High Energy Cosmic Rays Found on the LAMOST CCDs

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Abstract

1 Motivation

1.1 Ultra High Energy Cosmic Rays

2 Introduction

2.1 Current Status

3 Detector

3.1 The LAMOST Telescope

3.2 The CCD Cameras of the LAMOST Telescope

The LAMOST Charge-Coupled Device (CCD):

- 32 CCDs
- 16 for Blue band
- 16 for Red band
- Cooling:
  - Liquid Nitrogen cooling
  - at -130^0 Celsius
- e2v 203-82
  - back illuminated CCD

- 4K by 4K pixels
- 12 x 12 micron pixel size
- flatness better than 15 micron with 100% active area
- support 4 output readout modes?
- LAMOST uses two of the four amplifiers to generate output images

4 Online Data Taking / Observation

5 Offline Data Analysis – Bias Data

The analysis package is developed using Python language.

5.1 Raw Data Format

The raw data is available in Fits format, which can be read out using the astropy.io module with a couple simple lines, such as

def read_fits (filename):
from astropy.io import fits
return fits.getdata(filename, ext=0)

Where:

- filename: input data
- output data: raw data matrix

Note: the "ext=0" is used to read in the master

For more information on astropy module and FITs data format, please see astropy documentation [1] and application examples on astrophysics at [2] (in Chinese).

Figures 1 - 4 show a few examples of CCD images or sub-images.

5.2 From Image Frames to Pixels

During data taking, five bias images are taken simultaneously for all 32 CCDs.

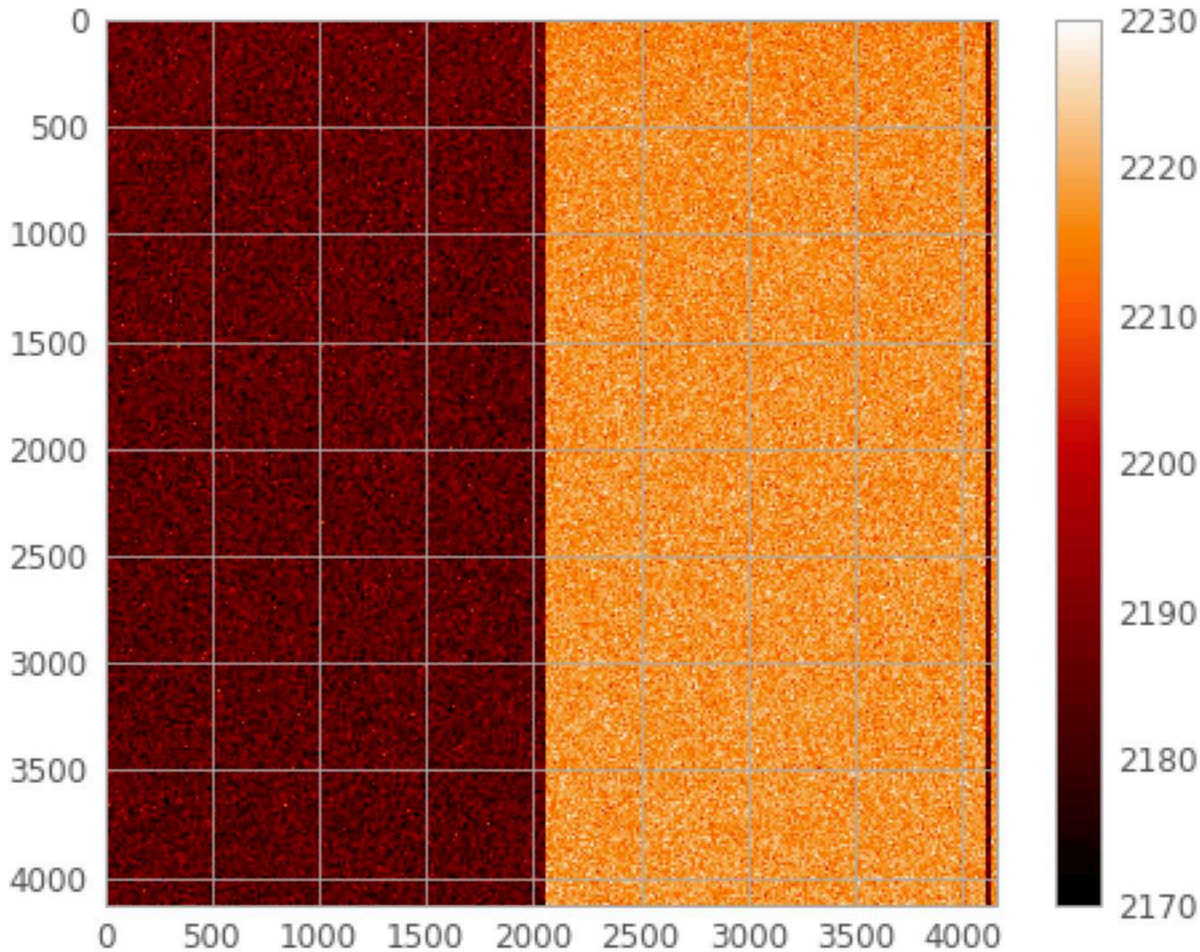

Figure 1: A image taken by the rb-16r CCD on 20150924.

