Real-time Timepix3 data clustering, visualization and classification with a new Clusterer framework

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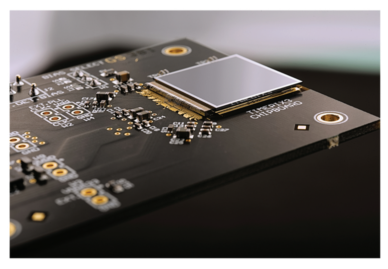
Timepix3 hybrid pixel detector

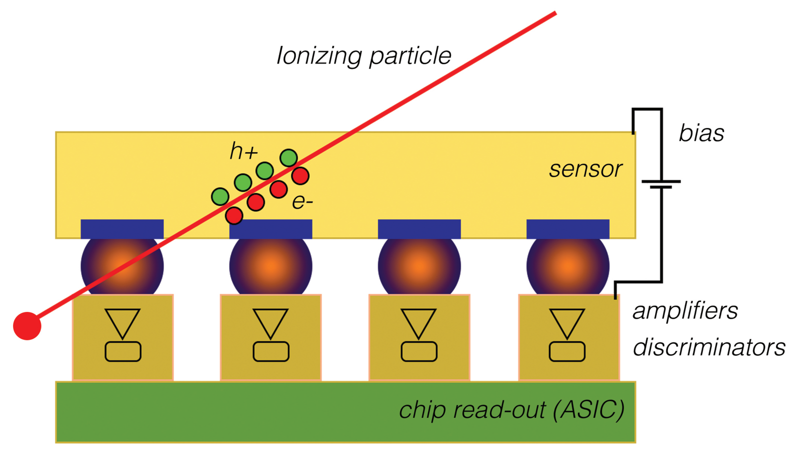
Timepix3 was developed by Medipix collaboration at CERN as a successor to previous Timepix device. Its hybrid architecture allows to attach sensors of different material to the ASIC. The chip offers resolution of 256 x 256 pixels with a pixel pitch 55 *μm* (sensitive area 1.98 *cm²*).

Main enhancements achieved in the new generation of Timepix chips are faster clock speed of the chip (supporting up to 1.56 *ns* time precision) and continuous data-driven readout mode while measuring both time over threshold (ToT) and time of arrival (ToA).Timepix3 has been tested and used in ATLAS and MoEDAL experiments in CERN.

Timepix3 device used in LHC tunnel



Detail of chip and its wirebonding



Schema of Timepix chip capturing electron-hole pairs

Katherine readout

Katherine readout is a newly developed readout for Timepix3 devices supporting all the capabilities of Timepix3 chip.

The readout is connected over VHDCI to the chip and using ethernet cable (allowing up to 100 *m* distance) to the measurement device.

Communication is done using UDP with up to 16 Mhits/s speed.

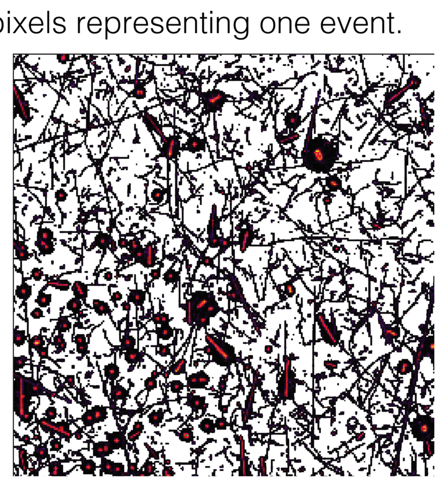
Katherine readout device.

