Calibration Magnet XY Stage System: Readout Automation and Field Maps

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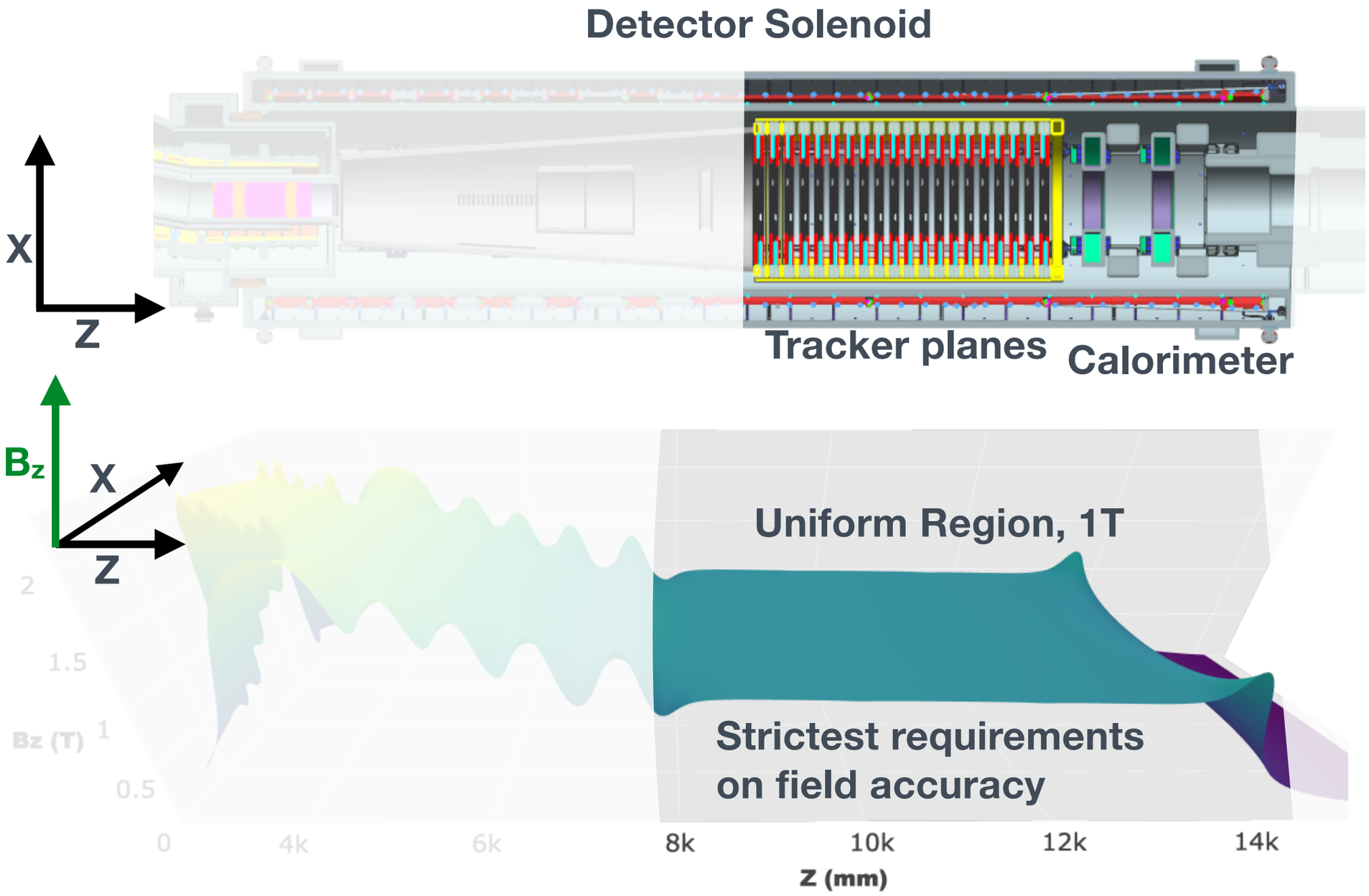
Final Presentation

21/09/2017

1 - Problem Statement

1. **Problem Statement**
2. Software Design
3. Calibration Process
4. Data Analysis
5. Conclusions

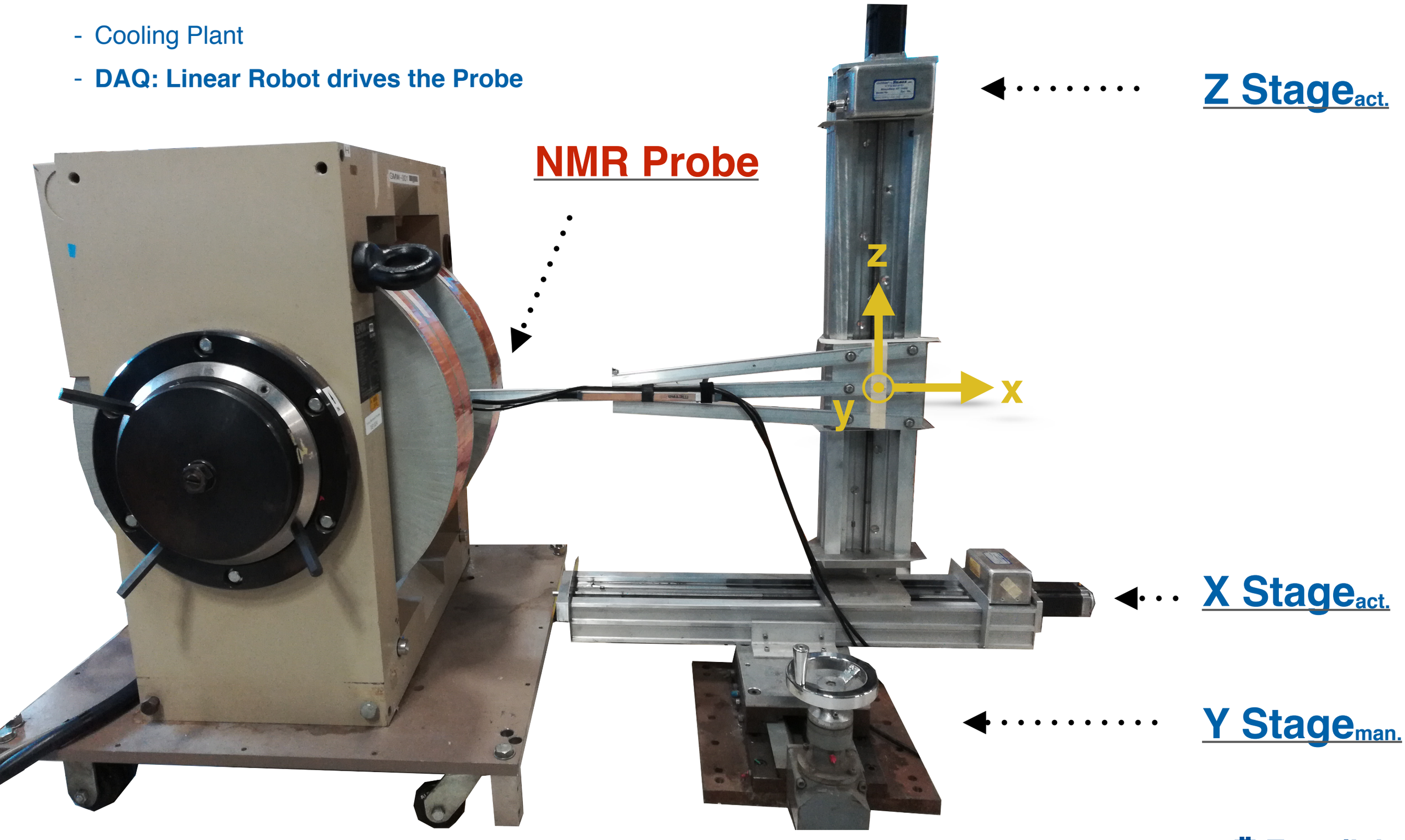
mu2e's Technical Requirements



- mu2e Detector Solenoid -> B: Accurate and Uniform -> Hall Probes
- Hall Probes Calibration -> Calibration Magnet

Calibration Magnet's DAQ System

- Cooling Plant
- **DAQ: Linear Robot drives the Probe**



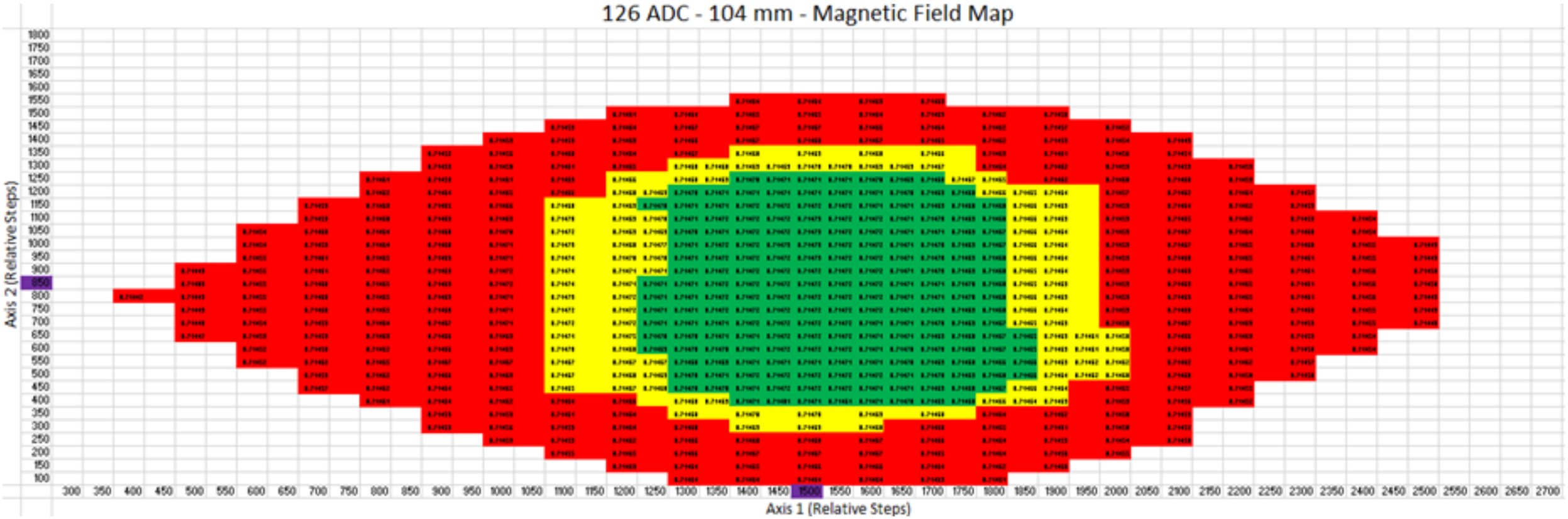
Starting Point

- **Field Mapping: Manual**

  - **Move** the Motors
  - **Acquire** the Signal
  - **Evaluate** Signal Quality
  - **Store** Data

- **Cons**

  - Human **Error:** Loss of **Precision**
  - Human Effort for Repetitive Work



Main Goal

- **Automatic 3D Field Mapping:**

  - Motion
  - Acquisition
  - Evaluation
  - Storage

2 - Software Design

1. Problem Statement
2. **Software Design**
3. Calibration Process
4. Data Analysis
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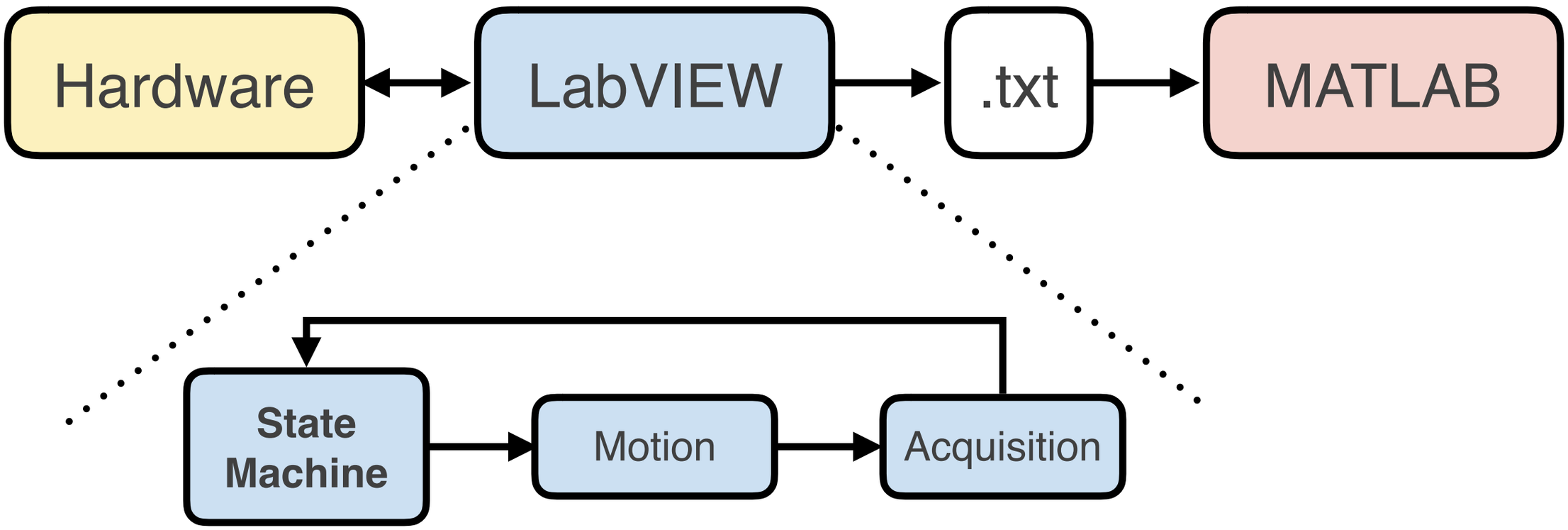
Blocks Diagram



- **Controller: LabVIEW**
- **Data Analysis: MATLAB**
- **Communication : .txt Log Files**

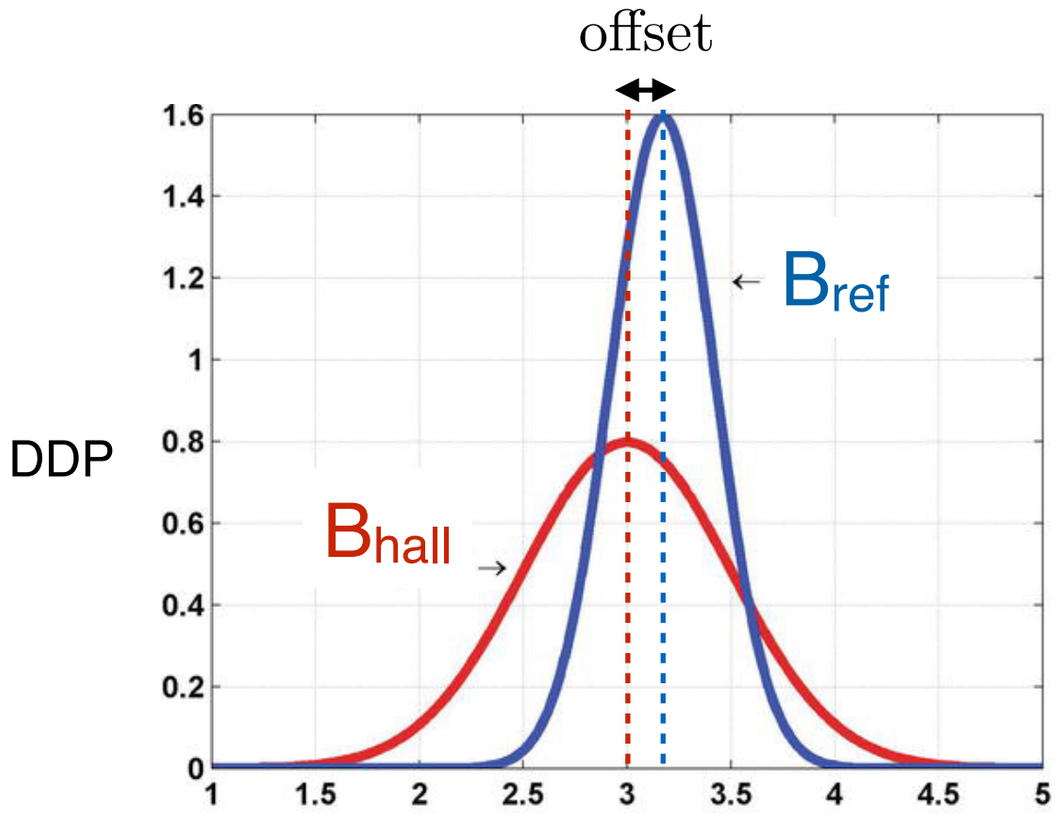
3 - Calibration Process

1. Problem Statement
2. Software Design
3. **Calibration Process**
4. Data Analysis
5. Conclusions

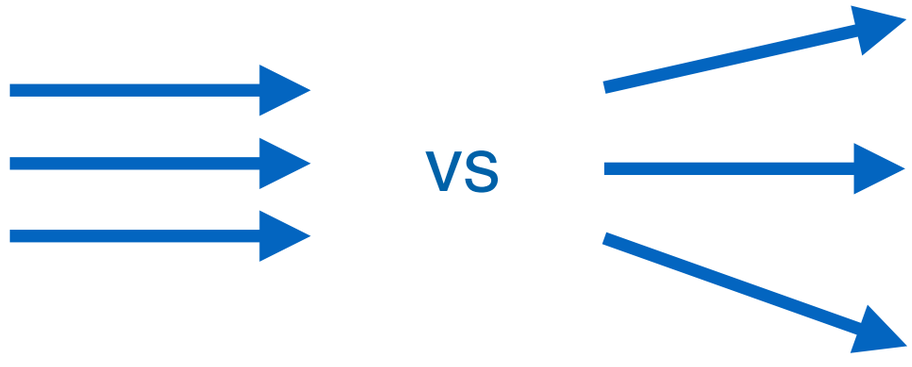
Reference Value

- **Requirements:**

1. **Accuracy**
   - offset (mean)
   - scale factor (dev)



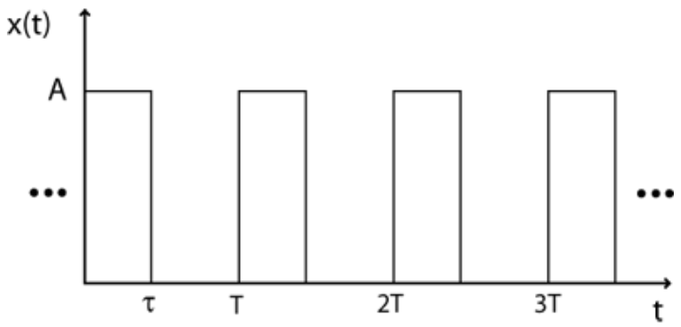
2. **Uniformity**
   - field lines

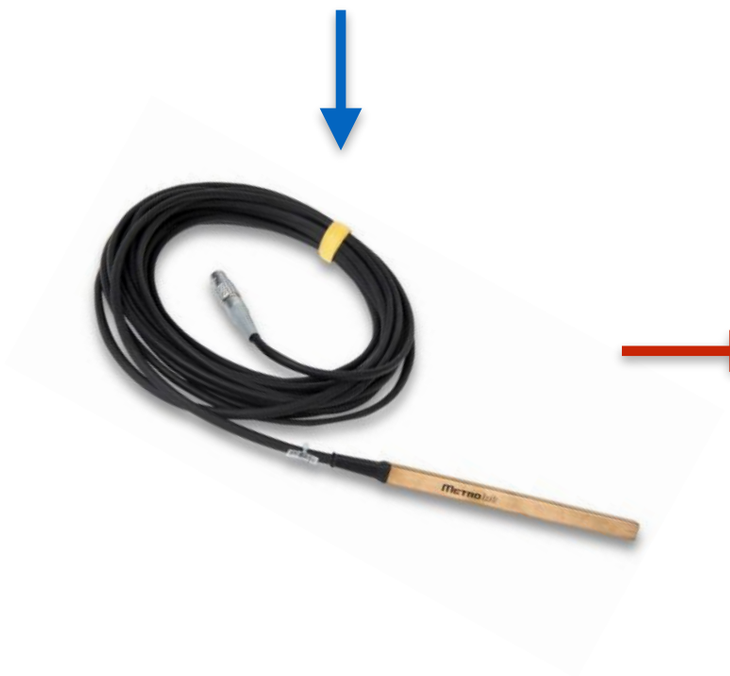


Fermilab

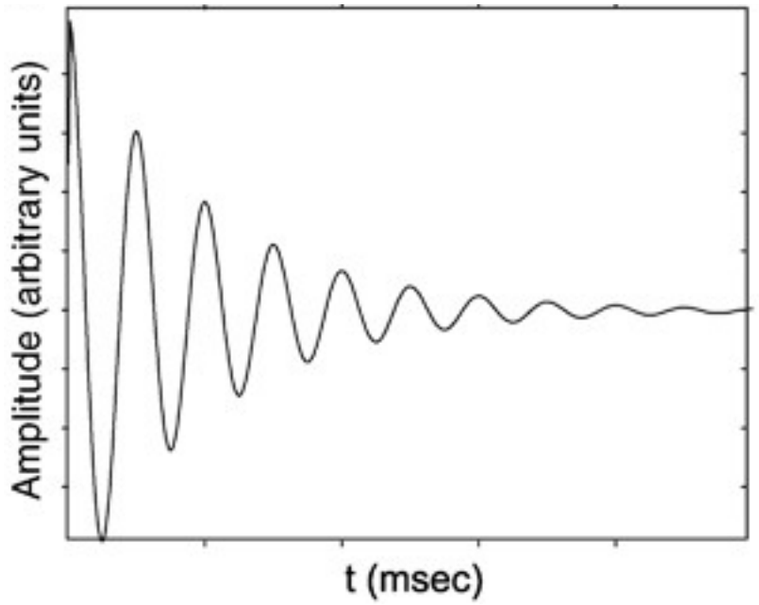
Blocks Diagram of PT2026 NMR Probe

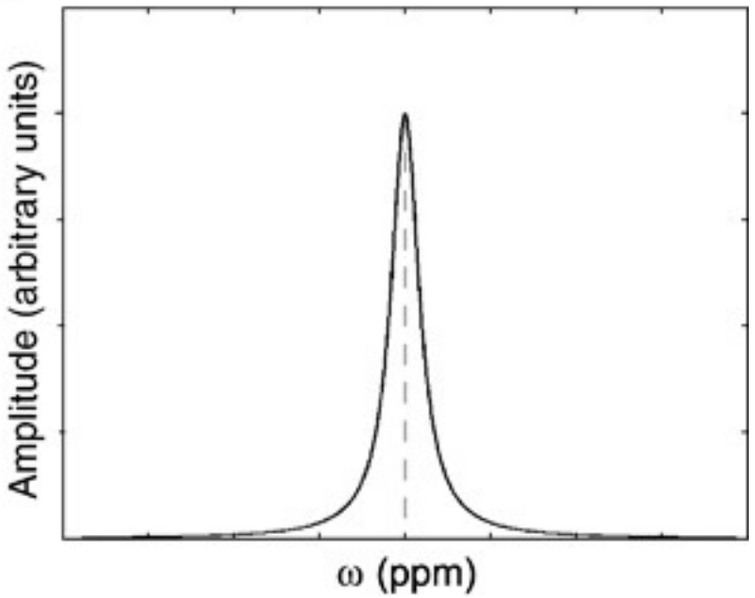
- **In:** Radio Frequency Energy Pulses





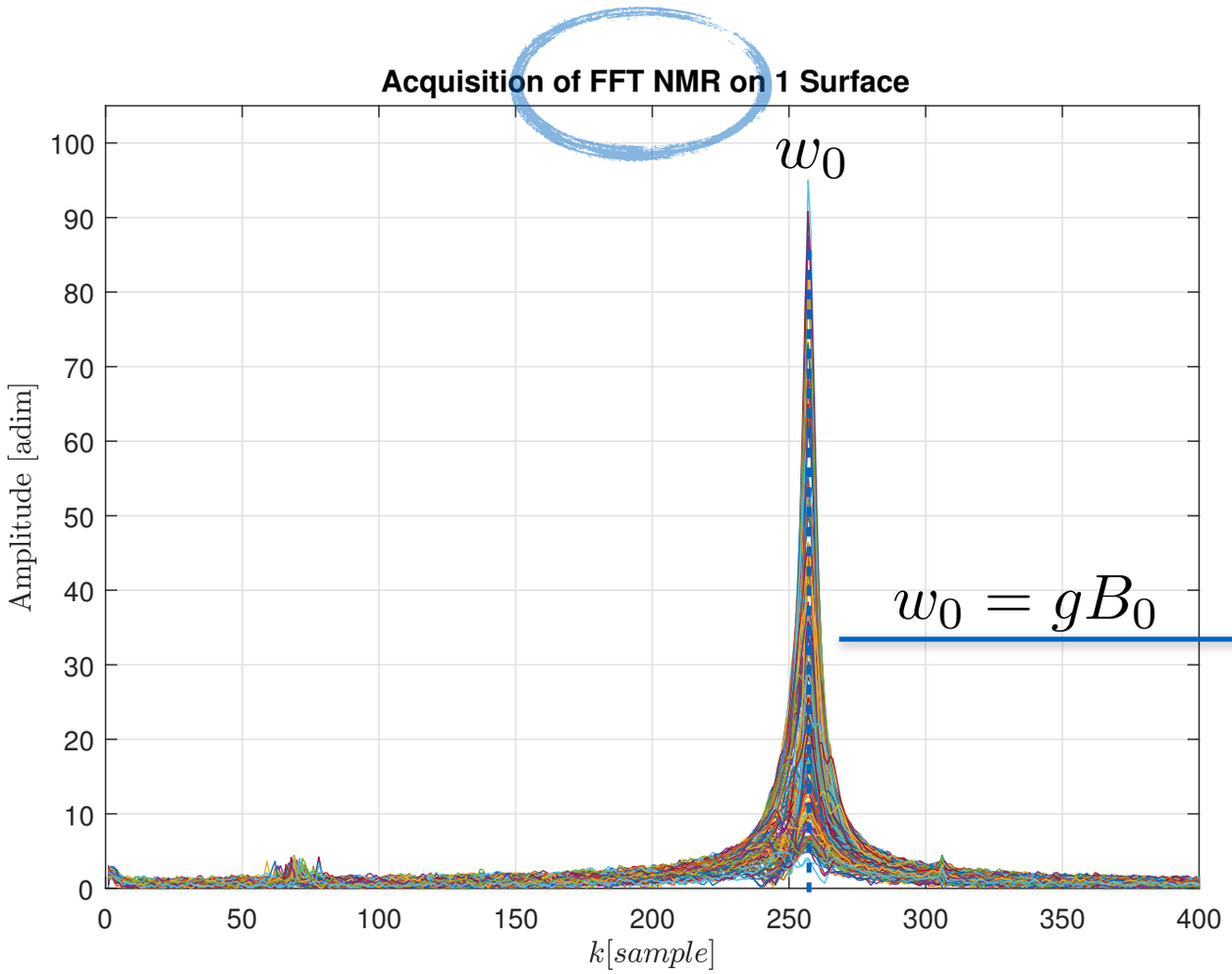
- **Out:** Free Induction Decay (on a lower energy state)