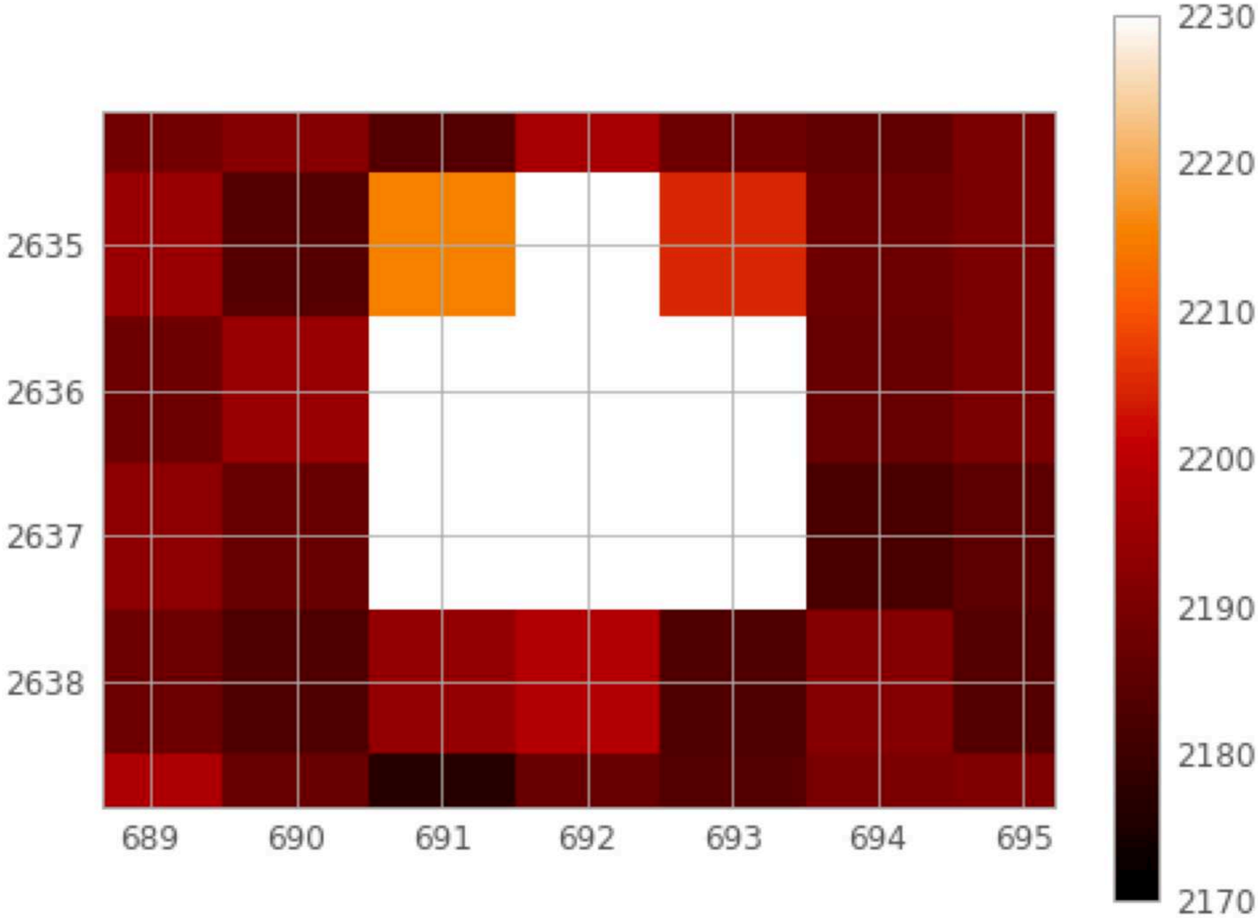

Figure 2: A sub-image taken by the rb-16r CCD on 20150924, a bright spot can be seen in the zoom-in region.

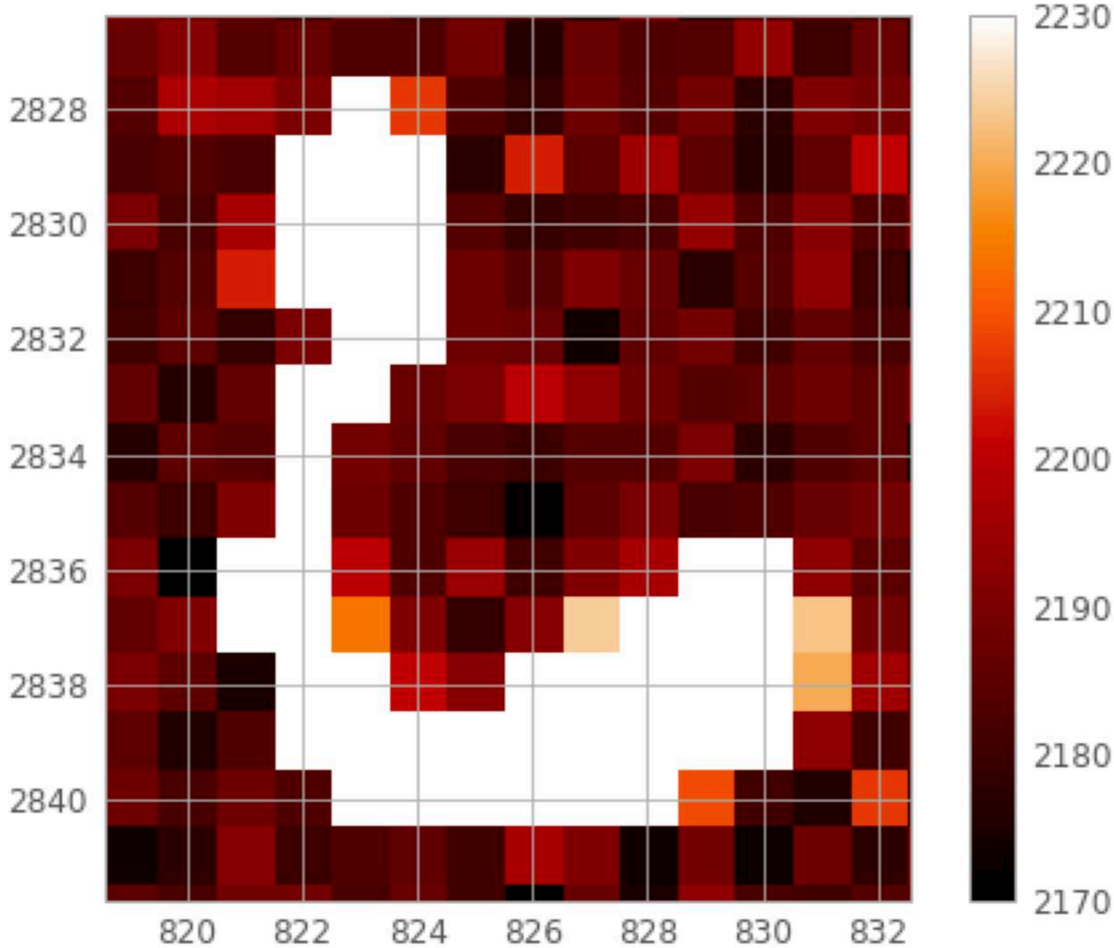

Figure 3: A sub-image taken by the rb-16r CCD on 20150923, a "worm" or a curly track is recorded in the zoom-in region.

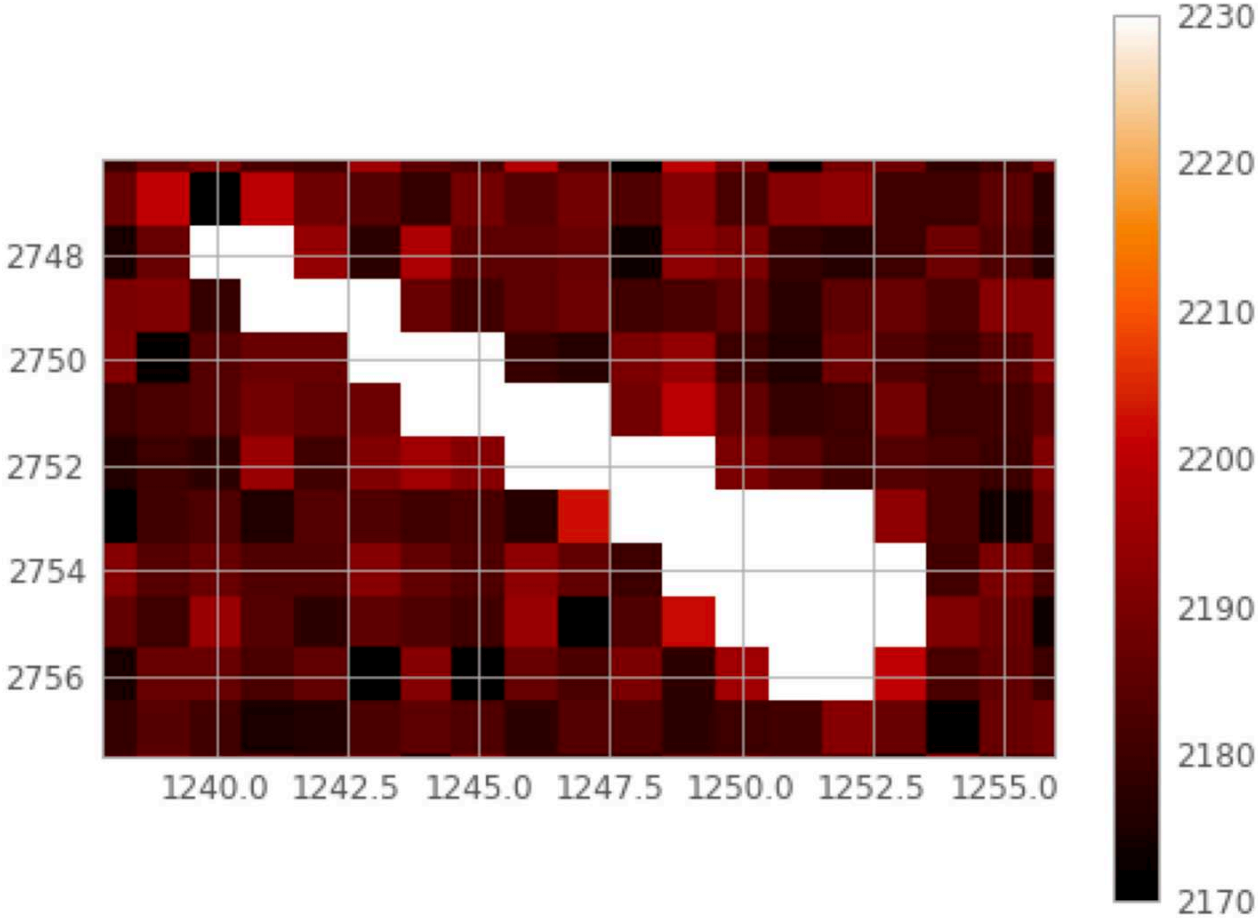

Figure 4: A sub-image taken by the rb-16r CCD on 20150923, a muon candidate is recorded in the zoom-in region.

