

Analysis of camera images

Here we present preliminary analysis of camera images from <https://api.credo.science> i.e. our goal is to extract the cosmic rays muons and to identify different types of background events. The idea is taken from [\[\[http://snap.lbl.gov/ccdweb/groom.pdf\]\]](http://snap.lbl.gov/ccdweb/groom.pdf) and [\[\[https://arxiv.org/abs/1511.00660\]\]](https://arxiv.org/abs/1511.00660)

Introduction

Muons arrive at sea level with an average flux of about 1 muon per square centimeter per minute [\[\[http://cosmic.lbl.gov/SKliewer/Cosmic_Rays/Muons.htm\]\]](http://cosmic.lbl.gov/SKliewer/Cosmic_Rays/Muons.htm). An smartphone has a detector size of about 4mm x 4mm, so 0.16 cm² (iphone), so about one muon every 6 mins or so goes through the camera sensor. When a cosmic ray enters the CMOS sensor the cosmic ray deposits a charge onto the sensor itself. If the sensor is not exposed to any sources of light, the cosmic ray will leave a track behind in the resulting image.

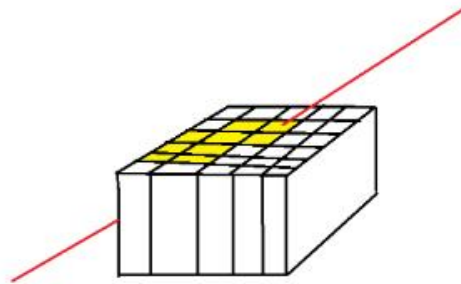
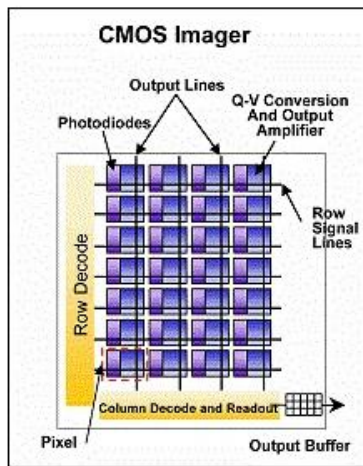


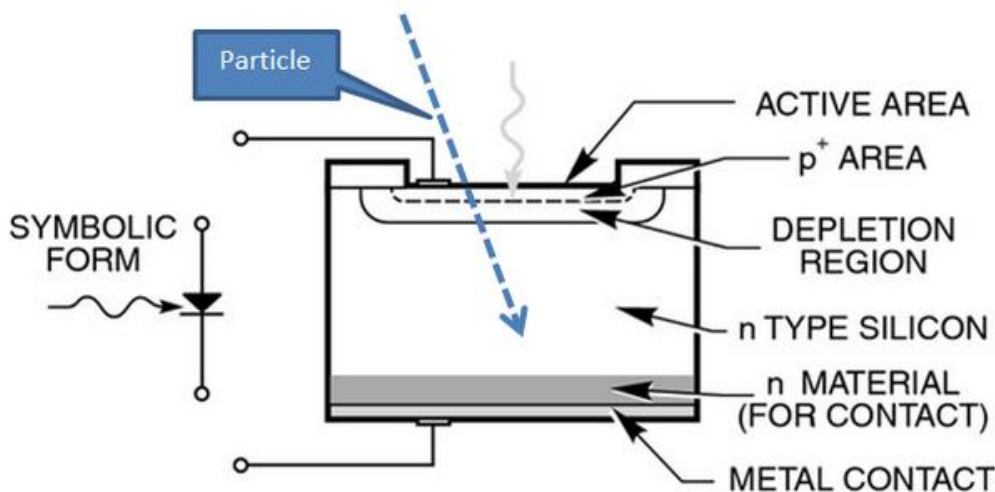
Figure 2. Red line indicates the path of the cosmic ray. Yellow indicates pixels triggered by the cosmic ray.



Inside the webcam is present the CMOS sensor that is the light-sensitive element. The CMOS sensor is in practice constituted by a matrix of pixels. Each pixel includes a photodiode and a conversion circuit / amplifier that converts the charge originated in the photodiode into a voltage that is read, pixel by pixel, and subsequently digitized into a numerical value **ranging from 0 to 255**. To select the color a tiny color filter (red, green and blue) is positioned above each pixel, resulting in a "mosaic" of colored pixels, then the image is processed in a timely manner (interpolation) to reconstruct the original image.

The active element, sensitive to particles, is the photodiode,

shown schematically in the image below.



The ionizing particle enters into the sensitive area from the "top window" and produces in its passage several hundred electron / hole pairs which are collected by the cathode / anode of the diode and produce the signal that is subsequently digitized.

We give some data from the literature on solid state sensors :

Silicon Band Gap = 1,115 eV

Couple Production Energy e/h (300°K) = 3,62 eV

Electron ionization power = 80 e/ μ m

As you can see from the data shown above, an electron which runs 10 μ m produces about 1000 charge carriers, and thus an easily detectable signal, also because the electronic detection is local on the chip. Actually the CMOS sensor is not optimized for the detection of the particles and therefore the detection efficiency is rather low, especially due to the fact that the sensitive region which is the depletion layer of the junction is very thin.

Besides muons the camera sensor can see also different types of events, due to the radioactivity of the local medium.

There are three different types of radioactive decays , which differ from the type of particle emitted as a result of the decay :

Alpha particles,

Beta particles

and Gamma radiation.

The alpha particles are not detected because the sensor is protected by a layer of glass (or other transparent material) that completely blocks the alpha particles.

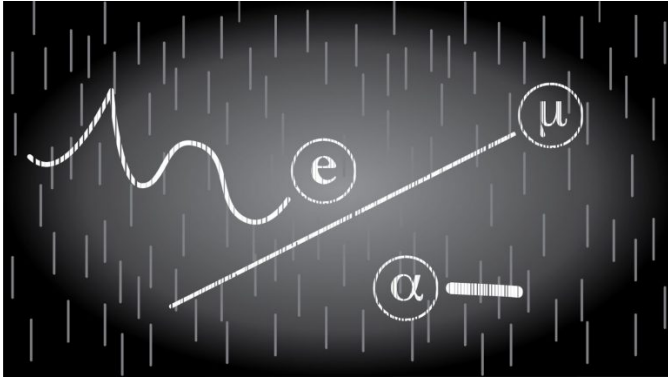
Beta particles are partially absorbed by the surface protection but a high percentage reach the sensitive part and is detected.

Cosmic rays, which are high-energy muons, are detected practically 100 %.