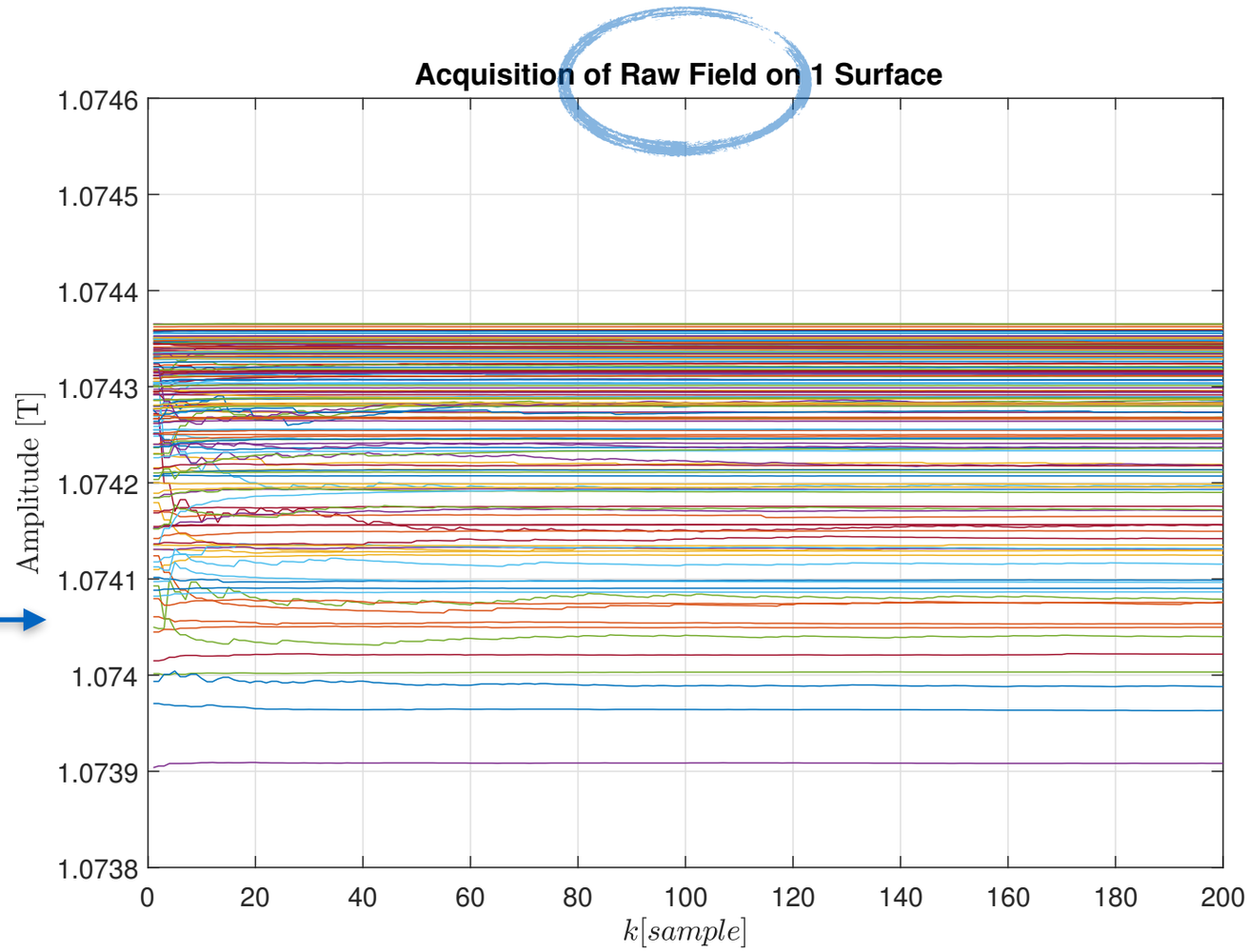


- **System Point of View**
- **FFT Based Probe**

Acquisition of a ‘Slice’ from NMR Probe

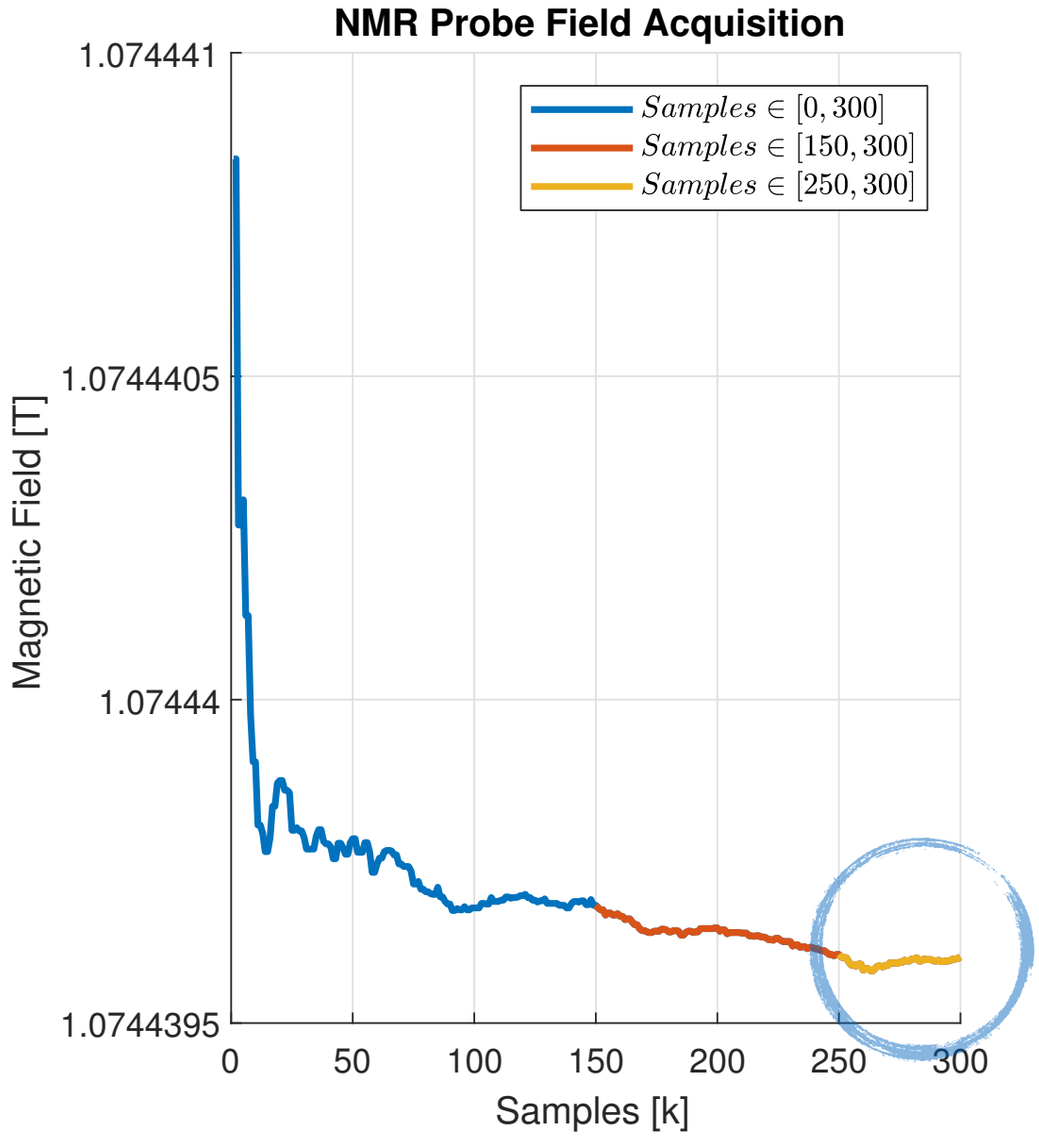


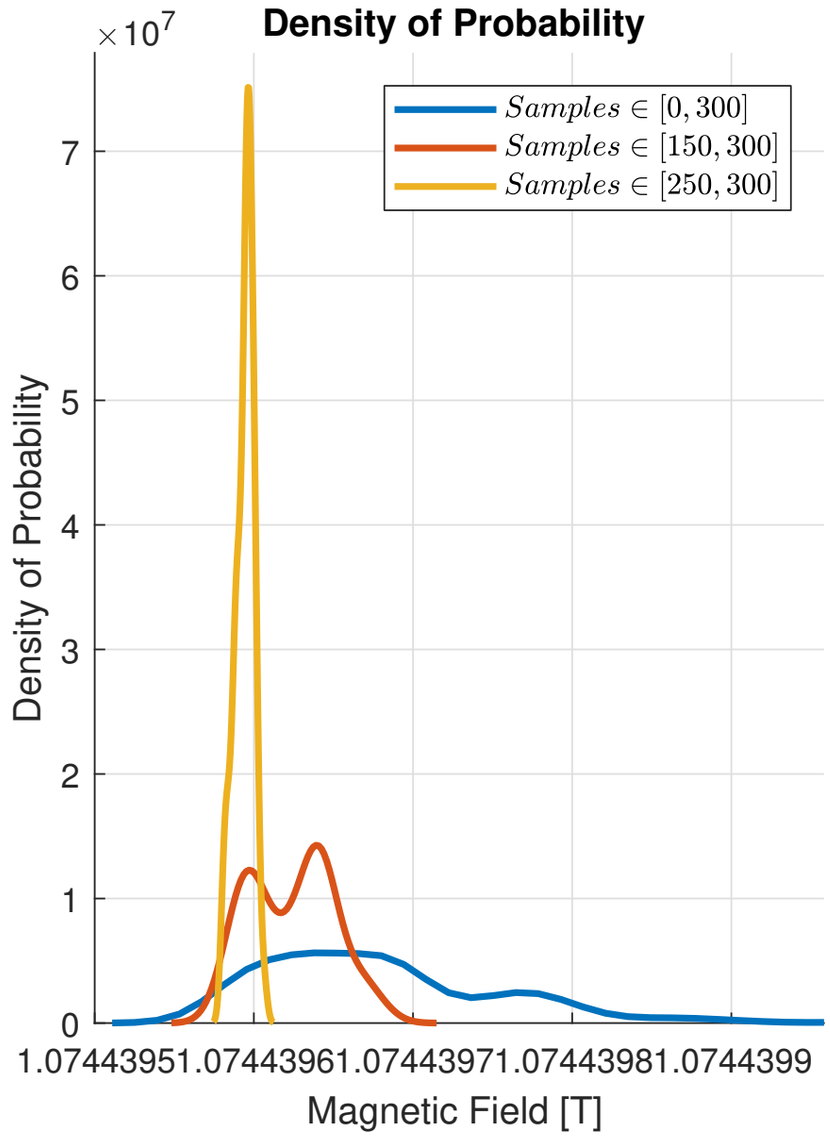
$w_0 = gB_0$



- **Slice:** Surface on XZ Plane
- (lx) FFT of FID Signals (overlapped)
- **Uniformity:** Shape
- **Amplitude:** Central Frequency (rx)
- **#Samples, Scalar Quality Factor**

Amplitude Signal (rx)

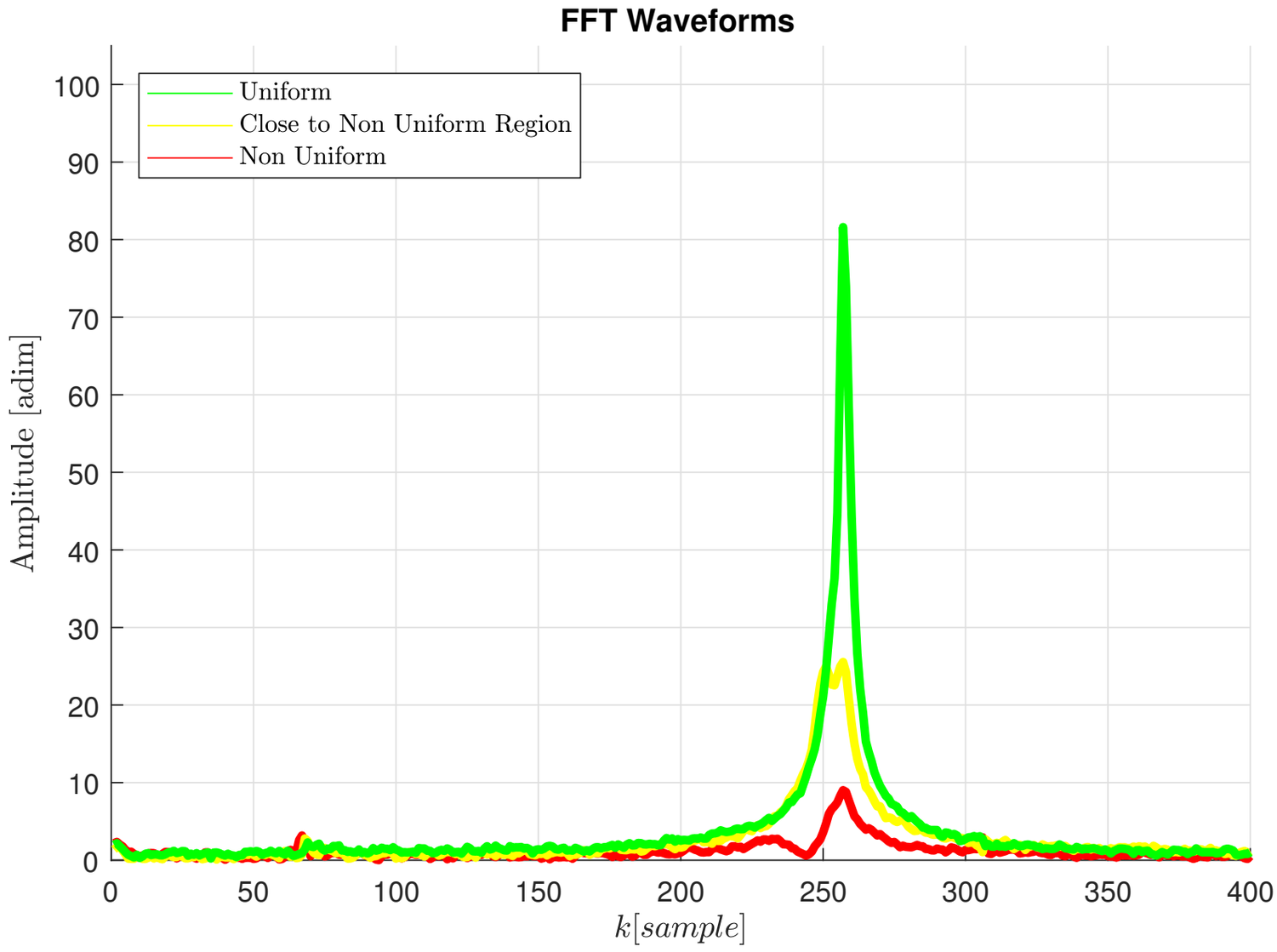




- (lx) Initial **Overshoot** corrupts the measurement
- (rx) after 250 samples : **Gaussian-like event,**
- Trade-off time-accuracy: **AVG on last 50 samples**

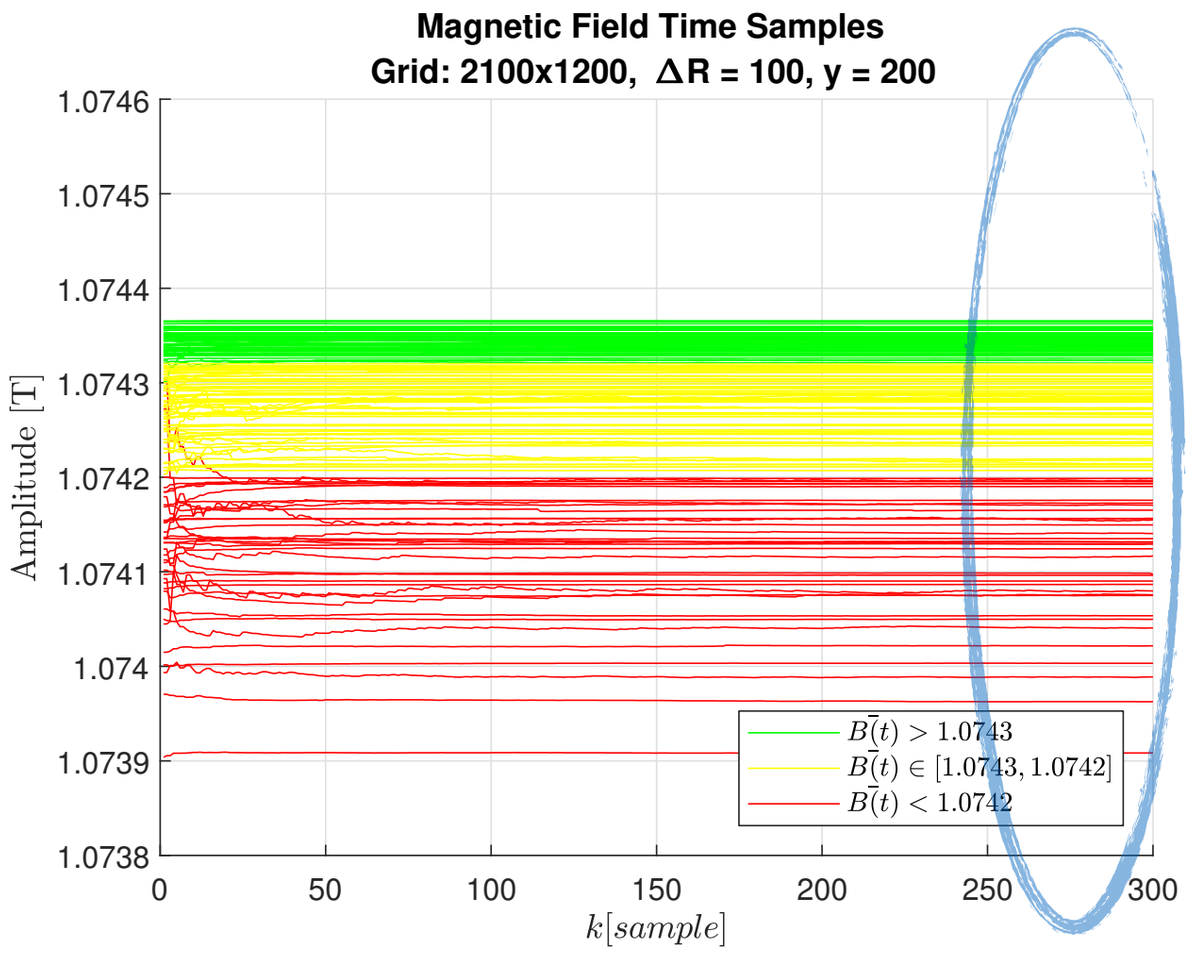
Fermilab

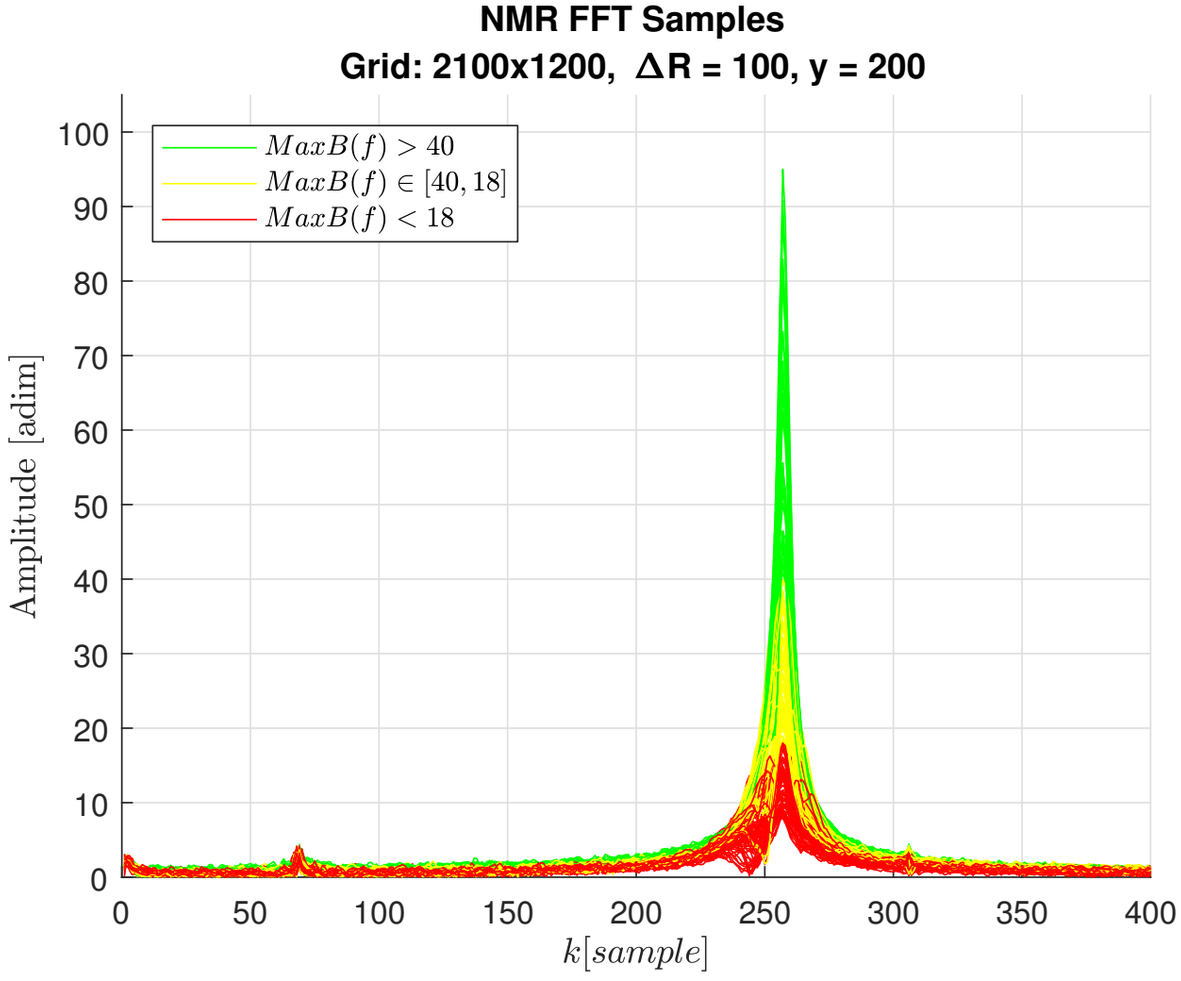
Waveforms FFT of FID Signal (Ix)



- **Bandwidth: 400** samples
- **Shape** encodes uniformity
- **Peak value** good shape estimation

Visualisation of Raw data





- **Amplitude Quality Factor: Average** on Last 50 Samples
- **FFT FID Quality Factor: Maximum** Value
- **Easy Graphical Evaluation**

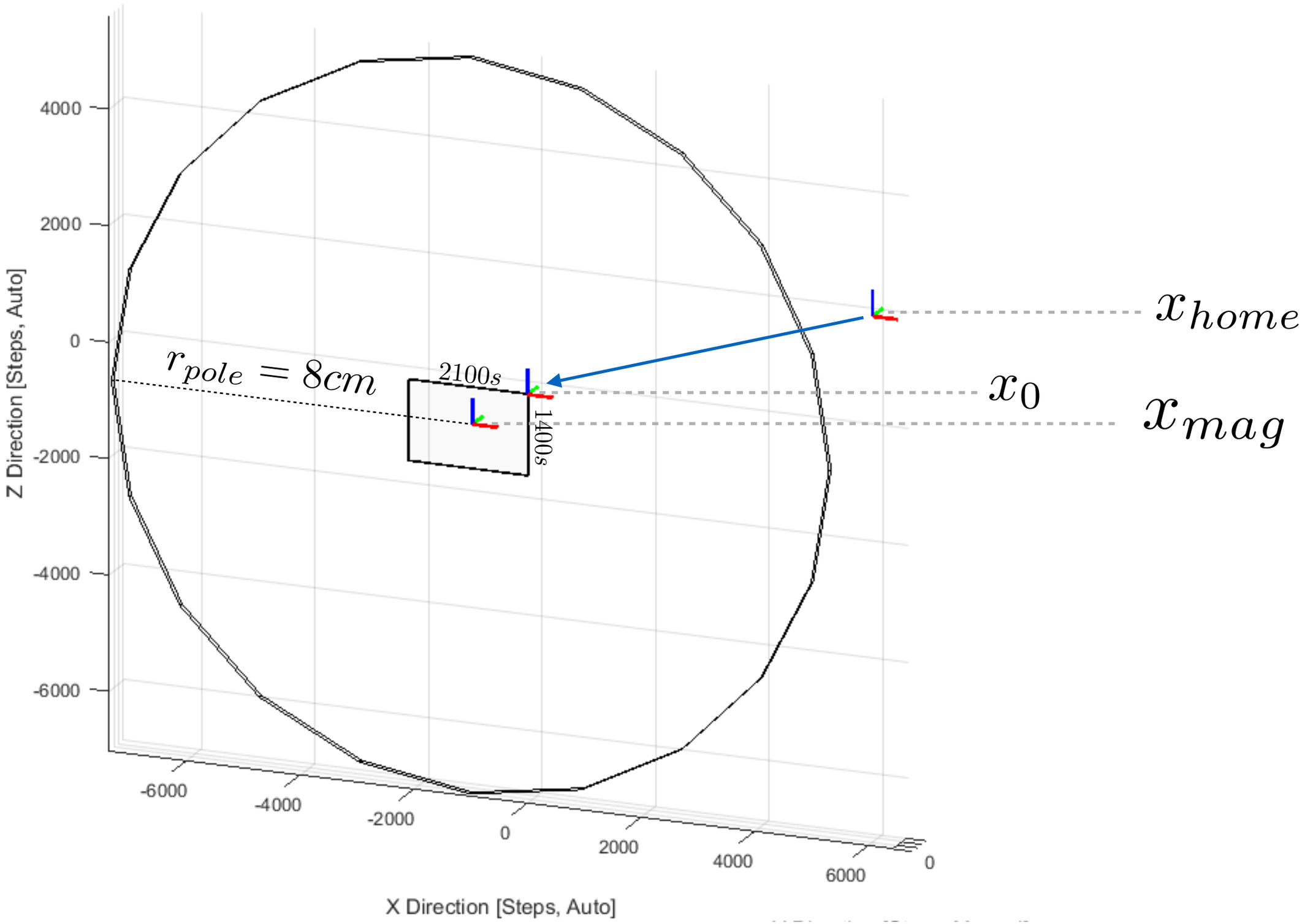
4 - Data Analysis

1. The Plant
2. Software Design
3. Calibration Process
4. **Data Analysis**
5. Conclusions

Data Analysis

- Searching Area
- 4 slices, 100 steps / 1,27 mm
- 3 slices, 50 steps / 635 um
- 1 slice, 20 steps / 254 um

Example of Searching Area



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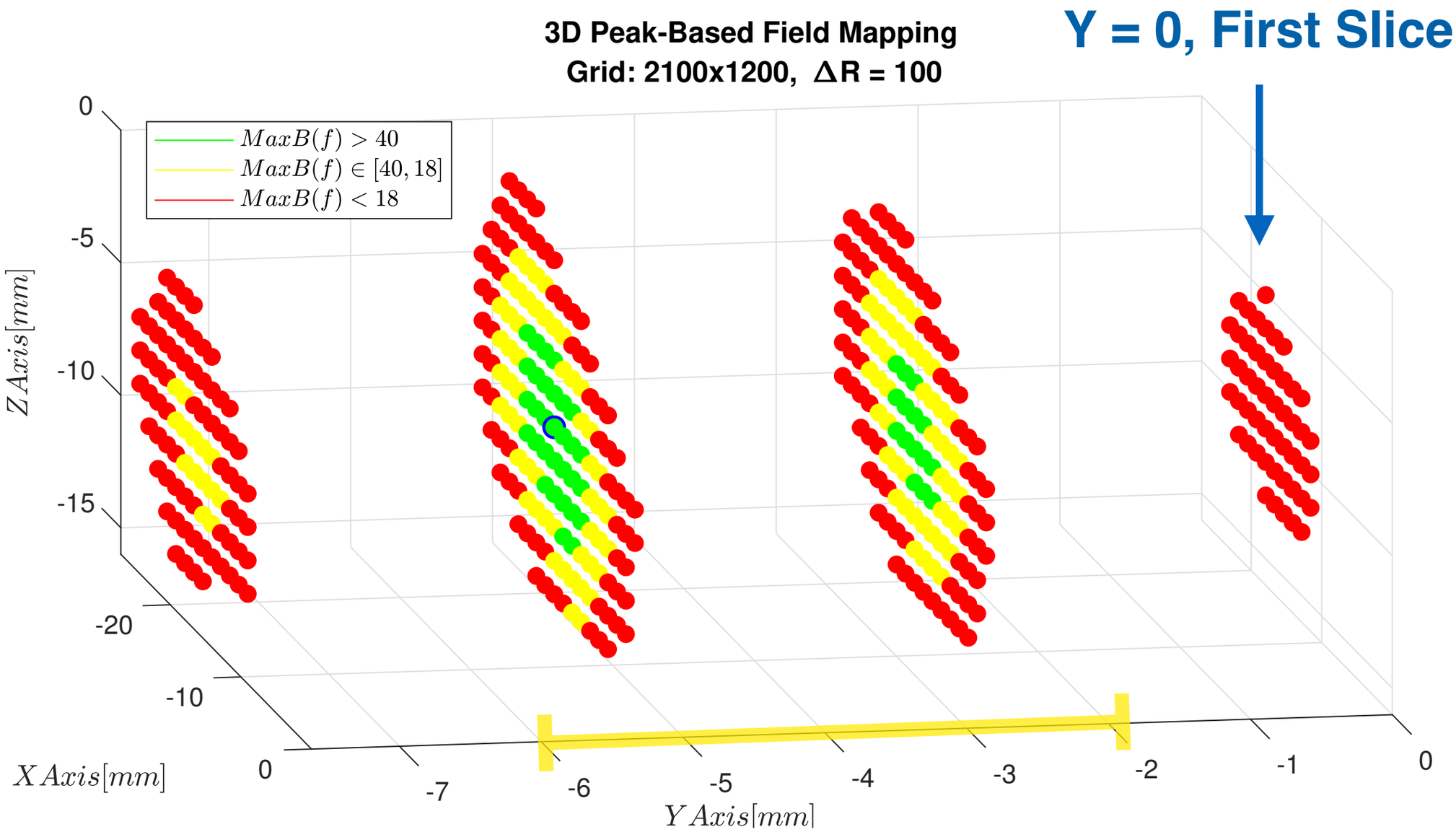
Data Analysis: 4 slices, 1.27mm [100 steps]

Slices	0mm, 2.54mm, 5.08mm, 7.6mm
Grid Resolution	1.27mm
Current	200A
Date	September 1st

