A Fully Digital Approach to Sub-Micron Resolution Particle Detection: The Particam Concept

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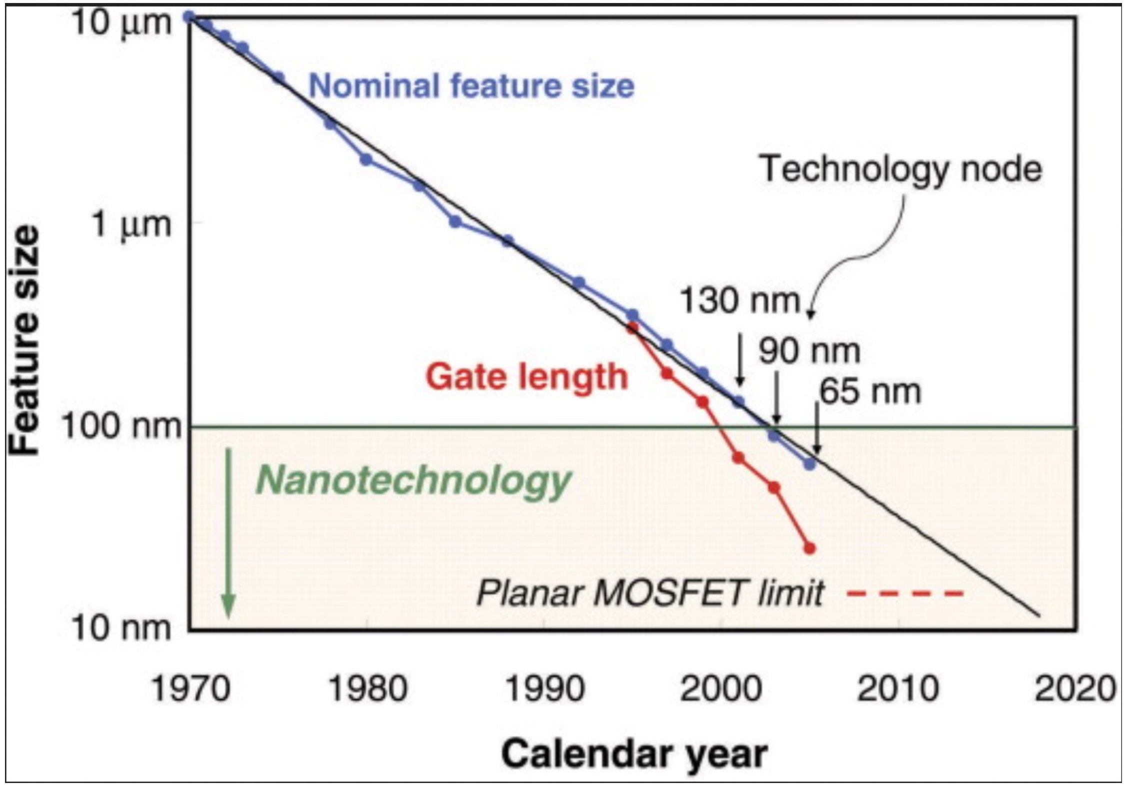
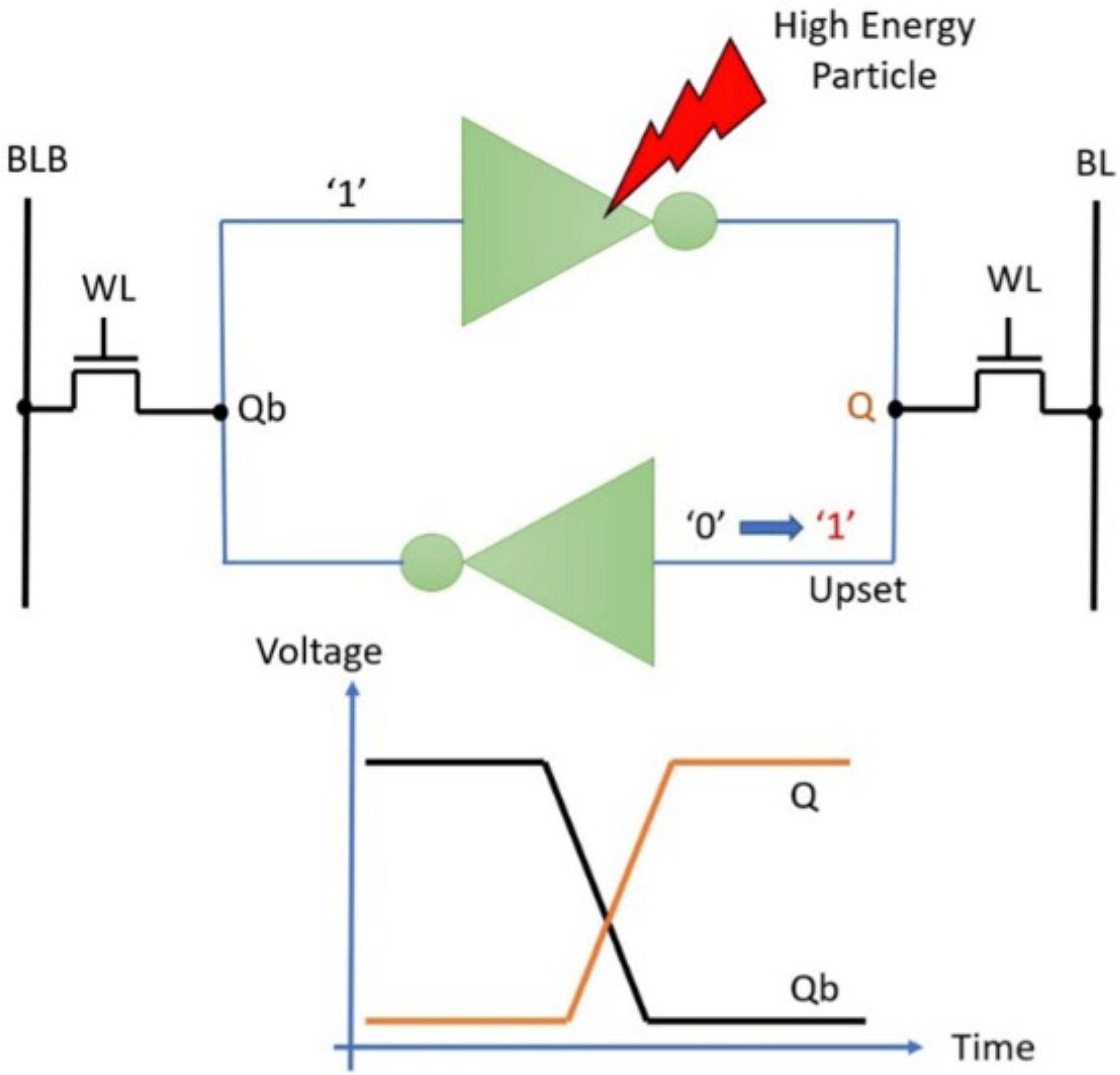


Introduction

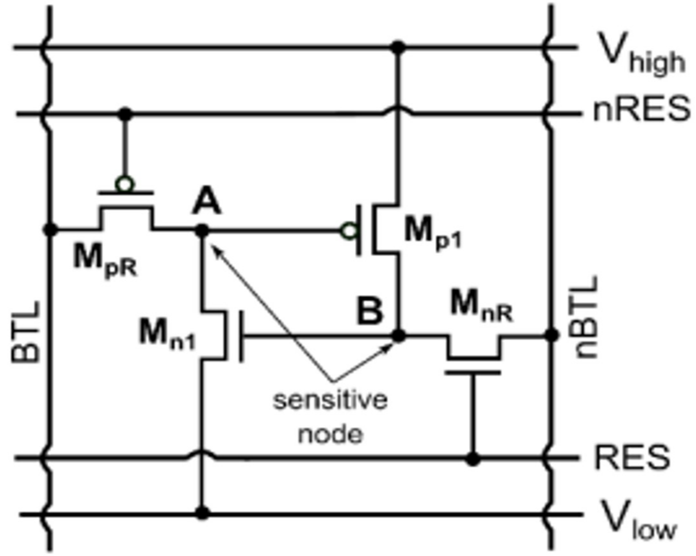
- The transition to smaller silicon feature sizes in particle physics has slowed down in recent years.
- Design becomes much more expensive and complex.
- Limitations due to bump bonds and transistor size for analogue circuits.
- A new approach is needed to achieve a sub-micron spatial resolution.

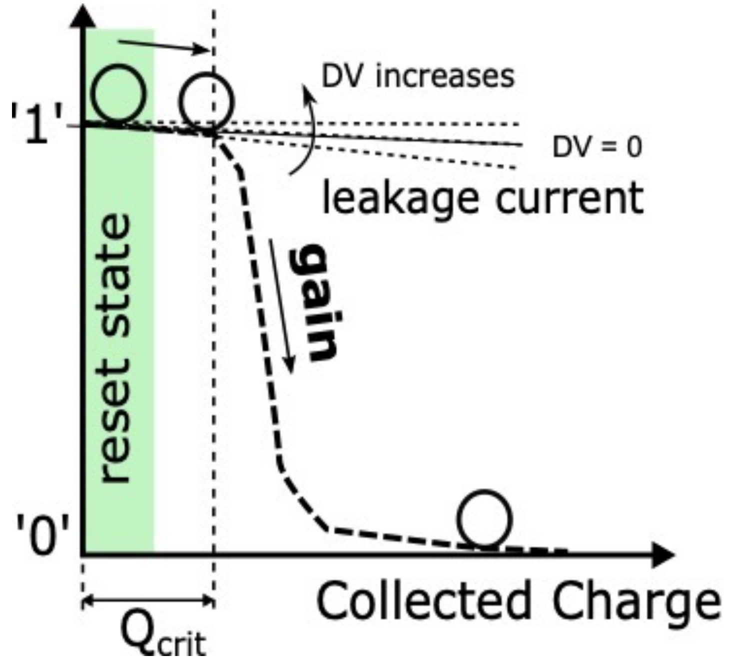
Particam Concept

- Uses the idea of Single Event Upset (SEU).
- Presence of particles may induce a flip of the memory content.
- A minimum charge (Q_{crit}) that forces the change in memory state.



