Use of 'LGAD' ultra-fast silicon detectors for time-resolved low-keV X-ray science

S. M. Mazza, C. Gee, H.F.W. Sadrozinski, B.A. Schumm,
A. Seiden, R. Padilla, Y. Zhao

The recent development of silicon diode Low Gain Avalanche Detectors (LGADs) [1, 2]. has enabled the design of granular (∼1x1 mm^2) fast-timing layers for the ATLAS and CMS tracking systems at the HL-LHC. These systems will allow the determination of the time-of-passage of minimum ionizing particles to a precision of better than 50 ps [3].

The essential design aspects of the LGAD can be described as: a region "p++" with a dopant concentration significantly greater than that of the bulk "p" region. This leads, after depletion, to an electric field large enough to provide amplification (by as much as a factor of 70) through multiplication of the signal. Because of this amplification, the "p" region can be made very thin (50 μm or less), leading to a fast signal and, in turn, precise timing.

Recently, groups developing LGADs for use in these particle physics applications have begun to explore the possibility of their application to other fields of science and technology [4].

In particular, the group at SCIPP (UC Santa Cruz) has become interested in the possible use of LGADs in the development of X-ray cameras with frame rates in excess of 100 MHz. The data shown here was taken at the Stanford Light source (SSRL) as shown in reference [5] and at the Fermilab testbeam facility as shown in reference [6].

As show in Figure 1 (Left) LGADs can detect low energy X-rays with a reasonable energy resolution (8% to 15%) thanks to the internal gain. In Figure 1 (Right) is shown how a thin LGAD can resolve single X-ray interaction in a bunch train of 500 MHz repetition rate.

A current limitation of classic LGAD technology is the granularity. Due to the high field in the multiplication layer, protection structures are needed at the edge of the readout pads. This introduces a dead region between pads, limiting the granularity. However several new technologies are being studied to overcome this limitation as outlined in these references [7, 8, 9]. These technologies, when refined, will allow to produce finely segmented LGADs to be used for X-ray detection.

In reference [6] it is shown how a spatial resolution of 10 μm or less is achievable with AC-coupled LGADs (FBK RSD production) using the shared charge information from several pads. The spatial resolution for different pad and pitch sizes is summarized in Figure 2.

The conclusion can be made that LGADs with a modest granularity (∼1x1 mm^2) are already capable of detecting low energy X-ray with a ∼ 10% energy resolution even in high repetition rate environment up to 500 MHz and more. New technologies will allow the LGAD granularity to be reliably reduced to the scale of 50 μm or less as was already shown possible for AC-LGAD devices. The internal gain, fast full charge collection time, modest energy resolution and precise position resolution would make LGAD devices suitable for low energy X-ray cameras with frame rates in excess of 100 MHz.

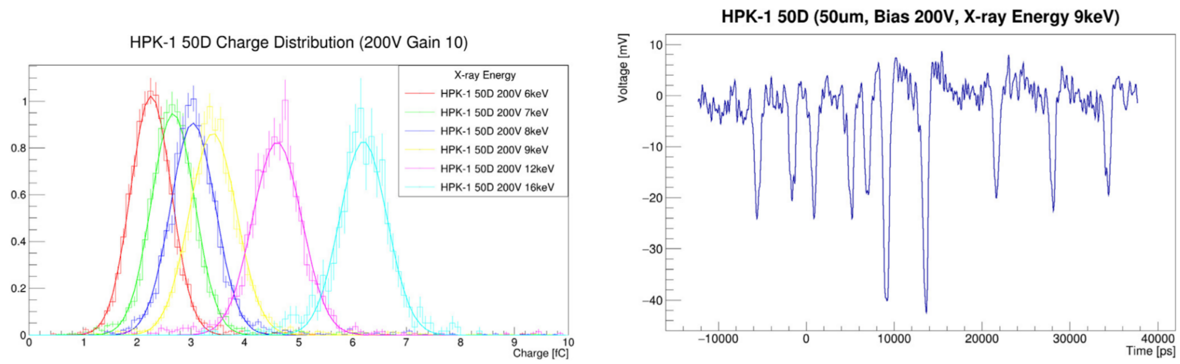

Figure 1: Left: Pulse-height distribution obtained by selecting events only single-absorption events, as described above, for each of the SSRL beam energies studied during the run. Right: Temporal response of a conventional LGAD to a 500 MHz stream of 9 KeV photons produced by the SLAC SSRL. [5]