5.2.1 Overscan Subtraction

"The CCD has hardware overscan(OS) regions of two columns at each end of the serial register. These areas are somewhat too small for a high signal to noise measurement and are suspected to be affected by the illumination of the imaging area, so they are not recommended as bias level reference."

EACH LAMOST CCD has

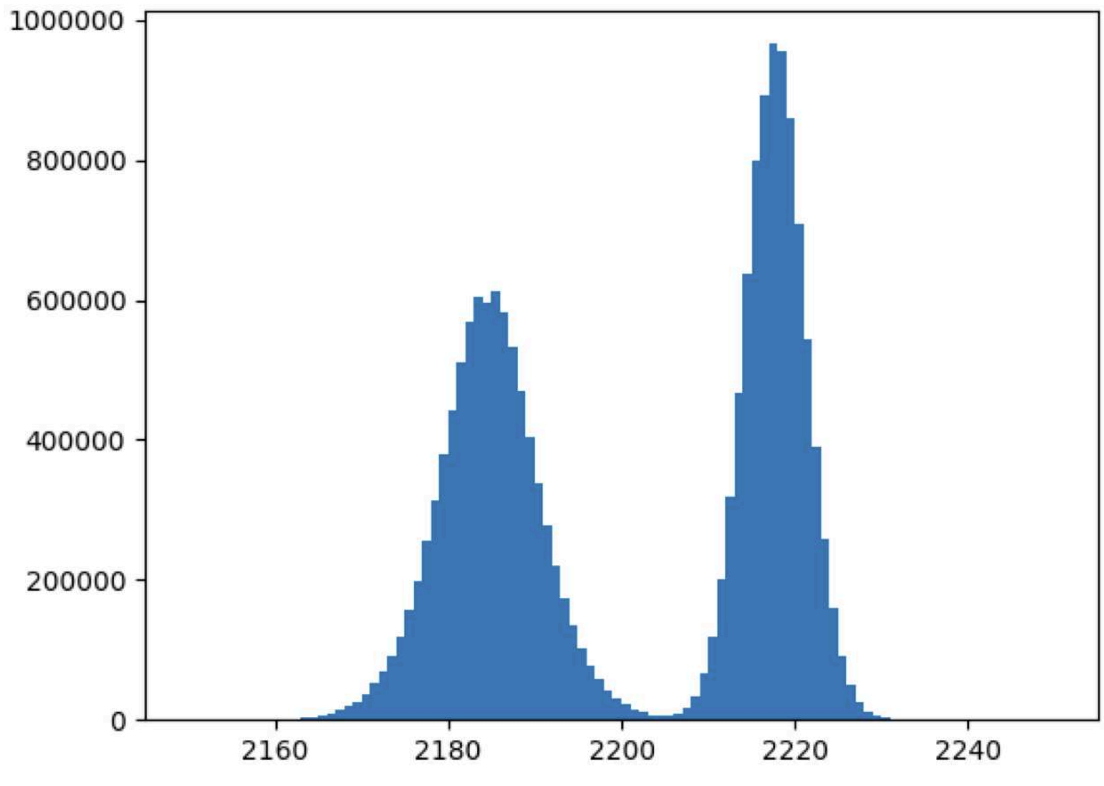

Figure 5: The distribution of pixel values of a image taken by the rb-16r CCD on 20150923.

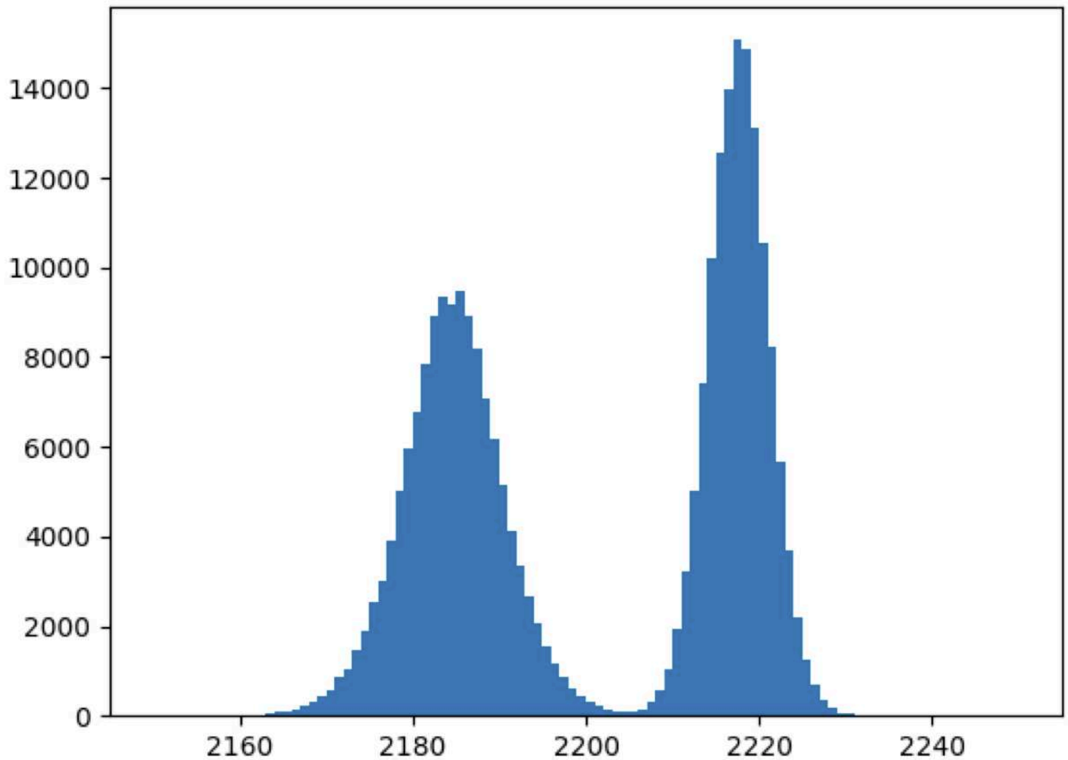

Figure 6: The distribution of pixel values of the overscan regions in a image taken by the rb-16r CCD on 20150923.

The first step in analyzing the bias images is to subtract overscan. The resulting image is called "net data", where:

net[y, x] = raw [y, x] - OS [y].

