CYGNO
- *Resume*

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Goals

○ Characterize the signal produced by the ^{55}Fe for the He-CF_4 and Ar-CF_4.

○ Study of the size and luminosity of the clusters in function of the source distance;

○ Studying the Vignetting effect and the behavior of the Field Cage un function of its voltage.

○ Separately studying these effects to improve the analysis capabilities.

Run number	distance (cm)	n. image	GEM voltage (V)	Gas Mixture ($HeCF_4$)	Transfer Field (KV/cm)
4062	1.6	140	460	60/40	2.5
4069	4	140	460	60/40	2.5
4076	6	140	460	60/40	2.5
4083	8	140	460	60/40	2.5
4090	10	140	460	60/40	2.5
4097	12	140	460	60/40	2.5
4104	14	140	460	60/40	2.5
4111	16	140	460	60/40	2.5
4061	pedestal	100	250	60/40	2.5

Table 2: *Data taken with LEMOn, $HeCF_4$ gas mixture, the radioactive source was placed at different distances. The three GEMs voltages were all set to 460 V. Pedestal run is taken without the presence of a radioactive source. New data taken in April 2021.*

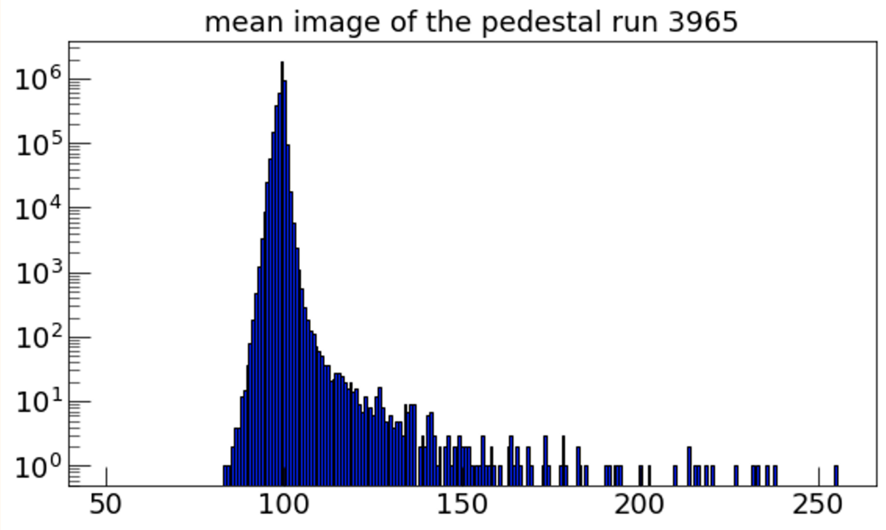
Run number	distance (cm)	n. image	GEM voltage (V)	Gas Mixture ($ArCF_4$)	Transfer Field (kV/cm)
4191	1.6	197	425/430/430	80/20	2.5
4192	4	197	425/430/430	80/20	2.5
4193	6	197	425/430/430	80/20	2.5
4194	8	197	425/430/430	80/20	2.5
4195	10	197	425/430/430	80/20	2.5
4196	12	197	425/430/430	80/20	2.5
4197	14	197	425/430/430	80/20	2.5
4198	16	197	425/430/430	80/20	2.5
4204	pedestal	100	250	80/20	2.5

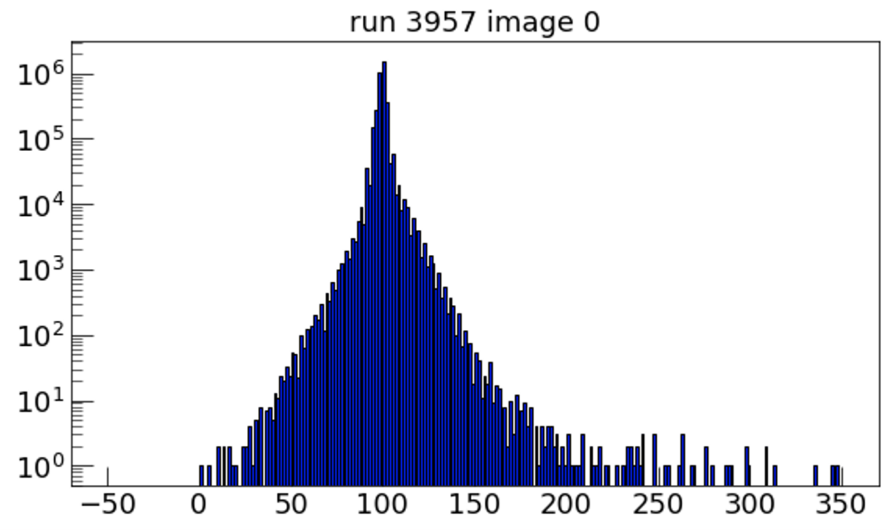
Table 3: *Data taken with LEMOn, $ArCF_4$ gas mixture, the radioactive source was placed at different distances. In this case the GEM were set to three different potential, but for the pedestal which was taken at a lower voltage. Pedestal run is taken without the presence of a radioactive source. New data taken in April 2021.*

Image processing and cluster recognition

Preliminary operations

●Most of the information in the image is around 100 photon per pixel, which also correspond to the mean value of the distribution of the pedestal run. We then used the pedestal run to create a pixel per pixel mask, working as thermal noise and broken pixel remover, which was set with a threshold value of the mean plus 1 std. deviation.





DBSCAN

Minimum Samples	Epsylon
20	6

- The new boolean image was the working table of the DBSCAN algorithm. The choice of the parameters was made by qualitative criterias both looking at the image to test its plausibility and studying the number of cluster in fucntion of the two parameters.

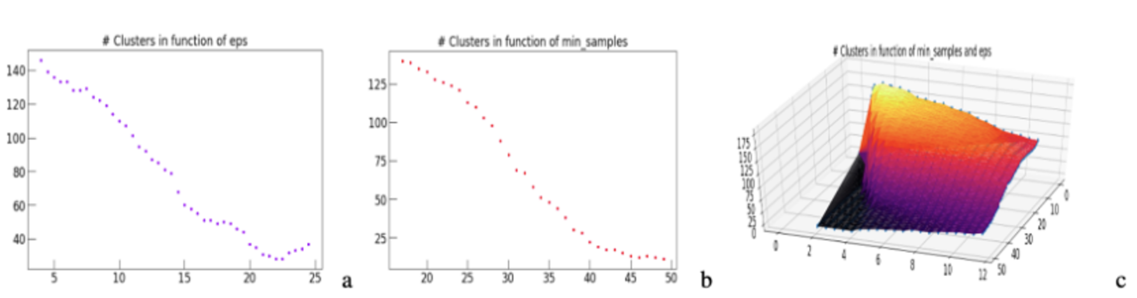


Figure 11: *Evaluation of DBSCAN's best parameters for a HeCF$_4$ mixture with nsigma* $=$ 1.0.

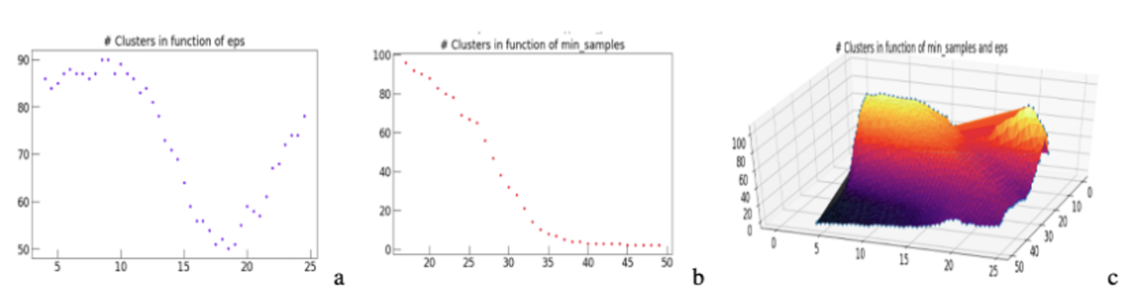


Figure 12: *Evaluation of DBSCAN's best parameters for a ArCF$_4$ mixture with nsigma* $=$ 1.0.

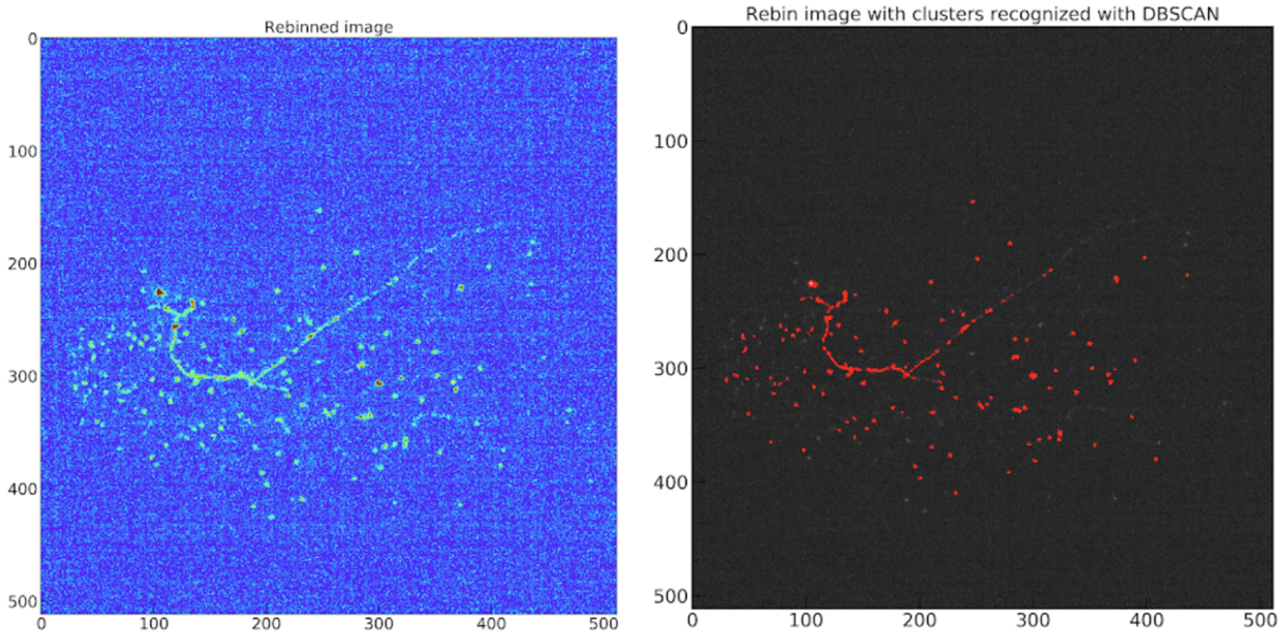
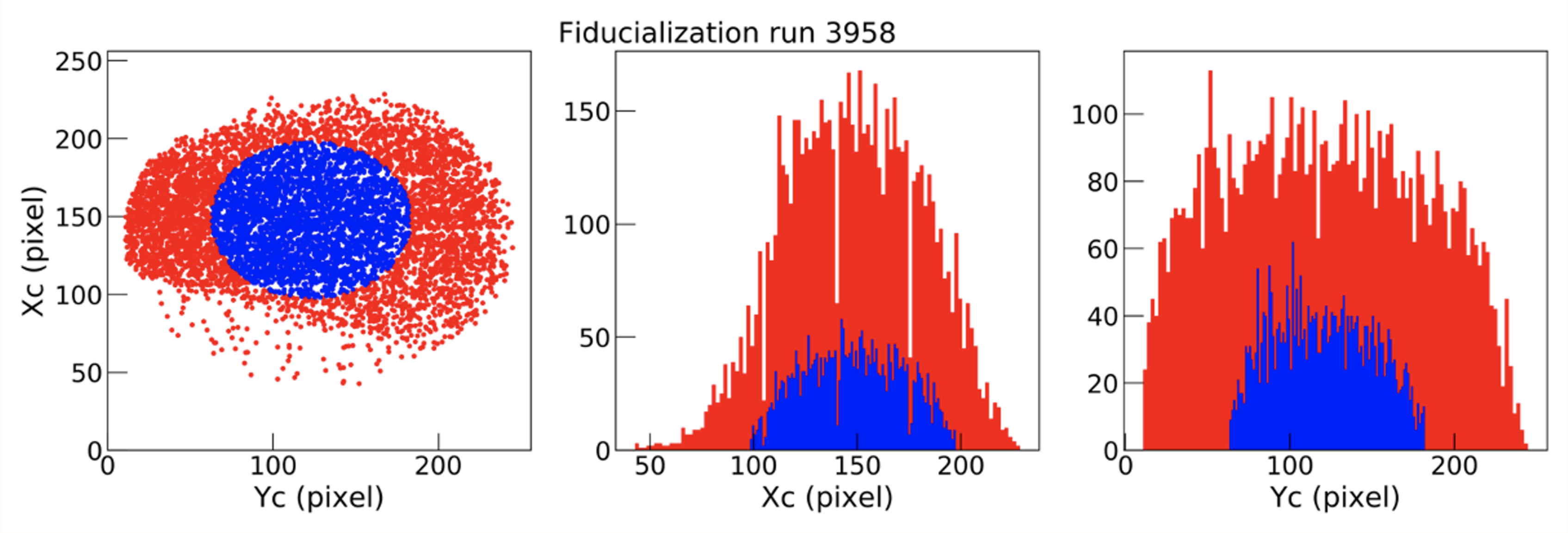