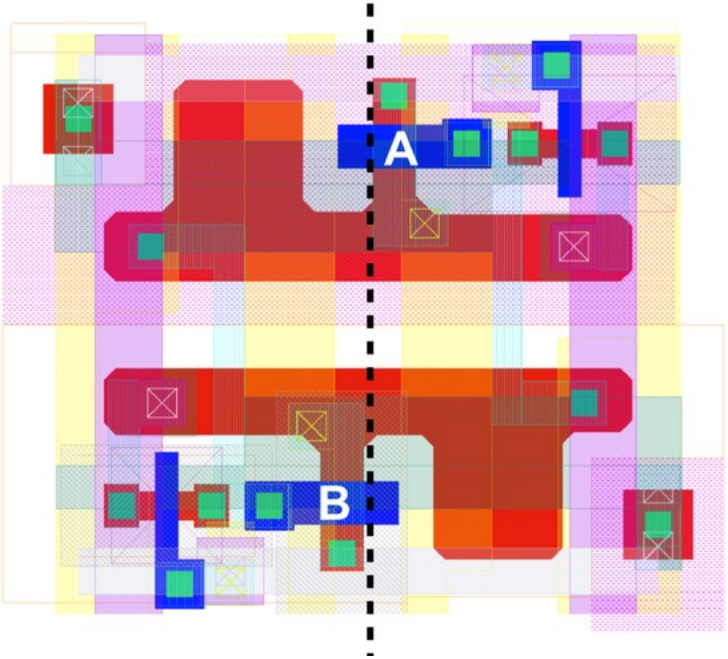
Particam Concept

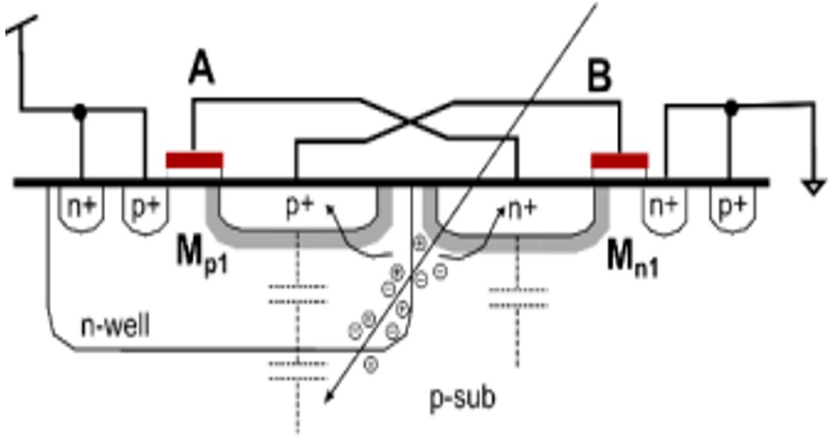


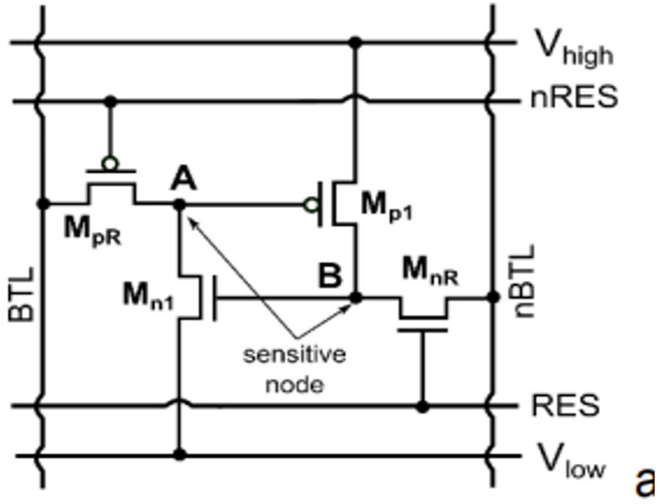


- This has four transistors: Mn1 and Mp1 (memory block) and MnR and MpR (for reset and read).
- During reset phase nodes A and B are pre-charged to Vdd and gnd respectively through the bitline then left floating.
- ISSUE: Leakage current on nodes A and B can change the memory state even if there is no particle (false event)
- → Periodic reset needed.

Particam Implementation



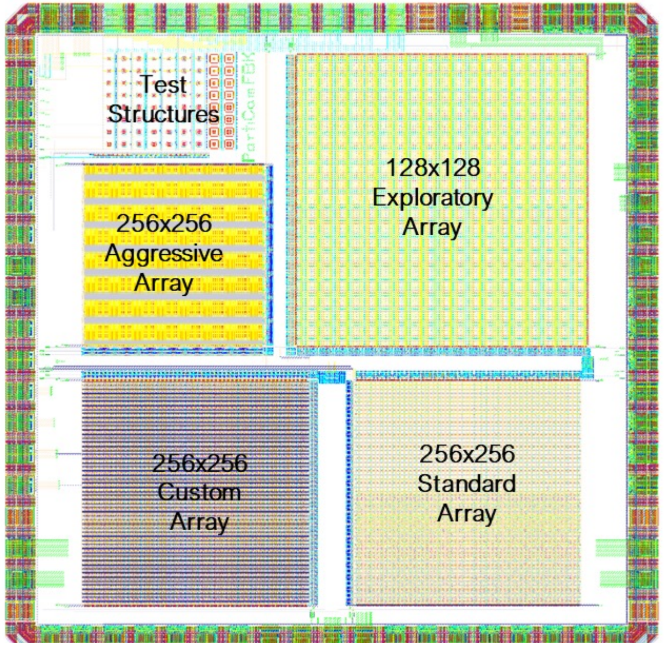


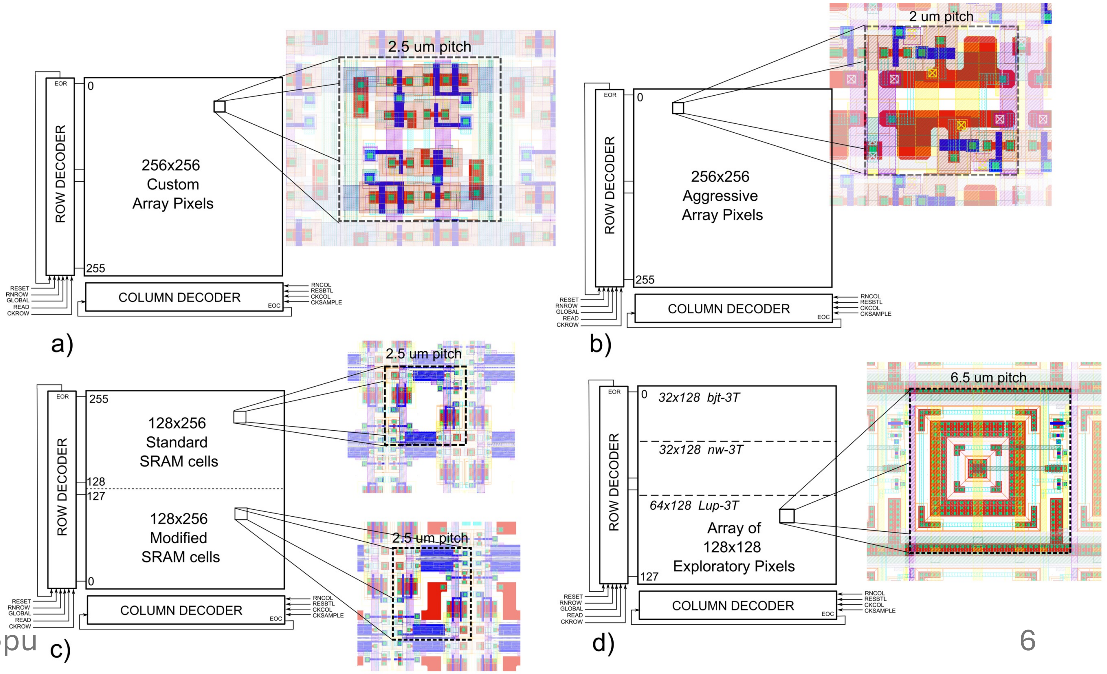


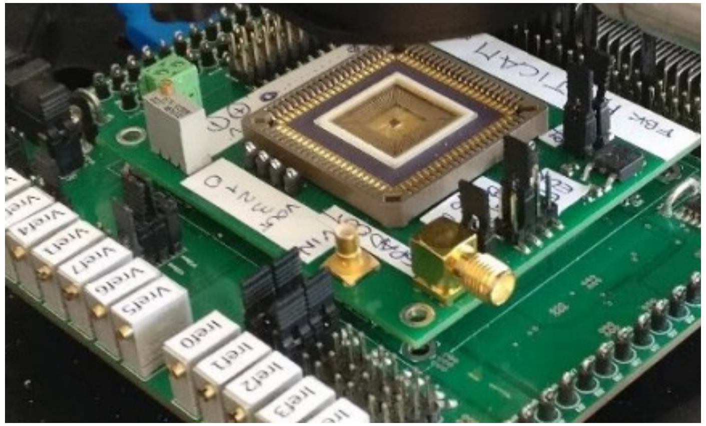
- The cell value is then readout by a column level sensor circuit.
- Enlarged junction for more charge collection.

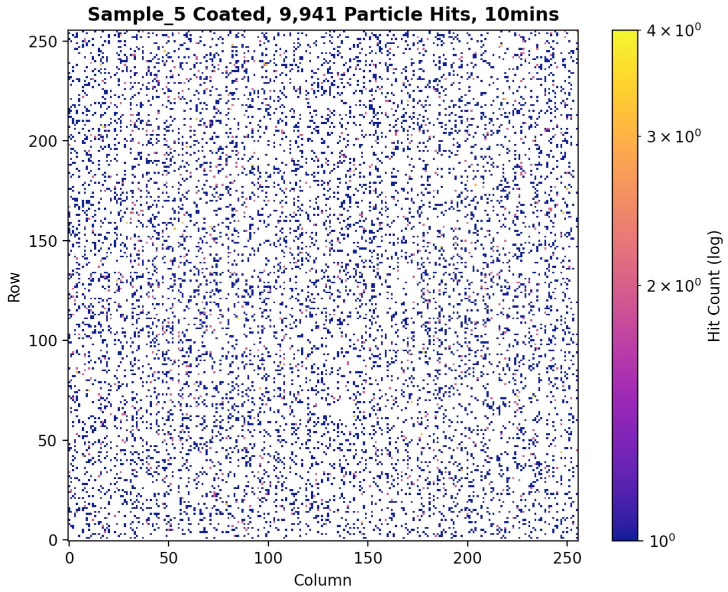
Particam Prototype

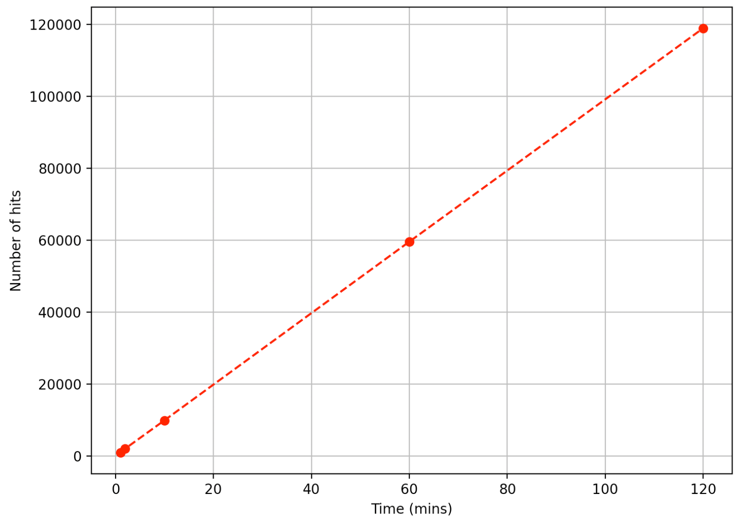
- **Designed by FBK.**
- **Realized in UMC 65nm low leakage technology and contains four arrays.**
- **Many different RAM cell designs.**
  1. **Standard array:** 256x256 pixels consisting of standard SRAM with 2.5 um pitch.
  2. **Custom array:** 256x256 pixels consisting of a novel with 2.5 um pitch.
  3. **Aggressive array:** 256x256 pixels consisting of a novel circuit with 2 um pitch.
  4. **Exploratory array:** 128x128 pixels based on different deeper junctions with 6.5 um pitch.
- **The chip can work in global or rolling shutter mode.**
- **Row and Column registers able to select each element of the array (for reading or reset specific row).**









