The Study report in AEgIS experiment

Summer Student Project Report

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24.06.19 - 30.08.19

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AEgIS EXPERIMENT

CONTENTS

1. ABSTRACT

The AEgIS experiment aims to measuring for the first time the free fall of antihydrogen in the Earth's gravitational field with percent order precision. In this summer student program, I was studying two topics of this experiment: Lock-in measurement for photo-electrons from anion molecules and building a test set up of interferometer.
Using the pure mcp background data, the signals corresponding time to the emissions of photo-electrons from anion molecules were selected.
For building a test set up of interferometer,the optimization of laser couplings was done.

2. Introduction

The AEgIS experiment aims to measuring for the first time the free fall of antihydrogen in the Earth's gravitational field with percent order precision. In this summer student program, I was studying two topics of this experiment.
First I was studying on cooling and trapping antiproton. For, the pulsed cold beam of antihydrogen will be produced by charge exchange among excited Ps atoms and cooled antiprotons. We need to cool antiprotons as possible as we can. Especially I was writing code to verify whether the cooling method works or not.
Secondly, I was building a test set up of interferometer.
In the experiment, we will measure the gravitational acceleration on antihydrogen by recording the time of flight and the vertical displacement of each antihydrogen. We adopted a Talbot-Lau Interferometer which consists of a position detector and three gratings including a light standing wave because of high resolution.
In this paper, I will report what I was doing during Summer Student program 2019.

3. Overview

According to the paper[1], the essential steps leading to the production of a pulsed cold beam of H^- and the measurement of g with AEGIS are the following (figure 1).

- Production of positrons (e+) from a Surko-type source and accumulator.
- Capture and accumulation of p^- from the AD in a cylindrical Penning trap.
- Cooling of the p^- to sub-K temperatures.
- Production of positronium (Ps) by bombardment of a cryogenic nanoporous material with an intense e+ pulse.
- Excitation of the Ps to a Rydberg state with principal quantum number n ~ 20.
- Formation of H^- by resonant charge exchange between Rydberg Ps and cold p^-.
- Pulsed formation of an H^- beam by Stark acceleration with inhomogeneous electric fields.

- Determination of *g* in a two-grating Moire´ deflectometer coupled with a position-sensitive detector.

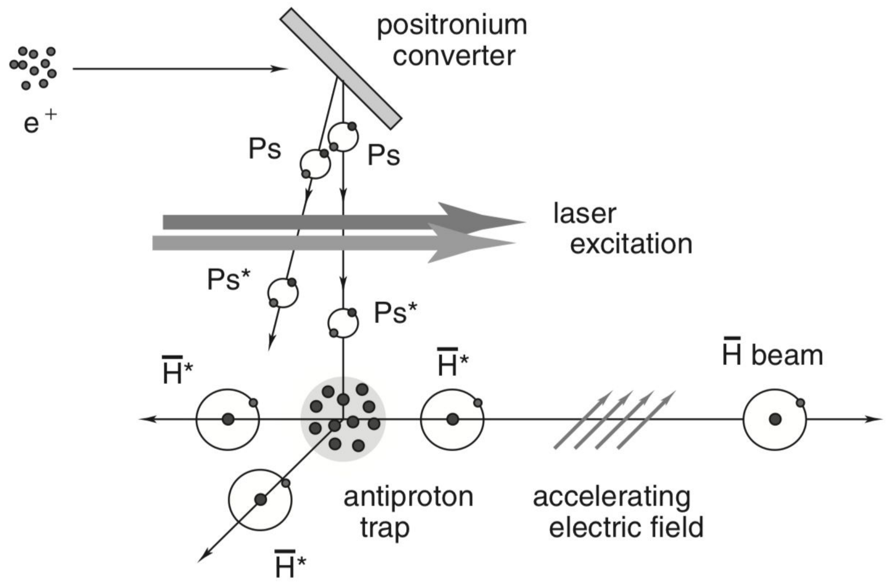


Figure 1. Proposed method for the production of a pulsed beam of cold $\bar{H}$ atoms.

AEgIS experiment has various projects to carry out.I was mainly studying the cooling of antiprotons called borelias experiment and upgrading the detector of antihydrogen.
As the detector of antihydrogen, we have used Moire´ deflectometer,but decided to adopt Talbot-Lau Interferometer instead of Moire´ deflectometer for higher precision measurements.

4. Borelias experiment

4.1. Cooling method of antiproton

Antihydrogen will be produced by the charge exchange reaction: $Ps * + \overline{P} \rightarrow \overline{H} + e-$

The reaction cross-section is in inverse proportion to the temperature of antiprotons.
To produce as much antihydrogen as we can, we need to cool antiprotons. We adopted sympathetic doppler cooling as a cooling method. This method is to cool antiprotons by cooling anions whose coulomb interactions between antiprotons enables us to carry out the cooling. For anions, we adopted C2- because of a well-known scheme. In this scheme, a selective fraction of C2 – molecules with high kinetic energies can be removed by two-stage laser induced photodetachment, hereby reducing the temperature of the remaining particles after reaching plasma equilibrium once again.[2]