Pixel acquisition

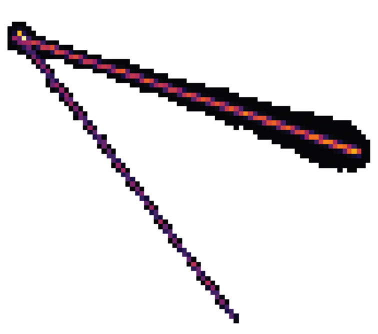
From all different read-out modes that are supported by Timepix3 chip, main focus is on the data-driven mode. Opposite to the frame-based mode, which requires manual setting of frame length and all pixel values are read out at the end of the frame (similiar to exposition time in regular CMOS camera chips), data-driven mode will for each pixel hit produce immediately record during measurement. The dead time before the pixel is ready to measure again is 475 *ns*. The measurement is thus continuous with length up to days. Values provided by each pixel hit are the following:

- **index** - pixel *x* and *y* position
- **ToA** - time in *ns* when pixels arrived (i.e. charge was over given threshold)
- **ToT** - time over threshold (with calibrated chip it provides energy in *keV*)

Pixels are provided by the readout in a chronologically unsorted stream (the pixel can be delayed up to 2000 *ns*). **Cluster** is a set of pixels representing one event.



Frame based output on whole chip (256 x 256) with integration time of 1 second measured in the ATLAS detector during collisions period.

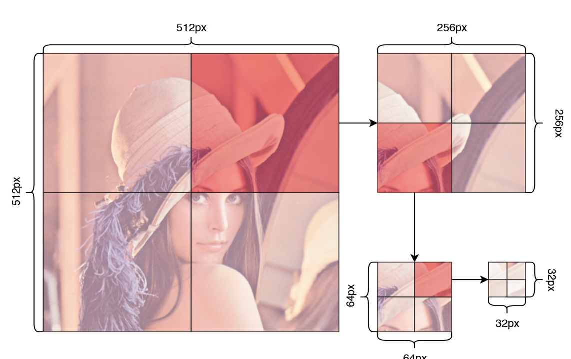


Example of one cluster. Original 256 x 256 image is cropped.

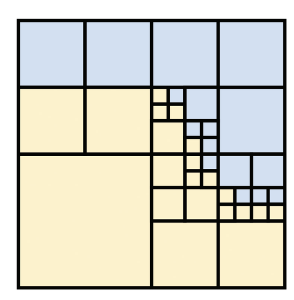
Connecting the pixels

Creating clusters is based both on pixel coordinates adjacency and time of arrival of cluster pixels in a given time window (based on material used and charge drift time, e.g. for Si sensor 200 *ns* is used).

To efficiently create clusters in real time, fast and robust spatial occupancy data stucture **quadtree** is used. In this tree structure, each node has four childern representing each quadrant of given range. Merging two quadtrees (when two clusters connects during the process) is done simply by joining leaves of the trees.



Quadtree nodes representation.

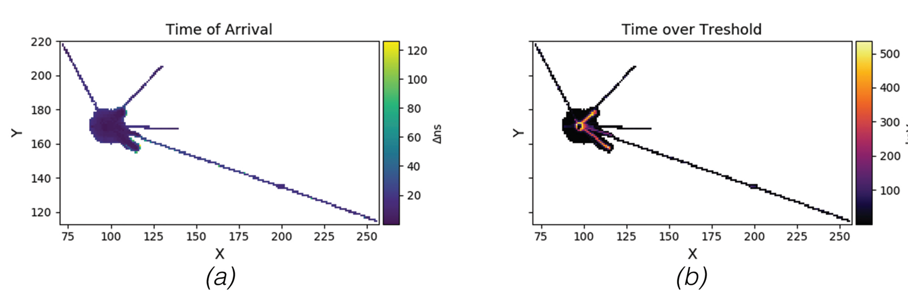


Memory optimization using Quadtree.

