# CSPAD-140k - a Versatile Detector for LCLS Experiments

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**Abstract**

With the successful operation of three 2.3 megapixel, 120Hz readout rate, hybrid pixel array detectors at the Linac Coherent Light Source (LCLS), the SLAC National Accelerator Laboratory detector group is now exploring additional applications based on the same detector platform. These megapixel cameras are based on the Cornell-SLAC hybrid Pixel Array Detector (CSPAD).
The CSPAD platform is developed around the CSPAD ASIC, a 36 kilopixel device, each pixel at 110x110µm$^2$. Important characteristics of the CSPAD (room temperature operation, 14bit on chip digitization with a purely digital data interface, and scaling modularity) make it an effective choice for designing detector variants that are optimized for a range of experiments and applications.
One of the first spin-off detectors based on this proven CSPAD platform is the CSPAD-140k: a 140 kilopixel detector, with an active area of approximately 4x4cm$^2$ and four ASICs, bundled in a small, inexpensive and easy-to-deploy package. Due to its versatility it has already been used successfully in several experiments at the CXI, XPP and XCS instruments at LCLS. The work also describes problems faced by scaling from a prototype system to a full size x-ray camera and presents the current status on the improvements achieved.

Keywords: hybrid pixel detector; free electron laser; electronics; ASIC; CSPAD;

## Introduction

With the successful operation of three 2.3 megapixel, 120Hz readout rate, hybrid pixel array detectors at the Linac Coherent Light Source (LCLS), the SLAC National Accelerator Laboratory detector group is now exploring additional applications based on the same detector platform. These megapixel cameras are based on the Cornell-SLAC hybrid Pixel Array Detector (CSPAD) [1][2][3], particularly the hybrid pixel detector ASIC. This ASIC, with 194x185 pixels of 110x110µm$^2$ size, is the central component of the CSPAD platform. Two ASICs, bump bonded to a single 500µm-thick high-resistivity silicon pixel array sensor, constitute a 2x1 module, which is the basic building block of all CSPAD cameras. The first detector variant based on this proven platform, the CSPAD-140k, uses two of these blocks, glued to a carrier, building up a 2x2 module with a total of about 140 kilopixels. The CSPAD-140k (Figure 1) is a 140 kilopixel detector, with an active area of approximately 4x4cm$^2$, bundled in a small, low-cost and easy-

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to-deploy package, suitable for various synchrotron and FEL applications. Development and performance optimization of this detector will be discussed in the following paragraphs.

(Figure 1 here; caption: The CSPAD 140k detector, an evolution of the pixel array detectors used successfully with megapixel cameras at LCLS.)

**Electronics and ASIC**

The pixel architecture is shown in Figure 2. It consists of a charge sensitive amplifier with two gain settings for collecting the detected signal. The sample and hold stage captures the amplifier output voltage and stores it for digitization. A comparator triggers when an externally supplied ramp falls below the stored signal voltage. A counter counts the clock cycles from the ramp start to the time point when the comparator fires. This implements a single slope analog to digital (A/D) converter. The counter values of all pixels are then readout one after the other.

(Figure 2 here; caption: Circuit diagram for a single CSPAD pixel. Functional elements in this circuit are described in the text.)

Basic parameters of the CSPAD ASIC are summarized in Table 1 and [1][2][3].

| | |
|---|---|
| pixel size | 110µm x 110µm |
| ASIC size | 185 x 194 pixels |
| frame rate | 120Hz |
| effective noise | 300e- in HG; 1000e- in LG |
| single 8keV Photon SNR | 7 in HG; 2 in LG |
| maximum photon count | 350 in HG; 2700 in LG |

[Table 1; caption: Basic physical and performance parameters of the CSPAD ASIC. (HG: high gain, LG: low gain mode)]

The first measurements performed at LCLS with a large 2.3 megapixel camera revealed that the single photon gain is smaller than expected from simulations and measurements with the prototype system. A comparison is shown in Figure 3. (Figure 3 here; caption: Comparison of a Monte Carlo simulated pixel histogram and a measured histogram. The Monte Carlo simulation used the CSPADs design parameters. The measurement was performed with an early 2.3 megapixel CSPAD version. The histogram shows the noise peak and the single 8keV photon peak. The measured gain for small signals is 4 times smaller than expected.) Further studies with these cameras showed complex crosstalk behavior between the pixels, partially due to on-chip and partially due to chip-PC-board-system interaction. The CSPAD-140k is especially suited for debugging these effects, as the 2x2 module with 4 ASICs is considerably simpler than the 2.3 megapixel cameras with 64 ASICs, while still using similar electronics and power cycling features. The electronics used in the CSPAD-140k are also much more easily accessible for probing or making modifications.

Figure 4 shows the measured ramp function with and without the ASIC. It can be seen that the firing of all the comparators within a short time modifies the external ramp signal. The modified ramp shows an undershoot, which accelerates the firing of comparators that have not yet reached their firing level. (Figure 4 here; caption: Screenshot of the ramp measured with and without the ASICs. The difference between the two ramp functions is shown in the lower trace with a fivefold magnification of the amplitude. The ramp exhibits undershoot when most of the comparators fire and the counters stop

counting.) Another aspect of this inter-pixel crosstalk is the modification of the ASIC bias voltages. Figure 5 shows the four external bias nodes during the A/D conversion process. (Figure 5 here; caption: Screenshot of the ASIC bias nodes during the A/D conversion process. When most pixels stop counting the comparator bias nodes exhibit undershoot.) When most of the comparators fire, the bias voltage nodes of the comparators exhibit undershoot. This undershoot increases the effective bias current in the comparators, which in turn makes the comparators faster and therefore fire earlier, increasing the correlation of comparator firing. This effect is amplified by the on-board circuitry that is needed for power cycling the LCLS 2.3 megapixel CSPAD cameras: in order to switch the biases on and off at a rate of 120Hz, the nodes cannot simply be tied to a constant voltage. The local power regulators, which have to serve up to 16 ASICs, cannot respond fast enough to sudden changes in supply current when many counters stop clocking. In the current compact camera design, the impulse response on the power nodes feeds through to the ramp generation circuitry.