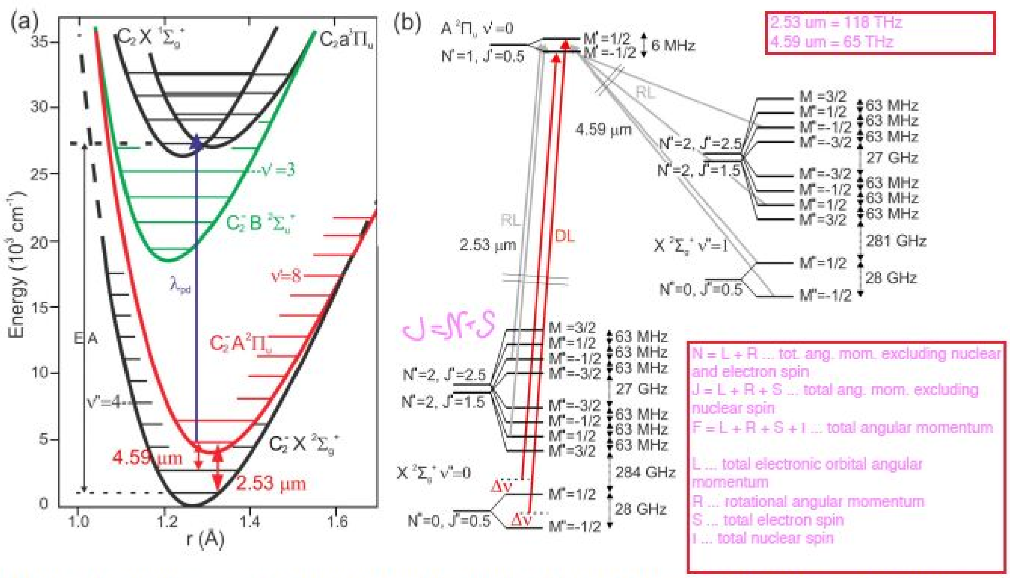


Figure 1. (a) Molecular potential energy of C_2^- versus internuclear separation with the electronic and vibrational levels including two neutral C_2 ($X^1\Sigma_g^+$, $a^3\Pi_u$) curves [37]. The X–A (red) cooling transitions and the photodetachment (blue, λ_{pd}) transition are indicated with arrows. (b) Zeeman splitted vib–rot sublevels in a 1 T field showing the laser for the Doppler cooling scheme. The electron spin $\frac{1}{2}$ is coupled to the rotational quantum number N to form the full angular momentum J and its projection M on the magnetic field axis. The $v'' = 0$ and $v'' = 1$ manifold of the X state and the excited A states are shown (not to scale). The two Doppler cooling lasers (DL, red) addressing the ground states at 2.54 μm are depicted with their detunings $\Delta\nu$. The six repumping lasers are sketched (RL, gray) at 2.54 μm and 4.59 μm, respectively. Reproduced from [25]. CC BY 4.0.

Figure2:Left:Molecular potential energy of C2- versus internuclear separation with the electronic and vibration levels including two neutral C2 curves.Light: Zeeman splitted vib-rot sublevels in a 1T field showing the laser for the Doppler cooling scheme

When the cooling occurs, the following cycles are repeated.
1.C2-molecules in the ground states are excited by uv lasers.
2.They are also excited by rf lasers and change C2 molecules by emitting photoelectrons.
3.They go to the ground states.
These procedures are repeated.This oscillation makes it possible to cool them.

4.2. experimental setup

The figure presents the experimental setup.The C2- anions fly through a digital Paul trap (K). The trap rf is driven by the function generator.
The C2- are in the stability diagram region of the trap (3MHz at 120 V) and fly straight through. At the center of the trap the ionization lasers photodetach C2- to neutral C2 and one electron. The light electron is outside the stability diagram and is kicked out radially from the trap to the detector MCP (J). The oscilloscope then records both the function generator and the MCP signal.

