, the effective dynamic range is [0.7 fC, 66 fC]. The mean RMS noise is 4.81 mV, the maximum Integral Nonlinearity (INL)of the linear fit is 0.70%
  - The measured bandwidth of the preamplifier is about [1.5 MHz, 872 MHz] ,and the gain on the passband is about 48.5 dB



Integration of the averaged output waveform versus equivalent injected charge.

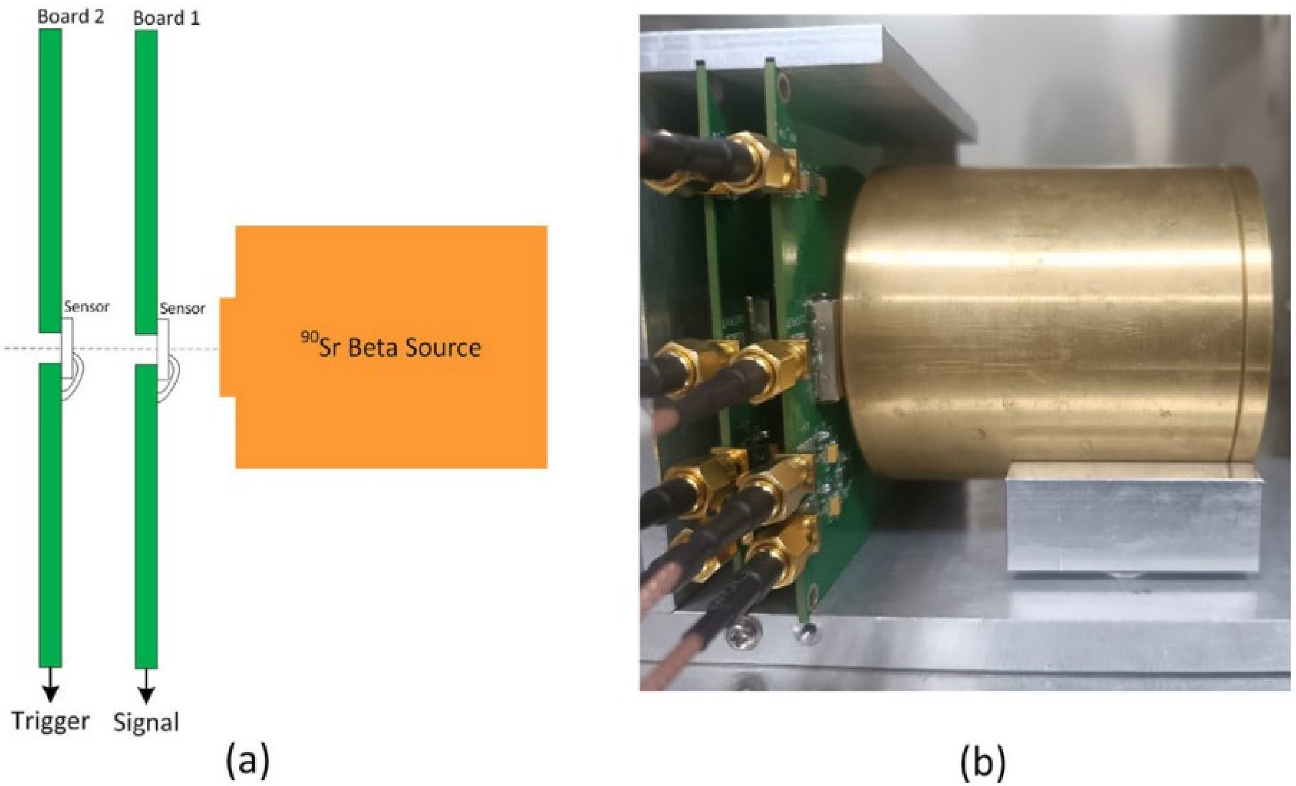


Frequency response curve of the single-channel preamplifier.

