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July 31, 2024

[ ]:
```
%matplotlib inline
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.mlab as mlab
from scipy.optimize import curve_fit
from scipy.stats import chi2
from scipy.stats import norm
import scipy.constants as scp
from scipy.integrate import quad
from tabulate import tabulate
from scipy import signal
import scipy.constants as const
from scipy.special import gamma
```

[ ]:
```
def sigma(x, y, dx, dy, label):
    s = np.abs(x-y)/np.sqrt(dx**2 + dy**2)
    print('Sigmaabweichung {} ='.format(str(label)), s)
    return s
```

---

1 Untergrundmessung

[ ]:
```
ug_t, ug_r = np.loadtxt('./data/untergrund.txt', skiprows=4, unpack=True,␣
↪delimiter=',')
```

[ ]:
```
ug_mw = np.mean(4 * ug_r)
ug_dmw = np.std(4 * ug_r)/np.sqrt(len(ug_r))

print("Mittelwert Untergrund = ({} +/- {})counts/10s".format(ug_mw, ug_dmw))
```

```
Mittelwert Untergrund = (15.583333333333334 +/- 1.1257070823199014)counts/10s
```

2 Zerfall der Silberisotope

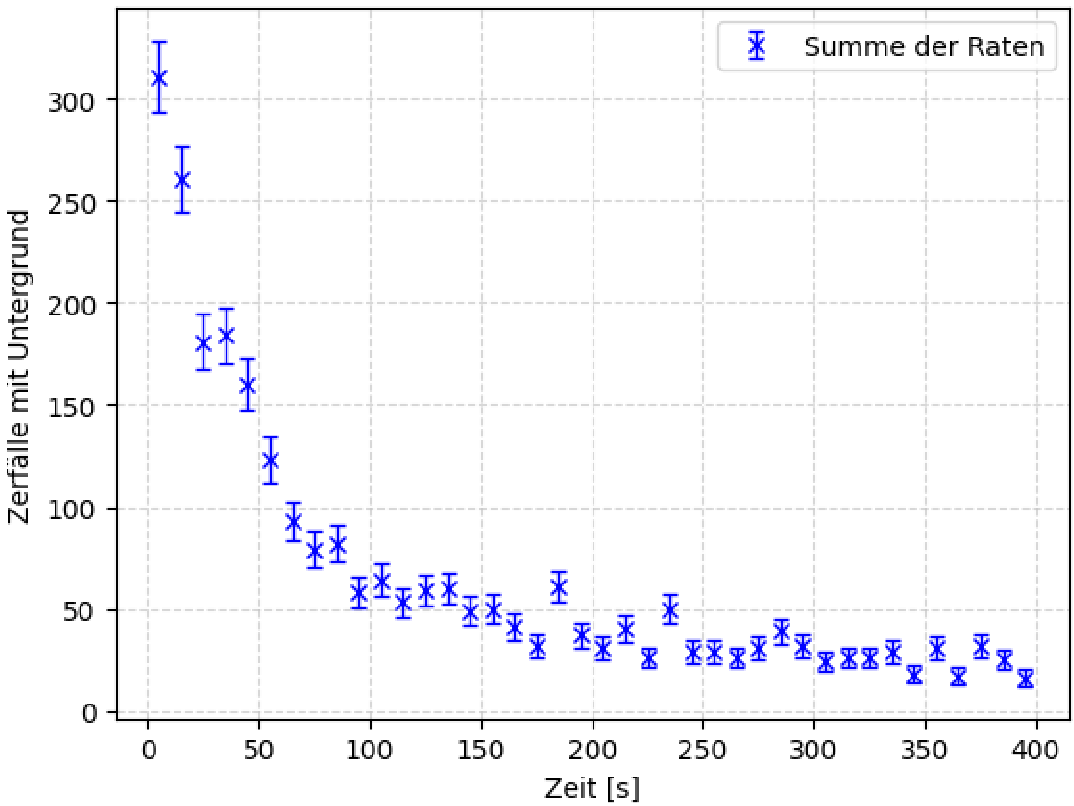
[ ]:
```
n1_t, n1 = np.loadtxt('data/silber1.txt', skiprows=4, delimiter=',',␣
↪unpack=True)
n2_t, n2 = np.loadtxt('data/silber2.txt', skiprows=4, delimiter=',',␣
↪unpack=True)
n3_t, n3 = np.loadtxt('data/silber3.txt', skiprows=4, delimiter=',',␣
↪unpack=True)
n4_t, n4 = np.loadtxt('data/silber4.txt', skiprows=4, delimiter=',',␣
↪unpack=True)
```

[ ]:
```
N = n1 + n2 + n3 + n4
dN = np.sqrt(N)
```

[ ]:
```
t = np.arange(5,405, 10)

plt.grid(alpha=0.5, linestyle='--')
plt.errorbar(t, N, yerr=dN, fmt='x', color='blue', label='Summe der Raten',␣
↪capsize=3, lw=1)
plt.xlabel(r'Zeit [s]')
plt.ylabel(r'Zerfälle mit Untergrund')
#plt.plot(X, linfit(X, *a1_popt_ac_680), color='lime',
#         label="\n".join([r"Fitgerade: $y = \alpha \cdot x + \beta$",
#                          r'$\alpha ={:.1f}\pm{:.1}$'.
↪format(a1_popt_ac_680[0], np.sqrt(a1_pcov_ac_680[0][0])),
#                          r'$\beta ={:.3f}\pm{:.3f}$'.
↪format(a1_popt_ac_680[1], np.sqrt(a1_pcov_ac_680[1][1]))]))
plt.legend()
```

