O9

June 13, 2017

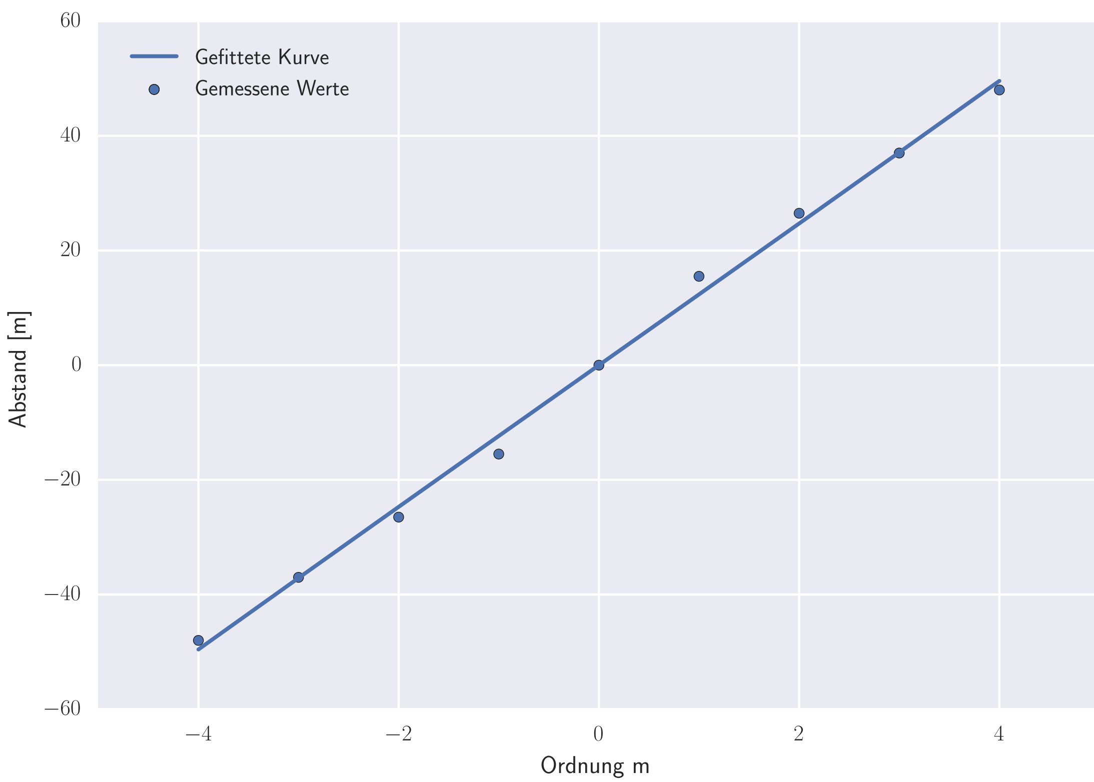
```
In [1]: # Preparations
        import math
        import pandas as pd
        import matplotlib.pyplot as plt
        import matplotlib.patches as mpatches
        import numpy as np
        from scipy import stats
        from scipy.optimize import curve_fit
        import seaborn as sns
        from IPython.display import Latex
        import warnings
        from functools import partial
        warnings.filterwarnings("ignore")
        %matplotlib inline
        %config InlineBackend.figure_format = 'svg'
        plt.rcParams['savefig.dpi'] = 75

        # plt.rcParams['figure.autolayout'] = False
        # plt.rcParams['figure.figsize'] = 10, 6
        plt.rcParams['axes.labelsize'] = 18
        plt.rcParams['axes.titlesize'] = 20
        plt.rcParams['font.size'] = 16
        plt.rcParams['lines.linewidth'] = 2.0
        plt.rcParams['lines.markersize'] = 8
        plt.rcParams['legend.fontsize'] = 14

        plt.rcParams['text.usetex'] = True
        plt.rcParams['text.latex.unicode'] = True
        plt.rcParams['font.family'] = "STIX"
        plt.rcParams['text.latex.preamble'] = "\\usepackage{subdepth}, \\usepackage

        results = {}

        sns.set(color_codes=True)

        def average(data):
            return 1 / len(data) * sum(data)
```

```
def error(data, average_of_data):
    s = sum([(x - average_of_data)**2 for x in data])
    return math.sqrt(s / (len(data) * (len(data) - 1)))

def std_deviation(error_of_average, length_of_dataset):
    return error_of_average * math.sqrt(length_of_dataset)

def average_with_weights(data, weights):
    d = data
    w = weights
    return (d * w**-2).sum() / (w**-2).sum()

def error_with_weights(weights):
    w = weights
    return 1 / math.sqrt((w**-2).sum())

def wavg(group, avg_name, weight_name):
    d = group[avg_name]
    w = group[weight_name]
    return (d * w**-2).sum() / (w**-2).sum()

def werr(group, weight_name):
    return 1 / math.sqrt((group[weight_name]**-2).sum())
```

```
In [2]: n = np.array([
            -4,
            -3,
            -2,
            -1,
            0,
            1,
            2,
            3,
            4
        ])

        l = 632.8e-9
```

