linear_gradientcopia

October 17, 2024

Using the commit 5a24ee841144107f8ba268f433ba13c78d59e847 in GIT, I have obtained the following results.

1 Linear gradient along x

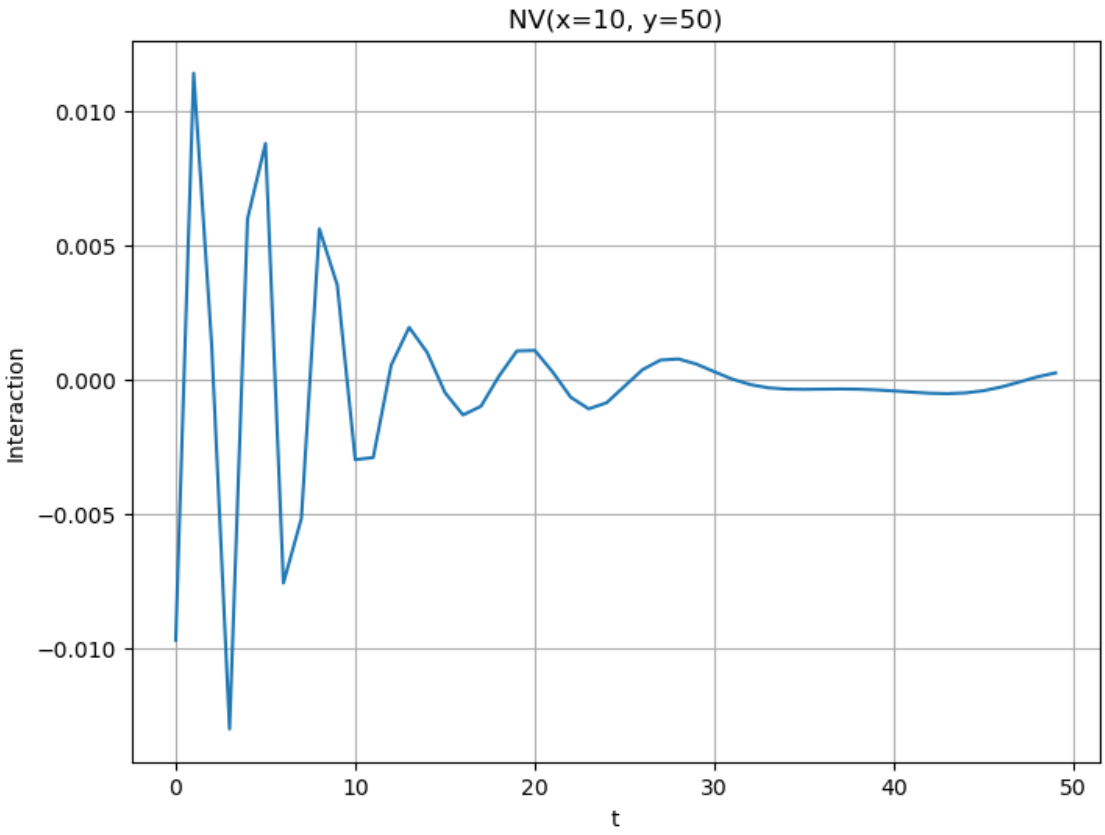
To check if the code properly works, I simulated an ensemble of protons that starts on the left edge of the chip and diffuses along x to the right edge in the presence of a strong linear magnetic field gradient, given by:

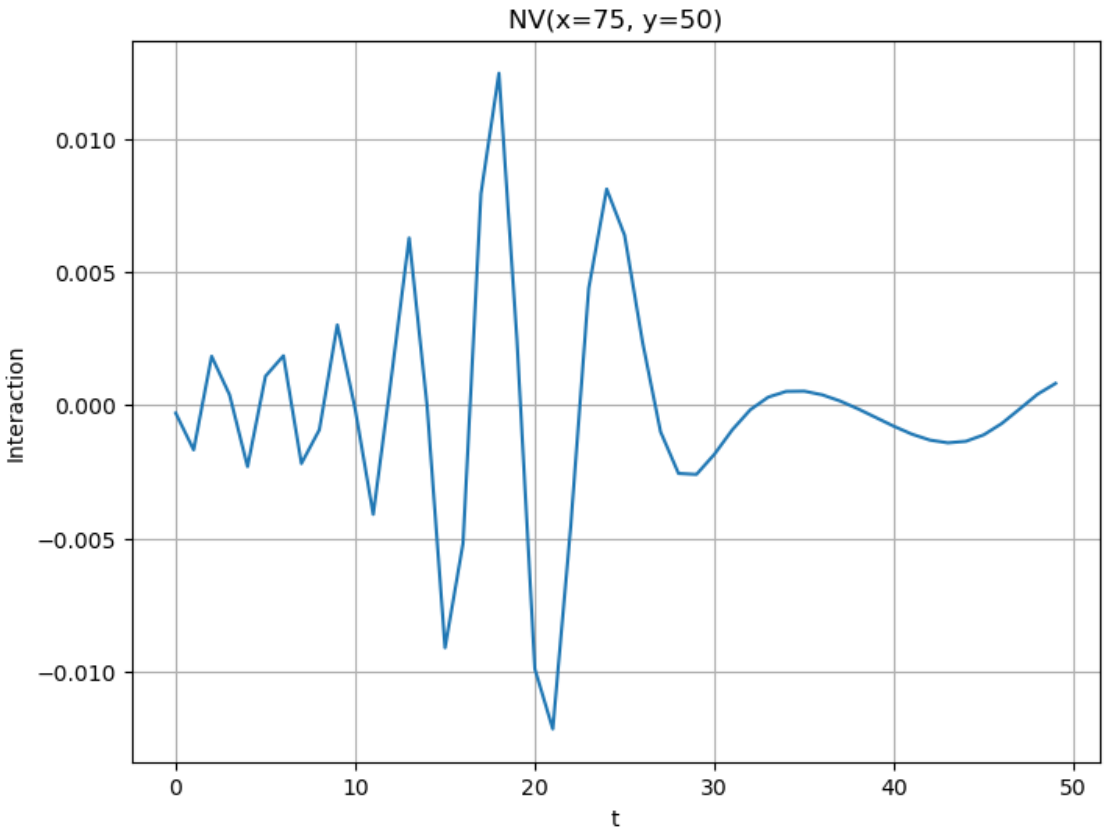
$$\vec{B}(x, y, z) = \vec{B_0} + B_x(x - x_0)\hat{x} \tag{1}$$

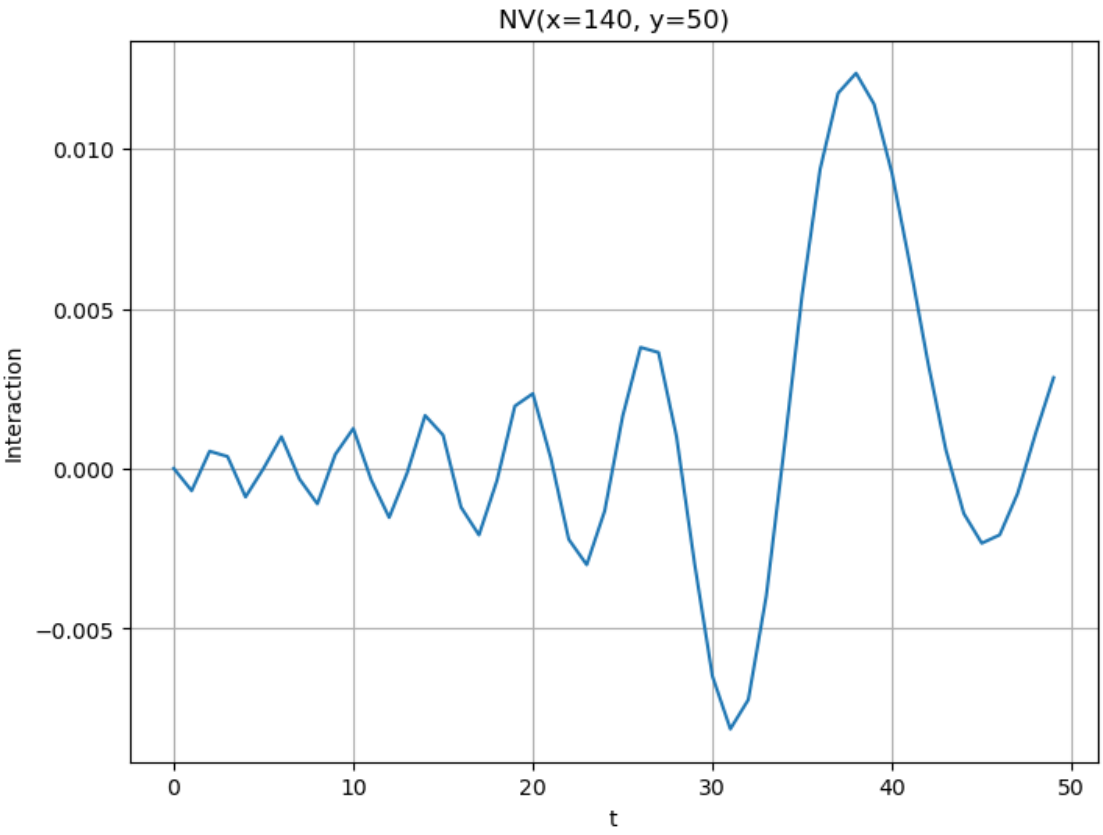
with $B_x = 1T/mm$ ($B_y = B_z = 0$), $|B_0| = 85mT$ and $x_0 = 0.75mm$ (the area of the chip is 1x1 mm^2).

