Preparation for Light Tightness Measurement of Shutter System in ALPS

Phatthamon Kongkhambut

Chiang Mai University, Thailand

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Abstract

The goal of the ALPS(Any Light Particle Search) group at DESY Hamburg is to observe Axion-like particles. Based on photon-axion coupling, the experiment is conducted to detect photons converted from axions behind an opaque wall. In this study, we study the light-tightness of the shutter system which is a part of the wall systems in ALPS. The CCD camera(SBIG) behaviors and the possible related noises are investigated before testing the shutter and its junction. Different setups are presented and analysed with respect to their light tight frame. Data analysis is based on Python language. The effective setup is presented to be the one without light-tight fabric covered due to the heat accumulation under the fabric caused the significantly high ADC value. New Shutter interface and shutter itself are also tested.

Contents

1 Introduction

1.1 ALPS

By shining high power 1064 nm laser light through a magnetic field, the coupling between magnetic field and photon produces axion-like particle. In Lagrangian shown in equation 1, axions could couple with gluons, photons and fermions.

$$\mathcal{L} \subset -\frac{\alpha_s}{8\pi}\frac{C_{ag}}{f_a} a G^b_{\mu\nu}\tilde{G}^{b,\mu\nu} - \frac{\alpha}{8\pi}\frac{C_{a\gamma}}{f_a} a F_{\mu\nu}\tilde{F}^{\mu\nu} + \frac{1}{2}\frac{C_{af}}{f_a}\partial_\mu a \overline{\psi}_f \gamma^\mu \gamma_5 \psi_f \tag{1}$$

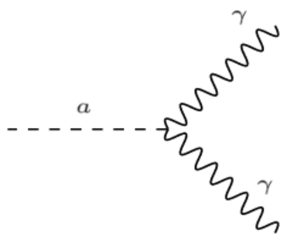

Figure 1: Feynman diagram of an axion decaying into two photons

We can simply get the interaction happening in ALPS II [1] experiment (Figure 2) by using the diagram in figure 1.

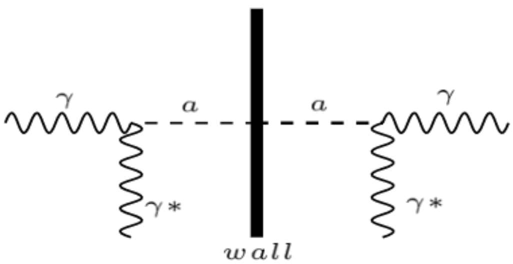

Figure 2: Feynman diagram of process in ALPS

Then, these axion-like particles are traveling through the wall and could couple into photons again under magnetic field in the reproduction region due to the same coulpling.Figure 3 shows the schematic view of ALPS IIc[2].

[1]ALPS II is the upgraded ALPS with HERA magnets in both front and back of the wall region
[2]Final stage of ALPS II, with HERA magnets, 100 meters arms

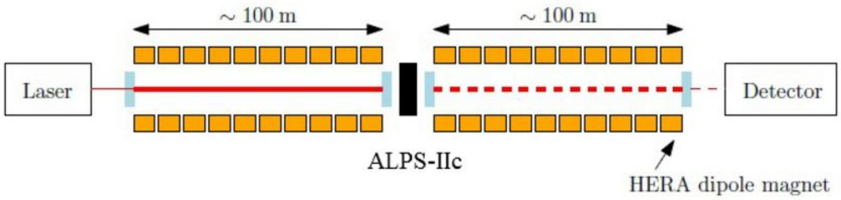

Figure 3: Schematic view of ALPS IIc. Right-handed side of the wall is the reproduction region of photons we want to detect.[3]

1.2 Aim of this study

In this study, we concentrate on the properties of only one component of the wall, the shutter. The shutter, see figure 4, is mounted in front of the shutter box (considered as the whole wall). Due to the small coupling constant of the axion-photon coulpling. This means that ALPS must be operated under very precise sensitivity. One of the challenge tasks is to quantitatively measure the attenuation of the wall, which leads to the purpose of this study.

Figure 4: Shutter

1.3 Noises

There are many possible noise sources that can affect the analysis.
1. Readout error from CCD chips.
2. Hot pixels : a *fixed pattern noise* caused by the defect of the individual pixel
3. Muons : a time-dependent very high signal caused by external muons
4. Dark count noise : an accumulated 'dark' signal [3] Ideally, the rate of dark count should be constant through time.