Nuclear Inst. and Methods in Physics Research, A 1040 (2022) 167222

Test results

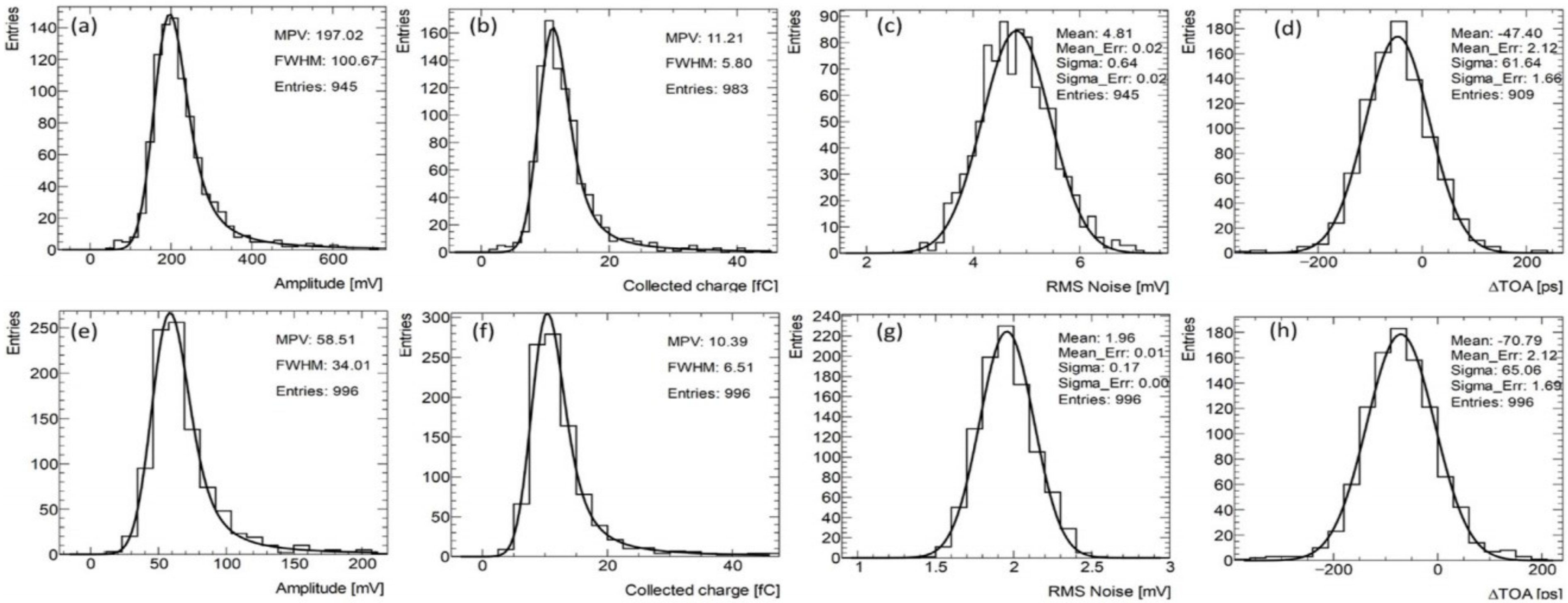
- β-scope tests
  - A β-scope was constructed for charge collection and time resolution studies with the LGADs mounted on our single-channel preamplifier boards
  - Two boards and the β source were fixed on a custom-made support structure for mechanical stability and correct alignment, and placed in a climate chamber
  - HPK Type 3.1 single LGADs, which have an active pad area of 1.3 × 1.3 mm^2 and thickness of 50 μm.
  - The output of Board 1 and 2 are read out by an oscilloscope. Board 2 serves as a trigger, with a threshold of 70 mV, while voltage scans are performed on Board 1
  - Use UCSC boards and set the β-scope for comparison



Schematic (a) and picture (b) of the β-scope.

Test results

- β-scope tests 20℃
  - The ENC and SNR of the two measurements are 0.27 fC, 40.96, and 0.35 fC, 29.85,respectively.
  - The jitter of our preamplifier and the UCSC preamplifier (with 2nd stage amplifier) is 7.12 ps and 9.78 ps respectively.