The small signal gain of a pixel depends on the actual ramp steepness the pixel sees around its pedestal value, and therefore on the comparator firing time. Figure 6 shows the measured variation of the gain of a pixel plotted against its average pedestal value (Figure 6 here; caption: Measured variation of the gain of a CSPAD pixel plotted against its average pedestal value. After the first pixel comparators fire the gain breaks down and most pixels show a small gain. Pixels with comparators which fire late show almost nominal gain). It can be seen that the majority of the pixels exhibit a smaller gain for small signals. This apparent smaller gain also affects the measured noise. In contrast, large signals will show the real gain. Furthermore, a camera showing the above effects can exhibit large signal crosstalk when areas of an ASIC are heavily illuminated, resulting in pedestal changes of the non-illuminated regions. As designed, the comparators in illuminated pixels fire later; therefore, their crosstalk contribution is missing at the time the comparators of the non-illuminated pixels fire. Due to this sequence, the comparators in the non-illuminated regions will fire on average a bit later, resulting in an unexpected increase of their digital pedestal value.

Modifications in the PCB power supply and improved bias and ramp generation have helped mitigate pixel crosstalk, and the new resulting cameras show a behavior much closer to the expected performance. As an example of the improved performance, Figure 7 shows a single photon histogram of copper fluorescence from a typical pixel measured with the CSPAD-140k. (Figure 7 here; caption: Measured histogram of a CSPAD-140k pixel illuminated with copper fluorescence in high gain mode.)

**CSPAD-140k: camera and applications at LCLS**

The pulsed nature of the LCLS allows using very short integration times. The CSPAD's hybrid pixel design enables electronic shuttering with signal integration times in the microsecond range; therefore, the detector can operate at room temperature without performance degradation from leakage current. For operation in vacuum, the temperature is stabilized by water cooling. For applications which need longer integration times, like experiments at synchrotrons, the design also supports utilization of a Peltier element to cool the detector. Figure 1 shows the basic elements of the CSPAD-140k camera. The camera housing, which includes the detector-ASIC hybrid and support electronics, is approximately 23.6cm long, 4.4cm wide and 4.8cm tall. Behind a black kapton window is a 2x2 module with approximately 4cm x 4cm active area and about 140 kilopixels. The CSPAD-140k module uses a fiber-optic interface to transfer data to the data acquisition system. Power and trigger signals are routed via a 26pin DSUB connector. The result is a small but robust interface which enables convenient deployment of the detector in an experiment chamber.

A variant designed with slight modification to the package has been built for installation at the MEC instrument, where it will be used as a suitable alternate detector capable of 120Hz readout, replacing a slow CCD camera in a Thomson spectrometer setup. Figure 8 shows a drawing of the MEC spectrometer with the CSPAD-140k (Figure 8; caption: View of a CSPAD-140k integrated as detector of a spectrometer in which will be used by the MEC instrument at LCLS).

A major advantage of the small and modular design of the CSPAD-140k is the capability to deploy multiple detectors in various mechanical arrangements. An interesting application of multiple CSPAD-140k modules is to tile them into an arc-like configuration in order to cover a larger angle relative to the interaction point. The multiple single-detector units represent a dedicated compound detector from the data acquisition system point of view. Figure 9 shows the concept for an upcoming experiment at the CXI instrument at LCLS (Figure 9; caption: View of an array of CSPAD-140k detectors organized in a compound detector; this design is under consideration for an upcoming experiment using the CXI instrument at LCLS).

The CSPAD-140k has already been used successfully in several experiments using the CXI [4], XPP and XCS instruments at LCLS. As an example, Figure 10 shows a single shot small angle scattering image recorded with CSPAD-140k using the XCS instrument. A dried colloidal dispersion was illuminated with unfocused monochromatic beam of 9.48keV energy. The detector was located 7.8m behind the sample.

(Figure 10; caption: Single shot image recorded with the CSPAD-140k using the XCS instrument of LCLS. A dried colloidal dispersion is illuminated with the LCLS unfocused beam at 9.48keV energy. The detector was located 7.8m behind the sample).

**Conclusions**

A small versatile x-ray camera based on the CSPAD platform has been built at SLAC. This system helped to characterize and improve the performance of all CSPAD cameras. In addition the CSPAD-140k has already been used for several experiments at LCLS and many more applications for this detector at synchrotrons and FELs are expected.