For the gamma radiation the sensitivity is rather low and appears to be greater at low energies, this is also due to the small thickness of the sensitive region of the CMOS sensor.

This results in two types of background seen by the camera sensor: "spots" and "worms", schematically shown in picture

below:



Worms show significant deflection along the trajectory, curving and/or kinking. They are most likely due to low-energy (MeV scale) electrons what exhibit multiple Coulomb scattering. Such electrons are a product of radioactive decay in the materials of the phone itself or in the surroundings. The source of these low-energy electrons is typically the Compton scattering of gamma rays from 40 K, and from isotopes from the U and Th decay chains. Much smaller, diffusion-limited hits are also observed (spots), and are generally attributed to nuclear recoil events, very low-energy Compton scatters (short worms), or low energy x-rays.

Method used

The analysis follow the idea presented in [[<http://snap.lbl.gov/ccdweb/groom.pdf>]] and [[<https://arxiv.org/abs/1511.00660>]] (see also [[<http://cosmicrayapp.com/2017/03/02/cosmic-ray-ccd-video/>]]) i.e.

- First we convert the RGB pixel values to a single gray-scale amplitude (luminance) using formula from: <http://scikit-image.org/docs/dev/api/skimage.color.html#skimage.color.rgb2grey>
compute luminance of an RGB image with formula:
 $Y = 0.2125 R + 0.7154 G + 0.0721 B$
- Second, we calculate a contour using the “marching squares” algorithm (implemented in python module: http://scikit-image.org/docs/stable/user_guide.html) to delimit the pattern of pixels that detected ionization above a particular threshold.
- Finally, several metrics (observables) are calculated for each event:
 - the total luminance above threshold (calles here the SIZE parameter)
 - the length and width parameter from Principal Component Analysis (PCA) [[http://www.cs.otago.ac.nz/cosc453/student_tutorials/principal_components.pdf]] or [[https://en.wikipedia.org/wiki/Principal_component_analysis]]

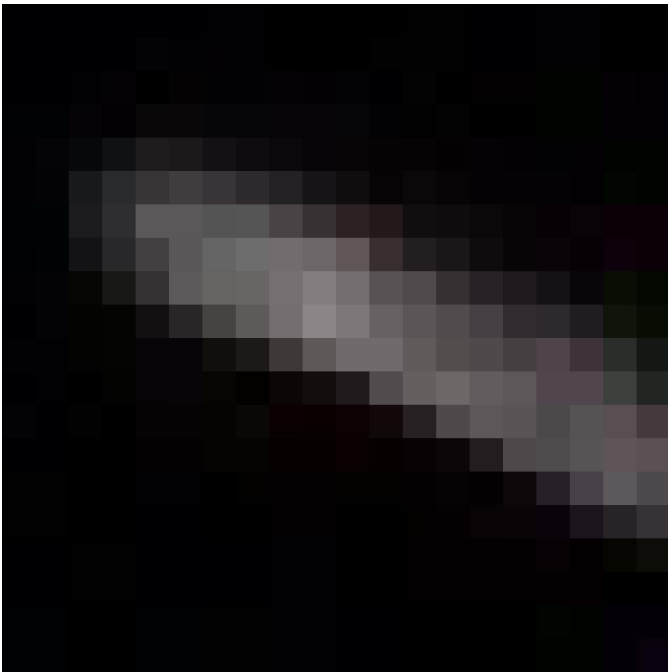
This scheme was implemented in the following python script: [script](#)

Script also gives possibility to convert the original image to the ascii format (pixel_x, pixel_y, luminance value)

Results

Example 1: muon like event





Original image

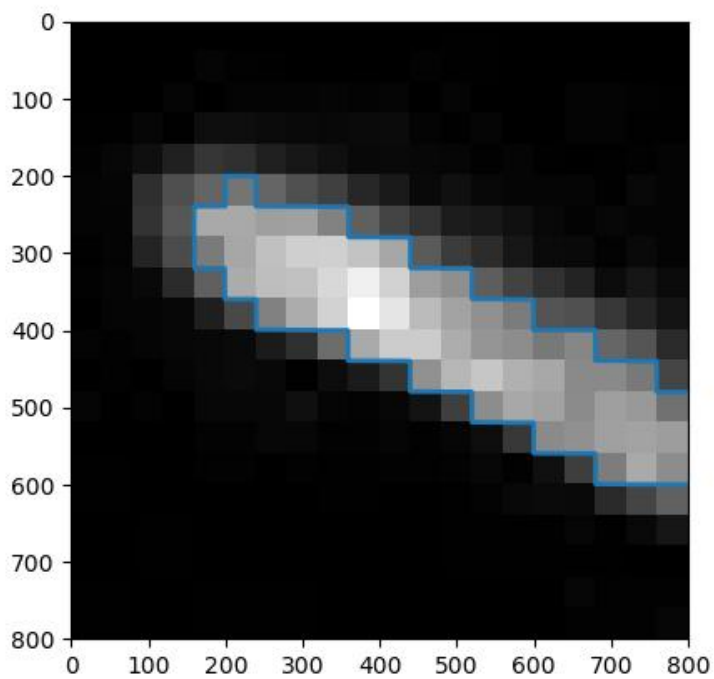
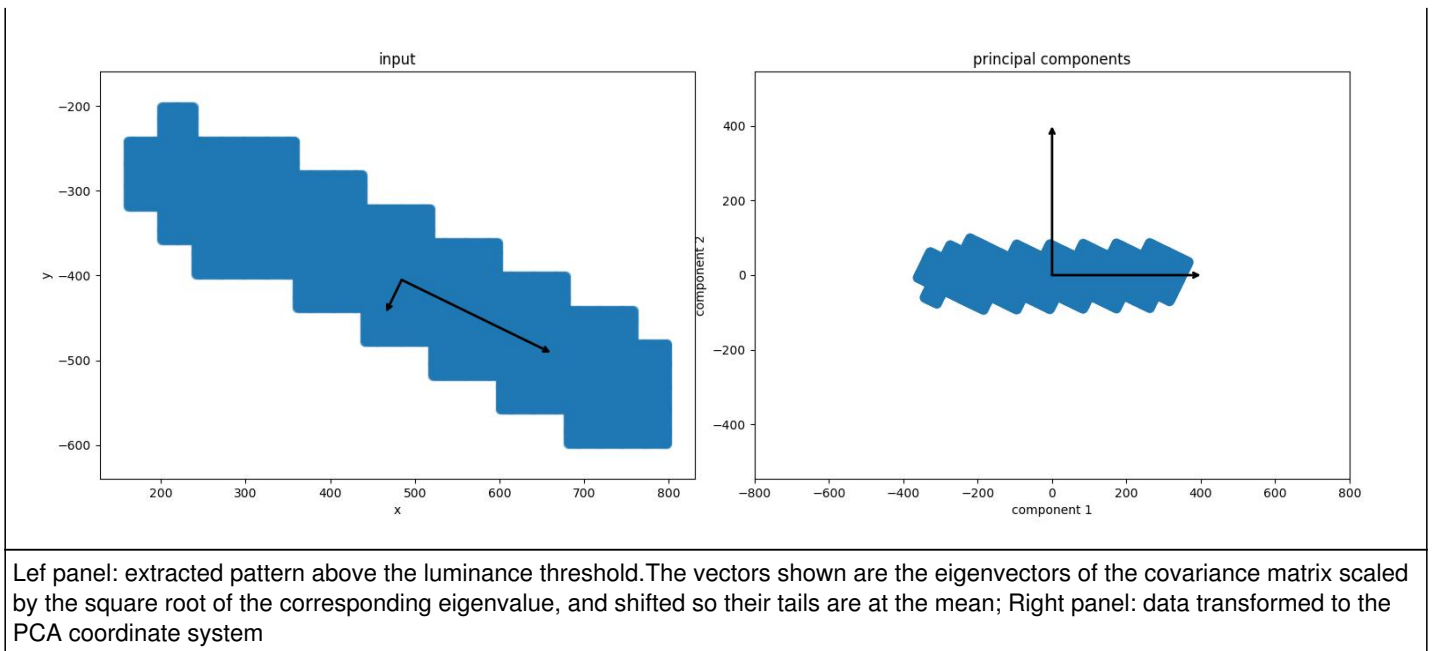