[ ]:
```
<matplotlib.legend.Legend at 0x185be13b040>
```




```
[ ]: y0 = ug_mw
     def exp(x, A1, l1, A2, l2):
         return A1 * np.exp(- x * l1) + A2 * np.exp(-x * l2) + y0
     s1_pop, s1_cov = curve_fit(exp, t, N, p0=[500, 0.02, 50, 0.001], sigma=dN,␣
      ↪absolute_sigma=True)

     print("A1=",s1_pop[0], ", Standardfehler=", np.sqrt(s1_cov[0][0]))
     print("l1=",s1_pop[1], ", Standardfehler=", np.sqrt(s1_cov[1][1]))
     print("A2=",s1_pop[2], ", Standardfehler=", np.sqrt(s1_cov[2][2]))
     print("l2=",s1_pop[3], ", Standardfehler=", np.sqrt(s1_cov[3][3]))

     l1 = s1_pop[1]
     dl1 = np.sqrt(s1_cov[1][1])
     l2 = s1_pop[3]
     dl2 = np.sqrt(s1_cov[3][3])
```

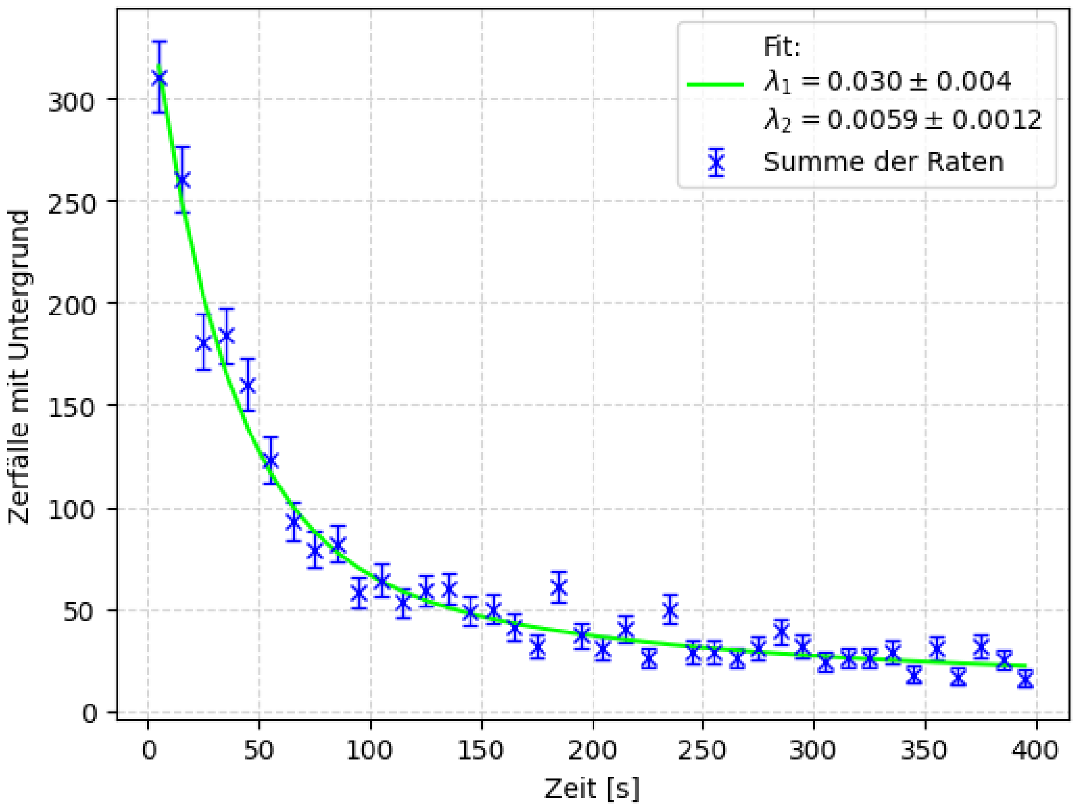
```
A1= 273.20338265849466 , Standardfehler= 21.160044268071253
l1= 0.02977712557206005 , Standardfehler= 0.004253726554796002
A2= 66.94410282445499 , Standardfehler= 19.99547056883678
l2= 0.005907494013643605 , Standardfehler= 0.0011985048945004134
```

[ ]:
```python
t = np.arange(5,405, 10)

plt.grid(alpha=0.5, linestyle='--')
plt.errorbar(t, N, yerr=dN, fmt='x', color='blue', label='Summe der Raten',␣
 ↪capsize=3, lw=1)
plt.xlabel(r'Zeit [s]')
plt.ylabel(r'Zerfälle mit Untergrund')
plt.plot(t, exp(t, *s1_pop), color='lime',
        label="\n".join([r"Fit:",
                          r'$\lambda_{} ={:.3f}\pm{:.3f}$'.format('1',␣
 ↪s1_pop[1], np.sqrt(s1_cov[1][1])),
                          r'$\lambda_{} ={:.4f}\pm{:.4f}$'.format('2',␣
 ↪s1_pop[3], np.sqrt(s1_cov[3][3]))]))
plt.legend()
plt.savefig('./plots/Silber_mit_UG.pdf', format='PDF')

#Fitcheck
chi_2 = np.sum((exp(t,*s1_pop) - N)**2 /dN**2)
dof = len(N) - 4 #dof:degrees of freedom, Freiheitsgrad
chi2_red = chi_2/dof
print("chi2 =", chi_2)
print("chi2_red =",chi2_red)
prob = round(1-chi2.cdf(chi_2,dof),2)*100
print("Wahrscheinlichkeit =", prob,"%")
```

```
chi2 = 52.473667233977125
chi2_red = 1.4576018676104756
Wahrscheinlichkeit = 4.0 %
```




```
[ ]: y0 = ug_mw - ug_dmw
     s2_pop, s2_cov = curve_fit(exp, t, N, p0=[500, 0.02, 50, 0.001], sigma=dN,␣
      ↪absolute_sigma=True)

     print("A1=",s2_pop[0], ", Standardfehler=", np.sqrt(s2_cov[0][0]))
     print("l1=",s2_pop[1], ", Standardfehler=", np.sqrt(s2_cov[1][1]))
     print("A2=",s2_pop[2], ", Standardfehler=", np.sqrt(s2_cov[2][2]))
     print("l2=",s2_pop[3], ", Standardfehler=", np.sqrt(s2_cov[3][3]))

     l1m = s2_pop[1]
     dl1m = np.sqrt(s2_cov[1][1])
     l2m = s2_pop[3]
     dl2m = np.sqrt(s2_cov[3][3])
```

