Magnetic Particle Imagining with a Cantilever Detector

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Abstract

We present a novel and potentially quantitative method that determines the magnetization of single micro scale particles. Our technique uses a standard Magnetic Force Microscopy setup, with an opposing field along with the magnetic field from the tip, varies the magnetic field that the particle being measured experiences. This magnetic field setup forms a zero field pocket, saturating other nearby particles, and thus, isolating the signal of the particle of interest. By driving the cantilever at half its resonance frequency and using a lock-in for 2nd harmonic detection on the cantilever resonance, we can isolate the signal from drive, increasing the sensitivity of the technique. We are able to precisely determine the particles distance from the cantilever through a single fit of the force response of the cantilever as a function of distance away from the sample. Utilizing a local moment model for the response of our sample particle we are able to extract an m-H curve for the particle, which has the same shape as bulk measurements of the sample material.

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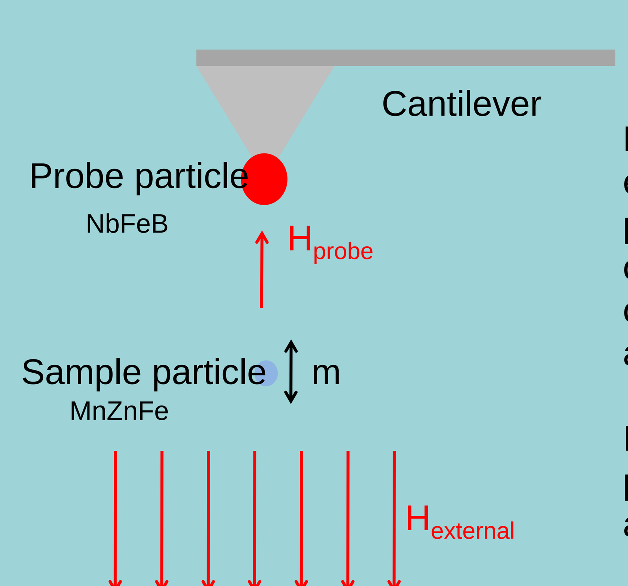
Introduction

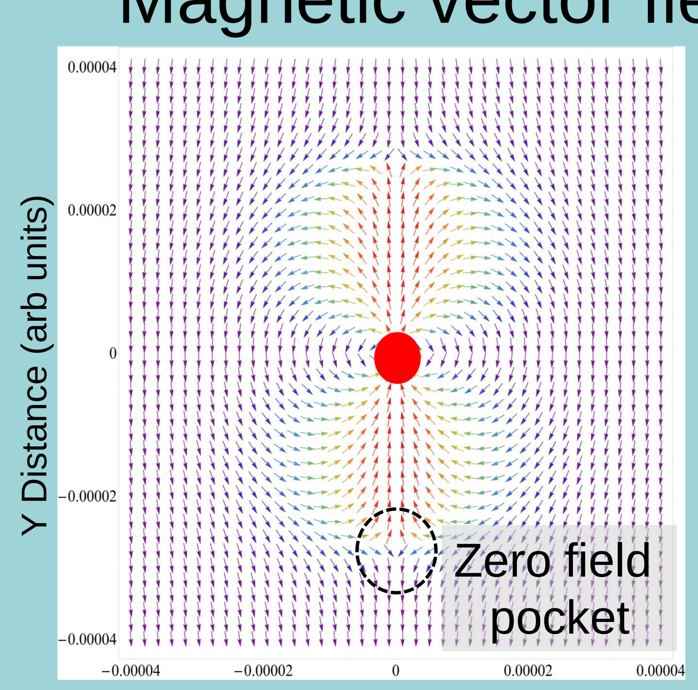
Cantilever Detection Configuration



By placing a magnet on the end of a cantilever and placing it in an external opposing field we can control the magnetic field at a point in-between.

