Radioactive Decay

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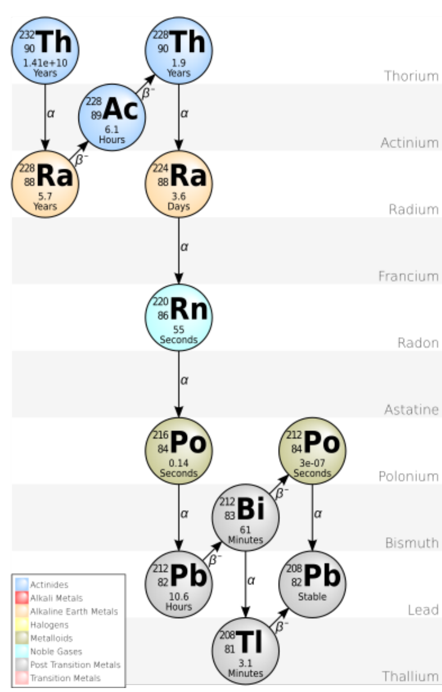
PHYS442 Spring 2025 Experiment Report

Abstract:
In this experiment radioactive decay of Radon gas, a product created in the Thorium decay chain, is investigated using a Wulf's electroscope and ionization chamber with high voltage applied. By measuring the intervals between electroscope discharges, ionization process due to radioactive decay is tracked and the decay constant (λ) and half-life ($t_{1/2}$) of Radon were determined for 16 runs with different high voltages and amount of radioactive material inside the chamber. The decay constant was found to be $(1.05 \pm 0.002) \times 10^{-2}$, yielding a half-life of 65.8 ± 0.2s. While this result deviates from the accepted value of 55.6s, the methodology successfully demonstrated the exponential nature of radioactive decay.

i Introduction and Theory

History: The study of radioactive decay, particularly of elements like thorium and its decay products, has played a pivotal role in the development of nuclear physics. After the discovery of radioactivity by Henri Becquell in 1896, it did not take longe before Thorium (Th-232) was identified as radioactive by Gerhard Schmidt and Marie Curie in 1898. Ernest Rutherford and Frederick Soddy (early 1900s) used thorium decay to establish the theory of radioactive transformation, proving that elements transmute into other elements via alpha/beta decay. Early experiments (using Wulf's electroscope like the one used in this experiment) provided historic methods to detect ionizing radiation before modern detectors (Geiger counters, scintillators) were available.



Decay of Thorium: Thorium-232 undergoes a natural decay series, eventually producing stable lead-208. Radon-220 (or Thoron) is one of the elements created in that chain. It is the only product in decay chain that has gas form and hence easy to transfer. Furthermore, it also has a moderate half life of 55.6 seconds. This makes Radon a good candidate for experimenting with and studying the radioactive decay event.

Theory: Radioactive isotopes decay in time, following the decay law:

$$N(t) = N_0 e^{-\lambda t} \tag{1}$$

where λ is the decay constant and N_0 is the initial number of isotopes. If we denote half life of an isotope as $t_{1/2}$, time it requires for a number of isotope particles to reduce in half, above equation can be written as:

$$N(t_{1/2}) = \frac{N_0}{2} = N_0 e^{-\lambda t_{1/2}}$$

If we rearrange and take the natural logarithm, half life of an isotope can be related to the decay constant by the following formula:

$$t_{1/2} = \frac{ln2}{\lambda} \tag{2}$$

Measuring λ:

One way of observing the decay event is using ionizing capacity of the charged particles produced in the decay. A sample of radioactive material is placed in a closure. A high voltage applied between two terminals, creating an air gap between them. When decay happens, a small current appears because of the ionized particles inside the closure. Measuring this current can give a measure of how the number of charged particles inside the enclosure changes in time, hence we can relate to how does decay process evolve over time. This current however, is too small to be measured using an ammeter and since we do not need to know the exact value, a Wulf's electroscope could be used instead.

Wulf's electroscope consist of 3 leafs, one of which is connected to the ground and it allows the electroscope to automatically discharge after a preset value of charge is achieved. The current needed to charge the electroscope is inversely proportional to the time it requires to charge. In our experiment we denote the interval for the electroscope to fully charge and discharge as s_i:

$$s_i = t_{i+1} - t_i \tag{3}$$

where t_i's are the time stamps in which the electroscope is discharged in a continuous measurment of around 5 mins. We can relate the current inside the enclosure in any instance as $1/s_i$. Moreover, we can also define T_i as the time measure corresponds to that current level:

$$T_i = \frac{t_{i+1} + t_i}{2} \tag{4}$$

We can plot $1/s_i$ vs. T_i to observe the behaviour of decay process over time and extract λ from that relation.

$$\frac{1}{s_i} = Ae^{-\lambda T_i} \tag{5}$$

Where A is a constant we do not need to know.

ii Setup and Method

1. **Setup**:
   The experimental setup consists of:

   - Wulf's Electroscope
   - Thorium Salt container
   - Ionization chamber connected to the high voltage
   - HV power supply (0-5 kV)
   - chronometer

In the setup of the apparatus for the experiment, thorium salt container is connected to the ionization chamber through a hose which can be opened and closed during the experiment. Electroscope and ionization chamber are also connected to each other and HV is supplied between the two (one end connected to the walls of the chamber and the other connected to the ground of the electroscope).

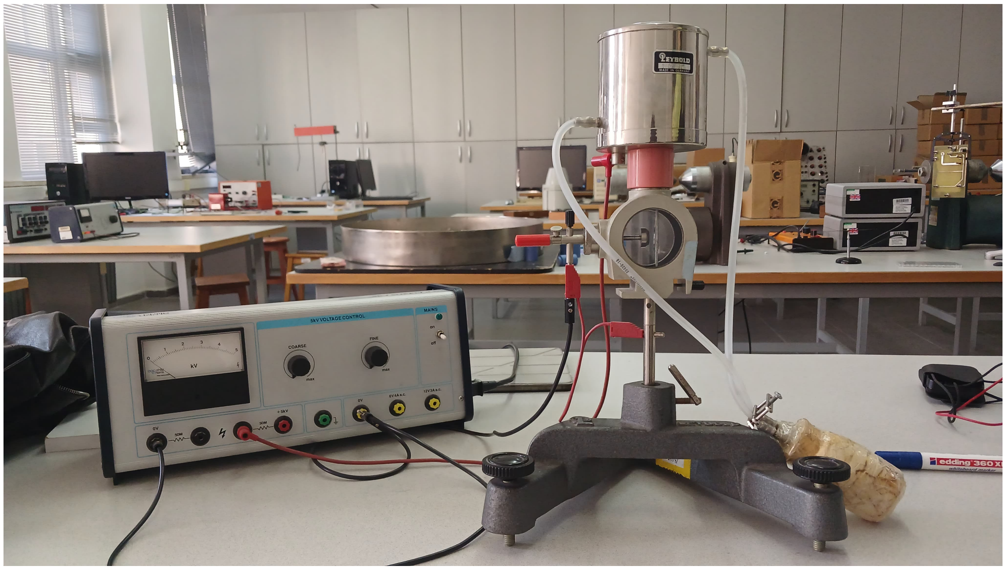


Figure 1: Experimental Setup with ionization chamber and Wulf's electroscope

2. **Method**:
   The experiment was conducted following these steps:

   1. Hose connected to the thorium salt container is shut and 3-4kV of HV is applied to observe if any residues remain in the ionization chamber. If so, ionization chamber is opened to the air and cleaned from any previous radioactive debris.

2. 2.5kV of HV is applied to the ionization chamber and hose coming from the container is temporarily opened and closed after squeezing it 2 times. Chronometer is then immediately started. Charge and discharge of the electroscope is observed. Time of every discharge is recorded.

3. High voltage is turned of and chamber opened to the air in order to clean it from radioactive materials before another run.

4. Previous two step is repeated for 3 4 and 5 number of squeezes. Also 3, 3.5 and 4 kV of HV is tested with 4 different number of squeezes, totaling to 16 test under different parameters.

5. Time measurements from each run is processed in the manner explained in Theory.

iii Data

There are total of 16 datasets which are combinations of HV values: {2.5, 3, 3.5, 4} kV and number of squeezes: {2,3,4,5}. Each run takes approximately 5 minutes and absolute time of each discharge is recorded. Full list of time points of each discharge in the absolute time scale and the interval between each discharge is presented in **data list**.