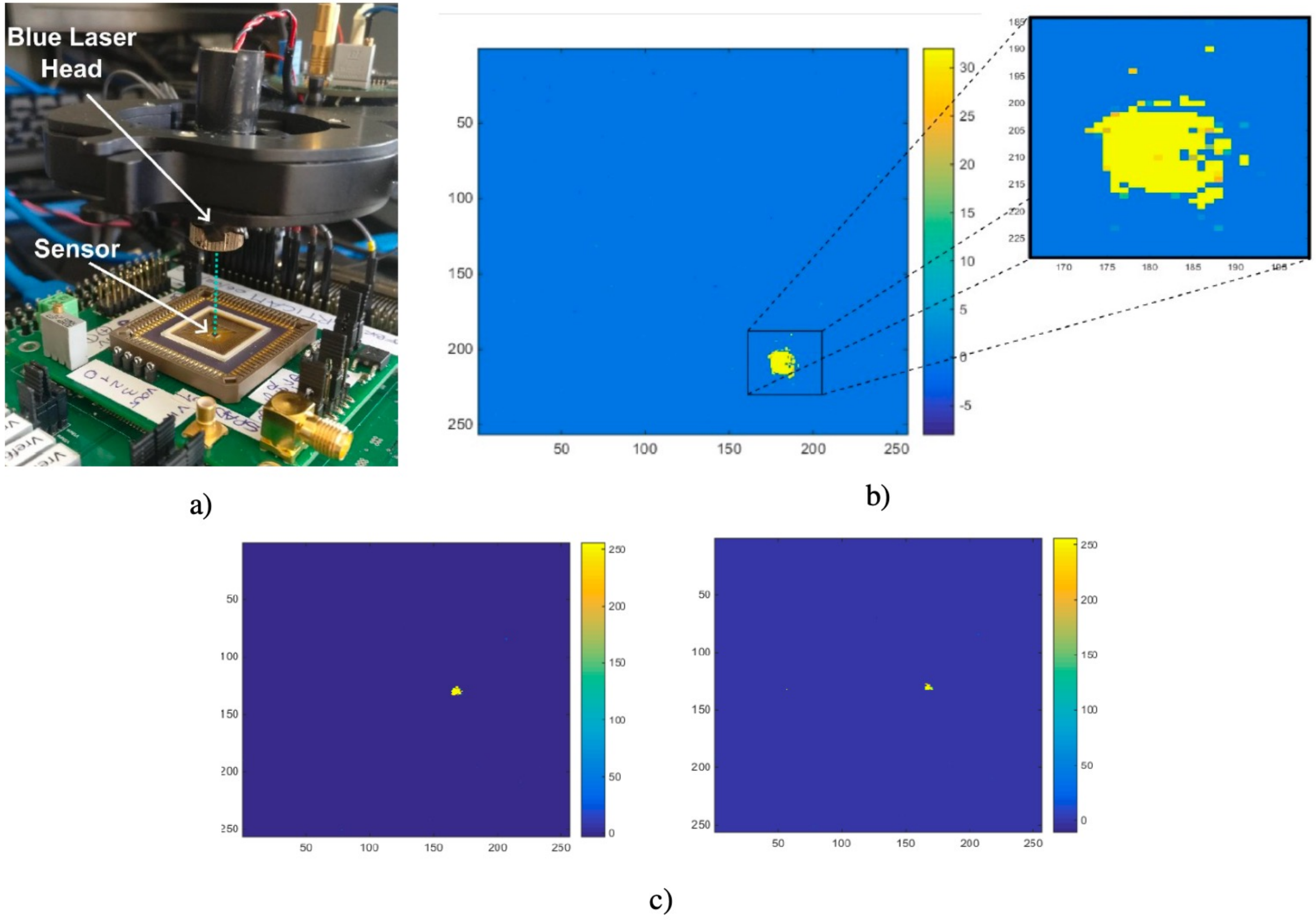


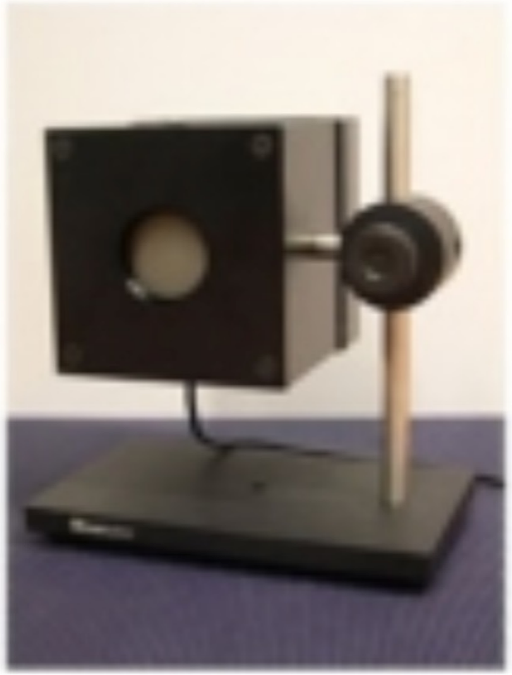
Response to α-particles

- Measurements performed by placing the Alpha source above the sensor.
- Hit number recorded for different exposure times and supply voltages.
- Very low Alpha particle detection efficiency.

Sensor Investigation

- Very low alpha particle detection efficiency
- Zero efficiency for other charged particles.
- Laser source investigation.
- *Useful as a laser sensor?!*



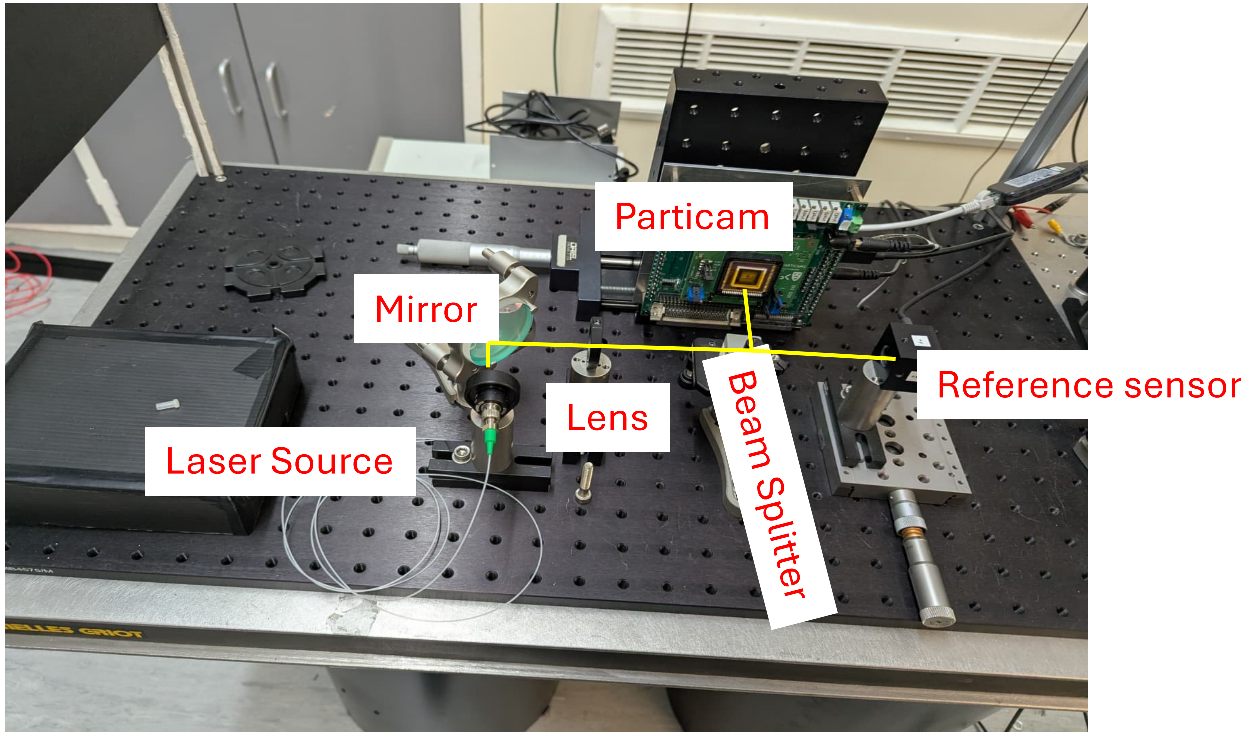


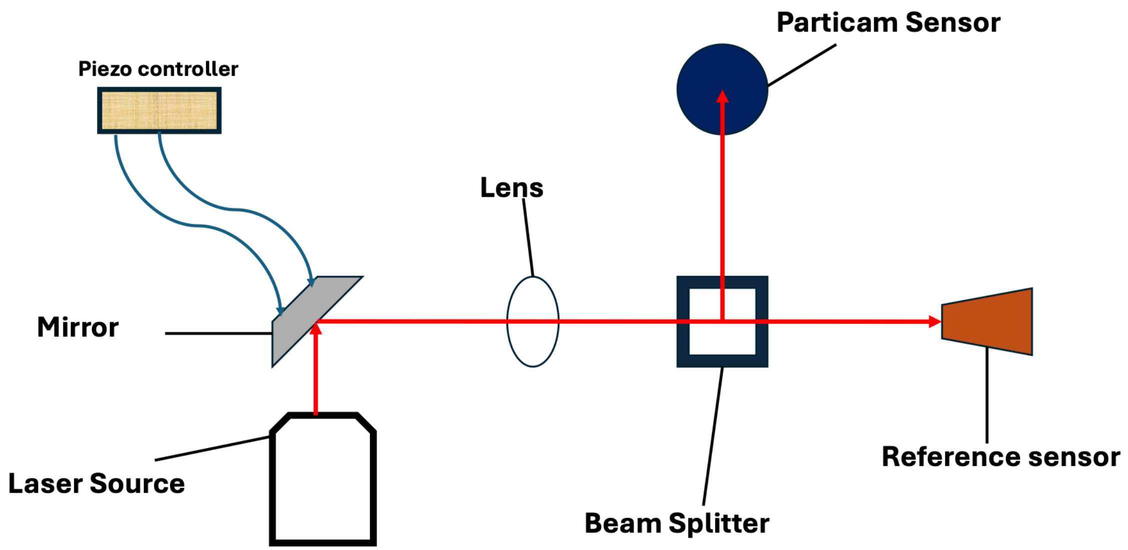
Laser Application

- Most sensors are analogue/semi-analogue.
- Precision alignment with high bandwidth.
- As a feedback loop to cater for vibration stability.
- Long range optical transmission e.g in space optics.

Laser Set-up

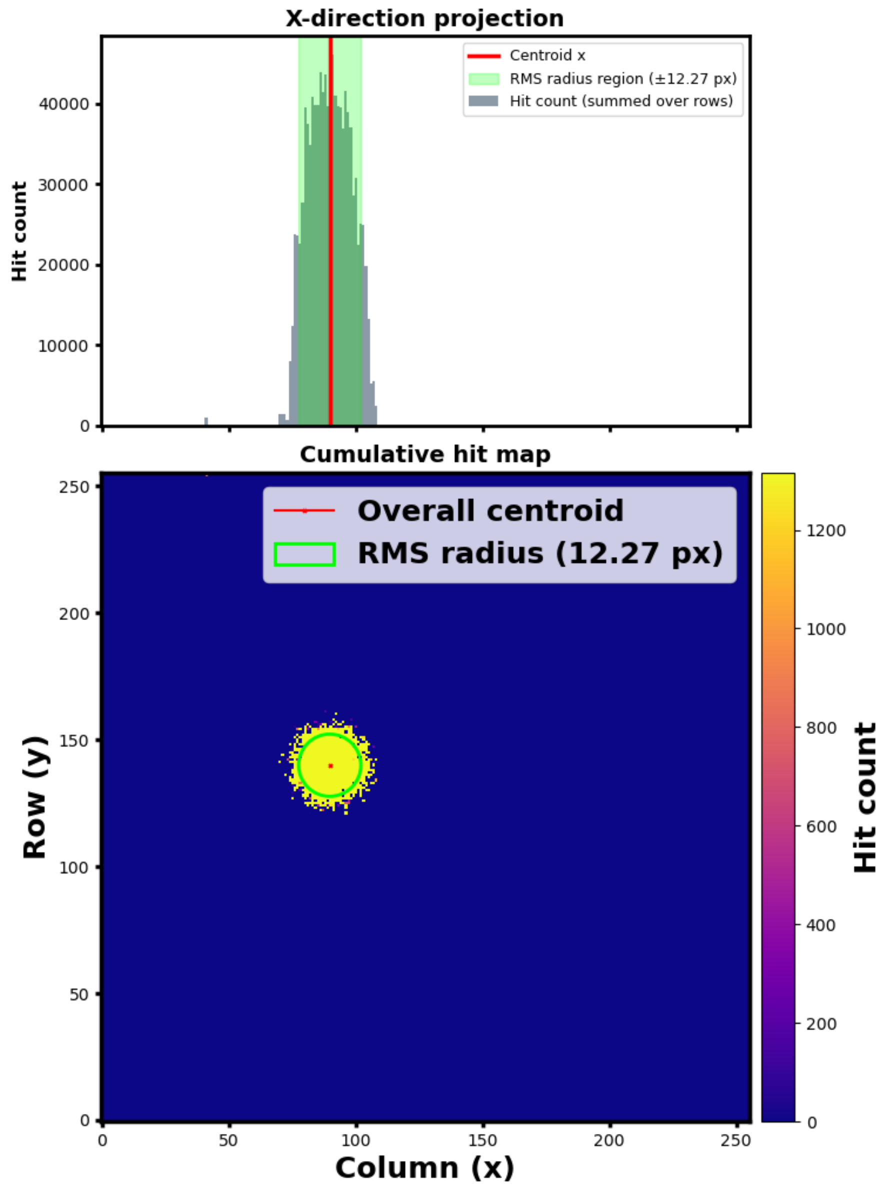
- A 780nm (infrared) continuous laser.
- OT-301 Precision position sensing amplifier.