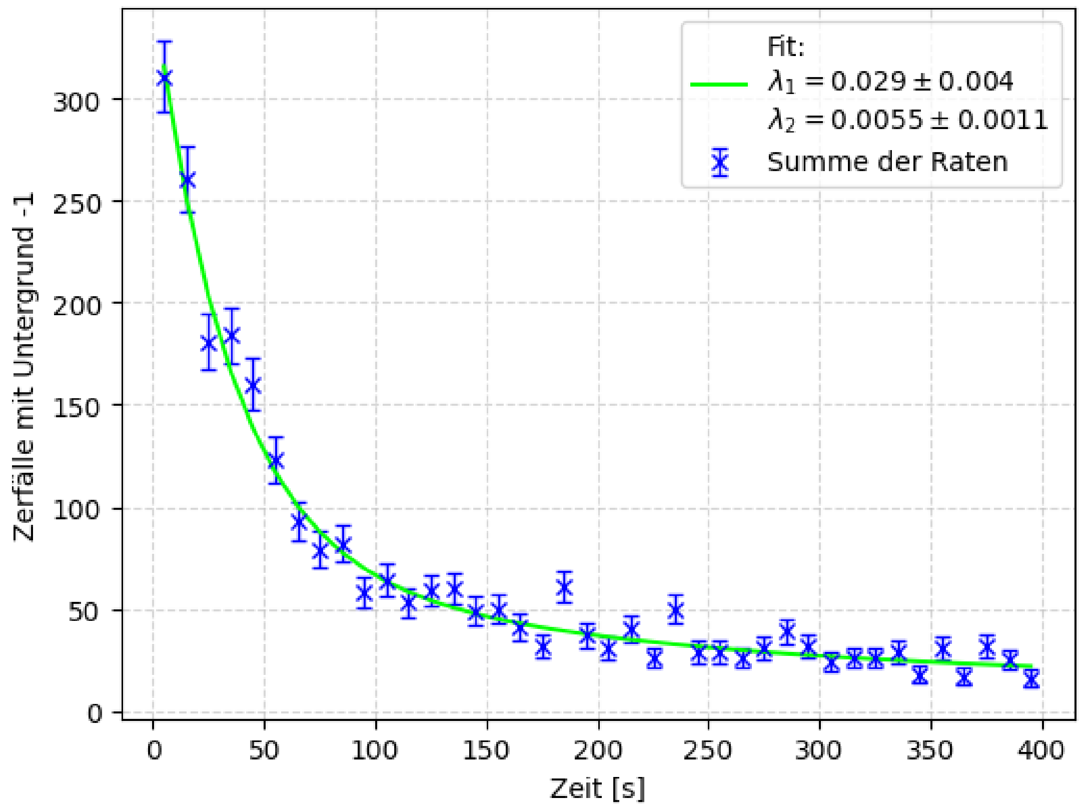
```
A1= 275.8716137602503 , Standardfehler= 20.21726960544724
l1= 0.029493262039445602 , Standardfehler= 0.004020363055628029
A2= 65.14069094119769 , Standardfehler= 18.265484797231323
l2= 0.005497506893630588 , Standardfehler= 0.001106710894171423
```

```
[ ]: t = np.arange(5,405, 10)
```

```
plt.grid(alpha=0.5, linestyle='--')
plt.errorbar(t, N, yerr=dN, fmt='x', color='blue', label='Summe der Raten',␣
 ↪capsize=3, lw=1)
plt.xlabel(r'Zeit [s]')
plt.ylabel(r'Zerfälle mit Untergrund -1')
plt.plot(t, exp(t, *s2_pop), color='lime',
        label="\n".join([r"Fit:",
                           r'$\lambda_{} ={:.3f}\pm{:.3f}$'.format('1',␣
 ↪s2_pop[1], np.sqrt(s2_cov[1][1])),
                           r'$\lambda_{} ={:.4f}\pm{:.4f}$'.format('2',␣
 ↪s2_pop[3], np.sqrt(s2_cov[3][3]))]))
plt.legend()
plt.savefig('./plots/Silber_mit_UG-1.pdf', format='PDF')

#Fitcheck
chi_2 = np.sum((exp(t,*s2_pop) - N)**2 /dN**2)
dof = len(N) - 4 #dof:degrees of freedom, Freiheitsgrad
chi2_red = chi_2/dof
print("chi2 =", chi_2)
print("chi2_red =",chi2_red)
prob = round(1-chi2.cdf(chi_2,dof),2)*100
print("Wahrscheinlichkeit =", prob,"%")
```

```
chi2 = 52.306929117782545
chi2_red = 1.4529702532717375
Wahrscheinlichkeit = 4.0 %
```



