Characterisation and System-Level Simulation of Fully Digital Pixel Architectures

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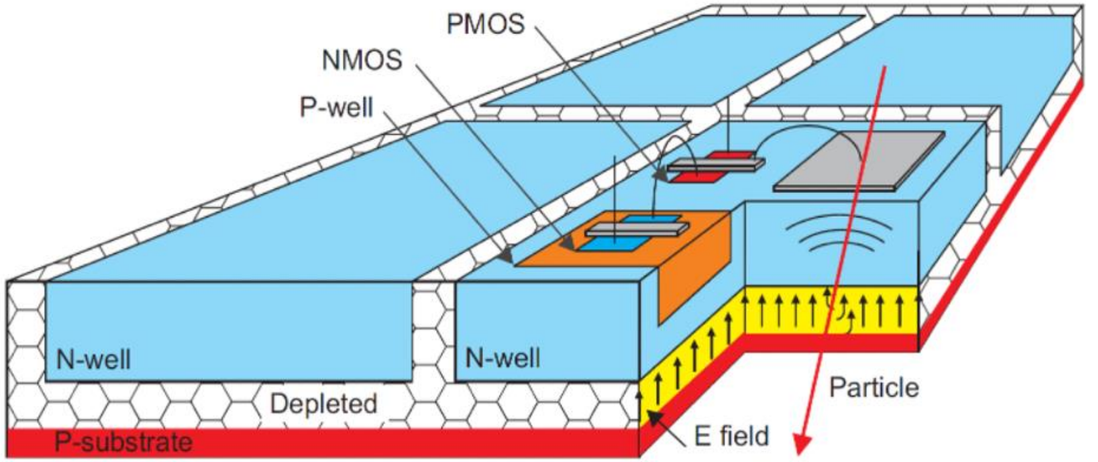
Motivation & Challenges

Analogue Scaling Limit:
Unlike digital logic, analogue transistors (CSAs, shapers) require specific voltage headroom and area to maintain Signal-to-Noise Ratio (SNR).

The Density Gap:
A conventional $2 \times 2\,cm$ sensor (with a 75 μm pitch) has $\sim 65k$ pixels;
Shrinking the pitch to $2.5\mu m$ (Particam goal) increases this to ~ 64 million pixel- a $1000 \times$ jump.



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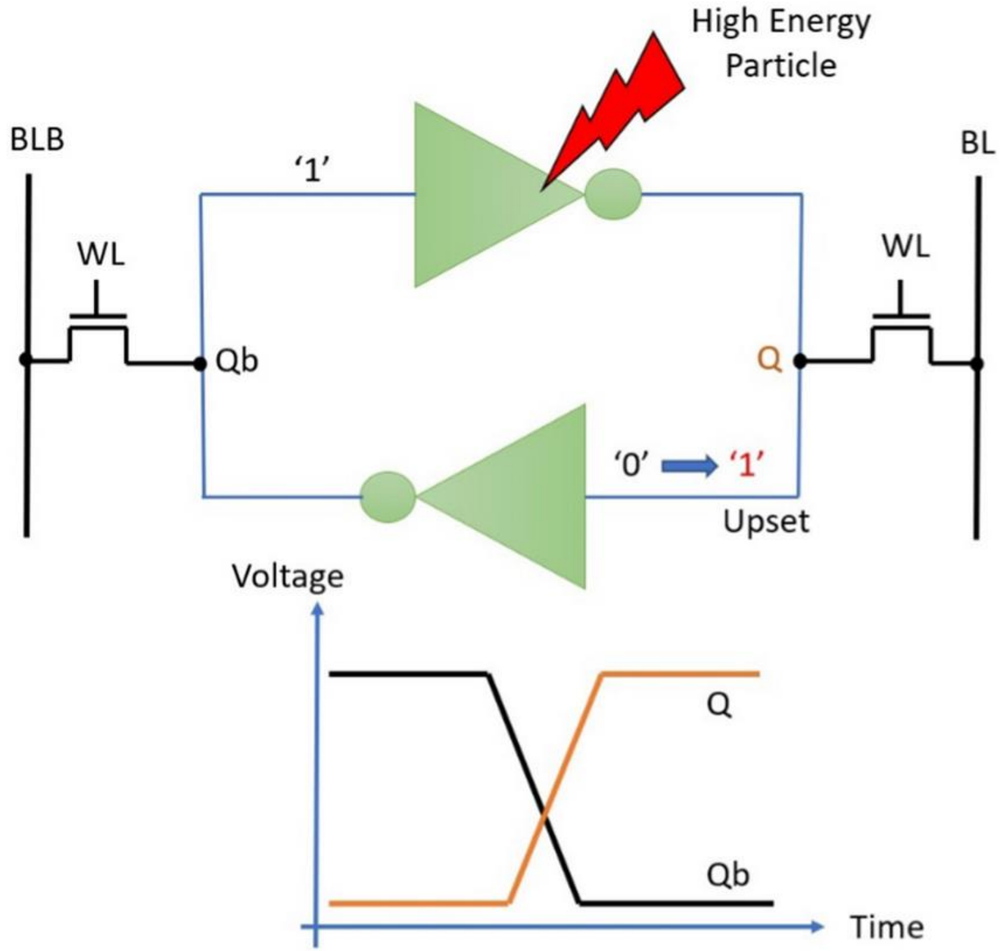
The Particam Concept-Fully Digital Sensor