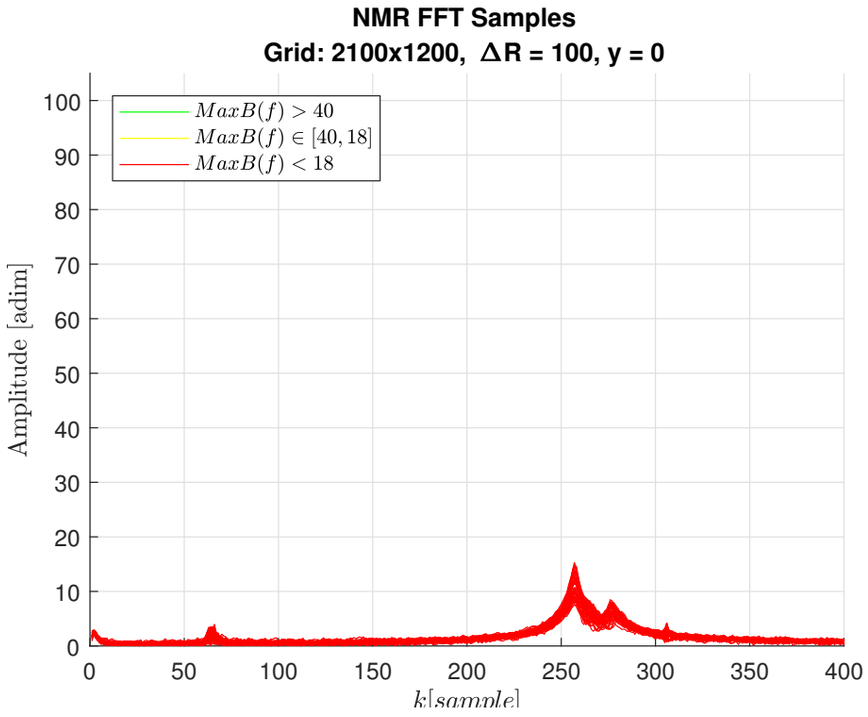
R = 1.27mm - 3D Map, Uniform Region

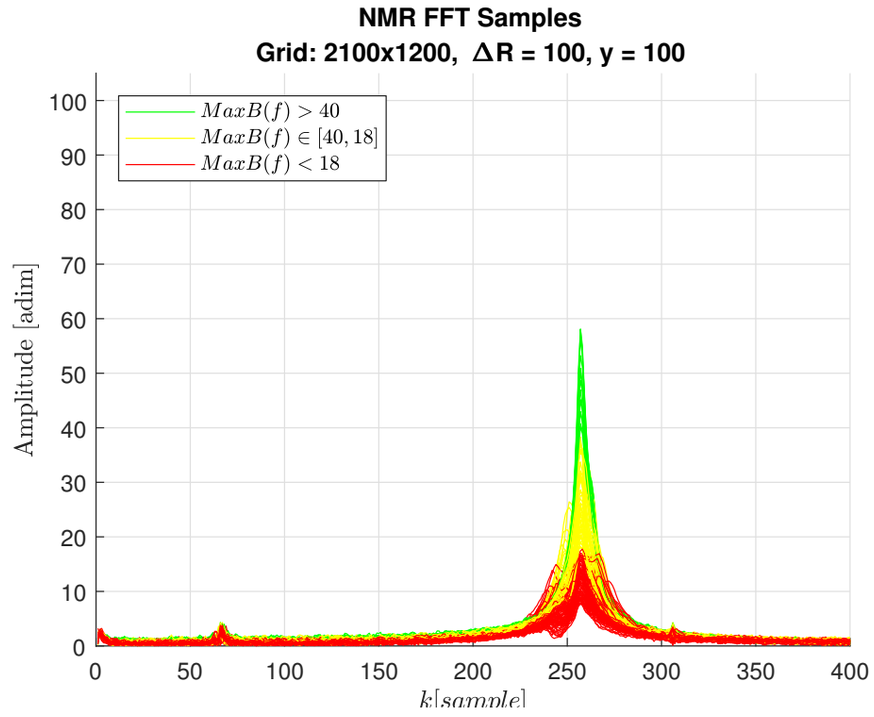


Colour **Thresholds** proportional to **Peak values**

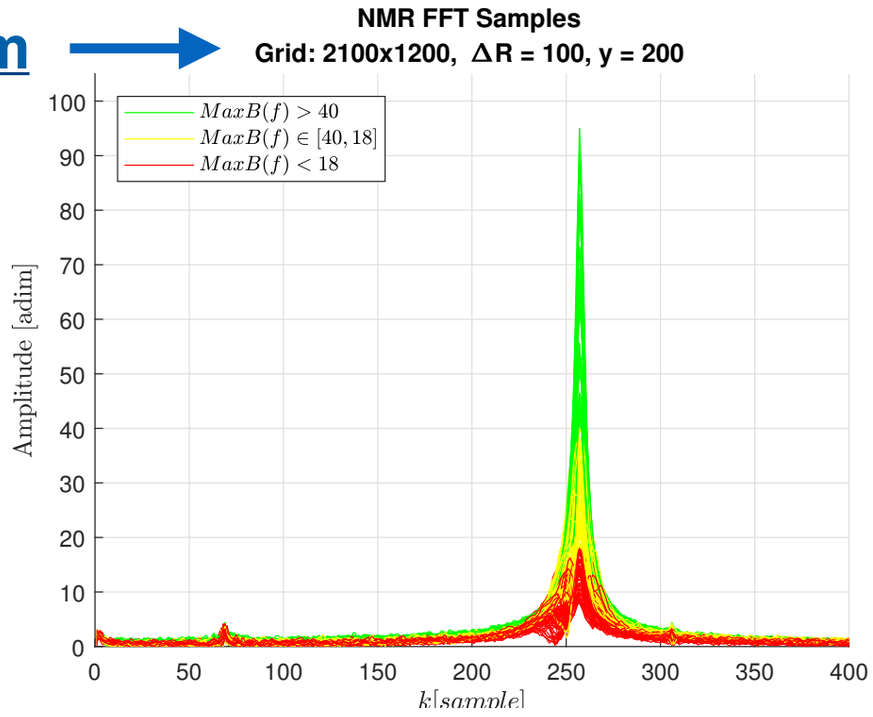
Expected Uniformity in (-6,-2) mm

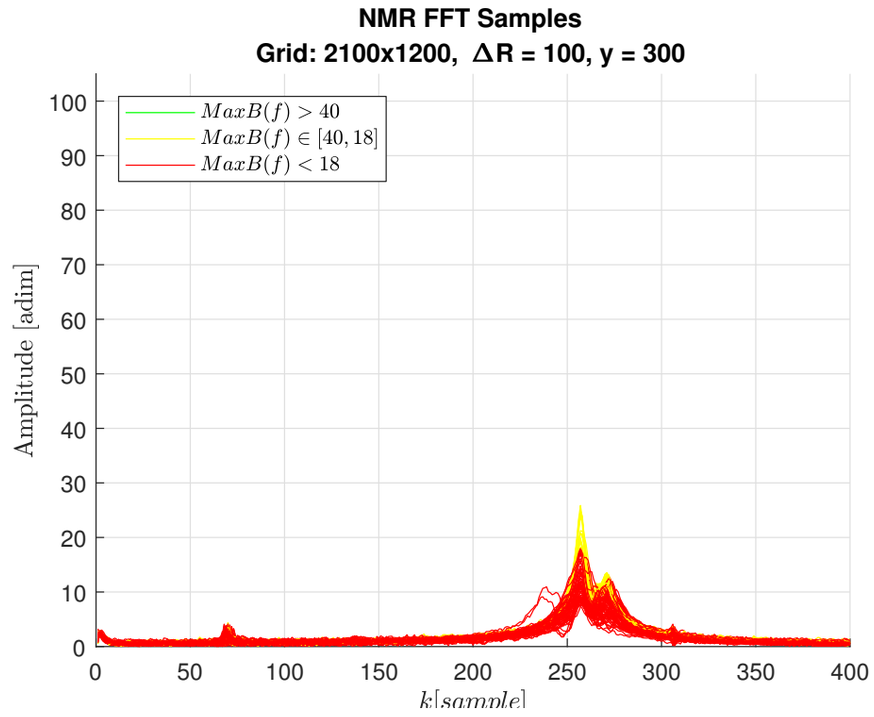
R = 1.27mm - FFT of Free Induction Decay Signal



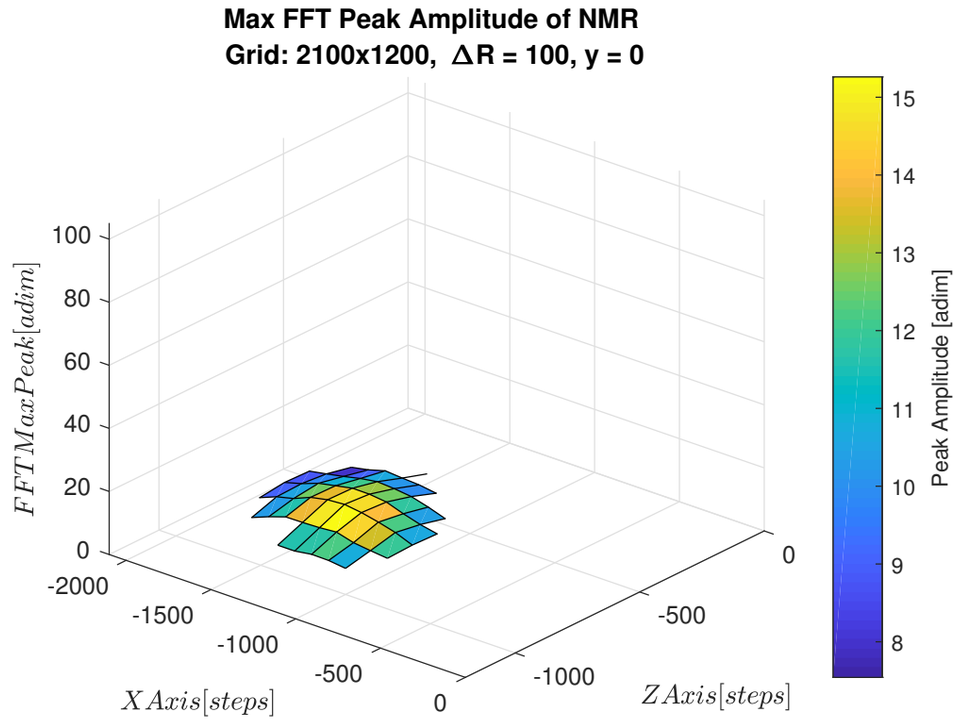


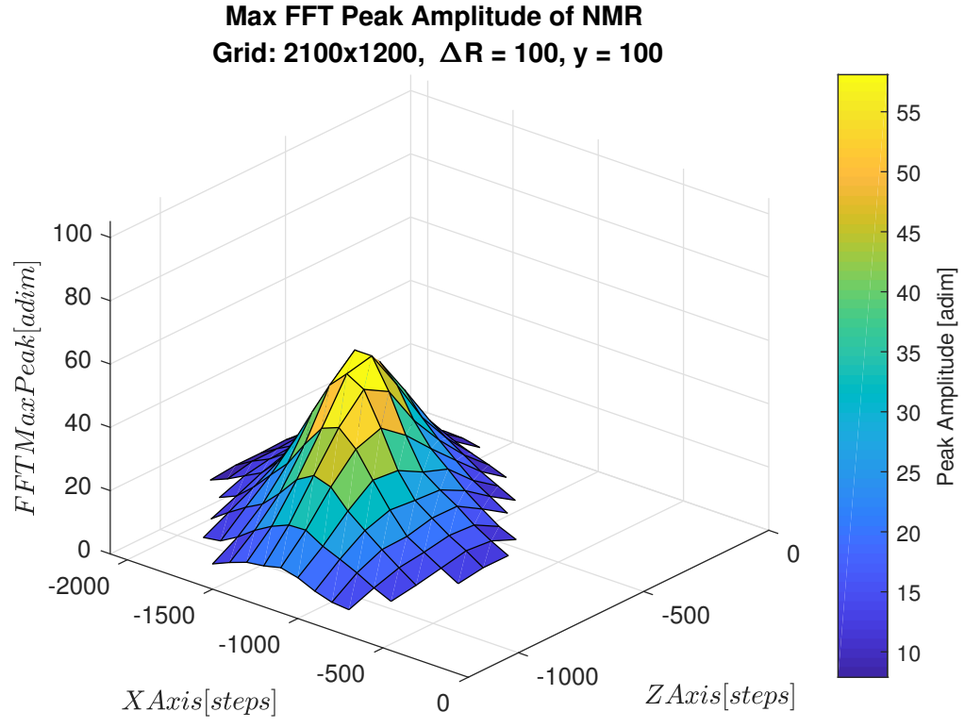
Uniform →

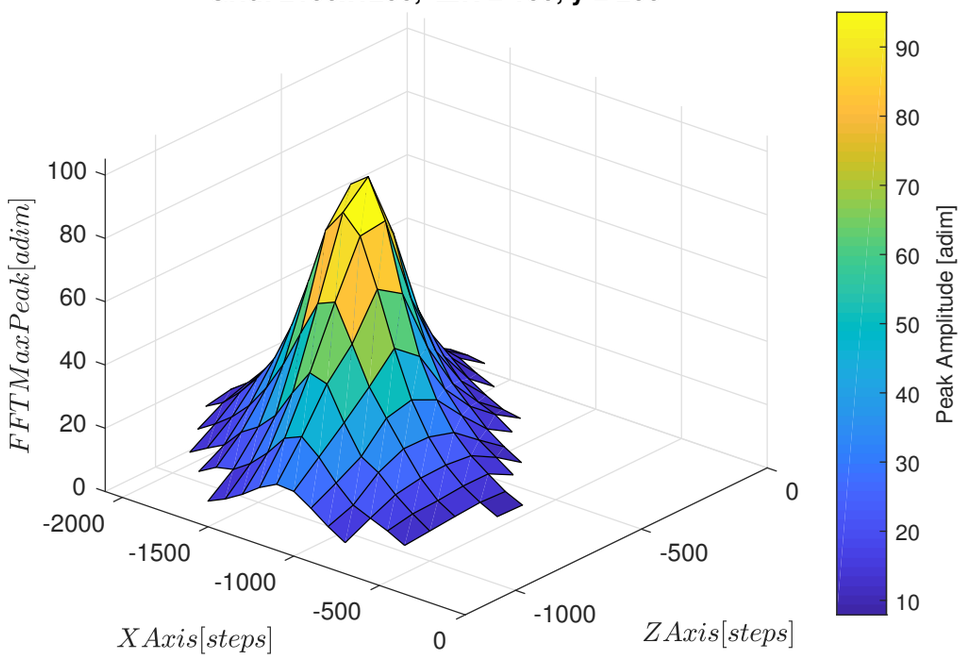


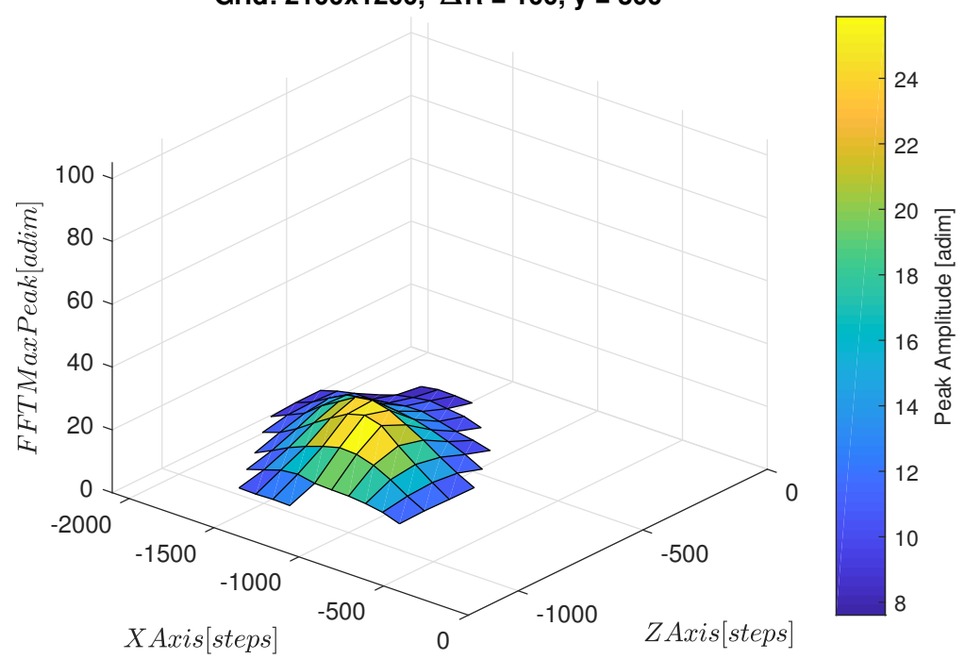


R = 1.27mm - Space Distribution of the Maximum Peak



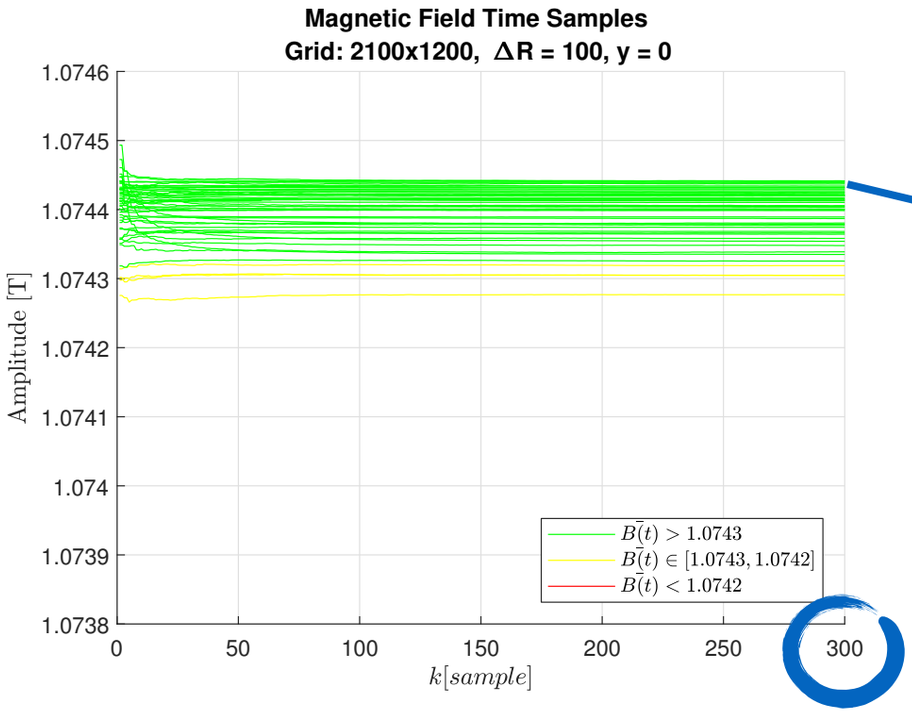


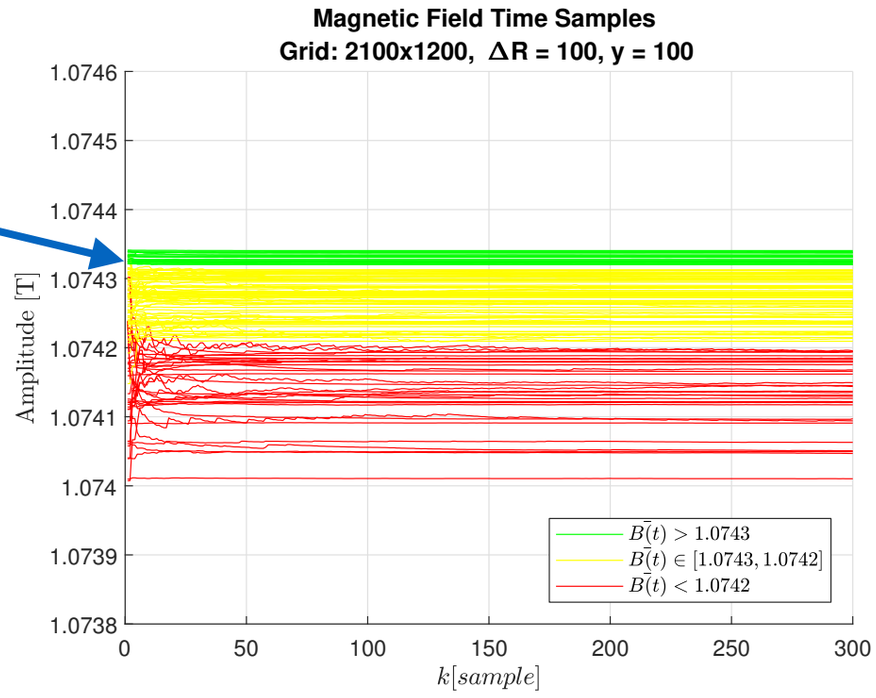


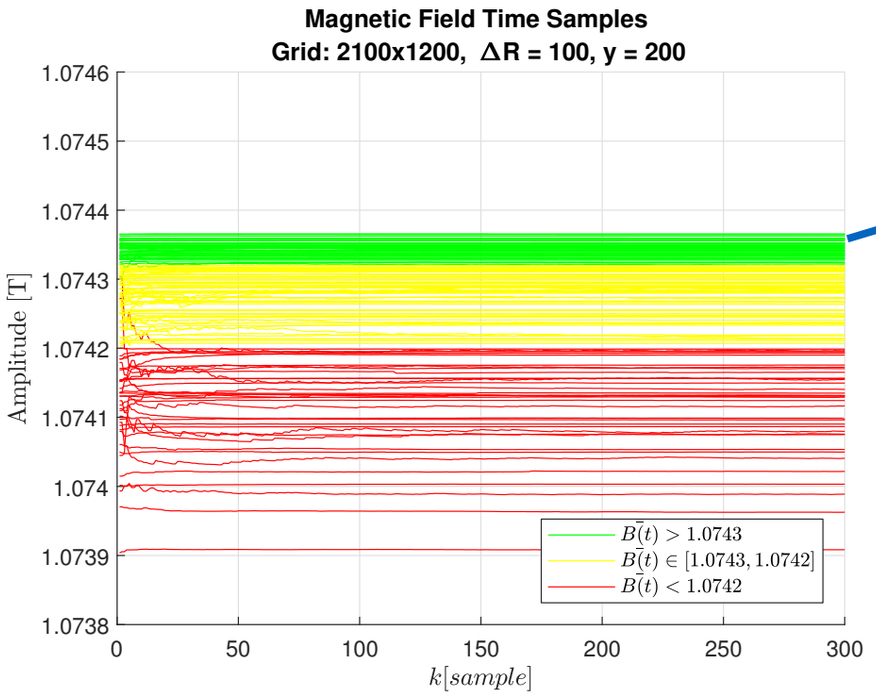


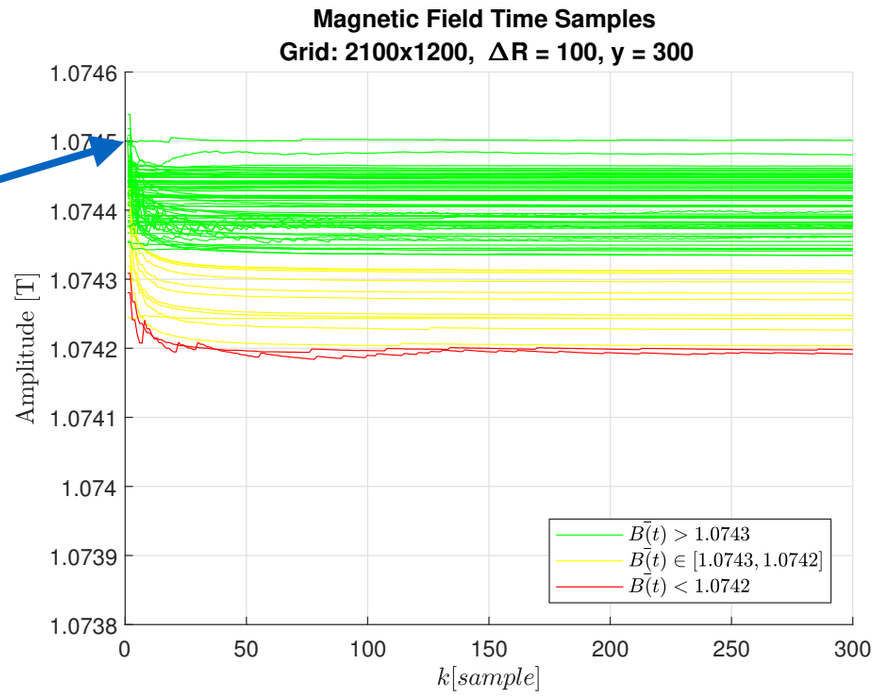
Fermilab

R = 1.27mm - Acquisition of Field Amplitude



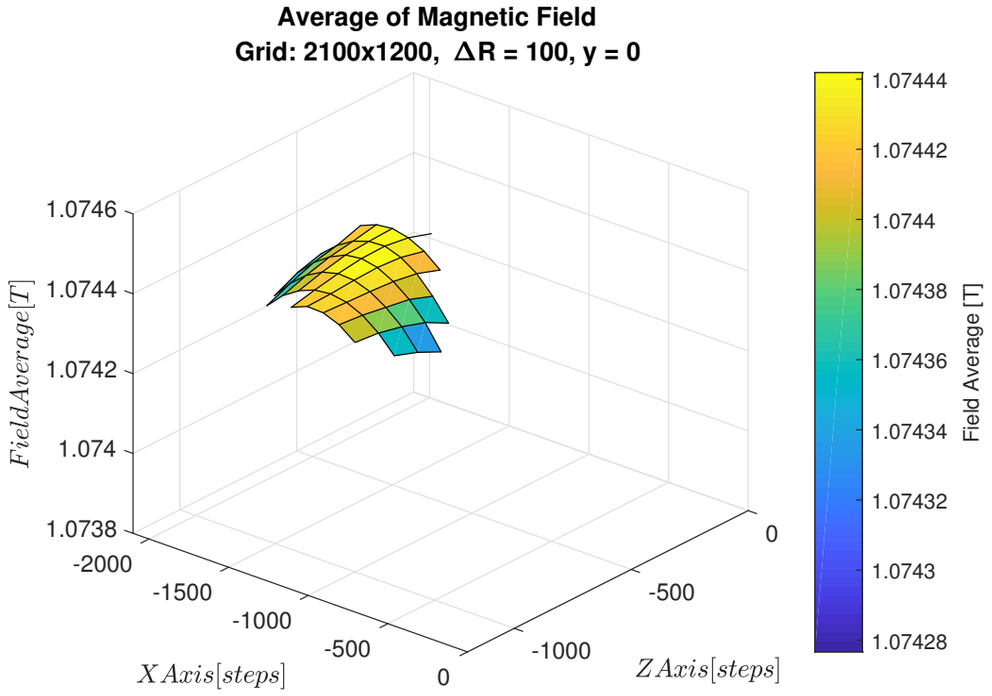


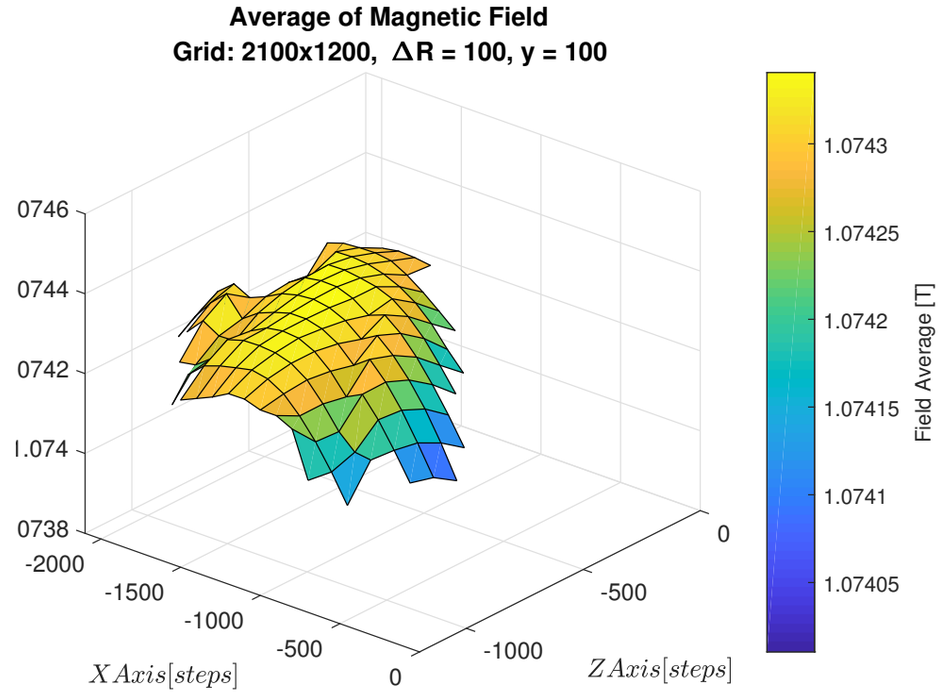




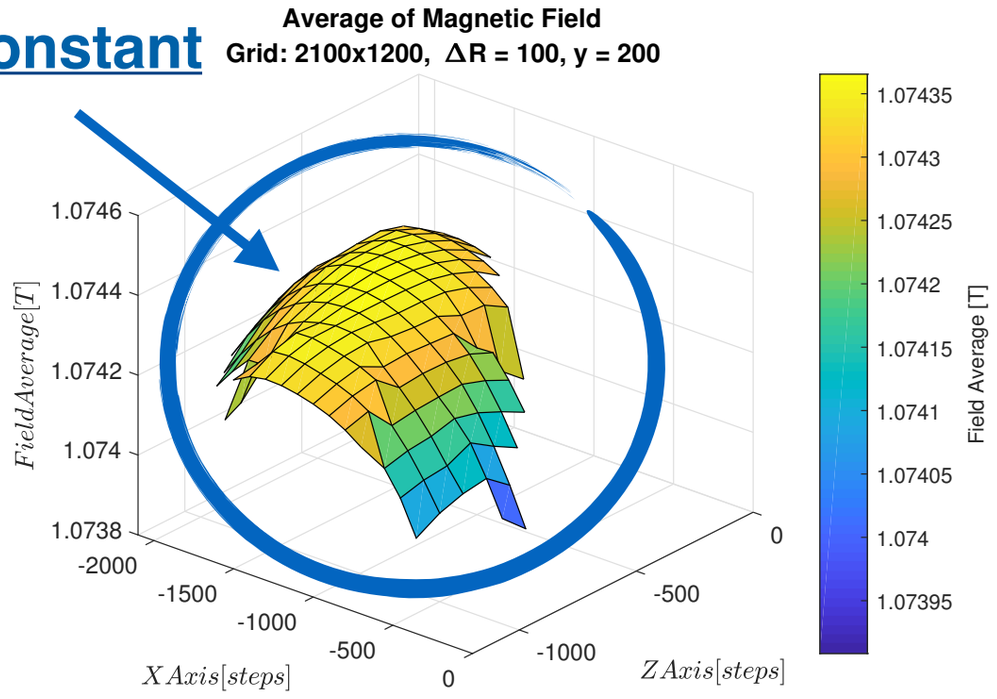
Fermilab

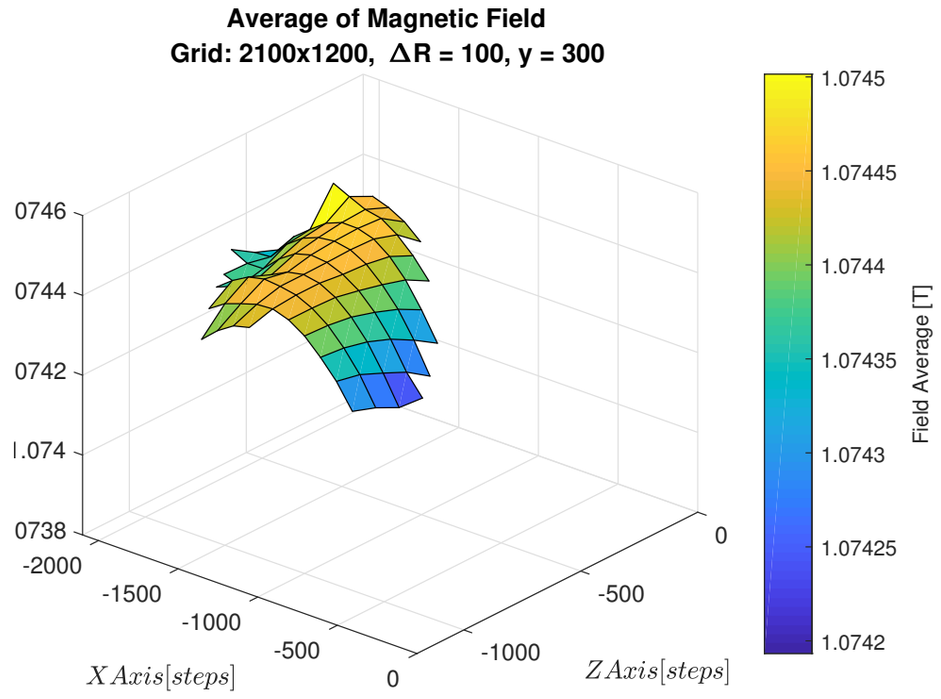
R = 1.27mm - Space Distribution of Average Amplitude