[ ]:
```
y0 = ug_mw + ug_dmw
s3_pop, s3_cov = curve_fit(exp, t, N, p0=[500, 0.02, 50, 0.001], sigma=dN,␣
 ↪absolute_sigma=True)

print("A1=",s3_pop[0], ", Standardfehler=", np.sqrt(s3_cov[0][0]))
print("l1=",s3_pop[1], ", Standardfehler=", np.sqrt(s3_cov[1][1]))
print("A2=",s3_pop[2], ", Standardfehler=", np.sqrt(s3_cov[2][2]))
print("l2=",s3_pop[3], ", Standardfehler=", np.sqrt(s3_cov[3][3]))

l1p = s3_pop[1]
dl1p = np.sqrt(s3_cov[1][1])
l2p = s3_pop[3]
dl2p = np.sqrt(s3_cov[3][3])
```

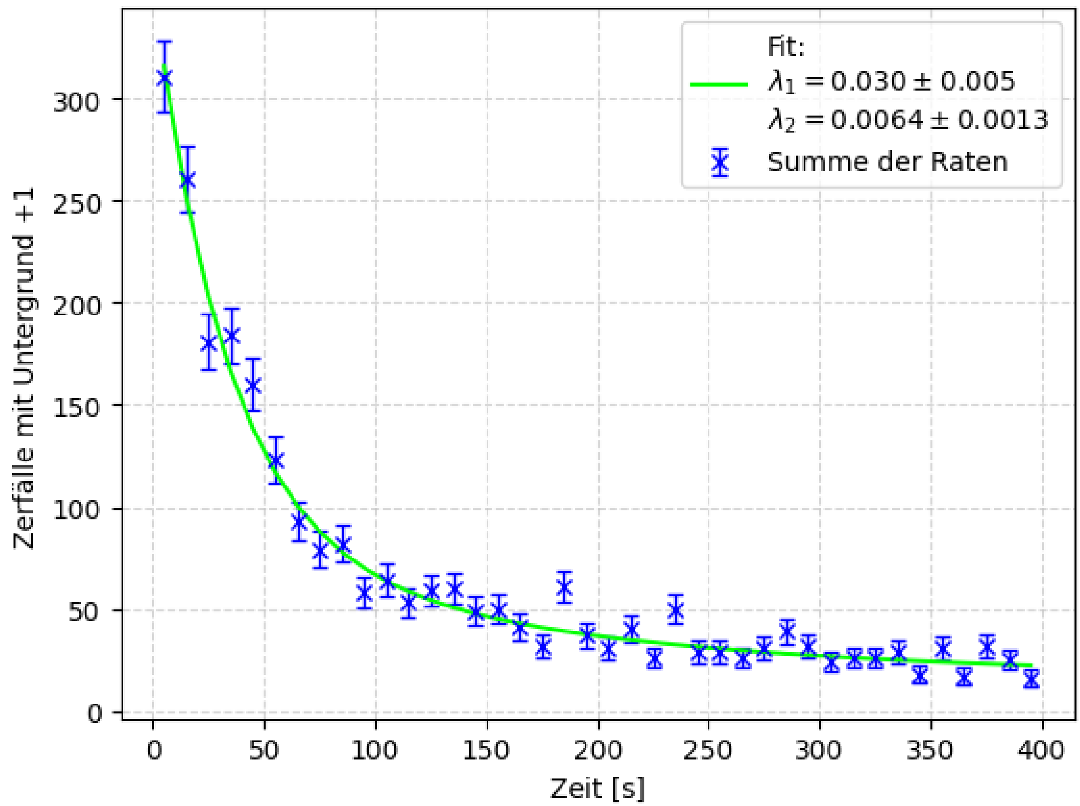
```
A1= 269.9621392034454 , Standardfehler= 22.438095483720453
l1= 0.03010727479762373 , Standardfehler= 0.0045444916051667035
A2= 69.32741599674702 , Standardfehler= 22.15348902417644
l2= 0.006374707676434155 , Standardfehler= 0.0013063042470345188
```

[ ]:
```
t = np.arange(5,405, 10)
```

```
plt.grid(alpha=0.5, linestyle='--')
plt.errorbar(t, N, yerr=dN, fmt='x', color='blue', label='Summe der Raten',␣
 ↪capsize=3, lw=1)
plt.xlabel(r'Zeit [s]')
plt.ylabel(r'Zerfälle mit Untergrund +1')
plt.plot(t, exp(t, *s3_pop), color='lime',
        label="\n".join([r"Fit:",
                         r'$\lambda_{} ={:.3f}\pm{:.3f}$'.format('1',␣
 ↪s3_pop[1], np.sqrt(s3_cov[1][1])),
                         r'$\lambda_{} ={:.4f}\pm{:.4f}$'.format('2',␣
 ↪s3_pop[3], np.sqrt(s3_cov[3][3]))]))
plt.legend()
plt.savefig('./plots/Silber_mit_UG+1.pdf', format='PDF')

#Fitcheck
chi_2 = np.sum((exp(t,*s3_pop) - N)**2 /dN**2)
dof = len(N) - 4 #dof:degrees of freedom, Freiheitsgrad
chi2_red = chi_2/dof
print("chi2 =", chi_2)
print("chi2_red =",chi2_red)
prob = round(1-chi2.cdf(chi_2,dof),2)*100
print("Wahrscheinlichkeit =", prob,"%")
```

```
chi2 = 52.6853292794104
chi2_red = 1.463481368872511
Wahrscheinlichkeit = 4.0 %
```



[ ]:
```python
diff1m = np.abs(l1 - l1m)
diff1p = np.abs(l1 - l1p)

diff1 = np.mean([diff1m, diff1p])

diff2m = np.abs(l2 - l2m)
diff2p = np.abs(l2 - l2p)

diff2 = np.mean([diff2m, diff2p])
```