Detection Mechanism:
Reproposing **Single Event Upset(SEU)** as the detection mechanism.

Detection Trigger:
A hit is registered when the deposited charge exceeds the Threshold Charge (Q_T)

Advantages:
1. **Area Efficiency**: Eliminate analogue amplifiers, leveraging high-density $65nm$ CMOS processes.
2. **Extreme Density**: Enables a pixel pitch of $2.5\mu m$, $1000\times$ higher density than before.



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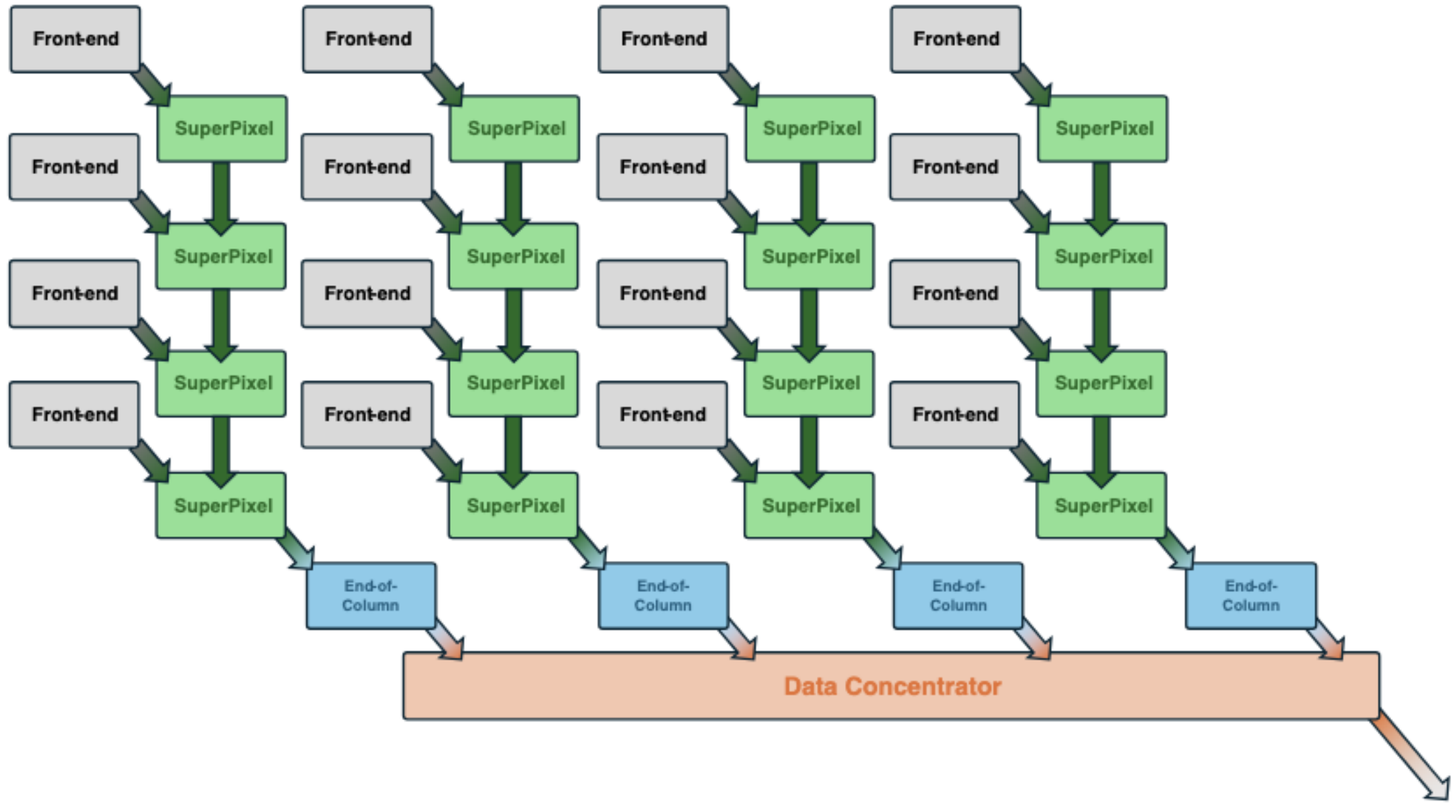
The PixESL Framework Architecture

Readout Modelling:
Spans seamlessly from the individual pixel frontend to global Data Concentration.