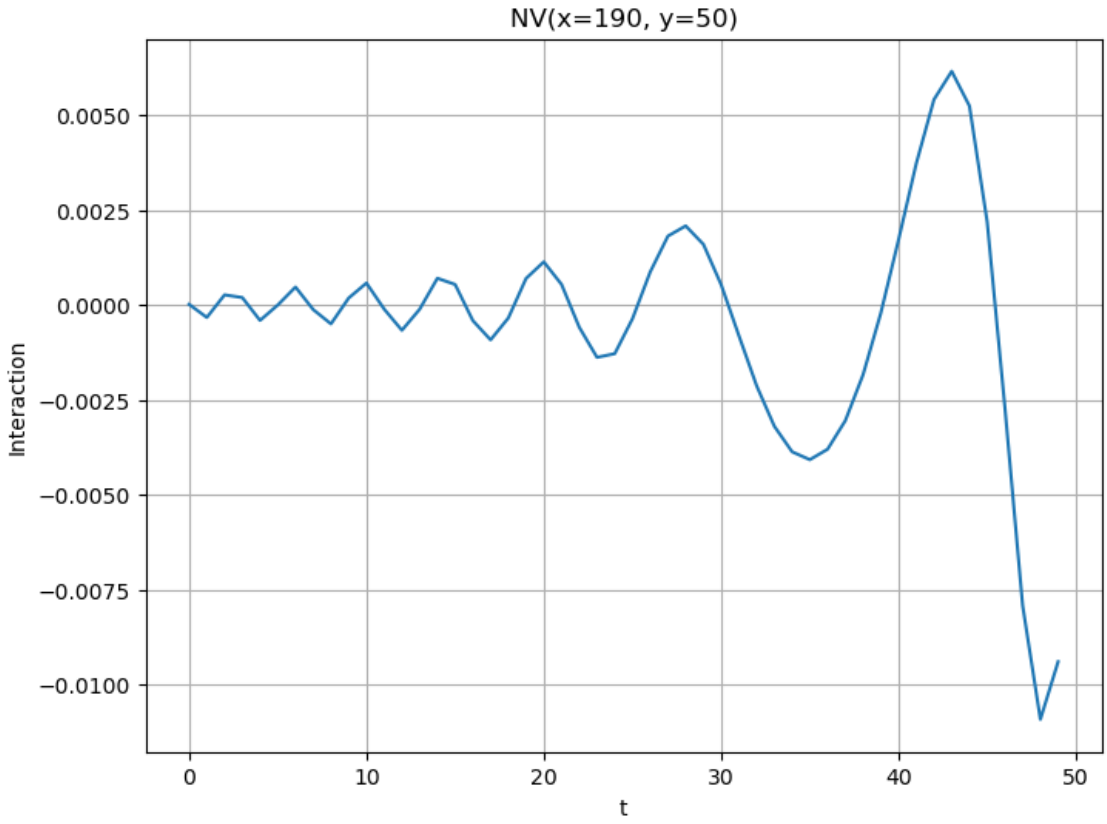
In this scatter plot, we can observe the interaction between the protons and the NV centers at different time steps.

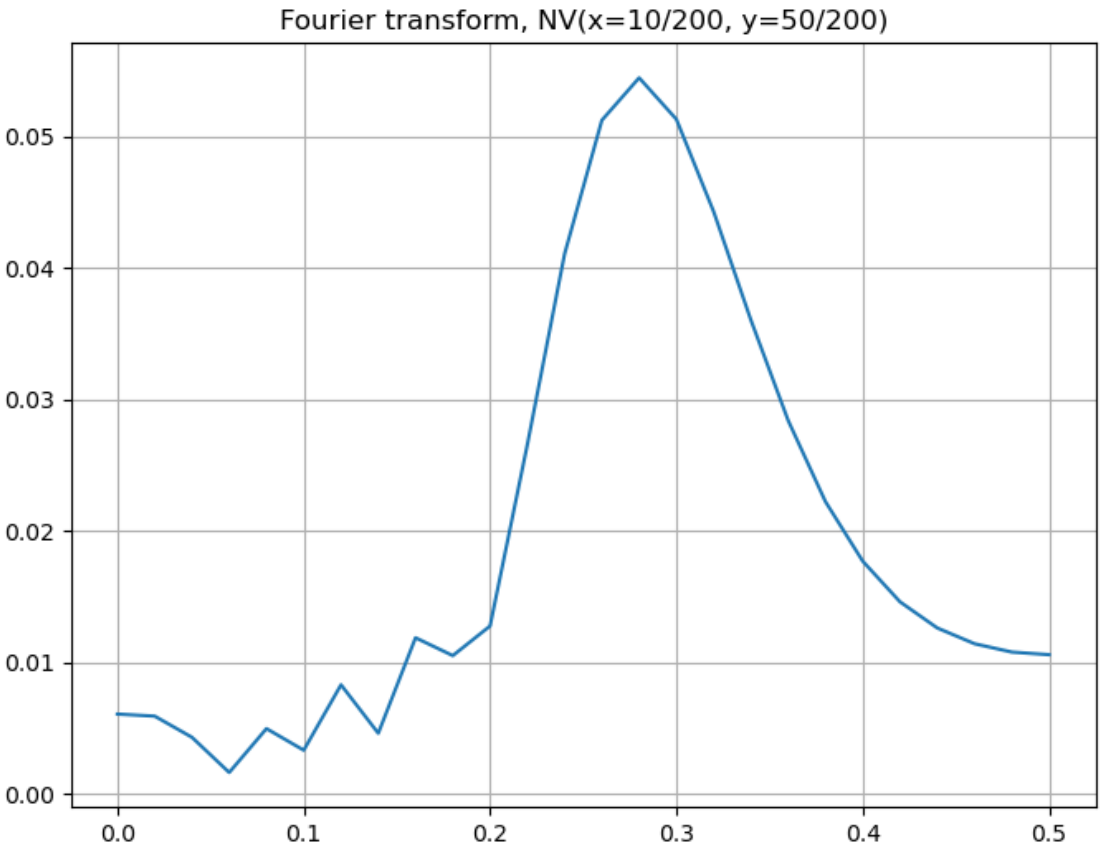
In these figures, I plotted the time evolution of the interaction for different NV centers with the same y coordinate and different x.