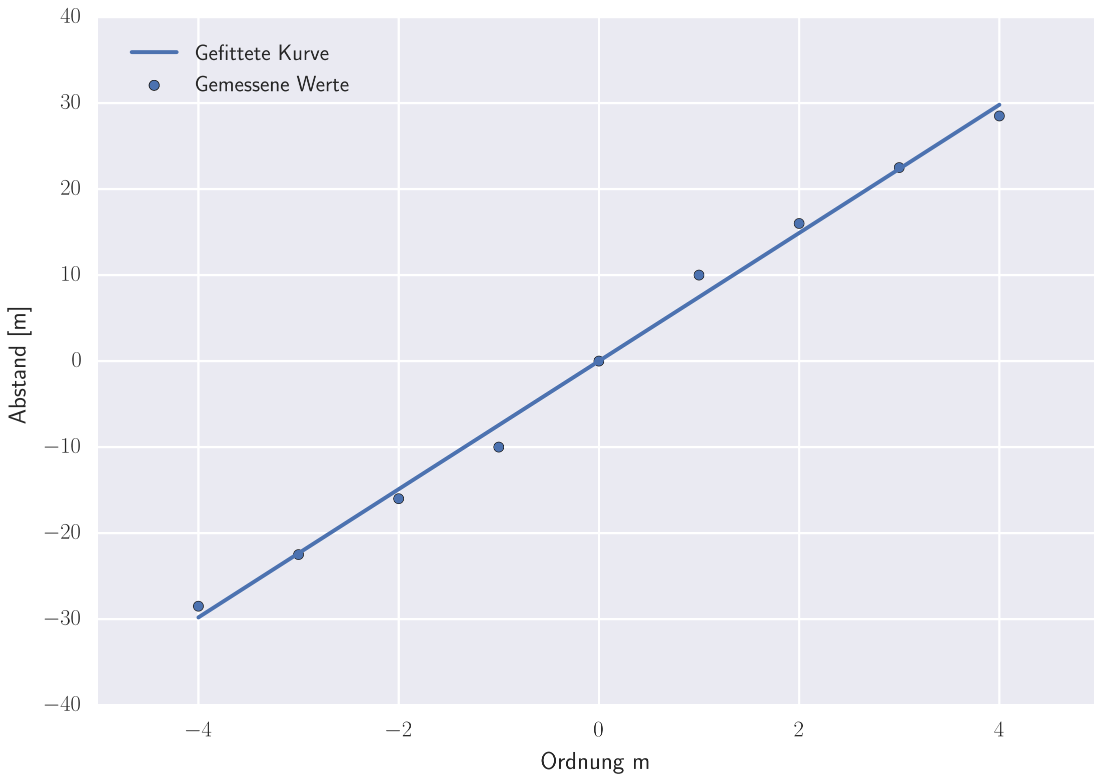
```
In [3]: # ------ S P A L T 3 0 u m ------ #
        x = [
            -48,
            -37,
            -26.5,
            -15.5,
            0,
            15.5,
            26.5,
            37,
```

```
    48
]
f = 550

def diffraction(n, b):
    return f * np.tan(np.arcsin(n*l/b))

v, covar = curve_fit(diffraction, n, x)

b30 = v[0]
f30 = np.sqrt(np.diag(covar))[0]

plt.scatter(n, x, label='Gemessene Werte')
plt.plot(n, diffraction(n, v), label='Gefittete Kurve')
plt.xlabel('Ordnung m')
plt.ylabel('Abstand [m]')
plt.legend(bbox_to_anchor=(0.02, 0.98), loc=2, borderaxespad=0.2)
plt.savefig('b30.png')
plt.show()
```