Figure 14: *Example of DBSCAN's cluster recognition on a sample image of He-CF $_4$ with our choice of parameters. The first image is the raw rebinned image of the signal, while the second one is a black and white version with the position of the recognized cluster superimposed in red.*

Spatial Selection

- The analysis was held only on cluster which were enclosed in a confidetial region free from the border effect of the field cage and of the optical effect of the lense. The selected region is almost perfectly centered in the image and has an elliptical shape, the major axis is 120 pixels and the minor axis is 100 pixels.



Correlation

- Another selection was done by measuring the pearson index for correlation of the clusters. We rejected clusters with an index bigger in modulus of 0.6

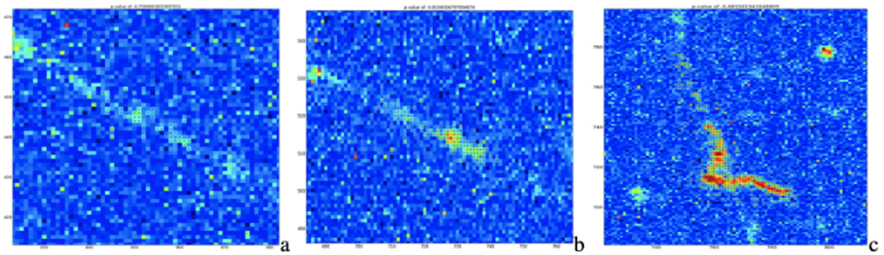


Figure 15: *Examples of cluster with a correlation index* $> |0.6|$. *The pixels identified as part of the cluster are indicated with a red dot. (a) p-value of* -0.76; *(b) p-value of* -0.83; *(c) p-value of* 0.68

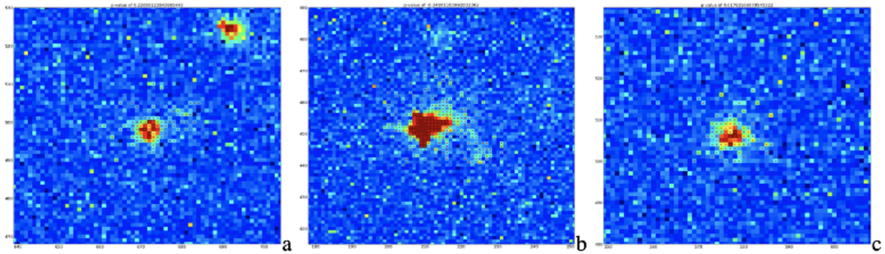
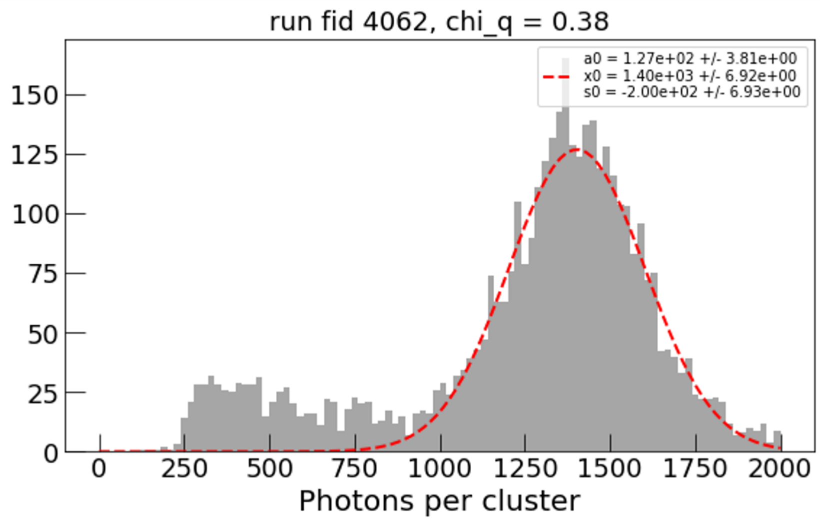


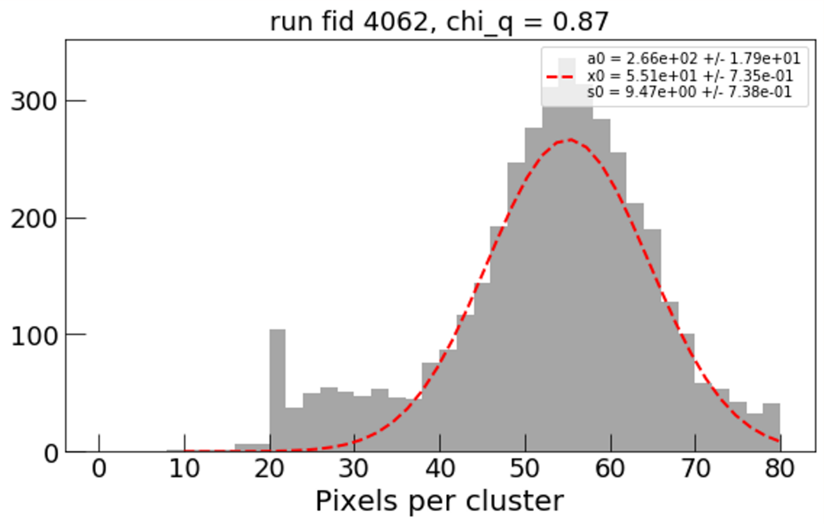
Figure 16: *Examples of cluster with a correlation index* $< |0.6|$. *The pixels identified as part of the cluster are indicated with a red dot. (a) p-value of* 0.22; (b) p-value of 0.24; (c) p-value of 0.018.

Gas mixture characterization

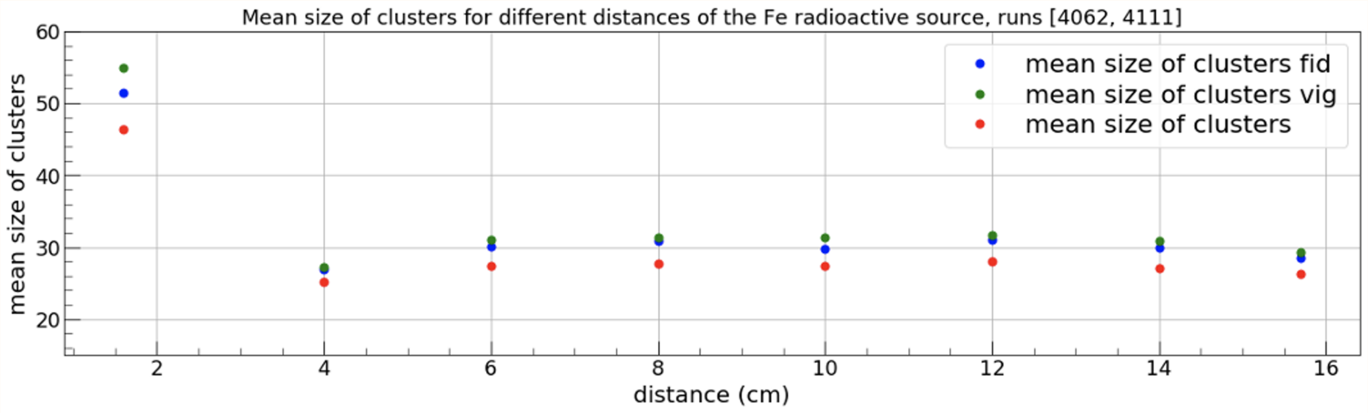
Gaussian Fit

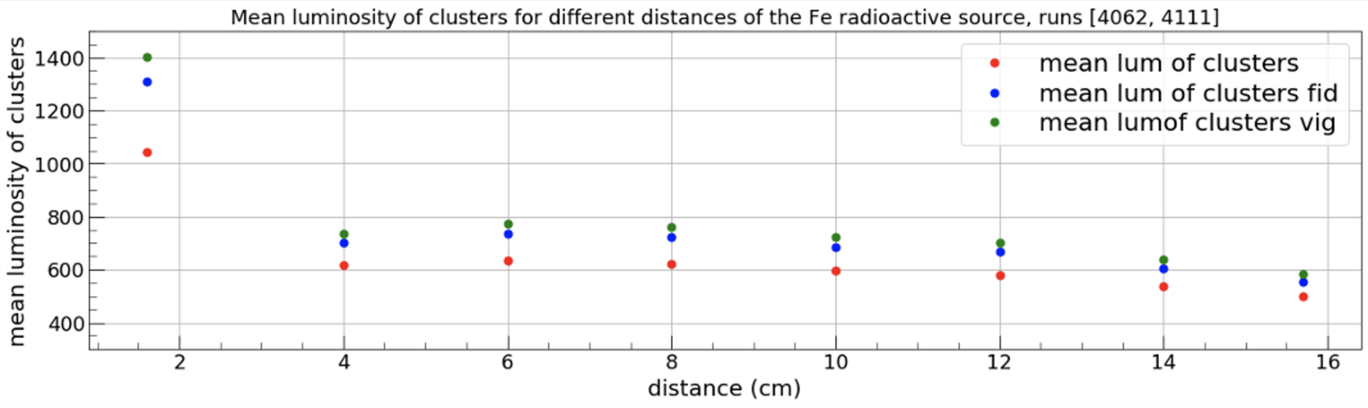
- The information obtained from the cluster recognition algorithm are the number of pixels and the number of photons per cluster. This data have been plotted on an histogram and fitted with a gaussian distribution.