Flat = Constant



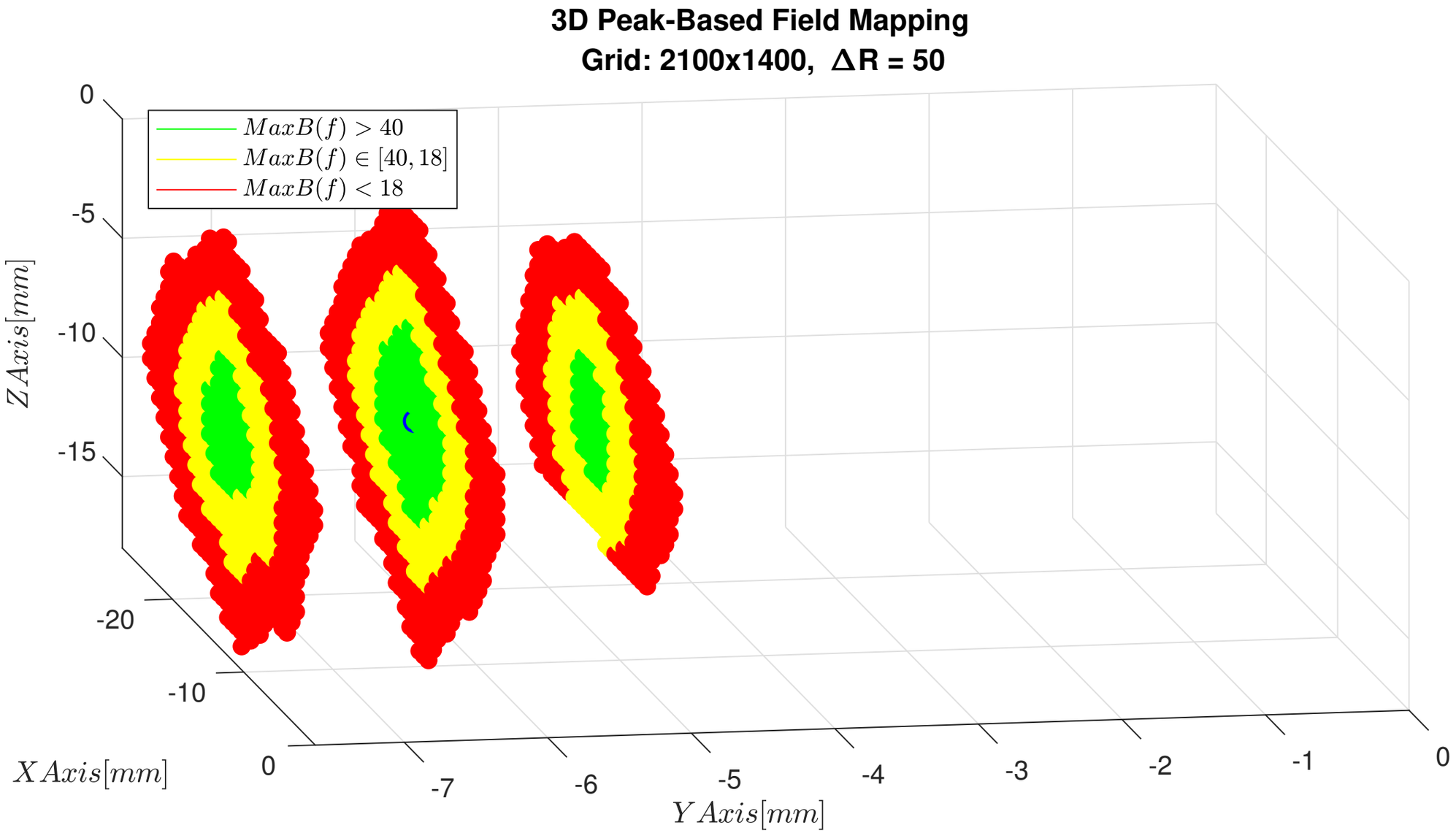


Fermilab

Data Analysis: 3 slices, 635um [50 steps]

Slices	5.08mm, 6.3mm, 7.6mm
Grid Resolution	635 um
Current	200A
Date	September 11th & 12th

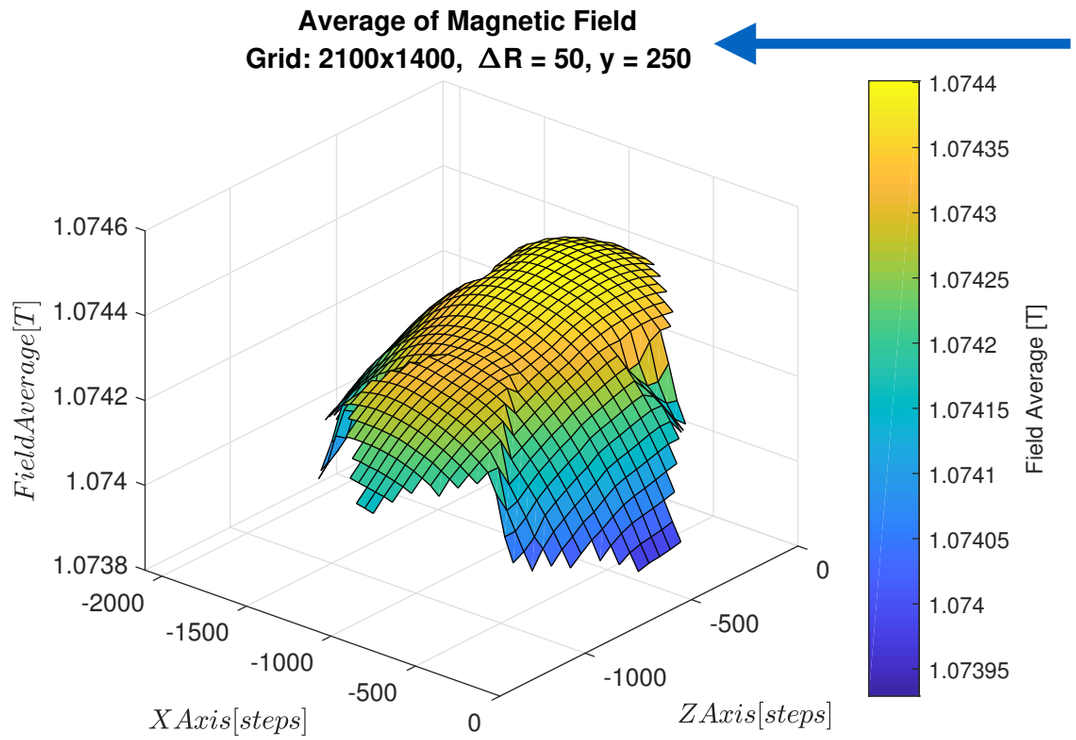
R = 635 um - 3D Map, Uniform Region



Uniformity are good.

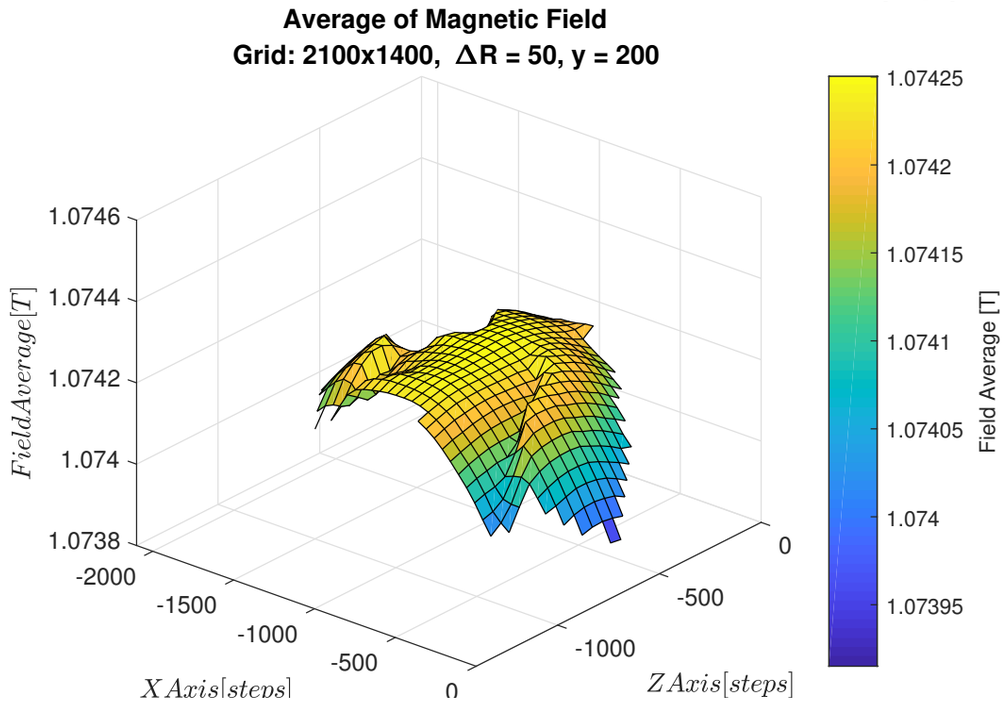
Amplitude value has been corrupted.

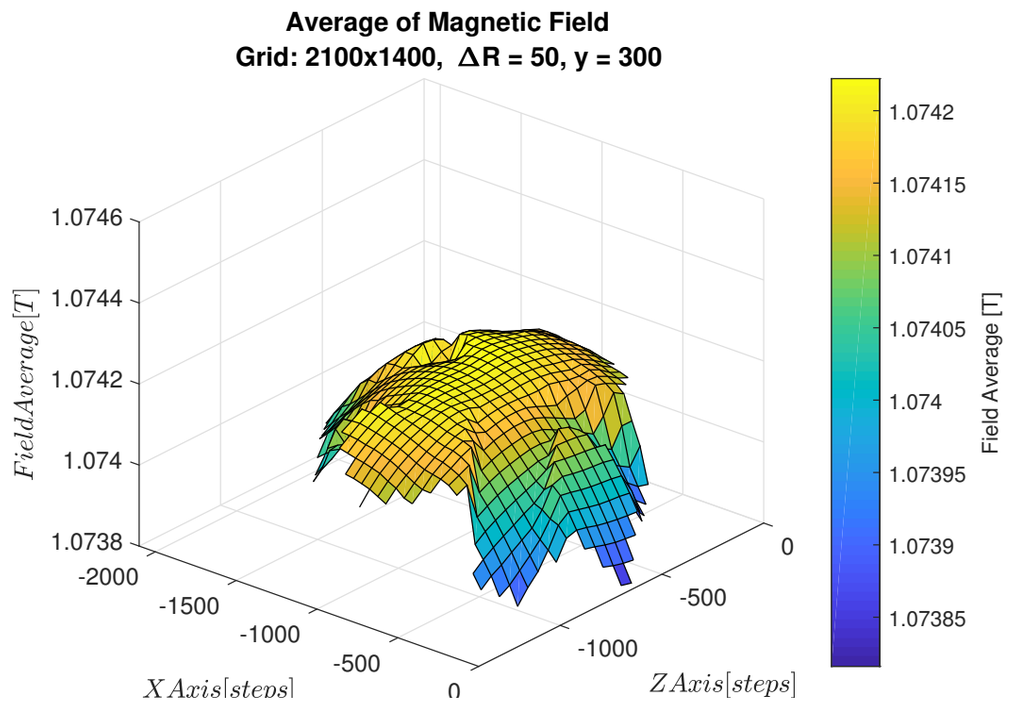
R = 635 um - Space Distribution of Average Amplitude



Linear Trend on Z

(magnet on < 1 day)

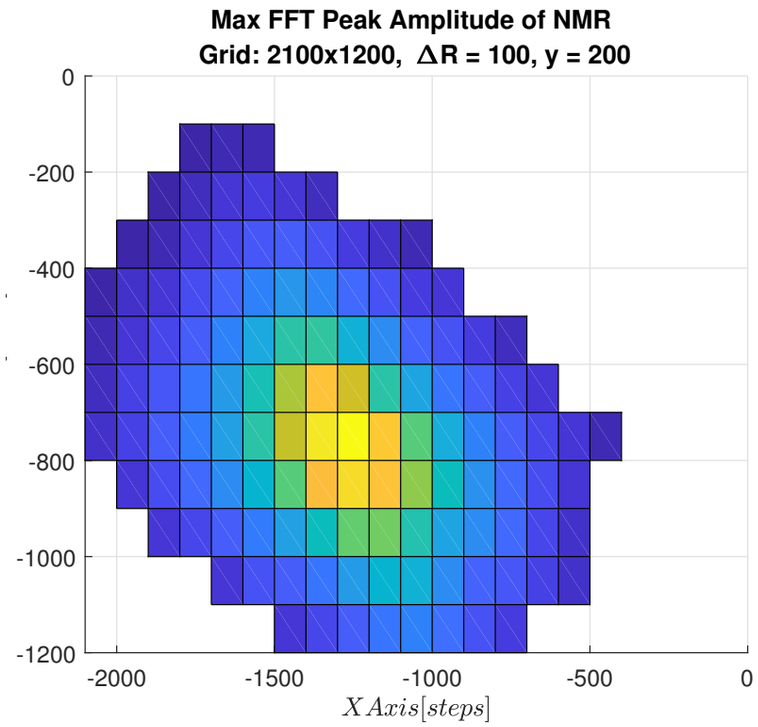




Fermilab

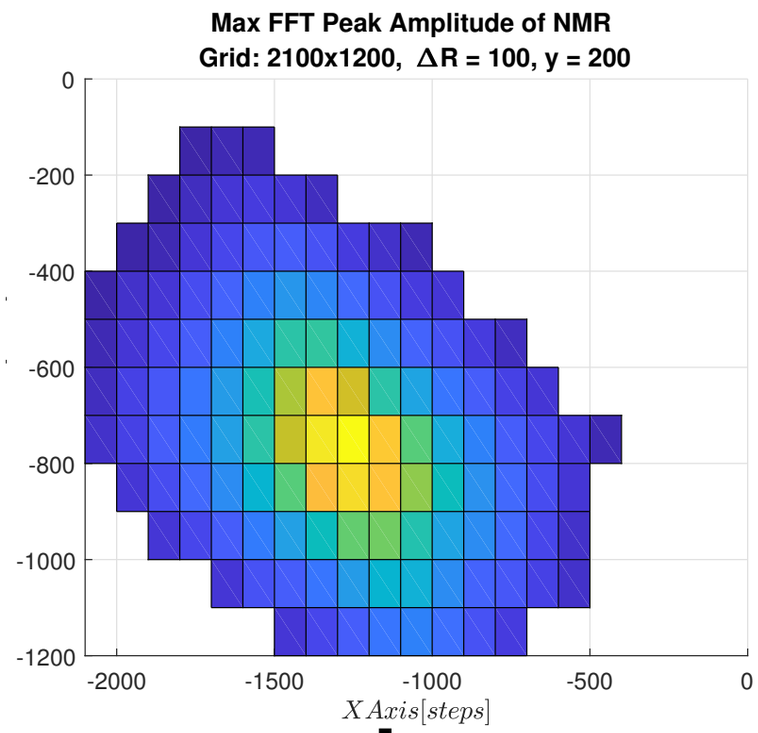
Resolution Comparison

1.27mm
[100 steps]

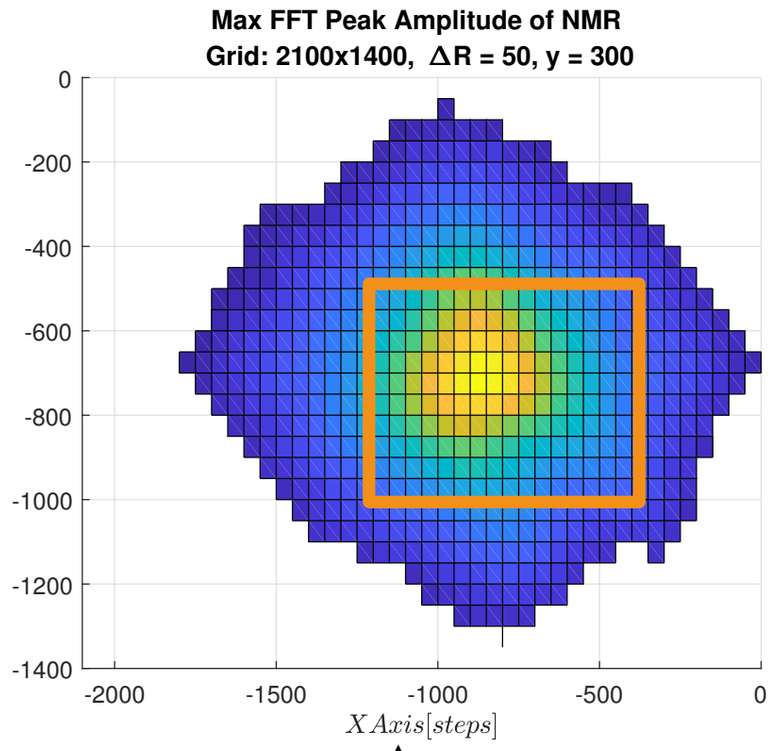


Resolution Comparison

1.27mm
[100 steps]



635um
[50 steps]



Backlash compensation

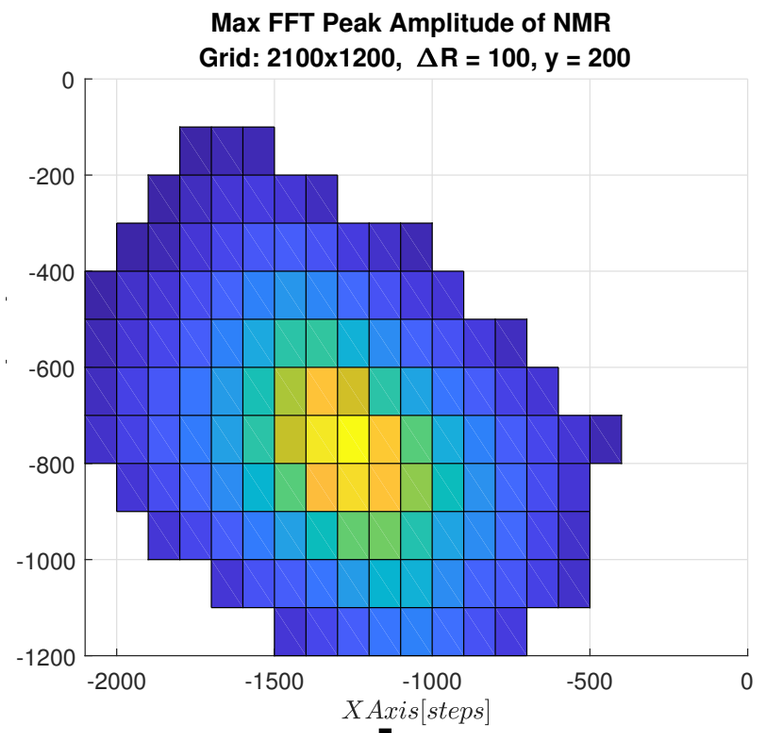
&

Resolution++

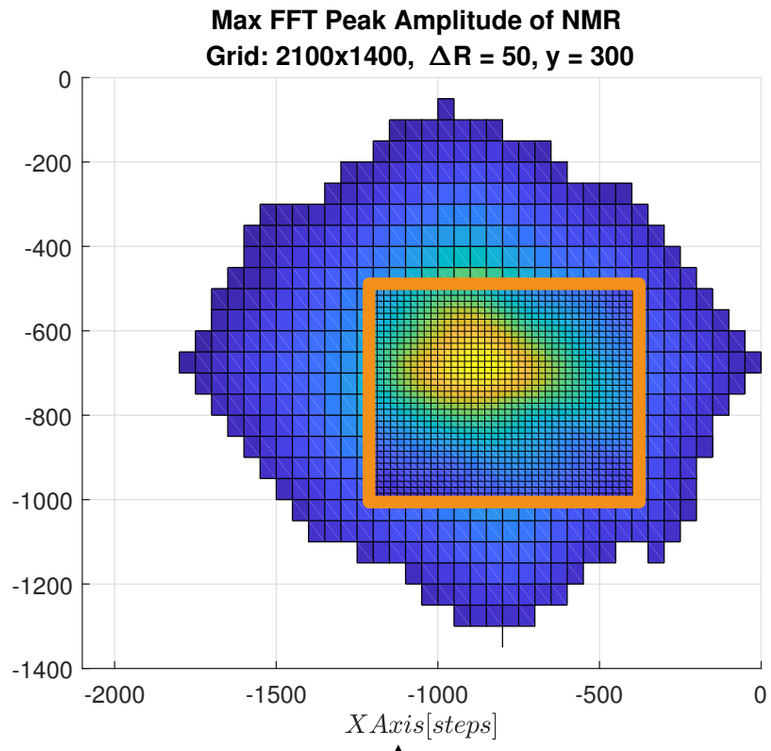
Fermilab

Resolution Comparison

1.27mm
[100 steps]



635um
[50 steps]



Backlash compensation

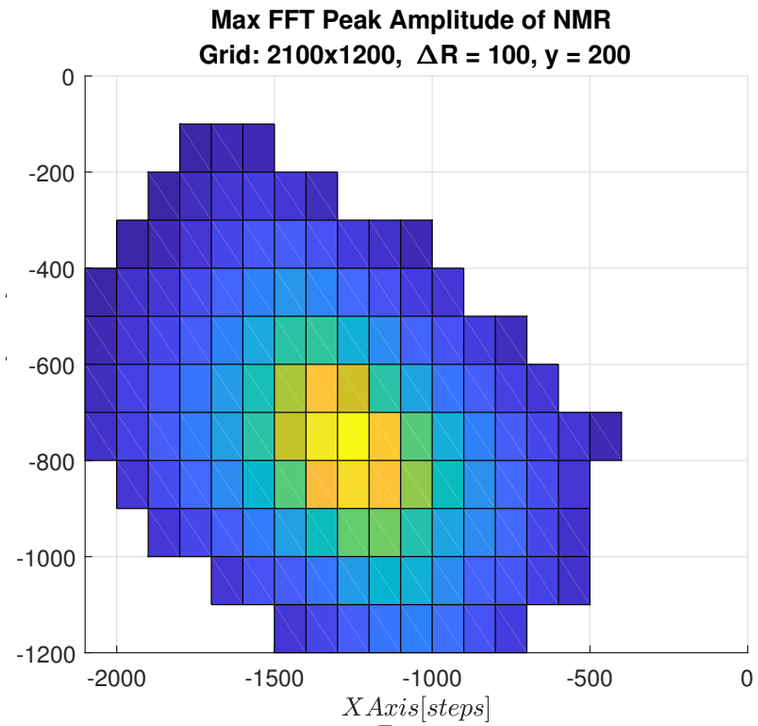
&

Resolution++

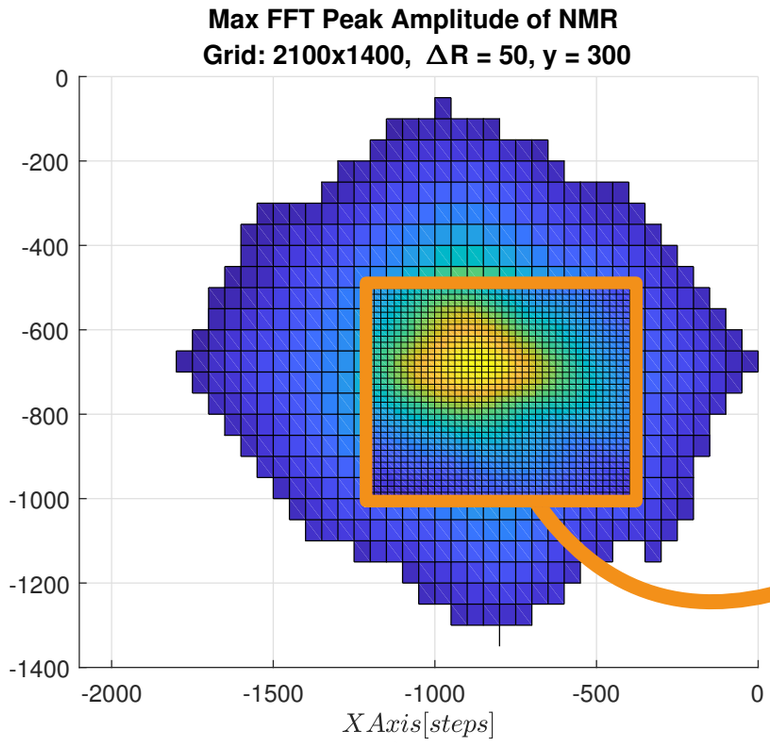
Fermilab

Resolution Comparison

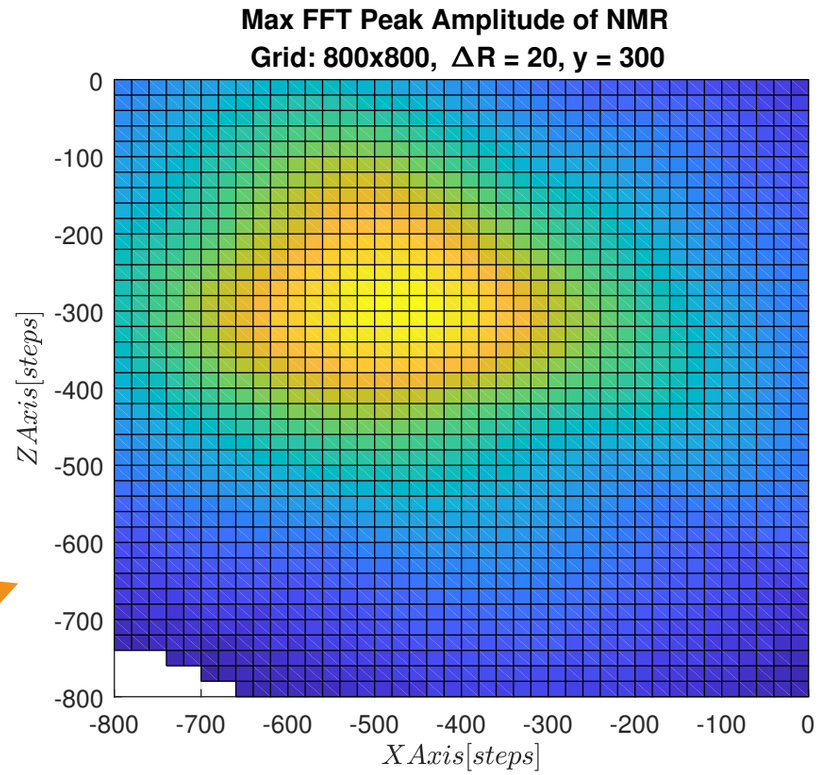
1.27mm
[100 steps]



635um
[50 steps]



254um
[20 steps]



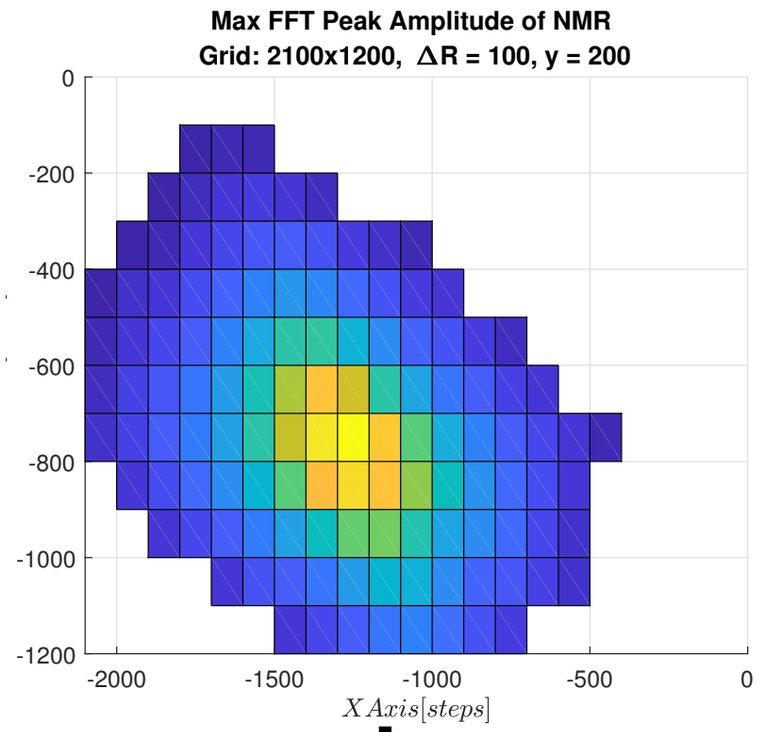
Backlash compensation

&

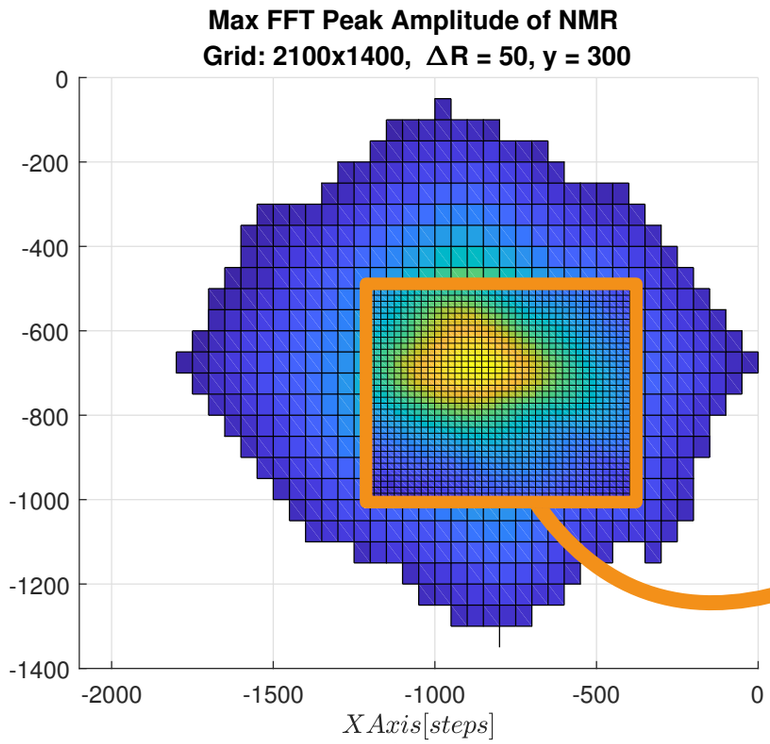
Resolution++

Resolution Comparison

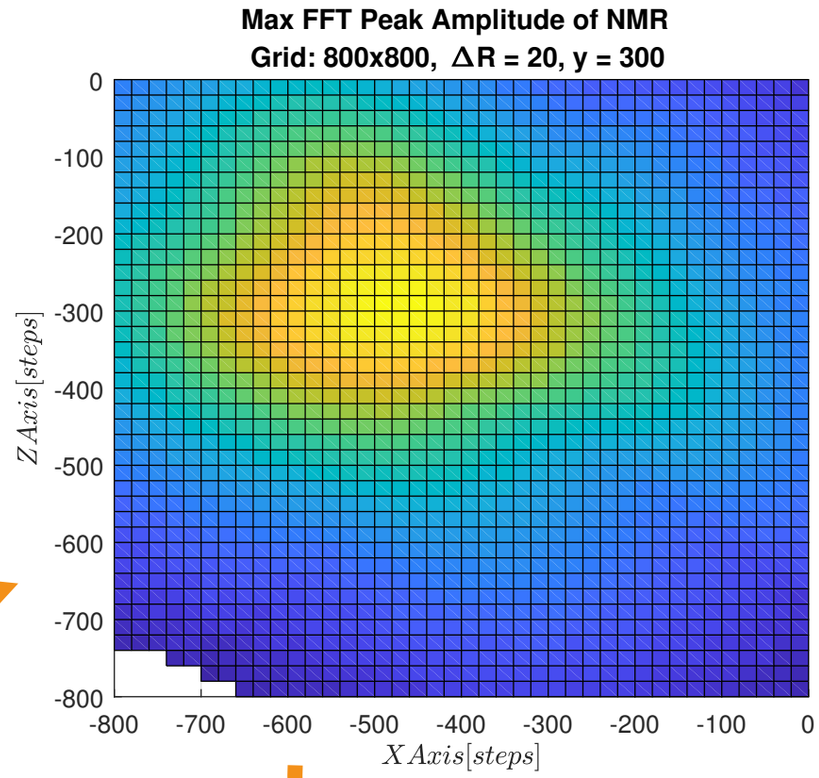
1.27mm
[100 steps]