As explained before, we expect to see an exponential increase in the time interval between two discharge as there are less and less decaying particles left in the chamber. One set which coincides with this behaviour the best is presented below. It is also worth mentioning that the uncertainty in the time measurements is ± 0.30 seconds.

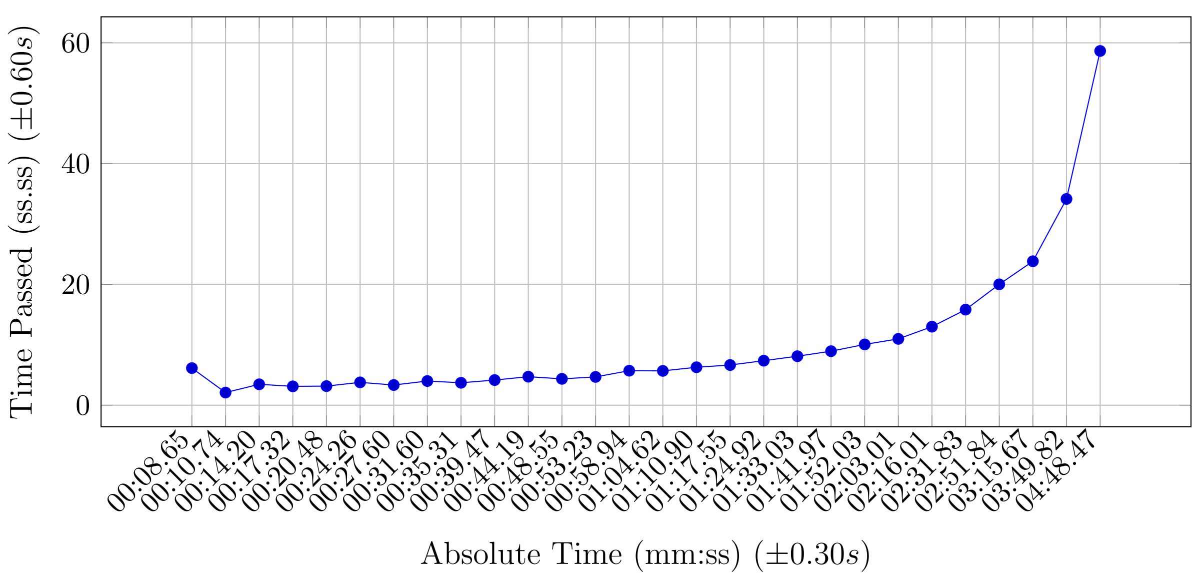


Figure 2: Time between discharges vs. Absolute Time (2.5 kV-3 squeezes)

iv Analysis

s_i and T_i datasets:

In this part, only the 2.5 kV and 3 squeeze dataset will be presented as an example. With that, keep in mind that all the calculations are done over all datasets and comparison between the results will be presented at the end.

As show in (3) and (4) s_i and T_i sets are obtained directly from the original dataset with the help of Code 1. Uncertainty in original measurements are given as $\pm 0.30s$ for t_i. Thus s_i and T_i has uncertainties $\pm 0.60s$ and $\pm 0.30s$, respectively.

$t_i(\pm 0.30s)$	$T_i(\pm 0.30s)$	$t_i(\pm 0.30s)$	$s_i(\pm 0.60s)$
8.65	**9.695**	10.74	**2.09**
10.74	**12.47**	14.20	**3.46**
14.20	**15.76**	17.32	**3.12**
17.32	**18.90**	20.48	**3.16**
20.48	**22.37**	24.26	**3.78**
24.26	**25.93**	27.60	**3.34**
27.60	**29.60**	31.60	**4.00**
31.60	**33.455**	35.31	**3.71**
35.31	**37.39**	39.47	**4.16**
39.47	**41.83**	44.19	**4.72**
44.19	**46.37**	48.55	**4.36**
48.55	**50.89**	53.23	**4.68**
53.23	**56.085**	58.94	**5.71**
58.94	**61.78**	64.62	**5.68**
64.62	**67.76**	70.90	**6.28**
70.90	**74.225**	77.55	**6.65**
77.55	**81.235**	84.92	**7.37**
84.92	**88.975**	93.03	**8.11**
93.03	**97.50**	101.97	**8.94**
101.97	**107.00**	112.03	**10.06**
112.03	**117.52**	123.01	**10.98**
123.01	**129.51**	136.01	**13.00**
136.01	**143.92**	151.83	**15.82**
151.83	**161.835**	171.84	**20.01**
171.84	**183.755**	195.67	**23.83**
195.67	**212.745**	229.82	**34.15**
229.82	**259.145**	288.47	**58.65**

Table 1: Midpoints and discharge durations for 2.5kV-3 squeeze

calculating σ_{1/s_i}:

For a function $f(s_i) = s_i^{-1}$, the uncertainty propagation formula is given by:

$$\sigma_f = \left| \frac{df}{ds_i} \right| \sigma_{s_i} \tag{6}$$

Taking the derivative of $f = s_i^{-1}$ with respect to s_i:

$$\frac{df}{ds_i} = -\frac{1}{s_i^2}$$

We calculate the uncertainty in $\frac{1}{s_i}$ as:

$$\sigma_f = \frac{\sigma_{s_i}}{s_i^2} = \frac{0.60}{s_i^2} = \sigma_{1/s_i} \tag{7}$$

This formula is used in Code 2 to create an uncertainty list for the s_i dataset. Below is the table for the example dataset used in plotting.

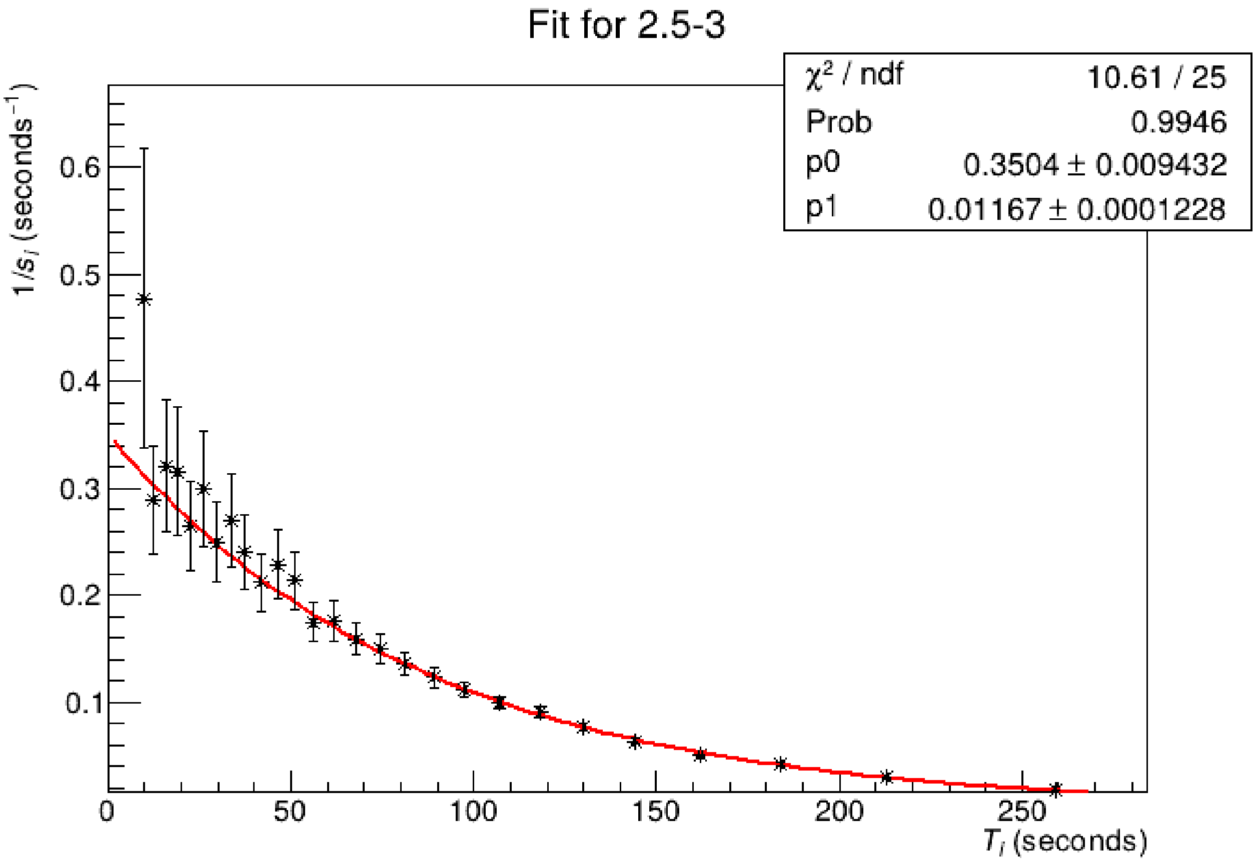
T_i	σ_{T_i}	$1/s_i$	σ_{s_i}
9.7	0.3	0.4780	0.1400
12.5	0.3	0.2890	0.0500
15.8	0.3	0.3210	0.0620
18.9	0.3	0.3160	0.0600
22.4	0.3	0.2650	0.0420
25.9	0.3	0.2990	0.0540
29.6	0.3	0.2500	0.0370
33.5	0.3	0.2700	0.0440
37.4	0.3	0.2400	0.0350
41.8	0.3	0.2120	0.0270
46.4	0.3	0.2290	0.0320
50.9	0.3	0.2140	0.0270
56.1	0.3	0.1750	0.0180
61.8	0.3	0.1760	0.0190
67.8	0.3	0.1590	0.0150
74.2	0.3	0.1500	0.0140
81.2	0.3	0.1360	0.0110
89.0	0.3	0.1230	0.0091
97.5	0.3	0.1120	0.0075
107.0	0.3	0.0994	0.0059
118.0	0.3	0.0911	0.0050
130.0	0.3	0.0769	0.0036
144.0	0.3	0.0632	0.0024
162.0	0.3	0.0500	0.0015
184.0	0.3	0.0420	0.0011
213.0	0.3	0.0293	0.0005
259.0	0.3	0.0171	0.0002

