Any Light Particle Search II.

ALPs II, Shutter Box light Tightness Measurements Report .

Aya Negm
Alexandria University, Egypt
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Abstract

This report addresses my work on the shutter box's light tightness measurements, for ALPs II experiment. The light tight enclosure for ALPS IIc and ALPS IIa is equipped with a shutter along the optical axis of the cavities(the shutter at the shutter box). This allows to open the shutter and check the spatial overlap between the PC and RC as well as the dual resonance. The check should be done without the use of any control light in the spatial and spectral acceptance range of the ALPS-II detector, and that's why the light tightness of the shutter must be maintained. My measurements was mainly testing the light tightness of the shutter box lid. The sensitivity and detection efficiency of the SBIG CCD was also measured. Analysis was done using python.

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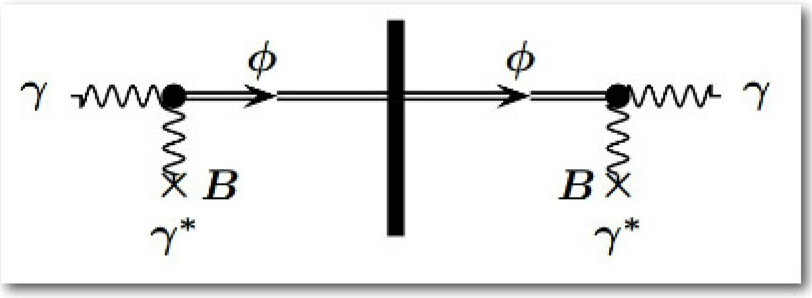
Introduction

ALPS , Light shining through a wall.

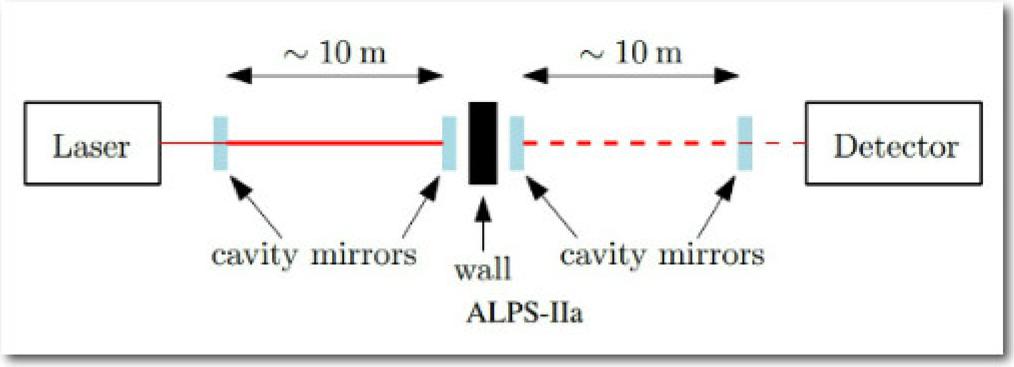
The Any Light Particle Search II (ALPS II) is a light shining through a wall experiment that searches for WISPs (Weakly Interacting Sub-eV Particles) in the mass range below 1 meV. Experiments of this type feature a light source typically from a strong laser shining at an opaque wall to photons but transparent to WISPs due to their vanishing interaction with ordinary matter and then attempt to observe this light passing through the barrier. laser photons can be converted to relativistic WISPs which exhibit coupling to a photon field, can thus be produced in front of the wall
some of these WISPs will then reconvert back to photons to create a measurable signal. Depending on the particle type, these conversion processes are induced by magnetic fields or happen by kinetic mixing. A previous light shining through a wall experiment, ALPS I, featured a Production Cavity (PC) to increase the number of photons circulating in the region before the wall. ALPS II will be the first experiment to use a Regeneration Cavity (RC) to resonantly enhance the probability that WISPs will reconvert back to photons after the wall . This requires that the PC and RC share the same resonant frequency and Eigenmode such that 95% of the light from the PC would couple to the RC if it were directly incident on it. This must be accomplished without allowing any of the photons circulating inside the PC to breach the wall and enter the regeneration side of the experiment as they will be indistinguishable from the signal photons we are attempting to measure.