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**Figure 1**

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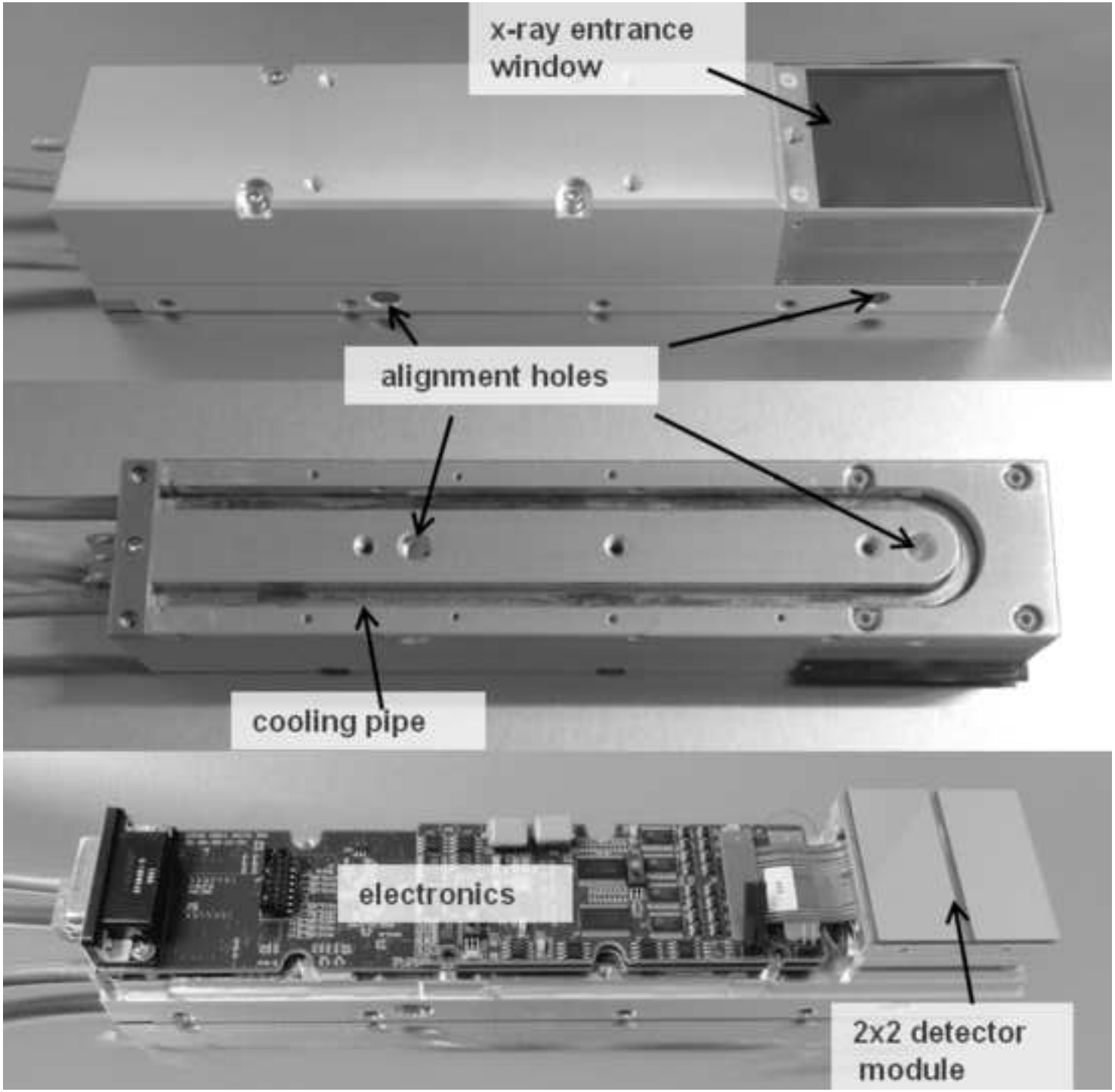

**Figure 2**

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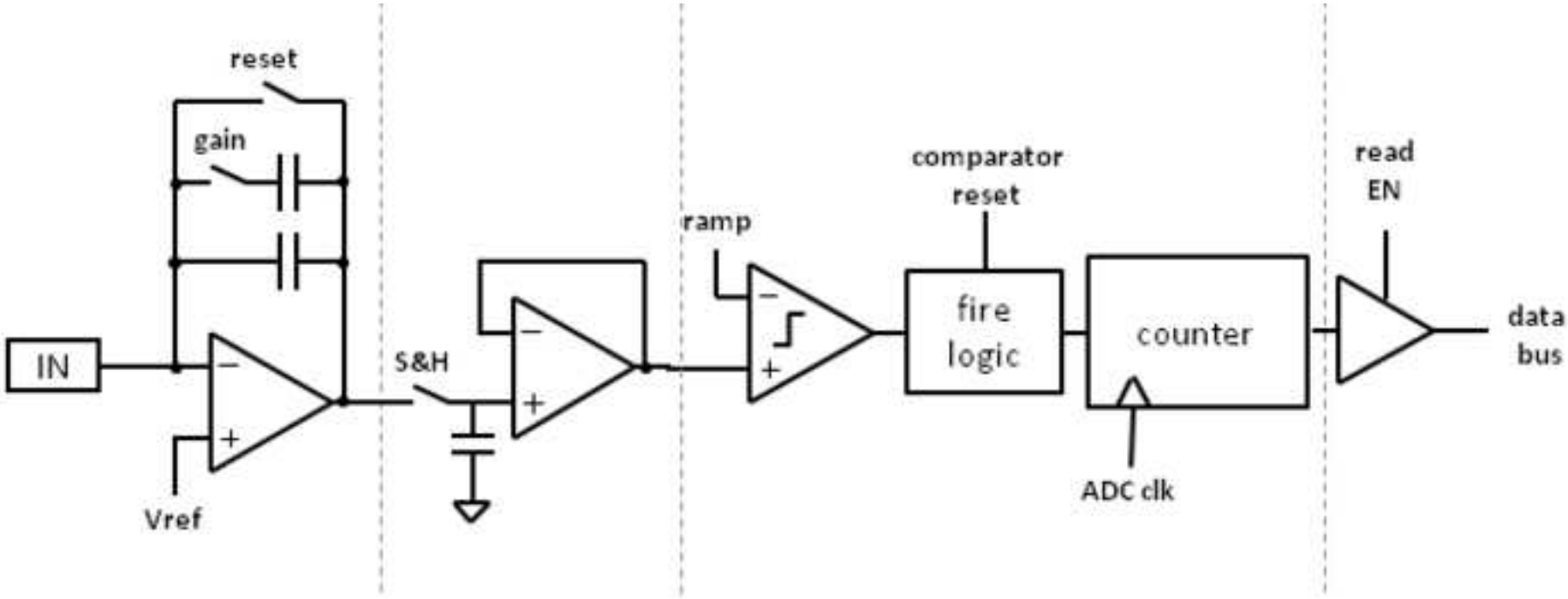

