An FPGA-Based Online Cluster Finding

An efficient data protocol for encoding preprocessed clusters of CMOS Monolithic Active Pixel Sensors

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Abstract

Application: The fixed target experiment CBM at FAIR will explore the structure and properties of nuclear matter under extreme conditions. The experiment will study various probes, among them open charm particles. These particles are identified by the reconstruction of their decay topology, which requires an ultra-thin high-resolution Micro-Vertex -Detector (MVD) , which is currently being prototyped. Due to its location close to the collision point, the MVD has to tolerate particularly high particle fluxes and track densities (>10^8 tracks/cm^2/s) [1]), which turns to high demands on its radiation hardness and rate capability.

Approach: The CBM - MVD will be equipped with CMOS Monolithic Active Pixel Sensors. Those sensors feature an on-chip zero suppression and 1-dimensional cluster finding[2]. To further reduce the data volume, we have explored an online 2-dimensional cluster finding. The study was carried out based on data taken with the MIMOSA-26AHR prototype during a test beam at CERN SPS.

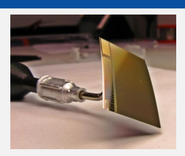
1-dim cluster finding on-chip

- **MIMOSA-26AHR CMOS sensors**
  - Zero-suppression logic
  - Encoding of fired pixels to **1-dim objects**
    - Line address (Status/Line)

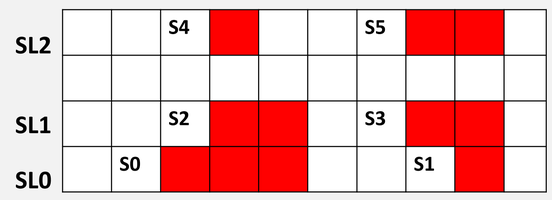
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bit(0-3)				Bit(0-10)											
number of *States*				The address of the line											OVF

    - Row address (State)

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Bit(0-1)	Bit(0-10)														
number of hit pixels	the address of the column												not used		



- Example



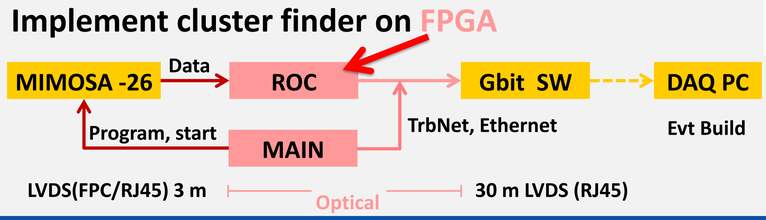
4 Clusters are encoded into 3 Status/Lines (**SL0-SL2**) and 6 states (**S0-S5**). In general, the number of states depends on the sensor's occupancy and response, i.e. the cluster shapes.

Online cluster finding concept

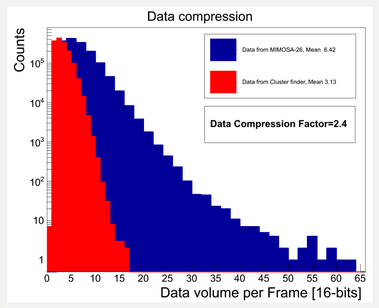
- **Cluster encoding format**

0	…	9	10	…	20	21	…	30	31
Bit(0-9)			Bit(0-10)			Bit(0-9)			Bit0
The Minimal Row			The Minimal Column			Index of the ShapeCode			OVF

  - 21 Bit for position information
  - 10 Bit for the shape index
  - 1 Bit for the overflow
- **Implement cluster finder on FPGA**