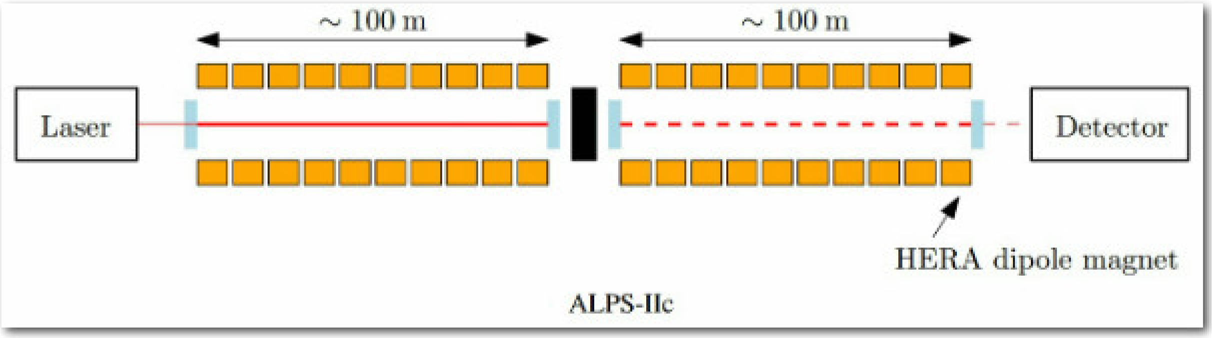
Experimental Design

ALPs II is planned to be realized in two stages:

ALPs-IIa: 10 m cavities without the HERA superconducting dipole magnets to test the optical subsystems related to maintaining the dual resonance of the PC and RC as well as single photon detection schemes at the output of the RC.



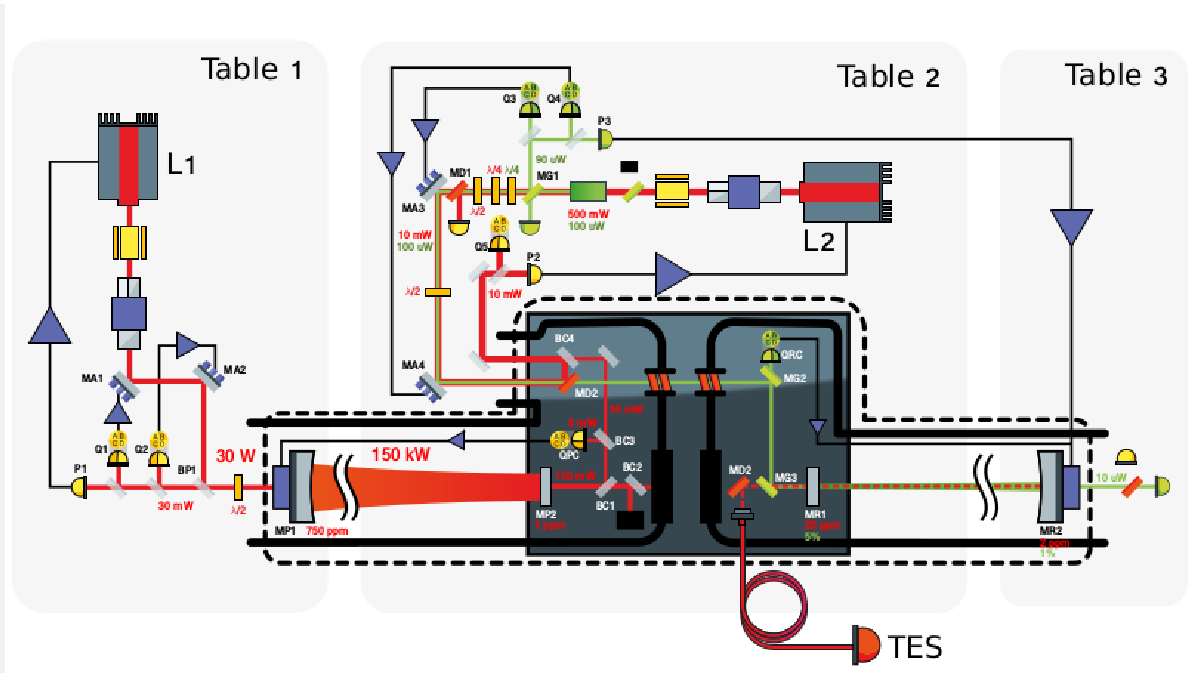
ALPs-IIc: represents the full scale experiment using 100 m cavities with light propagating through high magnetic fields using a 5.3 T HERA superconducting dipole magnets.



The PC can be injected with up to 35 W of 1064 nm light from a laser system With a power buildup factor of roughly 5000 there will be 150 kW of power circulating in the PC. The RC will have a power buildup factor of 40,000 for 1064 nm light. The resonant frequency of the RC must be within 2 Hz of the frequency of the light circulat-ing inside the PC to ensure the resonant enhancement of the reconversion probability of WISPs generated by the PC.