He-CF_4 obtained values





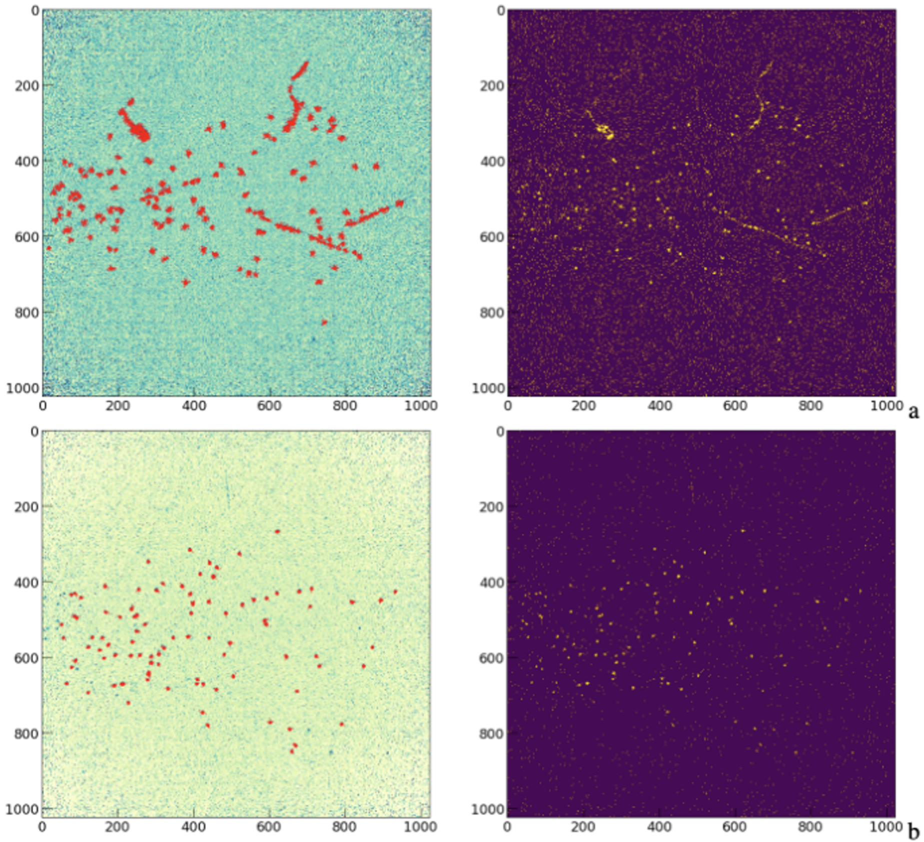
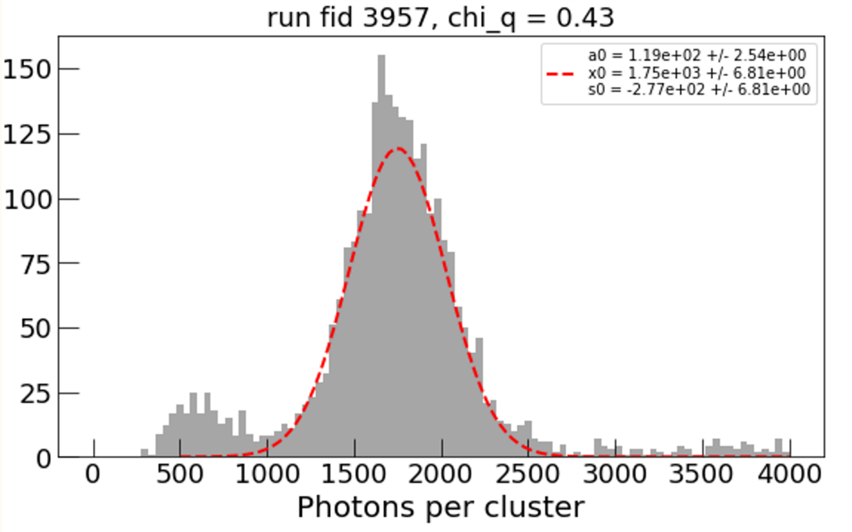
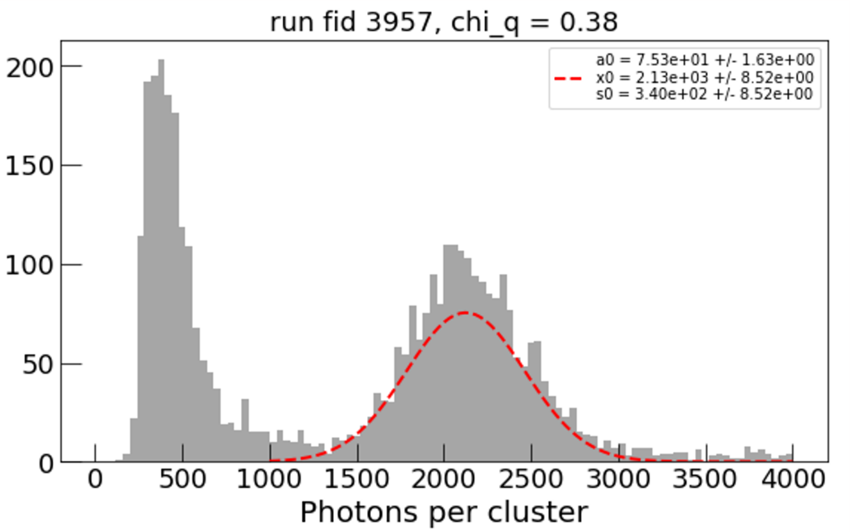


Figure 30: *Comparison of two images reconstructed by the DBSCAN algorithm with the same DBSCAN parameters. The image (a) is the image number 90 of the run 4062, while the image (b) is the image number 0 of the run 4069. The right side of the images are the over threshold pixels of the image.*

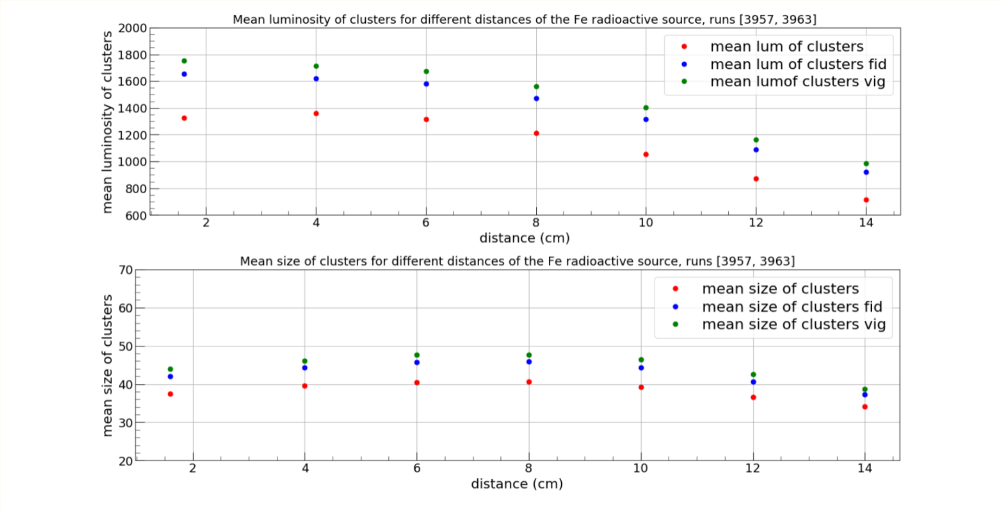
The role of the sigma

The decreasing trend of size and luminosity can be explained with the loss of the signal due to the merging of the border of the clusters with the background noise. Due to the diffusion the distributions widens, decreasing the photon density. If it goes under the threshold value the signal is lost. As a consequence a higher cut off should cause a higher loss.

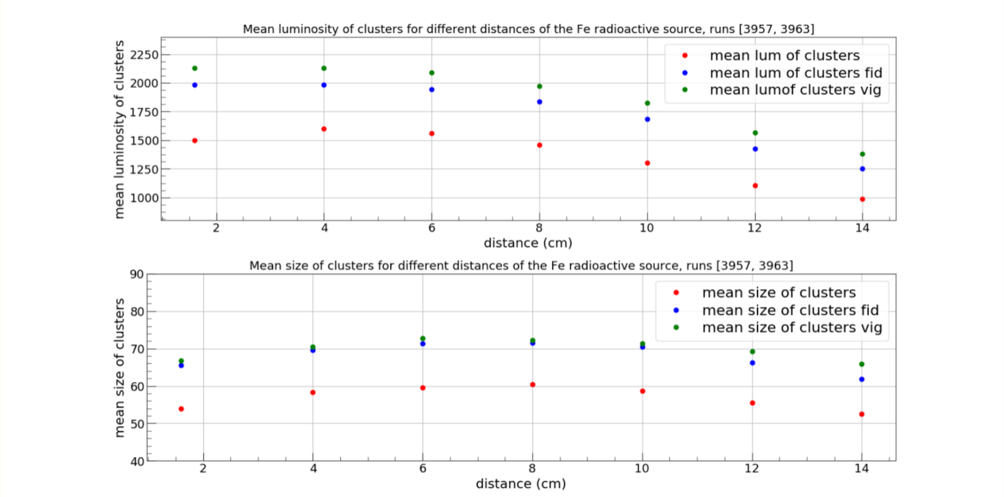




● Luminosity and size in function of the distance with a 1.5 sigma cut off, marks a 43% of signal loss between the first and last run.

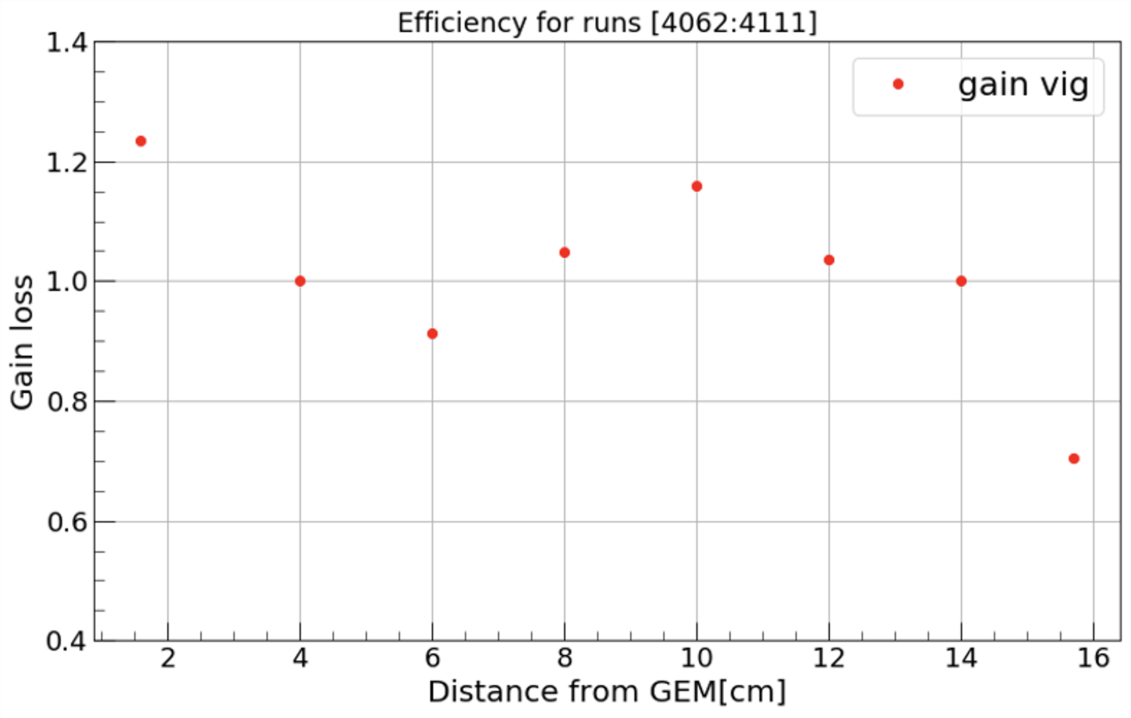


● Luminosity and size in function of the distance with a 1 sigma cut off, marks a 38% of signal loss between the first and last run. The runs are all more luminous and the clusters are bigger.