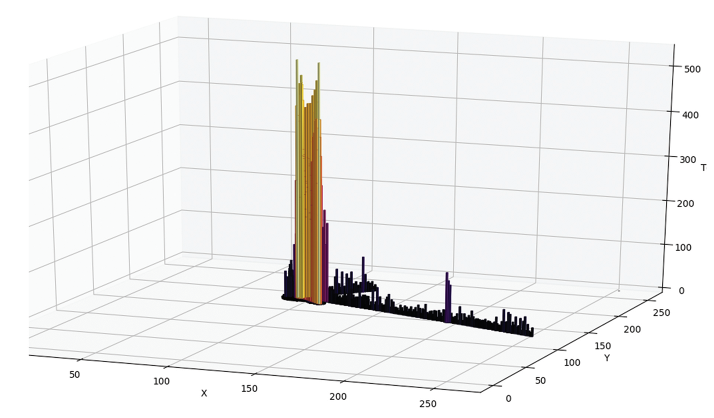
This allows quick spatial connection checking (with logarithmic time complexity). To tackle the partially sorted pixel input buffering is implemented. Clustering speed is above 1.5 MHit/s

Resulting clusters

The resulting clusters represent well separated events. Implicitly, basic event attributes are generated such as cluster size and cluster energy.



(a) shows relative pixel ToA. (b) image represents the energy in keV deposited in pixels (using calibrated detector). Image is cropped to the cluster.



3D representation of deposited energy

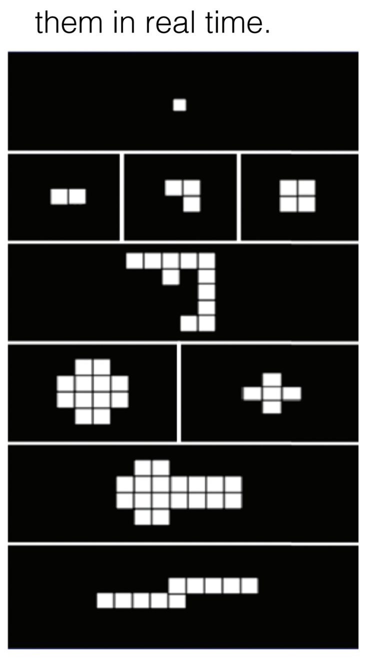
Data are stored for further analysis as a set of pixels representing individual clusters. All pixel details are preserved and the whole measurement can be replayed or further analyzed. During the measurement live representation of events occurring in chip is available.

Live classification

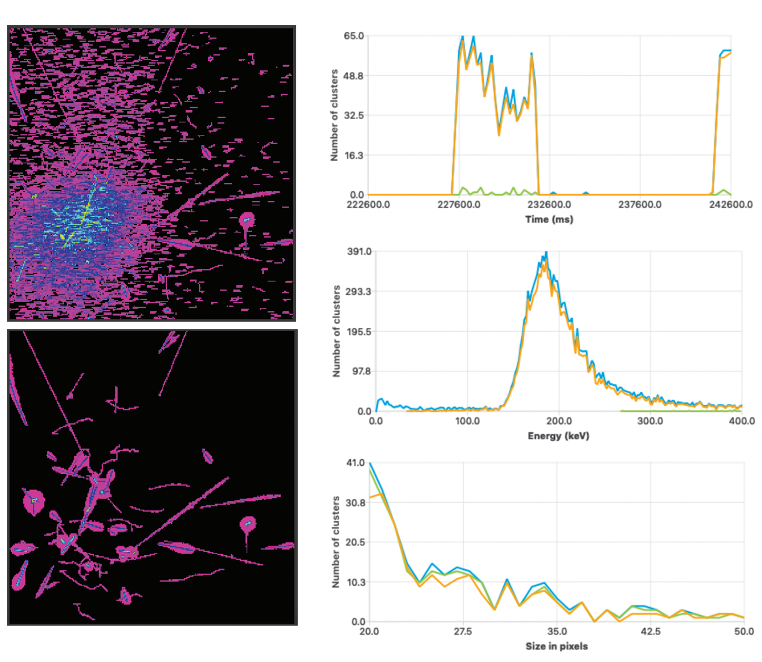
Given the basic characteristics of the clusters:

cluster size, total energy of cluster and roundness,

real-time classification can be performed using decision trees. With Clusterer software it is possible to online classify following basic categories and filter them in real time.