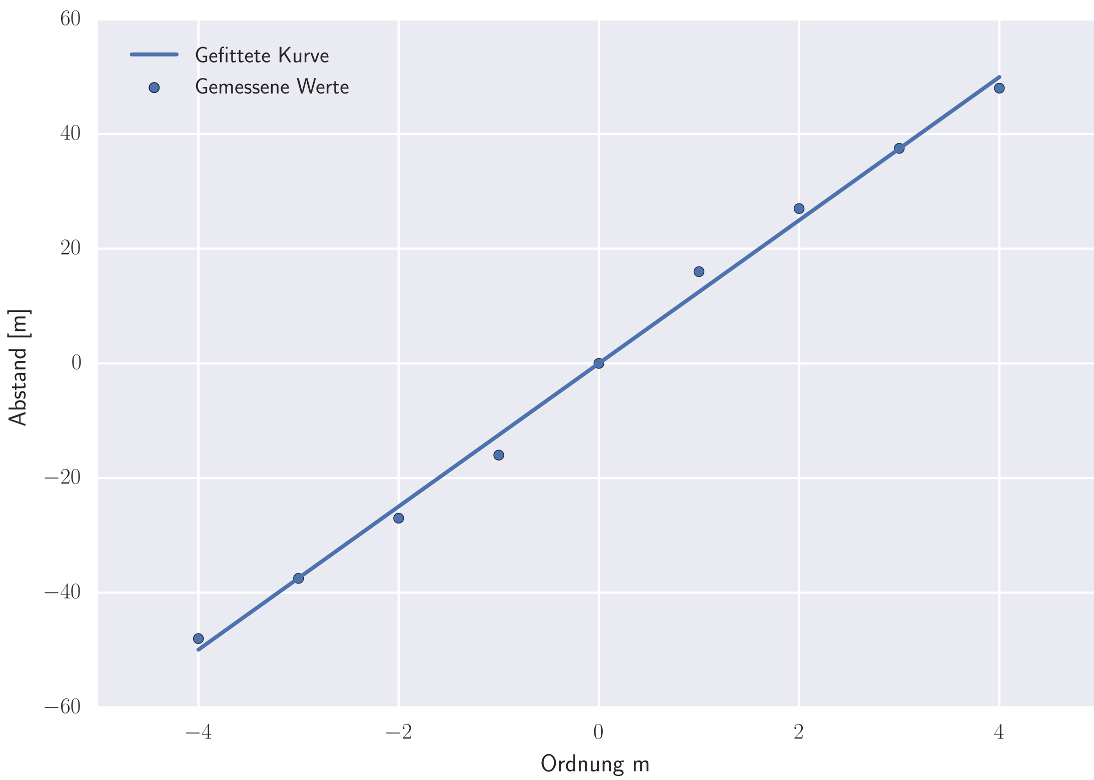

```
In [4]: # ------ S P A L T 1 0 0 u m ------ #
        b = 100e-6 #m
```

```
x = [
    -28.5,
    -22.5,
    -16,
    -10,
    0,
    10,
    16,
    22.5,
    28.5
]
f = 1000

def diffraction(n, b):
    return f * np.tan(np.arcsin(n*l/b))

v, covar = curve_fit(diffraction, n, x)

b100 = v[0]
f100 = np.sqrt(np.diag(covar))[0]

plt.scatter(n, x, label='Gemessene Werte')
plt.plot(n, diffraction(n, v), label='Gefittete Kurve')
plt.xlabel('Ordnung m')
plt.ylabel('Abstand [m]')
plt.legend(bbox_to_anchor=(0.02, 0.98), loc=2, borderaxespad=0.2)
plt.savefig('spalt100.png')
plt.show()
```



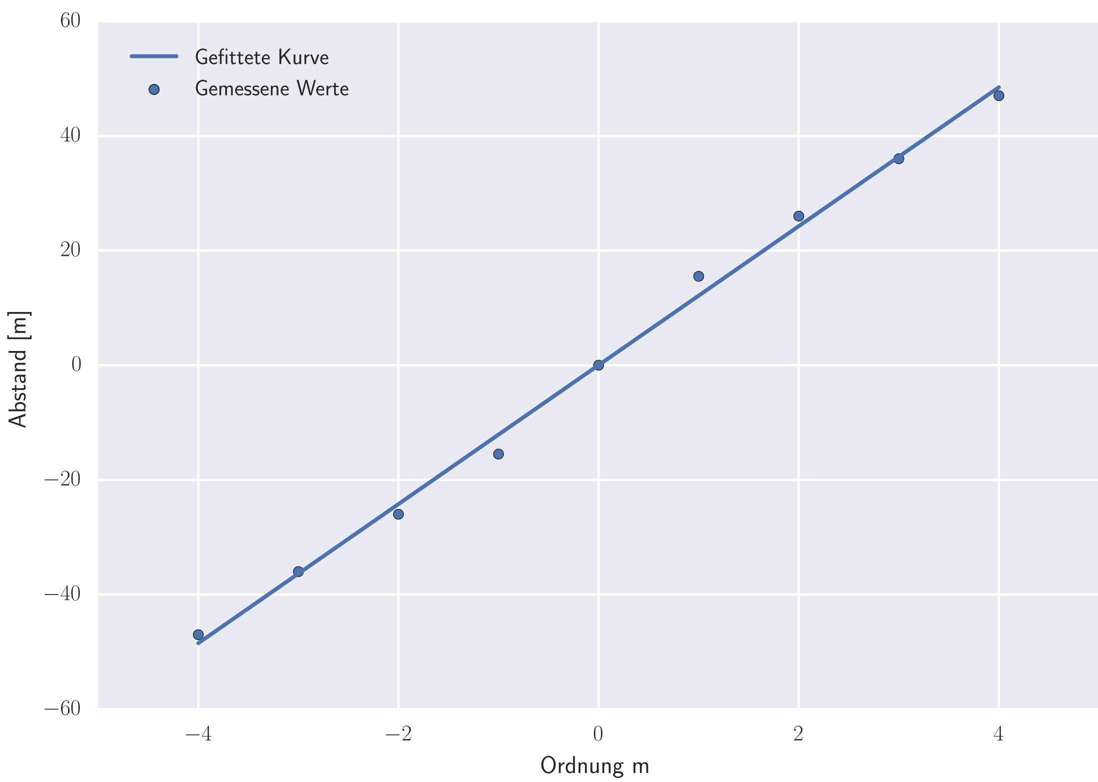

```
In [5]: # ------ A N T I S P A L T 1 2 4 u m ------ #
        b = 124e-6 #m

        x = [
            -48,
            -37.5,
            -27,
            -16,
            0,
            16,
            27,
            37.5,
            48
        ]
        f = 2030

        def diffraction(n, b):
            return f * np.tan(np.arcsin(n*l/b))

        v, covar = curve_fit(diffraction, n, x)

        b124 = v[0]
```

```
f124 = np.sqrt(np.diag(covar))[0]

plt.scatter(n, x, label='Gemessene Werte')
plt.plot(n, diffraction(n, v), label='Gefittete Kurve')
plt.xlabel('Ordnung m')
plt.ylabel('Abstand [m]')
plt.legend(bbox_to_anchor=(0.02, 0.98), loc=2, borderaxespad=0.2)
plt.savefig('antispalt124.png')
plt.show()
```