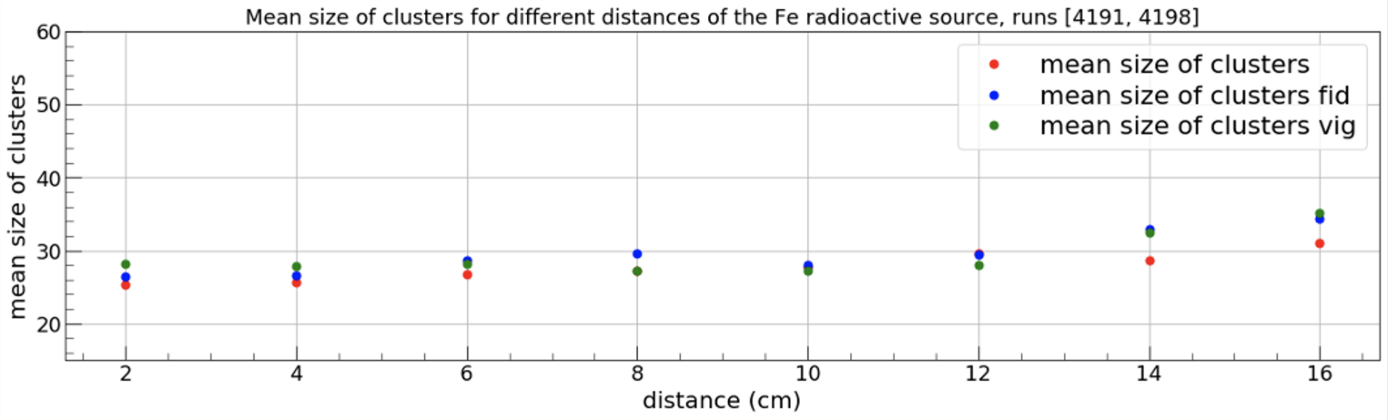


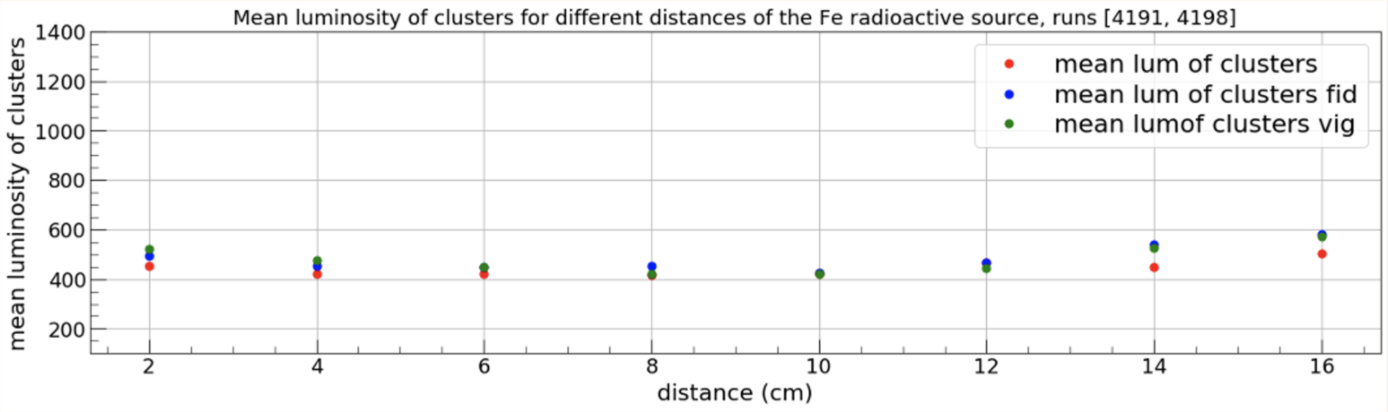
He-CF_4 Efficiency

●To estimate the efficieny of the sperimental set-up and to study the efficieny of the gas in function of the distance we used the average number of clusters per image.

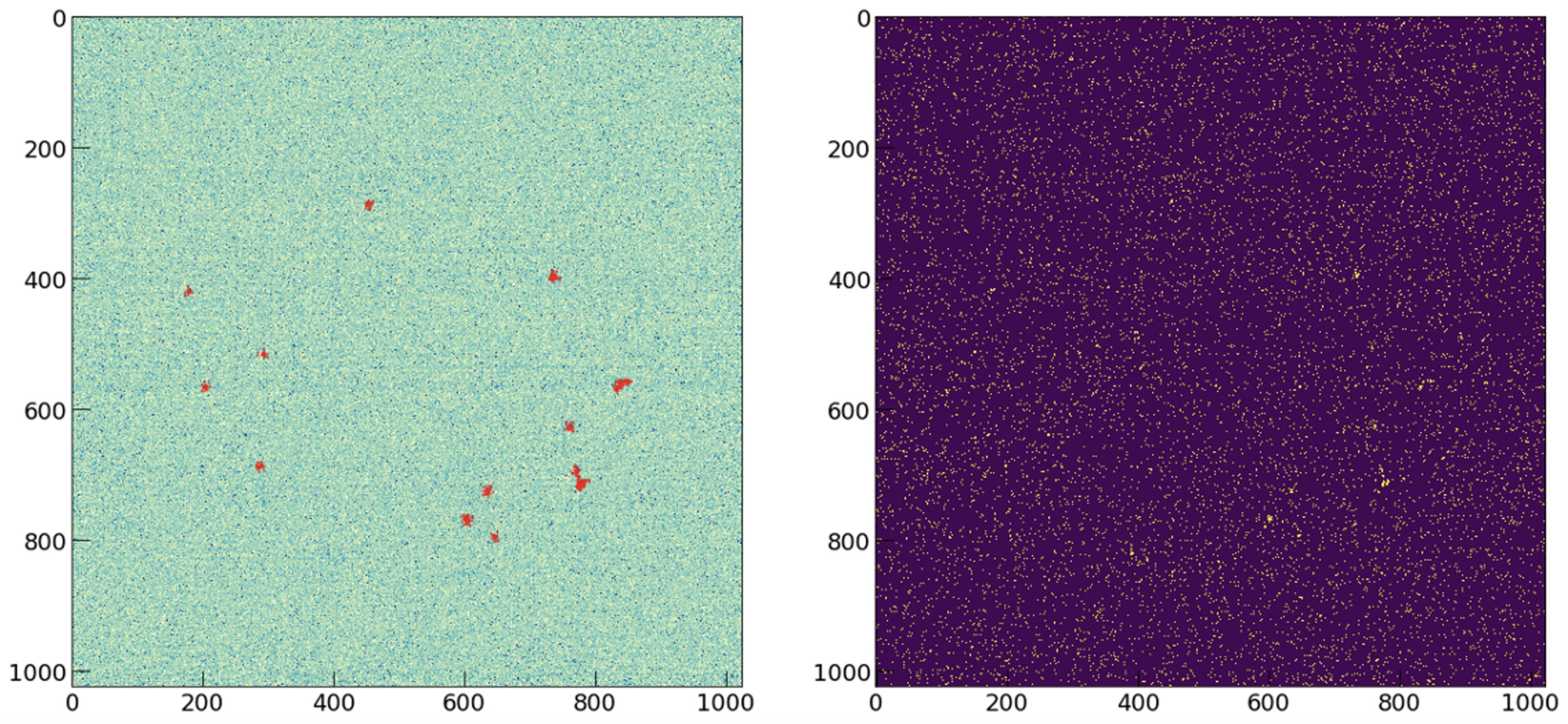


Ar-CF_4 obtained values



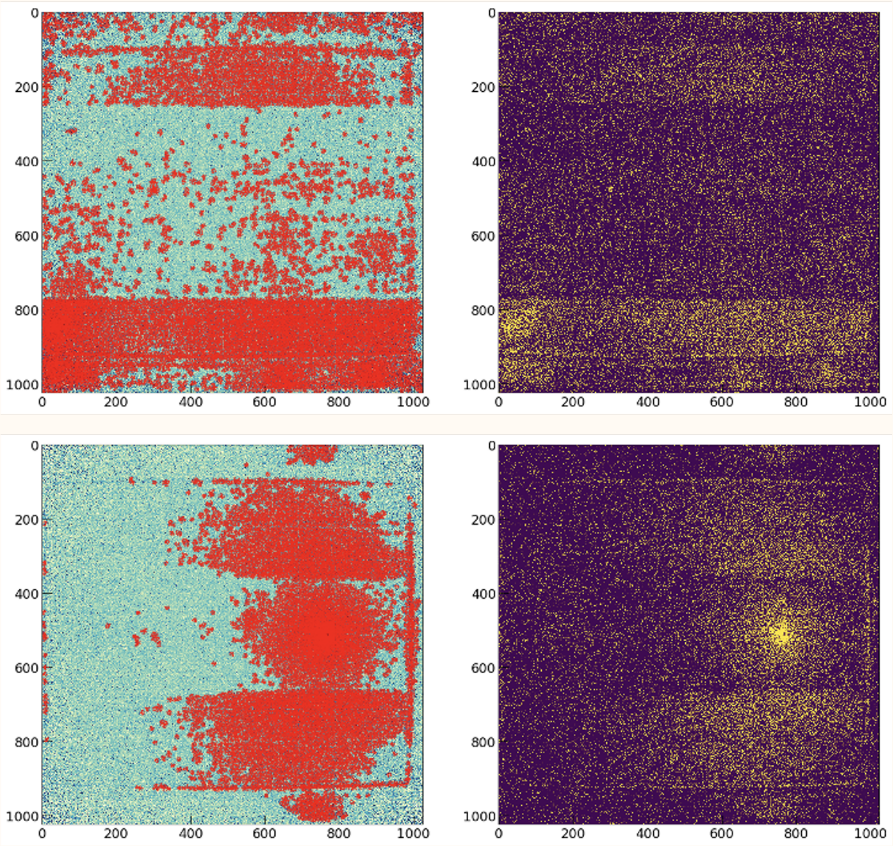


Sample image with Ar-CF_4 gas mixture

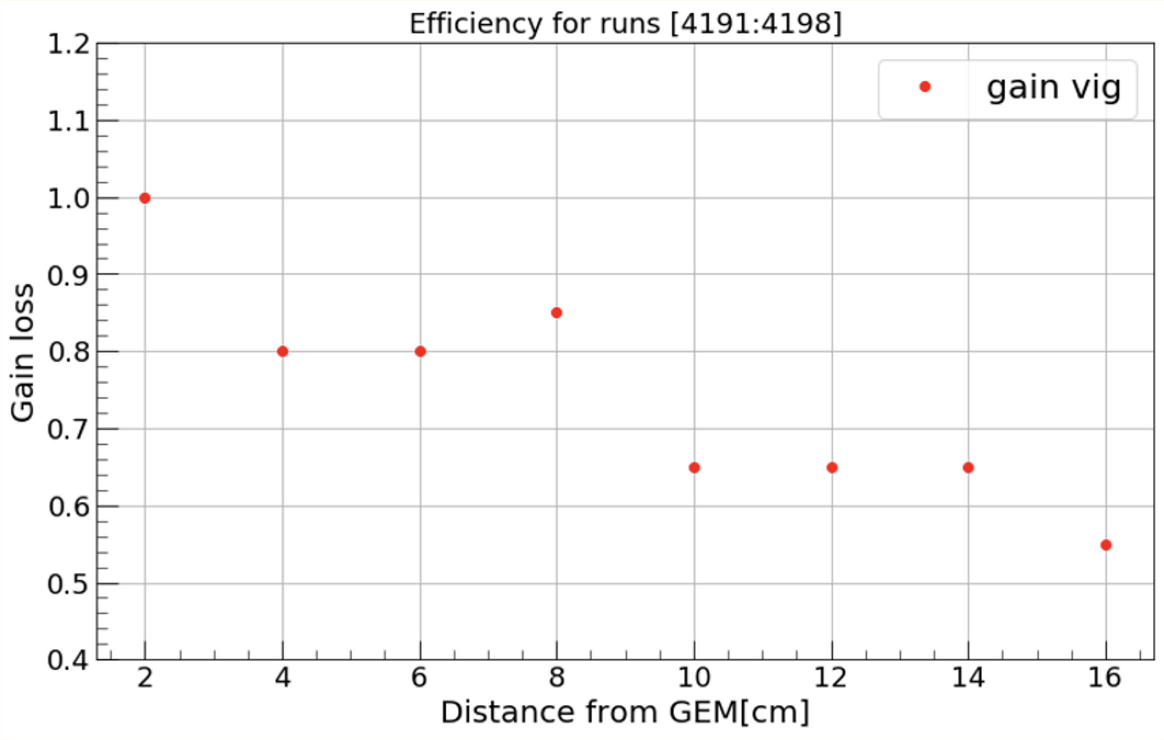


GEM instabilities

●Even if the GEM voltages were kept lower than the measures with the He gas, the Ar-CF_4 suffered of more frequent discharges, making the sperimental set up less stable. Having a lower voltage also caused a lower visibility on the events.