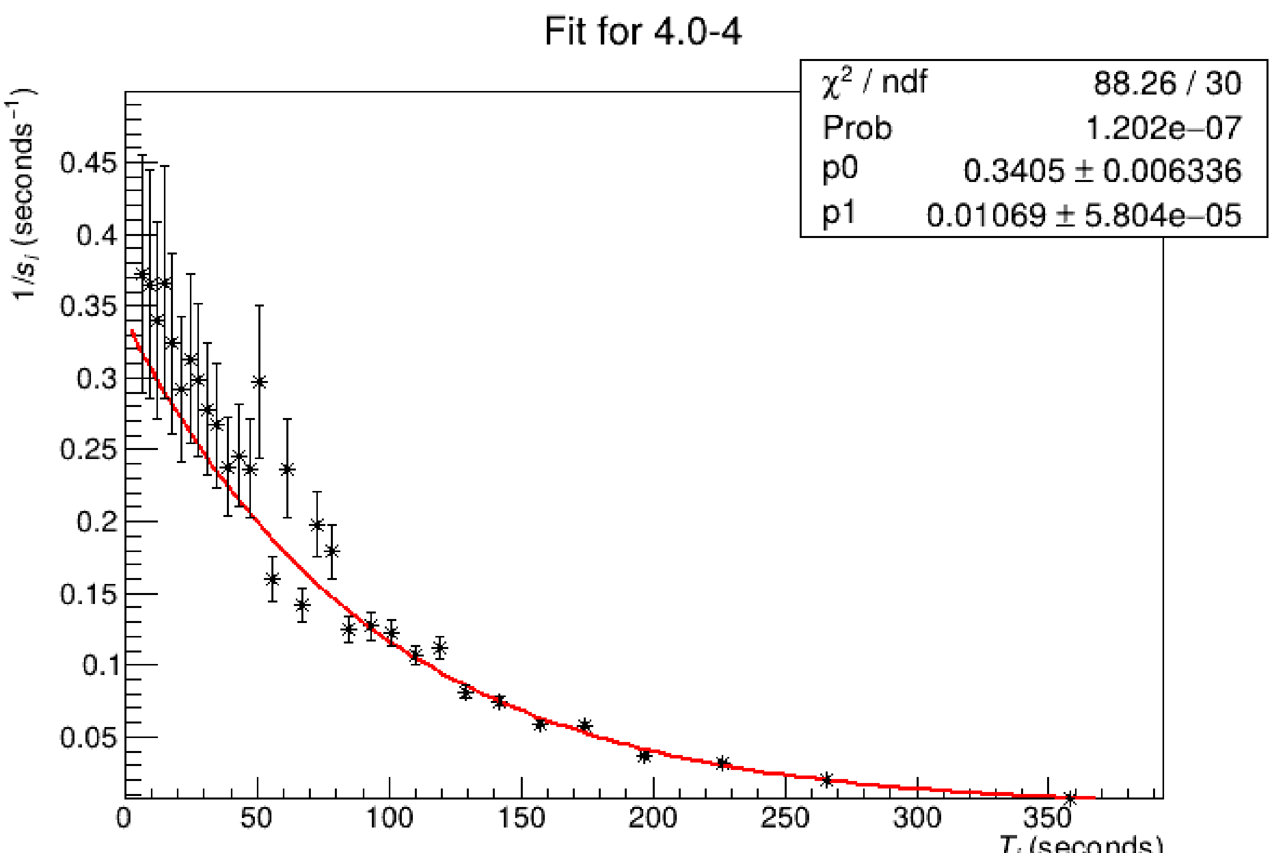
Table 2: Table of T_i and $1/s_i$ values for 2.5kV - 3 squeeze

Plotting $1/s_i$ vs T_i:

When we plot this data, we can observe an exponentially decaying regime.
Below are some fits for the function:

$$[p_0]e^{-[p_1]t} \rightarrow [A]e^{-[\lambda]t} \tag{8}$$


Fit for 2.5-3
χ² / ndf 10.61 / 25
Prob 0.9946
p0 0.3504 ± 0.009432
p1 0.01167 ± 0.0001228
1/s_i (seconds⁻¹)
T_i (seconds)


Fit for 4.0-4
χ² / ndf 88.26 / 30
Prob 1.202e−07
p0 0.3405 ± 0.006336
p1 0.01069 ± 5.804e−05
1/s_i (seconds⁻¹)
T_i (seconds)

Which is in form, similar to (5). Here p_1 is the found value for λ. For more detailed information about fitting, refer to Code 3. Full list of plots for all datasets are given in **Exponential Fits**.

In all fits, χ^2 value is the statistical measure that quantifies the goodness of fit between the data and the fitted line. Its mathematical formula is given as:

$$\chi^2 = \sum_{i=1}^{N} \frac{(y_i - f(x_i))^2}{\sigma_i^2} \tag{9}$$

where y_i represents the data points $f(x_i)$ predicted value from the fitted line. Moreover, dividing by σ_i (the uncertainty at that point) adds weight to data points. That is;

- Data points with **small uncertainties** (σ_i is small) contribute more to the χ^2 because they are considered more reliable.

- Data points with **large uncertainties** (σ_i is large) contribute less to the χ^2 because they are considered less reliable.

It is desirable to have χ^2/ndf (number of degrees of freedom) to be around 1. Otherwise it implies overestimated or underestimated uncertainties. It can be observed from the full list of exponential fits that some of the fits have high values of χ^2 and does not converge very well. On the other hand, fits which coincides with the data points well have a lower value for χ^2.

Mean value for λ:

Setup	λ	Uncertainty
2.5-2	0.00782	0.00013
2.5-3	0.01167	0.00012
2.5-4	0.01256	0.00013
2.5-5	0.00955	0.00010
3.0-2	0.01129	0.00009
3.0-3	0.01024	0.00011
3.0-4	0.01251	0.00012
3.0-5	0.01003	0.00010
3.5-2	0.01041	0.00016
3.5-3	0.00997	0.00012
3.5-4	0.01052	0.00010
3.5-5	0.01145	0.00009
4.0-2	0.01148	0.00010
4.0-3	0.00898	0.00009
4.0-4	0.01069	0.00006
4.0-5	0.01000	0.00007

Table 3: λ values

There are 16 different values for λ from each fit. Therefore, the final value is represented by the weighted average of those values. The weighted average is calculated as:

$$\lambda_m = \frac{\sum_{i=1}^{16} \lambda_i/\sigma_i^2}{\sum_{i=1}^{16} 1/\sigma_i^2}$$

where λ_i's are the individual values and σ_i's are their respective uncertainties.