The raw data is subtracted by the corresponing "OS" data, that is, the corresponding amplifier. There are two amplifiers for each CCD, one overscan

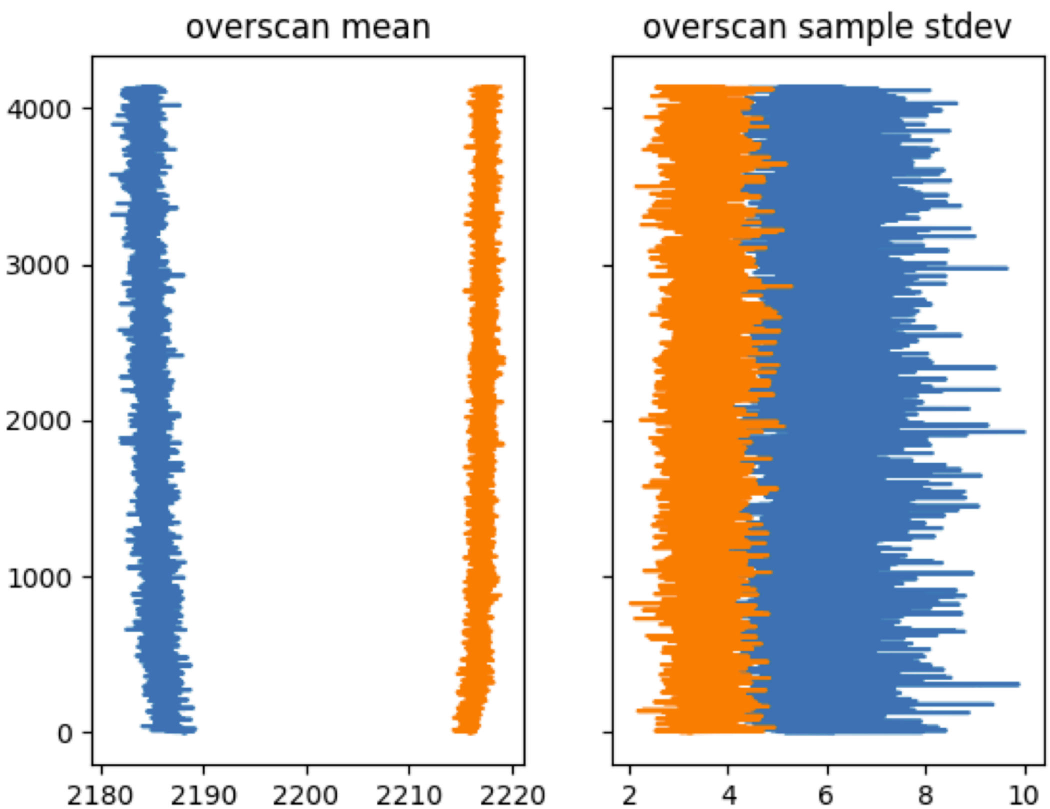

Figure 7: The distribution of mean values of the overscan regions in a image taken by the rb-16r CCD on 20150923.

The distributions after the subtraction for the two OS regions (L and R) are showed in figure 8

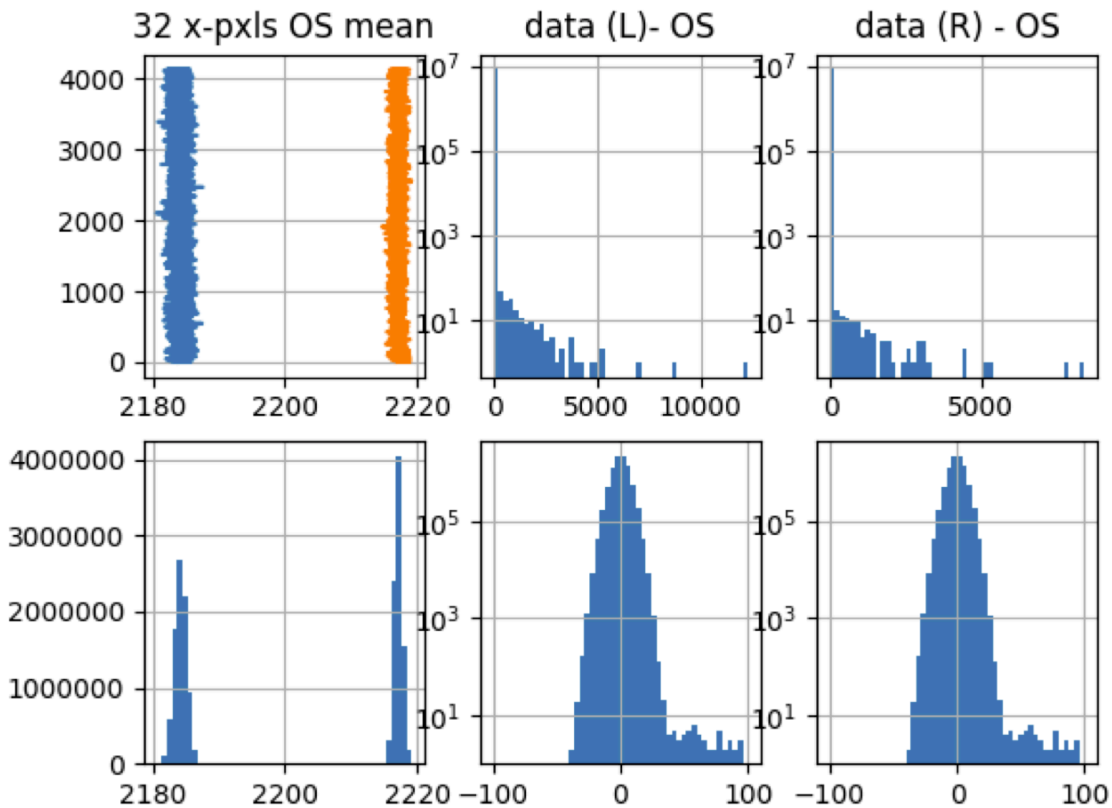

Figure 8: The distributions of pixel values after the subtraction of the over-scan regions in a image taken by the rb-16r CCD on 20150923.

5.2.2 Bias Subtraction

The second step is to form a "median image" from the 5 bias images. Each pixel have recorded five pixel values. The median value is found for each pixel. The median image is created using these median values.

The third step is to subtract the bias using the aboved median image. There are five biased images (five exposures) for each CCD. Each biased image is subtracted by the median image, pixel by pixel. The resulting