Ar-CF_4 Efficiency



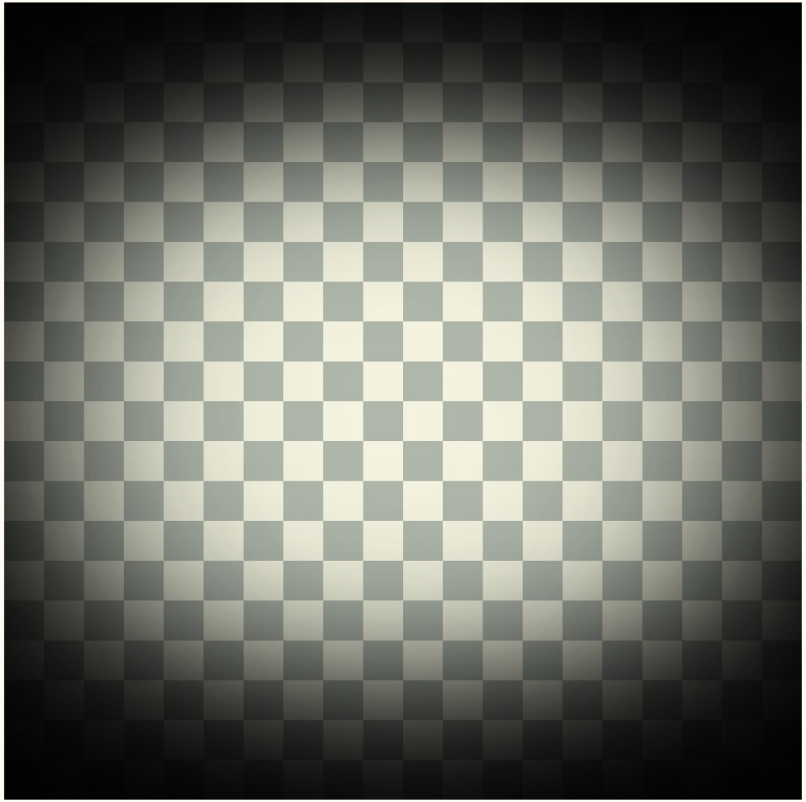
Conclusions

- A first manifest consideration is that the statistic on the Ar measurements is not enough to believe to have obtained conclusive results . Even if the number of studied image was the most numerous of all.
- The Ar efficiency, though, indicates the Ar not only as the less luminous and less stable, but also the one with less efficiency.
- The He mixture has the trend we expected, considered the loss for further distances. Due to the first run we couldn’t interpolate the points to measure the diffusion coefficient.
- Significant improvements of the quality of signal are determined by the spatial selection and the vignetting effect correction. The border effect of the field cage could explain this consideration.

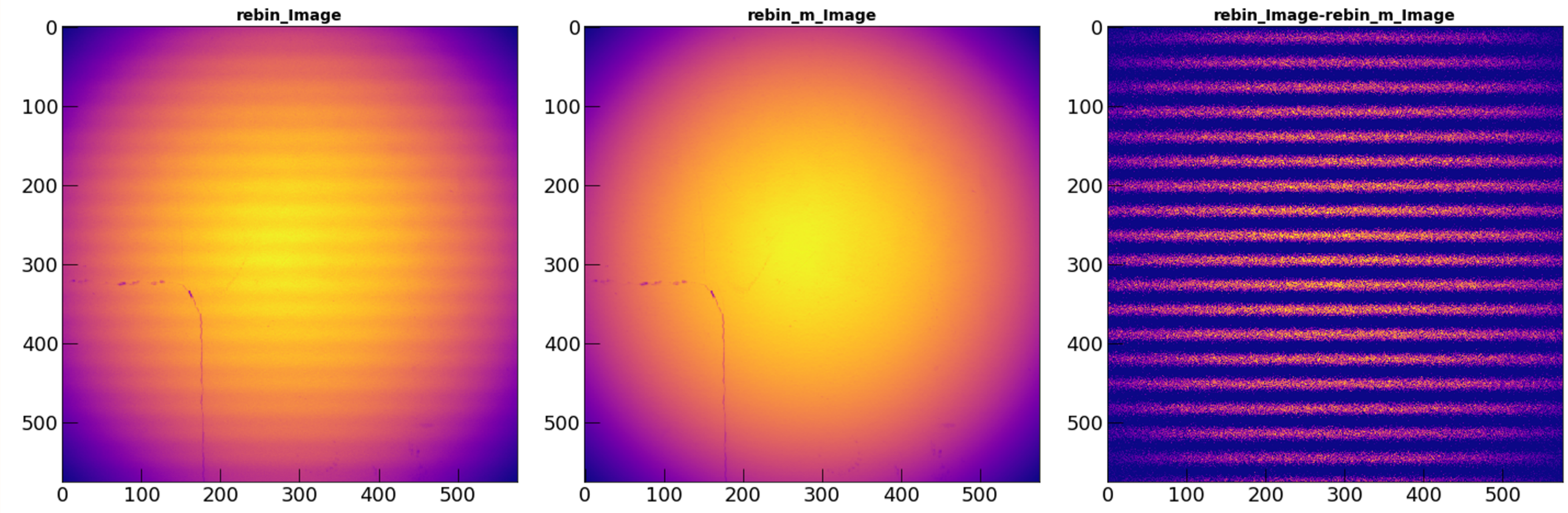
Optical and Electromagnetic Effect

Vignetting

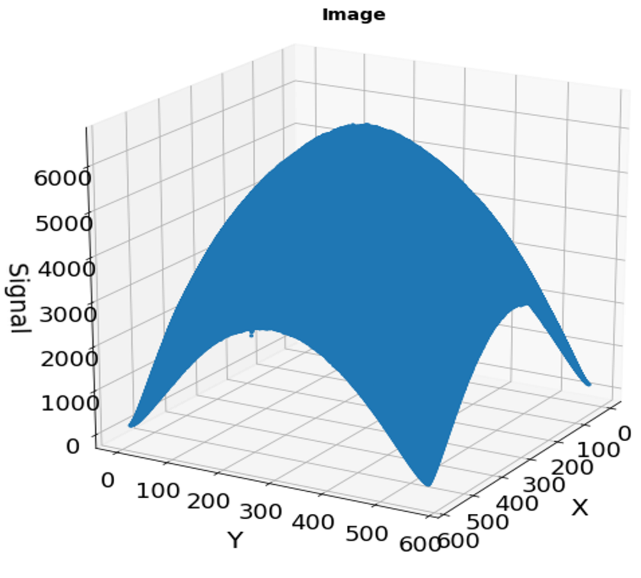
- In photography and optics, the vignetting is a reduction of an image's brightness or saturation toward the periphery compared to the image center.
- The major effect is generated by *$cos^4\theta$ vignetting.*
- *$cos^4\theta$ vignetting* describes the natural light falloff caused by light rays reaching the sensor with an angle. The light falloff is described by the *$cos^4\theta$* function, where θ is the angle of incoming light with respect to the optical axis in image space.

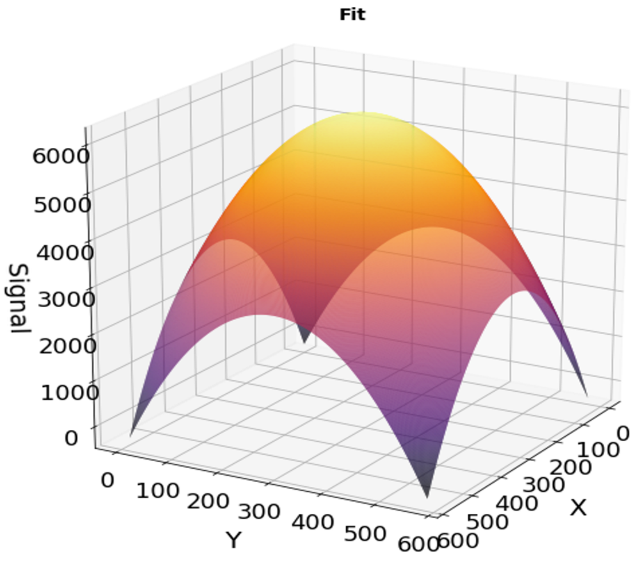


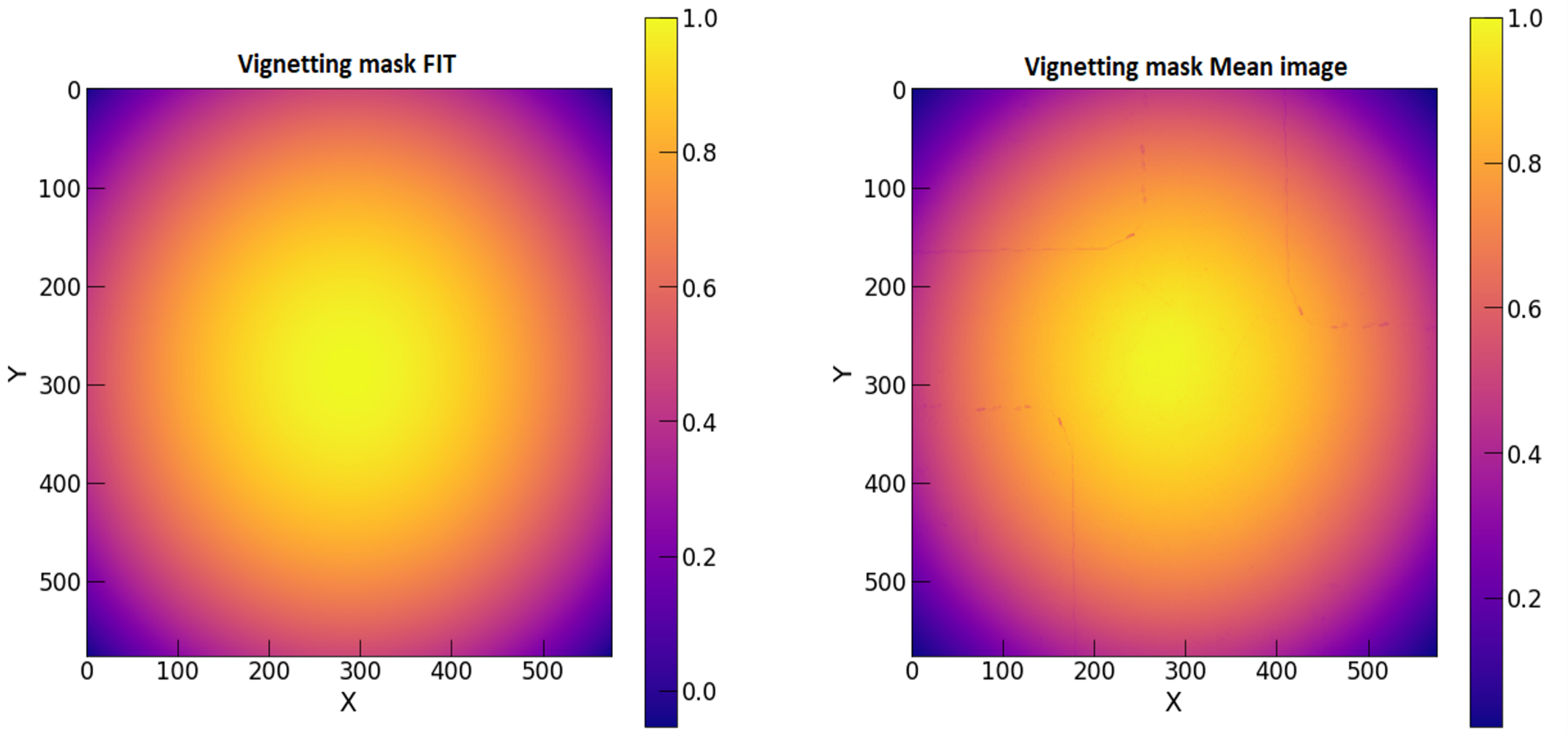
- To evaluate the true distortion caused only by vignetting without having interference due to the field cage, are needed datasets taken by illuminating a surface in a uniform manner.
- This type of measurement was carried out by extracting the camera from the detector and framing the laboratory wall, illuminated by a light as uniform as possible.