Similarly, σ_m is calculated as:

$$\sigma_m^2 = \sum_{i=1}^{16} 1/\sigma_i^2$$

After performing the calculations with the help of Code 4, the final value for λ_m is:

$$\lambda_m = 1.05 \times 10^{-2} \pm 2.4 \times 10^{-5} = (1.05 \pm 0.002) \times 10^{-2}$$

If we recall, half-life of the Radon gas is calculated as:

$$t_{1/2} = \frac{ln2}{\lambda}$$

And one can see its uncertainty must be similar to σ_{1/s_i} since it has the form $f(x) = 1/x$. From this, its uncertainty is:

$$\sigma_{t_{1/2}} = \frac{\sigma_m}{\lambda_m^2}$$

From the mean values and its deviation, half life of the Radon gas is calculated as $65.8 \pm 0.2s$. Which is not that far from the accepted value $55.6s$. Nonetheless, the experimental finding is 51 sigmas away from the real number.

Decay constants as a function of number of squeezes and voltages:

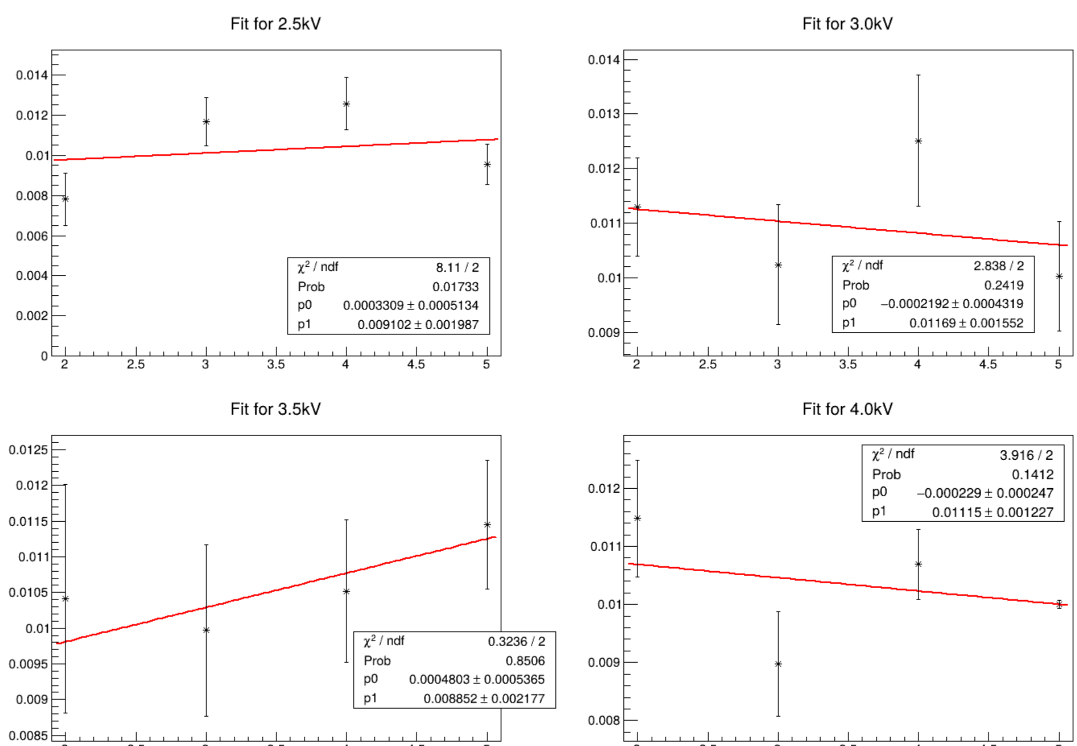


Figure 4: decay constant as a function of squeezes for each high voltage value

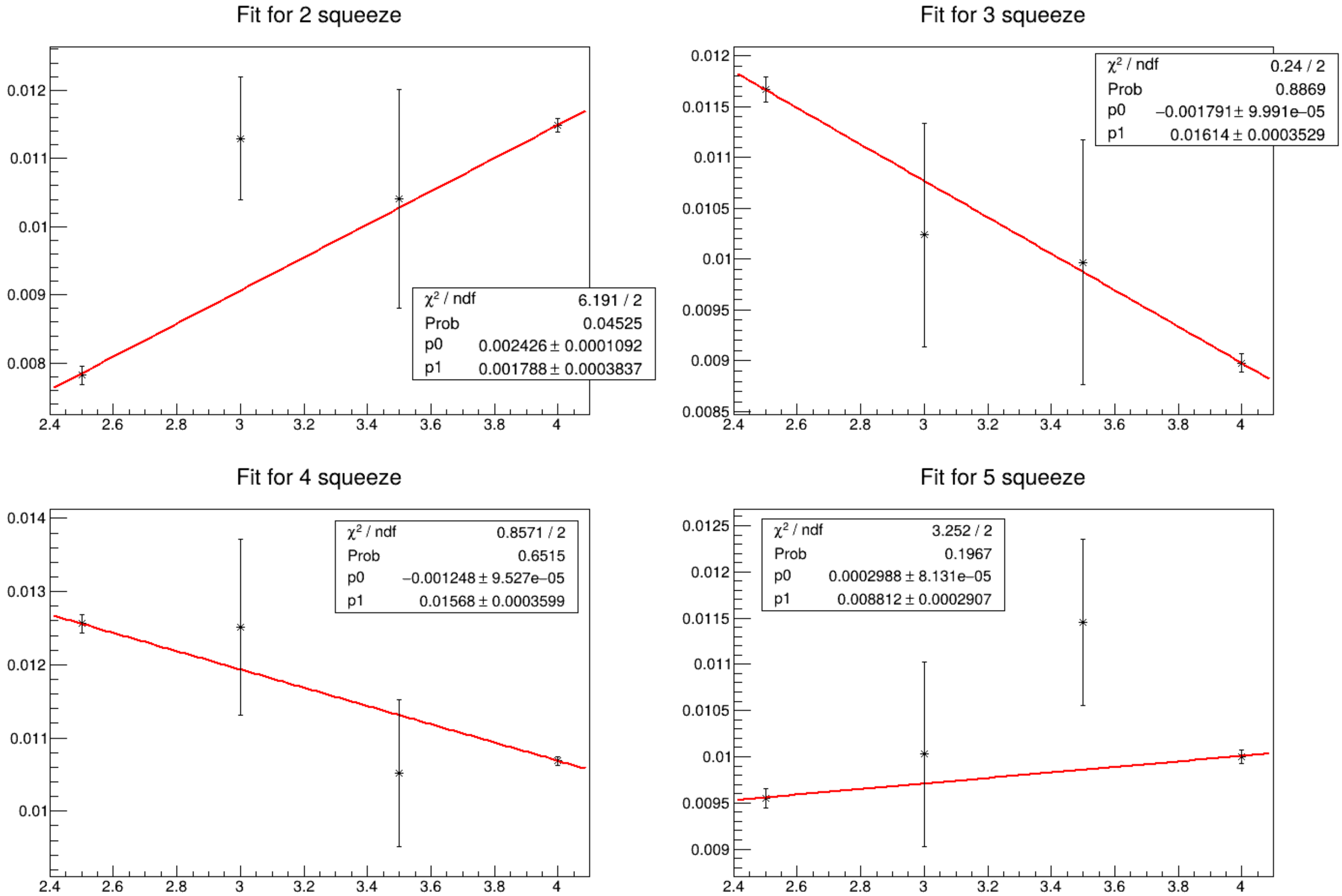


Figure 5: decay constant as a function of high voltage for each number of squeezes

V Conclusion

The experiment successfully extracted the decay constant and half-life of Radon gas, confirming the exponential decay model for radioactive decay. However, the deviation from the accepted half-life suggests systematic errors, some examples may be incomplete chamber purification or other unpredictible contributers to the discharge of the electroscope (side materials created during the decay chain or voltage fluctuations due to environment etc.) which results in outlier measurements throughout the experiment. Future work could improve accuracy by calibrating the electroscope sensitivity or extending measurement durations to capture later decay stages which inherintly has less uncertainty, further eleminating the human error in measurements.

The experiment also suffers from a simplification made while evaluating the data and extracting T_i and s_i values. Although s_i calculation does not change due to the behaviour of the decaying proceess, same does not apply to the T_i values.

T_i values represent the time in which the amount of decaying material $(1/s_i)$ corresponds to the overall measurement of around 5 minutes. Since the relation of decaying material with time is exponential, one should find an instant that corresponds to that discharge cycle (T_i) as a point more closer to the beginning of that cycle. Such point represents the average rate of decay in that cycle better compared to the arithmetic middle point used in the experiment.