635um
[50 steps]



254um
[20 steps]



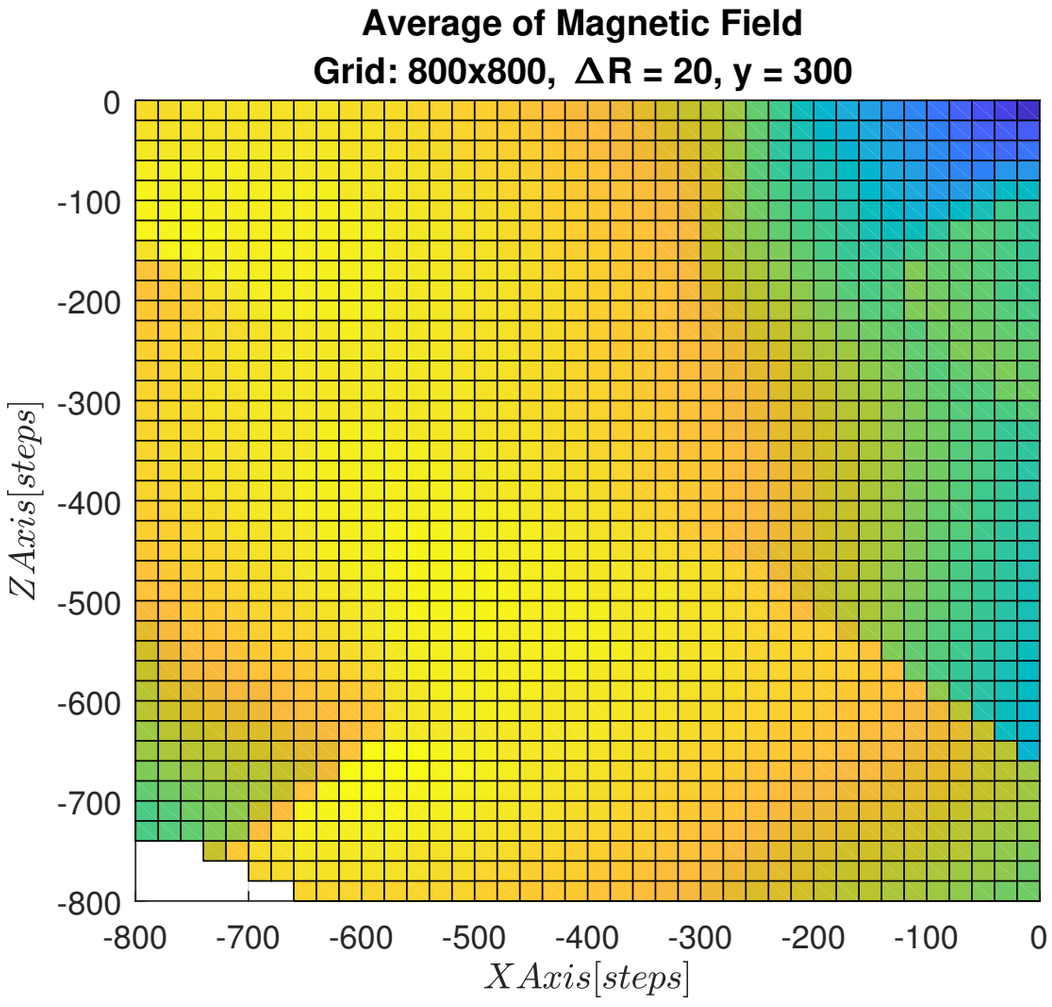
Backlash compensation
&
Resolution++

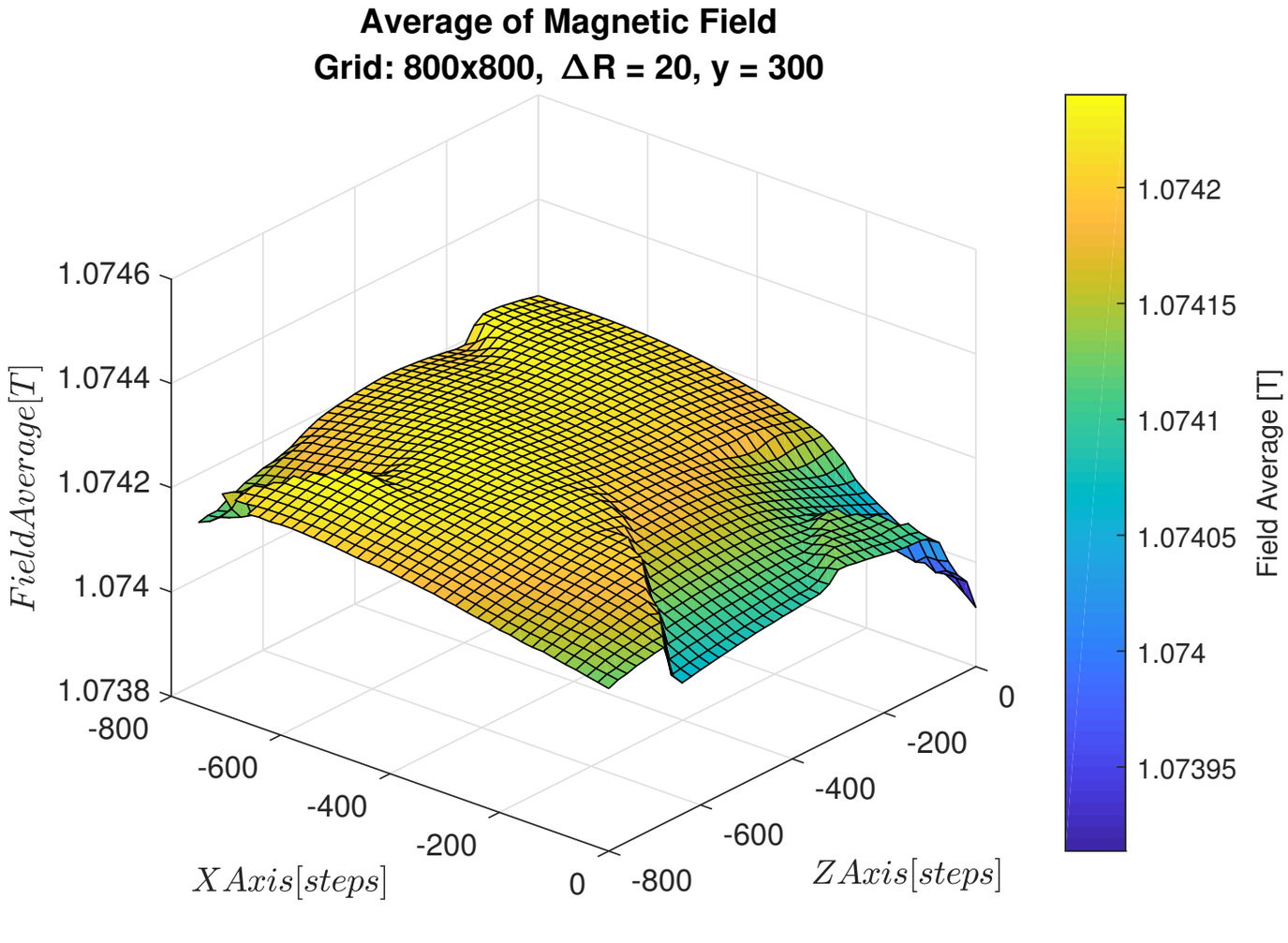
1

Data Analysis: 1 slice, 254um [20 steps]

Slices	7.6mm
Grid Resolution	254um
Current	200A
Date	September 12th

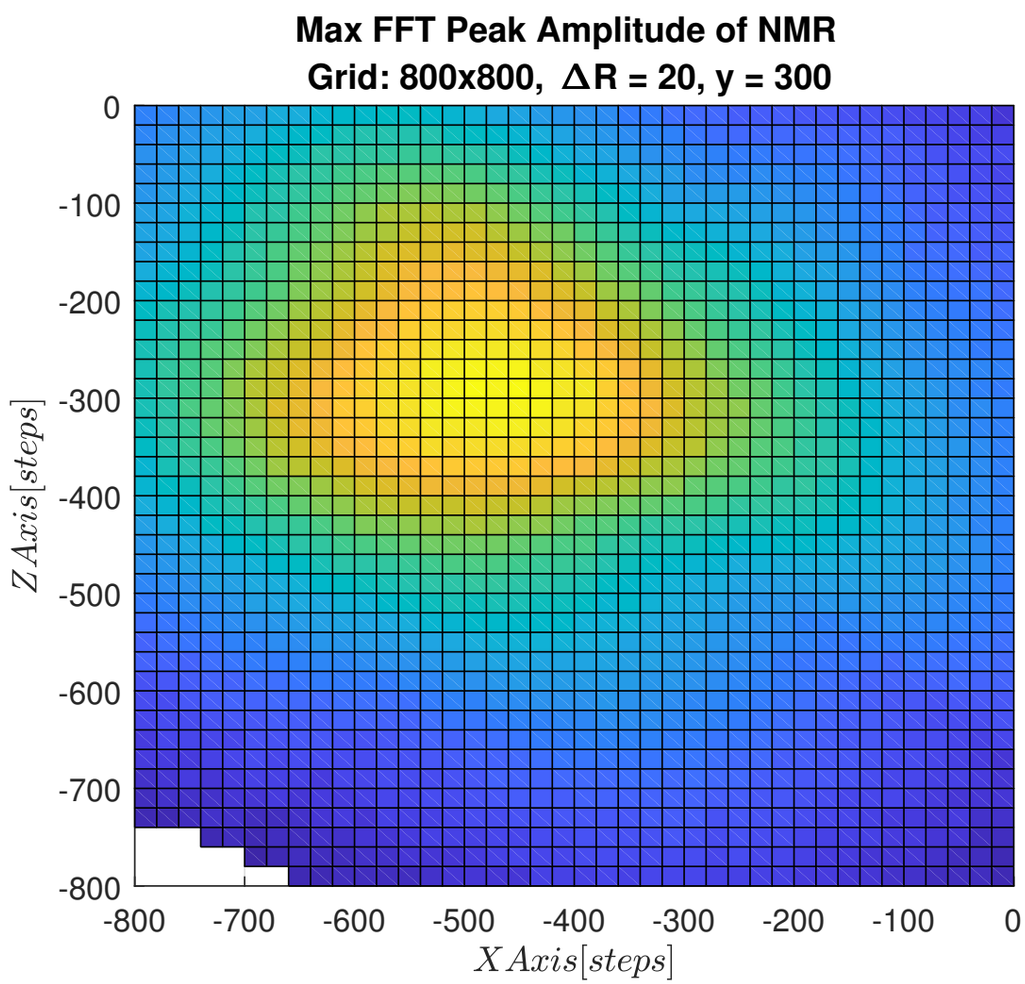
R = 254um - Space Distribution of Average Amplitude

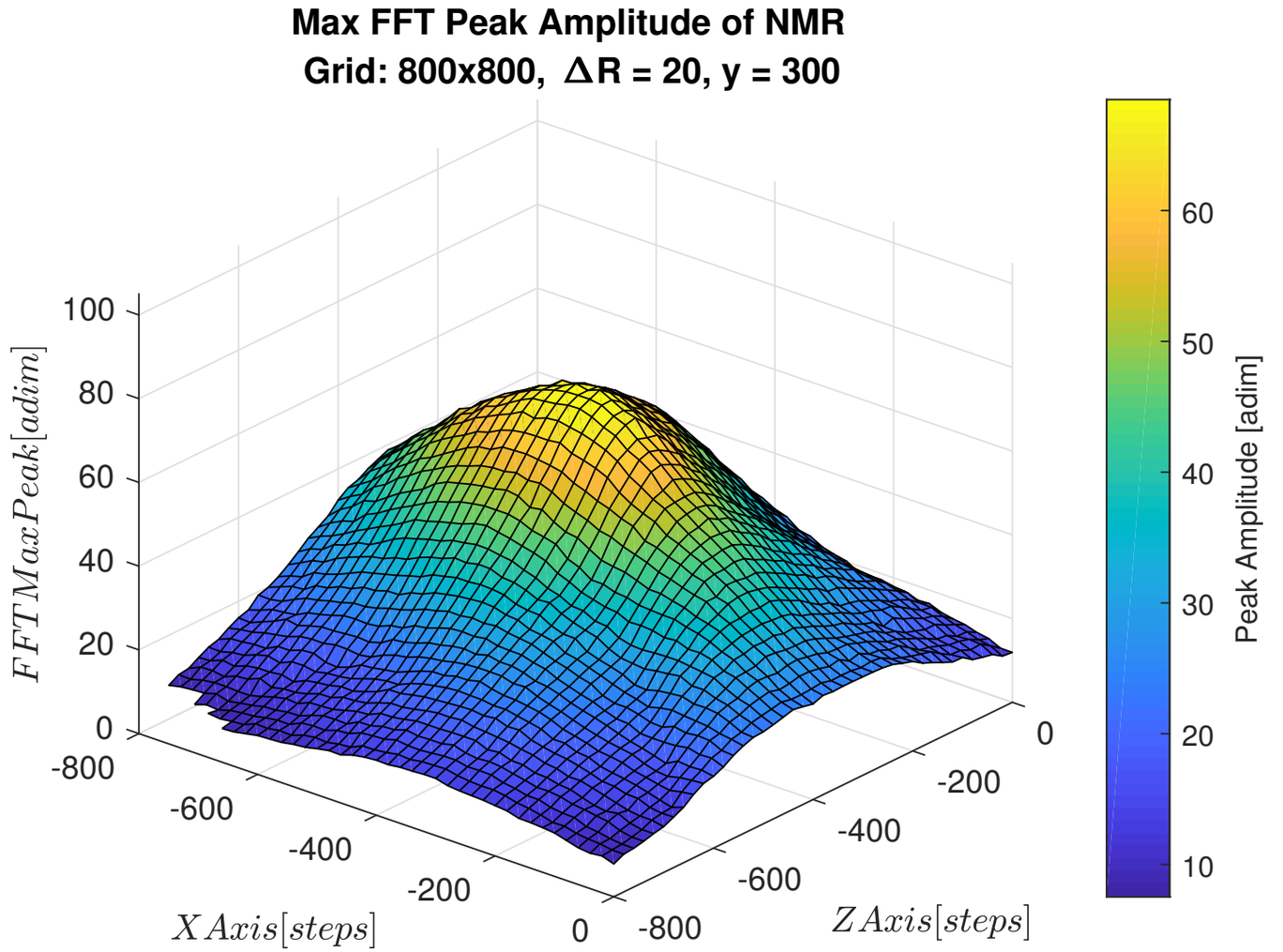




Flat Shape -> Good Constant Region

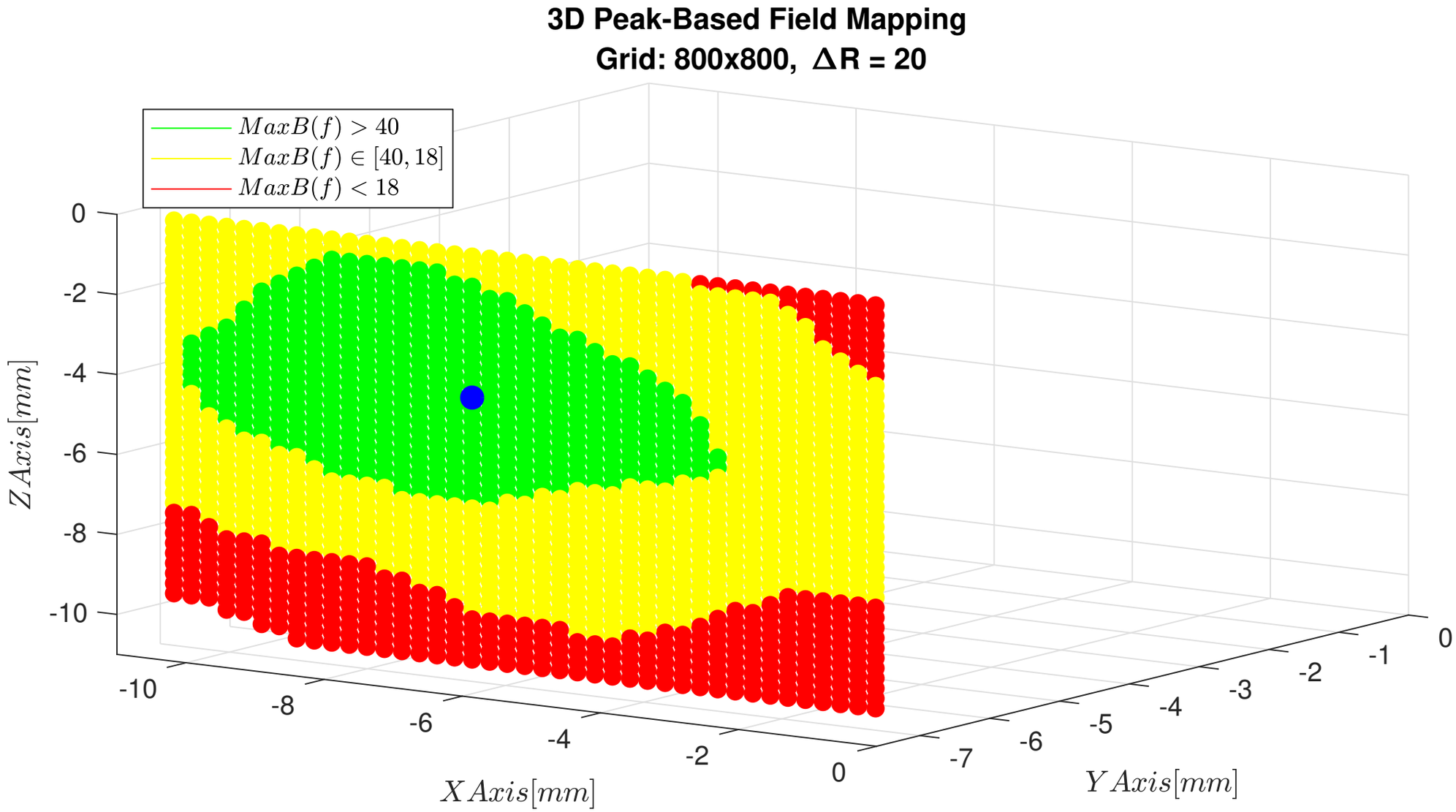
R = 254um - Space Distribution of Maximum FID Peak





Bell Shaped -> Uniformity Factor is good

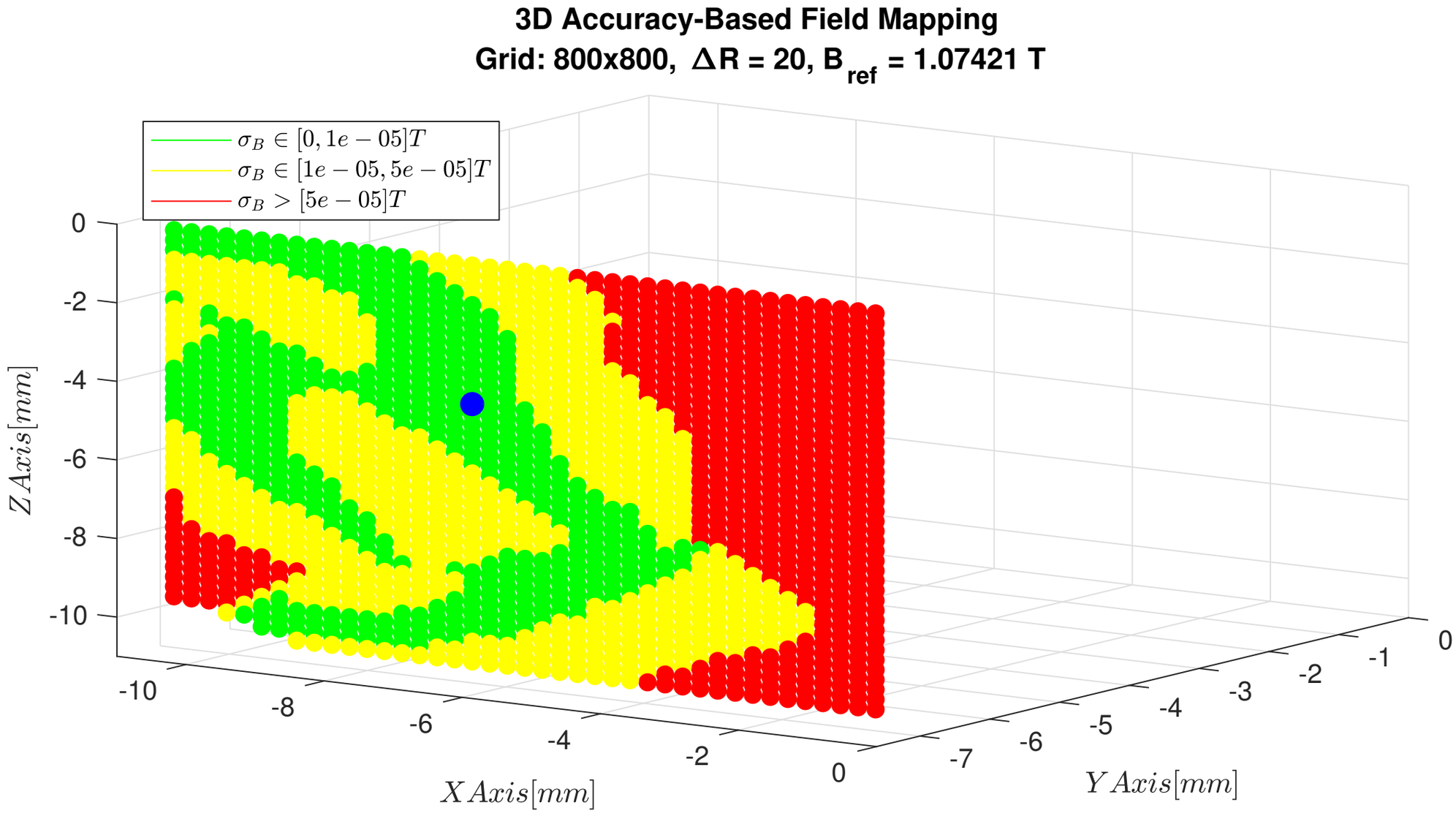
R = 254um - 3D Map, Uniform Region



Green area: points with good Uniform factor

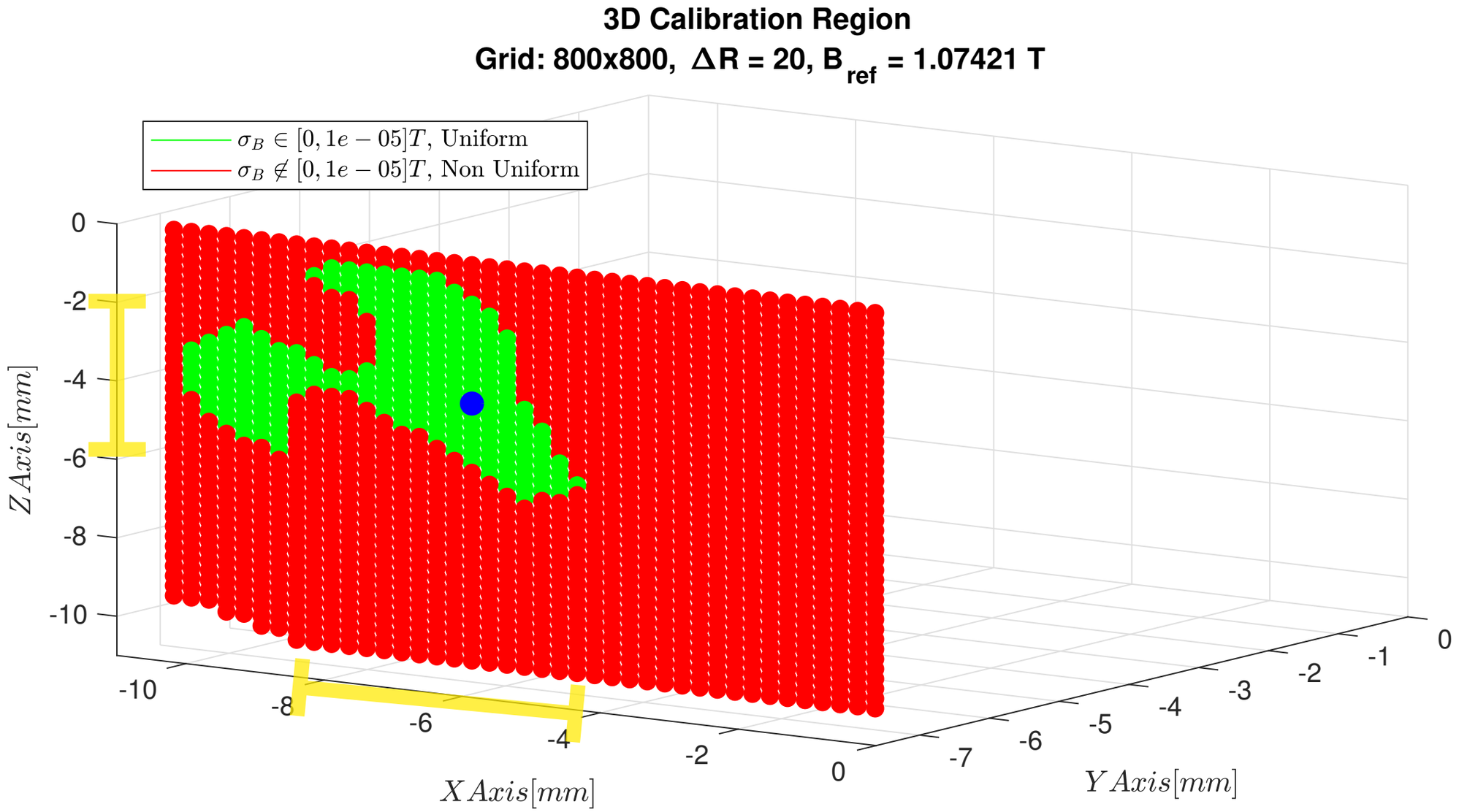
Blue point: Maximum Peak Value

R = 254um - 3D Map, Accurate Region



Green Area: points with 10^{-5} Accuracy respect to the **Amplitude of Blue Point**