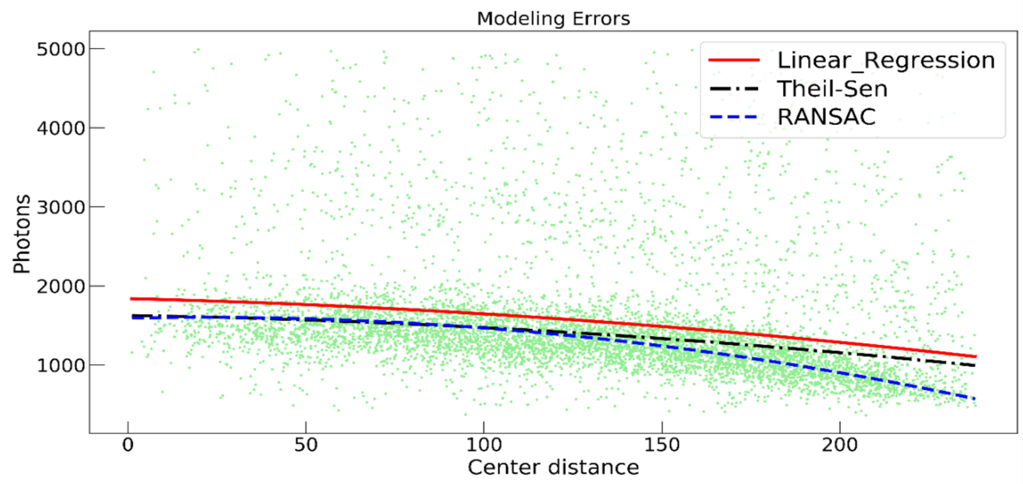
- The light, during the data taking, came mainly from above. To be quite sure to have an isotropy of the signal, three different datasets were taken by rotating the camera by 90° around the optical axis. However, the average image remains slightly noisy: in addition to brittle pixels that can cause bad corrections, there are lines due to the crack on the wall.
- The best option is to proceed with a 3D fit and then evaluate whether it actually differs from the average image.
- The result of the union of the three average images coming from the three different runs satisfies the request to have an uniform signal.

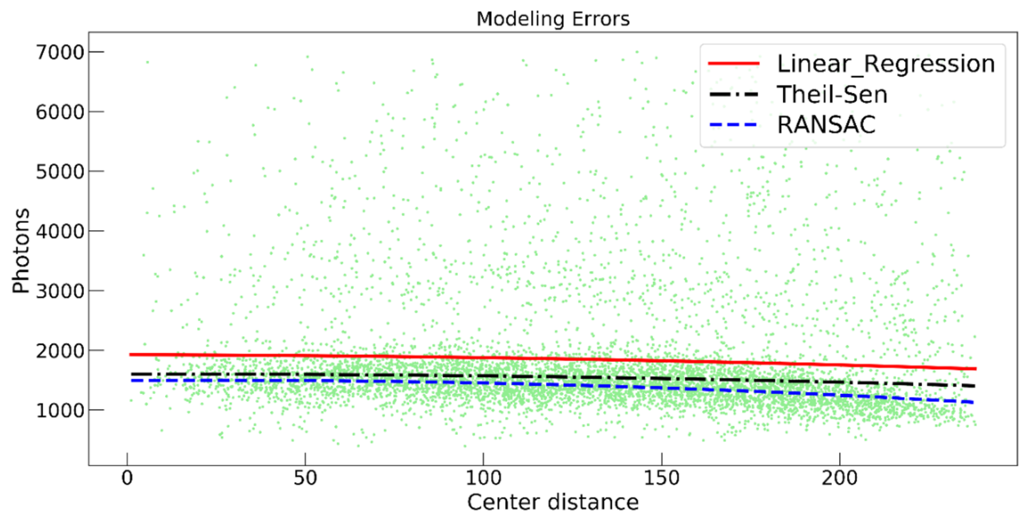





Vignetting mask FIT
Y
X
0
100
200
300
400
500
0.0
0.2
0.4
0.6
0.8
1.0
Vignetting mask Mean image
Y
X
0
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0

- The vignetting correction on the runs with the ^{55}**Fe** clusters show that the mask work well.



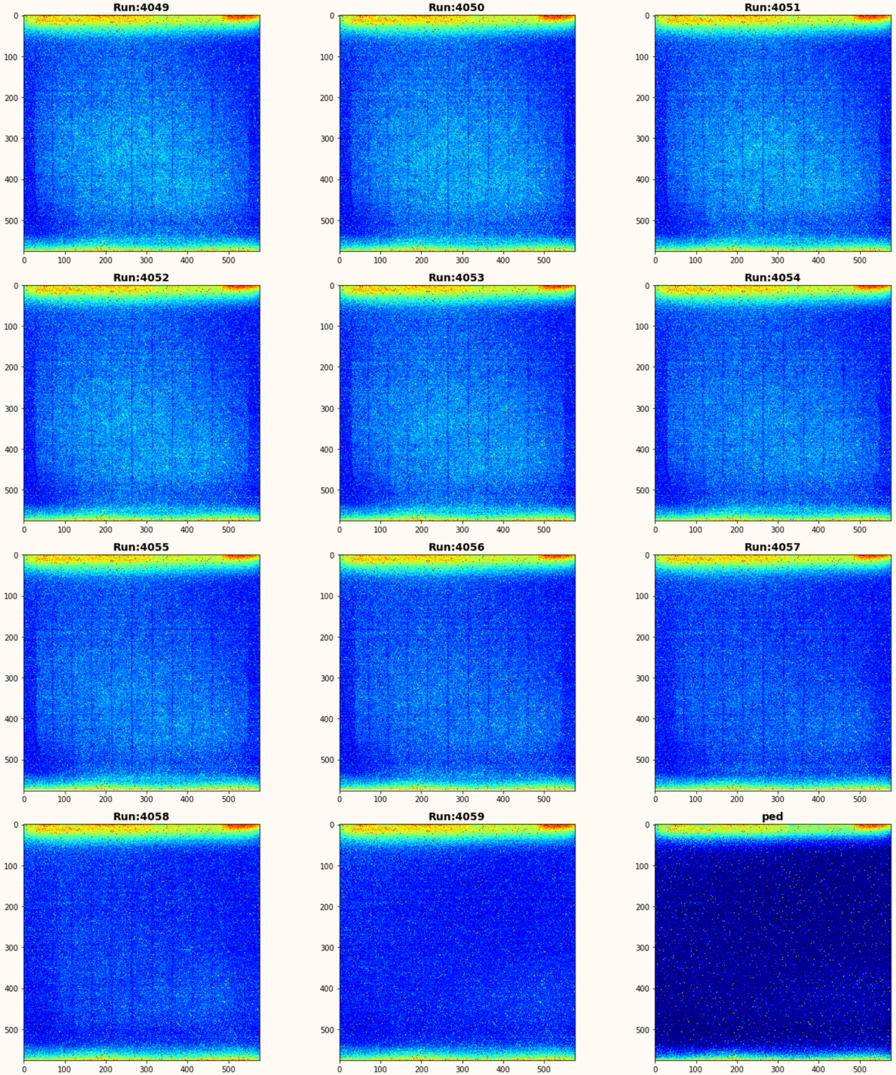


Field effect

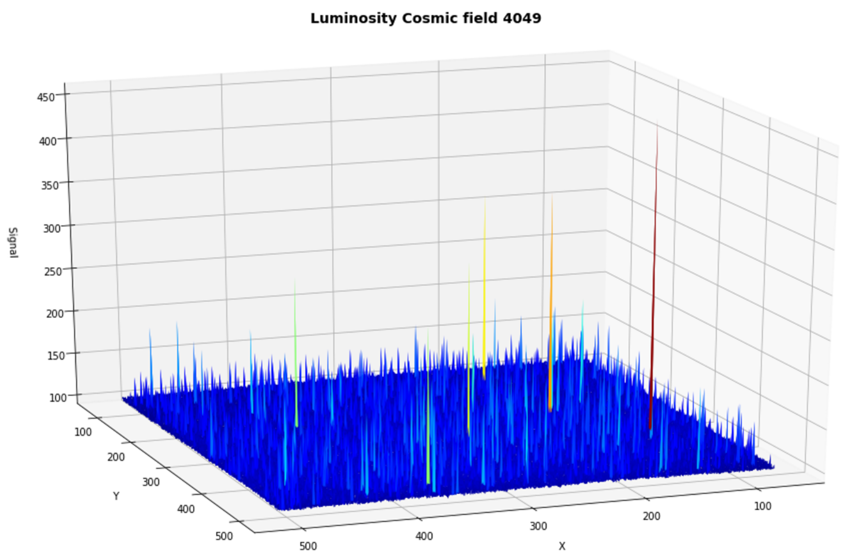
- TPC typically works with very high voltages to accelerate electrons to GEMs. This electromagnetic field causes distortion in the images.
- We expect this distortion effect to be less pronounced than the one caused by the optical system; on the other hand it is not constant, but it's a function of the tension applied to the ends of the instrument.
- Not having data taken with LEMOn with which to study this effect, runs taken with LIME were used.
- In order to have a uniform light over the whole image, but having to study the effect of the field cage, so we couldn't artificially light up the images, we averaged over images in which the source were cosmic rays, varying the voltage from a minimum of 0 to a maximum of 50 kV .

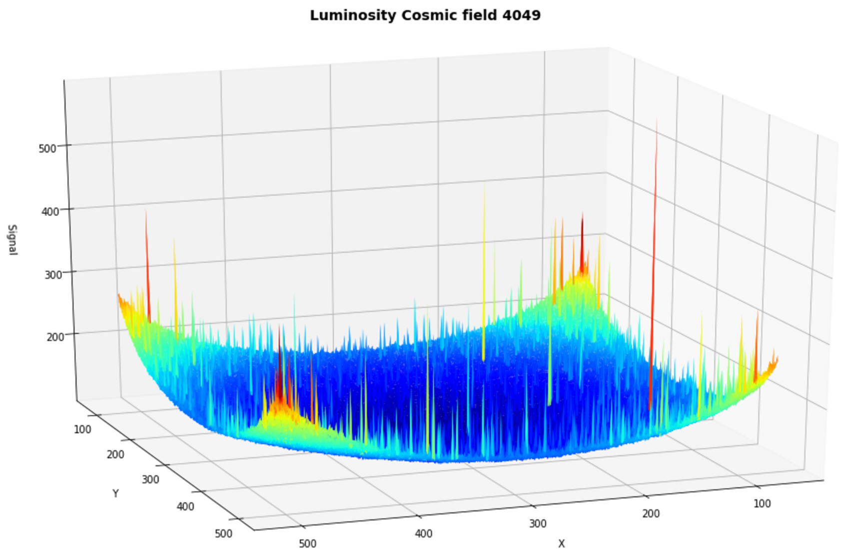
- Rebinned image for the Runs with cosmic rays signals.