[3]The virtual counted signal, one of the properties of CCD camera

1.4 CCD camera

In this study we use the SBIG ST 402-ME CCD camera. The chip inside is Kodak KAF-0402 contains 660 /*times* 915 pixels but only 510 /*times* 765 that exposed to light.

To control the camera, we used program driver package performed in C language from Santa Barbara Instrument Group. Important parameters, exposure time, CCD temperature, frame type, etc. can be set by the program.

Here are the definitions:

1. Exposure time : time that the CCD is exposed to light, Long exposure time leads to more light detected but also causes some time-dependent noises which is discussed before.

2. CCD temperature : This camera's cooling process is responsible by the cooling fan in the back part of the camera. CCD chip is charge-coupled device which is work at low tempeature. We set the CCD temperature at 0.0 °C all the measurement.

3. Frame type : The property of camera shutter, inner shutter, that could be selected to be opened or closed during taking data.

Dark frame ≡ taking data with inner shutter closed

Light frame ≡ taking data with inner shutter opened

2 Method

2.1 Experimental Set-up

2.2 Shutter Interface

This study uses a new device, shutter interface, figure 5, to keep the shutter stand still just in front of the camera. The previous study showed that the shutter box system is not light-tight. To reduce other parameters that caused leakage of light into the camera, shutter and camera needed to be mounted together by this interface.

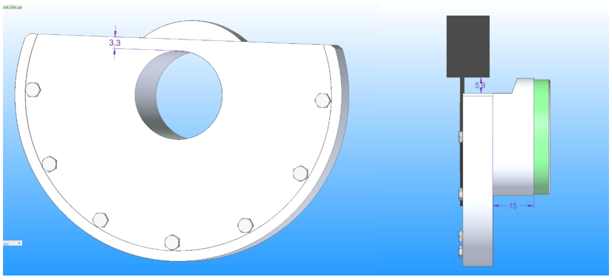

Figure 5: Shutter interface drafts
(left) : front view, (right) : side view (the black object is the shutter),

2.2.1 With Covering Fabric

Figure 6 shows the experimental set-up #1, with covering fabric. Front part of the camera and front part of the LED are under light-tight fabric. The aim of wraping eveything is to prevent light from the LED reaching the back of the camera, which previous work showed to be not light-tight [1].

Figure 6: Experimental set-up with Fabric

To detect heat deposition, there are three temperature sensors installed.

- In front of the camera (under the fabric)
- Behind the LED
- On the room's wall (Room temperature)

2.2.2 Without Covering Fabric

There was a problem about temperature raising inside the fabric in set-up #1. To reduce the environment effect as much as possible, we decided to conduct a set-up without the fabric, set-up #2, see figure 7.

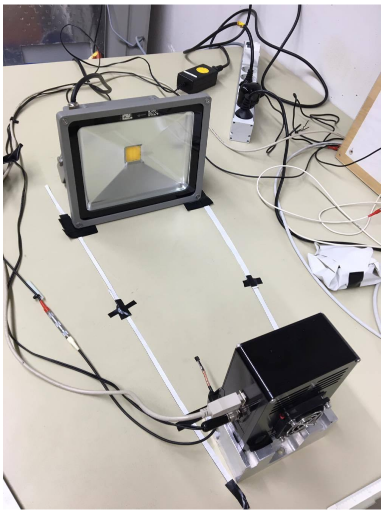

Figure 7: Experimental set-up without fabric using the same distance between the camera and LED

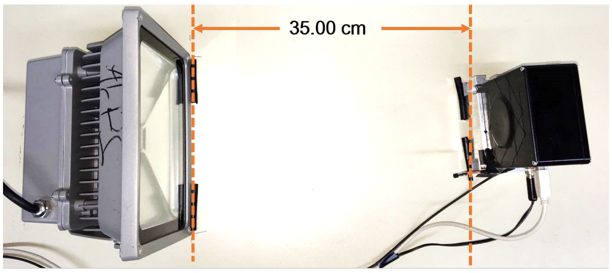

Figure 8: The fixed distance between LED and camera is 35 cm and these two are placed centering to each other

3 Results

3.1 Data Analysis

Raw data is saved in .fits file with size 1000×1000 pixels, figure 10. Different color gradient indicate different ADC value, see figure 9. We use unexposed region for determine the readout noise and pure fluctuations of the pixels. Further analysis will use 500×750 pixels, active region plus safety edge, exposed region minus 10 rows and minus 15 columns. This region shown in All programs are written in python language. Raw data are subtracted by 3.1.1, 3.1.2, and 3.1.3 respectievly.