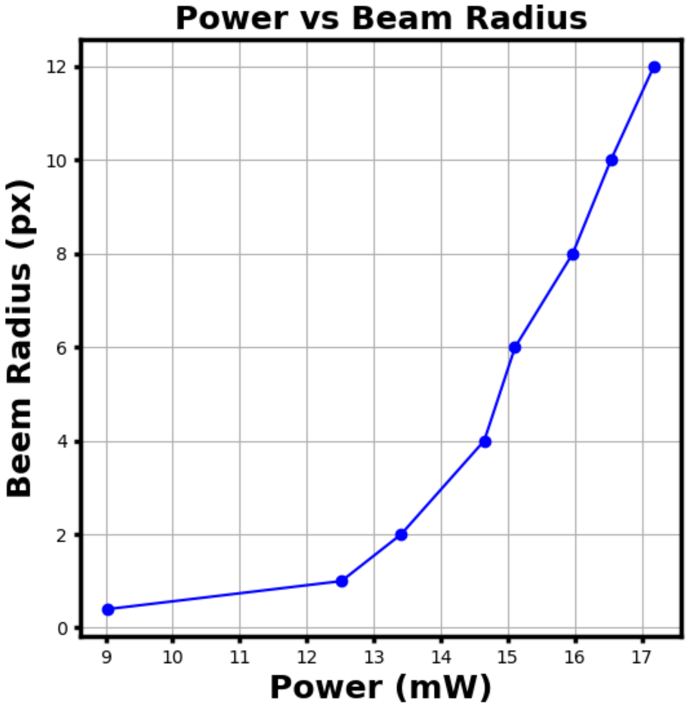
Laser Spot Centriod

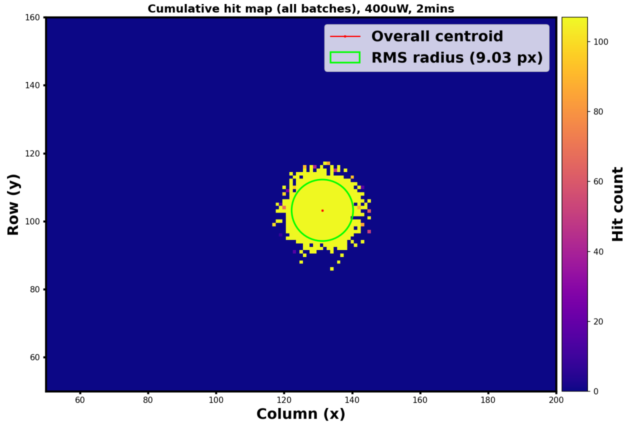
- Intensity-weighted centroid of a 2D hit-count matrix.
- rms_radius: intensity-weighted RMS radius.

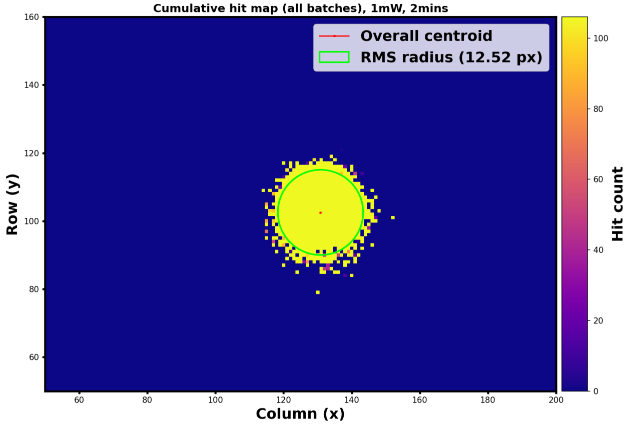


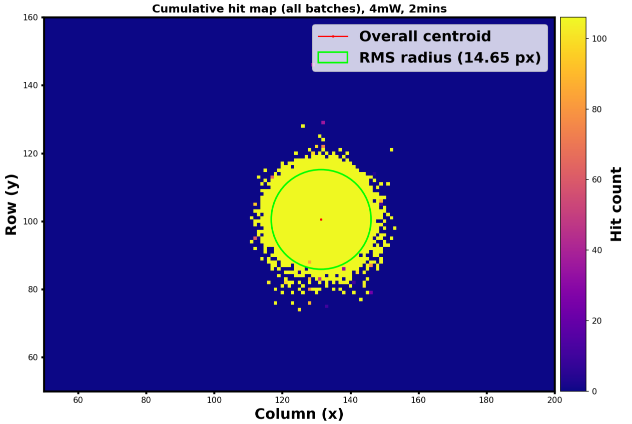
Laser Power

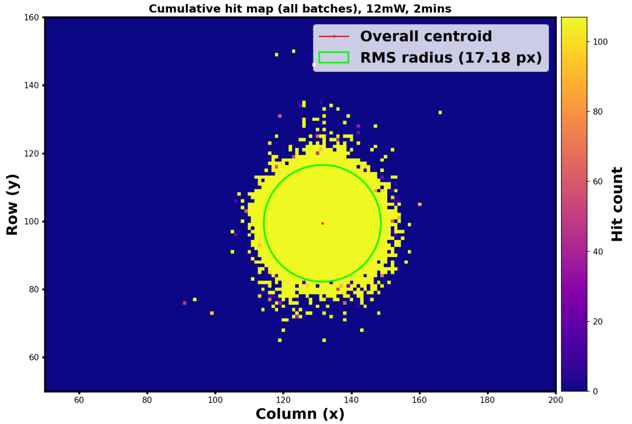
- Varying the laser power with a constant time.





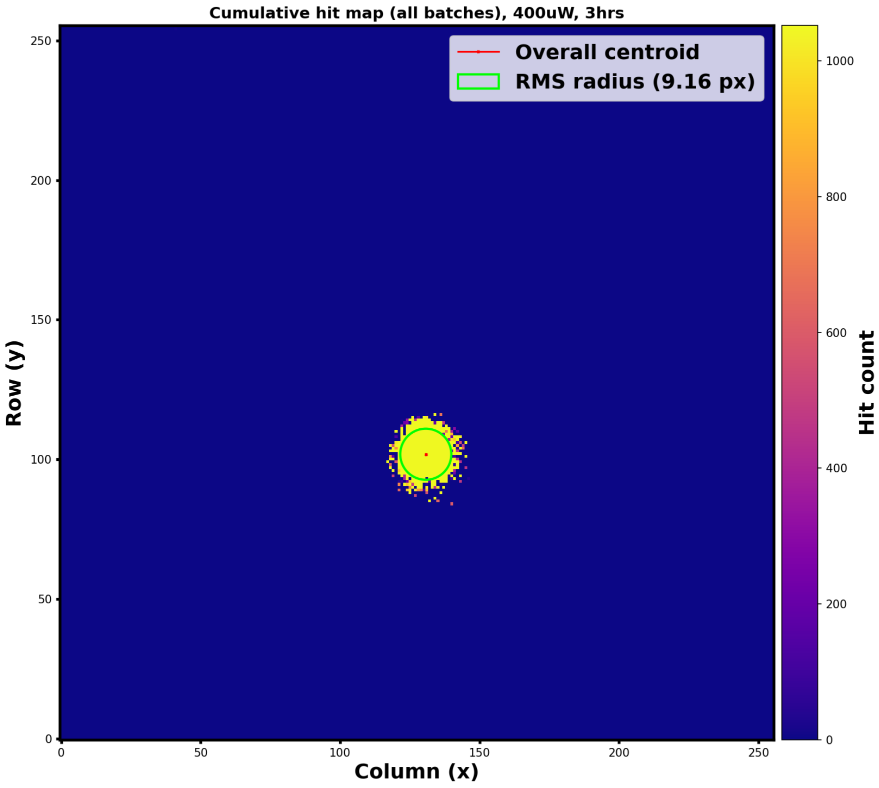


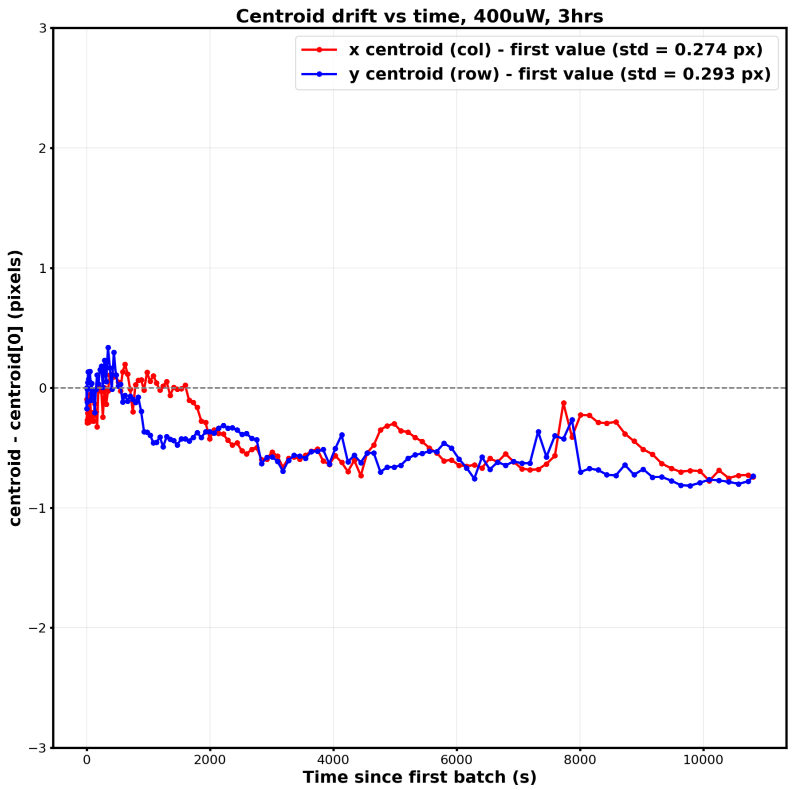




Laser Spot stability

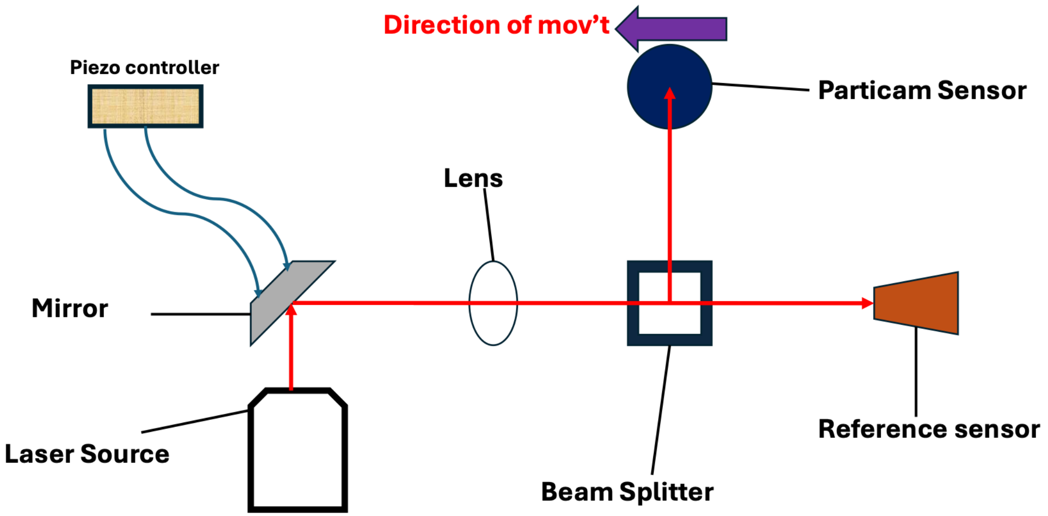
- Laser focused on the same sensor position.
- Monitor stability.
- Deviation only half a pixel = 1um over 3hrs.