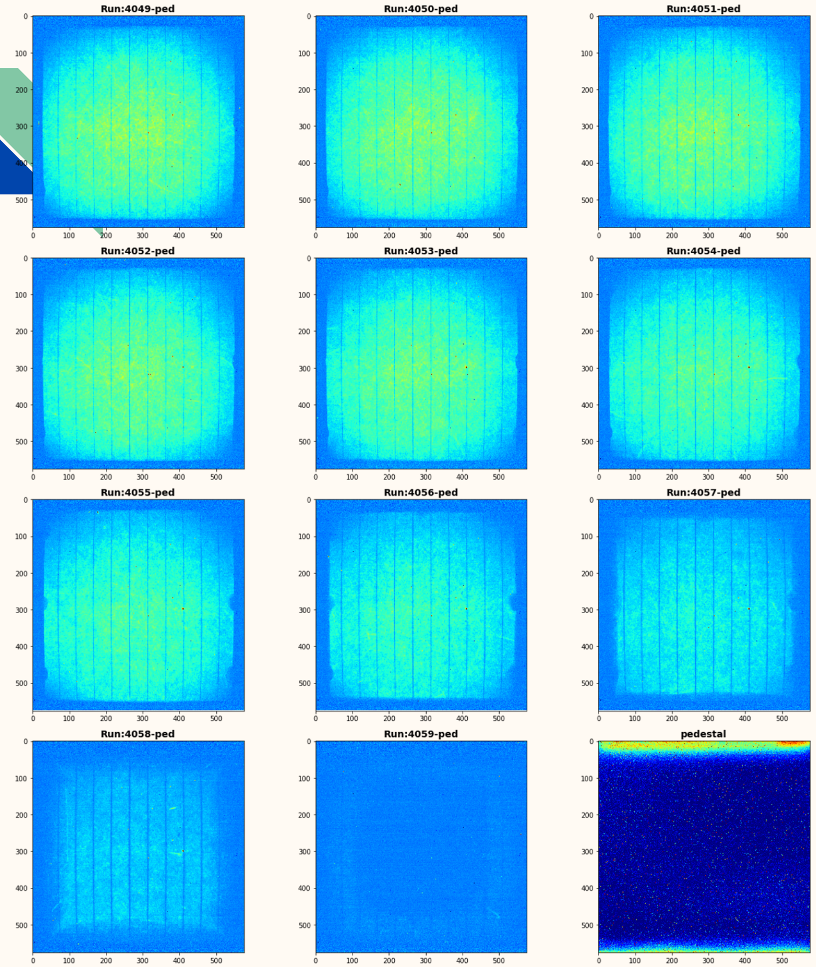
- It must require an elaboration before the extraction of the field information.



- The background must be subtracted on the image, because the vignetting effect didn’t affect it.
- If we made the correction on the row image, with the background, we obtain a bad grow up of the signal.






Run:4049-ped
Run:4050-ped
Run:4051-ped
Run:4052-ped
Run:4053-ped
Run:4054-ped
Run:4055-ped
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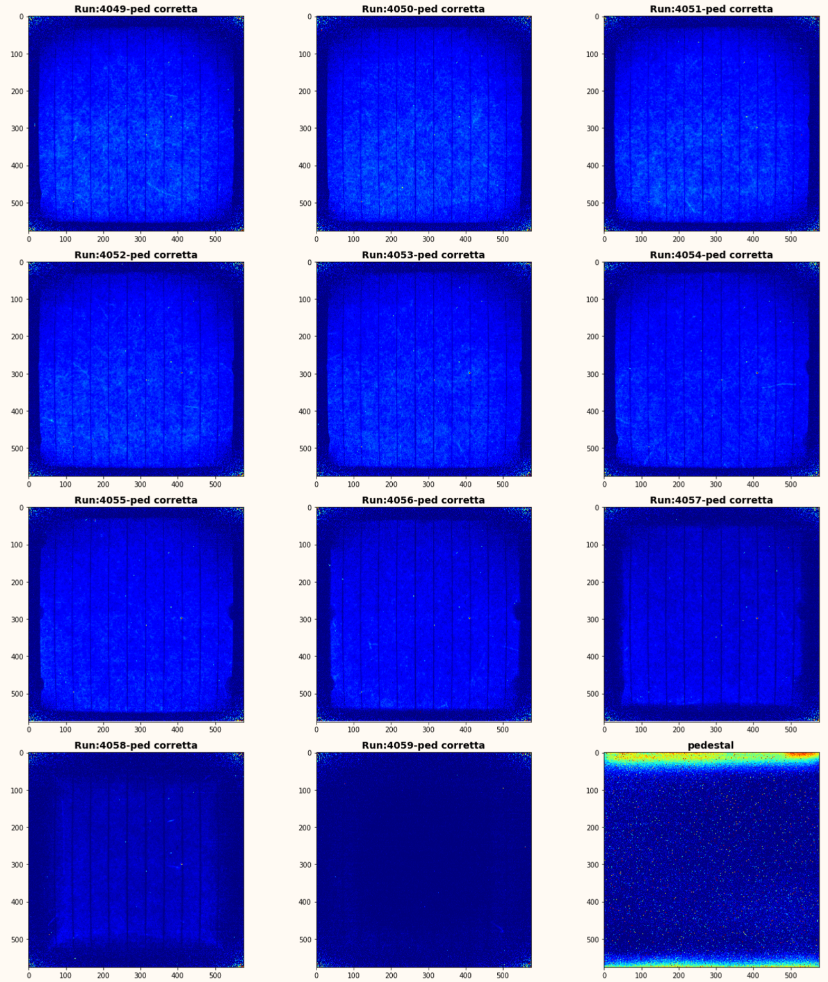
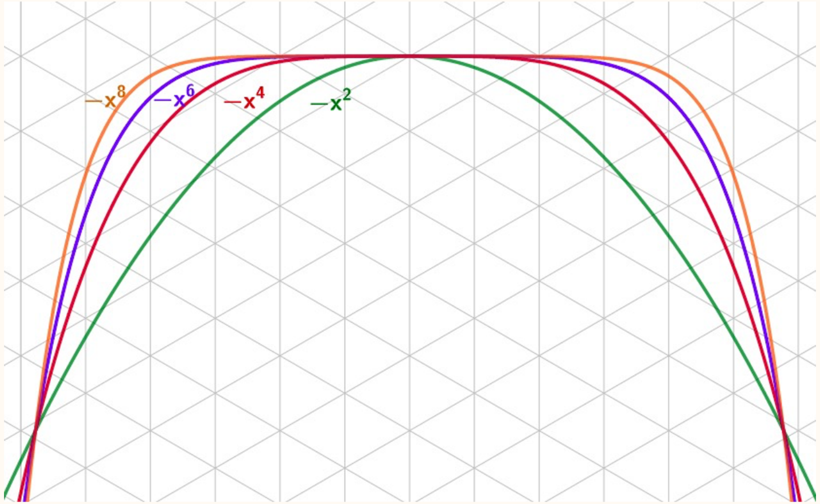
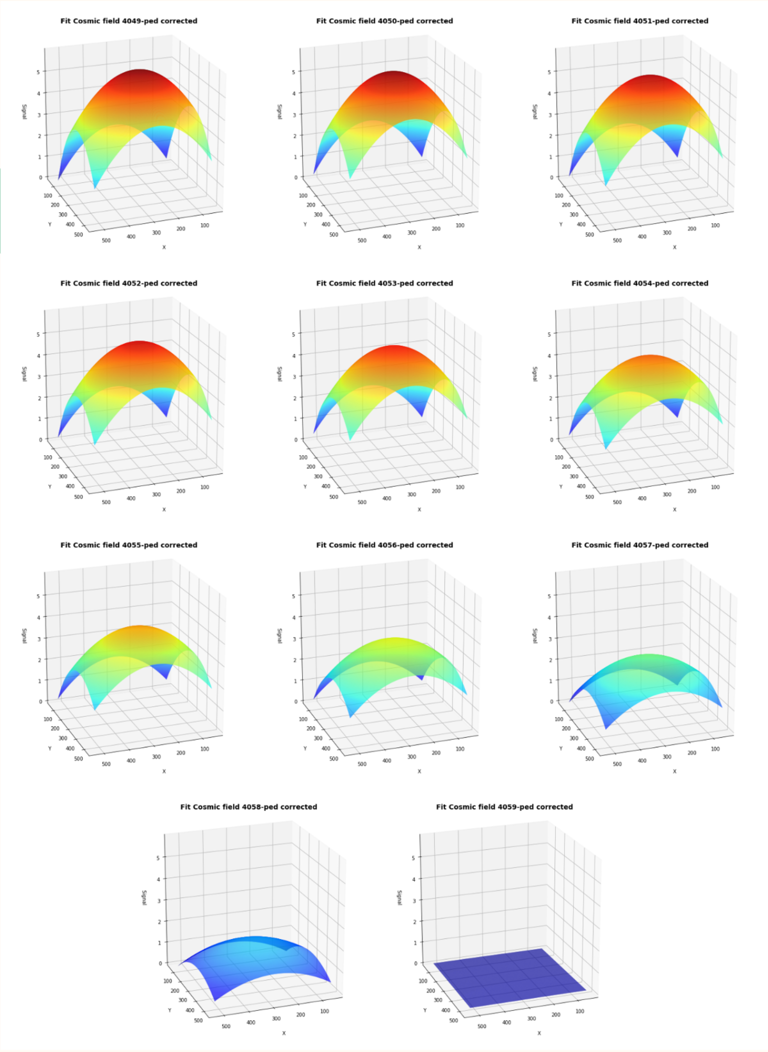
Run:4057-ped
Run:4058-ped
Run:4059-ped
pedestal

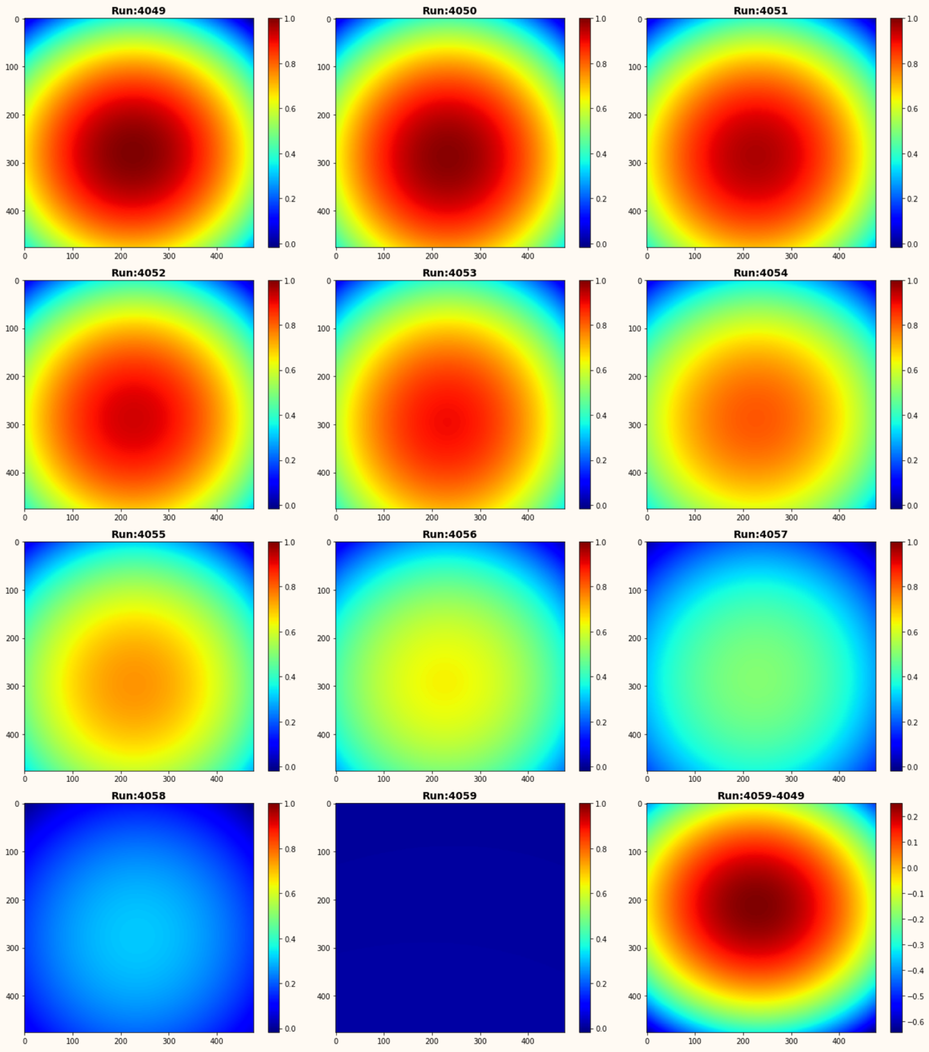

Run:4049-ped corretta
Run:4050-ped corretta
Run:4051-ped corretta
Run:4052-ped corretta
Run:4053-ped corretta
Run:4054-ped corretta
Run:4055-ped corretta
Run:4056-ped corretta
Run:4057-ped corretta
Run:4058-ped corretta
Run:4059-ped corretta
pedestal