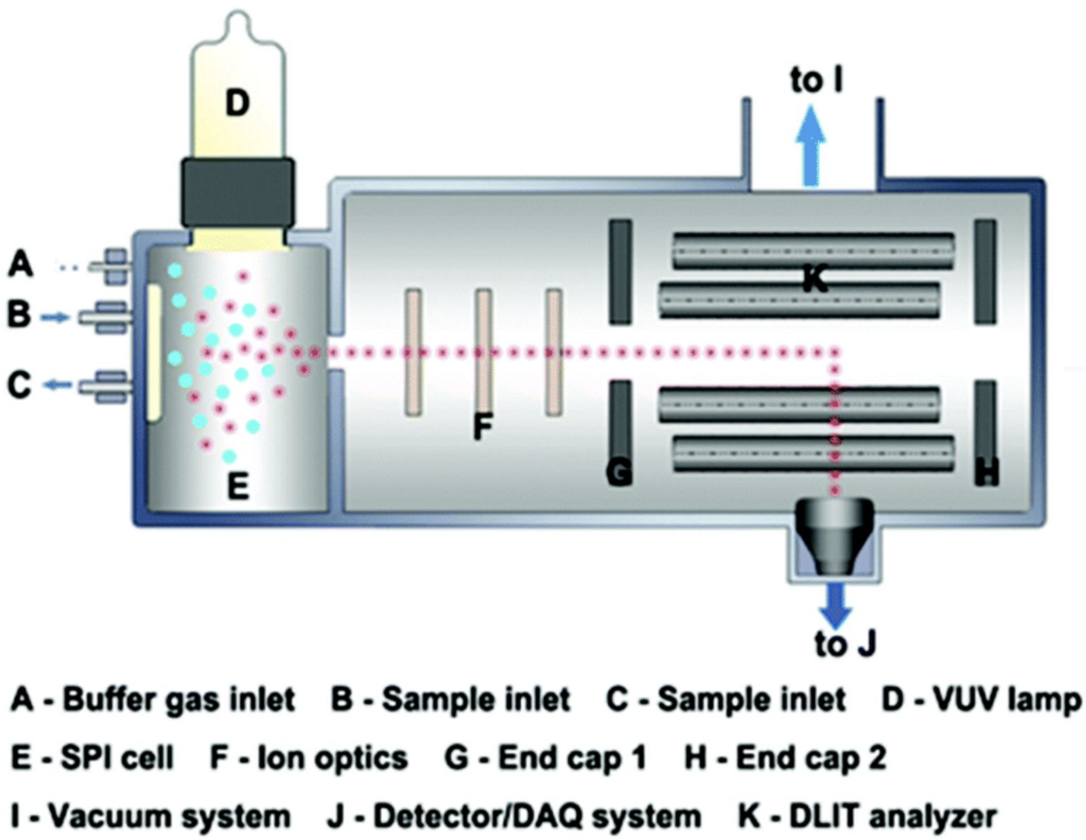
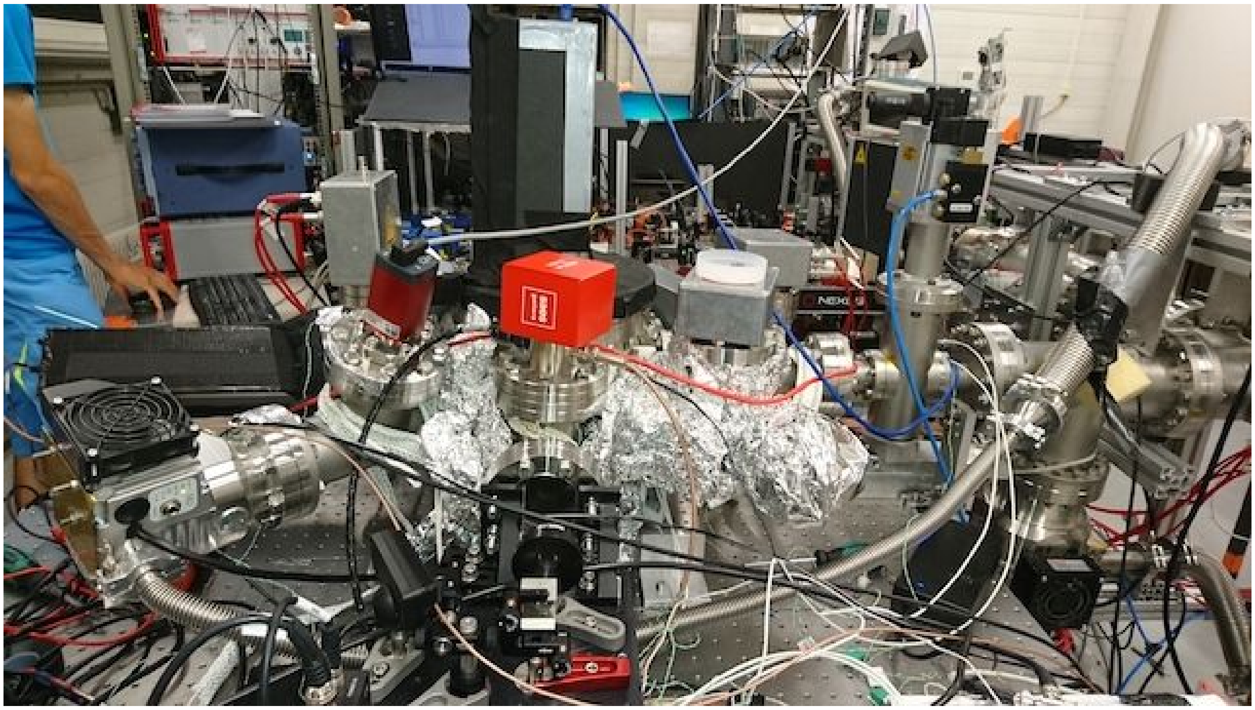


Figure3:This figure presents the experimental setup of trapping and cooling C2- molecules.



picture 1: This is the picture of the experimental testsetup of trapping and cooling C2-.

4.3. Lock-in measurement for photo-electrons from anion molecules

When the molecule travels in the trap, the photo-electron is too light and kicked out onto a detector (MCP). This detector signal is then correlated with the ion trap drive, thus the lock-in. When now the detector sees some signals above noise ones at the same time within 100ns that the RF of the trap rises, we know it was a photo-electron and we know that the laser photodetached the molecule.I made the program which then checked if there has been a signal on MCP within a 100ns window behind an rf flank.

4.4. code/result

In the function generator's data, the signals above 1.0V were selected(main1.c).And we found The time when the function generator square signal rises from '0' to '1'.Then the data enclosed in a blue circle were only selected because the value of voltage discretely change minus to plus when the function generator square signal rises from '0' to '1'.

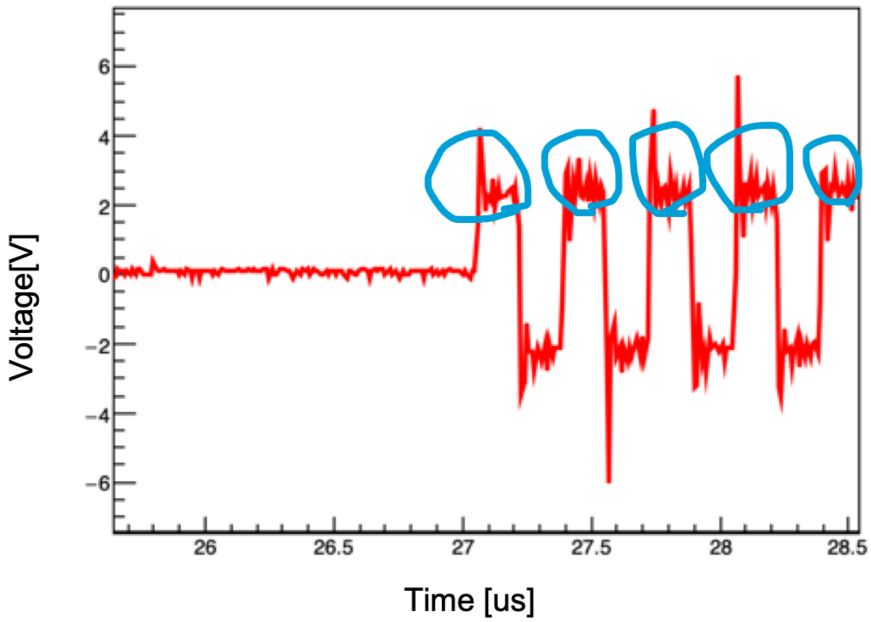


figure 4:the function generator's signal from 25.7us to 28.5us

We choose the signals whose time intervals were longer than 0.1us and recorded the time (main2.c).Then we checked the corresponding time in the MCP data and cutting out 100 ns(main3.c).