[ ]:
```python
l1 = l1
dl1 = np.sqrt(dl1**2 + diff1**2)

l2 = l2
dl2 = np.sqrt(dl2**2 + diff2**2)

print("Zerfallskonstante 1 = ({} +/- {})".format(l1, dl1))
print("Zerfallskonstante 2 = ({} +/- {})".format(l2, dl2))
```

```
Zerfallskonstante 1 = (0.02977712557206005 +/- 0.004264791028852181)
Zerfallskonstante 2 = (0.005907494013643605 +/- 0.0012762383341207255)
```

```
[ ]: T1 = np.log(2)/l1
     dT1 = T1 * np.sqrt((dl1/l1)**2)

     T2 = np.log(2)/l2
     dT2 = T2 * np.sqrt((dl2/l2)**2)

     print("Halbwertszeit 1 = ({} +/- {})".format(T1, dT1))
     print("Halbwertszeit 2 = ({} +/- {})".format(T2, dT2))
```

```
Halbwertszeit 1 = (23.27784053173779 +/- 3.333939175242526)
Halbwertszeit 2 = (117.33353922307714 +/- 25.348406665957704)
```

```
[ ]: T1_lit = 24.6
     T2_lit = 144.6

     _ = sigma(T1, T1_lit, dT1, 0, 'Halbwertszeit 1')
     _ = sigma(T2, T2_lit, dT2, 0, 'Halbwertszeit 2')
```

```
Sigmaabweichung Halbwertszeit 1 = 0.3965757618136601
Sigmaabweichung Halbwertszeit 2 = 1.0756676400312393
```

```
[ ]:
```

3 Indiumzerfall

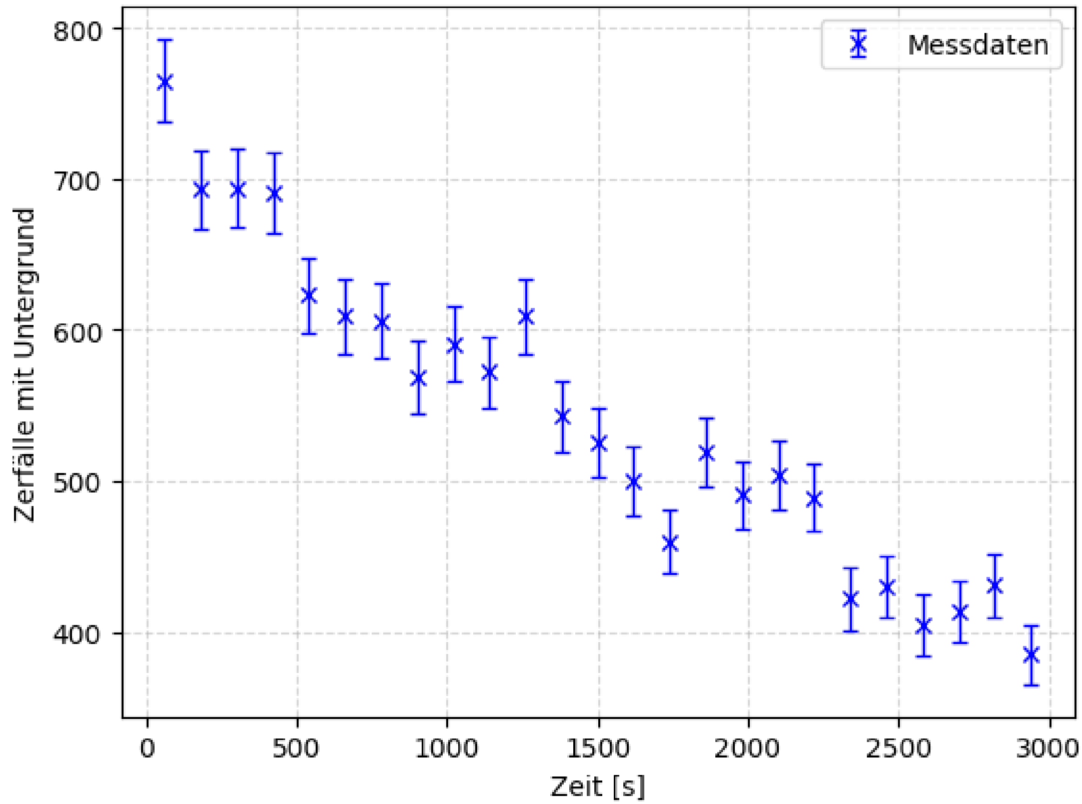
```
[ ]: ug_i = ug_mw * 3
     ug_di = ug_dmw * 3
```

```
[ ]: T_ind, Ni = np.loadtxt('data/indium.txt', skiprows=4, delimiter=',',␣
      ↪unpack=True)
     dNi = np.sqrt(Ni)
```

```
[ ]: t = np.arange(60,3060,120)

     plt.grid(alpha=0.5, linestyle='--')
     plt.errorbar(t, Ni, yerr=dNi, fmt='x', color='blue', label='Messdaten',␣
      ↪capsize=3, lw=1)
     plt.xlabel(r'Zeit [s]')
     plt.ylabel(r'Zerfälle mit Untergrund')
     #plt.plot(X, linfit(X, *a1_popt_ac_680), color='lime',
     #         label="\n".join([r"Fitgerade: $y = \alpha \cdot x + \beta$",
     #                          r'$\alpha ={:.1f}\pm{:.1}$'.
      ↪format(a1_popt_ac_680[0], np.sqrt(a1_pcov_ac_680[0][0])),
     #                          r'$\beta ={:.3f}\pm{:.3f}$'.
      ↪format(a1_popt_ac_680[1], np.sqrt(a1_pcov_ac_680[1][1]))]))
     plt.legend()
```