R = 254um - 3D Uniform and Accurate Region



Calibration Region ~ 4x2 mm

Less Time Constraints on project -> more samples, more resolutions

5 - Conclusions

1. The Plant
2. Software Design
3. Calibration Process
4. Data Analysis

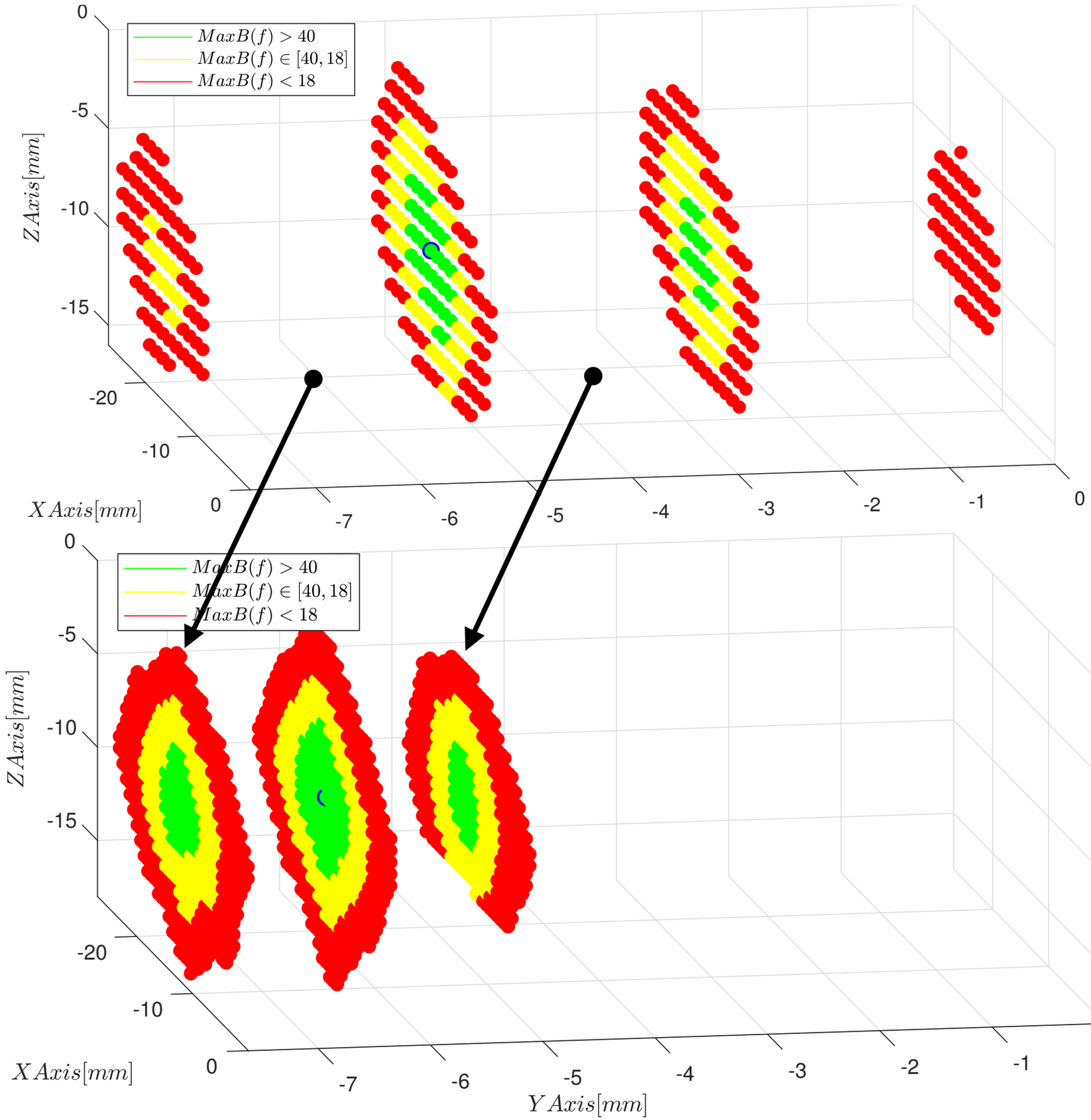
5. Conclusions

Calibration Process Requirements

- **Resolution:** Step Size (Motors, 12,7 um)
- **Accuracy:** Errors (NMR, 10^{-7} T)
- **Precision: Repeatability?**

- **Week 6**

- **Week 7**

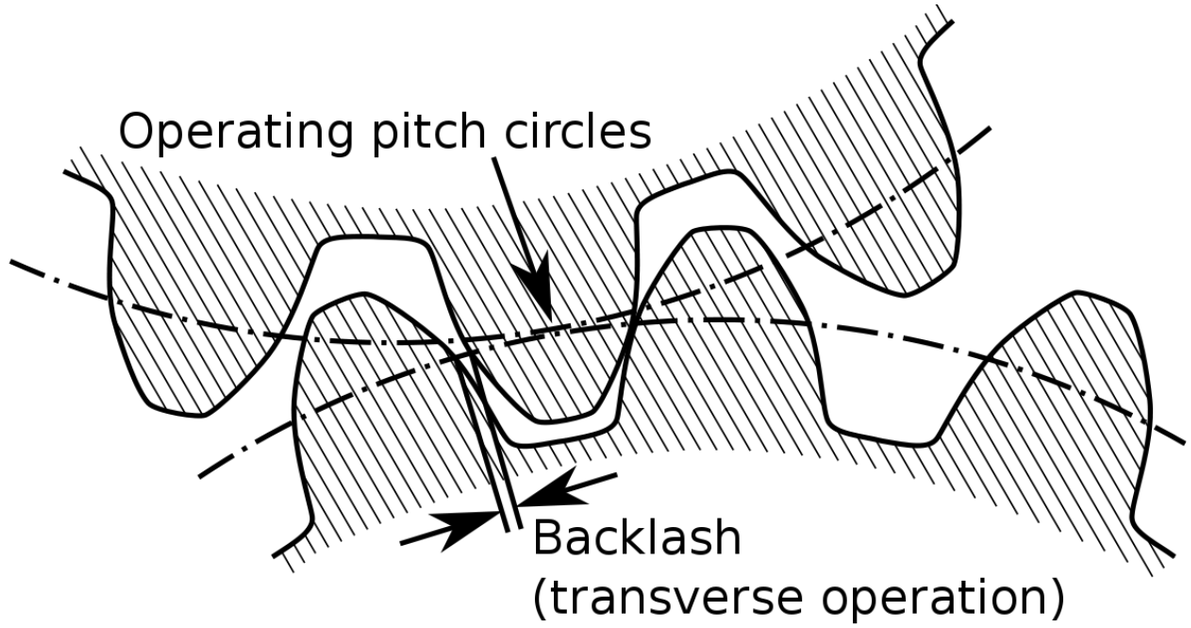


Fermilab

Precision Loss Source - Y Stage

- **Manual Motion**

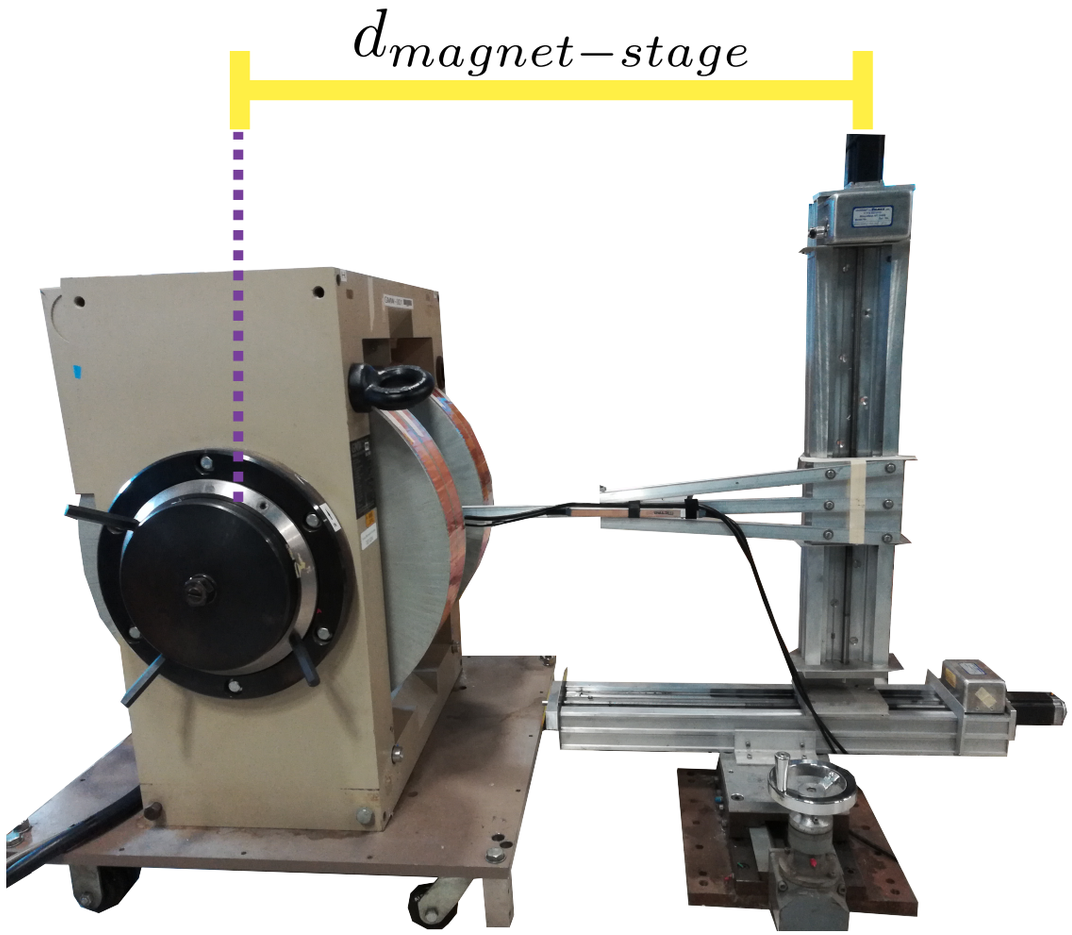
- **Unknown Backlash**



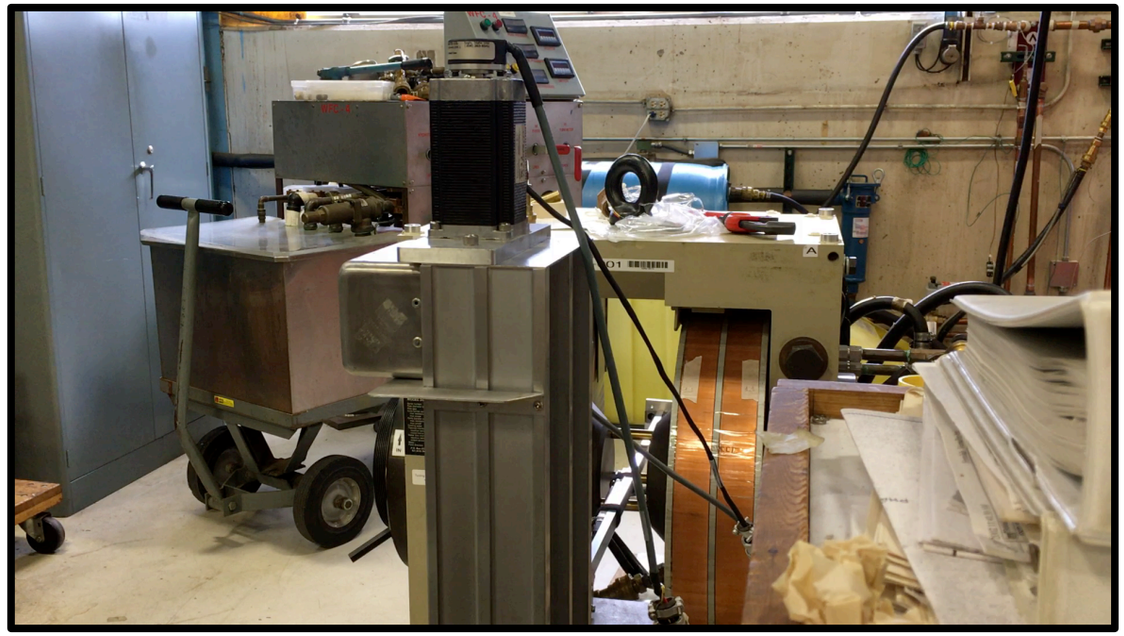
Human Control -> Unbounded Uncertainty -> Unbounded Precision

Precision Loss Source - Experimental Setup

- **Relative Position**



- **Small Inertia**



No Available CAD drawings,

Low robustness of mechanics

Suggestions

- **Software**:
  - **Hardware Errors** should be handled
  - **Faster Searching Algorithms** should be implemented
- **Calibration Plant** :
  - **An Actuated Y Stage** is strongly suggested
  - More interest in the **Mechanics of the experimental setup** should be considered (Precision)

Backup Slides

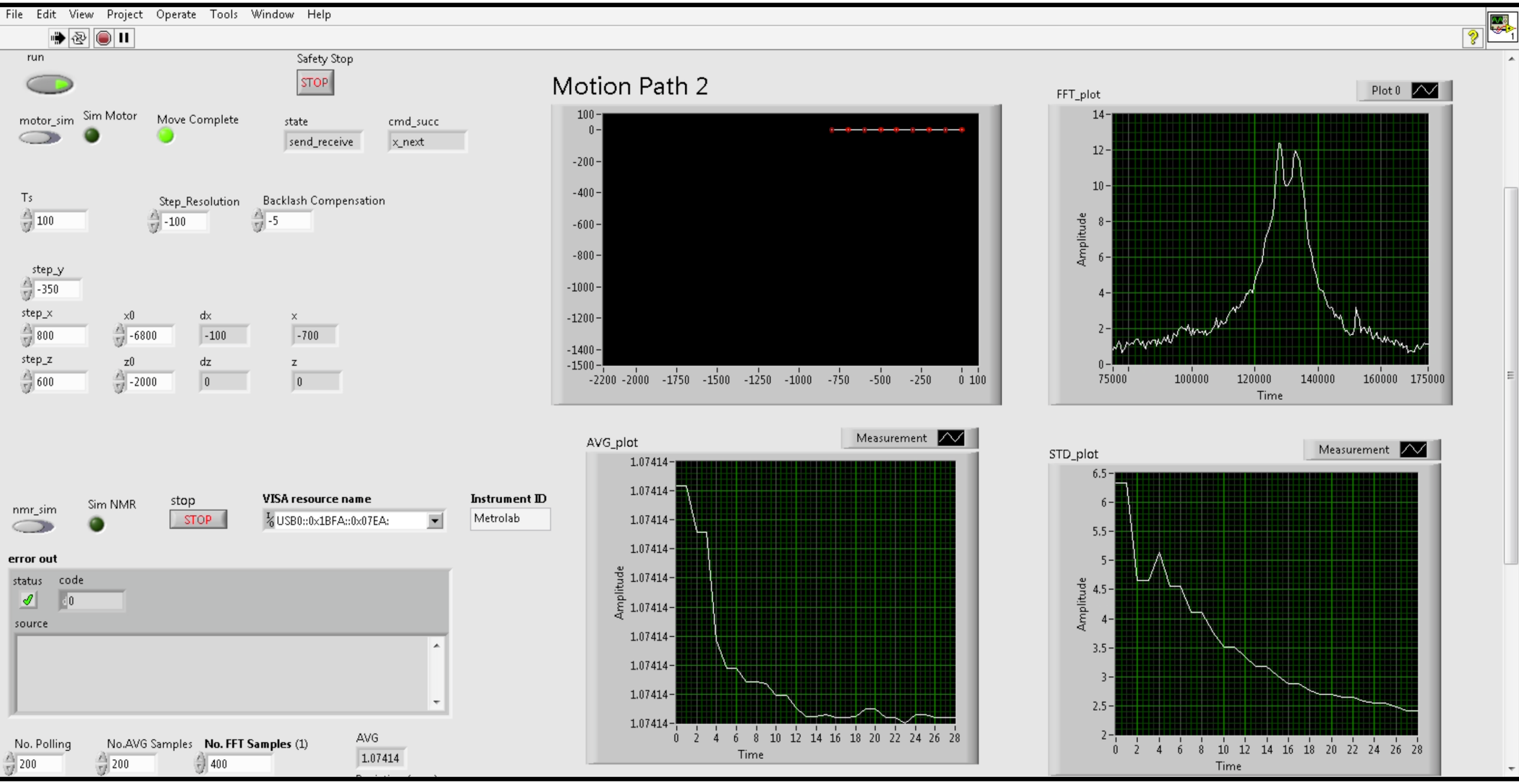
Bibliography

- Brian Pollack, Mu2e Magnetic Field Mapping
- John C. Edwards, Principles of NMR [http://www.process-nmr.com/nmr1.htm]

2 - Software Design

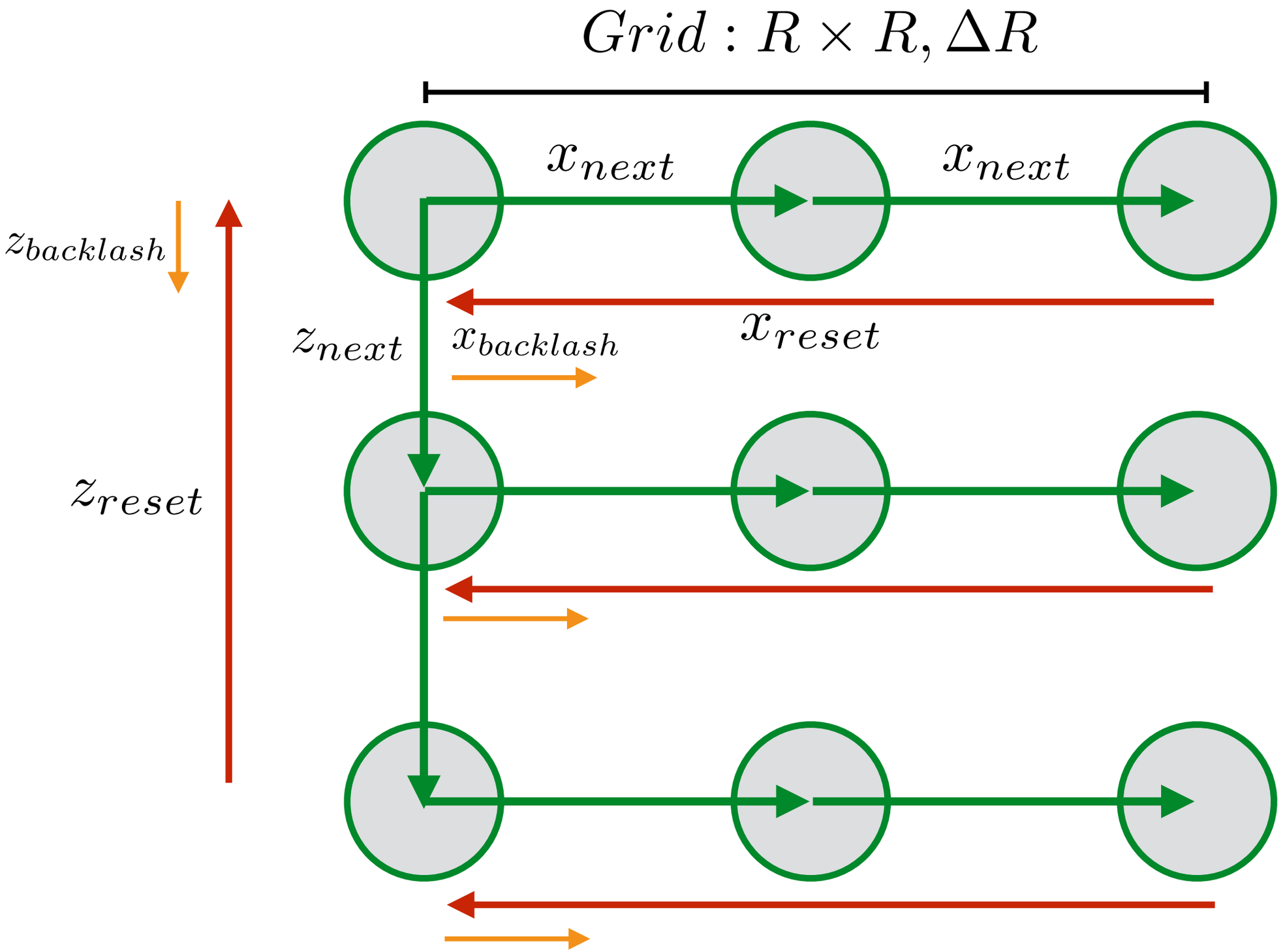
1. Problem Statement
2. **Software Design**
3. Calibration Process
4. Data Analysis
5. Conclusions

LabVIEW Interface

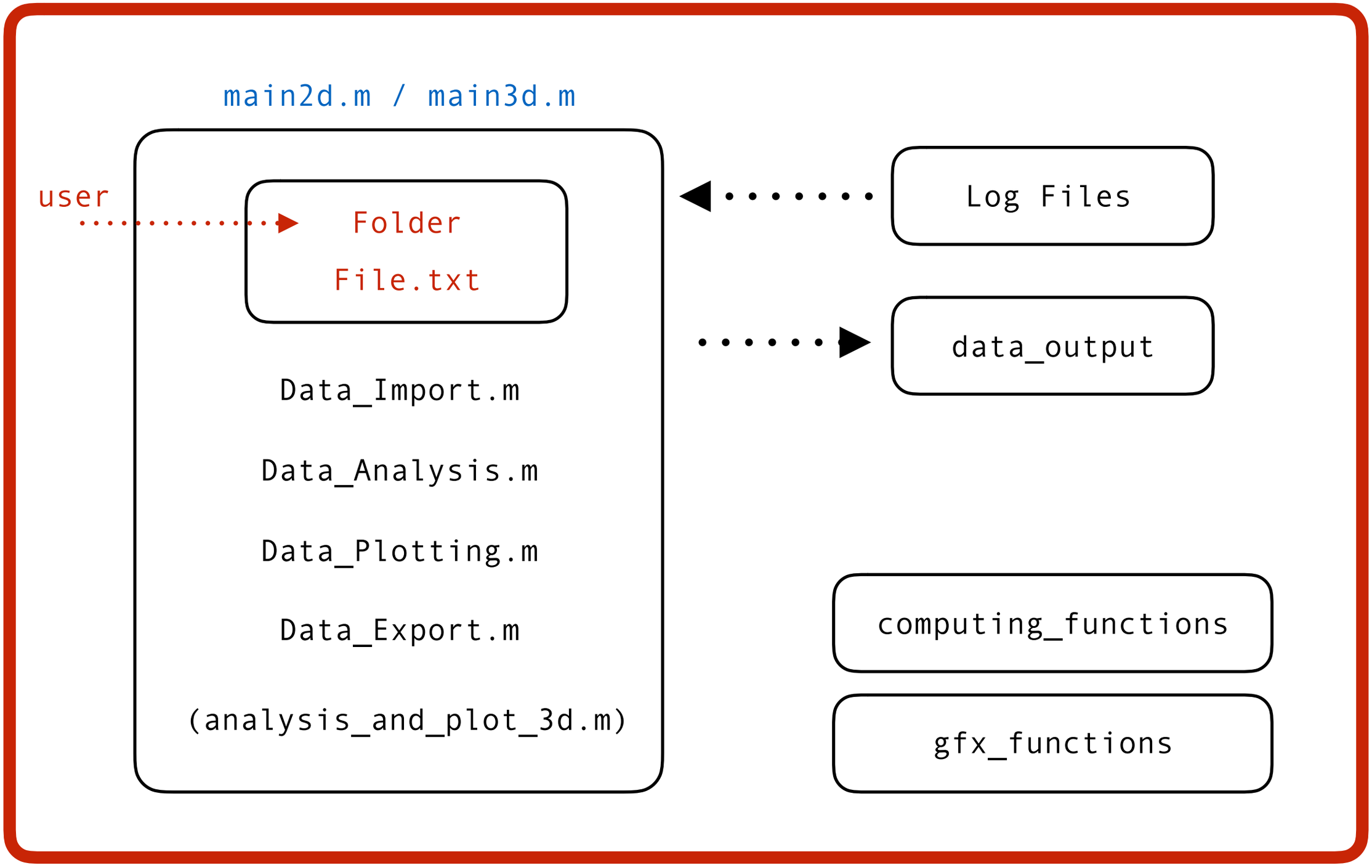


Fermilab

Raster Scan


$Grid : R \times R, \Delta R$
x_{next}
x_{next}
$z_{backlash}$
z_{next}
$x_{backlash}$
x_{reset}
z_{reset}

MATLAB Application



3 - Calibration Process

1. Problem Statement
2. Software Design
3. **Calibration Process**
4. Data Analysis
5. Conclusions

Calibration Process: Principles of NMR#1

- "A nucleus with spin 1/2 will have **2 possible orientations**.
  In the **absence of an external magnetic field**, these orientations are of **equal energy**.
  If a **magnetic field is applied**, then the **energy levels split**" [1]

- "Spin states which are **oriented parallel** to the external field are **lower in energy** than in the absence of an external field.
  In contrast, spin states whose orientations **oppose the external field** are **higher in energy** than in the absence of an external field." [1]

- "The **rotational axis of the spinning nucleus** cannot be orientated exactly parallel (or anti-parallel) with the direction of the applied field B_0 but must **precess about this field** at an angle, with an angular velocity given by the expression: $\omega_0 = gB_0$
  Where ω_0 is the precession rate called the **Larmor frequency**.
  The constant g is called the magnetogyric ratio." [1]

Calibration Process: Principles of NMR#2

- "This **precession process generates an electric field** with frequency ω_0.
  If we irradiate the sample with radio waves (MHz) the proton can absorb the energy and be **promoted to** the less favorable **higher energy state**.
  This absorption is called resonance because the frequency of the applied radiation and the precession coincide or resonate."[1]

- "While frequency is not a measure of energy, the simple relationship $E = h\nu$ makes this substitution understandable "[1]

Calibration Process: Principles of NMR#3

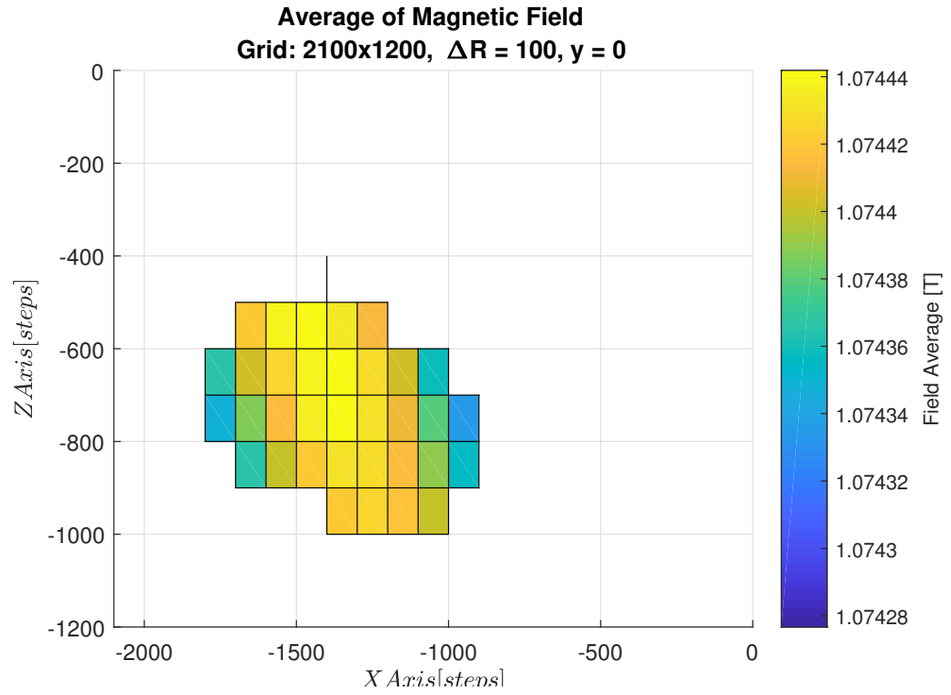
- "A single oscillator (transmitter) is used to generate a pulse of **electromagnetic radiation of frequency** ω"[1]
- "**When the pulse ends**, the nuclei relax and return to their equilibrium positions, and the signal decays.