**Figure 3**

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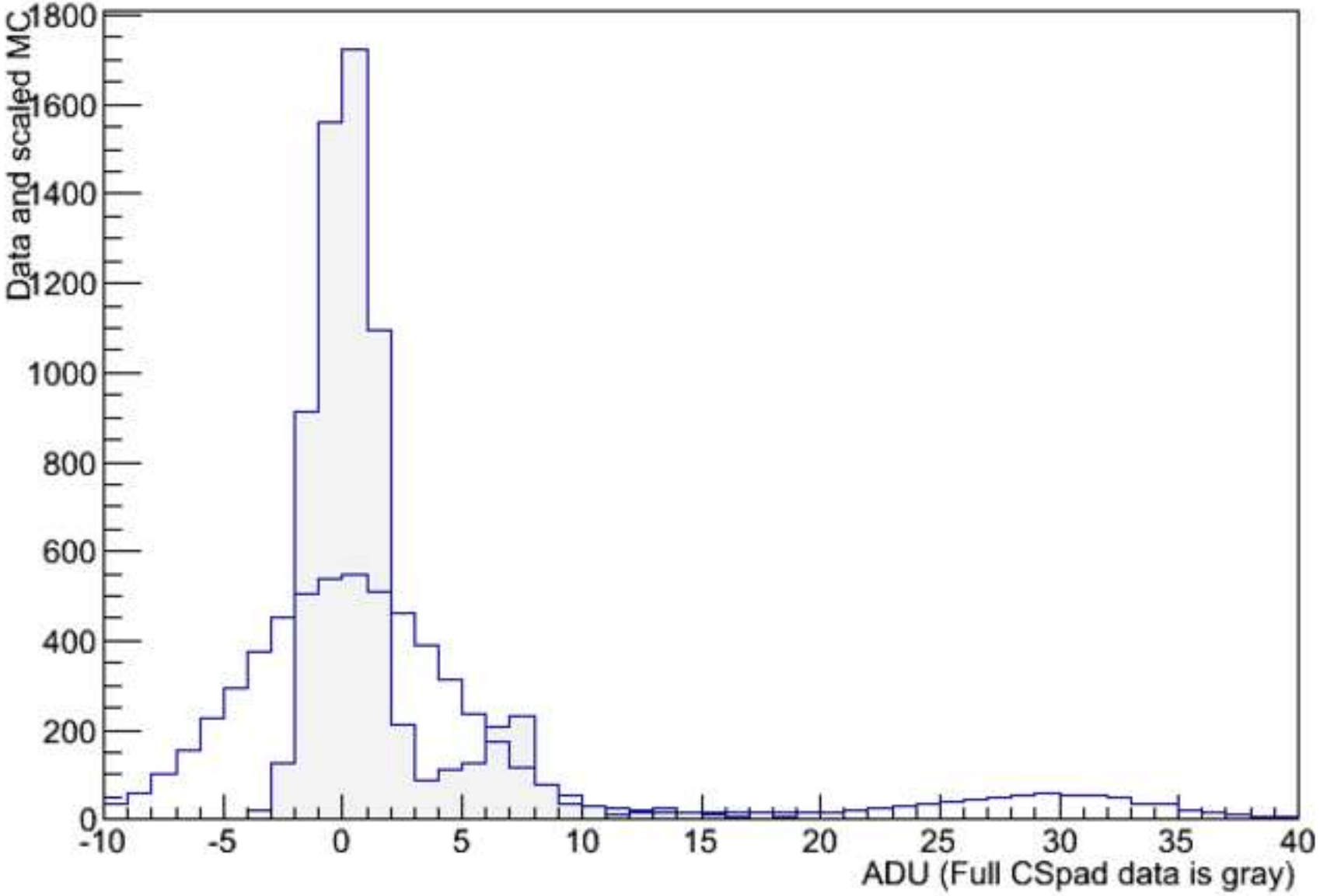

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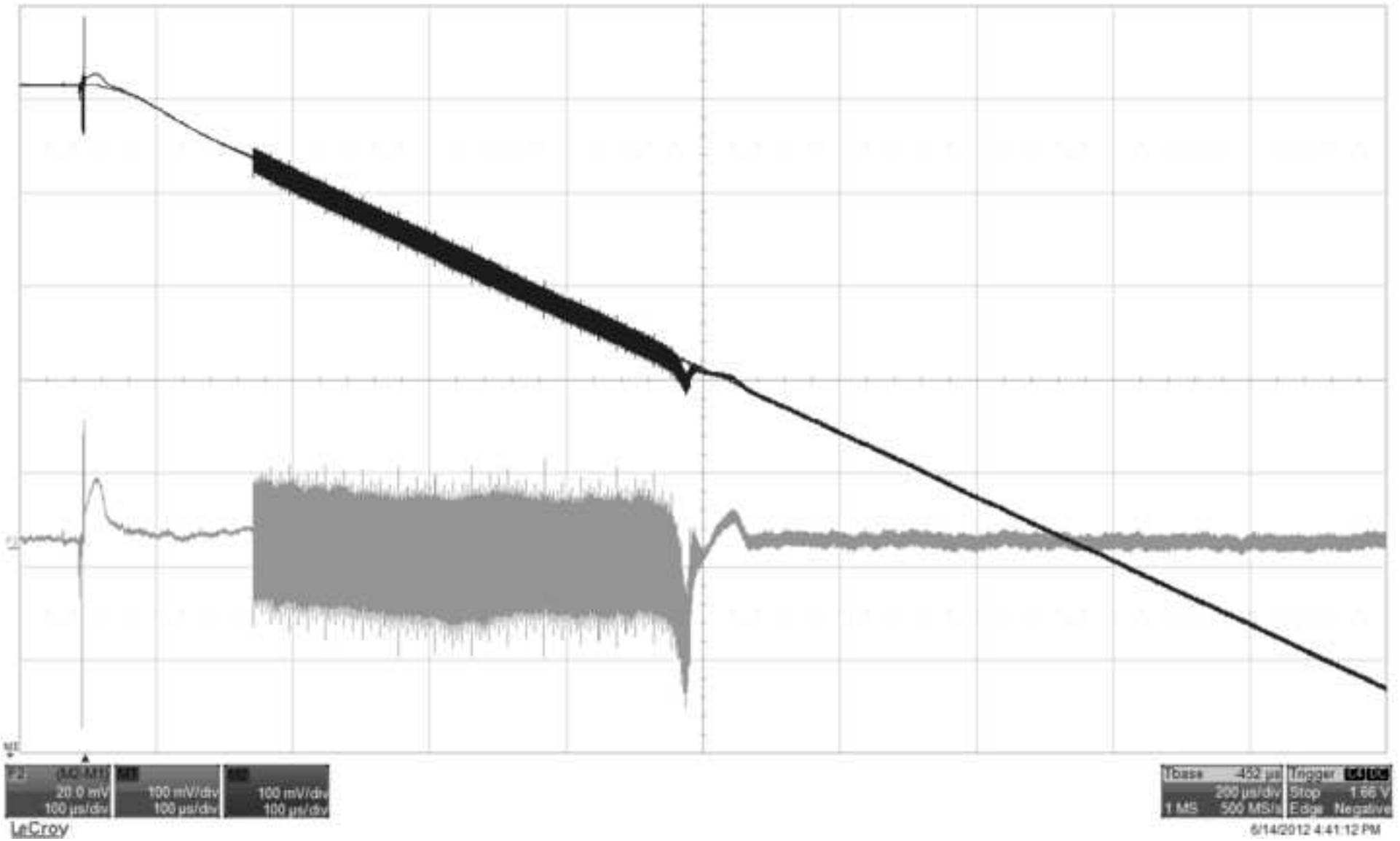