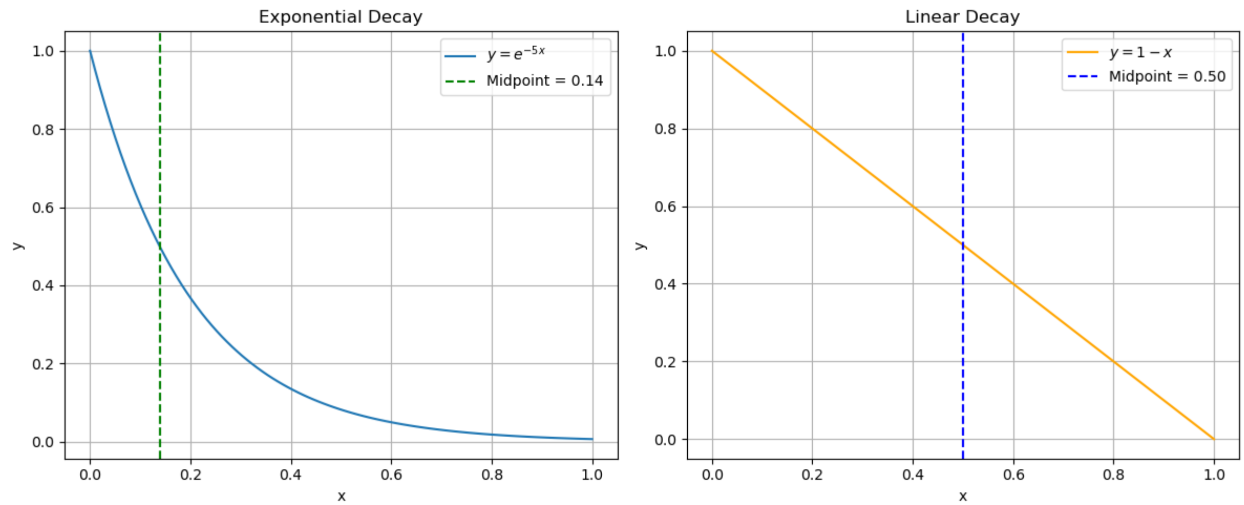


Figure 6: Comparison of T_i values on exponential and linear regime

With that said, under the trade-offs between simplicity and precision, the experiment succesfuly demonstrated the relation between decay constant λ and half life of the radioactive Radon gas while proving the reliability of Wulf's electroscope and ionization process as a measure of radioactive decay.

References

[1] E. Gülmez, *Advanced Physics Experiments*. Boğaziçi University, 1997.

[2] GitHub repository for codes and scripts used in this experiment: https://github.com/capta1Nemo/PHYS442-experiments.git