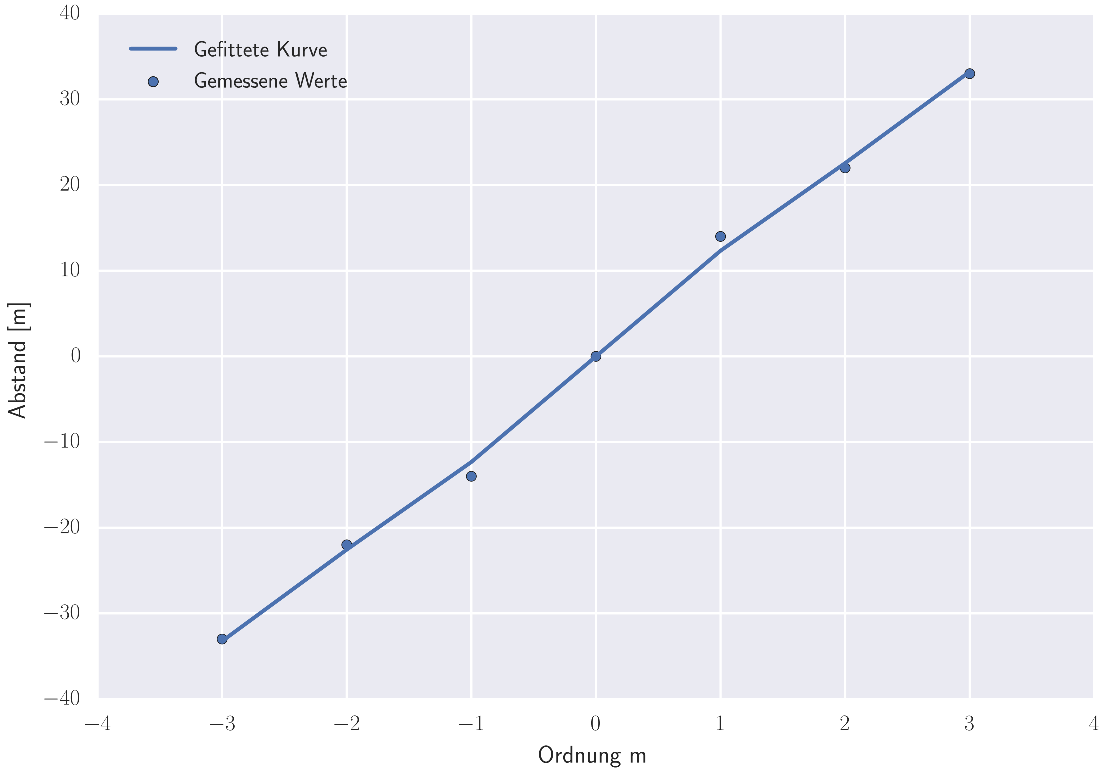
In [6]:
```
# ------ A N T I S P A L T H A A R ------ #
b = 50e-6 #m

x = [
    -47,
    -36,
    -26,
    -15.5,
    0,
    15.5,
    26,
    36,
```

```
    47,
]
f = 1000

def diffraction(n, b):
    return f * np.tan(np.arcsin(n*l/b))

v, covar = curve_fit(diffraction, n, x)

bhaar = v[0]
fhaar = np.sqrt(np.diag(covar))[0]

plt.scatter(n, x, label='Gemessene Werte')
plt.plot(np.linspace(n[0], n[-1], 1000), diffraction(np.linspace(n[0], n[-1
plt.xlabel('Ordnung m')
plt.ylabel('Abstand [m]')
plt.legend(bbox_to_anchor=(0.02, 0.98), loc=2, borderaxespad=0.2)
plt.savefig('haar.png')
plt.show()
```