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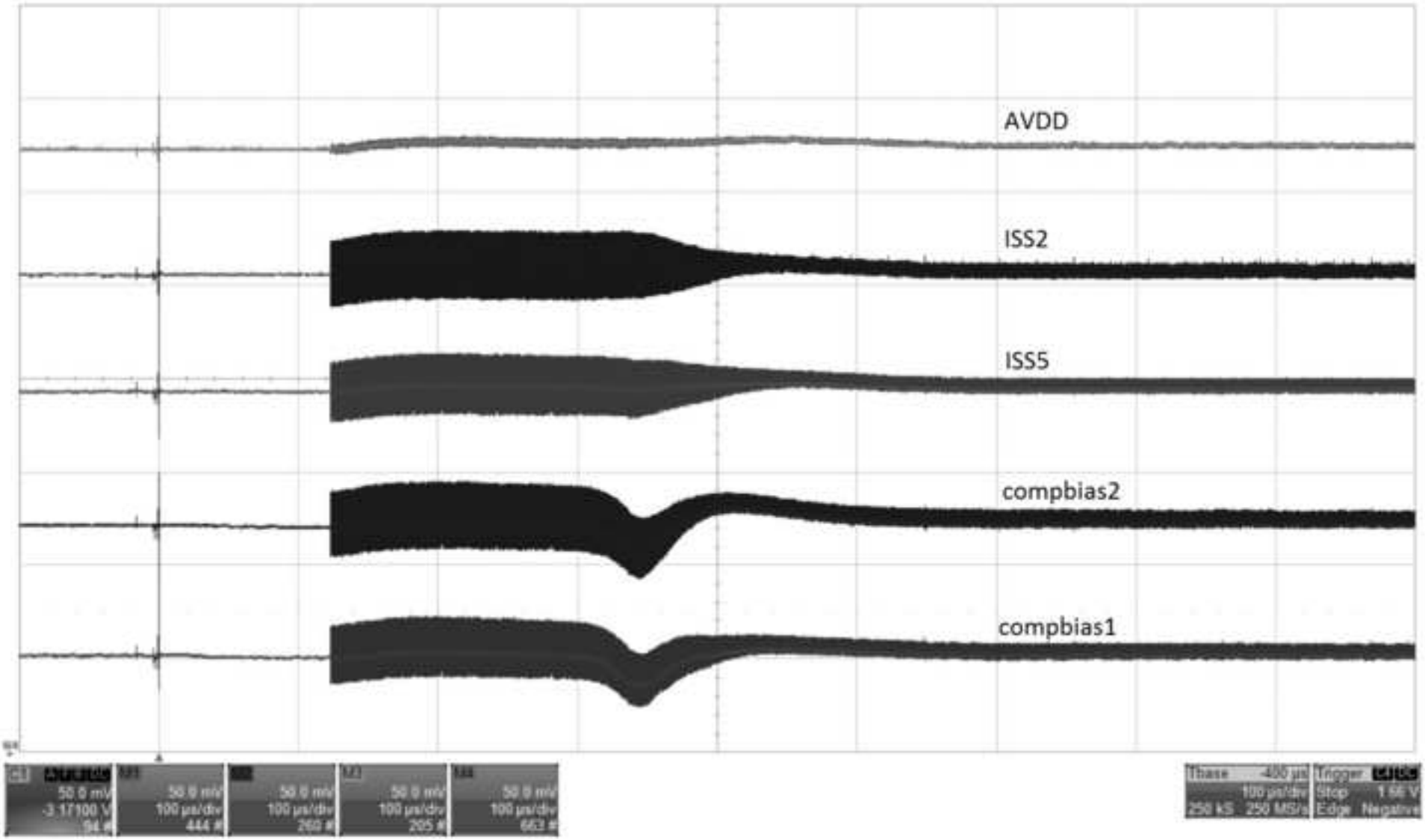