Note: Definitions
- *Active region ≡ actual exposed region contains 510×765 pixels*
- *Unexposed region ≡ virtual region that CCD should not contain any signal from light source but noise*
- *ADC value ≡ **A**nalog to **D**igital **C**onversion, the way to interpret voltage signal from CCD chips to numbers*

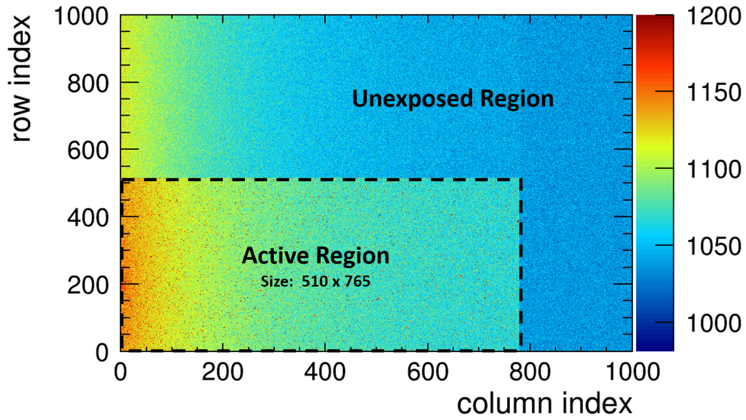

Figure 9: Active region and Unexposed region

3.1.1 Readout noise

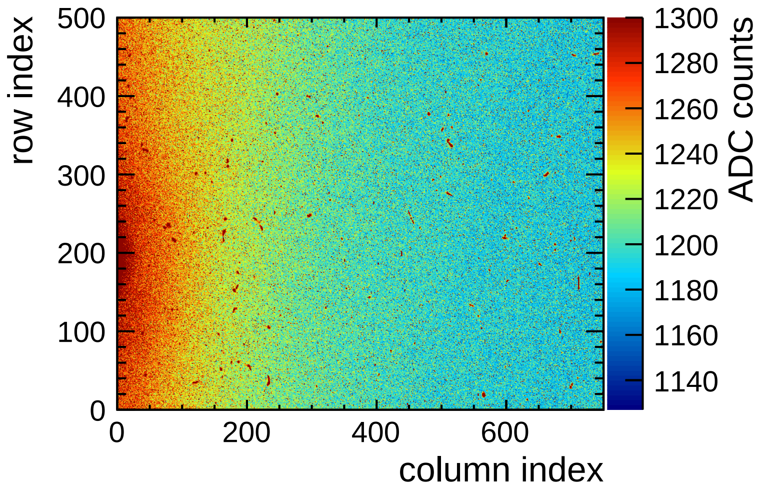

Figure 10: Effect of readout noise shown in the form of glower region in the left side

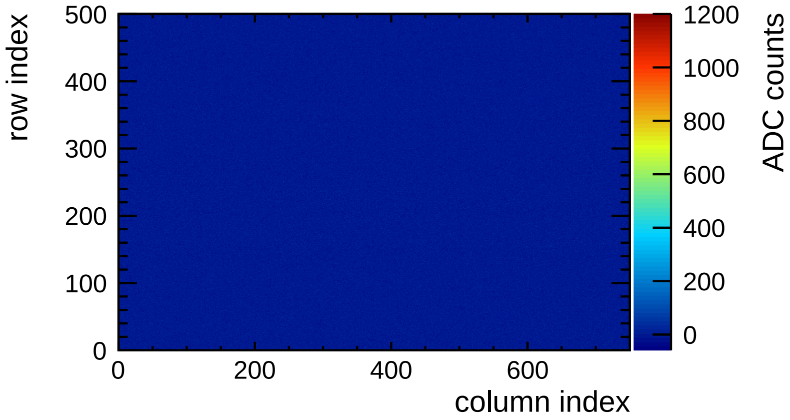

Figure 11: After correction readout effect

To eliminate readout noise, we subtract each active column (exposured row) by the mean of its corresponding virtual column, the column in unexposed region. Raw data always contains readout noise, see figure 10. This noise causes the glower region in the left part of the picture. Equation 2 shows the sum all ADC in active region, S. After subtract this, flat data shown in figure 11.

$$S = \sum_{i=1}^{500} \left[\sum_{j=1}^{750} ADC_{ij} - \frac{\sum_{j=520}^{1000} ADC_{ij}}{1000 - 520} \right] \tag{2}$$

3.1.2 Hot pixels noise

This can be subtracted by taking 100 data with dark frame, dark environment and zero exposure time, and calculate an average of each pixels. Then, compare each pixels average with the global average (use whole pixels mean). In this study, we use the criteria of higher than globals average at 6σ of standard deviation as the Hot pixel.