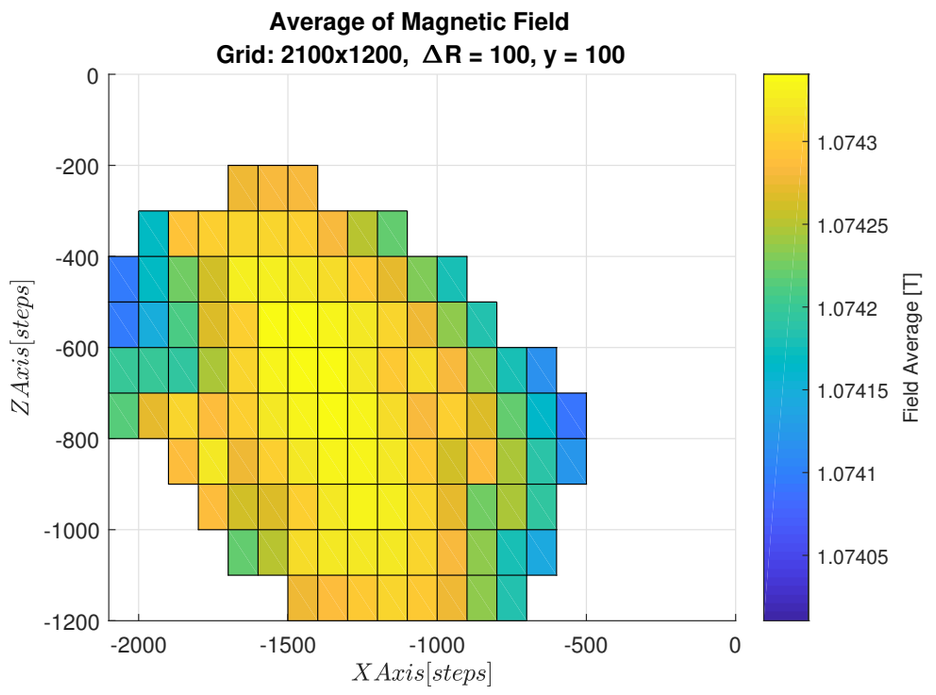
This decaying signal contains the **sum of the frequencies from all the target nuclei**. [..] It is mixed with a lower frequency signal to produce an interferogram of low frequency. This interferogram is digitized, and is called the **Free Induction Decay, (FID)**.
Fourier transformation of the FID yields a **frequency domain spectrum**." [1]

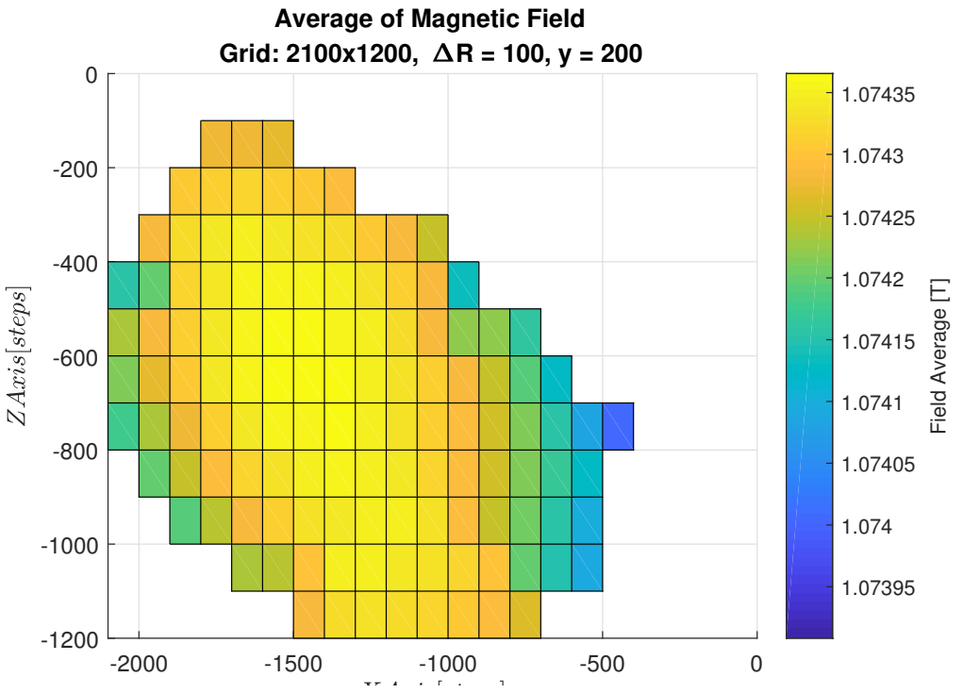
4 - Data Analysis

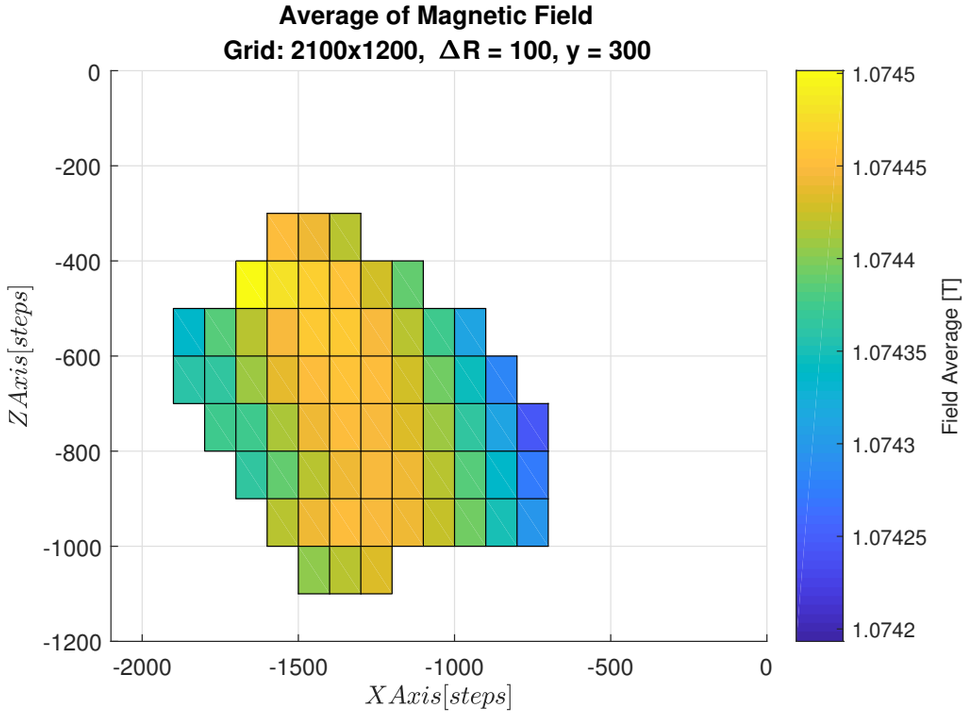
1. The Plant
2. Software Design
3. Calibration Process
4. **Data Analysis**
5. Conclusions

R = 1.27mm - Space Distribution of Average Amplitude



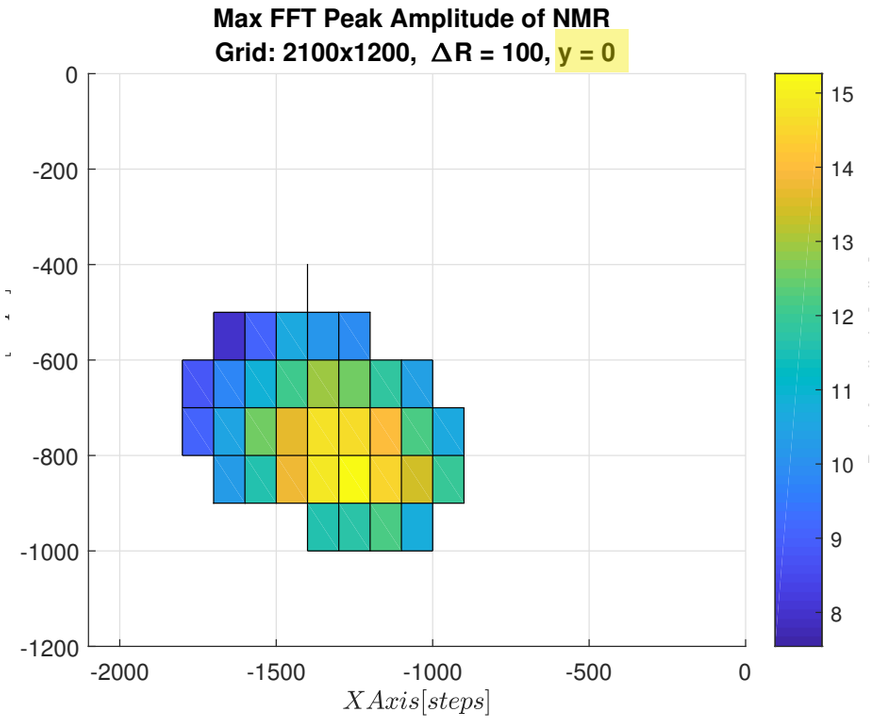


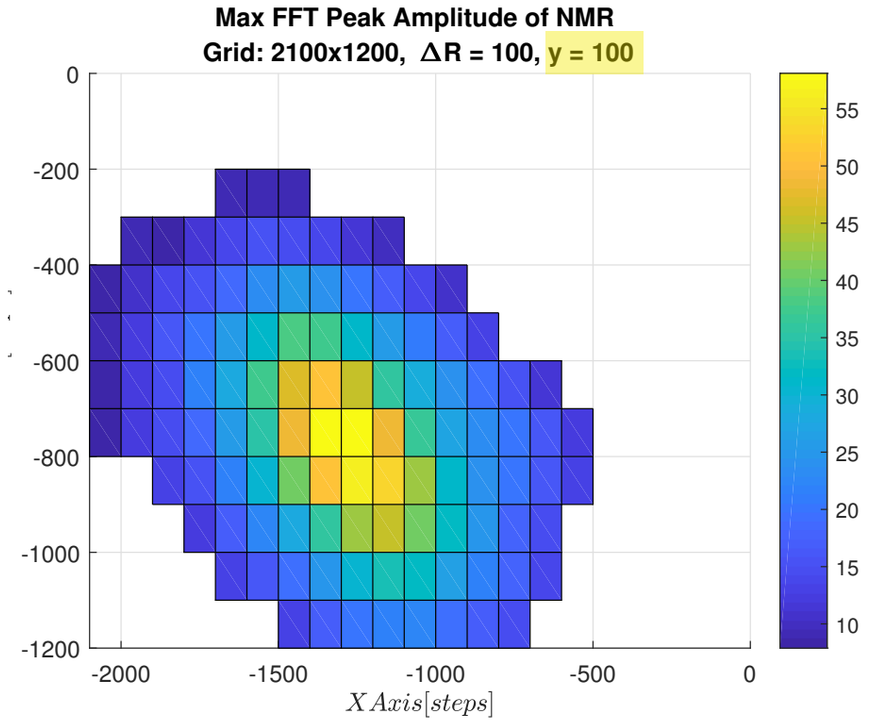


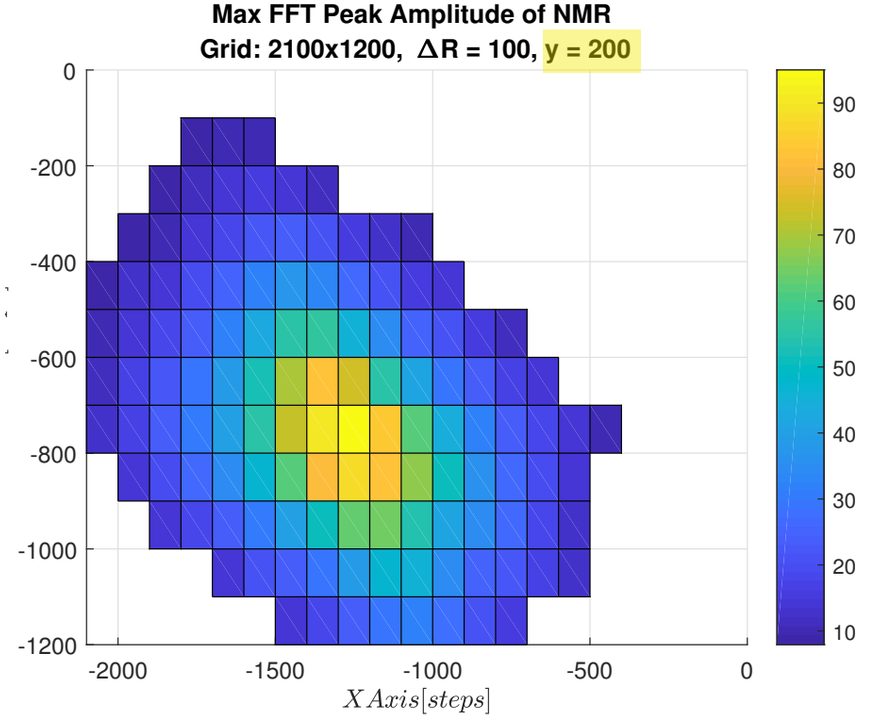


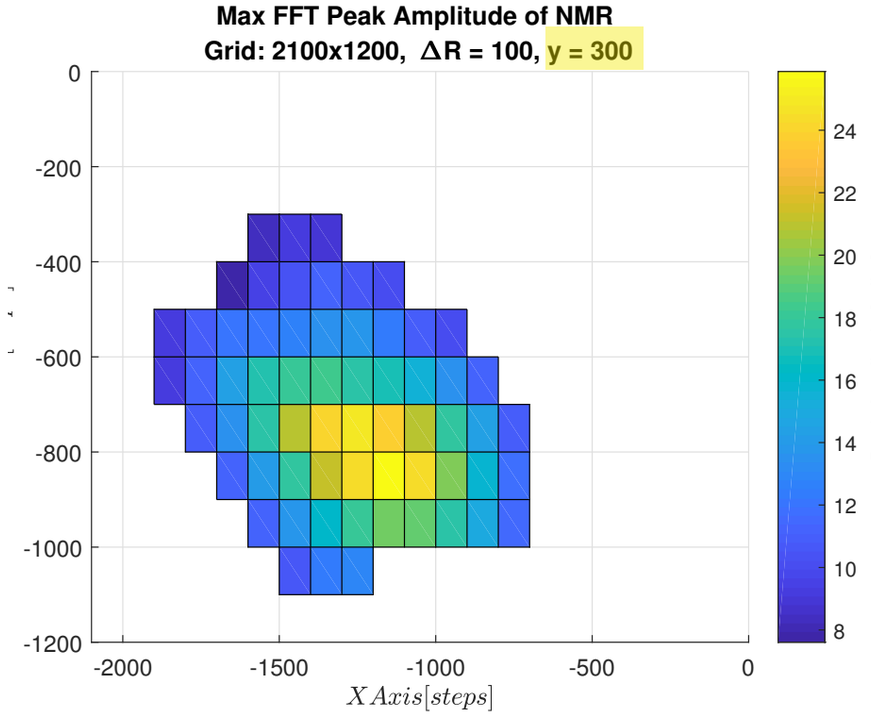
Fermilab

R = 1.27mm - Space Distribution of the Maximum FID Peak



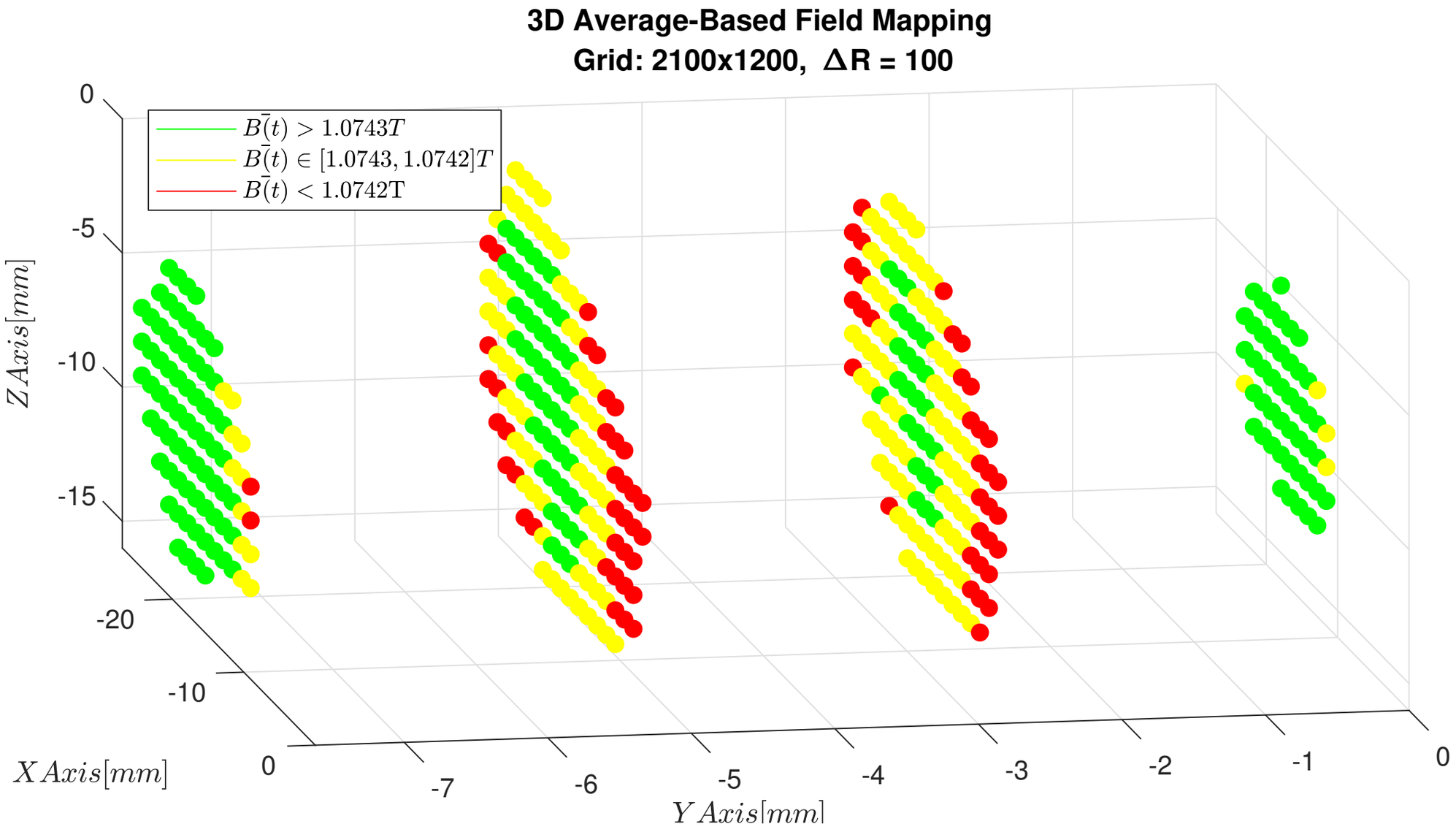






Fermilab

R = 1.27mm - 3D Map, Average Amplitude

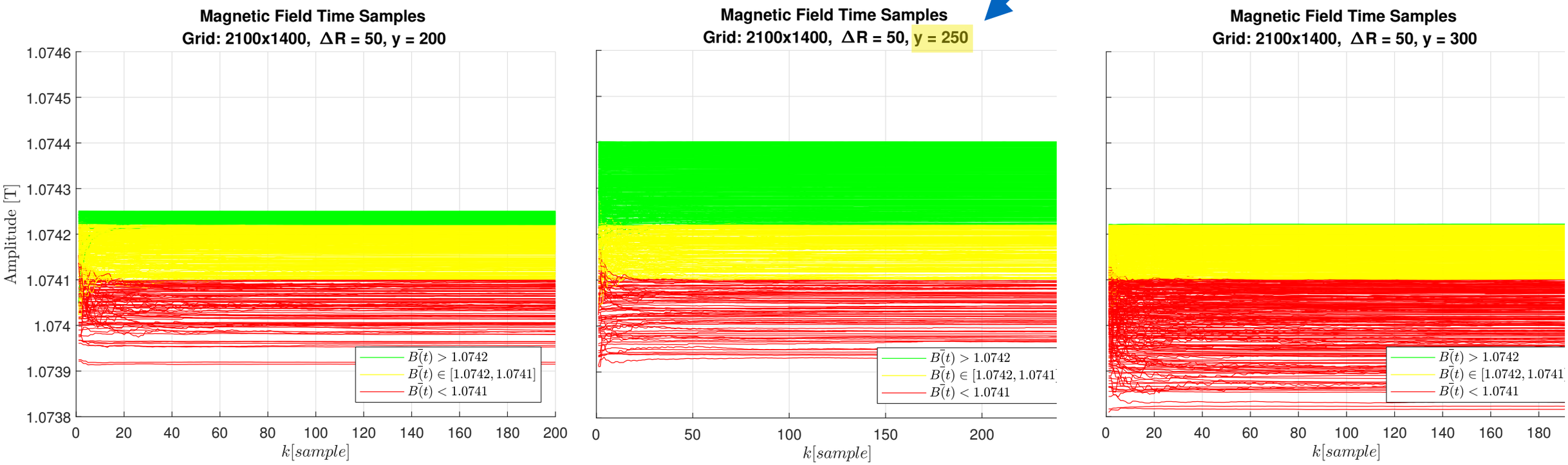


Close to poles, big average values (expected)

Let's try to increase resolution to evaluate accurate region

635um - Space Distribution of Average Amplitude

Strongest Field

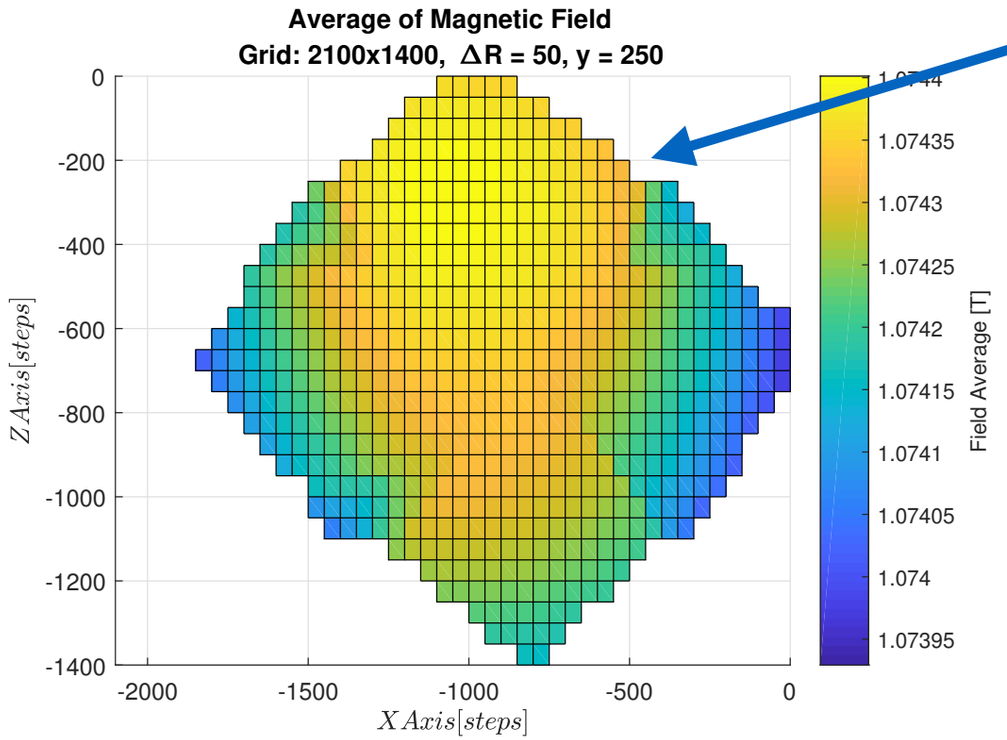


Lower Amplitude Values respect to week 6

Central > Others

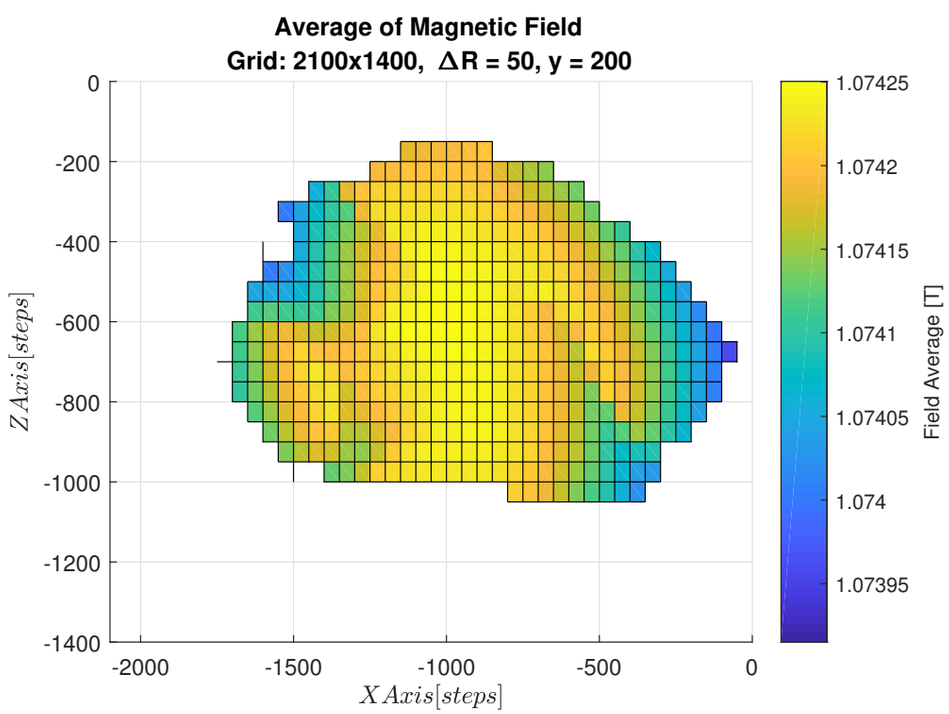
Fermilab

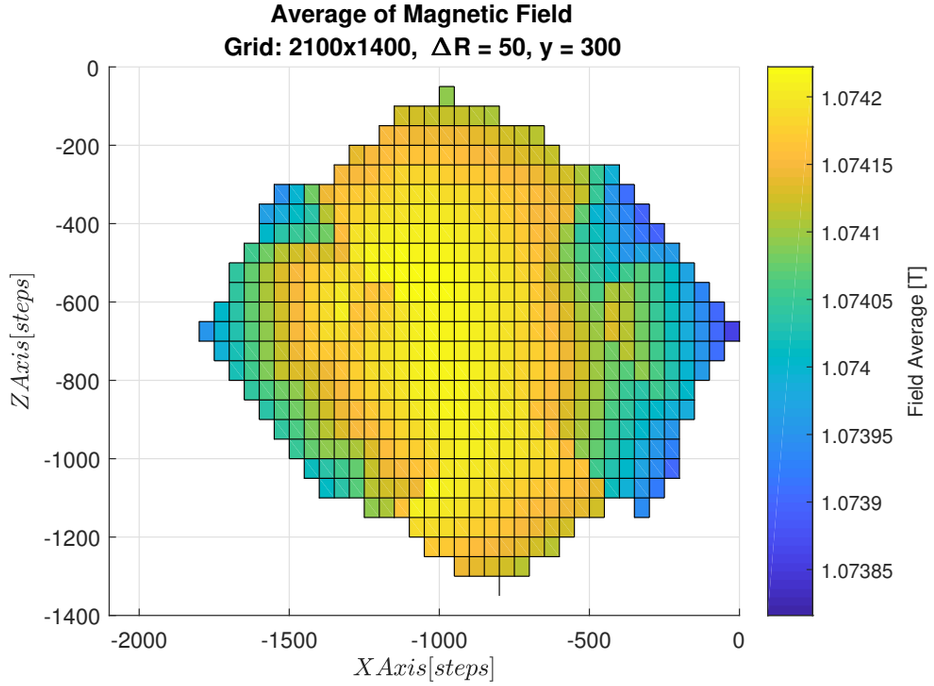
635um - Space Distribution of Average Amplitude



North: More Intense

(Results need to be discussed)