[ ]: <matplotlib.legend.Legend at 0x185bc8aa790>



[ ]:
```
def exp2(x,A,l):
    return A * np.exp(-x*l) + y0
```

[ ]:
```
y0 = ug_i
i1_pop, i1_cov = curve_fit(exp2, t[1:], Ni[1:], p0=[500, 0.0002], sigma=dNi[1:
↪], absolute_sigma=True)

print("A=",i1_pop[0], ", Standardfehler=", np.sqrt(i1_cov[0][0]))
print("l=",i1_pop[1], ", Standardfehler=", np.sqrt(i1_cov[1][1]))

li = i1_pop[1]
dli = np.sqrt(i1_cov[1][1])
```

```
A= 674.8062732895619 , Standardfehler= 12.917666736826769
l= 0.00022342259049030073 , Standardfehler= 1.1838945894853908e-05
```

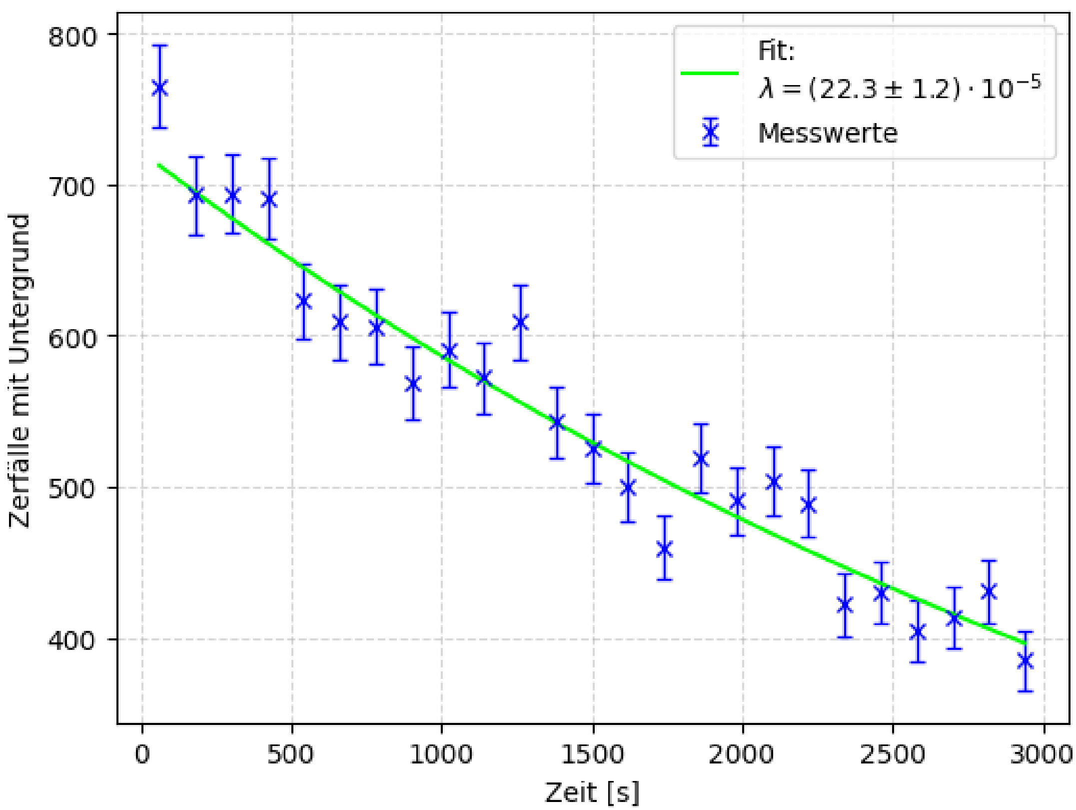
[ ]:
```
t = np.arange(60,3060,120)

plt.grid(alpha=0.5, linestyle='--')
```

```
plt.errorbar(t, Ni, yerr=dNi, fmt='x', color='blue', label='Messwerte',␣
 ↪capsize=3, lw=1)
plt.xlabel(r'Zeit [s]')
plt.ylabel(r'Zerfälle mit Untergrund')
plt.plot(t, exp2(t, *i1_pop), color='lime',
        label="\n".join([r"Fit:",
                          r'$\lambda =({:.1f}\pm{:.1f}) \cdot 10^{}$'.
 ↪format(i1_pop[1] * 1e5, np.sqrt(i1_cov[1][1]) * 1e5, '{-5}')]))
plt.legend()
plt.savefig('./plots/Indium_mit_UG.pdf', format='PDF')

#Fitcheck
chi_2 = np.sum((exp2(t[1:],*i1_pop) - Ni[1:])**2 /dNi[1:]**2)
dof = len(Ni[1:]) - 2 #dof:degrees of freedom, Freiheitsgrad
chi2_red = chi_2/dof
print("chi2 =", chi_2)
print("chi2_red =",chi2_red)
prob = round(1-chi2.cdf(chi_2,dof),2)*100
print("Wahrscheinlichkeit =", prob,"%")
```

```
chi2 = 24.805606637027854
chi2_red = 1.127527574410357
Wahrscheinlichkeit = 31.0 %
```



```
[ ]: y0 = ug_i - ug_di
     i2_pop, i2_cov = curve_fit(exp2, t[1:], Ni[1:], p0=[500, 0.0002], sigma=dNi[1:
      ↪], absolute_sigma=True)

     print("A=",i2_pop[0], ", Standardfehler=", np.sqrt(i2_cov[0][0]))
     print("l=",i2_pop[1], ", Standardfehler=", np.sqrt(i2_cov[1][1]))

     lim = i2_pop[1]
     dlim = np.sqrt(i2_cov[1][1])
```