3.1.3 Muons

Figure 12 shows the track of some muons hitting CCD chip during the high exposure time. To eliminate the effect of muons, the method is similar to hot pixels determination but since muon hitting pixels contain out of order very high ADC, median of ADC is used instead of mean ADC to determine critical value. By using median ADC + 6σ of the whole pixels, the muon map from this method shown in figure 13 and figure 14 for 3σ method.

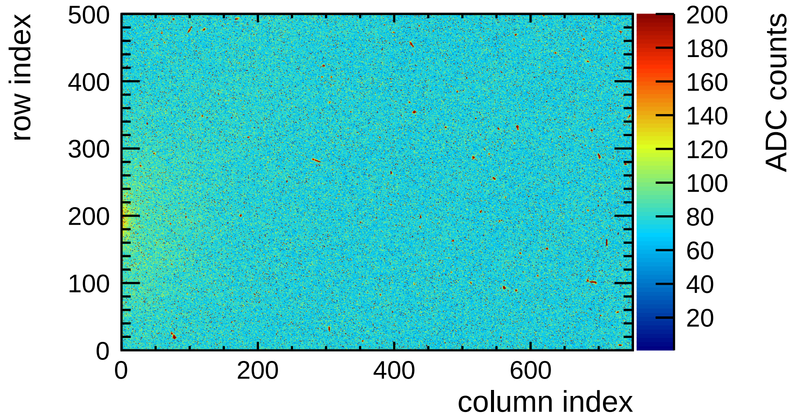

Figure 12: Data after subtracting readout noise shown the muons hit in red spots

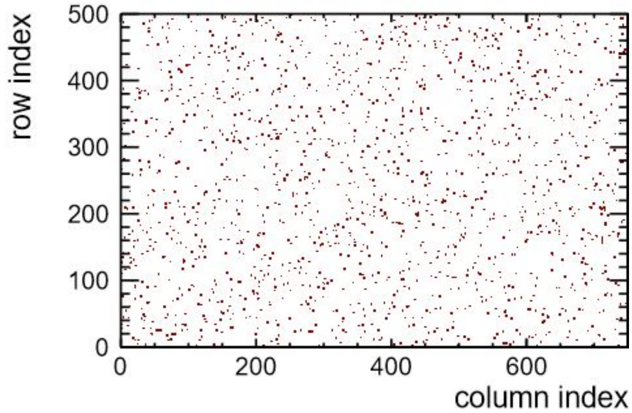

Figure 13: Muon map at criteria median + 6σ

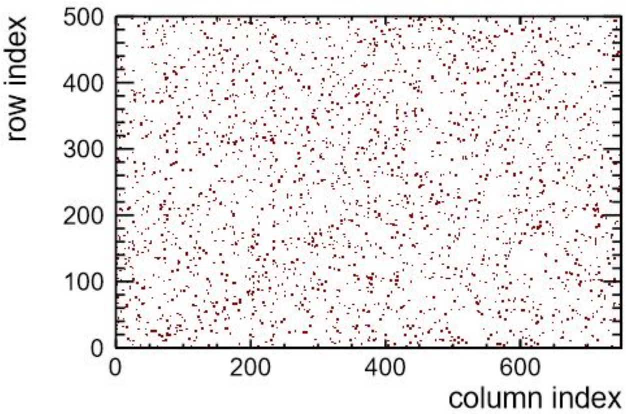

Figure 14: Muon map at criteria median + 3σ

By comparing the map from criteria 6σ, figure 13, with figure 12 roughly by eyes, we hardly determine any muon from the map, but with the lower criteria map, figure 14, some pixel clusters that were hit by muons appeared. This leads to a question of which criteria is appropriate for masking muons to perform further study.

3.2 Effect of the Covering Fabric

Figure 15: Back part of SBIG camera (front part is under the fabric)

We did the measurement with condition Light frame, 30 minutes exposure time over 1 hour to investigate the temperature dependent effect between 2 data taken. Temperature under fabric (in front of the camera sensor) rose up to 31°C,see figure 16, from the room temperature (at 23°C) and behind the LED rose to 40°C. In figure 16, two highest peaks represent the two measurements with 2 hours break between each measurement. Comparing to the without fabric setup, figure 17, small increase appeared during September 5, 2016 night when the without-fabric has been used.