The light tight enclosure for ALPS IIc and ALPS IIa will be equipped with a shutter along the optical axis of the cavities. This will allow us to open the shutter and check the spatial overlap between the PC and RC as well as the dual resonance. ALPS II will need to measure the regenerated photon signal corresponding to single photons over the course of several days. A single-photon counting detector is being used .

In order to reduce dark count of this detector and avoid photons from production cavity light-tight environment is required.



Shutter box Light tightness

The shutter on the shutter-box will acts as the ”wall” for the set up. The shutter

box will hold one of the regeneration cavity mirrors and mirrors to redirect the green

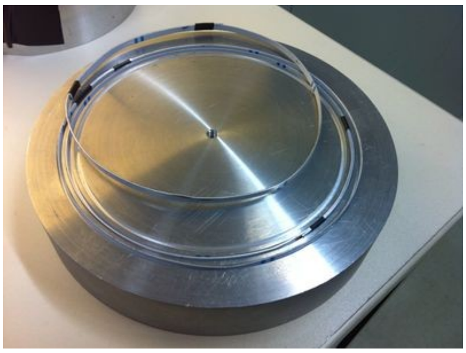
laser from the angled dichronic to the regeneration cavity. The regeneration cavity has to be kept aligned and resonant for the regenerated light, the shutter is used for checking the alignment.

Setup

the main goal from the setup is to determine the shutter box’s light tightness

- Shutter Box

Aluminum box with lid, the box has two holes , one for the shutter and the other hole for the camera connection, the shutter opening is taped with black tape . the box has three labyrinths for possible 3 steel rings to be installed in the grooves to increase the stabilization of the lid.

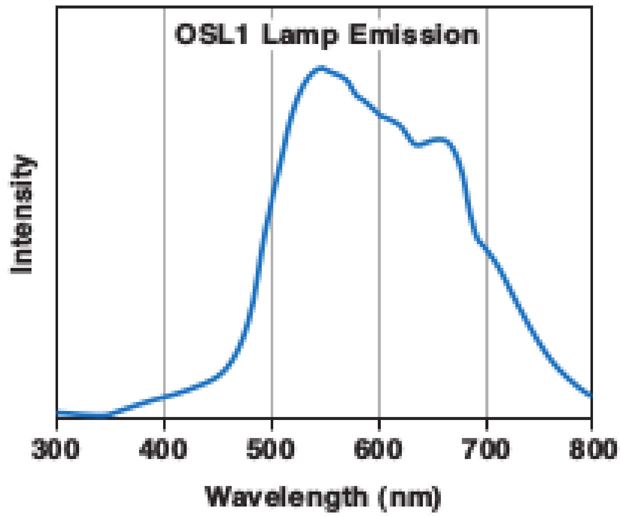


- Camera Connection

The camera is connected to the shutter box through on of the holes using a metal piece with four screw holes so it can be screwed to the shutter box .

- Light source

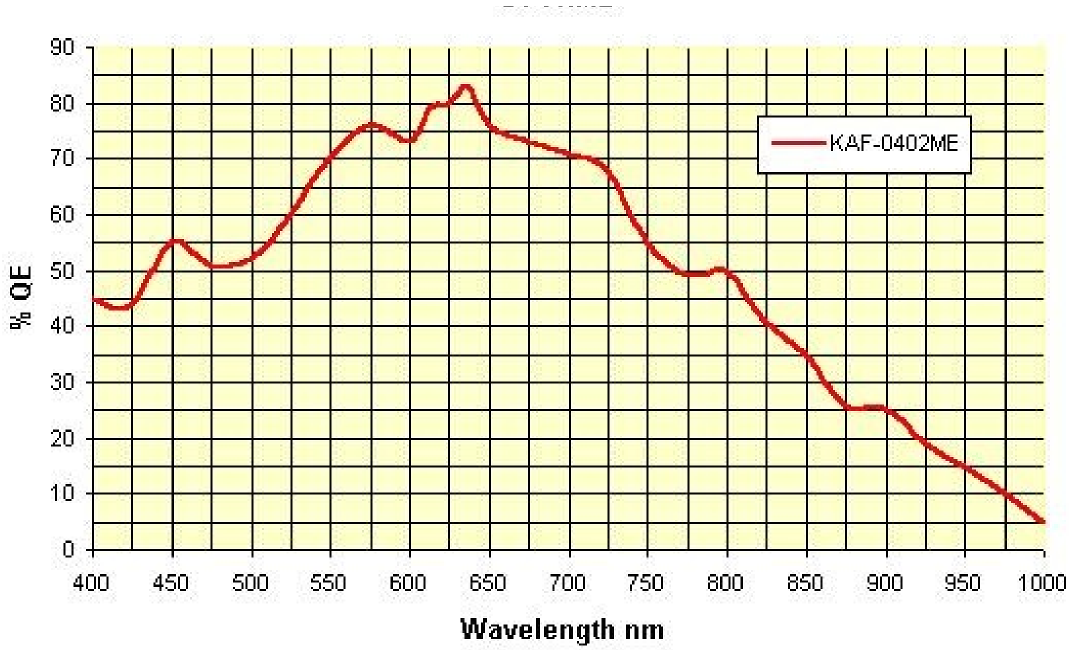
A High-Intensity Halogen OSL1 Lamp of 1 W (3200 K Color Temp) with illumination region of 10 cm square is connected to fiber bundles and therefore provide focused light.



