New digital algorithms for achieving sub-pixel resolution in hybrid pixel detectors working in single photon counting mode.

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HYBRID PIXEL DETECTORS DEALING WITH CHARGE SHARING

Hybrid pixel detectors are segmented devices used for photons and particles detection, consisting of a sensor and readout electronics. To improve the resolution of the detector and allow operation with high intensity photon fluxes, a pixel size is reduced. However, with decreasing pixel size, a charge sharing effect is more significant. To detect a photon irrespectively of charge sharing effect, the total photon energy should be reconstructed from fractional signals.

Therefore, the algorithms dealing with charge sharing are developed [1]. The spatial resolution of such detectors is limited by the pixel size, which must be large enough to fit all the functionality required by the complex algorithms. However, there are known methods applied for high energy physics [2] or integrating X-ray detectors that can improve the spatial resolution of a detector [3].

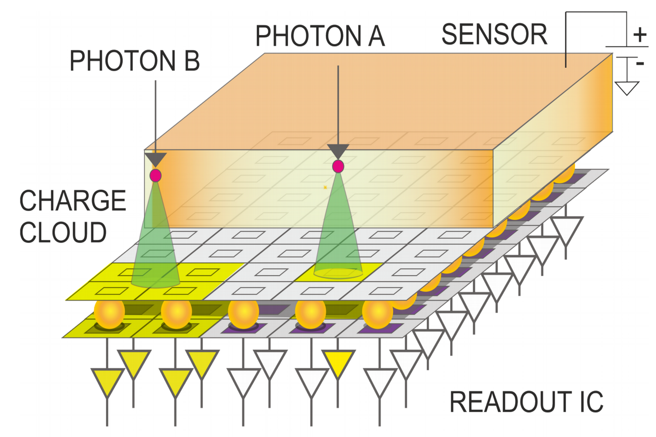

Fig. 1 The operation of a semiconductor hybrid pixel detector in case of charge sharing. (Fig. From [4])

THE REQUIREMENTS FOR THE ALGORITHM ACHIEVING SUB-PIXEL RESOLUTION

An alternative digital solution can be implemented on-chip dedicated to hybrid pixel detectors working in single photon counting mode. In this approach, charge sharing becomes the desired effect, since the information on the proportions of charge collected by the neighbouring pixels can be used to estimate the photon interaction position with a sub-pixel resolution.

MODEL ASSUMPTIONS

Sensor type	Photon Energy [keV]	Pixel size [μm]	Noise RMS [e-]	Erf^{-1} approx. error [μm]
Si	8	100	100	+/-0.03

OPTIMIZING CHARGE CLOUD SPREAD

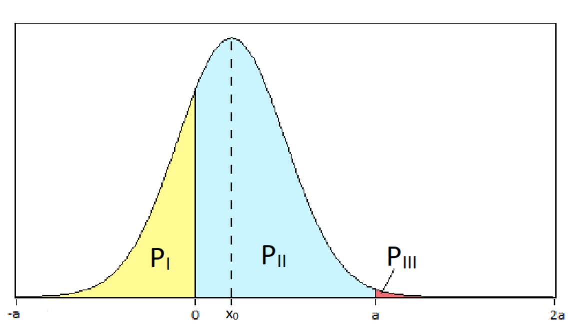

Fig. 2 Charge cloud distribution, a is pixel size, P_I, P_{II}, P_{III} - probability of charge collected by subsequent pixels, x_0 - interaction position.

To determine hit position x_0 based on the charge cloud distribution the inverse error function is used. The reletionship between reconstructed hit position x_a and P_I (Fig. 2) is decribed by Eq.1. Eq.2 describes reletionship between x_a and P_{III} (Fig. 2).

$$x_a = -\sigma_x \sqrt{2}\, erf^{-1}(2P_I - 1) \quad \text{Eq.1}$$

$$x_a = \sigma_x \sqrt{2}\, erf^{-1}(2P_{III} - 1) + a \quad \text{Eq.2}$$

The error parameter err = $x_0 - x_a$, where x_0 is interaction position and x_a is calculated hit position, was defined to evaluate the algorithm accuracy in the presence of random noise.

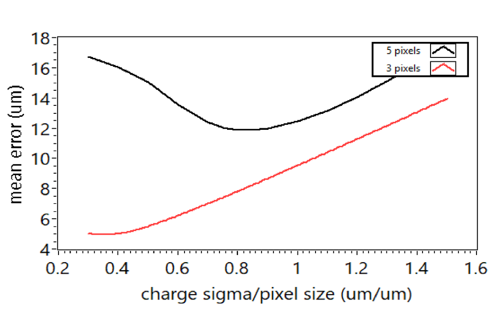

Fig. 3 Mean error for charge shared between 3 and 5 pixels.