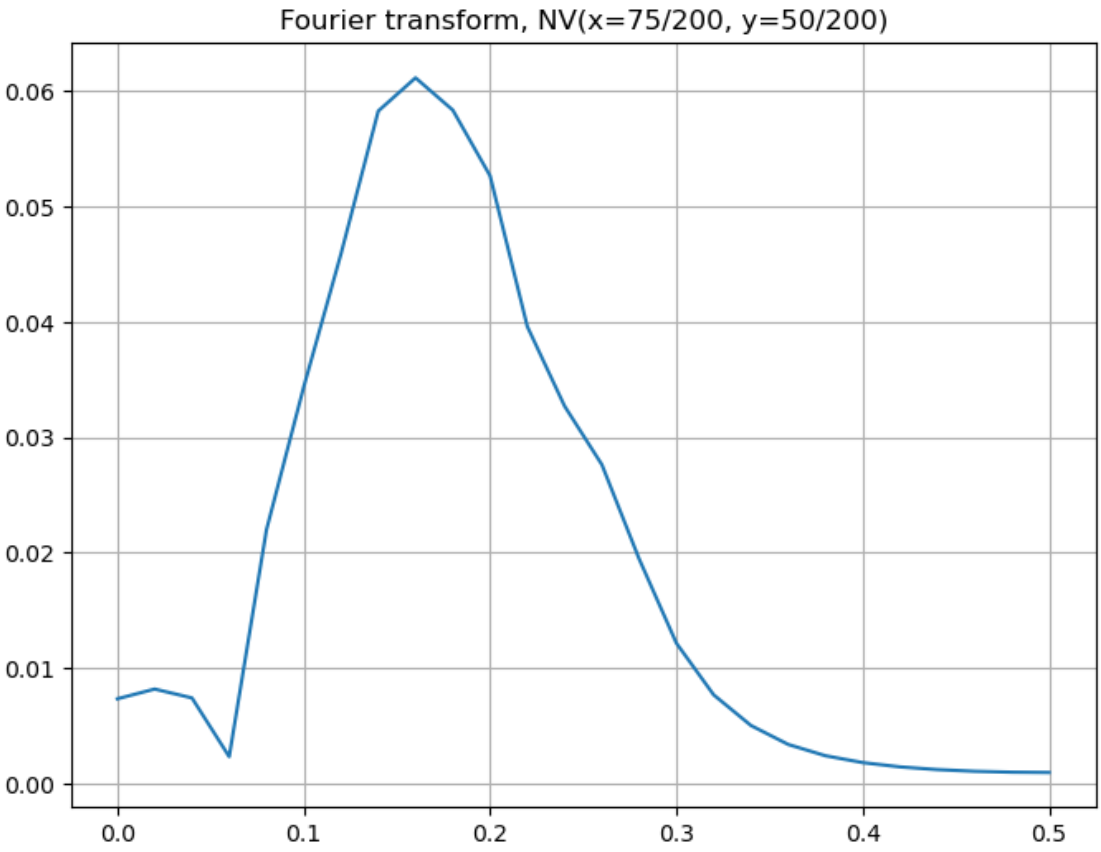

NV(x=10, y=50)
0.010
0.005
0.000
−0.005
−0.010
Interaction
0
10
20
30
40
50
t

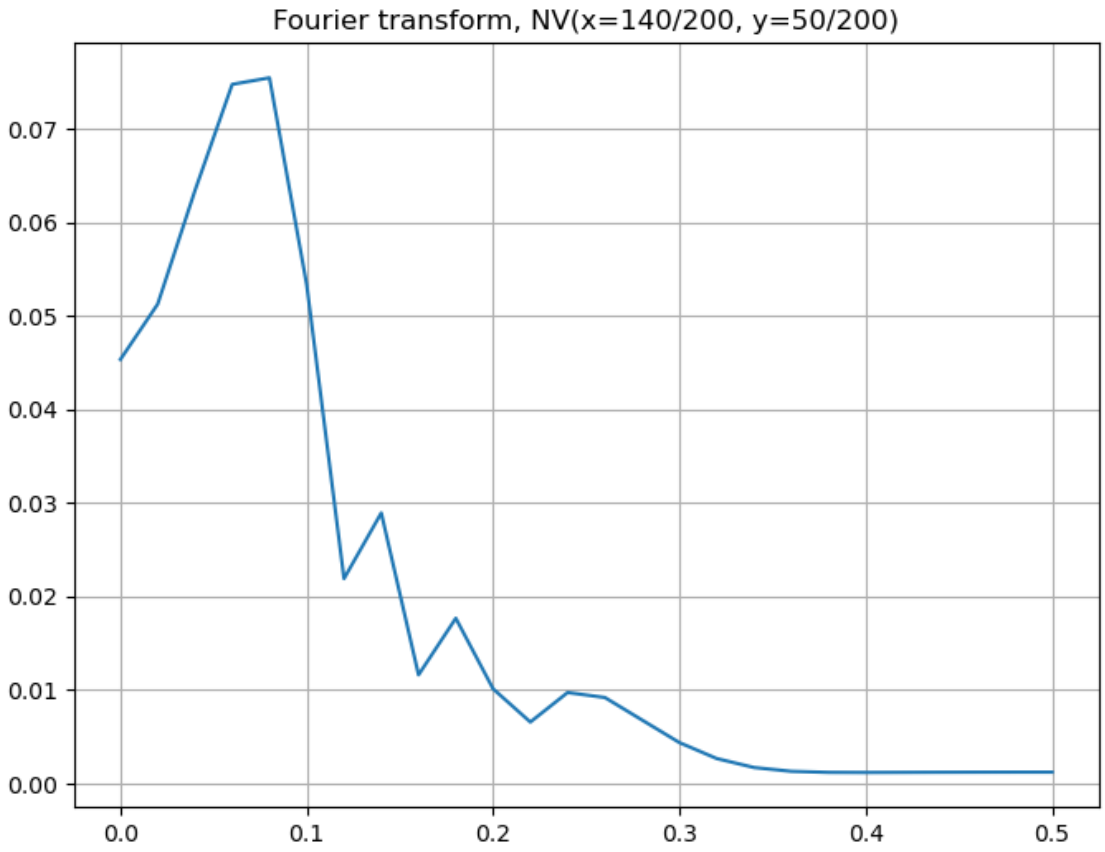

NV(x=75, y=50)
Interaction
0.010
0.005
0.000
−0.005
−0.010
0
10
20
30
40
50
t

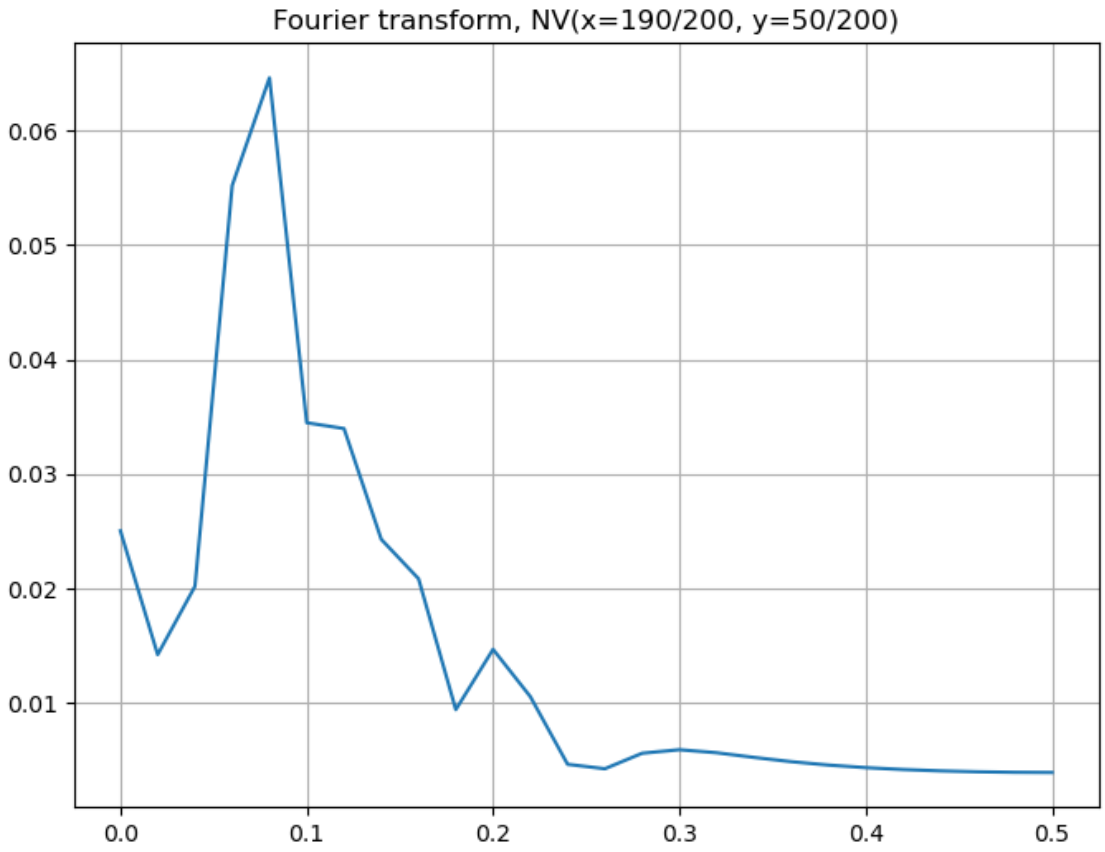

NV(x=140, y=50)
0.010
0.005
0.000
−0.005
Interaction
0
10
20
30
40
50
t


NV(x=190, y=50)
0.0050
0.0025
0.0000
−0.0025
−0.0050
−0.0075
−0.0100
Interaction
0
10
20
30
40
50
t

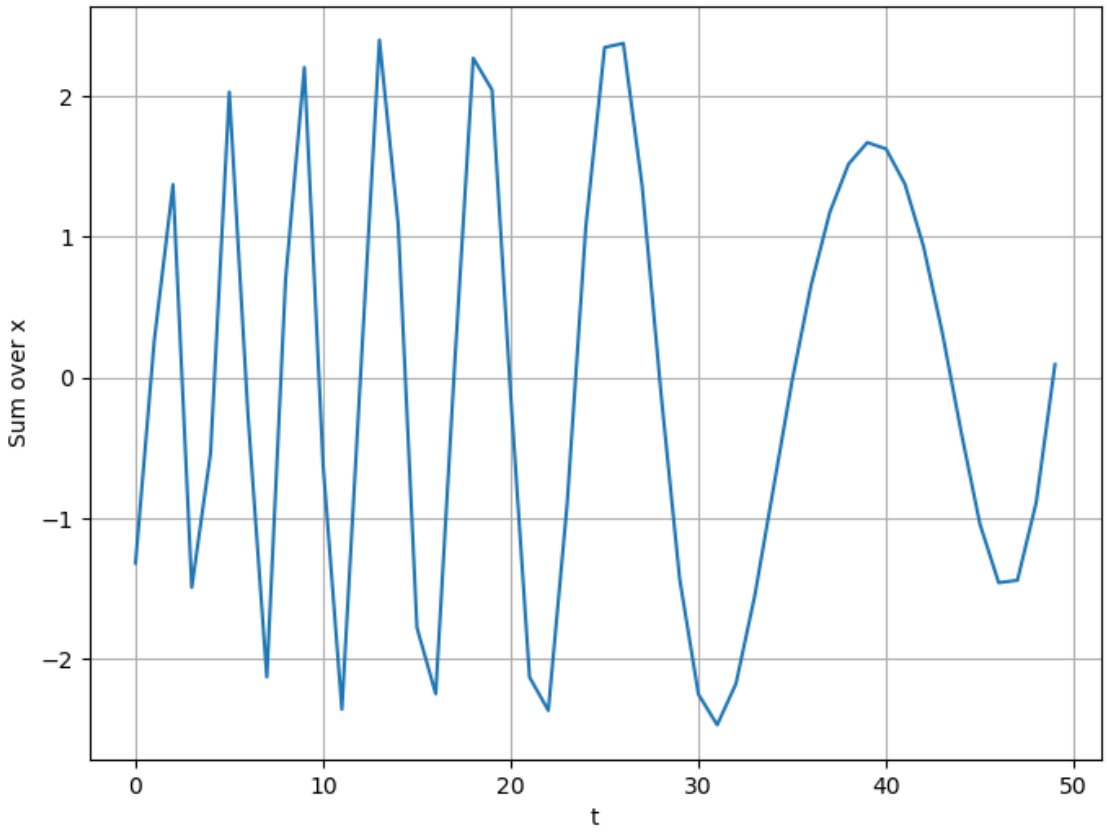

Fourier transform, NV(x=10/200, y=50/200)
0.05
0.04
0.03
0.02
0.01
0.00
0.0
0.1
0.2
0.3
0.4
0.5


Fourier transform, NV(x=75/200, y=50/200)
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.0
0.1
0.2
0.3
0.4
0.5

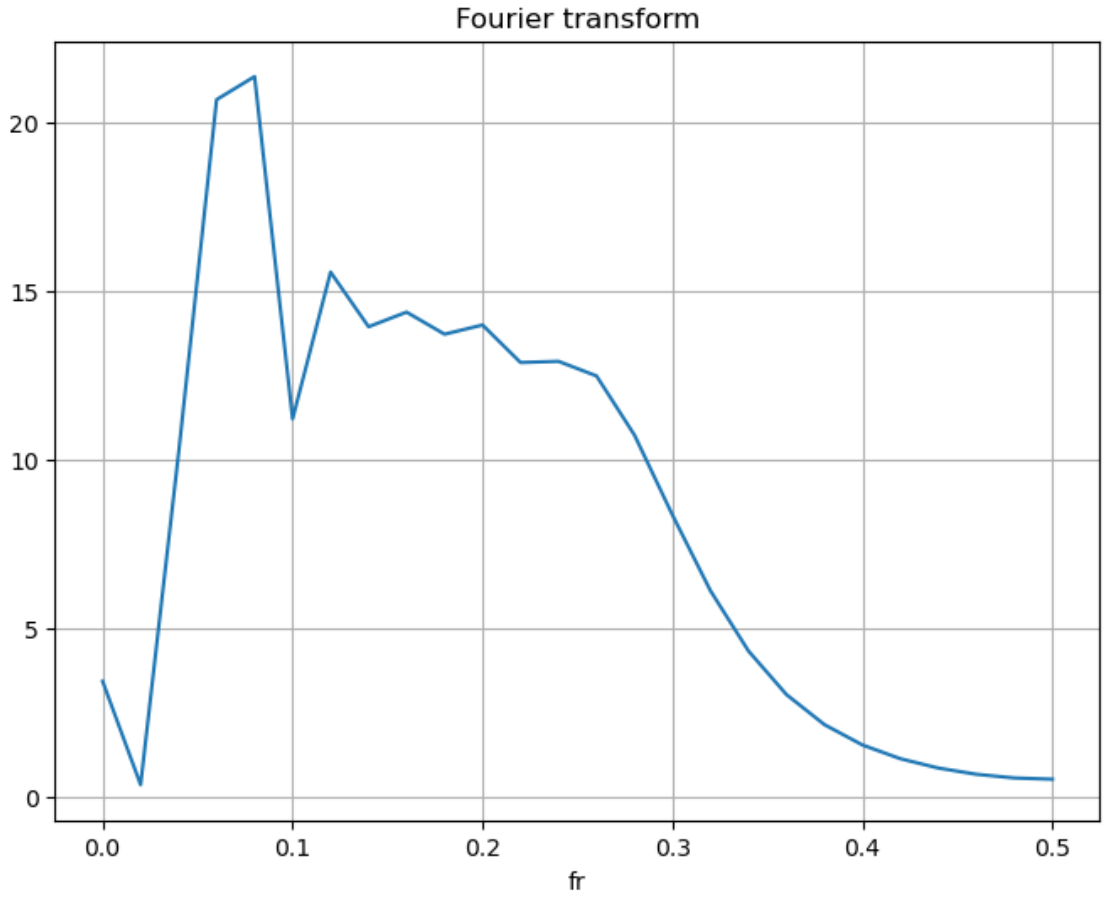

Fourier transform, NV(x=140/200, y=50/200)
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.0
0.1
0.2
0.3
0.4
0.5



If we sum up the interaction of all the NV centers in the same row, we can observe how the frequency changes over time (we can observe the same thing in the previous animation). It happens due to the strong magnetic field gradient.