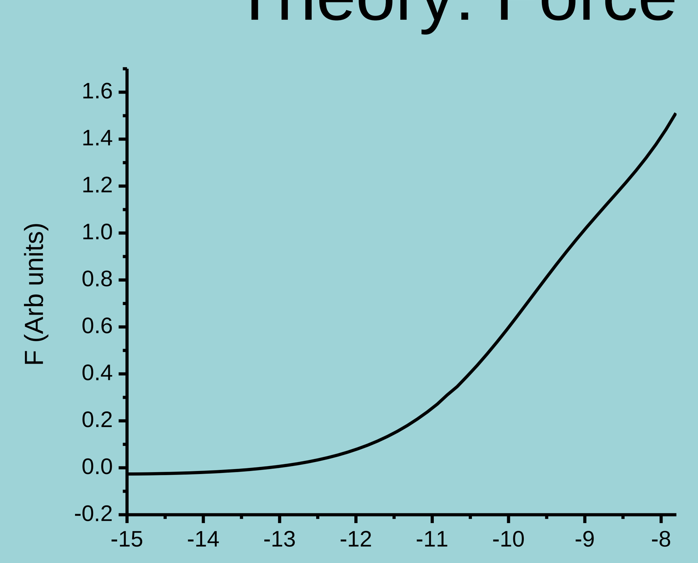
In this setup the magnetic particle on the cantilever also acts as the detector

Magnetic vector field



The particle generates a dipole which due to the external field creates a zero field pocket. By sweeping this pocket through a paramagnetic particle we can vary the magnetic field it is exposed to and measure its response as a function of magnetic field.

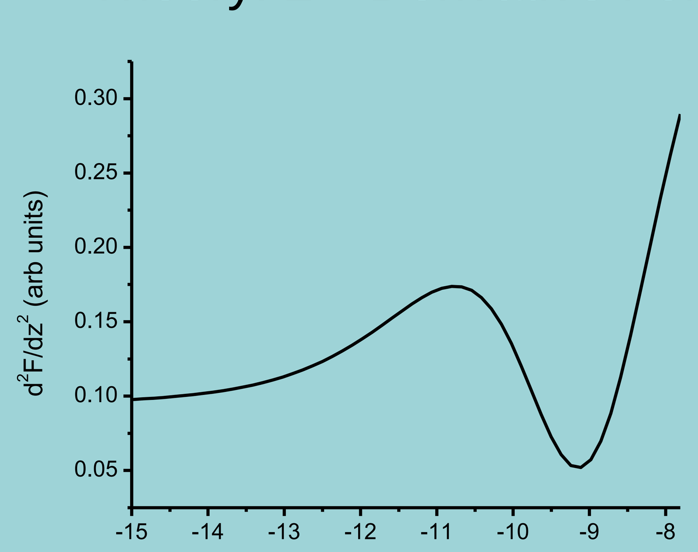
Theory: Force



The theory predicts a force distance curve that is relatively featureless.

However we do not measure the Force itself, but instead measure the 2nd derivative

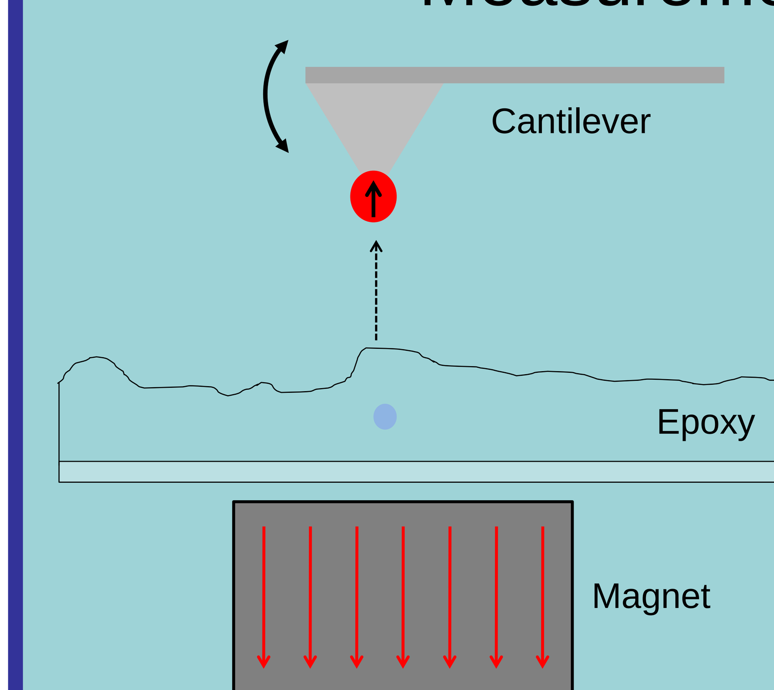
Theory: 2nd Derivative Force



For the same range, the 2nd derivative of the force has features which the model can be fit to, enabling a determination of the underlying parameters with a much higher degree of certainty.