Appendix

A.1 Exponential Fits

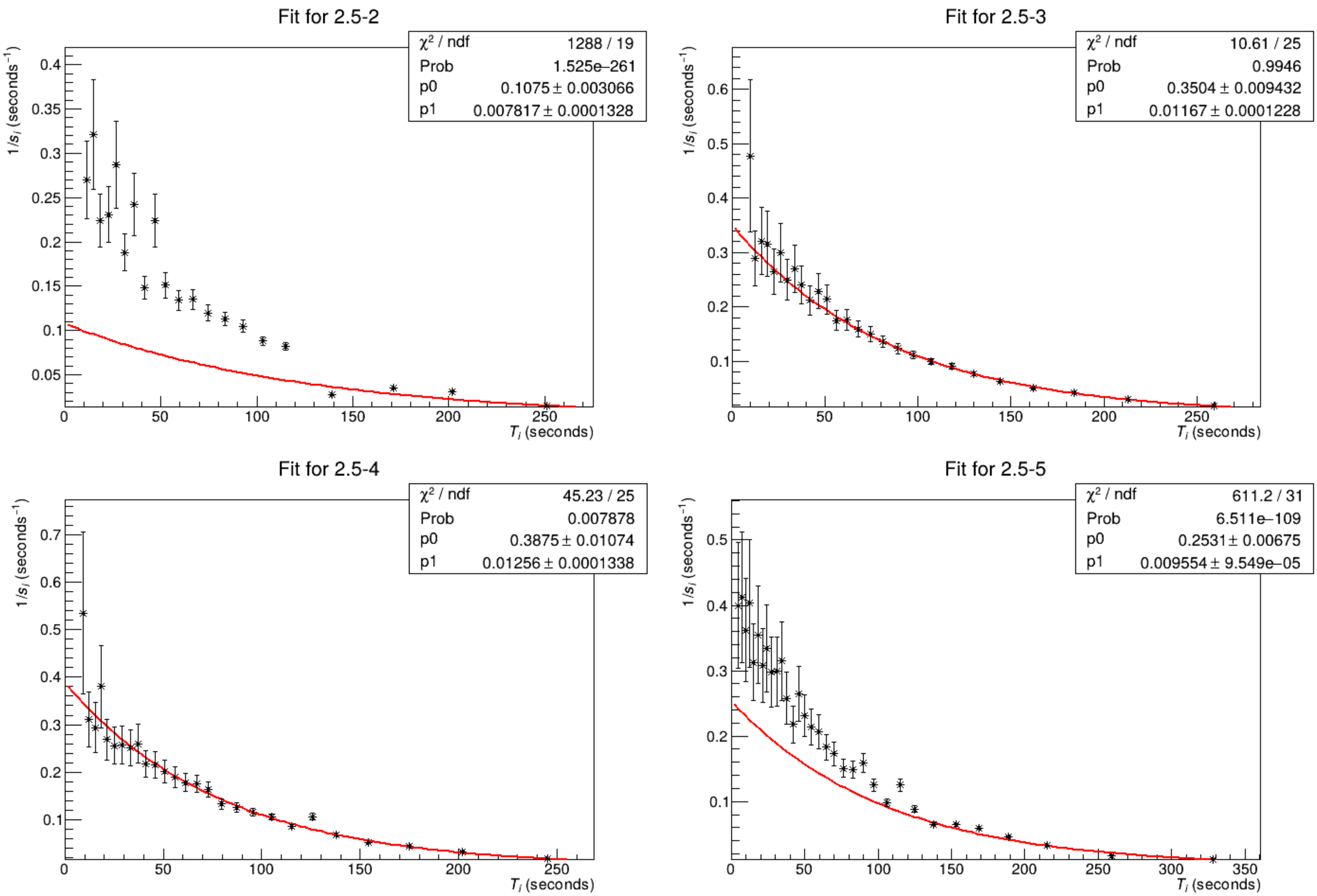


Figure 7: Exponential fits for all runs

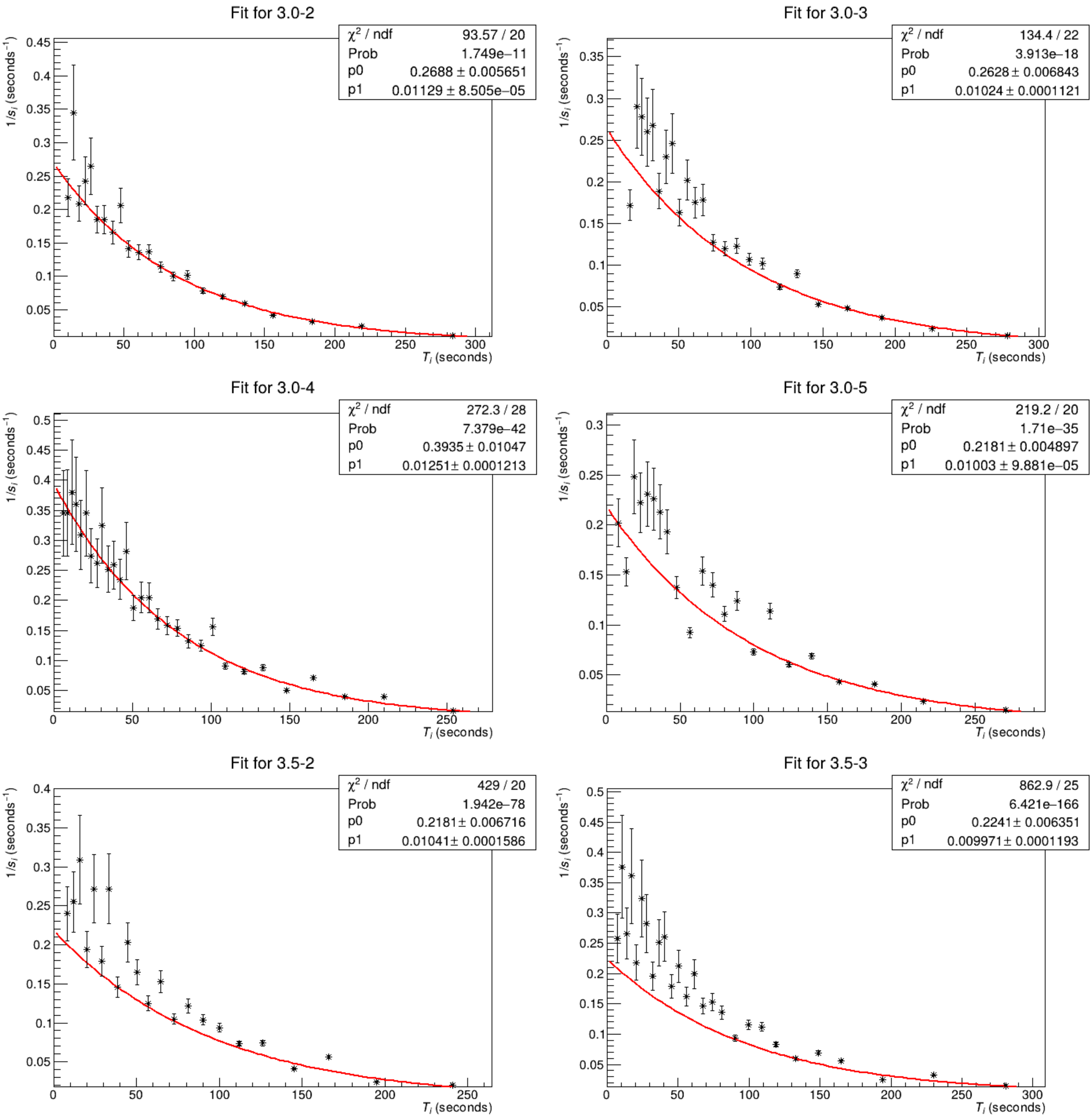


Figure 8: Exponential fits for all runs

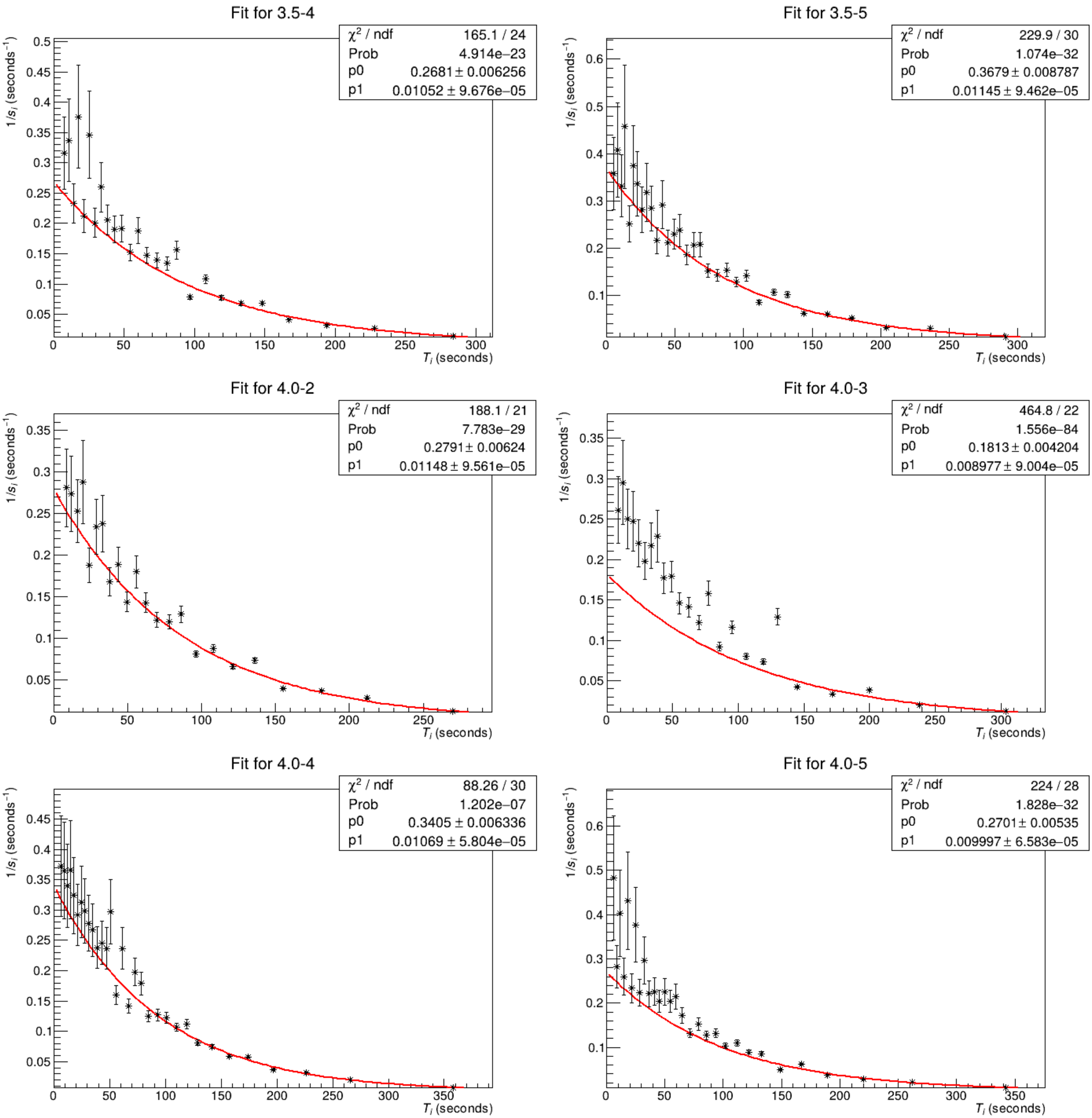


Figure 9: Exponential fits for all runs

Codes

```python
import numpy as np

def seconds(time_str):

    minutes, seconds_ms = time_str.split(':')
    seconds, milliseconds = seconds_ms.split('.')
    minutes = int(minutes)
    seconds = int(seconds)
    milliseconds = int(milliseconds)
    total_seconds = minutes * 60 + seconds + milliseconds / 100

    return float(f"{total_seconds:.5g}")

def mid_point(arr):
    arr=np.array(arr)
    midpoints = (arr[:-1] + arr[1:]) / 2
    return midpoints

file_path = './PHYS442-experiments/Radioactive-Decay/data.txt'
dict={}
keys=[]
count=0
append=False
with open(file_path, 'r') as file:
    for line in file:
        line=line.strip()
        if line=="start":
            append=True
        if not append:
            dict[line]=[]
            keys.append(line)
            count+=1
        if append:
            columns = line.split()
            if len(columns) > 1:
                dict[keys[count-1]].append(seconds(columns[1]))
        if line=="end":
            append=False

si={}
ti={}
for i in keys:
    si[i]=np.diff(dict[i])
    ti[i]=mid_point(dict[i])
```

Code 1: s_i and T_i Calculation Script

```python
import os

sigma_ti={}
for item in ti:
    sigma_ti[item]= np.full(len(ti[item]), 0.3)
```

```python

sigma_si={}
for item in si:
    sigma_si[item]=[]
    for j in si[item]:
        sigma_si[item].append(float(f"{0.6/(j**2):.2g}"))

output_dir = "./PHYS442-experiments/Radioactive-Decay/data"
os.makedirs(output_dir, exist_ok=True)
for key in keys:
    file_path = os.path.join(output_dir, f"{key}.txt")
    with open(file_path, 'w') as file:
        # Write the array to the file
        file.write('\n'.join(f"{x:.3g}\t{1/y:.3g}\t{sx:.2g}\t{sy:.2g}" for x, y, sx, sy in zip(ti[key], si[key],sigma_ti[key],sigma_si[key])))
```