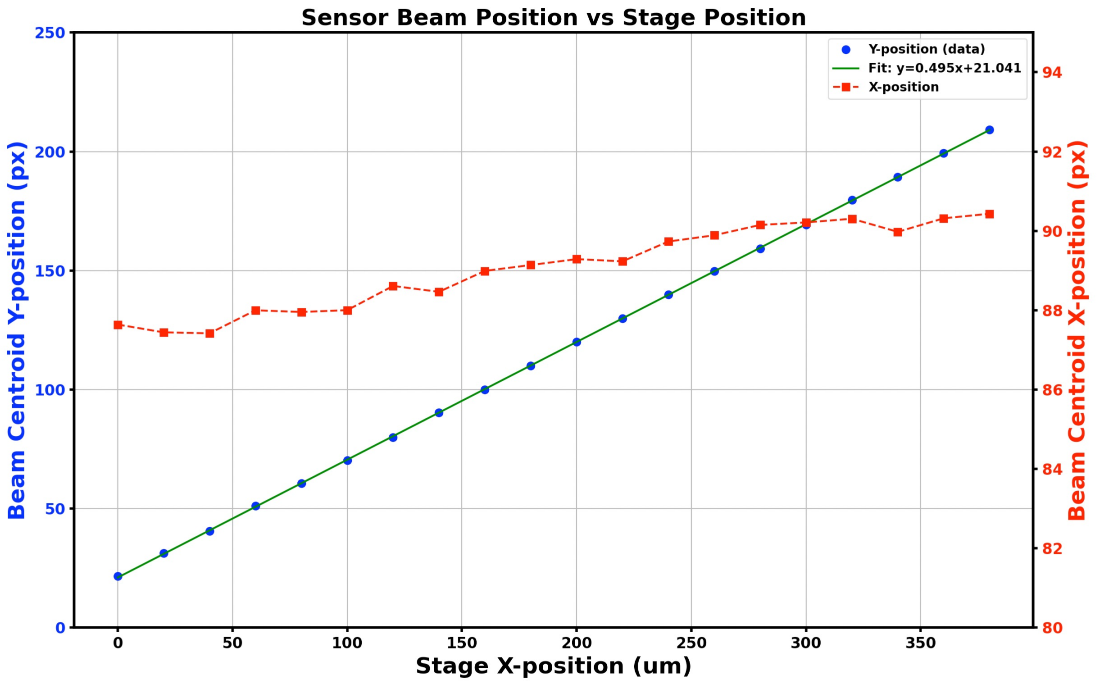




Particam Laser Spot Movement

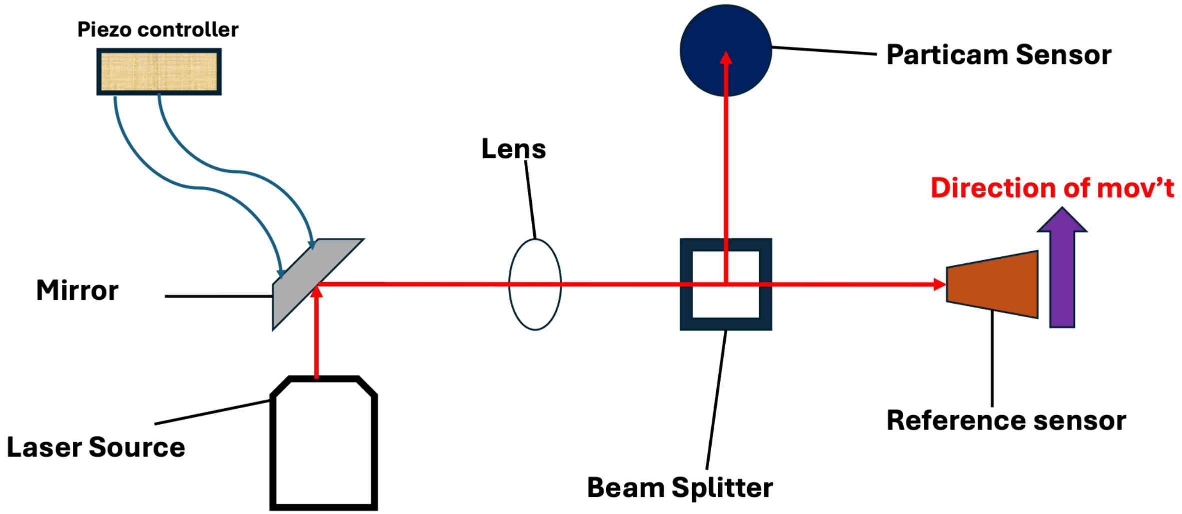
- Conversion: 1px = 2 um
- The centroid y-position = stage x-position due to the orientation of the sensor.
- Stage step size = 10 um.
- Fit: m = 0.495*2 = 0.99

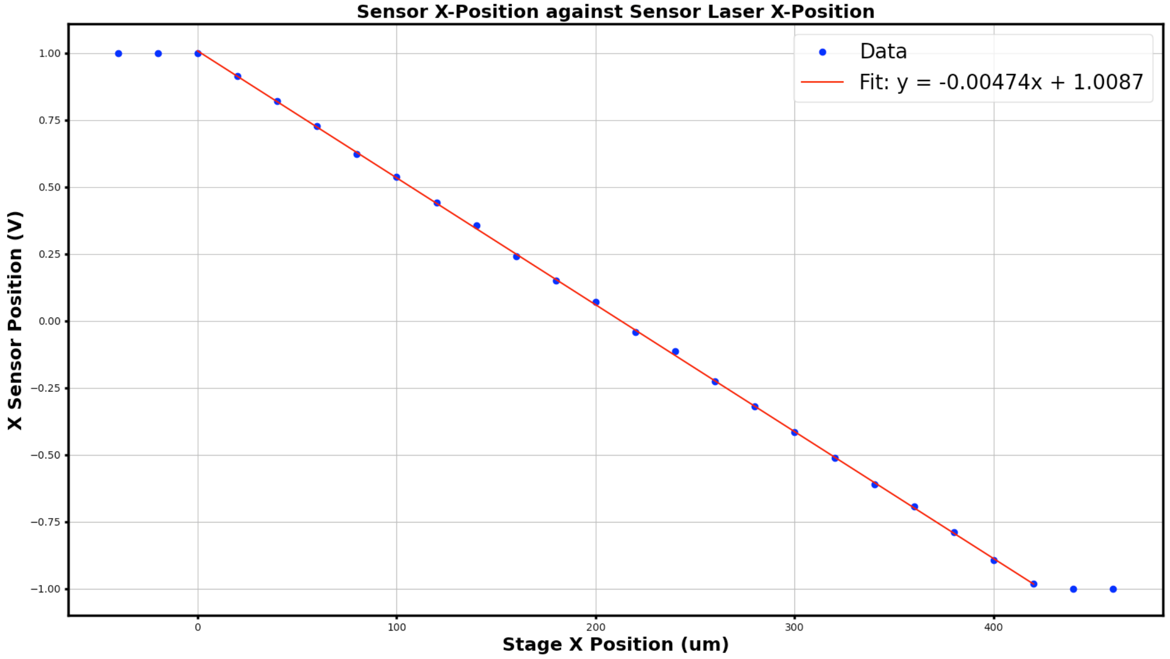




Position Sensor Laser Spot

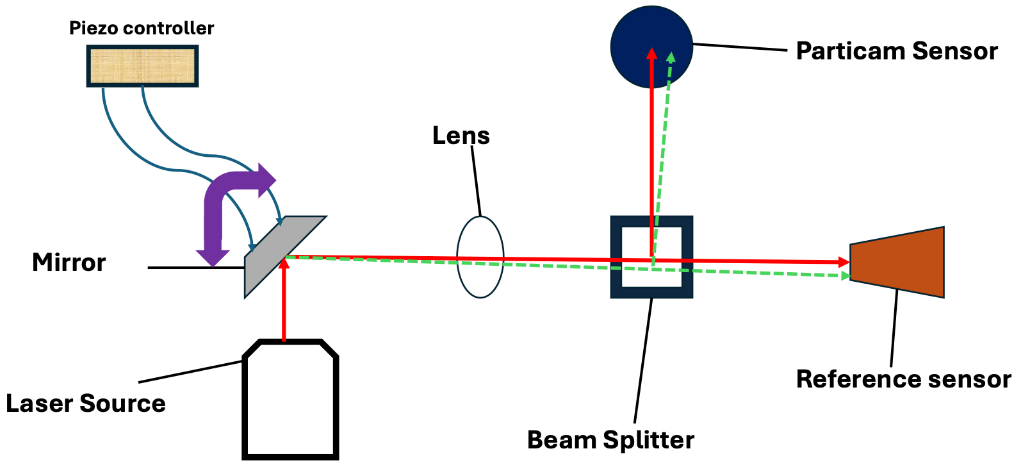
- Step size = 20 um (micrometer used limit).
- Position sensor (PS): 0.1 mm = 1 V.