Measurement/Data

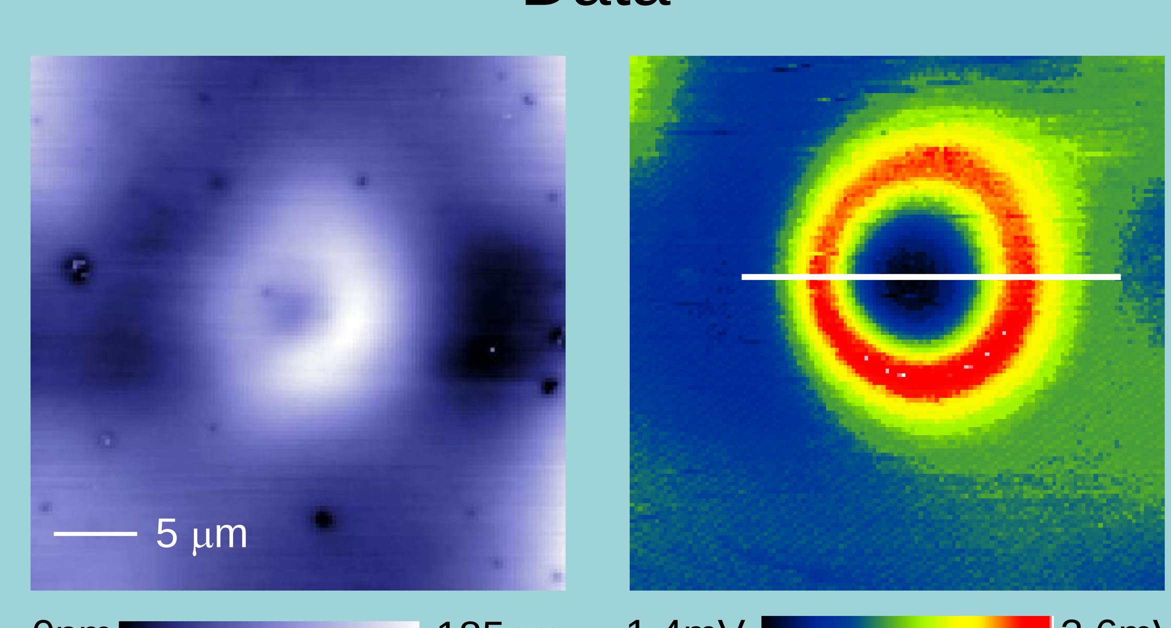
Measurement



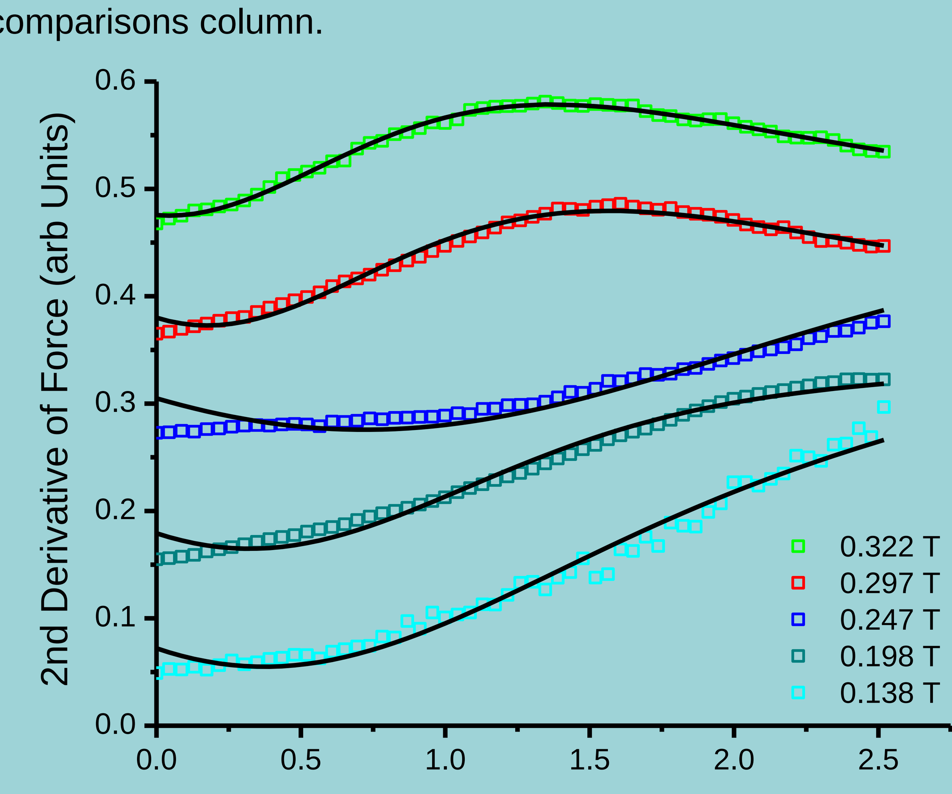
The data is taken by measuring the 2nd harmonic response as a function of the distance away from the surface of the epoxy.