Image converted to black and white scale with luminance contour (blue line)

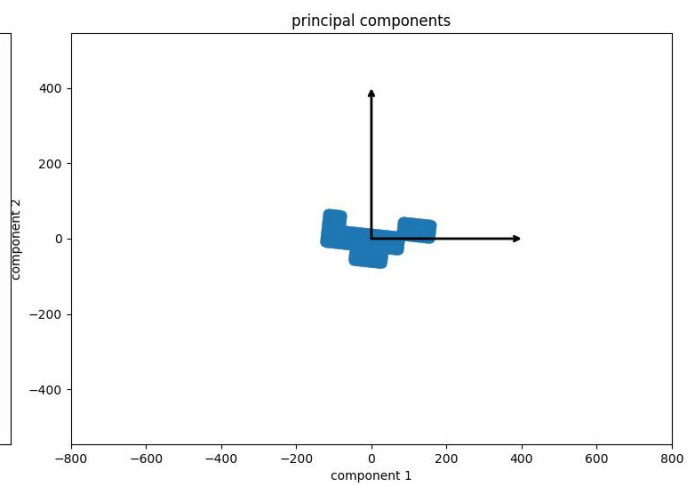
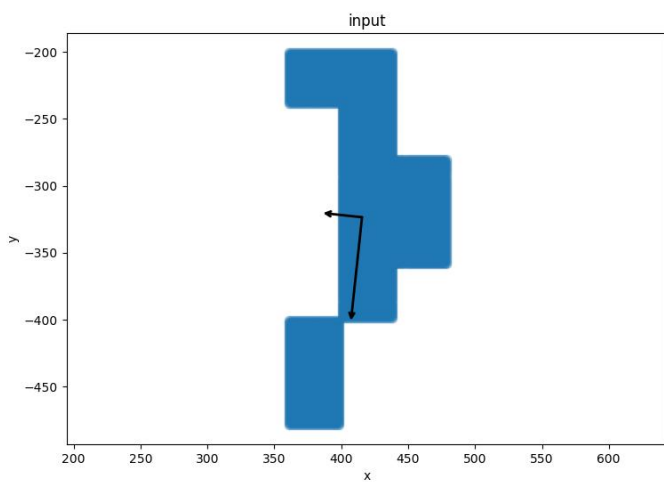
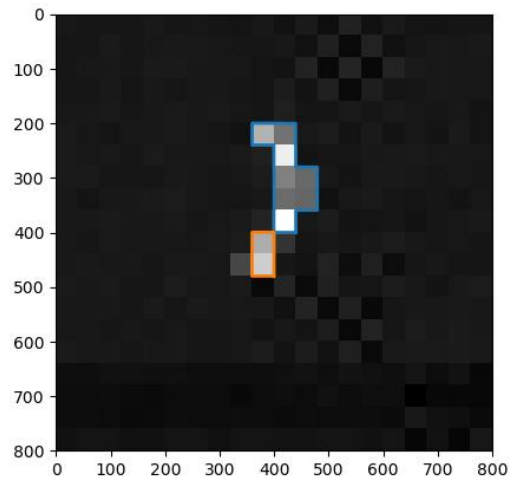


Output from the script:

```
Maximal luminance value in the image 0.527134117647
Results for the following luminance threshold: 0.23
Sum of luminance for all pixels present above the threshold: Size= 33398.2575686
Length= 195.85731498 Width= 42.2561762884 Length/Width= 4.63499852998
Effective area of ellipse A_eff=Length*Width*pi: 26000.3901493
Size/A_eff 1.28452909271
AAA 33398.2575686 4.63499852998
```