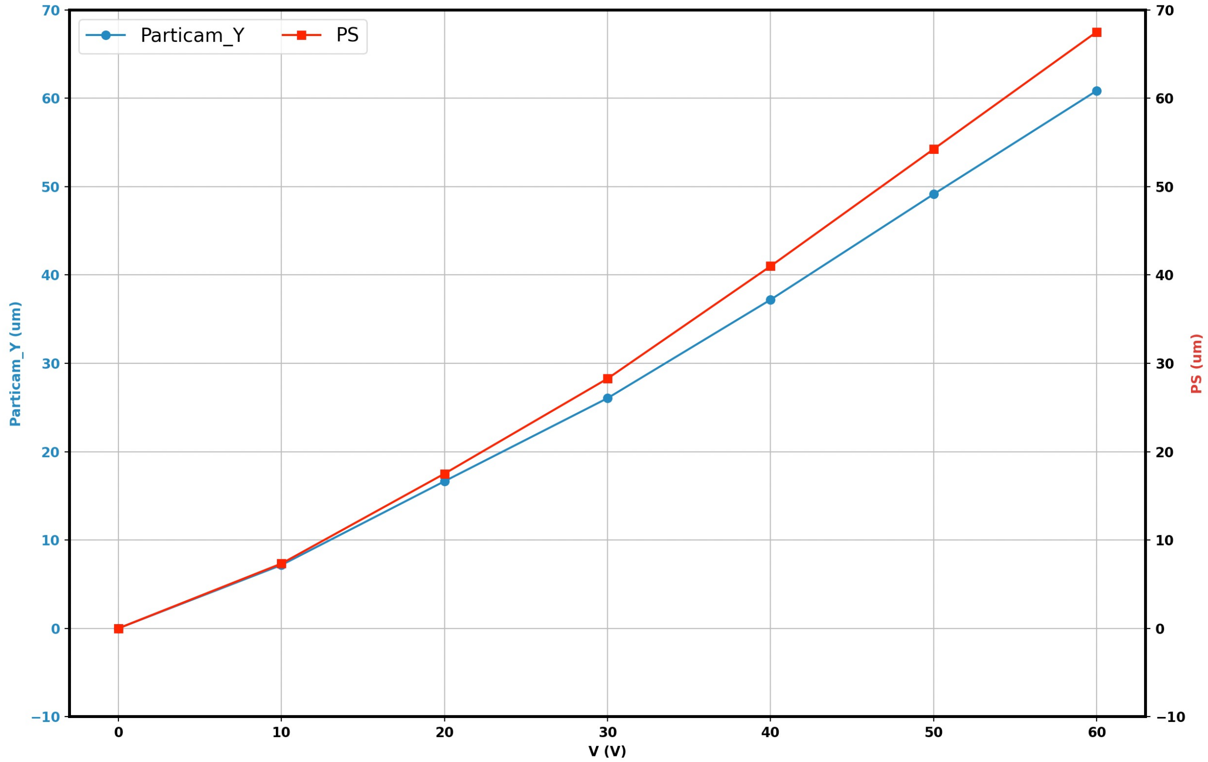




Piezo Mirror Movement

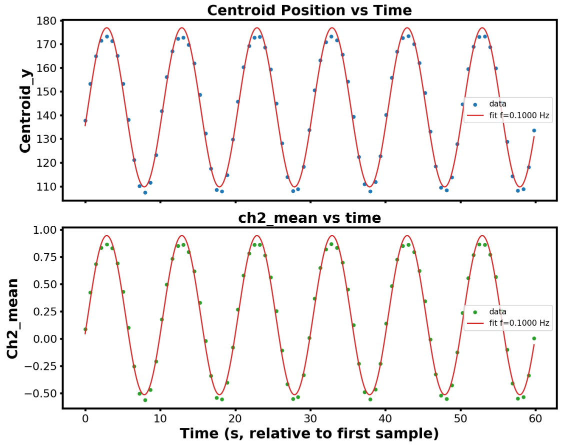
- Position sensor (PS): 0.1 mm = 1 V.
- Ramped voltage from 0 to 60 V.
- Both sensors agree.

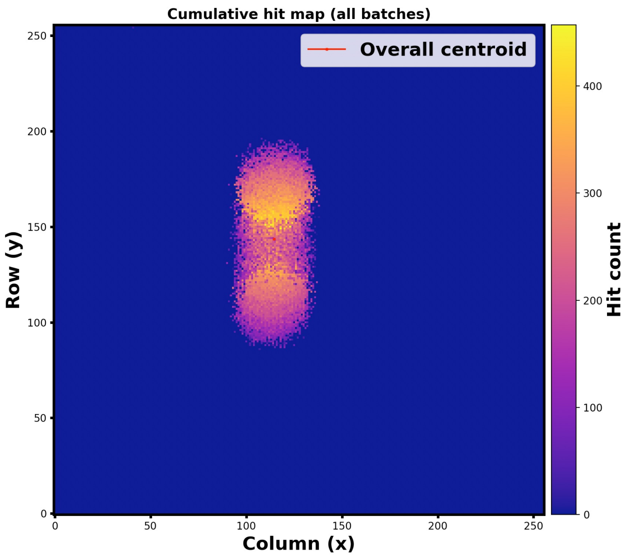


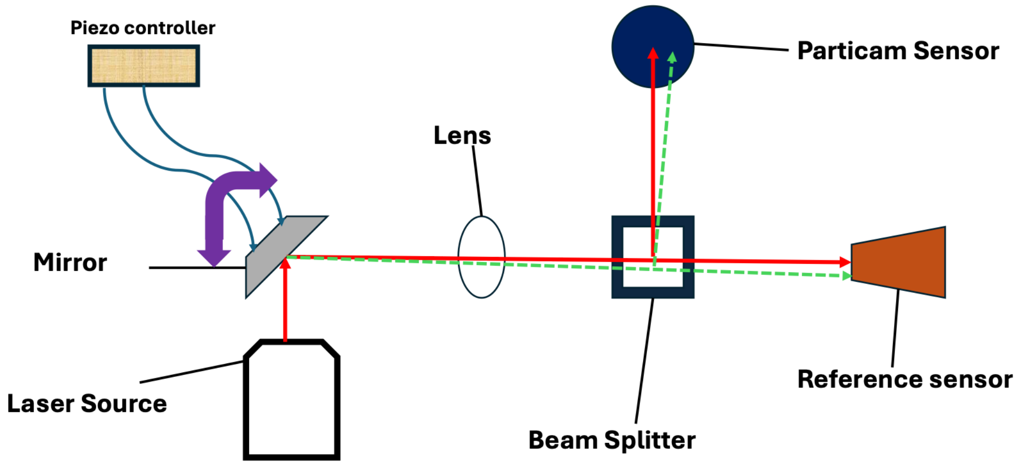


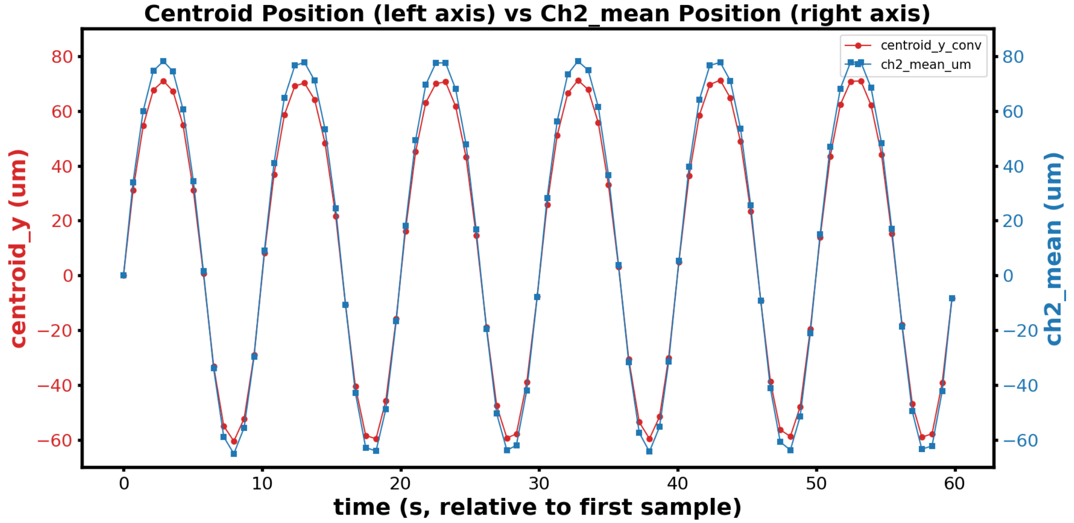
Time Dependence

- Mirror movement using a sine function.





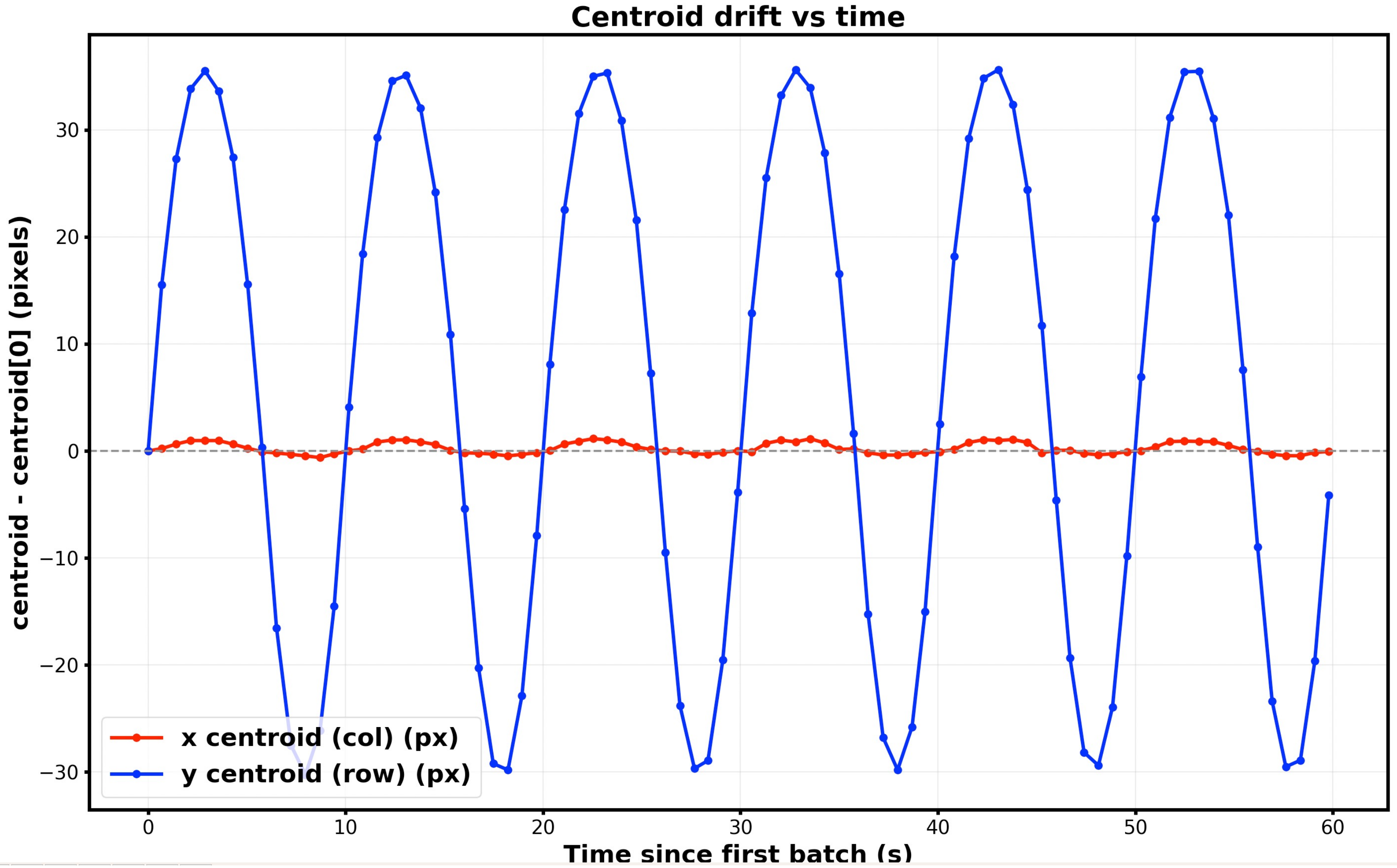




Conclusion

- Particam was used for position sensing.
- Tested against other position sensors.

- Optimize the data acquisition process.
- Run the experiment for different frequencies.
- Submitting a new chip.