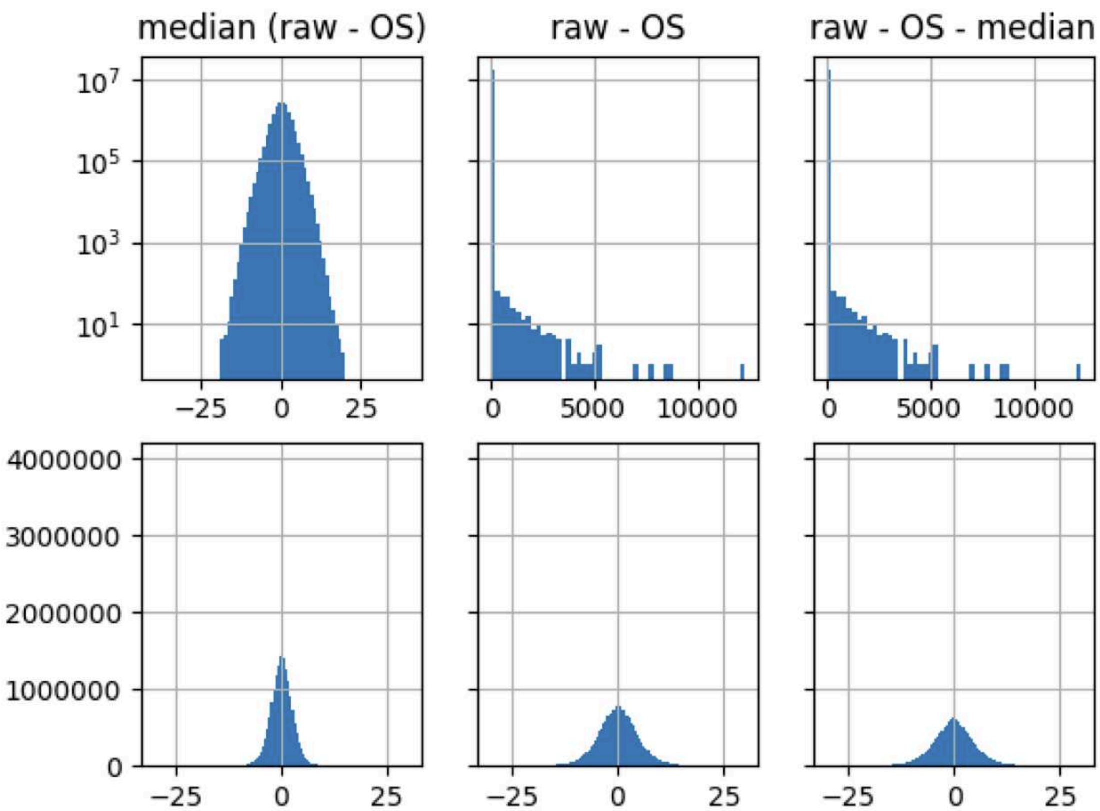

Figure 9: The distributions of pixel values after the subtraction of the OS and the median bias in a image taken by the rb-16r CCD on 20150923.

	Mean	Sstd
0	0.0	10.8
1	0.0	9.7
2	0.0	11.4
3	0.0	12.2
4	0.0	8.5
5	13.5	873.1

Table 1: The mean and standard deviation (Sstd) over all pixels in one image, where [0-4] are real data, [5] is the bias mediam. .

5.2.3 Hotcell and Hot-strip Removal

The mean and standard deviation for one 01r CCD are showen in table 1. These values are calculated over 4096 * 4136 pixels. The last row is calculated using the bias mediam image generated as described in section5.2.2.

5.2.4 Candidate Pixels

The selection criteria for candidate pixels is as following:

pixel value ¿ mean + 3 * sstd, where the mean and sstd are calculated as desribed in section5.2.3

These pixels (x, y, pValue) are saved for further analyzed.

5.3 From Pixels to Clusters

TODO: add find_cluster to this section.

This step is much faster than the previous step. For example, for data of December 2016, it takes 10 hours (on NAOC desktop machine) to run through the whole month's data, where the CCDs were recording data for 28 days.

Note: the systme information of the Linux desktop machine used at NAOC is listed below. [jdeng@localhost scripts]$ uname -a Linux localhost.localdomain 3.19.8-100.fc20.x86_64 #1 SMP Tue May 12 17:08:50 UTC 2015 x86_64 x86_64 x86_64 GNU/Linux

5.3.1 Cluster Selection Criteria

The following cuts are applied to select cluster candidate events:

- np ¿ 10, where np is the number of pixels in a cluster
- avgpV ¿ 120, where avgpV is the average pixle value in a cluster
- sumpV ¿ 400, where sumpV is the total pV in a cluster

The following variables are calculated for a cluster candidate event:

- wcoef
- weigV0, weigV1

5.4 Particle Identifications

5.4.1 Muon Selection Criteria

The following cuts are applied to select muon candidate events:

- weigV0 ¡ 0.03, where weigV0 is one of the two eigenvalues of the weighted covariance matrix with weigV0 ¡ weigV1, i.e, the smaller eigenvalue.

Fig. 10 shows a distribution of the variables weigV1 vs weigV0, where weigV0 and weigV1 are the two eigenvalues of the weighted covariance matrix (see section 5.3.1), with weigV0 ¡ weigV1. For a muon track, The weigV0 variable gives a measure of its track width, and the weigV1 variable gives a measure of its track length. The muon tracks are located on the left side on the figure with small weigV0 and large weigV1.

5.5 Data Sanity Check

5.5.1 Cluster Density

There are 32 CCDs. Total numbers of candidate clusters is showed in 11. The lines are the mean and the +/- 3 σ over the 32 CCDs. The data points of the two CCDs (02r and 08b) are found to be outside the + 3 σ region.

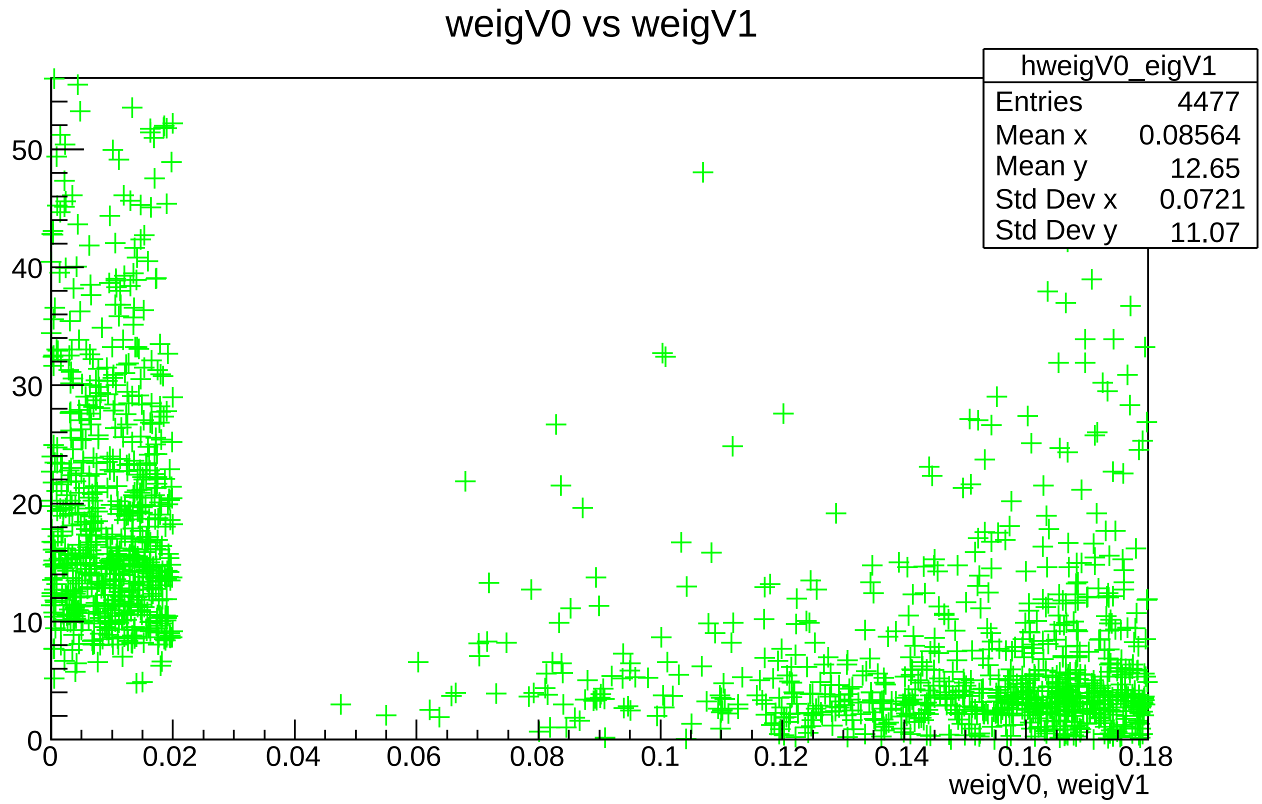

Figure 10: A distribution of the variables weigV1 vs weigV0.