OSL1 Spectrum
https://www.thorlabs.de/catalogpages/V21/1366.PDF

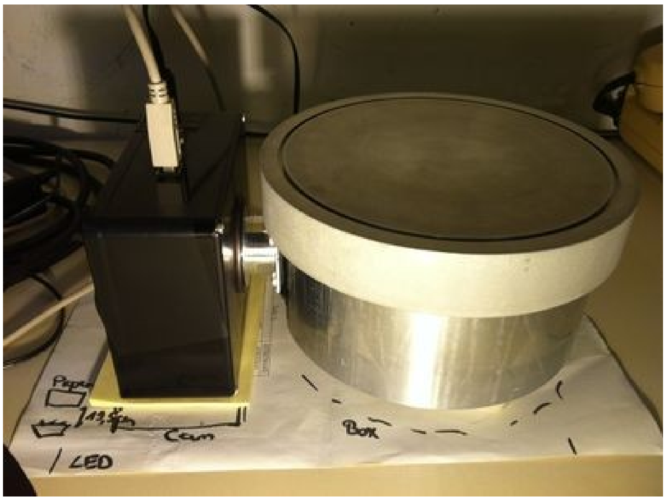
- SBIG ST 402-ME CCD camera

The SBIG camera has a Kodak KAF- 0402 chip (no anti-blooming effect included) to detect light, the camera has 360.000 pixel with a pixel array 765 x 510 pixels at 9 microns square. The dark current is 1 e^-/p/sec at 0 ºC, the A/D gain is 1.5e- /ADU. With a full well capacity 100,000 electrons.



SBIG Quantum Efficiency

For the light tightness measurements SBIG ST 402-ME was used which is operated by a software called CCDOPS', For a picture exposure time, shutter position (open=light frame or closed=dark frame) and operating temperature are indicated. The camera operates at 0 ^{o}c to decrease the dark current.