Example 2: worm like event

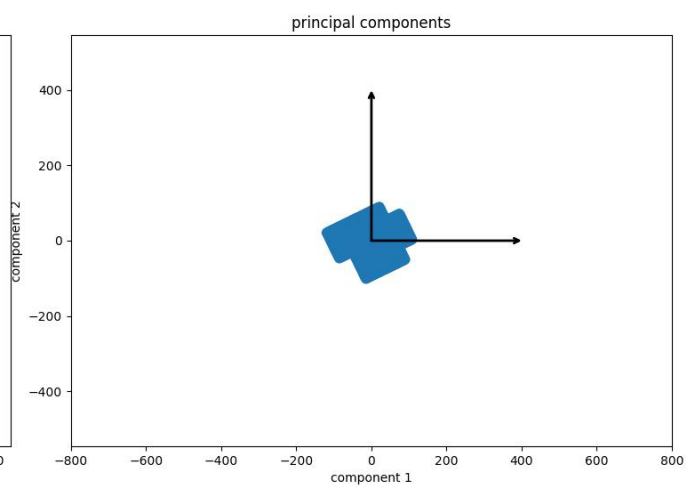
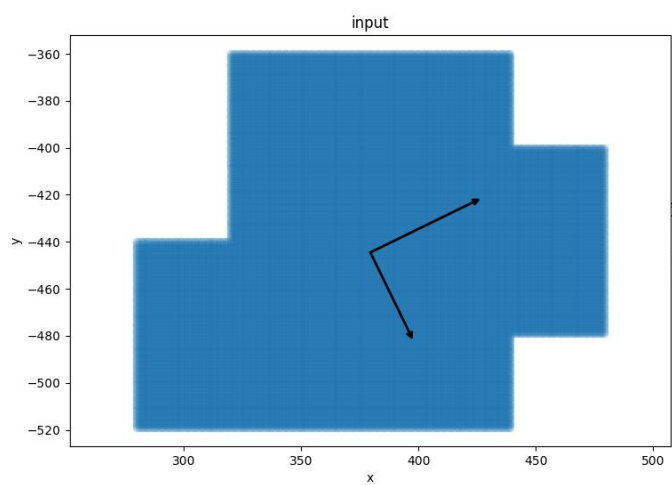
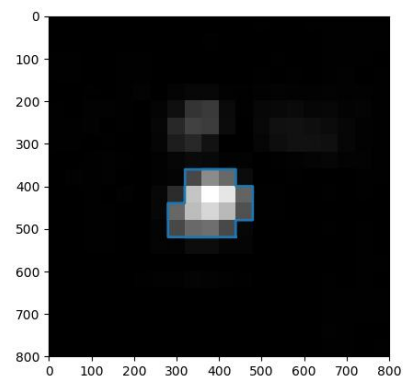
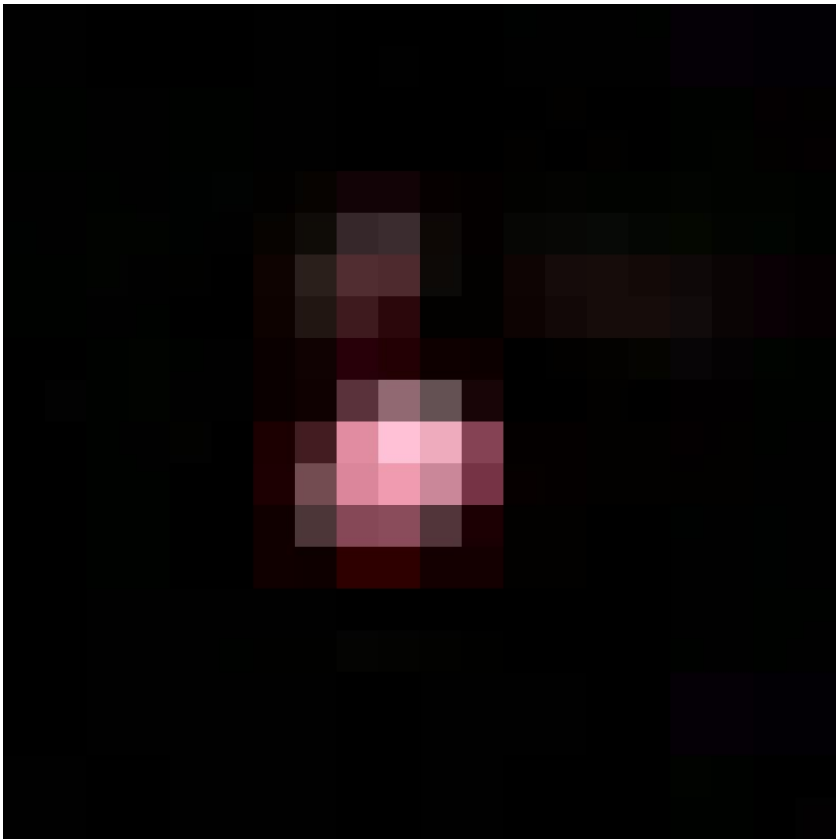




Output from the script:

```
Maximal luminance value in the image 0.556862745098
Results for the following luminance threshold: 0.23
Sum of luminance for all pixels present above the threshold: Size= 5746.0825098
Length= 77.5583578645 Width= 29.3121327332 Length/Width= 2.6459472796
Effective area of elippse A_eff=Length*Width*pi: 7142.09950418
Size/A_eff 0.804536888129
AAA 5746.0825098 2.6459472796
```

Example 2: spot like event



Output from the script:

Maximal luminance value in the image 0.814184313725
Results for the following luminance threshold: 0.23

```

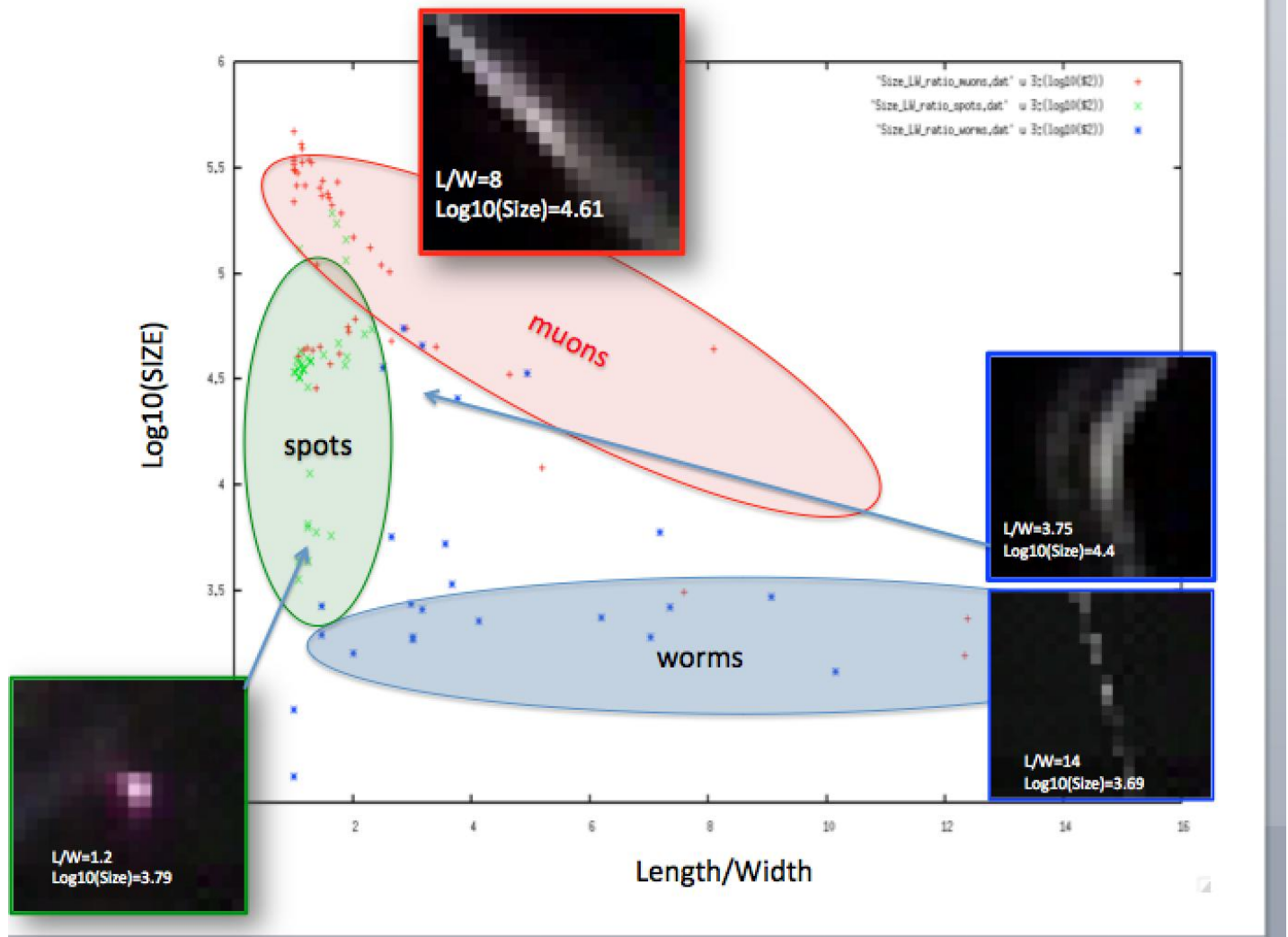
Sum of luminance for all pixels present above the threshold: Size= 11419.4785882
Length= 52.2335956316 Width= 41.3902342032 Length/Width= 1.26197874057
Effective area of elippse A_eff=Length*Width*pi: 6792.00002986
Size/A_eff 1.68131309453
AAA 11419.4785882 1.26197874057

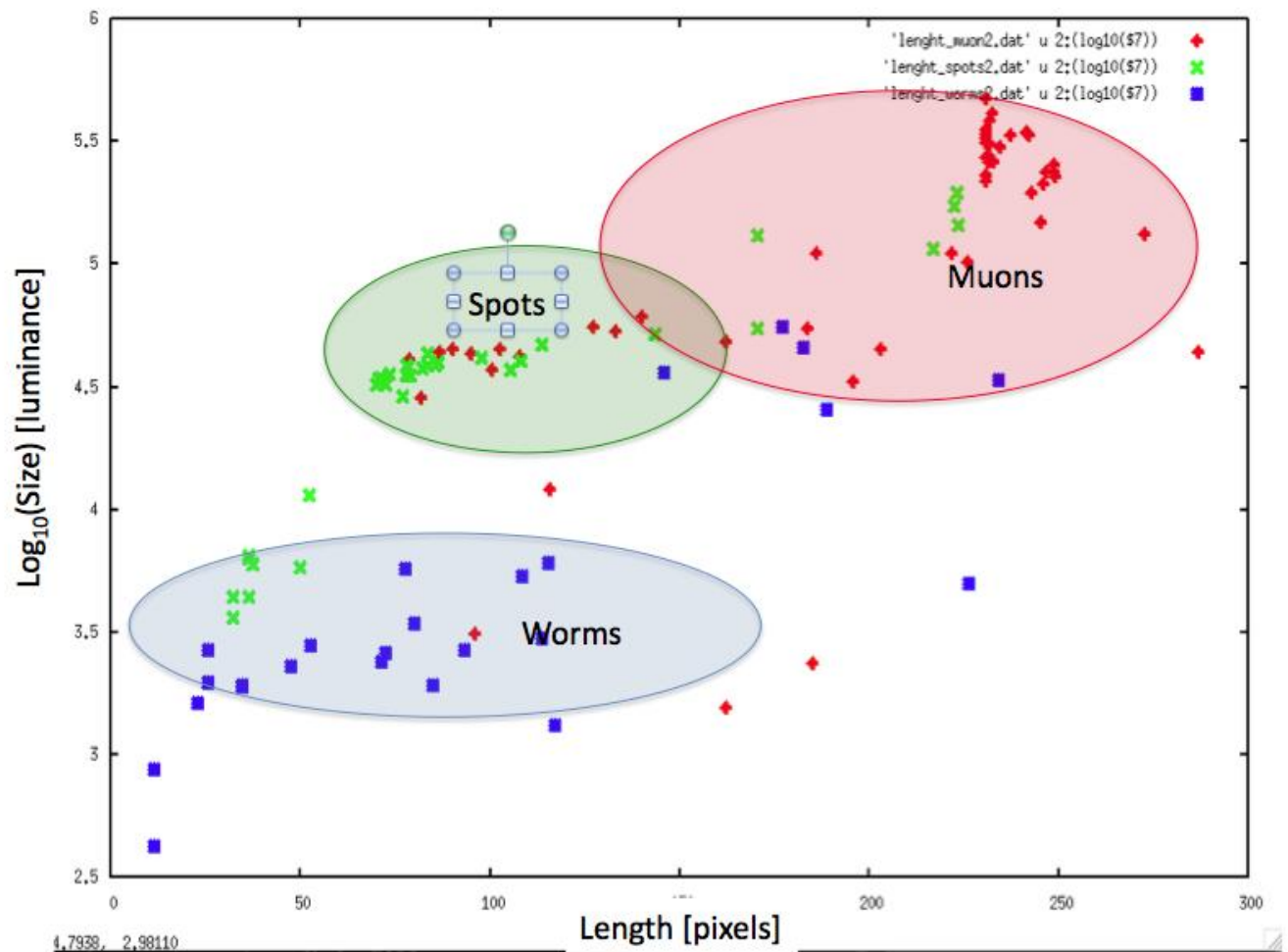
```