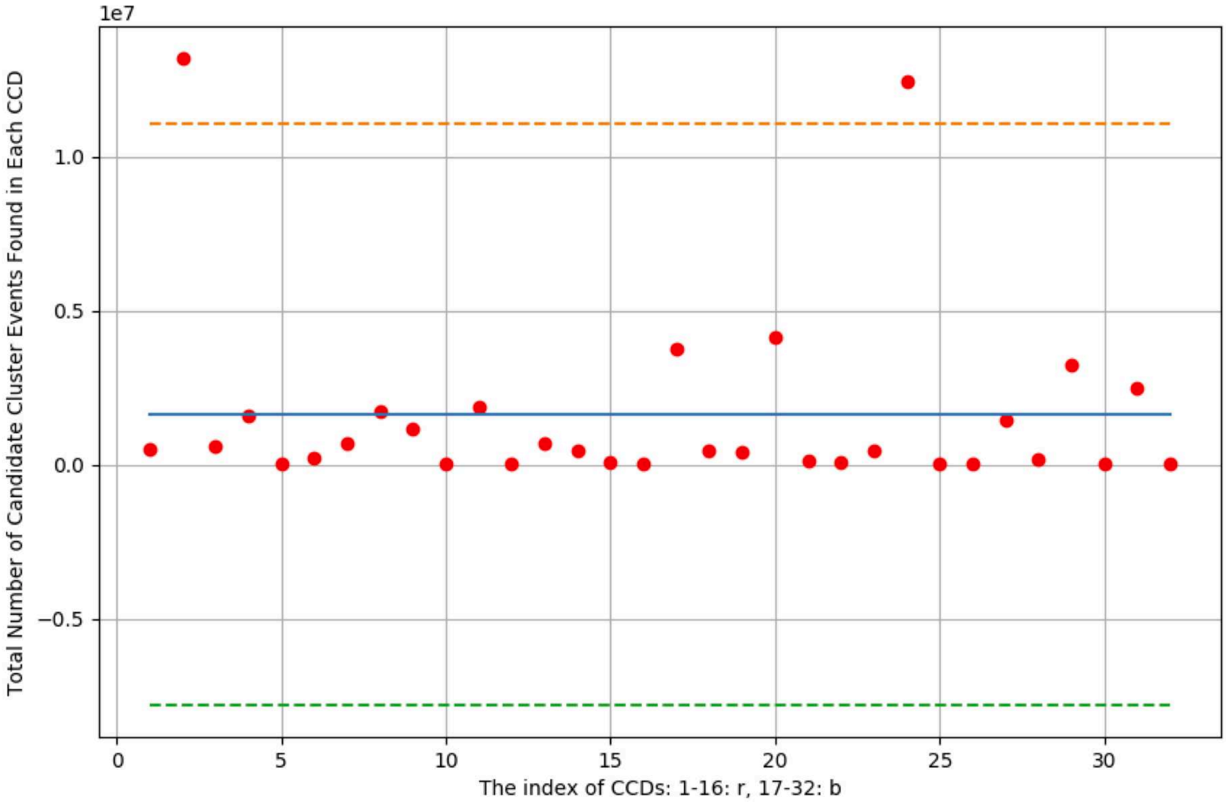

Figure 11: Total numbers of candidate cluster events found in the 32 CCDs of the year 2016 dataset.

Figure 12 shows the total numbers of candidate cluster events in log scale. The numbers of the 32 CCD detectors are distributed quite diversely over two orders of magnitude apart.

Further checking is needed to understand the diversity of the data of all 32 CCD detectors.

Note: the above two figures are not normalized to total exposure time. In the year 2016 dataset, there are 193 files in total, that is 193 days of data, each with 5 images. There are a few files unprocessed for the following detectors: 01r: 192 02r: 186 03r: 193 04r: 192 06r: 189 08r: 191 09r: 191 11r: 192 13r: 192 14r: 187 15r: 190 04b: 191 15b: 192

These files will be reprocessed.

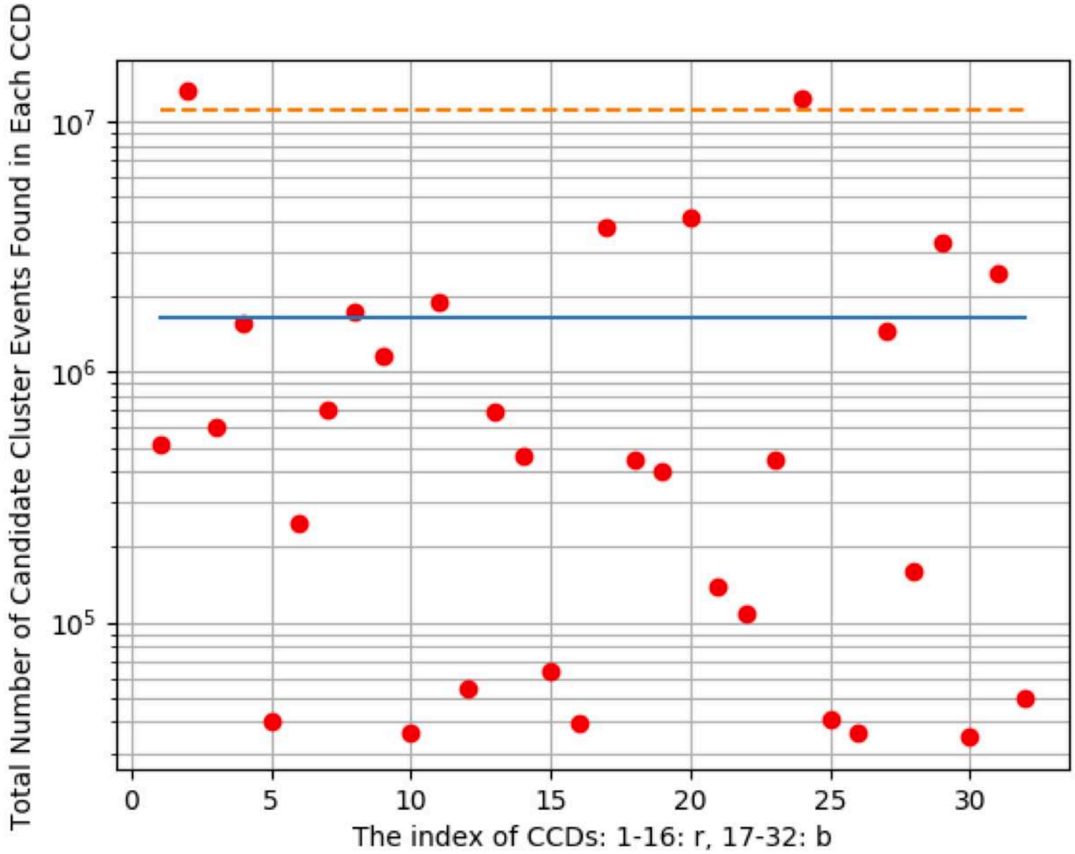

Figure 12: Total numbers of candidate cluster events found in the 32 CCDs of the year 2016 dataset, where the vertical axis is in log scale.