Backup

$$x_{\text{centroid}} = \frac{\sum_x \sum_y x \cdot I(x,y)}{\sum_x \sum_y I(x,y)}$$

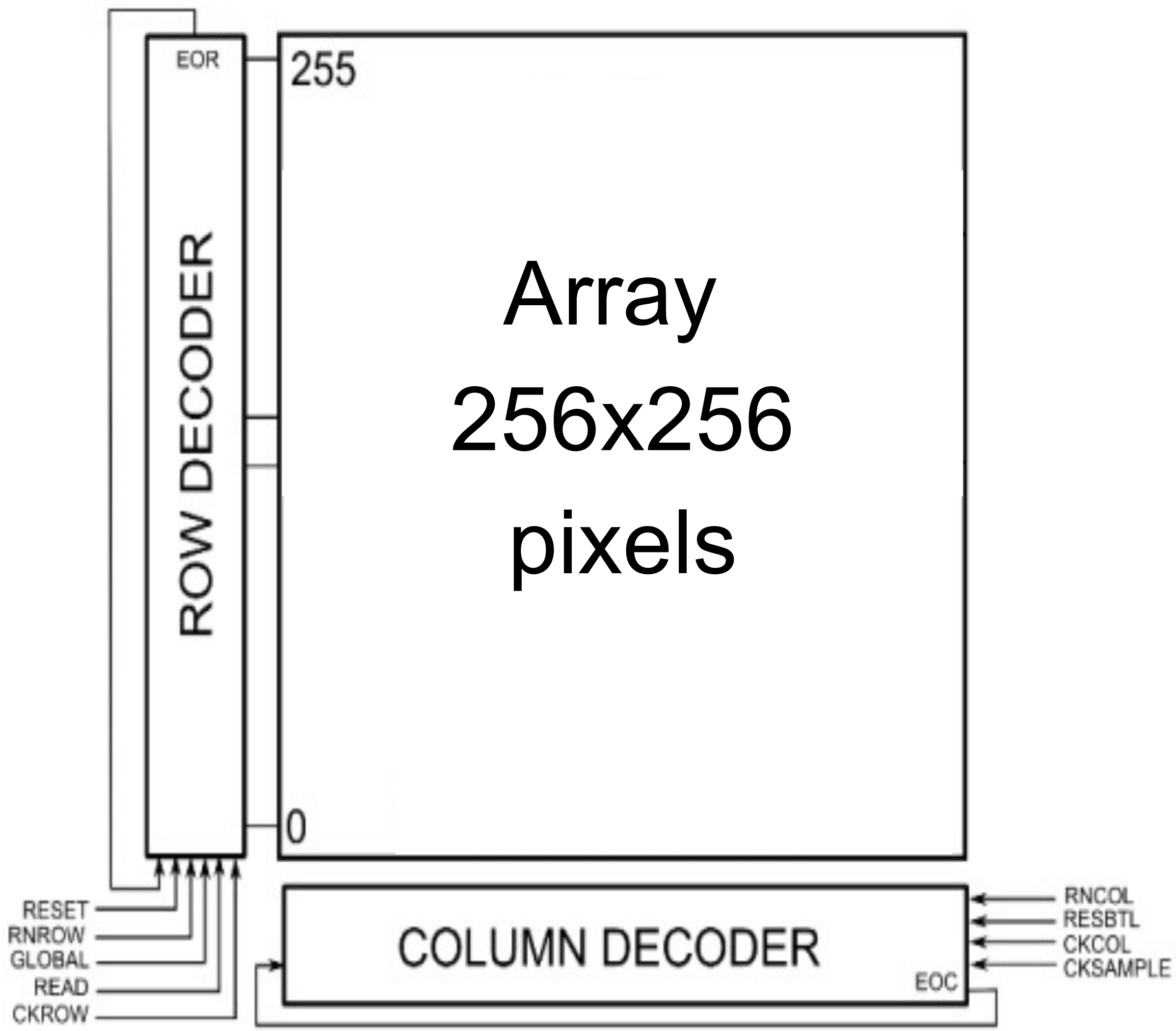
$$y_{\text{centroid}} = \frac{\sum_x \sum_y y \cdot I(x,y)}{\sum_x \sum_y I(x,y)}$$

Formula Components

- $I(x,y)$: The intensity (or hit count) at pixel coordinate (x,y).
- **Denominator** ($\sum\sum I$): The total sum of all intensities in the matrix.
- **Numerator**: The sum of each pixel's coordinate multiplied by its intensity weight.

Readout

- Decoder based readout.
- Decoders implemented as circular shift registers.
- Data is connected in groups 8 columns to output pads.
- Can be operated in either global or rolling shutter.
- Exploratory array has 128×128 pixel, other arrays have 256×256.



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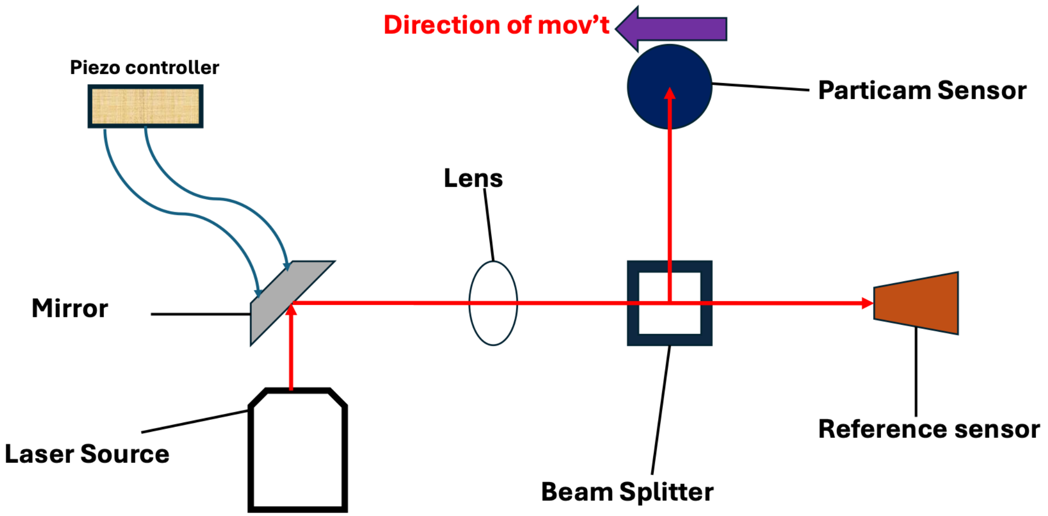
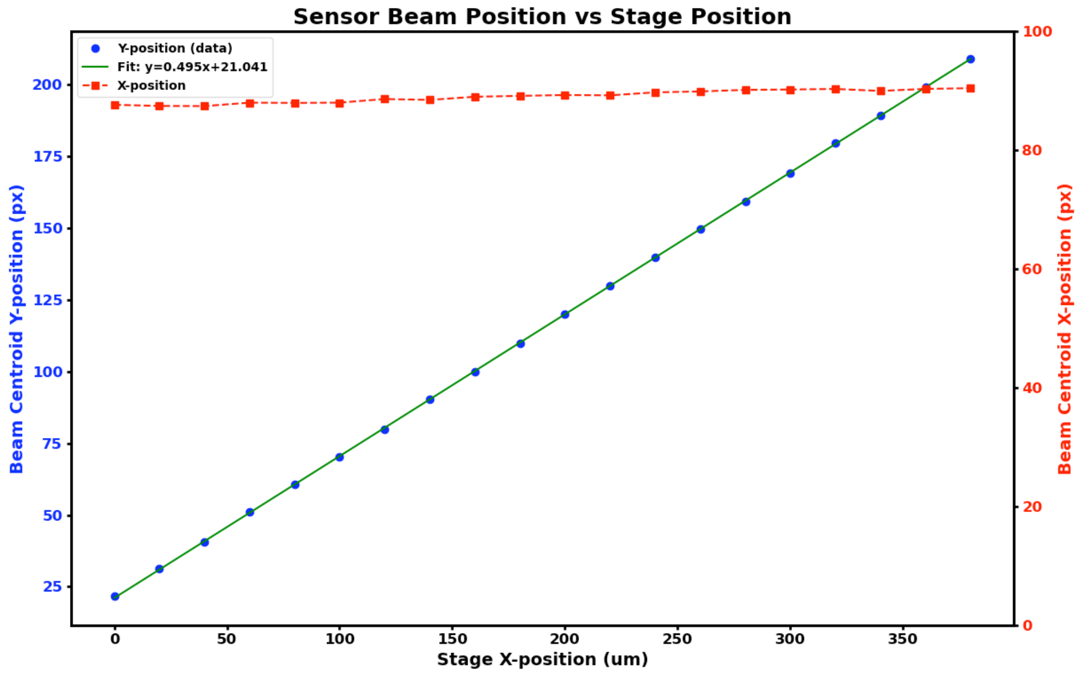
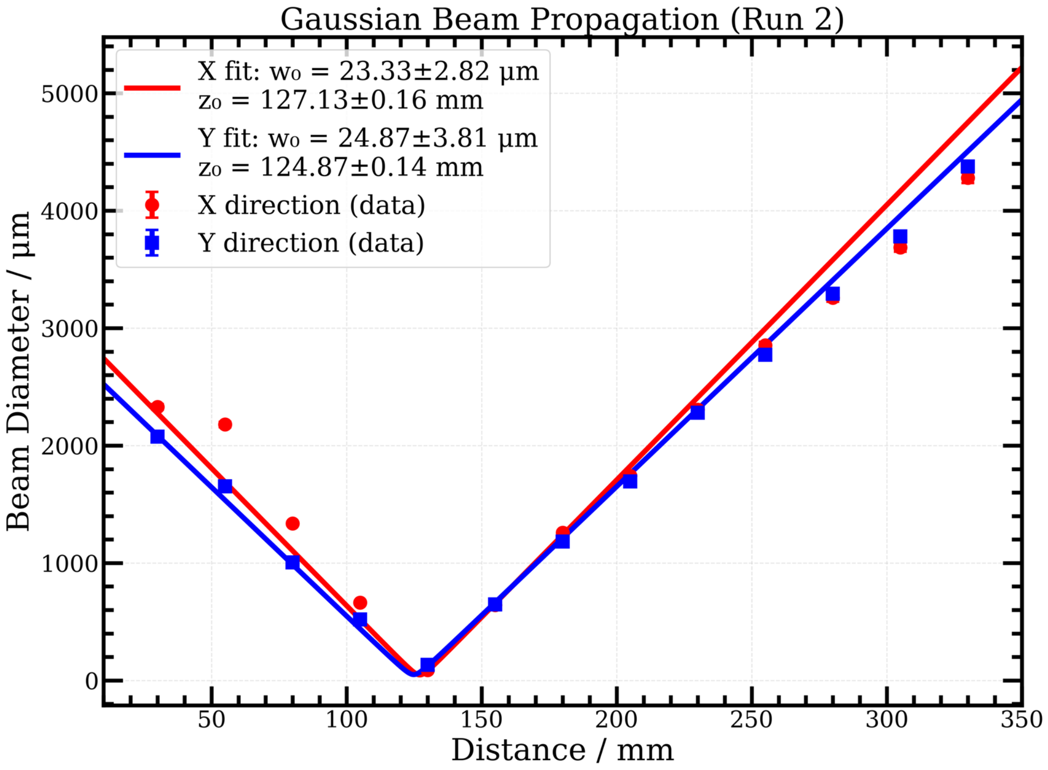
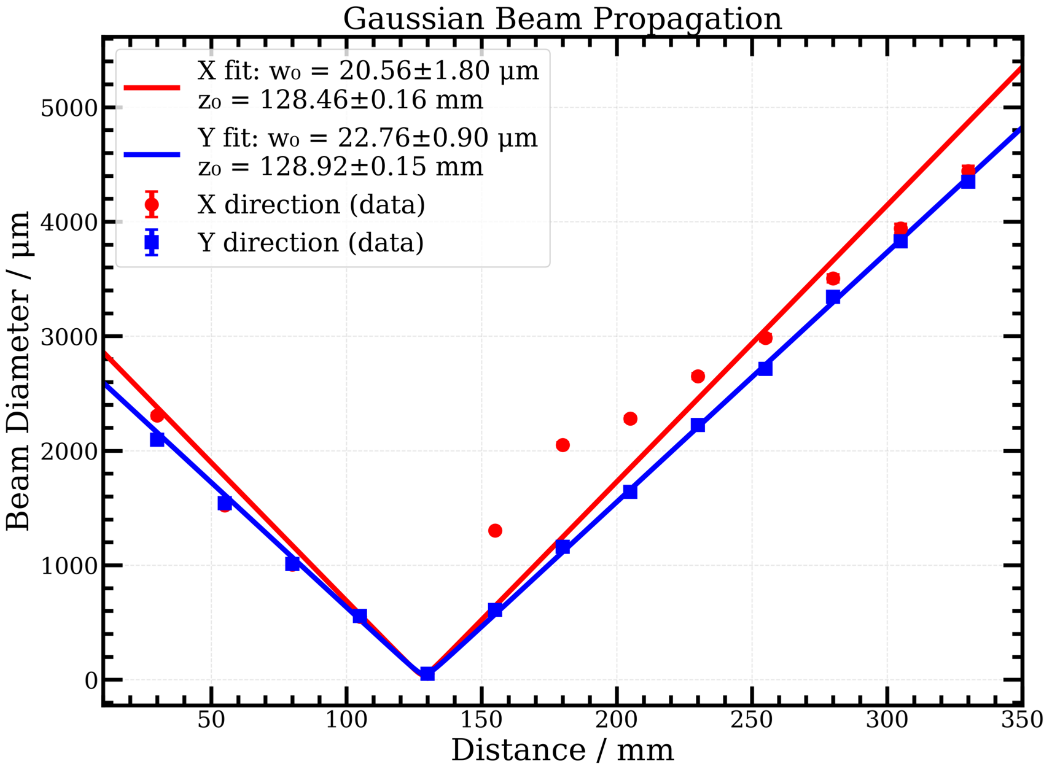