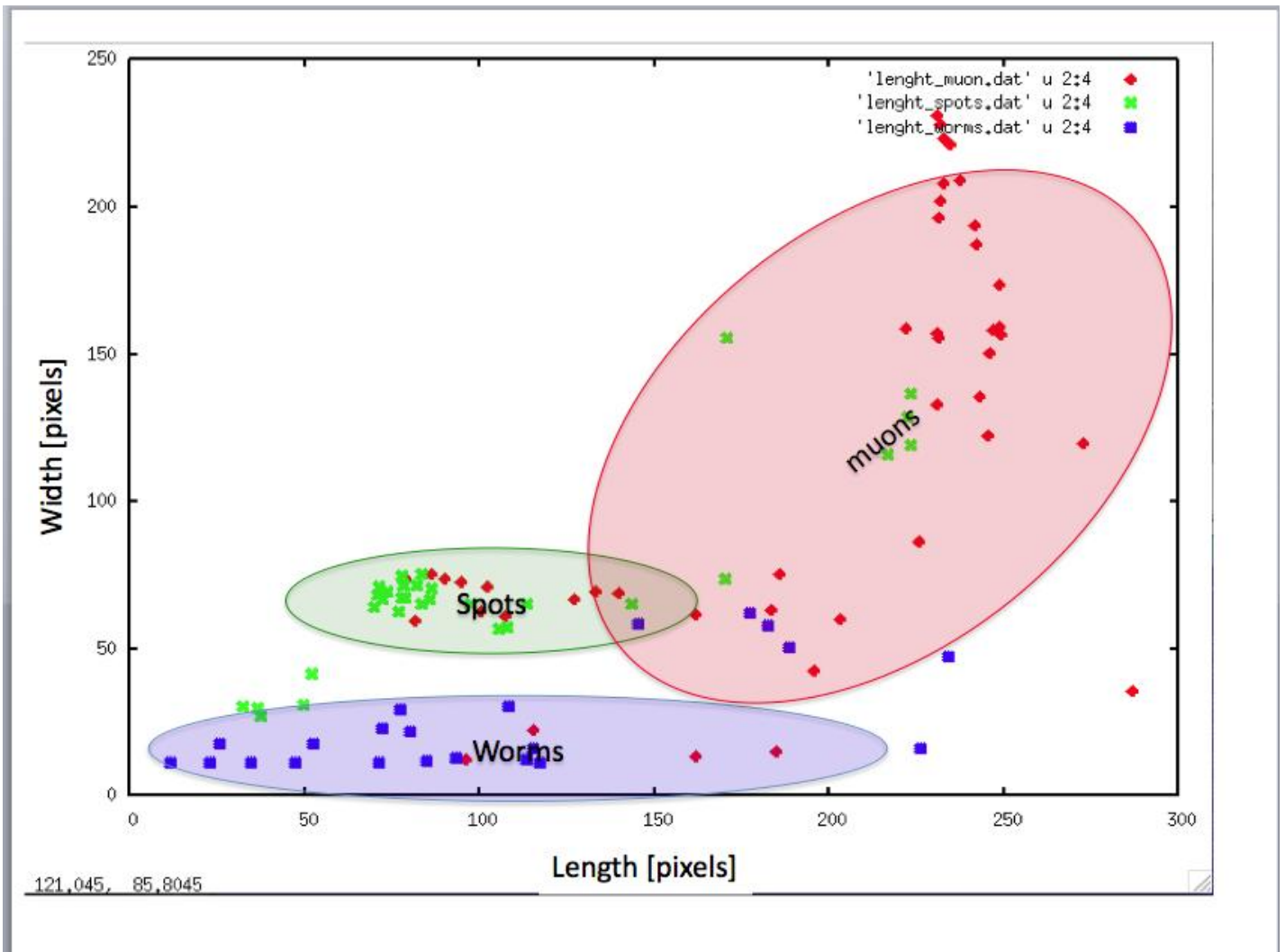
As we can see from examples above each class of event have different values of the SIZE and Length over Width parameter:

- muon like event : large value of SIZE and length/width
 - worm like event : small value of SIZE and large value of length/width
 - spot like event : large value of SIZE and small value of length/width
- The observed difference gives a possibility to identify muon from background events.

In figure we show the scatter plot of the Length/Width ratio as function of the SIZE parameter for about 116 camera images (from <https://api.credo.science/>). From this plot we can see quite well separation between different classes of events. This also allows for classification of events based off of their image.







For muon like events become possible to do track analysis. Giving some **known dimensions of the sensor and the orientation of the sensor** it becomes possible to trace back the direction that the cosmic ray entered the CMOS from, see [<https://arxiv.org/abs/1511.00660>] for more details.