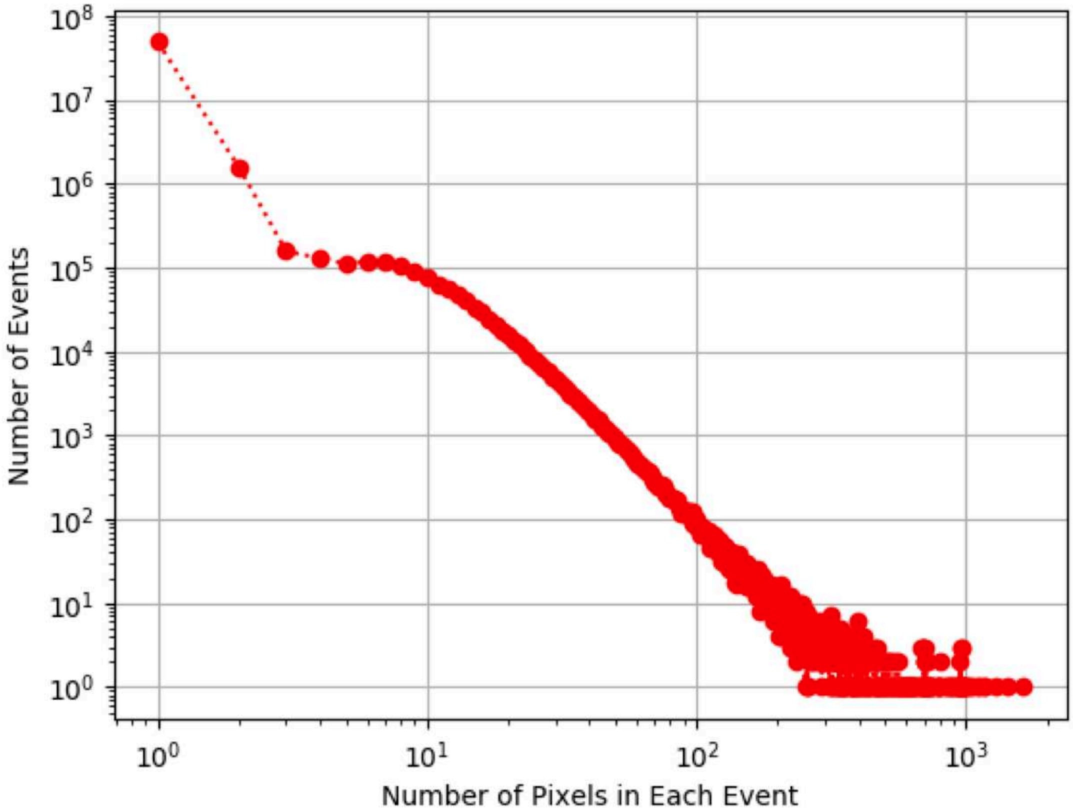

Figure 13: Number of pixels in 'cluster' events from the dataset of year 2016.

5.6 Event Display

5.6.1 From Raw Image to Clusters

Fig. 15 shows cluster candidate events found in a raw image taken on 20160101 using the 01b CCD. There are 39 clusters found from the raw image Fig. 14.

Fig 16 shows a muon candidate event found in the raw image of Fig. 14. The muon event has the following attributes: number of pixels in the cluster = 220
pVmin = 38.6
pVmax = 4895.9
sumpV = 131354.0
avgpV = 597.1
correlation coefficient = -1.0
weighted correlation coefficient = -1.0
eigen values of the covariance matrix= [0.55 , 1014.94]
weighted eigen values of the covariance matrix= [0.18 , 975.01]

5.6.2 ROOT Python Package

To check various distributions, use ROOT Python package for plotting.

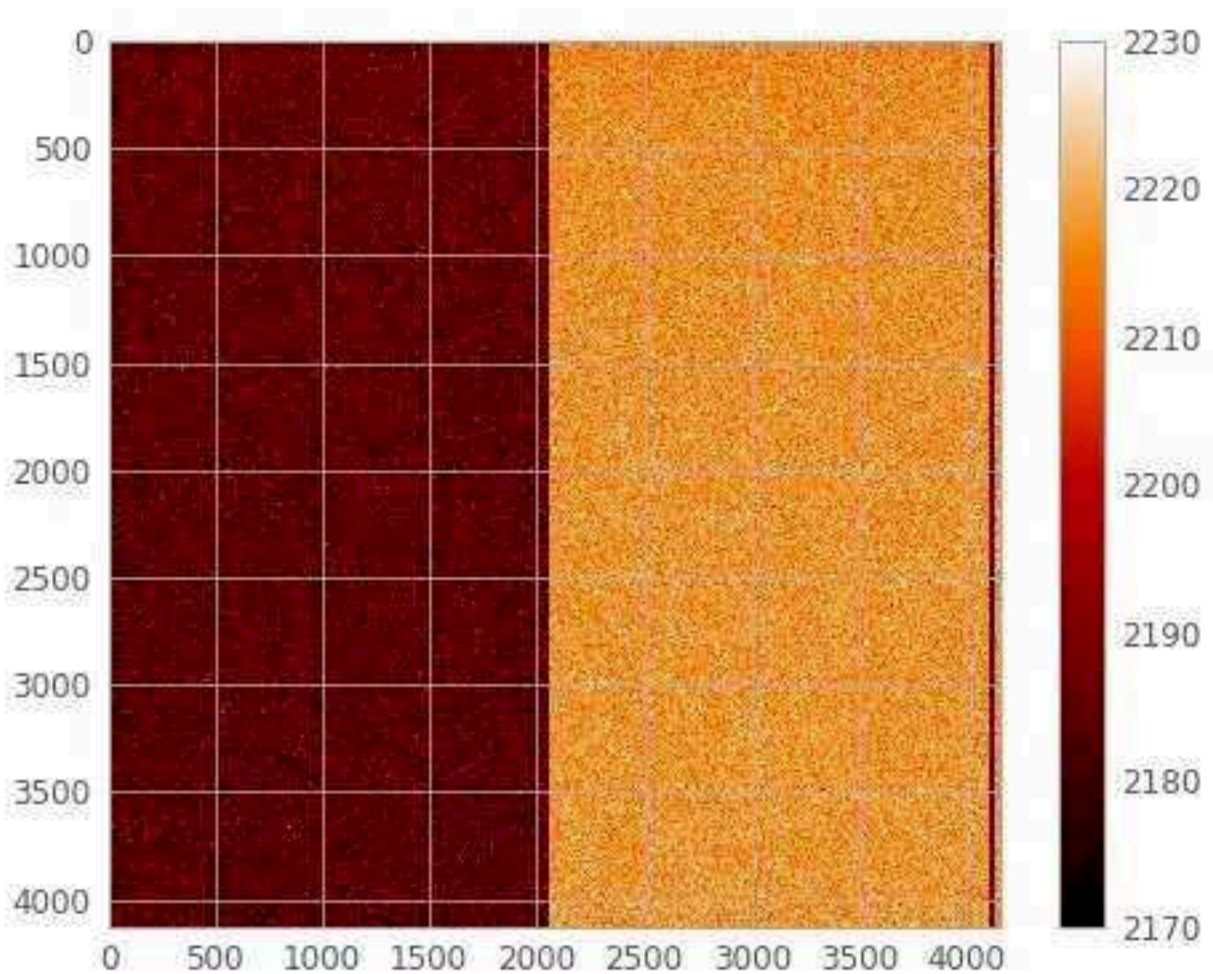

Figure 14: A raw image of the CCD 01b taken in 20160101.