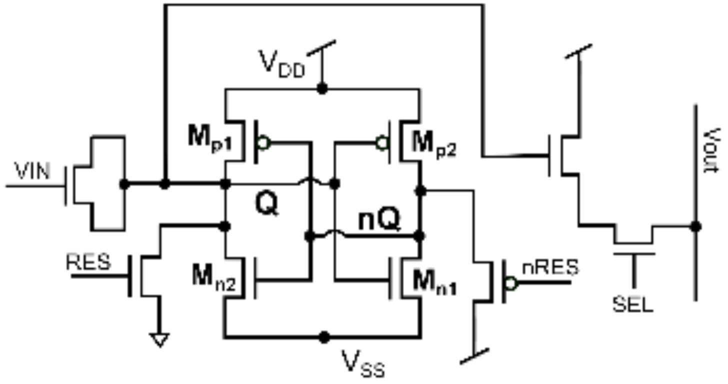
Beam Profiling

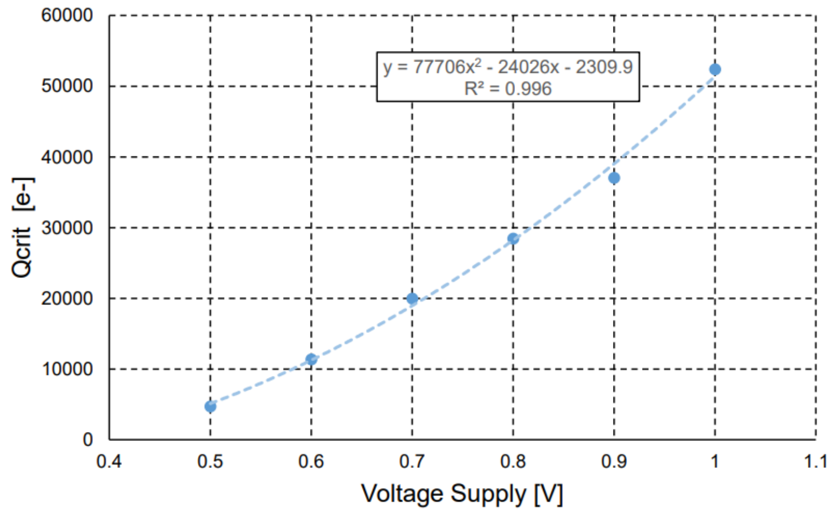
- A beam profiler was used to determine the size of the beam waist.
- Plots for two of the runs.





Experimental results: standard Array

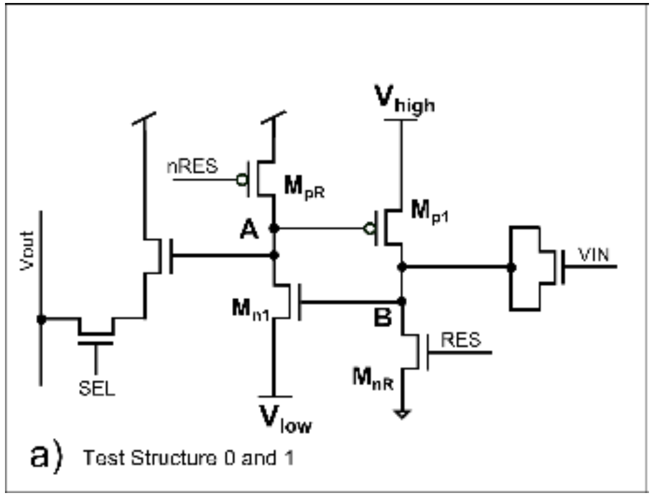


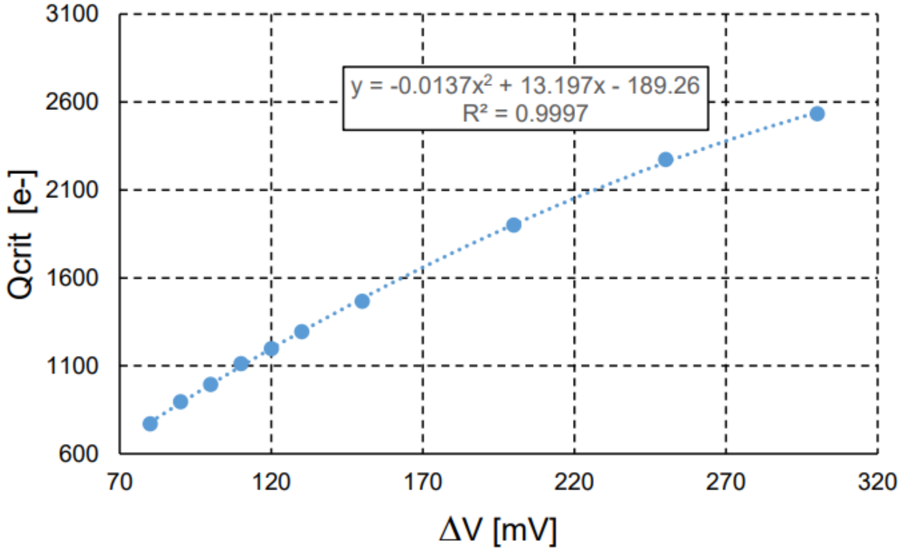


Test structure allows us to have an estimation of the minimum charge needed for changing the memory state

As expected Q_T reduces as the pixel voltage supply reduces, Q_T ~5 ke$^-$ working @ 0.5V → impact on the redout system.

Experimental results: custom array



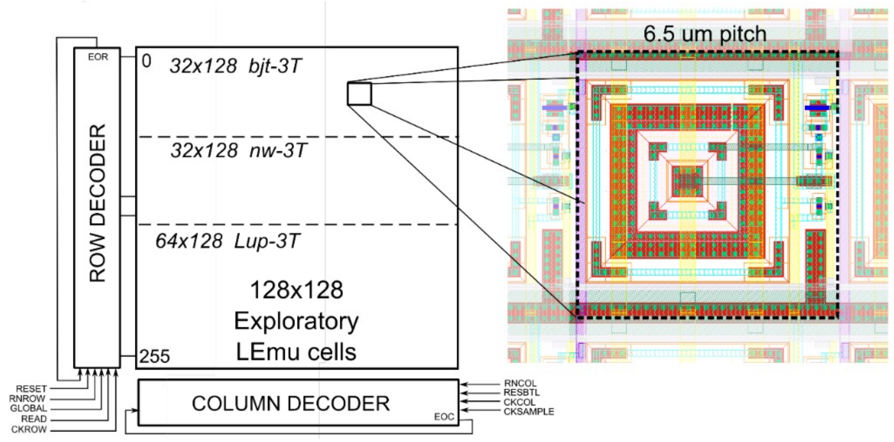


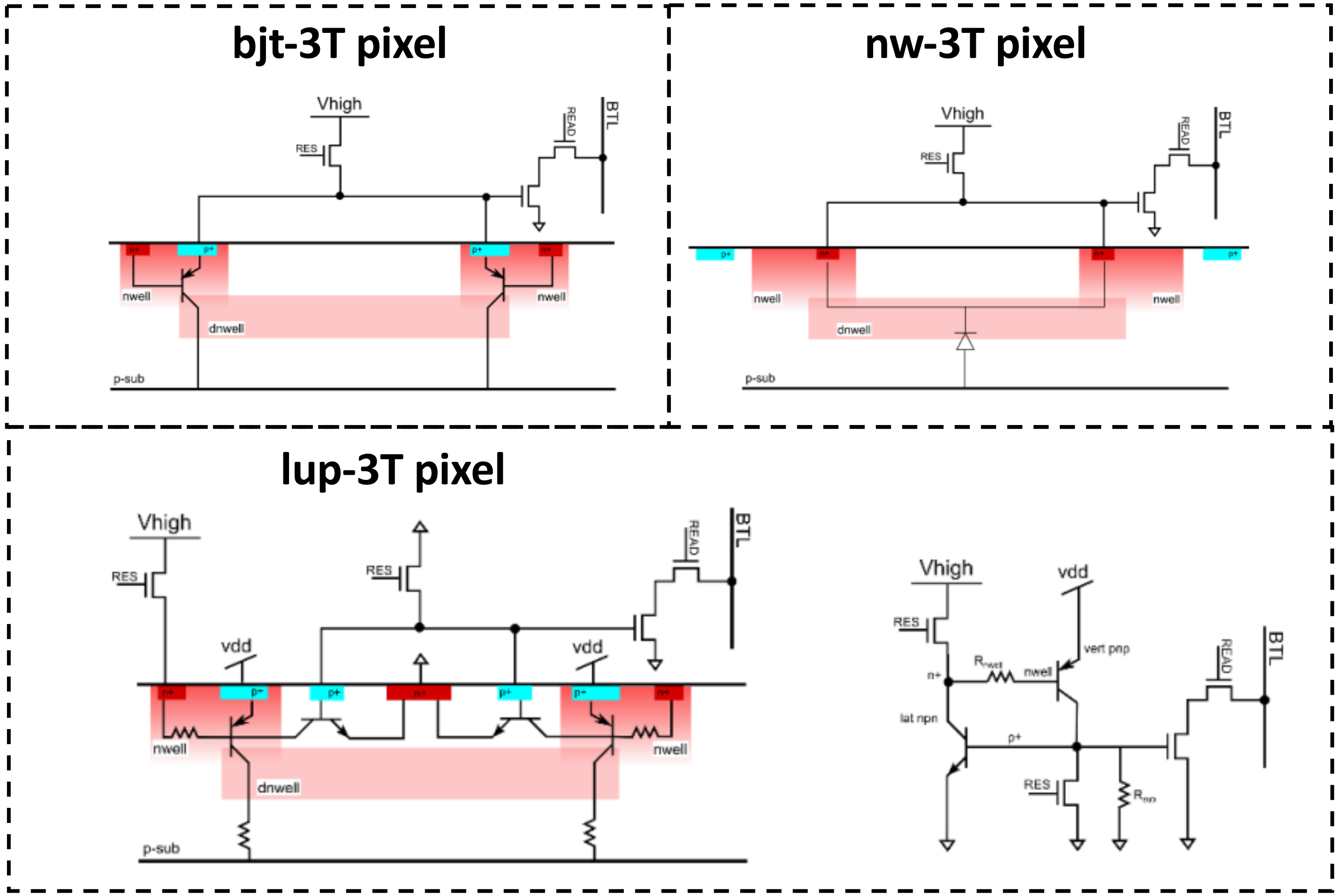
Q_T depends on DV and not any more on V_{dd}. DV is the difference between V_{low} and gnd (equal to V_{dd}-V_{high})

Test structure shows a minimum Q_T lower than 1ke$^-$

Not sensitive to a-particle. Not tested with laser.

“Exploratory” layout





Definition of three different pixels:

1. photo-transistor (3T pixel structure);
2. nwell junction (3T pixel structure);
3. “latch-up” (weak positive feedback) pixel (3T pixel structure);