main1.c

```
fp = fopen("fg.txt","r");
  outputfile = fopen("output1.txt","w");
  if(fp == NULL) {
    printf("cannot reload this file\n");
    return 0;
  }

  n=0;
  while(fscanf(fp,"%f %f\n",&time[n],&x[n])!=EOF) n++;
  fclose(fp);
  while(i<n){
 if(x[i]>=1.0){
    fprintf(outputfile,"%d %f %f\n",i,time[i]*1e6,x[i]);
       }
i++;
  }
  fclose(outputfile);
```

main2.c

```
fp = fopen("output1.txt","r");
  outputfile = fopen("output2.txt","w");
  if(fp == NULL) {
    printf("cannoy open this file. \n");
    return 0;
  }

  n=0;
  while(fscanf(fp,"%f %f %f\n",&a[n],&time[n],&x[n])!=EOF) n++;
  fclose(fp);
  while(i<n){

    if(time[i]-time[i-1]>=0.1){
      printf("%f %f\n",time[i],x[i]);

           fprintf(outputfile,"%f %f\n",time[i],x[i]);
    }
    i++;
  }
  fclose(outputfile);
```

main3.c

```
fp1 = fopen("mcp.txt", "r");
    if (fp1 == NULL) {
        printf("cannot open this file\n");
        return 0;
    }
    n = 0;
    while (fscanf(fp1, "%f %f\n", &t[n], &x[n]) != EOF) n++;
    fclose(fp1);

    fp2 = fopen("output2.txt", "r");
    if (fp2 == NULL) {
        printf("cannot open this file\n");
        return 0;
    }
    m = 0;
    while (fscanf(fp2, "%f %f\n", &s[m], &y[m]) != EOF) m++;
```

```
    fclose(fp2);

    outputfile = fopen("output3.txt", "w");

    for (j = 0; j < m; j++) {
        for (i = 0; i < n; i++) {
            if (s[j] <= t[i] * 1e6 && t[i] * 1e6 <= s[j] + 0.1) {
            printf("%f %f\n", t[i] * 1e6,y[i]);
            }
        }
    }


  fclose(outputfile);
```

We checked the programs correctly worked using the rf test data and the mcp background data without any laser or C2-.

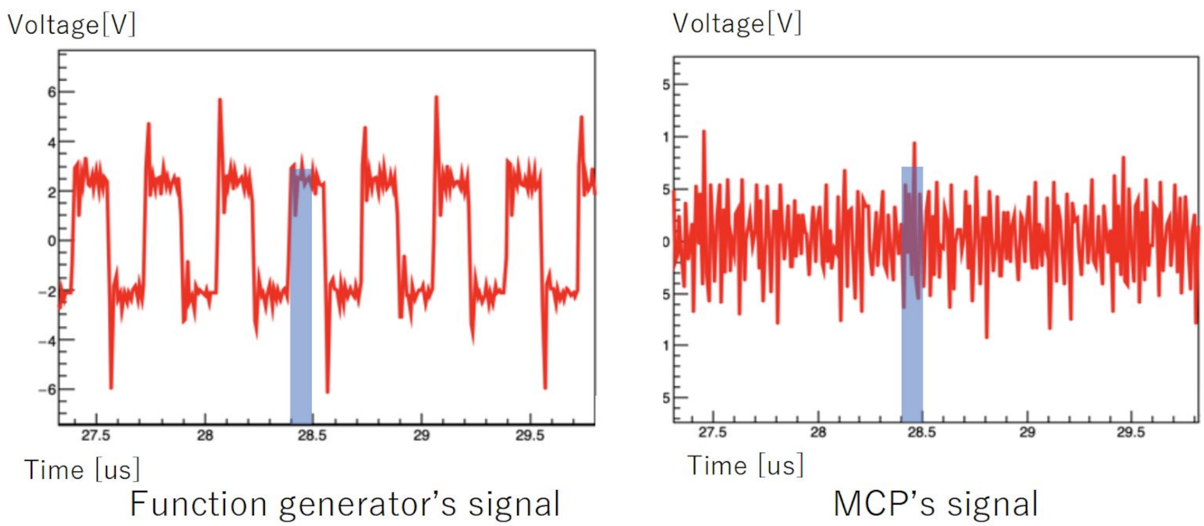


figure 5:Left:function generator's signals from 27.4us to 29.7us
Light:Mcp's background data from 27.4us to 29.7us