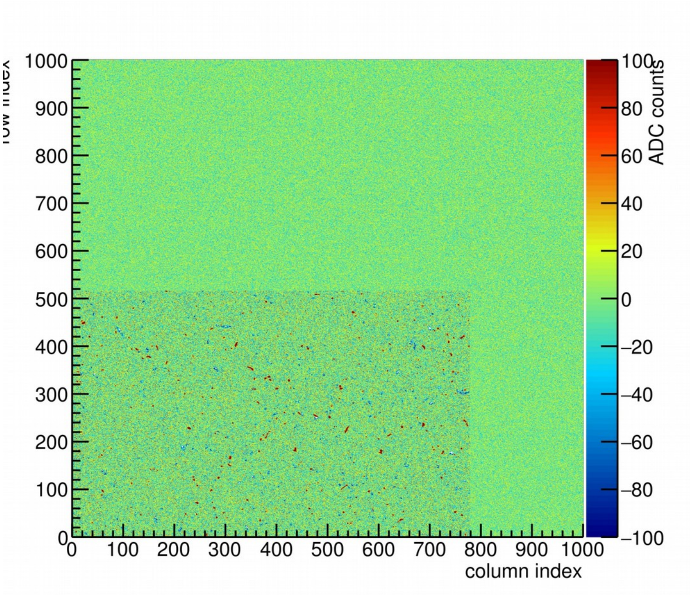
Full setup with camera connected

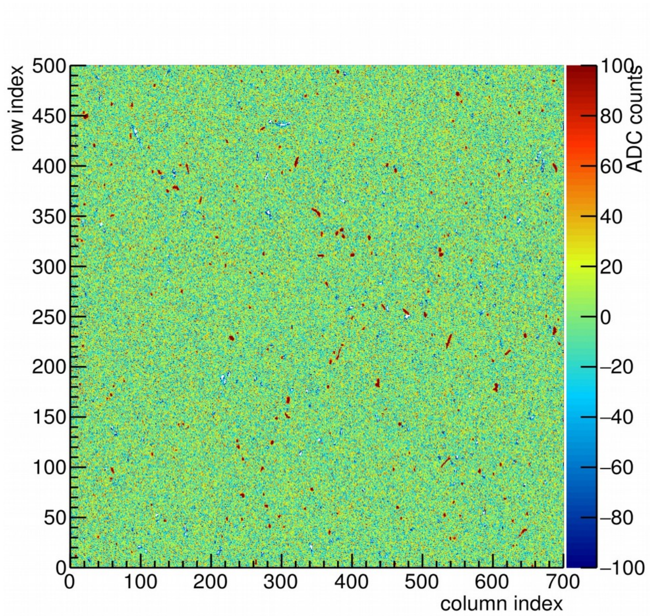
Analysis

the frames from the SBIG are saved in .fits file with size 1000x1000 pixels.
To analyze the pictures signal value for each pixel is summed up to get a total ADU(analog to digital units) value. Each frame contains several signal noises; readout noise which are readout errors by the camera chip , Dark current[1] , and Cosmic muons from external muons.

Only the area 510x765 pixels is an active region “exposed to light “the rest is not exposed to light but used to determine the readout noise and pure fluctuations of the pixels. To estimate readout noise , we subtract each active column (exposed row) by the mean of its corresponding virtual column”the column in unexposed region”. Raw data always contains readout noise,which causes the glowing region in the left part of the picture.

the total light leakage in the setup can be estimated by the ADU difference between a shutter open frame “light frame” and a shutter closed frame “Dark frame” .





Measurements

Three sets of measurements were taken with different exposure times, with the room light off,with 3 O-rings installed in the grooves, and the light source at a distance 4 cm from the shutter box.

Measurement set 1 : 10 light frames and 10 dark frames with exposure time 1800 sec.

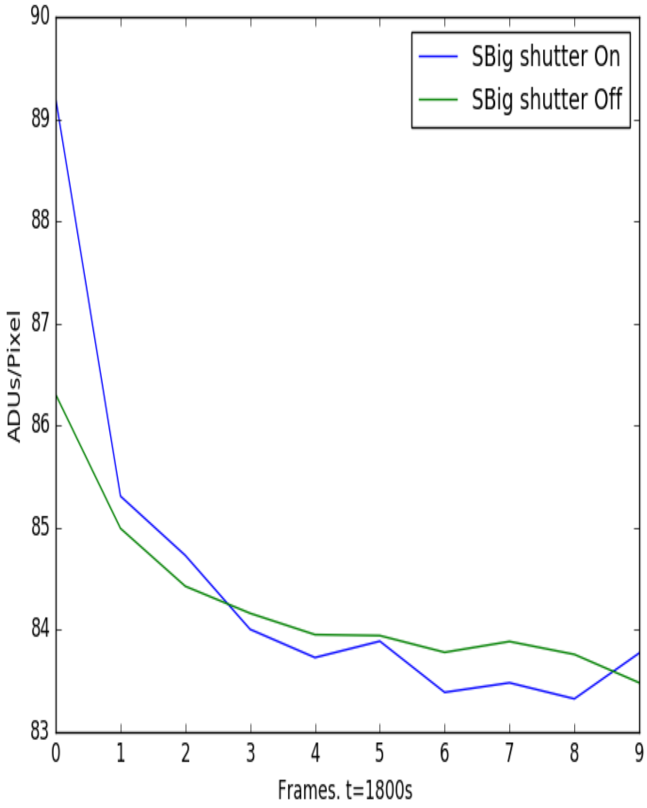
Measurement set 2 : 50 light frame and 50 dark frame with exposure time 600 sec.