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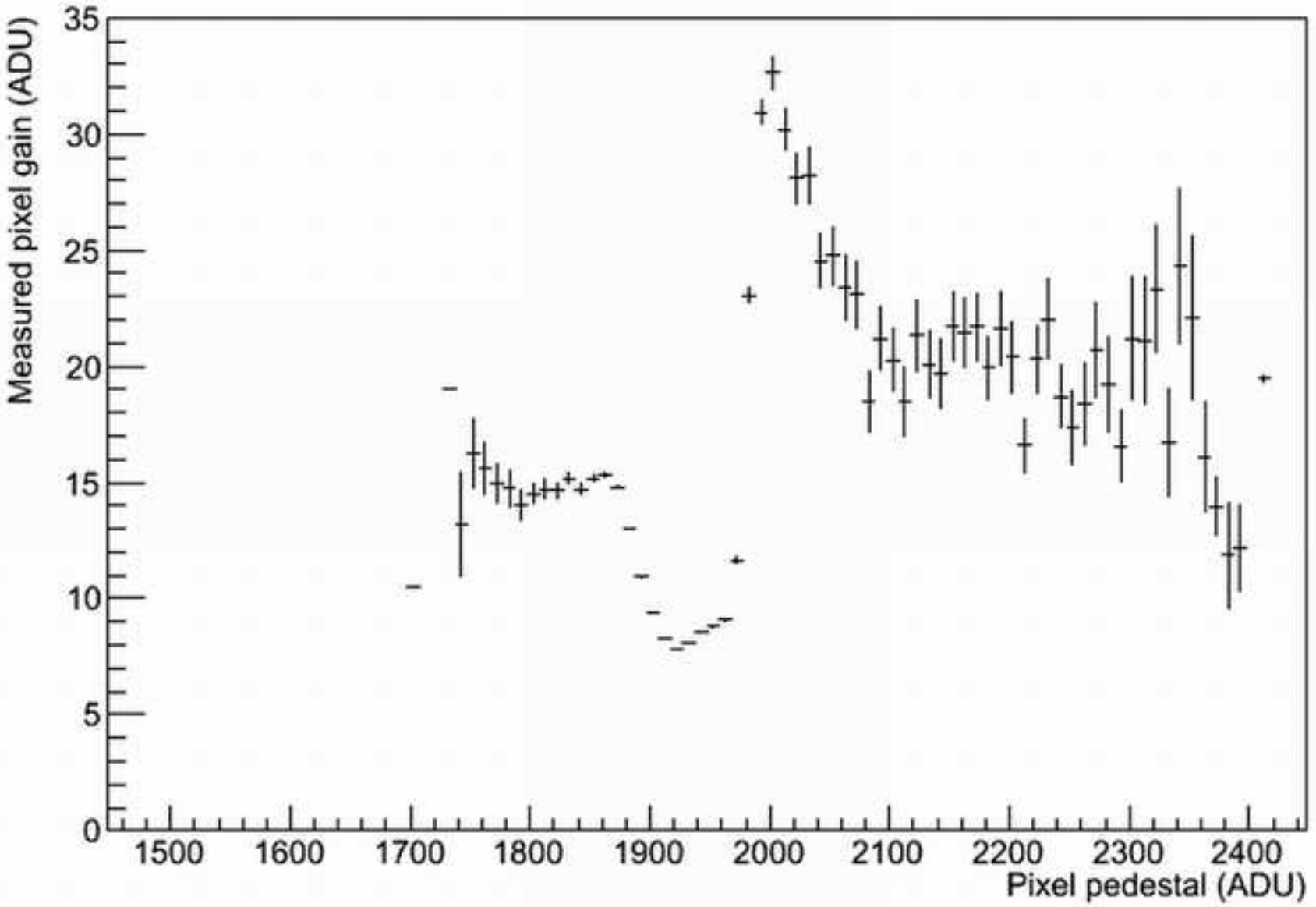

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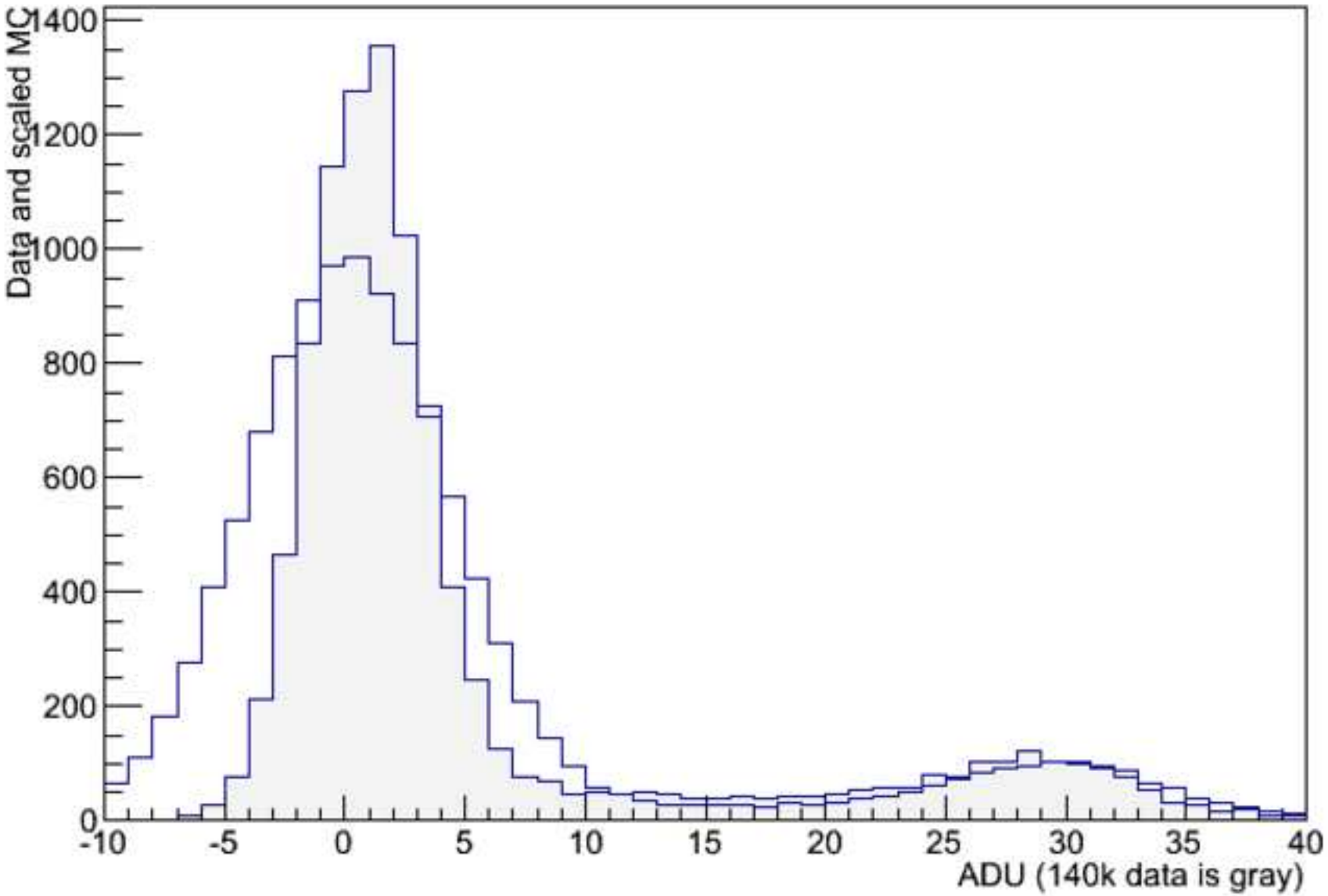