Code 2: uncertainty calculation and data generation script in python

```cpp

void batch_fit(const char* inputFolder = "./data", const char* outputFolder = "./results") {
    TSystemDirectory dir(inputFolder, inputFolder);
    TList *files = dir.GetListOfFiles();
    if (!files) {
        cout << "No_files_found_in_directory:" << inputFolder << endl;
        return;
    }
    // Open a results file to store p1 values
    TString resultsFile = TString(outputFolder) + "/fit_results.txt";
    ofstream results(resultsFile.Data(), ios::out);
    if (!results) {
        cout << "Error:Unable_to_open_results_file_for_writing!" << endl;
        return;
    }

    results << "Filename\tlambda_Value" << endl; // Header

    TIter next(files);
    TSystemFile *file;
    while ((file = (TSystemFile*)next())) {
        TString filename = file->GetName();

        if (!filename.EndsWith(".txt")) continue;
        TString filepath = TString(inputFolder) + "/" + filename;
        cout << "Processing:" << filepath << endl;

        TGraphErrors *mygraph = new TGraphErrors(filepath);
        TString title = TString::Format("Fit_for_%s", filename.Data());
        title.ReplaceAll(".txt", "");
        mygraph->SetTitle(title);

        TF1 *expo_fit = new TF1("expo_fit","[0]*exp(-[1]*x)");
        expo_fit->SetParameters(0.3, -0.01);
```

```cpp
        expo_fit->SetLineColor(kRed);
        expo_fit->SetLineWidth(2);

        mygraph->Fit(expo_fit);
        mygraph->GetXaxis()->SetTitle("T_{i}\\(\\text{seconds})");
        mygraph->GetYaxis()->SetTitle("1/s_{i}\\(\\text{seconds}^{-1})");

        // Extract and store the lambda value
        double p1 = expo_fit->GetParameter(1);
        double p1_err = expo_fit->GetParError(1);
        results << filename.Data() << "\t" << fixed << setprecision(5) <<
            p1 << "\t" << setprecision(5) << p1_err << endl;

        TCanvas *c1 = new TCanvas();
        mygraph->Draw("A*");
        gStyle->SetOptFit(1111);

        TString outputFilename = TString(outputFolder) + "/" + filename.
            ReplaceAll(".txt", ".png");
        c1->SaveAs(outputFilename);

        delete mygraph;
        delete expo_fit;
        delete c1;
    }

    results.close();
    cout << "Processing_complete.Check_the_output_folder:" << outputFolder
         << endl;
}
```

Code 3: Root exponential fit for 16 datasets

```python

def compute_weighted_mean(filename):
    data = np.loadtxt(filename, usecols=(1, 2), skiprows=1)

    lambda_values = data[:, 0]  # Second column (lambda values)
    uncertainties = data[:, 1]  # Third column (uncertainties)
    weights = 1 / uncertainties**2
    weighted_mean = np.sum(weights * lambda_values) / np.sum(weights)

    weighted_uncertainty = np.sqrt(1/np.sum(weights))

    return weighted_mean, weighted_uncertainty

filename = "./PHYS442-experiments/Radioactive-Decay/results/fit_results.
    txt"
mean, uncertainty = compute_weighted_mean(filename)
print(f"Weighted_Mean:{mean:}+-{uncertainty:}")
```

Code 4: Mean value calculation script in python

Additional Material

Full list of datasets

The dataset in text format can also be found in [2].

2.5kV - 2 squeezes		2.5kV - 3 squeezes	
Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)	Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)
00:09.39	00:03.47	00:08.65	00:06.14
00:13.09	00:03.70	00:10.74	00:02.09
00:16.21	00:03.12	00:14.20	00:03.46
00:20.67	00:04.46	00:17.32	00:03.12
00:24.99	00:04.32	00:20.48	00:03.16
00:28.48	00:03.49	00:24.26	00:03.78
00:33.79	00:05.31	00:27.60	00:03.34
00:37.93	00:04.14	00:31.60	00:04.00
00:44.67	00:06.74	00:35.31	00:03.71
00:49.13	00:04.46	00:39.47	00:04.16
00:55.76	00:06.63	00:44.19	00:04.72
01:03.23	00:07.47	00:48.55	00:04.36
01:10.62	00:07.39	00:53.23	00:04.68
01:18.95	00:08.33	00:58.94	00:05.71
01:27.79	00:08.84	01:04.62	00:05.68
01:37.35	00:09.56	01:10.90	00:06.28
01:48.68	00:11.33	01:17.55	00:06.65
02:00.83	00:12.15	01:24.92	00:07.37
02:37.08	00:36.25	01:33.03	00:08.11
03:05.90	00:28.82	01:41.97	00:08.94
03:37.98	00:32.08	01:52.03	00:10.06
04:44.84	01:06.86	02:03.01	00:10.98
		02:16.01	00:13.00
		02:31.83	00:15.82
		02:51.84	00:20.01
		03:15.67	00:23.83
		03:49.82	00:34.15
		04:48.47	00:58.65

2.5kV - 4 squeezes		**2.5kV - 5 squeezes**	
Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)	Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)
00:08.52	00:03.71	00:03.42	00:02.36
00:10.39	00:01.87	00:05.92	00:02.50
00:13.61	00:03.22	00:08.35	00:02.43
00:17.01	00:03.40	00:11.11	00:02.76
00:19.64	00:02.63	00:13.59	00:02.48
00:23.36	00:03.72	00:16.78	00:03.19
00:27.26	00:03.90	00:19.60	00:02.82
00:31.13	00:03.87	00:22.85	00:03.25
00:35.11	00:03.98	00:25.84	00:02.99
00:38.95	00:03.84	00:29.20	00:03.36
00:43.54	00:04.59	00:32.55	00:03.35
00:48.19	00:04.65	00:35.72	00:03.17
00:53.14	00:04.95	00:39.59	00:03.87
00:58.41	00:05.27	00:44.18	00:04.59
01:04.03	00:05.62	00:47.97	00:03.79
01:09.75	00:05.72	00:52.29	00:04.32
01:15.84	00:06.09	00:56.96	00:04.67
01:23.34	00:07.50	01:01.80	00:04.84
01:31.26	00:07.92	01:07.26	00:05.46
01:39.87	00:08.61	01:13.04	00:05.78
01:49.27	00:09.40	01:19.67	00:06.63
02:00.87	00:11.60	01:26.40	00:06.73
02:10.21	00:09.34	01:32.70	00:06.30
02:24.79	00:14.58	01:40.69	00:07.99
02:44.20	00:19.41	01:50.89	00:10.20
03:06.58	00:22.38	01:58.87	00:07.98
03:36.94	00:30.36	02:10.14	00:11.27
04:33.65	00:56.71	02:25.41	00:15.27
		02:40.99	00:15.58
		02:57.84	00:16.85
		03:19.56	00:21.72
		03:50.27	00:30.71
		04:46.81	00:56.54
		06:10.16	01:23.35

3.0kV - 2 squeezes		**3.0kV - 3 squeezes**	
Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)	Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)
00:07.84	00:02.56	00:13.18	00:04.41
00:12.43	00:04.59	00:19.01	00:03.85
00:15.33	00:02.90	00:22.46	00:03.45
00:20.12	00:04.79	00:26.06	00:03.60
00:24.23	00:04.11	00:29.90	00:03.84
00:28.00	00:03.77	00:33.63	00:03.73
00:33.42	00:05.42	00:38.92	00:05.29
00:38.82	00:05.40	00:43.26	00:04.34
00:44.85	00:06.03	00:47.33	00:04.07
00:49.70	00:04.85	00:53.46	00:06.13
00:56.81	00:07.11	00:58.41	00:04.95
01:04.15	00:07.34	01:04.12	00:05.71
01:11.45	00:07.30	01:09.75	00:05.63
01:20.26	00:08.81	01:17.64	00:07.89
01:30.22	00:09.96	01:25.97	00:08.33
01:39.98	00:09.76	01:34.13	00:08.16
01:52.71	00:12.73	01:43.45	00:09.32
02:07.04	00:14.33	01:53.24	00:09.79
02:23.98	00:16.94	02:06.79	00:13.55
02:47.86	00:23.88	02:17.97	00:11.18
03:19.21	00:31.35	02:36.97	00:19.00
03:58.29	00:39.08	02:57.85	00:20.88
05:30.46	01:32.17	03:24.97	00:27.12
		04:06.78	00:41.81
		05:09.98	01:03.20