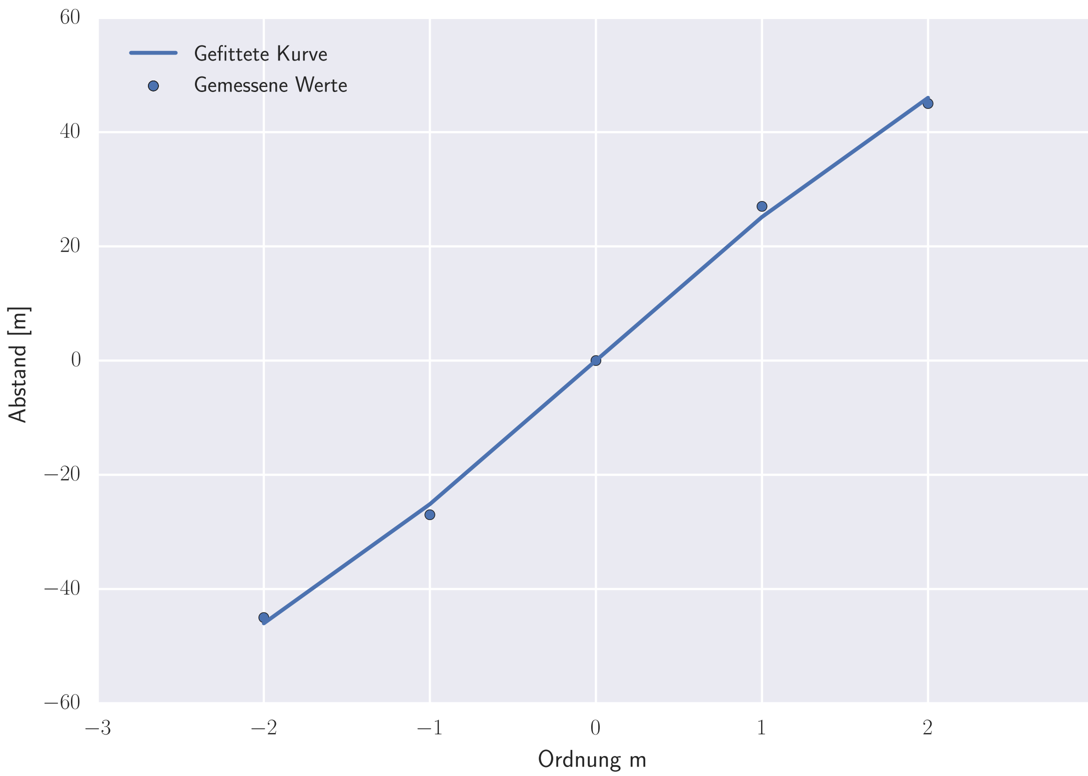

```
In [7]: # ------ L O C H 1 5 0 u m ------ #
        b = 150e-6 #m
```

```
n = np.array([
    -3,
    -2,
    -1,
    0,
    1,
    2,
    3
])

x = [
    -33,
    -22,
    -14,
    0,
    14,
    22,
    33
]
f = 2030

def diffraction(n, b):
    t = np.array([1, 1.22, 2.232, 3.288])
    return f * np.tan(np.arcsin(np.sign(n)*t[np.abs(n)]*l/b))

v, covar = curve_fit(diffraction, n, x)

b150 = v[0]
f150 = np.sqrt(np.diag(covar))[0]

plt.scatter(n, x, label='Gemessene Werte')
plt.plot(n, diffraction(n, v), label='Gefittete Kurve')
plt.xlabel('Ordnung m')
plt.ylabel('Abstand [m]')
plt.legend(bbox_to_anchor=(0.02, 0.98), loc=2, borderaxespad=0.2)
plt.savefig('loch150.png')
plt.show()
```



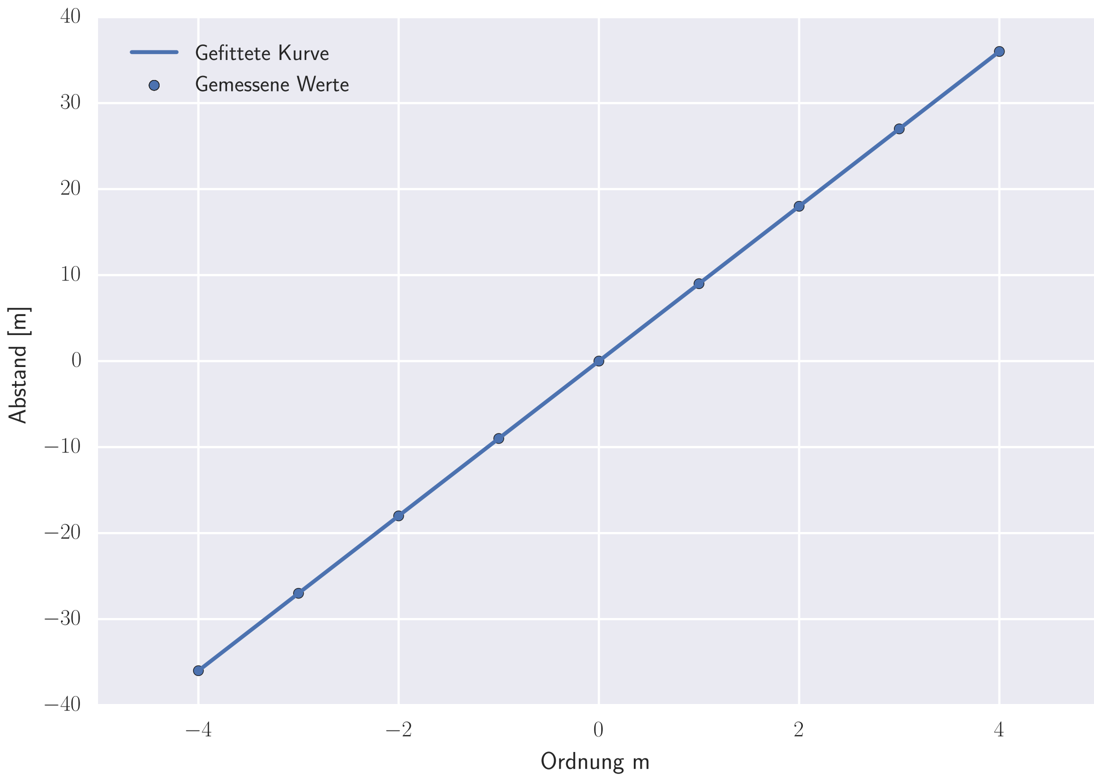
In [8]:
```
# ------ L O C H 7 5 u m ------ #
b = 75e-6 #m

n = np.array([
    -2,
    -1,
    0,
    1,
    2
])

x = [
    -45,
    -27,
    0,
    27,
    45
]
f = 2030

def diffraction(n, b):
    t = np.array([1, 1.22, 2.232, 3.288])
```

```
    return f * np.tan(np.arcsin(np.sign(n)*t[np.abs(n)]*l/b))

v, covar = curve_fit(diffraction, n, x)

b75 = v[0]
f75 = np.sqrt(np.diag(covar))[0]

plt.scatter(n, x, label='Gemessene Werte')
plt.plot(n, diffraction(n, v), label='Gefittete Kurve')
plt.xlabel('Ordnung m')
plt.ylabel('Abstand [m]')
plt.legend(bbox_to_anchor=(0.02, 0.98), loc=2, borderaxespad=0.2)
plt.savefig('loch75')
plt.show()
```