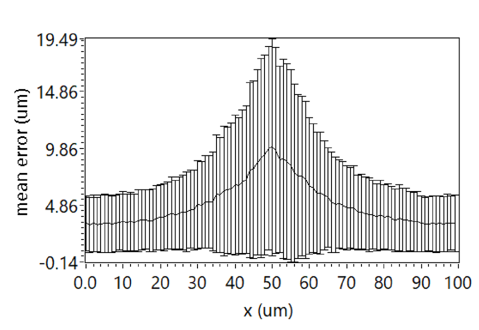

Fig. 4 Mean error for $\sigma_x/a = 0.35$ for charge shared between 3 pixels.

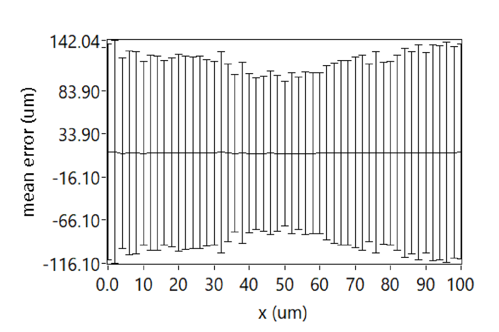

Fig. 5 Mean error for $\sigma_x/a = 0.85$ for charge shared between 5 pixels.

OPTIMIZING SUB-PIXEL RESOLUTION

The pixel is divided into sub-pixels.

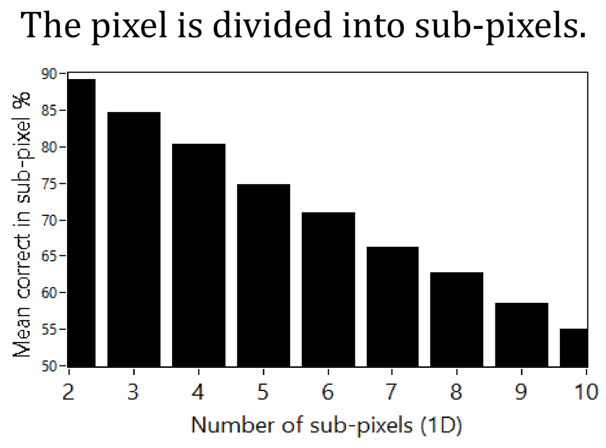

Fig. 6 Mean value of correctly assigned hits vs number of sub-pixels (1D) for $\sigma_x/a = 0.35$

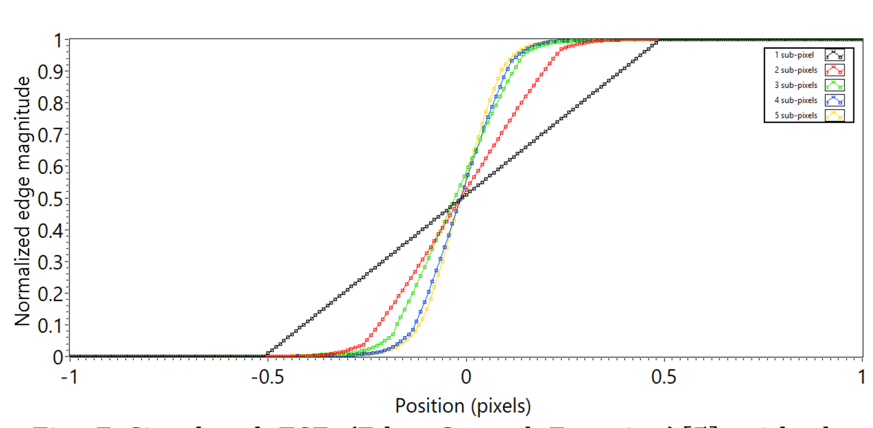

Fig. 7 Simulated ESF (Edge Spread Function)[5] with the following assumptions:
- the correct pixel is selected for photon interaction position
- P_I and P_{III} selection does not depend on noise