3.0kV - 4 squeezes		3.0kV - 5 squeezes	
Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)	Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)
00:04.49	00:02.31	00:05.40	00:01.64
00:07.39	00:02.90	00:10.35	00:04.95
00:10.28	00:02.89	00:16.87	00:06.52
00:12.91	00:02.63	00:20.90	00:04.03
00:15.69	00:02.78	00:25.40	00:04.50
00:18.93	00:03.24	00:29.72	00:04.32
00:21.83	00:02.90	00:34.15	00:04.43
00:25.48	00:03.65	00:38.84	00:04.69
00:29.29	00:03.81	00:44.03	00:05.19
00:32.37	00:03.08	00:51.33	00:05.32
00:36.34	00:03.97	01:02.17	00:07.24
00:40.20	00:03.86	01:08.65	00:06.48
00:44.46	00:04.26	01:15.81	00:07.16
00:48.01	00:03.55	01:24.82	00:09.01
00:53.35	00:05.34	01:32.87	00:08.05
00:58.22	00:04.87	01:46.63	00:13.76
01:03.11	00:04.89	01:55.44	00:08.81
01:09.04	00:05.93	02:11.94	00:16.50
01:15.35	00:06.31	02:26.48	00:14.54
01:21.84	00:06.49	02:49.59	00:23.11
01:29.39	00:07.55	03:14.06	00:24.47
01:37.37	00:07.98	03:56.07	00:42.01
01:43.77	00:06.40	05:05.16	01:09.09
01:54.76	00:10.99		
02:07.08	00:12.32		
02:18.43	00:11.35		
02:38.19	00:19.76		
02:52.27	00:14.08		
03:17.28	00:25.01		
03:42.92	00:25.64		
04:45.60	01:02.68		

3.5kV - 2 squeezes		3.5kV - 3 squeezes	
Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)	Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)
00:05.86	00:02.28	00:05.34	00:02.25
00:10.03	00:04.17	00:09.22	00:03.88
00:13.95	00:03.92	00:11.88	00:02.66
00:17.19	00:03.24	00:15.64	00:03.76
00:22.35	00:05.16	00:18.41	00:02.77
00:26.03	00:03.68	00:22.99	00:04.58
00:31.63	00:05.60	00:26.08	00:03.09
00:35.30	00:03.67	00:29.61	00:03.53
00:42.17	00:06.87	00:34.72	00:05.11
00:47.09	00:04.92	00:38.71	00:03.99
00:53.15	00:06.06	00:42.54	00:03.83
01:01.13	00:07.98	00:48.14	00:05.60
01:07.65	00:06.52	00:52.85	00:04.71
01:17.16	00:09.51	00:59.04	00:06.19
01:25.35	00:08.19	01:04.06	00:05.02
01:34.96	00:09.61	01:10.87	00:06.81
01:45.61	00:10.65	01:17.40	00:06.53
01:59.27	00:13.66	01:24.76	00:07.36
02:12.77	00:13.50	01:35.42	00:10.66
02:37.10	00:24.33	01:44.08	00:08.66
02:54.96	00:17.86	01:53.04	00:08.96
03:35.75	00:40.79	02:05.08	00:12.04
04:25.98	00:50.23	02:21.89	00:16.81
		02:36.34	00:14.45
		02:54.35	00:18.01
		03:34.55	00:40.20
		04:05.90	00:31.35
		05:16.88	01:10.98

3.5kV - 4 squeezes		3.5kV - 5 squeezes	
Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)	Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)
00:05.91	00:02.56	00:04.05	00:01.07
00:09.07	00:03.16	00:06.84	00:02.79
00:12.04	00:02.97	00:09.29	00:02.45
00:16.34	00:04.30	00:12.30	00:03.01
00:19.00	00:02.66	00:14.49	00:02.19
00:23.72	00:04.72	00:18.47	00:03.98
00:26.61	00:02.89	00:21.14	00:02.67
00:31.59	00:04.98	00:24.11	00:02.97
00:35.43	00:03.84	00:27.66	00:03.55
00:40.29	00:04.86	00:30.80	00:03.14
00:45.55	00:05.26	00:34.32	00:03.52
00:50.76	00:05.21	00:38.94	00:04.62
00:57.36	00:06.60	00:42.37	00:03.43
01:02.69	00:05.33	00:47.11	00:04.74
01:09.48	00:06.79	00:51.45	00:04.34
01:16.66	00:07.18	00:55.65	00:04.20
01:24.11	00:07.45	01:01.04	00:05.39
01:30.54	00:06.43	01:05.88	00:04.84
01:43.35	00:12.81	01:10.69	00:04.81
01:52.65	00:09.30	01:17.29	00:06.60
02:05.62	00:12.97	01:24.26	00:06.97
02:20.38	00:14.76	01:30.75	00:06.49
02:34.93	00:14.55	01:38.59	00:07.84
02:58.94	00:24.01	01:45.63	00:07.04
03:29.94	00:31.00	01:57.27	00:11.64
04:07.01	00:36.95	02:06.61	00:09.34
05:21.20	01:14.19	02:16.42	00:09.81
		02:32.41	00:15.99
		02:48.97	00:16.56
		03:08.30	00:19.33
		03:39.86	00:31.56
		04:12.47	00:32.61
		05:29.25	01:16.78

4.0kV - 2 squeezes		4.0kV - 3 squeezes	
Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)	Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)
00:06.56	00:03.00	00:06.70	00:01.97
00:10.12	00:03.56	00:10.53	00:03.83
00:13.77	00:03.65	00:13.92	00:03.39
00:17.73	00:03.96	00:17.92	00:04.00
00:21.20	00:03.47	00:21.97	00:04.05
00:26.53	00:05.33	00:26.51	00:04.54
00:30.80	00:04.27	00:31.57	00:05.06
00:35.01	00:04.21	00:36.17	00:04.60
00:40.96	00:05.95	00:40.53	00:04.36
00:46.26	00:05.30	00:46.17	00:05.64
00:53.19	00:06.93	00:51.77	00:05.60
00:58.74	00:05.55	00:58.64	00:06.87
01:05.73	00:06.99	01:05.73	00:07.09
01:13.91	00:08.18	01:13.95	00:08.22
01:22.26	00:08.35	01:20.28	00:06.33
01:30.00	00:07.74	01:31.13	00:10.85
01:42.32	00:12.32	01:39.73	00:08.60
01:53.64	00:11.32	01:52.20	00:12.47
02:08.79	00:15.15	02:05.77	00:13.57
02:22.44	00:13.65	02:13.51	00:15.90
02:47.70	00:25.26	02:37.09	00:15.42
03:14.42	00:26.72	03:07.10	00:30.01
03:49.80	00:35.38	03:32.80	00:25.70
05:10.67	01:20.87	04:22.94	00:50.14
		05:44.84	01:21.90

4.0kV - 4 squeezes		4.0kV - 5 squeezes	
Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)	Absolute Time($\pm 0.30s$)	Interval between discharges($\pm 0.60s$)
00:05.39	00:02.16	00:05.10	00:02.41
00:08.08	00:02.69	00:07.17	00:02.07
00:10.82	00:02.74	00:10.70	00:03.53
00:13.76	00:02.94	00:13.18	00:02.48
00:16.49	00:02.73	00:17.02	00:03.84
00:19.58	00:03.09	00:19.34	00:02.32
00:23.00	00:03.42	00:23.61	00:04.27
00:26.19	00:03.19	00:26.26	00:02.65
00:29.55	00:03.36	00:30.74	00:04.48
00:33.15	00:03.60	00:34.12	00:03.38
00:36.90	00:03.75	00:38.64	00:04.33
00:41.10	00:04.20	00:43.06	00:04.42
00:45.17	00:04.07	00:47.97	00:04.91
00:49.39	00:04.22	00:52.42	00:04.45
00:52.76	00:03.37	00:57.32	00:04.90
00:59.02	00:06.26	01:01.98	00:04.66
01:03.24	00:04.22	01:07.78	00:05.80
01:10.28	00:07.04	01:15.35	00:07.57
01:15.34	00:05.06	01:21.94	00:06.59
01:20.92	00:05.58	01:29.83	00:07.89
01:28.94	00:08.02	01:37.39	00:07.56
01:36.83	00:07.89	01:47.06	00:09.67
01:45.06	00:08.23	01:56.19	00:09.13
01:54.39	00:09.33	02:07.42	00:11.23
02:03.28	00:08.89	02:19.08	00:11.66
02:15.54	00:12.26	02:39.29	00:20.21
02:28.89	00:13.35	02:55.53	00:16.24
04:50.41	00:48.85	06:38.71	01:52.93
07:05.30	02.14.89		