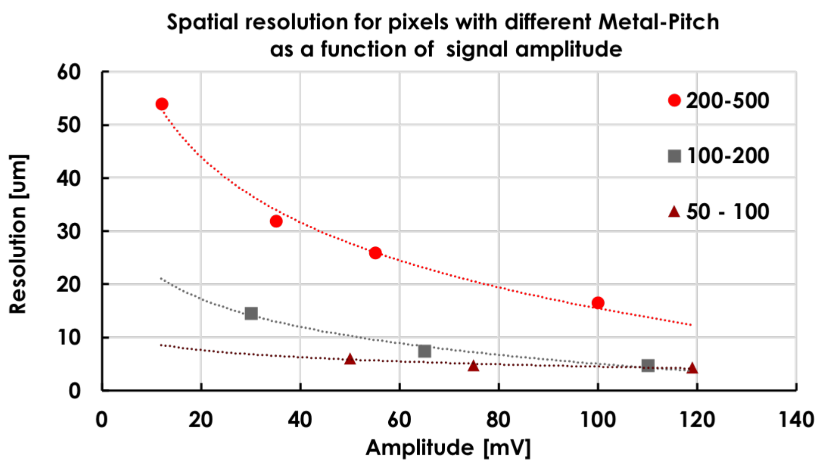

Figure 2: Spatial resolution on a AC-LGAD (FBK RSD production) represented as a function of signals amplitude for three pad-pitch geometries: 50-100, 100-200 and 200-500. [6]

References

[1] G. Pellegrini et al., *Technology developments and first measurements of Low Gain Avalanche Detectors (LGAD) for high energy physics applications*, *Nucl. Instrum. Meth.* **A765** (2014) 12 – 16.

[2] H. F. W. Sadrozinski et al., *Ultra-fast silicon detectors (UFSD)*, *Nucl. Instrum. Meth.* **A831** (2016) 18–23.

[3] ATLAS, *Technical Proposal: A High-Granularity Timing Detector for the ATLAS Phase-II Upgrade*, Tech. Rep. CERN-LHCC-2018-023. LHCC-P-012, CERN, Geneva, Jun, 2018.

[4] N. Moffat, R. Bates, M. Bullough, L. Flores, D. Maneuski, L. Simon et al., *Low gain avalanche detectors (LGAD) for particle physics and synchrotron applications*, *Journal of Instrumentation* **13** (mar, 2018) C03014–C03014.

[5] Z. Galloway, C. Gee, S. Mazza, H. Ohldag, R. Rodriguez, H.-W. Sadrozinski et al., *Use of "lgad" ultra-fast silicon detectors for time-resolved low-kev x-ray science*, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **923** (2019) 5 – 7.

[6] M. Tornago et al., *Resistive AC-Coupled Silicon Detectors principles of operation and first results from a combined laser-beam test analysis*, `arXiv:2007.09528`.

[7] N. Cartiglia, Signal formation and designed optimization of Resistive AC-LGAD (RSD), "`https://indico.cern.ch/event/813597/contributions/3727782/`."

[8] S. Mazza, Deep Junction LGAD: a new approach to high granularity LGAD, "`https://indico.cern.ch/event/813597/contributions/3727775/`."

[9] B. Schumm, Low Gain Avalanche Detectors: Towards Higher Granularity and Repetition Rate, "`https://agenda.hep.wisc.edu/event/1391/session/12/contribution/59`."