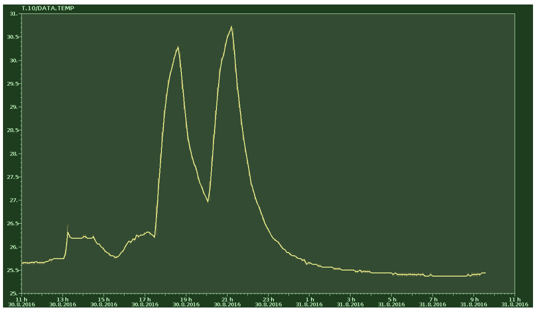

Figure 16: Temperature in front ofthe camera during two measurements.

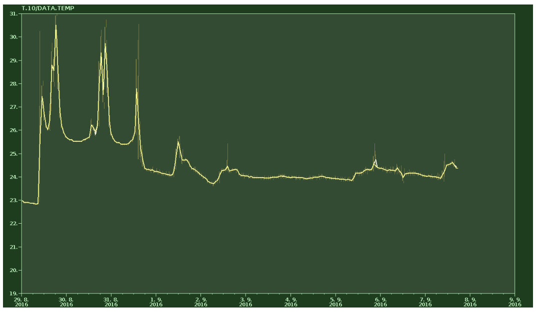

Figure 17: Temperature in front of the camera
(left part) : high peaks appeared with fabric-covered setup
(right part) : small increase appeared during September 5, 2016 night, without fabric

The difference ADC value between first 30 minutes data (colder temperature) and the last 30 minutes data (hotter temperature) is higher than 5σ of its uncertainty. These higher ADC value is caused by the photon from blackbody radiation and some electronics of the camera system working at high temperature.

As mentioned before about the light leakage through the back of the camera, we also conducted experiment to determine this amount of light. Result shows in table 1. Rate of light leackage,B, is determine by equation 3.

$$\frac{S_{10minLEDon} - S_{10minLEDoff}}{10mins} = B \tag{3}$$

Table 3.2 shows the sum ADC value from final data, which subtracted all noises as mentioned in 3.1, from different set-up with covering fabric and without covering fabric.

The with-fabric experiment shown is from the hotter temperature data.

At first the ADC value of the without-fabric are higher than the with-fabric data, minus sign in the fifth column of table 3.2. We assumed that it was caused by the leakage light still existing in the data. However, after correction, subtracting leakage light by the rate from table 1, ADC value of without-fabric is lower than with-fabric.

This leads to the conclusion that we should not cover fabric due to the difficulty of controlling system temperature and the ease of changing environmental condition: every new set-up we have to take the fabric off and tape them together again, which is irreproducible.

$S_(10minLEDon) - S_(10minLEDoff)$	437175.3808 ± 300110.86 ADC
B	43717.538 ADC/min

Table 1: Rate of ADC increase due to back's leakage of the without-fabric experiment

Criteria	$S_{\overline{fabric}}$	S_{fabric}	$S_{\overline{fabric}} - S_{fabric}$	$S_{\overline{fabric}_{corr.}} - S_{fabric}$
1 σ	30249201.540 ± 104358.541	30021104.947	228096.59	-1083429.55
3 σ	31404790.563 ± 195215.965	31182776.141	222014.421	-1089511.72
6 σ	32950569.697 ± 115901.620	32743373.673	207196.02	-1104330.12

Table 2: Sum ADC for each data in different criteria and differences between back's correction

Note : Description of the elements for table 3.2 are shown here:
- Criteria : different criteria of determining muon (median of all avtive pixels + $n\sigma\times$ std of all avtive pixels)
- $S_{\overline{fabric}} \equiv$ ADC of data without fabric
- $S_{fabric} \equiv$ ADC od data with fabric
- $S_{\overline{fabric}_{corr.}} \equiv$ADC of data without fabric after correction by subtract with $30 \times B$.

4 Suggestions for Improving Analysis Method

We have many ideas to improve the analysis method e.g. using circle region in 2D histogram in figure 18 as a criteria of determining hot pixels, investigate the different criteria of determining muon or using the whole new method. More details are discussed in this section.