From the Fourier transform, we can observe that we don't obtain a single narrow peak as we would expect for an oscillation with a constant frequency but a broad peak. It means that the frequency varies over time.



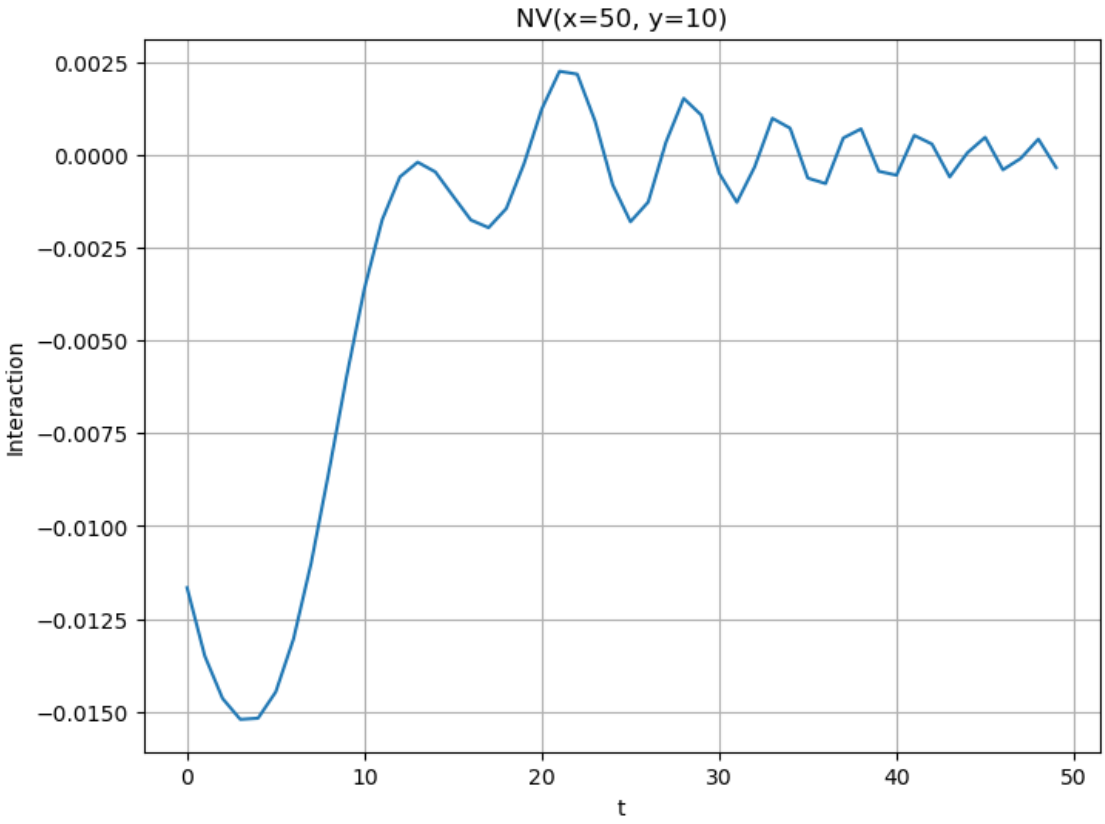
2 Linear gradient along y

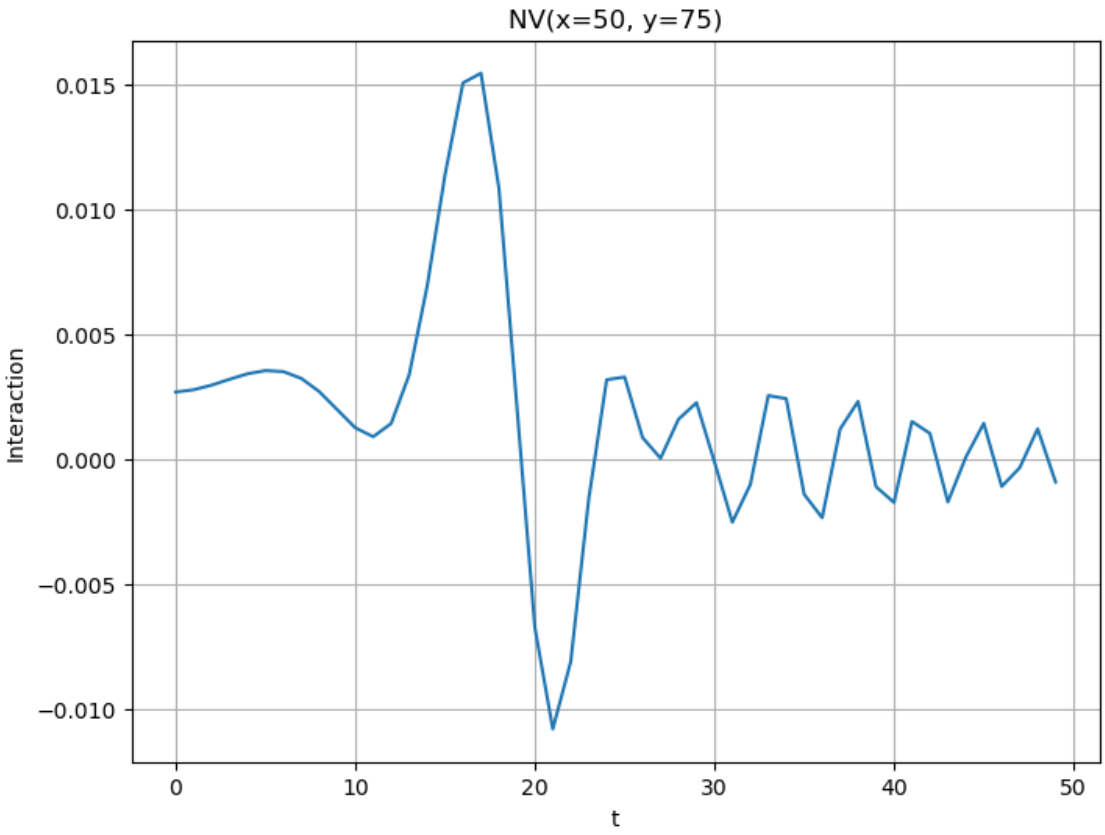
I also simulated an ensemble of protons that starts on the bottom edge of the chip and diffuses along y to the upper edge in the presence of a strong linear magnetic field gradient, given by:

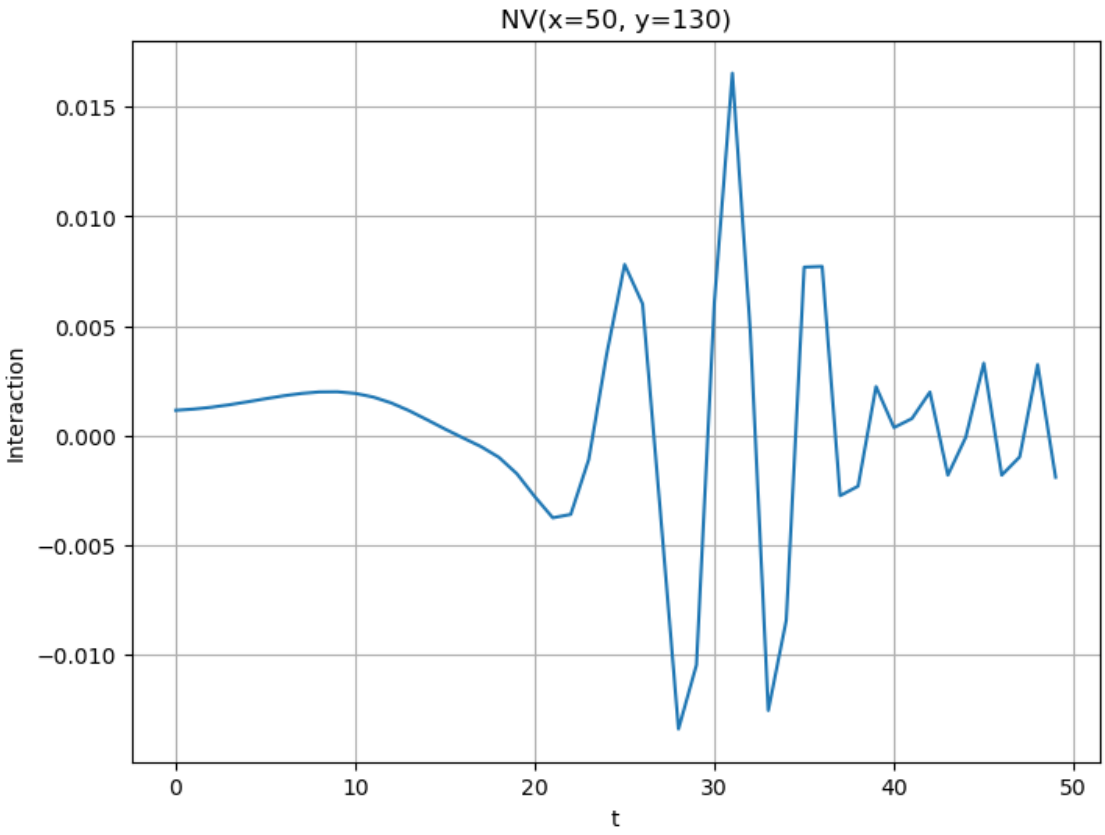
$$\vec{B}(x,y,z) = \vec{B_0} + B_y(y - y_0)\hat{y} \tag{2}$$