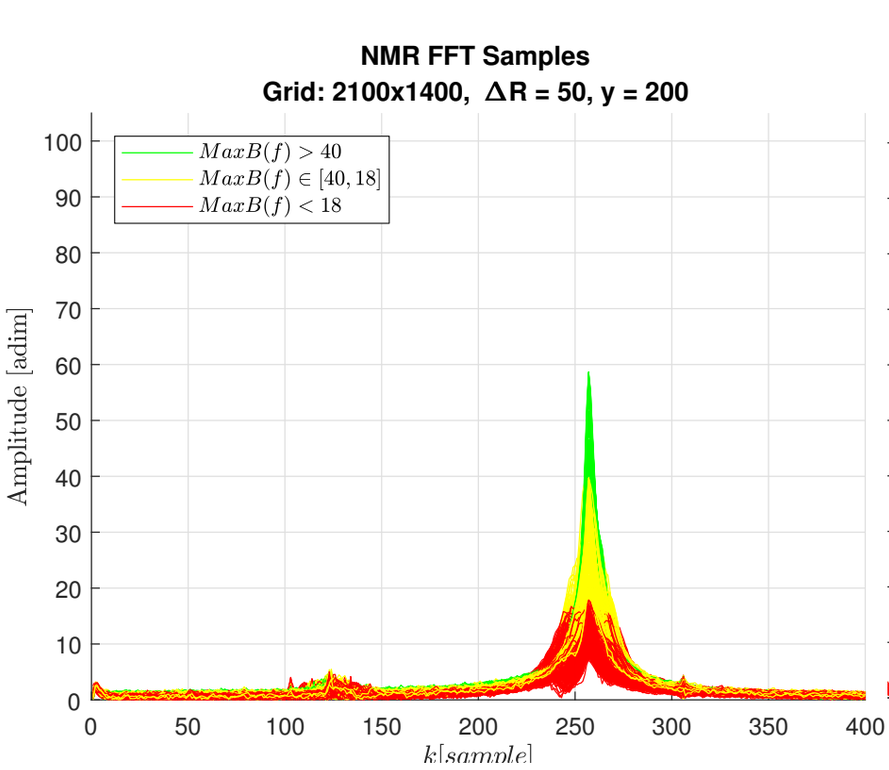


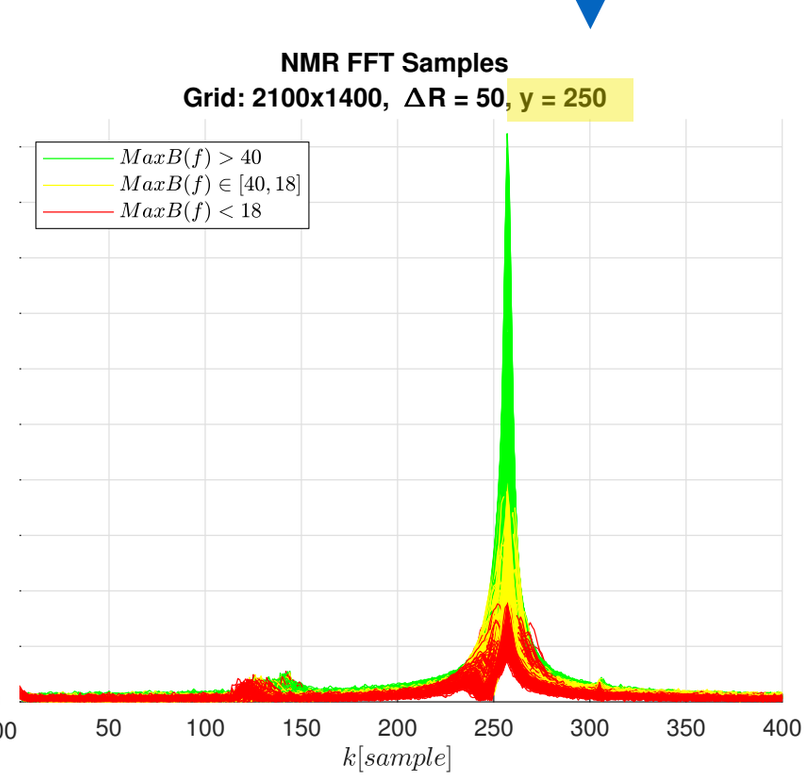


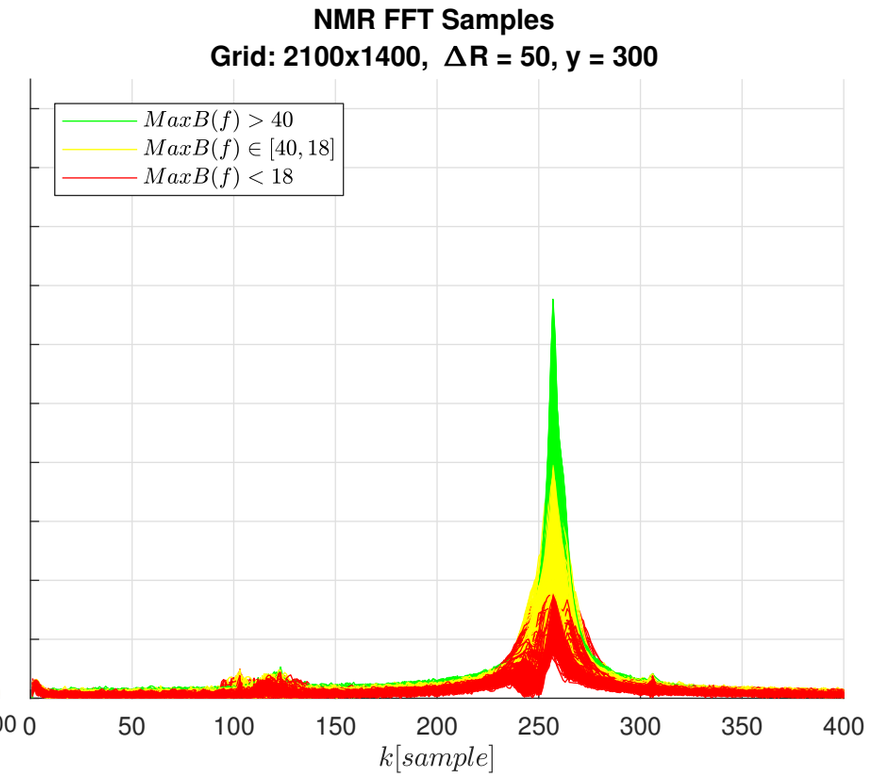
Fermilab

635um - FFT of Free Induction Decay Signal

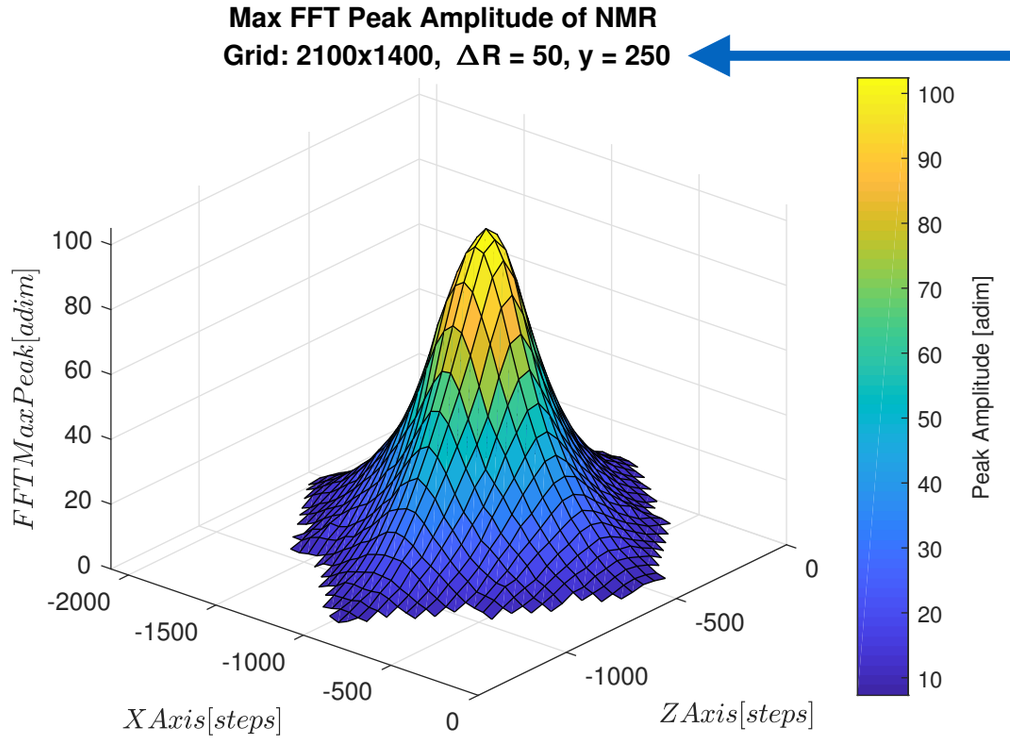
Uniform

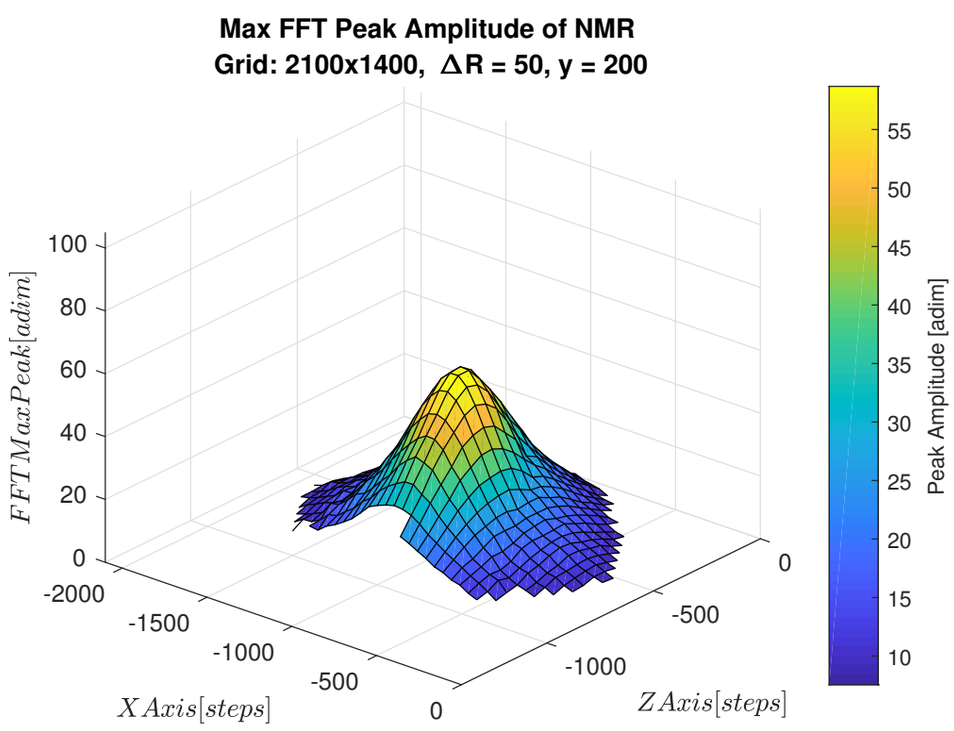


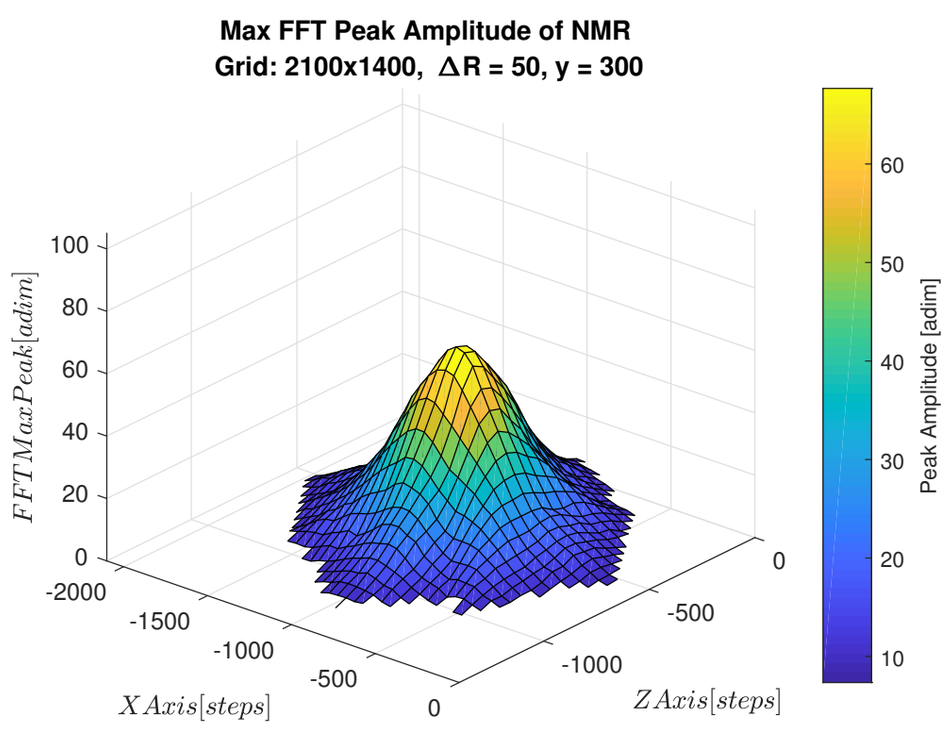




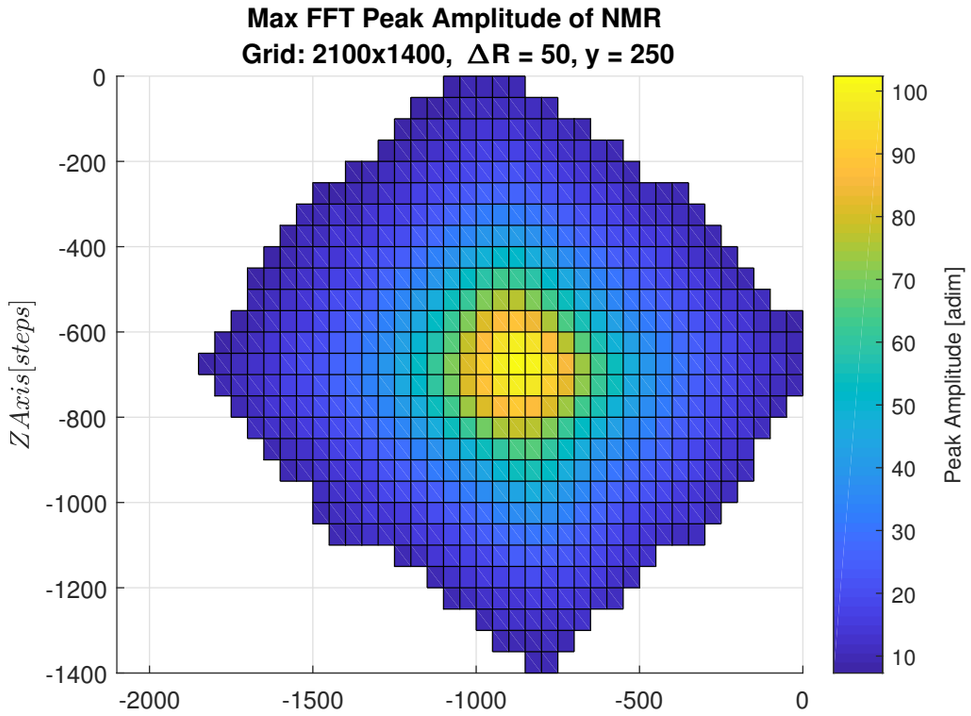
R = 635 um - Space Distribution of the Maximum FID Peak

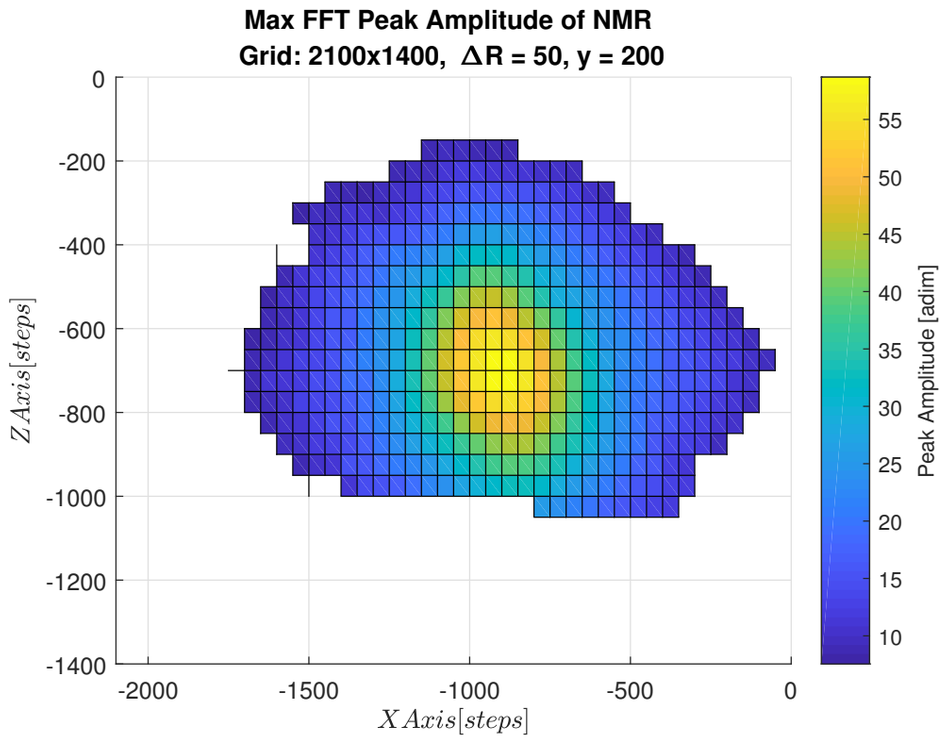


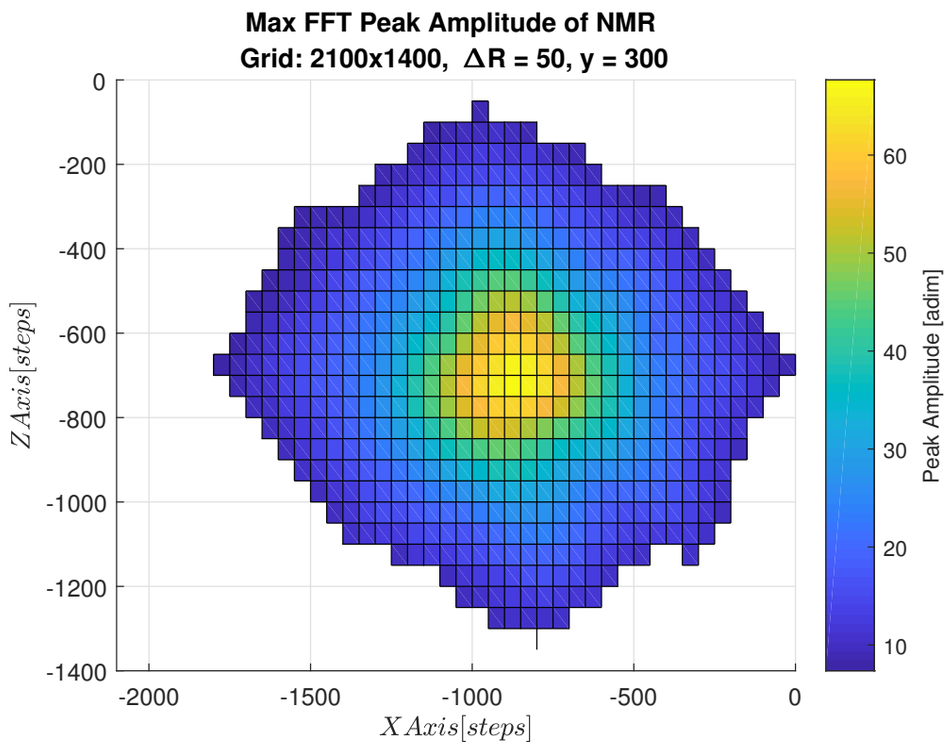




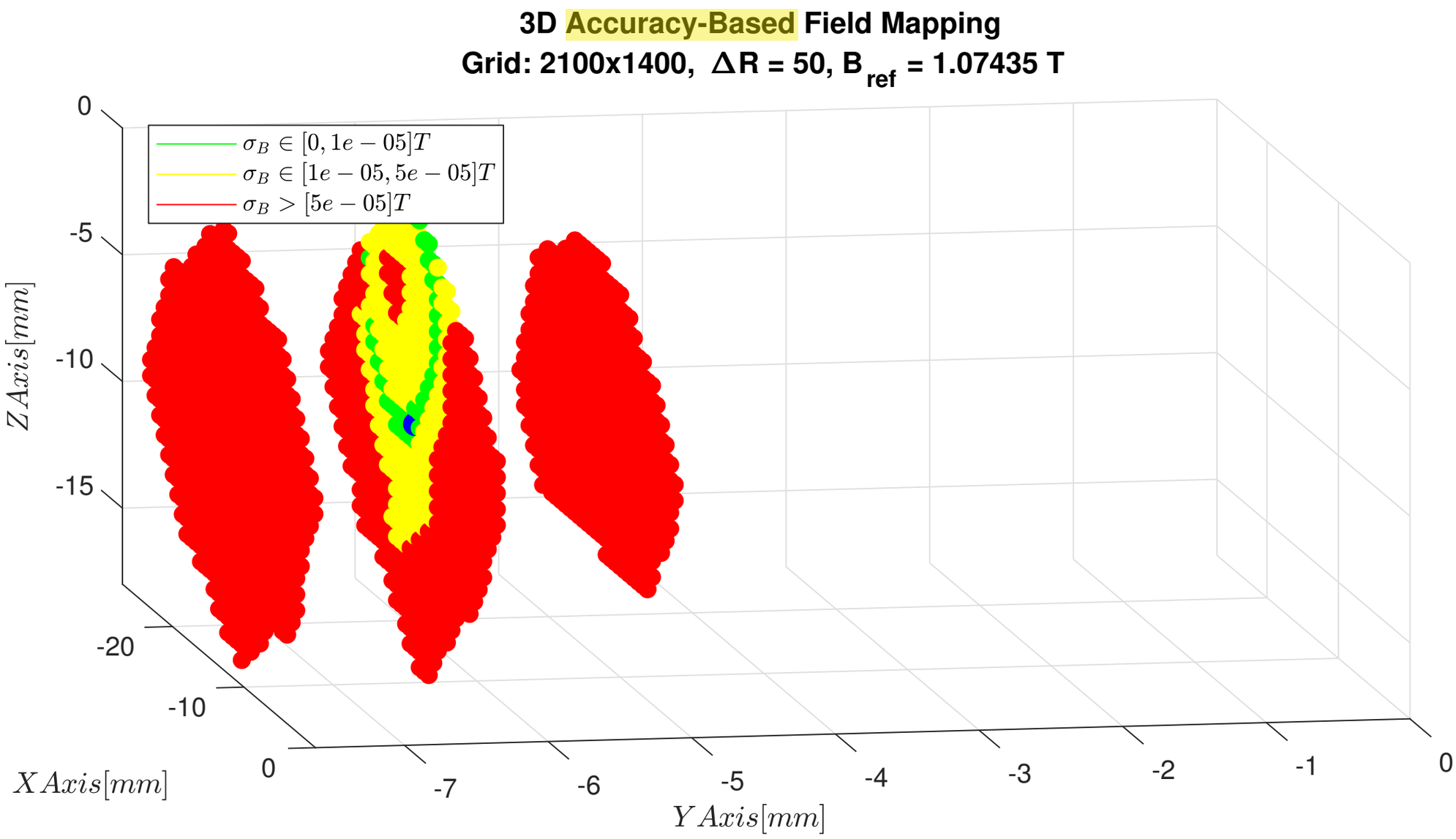
635um - Space Distribution of the Maximum FID Peak







635um - 3D Map, Accuracy Region #1

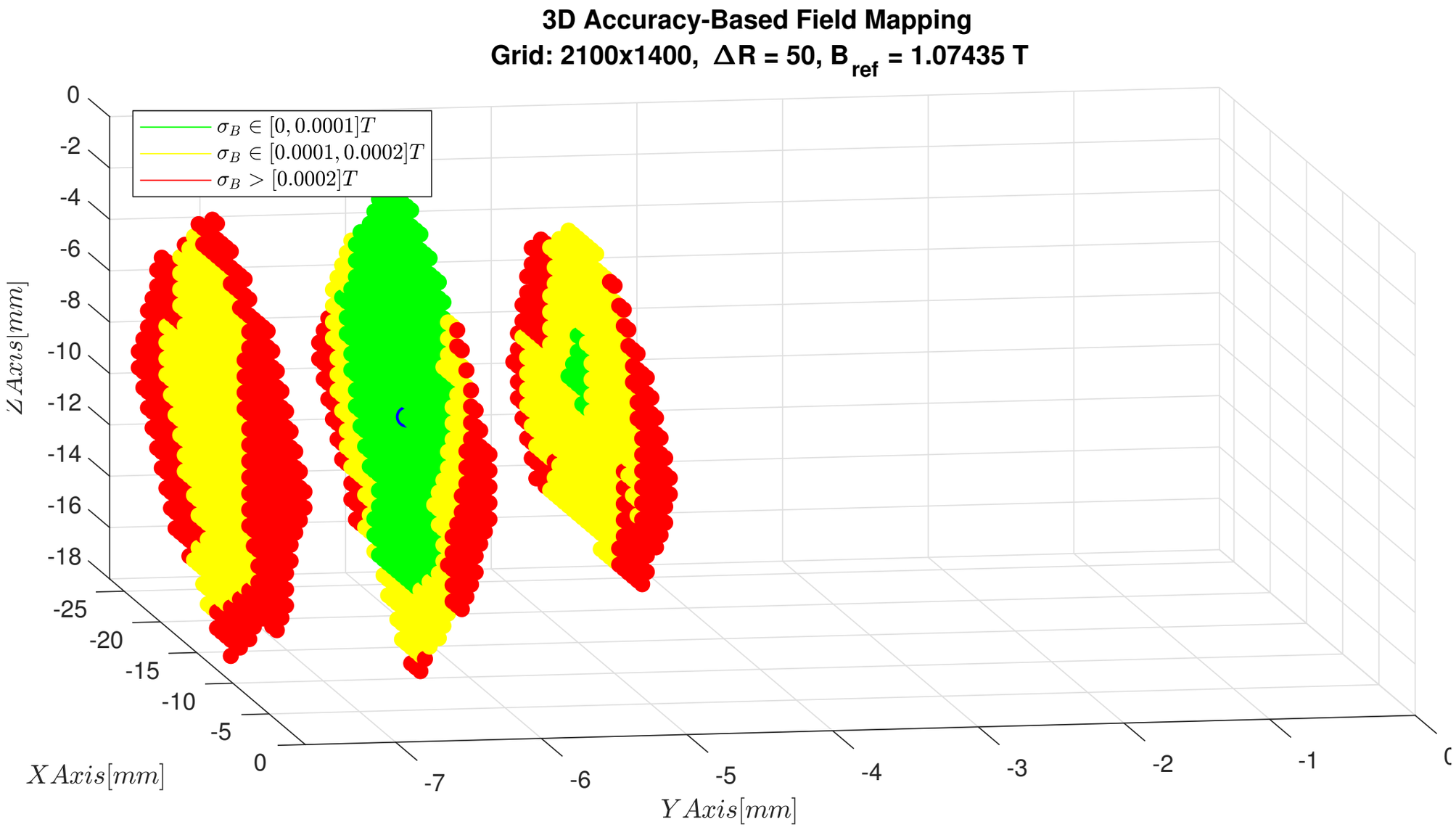


1 - Blue Point: Maximum Peak Value -> Most Uniform

2 - Plot Deviation respect to that value

Relaxed Requirements ? 10ppm -> 100ppm

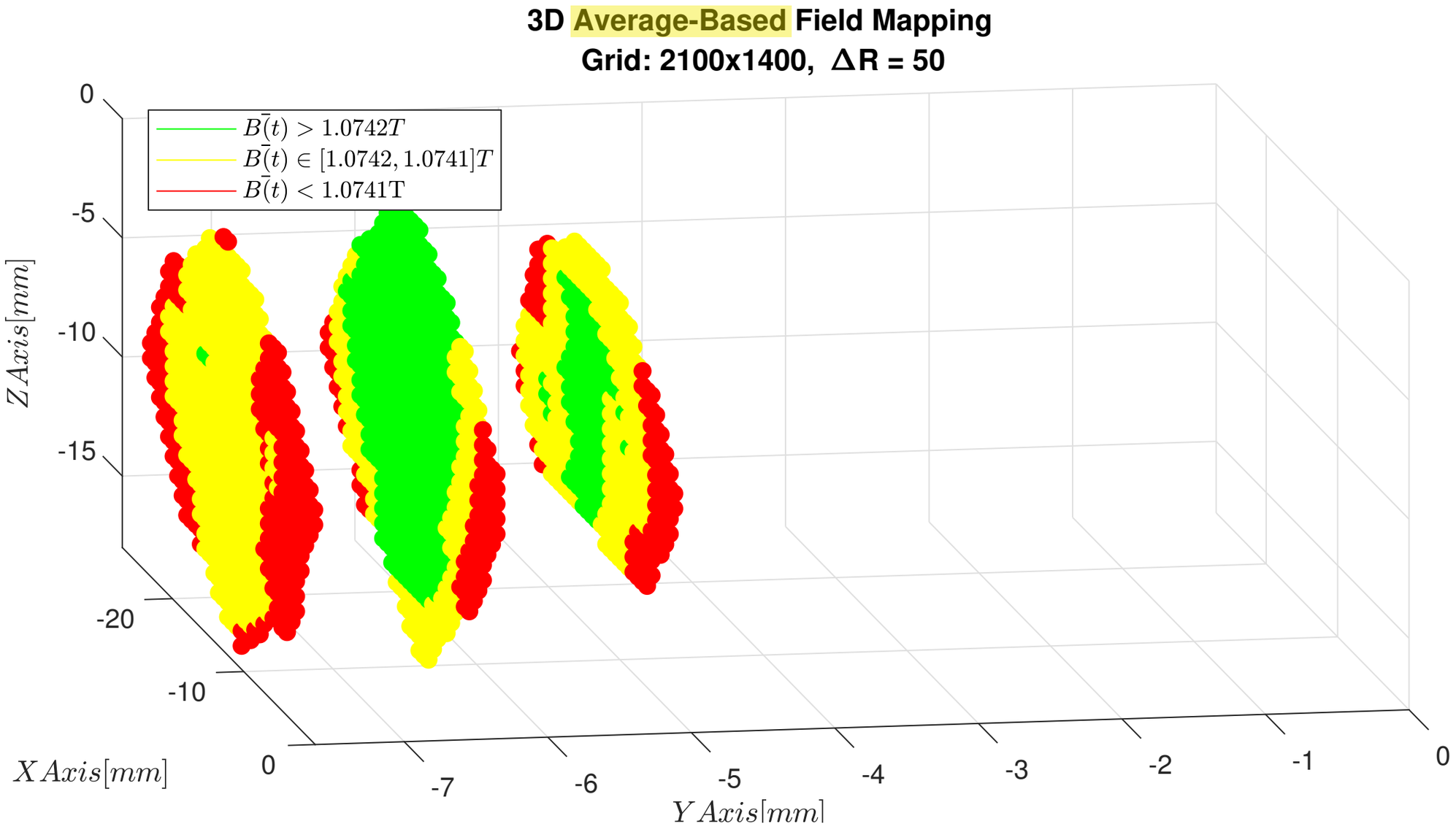
635um - 3D Map, Accuracy Region #2



Forced to Relaxed Requirements? (No)

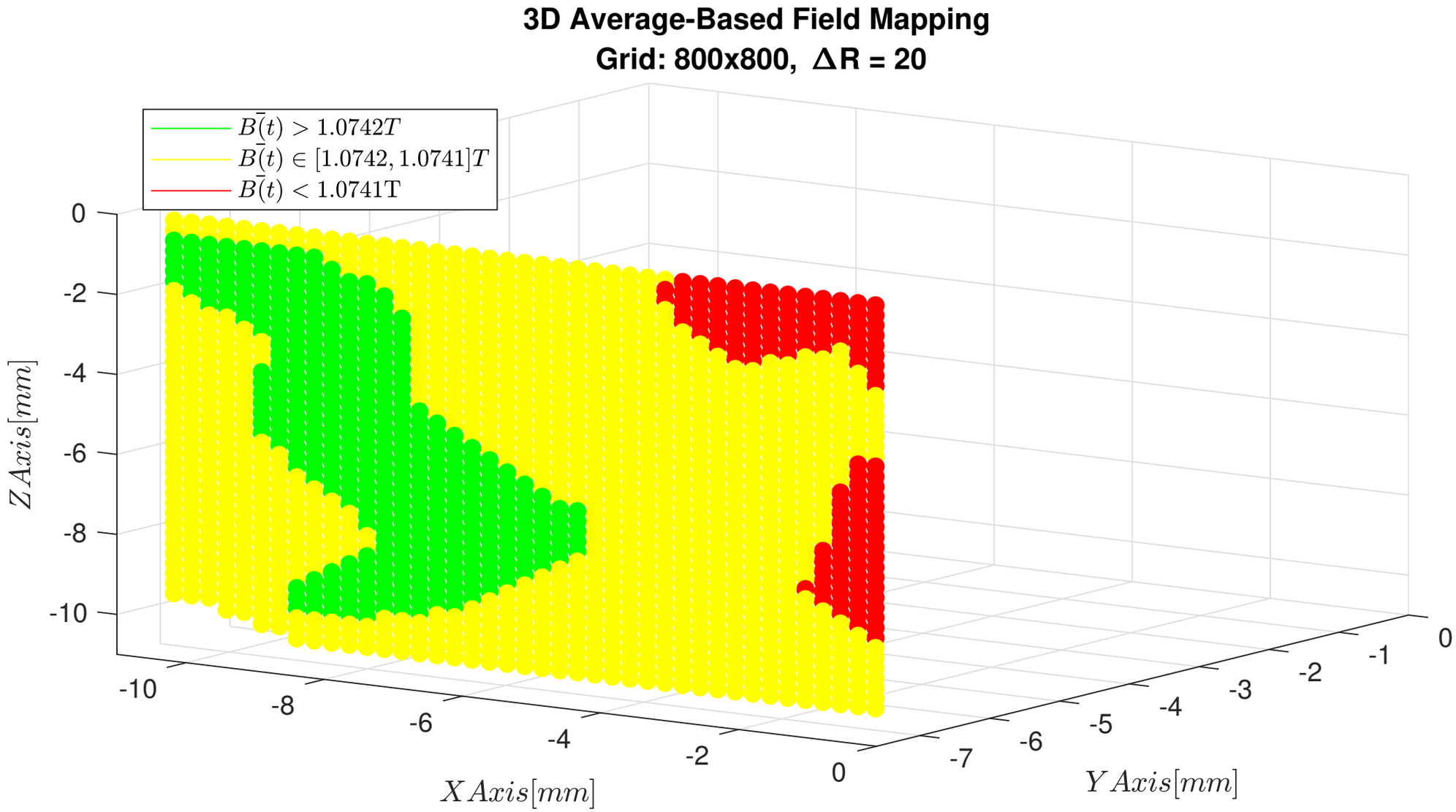
Remember the 250 samples? (Lower Bound)

635um - 3D map, Average Amplitude



Weird Distribution

254um - 3D map, Average Amplitude



Green Area:

Accuracy of this values respect to blue point

Troubleshoot

- **If, when the plat button is clicked, the motors keep on moving without any acquisition, the NMR Probe is experiencing a error: Stop the Program, Reset the motors' positions with the NI Software and Reset the Probe.**

- **to let the program run during the night NoSleep.exe MUST BE EXECUTED, else LabVIEW Program will shut down**

.. Read TROUBLESHOOT.pdf