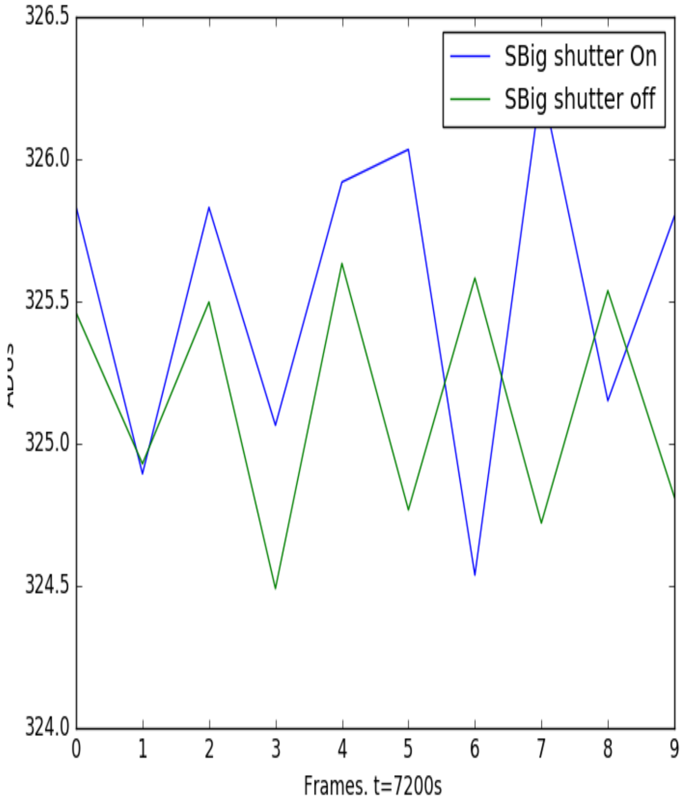
Measurement set 3: 10 light frames and 10 dark frames with exposure time 7200 sec.

Exposure time	**1800 sec**	**600 sec**	**7200 sec**
Mean ADUs	0.5867	0.0252	0.2161
Standard deviation	0.9388	0.1658	0.7317

[1] Dark Current is caused by thermally generated electrons that build up in the pixels of the CCD. The rate of dark current accumulation depends on the temperature of the CCD. Dark Current can be reduced by cooling the temperature and The remaining dark current is subtracted from an image using dark frames.

The first set of measurements showed an increase in the first couple of frames but wasn't observed in the other following frames. Which can be due to the camera thermalization working temperature , the camera chip works at 0 degrees and cools down within a minute but the chip surroundings causing the readout noise may need longer time to cool.





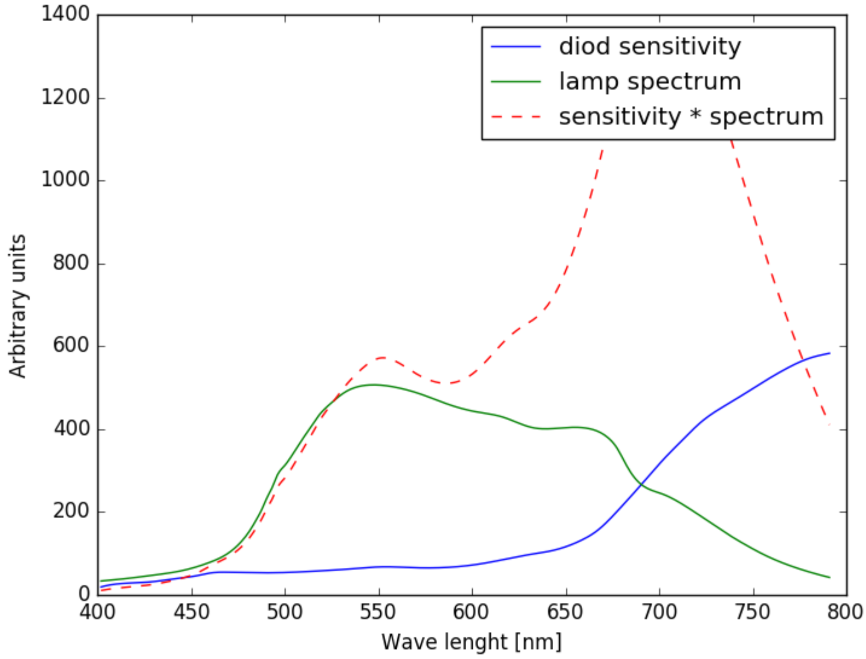
Measurements sensitivity

using the data from the SBIG quantum efficiency ε(λ)and the OSL lamp spectrum S(λ)the sensitivity, the effective efficiency of the CCD to a known spectrum of the OSL lamp "integrating the QE of over the spectrum range 400:800 nm " is calculated as follows;

$$\varepsilon_{effective} = \frac{\int S_{(\lambda)}.\ \varepsilon_{(\lambda)}\ d_{\lambda}}{\int S_{(\lambda)}\ d_{\lambda}} = 68\%$$

the sensitivity of measurements is the calculated in terms of the number of ADUs per sec, the SBIG gain which is the conversion ration from electrons to ADUs and equals 1.5 e^- / ADU, the pixel size which is 9 microns square and the SBIG effective deficiency $\varepsilon(\lambda)$. and is given in the unit photon/sec/cm^2.

$$\text{Sensitivity} = \frac{\textbf{ADUs/sec . Gain}}{\textbf{A . }\varepsilon_{\text{effective}}} = 161.71\ \boldsymbol{\gamma}\textbf{/sec/cm}^2$$



Detection Efficiency of SBIG CCD for (1064 nm) light

The setup of the detection efficiency measurements is IR laser , and SBIG CCD, a Narrow bandpass filter FLH1064-8 from Thorlabs have been installed in a front of the laser to purify IR light. And a lens with 50mm focus distance have been used to focus a laser beam of the camera chip. Two Neutral density ND filters with unknown attenuation A_1 and A_2.

for the measurements; 4 sets of measurements was taken with room light off and laser on and off .