Configurable Hierarchy:
Highly modular design supporting flexible connectivity (e.g., group pixels into SuperPixel).

Scalability:
Allows rapid testing of different routing and aggregation strategies for large-scale matrices.



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Particam Readout Architecture Design

Rolling-Shutter Scheme

1.Mechanism: Rows are activated sequentially to extract hit information.

2.Advantage: Minimises in pixel logic, enabling the $2.5\mu m$ pitch.

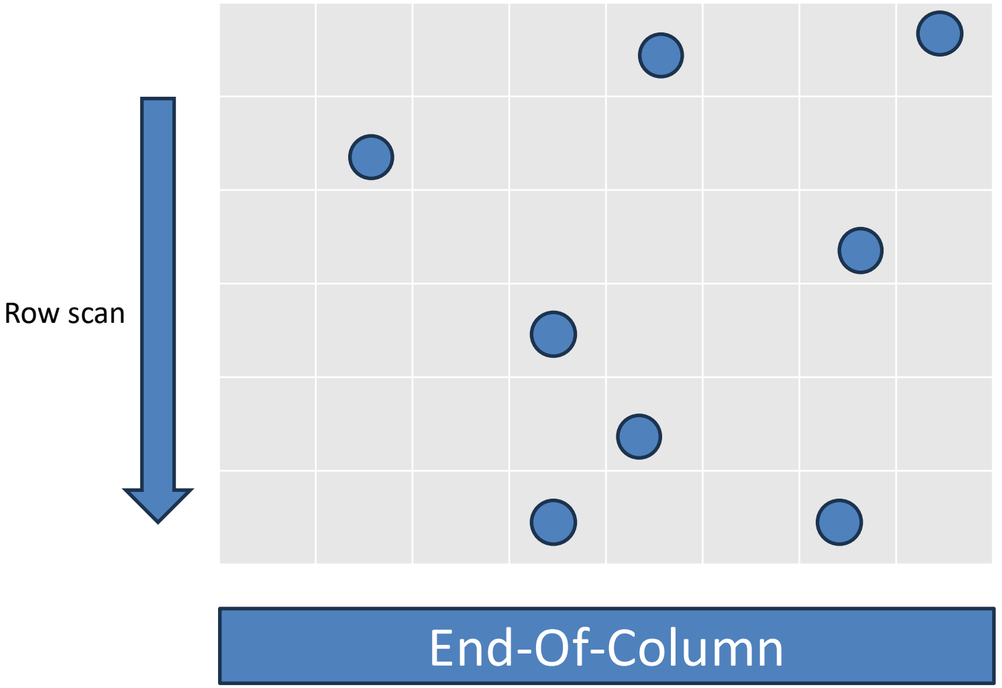
Two-Phase Operation

1.Acquisition Phase:

Particles are detected and latched in 1–bit pixel memory.

2.Readout Phase:

Column-wise scanning transfers data to End-Of-Column(EoC) buffer.