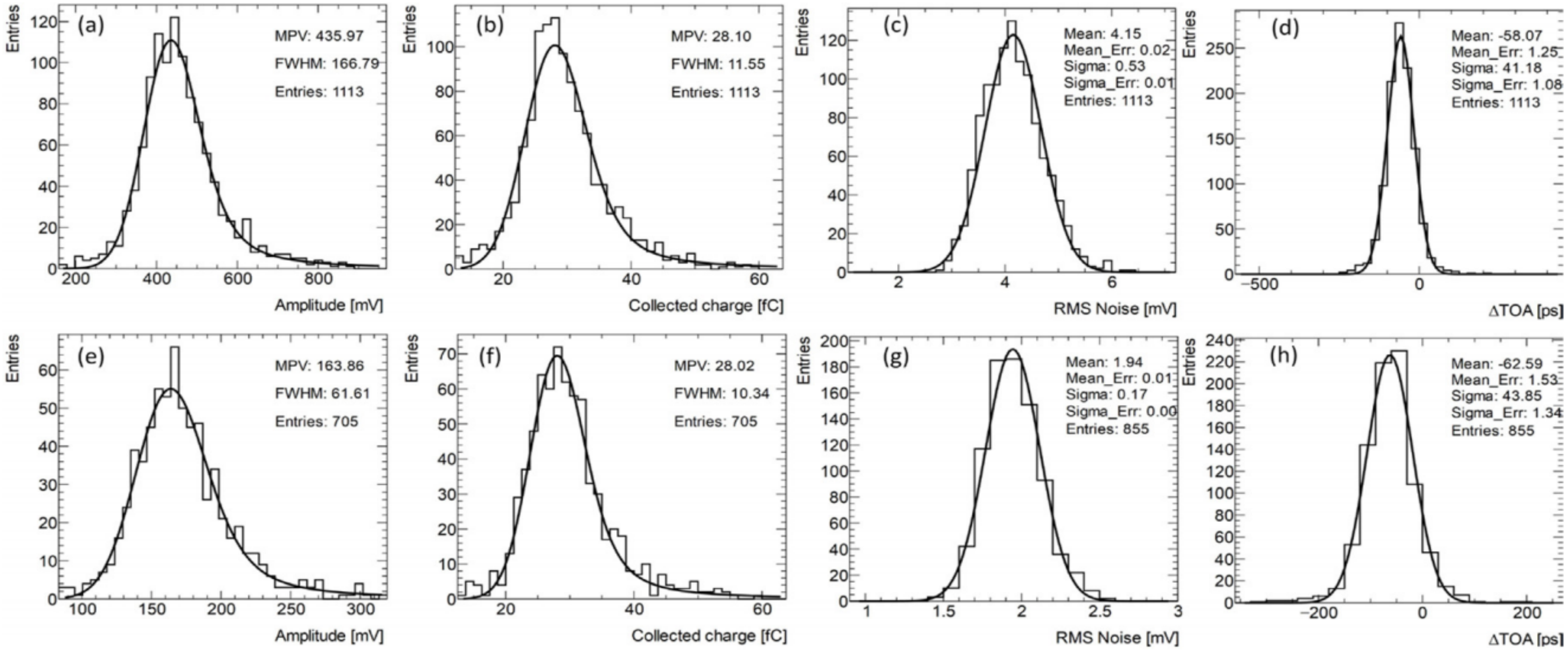


Distributions of output amplitude (a), collected charges (b), RMS noises (c), and ΔTOA (d) measured with our single-channel boards and un-irradiated HPK Type 3.1 single LGADs at −180 V bias and 20 ◦C, and corresponding results (e–h) is measured with UCSC boards and the 2nd stage amplifiers.

Nuclear Inst. and Methods in Physics Research, A 1040 (2022) 167222

Test results

- β-scope tests -30℃
  - The ENC and SNR using our boards and the UCSC boards are 0.26 fC, 105.05, and 0.33 fC, 84.46,respectively.
  - The time resolutions using the two types of boards are 29.12 ps and 31.01 ps.



Distributions of pulse amplitude (a), collected charges (b), RMS noises (c), and ΔTOA (d) measured with our single-channel boards and un-irradiated HPK Type 3.1 single LGADs at −180 V bias and −30 ◦C, and corresponding results (e–f) is measured with UCSC boards and the 2nd stage amplifiers.