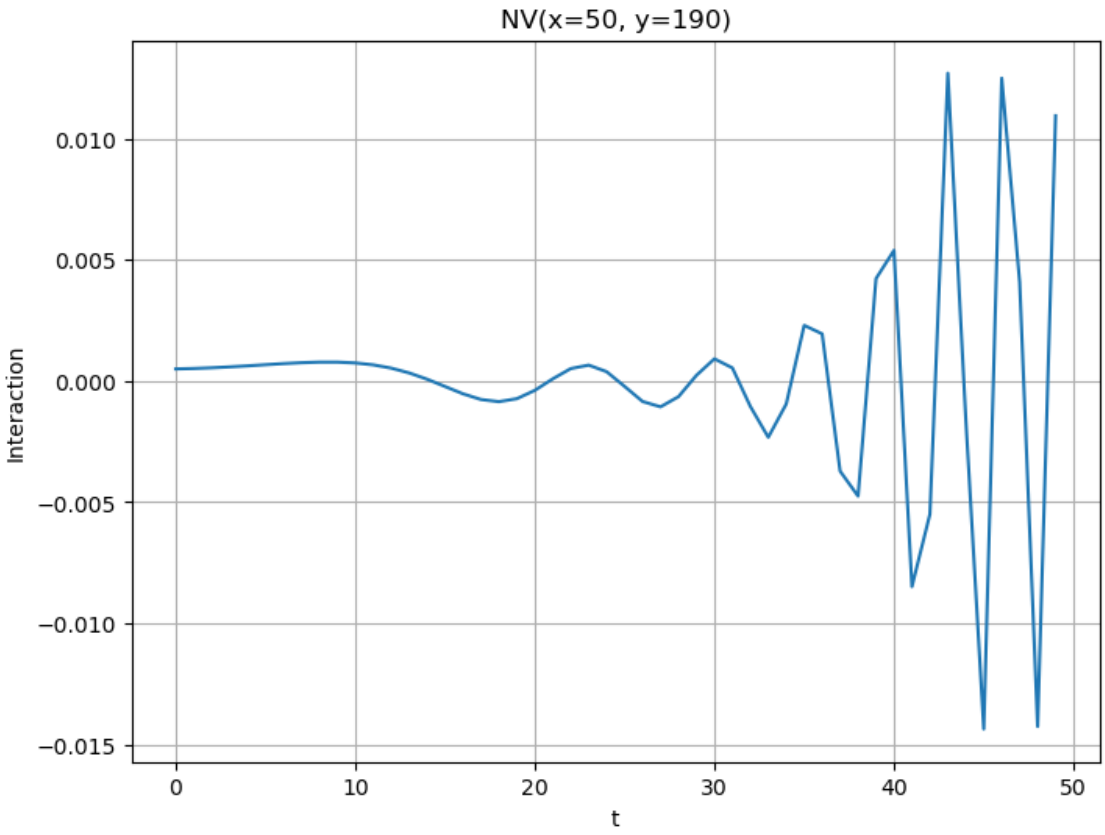
with $B_y = -1T/mm$ ($B_y = B_z = 0$), $|B_0| = 85mT$ and $y_0 = 0.2mm$.

As expected, the results are analogous to the previous section.

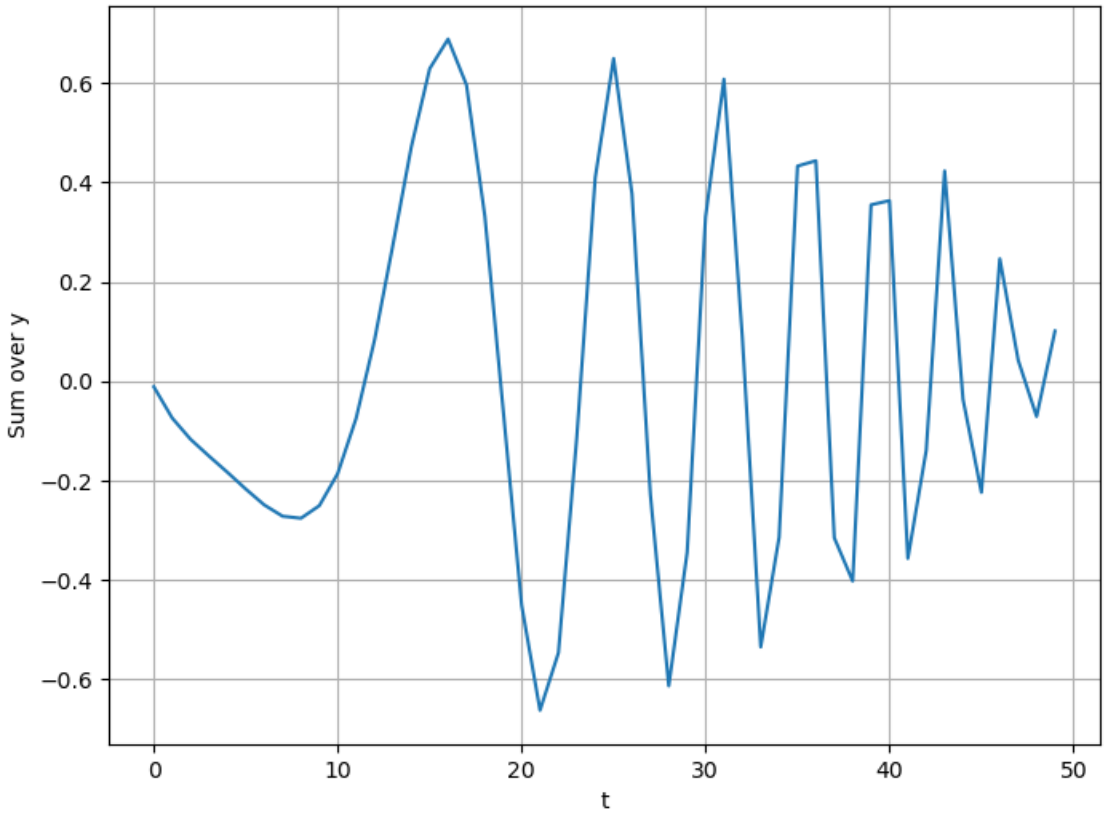

NV(x=50, y=10)
0.0025
0.0000
−0.0025
−0.0050
−0.0075
−0.0100
−0.0125
−0.0150
Interaction
0
10
20
30
40
50
t

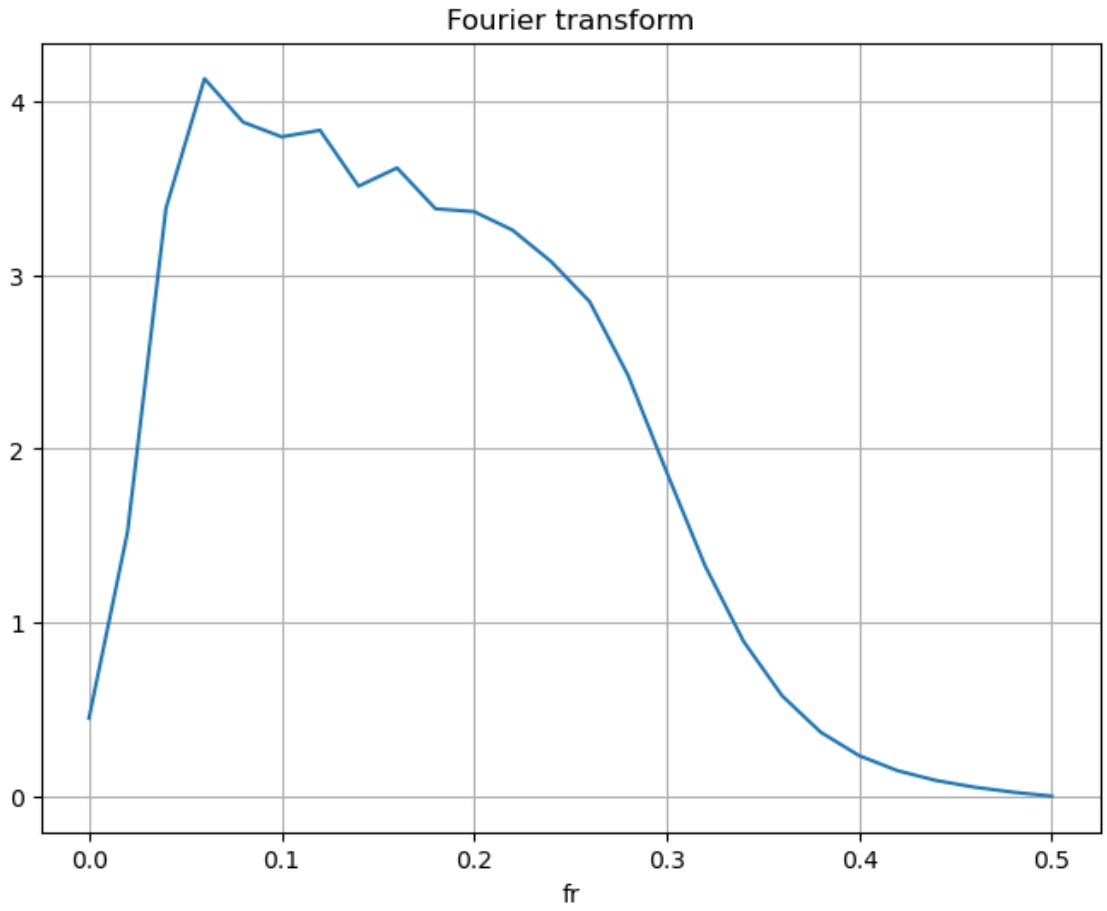

NV(x=50, y=75)
0.015
0.010
0.005
0.000
−0.005
−0.010
Interaction
0
10
20
30
40
50
t


NV(x=50, y=130)
Interaction
t
0.015
0.010
0.005
0.000
−0.005
−0.010
0
10
20
30
40
50