Two-phase operation

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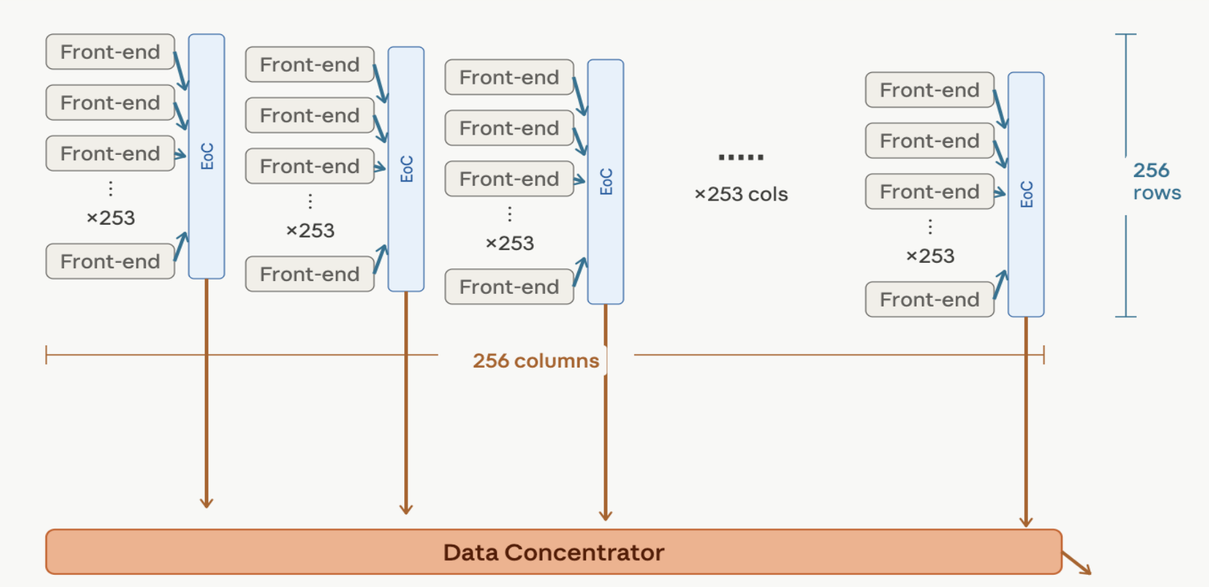
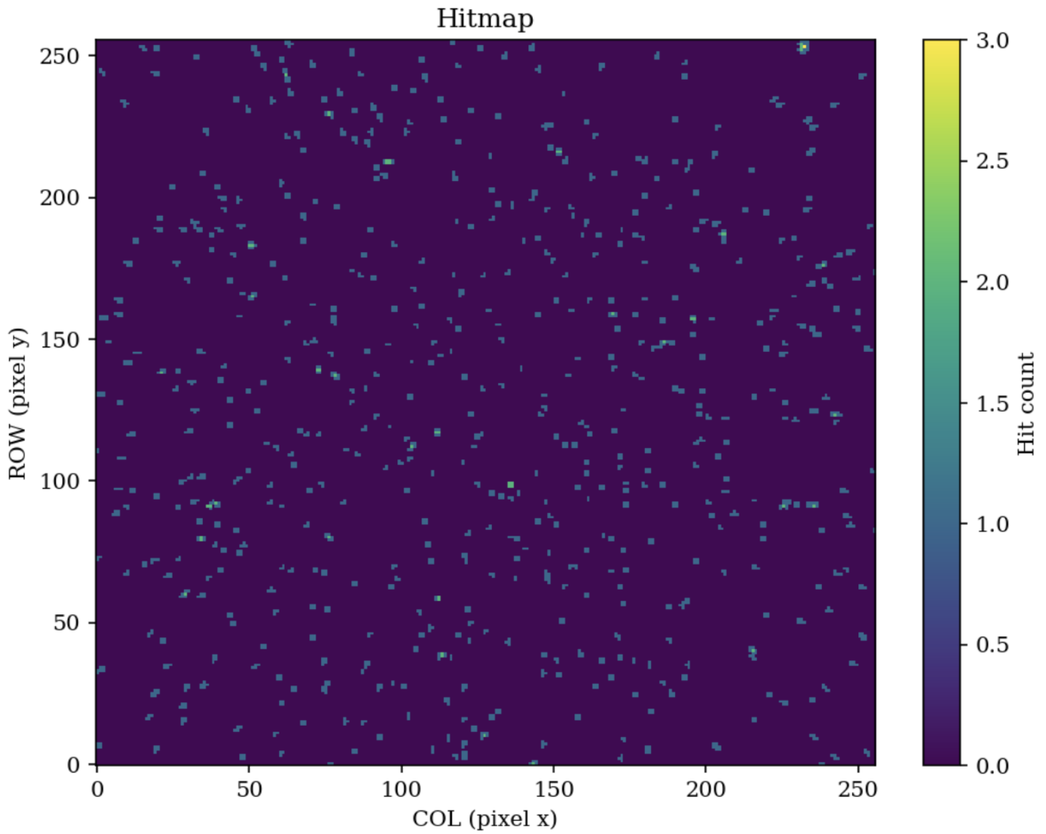
Scaling Up





I have implemented the Particam1 readout architecture in simulation using the PixESL framework.