Measurement set 1" with ND filter 1 installed": 10 laser on frames, 1 laser off frame, with espouser time 0.20 sec.

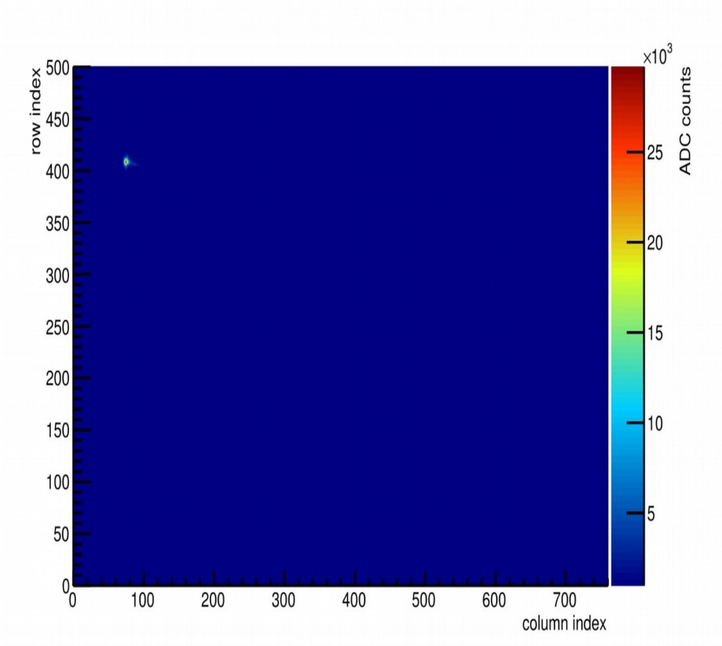
Measurement set 2 "with ND filter 2 installed" : 10 laser on frames, 1 laser off frame, with espouser time 0.17 sec.

Measurement set 3 “with ND filters 1 then 2 installed” : 10 laser on frames, 1 laser off frame, with exposure time 100 sec.

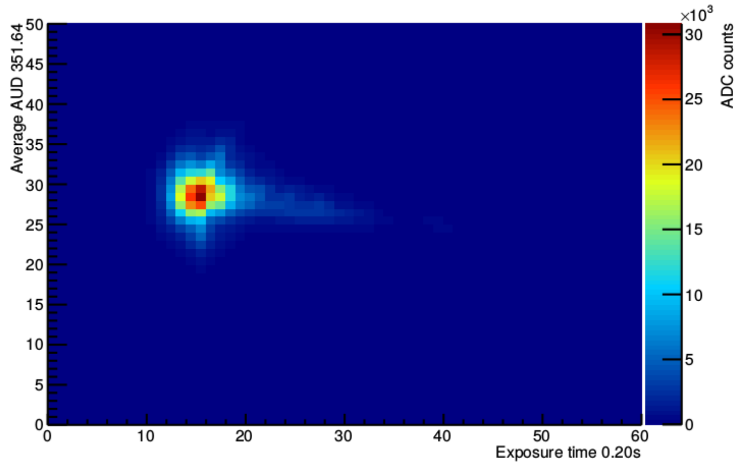
Measurement set 4[2] “with ND filters 2 then 1 installed”: 10 laser on frames, 1 laser off frame, with exposure time 100 sec.