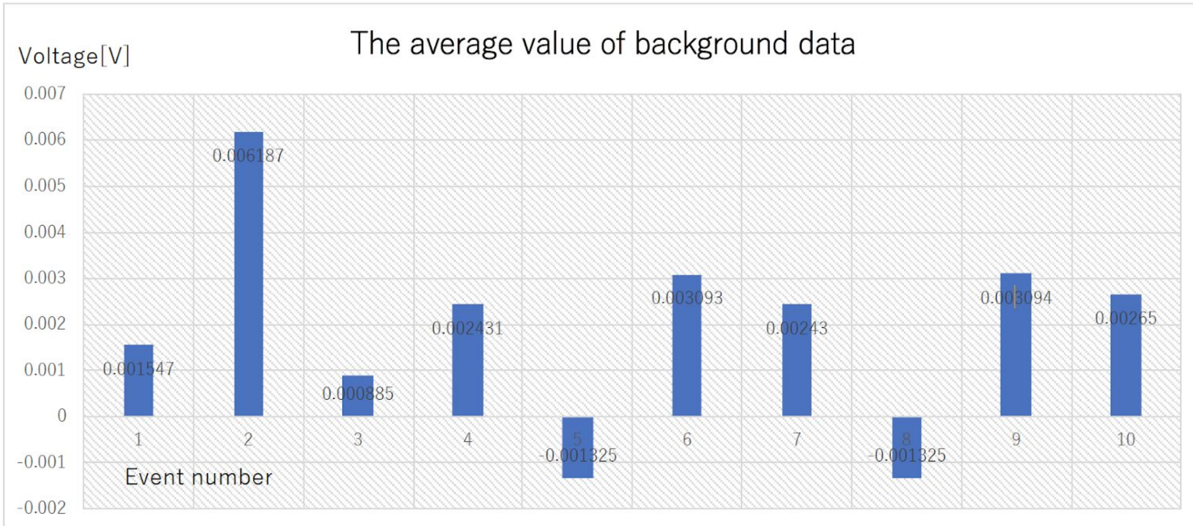


figure6:The signals picked up were summed.This figure presents these values from 27us to 30us.

The final MCP data will be recorded later.

5. Building a test set up of interferometer

5.1.Talbot-Lau Interferometer

In this experiment,Talbot-Lau Interferometer is composed of 2 material gratings,an optical grating such as a light standing wave and a sensitive position detector.In the first grating,it only counts antihydrogens.The second grating is not material one but a light standing wave to avoid the annihilation by interacting with material walls.The gravitational effect will be measured in it.Specifically the phase shift will be induced by the gravitational acceleration.
The third grating can be used to read the pattern which Talbot-Lau interferometer generates.

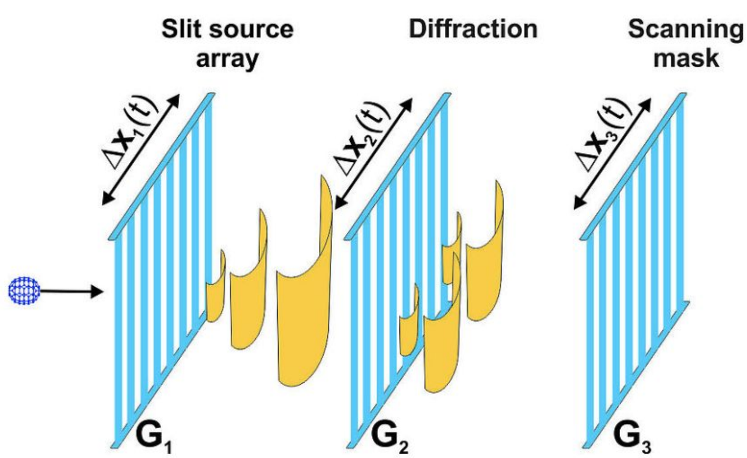


figure 7:This figure presents 3 gratings in Talbot-Lau Interferometer. [3]

5.2.Experimental Setup

We made a light standing wave for the first test setup.The components were as follows. They were a laser, an isolator,a circulator,2 mirrors and a powermeter.

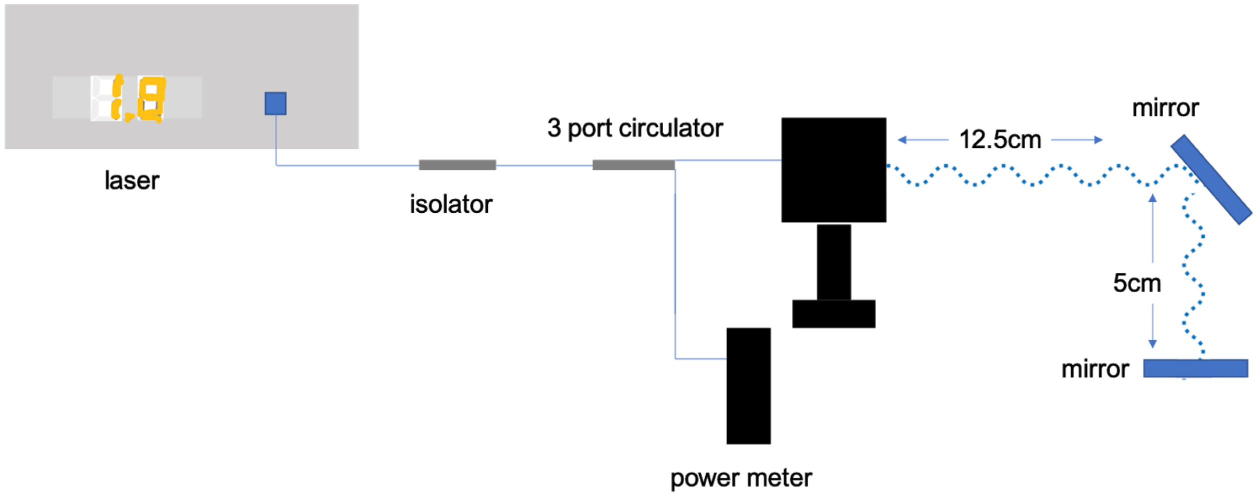
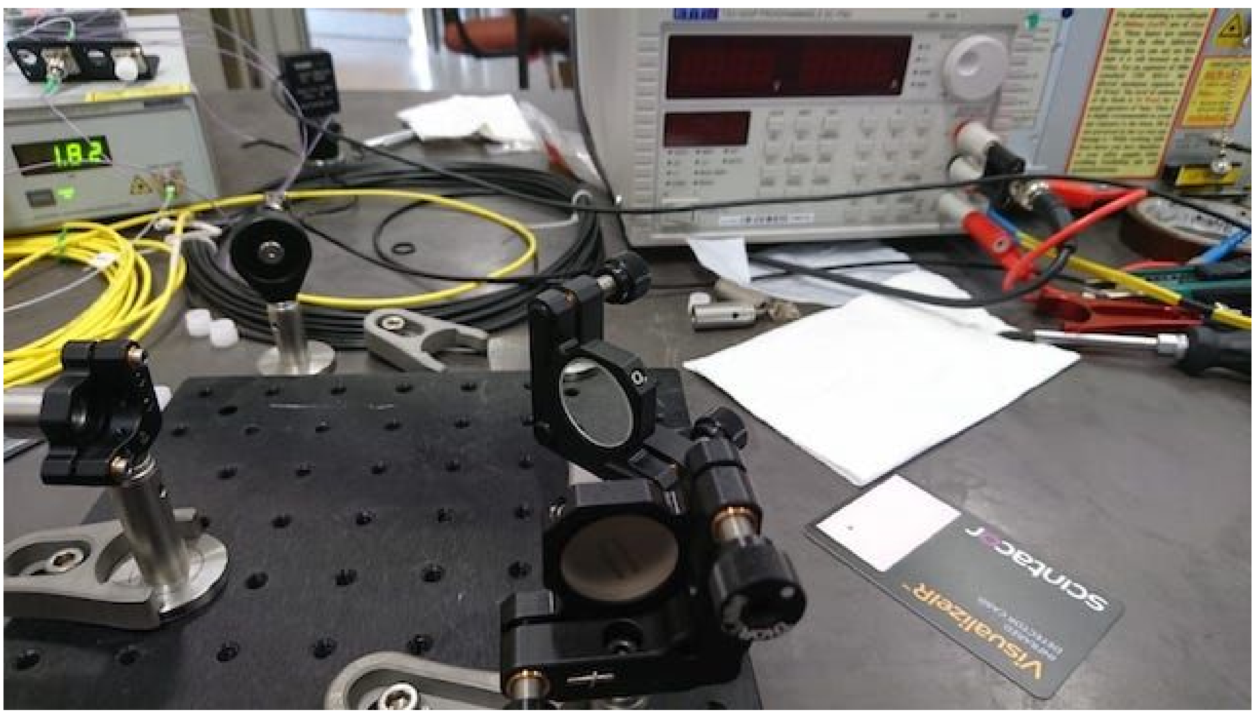