By varying the external magnet distances from the sample we can control the opposing magnetic field.

Data



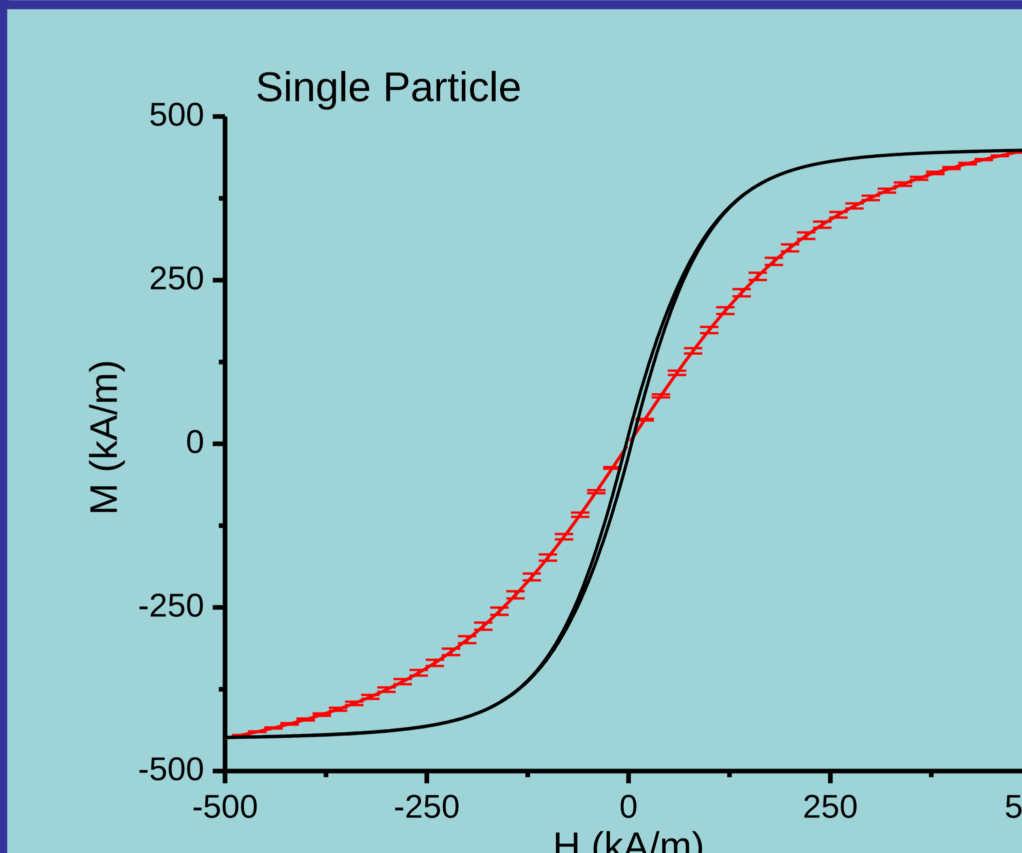
On the left a topograph of our buried particle. In the center there is a raised bump that marks the sample test particle. On the right is the 2nd harmonic force response when the cantilever is lifted 500nm off the surface. The white line marks the 2D cut of the data shown under the comparisons column.