CONCLUSIONS FOR THE ALGORITHM

- The allocation error calculated shows that with given photon energy and noise, the charge cloud spread should be chosen so that the charge is shared between 3 neighboring pixels (in 2D case: 3x3 pixels), therefore the algorithm should take into account the neighborhood size of 3x3 pixels.
- In this case, the parameters as detector thickness and bias voltage should be chosen such that the charge cloud sigma to pixel size ratio σ_x/a is equal to 0.35, since for that value the alocation error reaches minimum.
- The accuracy of allocation to a specific sub-pixel obtained for the pixel division into smaller and smaller areas decreases and reaches value below 50% for sub-pixel number greater than 10. It follows that to keep satisfactory accuracy (e.x. above 70%), the pixels can not be divided into more than 6x6 sub-pixels.
- ESF simulations indicate the possibility of image spatial resolution improvement using the presented algorithm, however the qualitative conclusions can be drawn only after implementation of the algorithm in a pixel.

ALGORITHM CONCEPT

A pixel circuitry consists of a charge sensitive amplifier (CSA), a discriminator (DISCR), an ADC and digital algorithm logic, including a charge sharing processing module and counters. The CSA converts an input signal into a voltage pulse with an amplitude proportional to charge collected. The DISCR serves as an event detector, checking if the output CSA voltage exceeds a threshold. The result of the comparison is sent to neighboring pixels. The ADC, triggered by the event detectors of the pixels belonging to a neighborhood, digitizes the output CSA voltage. The digital logic processes the ADC signals from the pixels belonging to a neighborhood. Basing on the proportions of charge collected by each pixel, the hit is assigned to a sub-pixel and a corresponding counter is incremented.

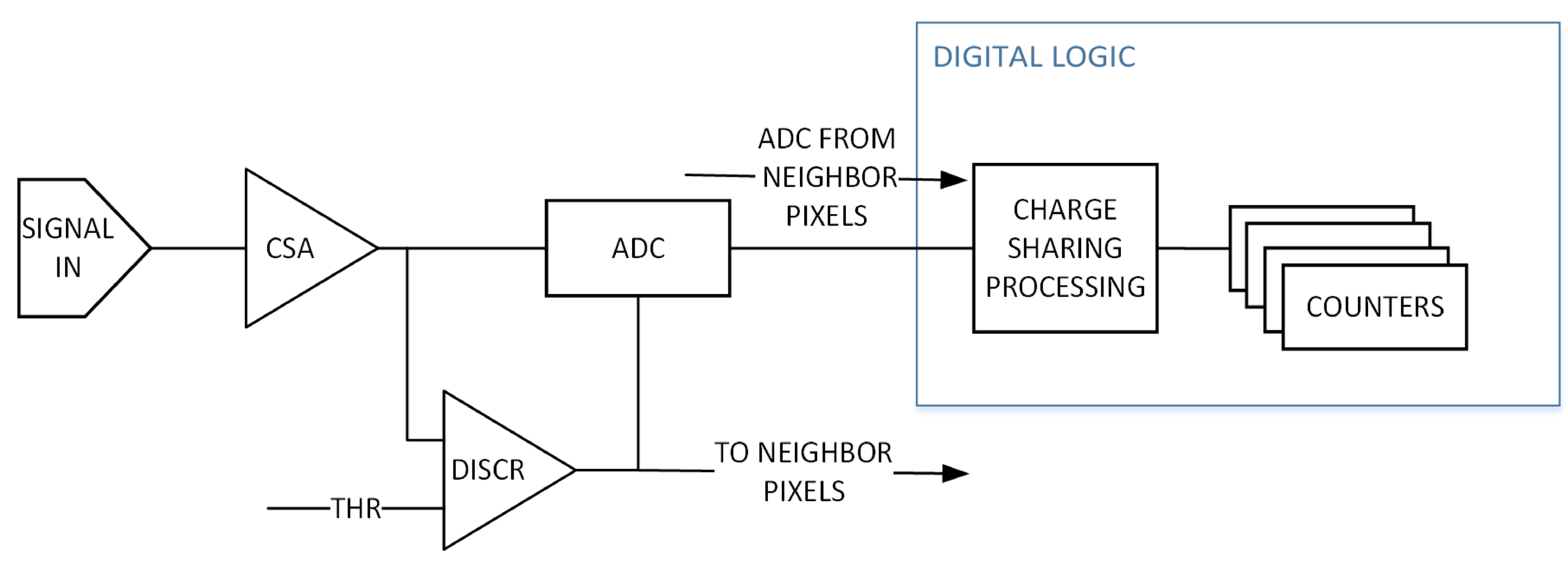

Fig. 8 A schematic diagram of the readout channel architecture allowing for hit allocation with sub-pixel resolution.

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References:

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