figure 8: This presents this experimental setup.



picture 2:This is the picture of the experimental setup.

The wavelength of laser was 1550nm because it was suitable to use this telecom wavelengths for the availability for a isolator, circulator and fiber optics for the standing wave test setup. The final laser Talbot-Lau interferometer will be probably made with a YAG laser for its power.

An isolator was used to prevent back reflections from re-entering the light source and protect the source from optical feedback and damage[4].An optical circulator is a three-port device that allows light to travel in only one direction[5].Port1 was connected to an isolator and port2 used for output. Port3 was connected to a powermeter to measure a standing wave.It is because the energy loss was minimized when the signals were transmitted from port1 to port2 according to the specification list[5].A light standing wave was produced by the reflection between 2 mirrors.A powermeter was used for the measurement of the light energy by monitoring the rising temperature.

Laser	Laser Source Model S1FC1550
Isolator	IO-H-1550APC
3 port Circulator	6015-3-APC
mirrors	PF10-03-P01
powermeter	PM16-401

5.3.Measurement

Before making a light standing wave, we measured the energy loss at several points of the setup by using powermeter.The primary power of the laser was 1800uW.
The results were as follows.

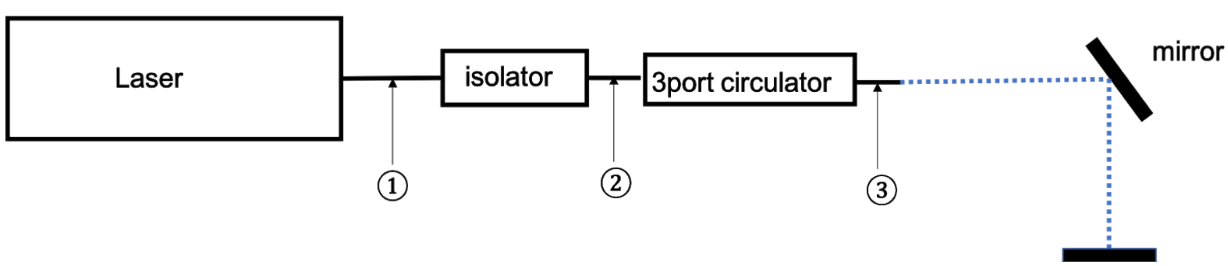


figure 9:This figure presents the energy loss measurement setup.