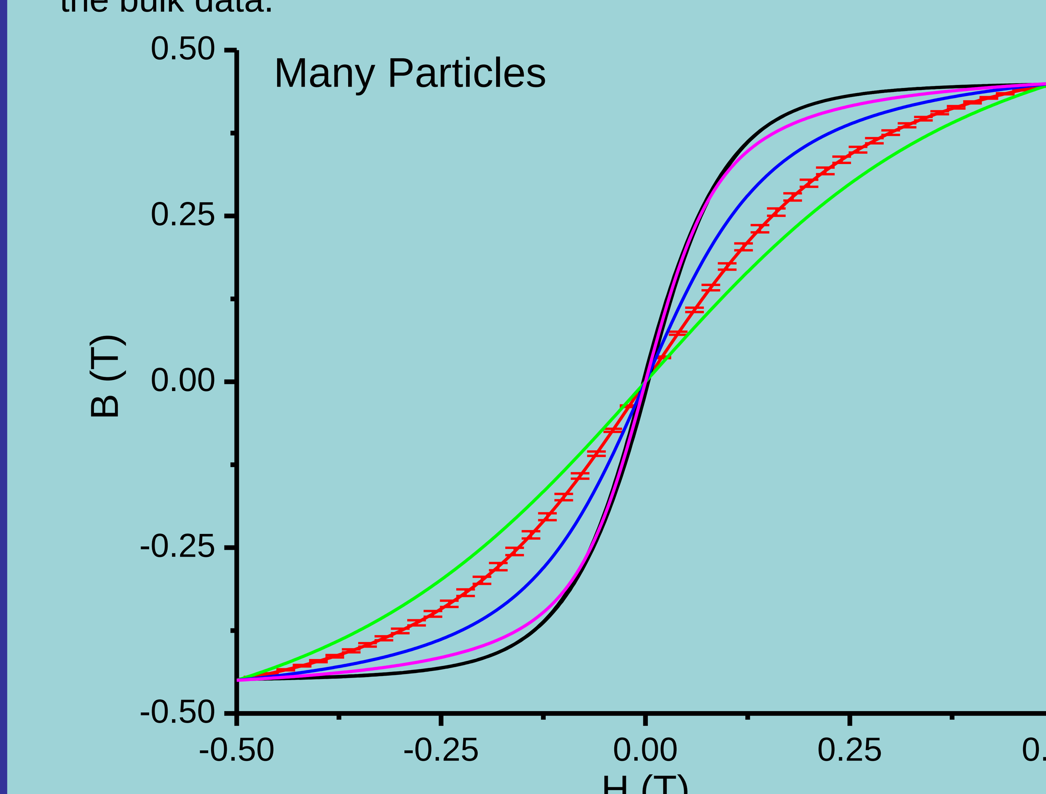
Plot of the 2nd harmonic force vs distance measured at the center of the particle.

We then fit this to a model of the 2nd harmonic force vs distance for a model using a ferromagnetic particle as the sample. This model works for all external fields using the same fitting parameters, however as the magnet is pulled back from the sample, fringing effects increase, and the data diverges from the model.