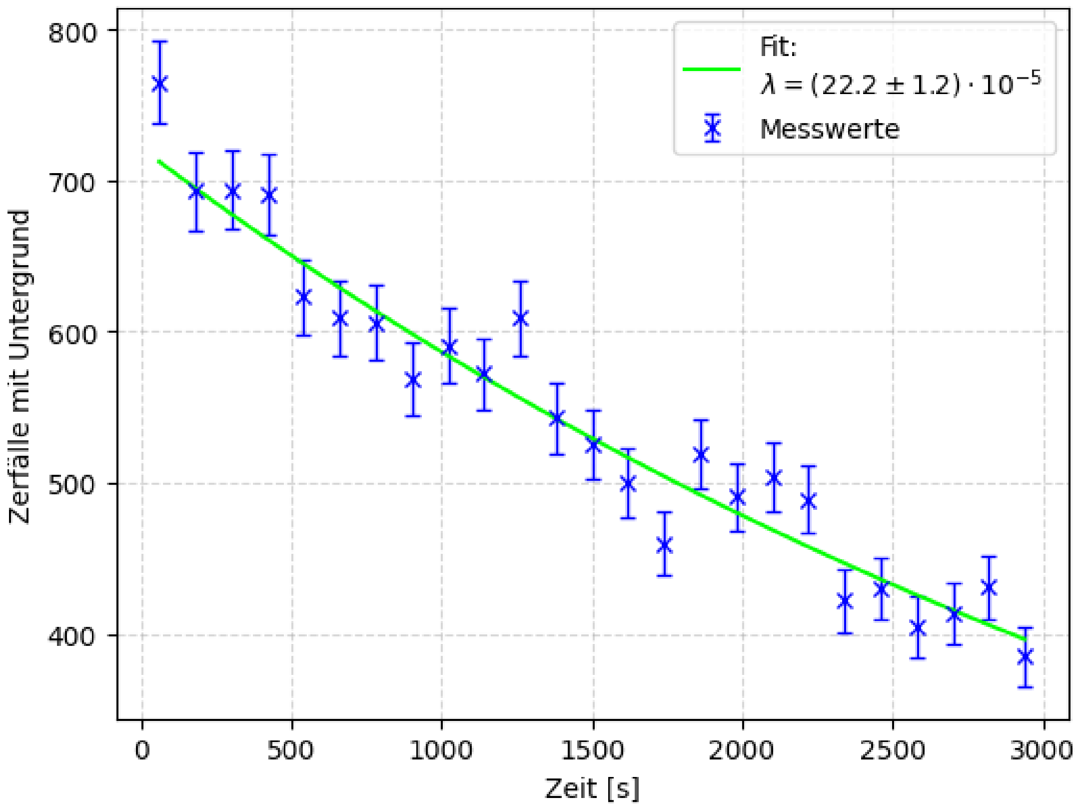
```
A= 678.0136906417098 , Standardfehler= 12.900931727309121
l= 0.00022185611816818426 , Standardfehler= 1.1753511837010672e-05
```

```
[ ]: t = np.arange(60,3060,120)

     plt.grid(alpha=0.5, linestyle='--')
     plt.errorbar(t, Ni, yerr=dNi, fmt='x', color='blue', label='Messwerte',␣
      ↪capsize=3, lw=1)
     plt.xlabel(r'Zeit [s]')
     plt.ylabel(r'Zerfälle mit Untergrund')
     plt.plot(t, exp2(t, *i2_pop), color='lime',
             label="\n".join([r"Fit:",
                               r'$\lambda =({:.1f}\pm{:.1f}) \cdot 10^{}$'.
      ↪format(i2_pop[1] * 1e5, np.sqrt(i2_cov[1][1]) * 1e5, '{-5}')]))
     plt.legend()
     plt.savefig('./plots/Indium_mit_UG-1.pdf', format='PDF')

     #Fitcheck
     chi_2 = np.sum((exp2(t[1:],*i2_pop) - Ni[1:])**2 /dNi[1:]**2)
     dof = len(Ni[1:]) - 2 #dof:degrees of freedom, Freiheitsgrad
     chi2_red = chi_2/dof
     print("chi2 =", chi_2)
     print("chi2_red =",chi2_red)
     prob = round(1-chi2.cdf(chi_2,dof),2)*100
     print("Wahrscheinlichkeit =", prob,"%")
```

```
chi2 = 24.804530106461538
chi2_red = 1.1274786412027973
Wahrscheinlichkeit = 31.0 %
```



[ ]:
```
y0 = ug_i + ug_di
i3_pop, i3_cov = curve_fit(exp2, t[1:], Ni[1:], p0=[500, 0.0002], sigma=dNi[1:
 ↪], absolute_sigma=True)

print("A=",i3_pop[0], ", Standardfehler=", np.sqrt(i3_cov[0][0]))
print("l=",i3_pop[1], ", Standardfehler=", np.sqrt(i3_cov[1][1]))

lip = i3_pop[1]
dlip = np.sqrt(i3_cov[1][1])
```

```
A= 671.6011821783825 , Standardfehler= 12.934649820289511
l= 0.00022501119626819482 , Standardfehler= 1.1925658317947085e-05
```