**Figure 8**

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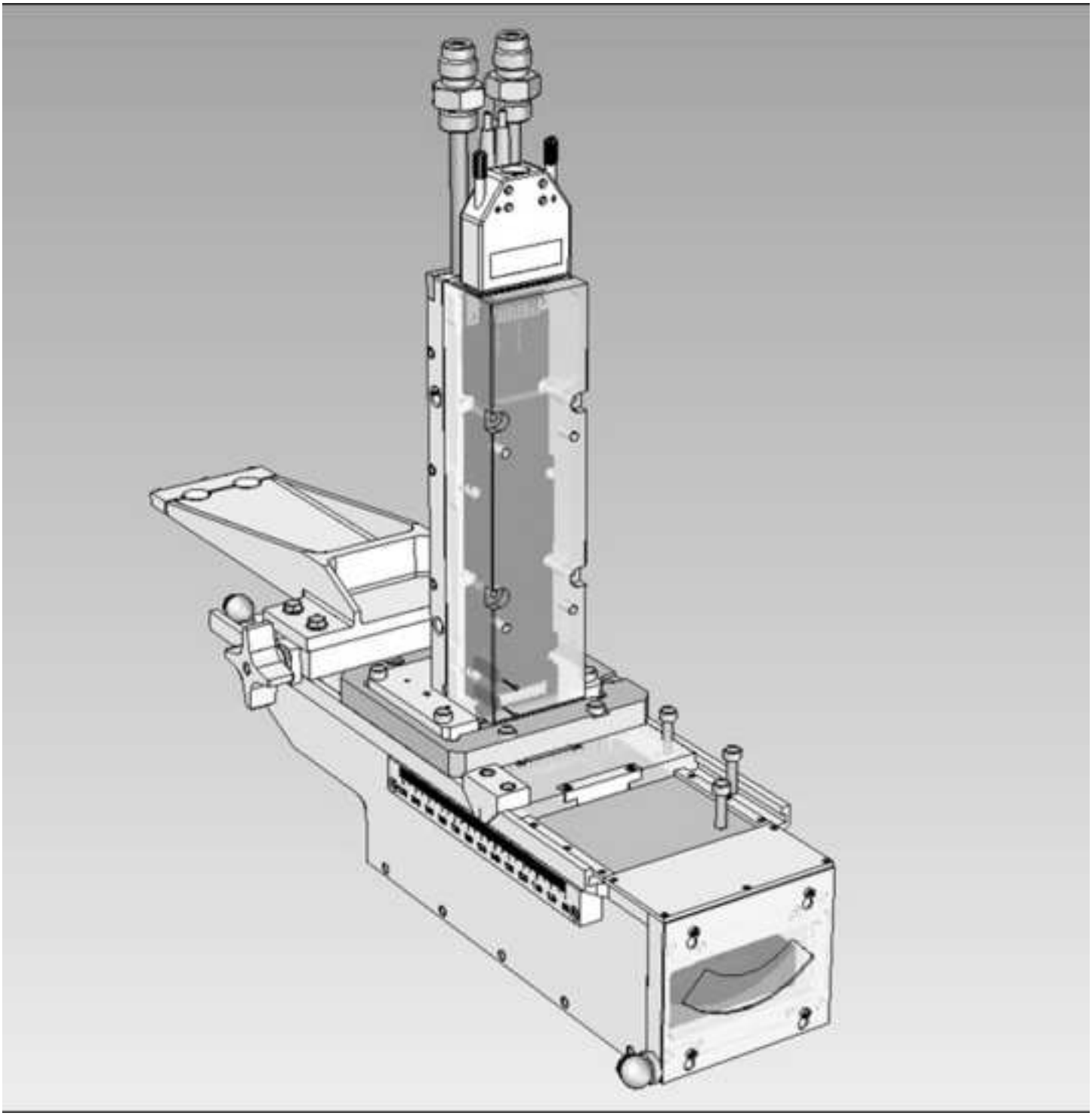