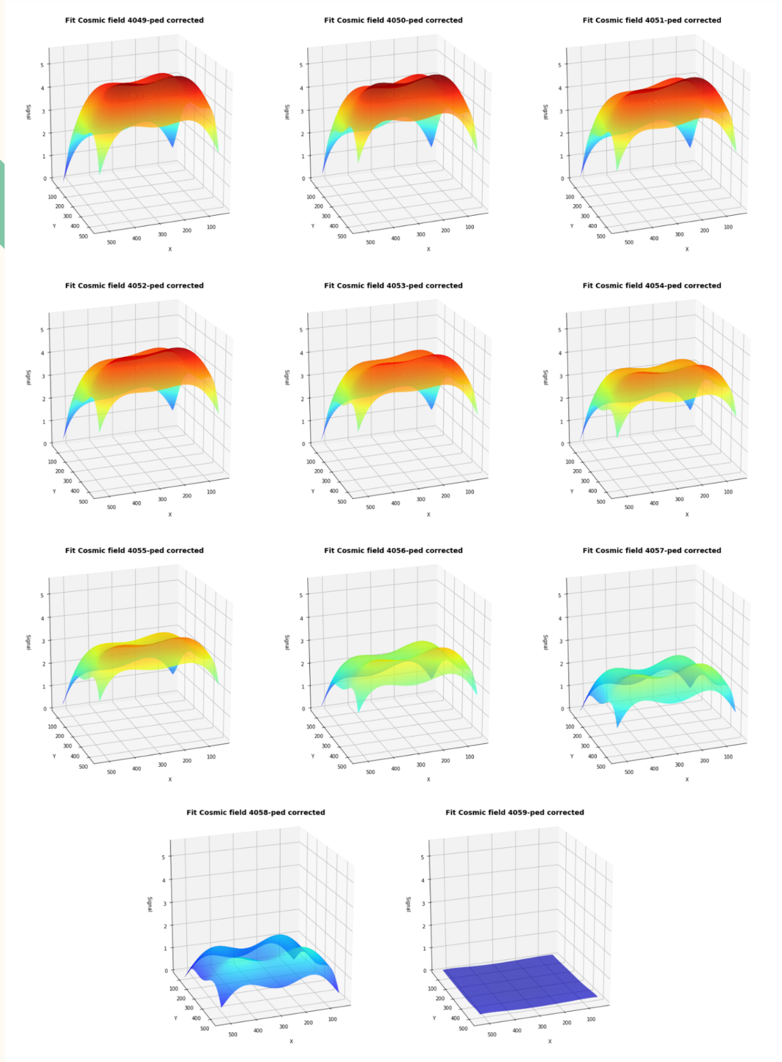
3D FIT

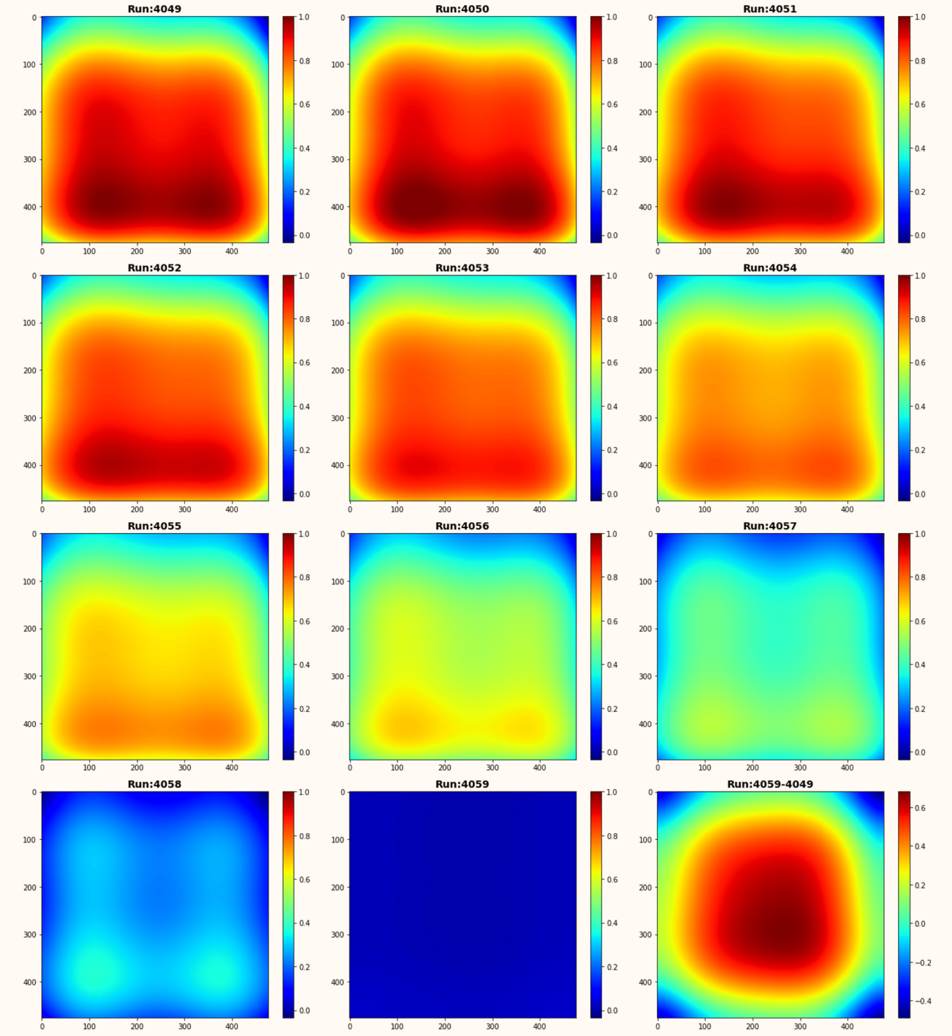
- The image was analyzed through a second degree fit because visually the signal seemed to have the same trend as that of the vignetting.
- From a deeper reflection and considering that the field, for higher voltages, increases the force with which it accelerates the charged particles and therefore the area in which the distortion becomes relevant narrows more and more towards the edges.
- For this reason what we want to observe is a central plateau which, with the increase of the potential, will tend to expand in such a way that, ideally, it tends to cover the whole area of the field cage in a uniform way.
- Taking the example of figure, we can see that a consistent way to better evaluate this trend is to perform 3D polynomial fits with a degree higher then the second.




Fit Cosmic field 4049-ped corrected
Fit Cosmic field 4050-ped corrected
Fit Cosmic field 4051-ped corrected
Fit Cosmic field 4052-ped corrected
Fit Cosmic field 4053-ped corrected
Fit Cosmic field 4054-ped corrected
Fit Cosmic field 4055-ped corrected
Fit Cosmic field 4056-ped corrected
Fit Cosmic field 4057-ped corrected
Fit Cosmic field 4058-ped corrected
Fit Cosmic field 4059-ped corrected

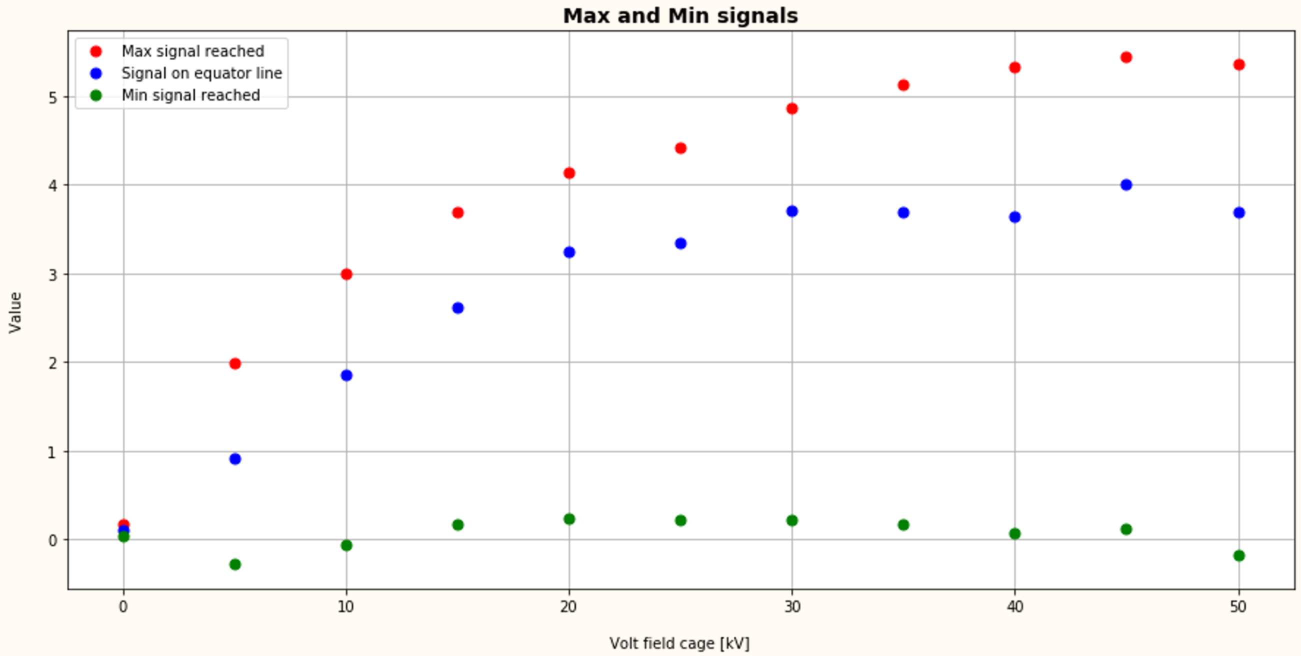

Run:4049
Run:4050
Run:4051
Run:4052
Run:4053
Run:4054
Run:4055
Run:4056
Run:4057
Run:4058
Run:4059
Run:4059-4049


Fit Cosmic field 4049-ped corrected
Fit Cosmic field 4050-ped corrected
Fit Cosmic field 4051-ped corrected
Fit Cosmic field 4052-ped corrected
Fit Cosmic field 4053-ped corrected
Fit Cosmic field 4054-ped corrected
Fit Cosmic field 4055-ped corrected
Fit Cosmic field 4056-ped corrected
Fit Cosmic field 4057-ped corrected
Fit Cosmic field 4058-ped corrected
Fit Cosmic field 4059-ped corrected
Signal
X
Y


Run:4049
Run:4050
Run:4051
Run:4052
Run:4053
Run:4054
Run:4055
Run:4056
Run:4057
Run:4058
Run:4059
Run:4059-4049

Trend of the field

- Estimate the difference that persists between the plateau value (maximum value) and the minimum value can give us an idea of how the trend increases in the field as a function of the increase in the applied potential.



RMS/mean value

- To evaluate if the field trend really tends to be constant, an RMS test normalized to the average fit value was performed.
- The RMS normalized in this way should return a value that identifies how far the fit differs from an ideal plane constructed at the level of the average signal of the fit itself.