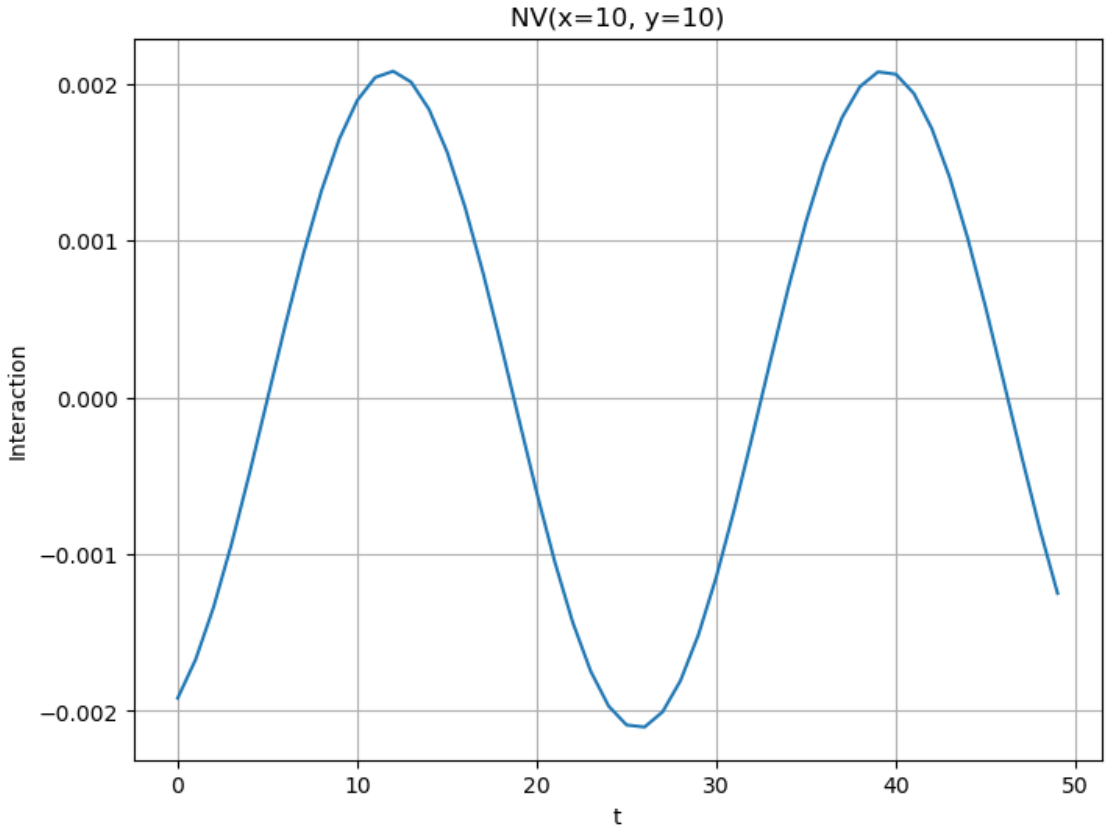


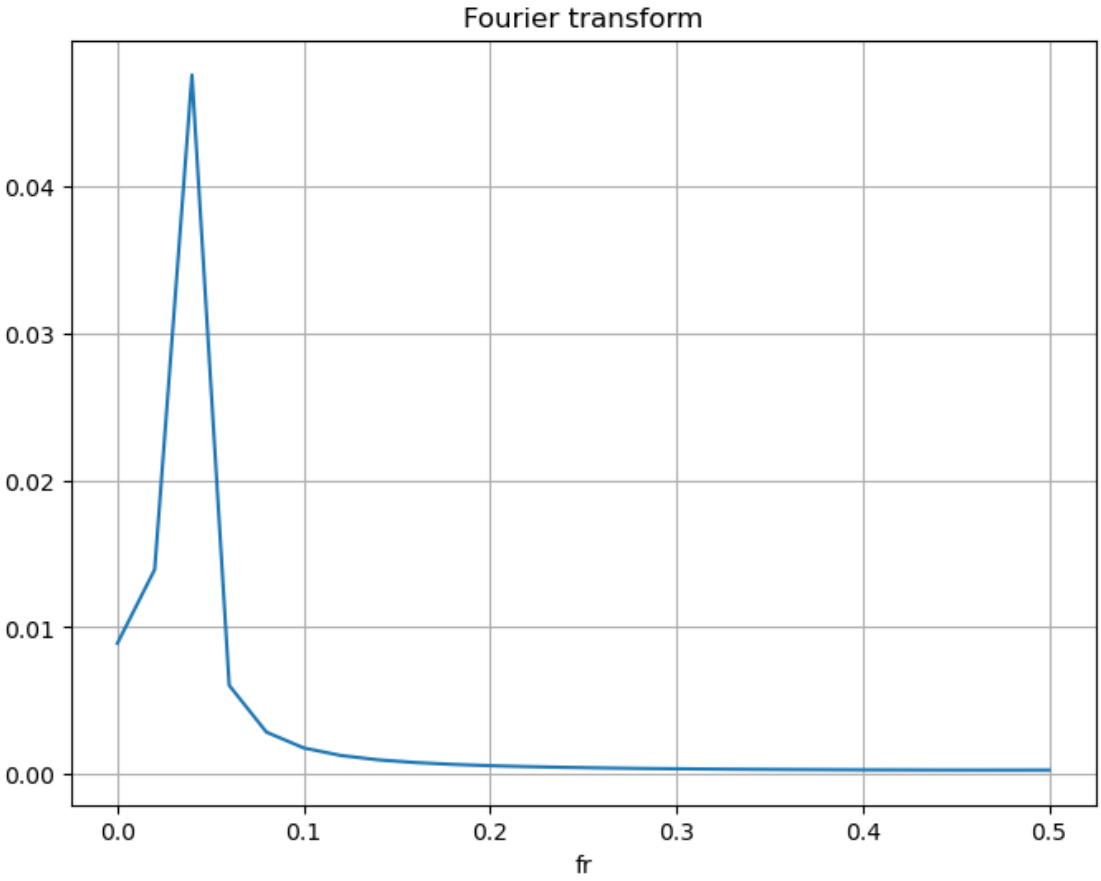
Sum over the same column.

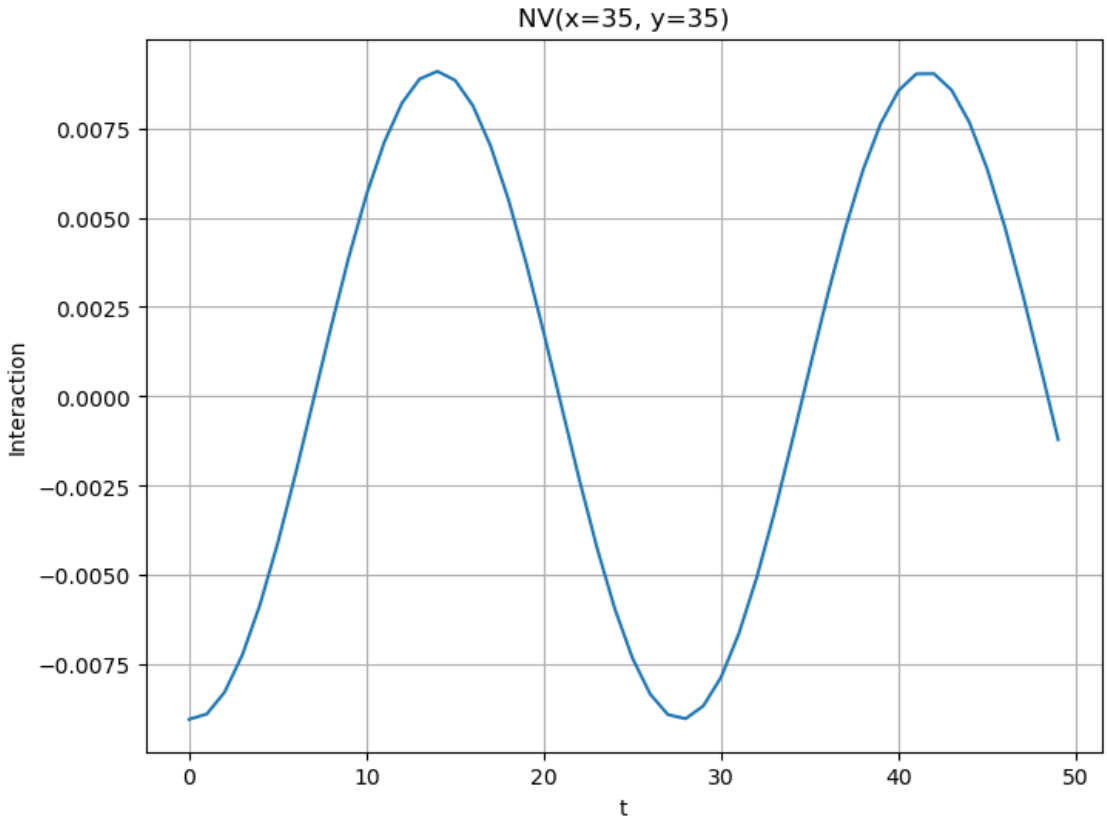

0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Sum over y
0
10
20
30
40
50
t