- **Data compression test with the 32 Bit cluster format**



2-dim Cluster Finding

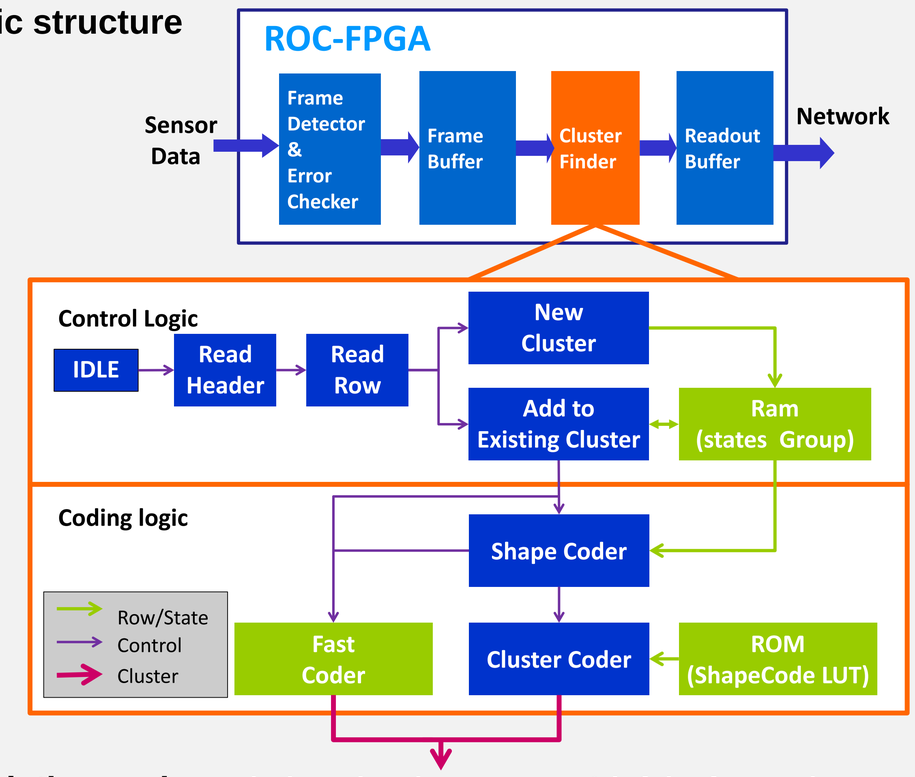
- **2-dim merging of the states, generating the following important information:**
  - Cluster size: Number of fired pixels
  - Cluster center: Center of Gravity
  - Cluster shape: Unique code, employing: $ShapeCode = \left(\sum_{i=1}^{M} 2^{(y_i - y_{\min}) \cdot W_x} \times 2^{(x_i - x_{\min})},\ W_x \right)$

M is the number of fired pixels in the cluster, (x_i, y_i) is the coordinate of pixel$_i$, and W_x is the cluster size in row direction.

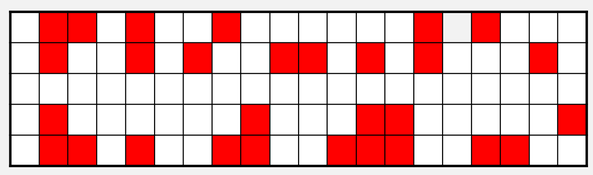
Here, the value of ShapeCode is determined by the cluster size. If the cluster size M <28 and W_x<16, the cluster information can be encoded into a 32 Bit word.