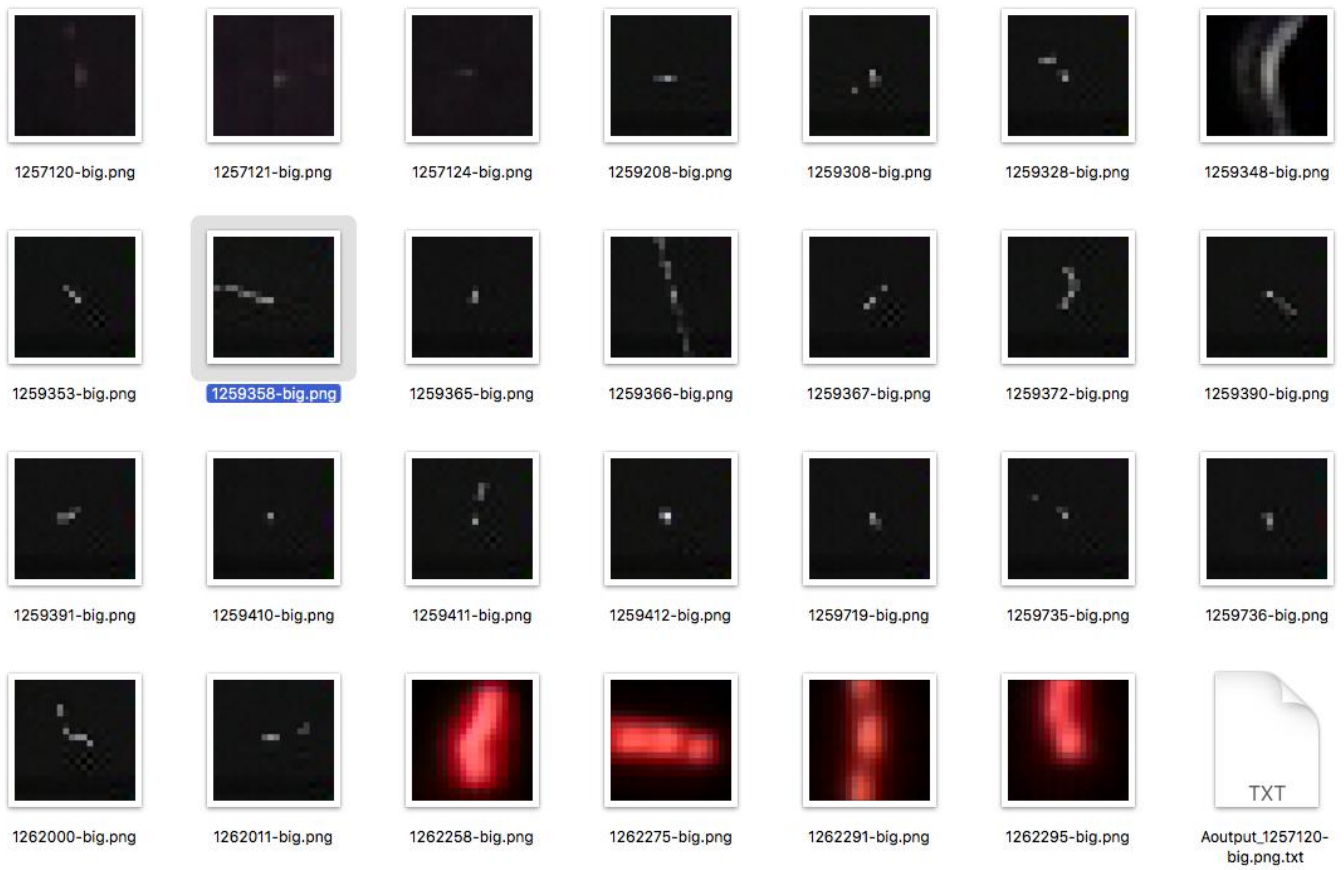
More references

[http://www.astro.rug.nl/~nobels/Characterising_the_cosmic_rays_in_a_CCD_nobels_and_bremer.pdf]
 [<https://www.bnl.gov/isd/documents/89281.pdf>]
 [<https://arxiv.org/pdf/1410.2895.pdf>]
 [<https://arxiv.org/abs/1208.1171>]
 [<https://arxiv.org/pdf/1708.01281.pdf>]