point	1	2	3
power[uW]	1800	711 ± 25	223 ± 13

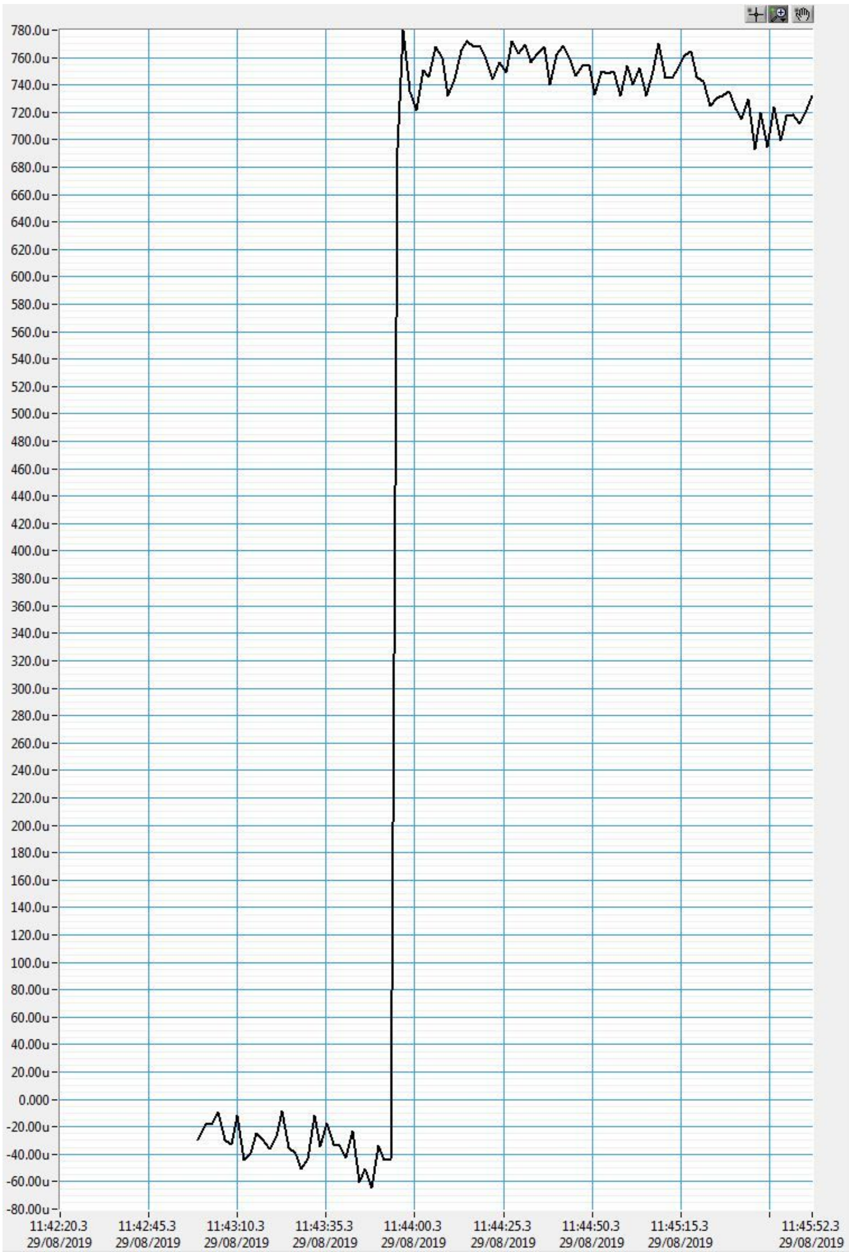


figure 9:This figure presents the output of the powermeter for measuring the energy loss of an isolator.When the signal went up,the laser was switched on.This difference of power means the output of lasers through the isolator.This power was 711 ± 25 uW.The primary power was 1800uW.Thus the energy lost in the isolator was 60%.

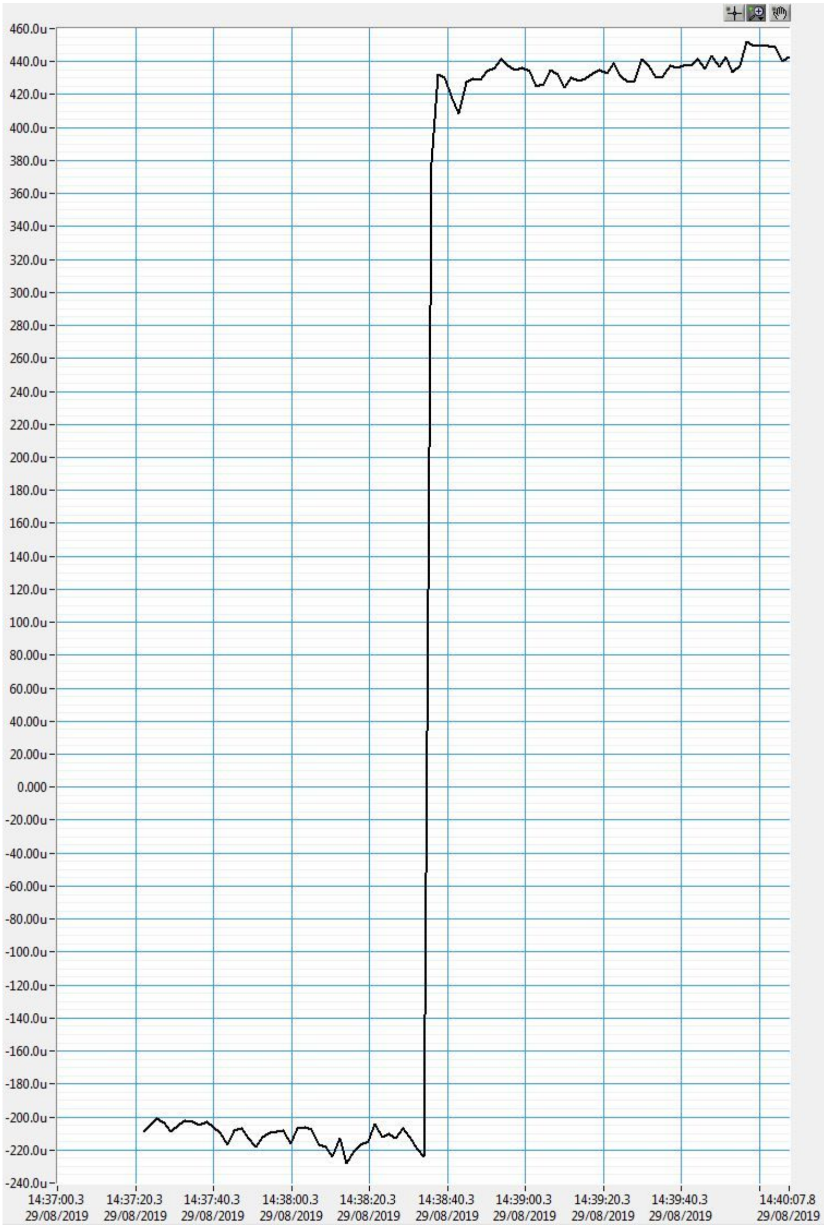


figure 10:This figure presents the output of the powermeter for measuring the energy loss of an isolator and a 3port circulator.When the signal went up,the laser was switched on.This difference of power means the output of lasers through the isolator and the 3port circulator.This power was 223 ± 13 uW.The primary power was 1800uW.Thus the energy lost in the isolator and the circulator was 88%.