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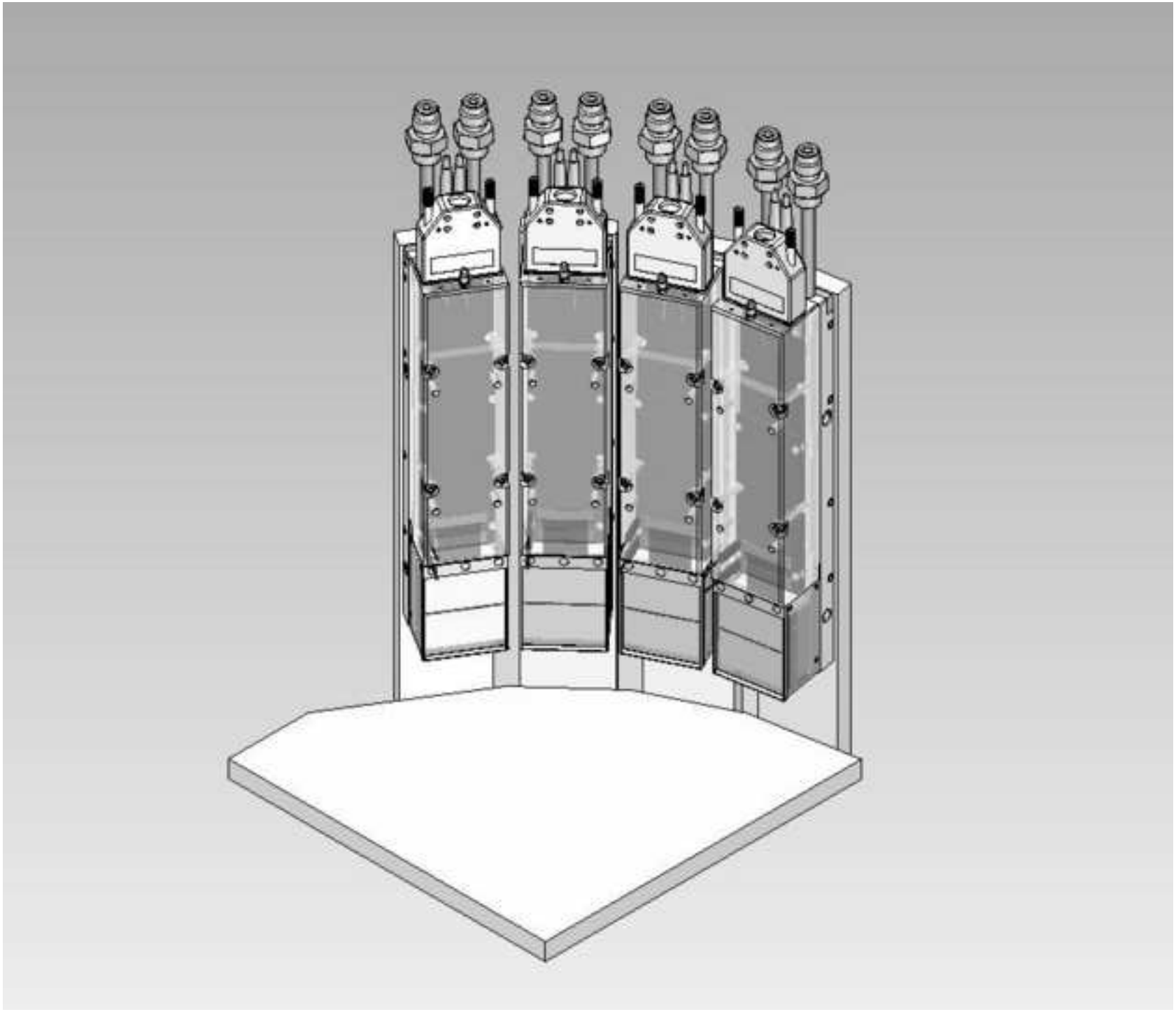

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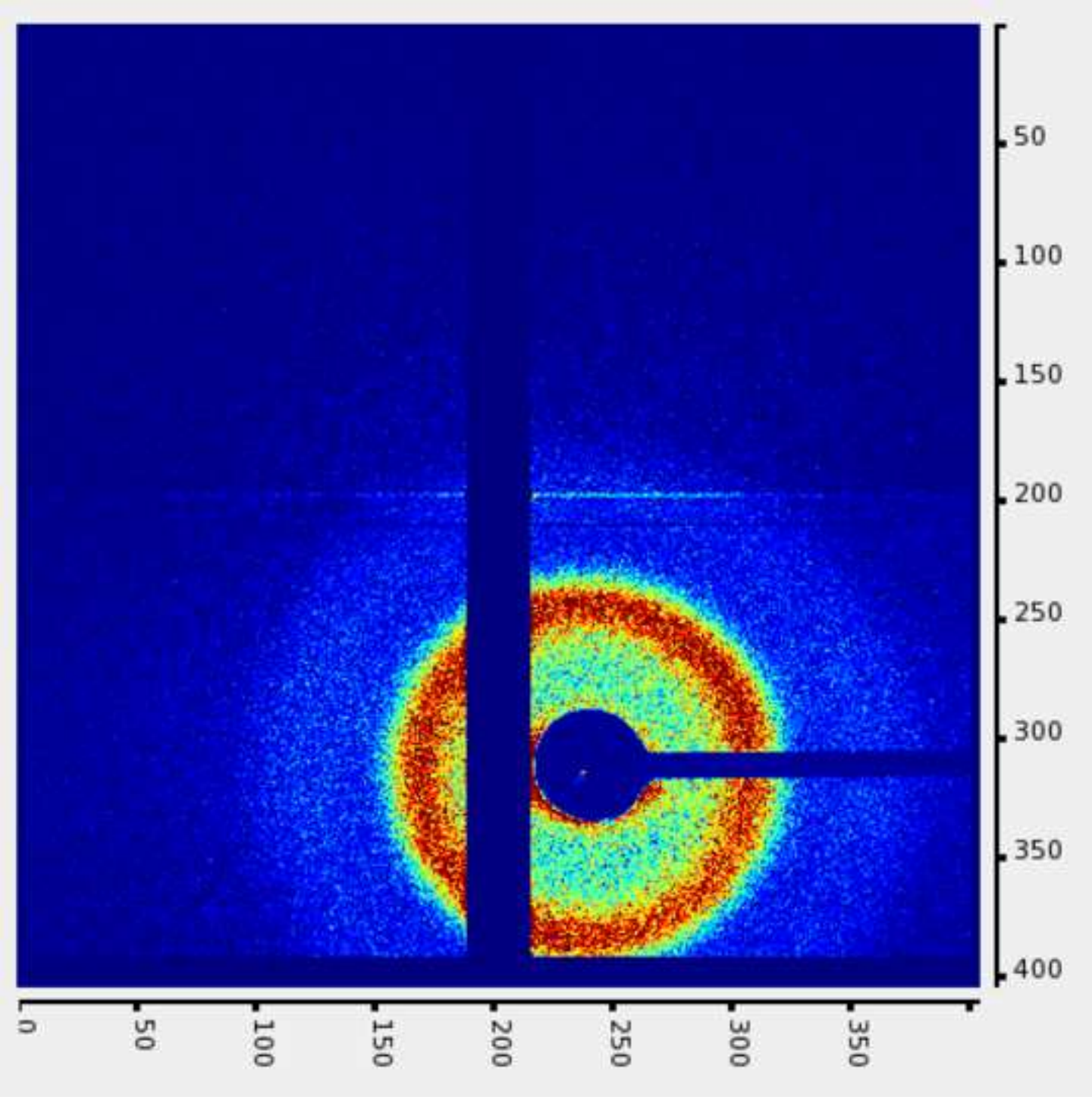

**Figure 10 (greyscale)**
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