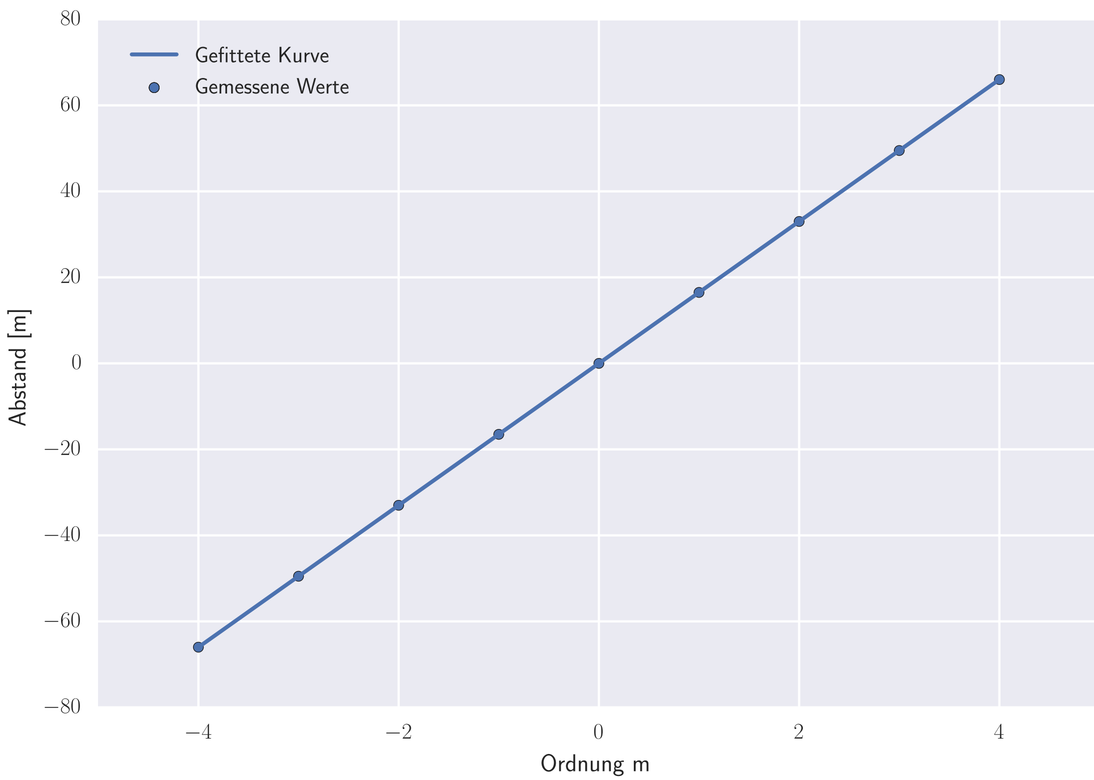

```
In [9]: # ------ P E R I O D I S C H O 50 W 1 0 4 u m ------ #
        b = 50e-6 #m

        n = np.array([
            -4,
            -3,
            -2,
```

```
    -1,
    0,
    1,
    2,
    3,
    4
])

x = [
    -36,
    -27,
    -18,
    -9,
    0,
    9,
    18,
    27,
    36
]
f = 2030

def diffraction(n, b):
    return f * np.tan(np.arcsin(n*l/b))

v, covar = curve_fit(diffraction, n, x)

b50 = v[0]
f50 = np.sqrt(np.diag(covar))[0]

plt.scatter(n, x, label='Gemessene Werte')
plt.plot(n, diffraction(n, v), label='Gefittete Kurve')
plt.xlabel('Ordnung m')
plt.ylabel('Abstand [m]')
plt.legend(bbox_to_anchor=(0.02, 0.98), loc=2, borderaxespad=0.2)
plt.savefig('periodic154.png')
plt.show()
```