The power of light standing wave would be expected less than 223uW.By adjusting the alignment of mirrors,we maximized the light reflection and produced a light standing wave.

For the alignment,the laser card was used because of the visualization of the invisible light.

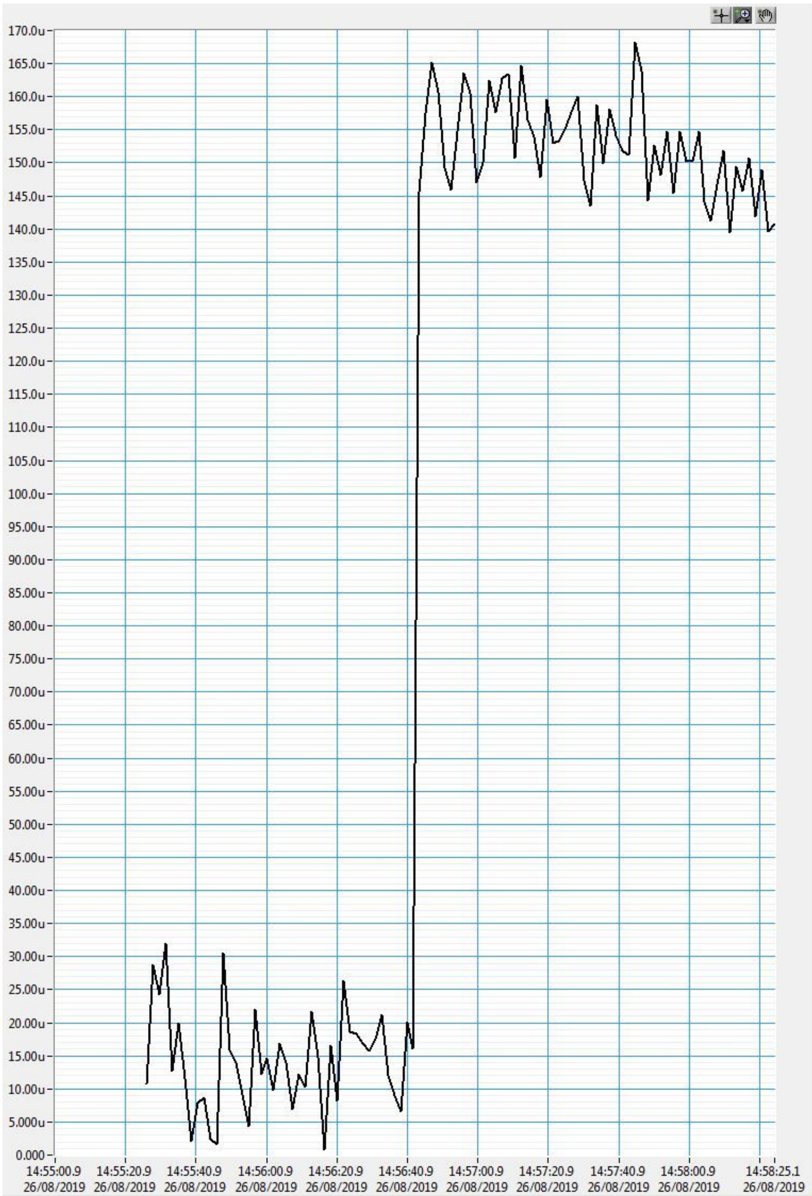


figure 11:This figure presents the output of the powermeter when a light standing wave was made.The difference means the power of the light standing wave. This power was 138 ± 10 uW.

6. CONCLUSION

borelias experiment

In the lock-in measurement for photo-electrons, this photo-electron signal is then correlated with the ion trap drive because the photo-electron was emitted when the C2- molecules were trapped.The program codes checking if there has been a signal on MCP within a 100ns window behind an rf flank were made.The final mcp measurement will be done. By comparing the mcp data and the background data, we know the laser was on resonance with the C2- photodetchment transition. Once this step is done, we can use this laser to Doppler cool C2-.

Building a test setup of Talbot-Lau interferometer
In the first step, the energy loss was measured in an isolator and a 3port circulator.The primary power was 1800uW.The power through the isolator was 711 ± 25 u and through the isolator and the 3port circulator 223 ± 13 uW.Thus the energy lost in the isolator was 60%.the energy lost in the isolator and the circulator was 88%.In the 2nd step,a light standing wave was made.The power was 138 ± 10 uW.

7. References

[1] Doser M et al. 2012 Class. Quantum Grav. 29 184009

[2]Sebastian Gerber et al 2018 New J.Phys.20 023024

[3]https://www.quantumnano.at/research/matter-wave-technologies/talbot-lau-interferometry/first-tli-for-molecules/

[4] https://www.thorlabs.com/images/TabImages/Fiber_Isolator_Lab_Fact.pdf

[5] http://res.abtronics.ru/pdf/746/890/754/abtronics_6015_2.pdf

8. ACKNOWLEDGEMENT

I would like to express my deep gratitude towards Michael Doser, my supervisor, for his support of my project. My special thanks to Sebastian Gerber,Emanuel Oswald and Christian Zimmer for their help. I would also like to extend my thanks to the Summer Student Team for supporting my life at CERN.