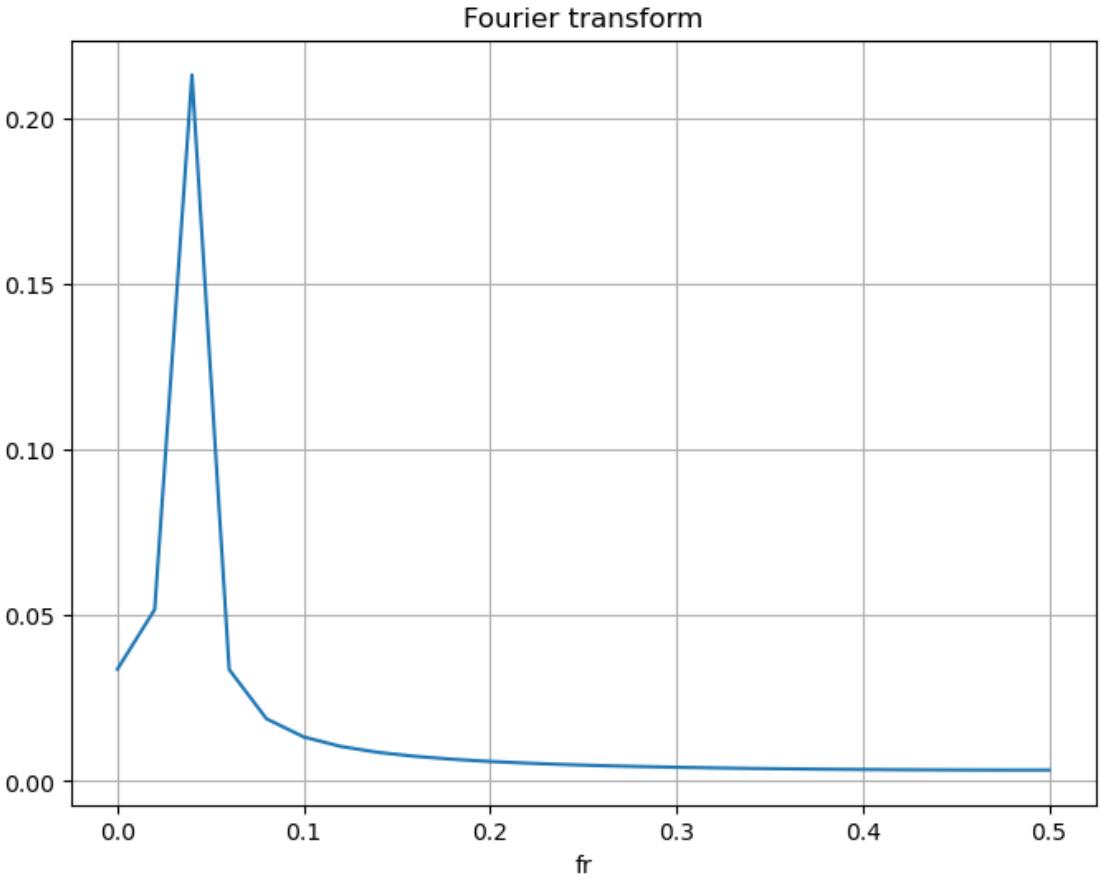

Fourier transform
4
3
2
1
0
0.0
0.1
0.2
0.3
0.4
0.5
fr

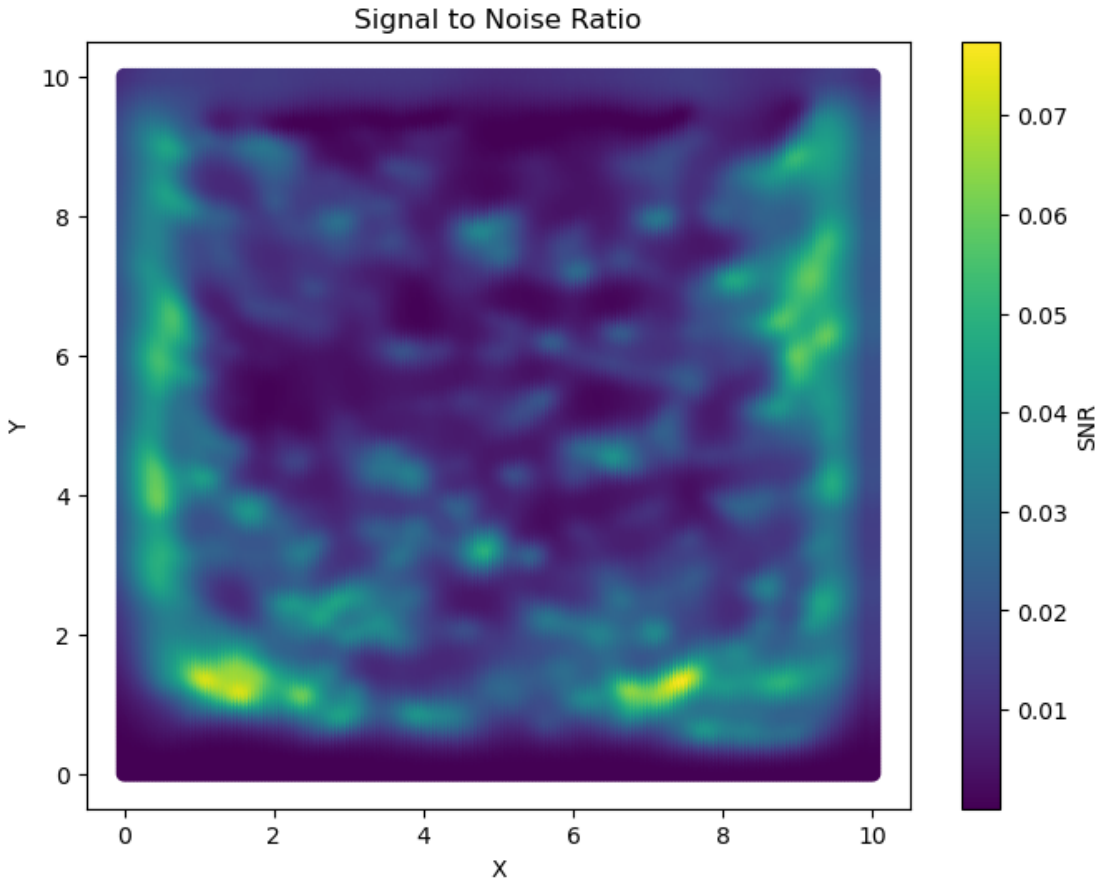
3 Simulation of 4000 protons which diffuse with a Brownian motion in a small mangetic field gradient



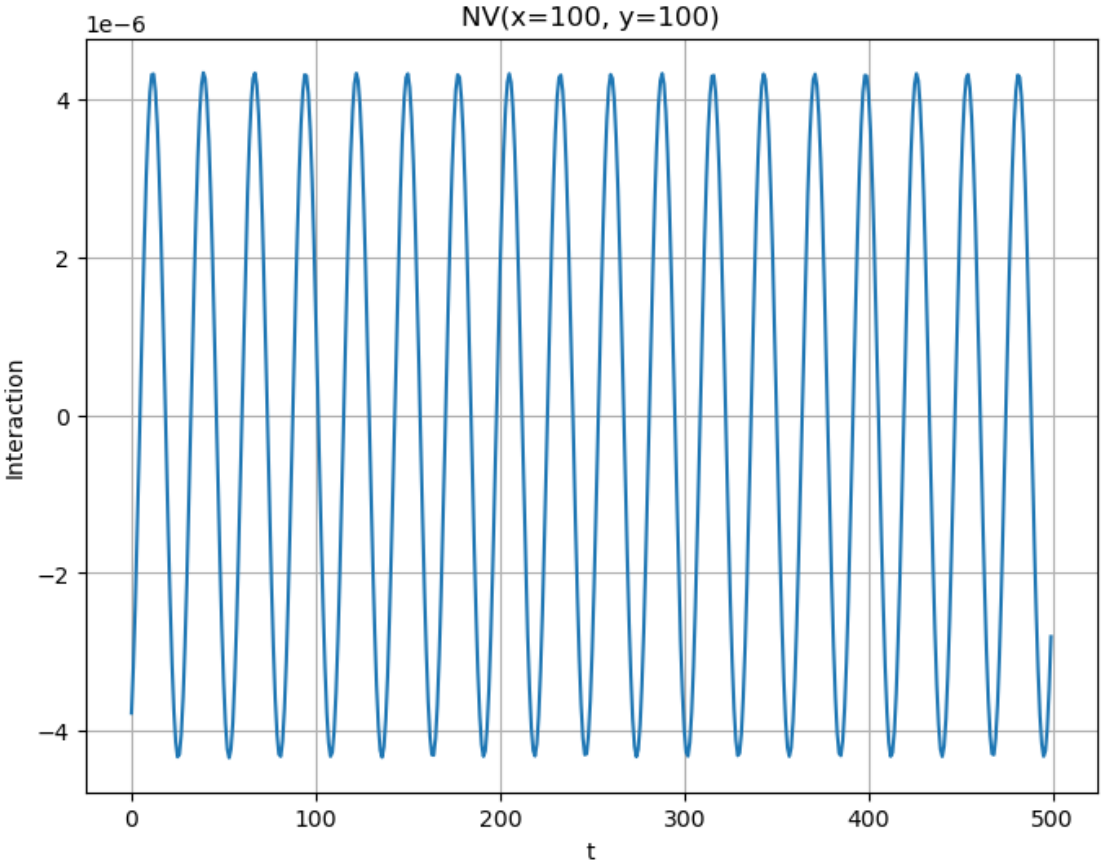

Fourier transform
0.04
0.03
0.02
0.01
0.00
0.0
0.1
0.2
0.3
0.4
0.5
fr

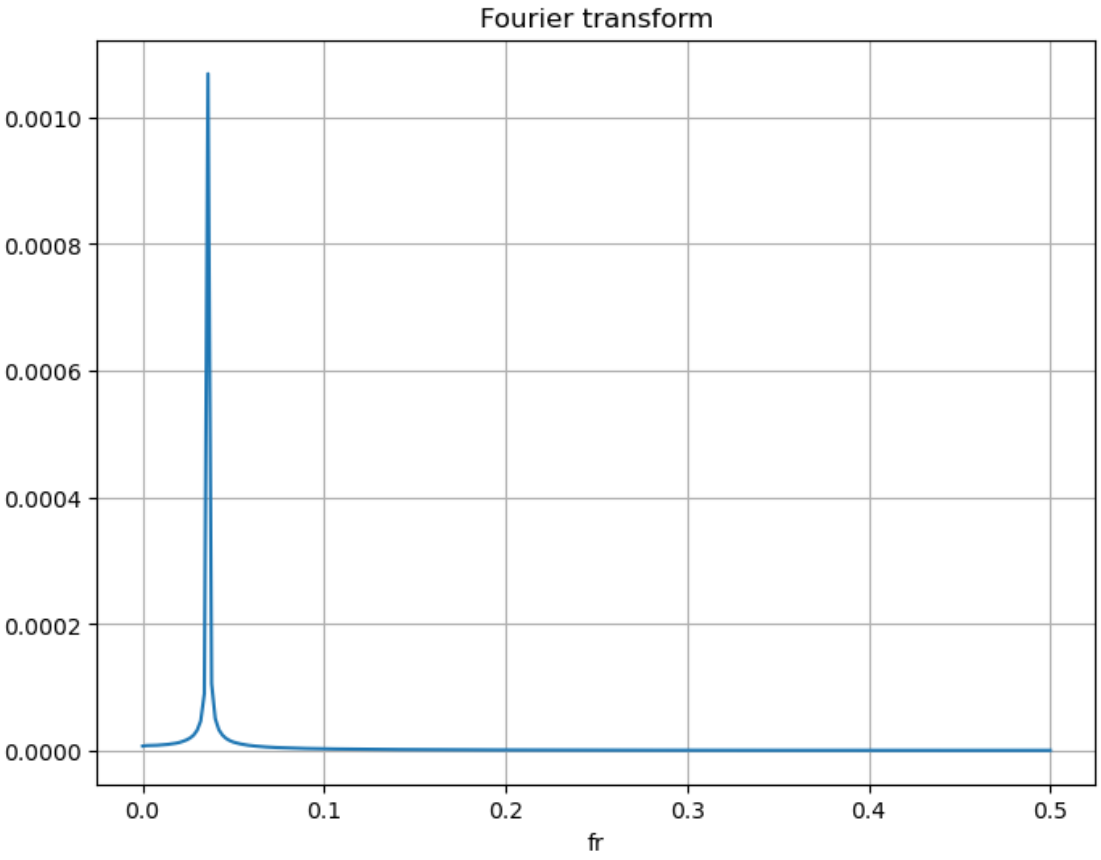

NV(x=35, y=35)
Interaction
0.0075
0.0050
0.0025
0.0000
−0.0025
−0.0050
−0.0075
0
10
20
30
40
50
t