Analysis

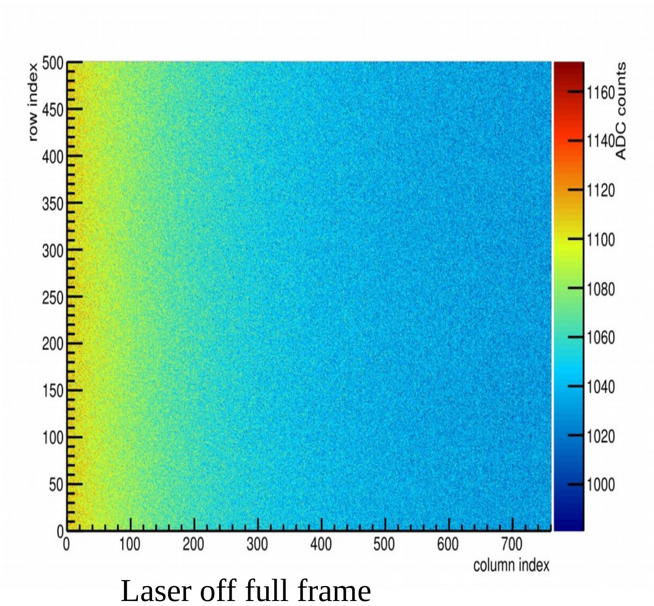
for the analysis the laser on frames were cut so we get the beam region only, and then subtracted from the laser off frame to get the ADUs counts of the beam region.



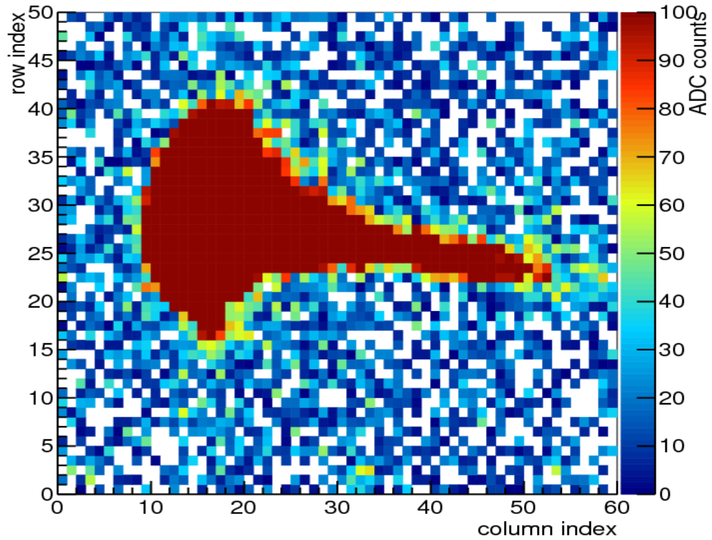
laser on full frame [500:700]



Laser on cut frame[50:60]



Laser off full frame



Laser on cut frame – laser off full frame

[2] Measurement sets 3 and 4 were taken with both filters but in different order to check that there is not impact from orders of filters. Only if one filter does not make influence of the other filter we can assume that their attenuation factors multiplies as in the equations.

The measurement of the detection efficiency is done by ;

- Measuring the ADU counts/ sec for the laser beam

Measurement set	**Set 1 “Nd1’**	**Set 2 “Nd2”**	**Set 3 “Nd3”**	**Set 4 “Nd4”**
ADU counts /sec ± std	5141331 ±150211	9189745 ±26515	572.5 ±11.7	552.8± 13.8

-Measuring the number of photons per second sent by the laser Nγ . Where λ = 1064 nm and the measured power of laser

Nγ= Plaser /Eγ,(1064 nm) = 1.872451909*10**13/(1.2398/1.064)= 1.6*1013 γ/sec

- The SBIG efficiency ε is calculated using the following equations,

Nγ. A1 . ε = Nd1

Nγ . A2 . ε = Nd2

Nγ. A1 A2 . ε = Nd3 [3]

- Calculating attenuation factors of the two filters.

A_1= Nd3/ Nd1= $6.01*10^{-5}$

A_2 =Nd3/Nd2 = $1.07*10^{-3}$

- Calculating CCD efficiency

ε = Nd2/ Nγ/A_2 = 0.00531

the quantum efficiency of the camera chip is expressed in terms of electrons, but in the previous calculations the camera efficiency is expressed in terms of photons per second per cm square ,We can recalculate it using known gain. However Efficiency of the camera, which gives ADUs from photons is indeed more convenient for measurement.

Conclusion

the light tight measurements done shows that the shutter box lid with the 3 O-rings is light tight since the difference between the mean ADUs with light on and the mean ADUs with light off is rather reasonable compared to the light tight measurements done shows that the shutter box lid with the 3 O-rings is light tight since the difference between the mean ADUs with light on and the mean ADUs with light off is rather reasonable compared to the measurements sensitivity calculated.

[3]Since the filters order doesn’t affect the measurements we can assume that their attenuation factors multiplies as in equation 3.

Acknowledgment

[1] Any Light Particle Search II,Technical Design Report.

[2] Aaron Spector, ALPS II technical overview and status report.

[3] Malina Reitmeyer, Report on light tightness measurements for the shutter box of the ALPS II experiment. April 2016.