Images used in this analysis

Remark: Classification of events to different classes is rather arbitray

worms like events



spot like events



1257100-big.png



1257109-big.png



1257110-big.png



1257119-big.png



1257636-big.png



1257698-big.png



1257700-big.png



1257701-big.png



1259211-big.png



1259212-big.png



1259213-big.png



1259280-big.png



1259281-big.png



1259288-big.png



1259289-big.png



1259357-big.png



1259426-big.png



1261957-big.png



1261987-big.png



1262217-big.png



1262256-big.png



1262257-big.png



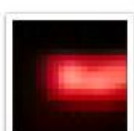
1262259-big.png



1262260-big.png



1262261-big.png



1262256-big.png



1262257-big.png



1262259-big.png



1262260-big.png

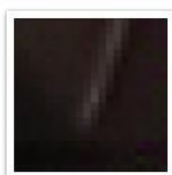


1262261-big.png

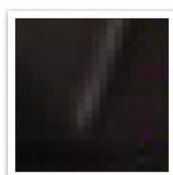
muon like events



1259205-big.png



1259216-big.png



1259217-big.png



1259296-big.png



1259298-big.png



1259299-big.png



1259302-big.png



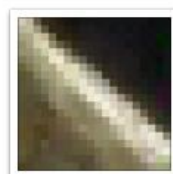
1259321-big.png



1259346-big.png



1259347-big.png



1259401-big.png



1259403-big.png



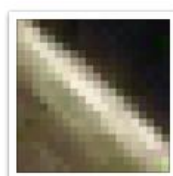
1259404-big.png



1259405-big.png



1259406-big.png



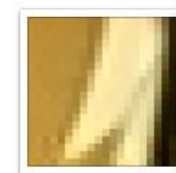
1259408-big.png



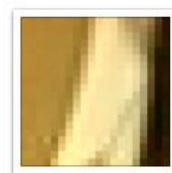
1259419-big.png



1259420-big.png



1259442-big.png



1259443-big.png



1259444-big.png



1259445-big.png



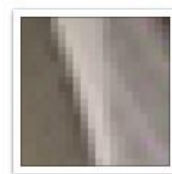
1259450-big.png



1259452-big.png



1259453-big.png



1259454-big.png



1259455-big.png



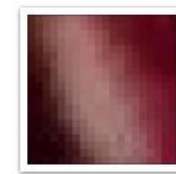
1259469-big.png



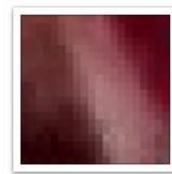
1259722-big.png



1259728-big.png



1261992-big.png



1261993-big.png



1262001-big.png



1262016-big.png



1262020-big.png



1262216-big.png





1262219-big.png



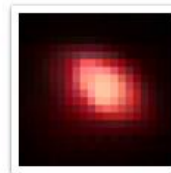
1262251-big.png



1262266-big.png



1262276-big.png



1262277-big.png



1262278-big.png



1262279-big.png



1262280-big.png



1262281-big.png



1262282-big.png



1262284-big.png



1262289-big.png



1262290-big.png



1262292-big.png



1262294-big.png



1262297-big.png



Aoutput_1259205-



Aoutput_1259216-

artefact events



1257626-big.png



1257635-big.png



1257653-big.png



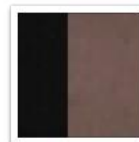
1257674-big.png



1259210-big.png



1259320-big.png



1259355-big.png



1259359-big.png



1259369-big.png



1259373-big.png



1259395-big.png



1259418-big.png



1259436-big.png



1259451-big.png



1259640-big.png



1259641-big.png



1259668-big.png



1259669-big.png



1259674-big.png



1259686-big.png



1259730-big.png



1261990-big.png



1261991-big.png



1261997-big.png



1262002-big.png



1262003-big.png

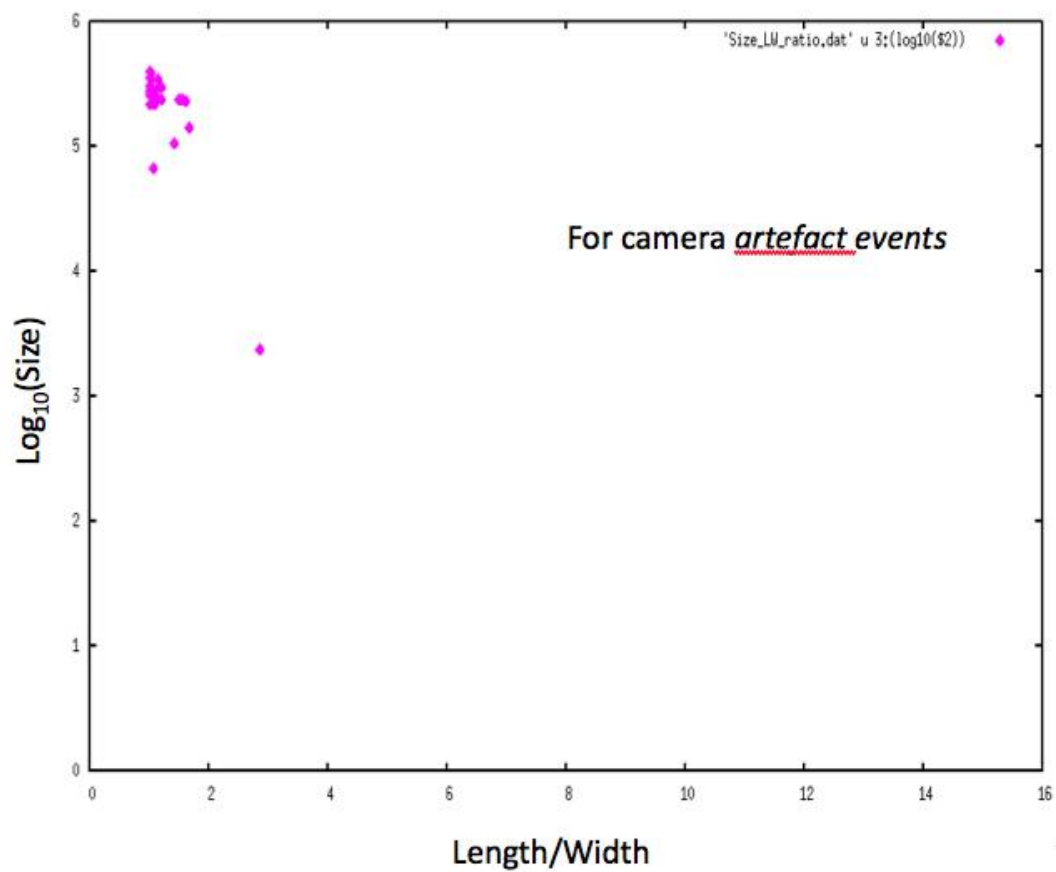


1262004-big.png



1262075-big.png



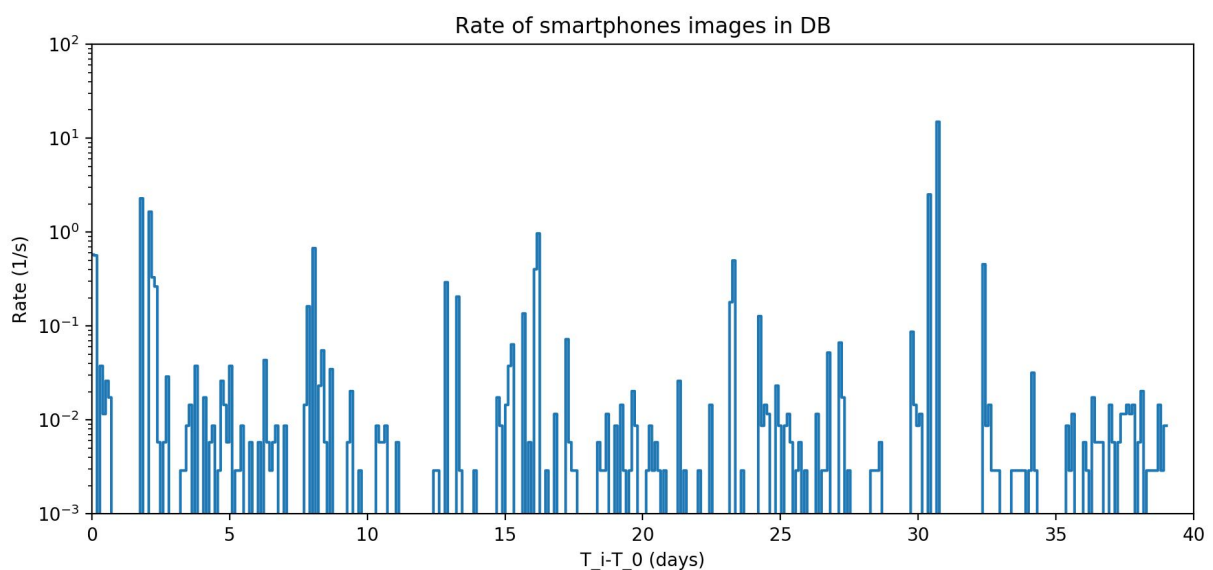


Technical details

Example of the python script which manipulate data from our DB (<https://api.credo.science>). Script shows how to read dump of DB in json format, extract some variables and make Rate plot.

[link to script](#)

Result of the script:



Files			
sketch.png	25.6 KB	10/18/2017	Dariusz Gora
sketch2.png	286 KB	10/18/2017	Dariusz Gora
CloudChamberParticles-768x432.jpg	32.4 KB	10/18/2017	Dariusz Gora
PCA-rotation_1259346-big.png.png	41.3 KB	10/18/2017	Dariusz Gora
1259346-big.png	7.48 KB	10/18/2017	Dariusz Gora
data_grayacle_with_countour_1259346-big.png.png	15.3 KB	10/18/2017	Dariusz Gora
1259372-big.png	7.87 KB	10/18/2017	Dariusz Gora
data_grayacle_with_countour_1259372-big.png.png	14.5 KB	10/18/2017	Dariusz Gora
PCA-rotation_1259372-big.png.png	36.1 KB	10/18/2017	Dariusz Gora
1261987-big.png	7.08 KB	10/18/2017	Dariusz Gora
PCA-rotation_1261987-big.png.png	74.2 KB	10/18/2017	Dariusz Gora
data_grayacle_with_countour_1261987-big.png.png	13 KB	10/18/2017	Dariusz Gora
Length_Size.png	213 KB	10/18/2017	Dariusz Gora
length_width.png	97.7 KB	10/19/2017	Dariusz Gora
worms_like_events_used_in_analysis.png	134 KB	10/19/2017	Dariusz Gora
spot_like_event_used_in_analysis.png	161 KB	10/19/2017	Dariusz Gora
muon_like_evenys_1.png	121 KB	10/19/2017	Dariusz Gora
muon_like_events_2.png	158 KB	10/19/2017	Dariusz Gora
muon_like_events_3.png	115 KB	10/19/2017	Dariusz Gora
Size_vs_length.png	110 KB	10/19/2017	Dariusz Gora
artefact_events.png	192 KB	10/19/2017	Dariusz Gora
Size_length_over_width_artefact_events.png	36.1 KB	10/19/2017	Dariusz Gora
Figure_1-1-1.png	56.3 KB	11/10/2017	Dariusz Gora