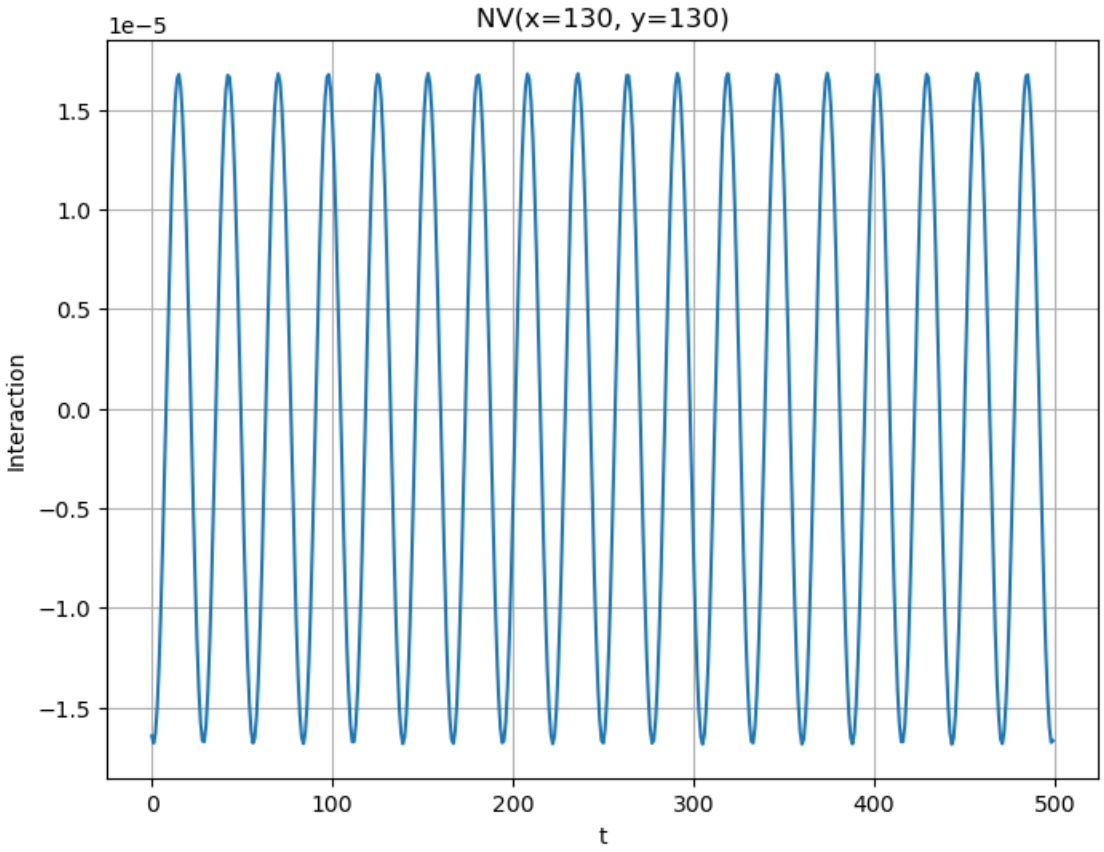

Fourier transform
0.20
0.15
0.10
0.05
0.00
0.0
0.1
0.2
0.3
0.4
0.5
fr

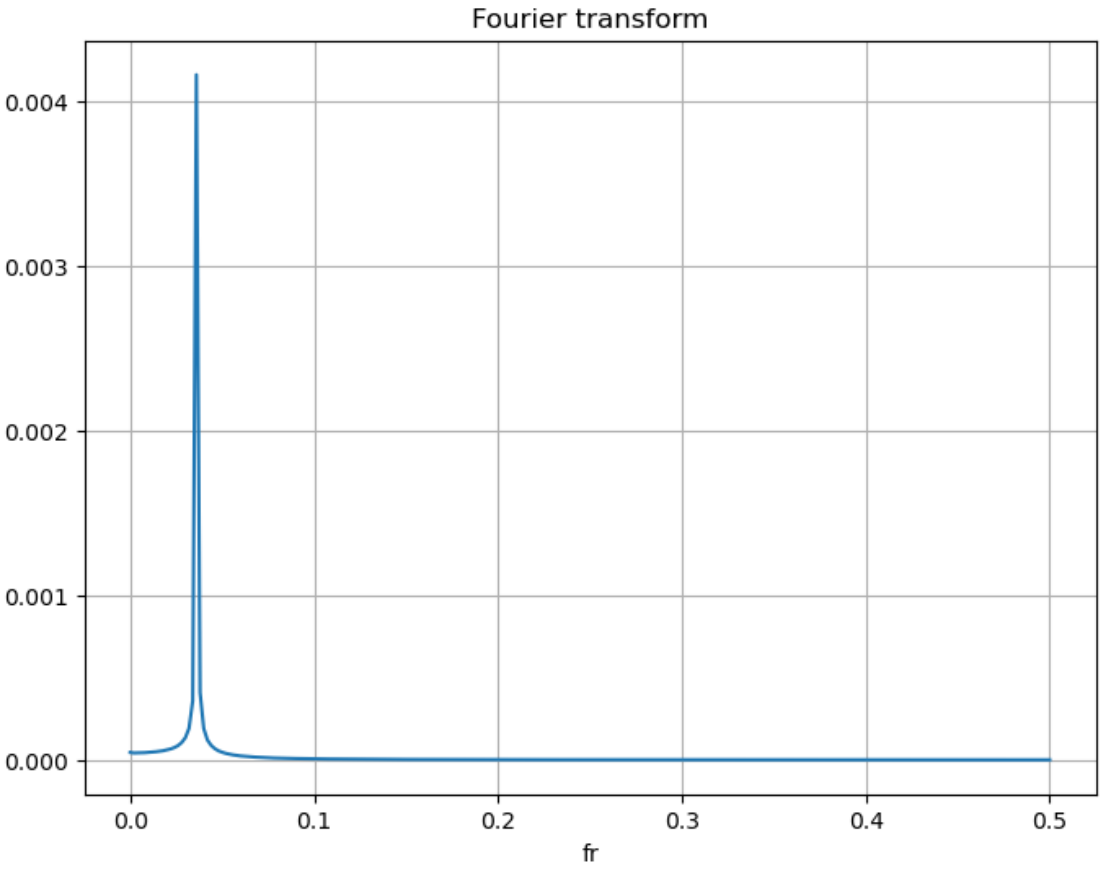

Signal to Noise Ratio
Y
X
SNR
0
2
4
6
8
10
0.01
0.02
0.03
0.04
0.05
0.06
0.07

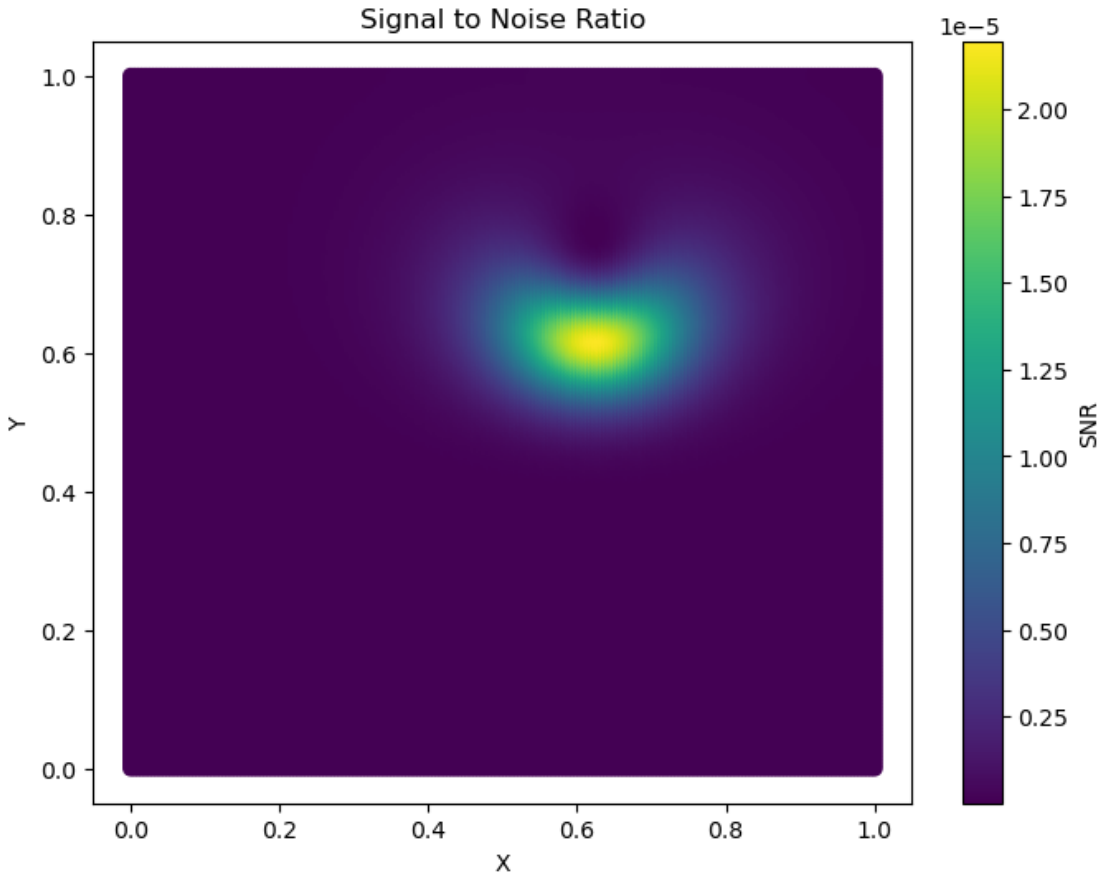
4 Single proton




Fourier transform
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0.0
0.1
0.2
0.3
0.4
0.5
fr


NV(x=130, y=130)
1e−5
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
Interaction
0
100
200
300
400
500
t


Fourier transform
0.004
0.003
0.002
0.001
0.000
0.0
0.1
0.2
0.3
0.4
0.5
fr


Signal to Noise Ratio
1e−5
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
SNR
1.0
0.8
0.6
0.4
0.2
0.0
Y
0.0
0.2
0.4
0.6
0.8
1.0
X