Test results

- β-scope tests summary

β-scope test results using our single-channel boards and UCSC boards (with 2nd stage amplifier) with un-irradiated HPK Type 3.1 single LGADs at 20 ◦C and −30 ◦C.
Sensor type: Un-irradiated HPK Type 3.1 single LGADs Bias Voltage: −180 V

Board type	USTC board		UCSC board	
Temperature	20℃	-30℃	20℃	-30℃
Amplitude MPV (mV)	197.3	435.97	58.51	163.86
Collected charges MPV (fC)	11.21	28.10	10.39	28.02
Mean RMS noise (mV)	**4.81**	**4.15**	**1.96**	**1.94**
$\sigma_{\Delta TOA}$ (ps)	62.91	41.18	65.06	43.85
Time resolution (ps) ($\sigma_{\Delta TOA}/\sqrt{2}$)	**44.49**	**29.12**	**46.01**	**31.01**
SNR (Amplitude MPV/ Mean RMS noise)	40.96	105.05	29.85	84.46
σ_{Jitter}(ps)(t_r/SNR)	**7.12**	**2.78**	**9.78**	**3.46**
ENC (fC) (Collected charges MPV/SNR)	0.27	0.26	0.35	0.33

- The results show that our boards have a better noise and time performance

Nuclear Inst. and Methods in Physics Research, A 1040 (2022) 167222

Test results

- Multi-channel preamplifier board tests

Charge gain and RMS noise of each channel on 9-channel board.

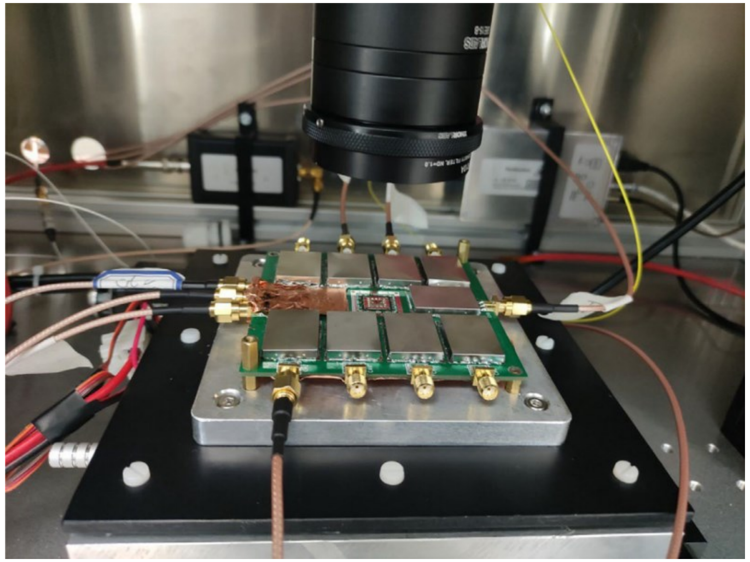
Channel number	1	2	3	4	5	6	7	8	9
Mean RMS noise (mV)	4.83	5.12	4.57	4.49	4.36	4.38	4.21	4.55	4.48
Charge gain (mV ns/fC)	18.75	18.56	19.01	18.17	18.25	18.16	18.15	17.80	17.68

The average charge gains of the 9 channels are 18.35 mV ns/fC, and the standard deviation is 0.39 mV ns/fC, showing a good uniformity.

Mean and sigma of collected charges and TOA distributions of channel 2, 3, 5, 9, measured with our 9-channel board and un-irradiated HPK Type 3.1 2 × 2 sensor at room temperature.

Channel number		2	3	5	9
Collected charges (fC)	Mean	40.19	40.67	41.91	43.93
	Sigma	1.30	1.18	1.30	1.40
TOA (ps)	Mean	4186.20	4178.97	4201.20	4204.83
	Sigma	15.48	15.10	14.84	15.19

The overall jitter of the test system is about 15 ps. It suggests that the 9-channel board works well for the readout of multi-pad LGADs.



Setup for laser-scanning TCT tests

Summary

- Compared to the UCSC single-channel preamplifier board followed by an external 2nd stage voltage amplifier, our board has a larger charge gain, higher SNR (or lower ENC), lower jitter, and simpler structure.
- A 9-channel preamplifier board, each channel of which has the same design as the single-channel preamplifier, is also developed for simultaneous readout of multiple LGAD channels.
- The electronic test results show that the total charge gain of our single-channel preamplifier reaches 20.58 mV ns/fC, with good linearity (maximum INL is 0.7%) in the input dynamic range ([0.7 fC, 66 fC]). The bandwidth of the amplifier is about [1.5 MHz, 872 MHz] with a voltage gain of 48.50 dB on the passband.

Thanks

Thanks for your attention!