4.1 Hot pixels

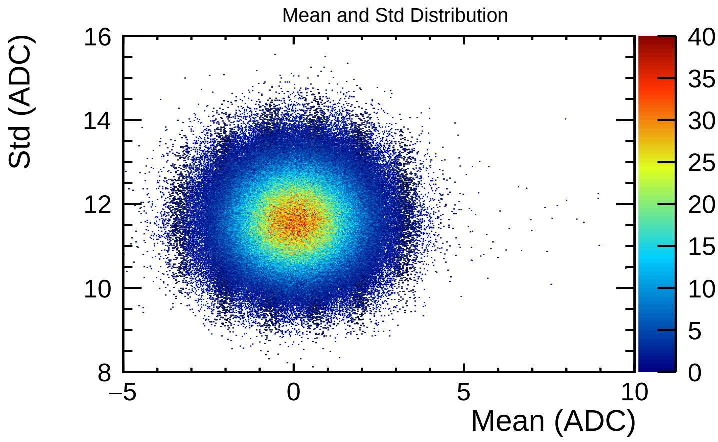

Figure 18: 2D Histogram of mean and standard deviation distribution in 500×750 pixels

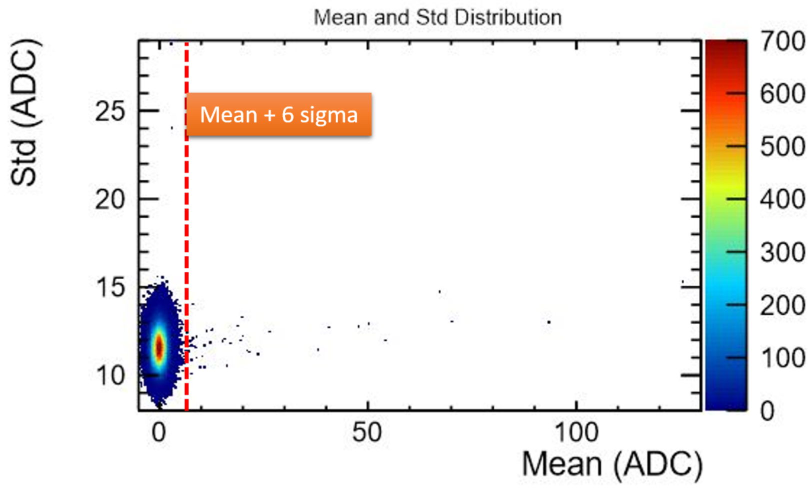

Figure 19: 2D Histogram of the whole view of mean and standard deviation distribution in 500×750 pixels, dashed line shows current criteria

Figure 18 shows the 2D Histogram of mean and standard deviation distribution of ADC from active pixels. Figure 19 also the distribution of the same data but zoomed out ti get the bigger view. Only 40 'hot pixels' is determined by the current method, cutting critical value at the mean + 6σ. This 2D plots might be a better material for determining hot pixels by circle area cut.

4.2 Determining muon

The current muon masks algorithm uses criteria of $median + 6\sigma$. As shown in figure 14 and 13, lower criteria make it easier to track muons by eyes. Table 3.2 also presents the differences between sum ADC for each muon's criteria. The study of effect of muon's criteria on analysis data should be done for better results.

5 Further Analysis

5.1 Shutter Interface Light Tightness

The data of determining shutter interface's light tightness needed to be analyzed in order to check its light tightness before conducting the experiment with the shutter. One possible way that light can leak through is the thread of the interface, which is locked with the camera.

5.2 Shutter light tightness

We have raw data of shutter light tightness measurement, which have 30 mins exposure time, LED on, taped junction between the shutter interface and the camera (just to make sure that this junction is light tight). These data needed to be analyzed further. Analysis method, which will be applied to this data also needed to be improved as mentioned in section 4.

6 Conclusion

The CCD camera behaviors are investigated and the possible noises in a very precise level are concerned and eliminated. Hot pixels, readout error, and muon (or any charged particle reached to the CCD chip) are taken into account in order to create and to modify the data analysis method. The set-up with fabric is shown to be insufficient and difficult to perform the measurement. One solution we suggested is to take the measurement with dark room and study quantitatively about the light passing through the back of camera. Note that the environment where the camera is placed also has to be taken into account: different objects placed behind the camera or even the wall colour of the room could effect the reflection of light to the back of the camera. The analysis of the shutter light tightness' data needed to be done in the future.

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Thanks all of my summie friends. Spending these leisure time with you is full fill my life here.

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References

[1] Report on light tightness measurements for the shutter box of the ALPS II experiment, *Malina Reitemeyer*

[2] The PIXIS 1024B CCD Camera at ALPS, *Jan Eike van Seggern*

[3] https://alpswiki.desy.de/Main_Page, retrieved on September 5, 2016