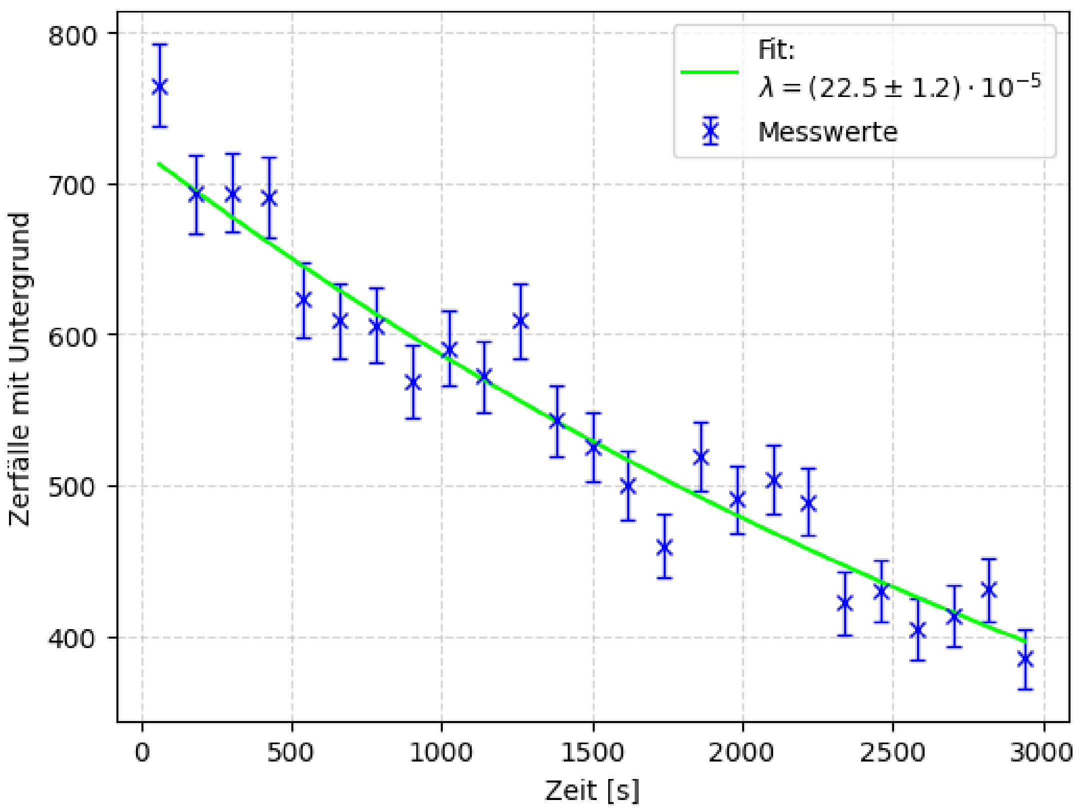
[ ]:
```
t = np.arange(60,3060,120)

plt.grid(alpha=0.5, linestyle='--')
plt.errorbar(t, Ni, yerr=dNi, fmt='x', color='blue', label='Messwerte',␣
 ↪capsize=3, lw=1)
plt.xlabel(r'Zeit [s]')
plt.ylabel(r'Zerfälle mit Untergrund')
plt.plot(t, exp2(t, *i3_pop), color='lime',
```

```
        label="\n".join([r"Fit:",
                          r'$\lambda =({:.1f}\pm{:.1f}) \cdot 10^{}$'.
 ↪format(i3_pop[1] * 1e5, np.sqrt(i3_cov[1][1]) * 1e5, '{-5}')]))
plt.legend()
plt.savefig('./plots/Indium_mit_UG+1.pdf', format='PDF')

#Fitcheck
chi_2 = np.sum((exp2(t[1:],*i3_pop) - Ni[1:])**2 /dNi[1:]**2)
dof = len(Ni[1:]) - 2 #dof:degrees of freedom, Freiheitsgrad
chi2_red = chi_2/dof
print("chi2 =", chi_2)
print("chi2_red =",chi2_red)
prob = round(1-chi2.cdf(chi_2,dof),2)*100
print("Wahrscheinlichkeit =", prob,"%")
```

```
chi2 = 24.80693417316548
chi2_red = 1.1275879169620673
Wahrscheinlichkeit = 31.0 %
```



[ ]:
```
diffim = np.abs(li - lim)
diffip = np.abs(li - lip)
```

```python
diffi = np.mean([diffim, diffip])

li = li
dli = np.sqrt(dli**2 + diffi**2)

print("Zerfallskonstante Indium = ({} +/- {})".format(li, dli))

Ti = np.log(2)/li
dTi = Ti * np.sqrt((dli/li)**2)

print("Halbwertszeit Indium = ({} +/- {})".format(Ti, dTi))
```

```
Zerfallskonstante Indium = (0.00022342259049030073 +/- 1.1943586955164254e-05)
Halbwertszeit Indium = (3102.4041885775036 +/- 165.84640843625795)
```

[ ]:
```python
Ti_lit = 54 * 60
_ = sigma(Ti, Ti_lit, dTi, 0, 'Halbwertszeit Indium')
```

```
Sigmaabweichung Halbwertszeit Indium = 0.8296580717054266
```

4 Tabellen für die Auswertung

[ ]:
```python
head = ['Time', 'N_ug']
tab = zip(ug_t, ug_r)

#print(tabulate(tab, headers=head, tablefmt="latex"))
```

[ ]:
```python
head = ['Time', 'N1', 'N2', 'N3', 'N4']
tab = zip(n1_t, n1, n2, n3, n4)

#print(tabulate(tab, headers=head, tablefmt="latex"))
```

[ ]:
```python
head = ['Time', 'N_In']
tab = zip(T_ind, Ni)

#print(tabulate(tab, headers=head, tablefmt="latex"))
```