- Dots - Photons and electrons (10keV)
- Small Blobs - Photons and electrons
- Curly Track - Electrons (MeV range)
- Heavy Blobs - Heavy ionizing particles with low range (i.e. alpha)
- Heavy Tracks - Heavy ionizing particles (i.e. protons)
- Straight Track - Energetic light charged particles (MIPs)



Basic filtration can be used while measurement is running to filter out given classes.

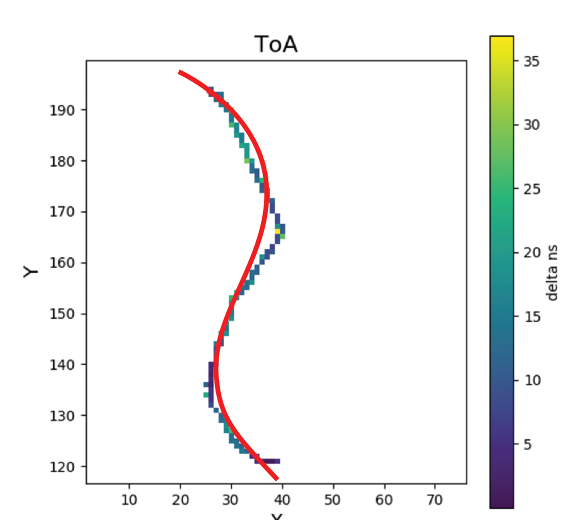
(a) Only heavy blobs and heavy tracks from the past 10 seconds are displayed.

(b) The right image shows the capabilities of simultaneous live statistics of different classes. Statistics are: number of clusters per second, energy and size histogram.

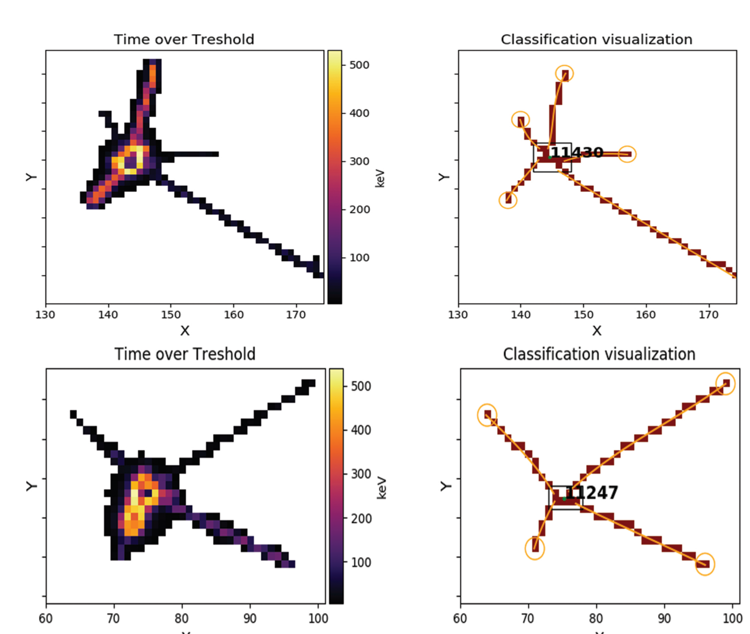
Cluster morphology

For futher cluster classification beyond the basic six groups, morphological analysis is introduced.

To gain better precision of curly track recognition, **winding** is measured. Using normalized polynomial interpolation, curvature of the track can be computed.



Visualization of polynomial aproximation of a track.



Visualization of skeletonization algorithm. Branches are marked, core (and its energy) of branches is found. Winding of branches is aproximated.

In exotic events, **skeletonization** is used to describe number of branches, their curvature, length and energy. Further investigation of possible classification based on these information is taking place.

Further details in:

Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout *(T Poikela et al 2014 JINST 9 C05013)*

Katherine: Ethernet Embedded Readout Interface for Timepix3 *(P. Burian et al 2017 JINST 12 C11001)*

3D track reconstruction capability of a silicon hybrid active pixel detector *(Bergmann, B., Pichotka, M., Pospisil, S. et al. Eur. Phys. J. C (2017) 77: 421.)*

Connecting the Dots 2019

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