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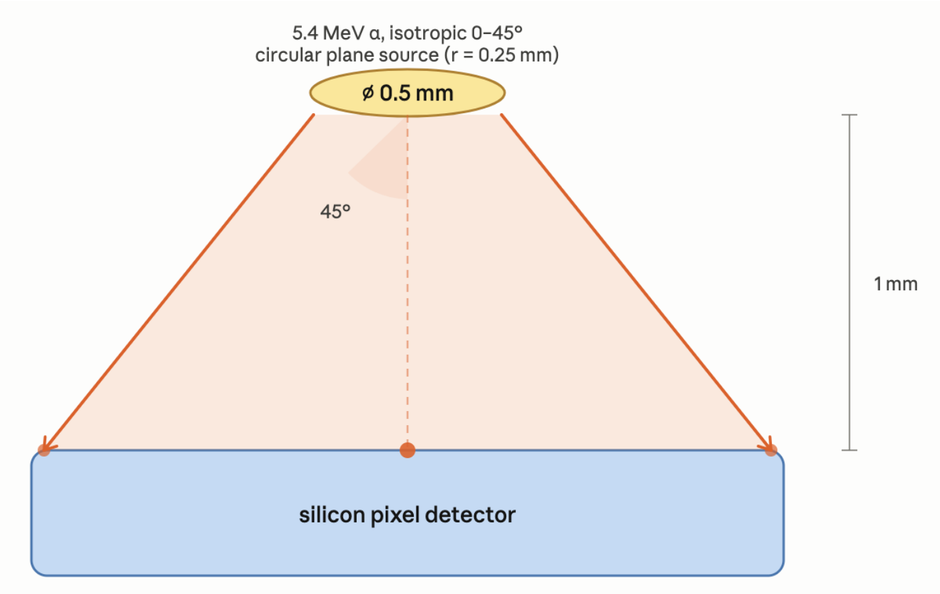
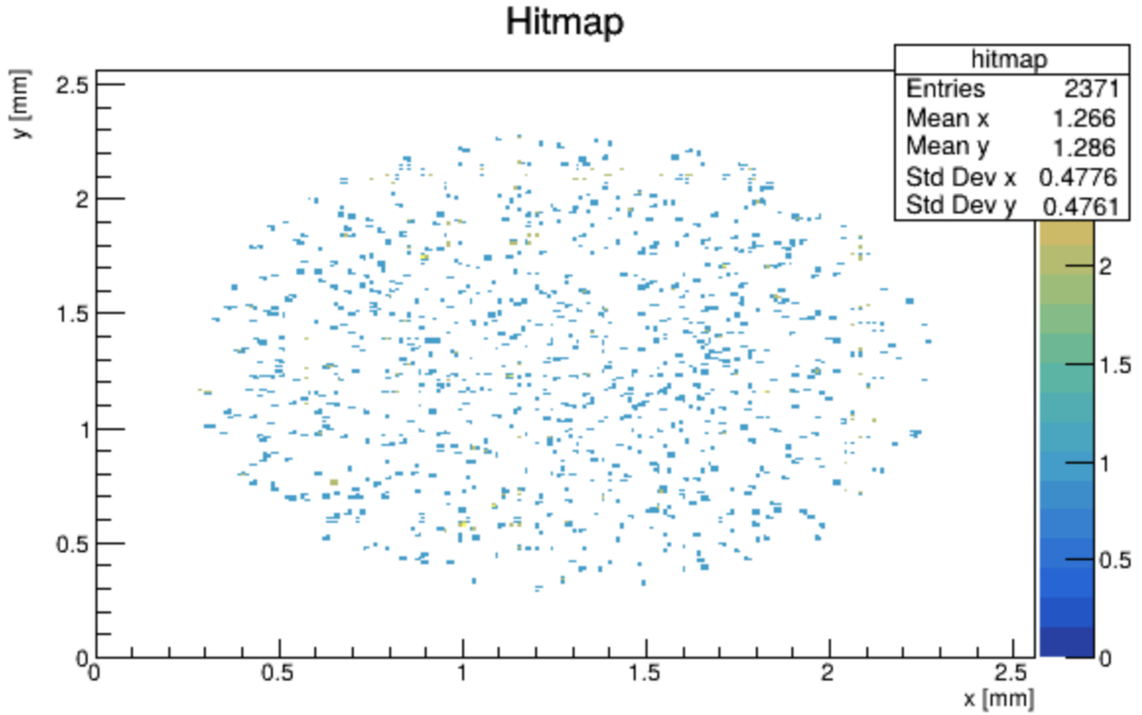
In Allpix²





I am using Allpix² to generate realistic inputs. By simulating a Am-241 alpha source, the resulting hit distributions can be used as input to the PixESL simulation.

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Further Directions

Modelling the Particam readout network within the PixESL framework.

Further Directions

1. Realistic input via Allpix²

Validate with physical charge distributions

2. Architecture exploration

Improve network efficiency and latency

3. Going to FBK for 2 years

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