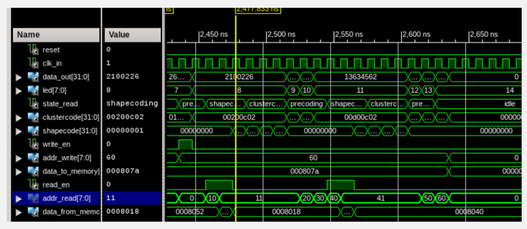
Implementation

- **Main logic structure**



- **Full simulation and stand-alone hardware test with fake frame data**



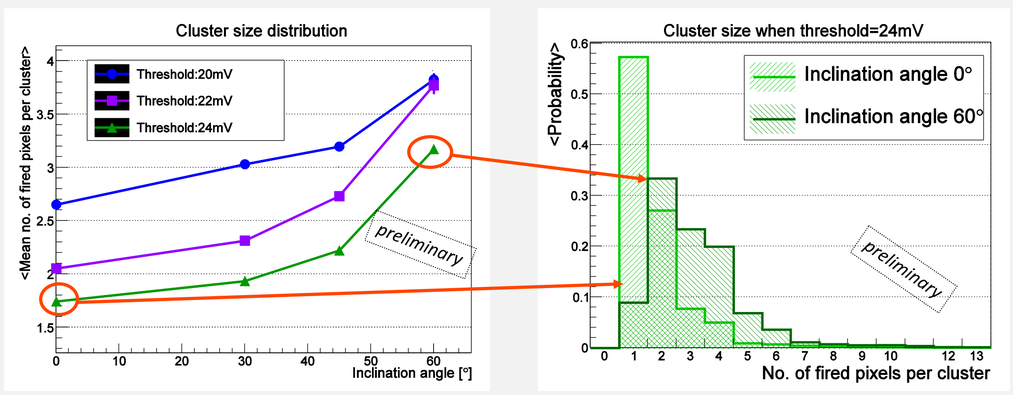


Device Utilization Summary (estimated values)			
Logic Utilization	Used	Available	Utilization
Number of Slice Registers	1190	28800	4%
Number of Slice LUTs	4309	28800	14%
Number of fully used LUT-FF pairs	900	4599	19%
Number of bonded IOBs	43	480	8%
Number of Block RAM/FIFO	6	60	10%
Number of BUFG/BUFGCTRLs	1	32	3%
Number of DSP48Es	2	48	4%

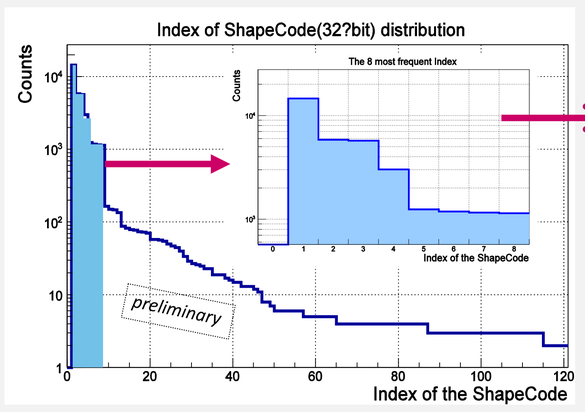
First simple hardware test : Output the cluster number: "1110"=14 clusters

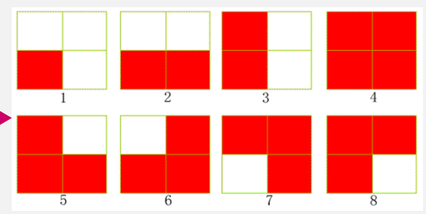
Study the response of the sensor

- **Analyses of the cluster size and shape from beam data (at the CERN-SPS)**
  - Dependence of the cluster size on the inclination angle for three different discriminator thresholds (sensor temperature=20°C)



  - Distribution of measured cluster shapes for all inclination angles and threshold =22mV, for a maxinum cluster width of 16 pixels, indexed according to their relative abundance.





  - The 8 most frequent cluster shapes correspond to 90% of all clusters.
  - <0.01% of the cluster shapes cannot be encoded by the algorithm presented due to the restriction to 32 Bit.
  - Less than 1024 different cluster shapes were found. Hence, the shape information can be compressed to 10 Bit, using a 1024x32 look-up table .

Conclusions

- An efficient data protocol for encoding preprocessed clusters has been introduced based on data from the recent beam test.
- The algorithm was tested with real data obtained from a beam test of the MIMOSA-26 prototype.
- It was implemented into an FPGA and tested with existing data.
- Next steps: optimize speed, test with online data (radioactive source, beam).

References

[1] S. Seddiki et al., CBM Annual Report, 2009.
[2] C. Hu-Guo et al., NIM A623 (2010) 480.

Acknowledgement

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