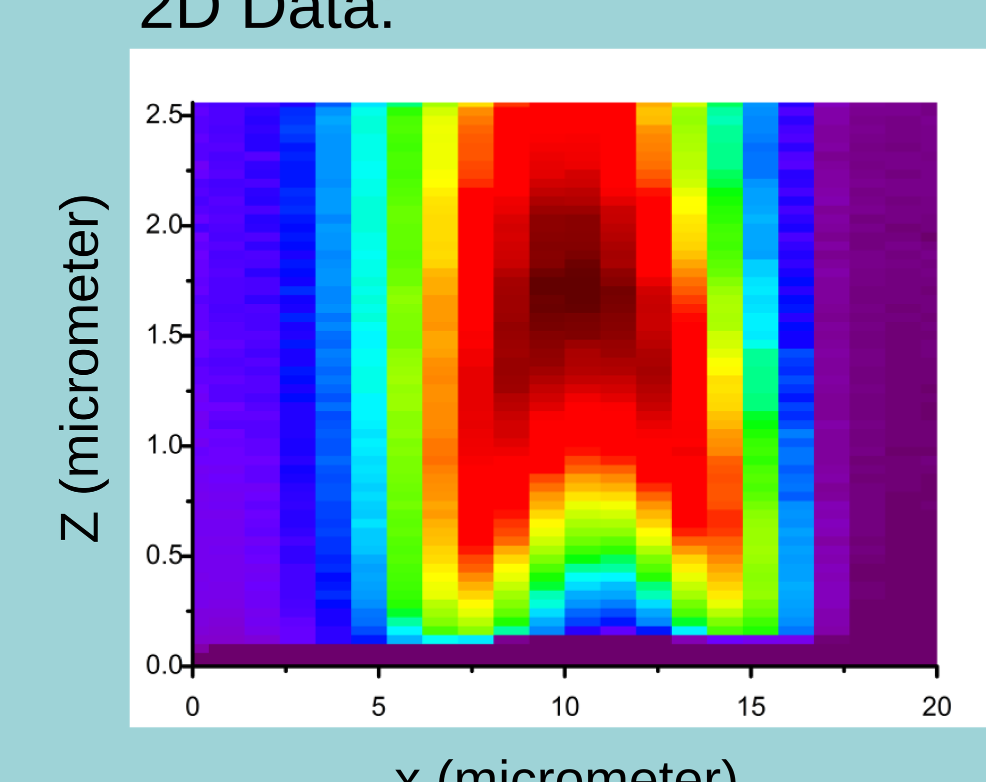
Comparisons



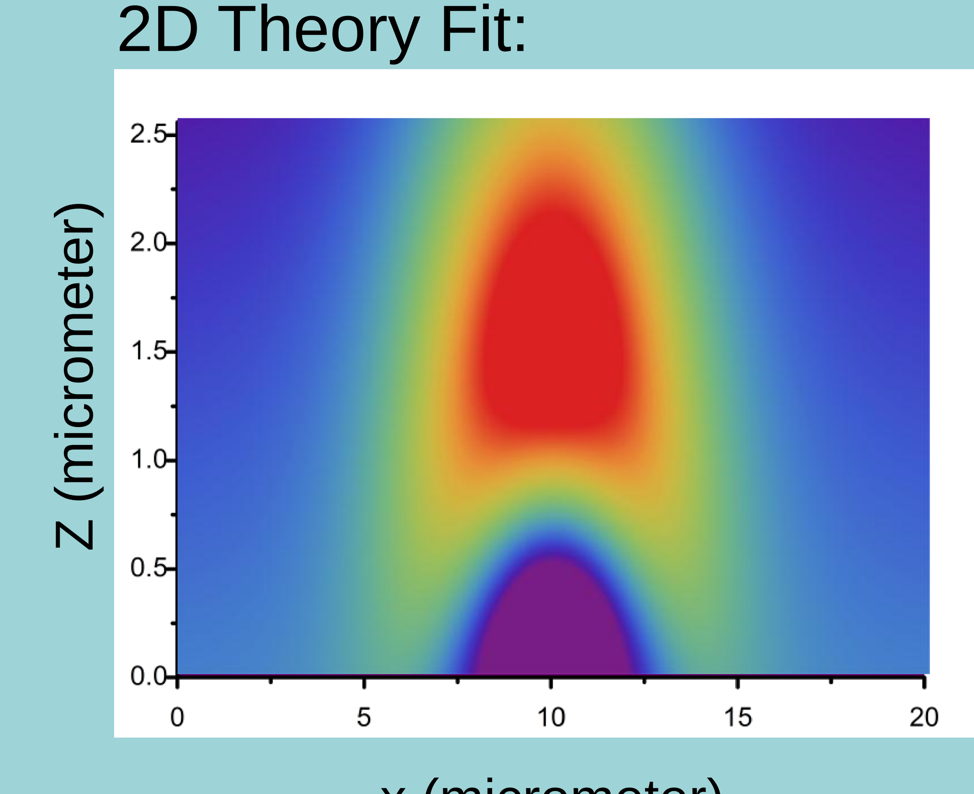
The fit to the model allows us to reproduce a unique M-H curve. Since the material is a soft ferromagnet, the curves shape is dependant on the shape of the particle only. By measuring multiple particles we can show that there is a distribution of shapes and agglomerates which matches the bulk data.



2D Data:



2D Theory Fit:



The parameters that are extracted from the 1D fits can be used to generate a full 2D plot of the 2nd harmonic response. This matches the data almost exactly when the magnet is near the sample, and the fringing fields are low. The data is taken from a slice along the white line as shown in the lift off data in the middle column. This data is for the magnet closest to the sample with an external field of B=0.322 T