In [10]:
```
# ------ P E R I O D I S C H O 28 W 5 0 u m ------ #
b = 28e-6 #m

x = [
    -66,
    -49.5,
    -33,
    -16.5,
    0,
    16.5,
    33,
    49.5,
    66
]
f = 2030

def diffraction(n, b):
    return f * np.tan(np.arcsin(n*l/b))

v, covar = curve_fit(diffraction, n, x)

b28 = v[0]
```

```
f28 = np.sqrt(np.diag(covar))[0]

plt.scatter(n, x, label='Gemessene Werte')
plt.plot(np.linspace(n[0], n[-1], 1000), diffraction(np.linspace(n[0], n[-
plt.xlabel('Ordnung m')
plt.ylabel('Abstand [m]')
plt.legend(bbox_to_anchor=(0.02, 0.98), loc=2, borderaxespad=0.2)
plt.savefig('periodic78.png')
plt.show()
```



In [22]:
```
sy = 0.5
sx = 5

x = 550
y = 66

sd = math.sqrt(
    (4*l*x/(y**2*math.sqrt((y**2 / x**2) + 1)) * sy)**2 +
    (4*l/(y*math.sqrt((y**2 / x**2) + 1)) * sx)**2
)
print(sd)
```

```
        print('{:.2E}±{:.2E}, {:.2E}, {:2f}'.format(b30, f30, math.sqrt(sd**2+f30
        print('{:.2E}±{:.2E}, {:.2E}, {:2f}'.format(b100, f100, math.sqrt(sd**2+f
        print('{:.2E}±{:.2E}, {:.2E}, {:2f}'.format(b124, f124, math.sqrt(sd**2+f
        print('{:.2E}±{:.2E}, {:.2E}, {:2f}'.format(bhaar, fhaar, math.sqrt(sd**2
        print('{:.2E}±{:.2E}, {:.2E}, {:2f}'.format(b150, f150, math.sqrt(sd**2+f
        print('{:.2E}±{:.2E}, {:.2E}, {:2f}'.format(b75, f75, math.sqrt(sd**2+f75
        print('{:.2E}±{:.2E}, {:.2E}, {:2f}'.format(b50, f50, math.sqrt(sd**2+f50
        print('{:.2E}±{:.2E}, {:.2E}, {:2f}'.format(b28, f28, math.sqrt(sd**2+f28
```

```
2.478343943738221e-07
2.82E-05±5.78E-07, 6.29E-07, 2.229621
8.50E-05±2.26E-06, 2.28E-06, 2.678183
1.03E-04±2.40E-06, 2.41E-06, 2.340610
5.23E-05±1.15E-06, 1.17E-06, 2.243173
1.27E-04±2.19E-06, 2.21E-06, 1.736531
6.23E-05±1.26E-06, 1.28E-06, 2.052618
1.43E-04±2.42E-09, 2.48E-07, 0.173625
7.79E-05±4.43E-09, 2.48E-07, 0.318261
```

1 Fehlerrechnung

Wir schätzen, dass die Brennweite f nur auf 5mm genau eigestellt wurde, da die Linsenmitte nicht immer korrekt eingestellt werden konnte. Zudem war auch sonst die Anlage ein wenig schwer zu vermessen. Zudem nehmen wir an dass wir die Interferenzmuster auf 0.5mm genau ausmessen konnten.