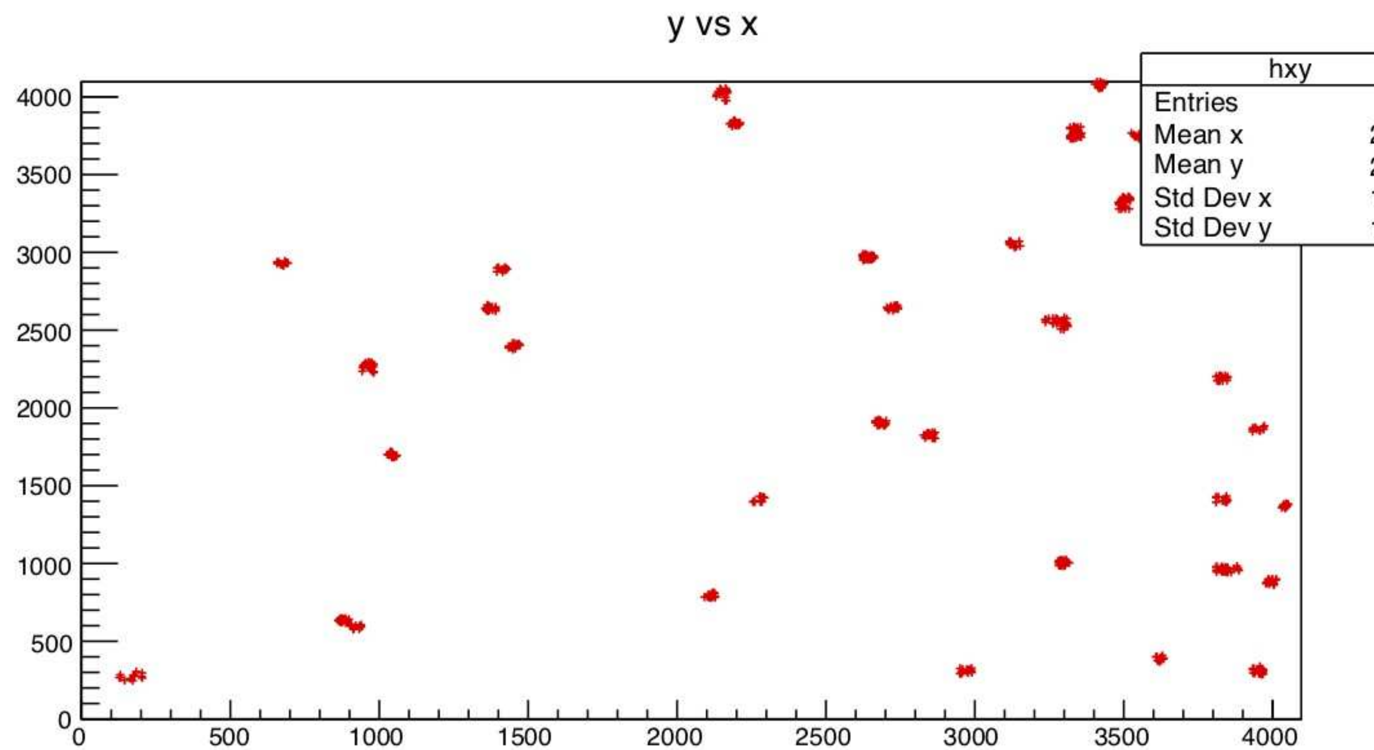

Figure 15: Clusters found in a raw image of the CCD 01b taken in 20160101.

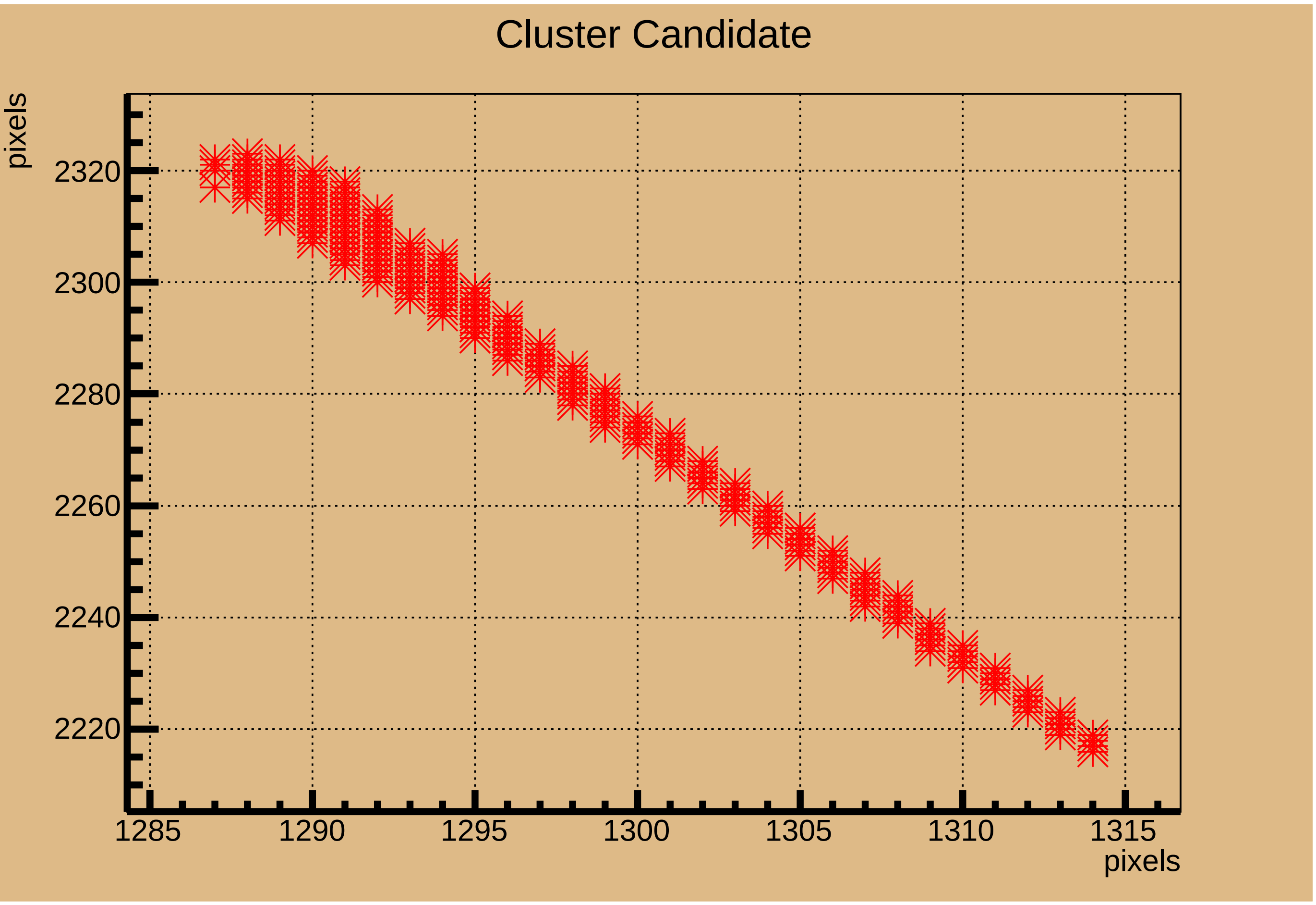

Figure 16: A muon candidate found in a raw image of the CCD 01b taken in 20160101.

5.7 Machine Learning

5.8 Noise Reduction

5.9 Energy Calibration

5.10 MC Simulation and Detection Efficiencies

6 Preliminary Results

6.1 Number of Expected Events

6.2 Statistics and Systematic Uncertainties

7 Future Prospective: Coming Next...

7.1 Ultra High Energy Cosmic Rays

7.2 Ultra High Energy Cosmic Neutrinos

7.3 Cosmic Neutrinos From the Big Bang

8 Conclusion

References

[1] *http://docs.astropy.org/*, Online Astropy Documentation.

[2] *http://blog.csdn.net/u013709332/article/details/45768763*, Python-Python - - - CSDN.NET.

[3] Lei Jia et al., *The UCAM CCD system of LAMOST*, Proc. SPIE 7733, Ground-based and Airborne Telescopes III, 77335E (7 August 2010); doi: 10.1117/12.856355.