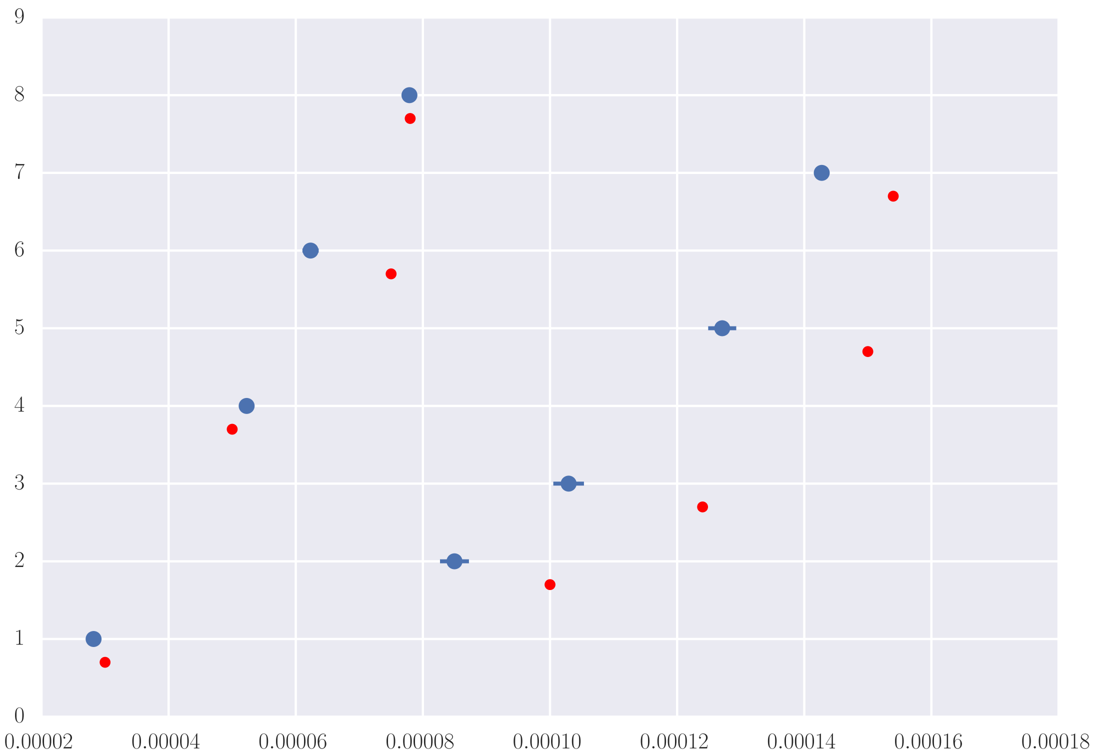
Damit müssen wir die Formel für den Fit
d = l/(sin(tan^-1(f/y))
nach f, der einzigen gemessenen Grösse ableiten was
derive d = l/(sin(tan^-1(f/y))
ergibt.
Somit ergibt sich dann der fortgepflanzte Fehler als
s_d = sqrt((dd/dy*s_y)^2 + (dd/df*s_f)^2)

```
In [23]: x1 = [
             b30,
             b100,
             b124,
             bhaar,
             b150,
             b75,
             b50,
             b28
         ]
         x2 = [
             30e-6,
             100e-6,
             124e-6,
```

```
        50e-6,
        150e-6,
        75e-6,
        154e-6,
        78e-6
    ]
    xerr = [
        math.sqrt(sd**2+f30**2),
        math.sqrt(sd**2+f100**2),
        math.sqrt(sd**2+f124**2),
        math.sqrt(sd**2+fhaar**2),
        math.sqrt(sd**2+f150**2),
        math.sqrt(sd**2+f75**2),
        math.sqrt(sd**2+f50**2),
        math.sqrt(sd**2+f28**2),
    ]
    labels=[
        'Spalt (b=30um)',
        'Spalt (b=100um)',
        'Antispalt (b=124um)',
        'Haar (b=50um)',
        'Loch (b=75um)',
        'Loch (b=150um)',
        'Gitter (b=50um, 2=104)',
        'Gitter (b=28um, w=50)',
    ]
    y1 = np.linspace(1, 8, 8)
    y2 = np.linspace(0.7, 7.7, 8)
    plt.errorbar(x1, y1, xerr=xerr, fmt='o', label='errechnet')
    plt.scatter(x2, y2, color='red', label='Soll')
    plt.yticks(y, labels, rotation='horizontal')
    plt.ylim((-1, 9))
    plt.xlabel('Gitterkonstante [m]')
    plt.savefig('results.png')
    plt.show()
```

```
   ---------------------------------------------------------------------------

   TypeError                                 Traceback (most recent call last)

   <ipython-input-23-3e23145977f4> in <module>()
    43 plt.errorbar(x1, y1, xerr=xerr, fmt='o', label='errechnet')
    44 plt.scatter(x2, y2, color='red', label='Soll')
---> 45 plt.yticks(y, labels, rotation='horizontal')
    46 plt.ylim((-1, 9))
    47 plt.xlabel('Gitterkonstante [m]')
```

```
/Library/Frameworks/Python.framework/Versions/3.5/lib/python3.5/site-packag
   1712         labels = ax.get_yticklabels()
   1713     elif len(args)==2:
-> 1714         locs = ax.set_yticks(args[0])
   1715         labels = ax.set_yticklabels(args[1], **kwargs)
   1716     else: raise TypeError('Illegal number of arguments to yticks')


/Library/Frameworks/Python.framework/Versions/3.5/lib/python3.5/site-packag
   3111             Sets the minor ticks if *True*
   3112         """
-> 3113         ret = self.yaxis.set_ticks(ticks, minor=minor)
   3114         return ret
   3115 


/Library/Frameworks/Python.framework/Versions/3.5/lib/python3.5/site-packag
   1593         # XXX if the user changes units, the information will be lost h
   1594         ticks = self.convert_units(ticks)
-> 1595         if len(ticks) > 1:
   1596             xleft, xright = self.get_view_interval()
   1597             if xright > xleft:


TypeError: object of type 'int' has no len()
```


9
8
7
6
5
4
3
2
1
0
0.00002
0.00004
0.00006
0.00008
0.00010
0.00012
0.00014
0.00016
0.00018